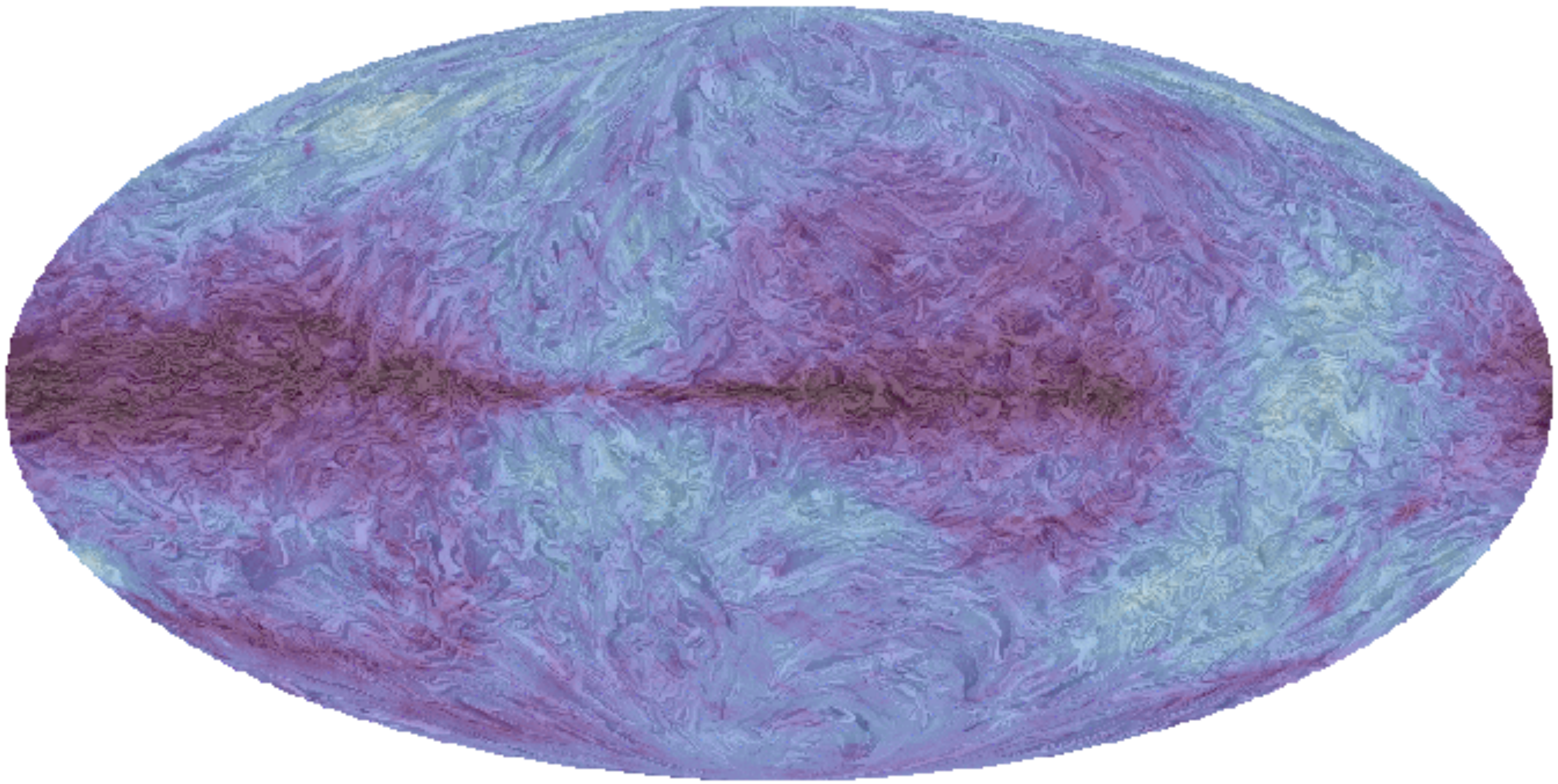
Decorrelation and the 3D ISM



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Decorrelation

- Perfect correlation across frequencies = relatively easy component separation
- Just measure dust at high frequency, synchrotron at low frequency, multiply by each map by a scalar, subtract
- The extent to which this does not work is "frequency decorrelation" (another way to say it: spatially varying spectral indices)
- **How much do foreground SEDs vary across the sky?**

Component Separation in BB

- Jointly model all pairwise *BB* auto and cross-spectra between frequencies (e.g., Choi & Page 2015, Planck Int. XXII, Planck 2018 XI, BICEP/Keck 2018)

- Equation for foreground component:

$$\mathcal{D}_{\ell,BB}^{\nu_1\times\nu_2} = A_\mathrm{d}\Delta'_\mathrm{d} f_\mathrm{d}^{\nu_1} f_\mathrm{d}^{\nu_2}\left(\frac{\ell}{80}\right)^{\alpha_\mathrm{d}} + A_\mathrm{sync}\Delta'_\mathrm{s} f_\mathrm{s}^{\nu_1} f_\mathrm{s}^{\nu_2}\left(\frac{\ell}{80}\right)^{\alpha_\mathrm{s}} + \epsilon\sqrt{A_\mathrm{d}A_\mathrm{sync}}(f_\mathrm{d}^{\nu_1} f_\mathrm{s}^{\nu_2} + f_\mathrm{s}^{\nu_1} f_\mathrm{d}^{\nu_2})\left(\frac{\ell}{80}\right)^{(\alpha_\mathrm{d}+\alpha_\mathrm{s})/2}$$

Component Separation in BB

Dust | Synchrotron | Dust-Synchrotron Correlation

$$\mathcal{D}_{\ell,BB}^{\nu_1 \times \nu_2} = A_{\mathrm{d}} \Delta'_{\mathrm{d}} f_{\mathrm{d}}^{\nu_1} f_{\mathrm{d}}^{\nu_2} \left(\frac{\ell}{80}\right)^{\alpha_{\mathrm{d}}} + A_{\mathrm{sync}} \Delta'_{\mathrm{s}} f_{\mathrm{s}}^{\nu_1} f_{\mathrm{s}}^{\nu_2} \left(\frac{\ell}{80}\right)^{\alpha_{\mathrm{s}}} + \epsilon \sqrt{A_{\mathrm{d}} A_{\mathrm{sync}}} (f_{\mathrm{d}}^{\nu_1} f_{\mathrm{s}}^{\nu_2} + f_{\mathrm{s}}^{\nu_1} f_{\mathrm{d}}^{\nu_2}) \left(\frac{\ell}{80}\right)^{(\alpha_{\mathrm{d}} + \alpha_{\mathrm{s}})/2}$$

Component Separation in BB

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SED Model Parameter *f*

Power spectrum slope α

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Power spectrum slope α

Dust Modified Blackbody

$$I_\nu = A \left(\frac{\nu}{\nu_0} \right)^{\beta} B_\nu \left(T_d \right)$$

Total dust intensity

Amount of dust

Dust composition

Dust temperature

- What if spectral parameters vary across the sky?

