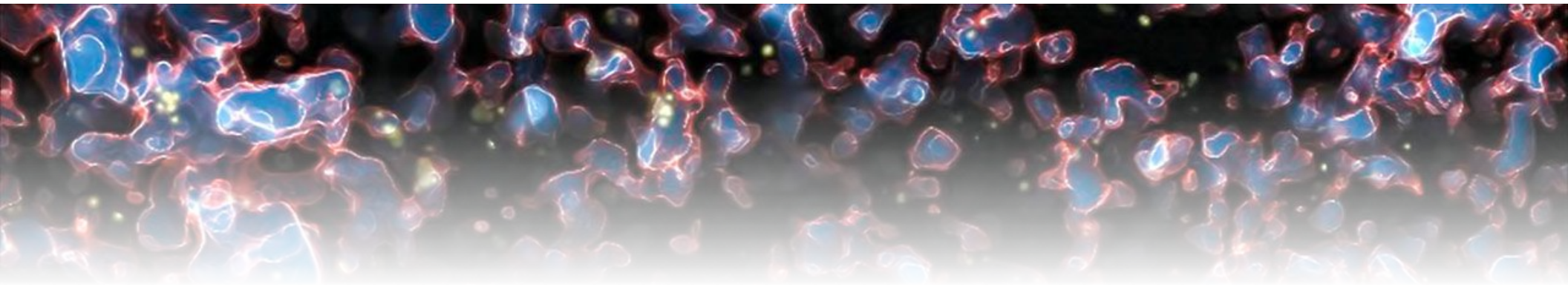
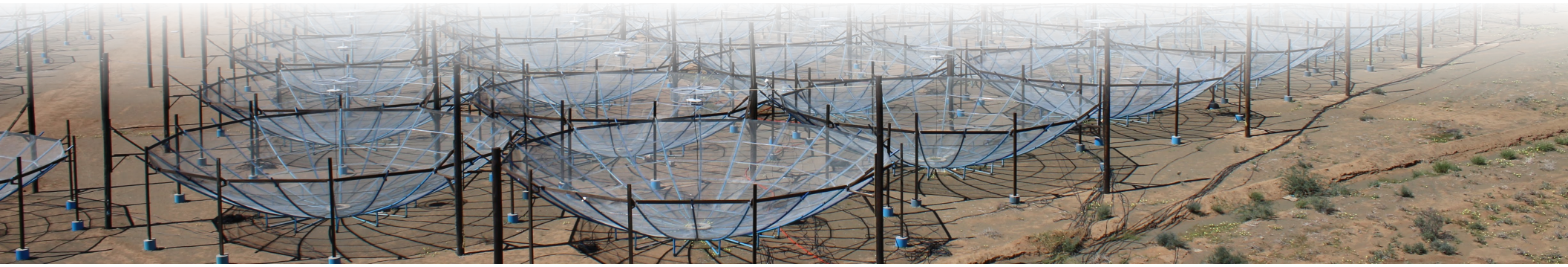


Mapping the universe with hydrogen: High redshift astrophysics at radio wavelengths

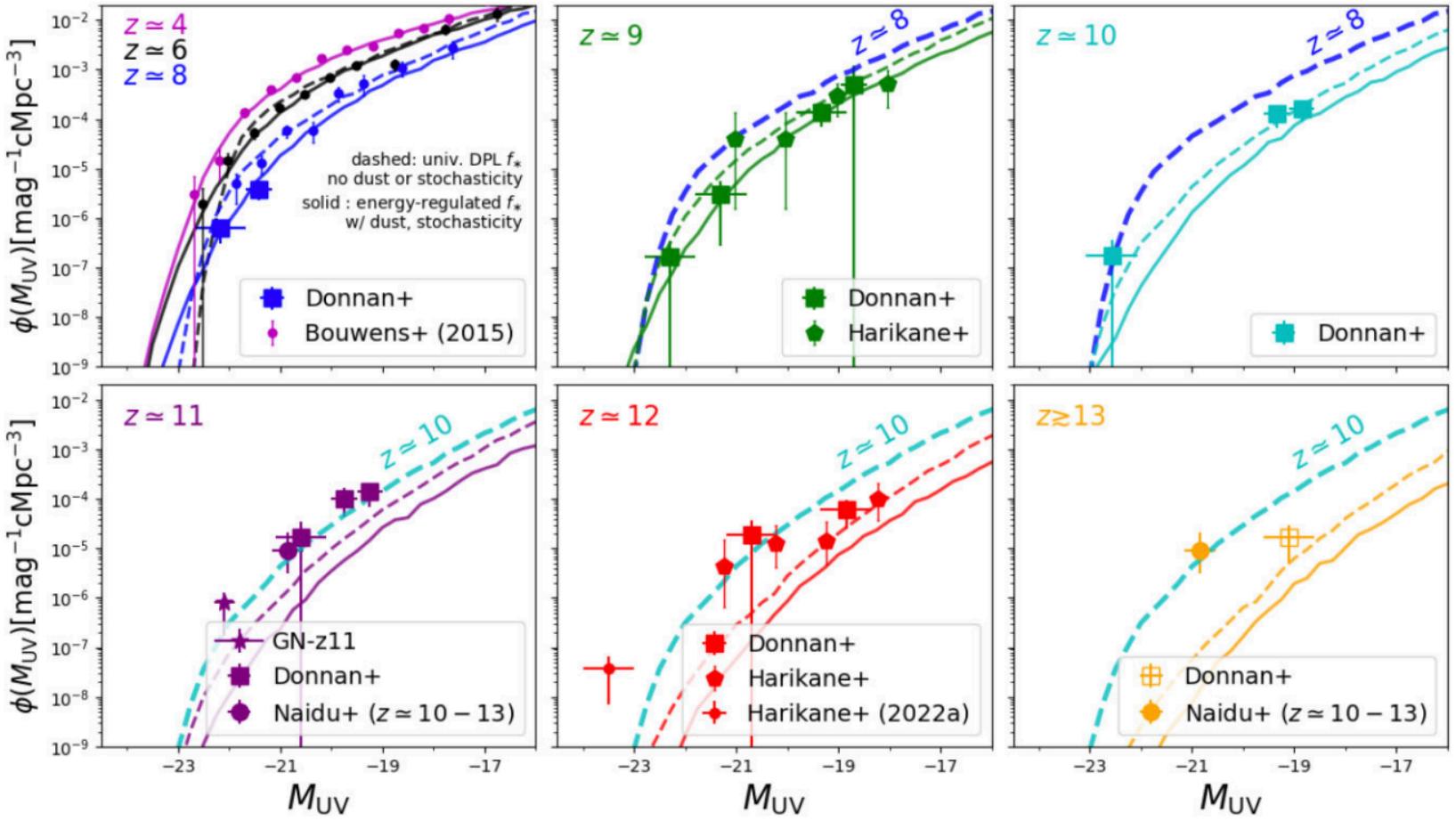
Nick Kern
Hubble Fellow

September 17, 2024
NHFP Symposium



New insights and questions from JWST…

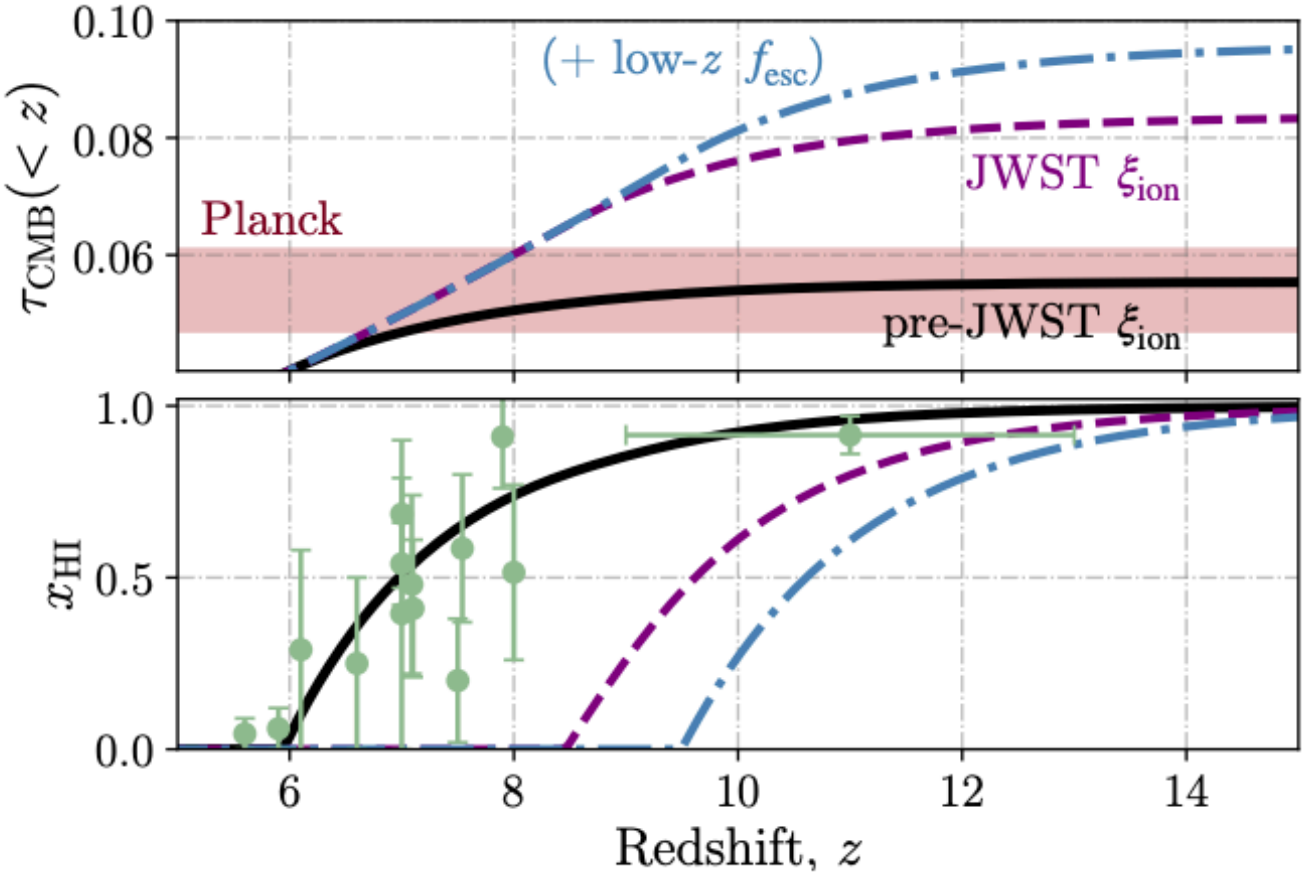
Low redshift calibration leads to high redshift discrepancy



