ALMA & CCAT

ALMA: Atacama Large Millimeter/sub-mm Array
CCAT-p: Cerro Chajnantor Atacama Telescope (prime)

ALMA: 66 dish (7, 12 m) interferometer

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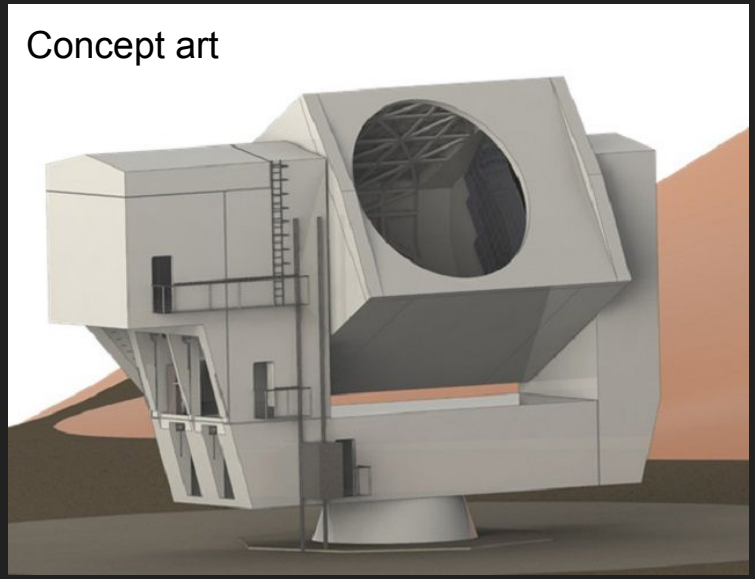
CCAT-p: Cerro Chajnantor Atacama Telescope (prime)

CCAT-p: single dish, 6 m diameter



Sub-mm

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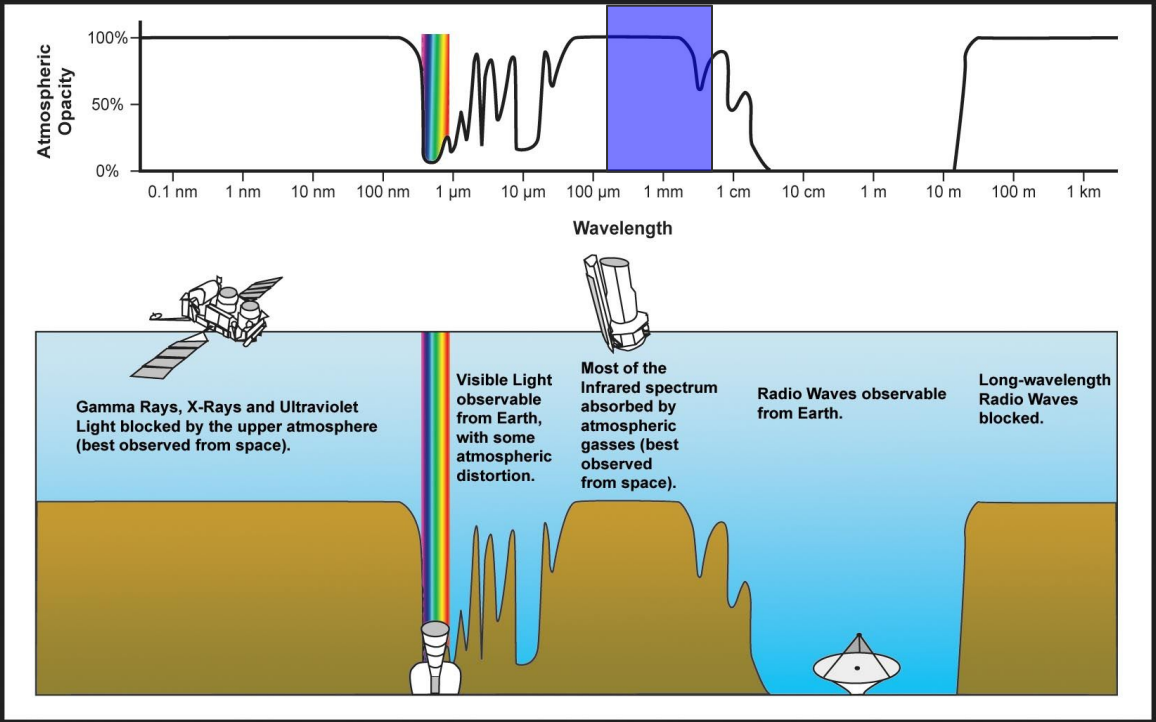

