PRIMA *The PRobe far-Infrared Mission for Astrophysics*

The Far-Infrared Enhanced Survey Spectrometer (FIRESS)

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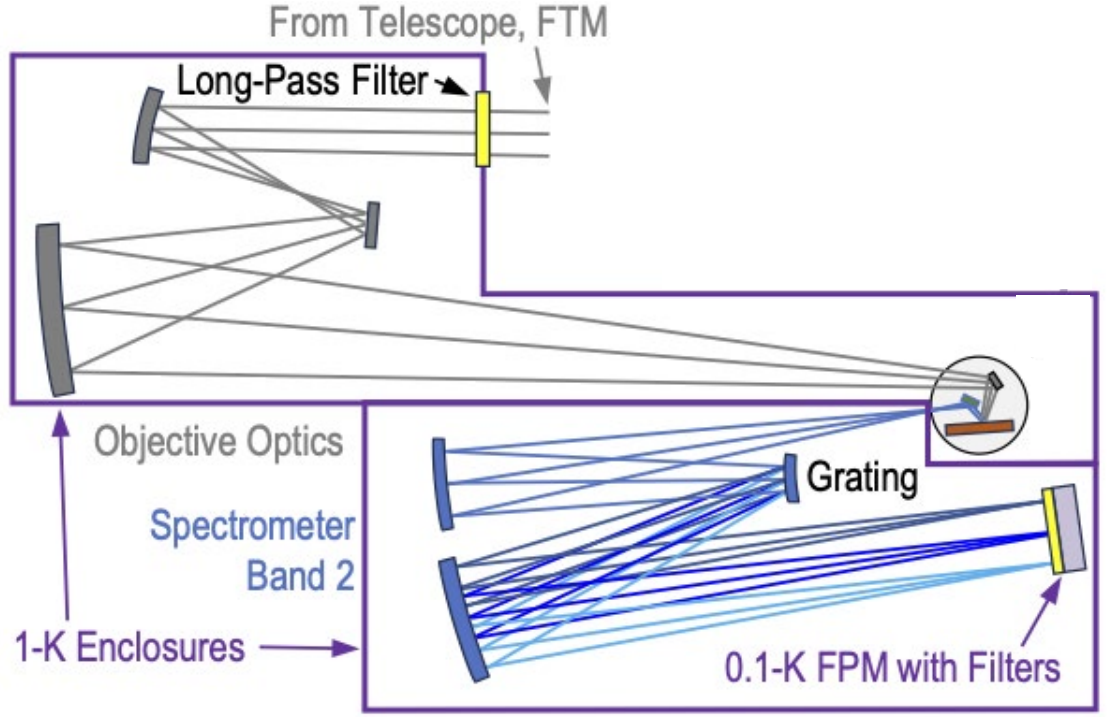
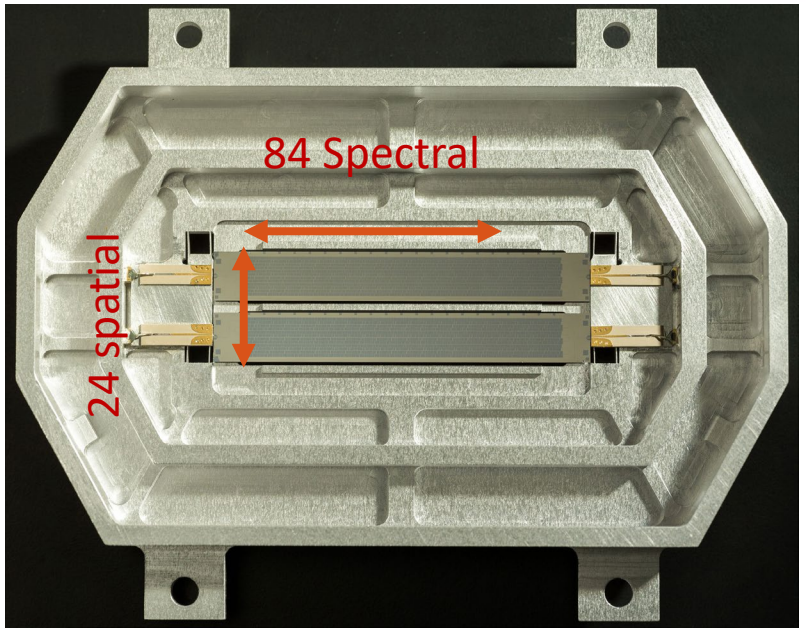
FIRESS Base Grating Modules

- 4 slit-fed grating modules spaced logarithmically with some wavelength overlap.
- R ~ 100, greater than 85 everywhere (including sampling and grating intrinsic R).
- Common detector array approach: 24 spatial x 84 spectral pixels. Spatial is 12 + 12 w/ gap.
- All detectors in all bands read out simultaneously.
- Band 1 and 2 common design and plate scale.
- All aluminum, no moving parts.



Parameter	Band 1	Band 2	Band 3	Band 4
Spectral range (μm)	24–43	42–76	74–134	130–235
Spectral sampling (μm)	0.23	0.41	0.73	1.29
Resolving power	95-150	85-120	90-125	95-130
Array format per band	24 spatial ×84 spectral pix, 900-μm pitch			
Pix size on sky (arcsec)	7.6		12.7	22.9
Pix pitch ratio to B1,2	-		5:3	3:1

