Title: 21cm cosmology

Date: Apr 29, 2010 04:00 PM

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Abstract: TBA

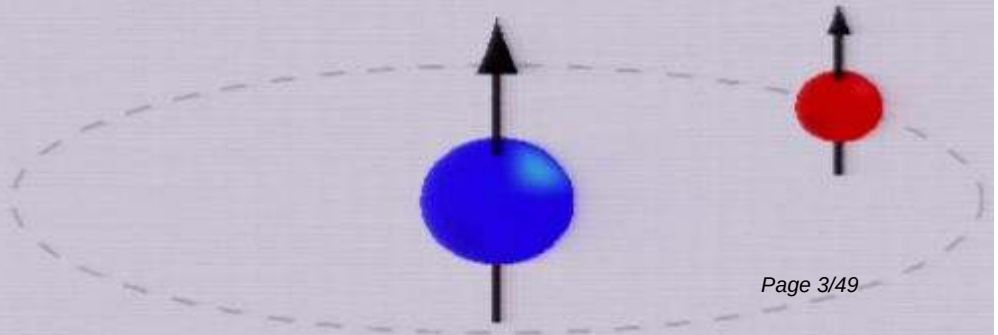
21cm cosmology

Ue-Li Pen

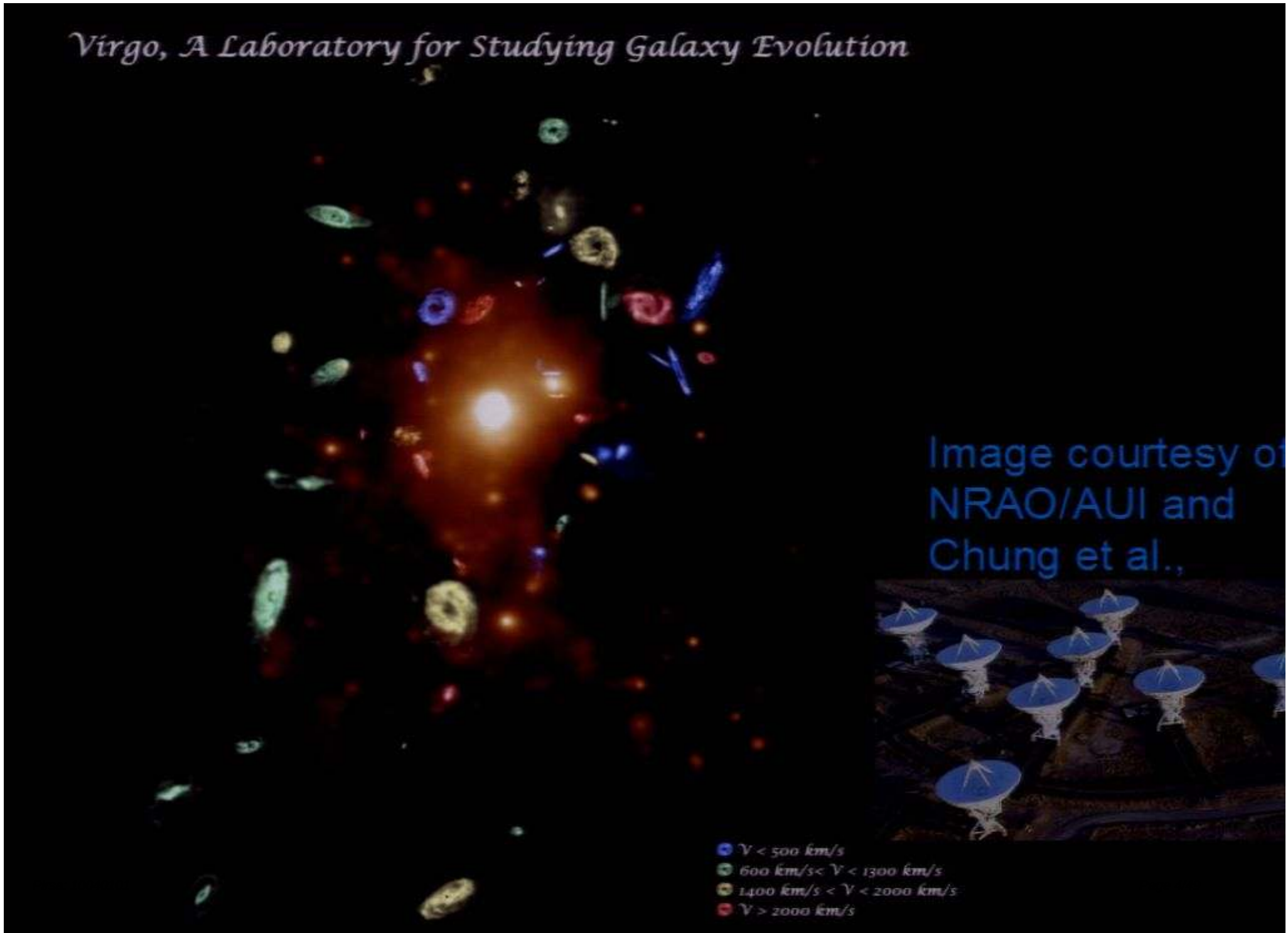
T. Chang, UP, J. Peterson, P. McDonald
PRL 100, 091303 (2008)
K. Masui, F. Schmidt, UP, P. McDonald,
PRD 81,062001 (2010)

21cm: HI hyperfine transition

- Hydrogen is the most abundant element in the universe
- 21cm line optically thin over most lines of sight to very high z
- Hyperfine transition when electron and proton spins flip: change in magnetic moment
- $h\nu = \alpha^4 m_e c^2 (m_e/m_p)$
- ν=1420.40575 MHz



Virgo, A Laboratory for Studying Galaxy Evolution



The 21 cm universe

Cosmological LSS treasure grove (UP04, Loeb&Zaldarriaga 04, Lewis&Challinor 07, etc)

Up to 10^{18} modes: $(\text{Jeans/Hubble})^3$

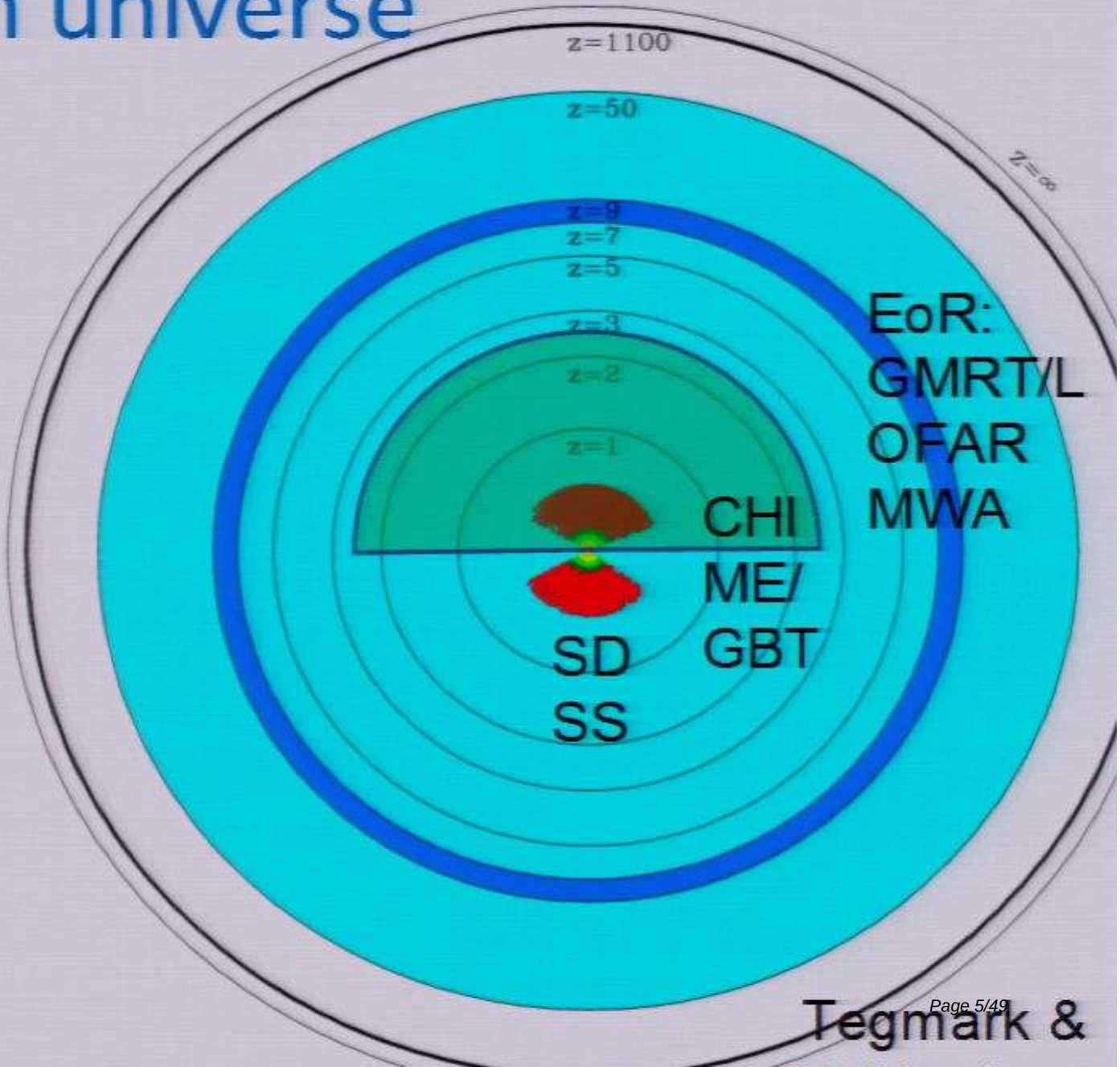
Physics: Lensing, gravity waves, primordial NG, BAO, AP

GW to $r \sim 10^{-8}$

$f_{NL} \sim 10^{-4}$

Astrophysics: EoR, galaxy evolution

Experiments NOW



Tegmark &

Fundamental Physics

- 0<z<2: BAO: w-w'
- z>2: Large angle lensing: modified gravity
- z>10: gravitational waves

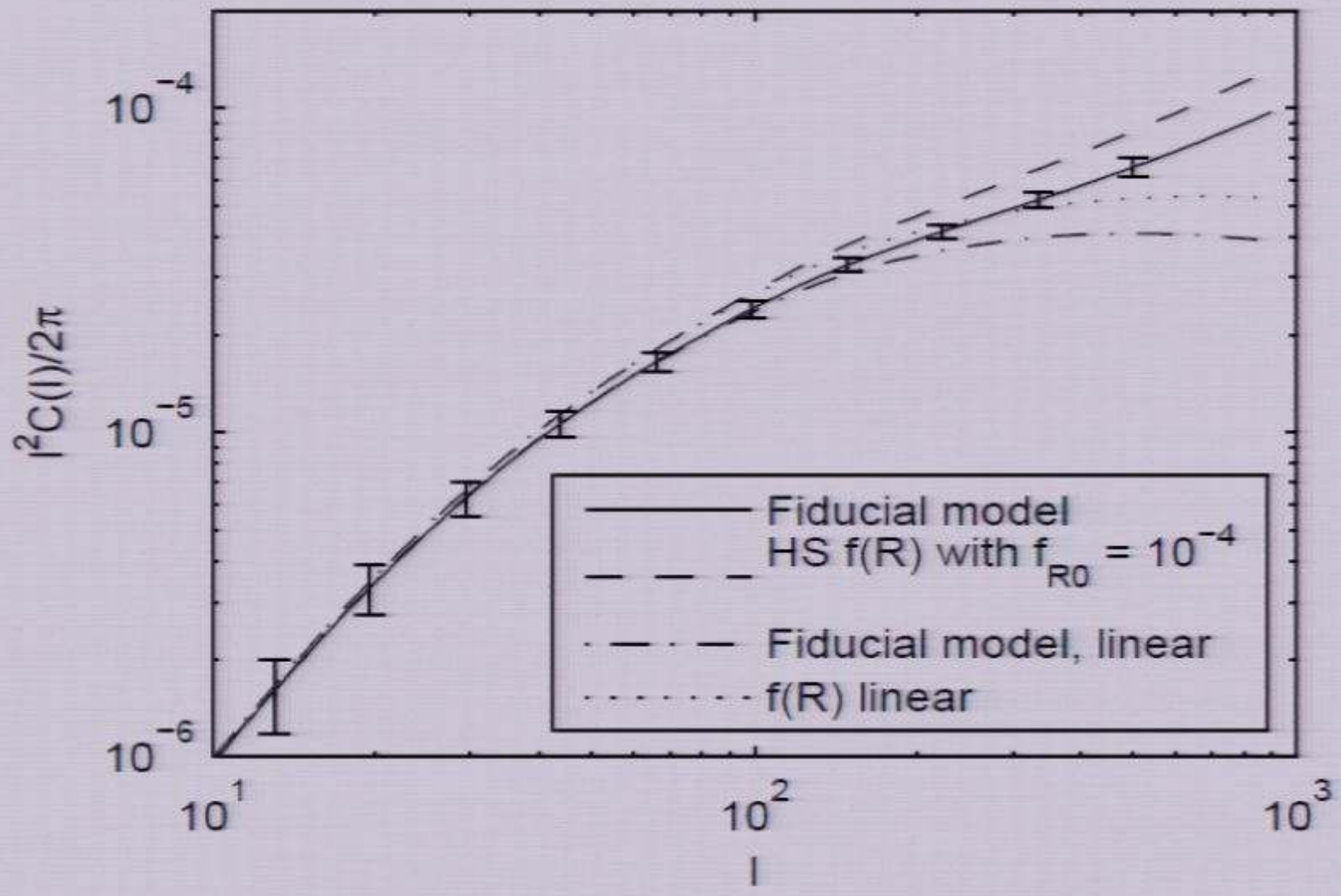


FIG. 1: The Weak lensing convergence power spectra for ΛCDM and the HS $f(R)$ model with $n = 1$ and $f_{R0} = 10^{-4}$. Galaxy distribution function is flat between z = 1 and z = 2.5.