ALMA:
35--940 GHz (8.5--0.32 mm)

CCAT:
100--1500 GHz (3--0.2 mm)

https://almascience.nrao.edu/about-alma/alma-site

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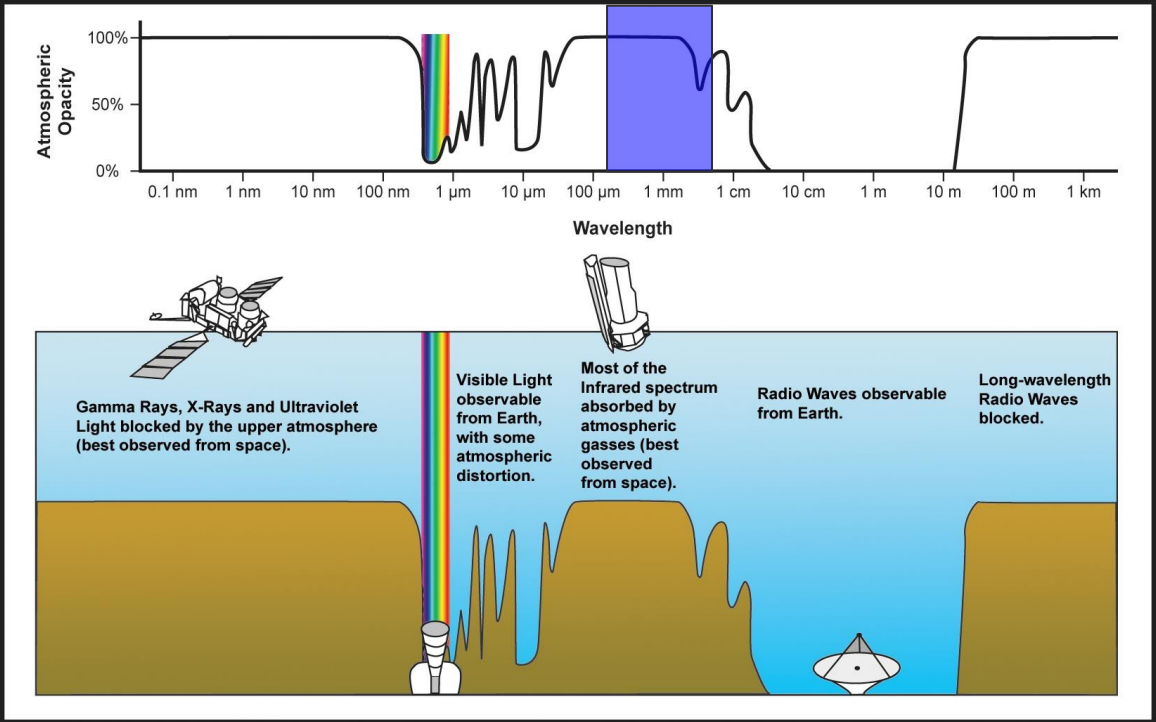

Call this range 10--0.1 mm or 1 cm to 100 micron.

$$\theta = 1.2\lambda/d$$

d = 6 m yields

7′ at 10 mm

4″ at 0.1 mm

d = 16 km yields

0.15″ at 10 mm

0.001″ at 0.1 mm

Sub-mm science

Molecular gas

- H_2 has no dipole moment
- CO(1-0): rotational energy state transition (angular momentum is quantized)
- Common lines: http://www.astro.wisc.edu/~sparke/book/errata/table1-8.pdf
- CO notes: http://w.astro.berkeley.edu/~ay216/08/NOTES/Lecture19-08.pdf

