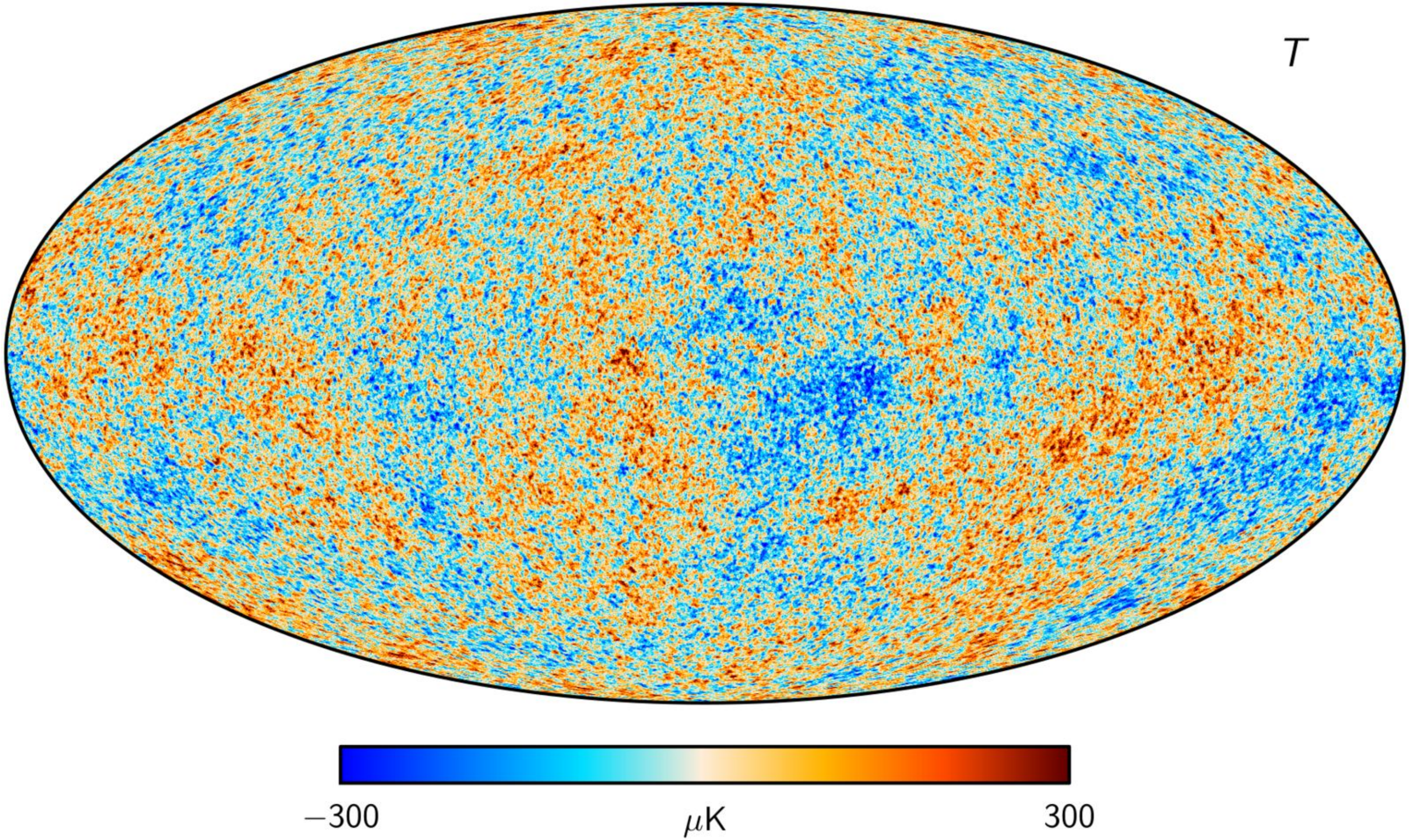
Cosmoglobe

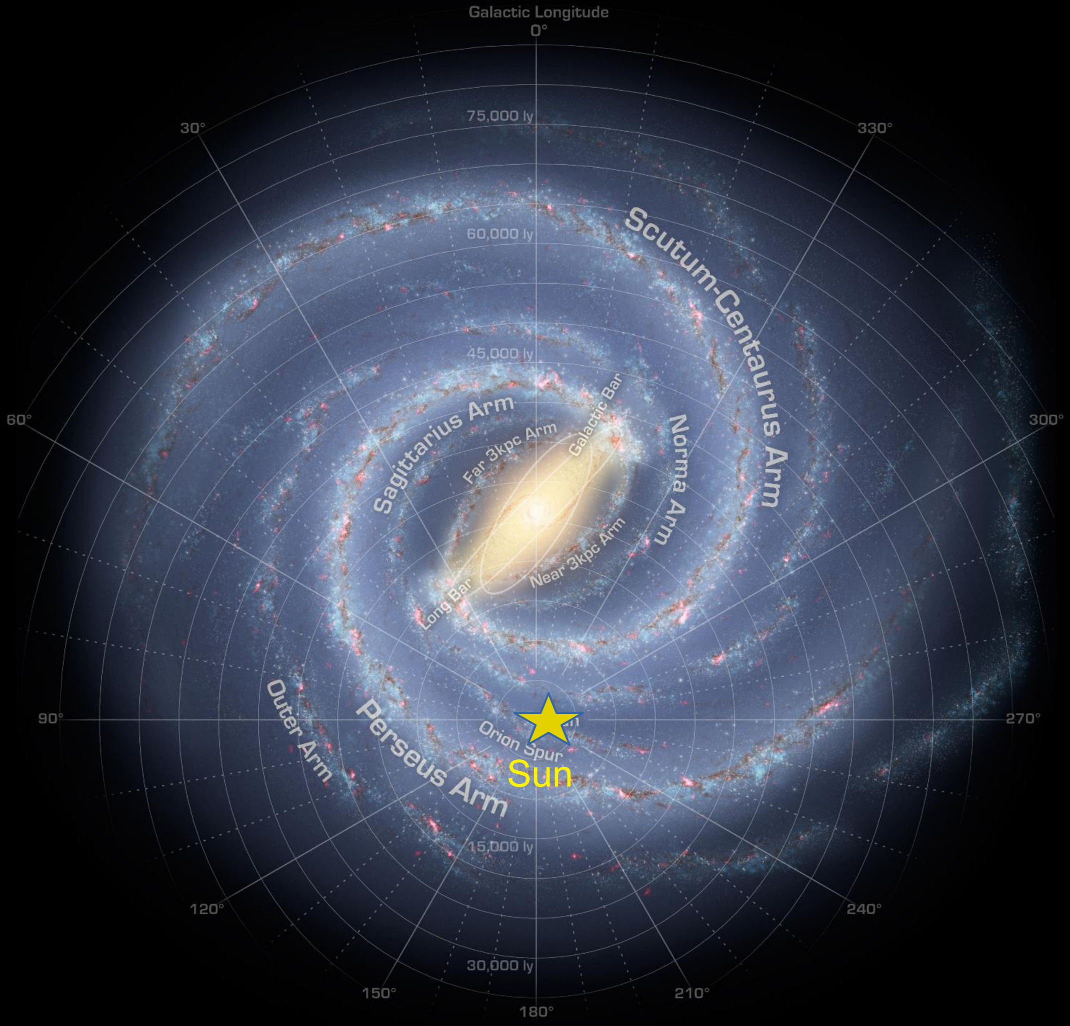
Cosmoglobe DR2: Global analysis of the microwave and infrared sky

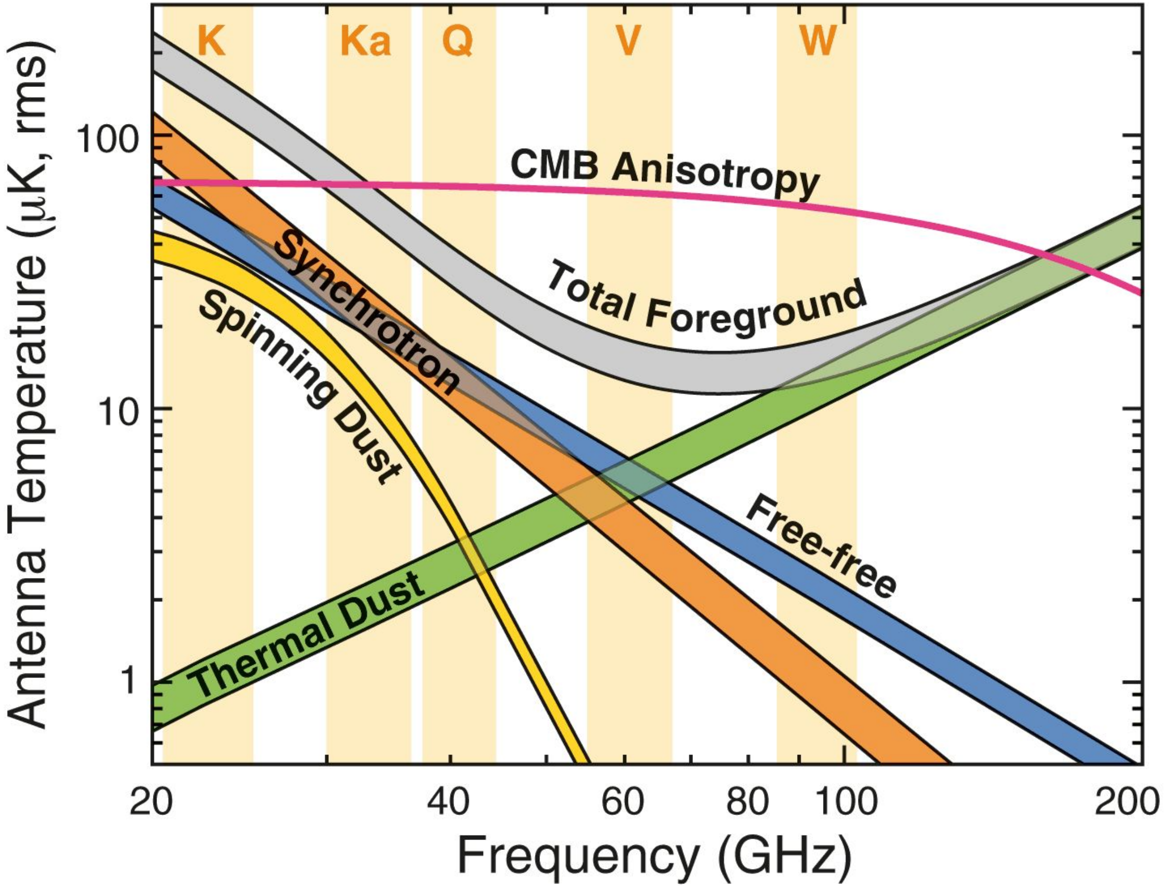
Eirik Gjerløw
University of Oslo

FIR 2025, 2-4 April 2025

The cosmic microwave background (CMB)

