Where in the Spectrum Are We?
A Look at Wavelength Calibration

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Wavelength Coverage

- Spectrometers measure a portion of the spectrum
- Higher resolution means light separated more finely
  - – EXES will have resolution of 1 part in 100,000
  - – best current in MIR is 1 part in 10,000
    - not true if looking at **really** bright objects
- Detector arrays have limited size => higher resolution means less wavelength coverage

Wavelength Calibration

- Need to know
  - which portion of spectrum
  - how much of the spectrum
  - how finely spectrum is separated
- Refer to a standard
  - measure features at known wavelength
  - would like at least two features
- Types of standards
  - arc lamps
  - atmospheric lines
  - absorption cells

Grating Equation

$$m \bullet \lambda = d(\sin \alpha - \sin \beta)$$

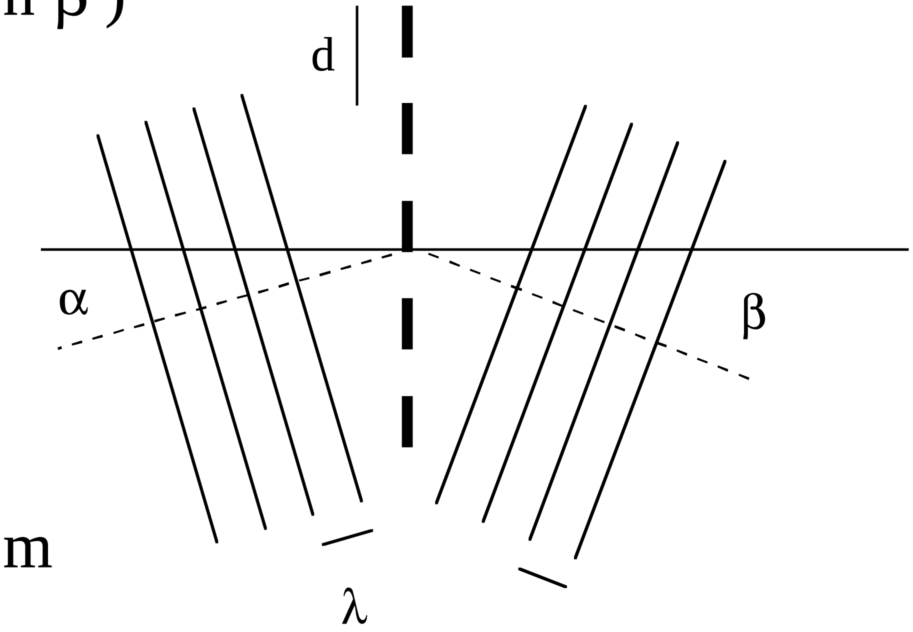
m = order (integer)

λ = wavelength

d = distance between grooves

α = angle of input beam

β = angle of diffracted beam



RHS is path length difference between maxima

α and β have same sign when on same side of grating normal

Dispersion

- Differentiate grating equation
- Input beam doesn't change, but can consider changes in output beam. Take $d\lambda / d\beta$

$$d\lambda / d\beta = d \bullet \cos\beta / m$$

- **Angular Dispersion** is $d\beta / d\lambda$
- can get spatial separation (**Linear Dispersion**) by mulitplying by focal length

$$dx / d\lambda = f_{len} \bullet d\beta / d\lambda = f_{len} \bullet d \bullet \cos\beta / m$$

Use of Theory

- Use Linear Dispersion to predict resolution and wavelength coverage
- Detectors have physical area
  - pixel size (= x_{pix})
  - number of pixels (= n_{pix})
- Separation of wavelengths
  - find $d\lambda$ with dx set to x_{pix}
- Range of wavelengths
  - find $d\lambda$ for 1 pixel times n_{pix}