Sunyaev-Zel'dovich effect

- CMB photons inverse compton scatter off electrons' thermal (tSZ) and bulk motion (kSZ)

https://science.nrao.edu/facilities/alma/naasc-workshops/nrao-cd-columbia18/AA_2018_2_Science_Columbia.pdf

Sub-mm science

https://almascience.nrao.edu/observing/highest-priority-projects

EHT VLBI (Sgr A*, M87): https://eventhorizontelescope.org/simulations-gallery

ALMA

ALMA Band	Wavelength coverage (mm)	Noise Temperature (K) Specification	Frequency (GHz)	Produced by	Receiver Technology	First light
1	6–8.5	26	35 – 50	TBD	HEMT	TBD
2	3.3–4.5	47	65 – 90	TBD	HEMT	TBD
3	2.6–3.6	60	84 – 116	HIA	SIS	2009
4	1.8–2.4	82	125 – 163	NAOJ	SIS	2013
5	1.4–1.8	105	163 – 211	OSO / NOVA	SIS	2016
6	1.1–1.4	136	211 – 275	NRAO	SIS	2009
7	0.8–1.1	219	275 – 373	IRAM	SIS	2009
8	0.6–0.8	292	385 – 500	NAOJ	SIS	2013
9	0.4–0.5	261	602 – 720	NOVA	SIS	2011
10	0.3–0.4	344	787 – 950	NAOJ	SIS	2012

ALMA Interferometry

Considerations (ALMA Primer)

- Angular resolution
- Maximum Recoverable Scale (MRS)
- Field of view
- Spectral resolution
- Noise
- Dynamic range

ALMA - technical handbook

1. Introduction
2. **Array Components**
3. Principles and Concepts of Interferometry
4. **Receivers**
5. The Correlators
6. **Spectral Setups**
7. **Imaging with ALMA**
8. Observing Modes
9. ALMA Sensitivity Calculator
10. **Calibration and Calibration Strategies**
11. ...

A. **Antennas**

https://almascience.nrao.edu/documents-and-tools/latest/documents-and-tools/cycle6/alma-technical-handbook

CCAT-p

CCAT-p

- Single-dish, high sensitivity and large FOV (~6 deg.!)
  - “Intensity mapping”: f_gas(z)
  - kSZ effect from clusters
- Multiple instruments
- Crossed Dragone design
  - Large FOV, preserves pol
  - https://arxiv.org/abs/1206.2402
  - Optics tubes to populate FOV
  - Pathfinders (~1 m) in recent yrs

