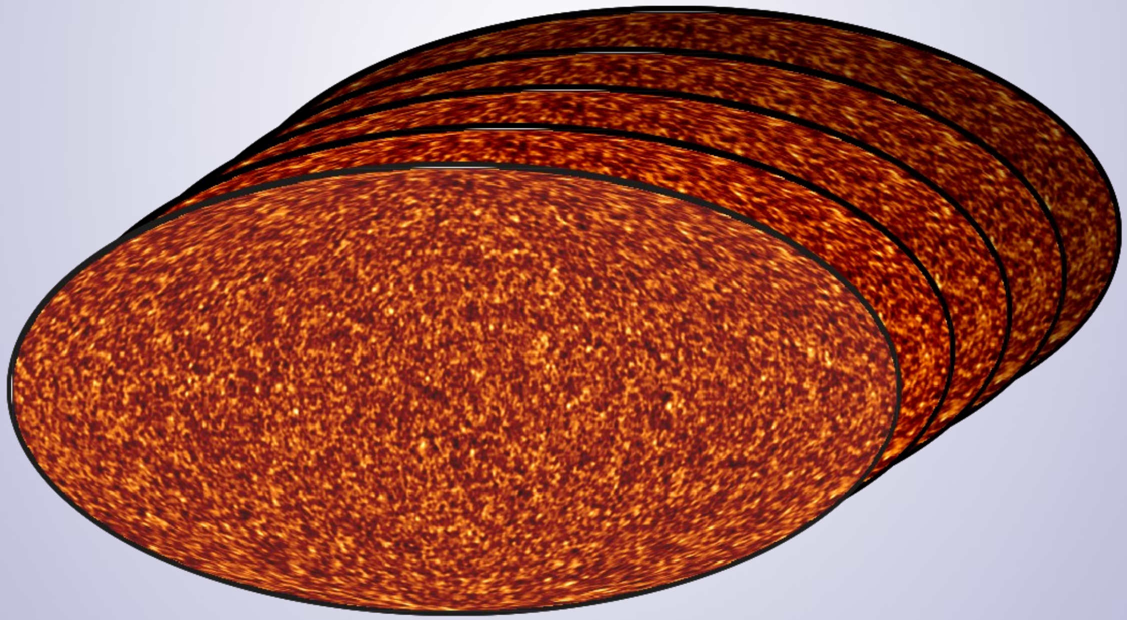
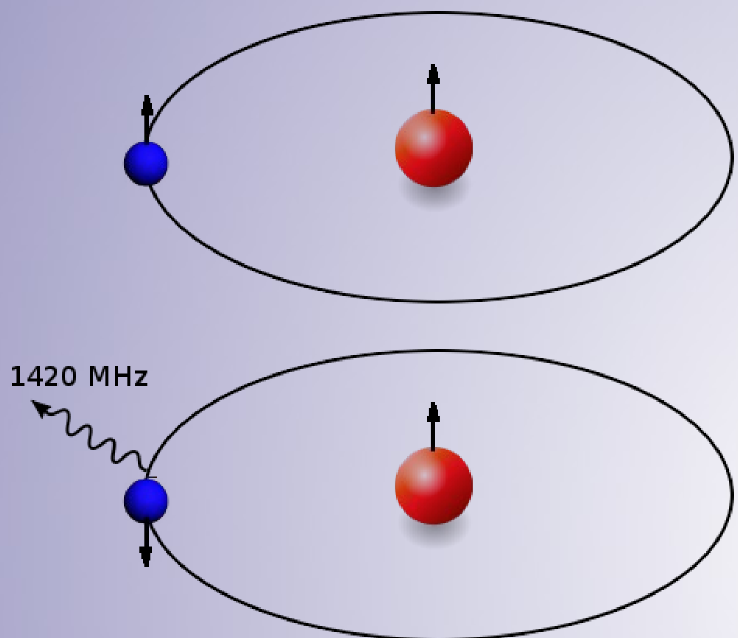
HI intensity mapping

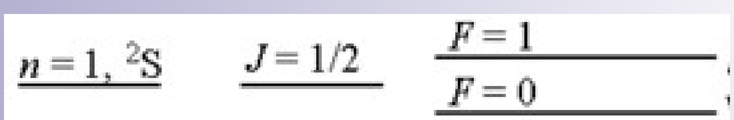
David Alonso – Oxford Astrophysics



IBERICOS, Aranjuez – March 2015

The 21cm signal





- Hyperfine transition
- Strongly forbidden

$$t_{1/2} \simeq A_{01}^{-1} = 1.11 \times 10^7 \,\mathrm{y}$$

- A 3D tracer of neutral hydrogen

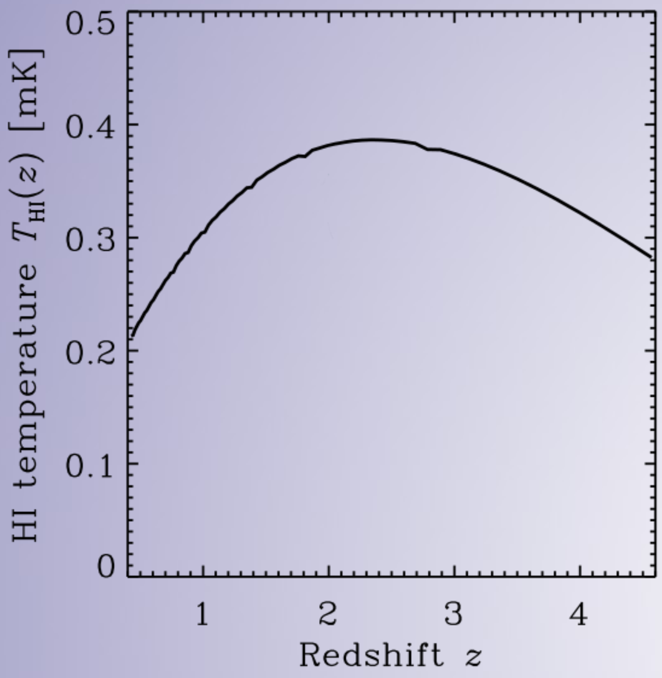
$$\nu = \frac{\nu_{21}}{1+z}$$

$$dL = \frac{3}{4} A_{10} h\nu_{21} n_{\rm HI}\, \phi(\nu)\, d\nu\, dA\, dr$$

$$T_{21}(z,\hat{\mathbf{n}}) = (0.19055\,\mathrm{K})\, \frac{\Omega_{\rm b}\, h\, (1+z)^2\, x_{\rm HI}(z)}{\sqrt{\Omega_{\rm M}(1+z)^3 + \Omega_\Lambda}}\, (1+\delta_{\rm HI})$$

Review: Furlanetto, Oh & Briggs. astro-ph/0608032

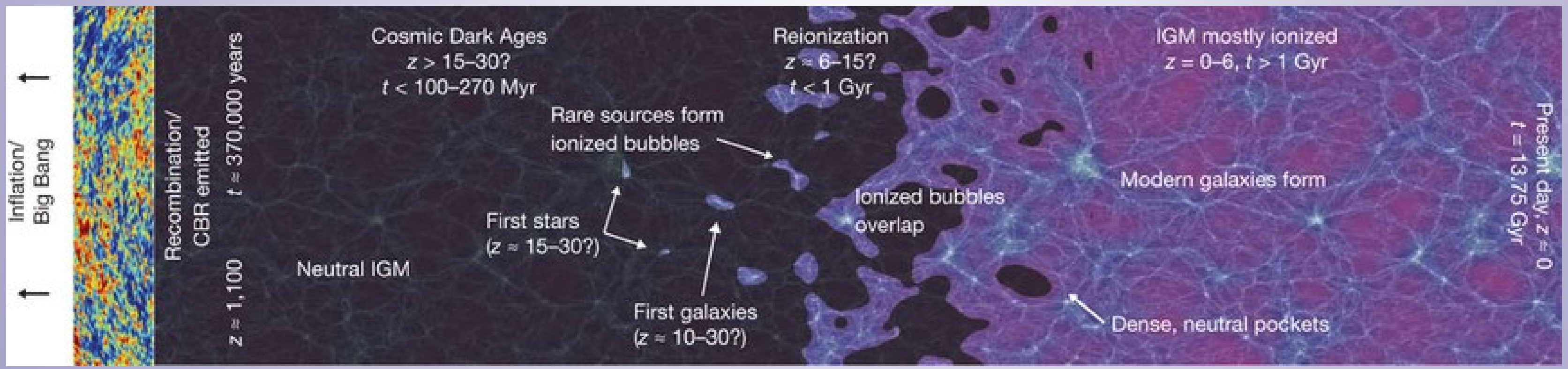
Neutral hydrogen in the Universe



- 21cm is ideal to study the physics of the EoR and the Dark Ages.
- At late times the Universe is ionized. HI inside galaxies (DLAs).

