Prospects for ground-based submillimeter spectroscopy:

New capabilities and challenges

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Astronomical capability of a ground-based single-aperture telescope

Background-limited sensitivity:

$$\text{NEFD} \sim \frac{h\nu\ (n(n+1))^{1/2}}{\eta_{inst}\eta_{tel}\eta_{atm}A_{tel}(\Delta\nu)^{1/2}}$$

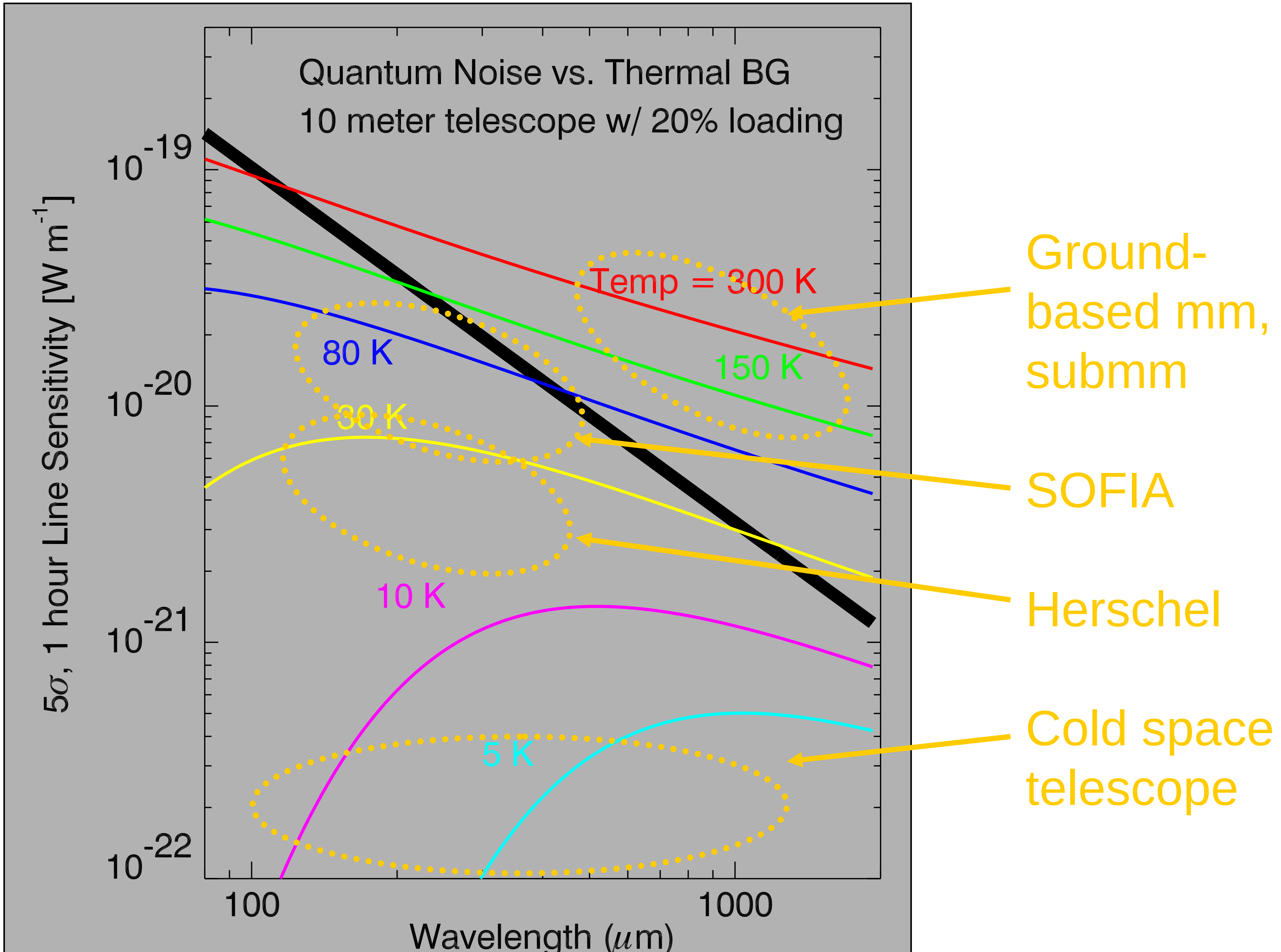
$$n = \varepsilon_{load}\eta_{inst}(e^{h\nu / kT} - 1)^{-1}$$

