DSL Mission Concept at Lunar Orbit

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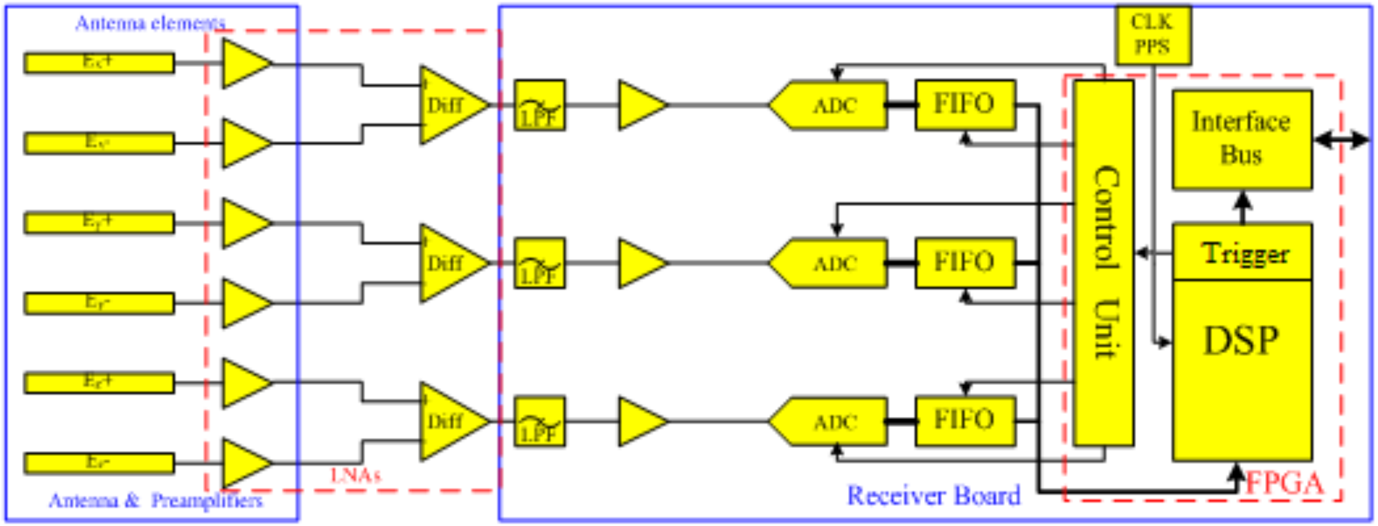
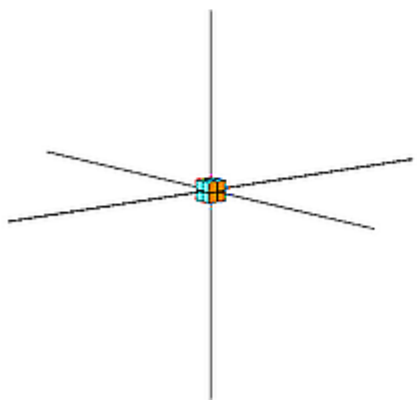
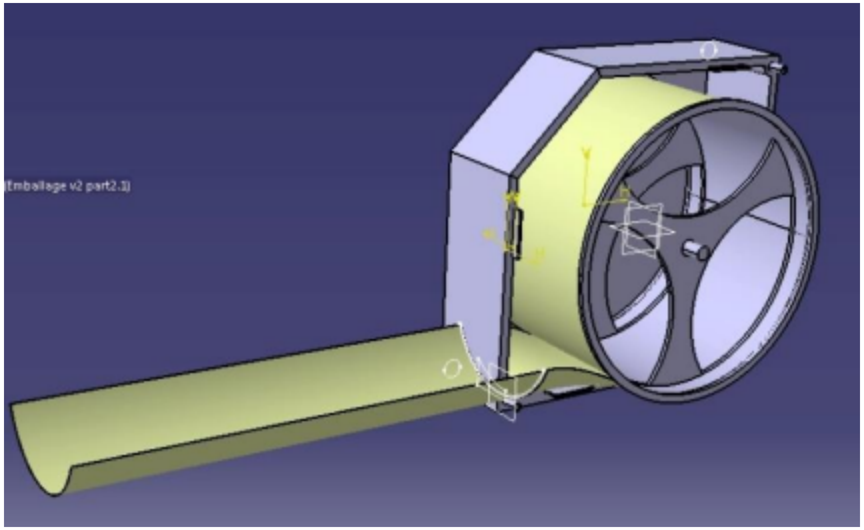
Payload onboard single nano-sat





