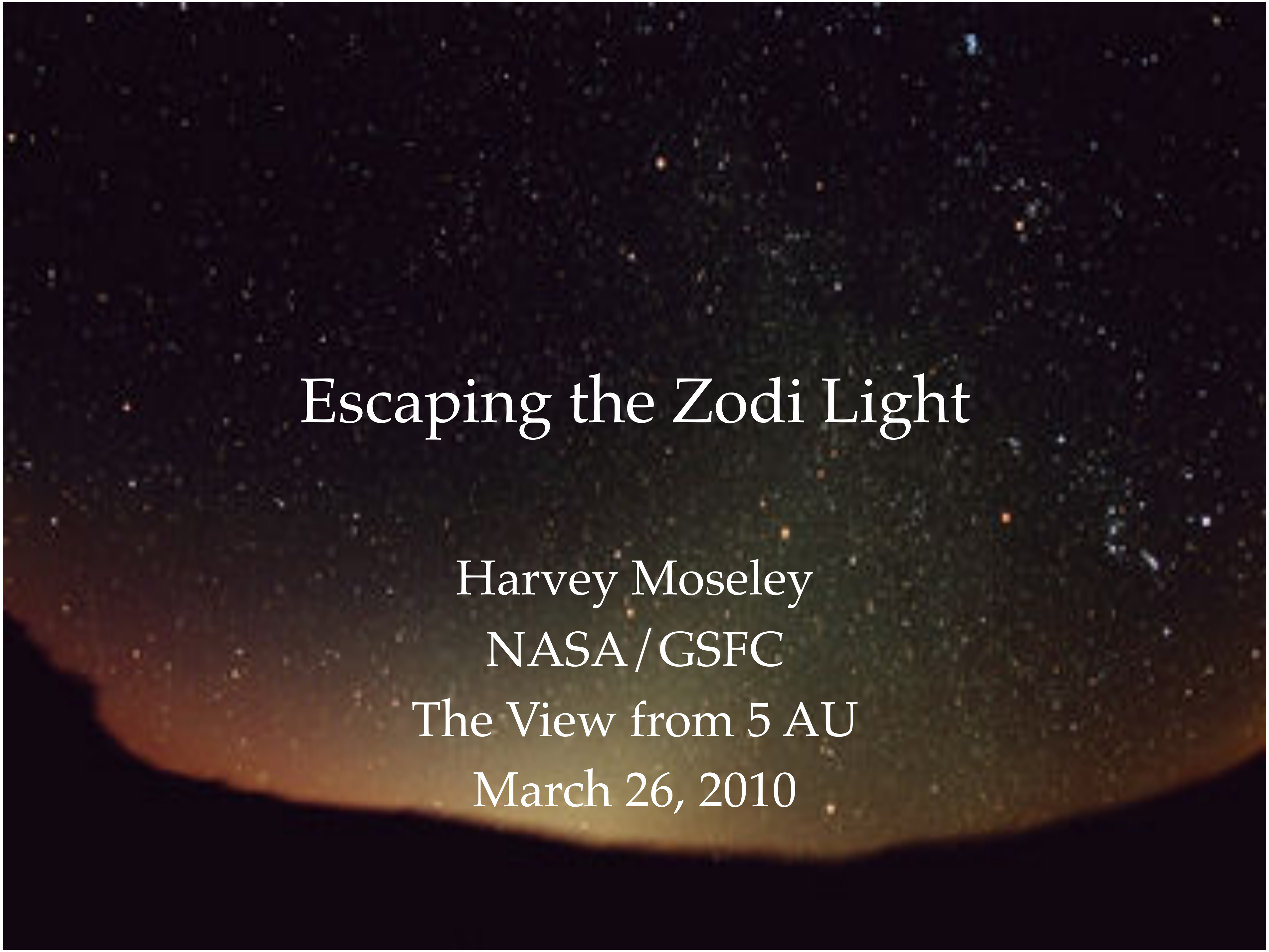


Escaping the Zodi Light

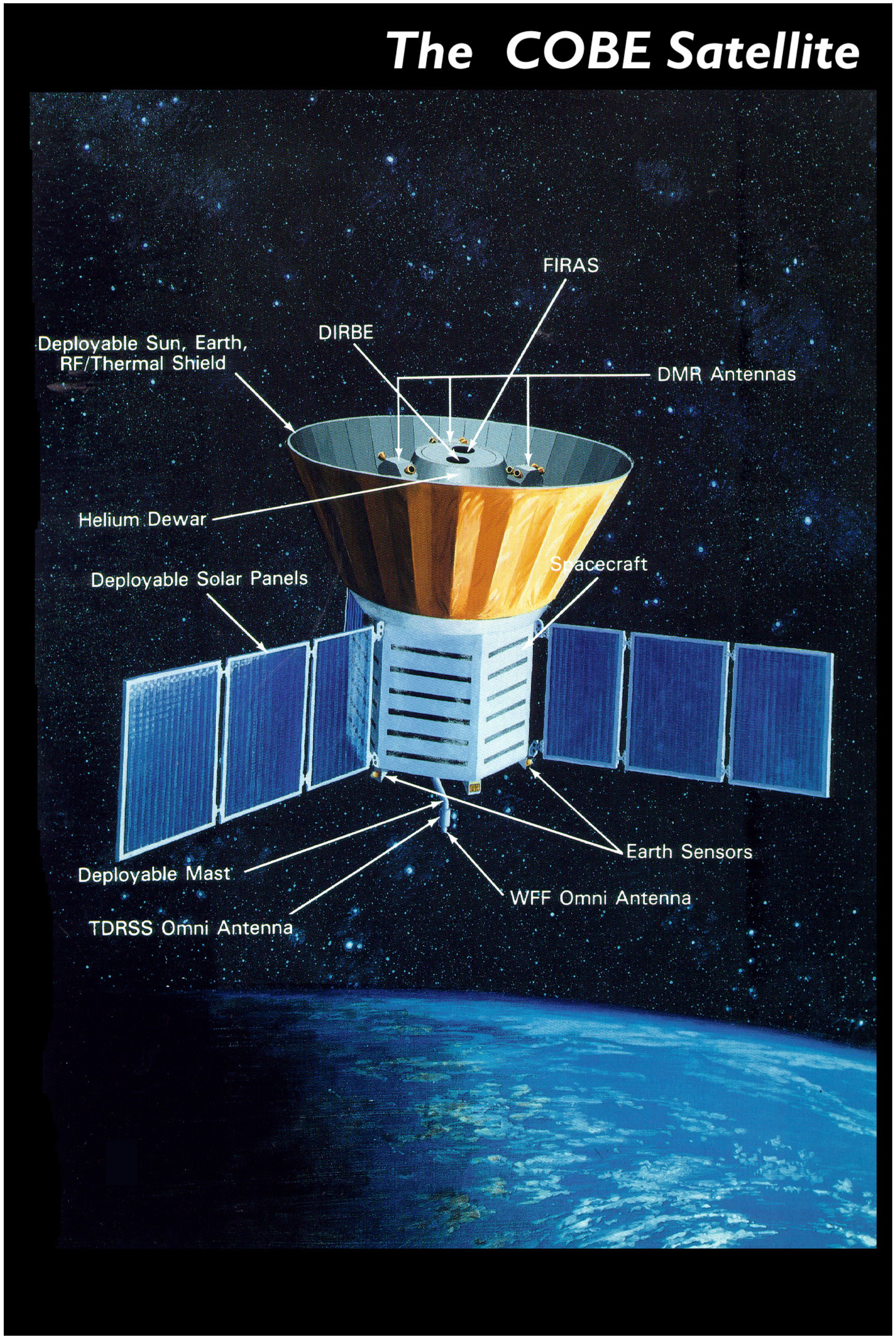
Harvey Moseley
NASA/GSFC

The View from 5 AU

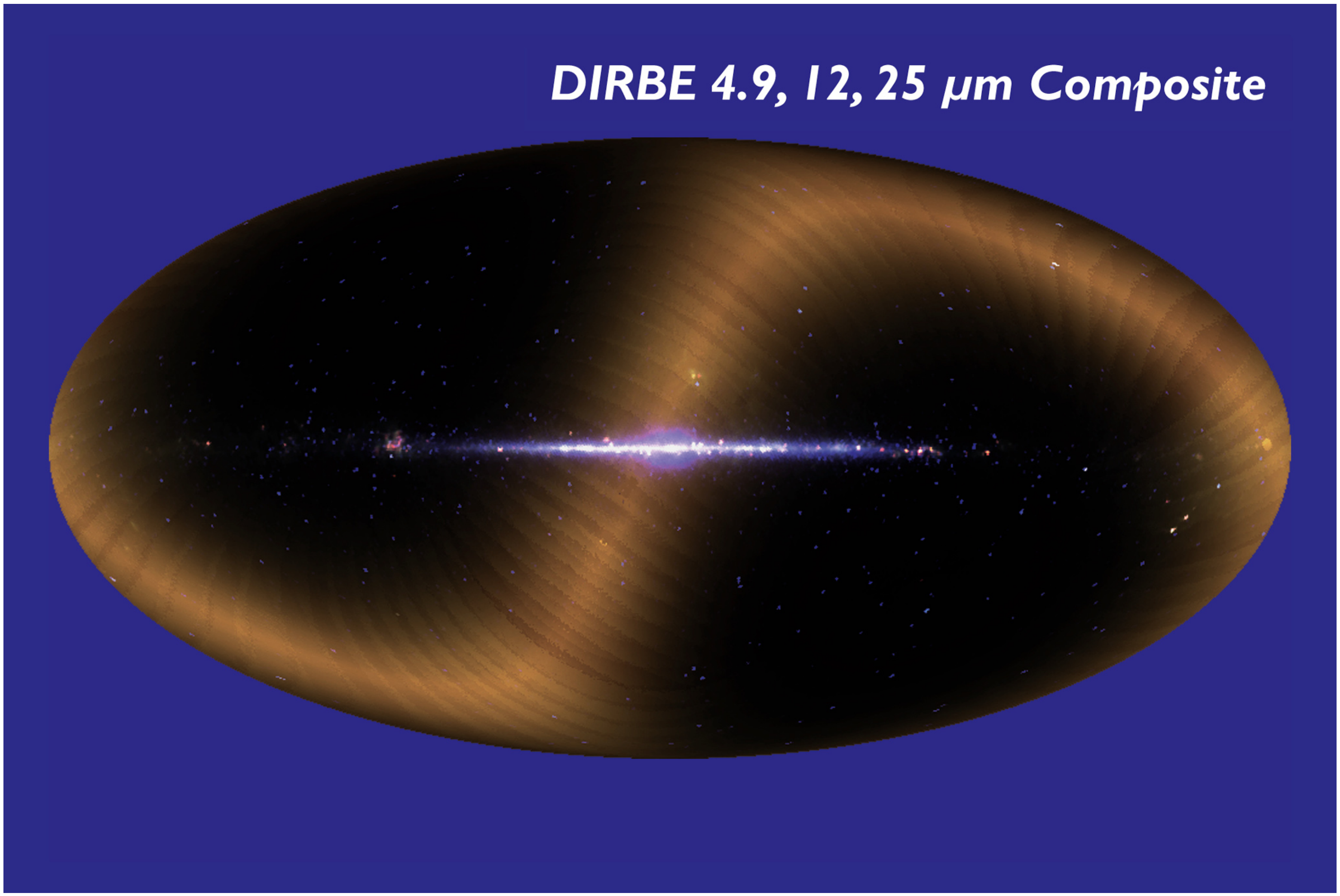
March 26, 2010

- The Galaxy and the Zodi Light are the dominant sources of diffuse light in the night sky
- Both are much brighter than credible levels of EBL