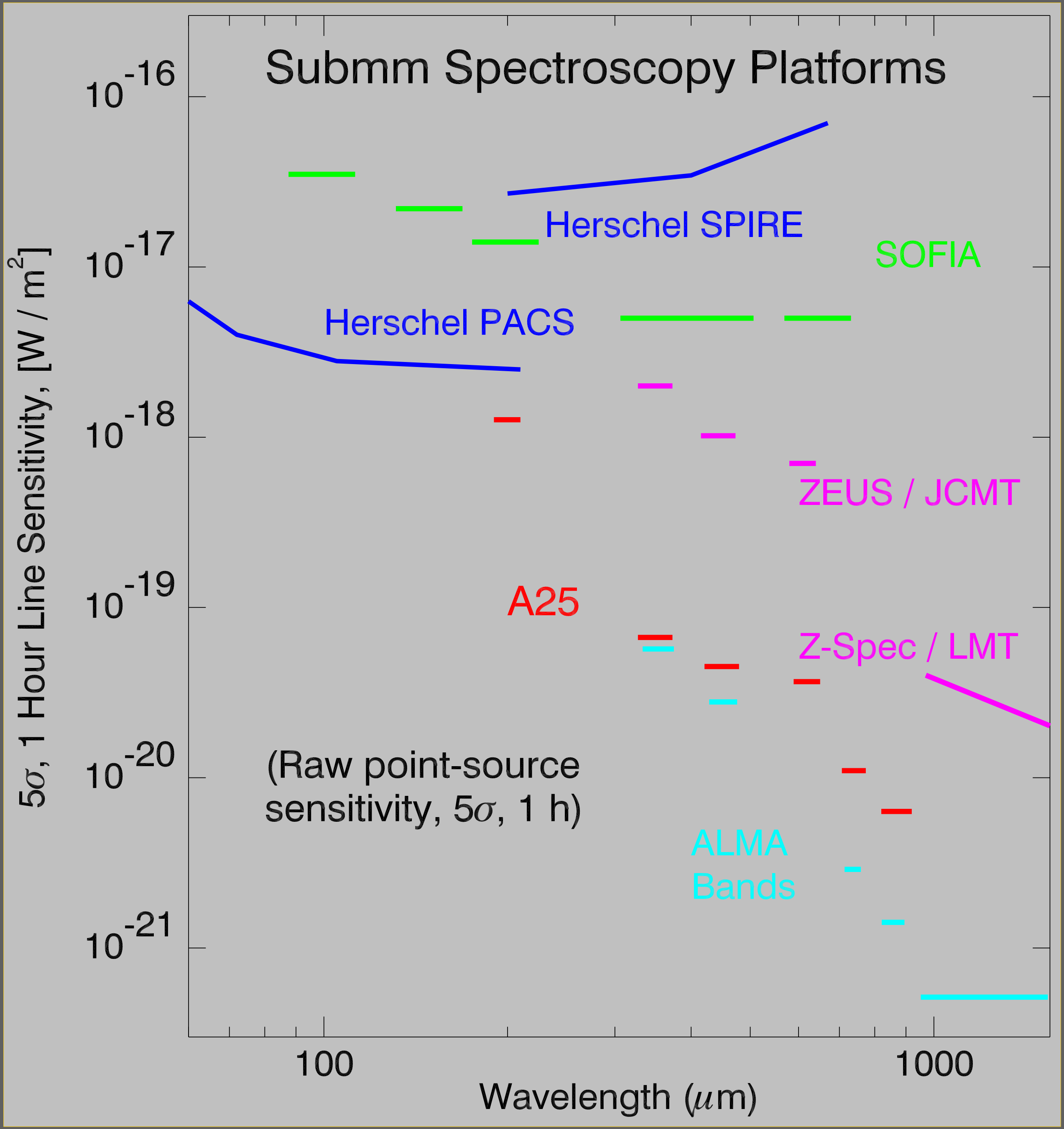
Telescope size, surface quality, site are important