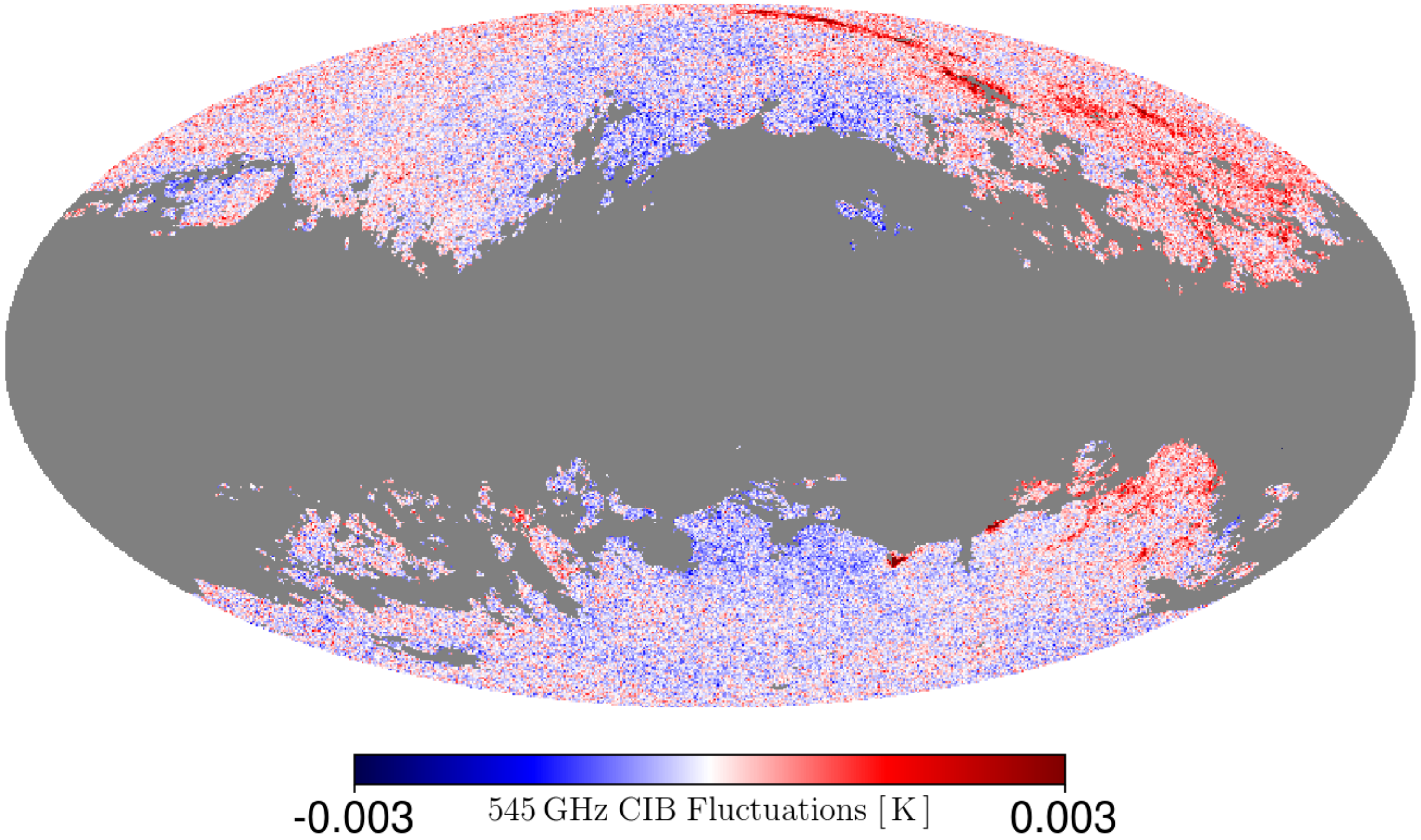
"Frequency Decorrelation"

- A foreground map at one frequency does not necessarily have the same spatial structure at a different frequency

- Easy to see in the CIB, for instance:

Planck 545 - Rescaled Planck 857

But also see Galaxy!



Do We Expect Decorrelation?