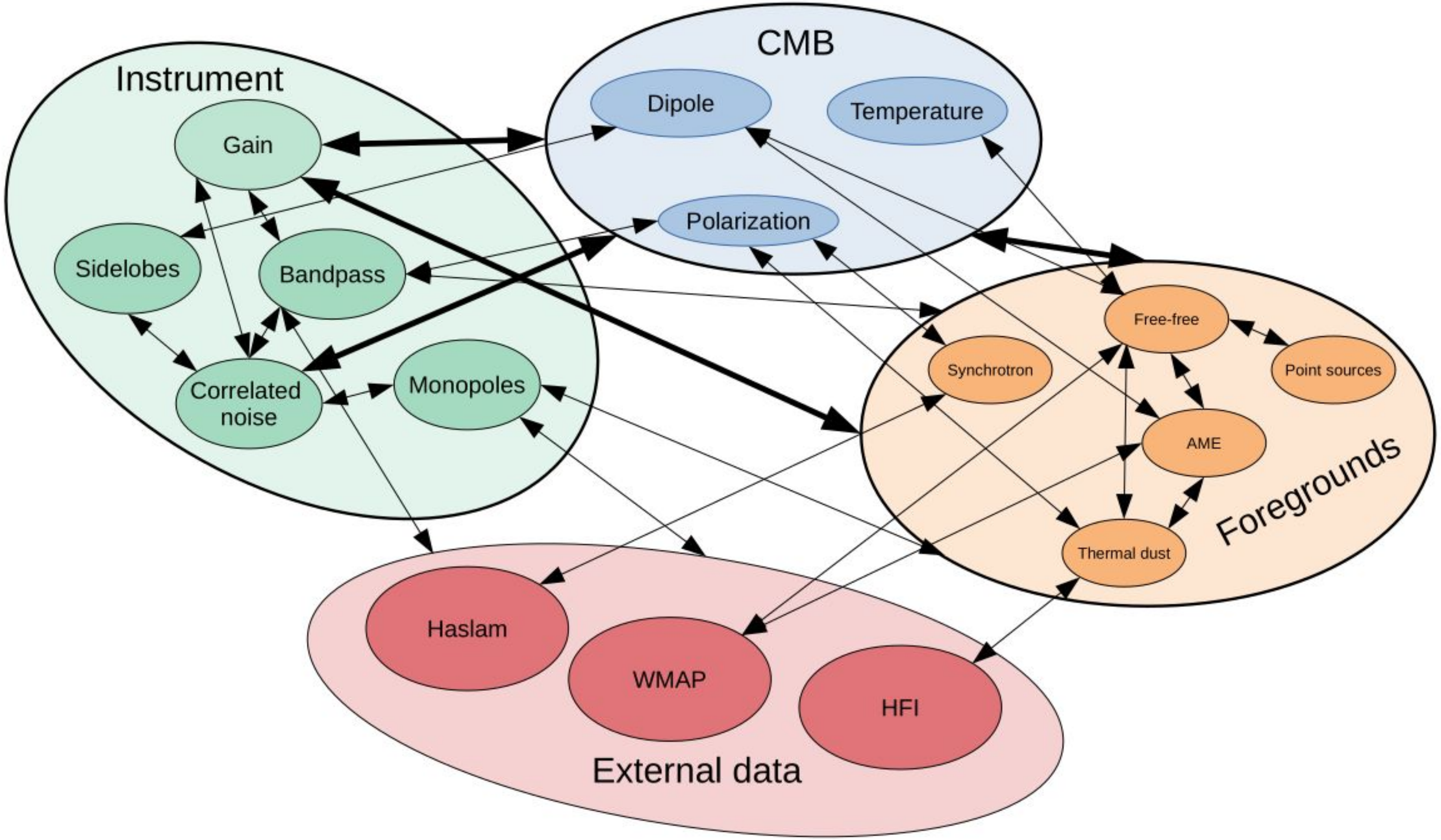



Galactic Longitude
0°
30°
330°
60°
300°
90°
270°
120°
240°
150°
210°
180°
75,000 ly
60,000 ly
45,000 ly
15,000 ly
30,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Far 3kpc Arm
Galactic Bar
Norma Arm
Near 3kpc Arm
Long Bar
Outer Arm
Perseus Arm
Orion Spur
Sun



K
Ka
Q
V
W
CMB Anisotropy
Total Foreground
Synchrotron
Spinning Dust
Free-free
Thermal Dust
Antenna Temperature (μK, rms)
100
10
1
20
40
60
80
100
200
Frequency (GHz)

Degeneracies between theory, astrophysics and instrumentation



Cosmoglobe algorithm in one slide

1. Write down an explicit parametric model for the observed data:

$$d_{j,t} = g_{j,t}\mathsf{P}_{tp,j}\left[\mathsf{B}^{\mathrm{symm}}_{pp',j}\sum_{c}\mathsf{M}_{cj}(\beta_{p'},\Delta^{j}_{\mathrm{bp}})a^{c}_{p'} + \mathsf{B}^{\mathrm{asymm}}_{j,t}\left(\boldsymbol{s}^{\mathrm{orb}}_{j} + \boldsymbol{s}^{\mathrm{fsl}}_{t}\right)\right] + n^{\mathrm{corr}}_{j,t} + n^{\mathrm{w}}_{j,t}.$$

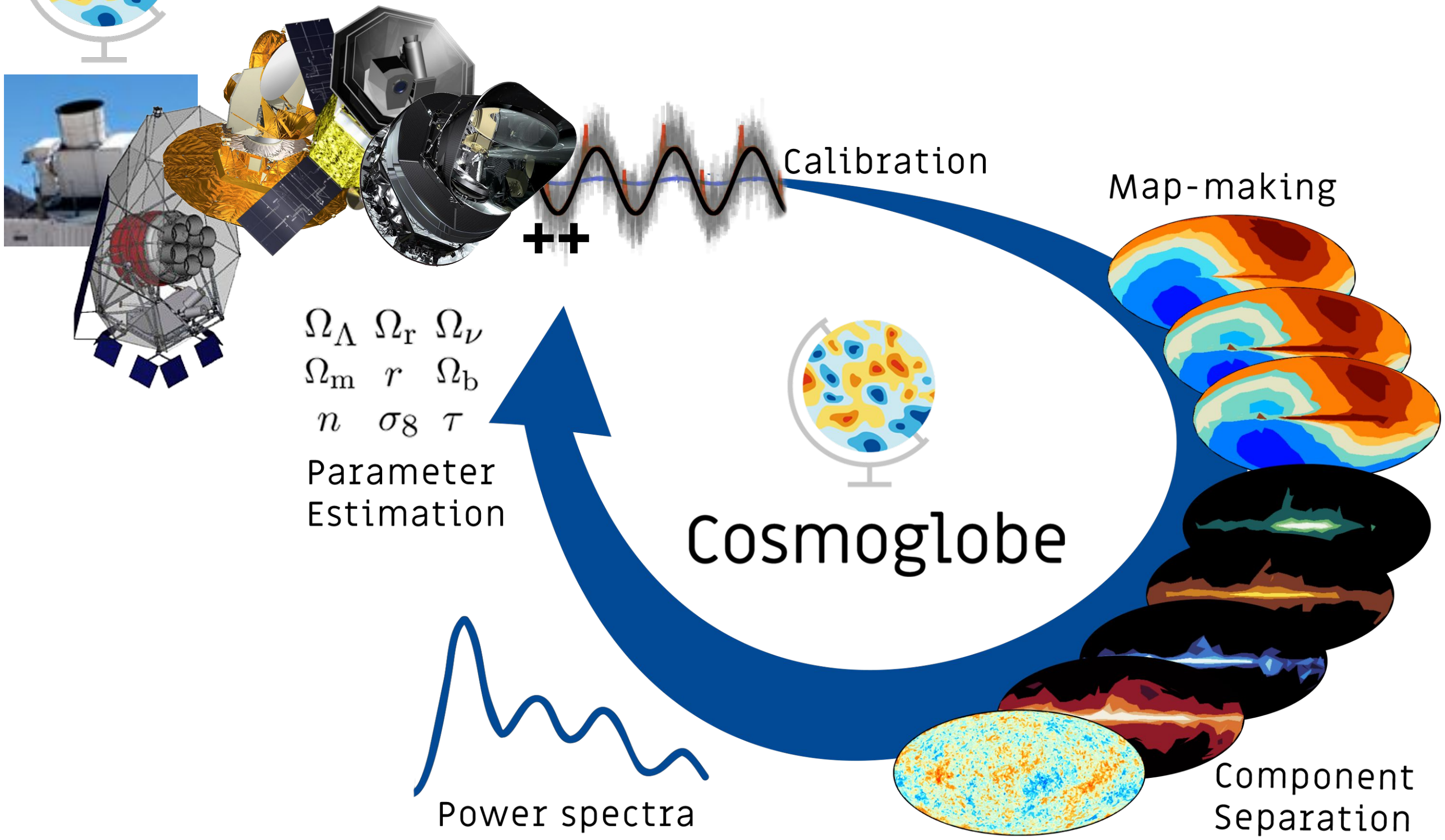
Let ω = {all free parameters}

2. Derive the joint posterior distribution with Bayes' theorem:

$$P(\omega \mid \boldsymbol{d}) = \frac{P(\boldsymbol{d} \mid \omega)P(\omega)}{P(\boldsymbol{d})} \propto \mathcal{L}(\omega)P(\omega),$$

3. Map out $P(\omega \mid \boldsymbol{d})$ with standard Markov Chain Monte Carlo (MCMC) methods, in particular Gibbs sampling

Global end-to-end analysis pipeline



Global analysis proof of concept:
BeyondPlanck - reanalysis of Planck LFI data

- Included data
  - ***Planck LFI 30, 44 and 70 GHz* time-ordered data**
  - ***Planck 857 GHz*** to constrain thermal dust intensity
  - ***Planck 353 GHz*** polarization-only to constrain thermal dust polarization
  - ***WMAP 33-61 GHz*** in T+P to constrain low-frequency foregrounds
  - ***Haslam 408 MHz*** to constrain synchrotron intensity
- Intermediate *Planck HFI* and *WMAP 23 GHz* data were ***not*** included, becau
  they have higher signal-to-noise ratios than Planck LFI

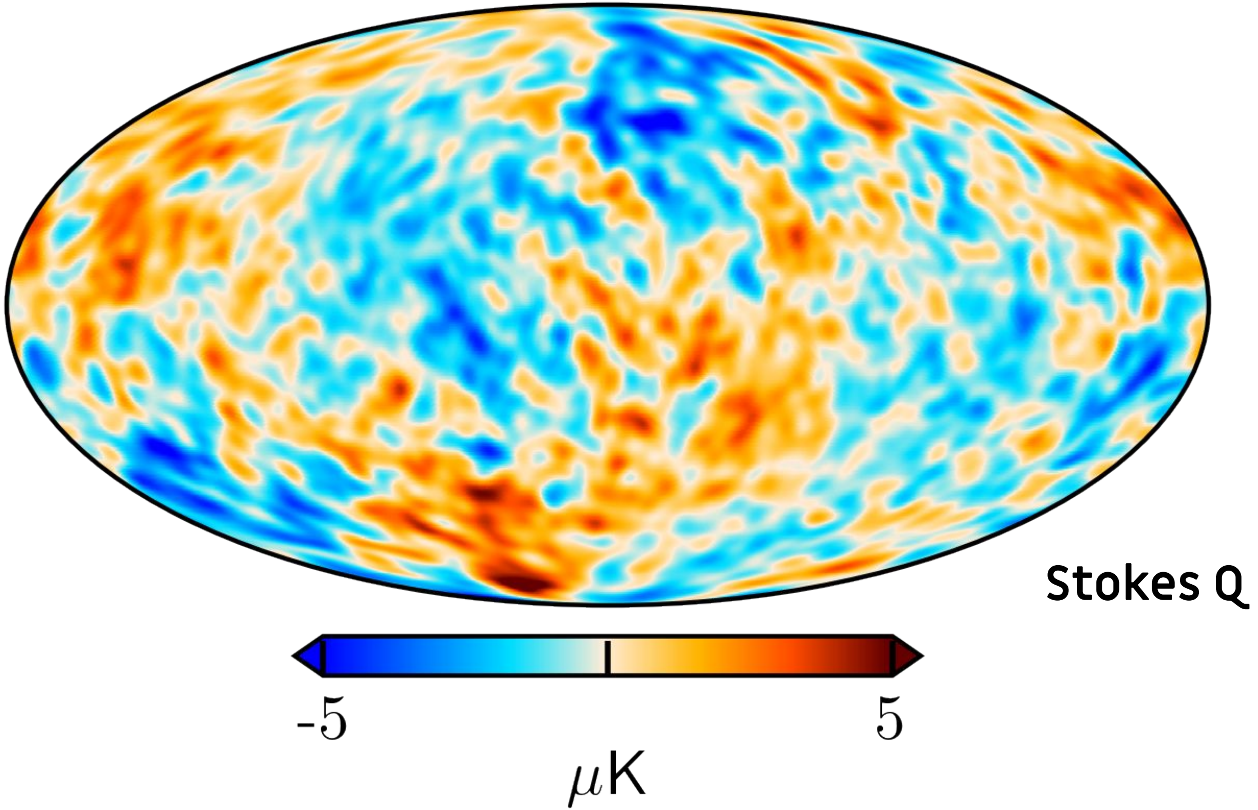
Cosmoglobe DR1: WMAP reanalysis

- Included data
    - ***WMAP 23-94 GHz time-ordered data***
    - ***Planck LFI 30, 44 and 70 GHz*** time-ordered data
    - ***Planck 857 GHz*** to constrain thermal dust intensity
    - ***Planck 353 GHz*** polarization-only to constrain thermal dust polarization
    - ***Haslam 408 MHz*** to constrain synchrotron intensity
- Intermediate *Planck HFI* still not included