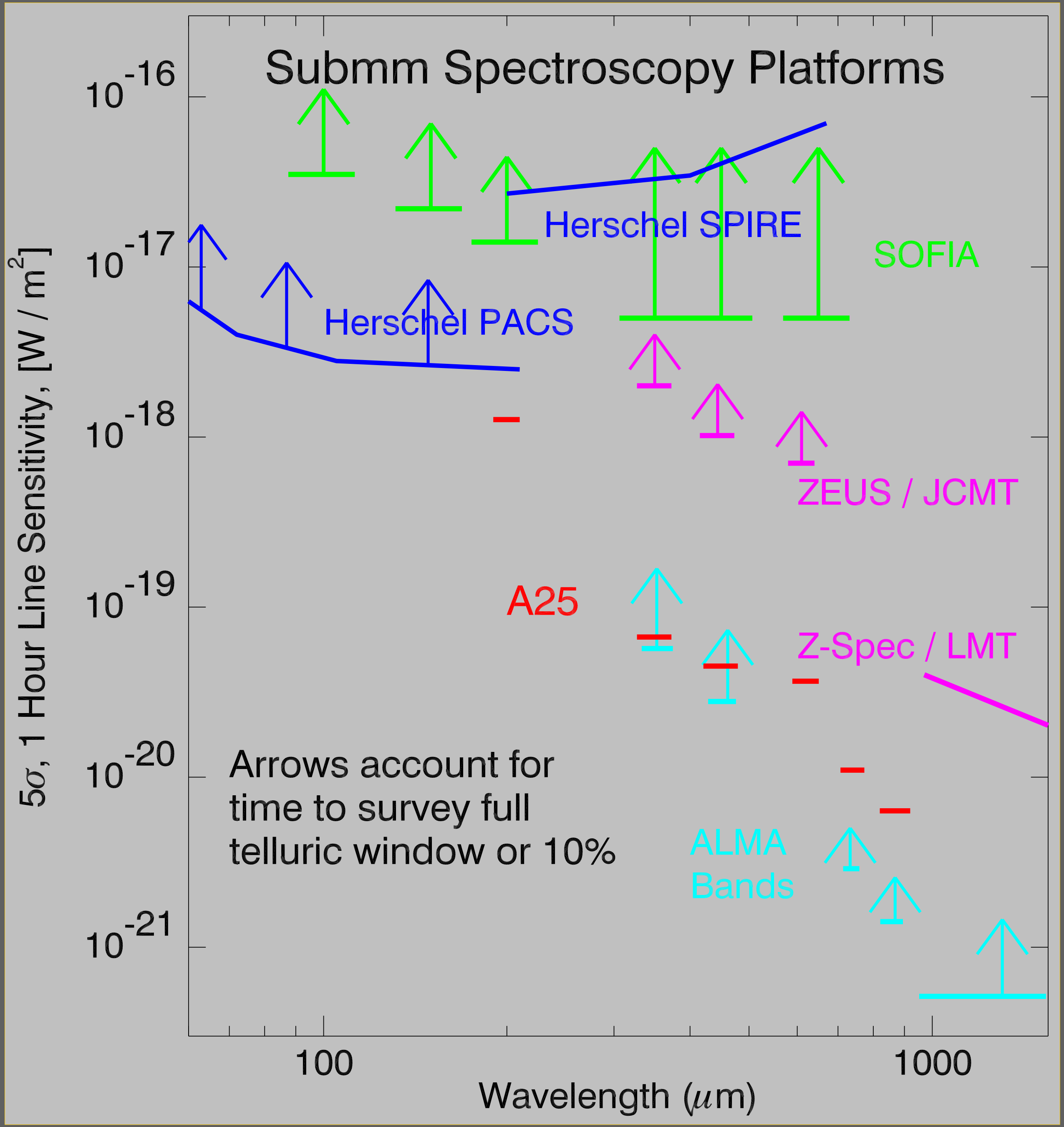
→ ALMA will have large **A**

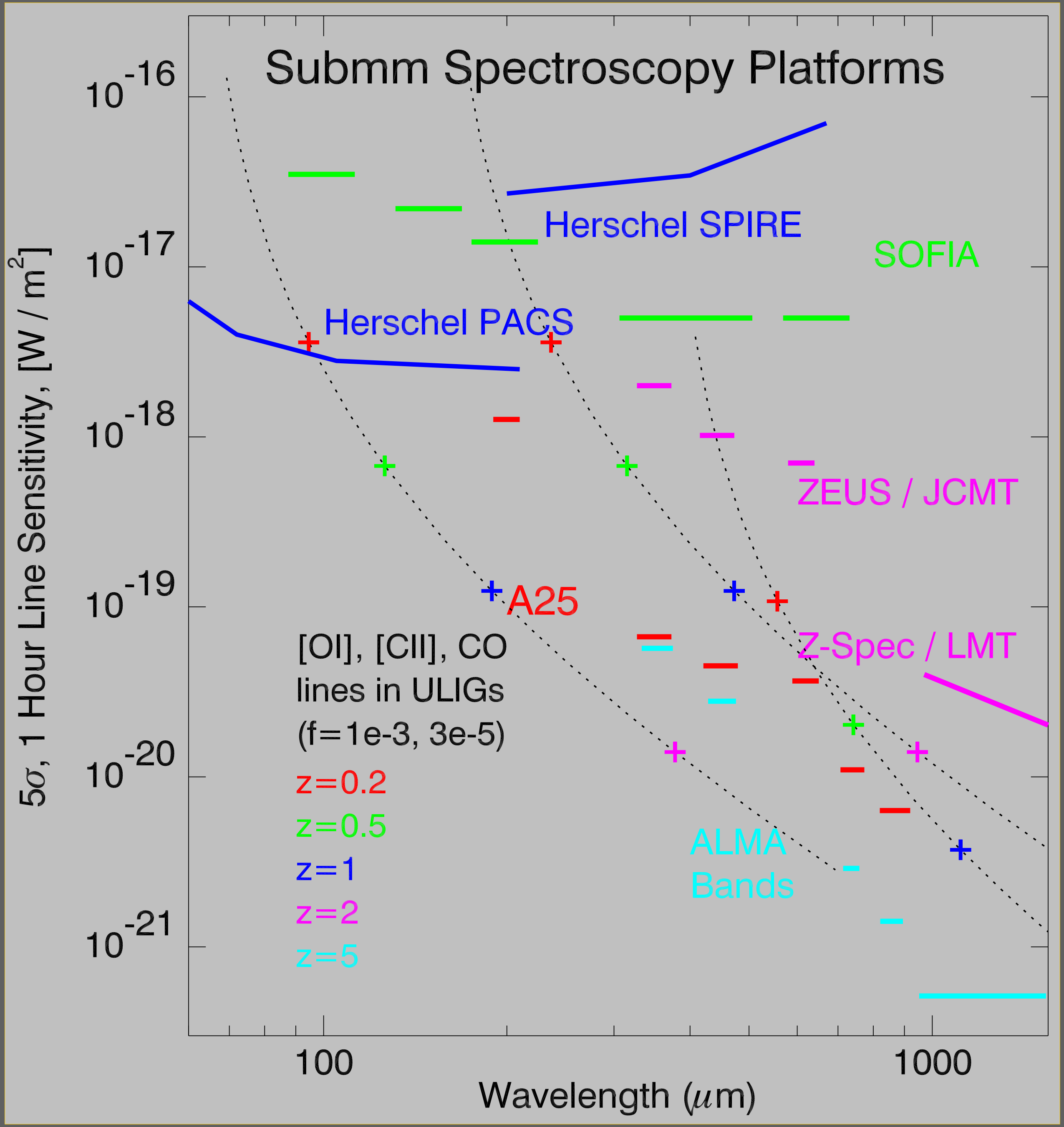
→ Single apertures can have large η's (sky and surface)

→ ***Broad bandwidth and multiple spatial beams provide further capability advantage***


