Removing Galactic Foregrounds

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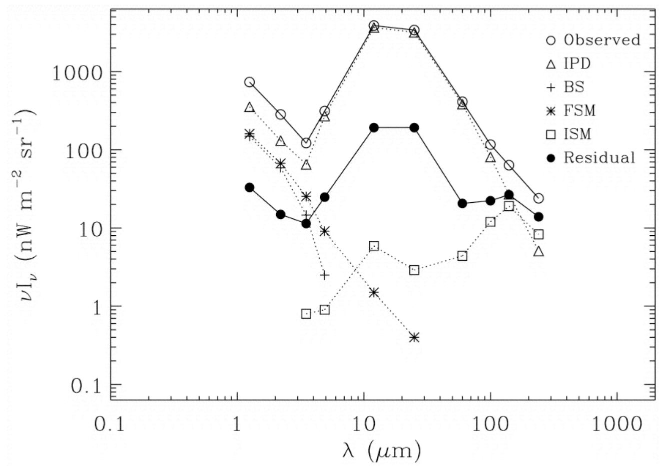
Galactic Emission

- Galactic emission consists of
  (a) direct light from stars, and
  (b) starlight scattered or absorbed and re-emitted by interstellar dust
- Potentially affects estimates of both mean intensity and spatial structure (i.e. fluctuations) of EBL.

DIRBE Result

Lockman Hole: (l,b)=(150,+52) (λ,β)=(135,+45)



Hauser et al. (1998)

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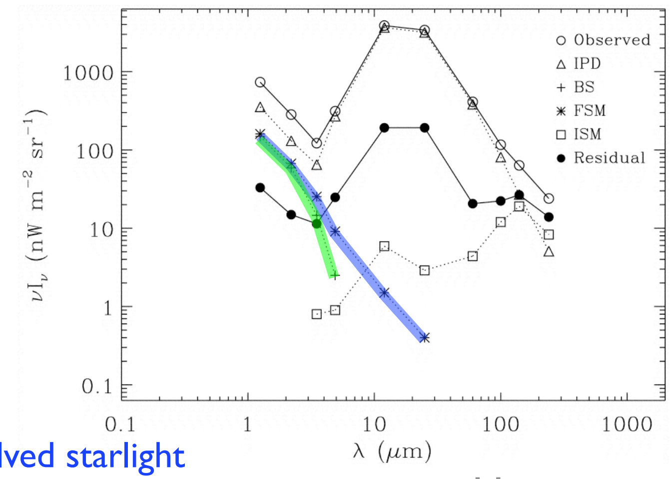

Hauser et al. (1998)

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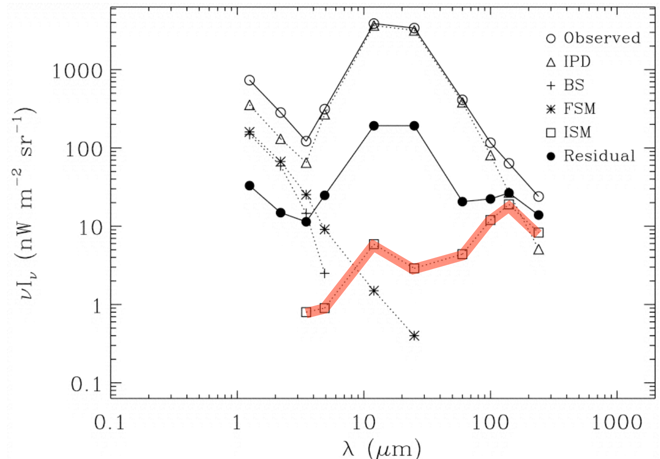
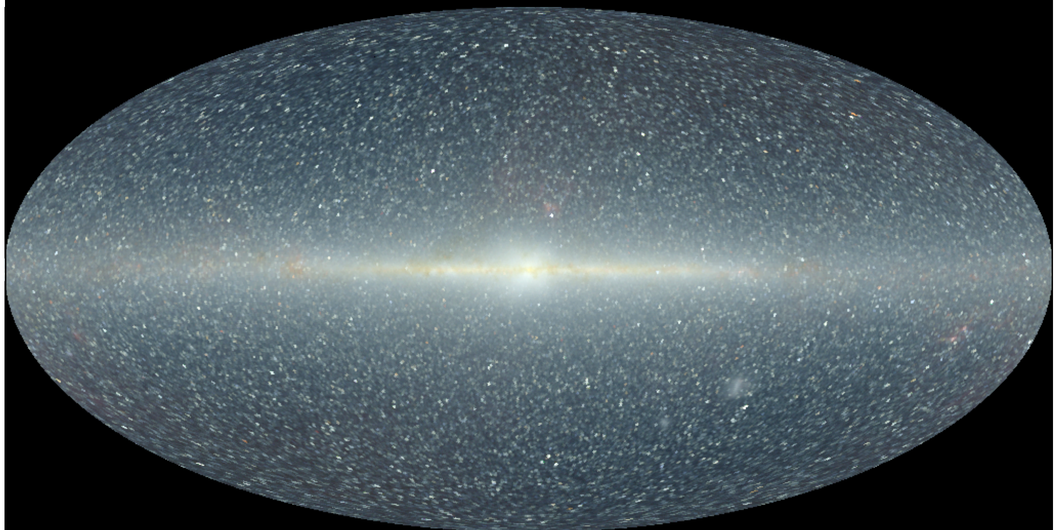


