A Concept of the Space Borne Dark Age Interferometric Array (DAIA)

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Outline

- Science objectives
- Suggested payload
- Mission concept
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- Heritage from previous studies/missions
- Conclusion

Moonlight in a Spring Night
（春江花月夜）

滟滟随波千万里，何处春江无月明！

江流宛转绕芳甸，月照花林皆似霰；

空里流霜不觉飞，汀上白沙看不见。

江天一色无纤尘，皎皎空中孤月轮。

江畔何人初见月？江月何年初照人？

人生代代无穷已，江月年年只相似；

不知江月照何人，但见长江送流水。

江水流春去欲尽，江潭落月复西斜。

斜月沉沉藏海雾，碣石潇湘无限路。

不知乘月几人归，落月摇情满江树。

——唐•张若虚

History of the Universe: Cosmic Timeline

10^{-43} second
Space and time disentangle; earliest meaningful time

10^{-33} second
Cosmic inflation creates seeds of matter clumps

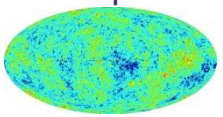
10^{-4} second
Protons form

10,000 years

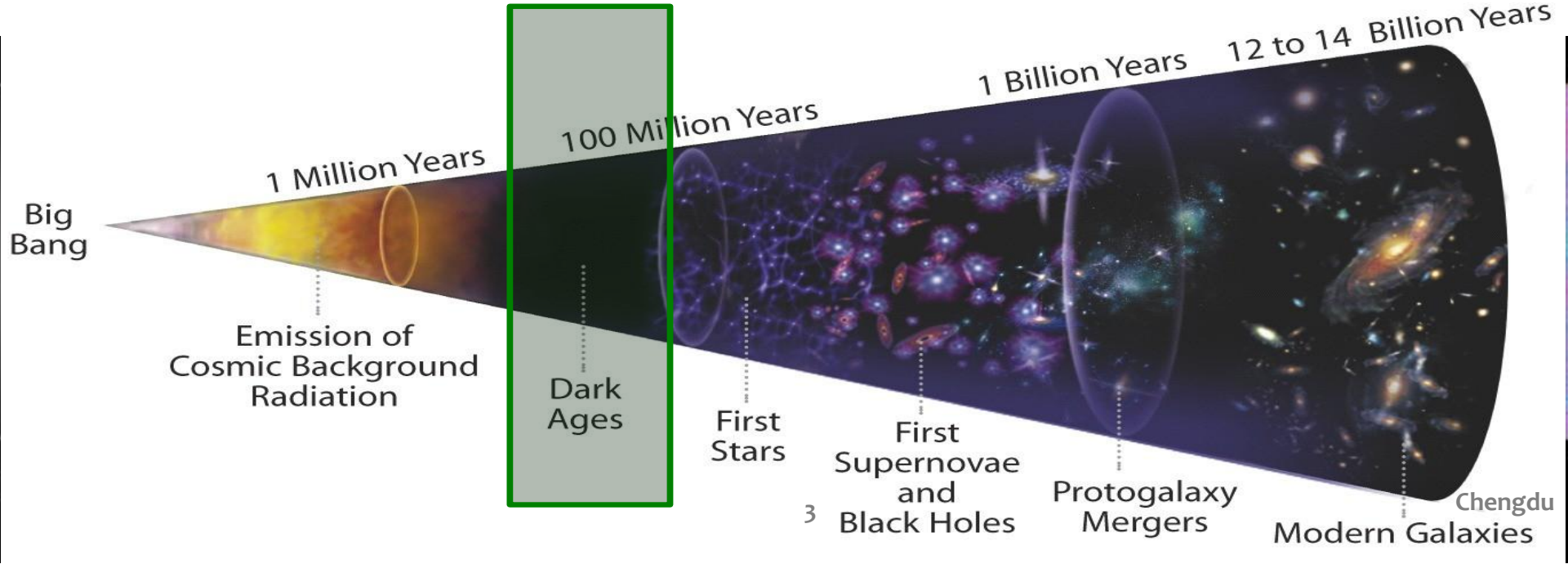
70,000 years
Matter becomes dominant component of cosmos; clumps begin to grow

100,000 years

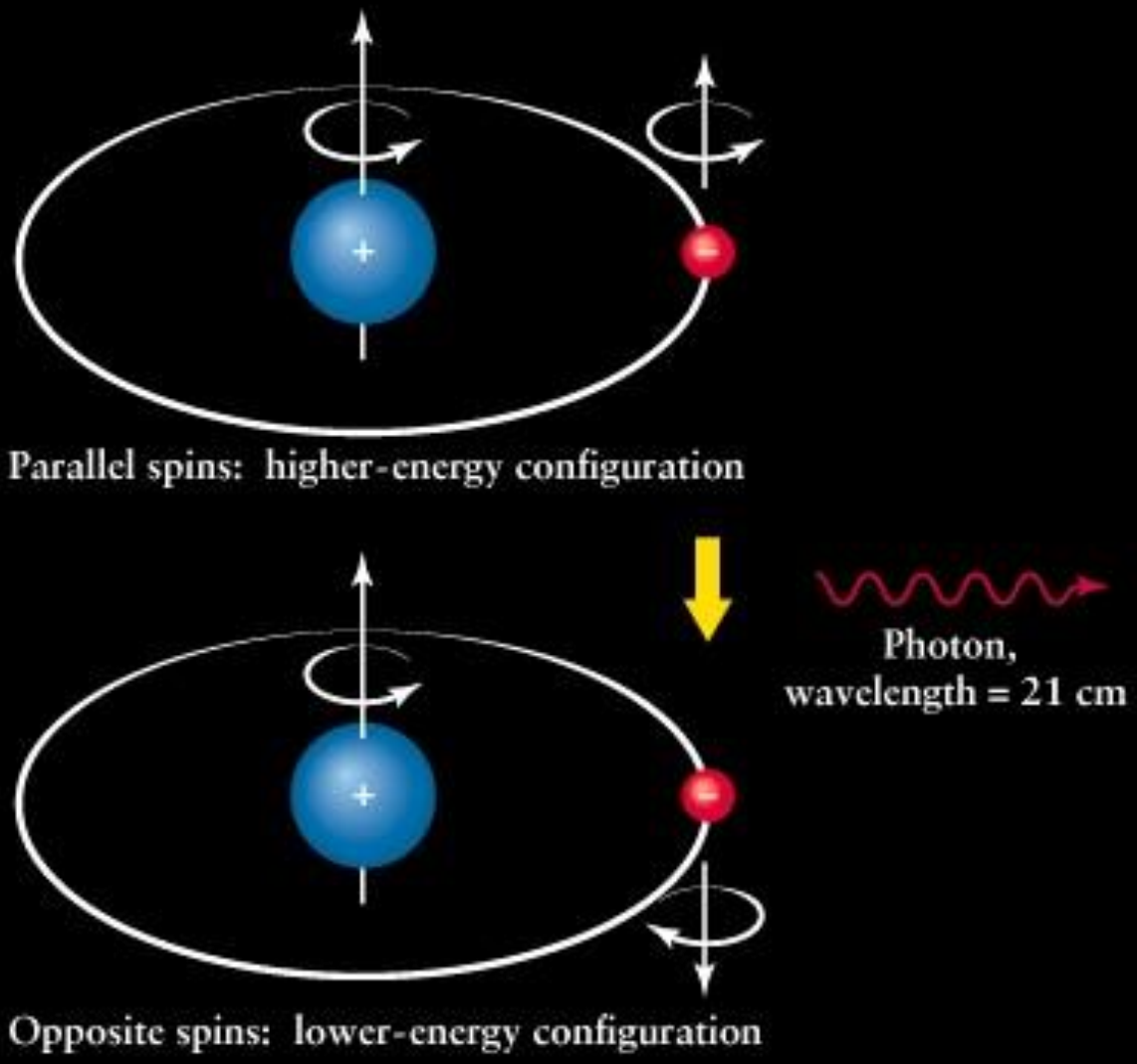
400,000 years
Recombination: neutral atoms form, releasing the microwave background



