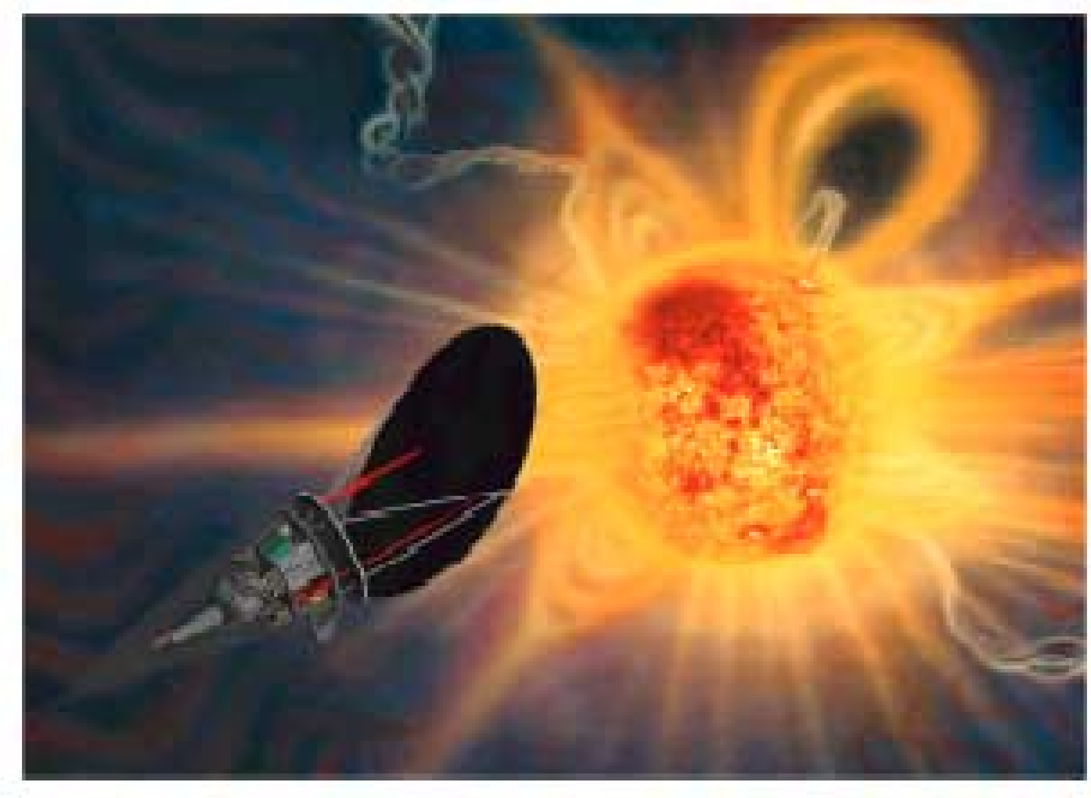
Future Capabilities for Solar/Stellar Observations

- Purpose/Goals of Session
  - inform community about future opportunities and encourage thought about how we might take advantage of these opportunities
  - layout the current strategic plans so community can identify “holes” in these plans and to encourage all to become proactive in filling those voids and promoting ***primary*** solar/stellar missions/facilities
- Agenda
  - Space-based solar missions - Don Hassler
  - Ground-based solar optical/IR - Tom Berger
  - Solar/stellar radio - Tim Bastian
  - Space-based stellar missions - Ken Carpenter
  - Ground-based stellar optical - Roberto Pallavicini
  - Ground-based stellar IR - Suchitra Balachandran

Future Capabilities: Space-Based Solar Physics



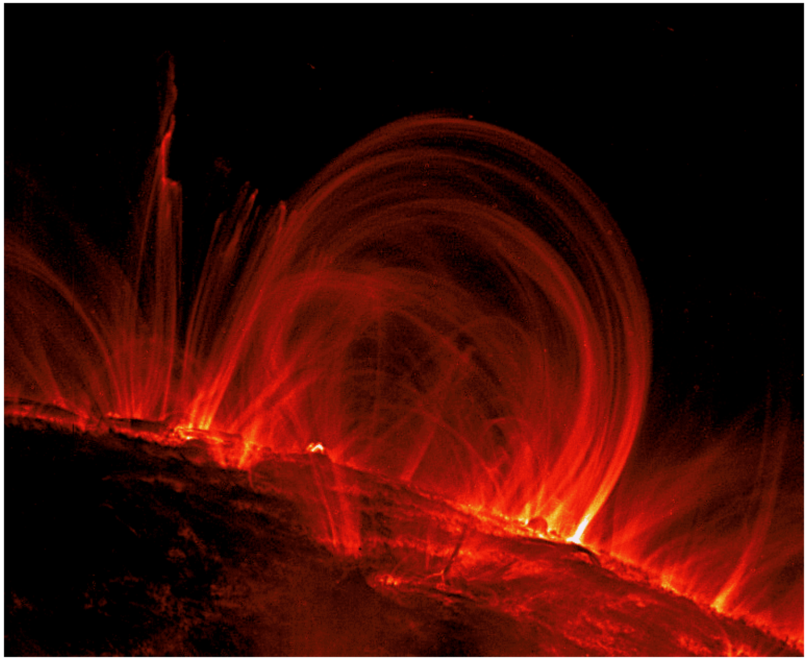
Donald M. Hassler
Southwest Research Institute

For 60 years there have been 3 major problems in Solar Coronal Physics!

- Why is the corona hot?
- Why does the corona have structure?
- Why is the corona active and unstable?

- Status? Progress means listing possible mechanisms. No agreement yet!

We know that parts of the corona are highly structured, multi-thermal, and dynamic!



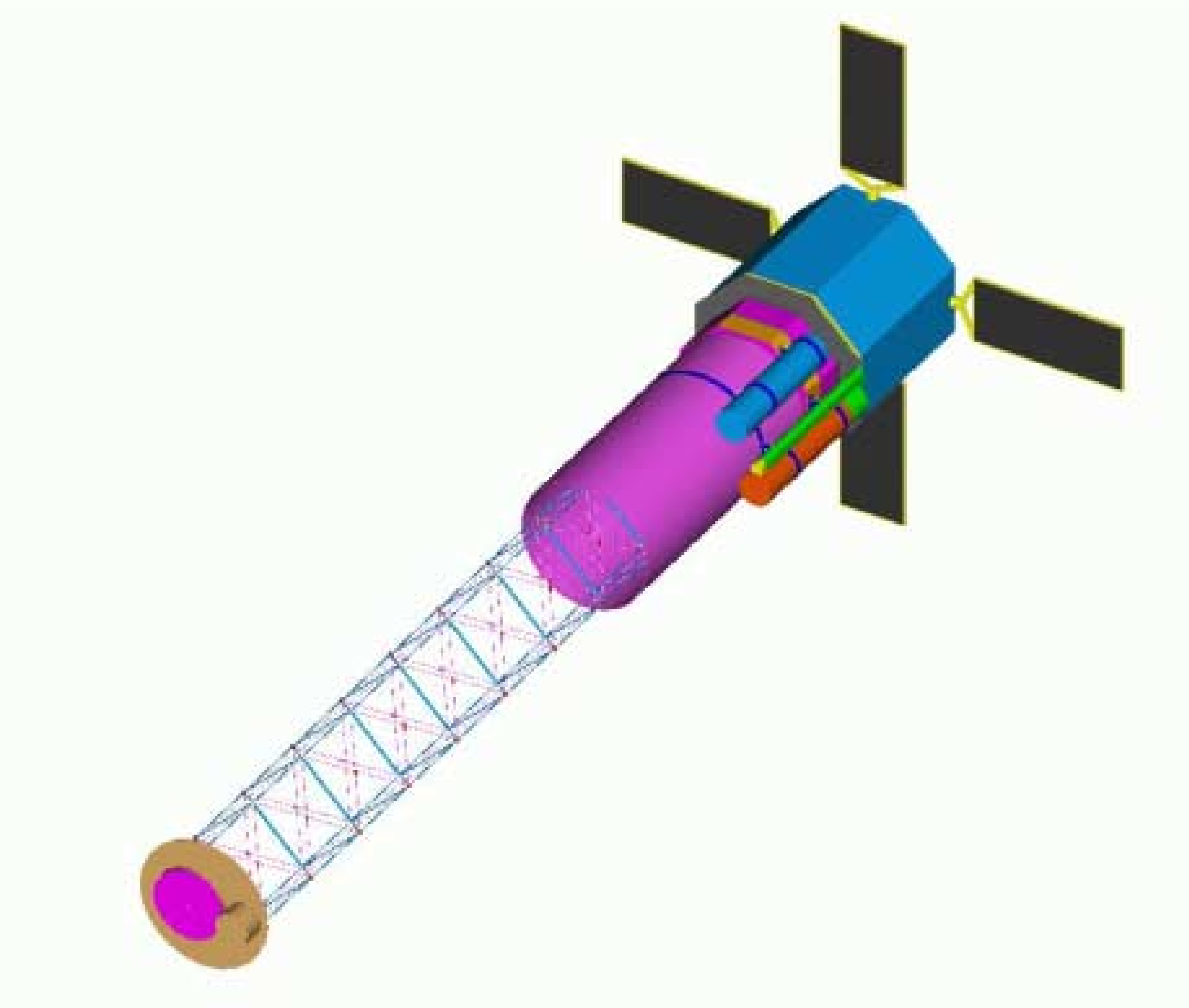
- **What do we need to make progress?!**

What do we need to make progress? (selected topics)

- Moderate time cadence, simultaneous, multi-thermal synoptic imaging and imaging spectroscopy (Solar Dynamics Observatory).
- Very high time and spatial (10-100 km) resolution imaging (RAM).
- Simultaneous, high time and spatial resolution imaging spectroscopy (spectral images) (ESSEX).
- Polar observations (to constrain theories of the Solar Dynamo and the Solar Cycle) (Solar Probe).
- *In-situ* direct measurements of the corona (Solar Probe).

Future Capability 1:

Very high spatial (10-100 km) resolution imaging (RAM)



Science Drivers: Spatial Scales

• “Global” MHD Scales	
– Active Regions;	10^5 km
– granulation scales	10^3 km
• Transverse scales	
– δT, δn	10^1 - 10^3 km
– $\delta B_\perp$ and j	<10 km
• Reconnection sites	
– location – size – dynamics	<10 km

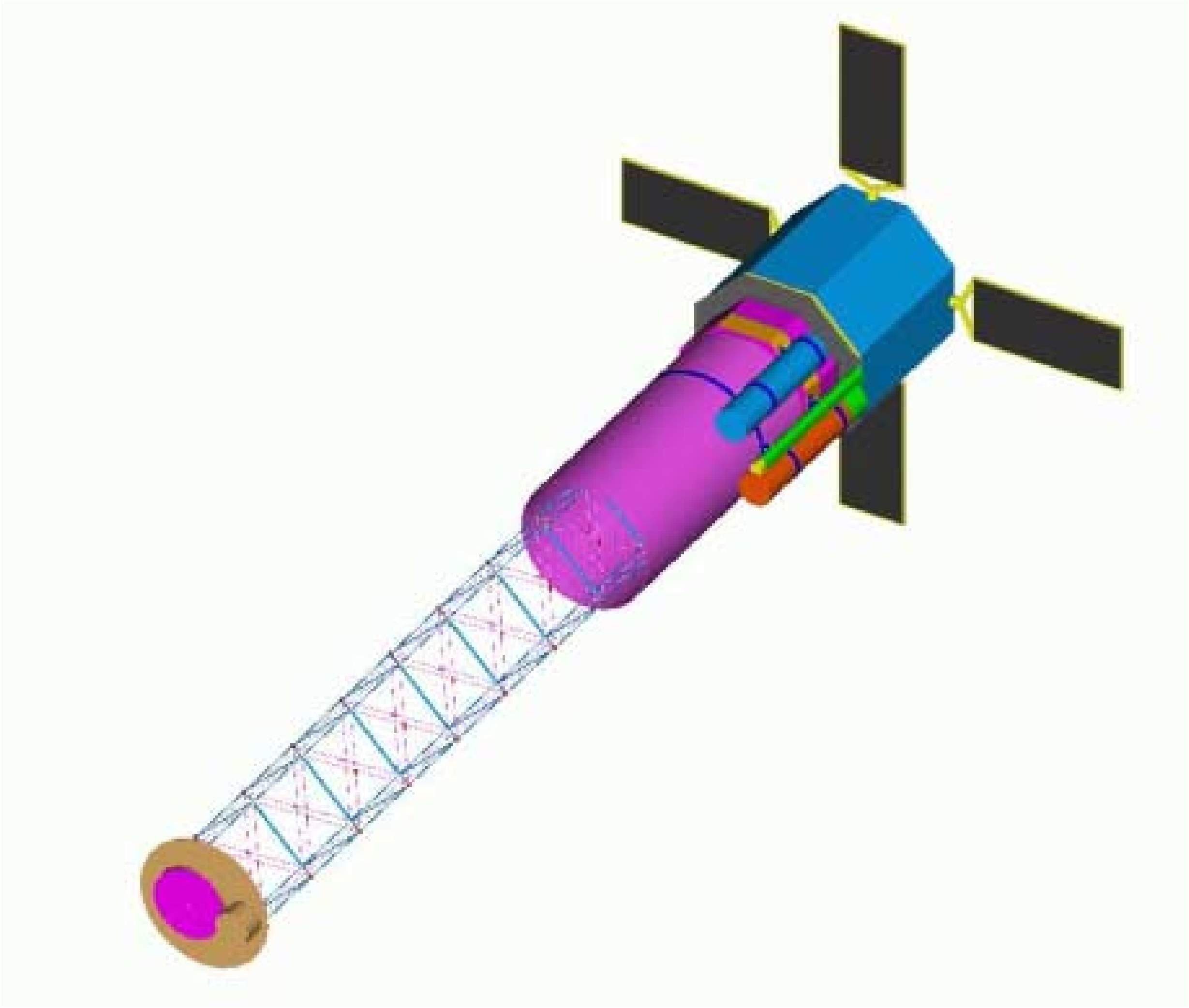
Science Drivers: Time Scales

Loop Alfven time	**~10 sec**
Sound speed vs. loop length	**~100 sec**
Ion formation times	**~1 - 10 sec**
Plasma instability times	**~10 - 100 sec**
Transverse motions	**1 - 100 sec**
Surface B evolution times	**minutes - months**

Imaging Requirements

- High spatial resolution
  - Magnetic reconnection sites
  - Loop - loop interactions
  - Loop oscillations
- High time resolution
  - Follow loop evolution
  - Detect waves - longitudinal and transverse
- Broad temperature response
  - Heating and cooling events
  - Density diagnostics

Reconnection Microscope (RAM)



Current Instrument Complement

- **RAM has an EUV imaging instrument:**
    - **A High Resolution Telescope - 0.01” second pixels.**

- **RAM has an EUV spectrograph:**
    - **High time resolution Imaging Spectrograph, with 0.01-0.2” performance**

- **RAM has an X-ray calorimeter, for imaging spectroscopy. 2 ev resolution from 0.3 to 10 keV**

- **RAM has an EUV context imager.**

Key Technologies

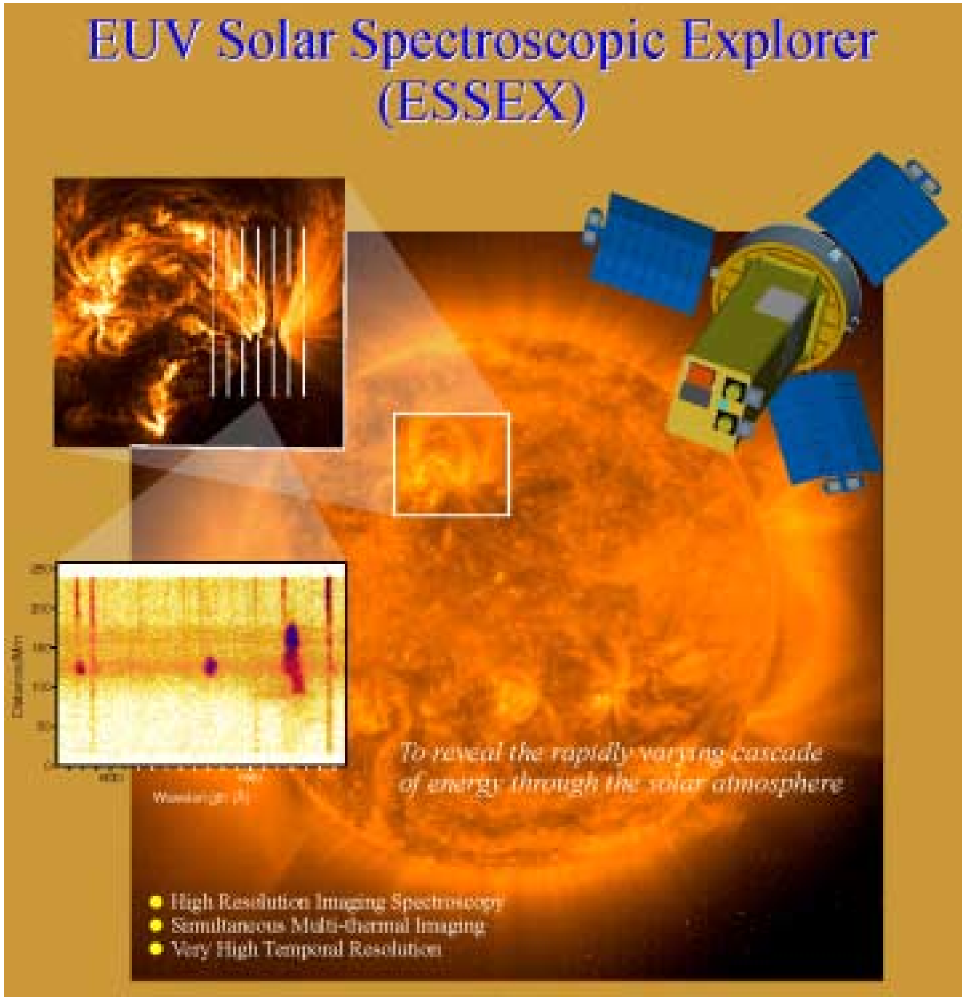
RAM uses a combination of innovative and proven technologies to yield exciting new science:

- **New Technologies**:
  - **Ultra-high precision optics (0.25m pathfinder mirror under development with partners ROSI and Bauer, Assoc.).**
  - **Cryogenic bolometers for soft x-ray spectroscopy.**
- **Heritage technologies:**
  - **Extendable Optical Bench: RAM re-uses the SRTM deployable mast to reduce cost, reduce risk, & improve reliability.**
  - **Image stabilization techniques: RAM extends techniques from TRACE and SOHO/MDI missions.**
  - **Multilayers based on TRACE heritage**

Extendable Optical Bench Prototype

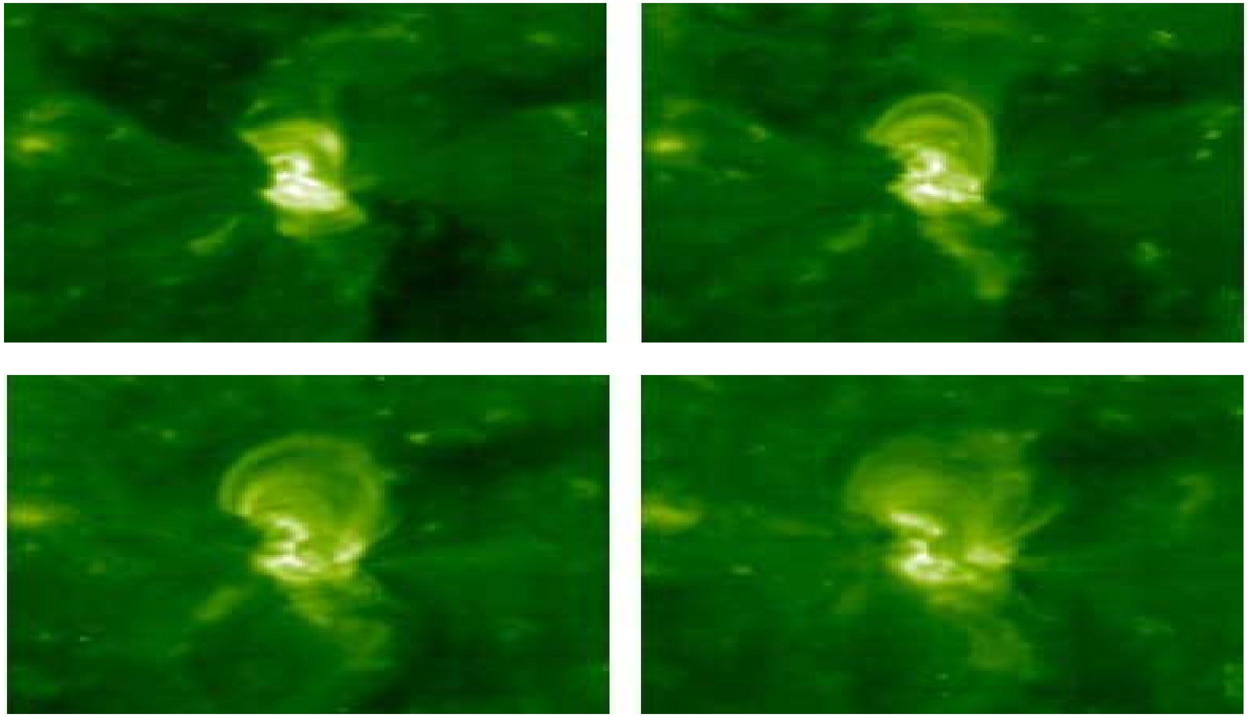
Future Capability 2:

High time resolution Imaging Spectroscopy



Limitations of Imaging

Significant ambiguities between **bulk motion** and **successive illumination** of adjacent features in any image sequence; between **density** and **temperature variations** in sequences from a single narrow spectral band; and between **temperature effects** and **temporal changes** in multi-wavelength image sets without strictly simultaneous exposures.



- **Figure 2:** Expansion of post-flare loops observed with EIT: Does the motion in the image plane correspond to genuine mass motion, or to successive illumination of nested loops? Imaging alone cannot discern the difference, while time/space resolved spectroscopy can measure directly the motion of the loops.

Imaging alone can't resolve total time derivatives.

This non-solar example image shows the difficulty in resolving the causes of motions observed in image sequences. Only partial time derivatives are truly measured, causing the visual confusion in this cloudscape.

Coronal phenomena such as wave propagation, simultaneous motion and heating or cooling of plasma, smooth acceleration, and unresolved differentiation all confound imaging measurements, and are all resolvable with spectroscopic measurements.

*Craig DeForest, “Decadal Survey Presentation”, 17 April 2001.

Outstanding Questions and Morphology of the Solar Transition Region

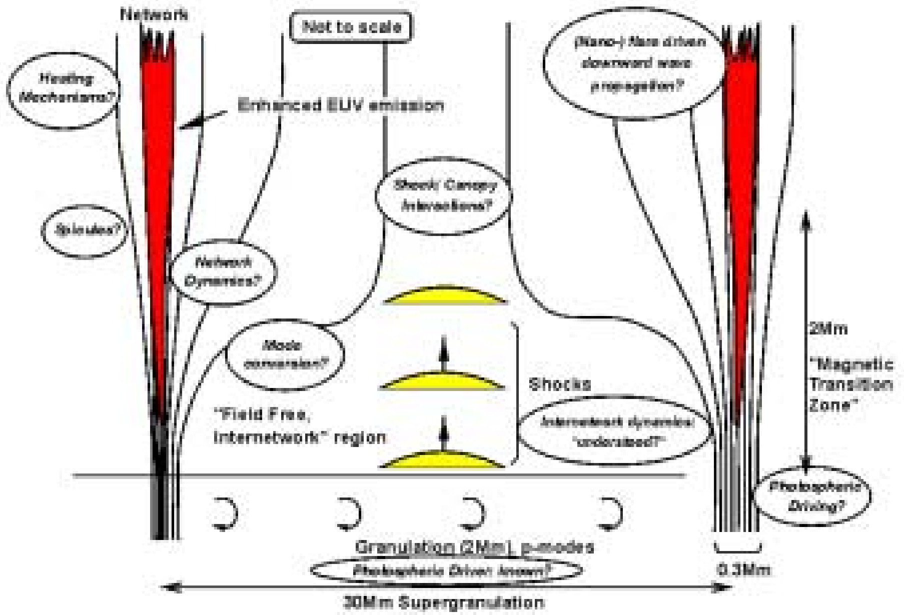


Figure 1 Cartoon depicting the general morphology of the solar magnetic field through the crucial magnetic transition zone. In the deep photosphere, turbulent plasma flows control the dynamics of the embedded field lines. In the corona, the field entrains the gas and guides its motion. In the intervening "magnetic transition zone," the field dominates where it is strong and gas motions dominate where their amplitudes are large (or the field is weak), thus the influence of one over the other is spatially mixed. Given the relatively large densities, and large amplitudes of unresolved motions in the low chromosphere, energy transfer to the higher layers is magnified.

Current SUMER-style Spectroheliograms

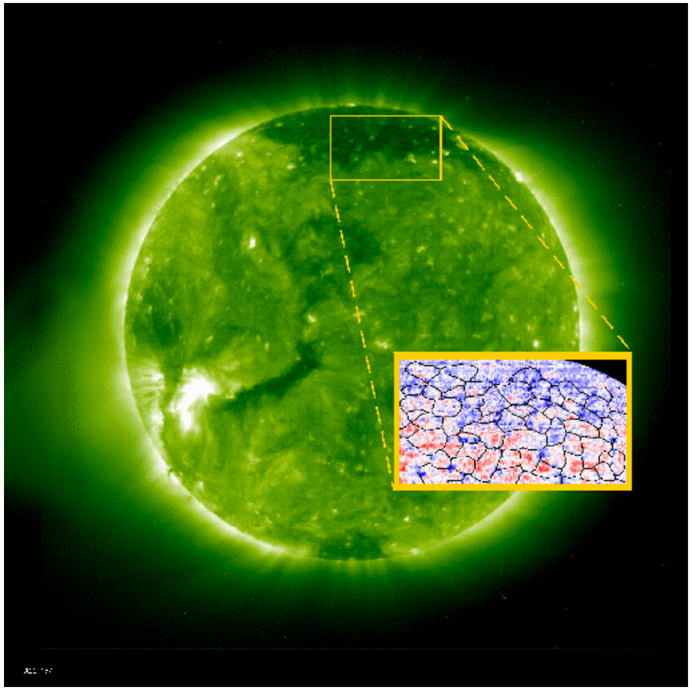


Figure X: SOHO/SUMER Doppler velocity map in Ne VIII 770 Å (0.8 MK) at the base of the corona superposed on a SOHO/EIT Fe XII 195 Å image formed at 1.5 MK. Blue regions are outflows within the polar coronal hole. Superposed is the Si II 1533 Å chromospheric network boundary pattern.

The Importance of Joint Imaging and Spectroscopy

Joint observations by EUV telescopes and spectrometers can encompass the best of both worlds: the rapid cadence of the imaging and diagnostic data from the spectrometer.

Even sparsely sampled raster scans, such as the one shown here, can resolve ambiguities in image data -- provided that the spectrometer's spatial resolution is high enough to match the imager.

Extremely high cadence, high resolution measurements of line profiles are needed to resolve individual reconnection events and the acceleration and wave motion that they engender.

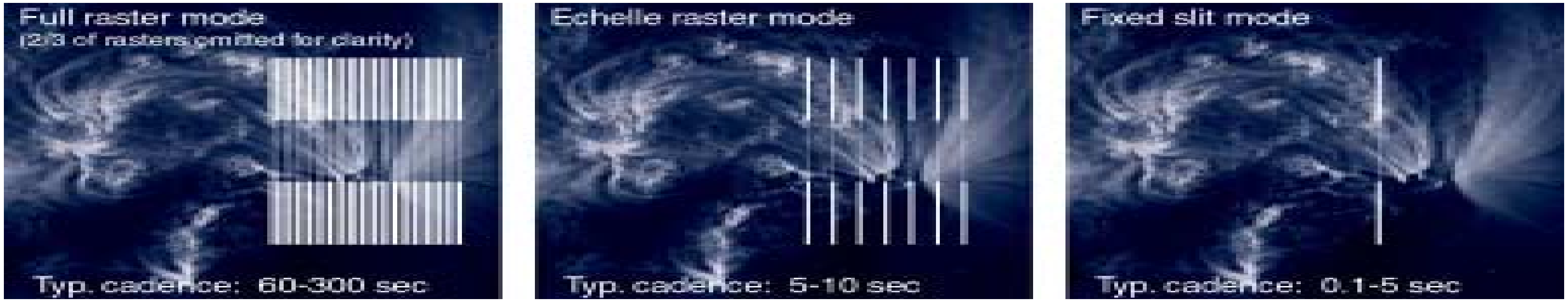


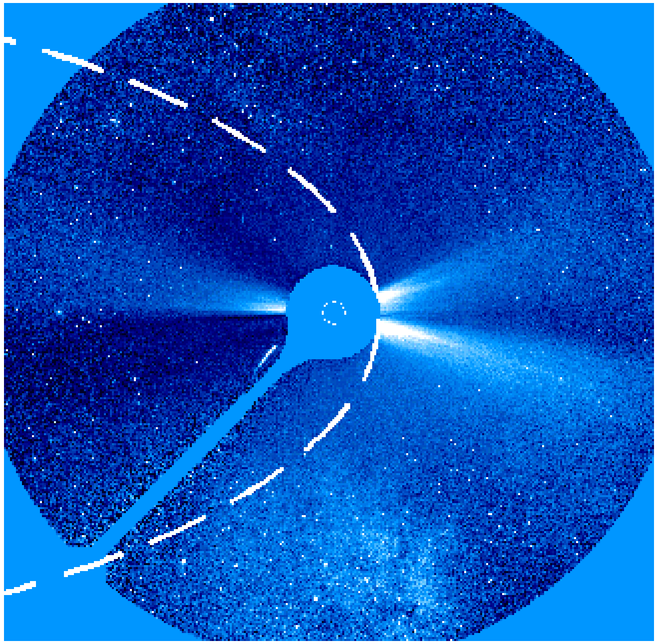
Figure 3: EUV Spectrometer Observing modes. Slit positions for the three principal observing modes are depicted, to scale, on a TRACE 171Å 200x200 arcsec^2 image showing coronal "moss" under an active region. Cadences are given for typical line selections and exposure times for each mode. Slit exposure times are typically 1-2 seconds for bright lines (used in the echelle scan); 1-5 seconds for a broader line selection (in the full scan).

High Resolution Imaging AND Spectroscopy

- Understanding the microscale processes that occur in all magnetized astrophysical plasmas requires BOTH:
  - High resolution/throughput imagers
  - High time resolution imaging spectrometers

Future Capability 3: Go to the Sun!

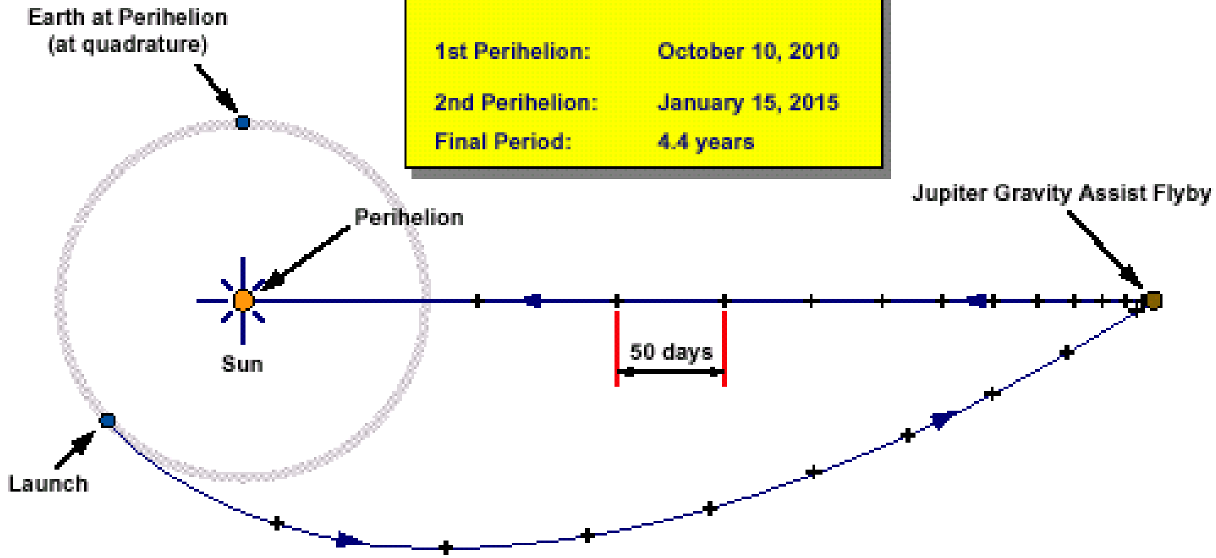
Solar Probe: a mission of discovery - NOT incremental science!



- Directly sample the corona and the inner heliosphere, where the solar wind is born!
- ONLY way to determine uniquely what heats the corona and accelerates the solar wind.
- First view of the Sun’s Poles!
- Polar magnetograms and sub-surface velocity maps will solve fundamental mysteries related to the solar dynamo and the origins of the solar cycle.

Jupiter Gravity Assist Trajectory

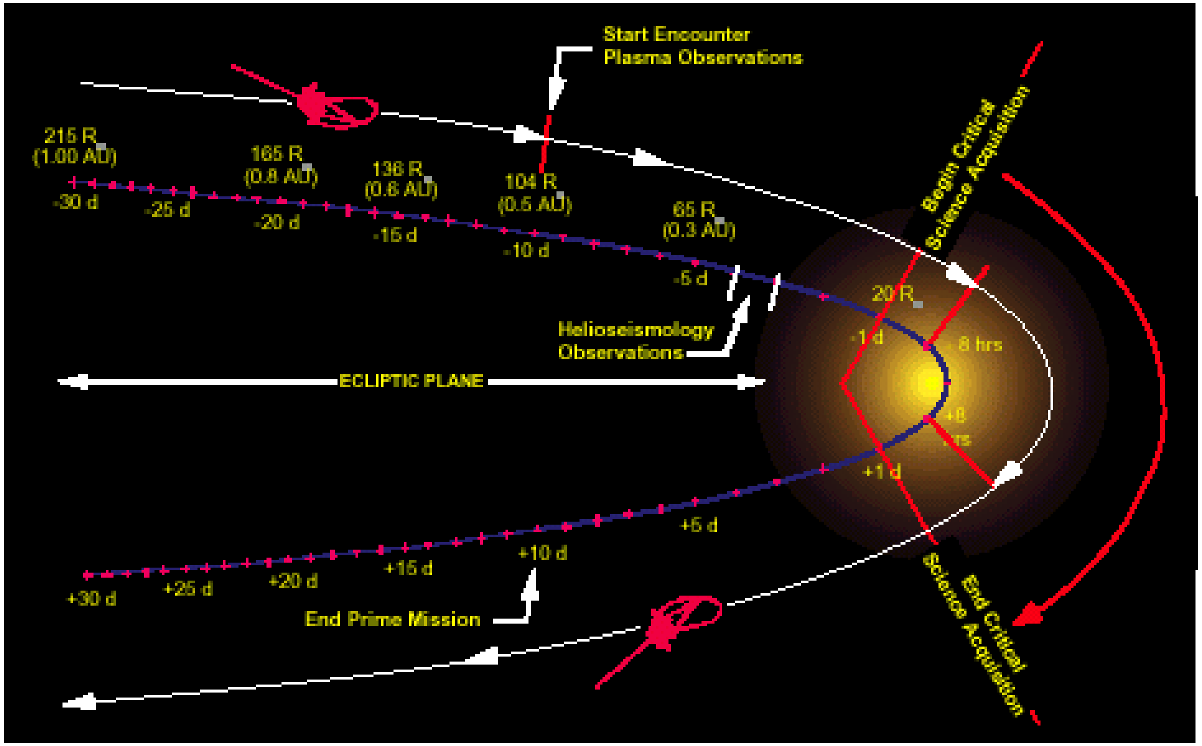
Launch:	**February 15, 2007**
Jupiter Gravity Assist Flyby:	**June 25, 2008**
1st Perihelion:	**October 10, 2010**
2nd Perihelion:	**January 15, 2015**
Final Period:	**4.4 years**



The planned trajectory for Solar Probe will take it from launch at Earth out to Jupiter, where the planet will be used for a gravity assist. This will alter the spacecraft trajectory to a highly elliptical orbit with a perihelion of 4 R_S and an aphelion of 5 AU. The mission duration is approximately 3.7 years from launch to first solar perihelion, and up to 8.1 years from launch to second perihelion.

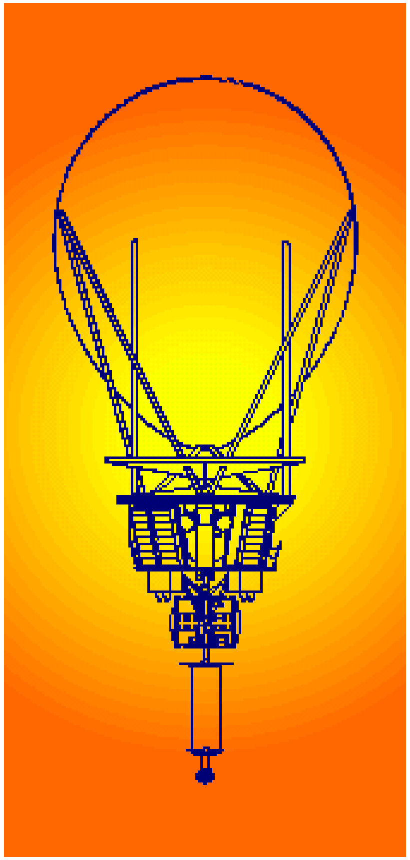
Solar Probe Mission Profile

(view from Earth)



As shown above, encounter measurements will start on approach to the Sun at 10 days prior to perihelion and will continue to 10 days after perihelion. During this time (within 0.5 AU), the inner heliosphere and the corona will be observed in-situ for the first time. Helioseismology measurements will begin at 4 days before perihelion (0.2 AU). The most intense observation period will take place during the two days centered on closest approach (the critical science acquisition period indicated in the figure).

Solar Probe Science Payload

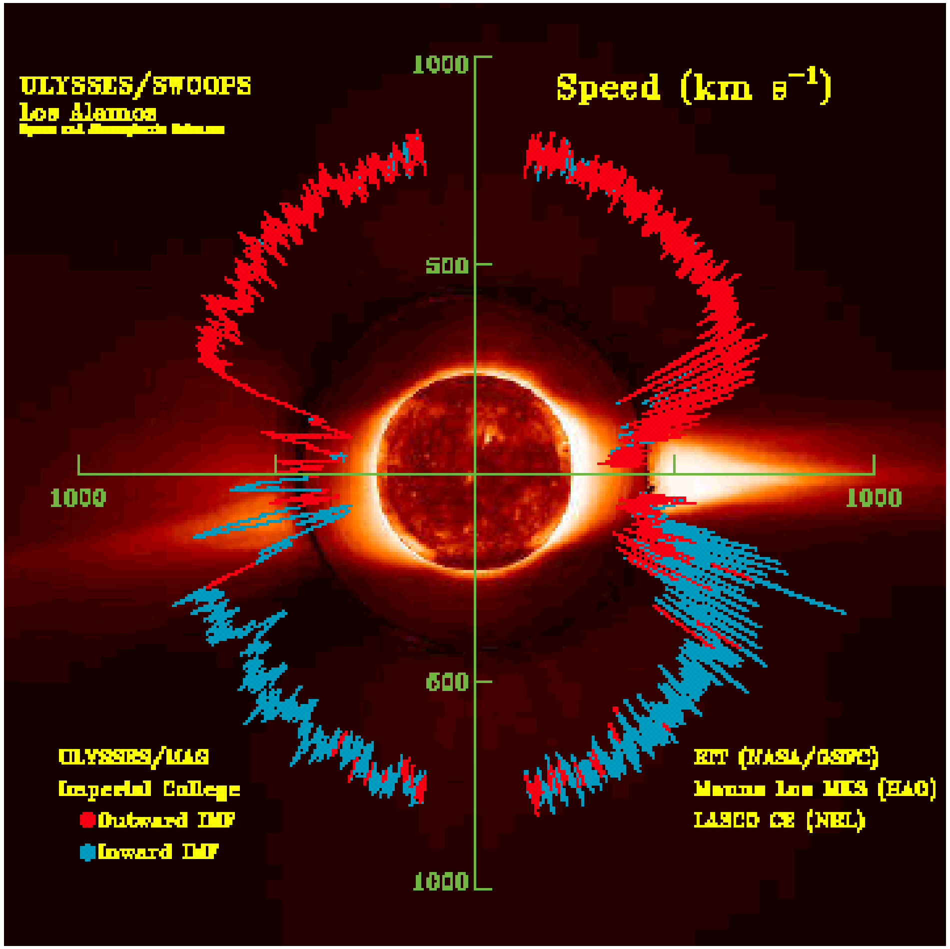


Remote Sensing Instruments
Visible Magnetograph/Helioseismograph
EUV Imager
All-sky, 3-D Coronagraph Imager

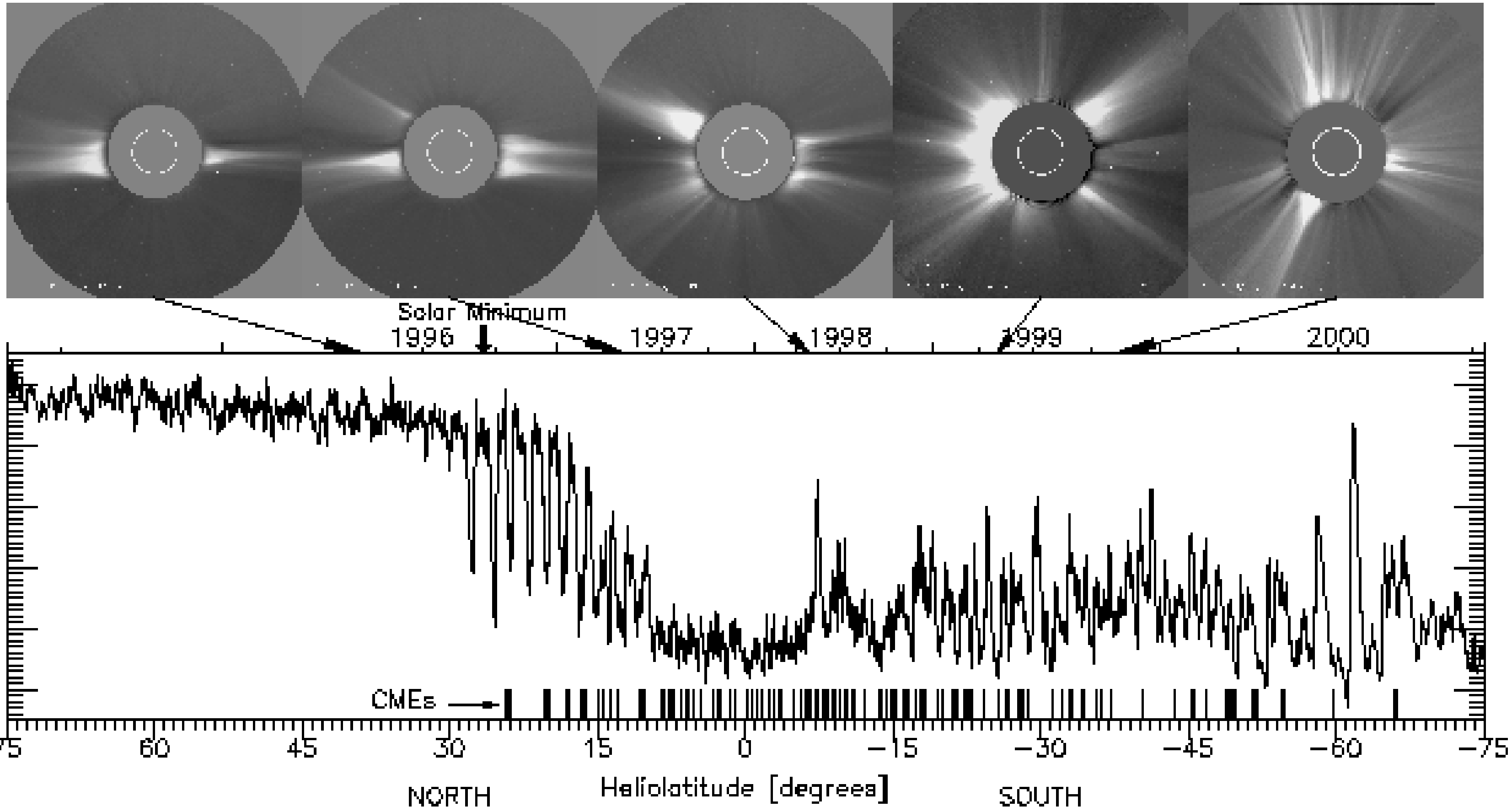
In-situ Instruments
Magnetometer (with boom cables)
Solar Wind Ion Composition and Electron Spectrometer
Energetic Particle Composition Spectrometer
Plasma Wave Sensor (with boom cables)
Fast Solar Wind Ion Detector

Total	21 kg	15 W

Ulysses Solar Wind Speed Observations



Measurements of the solar wind from the Ulysses mission show that solar wind velocities are 750-800 km/s over the Sun's polar regions and about 400 km/s over the equatorial regions (slow solar wind region). There are spatial variations in the latter region because Ulysses was moving into and out of high speed streams.

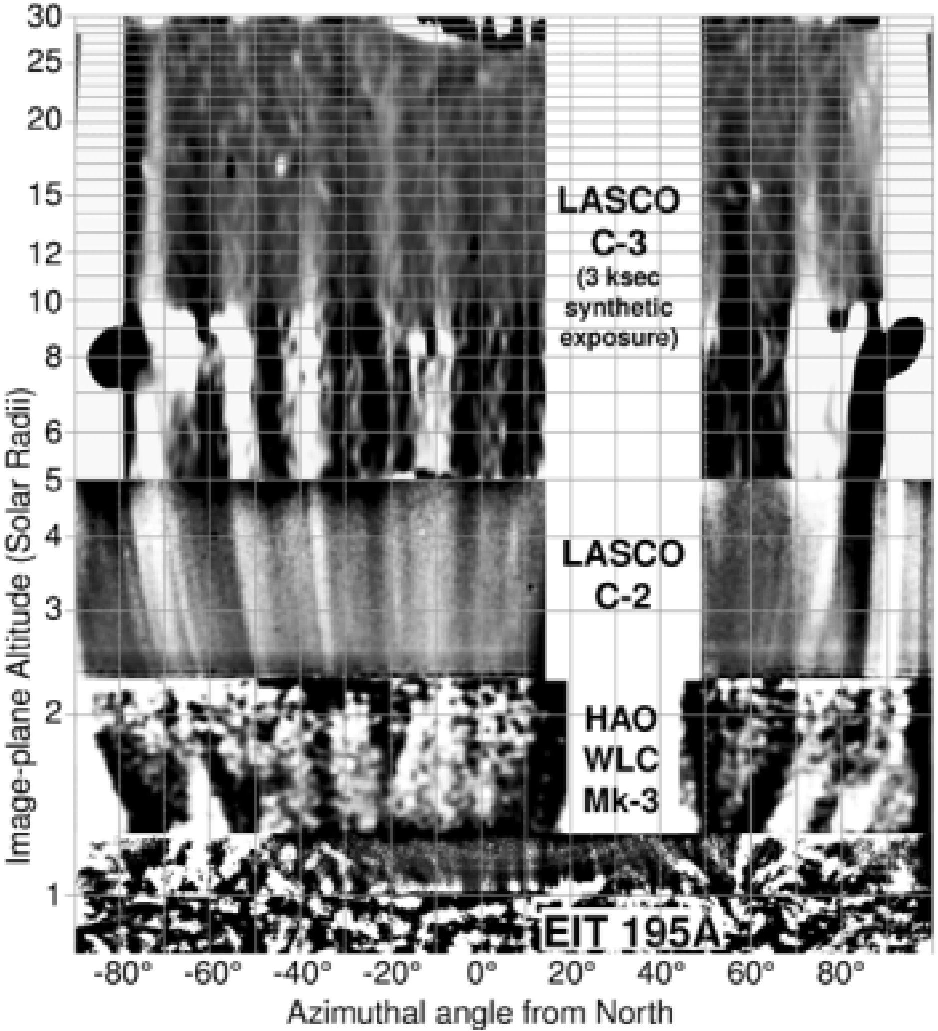

Solar Minimum
1996
1997
1998
1999
2000
800
700
600
500
400
300
V_P [km s^-1]
CMEs
75
60
45
30
15
0
−15
−30
−45
−60
−75
NORTH
Heliolatitude [degrees]
SOUTH

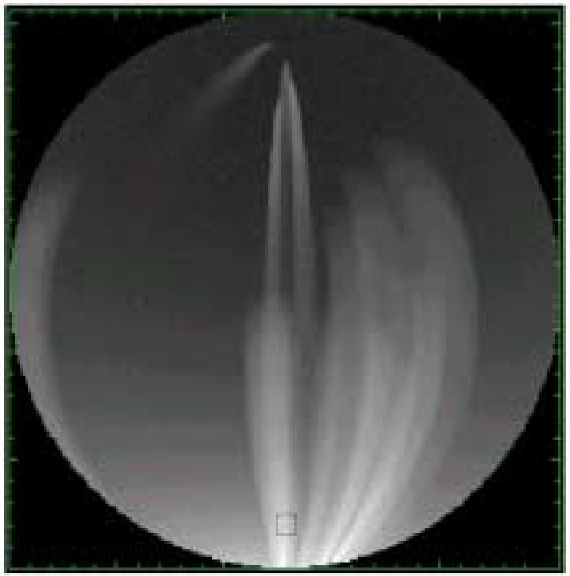
In-Situ Measurements

High time resolution, synchronized plasma, energetic particle, and field measurements, including mass resolved ion distribution functions, will resolve:

- solar wind heating and acceleration
- macroscopic coronal structure and composition
- fine scale spatial structures
  - plasma and magnetic structures in the helmet streamer belt
  - plume/interplume structure

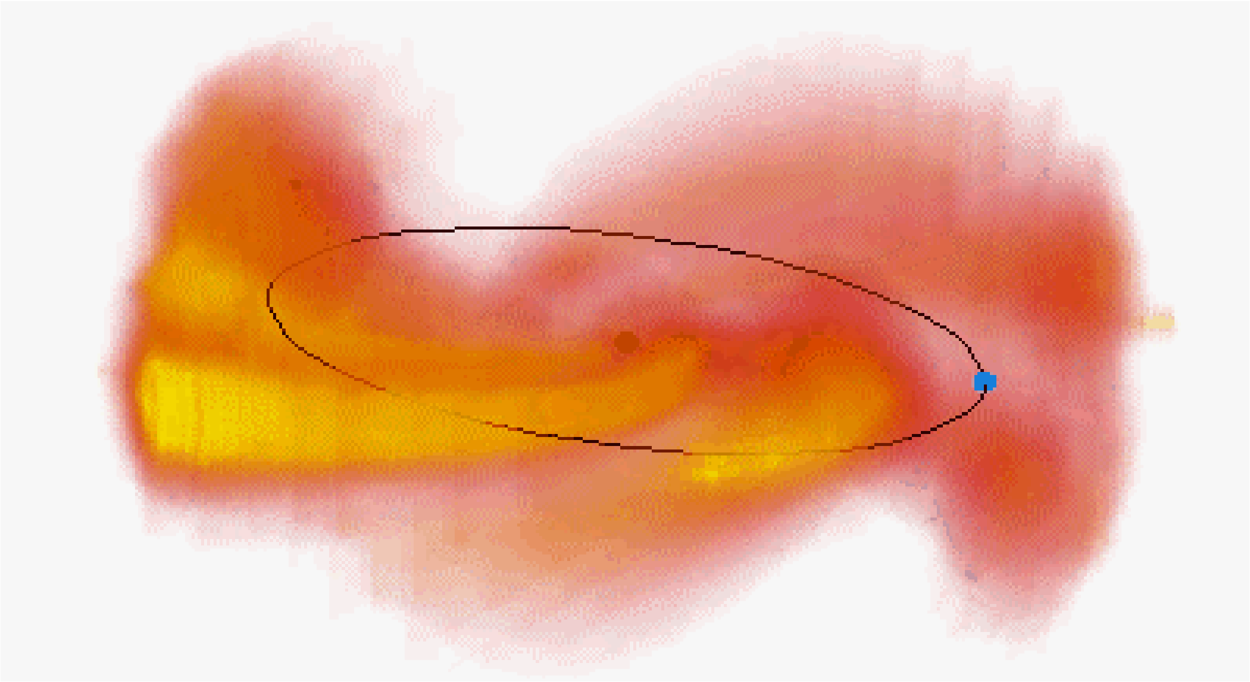
Simultaneous imaging of coronal structures (e.g. polar plumes) as the spacecraft flies through the corona is required to resolve inherent ambiguities in the interpretation of spatial and temporal changes seen in the *In-situ* measurements.





