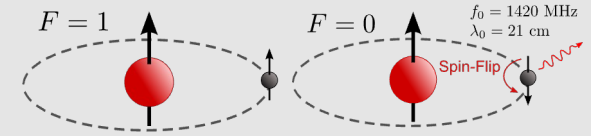# Joint analysis constraints on the physics of the first galaxies with low frequency radio astronomy data
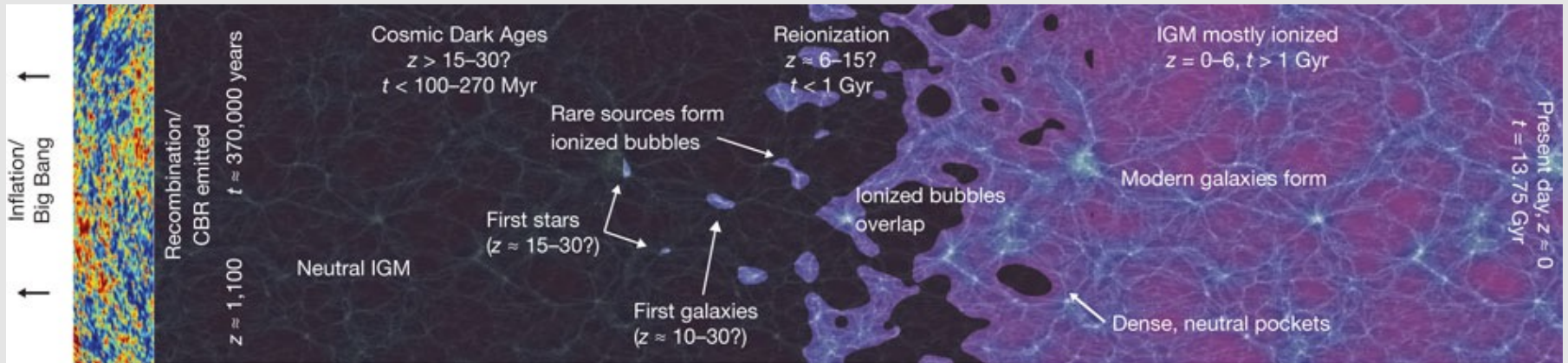
H.T.J. Bevins, S. Heimersheim, I. Abril-Cabezas et al.
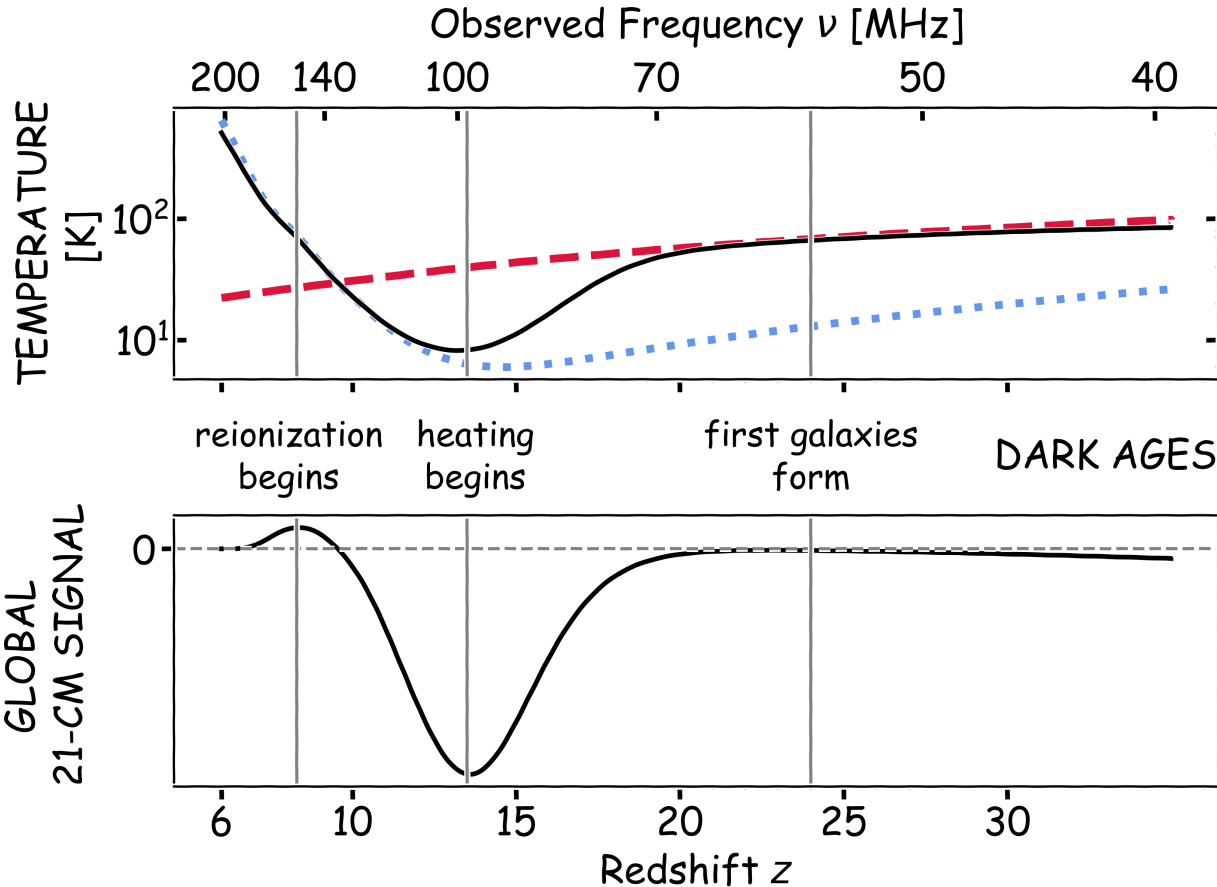arXiv: 2301.03298

