PRECISION ARRAY TO PROBE THE EPOCH OF REIONIZATION

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Our experiment is working toward a power spectrum detection of the redshifted 21cm hydrogen line from brightness temperature structures produced by the first stars. Using a dipole array we will:

(a) image the sky at many frequencies averaging over many months to achieve mK sensitivity,

(b) difference image in angle and in frequency (red shift or time),

(c) form a statistical summary to find signal.

EXPERIMENT CHALLENGES

- ***Challenge 1***: foreground radiation from cosmic ray electrons in the galactic magnetic field and point sources across the Universe is at least 20,000 times stronger than signal: 200 K vs 10 mK.
- ***Challenge 2***: analysis requires imaging full hemisphere and averaging results for months.
- ***Challenge 3***: human-generated interference requires running experiment at remote site.

APPROACH

Experiment, not a multi-use facility: design strictly for goal of detection of high redshift 21cm line of hydrogen.

Aperture synthesis principle: sample many *x-y* correlations of signals over plane; invert to form image of hemisphere above; average as sky drifts by.

"Precision" Dipole Array: design, develop, field test, feedback to next generation..quickly.

"Analog" path design/development in Bradley lab at NRAO.

"Digital" path design/development at Berkeley in CASPER/RAL.

Analysis led by Berkeley group, but growing involvement of others.

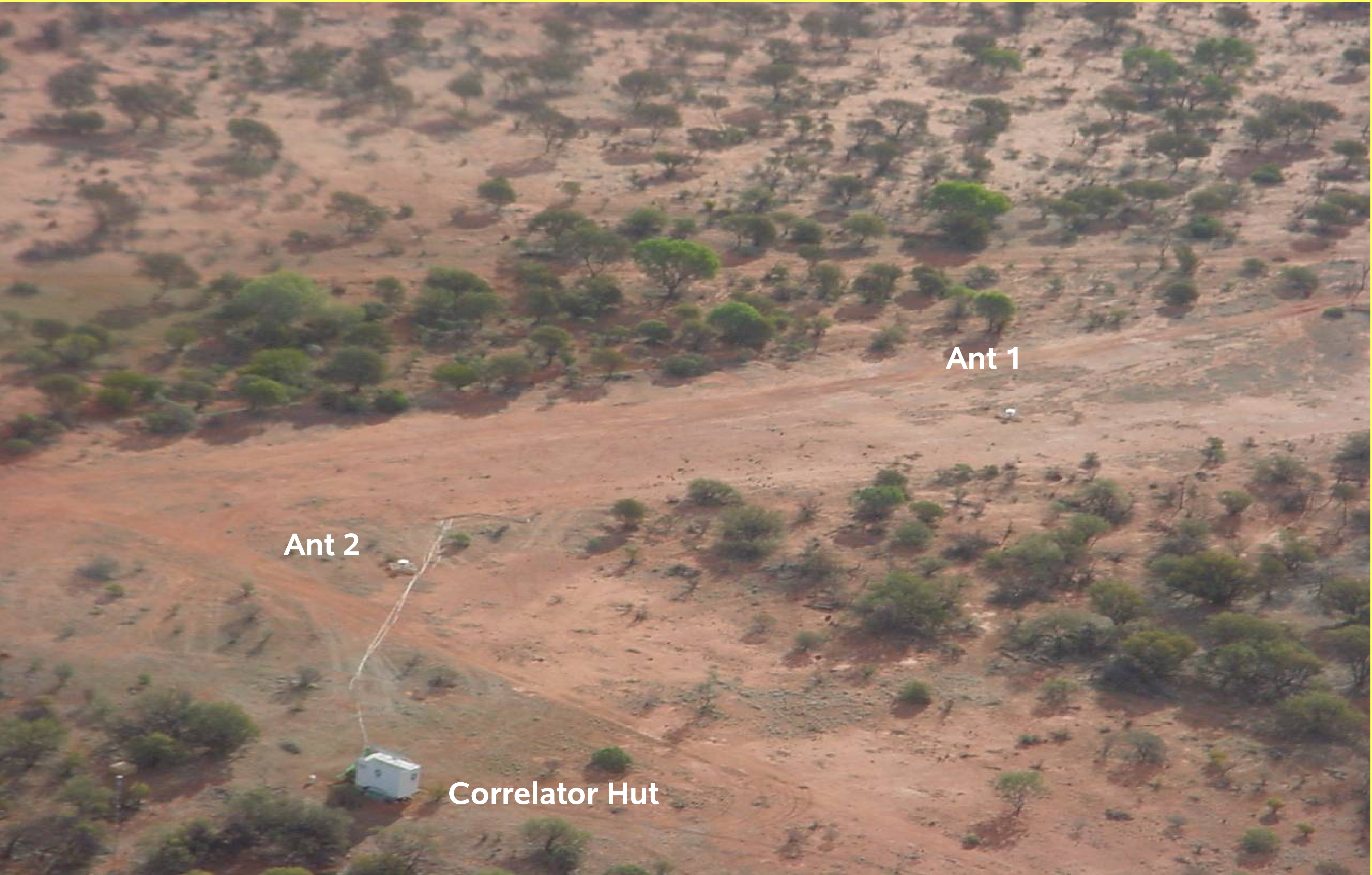
PAPER PROGRESS

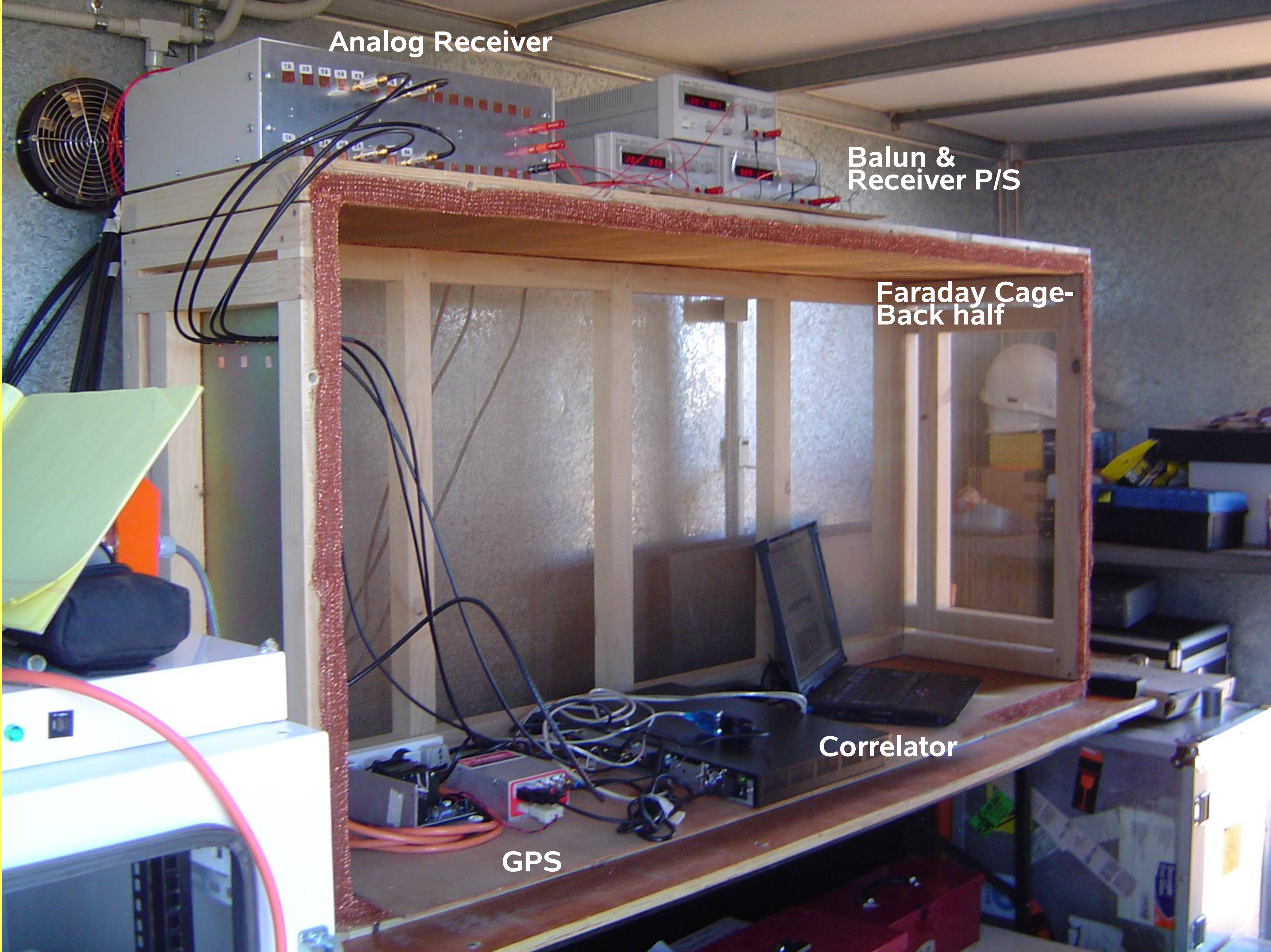
"in field", not "on paper"

