Cosmic IR Backgrounds

by

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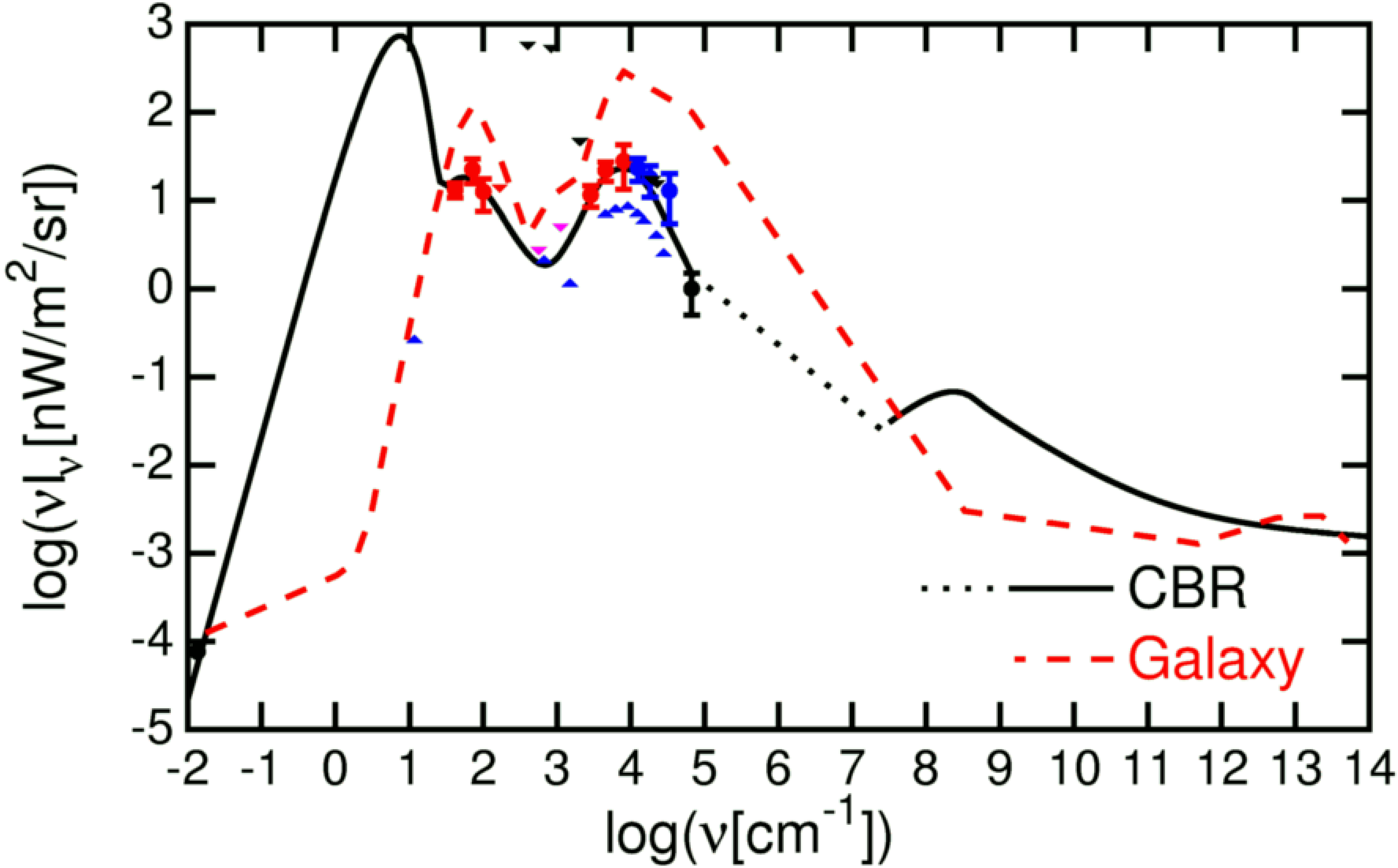
http://www.astro.ucla.edu/~wright/intro.html

See:

- http://www.astro.ucla.edu/~wright/cosmolog.htm
- http://www.astro.ucla.edu/~wright/DIRBE
- http://www.astro.ucla.edu/~wright/CIBR
- http://sirtf.caltech.edu

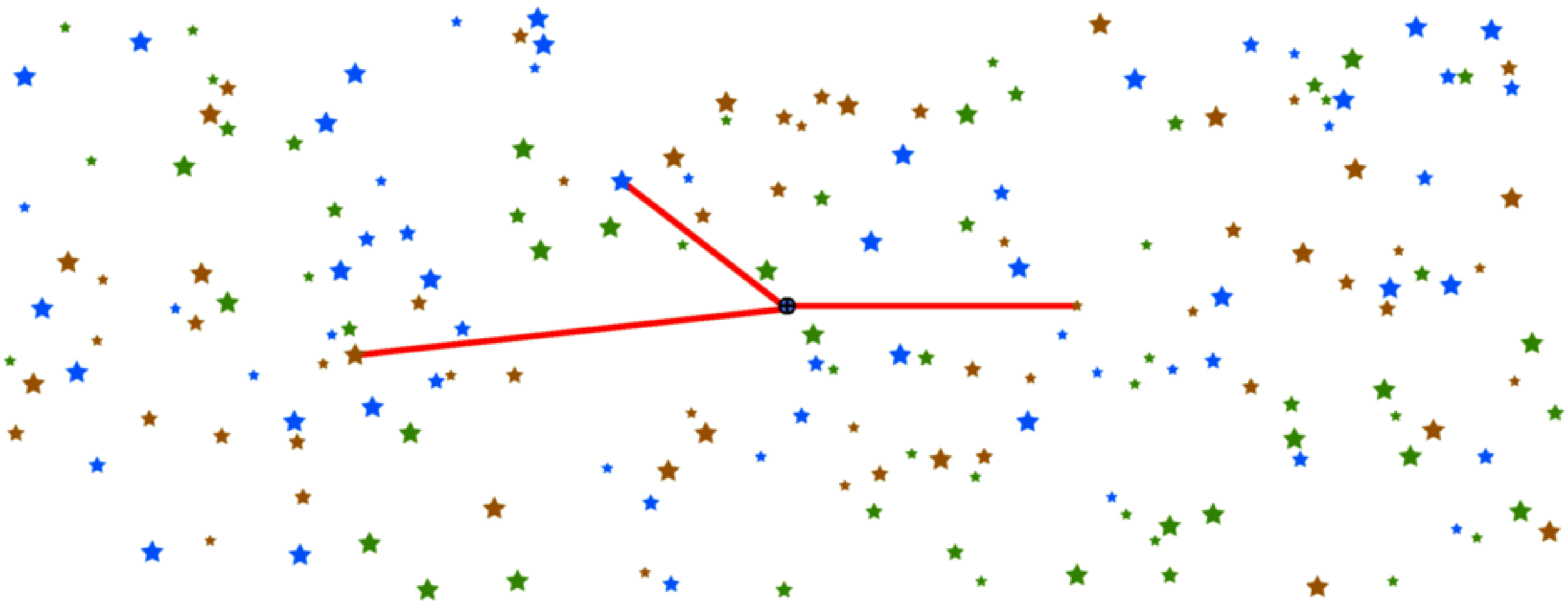
- I_ν - specific intensity, energy per (area×time×frequency×solid angle). 10^{-20} W/m^2/Hz/sr = 1 MegaJansky/sr [MJy/sr].
- $I = \int I_\nu d\nu$ - bolometric intensity, energy per (area×time×solid angle). 1 nW/m^2/sr.
- νI_ν - intensity per octave, energy per (area×time×logarithmic bandwidth ×solid angle). 1 nW/m^2/sr.
- $J_\nu = (4\pi)^{-1} \int I_\nu d\Omega$: mean intensity – the angle averaged intensity.
- $F_\nu = \int I_\nu \cos\theta d\Omega$: monochromatic flux, energy per (area×time×frequency). 10^{-20} W/m^2/Hz = 1 MegaJansky [MJy].

Wide window on the CBR



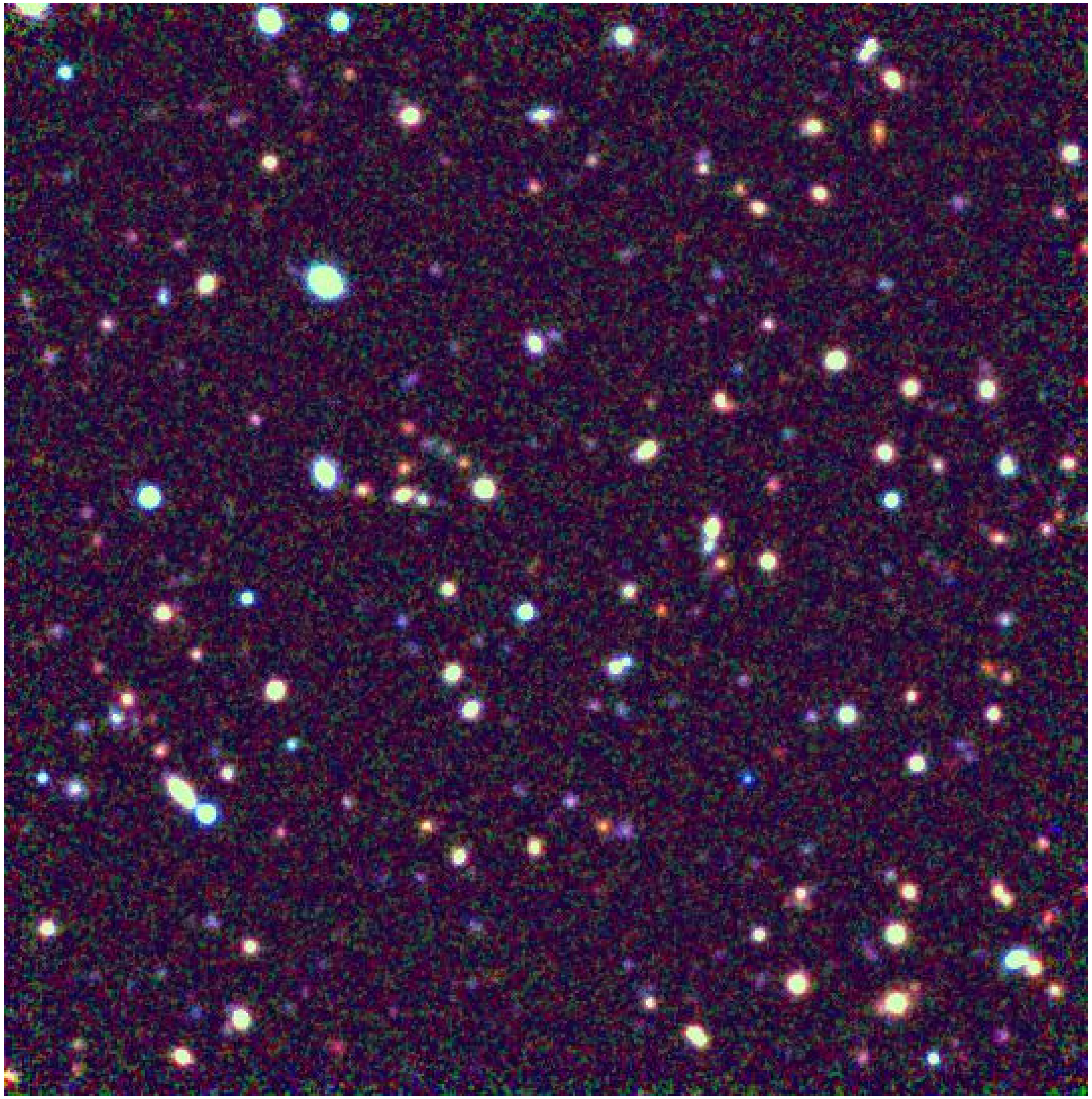
Backgrounds

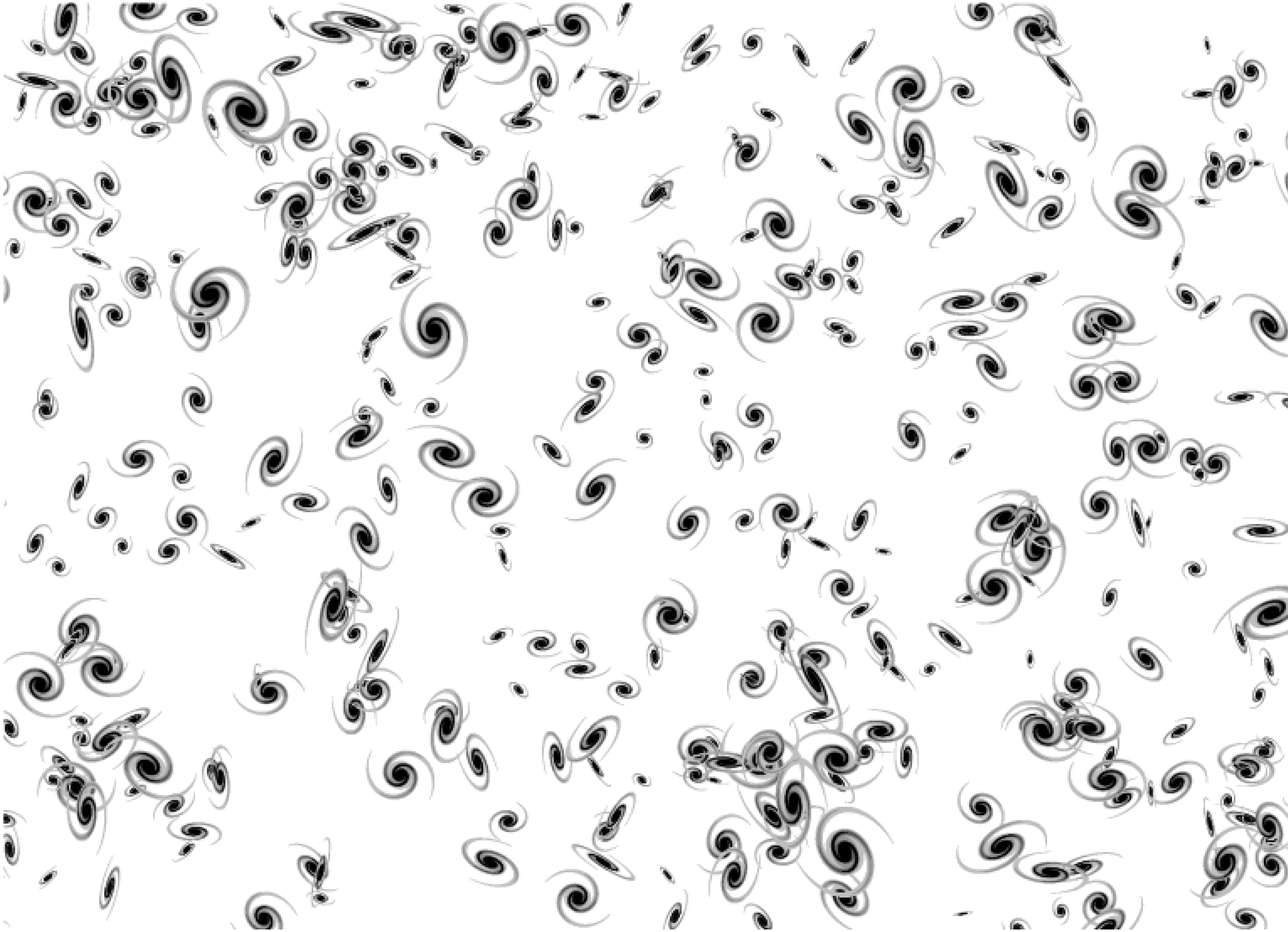
- Microwave – the CMB is 10,000 times brighter than the galactic foreground & the spectrum is very close to a blackbody
- Far Infrared – the FIRB is 10 times fainter than the galaxy with a spectrum similar to the galaxy
- Near IR and Optical – also 10 times fainter than galaxy
- X-ray – the XRB is 10 times brighter than the galaxy

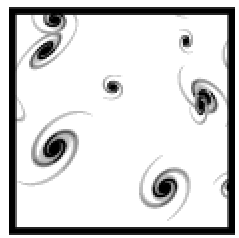


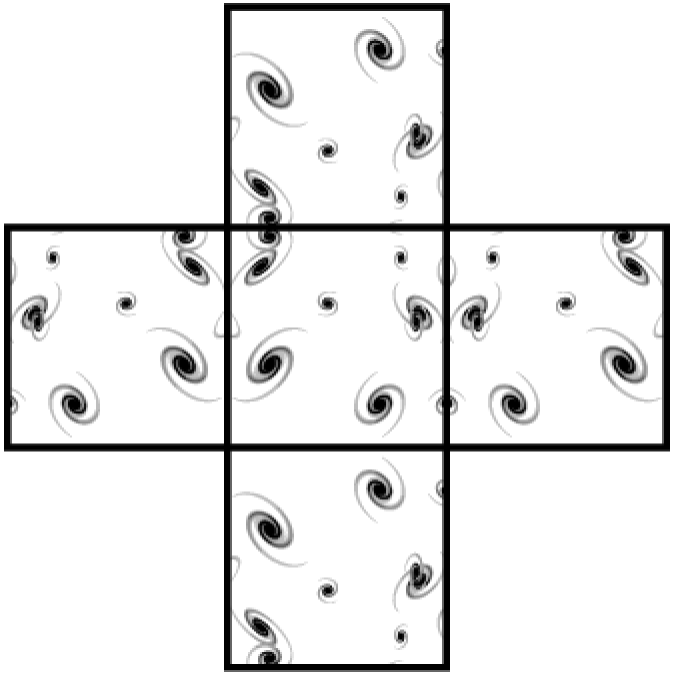
In a homogeneous unchanging Universe every line of sight will end on a star. So why is the night sky not as bright as the surface of a star? The Cosmic Infrared Background is what remains after this Olbers’ paradox is resolved.