- Successful measurements require the accurate removal of these foregrounds (with accurate zero points)
- Reduction of photon noise requires moving outside the Zodi – how far is far enough?

- The DIRBE instrument on COBE was developed to measure the absolute brightness of the sky in 10 bands from 1 - 300 μm



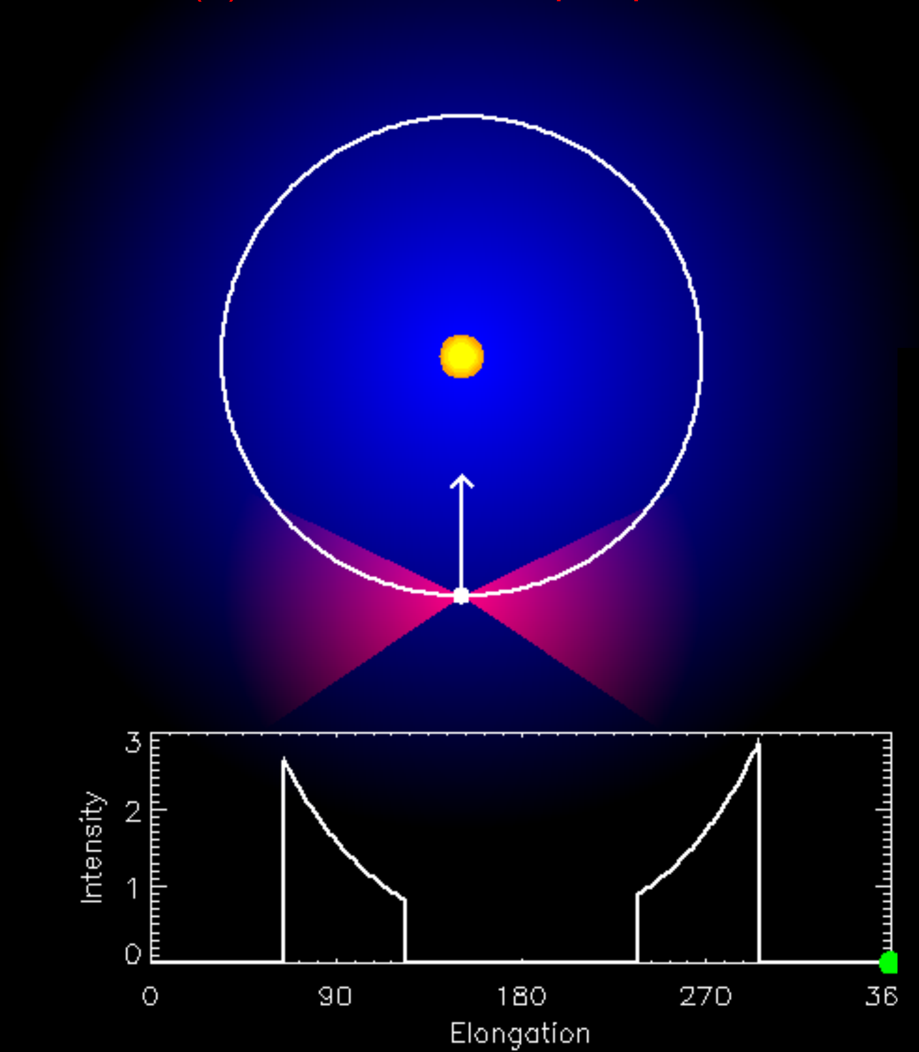
- COBE/DIRBE composite shows sky dominated by Zodiacal and Galactic emission



