Space Ultra Long Wavelength Array

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2014-02-25

outline

- Introduction and background
- Mission concept, operation Mode and Science
- Our Previous studies

Ultra Long Wavelength / Ultra Low Frequency

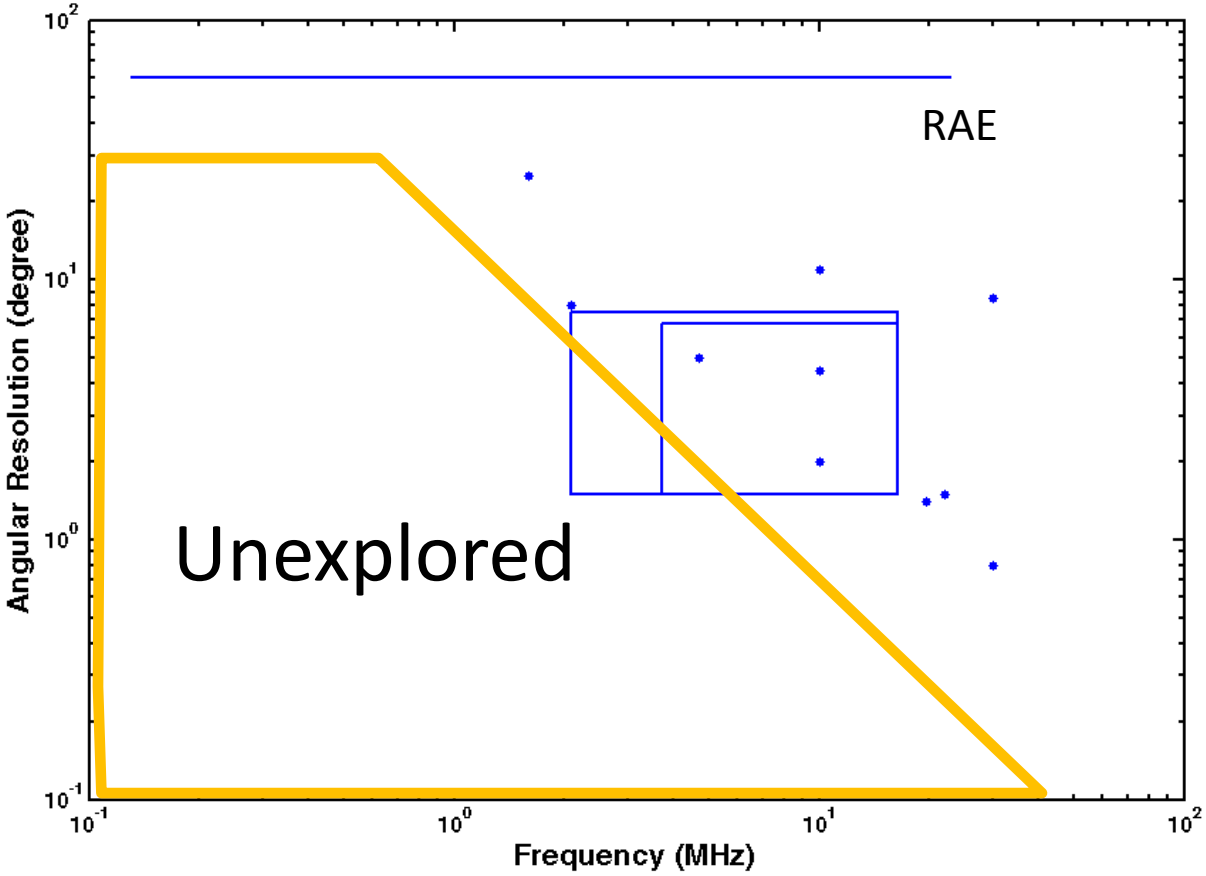
- Defined roughly as 0.1 ~ 30MHz
  - Science case well established: Solar Physics and Planetary Science, Galactic HII distribution, ancient extragalactic fossil emission, early epoch of the Universe…
- Difficulties:
  - Absorption from Earth's ionosphere hinders ground-based observations
  - Ground interferences from broadcast, communication, thunder storms, AKR …
  - Long baseline needed to get meaningful spatial resolution (wavelength=300m @ 1MHz)
- Advantages:
  - Because the obs frequency is low so technical difficulties in antenna design, pointing/attitude control, accuracy of position determination of antennas, synchronization, data transfer and processing are reduced -- very affordable
  - Can be implemented step by step

Past surveys, mostly ground-based

- For 23 surveys in f < 30MHz from 1961- c.a.2006

- If we want to improve angular resolution by 10 times, we need to reach
  - **6 deg @0.1 ~ 1 MHz**
  - **0.2 deg @1 ~ 10 MHz:**
  - 0.02 deg @10~30 MHz
  - Angular broadening by ISM and IPM
- If we want to improve sky coverage by 10 times we need to reach
  - **the Galactic Plane or a region > 100 sq deg @** 0.1 ~ 1 MHz:
  - **full sky @ > 1 MHz**

- **The last unexplored window of E&M spectrum**
- **Transformational science at an affordable price**



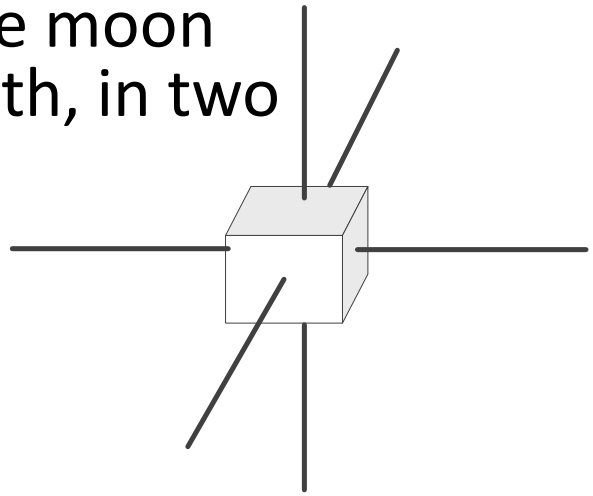
Science goals of a small feasible mission

- Observe the propagation of solar eruptions;
- Origin of high energy cosmic rays by searching ULW signatures and using the Askaryan effect;
- Full sky survey at ULW;
- Interplanetary radio emission;
- Paving the way for
  - search for exoplanets with iono-/magnetospheres
  - investigation of the Universe of the Epoch of reionization.
  - mapping of ionized Hydrogen and find out direct correlation between origin of cosmic rays and SNRs.