$$I_\nu = A \left(\frac{\nu}{\nu_0} \right)^\beta B_\nu \left(T_d \right)$$

Total dust intensity

Amount of dust

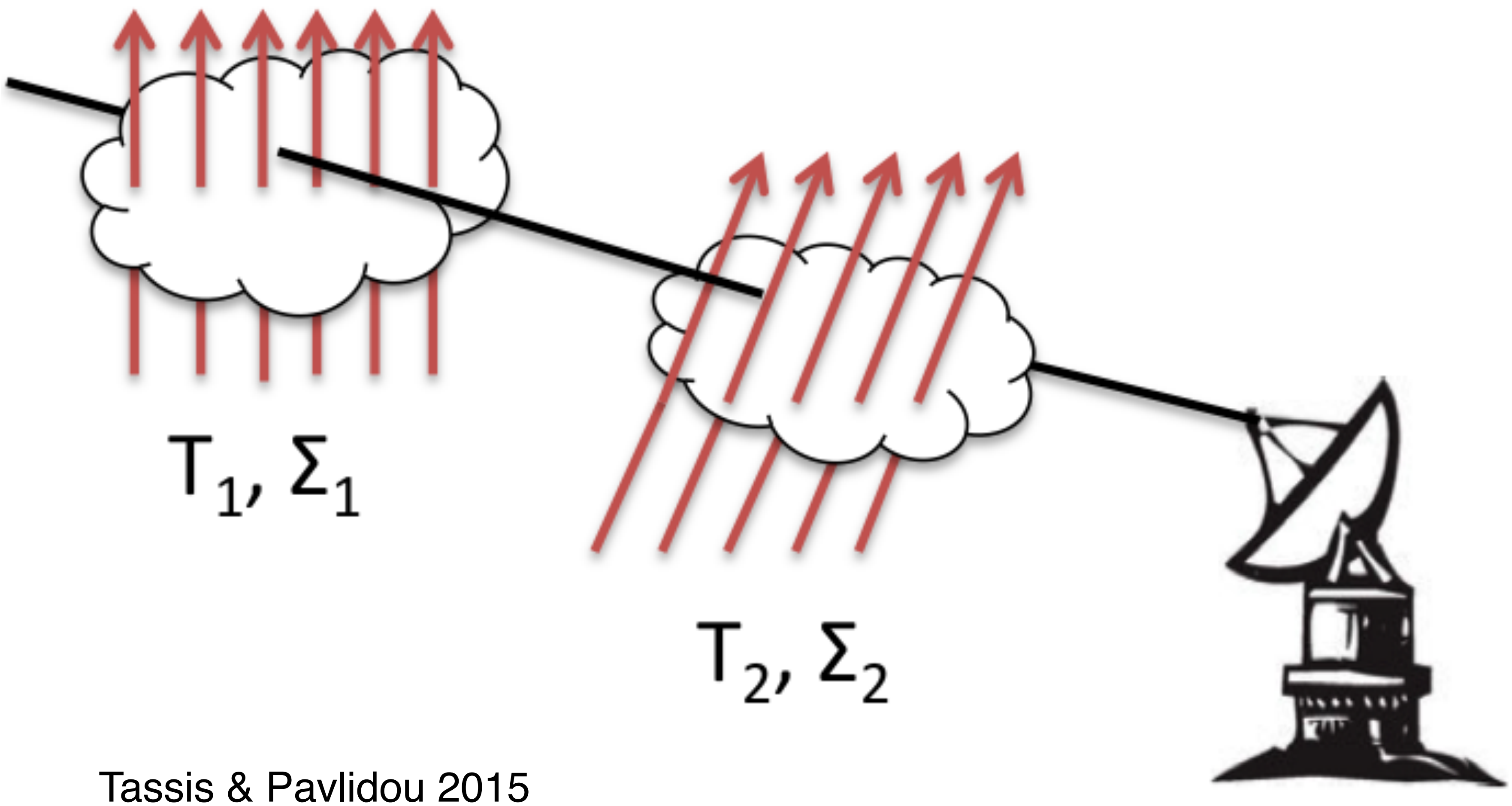
Dust composition

Dust temperature

- Temperature must vary!
- Composition varies, but unsure how much and what effect it has
- Remember that MBB is just a convenient fitting function, not the whole story

Decorrelation and Polarization

- Effect is perhaps more pernicious in polarization: can even change sign of *Q* or *U* between frequencies



Tassis & Pavlidou 2015

Component Separation in BB

Dust — Synchrotron — Dust-Synchrotron Correlation

$$\mathcal{D}_{\ell,BB}^{\nu_1\times\nu_2} = A_\mathrm{d}\Delta'_\mathrm{d} f_\mathrm{d}^{\nu_1} f_\mathrm{d}^{\nu_2}\left(\frac{\ell}{80}\right)^{\alpha_\mathrm{d}} + A_\mathrm{sync}\Delta'_\mathrm{s} f_\mathrm{s}^{\nu_1} f_\mathrm{s}^{\nu_2}\left(\frac{\ell}{80}\right)^{\alpha_\mathrm{s}} + \epsilon\sqrt{A_\mathrm{d}A_\mathrm{sync}}(f_\mathrm{d}^{\nu_1} f_\mathrm{s}^{\nu_2} + f_\mathrm{s}^{\nu_1} f_\mathrm{d}^{\nu_2})\left(\frac{\ell}{80}\right)^{(\alpha_\mathrm{d}+\alpha_\mathrm{s})/2}$$

SED Model Parameter *f*

Power spectrum slope α

SED Model Parameter *f*

Power spectrum slope α

Component Separation in BB

- Add decorrelation parameters to account for this effect

Dust — Synchrotron — Dust-Synchrotron Correlation

$$\mathcal{D}_{\ell,BB}^{\nu_1\times\nu_2} = A_{\rm d}\Delta'_{\rm d} f_{\rm d}^{\nu_1} f_{\rm d}^{\nu_2}\left(\frac{\ell}{80}\right)^{\alpha_{\rm d}} + A_{\rm sync}\Delta'_{\rm s} f_{\rm s}^{\nu_1} f_{\rm s}^{\nu_2}\left(\frac{\ell}{80}\right)^{\alpha_{\rm s}} + \epsilon\sqrt{A_{\rm d}A_{\rm sync}}\left(f_{\rm d}^{\nu_1} f_{\rm s}^{\nu_2} + f_{\rm s}^{\nu_1} f_{\rm d}^{\nu_2}\right)\left(\frac{\ell}{80}\right)^{(\alpha_{\rm d}+\alpha_{\rm s})/2}$$

SED Model Parameter *f* (Dust)

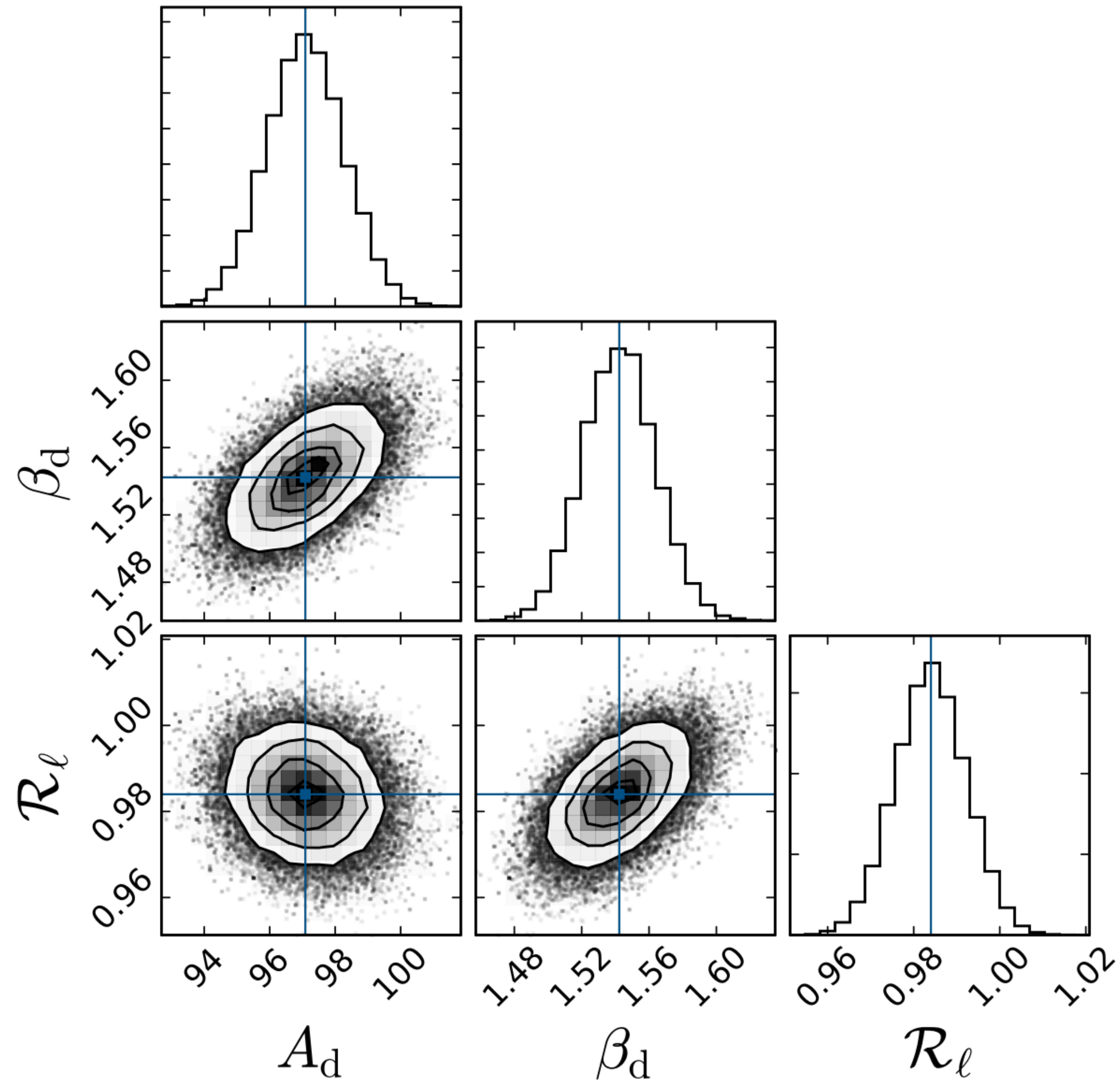
Power spectrum slope α (Dust)