First stars and galaxies

- How did the first stars formed?
- Astrophysics of the infant universe?

} 21-cm line

$F = 1$ $F = 0$ $f_0 = 1420$ MHz
$\lambda_0 = 21$ cm

Spin-Flip

Joint = SARAS3 + HERA experiments

Inflation/Big Bang

Recombination/CBR emitted $t \approx 370,000$ years

$z \approx 1,100$

Neutral IGM

Cosmic Dark Ages
$z > 15$–30?
$t < 100$–270 Myr

Rare sources form ionized bubbles

First stars
($z \approx 15$–30?)

First galaxies
($z \approx 10$–30?)

Reionization
$z \approx 6$–15?
$t < 1$ Gyr

Ionized bubbles overlap

IGM mostly ionized
$z = 0$–6, $t > 1$ Gyr

Modern galaxies form

Dense, neutral pockets

Present day, $z \approx 0$
$t = 13.75$ Gyr

Robertson+10

$\leftarrow x_{HI}(z) \rightarrow$

History of the 21-cm line

Observed Frequency ν [MHz]

TEMPERATURE [K]

T_γ

T_{gas}

T_S

reionization begins   heating begins   first galaxies form   DARK AGES

GLOBAL 21-CM SIGNAL

Redshift z

$$\propto x_{HI}\left(1 - \frac{T_\gamma}{T_S}\right)$$

3

Simulating the Signal

Semi-analytical approach
(e.g. Visbal+12; Fialkov+14,
Fialkov & Barkana 14, 19)

