# The Infra-red and the sub-millimeter sky

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The study of the interstellar medium was revolutionized by the discovery HI 21-cm line, the study of molecules in the millimeter band and the study of fine structure lines in the sub-millimeter and far-infrared. Separately, the discovery by COBE that half of the stellar light is reprocessed to far infrared band by dust completed this amazing revolution.

The UV through radio background is shown in Figure 1. See `https://www.gemini.edu/observing/telescopes-and-sites/sites#Transmission` The next two pages are from Ned Wright's UCLA homepage: `http://www.astro.ucla.edu/~wright/CIBR/`. Note that the unit he quotes should really be $I_\nu \nu$ (intensity multiplied by frequency, not simply spectral intensity).

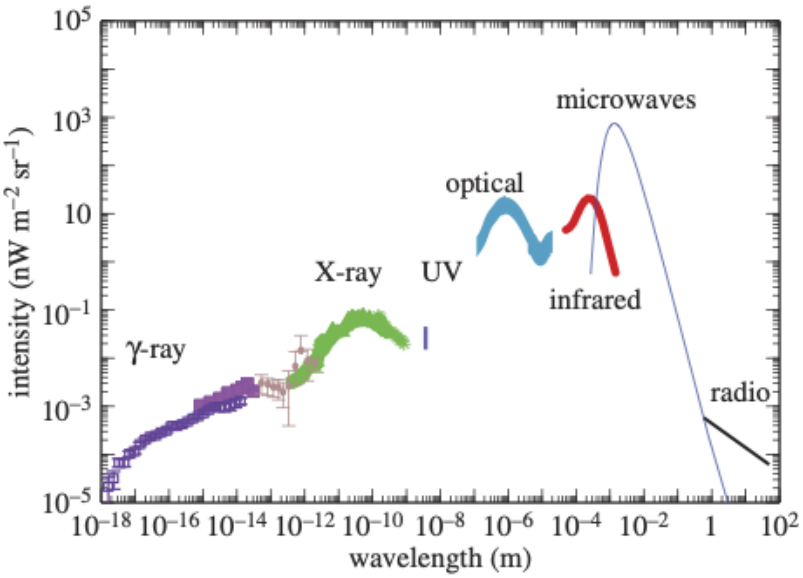
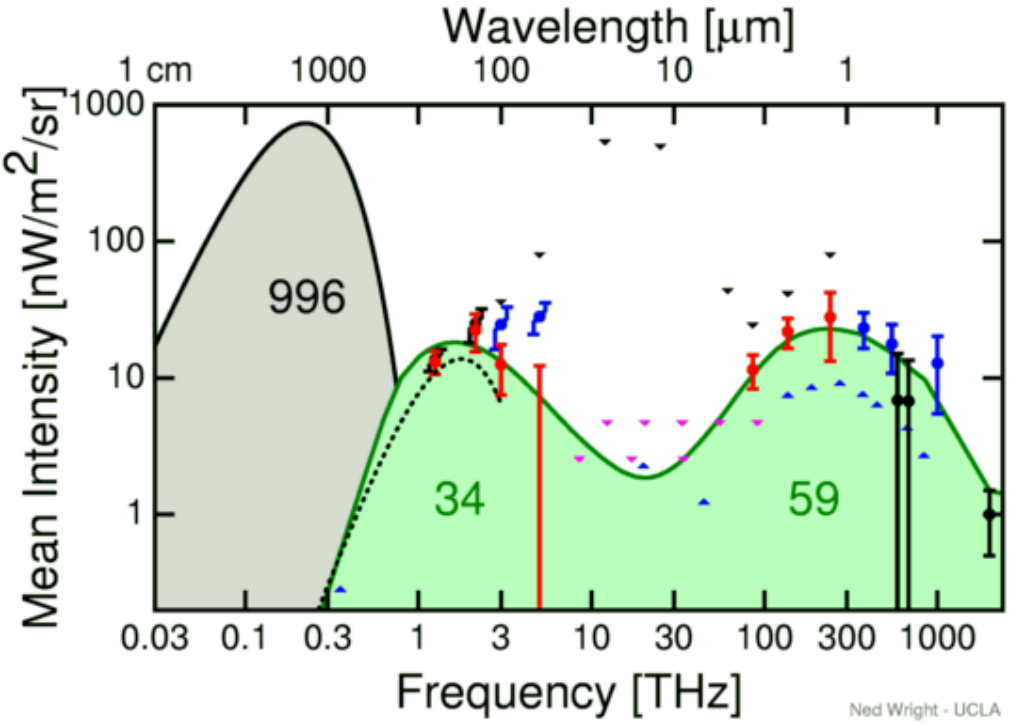



