Zodiacal Emission

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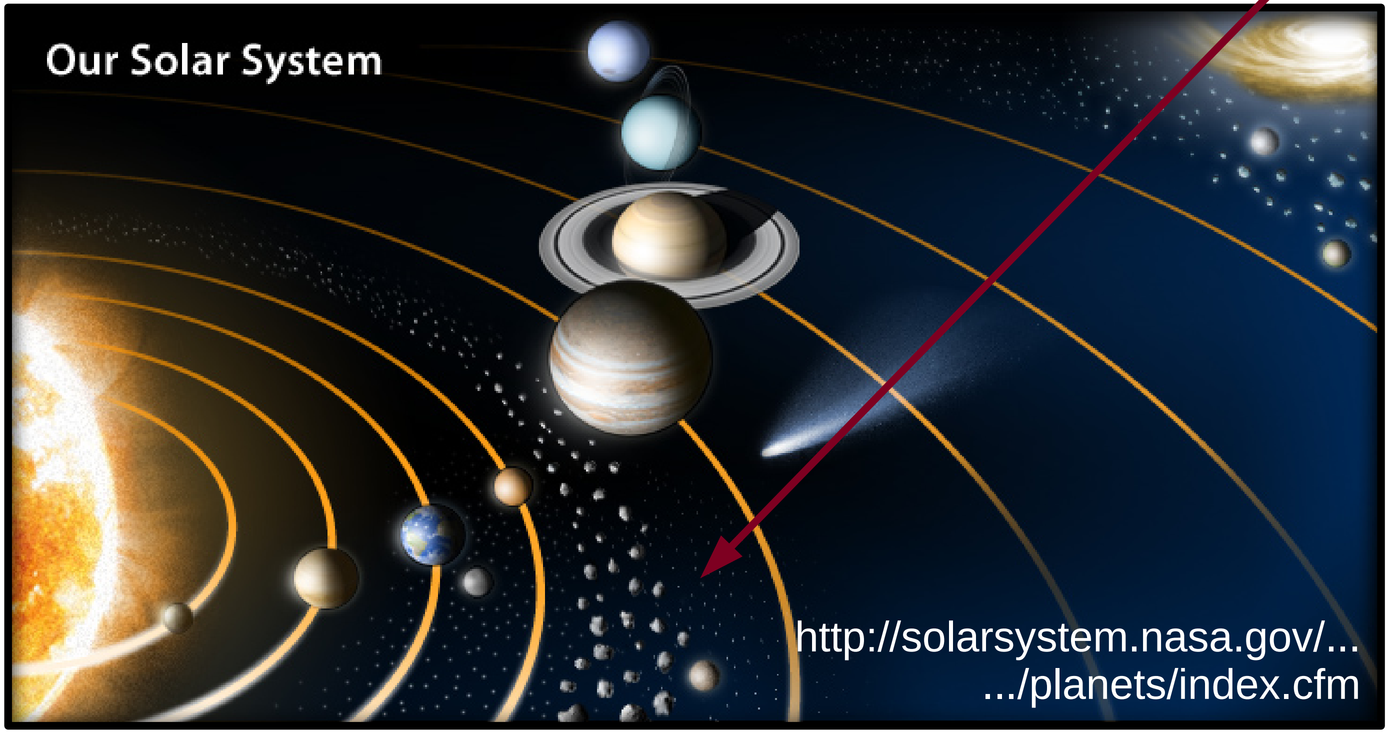
What is Zodiacal Emission?

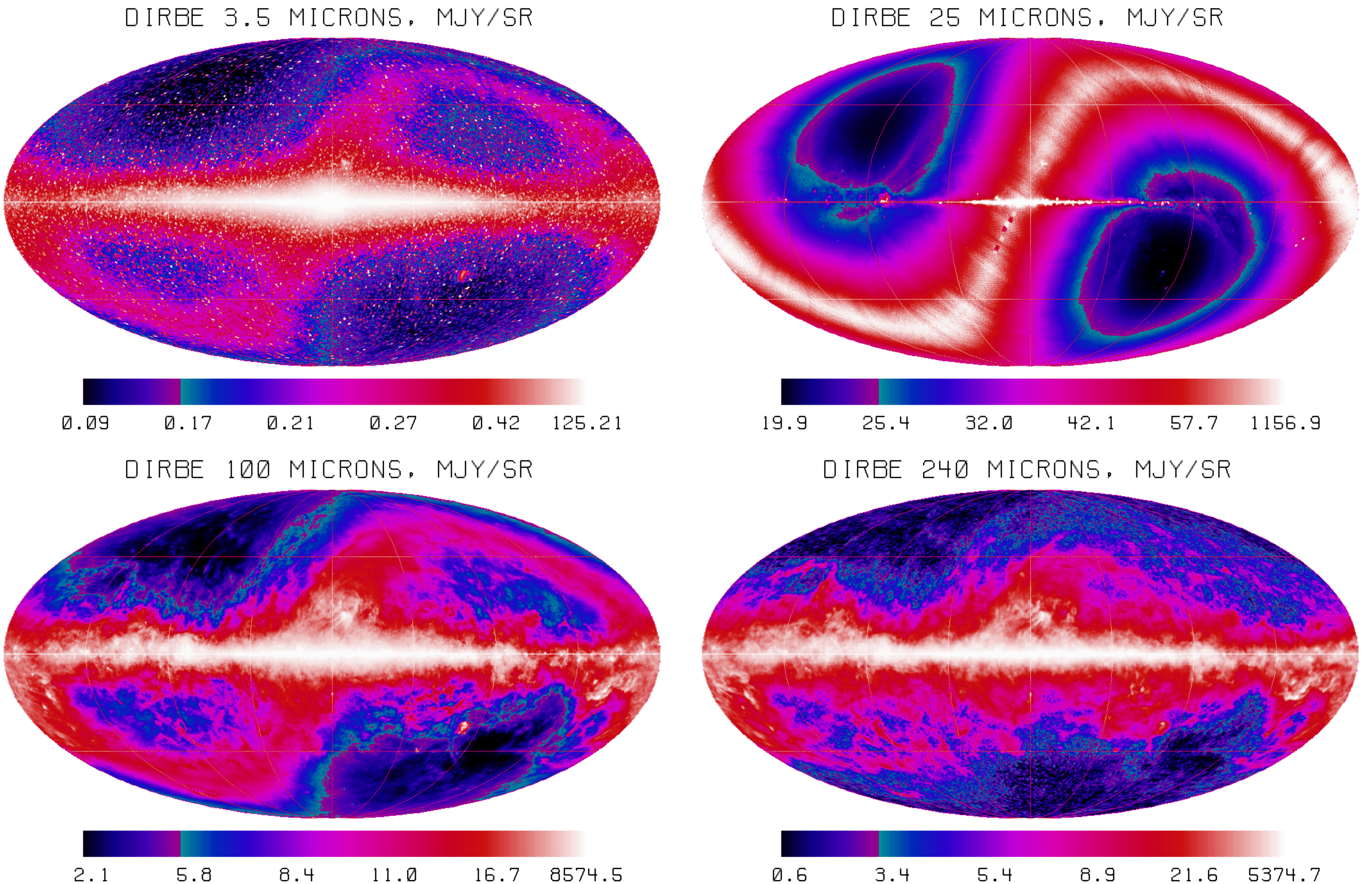
- There is “interplanetary” dust (IPD) in our Solar System, concentrated within the orbit of Jupiter, with an effective size of about 30 microns.
- This dust absorbs light from the Sun and re-emits it in the infrared and longer wavelengths.
- Because it is nearby, we see through different column depths when we observe the same distant point on the sky at different times of the year.



