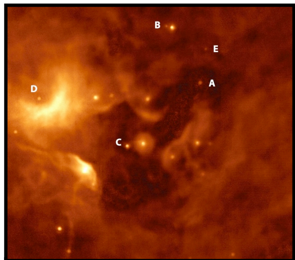
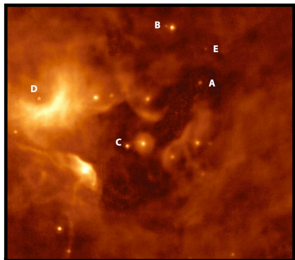


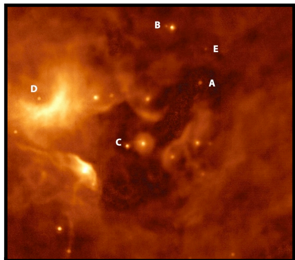
Mid-IR @ Gemini

Marie Lemoine-Busserolle
Gemini Observatory



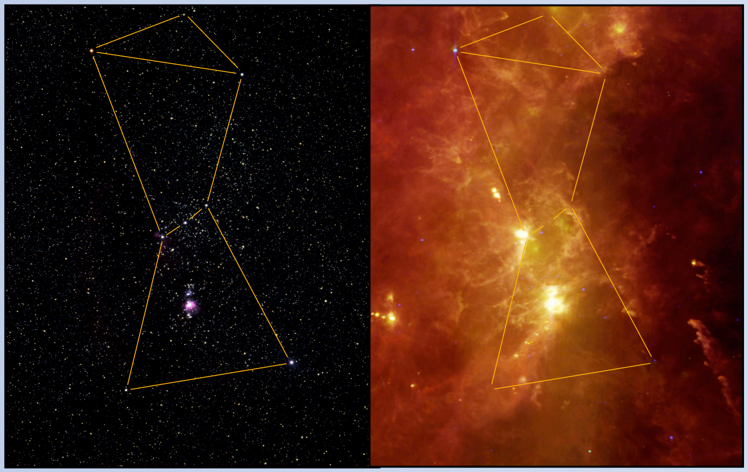
Overview

- Part 1 : general intro to mid-IR Science
- Part 2 : general intro to mid-IR observing
- Part 3 : Imaging mode (Michelle)
- Part 4 : Spectroscopy (Michelle)
- Part 5 : example of Michelle data



What is cool in the mid-IR?

- Dust, basically.

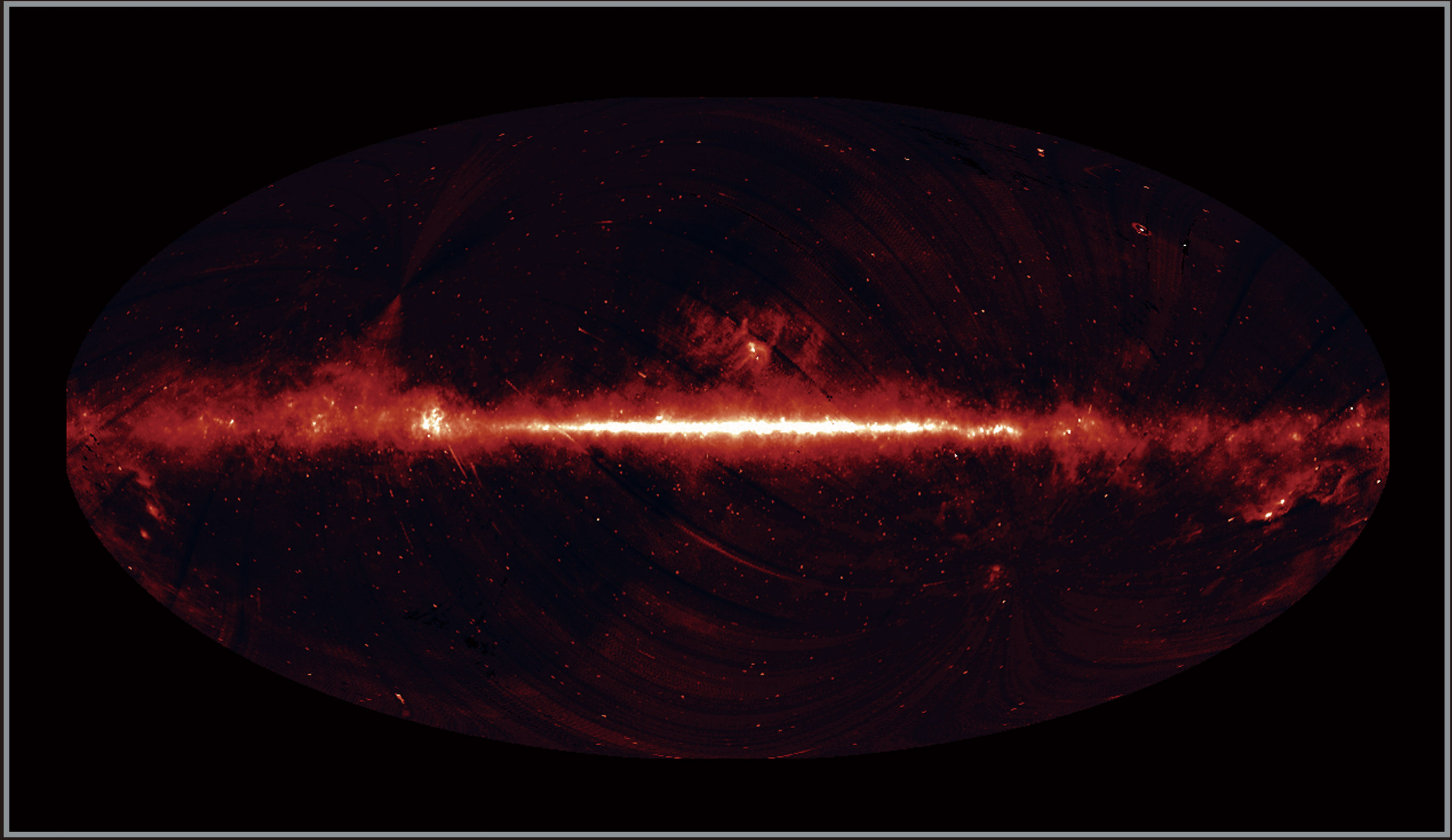


Absorbs visible light

Emits in the IR (~blackbody spectrum with λ_{peak} ~3000 μm K)

- Many obscured star forming regions only visible at 10 μm and longer
- Dust around accreting supermassive black holes emits strongly at 10 μm
- H_2 in protostellar disks emits at 12 and 17 μm --> test theories of planet formation

The Entire Sky as seen at Mid-Infrared wavelengths

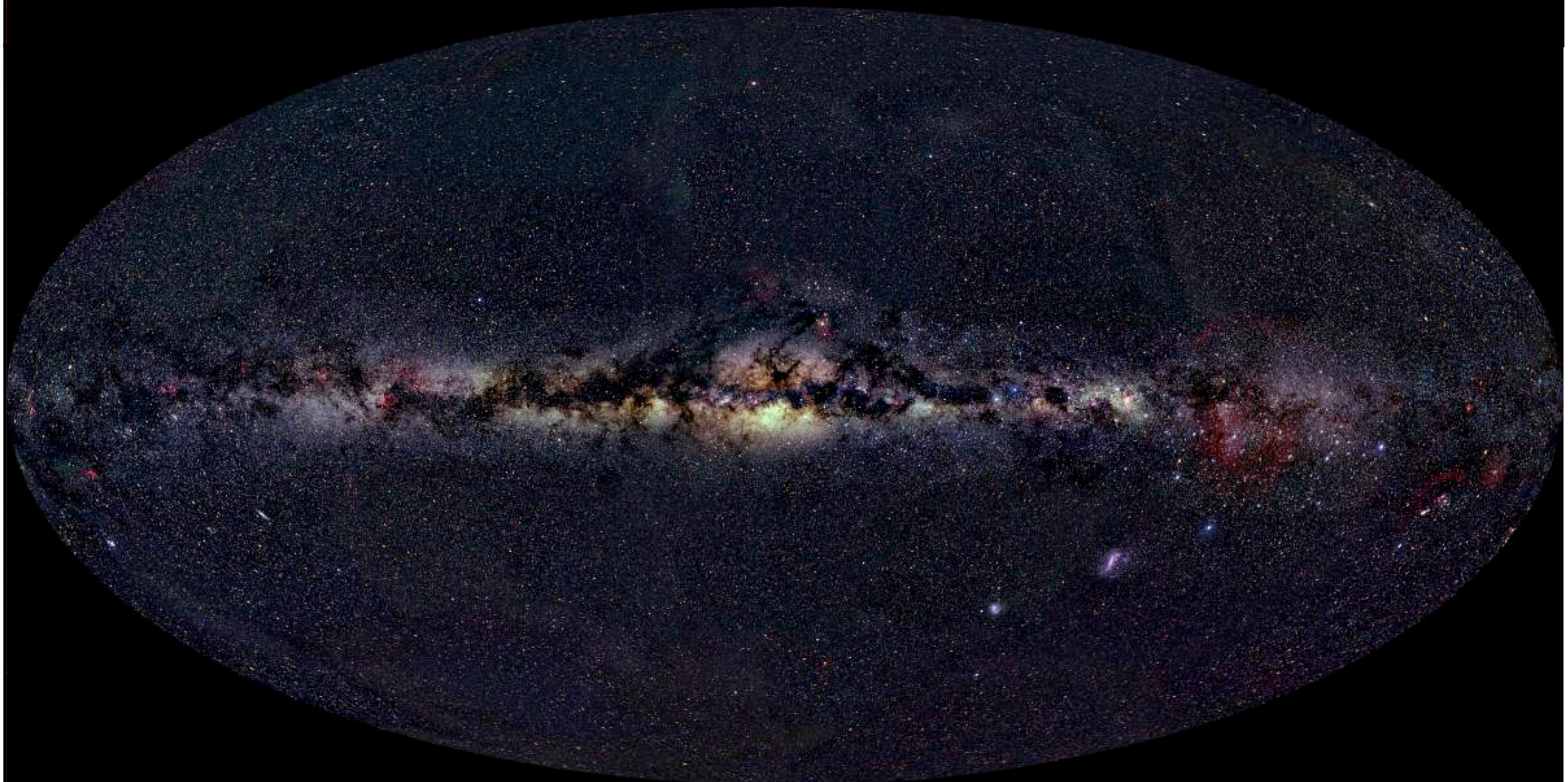


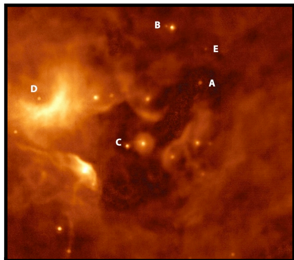
AKARI/Infrared Camera (wavelength: 9 μm)

JAXA

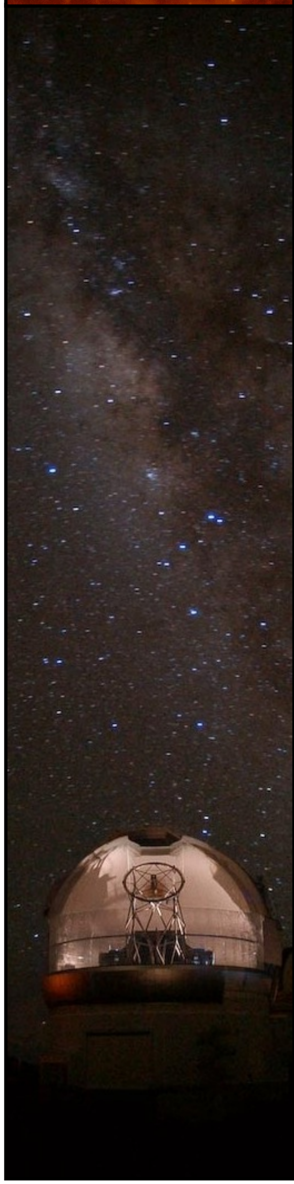
11th July, 2007

The Deep Sky





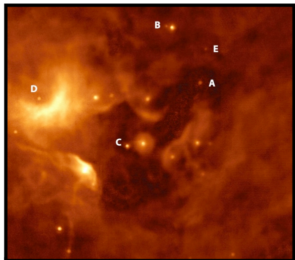
What is cool in the mid-IR?



Science in the Mid-IR

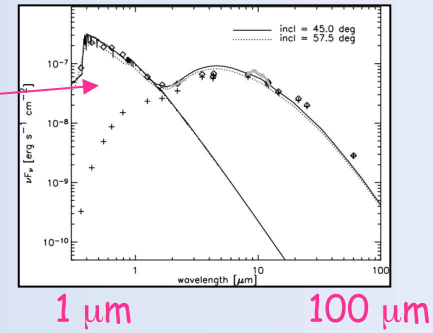
Q: What can you study in the mid-infrared?
A: Almost anything cold (100-300K) and/or dusty

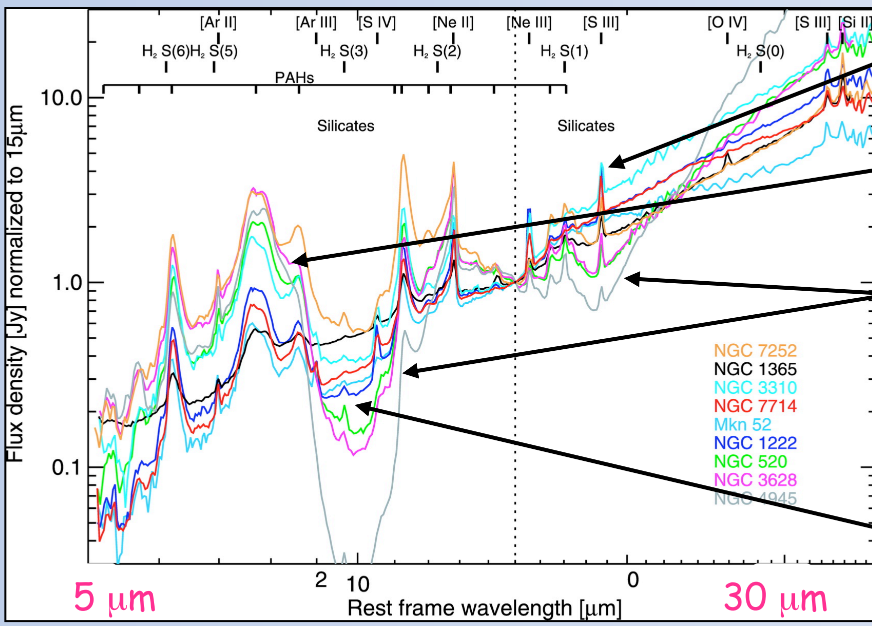
- Star Formation
- Accretion Disks
- Extra-solar Planets
- Galactic Center
- Planetary Science
- Comet and Asteroids
- Dust in Galaxies
- Starburst Galaxies
- Supernova Remnants
- Planetary Nebulae
- Debris Disks
- Much, much more…



Science in the mid-IR

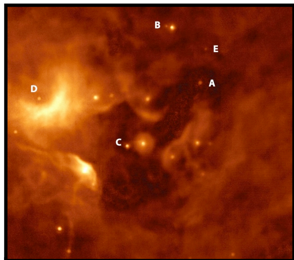
- Useful things in the mid-IR …
  - Broadband spectral energy distribution --> dust T & geometry
  - Many lines diagnostic of black hole & star formation activity, shocks, etc…





Starburst galaxies from Brandl et al. 2007

- Fine structure lines
- Aromatic + aliphatic hydrocarbons
- Broad 10 + 20 μm "silicate features" (Si-O bond stretch/bend)
- Atomic H and molecular H_2



Diffraction-limited Observing

The spatial resolution of a telescope of diameter D at a certain wavelength is given by:

$$\Theta = 1.22(\frac{\lambda}{D}) \text{ [radians]}$$

So in the visible, a 4-m telescope has the resolution:

$$\Theta_V = 1.22(\frac{550nm}{4m}) = 0.035''$$

However we don't ever get that resolution in the visible in reality because atmospheric seeing is ALWAYS much larger than that (seeing and resolution add in quadrature)

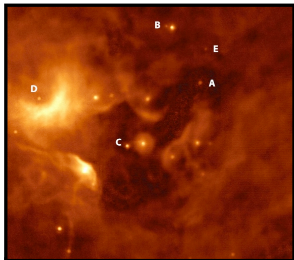
Since "good" seeing is 0.25", the visible is "seeing-limited"

However in the mid-IR, a 4-m telescope has the resolution:

$$\Theta_{MIR} = 1.22(\frac{10\mu m}{4m}) = 0.63''$$

We **CAN** get seeing better than (0.63x2=) 1.2" VISIBLE seeing regularly, so seeing does NOT normally affect Mid-IR observations

So we say that the mid-IR is "diffraction-limited"



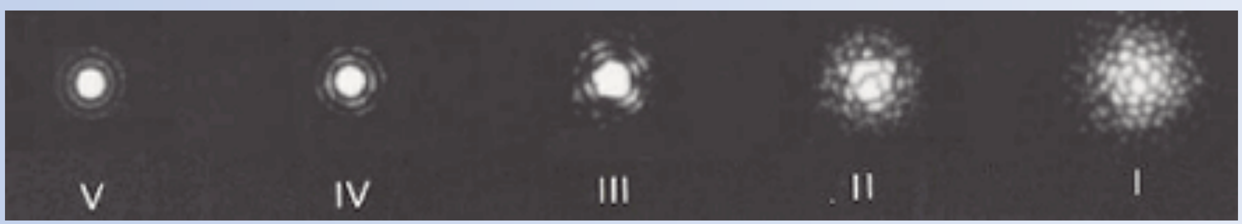
Diffraction-limited Observing

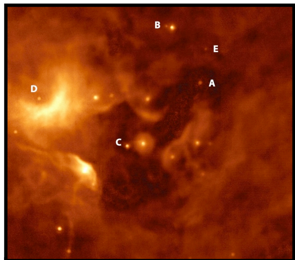
So in the visible, going from a 4-m telescope to a 8-m telescope does not gain you resolution (seeing-limited)!

But, in the mid-IR you would **gain a factor of two in resolution**!

Also, unlike the optical, one can regularly see "diffraction patterns" in mid-IR data.

These patterns are not seen in the optical because they are smeared out by seeing





Mid-IR Observing Reaps the Benefits of Large Aperture Telescopes

$$\frac{S}{N} \propto D \cdot \sqrt{t} \text{ when Source-Noise Dominated}$$

$$\frac{S}{N} \propto D^2 \cdot \sqrt{t} \text{ when Background-Noise Dominated}$$

Source Noise Dominated (optical)

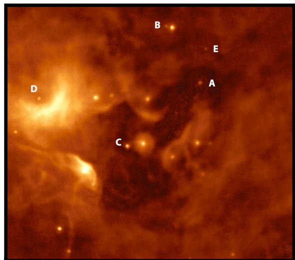
If 60min on a 4-m telescope, on a 10-m to achieve the same S/N only need ~10min

- 6x faster

Background Noise Dominated (mid-IR)

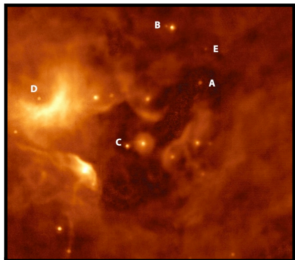
If 60min on a 4-m telescope, on a 10-m to achieve the same S/N only need ~1.5min

- 40x faster!!!!

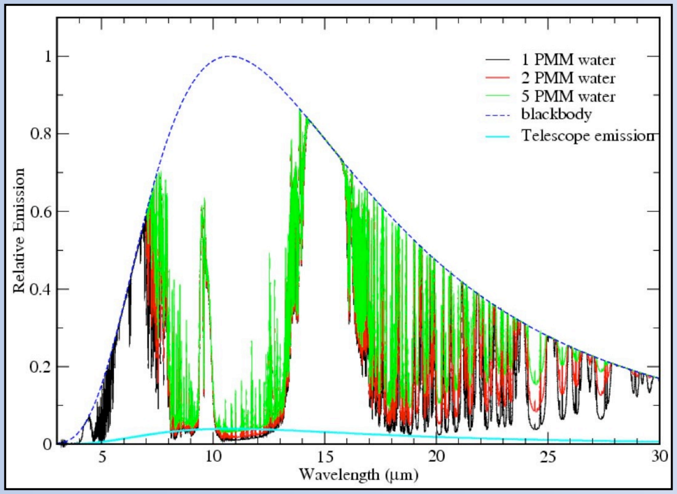


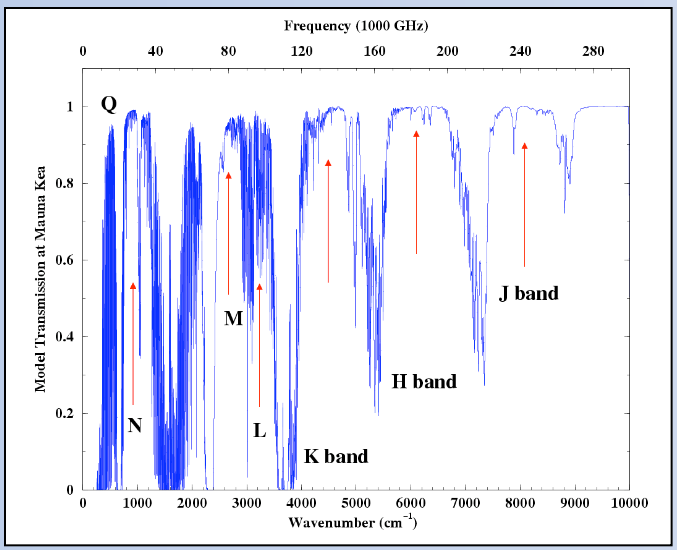
What is *not* cool in the mid-IR?

Observing in the thermal infrared ($\lambda \geq 5$ μm) presents special challenges to astronomers because the atmosphere, and any ground object in the field of view, typically radiates strongly and therefore introduces a large background. The background is often several orders of magnitude larger than the source signal in the N- and Q-bands (10 and 20 μm).



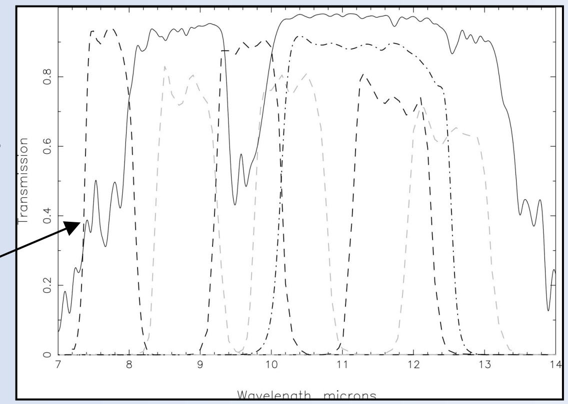
What is *not* cool in the mid-IR?



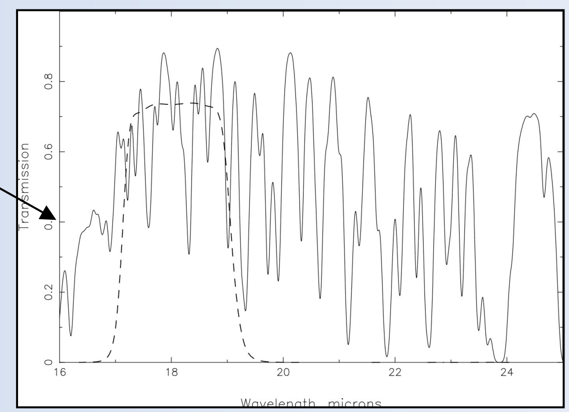


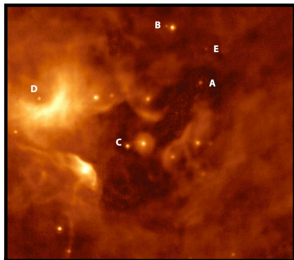
- 300 K blackbody peaks near 10 µm (telescope + atmosphere)
- H_2O, CO_2, O_3, N_2O, CH_4 lines

N band filters + atmospheric transmission

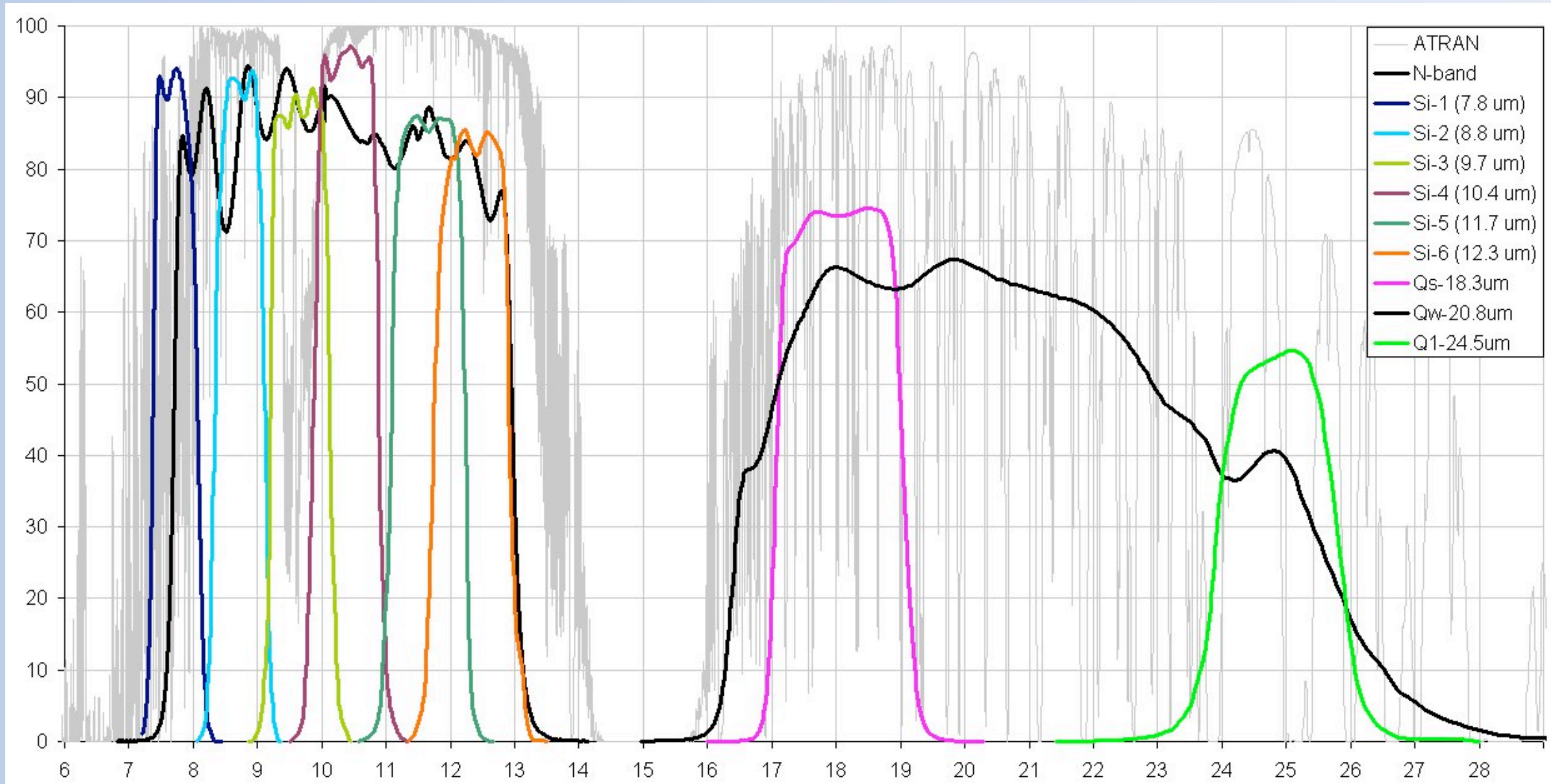


Q band filters + atmospheric transmission

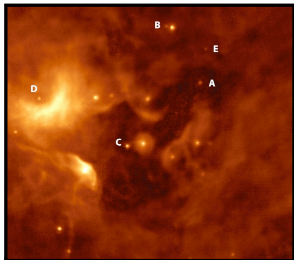




T-ReCS Filters



Wavelength (um)



