National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

LUNAR

DARE Science Instrument

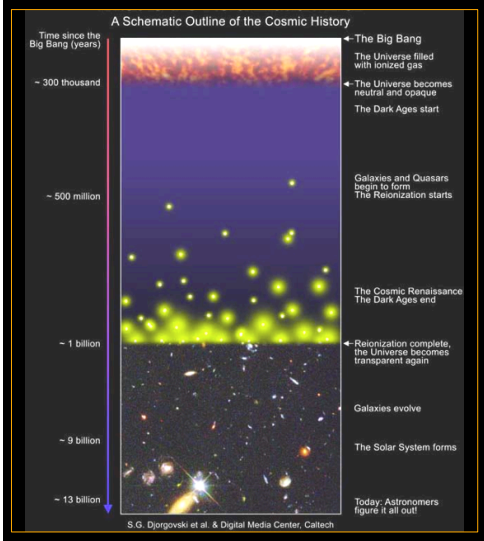
Joseph Lazio
Jet Propulsion Laboratory, California Institute of Technology

On behalf of DARE Science Instrument team

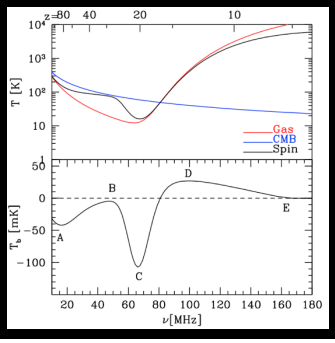
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

LUNAR

DARE Science Objective



Determine the nature of and epoch of formation for the first luminous sources in the Universe



National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Science Traceability Matrix

LUNAR

Science Goals	Science Objectives	Scientific Measurement Requirements: Observables	Scientific Measurement Requirements: Physical parameters	Instrument Functional Requirements		Projected Performance	Mission Functional Requirements (Top Level)
Understand the origin and destiny of the Universe	Determine the nature of and epoch of formation for the first luminous sources in the Universe	Frequency of onset of redshifted 21-cm absorption trough	Redshift at which first luminous sources produce a significant Lyman-alpha background.	Frequency range	40–120 MHz	40–120 MHz	Orbit around Moon
		Slope of deepening redshifted 21-cm absorption trough	Rate at which first stars produce Lyman-alpha photons	Spectral resolution	500 kHz	100 kHz	
		Frequency of the turning point at the maximum absorption of the redshifted 21-cm line	Redshift at which heating of intergalactic medium becomes significant	Temporal resolution	1 s	1 s	Lifetime = 3 yr
		Amplitude of maximum absorption in redshifted 21-cm signal		emporal ability	< xx dB gain variations over 30 min.		
				nsitivity	0.5 mK after th required integration time		Orientation of the spacecraft known to at least 1 degree
		Slope of redshifted 21-cm background signal at higher frequencies than absorption peak	Rate of heating of the intergalactic medium	alactic ise ontination of ystem mperature	T_{sys} 3 dB greater than an other contribution to T_{sys}		
				ntenna wer pattern	Only a single primary lobe over the required frequency rang	Only a single primary lobe over the required frequency range	
		Frequency of the turning point at the maximum of the 21-cm signal	Redshift at which gas temperature is much greater than that of the cosmic microwave background, $T_{gas} >> T_{CMB}$	bsolute alibration	known to at least 10% for each spectral channel		
				requency ructure	no spurious artifacts exceeding 0.5 mK in a 500 kHz spectral channel		
		Slope of declining emission in 21-cm background	Rate at which the ionizing background increases	lative pectral alibration	fitting a 3rd-order polynomial to the spectrum leaves residuals no larger than mK during an observation of a 2000 K		

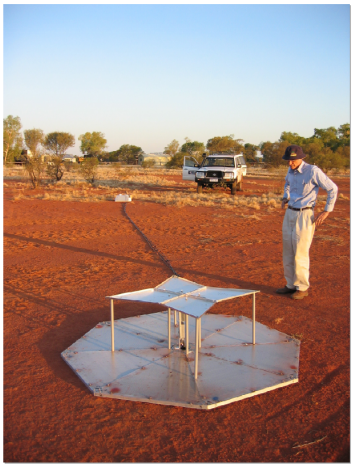
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Heritage

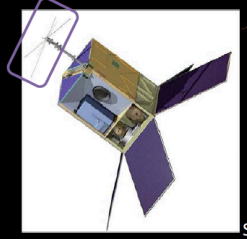
LUNAR

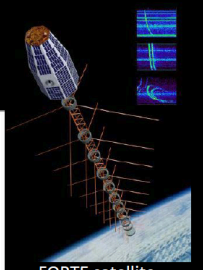
Ground

The Experiment to Detect the Global EOR Signature (EDGES)



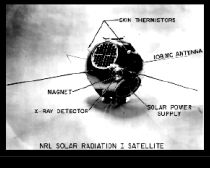
Space





FORTE satellite (LANL)

STPSat-1/CITRIS (NRL)



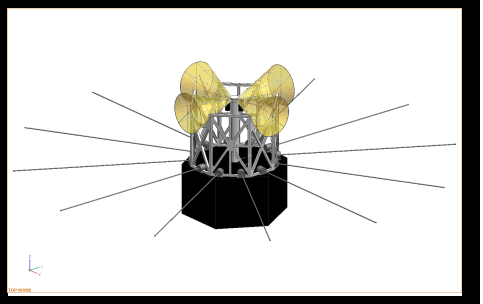
SOLRAD/GRAB (NRL)