Masui, Schmidt, Pen, McDonald 2010

Pirsa: 10040101

Gravity Waves

- K. Masui, in progress
- Analogous to lensing: shearing of cosmic structure.
- Memory effect: $h \sim 10^{-6}$ (inflation)
- Measure r, n_T at $z \sim 15$
- Requires $1/h^2$ modes
- Separates from lensing: tranverse traceless
- Structures available to $k \sim 10^{-2}$-10^{4}:horizon to Jeans scale, $\sim 10^{18}$ modes

Linear gravity wave memory

- GW in initial condition, then redshifts away

$$ds^2 = a(\eta)^2 \left[-d\eta^2 + (h_{ij} + \delta_{ij})dx^i dx^j\right].$$

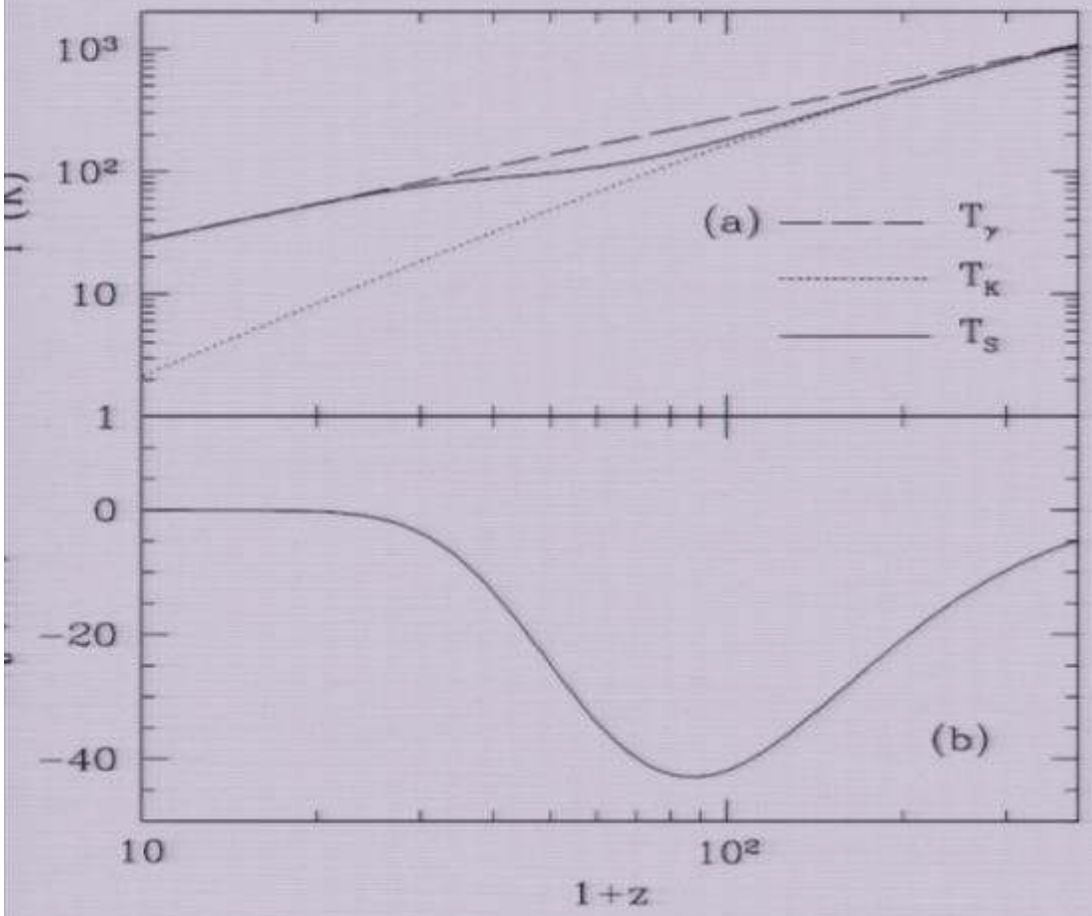
$$\tilde{x}^\alpha = (x^\alpha - \frac{1}{2}h_{\alpha\beta}x^\beta),$$

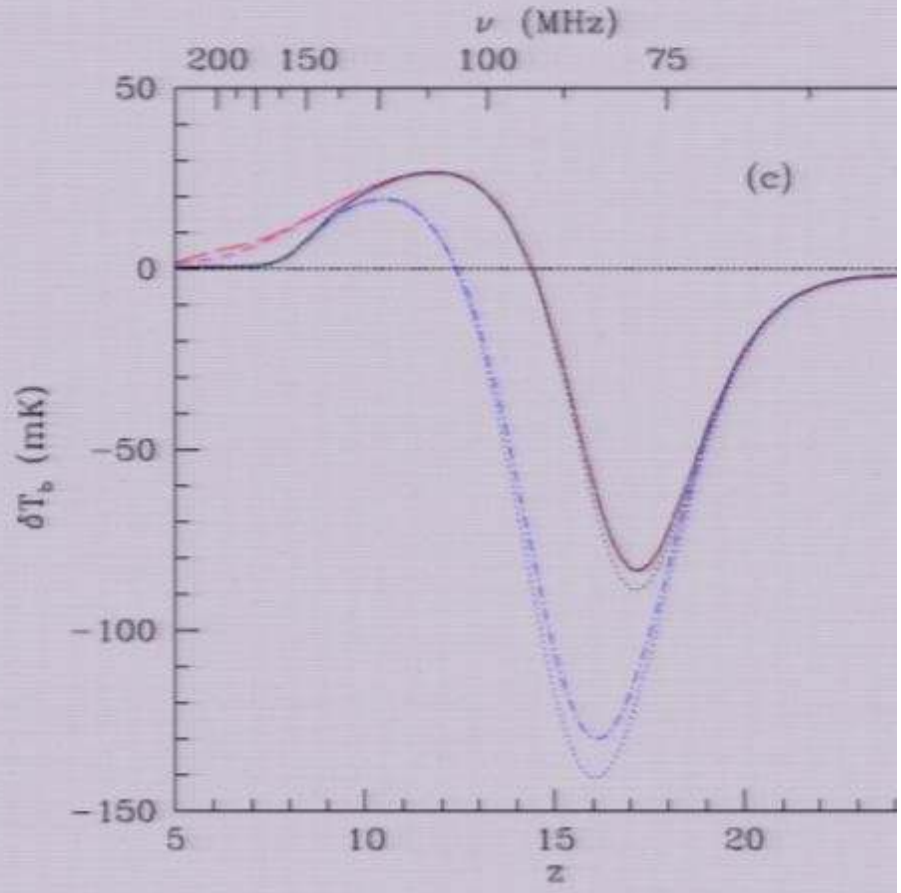
$$P(\overrightarrow{k}) = \tilde{P}(k) - \frac{k_i k_j h_{ij}}{2k}\frac{d\tilde{P}}{dk} + O(\frac{k_T}{k}h_{ij}) + O({h_{ij}}^2)$$

$$h_{ij} \propto \langle \partial_i \delta \partial_j \delta \rangle$$

$$r_{\min} = 2.7\times10^{-4}\left(\frac{50h/\mathrm{Mpc}}{k_{\max}}\right)^3\left(\frac{44(\mathrm{Gpc/h})^3}{V}\right)^{1/2}$$

Spin evolution





Furlanetto Oh & Briggs, 2006

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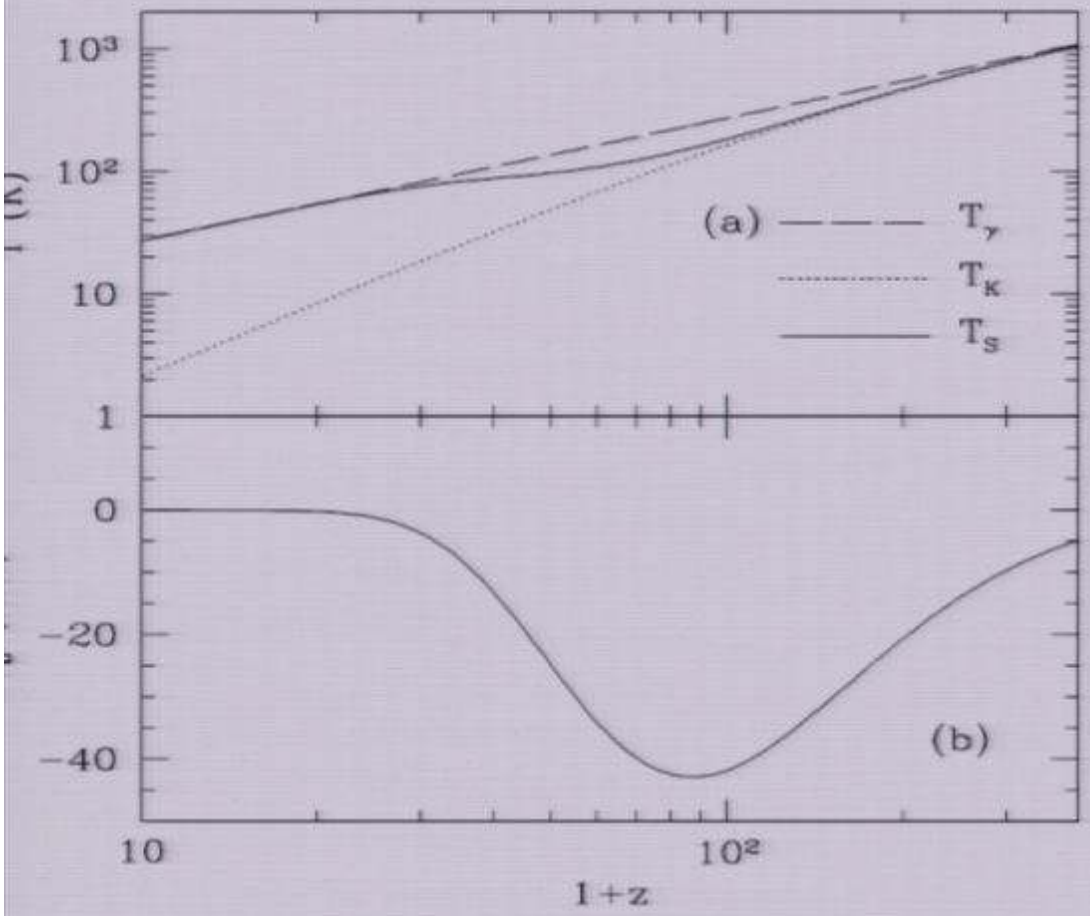