1 million years

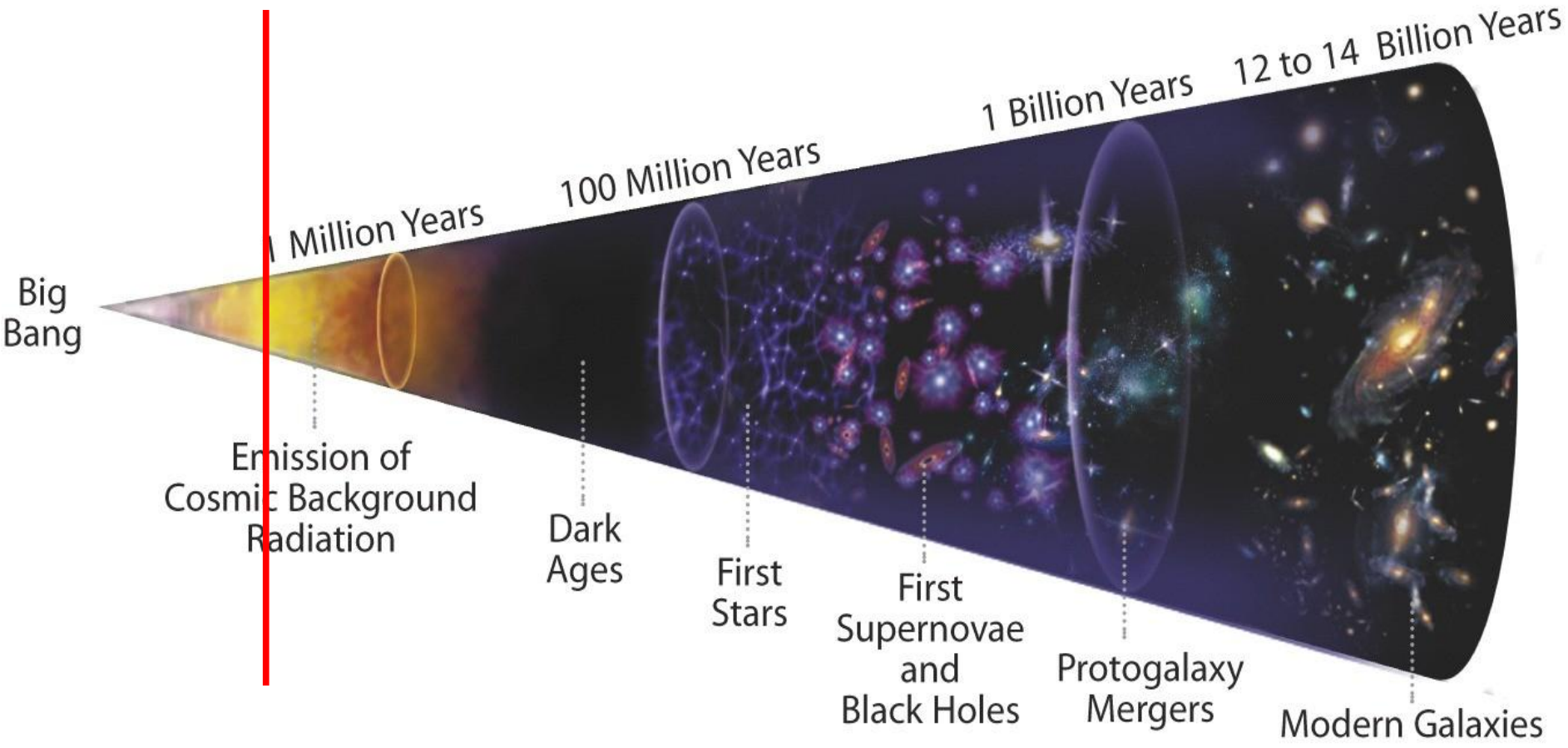


The *Moonlight* in the Dark Ages: 21cm radiation from HI



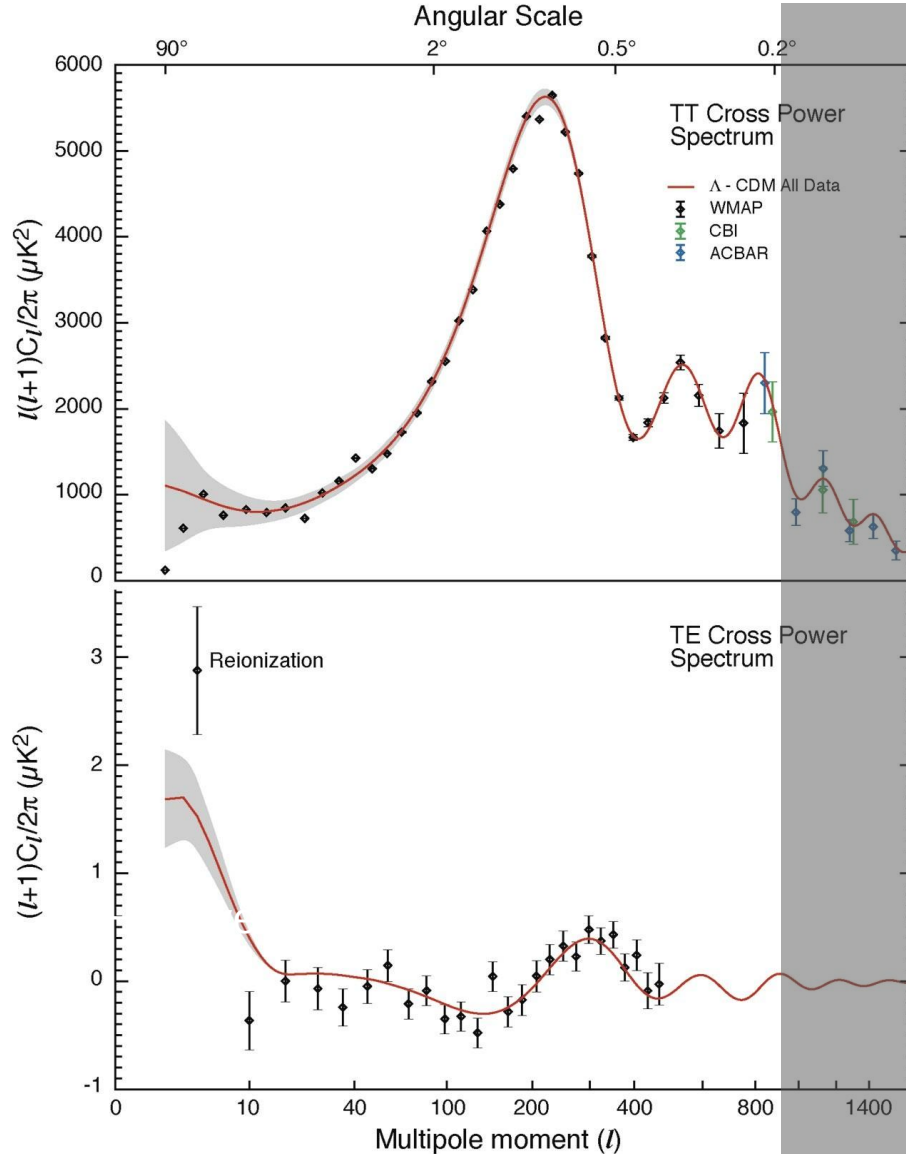
Why study Dark Ages:

