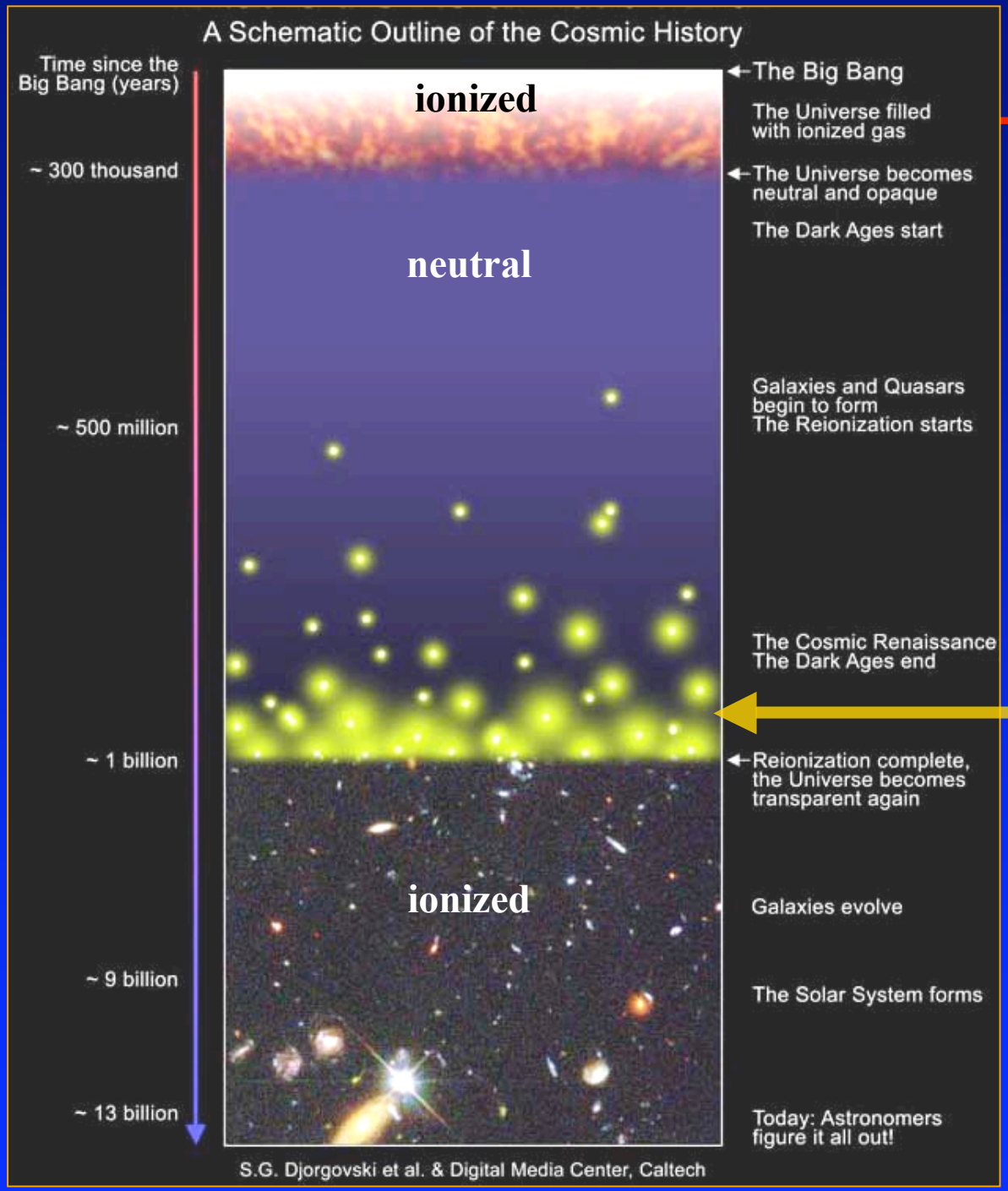
SAO / NRAO VHF development program

- Enables timely (key) research in cosmology
  - puts VLA ~ 3 yrs ahead of other low-ν facilities
  - raises profile of VLA/EVLA
  - greatly expands EVLA low-ν capability
- Brings together two active observatories
- Enables a broad range of legacy science
  - better sensitivity than P-band
  - broader FoV
  - high survey efficiency
  - enables better study of spectral indices @ low-ν

History of IGM



Epoch of Reionization (EoR)

- **bench-mark in cosmic structure formation indicating the first luminous structures**

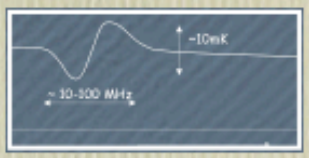
Key Science Questions

- What is the reionization history of the universe?
  - How did the neutral fraction of Hydrogen vary with time?
  - What is the history of heating in the IGM?
    - When did T_{spin} exceed T_{CMB}?
- When did stars, quasars, and LSS form?
  - How anisotropic was the ionization?