Element antenna



Outline

- Requirements
- Mission concept and preliminary design
- Summary

Qualitative requirements

- RFI free/minimum
  - Moon shielding is better than mitigation
- Long baseline for high resolution
  - Long distance high speed communication
- Dense UV coverage
  - Discover unknowns
- S-mission

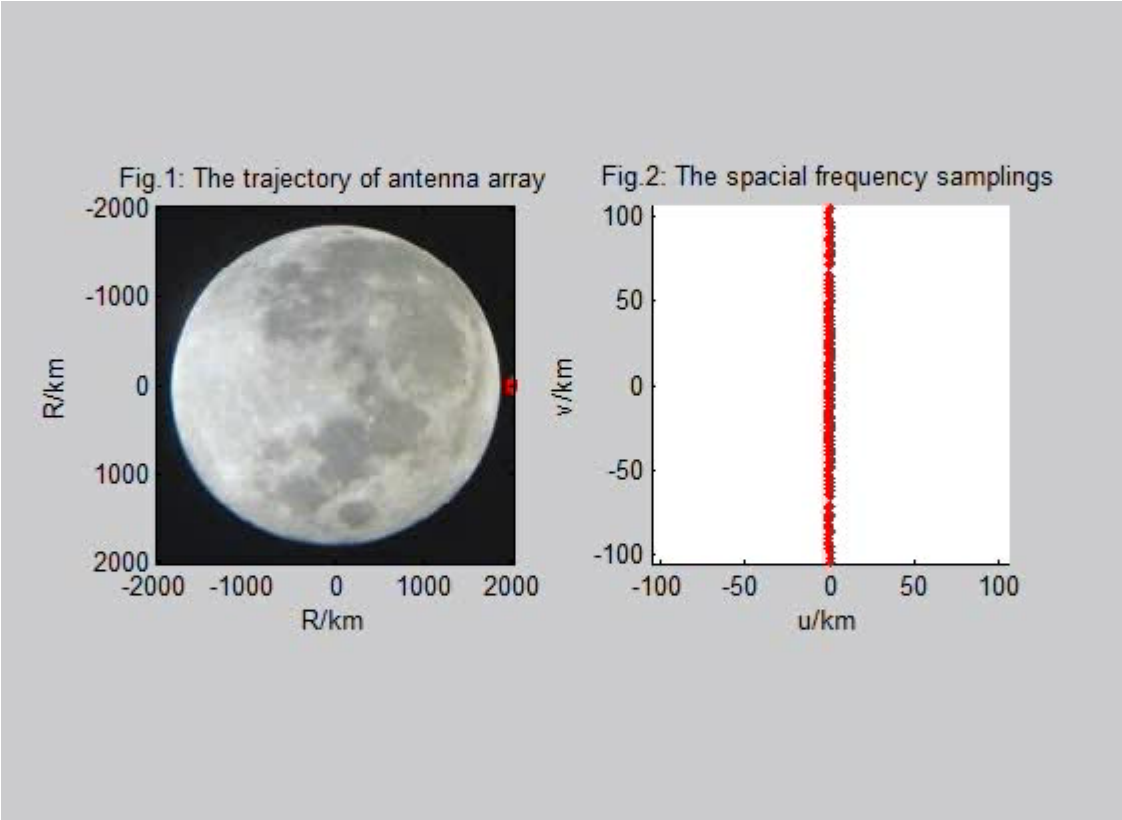
Quantitative requirements

- Angular resolution
- Frequency
- Spectral resolution
- Integration time
- Polarization