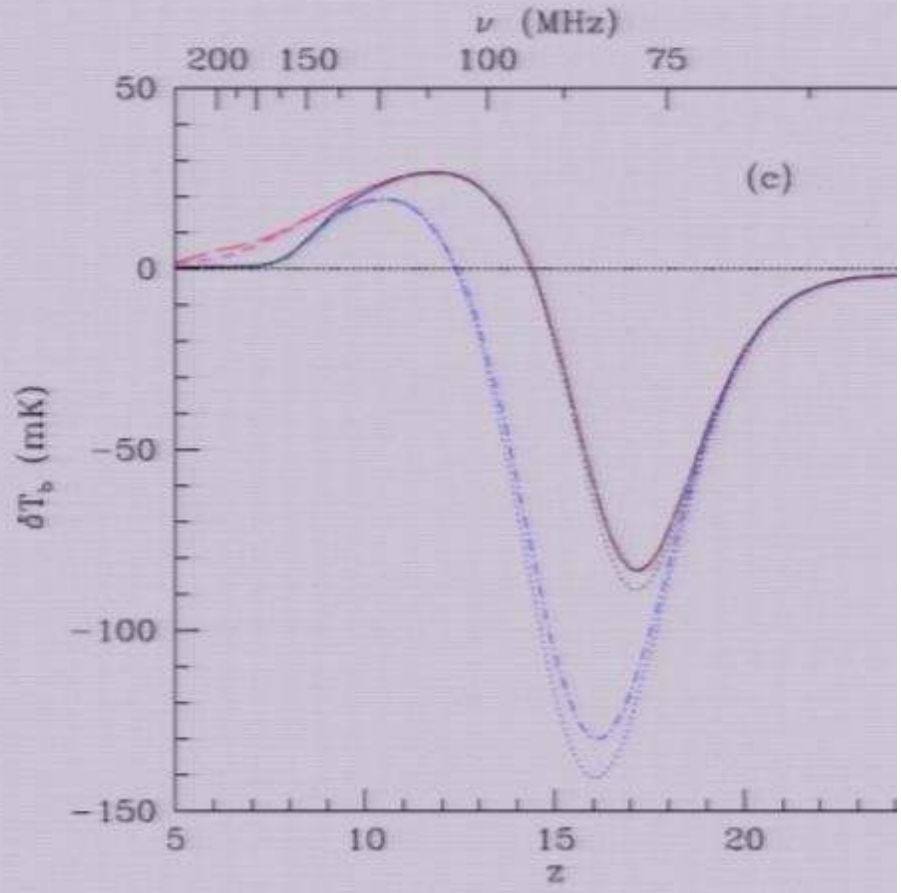

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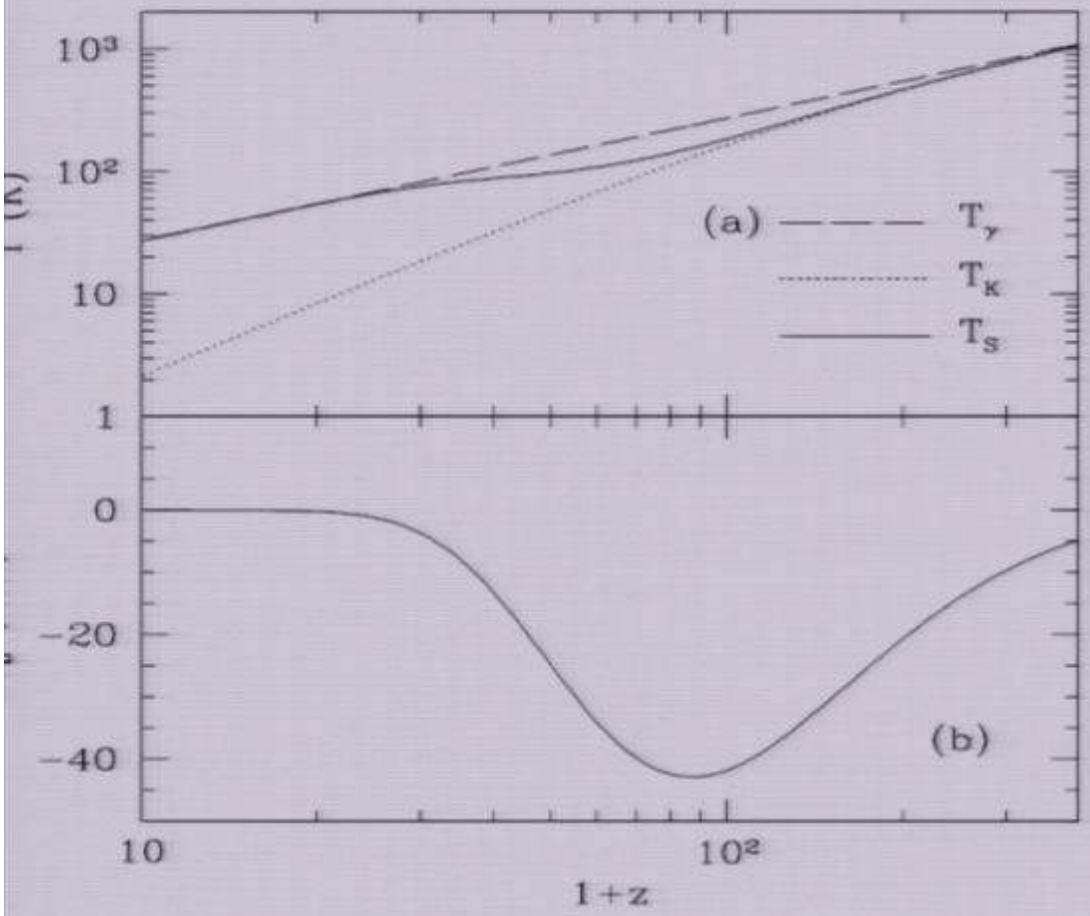

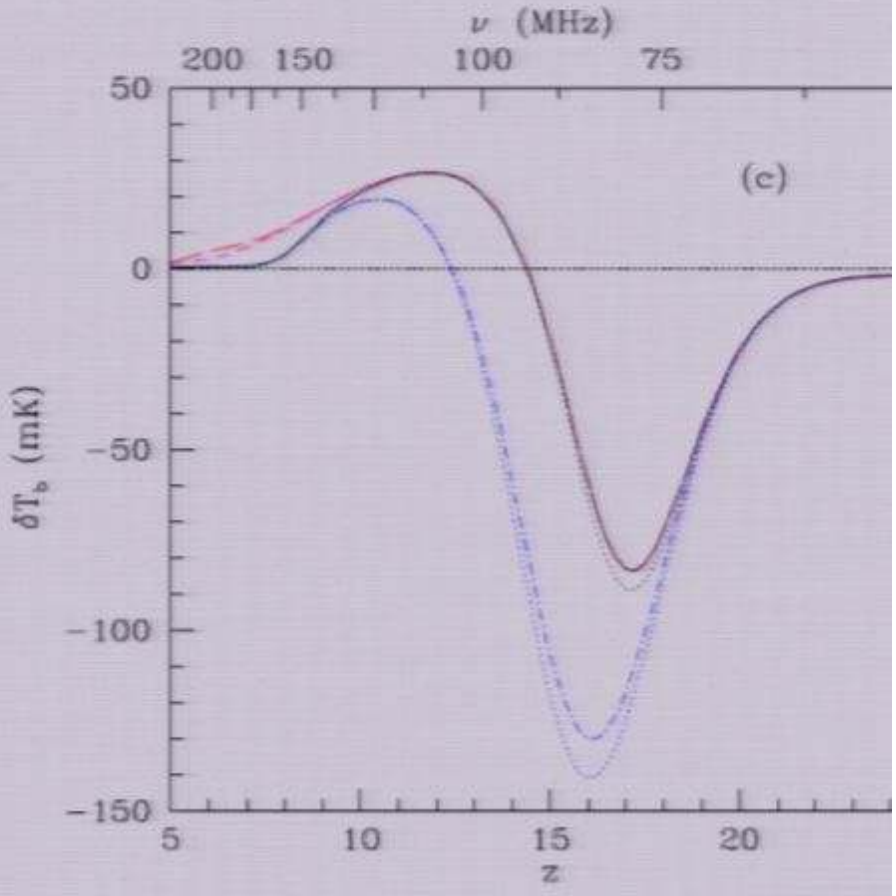

Furlanetto Oh & Briggs, 2006

Astrophysics

- Ω_{HI} evolution: redshift space distortions
- Cosmic reionization
- Ancillary science from same data set: Magnetic fields, pulsars, transients

Hydrogen: Then and Now

- 21cm first detected 1952 (Ewen and Purcell)
- Previous most distant emission redshift: z=0.3 using 1960's telescope (WSRT)
- Epoch of Reionization: z ~ 9
- z=1-3 BAO: dark energy from geometric distance measurement

$$T_b = 0.3\left(\frac{\Omega_{\rm HI}}{10^{-3}}\right)\left(\frac{\Omega_m + a^3\Omega_\Lambda}{0.29}\right)^{-1/2}\left(\frac{1+z}{2.5}\right)^{1/2}\ {\rm mK}$$

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Intensity Mapping

- Stars get fainter with distance: hard to see individually at cosmological distance. Galaxies still visible.
- Galaxies get fainter with distance: hard to see in HI. Large scale structure still visible?
- Large scale structure is LARGE: degree scale. High resolution not needed.
- Modest size, monolithic radio telescopes needed. (CPPM 2008, Wyithe&Loeb 2008)

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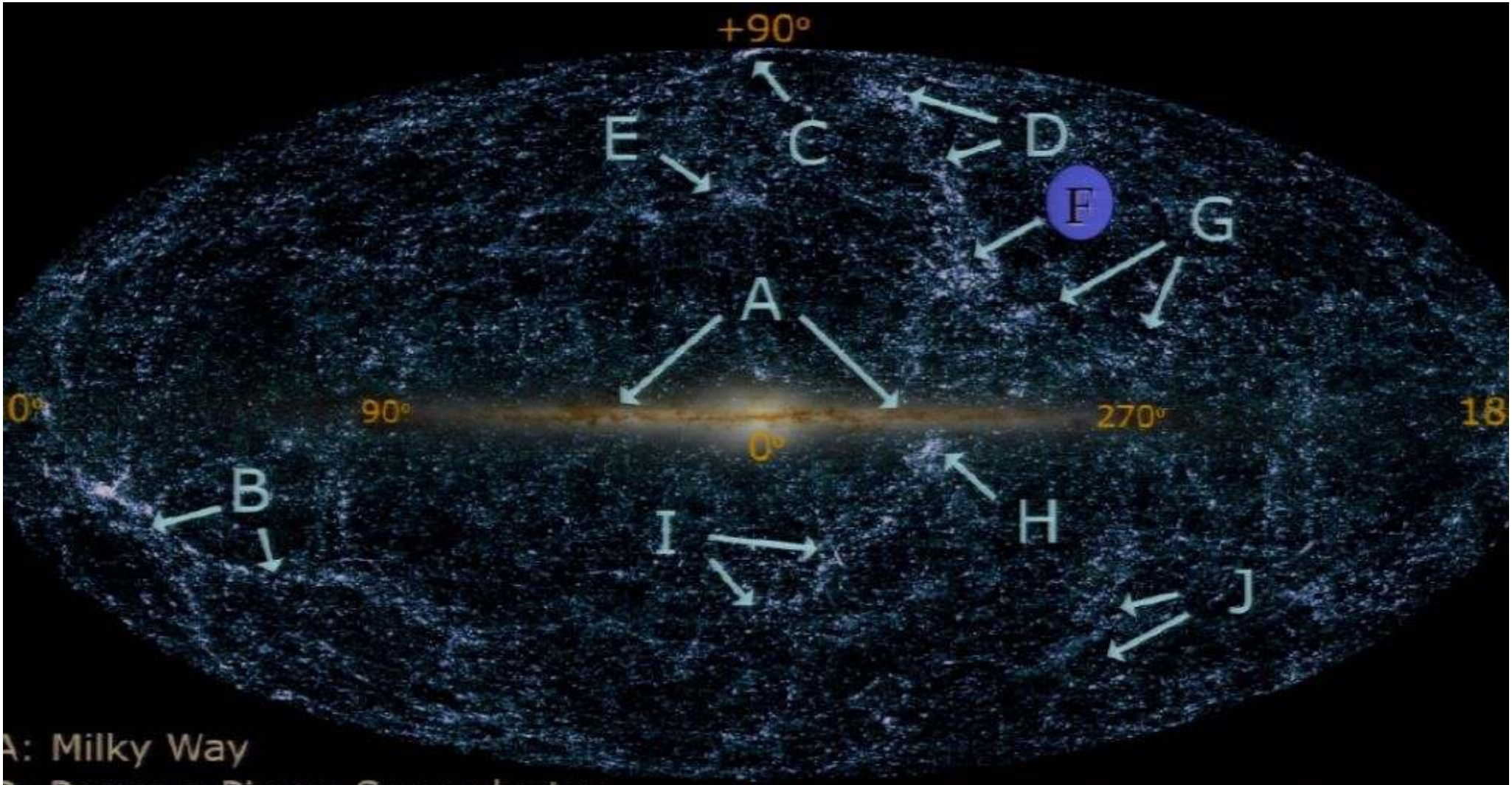

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B: Perseus-Pisces Supercluster
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D: Virgo Cluster/Local Supercluster
E: Hercules Supercluster
F: Shapley Concentration/Abell 3558

G: Hydra-Centaurus Supercluste
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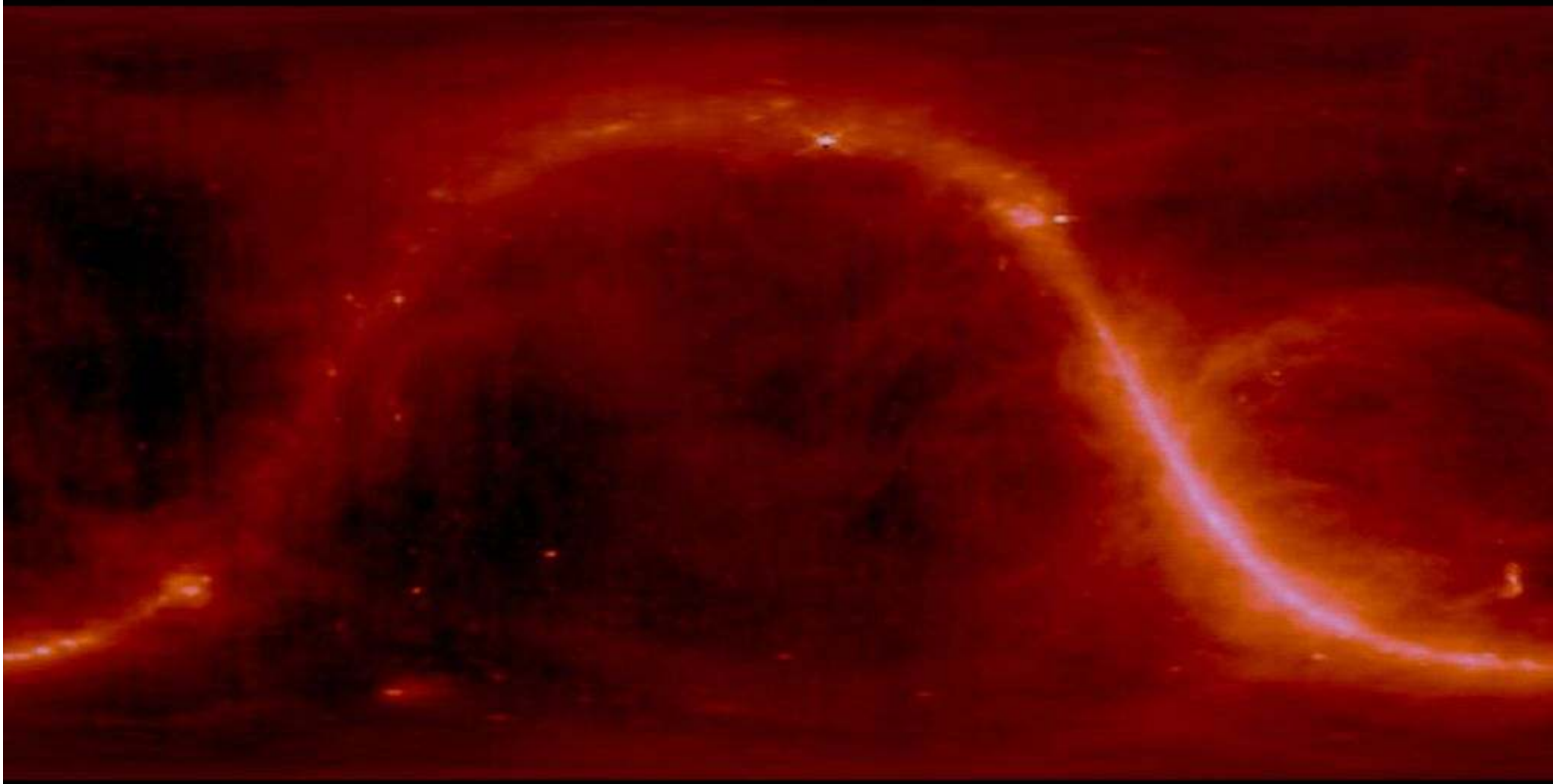
J: Horologium-Reticulum Supercluster