- Start in *2004*
- NSF funding: (1) *2005-2006* correlator development grant; (2) *2006-2008* experiment "starter" grant, including WA deployment; (3) *other funding* via parallel projects (CASPER, FASR) and Carilli MPG award; (4) new *2008-2011* NSF grant.
- PAPER in Green Bank: **PGB**. This has evolved from 2-antenna interferometer in 2004 August to 8-antenna array in 2006; 16-antenna array 2008 May; also, single-antenna test facility.
- PAPER in Western Australia: **PWA**. 4-dipole array deployed: 2007 July.
- PGB 8-antenna 2008 March with revised design.

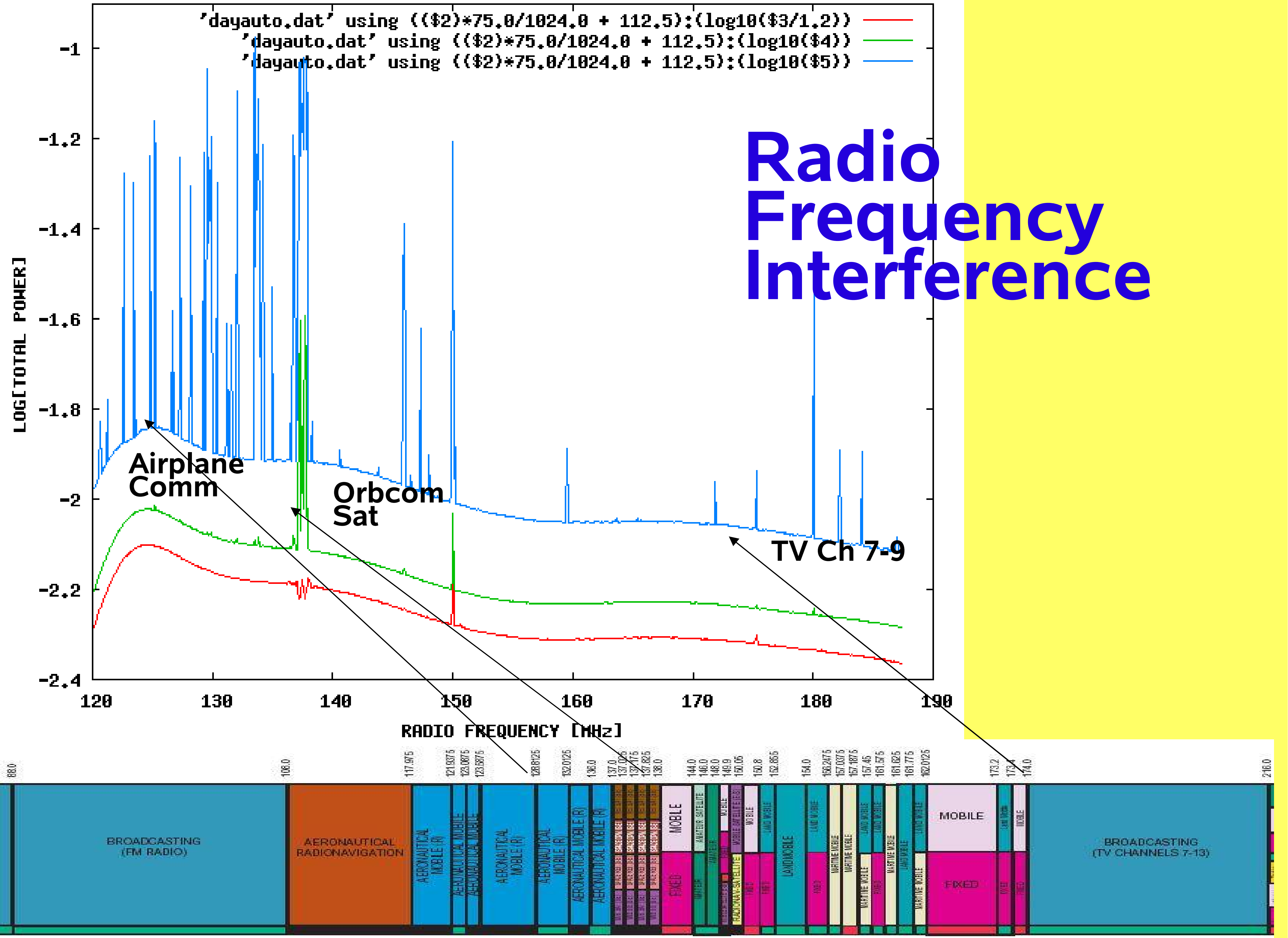

John Richards-lease holder;
Ron Beresford, CSIRO; DB

PWA-4 —Top Shed, Boolardy Station



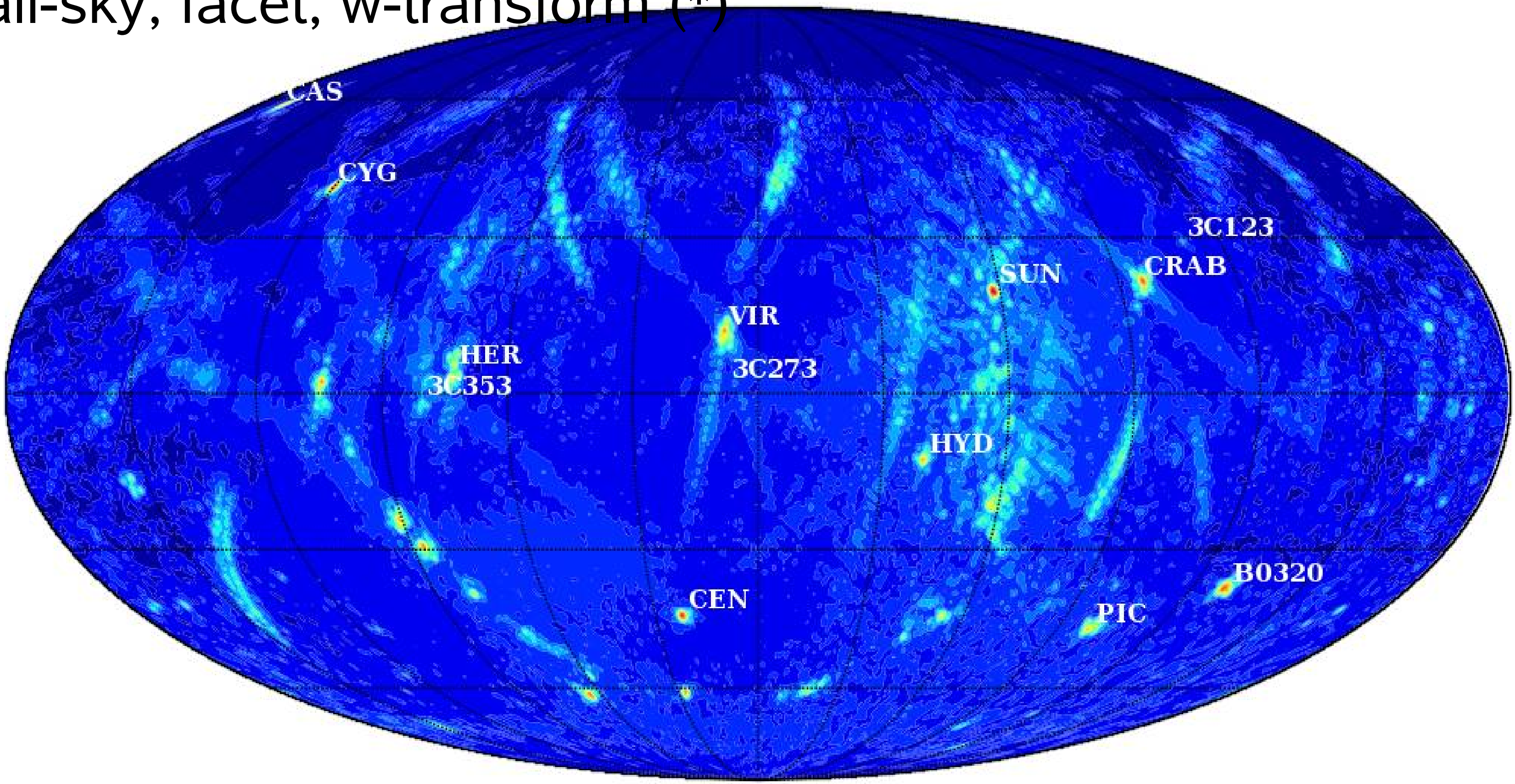

Analog Receiver
Balun &
Receiver P/S
Faraday Cage-
Back half
Correlator
GPS

Radio Frequency Interference



PAPER in Western Australia—2007 July

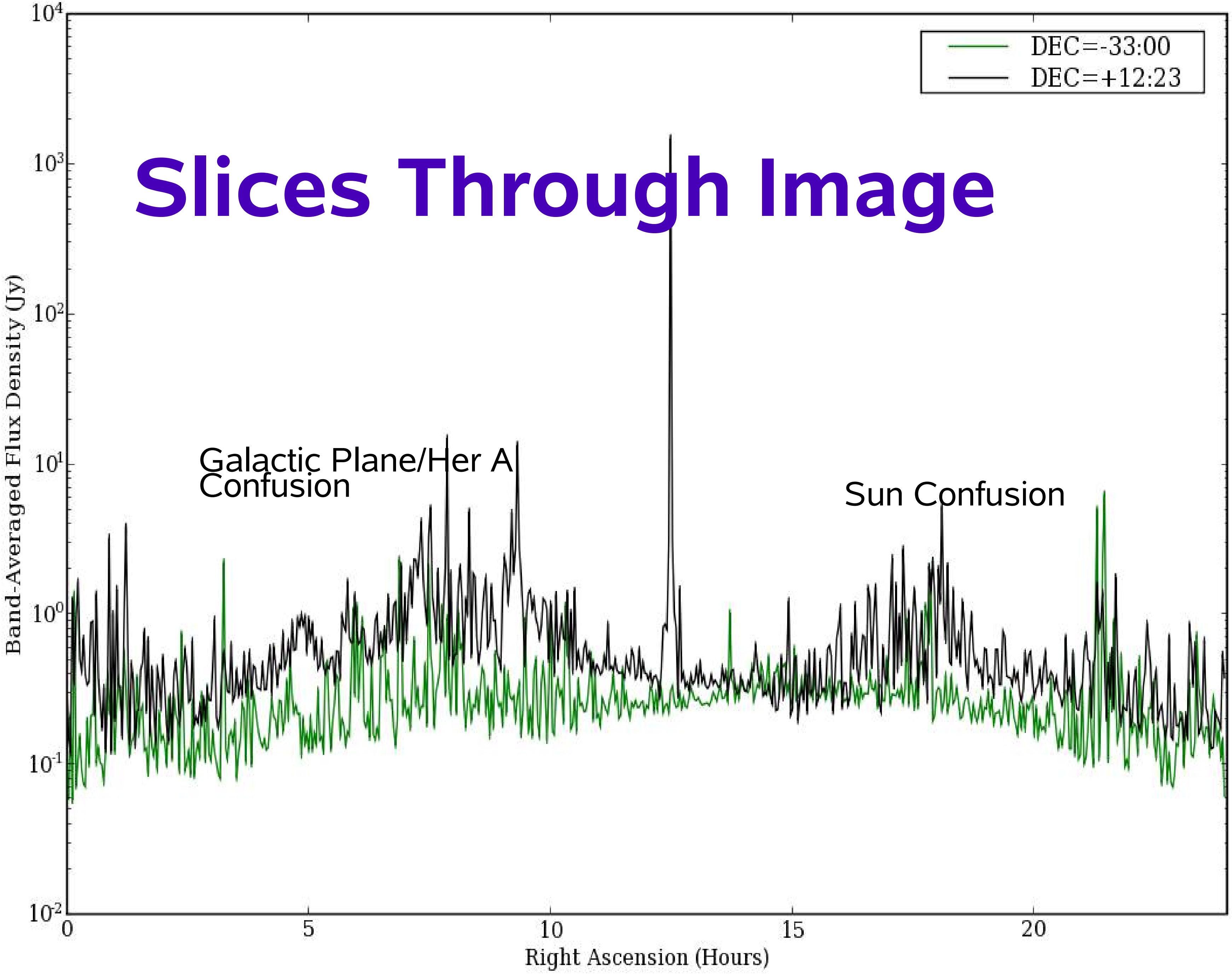
125-190 MHz
4 Dipole
24 hour integration
MFS, all-sky, facet, w-transform (*)