SED Model Parameter *f* (Synchrotron)

Power spectrum slope α (Synchrotron)

Planck Constraints

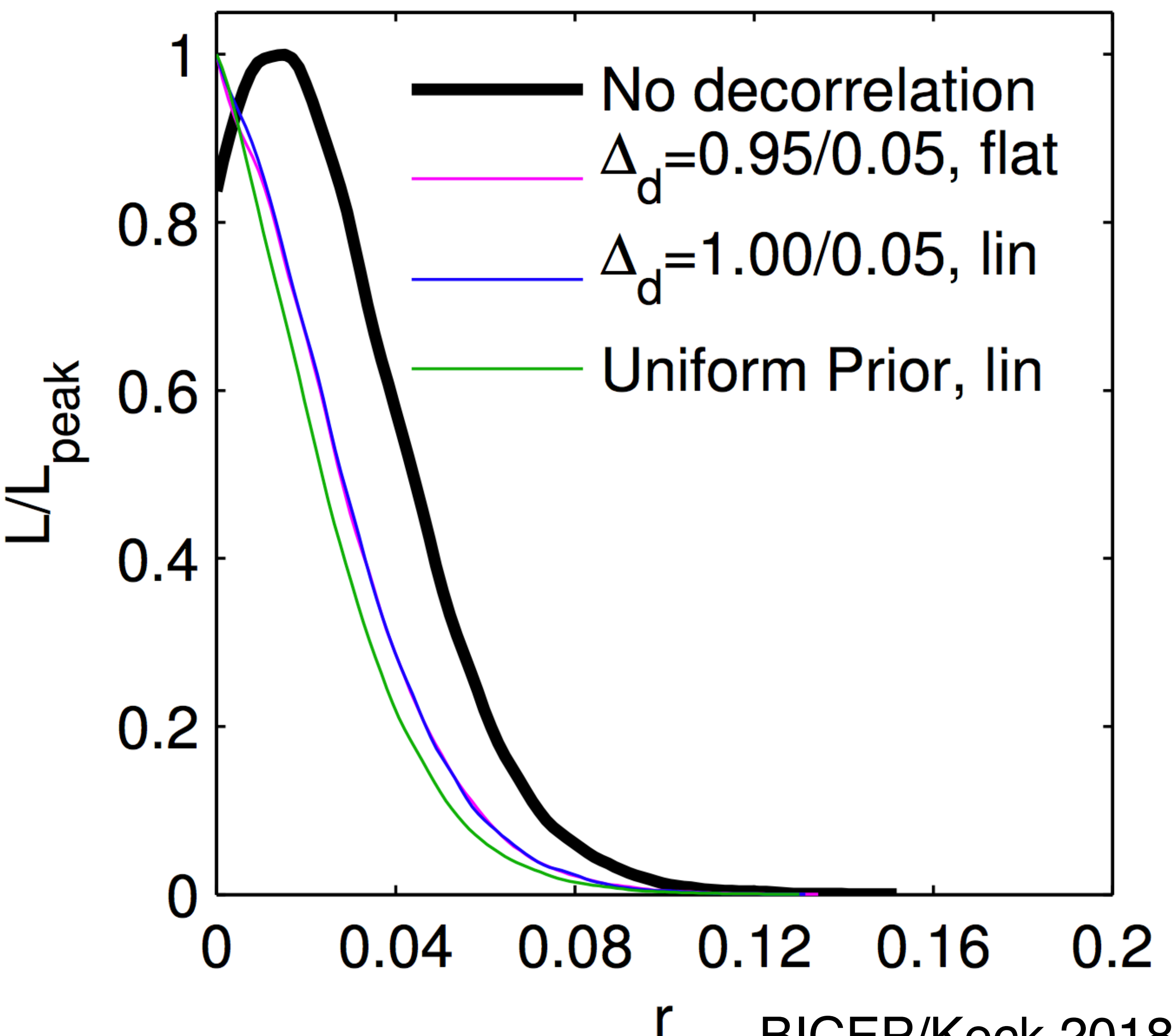
- Not detected in Planck polarization data



Planck 2018 XI

Component Separation in BB

- Accounting for decorrelation has a big impact on *r* constraints
- "Dust decorrelation, and foreground complexity more generally, will remain a serious concern."
- Can we make a prediction for how much decorrelation we should expect?