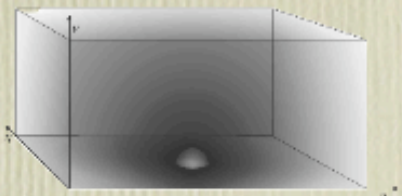
- How can the EOR by studied effectively?
  - Gunn-Petersen trough quasars
    - Ground-breaking, but limited because it is a *LOS* measure ($x_{HI} > 0.001$)
  - 21 cm signatures
    - Potentially paradigm changing, as a probe of *LOS and POS*

21 cm Signatures

- Global reionization step

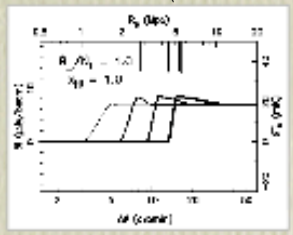


- Statistical properties – power spectrum & non-Gaussian statistics

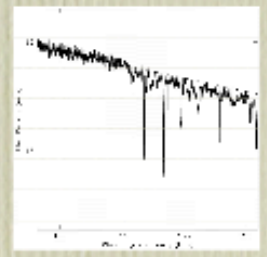


(Morales & Hewitt)

- Quasar bubbles – around known high redshift quasars & fossil HII regions 10-300 mK

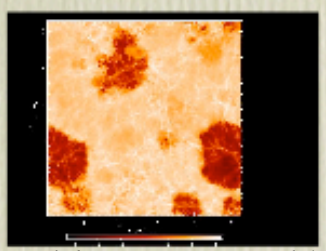


(Wyithe & Loeb)



(Carilli et al.)

- 21 cm forest
- Imaging



(Zaldarriaga et al.)

M. Morales

System Specifications I

- Crossed $\lambda/2$ dipole feed
  - $\lambda/4$ from ground
  - ~ $\lambda/3$ from focus
  - Collins balun (passive)
- Bandwidth - 178 - 208 MHz (l1.6 m)
- Primary beam - ~ 4.3°
- Synthesized beam - 5-15´ (D-config.)
- T_{sys} ~ 180 K (away from Galactic plane)
  - Includes anticipated spillover 20K
- A_e ~ 0.5 (~ 6600 m^2)
- Sensitivity ~ 10 mK in 50^h in 0.8 MHz channel

System Specifications II

- Supply: 15 VDC, 1A
- RF package (box/connectors) to NRAO spec.
- Two circuit-board design
  - temperature regulation of LNA / noise source
  - circuit elements compartmentalized w/in enclosure
- Amplification: 66 dB
- P_{in}(A-rack) ~ -60 dBm
  - Pout (cold sky) ~ -40 dBm
  - final padding to achieve P_{in}(A-rack)
- Polarization: CP out
  - purity: TBD

Relative Performance for VLA Low Frequency Systems

Table 1: VLA Low Frequency Systems

Band [MHz]	Passband [MHz]	A_e	T_{rx} [K]	T_{sky} [K]	D/λ	RMS(10min)* [mJy]	Δ/λ	Focus loss	FoV† [°]	(FoV/scaled rms)^{2}§ [$(°)^2\,mJy^{-2}$]
74	73-74.5	0.15	...	10^3	6	150	0.10	0.01	11	0.0054
VHF‡	178-202	0.5	60¶	100	16	0.9	0.27	0.08	4.1	3
320	305-337	0.4	100¶	25	27	1.4	0.43	0.24	2.5	0.17
1400	1240-1700	0.55	30	3	125	0.056	...	...	0.50	0.22

The VHF system design is optimized for sensitivity more so than existing low-ν systems.

Proposed Timeline

(01/28/05)

- Jan 28 ’05- NRAO design/logistics review
- Feb 15 ’05- First two prototype receivers delivered
  - » Single VHF *aperture* testing
  - » Single VHF *baseline* testing
- Feb 28 ’05- First report on RFI and performance
- Mar 15 ’05- Second report

  Internal go/no-go decision

  2 additional prototypes delivered
  - » VHF *subarray* testing (4 antennas)
- Apr 22 ’05- Final report on performance

  Begin h/w production
- Jun 1 ’05 - “Large” observing proposal for 2007.
- Jun-Oct’05-Large-N array ops/cal testing
- Nov 1 ’05 - D config **first science/proof of concept**

Testing

- SAO obligation
  - hardware assembly / bench tests
  - characterization (e.g., T_{rx}, T_{nd}, ν-response)
  - delivery ready for installation
  - technical support during testing
- Goals
  - evaluate impact on P, L, C, X band performance
    - determine mount type for dipoles
  - characterize real world performance
  - evaluate RFI
    - mitigation strategies
    - develop practical guidelines for VHF scheduling
  - connectivity with VLA IF and correlator
  - design minimum-effort installation procedure
  - design schedule around 4m-survey and EVLA activity