Brightness Spectrum

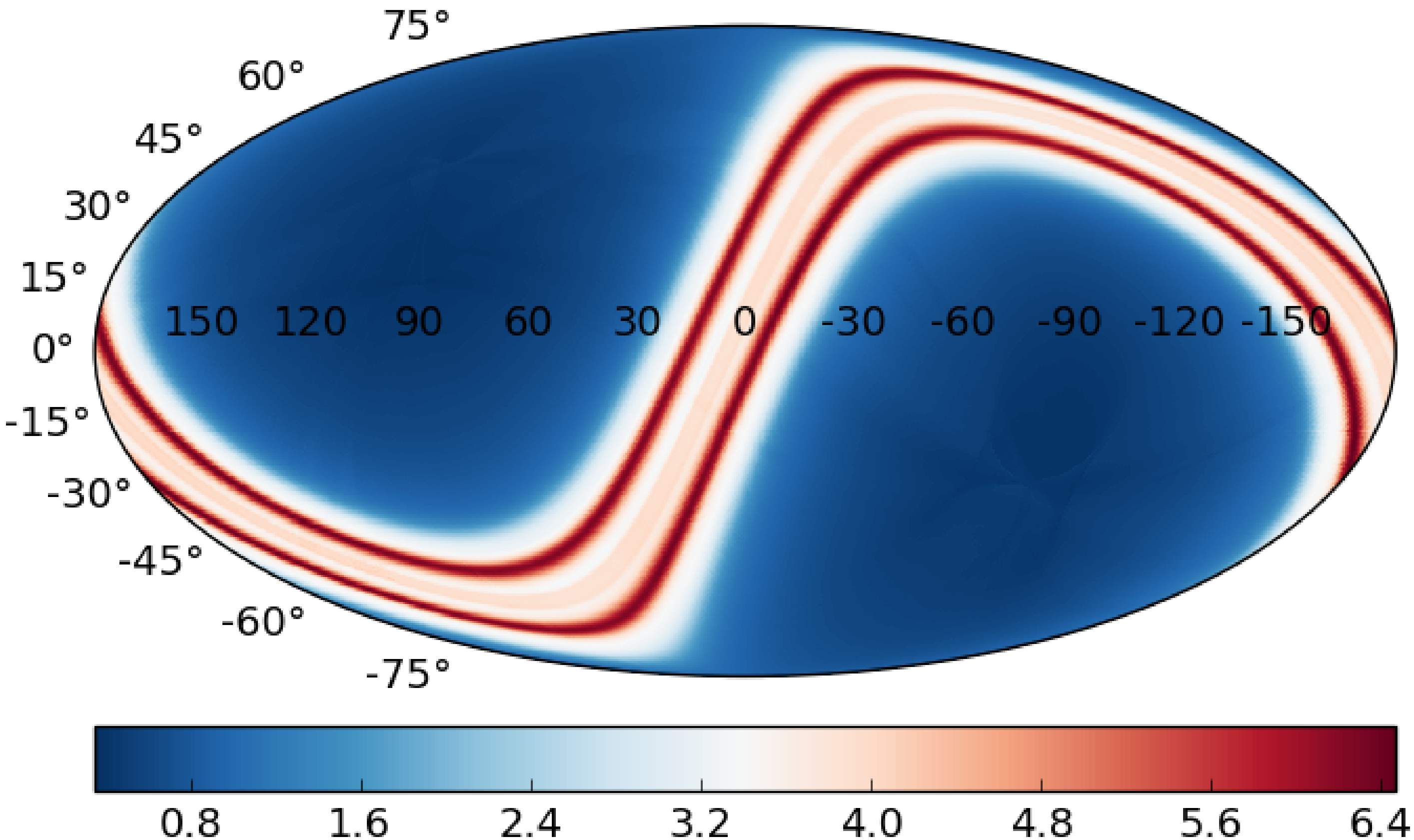
http://lambda.gsfc.nasa.gov/product/cobe/cobe_images/aaf.gif

Zodiacal emission dominates the sky brightness in the ~10 μm region.



It is mostly an optical/infrared phenomenon, but may be important for very sensitive experiments.