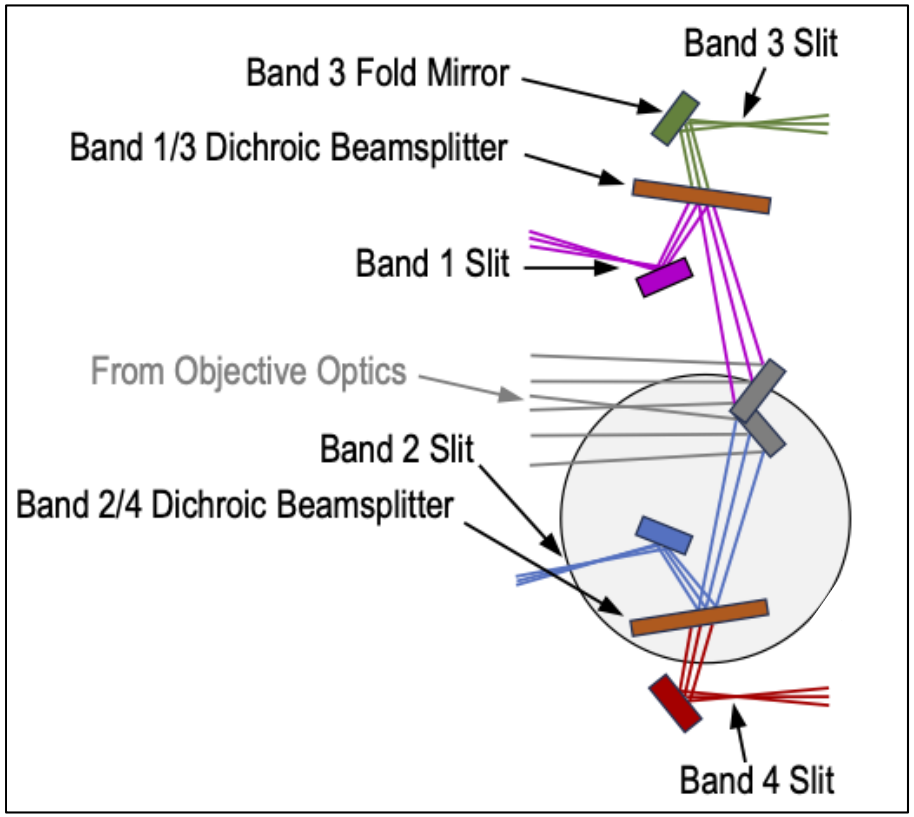


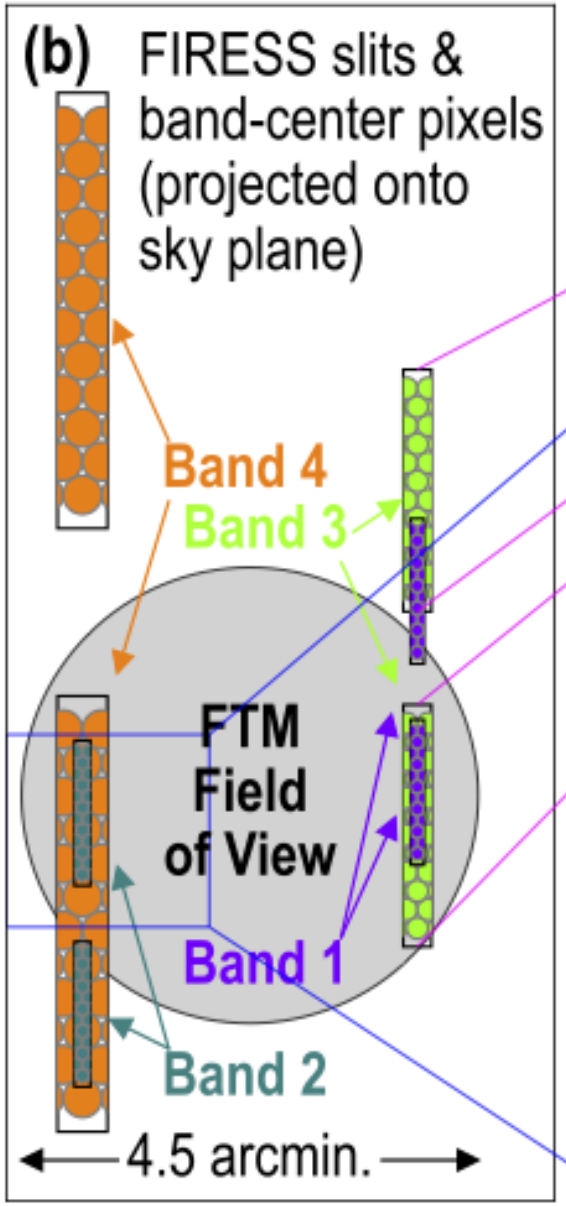
Prototype array in flight-like package

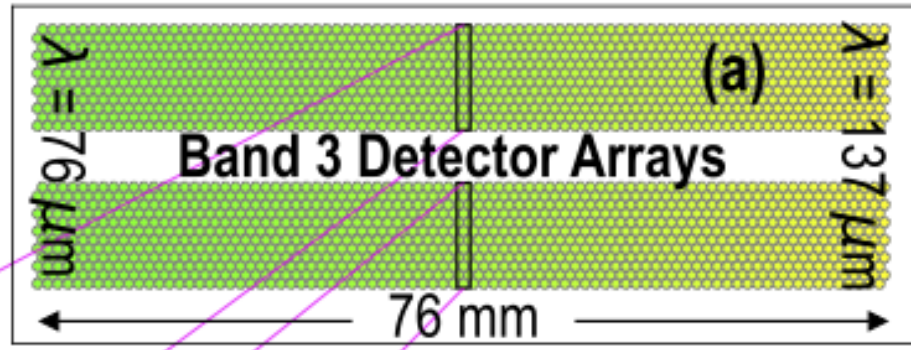
FIRESS Base Grating Modules: Orientation & Alignment

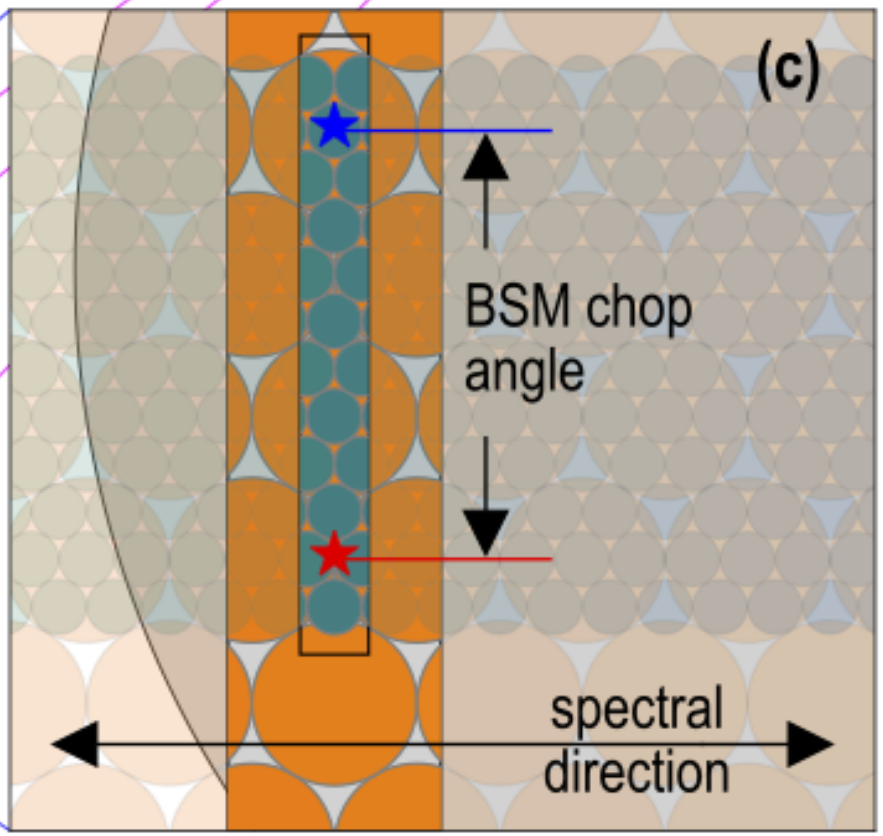
Bands 1 + 3 overlap, Bands 2 + 4 overlap

- Allows high-efficiency dichroics and dual-polarization operation.
- 2 pointings for full spectrum of a source, though all 4 bands read out.
- High-res mode couples all bands when engaged