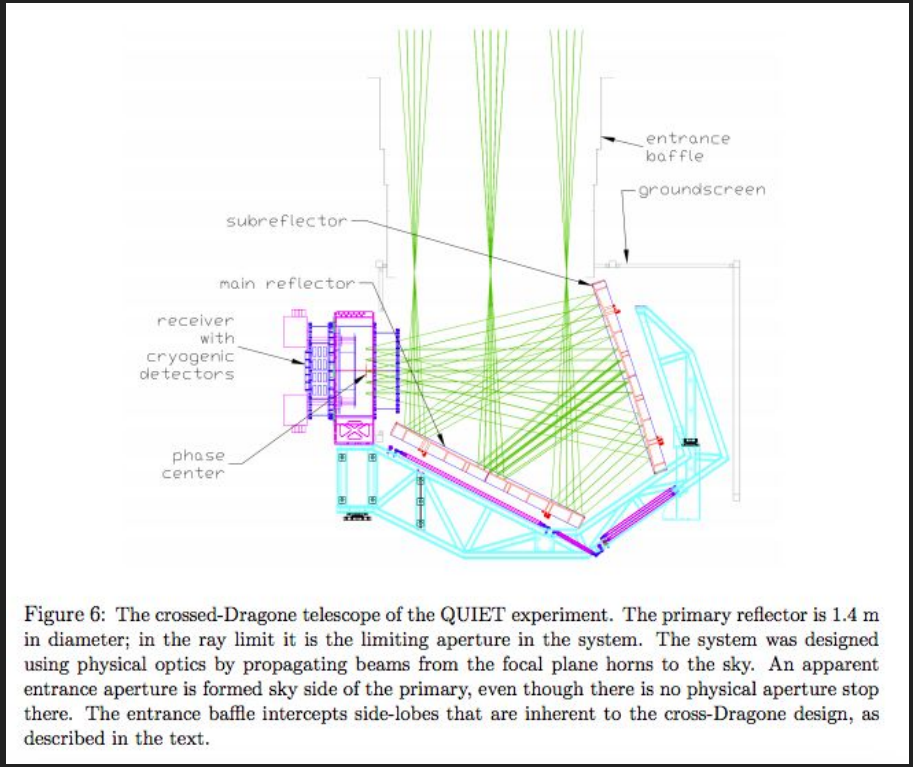

Figure 6: The crossed-Dragone telescope of the QUIET experiment. The primary reflector is 1.4 m in diameter; in the ray limit it is the limiting aperture in the system. The system was designed using physical optics by propagating beams from the focal plane horns to the sky. An apparent entrance aperture is formed sky side of the primary, even though there is no physical aperture stop there. The entrance baffle intercepts side-lobes that are inherent to the cross-Dragone design, as described in the text.

