Epoch of Reionisation and the Cosmic Dawn

EoR/Cosmic Dawn SWG

Cathryn Trott

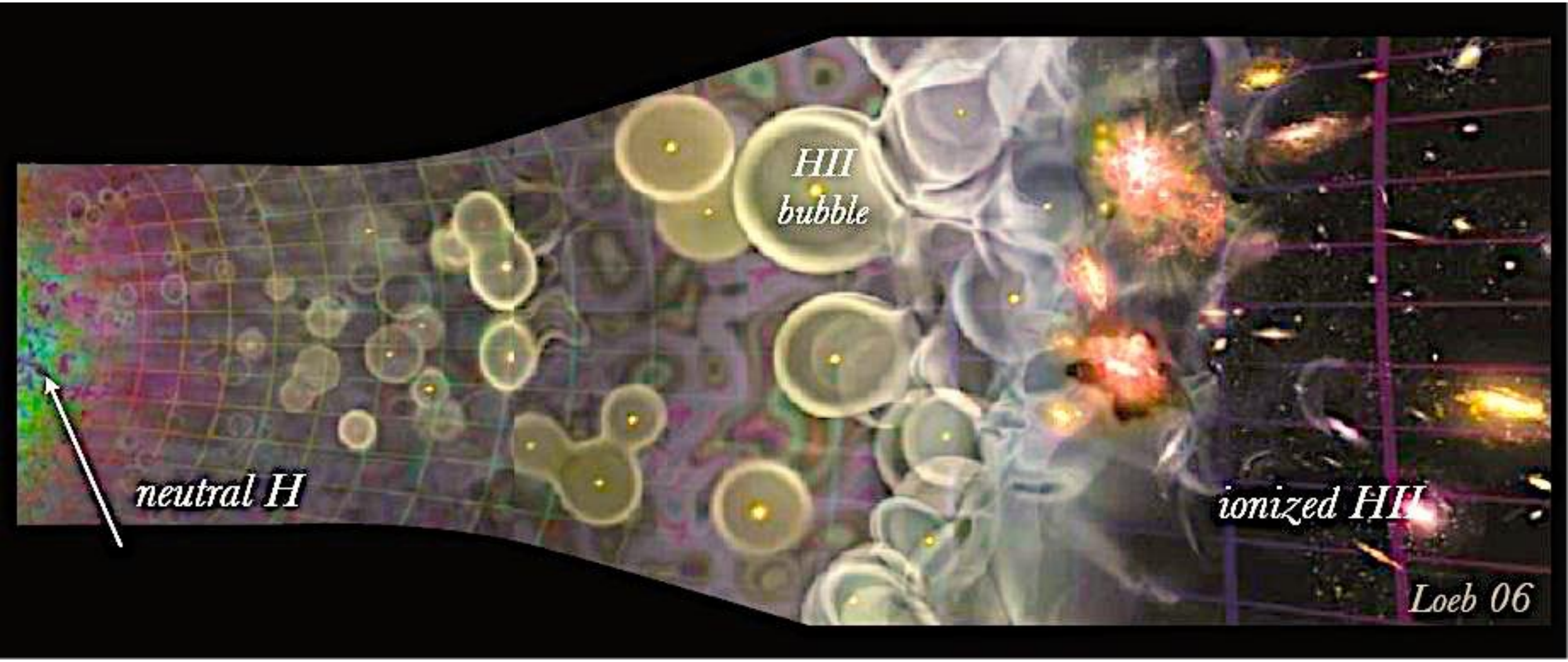
ICRAR
International Centre for Radio Astronomy Research

