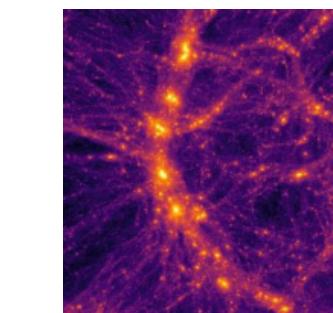
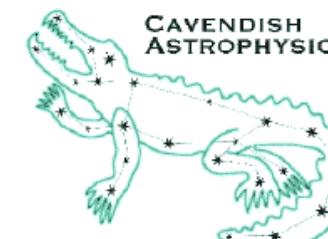
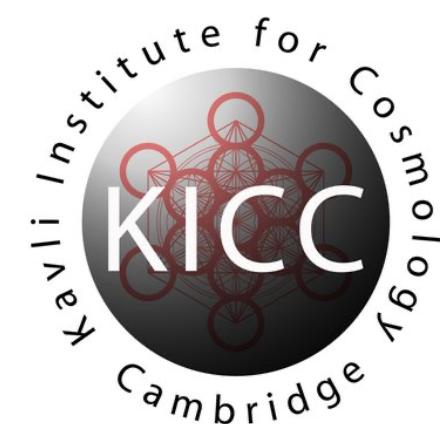
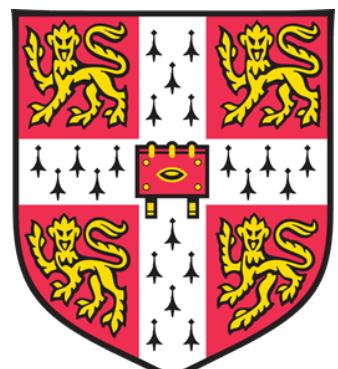


21 cm Cosmology as a probe of the high redshift Universe

Harry Bevins
Kavli Junior Fellow

With Thomas Gessey-Jones, Simon Pochinda, Jiten Dhanda, Stefan Heimersheim, Irene Abril-Cabezas, Anastasia Fialkov, Will Handley, Eloy de Lera Acedo, Rennan Barkana, Saurabh Singh

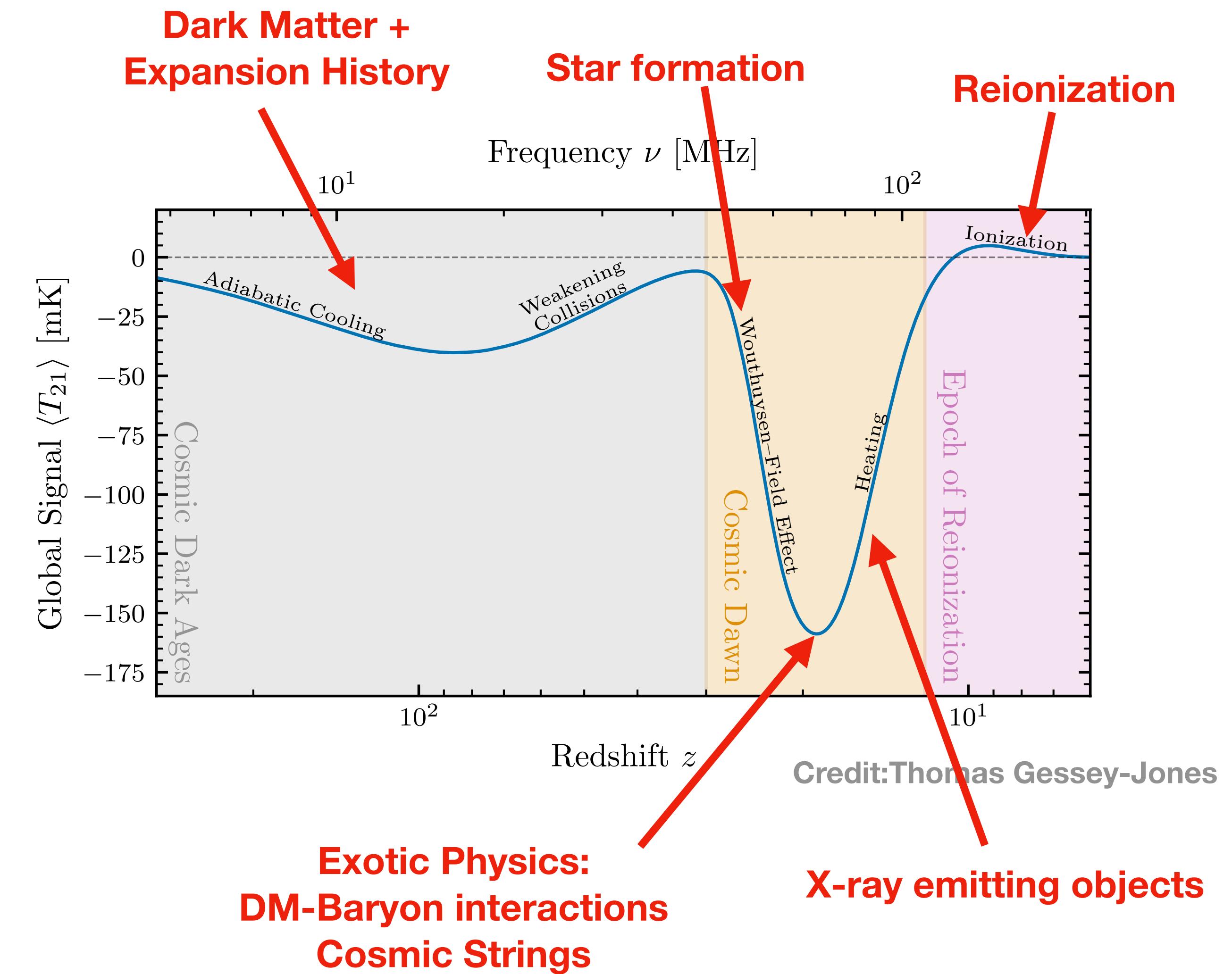


CosmicDawnLab



What can the signal tell us?