RMS away from strong sources: ~1 Jy/~1 K

(*) AIPY – Astronomical Imaging in Python – Aaron Parsons

Slices Through Image



PRECISION ARRAY TO PROBE EPOCH OF REIONIZATION

GALFORD MEADOW -- NRAO: GREEN BANK, WV

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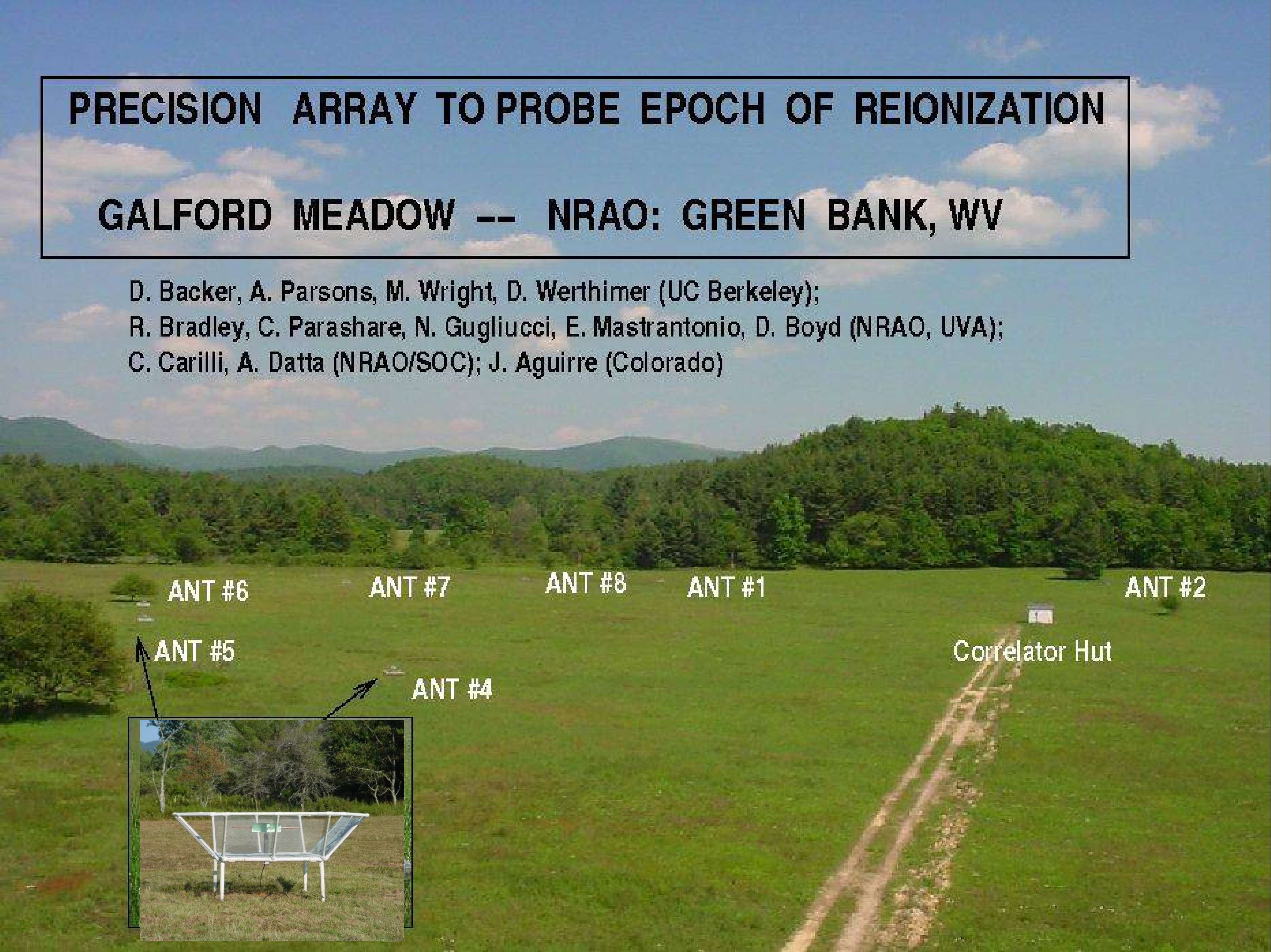
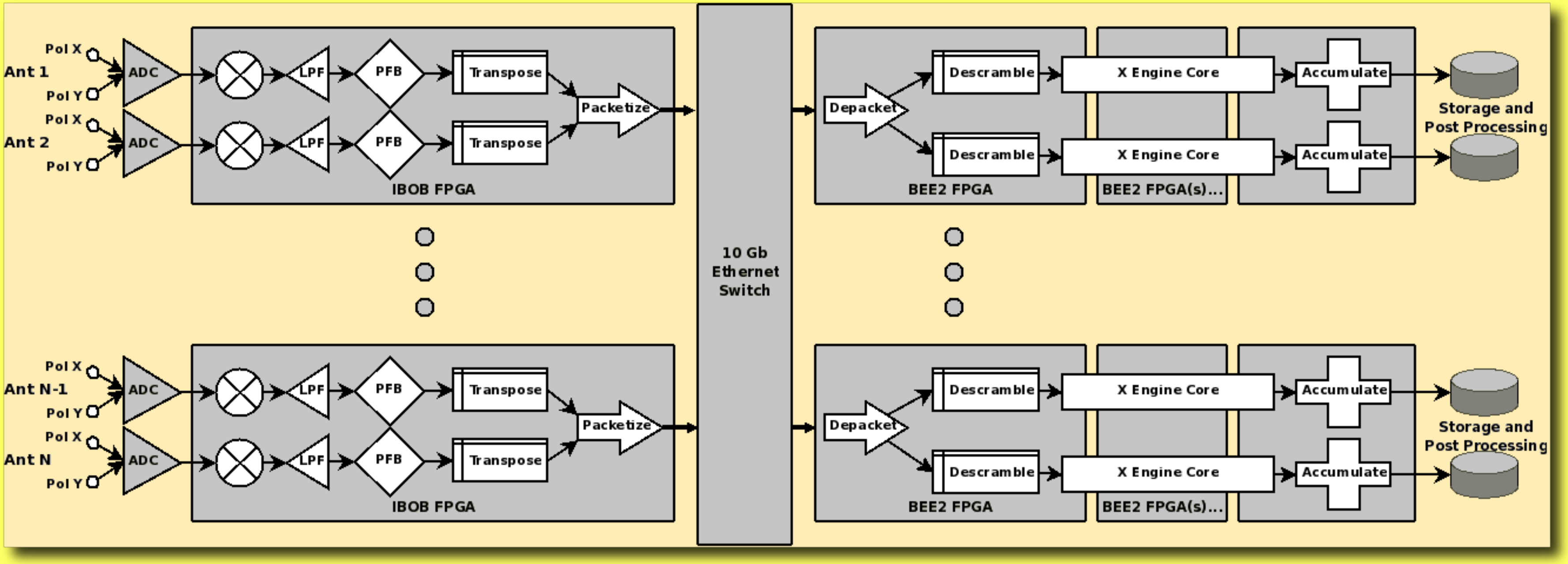
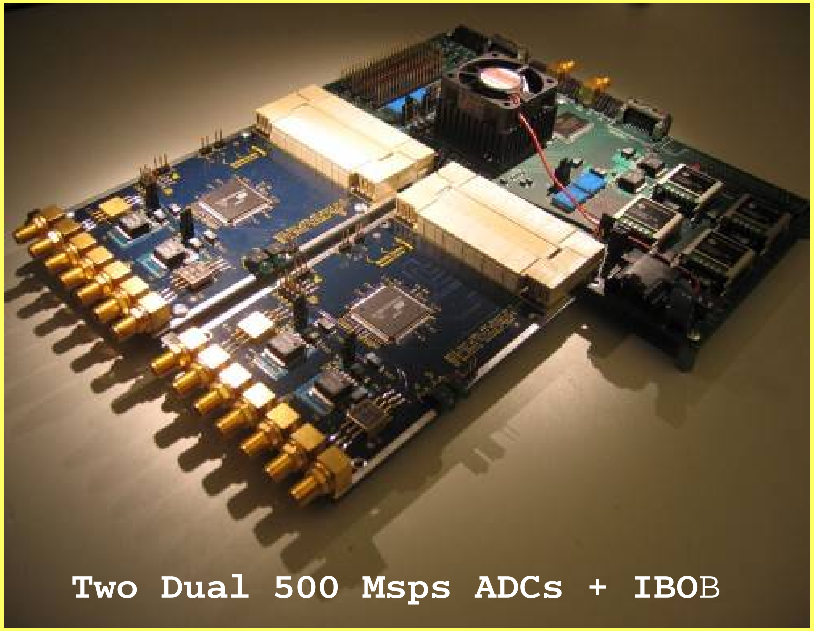
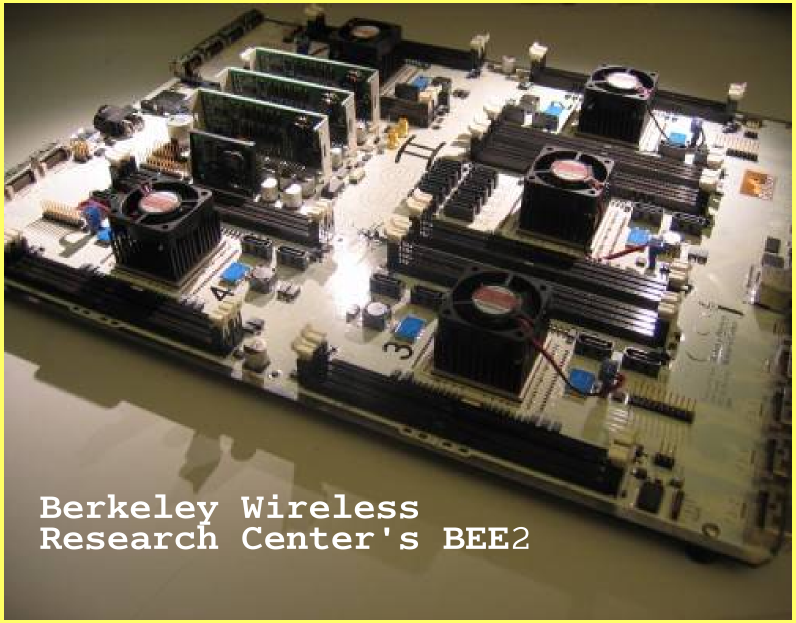
R. Bradley, C. Parashare, N. Gugliucci, E. Mastrantonio, D. Boyd (NRAO, UVA);
C. Carilli, A. Datta (NRAO/SOC); J. Aguirre (Colorado)