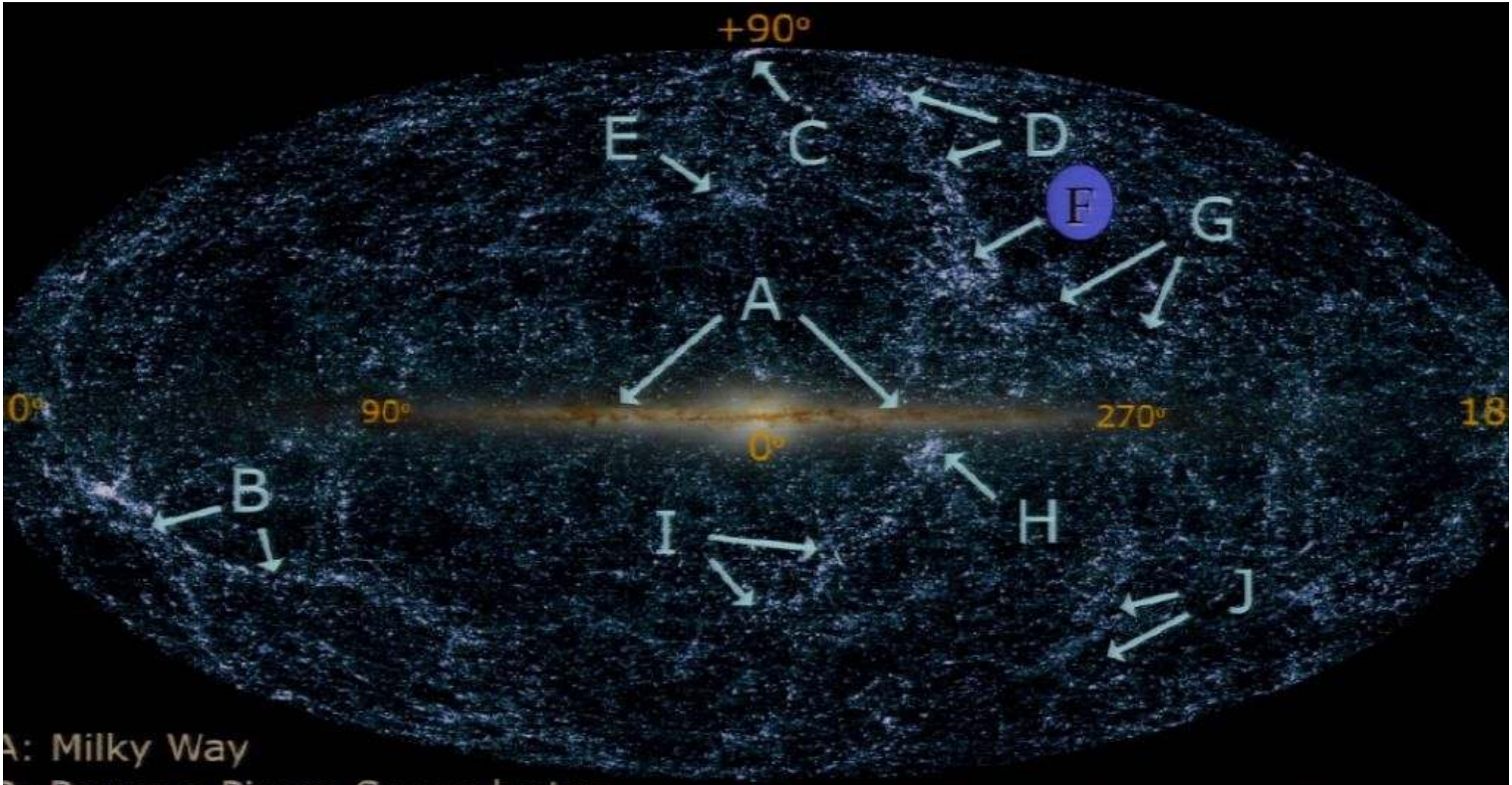
From: talk by O.

Foreground: Galactic Synchrotron



Haslam 408 MHz

Much brighter than signal, but no spectral



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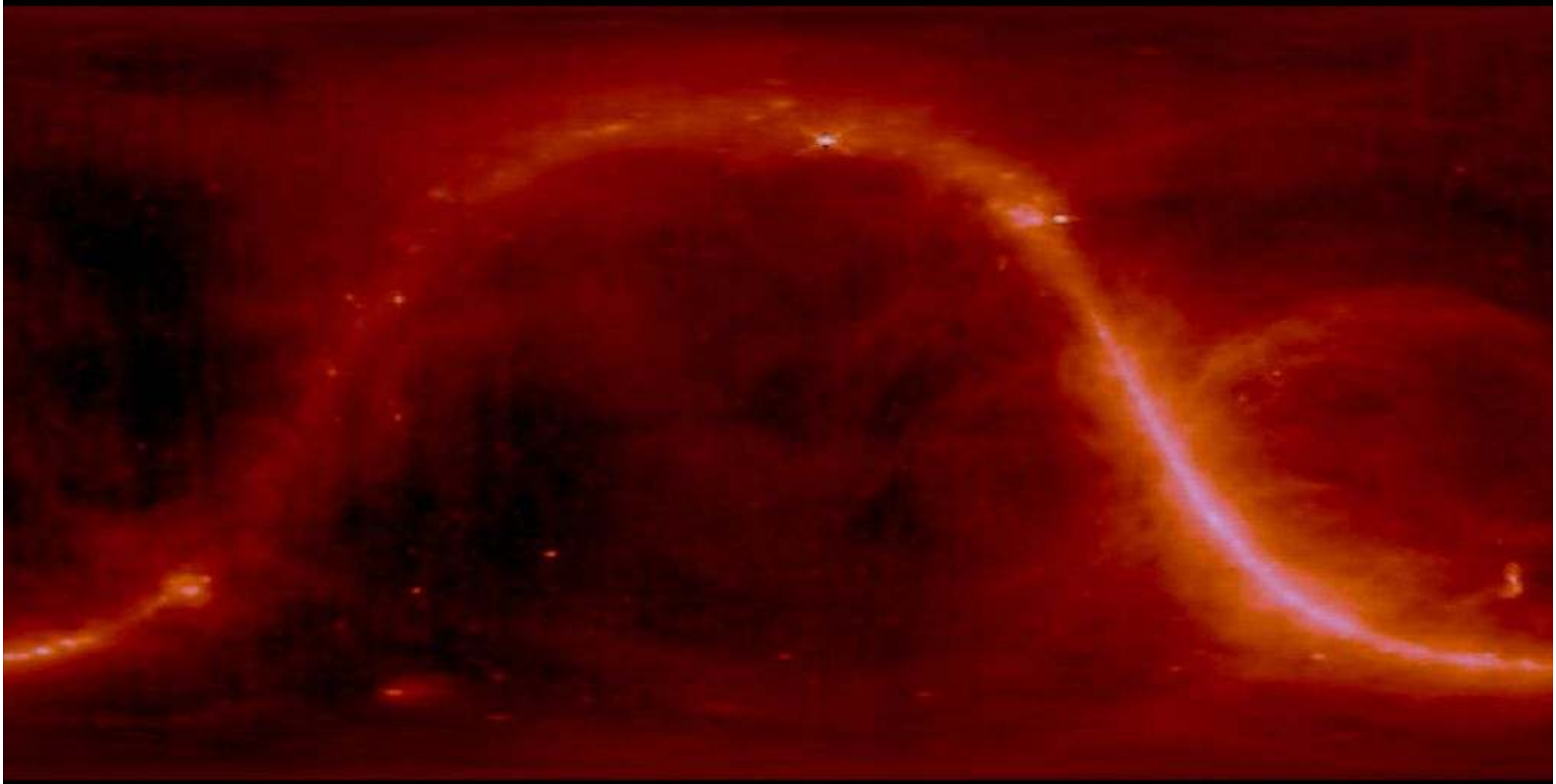

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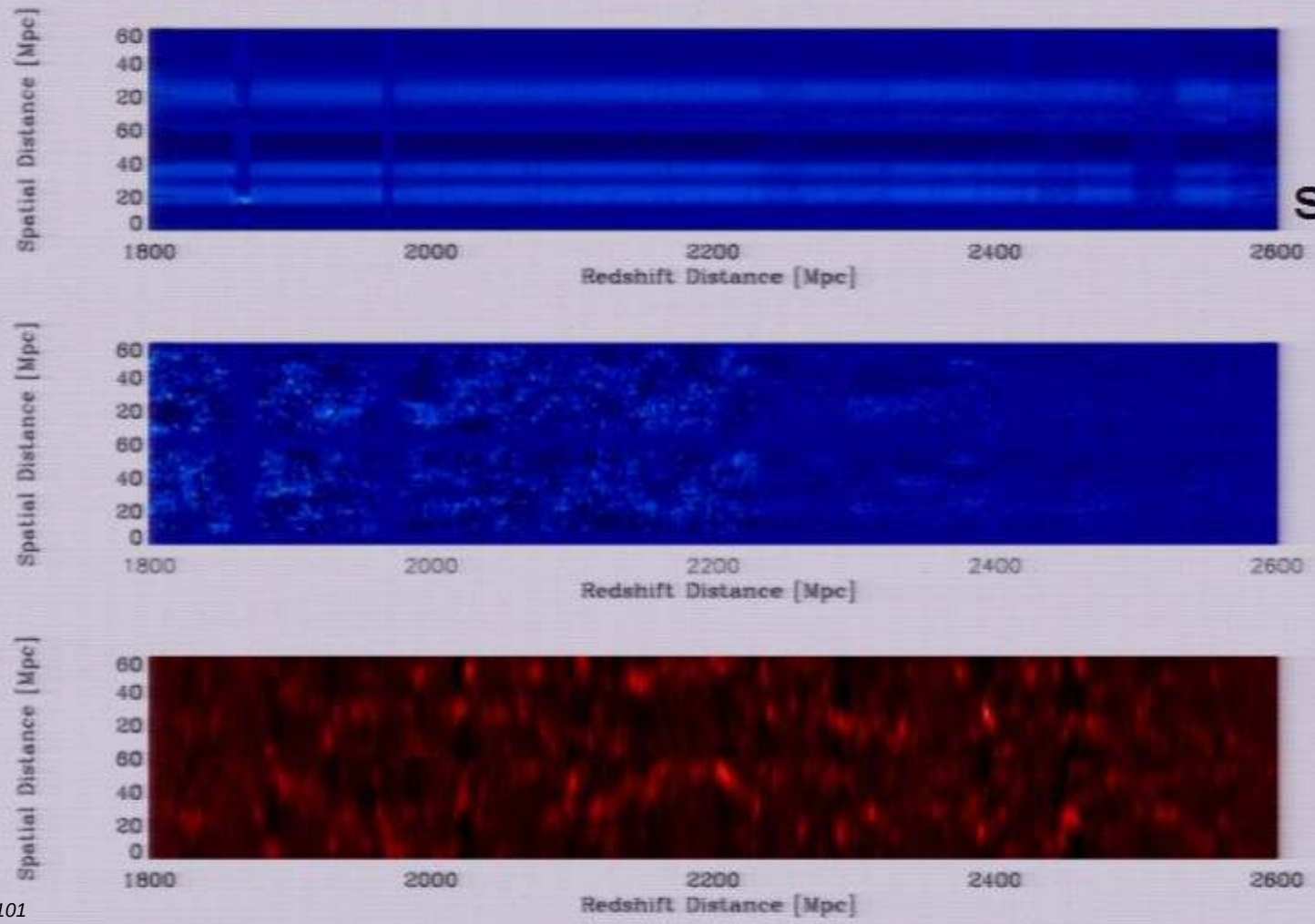
Robert C Byrd Telescope: 100m

HI content at z=0.8

Cross-correlating GBT HI & DEEP2 optical galaxies at z ~ 0.7-1.1



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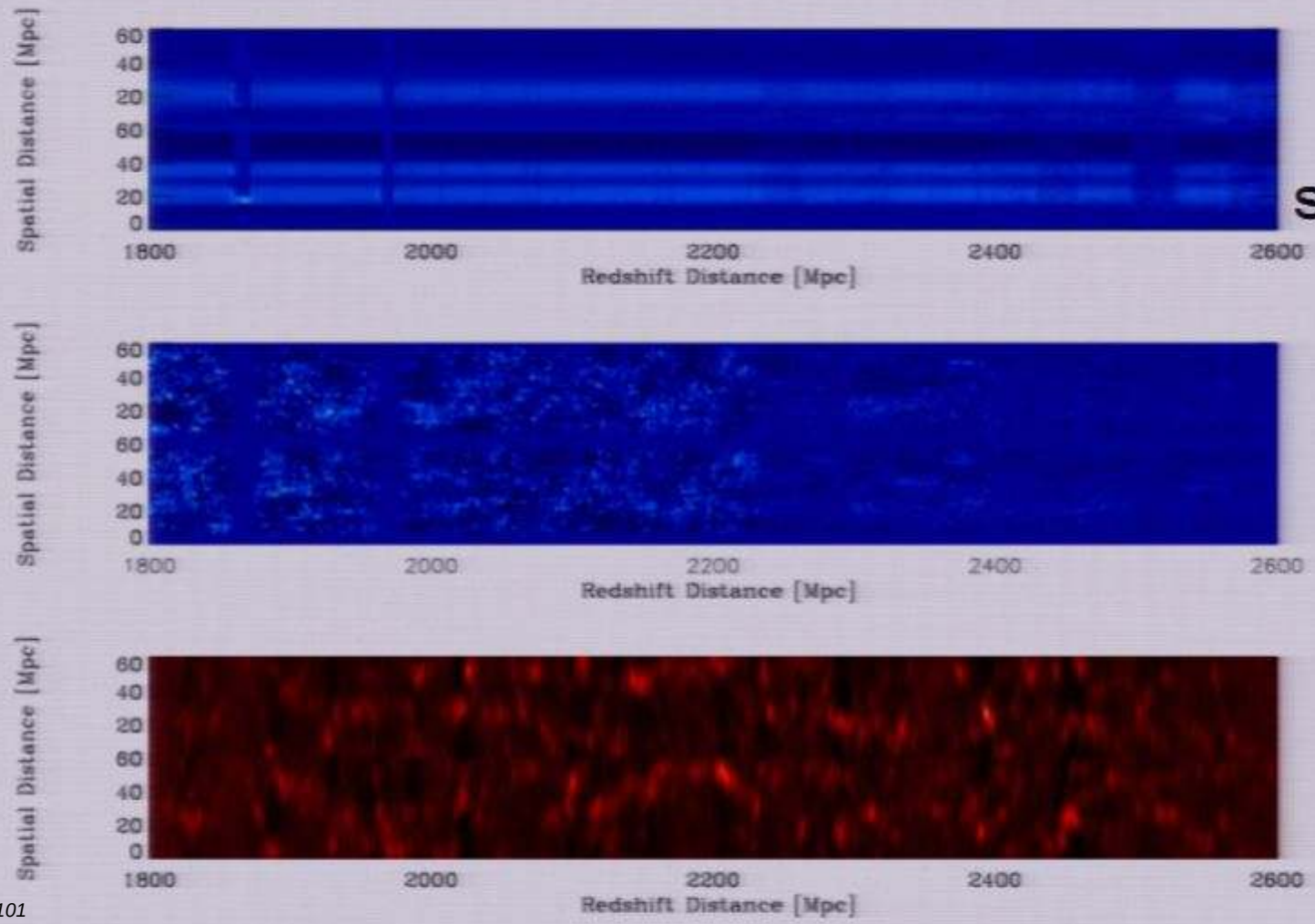