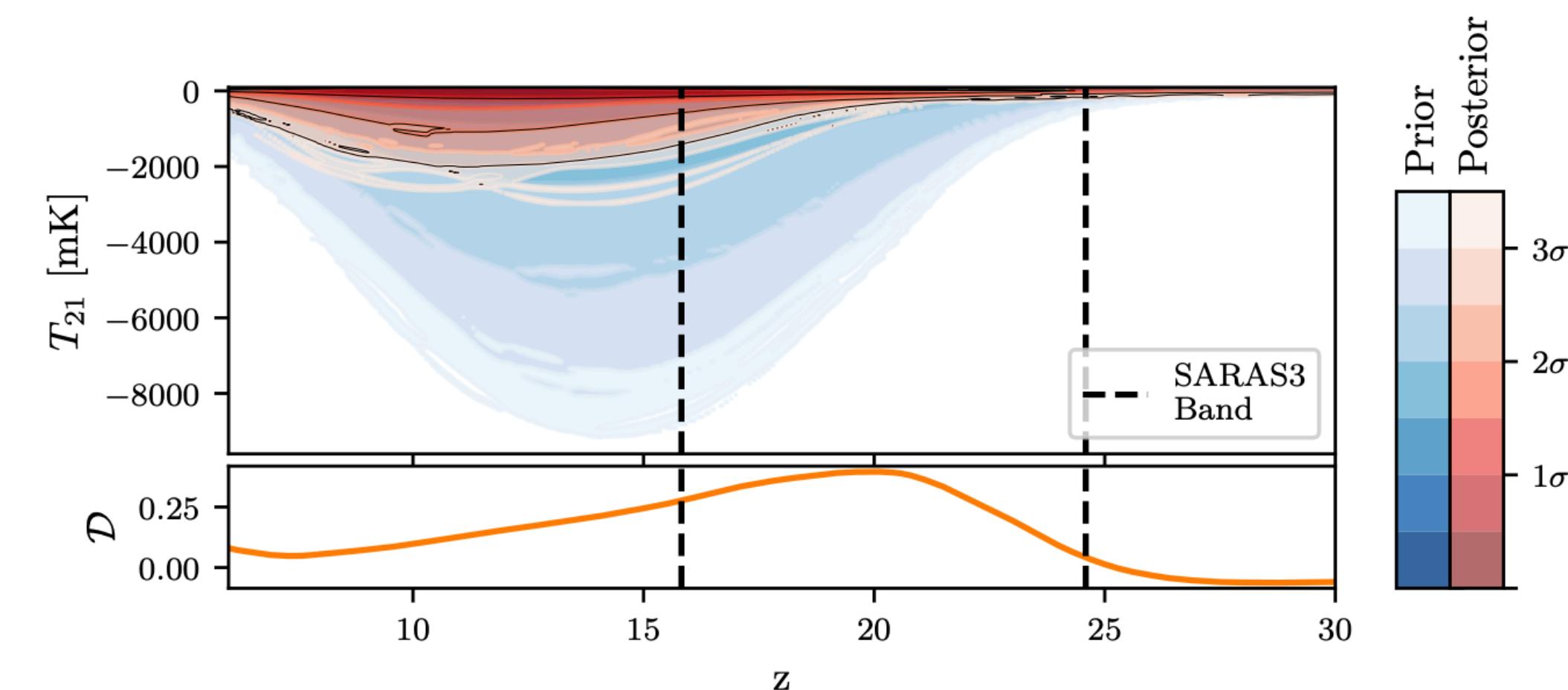
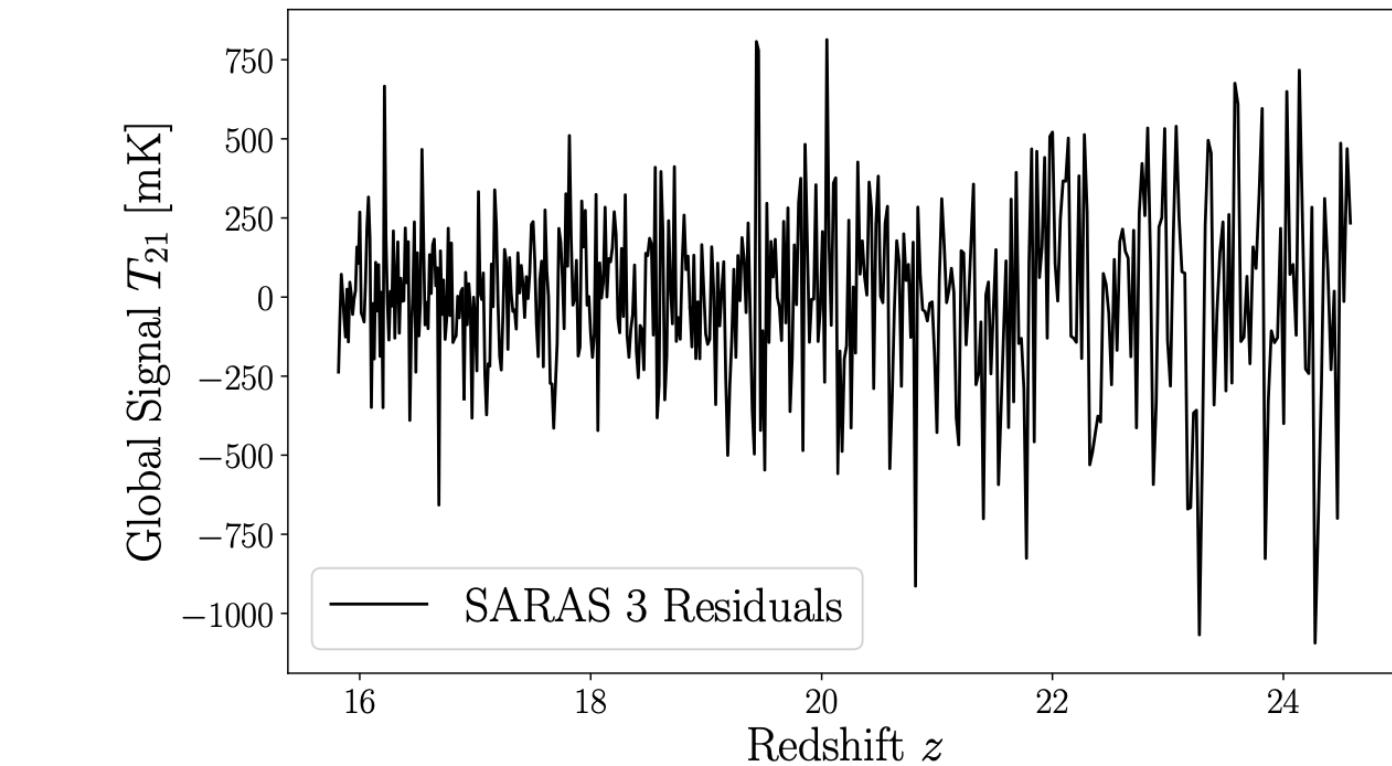
- In theory we can do tomography
- But focusing on two summary statistics for now
- Sky averaged 21-cm signal with single antennas
- Power spectrum with interferometers
- In house simulation suit called 21cmSPACE (A. Fialkov et al.)



