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: (Gem. N) 0.9-1.5 μm warm IFU; R=3000;
  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: (VLT) 1-1.8μm; 1600 microlenses coupled to
  fibers coupled to 4 long slits;
  R=2500; 28x28" or 14x14" FOV

- SINFONI: (VLT) 1-2.5 μm; R=1000 to 4500;
  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: (Gem. N) 1-2.5 μm; R=5300;
  2048 HAWAII-2 array;
  0.1X0.1" units; 3"X3" region of sky;
  5 fixed grating angles to cover J, H, K

- GNIRS: (Gem. S) 0.9-2.5μm & 2.9-5.5μm;
  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