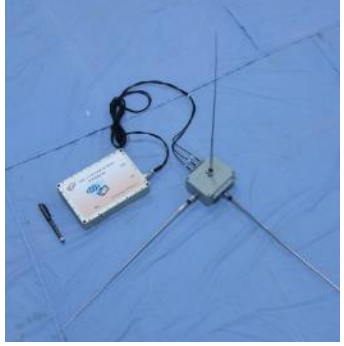
Mission concept
Operation mode and science

Mission concept and observation mode

- We propose to send three small/micro satellites to the circum-lunar orbit
- Each satellite carries one set of orthogonal wide angle ULW antennas (called an antenna station)
- Signal is digitized and downlinked to the ground to process.
- These antenna stations will observe the quiet ULW sky above the Earth's ionosphere, taking advantage of the shielding effect of the moon against ULW interference from the Earth, in two modes:
  1. Single station mode
  2. Interferometry mode



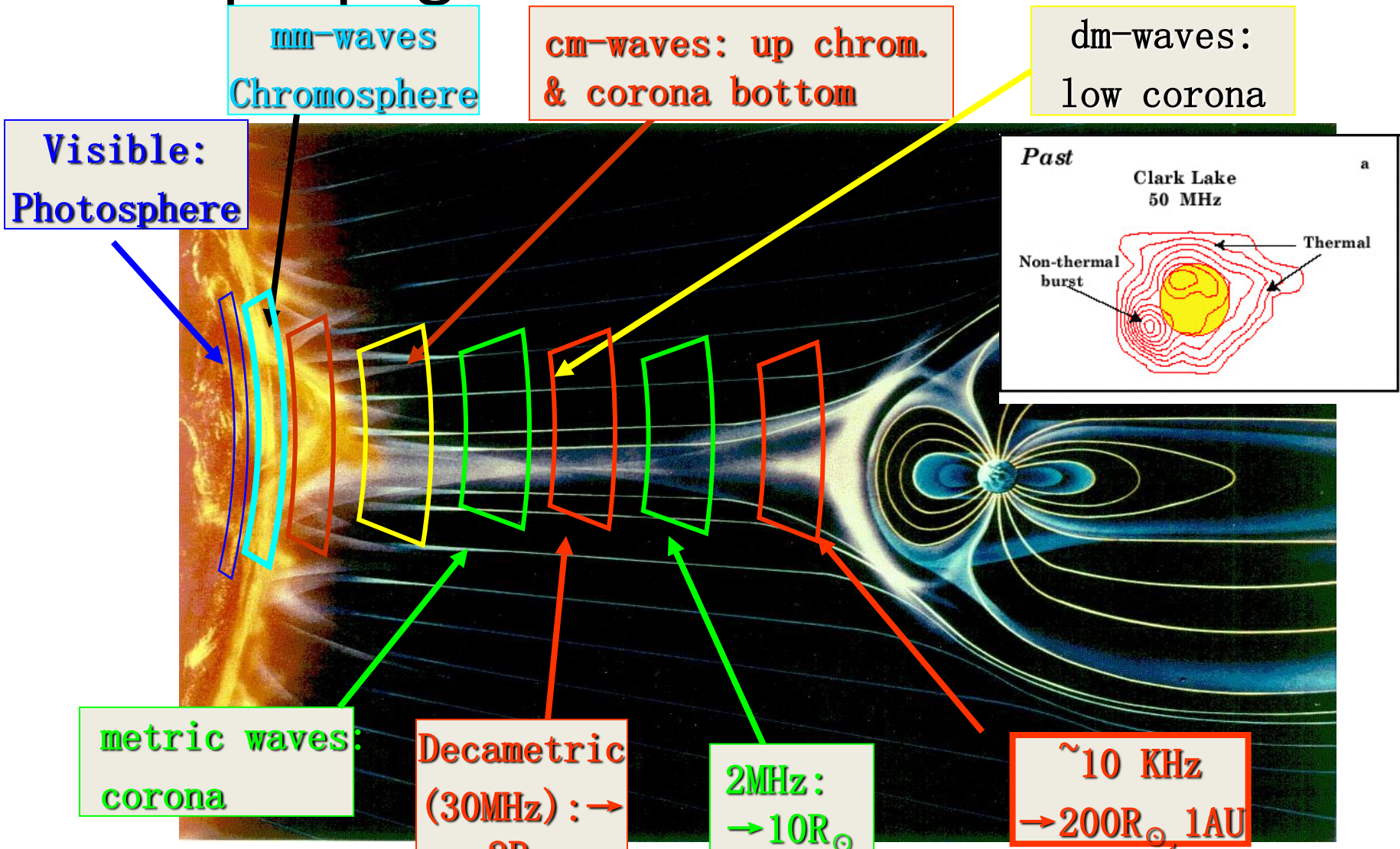
Single station mode



- One station is capable to locate one dominantly bright source in the sky within a few degrees by measuring the wave front.
  - Solar activity: realtime observe and monitor propagation of solar eruptions.
  - planetary emission from Jupiter and Saturn
  - time-domain study: flux and spectra
- ULW signatures of ultra high energy cosmic ray (UHECR) and ultra high energy neutrino (UHEN) using the Askaryan effect