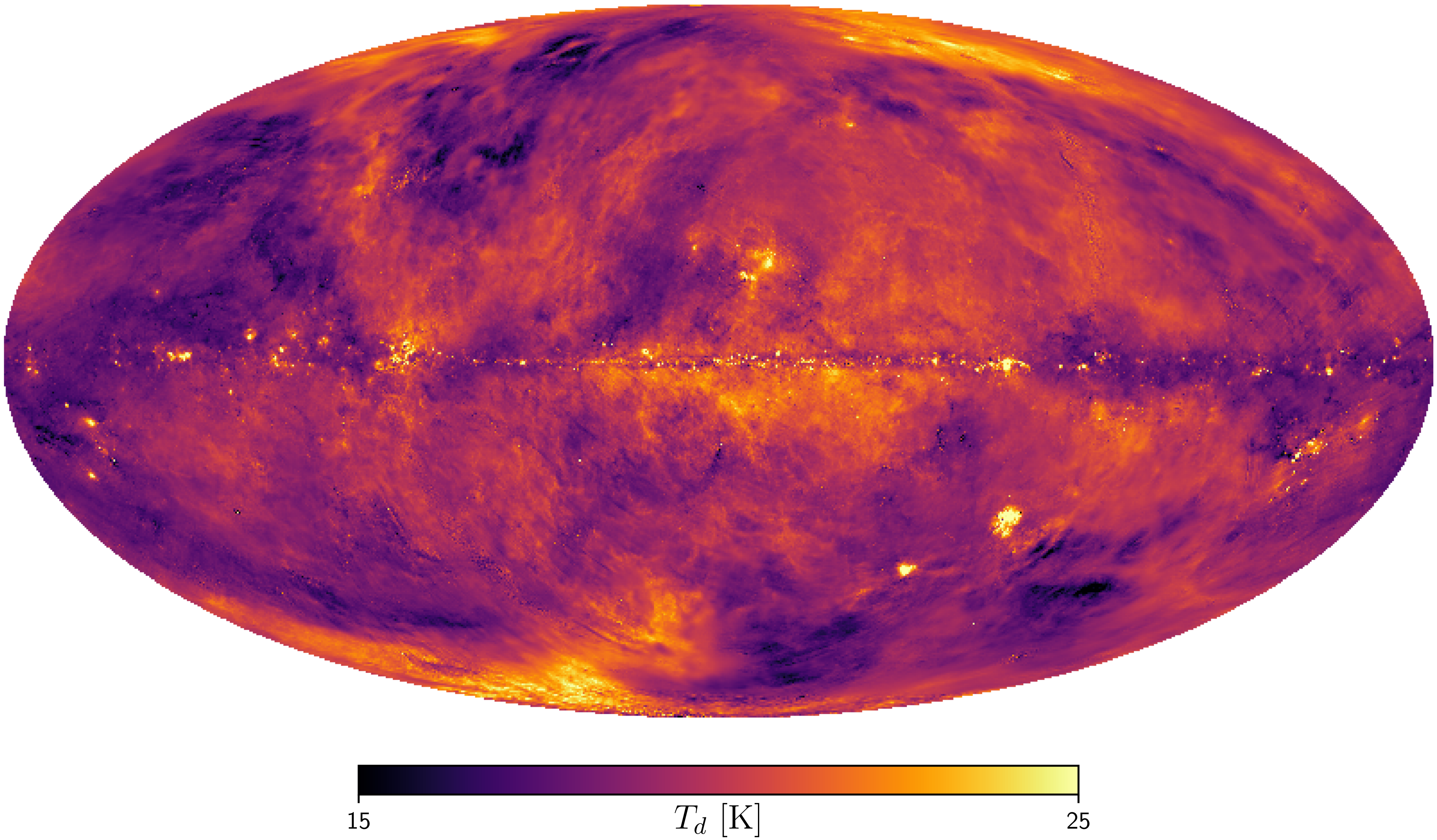
BICEP/Keck 2018

Decorrelation with HI

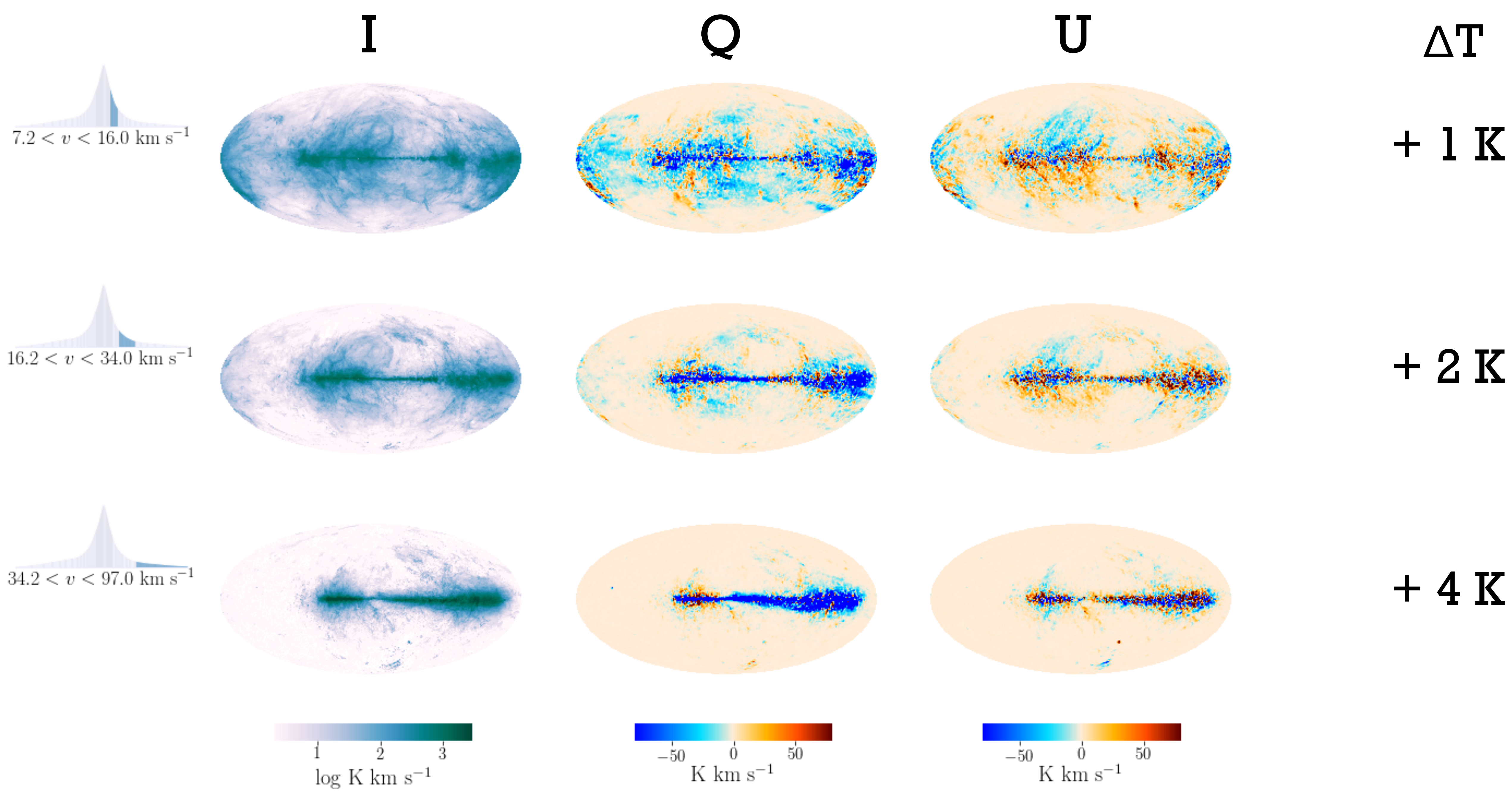
- HI gives us a 3D view of the dust density field *and* the magnetic field that threads it
- However, no information about dust spectral parameters
- Ansatz: To model the effect of gas of different velocities having different temperatures, perturb *Planck* dust temperature map with amplitude that scales as HI velocity

Decorrelation with HI

- Start with mean dust temperature map (GNILC):