The Chop-Nod Technique

The sky background is brighter and more *variable* in infrared:

- At J,H,K sky is stable enough to get sky frame every ~60-120sec
- At L (beginning to be background limited), stable over ~20sec
- At M (a bit more background limited), stable for only ~10sec
- At N, Q stable of only a fraction of a second (fully background limited)

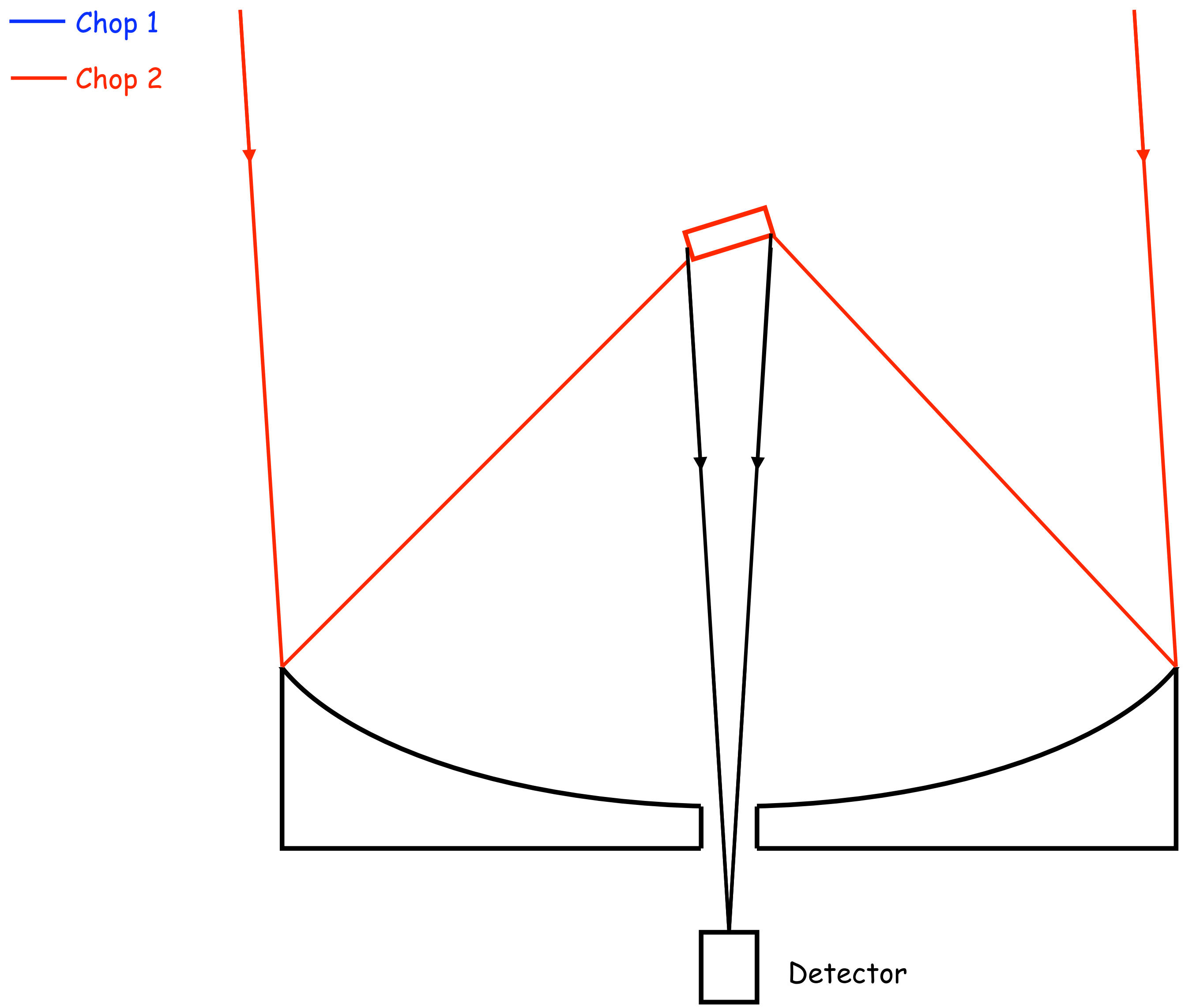
"Chopping"

- Refers to differencing the source frame and a nearby patch of sky
- This is done by moving the secondary mirror @1-50 Hz
- MAIN EFFECT: Removes thermal pattern of telescope and optics

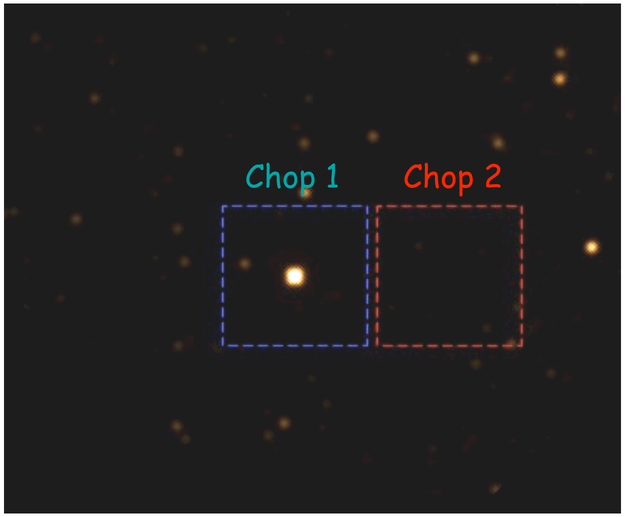
"Nodding"

- Refers to moving the whole telescope
- Performed once every 15-120 seconds
- MAIN EFFECT: Removes Sky Background

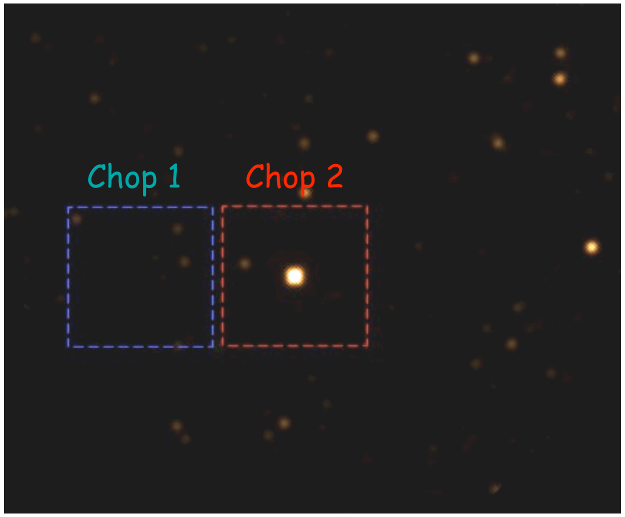
The Chopping (or Wobbling) Secondary



Nod A



Nod B



$= (\text{Source} + BG_{Sky} + BG_{Tele,Chop1}) - (BG_{Sky} + BG_{Tele,Chop2})$

$= \text{Source} + (BG_{Tele,Chop1} - BG_{Tele,Chop2})$

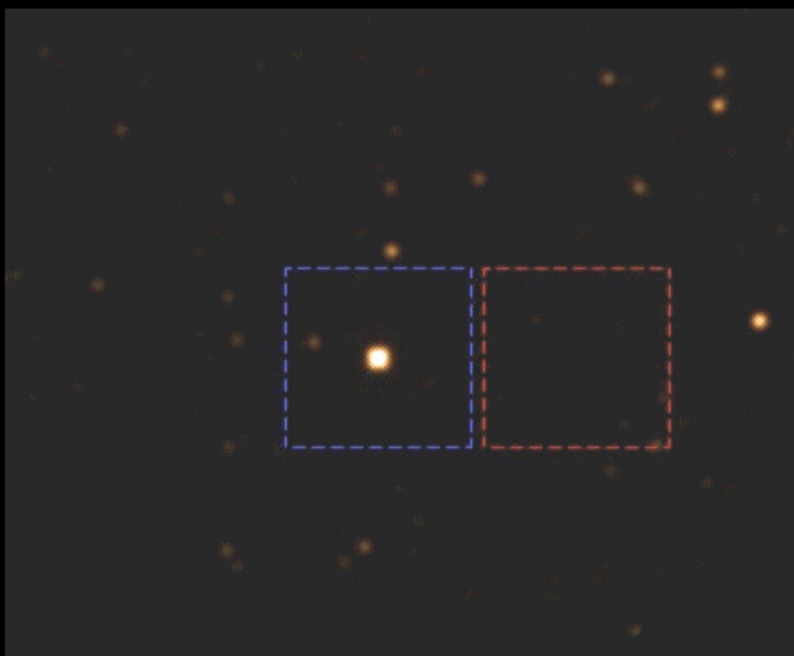
$= (\text{Source} + BG_{Sky} + BG_{Tele,Chop2}) - (BG_{Sky} + BG_{Tele,Chop1})$

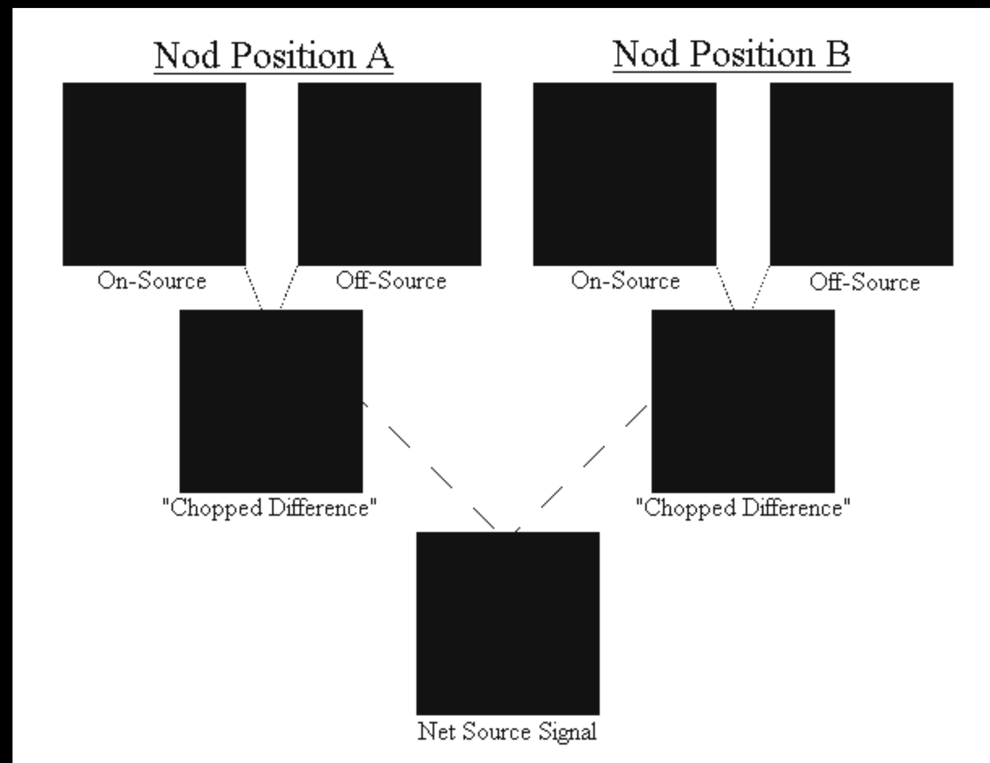
$= \text{Source} + (BG_{Tele,Chop2} - BG_{Tele,Chop1})$

$$\text{Net Source Signal} = \text{Signal}_{NodA} + \text{Signal}_{NodB}$$

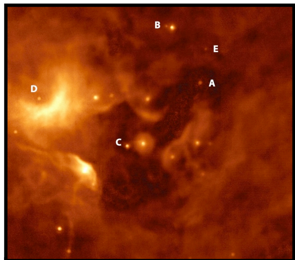
$$= \text{Source} + (BG_{Tele,Chop1} - BG_{Tele,Chop2}) + \text{Source} + (BG_{Tele,Chop2} - BG_{Tele,Chop1})$$

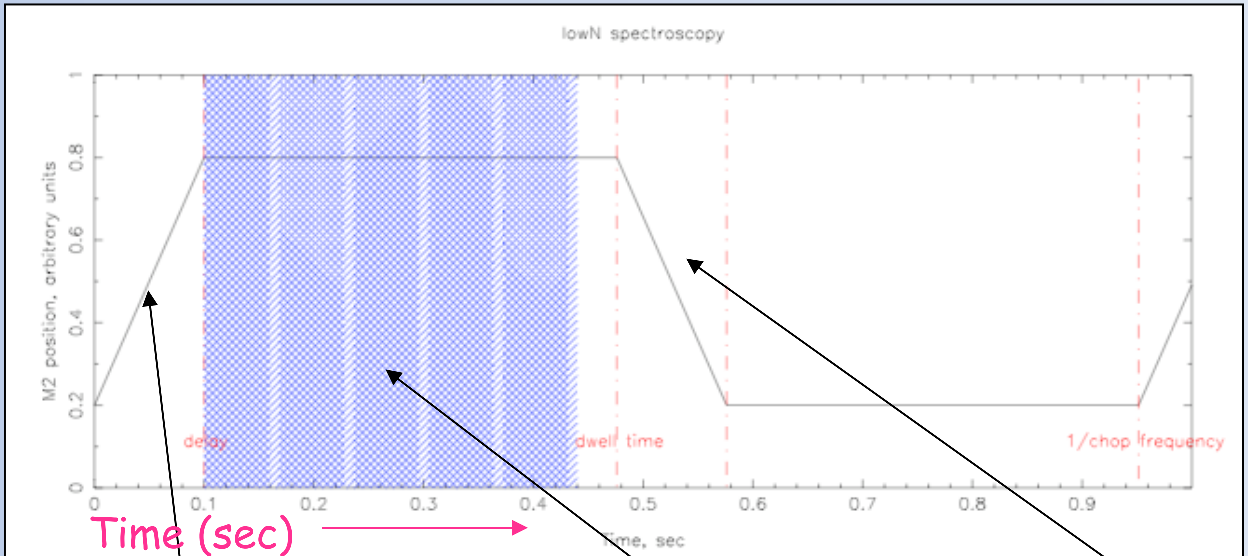
$$= 2 \times \text{Source}$$




Nod Position A
Nod Position B
On-Source
Off-Source
On-Source
Off-Source
"Chopped Difference"
"Chopped Difference"
Net Source Signal

Anatomy of a Michelle observation





Repeat for ~40 sec, then nod whole telescope

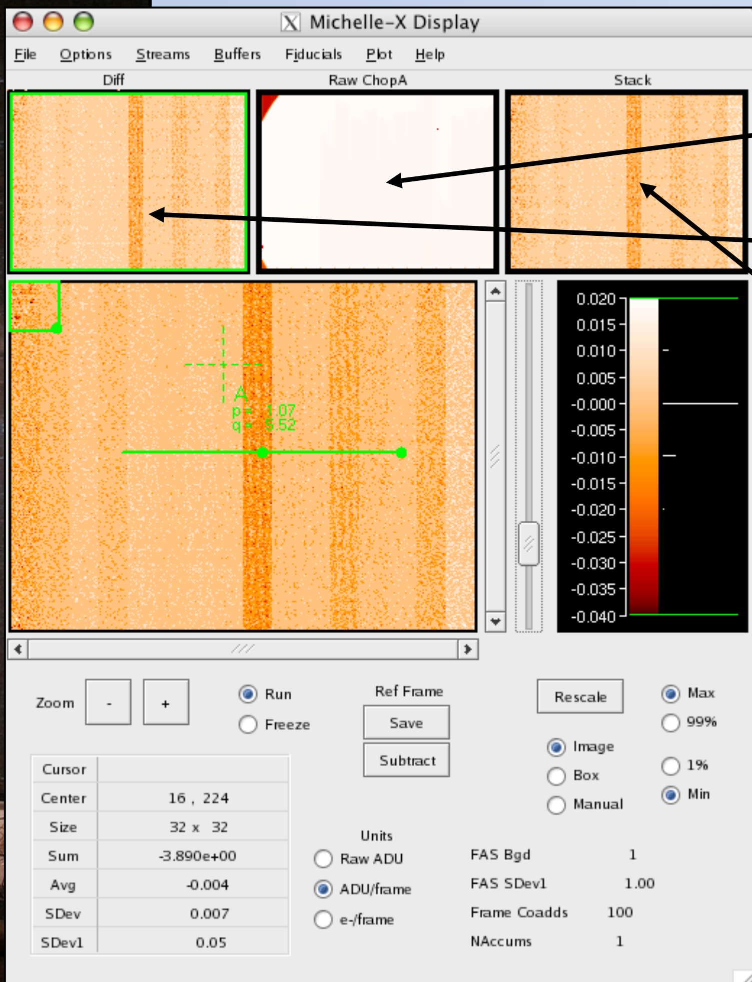
Move mirror to position A

Expose (~100 ms); read out (~8 ms); repeat

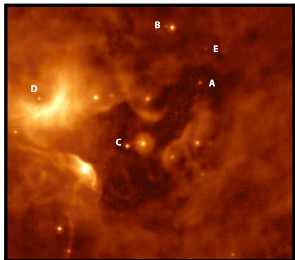
Move mirror to position B

- Chop beams saved separately at end of every nod
- Difference A-B also saved at end of every nod
- File written at end of whole observation; has as many extensions as nods

What you see in practice



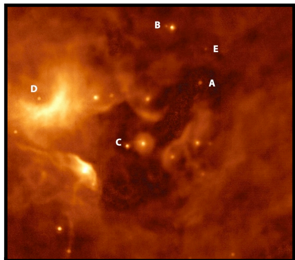
- MichX display tool
- Raw data (chop A, no background subtraction)
- The "diff": Chop A - Chop B for a single nod
- The "stack": total signal, chop- and nod-subtracted
- File only written on completion of whole observation
  - Can be tens of nods
- Final file format:
  - N20090915S0001[N][320,240,M]
  - N nods
  - M = 1,2,3 (diff, chopA, chopB)



Looking at data files

- Files only written to disk at end of observation.

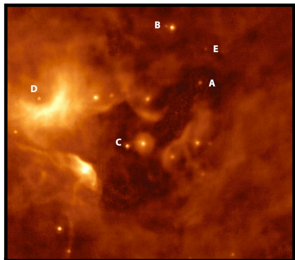
- To display a single nod diff image/spectrum
  - cl> display N20090915S0001[1]
- To display a single nod raw image/spectrum
  - cl> display N20090915S0001[1][*,*,2]
- To display the final, stacked image/spectrum
  - cl> mireduce N20090915S0001
  - cl> display rN20090915S0001[1]
  - Will see 1 positive and 2 negative images/spectra



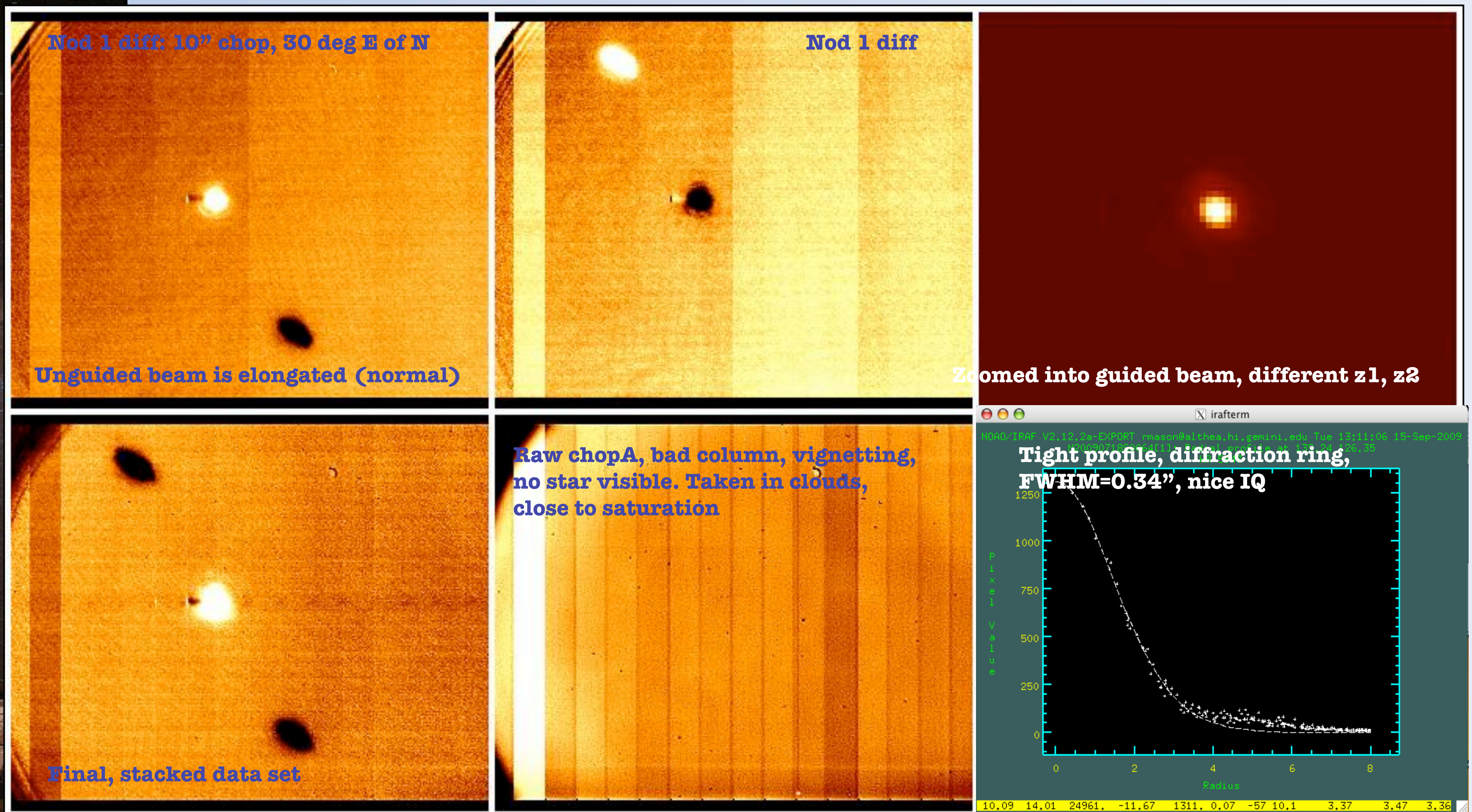
Michelle Imaging mode

In the N and Q windows the sky/telescope background is so bright that we can only integrate for of order 50 ms before we fill up the detector wells. We have to continuously read out the detector as we observe.

Michelle has a pixel size of 0.1″ on the sky. The array is 320 by 240 pixels with 16 channels of size 20 by 240 pixels. There are 4 groups of 4 channels each.