Constraints from global experiments

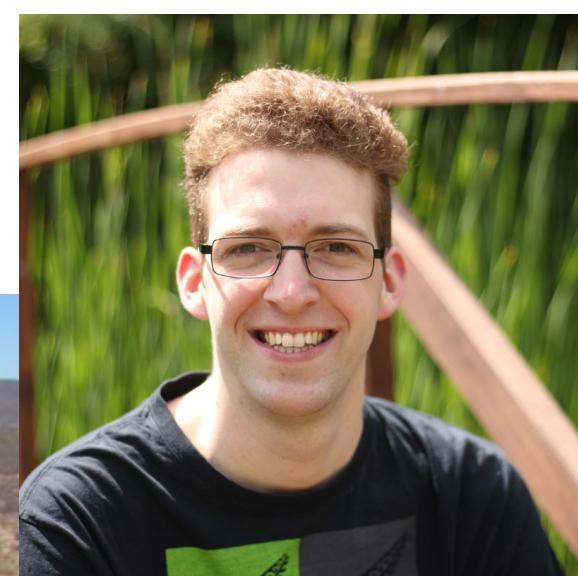
H. Bevins et al., Nature Astronomy, arXiv:2212.00464

- Upper limits on the sky-averaged signal from SARAS3 at $z=15-25$
- Working in a Bayesian framework with signal emulators
- Put weak limits on
 - the contribution of galaxies to radio background
 - X-ray luminosity of early sources
 - Star formation efficiency and minimum halo mass of early galaxies