- Dark matter halo minimum circular velocity to form stars V_c

- Star formation efficiency f_*

- X-ray efficiency of sources f_X

- CMB optical depth τ

- Strength of radio background — contribution to T_γ
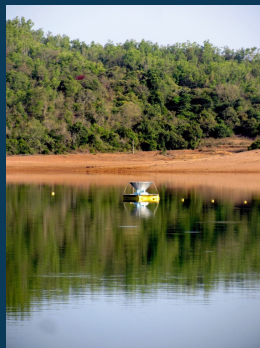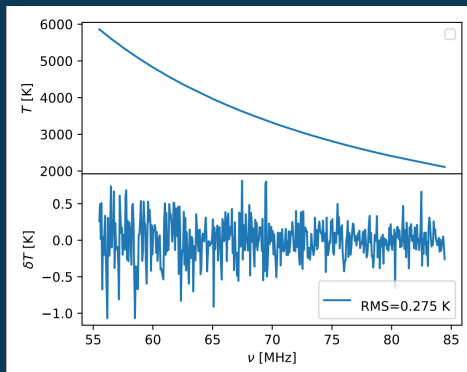 Radio background from galaxies (Reis+20)

4
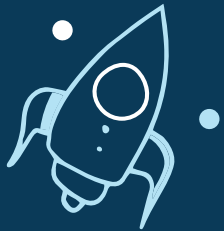
The 21-cm line

SARAS3 (India)
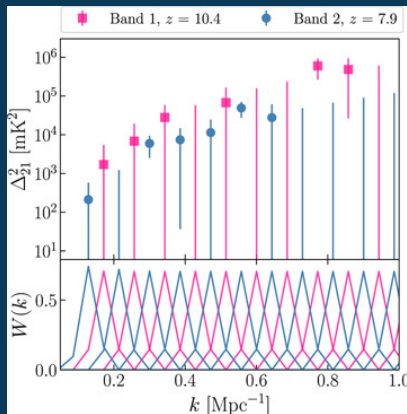z ~ 15-25