Mirocha & Furlanetto 2023

New insights and questions from JWST…

At face value, this leads to a *too early* reionization



Munoz et al. 2024

21 cm signal as an astrophysical probe

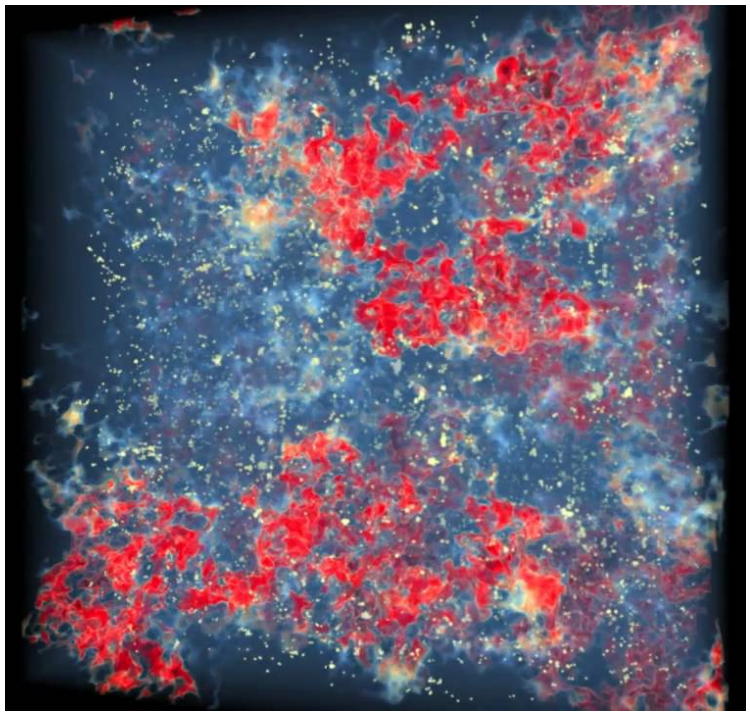
21 cm Brightness Temperature

Matter Overdensity

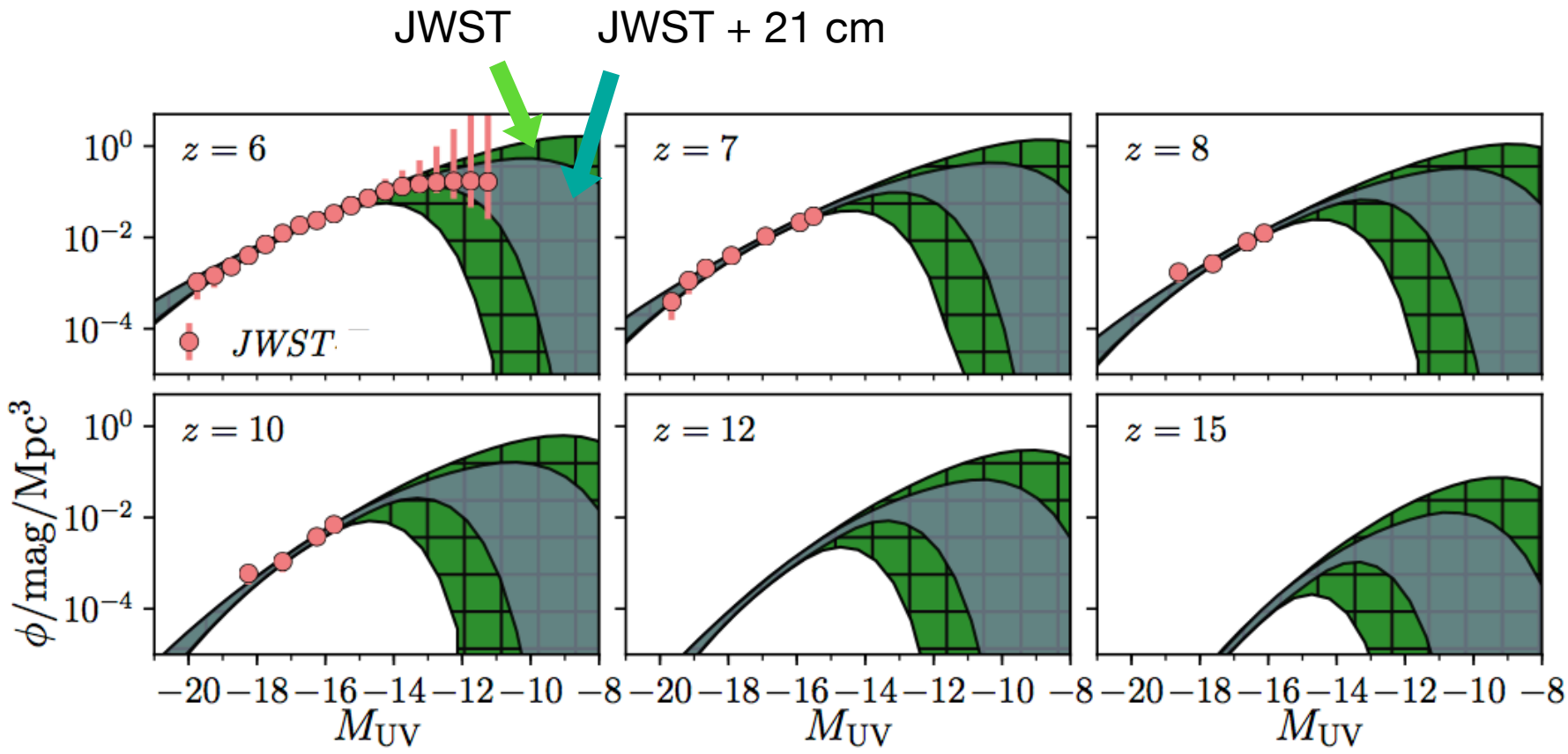
$$\delta T_b(\nu) \propto x_{\rm HI}(1+\delta)\left[1-\frac{T_\gamma(z)}{T_s}\right]$$