Duncan Watts

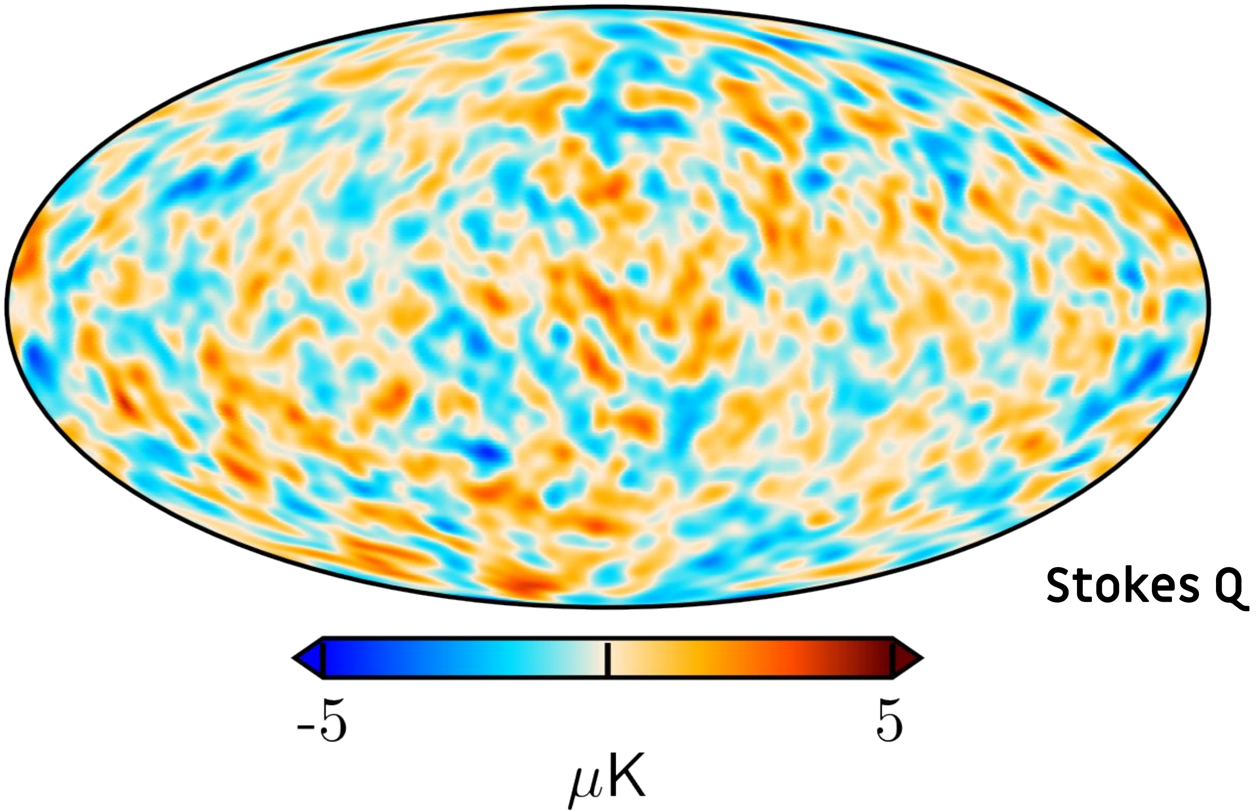
Cosmoglobe DR1: WMAP reanalysis

WMAP Q-band internal detector (Q1-Q2)/2 difference map: 9-year

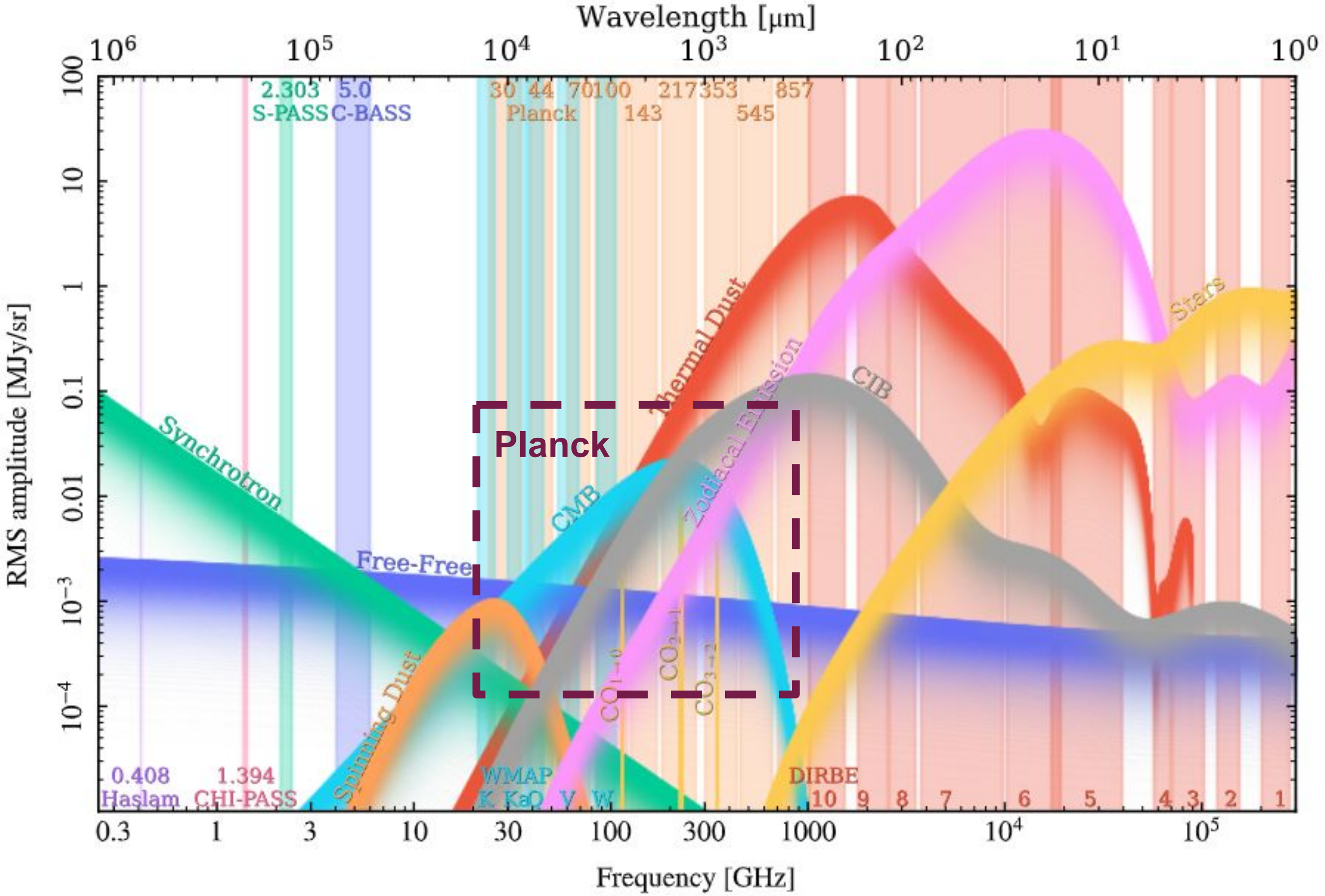


Cosmoglobe DR1: WMAP reanalysis

WMAP Q-band internal detector (Q1-Q2)/2 difference map: Cosmoglobe



Cosmoglobe DR2: DIRBE and the infrared sky



Cosmoglobe DR2 data (or: Cosmoglobe moves into the FIR-MIR regime)

- **DIRBE TODs for 10 wavelength bands between 1.25 and 240 μm**

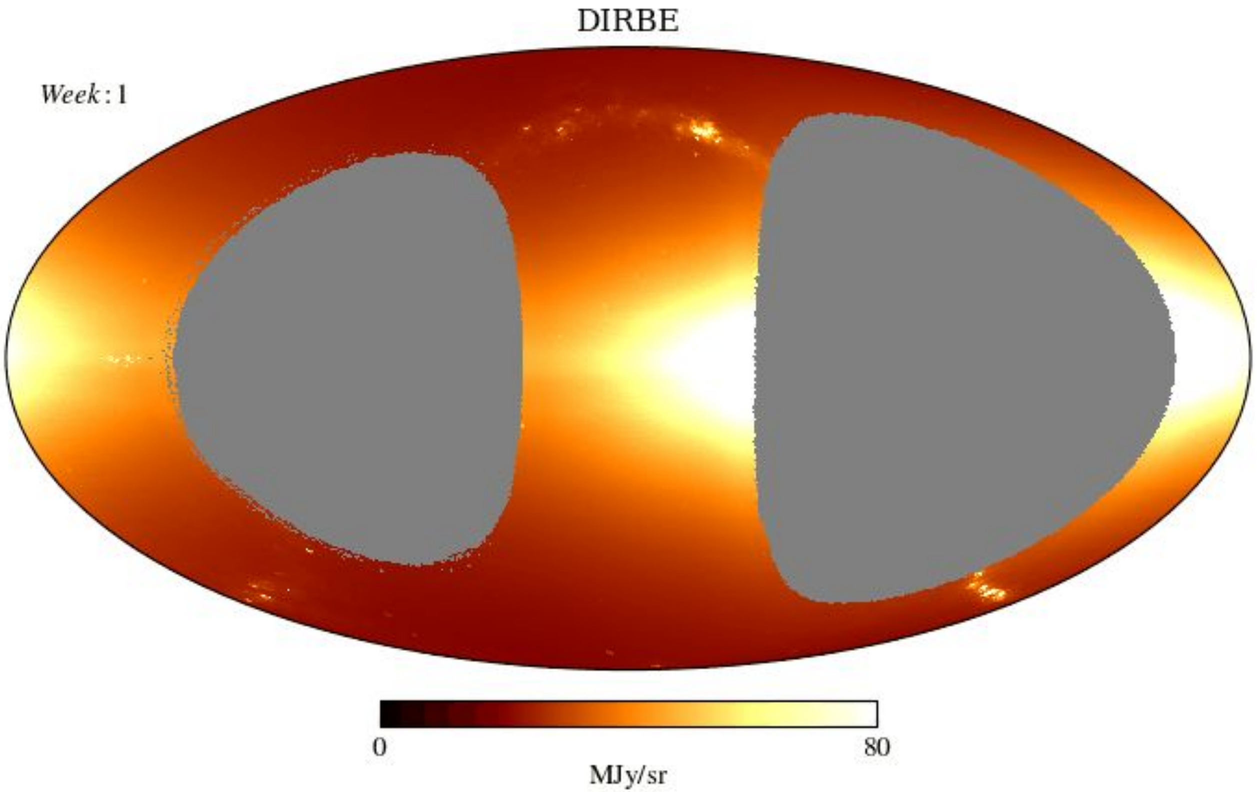
- Planck HFI DR4 Maps for 100 - 857 GHz
    - Pre-subtracted CMB and zodiacal light emission

- WISE point source catalog for identifying sources between 1.25 and 25μm

- GAIA for identifying star parameters, coupled to tabulated PHOENIX model spectra