Credit: arXiv 2104.03522

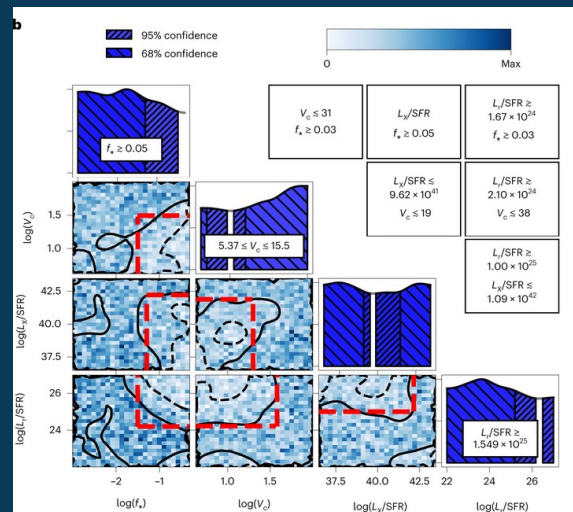Credit: H.T. Bevins

Bevins+ 22b

HERA (South Africa)
z = 8, 10

Credit: Kathryn Rosie
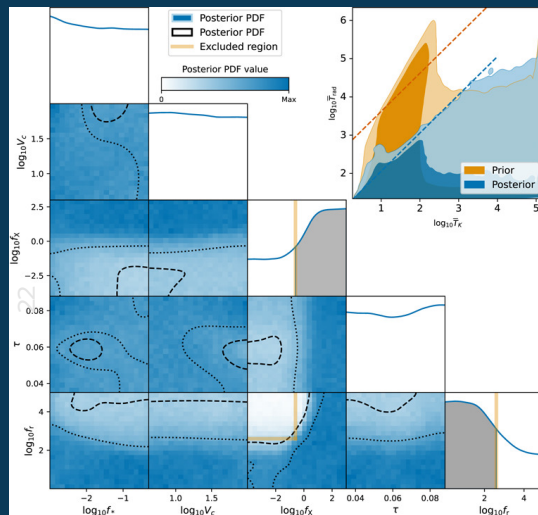

HERA Collaboration 22

HERA Collaboration 22

Parameter constraints from the joint analysis
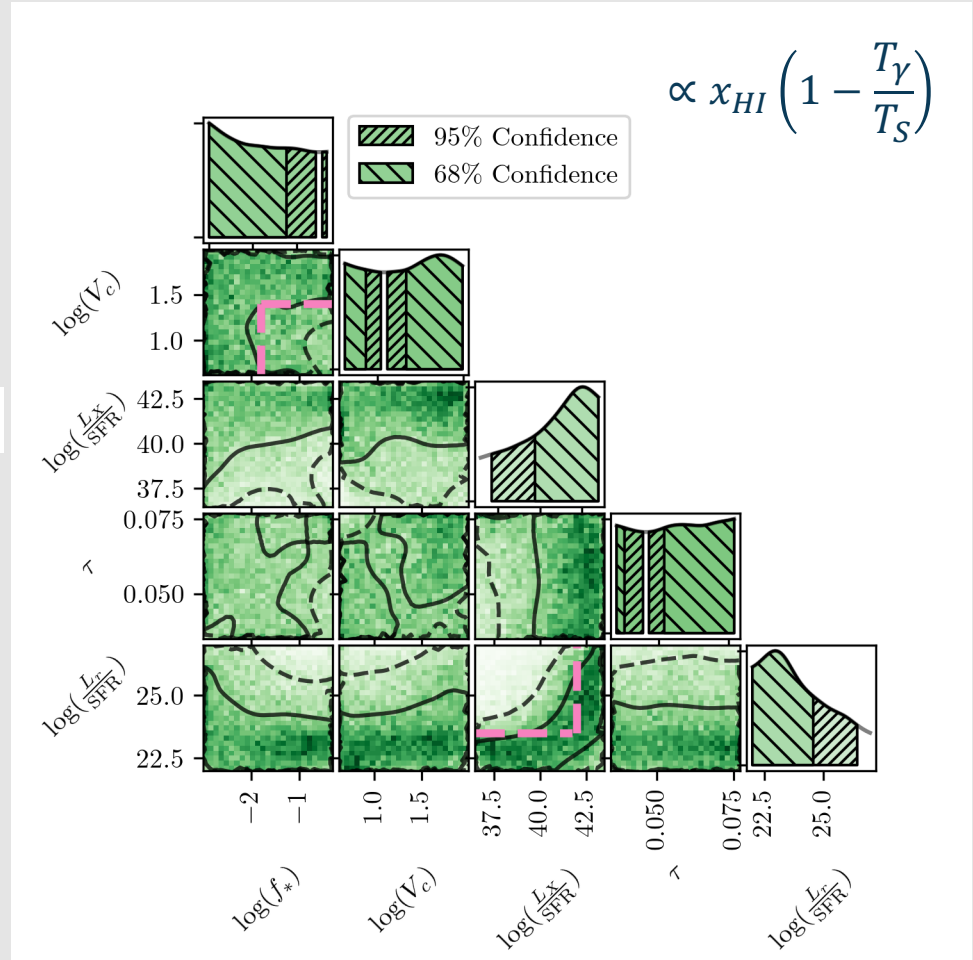
$$\mathcal{P}(\theta|D,\mathcal{M}) = \frac{\mathcal{L}(\theta)\pi(\theta)}{\mathcal{Z}},$$