Hydrogen Neutral Fraction

Spin Temperature

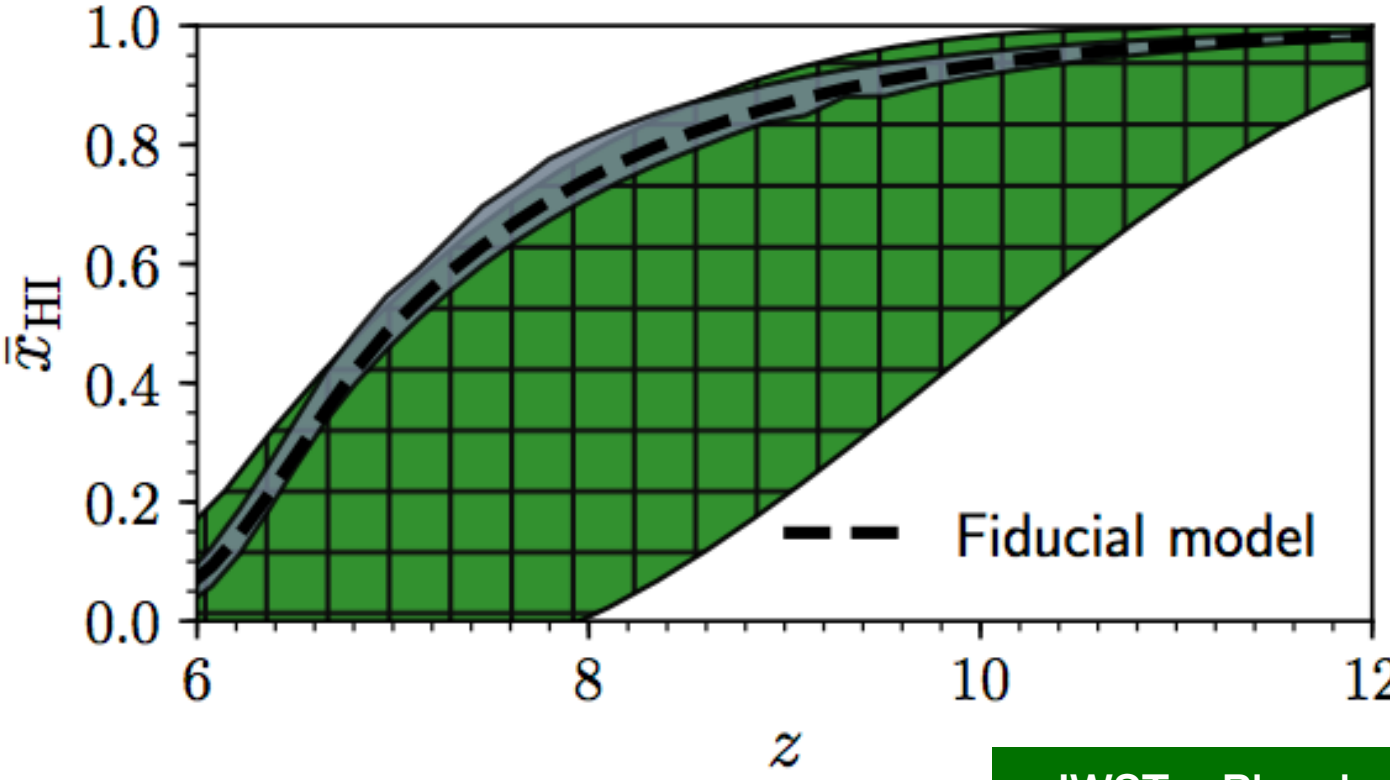


Probing bright and faint galaxies at the EoR



Park et al. 2019

Constraining the global neutral fraction

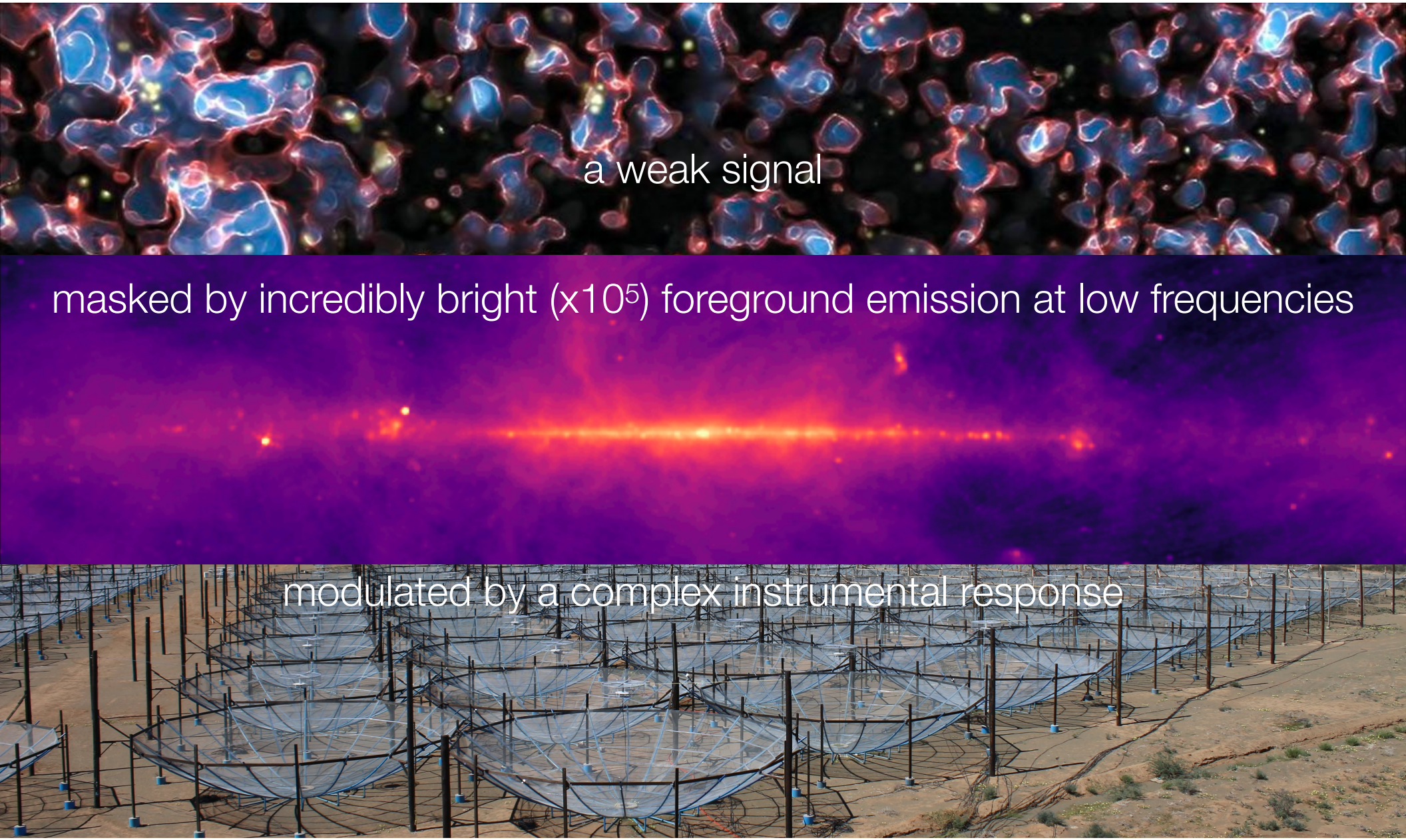


JWST + Planck

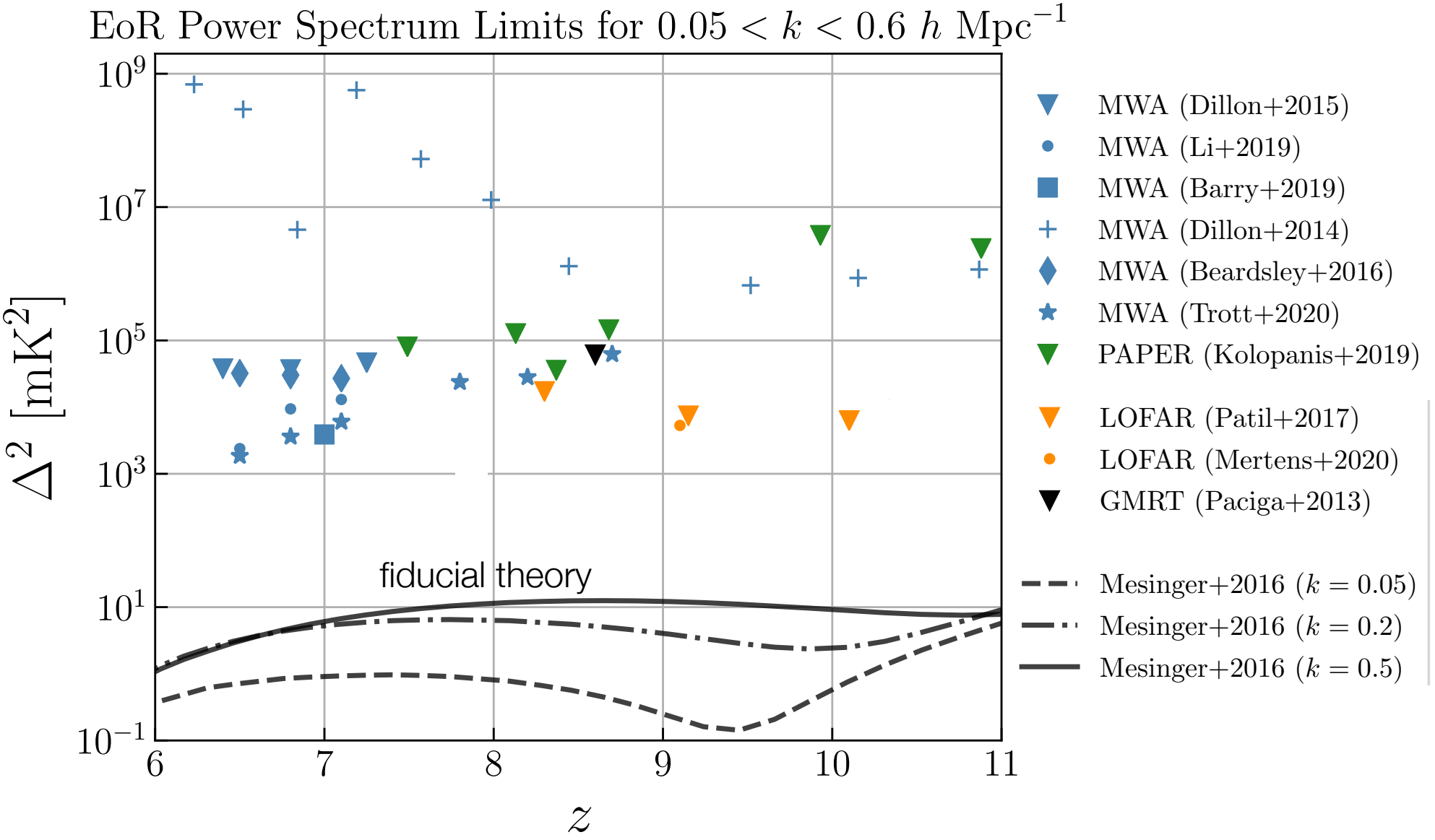
JWST + Planck + 21 cm

Park et al. 2019

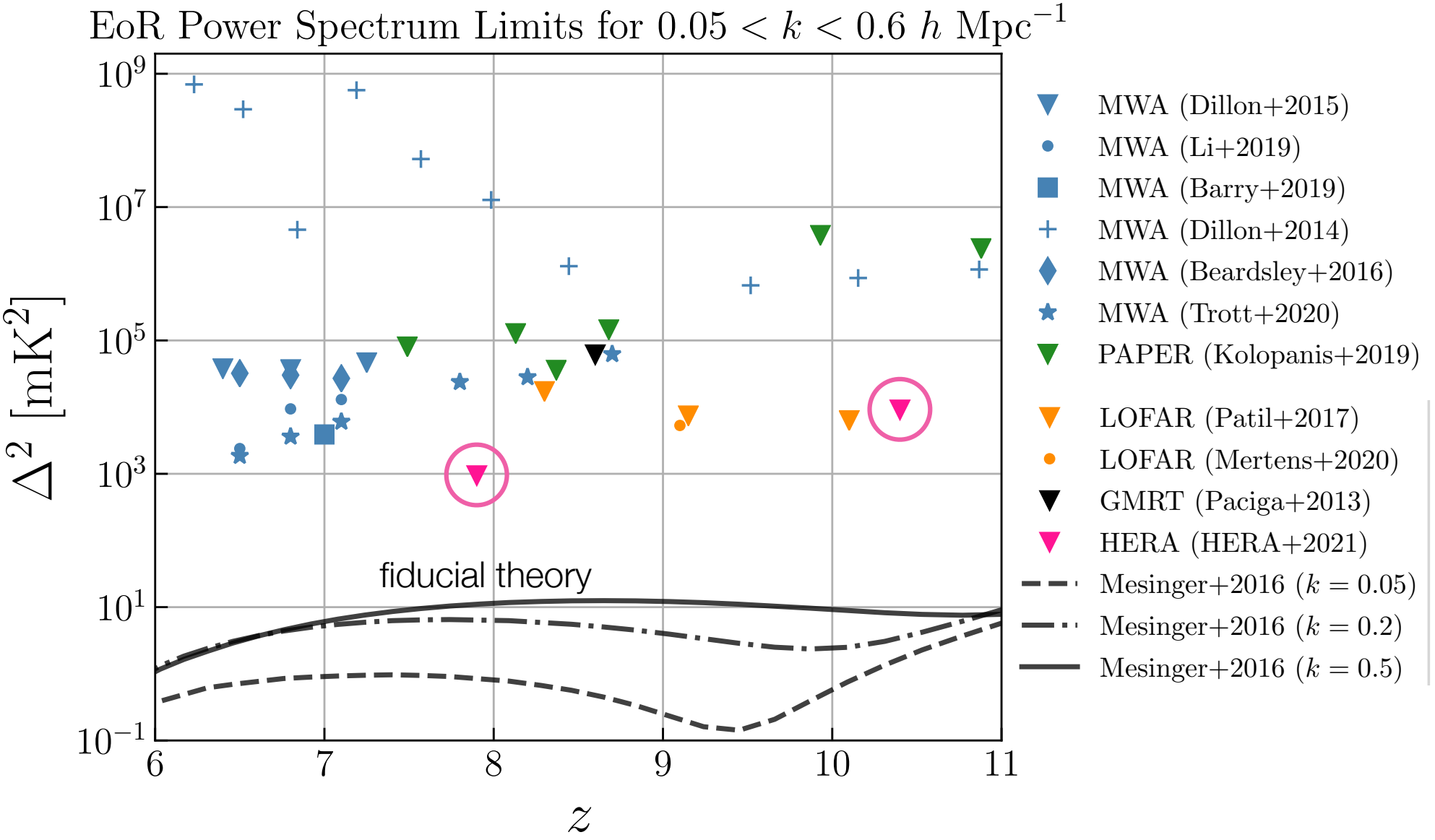
Bright foregrounds and complex systematics…



Power spectrum upper limits (prior to 2022)

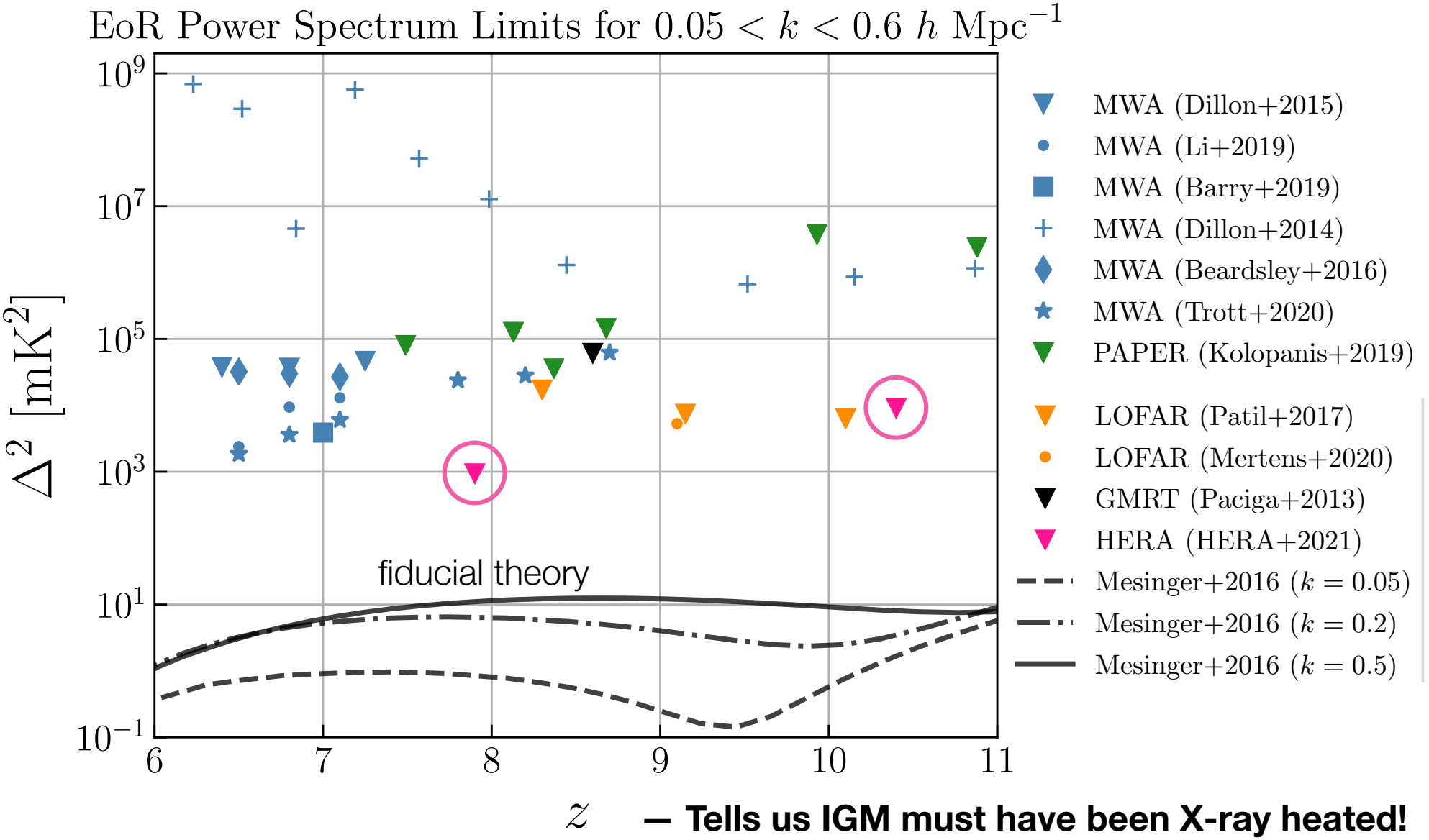


Significant improvement at z=7.9



HERA Collaboration 2022 (Lead: **NK**)

