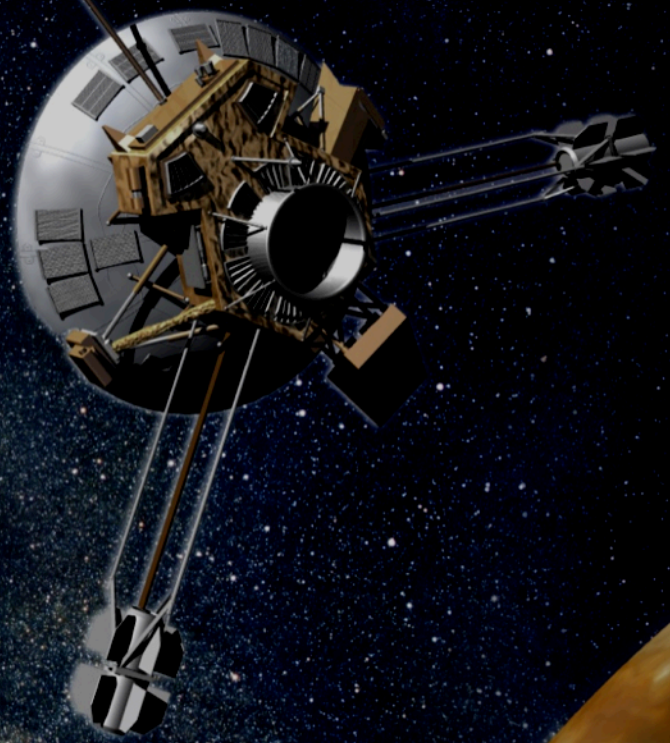
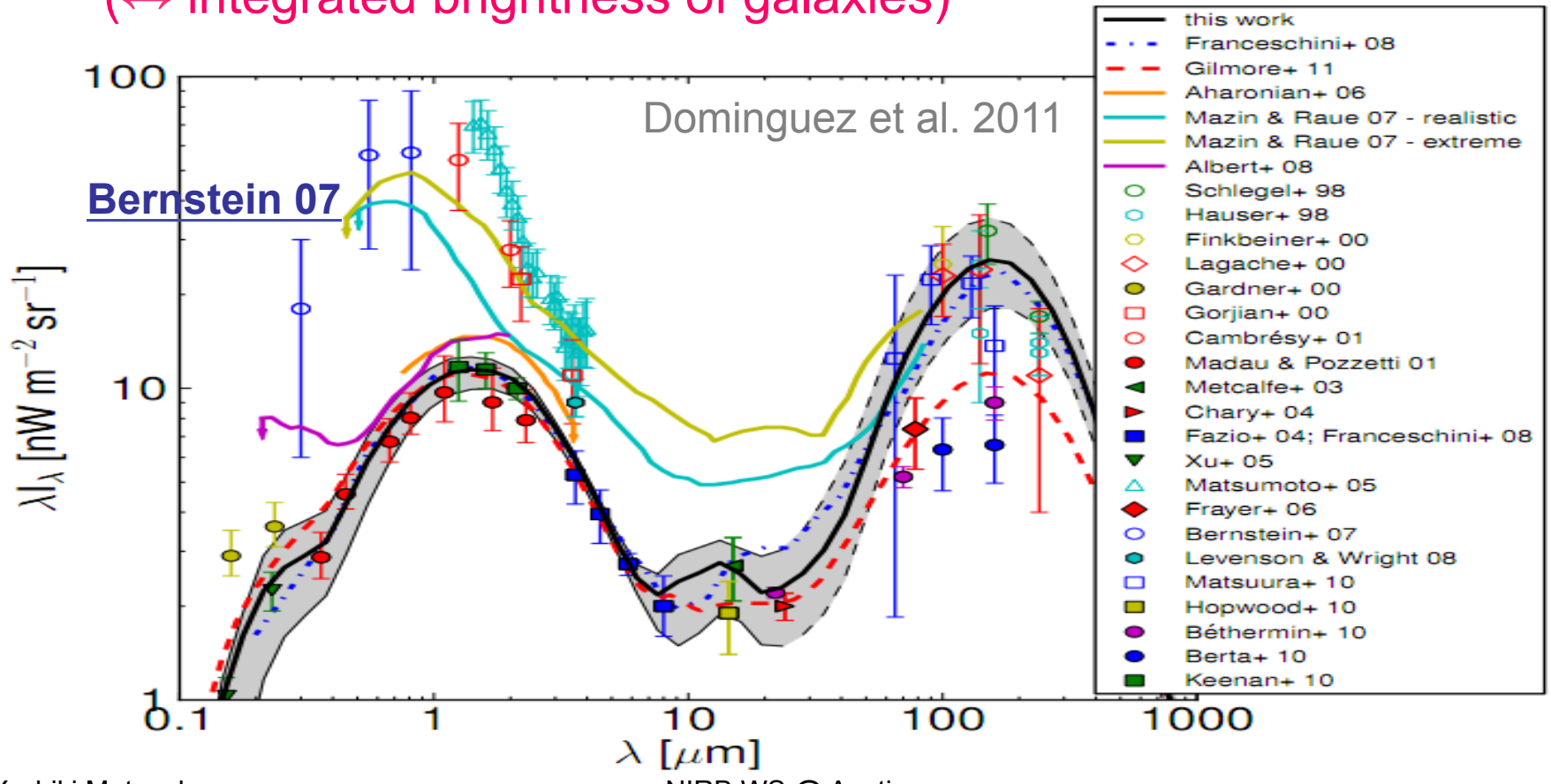
Abstract

- We have re-analyzed the all-sky imaging data taken by the IPPs on board the Pioneer 10/11 spacecrafts.
- The new constraints on the COB are obtained, which are
  - 7.9 ± 4.0 nW m^{-2} sr^{-1} at 0.39 – 0.50 μm,
  - 7.7 ± 5.8 nW m^{-2} sr^{-1} at 0.60 – 0.72 μm.
- The derived COB is consistent with the integrated brightness of galaxies in the Hubble deep field.

