National Aeronautics and Space Administration

UKIRT/Michelle

Mid-IR esCHELLE

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**Special thanks to Tom Kerr for providing expertise to answer all questions herein*

Lorentz Center
Mid-IR Astronomy Workshop
Nov 2018

United Kingdom Infrared Telescope (UKIRT)

A most excellent site for IR and Michelle

- **UKIRT: 40 years of operations**
  - 3.8 meter telescope
  - **Optimized for the infrared: 0.8 – 26 μm**
  - 1 Wide-field camera
  - 4 imager/spectrometer cameras
    - Michelle for mid-IR

- **Location:** 13,800 feet (4200m)
  - **SEEING**:
    - Median = 0.43″
    - best quartile: **<0.25"**
  - Workable hours **~70%**
  - **HIGH** and **DRY**

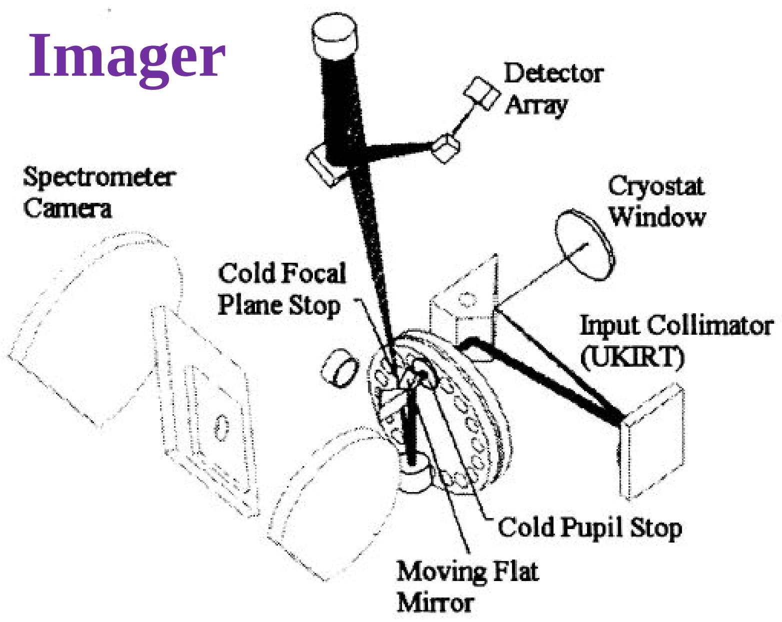
Photo credits: Tom Kerr and http://www.ukirt.hawaii.edu/

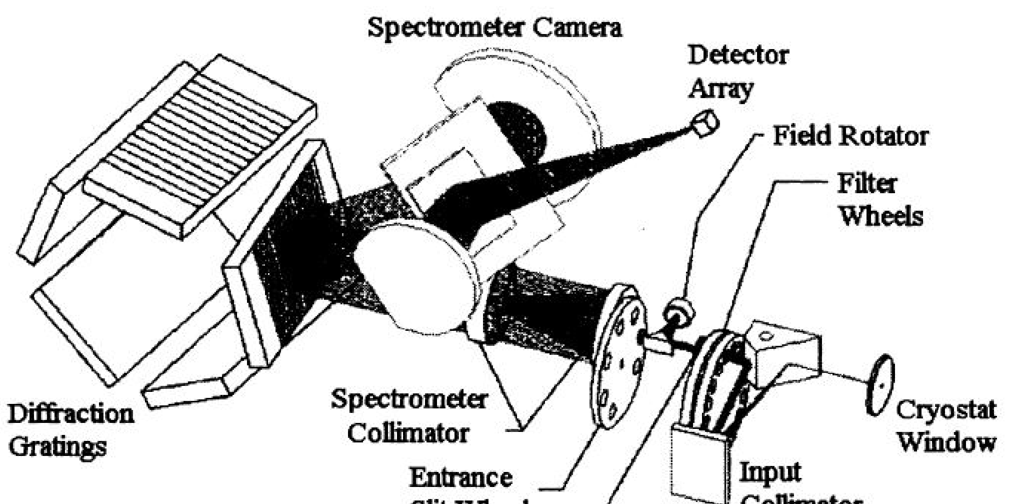
UKIRT @Cassegrain

3.8m primary
f/36.4
2.8´ unvignetted FOV

Michelle: Mid-IR esCHELLE

Imager





Spectrometer

8-26 μm imager & spectrograph

SBRC Si:As 320x240 pixels

- **Imaging**
  - 11 filters, broad and NB
  - 67.2" x 50.4" FOV
  - 0.21" per pixel
- **Imaging polarimetry**