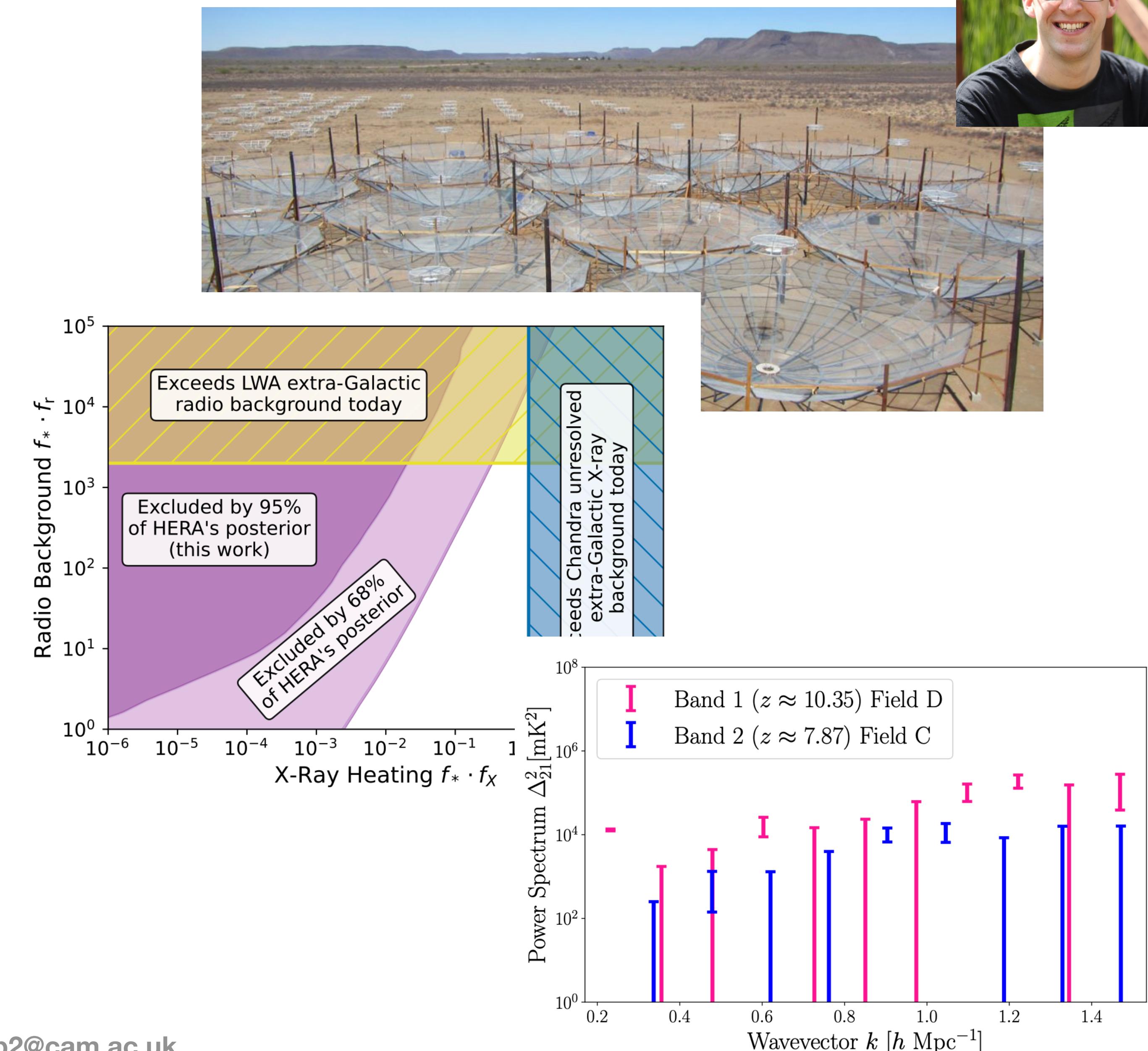


Constraints from the power spectrum

The HERA Collaboration, Stefan Heimersheim, ApJ, arXiv:2210.04912



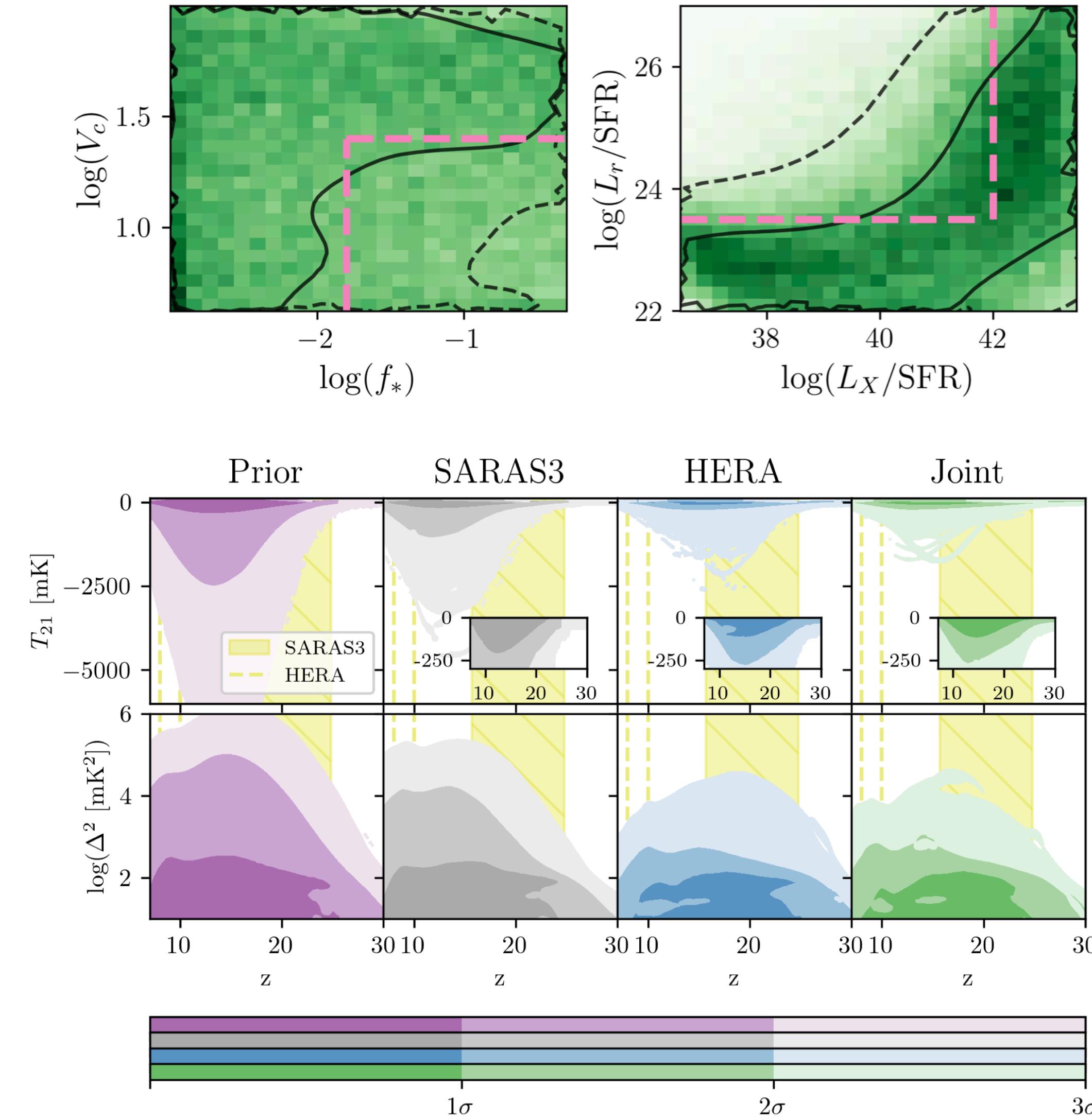
- Using the HERA interferometer
- Upper limits on the power spectrum at $z=8$ and $z=10$
- Able to constrain contribution of radio galaxies to the background
- And constrain the X-ray luminosity of early galaxies
- Somewhat tighter than SARAS3 but at different redshifts



Combination of power spectrum and global signal

H. Bevins, S. Heimersheim et al., MNRAS, arXiv:2301.03298

- Combination of SARAS3 and HERA limits
- Working in marginal parameter space using the existing results and normalising flows
- Combination gives us tighter constraints on L_X , L_r and the magnitude of the signals
- Interpolation between data points