Figure 1: Cosmic background (after subtracting contribution from our own Galaxy. From A. Cooray (Royal Society Open Service, 3, 150555).

# Cosmic InfraRed Background Radiation

The Cosmic InfraRed Background (CIRB) is the radiation from stars in many faint galaxies. It is what is left over after emission from our Solar System and our Galaxy has been subtracted away. Here are pictures of the sky before and after this foreground subtraction. The near-infrared (wavelengths near 2-3 microns) and optical (wavelengths near 500 nm) part of this extragalactic background light is just starlight redshifted into the infrared. But some starlight is absorbed by dust and re-emitted in the far-infrared (wavelengths near 100 microns). The figure below shows the cosmic near-infrared background in red in the center right, Rebecca Bernstein's optical cosmic background in blue on the far right, my recomputation of the far infrared background in red in the center left, the FDS 60 and 100 micron values in blue, the cosmic microwave background in gray on the far left.




The CMB is by far the largest of these radiation fields, with a total intensity of 996 nW/m$^2$/sr. The cosmic far-IR background, which was announced in January 1998, has a total intensity of 34 nW/m$^2$/sr, while the cosmic near-IR background found by Gorjian, Wright & Chary and Wright & Reese has a total intensity when combined with the optical background of slightly less than 60 nW/m$^2$/sr. Together these IR backgrounds add up to about 9% of the CMB's total intensity.

The black data points between 1 and 300 microns on this graph come from the DIRBE experiment on the COBE satellite. The red data points are my modified and new DIRBE results which use a different zodiacal light model than the one used by Hauser *et al.* (1998, ApJ, 508, 25). The blue lower limit symbols are based on integrating galaxy counts, while the purple upper limit symbols are based on limits on photon-photon collisions from gamma-ray astronomy. The black data points at wavelengths shorter than 1 microns come from
Dube, Wickes & Wilkinson (1979, ApJ, 232, 333),
Toller (1983, ApJL, 266, 79), and
Hurwitz, Martin & Bowyer (1991, ApJ, 372, 167).

## The Atmosphere: ALMA, CCAT-P, SOFIA

Molecular rotational lines and fine structure lines appear in the sub-millimeter through mid infra-red portion of the electromagnetic spectrum. It is precisely this range which is blocked by molecules ($O_2$, $H_2O$, $O_3$ for the sub-millimeter and other molecules in the mid-infrared ) in our atmosphere.

The observatories at the highest elevation are best suited to the study of these lines. Examples include Mauna Kea (14,000 feet;) ALMA in the Atacama desert of Chile (5000 m) and CCAT-P (nearly 5500 m). SOFIA is an airborne observatory, flying and observing at 12,000 m.


Figure 2:

The atmospheric transmission from SOFIA (and compared with Mauna Kea) is shown in Figure 3 while the transmission of the sky for ALMA can be found in Figures 4 and 6. The Mauna Kea (altitude 4.2 km) transmission spectrum and the traditional bands used by JCMT are shown in Figure 5. These bands are designed to avoid $H_2O$ The small features seen within the bands are $O_2$ and $O_3$.