- **Spectroscopy**
  - R=200 to 30,000
    - 91" long-slit
    - 0.38" per pixel
- **Spectro-polarimetry**

Figures from Glasse et al., 1997 SPIE 2871

Michelle on UKIRT & Gemini

Expected 60-80x more sensitive on Gemini actual ~2x

	Michelle on UKIRT	Michelle on Gemini*
Modes	Imaging Spectroscopy Polarimetry (both modes)	
Wavelengths	8-13, 16-28 µm	
Array type	SBRC Si:As	
Array Size	320 x 240	
Imaging FOV	**67.2" x 50.4"**	**26"**
Imaging Plate Scale	**0.21"/pix**	**0.10"/pix**
Optical Throughput	57%	57%
Spectroscopy Resl'n	R=200 – 30,000	
Slit width choices	1, 2, 3, 4, 8 pix	
Slit length	**91"**	**46"**
Low-Res Plate Scale	**0.38"/pix**	**0.18"/pix**
Optical Throughput	30%	30%

Figures from Glasse et al., 1997 SPIE 2871

Why was Michelle built and what is its current status?

- **Why was it built?**
  - Built 1997, Royal Observatory Edinburgh for UKIRT & Gemini
  - There was no equivalent mid-IR instrument in the northern hemisphere at a suitable mid-IR site
- **Michelle at UKIRT and Gemini**
  - SPIE paper presented in 1997
  - Commissioned at UKIRT: Aug – Nov 2001
  - Shared Gemini/UKIRT 2001-March 2004
  - Just Gemini April 2004 – about 2011'ish
  - Just UKIRT ~2013 to UKIRT
- **Current status**
  - Functional
  - At UKIRT/Mauna Kea
  - Used in the past 5 years for NASA orbital debris observations, Lockheed, various astronomy programs through U Hawaii and U Arizona

What was Michelle's most spectacular science result?

- **Astronomers Spot Evidence for Colliding Planet Embryos in Famous Star Cluster** *P. Michoud, Wolpert, 2007*
  - Warm dust emissions betray catastrophic collisions in an evolving young planetary system around an adolescent-age solar type star.

Gemini Observatory/Lynette Cook

Figure 1: Artist's rendering of what the environment around HD 23514 might look like as two Earth-sized bodies collide. Artwork by Lynette Cook for Gemini Observatory.

- **Free floating Brown Dwarf discovery**
  - *Legget et al., 2000*

- **A Young Erupting Pre-main Sequence Star Takes a (Long) Nap**
  - Pre-main seq. 0.8$M_{\odot}$, 10^6y
  - 37 years off, 1-2 years on
  - Si-dust evolution during outburst

V1647 Orionis: One year into quiescence"
by C. Aspin, T. Beck, B. Reipurth,
Astronom. J. 2008, pp. 423-440s