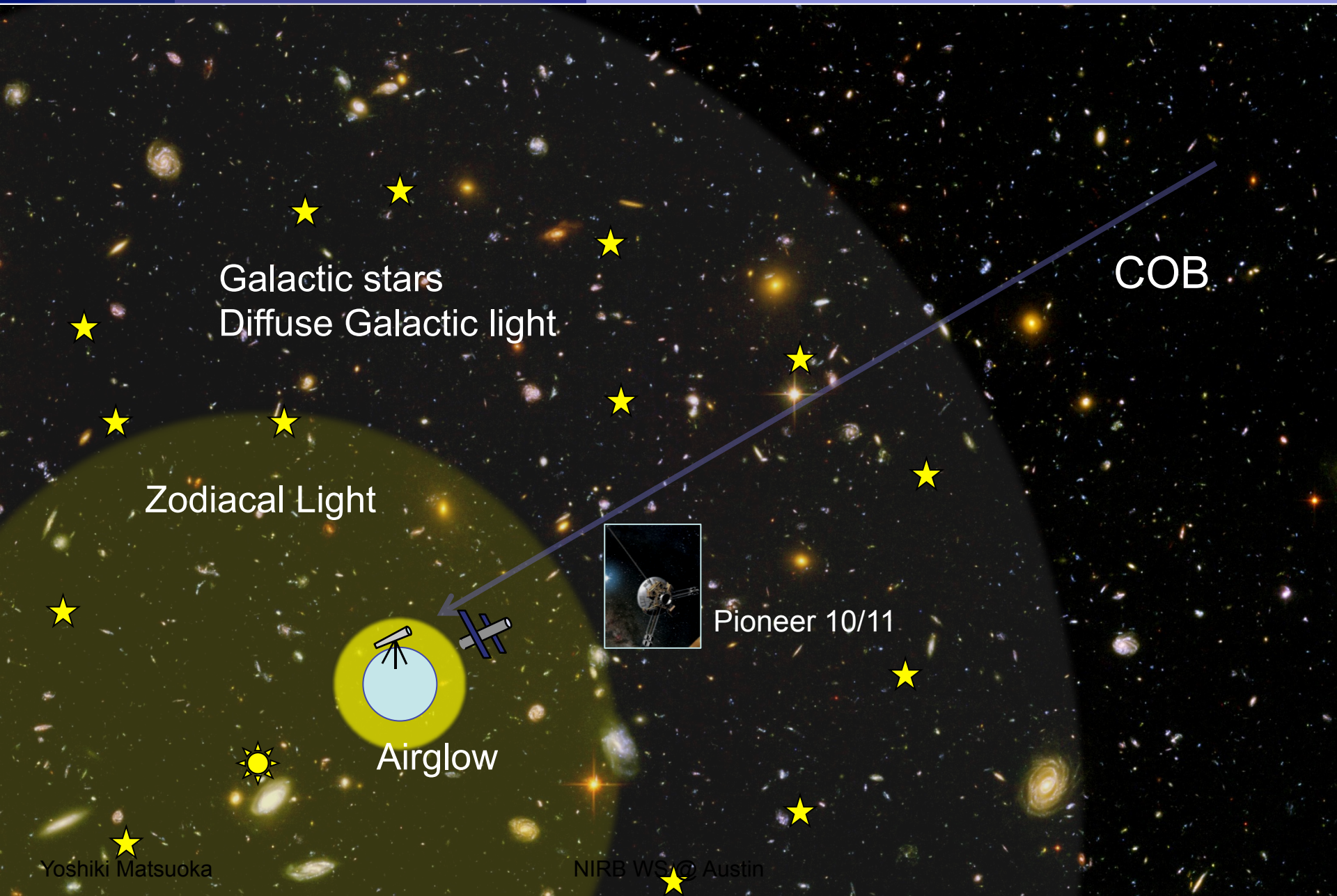


COB: The View from Pioneer 10/11

- Cosmic optical background (COB) = Optical component of the extragalactic background light (EBL)
- UV and optical light of all radiation sources in the Universe (↔ integrated brightness of galaxies)



COB: The View from Pioneer 10/11

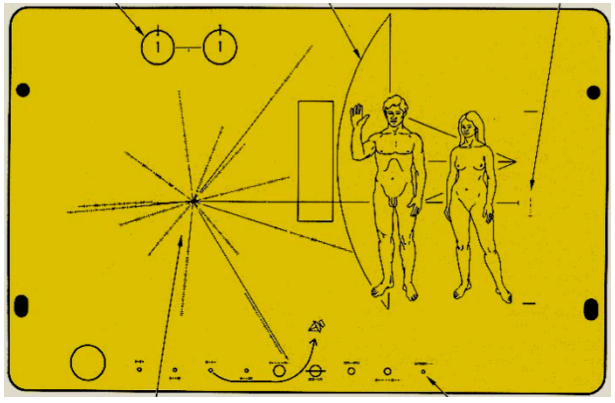


COB: The View from Pioneer 10/11

- NASA's Pioneer 10/11 spacecrafts
- "the first to be sent to the outer solar system and the first to investigate the planet Jupiter, after which followed an escape trajectory from the solar system"
- Launched: May 1972 (Pioneer 10)
  Apr 1973 (Pioneer 11)
- Comm. Stop: Jan 2003 (P10; D = 82 AU)
  Nov 1995 (P11; D = 45 AU)

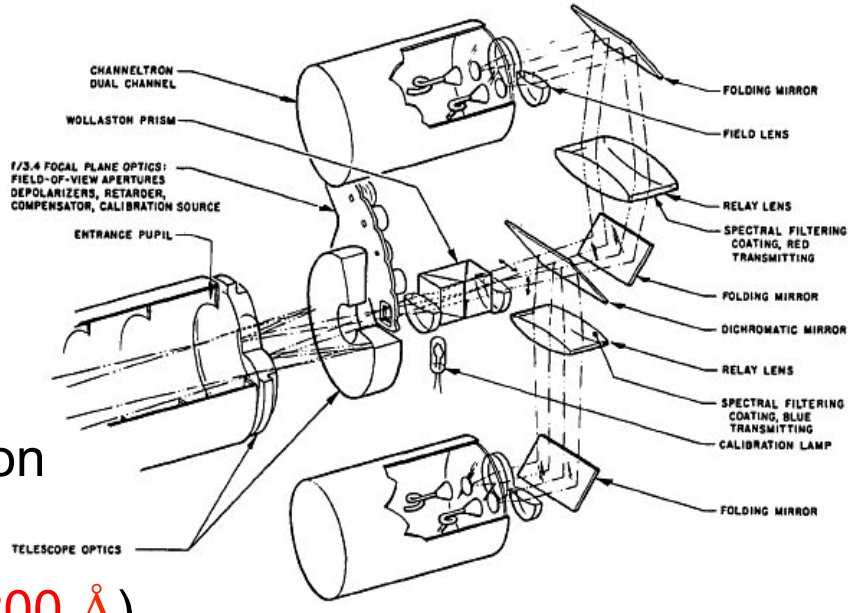
- Scientific instruments:

  magnetometer; plasma analyzer; charged particle detector; ionizing detector; non-imaging telescopes; sealed pressurized cells of Ar and N gas; UV photometer: IR radiometer; imaging photopolarimeter



