TEMPORAL, SPATIAL, SPECTRAL ASPECTS OF THE ZODIACAL LIGHT

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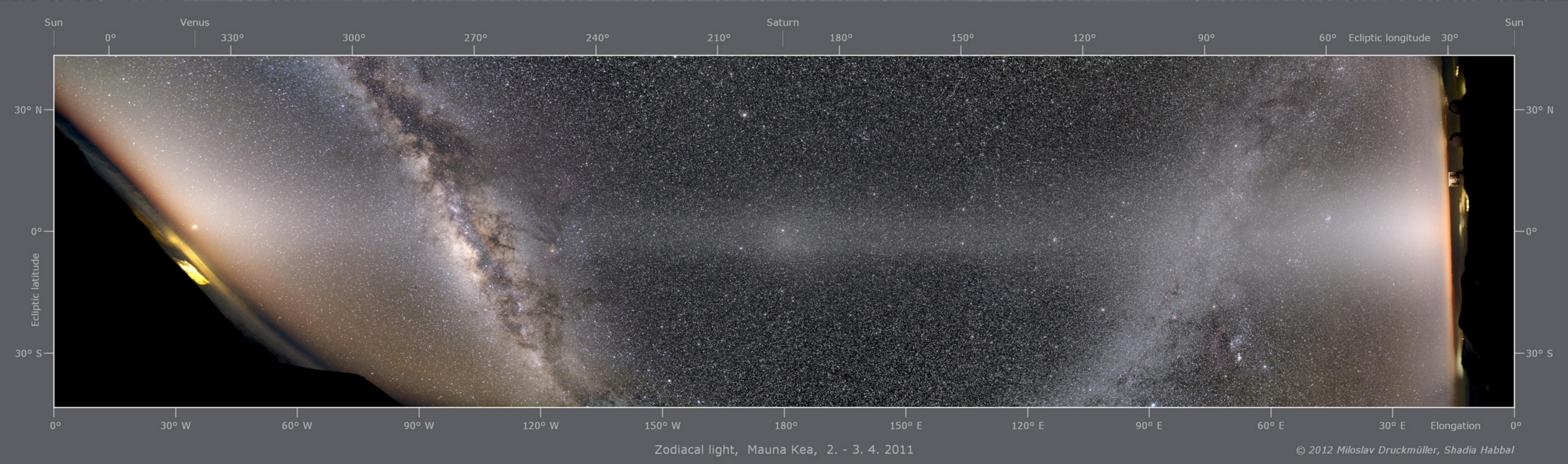
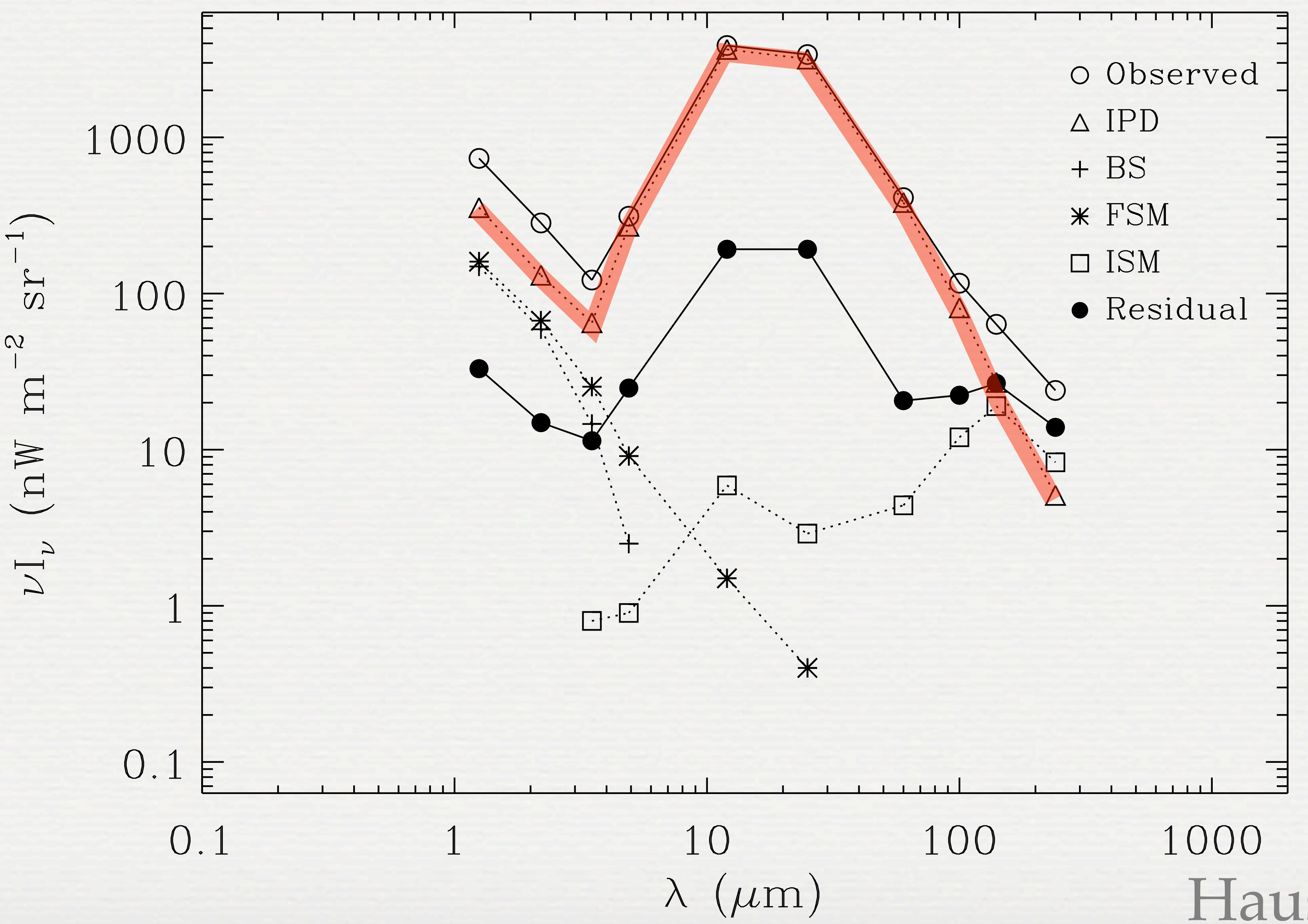


BASICS

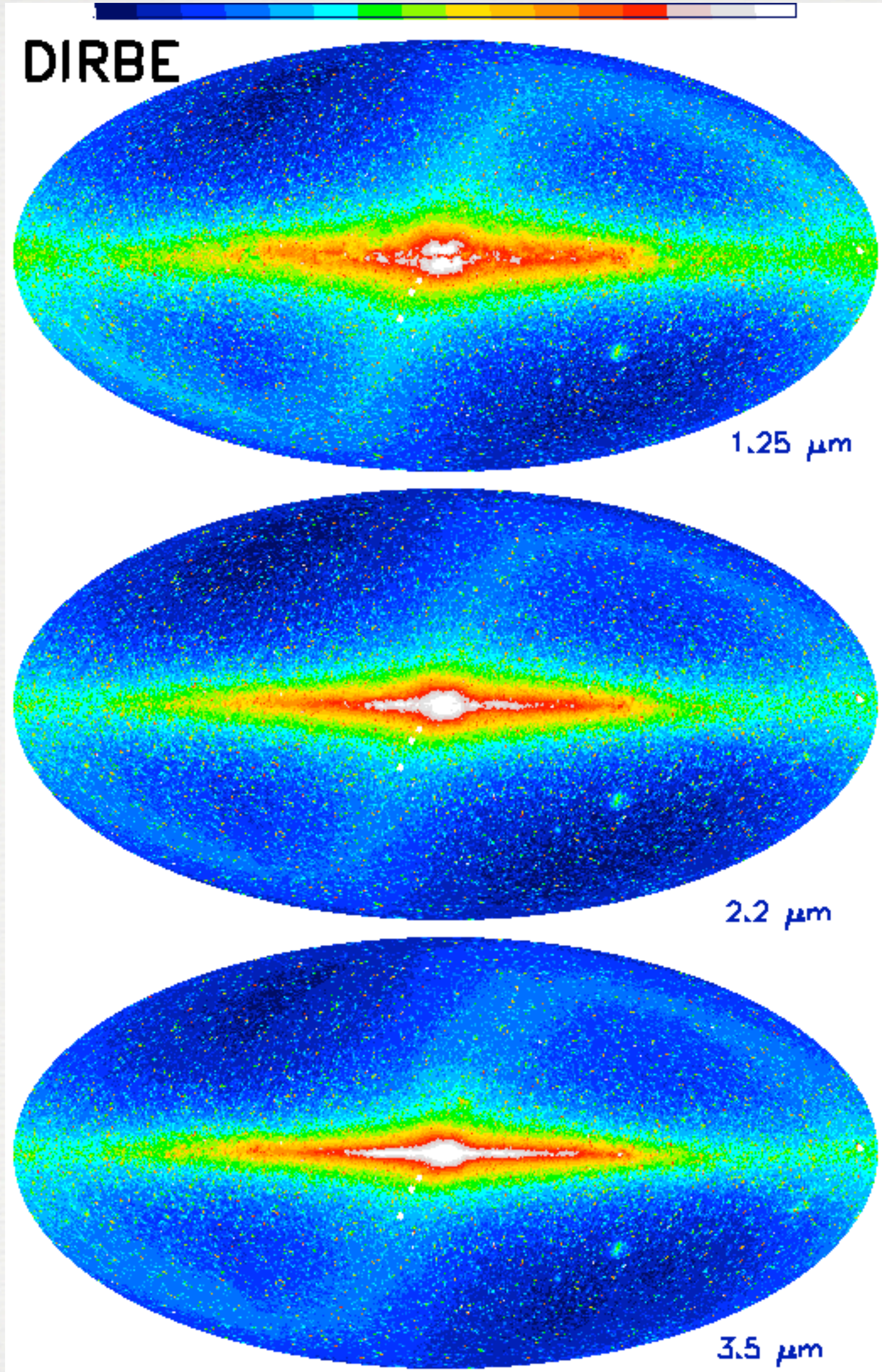
- INTERPLANETARY DUST = dust shed by asteroids and comets
- ZODIACAL LIGHT =
  (a) sunlight scattered by interplanetary dust (l < ~ 4 μm), or
  (b) sunlight absorbed by interplanetary dust and re-radiated as thermal IR emission (l > ~ 4 μm)