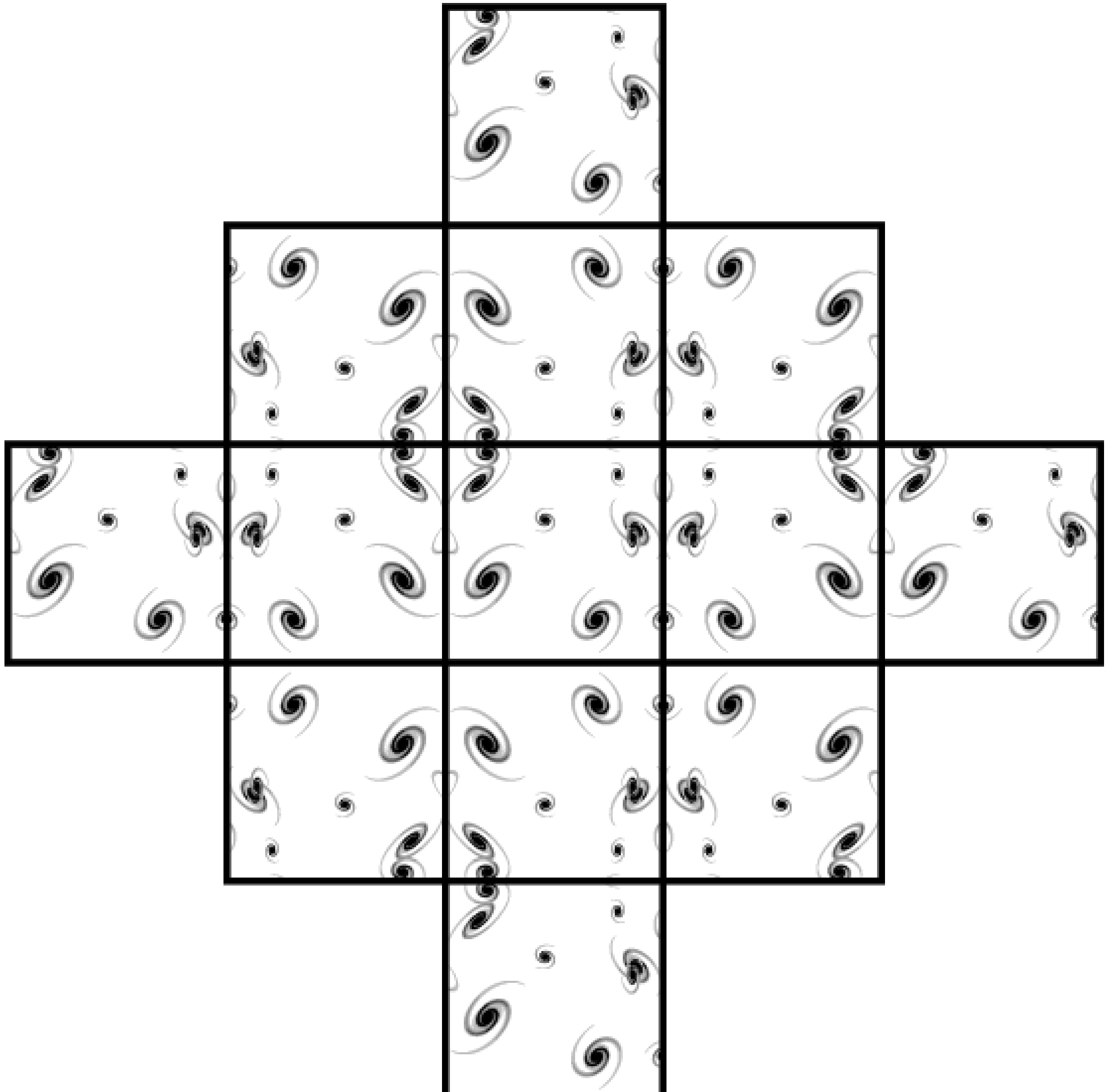
Sources of the CIRB

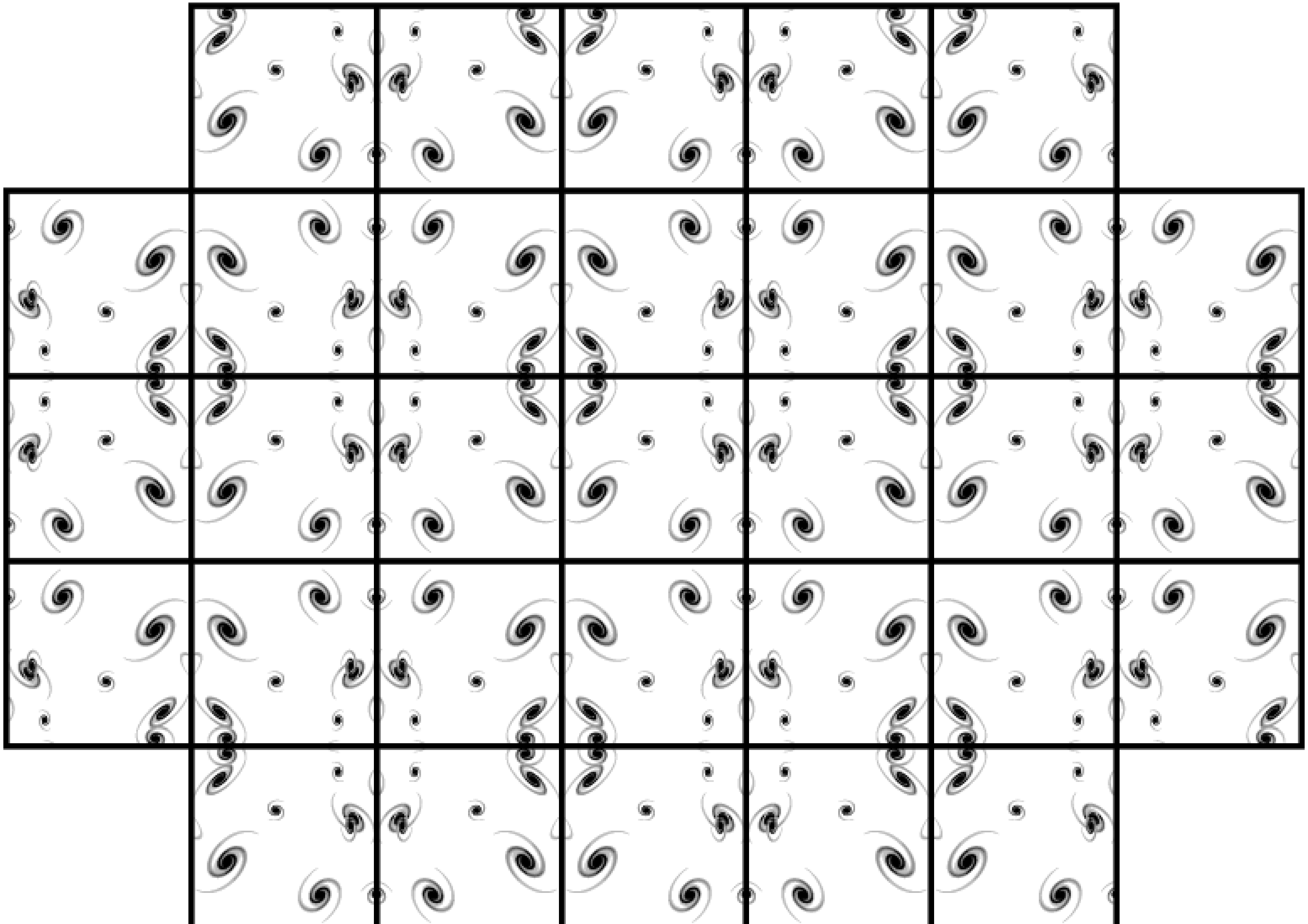


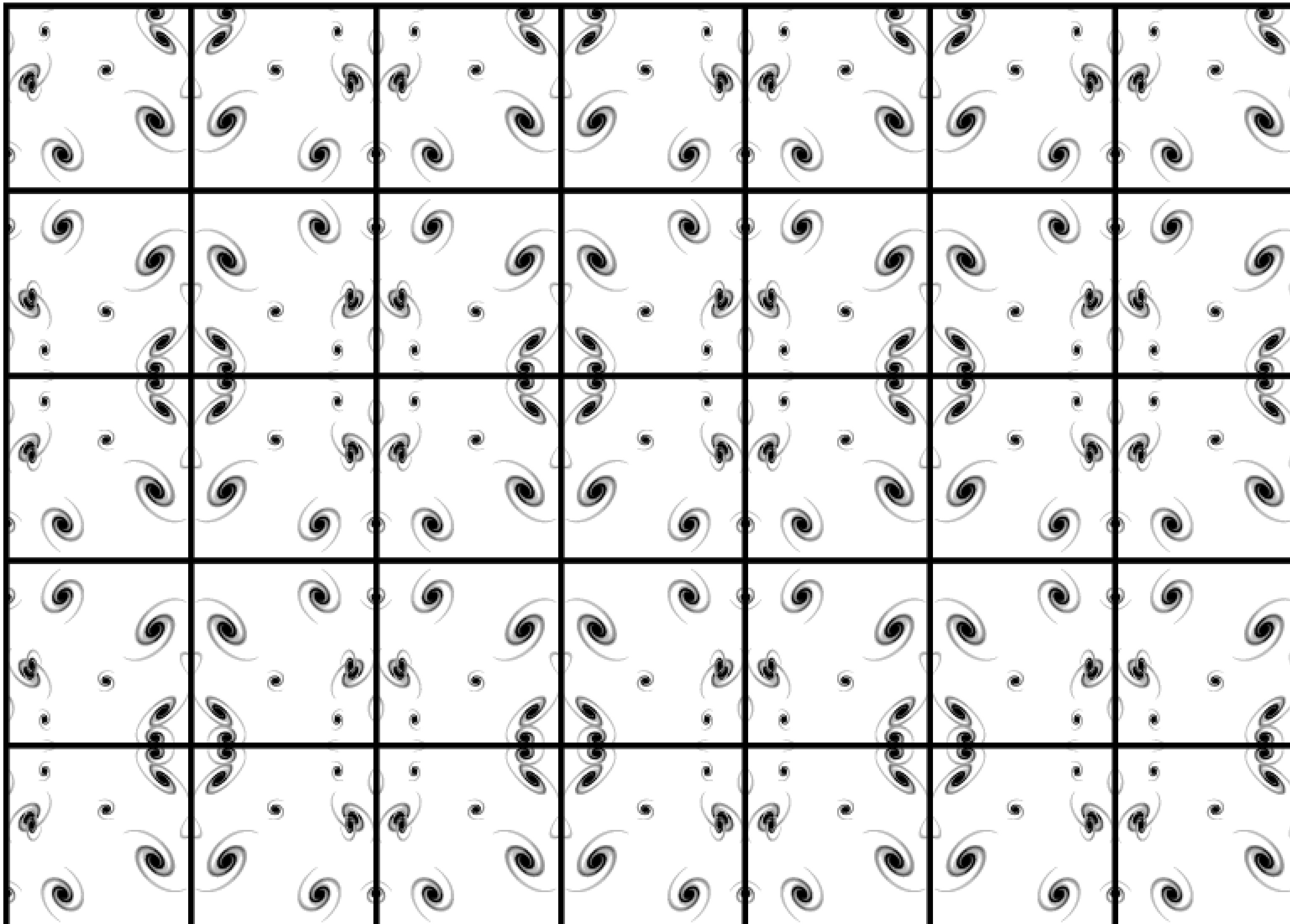






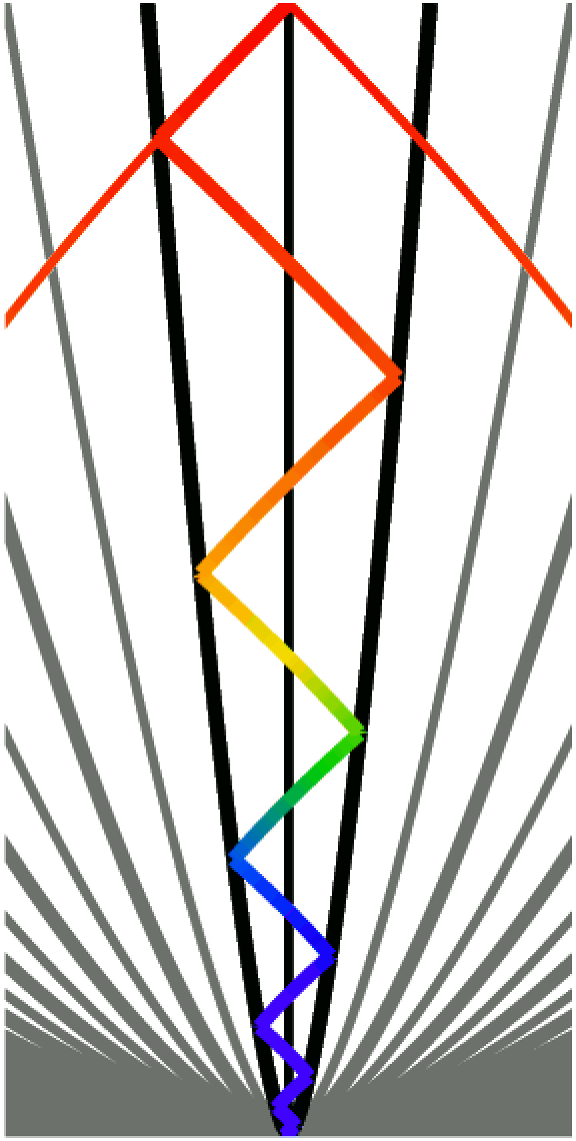






Expanding Mirrored Box

- The Universe is *homogeneous* & *isotropic*.
- Reflections in a mirrored box look like the Universe.
- Expanding mirrored box gives a redshift with $\lambda \propto a(t)$.



Consider a mirrored box, where the mirrors move with the galaxies in the Hubble flow, and define the *comoving luminosity density*:

$$\ell(t) = \frac{\sum_{\text{in box}} L_{gal}(t)}{V_{box}(t_\circ)}$$

For a static, unchanging Universe the energy density in the box now is

$$u(t_\circ) = \frac{4\pi J}{c} = \int_{-\infty}^{t_\circ} \ell(t_\circ) dt \rightarrow \infty \qquad \text{[Olber's Paradox]}$$

In an expanding Universe with scale factor $a(t)$, and $1 + z = a(t_\circ)/a(t)$, then:

$$u(t_\circ) = \frac{4\pi J}{c} = \int_0^{t_\circ} \frac{\ell(t)}{1+z} dt$$

The total energy produced, $\int \ell(t)dt$, is more than the CIRB energy density because it does not have the $(1+z)$ factor in the denominator. For the baryon density given by Big Bang Nucleosynthesis, $\Omega_B h^2 = 0.02$, if 1% of the baryons are converted from hydrogen to helium releasing 0.7% of their mass into energy, then

$$\int \ell(t)dt = 0.02 \times 0.01 \times 0.007 \times 10539.4 \frac{\text{eV}}{\text{cm}^3} = \frac{1}{68} \frac{\text{eV}}{\text{cm}^3}$$

$c/[4\pi]$ times this energy density is 56 nW/m^2/sr.

The relationship between time and redshift is

$$t = \frac{2}{3H_\circ(1+z)^{1.5}} \qquad \text{so} \qquad \frac{dt}{dz} = \frac{-1}{H_\circ(1+z)^{2.5}}$$

for the Einstein-de Sitter Universe with $\Omega = 1$, and the Hubble constant is $H_\circ = (2/3)/t_\circ$.

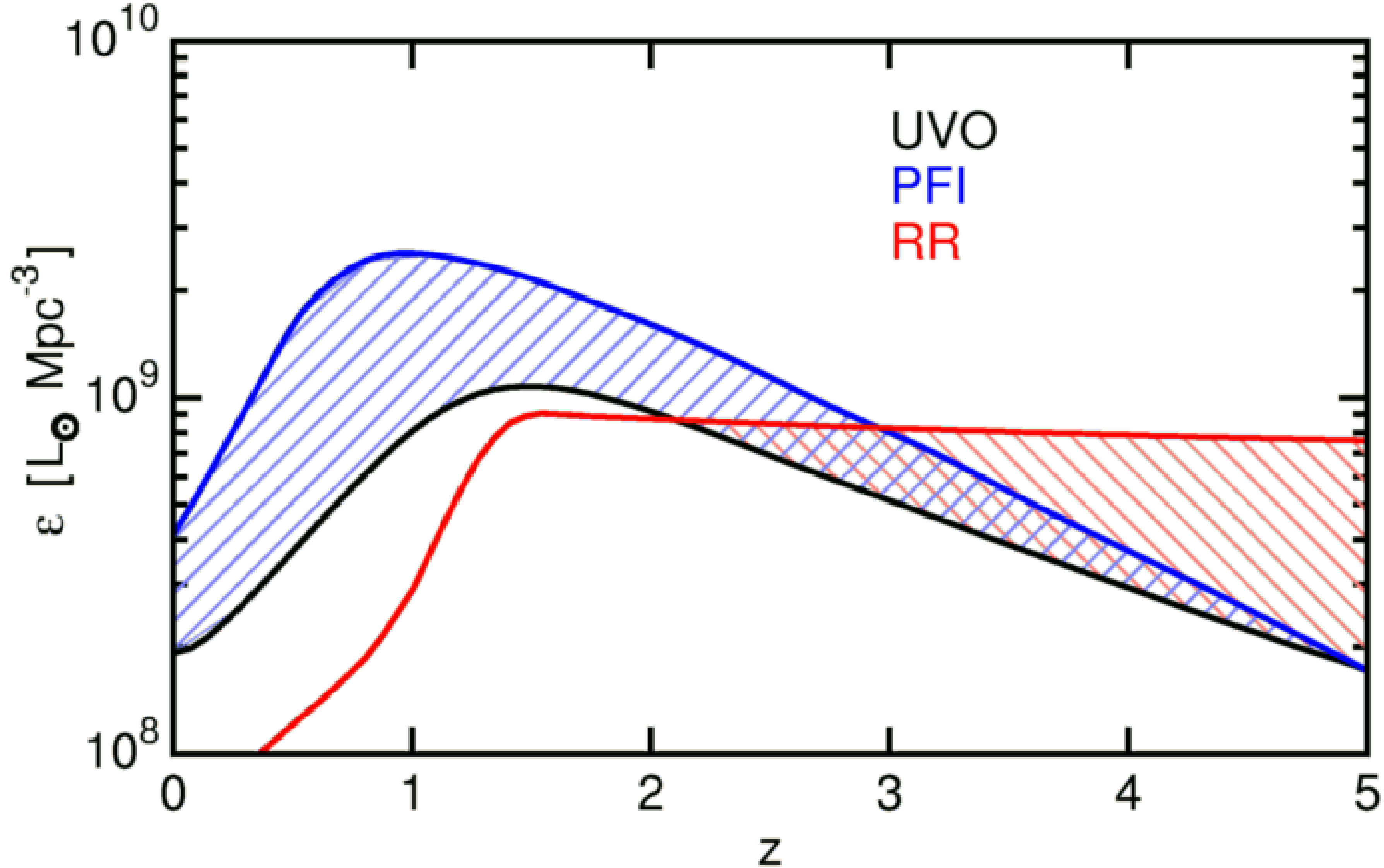
Thus if $\ell(t)$ is CONSTANT, the energy density of the CIRB would be

$$u = \frac{1}{H_\circ}\int \frac{\ell(t_\circ)}{(1+z)^{3.5}}dz = \frac{3}{5}\int \ell(t)dt = 0.6\ell(t_\circ)t_\circ$$

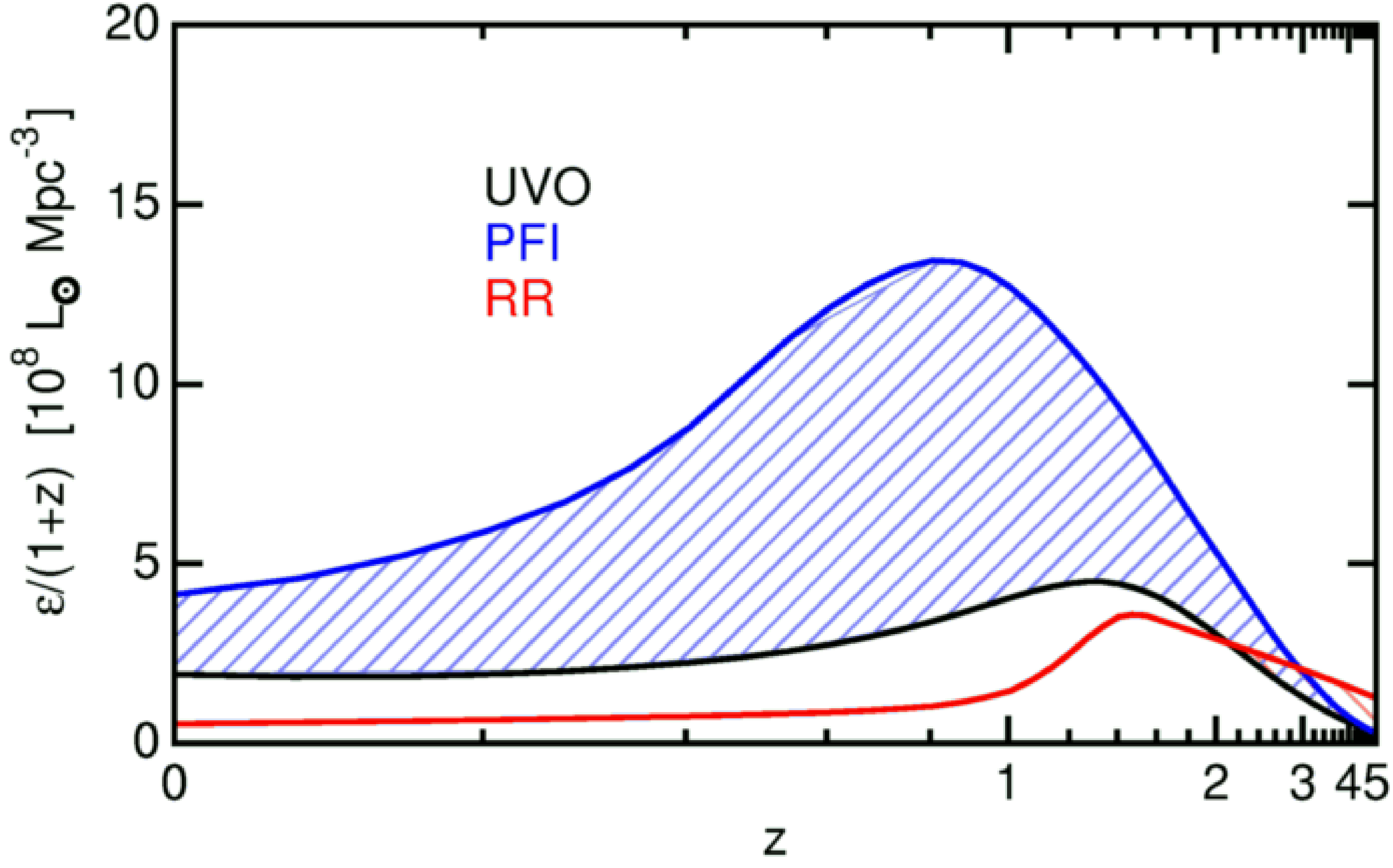
If $\ell(t)$ is proportional to $(1+z)$, then the energy density of the CIRB would be

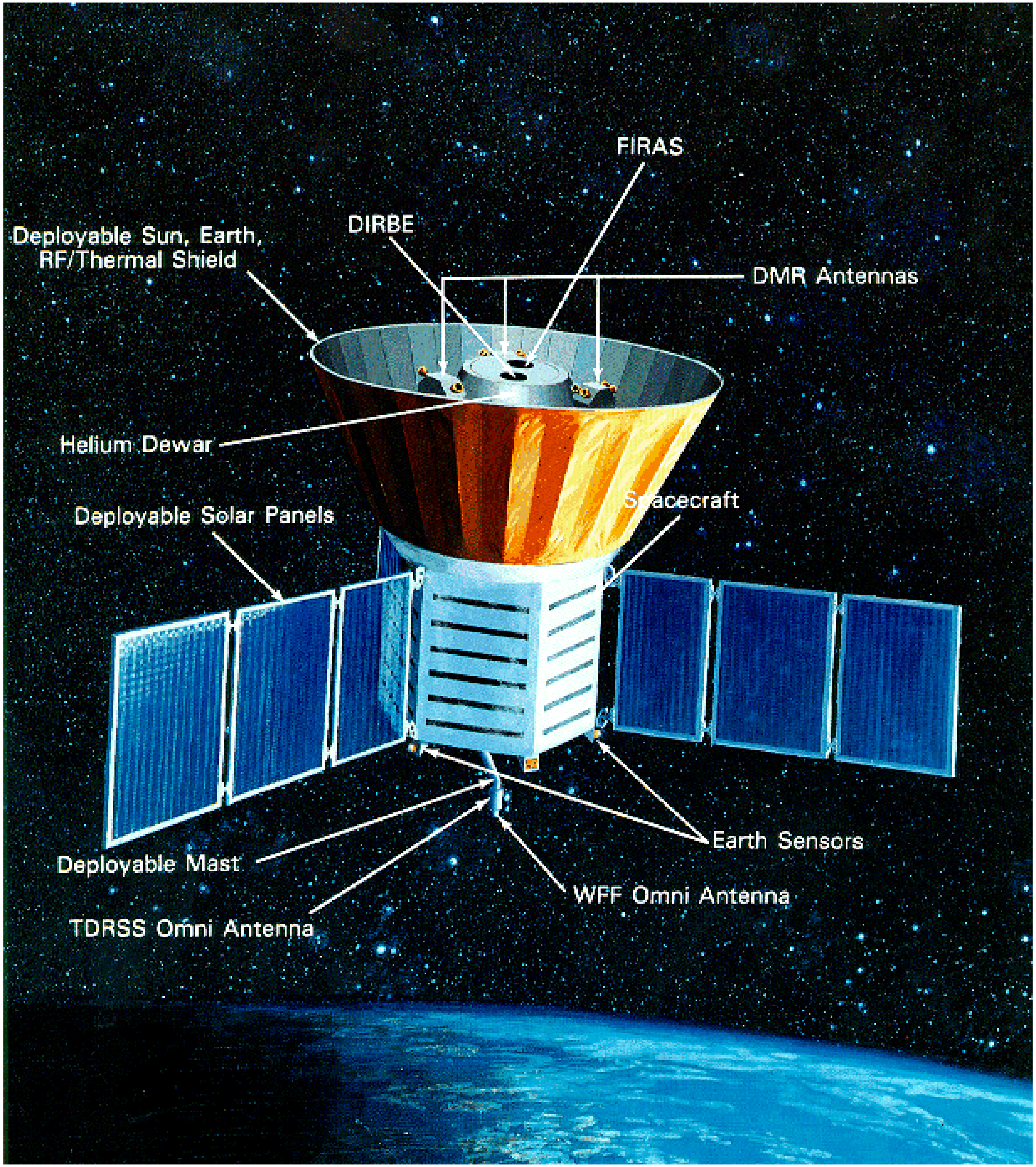
$$u = \frac{1}{H_\circ}\int \frac{(1+z)\ell(t_\circ)}{(1+z)^{3.5}}dz = \frac{1}{3}\int \ell(t)dt = \ell(t_\circ)t_\circ$$

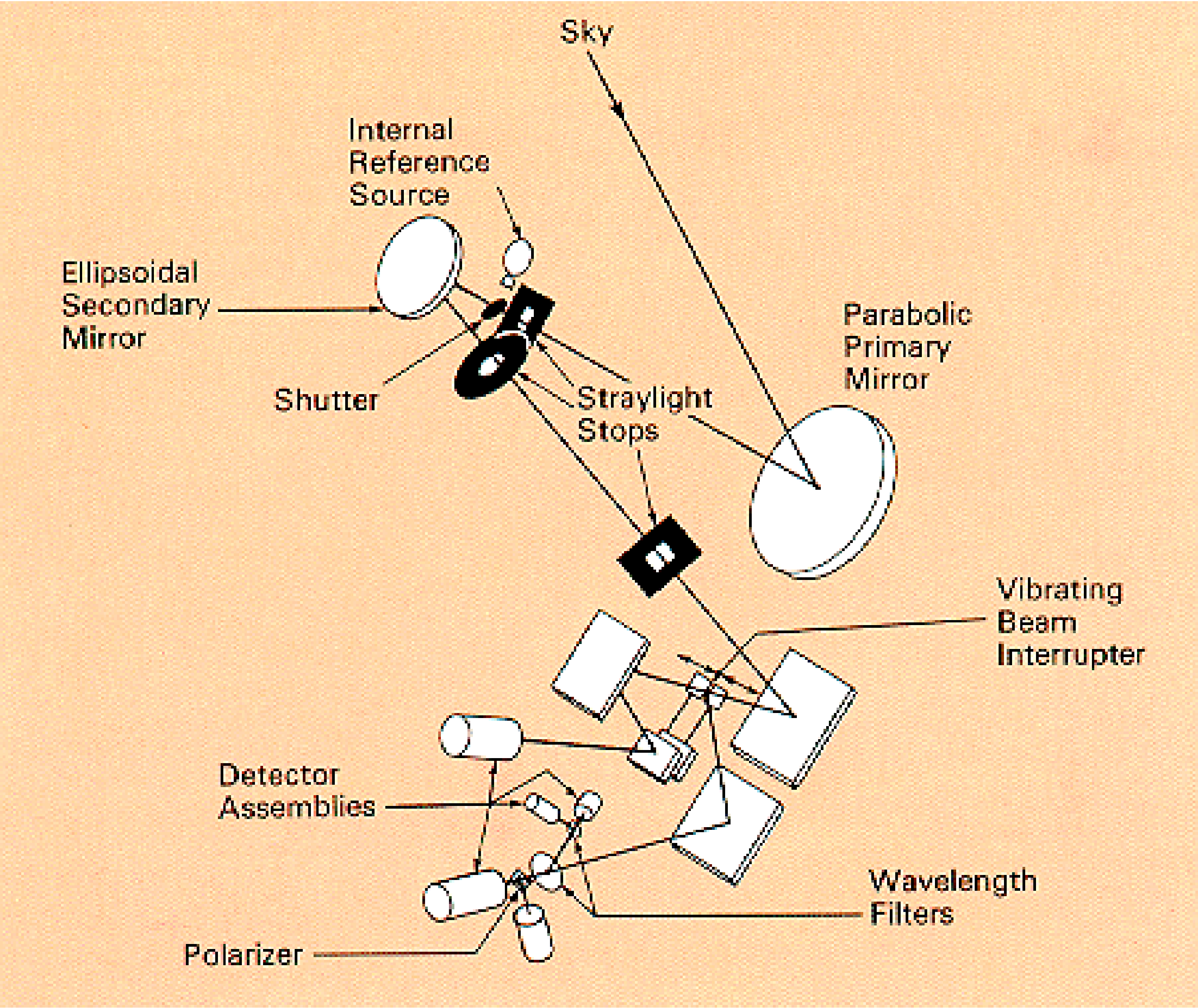
Luminosity density vs. redshift



L/(1+z) vs. time

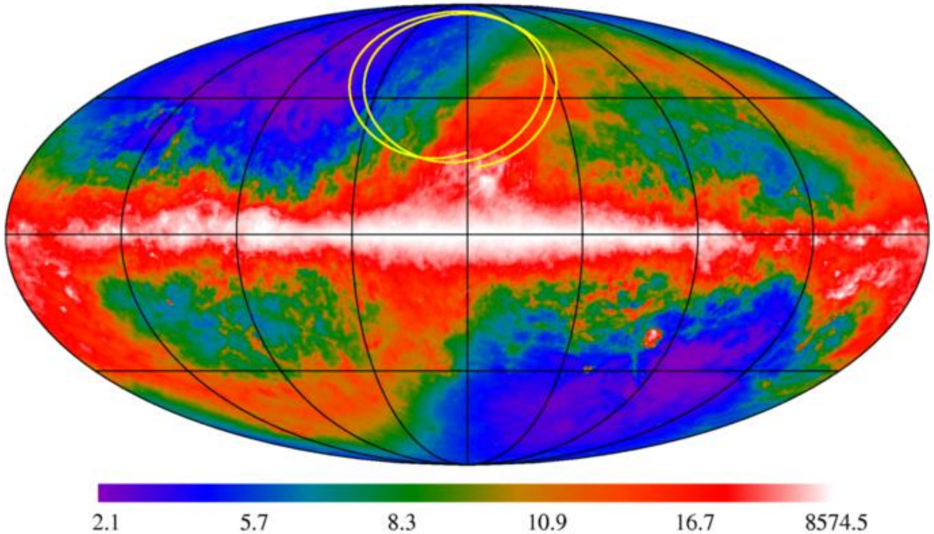


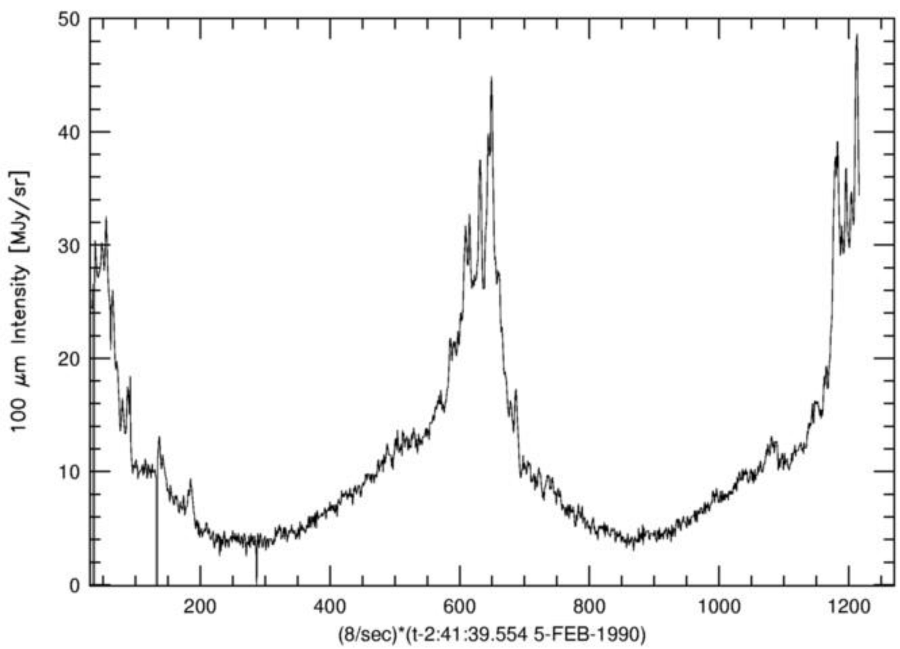

FIRAS
DIRBE
Deployable Sun, Earth,
RF/Thermal Shield
DMR Antennas
Helium Dewar
Spacecraft
Deployable Solar Panels
Earth Sensors
Deployable Mast
WFF Omni Antenna
TDRSS Omni Antenna


Sky
Internal Reference Source
Ellipsoidal Secondary Mirror
Parabolic Primary Mirror
Shutter
Straylight Stops
Vibrating Beam Interrupter
Detector Assemblies
Wavelength Filters
Polarizer