COB: The View from Pioneer 10/11

- Imaging Photopolarimeter (IPP)
  - 2.5-cm Maksutov telescope
  - Wollaston prism
  - multilayer filters
  - dual-channel Bendix channeltrons



- measures two orthogonal polarization components in the two wave bands (blue; 3900 – 5000 Å, red; 5950 – 7200 Å)
- Instantaneous FOV: 2.29° x 2.29°
- takes 64 exposures per one spacecraft spin (12.5 sec)

  → effective FOV: 2.29° x (2.29° + 5.625° sin *L*) ~ 10 deg^2
- *L*: "look angle" between the IPP pointing and spacecraft spin axis
- 1 data cycle = 10 rolls (8 for sky measurements, 1 for photometric calibration, 1 for dark-current and offset measurement)

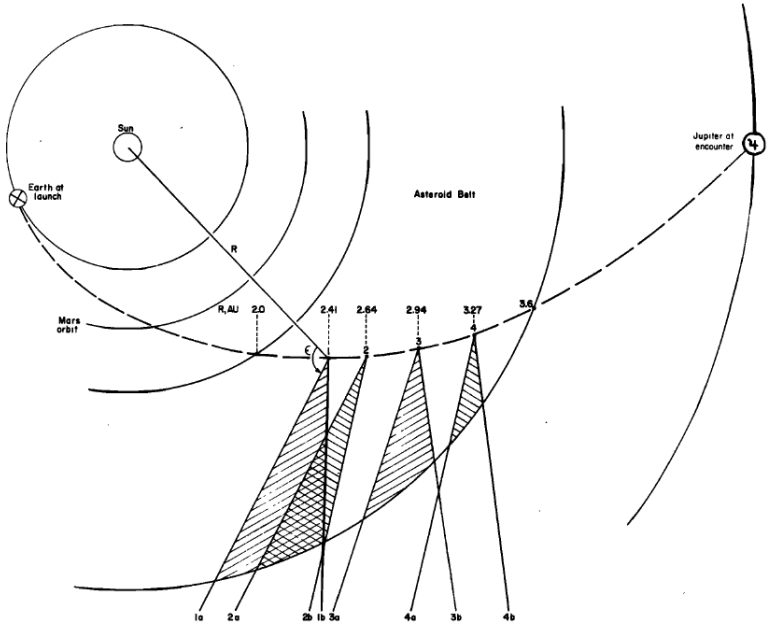
COB: The View from Pioneer 10/11

- ZL and COB measurements by the IPP
- Hanner et al. (1974)

  - monitored the sky brightness during the cruise phase of the Pioneer 10 at the heliocentric distances 2.4 – 4.8 AU.

  - ZL @ 2.4 AU < 10% ZL @ 1 AU

  - ZL undetectable @ > 3.3 AU



- Toller (1983)

  - attempted to detect the COB in the Pioneer 10 IPP data taken at the heliocentric distances > 3.3 AU (i.e., outside the ZL clouds)

  - COB < 4.5 x 10^{-9} erg s^{-1} cm^{-2} sr^{-1} $Å^{-1}$ at 4400 Å

    … comparable to the HST results by Bernstein et al. (2002-2007)

  - BUT the starlight subtraction is the fatal problem in his analysis.

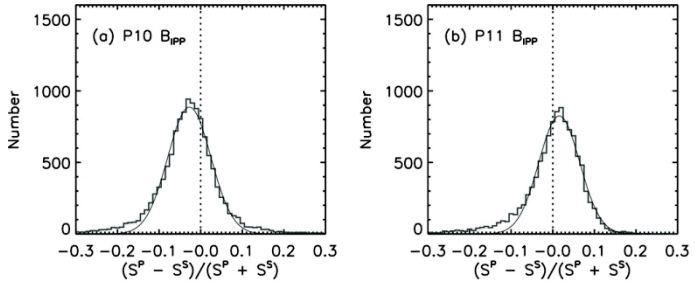
COB: The View from Pioneer 10/11

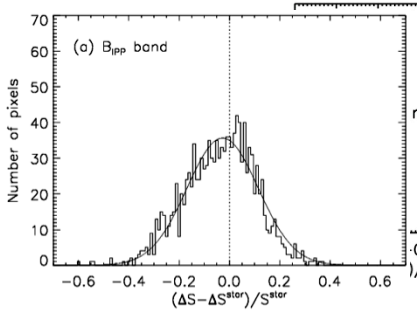
space craft	date	R (AU)	all #	good Q	corrupt	scatter. sunlight	abnorm. (global)	abnorm. (local)
Pio 10	354/'72	3.26	5696	60 %	25 %	5 %	7 %	3 %
Pio 10	093/'73	3.92	1344	75 %	5 %	0 %	14 %	6 %
Pio 10	149/'73	4.22	5504	61 %	19 %	10 %	5 %	6 %
Pio 10	216/'73	4.54	2816	51 %	3 %	0 %	2 %	45 %
Pio 10	237/'73	4.64	5312	57 %	24 %	5 %	12 %	3 %
Pio 10	279/'73	4.81	5248	57 %	21 %	8 %	10 %	4 %
Pio 10	021/'74	5.08	5504	59 %	27 %	4 %	6 %	4 %
Pio 10	068/'74	5.15	5376	67 %	29 %	1 %	1 %	2 %
Pio 11	057/'74	3.50	4544	73 %	11 %	1 %	10 %	4 %
Pio 11	106/'74	3.81	4672	74 %	5 %	6 %	10 %	4 %
Pio 11	148/'74	4.06	4672	77 %	3 %	9 %	9 %	2 %
Pio 11	178/'74	4.22	4608	73 %	3 %	9 %	11 %	4 %
Pio 11	236/'74	4.51	4544	82 %	10 %	3 %	1 %	5 %
Pio 11	267/'74	4.66	4416	71 %	9 %	3 %	6 %	12 %