CCAT-p

- Single-dish, high sensitivity and large FOV (~6 deg.!)
  - “Intensity mapping”: f_gas(z)
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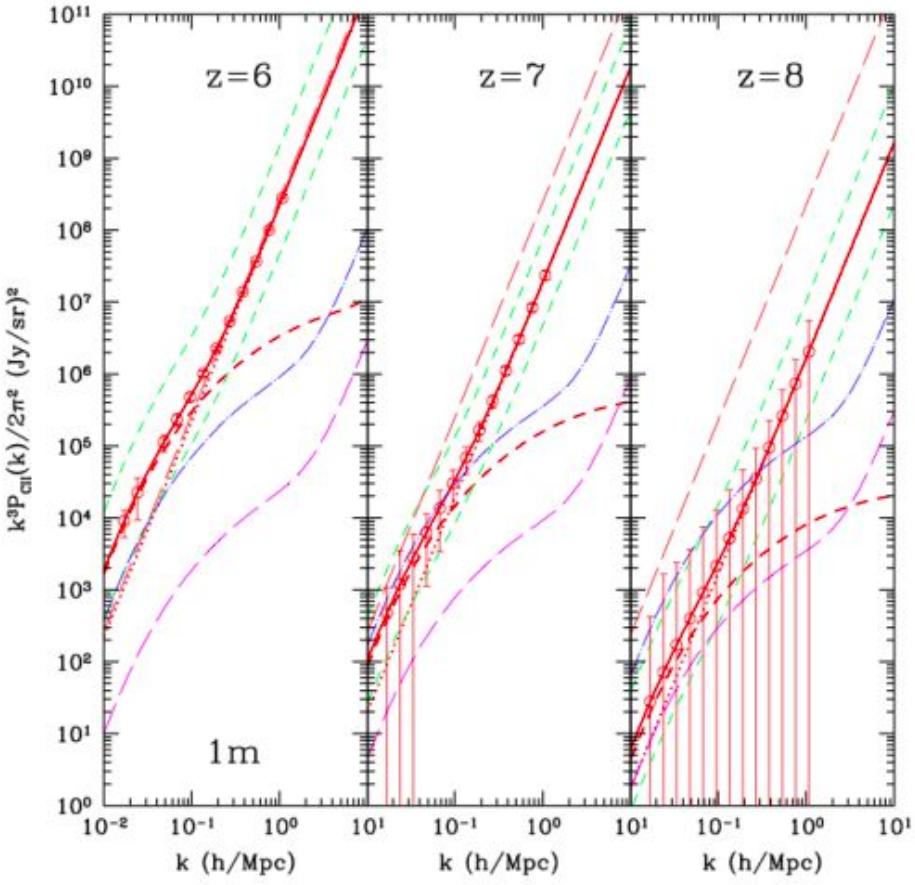