CAASTRO
ALL-SKY ASTROPHYSICS

Curtin University

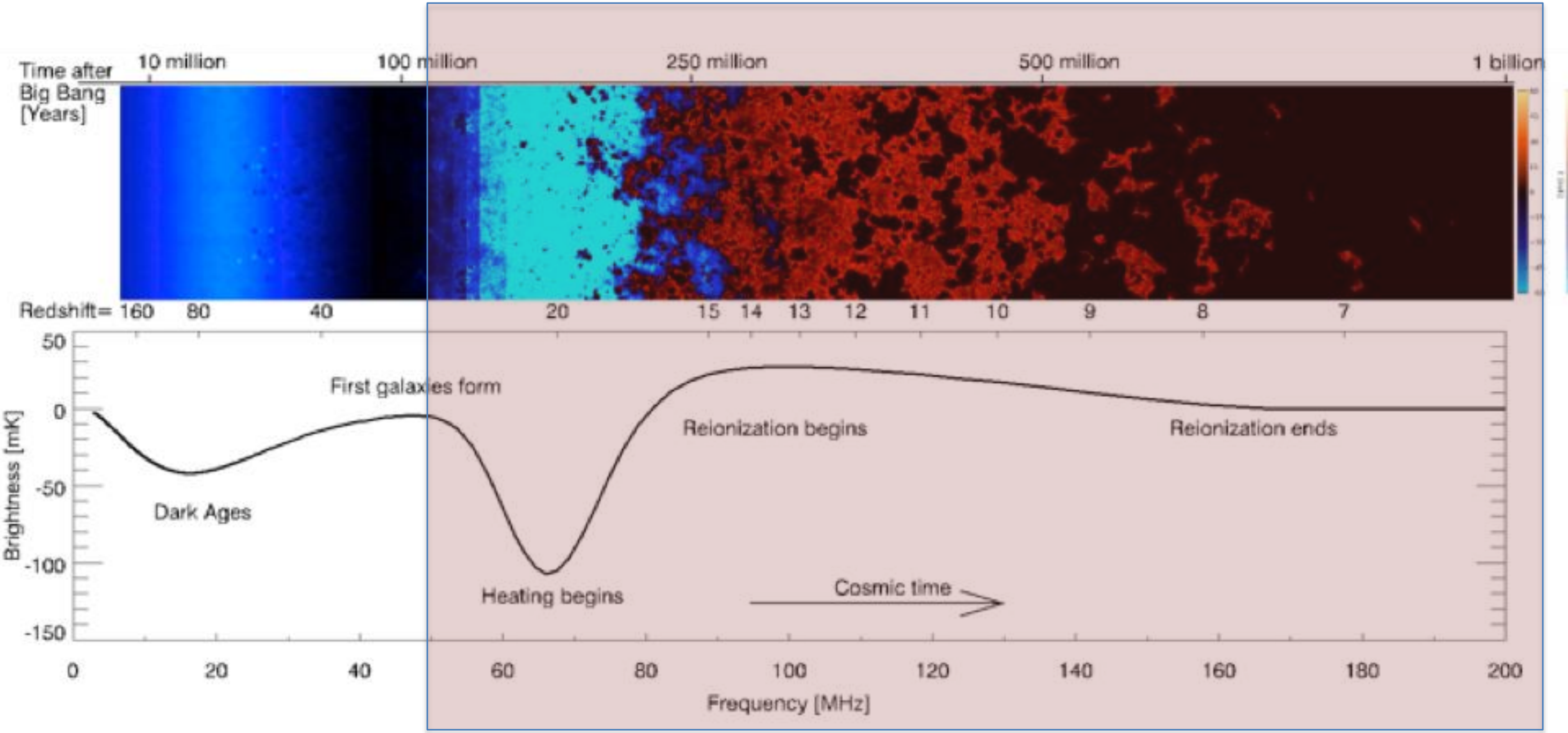
The University of Western Australia

EoR/CD: z=5.5-27 HI temperature fluctuations



Mapping the distribution of neutral hydrogen in the first billion years of the Universe

EoR/CD: z=5.5-27 HI temperature fluctuations



SKA-Low coverage

Temperature fluctuations encode astrophysics

$$T_b = 27 x_{\rm HI} \left(1 + \frac{4}{3}\delta_b\right) \left(\frac{\Omega_b h^2}{0.023}\right) \left(\frac{0.15}{\Omega_m h^2} \frac{1+z}{10}\right)^{1/2} \times \left(\frac{T_S - T_\gamma}{T_S}\right) \text{mK},$$

Ionisation fraction

Kinetic temperature

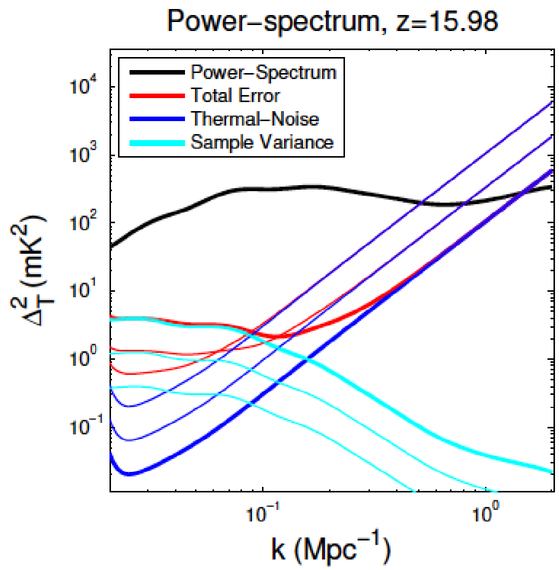
$$\delta_{T_b} = \beta_b \delta_b + \beta_x \delta_x + \beta_\alpha \delta_\alpha + \beta_T \delta_T - \delta_v ,$$

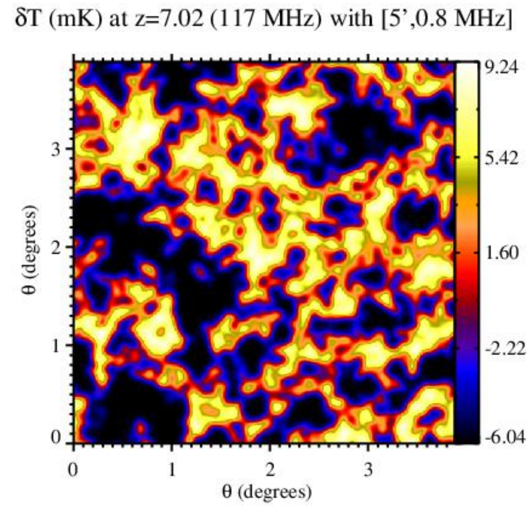
Matter density

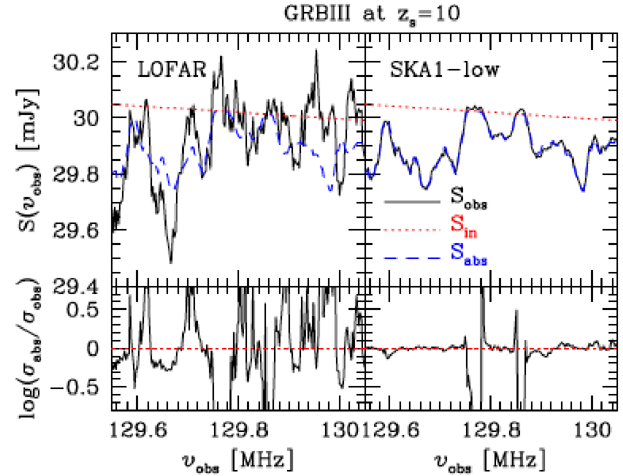
Photon coupling

Bulk gas motion

Three experiments: statistical, imaging, spectral line







Power spectrum; skewness; wavelet spectrum; PDF

Imaging in matched spectral bands, T_B

HI 21cm Forest: absorption against high-z sources (QSOs, GRBs)