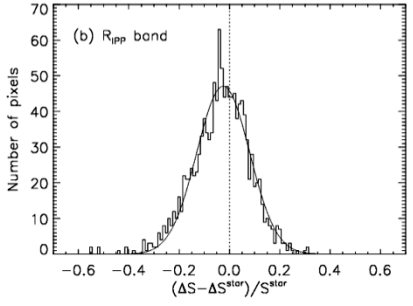
COB: The View from Pioneer 10/11

- Quality Assessment

Comparison between two polarization components

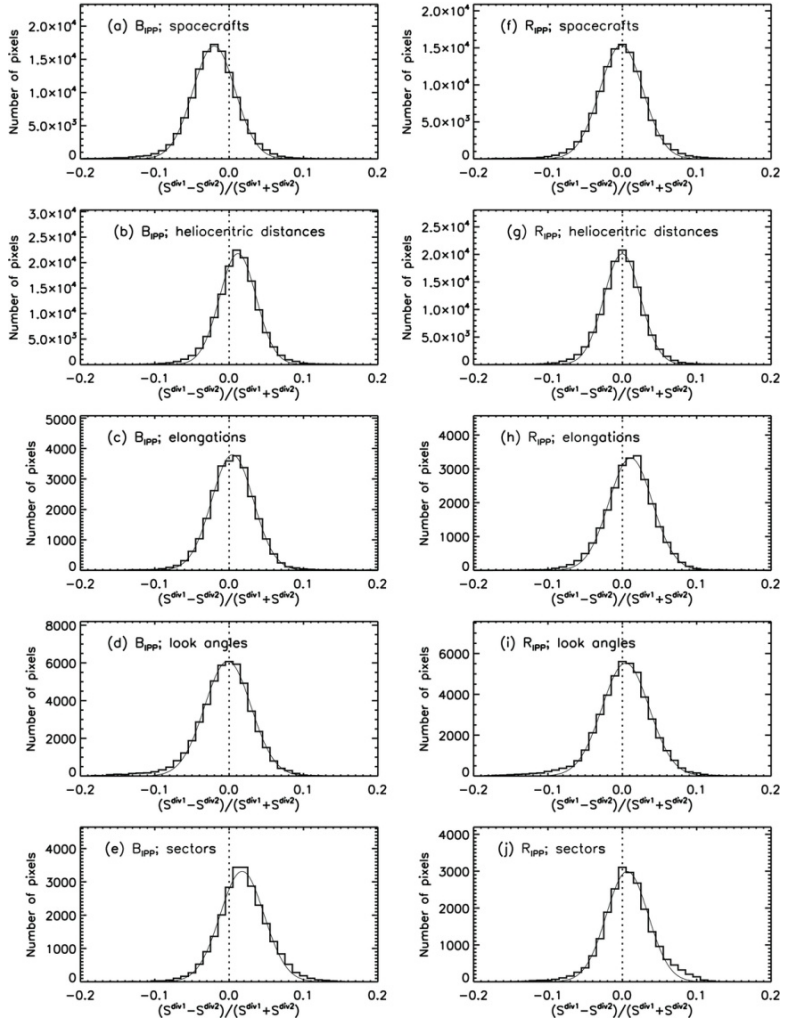






Comparison of differential brightness: IPP measured vs. stellar magnitudes

Comparison between data subgroups (spacecraft, distance to the Sun, …)



COB: The View from Pioneer 10/11

S: Brightness measured by the IPP

S^{star}: Brightness from the independent star catalogs

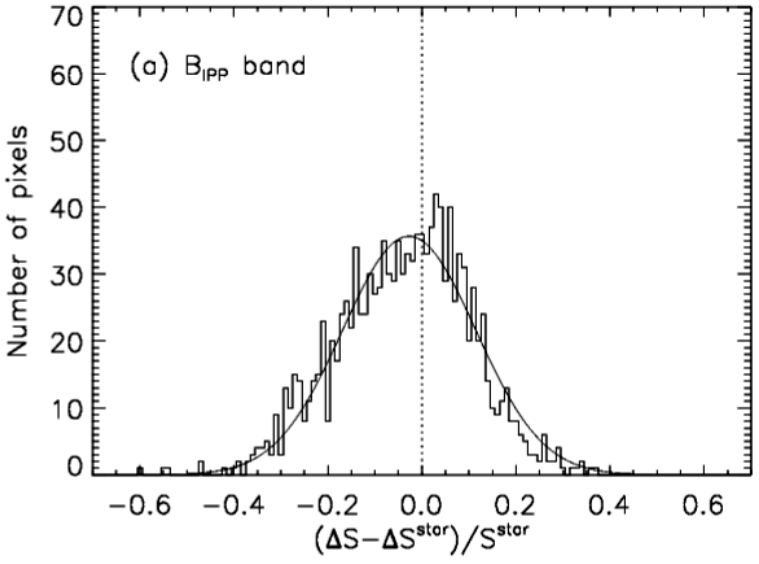
- S and S^{star} cannot be directly compared because (only) S includes the COB component.

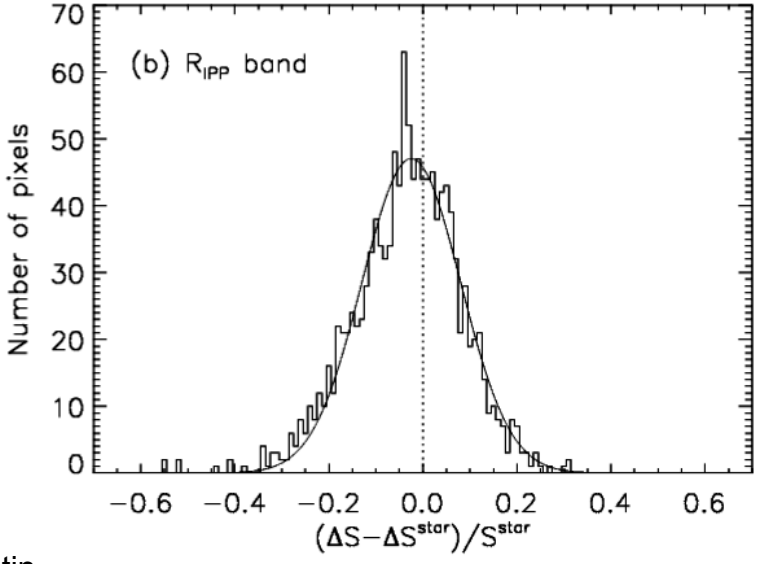
↓

ΔS: Brightness difference between any two IPP FOVs.