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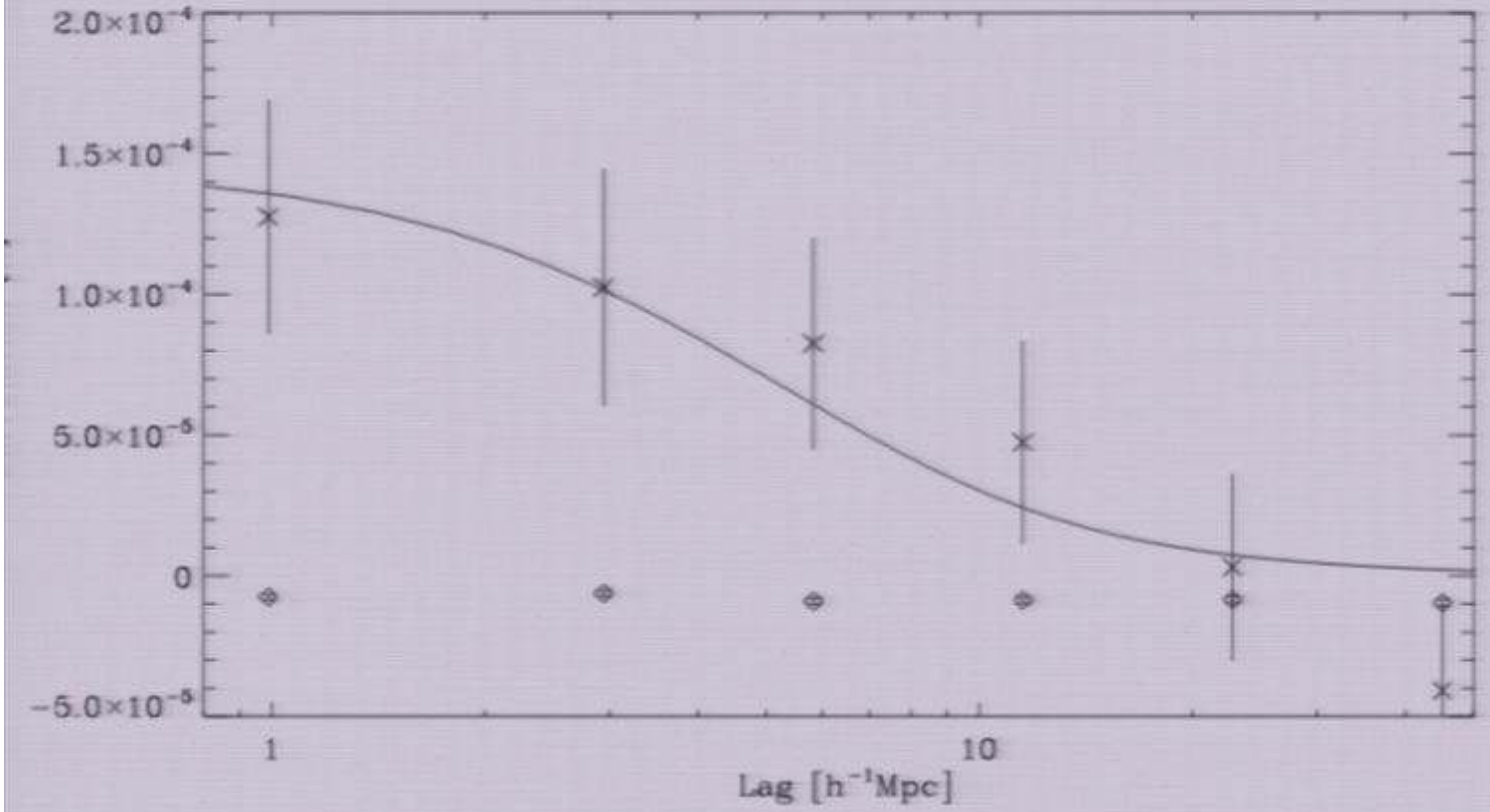

- Measure HI & optical cross-correlation on Mpc (spatial) x Mpc (redshift) comoving scal
- HI brightness temperature o these scales a z=0.8:
- $\Omega_{HI} = (4.5 \pm 1.0) \times 10$

  $T = 127 \pm 29 \mu K$
- Highest-redshi detection of HI emission at 4- sigma statistica significance.

Chang, Pen, Bandura, Peterson, accepted by Nature

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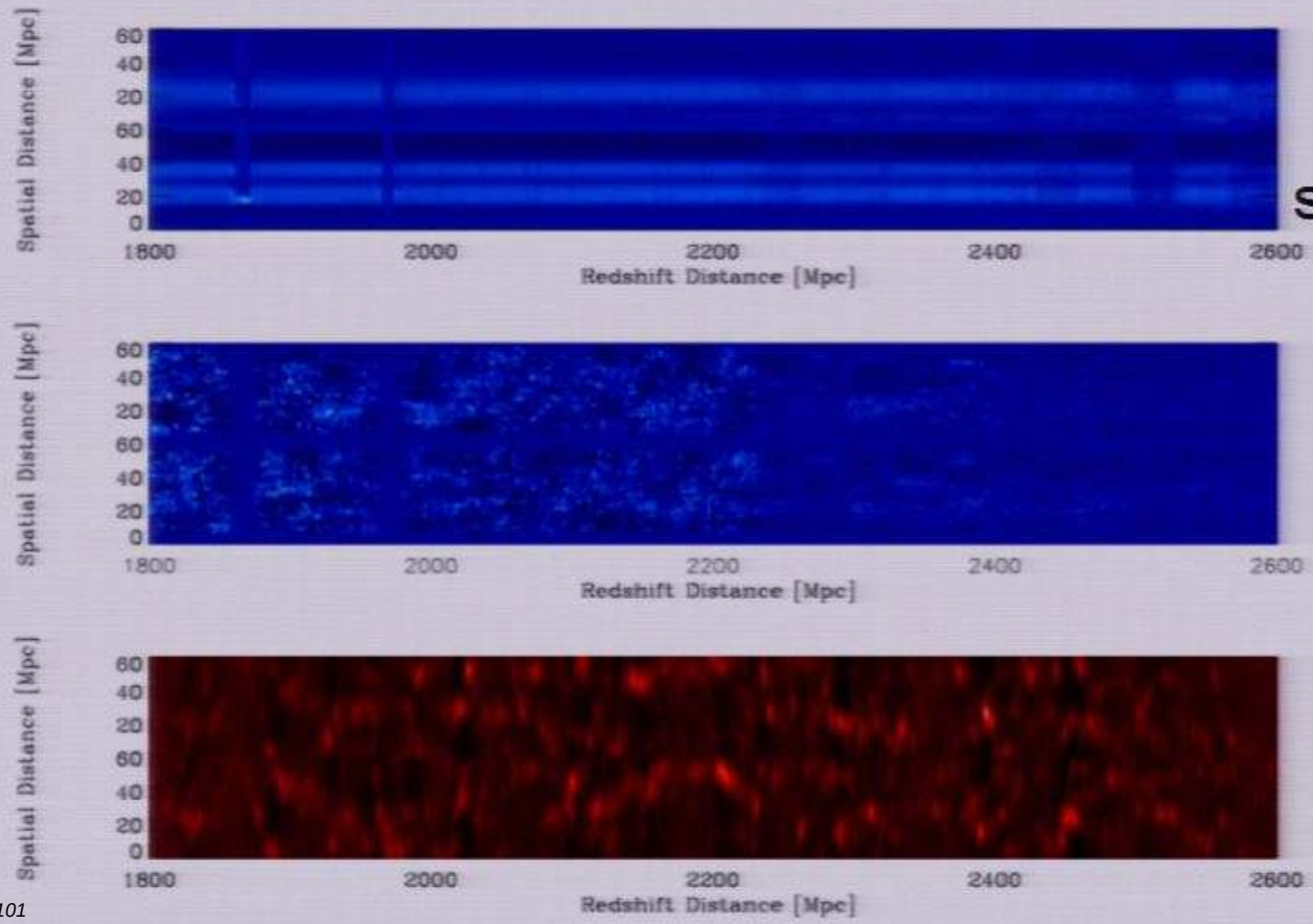

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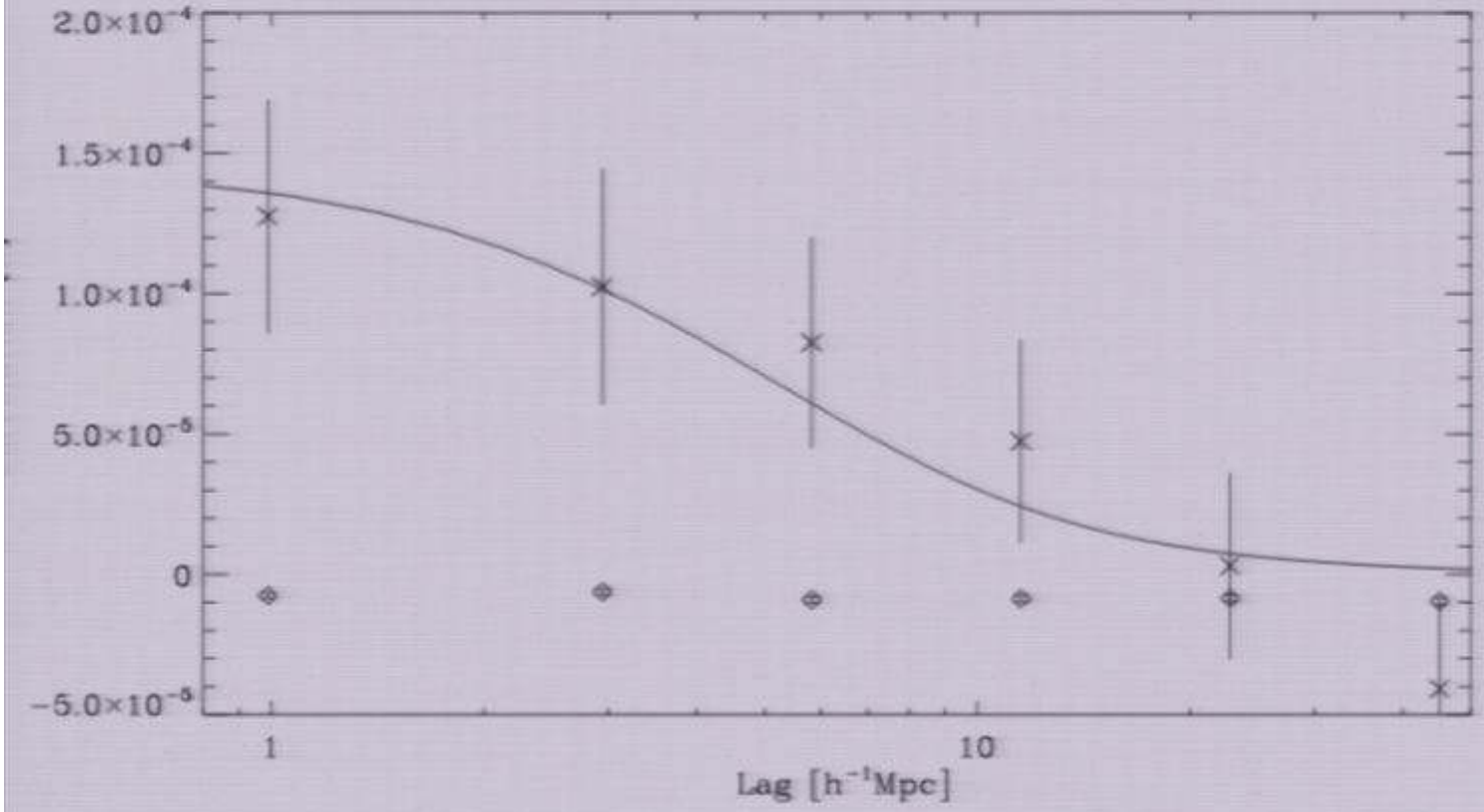