DIFFUSE SKY BRIGHTNESS AT THE LOCKMAN HOLE



Hauser et al. (1998)

1.25 - 3.5 μm
Scattered Light



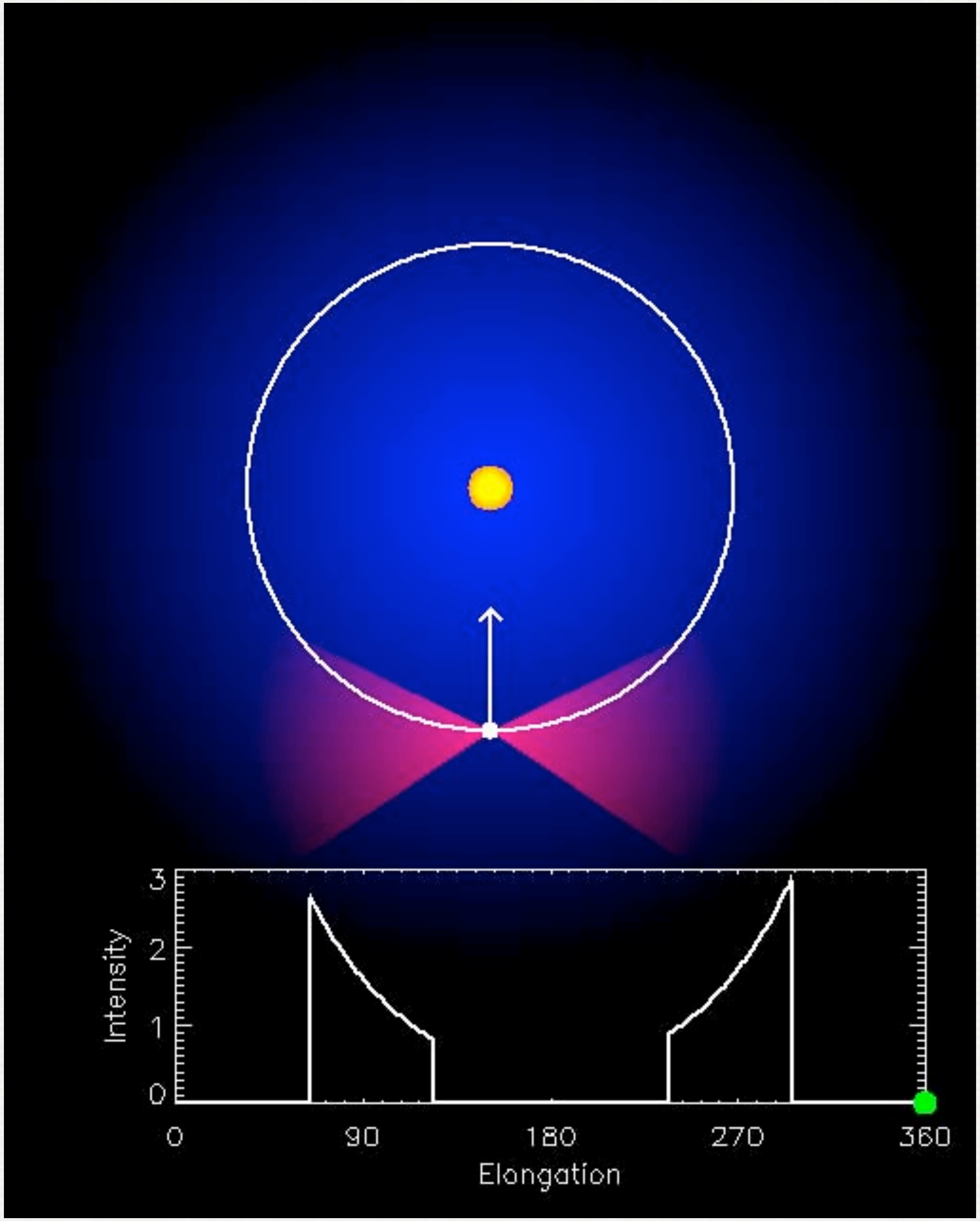
(1) TEMPORAL VARIATION

Changes in the intensity of the zodiacal light as a function of time while looking in a fixed direction in space.

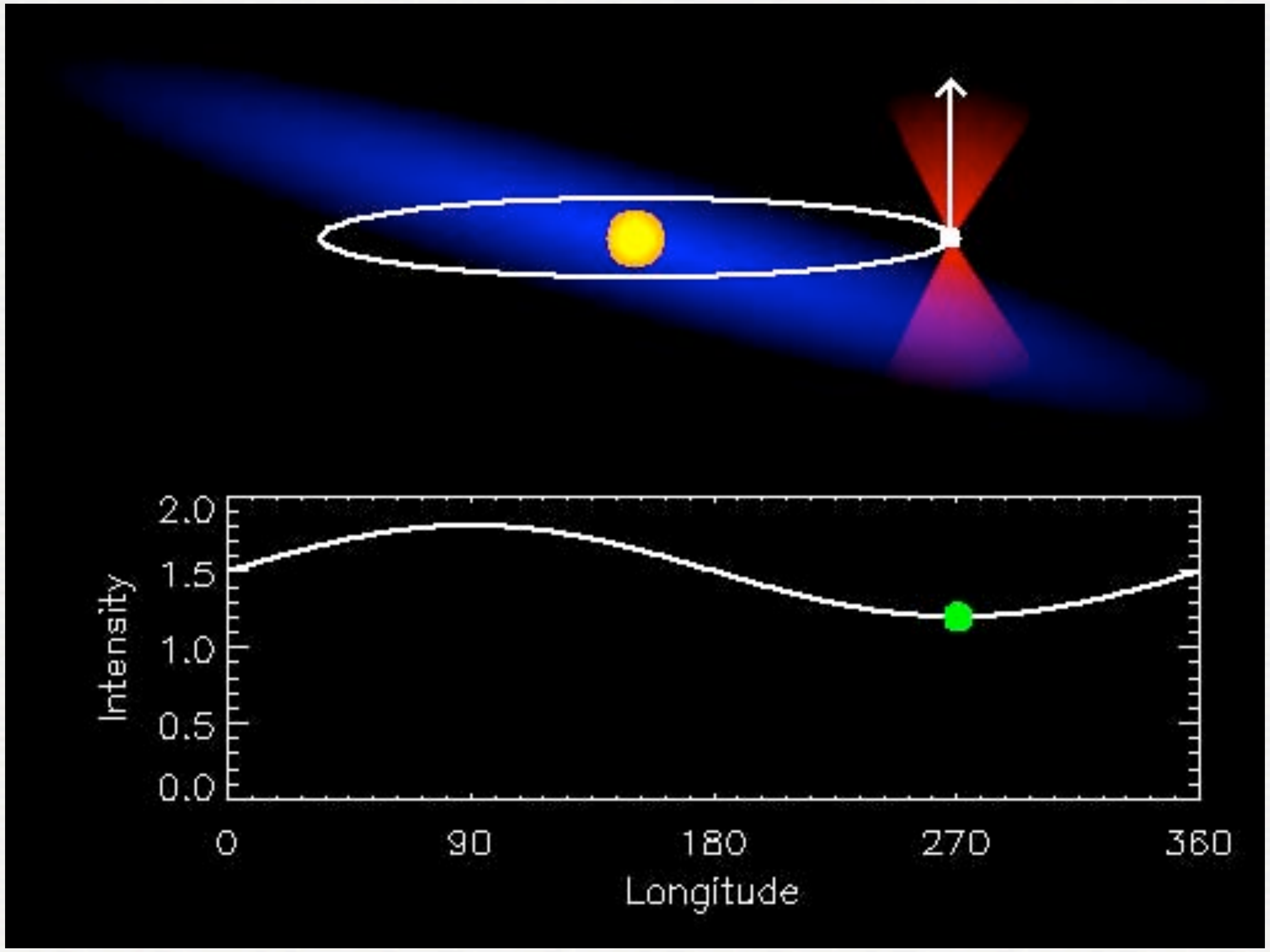
Assumption: the Galactic foreground and extragalactic background have constant intensities on the timescales of the experiment, and any temporal variation is from zodiacal light.

Orbiting within the IPD cloud causes periodic annual changes in the zodiacal light in a fixed direction.