- FIRAS Low-resolution maps, included for cross-checking calibration

Major new feature: Time-domain Zodiacal light modeling



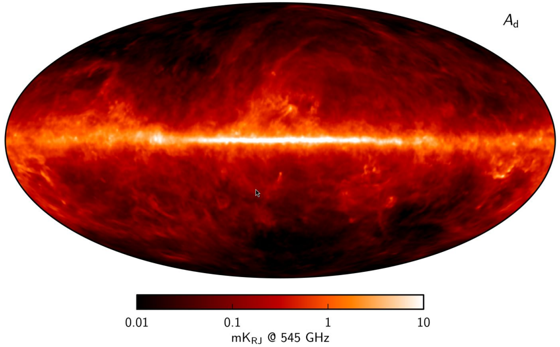
San et al.
2408.11004

One vs. three-component thermal dust model

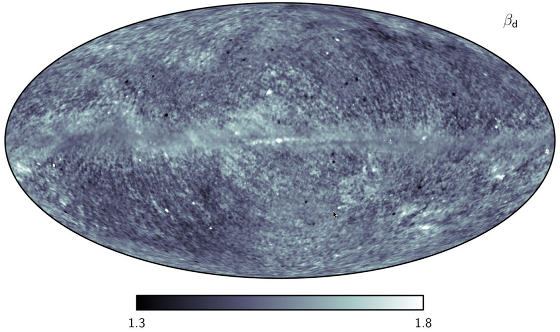
- One MBB dust component with spatially varying spectral parameters

- Three free parameters per pixel, only fits 30-1000 GHz

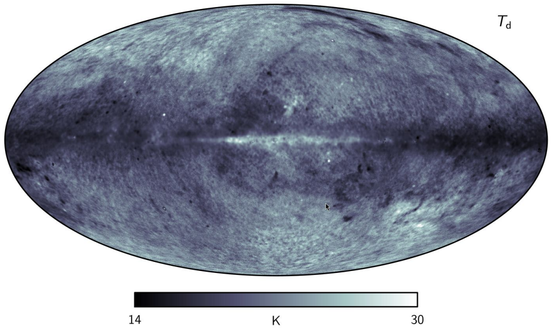
Amplitude



Planck



Spectral index, β, per pixel

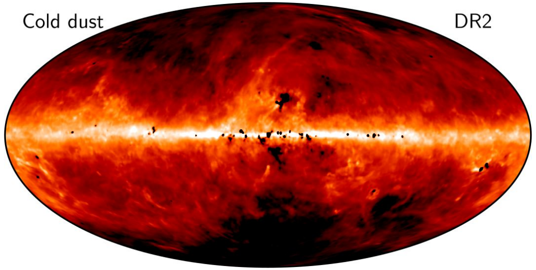


Temperature, *T*, per pixel

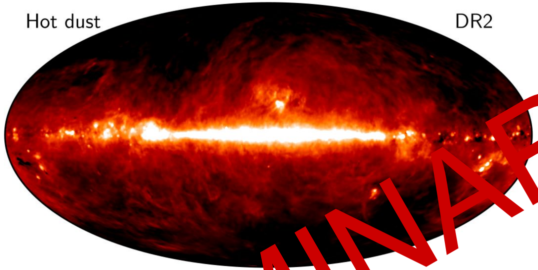
One vs. three-component thermal dust model

Cosmoglobe

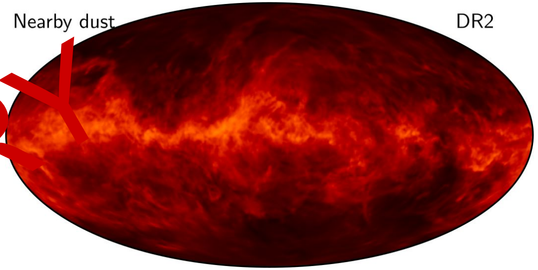
Cold dust



Hot dust



Near-by dust



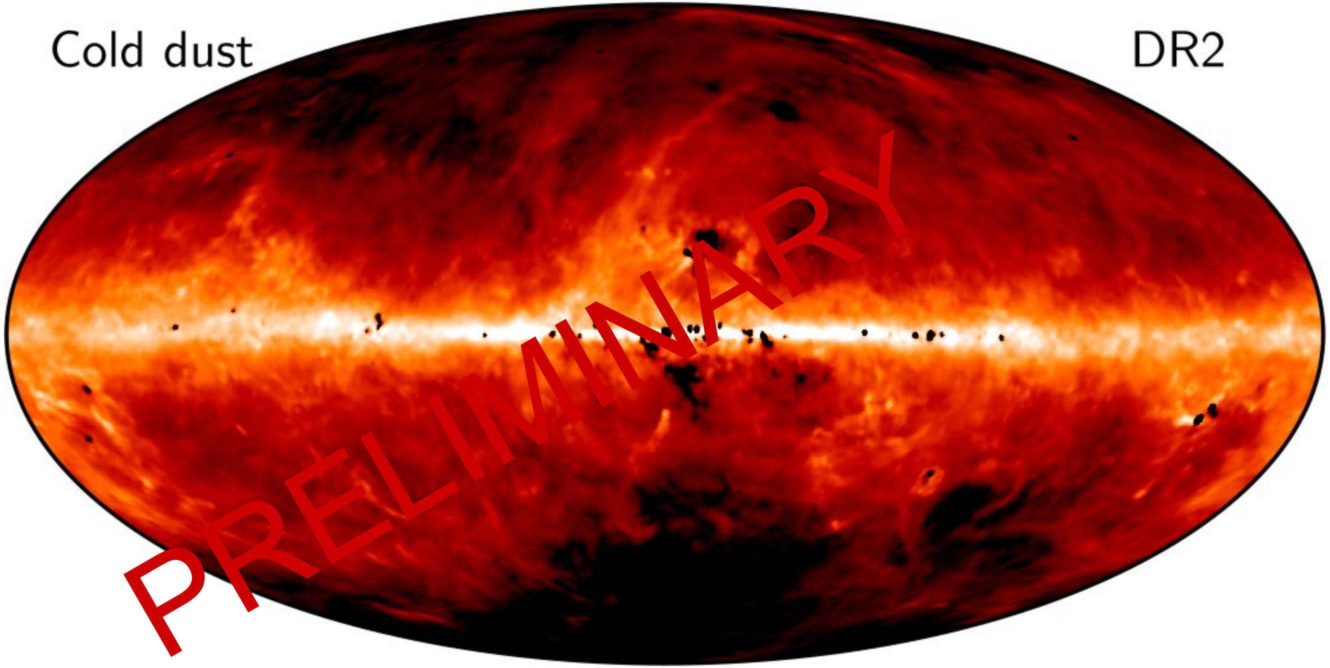
β = 1.59	T = 16.4K	β = 1.65	T = 26.9K	β = 1.50	T = 23.9K

PRELIMINARY

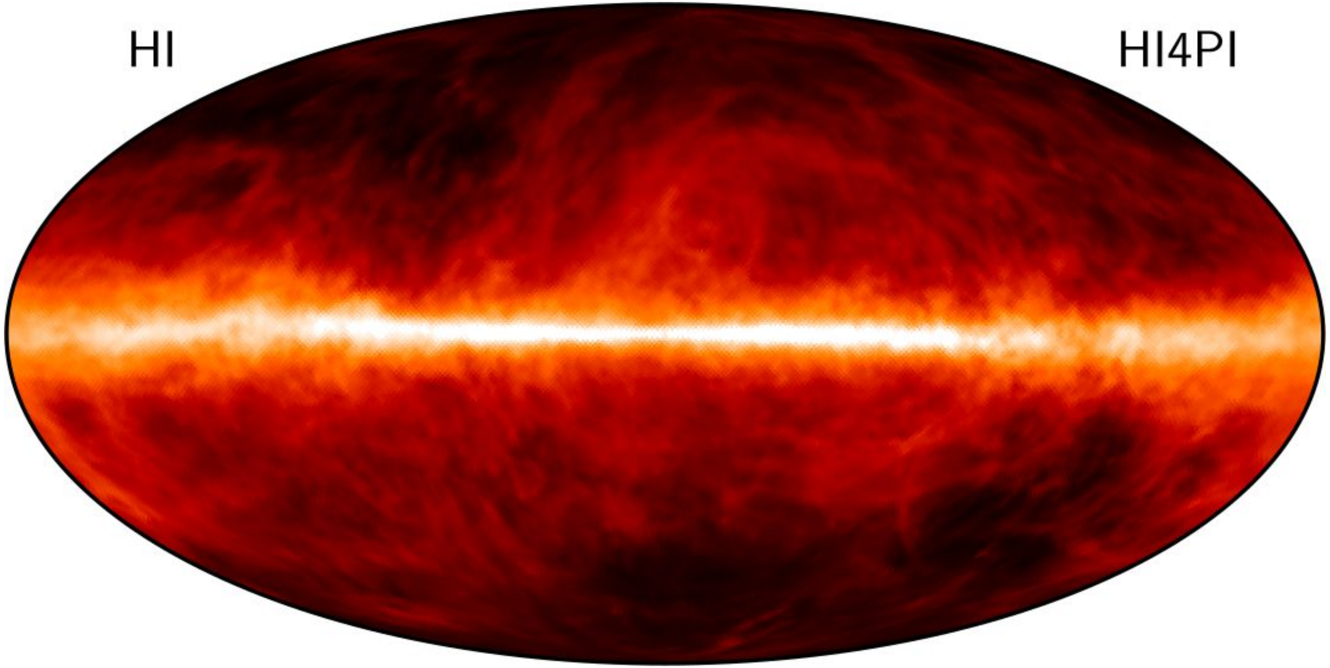
- Three MBB components, but each with spatially constant spectral parameters
- The spatial amplitude of the near-by dust is defined by GAIA absorption by Edenhofer et al.
- Only *two* free parameters per pixel; fits the entire frequency range from ~100 GHz to ~1μm surprisingly well

Eirik Gjerløw

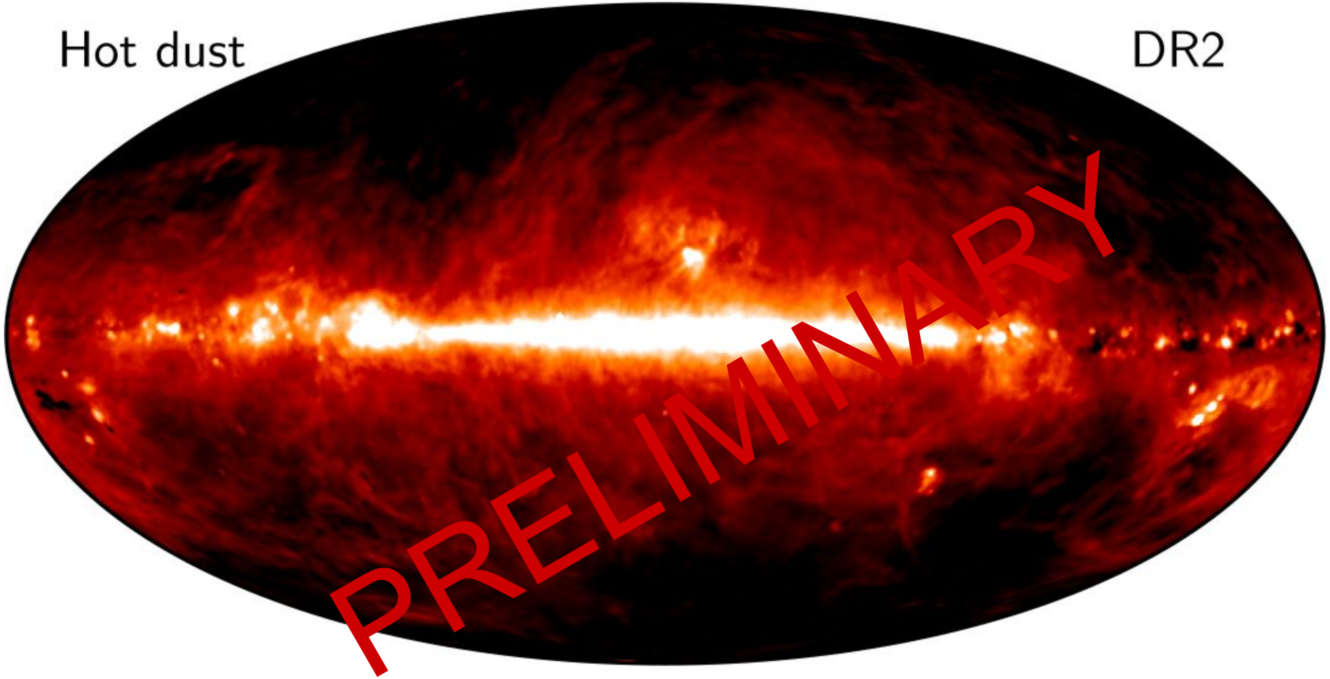
Cosmoglobe DR2 ***cold*** thermal dust component