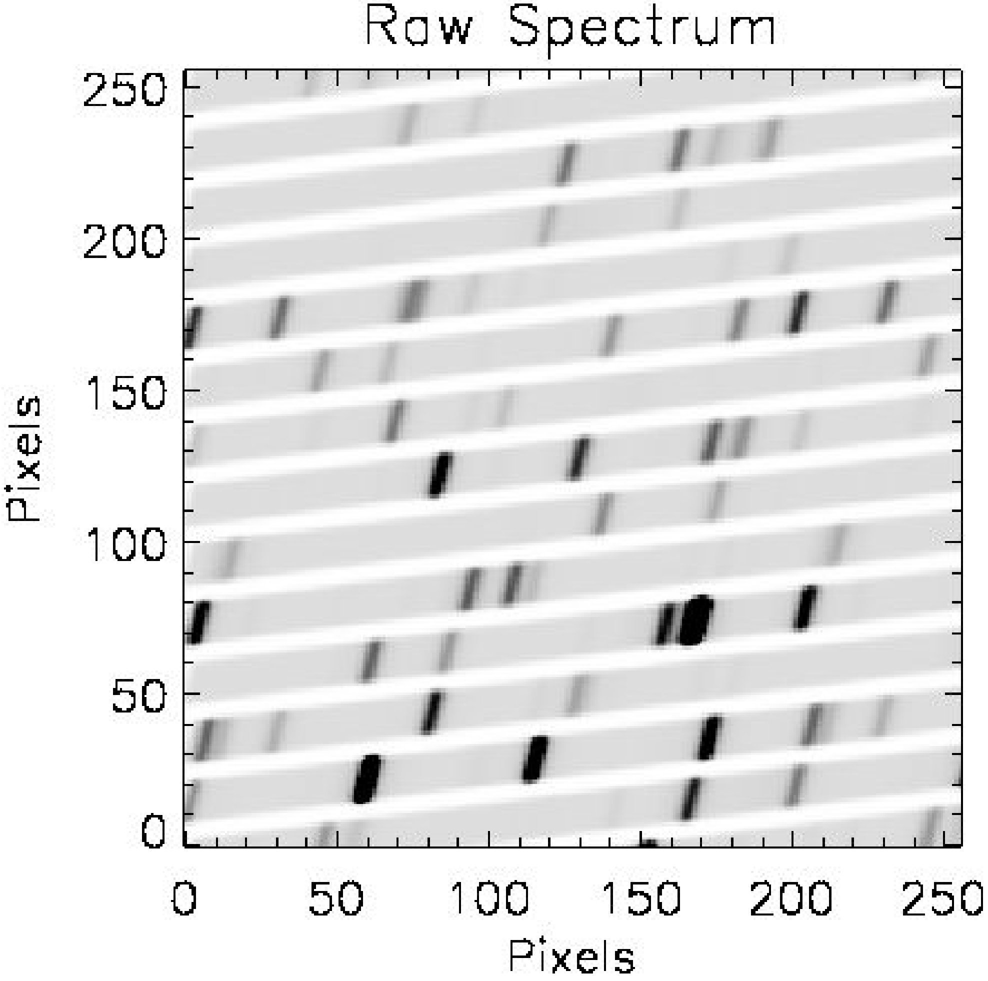
Apply to EXES echelon

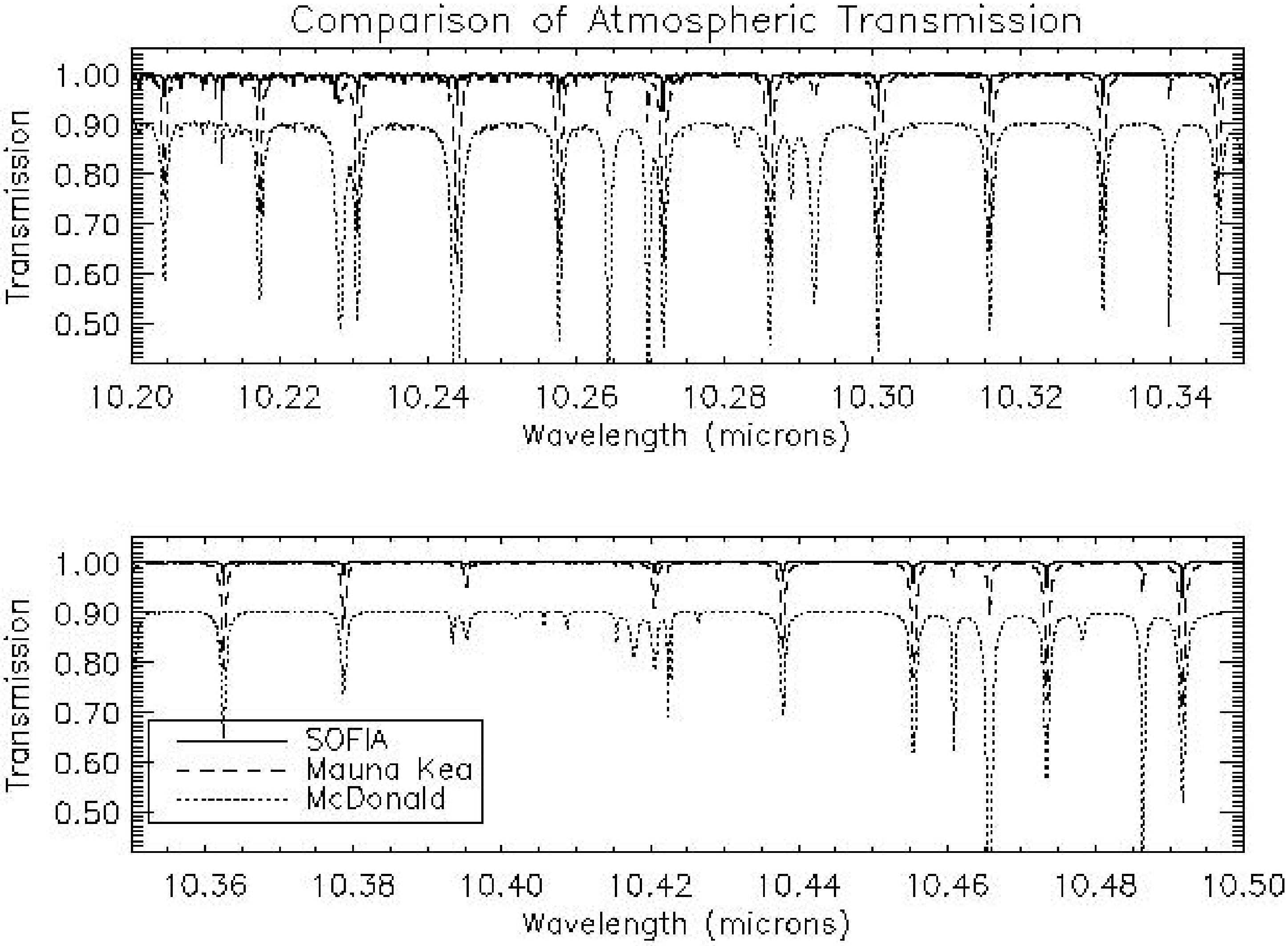
- Assume
  - $\lambda = 10\ \mu m$ $d = 7038.558\ \mu m$
  - $m = 1400$
  - $\alpha = \beta = 84^\circ$ (Littrow)
  - $f_{len} = 1\ m = 1000\ mm$
  - $x_{pix} = 50\ \mu m = 0.05\ mm$ (lens in front of detector)
  - $n_{pix} = 256$
- Calculate
  - $d\beta\ /\ d\lambda = 1.9\ rad\ /\ \mu m$
  - $dx\ /\ d\lambda = 1.9 \times 10^3\ mm\ /\ \mu m$
  - $0.05\ mm\ /\ d\lambda = 1.9 \times 10^3\ mm / \mu m \Rightarrow\ d\lambda = 2.6 \times 10^{-5}\ \mu m$ (resolution)
  - $n_{pix} \bullet d\lambda = 0.0067\ \mu m$ (wavelength coverage)