IPD cloud
64-124° elongation range observed by DIRBE

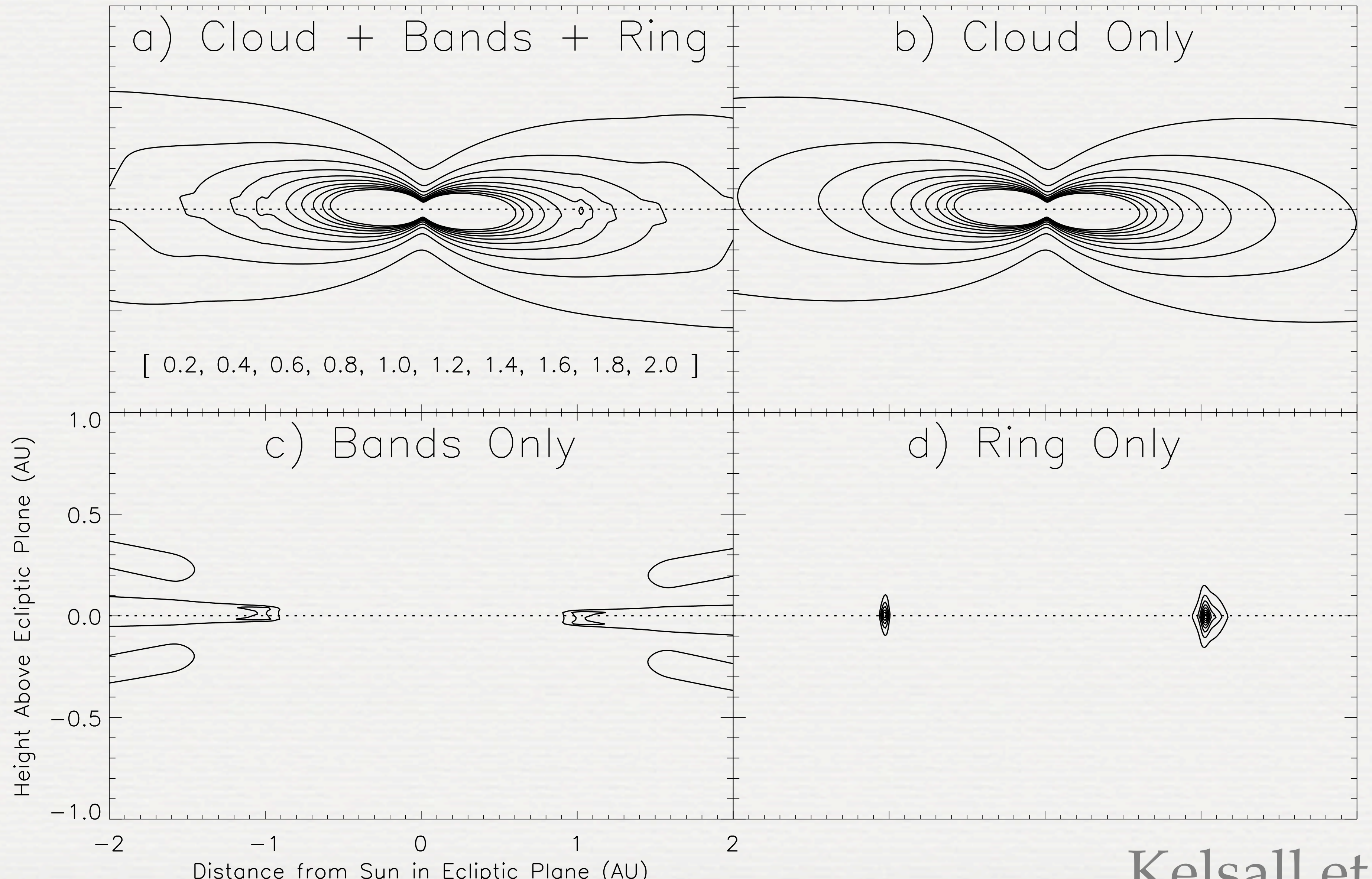


There is modulation even when looking at the ecliptic poles at a constant elongation = 90˚



These temporal variations are the primary constraints on DIRBE-based models of the zodiacal light. (Wright 1998; Kelsall et al . 1998)

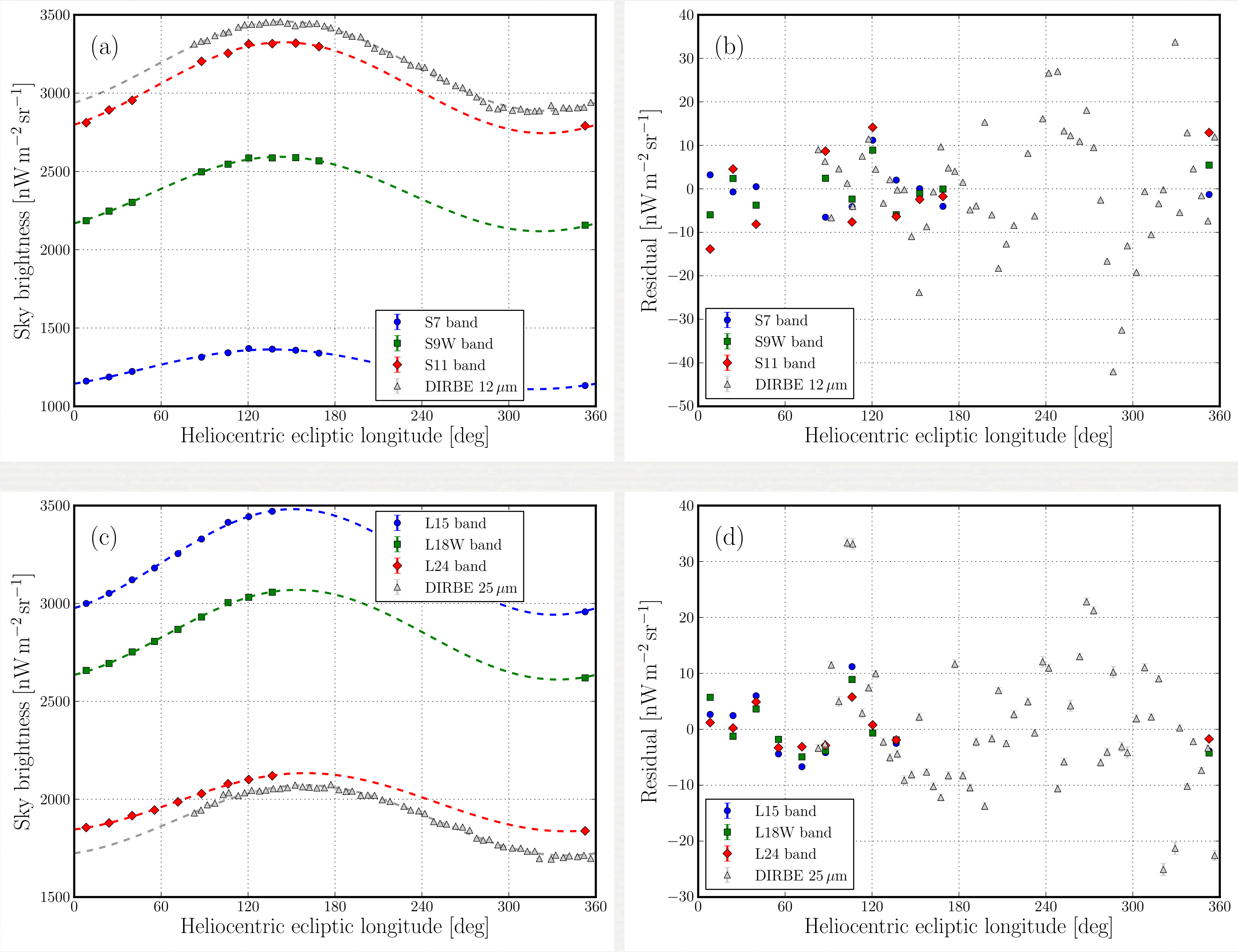
Models include a main cloud, asteroidal dust bands, and earth-resonant ring.



Kelsall et al. (1998)

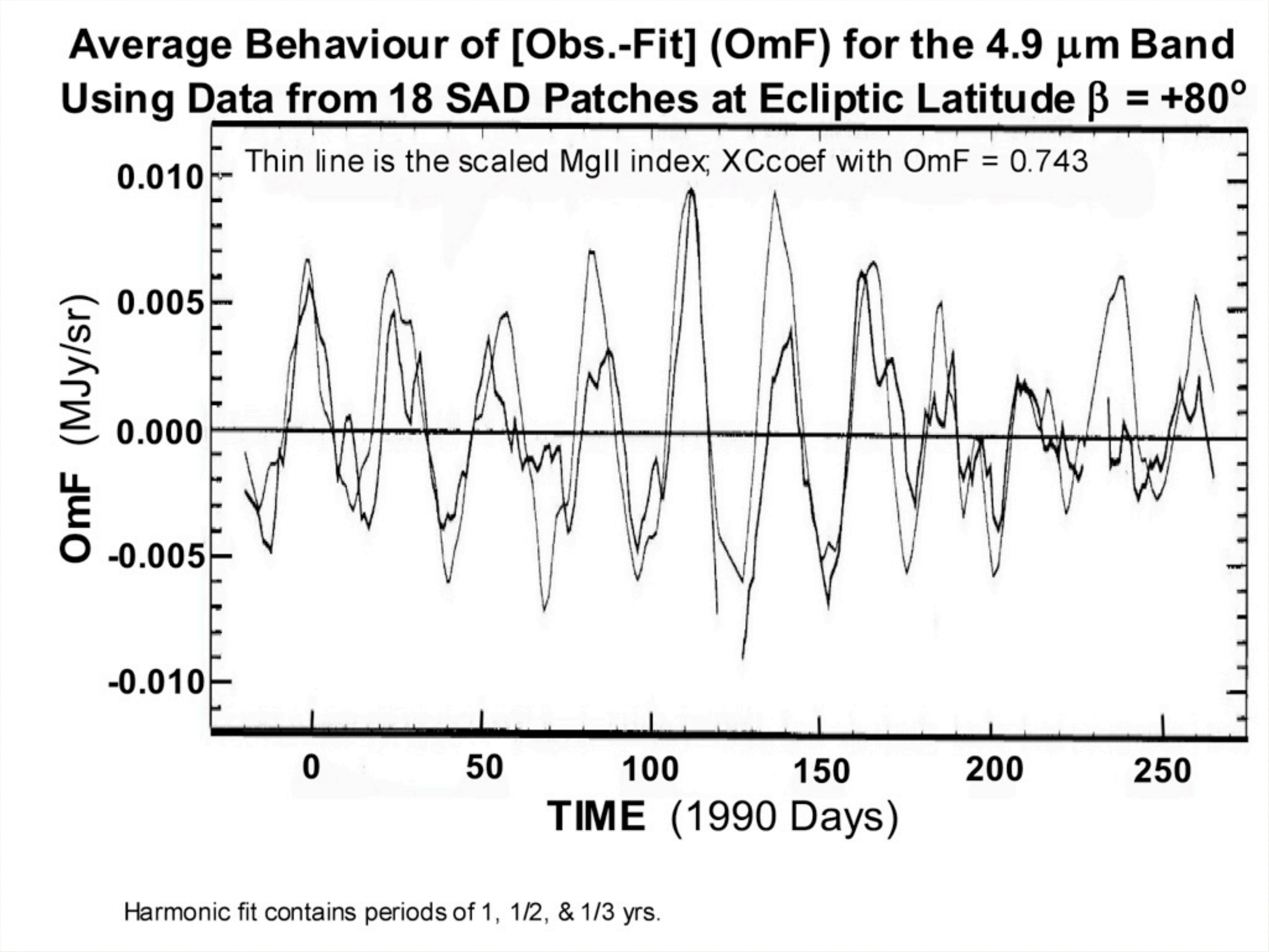
Akari and DIRBE NEP Variations

Sinusoidal fits and residuals as a function of time (i.e. longitude)



Pyo et al. (2012, arXiv:1202.4049v1)

DIRBE "Residuals" Correlate with Solar Activity!



Why?