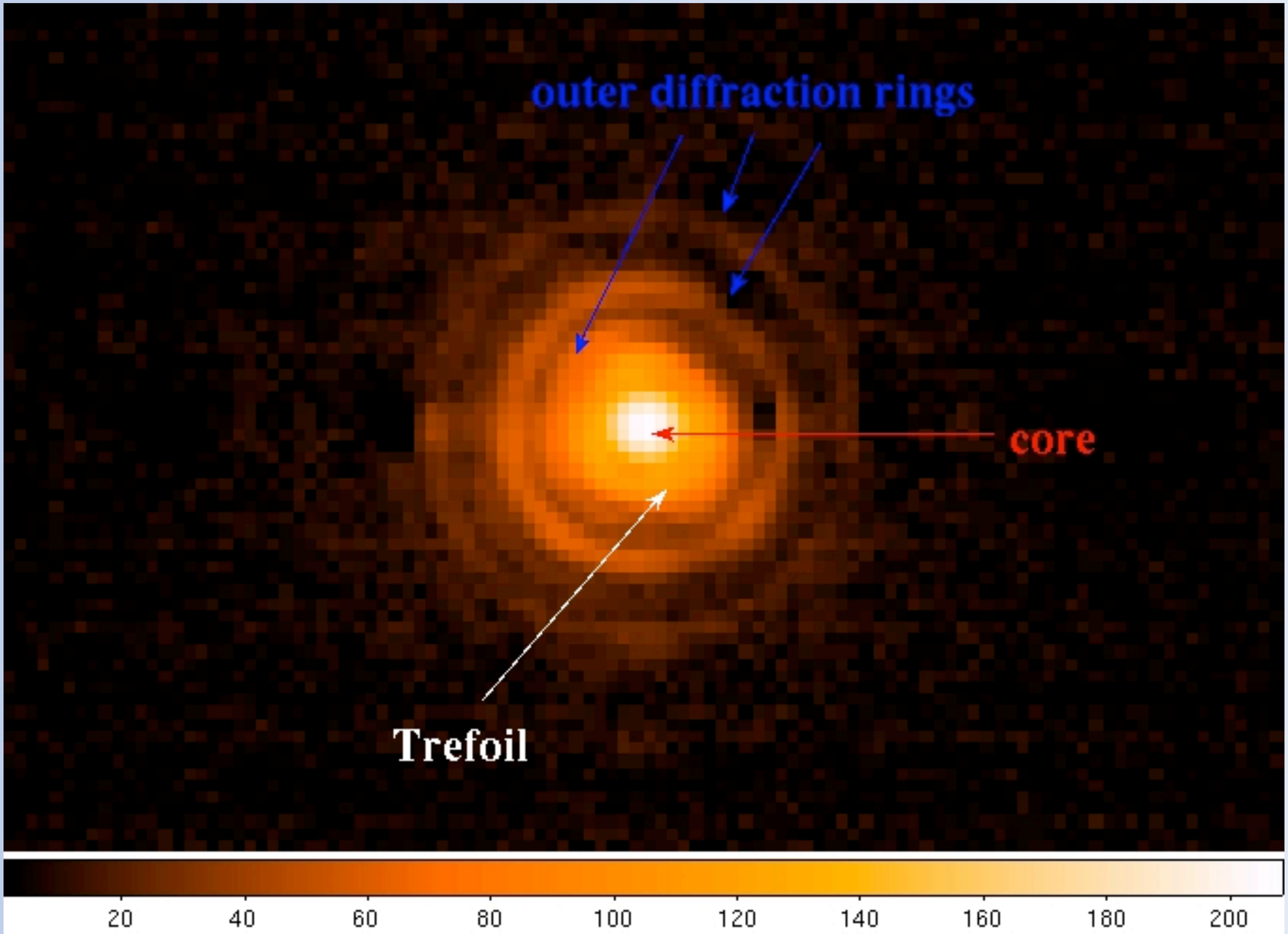


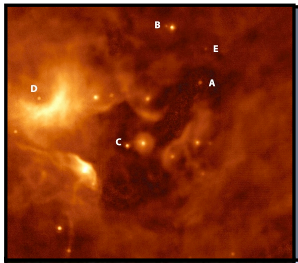
Imaging data example

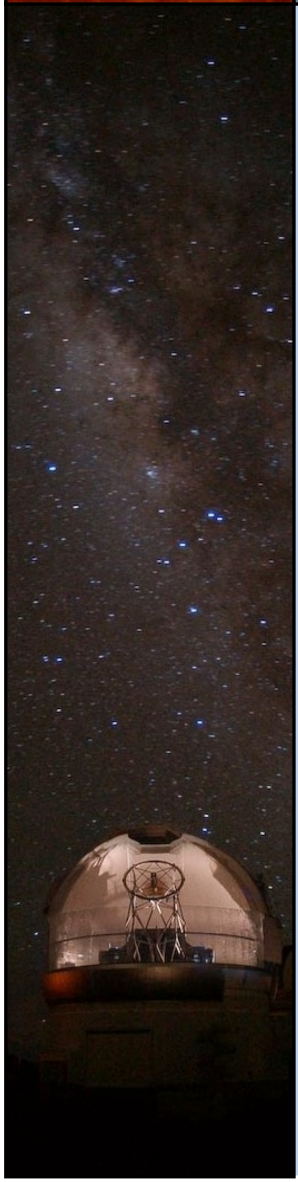


N20090718S0064; an N = 1 mag (~15 Jy) standard star

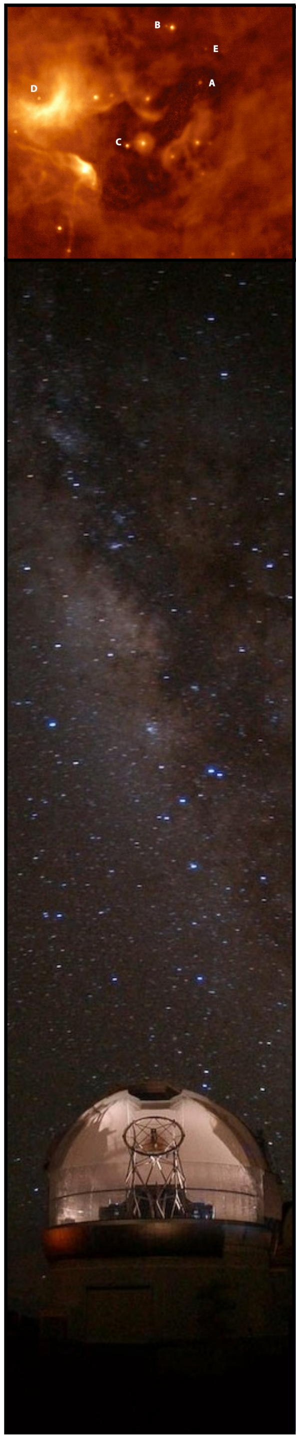
PSF Structure

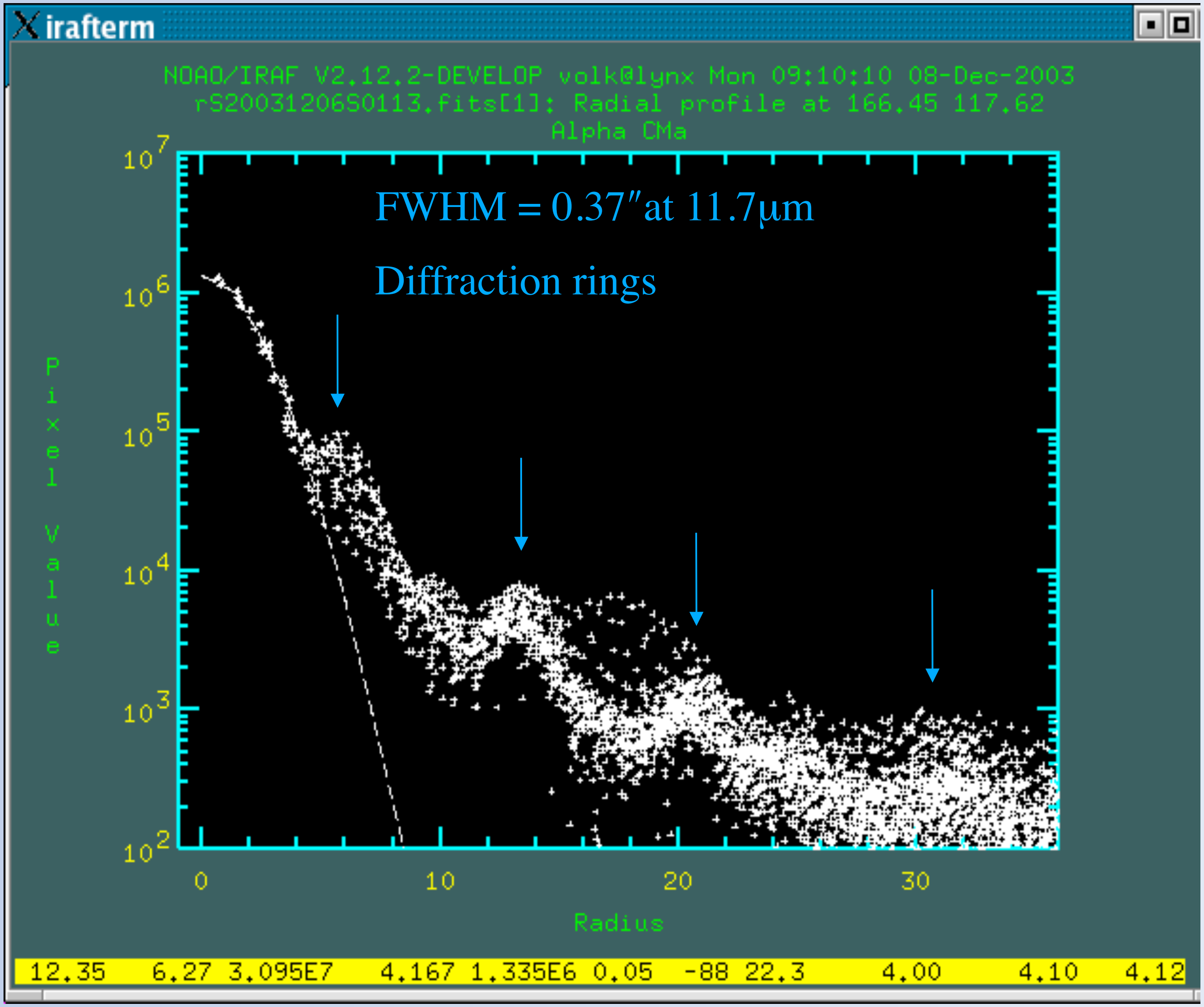


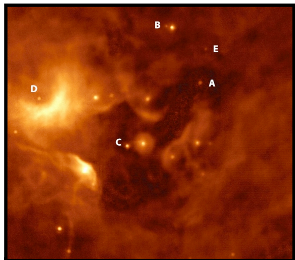




PSF Structure

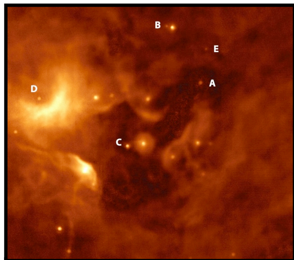






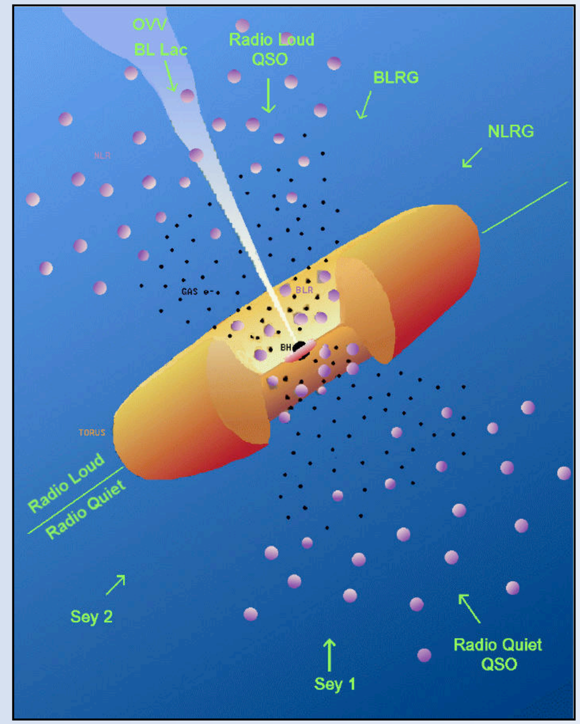
Imaging: data reduction guidelines

- http://www.gemini.edu/sciops/instruments/midir-resources/data-reduction/imaging-reduction
- Iraf script: gemini, midir, midirexamples
- http://www.iac.es/proyecto/blas-cabrera-gtc-instruments/media/cc_imaging_20070925.pdf

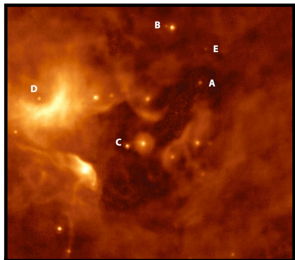


NGC1068 as a case study

- Unified model of active galactic nuclei (AGN)
  - All AGN powered by accreting SMBH
  - Look different because of orientation-dependent obscuration



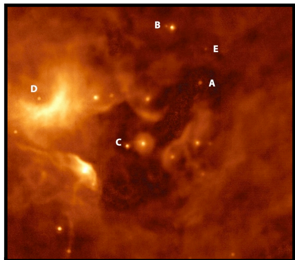
- Chemistry, geometry and origin of obscuration? Connection with galaxy evolution?



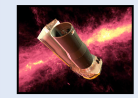
NGC1068 as a case study

- Torus emits strongly in MIR: SED and silicate feature constrain models of its physics and chemistry
- Torus is only a few pc in diameter (<<0.1" in nearest galaxies)
  - can also have emission from radio jets, circumstellar shells, narrow line region…

    --> SPATIAL RESOLUTION!
- NGC1068 is the "archetypal" type 2 AGN; relatively nearby at 14 Mpc; obvious candidate for N band spectroscopy



Ground vs Space

Gemini, VLT,  Subaru, GTC… vs IRAS, ISO,  Spitzer, Akari…

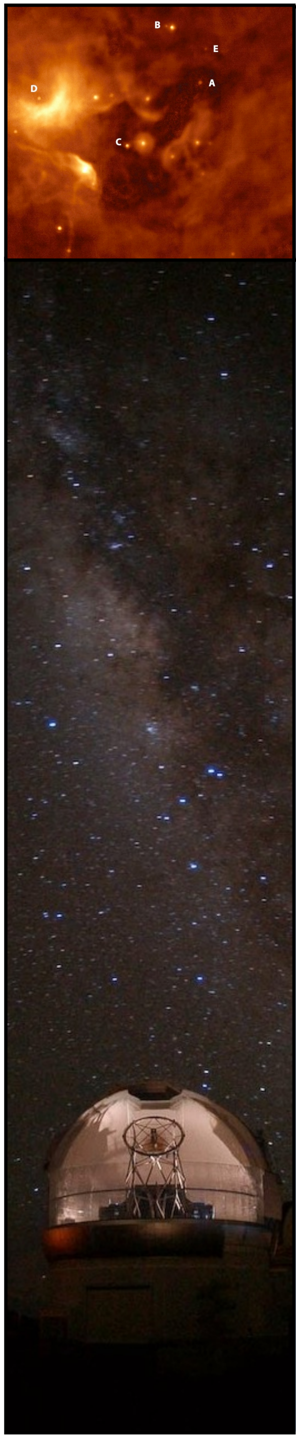
- Issues to consider include

* Sensitivity
* Spatial resolution
* Spectral resolution
* Wavelength coverage

Expense

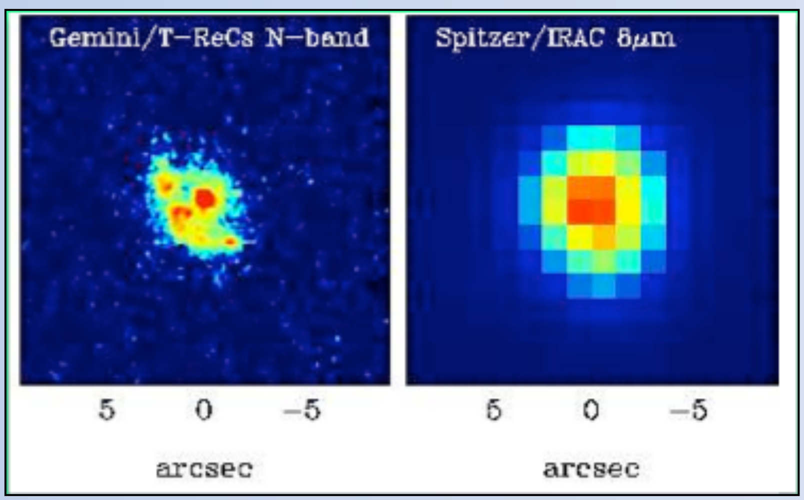
Upgrading/maintaining instrumentation

- Airborne observatories like KAO, Sofia are somewhere in between



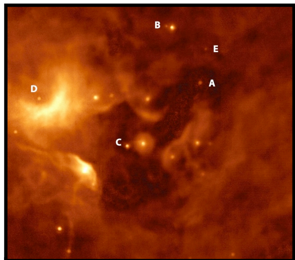
Spatial resolution

- Ground-based optical/NIR: seeing limited
- Ground-based MIR: diffraction limited
  - 8m telescope λ/D approx 0.3″ at 10 μm
  - Spitzer ~3″ at 10 μm (80 cm telescope)
  - IRAS ~30″ at 12 μm



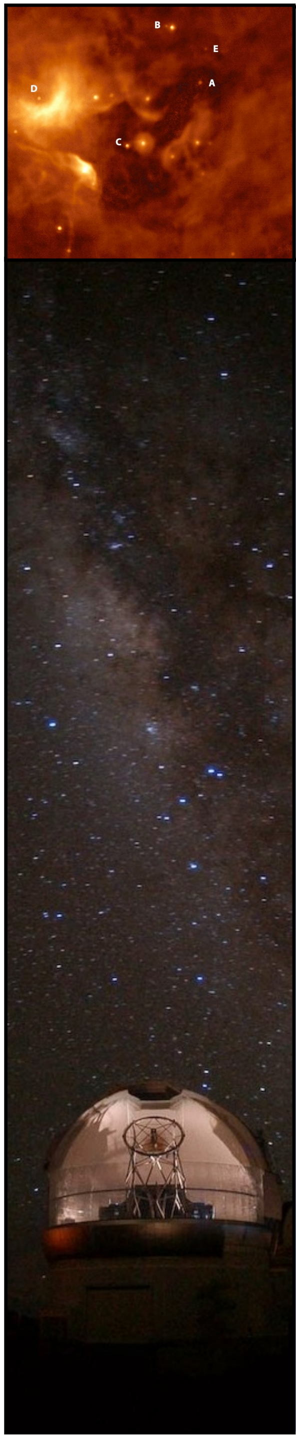
Left: Gemini South/ T-ReCS 10.4 μm

Right: Spitzer/IRAC 8 μm

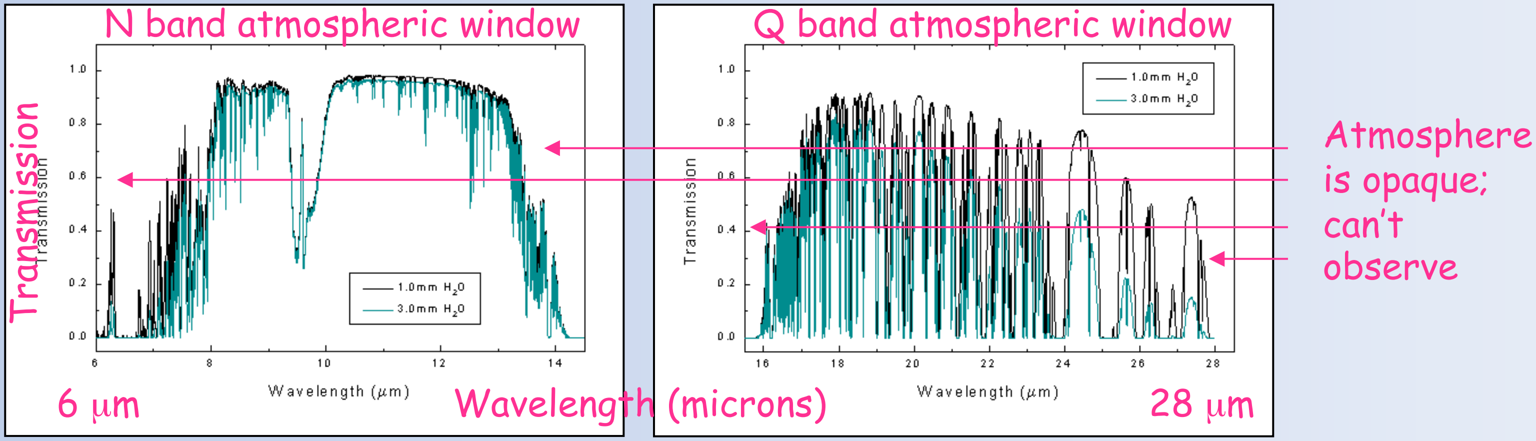


Sensitivity (I)

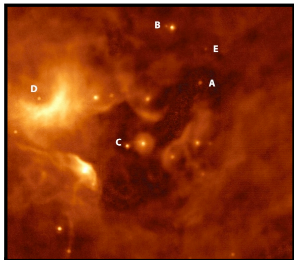
- If we can subtract out the background emission, why worry about it?
- Mean residual background level after chopping and nodding might be small, but rms not necessarily so
- Dominant source of noise in MIR (usually) random fluctuations in number of background (sky + telescope) photons arriving on a pixel
- Pixel-to-pixel variations in residual background then α sqrt(raw background level)
- If you're looking for a faint source you want the background noise to be as low as possible; then your 2σ smudge might be a 5σ detection…



Sensitivity (II)

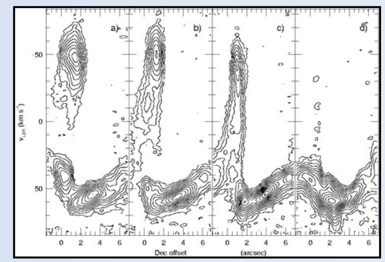


- Telluric lines (H_2O, O_3, CO_2 , N_2O, CH_4...) mean increased background and decreased transmission
- Also limit useful wavelength range
- Variable transmission --> inaccurate flux calibration
- Need a telluric standard star - close in time and space - to cancel atmospheric absorption lines

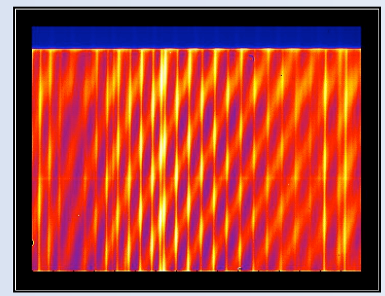


Spectral resolution

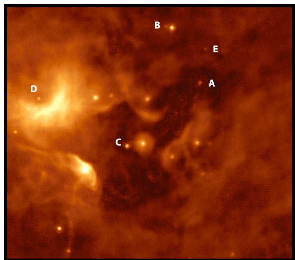
- Very high MIR spectral resolution (R> few thousand) not (yet) available from space
- Pros of high resolution
  - More information! →
  - Don't have to chop!



- Cons:
  - Lower sensitivity & λ-coverage
  - Spectral fringing →

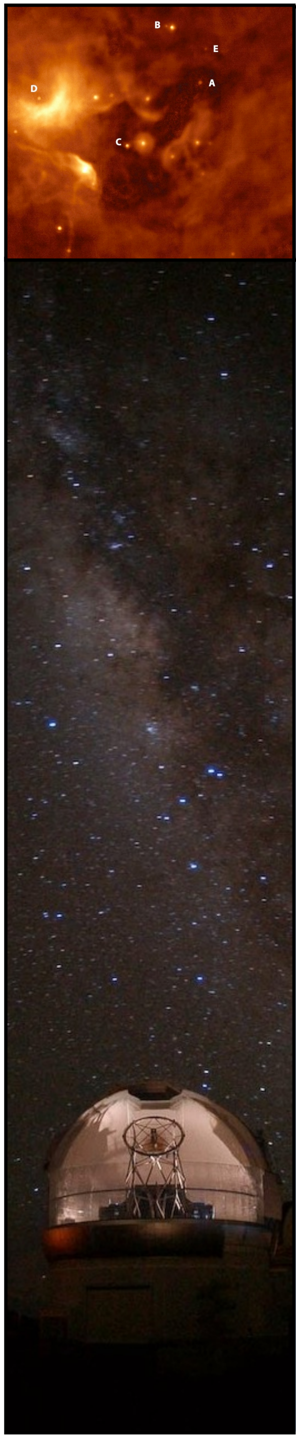


- For NGC1068, you want to know about a broad feature (10 μm Si-O bond stretch), so stick with low-res (R~200)



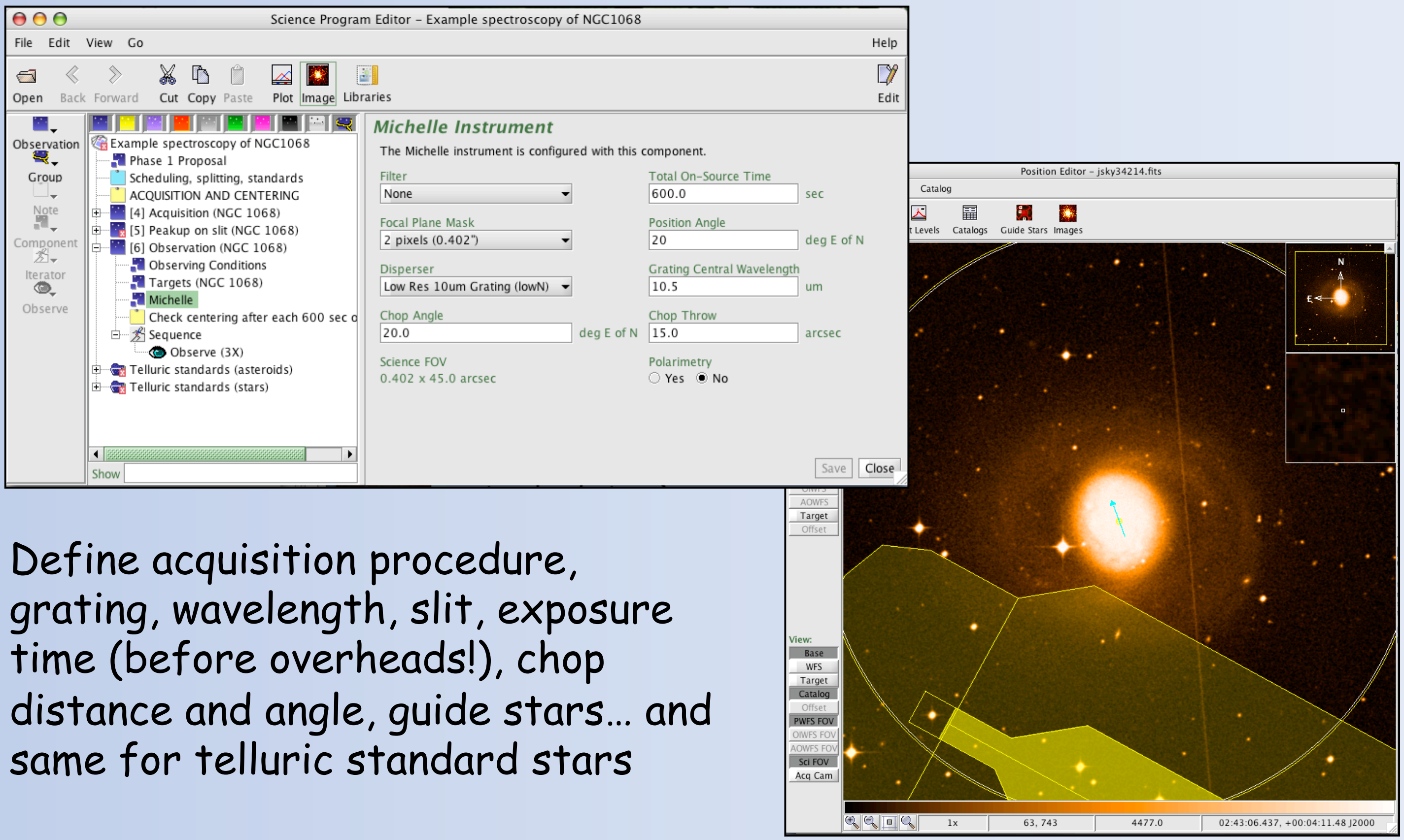
Ground vs Space

- In spite of the relatively low sensitivity and lack of wavelength coverage, we will observe from the ground at low spectral resolution because we need the spatial resolution
- NGC1068 would saturate Spitzer anyway… (hah hah)

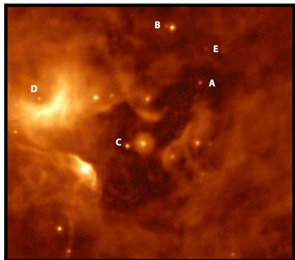


The Observations (I)

- NGC1068 N band spectra taken during commissioning of spectroscopy mode of Michelle on Gemini North

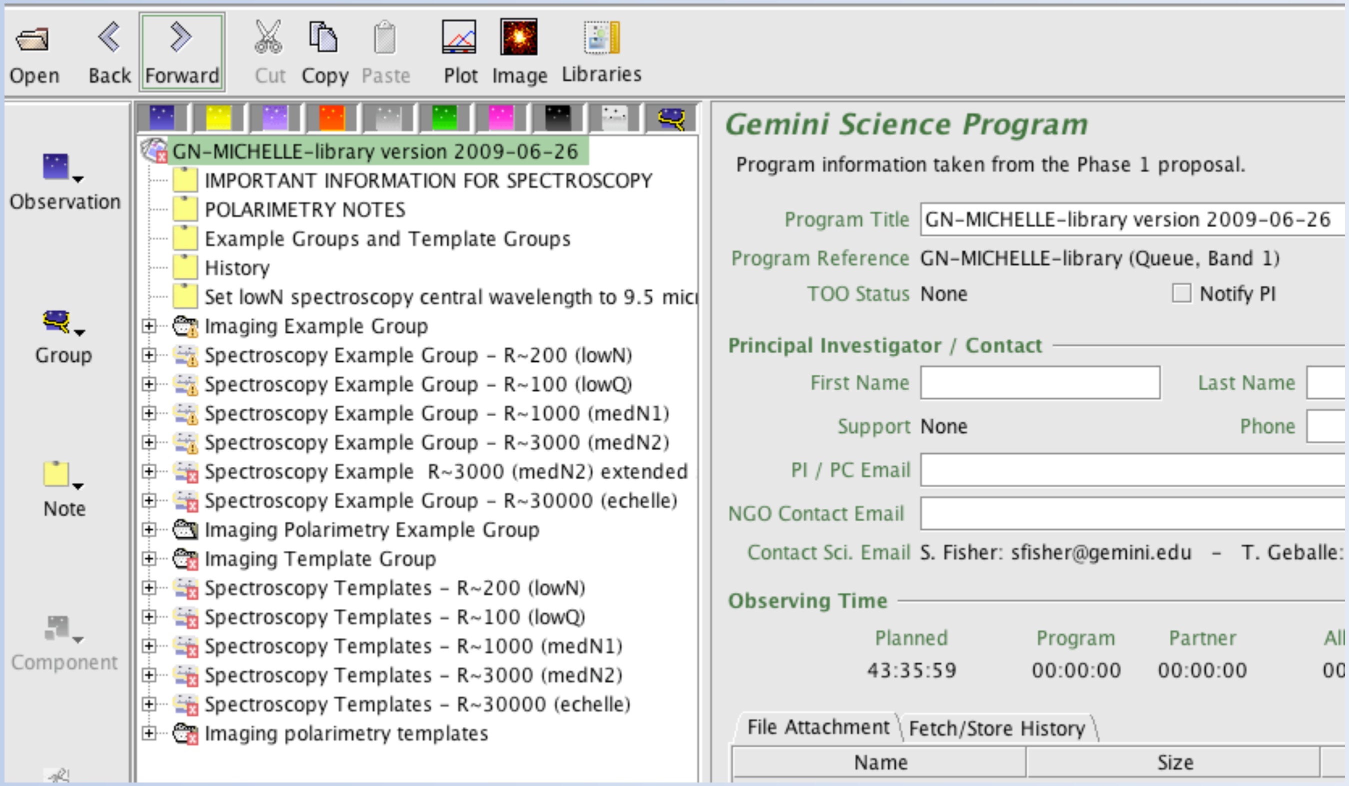


Define acquisition procedure, grating, wavelength, slit, exposure time (before overheads!), chop distance and angle, guide stars… and same for telluric standard stars

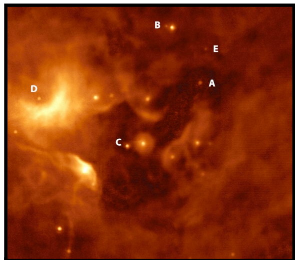


The Observations (II)

- Use the OT library for phase !!