Significant improvement at z=7.9



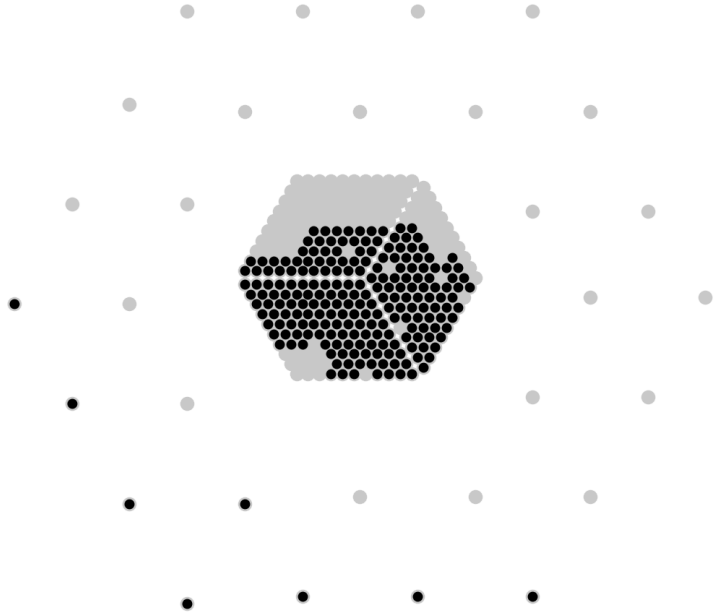
— Tells us IGM must have been X-ray heated!

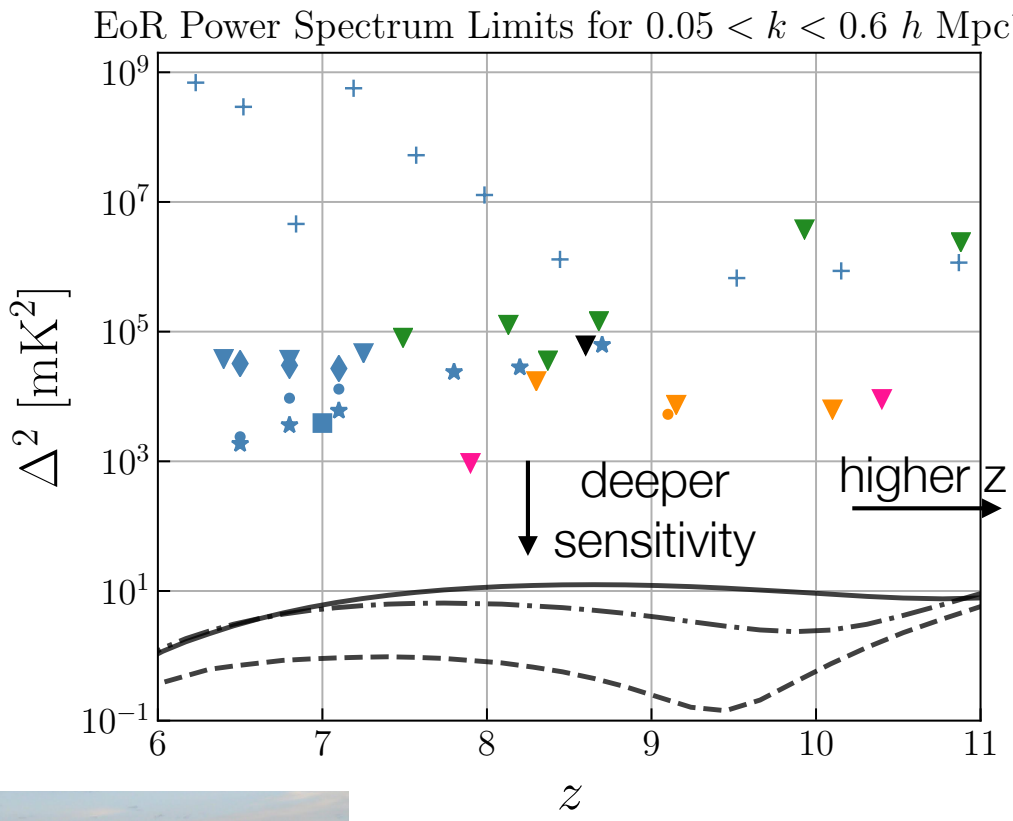
— Novel constraints on high-z HMXB sources!

HERA Collaboration 2022 (Lead: **NK**)

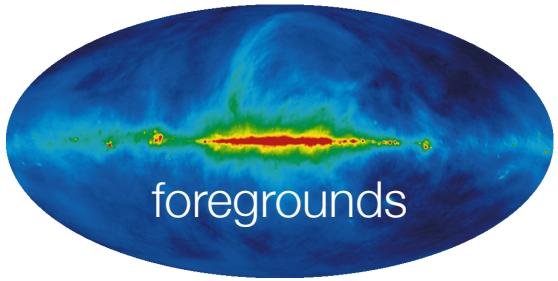
What's next for HERA?

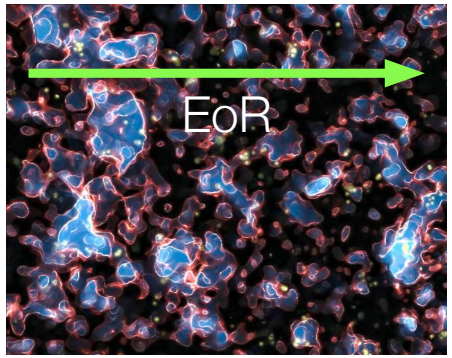
Currently analyzing Phase II data!