Pathfinder instruments: LOFAR, MWA, PAPER, GMRT, LWA

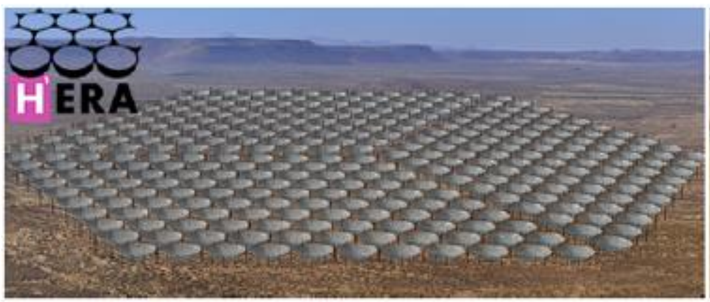
- Murchison Widefield Array (MWA; Australia)
- z = 6-10
- Resolution: 2 arcmin
- Array diameter ~3km
- Effective collecting area: 3,500 m^2

- Low-Frequency Array (LOFAR; Netherlands)
- z = 8-10.6
- Resolution: 4 arcsec
- Array diameter ~70km
- Effective collecting area: 18,000 m^2

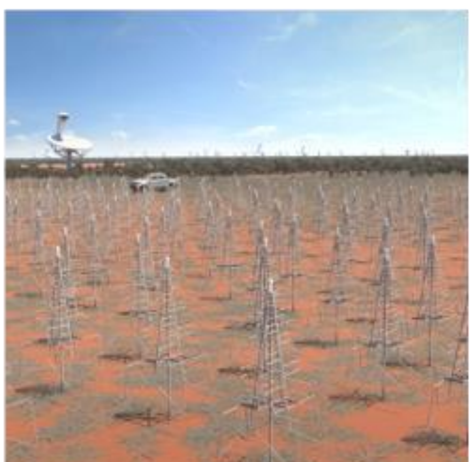
- Precision Array for Probing the Epoch of Reionisation (PAPER; USA, South Africa)
- z = 8-10.6
- Resolution: 30 arcmin
- Array diameter 200m
- Effective collecting area: 1,100 m^2

Future instruments: SKA, MWA++, HERA, LEDA

- Murchison Widefield Array Phase 2->3 (MWA; Australia)
- z = 6-11
- Resolution: 1 arcmin
- Array diameter ~5km
- Effective collecting area: 7,000 m^2

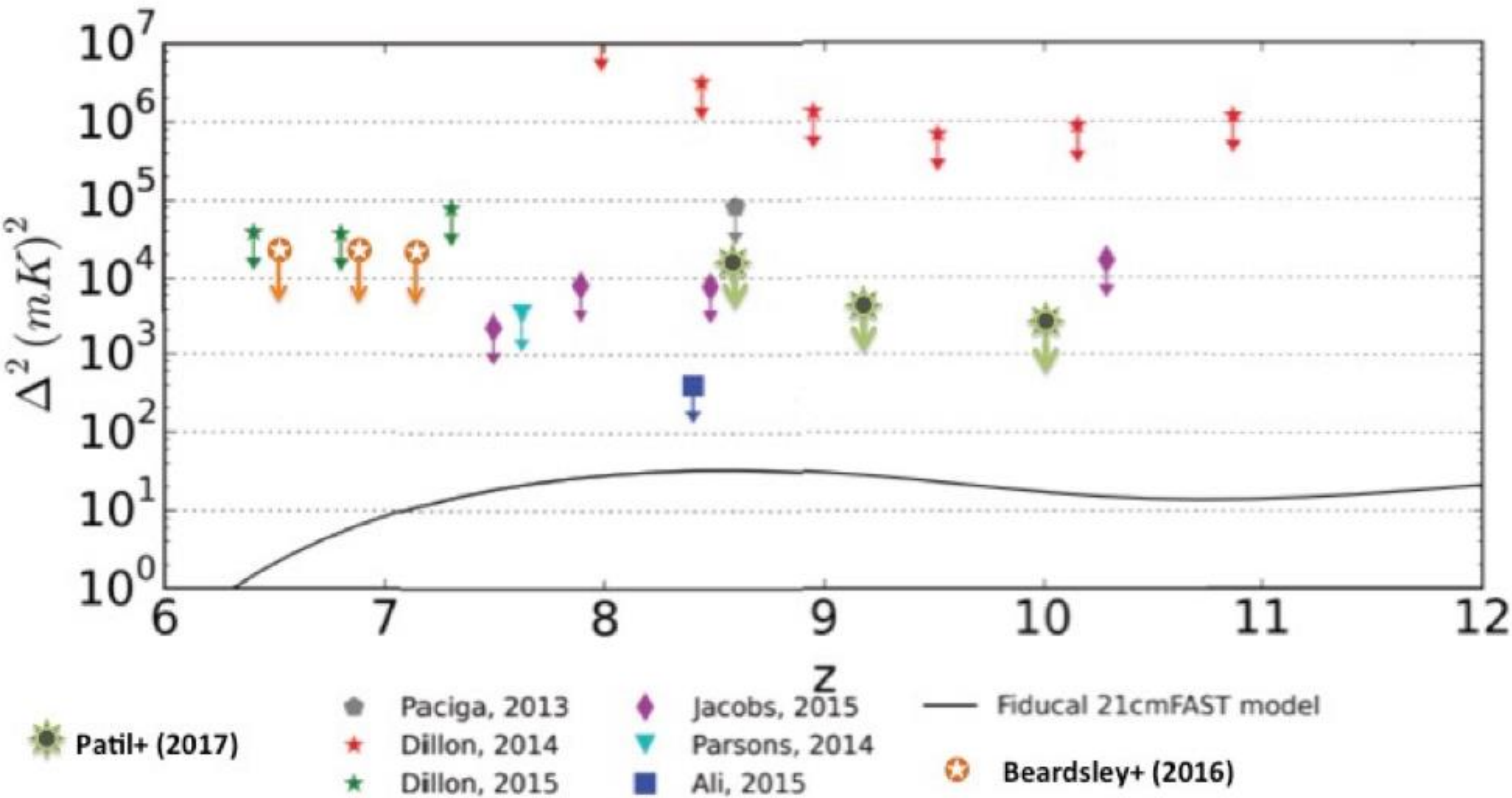


- Hydrogen Epoch of Reionisation Array (HERA; USA/South Africa)
- z = 6-13
- Resolution: 15 arcmin
- Array diameter 400m
- Effective collecting area: 53,000 m^2



