Planck 2013 results. XIV. Zodiacal emission

ArXiv/1303.5074

Planck Collaboration

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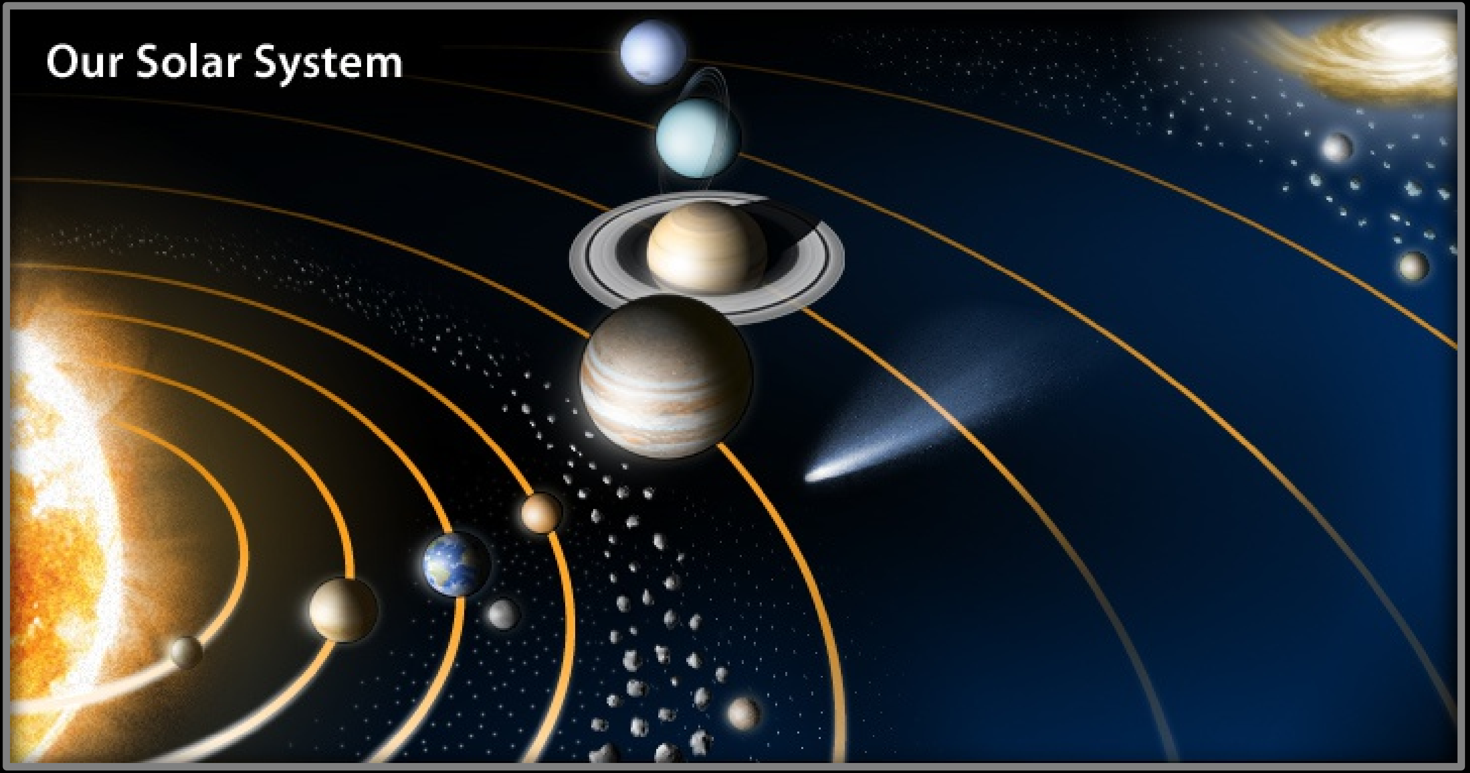
Our Solar System

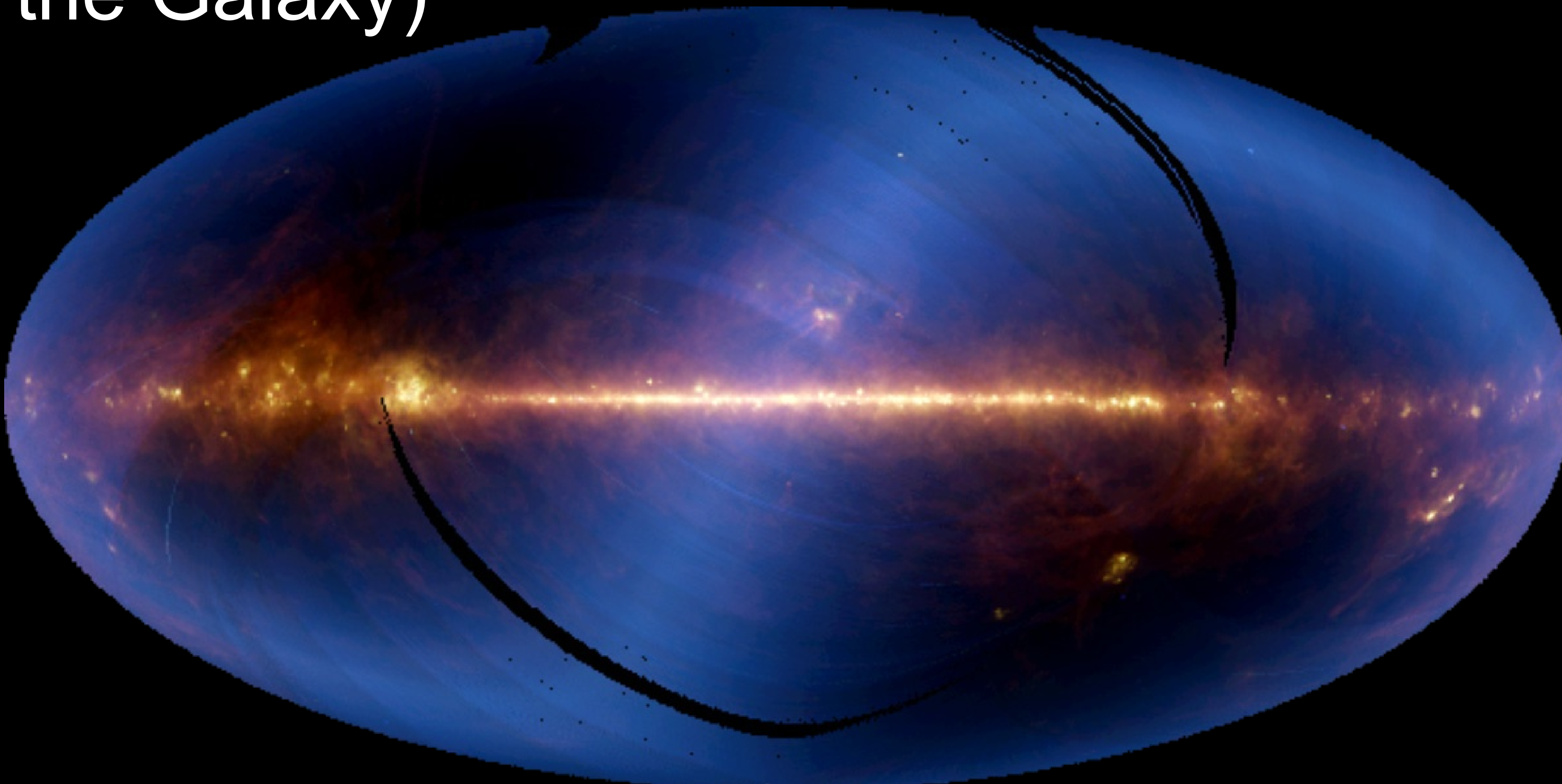


http://solarsystem.nasa.gov/planets/index.cfm

- There is Interplanetary Dust (IPD) in our Solar System, concentrated within the orbit of Jupiter.
- This IPD makes Zodiacal Light Emission (ZLE), to which Planck is sensitive

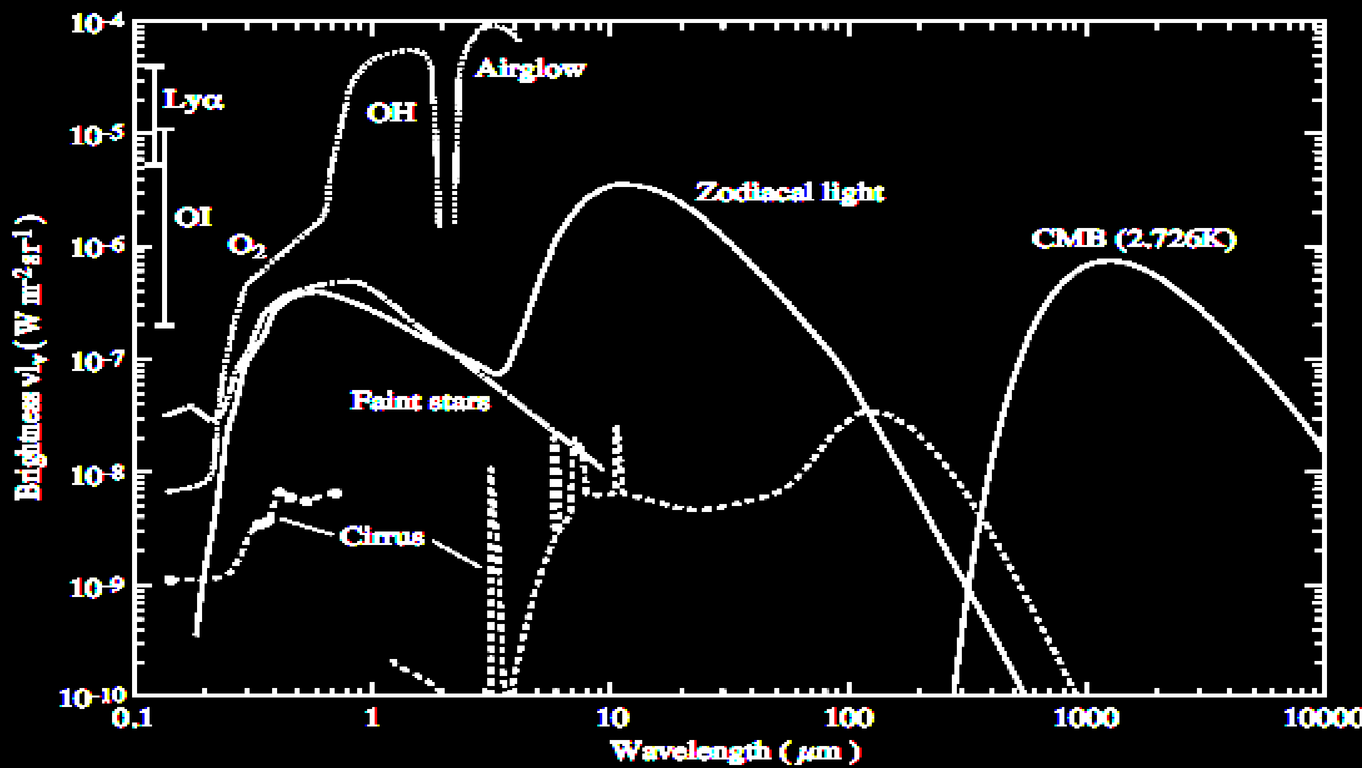
Zodiacal emission

...measured by IRAS (it's the white 'S', not the Galaxy)



http://coolcosmos.ipac.caltech.edu/image_galleries/IRAS/allsky.html

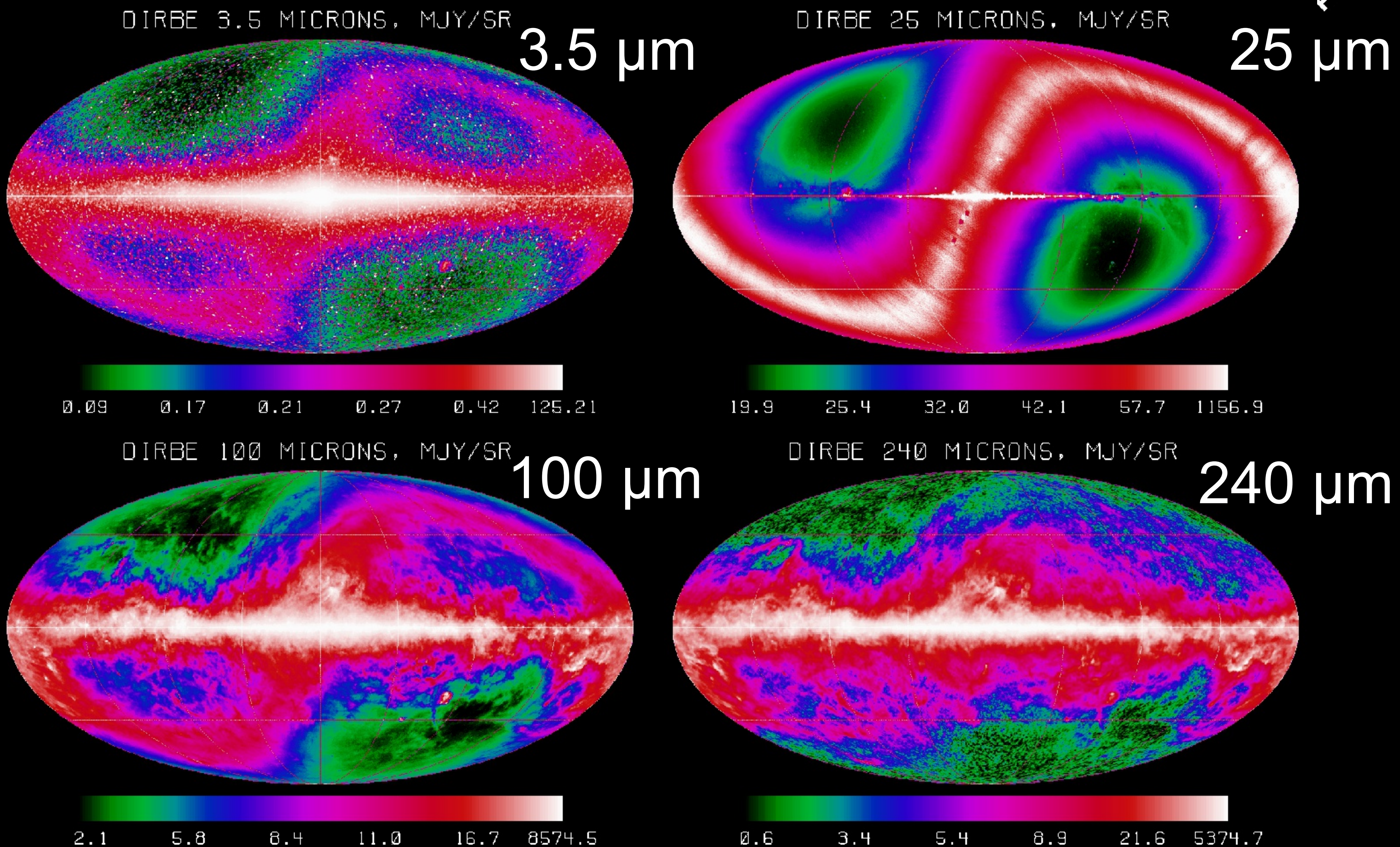
Comparison to other emissions



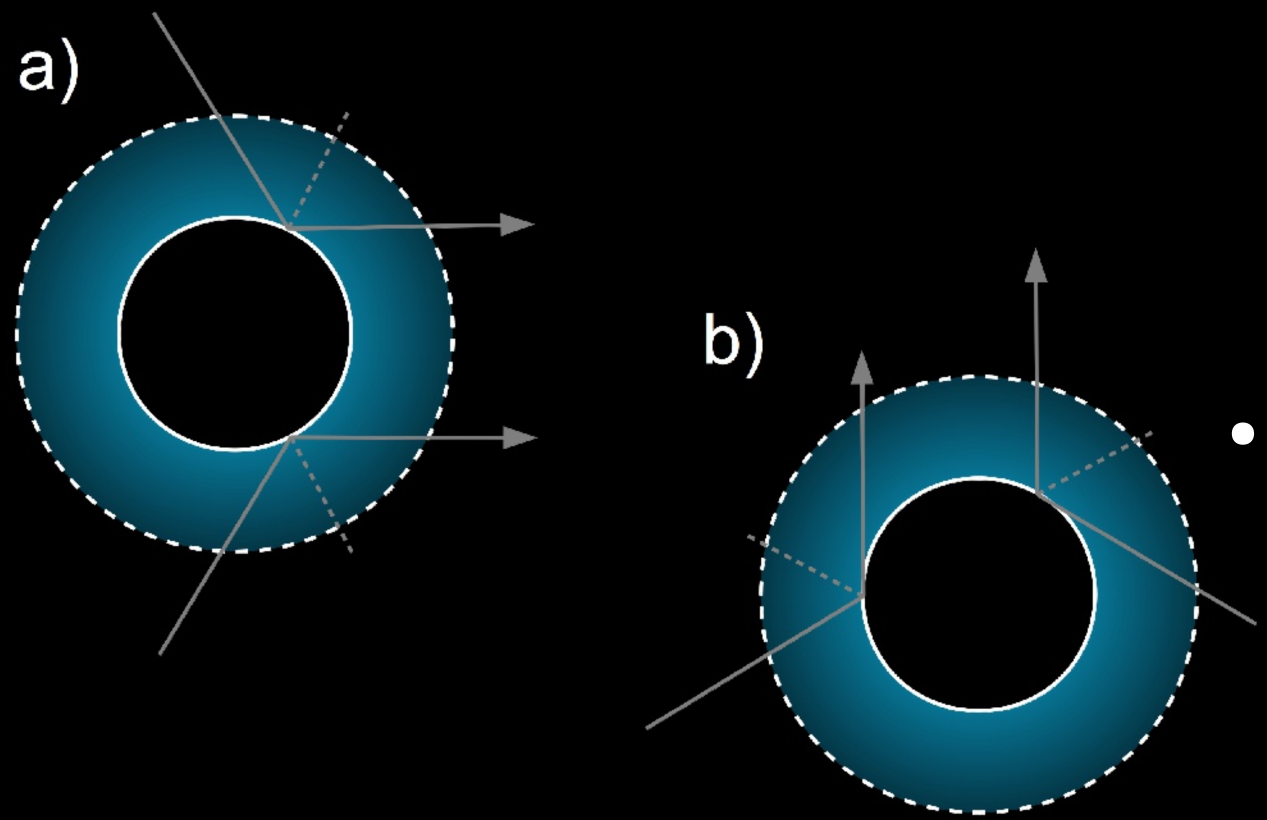
Zodiacal emission Dominates the sky brightness in the ~10 micron range

Fig. 1. Overview on the brightness of the sky outside the lower terrestrial atmosphere and at high ecliptic and galactic latitudes. The zodiacal emission and scattering as well as the integrated light of stars are given for the South Ecliptic Pole ($l = 276°$, $b = -30°$). The bright magnitude cut-off for the stellar component is $V = 6.0$ mag for $0.3 - 1$ μm. In the infrared, stars brighter than 15 Jy between 1.25 and 4.85 μm and brighter than 85 Jy at 12 μm are excluded. No cut-off was applied to the UV data, $\lambda \leq 0.3$ μm. The interstellar cirrus component is normalized for a column density of 10^{20} H-atoms cm^{-2} corresponding to a visual extinction of 0.053 mag. This is close to the values at the darkest patches in the sky. Source for the long-wavelength data, $\lambda \geq 1.25$ μm, are COBE DIRBE and FIRAS measurements as presented by Désert et al. (1996). The IR cirrus spectrum is according to the model of Désert et al. (1990) fitted to IRAS photometry. The short-wavelength data, $\lambda \leq 1.0$ μm, are from the following sources: zodiacal light: Leinert & Grün (1990); integrated starlight: $\lambda \leq 0.3$ μm, Gondhalekar (1990), $\lambda \geq 0.3$ μm, Mattila (1980); cirrus: $\lambda = 0.15$ μm, Haikala et al. (1995), $\lambda = 0.35 - 0.75$ μm, Mattila & Schnur (1990), Mattila (1979). The geocoronal Lyman α(121.6 nm) and the OI(130.4, 135.6 nm) line intensities were as measured with the Faint Object Camera of the Hubble Space Telescope at a height of 610 km (Caulet et al. 1994). The various references for the airglow emission can be found in Sect. 6

DIRBE


DIRBE 3.5 MICRONS, MJY/SR
3.5 µm
0.09 0.17 0.21 0.27 0.42 125.21
DIRBE 25 MICRONS, MJY/SR
25 µm
19.9 25.4 32.0 42.1 57.7 1156.9
DIRBE 100 MICRONS, MJY/SR
100 µm
2.1 5.8 8.4 11.0 16.7 8574.5
DIRBE 240 MICRONS, MJY/SR
240 µm
0.6 3.4 5.4 8.9 21.6 5374.7