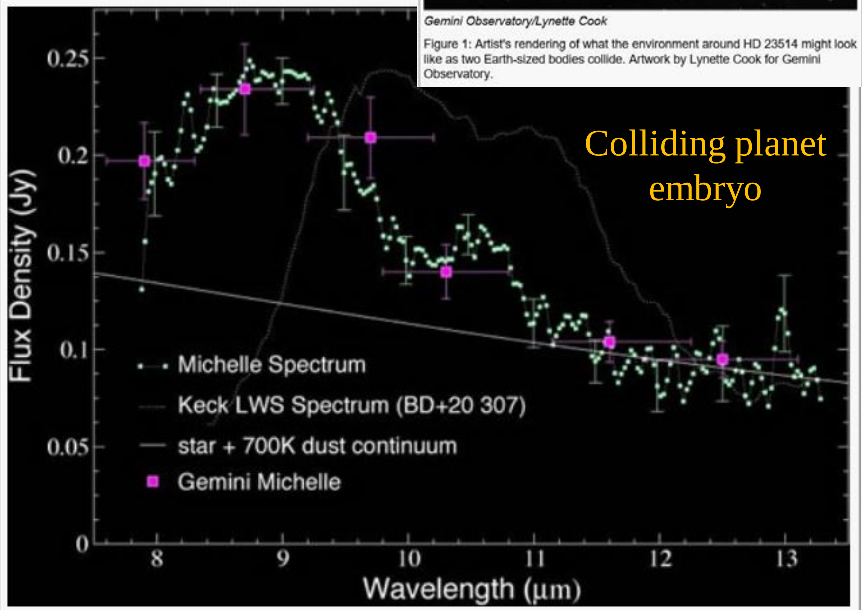
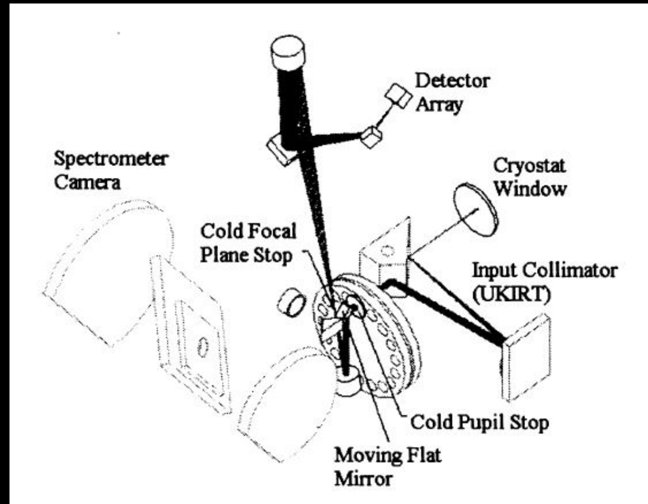


Figure 4: MICHELLE mid-infrared spectrum of HD 23514 obtained on the Gemini North telescope. For comparison, the mid-infrared, (dotted-line) spectrum of another dusty star BD +20 307 is also reproduced. Both reveal the presence of warm dust. HD 23514 has the warmer dust, reflected by its more "blue shifted" bump. For young stars and debris disks, the most prominent spectral feature in the N-band is silicate emission.

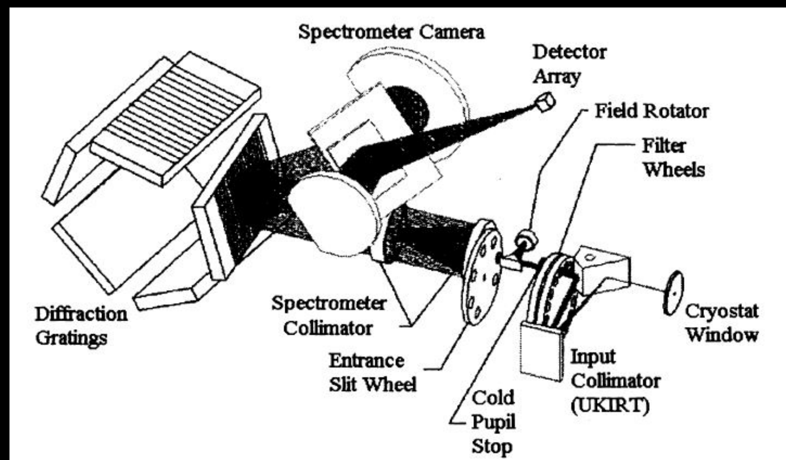
Figures from: ttps://www.gemini.edu/sciops/instruments/michelle/

How Michelle special?
What surprises did you encounter?

- **Special…One instrument, 3 modes**
  - Imaging
  - Spectroscopy
    - Also Echelle (!) *- special, part 1*
  - Polarimetry – *special, part 2*
    - Imaging polarimetry or spectro-polarimetry
  - Change modes instantly - *special part 3*



- **Special: Location, location, location**
  - Where seeing can be 0.18"
  - Can be as little as a few% humidity at 14,000'



- **Surprises**
  - How quickly commissioning went
    - Delivery Summer 2001, Aug
    - Science data by Nov 2001
  - How well it worked after taking a very long time to build

Figures from: Glasse et al., 1997 SPIE 2871

What noise, biases and problems do you suffer from most?

- **Interference/noise from fans that cool the electronics**
  - Pick-up from the fans to cool the warm electronics generating noise on the arrays
  - Read noise was very high: Few hundred e-
  - Took a long time to isolate the fans, but eventually solved this

- **Temperature stability**
  - JT system (Joules-Thompson) needle valve used for cooling to 4k
  - Contaminants build up, freeze, blocks coolant
    - Blows out, reforms, T fluctuations inconsistent, not gradual
  - Warming the instrument to purge is required maintenance

- **Sacrificial window over main, thick hygroscopic window**
  - Degrades with time, replace regularly
  - But only 1 day to replace (vs. without thin sacrificial window)

Figures from: Kerr 2004

How do you calibrate Michelle?