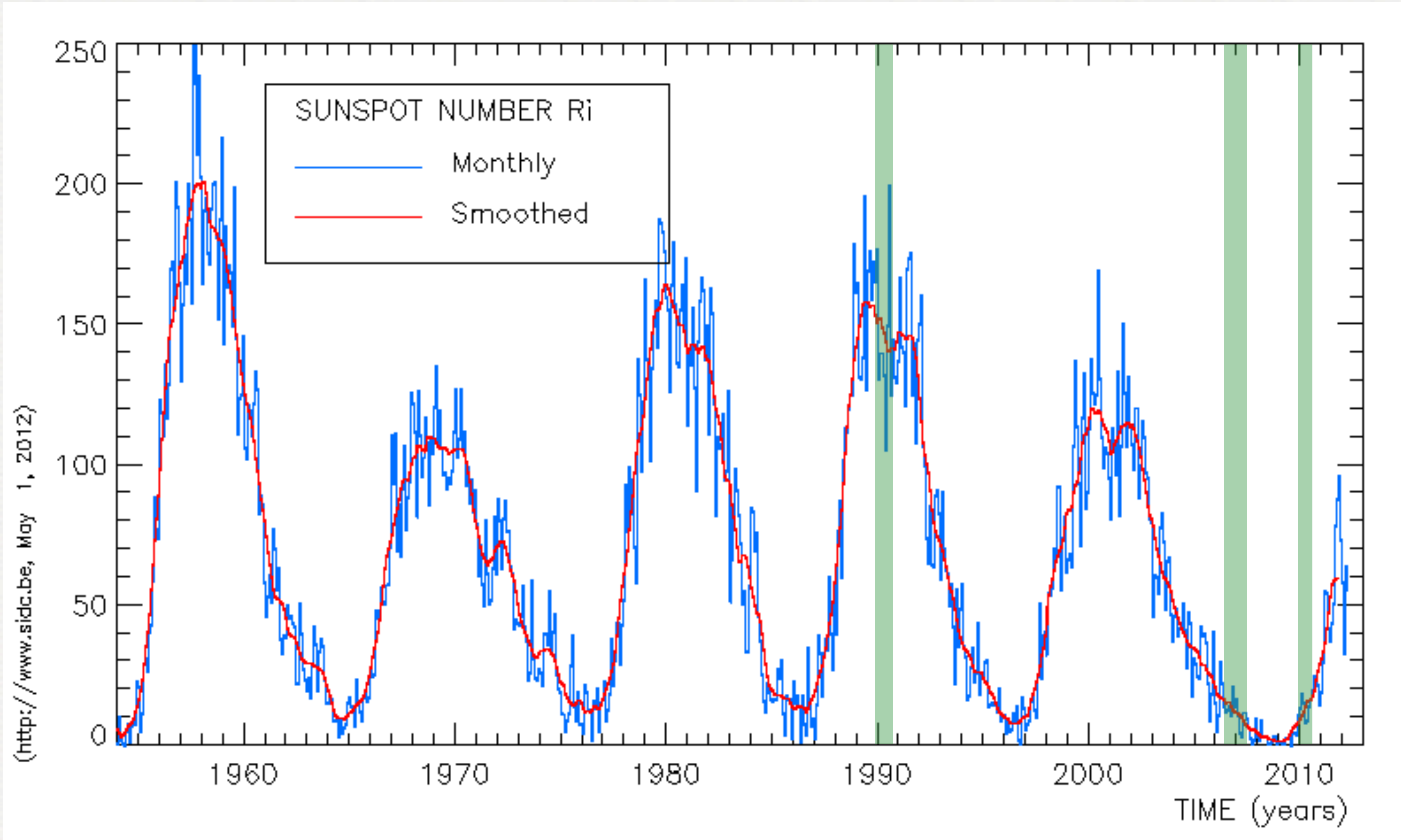
Fluorescent dust?

Magnetospheric interactions?

Amplitude ~ 6 nW m^{-2} sr^{-1} ~ 3%

T. Kelsall (in prep.)

DIRBE Akari WISE



SIDC - Solar Influences Data Analysis Center

http://sidc.oma.be/html/wolfmms.html

(2) SPATIAL FLUCTUATIONS

Changes in the intensity of the zodiacal light as a function of direction when measured at a particular time.

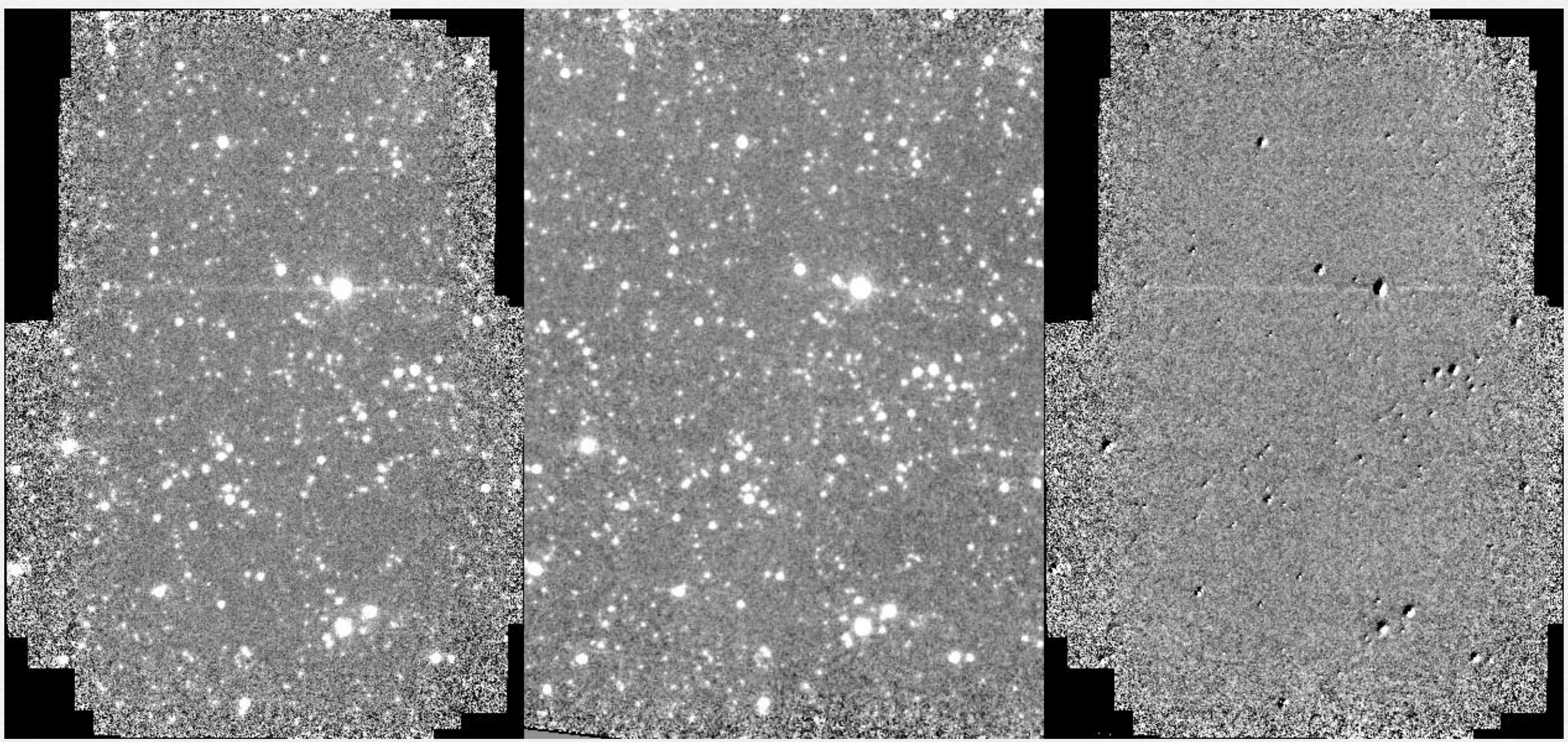
Spatial fluctuations provide alternate means of investigating the CIB that is insensitive to the absolute zero-point of the measurements.

Limits on Small-scale Zodi Fluctuations

- ISO observations at 25μm: <0.2% at scales ~3′-30′ (Ábrahám et al. 1997)