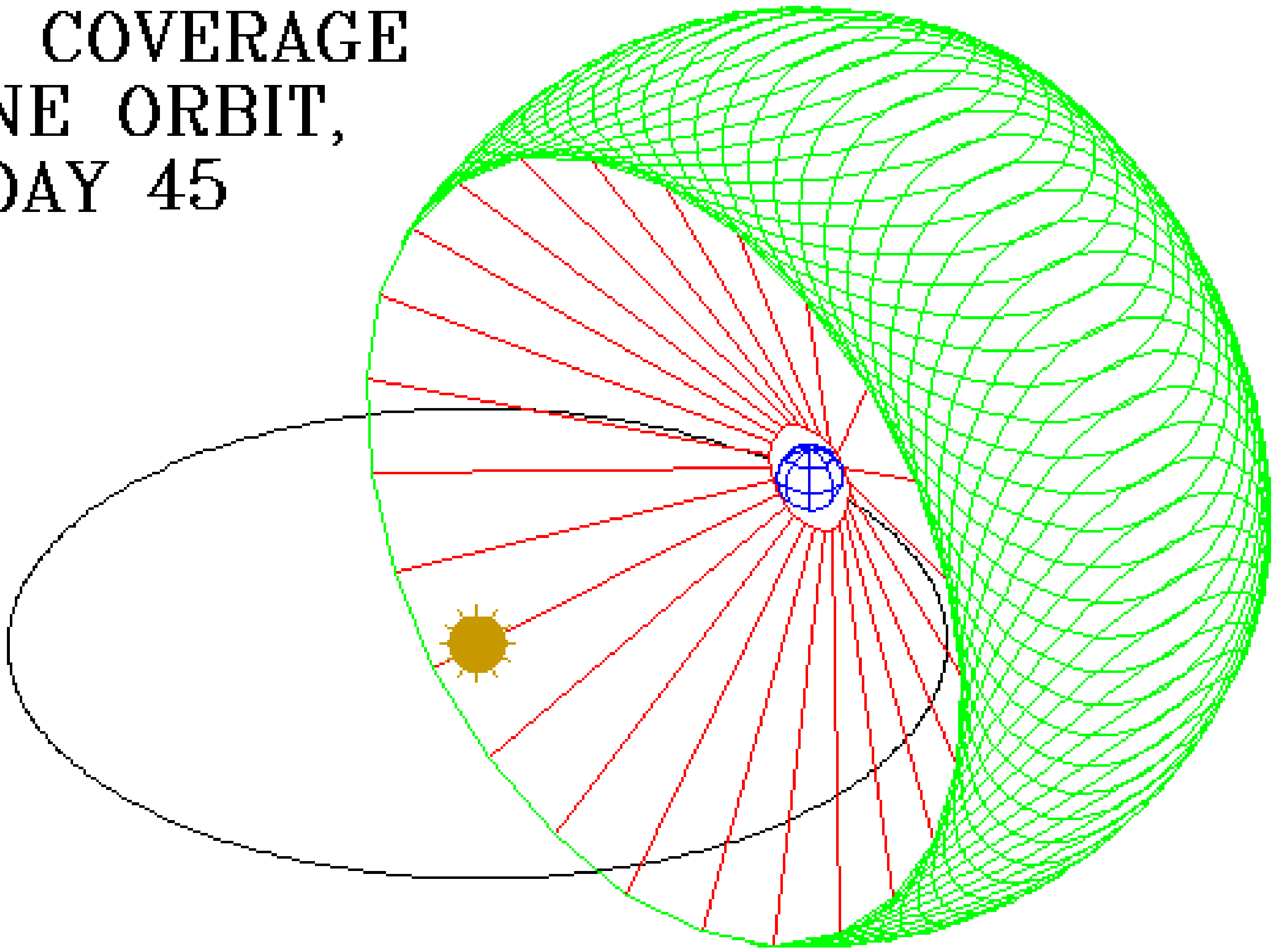
DIRBE Beam Size

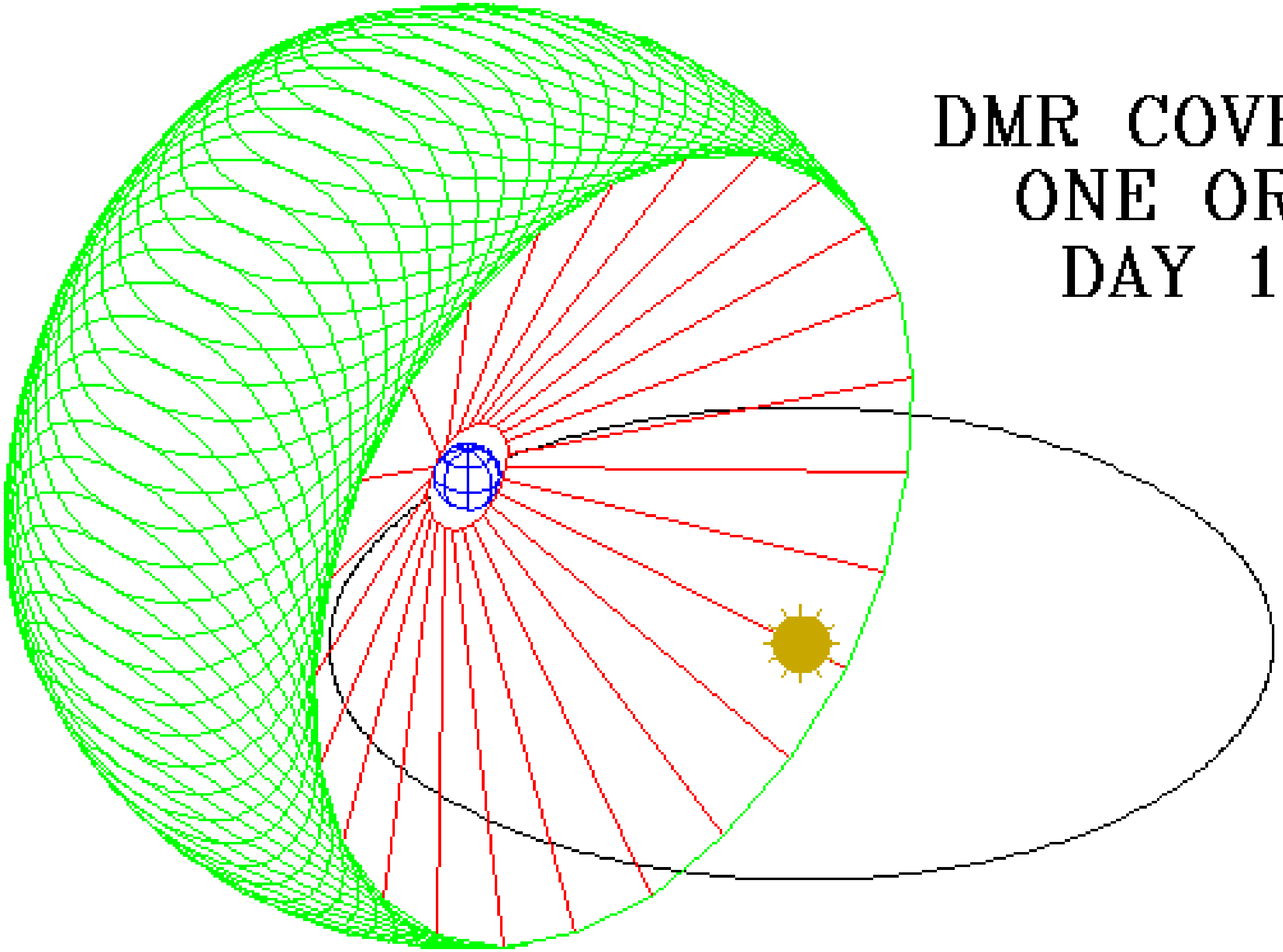
Band 8 with 5-Feb-90 Scan



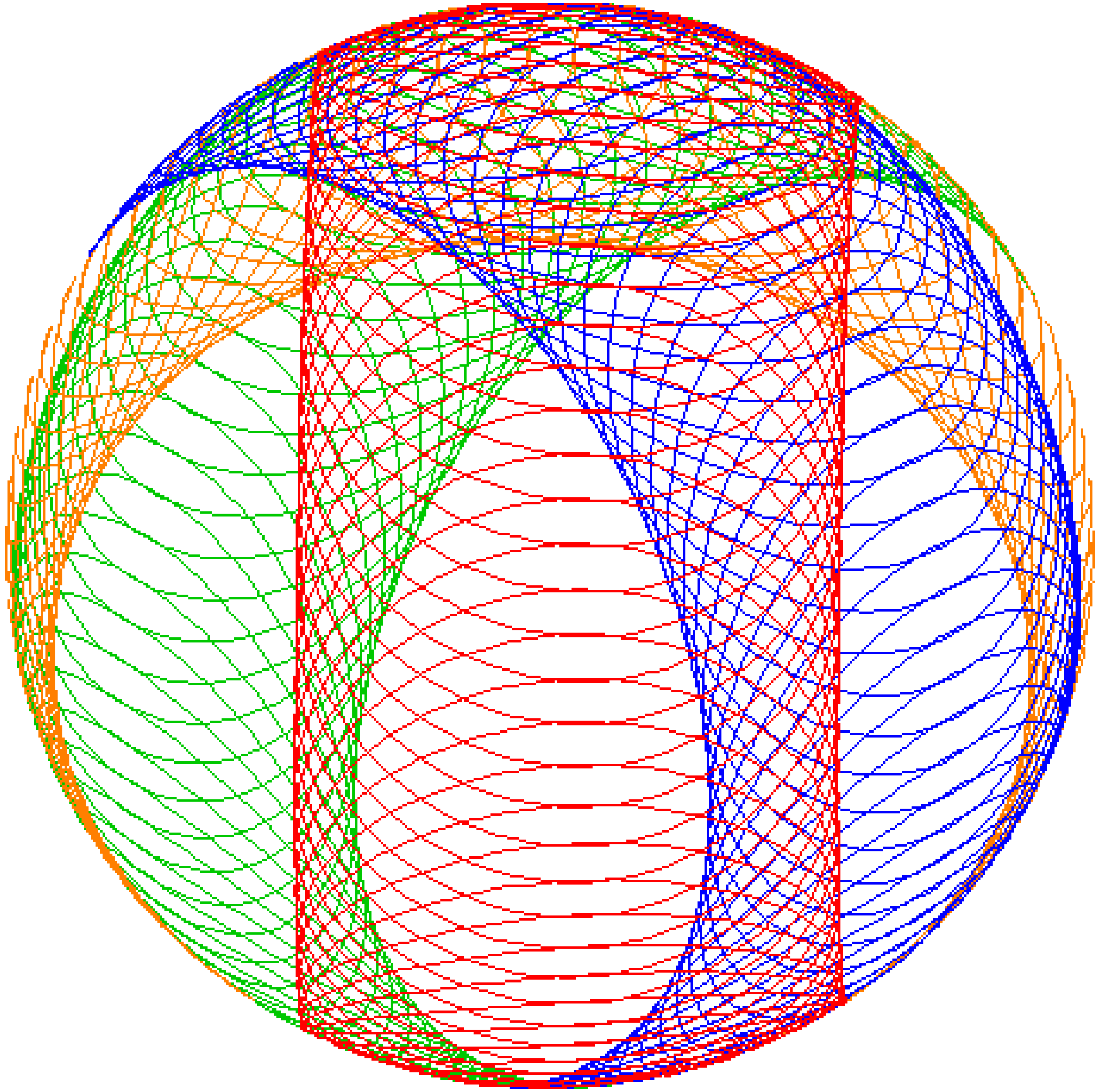


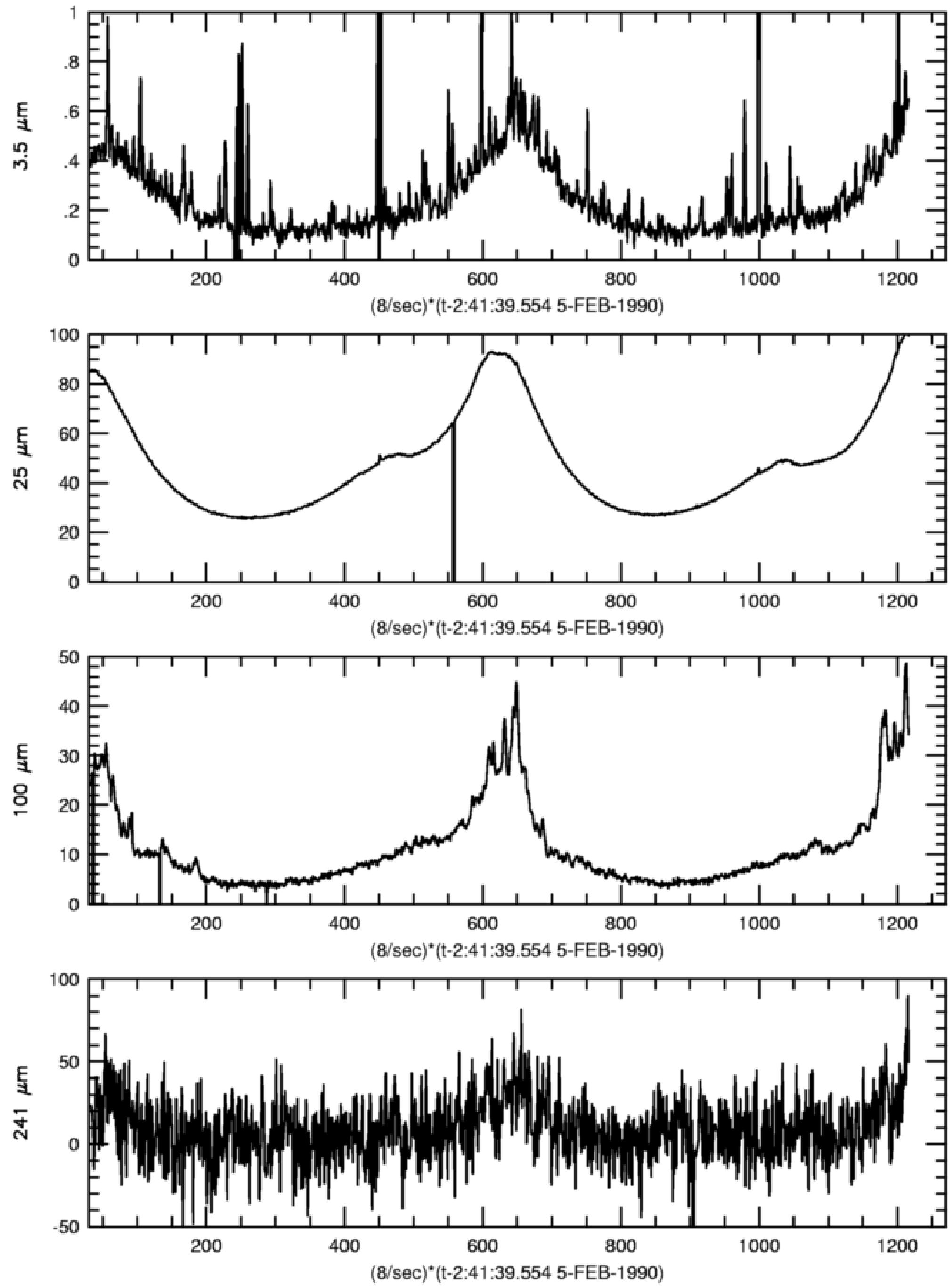
DMR COVERAGE
ONE ORBIT,
DAY 45



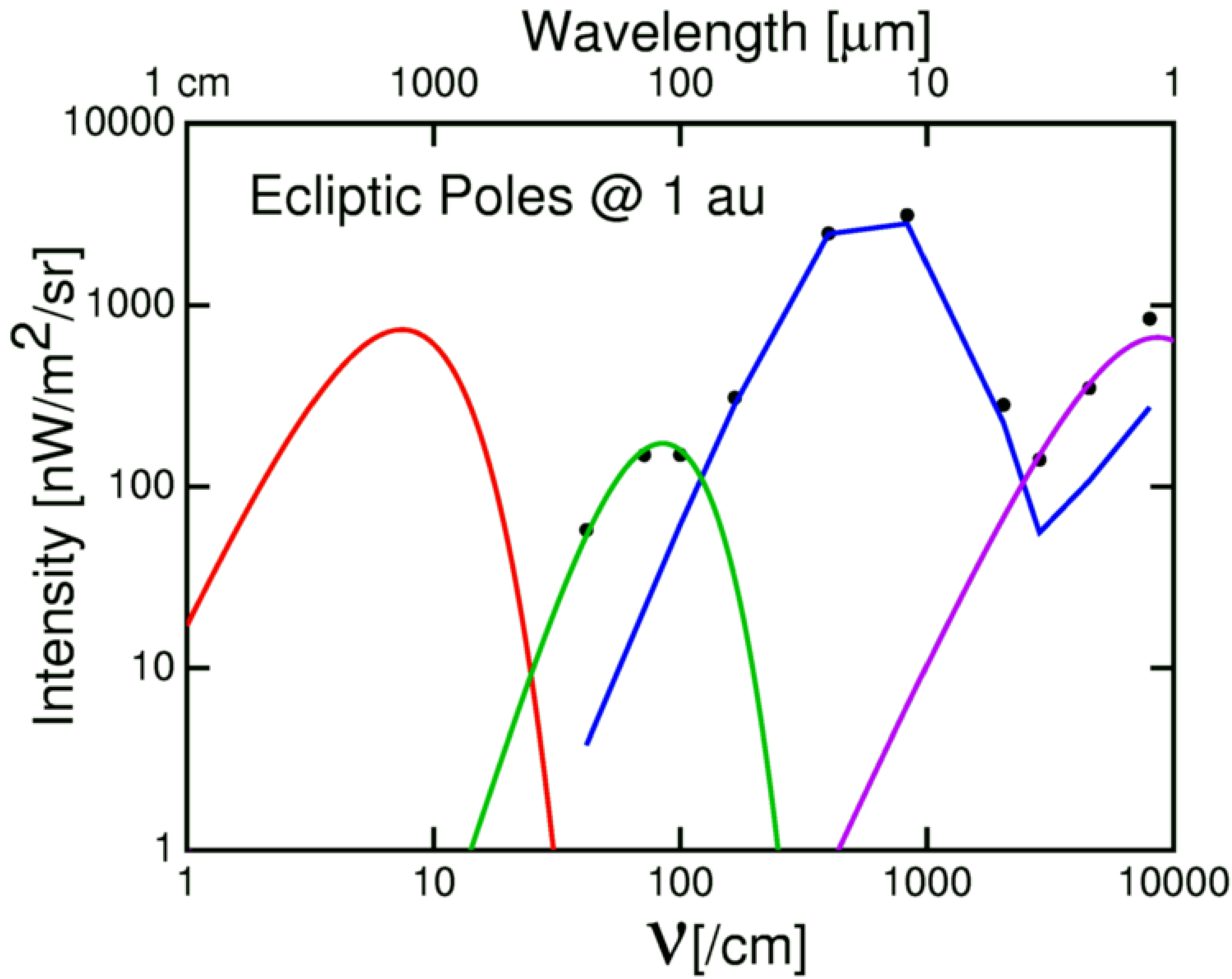


DMR COVERAGE
ONE ORBIT,
DAY 135

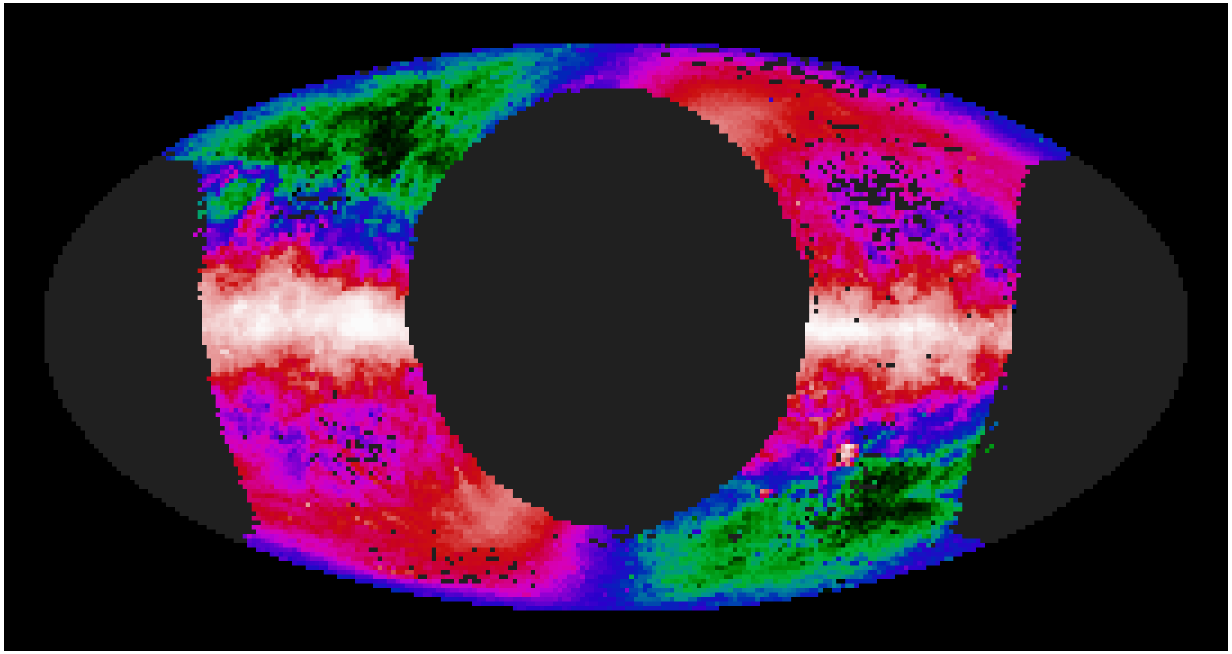



3.5 μm
(8/sec)*(t-2:41:39.554 5-FEB-1990)
25 μm
(8/sec)*(t-2:41:39.554 5-FEB-1990)
100 μm
(8/sec)*(t-2:41:39.554 5-FEB-1990)
241 μm
(8/sec)*(t-2:41:39.554 5-FEB-1990)

Bump Chart: Where is the CIRB?

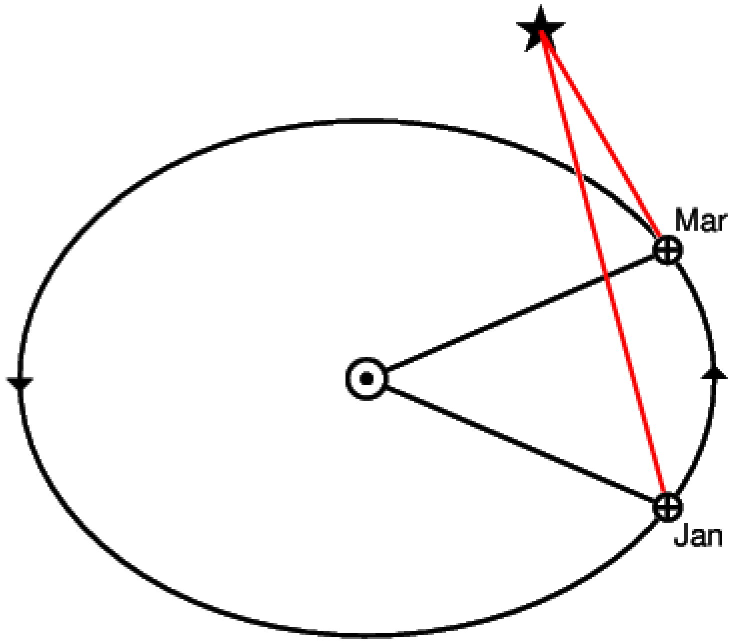


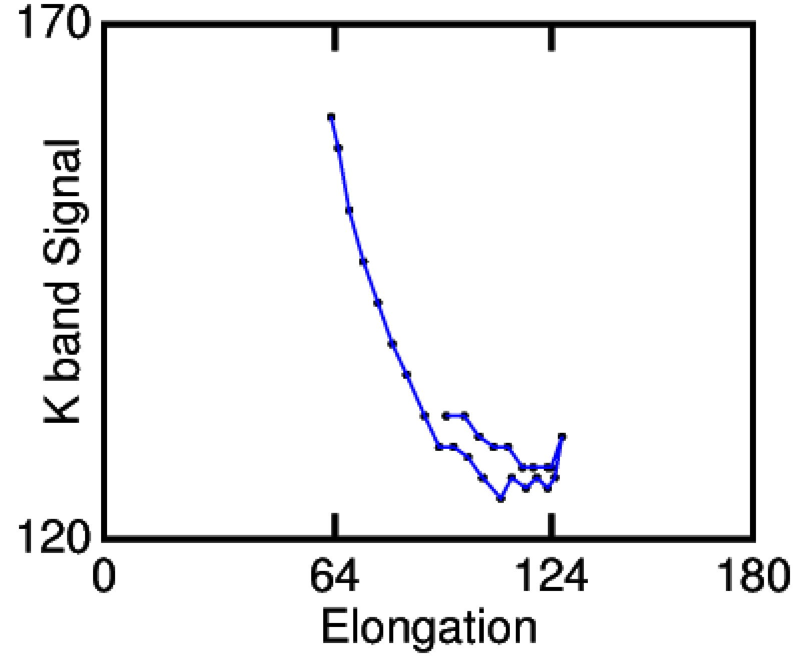
DIRBE 100 μm Weekly Maps



Note the triangles of zodiacal emission along the ecliptic on either side of the solar exclusion hole.

Extrapolation to Outside Solar system?