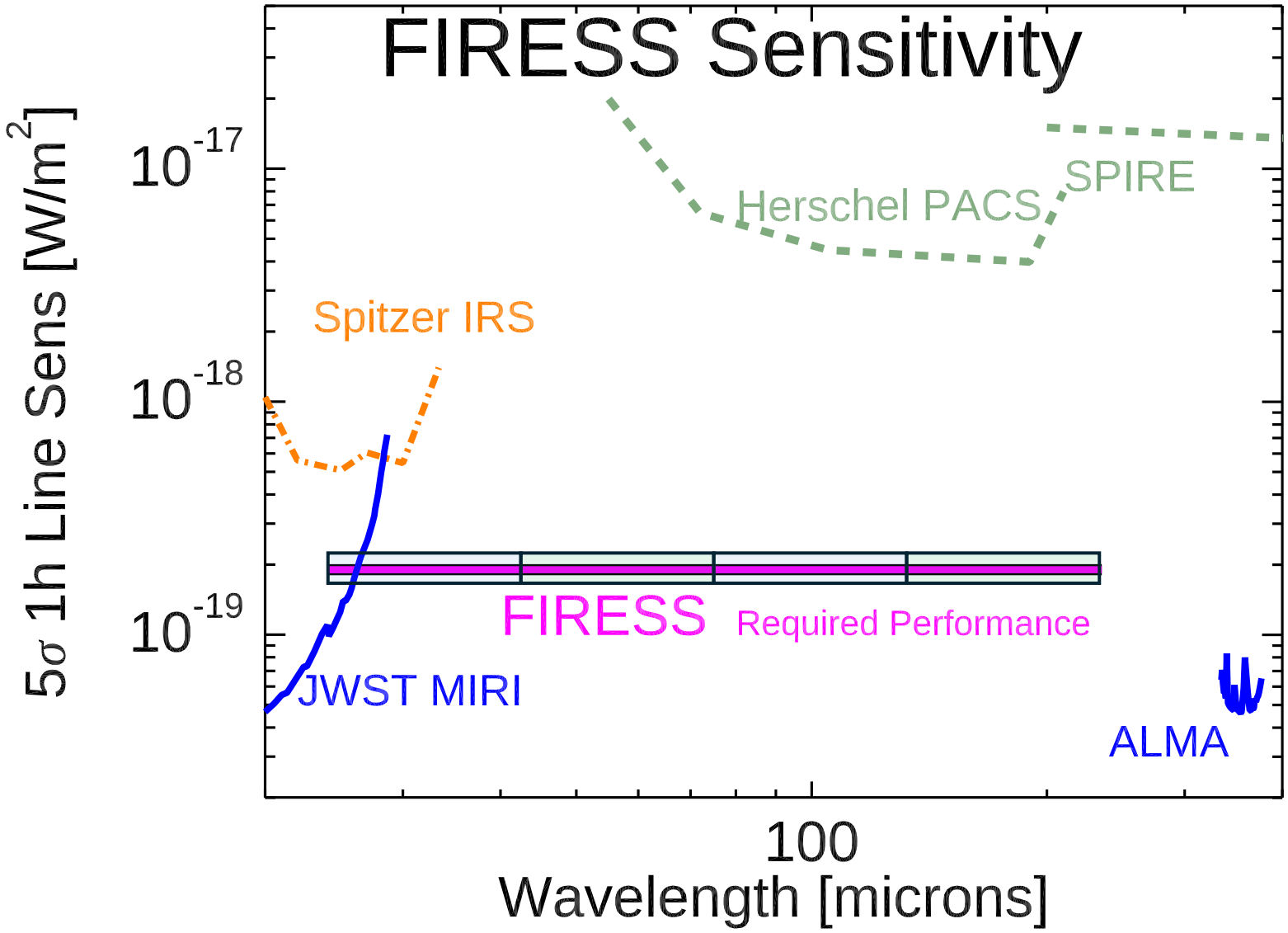








Point Source, Low-Res Mode: Required Sensitivity



5 sigma, 1 hour line required sensitivity:

1.9×10^{-19} W/m^2
(This is for an unresolved line)

Can scale sensitivity as 1/sqrt(time)

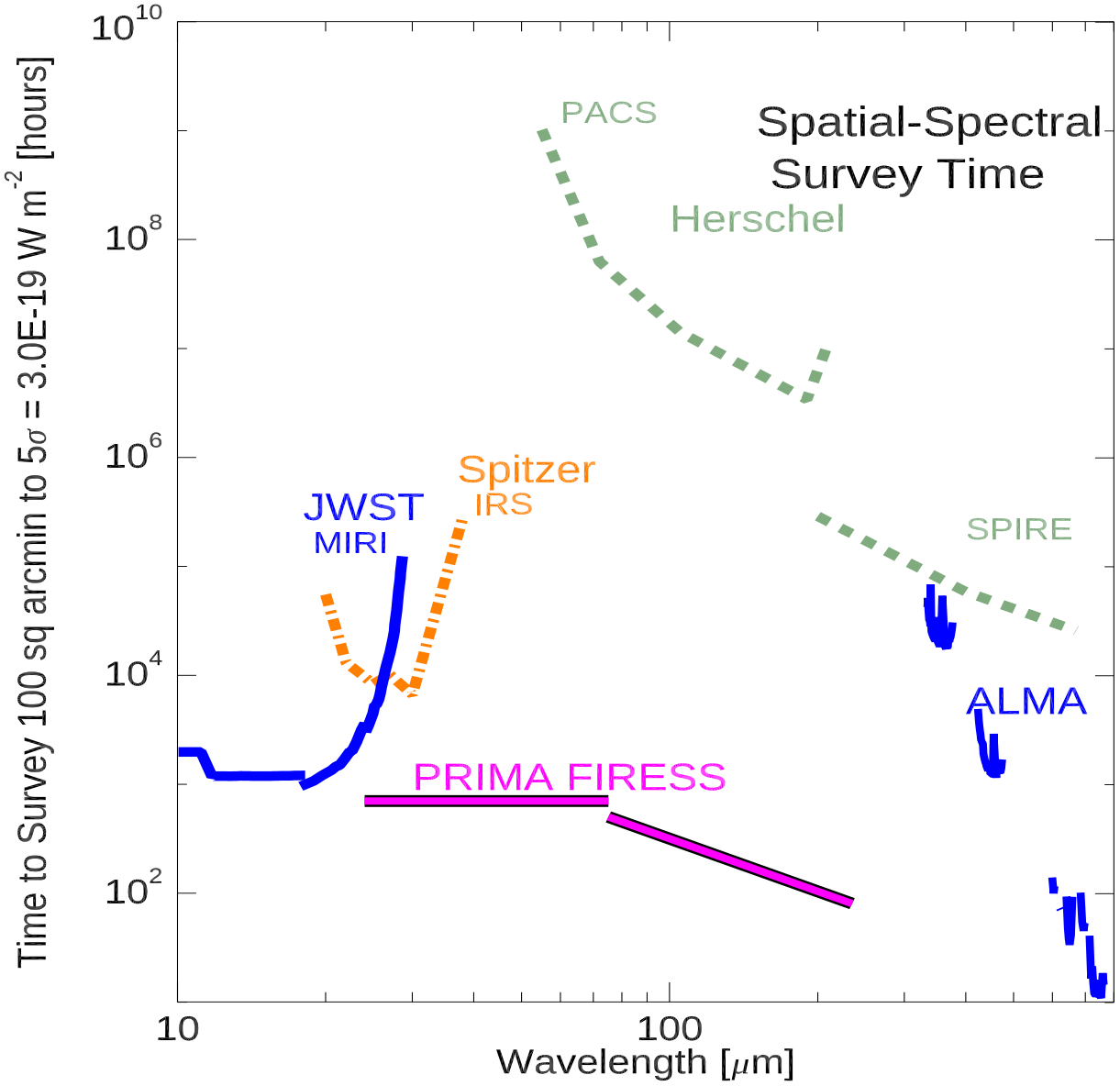
Should add 20% time overhead.

So: time to reach a 5 sigma detection of flux F in W/m^2 is

$1.2 \times (1.9e\text{-}19 / F)^2$

Bands 1 and 3 OR bands 2 and 4 at the same time.

Point Source, Low-Res Mode: Full-Band Mapping Speed



Mapping speed scales as sensitivitiy^2 x field of view.

This calculation includes the time to obtain a full spectrum, if that is not automatic (this applies to ALMA, PACS).

This is for 100 square arcminutes to 3×10^{-19} W/m^2 (5σ) in line emission.

