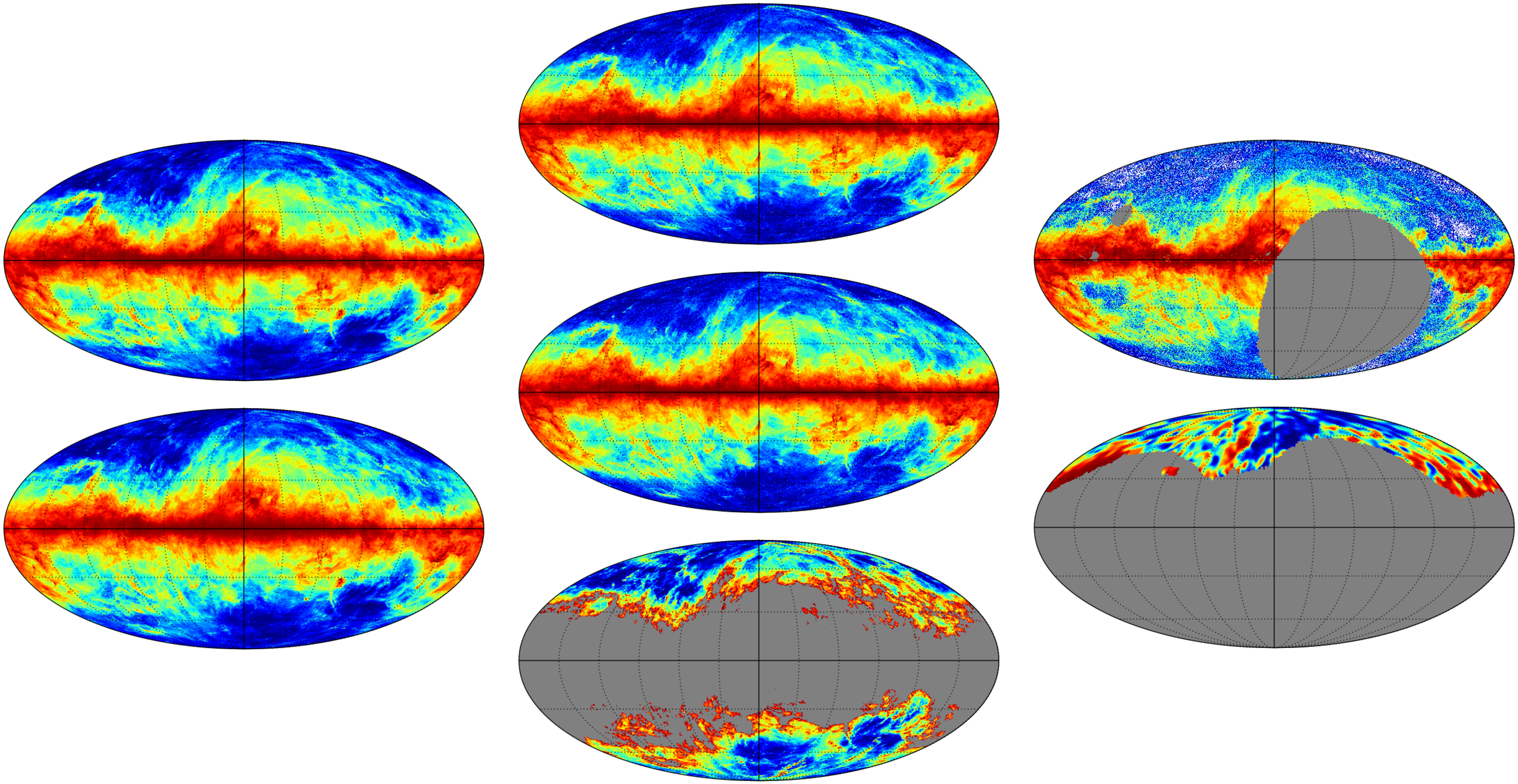
Which Galactic Dust Map Should I Use?
Insights from Extragalactic Tomography



Yi-Kuan Chiang
Johns Hopkins University
with **Brice Menard**

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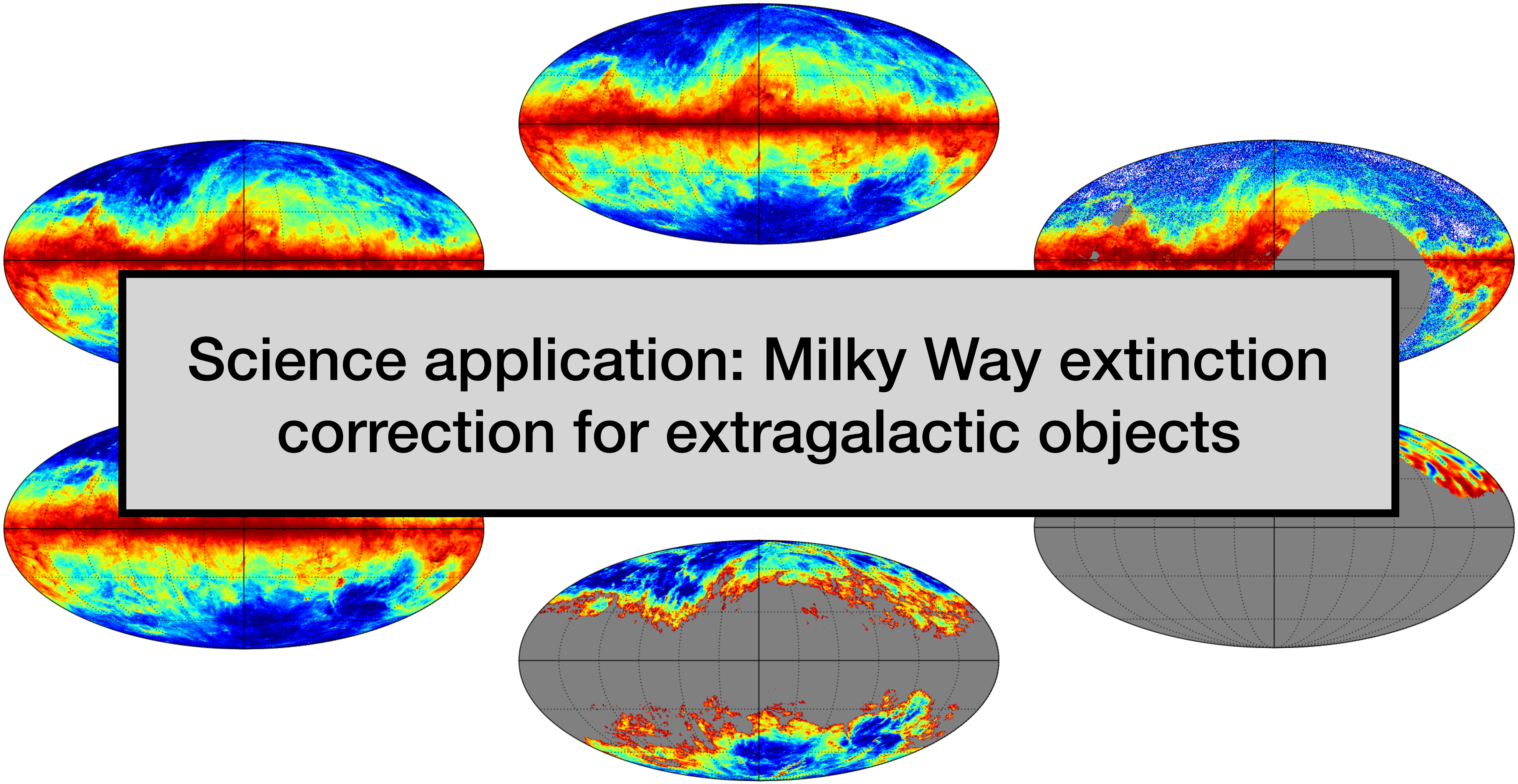
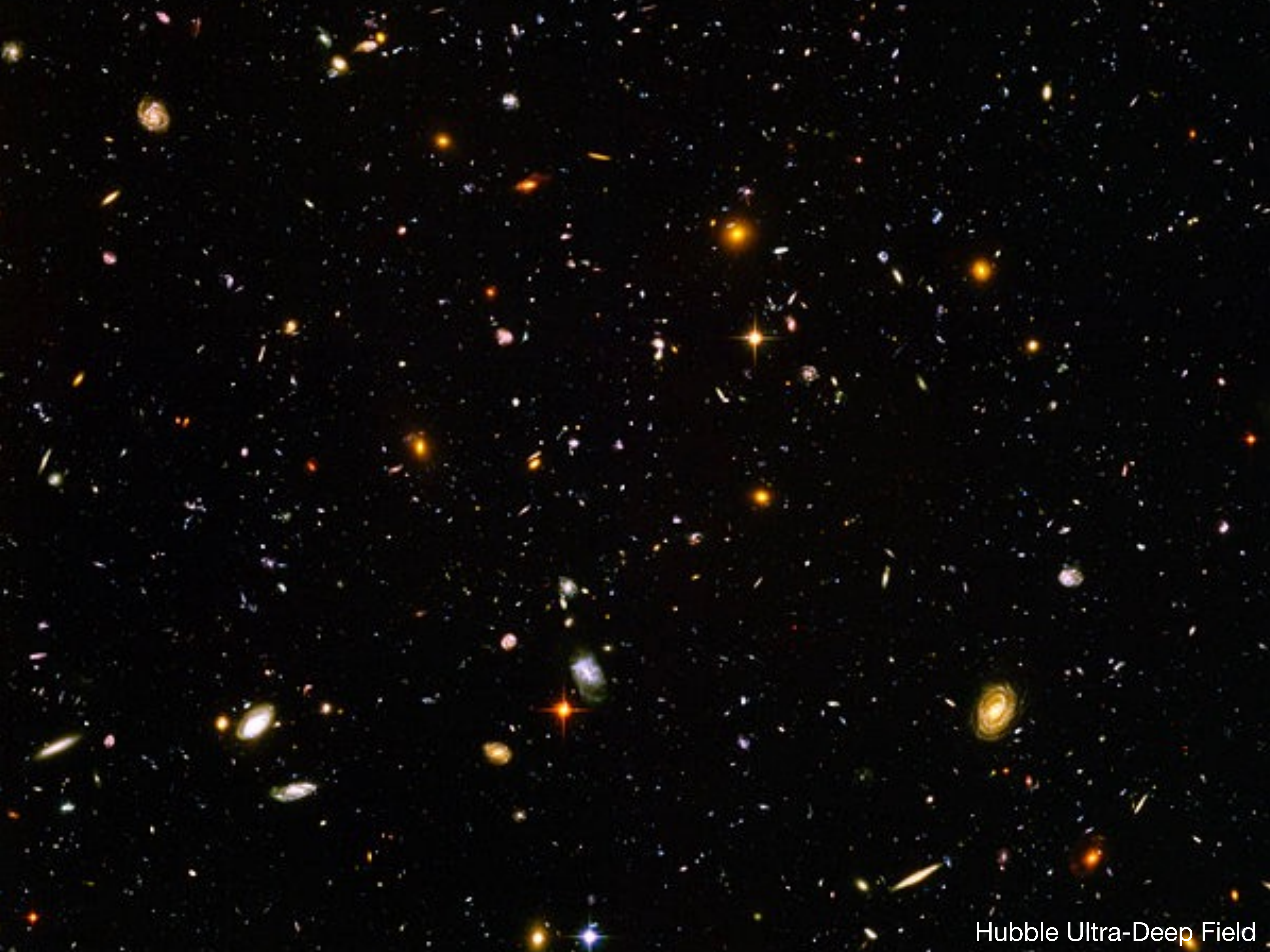


Science application: Milky Way extinction correction for extragalactic objects

Yi-Kuan Chiang
Johns Hopkins University
with **Brice Menard**



Hubble Ultra-Deep Field

Probing the 3rd spatial dimension

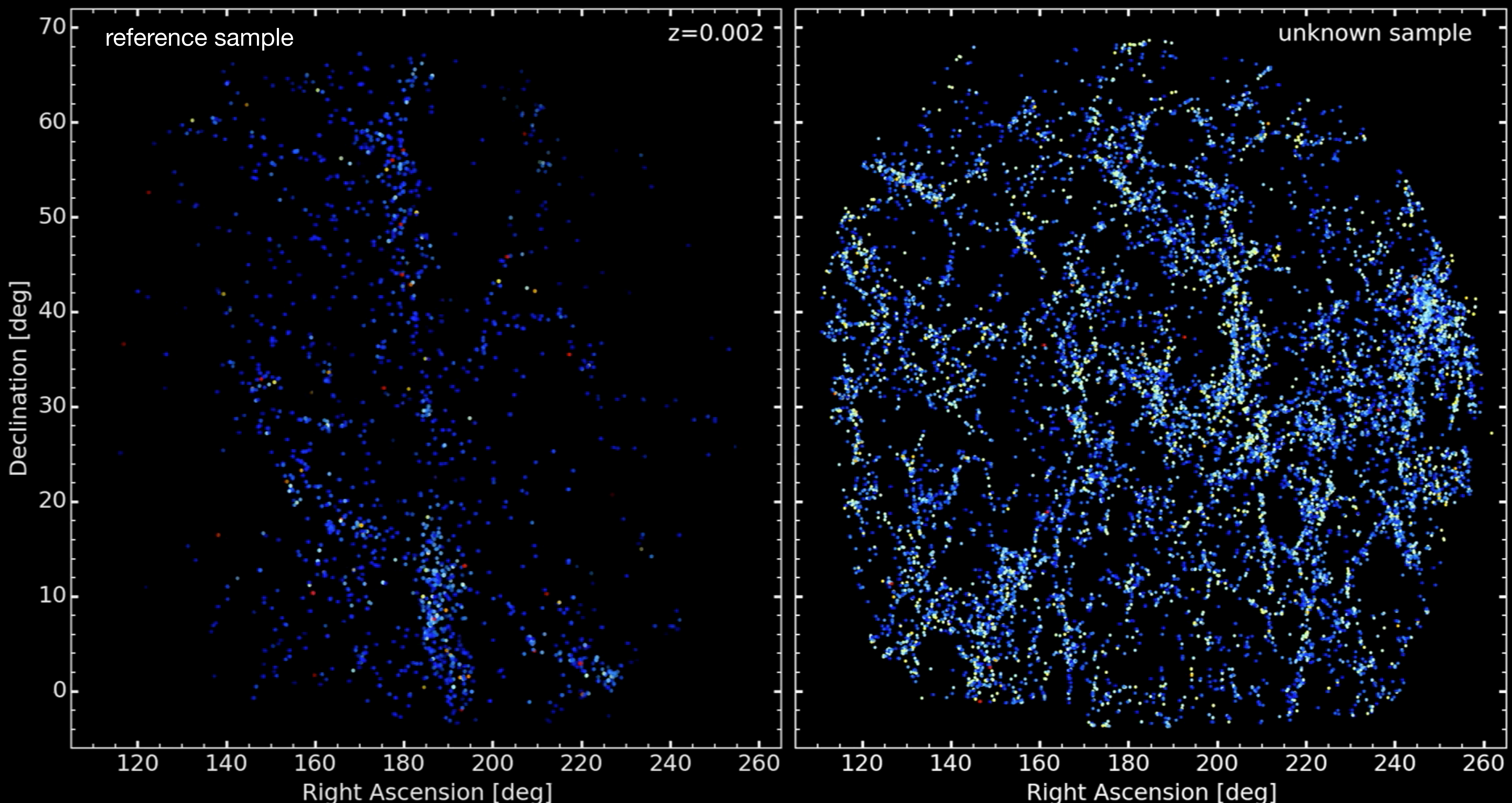
2D	→	3D
flux	→	luminosity
angular separation	→	physical size
column density	→	density
static image	→	time evolution

Hubble Ultra-Deep Field

Clustering Redshift Estimation

Propagating 3D information from an external data set to our 2D data

$$\bar{w}_{ur}(z_i) \propto \mathrm{p(z)}$$

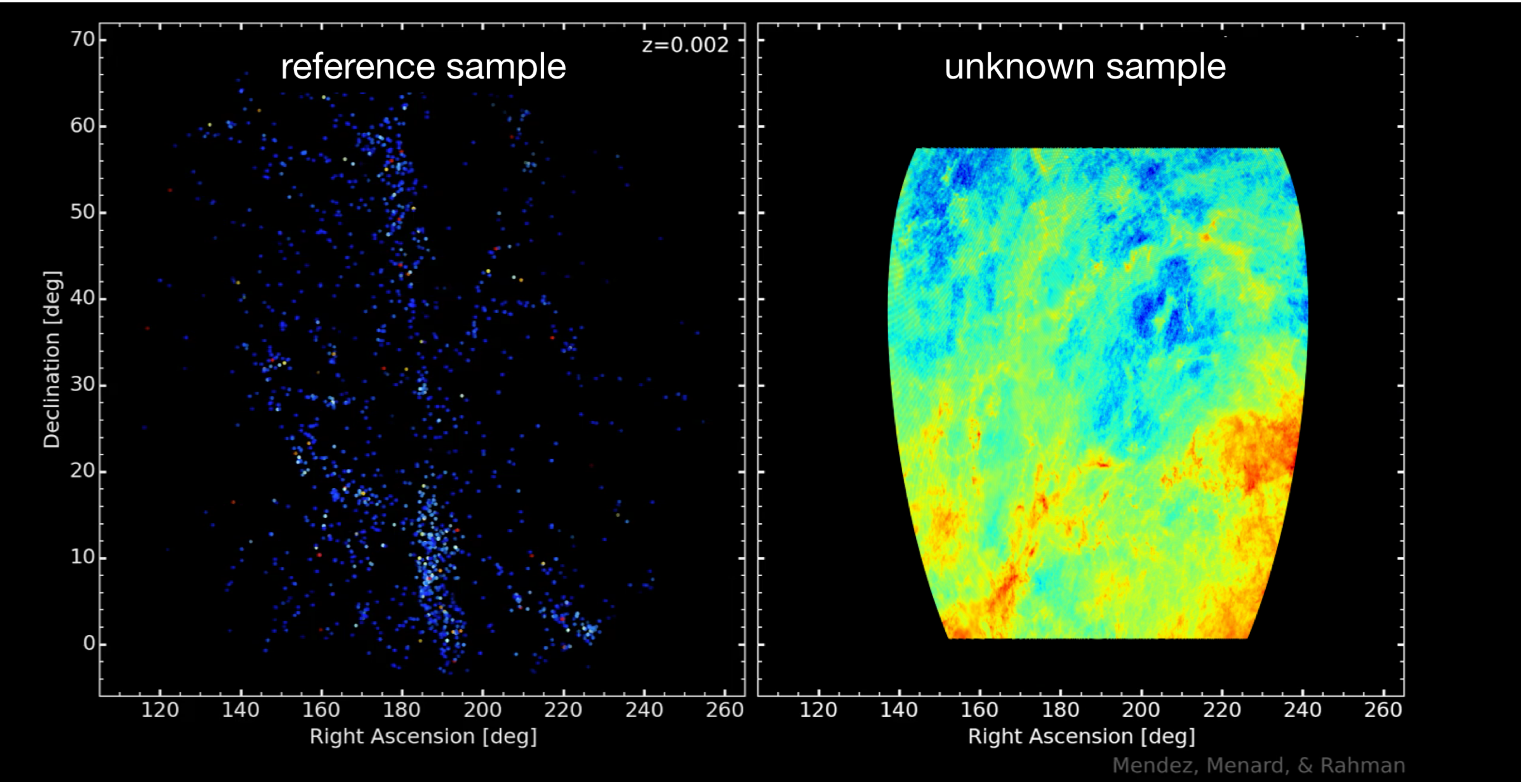


Mendez, Menard, & Rahman

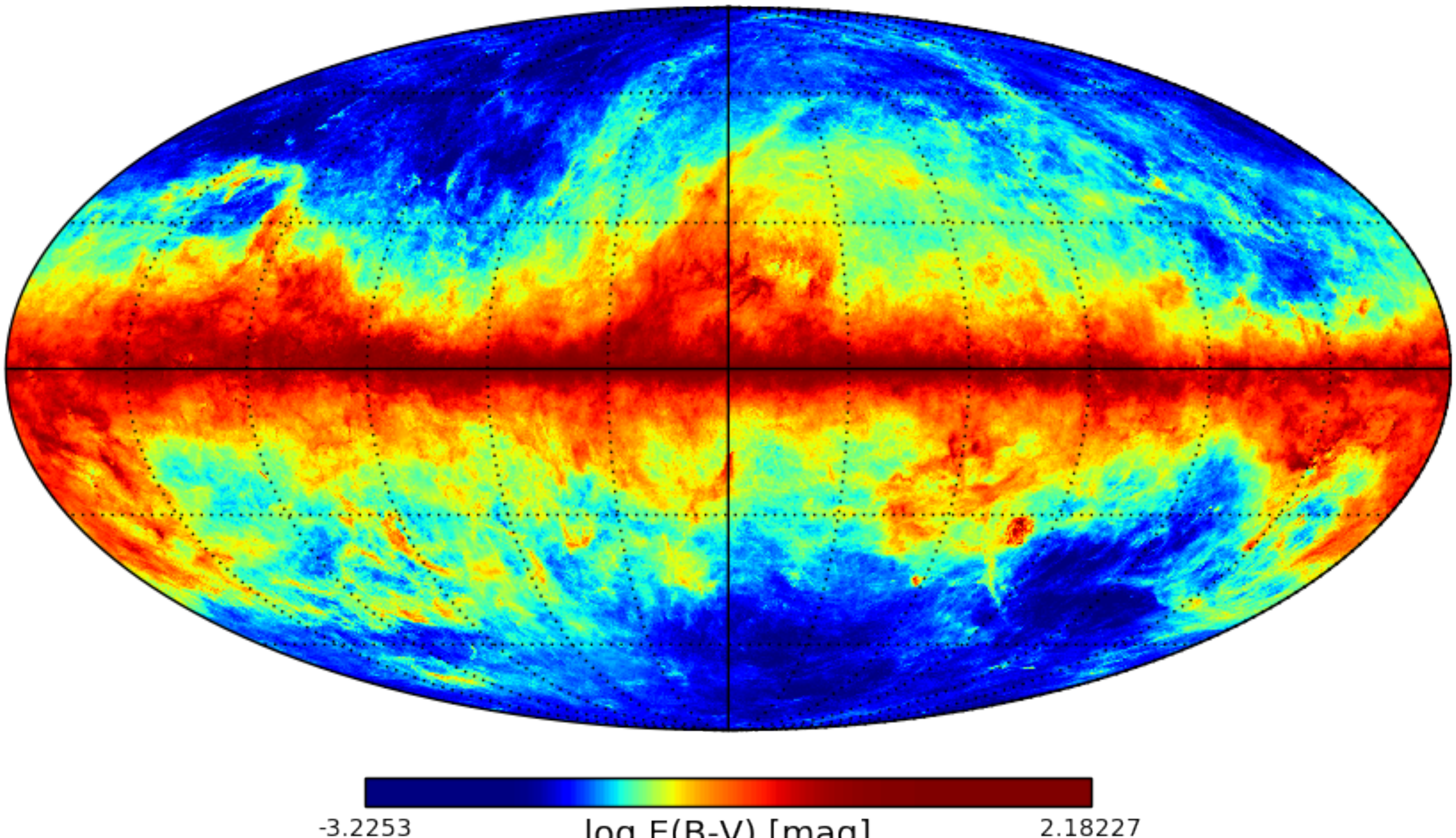
Also Works for Intensity Maps with LSS signatures

Propagating 3D information from an external data set to our 2D data

$$\bar{w}_{ur}(z_i) \propto \mathrm{p(z)}$$



Are there extragalactic signatures in Galactic dust extinction maps?