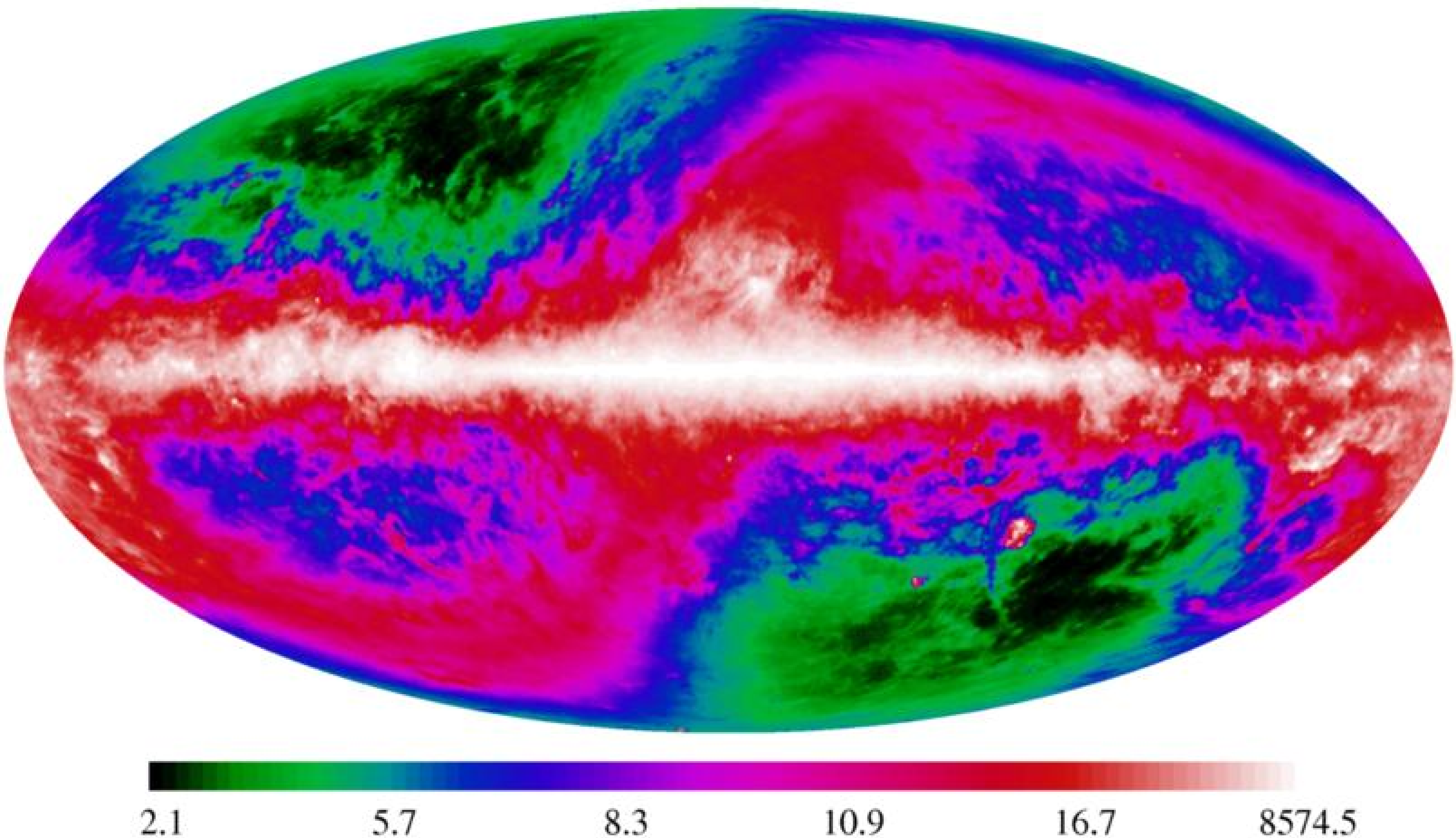




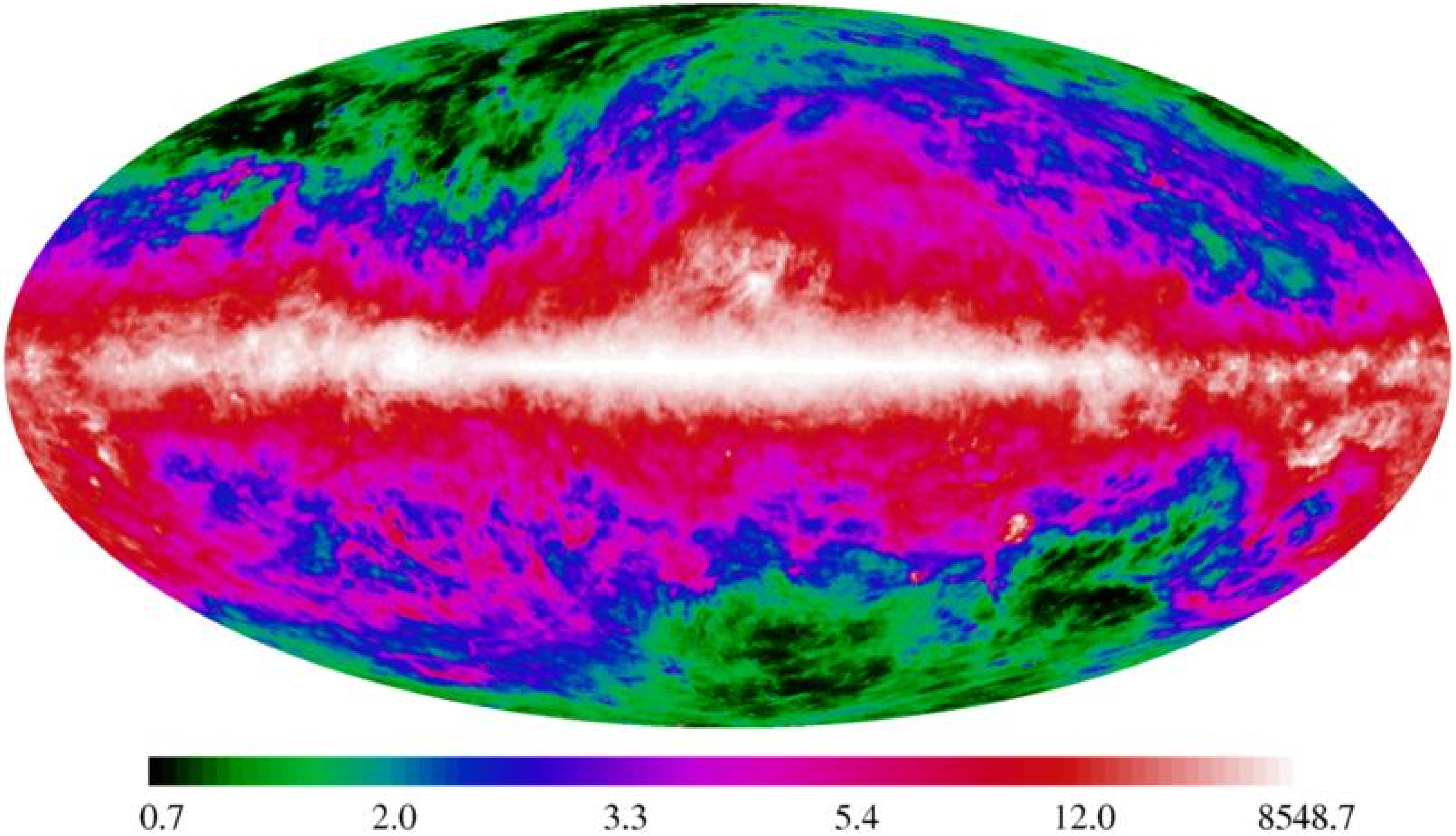
- Observe same spot on the sky through different amounts of interplanetary dust.

- Fit a model to the change in intensity *vs.* elongation (or time).

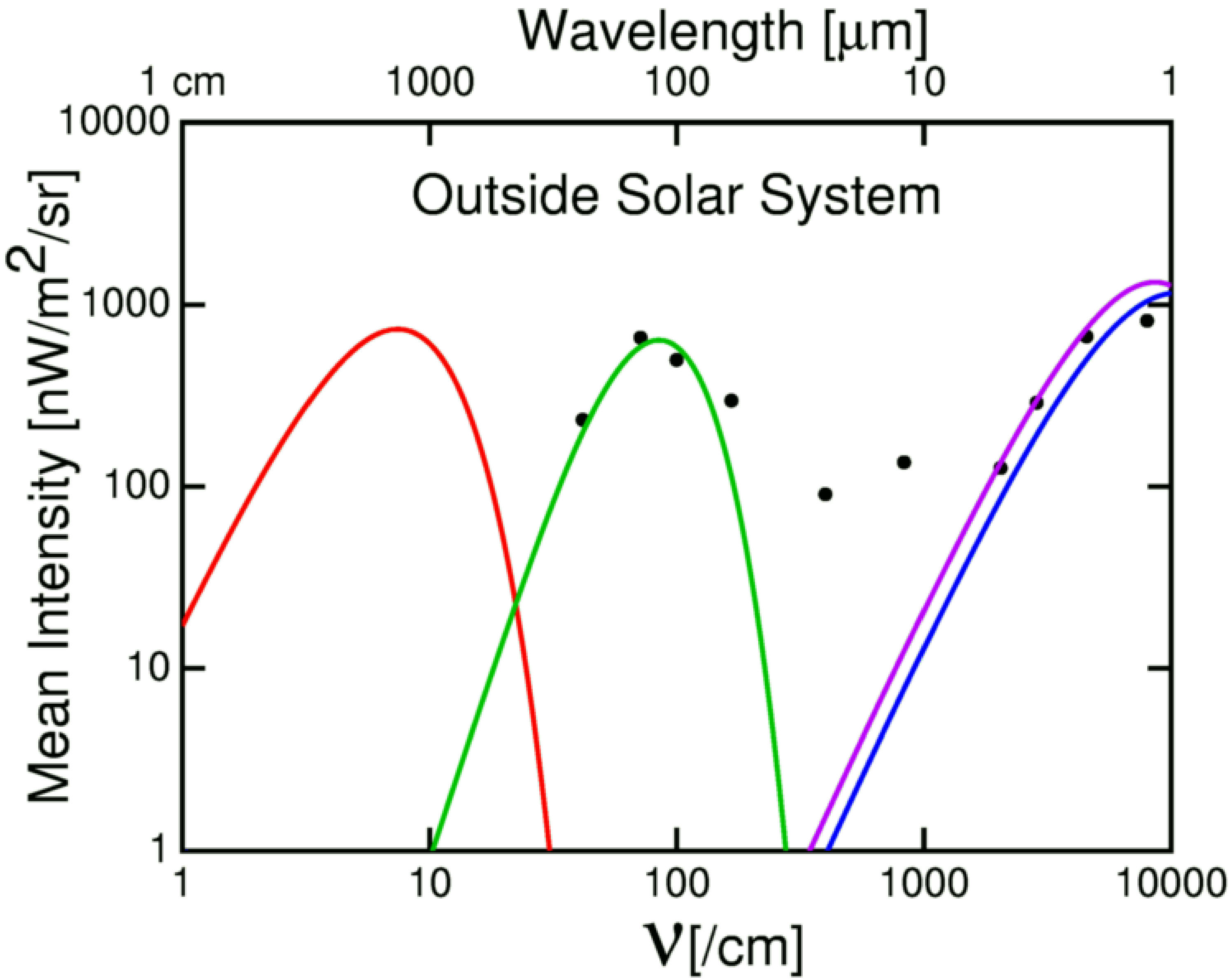
100 Micron Total



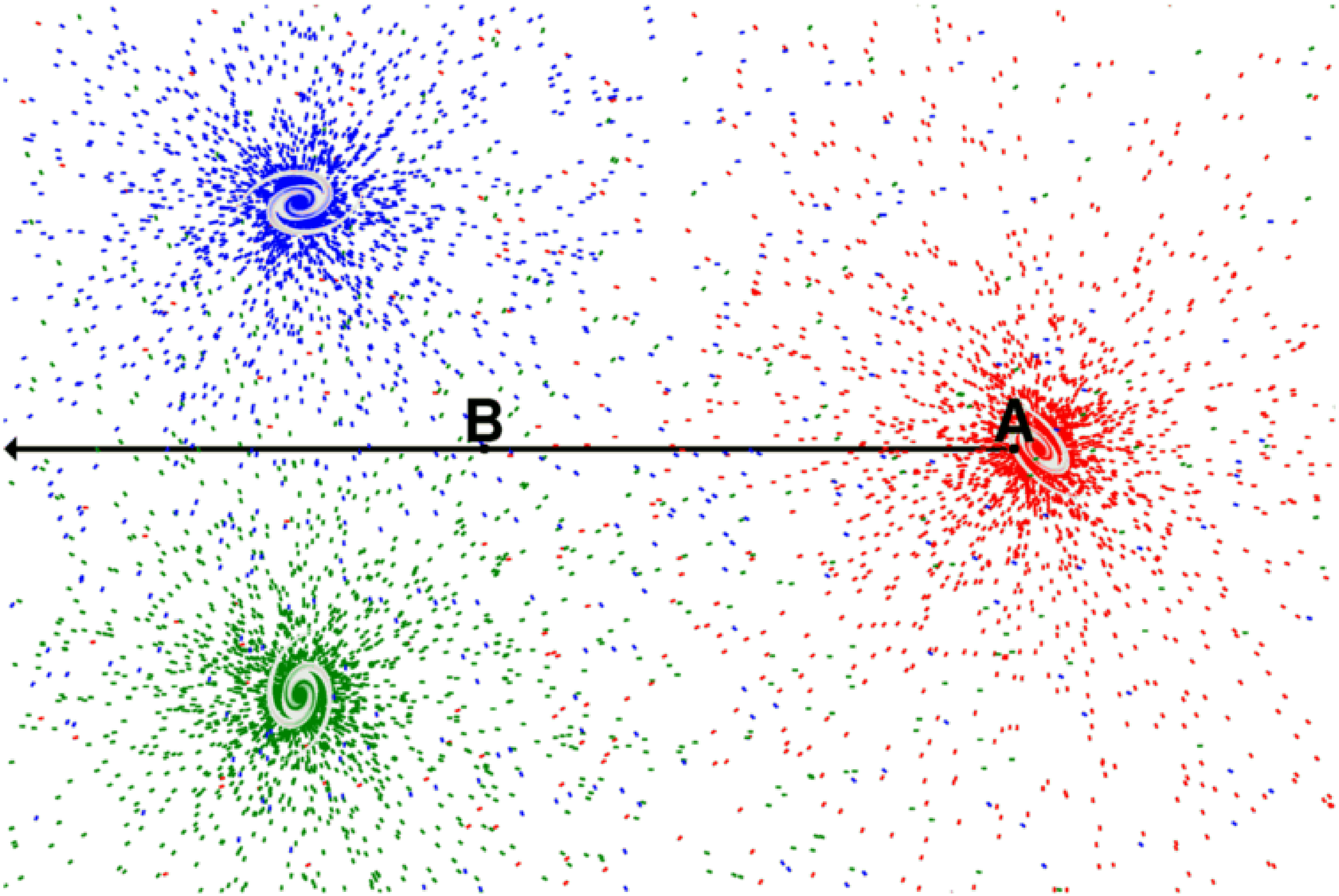
Zodi Subtracted 100 Micron



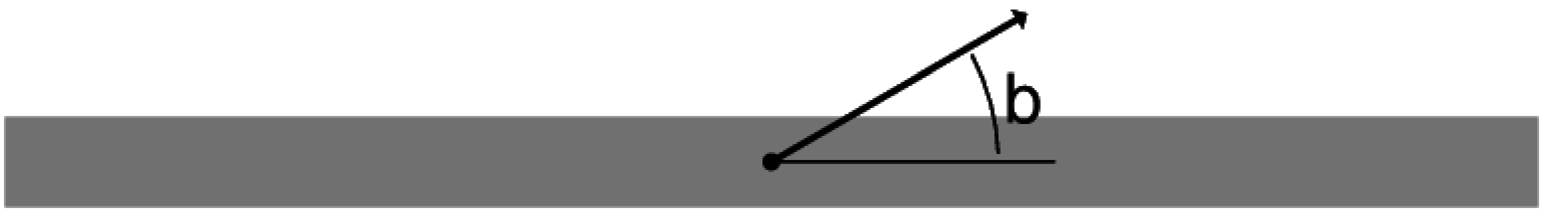
Still no CIRB Bump:



We want νJ_ν at B but sit at A

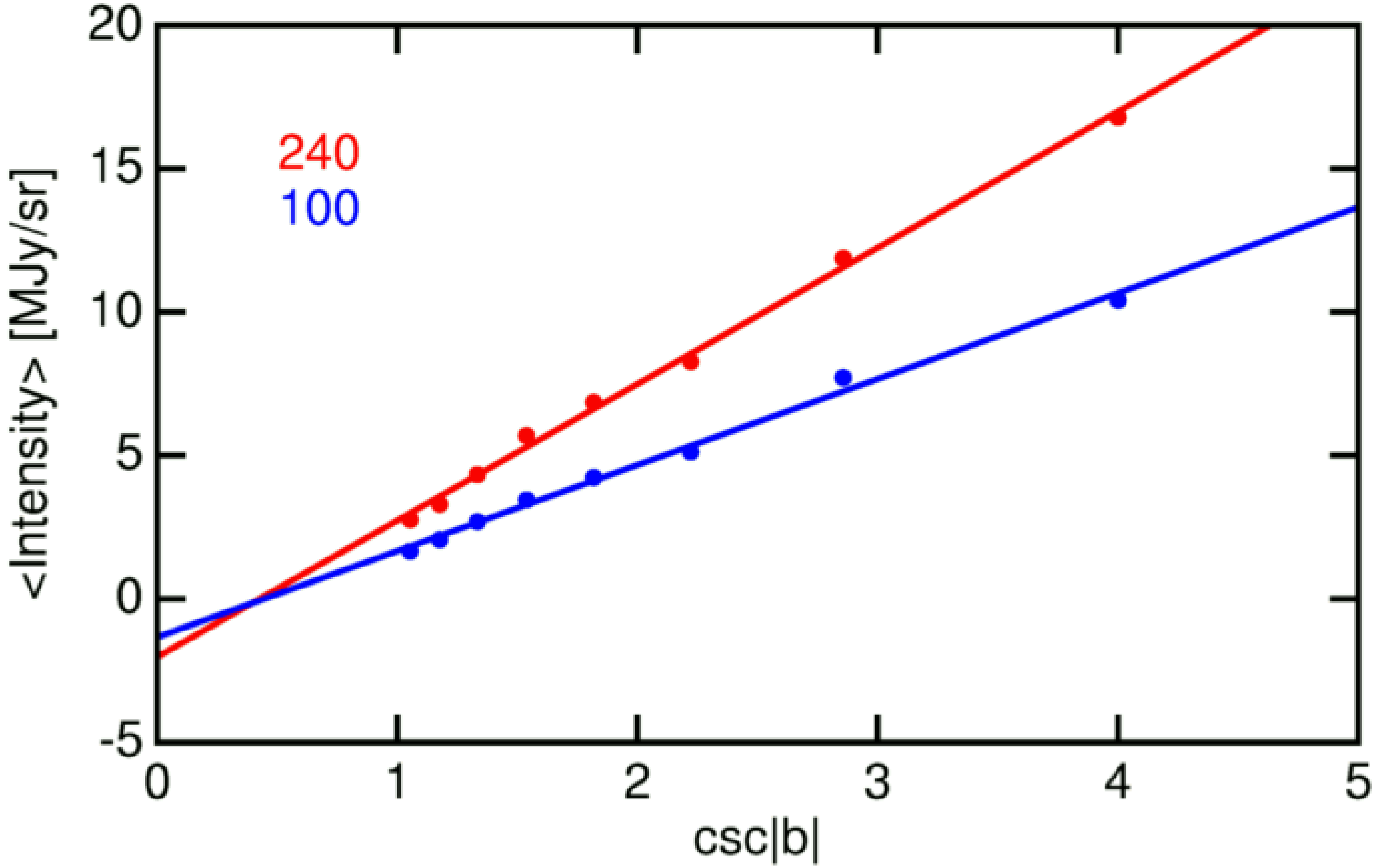


Extrapolation to NO Galaxy?

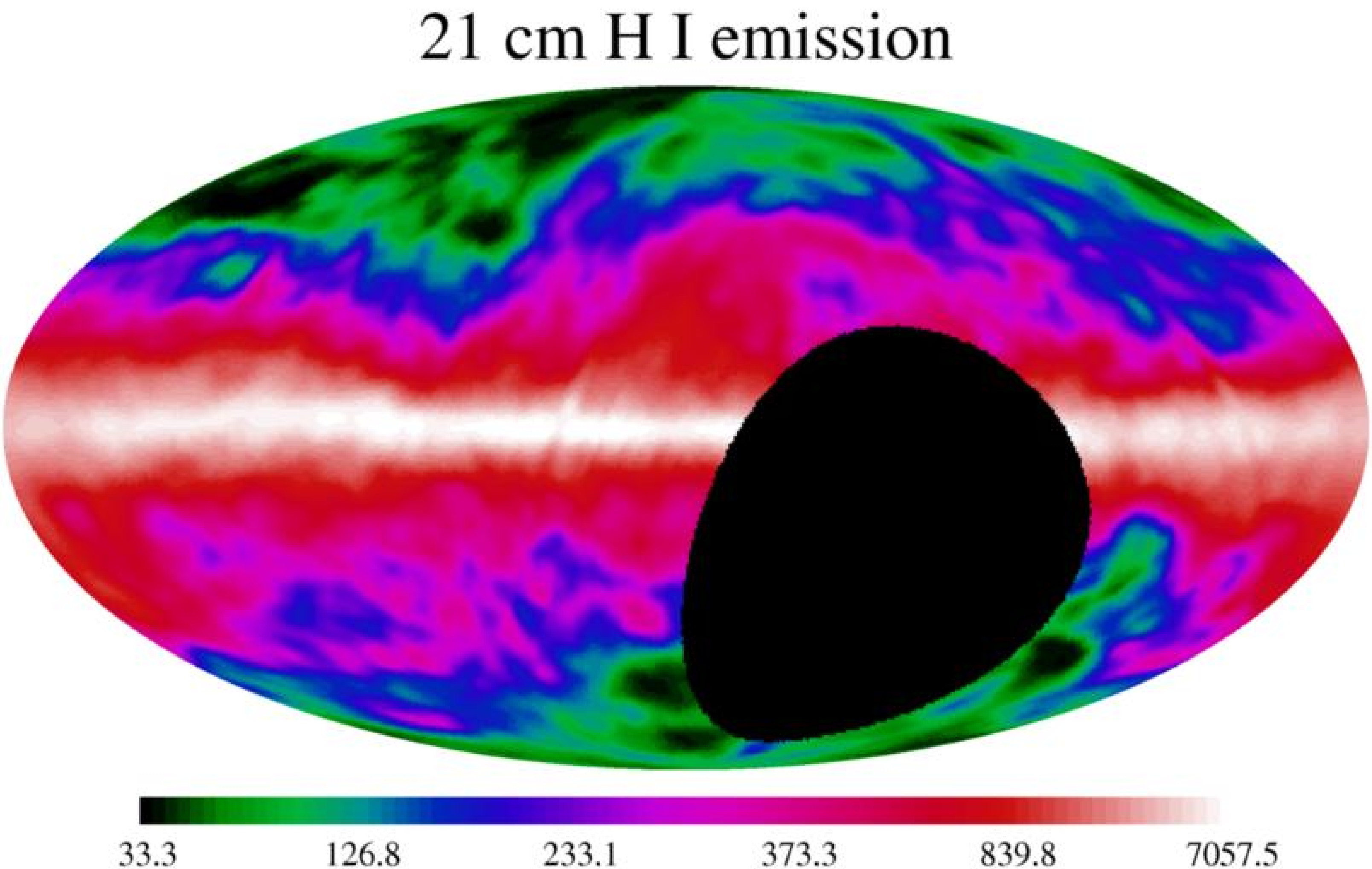


- Galaxy is a *very* thin disk
- Average column density $\propto \csc|b|$

Extrapolation to csc|b|=0 in Far IR



Atomic Hydrogen Map

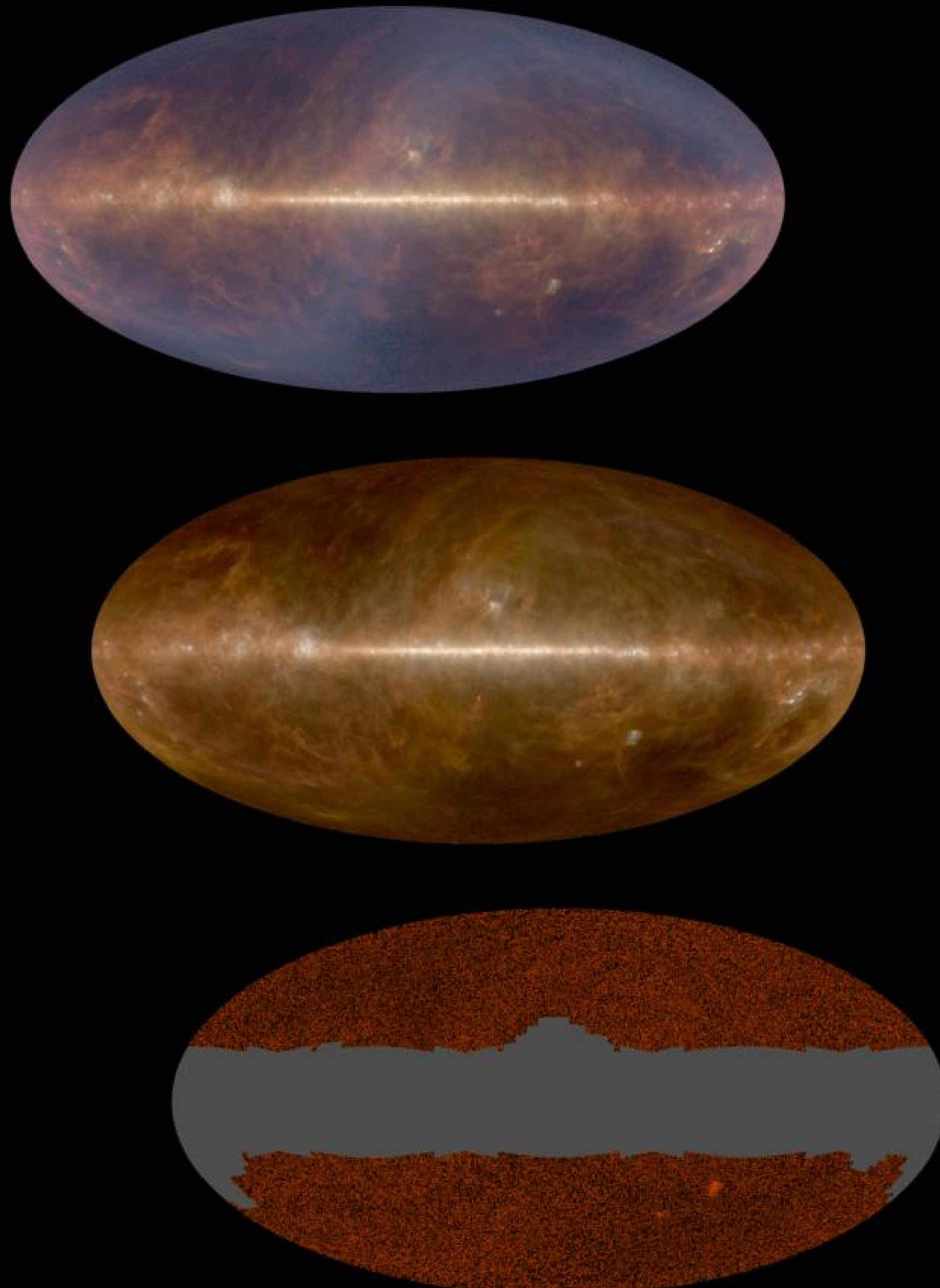


"The COBE Diffuse Infrared Background Experiment Search for the Cosmic Infrared Background. I. Limits and Detections", Hauser *et al.* (1998, ApJ, 508, 25)

"The COBE Diffuse Infrared Background Experiment Search for the Cosmic Infrared Background. II. Model of the Interplanetary Dust Cloud", Kelsall *et al.* (1998, ApJ, 508, 44)

"The COBE Diffuse Infrared Background Experiment Search for the Cosmic Infrared Background. III. Separation of Galactic Emission from the Infrared Sky Brightness", Arendt *et al.* (1998, ApJ, 508, 74)

"The COBE Diffuse Infrared Background Experiment Search for the Cosmic Infrared Background. IV. Cosmological Implications", Dwek *et al.* (1998, ApJ, 508, 106)