Use: 800 hours for 24 to 75 μm

$336 \text{ hours} \times (\lambda / 100\ \mu\text{m})^{-1.68}$ for 75 to 235 μm

Then for a different Depth and Area, scale time as:

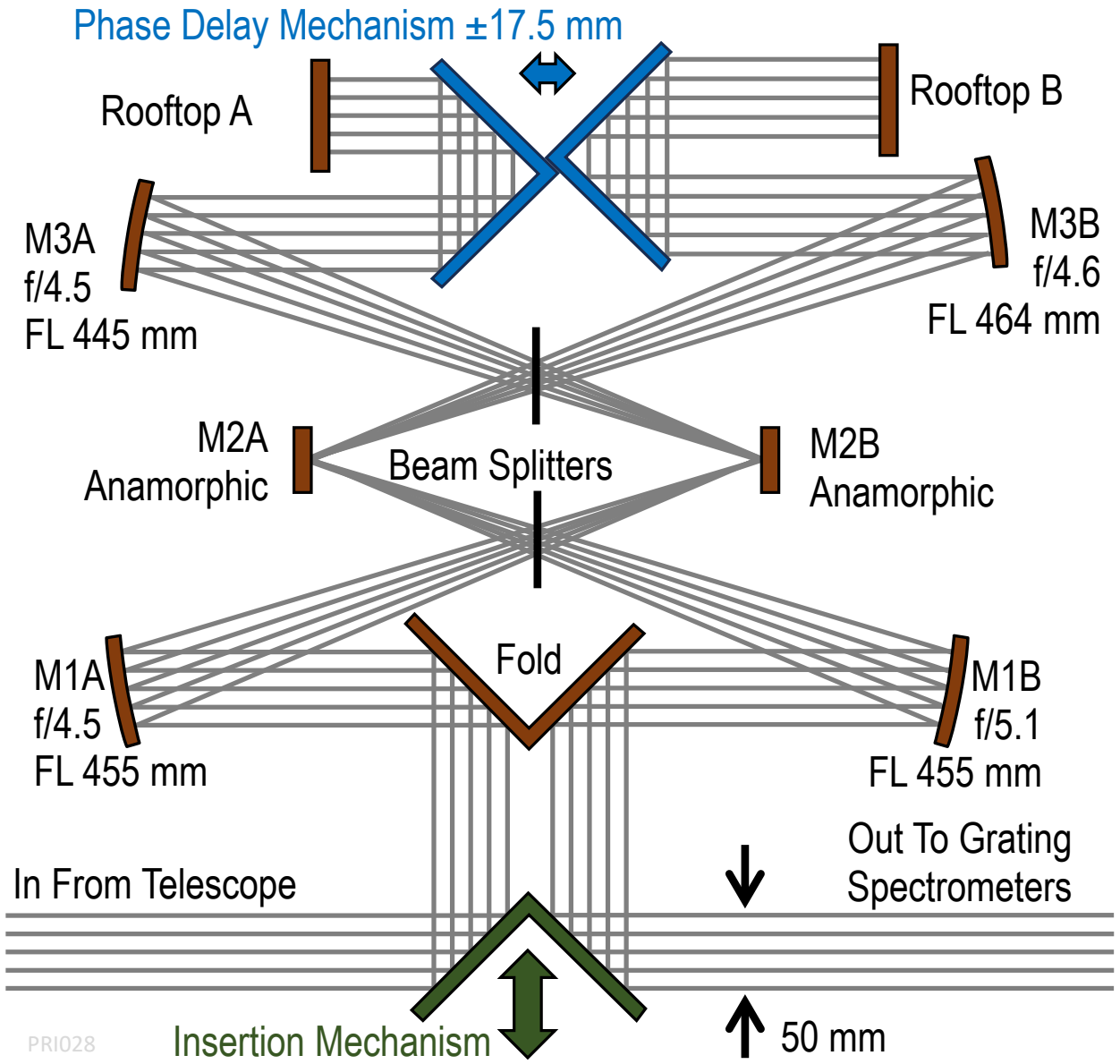
$(3 \times 10^{-19}\ \text{W/m}^2 / \text{Depth}\ (5\sigma))^2$

$\times$ (Area / 100 sq arcmin)

These estimates include overheads, which are small for PRIMA.

Note: JWST MIRI is overhead dominated in this calculation for 100 square arcminutes. MIRI can go deeper over smaller area more easily than the simple scalings would suggest.

FIRESS Fourier Transform Module (FTM)



Design credit: Fixsen & Kogut at GSFC

Attributes

Polarizing FTS but couples both polarizations.
- Polarizing splitters at 45 deg to one another.

Efficient: input and output ports are sky and grating modules slits -> White light position transmits all sky signal to gratings.

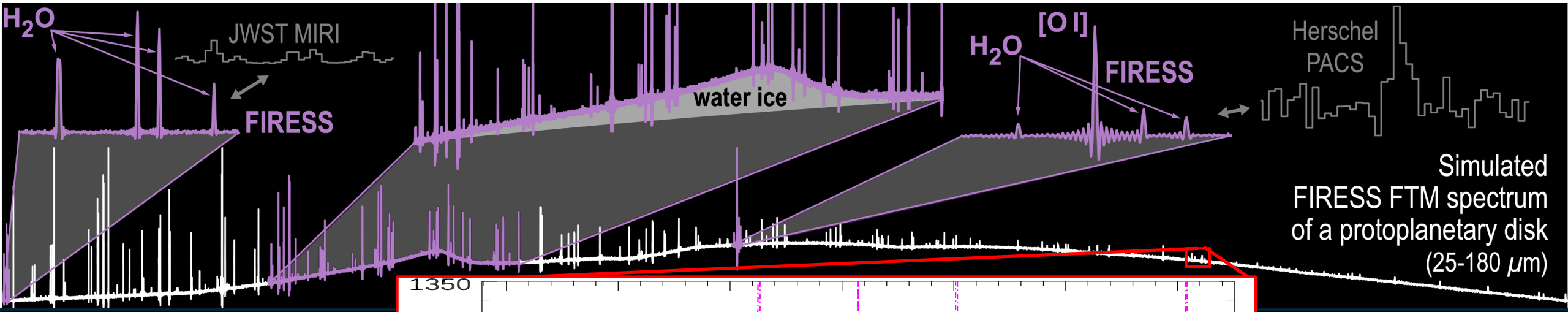
Couples to both slits
- 4.5 arcminute field of view.