Interstellar dust

Hauser et al. (1998)

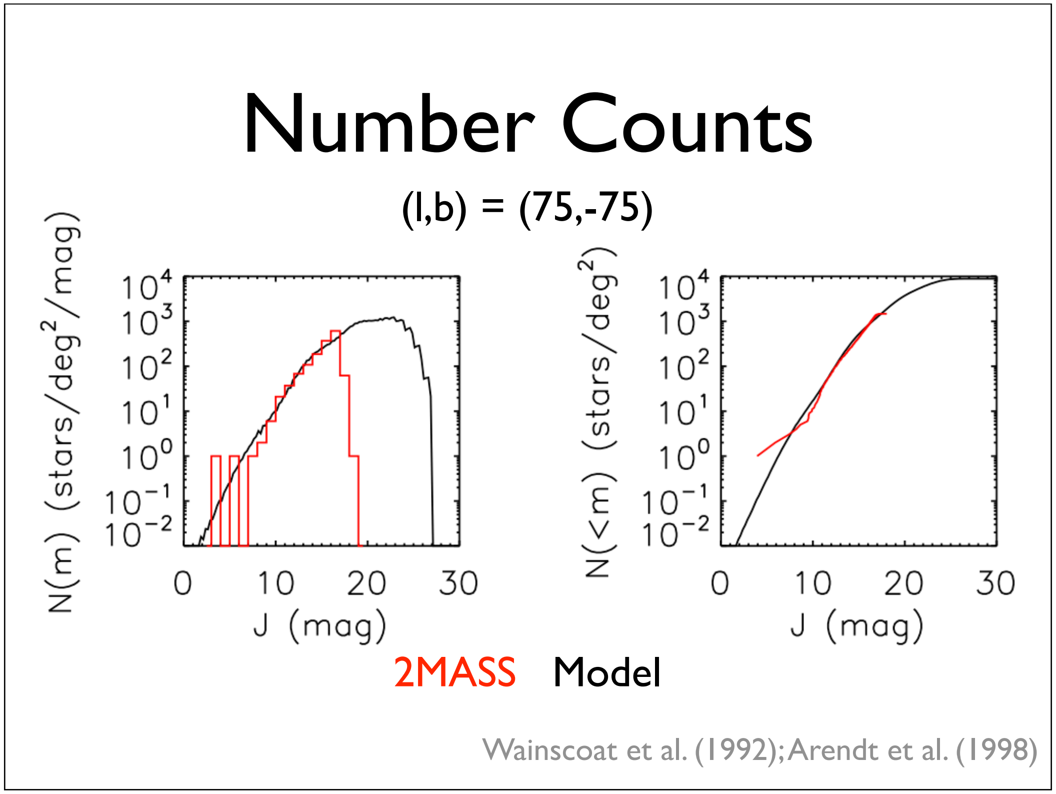
Direct Starlight



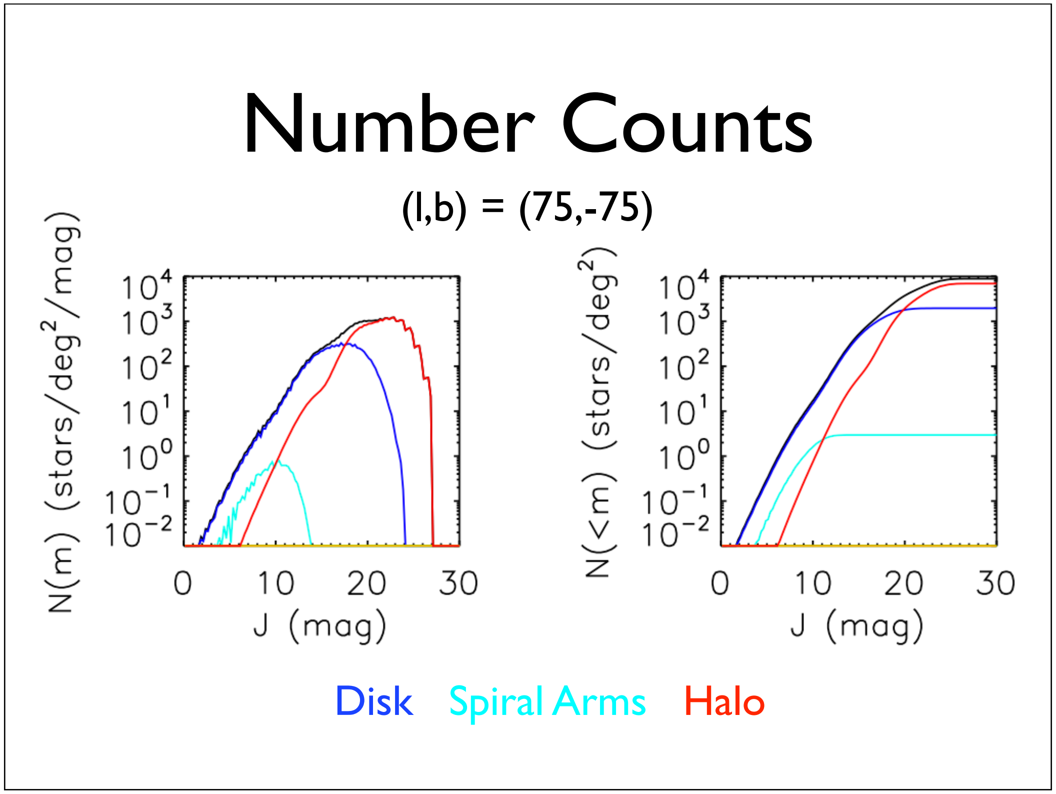
DIRBE 1.25, 2.2, 3.5 μm

Direct Starlight

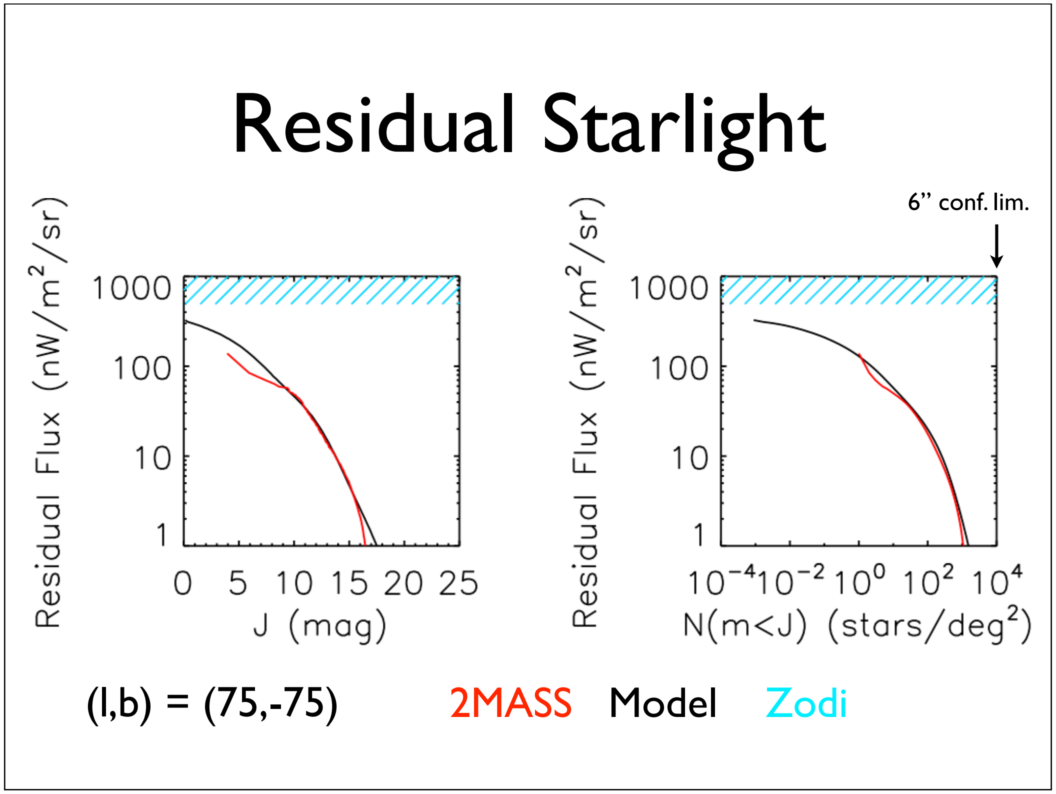
- Best solution is to resolve and subtract or exclude each star. (limited to ~4th mag. for DIRBE)
- Use other selected imaging or survey data if necessary, e.g. 2MASS, SDSS (Gorjian et al. 2000, Wright 2001, Levenson et al. 2007)
- Use models to subtract emission of stars below sensitivity or confusion limits. (e.g. Wainscoat et al. 1992)