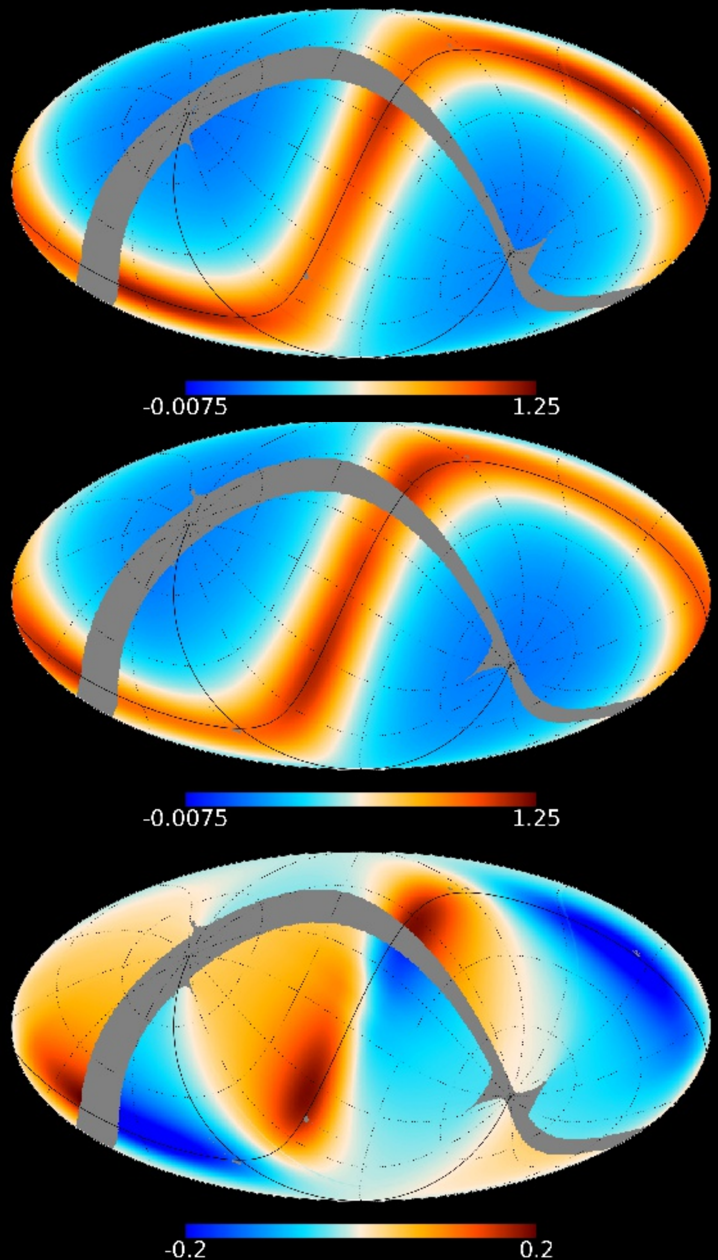
How we do it



- In successive surveys we observe similar, but different total columns of interplanetary (local) dust (IPD)
- Making differences of successive surveys allows us to remove “contamination”, but still be sensitive to the IPD

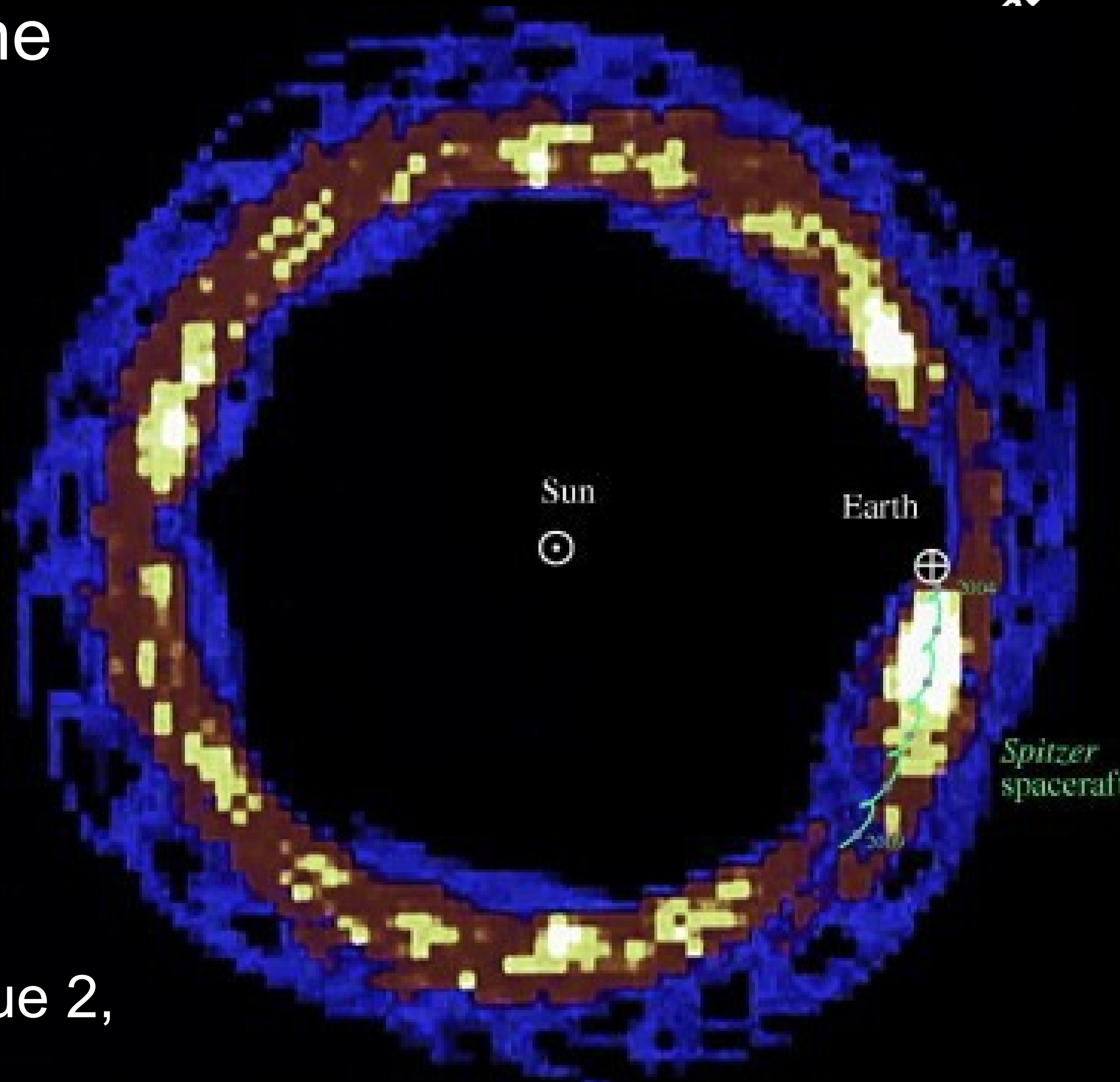
The Diffuse Cloud

- This is what we usually think about when we talk about the IDP
- It varies with our “cycloid” scanning strategy
- The difference is about what we will use to detect it.
- Top: Survey 1;
  Middle: Survey 2;
  Bottom: Survey Difference
  (Survey 2 minus Survey 1)



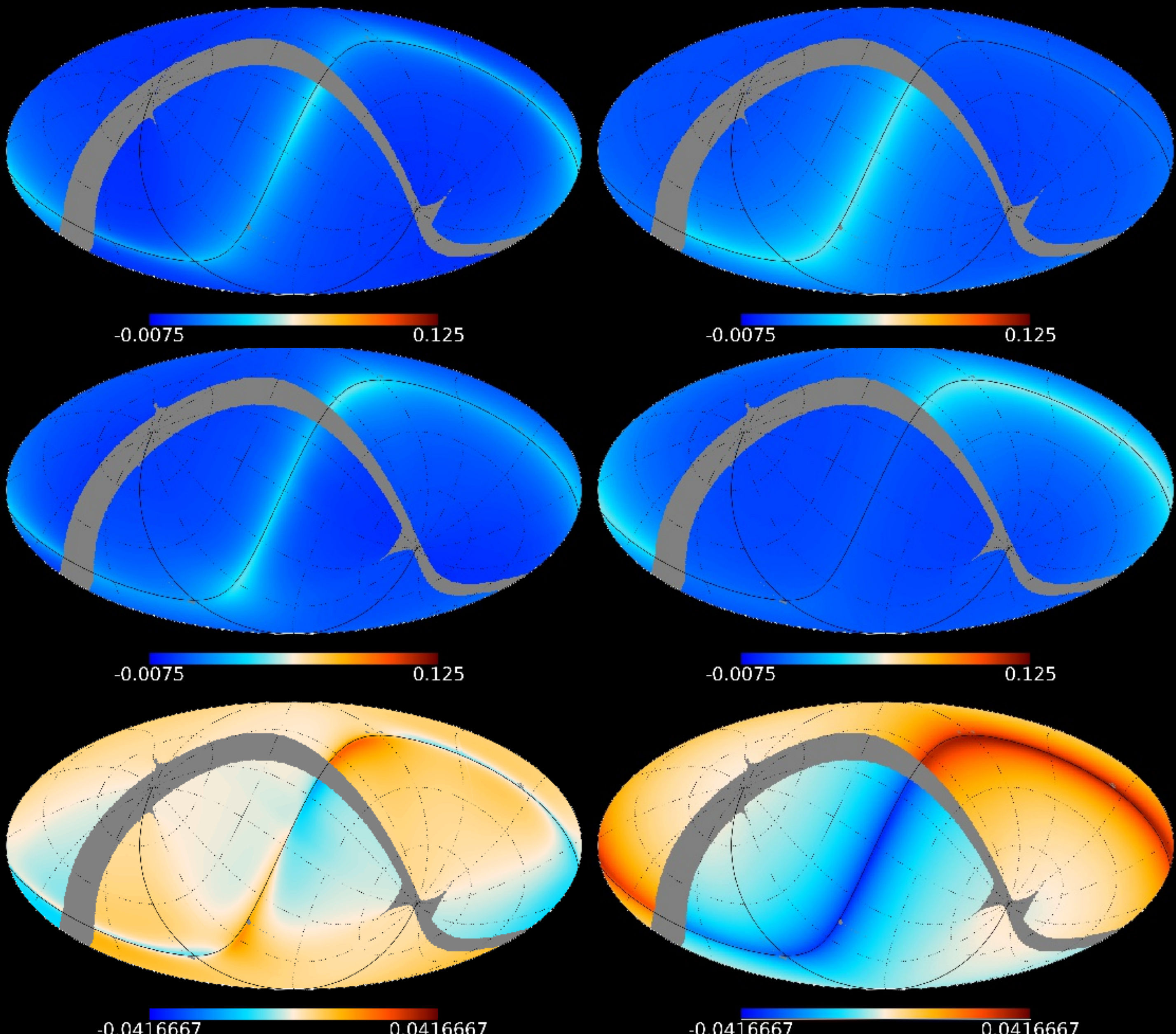
Circumsolar Ring (and Blob)

- A ring of dust in the Earth's orbit
- There is also a “Trailing Feature” behind the Earth



William T. Reach
Structure of the Earth’s circumsolar dust ring,
Icarus, Volume 209, Issue 2, October 2010, 848–850

Circumsolar Ring and Trail Fea.



- Top: Survey 1
- Mid: Survey 2
- Bottom: Survey Difference
- Left: Circumsolar Ring
- Right: Earth-Trailing Feature

Zodiacal Bands

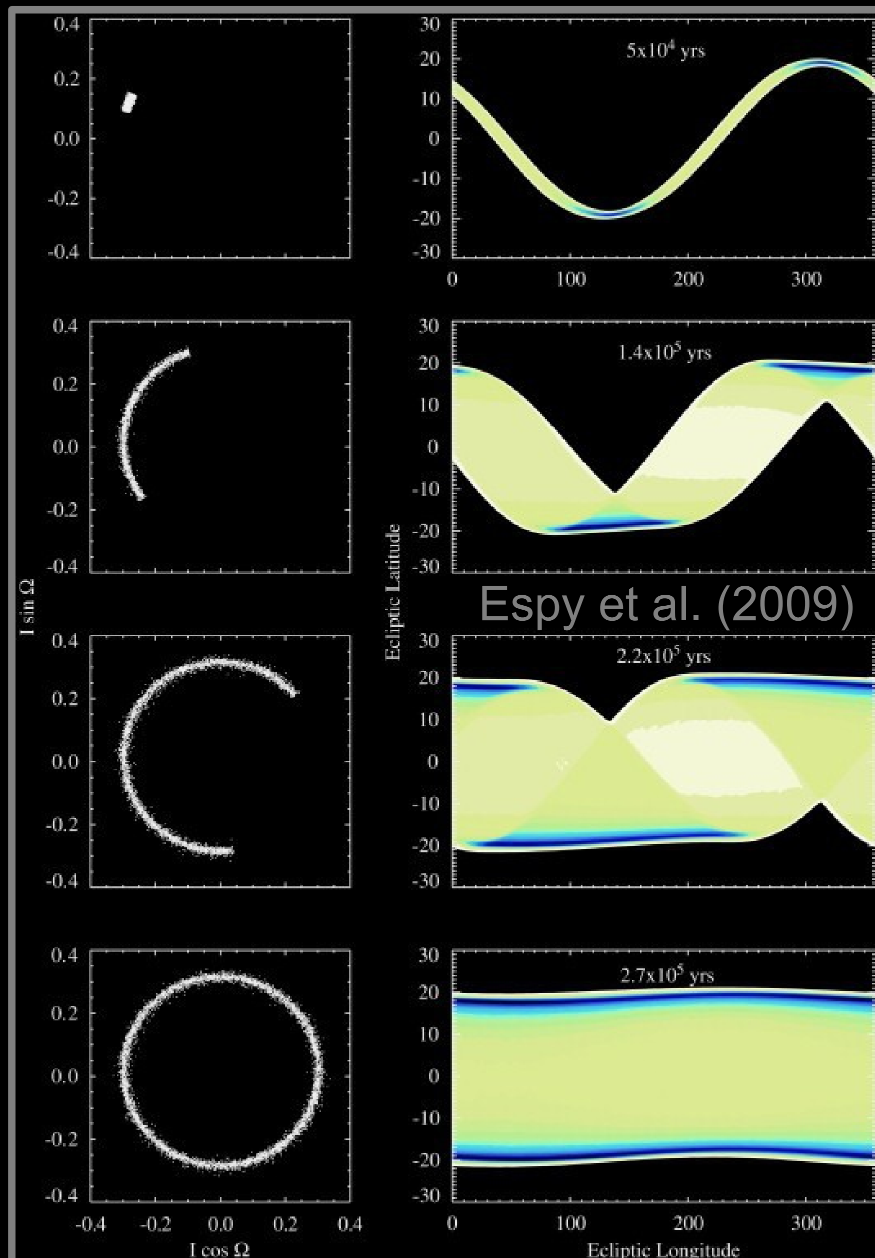
Artist's Impression (Don Davis)

- Asteroid collisions create dust
- Different velocities causes the debris to spread into a ring
- Perturbations from Jupiter cause the ring to spread out into a cylinder
- We see the "rims" of the cylinder more than the "center"

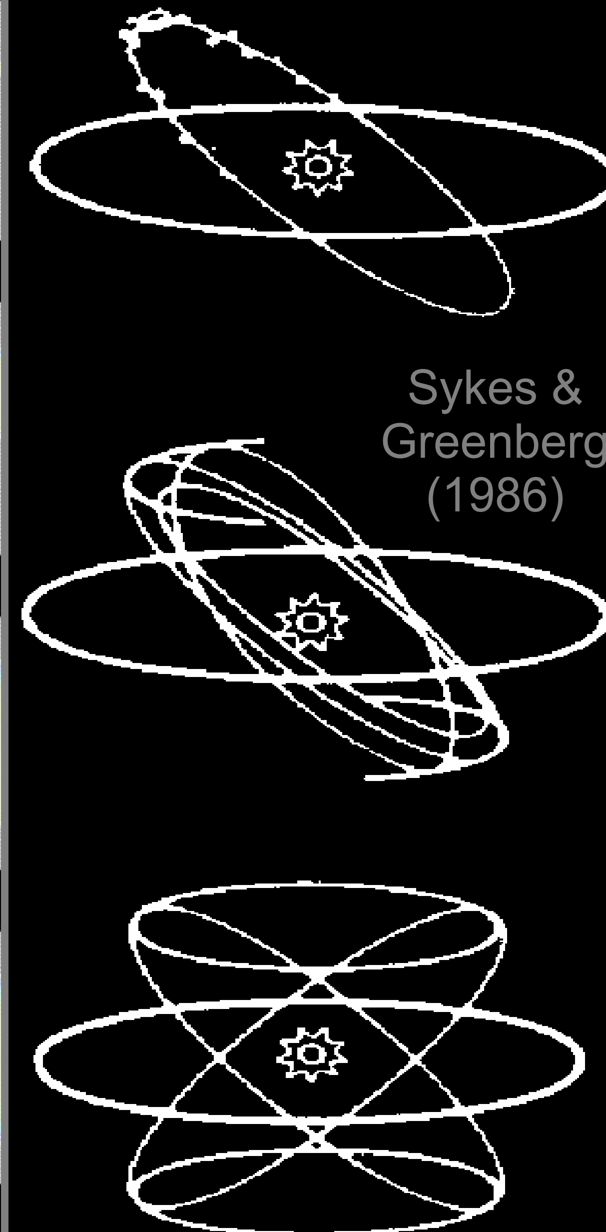
http://news.sciencemag.org/sciencenow/2011/09/was-the-dinosaur-killer-unfairly.html

What is a Zodiacal Band?

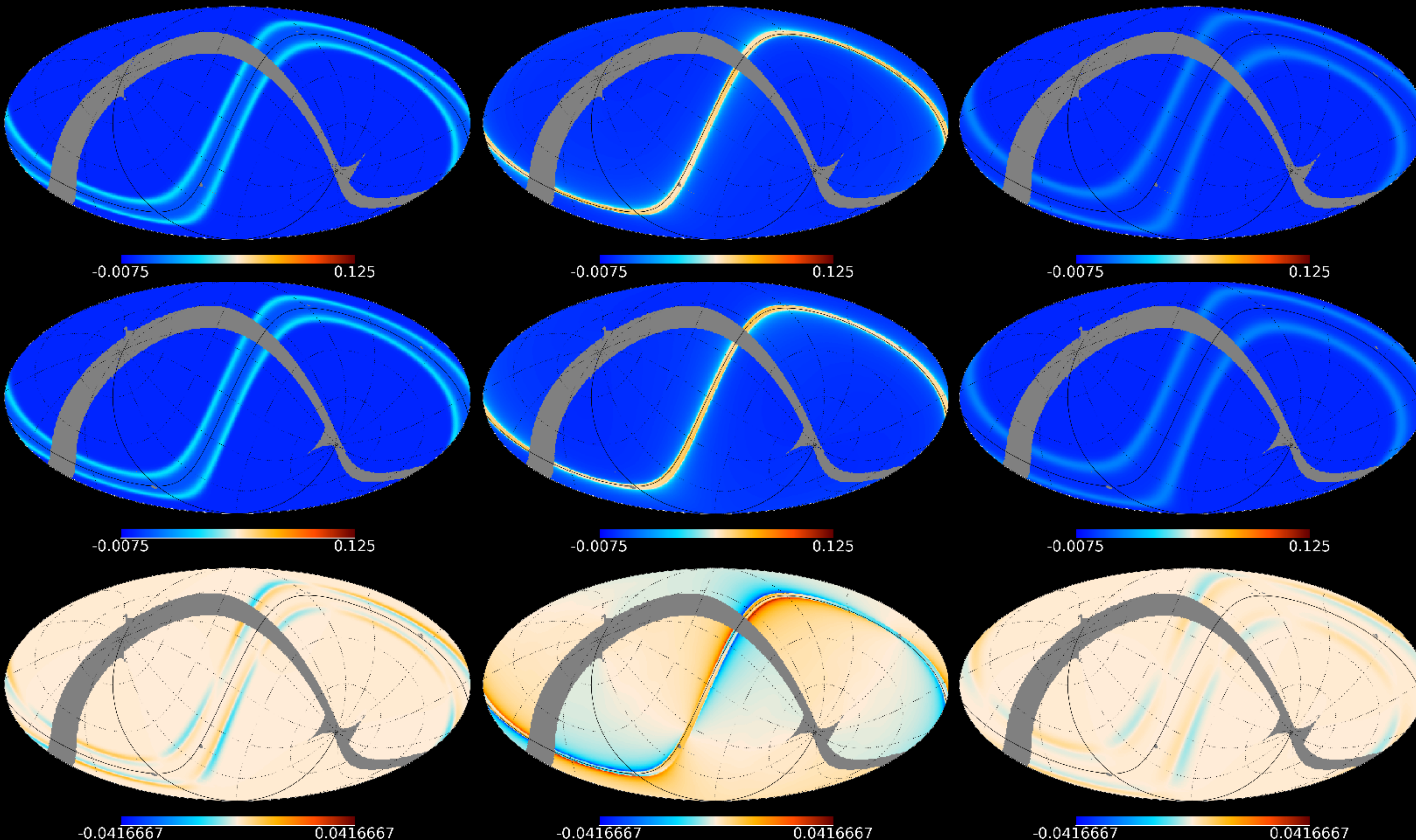
- An asteroid impacts another
- A ring is formed
- Jupiter perturbs the orbits to make a cylinter
- We see the "rim"