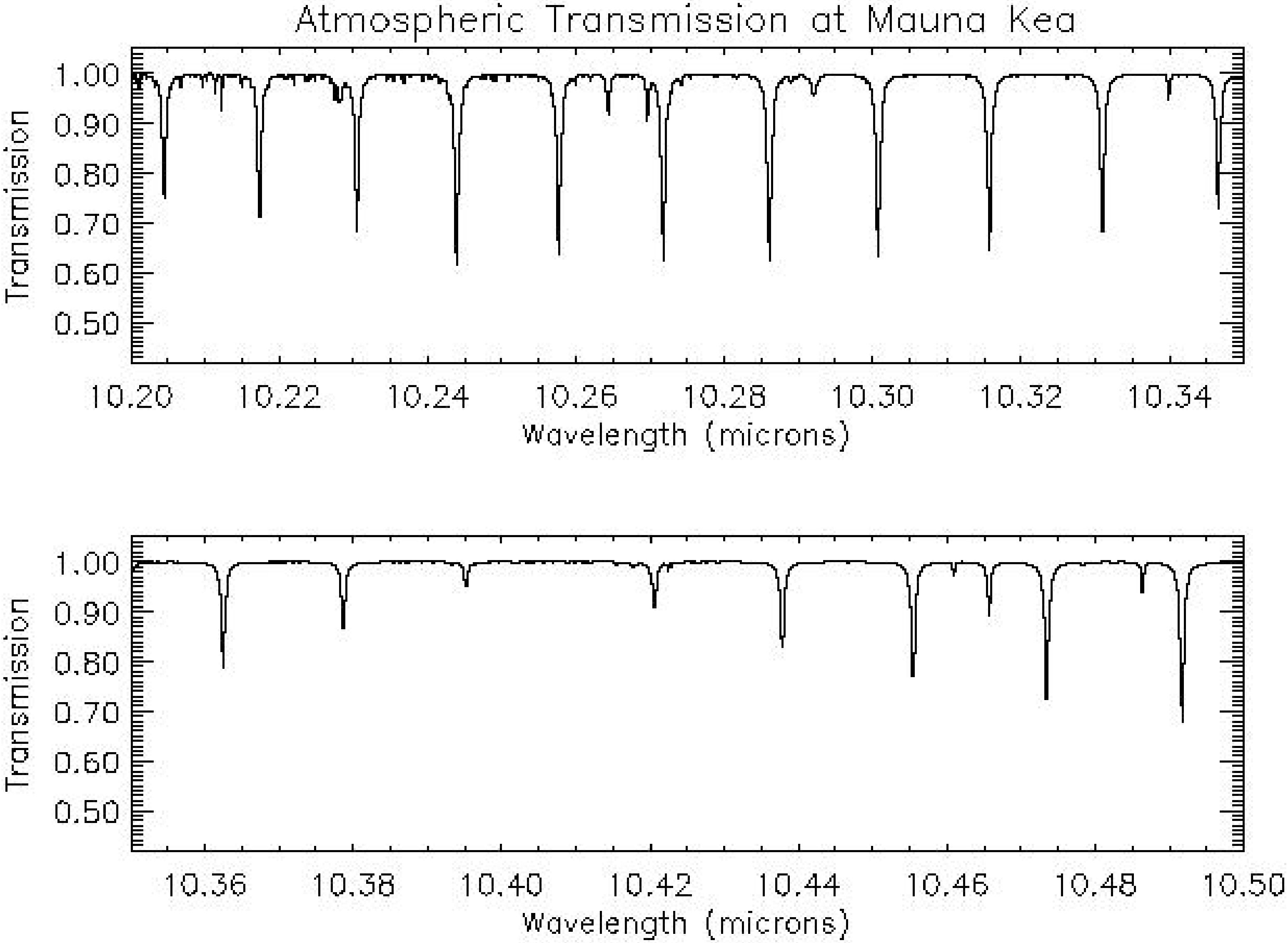
Cross-dispersion

- Calculate λ for m=1401 and everything else the same
  - λ =9.9929 μm
- Orders land on top of each other => confusion
- Each order has different central wavelength
  - disperse them in perpendicular direction
  - echelle grating
- Find that EXES gets ~10 orders on detector
  - total wavelength coverage ~10 times that calculated above