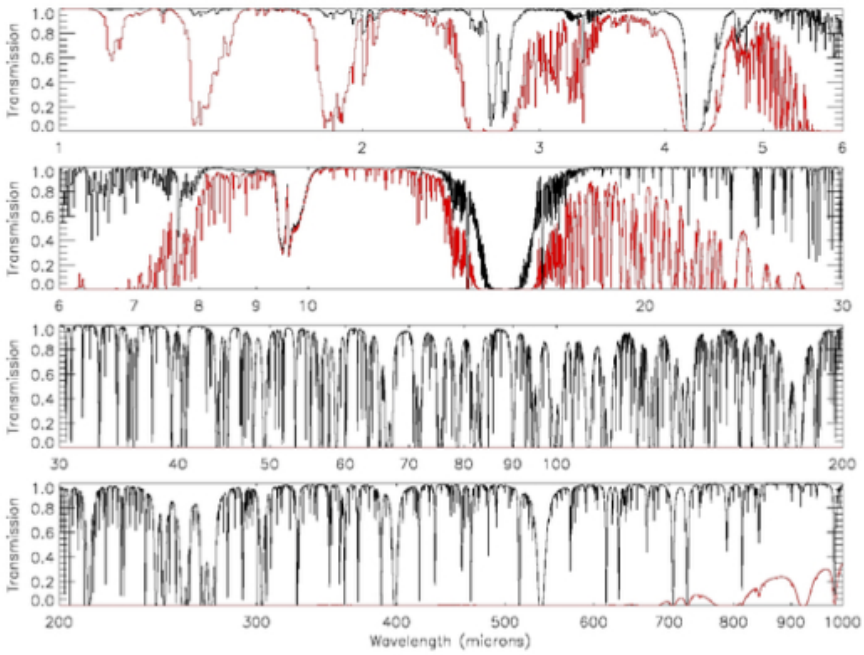



**Figure 3-4:** This is a plot showing the atmospheric transmission for SOFIA (black) at an altitude of 41K feet and 7.3 µm of precipitable water vapor compared to Mauna Kea (red) at an altitude of 13.8K feet and 3.4 mm water vapor over the range of 1 – 1000 µm. The transmission was calculated using the ATRAN code with a telescope zenith angle of 45°. and the data were smoothed to a resolution of R=2000.

Figure 3: SOFIA operated at altitudes above 99% of water vapor. Figure from "SOFIA Observer's Handbook for Cycle 5".

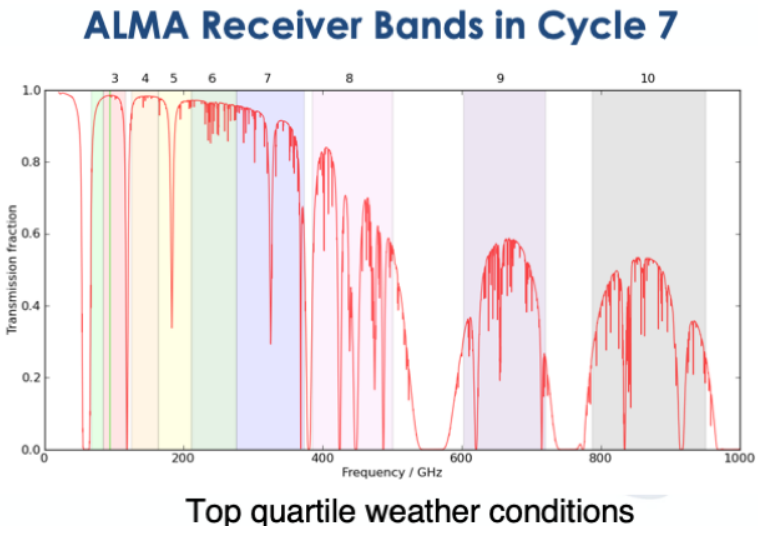



Figure 4: ALMA (excellent conditions). ALMA uses "Band $n$" designation with $n$ ranging from 3 to 10. The band numbers are shown on the top line.