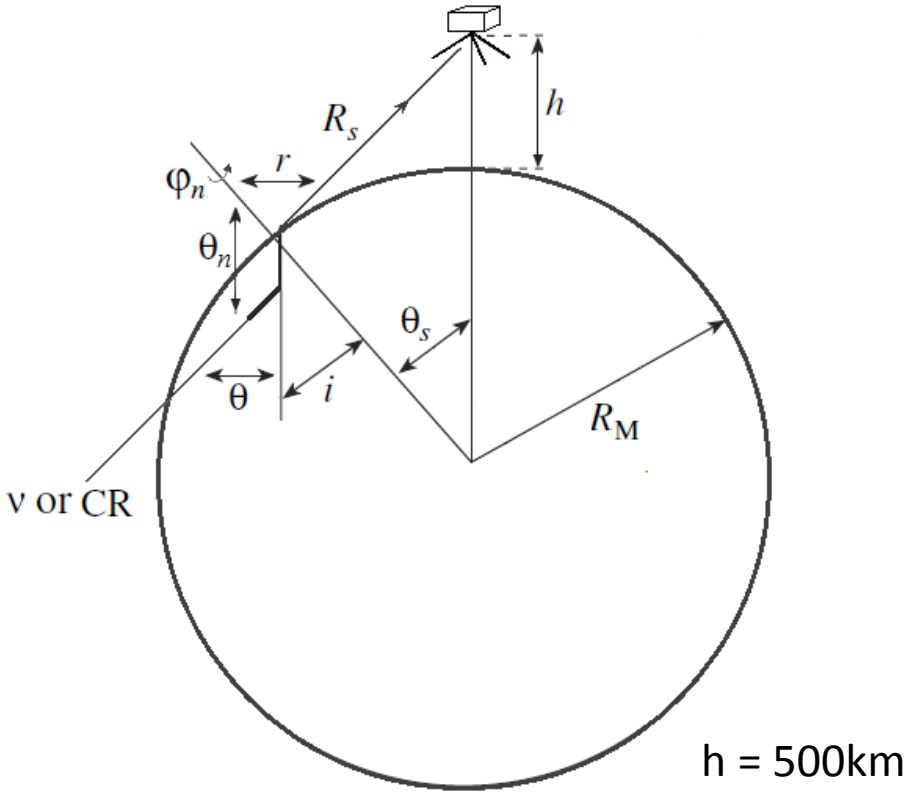
A particle cascade (shower) in a dielectric, for example as initiated by an ultra-high energy cosmic ray or neutrino, will have an excess of electrons which will emit coherent Cerenkov radiation, known as the Askaryan effect. (e.g. Saltzberg et al 2000)

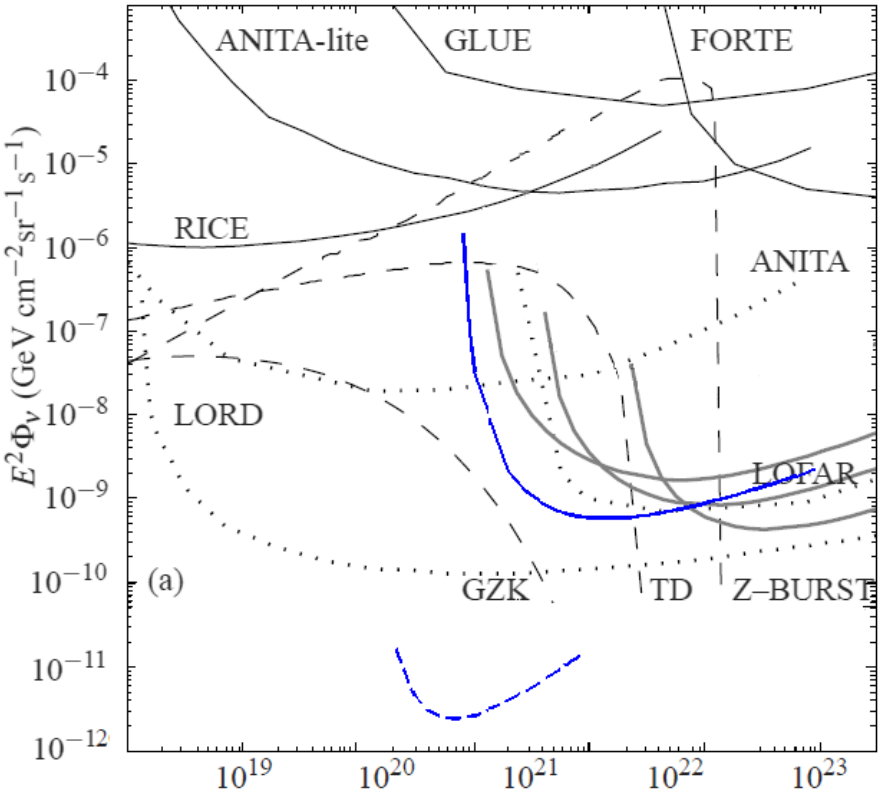
ULW is a critical band to observe the propagation of Solar bursts



Observe and monitor movement of coronal mass ejections, highly valuable scientifically.

Radio Detection of UHECR and UHEN in lunar regolith



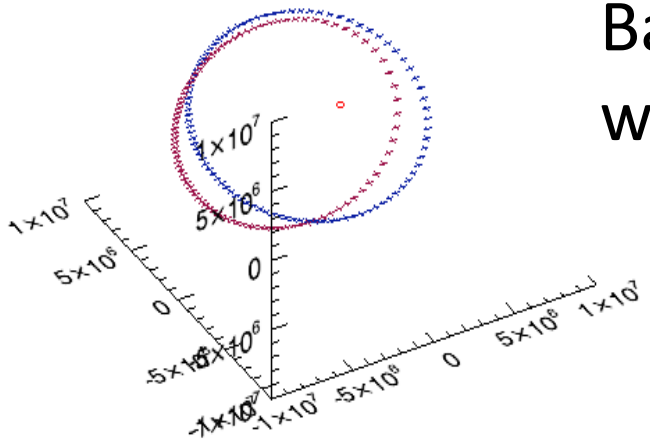


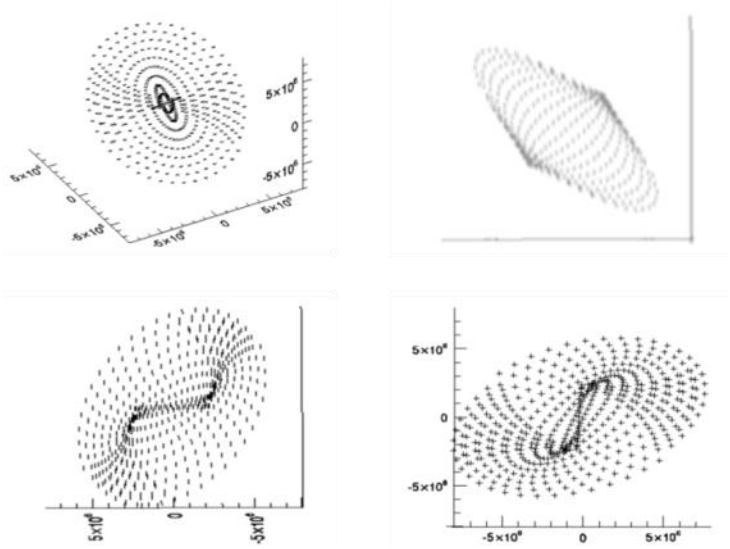
Scheme of the experiment on the detection of radio emission initiated by UHECR and UHEN in lunar regolith. Multiple stations can be used to measure direction and increase reliability of detection.