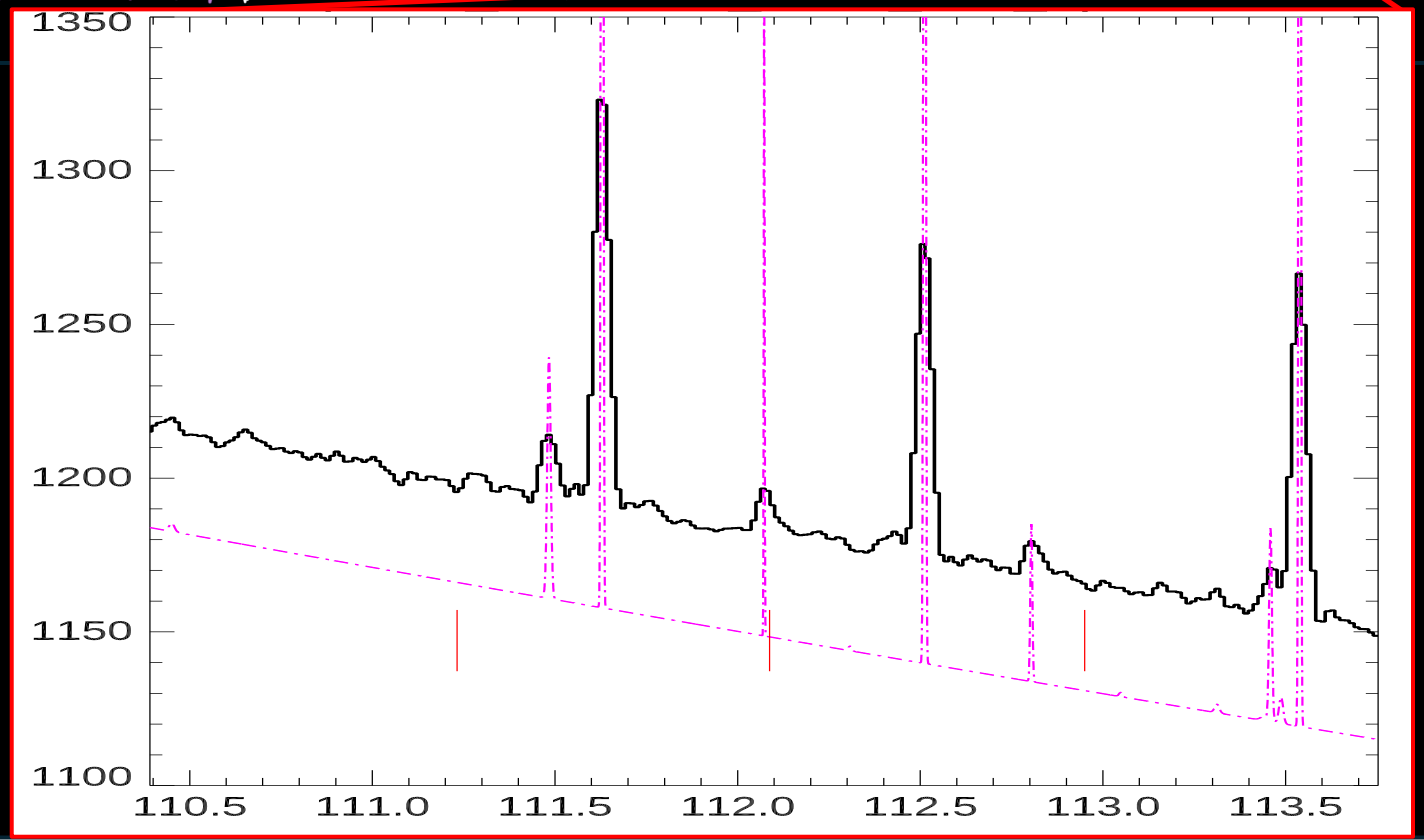
8x path folding: OPD / physical motion.
- **zero path at one side of scan.**

Max resolving power:
4,400 x (112 µm / λ)
(unapodized)

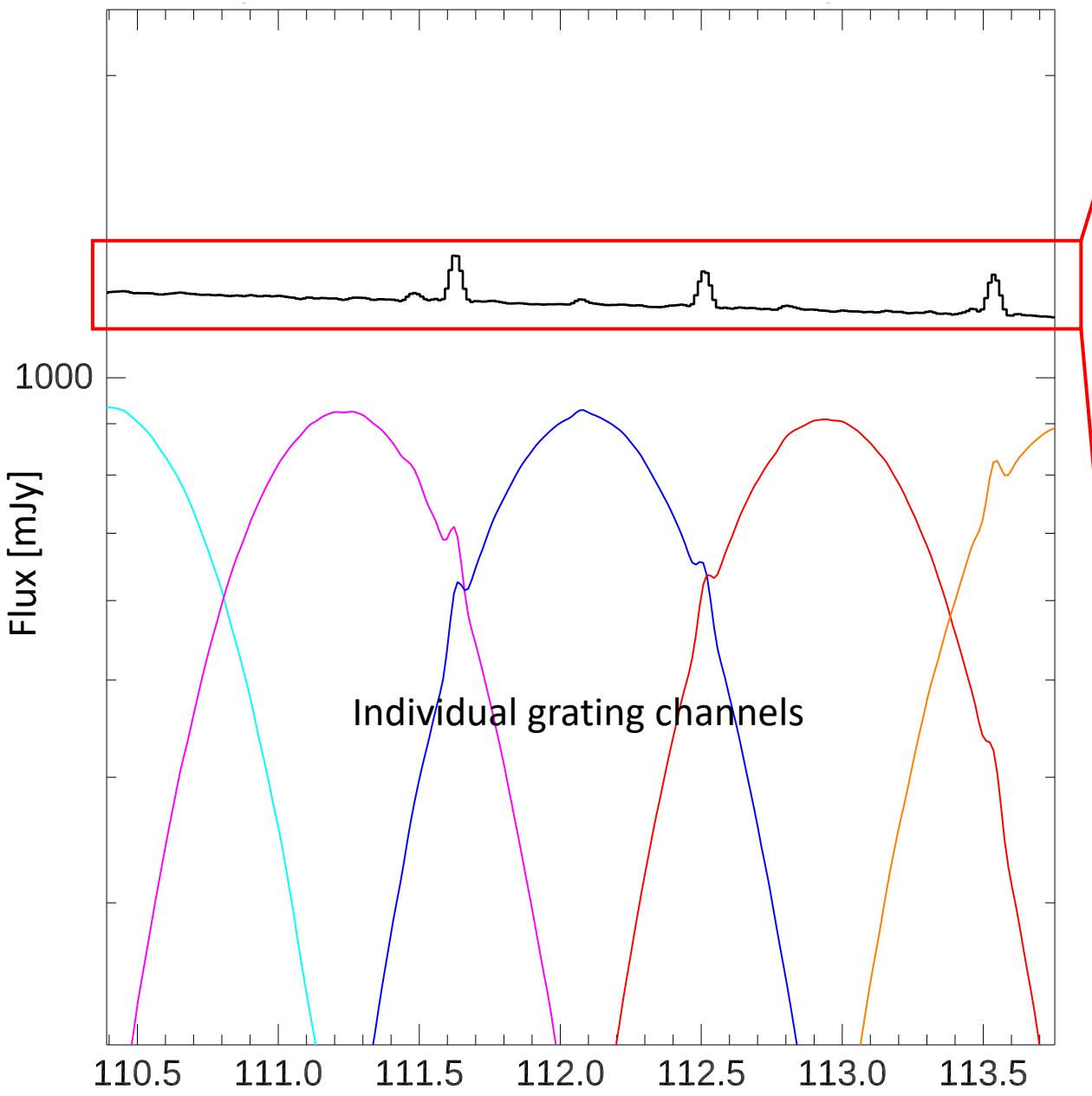
Can choose R up to this value, but is the same across the band.