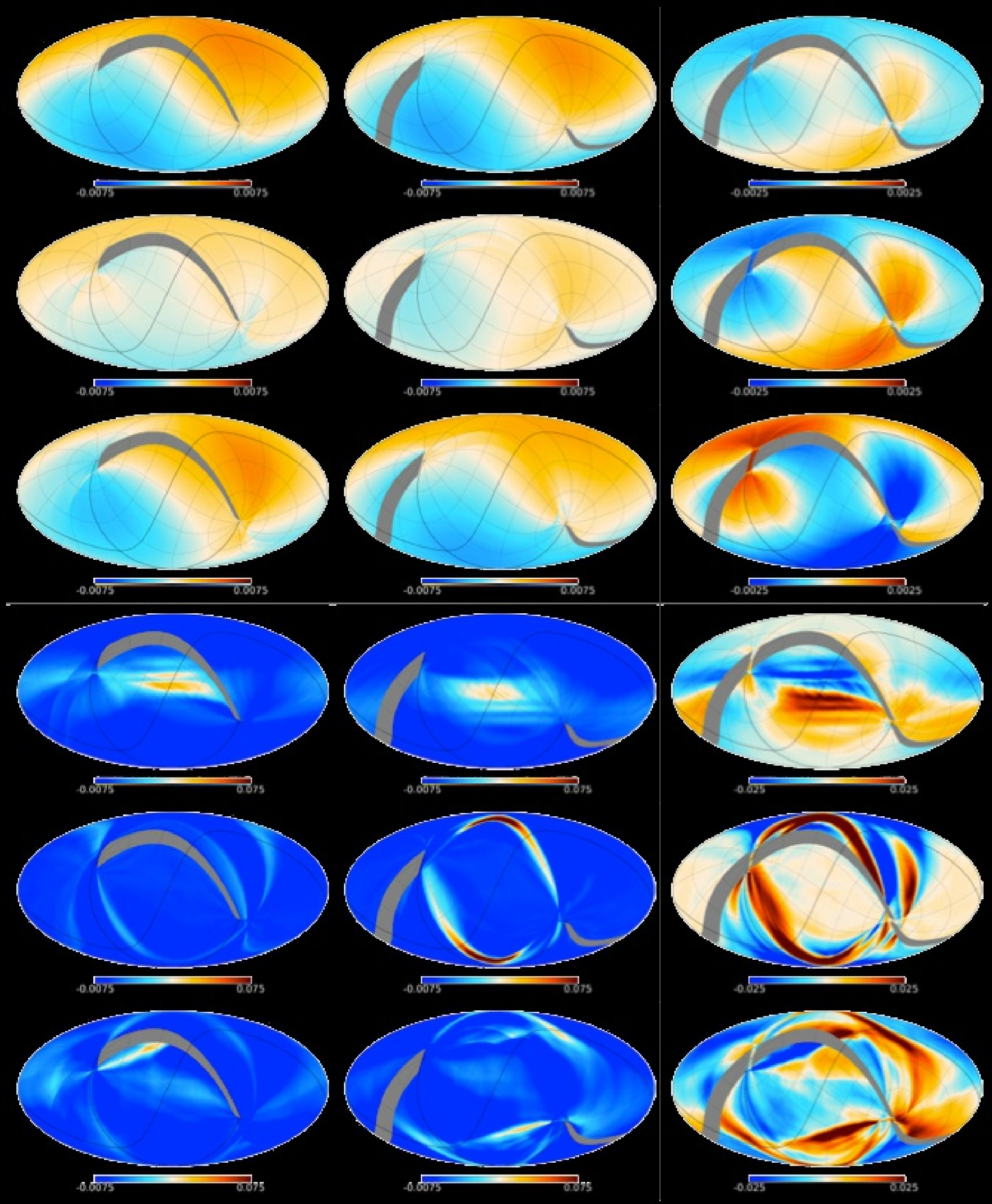
Espy et al. (2009)


Sykes & Greenberg (1986)

IRAS Dust Bands in Planck

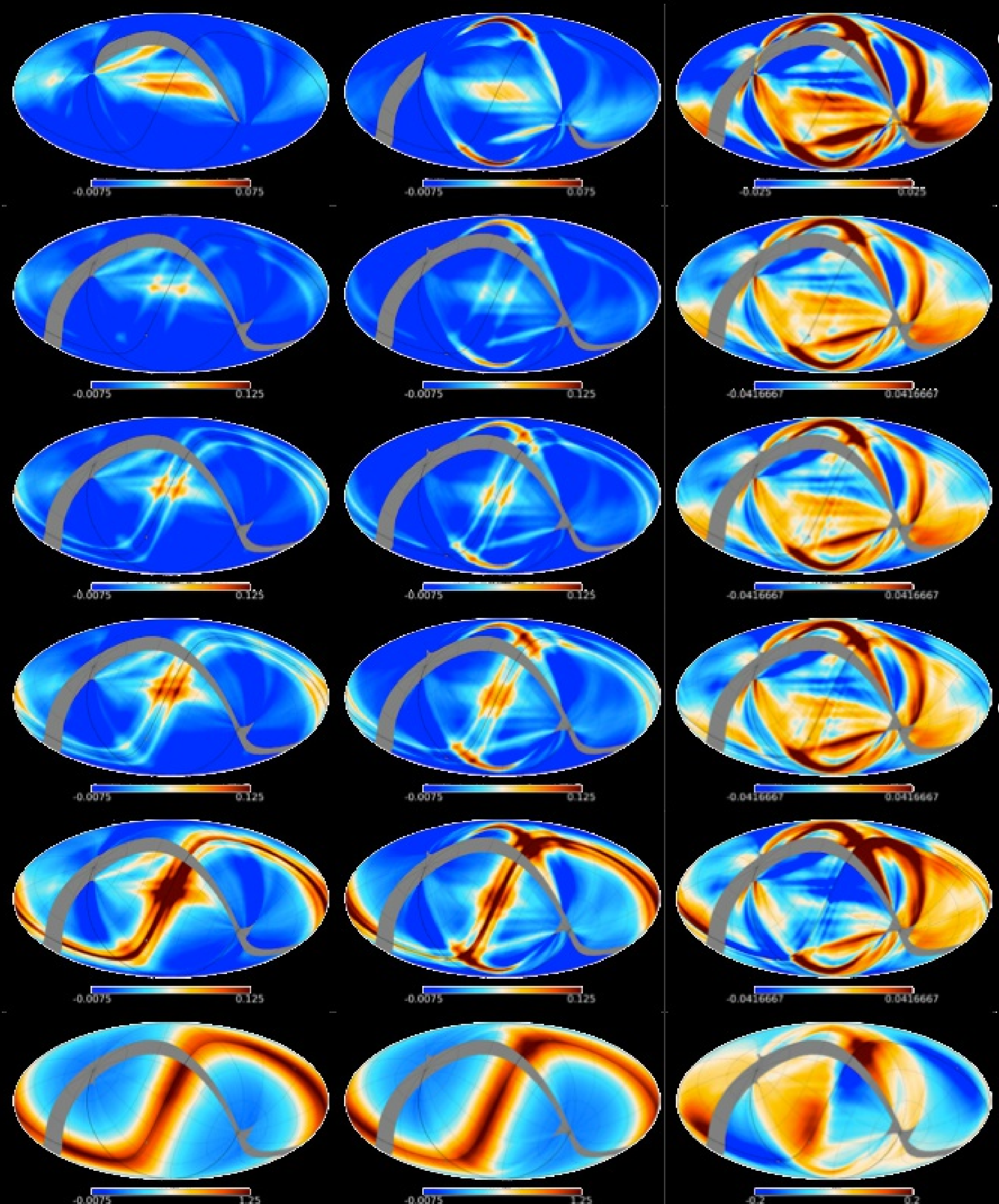


Far sidelobe templates



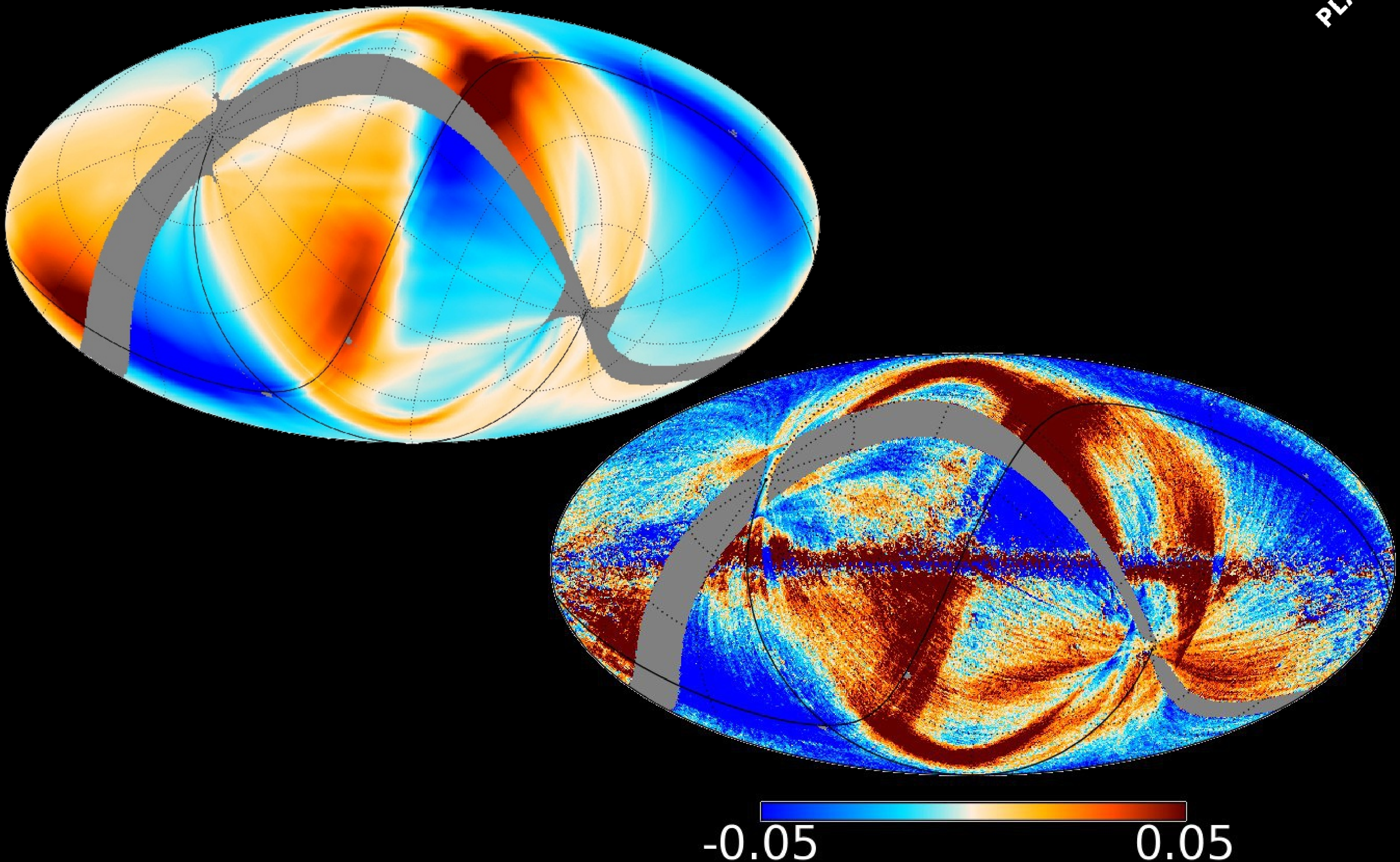
- 1: Dipole SR/Direct
  2: Dipole PR
  3: Dipole SR/Baffle
  4: Galaxy SR/Direct
  5: Galaxy PR (Banana)
  6: Galaxy SR/Baffle
- Left: Survey 1
  Middle: Survey 2
  Right: Survey 2 minus Survey 1
- We cannot detect the dipole through the FSLs

Orders of magnitude

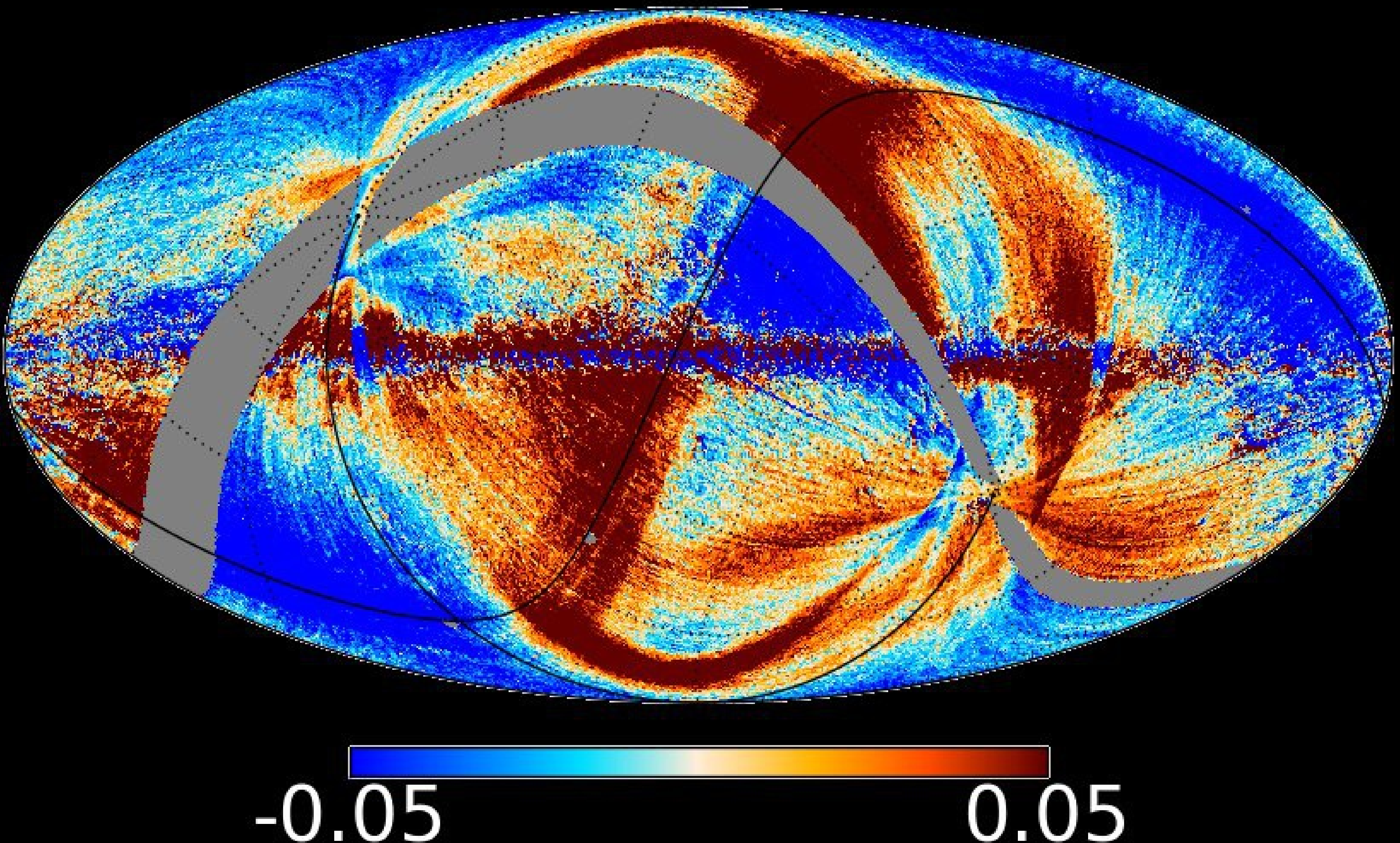


- Row 1: All Sidelobes
  Row 2: + Band 1
  Row 3: + Band 3
  Row 4: + Band 2
  Row 5: + C. Ring & Feat.
  Row 6: + Diffuse Cloud
- (The values used here are *indicative*; not from fits)