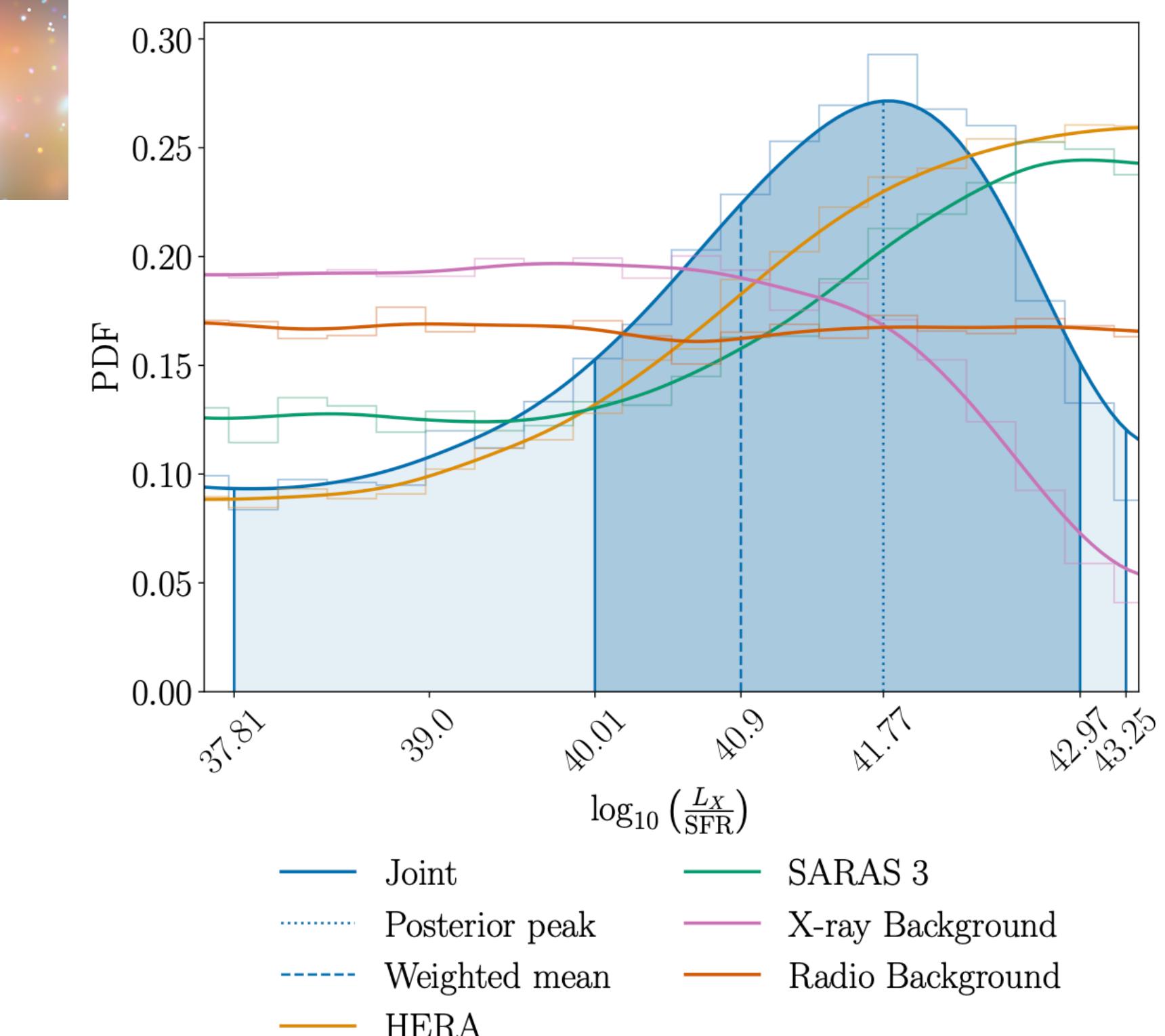
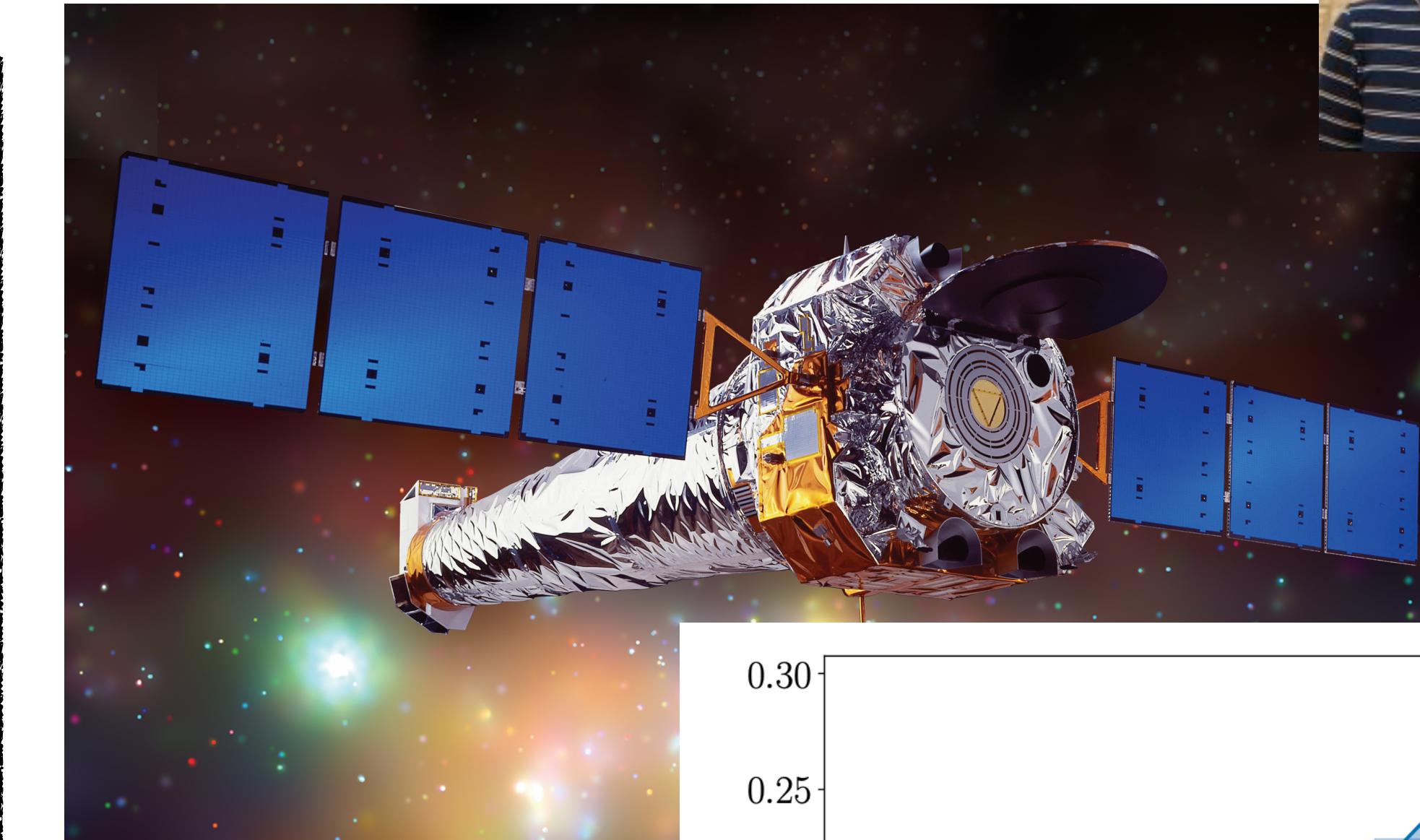


Inclusion of X-ray and radio backgrounds

S. Pochinda, ..., H. Bevins, ..., I. Abril Cabezas et al. arXiv:2312.08095



- Extending previous analysis
 - with X-ray background measurements from Chandra and other probes
 - with radio background measurements from ARCADE2 and LWA
- PopII and PopIII star formation efficiency split
- Complementary constraints from X-ray background and 21-cm