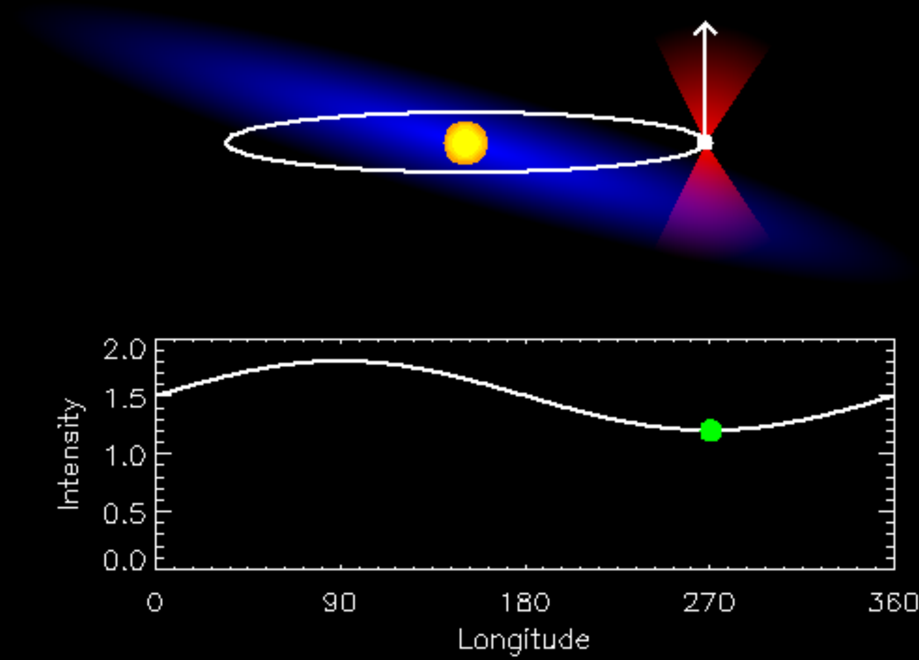
Zodi Light Variation

animation: Rick Arendt

(1) Towards the ecliptic plane



(2) Towards the ecliptic pole

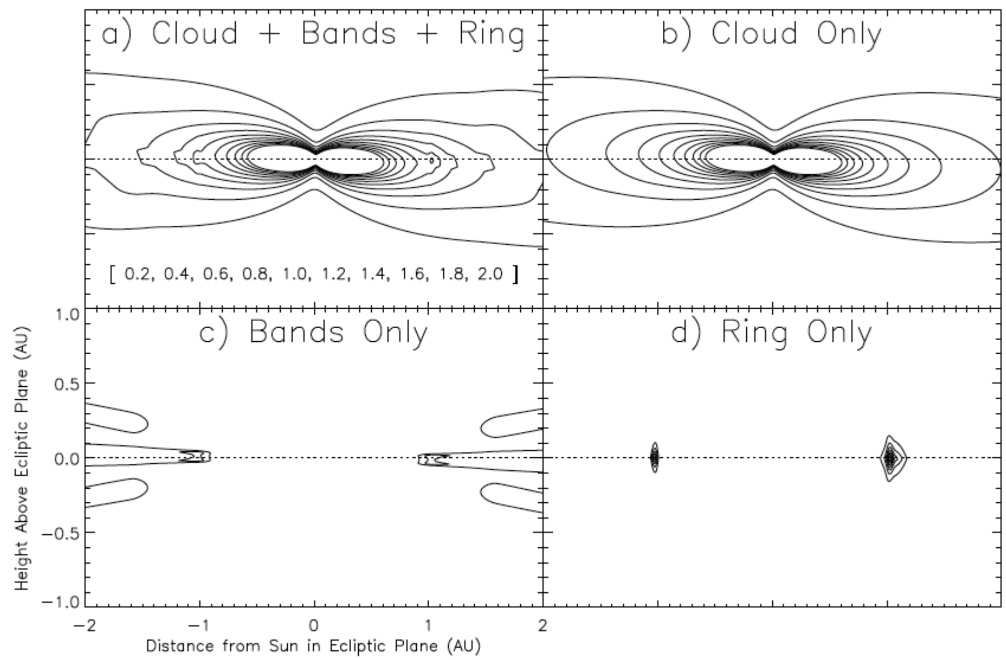


Removal of Zodi Light
How DIRBE Did It

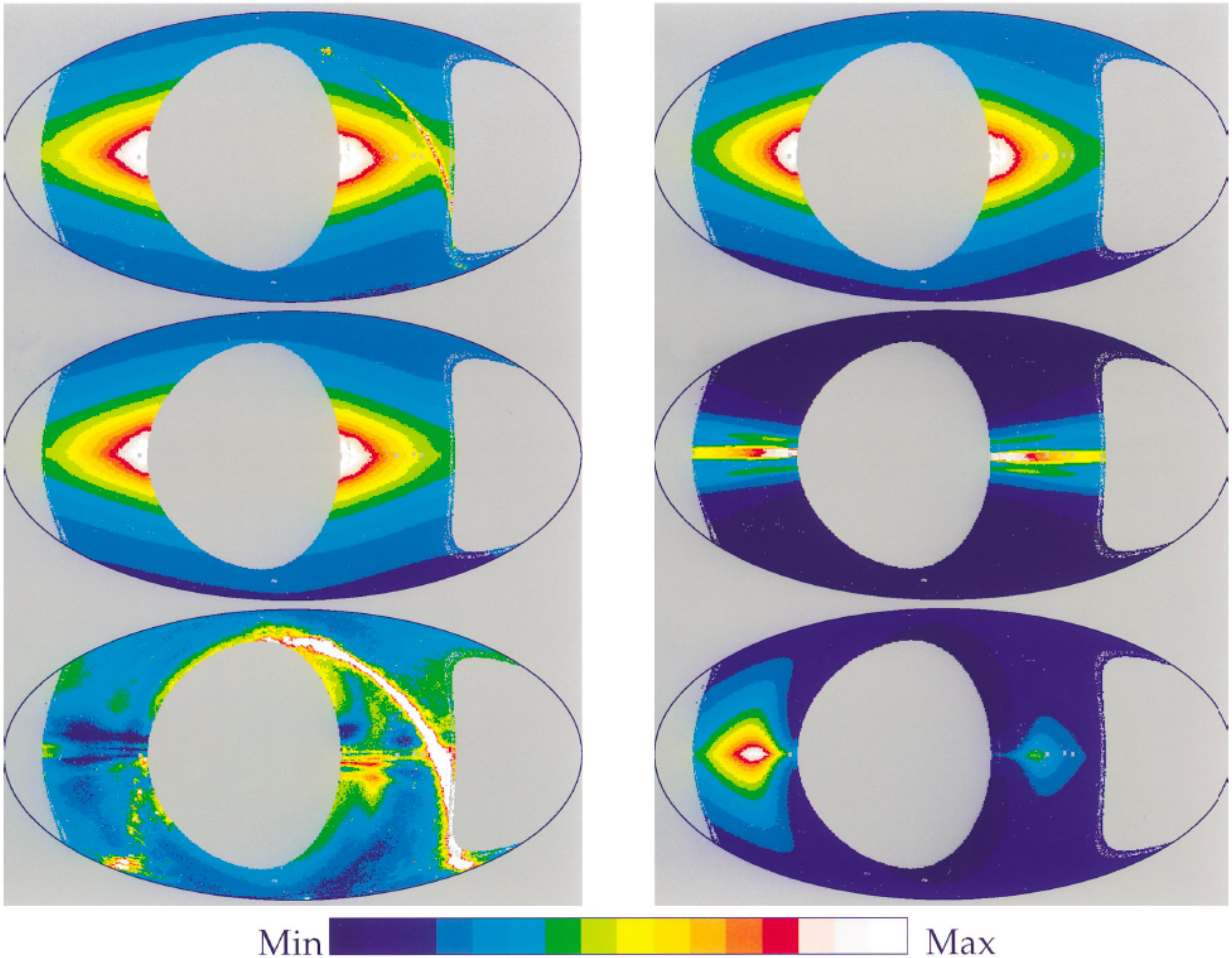
- DIRBE measured the Zodi cloud as the Earth moved around its orbit
  - 1/2 of the sky was covered each day
- With calibrated data in hand, need to subtract total Zodi signal
  - Physical model required