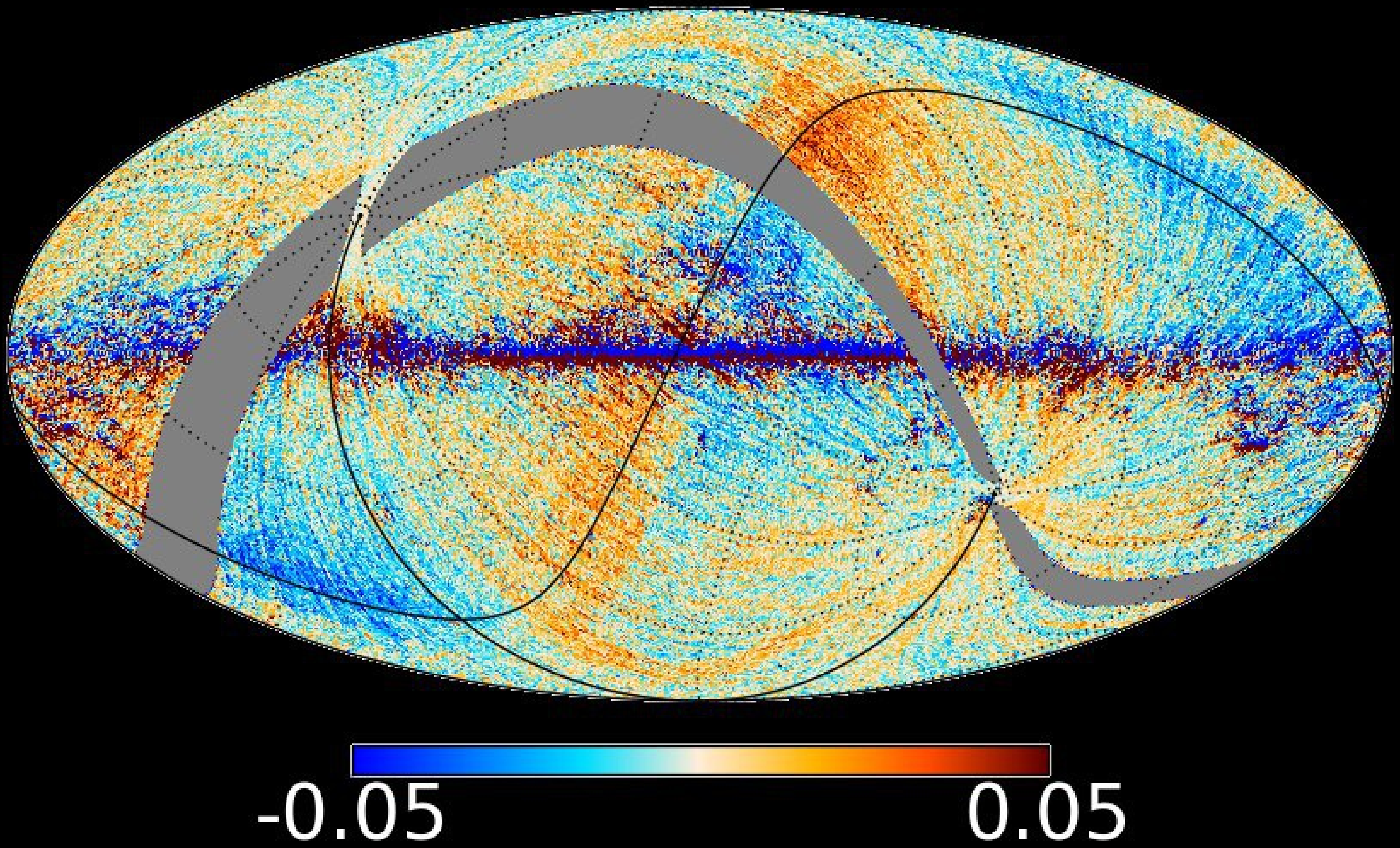
857 GHz



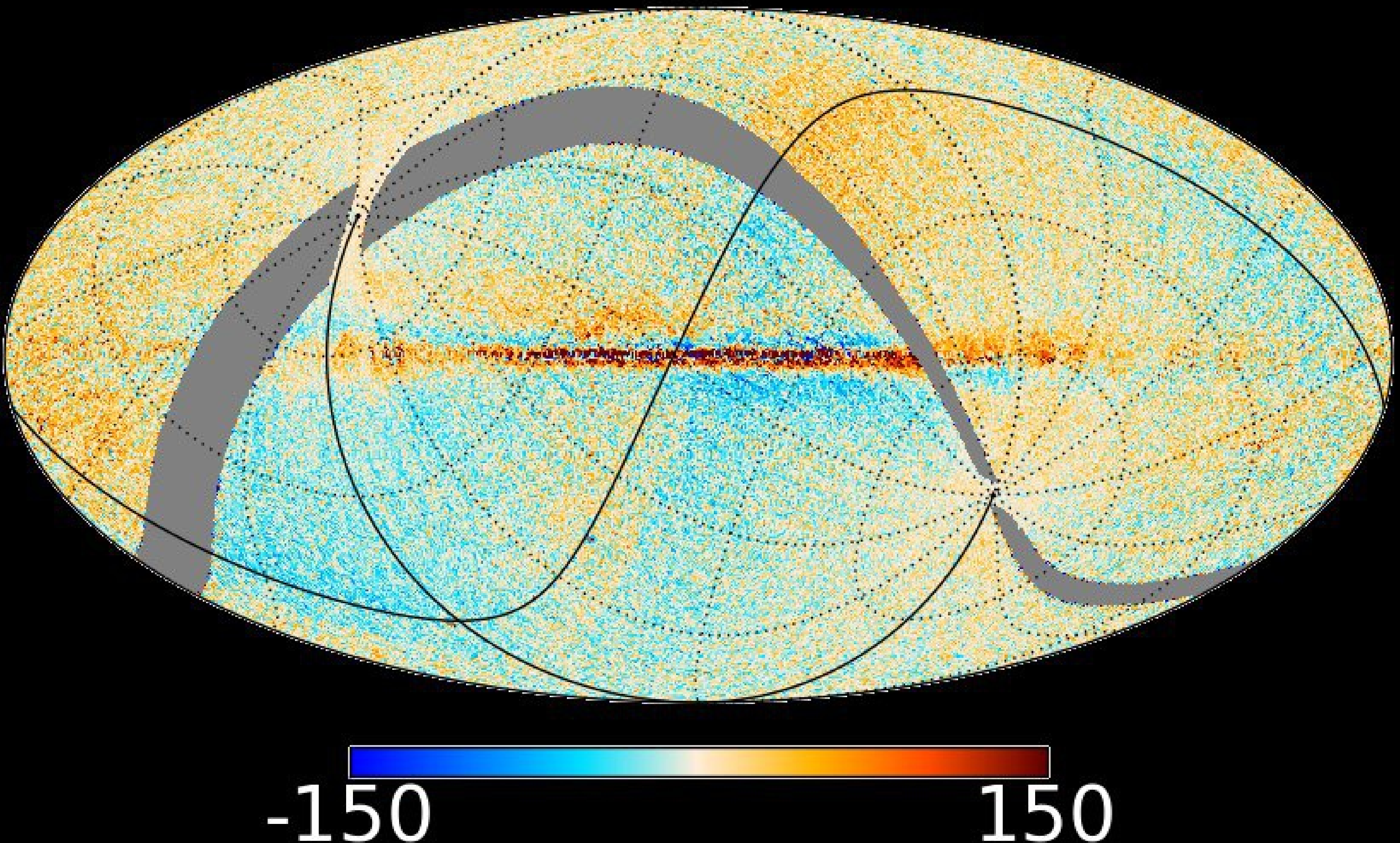
857 GHz



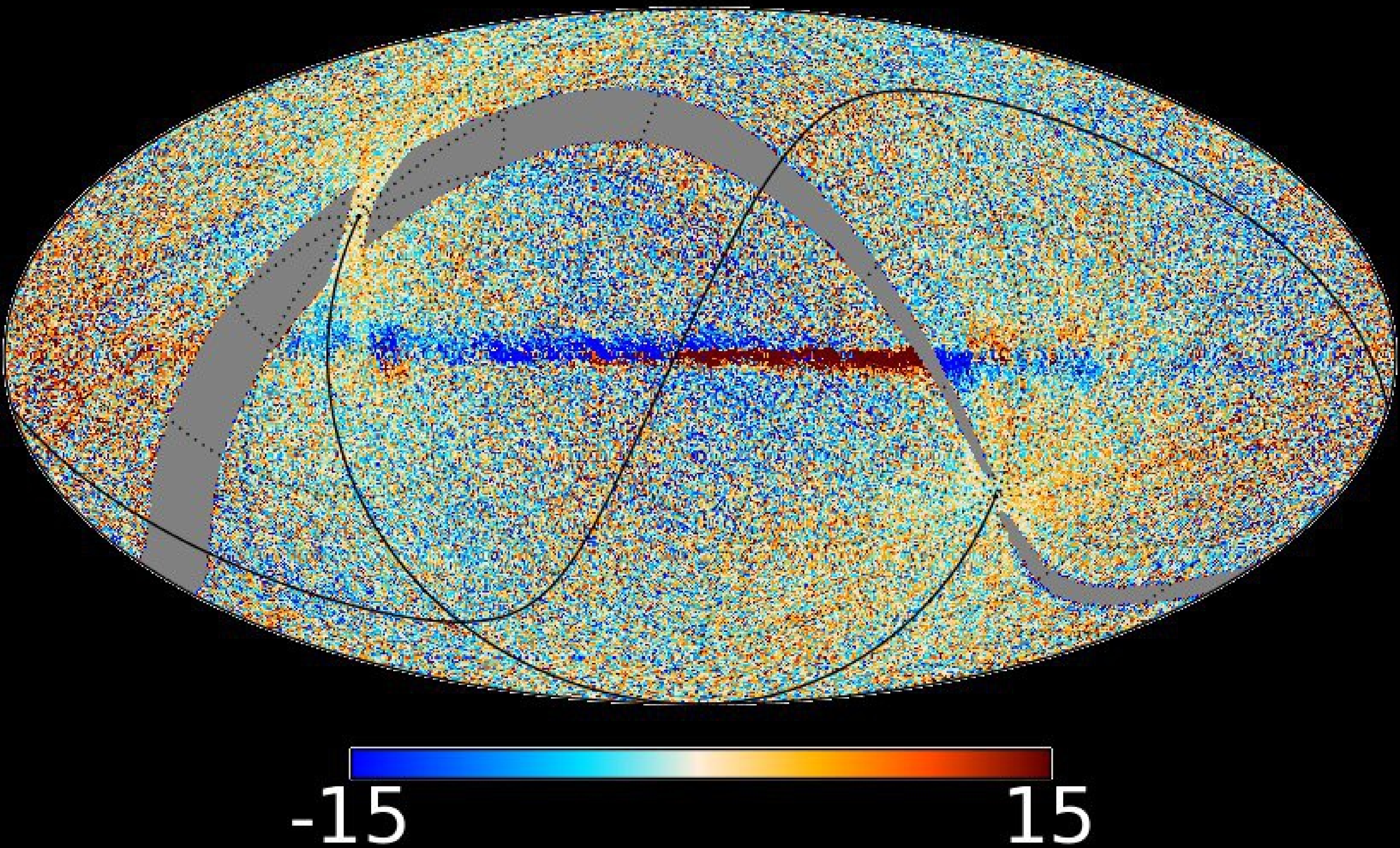
545 GHz



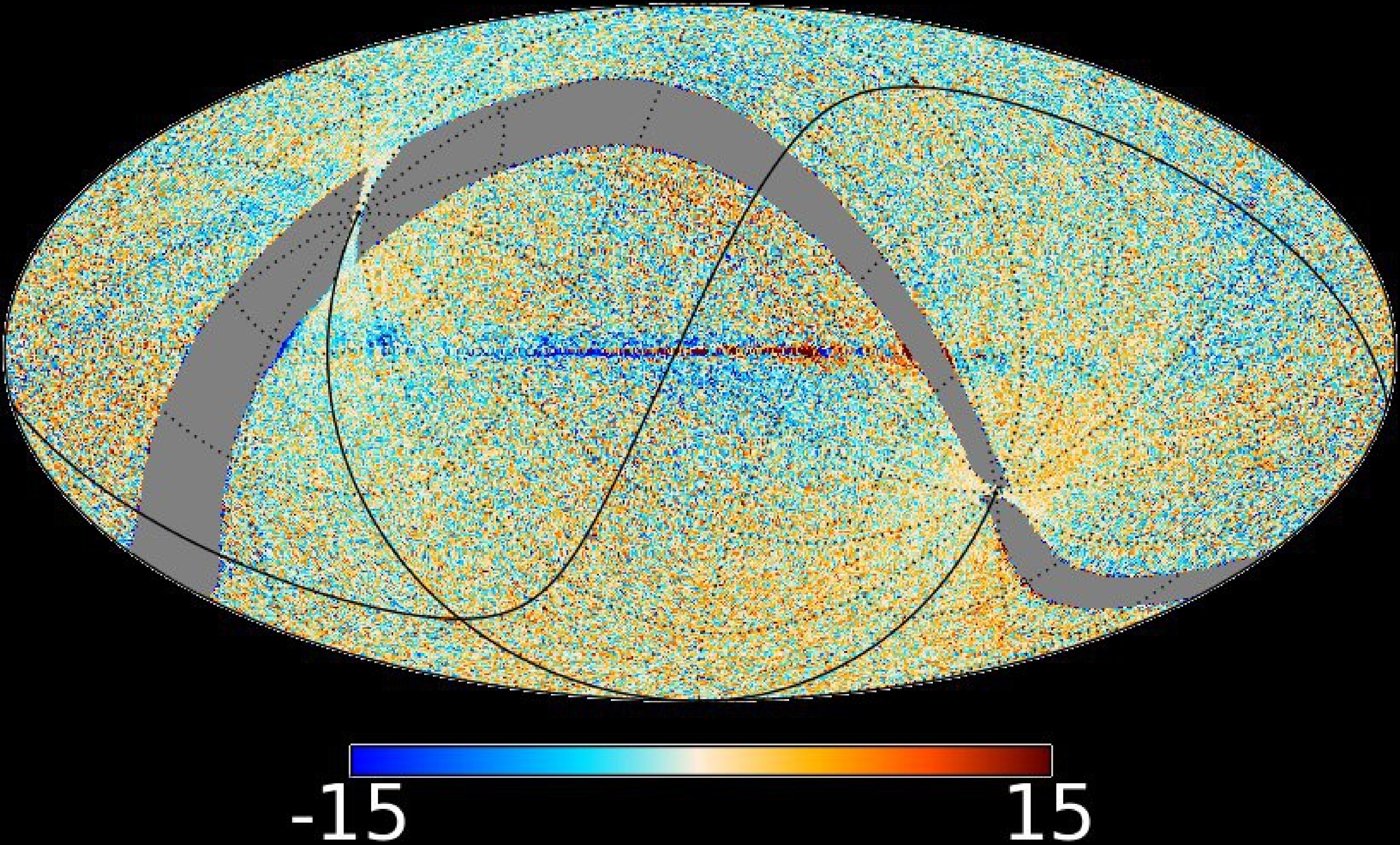
353 GHz



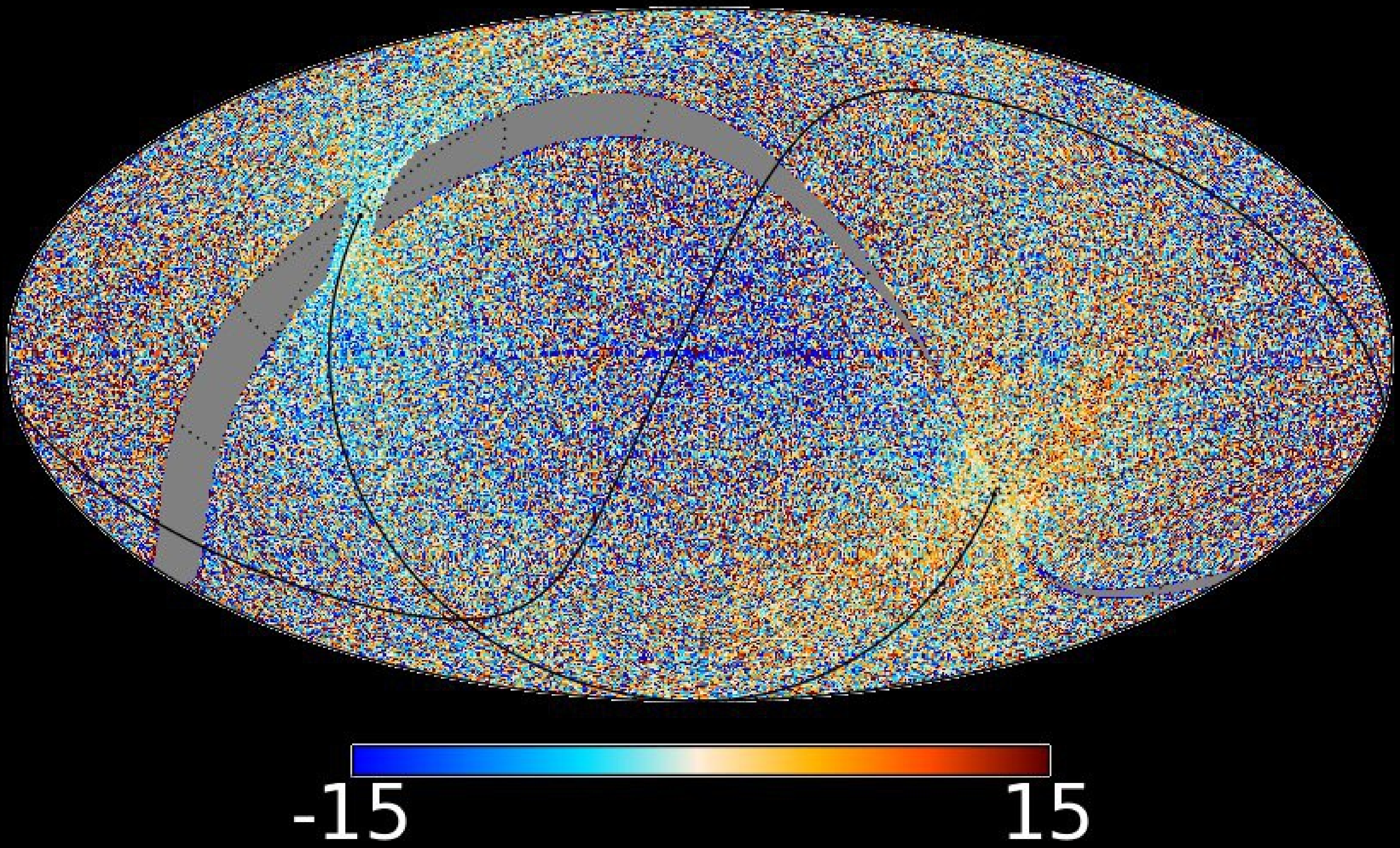
217 GHz



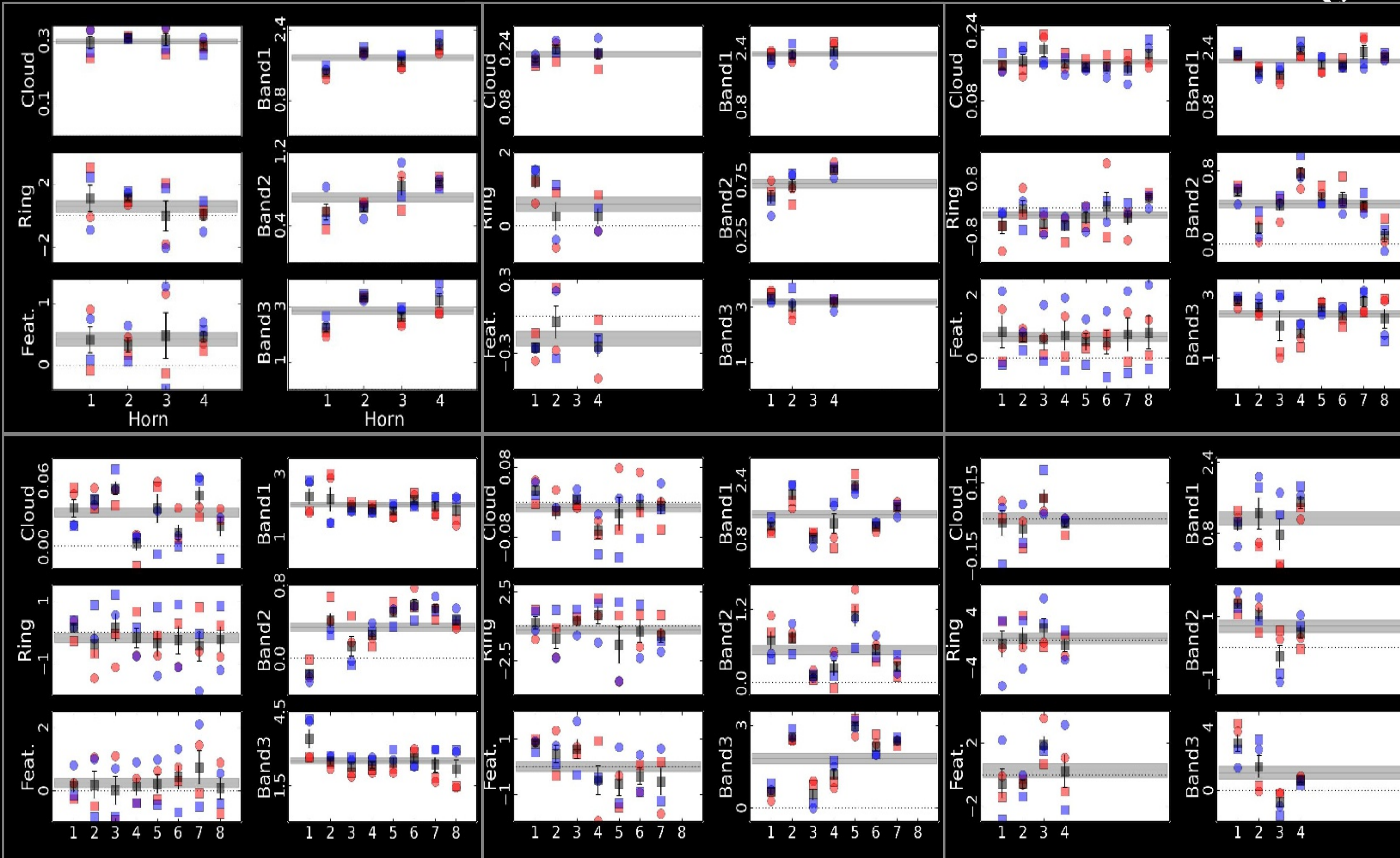
143 GHz



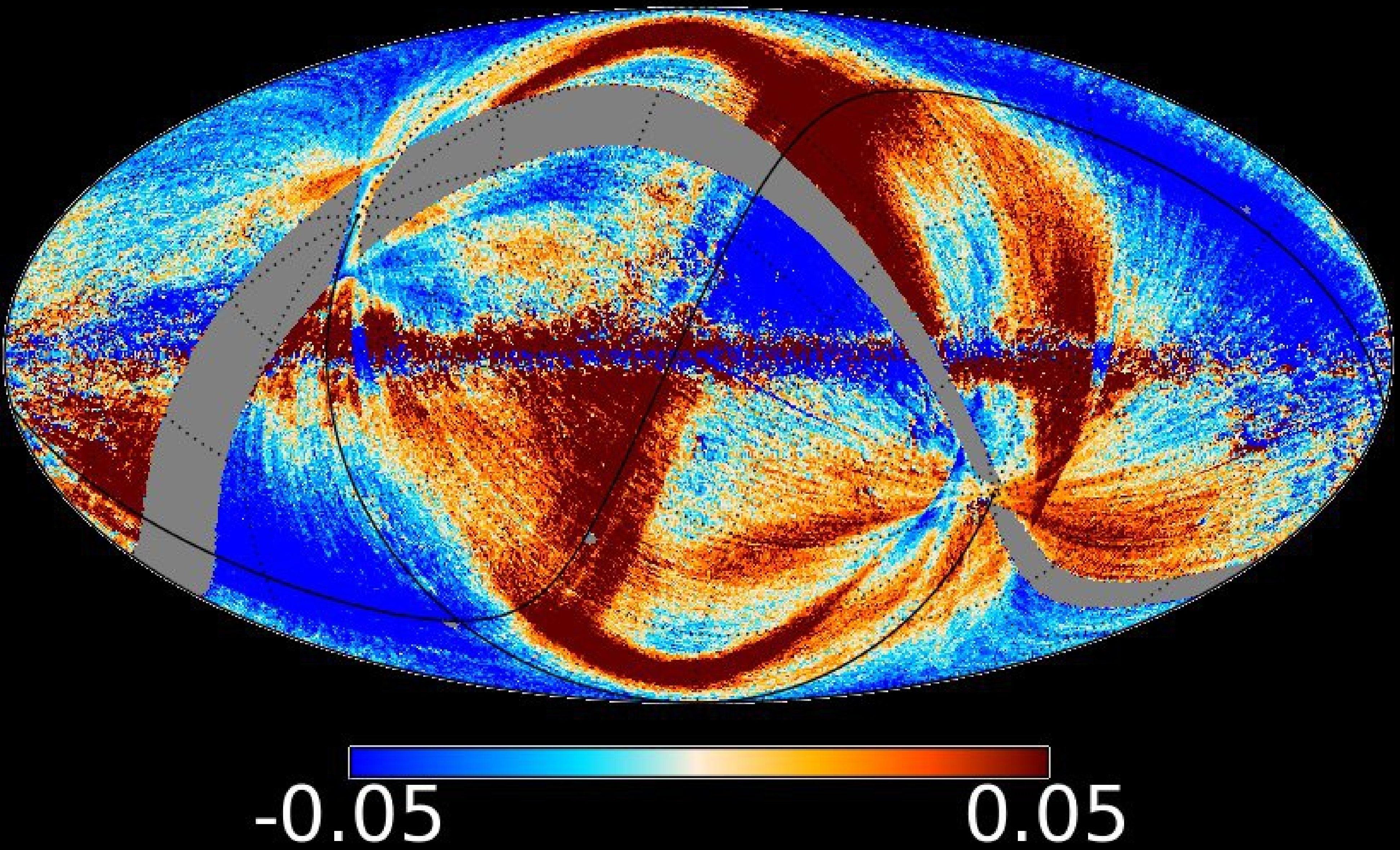
100 GHz



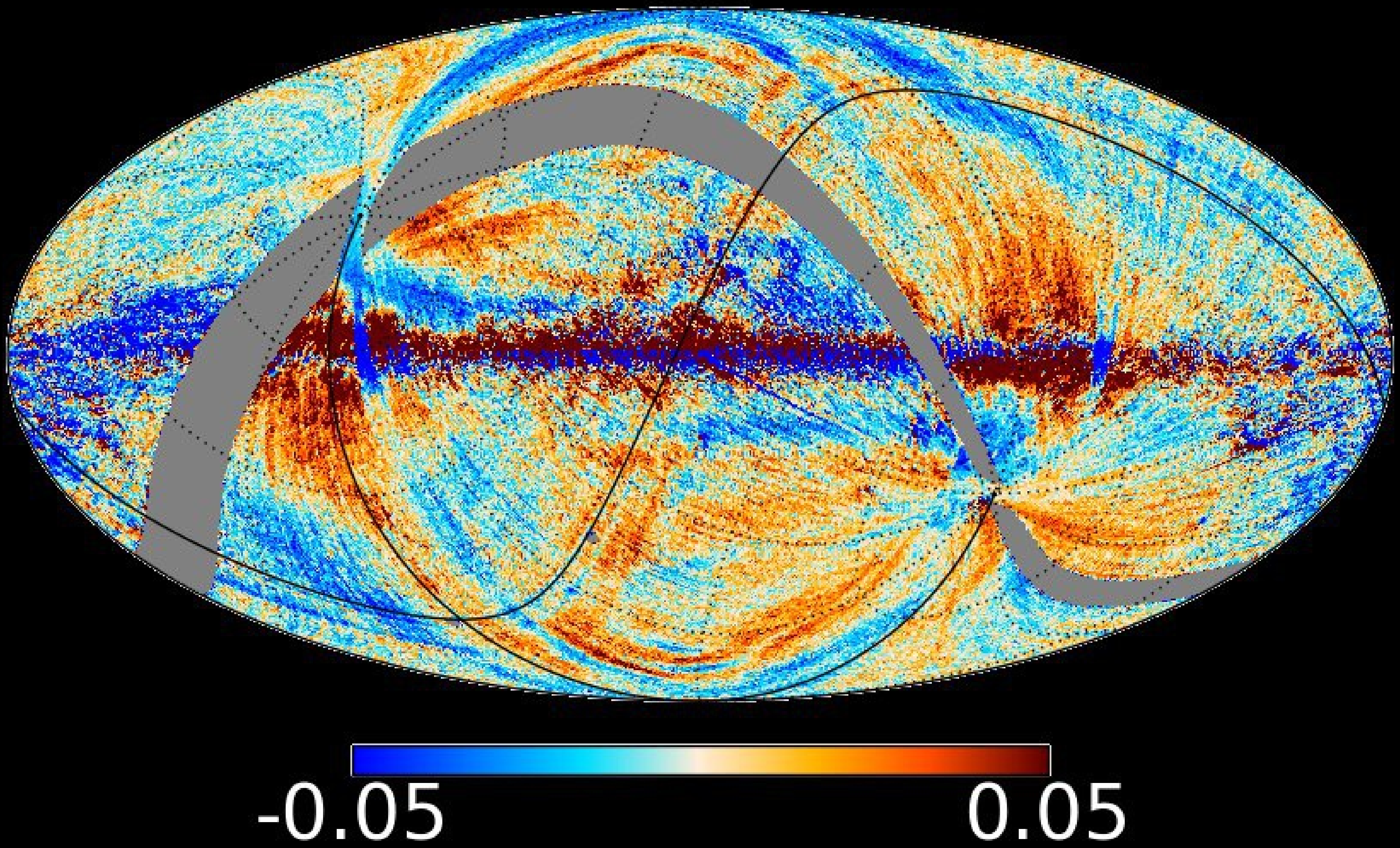
Fit results



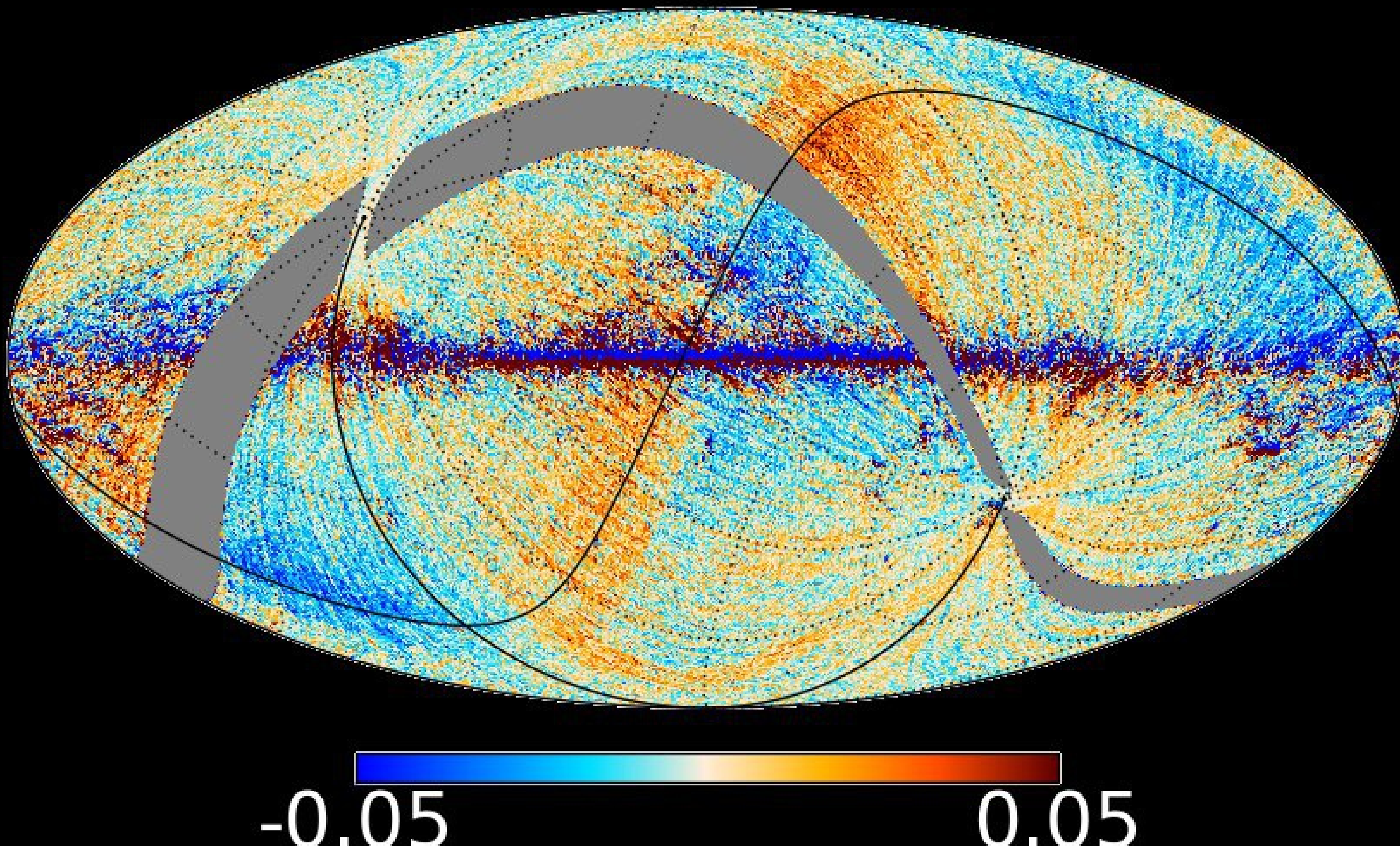