✔ Spectrally isolated
✔ Small obscuration
✔ Signal grows with z

✗ Difficult to observe many individual objects
→ Intensity mapping



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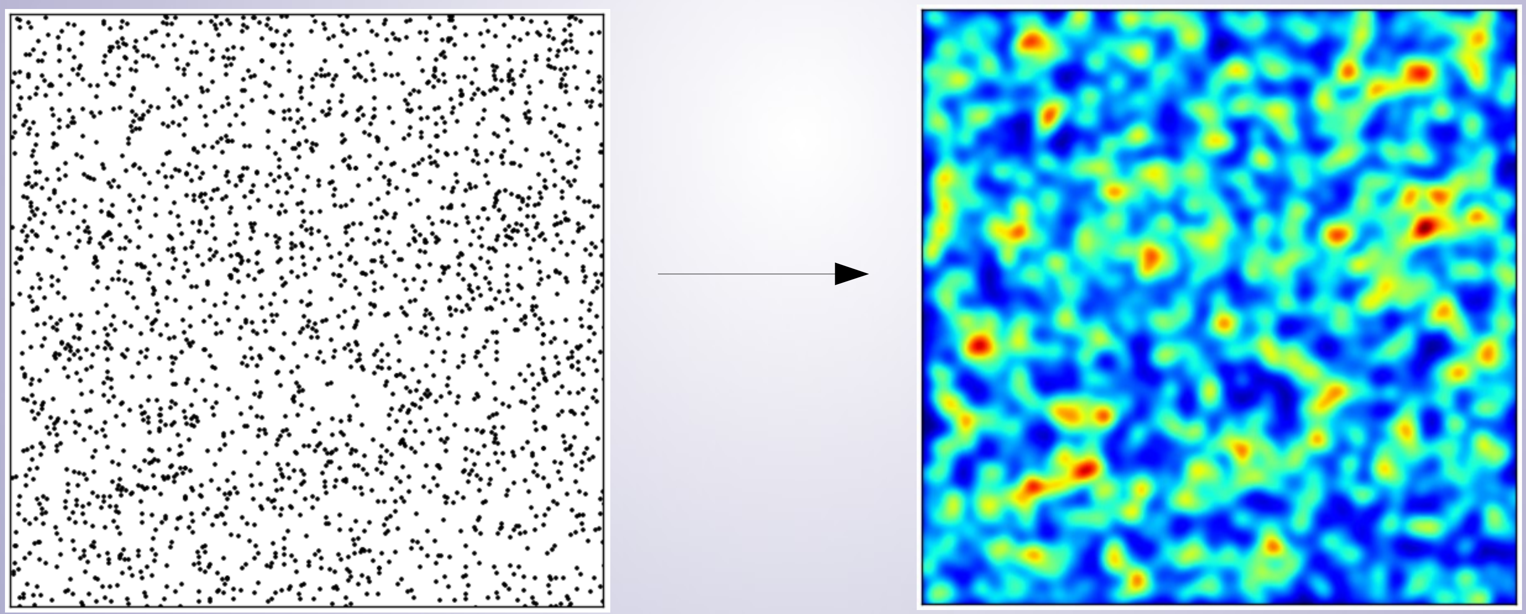
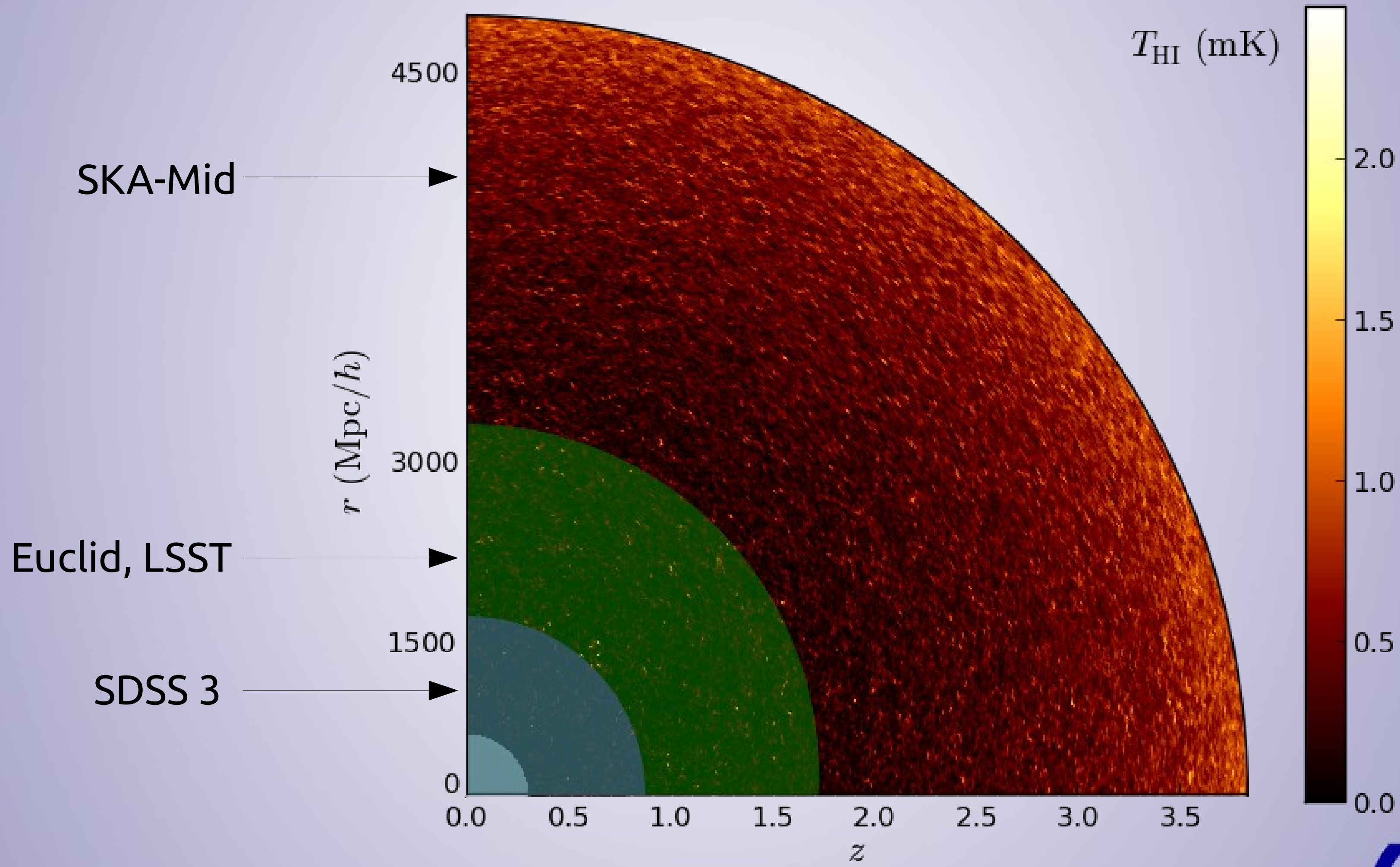
Intensity mapping

- Large pixels: joint emission from multiple galaxies instead of resolving them.
- We only care about large scales
- “Cheap” way to observe large volumes



Cosmology with intensity mapping

- Forecasts: constraining power competitive with largest redshift surveys.