ΔS^{star}: Corresponding difference from the star catalogs

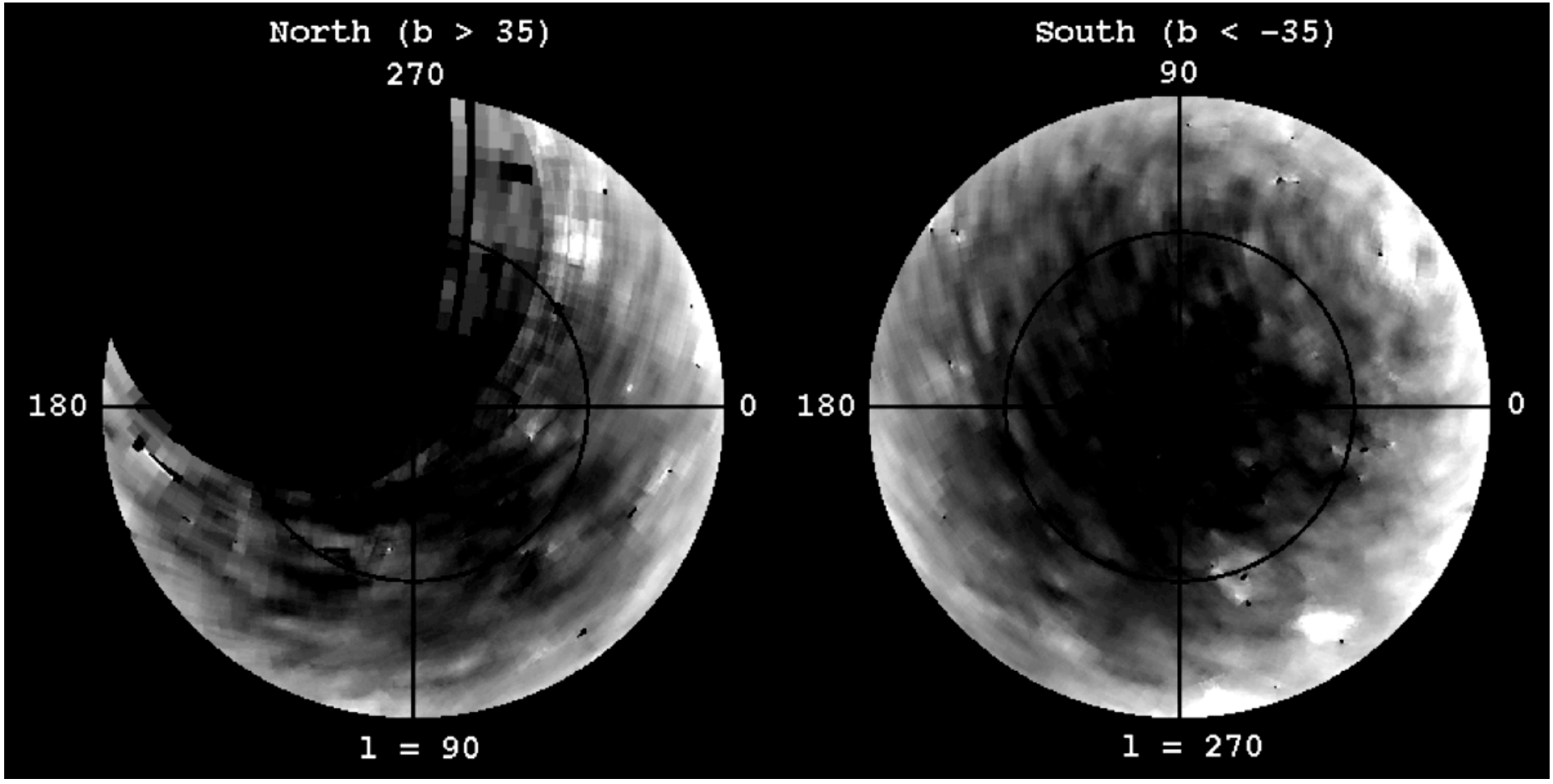
.. a few % systematic difference





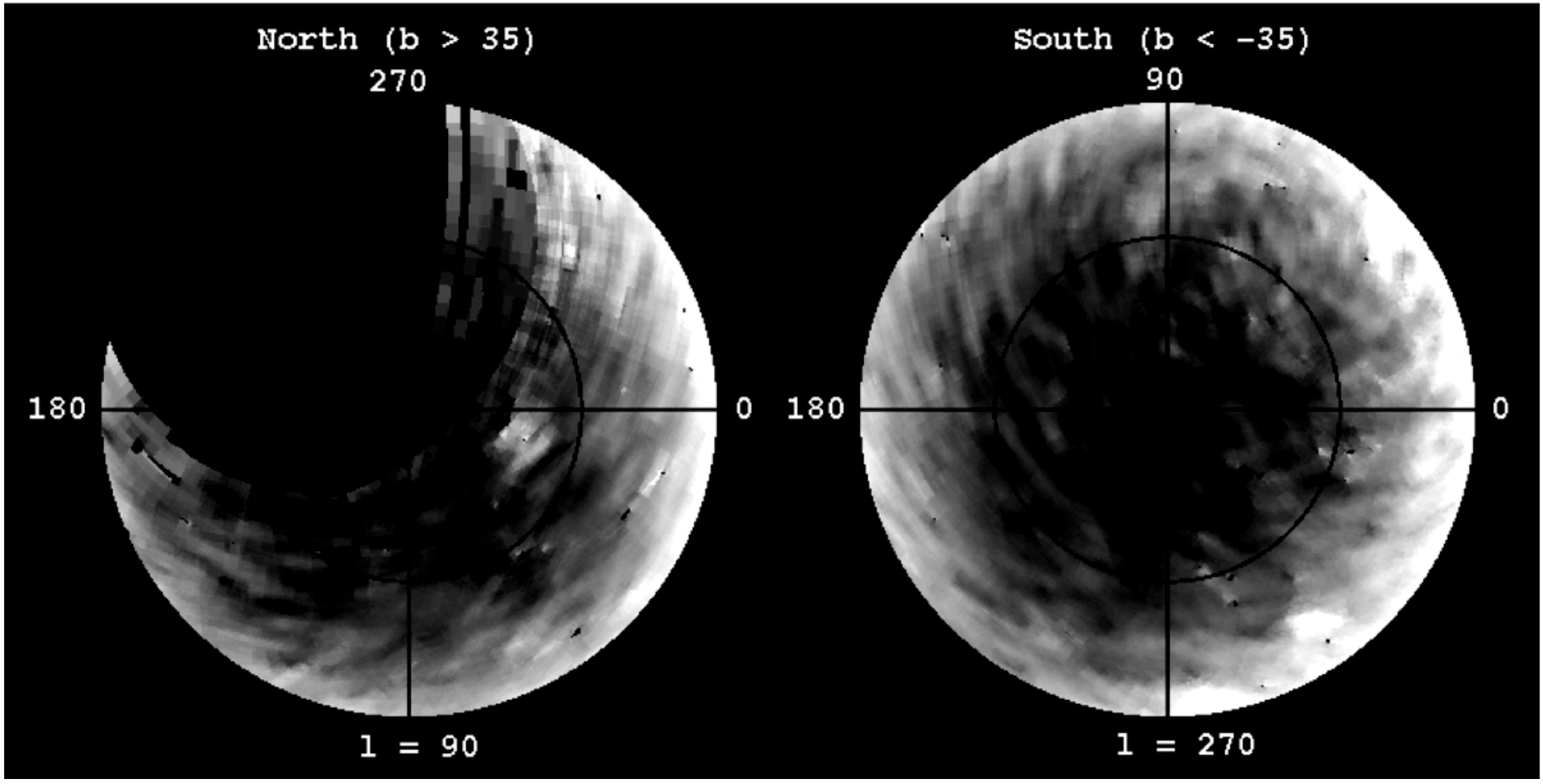
COB: The View from Pioneer 10/11

- IPP Blue-band brightness maps (north/south Galactic hemispheres at $|b| > 35^{o}$)



COB: The View from Pioneer 10/11

- IPP Red-band brightness map (north/south Galactic hemispheres at $|b| > 35^{o}$)



COB: The View from Pioneer 10/11

- Contribution of faint stars

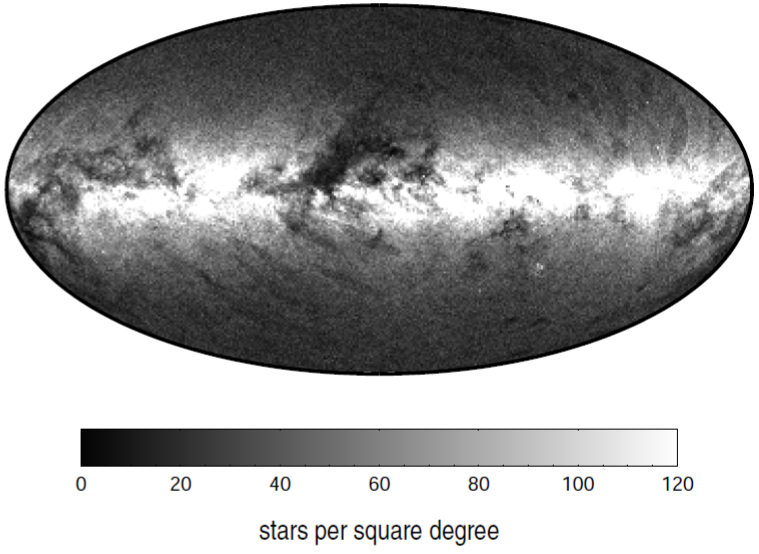