DIRBE Team IRB Results

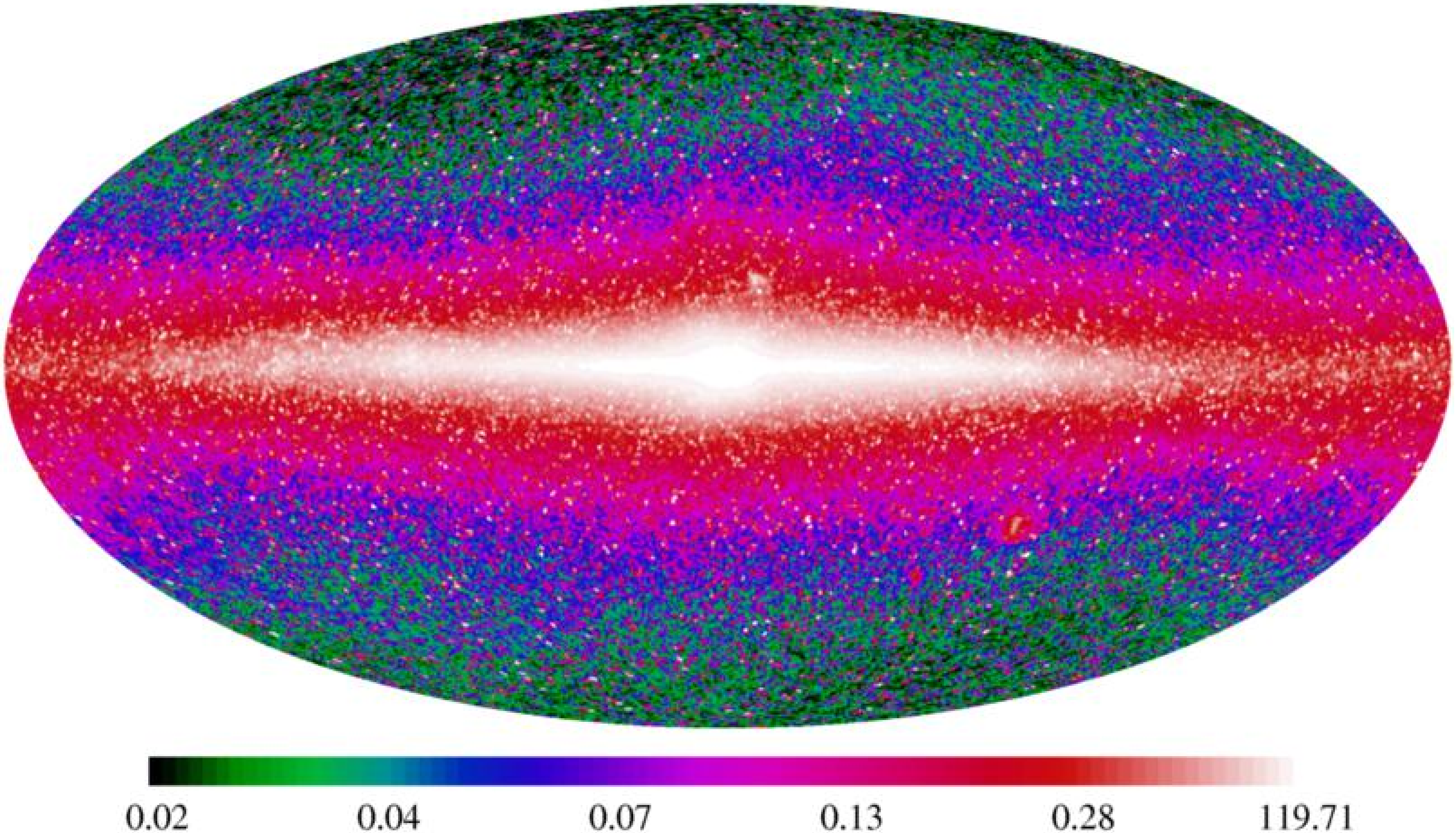
Hauser, ..., Wright (1998, ApJ, 508, 25)

λ [μm]	νI_ν [nW m^{-2} sr^{-1}]	I_ν [MJy sr^{-1}]
1.25	$< 75.$	< 0.031
2.2	$< 39.$	< 0.029
3.5	$< 23.$	< 0.027
4.9	$< 41.$	< 0.067
12.	$< 468.$	< 1.87
25.	$< 504.$	< 4.2
60.	$< 75.$	< 1.5
100.	$< 38.$	< 1.27
140.	25.0 ± 6.9	1.17 ± 0.32
240.	13.6 ± 2.5	1.09 ± 0.2

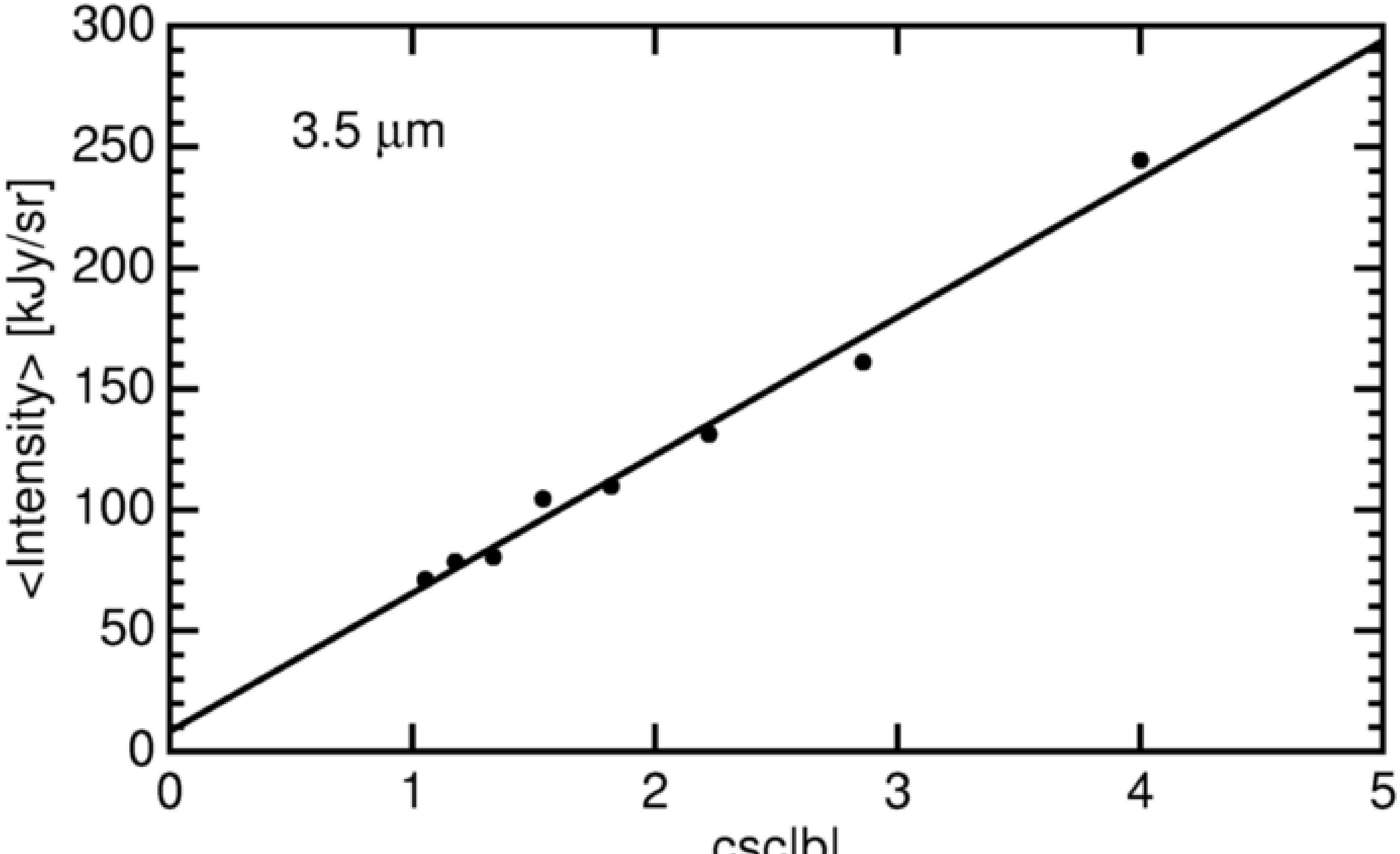
$$I_\nu \approx (1.3 \pm 0.4) \times 10^{-5} (\tilde{\nu}/100)^{0.64 \pm 0.12} B_\nu(18.5 \pm 1.2 \text{ K})$$

Fixsen *et al.*, 1998, ApJ, 508, 123

Zodi Subtracted 3.5 Microns



Extrapolation to csc|b|=0 at 3.5 μm



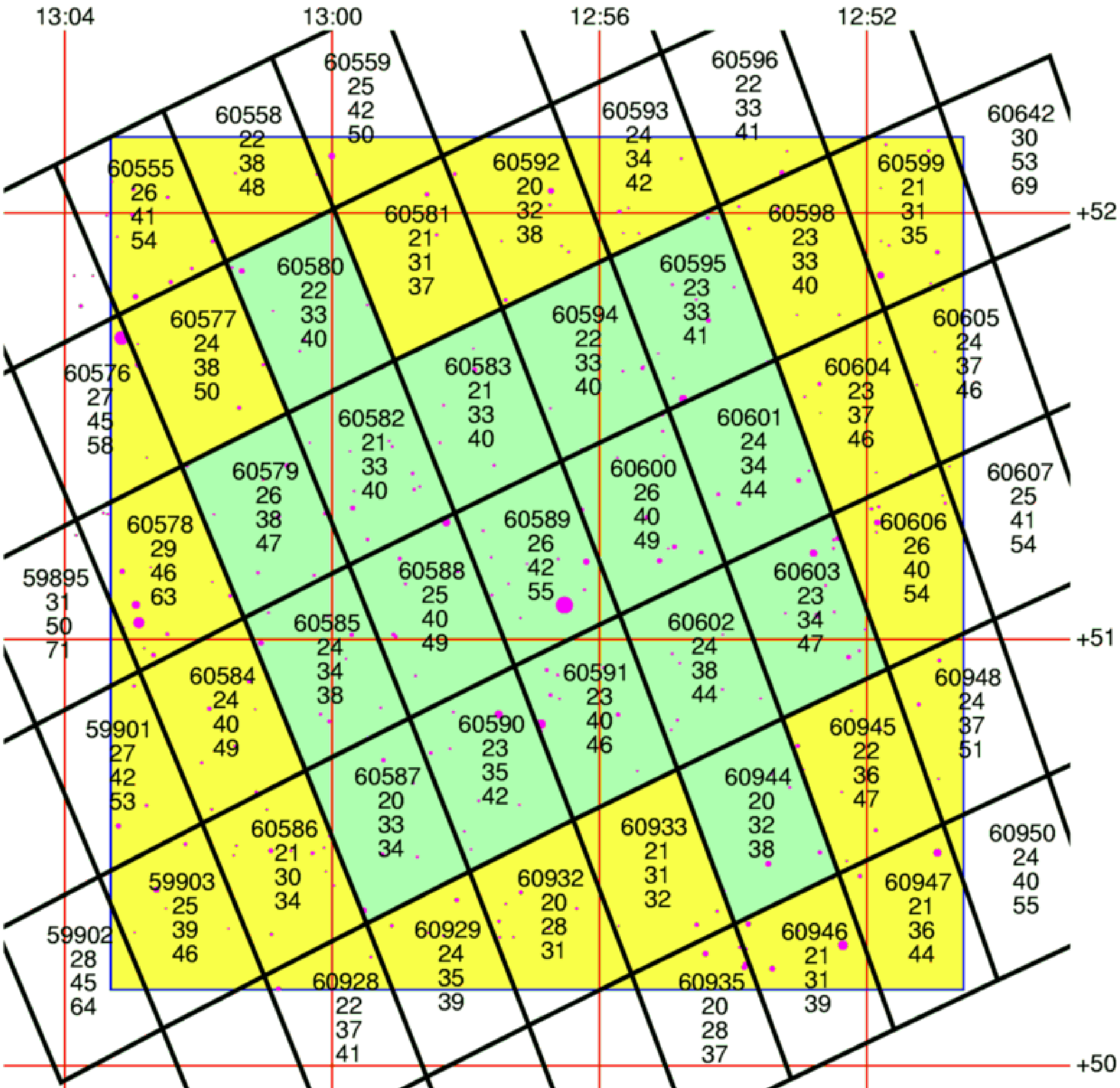
University of California
Los Angeles

Detecting the Cosmic Infrared Background at 2.2μm with Ground Based and Space Based Observations

A dissertation submitted in partial satisfaction of the
requirements for the degree
Doctor of Philosophy in Physics and Astronomy

by

Varoujan Gorjian
1998


13:04
13:00
12:56
12:52
+52
+51
+50
60559 25 42 50
60596 22 33 41
60558 22 38 48
60593 24 34 42
60642 30 53 69
60555 26 41 54
60592 20 32 38
60599 21 31 35
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60579 26 38 47
60600 26 40 49
60607 25 41 54
60578 29 46 63
60589 26 42 55
60606 26 40 54
59895 31 50 71
60588 25 40 49
60603 23 34 47
60585 24 34 38
60602 24 38 44
60584 24 40 49
60591 23 40 46
60948 24 37 51
59901 27 42 53
60590 23 35 42
60945 22 36 47
60587 20 33 34
60944 20 32 38
60586 21 30 34
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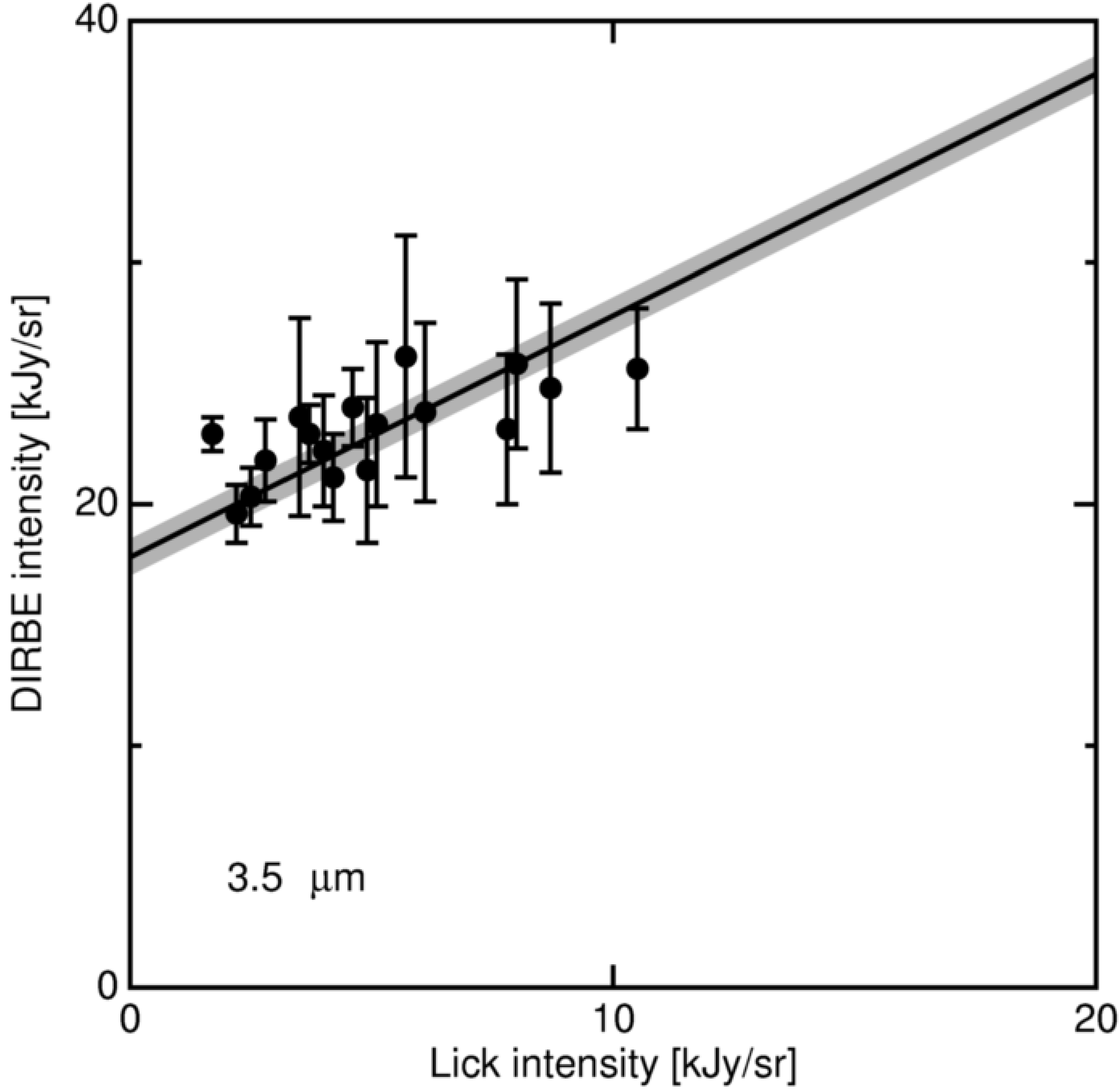
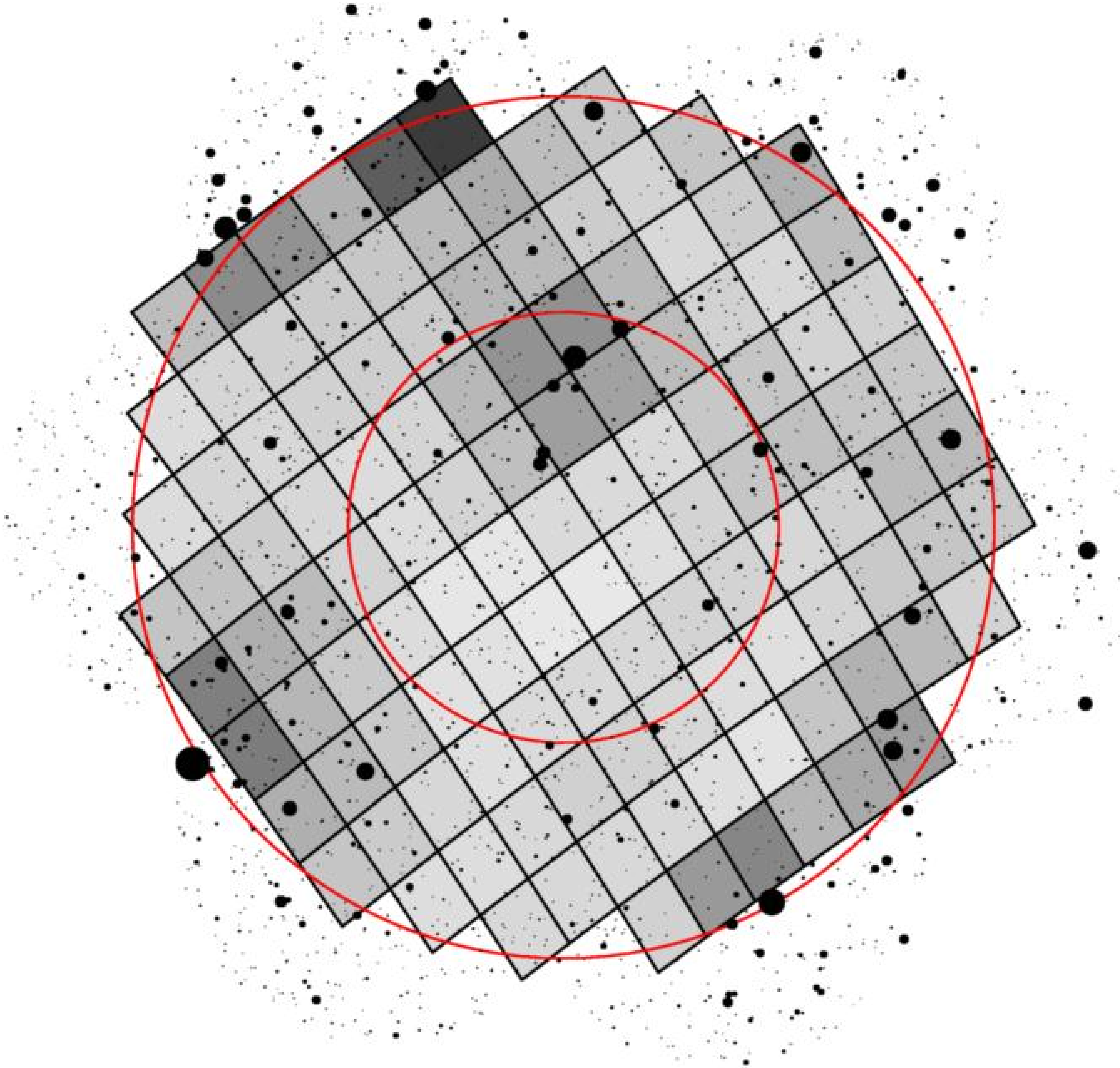
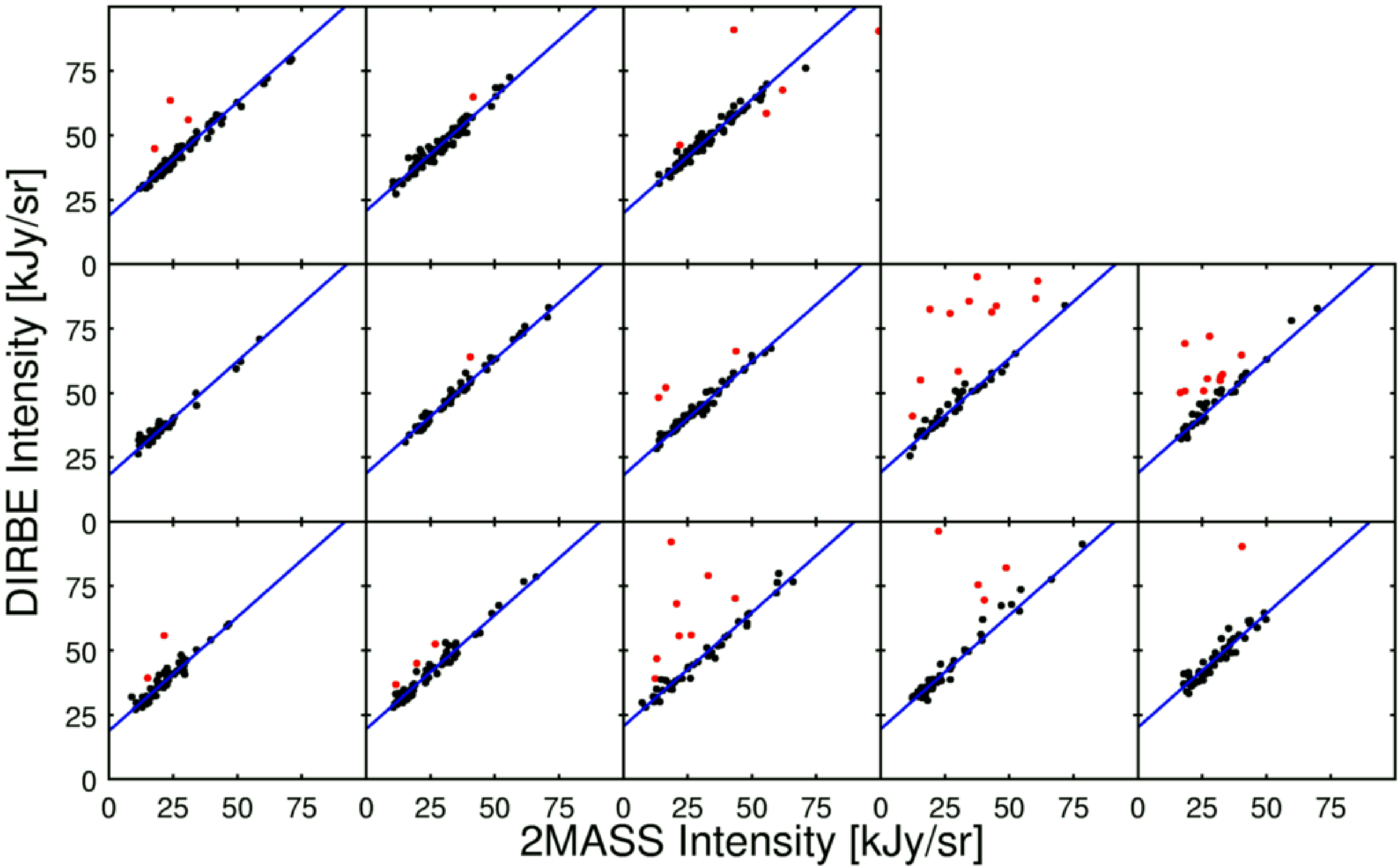


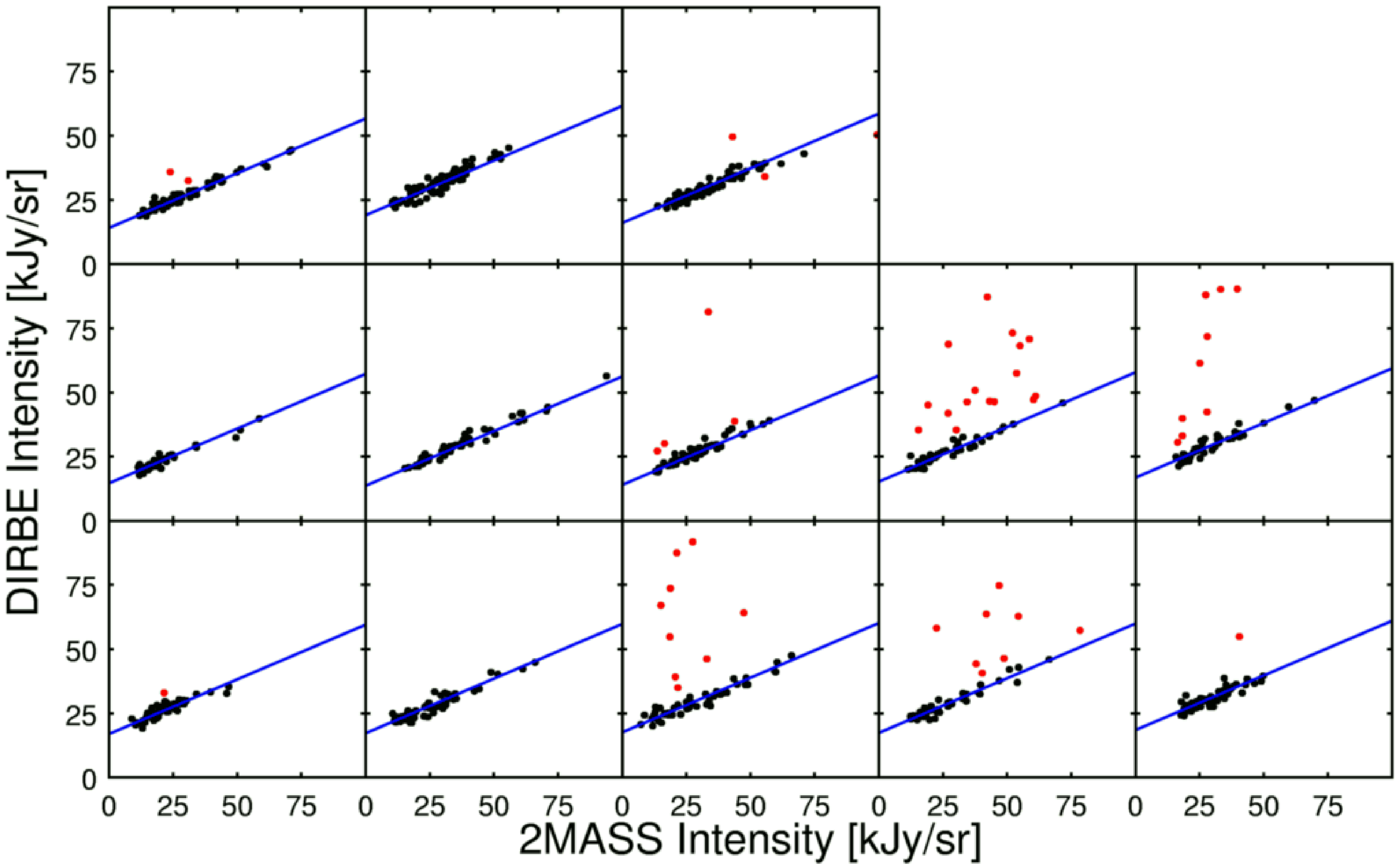
40
20
0
0
10
20
DIRBE intensity [kJy/sr]
Lick intensity [kJy/sr]
3.5 μm