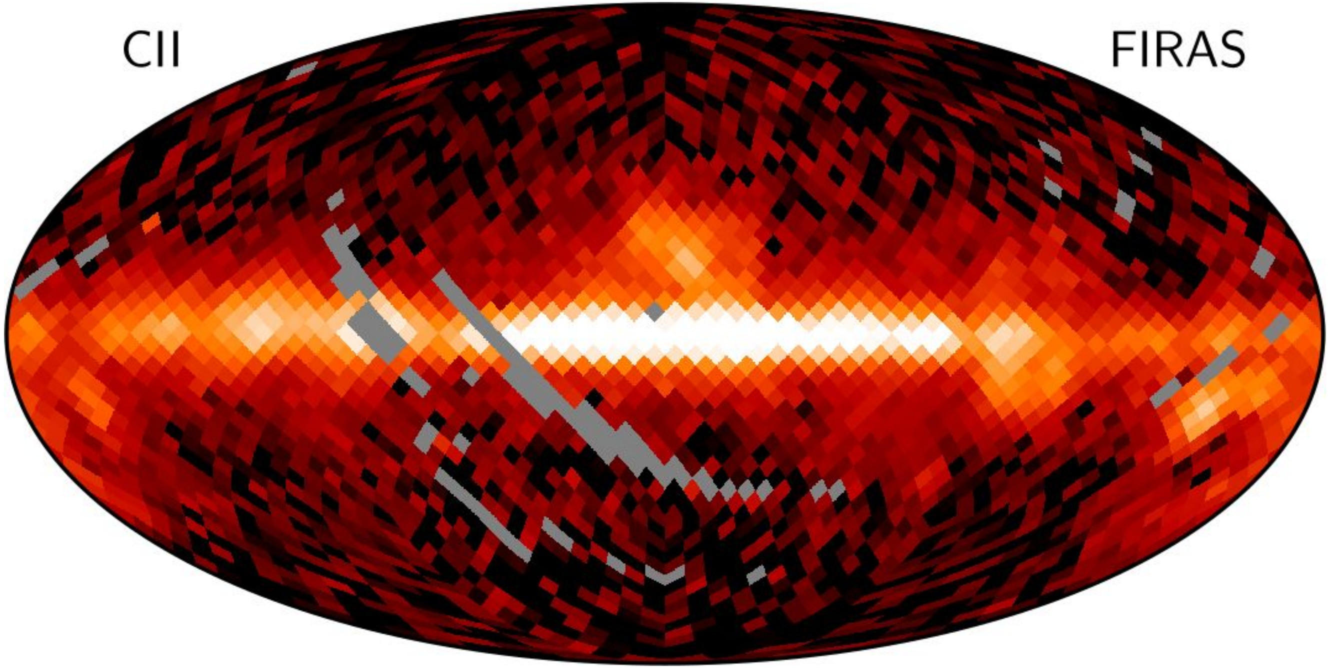
HI4PI (atomic hydrogen) map



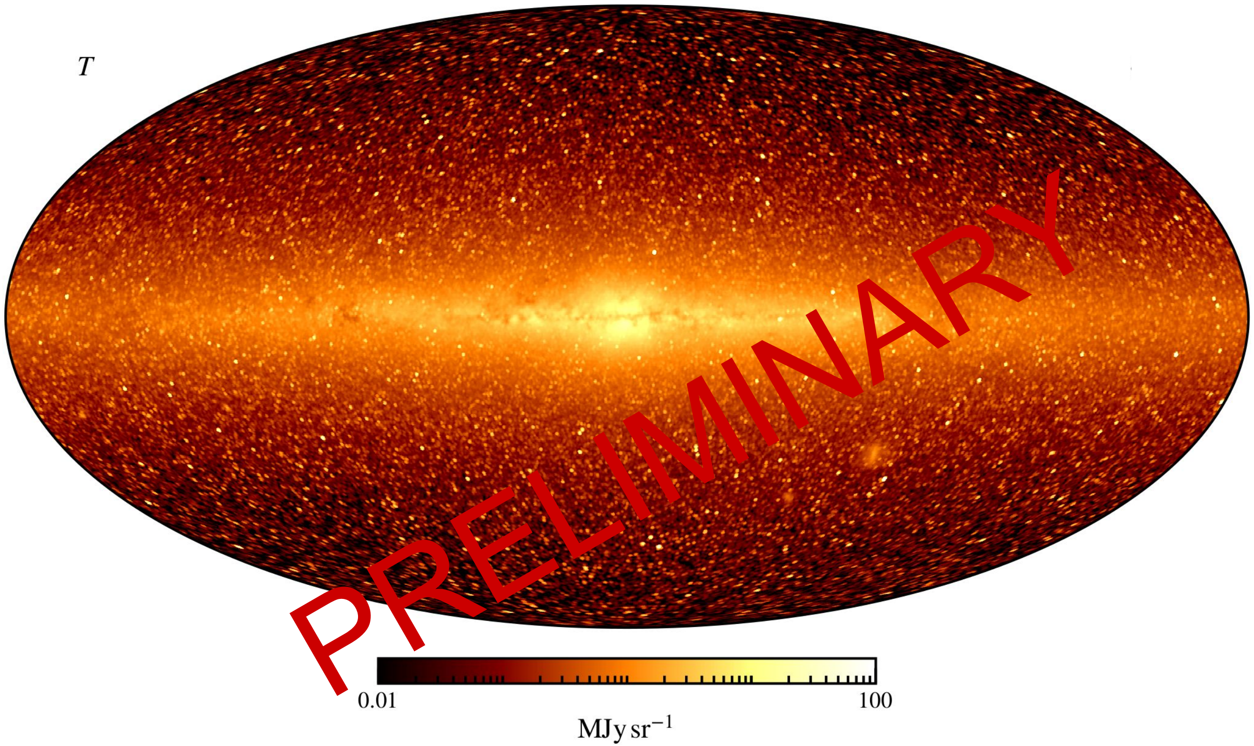
Cosmoglobe DR2 ***hot*** dust component



COBE/FIRAS C_{II} line emission amplitude

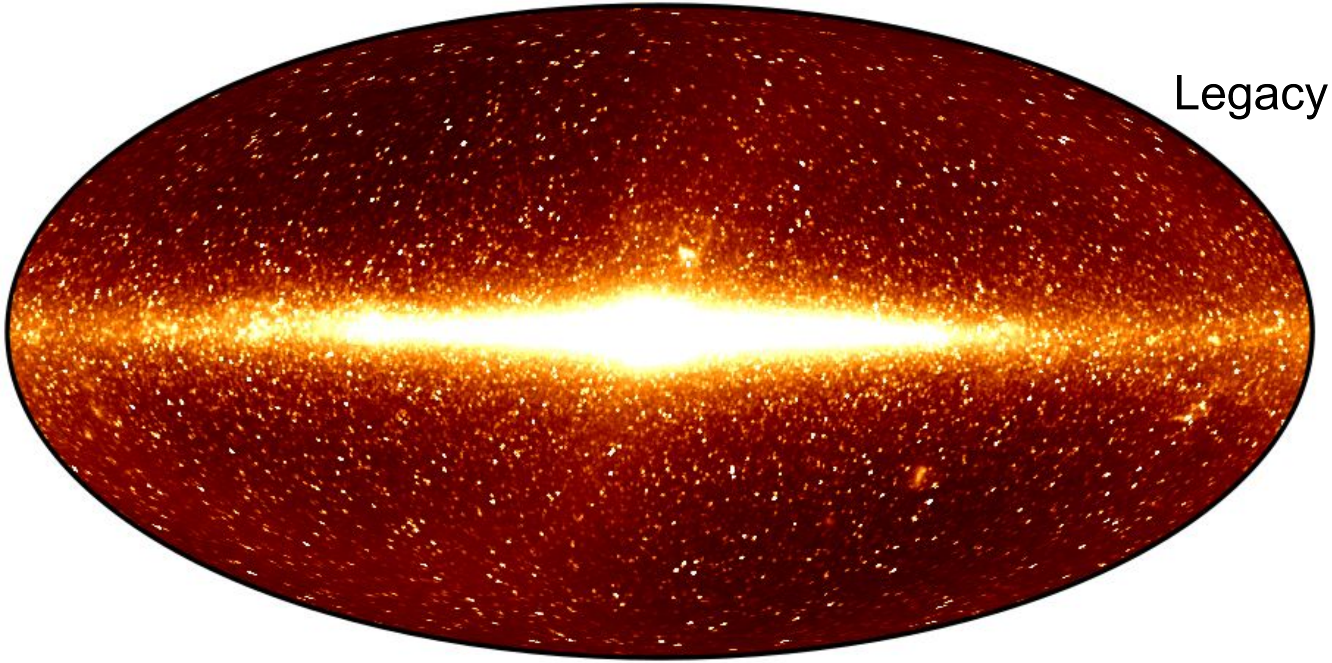


Cosmoglobe DR2 preview: Fitting star by star