- Spitzer observations at 8μm: <0.1 nW m^{-2} sr^{-1} at ~200″

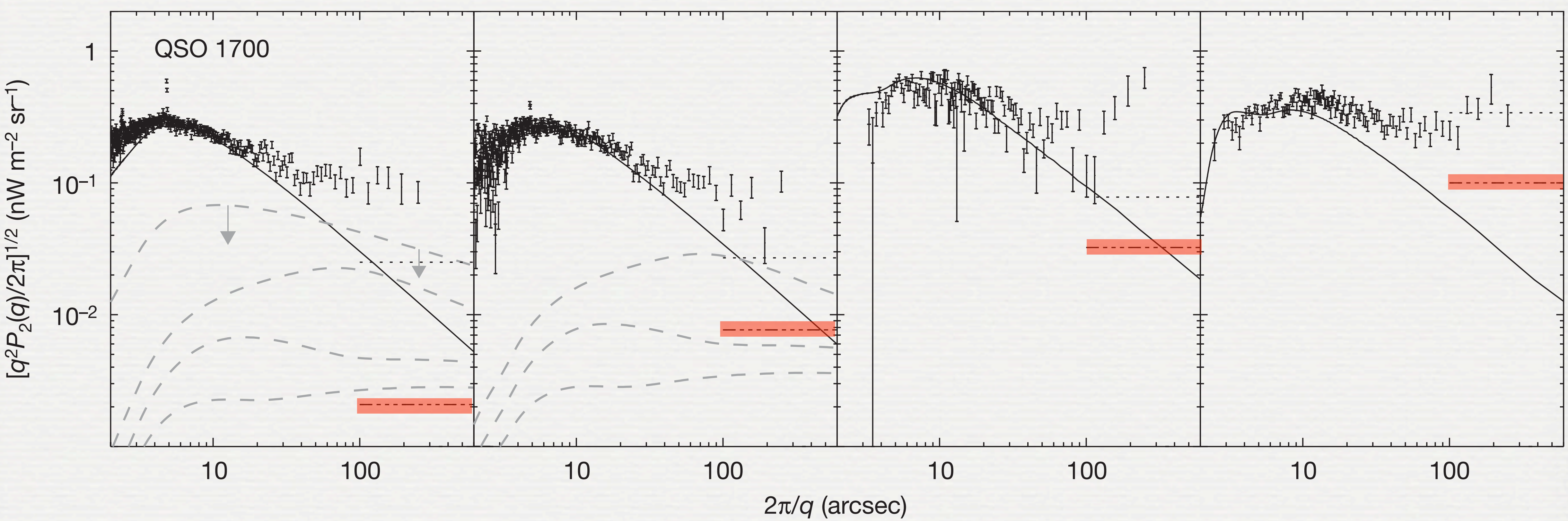
5′x10′ portion of the EGS field: 8 μm



Epoch 1 | Epoch 2 (+6mo) | Difference

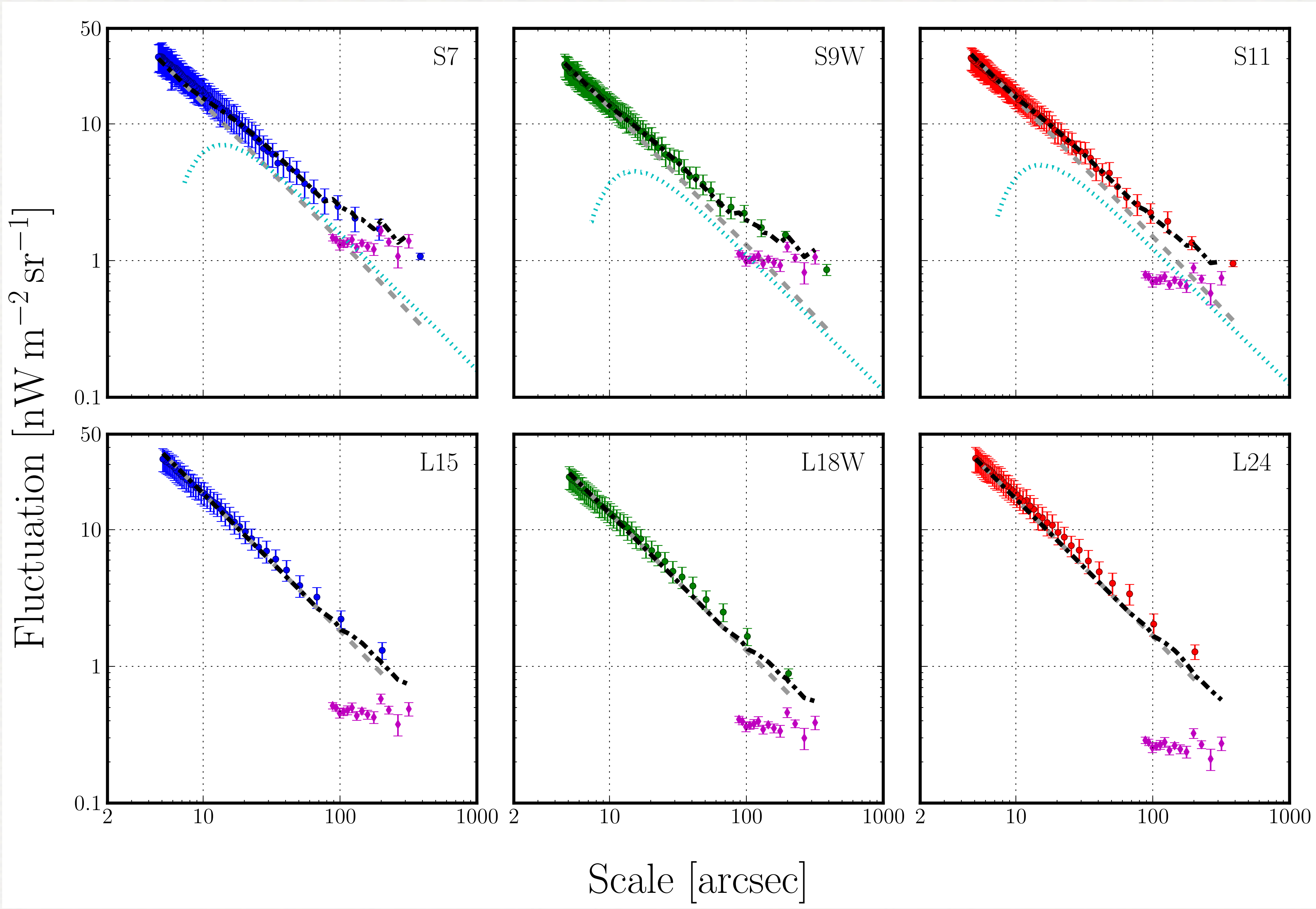
Fluctuation Spectra at 3.6, 4.5, 5.8, 8 μm

- Spitzer observations at 8μm: <0.1 nW m^{-2} sr^{-1} at ~200″



Kashlinsky et al. (2005)

Akari observations at 7-25μm: <0.02% at 200″ (Pyo et al. 2012)



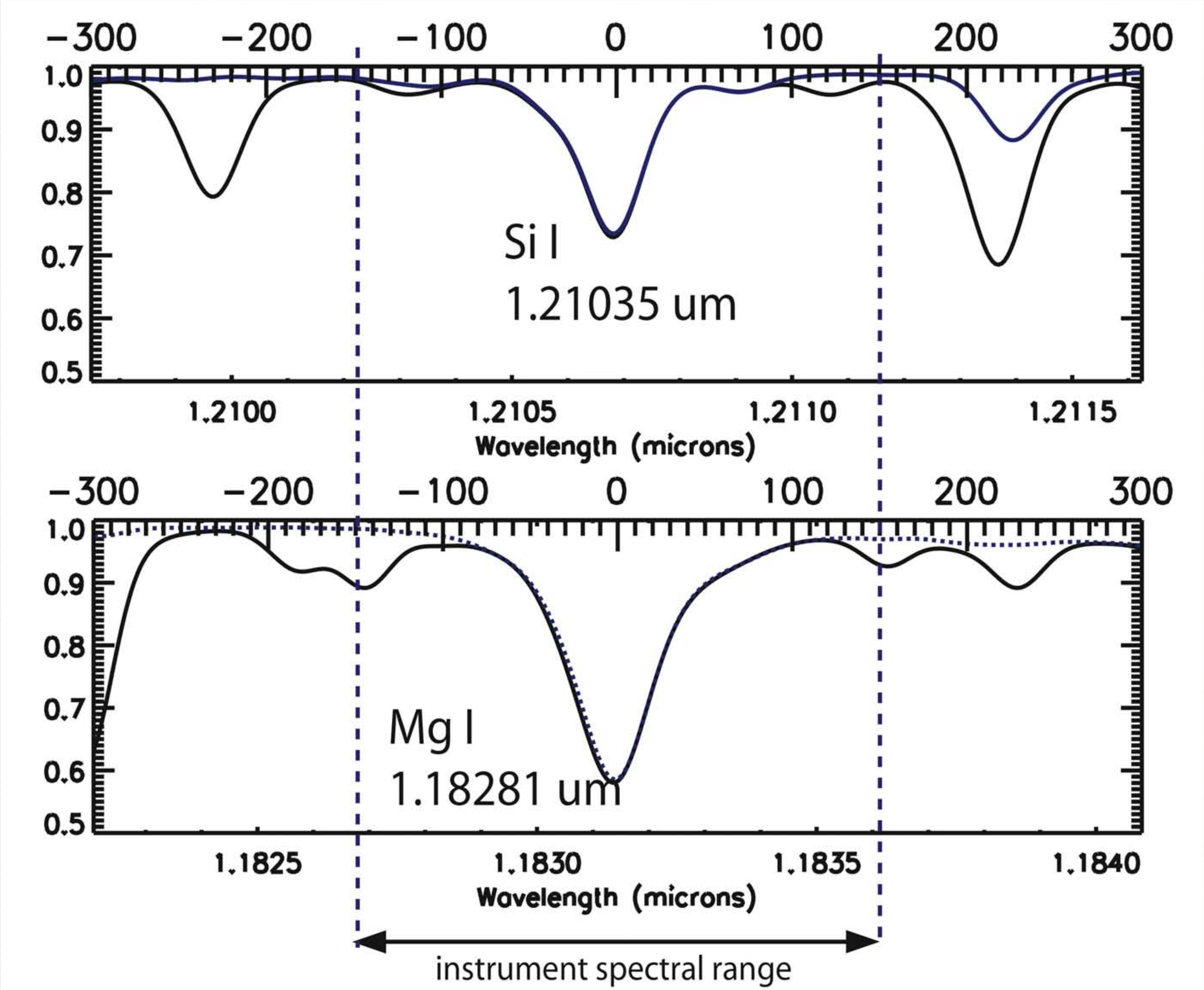
"The residual fluctuation power at 200″ after removing these contributions is at most 1.08 ± 0.22 nW m^{-2} sr^{-1} or 0.05% of the brightness at 24 μm and at least 0.52 ± 0.13 nW m^{-2} sr^{-1} or 0.02% at 18 μm. We conclude that the upper limit of the fluctuation in the zodiacal light is 0.02% of the sky brightness."