Large numbers of faint stars not seen by 2MASS



The faint stars expected are all attributed to the halo component.



2MASS limiting mag ~16; SDSS limiting mag ~20-22 (AB)

10^0 FWHM -> 600" FWHM for confusion
DIRBE = ~2520" FWHM

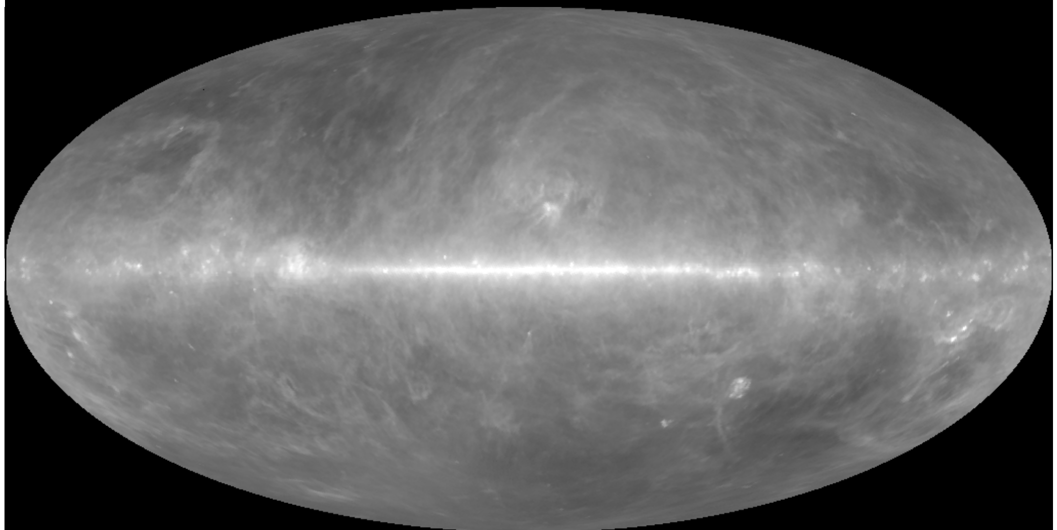
Model Limitations

- Model is statistical in nature. OK for mean values, but not for detailed structure.
- Model halo is symmetric. No warps. No tidal streams of disrupted dwarf galaxies or clusters. (Magellanic stream, Sgr dwarf stream, etc.)
- Other galaxies' tidal streams range from ~20 $nW/m^2/sr$ (major mergers) to < 1 $nW/m^2/sr$ (dwarf disruptions)

NGC 5907

Visible image from Martínez-Delgado et al. (2008)
Streams are <1-2 nW/m^2/sr at 3.6 μm (IRAC)

Interstellar Dust



DIRBE 100 μm

Interstellar Dust

- Mid-IR – Far-IR (3-300 μm) = thermal emission (+ emission bands from PAHs)
- Optical – Near-IR = scattered light (+ extended red emission (ERE) from ???)