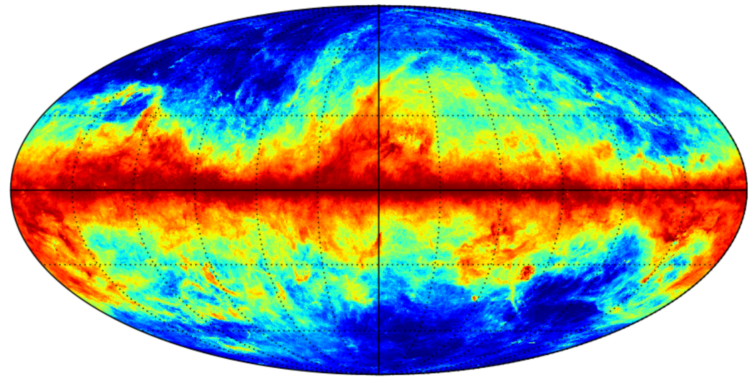
Schlegel, Finkbeiner & Davis (1998)

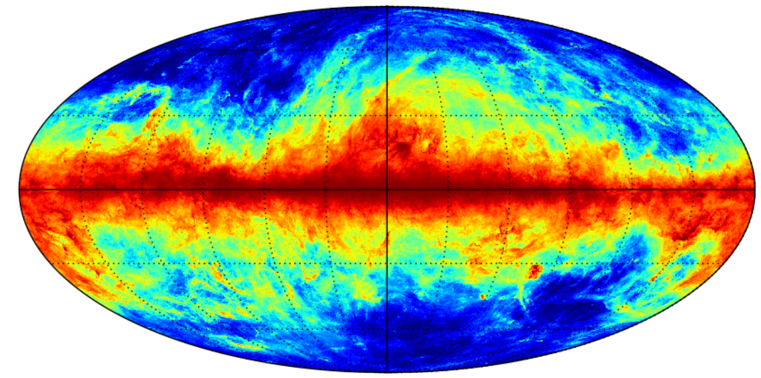
If so:

- Bias in magnitude corrections (especially UV properties of dusty galaxies)
- Imprint of the large-scale structure (impact on precision cosmology)

10+ dust maps currently available

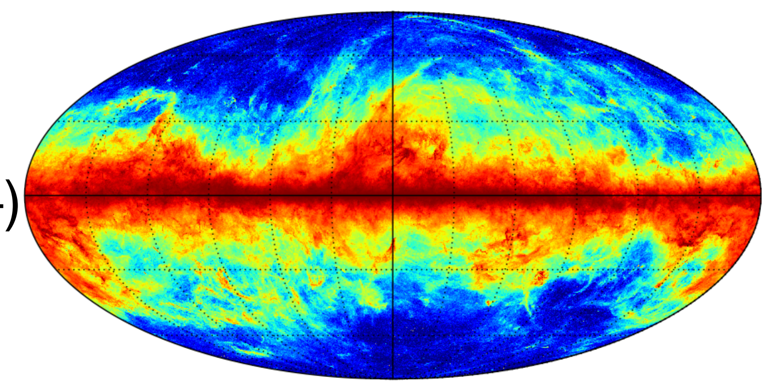
SFD
thermal

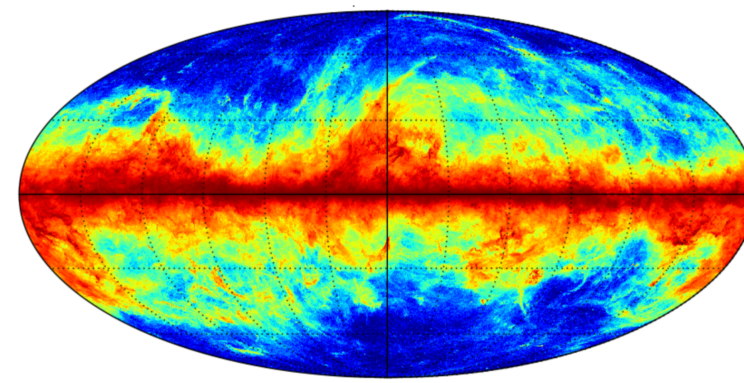




Planck 2013
(Miville-Deschênes+)
thermal

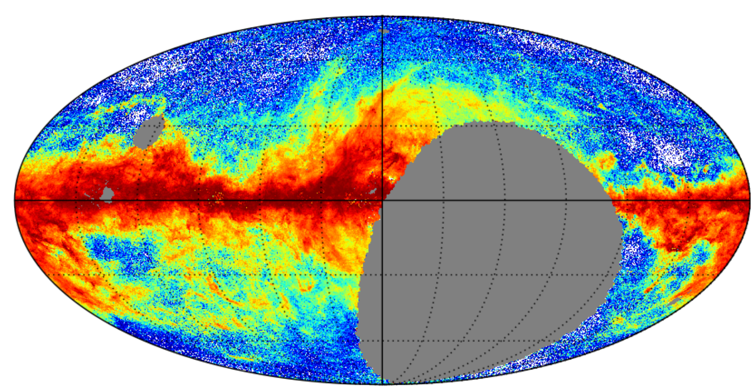
Planck 2015
(Ganiano, Boulanger+)
thermal



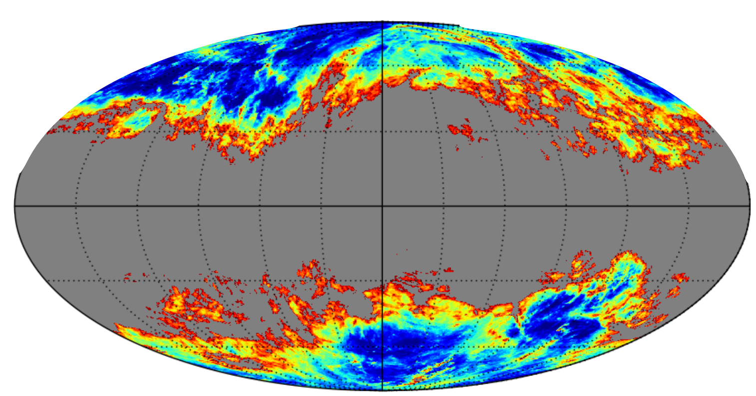


Meisner &
Finkbeiner 2015
2-components thermal

Schlafly et al. 2014
Pan-STARRS
stellar reddening



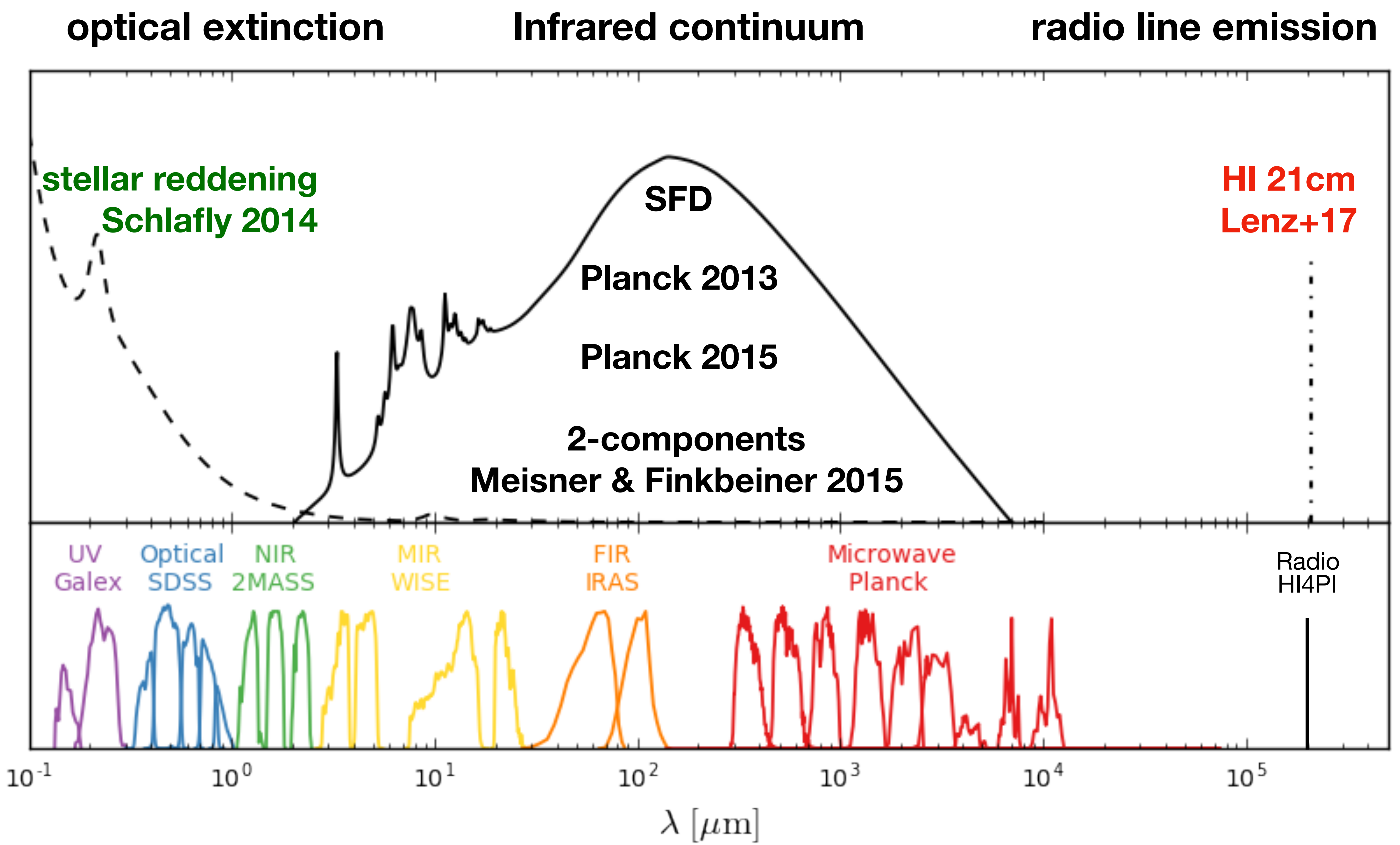
Lenz, Hensley, & Dore 2017
HI4PI
HI 21cm

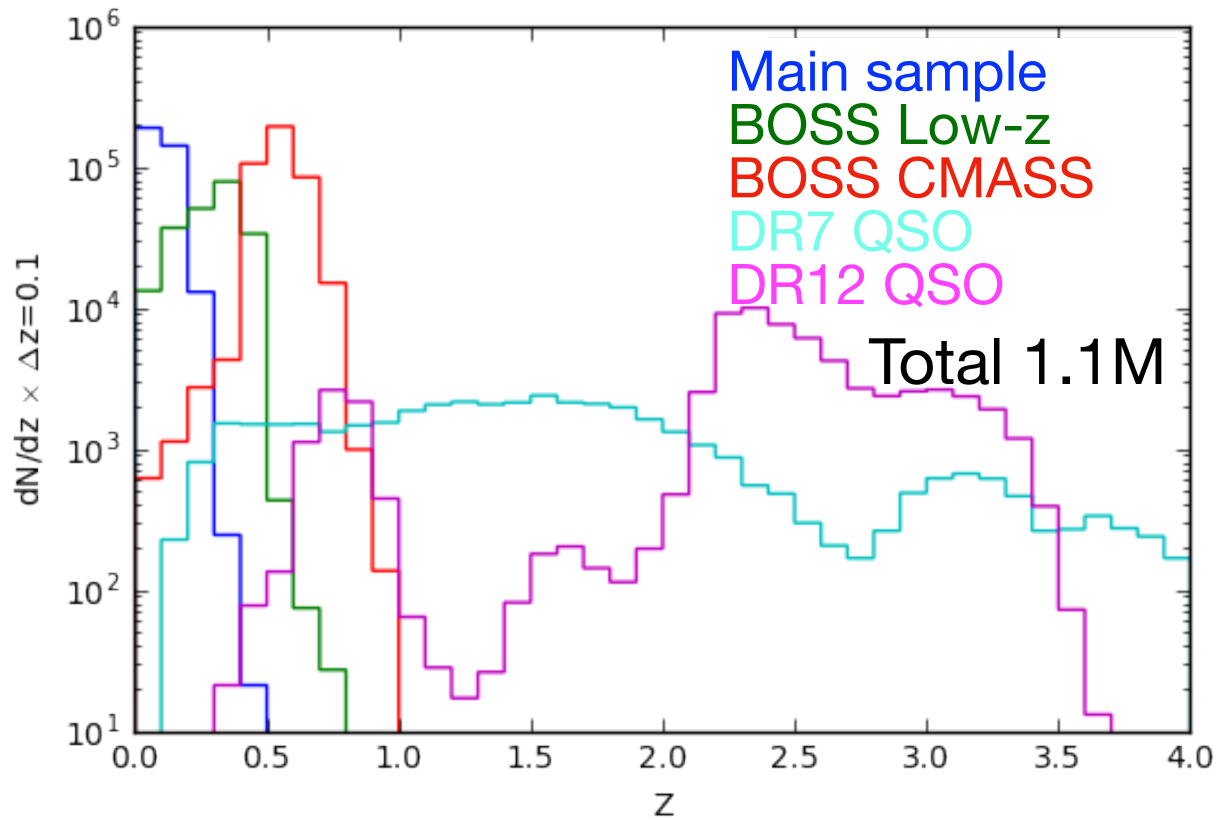


Also:

- Planck independent component separation maps…
- WISE PAH-based: Meisner & Finkbeiner 2014
- SDSS Galaxy reddening: Peak & Graves 2010

6 maps spanning the whole range of dust observables

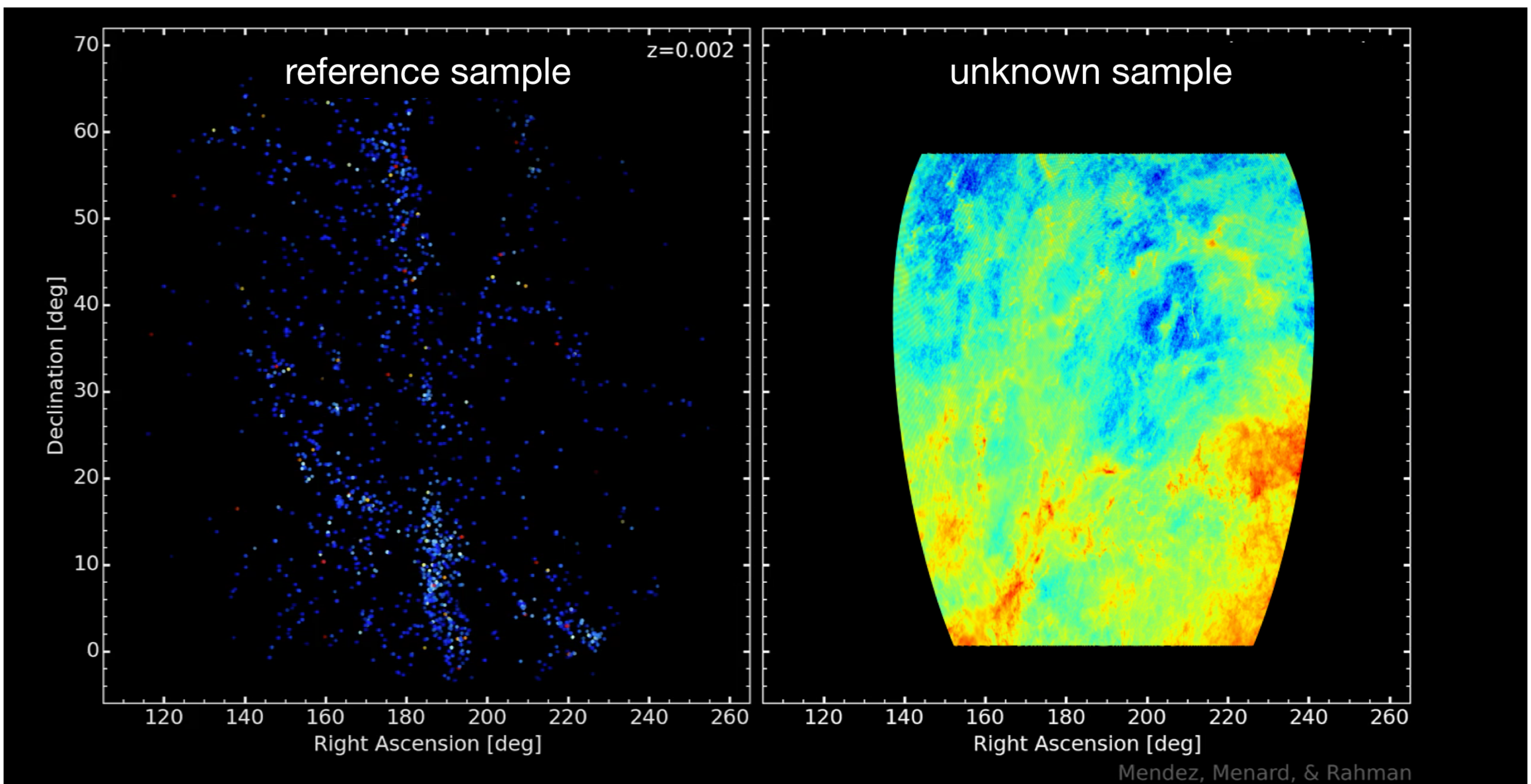




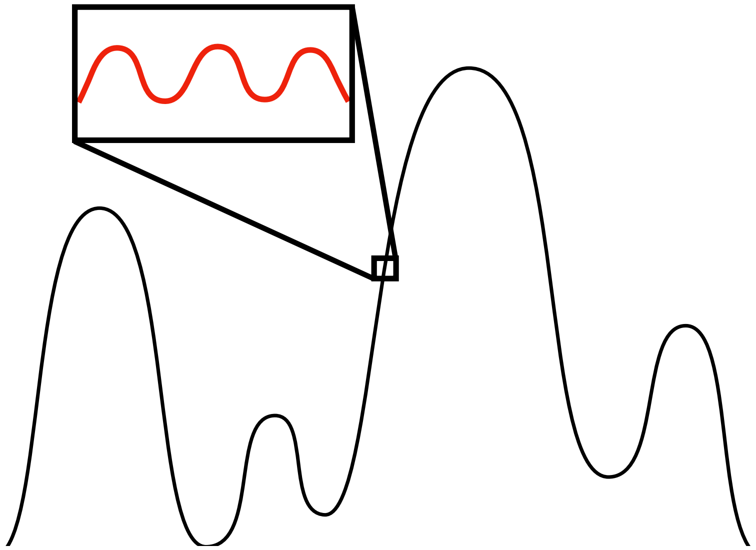
⟨dust map · SDSS⟩ (z)

$$\delta_{m,SFD} = \delta_{m,SFD}{}^{G} + \delta_{CIB}$$

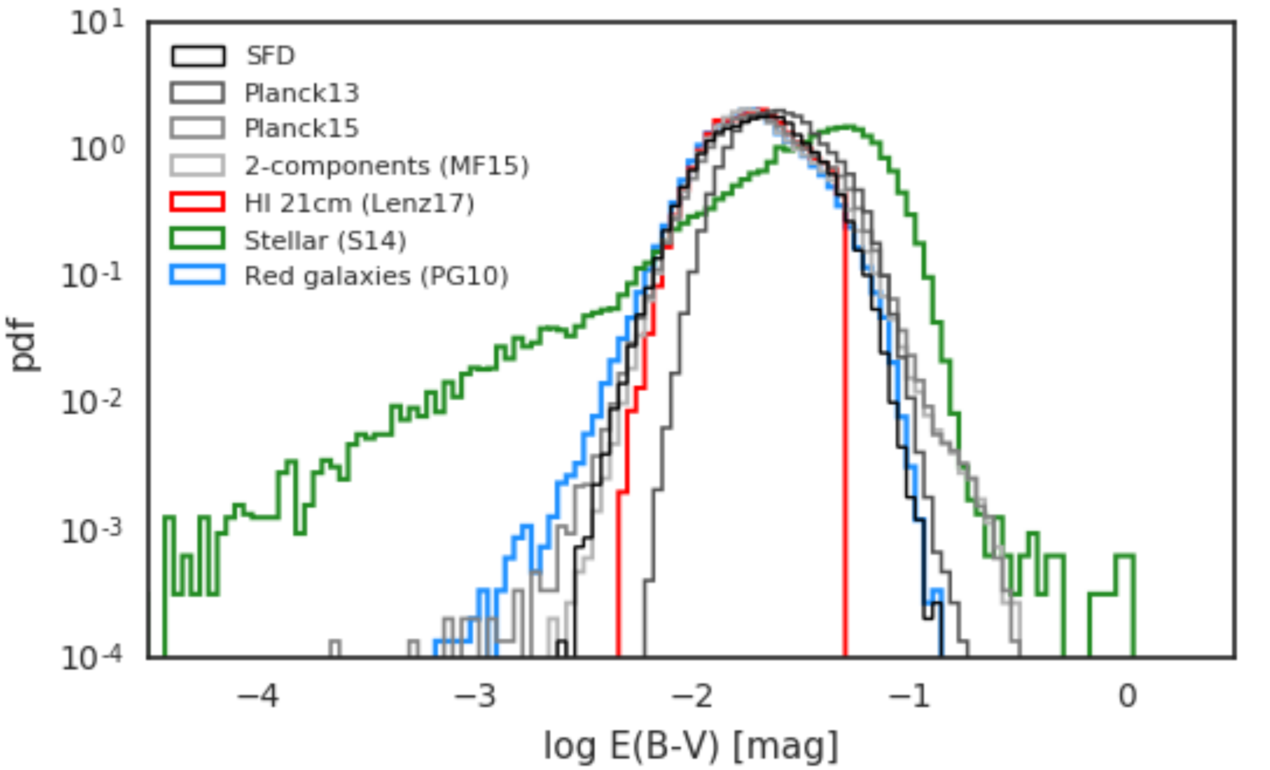
$$\langle \delta_{m,SFD} \cdot \delta_{gal} \rangle (z) = \langle \delta_{CIB} \cdot \delta_{gal} \rangle (z)$$



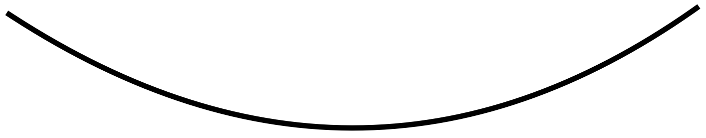
The analysis: challenges



- weak signal buried in huge foregrounds



- non- Gaussian pdf, spanning 2 orders of magnitude



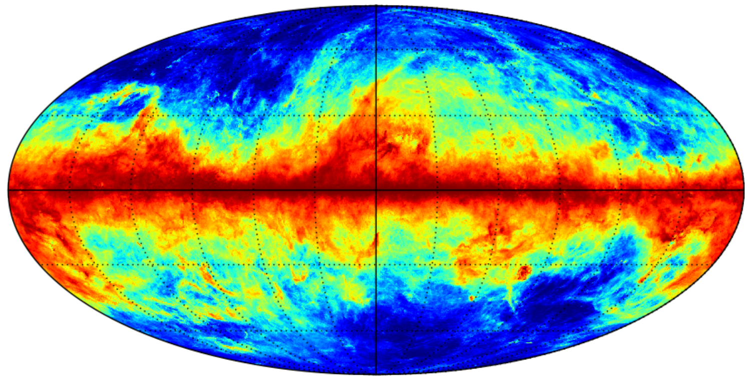
- foreground is correlated with the masks (e.g., *b* boundary)