Single Aperture VHF Testing

Feb/Mar 2005

- Install one system *(2d maint)*
  - attach to pre-drilled P-band
  - RF module to barrel cabin
- Electrical connection
  - verify P_{out}, stability
  - daisychain Rx's to A-rack
- On-line system parameters
  - mixers, filters, correlator
  - on/off and pointing scans
  - S/A sweeps, bandpass
- VHF performance *(1d/1n)*
  - $T_{sys}(\nu)$ - using noise diode
  - monitor daily repeatability
  - tip and point to estimate
    - spillover
    - solar interference
  - estimate 1st order efficiency
    - CygA / Cas A (for instance)
    - test different S/R positions
- Assess P/L/X impact *(1d/1n)*
  - mount/dismount…VHF ass'y
    - ratio noise power in each band
      - zenith or tracking near zenith
      - tipping scan
    - full array obs. in each band
      - line mode
      - flux cal source and blank sky
      - ratio RMS for bslns. to test ant.
- RFI environment *(1n +)*
  - S/A sweeps, various pointings
  - check linearity
  - monitor over 24h, multiple days
  - identify sources, WSMR?
- Measure 1st order 2D beam pattern
  - monitor VHF noise power
  - scan CygA / CasA
  - estimate sun avoidance angle

Single Baseline VHF Testing

Feb/Mar 2005

- Install second system *(1d)*
  - attach to pre-drilled P-band
- Electrical connection
  - verification
- Fringe test
  - unpolarized source
  - RCP/LCP stability
- Efficiency and $T_{sys}(\nu)$ (*1n)*
  - compare antennas
    - single aperture techniques
  - correlate single VHF bsln
    - observe flux cals & blank
    - Compare A_e and $(A_{ei} A_{ej})^{0.5}$
  - frequency dependence
- 2^{nd} ant P/L/X impact *(1d/1n?)*
  - mount/dismount…VHF ass'ies
    - ratio noise power in each band
      - zenith or tracking near zenith
      - tipping scan
    - full array obs. in each band
      - line mode
      - flux cal source and blank sky
      - RMS for bsln. *betw* test ants.
- RFI environment *(1n +)*
  - use correlator
    - broad band (12.5 MHz)
    - narrow band (< 1 MHz)
  - characterize impact of fringe rot'n
- Measure 2D beam pattern *(1n)*
  - Use second antenna as reference
  - holographic mode
  - consistency check, *reverse bsln*
  - frequency dependence
  - RCP/LCP squint

Subarray (4) VHF Testing

Mar/Apr 2005

- Install 3rd & 4th systems *(2d)*
  - attach to pre-drilled P-band
- Electrical connection
  - verification
- Fringe test
  - closure
- Efficiency and $T_{sys}(\nu)$ *(1n)*
  - compare antennas
    - single aperture techniques
  - correlate subarray
    - line mode
    - observe flux cals & blank
- RFI environment *(1n +)*
  - Generalize single bsln tests
- P/L/X impact on 3rd and 4th ants.
  - repeat earlier procedures *(1d/1n?)*
- Characterize polarization purity *(1n)*
  - determine D-terms
  - estimate stability over time
  - assess limitations on future DNR
  - evaluate design requirements
- Characterize spectral baselines *(<1d)*
- Image noise *(1n)*

Staffing for Activities on Site I

- Three phases of testing
  - Single VHF aperture testing
  - Single baseline testing
  - VHF subarray testing
- SAO contribution
  - 1 technical staff member
    - available on a rotating basis as required for testing
      - Kimberk
      - Leiker
      - Barrett (alt.)
  - 1 science staff member
    - on site / off site as required
  - Students/Fellows
    - one student @ SAO participating in h/w assembly p/t
    - more possible as available

Staffing for Activities on Site II

- NRAO contribution - proposed

	Single VHF aperture	Single VHF baseline	VHF subarray (4)	5 month full deployment
engineer	2 d	-	0.3	8 d
antenna tech	4 d	4 d	2 d	14 d
FE tech	4 d	1 d	2 d	14 d
s/w eng.	0.5 d	1 d as req.	0.5 d as req.	…
Carilli	8 d	5 d	10 d	10 d
Perley	4 d	2 d	4 d	5 d
SAO staff	4 d as req.	1 d as req.	7 d as req.	7 d as req.
Greenhill	8 d as req.	5 d as req.	10 d as req.	…

Turnover

- 2005 B/C-configurations
  - installation, testing
- 2005 D-configuration
  - first science
  - demonstration of real-world performance
    - noise, polarization
- 2006+
  - available for community use, all configurations
    - no specialized user knowledge over P-band
    - *jobserve* option
  - permanent mount option
    - users see just another band
  - removable mount option
    - users see j.a.b. … but it is scheduled as is 4m-band

Action Items

- ID antennas that have pre-drilled P-band balun plates
- ID how collimation reflectors could be attached to VHF ass'ies
- RFI source identification
- Determine how S/A sweeps can be recorded day by day
- Simulations to demonstrate mitigation of linearly polarized galactic foreground emission

Impact

- VHF Commissioning
  - phase 1: 4d/2n
  - phase 2: 2d/4n
  - phase 3: 4d/5n
  - will work to minimize impact on astronomy
    - night runs ~ 4-6^{h}
    - day runs ~ maintenance, s/w time
    - some tasks overlap ⇒ savings
    - intensive testing desired for coordination of SAO contrib.
- EVLA (long-term)
  - no impact once commissioned
    - (+) contribution of a new band
    - (+) sensitivity optimized (unlike 4m / P)
    - (+) expansion of user base and science