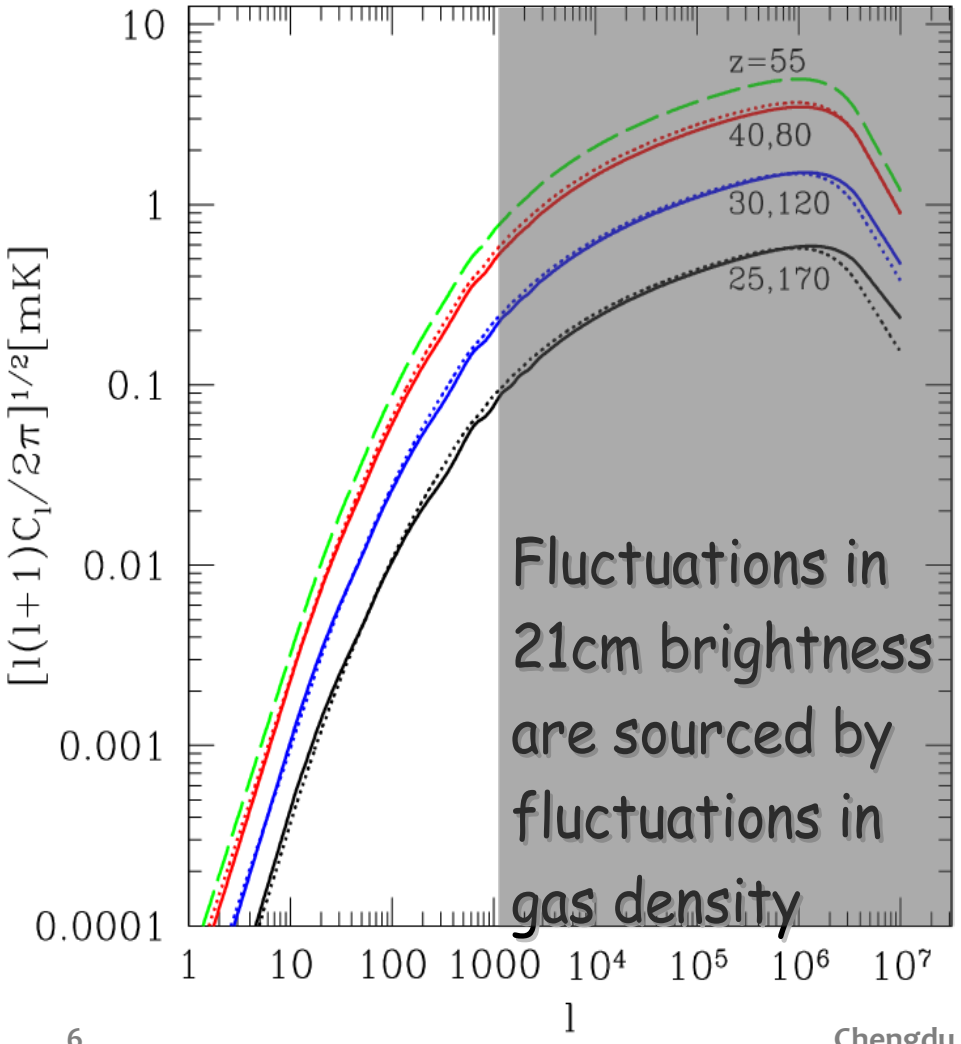
CMB is only a single snapshot at z=1100



Small scale power-spectrum; DM/DE properties

Precise Cosmology; Linear regime





Expected 21-cm signal

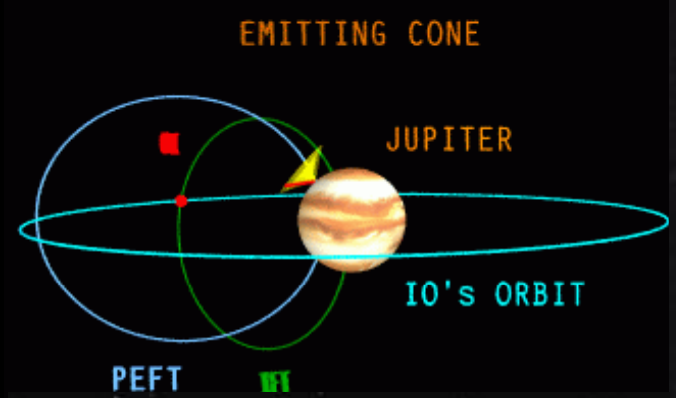
$$\delta T(\nu) \approx 16\,\mathrm{mK}\,(1+\delta)\,x_{HI}\,\frac{T_s - T_{CMB}}{T_s}\,\frac{\Omega_b h^2}{0.02}\left[\frac{0.15}{\Omega_m h^2}\,\frac{1+z}{10}\right]^{1/2}\left(\frac{0.7}{h}\right)$$

Redshifted 21cm radiation: (Burns et al. 2012)

z=1000~30 redshifted to 8~50m (5~35MHz)