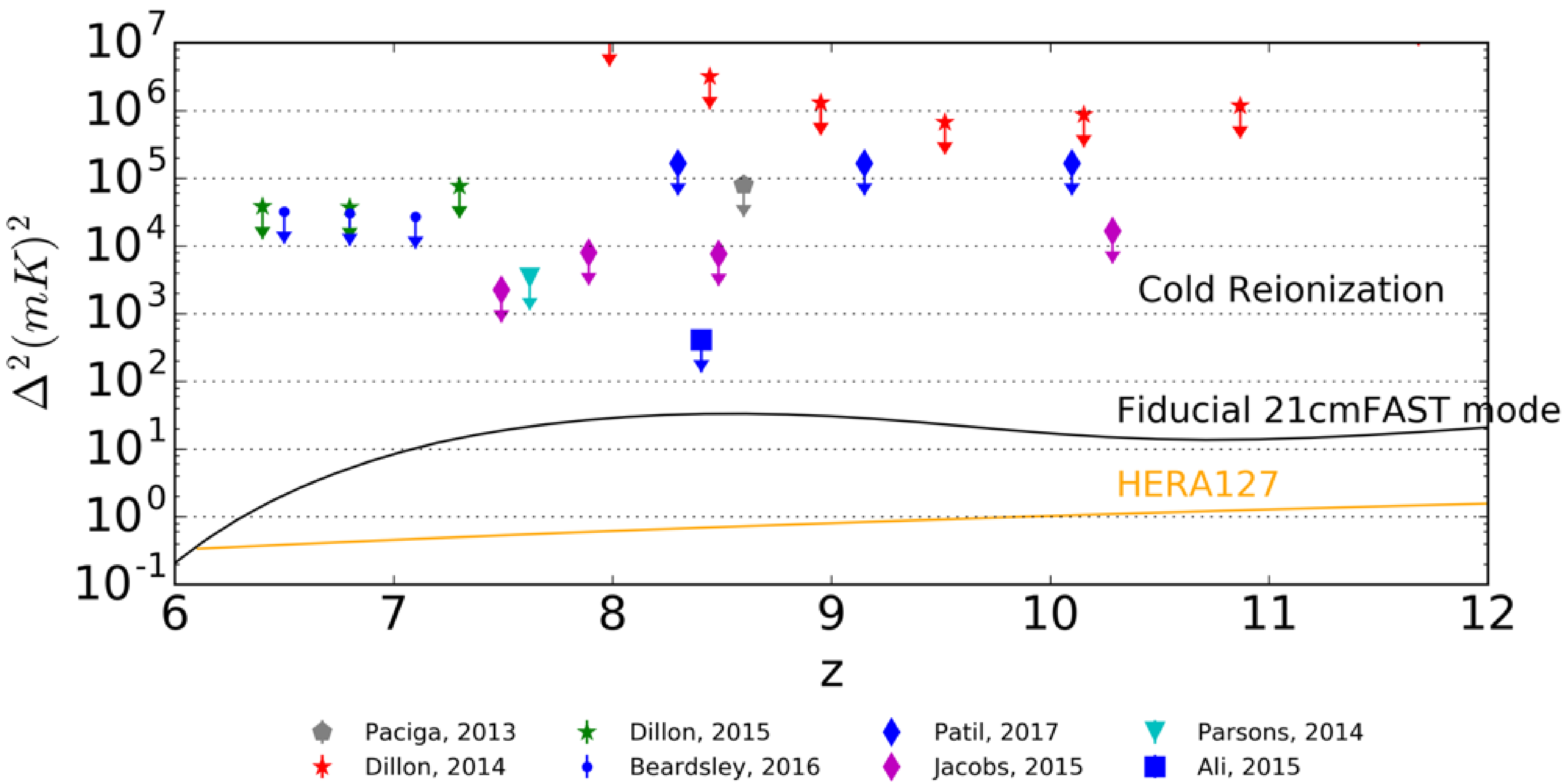
- Square Kilometre Array (SKA; Australia, international)
- z = 4-27
- Resolution: 3 arcsec
- Array diameter 50km
- Effective collecting area: 400,000 m^2

Current state of the field (any spatial wavemode)



Adapted from de Boer+ (2016)

Current state of the field (k=0.1 Mpc^{-1})