  - Spatial and temporal variations of signals constrain model parameters; integral through model provides total Zodi brightness.

Model - Geometry and Physical Parameters

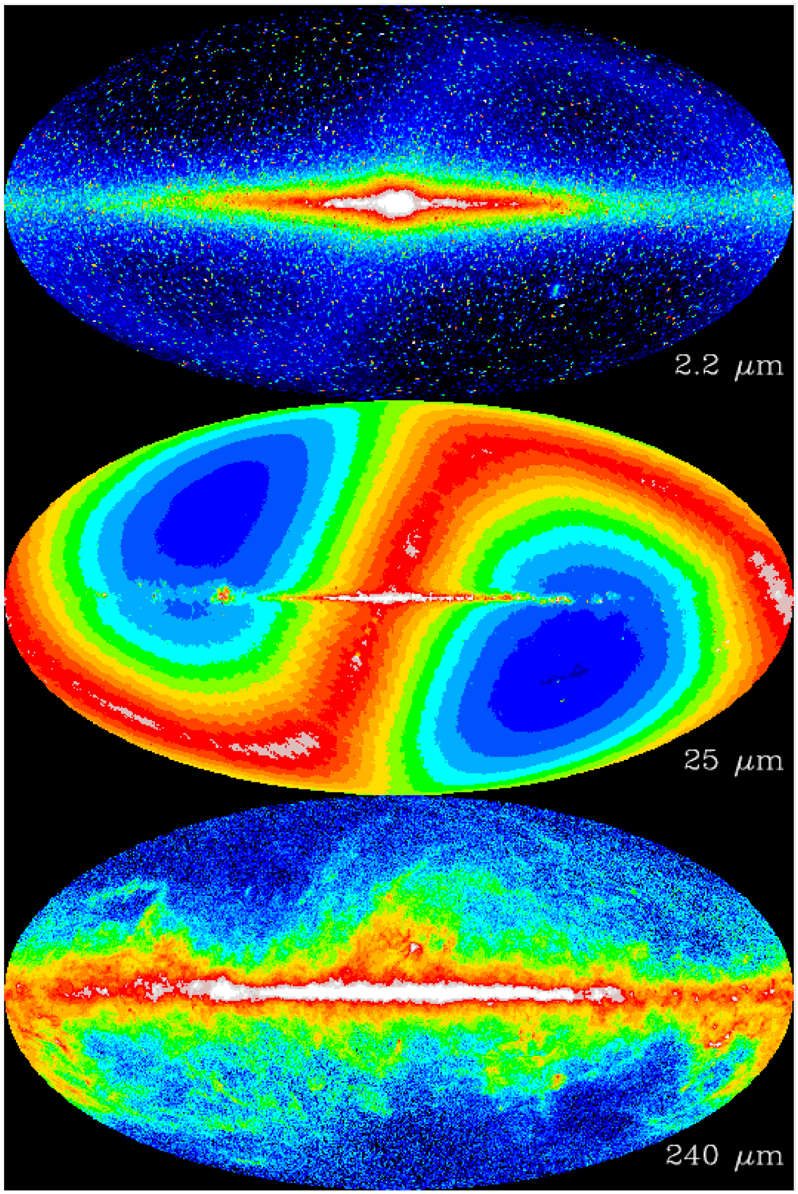
- Model includes main cloud plus dominant small scale features
- Physical parameters for dust, dust distribution included
- Best fit parameters derived
- Different main cloud models tested; range of variation in sky brightness used as estimate of systematic error