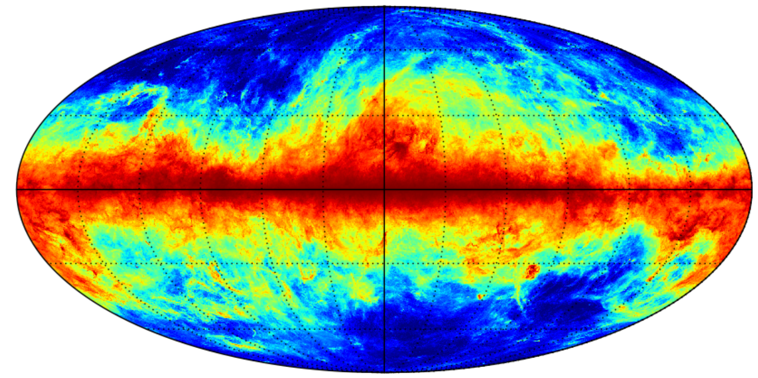
=> hard to measure reliable clustering on large scales

de-projecting 6 dust maps

1

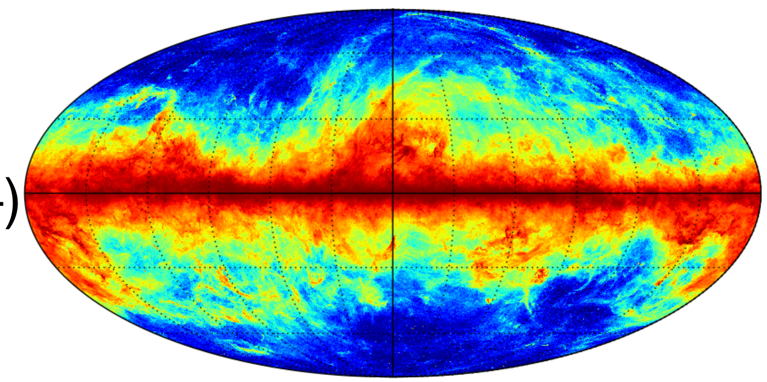
SFD
thermal

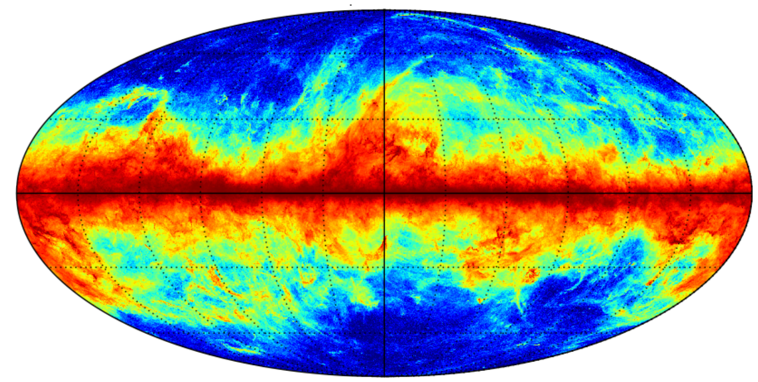




Planck 2013
(Miville-Deschênes+)
thermal

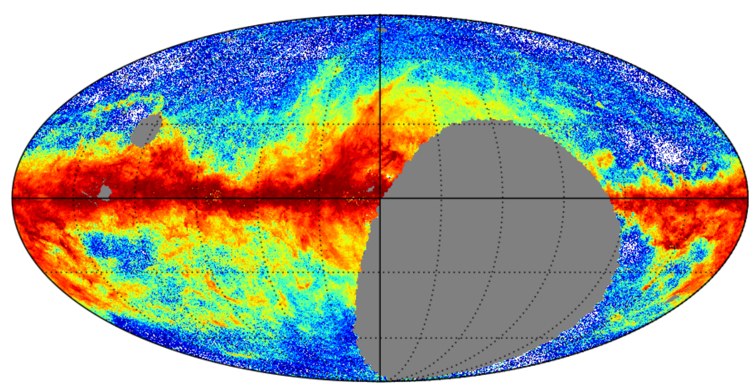
Planck 2015
(Ganiano, Boulanger+)
thermal



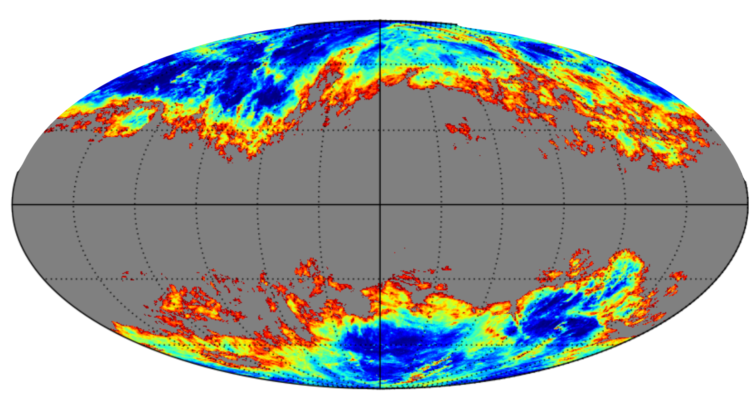


Meisner &
Finkbeiner 2015
2-components

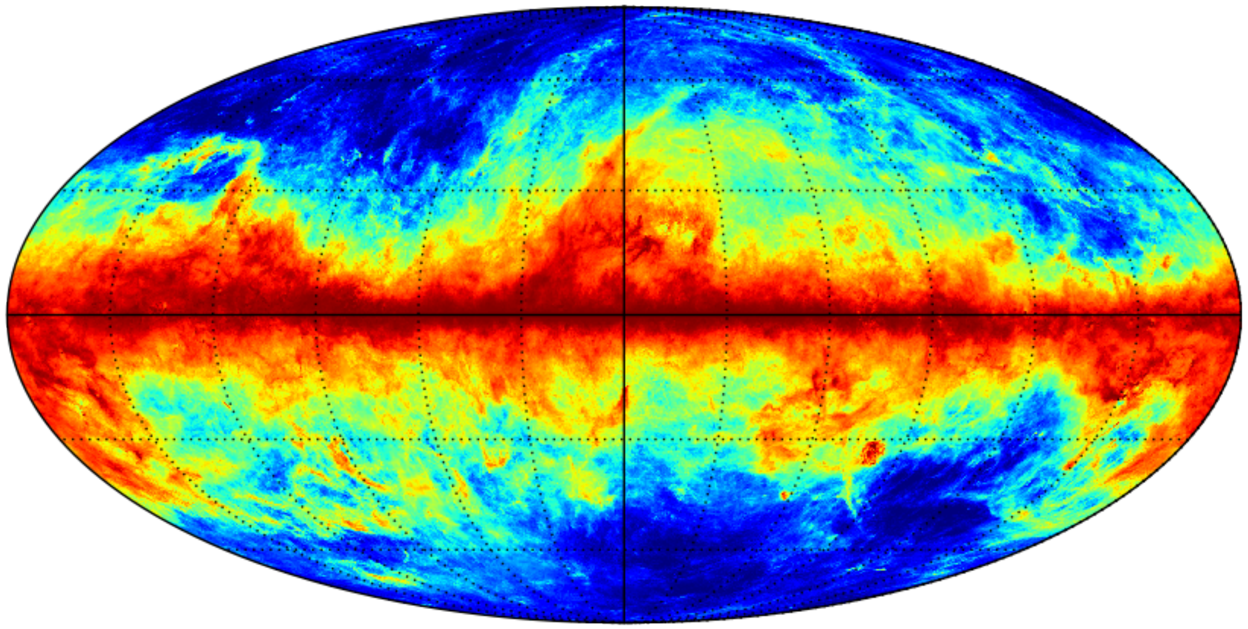
Schlafly et al. 2014
Pan-STARRS
stellar reddening

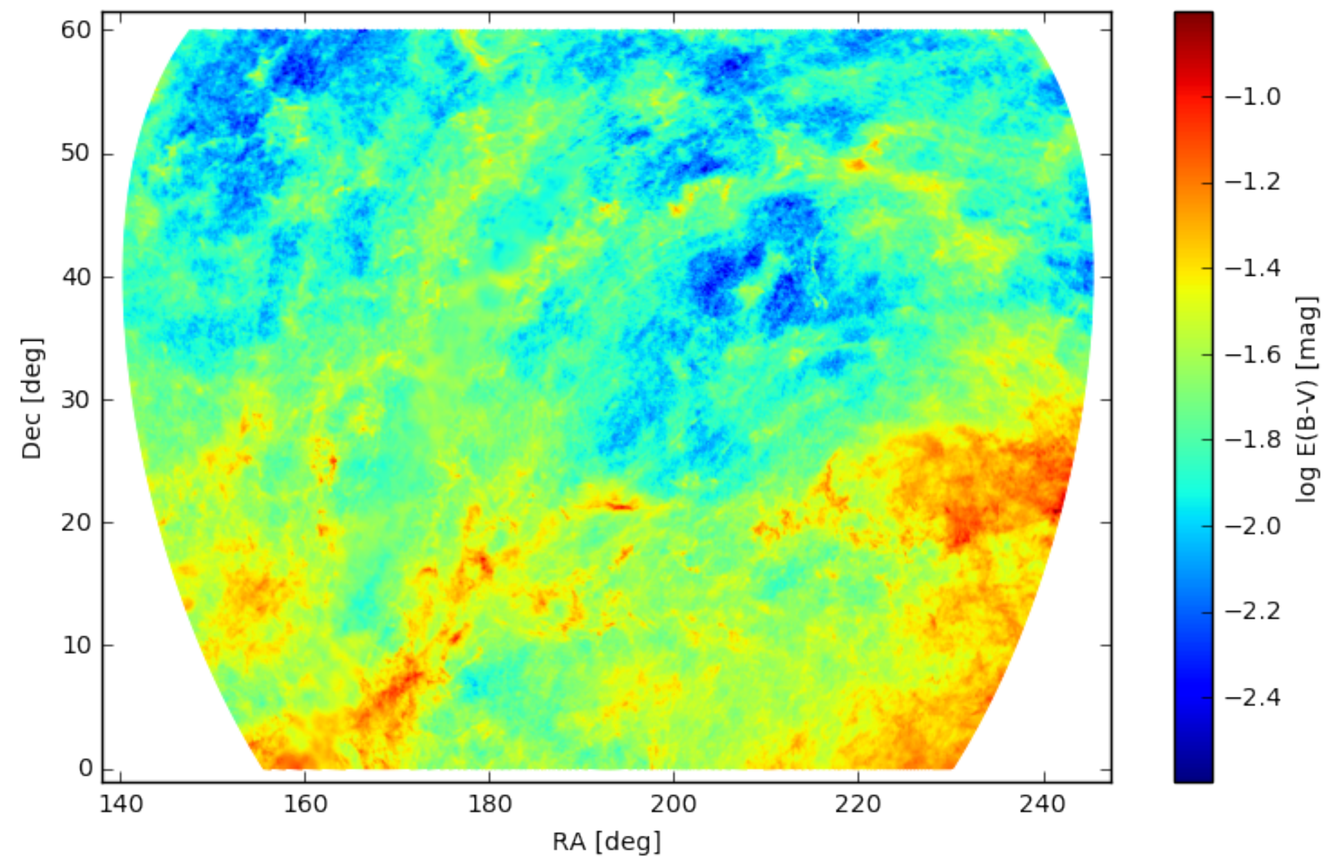


Lenz, Hensley, & Dore 2017
HI4PI
HI 21cm



Dust map 1: SFD — infrared emission from IRAS/COBE





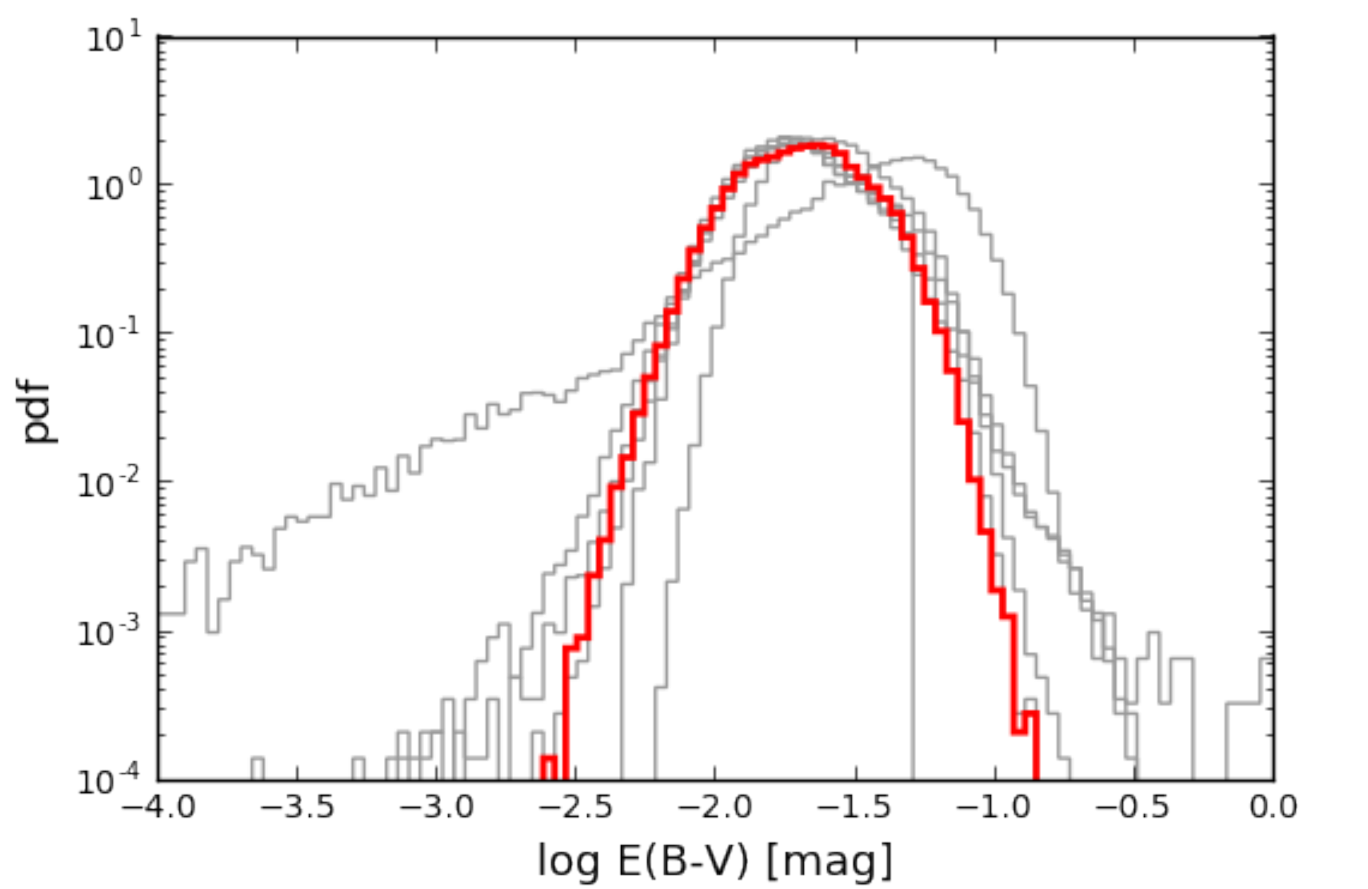
Authors:
Schlegel, Finkbeiner & Davis 1998

Citations: 10254

Angular resolution: 6.1 arcmin

Method: Infrared thermal modeling

Temperature map based on COBE/DIRBE 100, 240 μm (0.7° resolution)
Fold in IRAS 100 μm emission (6.1')



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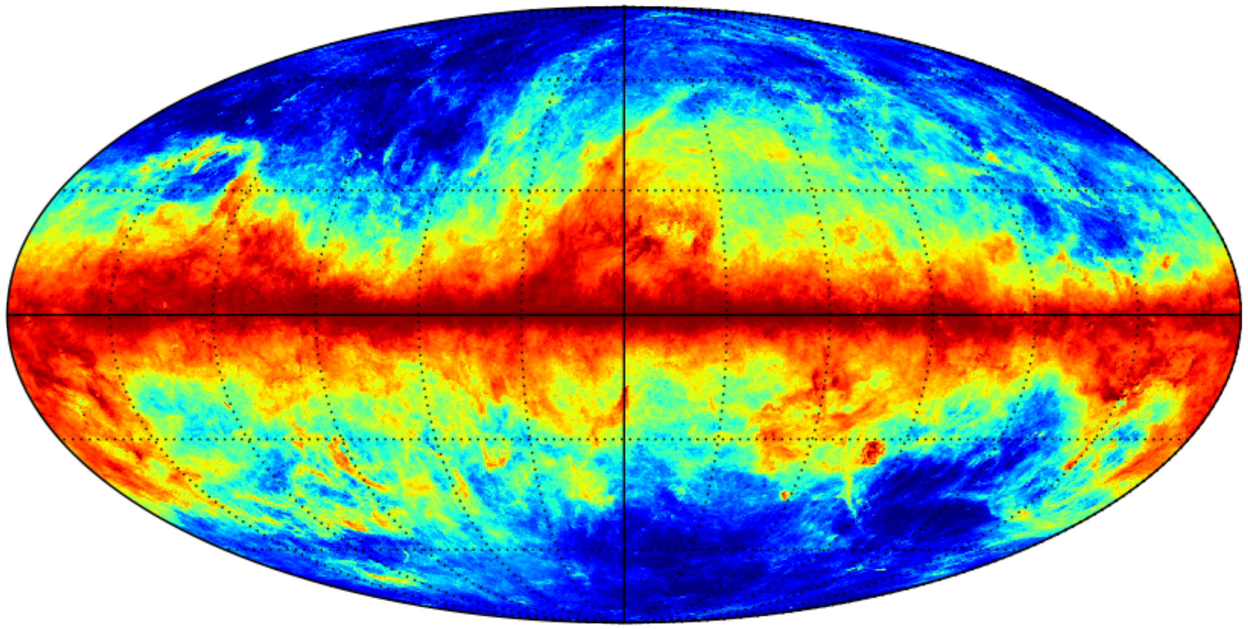
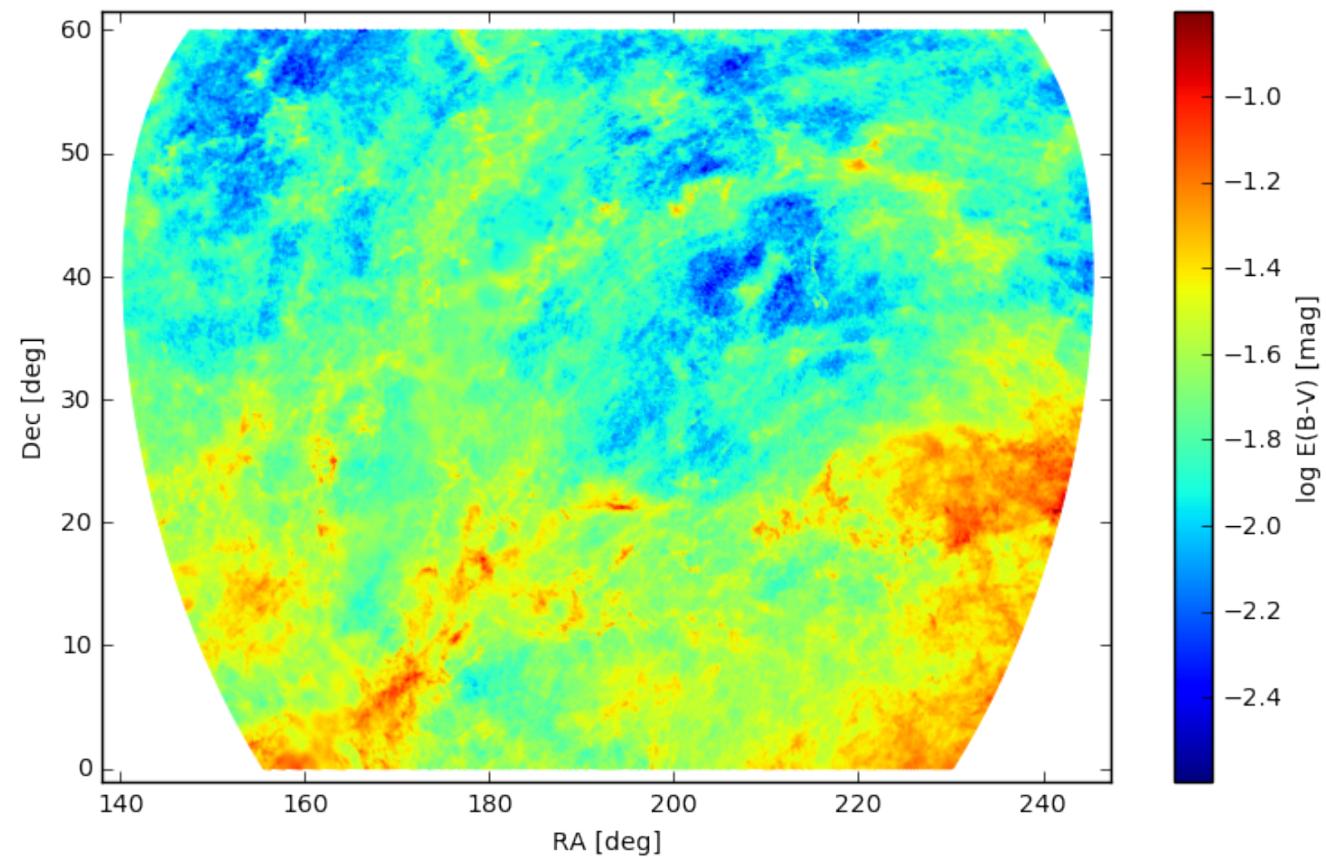
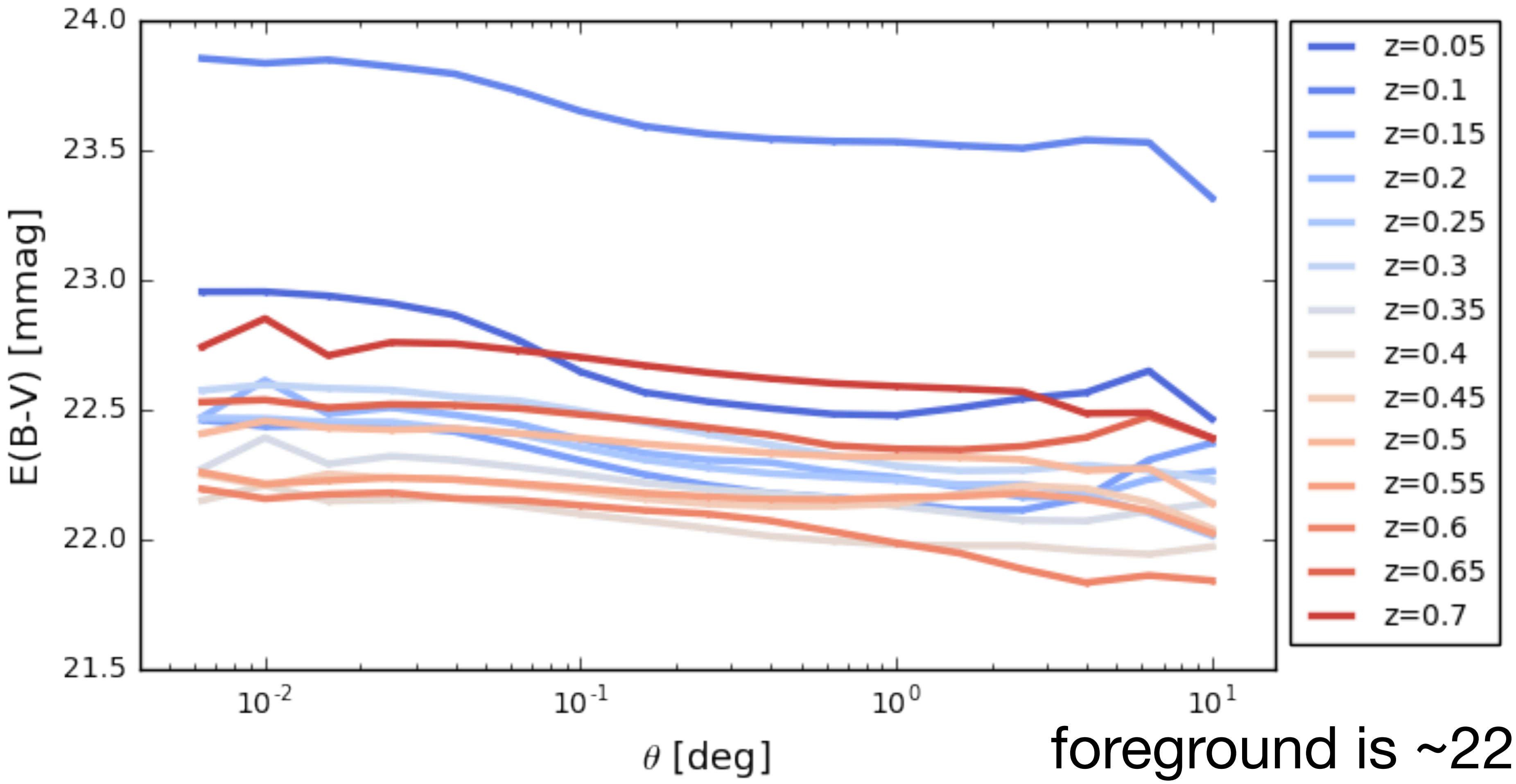
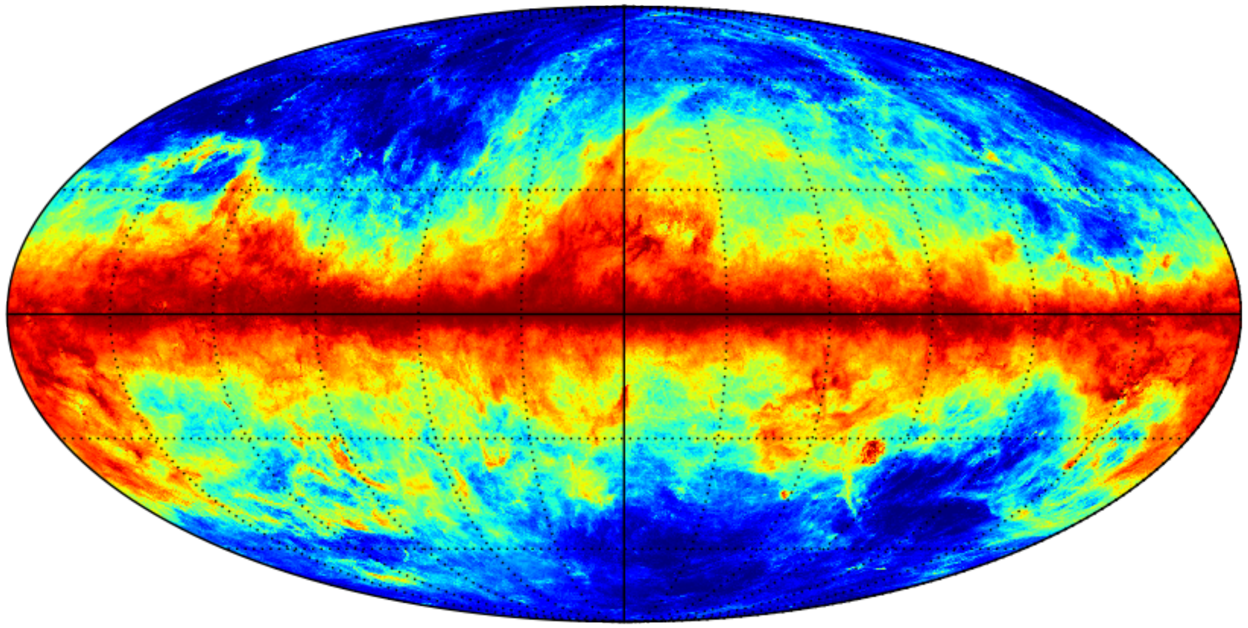