One more point - careful standard star selection, Cohen standards useful but avoid late K and M spectral types (or model out SiO/ silicate bands)



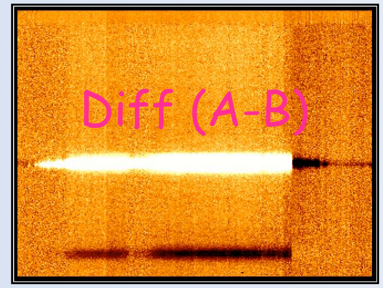
Data Reduction (I)

Spectral →

Spatial ↑

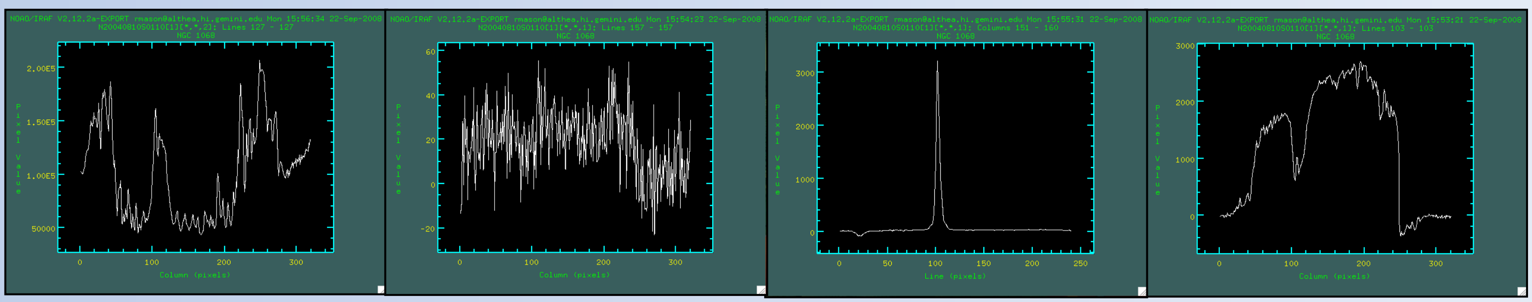
Filename[1][320,240,2]

Filename[1][320,240,3]



Filename[1][320,240,1]

[1] signifies nod 1; 3 more images for every other nod (may have many tens), all in one file

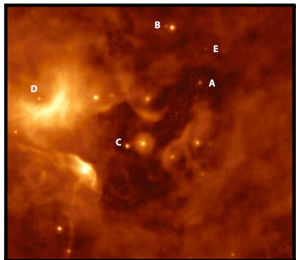


Line cut through chopA

Line cut through sky in diff image

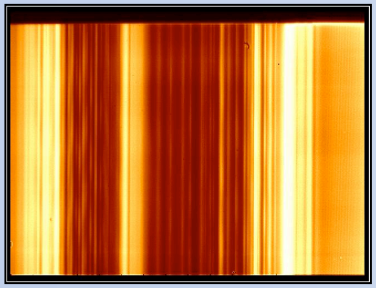
Column cut through diff image

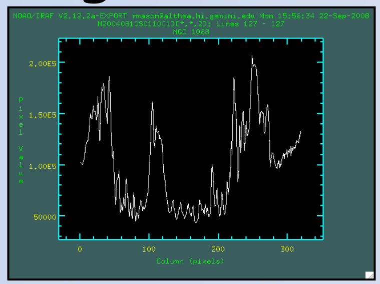
Line cut through galaxy spectrum



Data Reduction (I)

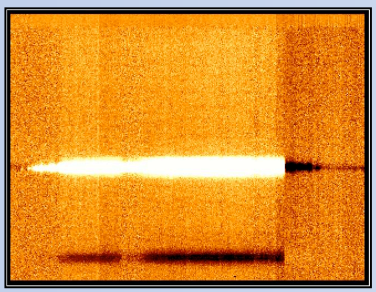
- Check raw background level in individual nods

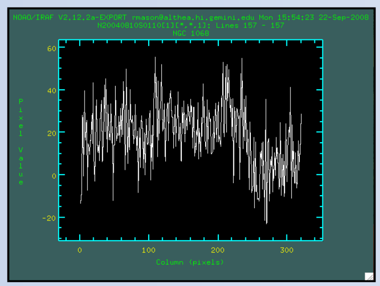




Are any frames saturated? Clouds, high water vapour…

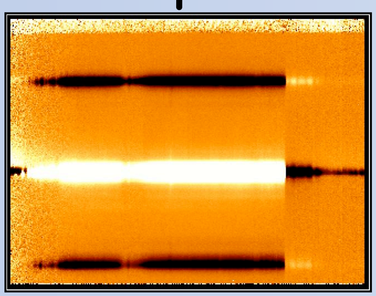
- Check rms of residual background





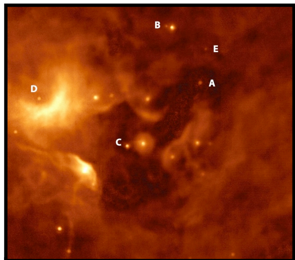
Are any frames unusually noisy? Random sky noise or “stripy” instrumental noise…

- Do chop/nod subtraction --> single “stacked” file



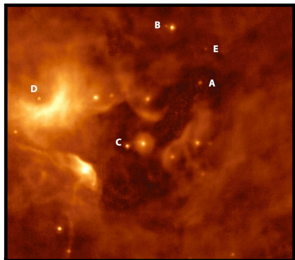
Final image has 1 +ve and 2 -ve spectra

Can register target during stacking if bright and compact

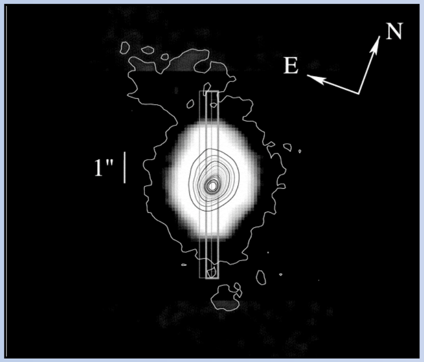


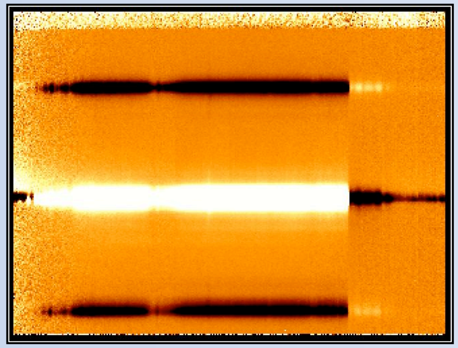
Data Reduction (II)

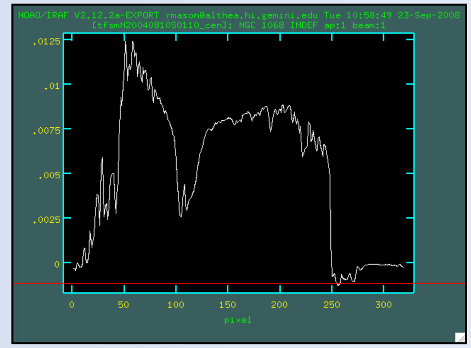
- A few things we don't need to do:
- The detector bias chops out with the sky+telescope background
- The dark current also chops out
- To flatfield or not to flatfield?
  - MIR detectors fairly flat anyway
  - Unnecessary when science target and standard star on same row
  - With extended sources, experiment!



Data Reduction (III)







Spectral Extraction

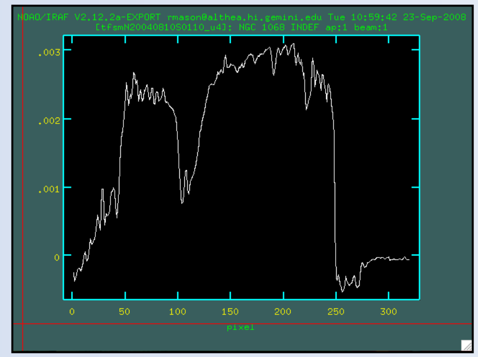
Real spatial information - extract spectra in steps along slit

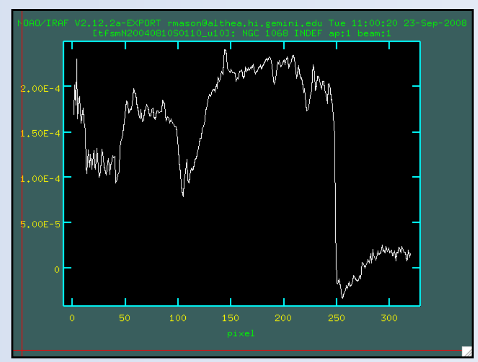
Size of steps depends on angular resolution (we used 0.4" steps, slit was 0.4" wide)

Trace curvature of spectra across array? Not important for wide aperture extractions, is important here!

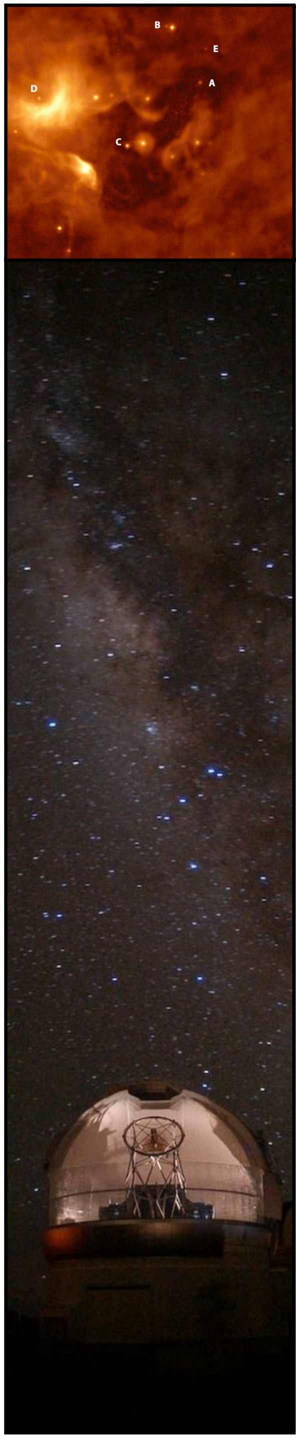
Worth fitting and removing any background not removed by chop/nod procedure?

Negative spectra not useful (unguided)

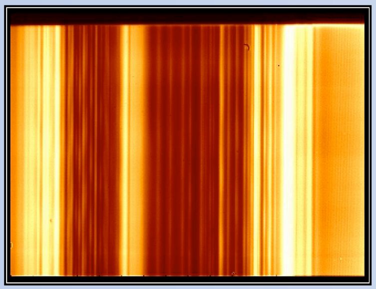




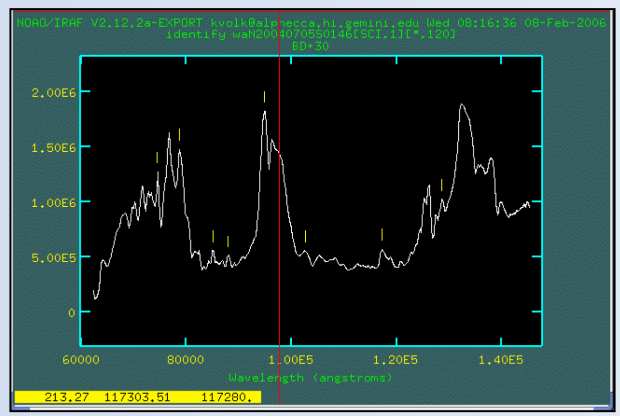
Data Reduction (IV)

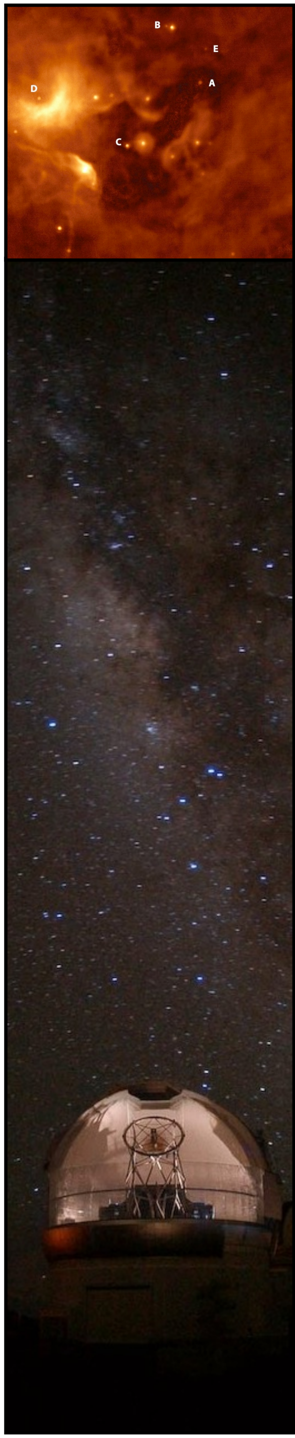


- Wavelength calibration procedure is similar to optical/NIR
  - Identify calibration lines, fit, apply to science data
- Except
  - No arc lines; use sky lines in raw data instead



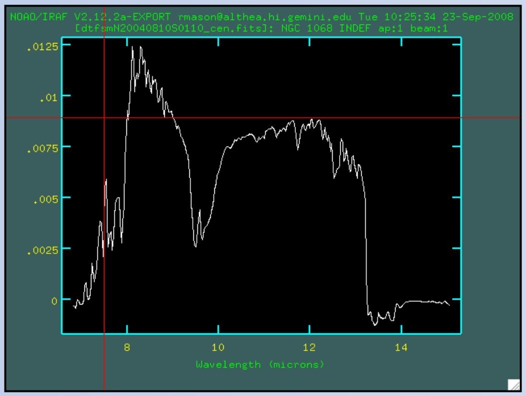
pixel	wavelength	Line ID
47.78	74619.2101	74670.
63.93	78813.4841	78750.
88.50	85166.8354	85140.
99.62	88033.285	88020.
126.45	94941.4424	95030.
156.33	102622.713	102600.
213.27	117303.511	117280.
257.31	128759.52	128770.



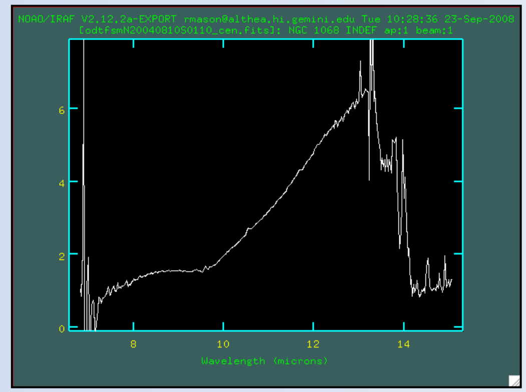


Data Reduction (V)

- Divide galaxy spectra by standard star, multiply by blackbody curve

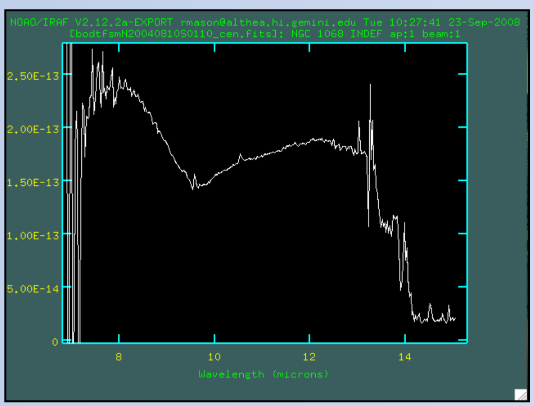


Divide by standard

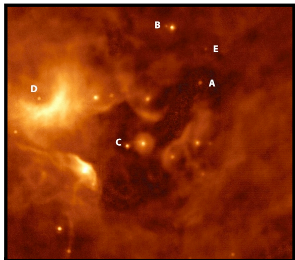


Atmospheric lines gone; spectrum much "smoother"; note strong rise to red

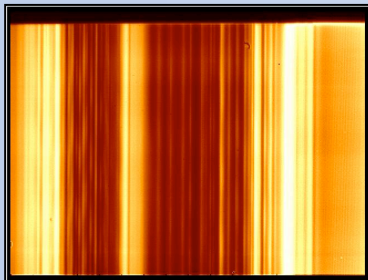
Multiply by blackbody

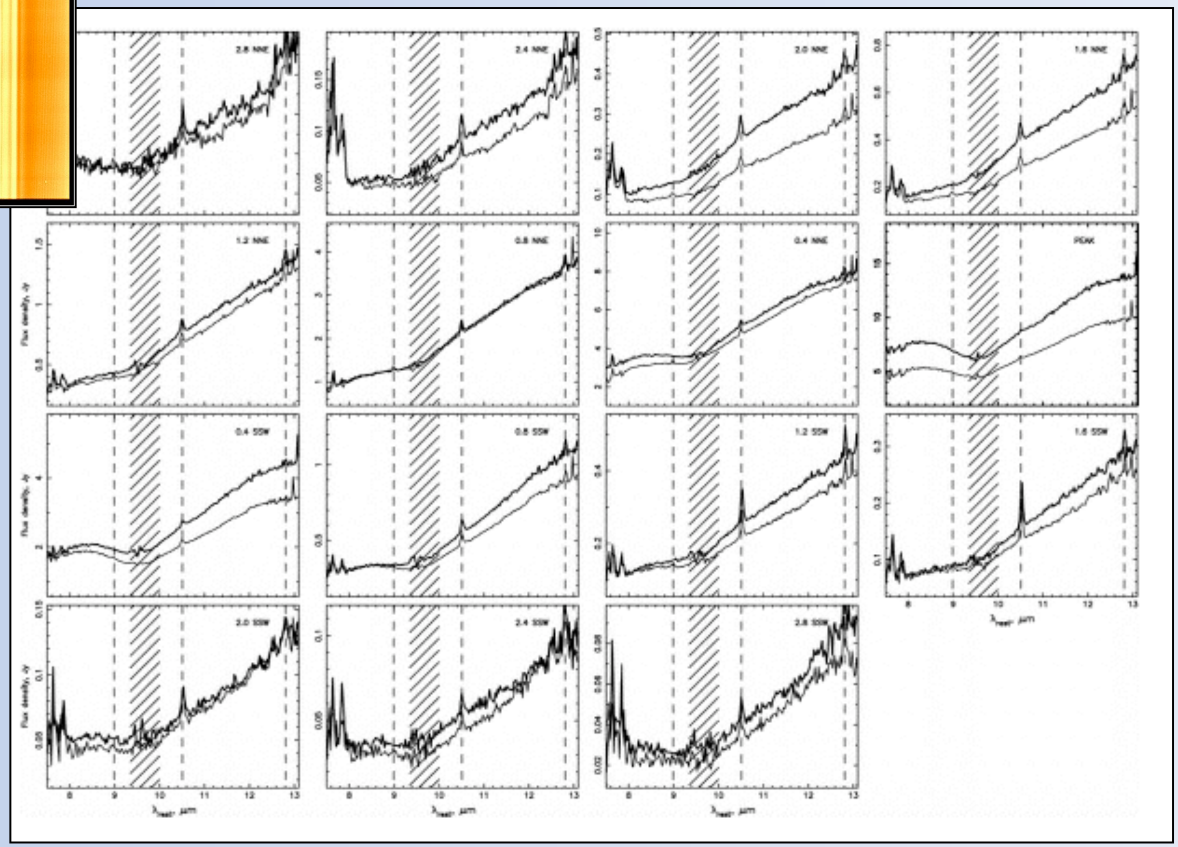


Now see "true" galaxy spectrum; silicate feature and emission lines; messy at ends (atmosphere nearly opaque) also in O_3 band

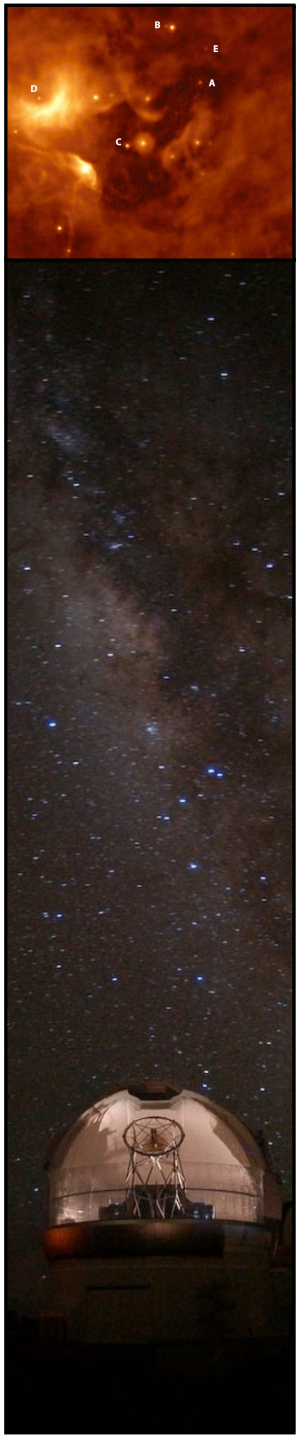


Final Data Set

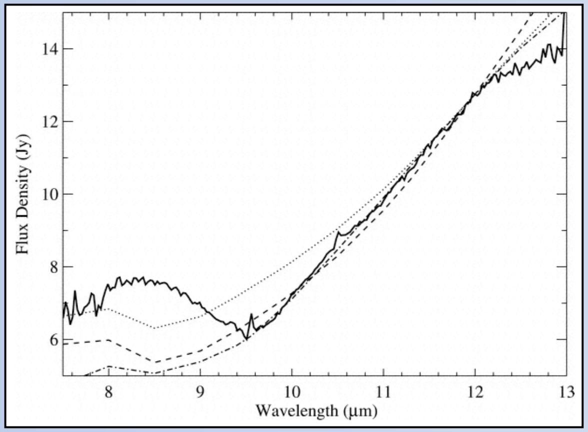


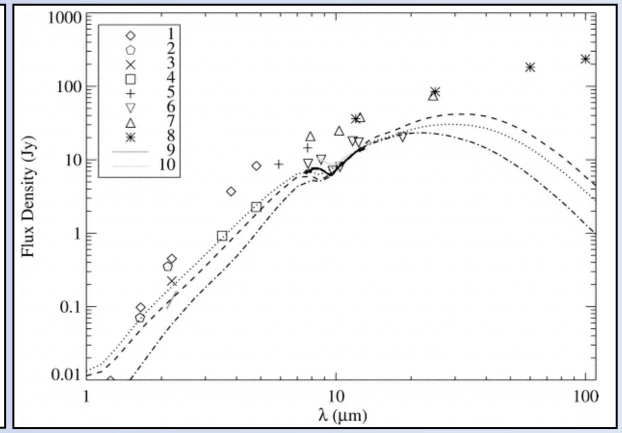


Wavelength calibrated, flux calibrated 8-13 μm spectra of NGC1068 from 2 different nights extracted in 0.4″ steps along the slit, covering the nucleus and ionisation cones

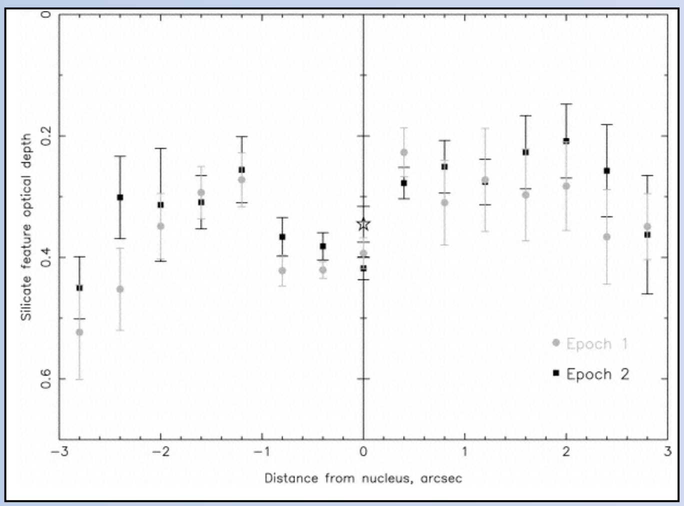


Results



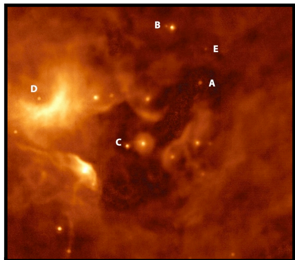


Radiative transfer modelling of Michelle nuclear spectrum and whole IR SED give torus parameters and intrinsic AGN luminosity



Silicate feature strength measured in all spectra along slit reveals large, cold disk of material around the nucleus

Spectra themselves reveal previously unknown complexity in emission lines, continuum shape and silicate feature profile on very small scales



The finished product

Spatially Resolved Mid-Infrared Spectroscopy of NGC 1068: The Nature and Distrib

http://adsabs.harvard.edu/abs/2006ApJ...640..612M

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http://adsabs.harvard.edu/abs/2006ApJ...640..612M

Title:	Spatially Resolved Mid-Infrared Spectroscopy of NGC 1068: The Nature and Distribution of the Nuclear Material
Authors:	Mason, R. E.; Geballe, T. R.; Packham, C.; Levenson, N. A.; Elitzur, M.; Fisher, R. S.; Perlman, E.
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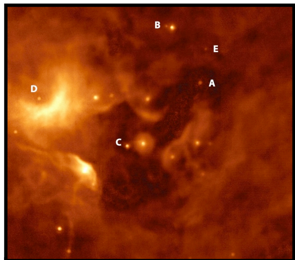
Abstract Copyright:	(c) 2006: The American Astronomical Society
DOI:	10.1086/500299
Bibliographic Code:	2006ApJ...640..612M

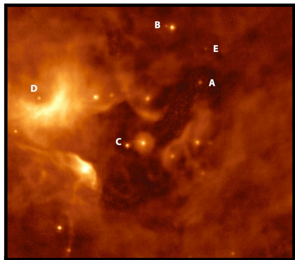
Abstract

We present spatially resolved, near-diffraction-limited 10 μm spectra of the nucleus of the Seyfert 2 galaxy NGC 1068, obtained with Michelle, the mid-IR imager and spectrometer on the 8.1 m Gemini North Telescope. The spectra cover the nucleus and the central 6.0"×0.4" of the ionization cones at a spatial resolution of approximately 0.4" (~30 pc). The spectra extracted in 0.4" steps along the slit reveal striking variations in continuum slope, silicate feature profile and depth, and fine-structure line fluxes on subarcsecond scales, illustrating in unprecedented detail the complexity of the circumnuclear regions of NGC 1068 at mid-IR wavelengths. A comparison of photometry in various apertures reveals two distinct components: a compact (radius<15 pc), bright source within the central 0.4"x0.4" and extended, lower brightness emission. We identify the compact source with the AGN-obscuring torus, and the diffuse component with dust in the ionization cones. While the torus emission dominates the flux observed in the near-IR, the mid-IR flux measured with apertures larger than about 1" is dominated instead by emission from the ionization cones; despite its higher brightness, the torus contributes <30% of the 11.6 μm flux in the central 1.2" region. Many previous attempts to determine the torus spectral energy distribution are thus likely to be significantly affected by contamination from the extended emission. The observed spectrum of the compact source is compared with clumpy torus models. The models require most of the clouds to be located within a few parsecs of the central engine, in agreement with recent mid-IR interferometric observations. We also present a UKIRT/CGS4 5 μm spectrum covering the R(0)-R(4) lines of the fundamental vibration-rotation band of ^{12}CO. None of these lines was detected, and we discuss these nondetections in terms of the filling factor and composition of the nuclear clouds.