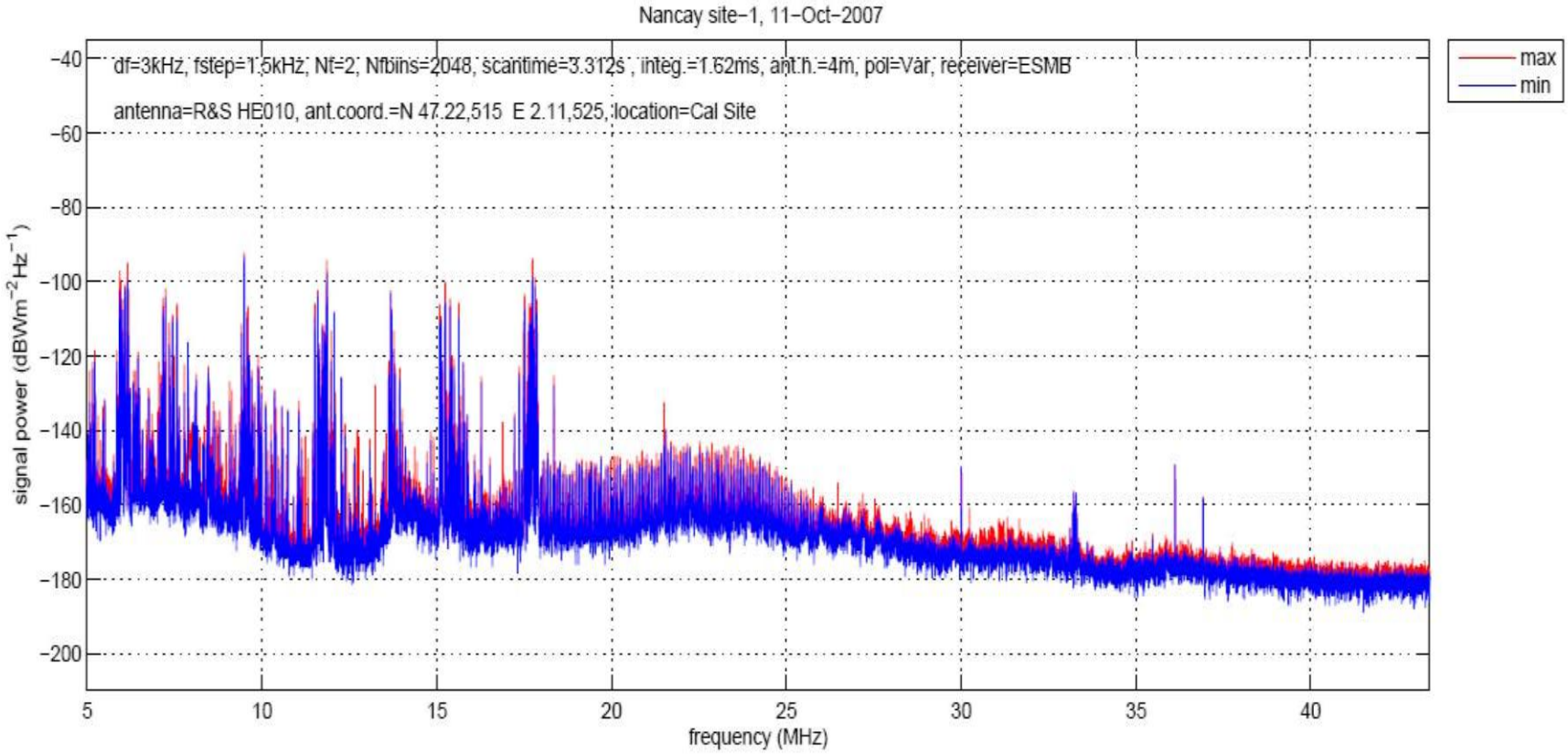
More interesting/important scientific issues

- Extragalactic Survey
- Galactic cosmic-ray detection
- Magnetized Planets
- Exoplanet Transit detection



How to Detect ?

- **Interference**: very crowded spectrum on the Earth



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From science to technical requirements

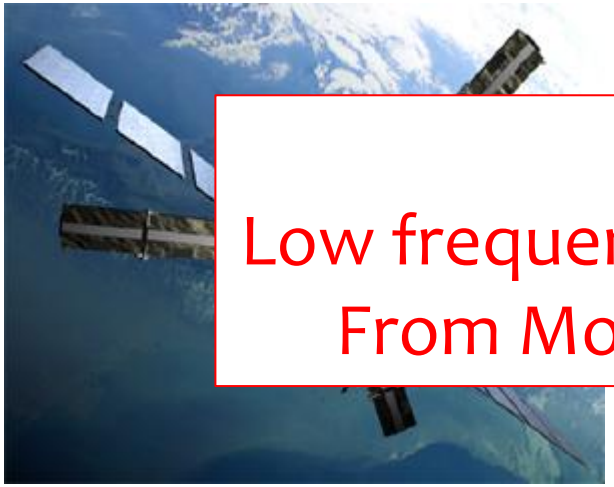
- **Scientific input**: Imaging + spectrum
  - 1 ~ 30MHz band width
  - Spectral resolution: 1kHz
  - Image of large field of view (FOV)
  - Image refresh time: hours to years

- **Technical requirements**:
  - huge aperture : Large collecting area for high sensitivity
  - Far from the Earth: Escape from Earth/Sun initiated radio interference
  - Quick image with large FOV by low frequency interferometric radiometry
  - Wide frequency band and digital receiver for spectral analysis
  - Large baseline for high resolution
  - At the shadow of Earth/Sun to avoid radio interference

Suggested Payload

-- 1 – 30MHz Synthetic Aperture Radiometer

- Cross dipole antenna on board nano-sat platforms
- Aperture synthesis with a large scale array of ~15 satellites in the lunar orbit
- Full coverage and small baseline over UV plane by orbit maneuver
- Observing in the far side of the Moon, telemetry in the near side
- The normal of the orbit plane is pointing to the center of the observed area



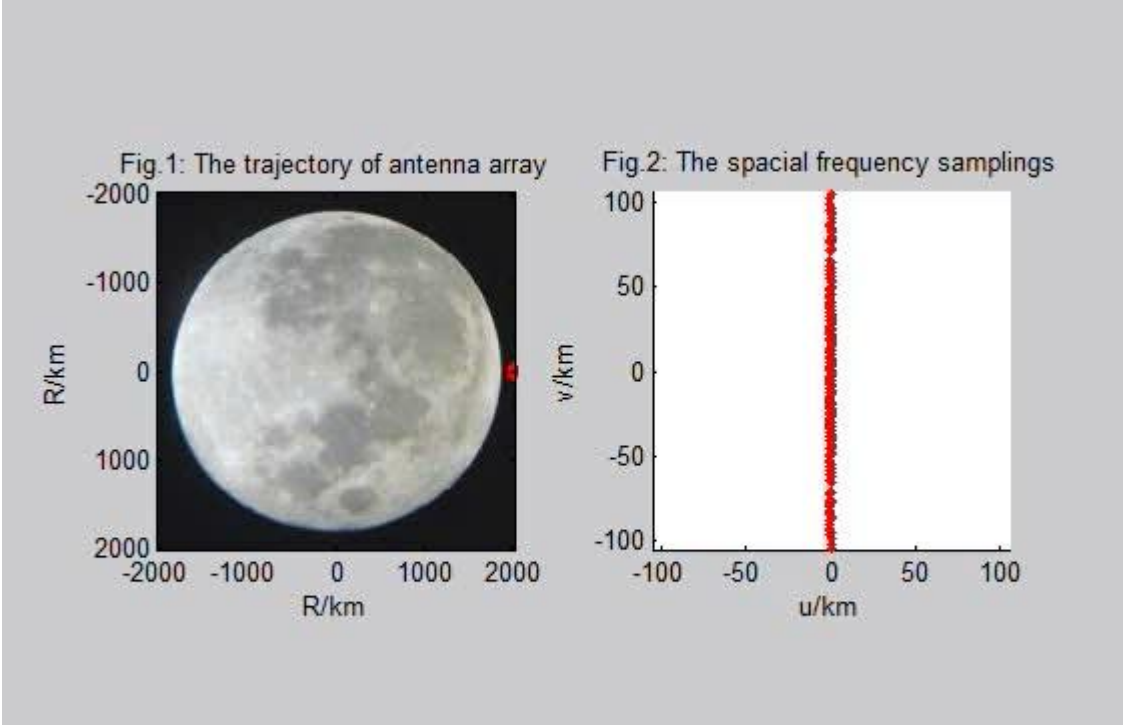
From space to Earth surface (SMOS/ESA)

DAIA
Low frequency radio observatory
From Moon Orbit to Space!