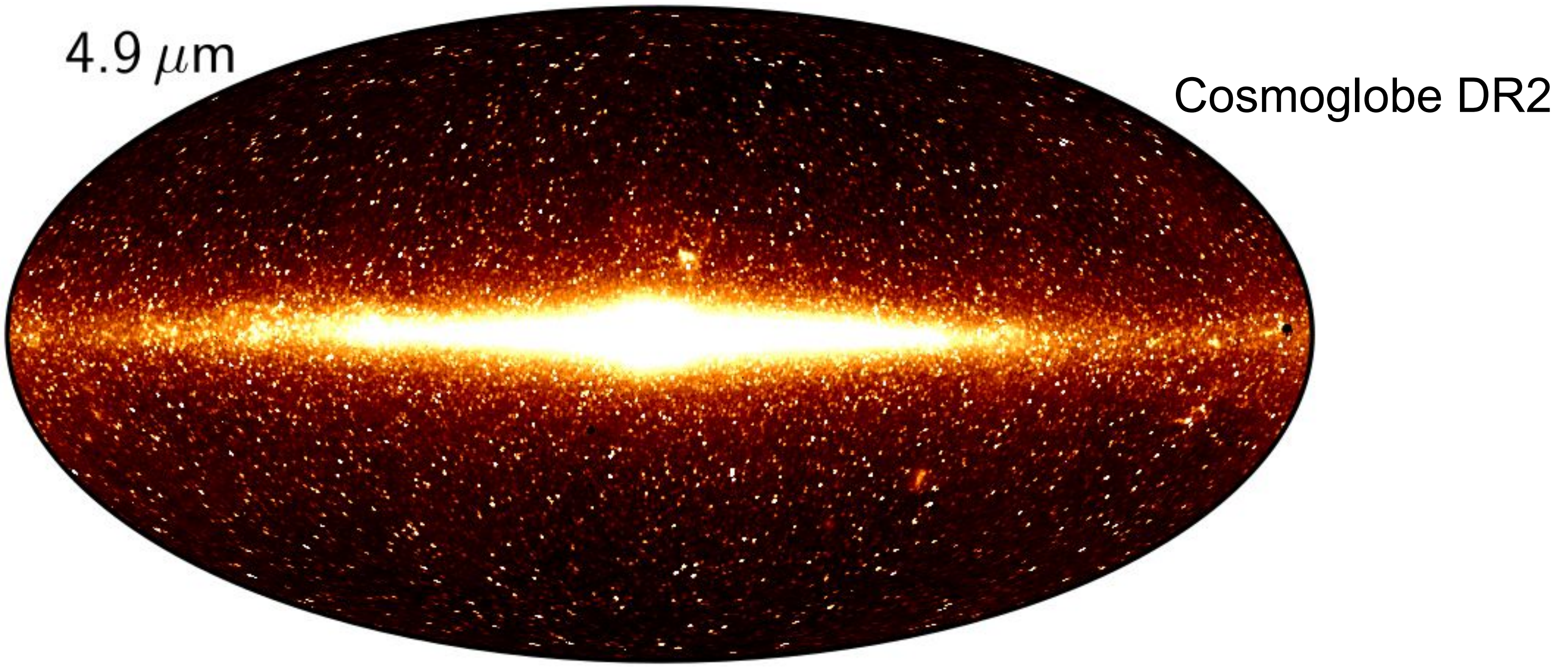
Mathew Galloway

Cosmoglobe DR2 versus legacy DIRBE at **4.9 μm**

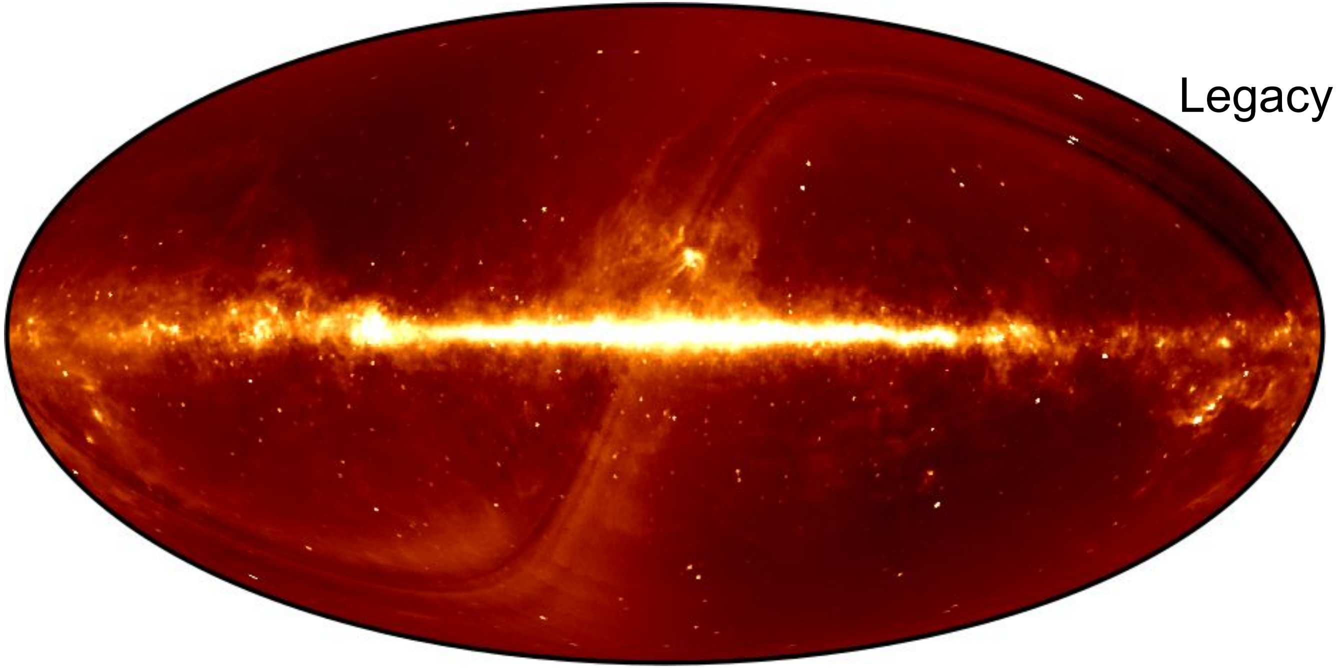


Legacy DIRBE

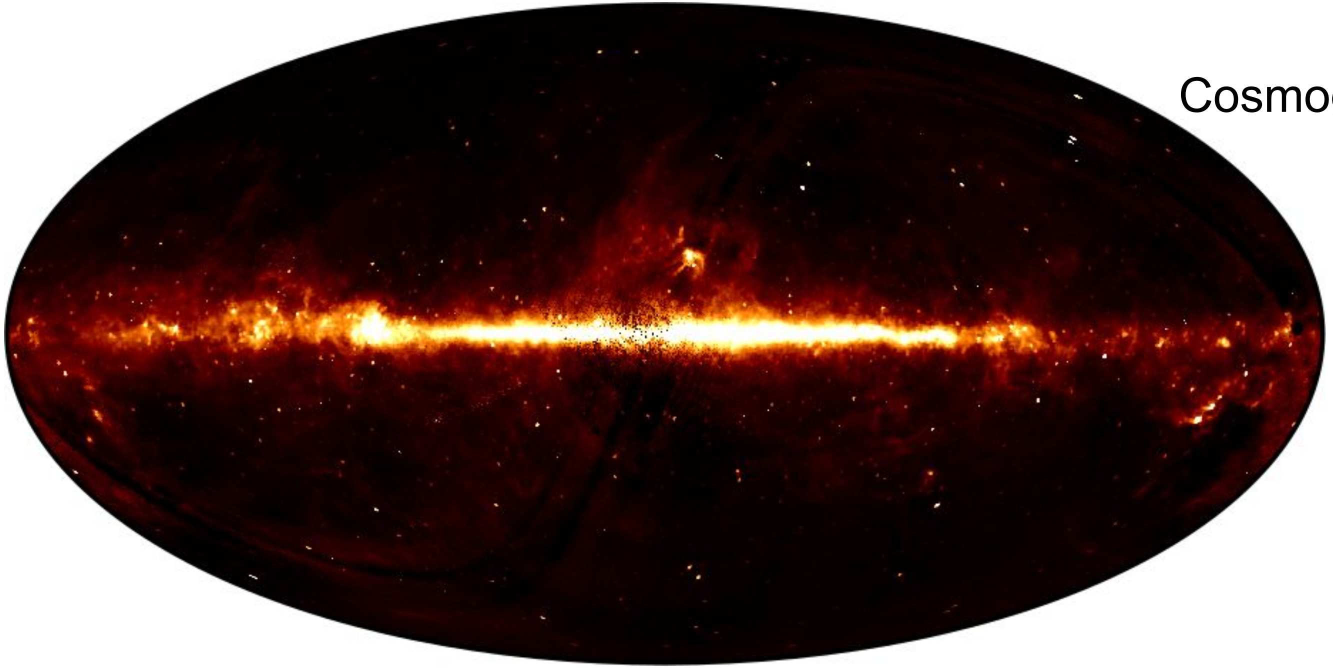
Cosmoglobe DR2 versus legacy DIRBE at **4.9 μm**