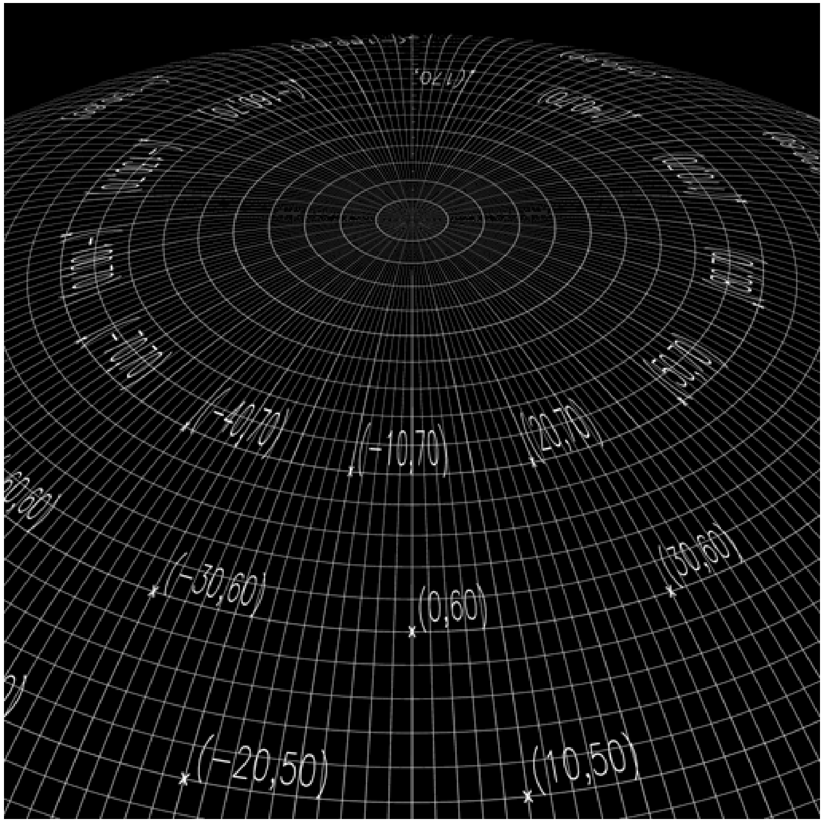
A coronal fly-through is the ONLY way to reconstruct the 3-D coronal structure!

The Hemispheric Imager’s 180 deg. FOV permits true tomographic reconstruction of 3-D coronal structure and context for the in-situ package



Reconstructed image of the heliosphere out to 1.5 AU, derived by tomographic reconstruction from HELIOS photometer data. Solar Probe will permit reconstruction of the corona and inner heliosphere with 1,000 times better spatial resolution.

Solar Probe will provide an unprecidented view of the both of the Sun’s Poles during both Solar Minimum and Solar Maximum!



Perspective view of Sun’s Pole from Solar Probe three days before Perihelion.

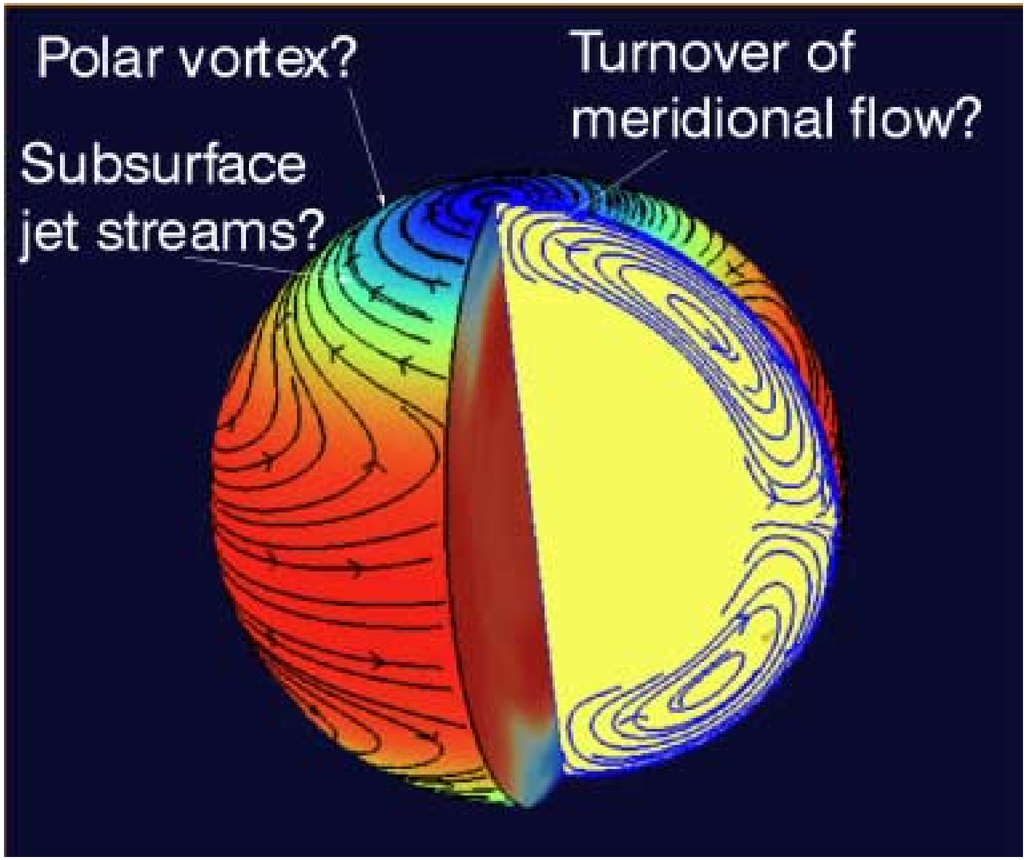
Observations of the Sun’s Poles: Polar Magnetic Field

- The Solar Probe magnetograph will provide the first high resolution maps and time series evolution studies of the *polar* magnetic field.
- Solar Probe magnetograms will be the highest resolution magnetograms of the photosphere ever obtained.

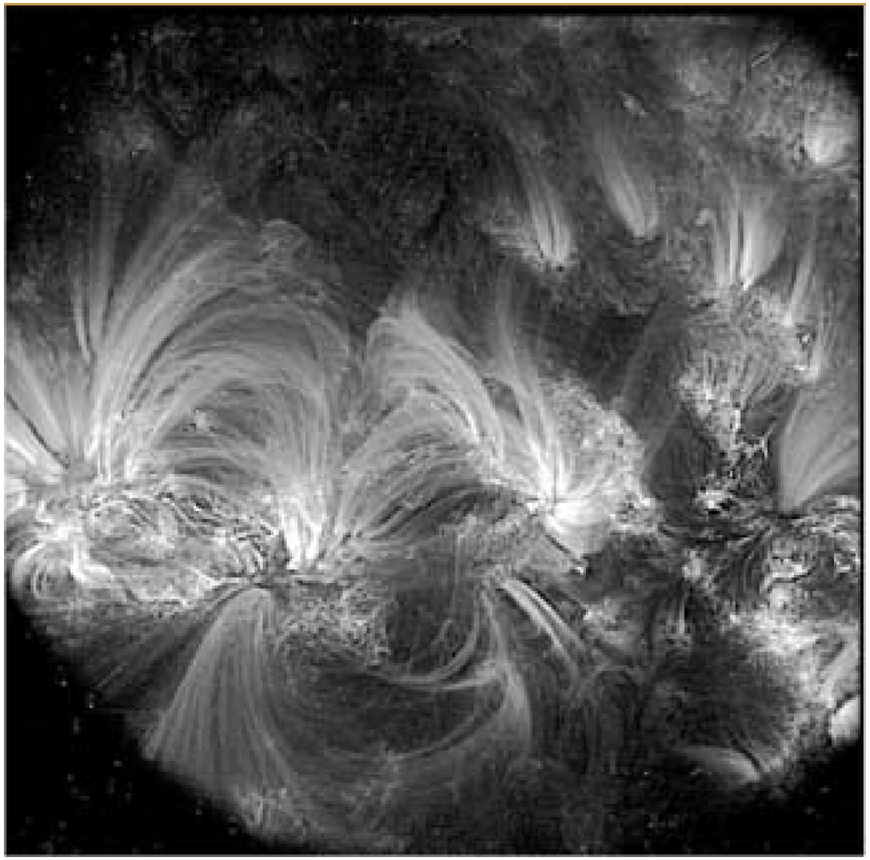
Solar Probe magnetograms will provide important constraints on theories of the Solar Dynamo

- The poloidal component of the magnetic field, a key ingredient to the dynamo mechanism, is predicted to be strongest at the poles.
- Models suggest that transport of magnetic flux by meridional circulation is crucial for the solar cycle and the operation of the dynamo, because it couples toroidal and poloidal field components, and links the surface field to the shear layer at the base of the convection zone.

Solar Probe helioseismology will provide maps of the polar sub-surface velocity flow patterns, solving fundamental mysteries related to the sub-surface origins of the solar cycle.



Ultra-high (35 km) resolution images of the corona and solar surface, including the poles!



Solar Probe will provide EUV imaging of the corona and solar surface with a resolution 10 times higher than TRACE.

Summary

- Moderate time cadence, simultaneous, multi-thermal synoptic imaging and imaging spectroscopy (Solar Dynamics Observatory-SDO).
- Very high time and spatial (10-100 km) resolution imaging (RAM).
- Simultaneous, high time and spatial resolution imaging spectroscopy (spectral images) (ESSEX).
- Polar observations (to constrain theories of the Solar Dynamo and the Solar Cycle) (Solar Probe).
- *In-situ* direct measurements of the corona (Solar Probe).

Ground-based Solar Optical Observations

A Survey of Present and Future Capabilities

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Survey of Current Capabilities

Bias: imaging and polarimetry
Excluded: full-disk patrol, networks (helioseismic, space-weather), coronographs

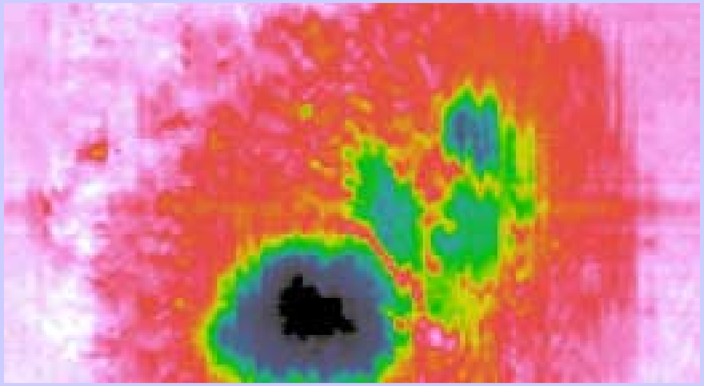
- **KPVT**: Full-disk images and magnetograms
- **McMath Pierce**: 1.52m heliostat all-reflecting telescope
- **VTT**: 0.7m vacuum heliostat reflector, adaptive optics
- **THEMIS**: 0.9m f/16.7 helium pressurized, domed reflector
- **Big Bear:** 0.65m vacuum domed reflector
- **“SVST”:** 0.48m f/45 vacuum turret refractor, adaptive optics
- **DST:** 0.76m f/72 vacuum turret reflector, adaptive optics
- **DOT:** 0.45m f/4.4 open-air reflector, speckle imaging

McMath-Pierce

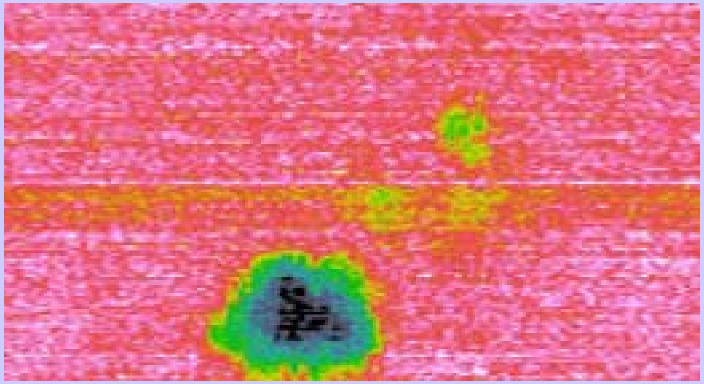
Kitt Peak, Az.

- 1.52m heliostat all-reflecting off-axis
- Commissioned: Sputnik-era
- Main goal: IR imaging and spectroscopy
- Strengths: large aperture, all-reflecting
- Weaknesses: site, telescope seeing
- Instruments:
  - 0.3 to 20 µm FTS
  - ZIMPOL I visible polarimeter
  - 1 to 5 µm imager and polarimeter
  - 1.56 µm imaging vector polarimeter
  - 6 to 15 µm imager (NASA)
  - 12 µm vector polarimeter (NASA)

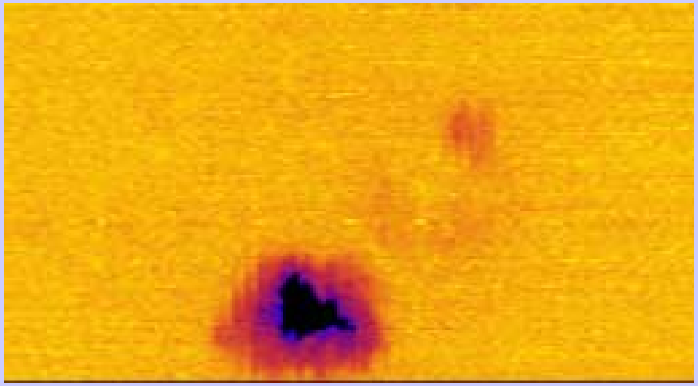
McMath 4 μm IR Imaging Example: Acid Rain



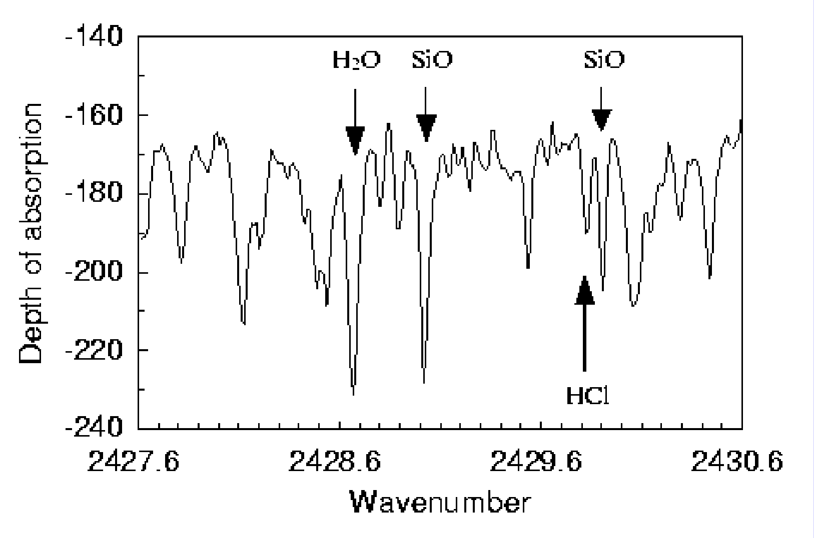
IR Continuum



HCl Molecular Line

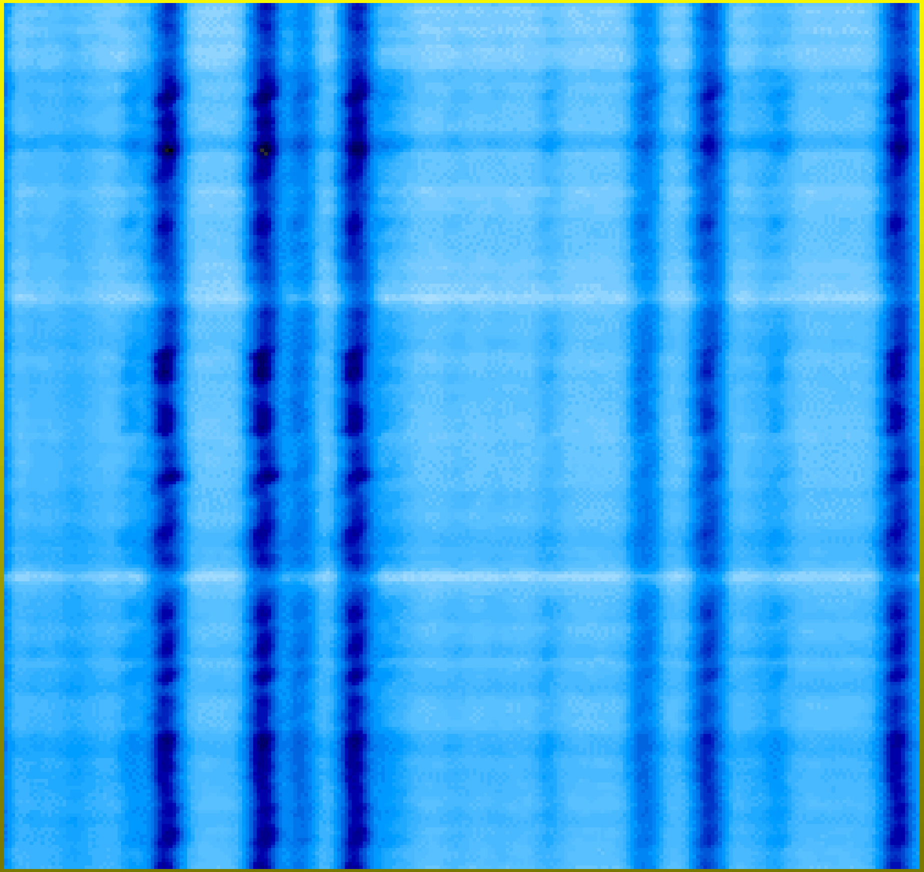


H_20 Molecular Line



Courtesy C. Keller

CO 4.67 μm IR Lines: McMath-Pierce FTS



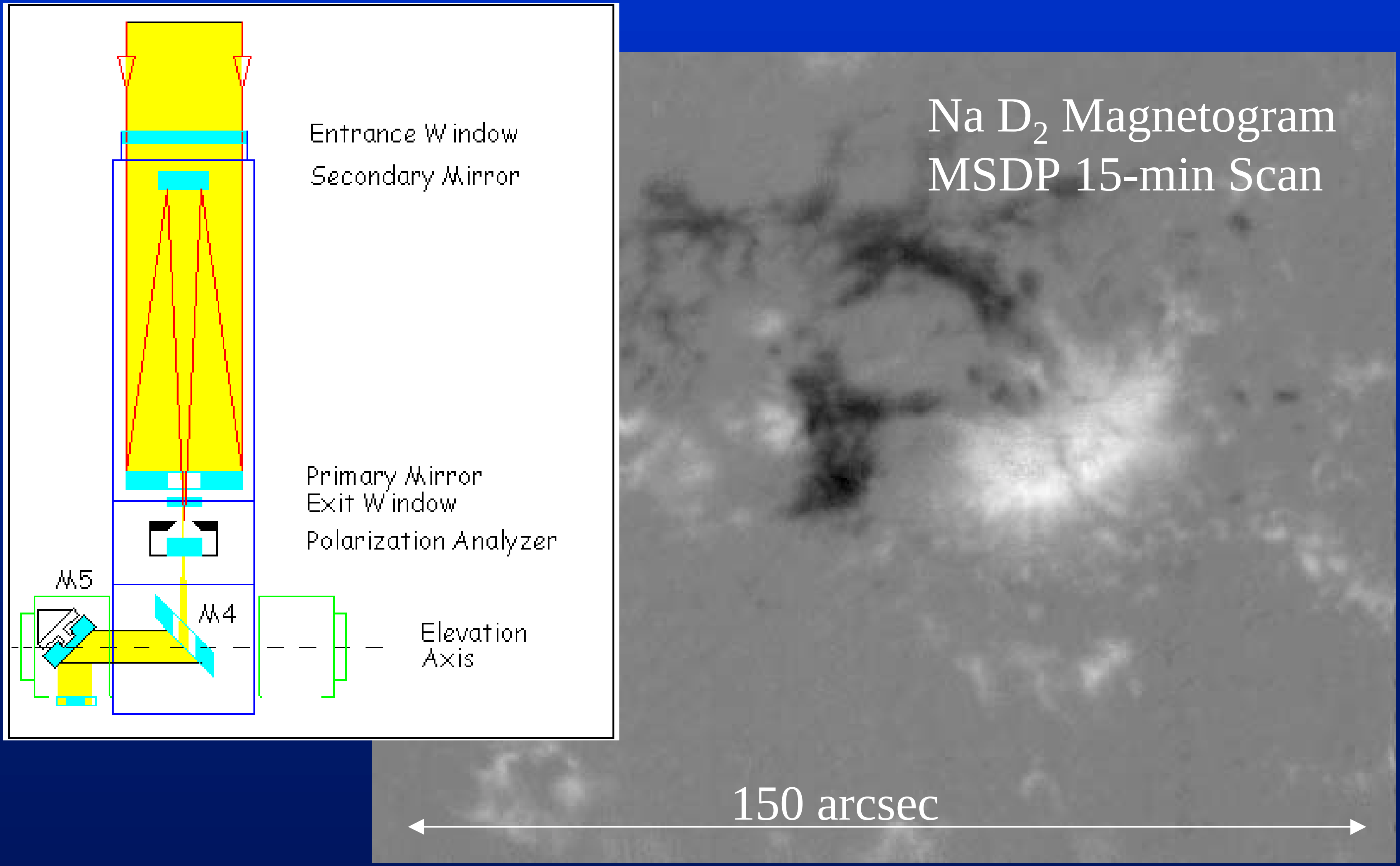
Courtesy H. Uitenbroek

THEMIS

Tenerife, Esp.

- 0.9m f/16.7 helium pressurized reflector
- Alt-az integrated dome mounting
- Commissioned: March 2000
- Main goal: high precision spectropolarimetry
- Strengths: good site, low instrumental polarization
- Weaknesses: vertical optical bench/complex optical paths
- Instruments:
  - MTR: multi-line spectroscopy
  - MSDP: double-pass imaging spectrometer
  - IPM: birefringent/Fabry-Perot imaging filter system

THEMIS

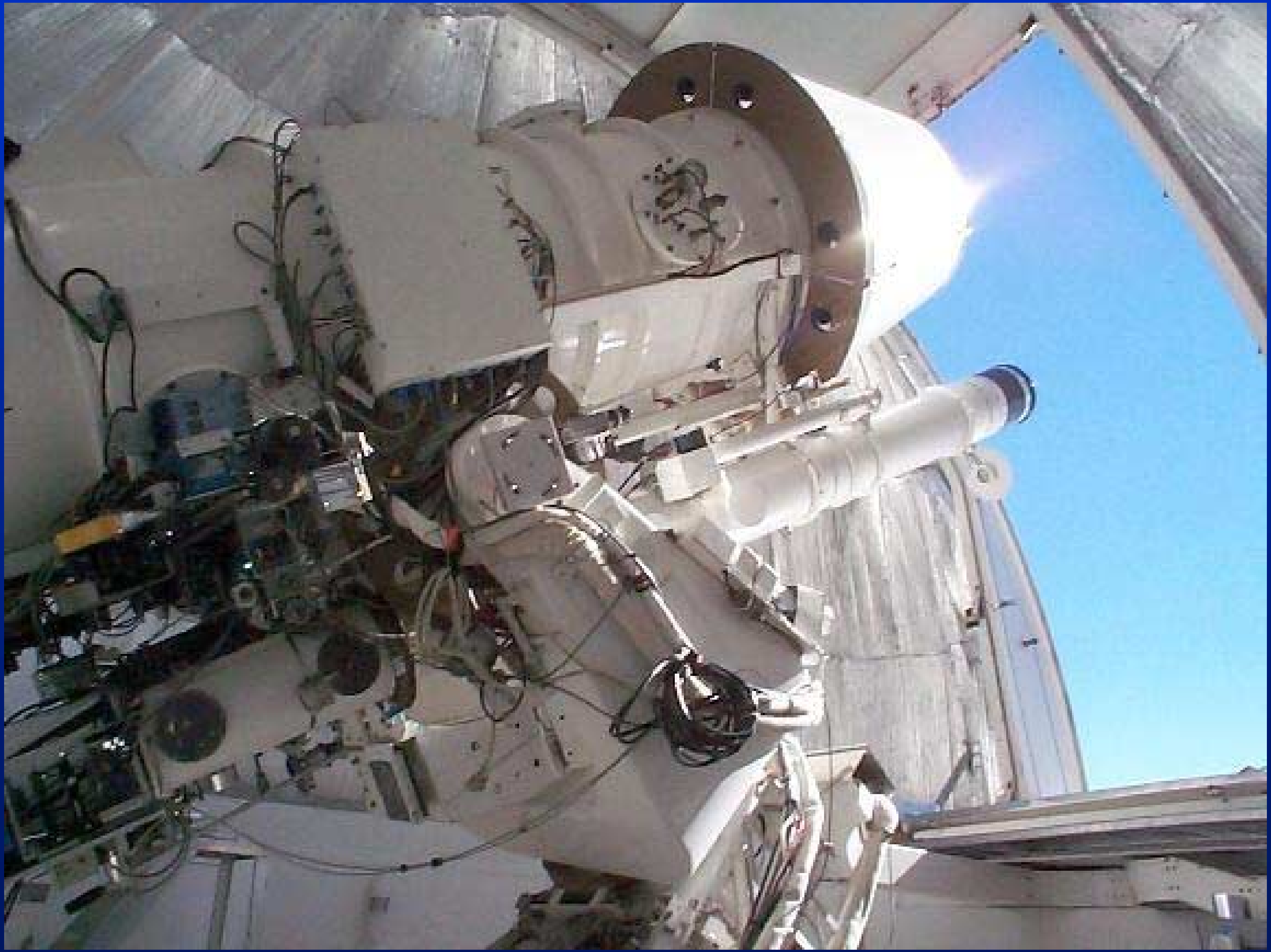

Entrance Window
Secondary Mirror
Primary Mirror
Exit Window
Polarization Analyzer
M5
M4
Elevation Axis
Na D_2 Magnetogram
MSDP 15-min Scan
150 arcsec

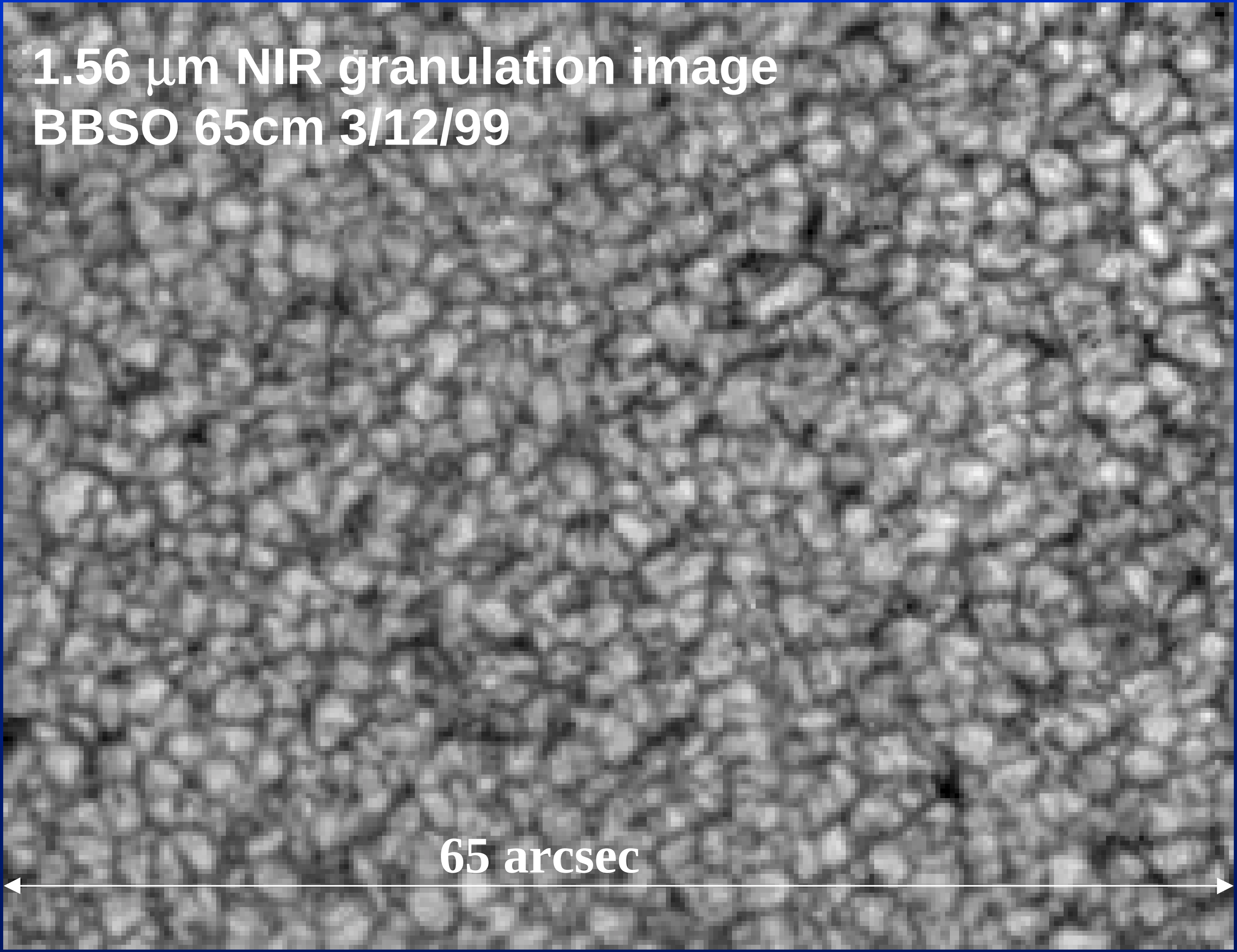
Big Bear Solar Observatory

Big Bear, Ca.

- 0.65m vacuum reflector
- Equatorial mount
- Commissioned: 1969
- Main goal: high resolution imaging and magnetograms
- Strengths: very good site, low instrumental polarization
- Weaknesses: dome seeing, instruments on telescope
- Instruments:
  - Video magnetograph
  - Birefringent narrow-band tunable filter
  - 0.2m full-disk Hα telescope

Big Bear





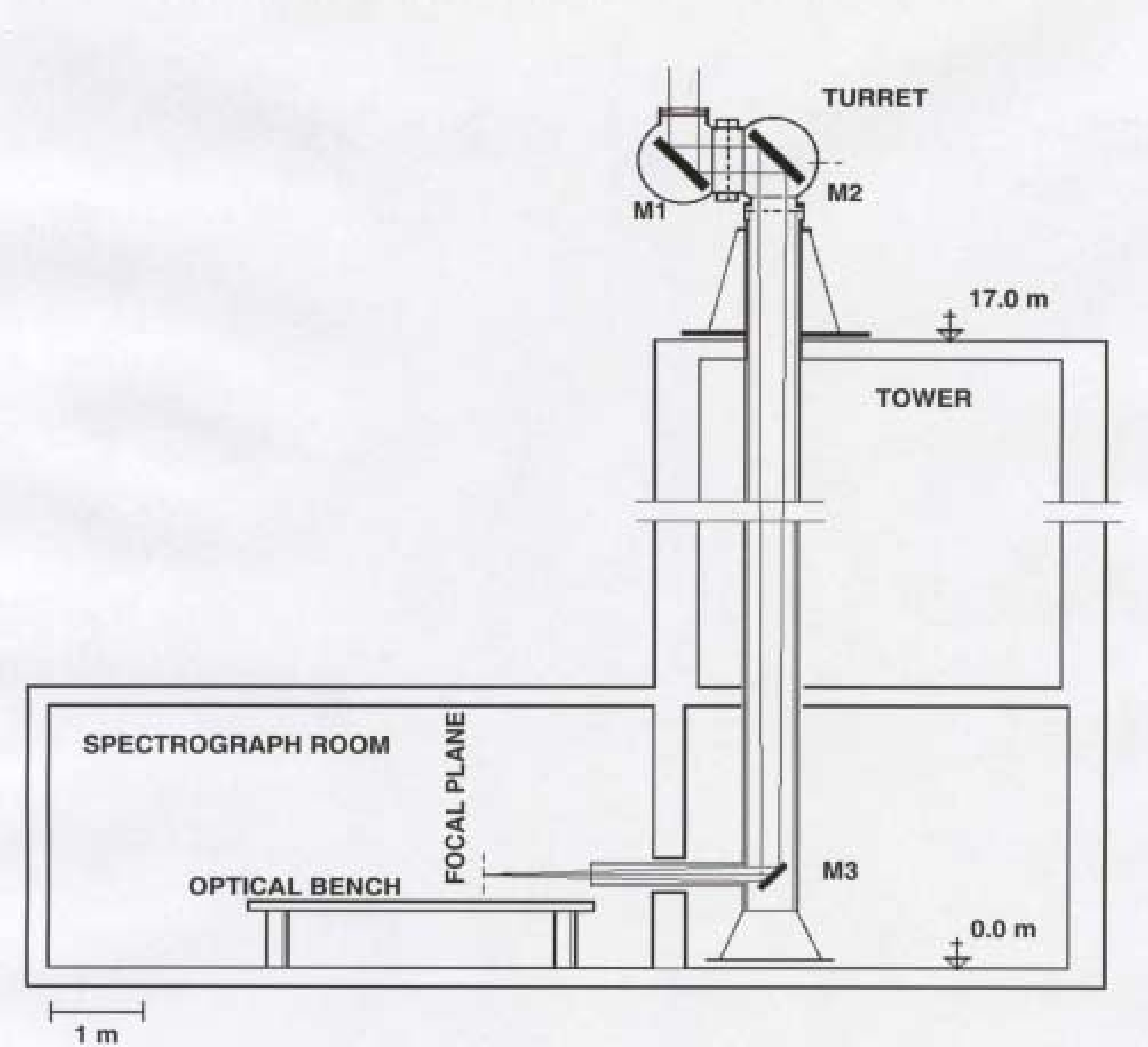
1.56 μm NIR granulation image
BBSO 65cm 3/12/99

Swedish Vacuum Solar Telescope

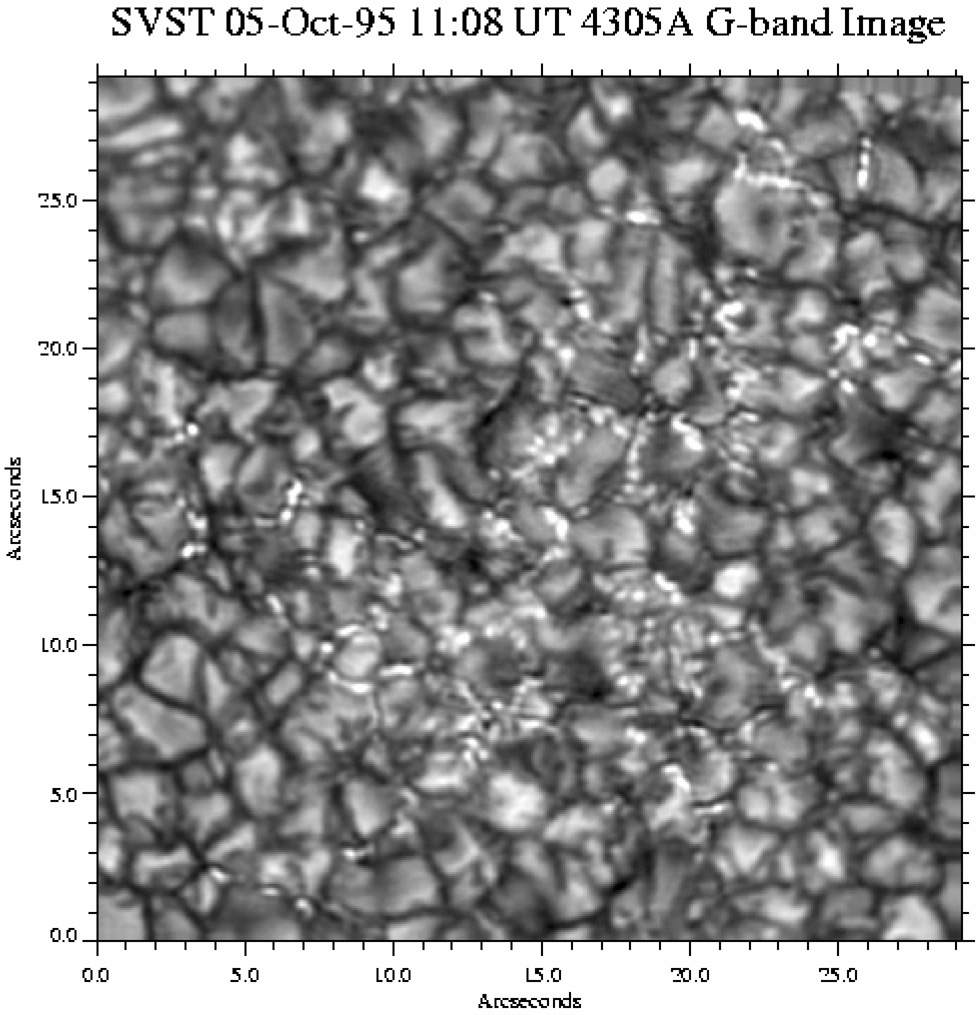
La Palma, Esp.

- 0.48m f/45 vacuum refractor
- Alt-az turret mount
- Commissioned: 1986
- Decommissioned: 2000
- Main goal: high resolution imaging
- Strengths: excellent site, simple optical paths and lab area
- Weaknesses: none – well, okay: image rotation, inst. polarization
- Instruments:
  - 3m Littrow spectrograph
  - SOUP: birefringent tunable narrow-band imaging filter
  - La Palma Stokes Polarimeter
  - Wide-band imaging filters (G-band, Ca II, etc.)

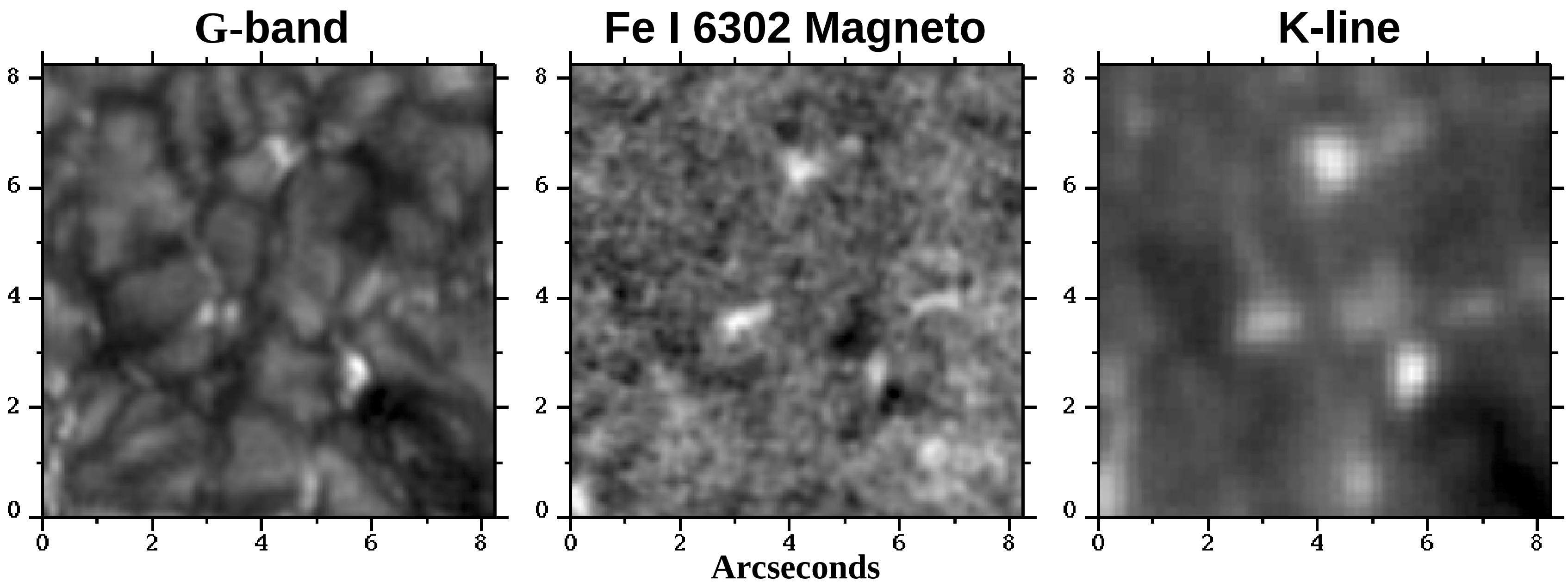
SVST
Optical Layout



SVST Phase Diversity Imaging



SVST



SVST Raw Image Comparison

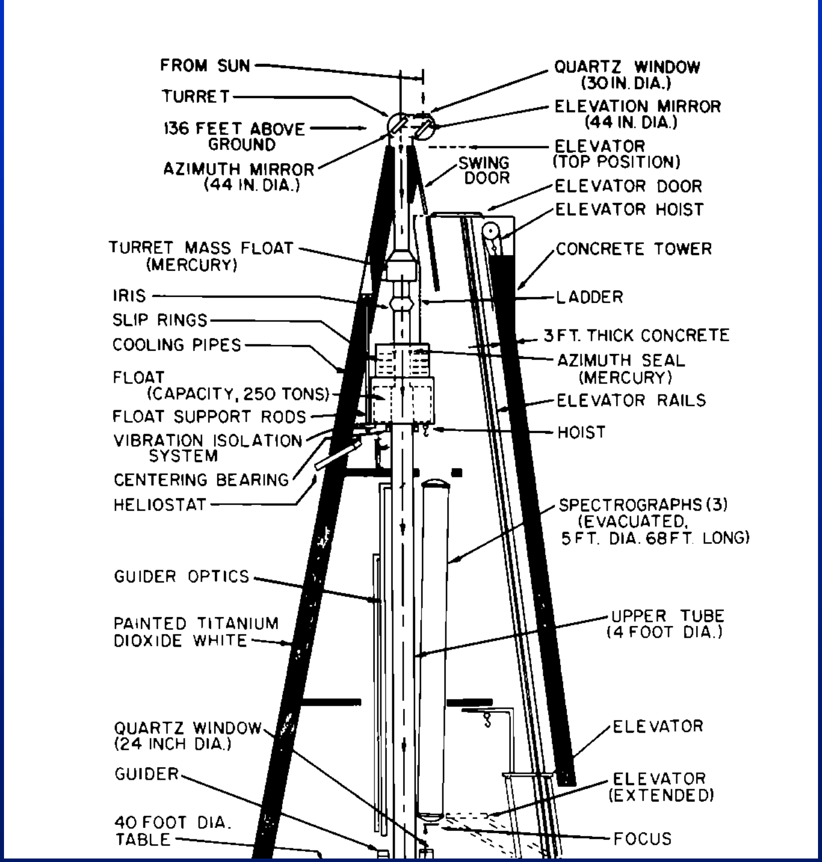
Dunn Solar Telescope

Sacramento Peak, NM

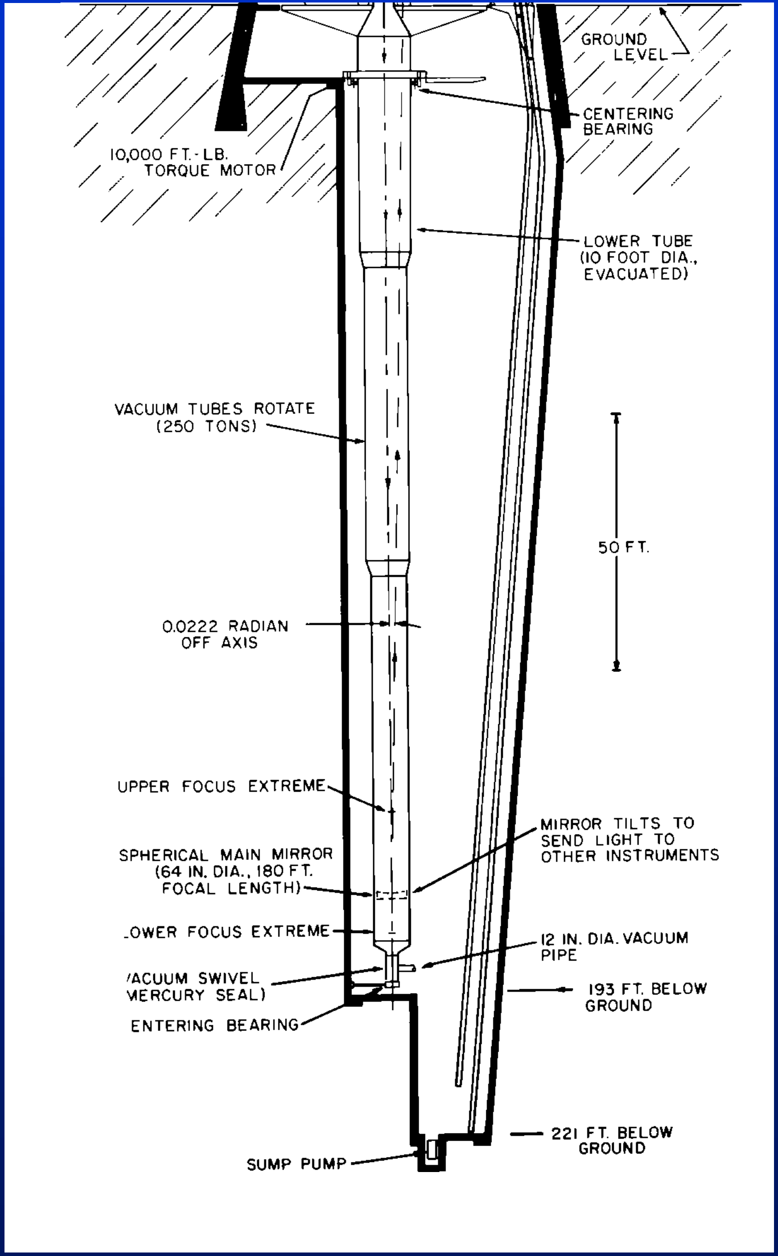
- 0.76m f/72 vacuum reflector
- Alt-az turret mount
- Commissioned: 1972
- Main goal: high resolution imaging and polarimetry
- Strengths: good site and design, adaptive optics
- Weaknesses: complex instrumentation
- Main Instruments:
  - Advanced Stokes Polarimeter: spectropolarimeter
  - UBF: birefringent tunable narrow-band imaging filter
  - Wide-band imaging filters (G-band, Ca II, etc.)