From Earth surface to space (ALMA)

DAIA array design

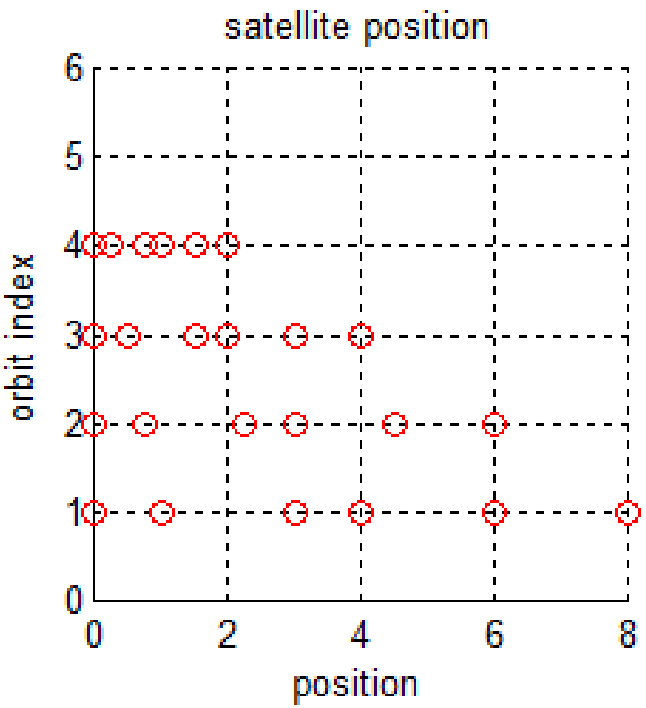
- **Minimum redundancy configuration, 83 independent baselines with 15 element antennas**
- **Full UV coverage every half orbit, spacing between elements varies from orbit to orbit by maneuver**
- **High density UV plane every 10 days**
- **Simplify the formation maintenance and maneuver**
- **~10days/month without Earth/Sun interference free**