$$\theta = \{\theta_I, \theta_{fg}, \theta_{21}\} \to \{\theta_{21}\} \to \text{MARGARINE} \to \log(\mathcal{P}(\theta_{21}|D,\mathcal{M}) \to \log(\mathcal{L}(\theta_{21})),$$
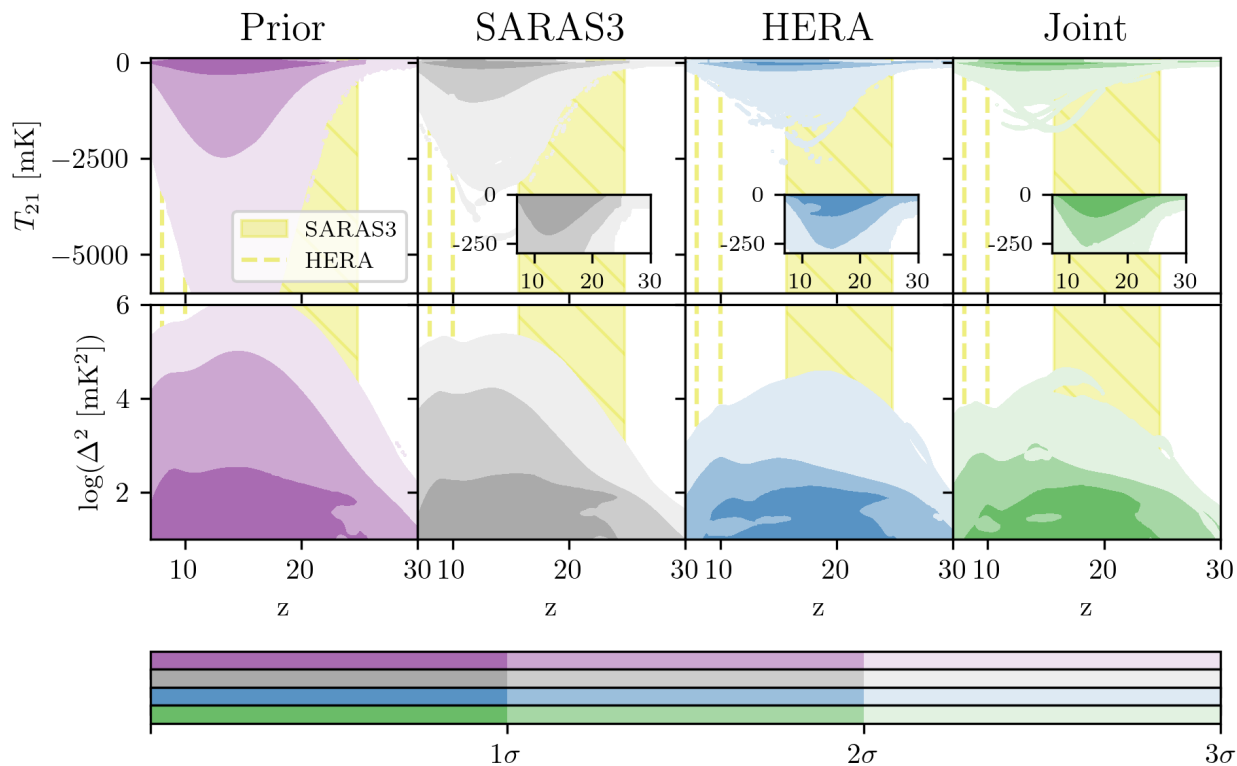
margarine (Bevins+22a)

$$\log(\mathcal{L}_{\text{joint}}(\theta_{21})) = \log(\mathcal{L}_{\text{HERA}}(\theta_{21})) + \log(\mathcal{L}_{\text{SARAS3}}(\theta_{21})),$$

Tightest constraints to date on the astrophysics of galaxies at Cosmic Dawn

$$\propto x_{HI}\left(1 - \frac{T_\gamma}{T_S}\right)$$

# Functional constraints on global and power spectrum signal

Theoretical parameter space reduction:
- Prior: 100%
- SARAS3: 92%
- HERA: 80%
- Joint: 65%

Posteriors calculated from representative samples using neural networks.

Key take-aways

- 21-cm: promising probe of the early universe

- First joint analysis between global signal data and interferometric limits

- margarine as novel methodology

- Emulators to derive functional constraints
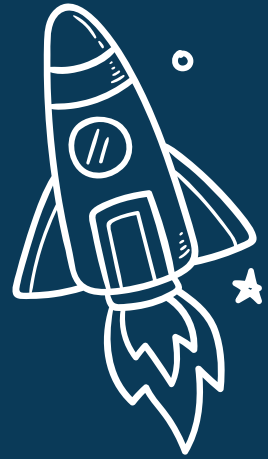
Goal: interpret the 21-cm signal and understand formation of first stars and galaxies