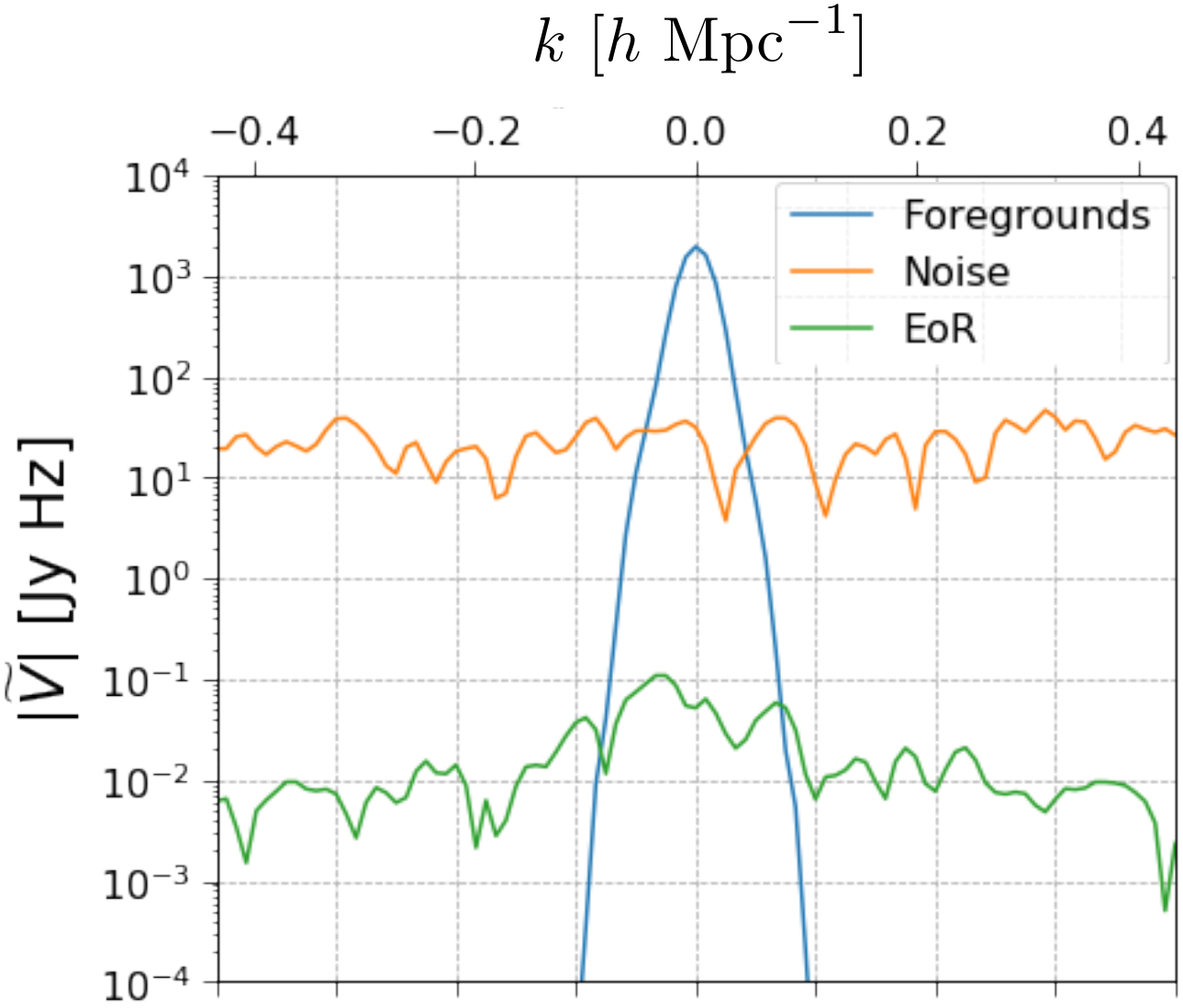




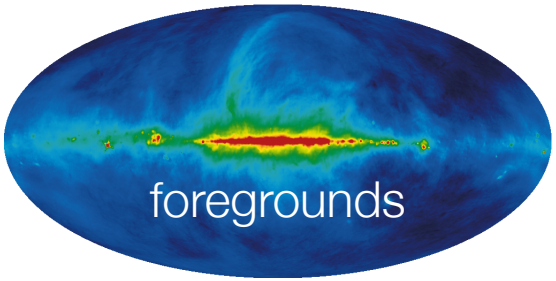
The scale of the problem

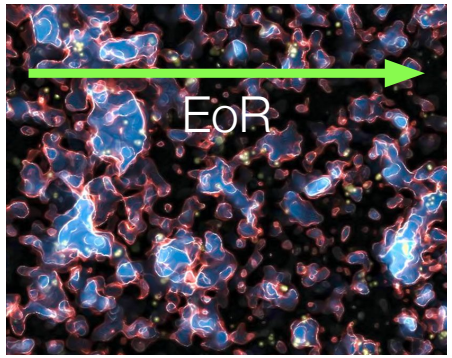


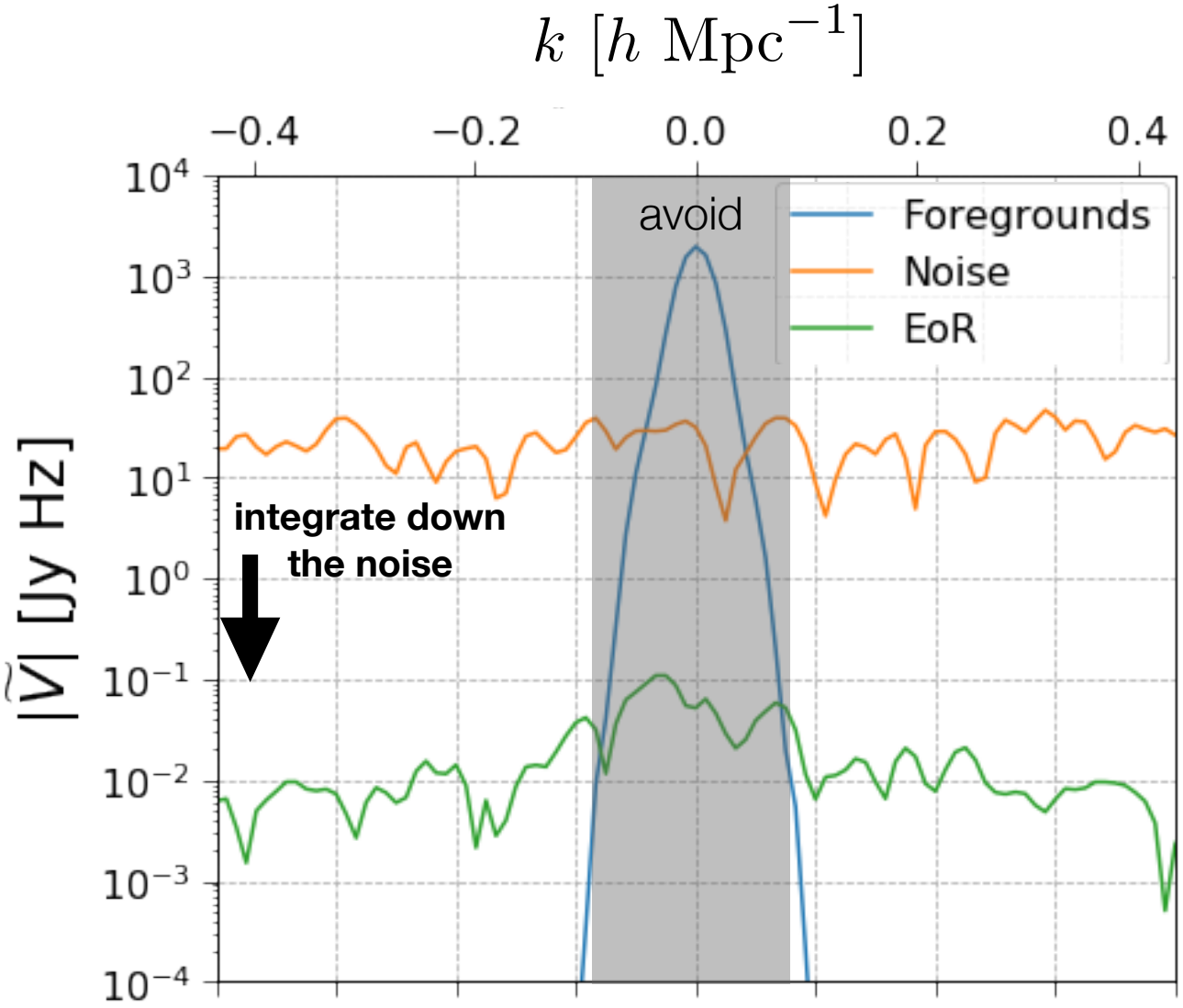




The scale of the problem

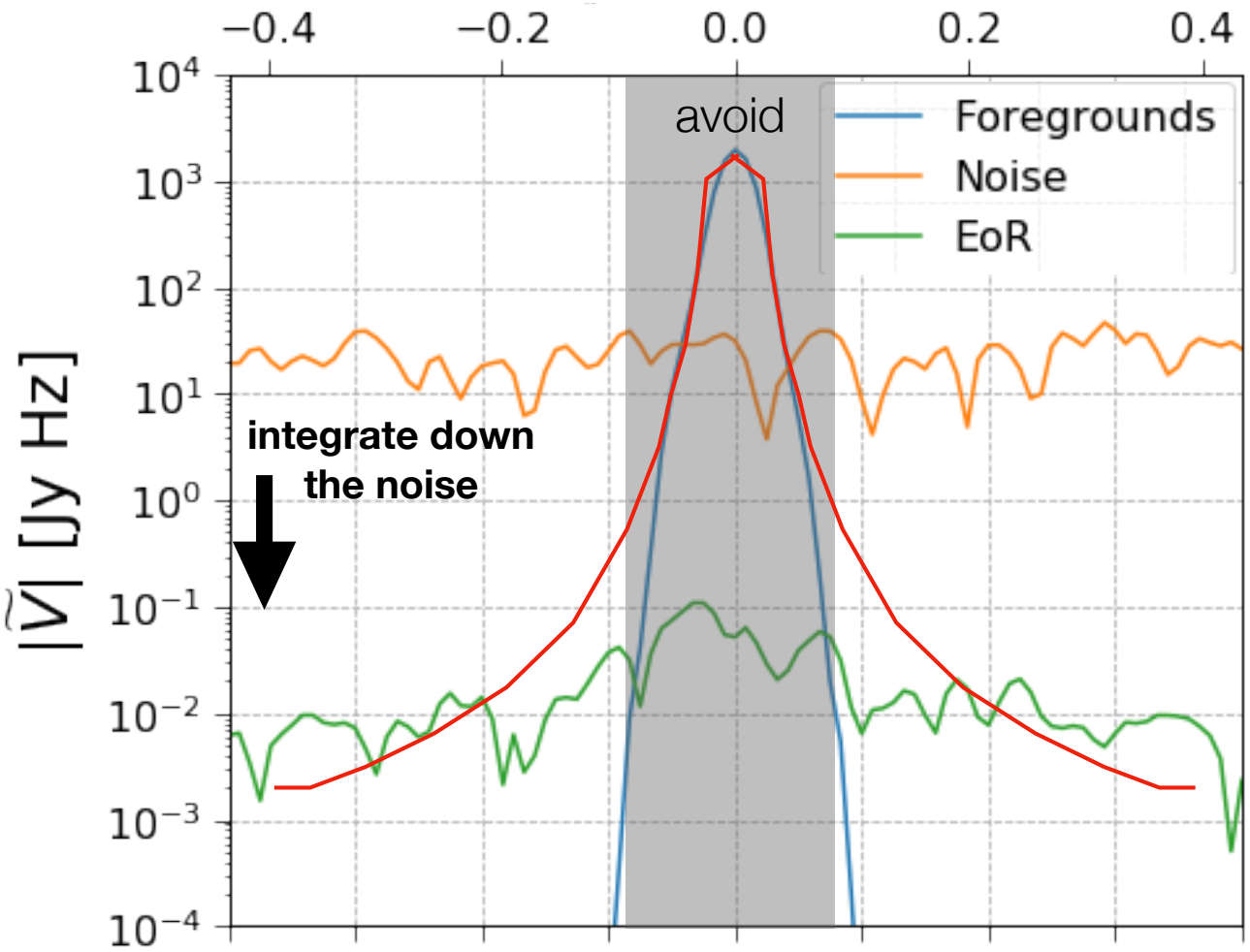


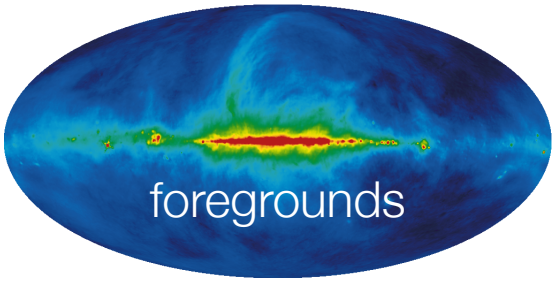


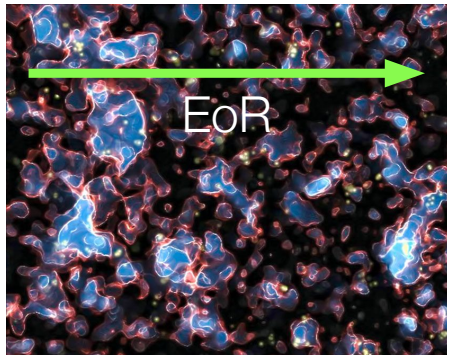


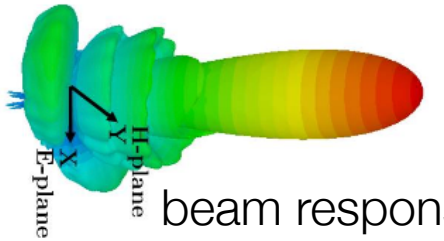
The scale of the problem

Systematics spoil the FG avoidance paradigm





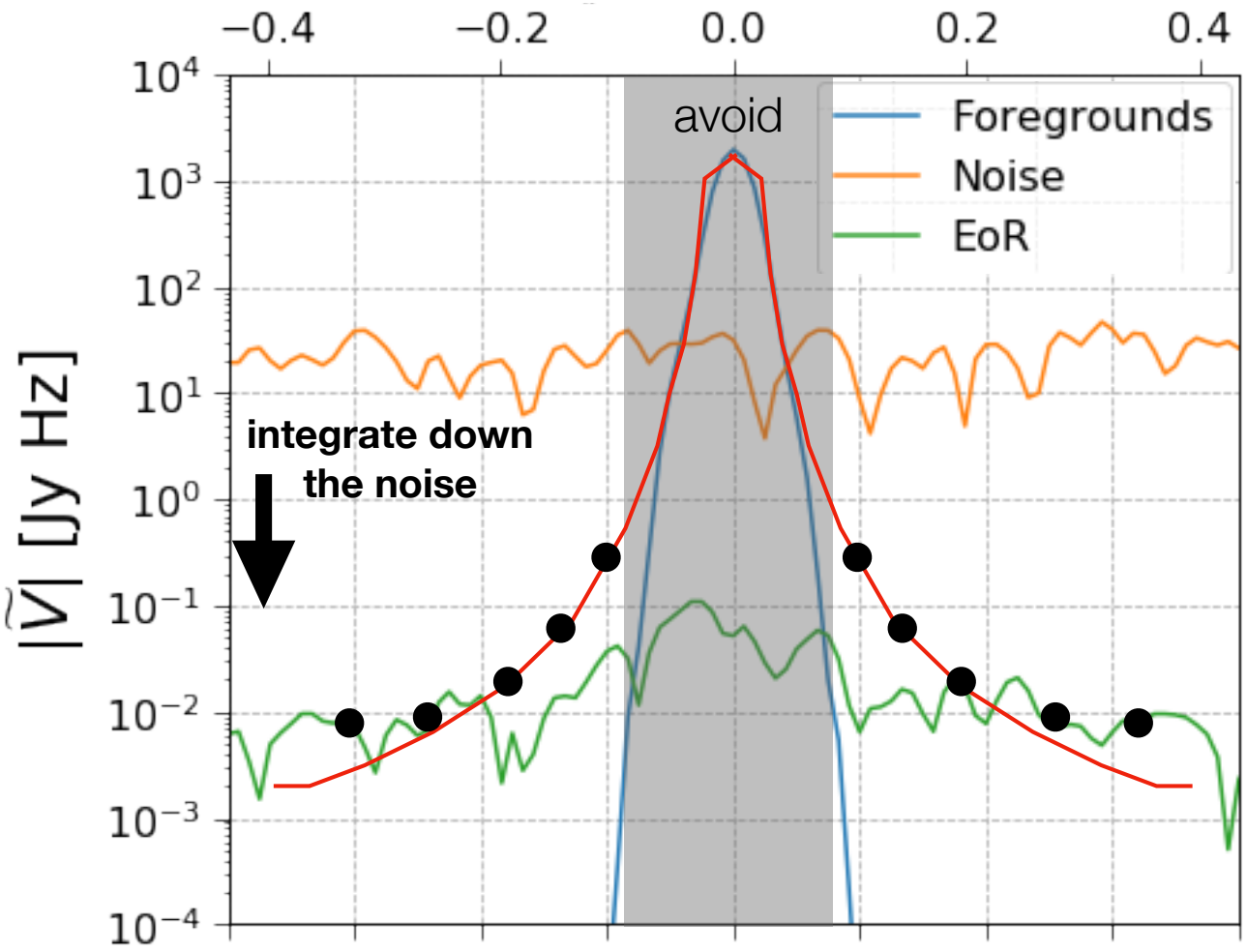


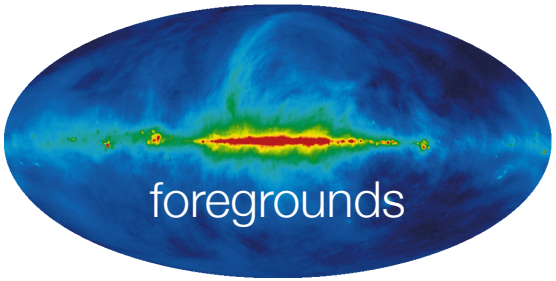