(3) SPECTRAL SIGNATURE

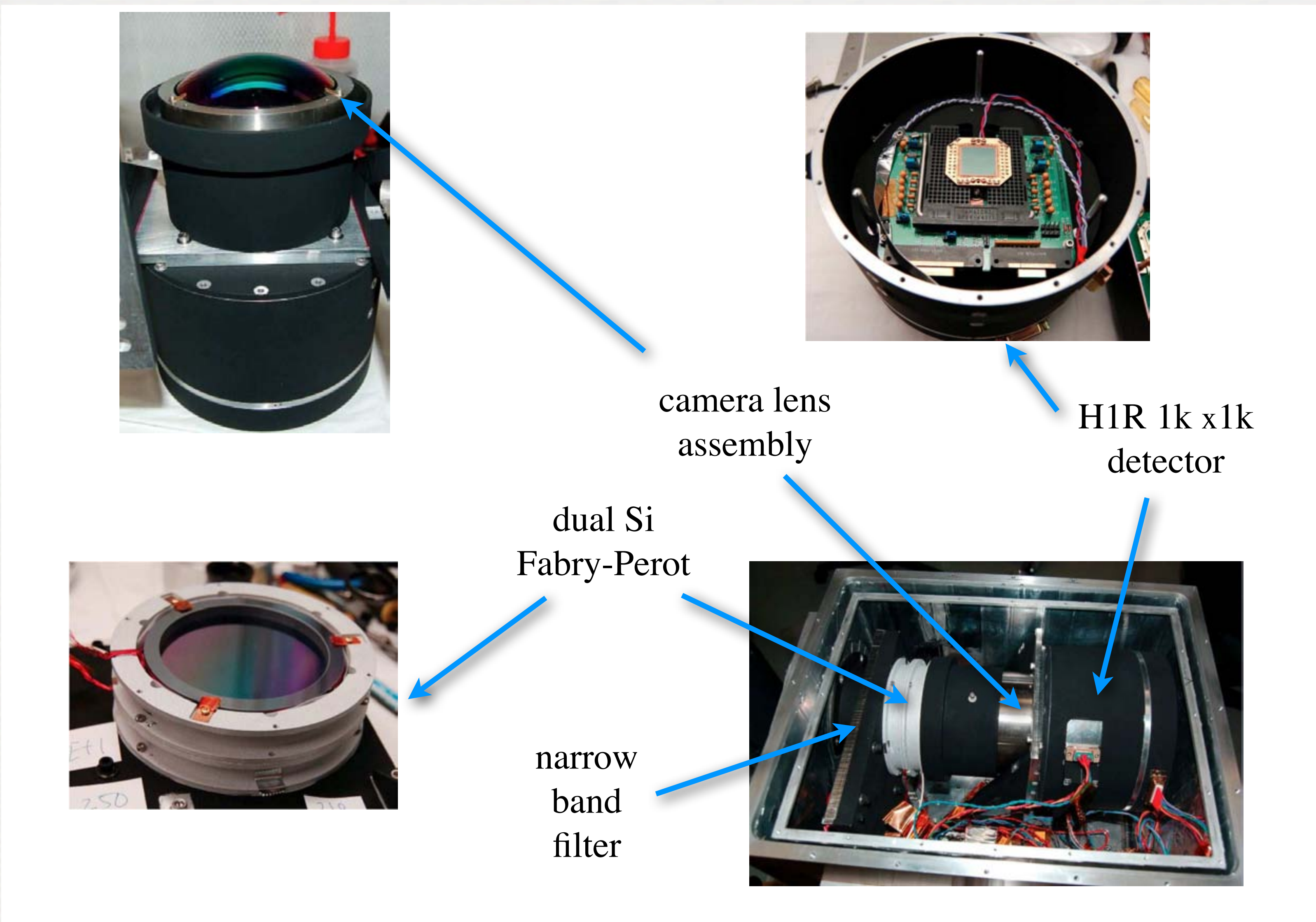
- Scattered zodiacal light has the same spectrum (Fraunhofer absorption lines) as the Sun.
- In the near-IR CIB, the lines are shifted and smeared by a the wide range in redshift.
- Comparison of the observed depth of the lines to the their depth in the solar spectrum can reveal the absolute brightness of the zodiacal light.
- Reynolds, Madsen & Moseley (2004): WHAM – Mg I 5184Å
  Older measurements aimed at kinematics: late 1960s - 1970s

FRAUNHOFER LINES IN THE J BAND

Need to select strong lines that are distinct from telluric lines and not obscured by OH emission lines



Dual-etalon Fabry-Perot Spectrometer
A. Kutyrev (UMCP/GSFC), PI



300 km/s bandwidth
15 km/s resolution

Multiple Filters

Fig. 5.— The components of the instrument. The current single channel prototype spectrometer has been built and field tested at the Goddard Geophysical and Astronomical Observatory (GGAO) in Maryland. A number of observing runs day and night time has been carried out to characterize the instrument. It has been verified that the instrument is performing according to the design and estimates.

Example Scattered Light Spectrum

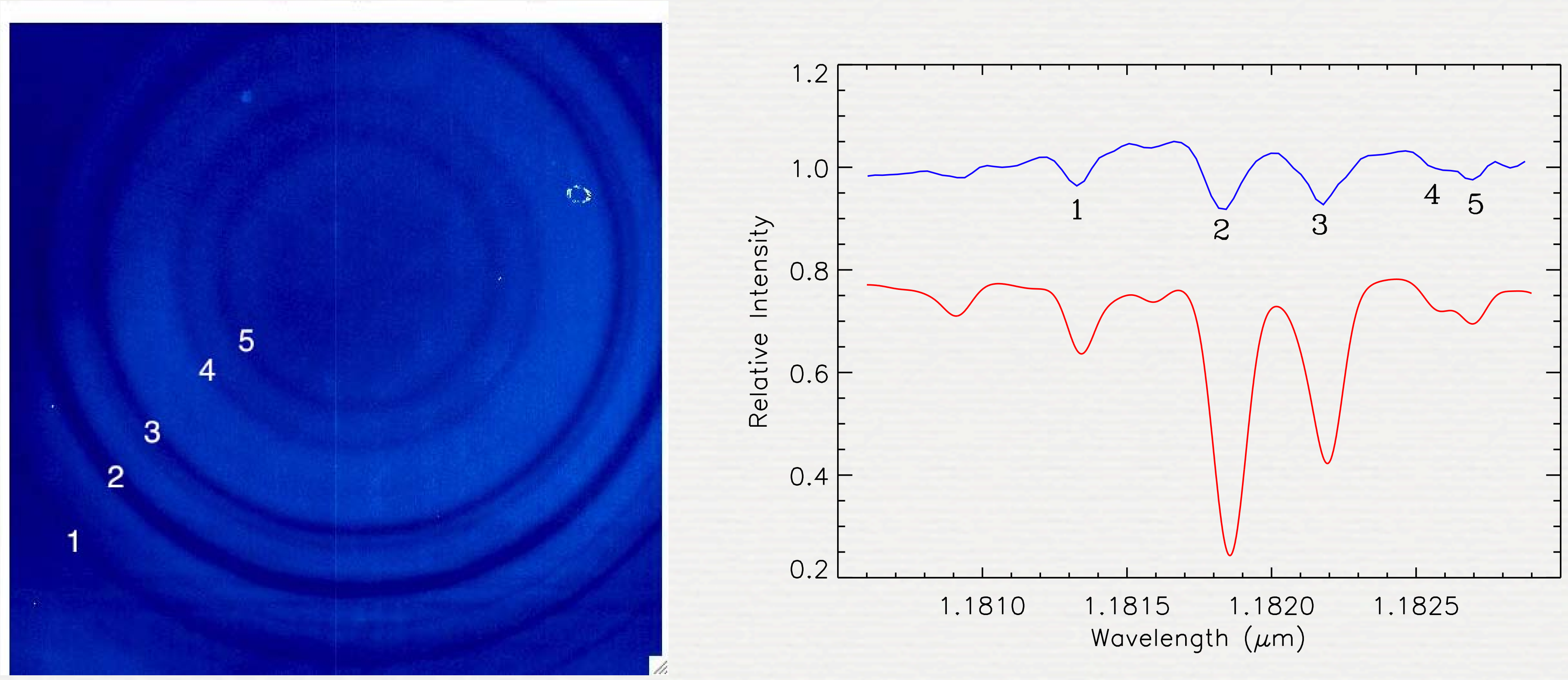


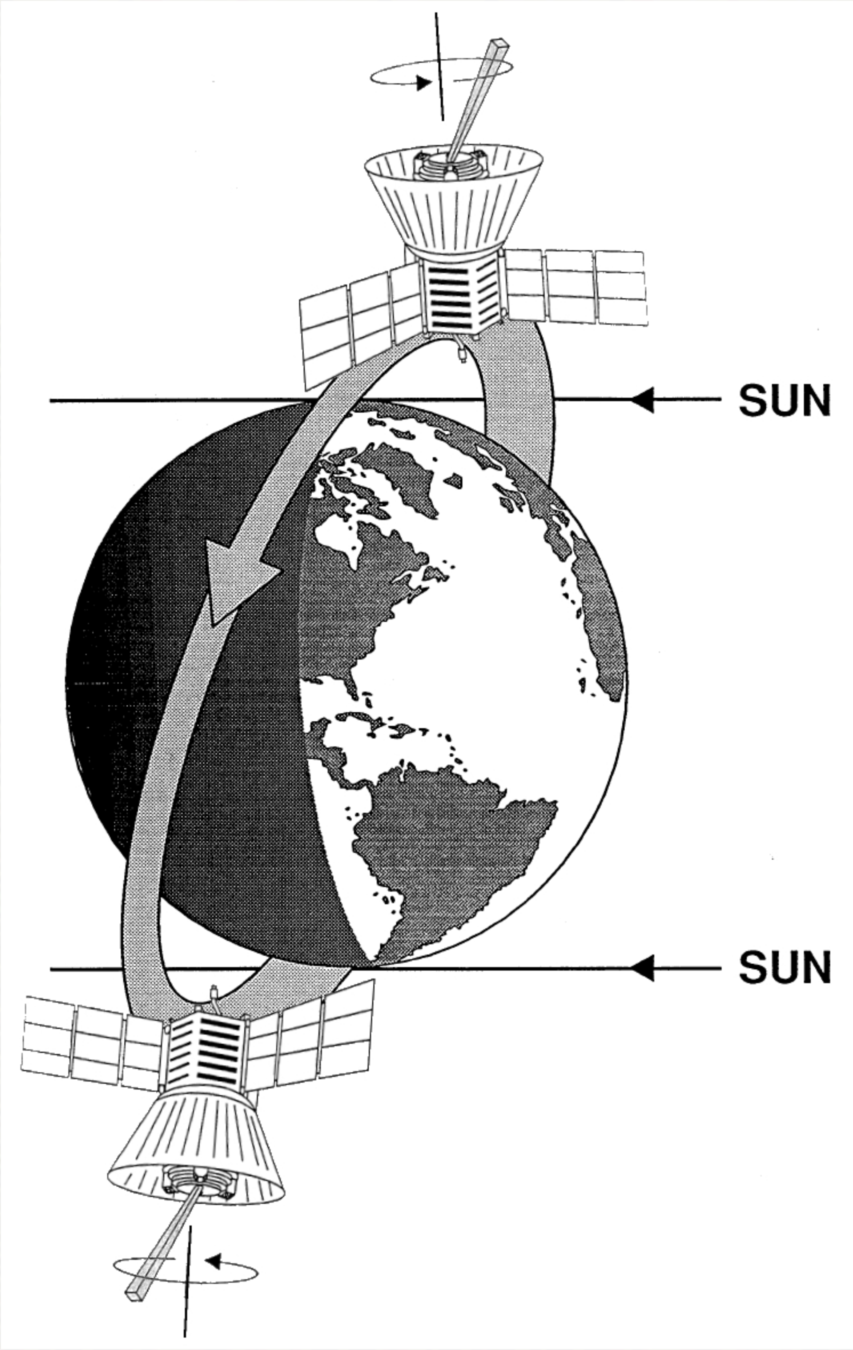
Fig. 6.— **Left**: Narrow-band image of the sky in which the wavelength is a function of radius. **Right**: An example of the daytime solar spectrum obtained at $\sim 1.18\ \mu m$ (blue). For comparison the NSO solar spectrum (including telluric lines) is shown in red (offset by 0.2 for clarity). The numbered lines are also identified in the image at the left.