Papers based on Gemini mid-IR data

- http://www.gemini.edu/sciops/instruments/midir-resources/midir-papers
- “Characterization of the mid-IR image quality at Gemini South”. http://www.gemini.edu/sciops/instruments/miri/Li-Gemini-MIR-SPIE-June2010.pdf.
- See Mason et al. 2008 (SPIE) “Observing Conditions and Mid-IR Data Quality”, also Westphal 1974.



Advantages and Disadvantages of Mid-IR Observing

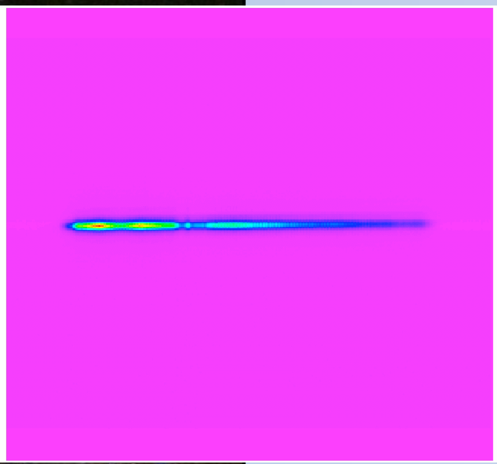
Advantages

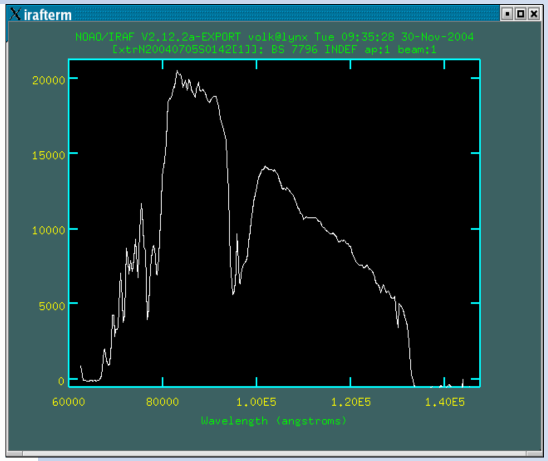
- Better Seeing (half of visible)
- Maximum use of telescope aperture (time to a given S/N goes as $1/D^4$)
- Diffraction-limited observing
- AO not necessary, or cheaper/ easier
- Can observe when moon is up, bad light polluted sights, even during day
- Free sky, dark, and bias subtraction
- Time-series data: On the fly knowledge of data quality, clouds, can throw out image subsets

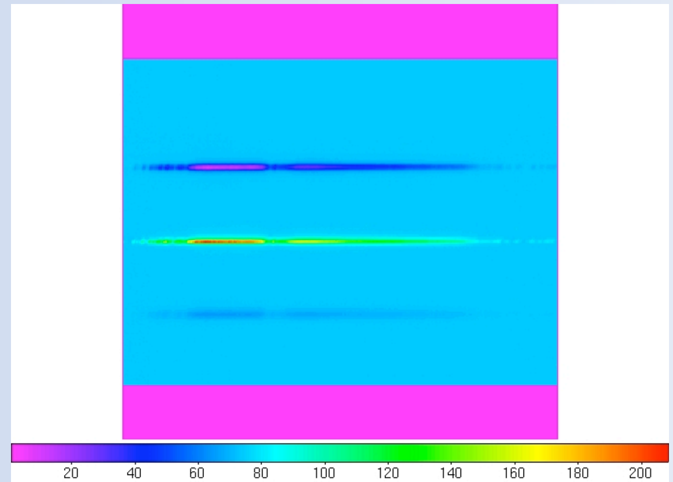
Disadvantages

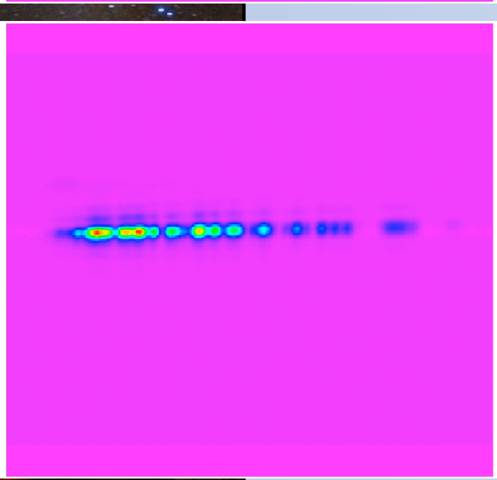
- Can't observe through even thin cirrus - must be clear
- Need low water-vapor as well for 20um work
- A lot of overheads in the observing process
- Very-sensitive to mirror imperfections

LowN and lowQ spectra





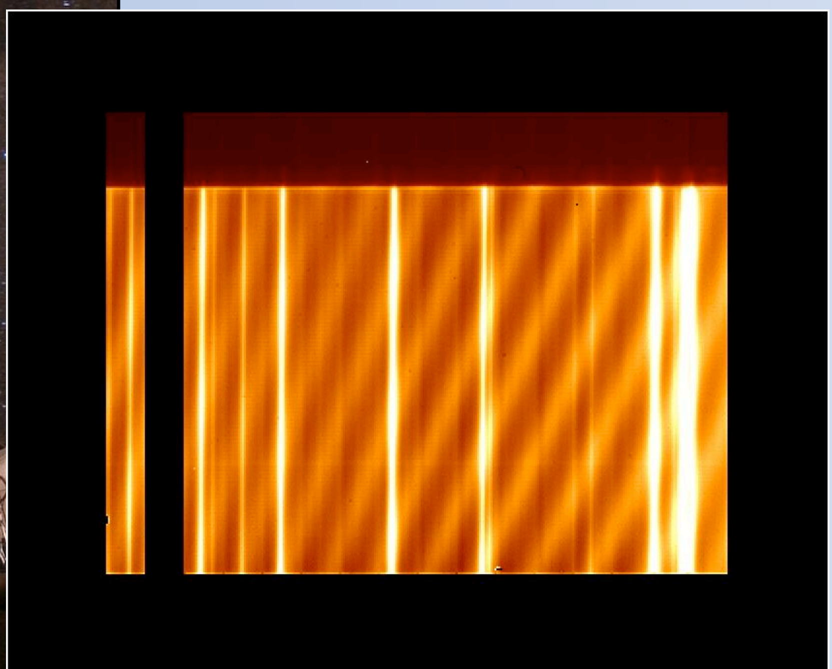




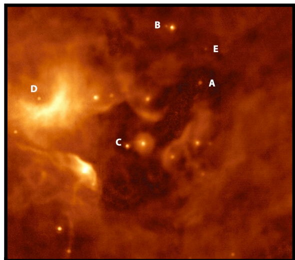
Clockwise from top left: (1) Raw lowN spectrum, not chopping along the slit so only one spectral trace evident. (2) Line cut along lowN spectrum of standard star (note blue spectral shape). (3) Stacked lowN spectrum, beams not well balanced. (4) Raw lowQ spectrum, not chopping along slit, “gaps” are telluric water absorption lines

MedN1, medN2 and echelle spectra

- Characterised by strong fringing, esp. medN modes.



Raw medN2 spectrum of NGC 1068. Note vertical sky lines and diagonal fringing. Bad channel is towards left of array, galaxy spectral trace is barely visible just below centre.



Useful tools

Data Reduction Utilities in IDL and IRAF

Additional Michelle Data Reduction Tools/Utility Scripts

This page provides links to a number of IRAF or IDL tasks that are useful utilities for either Michelle data reduction, or examining a set of data. Some of the IRAF tasks are likely to be released with the next revision of the Gemini IRAF package, whereas others are private routines that are never going to be part of the Gemini/IRAF package.

The IDL utilities cannot be officially supported because they use IDL, which is not freely available software, but are provided here for use by Michelle PIs if they so wish.

Questions about these routines should be directed to Scott Fisher (IDL) or Kevin Volk (IRAF). Note, however, that we do not guarantee that we will be allowed to support these routines. You may be on your own with them.

The IRAF scripts were written by Kevin Volk, usually initially for his own use, and so do not necessarily comply with the coding standards that are enforced for the Gemini IRAF package. Some of the IRAF scripts have a help page in the usual IRAF format, which can be displayed within IRAF via the `help` command by specifying the path to the help file and specifying the `file_template` flag. For example

```
cl> help /some/file/path/miclean.hlp file_template+
```

will show the help page for `miclean.cl` provided that the path ("/some/file/path/" above) is replaced by the proper path to where the file is stored. Not all the scripts have help files at the moment.

The IRAF tasks can be defined at the IRAF prompt as in the following example:

```
cl> task miclean = /some/file/path/miclearn.cl
```

where again one has to provide the proper path to the script file.

The IDL Defringing Widget

The IDL procedure `mdefringe.pro` is a widget for defringing Michelle spectra working with the stacked data file. This procedure works in IDL versions 6 and 7. It will probably not work in earlier versions of IDL. The procedure can read in a Michelle stacked image and display a two-dimensional fourier transform of the image. If one then masks out regions of the fourier image with the cursor, these are blanked off. Once regions are blanked off one can transform the fourier image back to the original domain and see what effect the masking has had. Especially for Michelle medN2 spectroscopy this is able to get rid of a large part of the spectral fringes in the data. It works better than the IRAF routine for defringing the one-dimensional extracted spectra in the test cases we have been working with.

For low-resolution N-band spectra the defringing in IRAF is usually quite sufficient and this tool is not needed for such data. For the medN1 Michelle spectral mode the results of using the IDL procedure appear to be less satisfactory than is the case for the medN2 mode, but its still better than what the IRAF defringing produces.

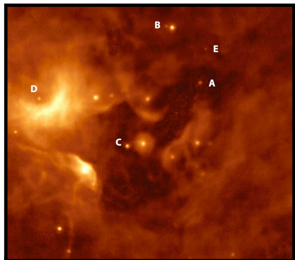
Link to the IDL procedure mdefringe.pro

This IDL procedure requires the installation of the IDL Astronomy User's Library for it to work.

An example of the use of the procedure is given here.

Noise Masking procedures

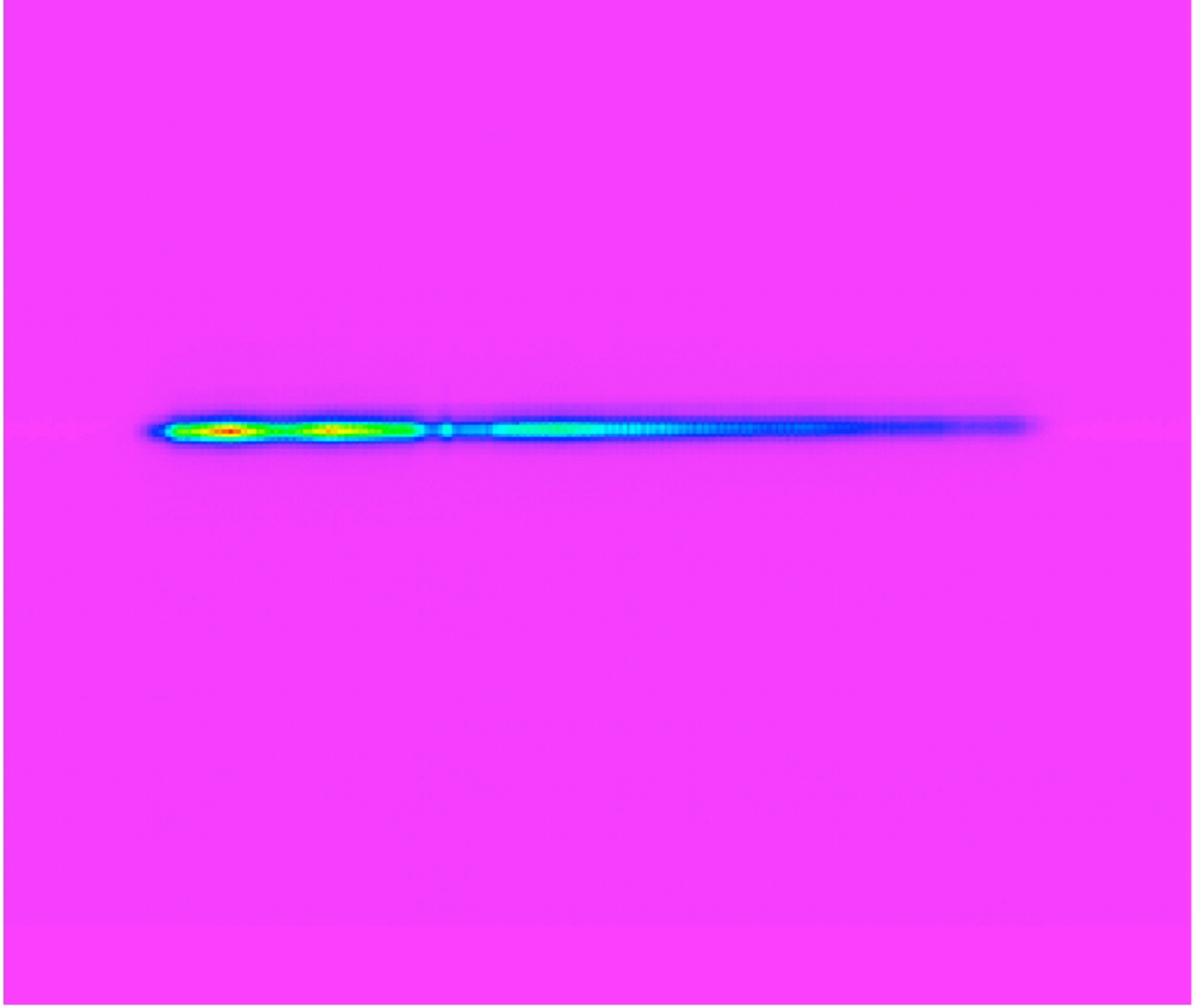
Once a stacked Michelle or T-ReCS image has been read into IDL, the following two procedures can be used to remove vertical or horizontal pattern noise. These are stand-alone IDL procedures, originally written by Jim deBuizer (here is a link to his professional web page where there is a link to his IDL tools for T-ReCS image reduction for anyone who may be



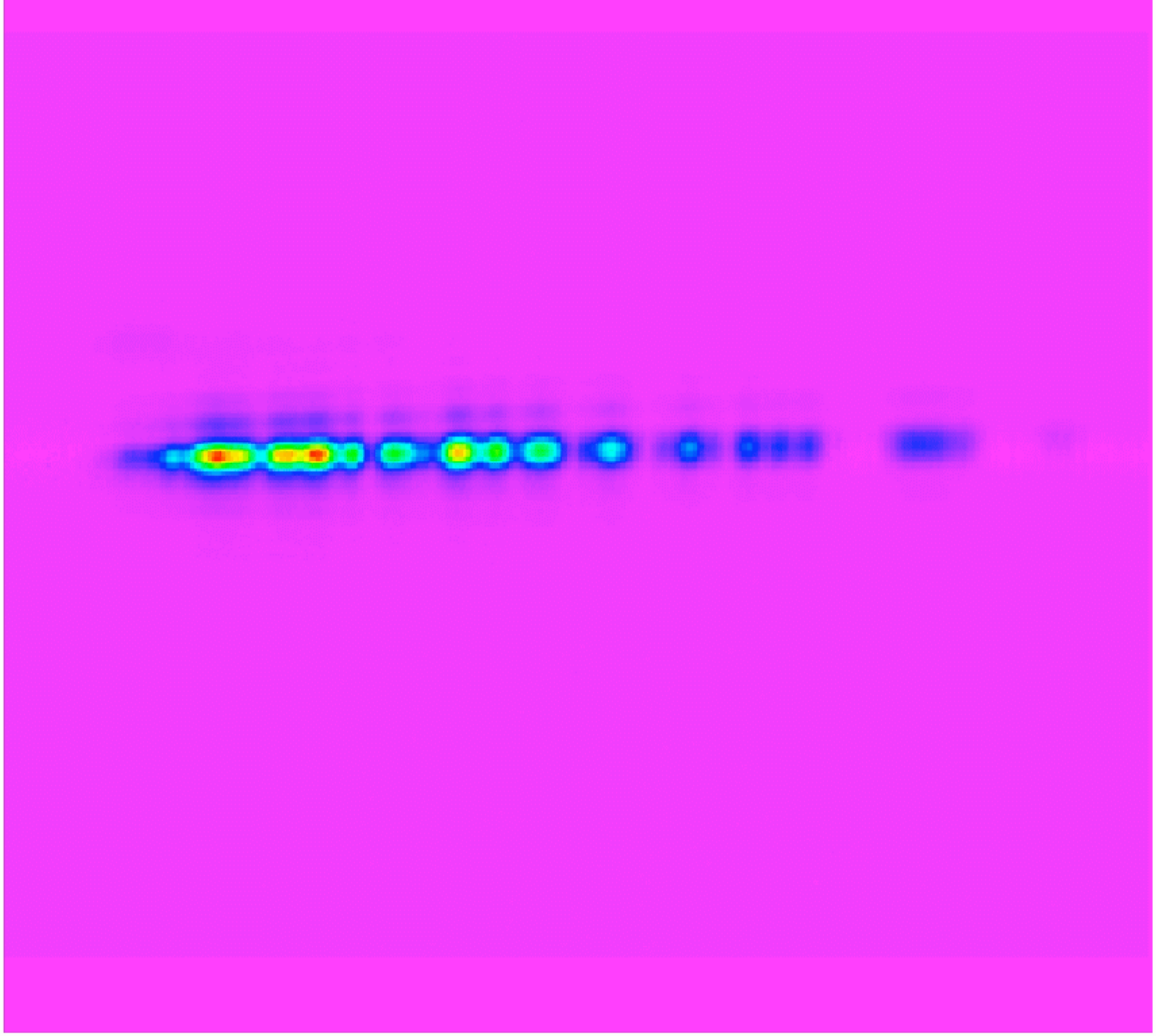
With spectroscopy we use the same process of chopping and nodding to remove the atmospheric contribution. The frame times can be somewhat longer than for imaging because we are spreading out the light from the slit over the entire detector, but we have to compromise between filling the detector wells and chopping/nodding fast enough to get a good atmospheric correction.

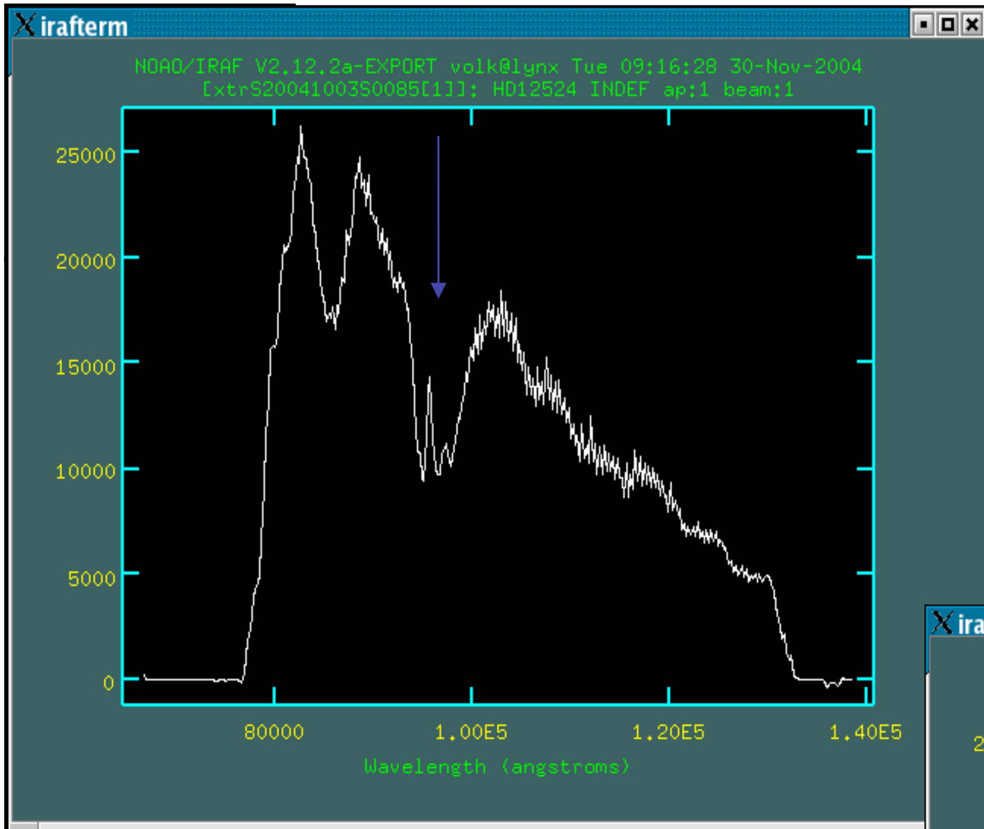
At higher resolution one can use nod-only observations without difficulty, especially in cleaner parts of the N-band window.

Raw Spectra Are Rather Ugly,



Especially in Q-band....





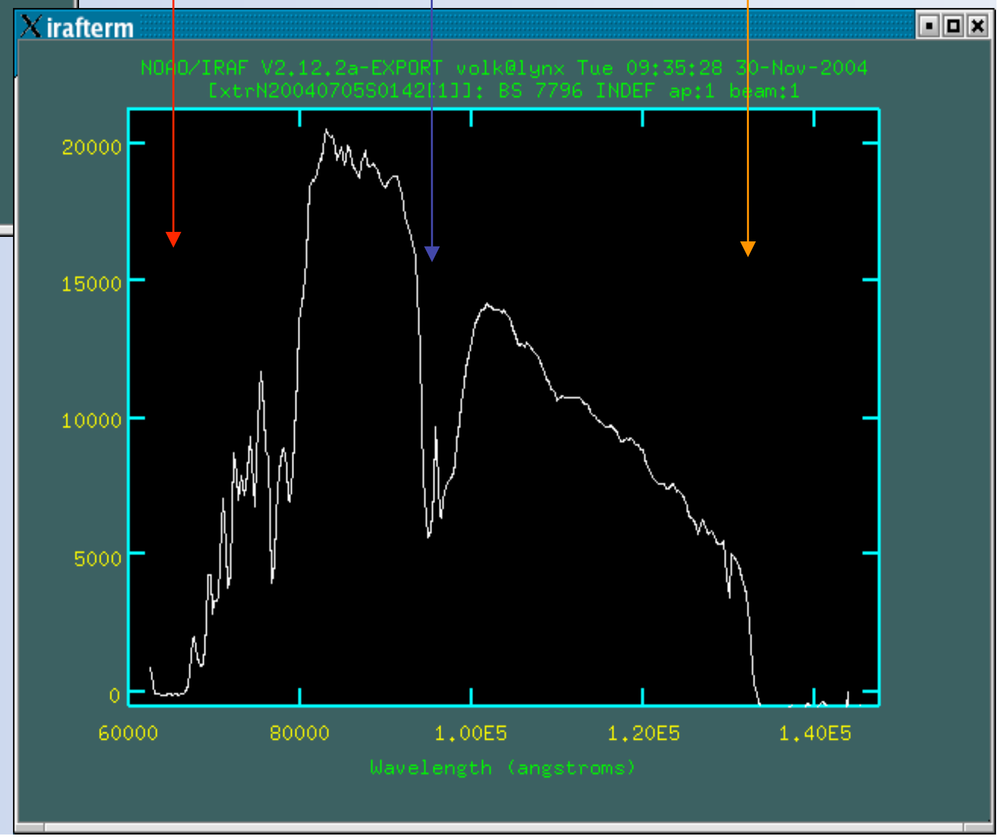
Michelle

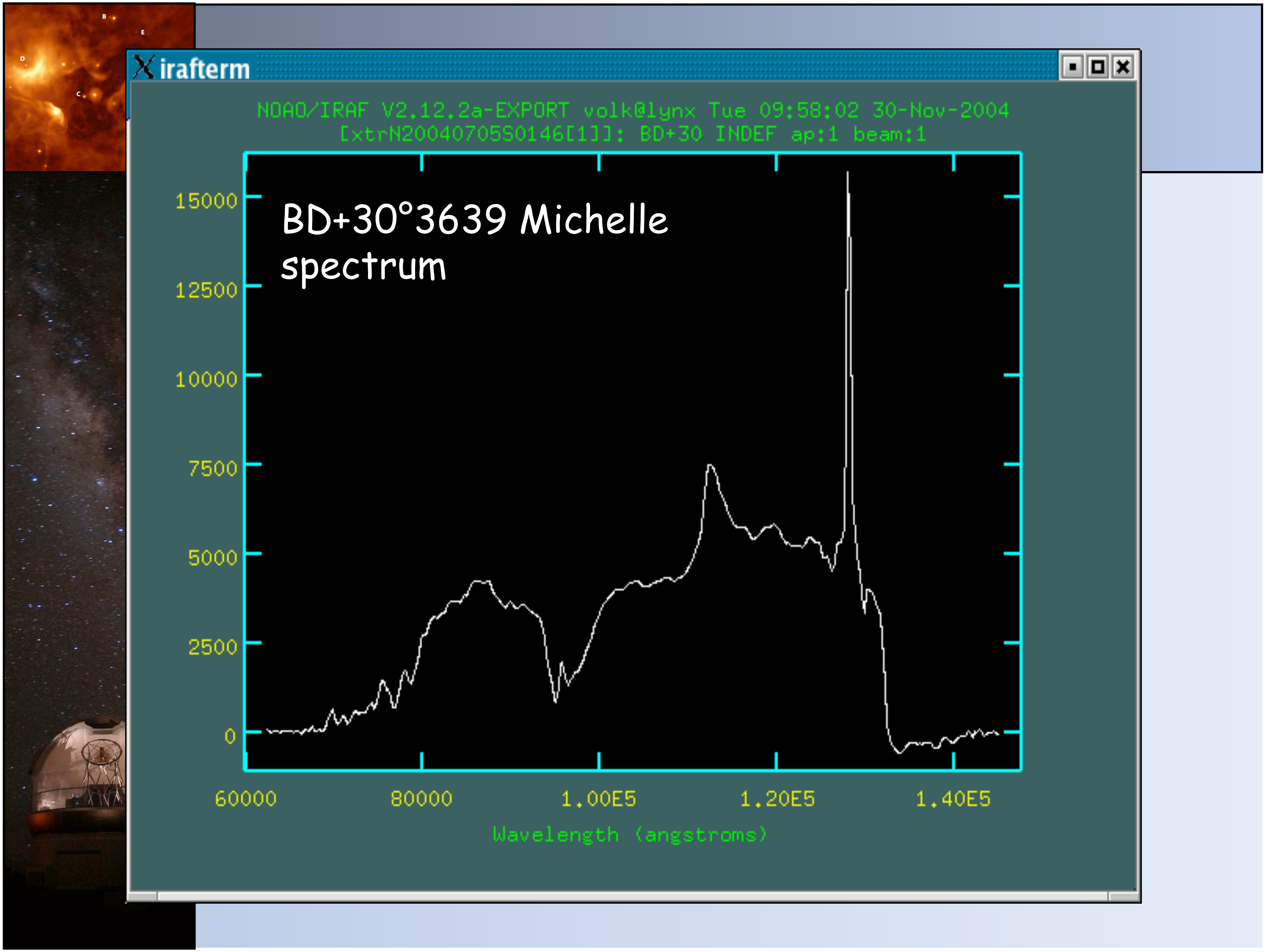
Filter edge

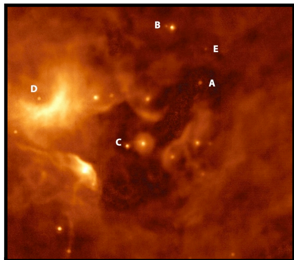
Second order begins

O_3 band

T-ReCS



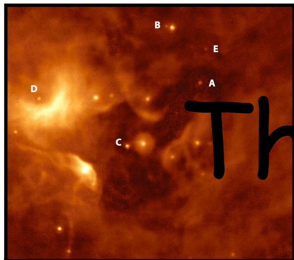

irafterm
NOAO/IRAF V2.12.2a-EXPORT volk@lynx Tue 09:58:02 30-Nov-2004
[xtrN20040705S0146[1]]: BD+30 INDEF ap:1 beam:1
BD+30°3639 Michelle spectrum
15000
12500
10000
7500
5000
2500
0
60000
80000
1.00E5
1.20E5
1.40E5
Wavelength (angstroms)