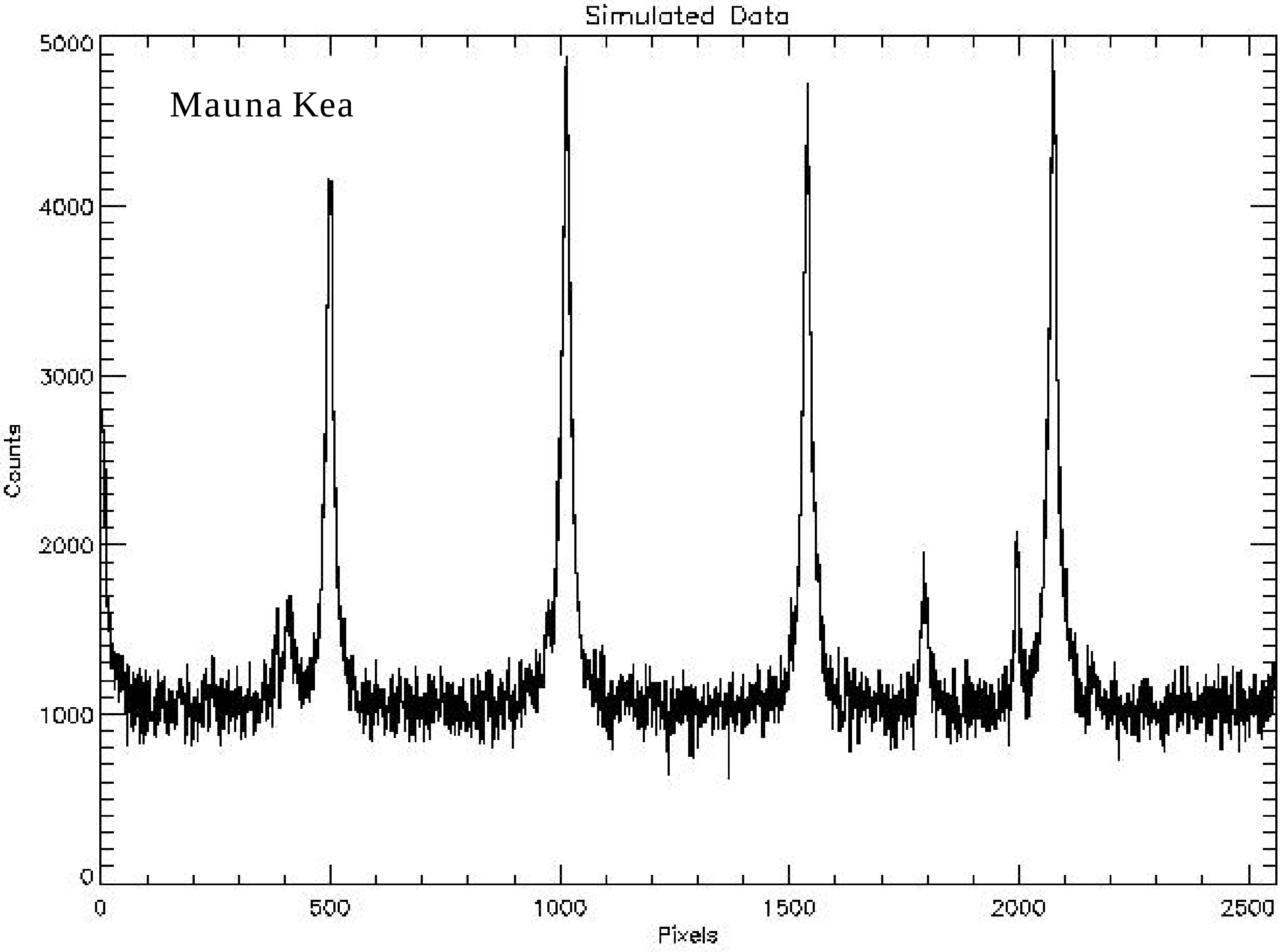
2D echellogram




Comparison of Atmospheric Transmission
Transmission
1.00
0.90
0.80
0.70
0.60
0.50
10.20
10.22
10.24
10.26
10.28
10.30
10.32
10.34
Wavelength (microns)
Transmission
1.00
0.90
0.80
0.70
0.60
0.50
SOFIA
Mauna Kea
McDonald
10.36
10.38
10.40
10.42
10.44
10.46
10.48
10.50
Wavelength (microns)