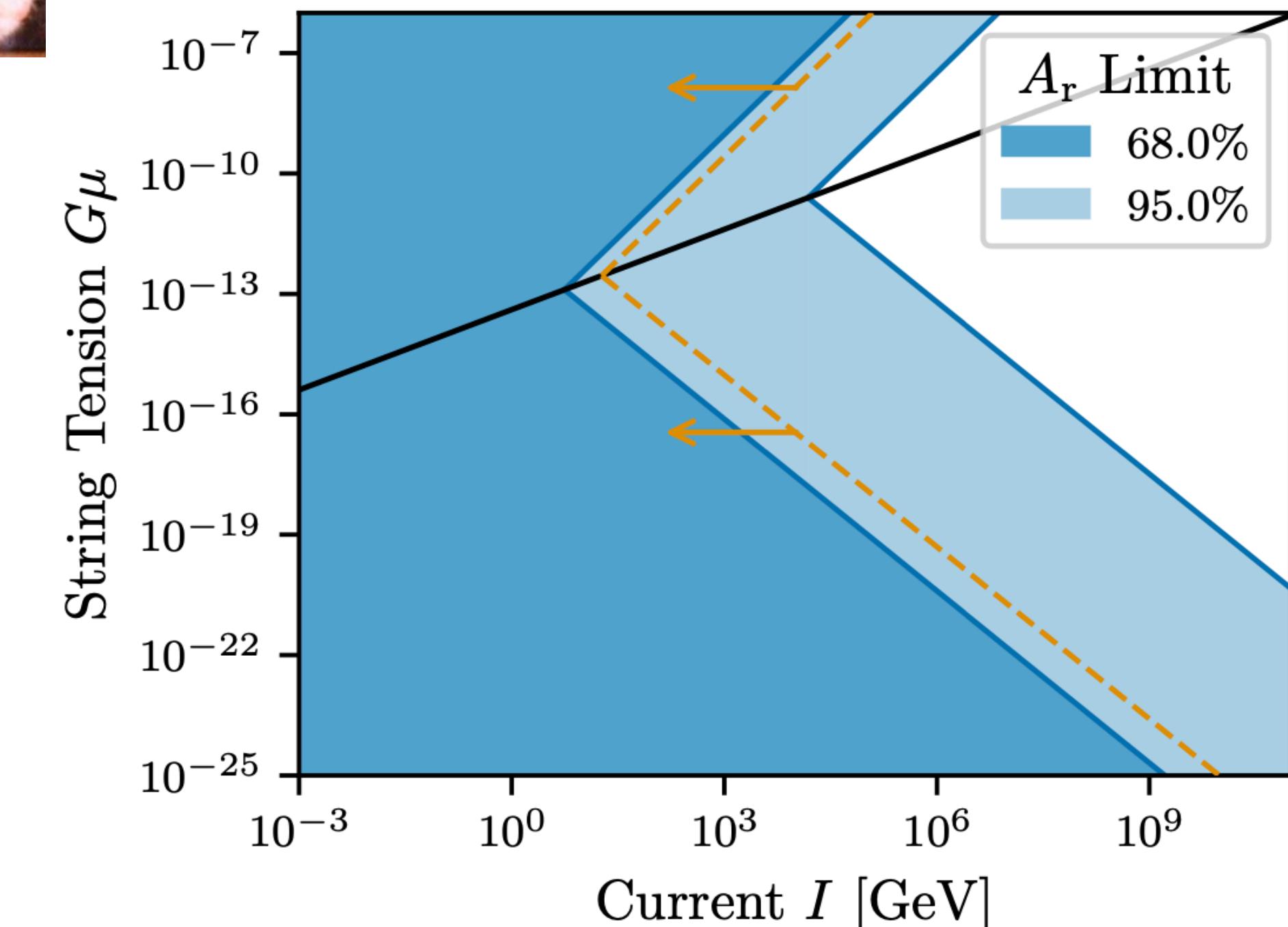


Exotic physics?

T. Gessey-Jones, S. Pochinda, H. Bevins et al., arXiv:2312.08828



- Radio background from Superconducting Cosmic Strings
- Single additional model parameter
- Using SARAS3, HERA and the X-ray limits
- No strong constraints
- Inclusion of astrophysical uncertainties

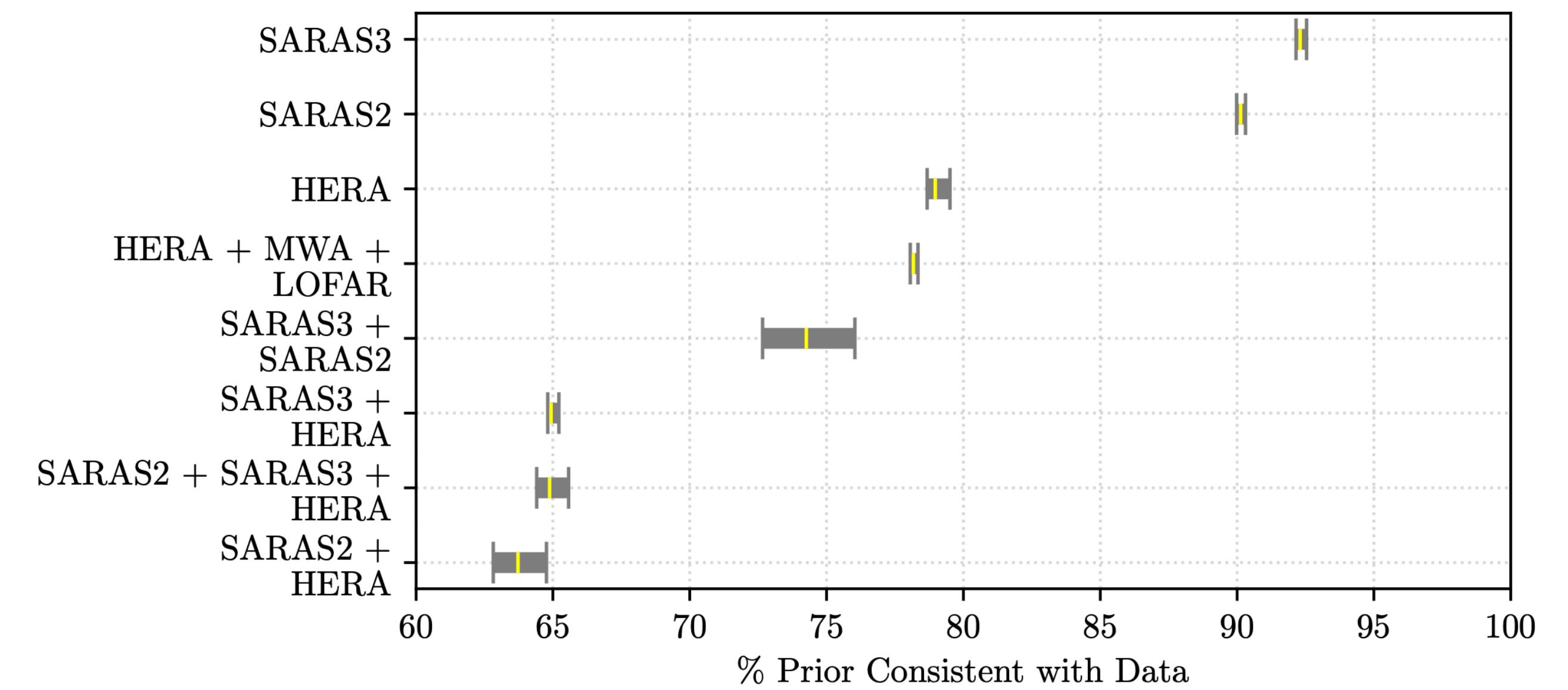


Constraining power of our data

H. Bevins, W. Handley et al., MNRAS, arXiv:2205.12841

- Calculate marginal KL-divergences over the common signal parameters
- Marginalising over nuisance parameters with normalising flows
- Assess the constraining power of the data sets in just the signal parameter space