| | | |
|---|---|---|
| Spectral Bands | 1100 μm | 8.1–10.4 $cm^{-1}$ (243–312 GHz) |
| | 850 μm | 11.2–12.1 $cm^{-1}$ (336–363 GHz) |
| | 750 μm | 12.9–13.9 $cm^{-1}$ (387–417 GHz) |
| | 450 μm | 21.1–23.5 $cm^{-1}$ (633–705 GHz) |
| | 351 μm | 26.2–29.2 $cm^{-1}$ (786–876 GHz) |
| | 349 μm | 28.8–29.9 $cm^{-1}$ (864–897 GHz) |

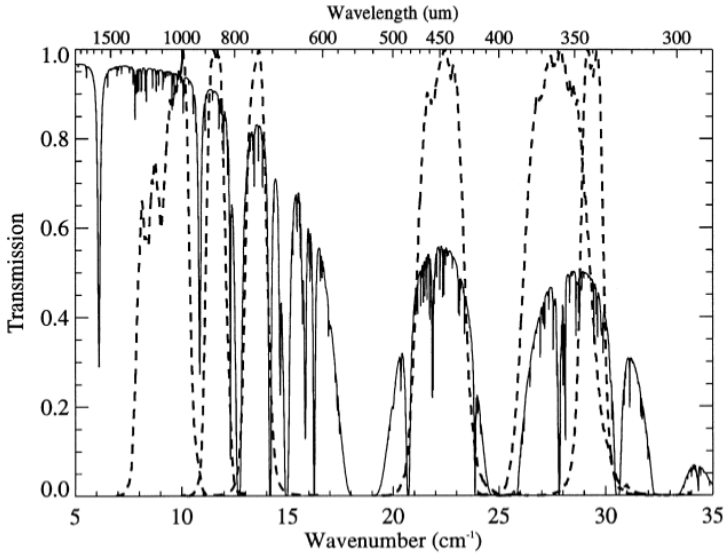



Figure 5: The transmission of the sky as measured by JCMT, atop Mauna Kea. The various bands of JCMT are shown by dashed lines. From Naylor, D. A. et al. (2000, MNRAS 315, 622).

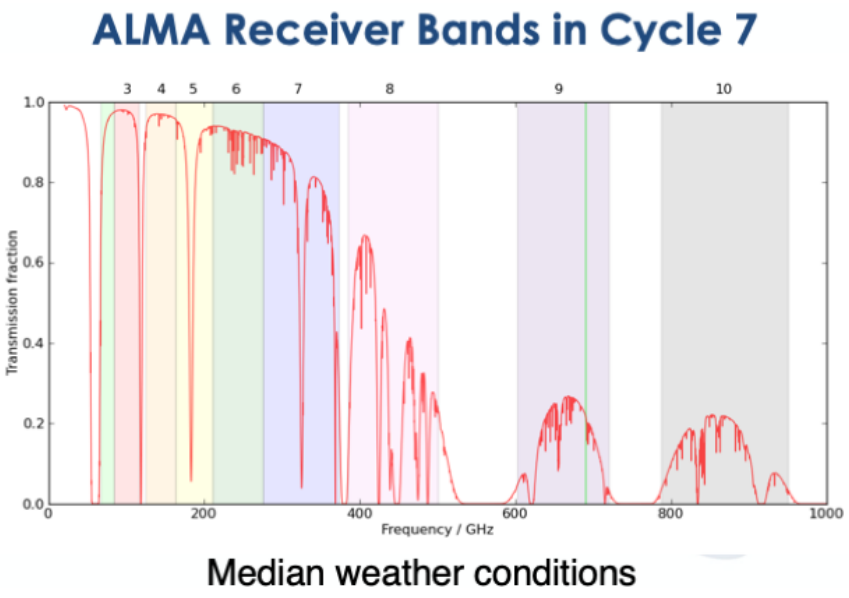



Figure 6: Same as Figure 4 except for median conditions.