  - Bright ($m_V < 6.5$) stars in the Yale Bright Star Catalog and the USNO Photoelectric Catalog have already been subtracted.

- Fainter stars… all-sky catalogs: - Tycho-2 Catalog (6 – 10 mag), - GSC-II Catalog (9 – 20 mag) and Galactic star-count model: - TRILEGAL (> 20 mag) are used to derive the starlight contributing to each IPP FOV

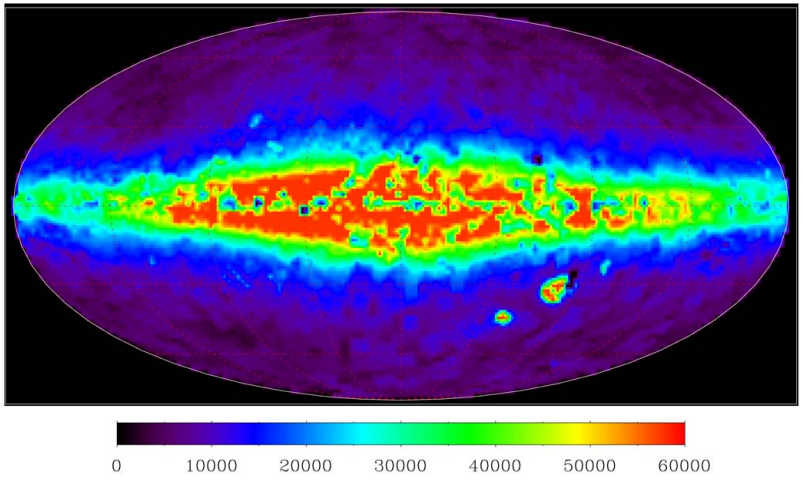
  ↓

- "Diffuse emission map"

Tycho-2 stars (Høg et al. 2000)



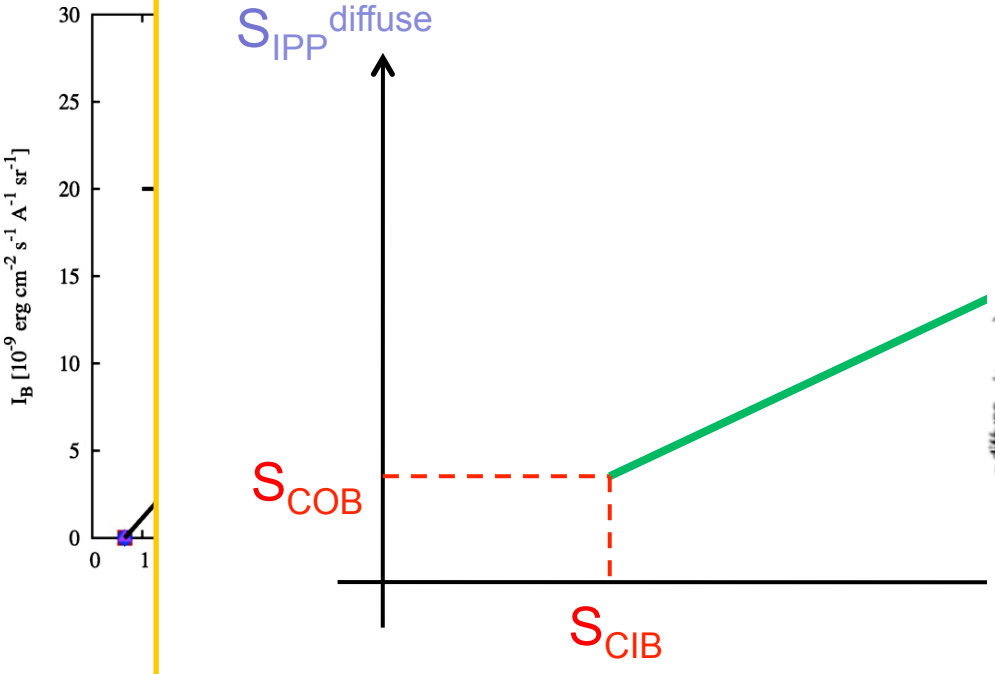
GSC-II stars (Lasker et al. 2008)