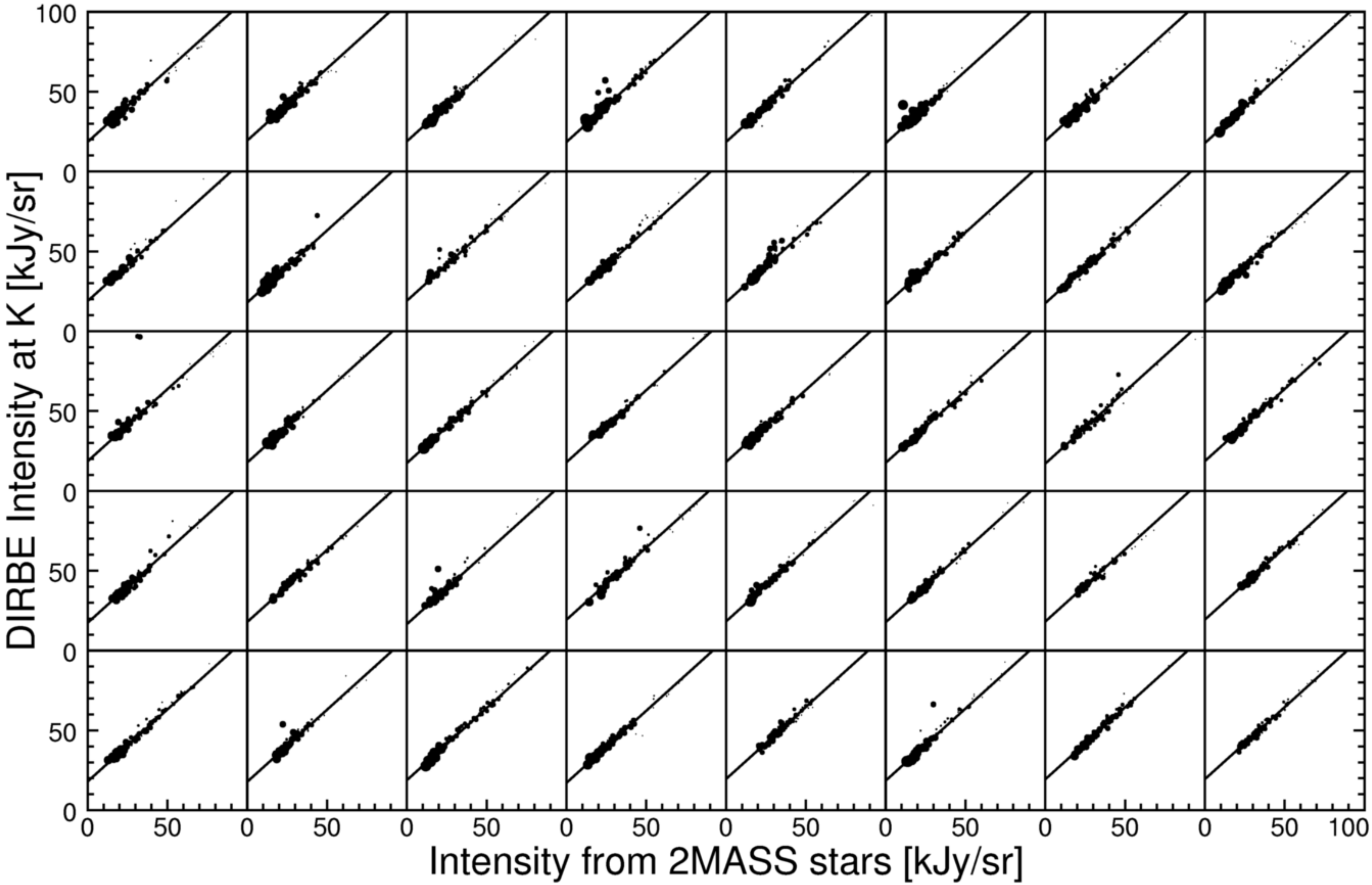
DIRBE vs. 2MASS Fits at K



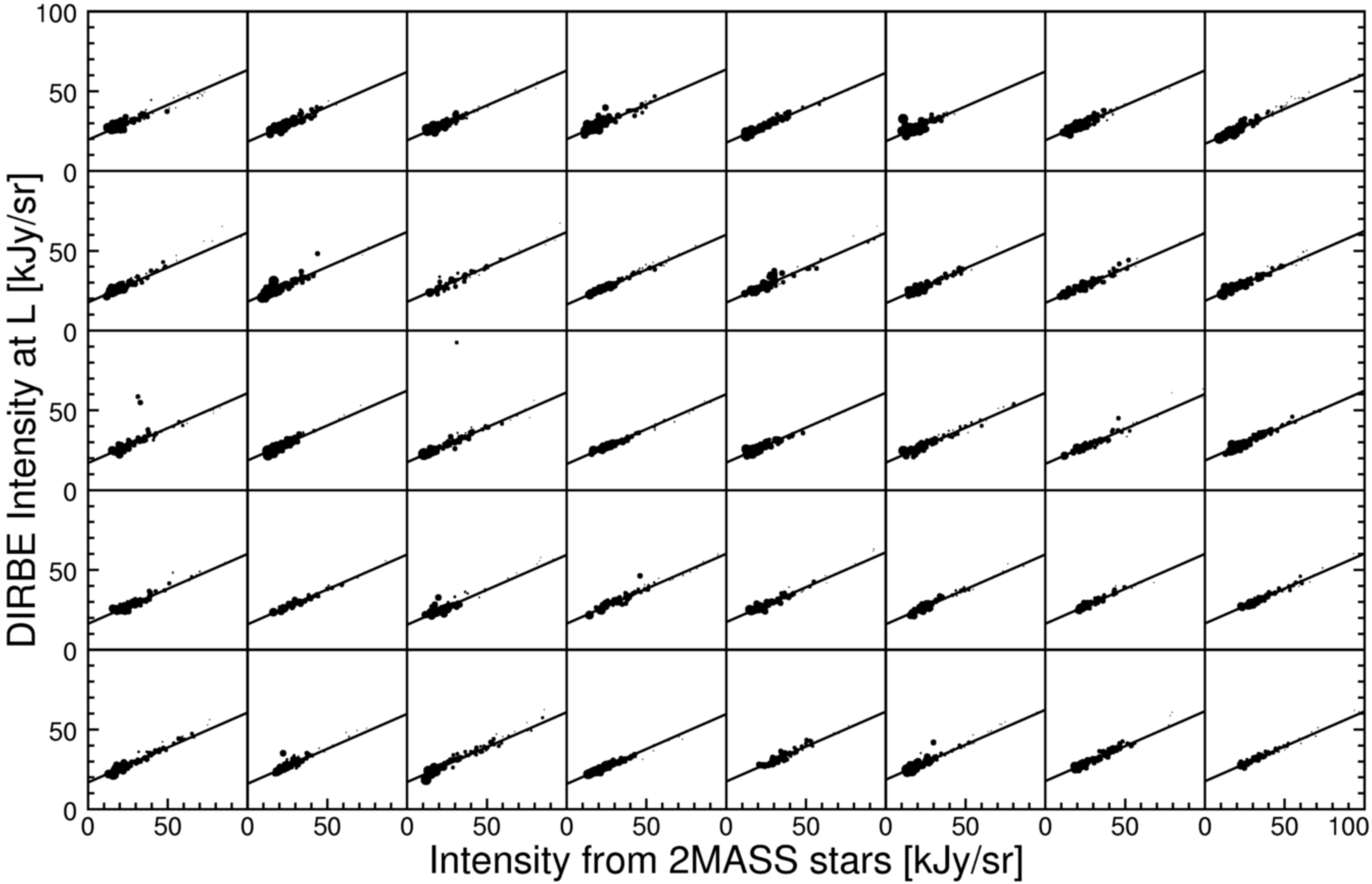
DIRBE at L vs 2MASS at K



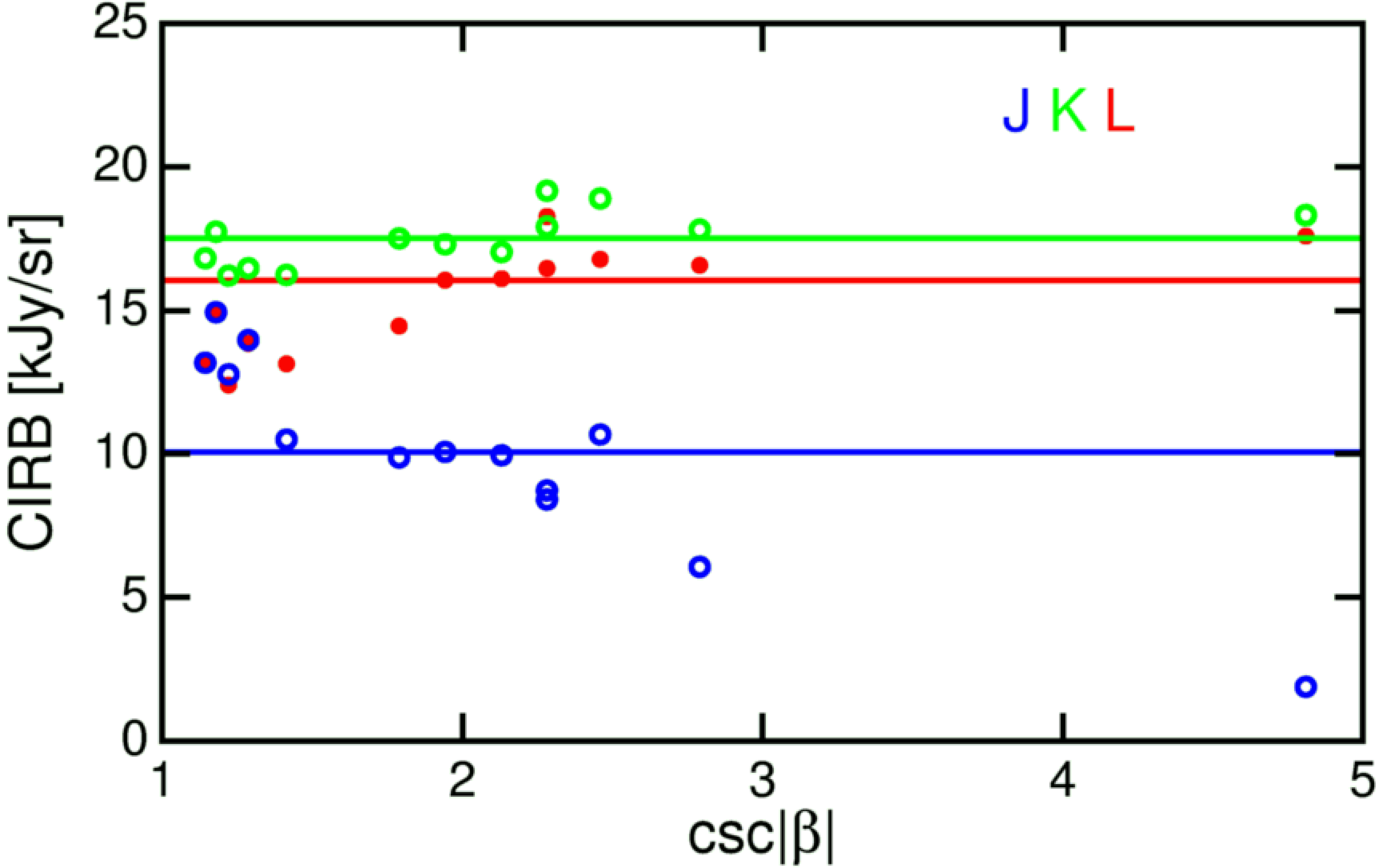
More DIRBE vs. 2MASS Fits at K



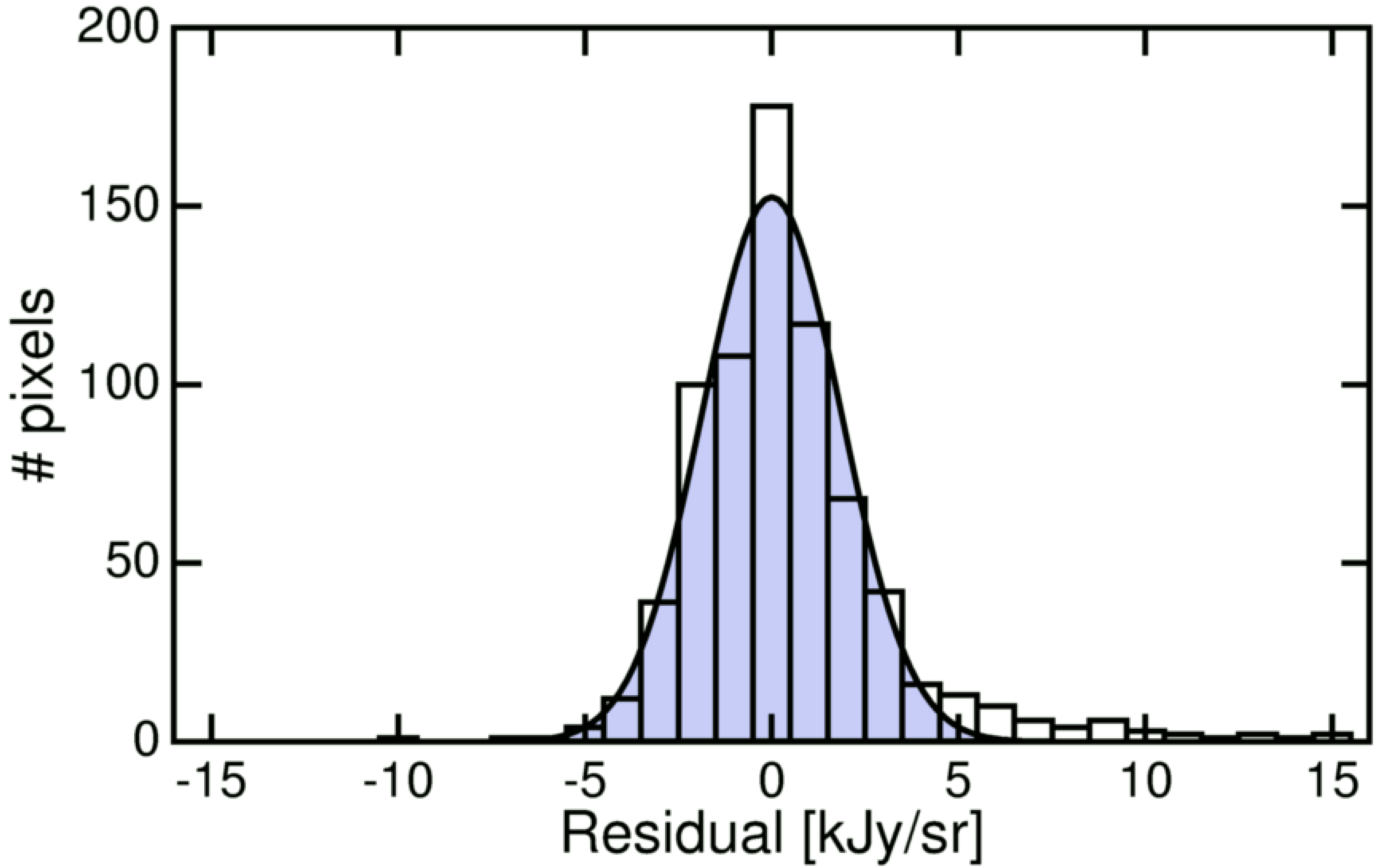
More DIRBE at L vs 2MASS at K



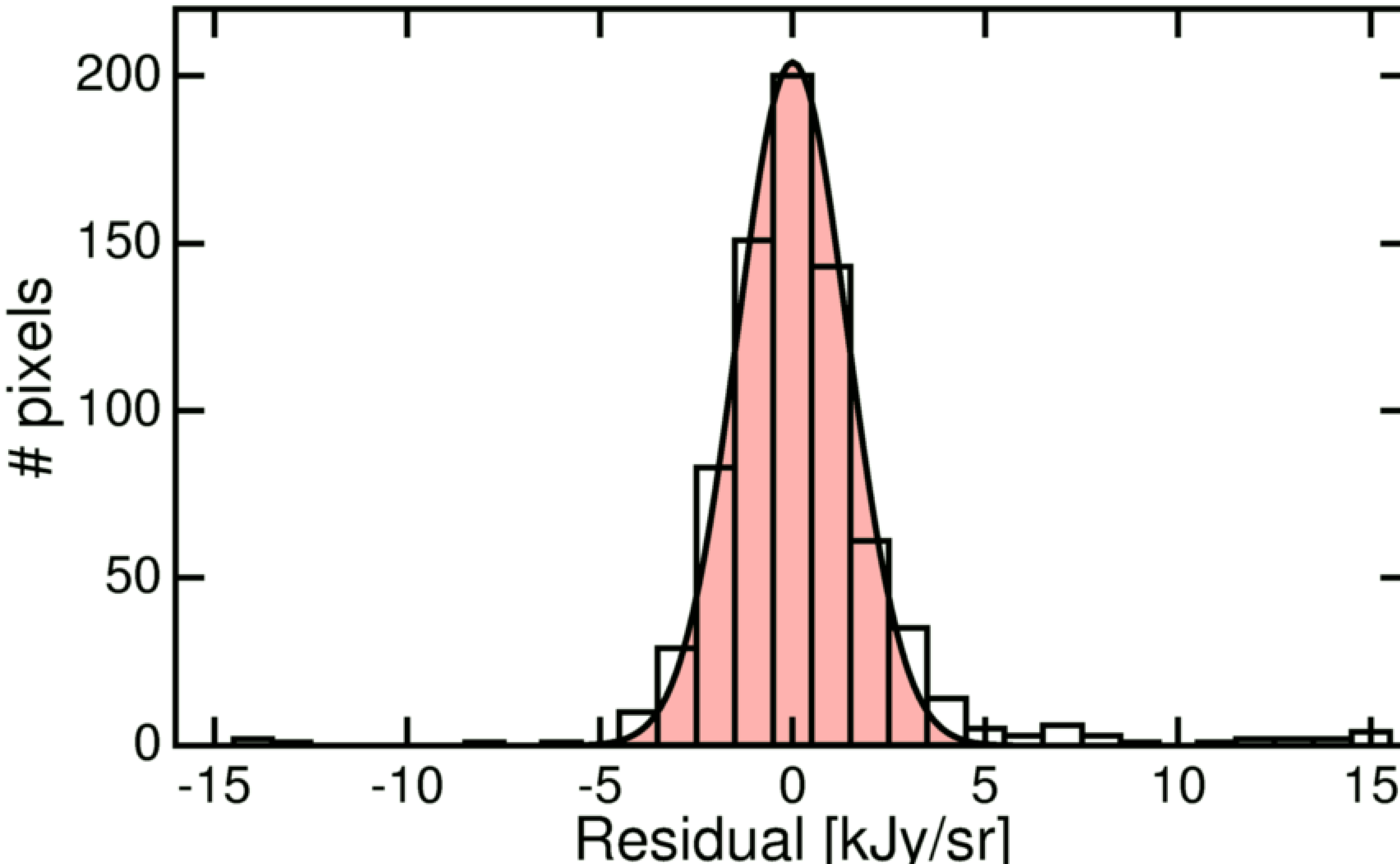
DIRBE-2MASS at J, K & L

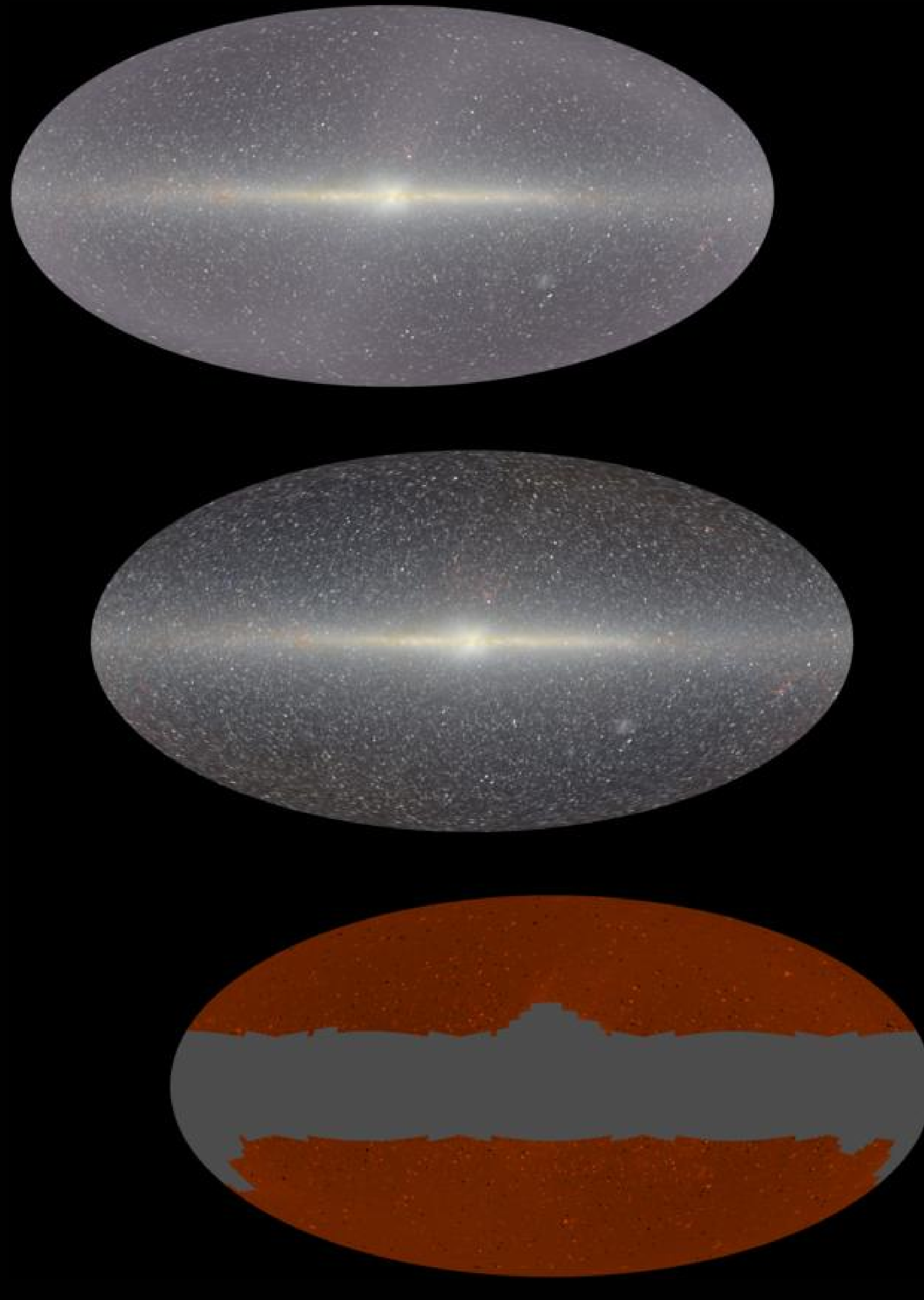


DIRBE-2MASS Residuals at K: σ = 1.83 kJy/sr



DIRBE-2MASS Residuals at L: σ = 1.43 kJy/sr

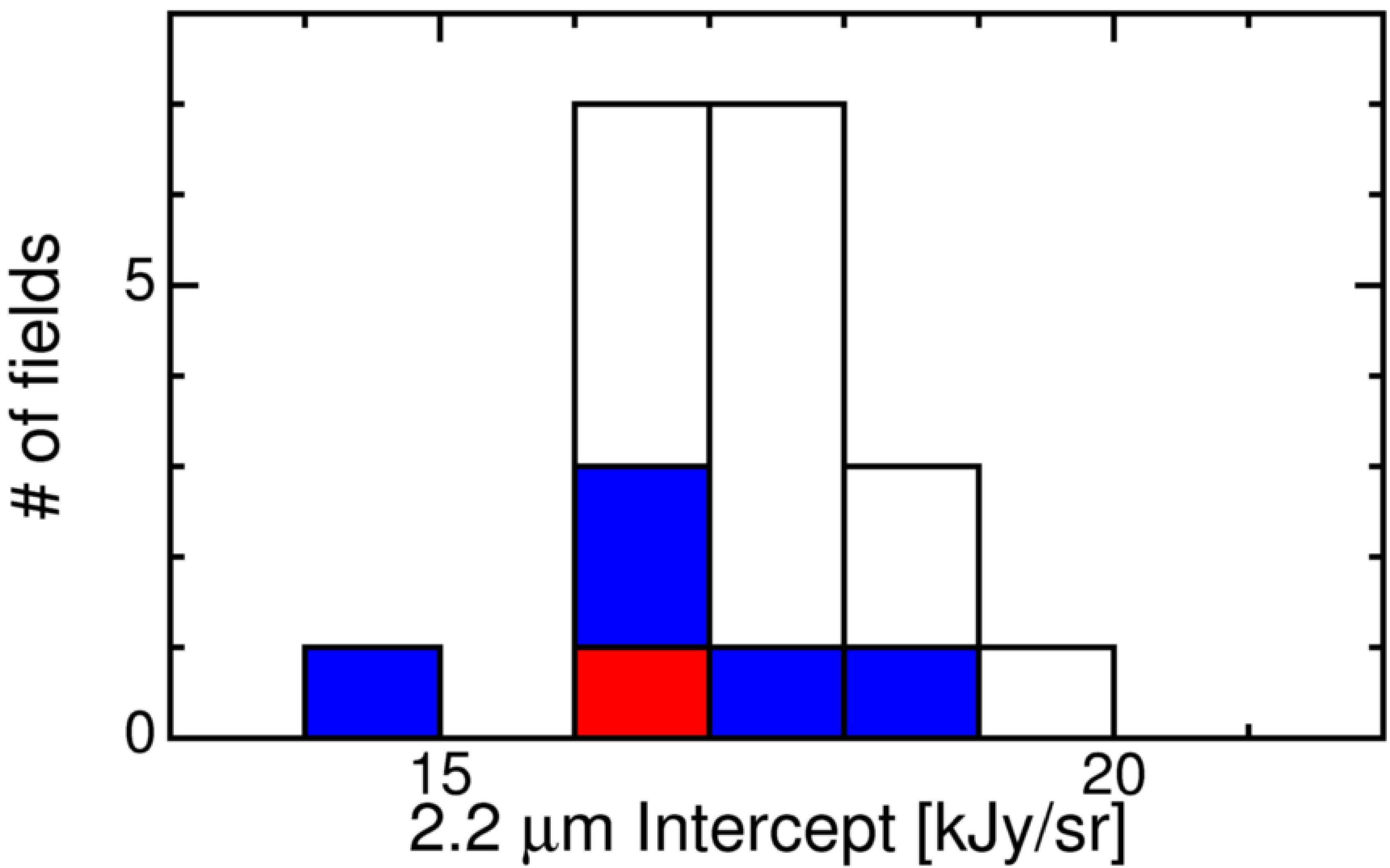




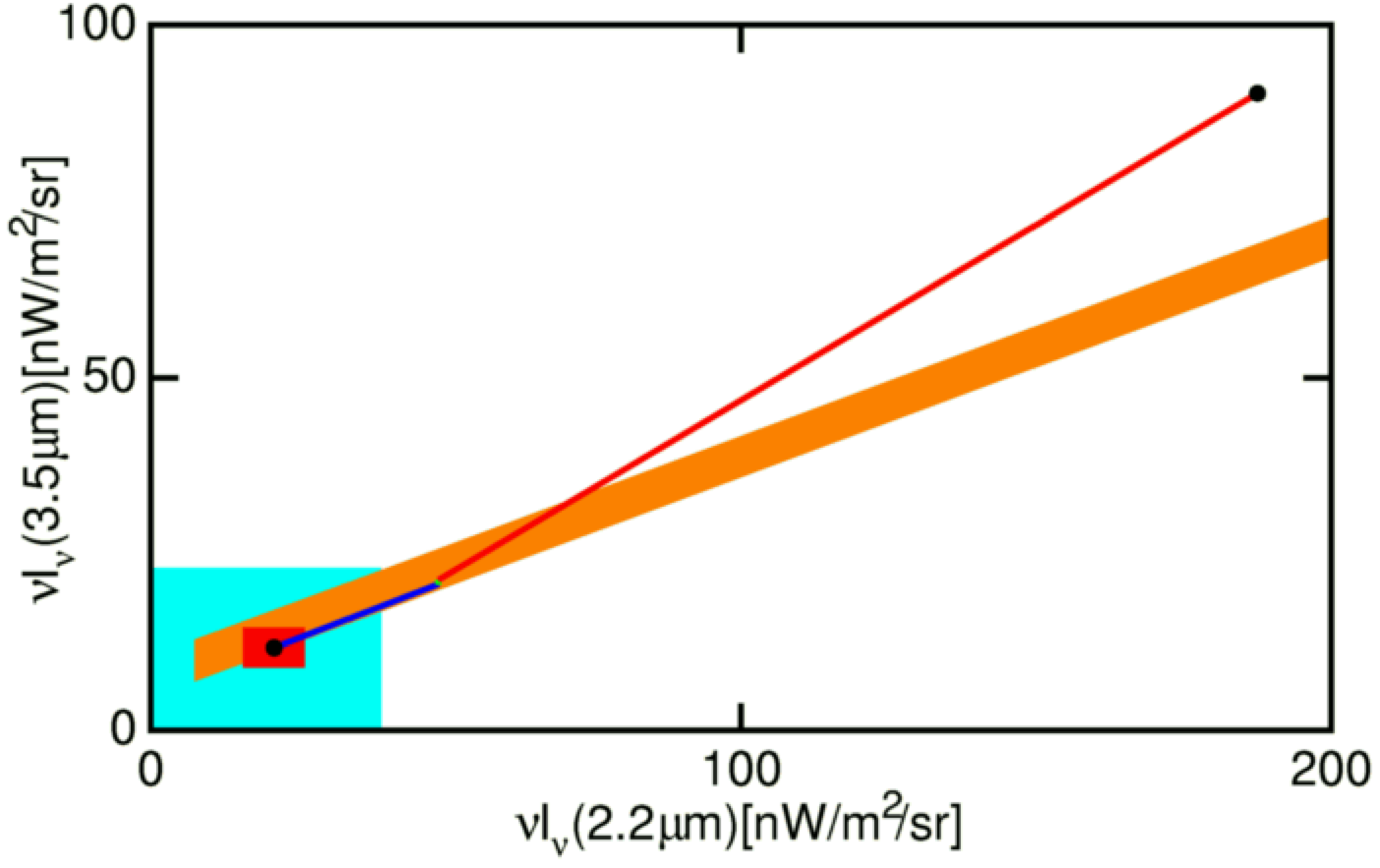
RESULTS

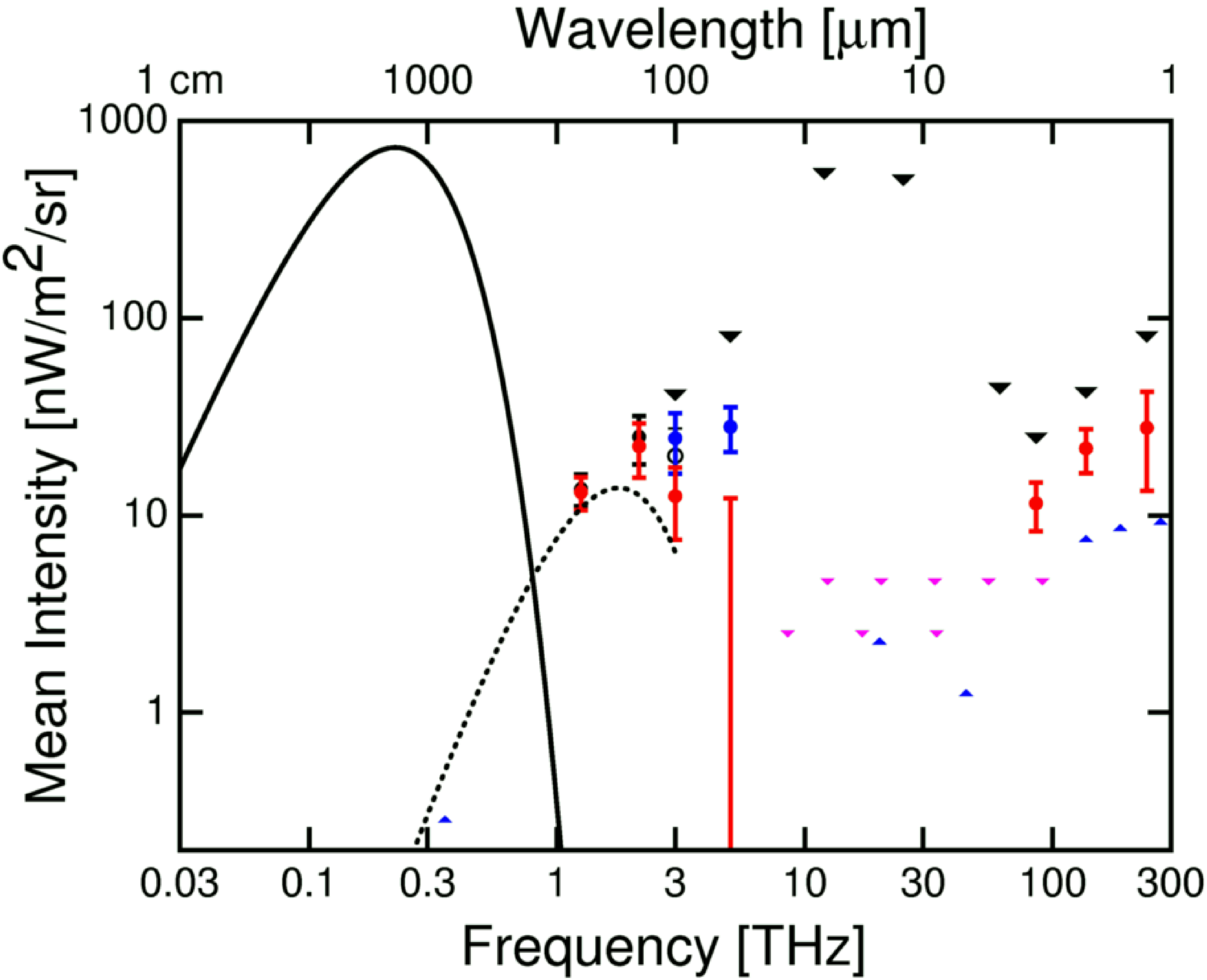
Region	$I_\nu(2.2)$ kJy/sr	$I_\nu(3.5)$ kJy/sr
Dark Spot	16.4 ± 2.3	12.8 ± 1.8
NGP	16.7 ± 0.4	15.0 ± 0.3
SGP	18.9 ± 0.5	17.7 ± 0.3
HQB ($\|b\| > 60°,\ \|\beta\| > 45°$)	16.9 ± 0.9	14.2 ± 0.4
B45 ($\|b\| \approx 45°,\ \|\beta\| > 45°$)	17.3 ± 0.6	13.4 ± 0.4
NEP	14.9 ± 2.0	11.9 ± 1.2
Mean	16.9 ± 0.6	14.2 ± 0.9
Systematic error	± 4.4	± 3.7

2.2 μm CIRB Results



Near IR Decomposition





Wavelength [μm]
1 cm
1000
100
10
1
Mean Intensity [nW/m2/sr]
1000
100
10
1
0.03
0.1
0.3