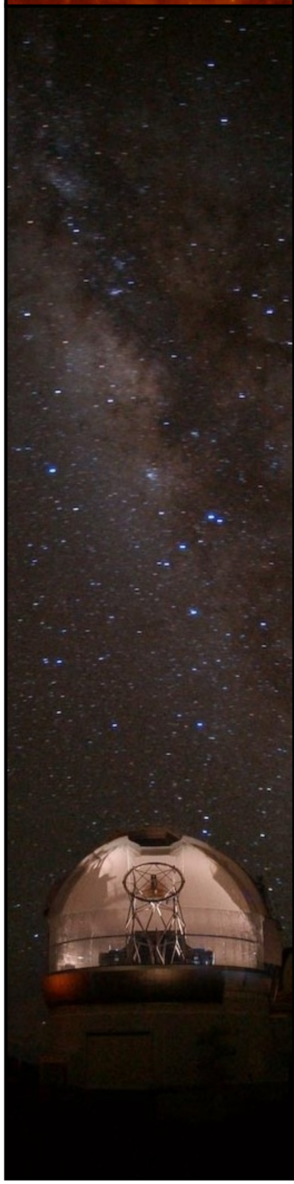
Michelle Spectroscopic Modes:

Name	Wavelengths	Dispers.	Resolution	Coverage
lowN	7-14	0.024	200	7.7
lowQ	16-26	0.031	110	9.9
medium	7-26	0.0047	1000	1.5
high	7-26	0.0016	3000	0.5
echelle	7-26		30000	0.05
TEXES	5-25		~100000	~0.02

Wavelengths are in μm, dispersions are in μm/pixel, coverage values are in μm.



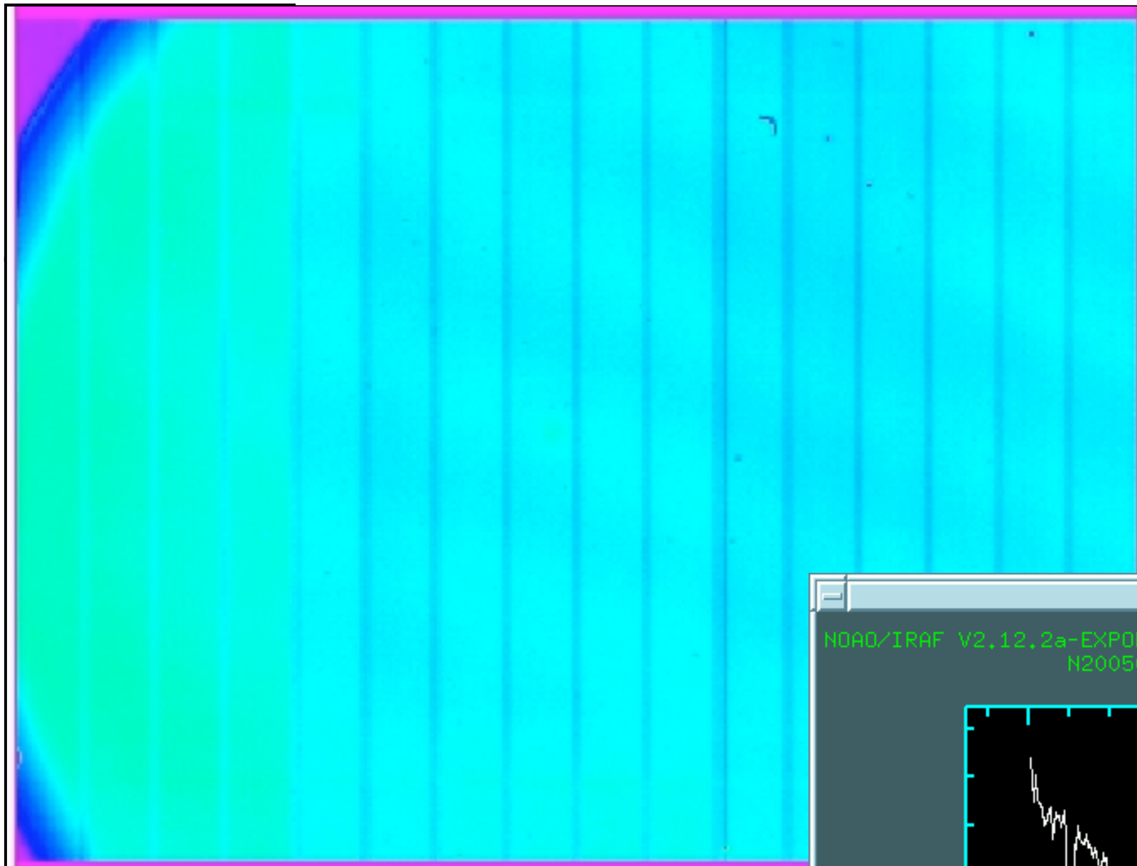
Things to look for in Michelle data



A 1 Jy point source in N-band should be easily visible in the individual difference images for a nod. A source of some tens of Jy can be seen in the raw on-source image if one looks for it.

At Q-band the background is about 3 times higher than at N-band so these values have to increase by roughly a factor of 3.

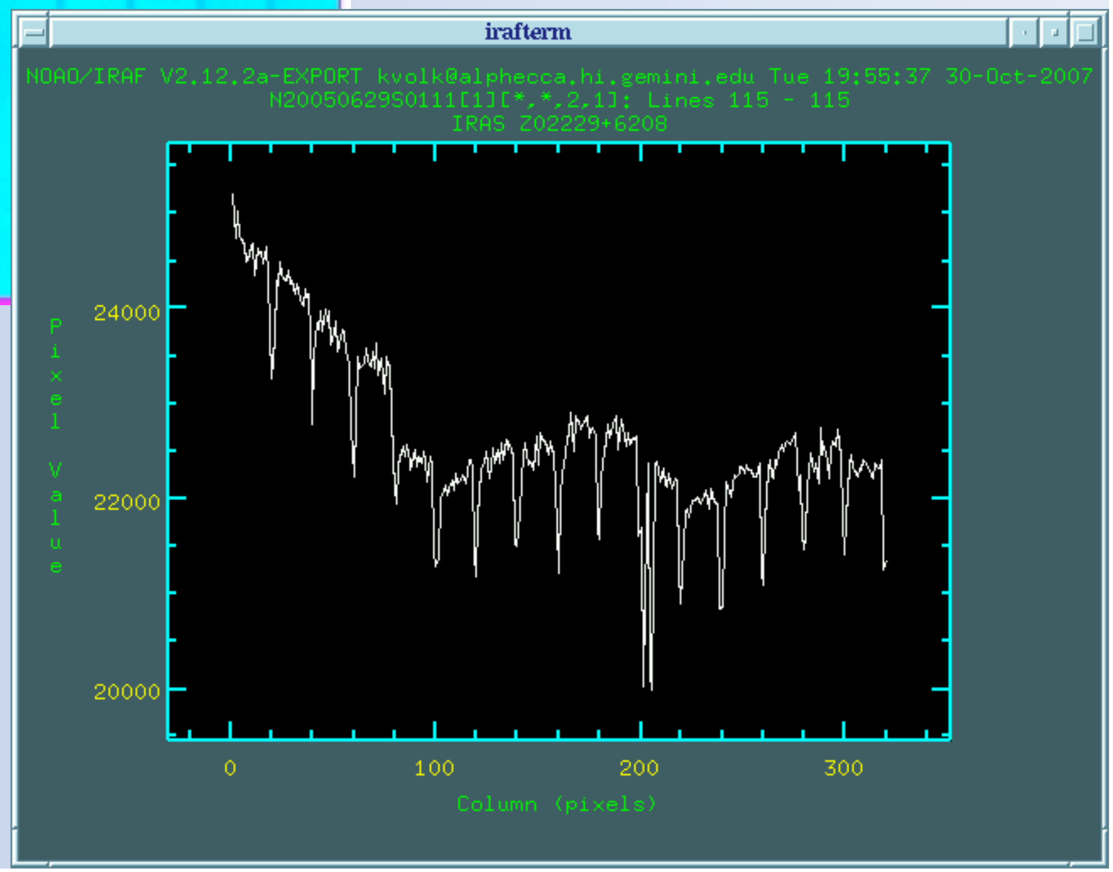
A standard star of 5 to 7 Jy is quite bright enough for N-band imaging. If a standard is to be used at Q as well, it should be 15-20 Jy in brightness at N-band. This is also a good brightness for a low-N spectroscopy standard.

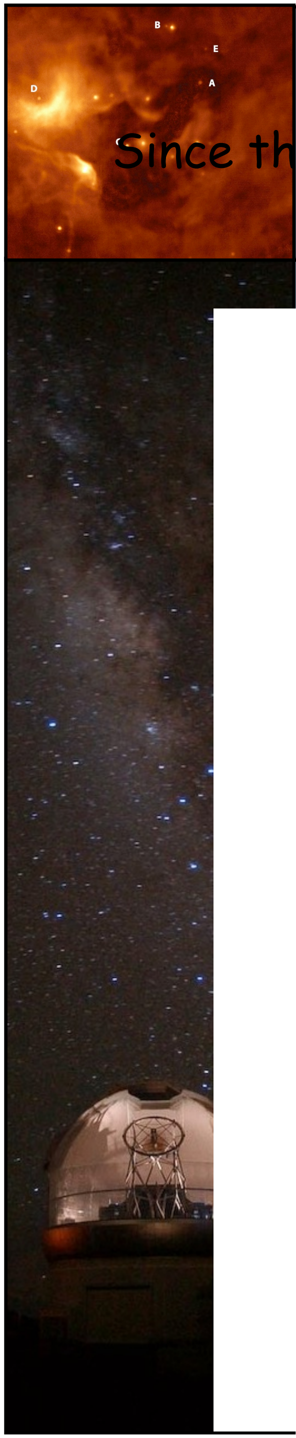


Michelle raw image

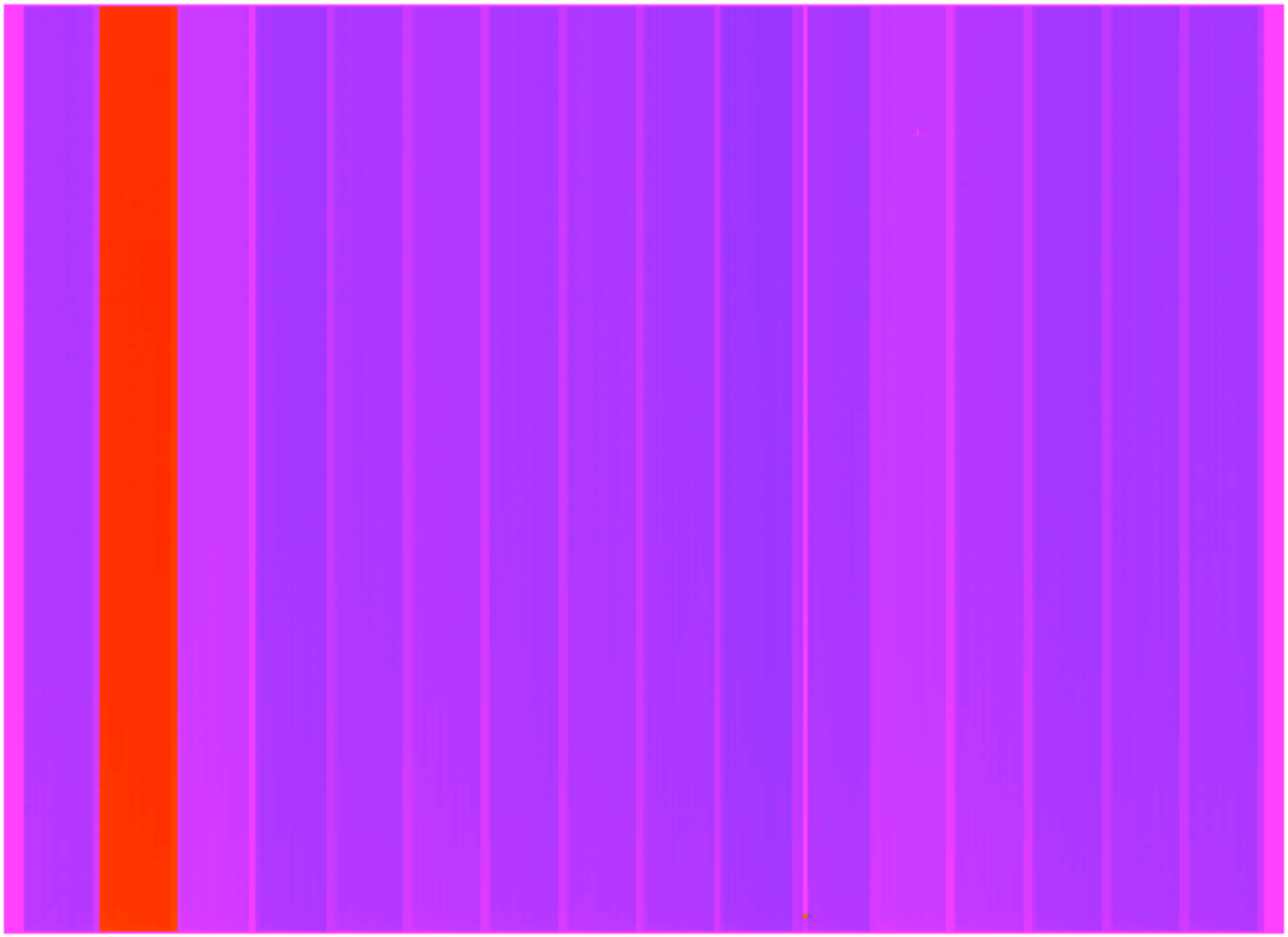
Line cut

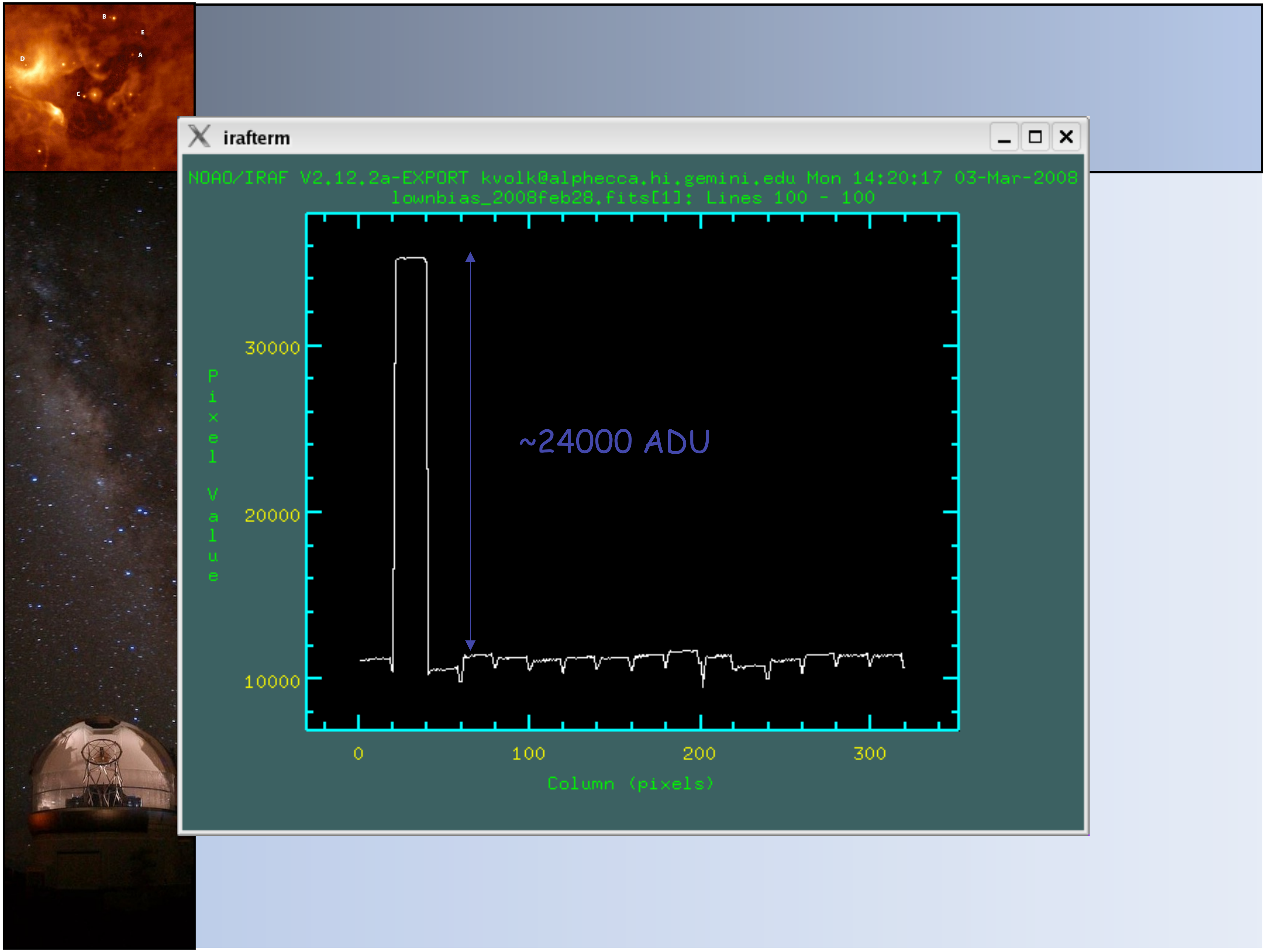
"staircasing"



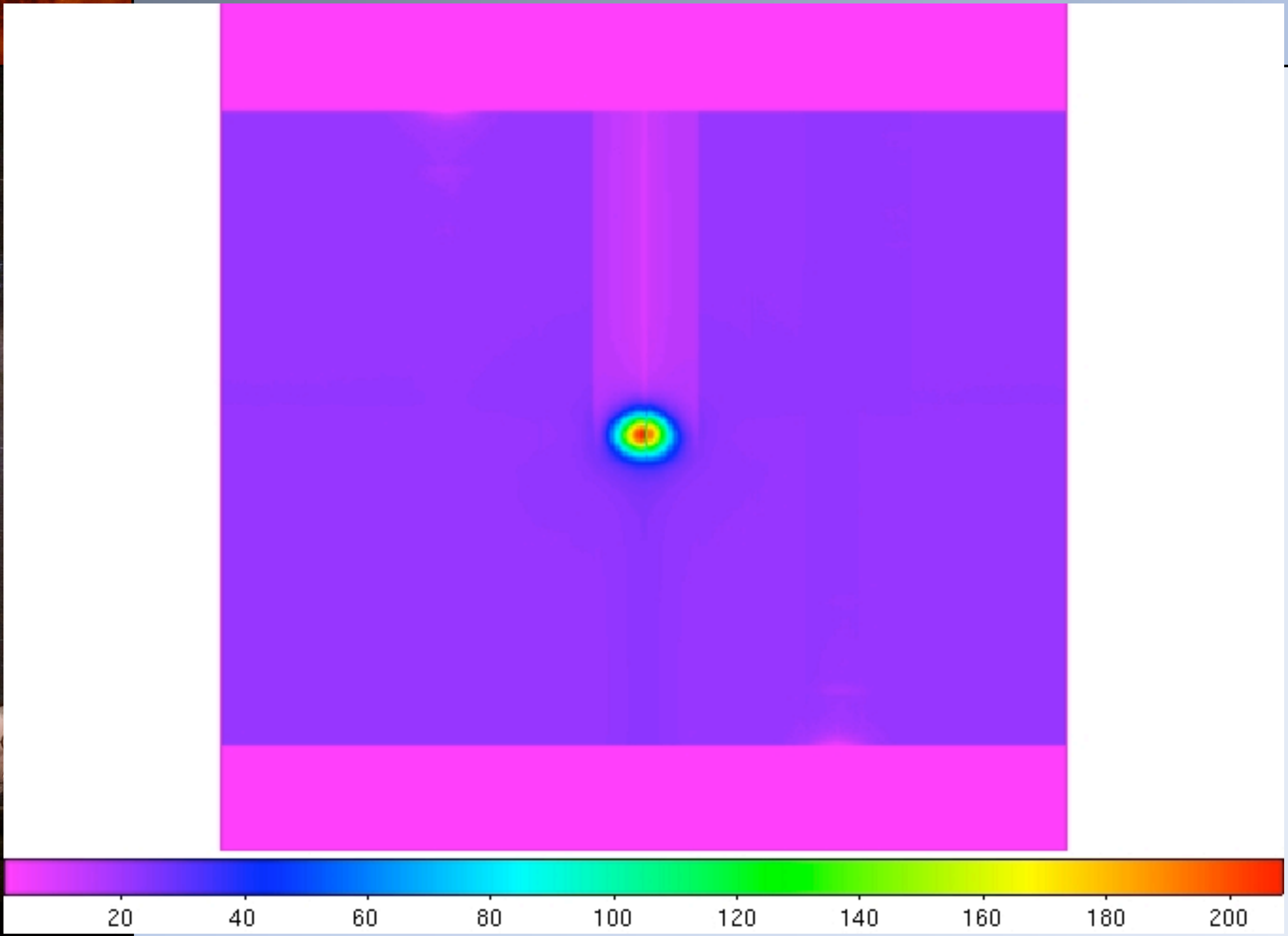


Since the last cool-down Michelle has a bad channel

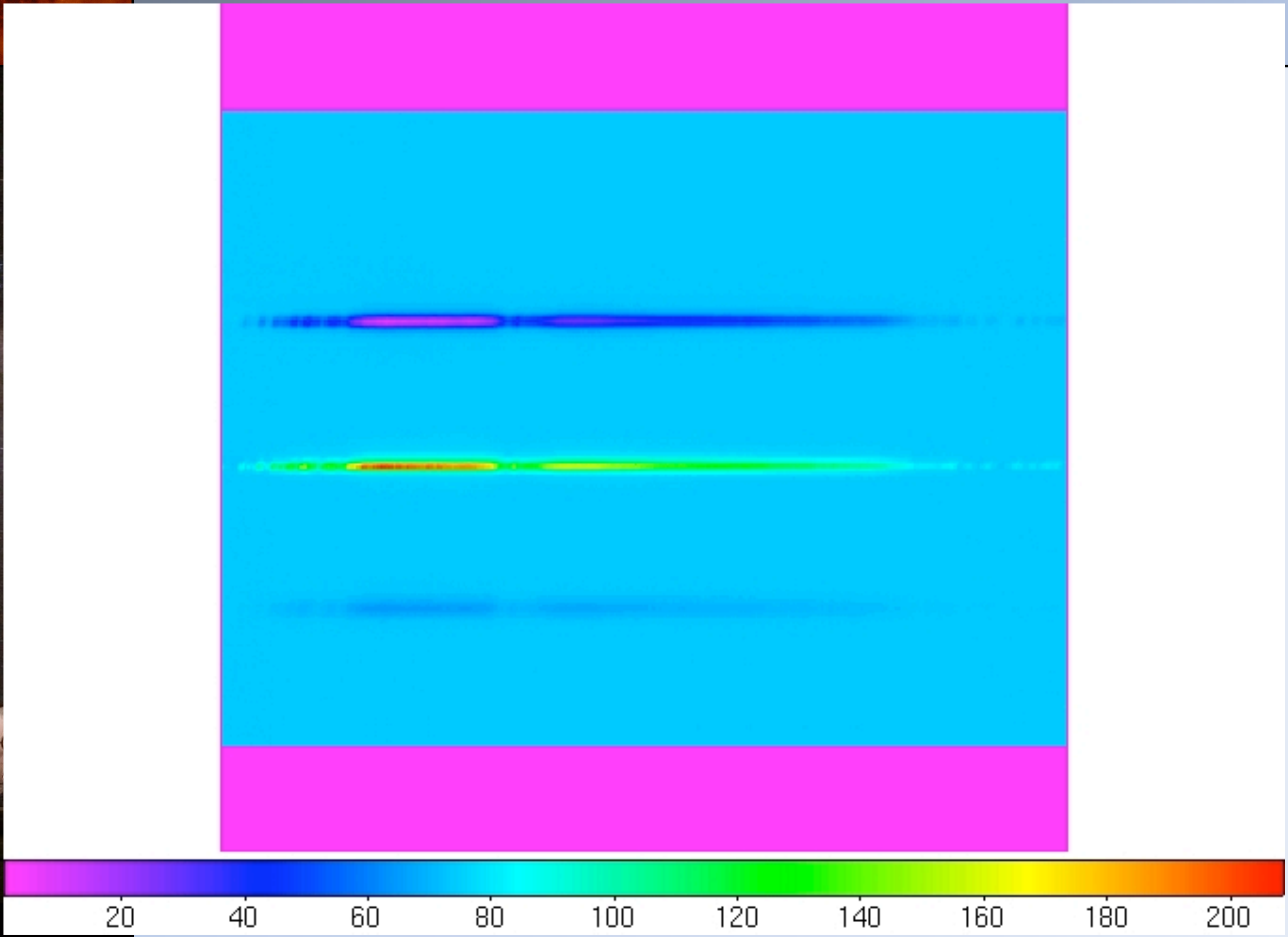



irafterm
NOAO/IRAF V2.12.2a-EXPORT kvolk@alphecca.hi.gemini.edu Mon 14:20:17 03-Mar-2008
lownbias_2008feb28.fits[1]: Lines 100 - 100
30000
20000
10000
Pixel Value
0
100
200
300
Column (pixels)
~24000 ADU