Array design = Optimize the UV coverage

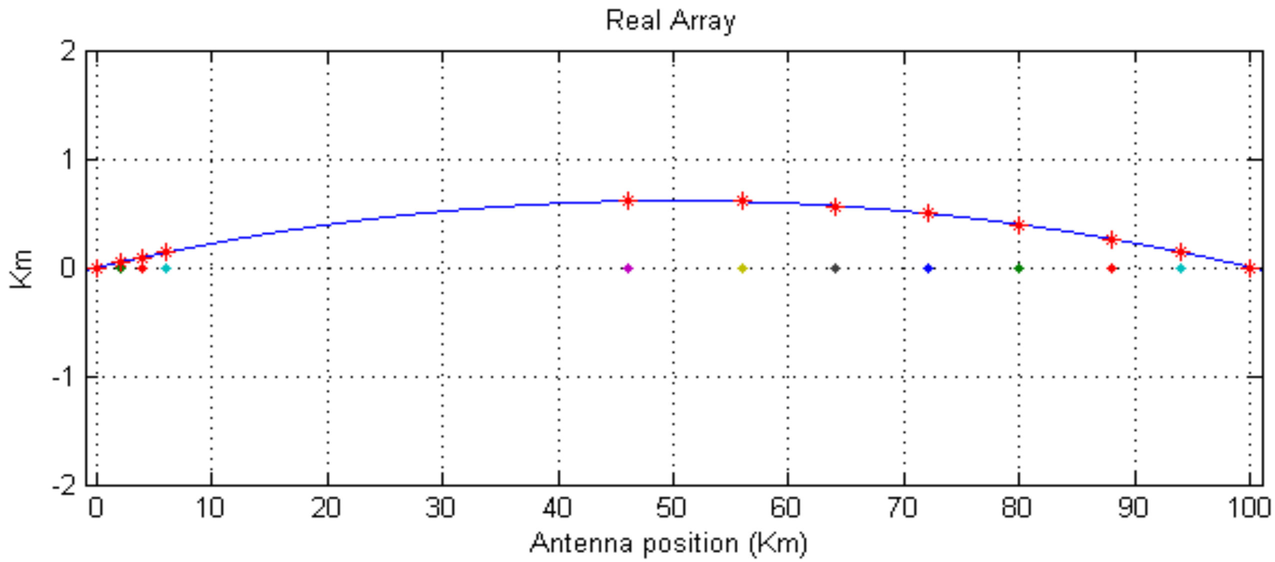
DSL array at Lunar orbit

- **Linear array along the same orbit**
- **Dish UV coverage every half orbit**
- **Baseline's length varies from orbit to orbit by maneuver, Full UV coverage (Nyquist) every 10 days**
- **UV coverage is configurable in orbit according to particular scientific goal**
- **Linear array simplifies the formation maintenance and maneuver**
- **30% of the life time is RFI FREE**