Zodi is “Seen” in Temperature by Planck



- It is really only “seen” in differences between observations taken ~6 months apart.
- The total signal depends on the details of how the sky is scanned

Brightness Spectrum

Zodiacal emission is subdominant in the microwave.

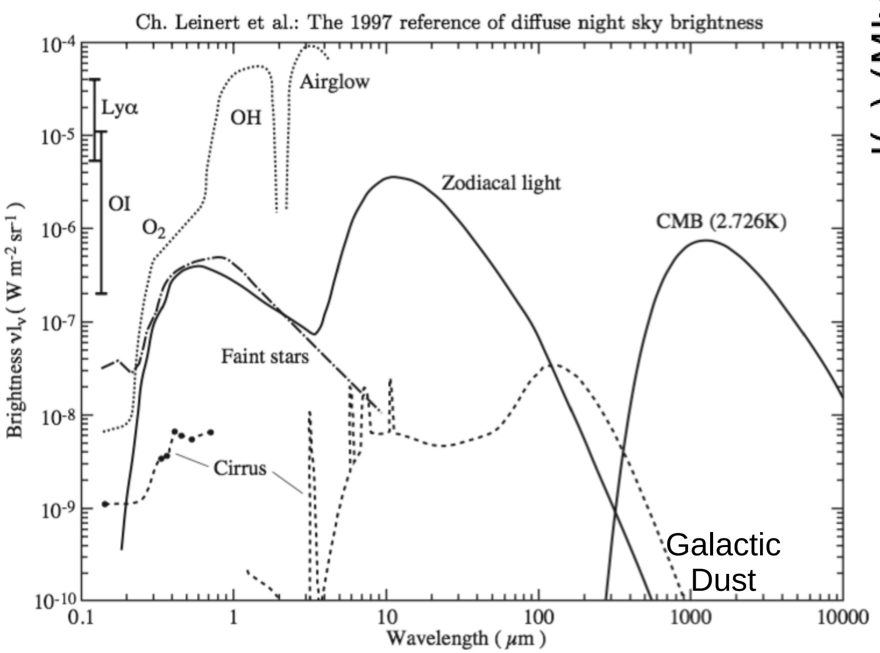
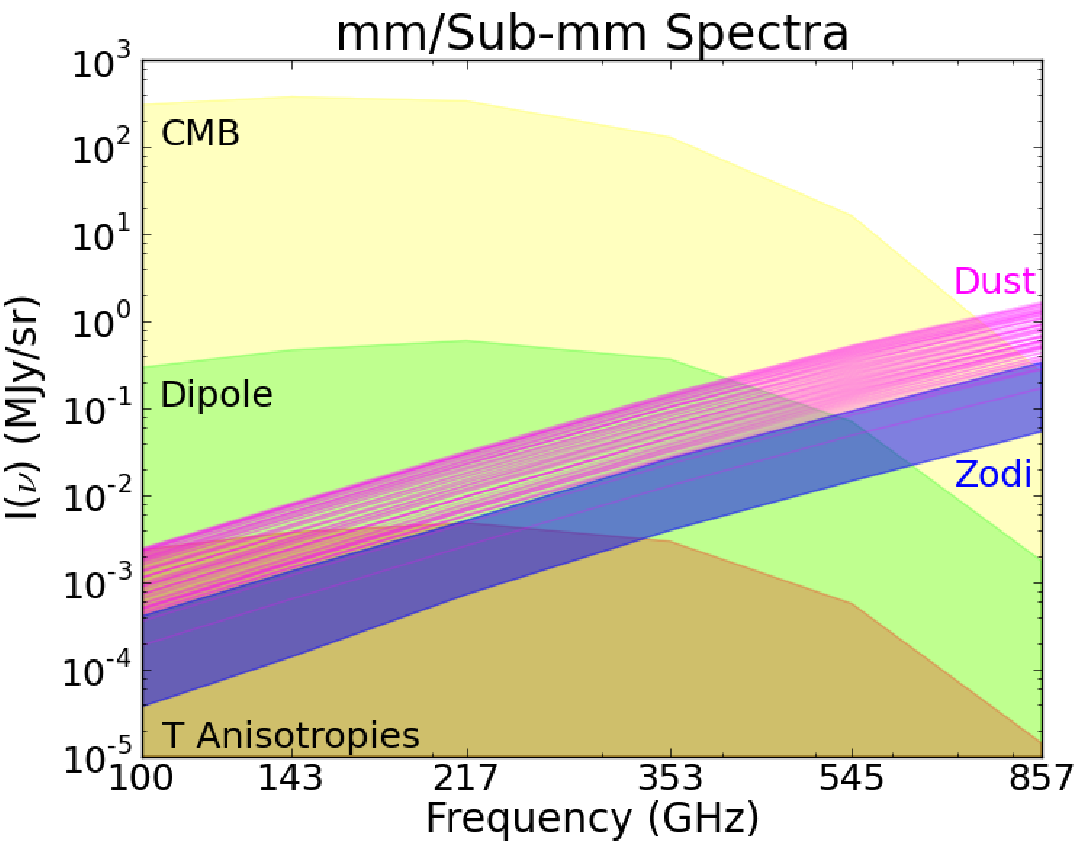