DST

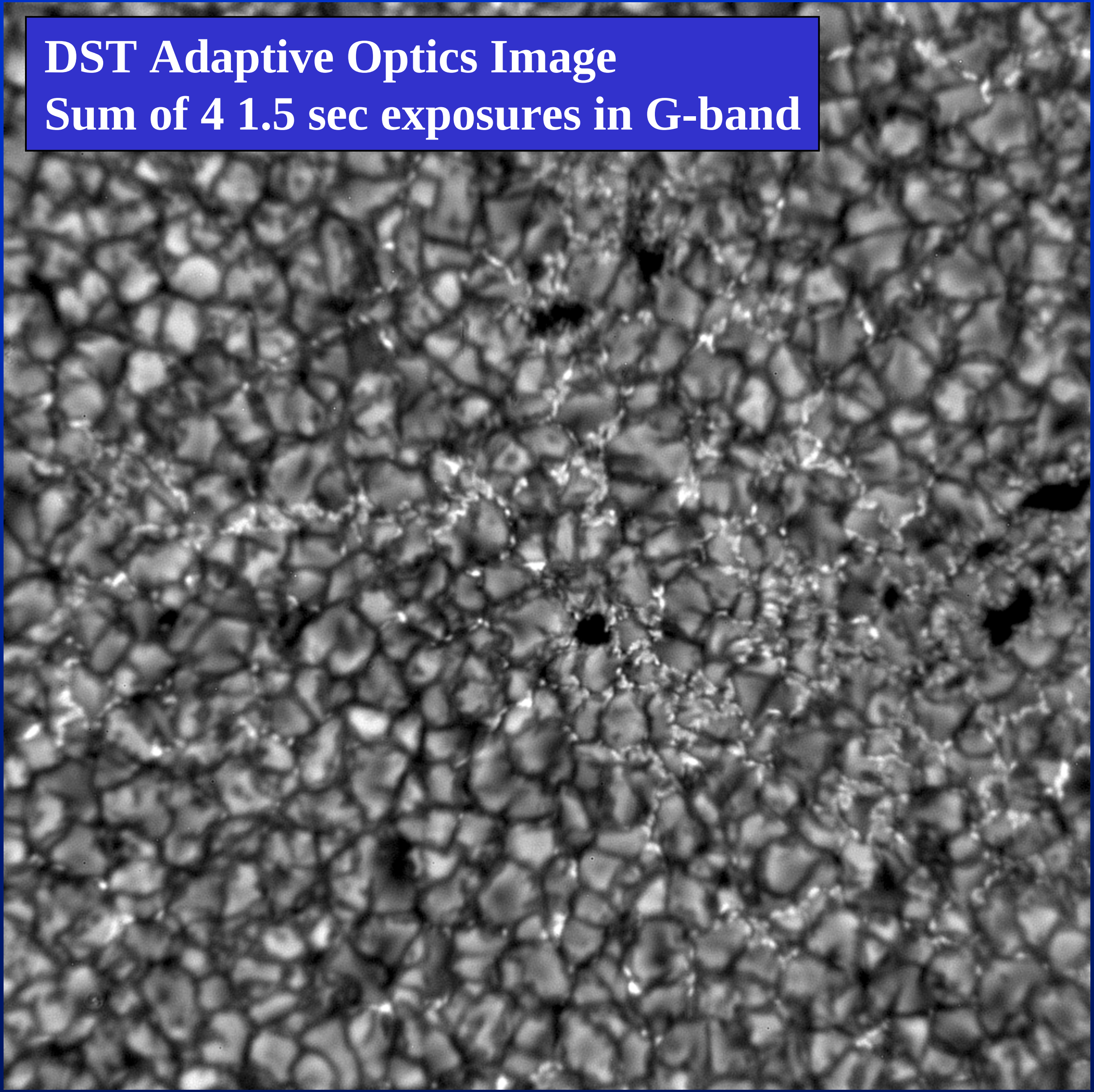
Optical Layout



Above Ground

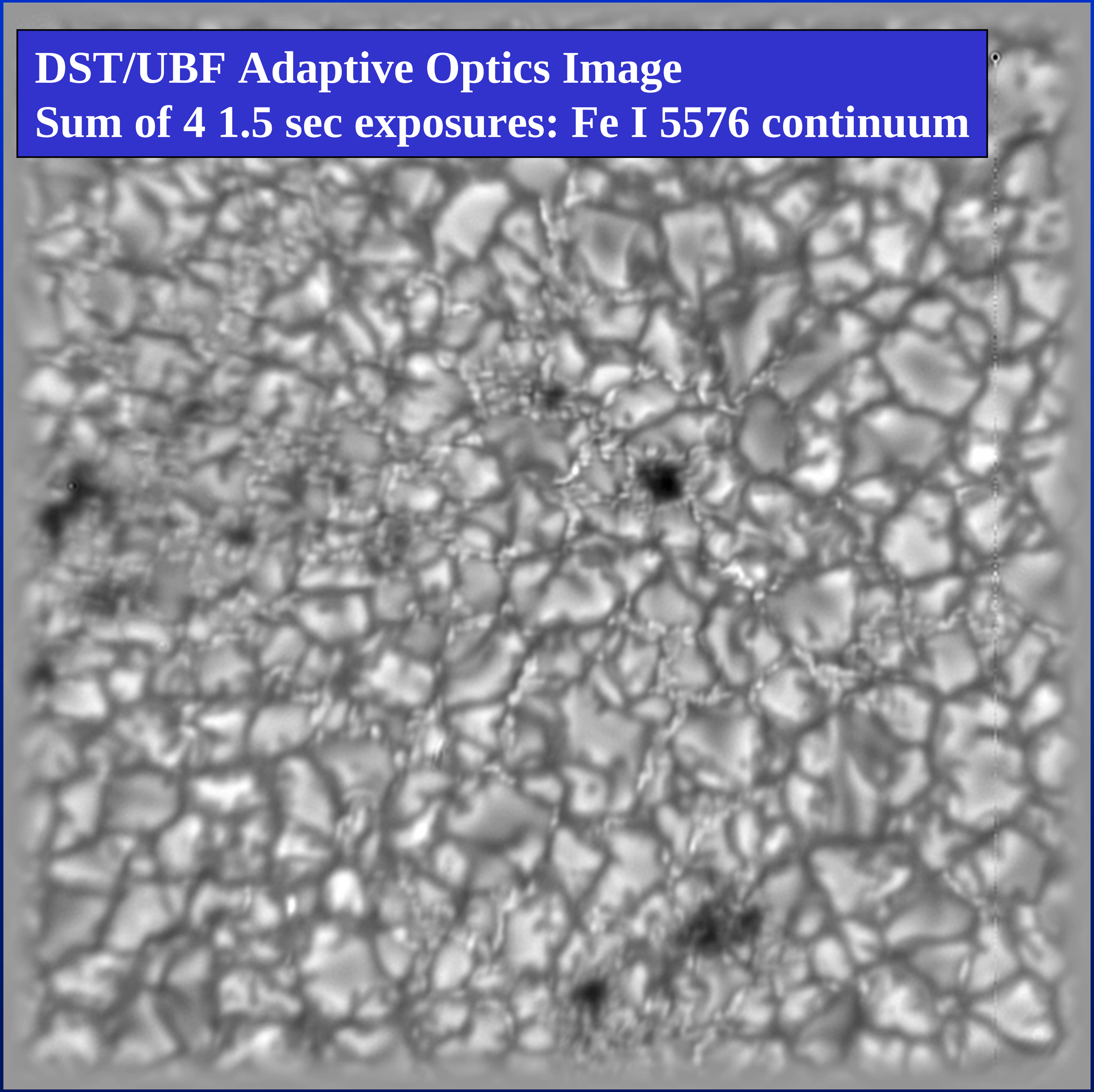


Below Ground

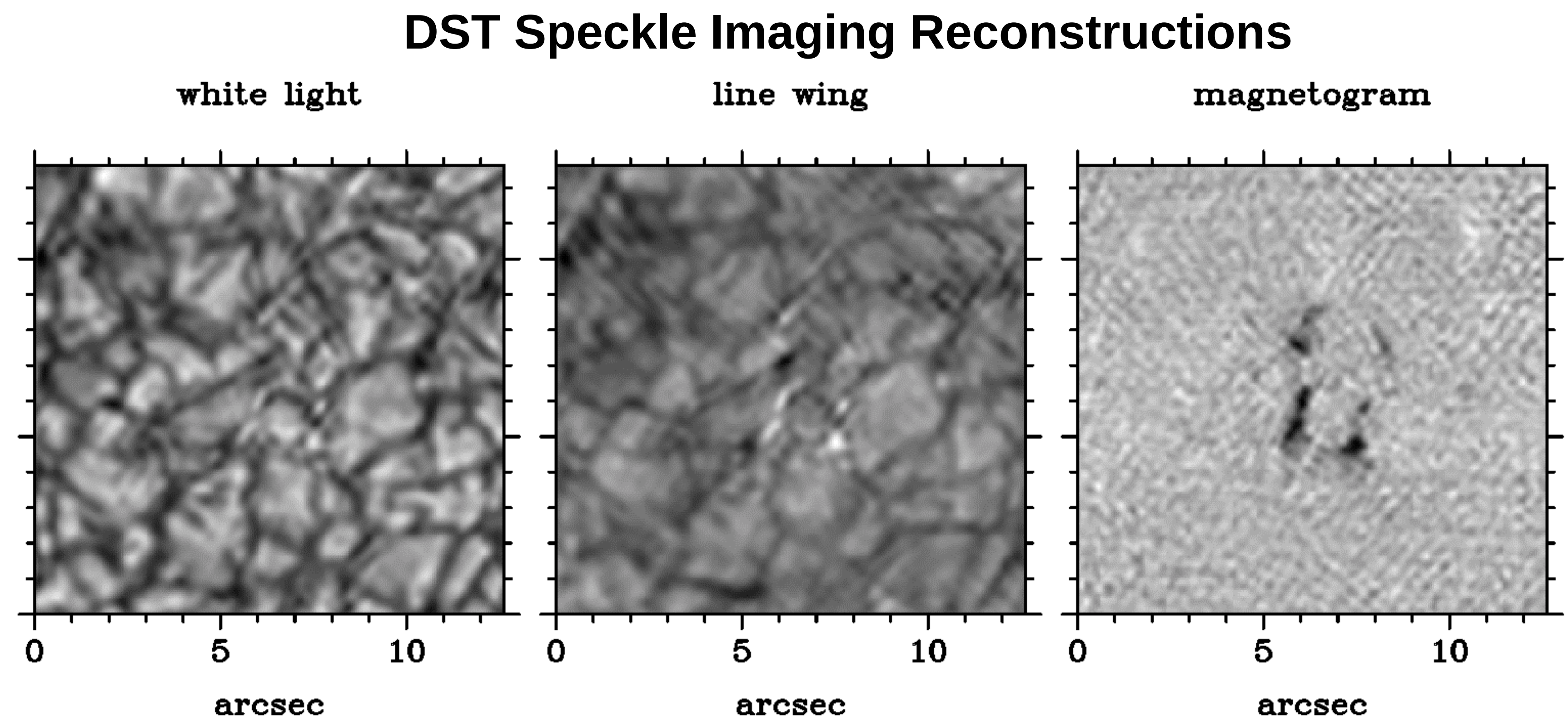


DST Adaptive Optics Image
Sum of 4 1.5 sec exposures in G-band

DST/UBF Adaptive Optics Image
Sum of 4 1.5 sec exposures: Fe I 5576 continuum



DST

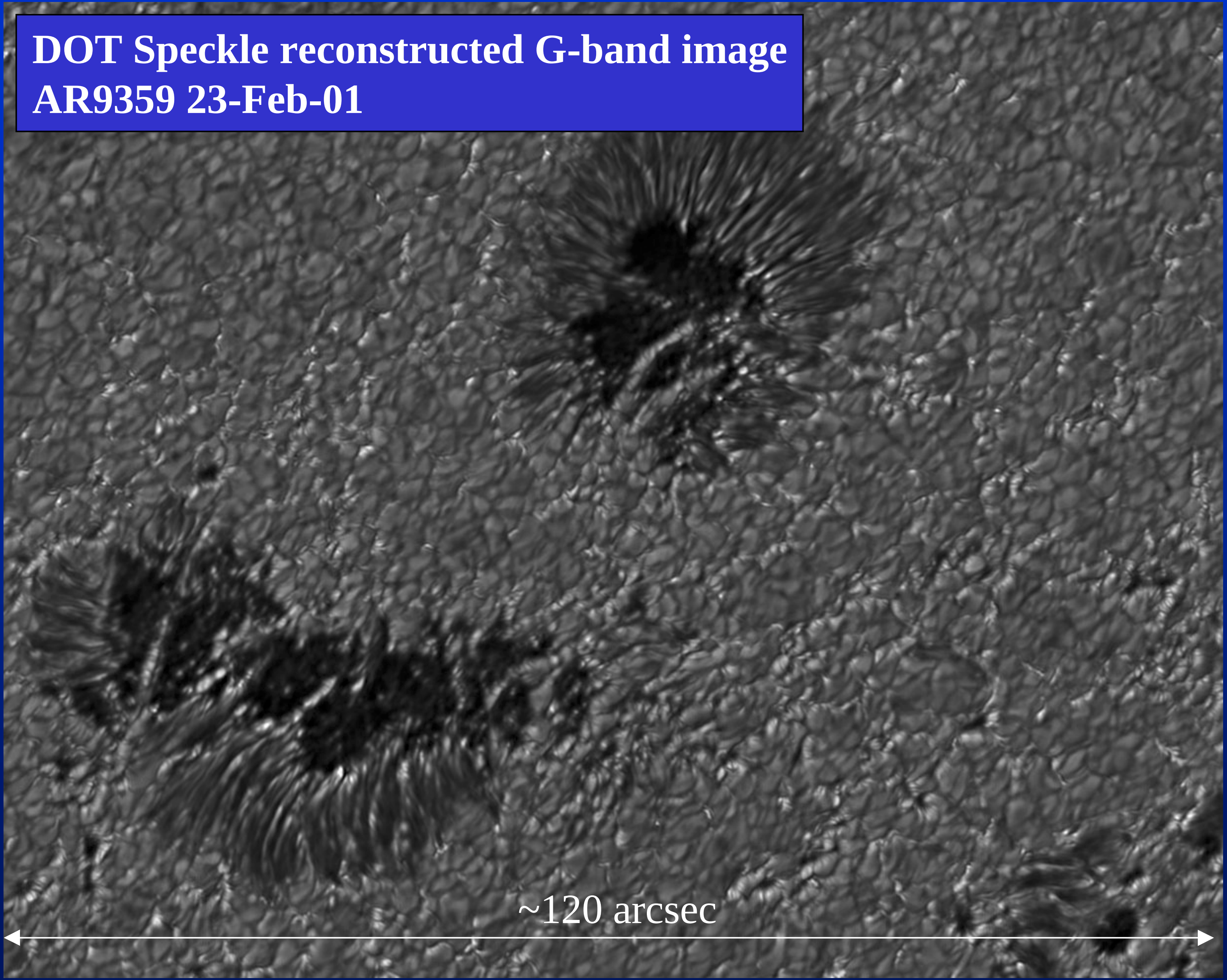

DST Speckle Imaging Reconstructions
white light
line wing
magnetogram
0
5
10
arcsec
0
5
10
arcsec
0
5
10
arcsec

Dutch Open Telescope

La Palma, Esp.

- 0.45m f/4.4 open-air reflector
- Equatorial mount
- Commissioned: 1998
- Main goal: high resolution imaging
- Strengths: excellent site, open design
- Speckle imaging reconstruction
- Weaknesses: inst. Mount on telescope
- Main Instruments:
  - Focal-plane CCD camera

DOT Speckle reconstructed G-band image AR9359 23-Feb-01



DOT

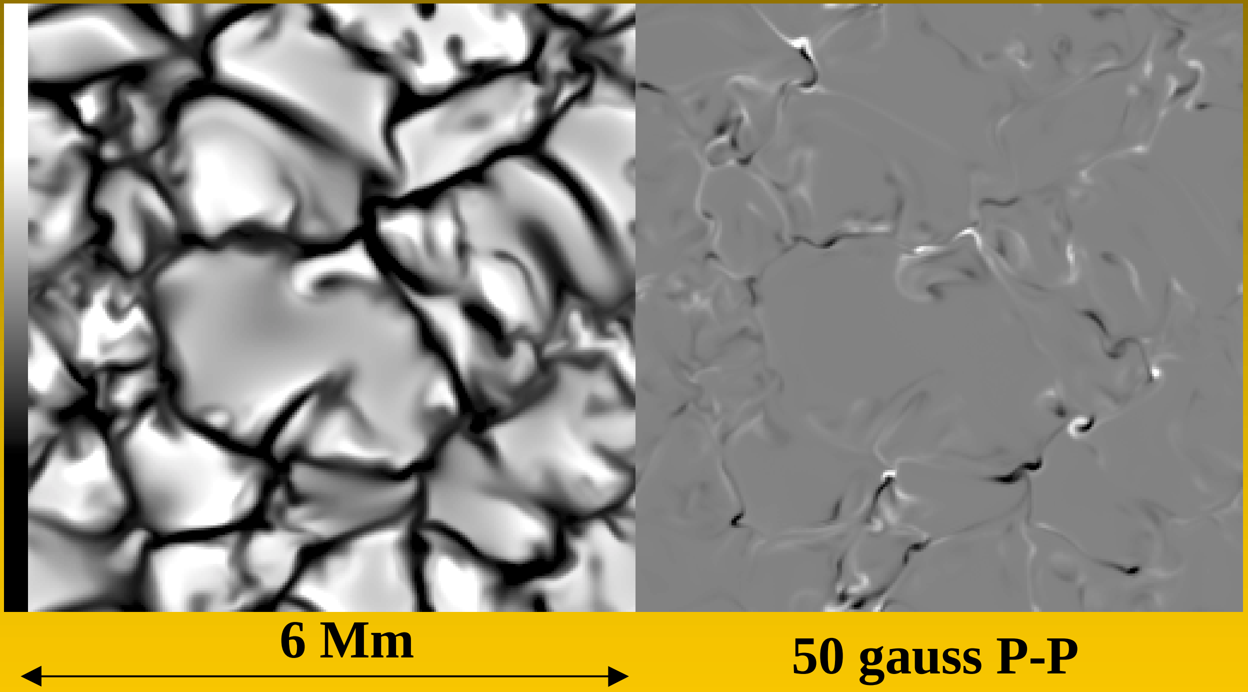
Speckle imaging movie: 22-Sep-99 Sunspot in G-band

Why We Need to do Better

- **Still not resolving the details of convection-flux interactions**
  - Spatial and temporal resolution of current telescopes is inadequate to capture the smallest scale dynamics of
    - Granulation
    - Sunspot penumbrae
    - Filaments
- **Polarimetry is photon starved**
  - Vector magnetogram resolution is compromised by need to integrate over several seconds to get adequate S/N
- **Progress in solar science requires "movie processing" not just image processing**
  - Need to have uniform high resolution time series in order to track formation and dispersal of magnetic flux

Numerical MHD Simulation

1 gauss horizontal field at box bottom
23 km grid resolution

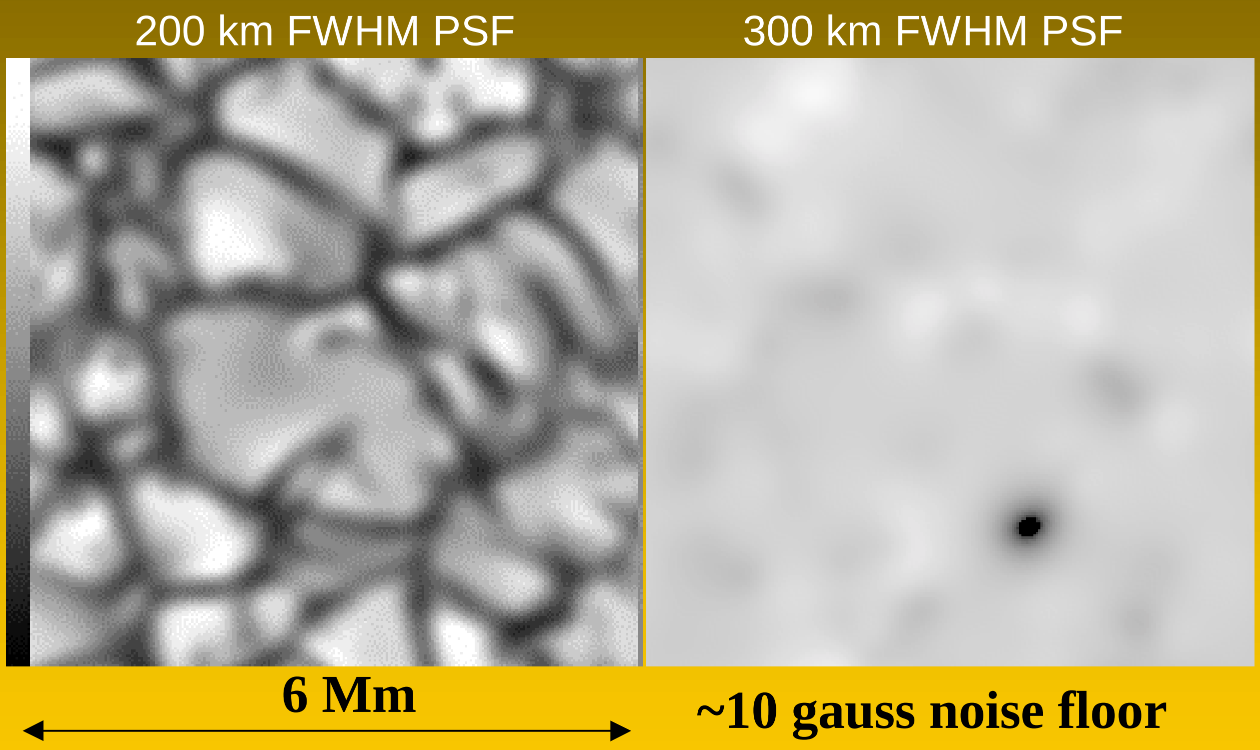


50 gauss P-P
3 gauss RMS

Courtesy Åke Nordlund

Numerical MHD Simulation

1 gauss horizontal field at box bottom

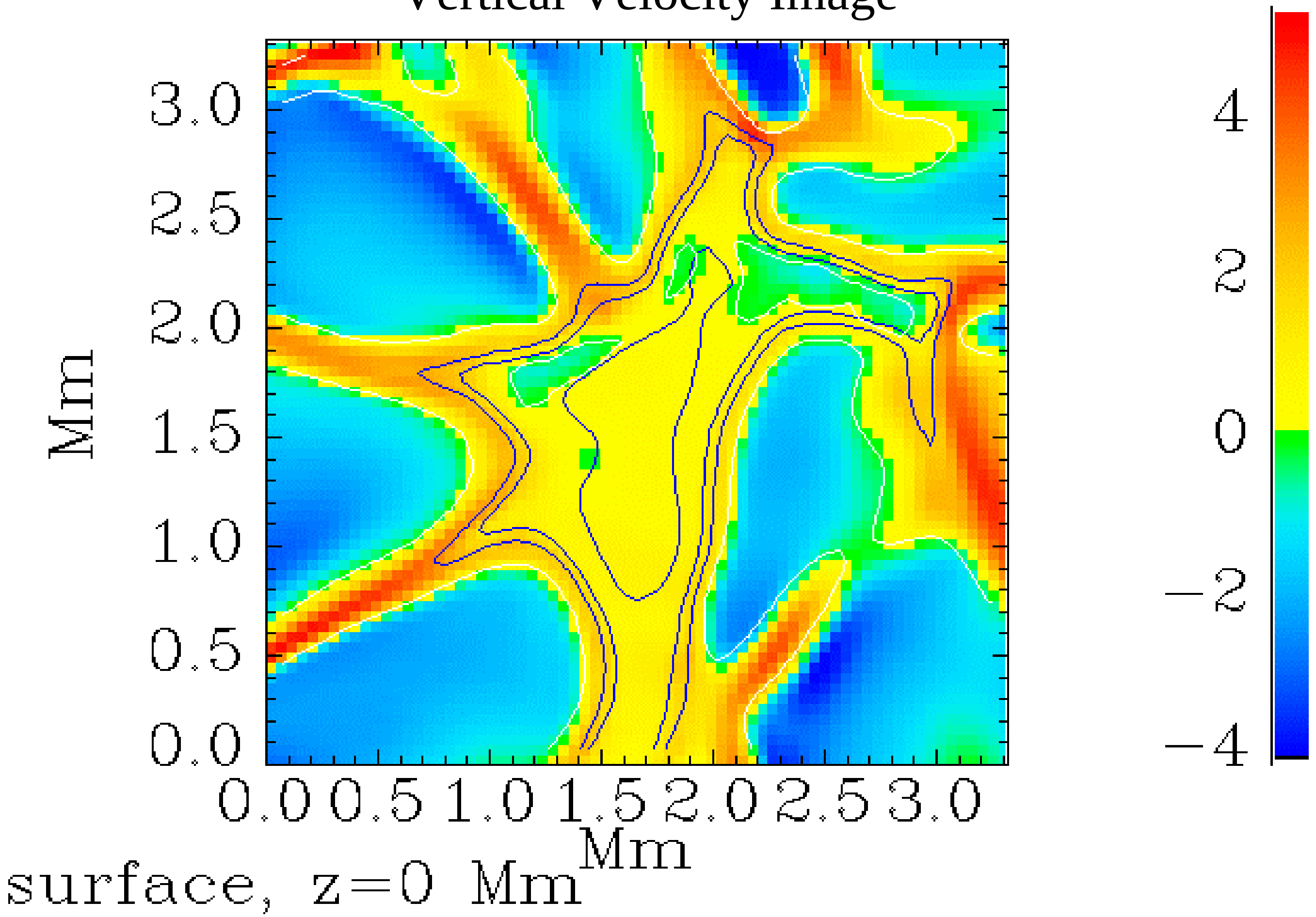


Courtesy Åke Nordlund

Numerical MHD Simulation

Micropore Formation Case: 1.5 kgauss field

Vertical Velocity Image



Courtesy Bob Stein

Why We Need to do Better

High spatial resolution polarimetry is photon starved

- **Some simple calculations with a few assumptions**:
  - Unobscured aperture
  - 10% overall efficiency (including detectors)
  - Maximum horizontal motion of 5 km/s
  - Solar image is not allowed to evolve more than half a pixel
  - Spectral resolution of 150,000
  - Nyquist sampled in space (diffraction-limited) and spectrum
  - Look at a single spatial and spectral pixel
- **Need photons for high sensitivity:**
  - 10^{-5} requires 10^{10} photons: typical CCD exposure 10^5, need 10^5 exposures
- **Need photons for high spatial resolution:**
  - $3 \cdot 10^8$ photons/Å/s per diffraction-limited resolution sampling element
  - high spatial resolution magnetic field studies: 0.1 Å, 0.02s, 1% efficiency: only 6000 photons per exposure
  - high spatial resolution polarimetry is rarely very sensitive

Courtesy C. Keller

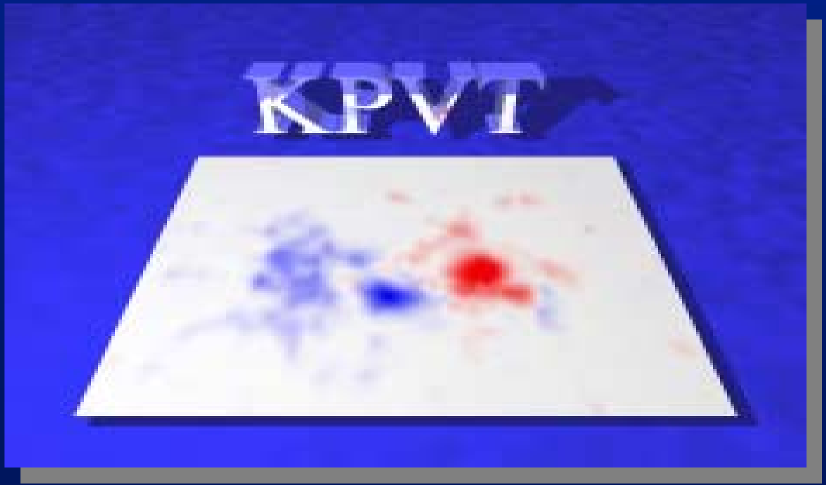
The Future

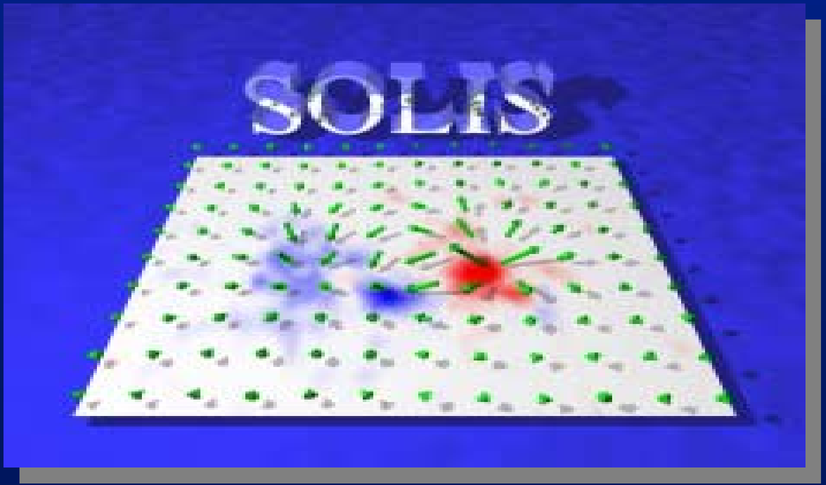
- **SOLIS**: Synoptic Optical Long-Term Investigations of the Sun
  - Replacement for the KPVT
  - Full-disk 1 arcsec vector magnetograms, several per day
- **NSST**: New Swedish Solar Telescope
  - Replacement for the SVST: 1m refractor
  - Very high resolution imaging and polarimetry, adaptive optics
- **GREGOR**: Gregorian Telescope on Tenerife
  - Replacement for the Gregory Coude Telescope: 1.5m reflector
  - Very high resolution imaging and polarimetry, adaptive optics
- **ATST**: Advanced Technology Solar Telescope
  - Completely new instrument and site: 4m off-axis reflector, adpative optics
  - Extremely high resolution imaging
  - Very high sensitivity polarimetry
  - NIR imaging and polarimetry
  - Limited coronagraphic capability

SOLIS

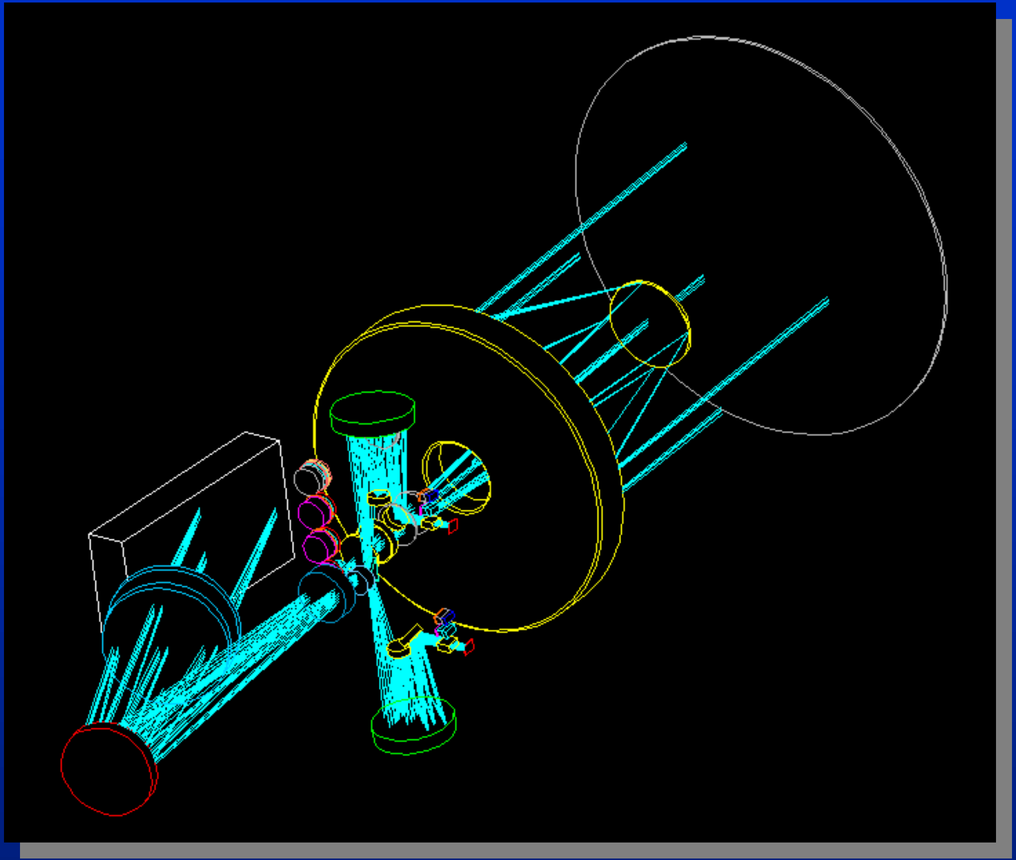
Synoptic Optical Long-term Investigations of the Sun

- 0.5m Vector Spectromagnetograph
- 0.1m Full-disk patrol
- Integrated sunlight spectrometer
- Kitt Peak site
- Equatorial mount
- Status: mount complete, optics in fab, cameras in test





SOLIS/VSM



- Capabilities
  - Full-disk scan in 900 sec
  - Spatial resolution: 2 arcsec
  - Spectral resolution: 200,000
  - Polarimetric sensitivity: 2×10^{-4}
- Polarimetry: 3/day each of
  - Fe I 630.15, 630.25nm: I,Q,U,V
  - Ca II 854nm: I,V
  - He I 1083nm: I
- Instrument Features
  - 0.5m f/6.6 modified RC telescope: low instrumental polarization
  - Active secondary, helium cooled
  - Active Littrow grating, 79 lines/mm
  - Offner reimaging optics: splits spectrum to two cameras
  - 1024 x 256 16µm pixel CCD, backside illum, <35 e- read noise @ 300 f/sec

NSST

New Swedish Solar Telescope*

- 0.92m f/21 refractor
- La Palma site
- Alt-az turret on 17m tower
- Vacuum beam path
- Wavelength range: 390 – 900 nm
- Adaptive optics on the lab bench
- Simplest possible optical paths
  - Only 3 elements between atmosphere and adaptive optics
  - Field lenses/mirrors allow flexible observing modes
- Lead Institution: Swedish Royal Academy, Stockholm Observatory
- Status: turret installed, optics in final figuring; First light: 2002

* Provisional name

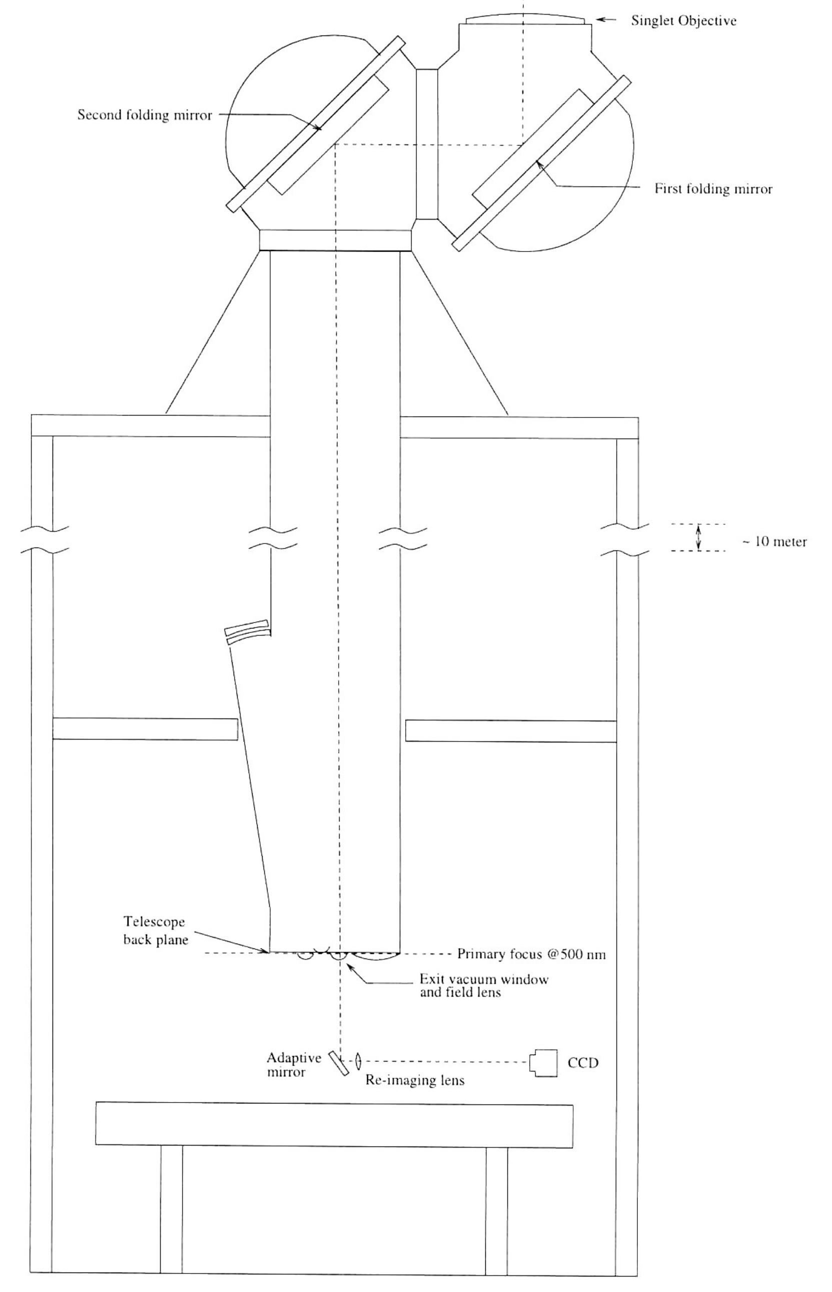
NSST

- **Capabilities**
  - Singlet primary lens and relay mirrors: $\lambda/40$ – $\lambda/30$ wavefront error
  - Adaptive optics corrects up to 15th Zernike mode
  - 390nm PSF HWHM: 0.10 arcsec = 72 km
  - 900nm PSF HWHM: 0.21 arcsec = 145 km
- **Observing modes**
  - High-resolution narrow-band
  - High-resolution achromatic Schupmann
  - Low-resolution full-disk patrol
- **Instruments**
  - Wide-band imaging filters
  - SALAD: imaging vector polarimeter
  - LPSP: La Palma Stokes Polarimeter on 2m Littrow spectrograph
  - ZIMPOL II

NSST

Narrow-band Observing Mode

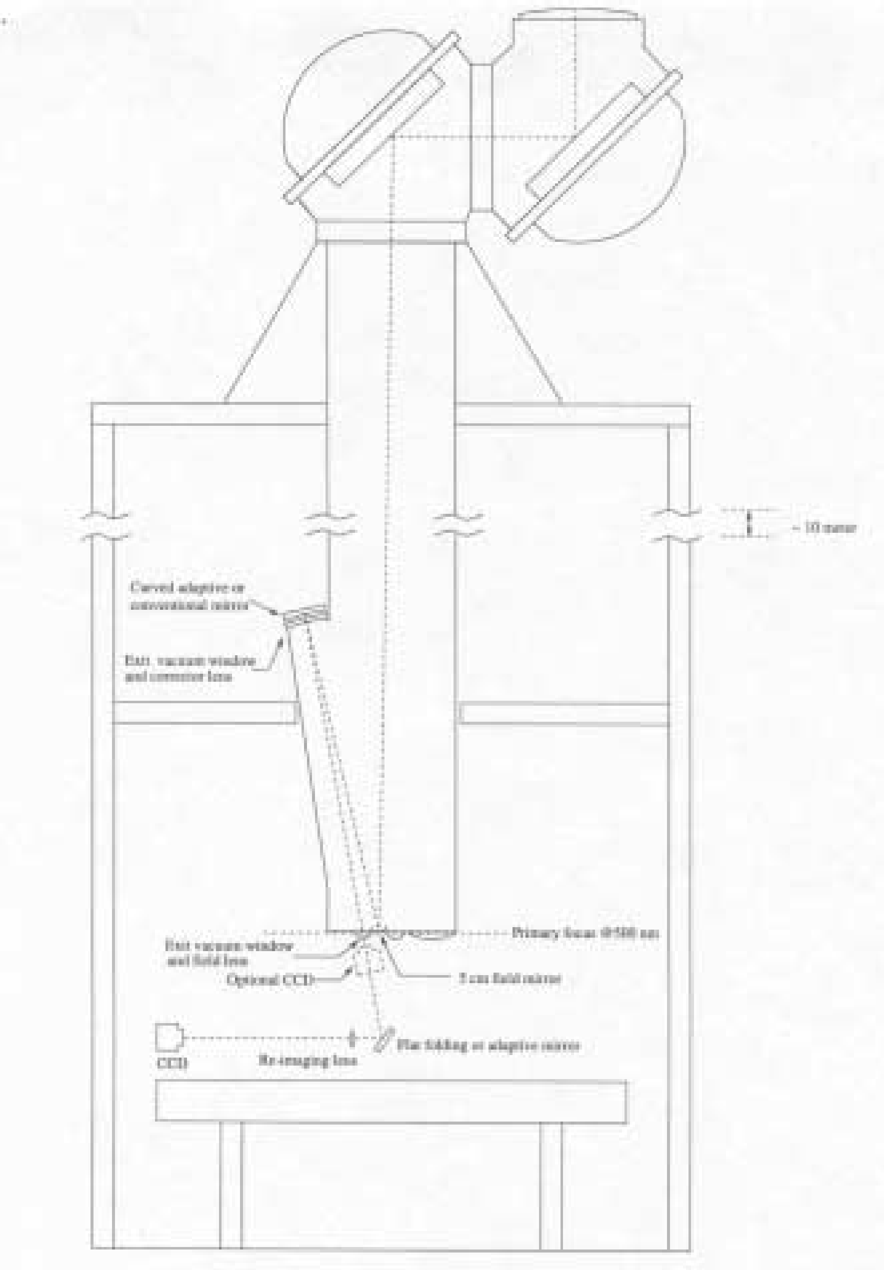
- Advantages
  - Simplest possible optical path gives maximum image quality at camera
- Disadvantages
  - No correction for singlet primary lens chromatic aberration: only one wavelength in focus at camera and no spectrographic capability



NSST

Wide-band Observing Mode

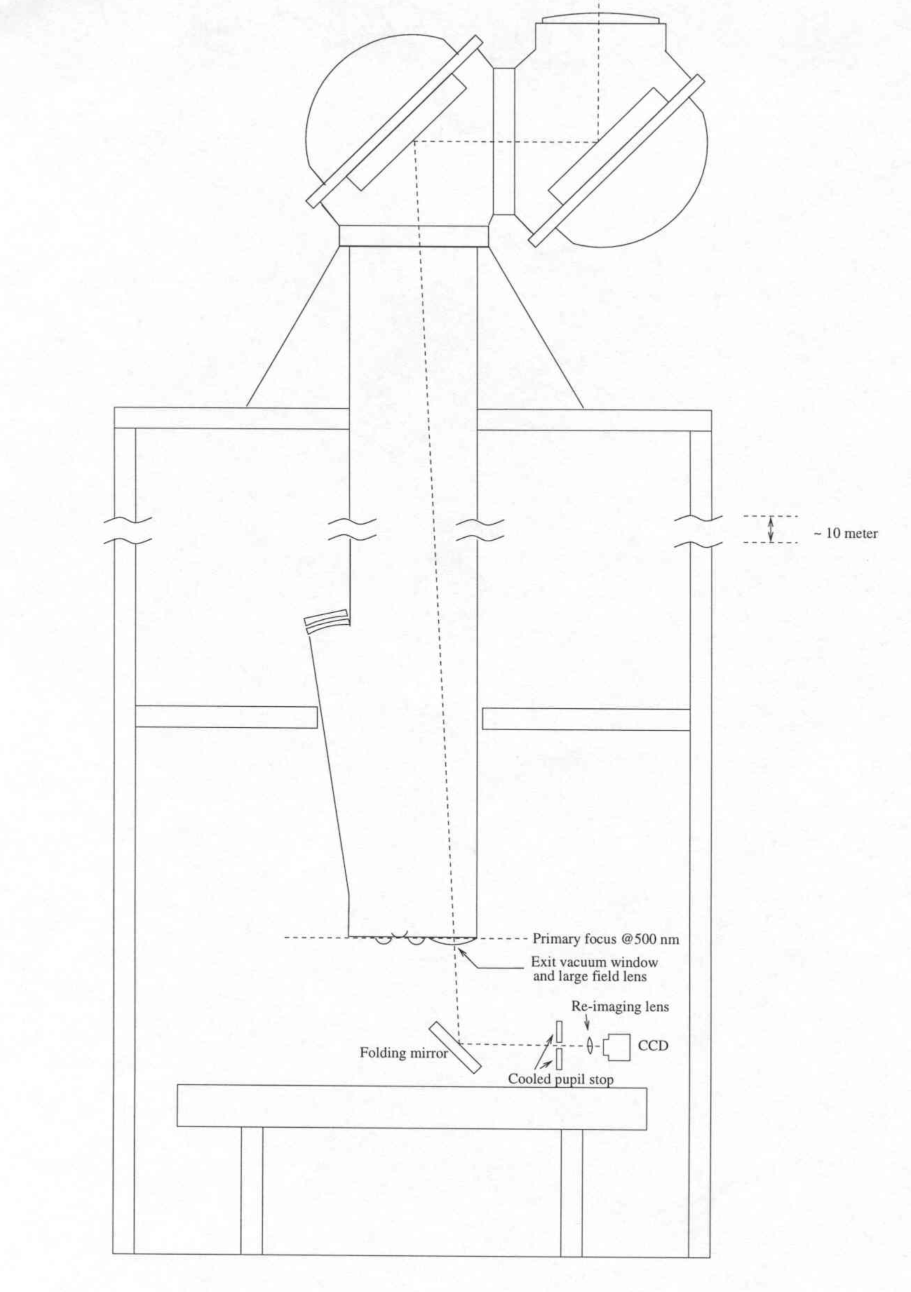
- Schupmann mirror completely corrects chromatic aberration of singlet primary and moves focus out of vacuum (1.5% magnification).
- Advantages
  - Allows multiple cameras imaging different wavelengths at same focal plane or use of spectrograph
  - Schupmann mirror can be adaptive
- Disadvantages
  - FOV restricted by strong power on corrector system
  - Adds 6 optical surfaces to beam path



NSST

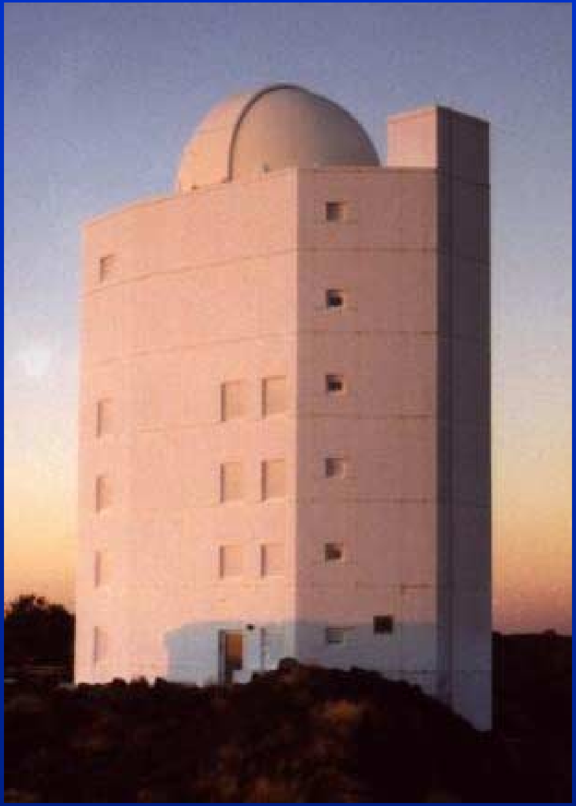
Full-disk Observing Mode

- Large field lens reimages primary at cooled aperture stop
- Aperture stop of 10cm and reimaging lens give full-disk FOV with ~1 arcsec/10 µm pixel
- Uses:
  - Full-disk patrol
  - “Poor-seeing” coordination with satellites
  - Fast Stokes maps of active regions



GREGOR

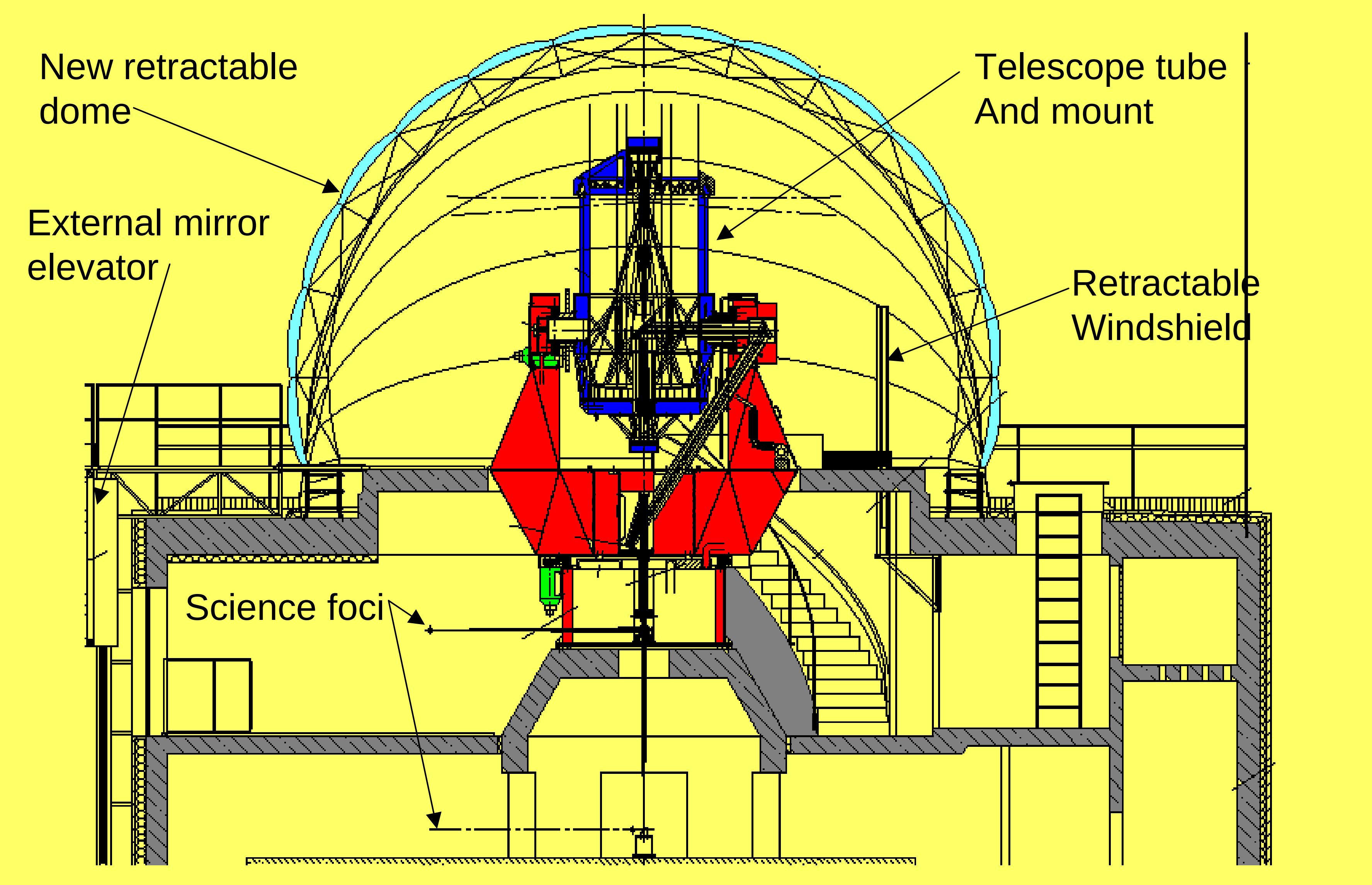
- 1.5m “Triple Gregorian”
- Site: Izaña, Tenerife
- Open Telescope tube, fully retractable dome (thanks to DOT)
- Alt-az mount
- Lightweighted structure
- Integrated adaptive optics system
- Focus redirectable to two laboratories
- FOV 300 arcsec, f_{eff} = 75m, F_{sys}/50
- Low Instrumental Polarization
- NIR and possibly TIR capability
- Dead reckoning pointing and tracking
- Lead Institution: Kippenheur Institut for Sonnenphysik
- Status: proposal accepted?