Quantum Noise vs. Thermal BG
10 meter telescope w/ 20% loading
Temp = 300 K
150 K
80 K
30 K
10 K
5 K
10^{-19}
10^{-20}
10^{-21}
10^{-22}
5σ, 1 hour Line Sensitivity [W m^{-1}]
100
1000
Wavelength (μm)
Ground-based mm, submm
SOFIA
Herschel
Cold space telescope


Submm Spectroscopy Platforms
Herschel SPIRE
SOFIA
Herschel PACS
ZEUS / JCMT
A25
Z-Spec / LMT
(Raw point-source sensitivity, 5σ, 1 h)
ALMA Bands
5σ, 1 Hour Line Sensitivity, [W / m2]
10-16
10-17
10-18
10-19
10-20
10-21
100
1000
Wavelength (μm)


Submm Spectroscopy Platforms
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
5σ, 1 Hour Line Sensitivity, [W / m^2]
100
1000
Wavelength (μm)
Herschel SPIRE
SOFIA
Herschel PACS
ZEUS / JCMT
A25
Z-Spec / LMT
Arrows account for
time to survey full
telluric window or 10%
ALMA
Bands



Submm Spectroscopy Platforms
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
5σ, 1 Hour Line Sensitivity, [W / m^2]
Herschel SPIRE
SOFIA
Herschel PACS
ZEUS / JCMT
A25
Z-Spec / LMT
[OI], [CII], CO
lines in ULIGs
(f=1e-3, 3e-5)
z=0.2
z=0.5
z=1
z=2
z=5
ALMA
Bands
100
1000
Wavelength (μm)

Challenges for far-IR through mm spectrometers for ground-based telescopes

Best use of good weather depends on scientific goals

- Spectral mapping of galactic regions, nearby galaxies:
  ➔ Optimize number of spatial elements with sufficient spectral coverage
- Galactic nuclei, point sources w/ known redshifts:
  ➔ Optimize sensitivity w/ a few spectral elements → maximize throughput
- Follow up of point sources w/ unknown redshifts:
  ➔ Maximize number of simultaneous spectral resolution elements (Width of telluric bands presents the fundamental limit) $\delta\nu / \nu \sim 0.1$
- The future → multi-object submm spectroscopy?
  ➔ $\delta\nu / \nu \sim$ 0.1--0.4 *AND* $N_{sources} \sim$ 10-100

Spectrometer Architectures

- Heterodyne receivers provide the highest spectral
  - But suffer from quantum noise
    $NEP_{QN} \sim h\nu\, [\delta\nu]^{1/2}$ vs. $NEP_{BG} \sim h\nu\, [n\, (n+1)\, \delta\nu]^{1/2}$
  - Also offer limited bandwidth:
    - 10 GHz IF bandwidth at 1 THz gives $\nu\, /\, \Delta\nu \sim 100$
- Fourier transform spectrometer (FTS) couples the full
  - Sensitivity penalty
- Fabry-Perot naturally accommodates spectral mapping
  - But scanning time results in sensitivity penalty, esp for searching
- *Grating spectrometer is the best choice for point sources*
  - 1^{st} order → octave of instantaneous bandwidth
  - Good efficiency
  - But only moderate resolution

Instrument size an issue for long λ grating systems
Conventional broadband grating systems are huge when scaled to λ~100 μm

For example: SIRTF IRS Long-Hi module: 40 x 15 x 20 cm for R=600 at 37 μm.
→For 200 μm, this module would be over 2 meters in size.

→Much larger than required by fundamental limit: L ~ R x λ.