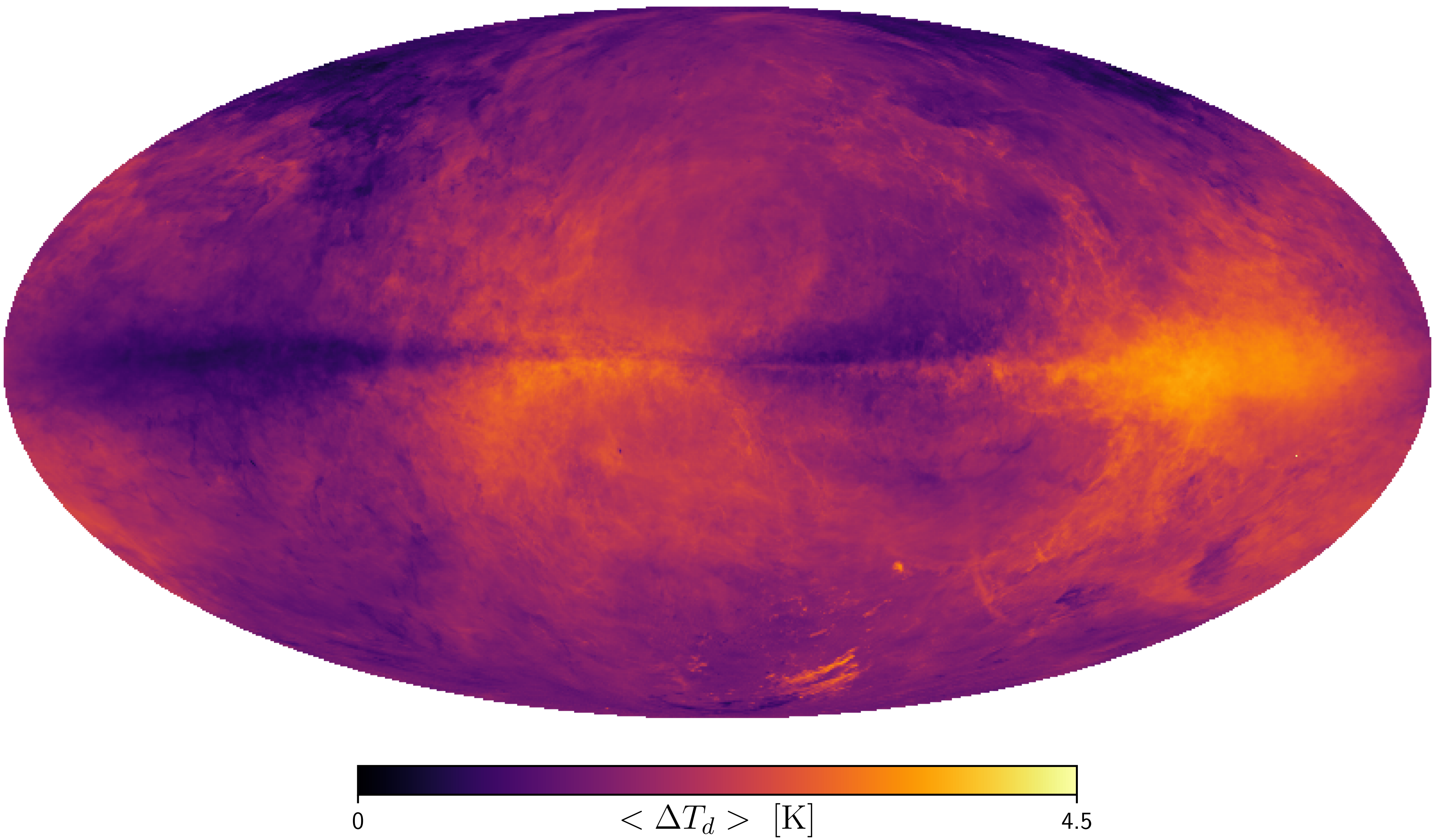


Decorrelation with HI



Decorrelation with HI

- Note: plane gets masked in all analysis

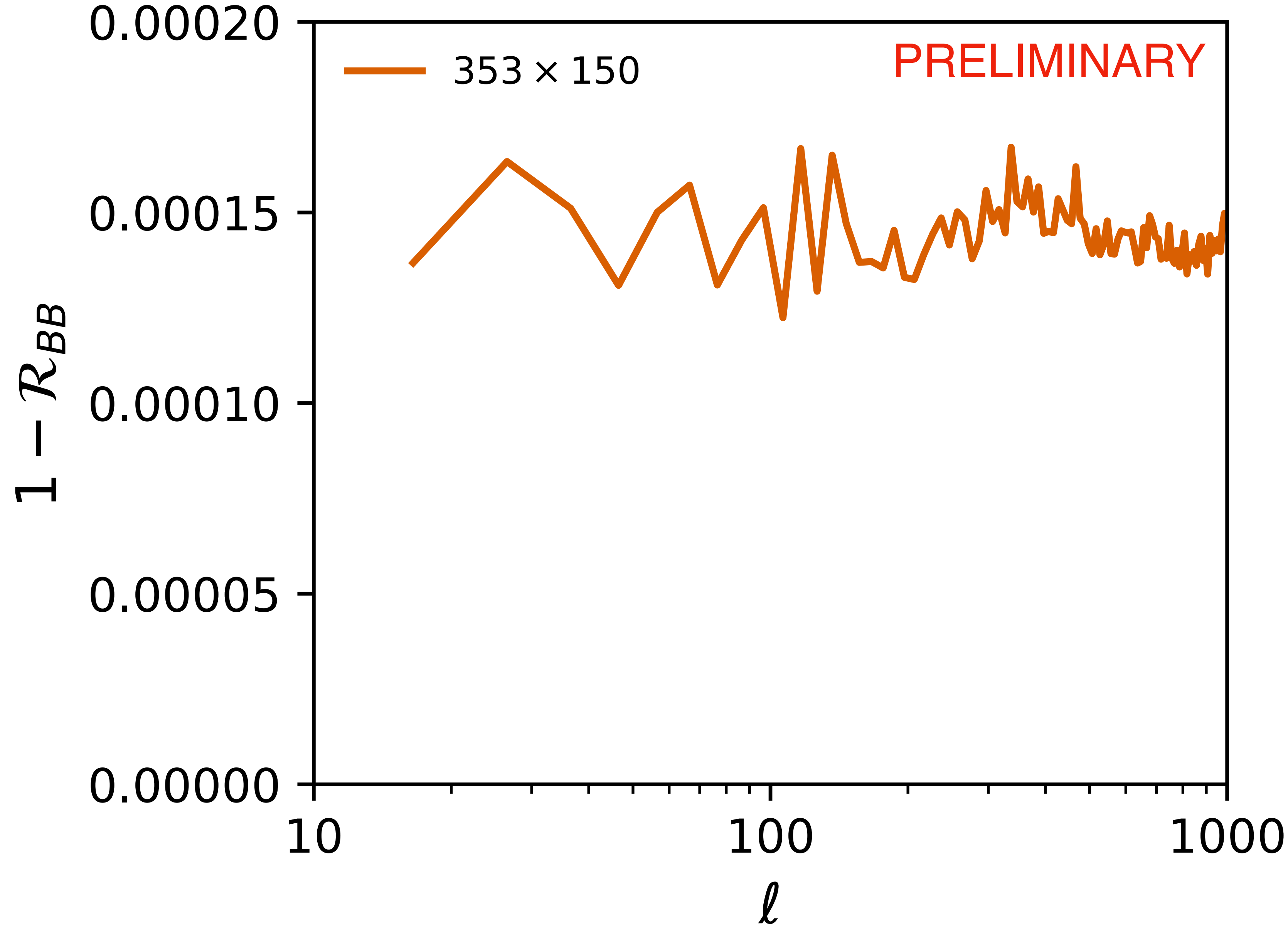


Decorrelation with HI