Gregory Coude Telescope
Site of the new GREGOR

GREGOR

Cross Section



New retractable dome

Telescope tube And mount

External mirror elevator

Retractable Windshield

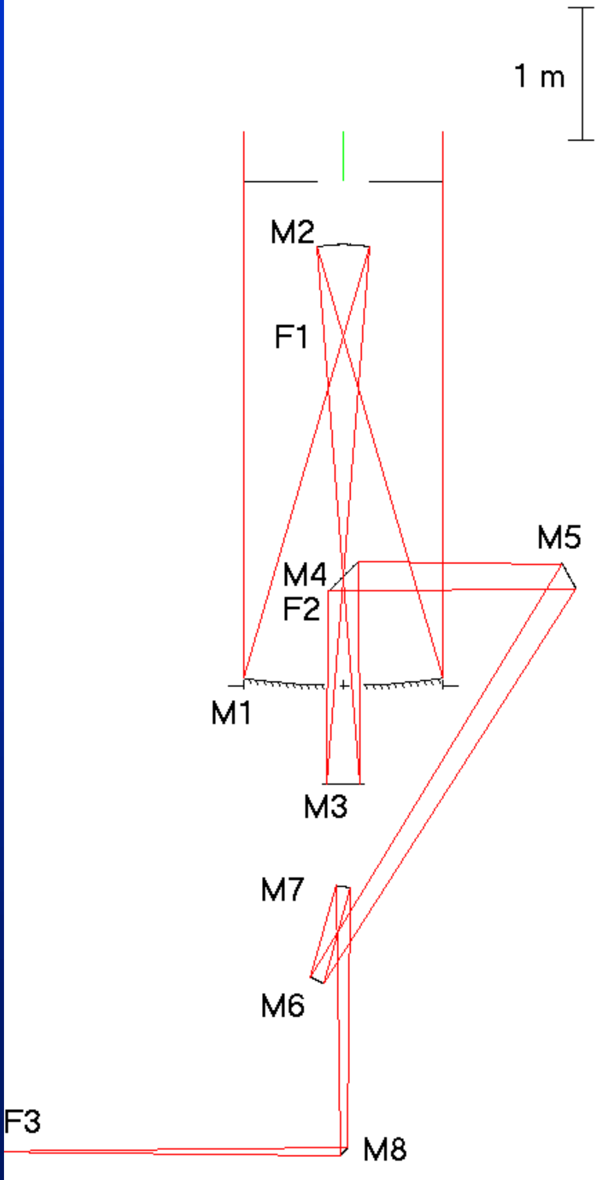
Science foci

GREGOR

Optical Layout

- Triple Gregorian optics
- F/1.75 1.5m SiC primary
- 300 arcsec FOV at F1
- Polarimetric calibration optics at F2
- 110mm pupil at M6 and M7 for adaptive optics
- F/50 tertiary focus, F_{eff} = 75m
- 400nm PSF HWHM: 0.06 arcsec = 41 km
- 1.56μm PSF HWHM: 0.22 arcsec = 160 km

- AO system
  - 66 degrees-of-freedom (corrects to Z10) @150Hz
  - Goal: Strehl ratio > 0.5 for 20% of time



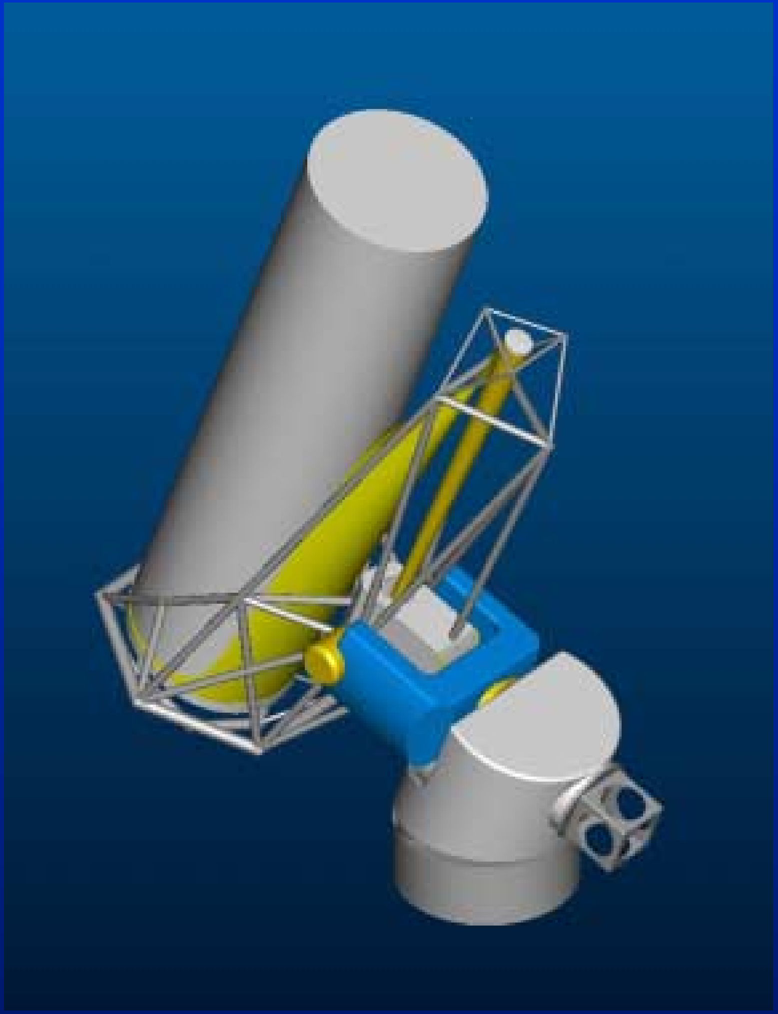
GREGOR

Instrumentation

- **Filtergraph**
  - Redeployment of Gottingen FPI from VTT
  - Installation in main observing room
- **UV Spectropolarimeter**
  - Redeployment of Freiburg POLIS from VTT
  - Installation in main observing room
- **General Purpose Grating Spectrometer**
  - Refurbishment of present Czerny-Turner from GCT
  - Installation in spectrograph room

ATST

Advanced Technology Solar Telescope



- 4m f/4 active off-axis parabolic primary
- Gregorian secondary (and cooling tower)
- Site: ??
- Open telescope structure, retractable dome
- Alt-az mount (not equatorial as shown!)
- Very low scattered light (no spiders)
- FOV goal: 5 arcmin, min = 3 arcmin
- Actively cooled optics: ambient temps.
- Integrated AO
- Wavelength coverage: 350nm – 35µm
- Coronagraphic capabilities (off pointing)
- Lead institute: National Solar Observatory
- Status: proposal to NSF for design study in final draft

ATST

- Capabilities/Goals
  - Scattered light < 10^{-5} at $r/R_{sun} = 1.1$ and $\lambda > 1\mu m$
  - 400nm PSF HWHM: 0.02 arcsec = 15 km
  - 4µm PSF HWHM: 0.21 arcsec = 153 km
- Observing Modes
  - Ultra-high resolution imaging
  - 10^{-4} Polarization sensitivity with <1 second integrations
  - High resolution NIR imaging and spectroscopy
  - NIR coronagraphic imaging and polarimetry (if offpointing is ok)
- Baseline Instruments
  - Tunable filter visible imager
  - Visible vector spectropolarimeter
  - NIR imager
  - NIR spectrograph

ATST

Major Challenges

- Everything
- But especially
  - Thermal control: Primary focus heat stop has ~2.4 MW/m^2 irradiance
    - Active liquid or air cooled optics is a must
    - TIR capability requires ambient temperatures on all telescope structure
  - Contamination control: open design has high particulate loading
    - Scattered light and IR emissivity may require frequent cleaning of mirrors
  - Site: needs very large r_0 (~20-30cm) for significant periods of time
  - Adaptive Optics:
    - DOF ~ $(D/r_0)^2$: r_0 20cm -> 400 DOF adaptive mirror -> 1200 actuators
    - Off-axis design puts skewed pupil on AO mirror
    - Alt-az mount + off-axis optics rotates a variable phase pupil across the AO mirror
    - Multi-conjugate AO required to correct over full FOV

Future Instrumentation for Solar and Stellar Research at Radio Wavelengths

T. S. Bastian

NRAO

Ground Based Radio Initiatives: the Next 10 yrs

- EVLA – Expanded Very Large Array
- ALMA – Atacama Large Millimeter Array
- CARMA – Combined Array for Research in Millimeter Astronomy
- FASR – Frequency Agile Solar Radiotelescope
- ATA – Allen Telescope Array, formerly the 1HT.
- LOFAR - a LOw Frequency ARray

And Beyond …

- SKA – Square Kilometer Array

How do Radio Telescopes Image the Sky?

High resolution imaging radio telescopes exploit Fourier synthesis techniques.

The basic element is not a single antenna, but a pair of antennas: an interferometer.

The signals from a pair of antennas are multiplied and integrated – correlated - after compensating for the difference in geometrical path length.

The output from the correlator is a single Fourier component of the radio brightness distribution on the sky.

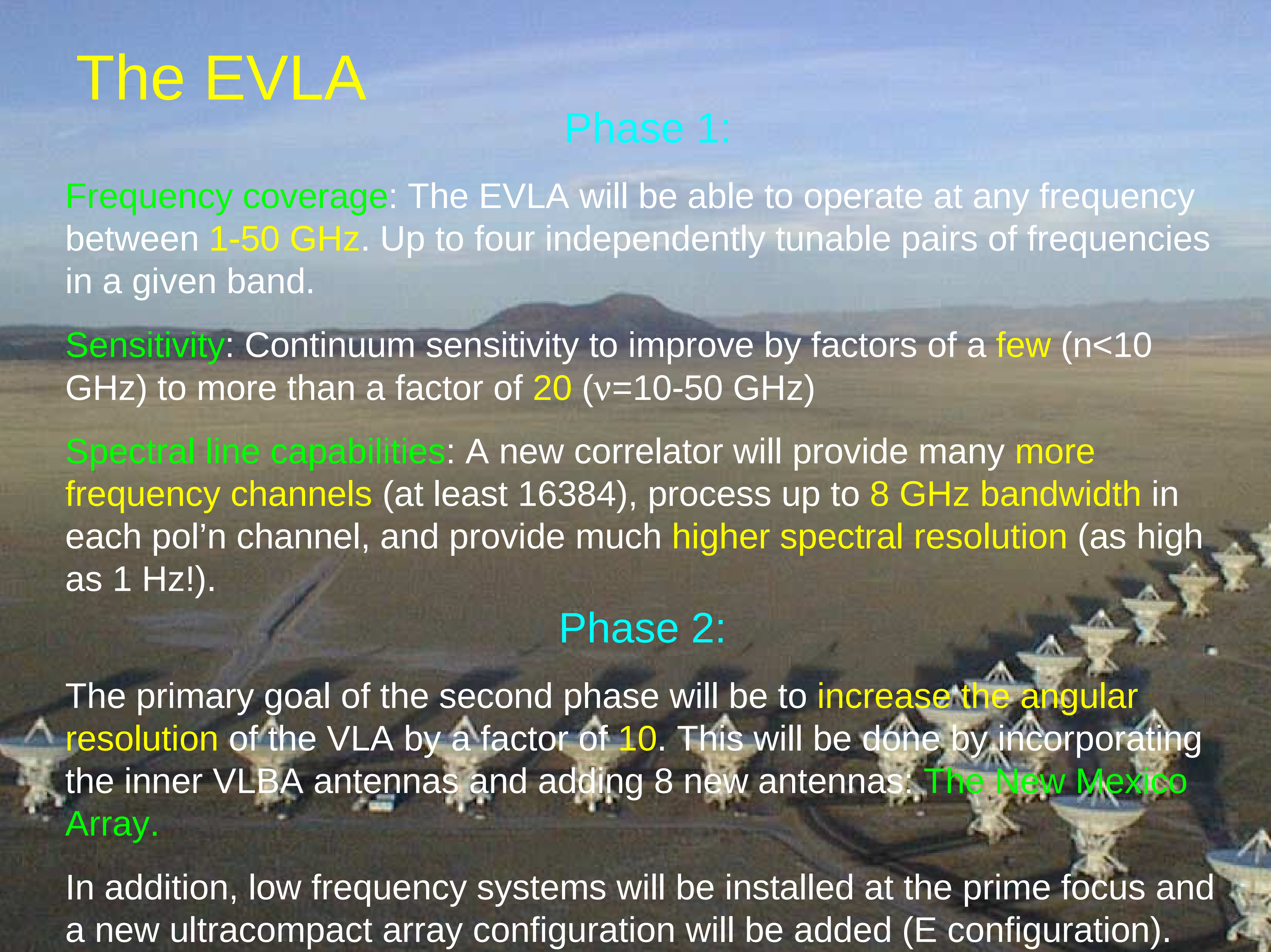
If the distance between two antennas – the baseline – is L, then the angular scale to which the interferometer is sensitive is approximately $\theta = \lambda / L$.

By deploying N antennas over a two dimensional area, one can measure N(N-1)/2 Fourier components of the 2D radio brightness I instantaneously on a large number of angular scales and orientations.

An inverse Fourier transform of the measured Fourier components yields I*B, the convolution of I with the instrumental response function B. Deconvolution techniques are used to recover I.

The sensitivity of a radio telescope depends on the collecting area, the sensitivity of the receivers, and the signal bandwidth, and the integration time.

The imaging fidelity depends upon how well the Fourier transform of the sky is sampled, how well sources of systematic error are eliminated, and how well deconvolution algorithms perform.



The EVLA

Phase 1:

Frequency coverage: The EVLA will be able to operate at any frequency between 1-50 GHz. Up to four independently tunable pairs of frequencies in a given band.

Sensitivity: Continuum sensitivity to improve by factors of a few (n<10 GHz) to more than a factor of 20 (ν=10-50 GHz)

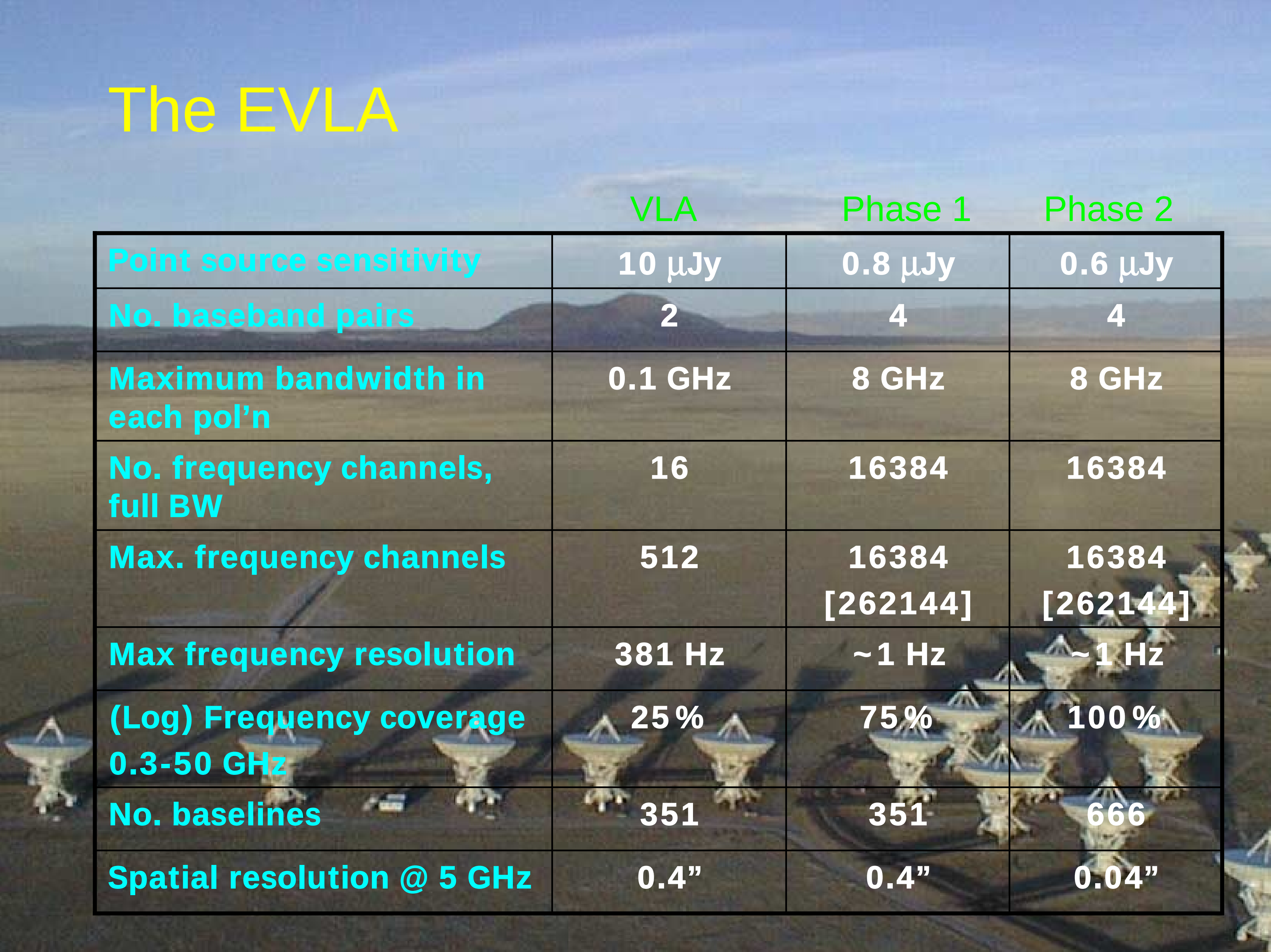
Spectral line capabilities: A new correlator will provide many more frequency channels (at least 16384), process up to 8 GHz bandwidth in each pol’n channel, and provide much higher spectral resolution (as high as 1 Hz!).

Phase 2:

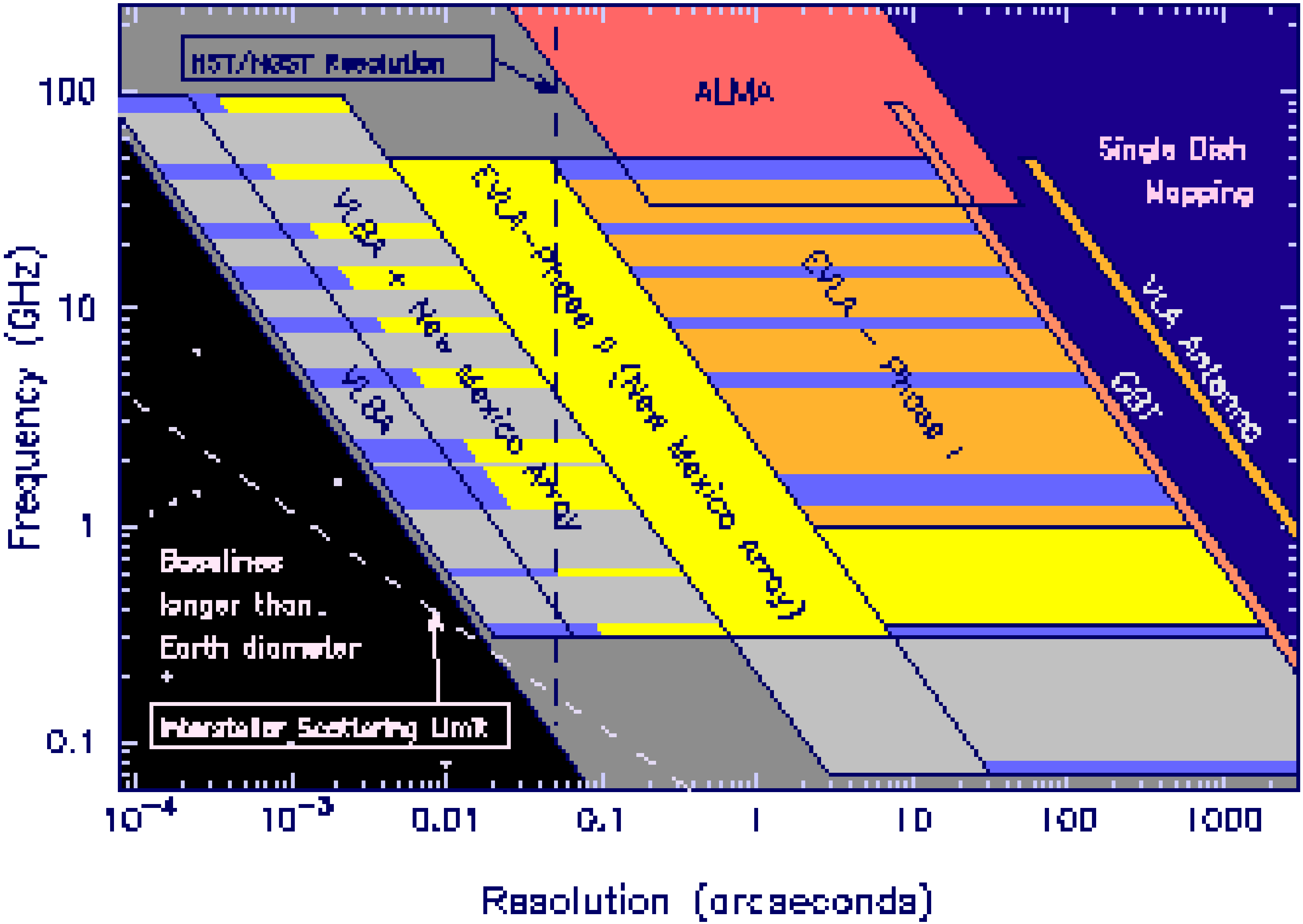
The primary goal of the second phase will be to increase the angular resolution of the VLA by a factor of 10. This will be done by incorporating the inner VLBA antennas and adding 8 new antennas: The New Mexico Array.

In addition, low frequency systems will be installed at the prime focus and a new ultracompact array configuration will be added (E configuration).

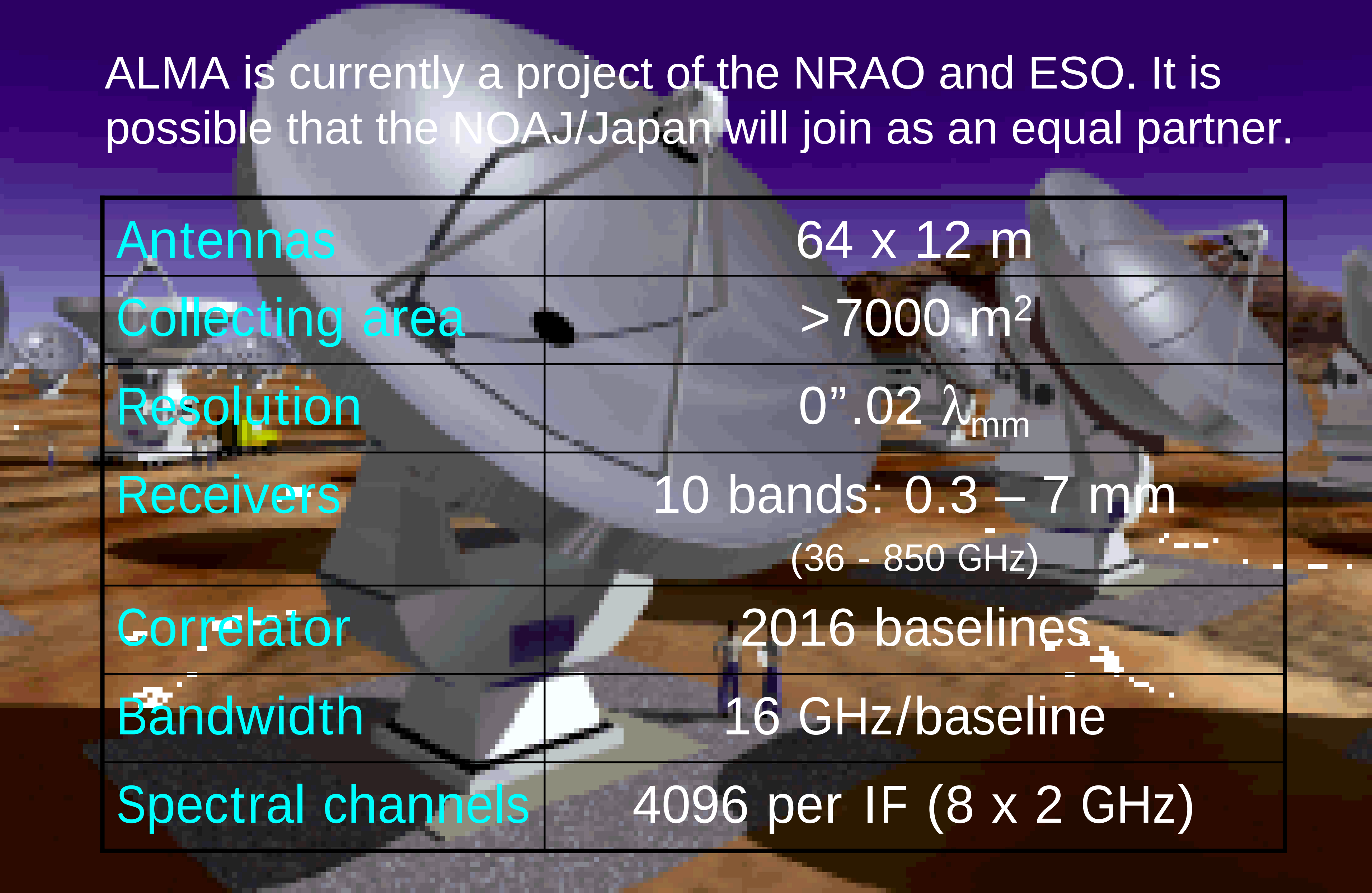
The EVLA



	VLA	Phase 1	Phase 2
Point source sensitivity	10 μJy	0.8 μJy	0.6 μJy
No. baseband pairs	2	4	4
Maximum bandwidth in each pol'n	0.1 GHz	8 GHz	8 GHz
No. frequency channels, full BW	16	16384	16384
Max. frequency channels	512	16384 [262144]	16384 [262144]
Max frequency resolution	381 Hz	~1 Hz	~1 Hz
(Log) Frequency coverage 0.3-50 GHz	25%	75%	100%
No. baselines	351	351	666
Spatial resolution @ 5 GHz	0.4"	0.4"	0.04"


HST/NGST Resolution
ALMA
Single Dish Mapping
VLBA + New Mexico Array
VLBA
EVLA - Phase II (New Mexico Array)
EVLA - Phase I
VLA Antenna
GBT
Baselines longer than Earth diameter
Interstellar Scattering Limit
100
10
1
0.1
Frequency (GHz)
10^{-4}
10^{-3}
0.01
0.1
1
10
100
1000
Resolution (arcseconds)

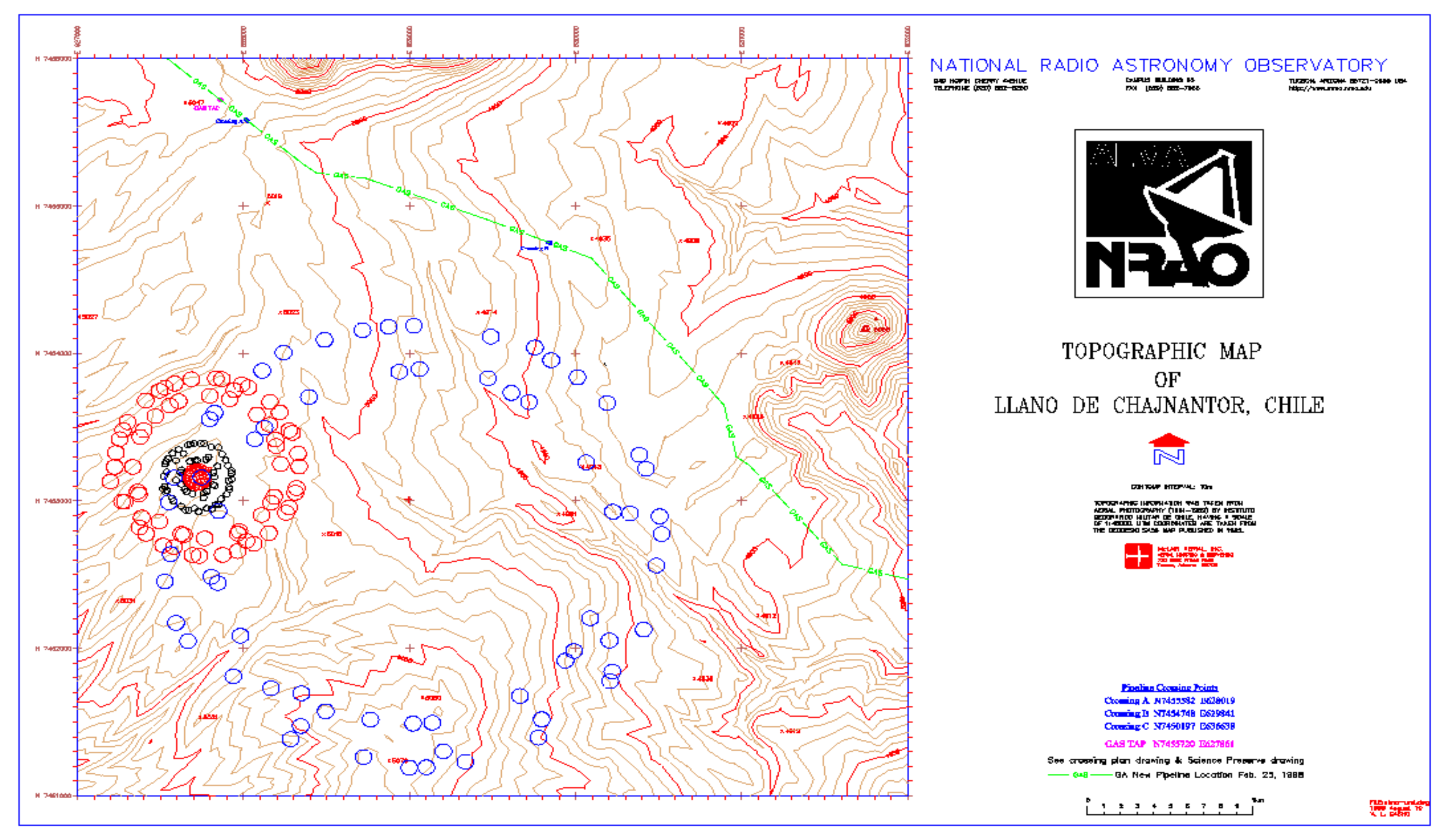
ALMA



ALMA is currently a project of the NRAO and ESO. It is possible that the NOAJ/Japan will join as an equal partner.

Antennas	64 x 12 m
Collecting area	>7000 m^2
Resolution	0".02 λ_{mm}
Receivers	10 bands: 0.3 – 7 mm (36 - 850 GHz)
Correlator	2016 baselines
Bandwidth	16 GHz/baseline
Spectral channels	4096 per IF (8 x 2 GHz)

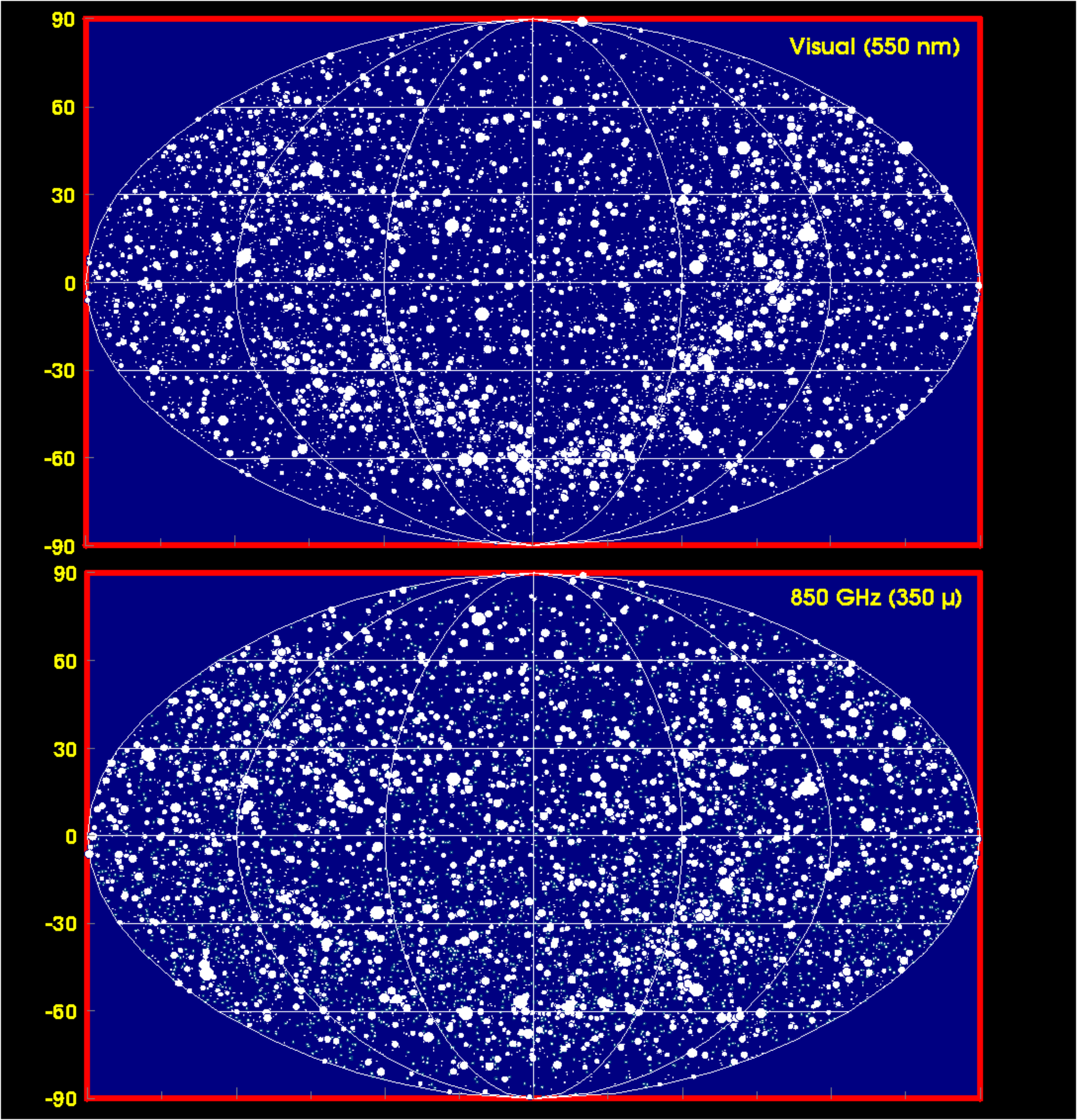
Configurations



Nested rings with diameters of 150 m, 420 m, 1.1 km, 3 km, and 14 km provide resolutions from 1.4” to 15 mas at 1 mm.

ALMA Science

- Formation of galaxies and clusters
- Formation of stars
- Formation of planets
- Creation of the elements
  - Old stellar atmospheres
  - Supernova ejecta
- Low temperature thermal science
  - Planetary composition and weather
  - Structure of Interstellar gas and dust
  - Astrochemistry and the origins of life



from R. Simon

ALMA Timeline

- Design and Development Phase Jun 1998 - Oct 2001
  - International partnership established 1999
  - Prototype antenna contracts Feb 2000
  - Delivered to VLA site 4Q2001
  - Prototype interferometer 2Q 2002

- Construction Oct 2001-2010
  - Production antenna contract 1Q 2003
  - Production antenna at Chajnantor 2Q 2004
  - Interim operations late 2005
  - Full operations 2010

CARMA

Combine the six 10.4 m antennas at OVRO with the nine 6.1 m BIMA antennas .

772 m^2 collecting area (~0.1 ALMA)

Frequency coverage:

- 115 GHz
- 230 GHz
- 345 GHz (planned)

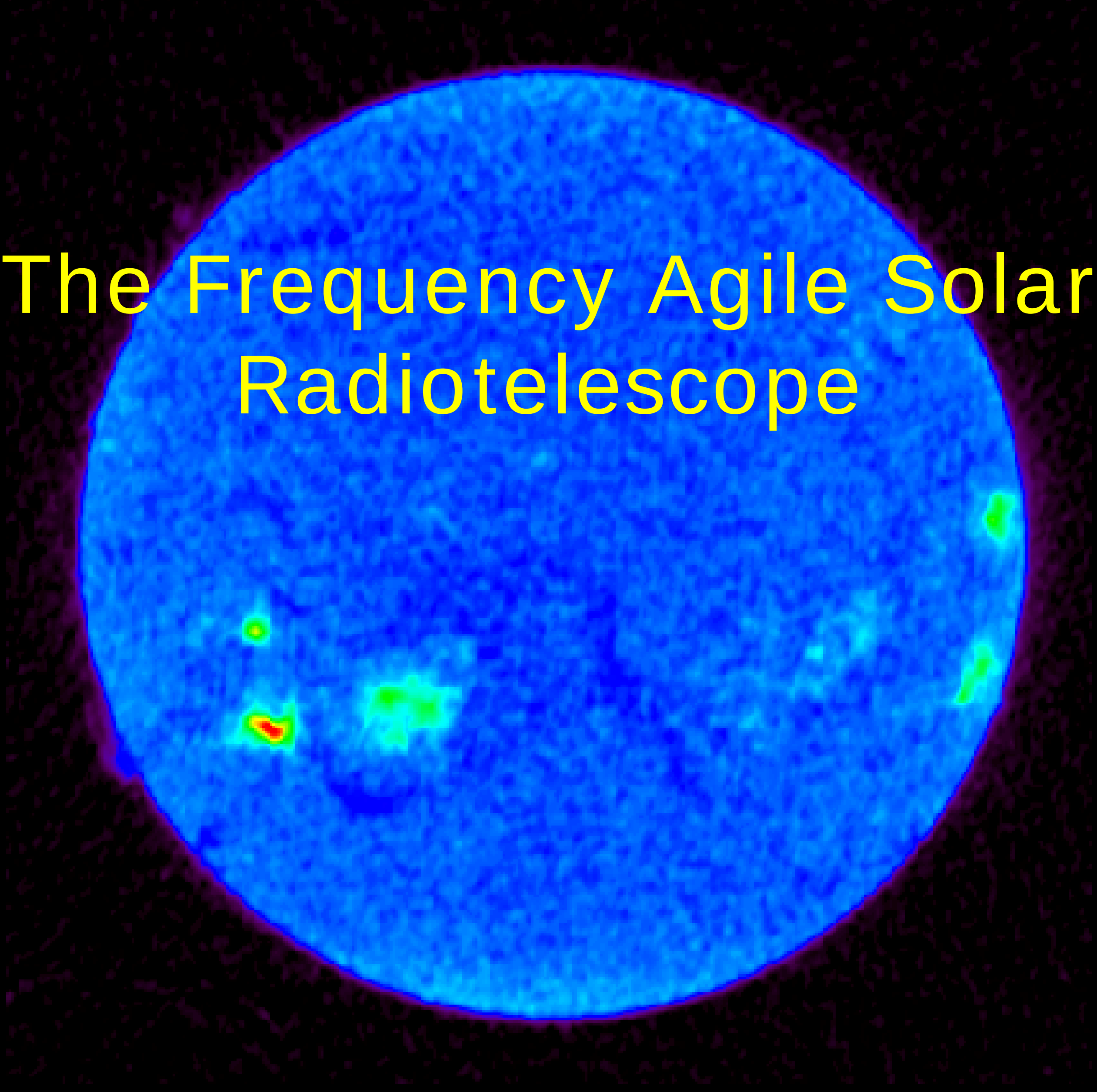
4 configurations with up to 0.1” resolution

CARMA will be the best mm-λ array for a period of several years. After completion of ALMA, it will continue to provide access to the northern sky.

The current timeline calls for site construction and moving the OVRO antennas in 2003. The BIMA array will be moved in 2004. The array will become operational in 2005.

CARMA science will concentrate on detecting, identifying, and mapping emission from organic molecules in a variety of contexts (e.g., comets), protostellar and protoplanetary disks, star formation, emission from molecular gas and dust at high z, and the cosmic microwave background.

The Frequency Agile Solar Radiotelescope



FASR FREQUENCY-AGILE SOLAR RADIOTELESCOPE

What is FASR?

The Frequency Agile Solar Radiotelescope is a solar-dedicated instrument designed to perform broadband imaging spectroscopy.

It will be designed to support temporal, spatial, and frequency resolutions well-matched to problems in solar physics.