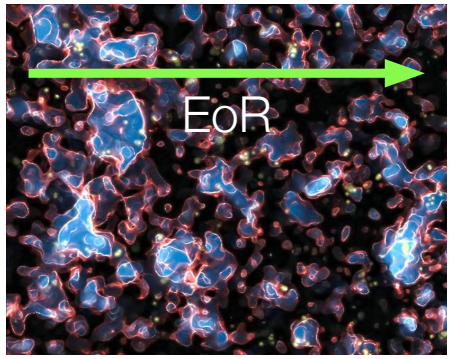
beam response

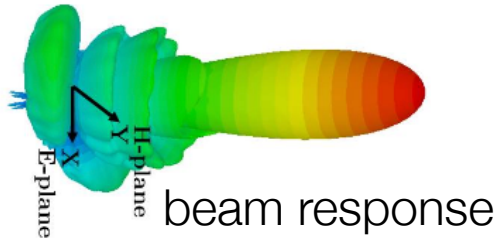
The scale of the problem

Systematics spoil the FG avoidance paradigm



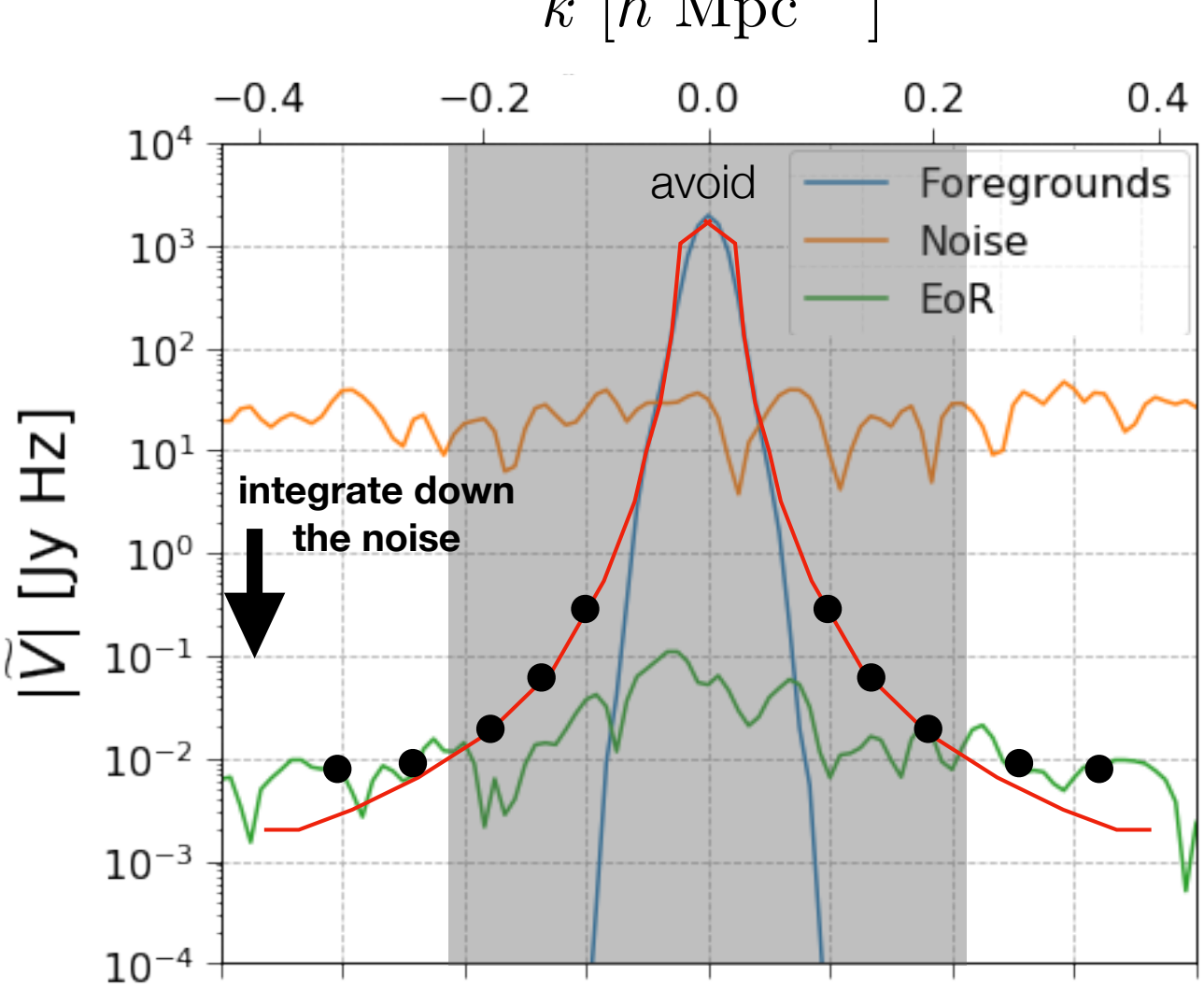


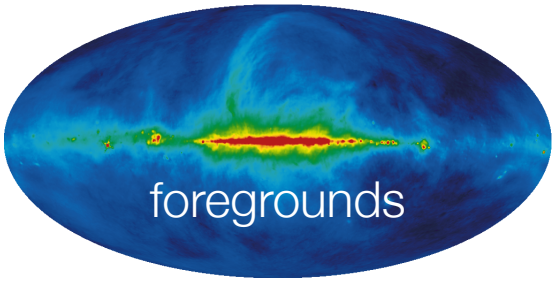


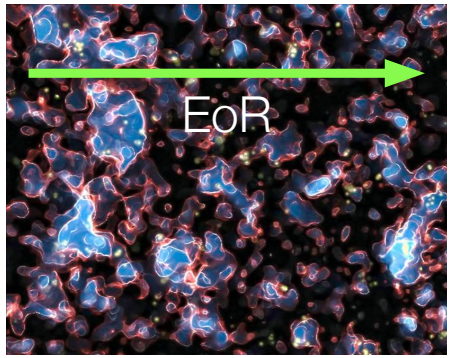


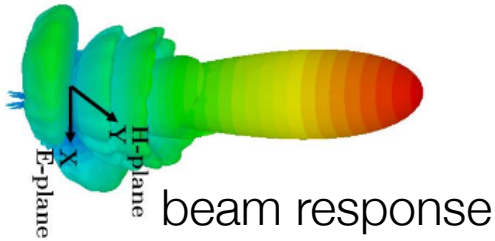
The scale of the problem

Systematics spoil the FG avoidance paradigm





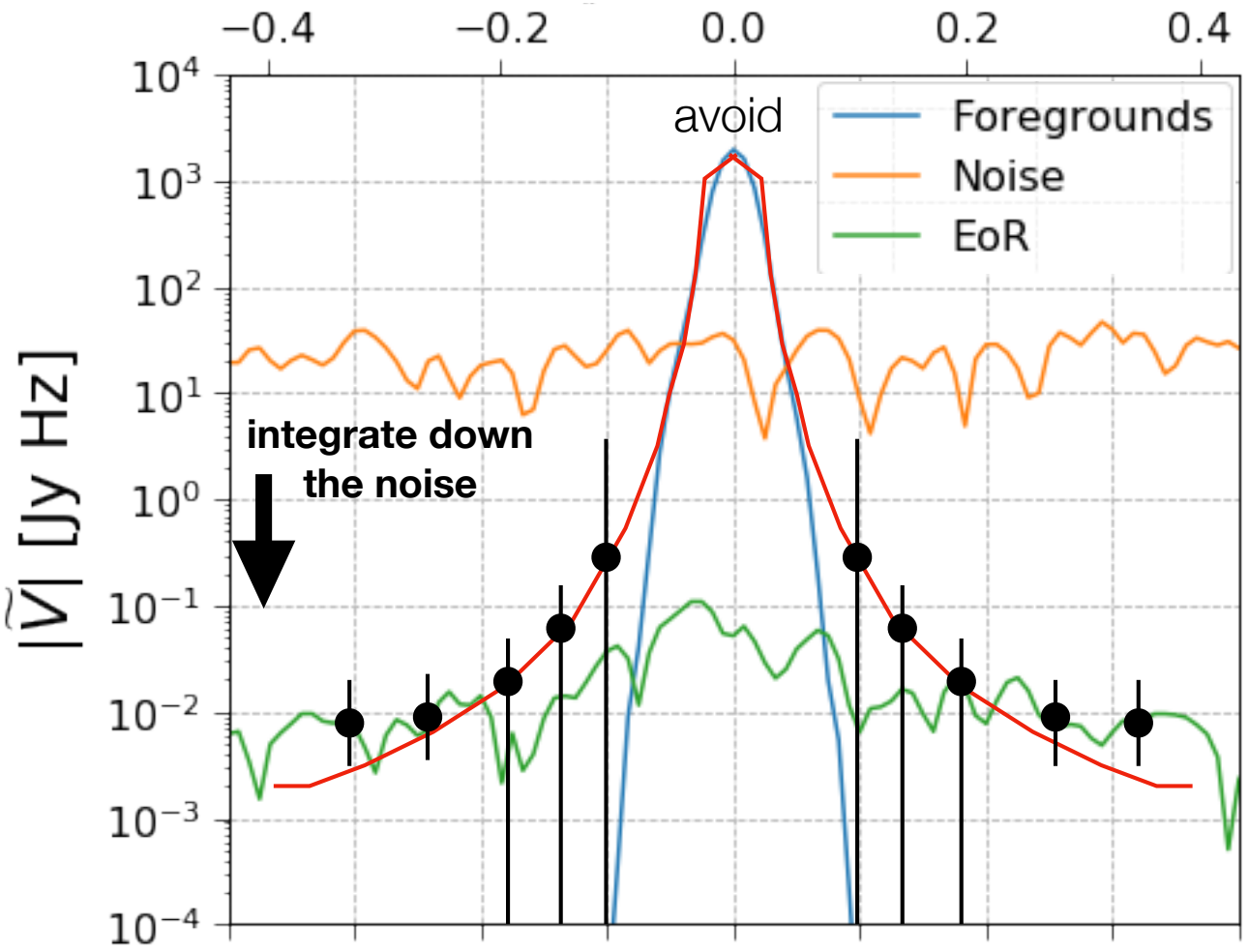


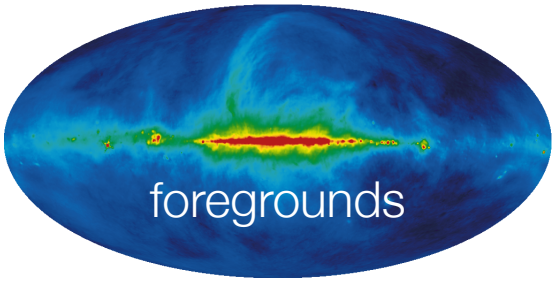


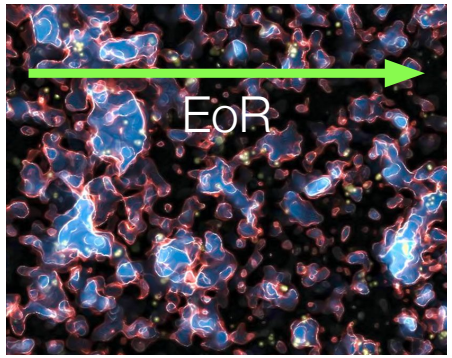