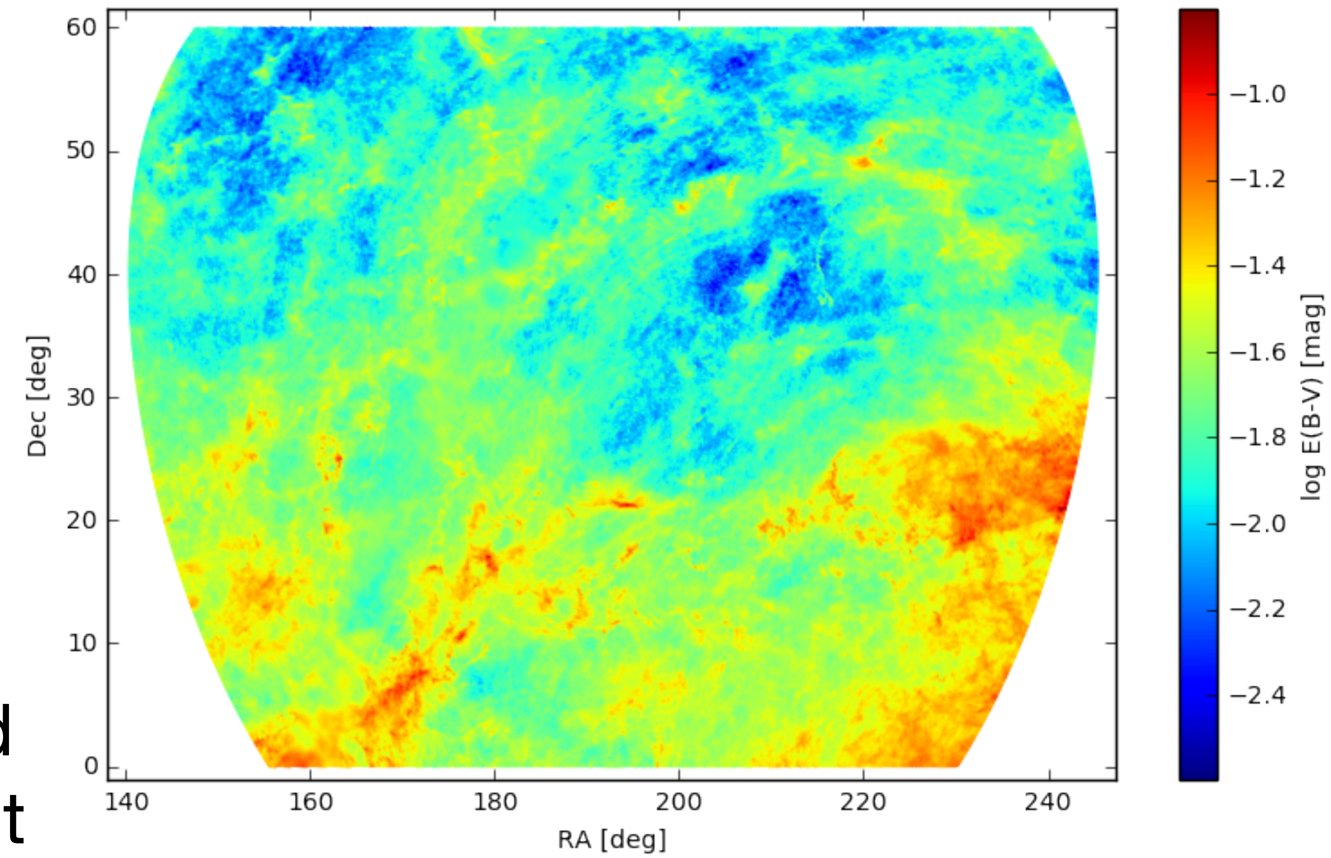




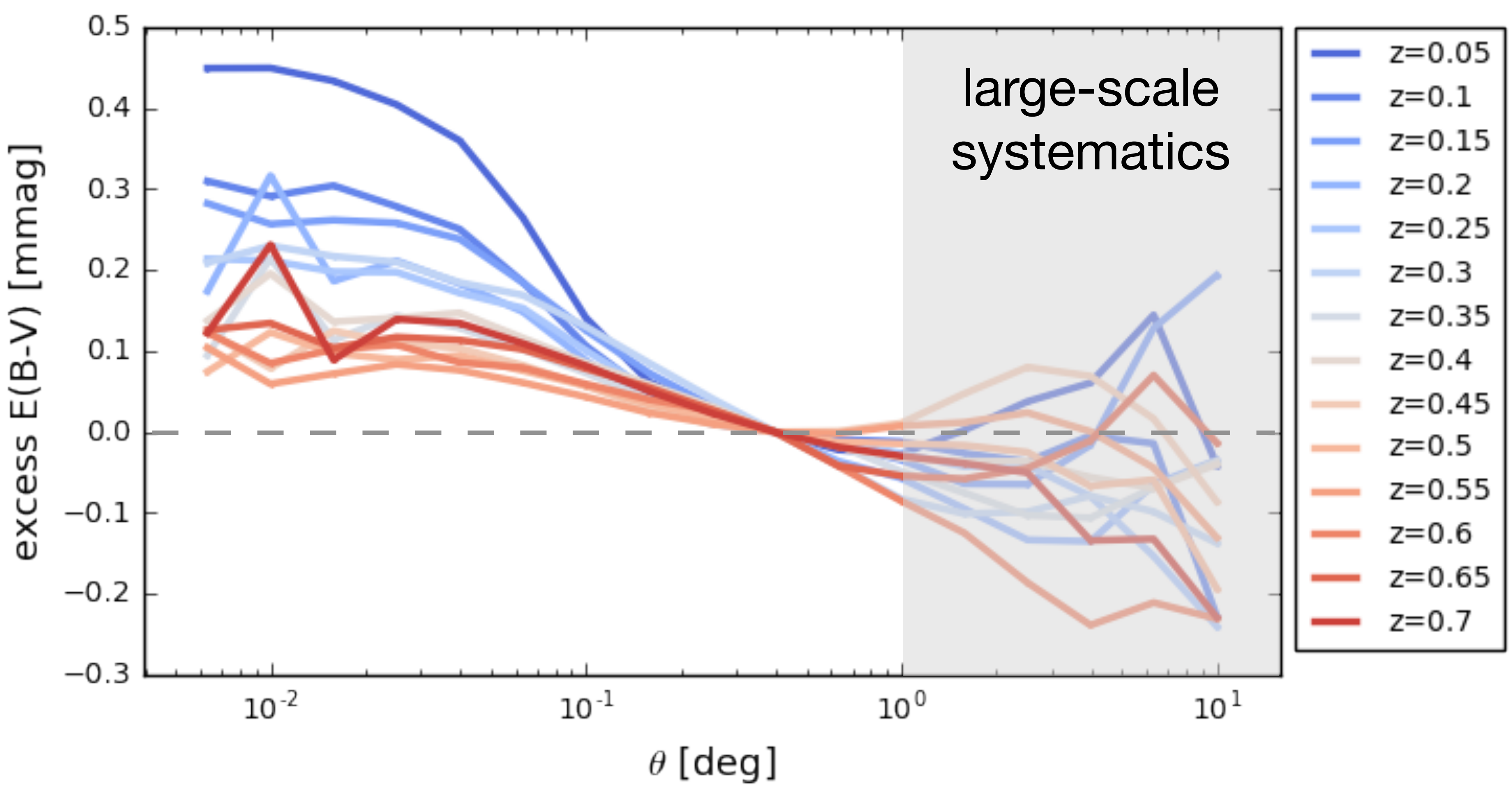
foreground is ~22-24 mmag

Dust map 1: SFD — infrared emission from IRAS/COBE

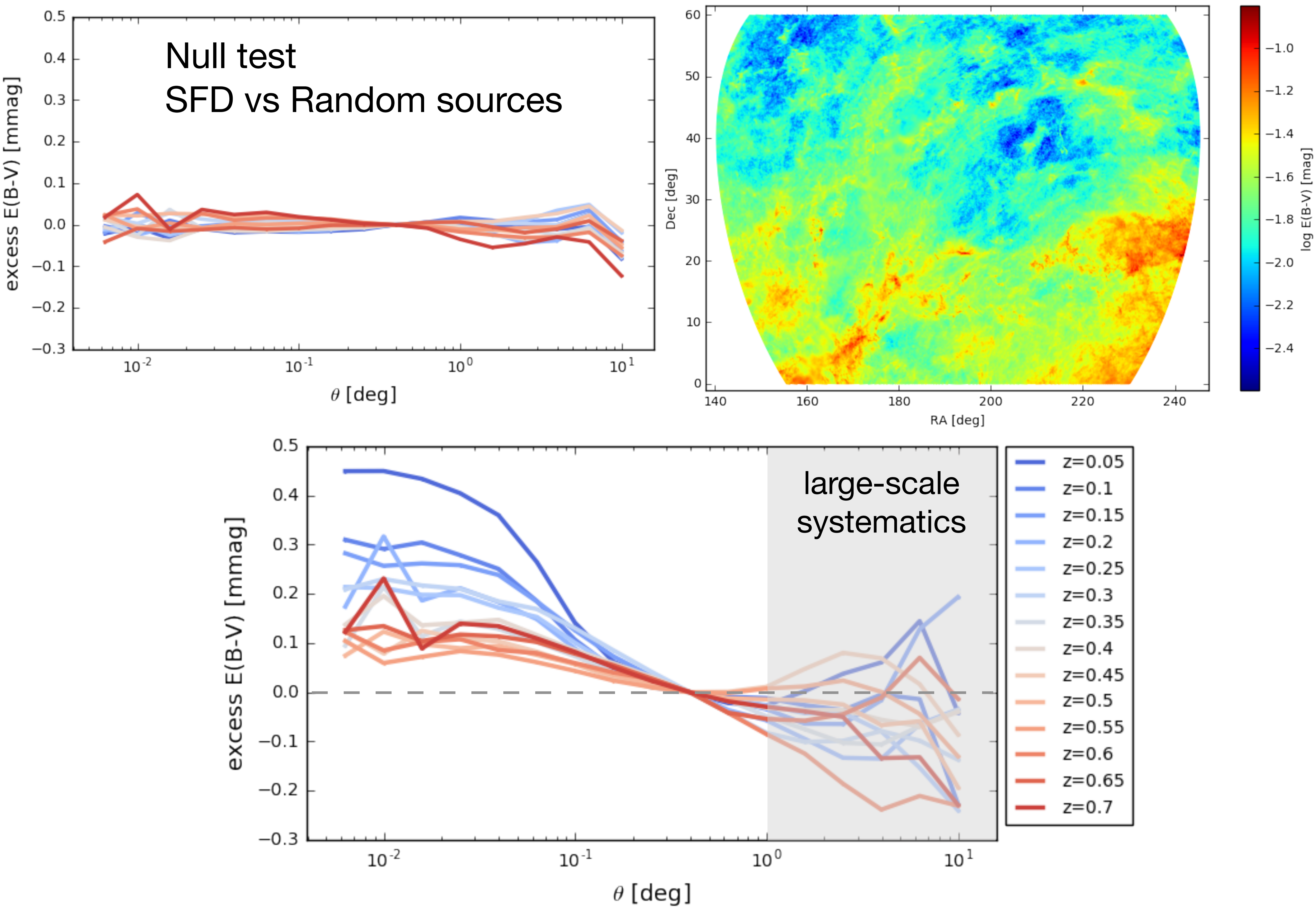




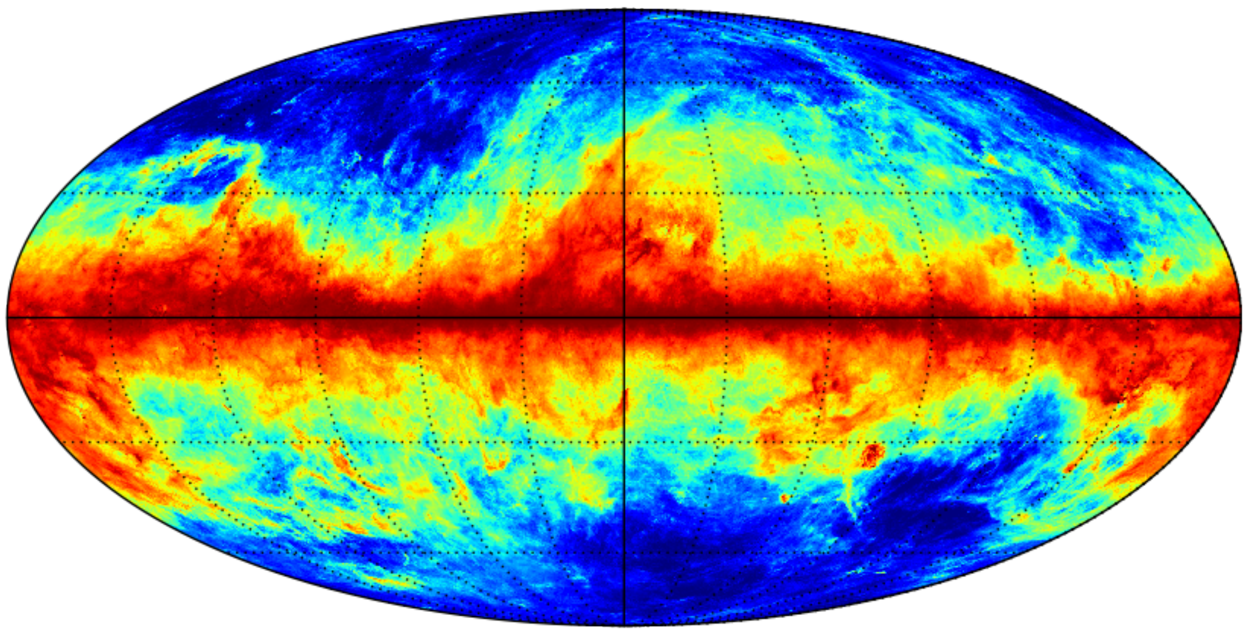
Use local background (0.4 deg) as zero point

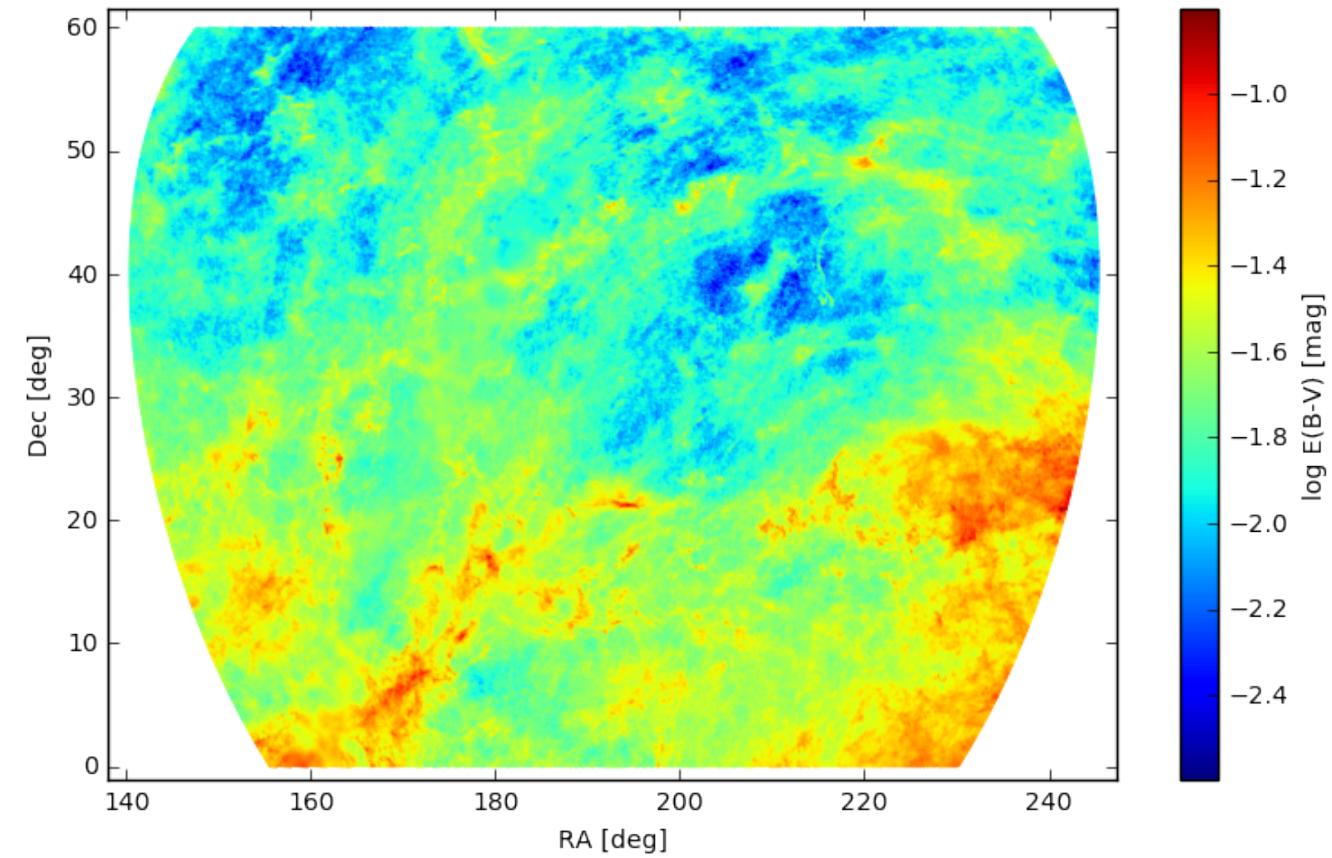


Dust map 1: SFD — infrared emission from IRAS/COBE



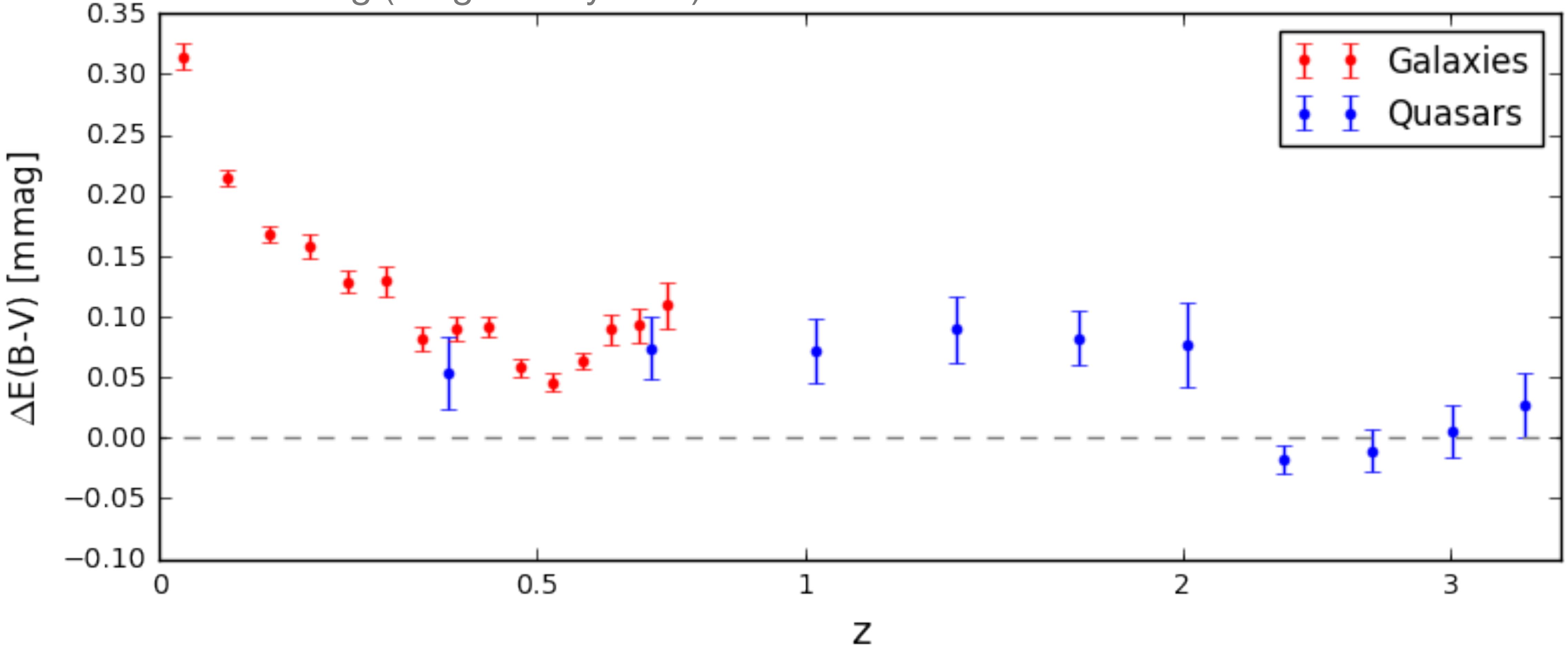
Dust map 1: SFD — infrared emission from IRAS/COBE