857 GHz Zodi not removed



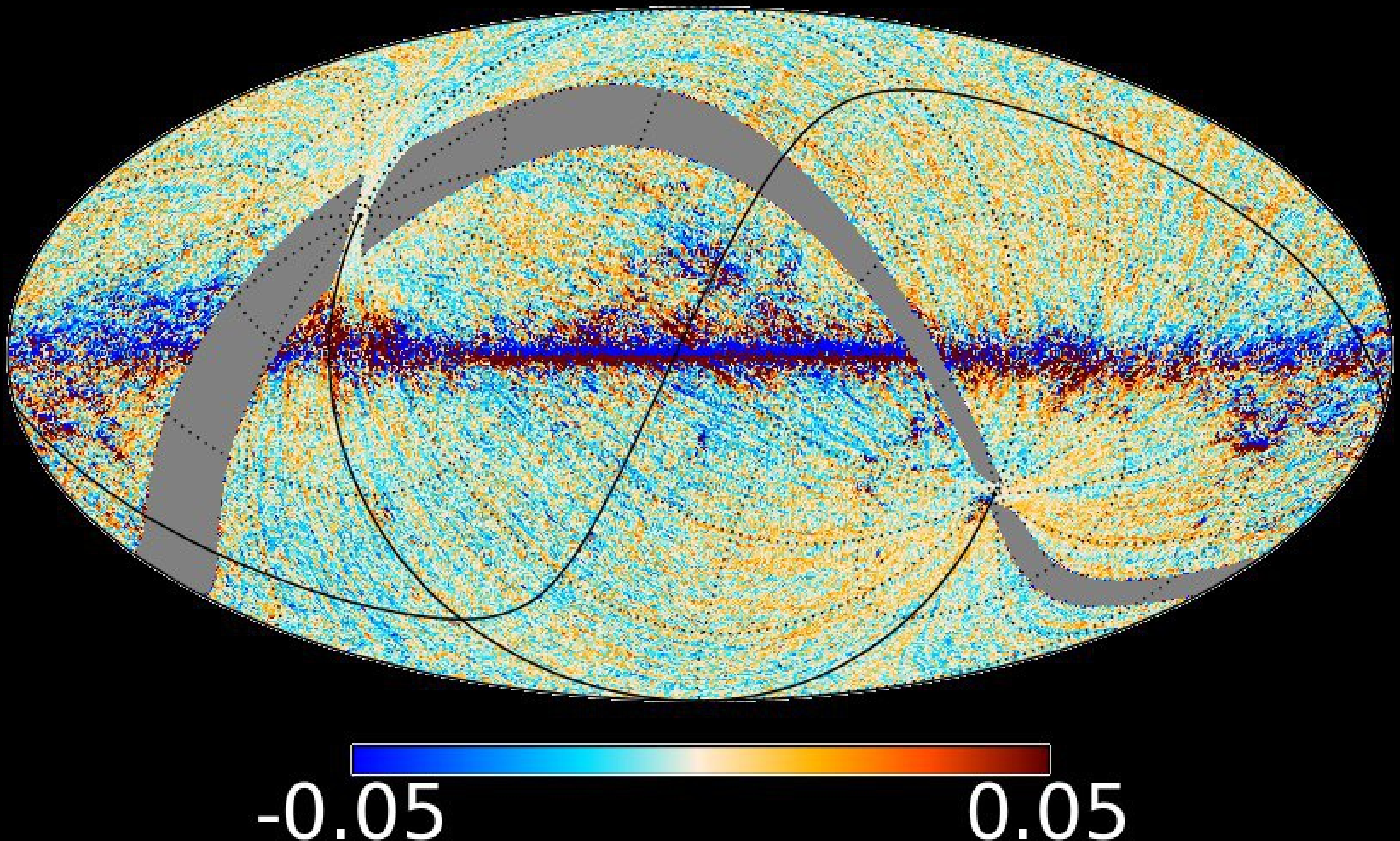
857 GHz Zodi removed



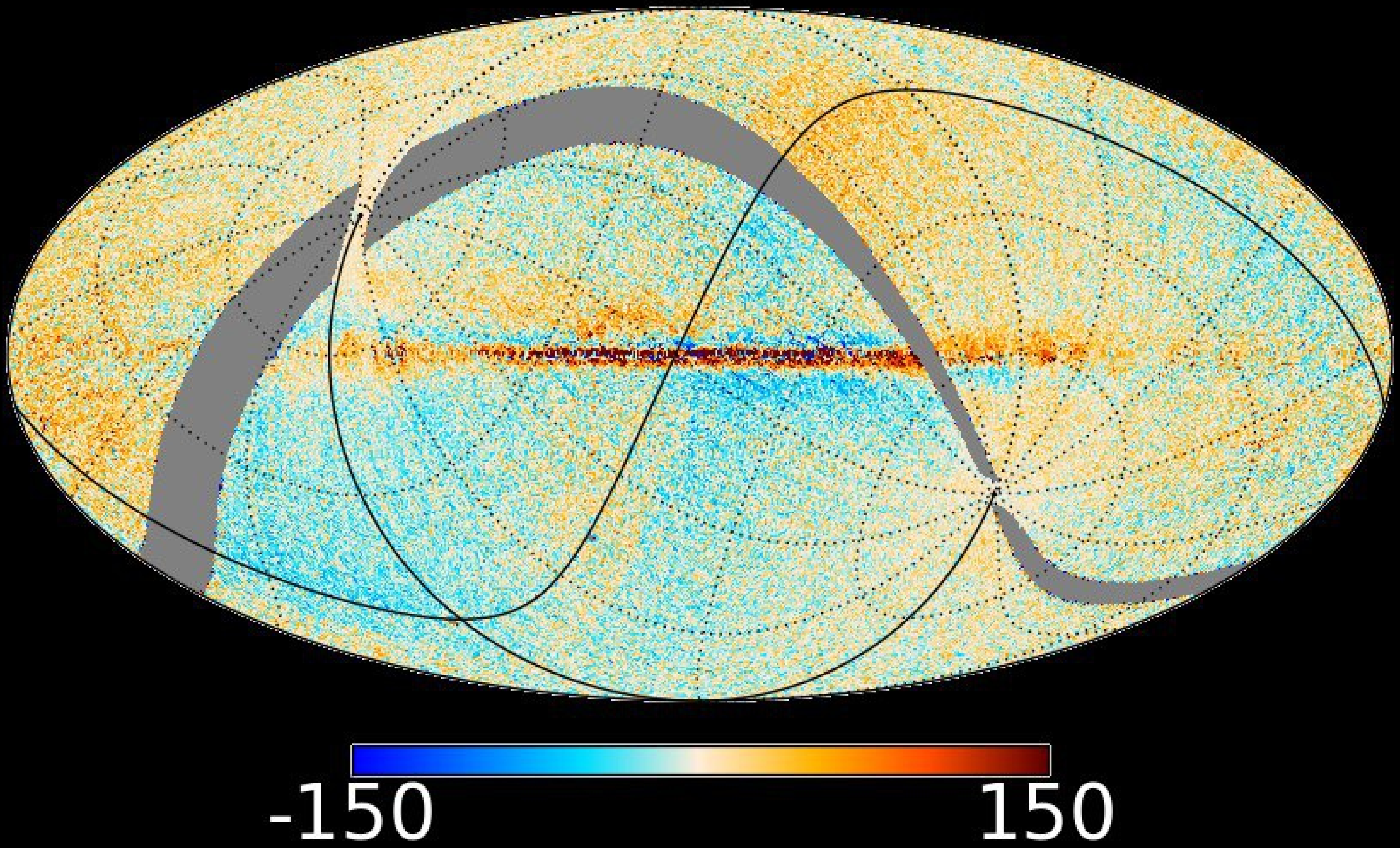
545 GHz zodi not removed



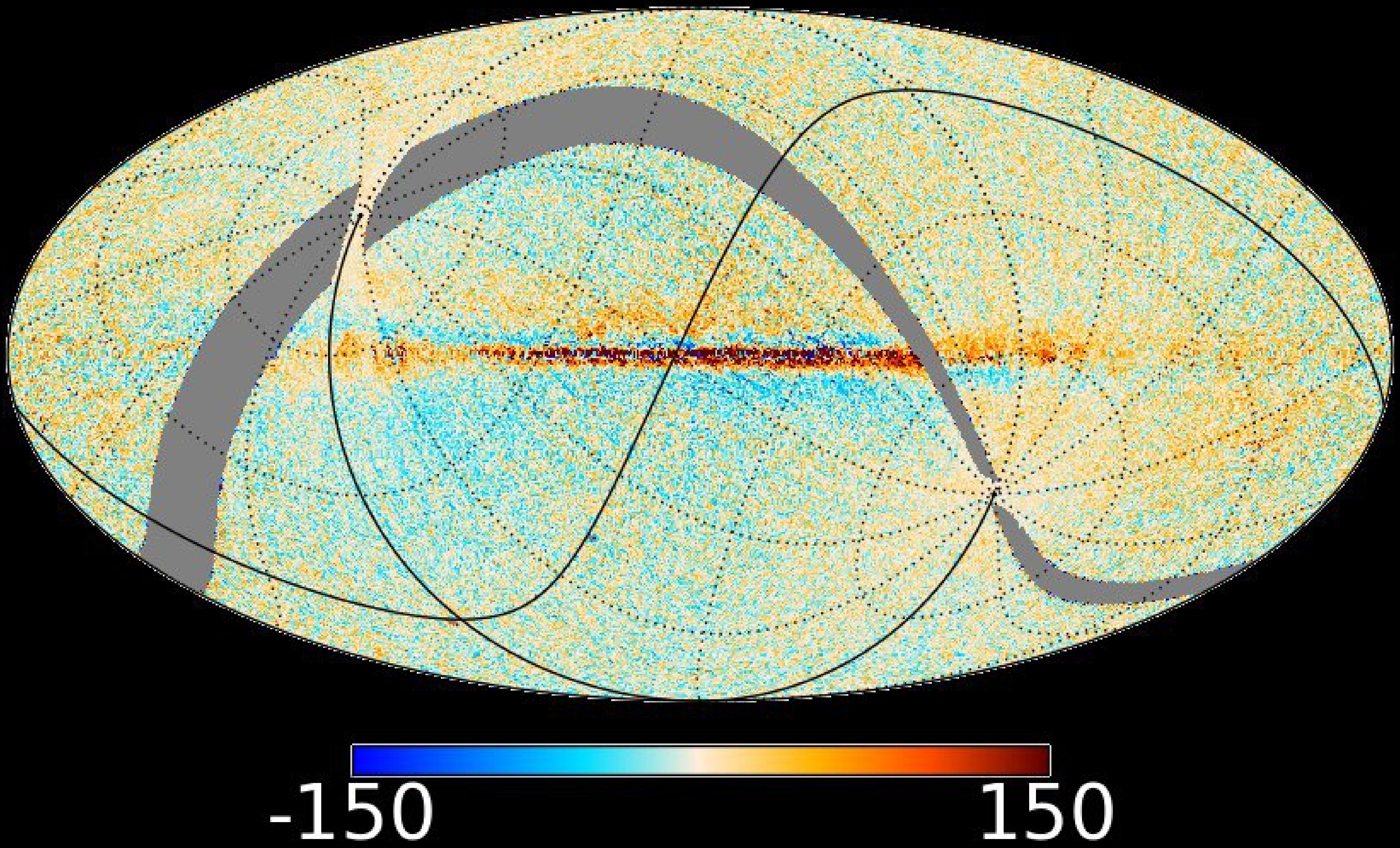
545 GHz Zodi removed



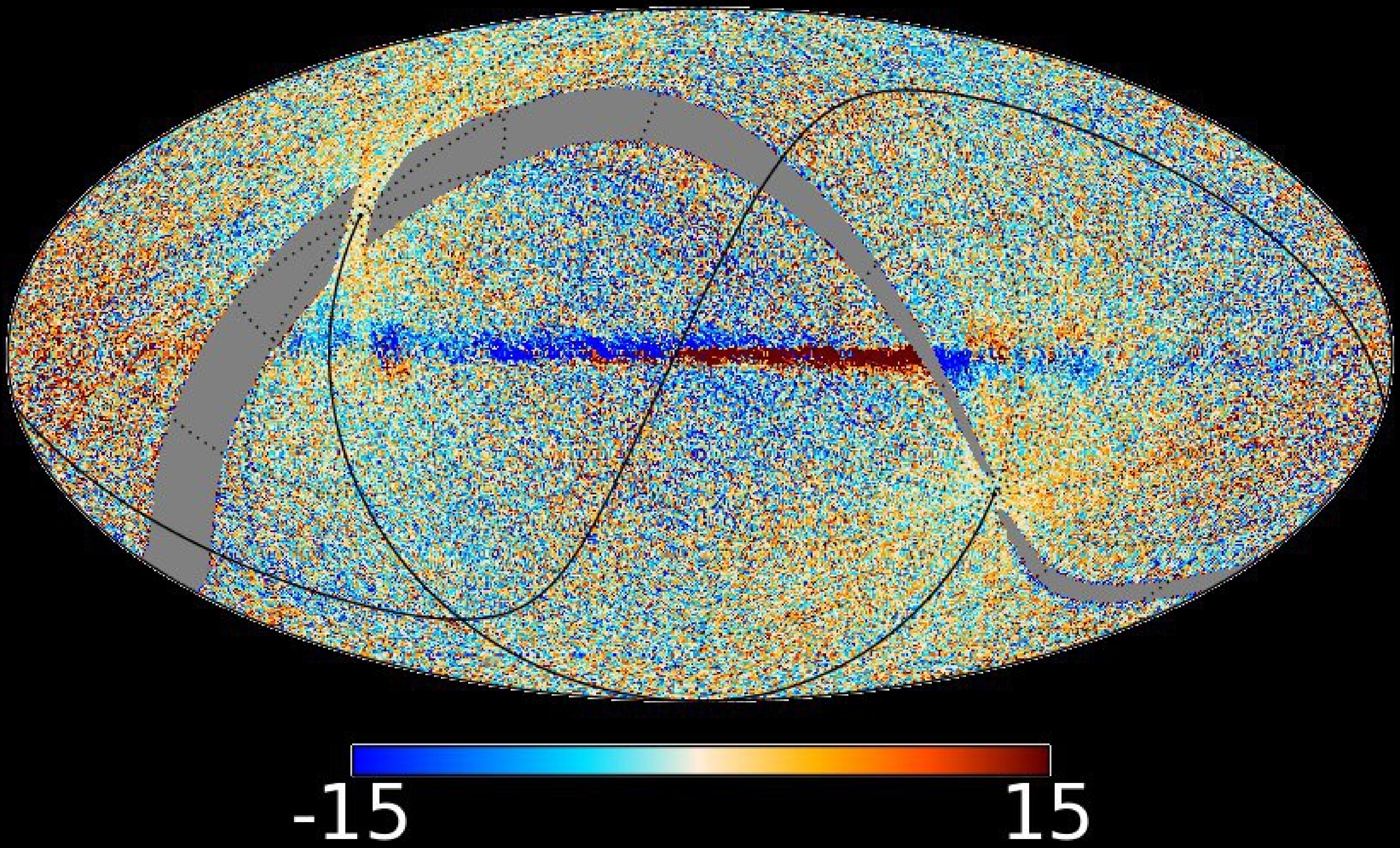
353 GHz Zodi not removed



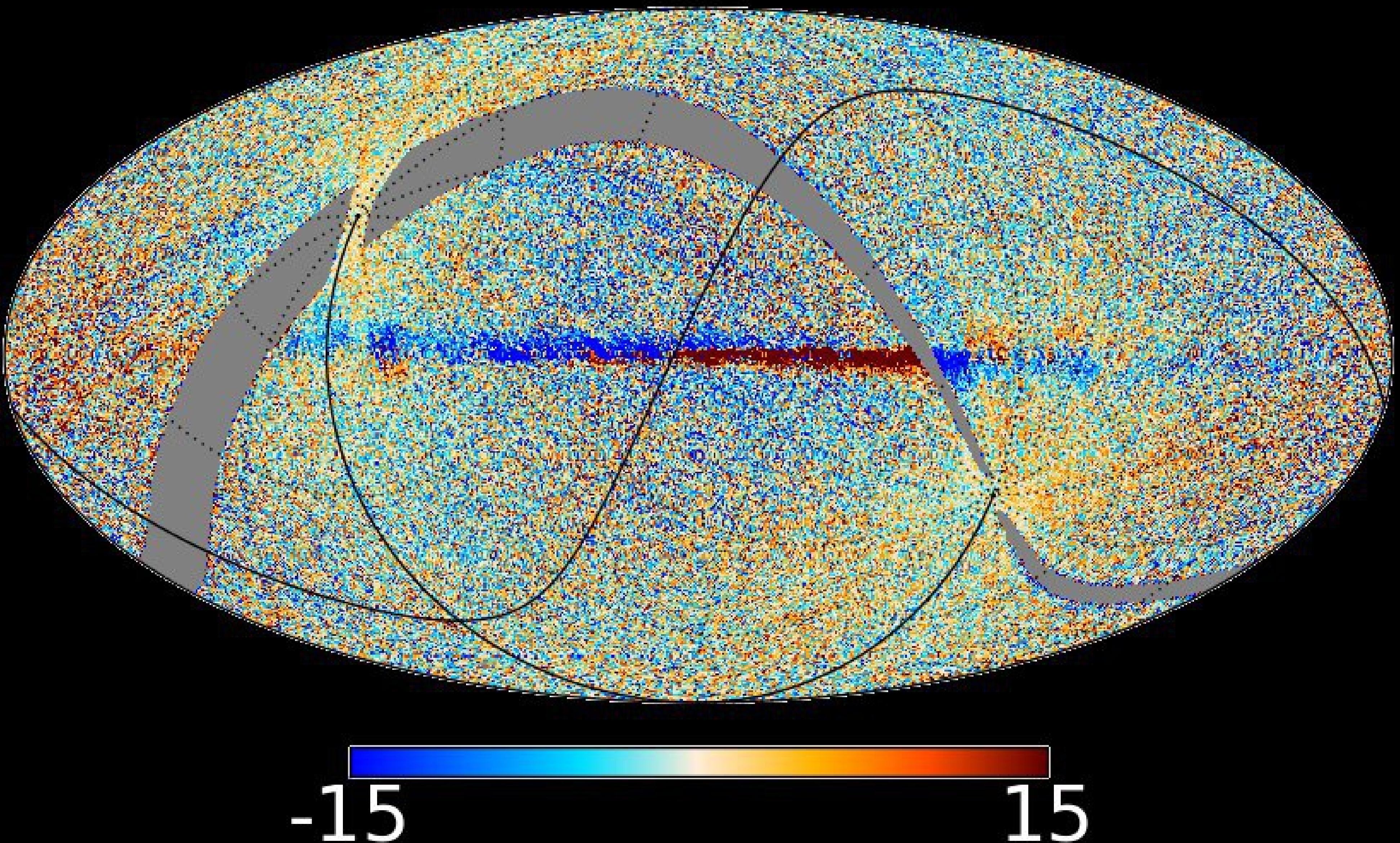
353 GHz Zodi removed



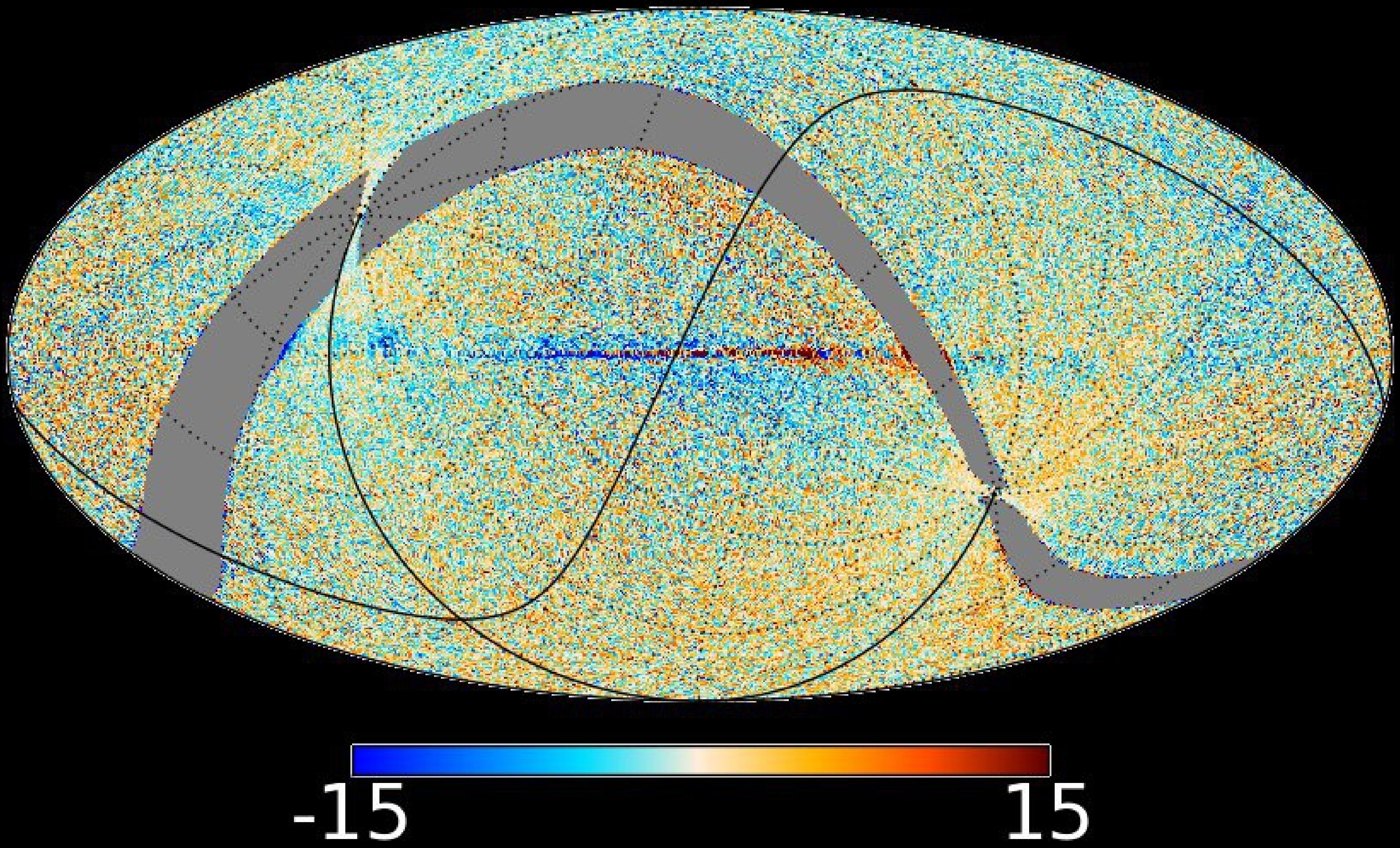
217 GHz Zodi not removed