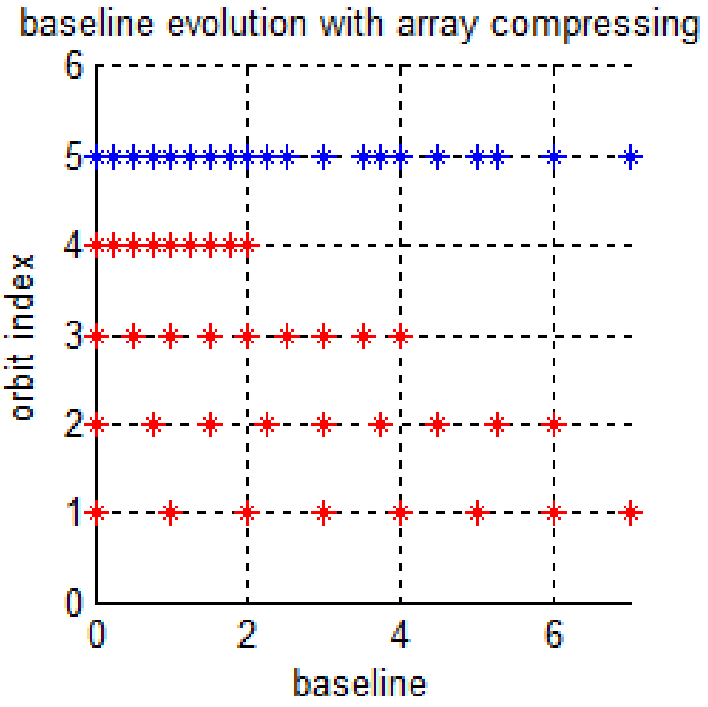


Mother Satellite

Elements positions: 0 3 6 10 18 34 39 56 59 64 82 83 94 96 105 km

Full coverage in UV plane





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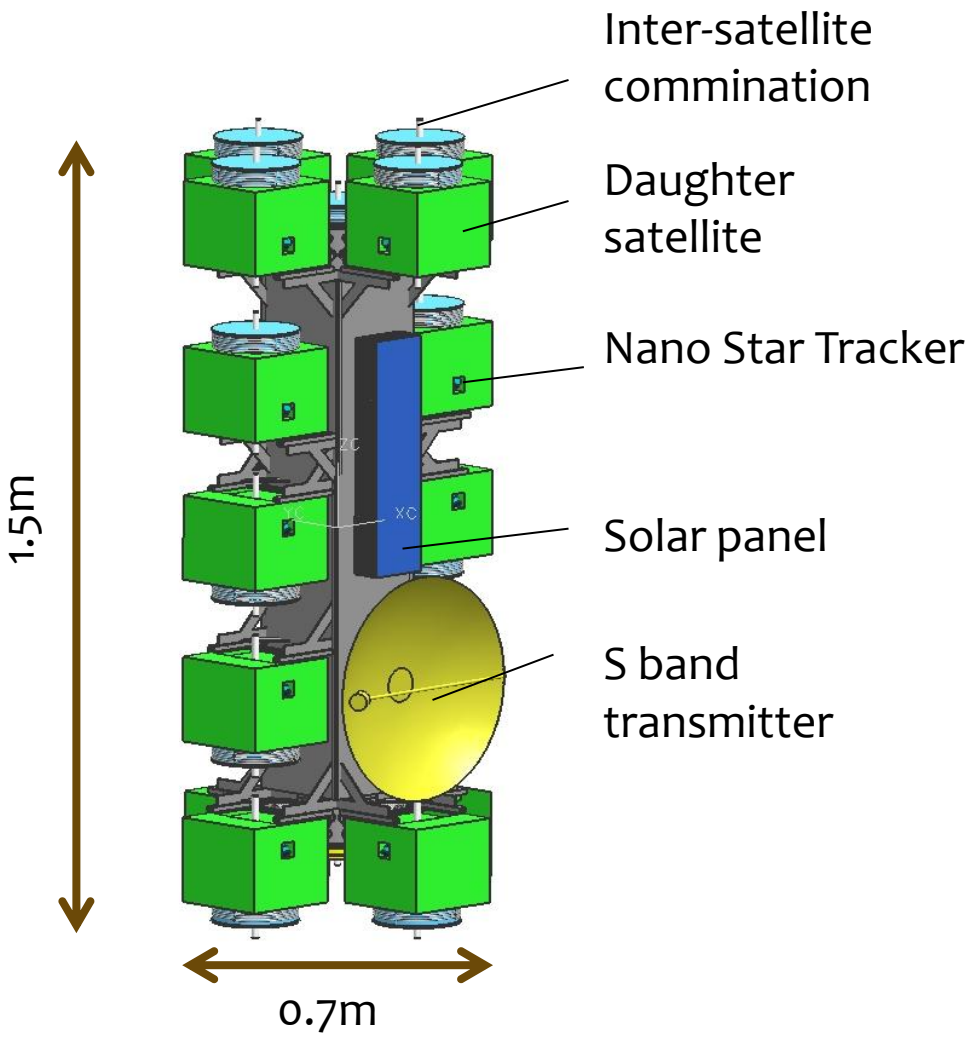
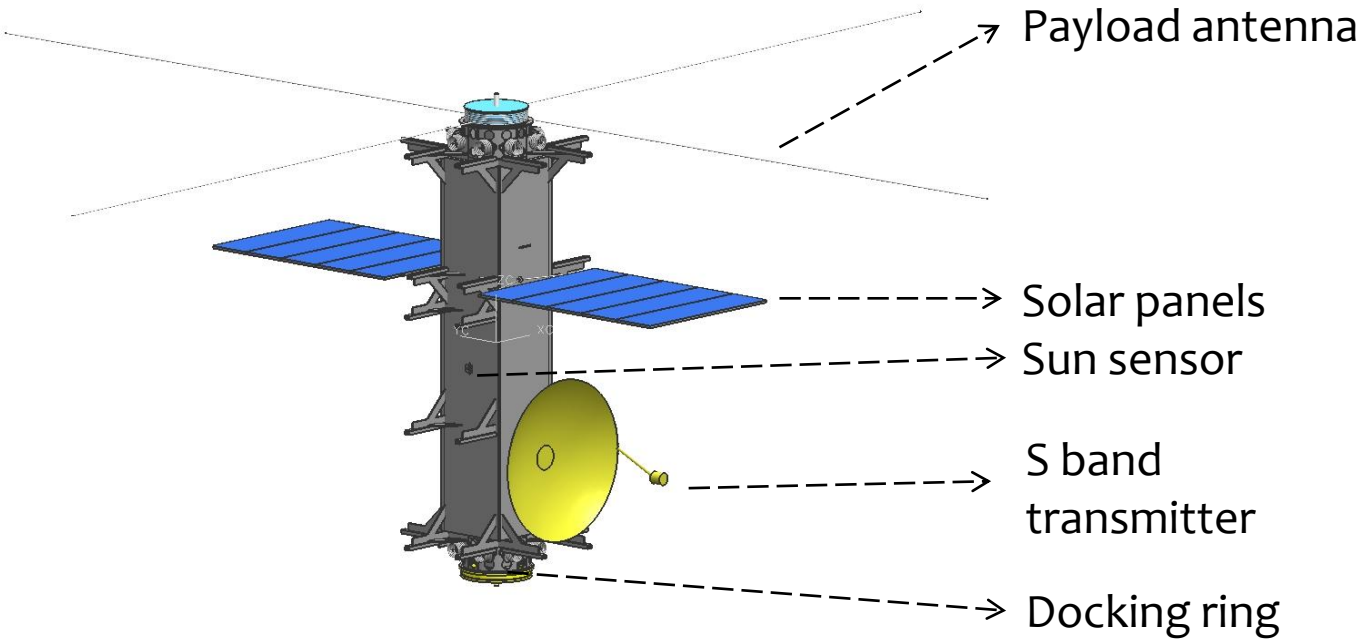
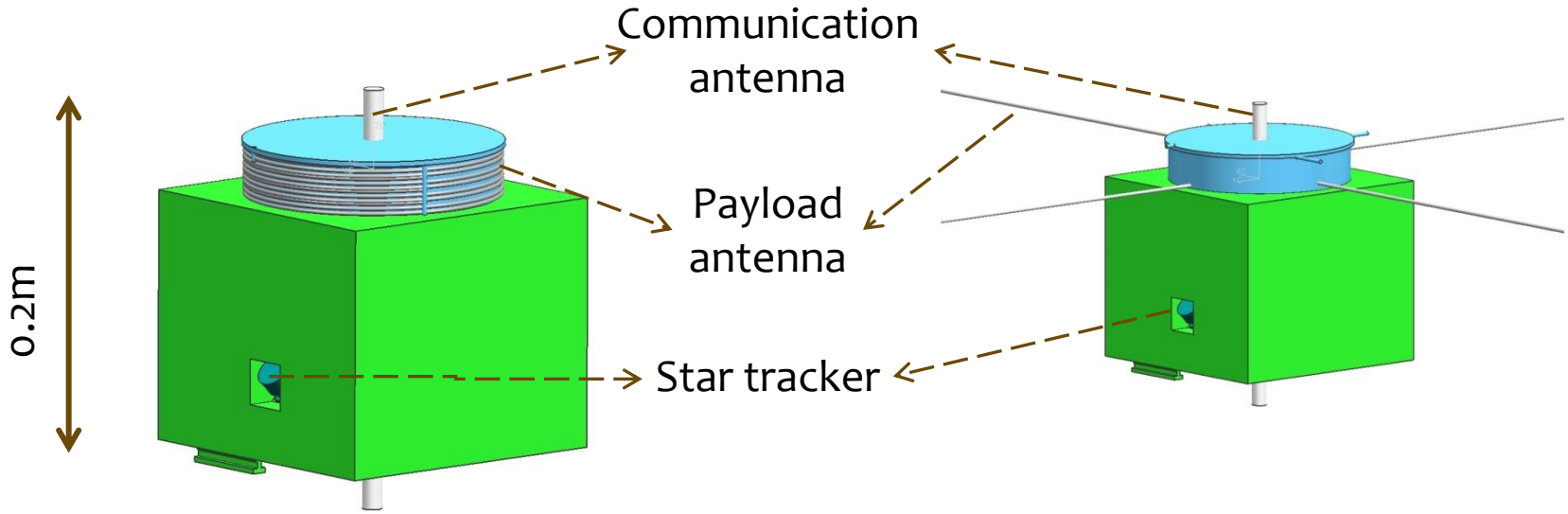
Bunched satellite