Fig. 1. Overview on the brightness of the sky outside the lower terrestrial atmosphere and at high ecliptic and galactic latitudes. The zodiacal emission and scattering as well as the integrated light of stars are given for the South Ecliptic Pole ($l = 276°$, $b = -30°$). The bright magnitude cut-off for the stellar component is $V = 6.0$ mag for $0.3 - 1$ μm. In the infrared, stars brighter than 15 Jy between 1.25 and 4.85 μm and brighter than 85 Jy at 12 μm are excluded. No cut-off was applied to the UV data, $\lambda \leq 0.3$ μm. The interstellar cirrus component is normalized for a column density of 10^{20} H-atoms cm^{-2} corresponding to a visual extinction of 0.053 mag. This is close to the values at the darkest patches in the sky. Source for the long-wavelength data, $\lambda \geq 1.25$ μm, are COBE DIRBE and FIRAS measurements as presented by Désert et al. (1996). The IR cirrus spectrum is according to the model of Désert et al. (1990) fitted to IRAS photometry. The short-wavelength data, $\lambda \leq 1.0$ μm, are from the following sources: zodiacal light: Leinert & Grün (1990); integrated starlight: $\lambda \leq 0.3$ μm, Gondhalekar (1990), $\lambda \geq 0.3$ μm, Mattila (1980); cirrus: $\lambda = 0.15$ μm, Haikala et al. (1995), $\lambda = 0.35 - 0.75$ μm, Mattila & Schnur (1990), Mattila (1979). The geocoronal Lyman α(121.6 nm) and the OI(130.4, 135.6 nm) line intensities were as measured with the Faint Object Camera of the Hubble Space Telescope at a height of 610 km (Caulet et al. 1994). The various references for the airglow emission can be found in Sect. 6



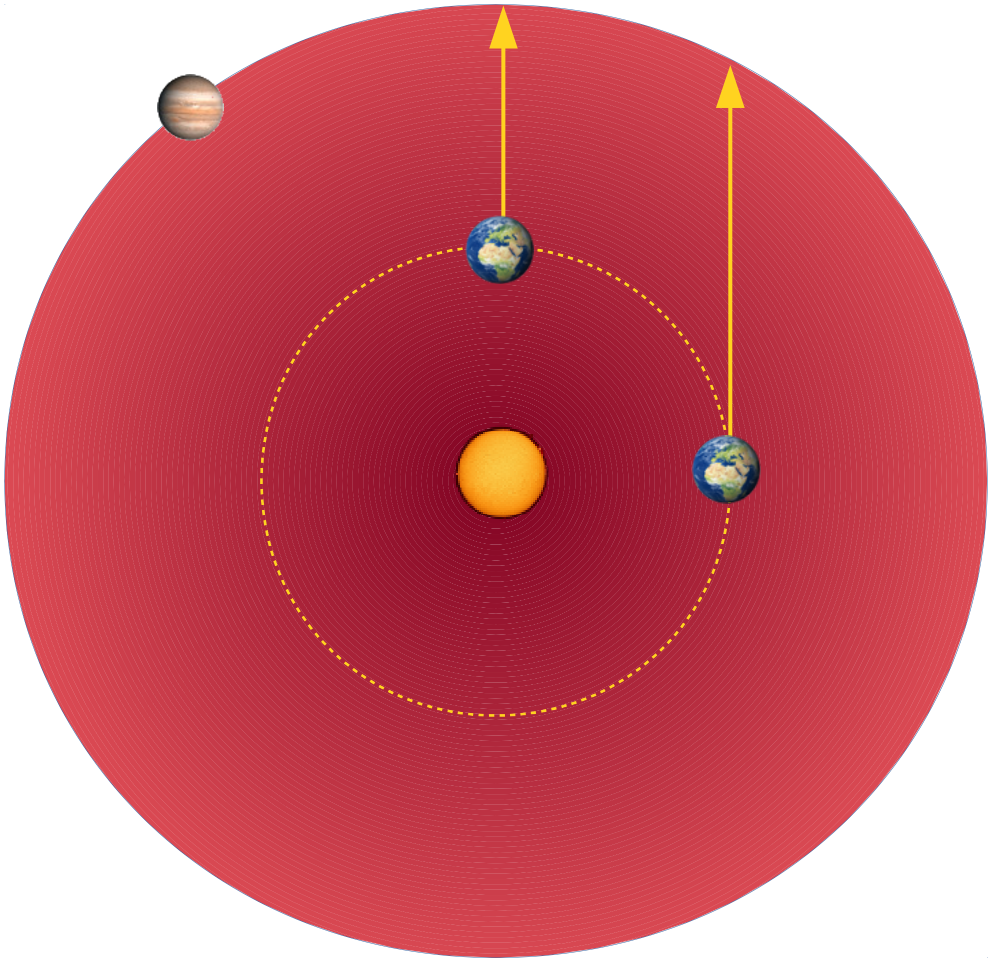
The brightest regions of the sky in Zodi are comparable to the dimmest regions in Galactic emission.

(Lack of) Polarization

- DIRBE detected ~10% polarization in *reflection*, at ~1-3 μm (Berriman et al., 1994) but there are no published polarization detections in emission.
- Siebenmorgen (1999) assumed the Zodiacal emission was unpolarized in the mid-infrared to set limits on ISO-CAM instrumental polarization (to 1±0.3%).
- The Planck/HFI team has tried to set limits on Zodiacal emission polarization at 350 μm but has not been able to get anything meaningful to this point (Planck/HFI Collaboration; private communication/thoughts).