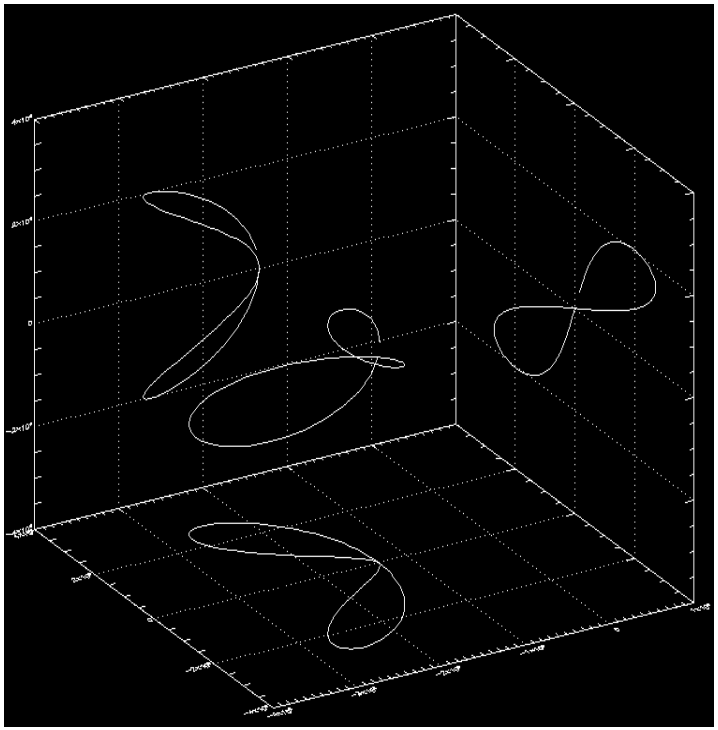
The cosmic ray (dashed) and neutrino (solid) flux limit is calculated for the sensitivity of a single station. *f = 30MHz.* Comparison is made with cosmic ray and neutrino fluxes calculated in various theoretical models.

Interferometer mode: with very few stations, no instantaneous beam

Baseline formed by two satellites with unrelated orbits

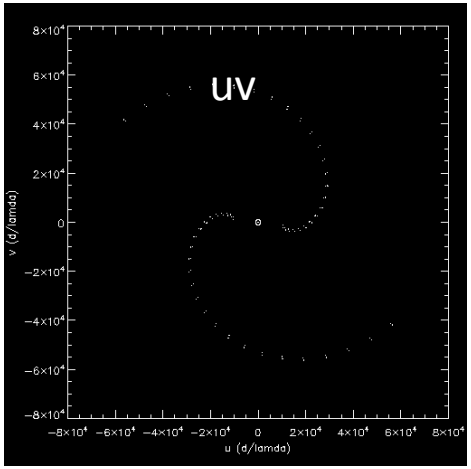


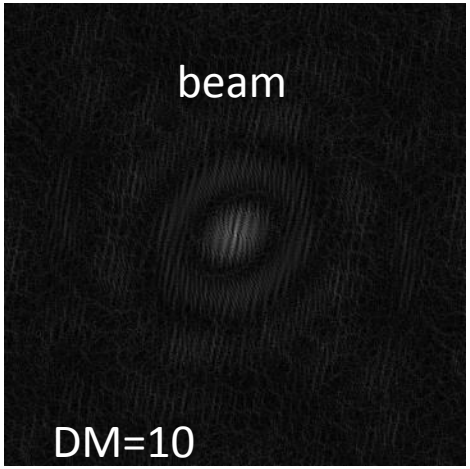


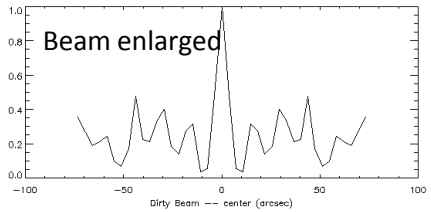


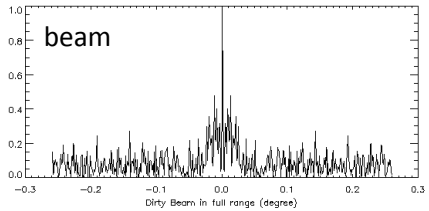
Simulation of three antennas (i=0) sharing the same perilune forming beams in polar directions.

Beam S/N (directivity measure, DM) is used to measure imaging quality.