FASR involves NJIT, NRAO, UMd, Berkeley SSL, and Lucent

Strawman FASR Specifications

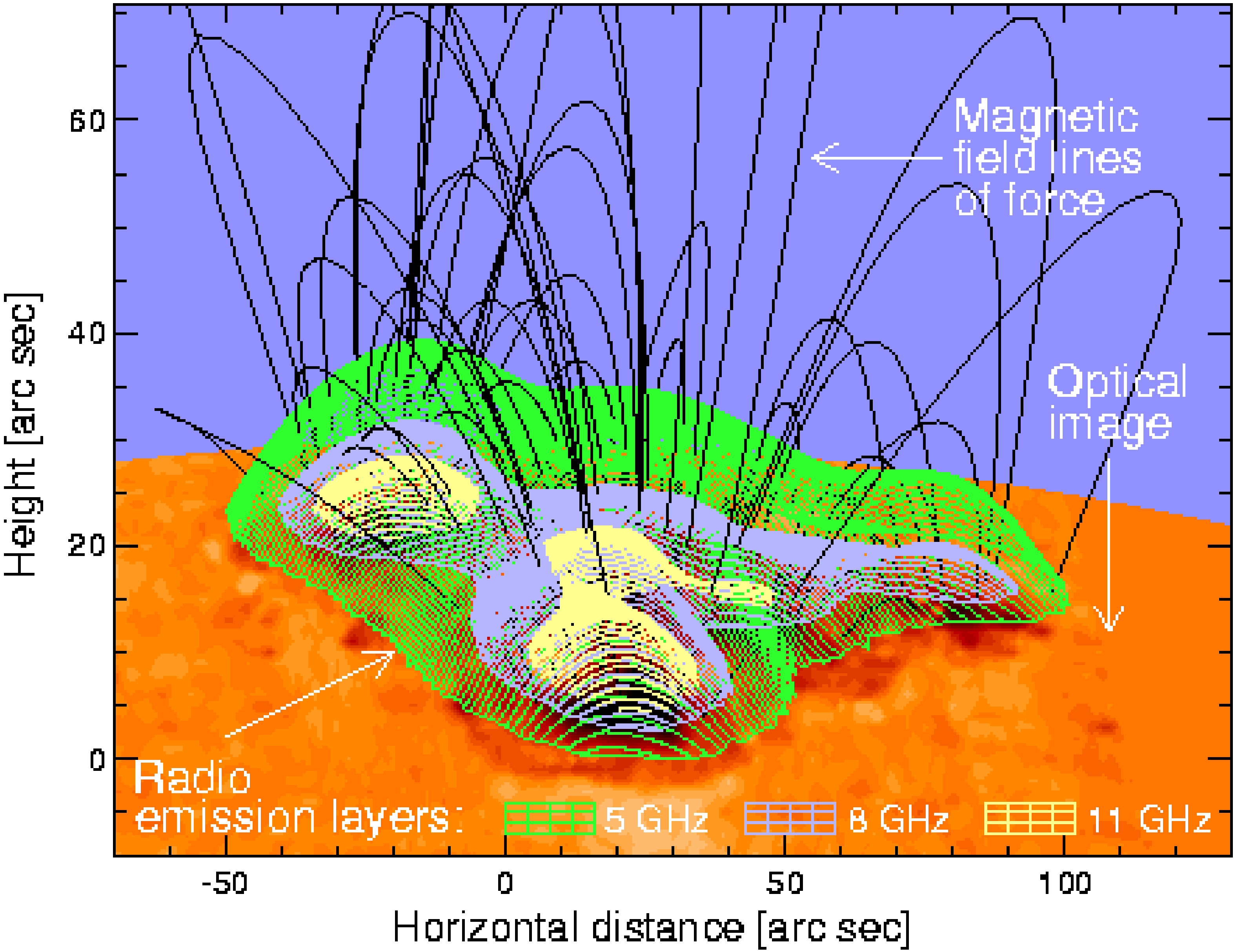
Frequency range	~0.1 – 30 GHz
Frequency resolution	<1%, 0.1 – 3 GHz 3%, 3 – 30 GHz
Time resolution	<0.1 s, 0.1 – 3 GHz <1 s, 0.3 – 30 GHz
Number antennas	~100 (5000 baselines)
Size antennas	D = 2 – 5 m
Polarization	0.1 - 3 GHz, full 3 – 30 GHz, dual
Angular resolution	$20/\nu_9$ arcsec
Field of View	$19/(D\nu_9)$ deg

FASR Science

- Nature & Evolution of Coronal Magnetic Fields
  - Measurement of coronal magnetic fields
  - Temporal & spatial evolution of fields
  - Role of electric currents in corona

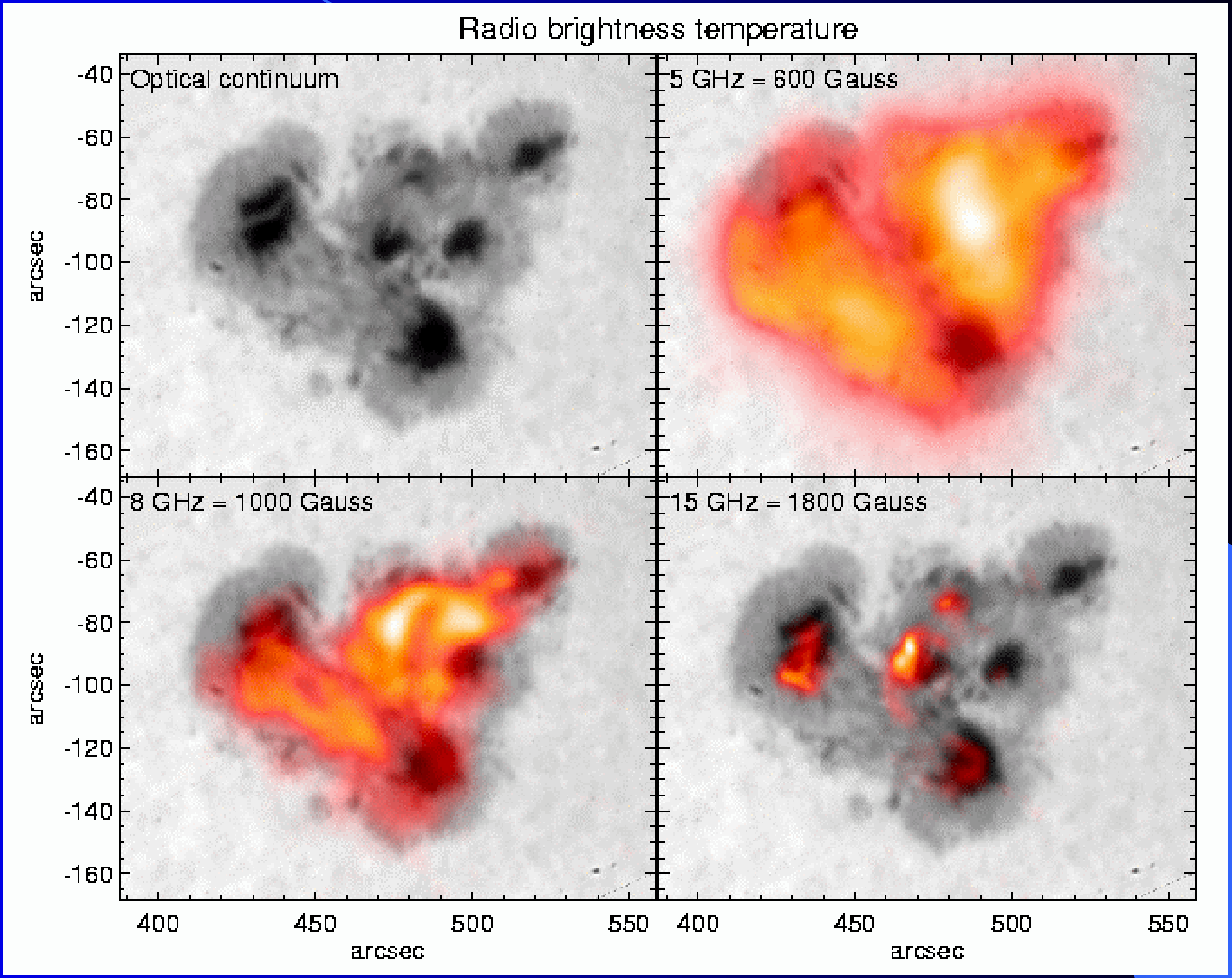
- Coronal Mass Ejections
  - Birth
  - Acceleration
  - B, n_{rl}, n_{th}
  - Prominence eruptions

- Flares
  - Energy release
  - Plasma heating
  - Electron acceleration and transport


Magnetic field lines of force
Optical image
Radio emission layers:
5 GHz
8 GHz
11 GHz
Height [arc sec]
60
40
20
0
-50
0
50
100
Horizontal distance [arc sec]

from J. Lee

Region showing strong shear: radio images show high B and very high temperatures in this region



from Lee et al (1998)

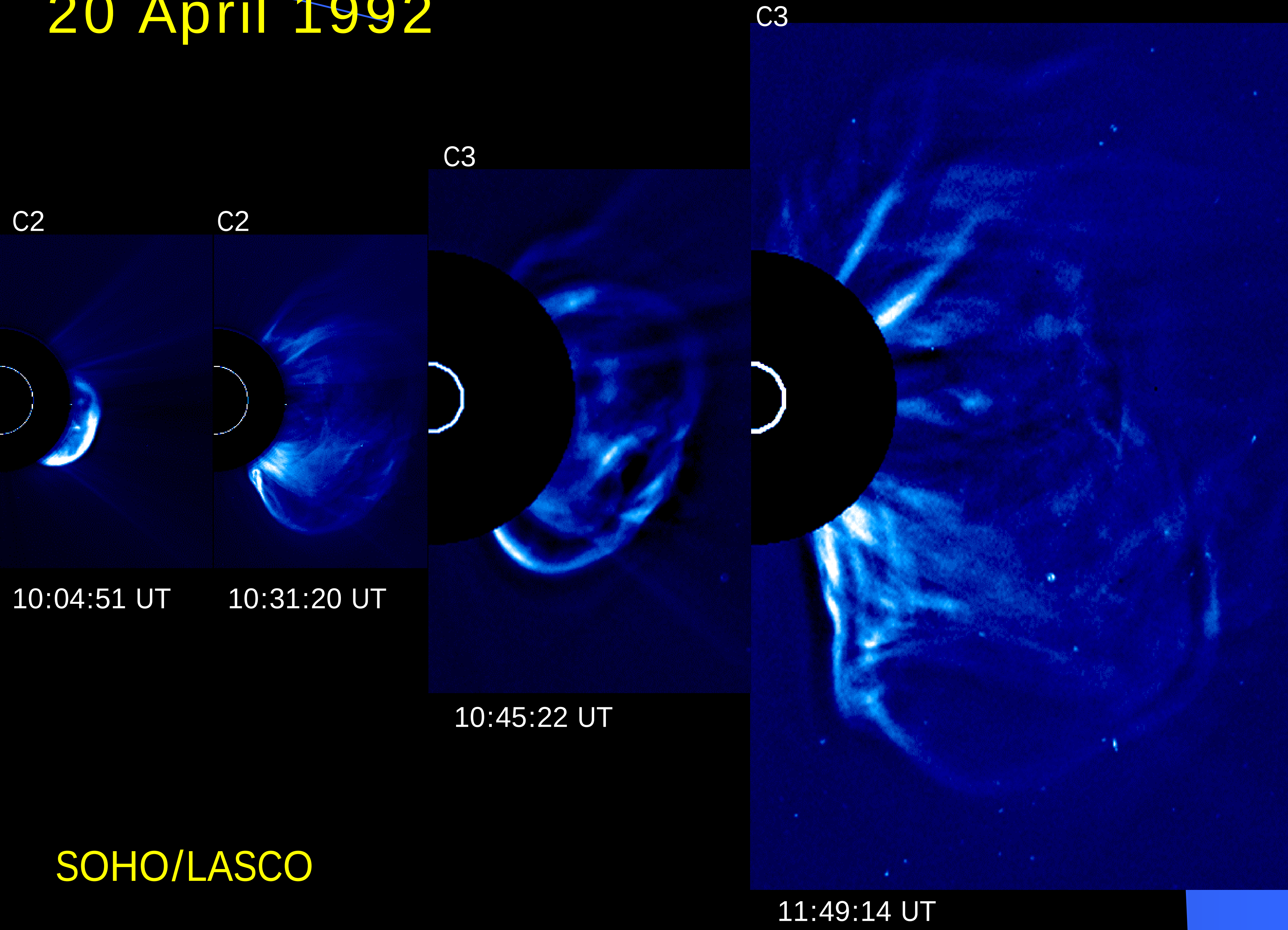
FASR Science

- Nature & Evolution of Coronal Magnetic Fields
  - Measurement of coronal magnetic fields
  - Temporal & spatial evolution of fields
  - Role of electric currents in corona

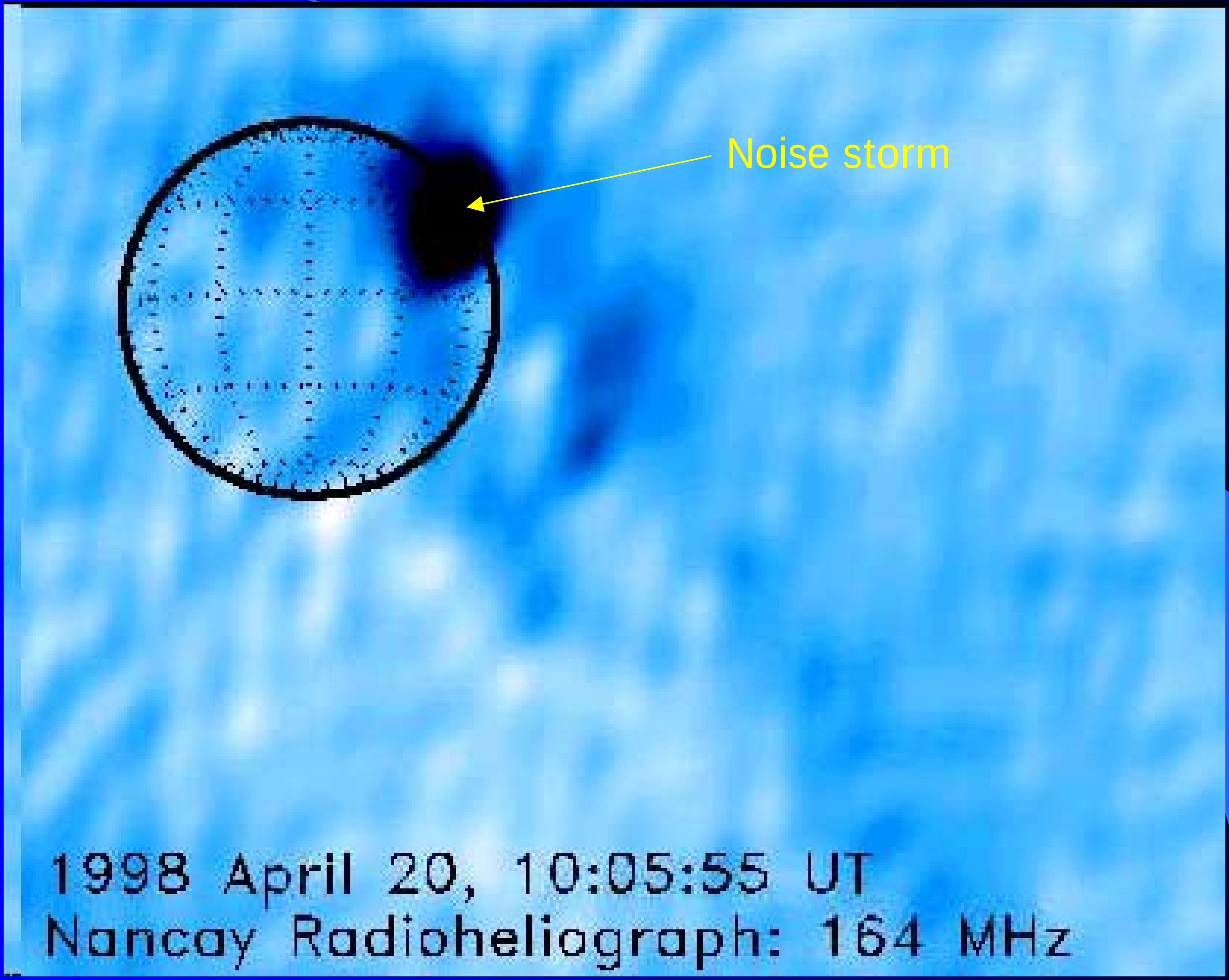
- Coronal Mass Ejections
  - Birth
  - Acceleration
  - B, n_{rl}, n_{th}
  - Prominence eruptions

- Flares
  - Energy release
  - Plasma heating
  - Electron acceleration and transport

20 April 1992



SOHO/LASCO

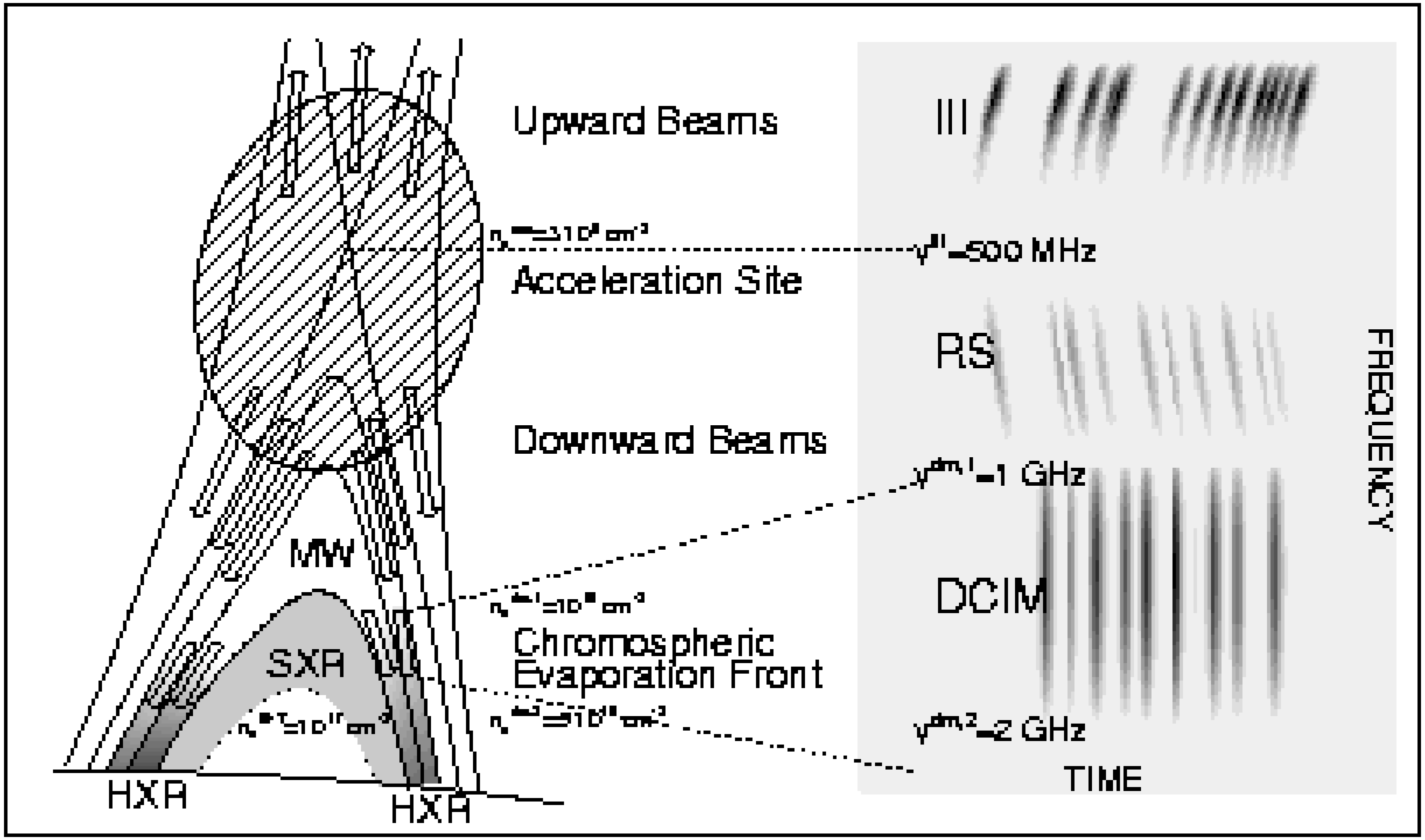


Bastian et al. (2001)

FASR Science

- Nature & Evolution of Coronal Magnetic Fields
  - Measurement of coronal magnetic fields
  - Temporal & spatial evolution of fields
  - Role of electric currents in corona
- Coronal Mass Ejections
  - Birth
  - Acceleration
  - B, n_{rl}, n_{th}
  - Prominence eruptions
- Flares
  - Energy release
  - Plasma heating
  - Electron acceleration and transport

As a comprehensive, dedicated solar instrument sensitive to magnetic fields, eruptive phenomena, their locations, and physical properties, FASR is an excellent instrument for LWS/space weather programs.



from Aschwanden & Benz 1997

FASR Science (cont)

- The “thermal” solar atmosphere
  - Coronal heating - nanoflares
  - Thermodynamic structure of chromosphere in AR, QS, CH
  - Formation & structure of filaments/prominences

- What about night time observing??

See S. White

Status and Plans

The NAS/NRC Astronomy and Astrophysics Survey Committee has recommended an integrated suite of three ground and space based instruments designed to meet the challenges in solar physics in the coming decade. These are:

Advanced Technology Solar Telescope (O/IR)

Frequency Agile Solar Radiotelescope (radio)

Solar Dynamics Observatory (O/UV/EUV)

FASR is currently under review by the NAS/NRC Solar and Space Science Survey Committee.

Plans

- 2002-2003 Technical study (NSF/ATI)
- 2003-2004 Design, develop, prototype susbsystems
- 2005-2006 Construction
- 2006 Operations commence

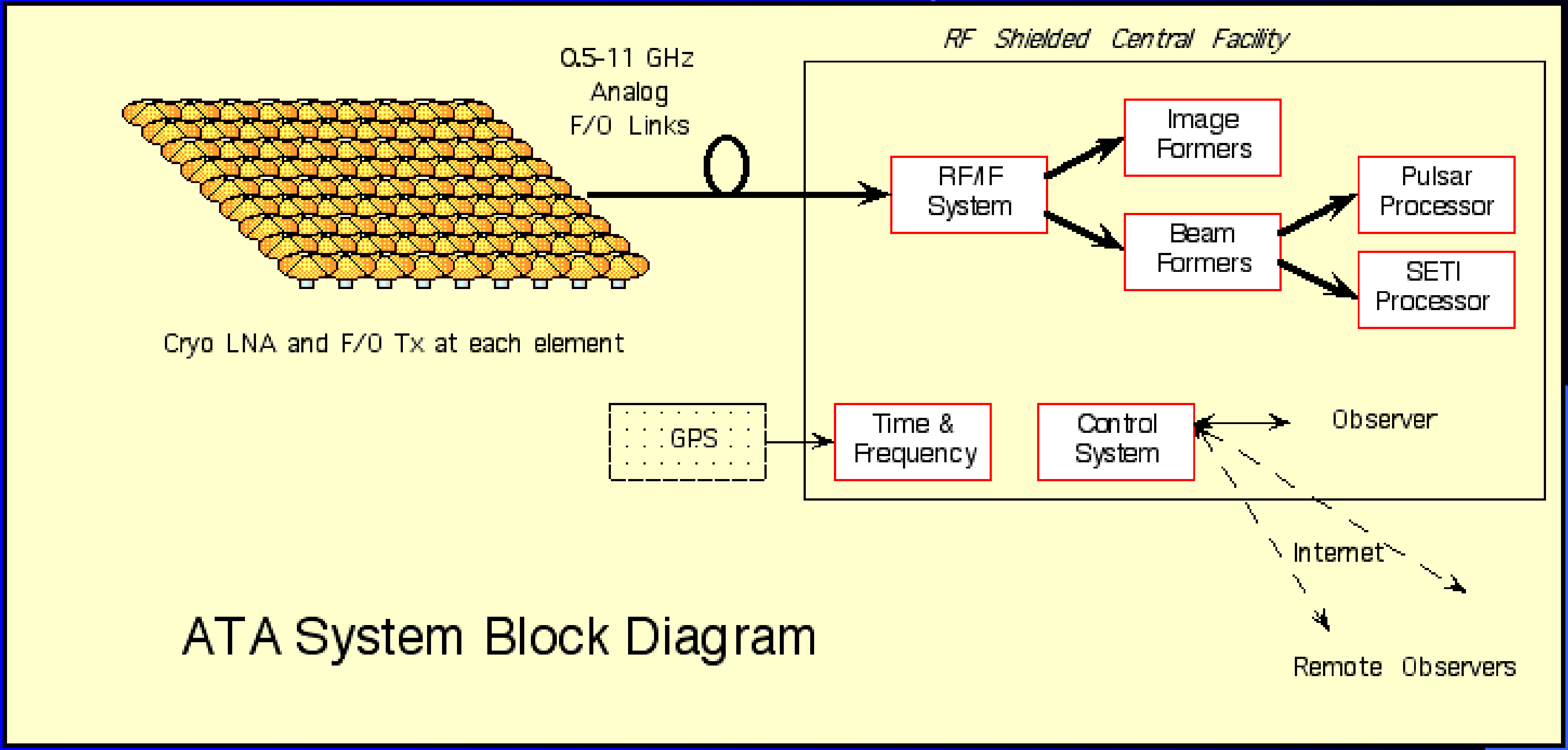
The ATA

The ATA is a project of the SETI organization. It is being largely funded by Paul Allen (co-founder of Microsoft) although Nathan Myhrvold (former Chief Technology Officer to Microsoft) has also contributed.

The primary purpose of the ATA is to do SETI work. Unlike the other instruments discussed today, its main function will not be as an imaging instrument. Rather, it will be a beam forming instrument.

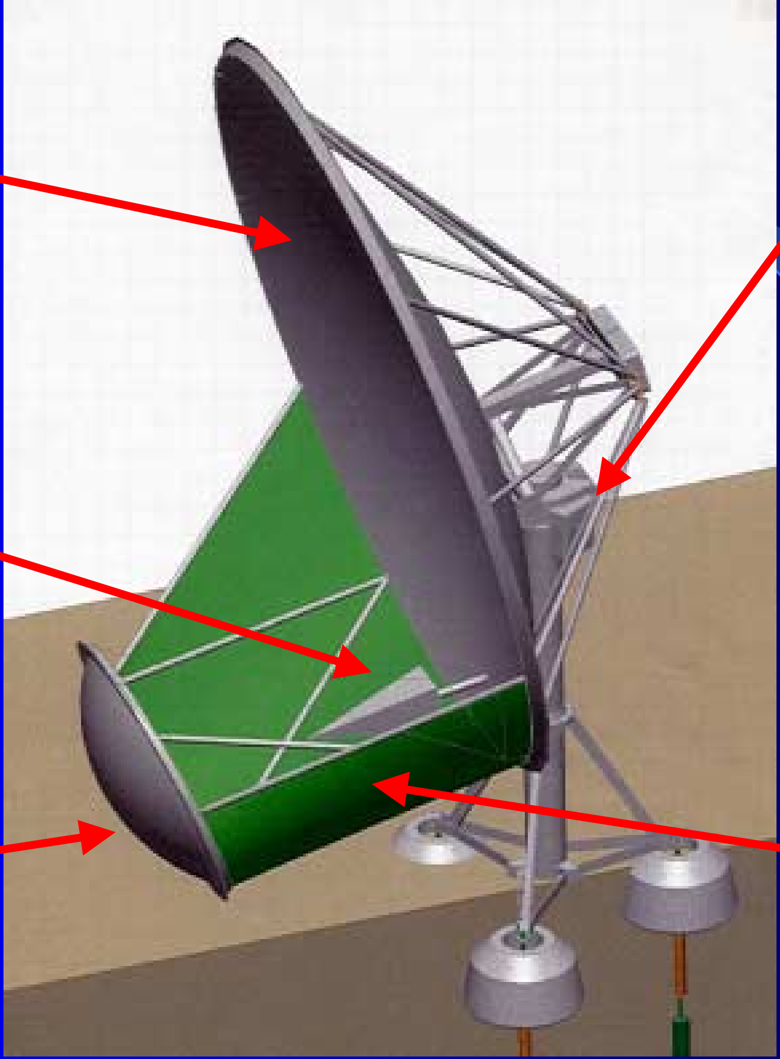
The ATA will use 350 x 6.1 m antennas to form a pencil beam. The beam will be placed on a target and sophisticated DSP techniques will be used to search for signals over a frequency range of 0.5-11.5 GHz.

Overview



ATA System Block Diagram

Offset Gregorian Antenna



6.1 m x 7.0 m Primary

Az-El Drive

Log-periodic Feed

2.4 m Secondary

Shroud
(feed can't see
ground or array)

ATA Performance

Number of Elements	350		
Element Diameter	6.10	m	
Total Geometric Area	1.02E+04	m^2	
Aperture Efficiency	63%		
Effective Area	6.44E+03	m^2	
	2.33	K/Jy	
System Temperature	43	K	
System Eqiv. Flux Density	18	Jy	
Ae/Tsys	150	m^2/K	
Effective Array Diameter	687	m	Natural Weighting
Frequency	1	10	GHz
Primary FoV	3.5	0.4	degree
Synthesized Beam Size	108	11	arc sec
Number of Beams	>4		
Continuum Sensitivity			
BW	0.2	GHz	Confusion
Flux Limit in 10 sec	0.41	mJy	0.1 mJy at 1.4 GHz
Spectral Line			
Resolution	10	km/s	
Frequency	1	10	GHz
BW	3.E+04	3.E+05	Hz
Integration Time	1000	1000	sec
RMS brightness	0.70	0.22	K

ATA Science

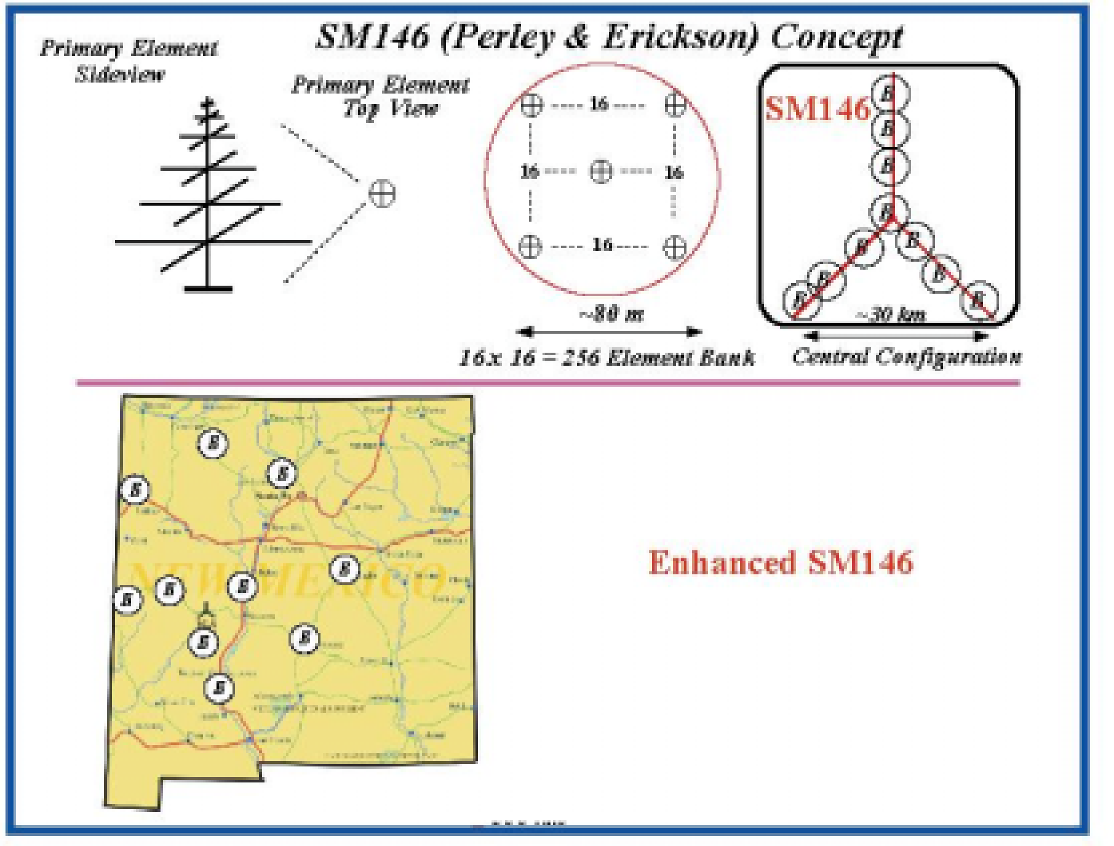
- SETI
  - 100,000 FGK stars
  - Galactic plane survey (2nd generation DSP)
- HI
  - All sky HI, z < 0.03, Milky Way at 100 s
  - Large area to z ~ 0.1 or more
  - Zeeman
- Temporal Variables
  - Pulsar Timing Array
  - Pulsar survey followups
  - Extreme Scattering Events
  - Transients

Not an exhaustive list!!

LOFAR is a concept for an imaging array operating between 10 – 240 MHz with arcsec resolution. It is being pursued by the NRL, NFRA, & MIT/Haystack.

- High Redshift Universe
  - unbiased sky surveys, select highest z galaxies
  - trace galactic & intergalactic B fields
  - Epoch of Reionization: search for global signature, detect and map spatial structure
- Cosmic Ray Electrons and Galactic Nonthermal Emission
  - map 3D distribution, test expected origin and acceleration in SNRs
- Bursting and Transient Universe
  - broad-band, all-sky monitoring for variable/transient sources
  - search for coherent emission sources; e.g. from stars, quasars, & extra-solar planets
- Solar-Terrestrial Relationships
  - study fine-scale ionospheric structures
  - image Earth-directed CMEs (as radar receiver)

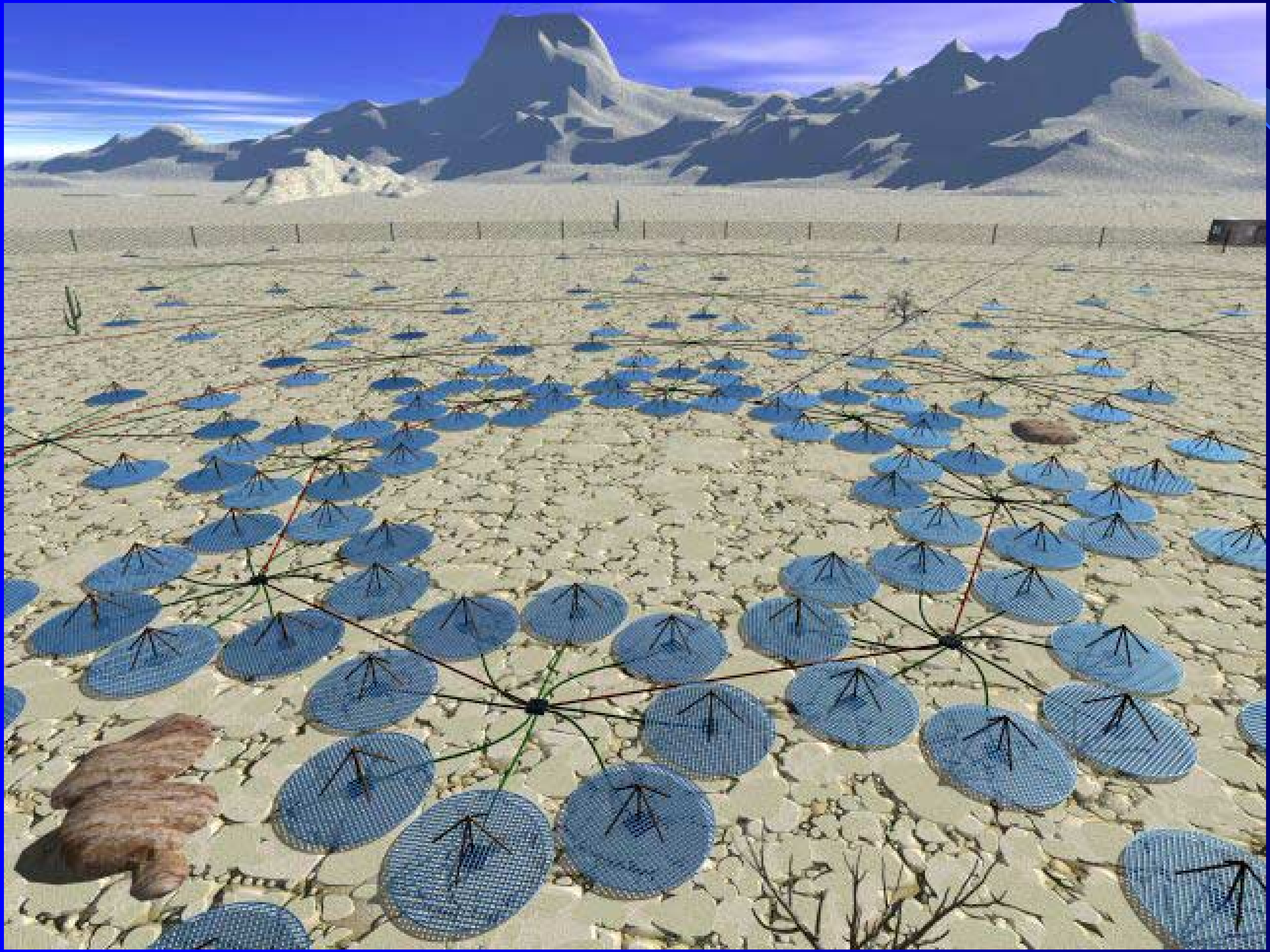
SM146 Concept
(VLA Scientific Memorandum #146)



- Perley & Erickson concept
  - Standalone stations along VLA arms
    - VLA arm easement enough room for 100 m stations
    - Logistical issues remain – how will the cows like them?
  - Might proceed with EVLA-I
- Augmented SM146
  - Addition of A+ capability
  - Might proceed with EVLA-II

High Sensitivity Station

Prototype for LOFAR Low Frequency Antennas



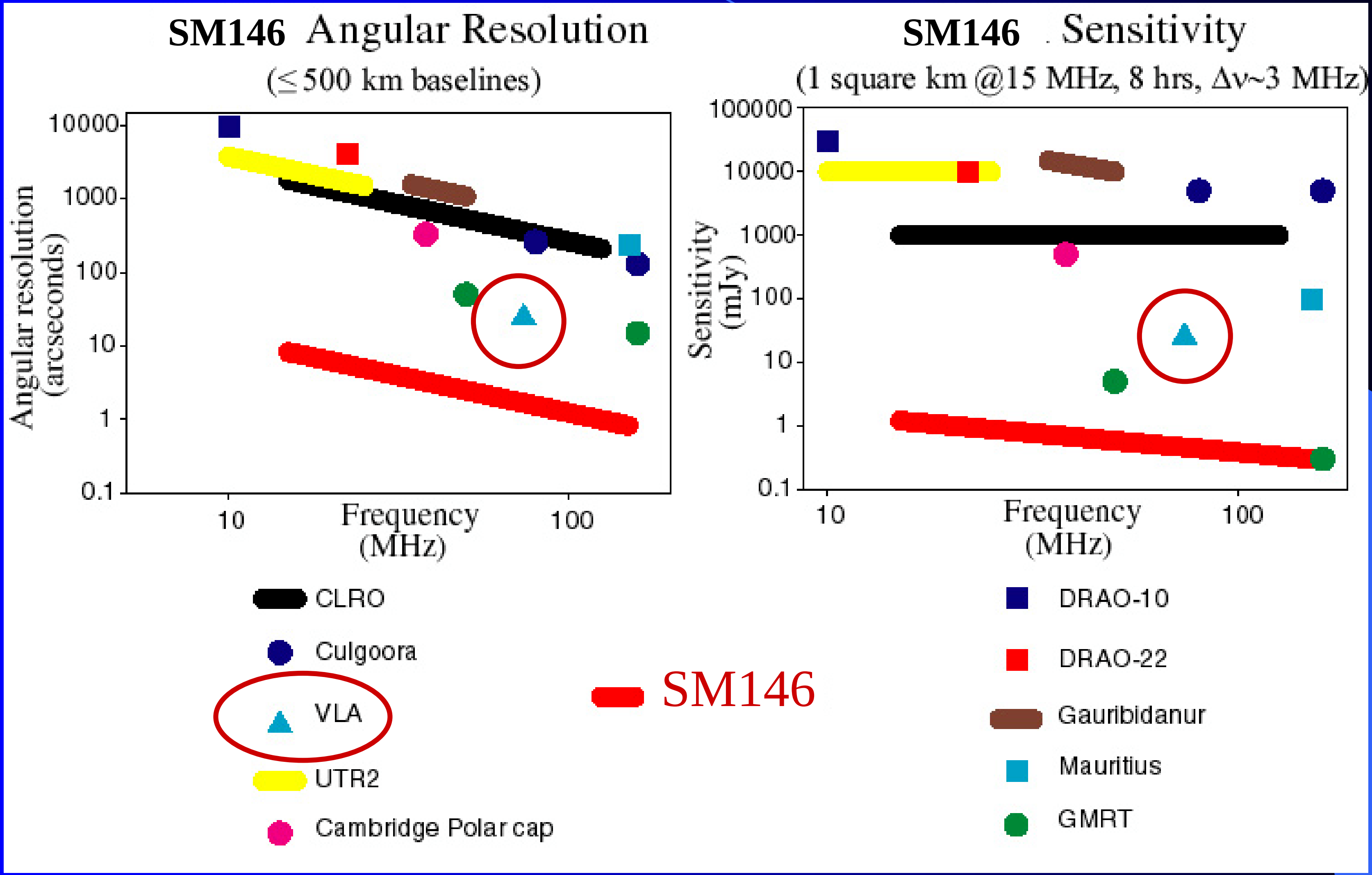
Analogous to one VLA antenna but with >10X the sensitivity

~100 meter diameter

@74MHz:

VLA antenna ~ 125 m^2
LWA Station ≥ 1500 m^2

SM146 CAPABILITY



Relationship to LOFAR

- SM146 is largely independent of LOFAR

- LOFAR is much more complex than SM146
  - It has a substantial technology development element as well as purely scientific goals
    - Larger Freq. Range (LOFAR: 10-240 MHz; SM146: 10-90 MHz))
    - Many more stations (>100)
    - Complex configuration (log spiral)
    - MUCH more software, etc ...

- SM146 and LOFAR: parallel, mutually beneficial
  - SM146 development clearly meshes with LOFAR technical developments for low frequencies (< 100 MHz)
  - Might SM146 develop into the low frequency portion of LOFAR?

SKA

Finally, it is worth mentioning SKA. No one knows what exactly it will be, what it will do, where it will be, or how we'll do it, but it's generally agreed that it's the next big thing.

And we know it's real, because it has a web site (several, in fact).

The SKA project is presently an international consortium. The US partner is itself a consortium of

UC Berkeley
SETI Inst.
MIT/Haystack
Cornell/NAIC
NRAO

Caltech/JPL
Harvard SAO
Univ Minnesota
Ohio State Univ
Georgia Tech

SKA Design Goals

Aeff/Tsys	2 x 104 m^2/K
Frequency range	0.15-20 GHz
Imaging FOV	1 deg^2 @ 1.4 GHz
Number pencil beams	100
Max primary beam separation	1 deg @ 1.4 GHz
Number spatial pixels	10^8
Angular resolution	0.1 asec @ 1.4 GHz
Surface brightness sensitivity	1 K @ 0.1 asec
Bandwidth	$0.5 + \nu/5$ GHz
Spectral channels	10^4
Frequency bands	2
Dynamic range	10^6 @ 1.4 GHz
Polarization purity	~40 dB

Originally conceived as a “red shift machine” operating at 1.4 GHz and below, the basic idea behind SKA is to push to extremely high sensitivity. For spectral line work, an increase in bandwidth is not an option. And receiver technology is now approaching quantum limits. The solution, therefore, is to exploit an extremely large collecting area: one square kilometer.

To put that in perspective, that’s 100 VLAs!

The community – both national and international – is behind the basic concept. But the detailed specifications and how to build it at reasonable cost have not been determined.

Several concepts are being considered. A few are:

Large-N arrays (US)
Large-f-ratio mirrors with derigibles (Canada)
Many Arecibos (China)
Adaptive reflectors (NFRA)

Additional Information

EVLA	www.aoc.nrao.edu/doc/vla/EVLA/EVLA_home.shtml
CARMA	www.mmarray.org
ALMA	www.alma.nrao.edu
FASR	www.ovsa.njit.edu/fasr
ATA	www.seti.org/science/ata.html
LOFAR	rsd-www.nrl.navy.mil/7213/lazio/decade_web/index.html See also www.astron.nl/lofar
SKA	usska.org/main.html

Future Capabilities for Space-Based Stellar Observations

Kenneth G. Carpenter

Laboratory for Astronomy and Solar Physics

NASA - Goddard Space Flight Center

Presented at the 12th Cambridge Workshop on “Cool Stars, Stellar Systems, and the Sun”, held in Boulder, CO July 30-August 3, 2001

Version for Proceedings, updated August 8, 2001

Outline of Talk

Facilities Planned for the Near-Future

Planned Intermediate-Horizon Missions

Far-Horizon Missions

Facilities Planned for the Near-Future

HST: ACS, COS and WFC3
SIRTF
ISAS: ASTRO-F

Note: Although they are not discussed in the following slides, it should be noted that ASTRO-E & NICMOS are scheduled for ‘second chances’ , with a new launch attempt for an ASTRO-E clone now approved and the installation of a new cooling system for NICMOS expected to bring it back to life during HST Servicing Mission 3b.

Advanced Camera for Surveys (ACS) will bring large gains to HST imaging capability after SM3b (Jan. 2002)

Wide-Field Channel (WFC)

- ACS/WFC: 10x increase in “discovery potential” vs. WFPC2
- high throughput, wide field, optical & NIR (I band), spectral response = **350 - 1050 nanometers**
- optimized for surveys in the near-infrared to search for galaxies and clusters of galaxies in the early universe.
- **202" × 202" field of view with 0.049" pixel size**
- 2 butted 2048 × 4096, 15 µm/pixel CCD detectors
- **45% throughput at 700 nanometers (incl. HST OTA)**
- half critically sampled at 500 nanometers

High Resolution Channel (HRC)

- field of view comparable to WFPC2 Planetary Camera (PC), but with 2x resolution & far better UV/blue sensitivity, **200-1050 nm spectral response, 25% throughput at 600nm**
- has High Contrast Coronagraph (HCC) subchannel for imaging of faint targets near bright objects--subdwarfs, large planets, galaxy cores, QSO host galaxies
- **29.1" × 26.1" field of view with 0.028" × 0.025" pixel size**
- 1024 × 1024, 21 µm/pixel, near UV-enhanced CCD detector
- critically sampled at 500 nanometers

Solar Blind Channel (SBC)

- nearly identical device to STIS FUV, many more filters
- study hot stars, quasars,aurora
- **115-180 nm spectral response**
- **34.59" × 30.8" field of view**
- **0.033" × 0.030" pixel size**
- 1024 × 1024, Csl 25 µm/pixel MAMA detector (STIS spare)
- 6% throughput at 121.6 nm

HST: Cosmic Origins Spectrograph (COS)

“Spectroscopy lies at the heart of astrophysical inference.”

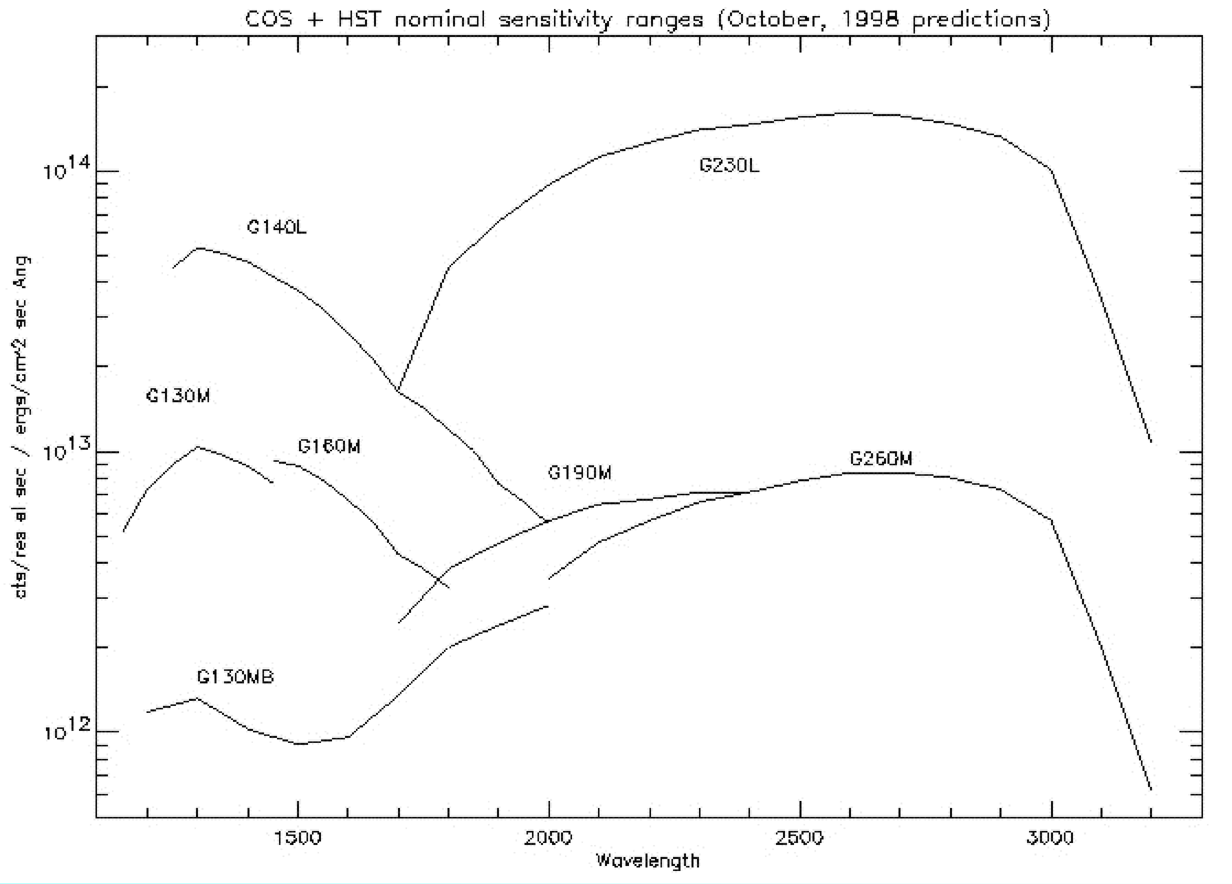
to be launched on HST Servicing Mission 4 ~ Jan. 2004

Science Goals

- Large-scale structure, the IGM, and origin of the elements.
- Formation, evolution, and ages of galaxies.
- Stellar and planetary origins and the cold interstellar medium.
- Other
  - AGN monitoring campaigns
  - UV upturn in elliptical galaxies
  - **UV monitoring of distant supernovae**
  - **observations of SN1987A as it impacts circumstellar rings**
  - **stellar winds and UV properties of LMC/SMC massive stars**
  - **monitoring of CVs and other high-energy accretion systems**
  - **SEDs of YSOs; diagnostics of heated accretion columns**
  - **chromospheres of cool stars**
  - planetary aurorae and cometary comae
  - detection of faint UV emission in ISM shocks

COS Sensitivity

COS is designed to break the "1 x 10^{-14} flux barrier" for moderate resolution UV spectroscopy, enabling order of magnitude increases in accessible UV targets for a broad range of science programs

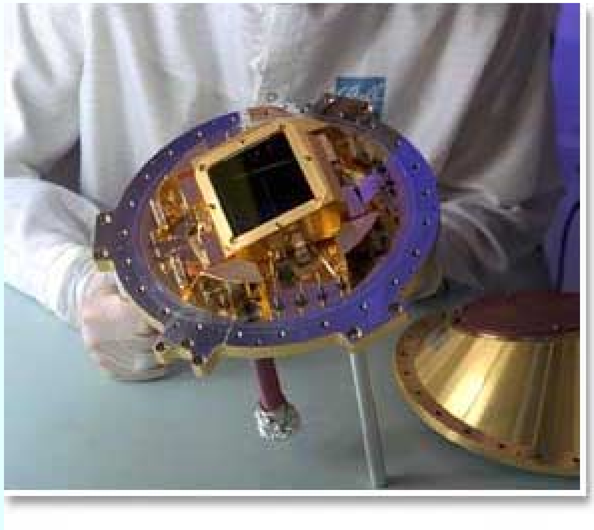


COS Spectroscopic Modes

Grating	Nominal Wavelength Coverage [a]	Wavelength Range per Exposure	Resolving Power (R = l/Dl) [b]
G130M	1150 - 1450 Å	300 Å	20,000 - 24,000
G160M	1405 - 1775 Å	375 Å	20,000 - 24,000
G140L	1230 - 2050 Å	> 820 Å	2500 - 3500 ← **“survey” mode**
G190M	1700 - 2400 Å	3 x 45 Å	20,000 - 27,000
G260M	2400 - 3200 Å	3 x 55 Å	20,000 - 27,000
G230L	1700 - 3200 Å	1000 Å	850 - 1600 ← **“survey” mode**
G130MB	1150 - 1800 Å	3 x 30 Å	20,000 - 30,000

Highest Sensitivity Medium Resolution Spectrograph on HST
Signal/noise capabilities to > 100
Wavelength accuracy: 15 km/s requirement, 10 km/s goal

HST: Wide Field Camera 3 (WFC3)

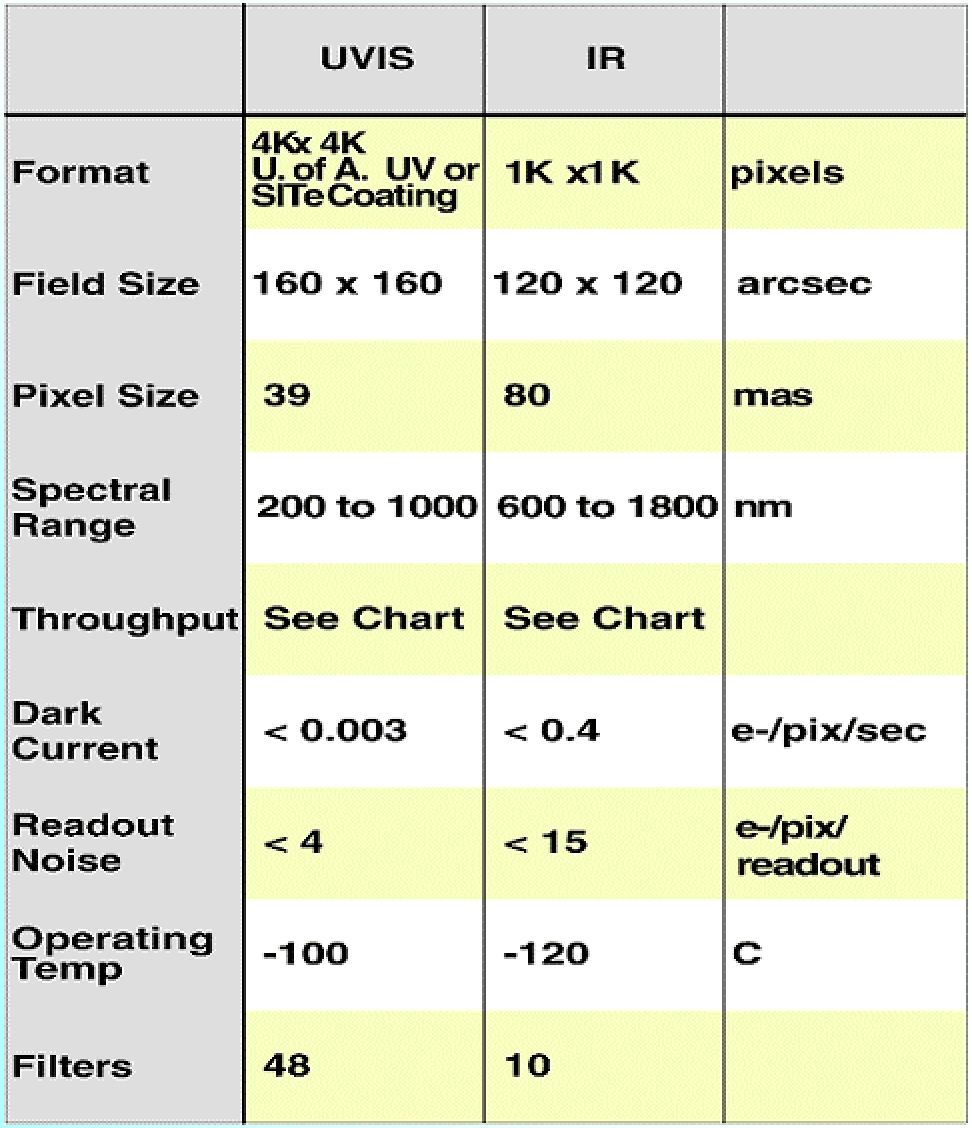


- Instrument is a 2-channel camera with panchromatic coverage from UV to near IR
- blue optimized 4k x 4k CCD is the visible channel detector (similar to ACS/WFC, but with different wavelength optimization)
- 1kx1k IR detector channel offers very substantial gains in capabilities vs. NICMOS
  - up to 10x gain in field of view
  - potential gains of 2-3x in sensitivity due to superior detector performance
- IR channel enables high angular resolution, wide areal coverage, low-background imaging from 1.0-1.9 microns