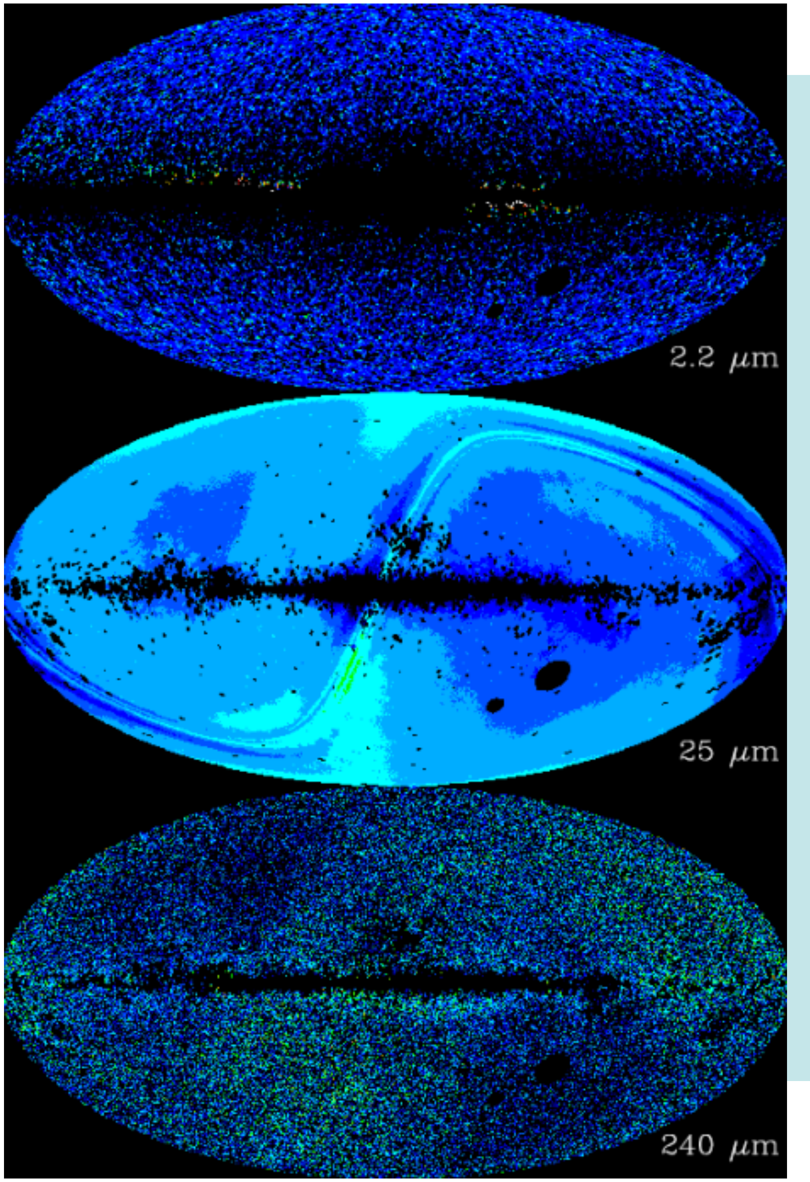
Week 22 (90106 - 90112): 25 µm



Observed sky



Residual Sky after foregrounds removal

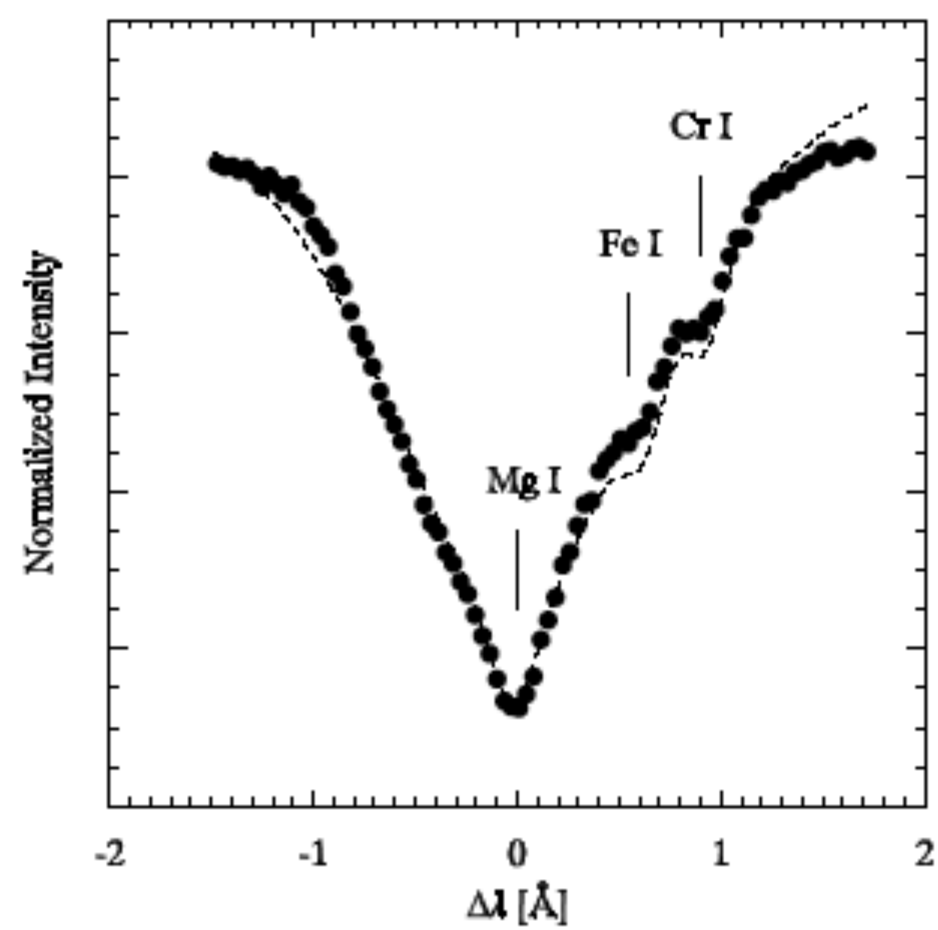


Model-Independent Techniques

- Techniques that can provide measurements of the absolute brightness of the Zodi in a model-independent way are essential
  - Solar Absorption lines to “tag” Zodi emission
  - Polarization as a tracker of Zodi
    - Calibrate polarization through annual motion of the Earth through the Zodi.

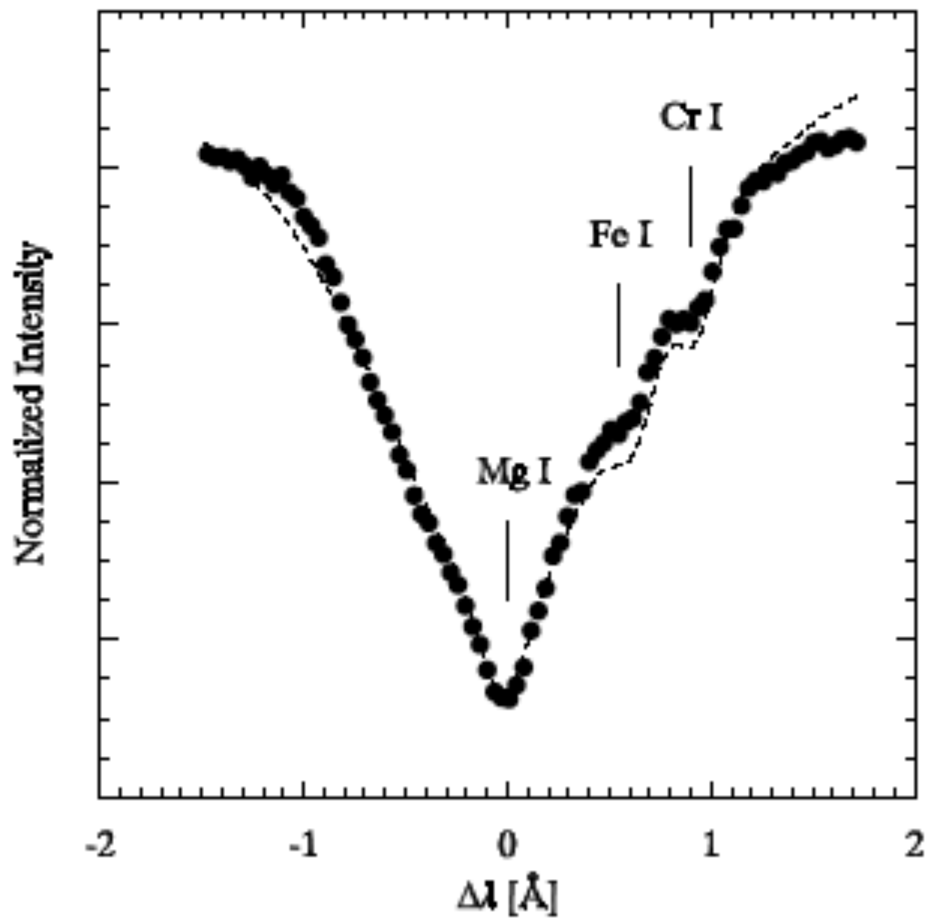
Using Solar Spectral Features to Tag Zodiacal Emission

- Solar absorption lines are seen in the scattered zodiacal light.
- Zero level of Zodi light can be set by adjusting to match solar equivalent width, as in Bernstein et al (2002).