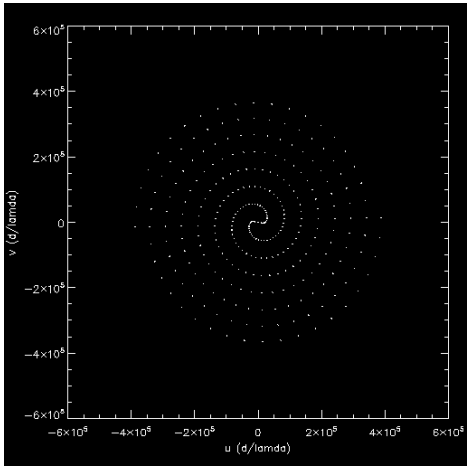


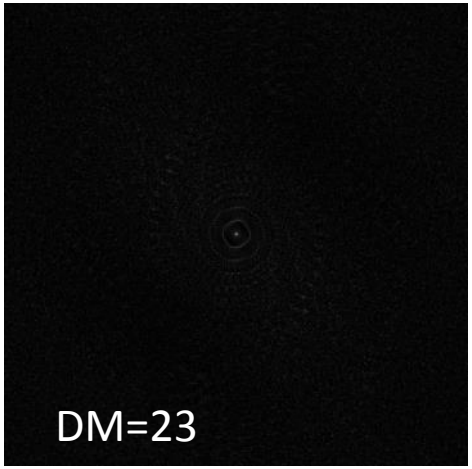


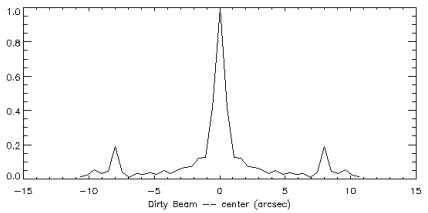


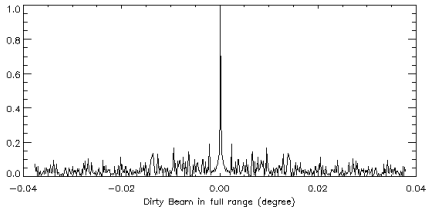


1 hr

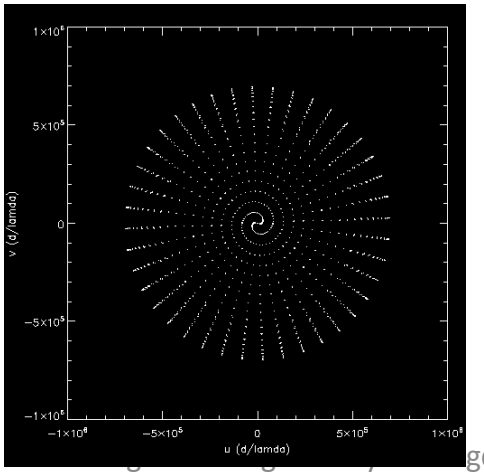


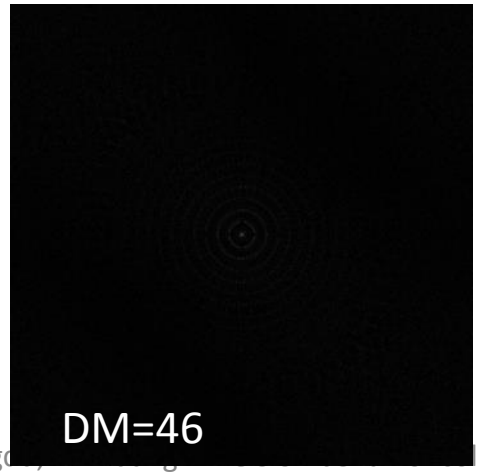


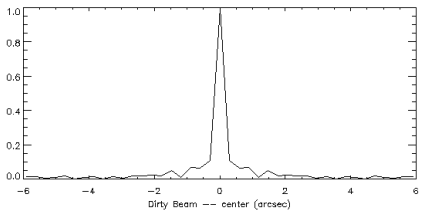


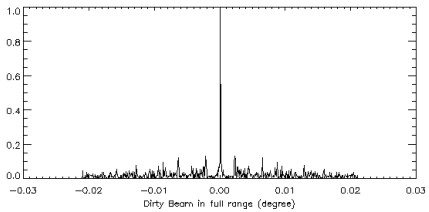


6 hr





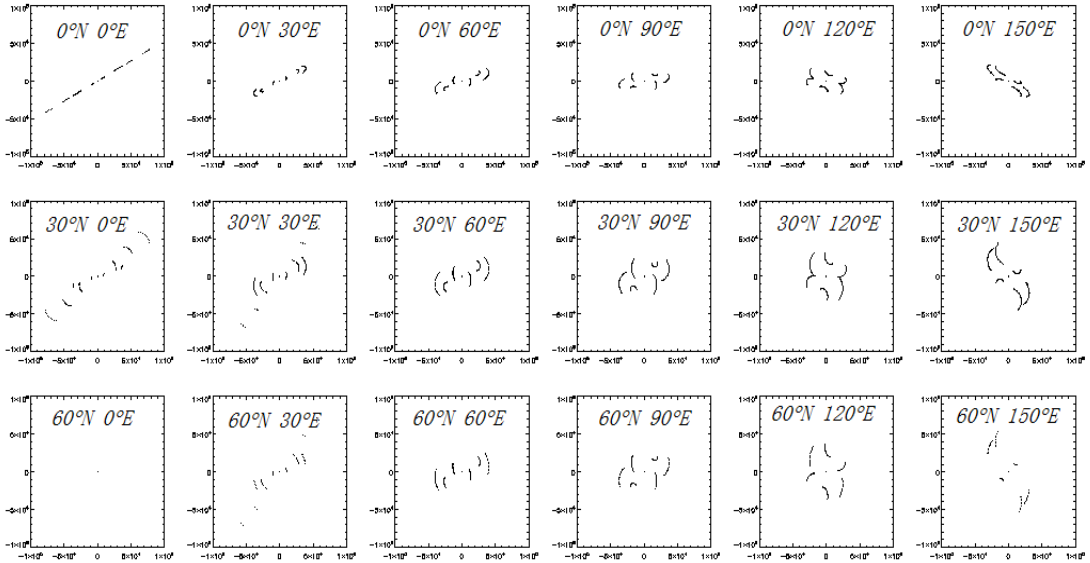


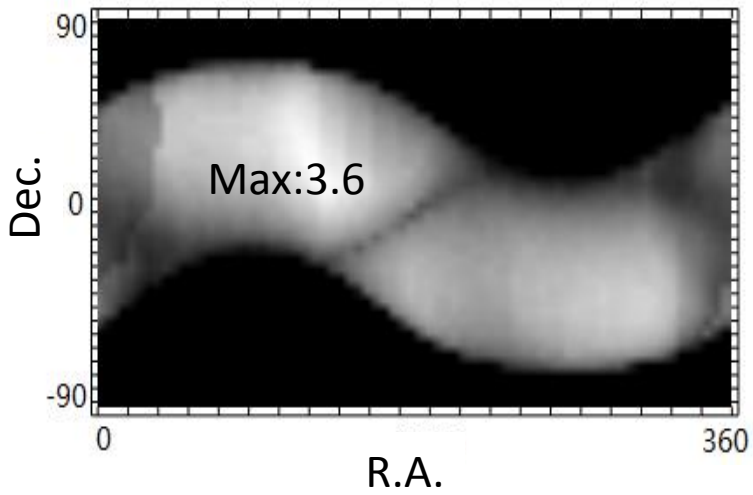


24 hr

uv coverage of three stations looking at anti-nadir direction

uv coverage for different line of sight in one orbit (*i*=28deg)