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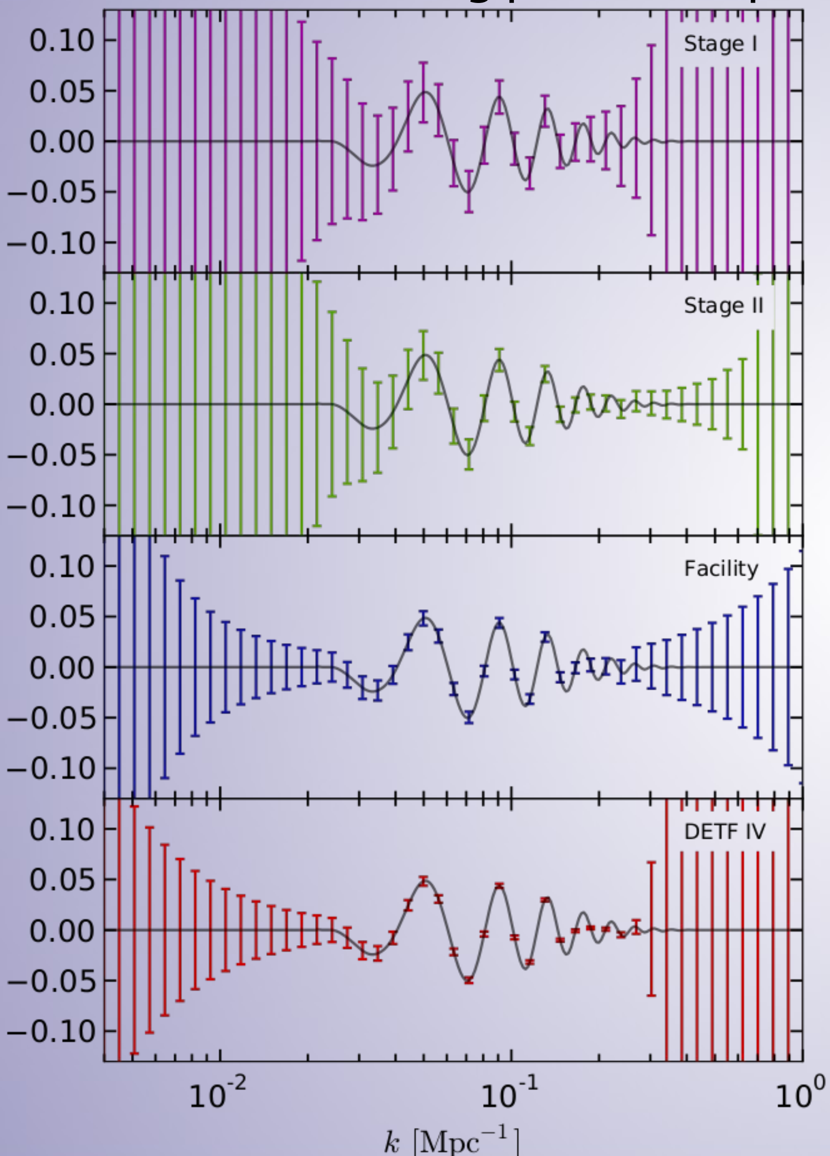
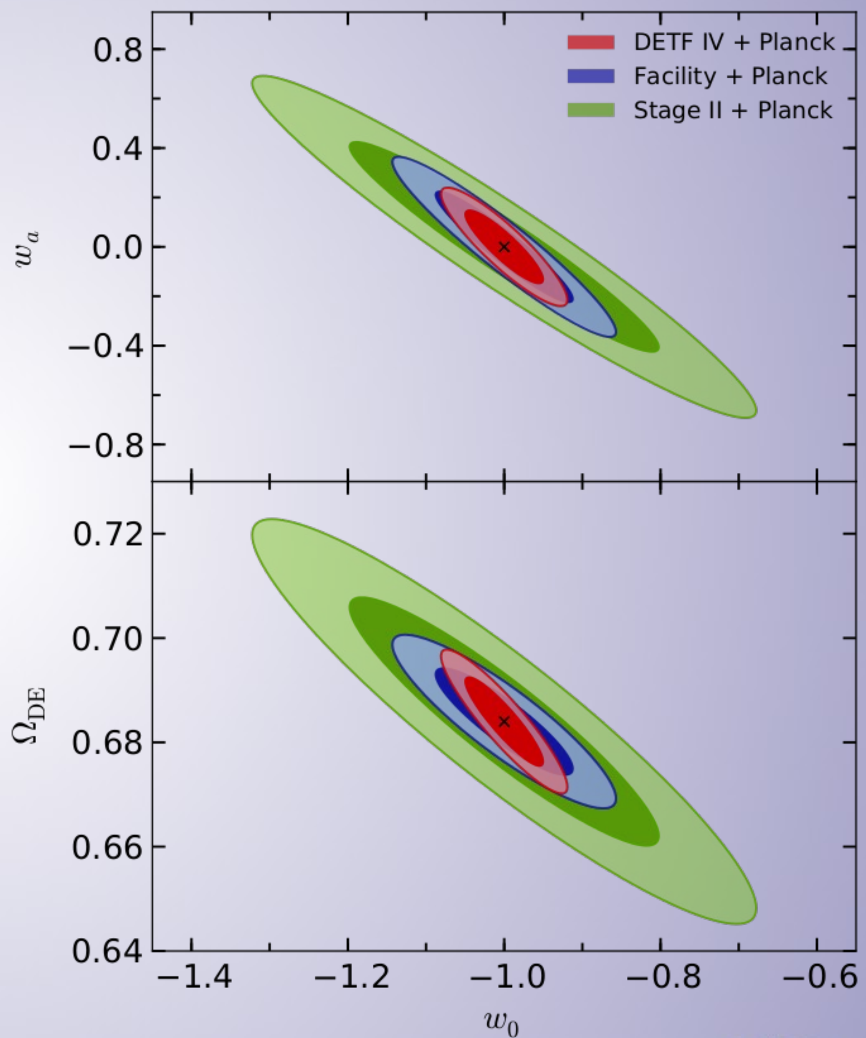




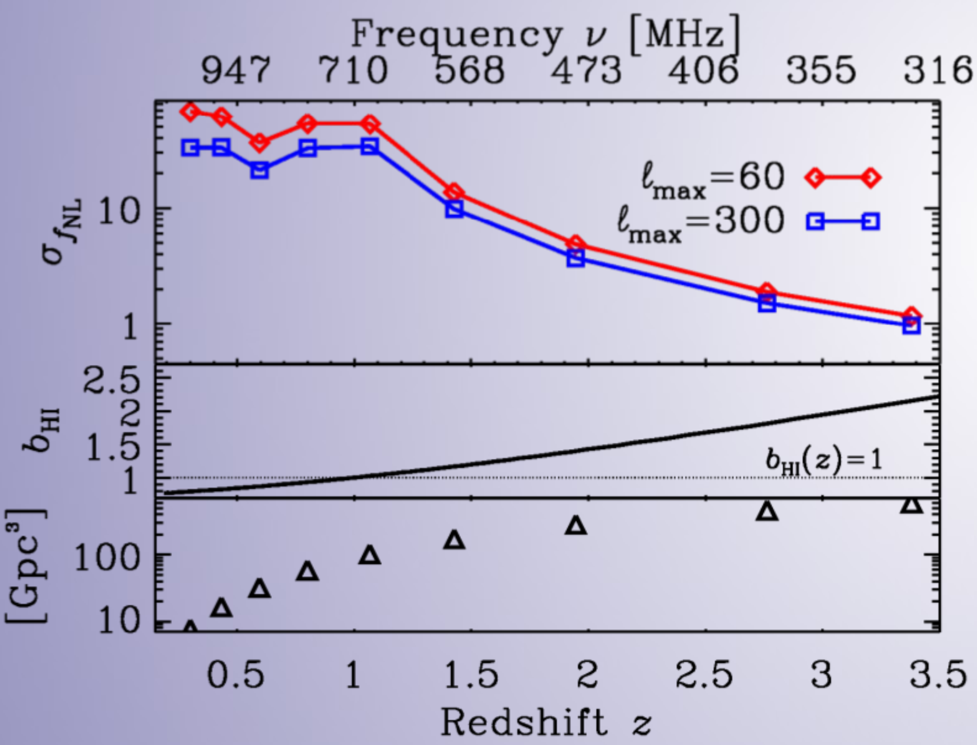
Bull et al. 1405.1452

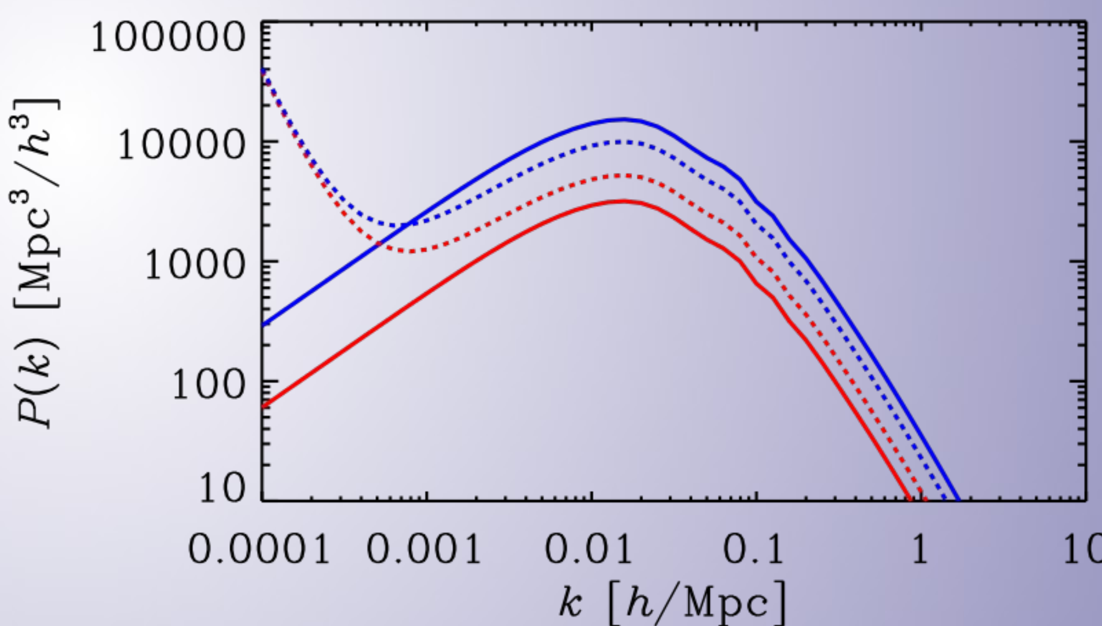
Ultra-large scales

Ultra-large scale cosmology

- Primordial non-Gaussianity

$$\Delta b_M(k, f_{\rm NL}) = f_{\rm NL}\,[b_M(k,0)-1]\,\frac{3\delta_L \Omega_{\rm m0} H_0^2}{c^2 k^2 T(k) D(z)}$$