PAPER/CASPER Packetized Correlator

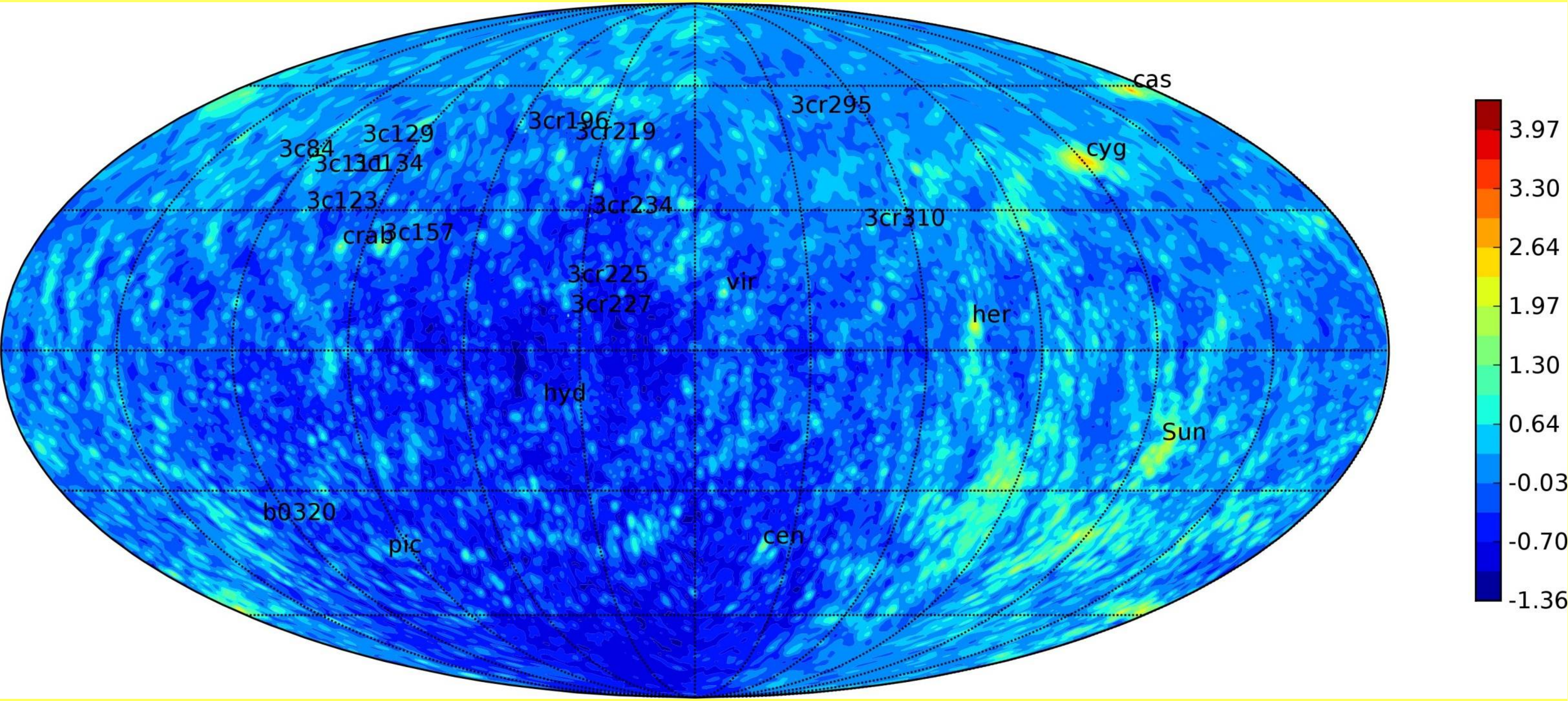




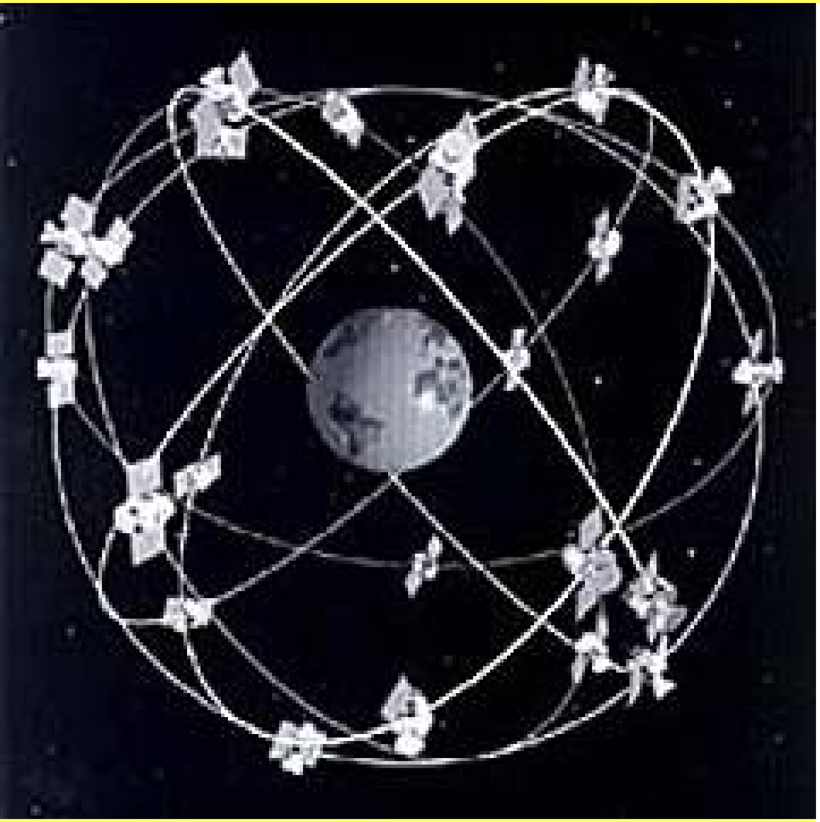


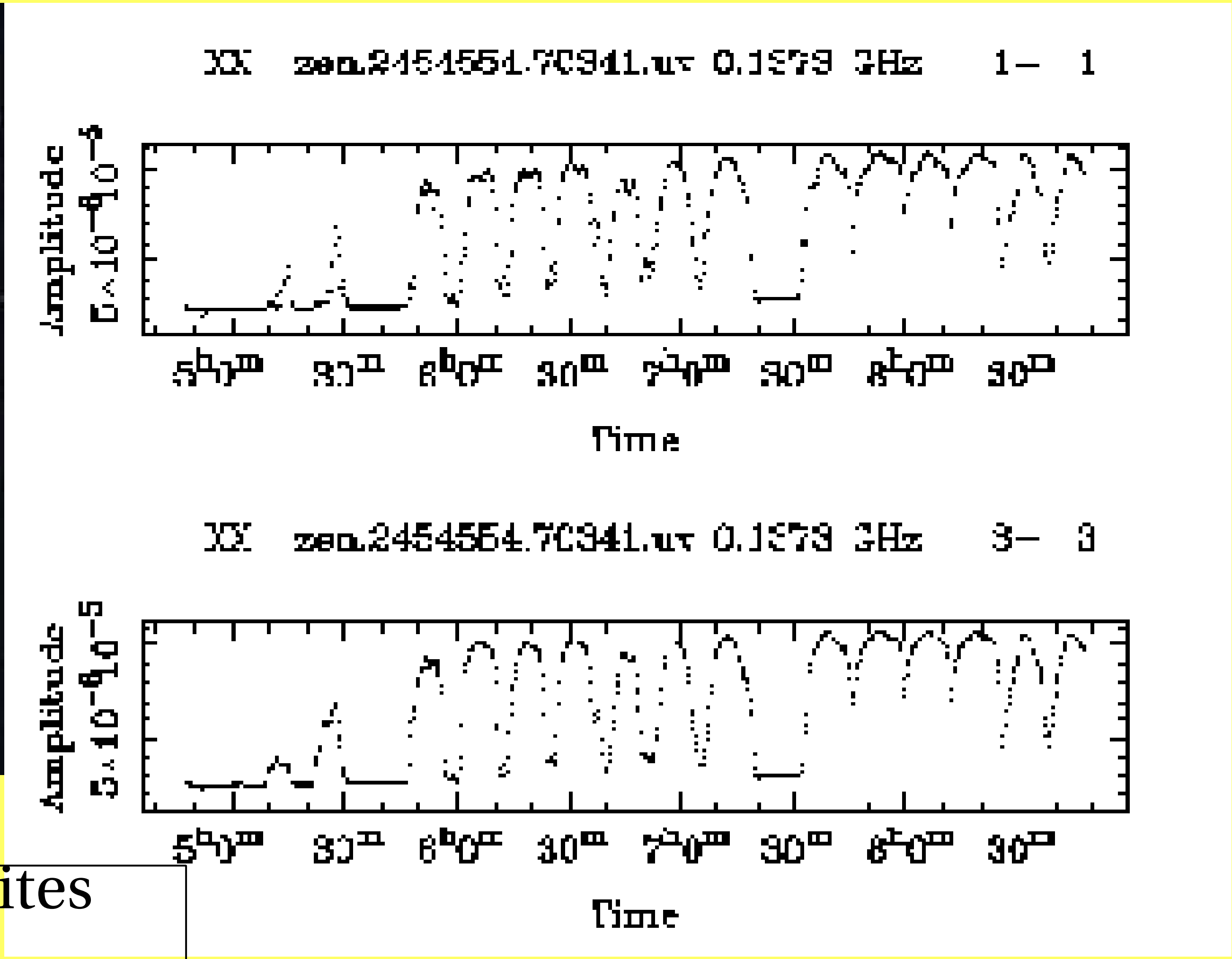
PAPER in Green Bank—2008 Mar

130-170 MHz
7 Dipole
24-hour integration



ORBCOM LEO Satellite Constellation



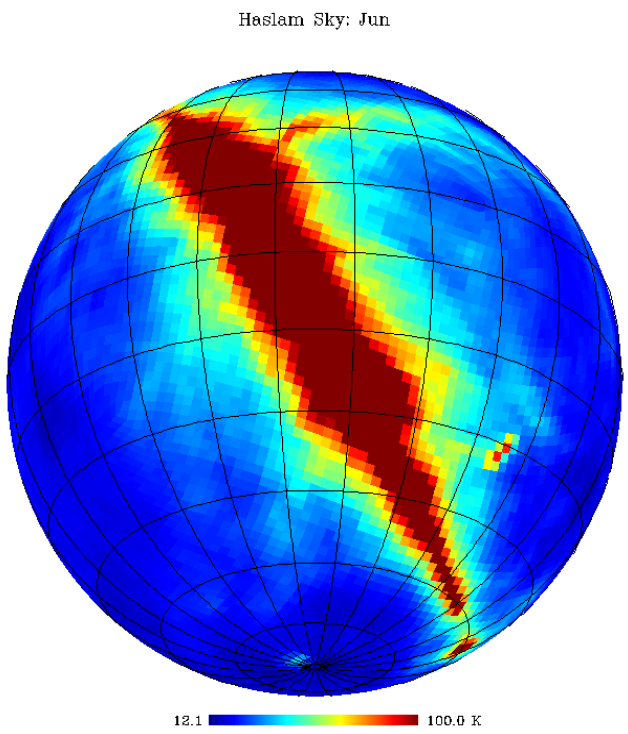


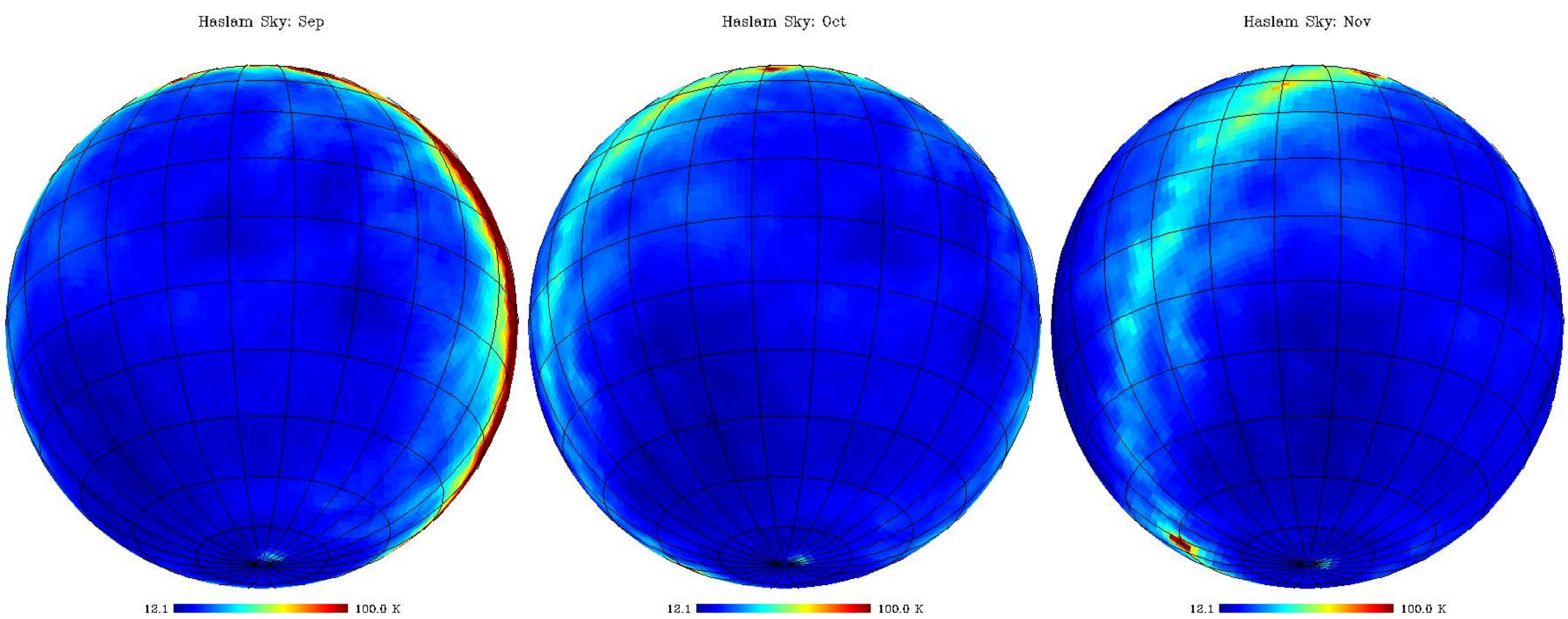
137.0-137.5 MHz; ~30 satellites

Subsystem under development:
--relative antenna gain
--global ionosphere

Annual Campaign:

Galaxy ~beyond horizon at night
when ionosphere is at minimum TECU:
Australian Spring: Sep-Nov (below),
not Winter (e.g., Jun; left)





SUMMARY

- *Step by step approach* successful
- *Green Bank test array* essential
- *AIPY* and related calibration/imaging just starting: beam fitting; polarization soon
- Gearing up for *PWA-32 deployment* 2008 Sep
- *Funding looks good* for buildout to PWA-128 in 2009: power spectrum detectability dependent on configuration, foreground removal, other systematics.
- *Long term vision*: ~100M USD effort with decision point mid-decade.