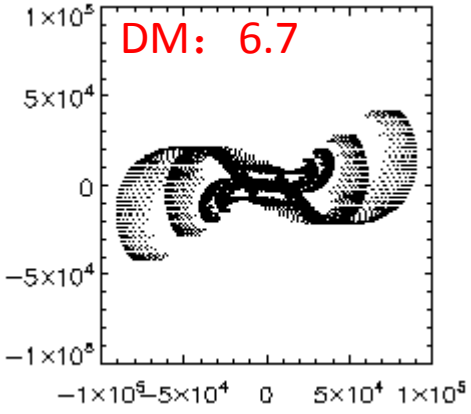




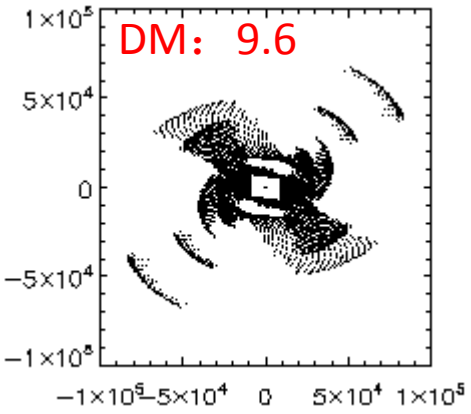
Simulation of three satellites each carrying orthogonal wide-field dipole-type antennas looking at local zenith direction.

Map DM for the whole sky after one orbit.

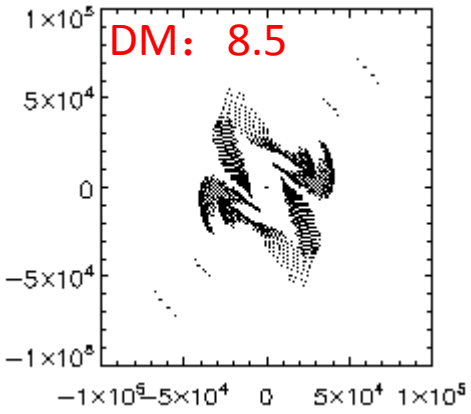
uv coverage after one precession period



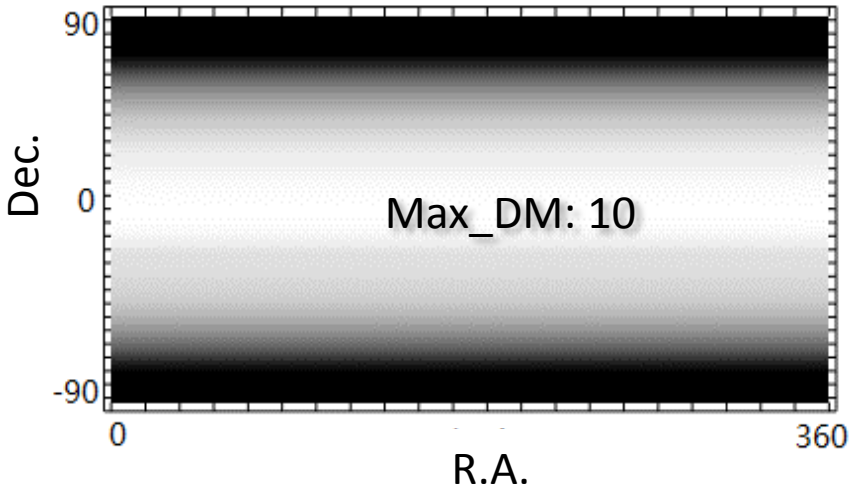
Dec. = 0



Dec. = 30



Dec. = 60



uv coverage is greatly improved. Beam is suitable for full sky survey after one precession period

downlink bandwidth

- Downlink bandwidth requirement for one station

obs freq. Sample bits int. time no. of pol.

$$\frac{2 * B_{obs} * b_{sam} * t_{int} * \mathrm{n_p}}{t_{downlink}} = \frac{2 * 10\mathrm{MHz} * 1 * \left(\frac{3600s * 24}{60}\right) * 2}{3600s * 6} = 2.7 \text{ （Mbps）}$$

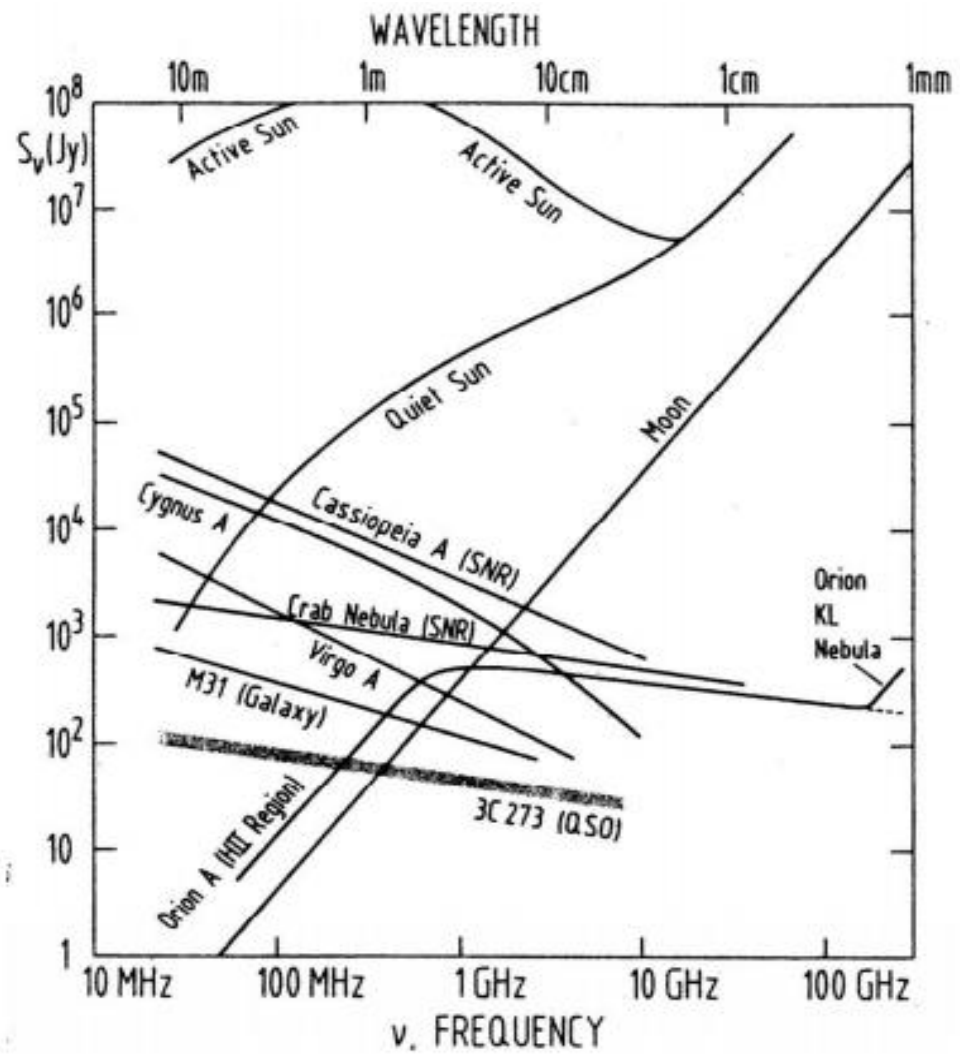
Observing at 10MHz, 1bit sample at 20MHz, 1 second integration per minute, 6 hour/day downlink time.