1
3
10
30
100
300
Frequency [THz]

Discrepancy between Counts & Measurements

- Rebecca Bernstein gets about 2× more optical extragalactic background light than one derives from the sum of the galaxy counts:

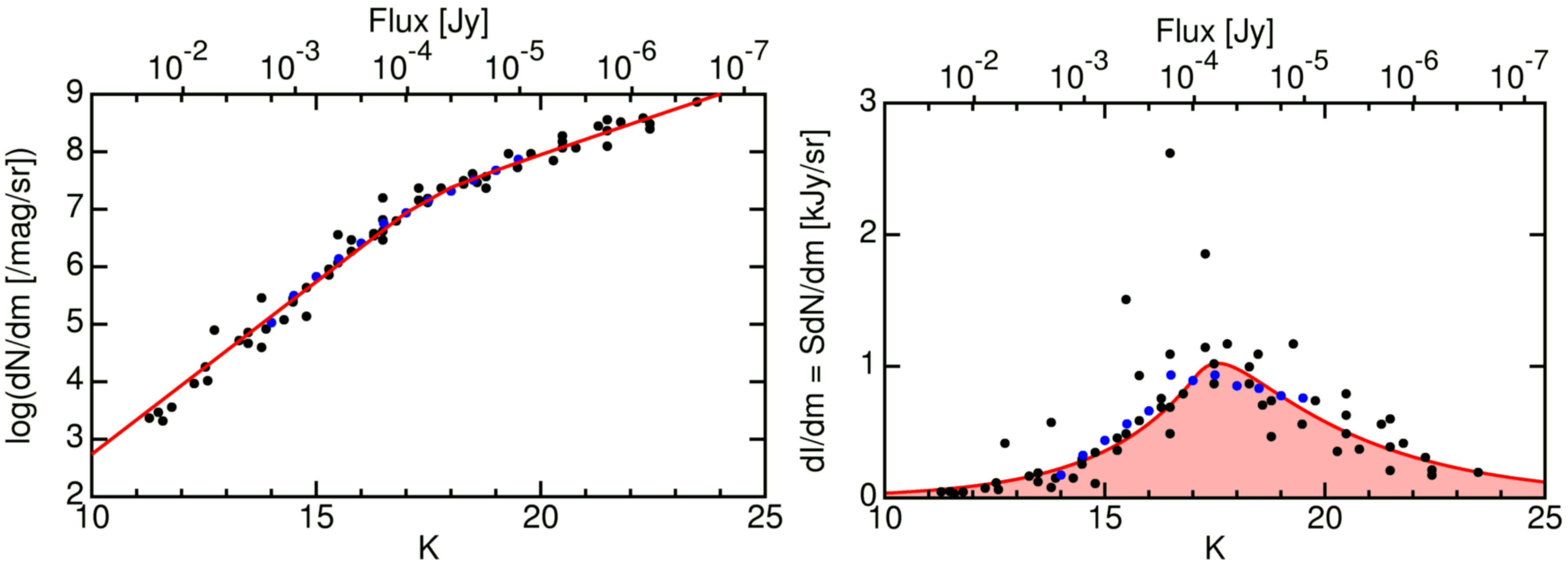
$$I_{counts} = \int S dN = \int S \left| \frac{\partial N}{\partial \ln S} \right| d \ln S$$

$$I_{obs} \approx 2 \times I_{counts}$$

- Wright gets about $(2 \pm 0.5)\times$ more near infrared cosmic background light than is expected from deep K-band counts.

Both measurement involve difficult and uncertain zodiacal light corrections but they use entirely different techniques.

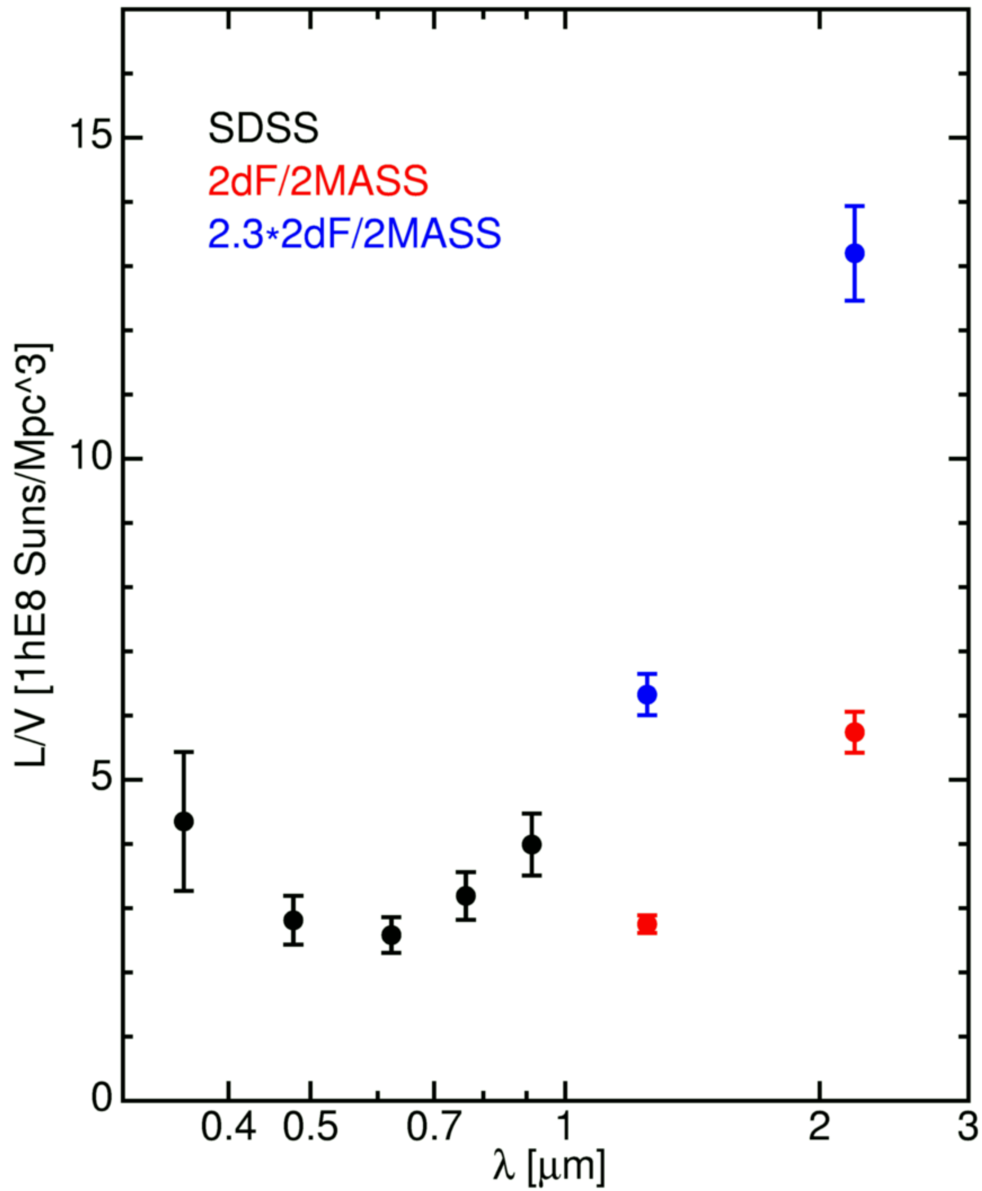
2.2 μm Galaxy Counts



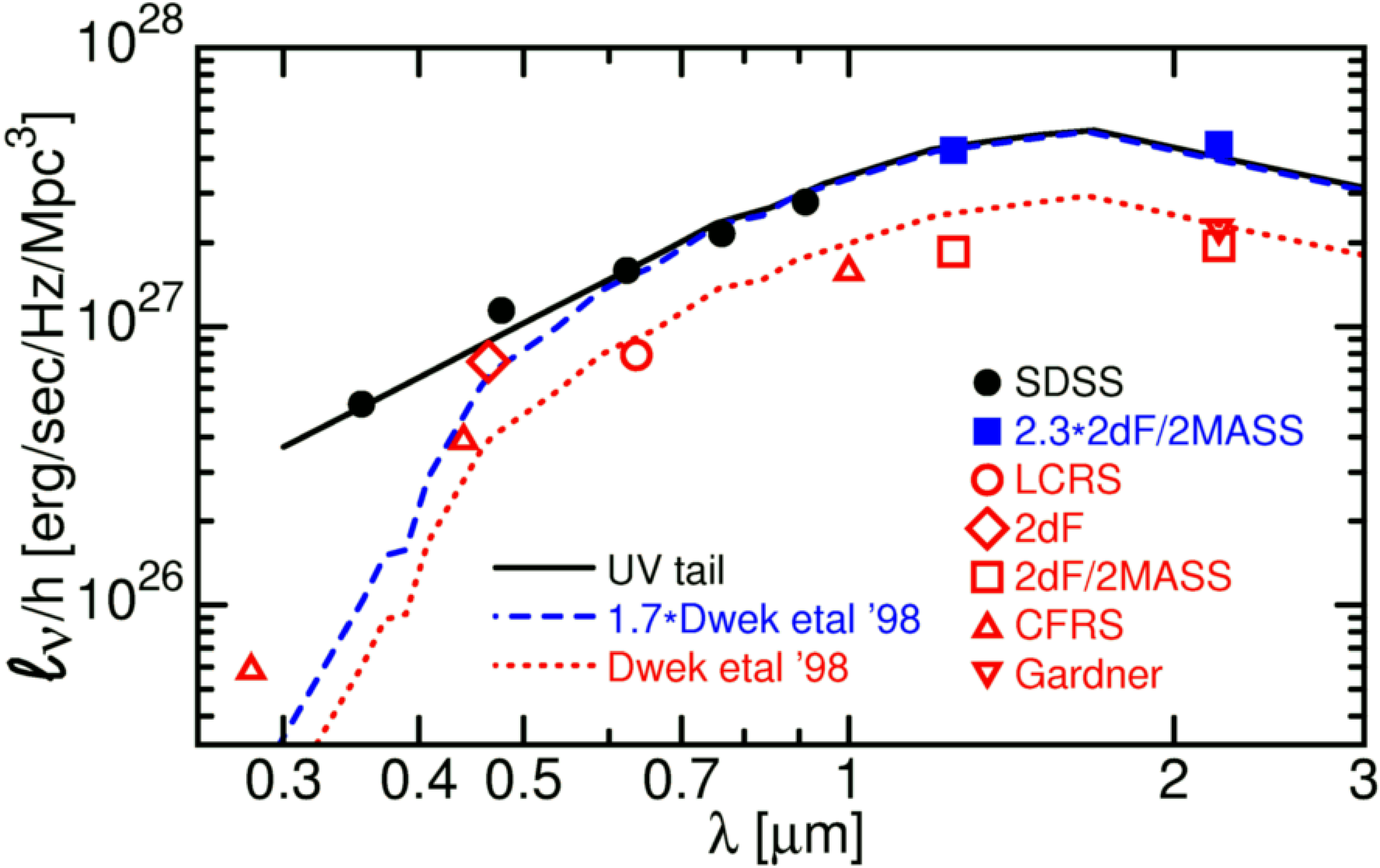
- K counts from Figure 1 of Madau & Pozzetti, MNRAS, 312, L9-L15 (2000)
- CADIS counts from Huang etal astro-ph/0101269
- Integral under fit gives 6.3 kJy/sr or 8.6 nW/m^2/sr

Undercount of Faint, Fuzzy Edges

- SDSS from astro–ph/0012085
- 2dF redshifts with 2MASS photometry from astro–ph/0012429
- Need to multiply IR values by 2 to 2.6 for continuity with SDSS