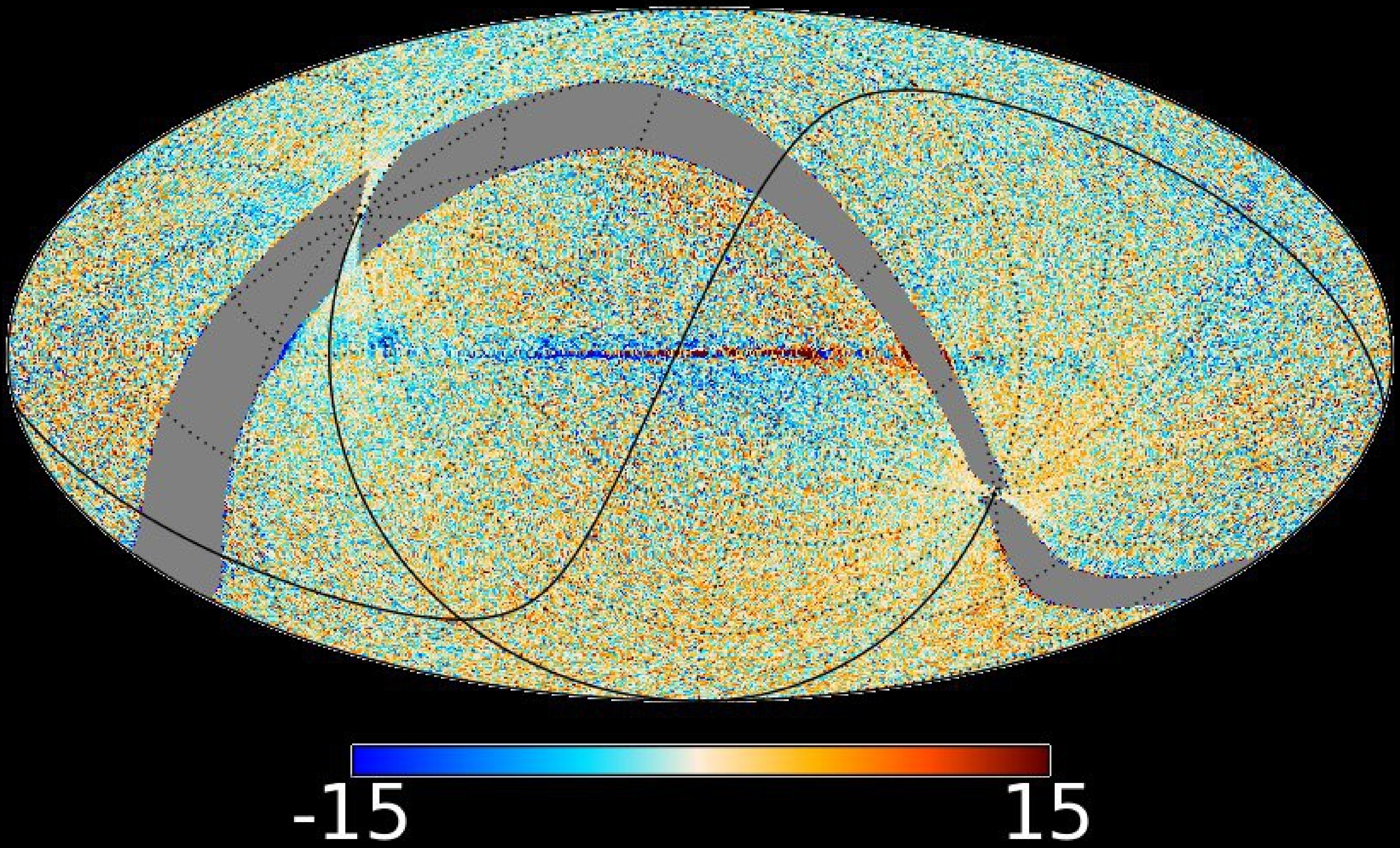
217 GHz Zodi removed



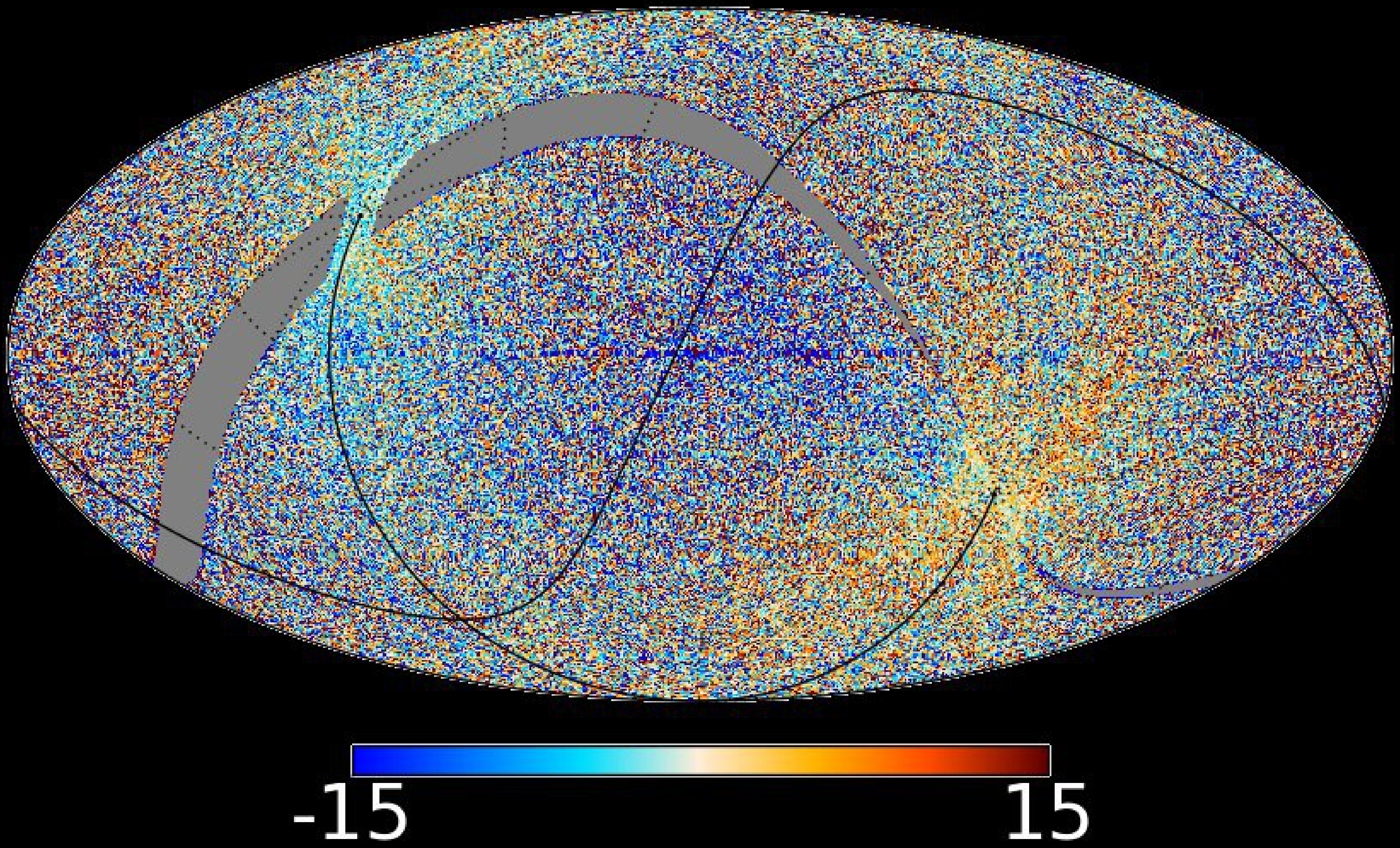
143 GHz Zodi not removed



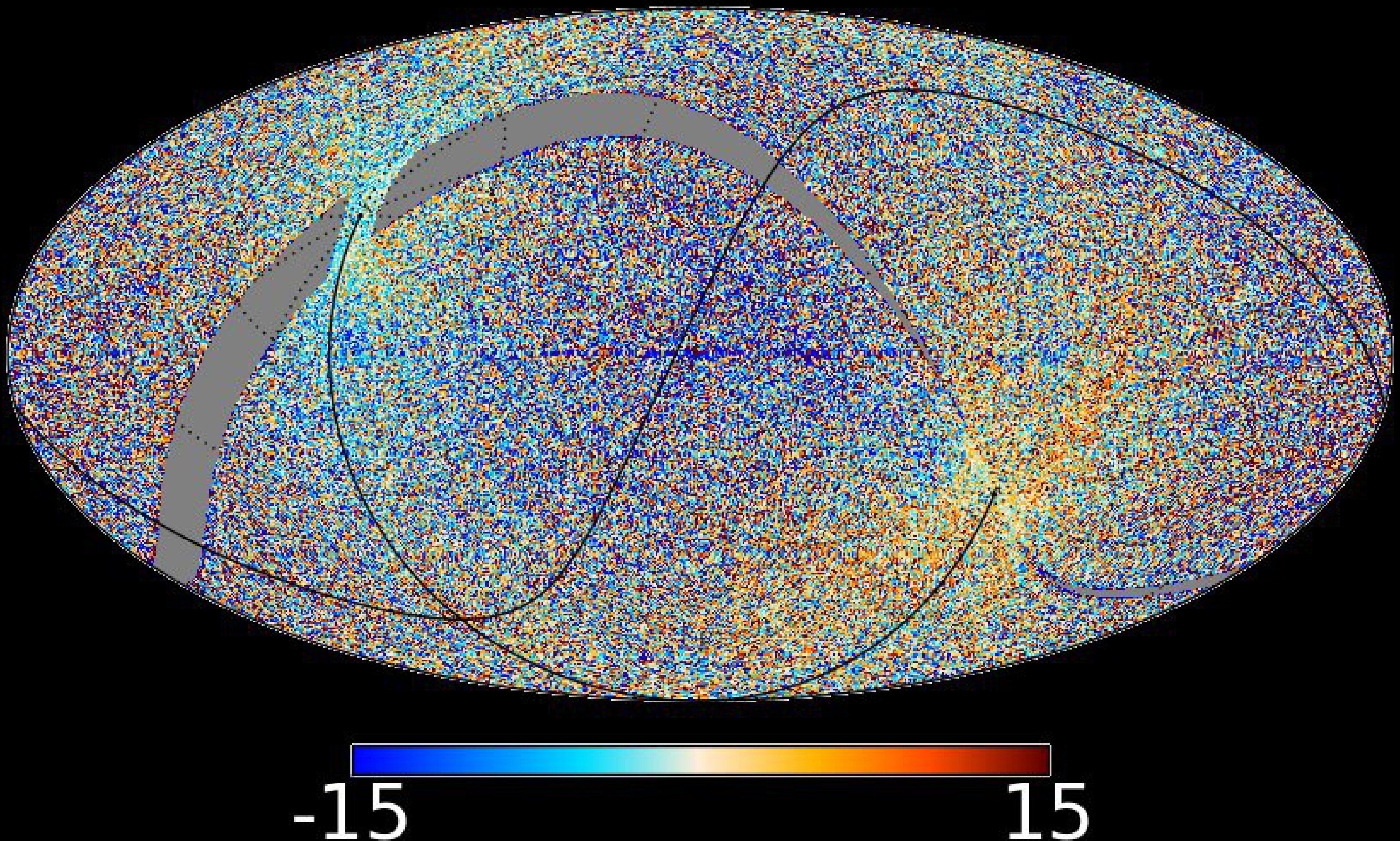
143 GHz Zodi removed



100 GHz Zodi not removed

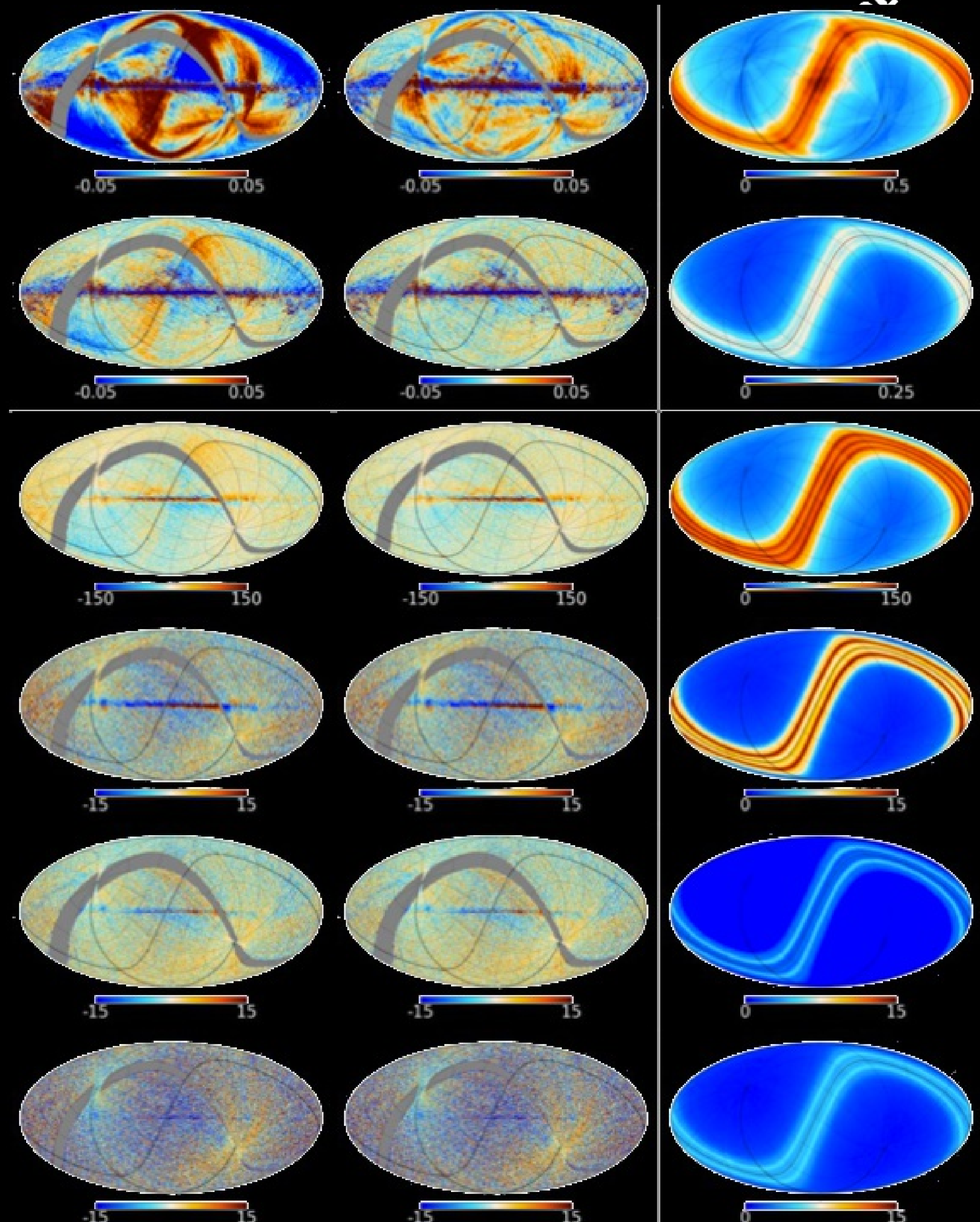


100 GHz Zodi removed

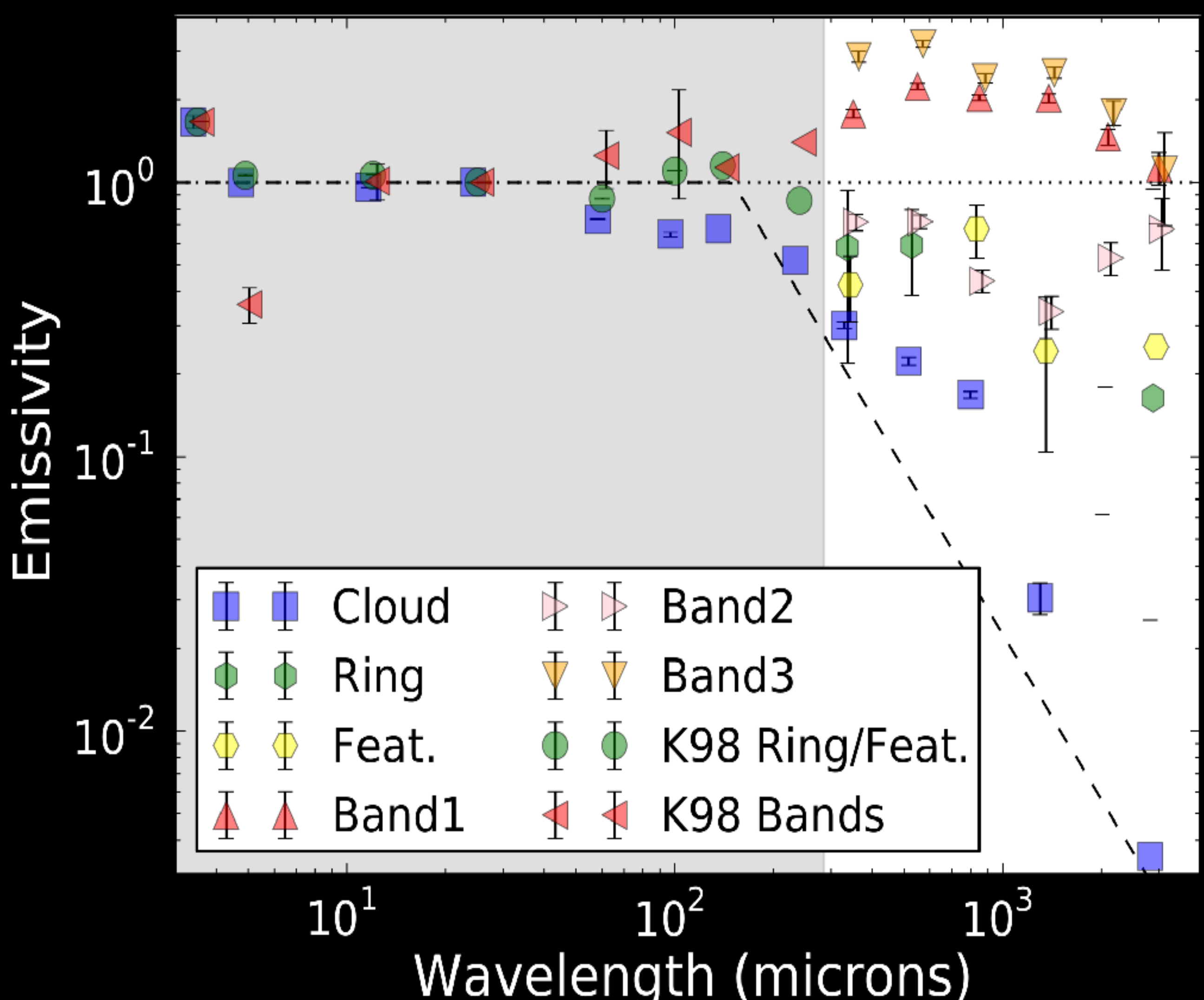


The data

- We fit to the survey *differences*
- Left: Before Zodi Removal
- Middle: After Zodi Removal
- Right: Difference