Reionization Experiment: PAPER

D. C. Backer

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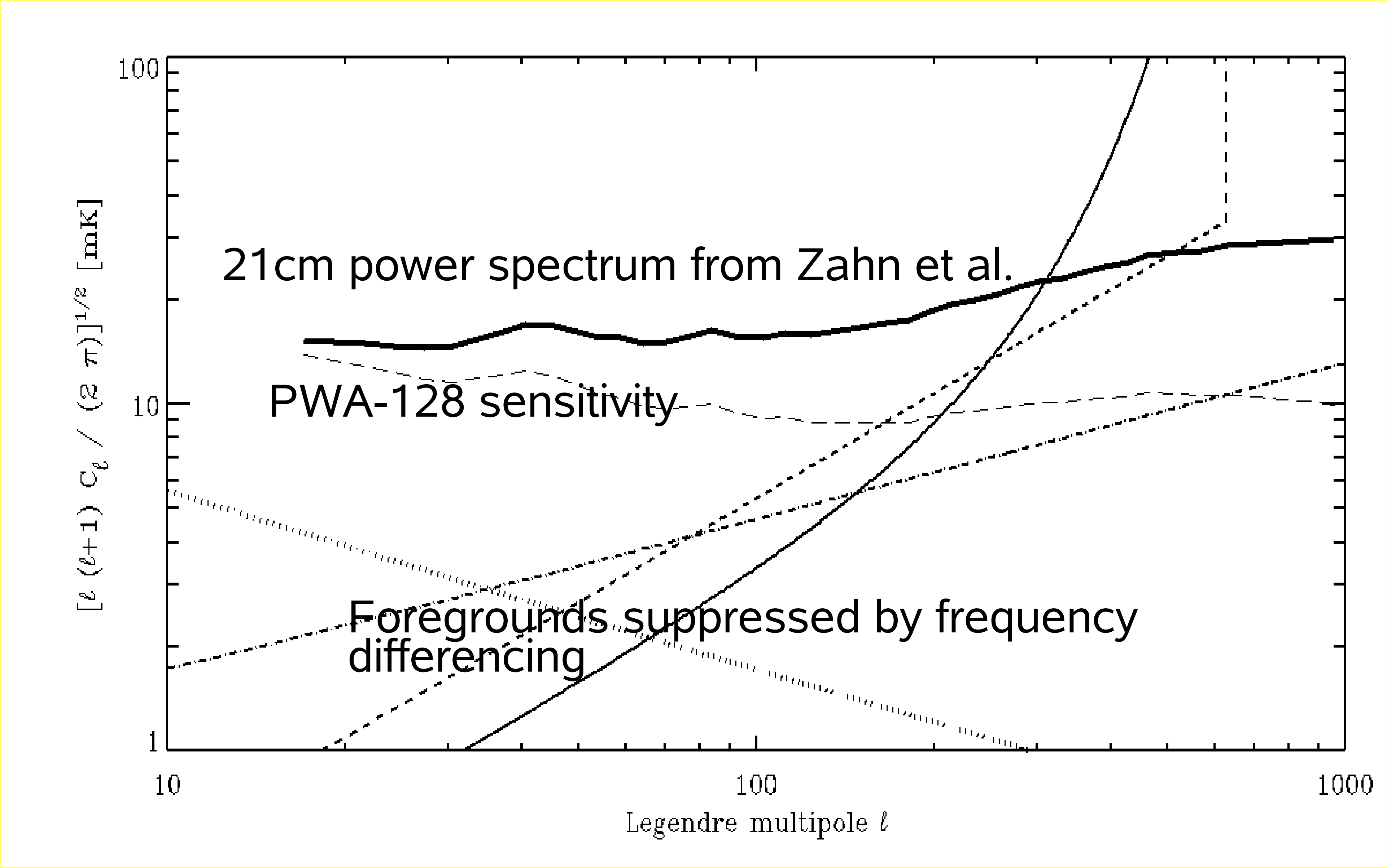
PAPER: Precision Array to Probe the Epoch of Reionization

- *epoch of reionization*
- *Green Bank test array:* ***PGB***
- *Western Australia deployment:* ***PWA***
- *Future*

Power Spectrum of 21cm Fluctuations



Foregrounds, and Other Challenges

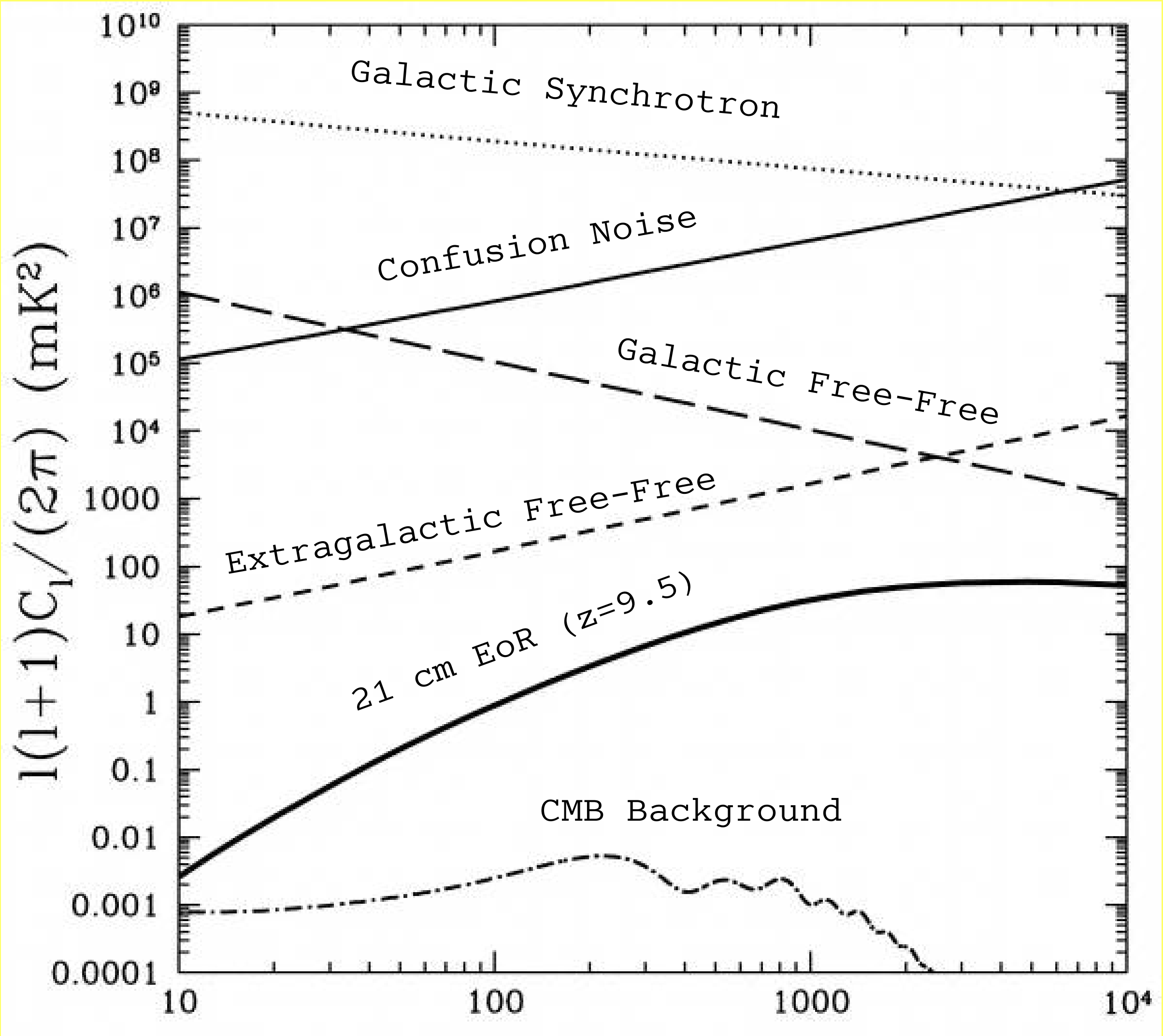
"If it were easy, it would have been done already"

Point Sources (+ Ionosphere)