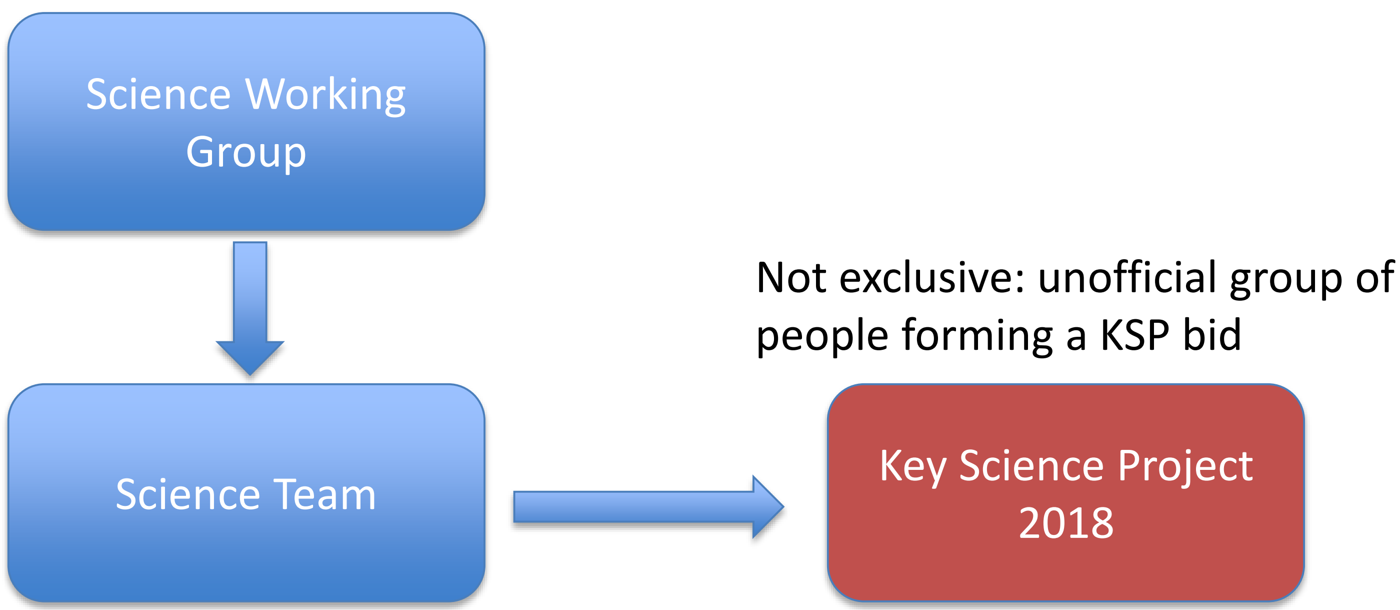


Courtesy Danny Jacobs

Science Working Group

Chair: Jonathan Pritchard (Imperial College London)

Board: Leon Koopmans (NL Representative)
Garrelt Mellema (SW Representative)
Gianni Bernardi (SA Representative)
Cath Trott (AU Representative)
Abhirup Datta (IN Representative)
Andrei Mesinger (IT Representative)
XXX XXX (CN Representative – TBD)



Science Team → KSP → E2E Simulations

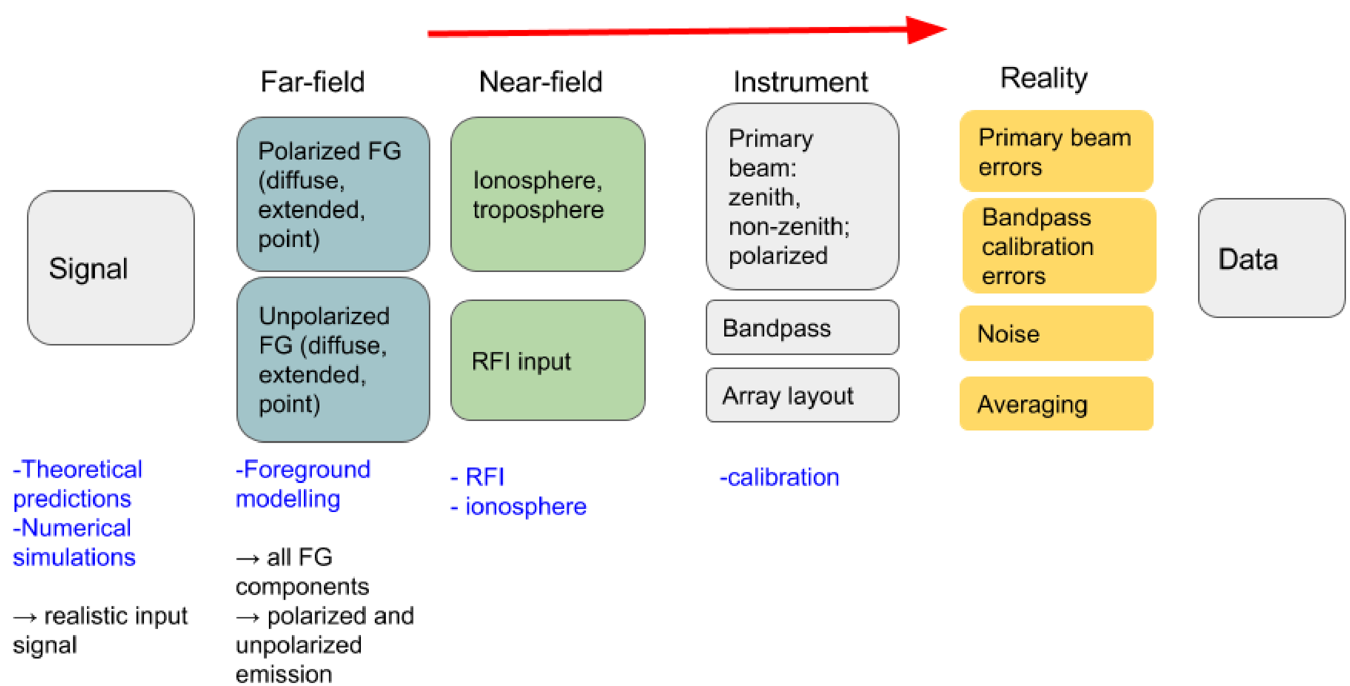
Lead: Leon Koopmans (Kapteyn Institute)

Science Working Group

Australian members:

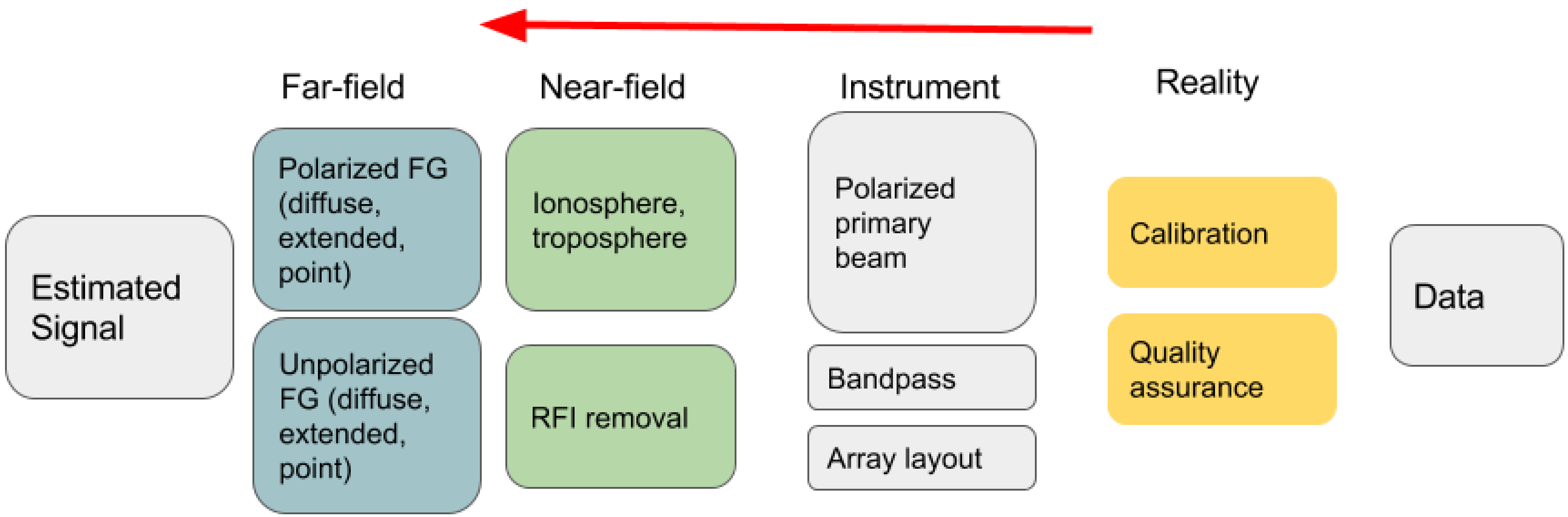
Cath Trott, Stu Wyithe, Rachel Webster, Bart Pindor, Daniel Mitchell, Ben McKinley, Chris Jordan, Randall Wayth, Steven Murray, Katie Mack

Input Components



Science Team → KSP → E2E Simulations

Extraction Components



-Signal extraction
-Signal interpretation

→ parameter estimation

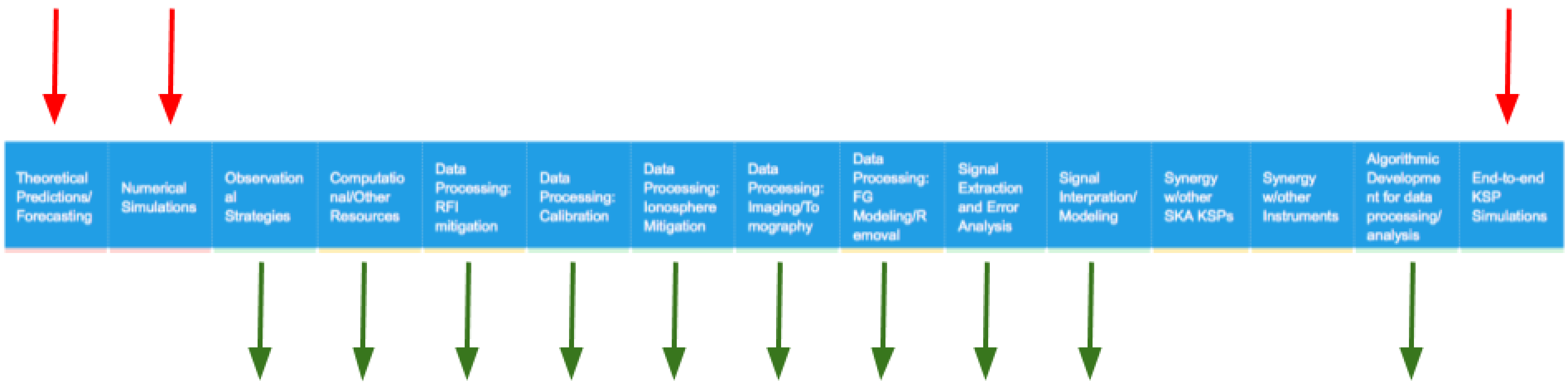
-Foreground removal/treatment

-RFI
- ionosphere

-calibration and imaging

Science Team → KSP → Focus Groups

Umbrella task - Input + Extraction



Key questions:

- how do we link these individual FG/tasks together to get a truly realistic end-to-end simulated dataset?
- how much do we create ourselves? How much can we rely on existing tools (e.g., 21cmFAST+OSKAR+existing PS estimator)
- how complicated a model can be discriminated?