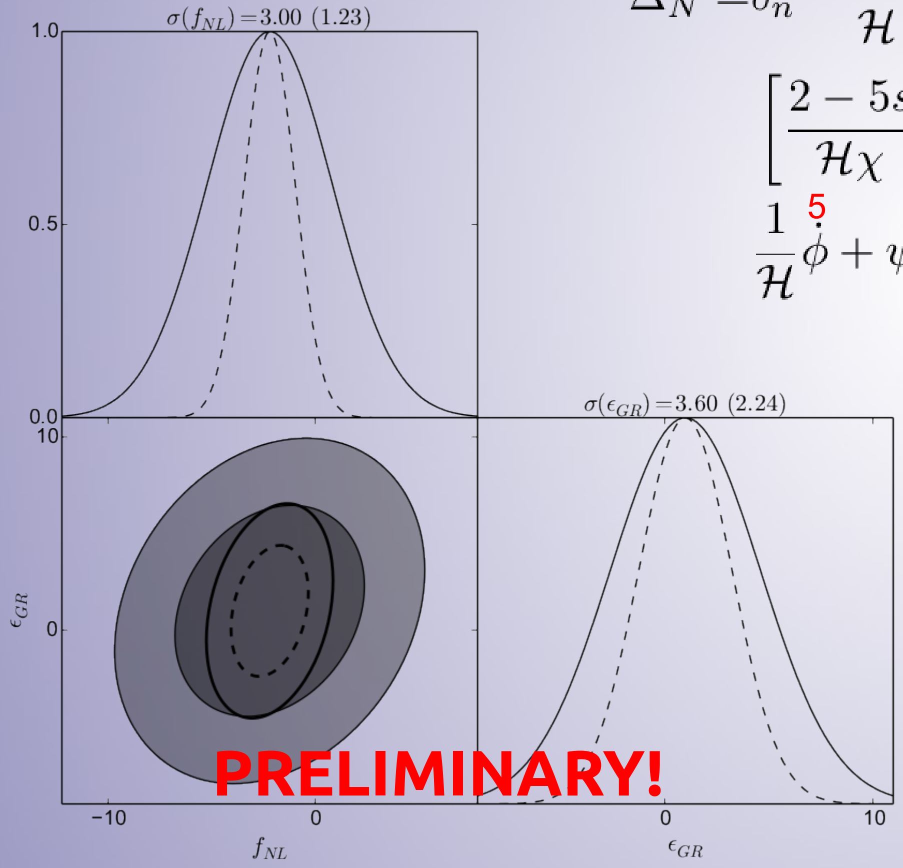


Camera et al. ArXiv:1305.6928

Ultra-large scales

Ultra-large scale cosmology

- GR effects in LSS



Density, RSDs, Lensing, 1–7

$$\Delta_N = \delta_n - \frac{1}{\mathcal{H}}\frac{\partial v_r}{\partial \chi} + (5s-2)\left[\kappa - \frac{1}{\chi}\int(\phi+\psi)d\eta\right] + \left[\frac{2-5s}{\mathcal{H}\chi} + 5s - \frac{\partial \ln(a^3\bar{n})}{\mathcal{H}\partial\eta} + \frac{\mathcal{H}'}{\mathcal{H}^2}\right]\left[\psi + \int(\dot{\phi}+\dot{\psi})d\eta - v_r\right] + \frac{1}{\mathcal{H}}\dot{\phi} + \psi + (5s-2)\phi$$

Bonvin & Durrer, arXiv:1105.5280
Challinor & Lewis, arXiv:1105.5292
Hall, Bonvin & Challinor, arXiv:1212.0728

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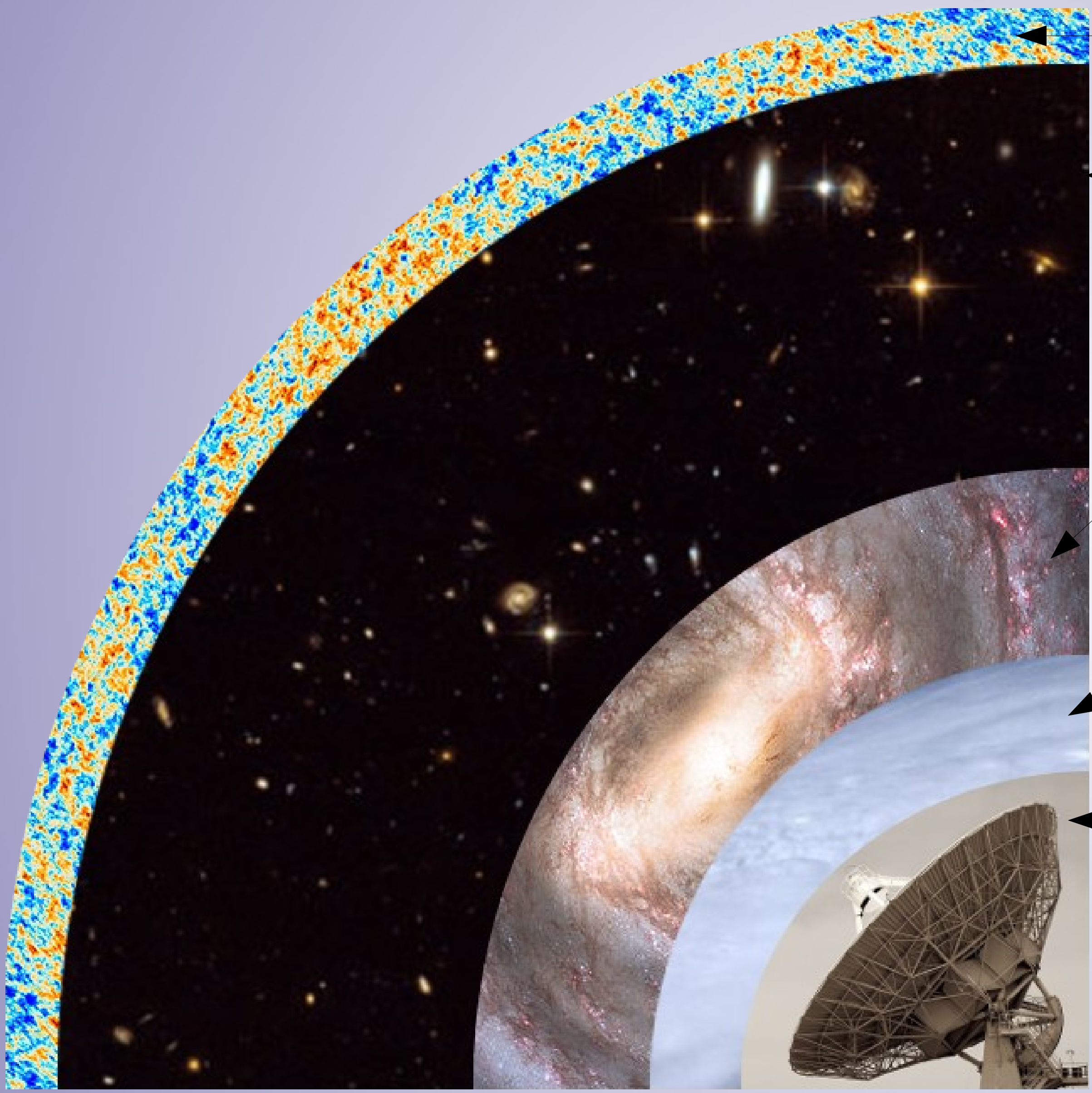
Radio foregrounds