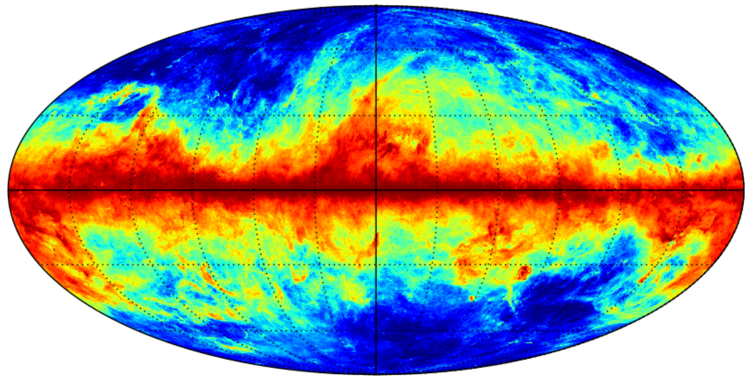
⟨SFD • SDSS⟩ (z)

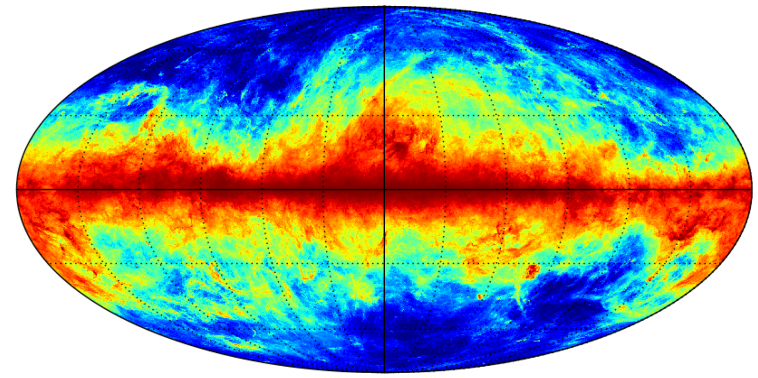
Integrated correlation function from 0 to 0.4 deg (weighted by $\theta^{-0.8}$)



How about other infrared based maps?

SFD
thermal



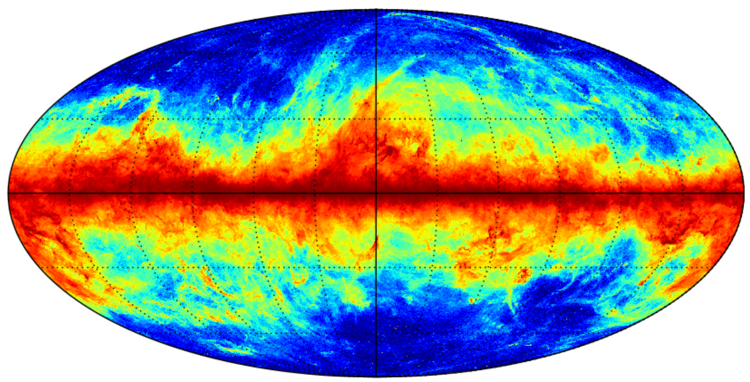


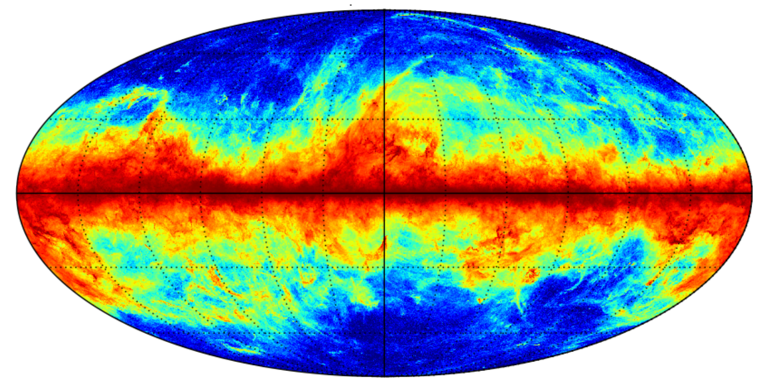
2

Planck 2013
(Miville-Deschênes+)
thermal
4 bands

3

Planck 2015
(Ganiano, Boulanger+)
thermal
6 bands

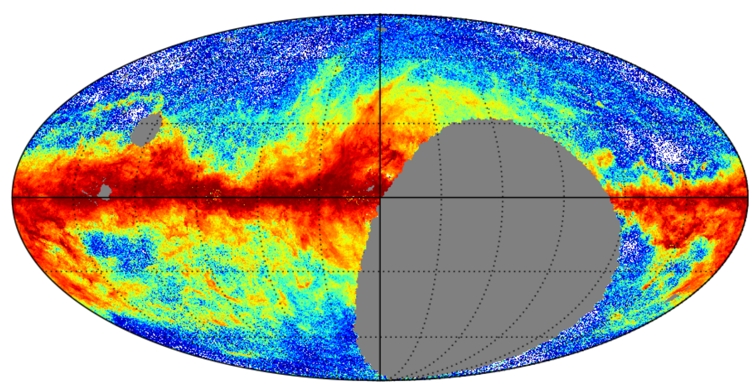




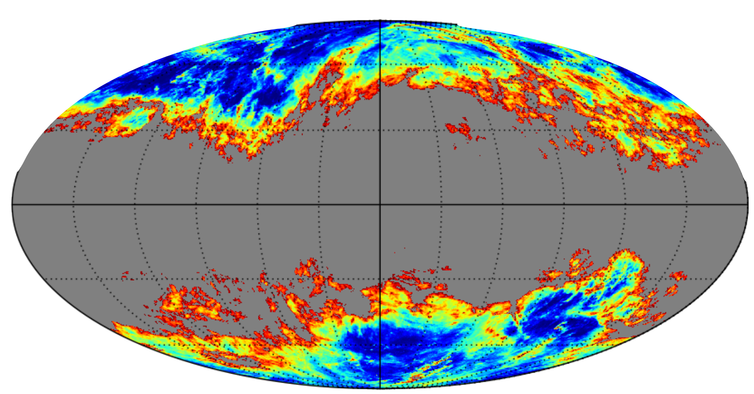
4

Meisner &
Finkbeiner 2015
2-components
9 bands

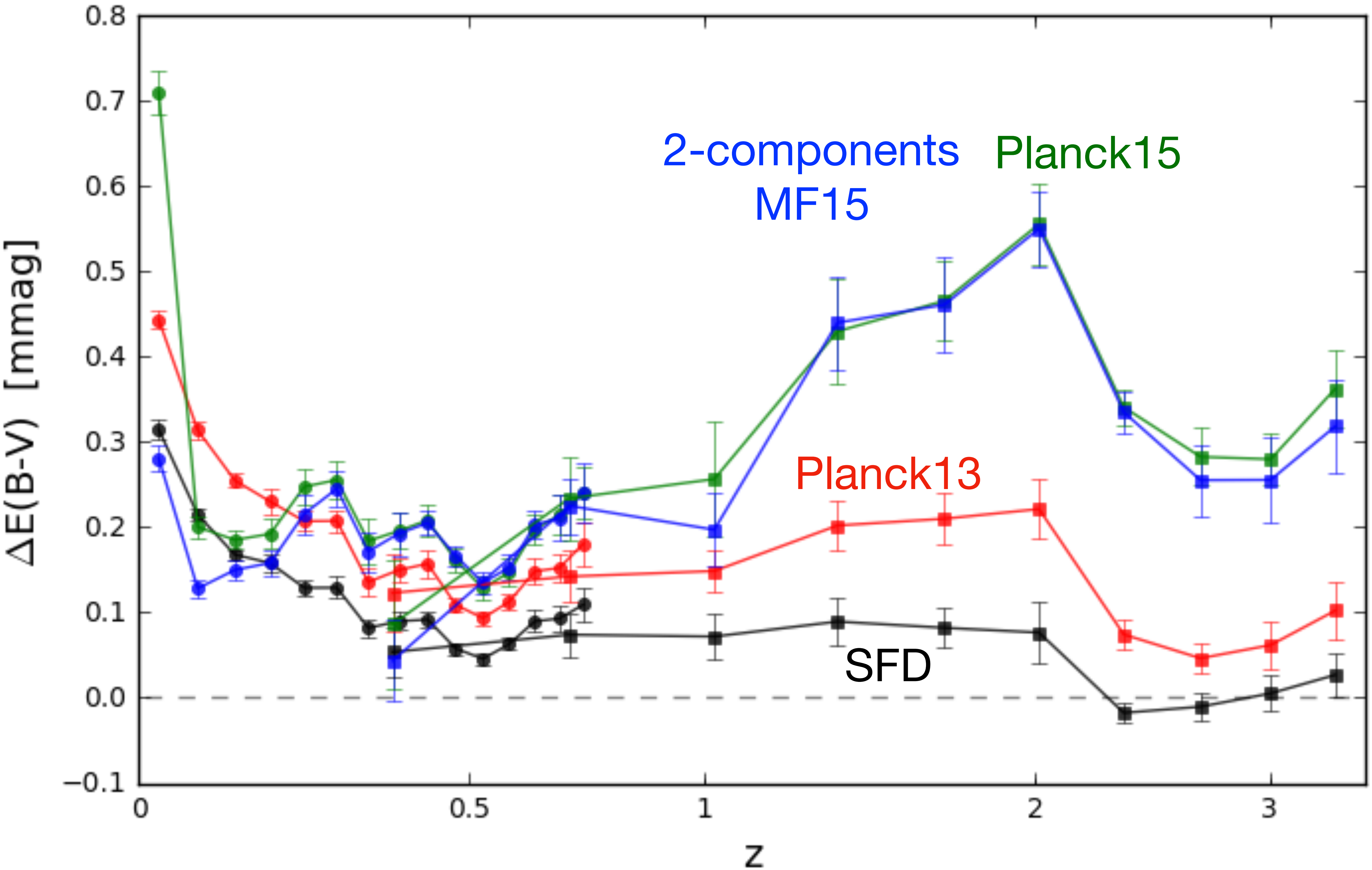
Schlafly et al. 2014
Pan-STARRS
stellar reddening



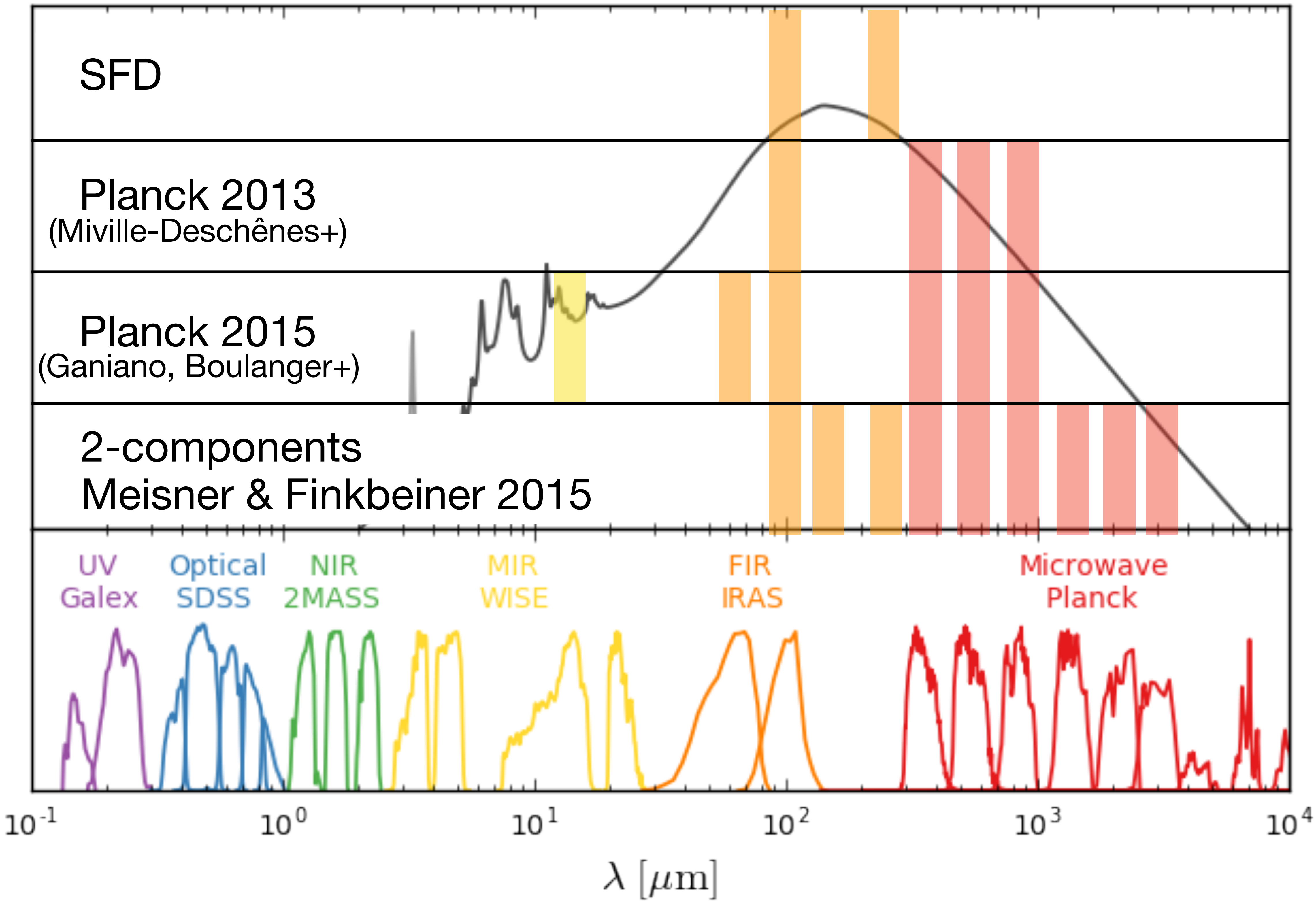
Lenz, Hensley, & Dore 2017
HI4PI
HI 21cm



Extragalactic contributions in 4 thermal dust maps

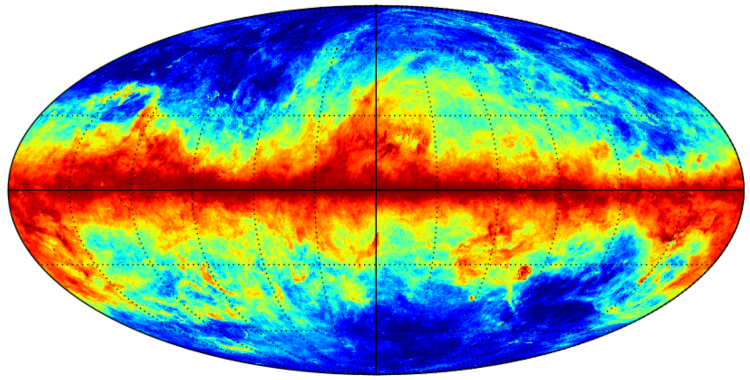


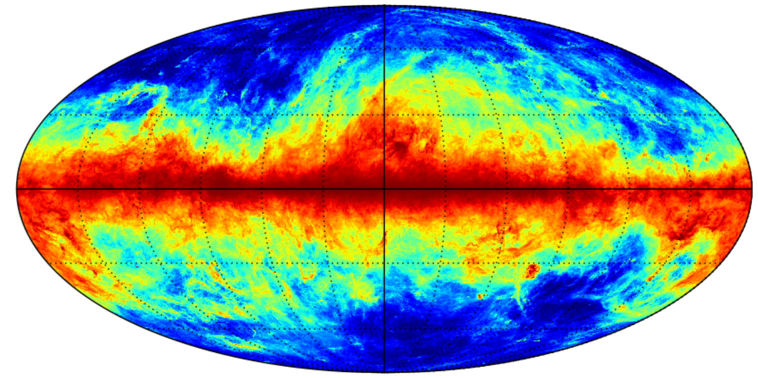
CIB anisotropy is detected in SFD up to z~2
How about other infrared based maps?