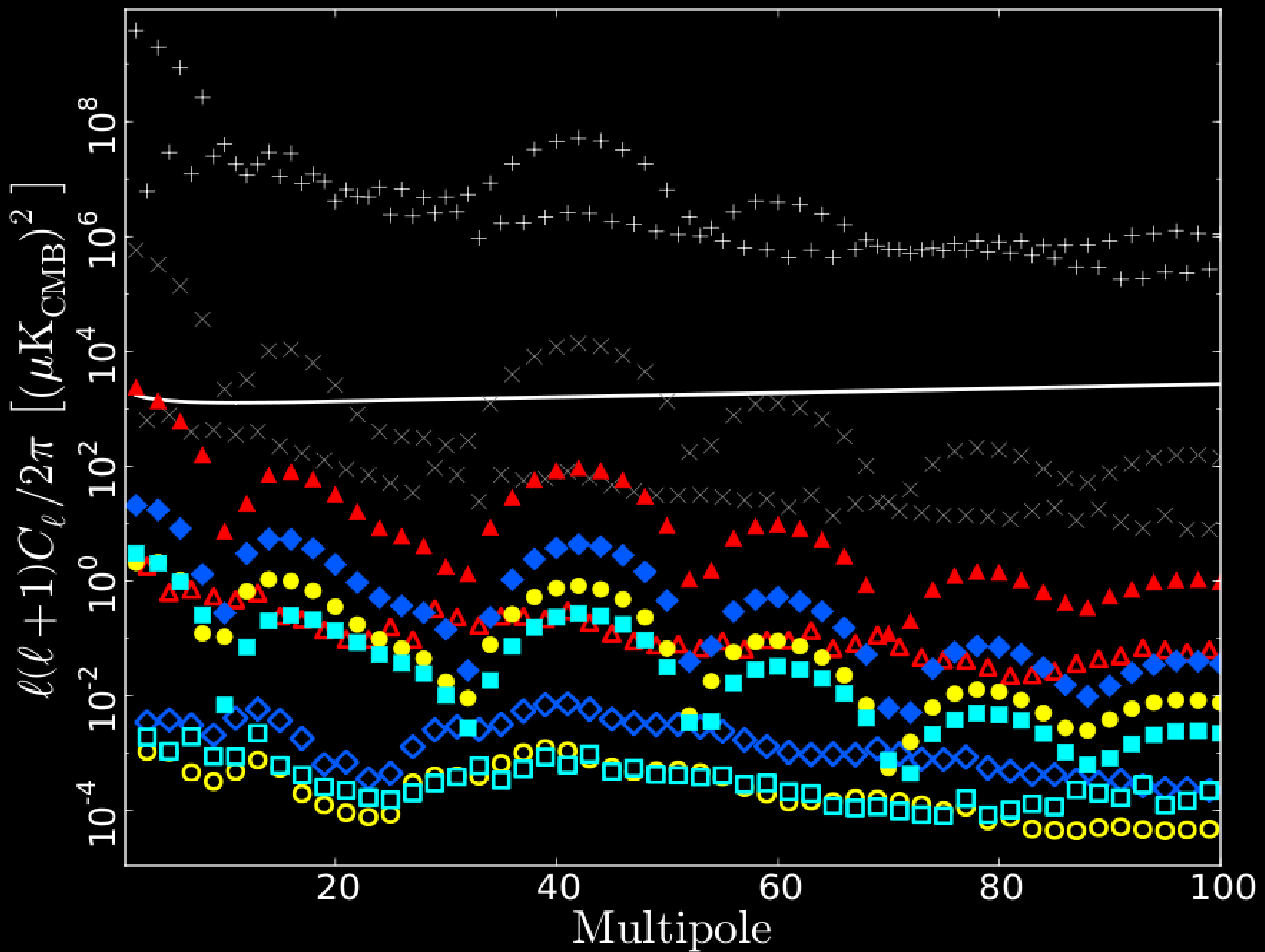


Emissivities



- The Diffuse Cloud descends as expected (Fixsen&Dwek)
- The Dust Bands are different
  - Band 2 is different from Bands 1 & 3
- I don't know what to make of the Ring and Feature

Power spectrum contamination



857	+	545	x
353	▲	217	♦
143	●	100	■

- Note that each major y-tick is *two* orders of magnitude
- The solid line shows ΛCDM
- Odd multipoles unfilled

Far sidelobes

Table 4. Fit coefficients for the Galaxy seen through the far sidelobes.

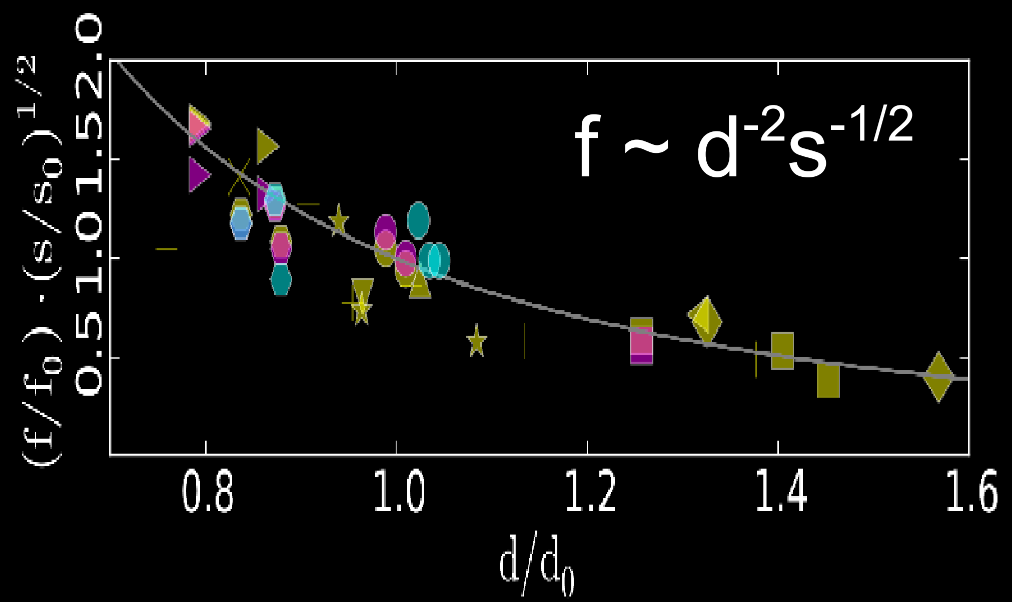
ν (GHz)	PR Spill.	Pred.[a]	SR Spillover Direct	SR Spillover Baffle	Pred.[b]
100	-25.8 ± 5.7	7	26.3 ± 15.7	56.7 ± 5.7	10
143	-9.1 ± 4.1	6	13.0 ± 4.8	23.8 ± 5.4	10
217	0.6 ± 1.1	5	6.3 ± 2.1	6.5 ± 1.3	6
353	-1.2 ± 0.5	1	-4.3 ± 2.1	3.6 ± 0.7	1
545	7.7 ± 1.7	15	8.8 ± 3.1	7.9 ± 1.0	1
857	17.1 ± 3.4	1.5	23.9 ± 4.2	16.7 ± 3.1	0.005

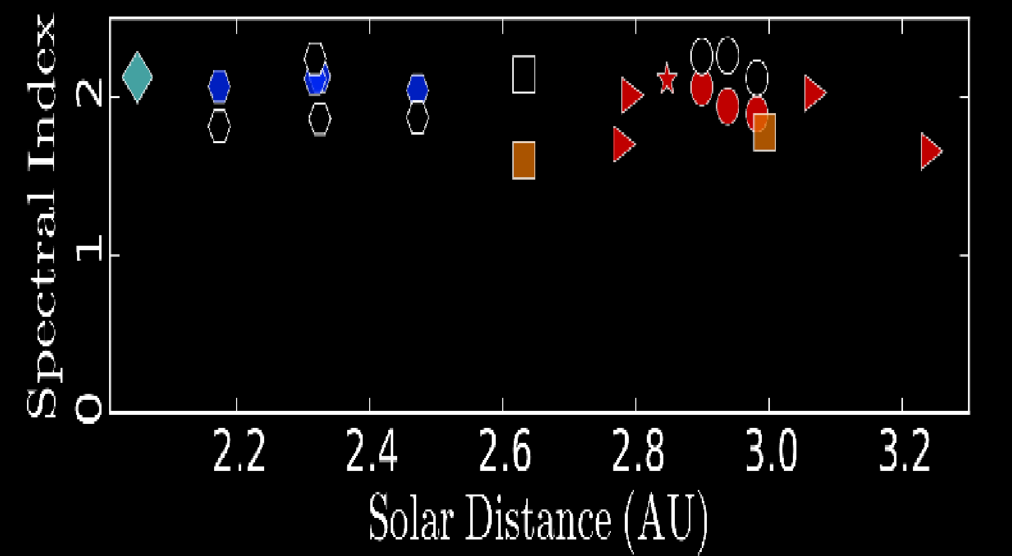
Notes. [(a)] The (unit-less) value we would expect for the fit to the primary spillover sidelobe contribution. It is the ratio of the primary spillover at the given frequency over the spillover at 353 GHz, as calculated in table 2 of Tauber et al. (2010). If all our data and predictions were perfect, this value would match the corresponding fit value in the Col. labelled 'PR Spill.'; [(b)] The (unit-less) value we would expect for the fit to the secondary spillover sidelobe contribution. It is the ratio of the secondary spillover at the given frequency over the spillover at 353 GHz, as calculated in table 2 of Tauber et al. (2010). If all our data and predictions were perfect, this value would match the corresponding fit values in the Cols. labelled 'SR Spill.'.

- Our fits to the Primary Spillover would indicated that the sidelobes are over-predicted.
- The opposite is true for the Secondary Spillover.
- We take this as an indication that the calculations are not too wrong.

Asteroids (and one comet)

- Ceres, Pallas, Juno, Vesta, Hebe, Flora, Metis, Hygiea, Victoria, Egeria, Eunomia, Psyche, Melpomene, Fortuna, Massalia, Amphitrite, Eugenia, Europa, Thisbe, Nemesis, Bamberga, Davida, Interamnia, Christensen





And anomalies

- It's hard to imagine a local signal with a CMB anisotropy spectrum
- Our motions should be in the Ecliptic, and not perpendicular to it – and would be visible as a dipole
- The Solar System is basically symmetric about the Ecliptic plane
  - It shouldn't asymmetrically add (or subtract) power to one hemisphere and not the other

And component separation

- Two sets of HFI maps are provided
  - One without Zodi removal
  - One with Zodi removal
- The component separation teams used maps withOUT Zodi removal
- Improvement in the frequency modeling will improve the removal

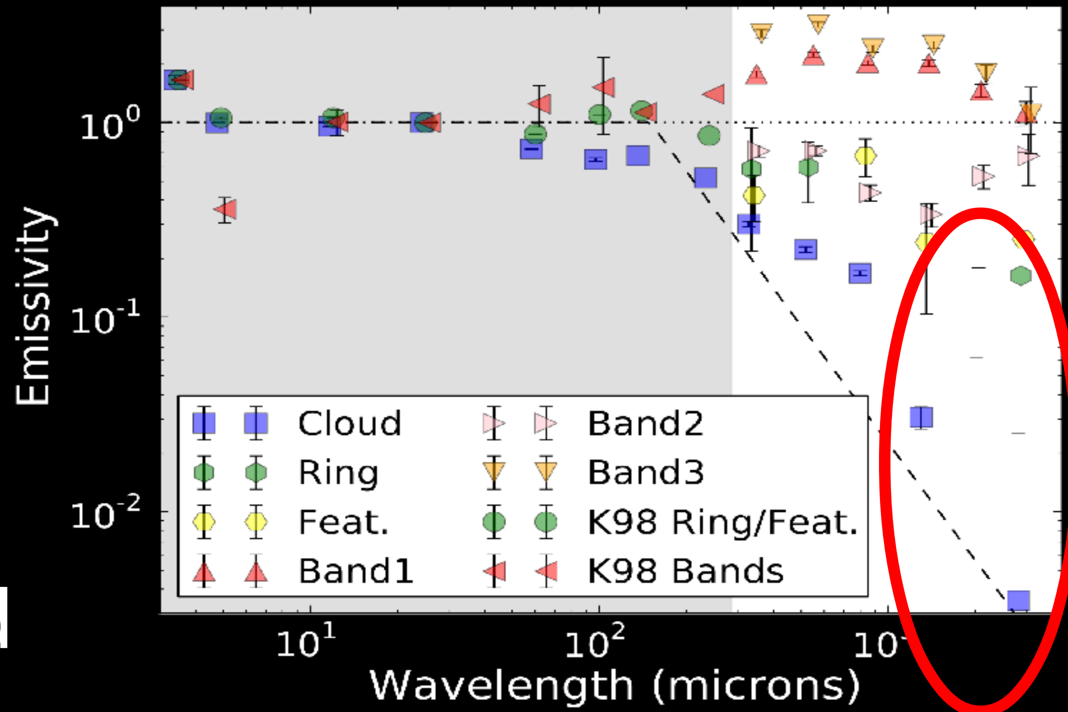


Table 2. Emissivities of the diffuse cloud, circumsolar ring, and Earth-trailing feature from fit result averages.

ν (GHz)	Cloud	Ring	Feature
857	0.301 ± 0.008	0.578 ± 0.359	0.423 ± 0.114
545	0.223 ± 0.007	0.591 ± 0.203	-0.182 ± 0.061
353	0.168 ± 0.005	-0.211 ± 0.085	0.676 ± 0.149
217	0.031 ± 0.004	-0.185 ± 0.143	0.243 ± 0.139
143	-0.014 ± 0.010	-0.252 ± 0.314	-0.002 ± 0.180
100	0.003 ± 0.022	0.163 ± 0.784	0.252 ± 0.455

Out-of-band leaks

- Since Zodiacal emission is so much brighter at ~10 microns than at 100 GHz allows us to set limits on blue leaks.
- See the poster by Locke Spencer for the Planck Collaboration.

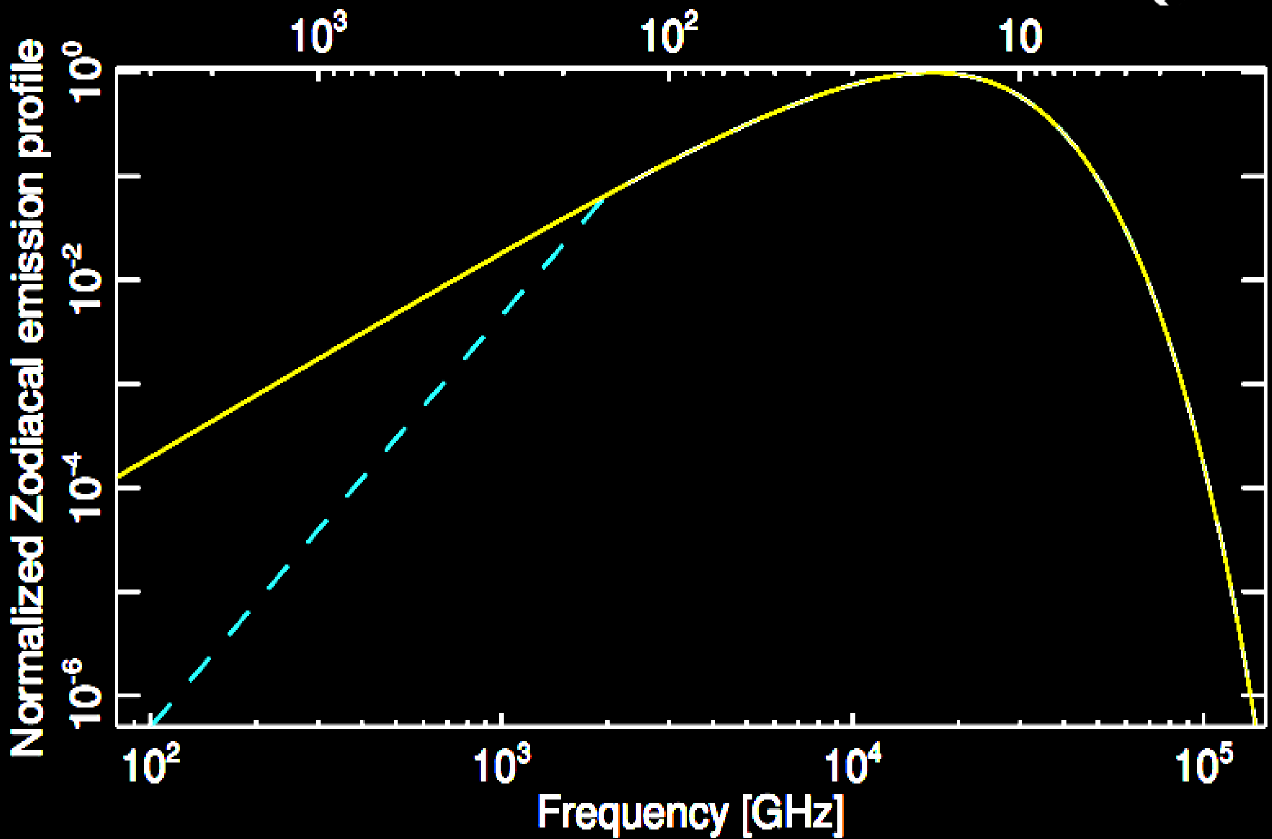
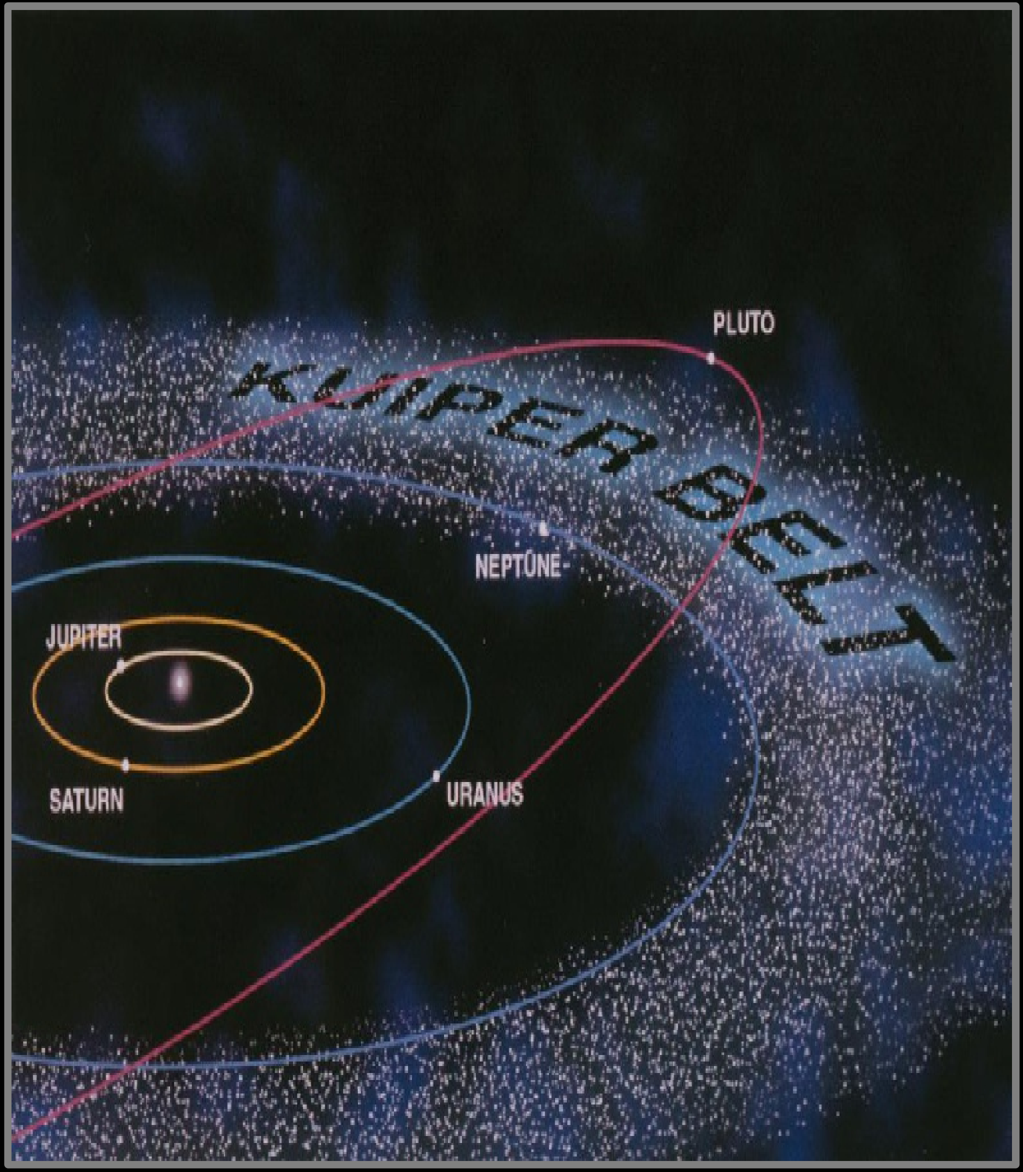


Fig. 18. The spectrum of the diffuse cloud in the Ecliptic plane. The blue curve represents the spectrum one would see assuming that uniform cloud emissivity of unity. The dotted red line shows the modification expected with a $1/\lambda^2$ emissivity proportionality for frequencies below 2 000 GHz (i.e., wavelengths longer than 150 μm).