WFC3 Specifications

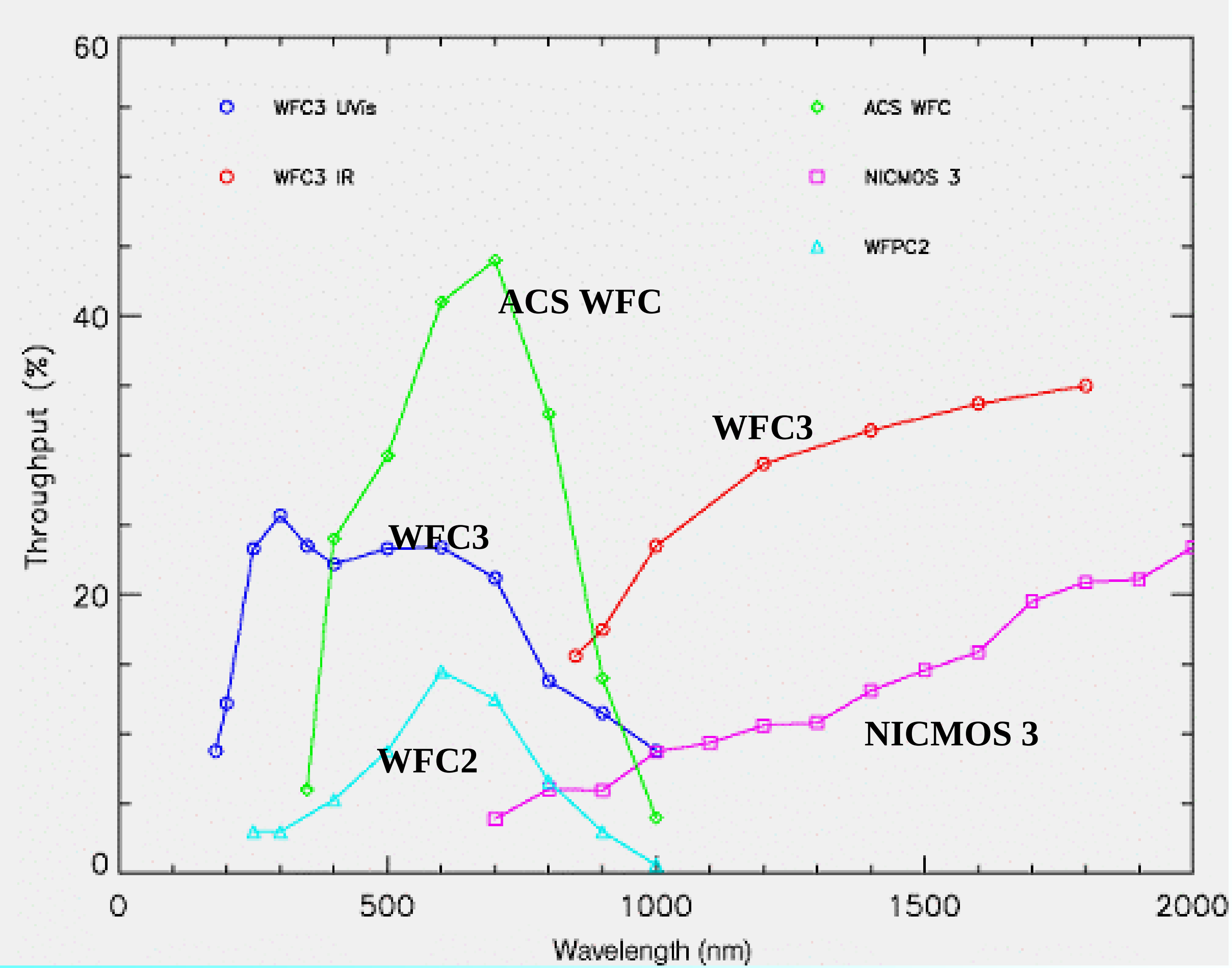
“Imaging lies at the heart of astrophysical inference.”

to be launched on HST Servicing Mission 4 ~ Jan. 2004



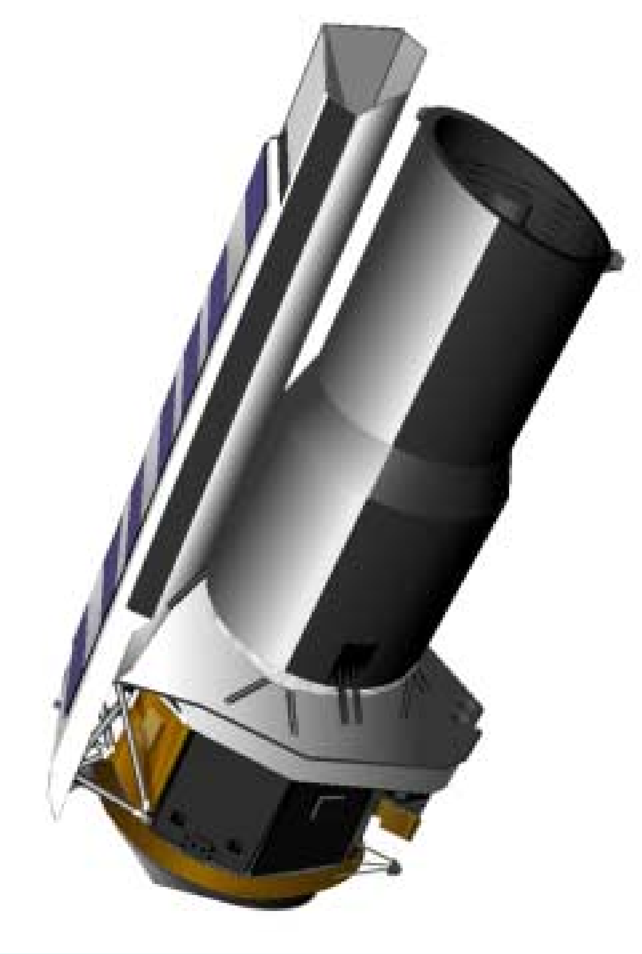
	UVIS	IR	
Format	4Kx 4K U. of A. UV or SITe Coating	1K x1K	pixels
Field Size	160 x 160	120 x 120	arcsec
Pixel Size	39	80	mas
Spectral Range	200 to 1000	600 to 1800	nm
Throughput	See Chart	See Chart	
Dark Current	< 0.003	< 0.4	e-/pix/sec
Readout Noise	< 4	< 15	e-/pix/ readout
Operating Temp	-100	-120	C
Filters	48	10	

WFC3: Throughput



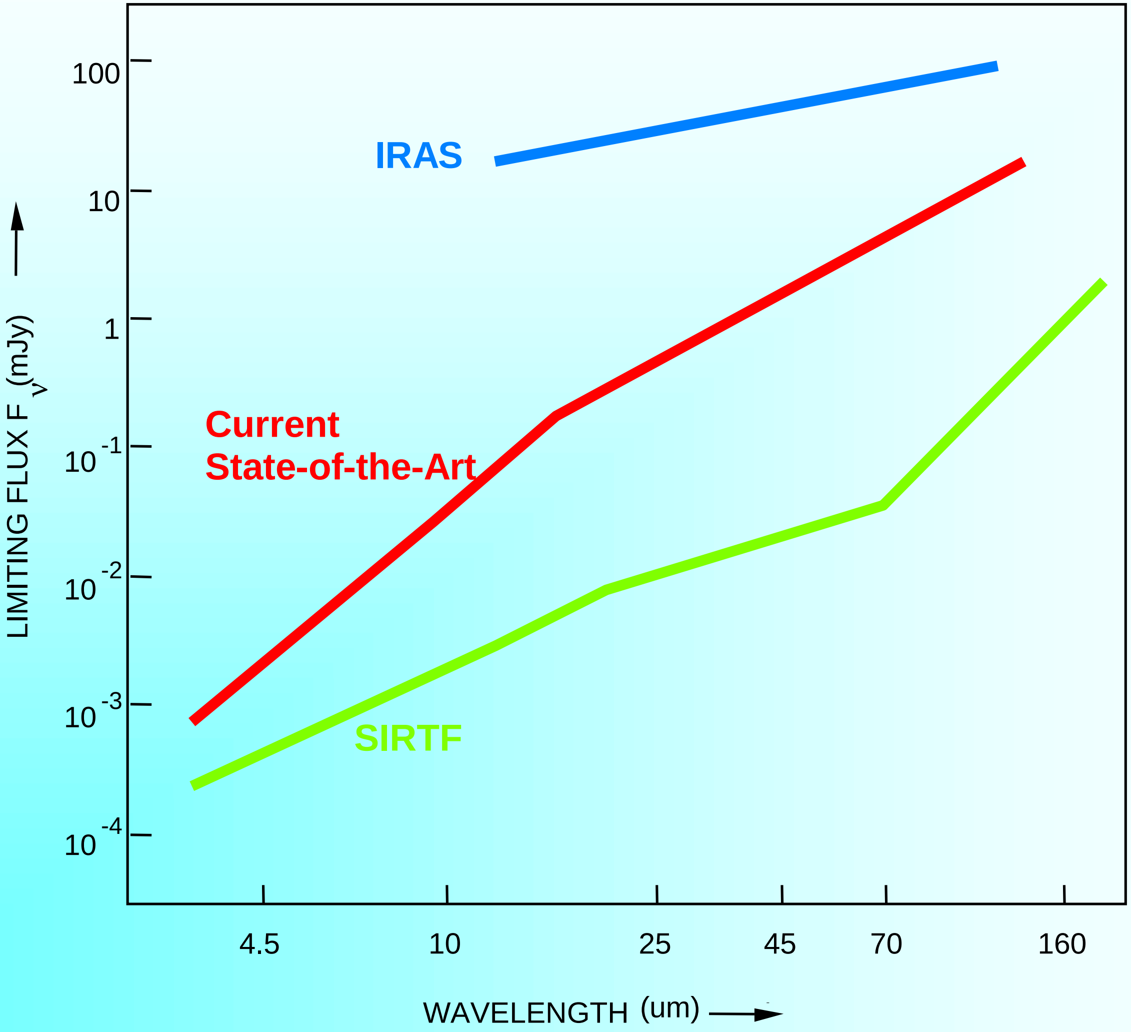
Space Infrared Telescope Facility

- **Infrared Great Observatory**
  - Background Limited Performance 3 -- 180um
  - 85 cm f/12 Beryllium Telescope, T < 5.5K
  - 6.5um Diffraction Limit
  - New Generation Detector Arrays
  - Instrumental Capabilities
    - Imaging/Photometry, 3-180um
    - Spectroscopy, 5-40um
    - Spectrophotometry, 50-100um
  - Planetary Tracking, 1 arcsec/sec
  - >75% of observing time for the General Scientific Community
  - 2.5 yr Lifetime/5 yr Goal
  - Launch in July 2002 (Delta 7920H)
  - Earth-Trailing Solar Orbit
- **Builds upon heritage of IRAS, COBE, ISO**
- **Cornerstone of NASA's Origins Program**



SIRTF

SIRTF Sensitivity Comparisons



SIRTF Primary Scientific Programs

- Protoplanetary Disks and Planetary Debris Disks
- Brown Dwarfs and Super Planets
- Ultraluminous Galaxies and Active Galactic Nuclei
- The Early Universe

The SIRTF mission is driven only by the requirements of these programs, which are called out for SIRTF in the Bahcall (Decade) Report.

The resulting system will have very powerful capabilities in many other scientific areas, allowing SIRTF to be an ***observatory for the entire scientific community.***

In addition, SIRTF will have great potential for the ***discovery*** *of new phenomena in the Universe, and the mission must exploit this potential.*

Astro-F

- planned by ISAS
  (Japan’s Institute for Space and Astronautical Science)
- originally named IRIS (Infrared Imaging Surveyor)
- is a 70 cm cooled telescope
- observes from K-band to 200 µm.
- will perform an all-sky survey at wavelengths > 50 µm
- In the near- and mid-infrared ranges, large-format arrays are employed for a deep sky survey in selected sky regions
- sensitivity is much higher than that of the IRAS
  - 50-100x higher sensitivity at 100 µm, > 1000x at mid-IR wavelengths
  - The detection limits are 1 - 100 µJy in the near-mid IR and 10-100 mJy in the far-IR
- diffraction-limited angular resolution at wavelengths longer than 10 µm with pixel sizes less than 1 arcmin
- capable of low-resolution spectroscopy
  - prism spectroscopy in the near- and mid-IR
  - FTS for the wavelength range from 50 to 200 µm
- The launch now scheduled for 2003

Astro-F Science Instruments

- Two Focal-Plane Instruments
  - Far-Infrared Surveyor (FIS)
    - photometer optimized for all-sky survey with far-infrared arrays
    - will produce catalogs of infrared sources
    - can be operated as an imager or a Fourier-transform spectrometer in the pointing mode. The resolution of the spectrometer is about 0.2cm^{-1}
  - Infrared Camera (IRC)
    - three-channel camera that covers the wavelength bands from 2-25 μm
    - has the capability to perform low-resolution spectroscopy with prisms/grisms on filter wheels
    - The field of view of the IRC is 10 arcmin and the spatial resolution is approximately 2 arcsec.
    - Large format arrays are used to attain the deep survey with wide field and high angular resolution.
    - IRC observations are carried out only in pointing mode.

Astro-F: Key Science

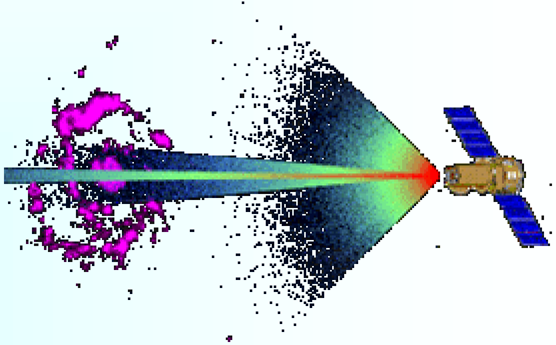
- Search for primeval galaxies, tracing the evolution of the luminous infrared galaxies and normal galaxies to high redshifts (z>3)
- Systematic investigation of the star formation process
  - **ASTRO-F will detect, at 100 - 200 µm, protostars in the very early stages when gas is still accreting onto newly born stars**
  - **ASTRO-F will be able to detect brown dwarfs and super planets in nearby star-formation regions and also field brown dwarfs**.
- Evolution of planetary systems
  - **ASTRO-F can trace the evolution of the protoplanetary disks beyond the weak-line T Tau stage**, which the previous surveys missed. The debris of the planetary formation around normal stars will also be extensively surveyed.

Planned
Intermediate Horizon Missions

GALEX, (KEPLER),
FAME, SIM, GAIA,
CON-X,NGST, TPF

The Galaxy Evolution Explorer (GALEX)

- GALEX uses the space ultraviolet to simultaneously measure:
  - redshift (using metal lines and the Lyman break)
  - extinction (using the UV spectral slope)
  - star formation rate (using theUV luminosity which is proportional to the instantaneous star formation rate).



- Slitless grism spectroscopy is highly efficient, providing 100,000 galaxy spectra in one year.
- The 50 cm telescope, operating from 1300-3000 Å, is
  - simple, cost-effective, efficient
  - exploits MCP detectors and optical coatings which are flight-proven and cutting-edge to attain deep, broad-band imaging and spectroscopy
- A rich survey catalog will be produced and distributed to the community with the assistance of an Associate Investigator Program
- launch planned for April, 2002

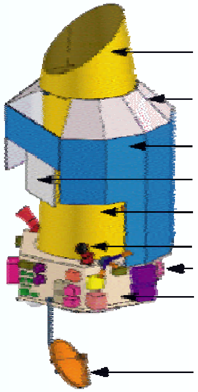
GALEX Science Highlights

- Galaxies:
  - 100,000 spectra; 10,000 resolved images inside 100 Mpc; 10,000,000 unresolved
  - History/distribution of star formation, Microhistory of star formation (bursts)
  - role of companions in driving star formation
  - Evolution in IMF; Volume limited census of local UV galaxy properties
  - Low surface brightness galaxies; Elliptical galaxies: UV rising flux turn-on
  - The extragalactic FUV & MUV background: census of total star formation to z~2
- QSOs:
  - 10,000 spectra; 1,000,000 in All-Sky Imaging Survey
  - 1000 QSOs visible in the rest EUV for the HeII Gunn-Peterson test; QSO death and galaxy evolution
  - Evolution & physics of black hole accretion disks; Large-scale structure evolution
  - QSO time variability survey
- Stellar Evolution:
  - 1000 accreting white dwarf spectra; 100,000 post main-sequence stars
  - White dwarf cooling physics ; The nature of ultra-soft X-ray sources
  - Paths to accretion-induced collapse; The evolution of disks around white dwarfs

Kepler

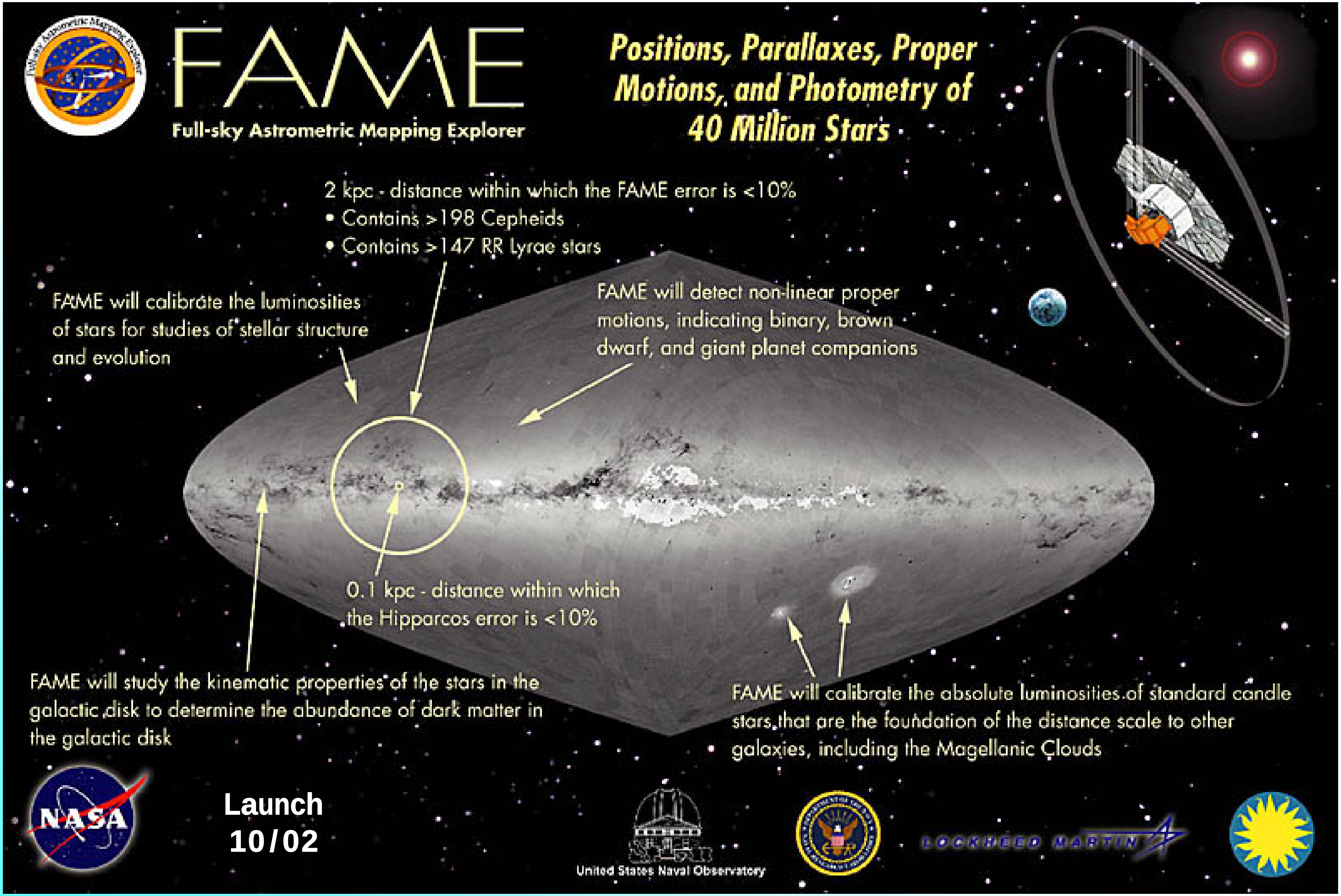
- Candidate Discovery Mission (see Basri poster)
  - Currently in Phase A Study (down-selection in 9/01, launch 8/05)
- Purpose: explore the structure and diversity of planetary systems by observing a large sample of stars to
  - Determine the frequency of terrestrial and larger planets in or near the habitable zone of a wide variety of spectral types of stars.
  - Determine the distributions of their sizes and orbital semi-major axes
  - Estimate the frequency of planets and orbital distribution of planets in multiple-stellar systems.
  - Determine the distributions of semi-major axis, albedo, size, mass and density of short-period giant planets
  - **Determine the properties of those stars that harbor planetary systems**
    - **The spectral type, luminosity class, and metallicity for each star showing transits are obtained from ground-based observations**
    - **Rotation rates, surface brightness, inhomogeneities and stellar activity are obtained directly from the Kepler photometric data**
    - **Stellar age and mass is determined from Kepler p-mode measurements.**

Kepler Design



- Schmidt telescope with 0.95-meter aperture and 105 deg^2 FOV
- It is pointed at and records data from just a single group of stars for the four year duration of the mission.
- The single photometer is composed of an array of 42 CCDs
  - Each 50x25 mm CCD has 2048x1024 pixels.
  - The CCDs are read out every three seconds to prevent saturation.
  - Only the information from the CCD pixels where there are stars brighter than mv=14 is recorded.
  - The CCDs are not used to take pictures. The images are intentionally defocused to 25 arc seconds to improve the photometric precision.)
- The instrument has the sensitivity to detect an Earth-size transit of an m_v=12 G2V (solar-like) star at 4 sigma in 6.5 hours of integration.
- The instrument has a spectral bandpass from 400 nm to 850 nm.
- Data from the individual pixels that make up each star of the 100,000 main sequence stars brighter than mv=14 are recorded continuously and simultaneously.

Full-sky Astrometric Mapping Explorer



FAME

Full-sky Astrometric Mapping Explorer

Positions, Parallaxes, Proper Motions, and Photometry of 40 Million Stars

2 kpc - distance within which the FAME error is <10%
- Contains >198 Cepheids
- Contains >147 RR Lyrae stars

FAME will calibrate the luminosities of stars for studies of stellar structure and evolution

FAME will detect non-linear proper motions, indicating binary, brown dwarf, and giant planet companions

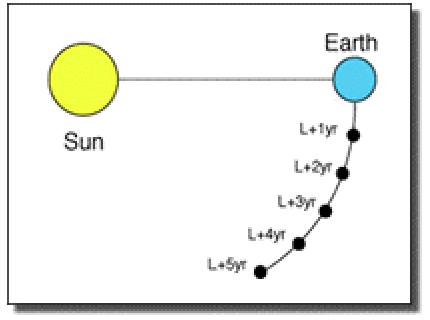
0.1 kpc - distance within which the Hipparcos error is <10%

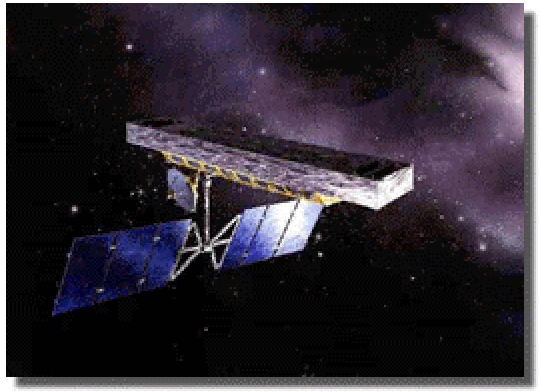
FAME will study the kinematic properties of the stars in the galactic disk to determine the abundance of dark matter in the galactic disk

FAME will calibrate the absolute luminosities of standard candle stars that are the foundation of the distance scale to other galaxies, including the Magellanic Clouds

Launch 10/02

Space Interferometry Mission (SIM)

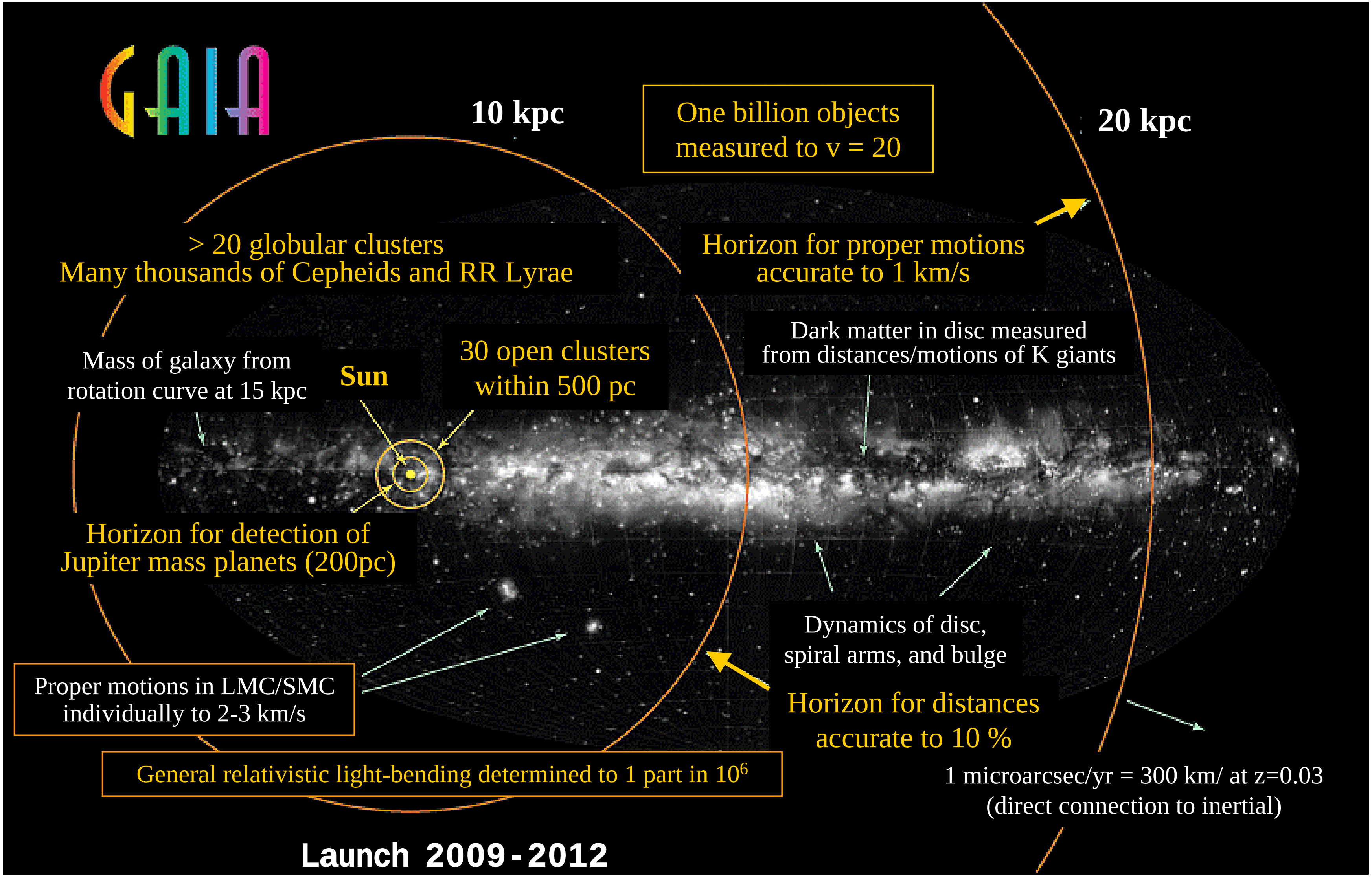




Baseline	10 m
Wavelength range	0.4 - 0.9µm
Telescope Aperture	0.3 m diameter
Astrometric Field of Regard	15° diameter
Astrometric Narrow Angle Field of View	1° diameter
Imaging Field of View	1 arcsec
Detector	Si CCD

Solar Orbit	Earth-trailing
Science Mission Duration	5 years (launch in 2009)
Wide Angle Astrometry	**4 µas mission accuracy**
Narrow Angle Astrometry	**1 µas mission accuracy**
Limiting Magnitude	20 mag
Imaging Resolution	10 milliarcsec
Interferometric Nulling	Null depth 10-4

GAIA



10 kpc

One billion objects measured to v = 20

20 kpc

> 20 globular clusters
Many thousands of Cepheids and RR Lyrae

Horizon for proper motions accurate to 1 km/s

Mass of galaxy from rotation curve at 15 kpc

Sun

30 open clusters within 500 pc

Dark matter in disc measured from distances/motions of K giants

Horizon for detection of Jupiter mass planets (200pc)

Dynamics of disc, spiral arms, and bulge

Proper motions in LMC/SMC individually to 2-3 km/s

Horizon for distances accurate to 10 %

General relativistic light-bending determined to 1 part in 10^6

1 microarcsec/yr = 300 km/ at z=0.03
(direct connection to inertial)

Launch 2009 - 2012

GAIA Compared with Hipparcos

Parameter	**Hipparcos**	**GAIA**
Magnitude limit:	12	20 - 21 mag
Completeness:	7.3 – 9. 0	~20 mag
Bright limit:	~0	~3 - 7 mag
Number of objects:	120 000	26 million to V = 15 250 million to V = 18 1000 million to V = 20
Effective distance limit:	1 kpc	1 Mpc
Quasars:	None	$\sim 5 \times 10^5$
Galaxies:	None	10^6 - 10^7
Accuracy:	~1 milliarcsec	4 μ arcsec at V = 10 10 μ arcsec at V = 15 200 μ arcsec at V = 20
Broad band:	2-color(B and V)	4-color to V = 20
Medium band:	None	11-color to V = 20
Radial velocity:	None	1- 10 km/ s to V = 16- 17
Observing program:	Pre- selected	On- board and unbiased

The Constellation X-ray Mission

An X-ray VLT

- **Use X-ray spectroscopy to observe**
  - **Black holes: gravity in their vicinity & their evolution**
  - **Large scale structure in the Universe & trace the underlying dark matter**
  - **Production and recycling of the elements**
- **Mission parameters**
  - **Telescope area:** 1.5 m^2 at 1.5 keV
    100 times XMM/Chandra for high resolution spectroscopy
  - **Spectral resolving power:** 300-3,000
    5 times improvement at 6 keV
  - **Band pass:** 0.25 to 40 keV
    100 times more sensitive at 40 keV

Constellation-X Capabilities

Spectroscopy X-ray Telescope

- 0.25 to 10 keV coverage
- resolution of 300-3000 with 2 eV calorimeter array and reflection grating CCD
- angular resolution matched to confusion limit
  - 5-15 arcsec
  - 5 arcsec pixels
  - 2.5 arcmin FOV

Hard X-ray Telescope

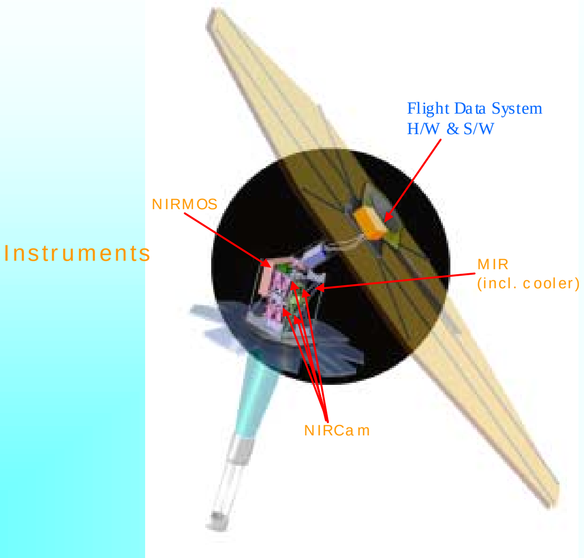
- 10 to 40 keV
- 1,500 sq cm at 40 keV
- energy resolution < 1 keV
- 60 arcsec HPD angular resolution
- Overall factor of 20-100 increased sensitivity

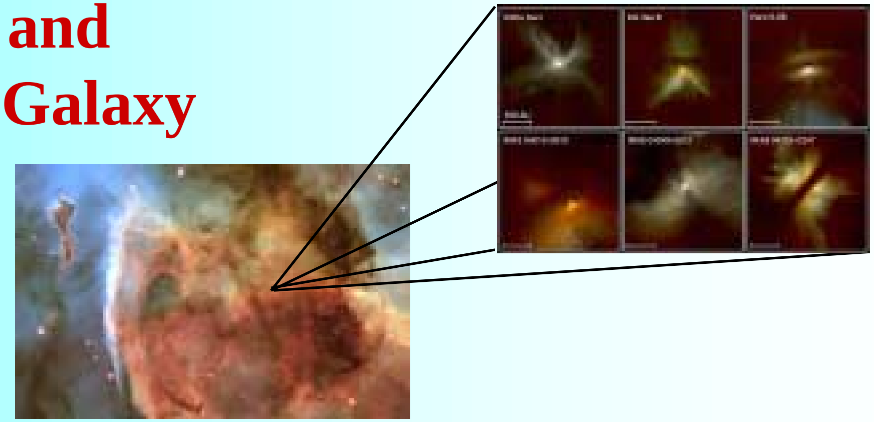
Launch 2009

NGST: Key Science Objectives

- Detect and Characterize the First Stars and Galaxies to Form after the Big Bang
    - *"First Light" Machine*
- Measure the Complete Formation Processes of Galaxies and the Creation of Heavy Elements
    - *Visiting a Time When Galaxies Were Young*
- **Study the Details of Star and Planet Formation in our Galaxy**
    - *Prolog to Astrobiology*

ISIM is the Payload of NGST

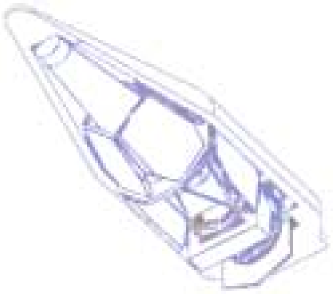


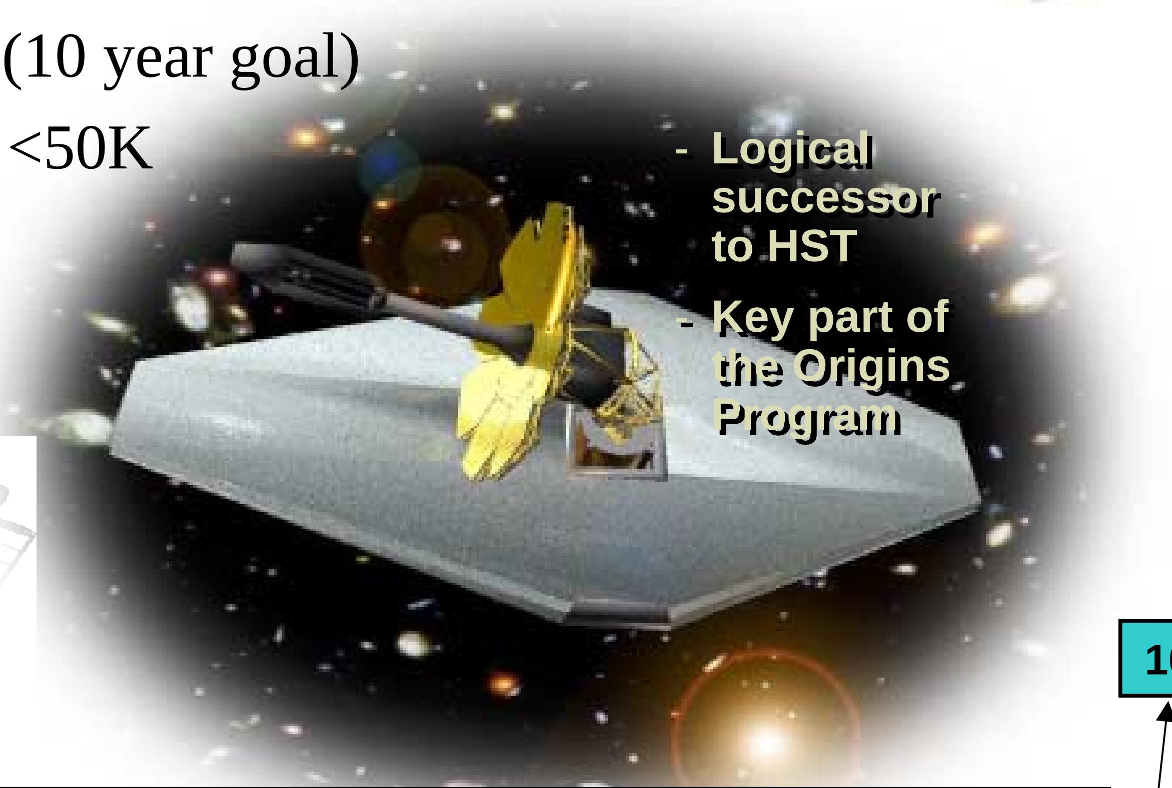


http://www.ngst.nasa.gov

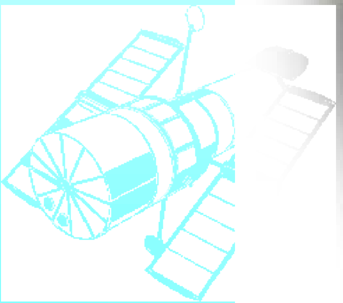
NGST at a Glance

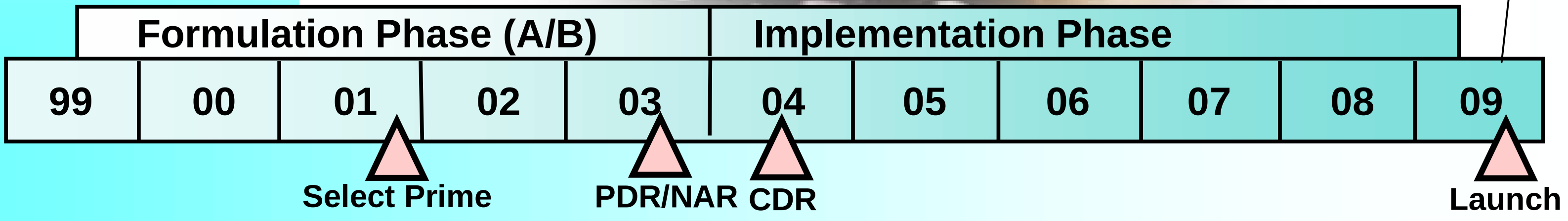
- Primary Mirror: 8 m .. 7 m ... 6 m ← ***Standby for Live Update!***
- 0.6-10+ µm Wavelength Range
- 5 year Mission Life (10 year goal)
- Passively Cooled to <50K
- L2 Orbit





- **Logical successor to HST**
- **Key part of the Origins Program**





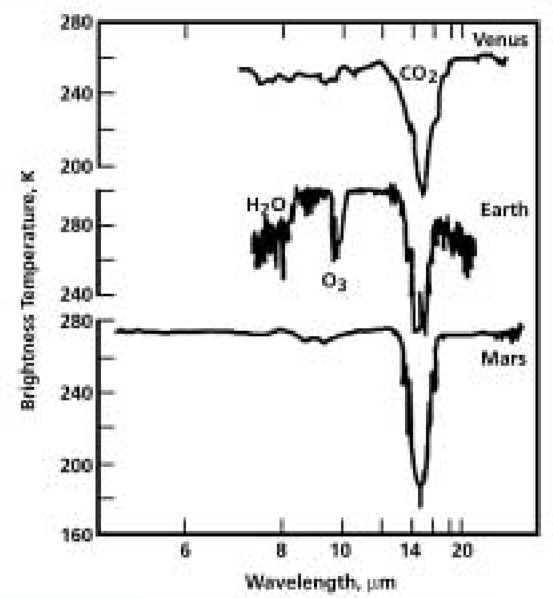
Formulation Phase (A/B)					Implementation Phase					
99	00	01	02	03	04	05	06	07	08	09

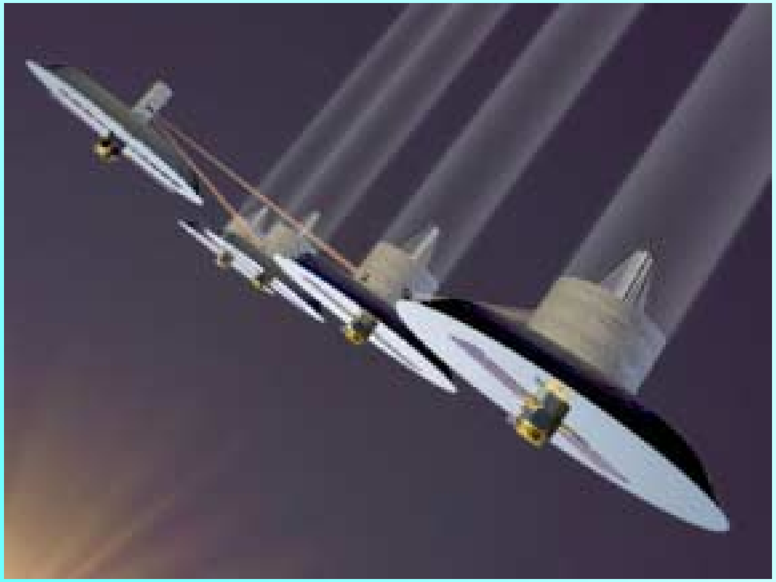
Recommended Instruments for NGST Goals

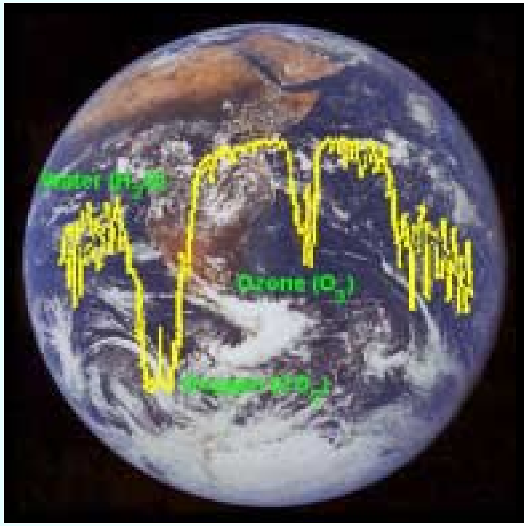
- 4´ x 4´NIR Camera (8k x 8k pixels)
  - Nyquist sampled at 2 µm, 0.6-5 µm, *R*~100 grism mode
    - First light, galaxy formation, dark matter, supernovae, young stars, Kuiper Belt Objects (KBO), stellar populations
- 3´ x 3´ NIR *R*~1000 Multi-Object Spectrograph
  - Simultaneous source spectra, 1-5 µm
    - Gal formation/diagnostics (clustering, abun., star form., kinematics), Active Galactic Nuclei, young stellar clusters (Initial Mass Function (IMF)/stellar populations)
- 2´ x 2´ Mid IR Camera/*R*~1500 Spectrograph
  - Nyquist sampled at ~10 µm, 5-28 µm, grisms & slit
    - Physics of old stars at high redshift, z~5 obscured star form. & Active Galactic Nuclei to *z* ~ 5, PAHs to *z*~5, Ha to z~15 , cool stellar IMF, protostars and disks, KBO sizes, comets

Terrestrial Planet Finder(TPF) and IRSI/Darwin

- Science: Detect Earth-like planets; perform spectroscopic analysis on planetary atmospheres; perform synthetic imaging & astrophysics
- Instruments: IR Nulling interferometer or visible coronagraph (TPF opt)
- Target: Survey stars within 5-15 parsecs
- Mission Duration: Five years







TPF and IRSI/Darwin

- Orbit: TPF: Earth-trailing, 1 AU from the Sun; gradually drifts away from Earth, reaching 0.6 AU in five years
  Darwin: L2

- Launch: 2010 on EELV; no post-injection trajectory correction maneuvers -- injection accuracy of the launch vehicle is adequate.

- Spacecraft: Four collector spacecraft; one combiner spacecraft.

- Formation: 45-135 m baseline for planet-finding;
  up to 1 km baseline for astrophysics.

- Operations: Planet finding: 8 hours to rotate spacecraft 360 degrees.
  Spectroscopy: slow, 3 degrees/hour continuous rotation.
  Astrophysics: various, slow drift at 45 m to 1 km baseline.

Far-Horizon Missions

“Next HST”, SPIRIT/SPECS, SI, MAXIM, XEUS, PI

UV/Optical Follow-on to HST

- SUVO, HST2, NHST ...
- 4 - 8 m filled-aperture
- original concept: spectroscopy only
- likely concept: imaging as well
- workshop scheduled winter 2002 at STScI to define science requirements and best architecture

See also poster by Wamstecker et al. on “World Space Observatory”

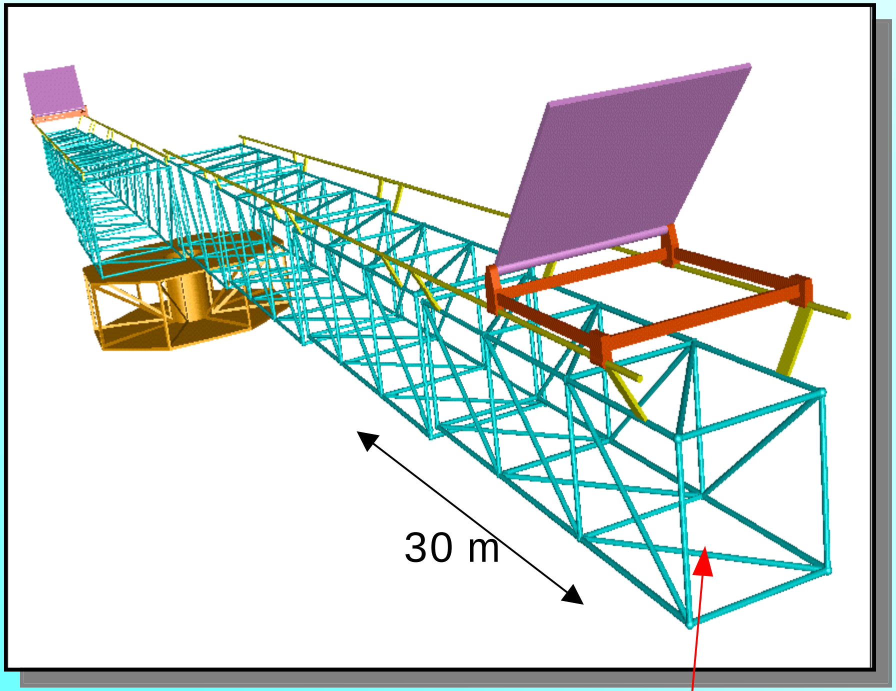
SPIRIT and SPECS: Far IR/sub-mm Space Interferometry

SPIRIT ~2010

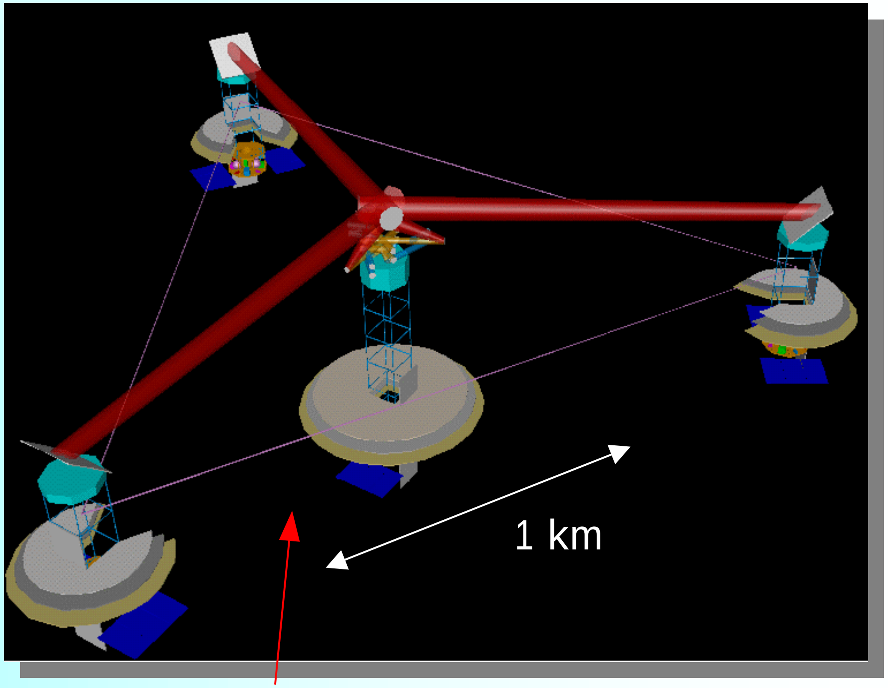
Space IR Interferometry Telescope

SPECS ~2015

Submillimeter Probe of the Evolution of Cosmic Structure



Deployable truss



Tethered spacecraft formation

http://space.gsfc.nasa.gov/astro/specs

Far-IR/Sub-mm Science Overview

NAS Decadal Report recommends:

– Develop enabling technologies this decade

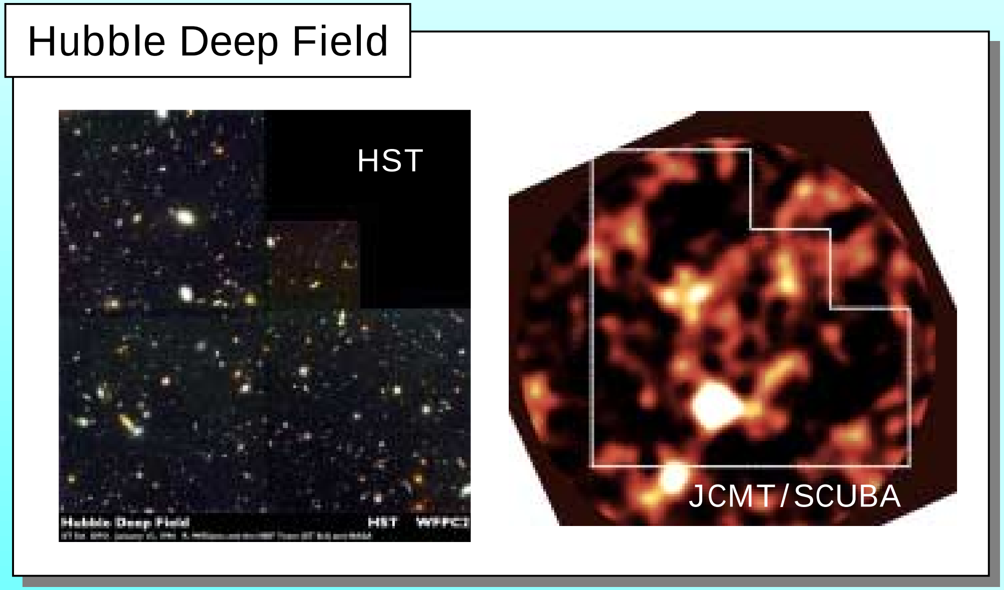
– Space-based far-IR interferometer next decade

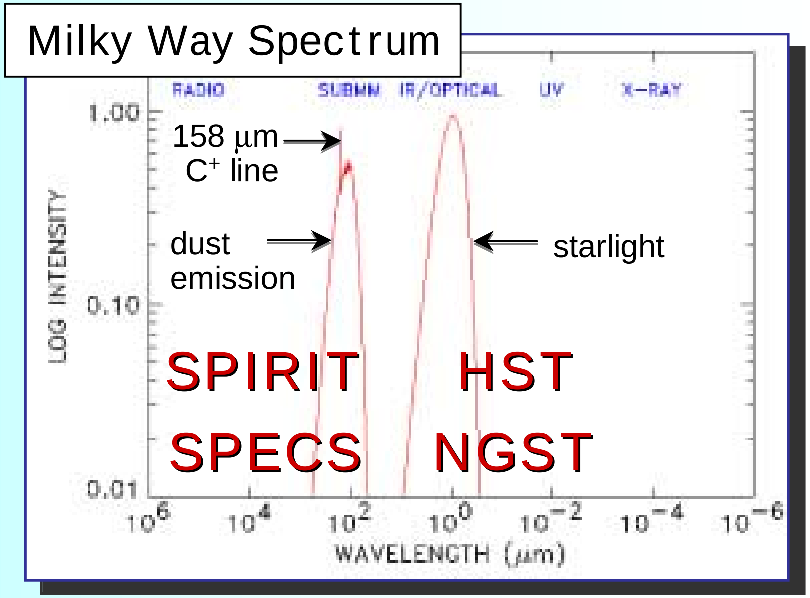
Science goals are major OSS objectives:

– How did structure in the universe (galaxies, stars, planets) form and evolve over time?