IM signal

Extragalactic foregrounds:
- Point sources
- E.G. free-free

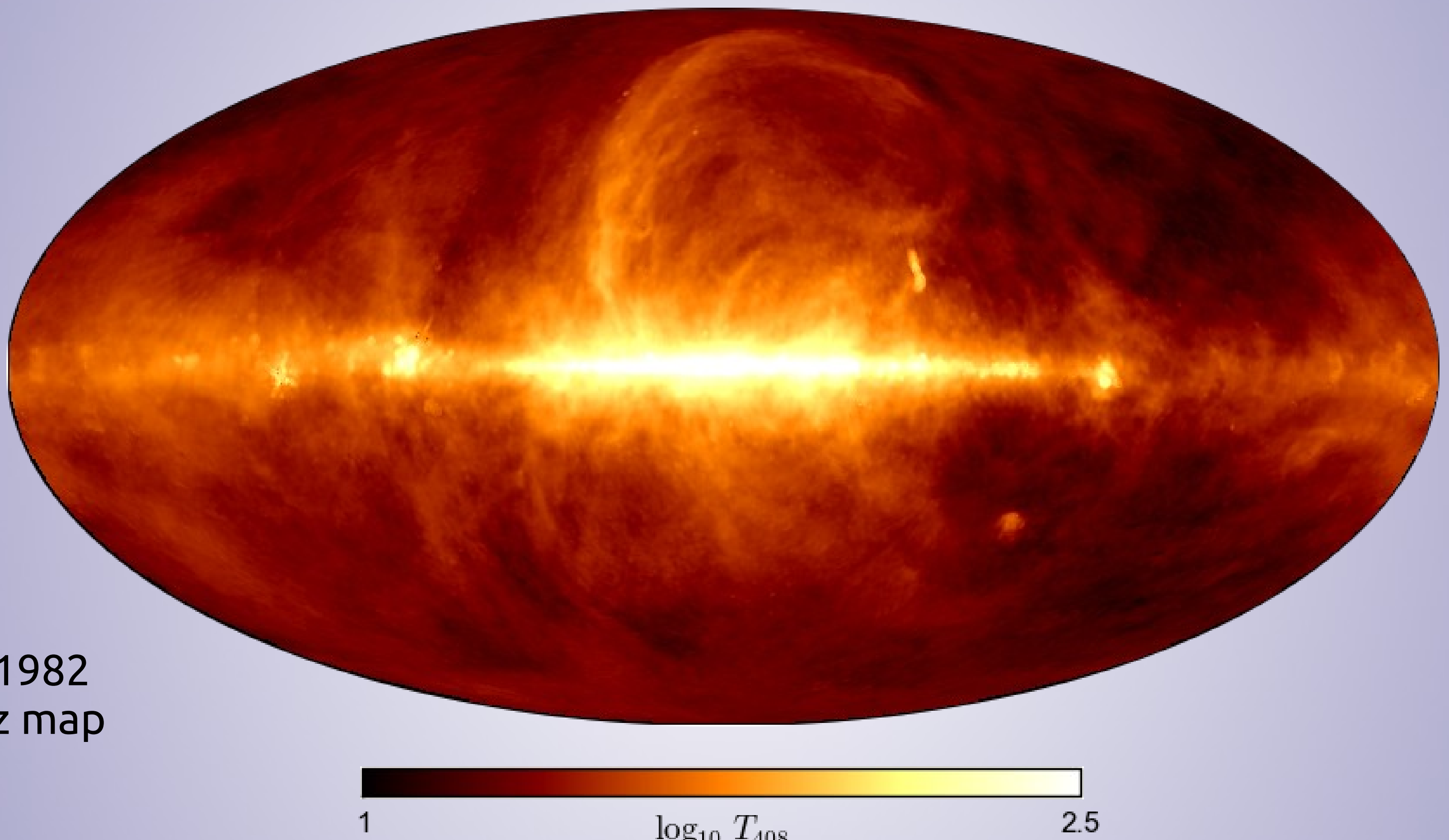
Galactic foregrounds:
- Synchrotron (I,Q,U)
- Free-free
- Dust

Earth:
- Atmosphere: clouds, H_2O, ionosphere
- RFI

Instrument:
- Spillover
- Gain fluctuations
- Beam fluctuations
- Polarization leakage

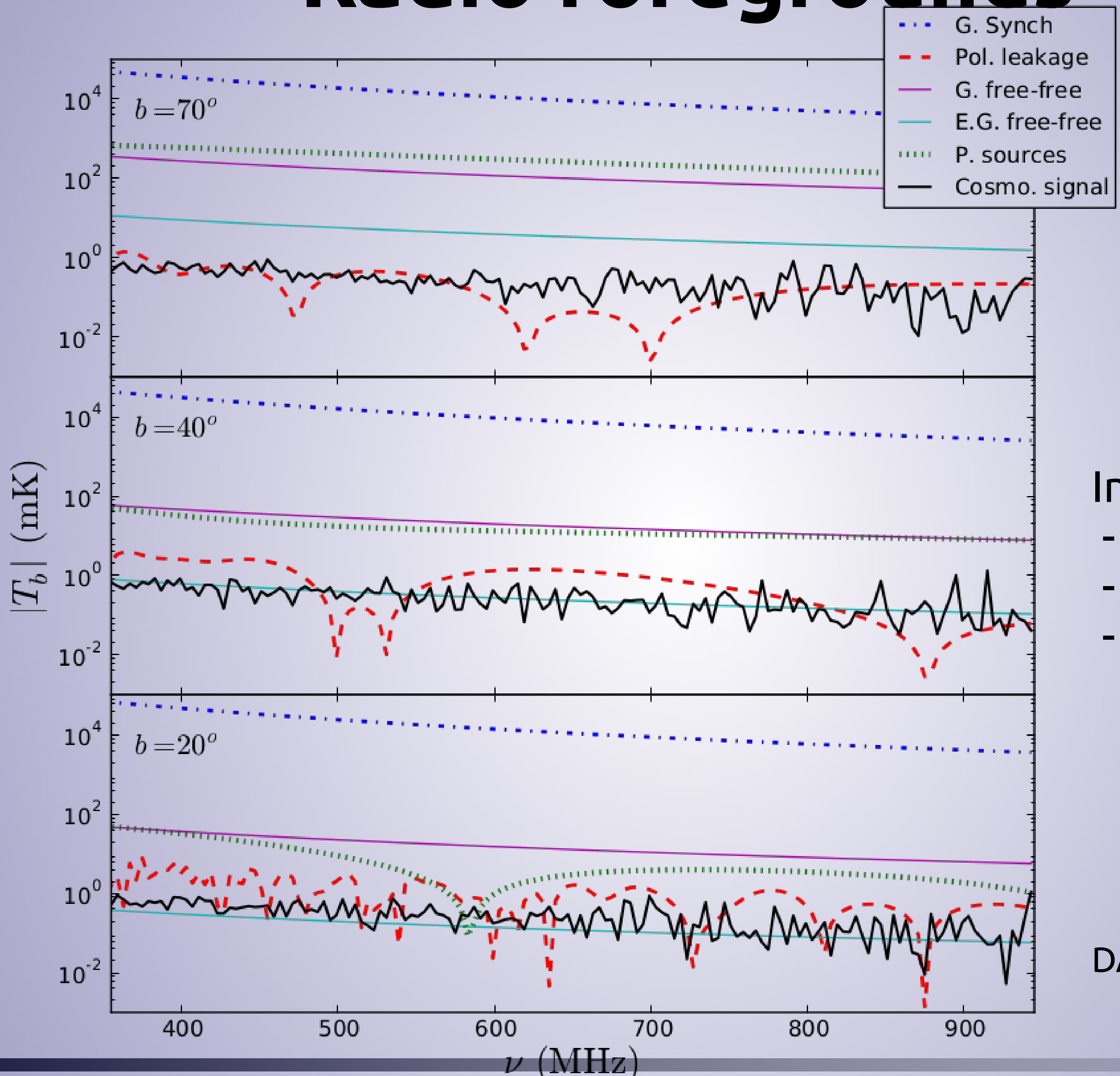
Radio foregrounds

Galactic synchrotron



Haslam 1982
408 MHz map

Radio foregrounds



Instrumental effects:

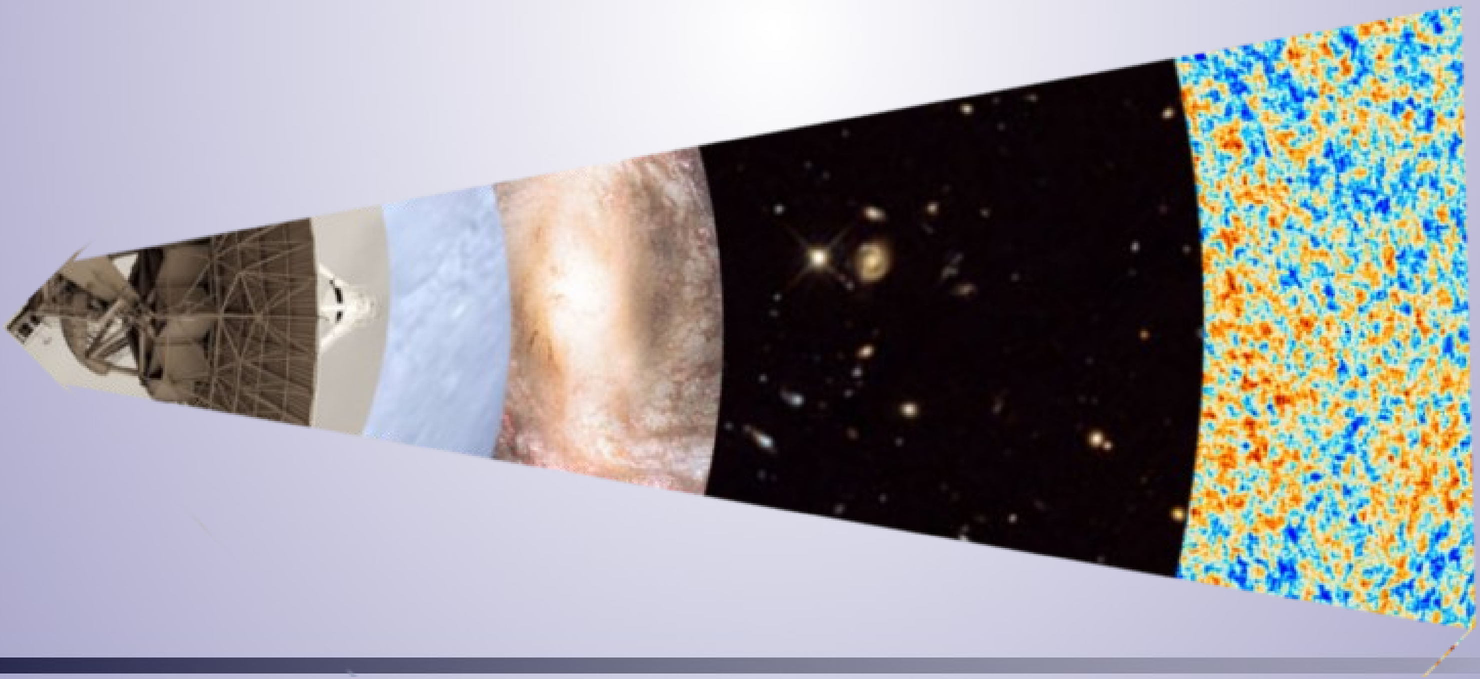
- Beam convolution
- Polarization leakage
- Noise

DA et al. ArXiv:1405.1751.

Intensity mapping simulations

Foregrounds will have an important effect on the recovered IM signal.

- The foreground-cleaned measurements will probably be biased → transfer function must be accurately characterized.
- Foreground subtraction will induce extra variance in the power spectrum.
- It could also affect the correlation structure of the measurements.
- The performance of different cleaning methods must be studied.



Blind foreground subtraction

- Blind methods: minimize assumptions about foregrounds → foregrounds are ν-smooth

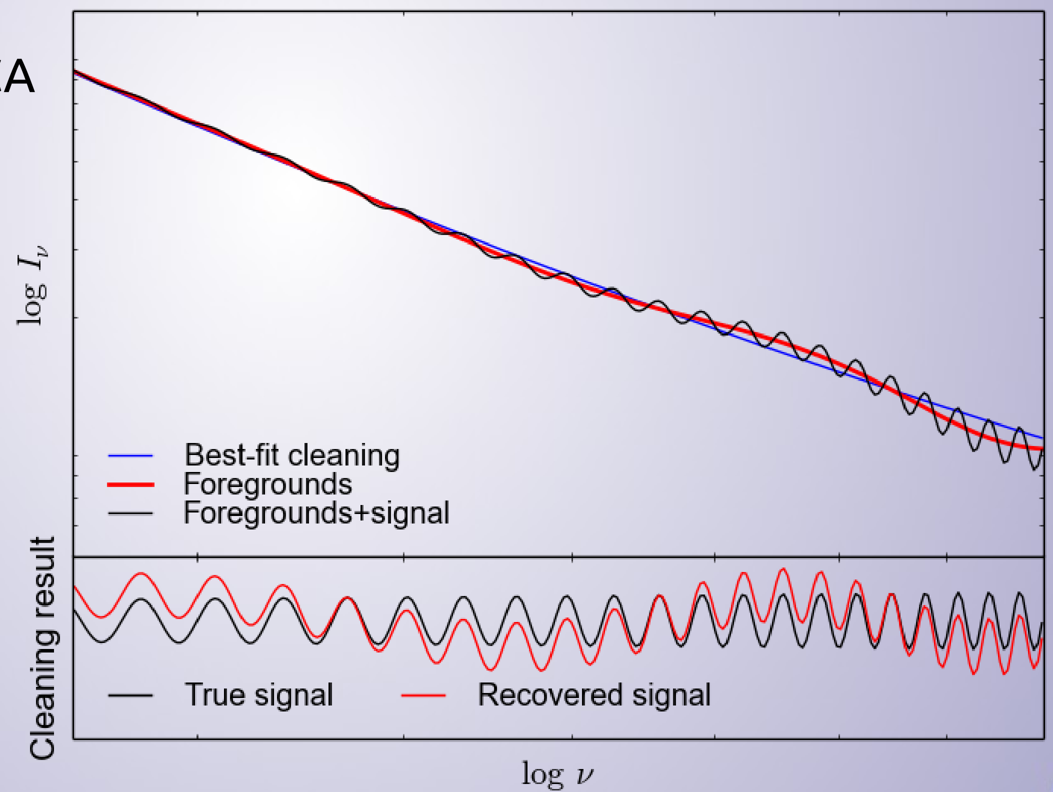
- Blind source equation

$$T(\nu,\theta)=\sum_{k=1}^{N_{\rm fg}} f_k(\nu)\,S_k(\theta)+T_{\rm cosmo}(\nu,\theta)+T_{\rm noise}(\nu,\theta)$$