Cosmoglobe DR2 versus legacy DIRBE at **12 μm**

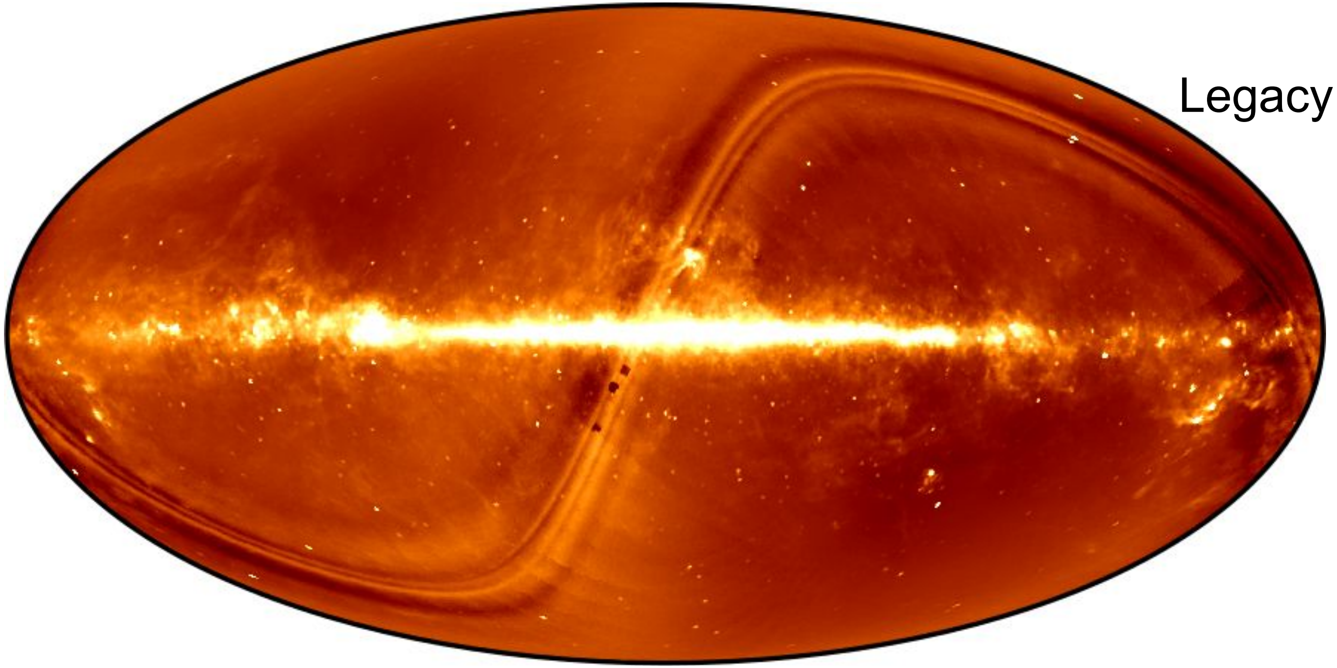


Cosmoglobe DR2 versus legacy DIRBE at **12 μm**



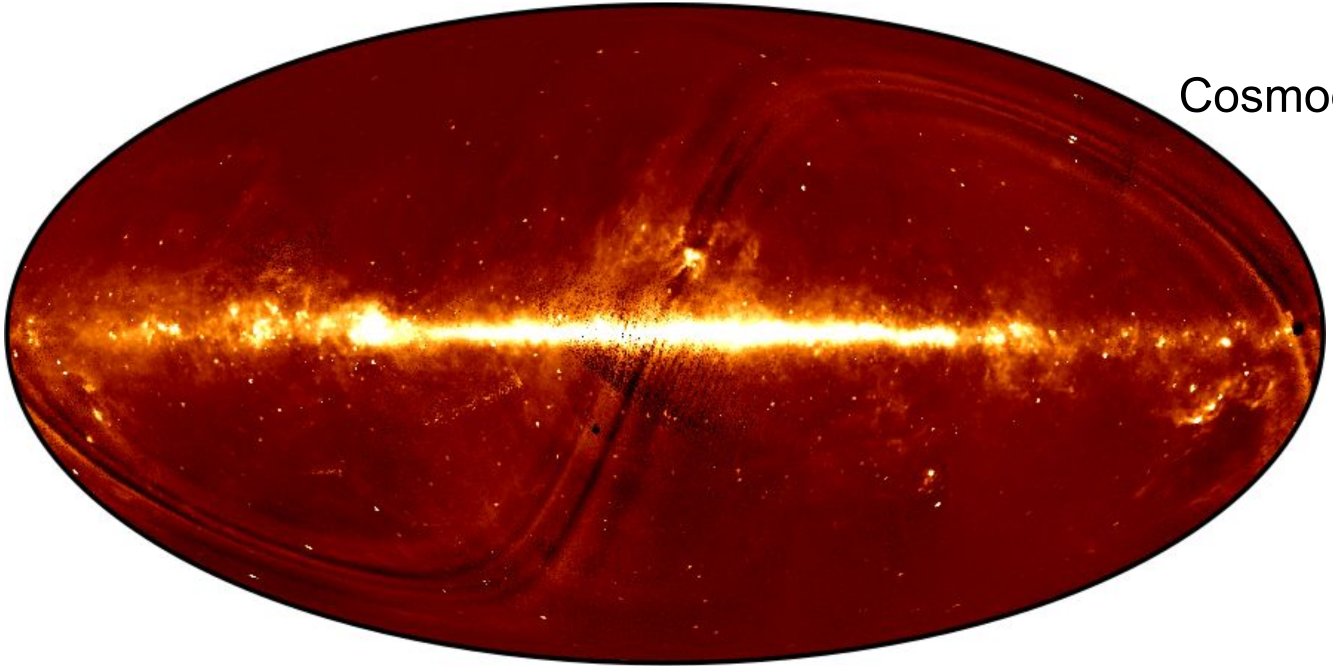
Cosmoglobe DR2

Cosmoglobe DR2 versus legacy DIRBE at **25 μm**



Legacy DIRBE

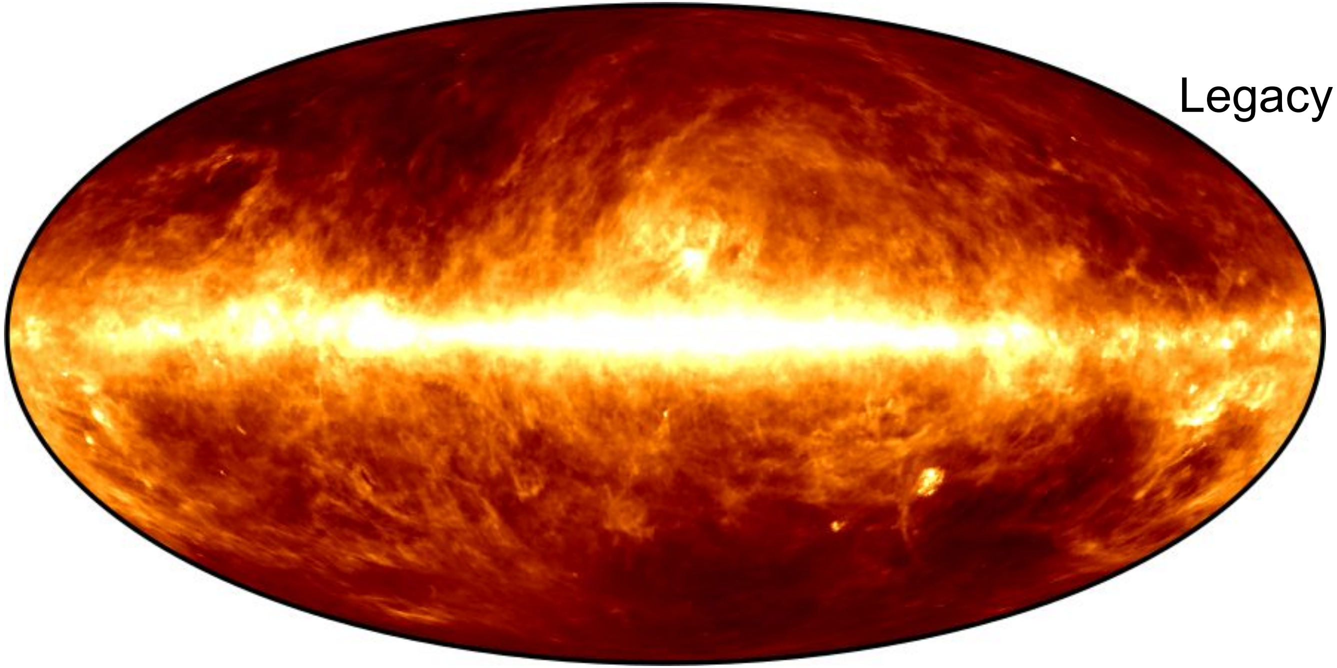
Cosmoglobe DR2 versus legacy DIRBE at **25 μm**



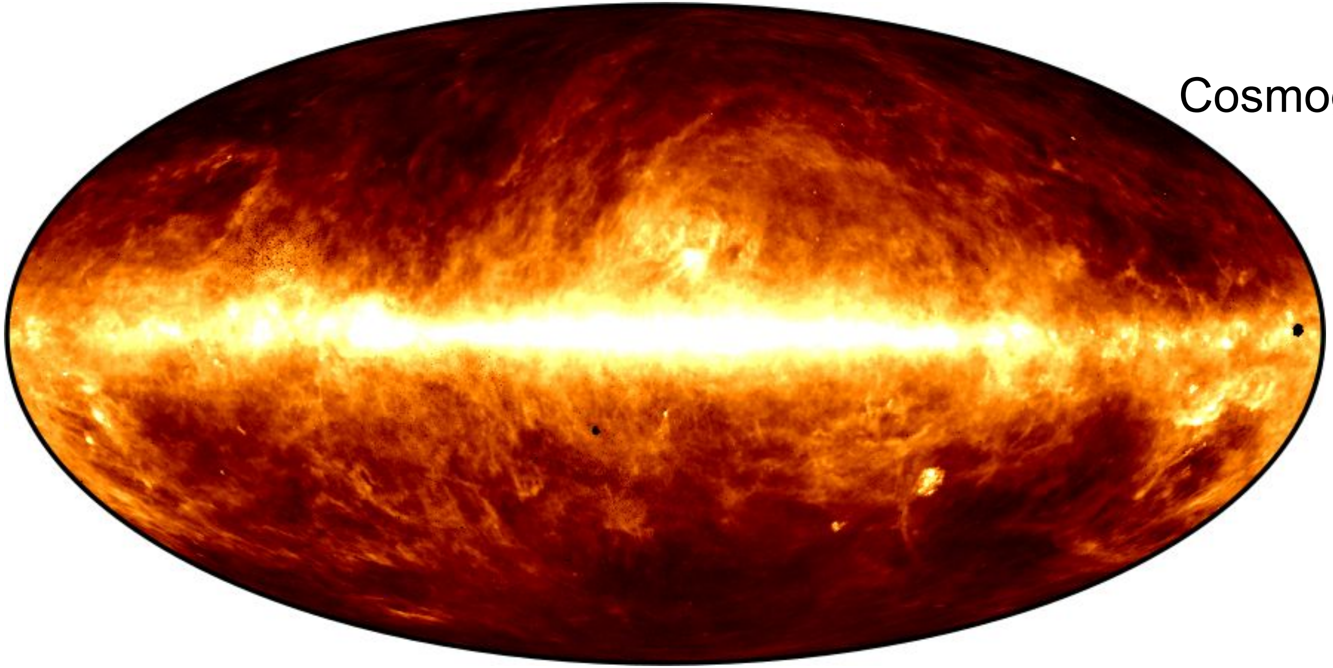
Cosmoglobe DR2

Still work to be done on zodi fitting in Cosmoglobe – need help from AKARI, IRAS and others