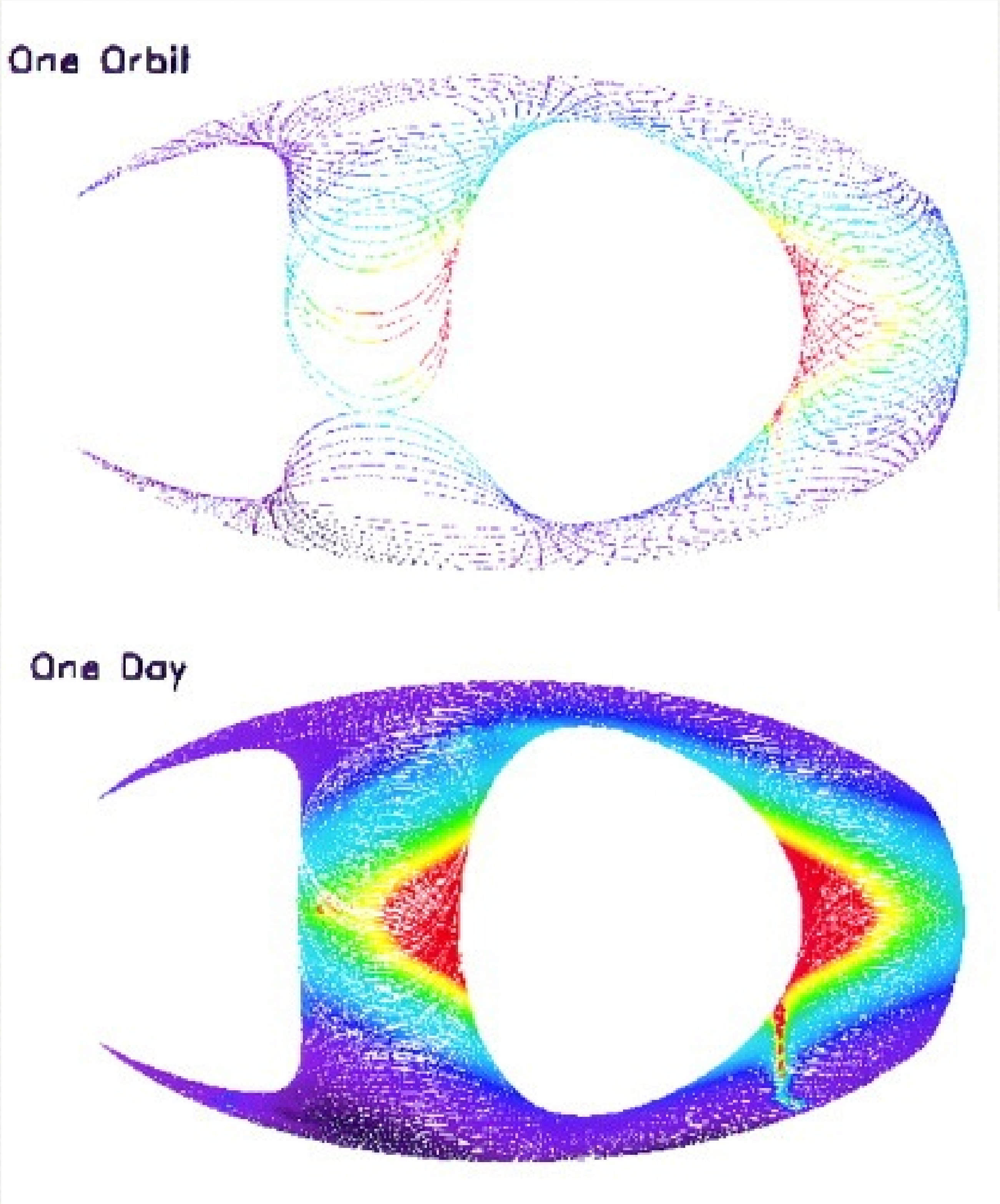
SUMMARY

- Temporal Variation – Good constraint for models of the IPD cloud and zodiacal light – Still zero-point uncertainties – Contains large solar-modulated effects of unknown origin.
- Spatial Fluctuation – Necessary to know for comparison with measurement of EBL fluctuations – only upper limits established so far – these limits seem sufficient, but some extrapolation is required.
- Spectral Signature – Good constraint on ZL and on IPD kinematics – Practical difficulties with telluric and OH lines.

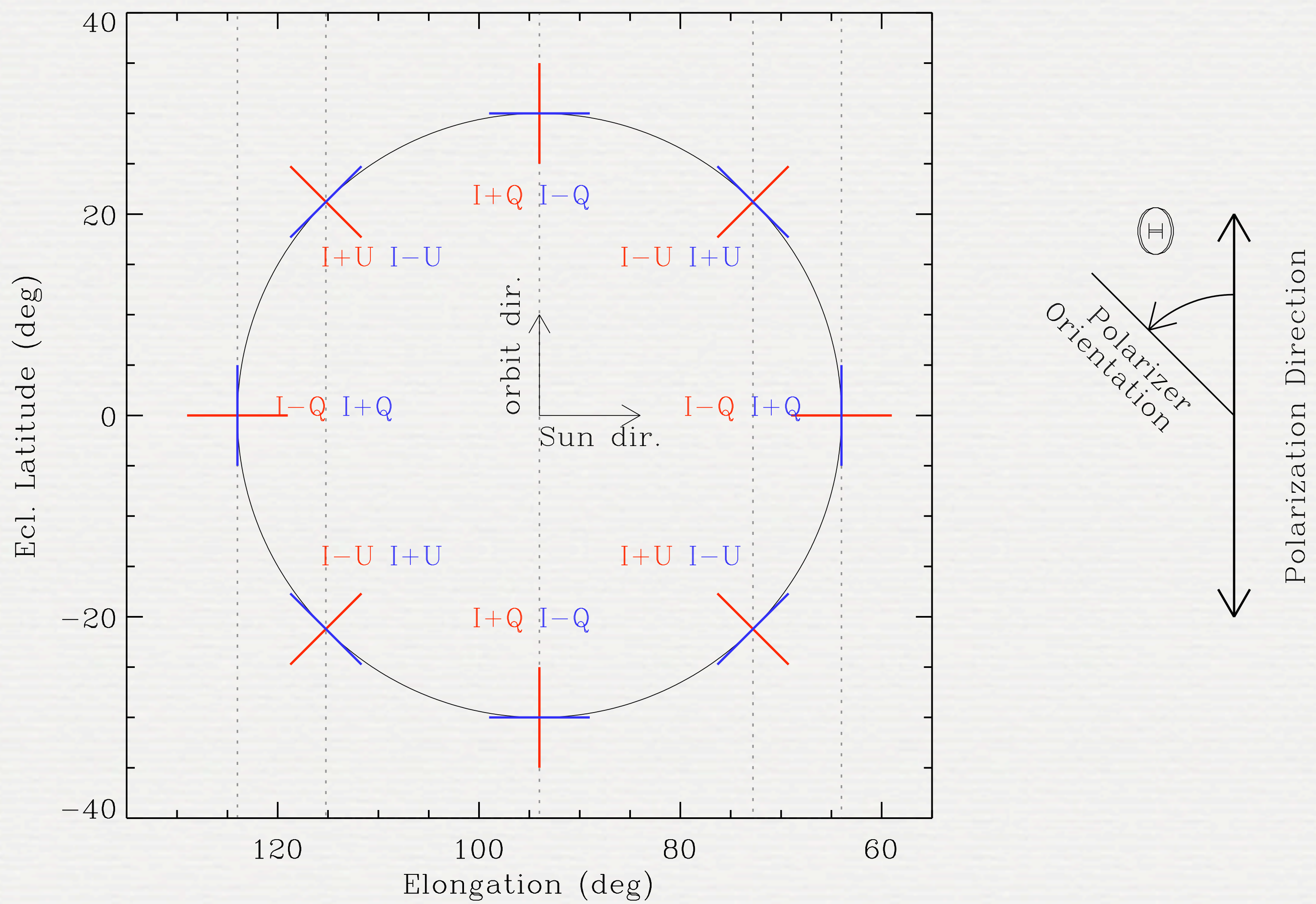
The End

But what about polarization?