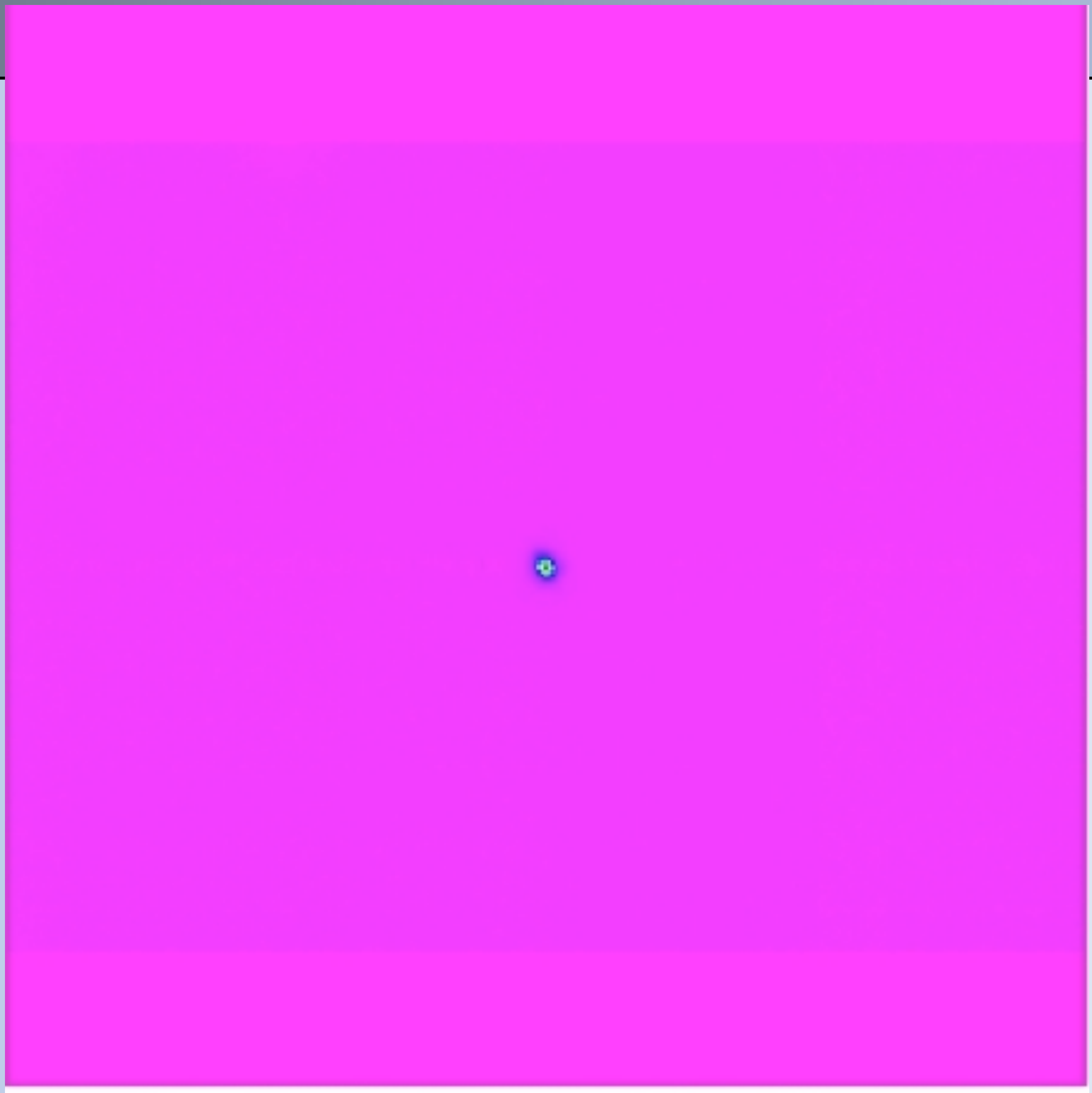
The "Hammer Effect"

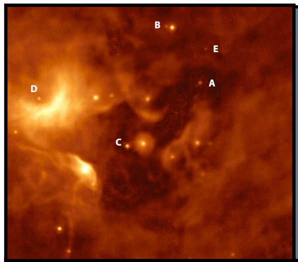


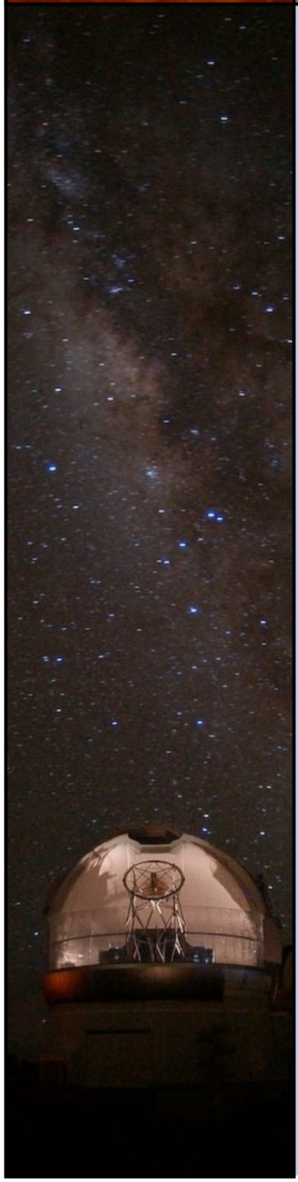
Raw stacked low-N spectrum

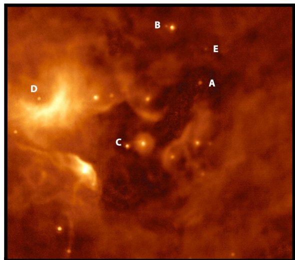


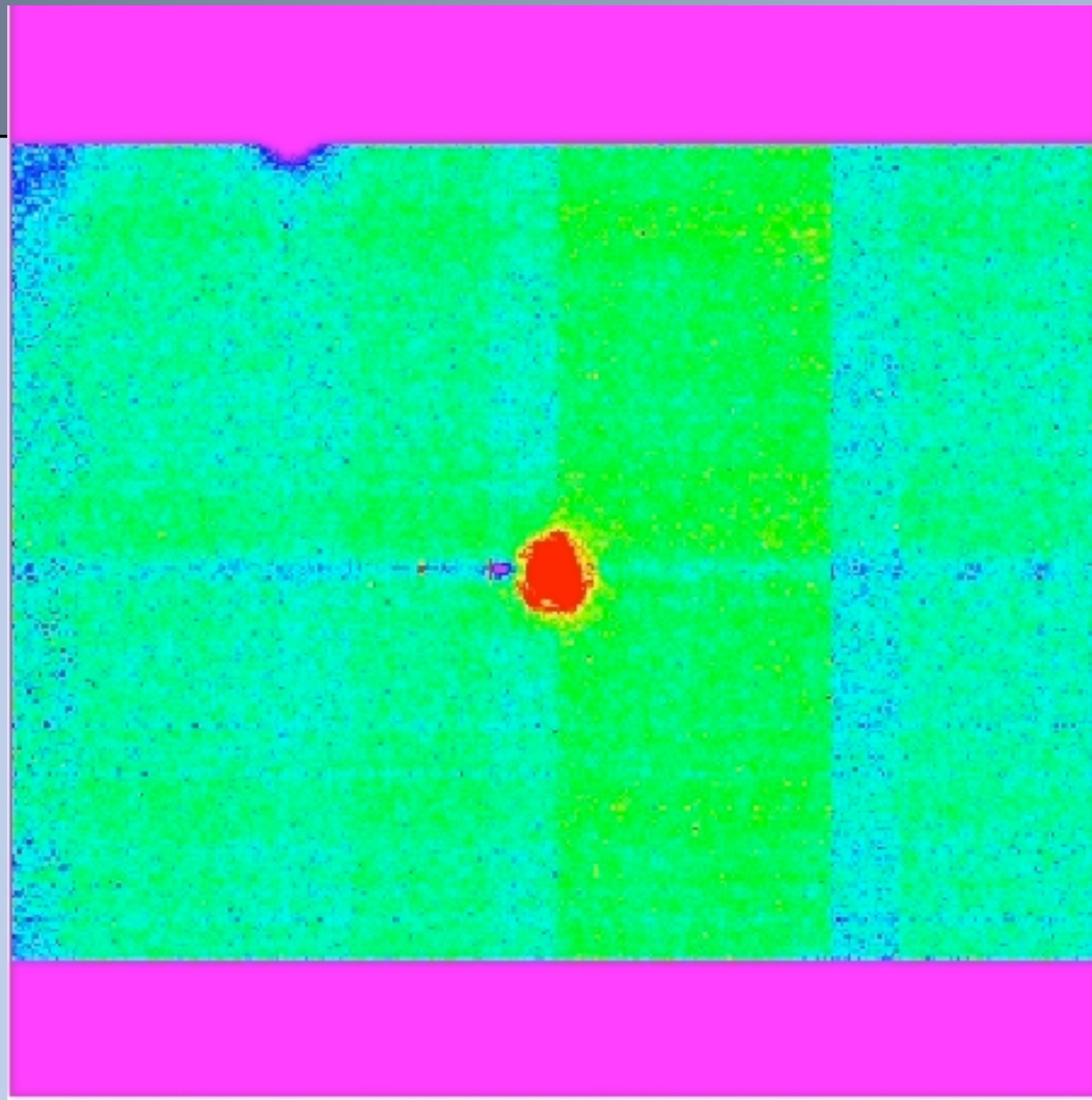
Michelle noise (and removal of same)