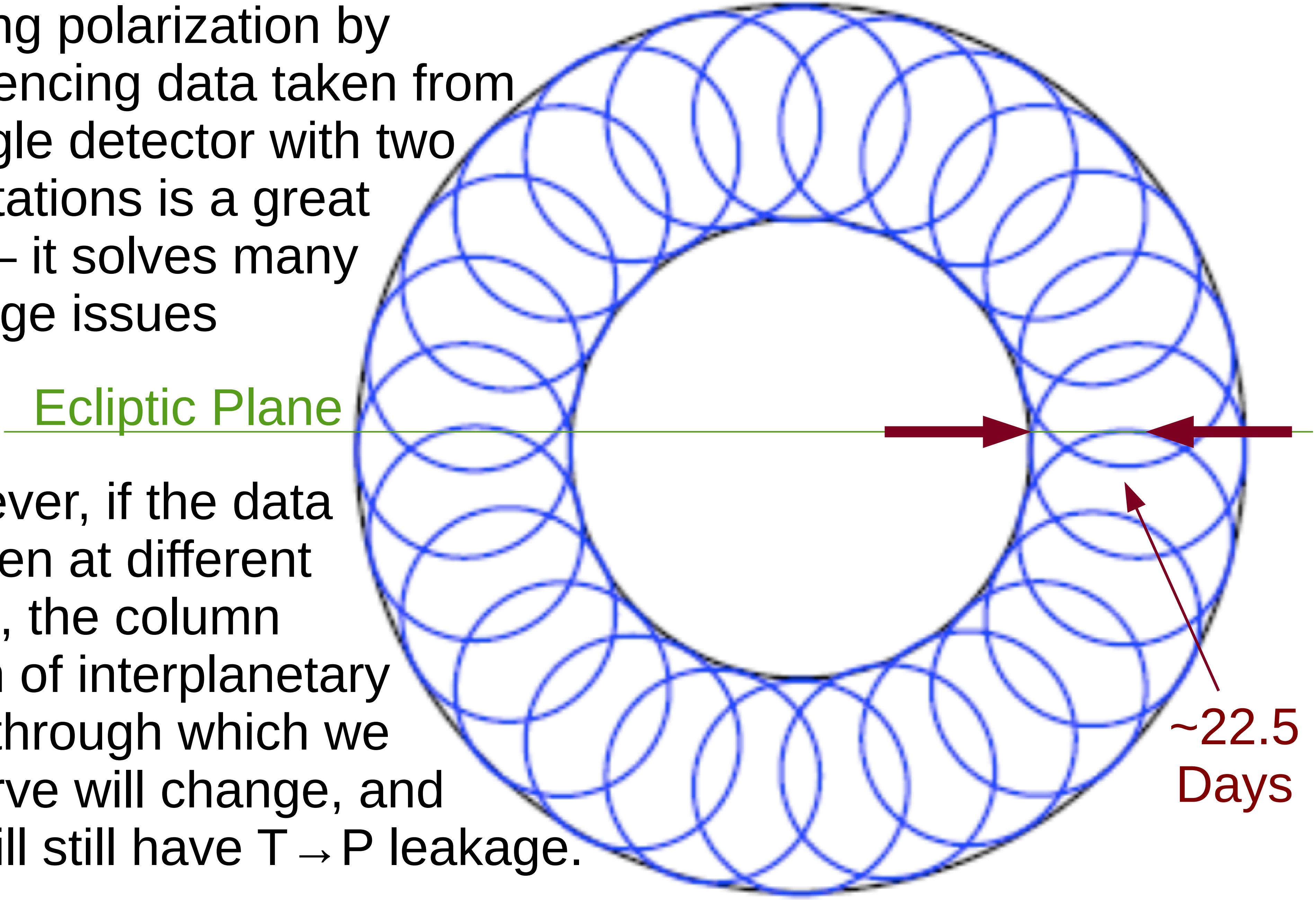
Zodi Emission is (often) Time-Varying

- If we observe a given position on the sky at different time, we will be looking through different column depths of this dust.
- This might cause T2P leakage, if not accounted for



Differencing Detectors Over Time

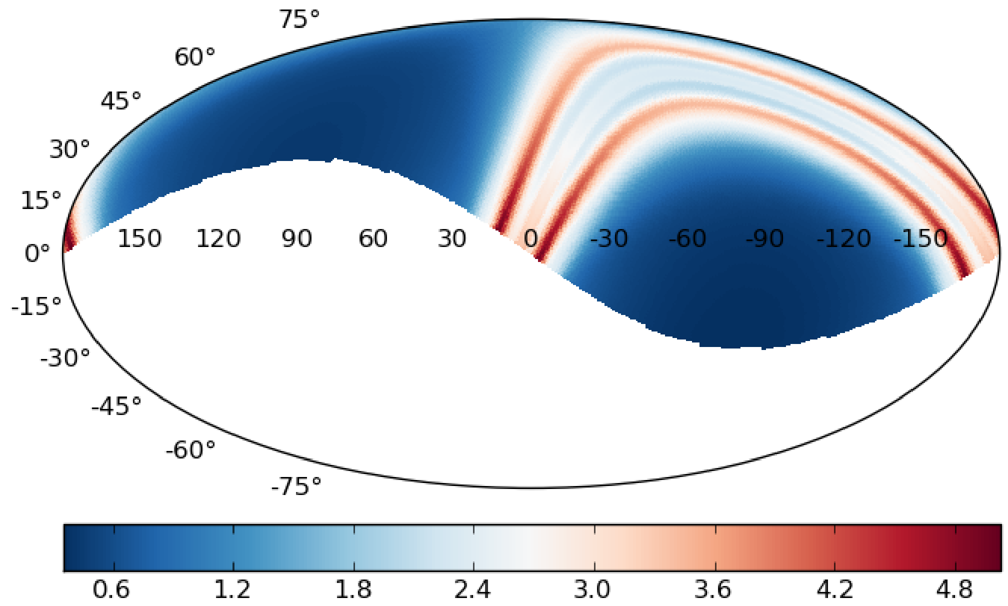
Getting polarization by differencing data taken from a single detector with two orientations is a great idea – it solves many leakage issues