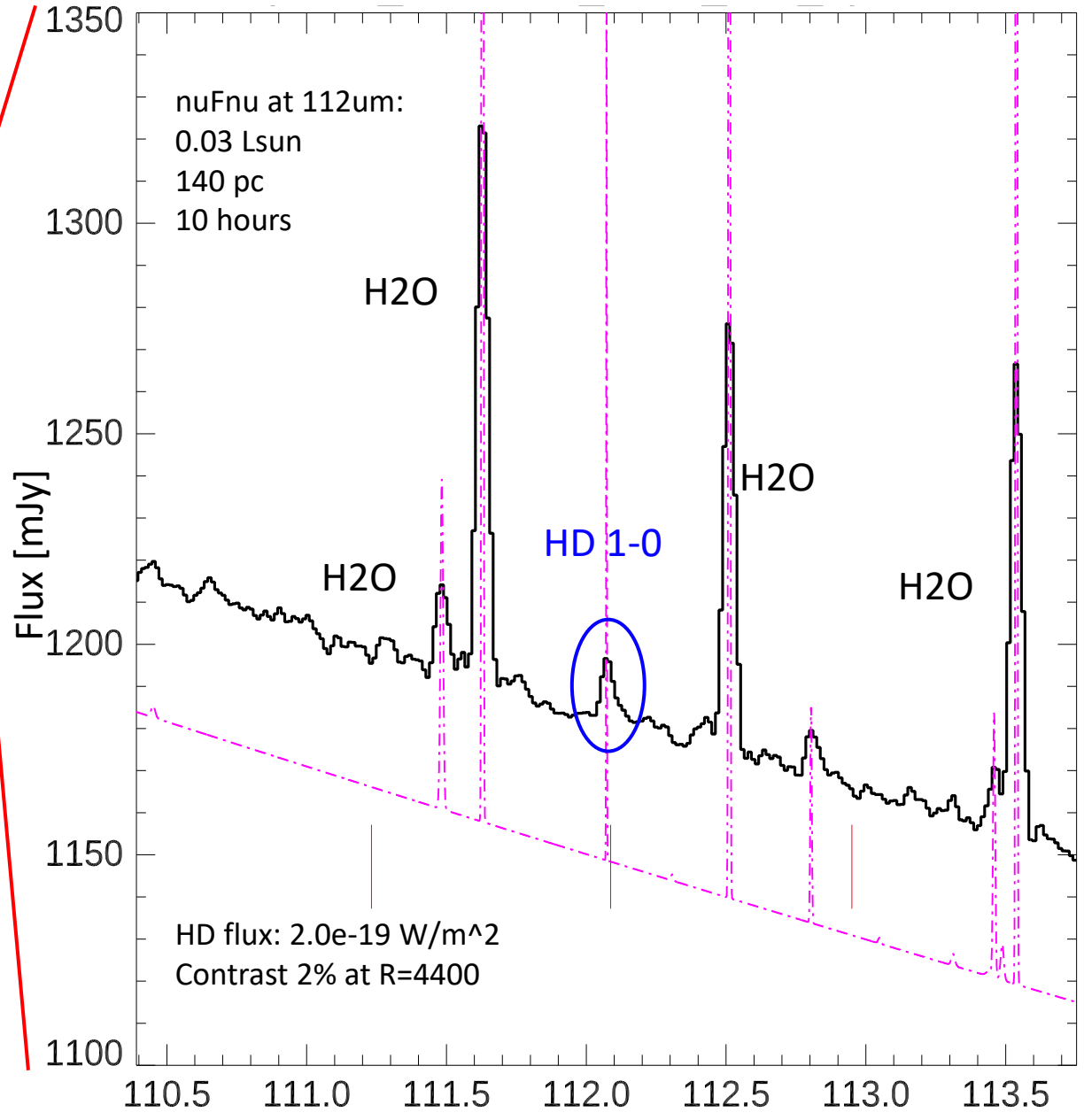
FIRESS FTM Full Band Capability



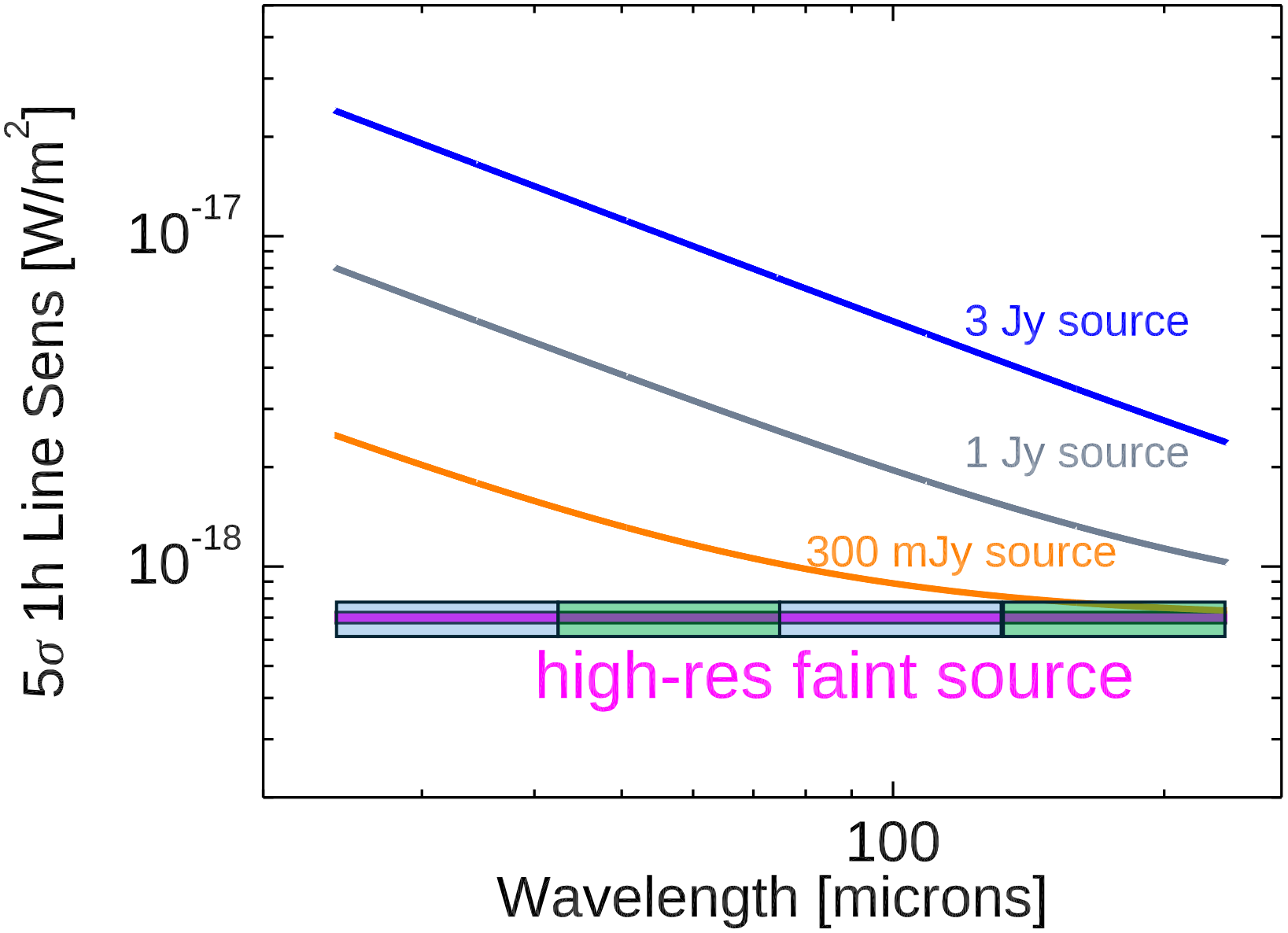


Disk at 140 pc,
M_{gas} = 0.75 $M_{jupiter}$
(below requirement)


1000
Flux [mJy]
Individual grating channels
110.5
111.0
111.5
112.0
112.5
113.0
113.5


1350
1300
1250
1200
1150
1100
Flux [mJy]
nuFnu at 112um:
0.03 Lsun
140 pc
10 hours
H2O
H2O
H2O
H2O
HD 1-0
HD flux: 2.0e-19 W/m^2
Contrast 2% at R=4400
110.5
111.0
111.5
112.0
112.5
113.0
113.5

High-Res Mode – Required Sensitivity



Relative to low res, using the FTS incurs additional losses and the penalty for forming the interferogram.