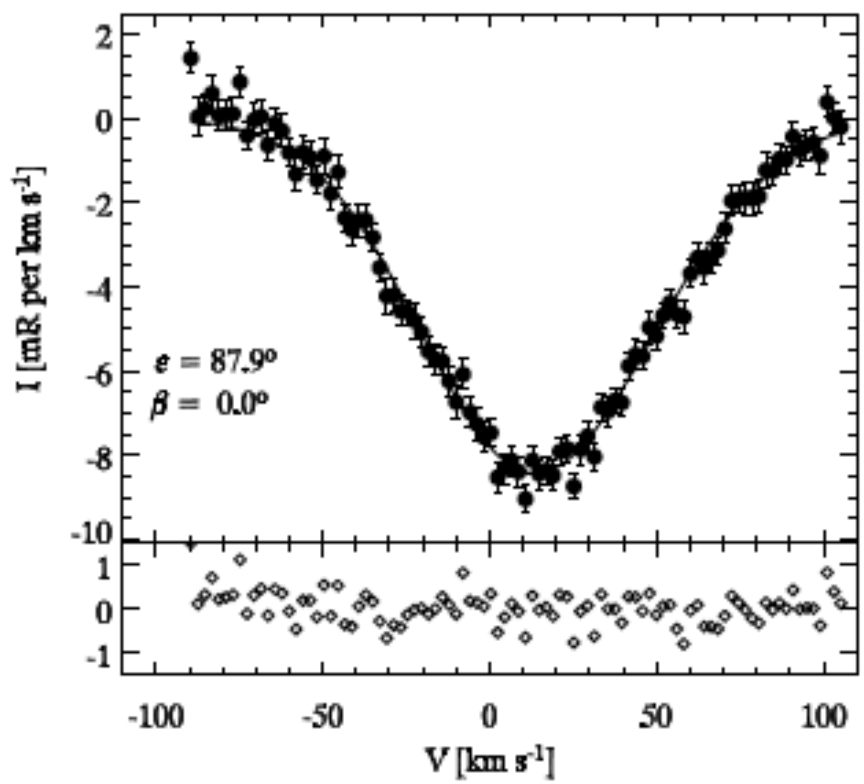
Using Solar Spectral Features to Tag Zodiacal Emission

- Solar absorption lines are seen in the scattered zodiacal light.
- Zero level of Zodi light can be set by adjusting to match solar equivalent width, as in Bernstein et al.
- At right is the 5184A line of MgI, measured for calibration in the twilight sky



Spectral Features in Zodi Easily Measured

- Using the WHAM instrument, the line can be measured in the Zodi in 600s! (Reynolds, Madsen, and Moseley, 2004)
- Method is sound and practical, limited in the near IR by OH airglow
- Experiment should be done to resolve the background problem. We and others (Bock et al., 2006) are interested in pursuing this.



What Could Go Wrong?

- Fluorescence
  - Kelsall may have discovered this in DIRBE data
- Transiently heated small grains
  - Any such mechanisms results in NIR radiation without solar spectral features
- Similar spectral features in Galactic background (wide range of stellar types)

Stellar Background

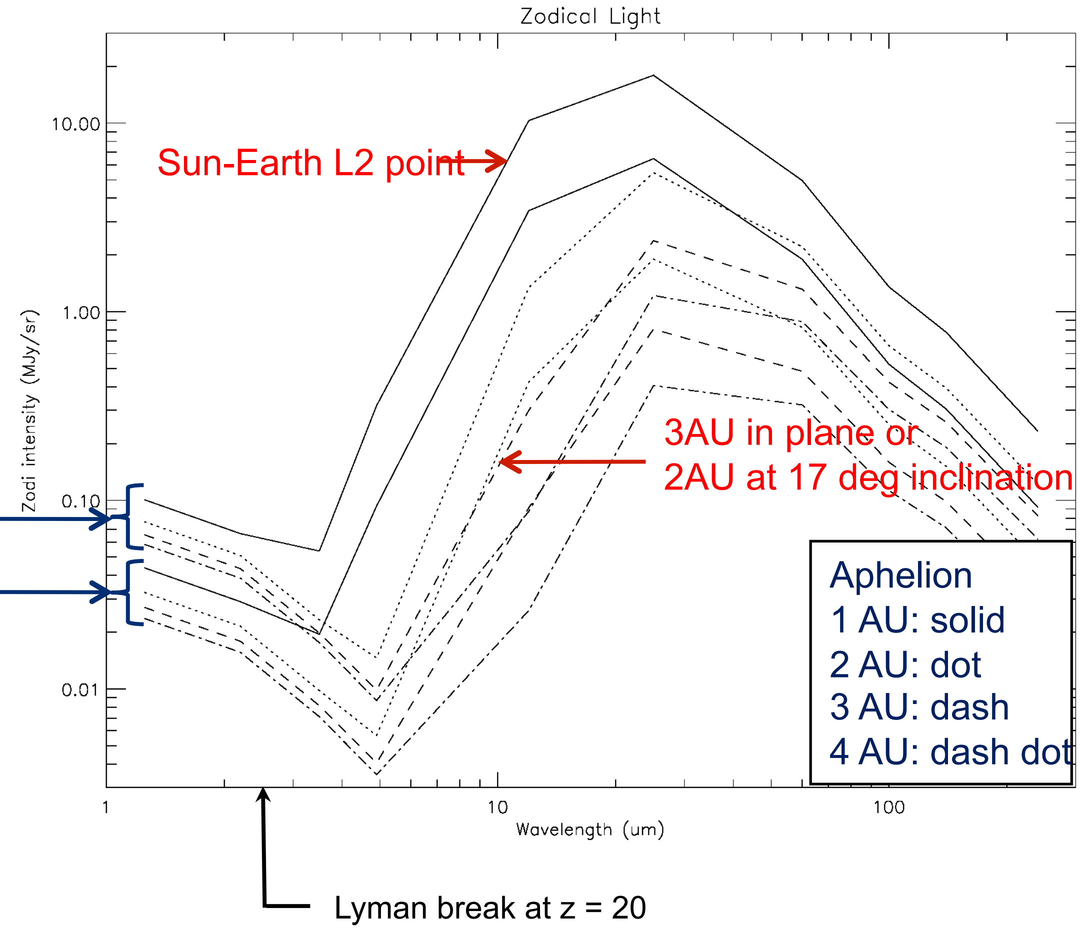
- Stellar absorption lines can confuse extraction of Zodi brightness
  - Spatially resolve and subtract stars (CYBER – Jamie Bock)
  - Mask stars (GSFC-Zodi Alexander Kutyrev)
- Contamination becomes more important as we move into the outer Solar system where the Zodi is faint
  - Need robust procedure for removal of stars if spectral technique is used.