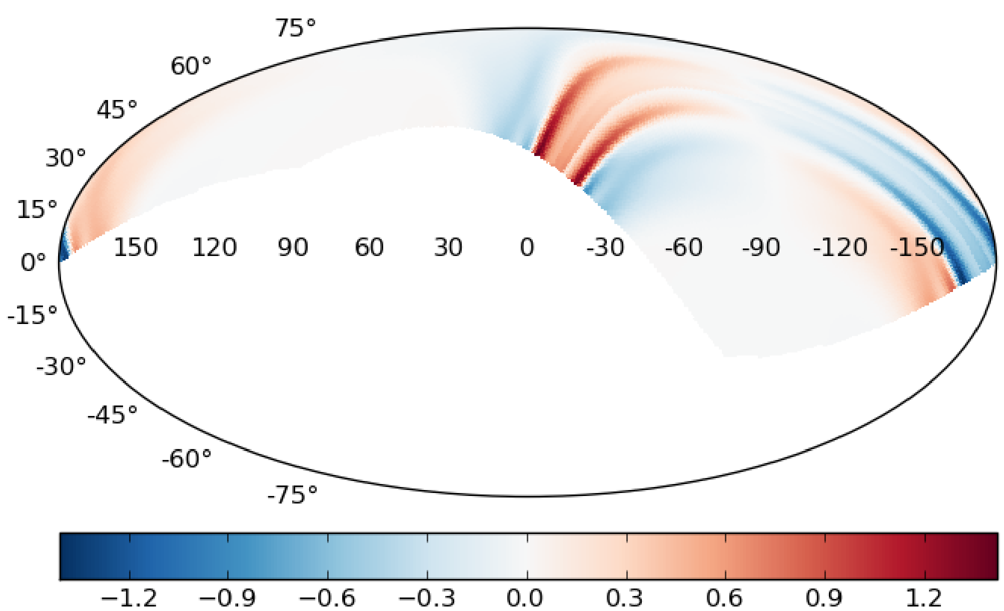


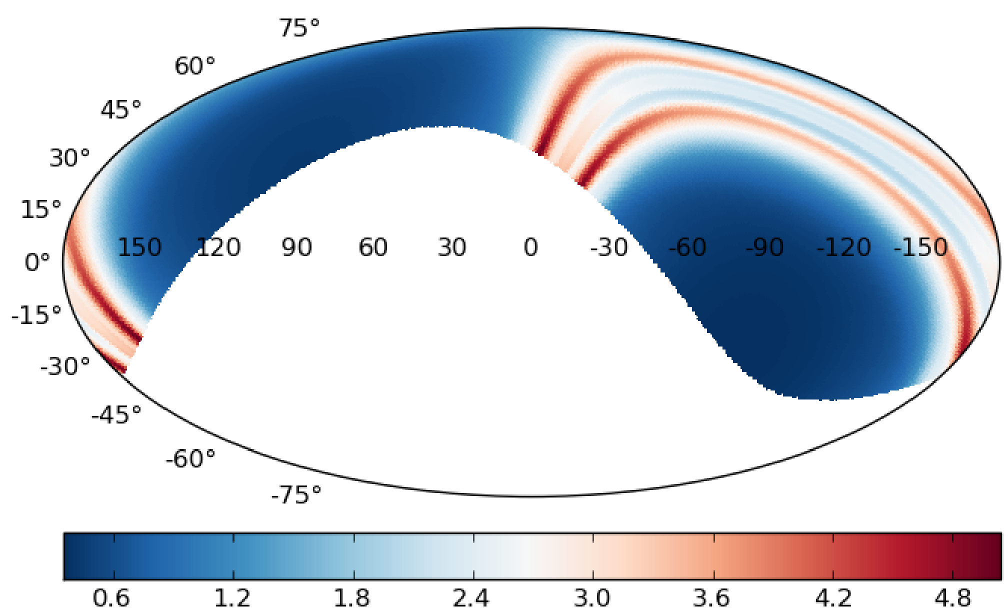
However, if the data is taken at different times, the column depth of interplanetary dust through which we observe will change, and we will still have T→P leakage.

143 GHz Zodi Estimate Jan.-Feb. 2025

- Measure sky from Earth on 2025-01-01
- Measure sky from Earth on 2025-02-01
- Difference implies ~1 microK leakage from Zodi







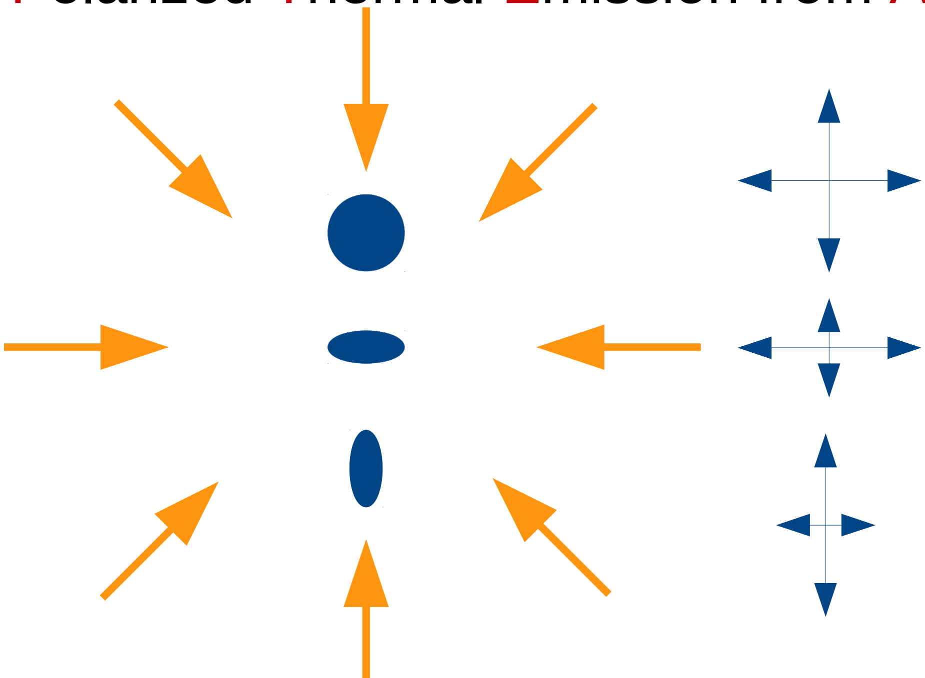
Summary

- Thermal emission from inter-planetary dust is less bright than that of Galactic dust, but needs to be investigated, since it appears time-variable.
- The variability depends on details of the scan strategy, but large-scale excursions of around a micro-Kelvin are possible.
- It's probably not our biggest challenge, but one that should be considered
  - I can do this if the baseline scanning strategy is documented (i.e., $\lambda=\lambda_{Earth}$+Acos(...)+...; β = Bcos(...)+...).