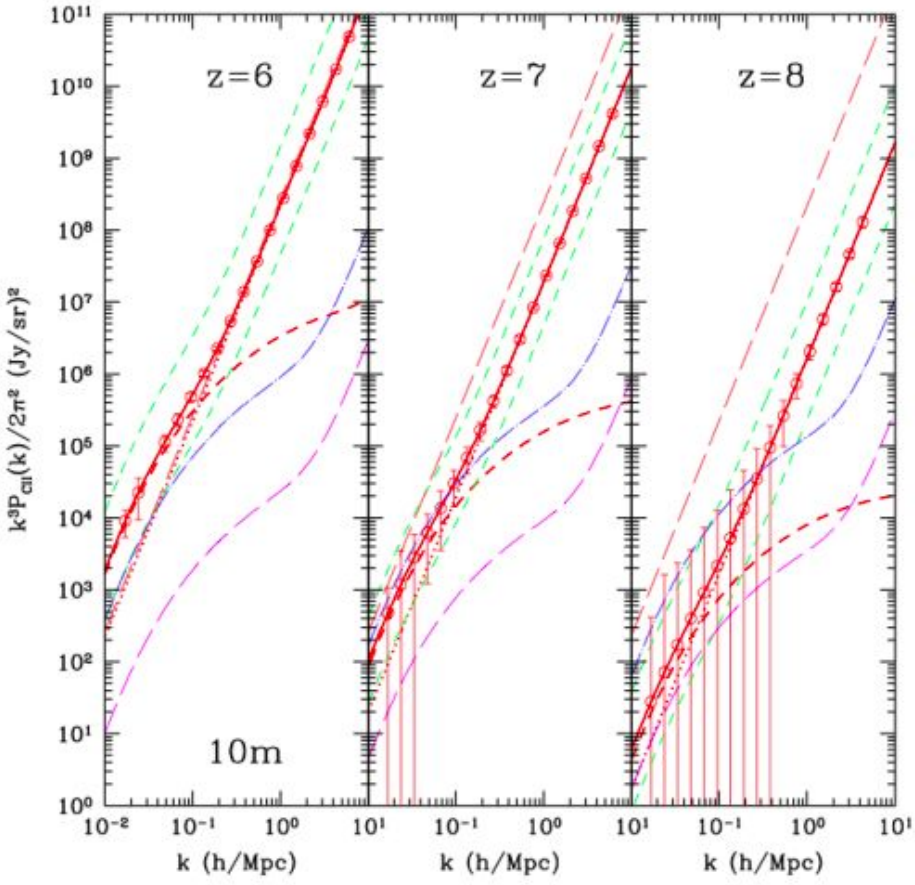
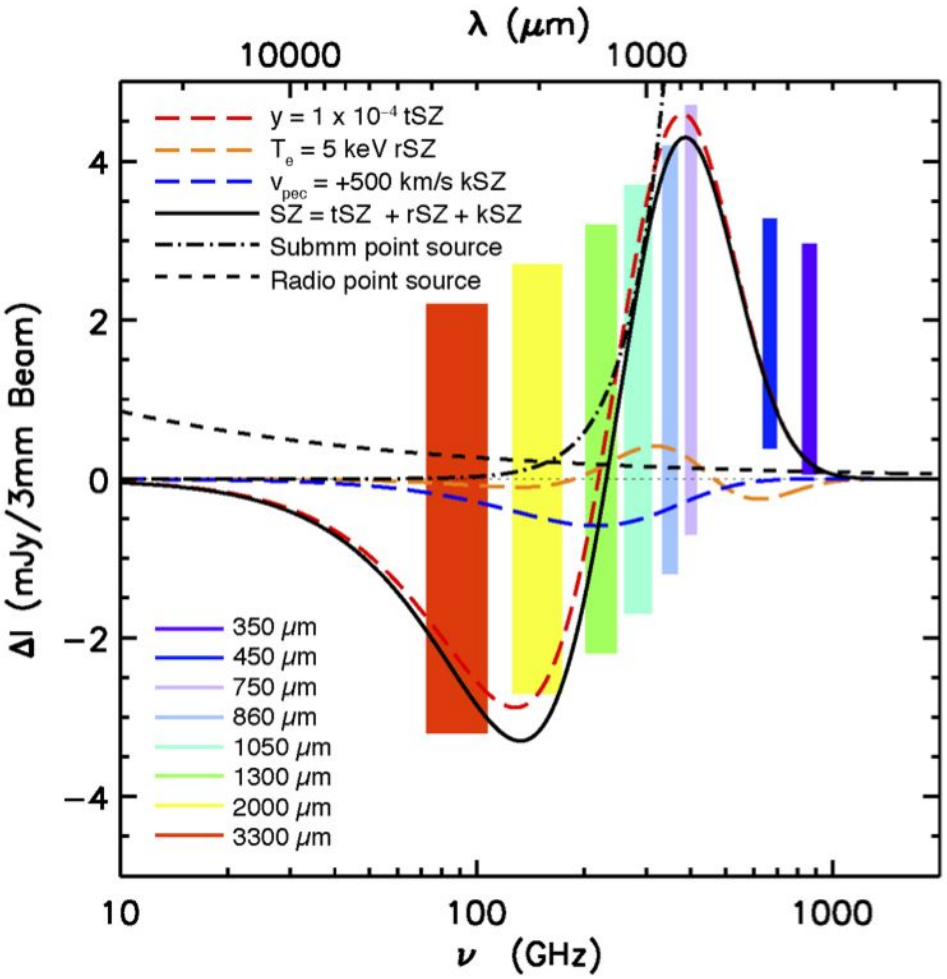
http://www.ccatobservatory.org/docs/ccat-technical-memos/ccatp_im_v2.pdf