- Initial results yield *very little decorrelation*

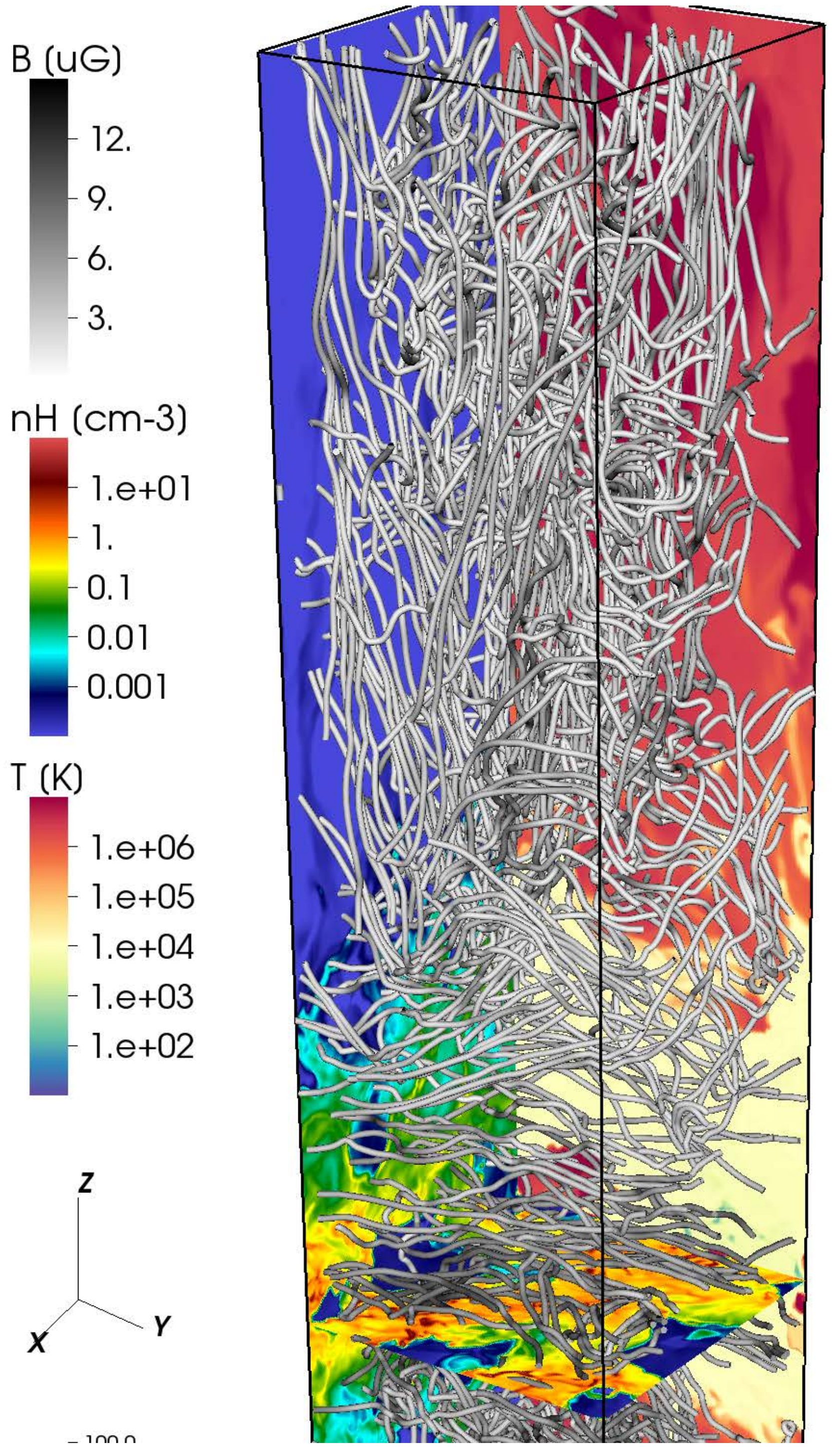
- 1% decorrelation might worry us only for r < 0.01 (Planck 2018 XI)

- So are we in the clear?