$$\kappa = 100 \exp(-\mathcal{D}_{KL}) \approx 100 \frac{V_\pi}{V_p}$$

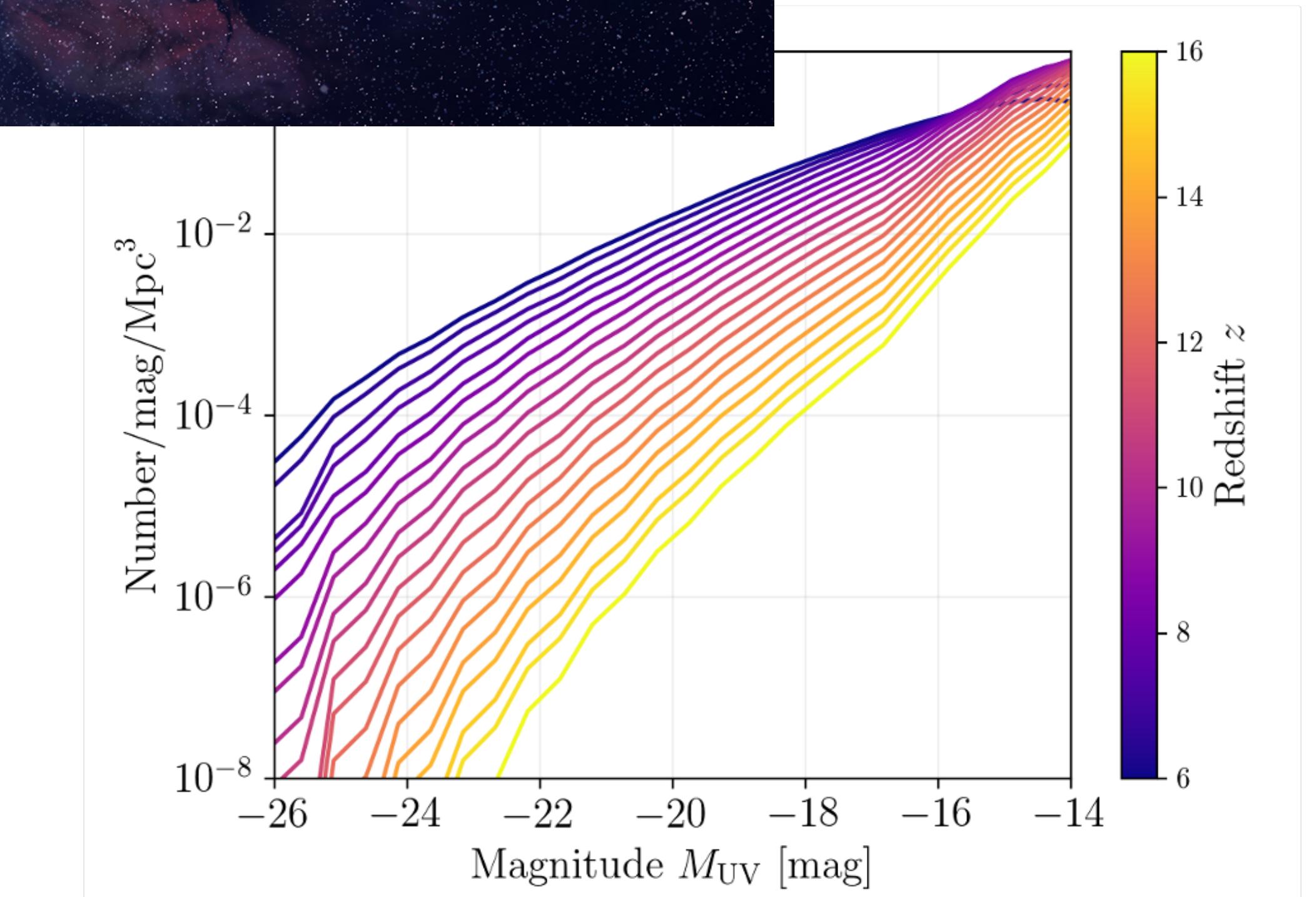
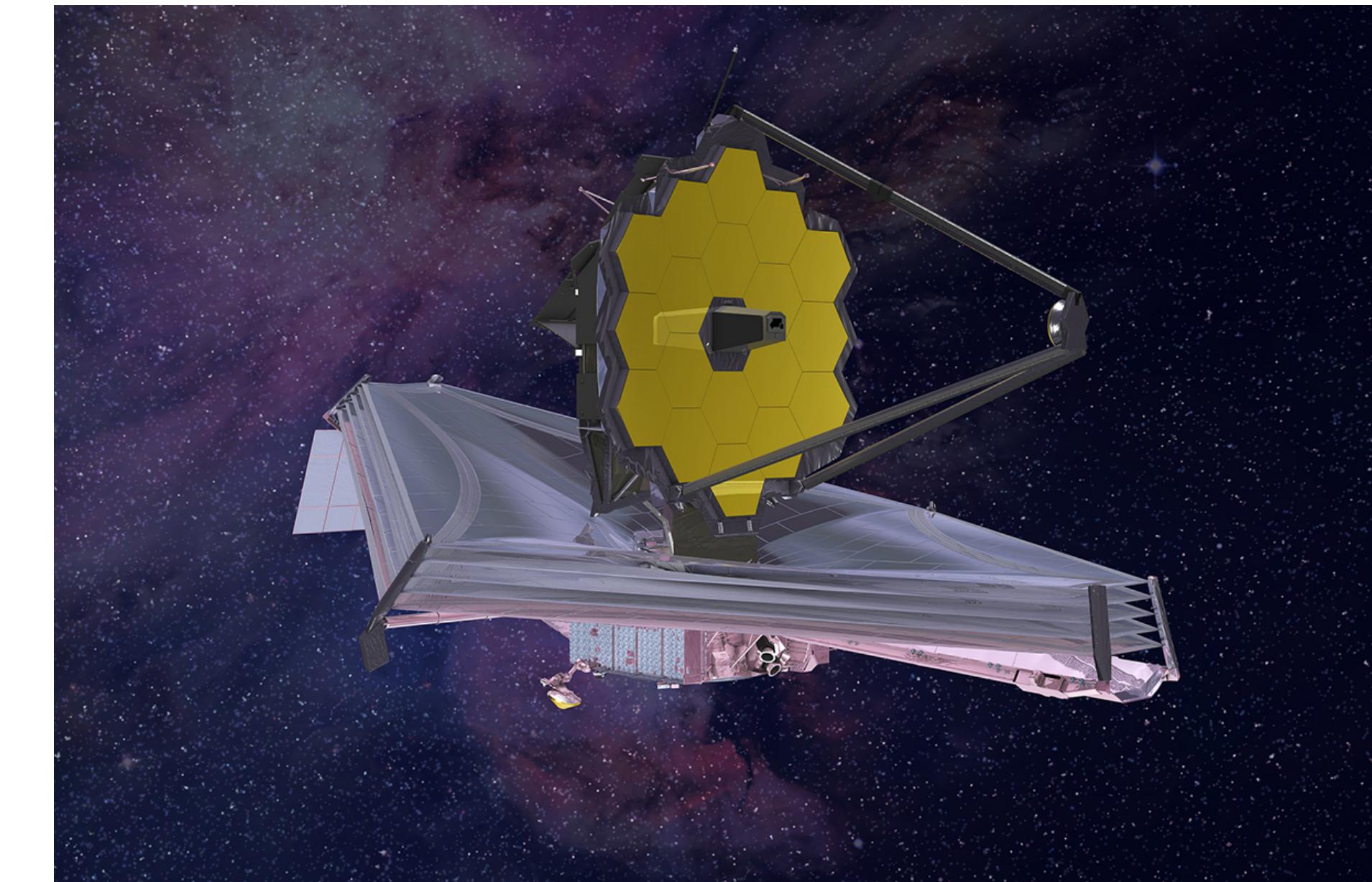