http://www.ccatobservatory.org/index.cfm/page/science/science-facts/kSZ.htm


z=6
z=7
z=8
1m
$k^3P_{cll}(k)/2\pi^2$ (Jy/sr)^2
k (h/Mpc)
k (h/Mpc)
k (h/Mpc)


z=6
z=7
z=8
10m
$k^3P_{cll}(k)/2\pi^2$ (Jy/sr)^2
k (h/Mpc)
k (h/Mpc)
k (h/Mpc)


λ (μm)
10000
1000
y = 1 x 10⁻⁴ tSZ
T_e = 5 keV rSZ
v_pec = +500 km/s kSZ
SZ = tSZ + rSZ + kSZ
Submm point source
Radio point source
350 μm
450 μm
750 μm
860 μm
1050 μm
1300 μm
2000 μm
3300 μm
ΔI (mJy/3mm Beam)
4
2
0
−2
−4
10
100
1000
ν (GHz)

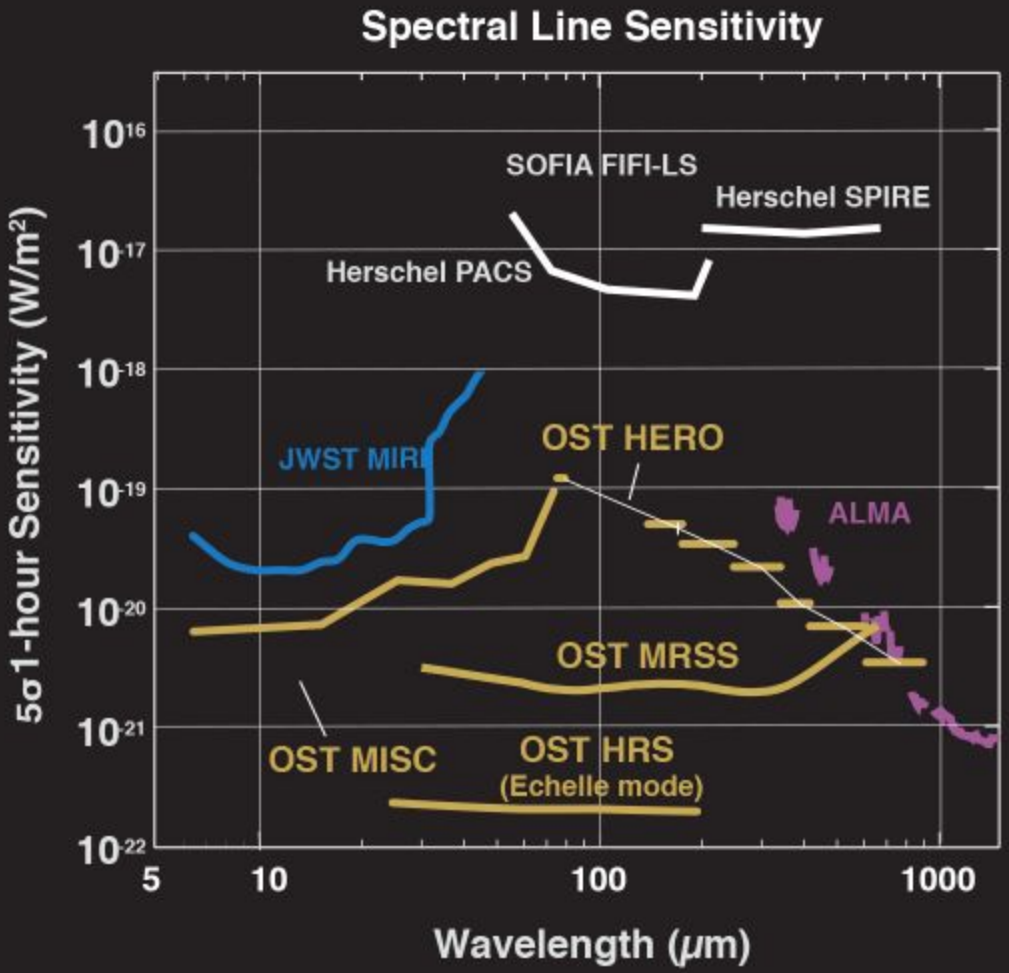
Adjacent or overlapping telescopes on EM spectrum

Far-IR: Herschel, SOFIA, Origins (decadal)

Sub-mm single dish: Caltech Sub-mm Observatory, IRAM 30m (Spain), LMT (Mexico), JCMT 15m (Hawaii), SMT 10m (Arizona) & 12m ALMA prototype (Kitt Peak), SPT 10m (SP)

Sub-mm interf: PdBI->NOEMA (French Alps), CARMA (CA now defunct), SMA (Hawaii/CfA), Simons Observatory (Chile, CCAT-p design)

Lower freq: JVLA (and ngVLA), GBT, GMRT


Spectral Line Sensitivity
SOFIA FIFI-LS
Herschel SPIRE
Herschel PACS
JWST MIRI
OST HERO
ALMA
OST MRSS
OST MISC
OST HRS
(Echelle mode)
5σ1-hour Sensitivity (W/m²)
10¹⁶
10⁻¹⁷
10⁻¹⁸
10⁻¹⁹
10⁻²⁰
10⁻²¹
10⁻²²
5
10
100
1000
Wavelength (μm)

REFERENCES

ALMA Community Day at Columbia last year, hosted by Statia Cook / NRAO:
https://science.nrao.edu/facilities/alma/naasc-workshops/nrao-cd-columbia18/program

NRAO Essential Radio Astronomy (Condon & Ransom):
https://science.nrao.edu/opportunities/courses/era/

ALMA science portal:
https://almascience.nrao.edu/

Notes from an undergrad radio course:
https://casper.berkeley.edu/astrobaki/index.php/Undergraduate_Radio_Lab