Cosmoglobe DR2 versus legacy DIRBE at **100 μm**



Cosmoglobe DR2 versus legacy DIRBE at **100 μm**

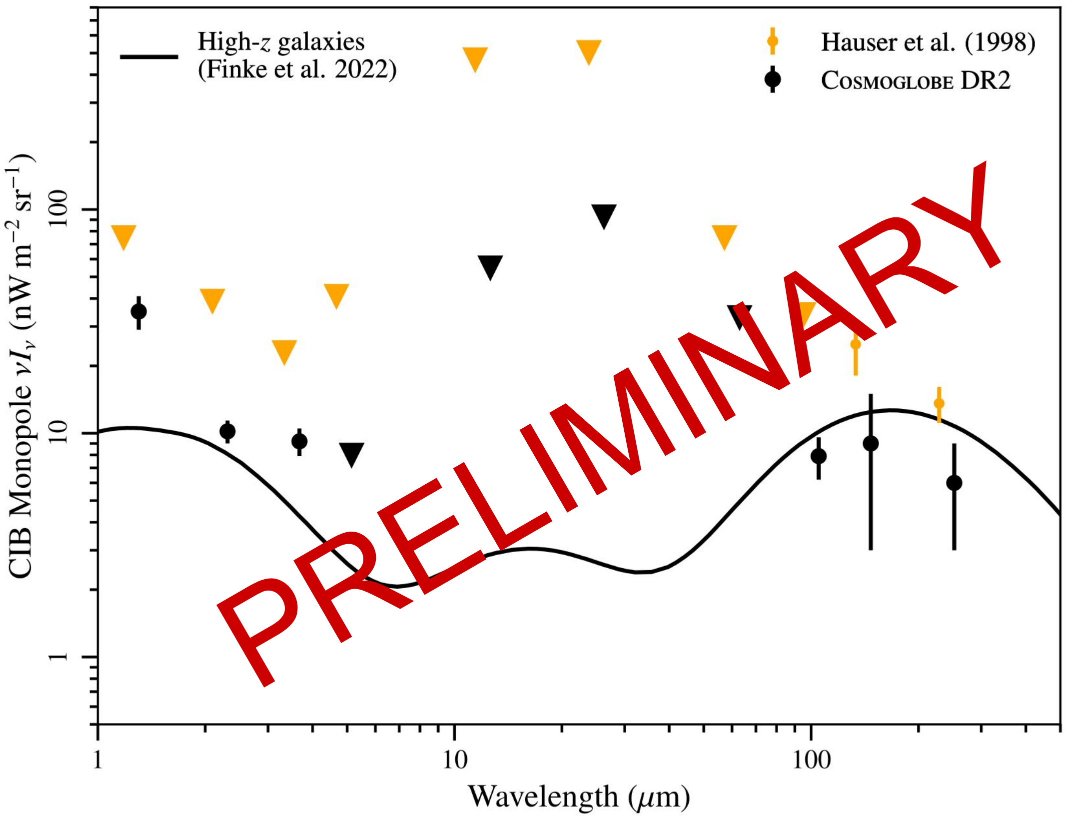


Cosmoglobe DR2

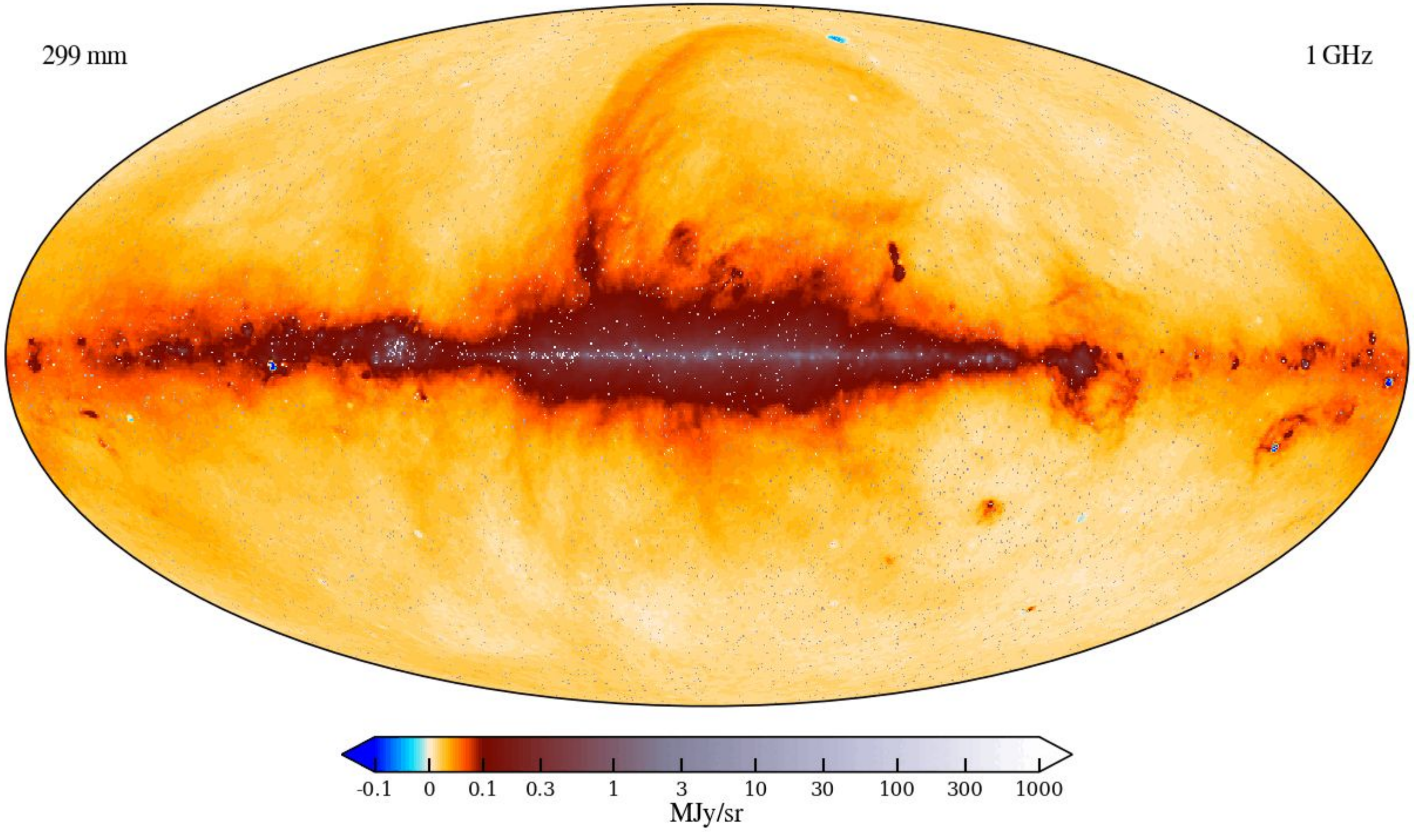
The DIRBE 100 μm map has been a cornerstone for Galactic and CMB dust modelling for three decades

⇒ significant zodiacal light contamination in all published products derived from this map

Cosmoglobe DR2: The CIB monopole spectrum

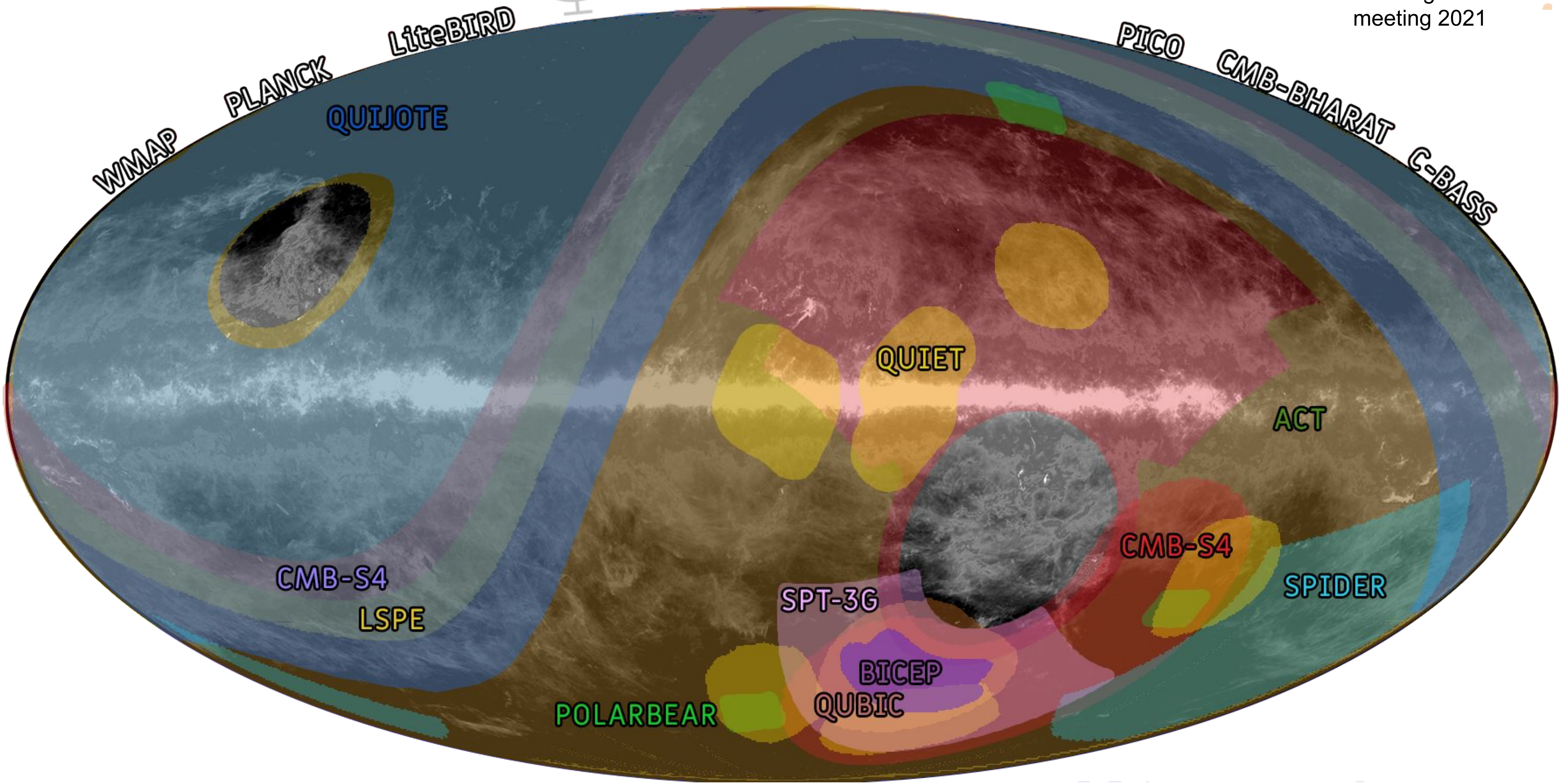


Cosmoglobe DR2 Sky Model



Cosmoglobe

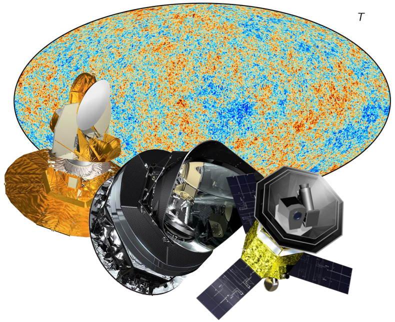
Figure from
Cosmoglobe Kickoff
meeting 2021



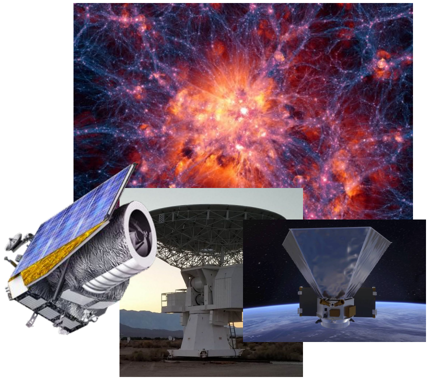
Cosmoglobe

-mapping the universe from the Milky Way to the Big Bang

Early universe

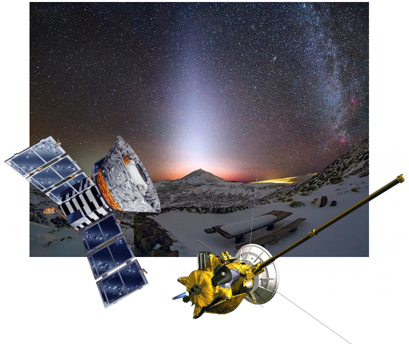


Large-scale structure



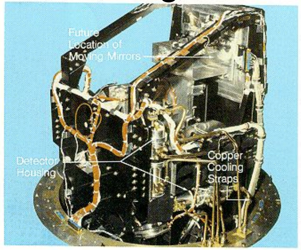
Milky Way

Solar system



Funded near-term efforts

Interferograms

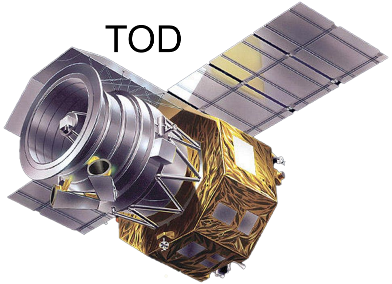


Test unit being prepared for vibration test. Horn, calibrator, and mirror mechanism are not shown.

COBE-FIRAS

Absolute calibration

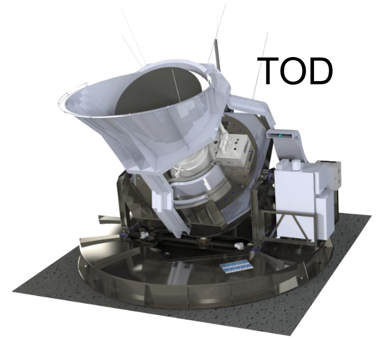
TOD



AKARI

Dust, CIB, zodi, sources…

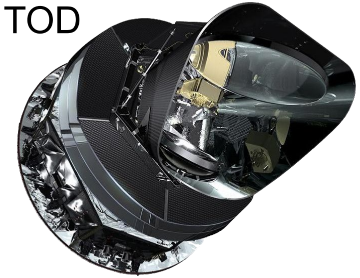
TOD



Simons Observatory

CMB, B-modes, clusters, lensing…

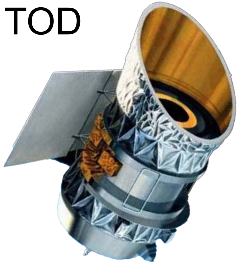
TOD



Planck HFI

CMB, LCDM, dust, CIB, SZ…

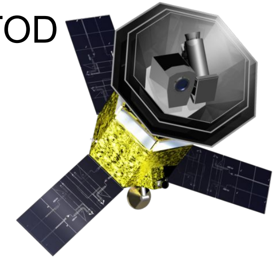
TOD



IRAS

Dust, zodi, sources…

TOD



LiteBIRD

CMB B-modes, polarization

Summary

- Joint end-to-end analysis of multiple complementary experiments has been demonstrated to produce ***better results with less effort*** than traditional stand-alone analysis pipelines
- With Cosmoglobe DR2 we have now completed this work for ***LFI, WMAP, and DIRBE***, and we are currently preparing to include ***AKARI, FIRAS, HFI, IRAS, LiteBIRD, Simons Observatory*** and more in the next few years
- The ultimate long-term goal of Cosmoglobe is to build ***one single state-of-the-art model of the astrophysical sky*** across the electromagnetic spectrum, using all leading available large-scale experiments
- Cosmoglobe allows for ***maximal utilization*** of experimental data - new FIR/submm experiments can be combined with already existing datasets to mitigate systematics.

Funding

This project has received EU funding from the European Research Council (ERC) and Research and Innovation Staff Exchange (RISE) under the Horizon 2020 Research and Innovation Programme

- CMB-Inflate
  - EU RISE Grant agreement No. 101007633 - PI G. Patanchon - 2021-2025
- Cosmoglobe
  - EU ERC-CoG Grant agreement No. 819478 - PI I. K. Wehus - 2019-2025
- bits2cosmology
  - EU ERC-CoG Grant agreement No. 772253 - PI H. K. Eriksen - 2018-2023
- BeyondPlanck
  - EU COMPET-4 Grant agreement No. 776282 - PI H. K. Eriksen - 2018-2020
- Global Component Separation Network
  - Diku/RCN INTPART Grant agreement No. 274990 - PI I. K. Wehus - 2018-2023