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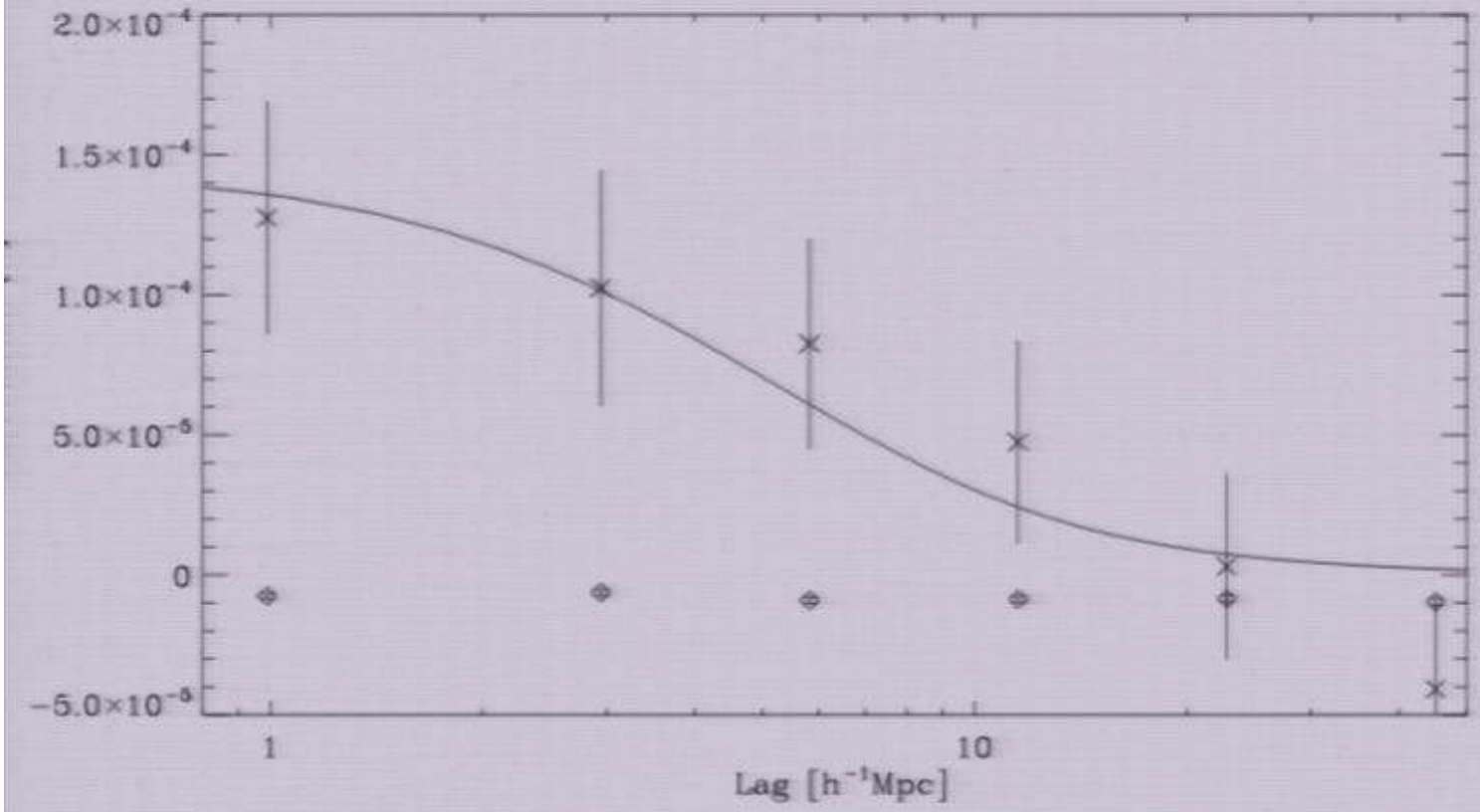
- 300 h allocated to measure z~1 power HI spectrum, redshift distortion, Ω_{HI}



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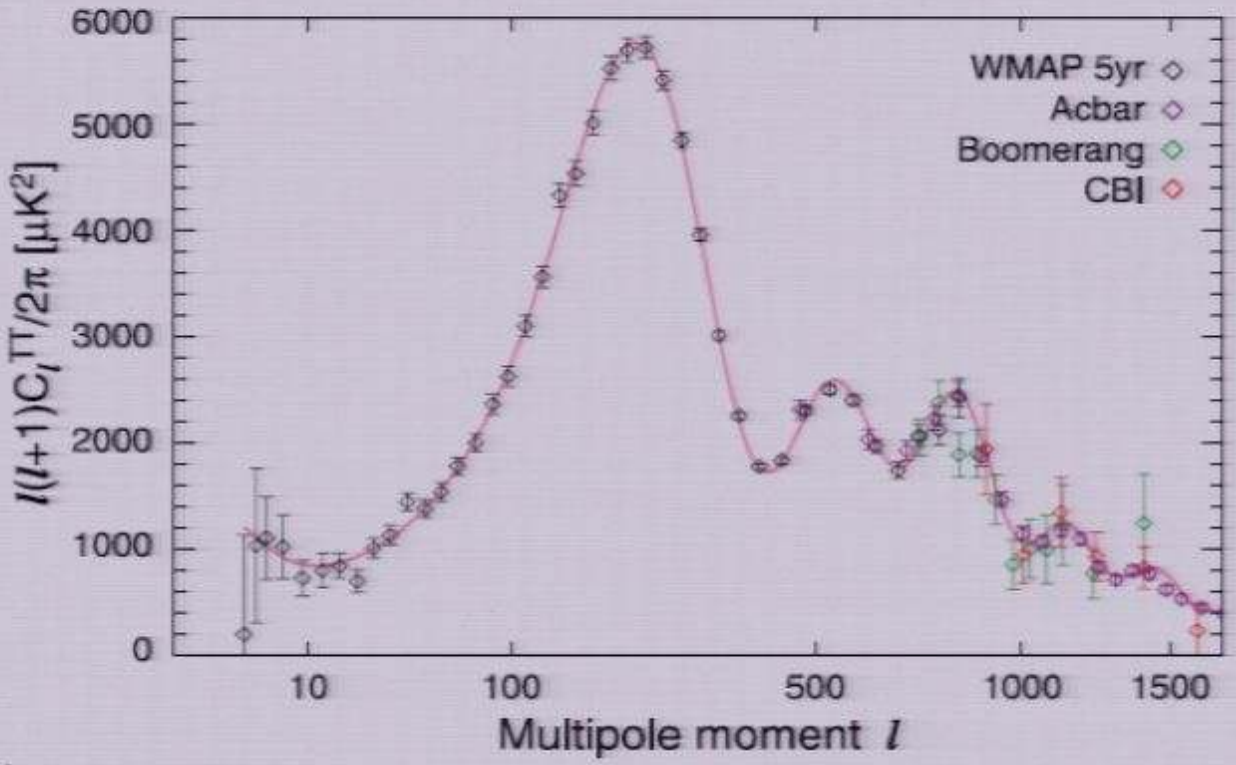
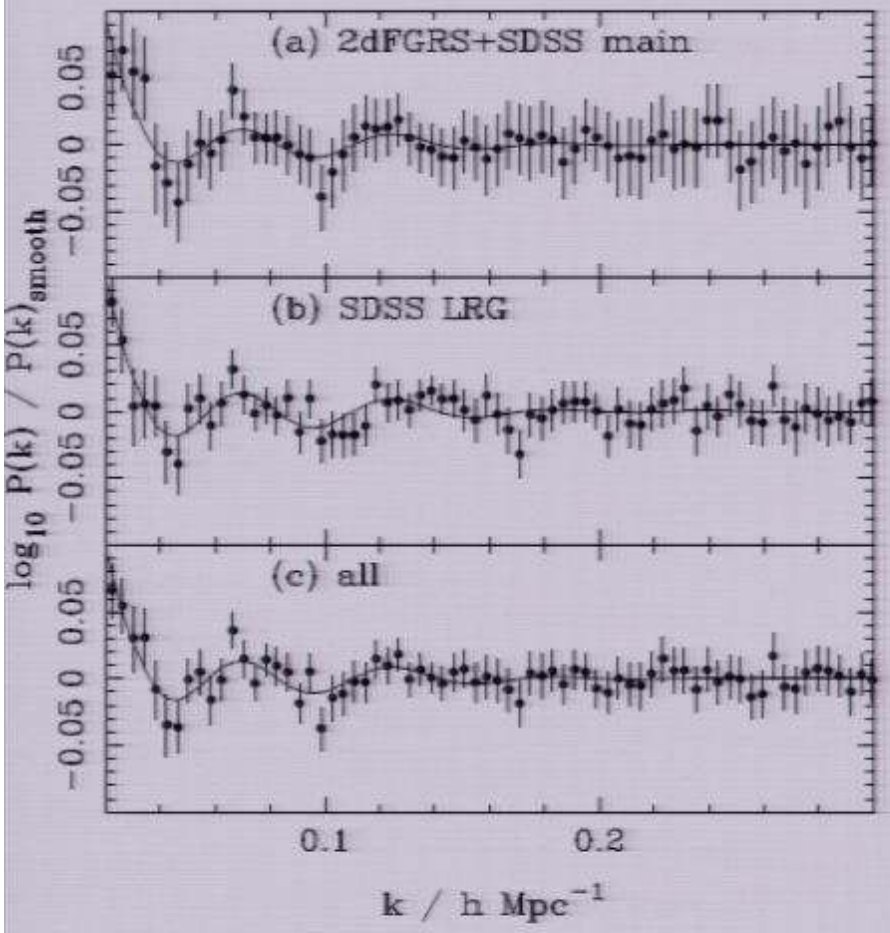
Baryon Acoustic Oscillations – Dark Energy Probe

- CMB acoustic oscillations: imprinted standard ruler, 100 Mpc.
- Present in current matter distribution
- Kinematic metric of universe



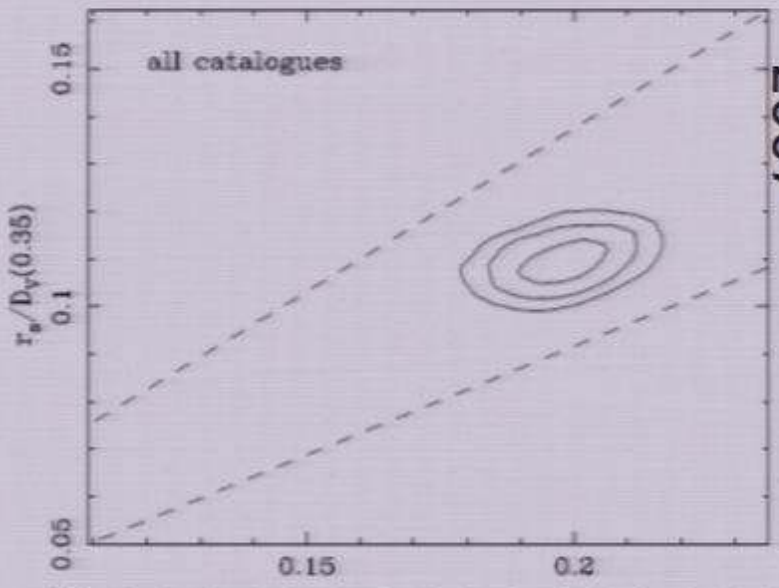
WMAP5 and other, Nolta et al (2008)

Present LSS BAO Detections

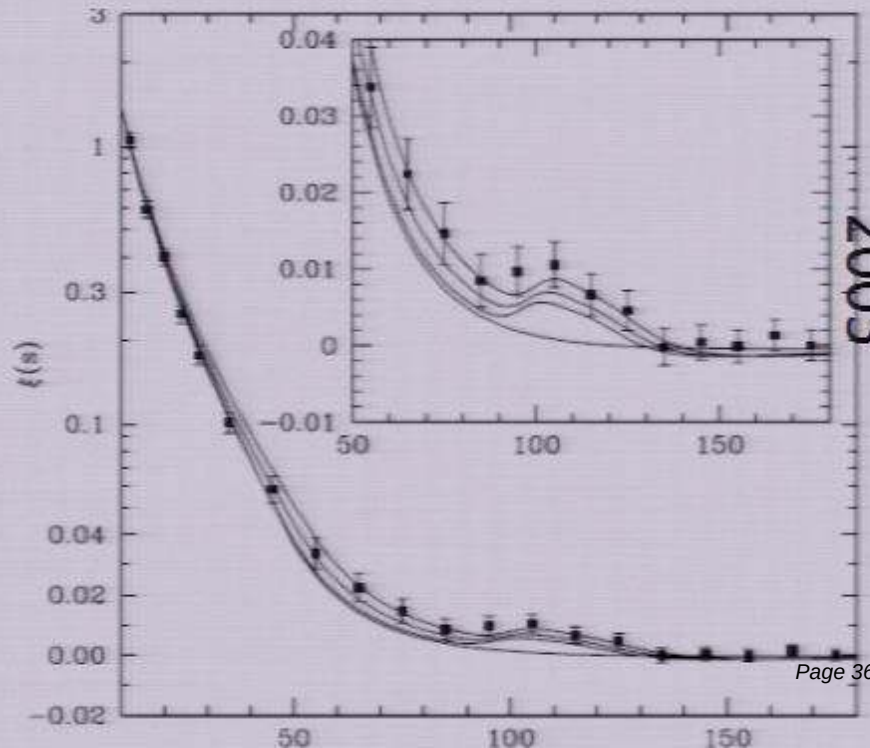


ure 2. BAO in power spectra calculated from (a) the combined SDSS 2dFGRS main galaxies, (b) the SDSS DR5 LRG sample, and (c) the bination of these two samples (solid symbols with 1σ errors). The data correlated and the errors are calculated from the diagonal terms in the riance matrix. A Standard ΛCDM distance–redshift relation was as- ed to calculate the power spectra with $\Omega_m = 0.25$, $\Omega_\Lambda = 0.75$. The er spectra were then fitted with a cubic spline × BAO model, assuming fiducial BAO model calculated using CAMB, as described in Section