$$x_i=T(\nu_i,\theta)\quad A_{ik}=f_k(\nu_i)\quad s_k=S_k(\theta)$$

$$\mathbf{x}=\hat{\mathbf{A}}\cdot\mathbf{s}+\mathbf{n}$$

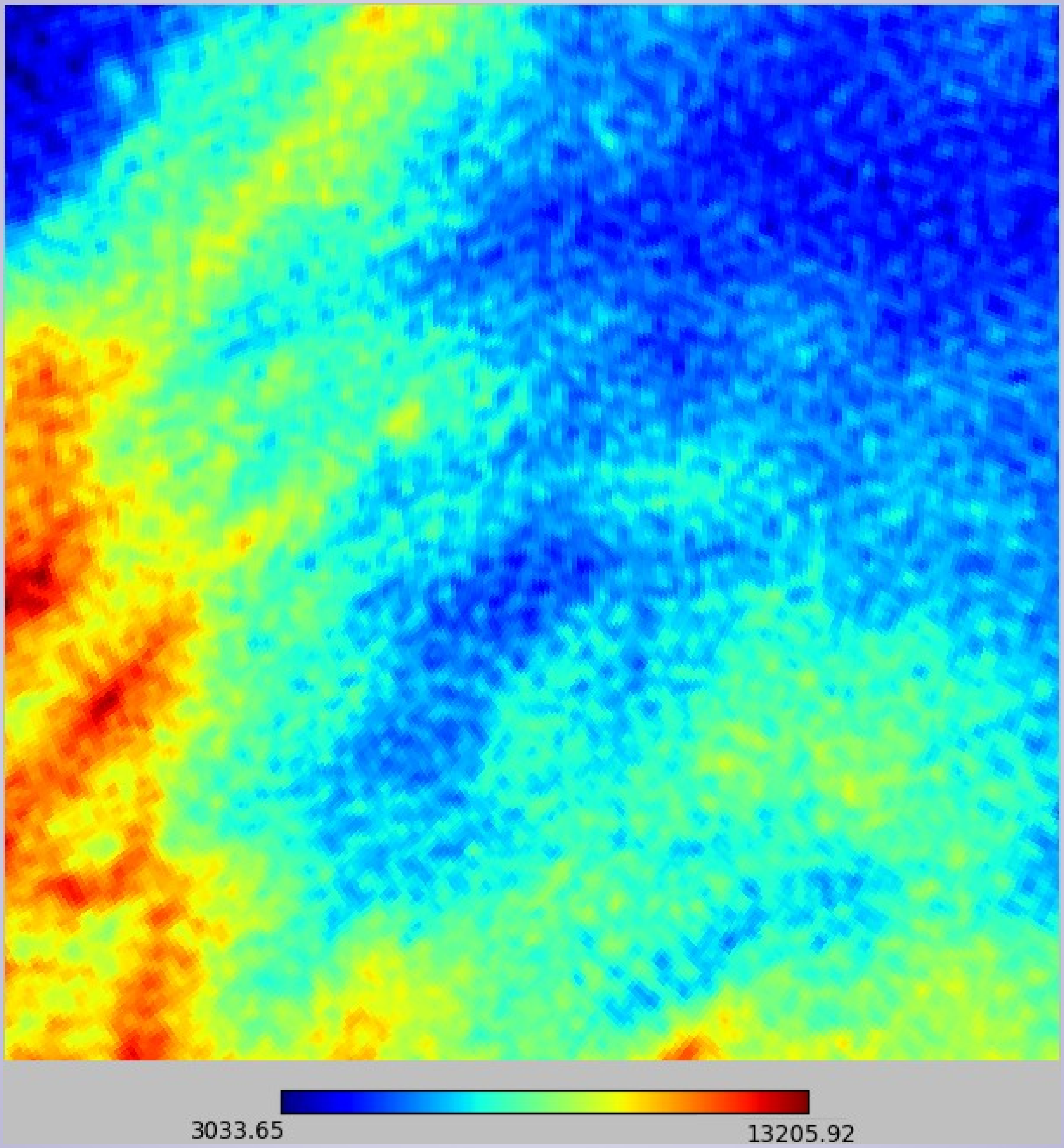
- Methods: LOS fitting, PCA, ICA



DA, Bull, Ferreira & Santos.
ArXiv:1409.8667

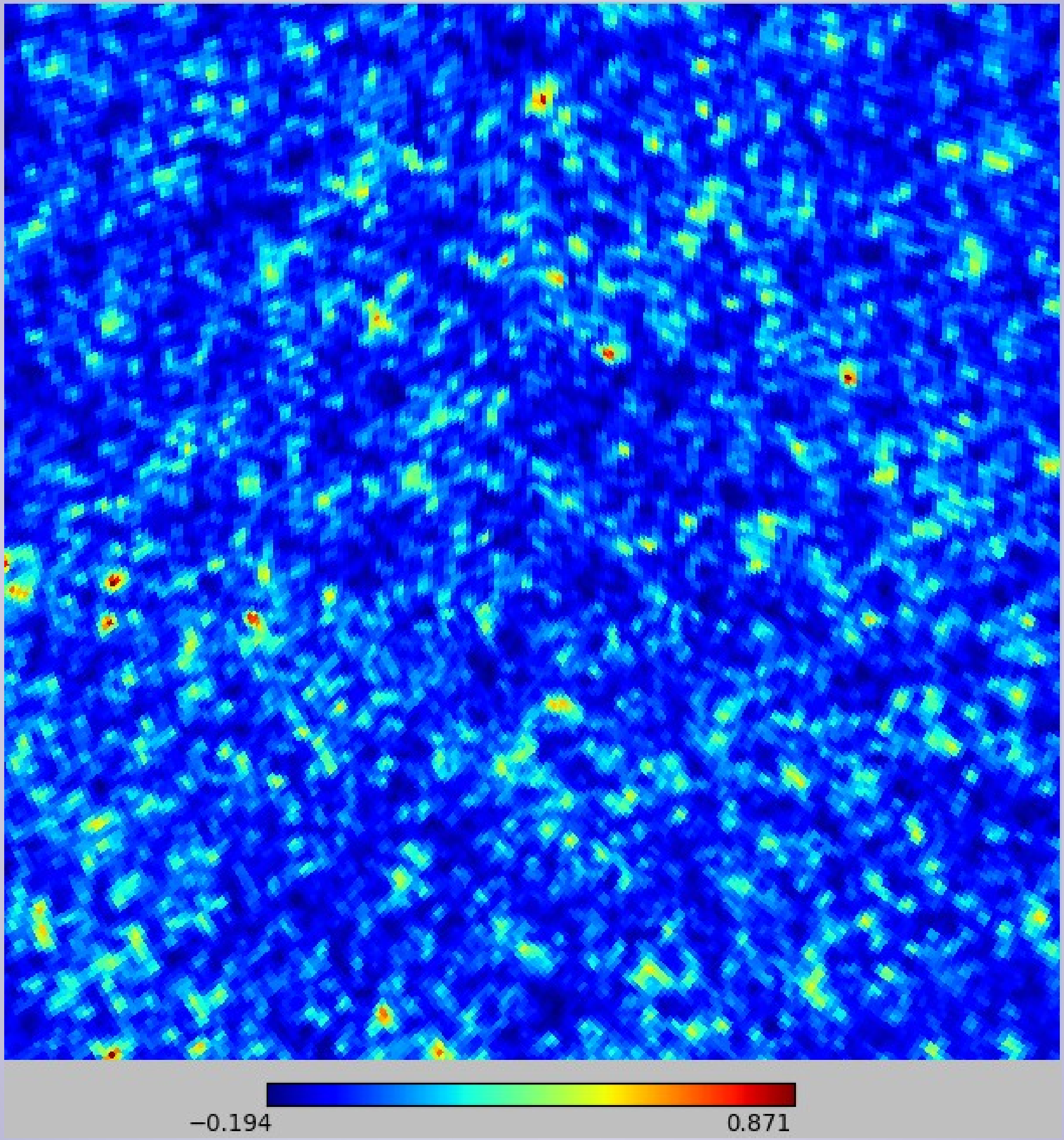
Blind foreground subtraction

Signal+FG



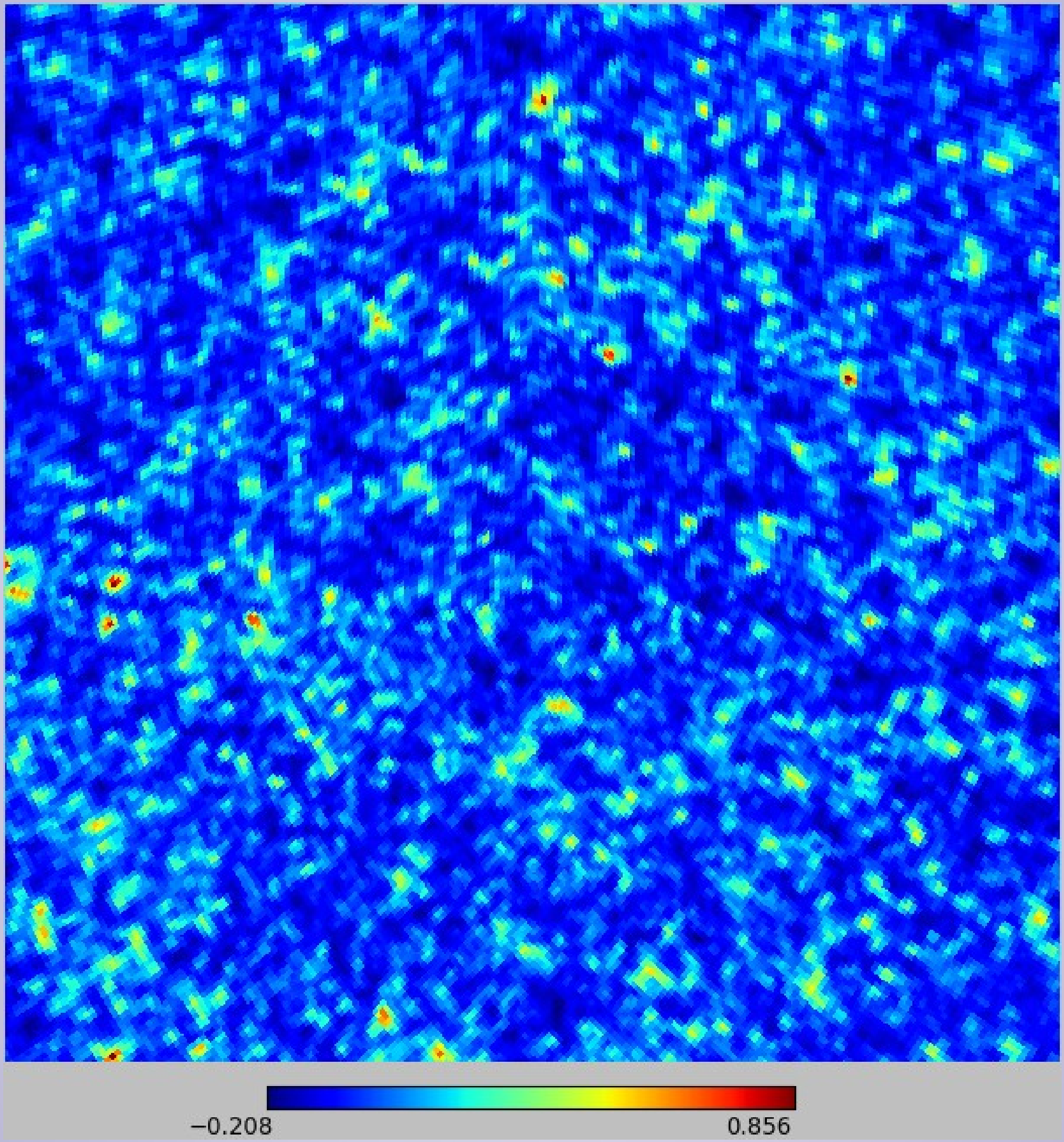
Blind foreground subtraction

Signal only

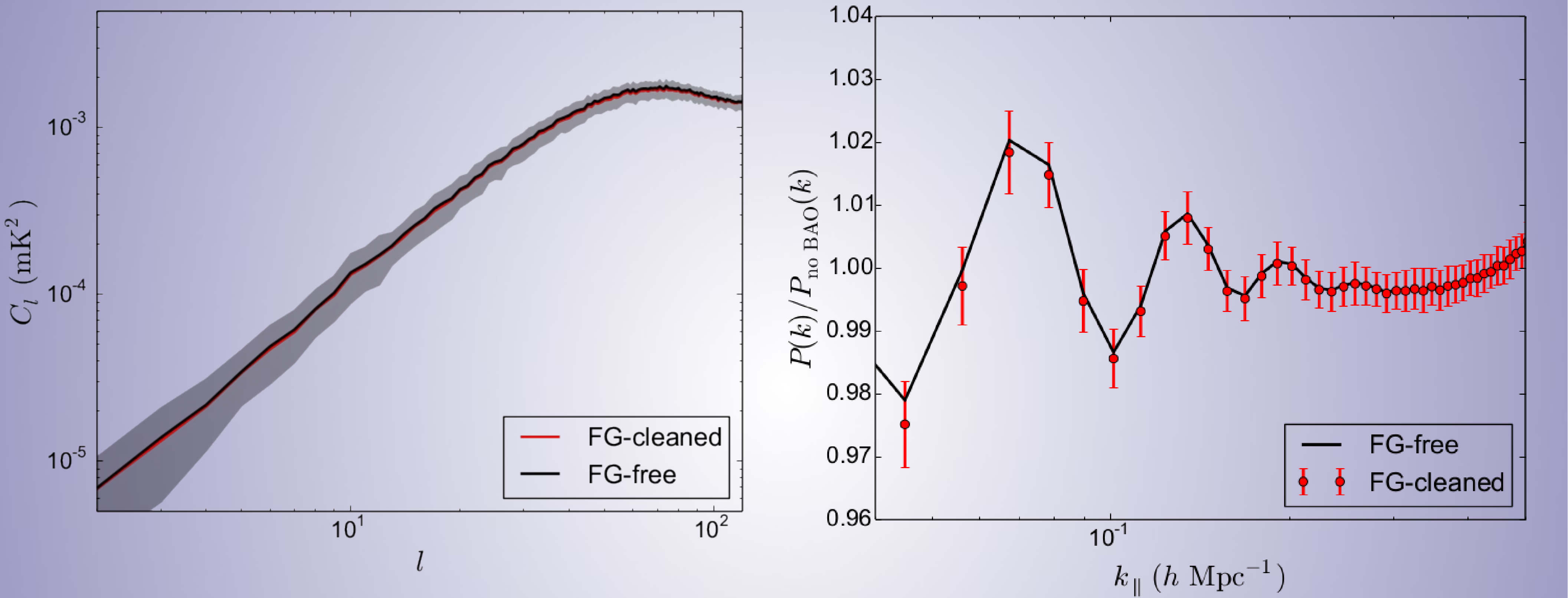


Blind foreground subtraction

Cleaned map



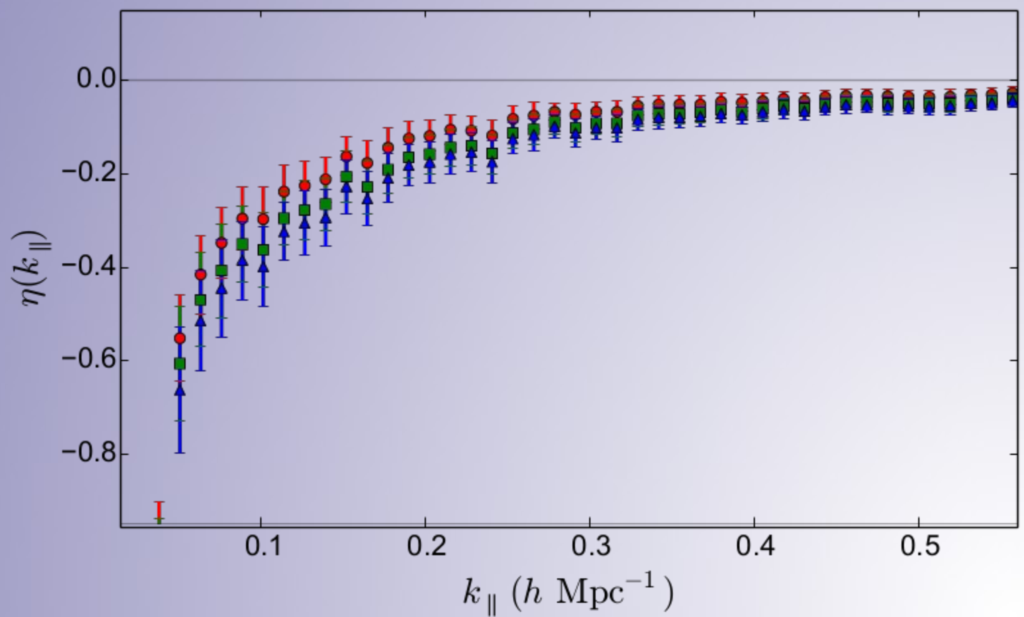
Blind foreground subtraction



Most important features still observable! (BAO, shape...)

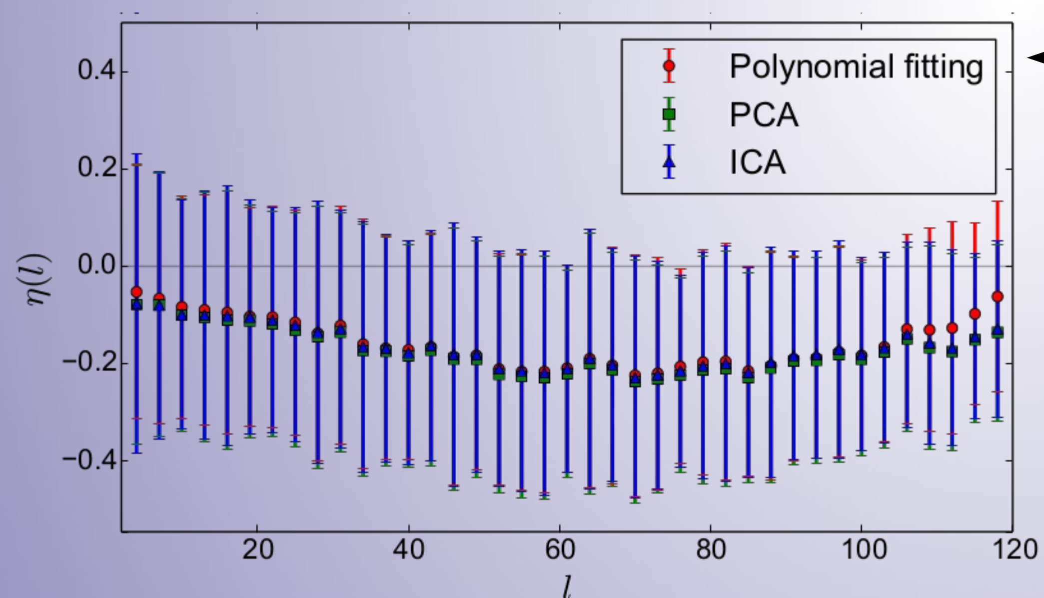
Oxford Physics

Blind foreground subtraction



Bias and variance of the recovered power spectrum

Radial scales:
- Significantly larger contamination on large scales (dominated by foregrounds)
- Larger variance on large scales



Angular scales:
- Bias ~ 20% of errors
- Uncertainties increased by ~20%
- Similar bias across all scales

Overall: **equivalent** results found for **all methods**

Conclusions

- Intensity mapping is a potentially powerful cosmological probe.
- Forecasts show it to be competitive with next-generation redshift surveys.
- IM gives us access to extremely large volumes, and allows us to study cosmology on ultra-large scales.
- Relativistic contributions could be difficult to detect.
- Observational challenges: huge (10^5) galactic and extragalactic foregrounds.
- Computational challenges: fast simulations to study errors, systematics, model independence...
- Blind foreground subtraction: simplest but efficient methods.
- For smooth foregrounds, main cosmological observables are preserved.
- Instrumental effects (beam, polarization leakage) may be a lot more important.

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Obrigado! ¡Gracias!