de-projecting 6 dust maps

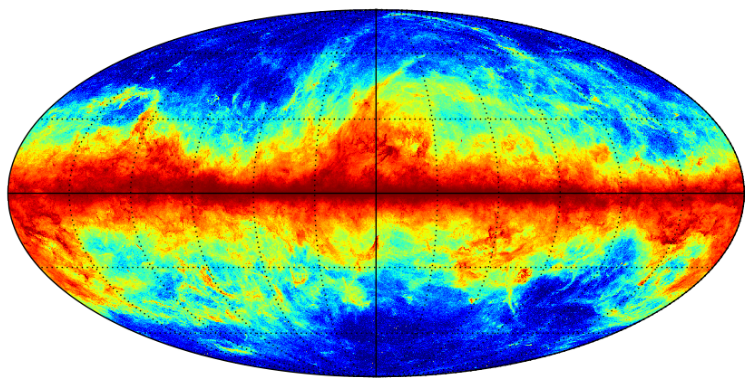
SFD
thermal

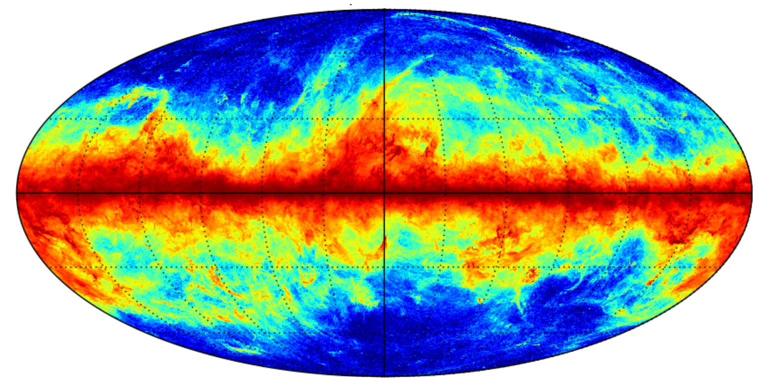




Planck 2013
thermal

Planck 2015
thermal

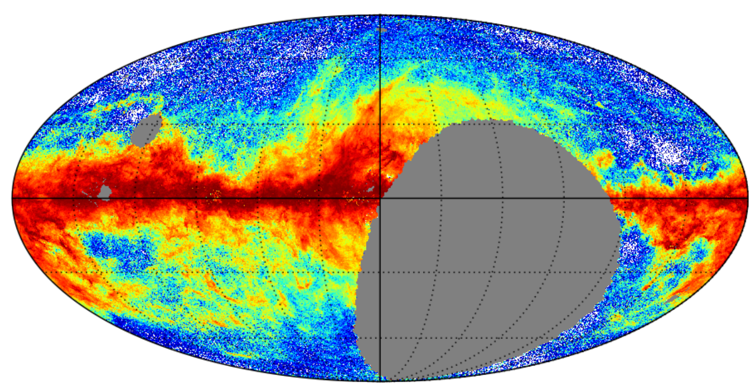




Meisner &
Finkbeiner 2015
2-components

5

Schlafly et al. 2014
Pan-STARRS
stellar reddening



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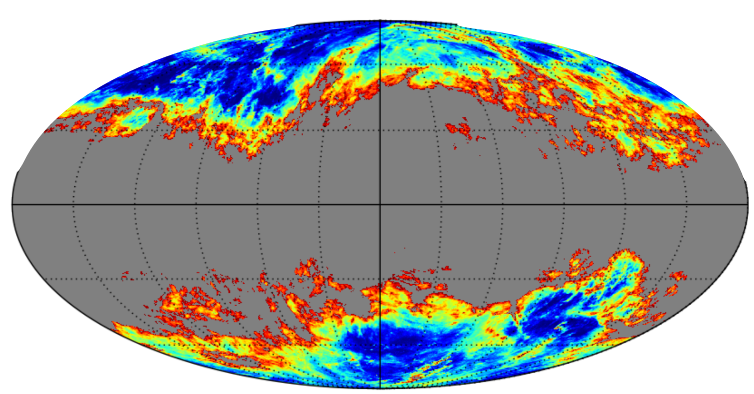
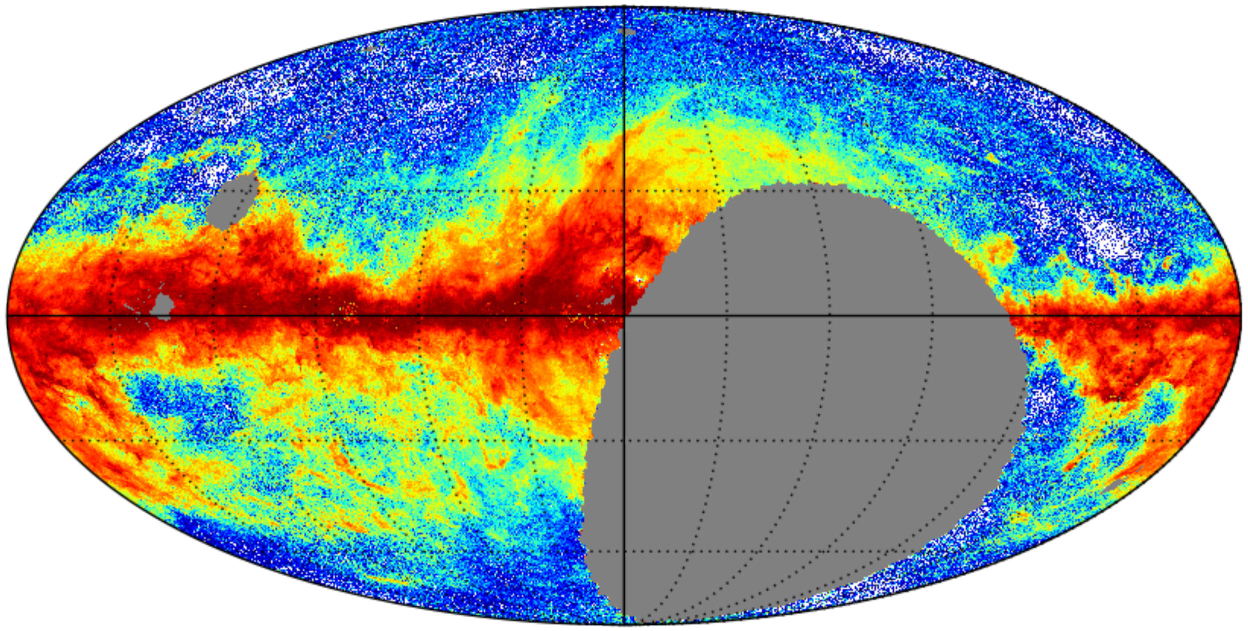
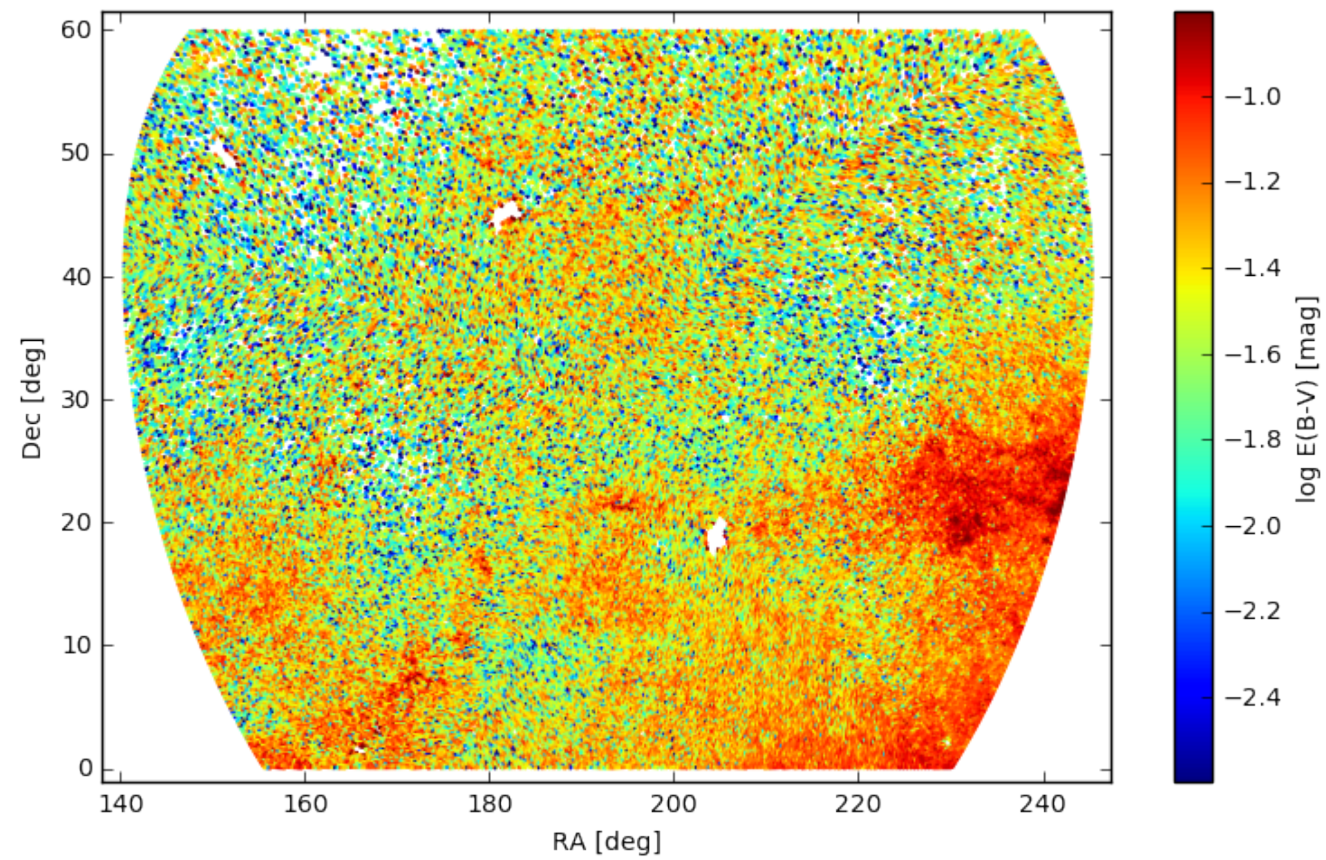
HI 21cm



Dust map 5: Stellar reddening in Pan-STARRS1 (4.5kpc)



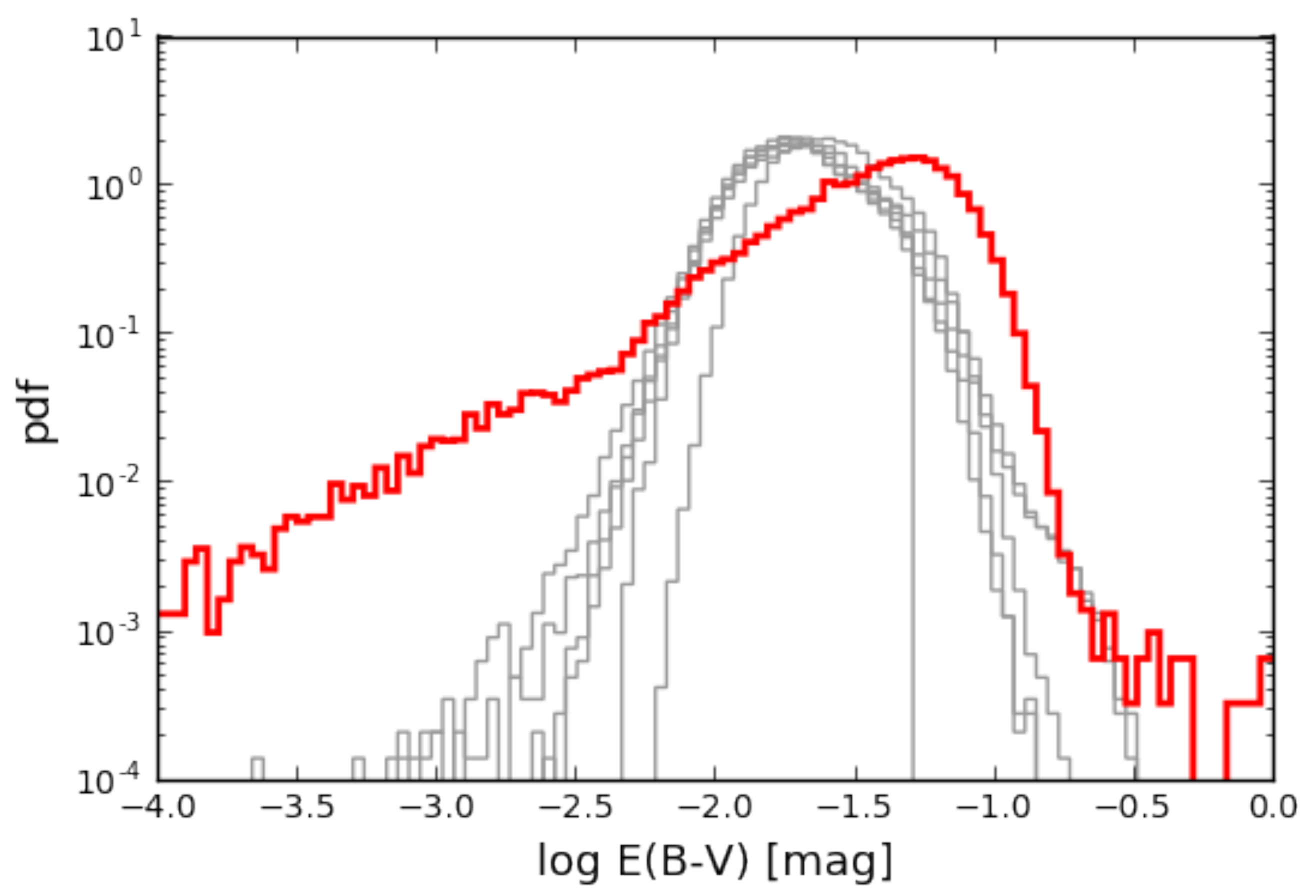


Authors: Schlafly et al. 2014

Citations: 48

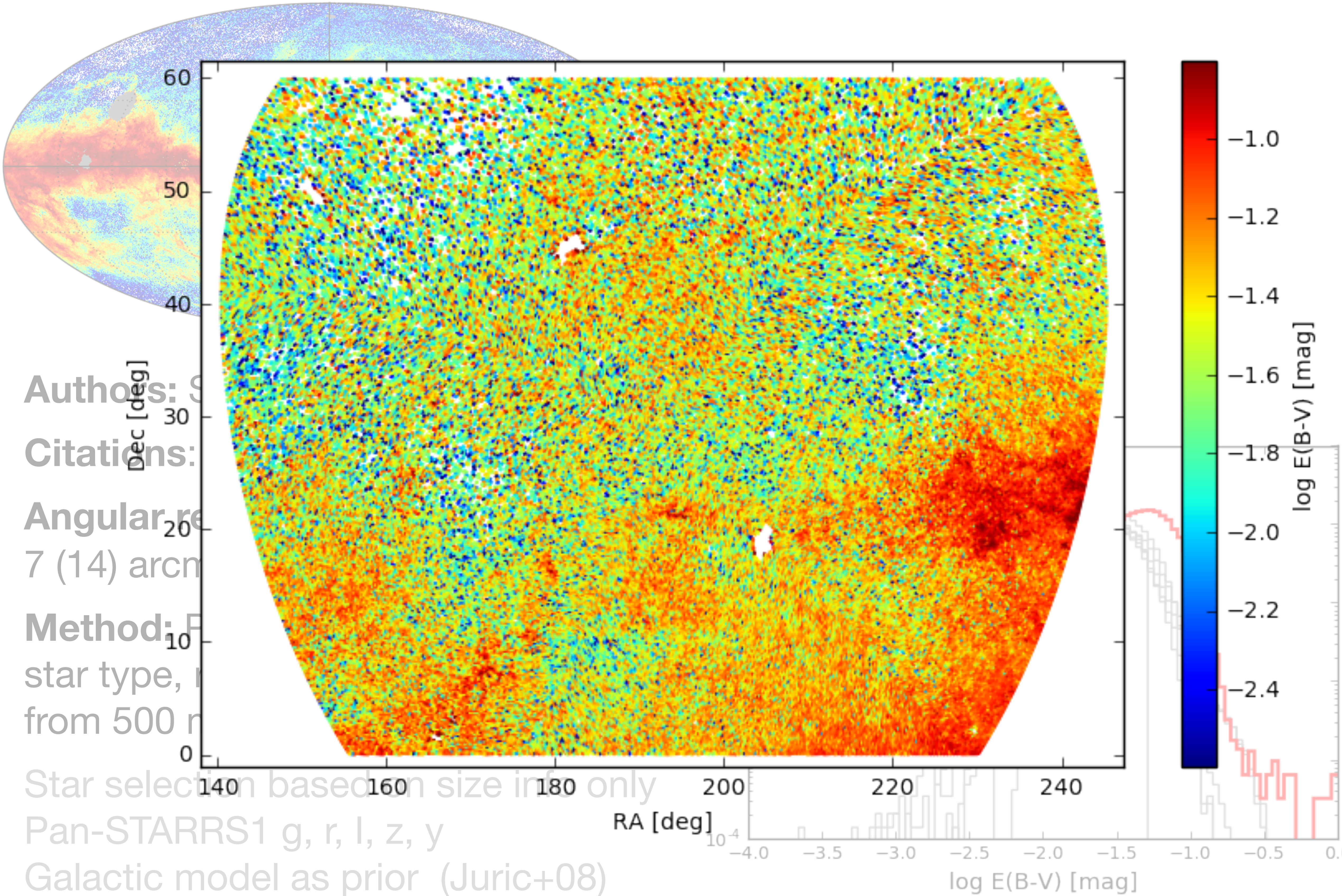
Angular resolution:
7 (14) arcmin at |b|<30 (>30)

Method: Photometric modeling of star type, reddening and distance from 500 million point sources



Star selection based on size info only
Pan-STARRS1 g, r, I, z, y
Galactic model as prior (Juric+08)

Dust map 5: Stellar reddening in Pan-STARRS1 (4.5kpc)



Authors: S

Citations:

Angular re
7 (14) arcm

Method: F
star type, r
from 500 r

Star selection based on size info only
Pan-STARRS1 g, r, I, z, y
Galactic model as prior (Juric+08)

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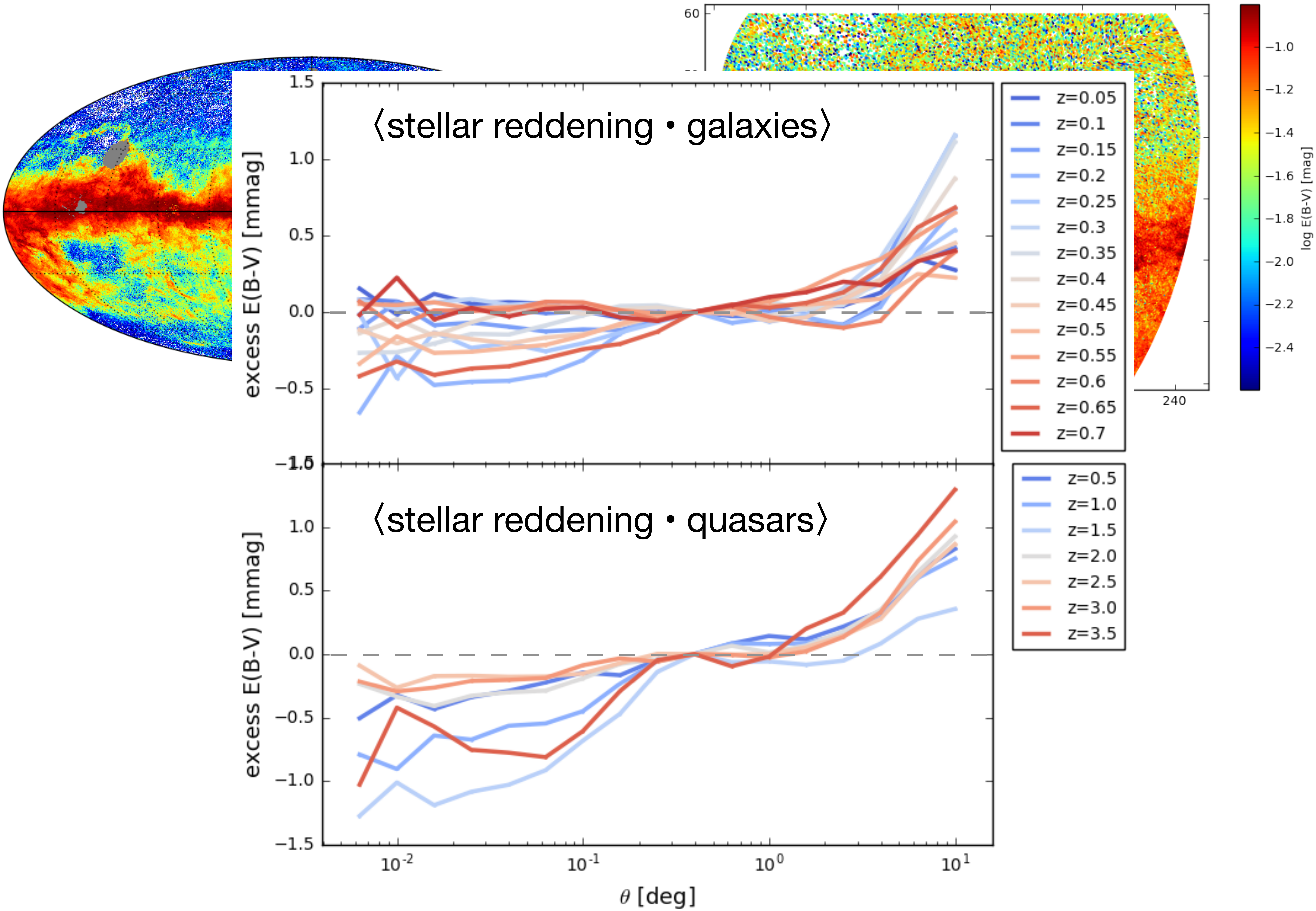

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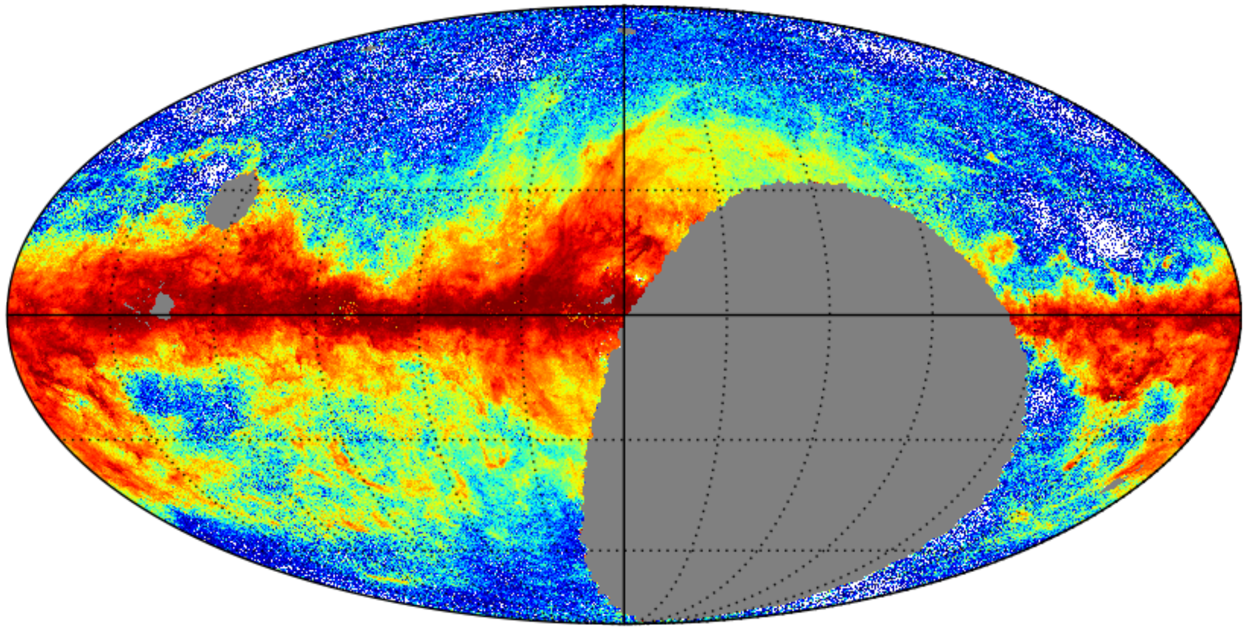
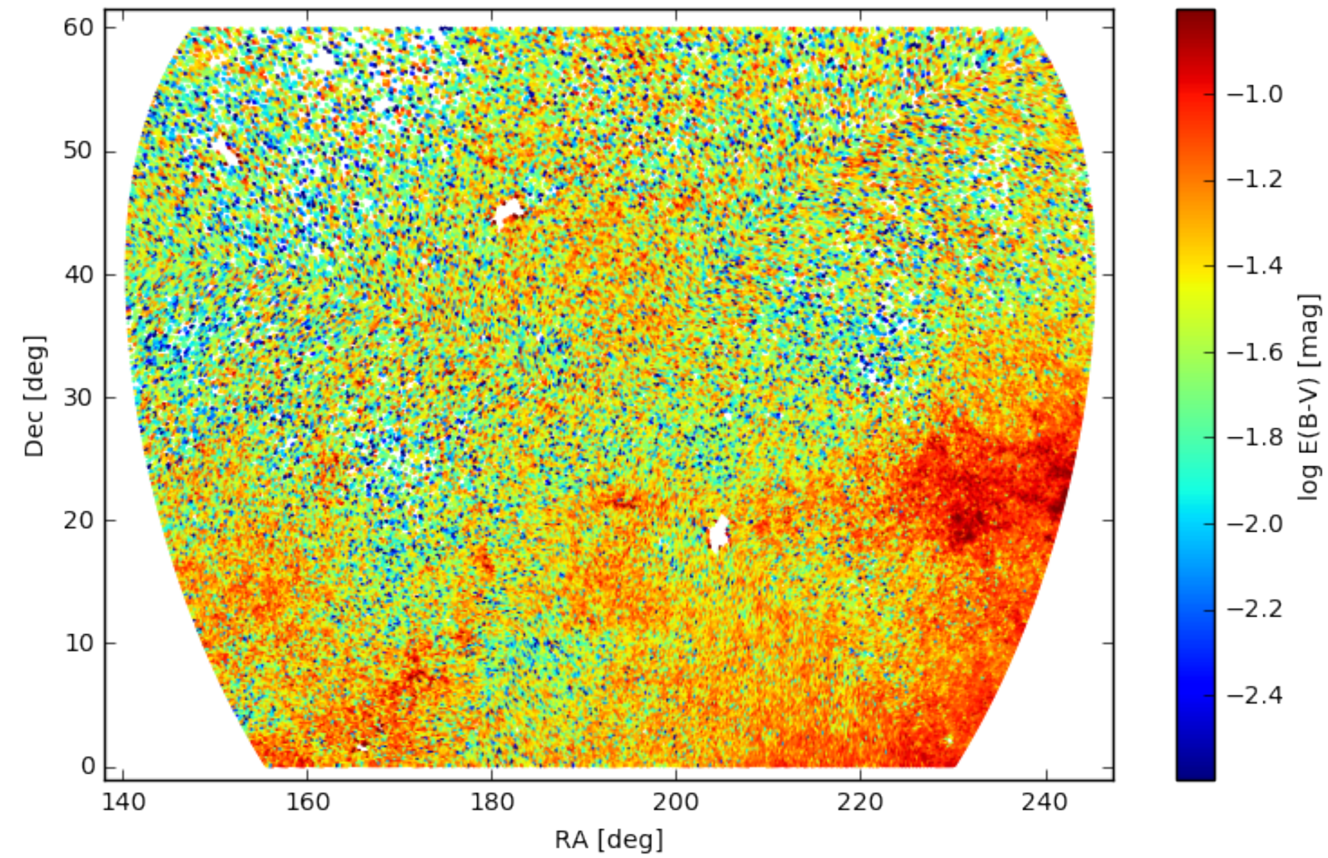
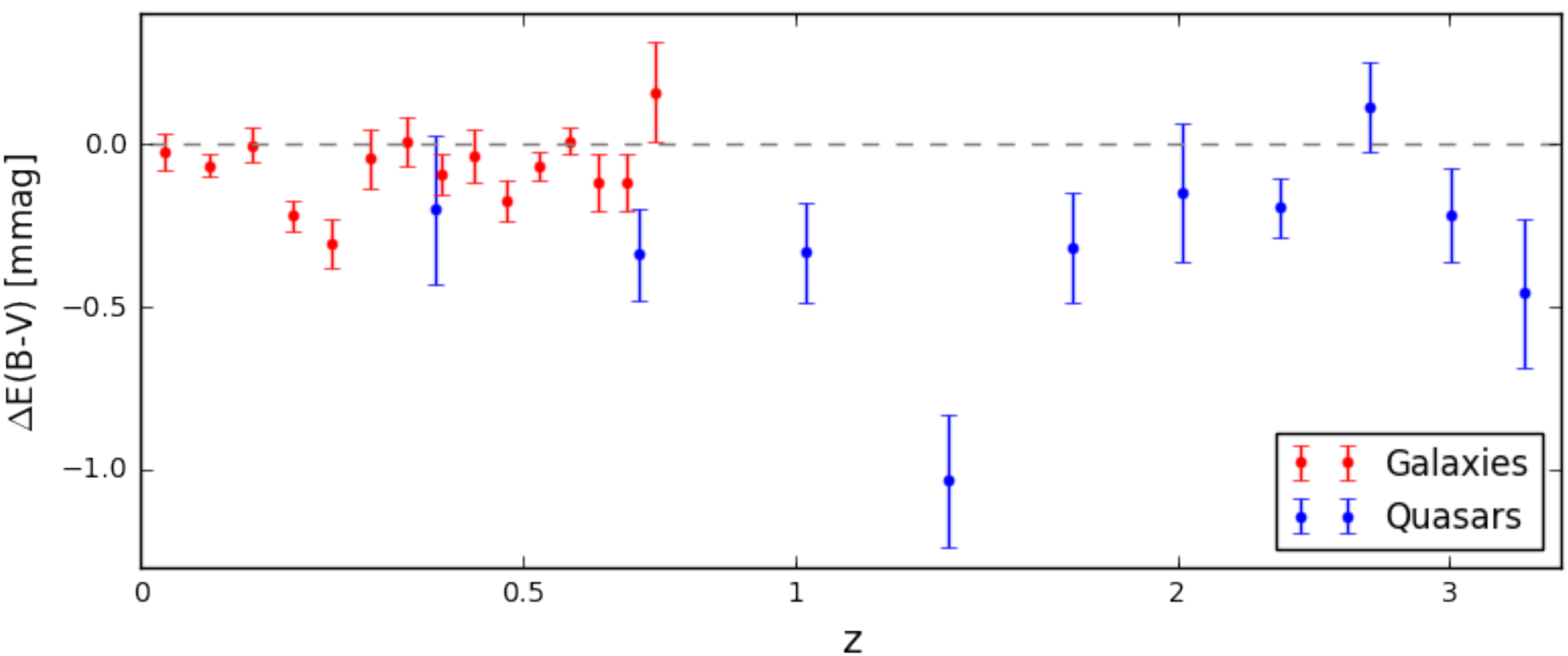