Mother Satellite

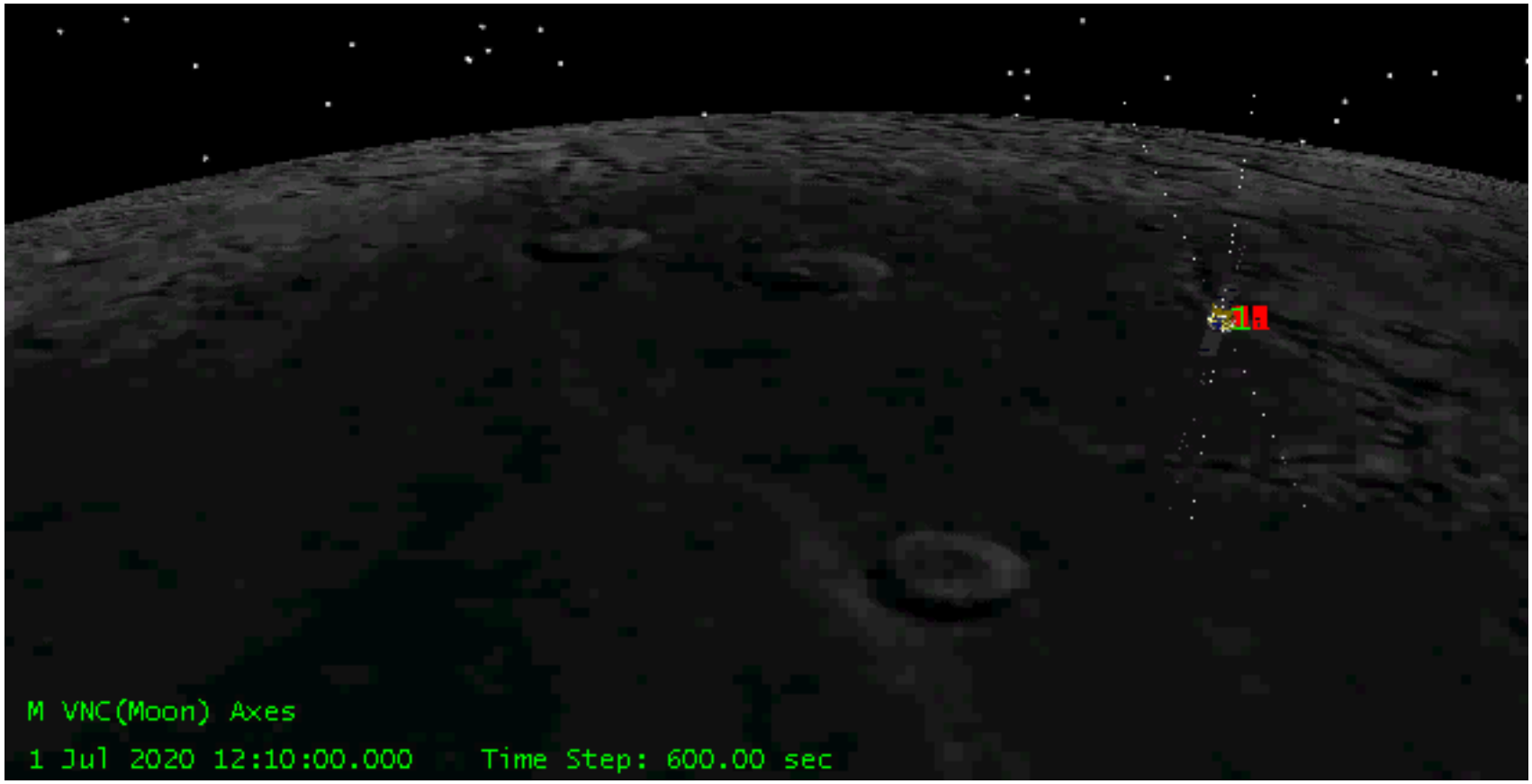


Daughter satellite



- **function:** Observation, synchronization and communication
- **Element antenna:** Circular polarized cross dipole
- **Receiver:** Wide band and fine spectral resolution
- **Correlator:** Central correlation

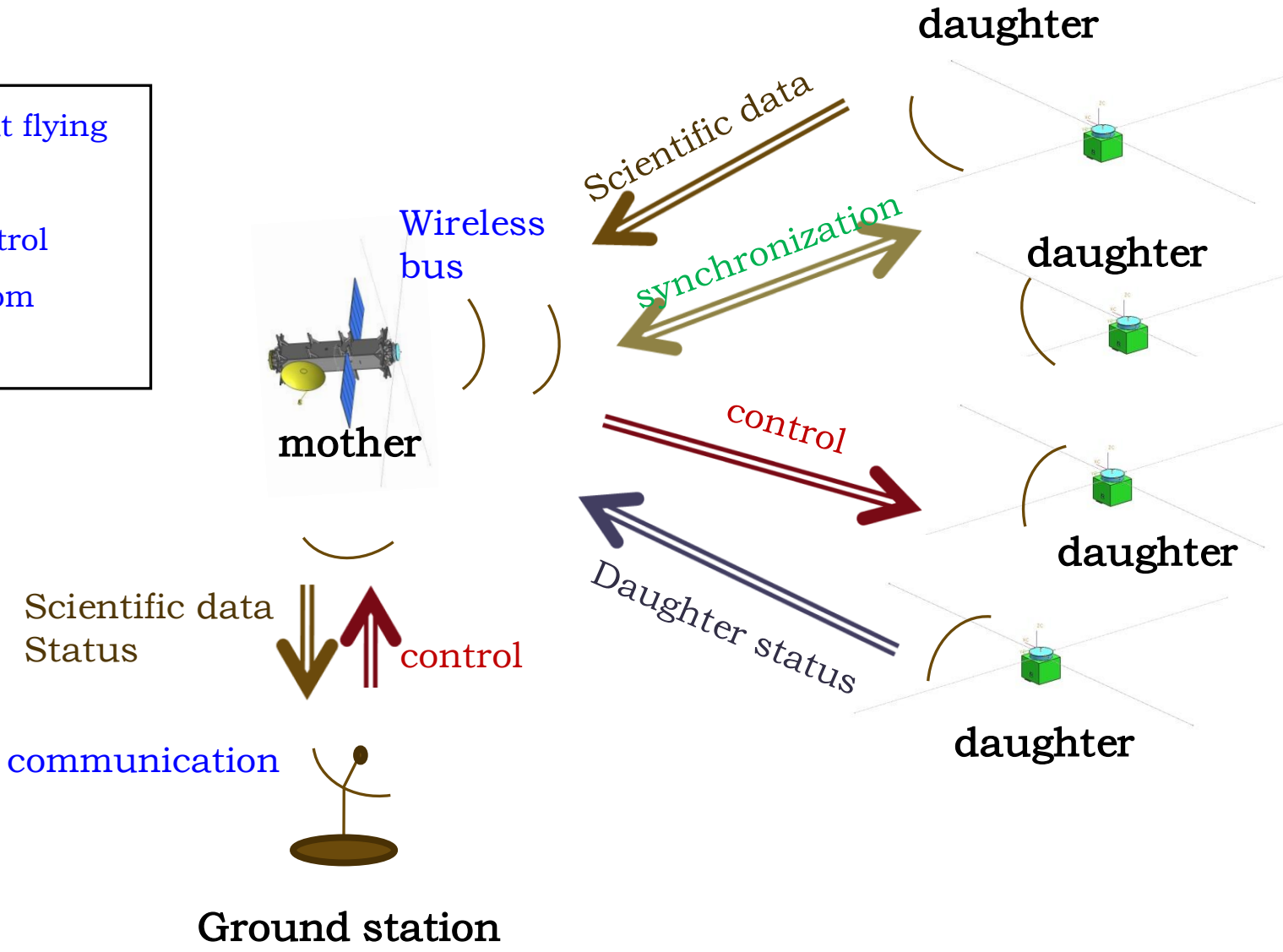
Mission concept



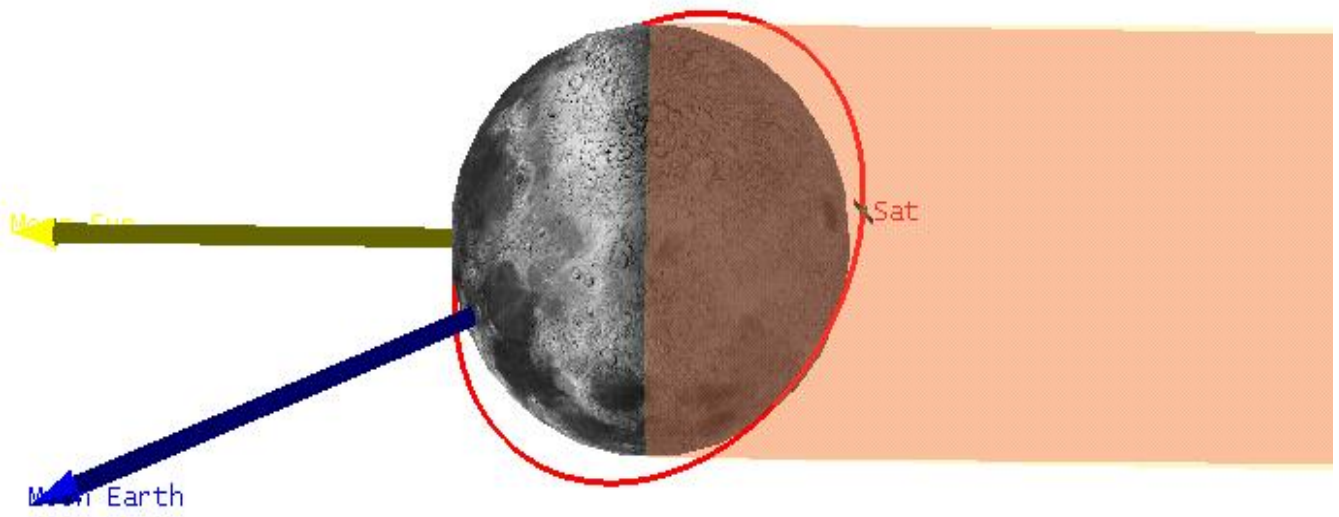
Baselines change from 105km to 10.5km within 5 days needs 11.6g cold gas for 14 satellites maneuver