Map S/N is limited by downlink bandwidth

Three stations mapping sensitivity (10MHz obs freq., 1/60 duty cycle to throttle downlink to 2.7 Mbps / station, 1MHz BW, incl. loss of sensitivity from 1 bit sampling.)

	$\sigma_{point\ source}$	$\sigma_{extended\ source}$
1 day	65 Jy	3×10^{11} K
1 mnth	12 Jy	6×10^{10} K
1 year	3 Jy	2×10^{10} K
3 years	2 Jy	1×10^{10} K

	S/N Cas A, Cyg A	S/N 3C273
1 day	~500	
1 mnth	~3000	8
1 year		33
3 years		50



Extended source sensitivity can be improved by choosing shorter baselines.

Possibly without precession onboard clock and ranging

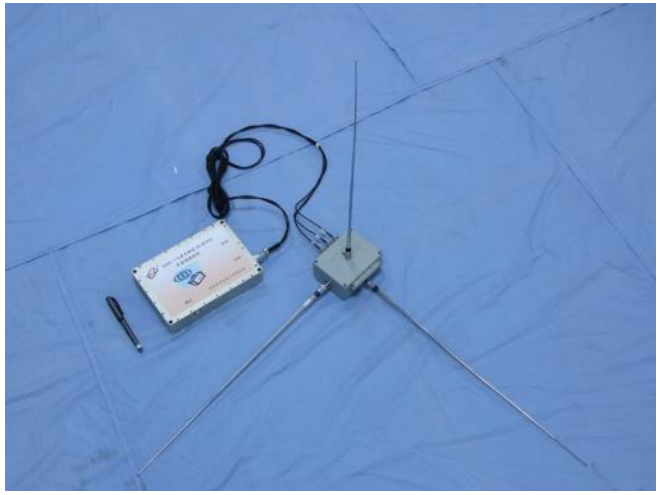
- Stations have wide field of view (FoV). Many strong sources are in FoV all the time.
- No ionosphere to disturb phase in different line of sight.
- Strong sources can be used for timing/phase calibration frequently on the ground.
- Greatly reduce complexity and cost of mission

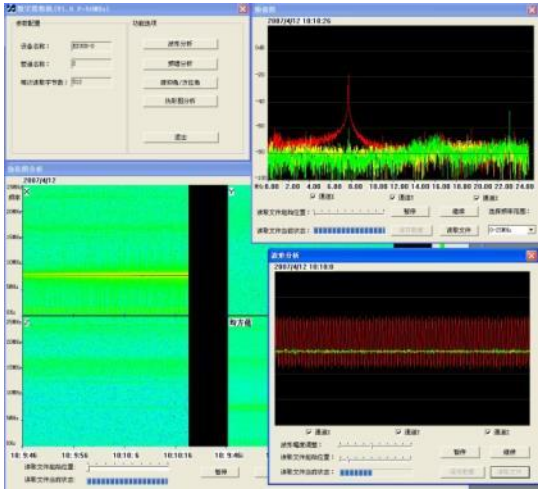
Our Previous studies

Previous study

- Funded in a space science program by China National Space Agency in 2007
- To make preliminary study of requirements and propose technical paths to do ULW observation in earth orbit and on lunar surface
  - Produce prototype and make analysis
  - What can be done with one antenna station?
  - What can be done with a few antennas?
- Institutes involved: NAOC, SHAO, Inst. of Electronics of CAS