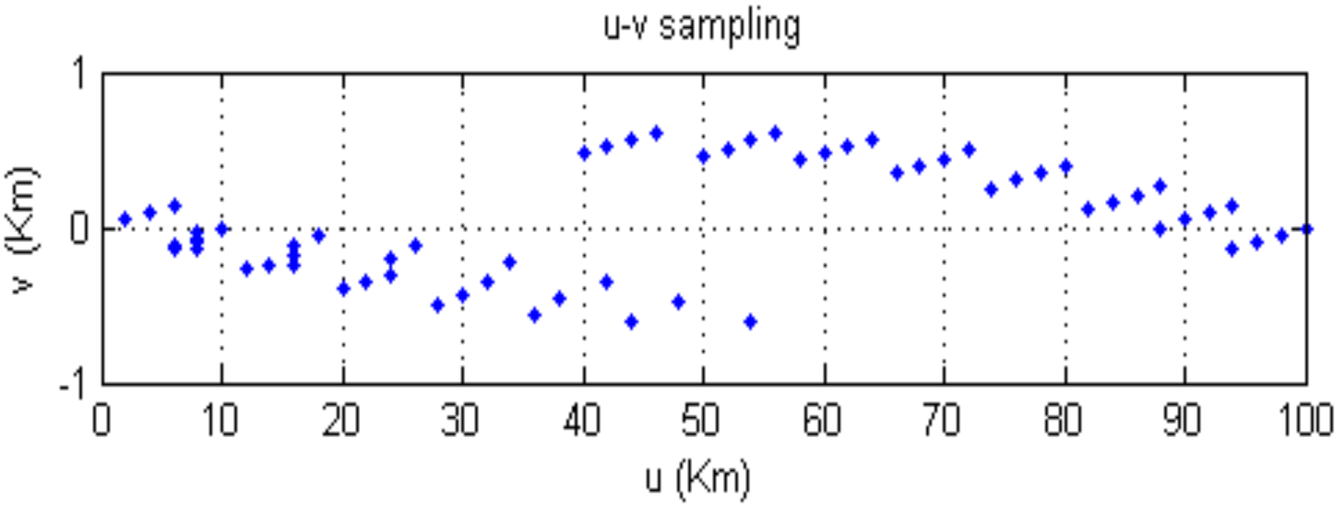


Example array: 1 4 10 22 24 35 39 52 63 71 74 78 79 **km**

Snapshot



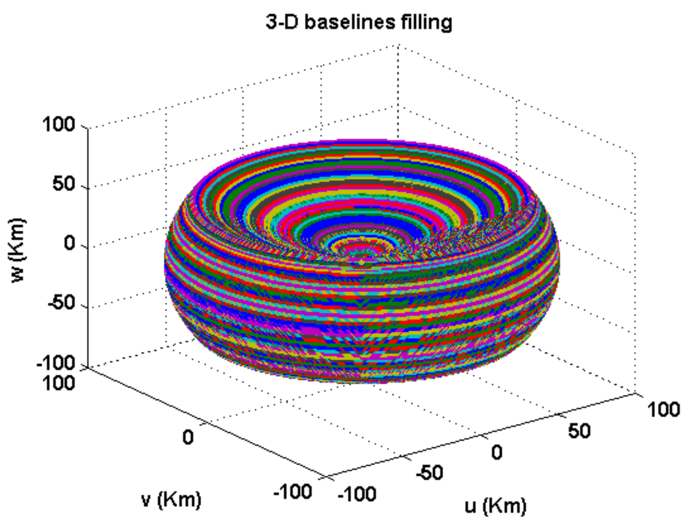
Real Array
2
1
0
-1
-2
Km
0 10 20 30 40 50 60 70 80 90 100
Antenna position (Km)

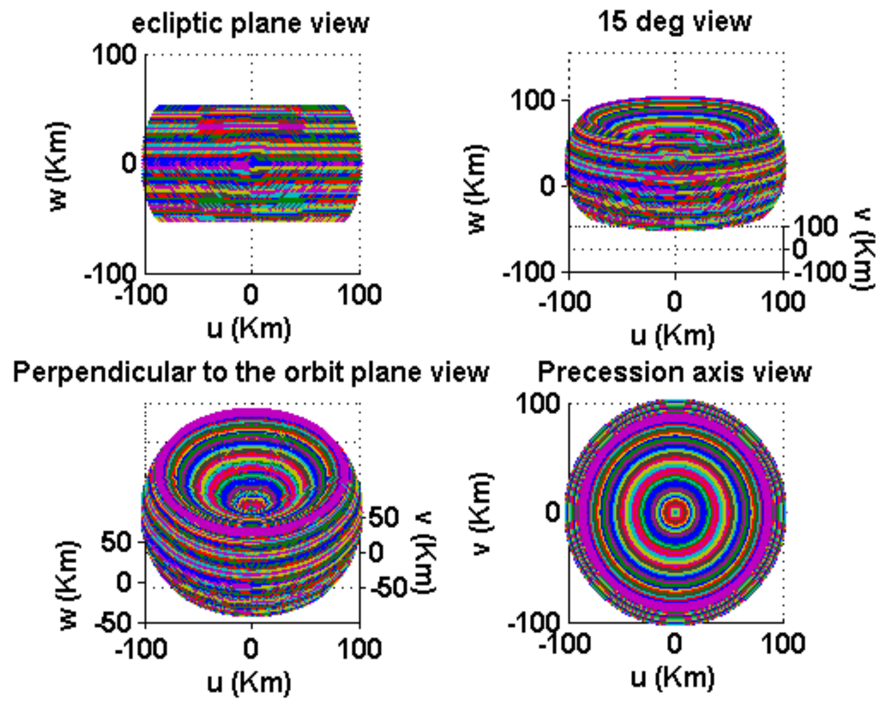


u-v sampling
1
0
-1
v (Km)
0 10 20 30 40 50 60 70 80 90 100
u (Km)