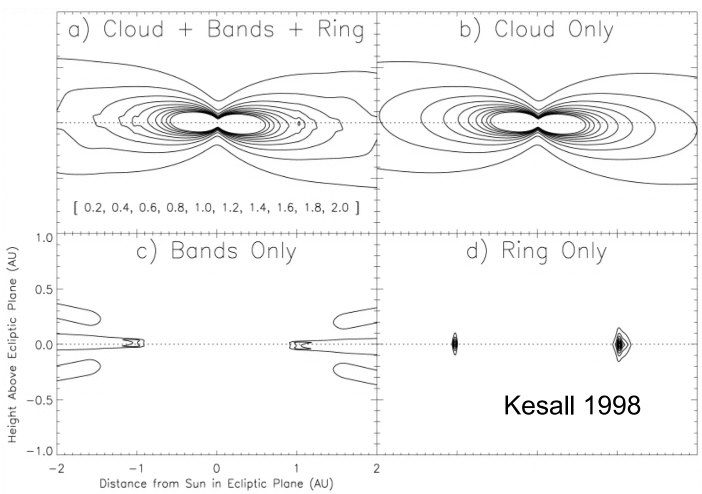
Linear Polarization

- Arendt et al. have proposed to use the polarization of the Zodi light to estimate its contribution.
- This is in principle a useful approach, but DIRBE was not a good enough polarimeter to enable this.

25X – 100X reduction in Zodiacal background possible within 1-4 AU, 0-45 deg inclination trade space

An extra Zodiacal orbit can reduce required telescope collecting area by nearly 2X relative to a Sun-Earth L2 orbit.

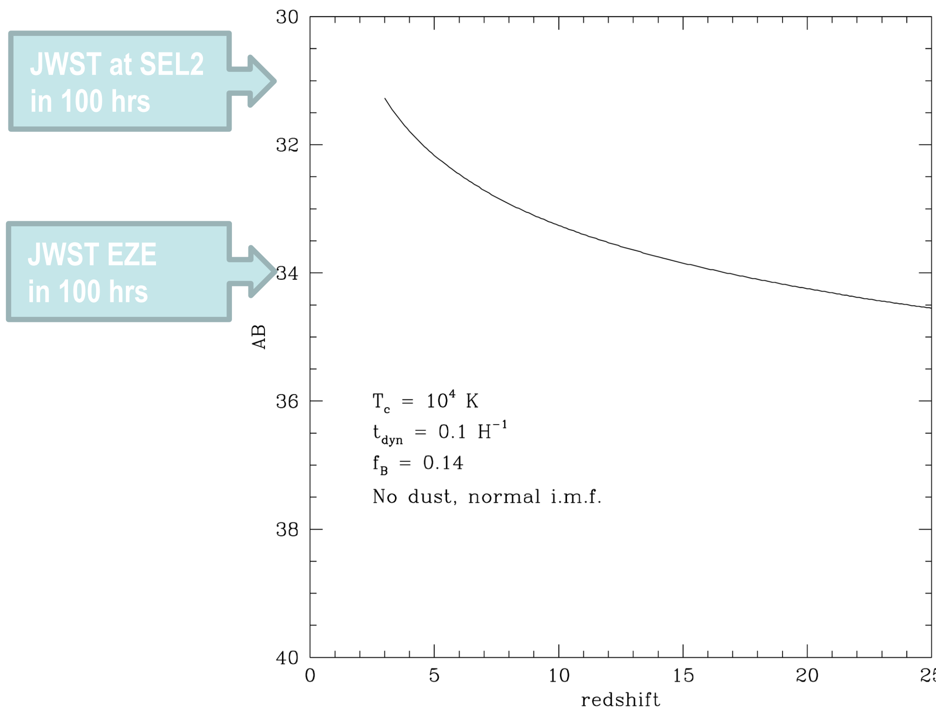




The future of visible/infrared space astronomy lies outside the Zodical cloud

- An Zodical light-limited observatory can achieve a 5-15 fold increase in sensitivity over JWST <u>through orbit choice alone</u> with no increase in telescope aperture or improvement in detector technology.
- The cosmological reach of a 6 m class observatory in an extra-Zodical orbit would span the galaxy formation epoch.
  - Hence, it would not be necessary to replace it with a larger aperture system to probe deeper into the past.
  - **Particularly if it were sustained for a HST-like 20 yr lifetime by servicing**