Interstellar Dust

- Not resolvable and highly structured.
  No useful statistical models.
  So techniques applied to stars don't work here.
- Not time variable. Not illuminated by a well-known source with well-defined geometry. Too big to fly beyond.
  So techniques applied to zodiacal light don't work here.

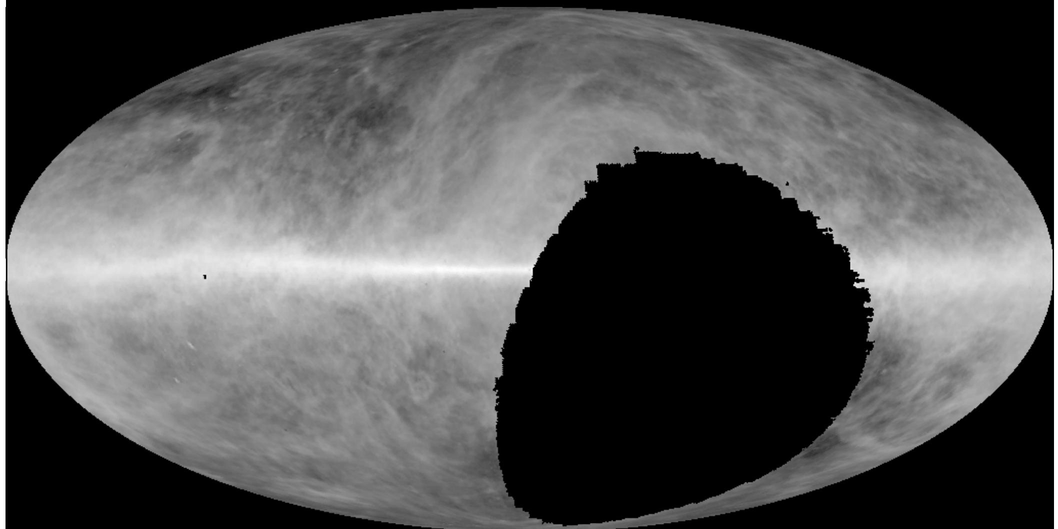
Interstellar Dust

- General solution is to use a scaled spatial template to subtract the dust emission.
- A good template will
  (a) have a strong correlation with the dust emission or scattering.
  (b) have spatial resolution similar to the data being analyzed.
  (c) not have any EBL signal of its own.

Line Emission Templates

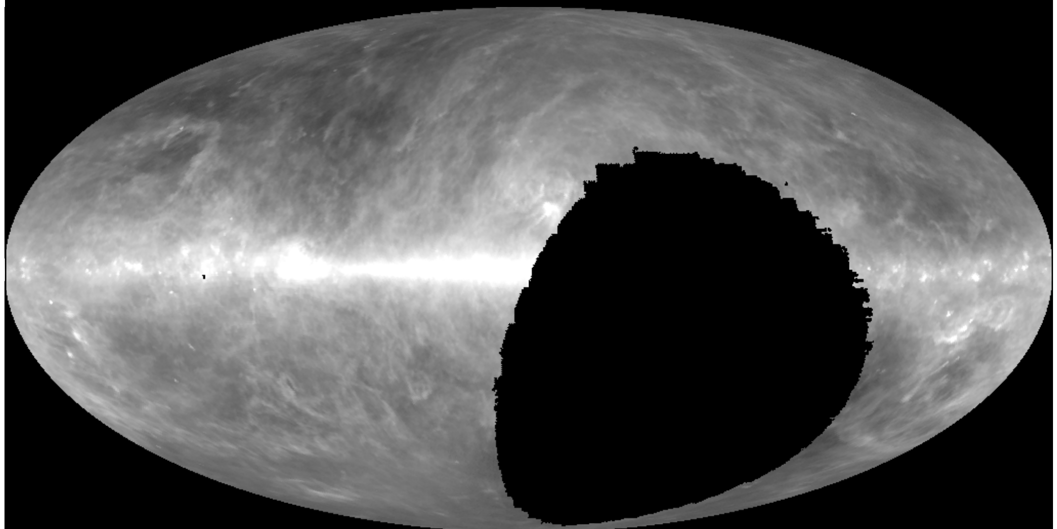
- 21 cm H I line surveys
  Bell Labs: Stark et al. (1992)
  Leiden-Dwingeloo: Hartmann & Burton (1997)
  IAR: Arnal et al. (2000) and Bajaja et al. (2005)
- + No EBL component
  – Can have variable relation to dust emission
  – Doesn't trace dust in all phases of the ISM
- Used for 100μm DIRBE analysis (Arendt et al. 1998)