Percival et al 2007



Eisenstein et al 2005

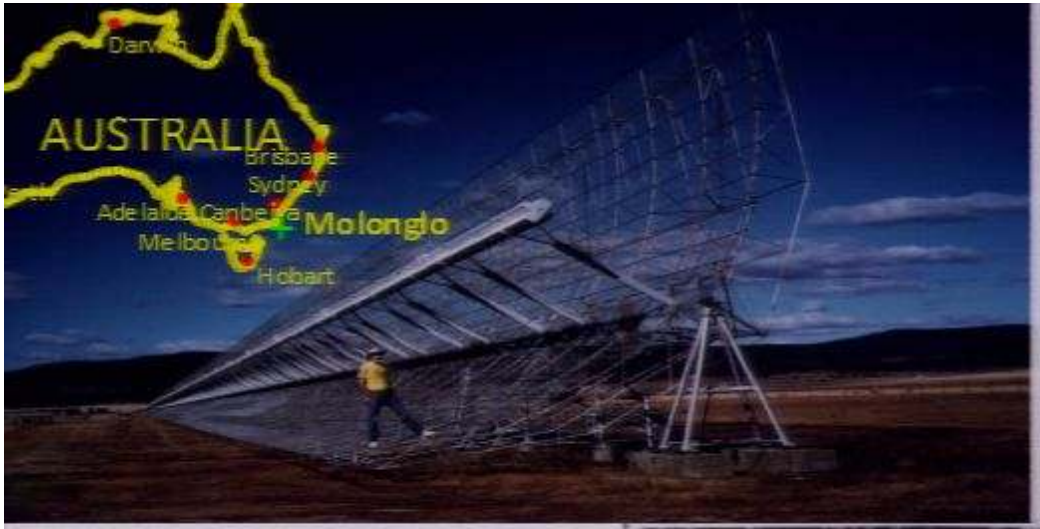


Radio Mapping Experiments

- Redshifted 21cm Hydrogen transition: 300MHz-1.4 GHz, radio maps
- Large area survey, large field of view, low surface brightness: like CMB. Signal ~ 50-200 μK
- Foregrounds large -- ~K, but smooth (spatially and spectrally).
- Potential challenges: frequency dependent beam, polarization leakage, calibration
- Pilot data from Parkes, GBT (UP et al, 3/2009)

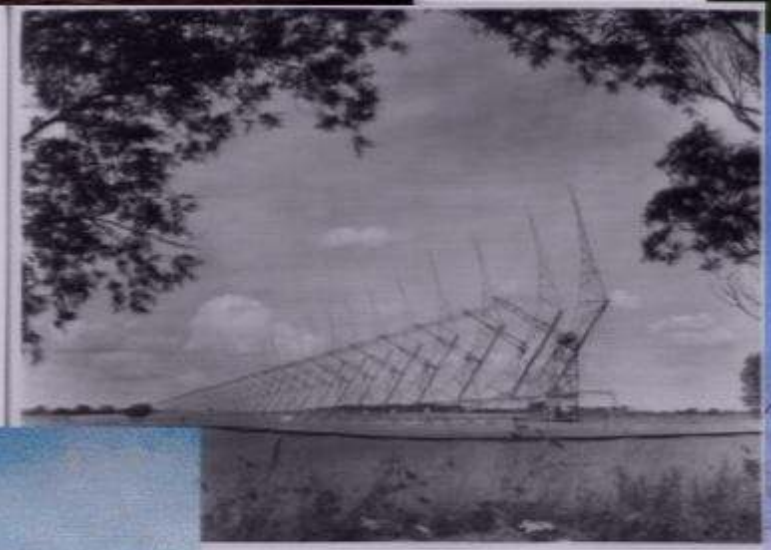
Dedicated Survey Experiment

- Low frequency technology cheap, modest size: $(100\ m)^2$ to $z<2$
- Large field of view: receiver arrays
- High surface brightness sensitivity: compact arrays
- Stable, reliable: no moving parts
- Technologies: aperture arrays (Wyithe, Loeb, Geil 2008), cylinders (Peterson et al)



Northern Cross

Molonglo



Cambridge

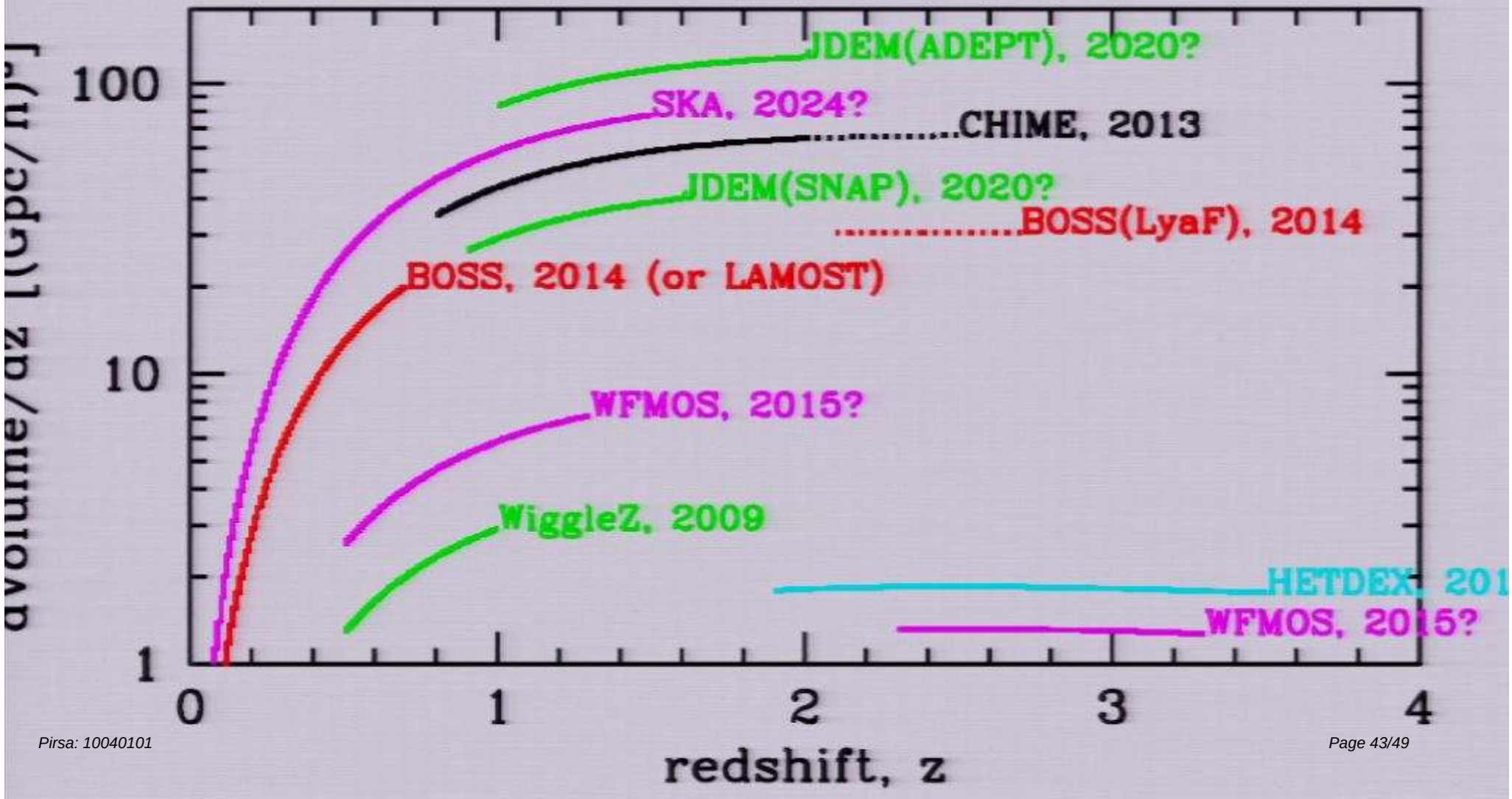
CMU cylinder under construction:
U. Seljak, J. Peterson, K. Bandura, K. Sigurdso

CHIME

- Cosmic (Canadian) Hydrogen Imaging Experiment
- Proposal for cylinders in Penticton (DRAO, BC) (see also CRT: DAPNA/FNAL/IAA)
- Collaboration: M. Halpern, K. Sigurdson (UBC), M. Dobbs (McGill), UP, J.R. Bond, T. Chang (CITA), J. Peterson (CMU) + others