Top level configuration

- Linear format flying
- Central correlation/control
- Downlink from mother



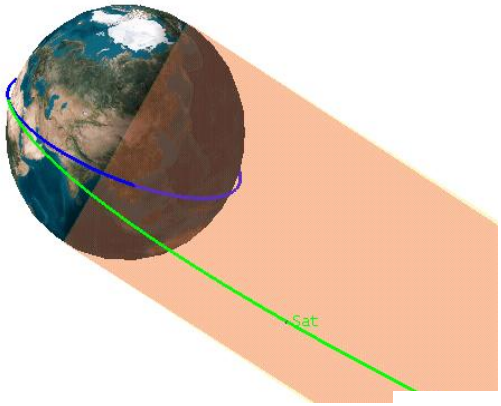
Target orbit analysis

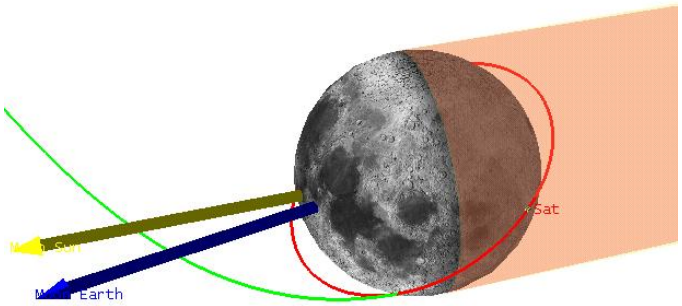


Orbit altitude: 300km

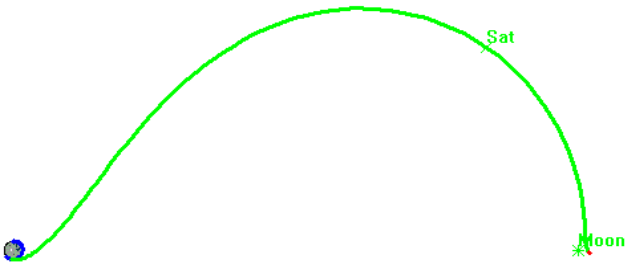
Sun/Earth free: 10 days(4240min)/month

Transfer orbit





Escape velocity from 200km parking orbit is 13.2km/s



Transfer duration is 5 days

Delta velocity for moon capture is 0.8km/s

Technical solution

Launch	• Launch into lunar orbit by LM-2D or Vega plus a upper stage
Wireless bus	• CCSDS Proximity-1 • SOIS
Relative distance	• Dual One-way Ranging，DOR
Time synchronization	• Dual time comparison
Relative positioning	• Relative distance • Relative spatial angle
Attitude measurement	• Star tracker
Payload	• Radio synthetic aperture radiometer in lunar orbit with 15 nano-sat

Preliminary specifications

Mission:

- Orbit: 300km
- Number of satellites: 15 (1 mother + 14 daughters)
- Mass: 10kg*14 + 110kg
- Power : 10W*14 + 100W
- Downlink rate: <1Mbps
- Life time: 3 years

Payload

- Frequency: 1MHz-30MHz
- Frequency resolution: 1KHz
- Sensitivity: <0.1K/s (single element)
- Polarization: Circular
- Antenna: Cross dipole, 2.5m each stick
- Baseline: 1km to 105km (down to 100m)
- Angular resolution: 6’@1MHz, 12”@30MHz
- Imaging time: <1 hour (half orbit)

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Potential areas of collaboration

- High radiation efficiency dipole antennas
- Low noise receivers
- Mother and daughter satellites
- Release mechanism
- Launch service
- Imaging retrieval algorithm
- Ground station
- Science.

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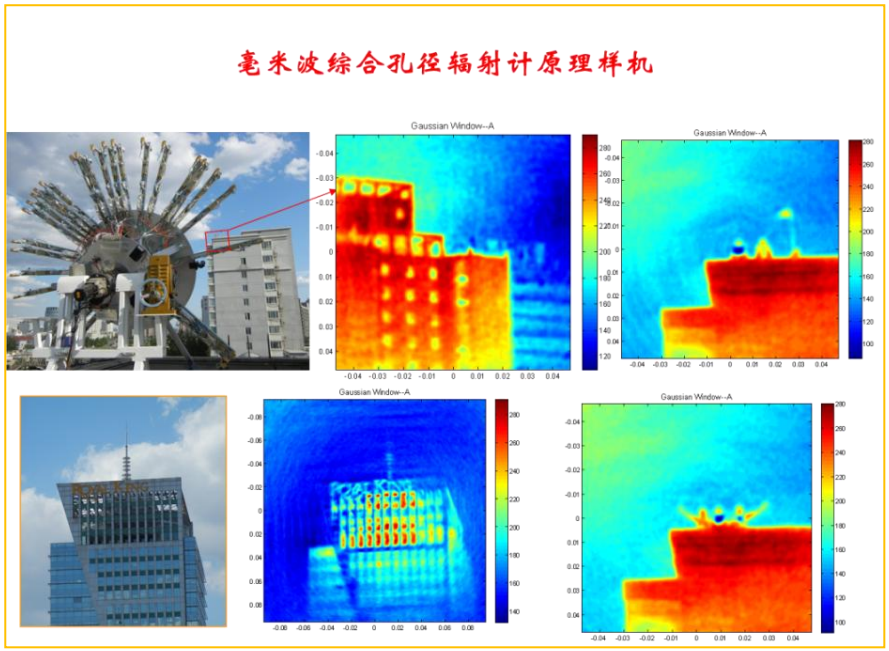
Related Projects/Proposals

- **DALI**: Dark Age detection, NASA/NAL
- **LOFAR**(ASTRON), **21CMA**(China)
- **OLFAR**: Low frequency radio telescope in space,
- **DARE**: Probing the First Stars and Black Holes in the Early Universe with the Dark Ages Radio Explorer, NASA
- **DARIS, SURO**, etc.

Heritage from previous studies/missions

- NSSC developed 5 microwave interferometers in recent 10 years and all of them are focused on space implementation.
- ESA moves rapidly with highlights on the SMOS for microwave interferometry demonstration and Planck for space borne radio astronomy



Conclusion

- The Dark Ages is one of the last explored epochs of the Universe, the redshifted 21cm radiation from the neutral Hydrogen in DA allow us to probe this epoch.
- The probe/study of DA will give the great contribution to the evolution of the power spectrum and the precise cosmology.
- Space mission is the only way to avoid ionosphere and interference. Lunar orbit is more feasible thanks to RFI free at the far side of the moon.
- DAIA gives more than 100km baseline and full UV coverage by 15 satellites.
- Both CAS and ESA are strong at radio astronomy, nano satellite and Interferometric radiometer.