When is enough, enough?

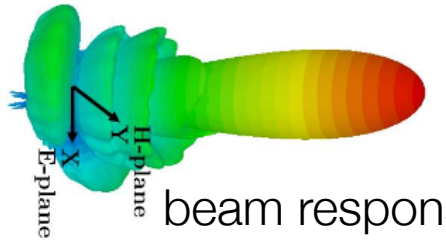
The scale of the problem

Systematics spoil the FG avoidance paradigm









beam response

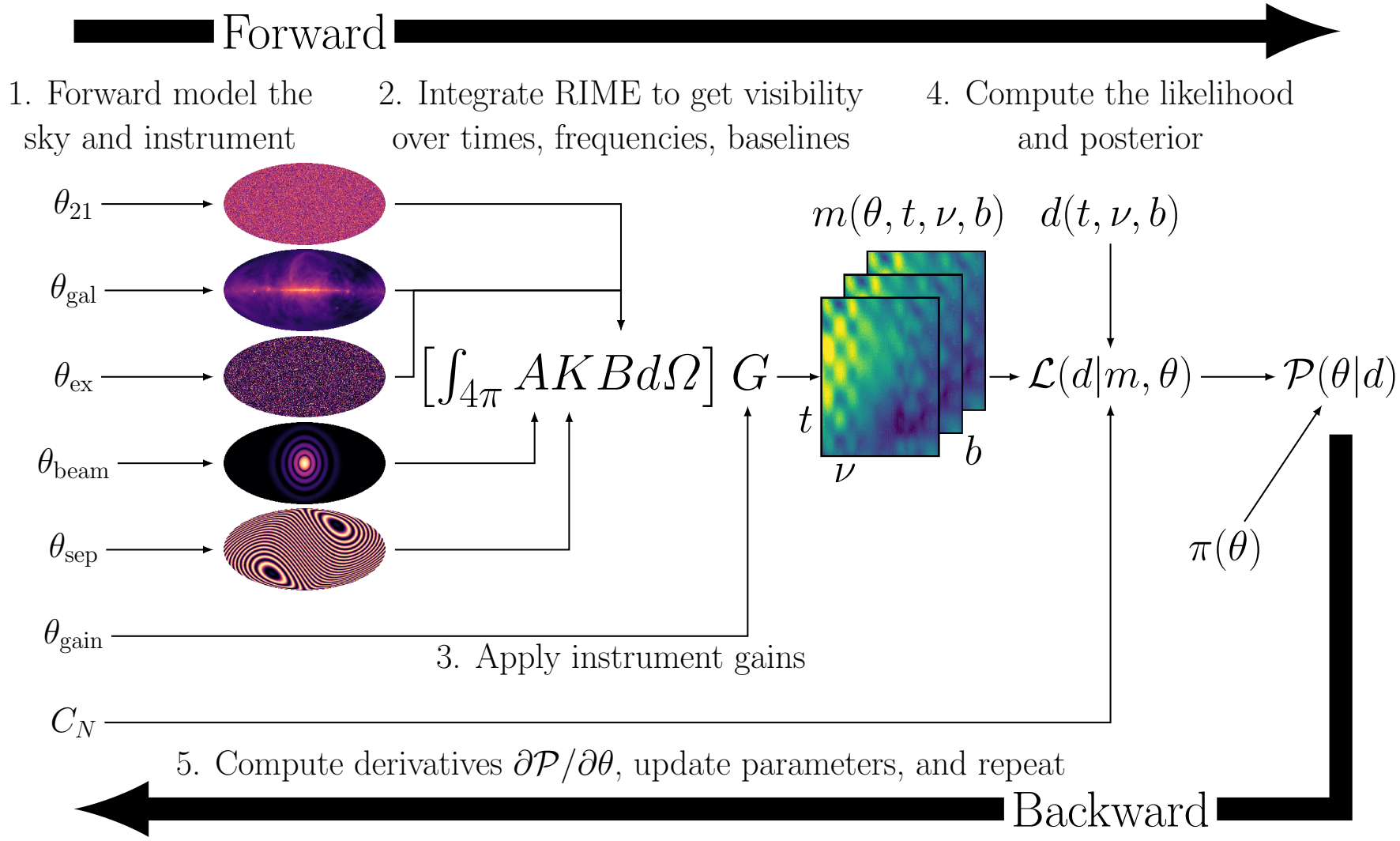
<u>Errorbar contribution:</u>

- Noise
- Foreground uncertainty
- Instrumental uncertainty

When is enough, enough? Can we determine this robustly?

Next-generation analysis frameworks: How do we get to a *robust* detection?

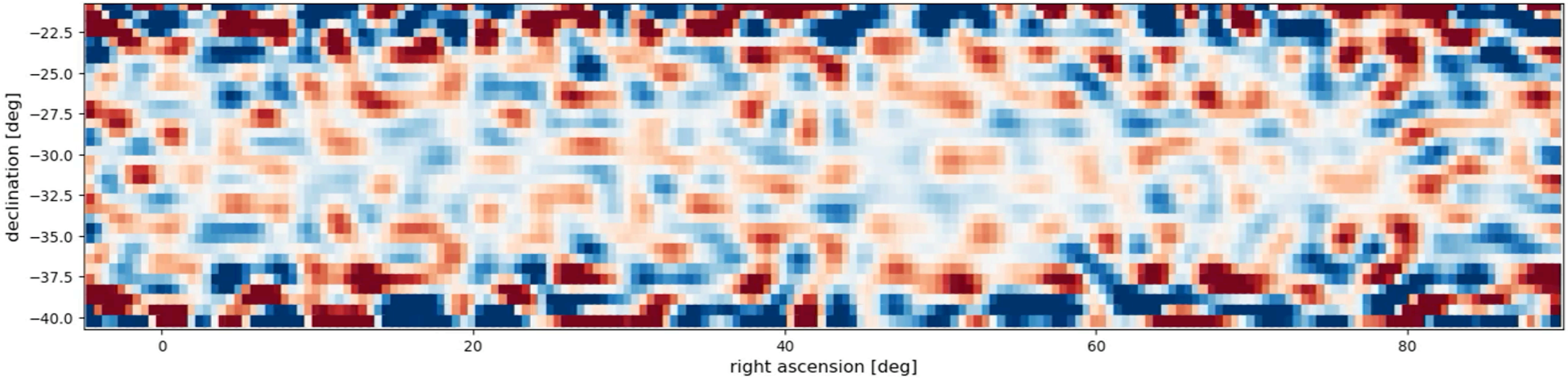
`BayesLIM`: the first end-to-end Bayesian forward model for 21 cm telescopes