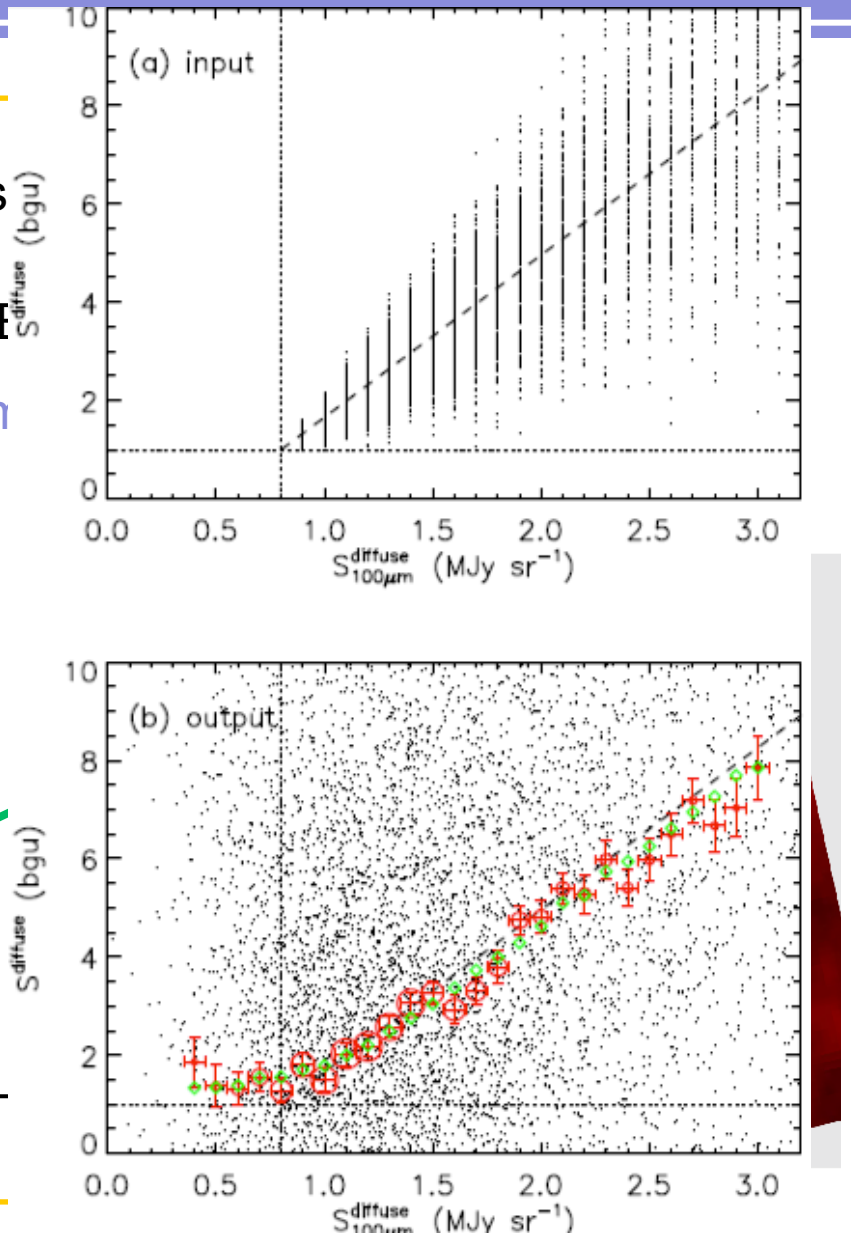


COB: The View from Pioneer 10/11

- F
- "
  ir
  w
  s

$$S_{IPP}^{diffuse} = S_{IPP} - S_{IPP}^{s}$$
$$= S_{DGL} + S_{COB}$$
$$= a_{DGL} (S_{100un}$$