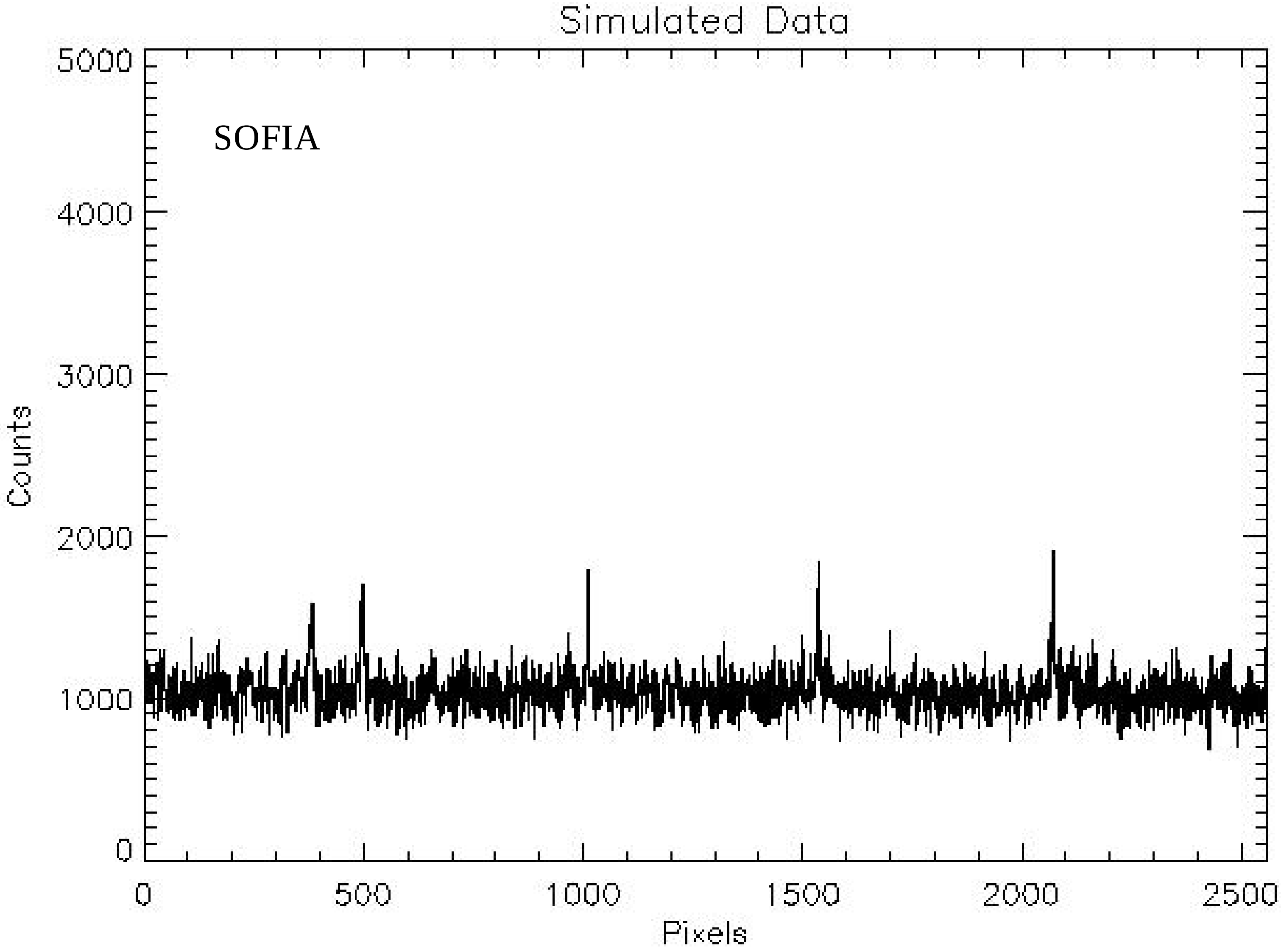
Atmospheric Transmission at Mauna Kea


Simulated Data
Counts
Pixels
0
1000
2000
3000
4000
5000
0
500
1000
1500
2000
2500

Mauna Kea

Do the wavelength calibration

- Identify pattern to find where we are
- Calculate λ as a function of pixel number
- Why are lines in emission instead of absorption?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Introduce features

- Arc lamps
    - gas discharge lamps like we’ve seen
- Absorption cells
    - gas in front of bright source

EXES calibration gas requirement

- Need lines not provided by atmosphere
- pressure can’t be too high
  - broaden the lines
- Concentration can’t be too low
  - lines not detected
  - number of molecules
    - pressure
    - path length
- Want emission, not absorption
  - need to have cold background

Current Plan

- SO_2, NH_3, and HDO
- 5” long, 2.5” diameter tube with mirror at back end
  - gas pressure P = 0.004 - 0.02 atm
  - gas temperature T = 240 - 300 K
  - gas volume V ~ 0.5 l

Why these molecules?

- complicated spectra - lots of lines
- HDO lines offset from H_2O
  - heavier molecule
    - think of molecule as masses on spring
    - having heavier molecule changes frequency of vibration
- SO_2 lines offset from CO_2
- not too toxic

HITRAN

- Molecular Database
- Developed for atmospheric studies (?)
- Contains ~35 molecules
  - line wavenumbers, strengths, energy levels, broadening
- Predicts spectrum as function of temperature and chemical constituency
- PC or Unix (PC works better)
- Contact information:
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  - ONTAR Corp, 508-689-9622