21cm X JWST?

J. Dhandha, S. Tachella, A. Fialkov, H. Bevins et al. in prep.



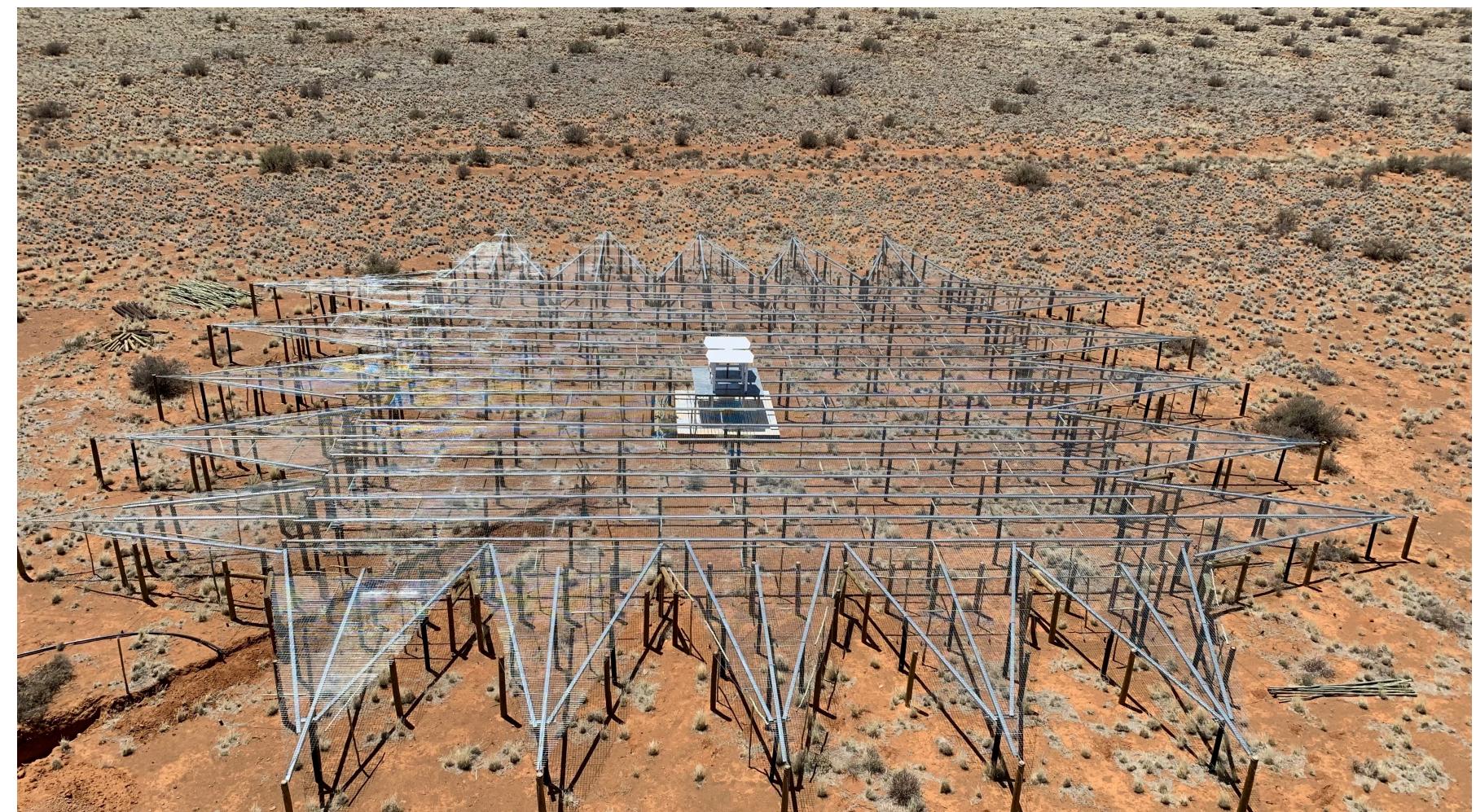
- UV Luminosity Function and 21-cm signal are both strong functions of star formation
- Currently investigating joint constraints from HERA, SARAS3 and JWST
- Using self consistent semi-numerical simulations of both UVLF and 21-cm
- Bayesian framework



REACH

De Lera Acedo,.., H. Bevins et al., Nature Astronomy, arXiv:2210.07409

- Attempting to look for the global experiment
- Based in the Karoo Radio Observatory in South Africa
- Currently going through commissioning with our first antenna
- Multi-national collaboration with members in UK, across Europe, South Africa and America
- Strong contingent of junior researchers and PhD students



Conclusions

- Developing tools for analysis of 21-cm data
- Exploring synergies with other probes
 - X-ray and radio backgrounds
 - JWST
 - Intensity mapping
 - Lyman- α forest
 - etc
- Working on experimentation in Cambridge
- Preparing for the SKA and the big data era
- Talk available at: <https://github.com/htjb/Talks>