Polarized Synchrotron

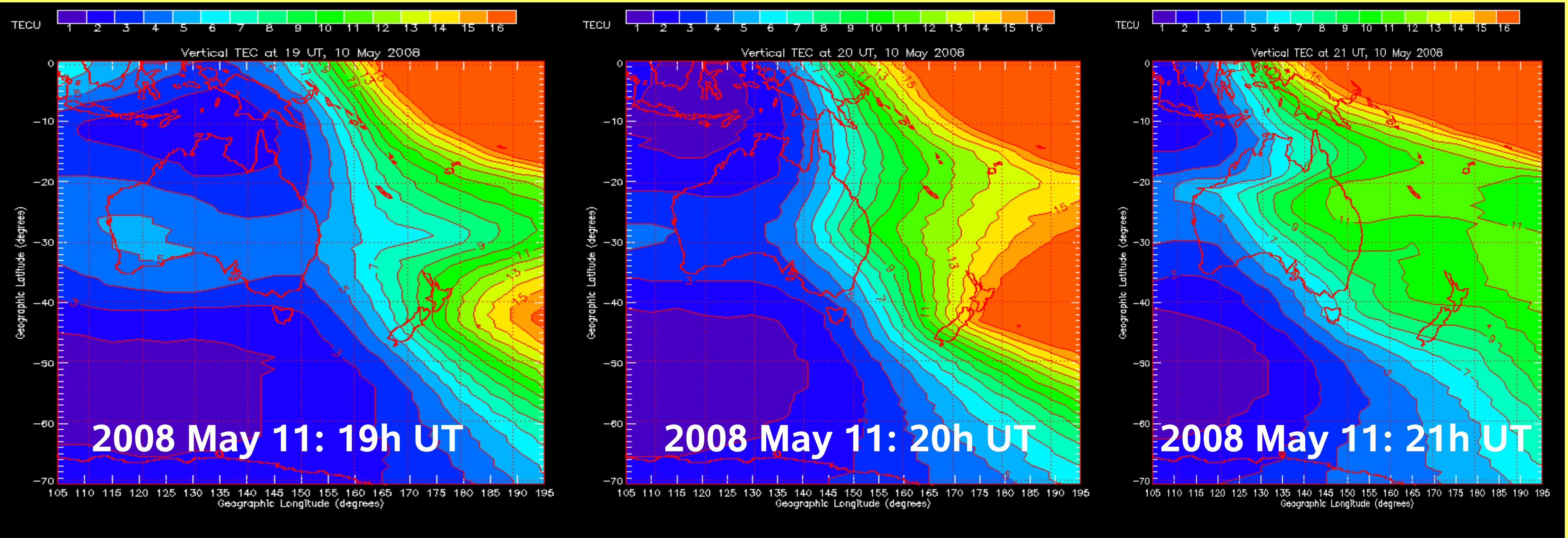
Confusion Noise

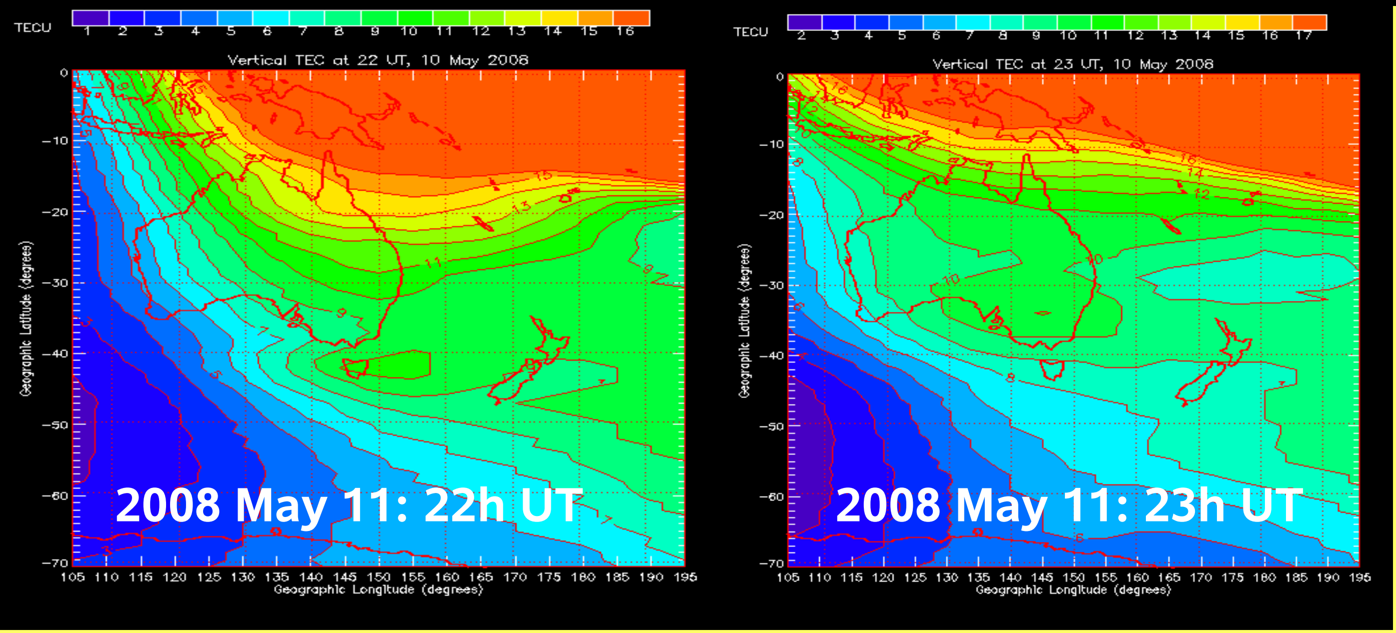
Free-Free Emission



Santos et al. (2005)

Ionospheric Corruption -- “Seeing”





http://www.ips.gov.au/Satellite

dark blue: 1 TECU = 10^{16} e/m^2

green: 10 TECU

~50 cycles @ 150 MHz

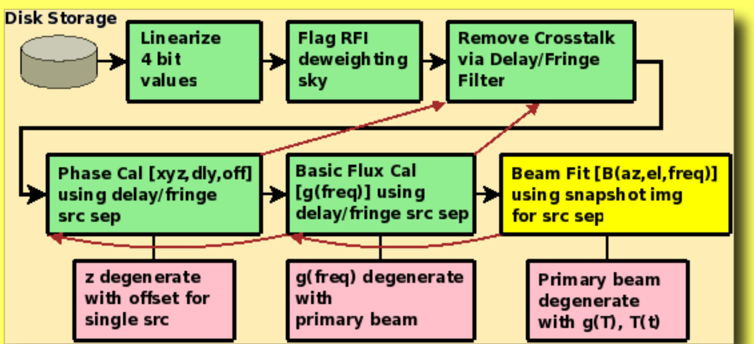
Two Calibration/Imaging Paths…

Parameter Space:

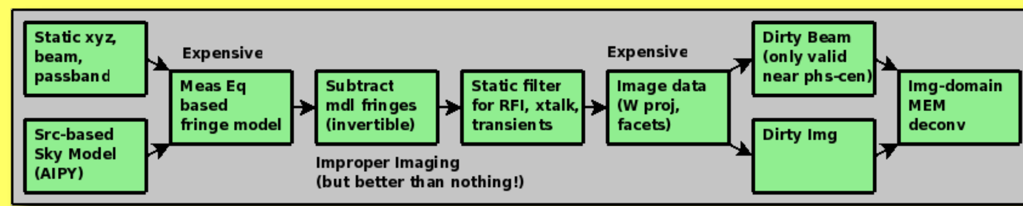
$$V_{ij}(\nu,t) = \sum_{s=srcs} g_i(\nu) g_j^*(\nu) I_{s,\nu_0} \left(\frac{\nu}{\nu_0}\right)^{\alpha_s} e^{2\pi i(\vec{b}_{ij}(\nu,t)\cdot\hat{s}_s+\nu\tau_{ij}+\phi)}$$

Bootstrap: Direct, fast, imperfect

"Sometimes you can't get started because you can't get started" - Don Backer



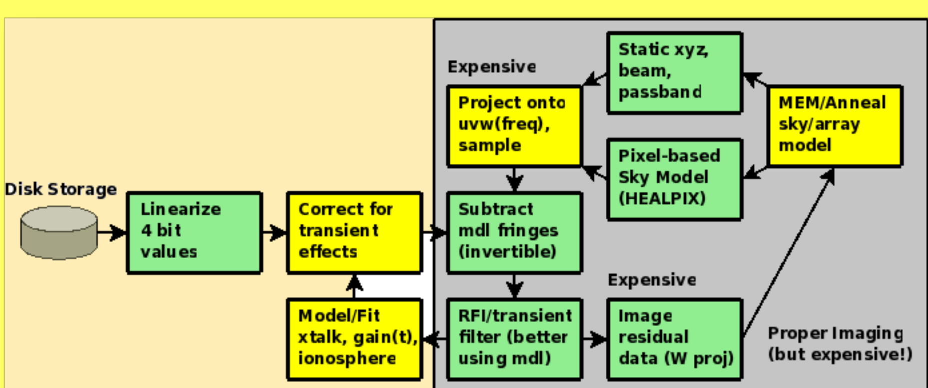
- Does not rely (excessively) on priors
- Takes advantage of wide bandwidth
- Addresses degeneracies one at a time



- **<u>AIPY: Another imaging package? Why?</u>**
- Inherently wide-field (native W projection)
- Large relative bandwidth brings new tools
- Non-tracking primary beam changes imaging

Secondary advantages:
- "Be in control of thy tools"
- In-house expertise
- Python is modular, object oriented, extendible

Model-Fit: Clean, correct, expensive



- Many parameters are strongly degenerate,
- requiring simultaneous fitting to tease
- them apart.
- Proper image deconvolution involves using
- the full measurement equation.
- Various parameters (ionosphere,gain,xtalk)
- change on different timescales.
- Huge parameter space, different variance
- in parameters -> simulated annealing?
- If parameter space is not smooth,
- this is <u>not</u> an easy problem.