Minimum brightness of the first galaxies

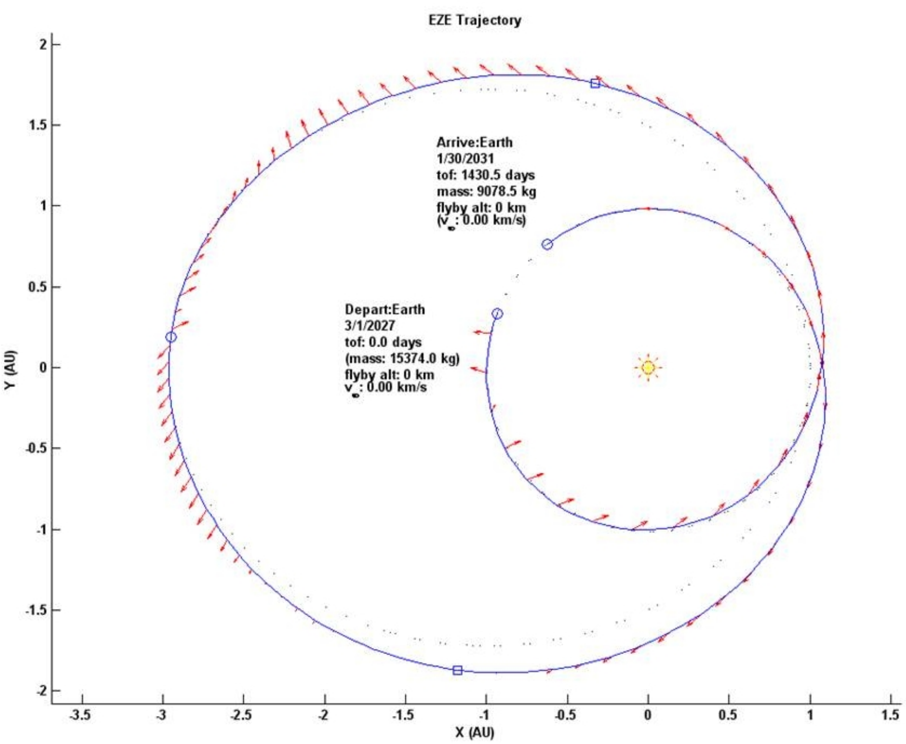


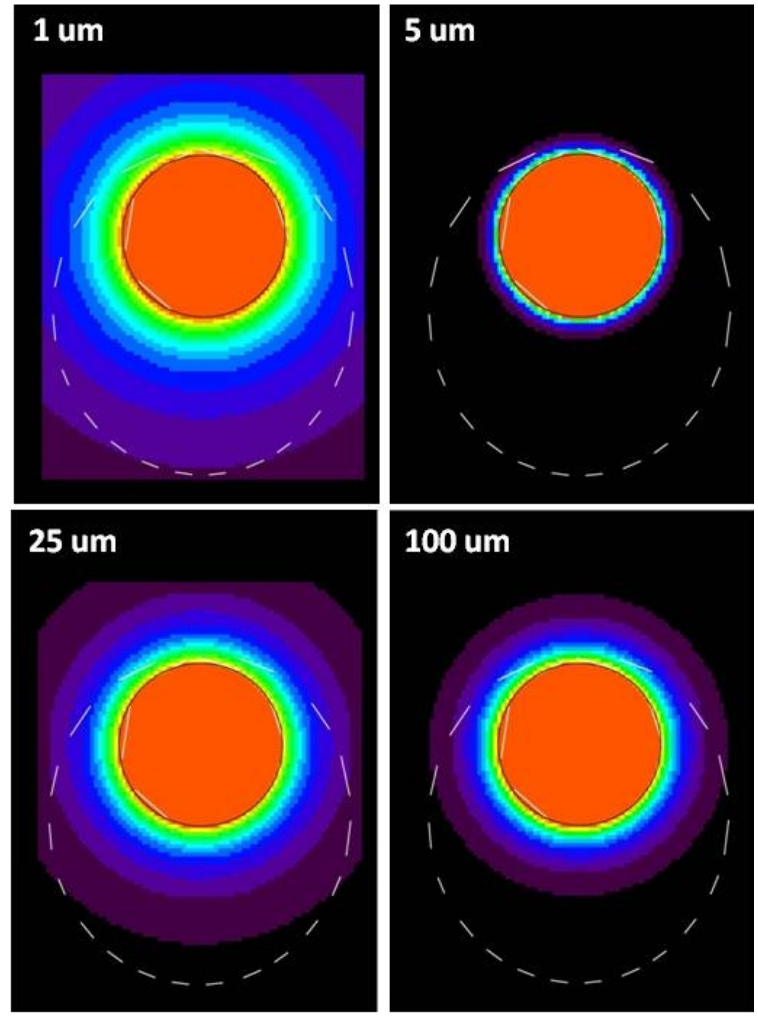
Stiavelli, M. et al. (2008): http://www.stsci.edu/jwst/science/whitepapers/first_light_study_V.pdf

Greenhouse

Serviceable trajectory for a flagship-class EZE mission

- 1x3 AU zero inclination orbit
- start & end at Earth-Moon L1
- 4 year period (non-Keplerian)
- Delta-V 2.12 km/s (low-thrust)



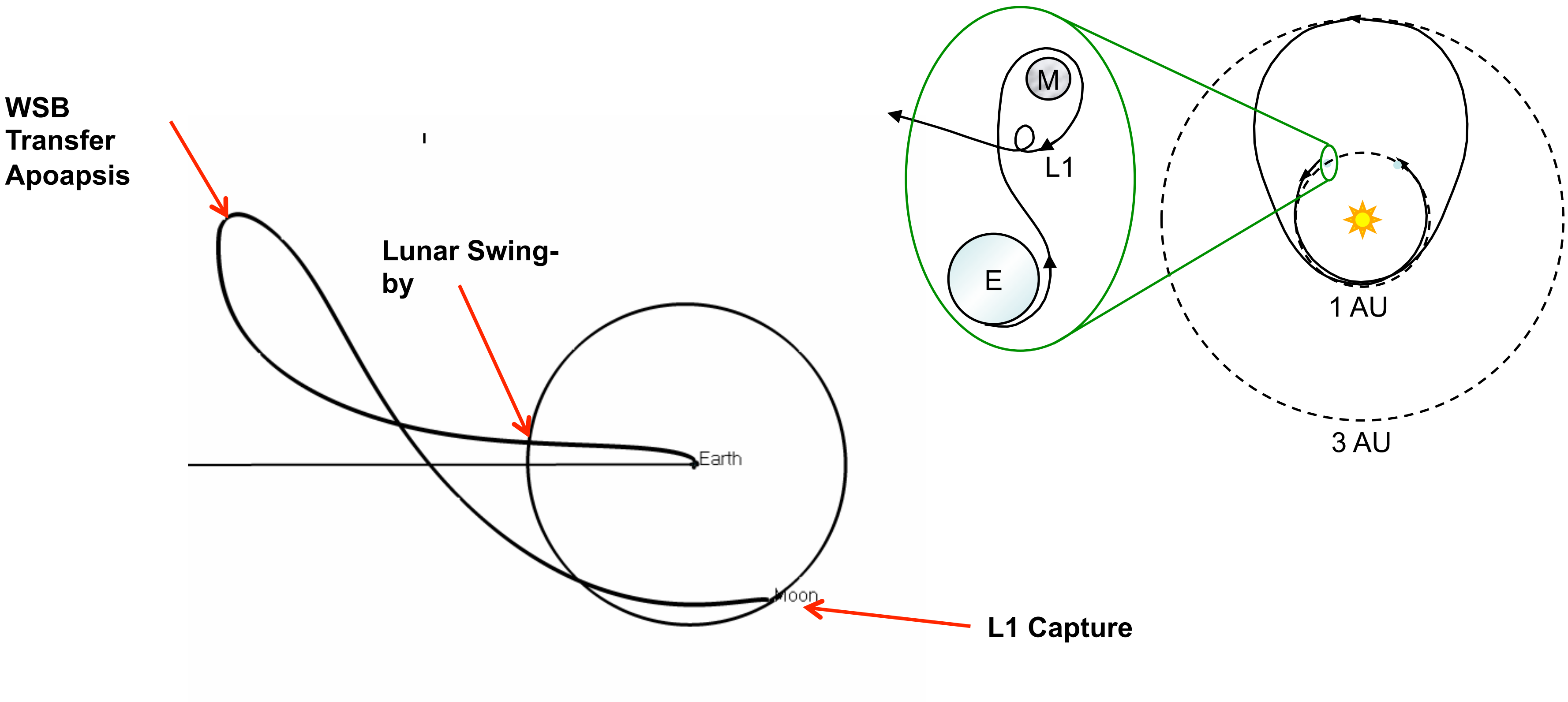


EZE 1x3 AU trajectory shown with dash length equal to 1 month of flight time. Zodiacal background is shown with a linear scale normalized to 1 AU

Greenhouse

Earth-Moon L1 capture for servicing feasible

- Weak Stability Boundary (WSB) transfer to Earth-Moon L1
  - ΔV required for WSB transfer and 1 year of station keeping: 180 m/s
  - Transfer time for L1 insertion: 140 – 180 days



Questions

- How dark is dark enough?
- How far out do we go to reach this limit
- Inclination?

Technologies We Need

- Noiseless Detectors
  - Lower read noise, or make real photon counters
- Lots of such pixels
- Large AΩ spectrometers with ability to remove stellar emission.
- Next Generation Microshutters?

Summary

- The detection of extragalactic infrared backgrounds is difficult because of bright and complex foregrounds
  - Physical Models of Zodiacal light were required to determine "zero point"
- Escaping the Zodi provides significant step in IR system sensitivity.
  - Especially in the mid-IR
- At this point, we know little about the spatial distribution and brightness of the Zodi at large Heliocentric distances – need more info for mission optimization