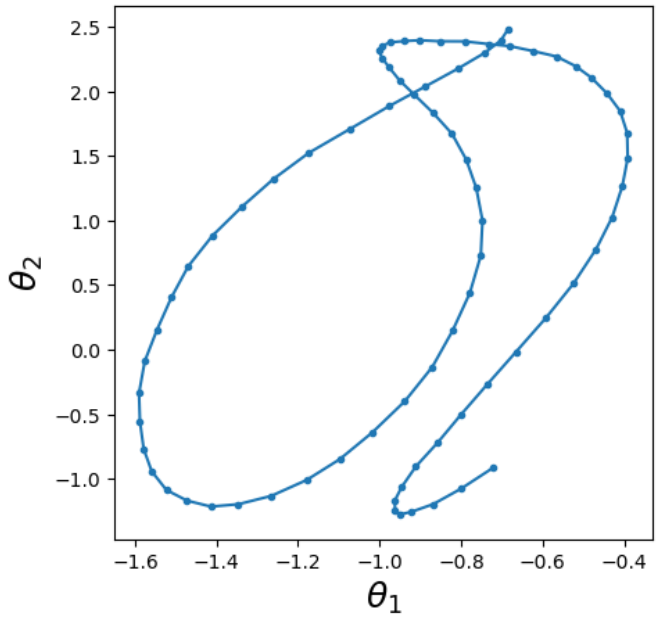


Kern 2023

MCMC sampling of signal + FG + instrument

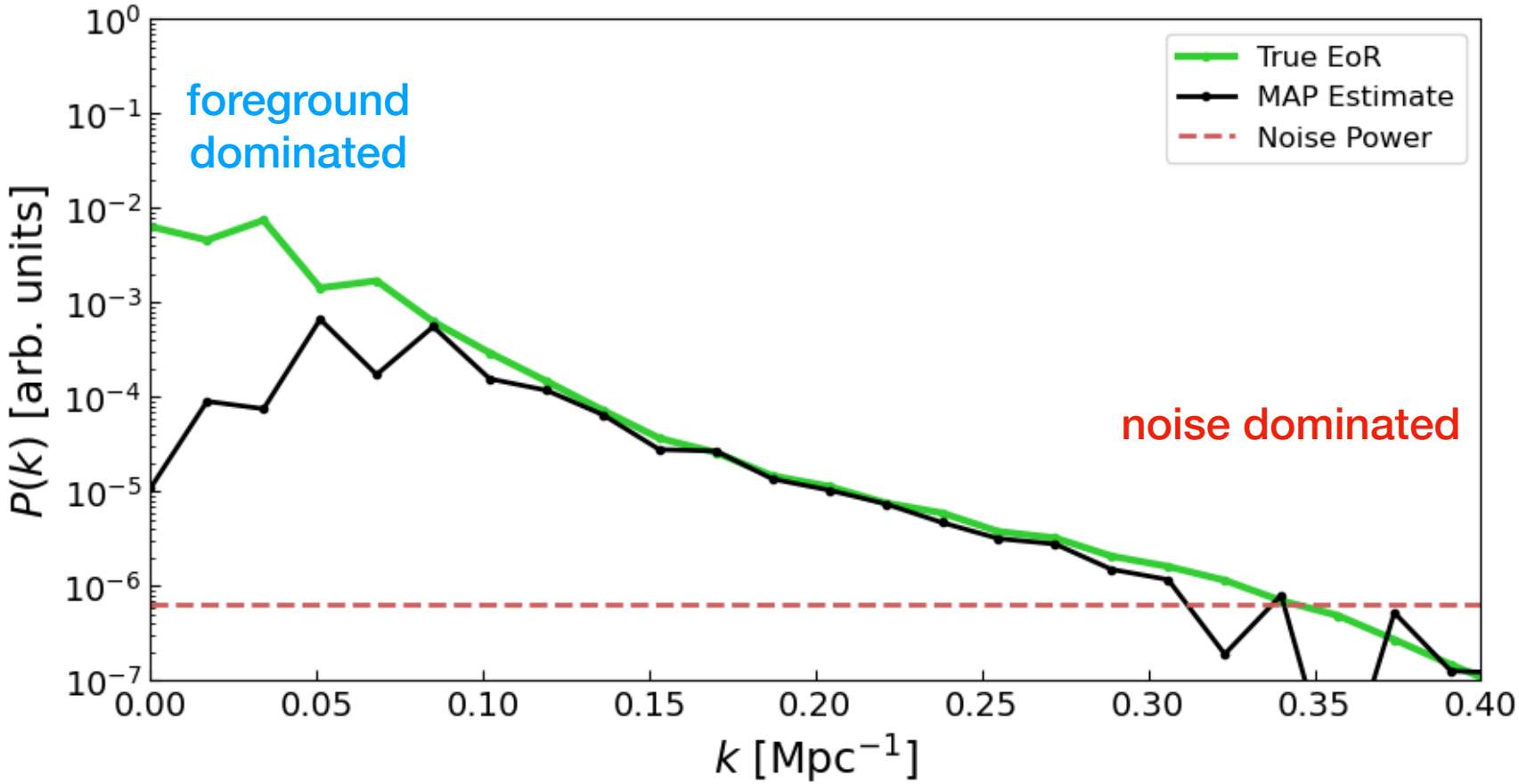
Visualizing the EoR component of the full model (EoR + FG + Instrumental Beam)



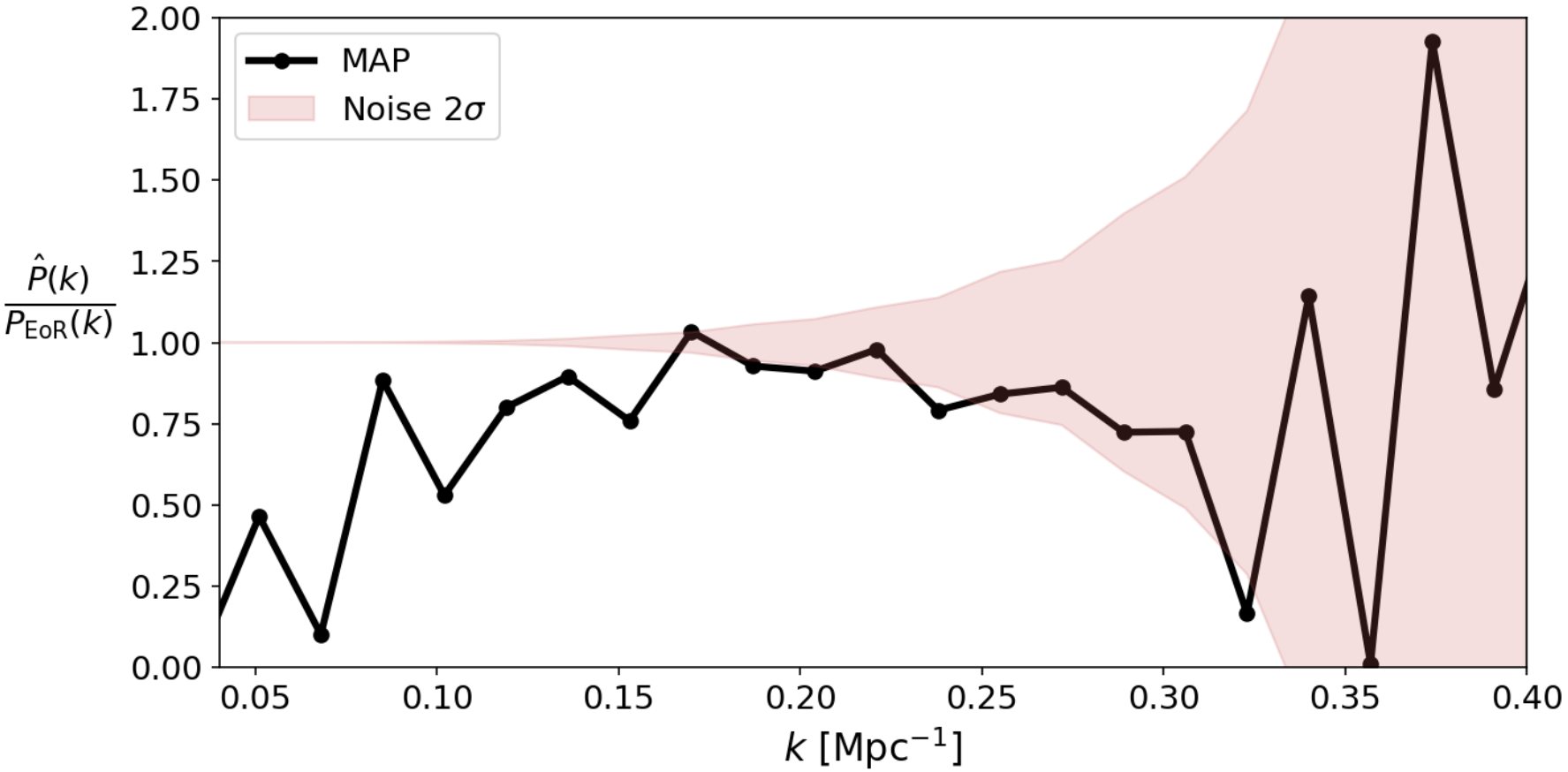


- HERA-91 array (max 60-meter baseline length)
- 20k point source FG model
- Full-sky diffuse galactic FG model (spherical harmonics)
- Full-sky, chromatic beam model (spherical cap harmonics)
- Full-FoV EoR model (spherical stripe harmonics)
- In total, ~60k parameters (~100 beam, ~30k EoR, ~30k FG)
- ~10% normal priors on all parameters

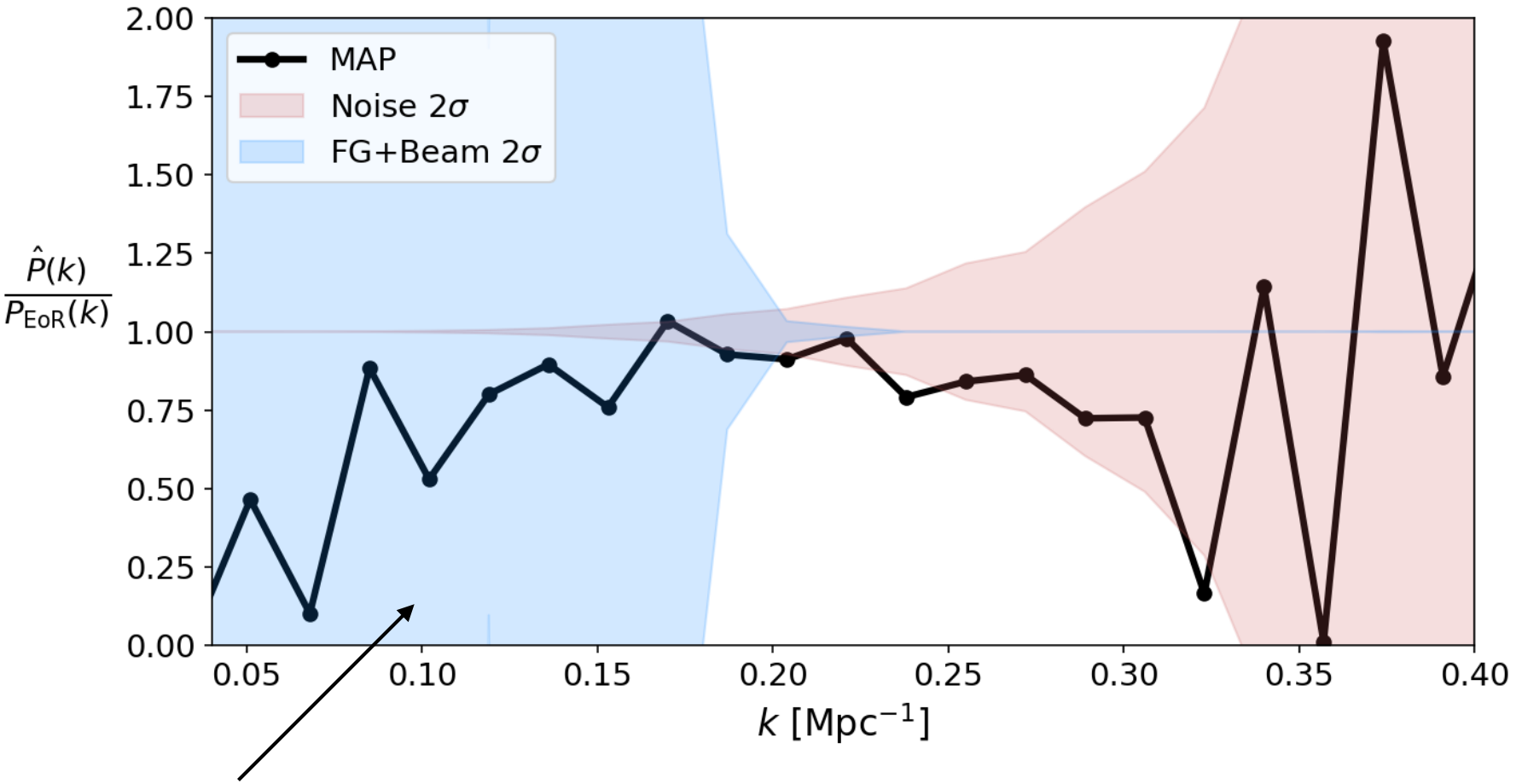
Optimizing to the posterior maximum



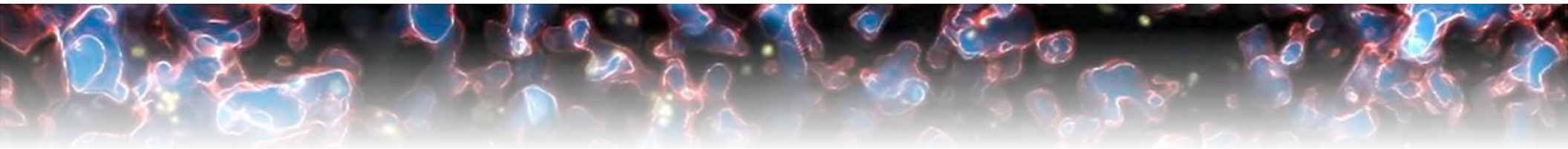
Posterior marginalization for robust uncertainties



Posterior marginalization for robust uncertainties



first end-to-end
uncertainty model



Revealing the high redshift universe with 21cm

- HERA's 21cm observations are a novel probe of high-z astrophysics, and are already **narrowing down** on IGM physics at Cosmic Dawn

- New observations from HERA Phase II will push to **higher redshifts** to constrain **more complex IGM heating models**, aiming for a first detection

- Ambitious forward modeling frameworks will be a paradigm shift in enabling a robust **first detection from HERA**