COB: The View from Pioneer 10/11

- **DGL subtraction**

  IPP diffuse emission map at $|b| > 35^{o}$

  ↕

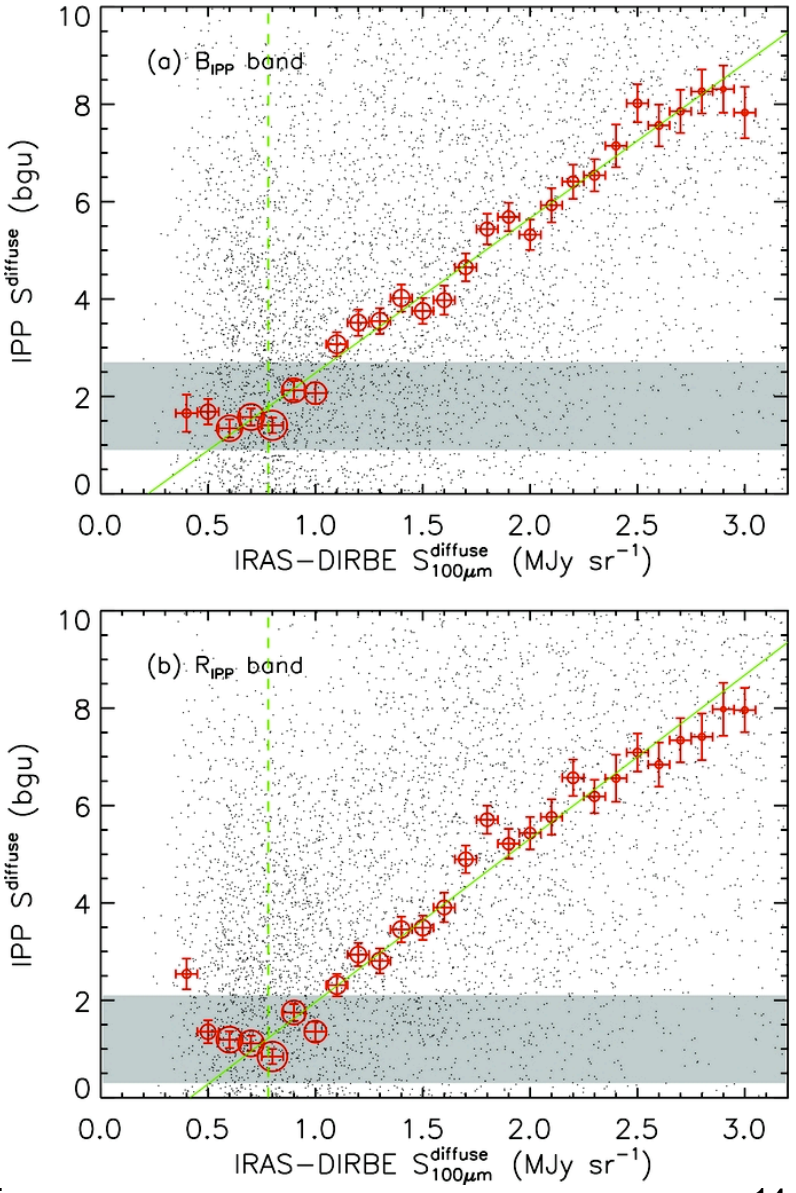
  IRAS/DIRBE 100 μm emission map (Schelgel et al. 1998)

  - Derived DGL/100 um brightness ratios are in good agreement with the previous measurements.

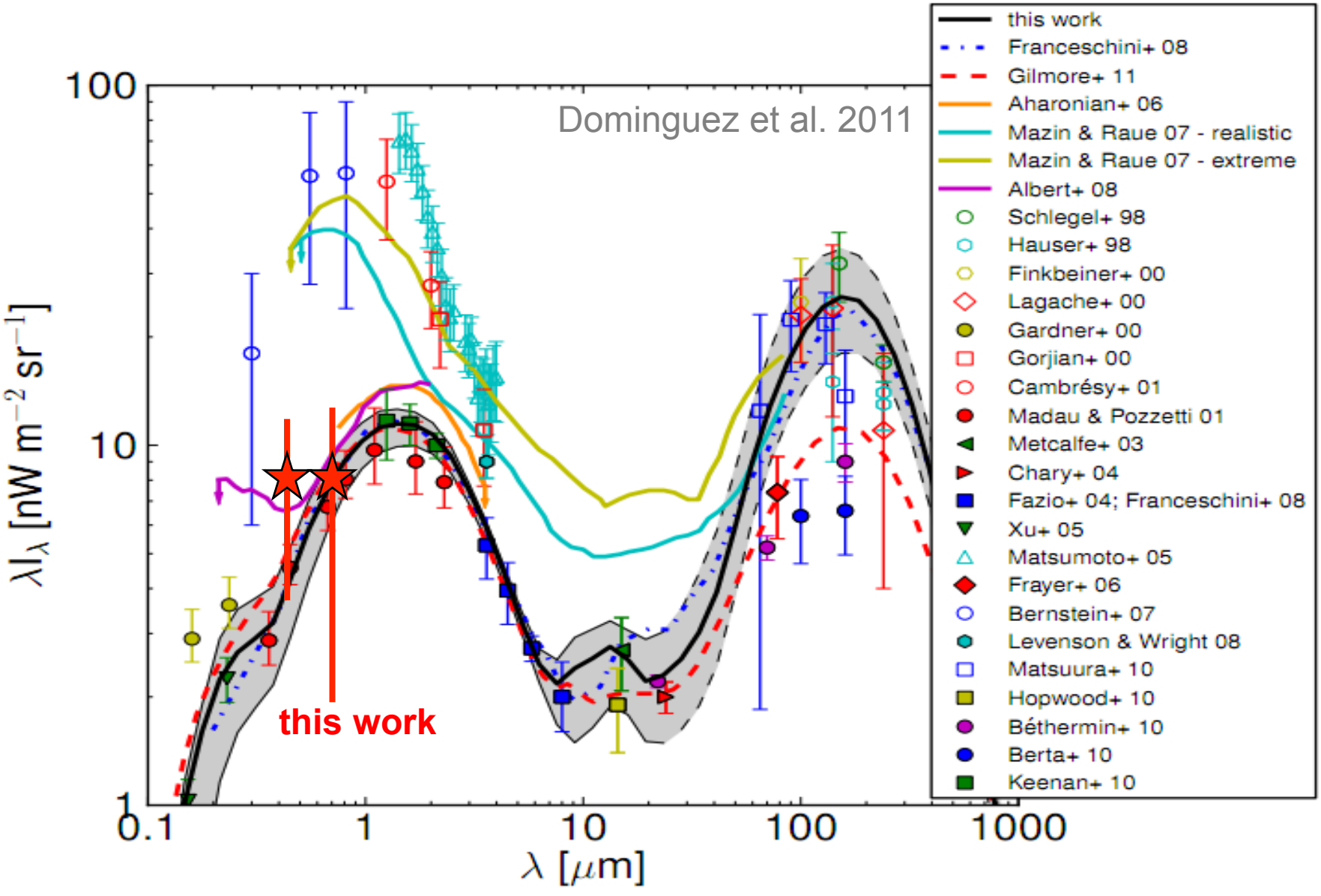
- **Residual COB**

  - 7.9 ± 4.0 nW m^{-2} sr^{-1} at Blue band
  - 7.7 ± 5.8 nW m^{-2} sr^{-1} at Red band

  ($I_{CIB} = 0.78 \pm 0.21$ MJy sr^{-1} at 100μm ; Lagache et al. 2000)



COB: The View from Pioneer 10/11



Summary

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- The new constraints on the optical EBL (COB) are obtained, which are
  - 7.9 ± 4.0 nW m^{-2} sr^{-1} at 0.39 – 0.50 μm,
  - 7.7 ± 5.8 nW m^{-2} sr^{-1} at 0.60 – 0.72 μm.
- The derived COB is consistent with the integrated brightness of galaxies in the Hubble deep field.
- Reference: Matsuoka et al. 2011, ApJ, 736, 119