Faint source requirement:
7×10^{-19} W / m^2 [5σ, 1 hour]

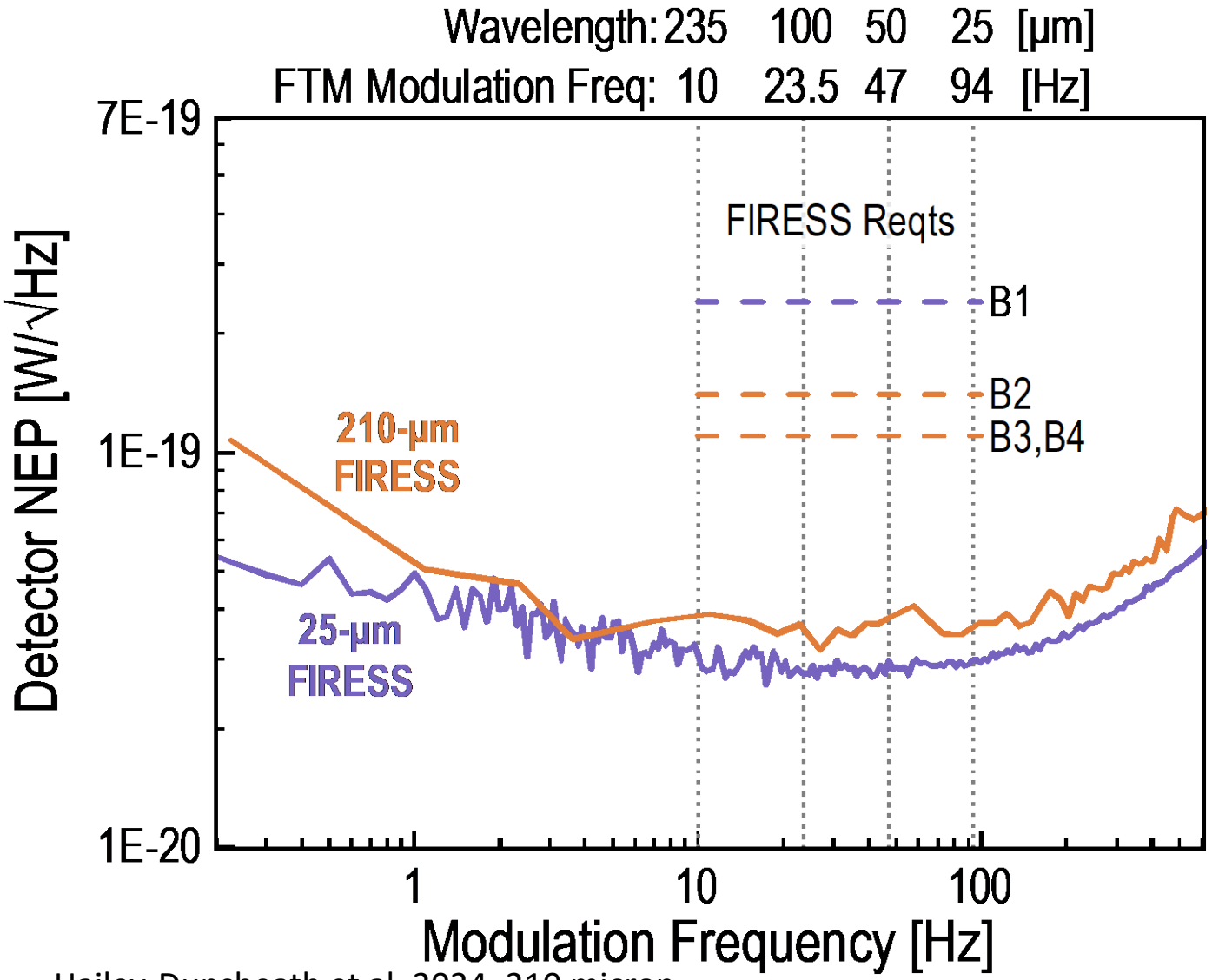
For a source with flux **S** in Jy, at wavelength λ, add in quadrature with the above this:
8×10^{-18} W m^{-2} × S × $(24/\lambda)^{1.035}$
to account for source photon noise.

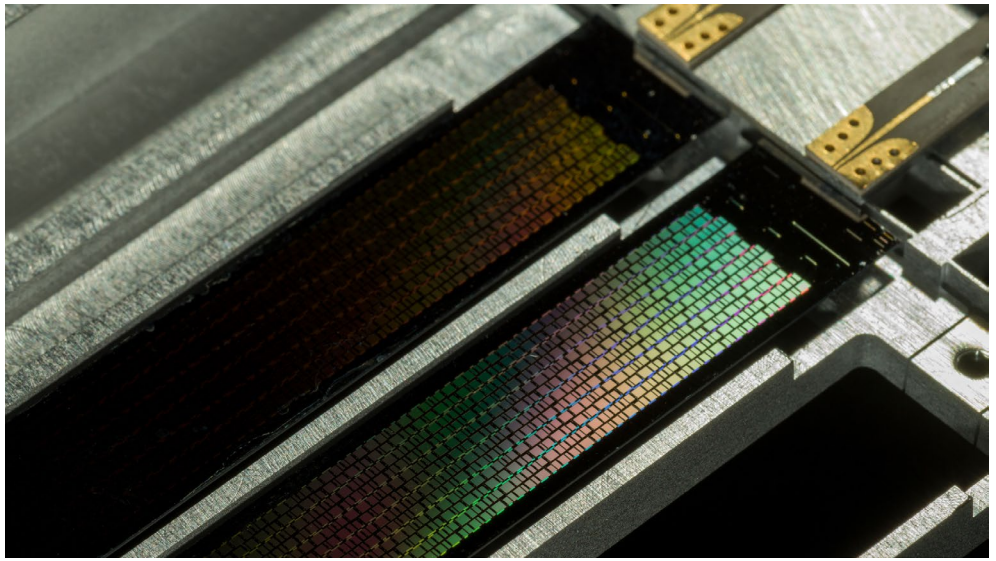
Then scale time to required depth **F**.
Time = 1.2 x (Sens / F)^2

Sensitivities apply to unresolved features. Resolving a feature degrades the sensitivity to integrated emission.

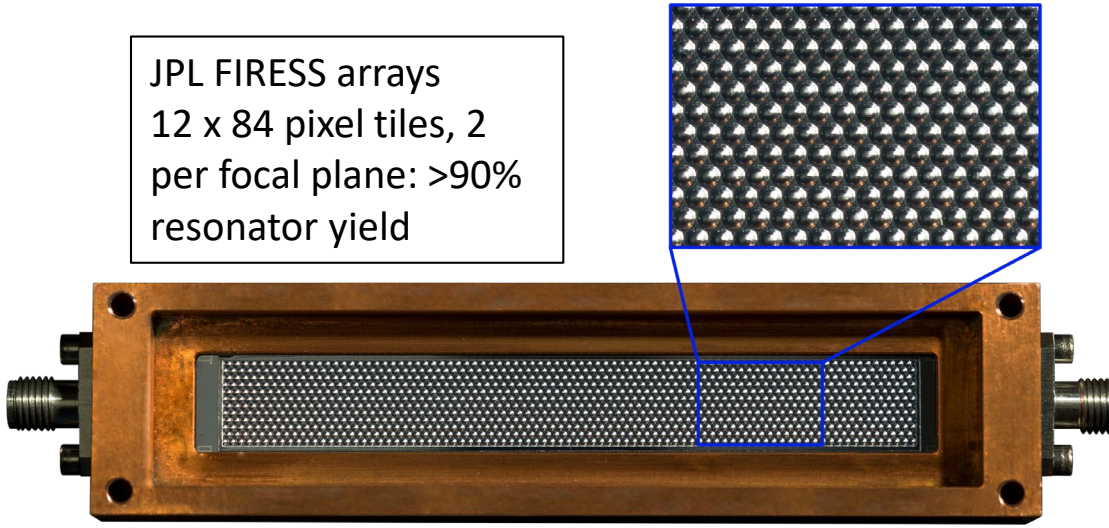
And remember, only 2 bands at a time.