Prototype hardware and software



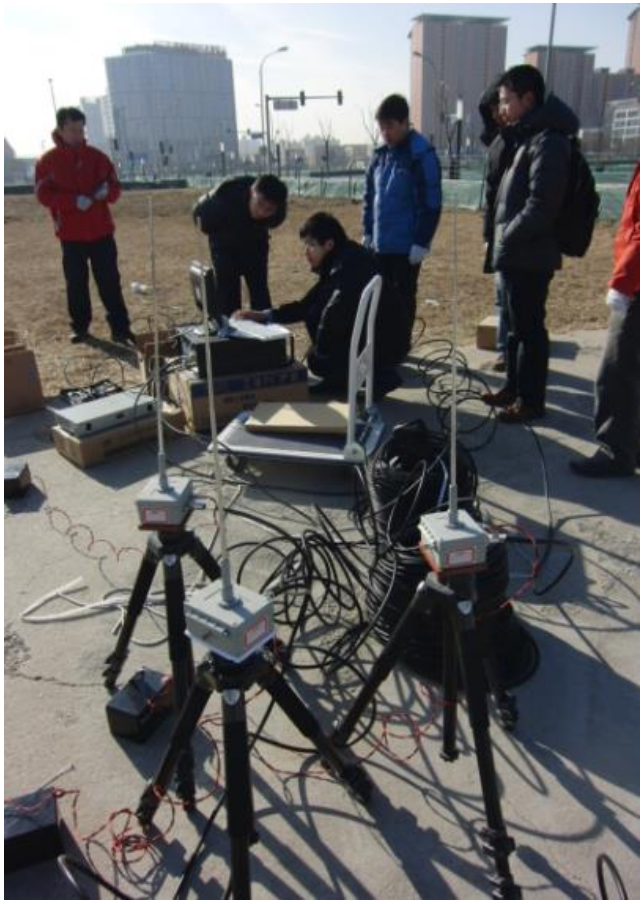


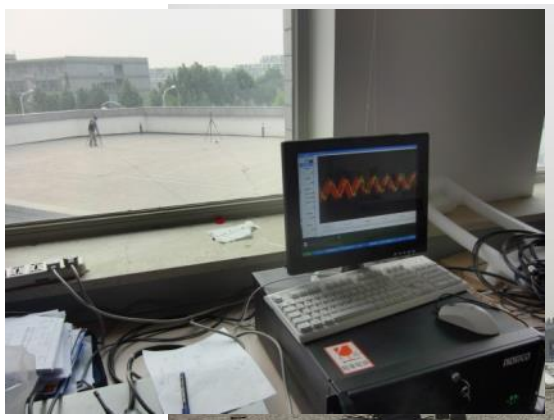
Vectorized E&M wave/field detector prototype

- We have developed data processing pipeline prototype: clarify method, requirements on processing power, data volume, data link throughput
  - Validation from ground with prototype hardware

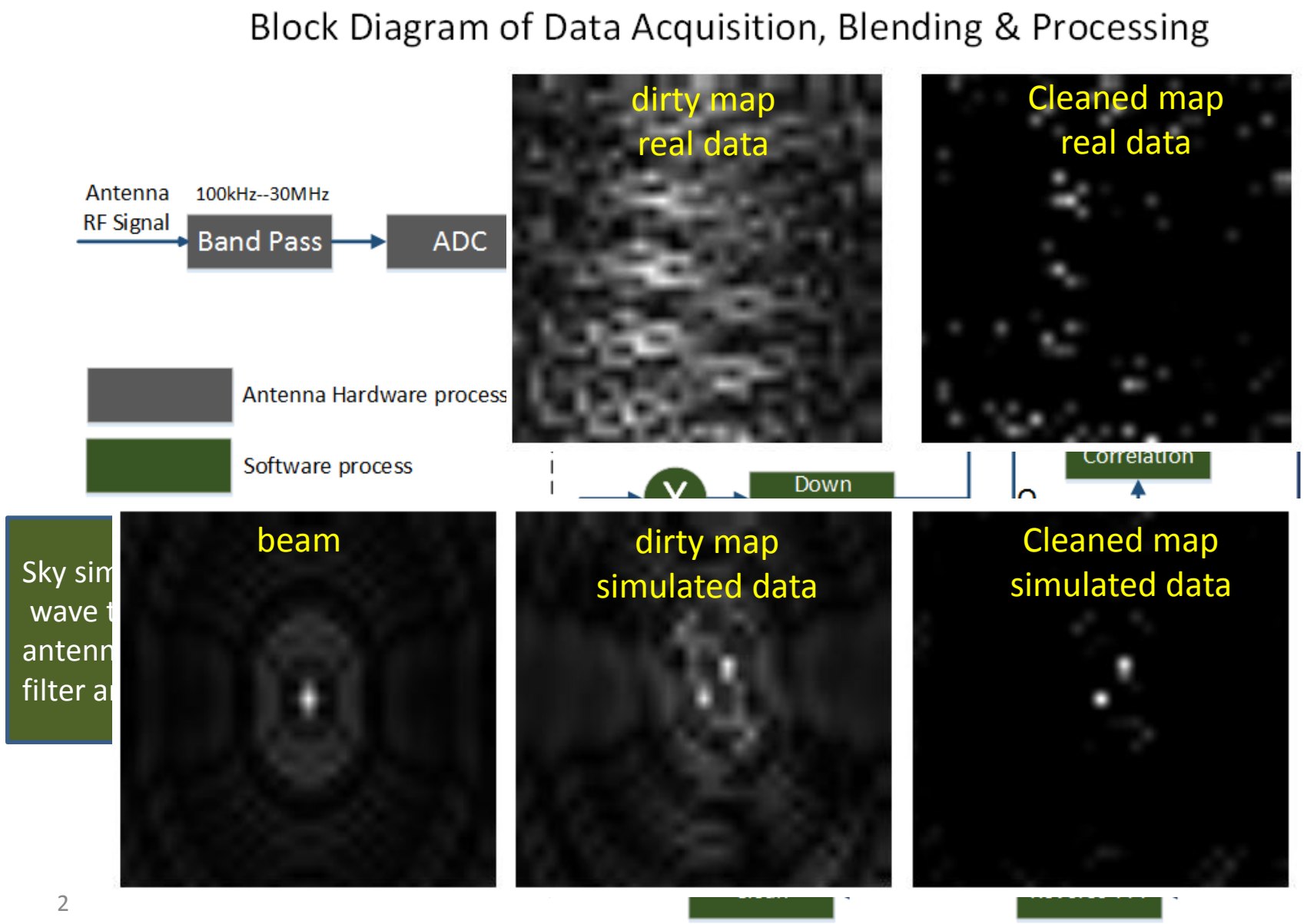
Prototype antenna, receiver and onboard processing

- Very simple monopole antenna that directly sample the electric field





Data processing pipeline interfaced with simulator and the prototype antennas



collaboration

- Sharing between partners from China and Europe
  - Spacecraft Platform: small or microsats, many mature models to select from
  - Launcher
  - Payload: antenna, amplifiers, backend, clocks, avionics
  - Ground Stations
  - Ground Operations
  - Science exploitation
- The two proposing groups from China and the Netherlands have already established cooperation on space ULW radio explorer since 2006. A joint Ph.D. training program “Ultra-Long-Wavelength Astronomy: toward a new look at the Universe” was carried out from 2008 to 2011 (by Linjie). A new Ph.D. student (Mo) from NAOC is going to graduate soon.

Summary

- Three small/micro satellite in circum-lunar orbit to observe 0.1~30MHz ULW band
- Observe and monitor propagation of solar eruptions with a position accuracy of 1-2 degrees in realtime
- Ultra high energy cosmic rays and neutrino detection
- Full sky survey to provide a quantum leap in angular resolution and sensitivity in a virtually unexplored E&M band
- Highly scalable and flexible. Mature technology

Thank you