- **Wavelength calibration**
  - Calibration at resolving powers 50-30,000
  - 4-inch diameter integrating sphere with 2 or more arc lamps
  - Arc lamps, integrating spheres for low-res spectroscopy
    - Higher order lines of **Xenon, krypon, argon** arc lamps
  - Echelle: Fabry-Perot etalon = grid of absorption features
    - 4mm thick germanium etalon (90% reflective)
- **Flat fielding**
  - Simple, room-T low emissivity plate
  - Fall-back: integrating sphere + flat plate with pinholes = point-sources
- **Sky Correction**
  - Flat field Black Body @ $T_{effective}$ (~275K) of combined sky+Tel continuum emission
- **Telescope Simulator**
  - Uniform illumination of the focal plane just inside the cryostat window
- **Polarimetry**
  - Provide rotation of 2 half-wave plates

How do you calibrate Michelle?

- **The calibration unit will comprise:**
  - Static, 2.5 to 20µm (infragold coated), 4 inch diameter **integrating sphere** with two pencil-type arc lamps mounted in it.
  - **An 'Offner relay' telescope simulator** to reimage the exit pupil of the integrating sphere onto the telescope focal plane, with access to a focal plane where an ambient temperature pinhole target can be inserted
  - **Optics to relay light** from the exit port of the integrating sphere onto the focal plane of the Offner relay.
    - lens or mirror with a focal length of ~300mm, to match an f/4.3 beam from a 9mm diameter exit port in the integrating sphere onto the f/35 and 70mm diameter beam required by the Offner relay.
    - The exit port and Offner focal plane would be placed at the two foci of the relay lens/mirror.

How do you calibrate Michelle?
Engineering tests & checks

- **Mechanism and microswitch tests**
  - Array translation & rotation
    - *Position of object on array*
  - Image extractor repeatability
    - *Position of object on array*
  - Grating repeatability
    - *~few pixel discrepancy expected*
  - Slit repeatability
    - *Slit position should repeat to <<1pix*
  - Internal focus
- **Array tests**
  - Bias/clock
  - Read-noise
    - *(Bias1-bias2)/sqrt(noise)*
  - QE
    - *2 pixel slit throughput*

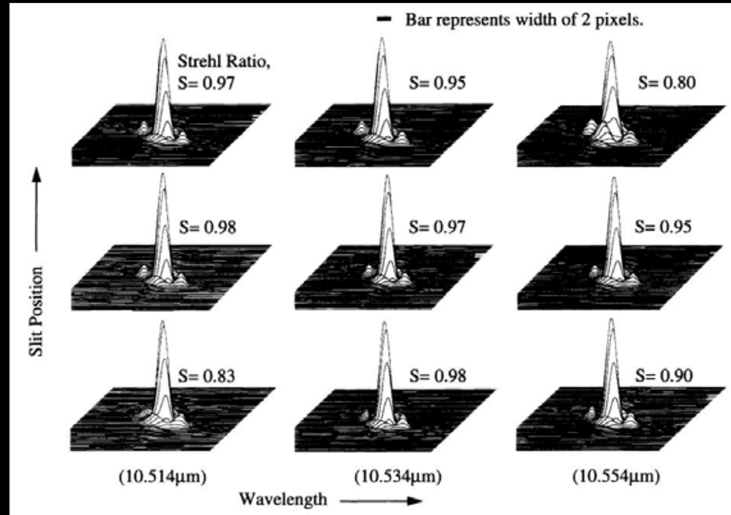


Figure 4. Predicted Point Spread Functions across a 12.8mm square detector array for echelle spectroscopy. The bar shows the width of two 50μm square pixels.