KSP Focus Groups

A) Theory/Numerical Simulations

A1: Theory/Physics for understanding model space/subgrid physics

A2: Full numerical simulations for calibration

A3: Fast simulations for analysis

A4: Foreground Studies and simulations

B) Observational Strategies

B1: Interferometric

B2: Global Signal

B3: 21cm Forest

C) Data Processing

C1: RFI Excision

C2: Calibration/Ionosphere

C3: Imaging/Sky-model building

C4: Foreground Fitting/Removal

C5: New Algorithmic Development/Computational and Other Resources

D) Signal Extraction and Error Analysis

E) Signal Analysis and Interpretation

F) Synergy (SKA + Other instruments)

G) End-to-End (Data) Simulations

KSP Focus Groups

A) Theory/Numerical Simulations

A1: Theory/Physics for understanding model space/subgrid physics

A2: Full numerical simulations for calibration

A3: Fast simulations for analysis

A4: Foreground Studies and simulations

B) Observational Strategies

B1: Interferometric

B2: Global Signal

Australian-led

B3: 21cm Forest

C) Data Processing

C1: RFI Excision

C2: Calibration/Ionosphere

C3: Imaging/Sky-model building

C4: Foreground Fitting/Removal

C5: New Algorithmic Development/Computational and Other Resources

D) Signal Extraction and Error Analysis

E) Signal Analysis and Interpretation

F) Synergy (SKA + Other instruments)

G) End-to-End (Data) Simulations

KSP Focus Groups

A) Theory/Numerical Simulations

A1: Theory/Physics for understanding model space/subgrid physics

A2: Full numerical simulations for calibration

A3: Fast simulations for analysis

A4: Foreground Studies and simulations

B) Observational Strategies

B1: Interferometric

B2: Global Signal

Australian-involvement

B3: 21cm Forest

C) Data Processing

C1: RFI Excision

C2: Calibration/Ionosphere

C3: Imaging/Sky-model building

C4: Foreground Fitting/Removal

C5: New Algorithmic Development/Computational and Other Resources

D) Signal Extraction and Error Analysis

E) Signal Analysis and Interpretation

F) Synergy (SKA + Other instruments)

G) End-to-End (Data) Simulations

Science Team meetings

Stockholm, SW – August 2015

Groningen, NL – October 2015

Goa, IN – November 2016

Pisa, IT – March 2017

Zagreb, CR – October 2017

EoR/CD suite of experiments – stations (BD)

Power Spectrum ↑↓

Tomography ↑↓

HI absorption ↑↓

Shallow
2 beams

10,000 sq. deg = 4 sr; b>30 degrees; BW = 50-250 MHz
10 hours/field; drift scan; Δt = 5-10s; Δν = 5 kHz (averaged to 40-100kHz)
2,500 hours

Medium
2 beams

1,000 sq. deg; **b>20** degrees; **BW = 50-350 MHz**
100 hours/field; pointed; Δt = 5-10s; Δν = 5 kHz (40-100kHz)
2,500 hours