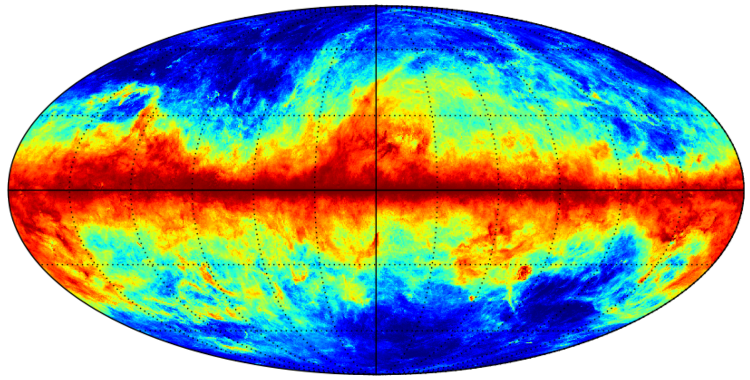


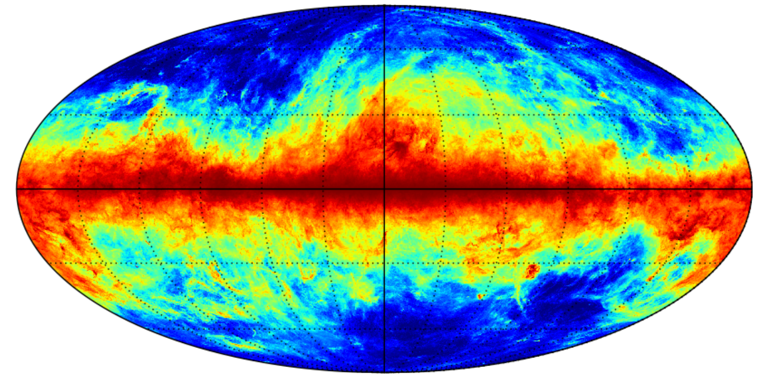
(Expected) presence of extragalactic sources in the point source catalog



de-projecting 6 dust maps

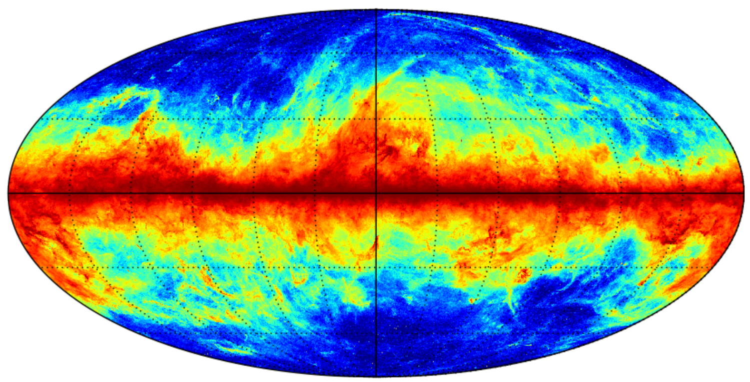
SFD
thermal

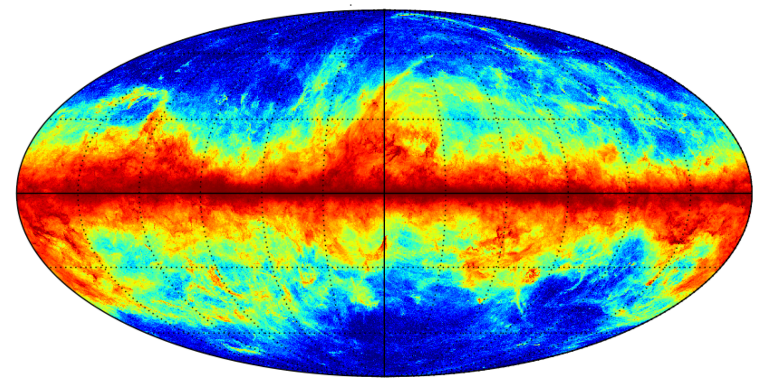




Planck 2013
thermal

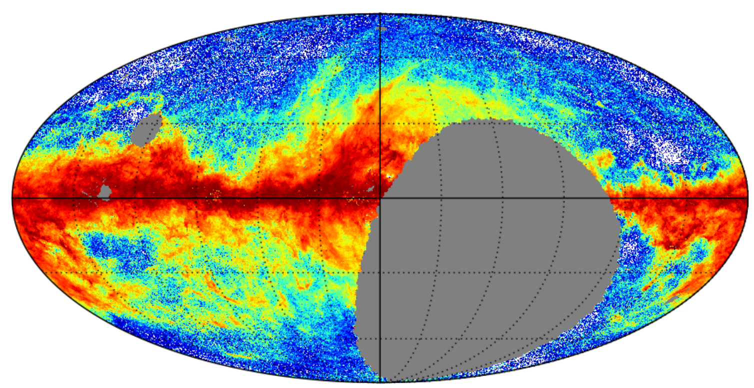
Planck 2015
thermal





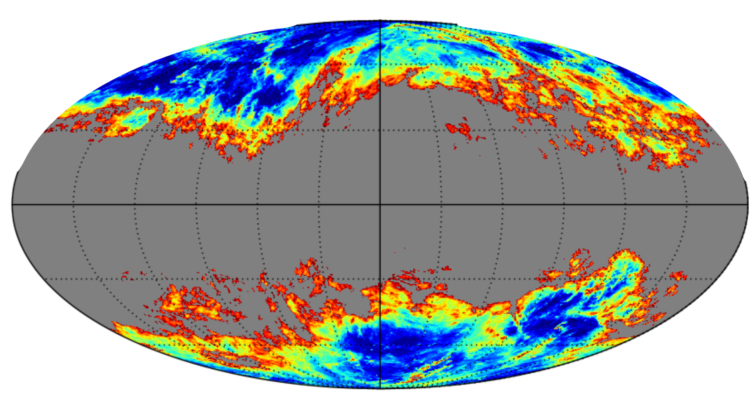
Meisner &
Finkbeiner 2015
2-components

Schlafly et al. 2014
Pan-STARRS
stellar reddening

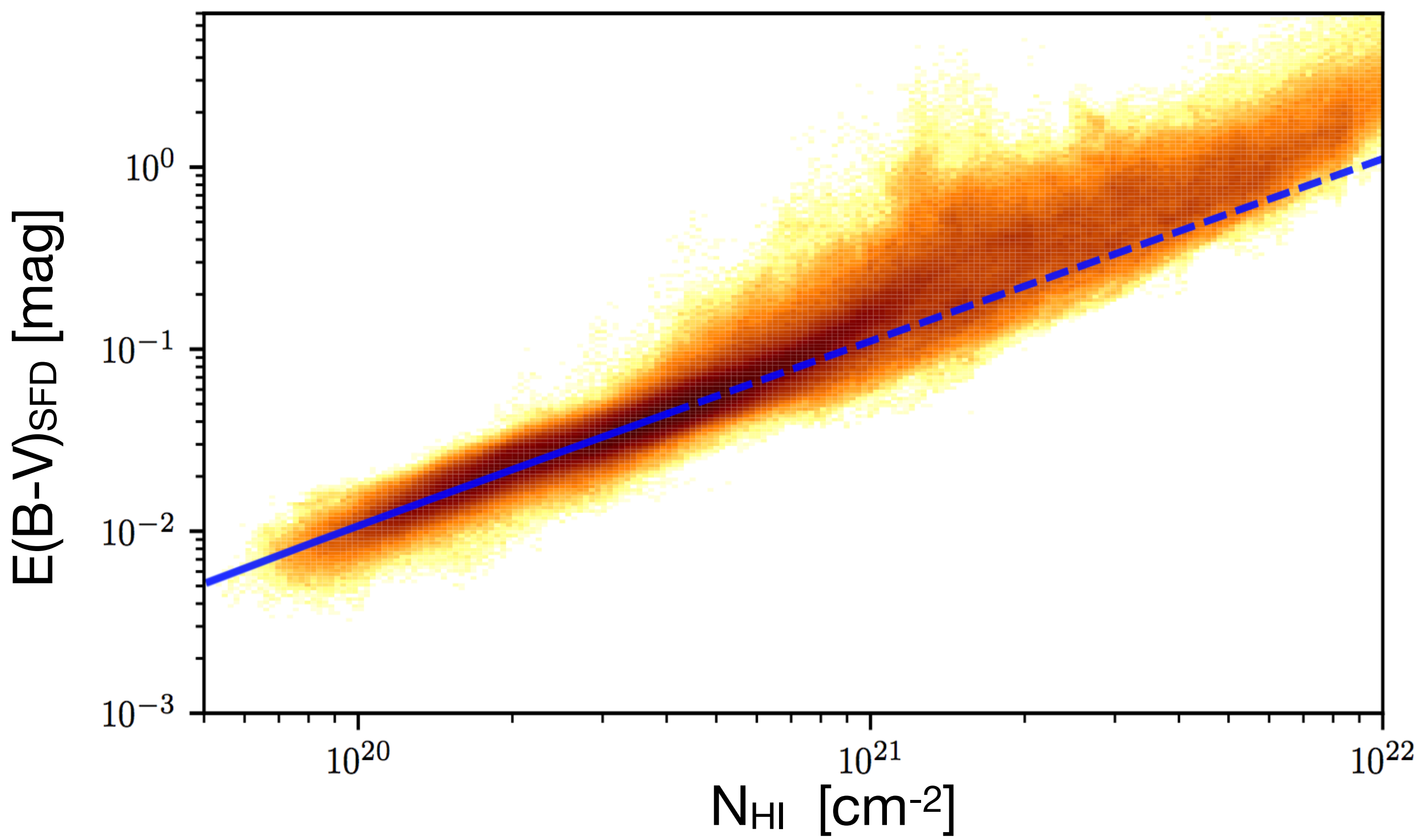


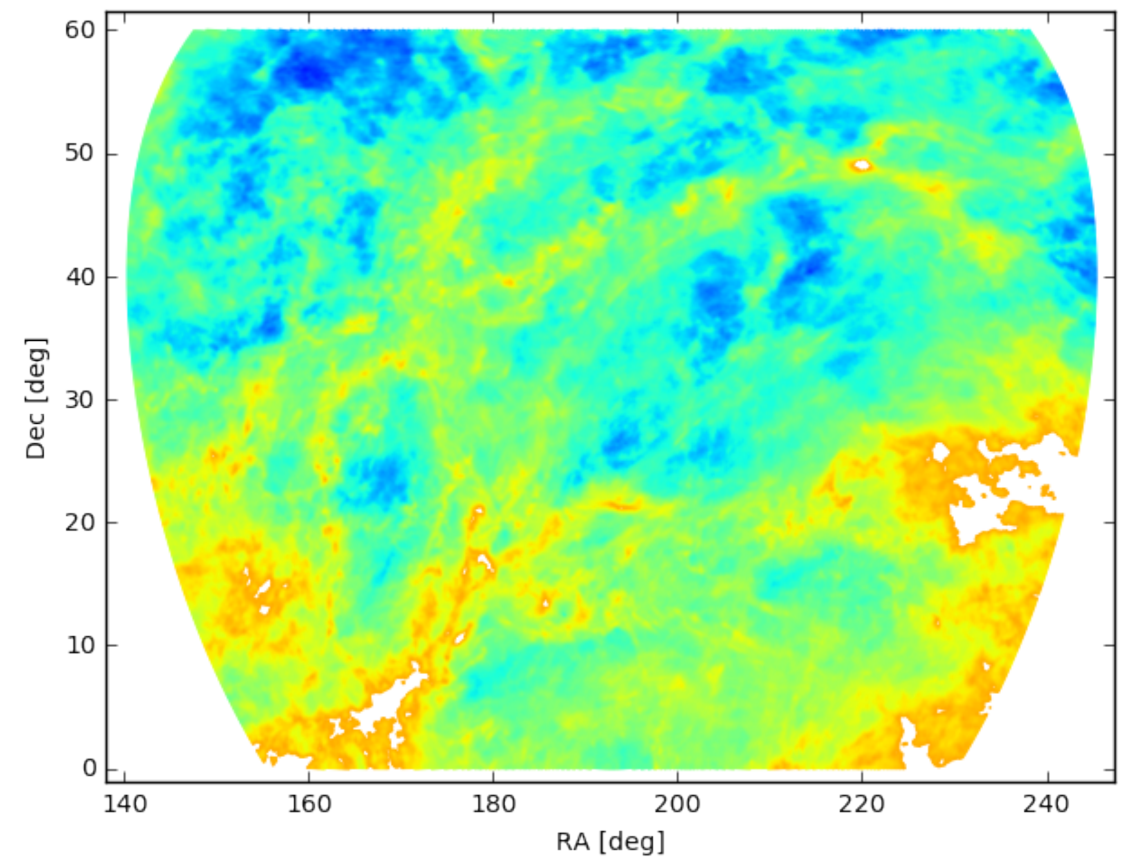
6

Lenz, Hensley, & Dore 2017
HI4PI
HI 21cm



Dust map 6: Neutral Hydrogen 21cm emission — HI4PI





Authors: Lenz, Hensley, & Dore 2017

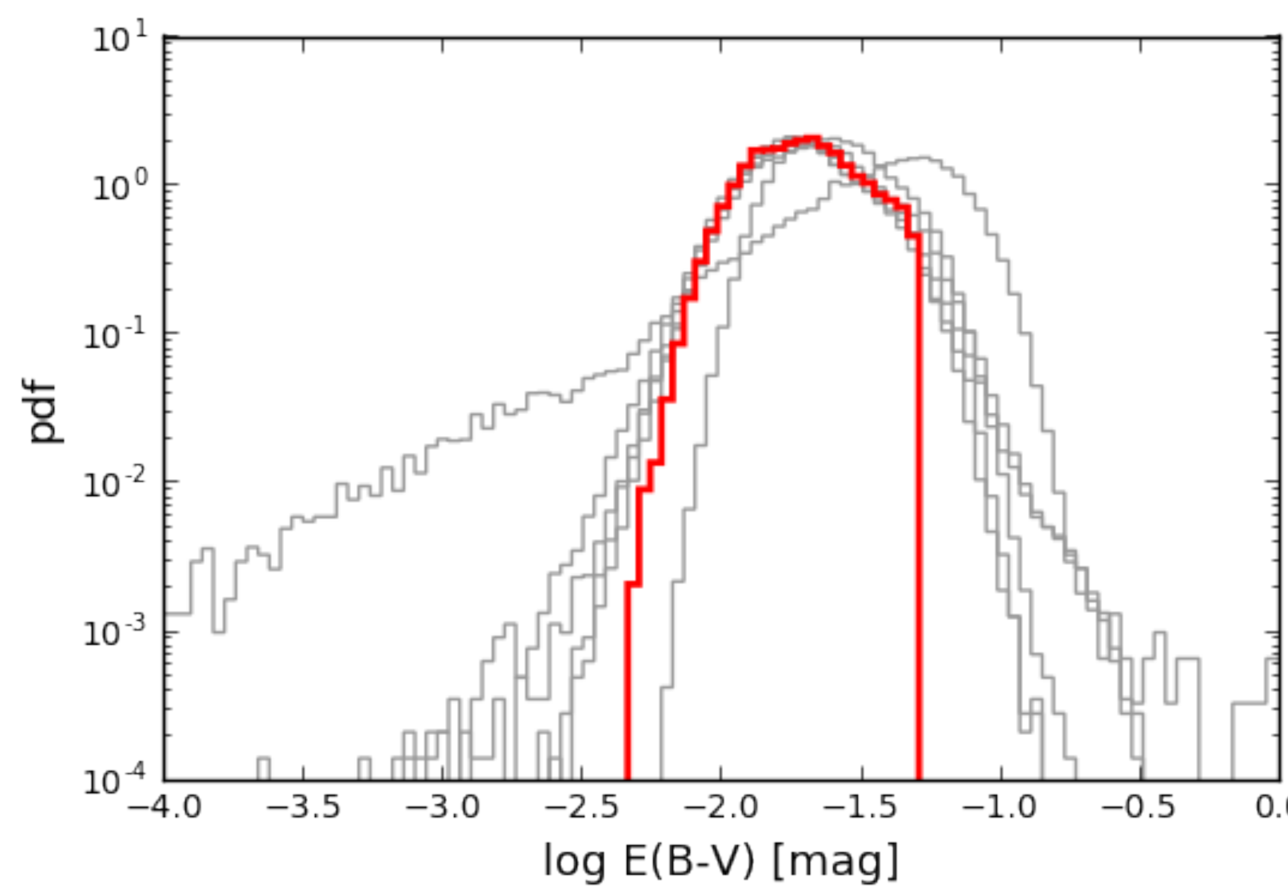
Citations: 1

Angular resolution: 16'1 arcmin

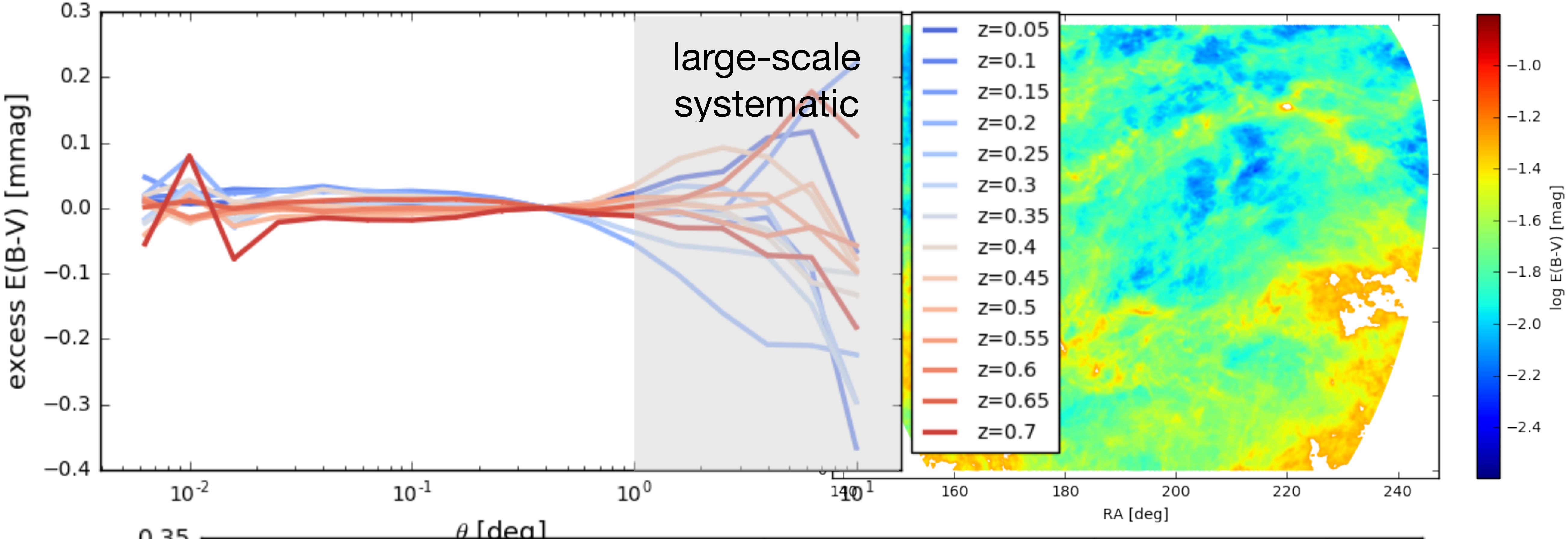
Method: HI 21 cm in HI4PI survey

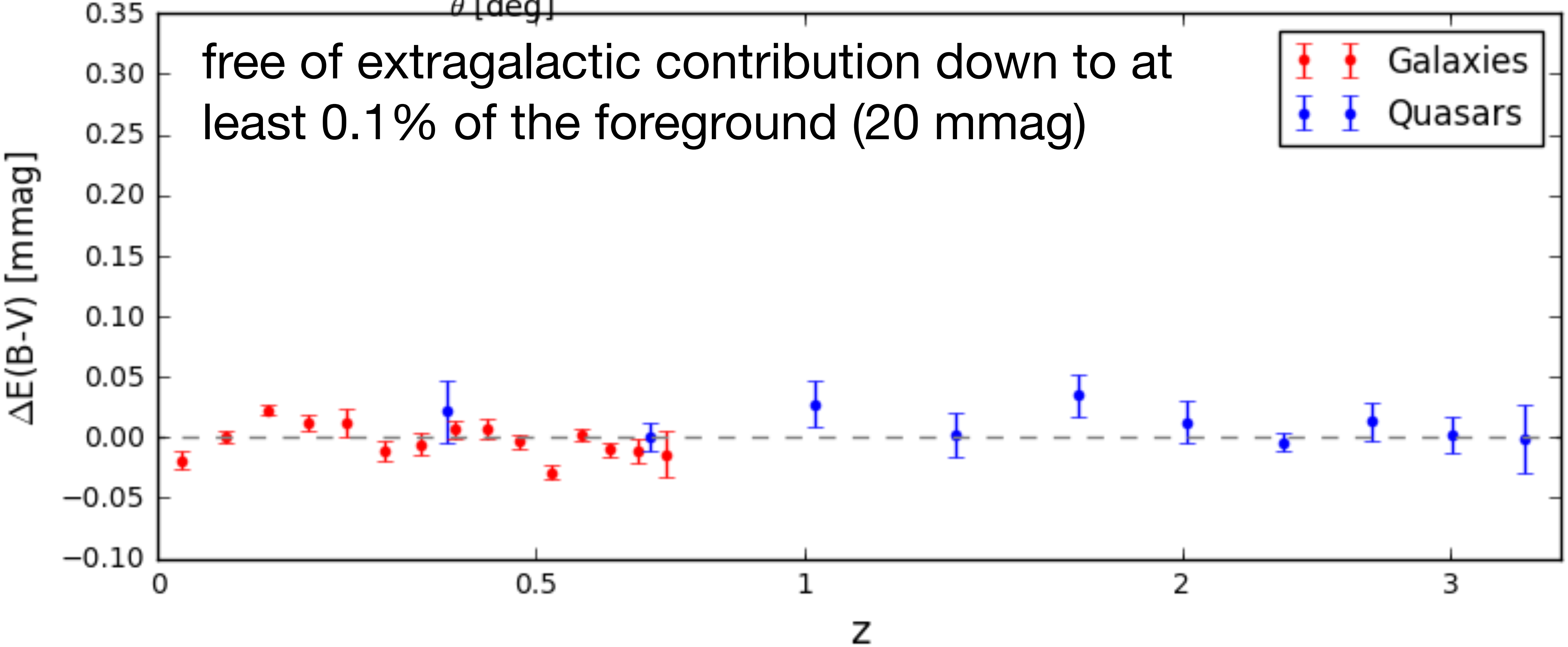
data merged from the Effelsberg-Bonn HI Survey (**EBHIS**) and the Galactic All-Sky Survey (**GASS**)