– What is the cosmic history of energy release?

– What is the history of chemical element formation & dissemination?

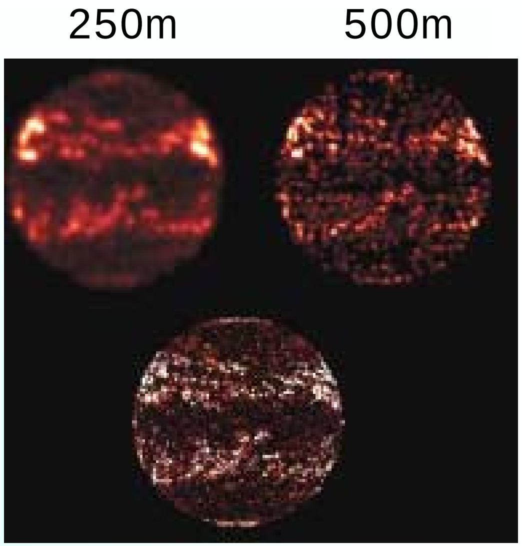

Hubble Deep Field


Milky Way Spectrum

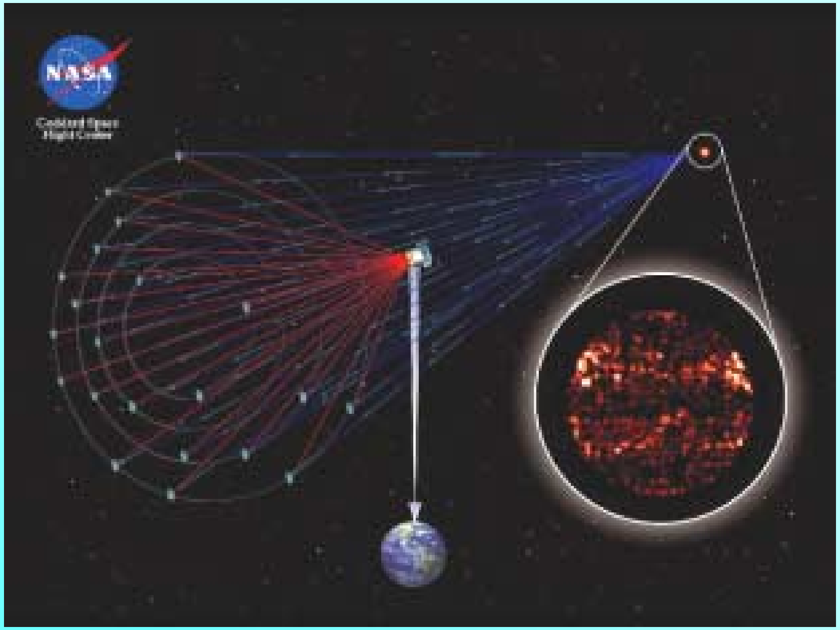
- Many objects have no UV/optical counterparts
- Star and planet formation are totally hidden

- Half of the energy is in the far-IR

Stellar Imager (SI)



- UV-Optical Fizeau Imaging Interferometer, 60 microarcsec resolution at C IV 1550 A
- 30 “mirrorsats” formation-flying with central beam-combining hub, maximum baseline ~500 m
- Launch > 2015, into Lissajous orbit around L_2
- Mission duration: 10 years
- Produces about 1000 pixels/stellar image



Prime Science Goals

image surface features of other stars and measure their spatial/temporal variations

to understand the underlying dynamo process(es) and

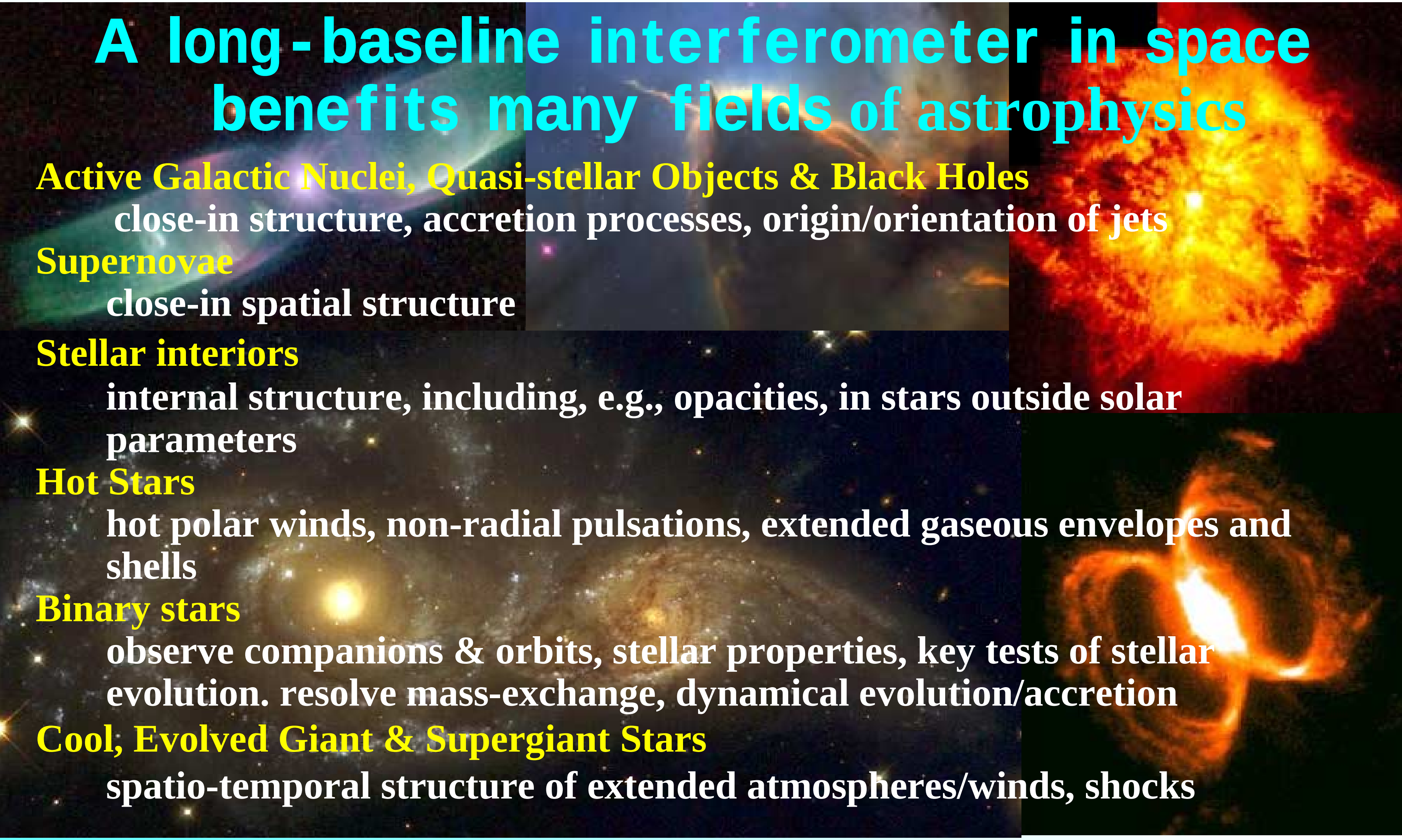
enable improved forecasting of solar/stellar activity and its impact on planetary climates and life

http://hires.gsfc.nasa.gov/~si

Primary SI Mission

- A Population study of cool stars
  - To understand the dynamo, we need to know how magnetic fields are generated & behave in different circumstances - the sun is only one example and provides insufficient constraints on theories of dynamos, turbulence, structure, and internal mixing
    - we must observe other stars to *establish how mass, rotation, brightness and age affect the* ***patterns of activity*** & determine:
      - What determines cycle strength and duration? Can multiple cycles exist at the surface? How do polar spots form?
      - How common is solar-like activity? What are extremely (in)active stars like? What are Maunder-minimum states like?
- Asteroseismology (acoustic imaging) to look beneath surface
  - Although its clearest manifestations are visible on the stellar surface, a full understanding of the dynamo requires a knowledge of the underlying layers
    - Where is the seat of the dynamo? What determines differential rotation and meridional circulation, and what role do they play in the dynamo?
    - What is the impact of magnetic deceleration on internal rotation and stellar evolution? How are stellar interiors modified in extremely active stars?

SI and General Astrophysics



A long-baseline interferometer in space benefits many fields of astrophysics

Active Galactic Nuclei, Quasi-stellar Objects & Black Holes

close-in structure, accretion processes, origin/orientation of jets

Supernovae

close-in spatial structure

Stellar interiors

internal structure, including, e.g., opacities, in stars outside solar parameters

Hot Stars

hot polar winds, non-radial pulsations, extended gaseous envelopes and shells

Binary stars

observe companions & orbits, stellar properties, key tests of stellar evolution. resolve mass-exchange, dynamical evolution/accretion

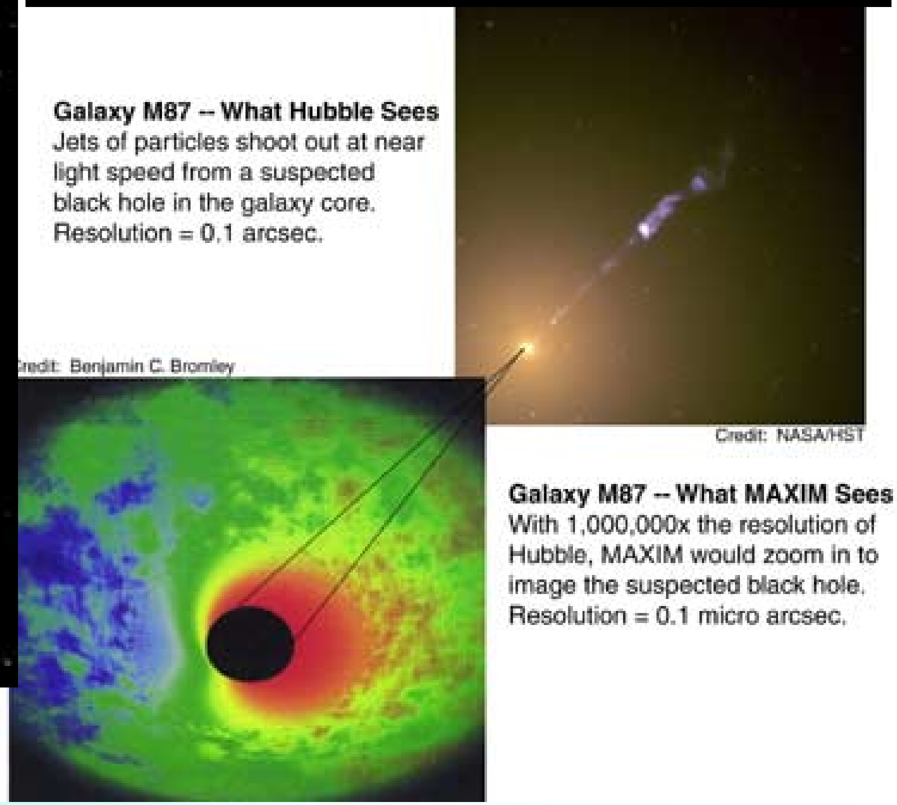
Cool, Evolved Giant & Supergiant Stars

spatio-temporal structure of extended atmospheres/winds, shocks

Micro-Arcsecond X-ray Interferometry Mission (MAXIM): *Image a Black Hole!*

Direct image of a black hole event horizon

- **Fundamental importance to physics**



Galaxy M87 -- What Hubble Sees
Jets of particles shoot out at near light speed from a suspected black hole in the galaxy core.
Resolution = 0.1 arcsec.

redit: Benjamin C. Bromley

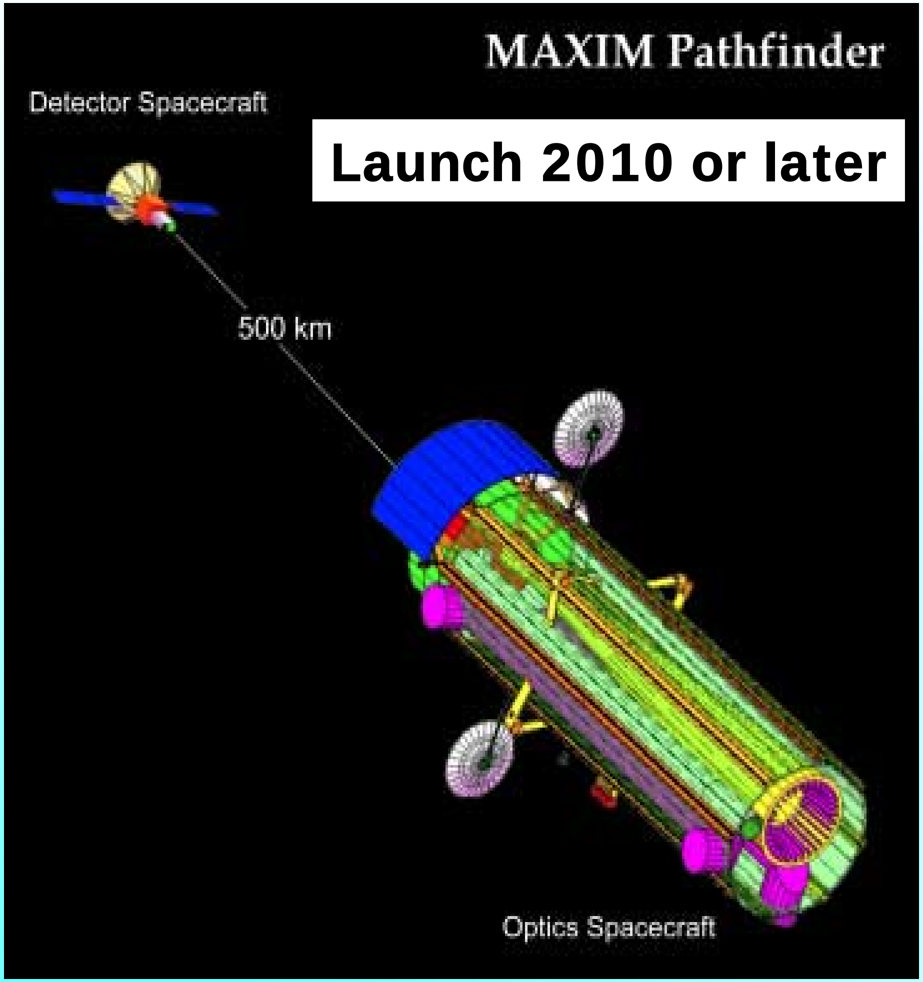
Credit: NASA/HST

Galaxy M87 -- What MAXIM Sees
With 1,000,000x the resolution of Hubble, MAXIM would zoom in to image the suspected black hole.
Resolution = 0.1 micro arcsec.

http://maxim.gsfc.nasa.gov/

MAXIM Pathfinder:

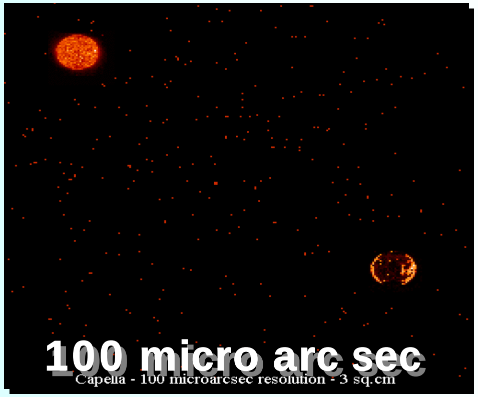
Demonstrate an X-ray interferometer in space



Launch 2010 or later

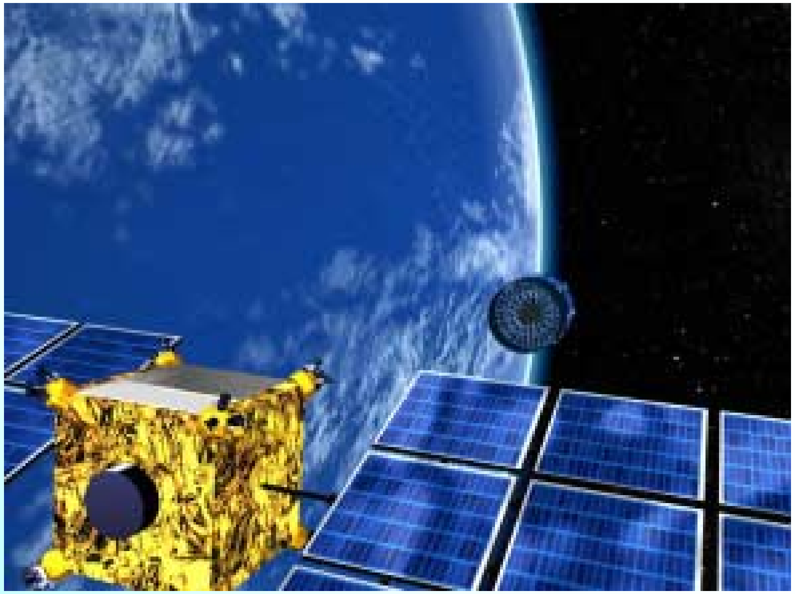
Two formation-flying spacecraft separated by 500 km

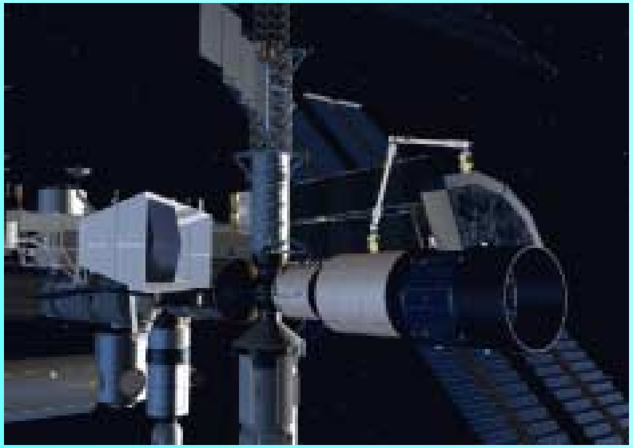
- 100 micro-arc sec resolution
  - ➤ ***1000 times better than Chandra!***
- 1 to 2 m baseline
  - ➤ **optics on single spacecraft**
- Science:
  - ➤ **Imaging nearby stars**

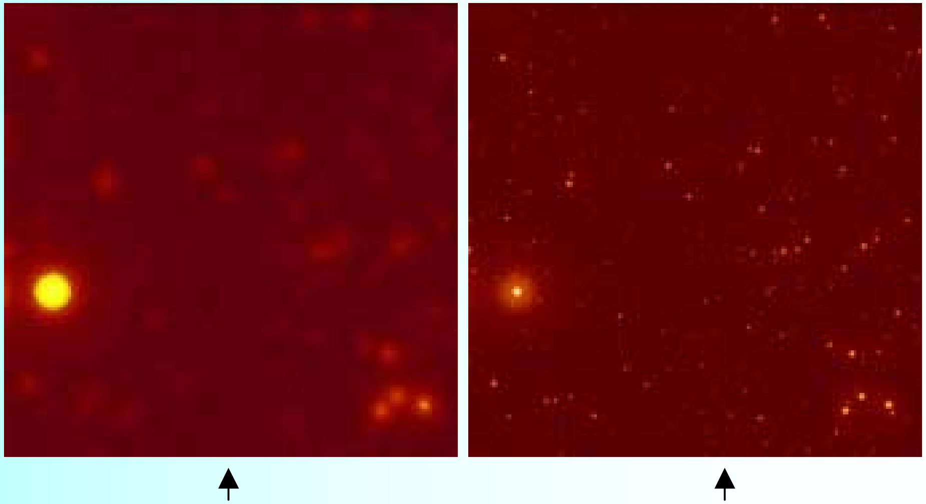


Xeus

- A potential follow-on to ESA's Cornerstone Spectroscopy Mission (XMM-NEWTON).
  - It will be around 250 times more sensitive
- It will be a permanent space-borne X-ray observatory with a sensitivity comparable to the most advanced planned future observatories such as NGST, ALMA and Herschel
- Planned for refurbishment/enlargement at ISS
- The scientific goals include the study of the:
  - First massive black holes.
  - First galaxy groups and their evolution into the massive clusters observed today
  - Evolution of heavy element abundances
  - Intergalactic medium using absorption line spectroscopy. ...



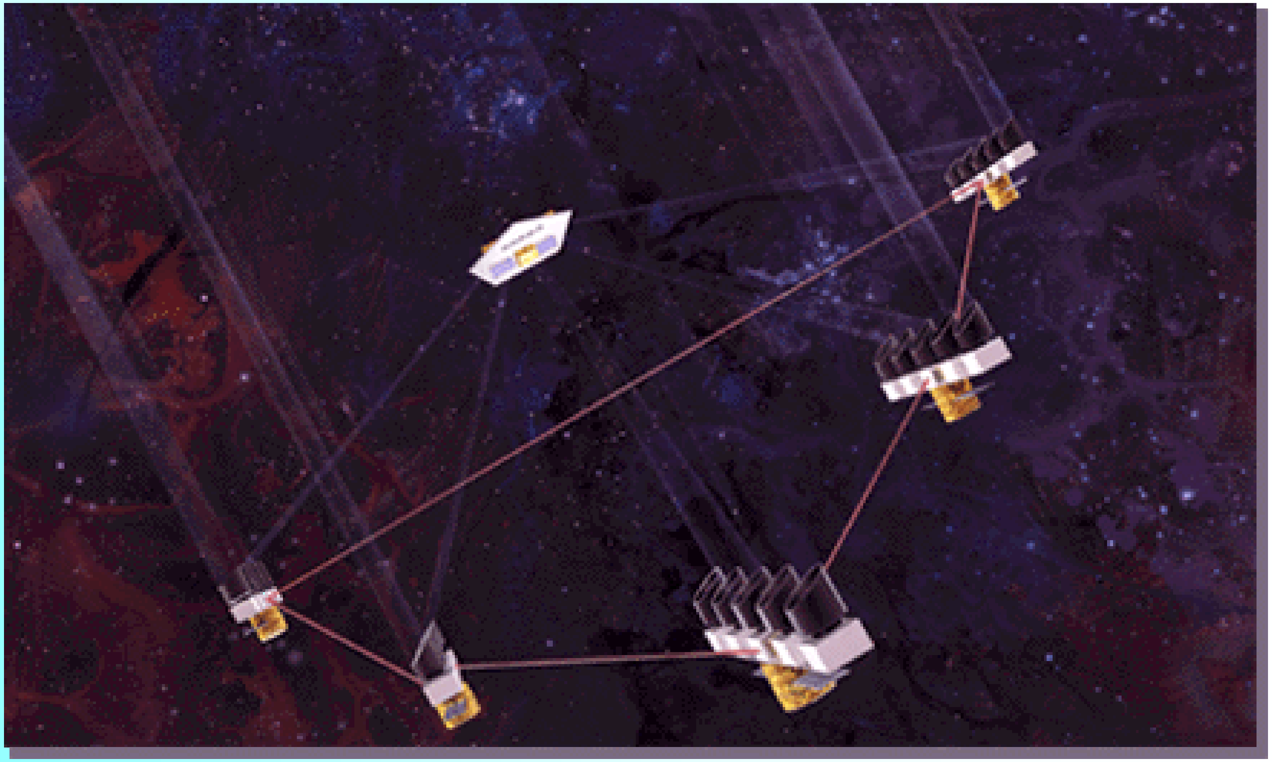




XMM - Deepfields - Xeus

Planet Imager (PI)

- Ultimate Goal of NASA Origins Program: Obtain resolved images of terrrestrial-type planets around other stars
- Strawman Concept: An interferometer composed of interferometers: 5 formation flying interferometers, each composed of five 8-m mirrors (to yield 25x25 pixel images)



Summary

- Surveys:
  GALEX, ASTRO-F, KEPLER (prec. Phot.)
- Great Observatories: SIRTF
- High Sensitivity/High Resolution/Large FOV/Broad Wavelength Coverage Cameras: ACS, WFC3
- High Sensitivity Spectrographs:
  COS, SUVO/HST2, CON-X
- Precision Astrometry: FAME, SIM, GAIA
- Ultra-High Angular Resolution Imaging Inteferometers:
  SPECS, SI, MAXIM, PI

Ground-based optical instrumentation for stellar studies

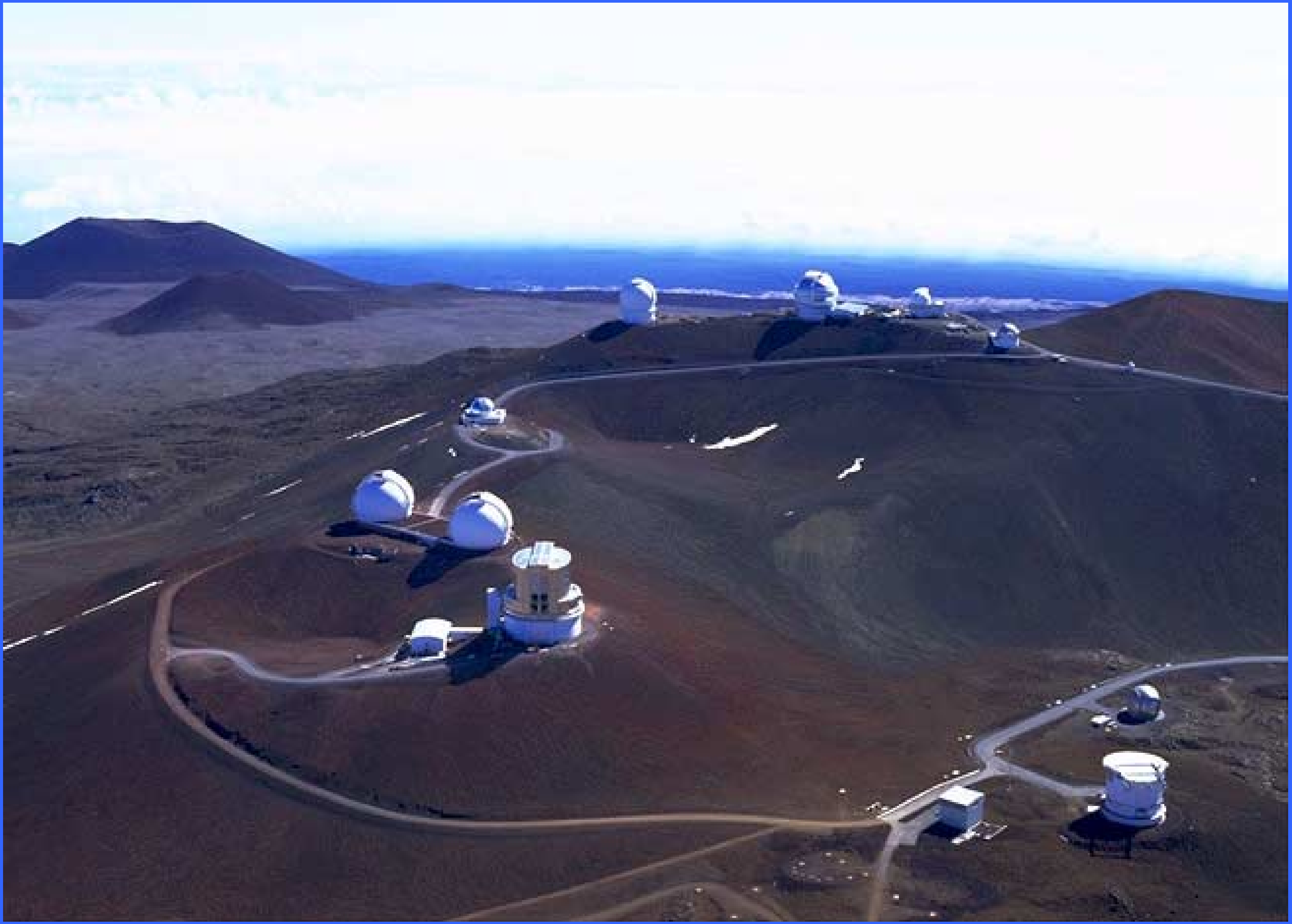
Roberto Pallavicini
INAF/ Osservatorio Astronomico di Palermo
Italy

Year 2000: a crucial time

- advent of large 8-10m class telescopes throughout the world
- new role of 4m class telescopes
- renewed interest in small (1m class, robotic) telescopes
- new observing strategies needed

On top of La Silla, Chile

On top of Mauna Kea, Hawaii



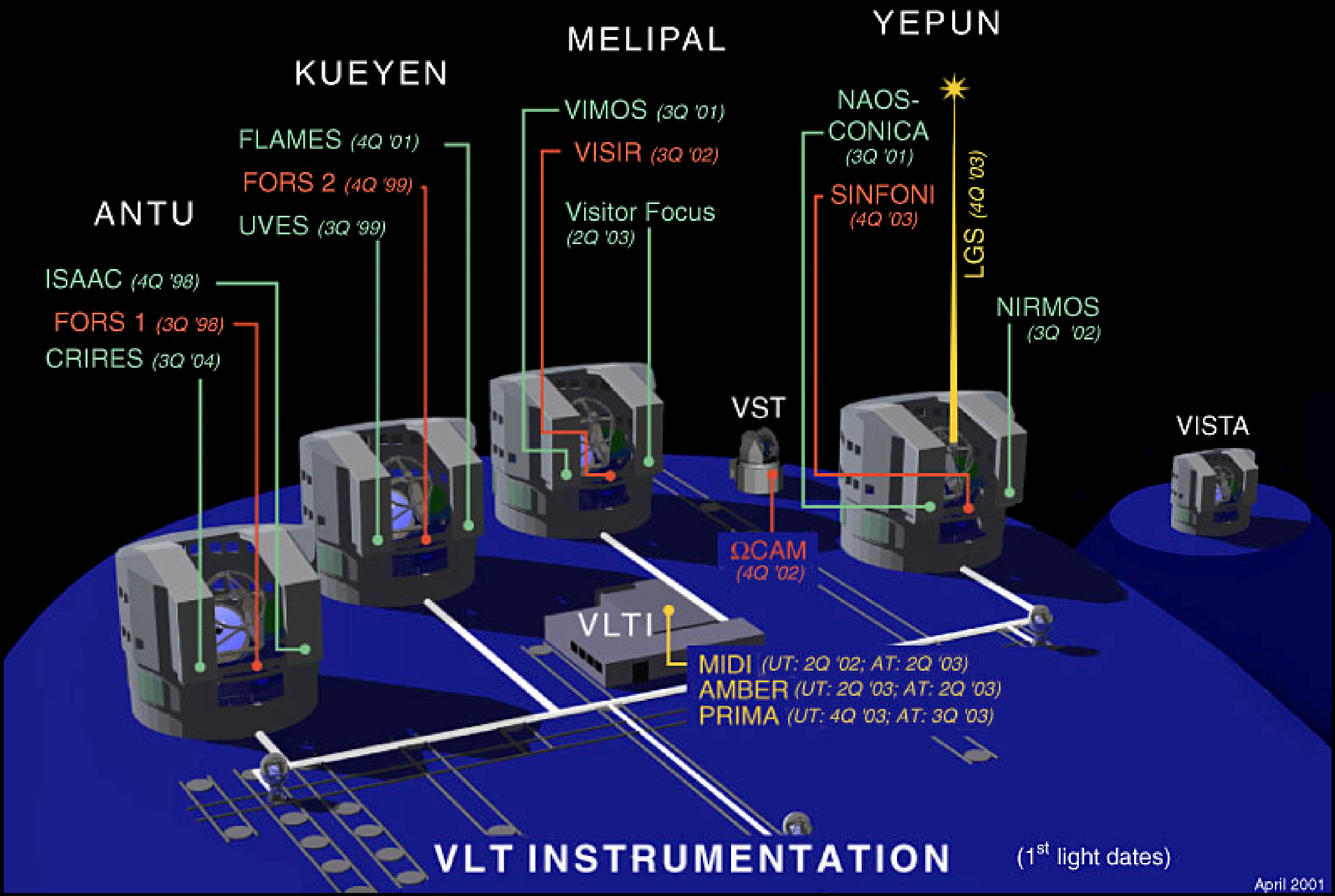
The VLT Array on the Paranal Mountain

ESO PR Photo 14a/00 (24 May 2000)

© European Southern Observatory

Technical developments

- new improved optical detectors
- fiber-feed, multi-object and IFU capabilities
- Adaptive Optics (AO) modules at all major telescopes
- coherent beam combination (interferometry)
- new IR detectors/instruments to complement optical instrumentation



ANTU

ISAAC *(4Q '98)*

FORS 1 *(3Q '98)*

CRIRES *(3Q '04)*

KUEYEN

FLAMES *(4Q '01)*

FORS 2 *(4Q '99)*

UVES *(3Q '99)*

MELIPAL

VIMOS *(3Q '01)*

VISIR *(3Q '02)*

Visitor Focus *(2Q '03)*

YEPUN

NAOS-CONICA *(3Q '01)*

SINFONI *(4Q '03)*

LGS *(4Q '03)*

NIRMOS *(3Q '02)*

VST

ΩCAM *(4Q '02)*

VISTA

VLTI

MIDI *(UT: 2Q '02; AT: 2Q '03)*

AMBER *(UT: 2Q '03; AT: 2Q '03)*

PRIMA *(UT: 4Q '03; AT: 3Q '03)*

VLT INSTRUMENTATION

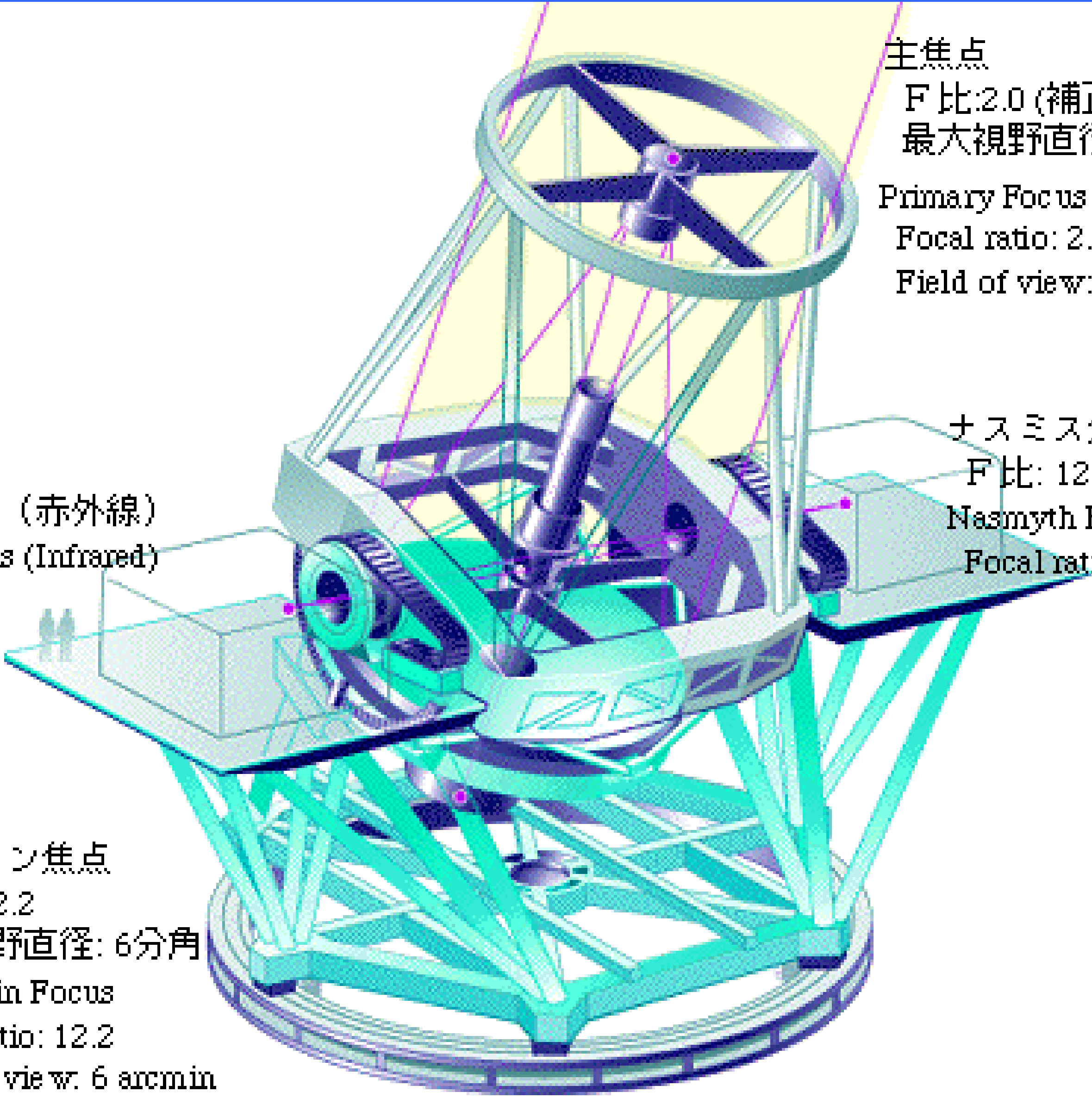
(1st light dates)

April 2001

8-10m telescopes

- only two (Keck I and II) available in the 90's
- several available at the turn of the century (the 4 VLT units, Gemini North and South, Subaru, HET)
- others under construction (LBT, GTC, SALT)
- and plans already for 30-100m telescopes...

The SUBARU telescope at Mauna Kea



主焦点
F 比:2.0 (補正レンズ込み)
最大視野直径: 30分角

Primary Focus
Focal ratio: 2.0 (with corrector)
Field of view: 30 arcmin

ナスミス焦点（可視光）
F 比: 12.6

Nasmyth Focus (Optical)
Focal ratio: 12.6

ナスミス焦点（赤外線）
Nasmyth Focus (Infrared)

カセグレン焦点
F 比: 12.2
最大視野直径: 6分角

Cassegrain Focus
Focal ratio: 12.2
Field of view: 6 arcmin

遠藤孝悦・画　日経サイエンス1996年2月号より
Illustration by Takaetsu Endo, taken from Nikkei Science 1996

6m class telescopes

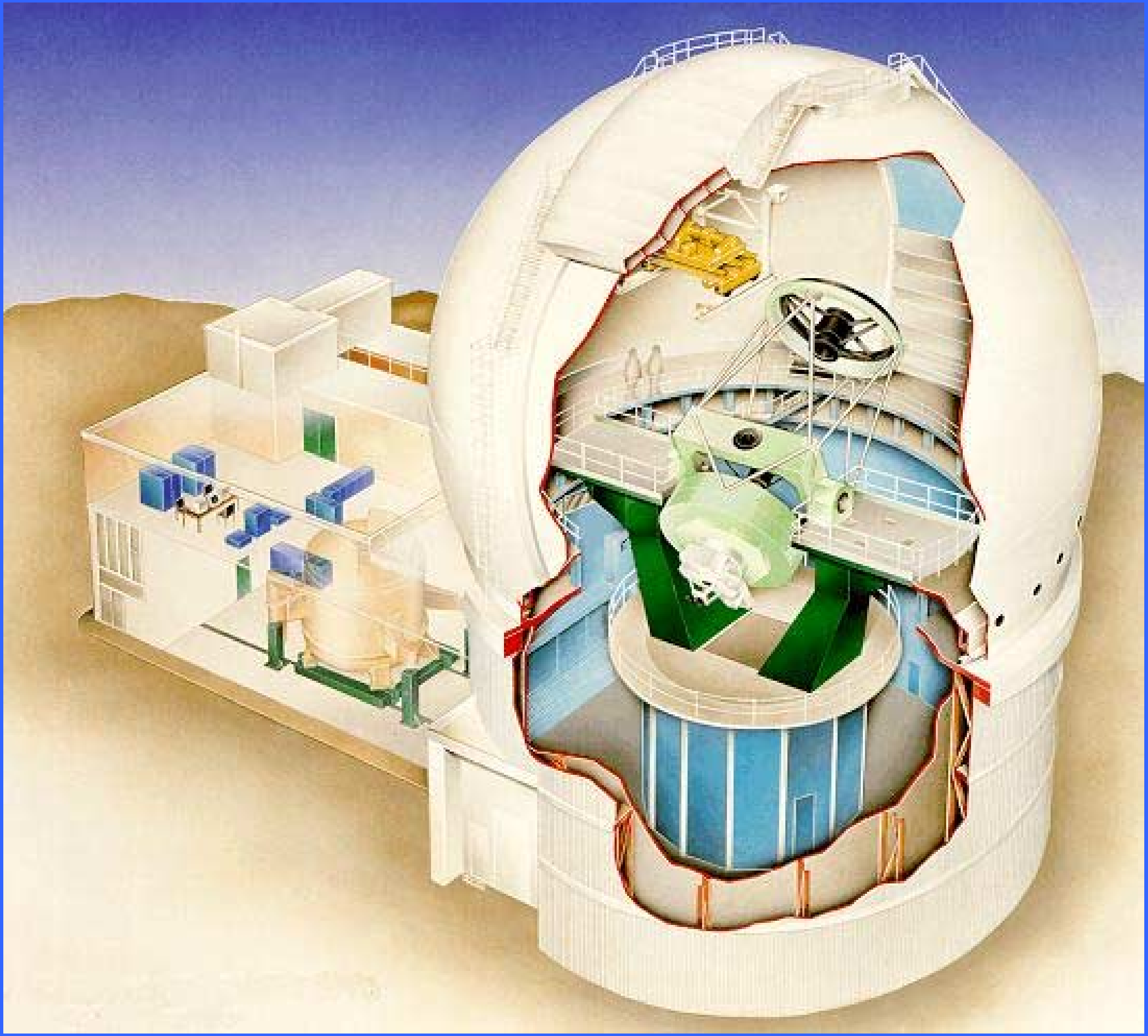
- Converted (monolithic) MMT (twin of Magellan and also test-bench for the LBT)
- Magellan I (and, in the future, Magellan II)
- in addition to the "venerable" ones (Palomar 5m and Bolshoy 6m telescopes)

4m class telescopes

- the “classical” ones (Mayall at Kitt Peak, Blanco at CTIO, ESO 3.6m at La Silla, CFHT at Mauna Kea, AAT in Australia, WHT at La Palma, Calar Alto in Spain)
- the “new technology” ones (ESO NNT at La Silla, WIYN at Kitt Peak, TNG at La Palma, ARC at Apache Point)
- and those under construction (SOAR at Cerro Pachon, LAMOST in China)

The William Herschel Telescope (WHT) at La Palma

The William Herschel Telescope (WHT) at La Palma



A matter of perspective

- until the end of the '90s, 4m class telescopes were the "giant ones" for the average user
- now they are big, but not as "big" as before, with strong impact on the smaller/older ones
- "small" telescopes (< 1m) being closed down at many largest observatories
- role of small telescopes must be reassessed

ESO

New Technology Telescope (NTT)

La Silla, Chile

The Italian National Telescope Galileo (TNG) at La Palma is very similar to NTT

TSU/SAO 0.8m Automatic Photoelectric Telescope

One of several automatic telescopes operated by Tennessee State University at Fairborn Observatory in Southern Arizona

Other considerations

- “private” vs “public” telescopes
- “national” vs “international” telescopes
- “Northern” vs “Southern” telescopes
- “specialized” vs “general purpose” instruments
- instrument complexity (and cost) increasing with telescope aperture
- competition with extragalactic work also increasing with telescope aperture

Advances in optical instrumentation

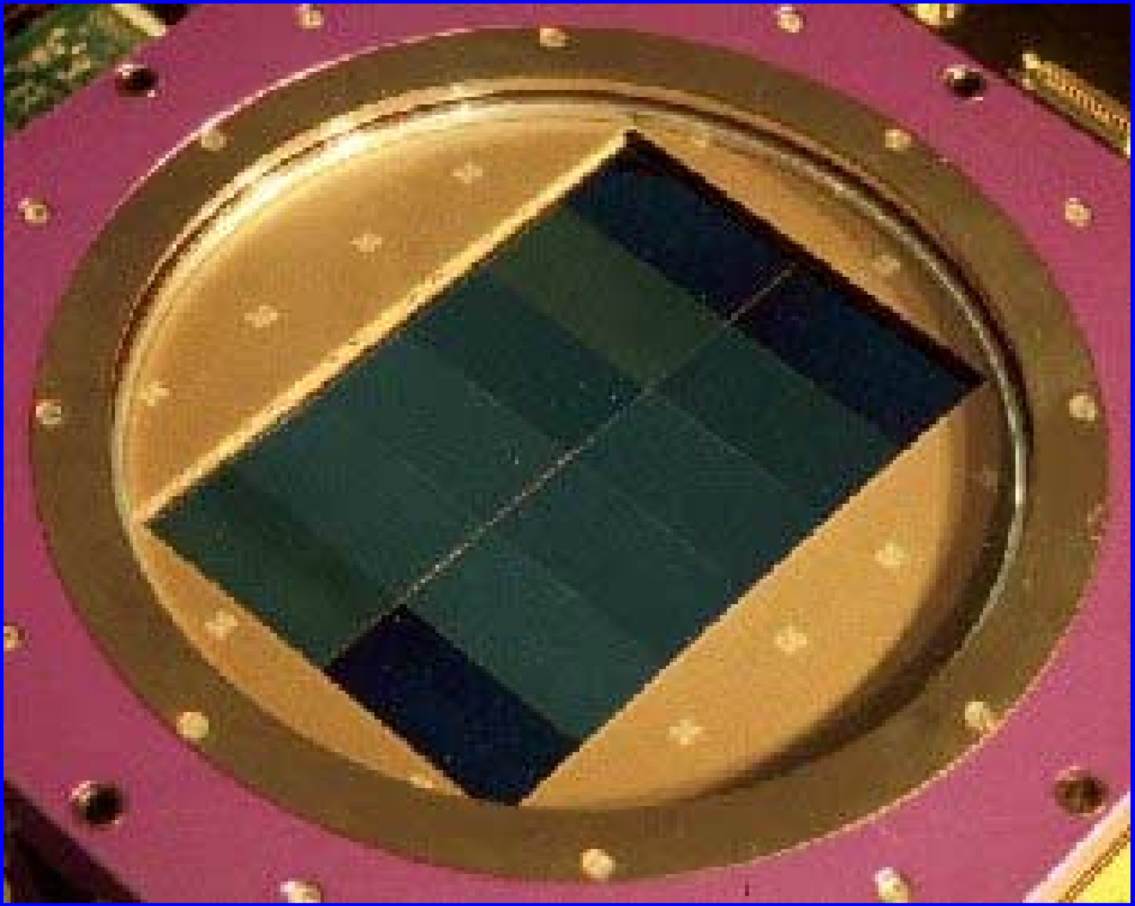
(from a "stellar" point-of-view)