SUN
SUN


One Orbit
One Day

Angle Definitions

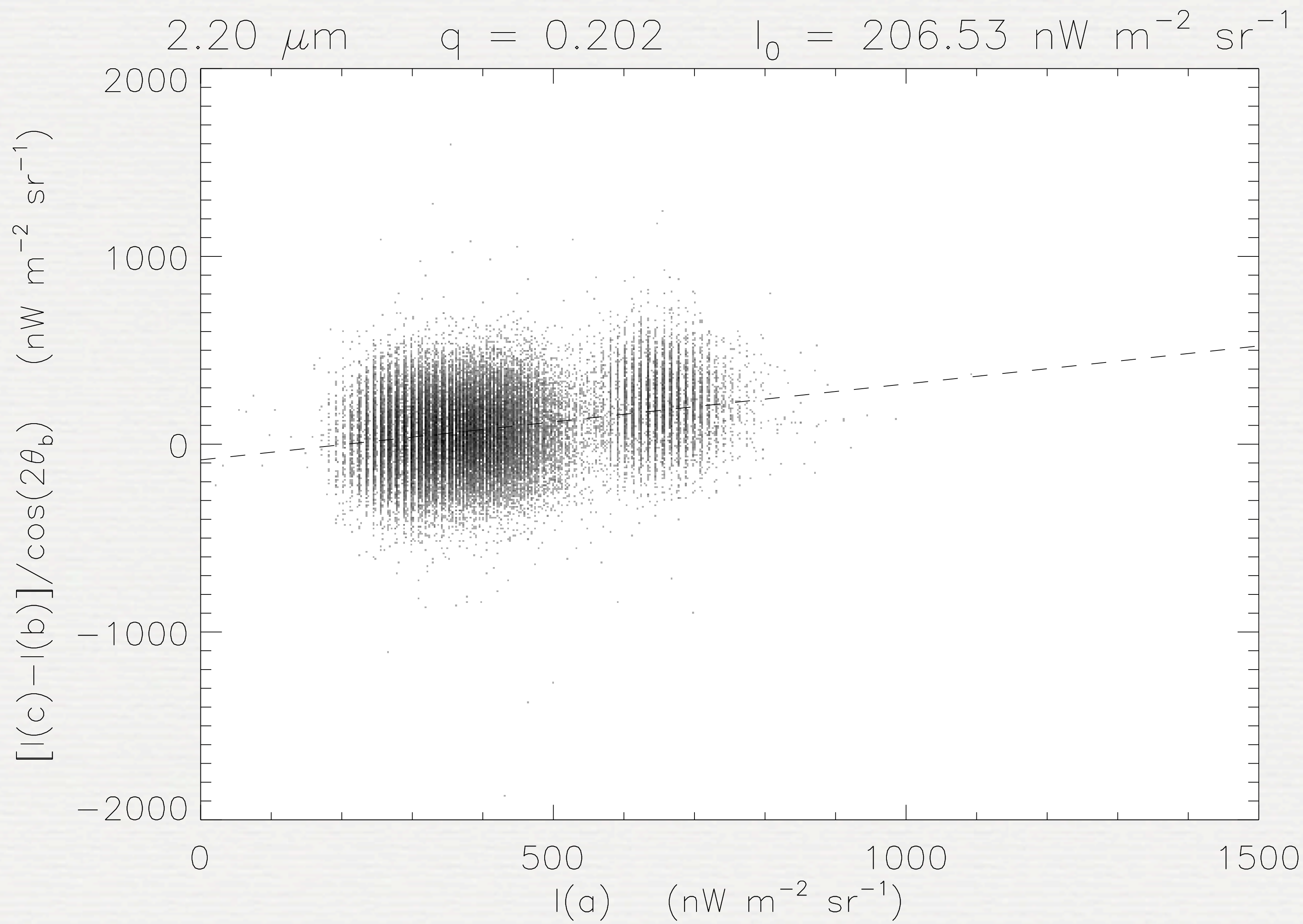


Polarization Fitting

$$\frac{(I_b - I_c)}{\cos 2\theta_b} = 2qI_a + (-2q)I_0$$

$$m = 2q \text{ and } b = -2qI_0$$

Example Fit



2.20 μm q = 0.202 I0 = 206.53 nW m−2 sr−1
2000
1000
0
−1000
−2000
0
500
1000
1500
I(a) (nW m−2 sr−1)
[I(c)−I(b)]/cos(2θb) (nW m−2 sr−1)

Variation of I_0 with Galactic Latitude

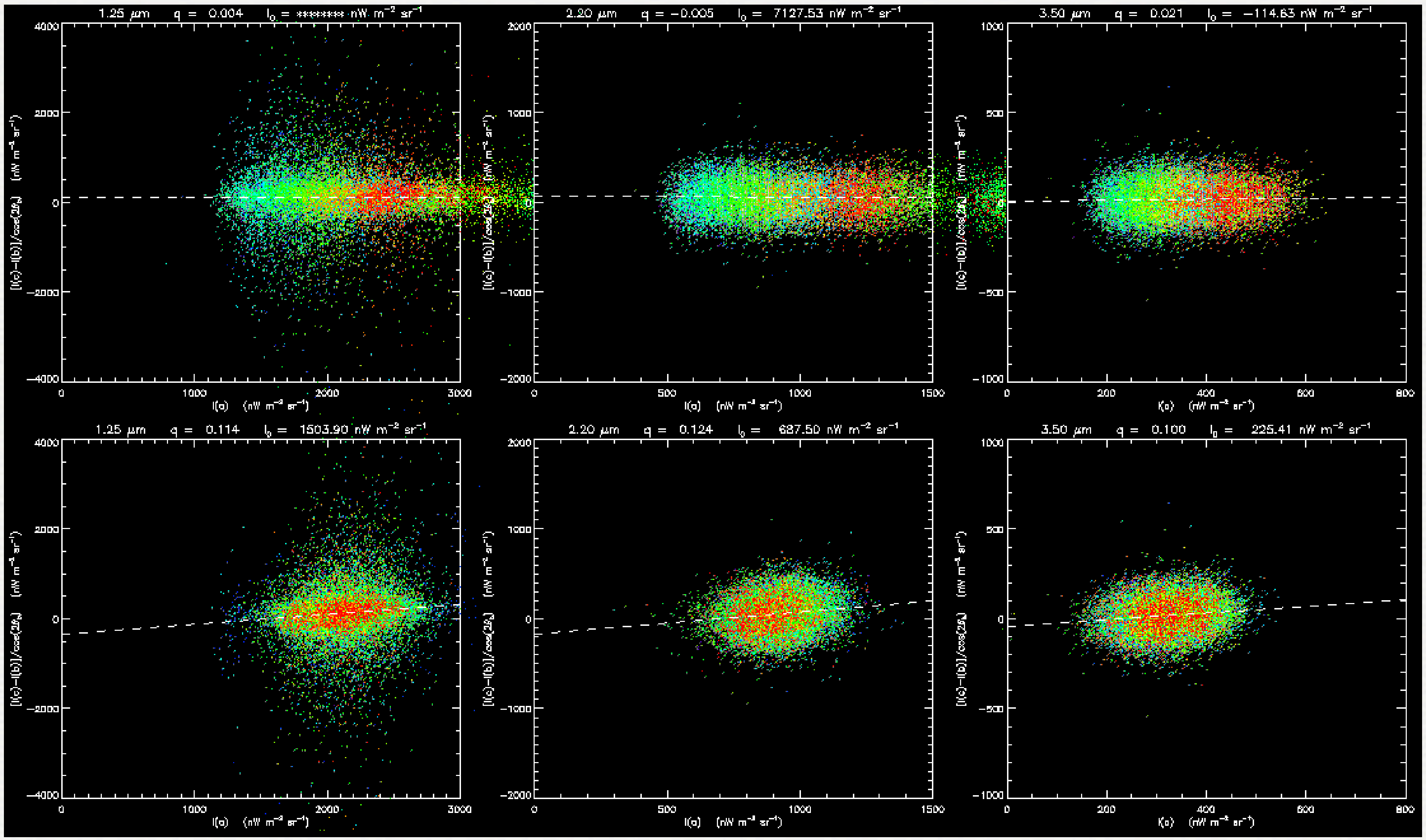


Figure 2: Polarization correlations for patch at pixel 000000, ecliptic $(l, b) = (315, 35.3)$, galactic $(l, b) = (60.3, -12.2)$.

Problematic results: I_0 is correlated with ecliptic latitude

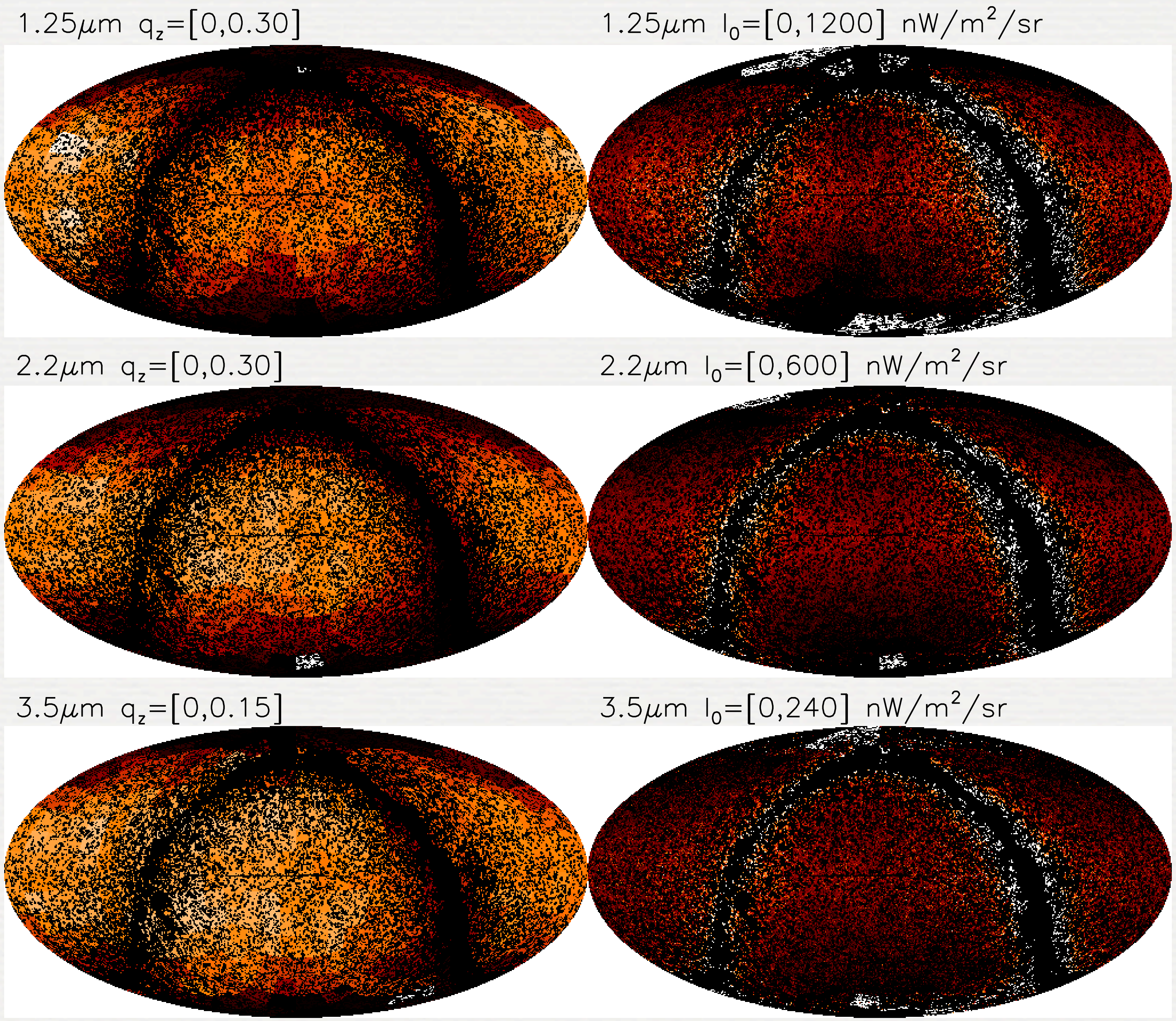


Figure 3: Ecliptic Mollweide maps of the fractional polarization (left) and the constant background intensity: Galactic + cosmic IR background (right). The rows from top to bottom show results at 1.25, 2.2, and 3.5 μm.

(a) Unmodulated zodi?

(b) Noise limitations?

(c) Procedural error?