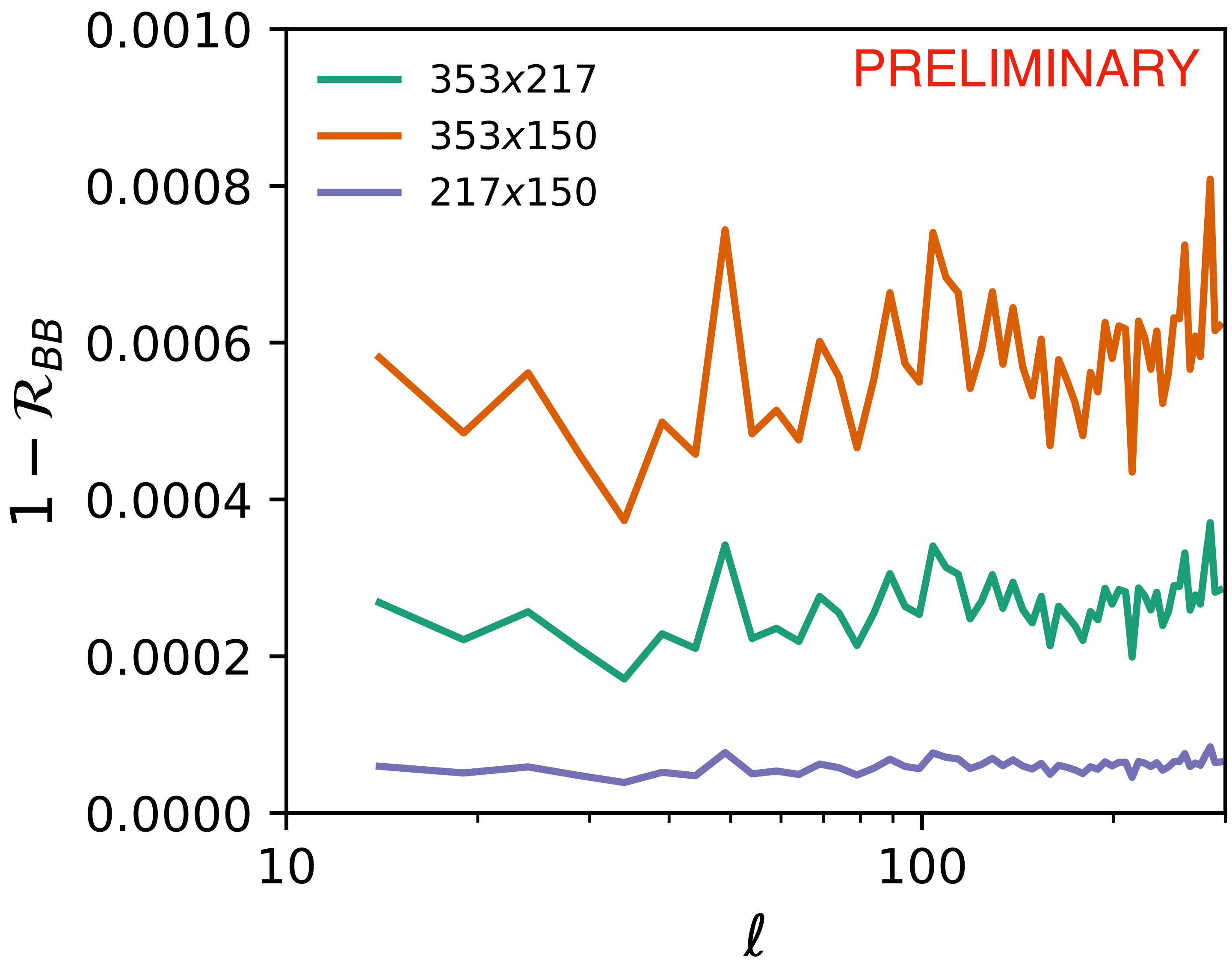
Decorrelation with MHD Sims

- Another approach: MHD simulations (Kim & Ostriker 2017)
- In addition to 3D density field and magnetic fields, also get 3D radiation field *and thus dust temperatures*
- Drawback: looks like *a* galaxy, not *the* Galaxy



Decorrelation with MHD Sims

- Once again, *very little decorrelation*
- Why so little?



Decorrelation and MBB

- If you only adjust the dust temperature, very hard to get decorrelation if using modified blackbodies:

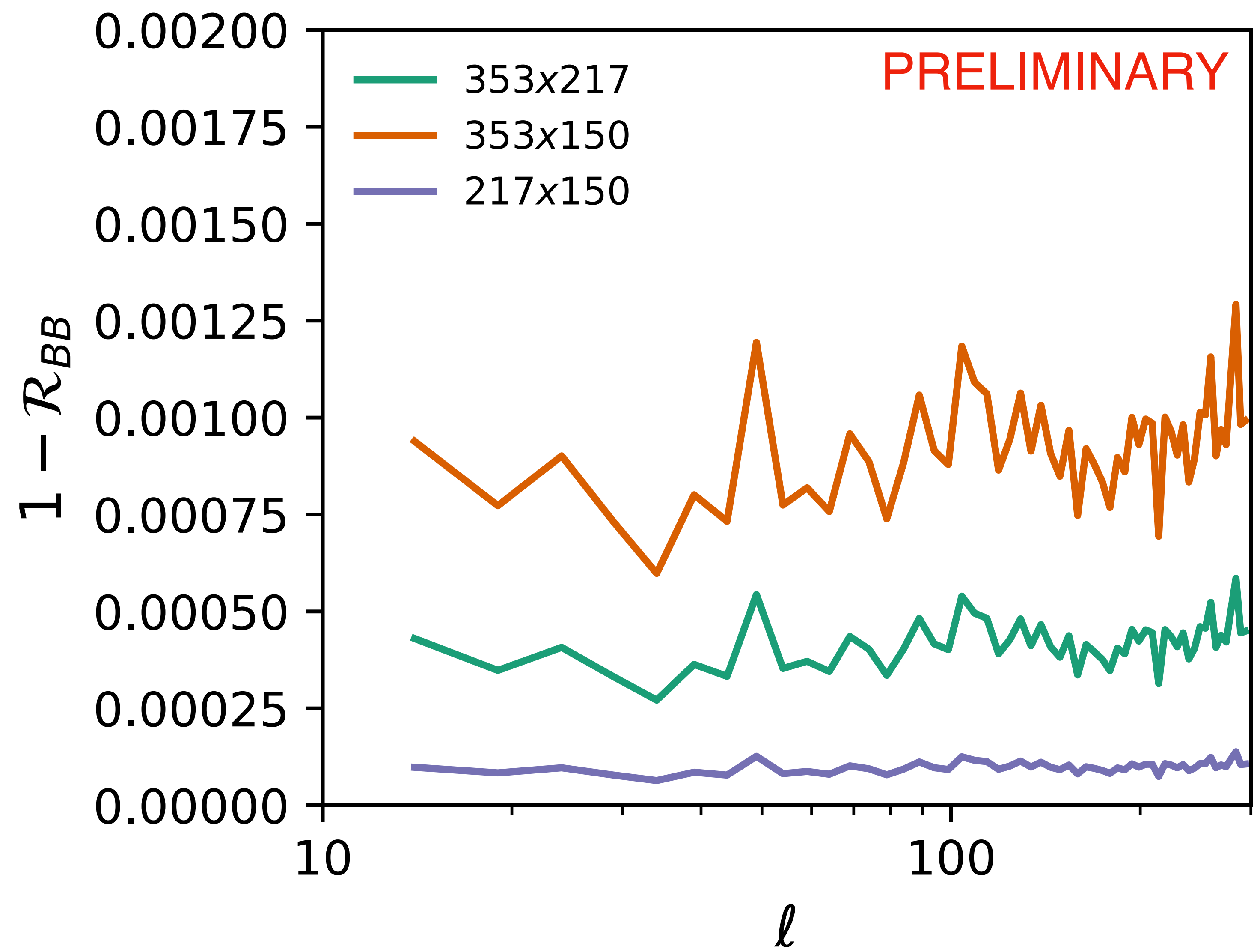
$$I_\nu = A_d \left(\frac{\nu}{\nu_0} \right)^{\beta} B_\nu \left(T_d \right) \approx A'_d \left(\frac{\nu}{\nu_0} \right)^{2+\beta} T_d$$

- Intensity scales as first power of T at long wavelength, T cancels out to first order in ratios between frequencies

MHD Sims + Physical Dust Model

- Can be a little more realistic with a physical dust model

- More decorrelation
- Big caveat: dust composition still fixed, unmodeled “β” variations could still exist
- Establishes “decorrelation floor”



Looking Ahead

- Our most realistic predictions suggest decorrelation at the 10^-3 level, but likely an underestimate

- With HI approach, can actually map out decorrelation to identify most potentially problematic regions of the sky—stay tuned!

- Of course, only the dust half of the equation, will have synchrotron decorrelation too; needs more work to model spatially varying synchrotron SEDs

- 3D effects are also important in map-based component separation (McBride, Bull, & BH, in prep)