$N_{H\,I}$ Template



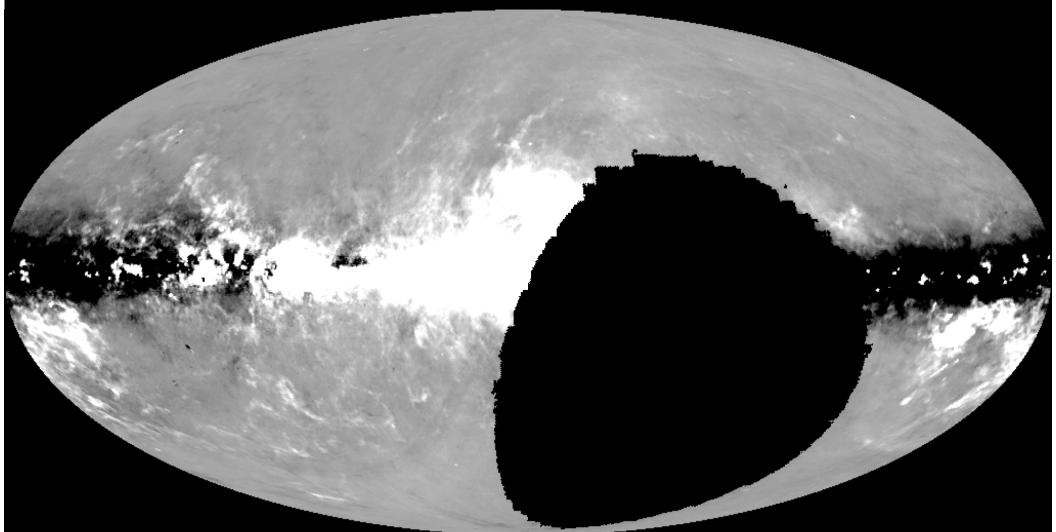
Bell Labs H I (Stark et al. 1992)

Far-IR Emission



DIRBE 100 μm

Residual Emission



100 µm - A * Bell Labs H I   (range = ±150 $nW/m^2/sr$)

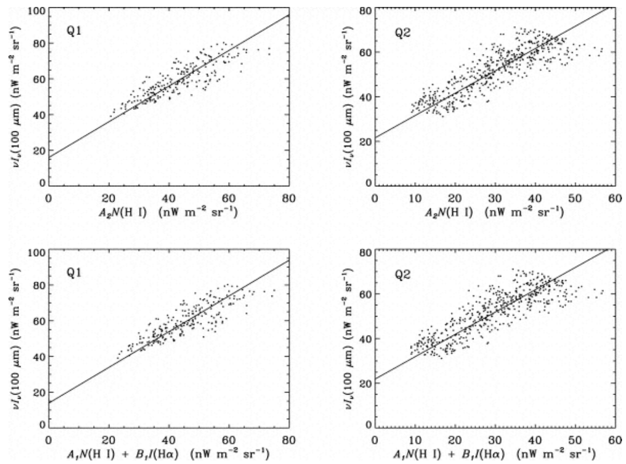
Line Emission Templates

- Deficiencies can be addressed using multiple emission lines.
- H I + [C II] (158 μm) used by Fixsen et al. (1998) for analysis of FIRAS data.
- H I + Hα (6563Å) used by Odegard et al. (2007) for reanalysis of DIRBE data.

H1 - 100 μm Correlation

H I only

H I + Hα



Extrapolation of mean EBL is good, but dispersion is real, not noise, and is not reduced by adding the Hα template

Odegard et al. (2007)