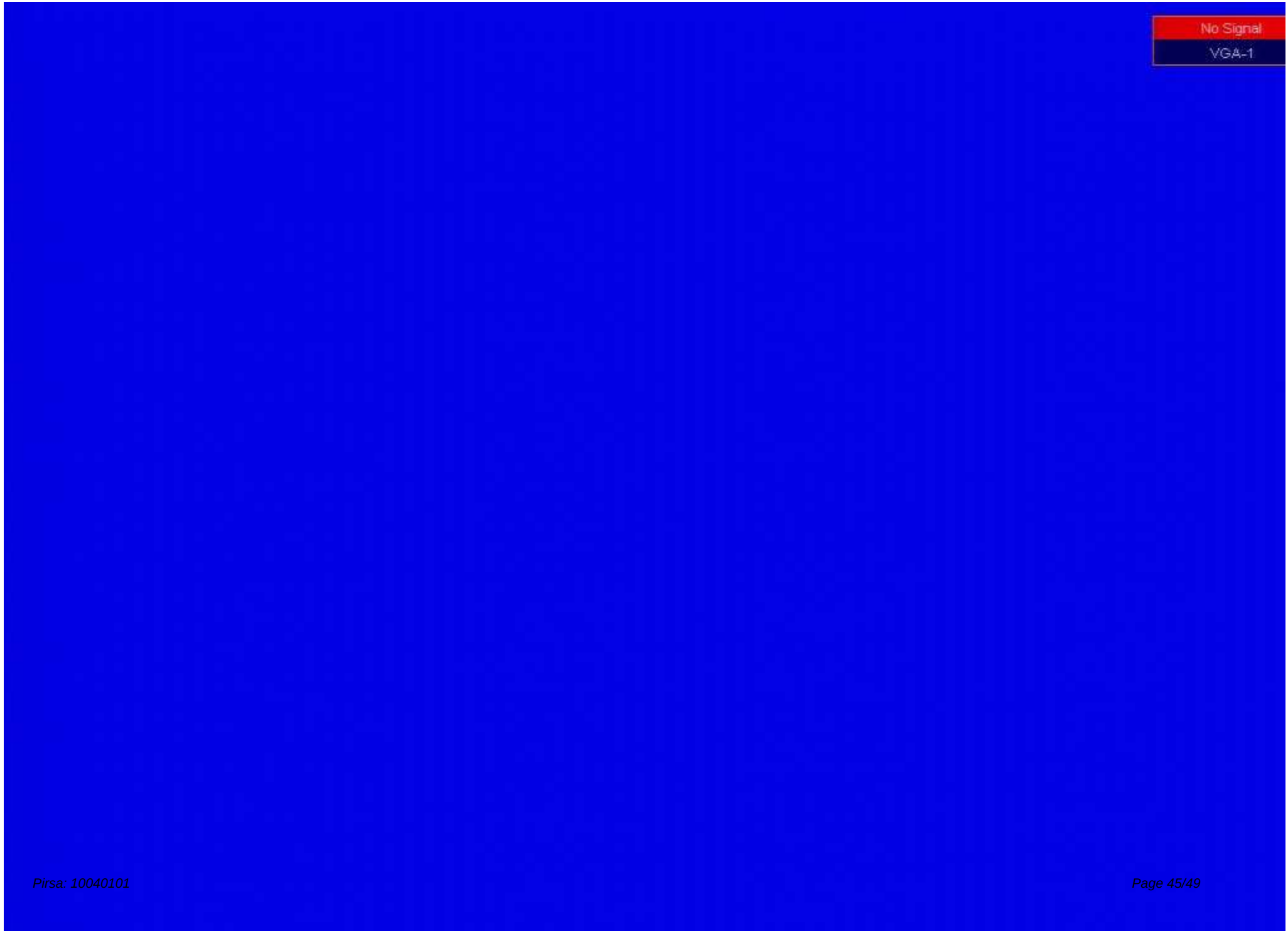
DRAO Penticton CLAR Site

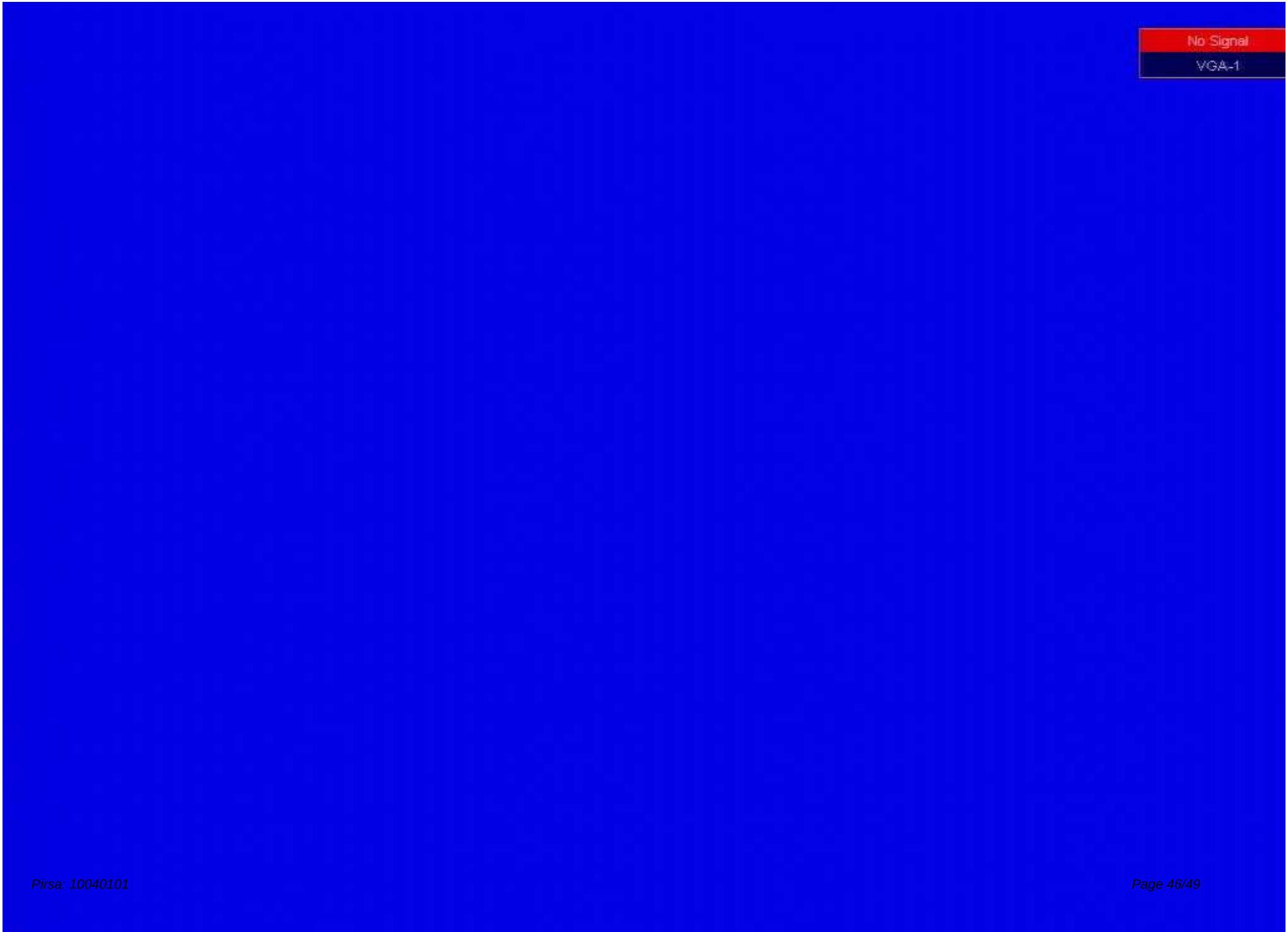
BAO survey volumes



Conclusions

- 21cm cosmology: probes of dark energy (BAO), modified gravity (lensing), Inflation (tensor modes)
- Lack of substantial low frequency telescope investment in 30 years.
- Intensity Mapping: 21cm unresolved galaxies, accessible in redshift desert z=1-3.
- Initial HI detection with GBT at z~1
- Prototypes and observations under way. Cylinder telescopes a promising technology.


No Signal
VGA-1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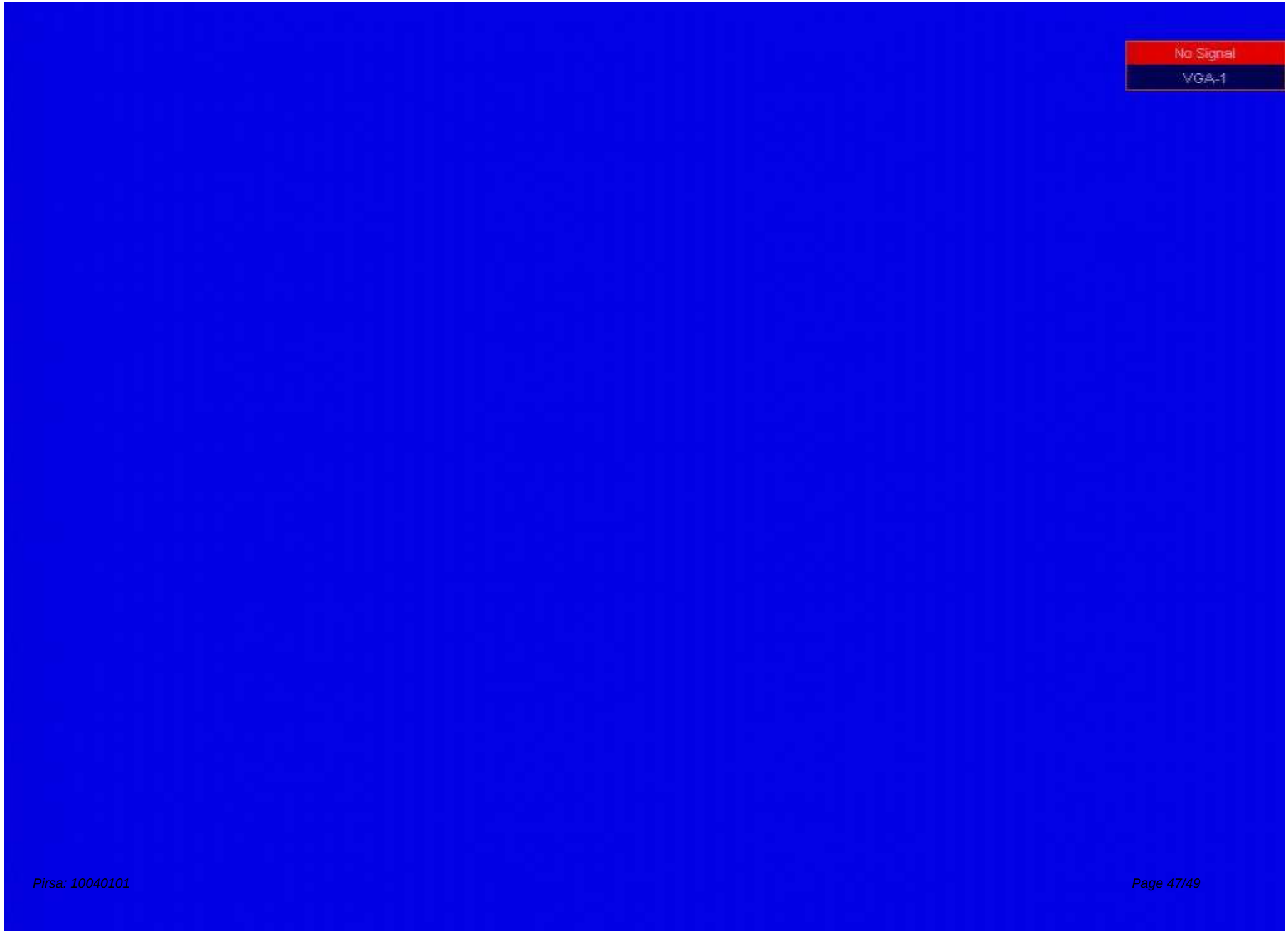
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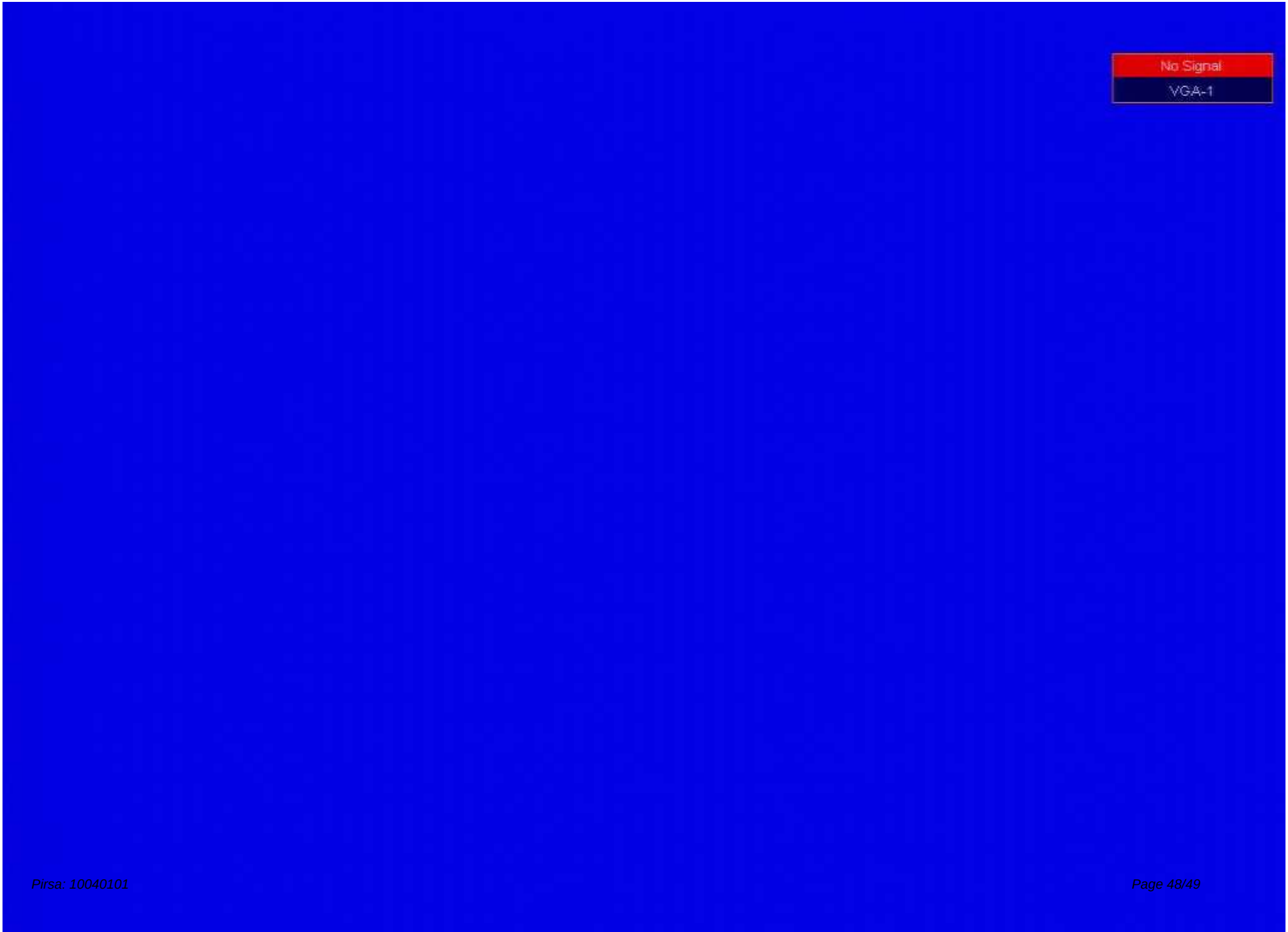
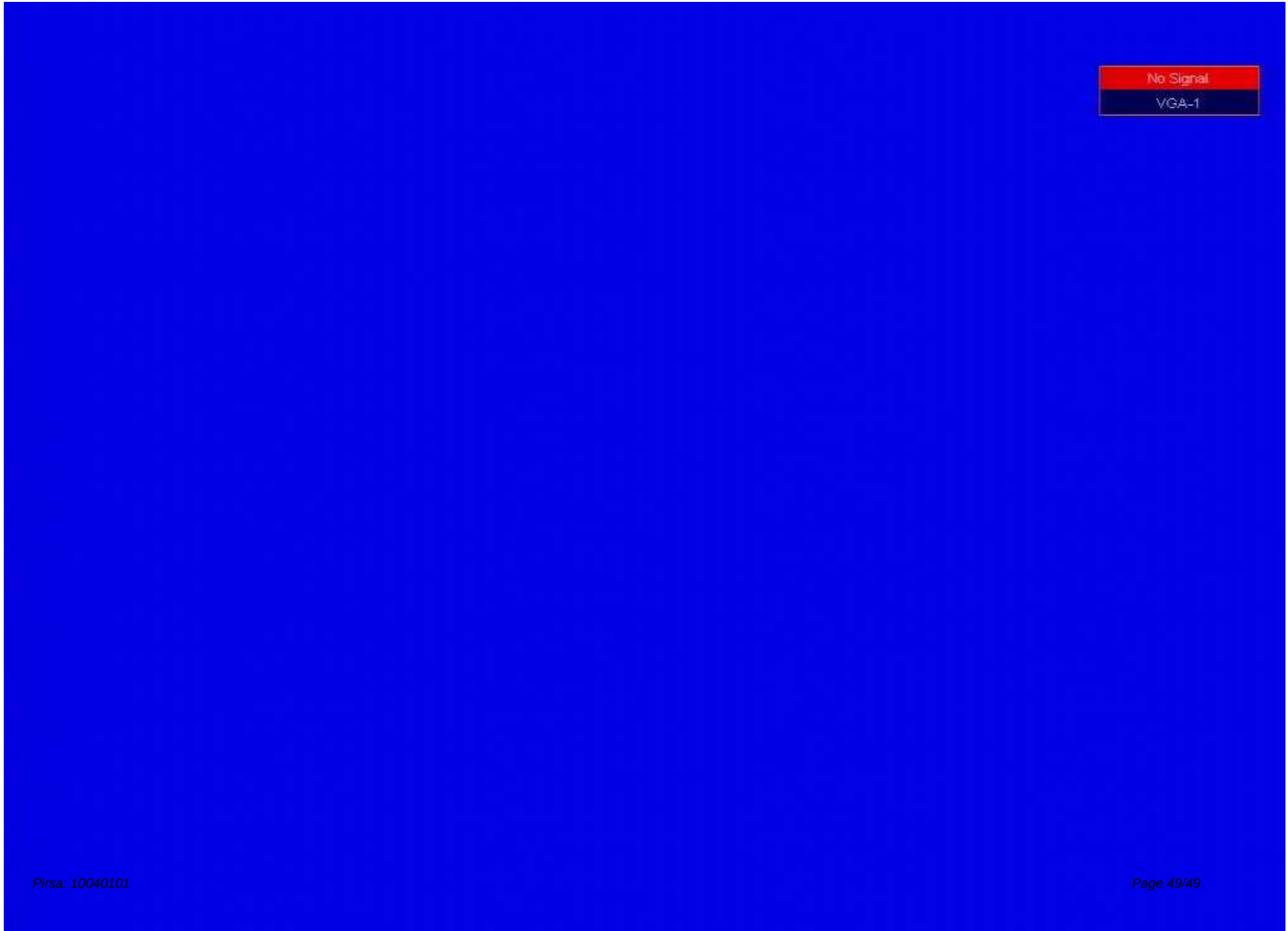

No Signal
VGA-1


No Signal
VGA-1