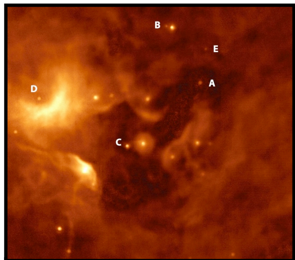


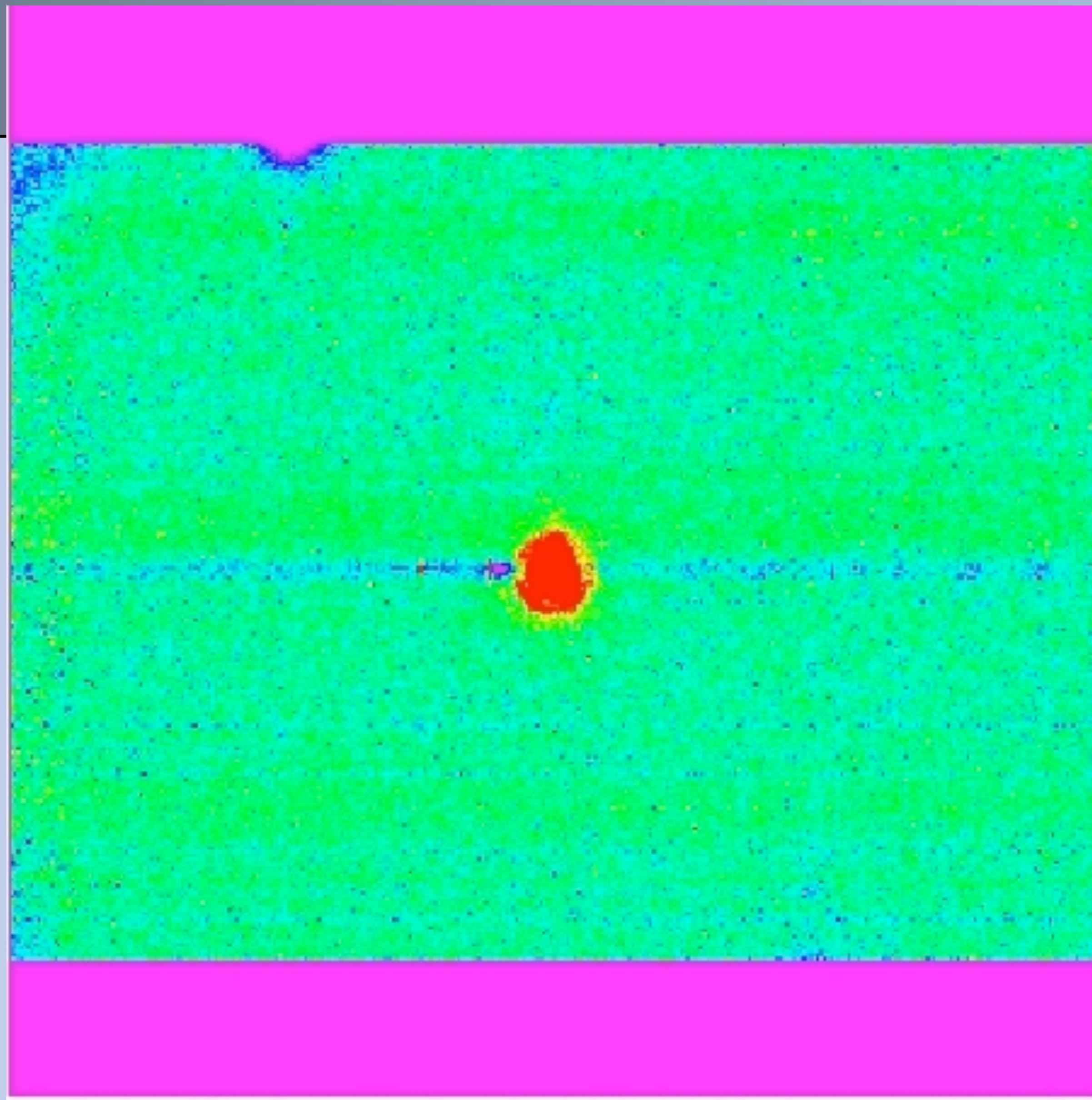


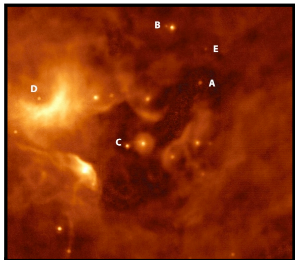


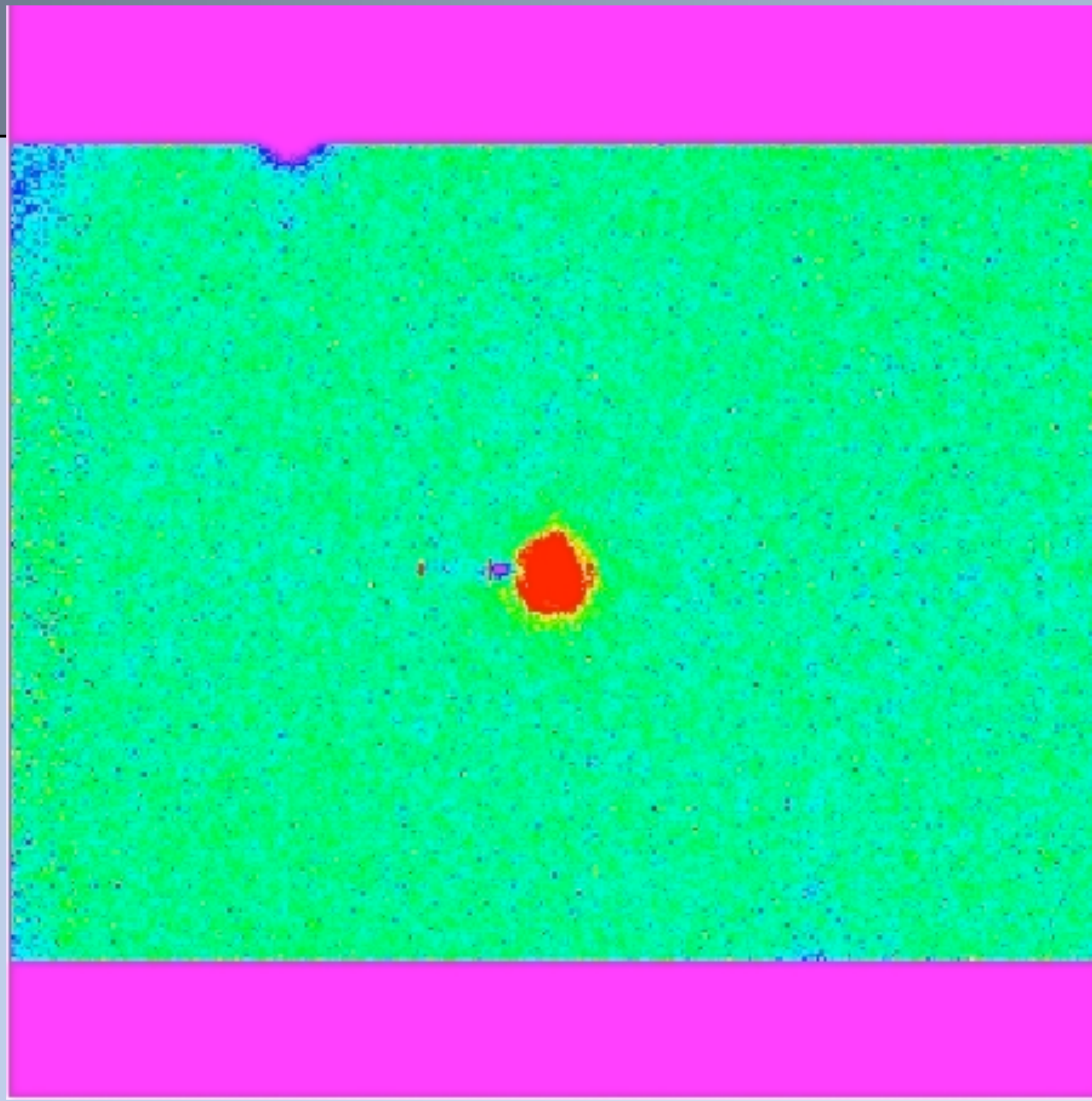

B
E
D
A
C



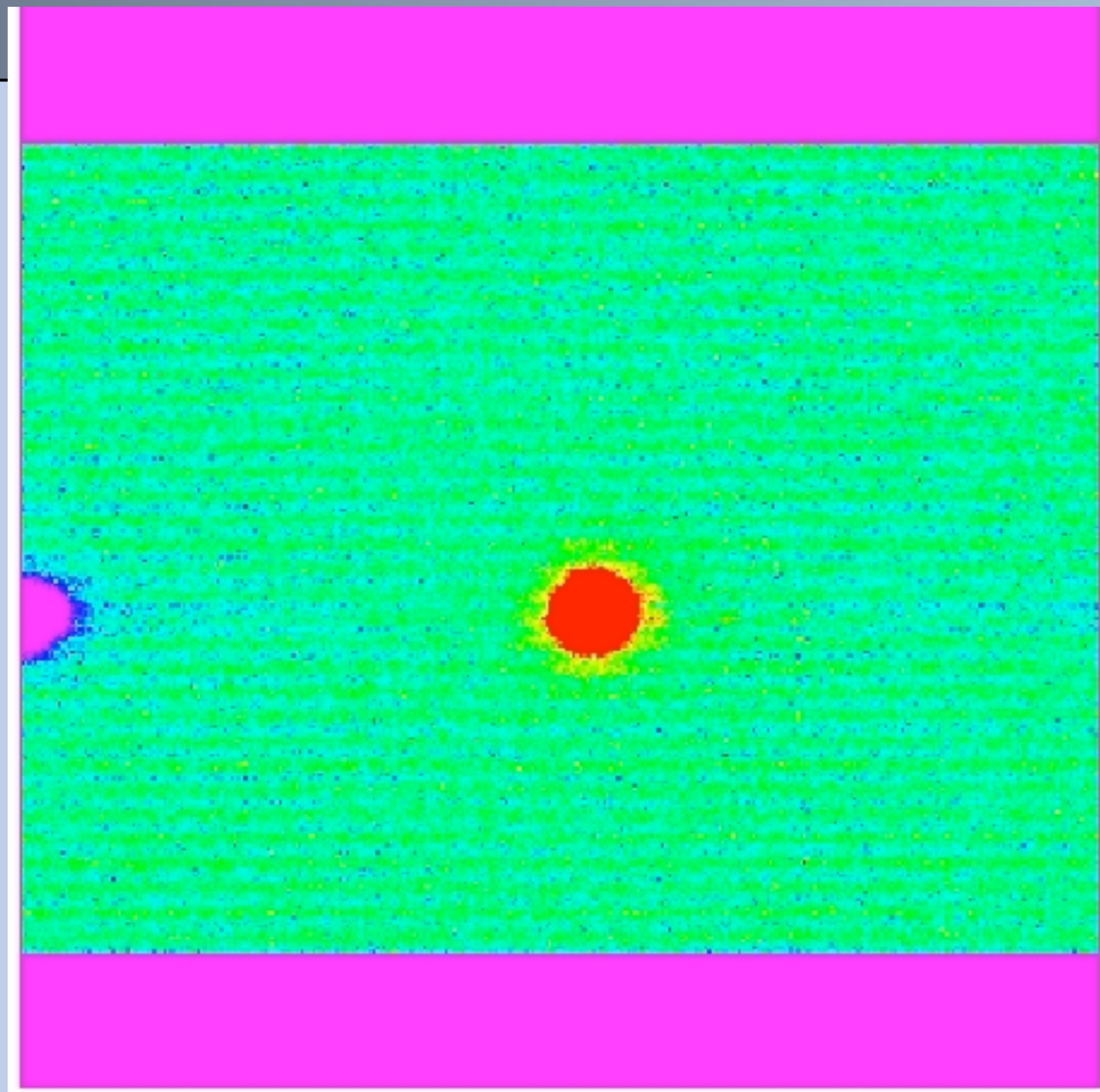

B
E
A
D
C



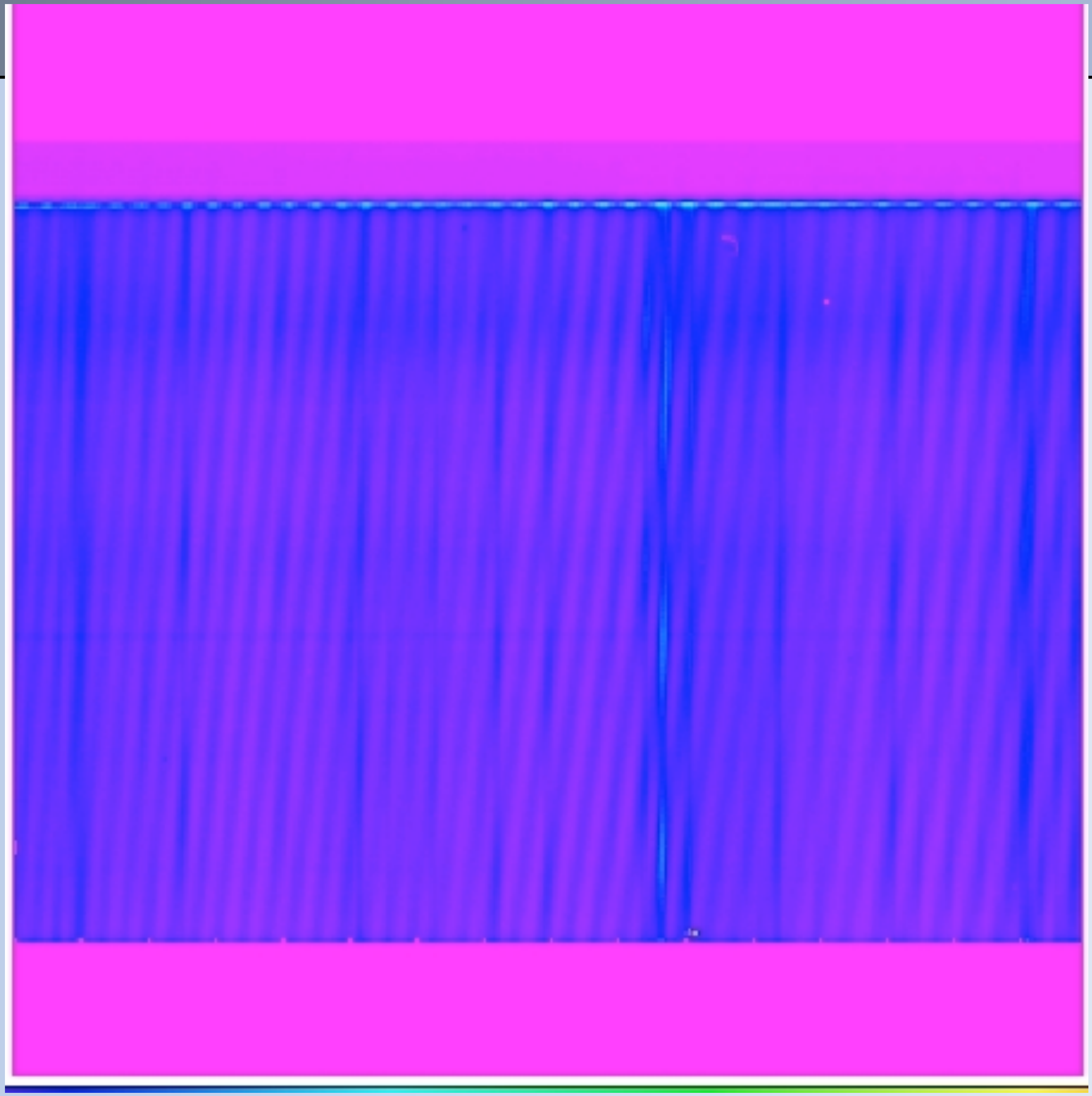

B
E
A
D
C



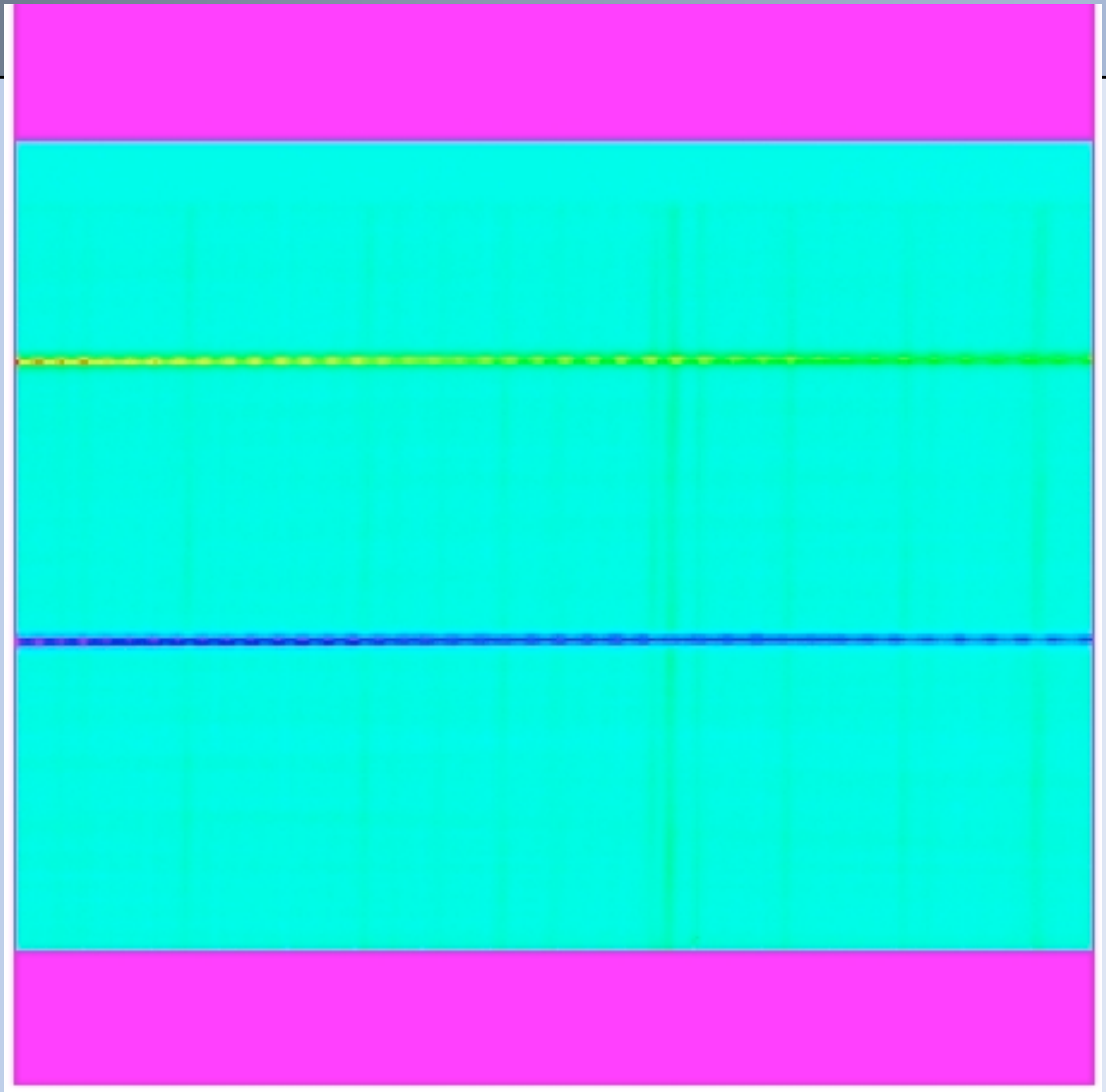
"Pin-stripe" noise

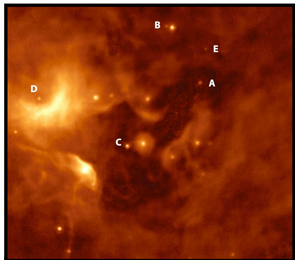


Med N-1 spectral Raw Frame: Fringing

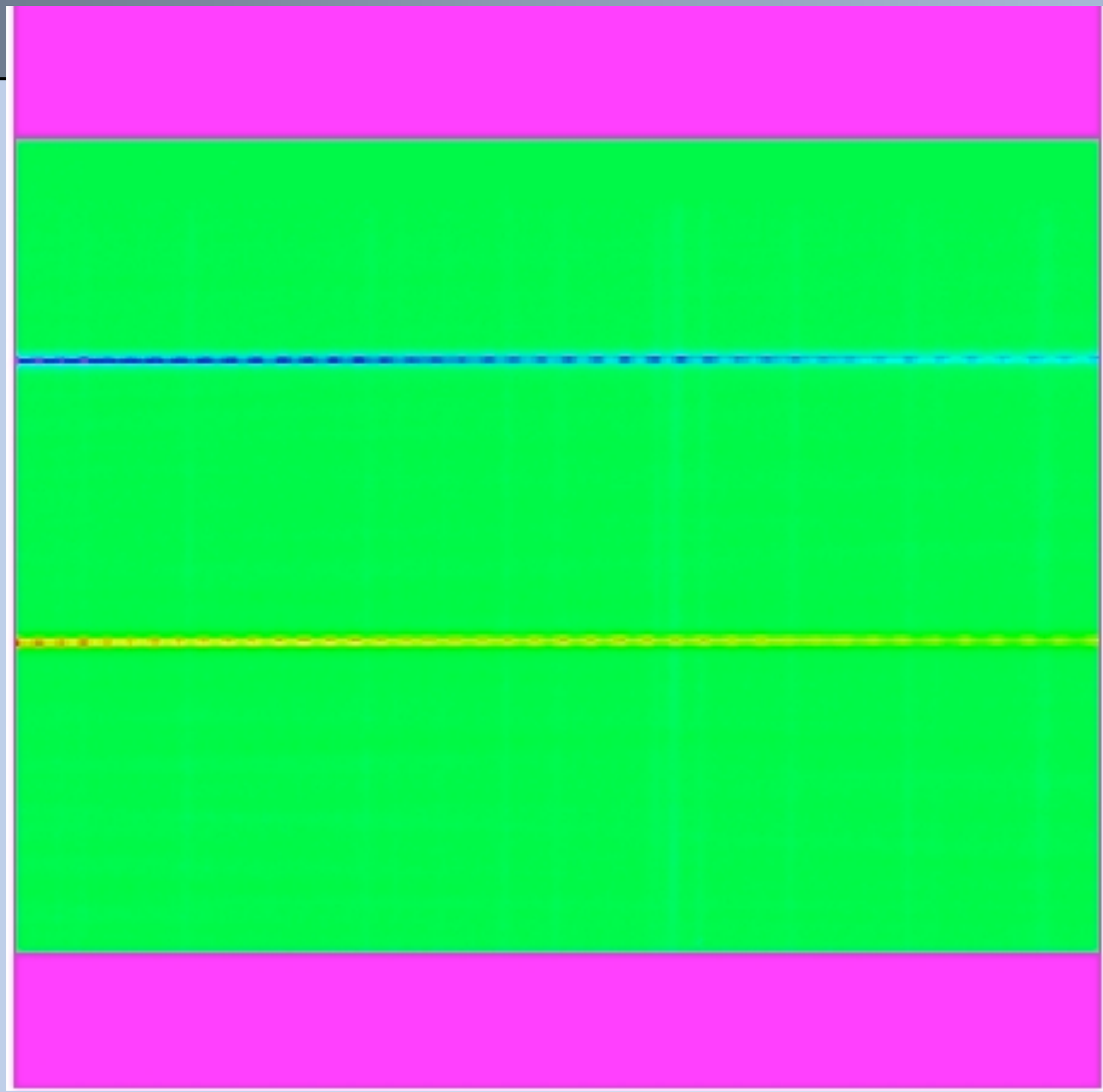


Difference Frame of Standard Star

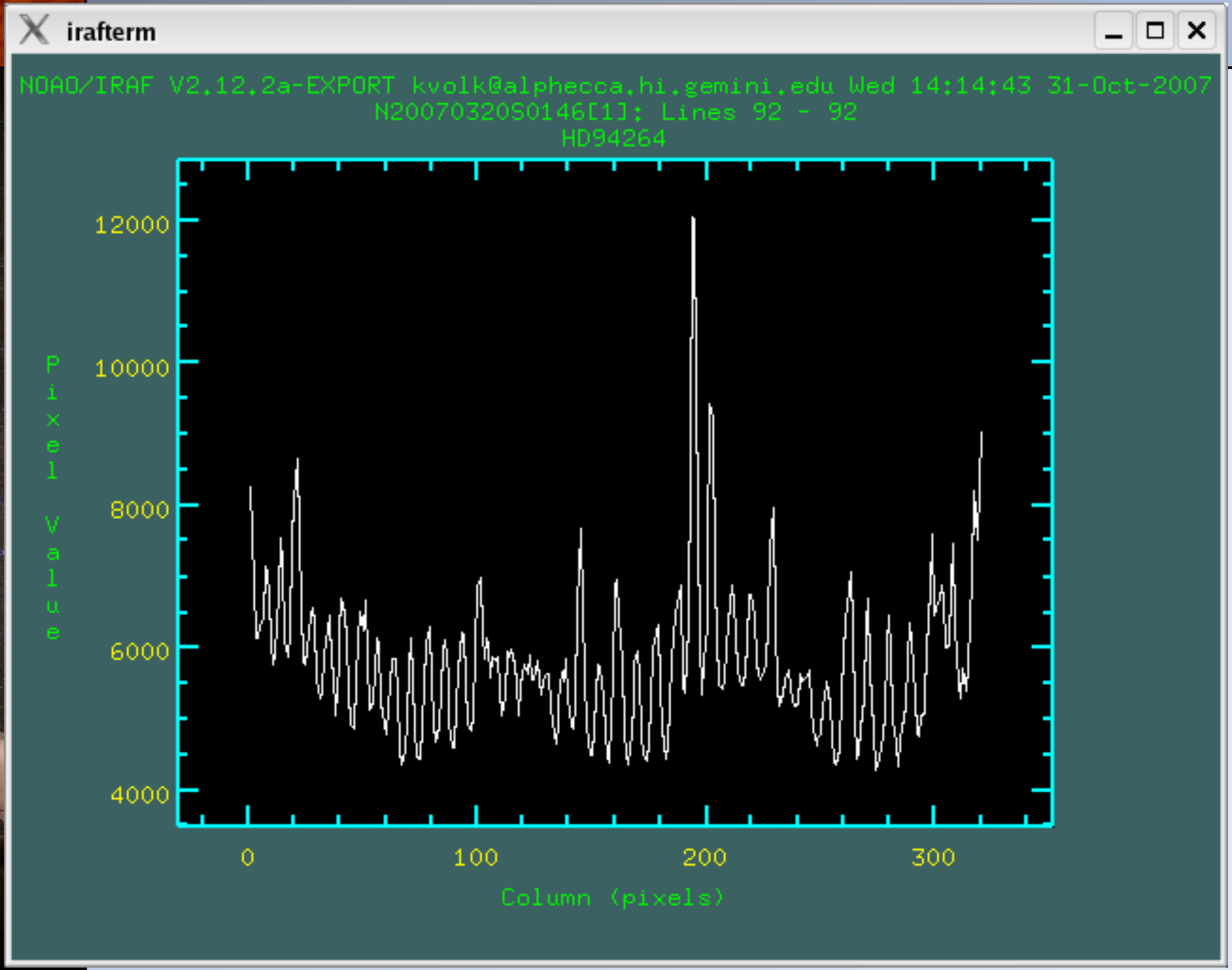




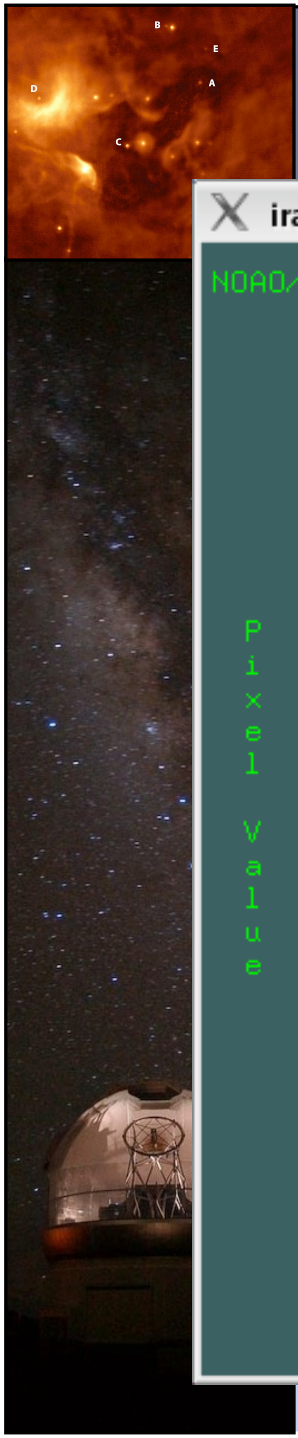
Stacked Difference Spectrum

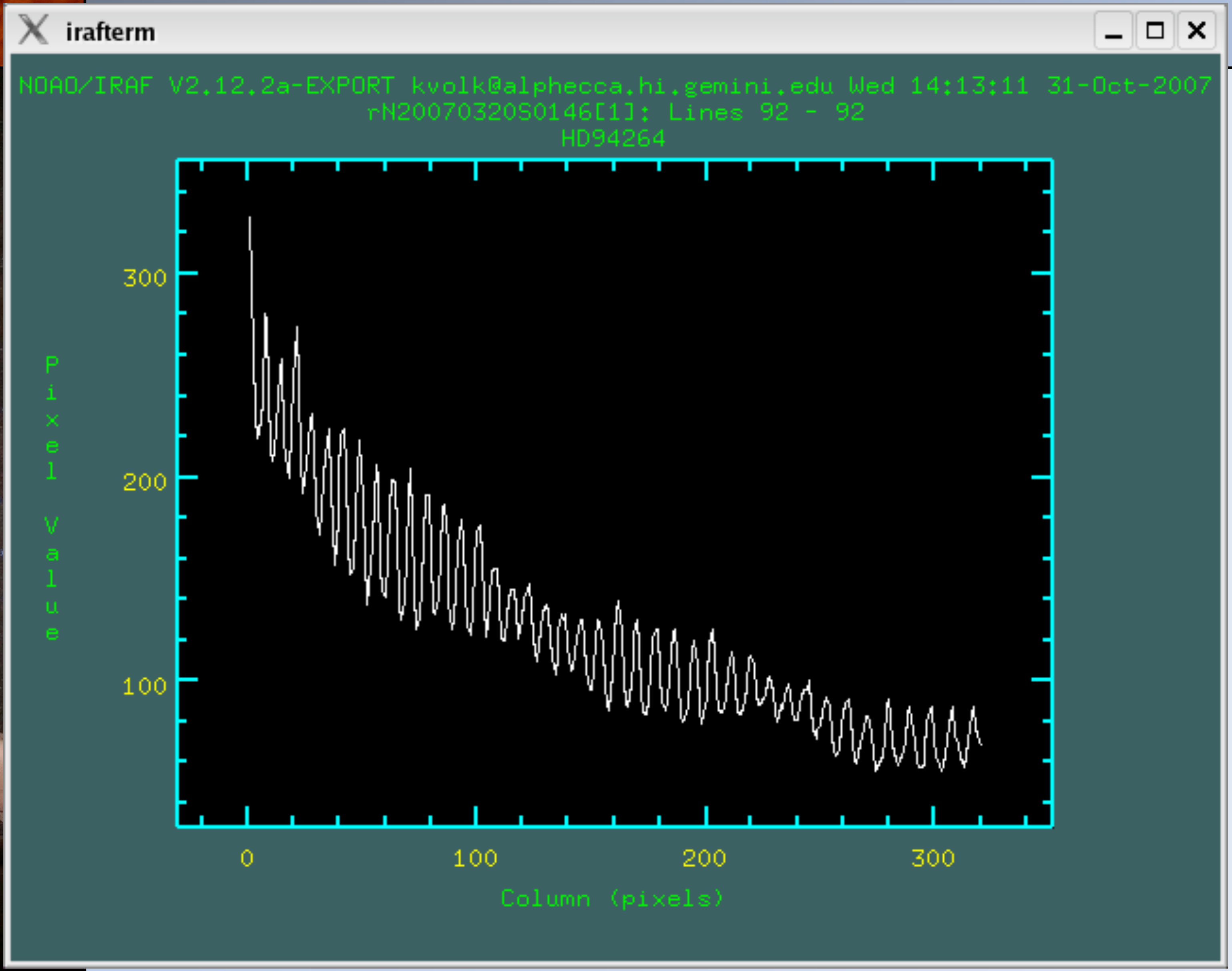


Raw Med-N1 Spectrum: Fringing

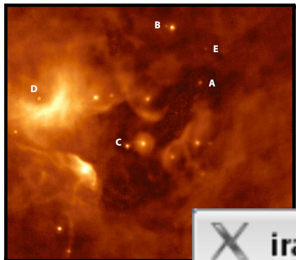


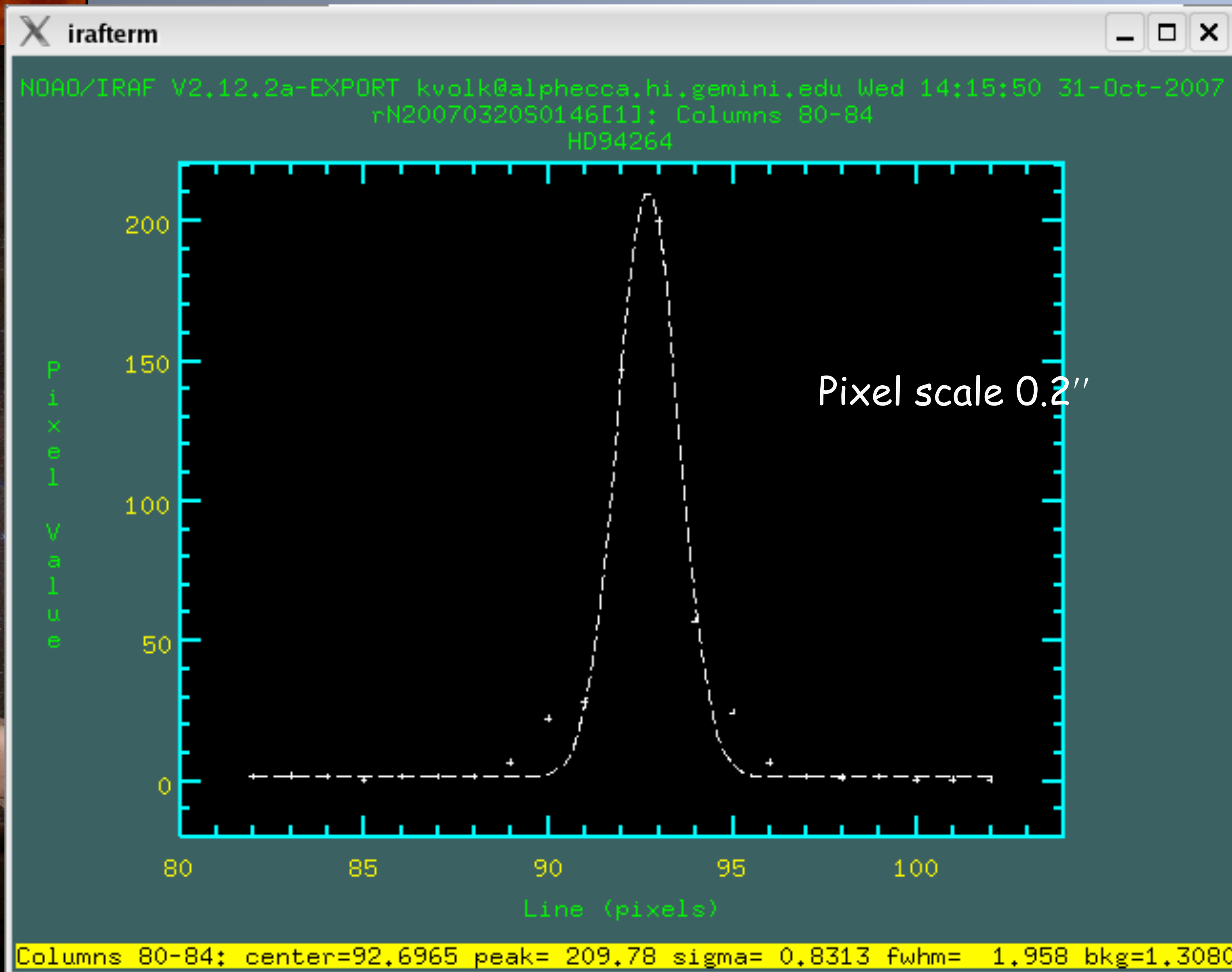
Residual Fringing



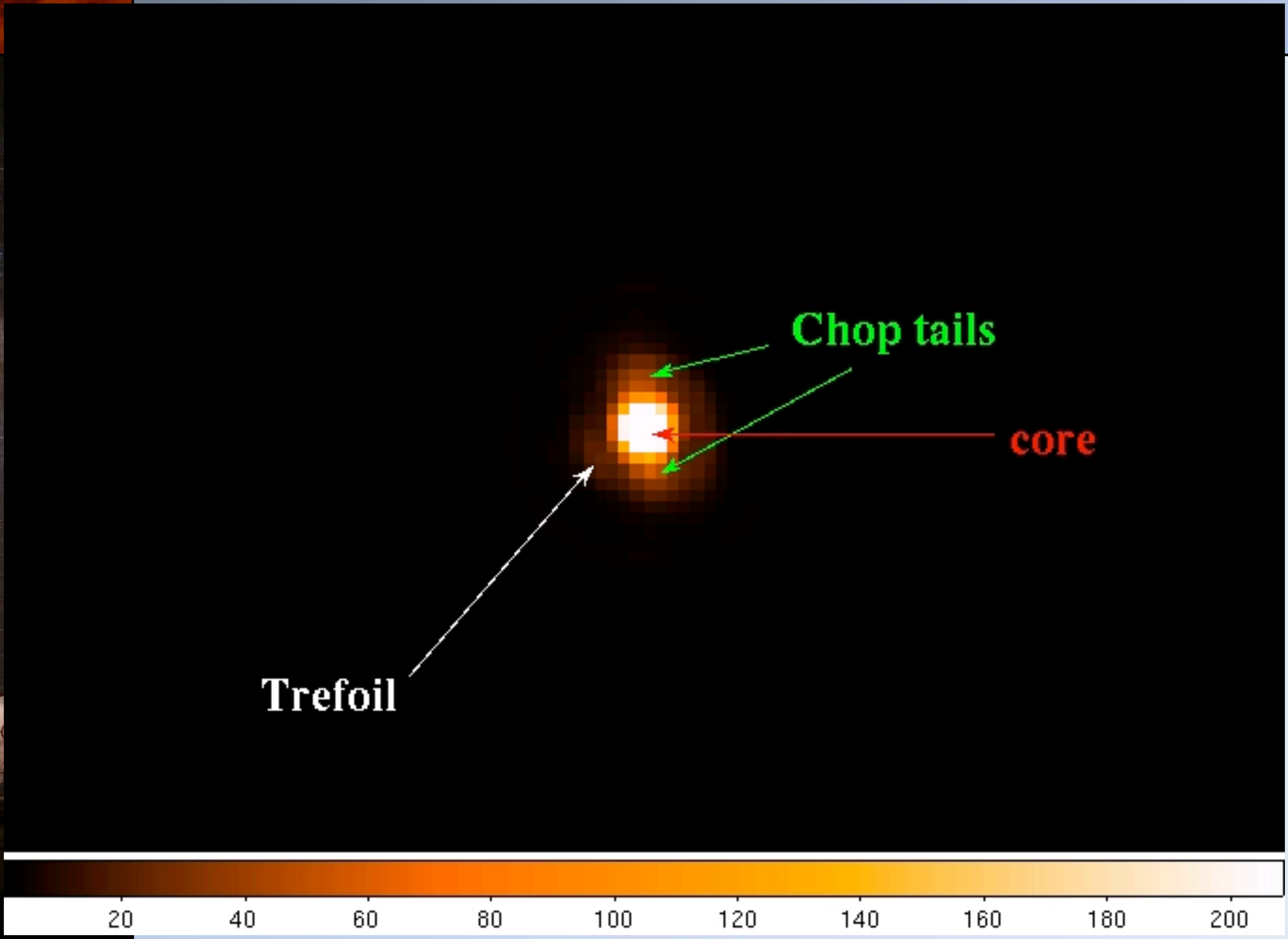


Typical Spectral Cross-cut

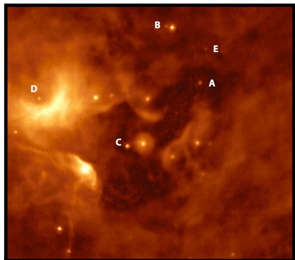


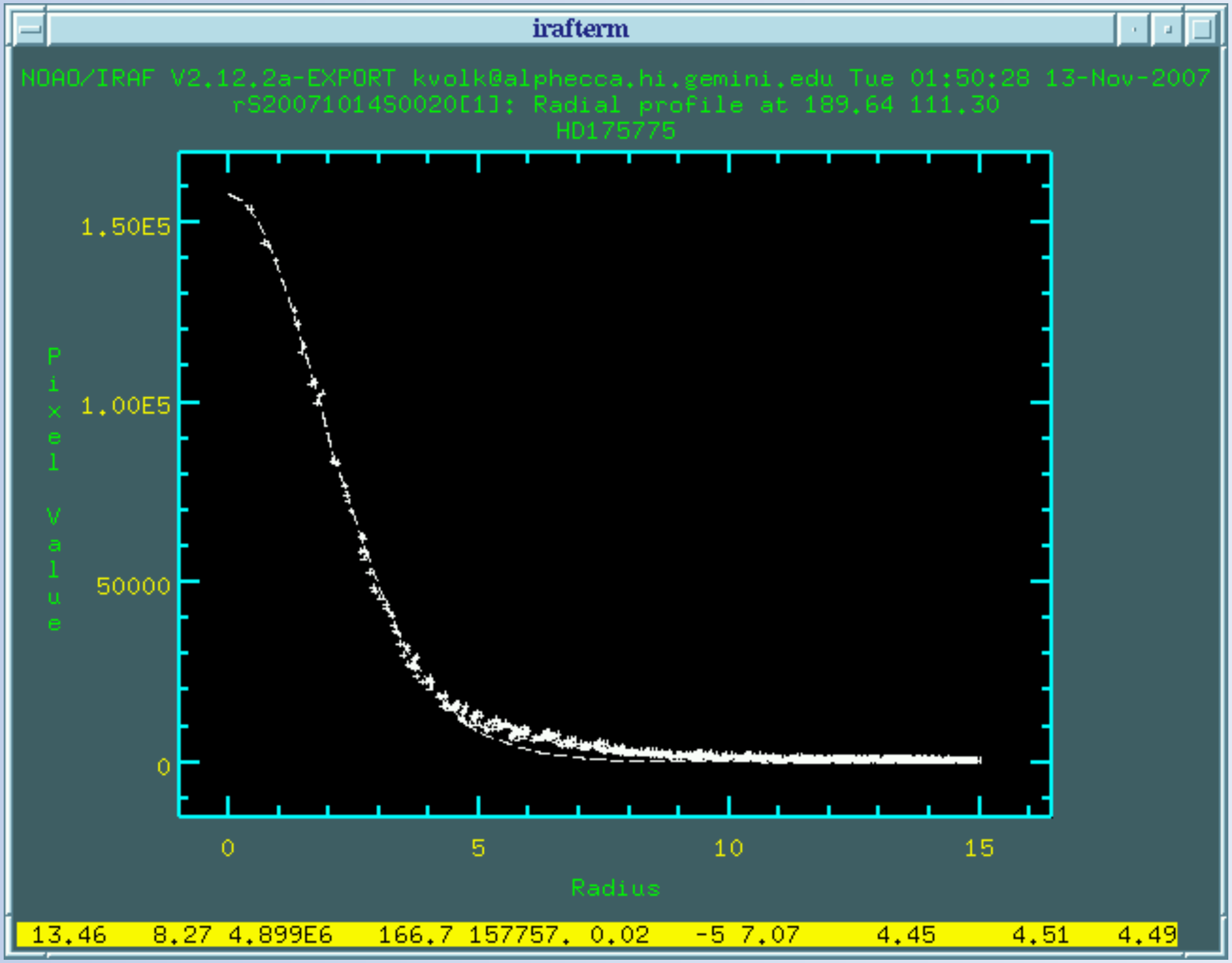


Chop Tails--A Problem With the Michelle PSF



Fair Seeing PSF





Poorer Seeing PSF