Both 210 micron and 25 micron KIDs showing excellent performance





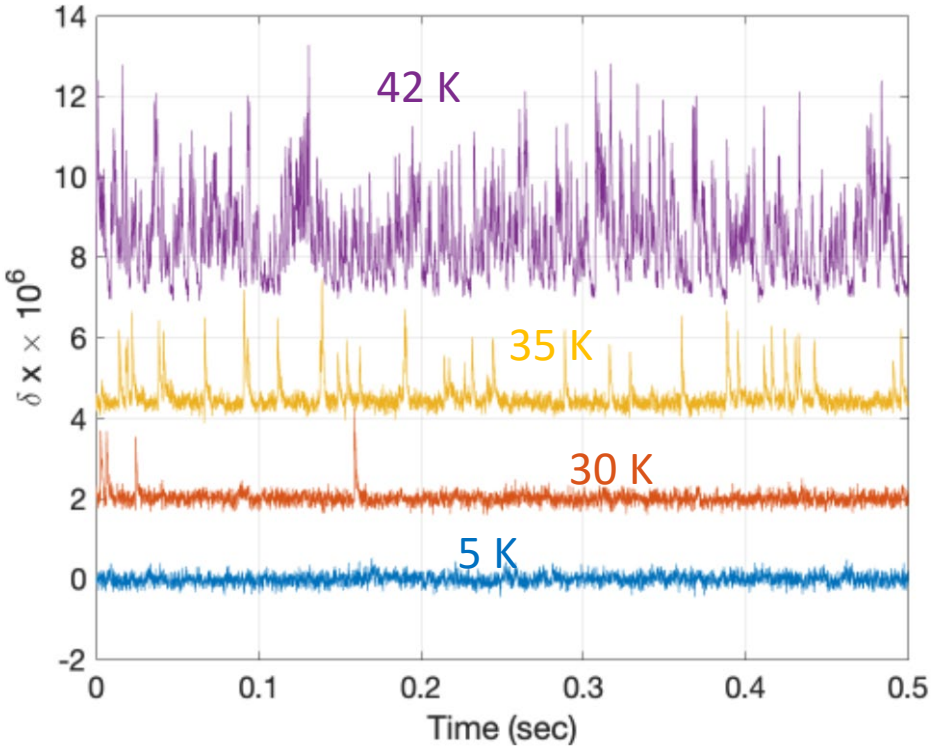
JPL FIRESS arrays
12 x 84 pixel tiles, 2 per focal plane: >90% resonator yield

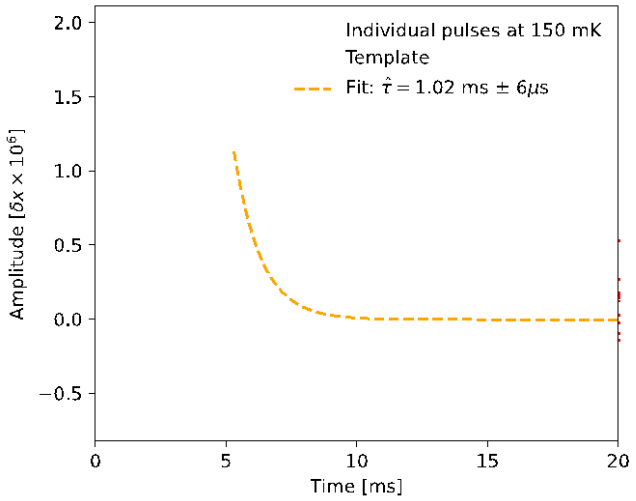


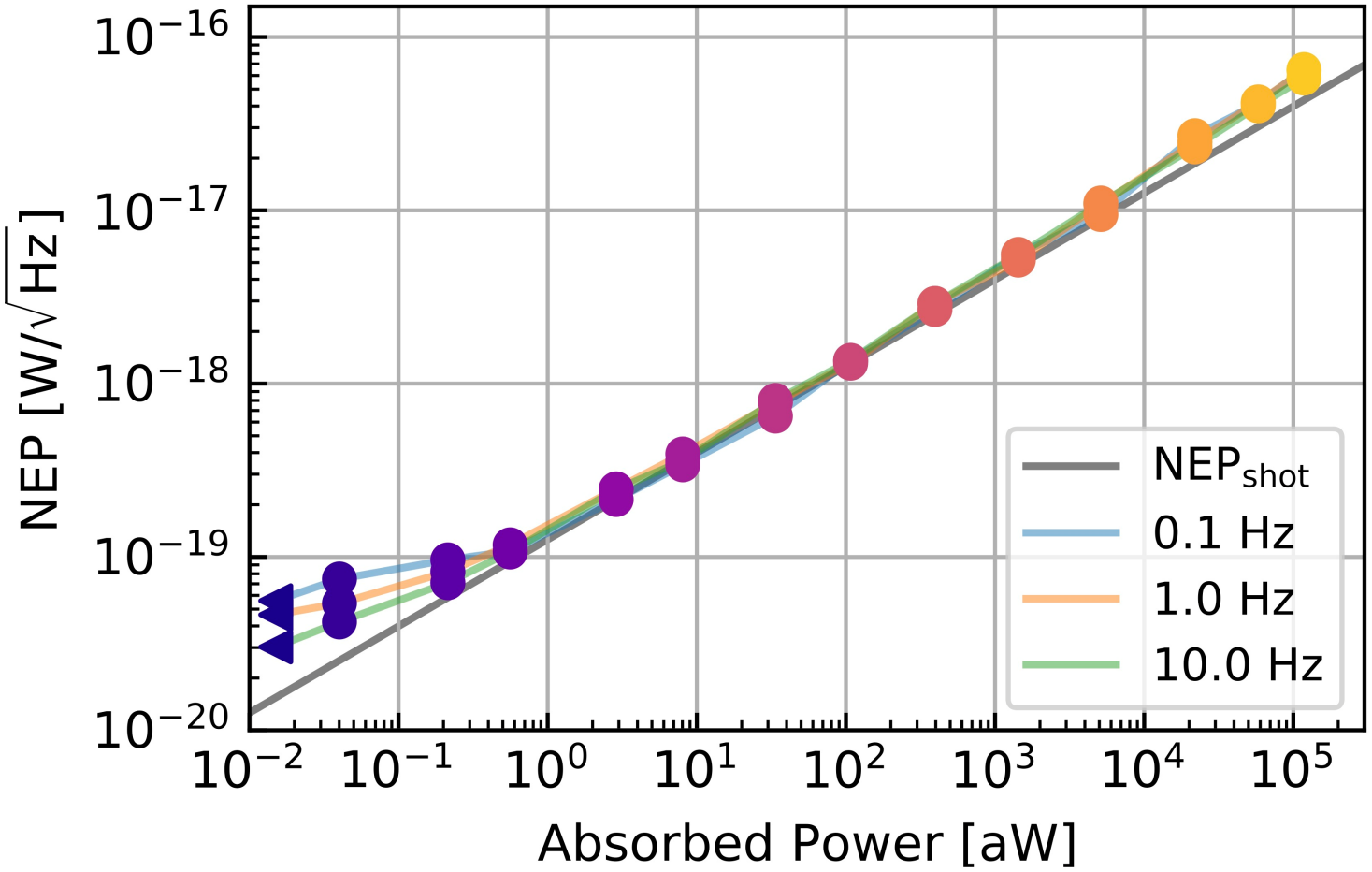
Microlens arrays for FIRESS, developed at GSFC

Hailey-Dunsheath et al. 2024, 210 micron
Foote et al. 2024 – array characterization
Day et al. 2024 – 25 micron

Single-Photon and Excellent Sensitivity at 25 microns







Day et al. 2024 on the arXiv