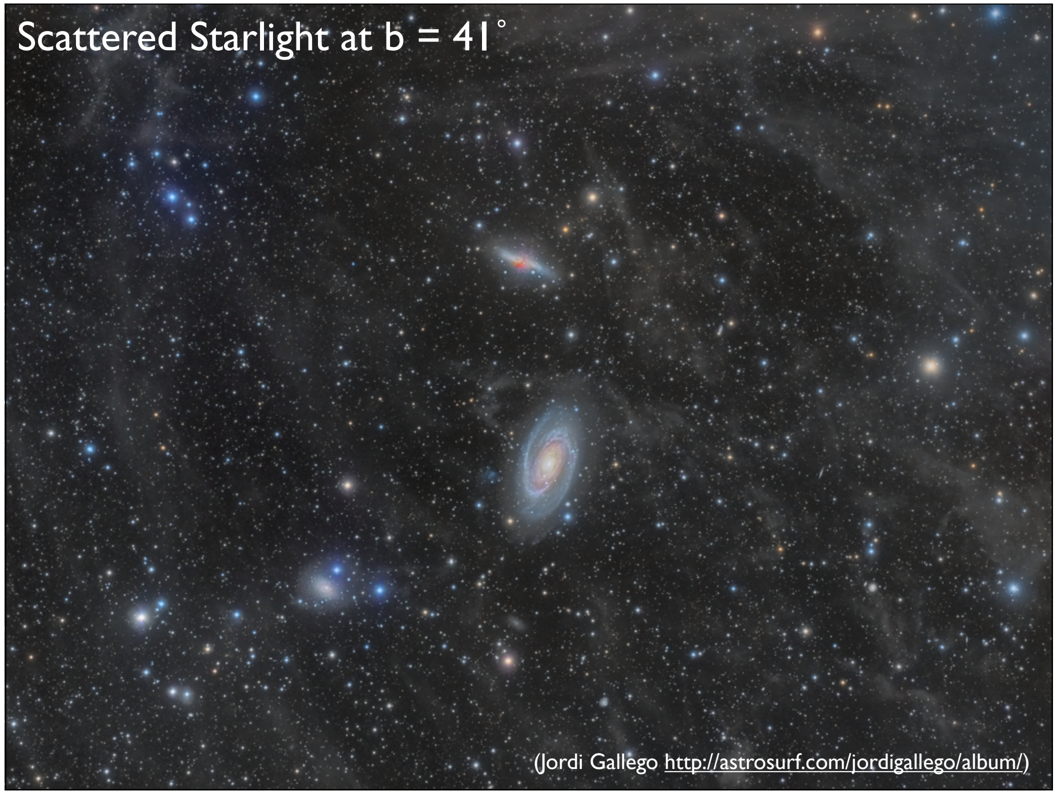
Continuum Templates

- Mid- and Far-IR surveys
  IRAS, DIRBE, AKARI, WISE, PLANK
- + Good sensitivity to faint emission
  + Can trace ISM in any phase
  – Requires extrapolation in wavelength
  – May be at low spatial resolution
  – Contains an EBL signal
- Use of multiple templates can allow some fitting of spectral variations