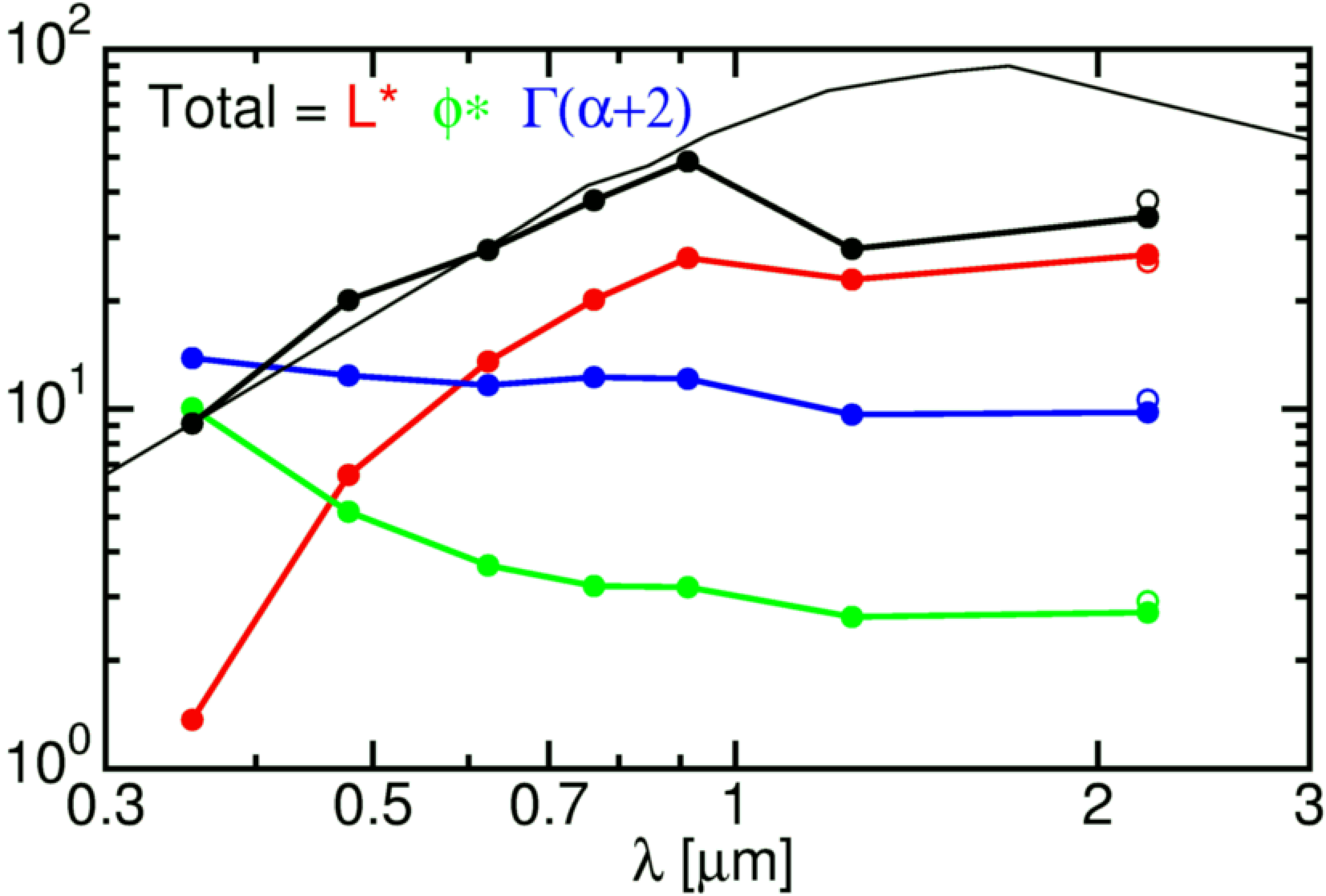


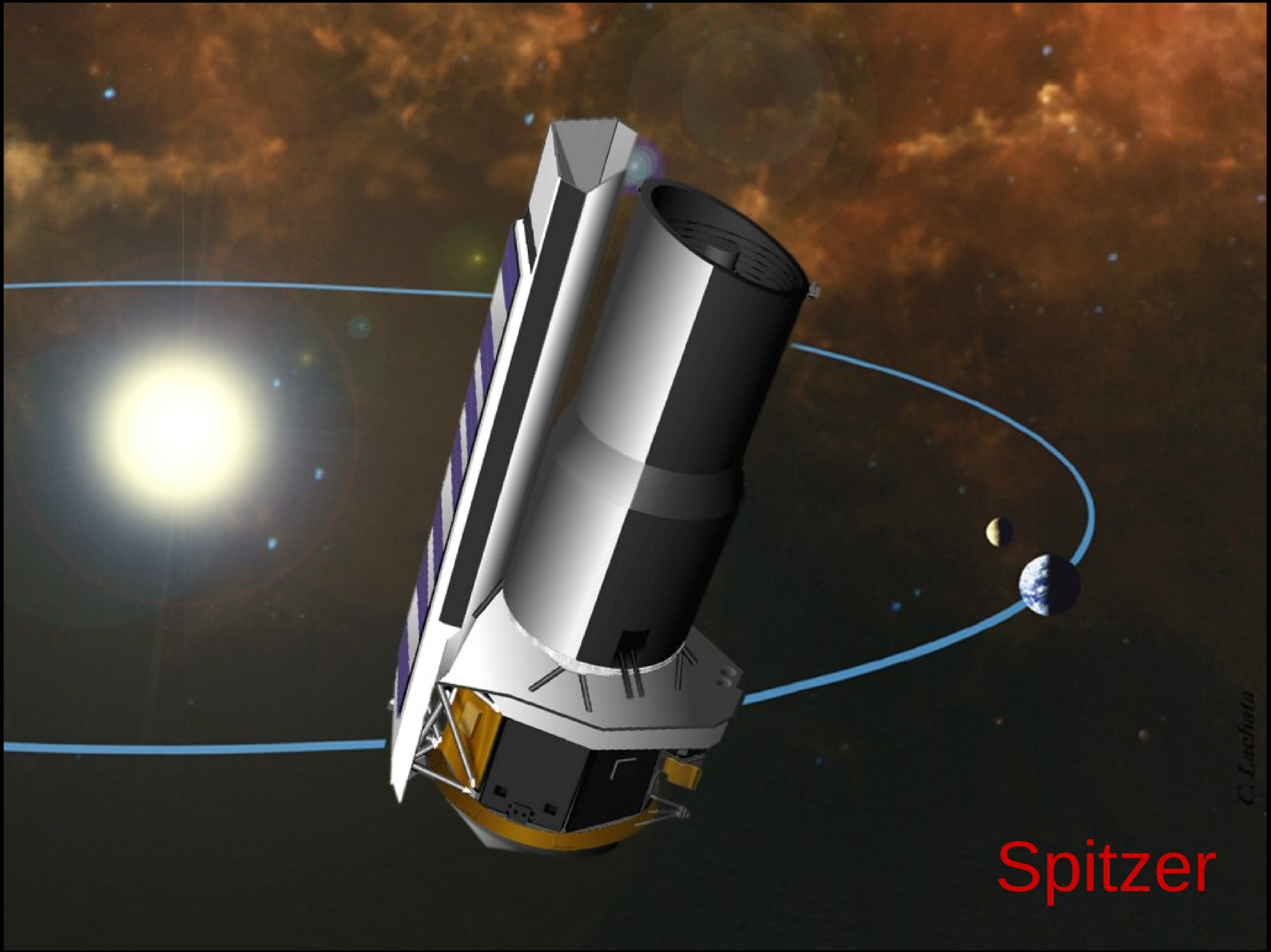
Local Luminosity Density



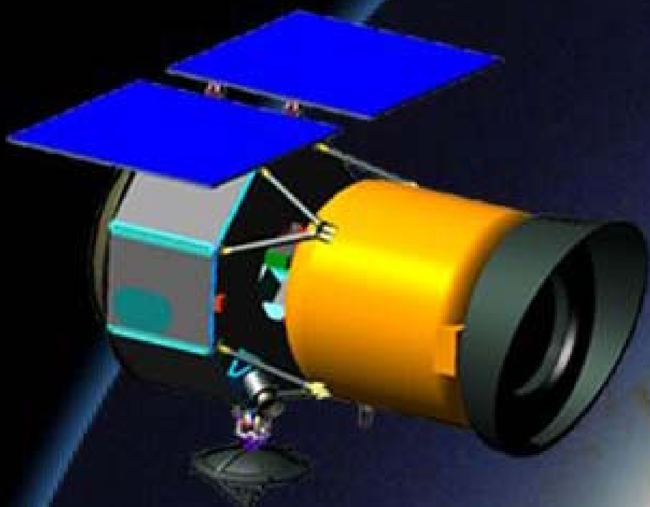
L* causes 55% of jump

$$n(L)dL = (L/L^*)^{\alpha} e^{-L/L^*} dL/L^*$$




Spitzer
C. Lachata

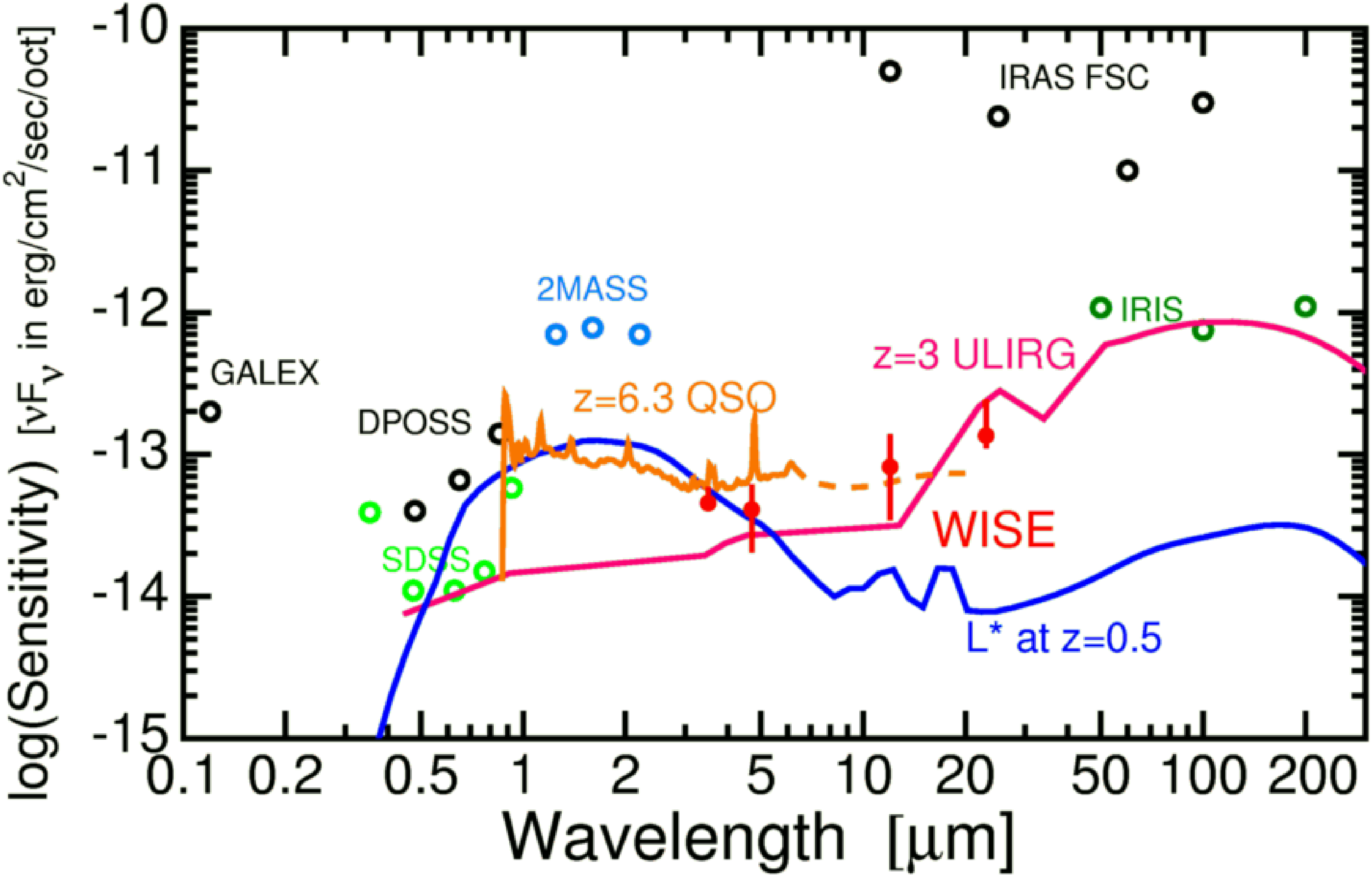
Wide-field Infrared Survey Explorer



I am the PI on a MIDEX proposal for WISE, an all-sky survey in 4 bands from 3 to 24 μm. WISE will find and study the closest stars to the Sun, the most luminous galaxies in the Universe, and also map the large-scale structure out to redshift z=0.7, covering the peak of the galaxy S^2dN/dS.

Now in phase B, WISE will fly in 2009.

WISE and the distant Universe



WISE detects very distant QSOs

γ-Ray Connection

- The reaction $\gamma_1 + \gamma_2 \to e^+ + e^-$ has a threshold of $E_1 E_2 > (m_e c^2)^2$.
- The peak cross-section of 1.7×10^{-25} cm^2 occurs at twice the threshold energy.
- 1 MJy/sr corresponds to a photon density of 0.63 cm^{-3}oct^{-1}.
- Expect absorption of γ-rays over distance of 3 Mpc for 1 MJy/sr, or $450/\lambda[\mu\mathrm{m}]$ Mpc for 20 nW/m^2/sr, at $E \approx 400\lambda[\mu\mathrm{m}]$ GeV.
- Only 3 extragalactic γ-ray sources are observed at $E \gtrsim 300$ GeV with mean distance of 160 Mpc.
- NEED MORE SOURCES!!

Solar Tower Atmospheric Cherenkov Effect Experiment

- Collecting area of 100 m diameter telescope
- Optical Quality: Don’t Ask!

Ablaze in the distance

- Blazar H1426+428 has a flux of 4×10^{-12} erg/cm^2/sec at E > 1 TeV.
- z = 0.129
- 96% absorption at 1 TeV for my CIRB
- This is definitely a caveat to remember!

HESS is going great

Claimed limit on CIRB

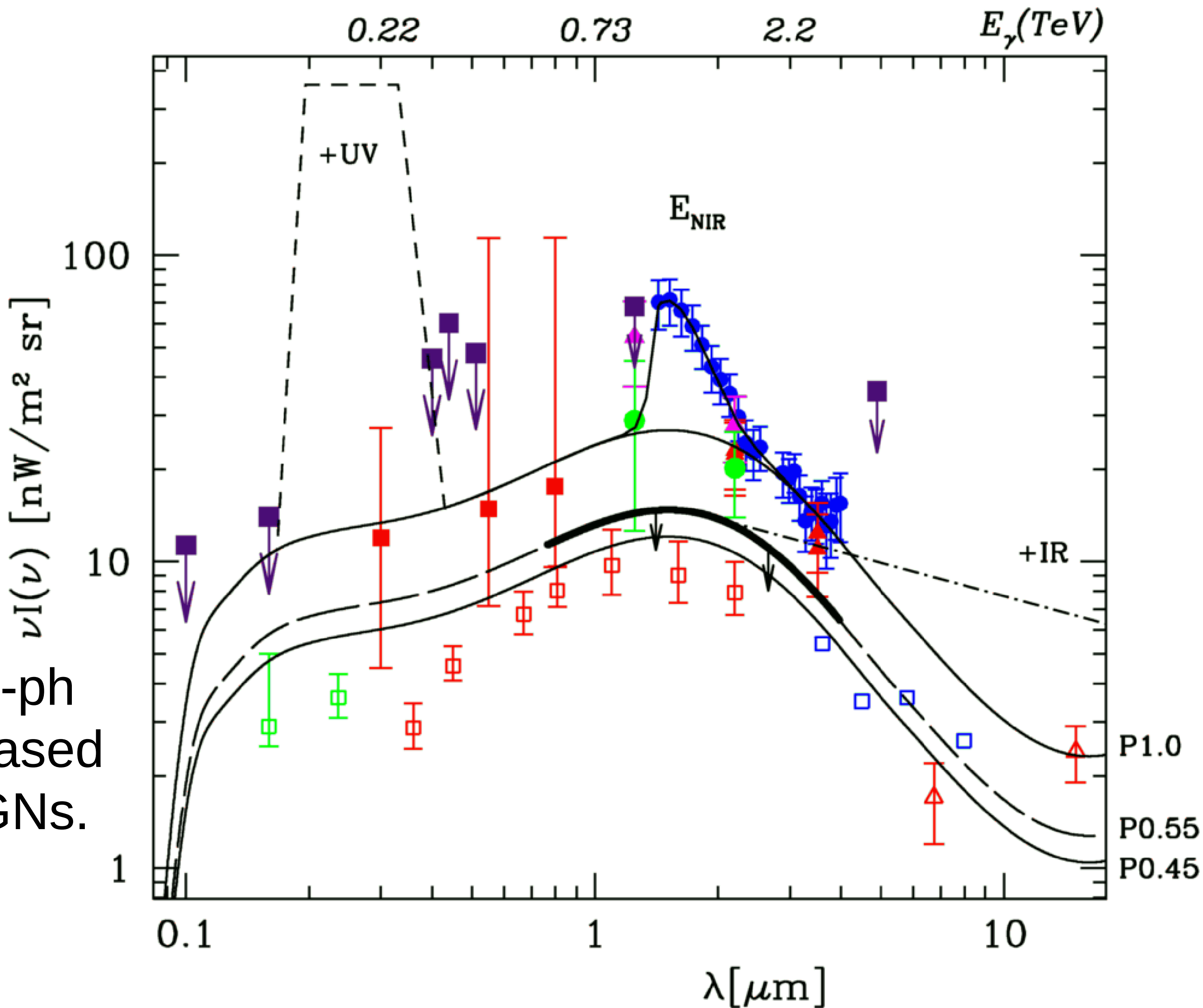
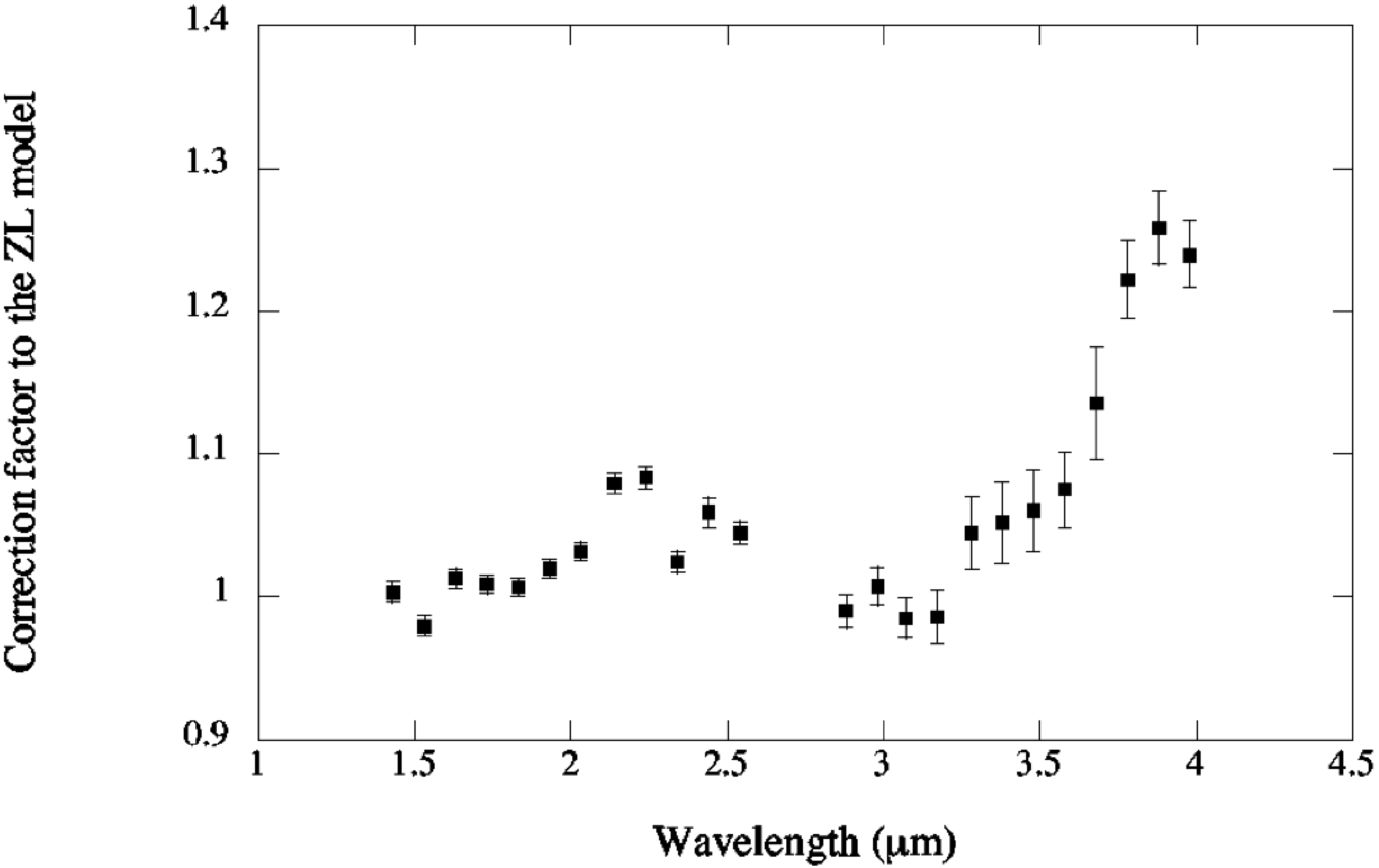


Fig1 of astro-ph 0508073. Based on only 2 AGNs.

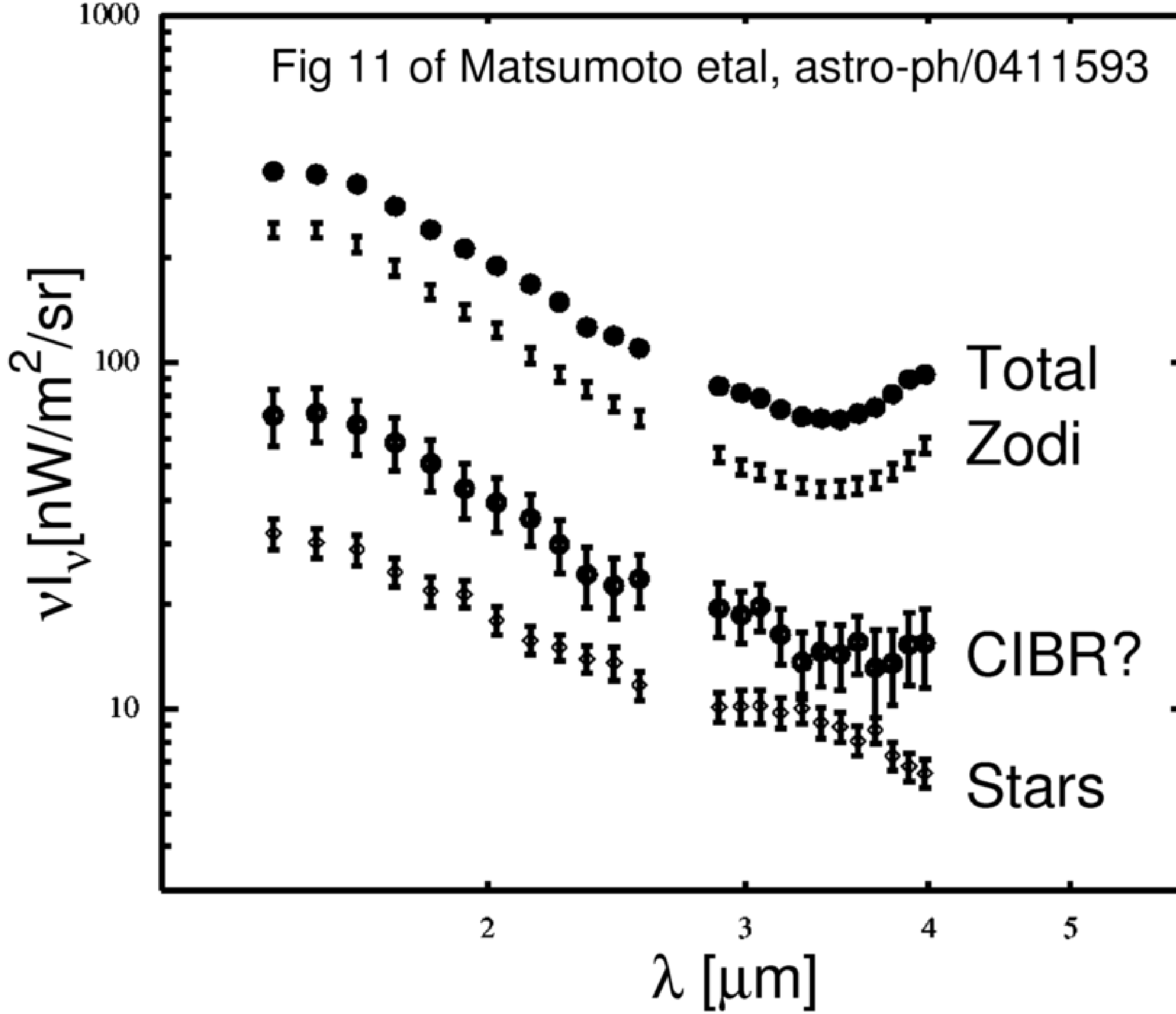
Blue points: Matsumoto etal

- Scanned a line on sky.
- Correlated signal with zodiacal light model.
- Extrapolated to the model zeropoint.
- Scale factor of the correlation often off by 10% or more.

Correlation Slope



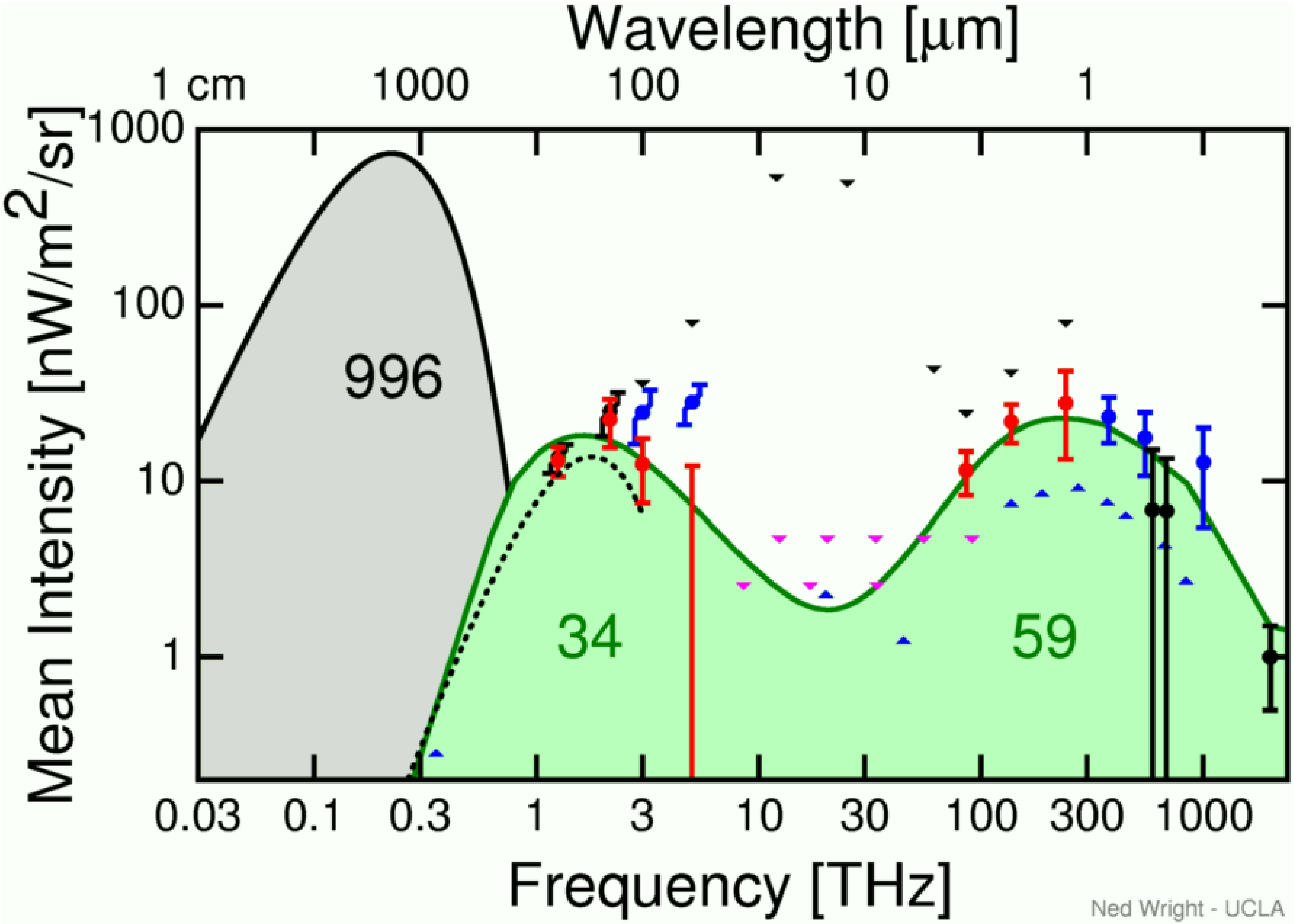
Zodi dominates the total signal



Zodi errors underestimated

- A 7% error in the zodi, as suggested by the 7% change in the correlation scale factor when moving off the DIRBE datum at 2.2 μm, reduces the CIRB by 0.07*260 = 18 nW/m^2/sr.
- This would be a systematic reduction in the rise at 1.5 μm, bringing Matsumoto etal more in line with my values, but these are still higher than the H.E.S.S. limits.

Cosmic Optical & IR Background



Discussion: CIRB

- The CIRB has been detected in both the far IR and the near IR windows through the interplanetary dust, but measurements between 5-60 μm are impossible from 1 AU
- Bolometric OIR background is about 100 nW/m^2/sr
- Ratio of optical plus near IR to the far IR is about 2:1 but γ-ray data says more like 1:1

Discussion: ΔX

- For UVO "Madau" curve, fuel burn over current energy density ratio is f/U_o = 1.9
- Current CIRB bolometric energy density is about 100 $nW/m^2/sr$
- Therefore ΔX = -0.033
- Madau curve with Rowan-Robinson addon at high z burns more fuel at high redshift, so f/U_o = 2.3, ΔX = -0.04
- At 1/3 solar from cluster gas, ΔX = -0.02
- Do we need more baryons [CMB], more AGN, or less CIRB [zodi]?

White Dwarf Helium Reservoir?

- Oppenheimer *et al.* (2001) claim 3% of local halo in old WDs

$$\Delta X = -0.04h \, \frac{f_{WD}}{0.03} \, \frac{M_H}{5 \times 10^{11}} \, \frac{\ell_{\mathrm{ONIR}}}{5.6h \times 10^8} \, \frac{3 \times 10^{10}}{L_{\mathrm{MW}}}$$

- BUT Richer on 2 Apr 2001 withdrew the claimed detection of faint, high proper motion stars in the HDF [astro-ph/9908270]
- The Oppenheimer *et al.* objects do not have a halo velocity distribution, and can not be part of a spherical halo.

CONCLUSION

- CIRB is 7-10% of CMB energy density.
- Zodiacal dust (interplanetary dust) is the major foreground source, and uncertainties in modeling it are the major uncertainty in the near-IR background.
- HESS, STACEE, MAGIC and VERITAS are measuring the interplanetary dust cloud by observing Active Galactic Nuclei in γ-rays.

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- DIRBE: http://www.astro.ucla.edu/∼wright/DIRBE/
- SIRTF: http://sirtf.caltech.edu/
- http://xxx.lanl.gov/abs/astro-ph/9909428 (Dark Spot)
- http://xxx.lanl.gov/abs/astro-ph/9912523 (Histogram)
- http://xxx.lanl.gov/abs/astro-ph/0004192 (2MASS)