- wide field imaging
- high-resolution spectroscopy
- multi-object (and IFU) spectroscopy
- accurate radial velocities
- interferometry

Wide Field Imaging

- Science: accurate photometry of stellar clusters (open and globular), star forming regions, Local Group galaxies, C-M diagrams, stellar evolution
- present facilities: CFHT12K, AAT WFI, INT WFC, Kitt Peak MOSA, ESO 2.2m & EIS public survey
- future facilities (CFHT MegaCam, VST OmegaCam and VISTA at ESO, Subaru Suprime-Cam, MMT Megacam, LBT PFC)

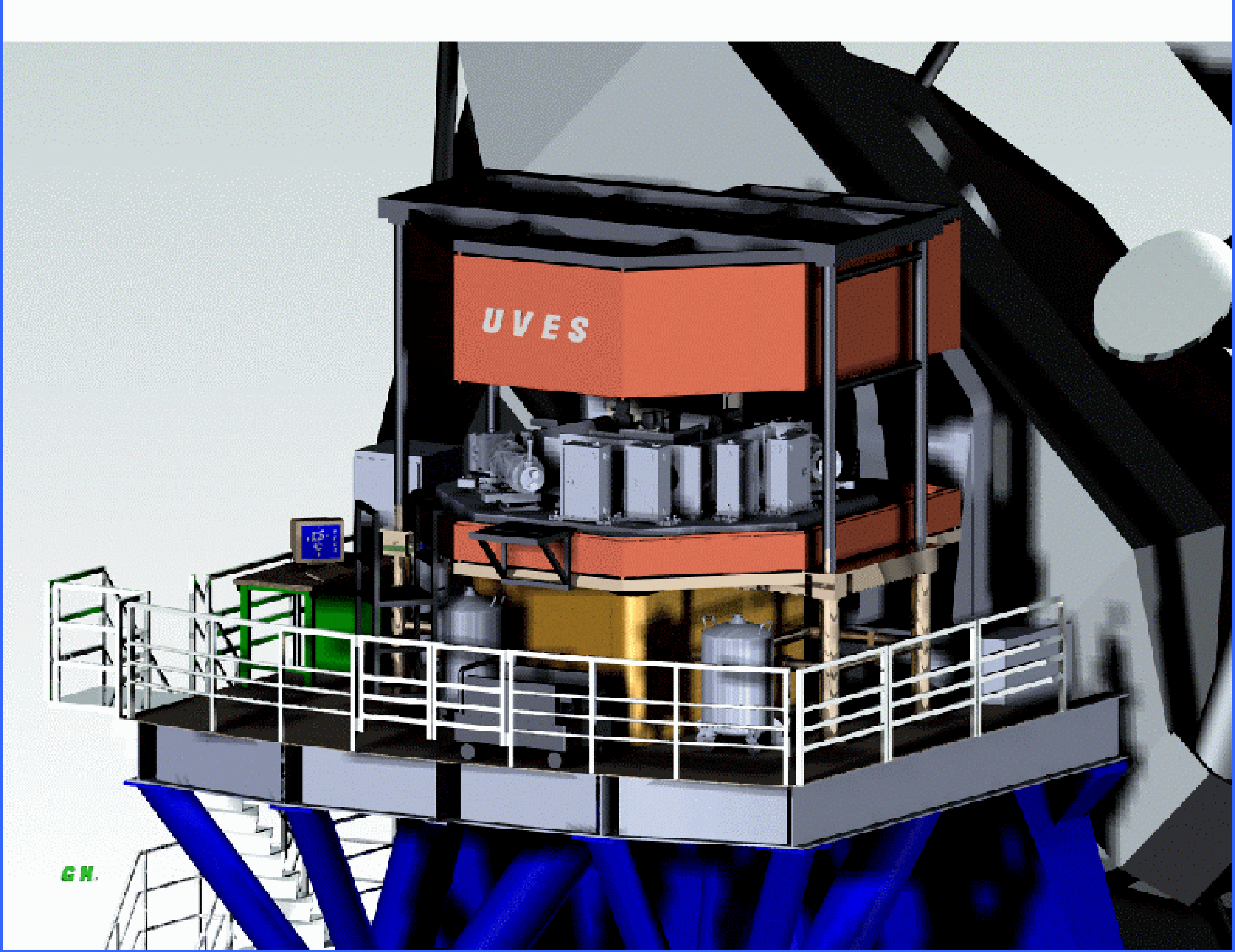
CFHT12K: a 12Kx8K CCD camera at CFHT



High Resolution Spectroscopy

- Science: chemical abundances, line profiles, convection and rotation, stellar atmospheres, radial velocities, stellar activity, Doppler imaging
- HR spectrographs on ≤ 4m telescopes (UCLES at AAT, UES at WHT, SARG at TNG, FEROS at ESO 1.5m + Kitt Peak, Cerro Tololo, CFHT, etc.)
- HR spectrographs on 8-10m class telescopes (HIRES at Keck, UVES at VLT, HRS at HET, HDS at Subaru, HROS at Gemini South)

The UVES spectrograph at the VLT

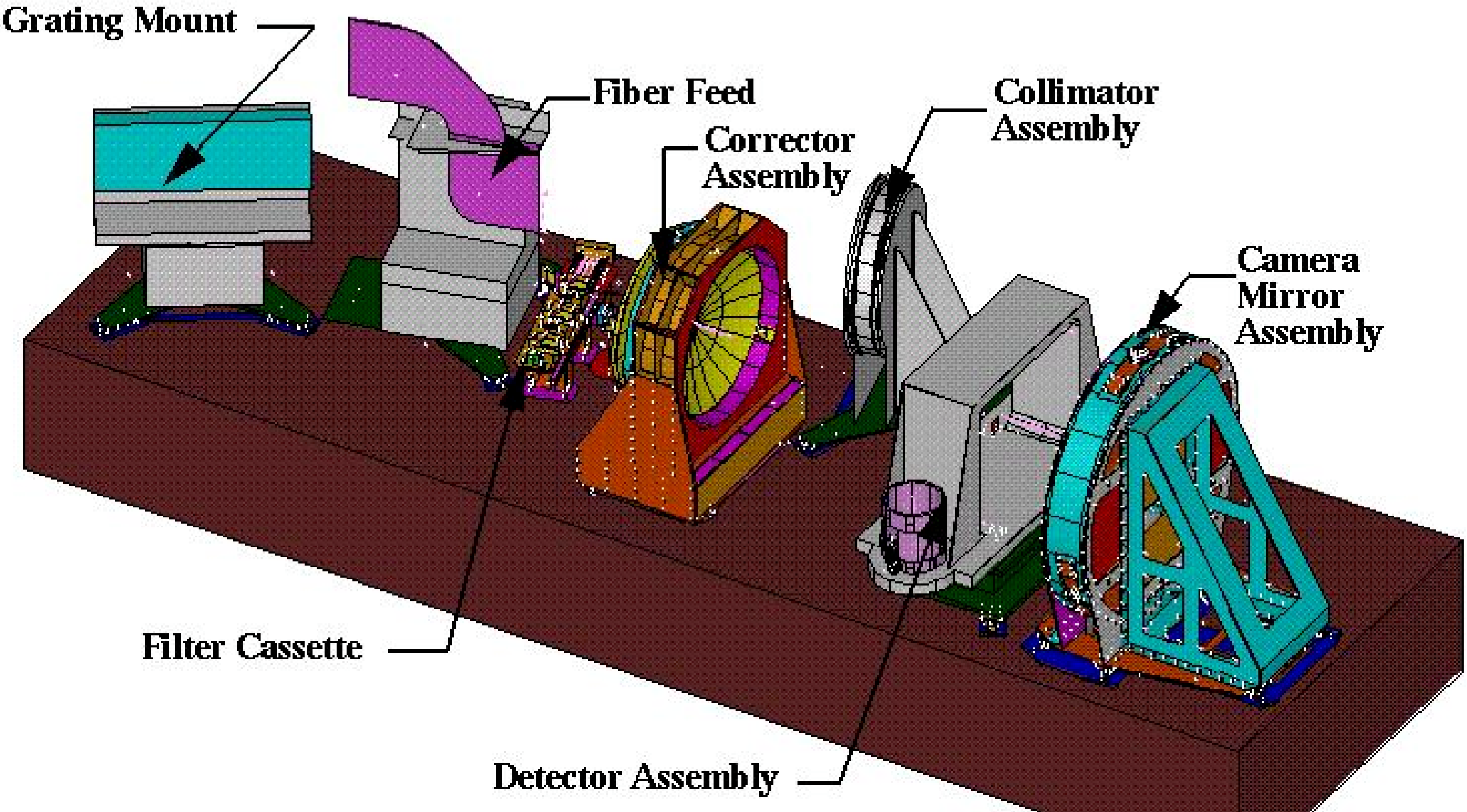


Multi-object spectroscopy

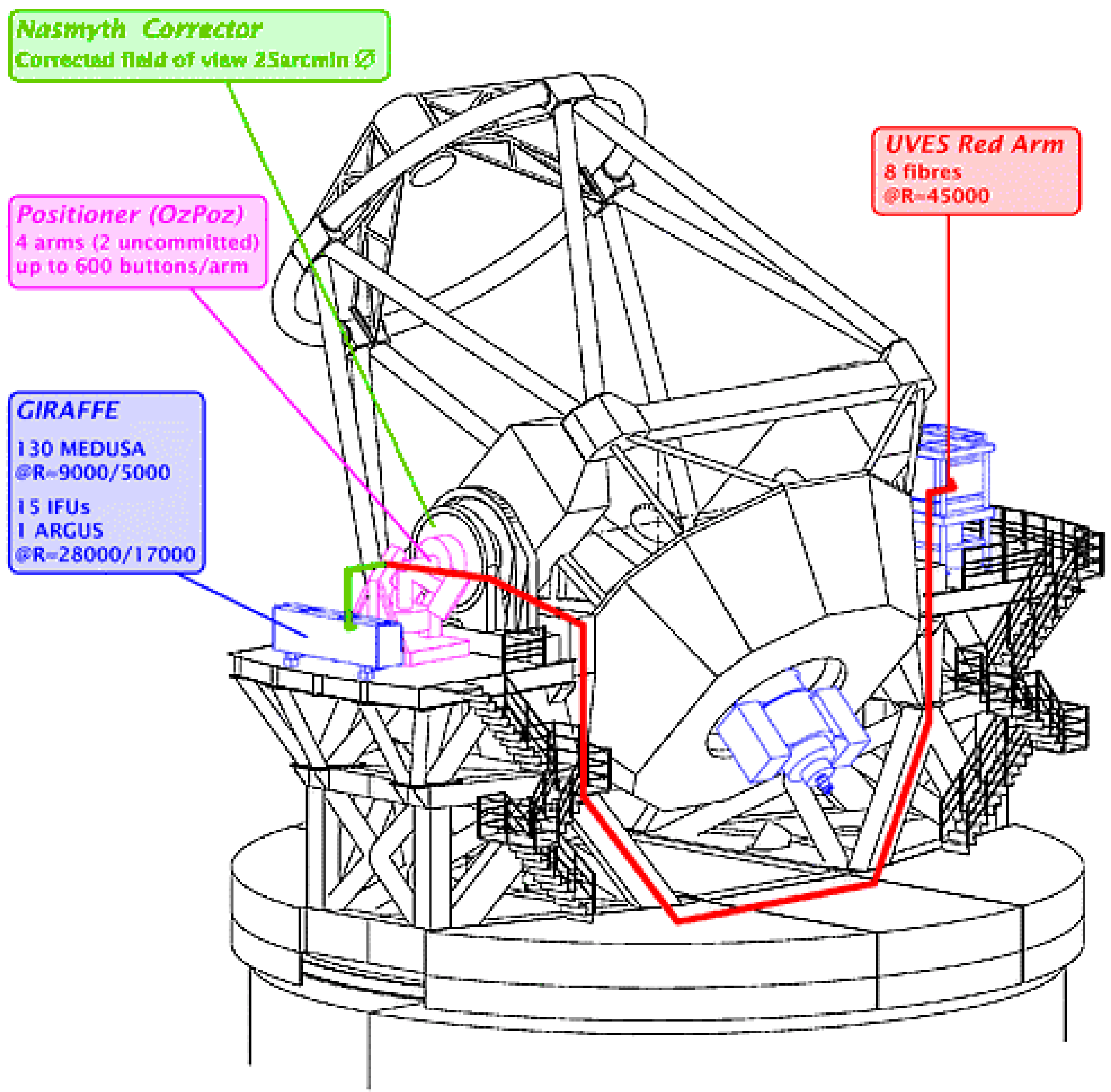
- *low-resolution* multi-slit spectrographs, mostly for extragalactic work, available or being developed (LRIS at Keck, VIMOS at ESO, GMOS at Gemini, LRS at HET, OSIRIS at GTC, MODS at LBT)
- fiber-feed multi-object spectrographs being developed also for stellar work (*at moderate resolution*: 2dF at AAT, WYFFOS at WHT, HECTOSPEC at MMT; *at higher resolution*: HYDRA at WYIN and CTIO, HECTOCHELLE at MMT, FLAMES at VLT)

2dF multi-object facility at AAT

2dF fibre positioner



Hectochelle Spectrograph



Nasmyth Corrector
Corrected field of view 25arcmin Ø

UVES Red Arm
8 fibres
@R=45000

Positioner (OzPoz)
4 arms (2 uncommitted)
up to 600 buttons/arm

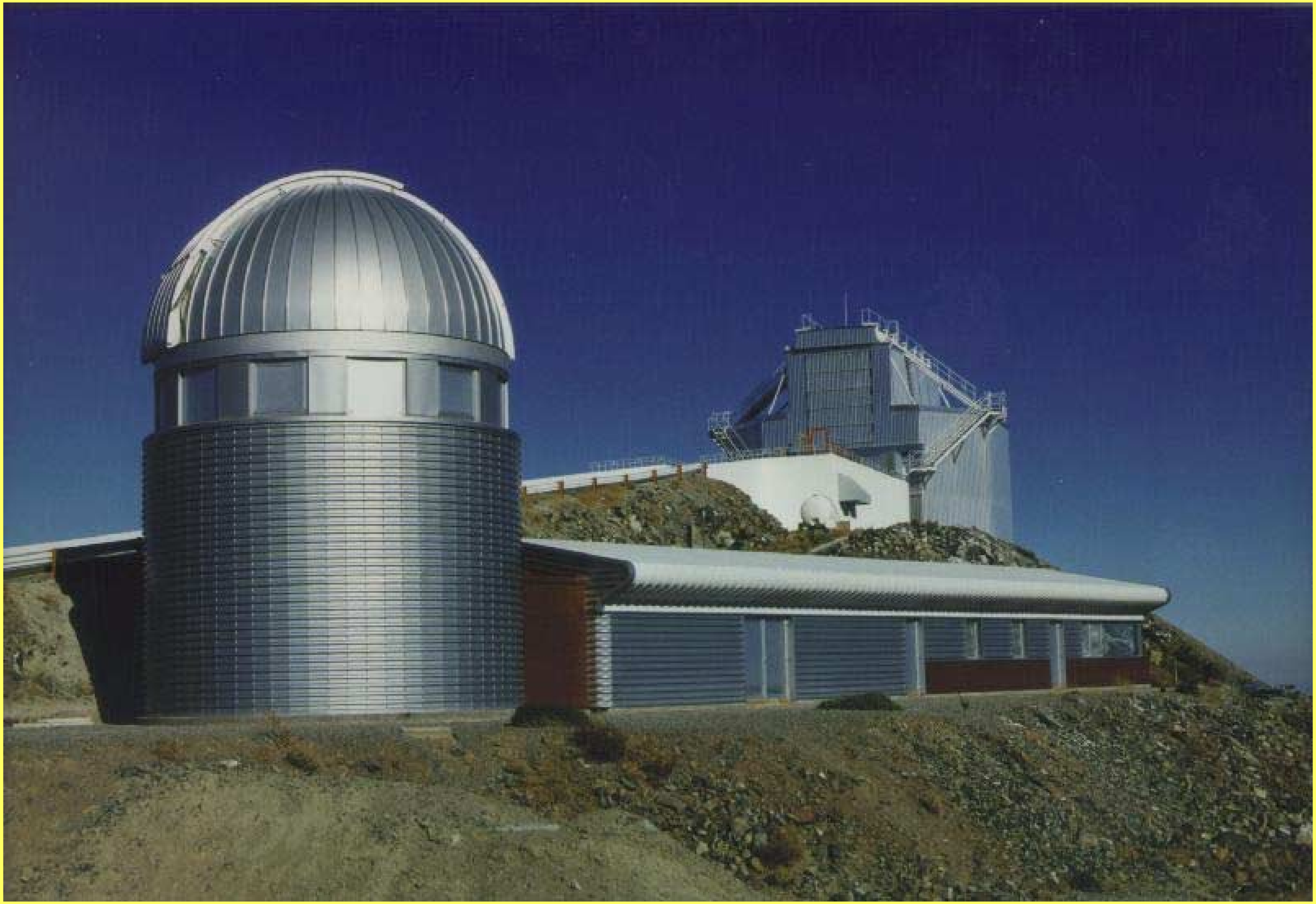
GIRAFFE
130 MEDUSA
@R=9000/5000

15 IFUs
1 ARGUS
@R=28000/17000

Precise radial velocities

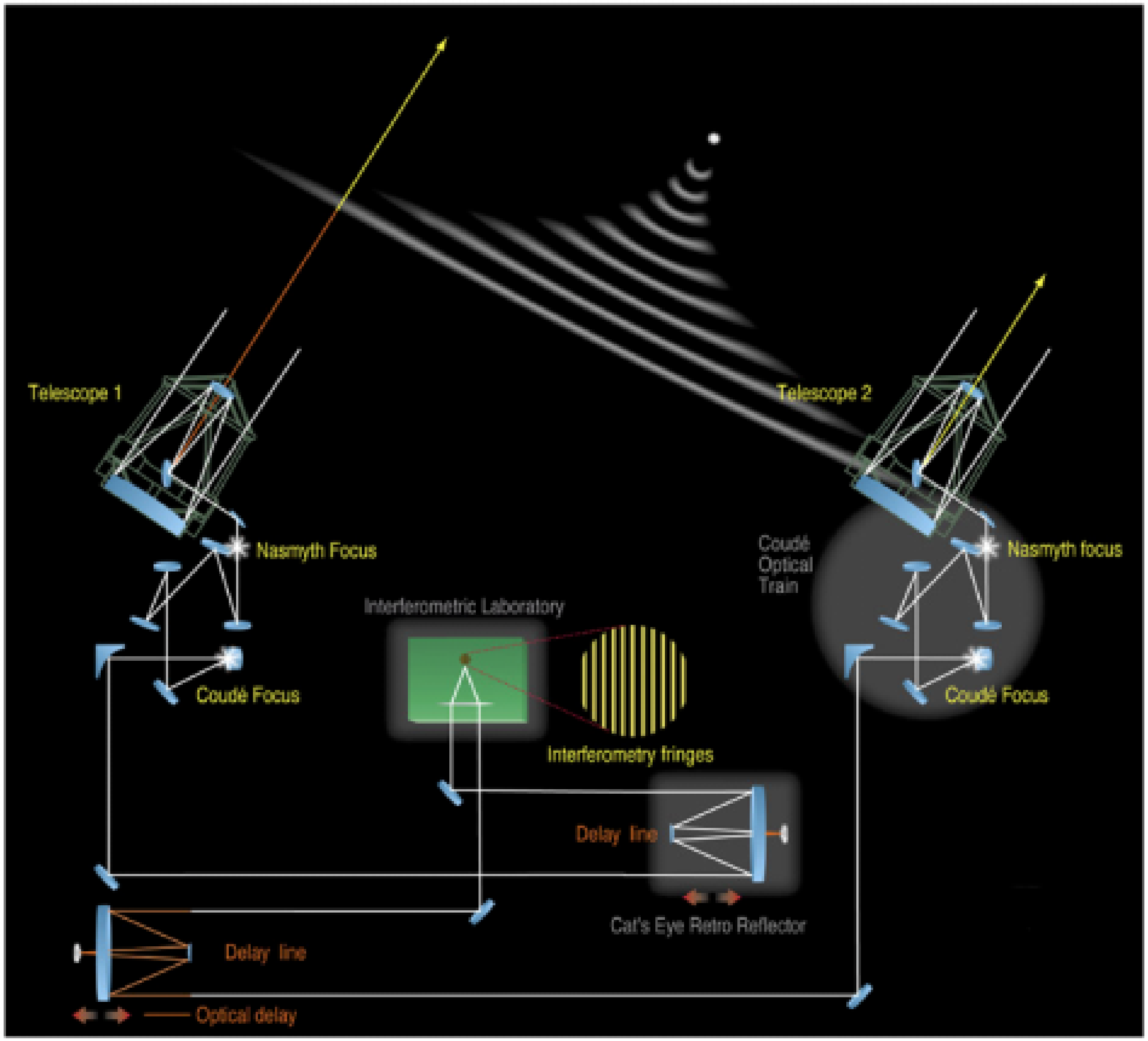
- science: search for planets around nearby stars, velocity fields in stellar atmospheres
- several RV survey programmes for extrasolar planets currently underway (Lick, AAT, HIRES at Keck, Elodie at HPO, Coralie at ESO)
- projects under development: HARPS (1m/s accuracy) at the ESO 3.6m telescope at La Silla
- require accurate determination of velocity fields in stellar atmospheres (convection, pulsations, etc.)

Extrasolar planet search at ESO La Silla



Interferometry

- Science: detection of extrasolar planets, close binary stars, pre-main sequence stars, surface structures, circumstellar envelopes
- technique developed and used so far on small (< 1m) telescope arrays
- programmes under development at large (8-10m class) telescopes with or without auxiliary telescopes (Keck I+ II, VLTI, LBT, Magellan)



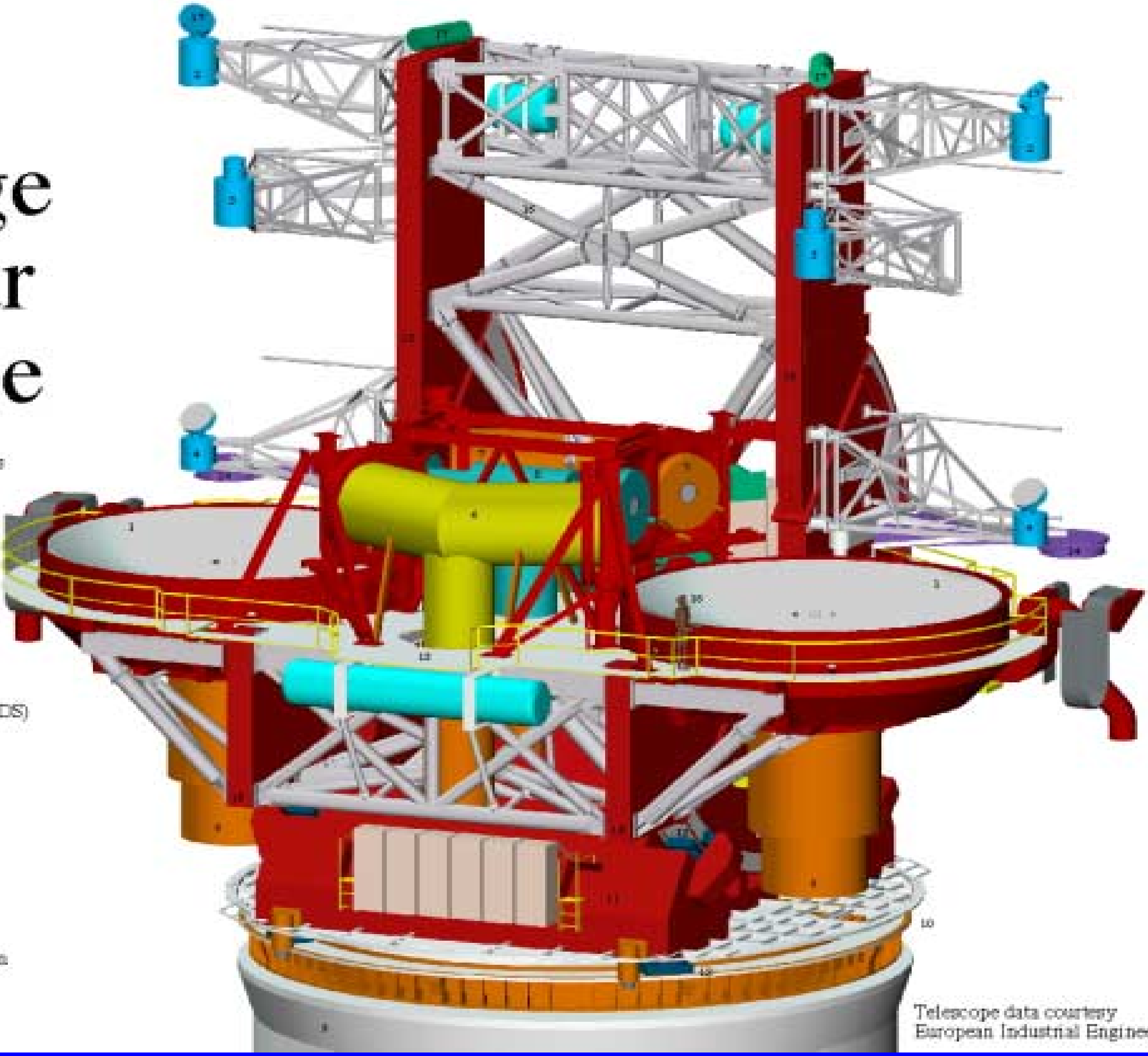
Overview of the VLT Interferometer

ESO PR Photo 10c/01 (18 March 2001)

The two Keck telescopes at Mauna Kea

LBT

The Large Binocular Telescope



1. Twin, 8.4 meter, f/1.1 borosilicate glass honeycomb primary mirrors
2. f/15 adaptive Gregorian secondary mirrors (retracted)
3. Prime focus cameras
4. Tertiary mirrors (retracted)
5. On-axis interferometric beam-combiner
6. Forward bent beam-combiner
7. Twin near-infrared spectrographs (LUCIFER)
8. Twin UV / Visible spectrographs (MODS)
9. Telescope pier (21 m tall)
10. Azimuth track (13 m diameter)
11. Azimuth platform
12. Hydrostatic bearings for alt-az motion
13. Instrument platform
14. Mirror covers (retracted)
15. C-rings (17 m tall)
16. Wind bracing
17. Laser guide-star launch optics

18. Scale comparison: 1.8 meter tall person

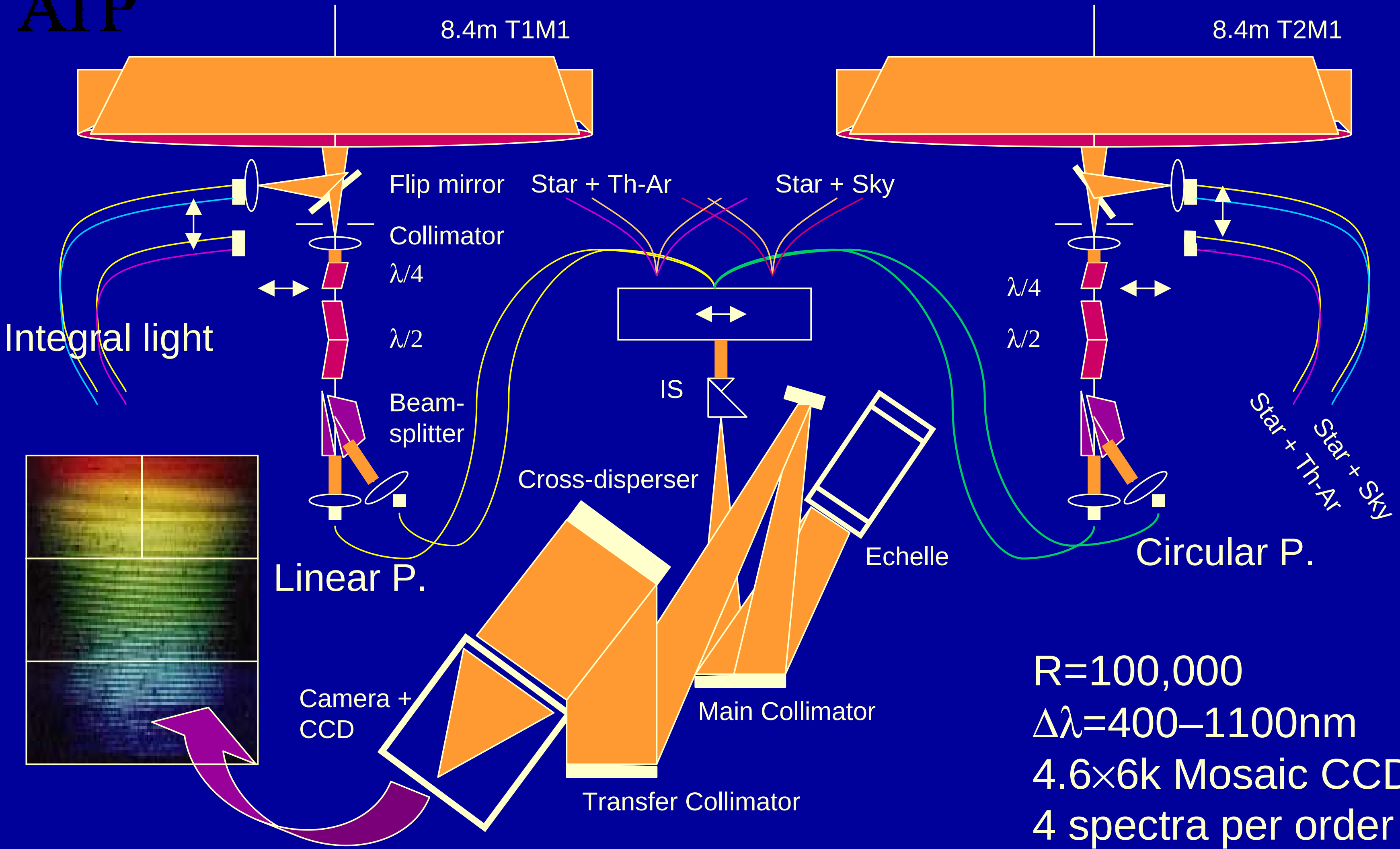
Telescope data courtesy
European Industrial Engineering S.r.l.

What is missing on large telescopes

- VHR (R= 200,000 - 400,000) spectroscopy (available only with the UHRF at the AAT, proposed but not yet approved for Gemini, the VLT and the LBT)
- Polarimetry (under development at CFHT, proposed for the LBT as PEPSI and for Gemini as a possible future upgrade of HROS)
- Faint object/AO medium-resolution spectroscopy (ESI at Keck, proposed for the VLT as AVES)

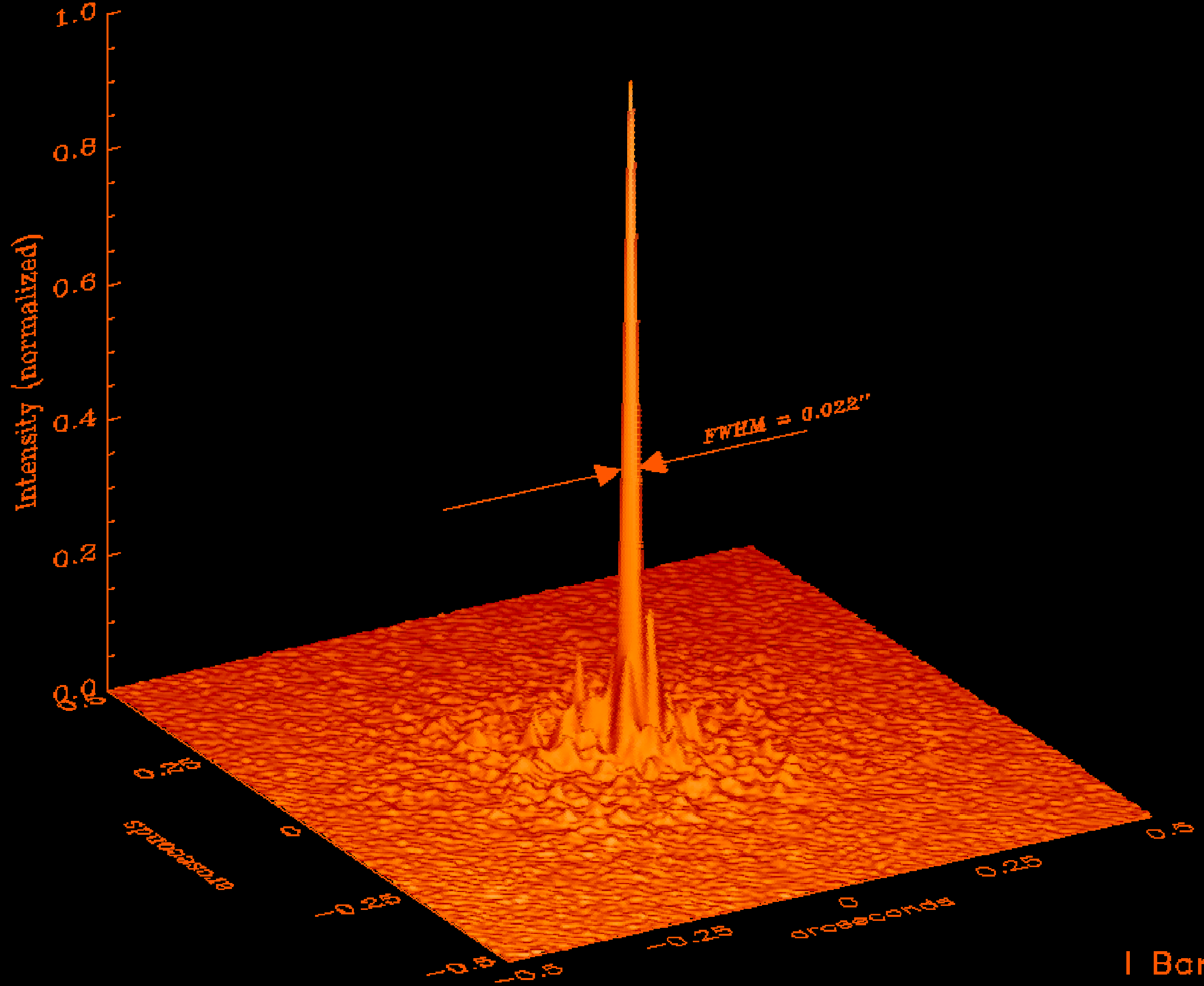
PEPSI proposal

The **P**otsdam **E**chelle **P**olarimetric and **S**pectroscopic **I**nstrument for the LBT



R=100,000
Δλ=400–1100nm
4.6×6k Mosaic CCD
4 spectra per order

KECK Adaptive Optics

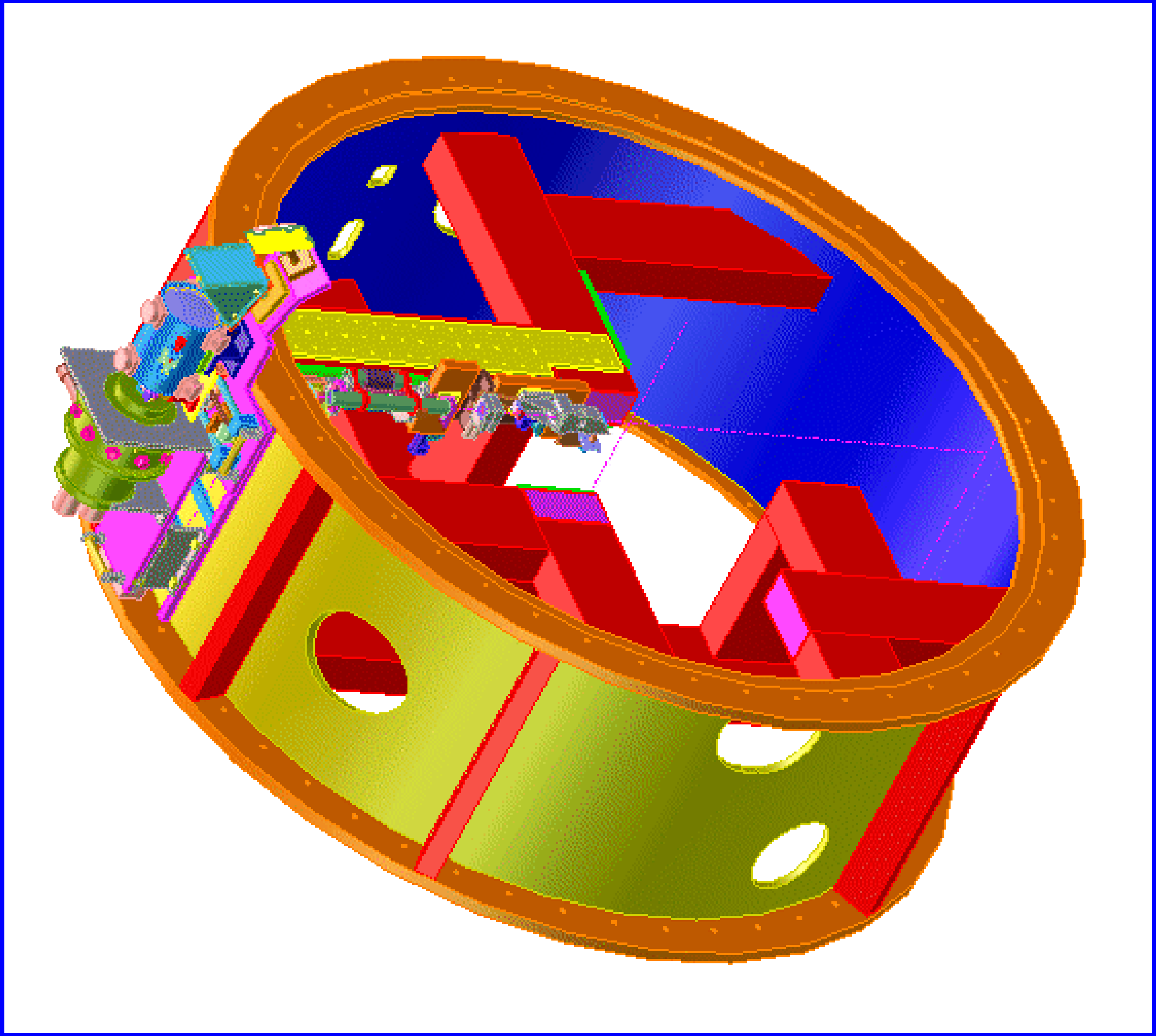


I Band

850 nm (+/−10)

Strehl = 6%

AVES-IMCO mounted on NAOS



Role of 2-4m class telescopes

- whenever larger apertures are not needed
- for preparatory work & surveys (e.g. VST, VISTA and the EIS survey at ESO)
- for dedicated programmes/instruments (e.g. 2dF at AAT, SLOAN survey, WIYN at Kitt Peak)
- for training new generations of young astronomers at national/institutional level)

Dolores and SARG at Telescopio Nazionale Galileo

Role of 1m-class telescopes

- small (1m class) telescopes are virtually disappearing at all major international observatories
- they are ideally suited for long-term programmes (mostly photometric but also spectroscopic) on relatively bright nearby stars (for monitoring stellar variability and activity)
- robotic telescopes appear to be the most effective way to satisfy this increasing demand

CONCLUSIONS (I)

- the advent of large (8-10m) class telescopes equipped with novel instruments is opening up tremendous opportunities for cool star research (e.g. for very faint nearby stars and brown dwarfs as well as for stars in distant clusters and Local Group galaxies)
- 2-4m class telescopes will continue to play an important role in the next several years for both preparatory/survey work and for dedicated programmes (e.g. open clusters, extrasolar planets)

CONCLUSIONS (II)

- Small aperture (1m class) robotic telescopes (both photometric and spectroscopic) will play a unique role for stellar activity studies, long-term monitoring and stellar variability
- AO will be crucial for imaging and spectroscopy not only at IR wavelengths but also in the optical
- Interferometry will have a tremendous impact on HR imaging of stars and extrasolar planet detections

The Future of Ground-Based (Stellar) Infrared Instrumentation

Suchitra C. Balachandran
(University of Maryland)

This talk is based on wisdom borrowed from:

Alan Tokunaga (IfA)
John Carr (NRL)
Sandy Leggett (UKIRT)
Guenter Wiedemann (Munich)

My thanks to them for answering numerous questions

- I will not exhaustively detail all IR instrumentation available on all telescopes. For that information, I recommend the following website which contains a list of currently available and planned instruments:

- http://www.mso.anu.edu.au/nifs/other.shtml

- this website categorizes spectrographs, cameras, and *surveys* with links to the various instrument webpages

Advances in IR instrumentation - I

DETECTORS (NEAR-IR)

- HgCdTe (originally NICMOS)
  - typically used from 1-2.5 µm
  - possible to use different doping agents to extend cut-off to longer wavelengths - 5µm, 14µm etc. (of interest to NGST)

- InSb (originally SBRC)
  - used from 1-5 µm

- both currently available in 1024 X 1024 format

- development in progress for 2048 X 2048 HgCdTe arrays - called HAWAII-2 - made by Rockwell in collaboration with IfA

- HAWAII-2 engineering arrays are currently in use (e.g., FLAMINGOS)

- science grade arrays are expected within a year

- read noise 10e^- (2 to 5 e^- with multiple reads)

- while the development of large arrays is spurred by cosmology, stellar interest centers on the large wavelength coverage that can be obtained with cross-dispersed low- and high-resolution spectrographs

- low read noise useful at moderate/high spectral resolution

- the combination of low read noise and large format will make the near-IR detector comparable to the optical CCD in sensitivity and wavelength coverage

DETECTORS (MID-IR)

- Blocked Impurity Band (BIB) Arrays

- currently being made by Boeing (256 x 256) & Raytheon (320 x 240) with plans for larger format (1K) arrays

- detector material is silicon doped with arsenic (5-28 mm) or antimony (longer wavelengths)

- high gain mode used in high background applications (typically ground-based imaging); read noise ~ 2500 e^-

- low gain mode used in low background applications (typically spectroscopy); read noise ~ 400 - 1000 e^-

- plans in progress for increasing array format to 1 K and for lowering read noise possibly by marrying BIB technology with Rockwell's HAWAII multiplexers

Advances in IR instrumentation - II

ADAPTIVE OPTICS

- diffraction limit for 8m telescope in K band is 0.06 "
- major push on ALL large telescopes to achieve near diffraction limit in the near-IR with adaptive optics
- AO is being driven by the scientific requirement for high angular resolution
- natural guide star AO is the first step with laser guide star AO planned on all telescopes
- natural star AO in use at Keck for imaging since early '99; Keck II will shut down in Sept. '01 for engineering for laser guide star AO system
- Gemini's ALTAIR is under construction; Hokupa'a borrowed from IfA has been used at Gemini North

Seeing	Strehl Ratios	
	J-band	K-band
0.45"	50%	80%
0.65"	25%	62%

- SUBARU AO being tested on telescope

- VLT AO - NAOS - construction near completion

- push for MCAO - multi-conjugate adaptive optics - at Gemini South
  - diffraction limited images with uniform image quality over 1' FOV
  - will reach NGST capability 5 years before NGST!

    (see proceedings from Lick 2000 workshop)

- high angular resolution provided by AO will aid in planet and other faint companion searches

- AO will also allow higher resolutions with smaller instruments (e.g., IRCS on Subaru gives R=20,000 with 0.15" slit)

Advances in IR instrumentation - III

INTEGRAL FIELD UNITS

- spurred by larger detectors and AO, Integral Field Unit spectrographs are being constructed in the near-IR for the large telescopes

- essentially these are "area spectrographs", producing a spectrum of each unit in the field imaged by the spectrograph - AO allows for smaller unit size

- fibers (CIRPASS - Gemini North; NIRMOS - VLT)

- image slicer/aligner (SINFONI - VLT; NIFS - Gemini)

SCIENCE

- PMS stellar jets
- outflows from AGB stars
- spectra of stars in crowded fields
- stellar populations in galaxies including Galactic Center

- CIRPASS: 0.9-1.5 µm warm IFU; R=3000;
  (Gem. N) 2048 HAWAII-2 array;
  499 element IFU - fed to fibers;
  various FOV from 13"X5" to 1.8"X0.7"
  demo science projects solicited for 2001B

- NIRMOS: 1-1.8µm; 1600 microlenses coupled to
  (VLT) fibers coupled to 4 long slits;
  R=2500; 28x28" or 14x14" FOV

- SINFONI: 1-2.5 µm; R=1000 to 4500;
  (VLT) 1024 HgCdTe array;
  32 X 32 spatial pixels;
  8 X 8"; 3.2 X 3.2 "; 0.8 X 0.8 " FOV;
  in use as SPIFFI without AO

- NIFS: 1-2.5 µm; R=5300;
  (Gem. N) 2048 HAWAII-2 array;
  0.1X0.1" units; 3"X3" region of sky;
  5 fixed grating angles to cover J, H, K

- GNIRS: 0.9-2.5µm & 2.9-5.5µm;
  (Gem. S) 1024 InSb array
  R=600 - 6000;
  spatial elements: 625 low res; 972 high res

Cameras & Low/Medium Resolution Spectrographs

- concept of 'camera' and 'spectrograph' as two distinct instruments has faded in the IR

- cameras have narrow band filters/grisms/gratings offering low to moderate resolution spectra

- spectrographs offer imaging modes which are used for science; for instance imaging mode of Keck's NIRSPEC (echelle spectrograph) is in great demand with AO

- multi-object spectrographs (MOS) typically using slit masks

SCIENCE

- high-resolution imaging: detect companions; binary masses from orbits
- cross-dispersed spectra: for classification of cool dwarfs
- MOS: cluster studies

ISAAC (in use at VLT) 1-5μm; imaging + long slit spectroscopy R=500/3,000/10,000

CONICA (VLT) 1-5μm; high spatial resolution imaging 73" to 14" fields, coronagraphic masks; AO; spectroscopic imaging with filters & tunable Fabry-Perot; grisms

NIRMOS (VLT) 1-1.8μm; 4 - 2048 detectors
imaging mode: 4 - 6X8' fields
MOS: 190 slits on 4 masks; R=2500 with grisms
IF spectroscopy

NIRI (Gemini N) 1-5μm imager+grism R=400-1500; coronagraph

GNIRS (Gemini S) 1-5μm; R=600-18,000; long slit; cross dispersed; 2 IFUs; polarimetry

FLAMINGOS (Gemini S) 1-2.5 μm; MOS and imager; slit masks; R=300-2400; 2048 array; demo science 2001B

NIRC/NIRC2 (Keck) 1-5μm; 256 InSb --> 1024 InSb; coronagraph

IRCS (Subaru)   camera+grism (R=100-2000) + cross-dispersed echelle (R upto 20,000 with AO 0.15" slit)

CIAO (Subaru)   1-5μm coronagraphic imager with AO
8 occulting masks ranging from 0.1" to 3.0";
expect to detect 7 mag. fainter companion @0.2"; 15 mag. @1.0"

High Resolution Spectrographs

- High resolution IR spectrographs have only been available for a decade - CSHELL (IRTF) and CGS4 (UKIRT) were the pioneering instruments

- 4 echelle spectrographs are expected to be available on the large telescopes

PHOENIX (KPNO, Gemini S)

- 1-5µm; 1024 InSb; single order; R upto100,000

NIRSPEC (Keck)

- 1-5µm;1024 InSb; cross-dispersed echelle; R=2,000 and 35,000 (slit width = 0.27")
- [has 256 HgCdTe slit viewing camera also used for science imaging]
- K band in 2 settings; L band (3.1-3.9µm) 4 settings

IRCS (Subaru)

- 1-5µm; 1024 InSb; cross-dispersed echelle;
- R=20,000 with AO and 0.15" slit;
- J band in 1 setting; H in 2; K in 2; L in 6

CRIRES (VLT)

- 1-5μm; one or several 1024 InSb; single order;
- R upto100,000;
- long slit spectroscopy 50" slit
- unfortunately CRIRES which was originally designed to be a cross-dispersed spectrograph will now only be a single-order instrument - no cross-dispersed spectrograph in the southern hemisphere

SCIENCE

- abundances/atmospheres
- star formation
- magnetic fields
- circumstellar matter
- extrasolar planets

- with the large-format, low read-noise detectors which will shortly become available, high-resolution spectroscopy at IR wavelengths will equal optical spectroscopy in its sensitivity

- with the added advantage of observing regions which are obscured in the optical, it is hoped that IR echelle spectrographs will become routinely available at large telescopes

MID-IR Cameras/Spectrographs

- VISIR (VLT) 8-25 μm IR imager and long-slit spectrograph
  diffraction limited imaging 80"x80" field;
  R=250, 7000, > 30,000 @ 10μm
  R ~ 3000 and > 15,000 @ 20μm.

- MICHELLE (Gemini N & UKIRT): 8-25μm imager + spectrograph;
  R=200 - 30,000

- COMICS (Subaru)
  OSCIR --> T-RECS (Gemini S)
  LWS --> LWIRC (Keck)
  imaging and low-res (R=100 - 1000) spectroscopy
  MIRLIN (JPL/Keck) - imager

SCIENCE:

- dust/molecular features in L & T dwarfs
- circumstellar environments in PMS, AGB stars

SOFIA

- 2.7m telescope; 5-300 µm; first light Oct 2004; science Jan 2005

- first light instruments:
- AIRES: 7-210 µm, R=10,000 echelle spectrograph
- FORCAST: 5-40 µm mid-IR camera
- TEST CAMERA: 1-5µm

- variety of P.I. instruments
- http://sofia.arc.nasa.gov

- EXES: 5-28µm echelon spectrometer; R=2,000; 10,000; R=100,000 cross-dispersed; a similar visitor instrument now at the IRTF (Lacy, Texas)

SCIENCE

- very early stages of star formation when stars are obscured by dense foreground dust and so invisible in near-IR
- environments of PMS stars (T Tauri, H-H, Ae/Be) - shells, envelopes, outflows
- circumstellar environments around older stars