Linear regression to SFD reddening scale (up to $N_{HI} = 4 \times 10^{20}$ cm^{-2})



Dust map 7: Neutral Hydrogen 21cm emission — HI4PI

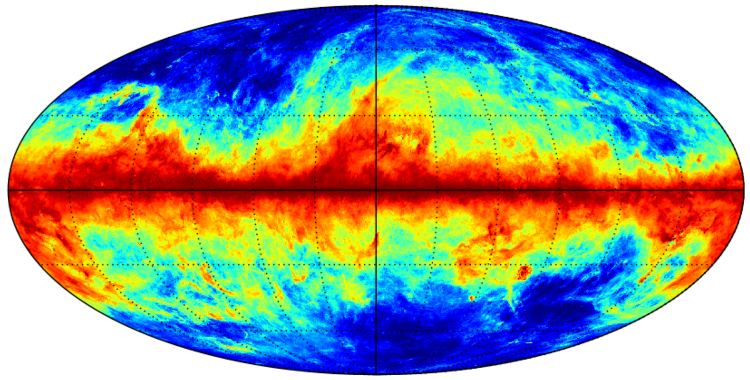




Are there extragalactic signatures in Galactic dust maps? YES

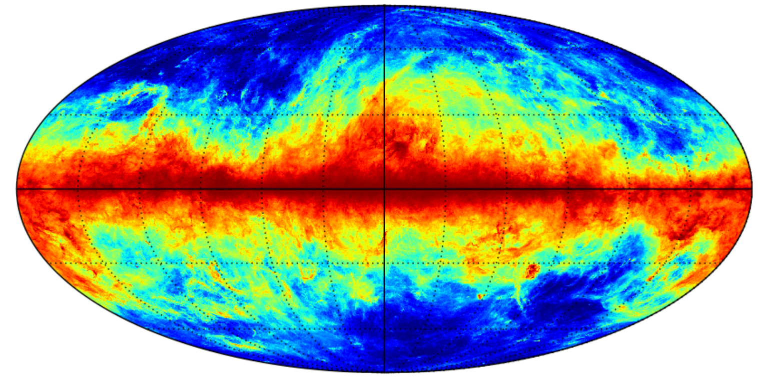
1

SFD



yes

2



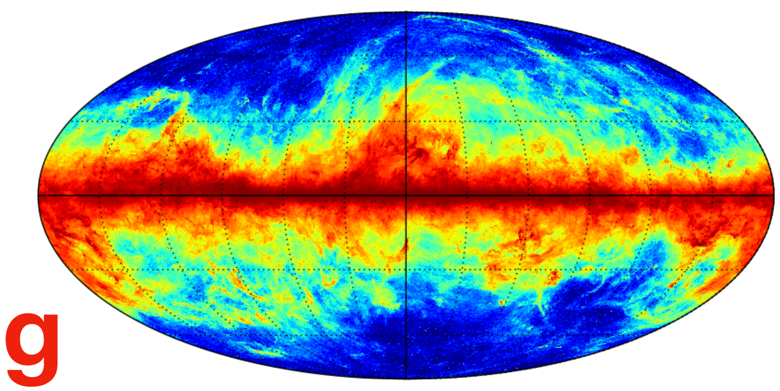
Planck 2013

yes

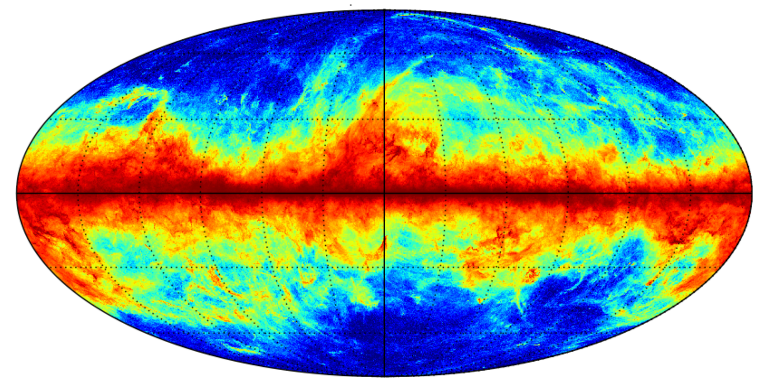
3

Planck 2015

yes, strong



4



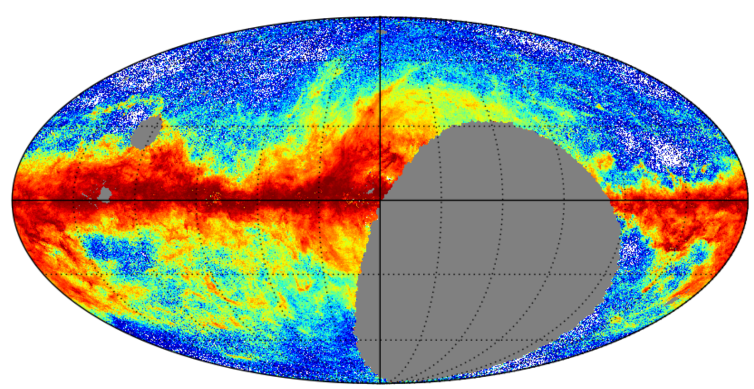
Meisner &
Finkbeiner 2015
2-components thermal

yes, strong

5

Schlafly et al. 2014
Pan-STARRS
stellar reddening

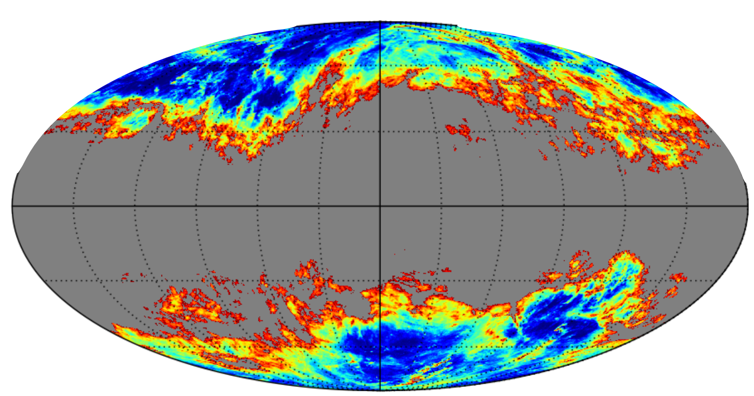
yes, anti-corr



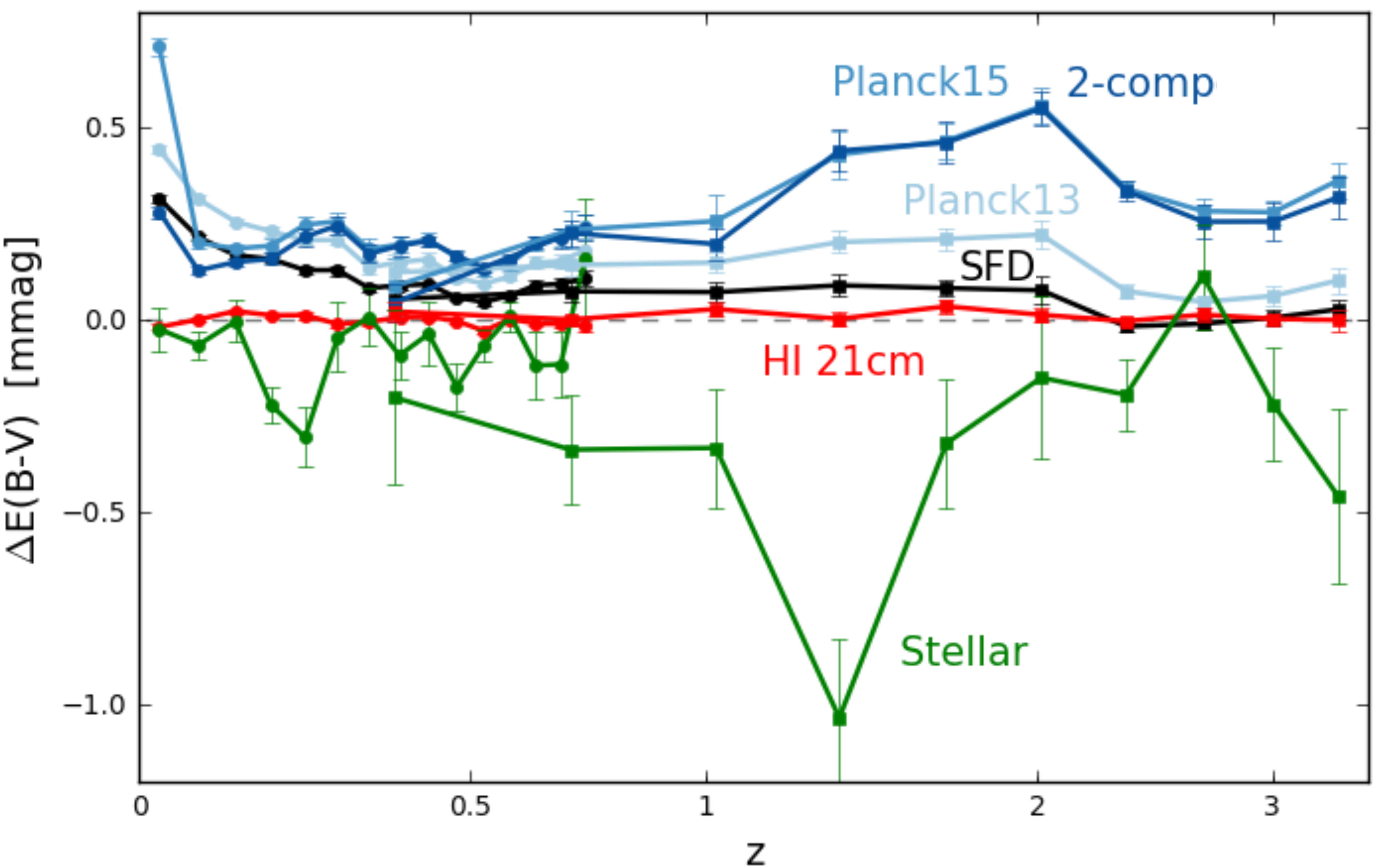
6

Lenz, Hensley, & Dore 2017
HI4PI
HI 21cm

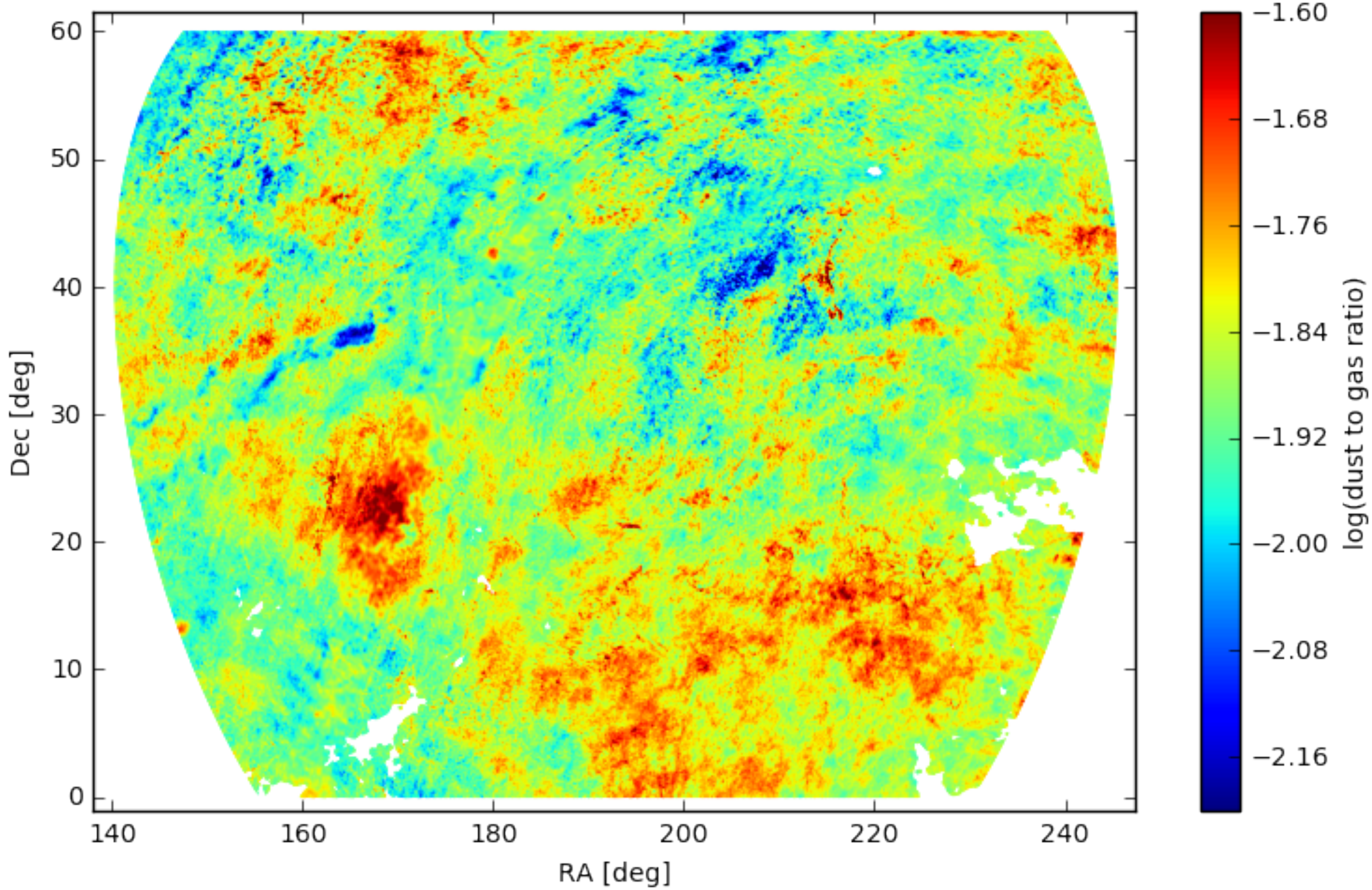
no



Are there extragalactic signatures in Galactic dust maps? YES — a 3D view



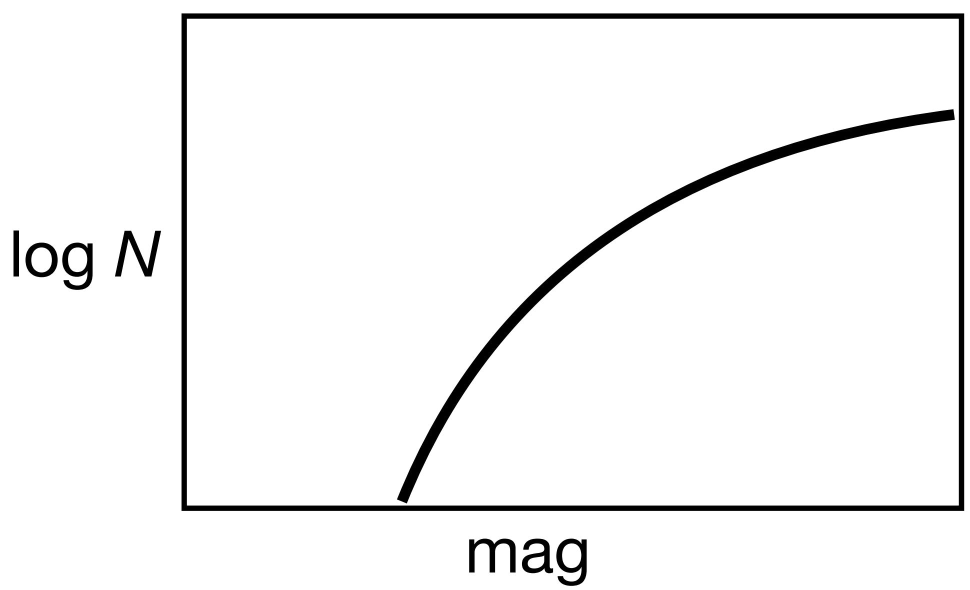
Extra Variance in HI-Derived Dust Map due to Dust-to-Gas Ratio Modulation

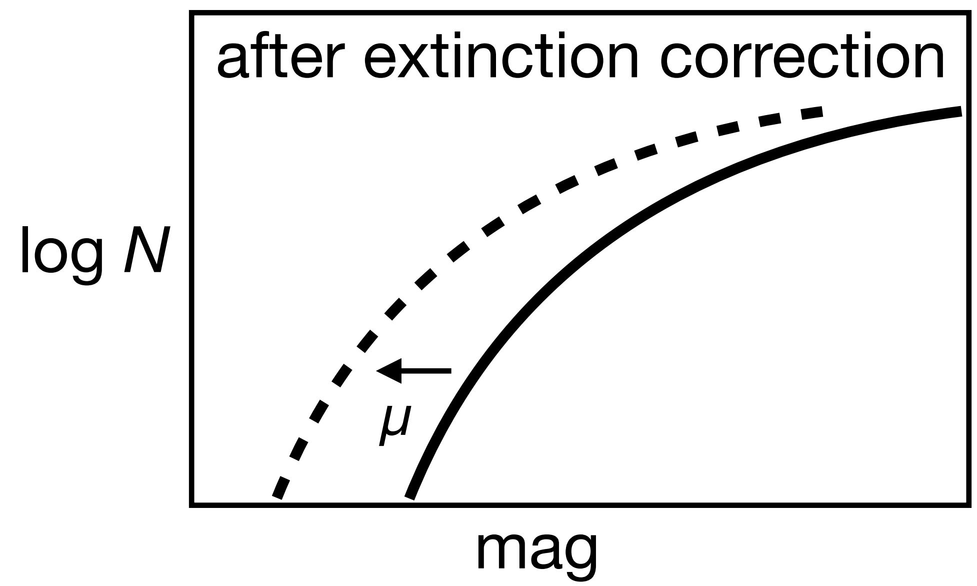


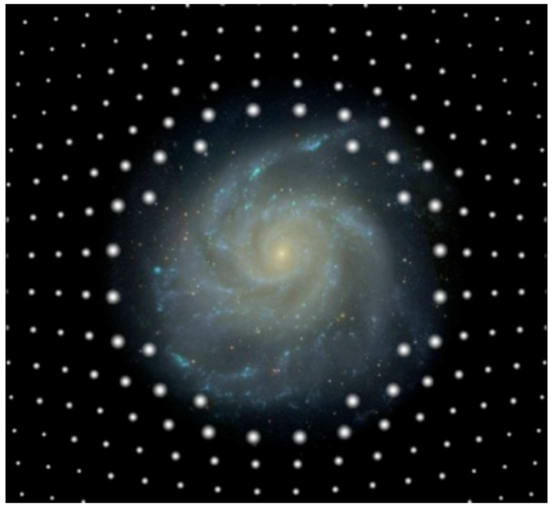
- The HI-based dust map is free of extragalactic contribution.
- However, it is limited by dust-to-gas ratio modulations (10 deg structures).

Extinction Over-correction (“Magnification”) bias

Similar to gravitational lensing magnification effect but no area dilatation







	lensing	extinction correction
Brightness Magnification	μ	$\boldsymbol{\mu_{ext} = e^{\tau} = 10^{0.4 A(\lambda)}}$
Number Count Bias	$1 + (\alpha - 1)\,\delta\mu$	$\boldsymbol{1 + \alpha\,\delta\mu_{ext}}$
Clustering Bias $w_{s,l}(\theta)$	$(\alpha_s - 1)\, w_{\mu,l}(\theta)$ $= (\alpha_s - 1)\, b_l\ w_{\mu,m}(\theta)$	$\alpha\, w_{\mu\_ext,\, l}(\theta)$ $= \alpha\, b_l\ w_{\mu\_ext,m}(\theta)$ $= \alpha\, b_l\, b_{CIB}\, w_m(\theta)$ $= \boldsymbol{\alpha\ \langle \delta\mu_{ext}(\theta) \rangle_l}$

what I measured

Amplitude of the bias: 1% effect in E(B-V); at high latitude it’s $10^{-3} \sim 10^{-4}$ effect in optical magnitudes

Which Dust Map Should I Use?

- For lower variance: IR thermal maps like SFD and Planck
- For minimum bias: HI 21 cm map
- Close to the Galactic plane : stellar reddening is a more direct measurement

Precision Cosmology that Involves Extinction Correction

- 1-pt statistics (e.g., supernova): percent level bias due to 1-halo term CIB
- 2-pt statistics (any clustering, BAO etc): sub-percent level extra correlation

For Galaxy Evolution Studies

- Up to 10 percent bias in $e^{-\tau}$ if you're studying UV properties of (U)LIRGs, DSFGs

- Solution for 1-pt statistics: Stack your sample in SFD or Planck and de-bias using the stack in HI 21cm

Conclusion

- By applying clustering-based redshift tomography, we detect extragalactic signatures up to z~3 in 5 out of the 6 Galactic dust maps considered

- The effect is on 1% level (0.1 mmag) in E(B-V) at ~10 arcmin

- HI derived dust map is free of extragalactic contribution at least down to 0.05% level

- For dusty galaxy studies and precision cosmology (using galaxies as tracers or SNe), the impact of extinction correction biases need to be studied