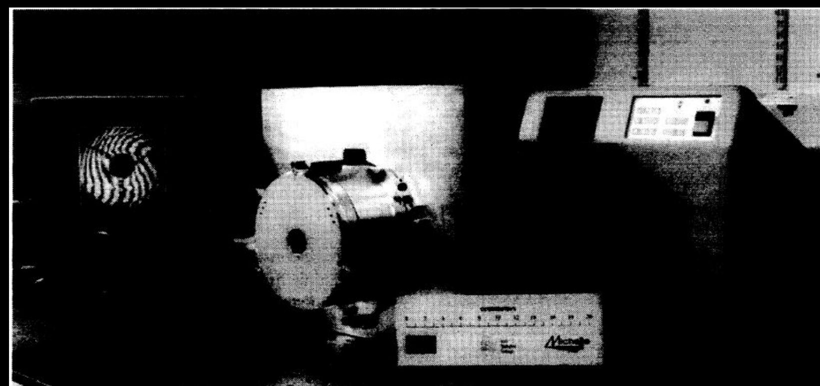


Figure 3. The spectrometer collimator (centre) undergoing interferometric testing. (Photography by Photolabs, Royal Observatory Edinburgh, 1996.)

Figures from: Glasse et al., 1997 SPIE 2871

What is the best performance that you ever achieved (in terms of the fundamental noise limit) and how did you achieve it?

- **Isolating fans greatly improved performance**
- **Temperature stability matters**
- **Best performance?**
  - When all the electronics, cryo-cooling are all behaving as expected
  - Unknown quantitative ‘best performance’

If you had a magic wand, what specific improvements would you make to Michelle/UKIRT?

- **Stabilize array temperature**
  - Replace JT-valve with something else
- **Cold finger contact**
  - Actual contact of the cold finger is often an issue
- **Cryogenics**
  - Something other than Liq He required
  - Array that can be run at warmer temps – easier to deal with
- **Array**
  - Replace array with higher QE
  - less noise
  - fewer cosmetic issues
- **Guide with near-IR option**

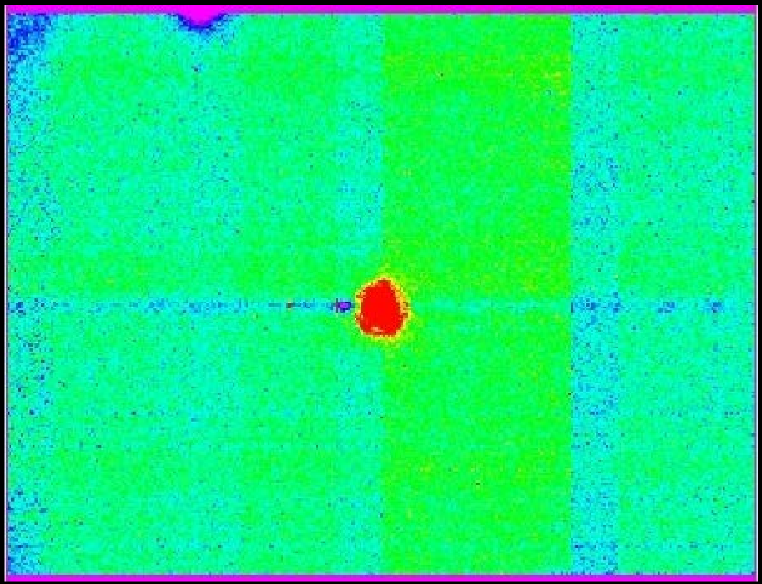


Figure from:

https://www.gemini.edu/sciops/instruments/midir-resources/data-reduction/data-format-and-features#noise

What piece of advice would you give builders of thermal IR instruments for 30m class telescopes?

- **Chopping warnings**
  - ENSURE that if you must chop with a secondary that it communicates DIRECTLY with the instrument (**note: BIG issues with Gemini, not UKIRT)*
  - Better yet, get an array that doesn't require chopping → improve efficiency by at least 2x
    - Also, deeper wells, faster read-outs, better baffling in the instrument
- **Segmented mirrors**
  - Think long and hard about how emissivity is affected by gaps between segments
- **Minimize emissivity of the instrument/telescope**
- **Don't limit yourself to just thermal IR**
  - Consider multi-spectral, expanding to Visible, near-IR reflected simultaneously
- **Think about how to be different from/complementary to JWST**
  - Design for better spatial resolution, larger FOV
  - JWST is now OLD technology – capitalize on NEW technology

References

- Glasse A., Atad-Ettedgui, and Harris, 1997. The Michelle mid-infrared spectrometer and imager, SPIE 2871, 1197.
- Glasse A. 1998. Calibrating Michelle – Cryostat CDR Sec 4.19.
- T. Kerr, 2004. Basic Michelle Engineering Tests and Checks.