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Science Instrument

LUNAR

- Broadband RF spectrometer
- Important to design as integrated whole, *but* …
- Illustrate RF signal flow by considering sub-systems
  - Antenna
  - Receiver
  - Digital Spectrometer

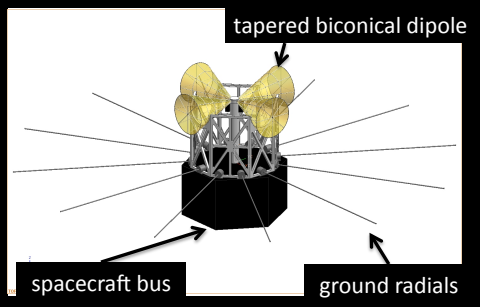


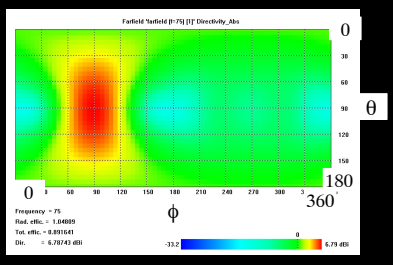
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Science Instrument
Antenna

LUNAR

- Tapered biconcial dipole topology
  - Low-mass, compact design to cover the frequency range
  - Other topologies would be large, probably requiring deployment
    - E.g., log-periodic
  - Constructed from an internal wire frame covered with knitted gold-plated wire mesh used on deployable communication antennas
  - Dielectric support structure is an Astroquartz/Kevlar fiber and cyanate ester resin composite
    - good thermal stability
    - low RF loss
    - coated by a high resistivity Ge coating to bleed off any solar wind induced charge
- Ground radials improve forward gain
  - Effective as a solid ground plane
  - Far easier to deploy, with demonstrated history
  - 12 radial extensions formed by deployable beryllium copper antenna elements





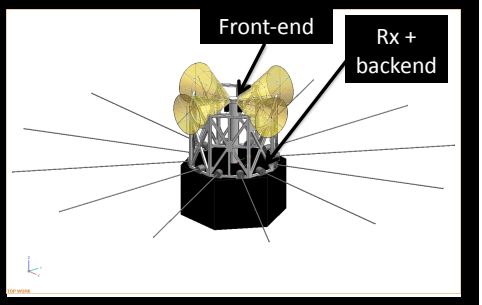
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Science Instrument Receiver

LUNAR

Designs considered

- Single-ended design, with cascaded amplifiers
  - Provides a poor match to the Science Antenna
- Ferrite isolator
  - physically large, may not operate over the entire frequency range
- Balanced design
  - Minimizes the reflection to the Science Antenna
- **Balun**
  - – Uses active elements near the Science Antenna to match its impedance variations
  - – considerable ground heritage, but, on a spacecraft, has thermal considerations
- Active isolator
  - Requires an additional ±12 VDC and qualification of a second amplifier
- Current Feedback Amplifiers
  - Requires qualification of a second amplifier

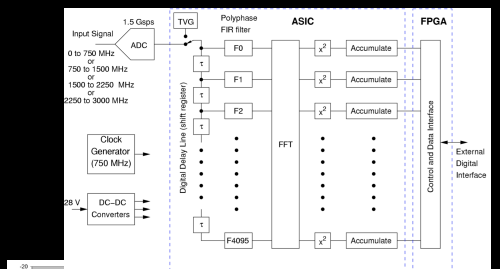


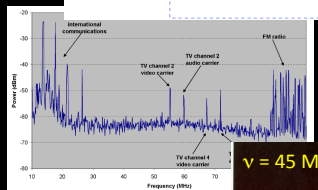
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

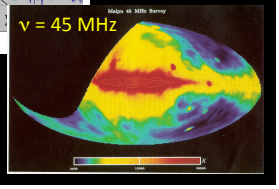
Science Instrument Digital Spectrometer

LUNAR

- 40-120 MHz with 10 kHz spectral resolution ➔8k point spectrum
  - Cf. GUPPI = 4k spectrum over 800 MHz
- Basic design = ADC + polyphase spectrometer
  - – Several rad-hard ADCs available
  - – Rad-hard Xilinx and Actel FPGAs available
- Data compression not an option
- High bit depth not needed
- Limiting factor is downlink data rate





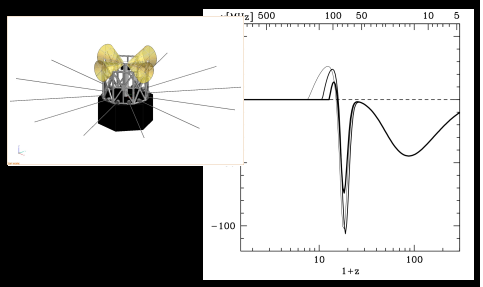


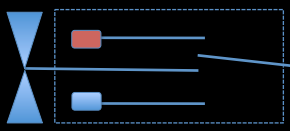
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Calibration

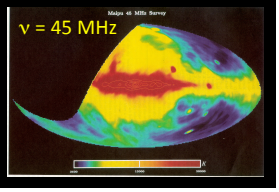
LUNAR

- Based on proven ground-based techniques, viz. EDGES
- Absolute calibration less important than relative spectral calibration
- 3-input switching allows power from antenna to be determined
- Variation of sky temperature also allows antenna to be calibrated





3-input system



National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Summary: Science Instrument

LUNAR

- Science requirement dictates broadband RF spectrometer
- Design draws on long ground- and space-heritage
- Implementation at high TRL
- Ready to begin building!