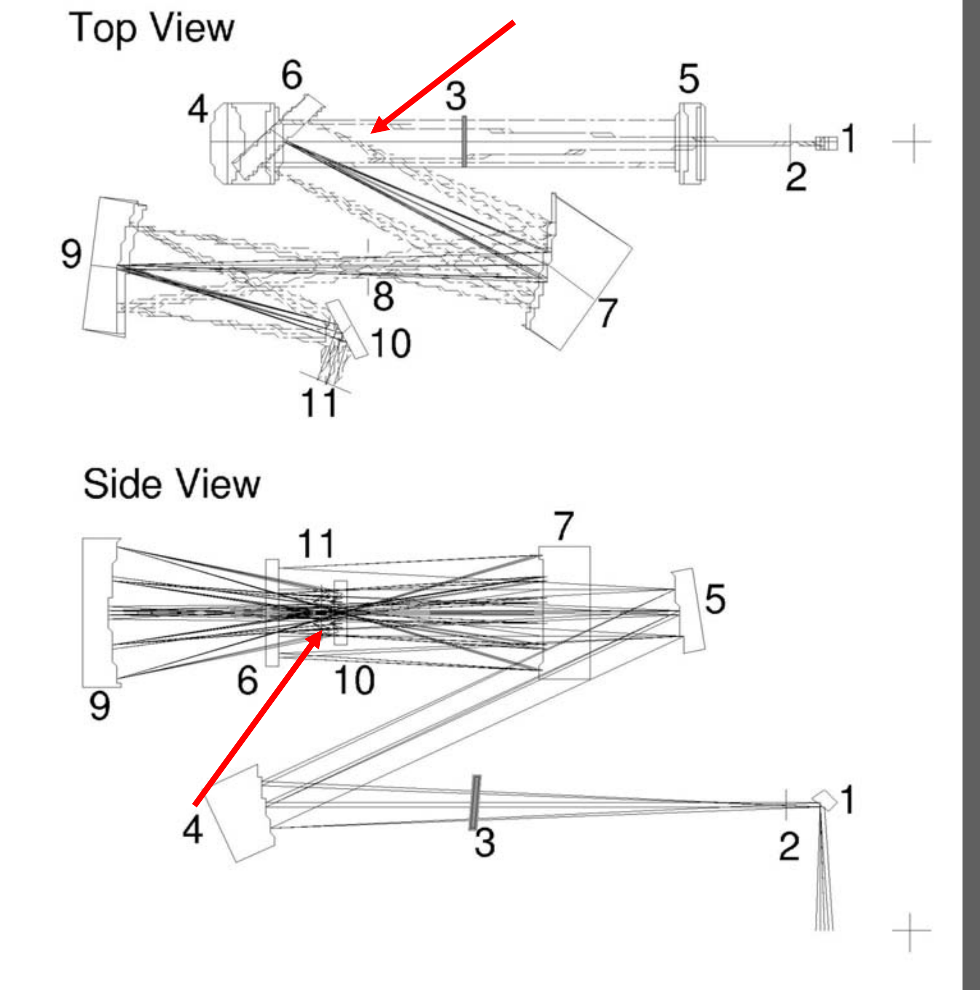


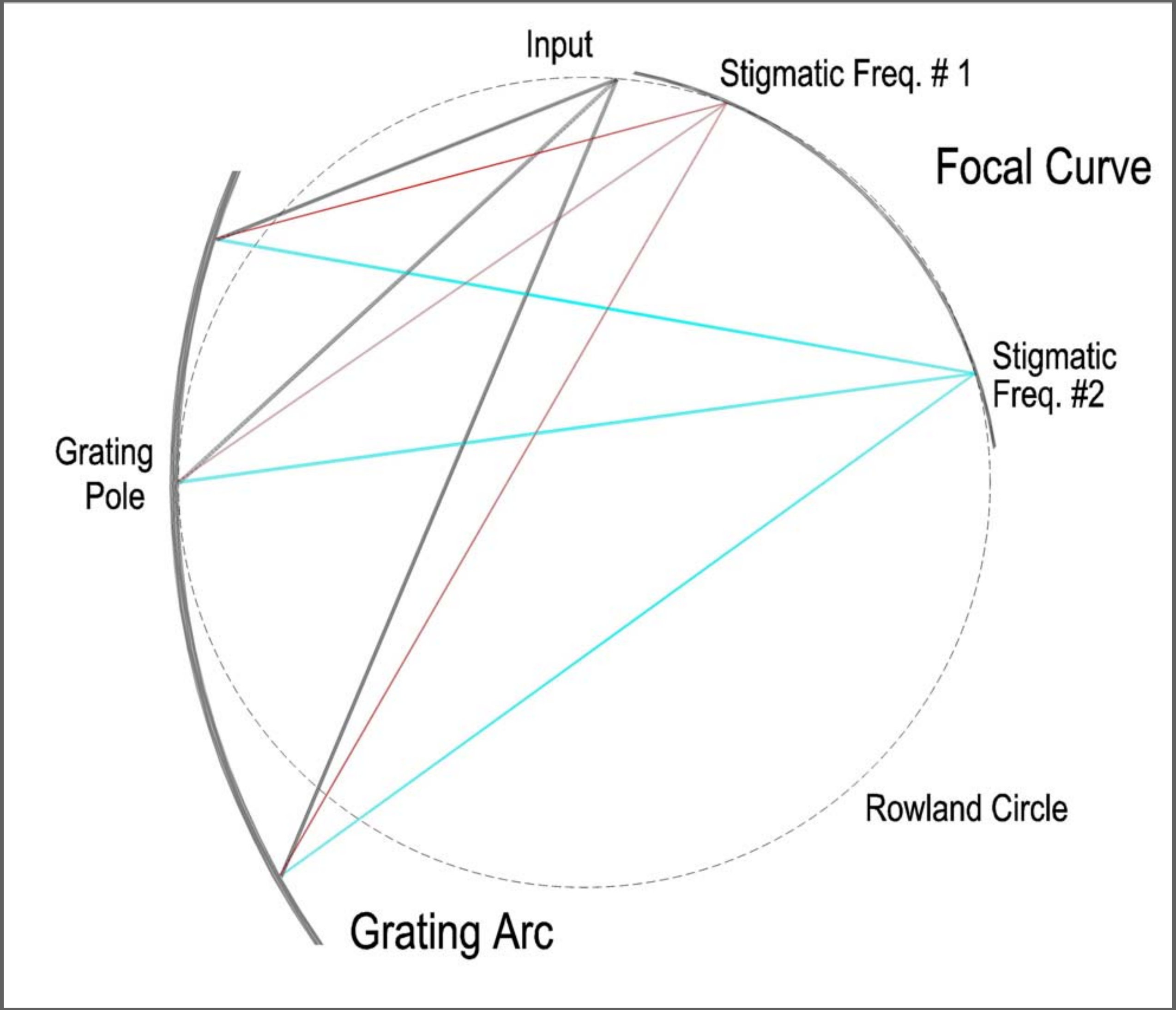
Figure 5. The IRS long-high module optical layout.

SIRTF IRS long-high module--Roellig et al. 1999

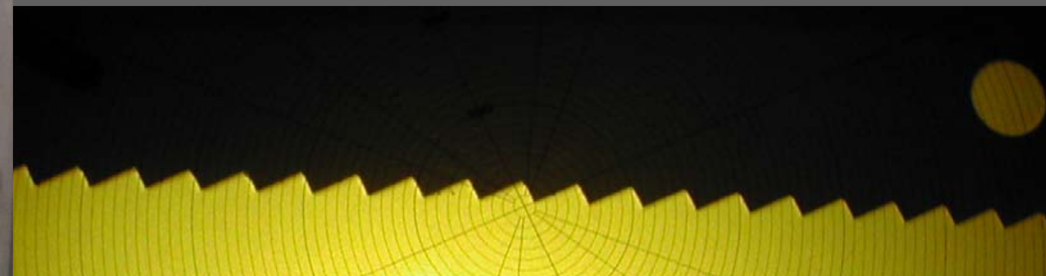
A solution – curved grating in waveguide

Each facet positioned to provide perfect performance at two frequencies

➔ System is diffraction-limited over the full band.



New work in submillimeter-wave broadband systems: Z-Spec for CSO / 30 m / LMT



Summary -- toward the future

- A very large single-aperture telescope at the world's best site can provide a spectroscopy platform with raw sensitivity approaching that of ALMA in the short submillimeter windows
  - And large bandwidth and / or many spatial beams can provide a substantial advantage for spatial / spectral surveying
  - 200 μm window is completely unique to Atacama (or South Pole)
- Such a platform will allow probing of the dense atomic / ionized ISM at redshifts of up to 2 – near the peak of the star-formation activity.
- The submillimeter is the final technical frontier and spectrometer and detector technology will continue to improve and adapt to new scientific questions
  - Not all the photons focused in the field of the telescope are yet detected with $\delta\nu / \nu = 1000$!