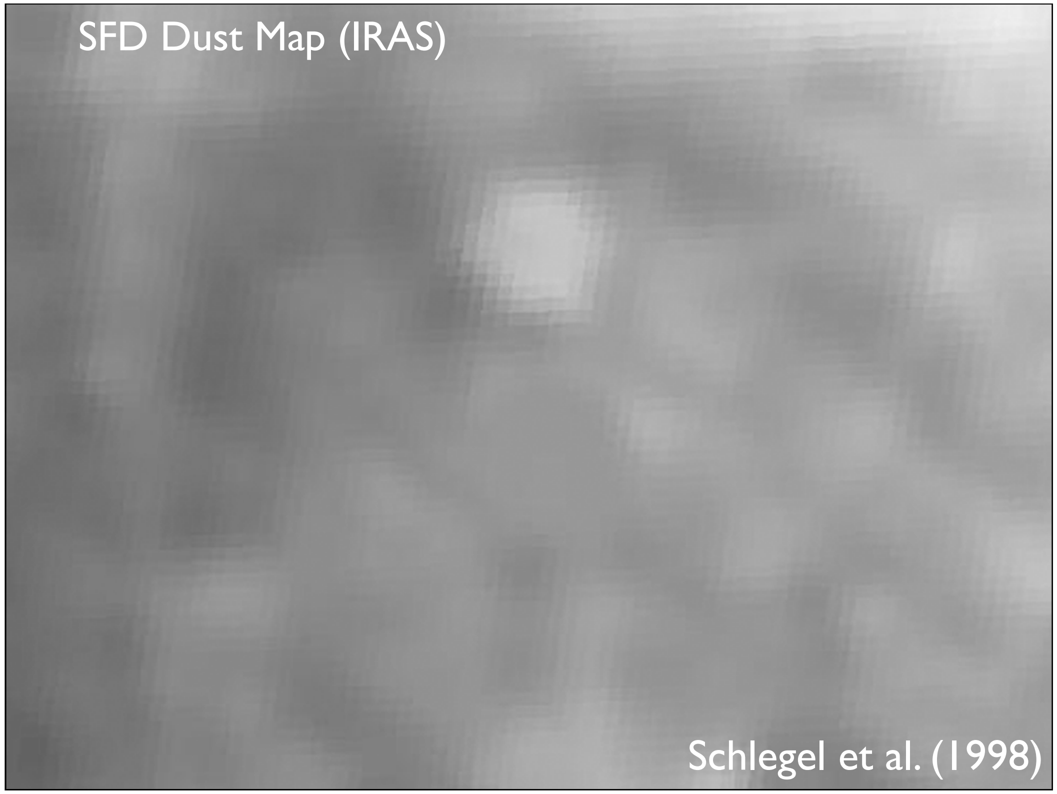
Continuum Templates

- DIRBE analysis (Arendt et al. 1998) used 100 & 140 μm templates to model 240 μm emission. Improves isotropy at the cost of larger uncertainty of the mean EBL level.
- Used 100 μm template at < 10 μm. Limited by the difficulty in detecting any high latitude ISM above the confusion from starlight.
- FIRAS analysis (Fixsen et al. 1998) used DIRBE 140 & 240 μm templates.

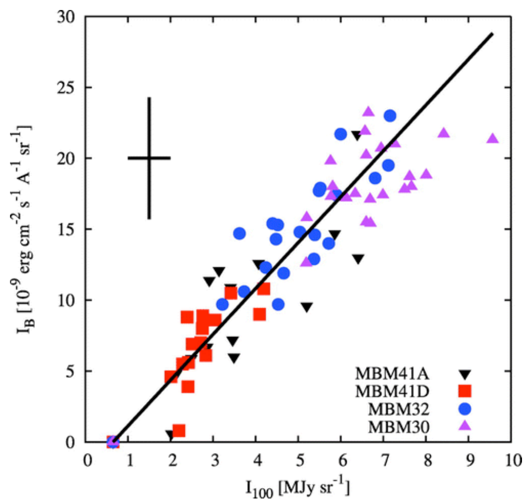
Scattered Starlight at b = 41°



(Jordi Gallego http://astrosurf.com/jordigallego/album/)


SFD Dust Map (IRAS)
Schlegel et al. (1998)

Scattered Light at B vs. Thermal Emission at 100 μm



Suggests that mean ISM levels can be accurate to <5 nW/m^2/sr;

ISM structure can be accurate to <25 nW/m^2/sr

Witt et al. (2008)

DIRBE Result

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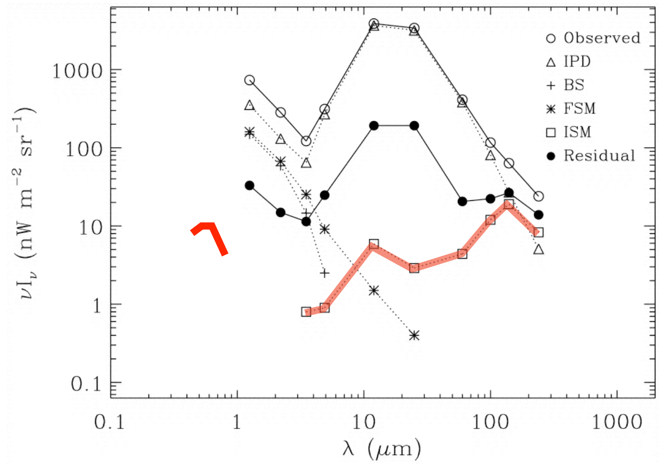

scaled from Witt et al (2008) Hauser et al. (1998)

Summary

- At optical to near-IR wavelengths,
  - Unresolved direct starlight could affect EBL estimates (at ~1 $nW/m^2/sr$) if the Galactic halo is brighter or more structured than expected.
  - Systematic errors caused by scattered light and ERE could be often be > 1 $nW/m^2/sr$
- At mid-IR to far-IR wavelengths systematic errors due to dust emission may be 1-7 $nW/m^2/sr$