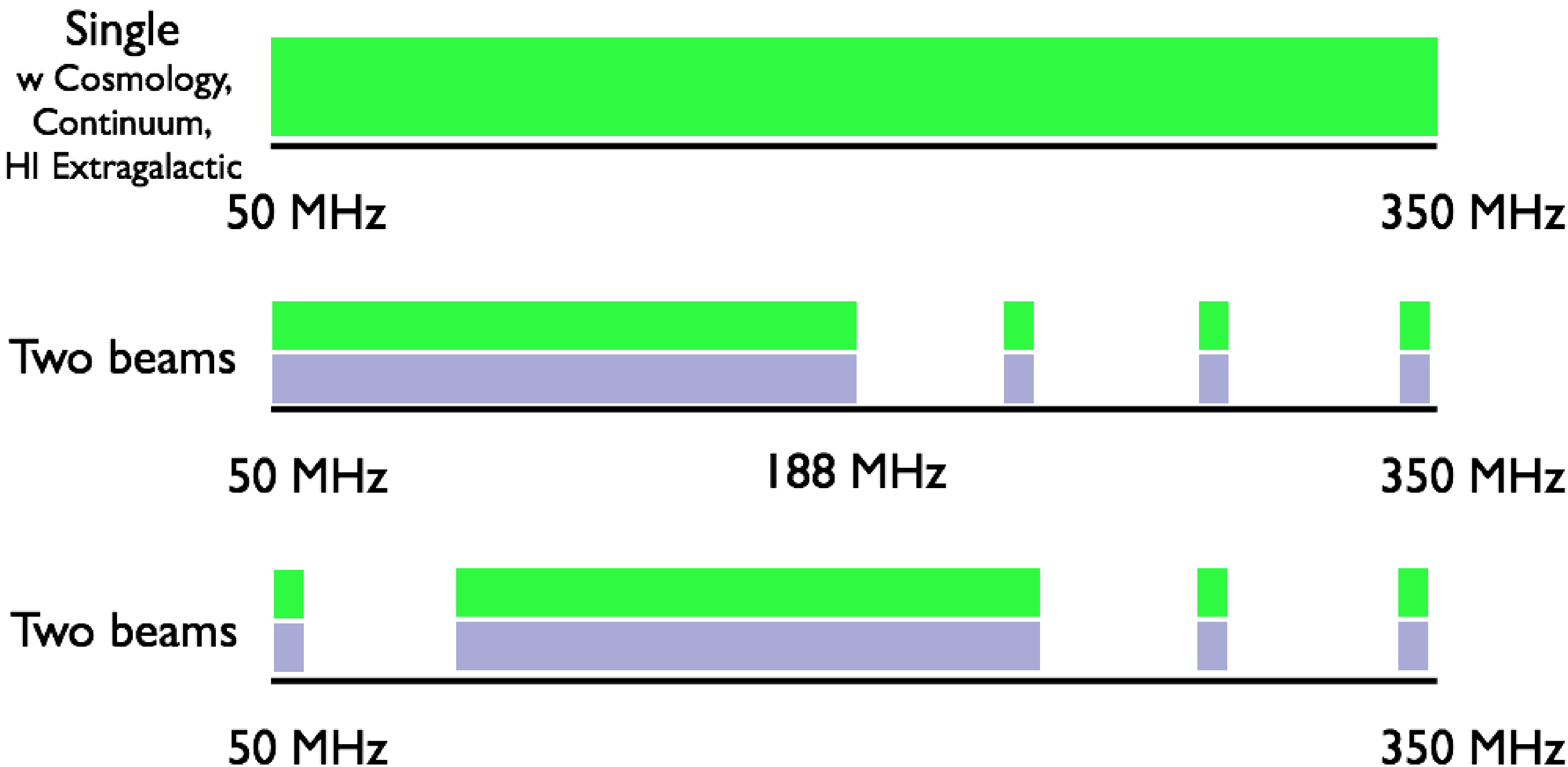
Deep

100 sq. deg; b>30 degrees; BW = 50-250 MHz
1000 hours/field; pointed; Δt = 5-10s; Δν = 5 kHz (40-100kHz) **2,500 hours**

HI Forest: absorption line; targetted toward high-z continuum AGN
1000 hours**; Δν = 1 kHz; **50-350 MHz**

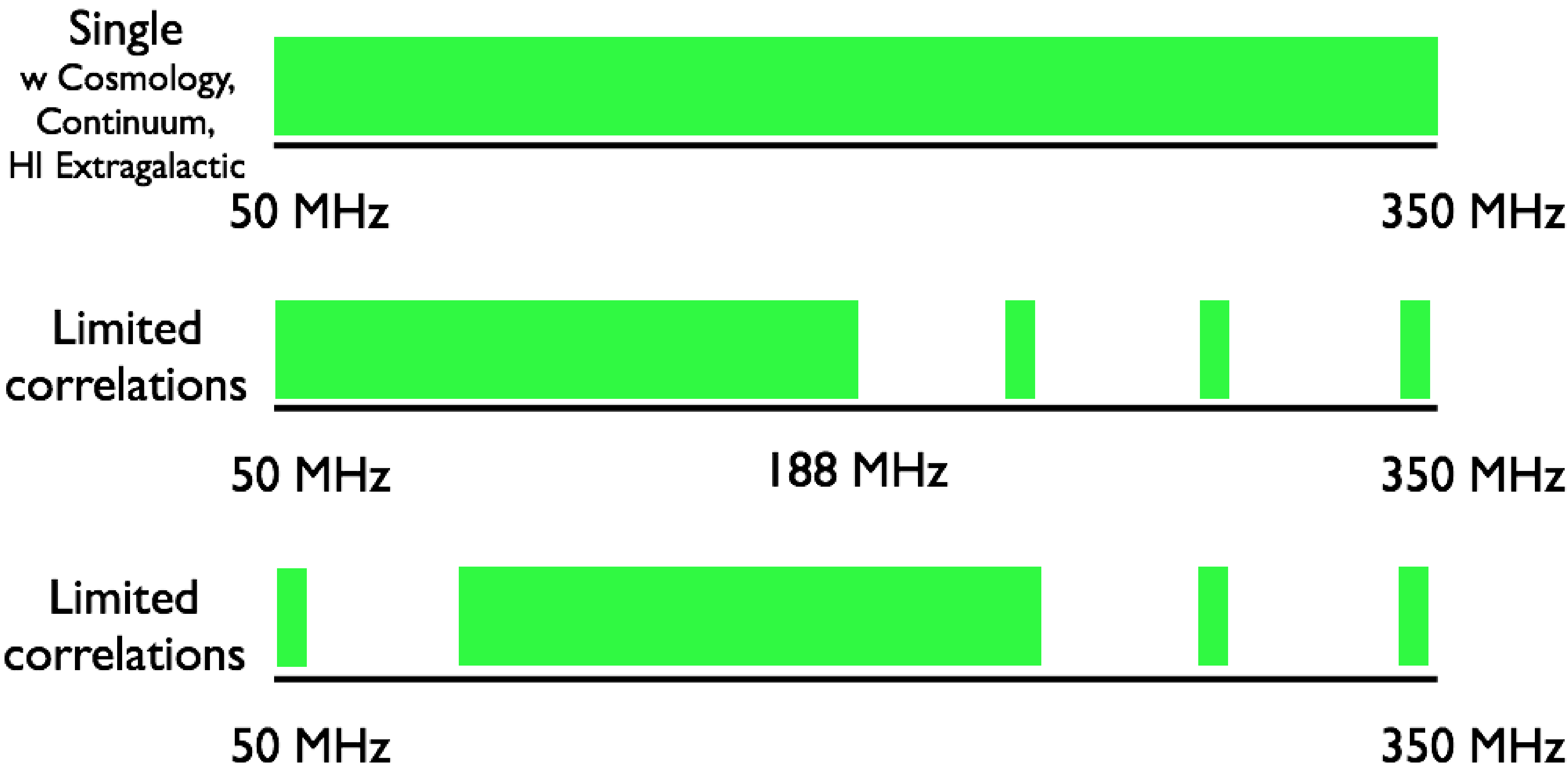
EoR/CD frequency coverage – standard

Flexibility in assigning correlator



EoR/CD frequency coverage - flexible

Flexibility in assigning correlator



Reducing bandwidth can offset reduction in sensitivity for substations if correlator capacity is limited

Summary

The EoR/CD Science Working Group is very active, collaborative and productive

In the absence of firm Key Science Program plans, the Science Team are developing a non-exclusive proposal for the five-year EoR/CD experiments

Commensality with EoR/CD for sky surveys and transients will yield a high return on investment for telescope use time

Development of the KSP has led to improved and productive collaboration between existing EoR instrument teams (in particular LOFAR and MWA).