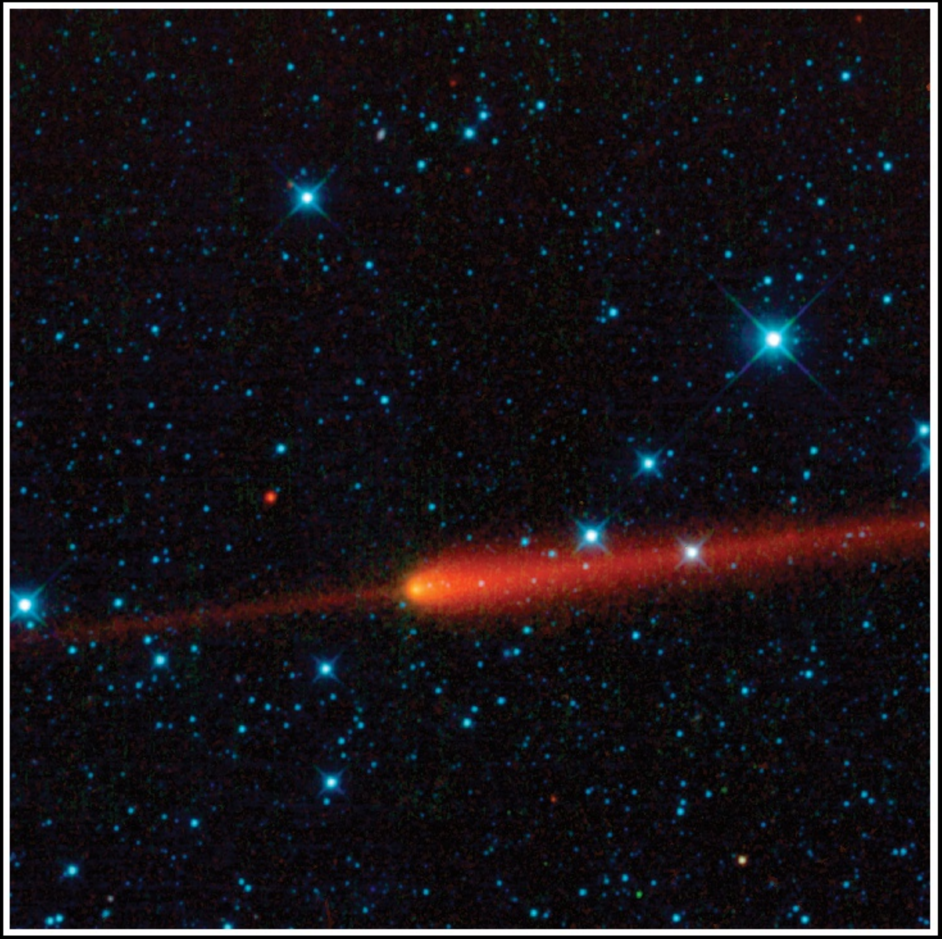
What's next? Kuiper belt



- Planck should be able to put tight, long-lasting limits on dust in the outer solar system.
- This analysis would necessarily be different from that presented here, as the parallax is smaller at these distances

http://discovery.nasa.gov/SmallWorlds/images/Kuiperbelt.jpg

What's next? Comet tails



Comet 65/P Gunn

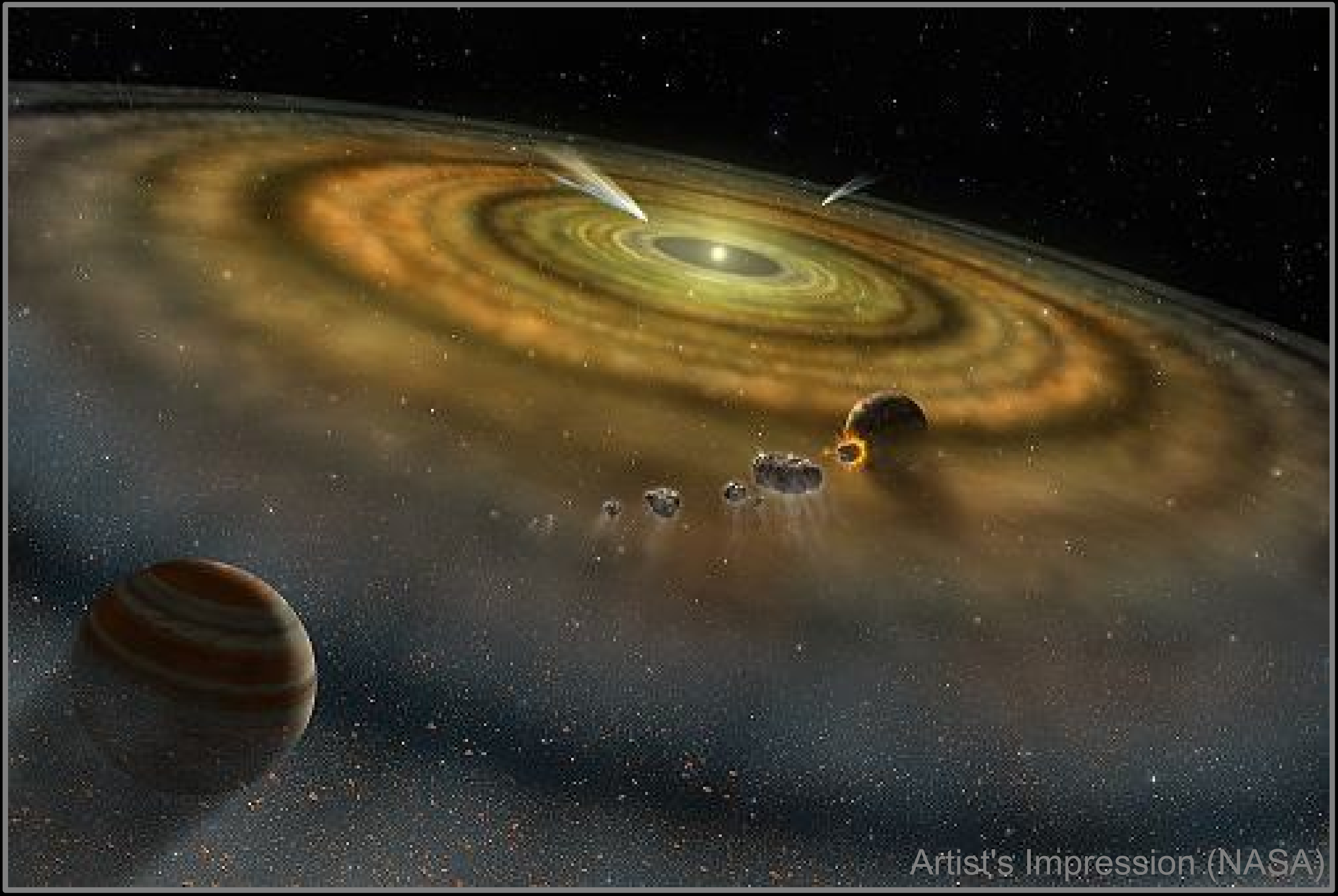
Wide-field **I**nfrared **S**urvey **E**xplorer

NASA/JPL-Caltech/WISE Team

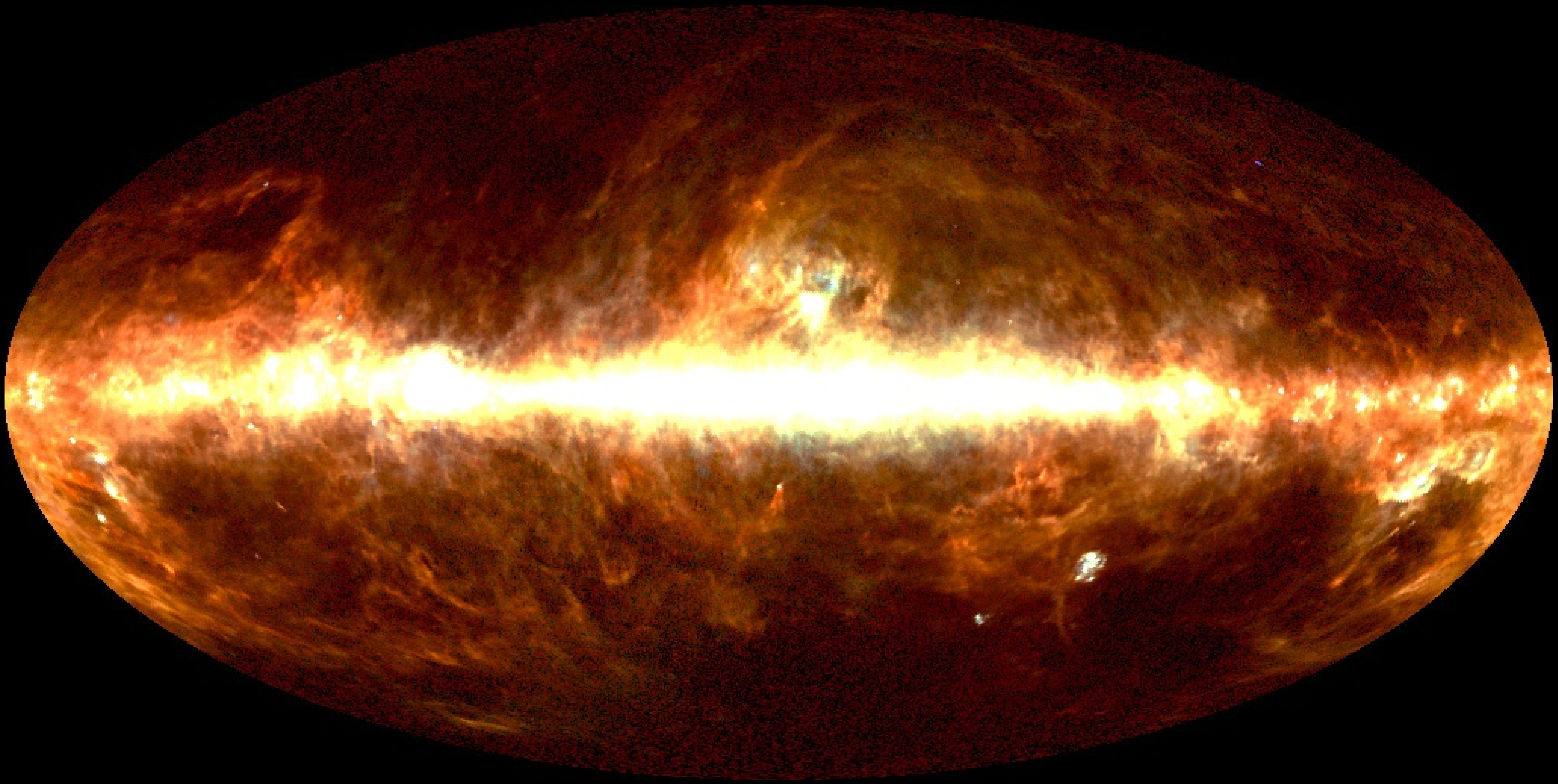
WISE 2010-020

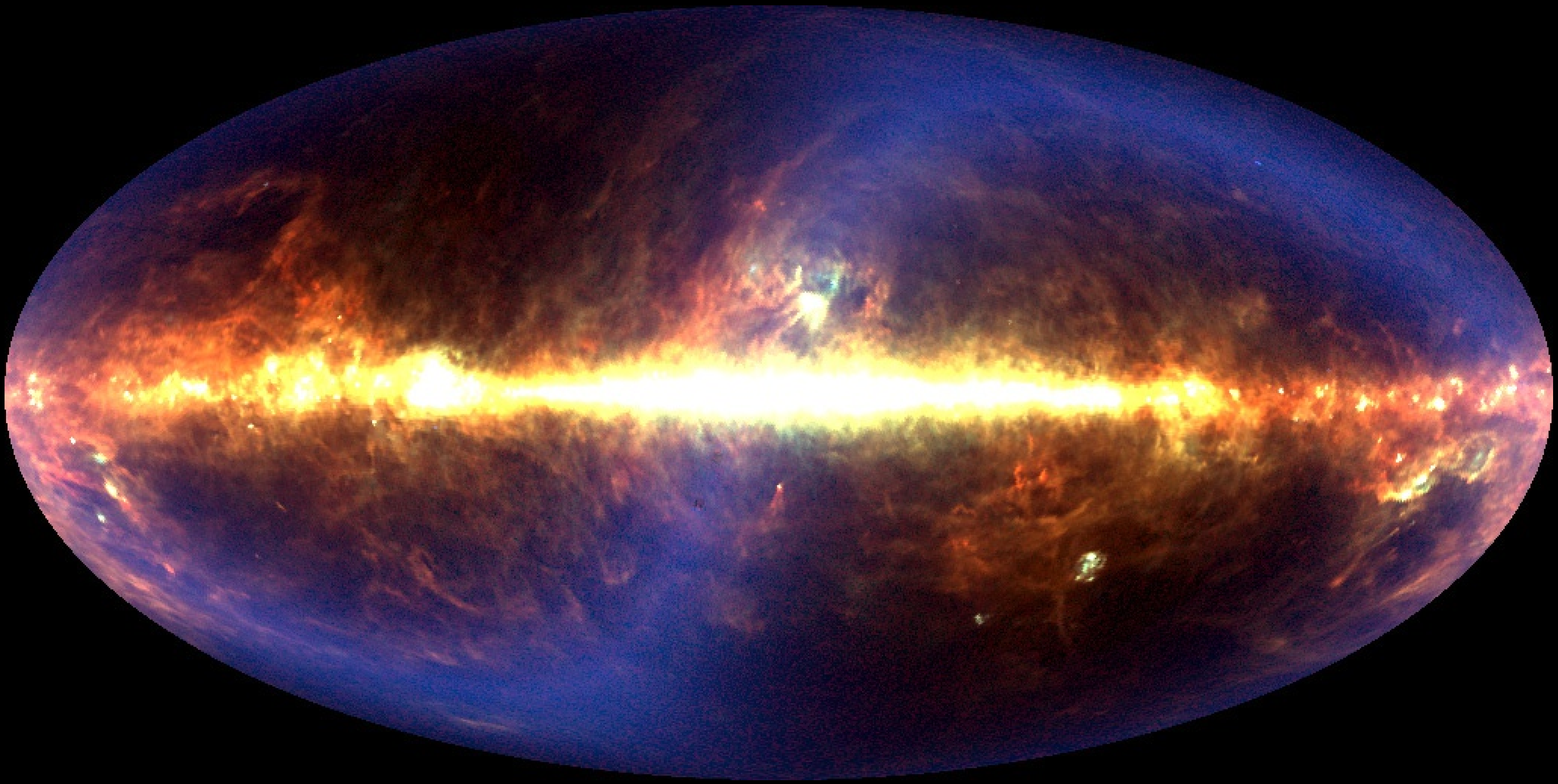
wise.astro.ucla.edu

Thanks!




THE ASTEROID IS CERTAIN TO HIT US! AND WHEN IT DOES, IT'LL DESTROY THIS WHOLE PLANET!
WE'RE DOOMED! DOOMED!!
NOTHING CAN SAVE US!"
V-615
1





Characteristics of Zodi Bands

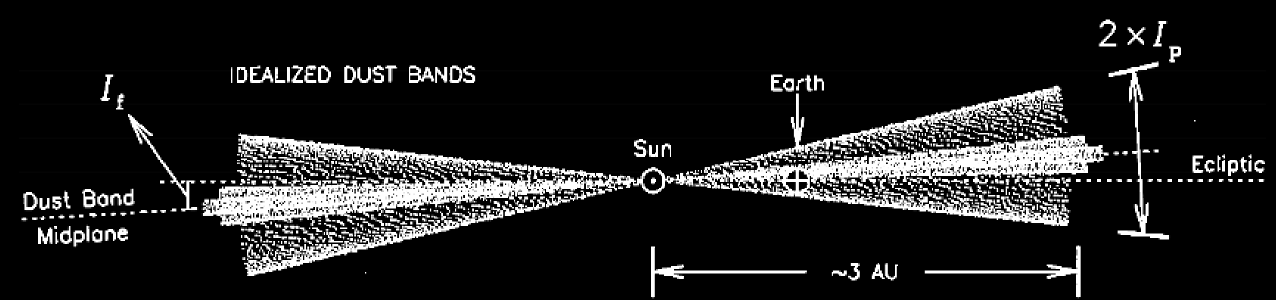
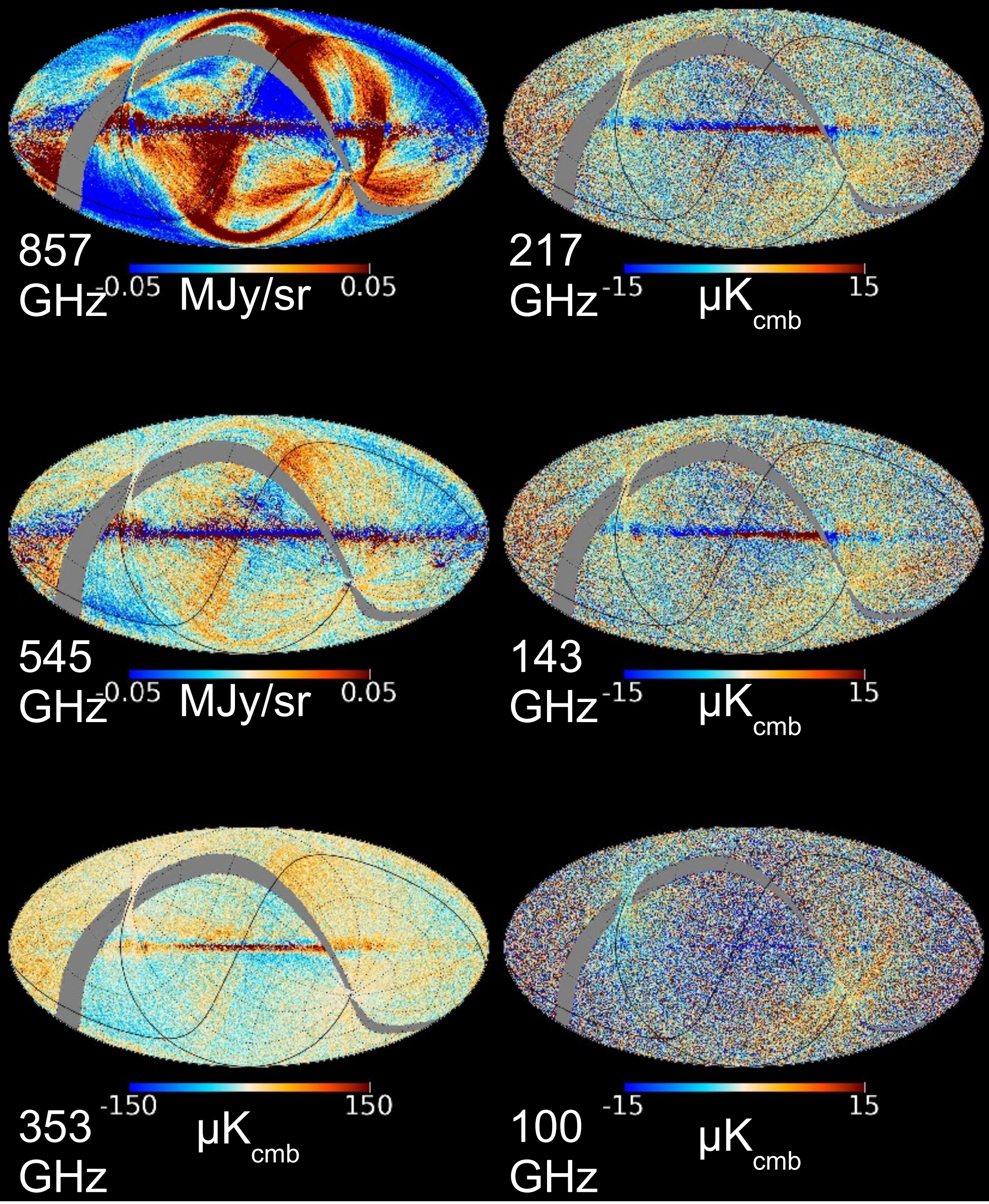


FIG. 2. Cross section through *idealized* dust bands. Dust particles are produced by the gradual comminution of asteroid families and decay toward the Sun under the influence of drag forces. The narrow Themis and Koronis dust bands are embedded within the wider Eos dust band. The angular width of each dust band is twice the proper inclination (I_p) of its parental asteroid family. The midplane of the dust bands is inclined to the ecliptic by the forced inclination (I_f). Earth (⊕) orbits the Sun within the dust bands. The spatial density of dust particles is enhanced near their extremes in latitude, which results in the "bands" of emission that were observed by the Infrared Astronomical Satellite (see Fig. 1).

Grogan et al. (2001)

The data


857 GHz
-0.05 MJy/sr 0.05
217 GHz
-15 μK cmb 15
545 GHz
-0.05 MJy/sr 0.05
143 GHz
-15 μK cmb 15
353 GHz
-150 μK cmb 150
100 GHz
-15 μK cmb 15