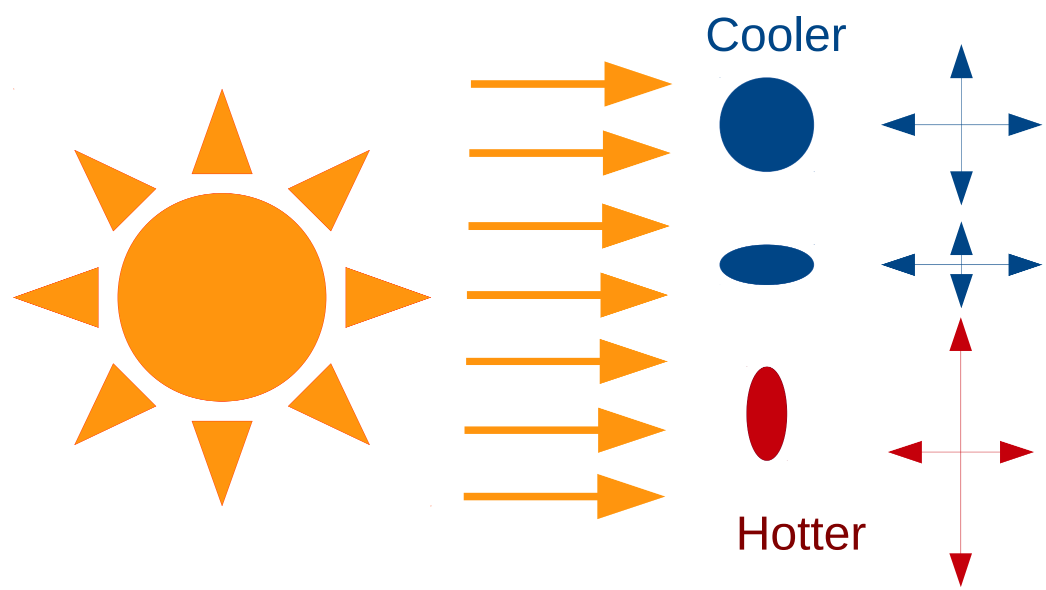
Thank You!

PTEAR for Dummies (like me)

Polarized Thermal Emission from Anisotropic Radiation (and asymmetric grains)



In an isotropic radiation field, all grains will have the same temperature, and radiation coming out of the plane of the transparency will have no net polarization.



In an Anisotropic field, some asymmetric grains will have higher temperatures, and a net polarization will be seen. I don't believe this has ever been seen in the Zodi.

PTEAR and Zodiacal Reflection

For sub-micron-sized particles in Galactic clouds, PTEAR may be expected to give less than ~percent polarization. But for ~30 μm (Zodi) particles?

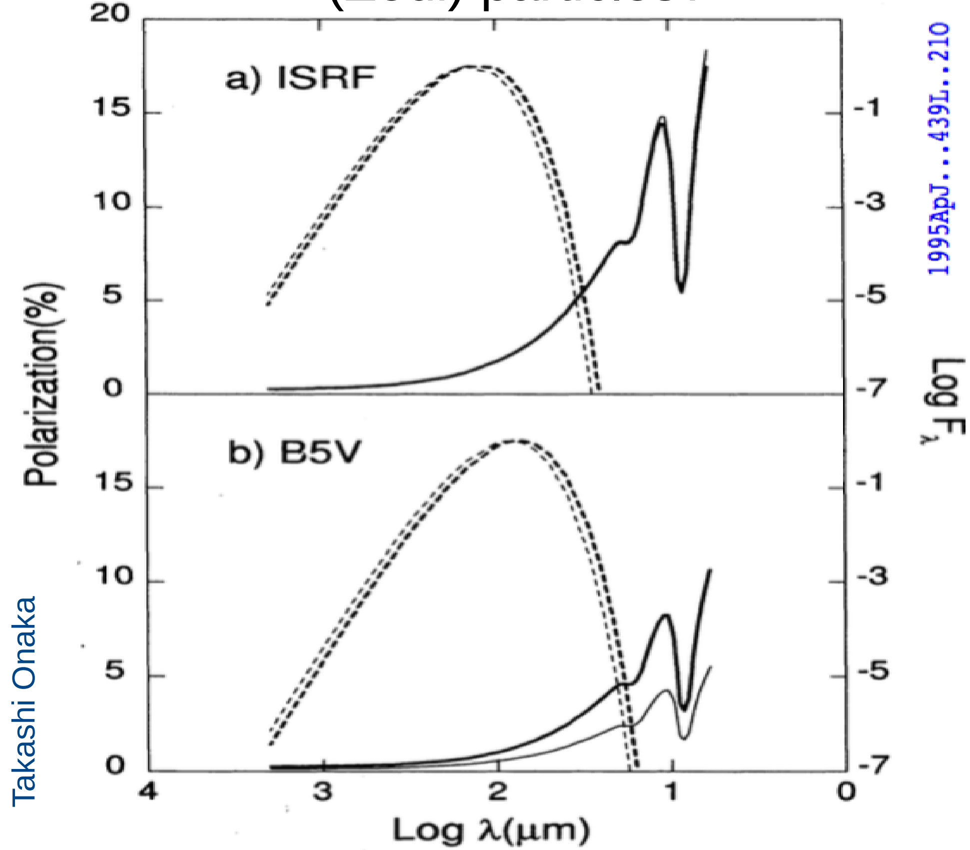
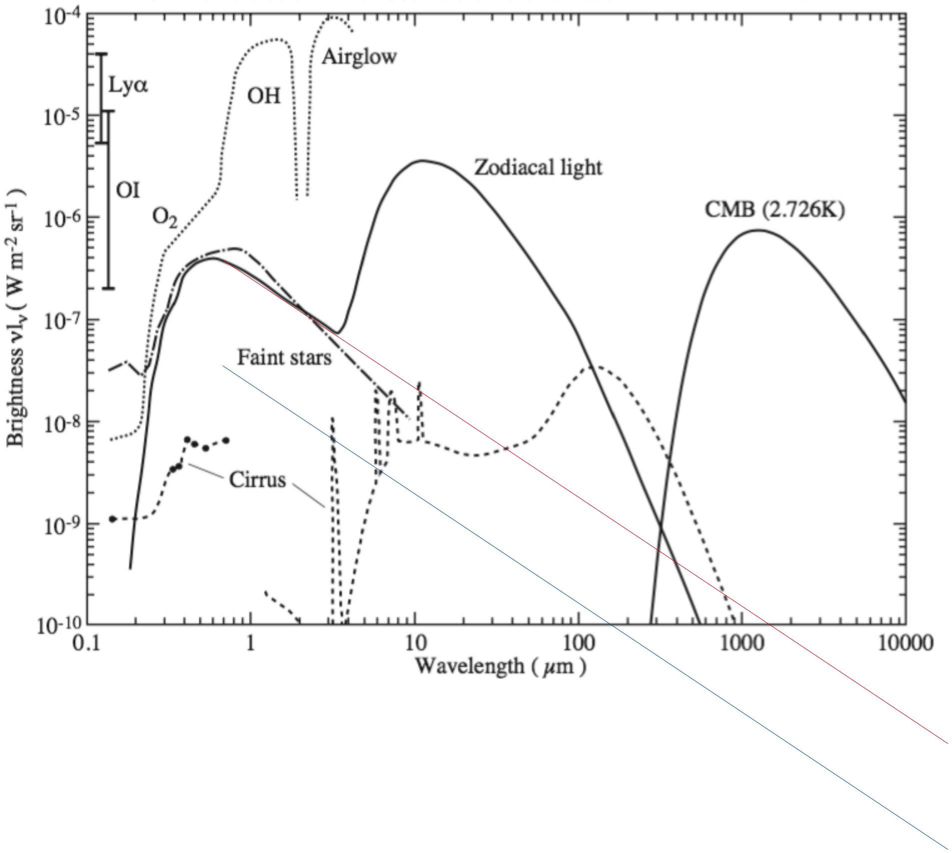
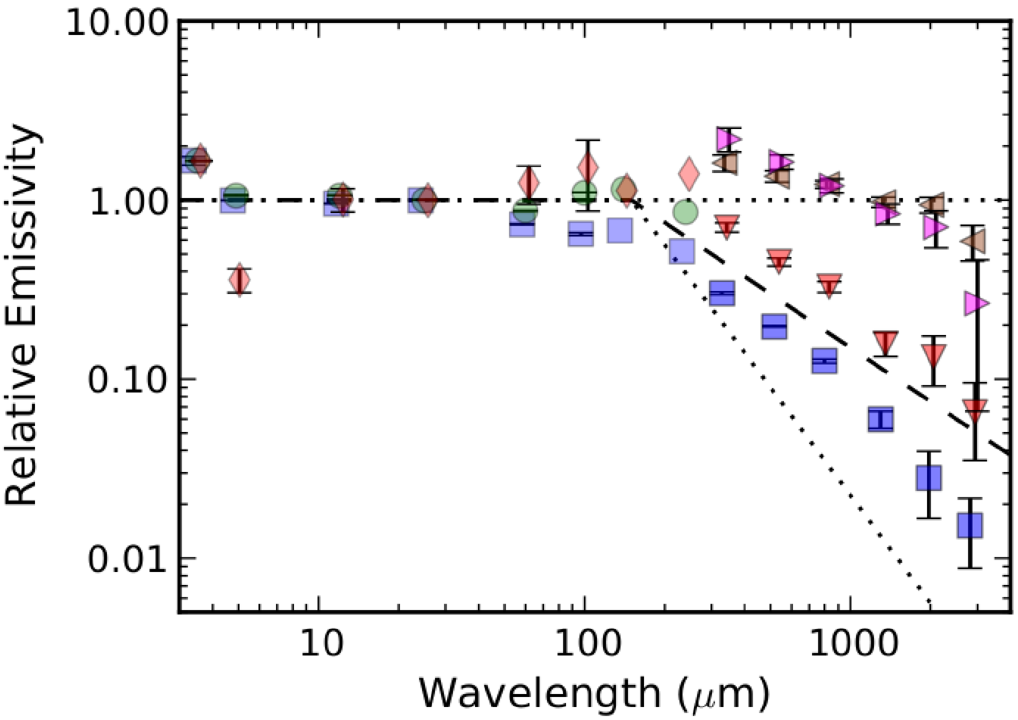


FIG. 2.—Spectra of the polarization (*solid curves*) and the total thermal emission (*broken curves*) in the logarithmic scale from a dust cloud of oblate grains with the axial ratio = 3 immersed in an anisotropic radiation field with $\beta = 0$. The polarization refers to the left abscissa and the total emission to the right abscissa. The total emission is normalized at its peak. Thick curves indicate the results of grains with the body symmetry axis = 0.1 μm, while thin curves depict those with 0.03 μm. In (*a*), a dust cloud is assumed to be illuminated by the ISRF from one direction. In (*b*), a dust cloud is illuminated by a B5 V star at the distance of 0.5 pc. The polarization is defined as positive in the direction perpendicular to the radiation.

At some level, one will also expect to detect the polarized component of the reflected Zodi. (But we're extrapolating 3 orders of magnitude in wavelength and more in brightness...)



Planck (& DIRBE) Zodi Emissivities



- Planck emissivities for 350 microns and longer
- DIRBE measures for 240 microns and shorter
- Bands 1 & 3 have shallower drop-off, perhaps indicating a larger effect particle size.

857 GHz Zodi Estimate Jan.-Feb. 2025

- Measure sky from Earth on 2015-01-01
- Measure sky from Earth on 2015-02-01
- For comparison only