u-v-w filling

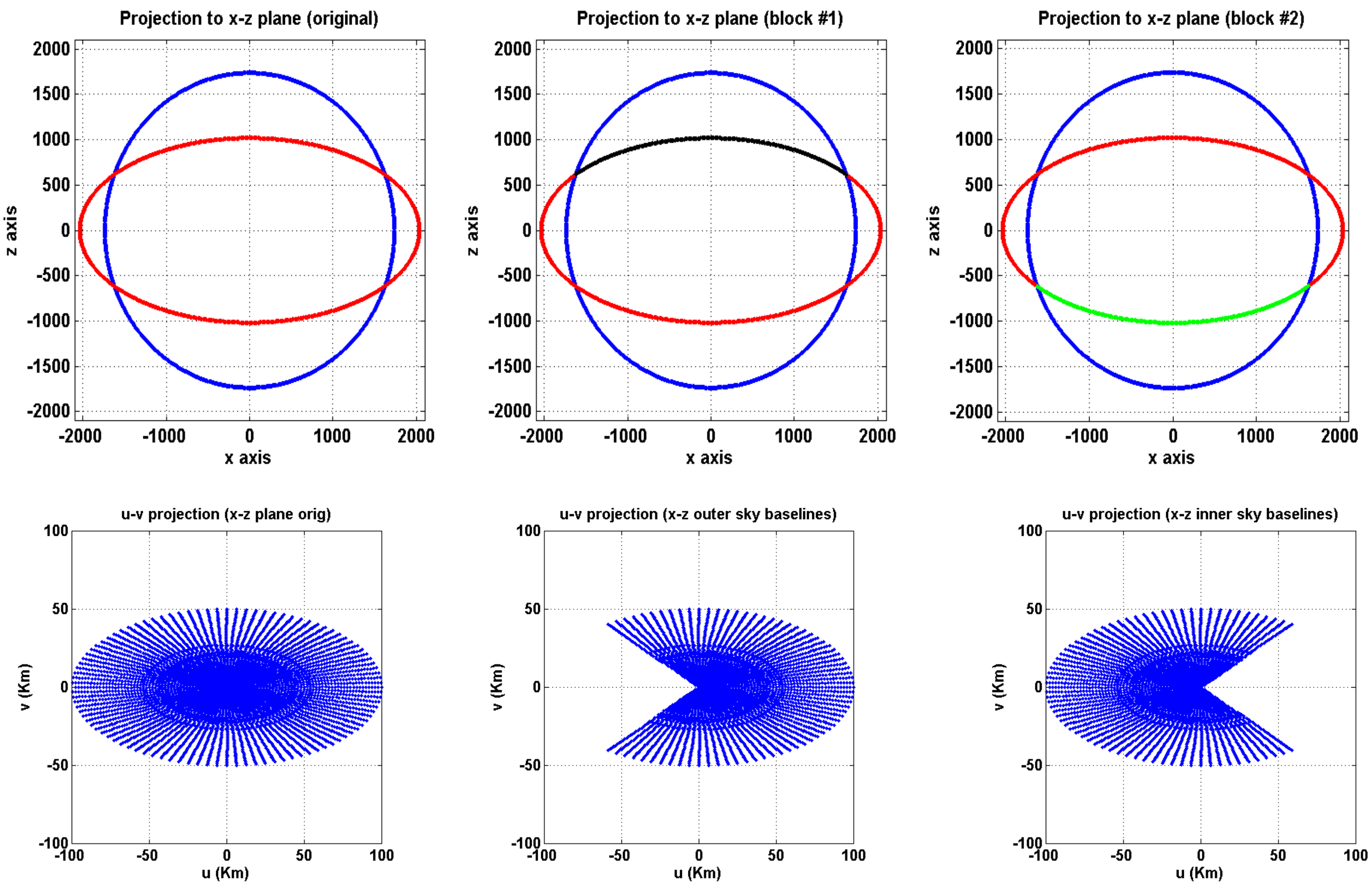
- 3-D u-v filling after a full precession period (360°);
- In DSL case, ~450 days is required to have a full u-v filling in 3-D(0.76° precession per day);



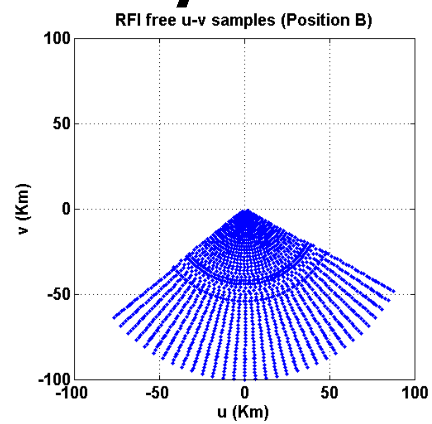


6° precession per orbit is assumed for better demonstration.

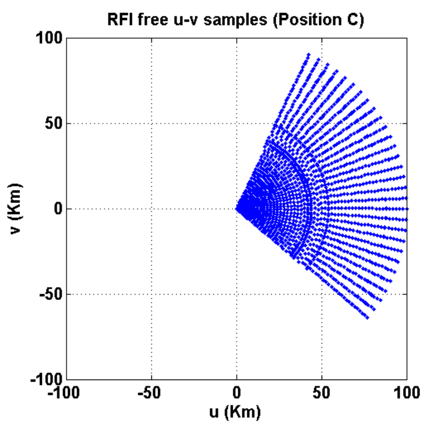
Moon blockage

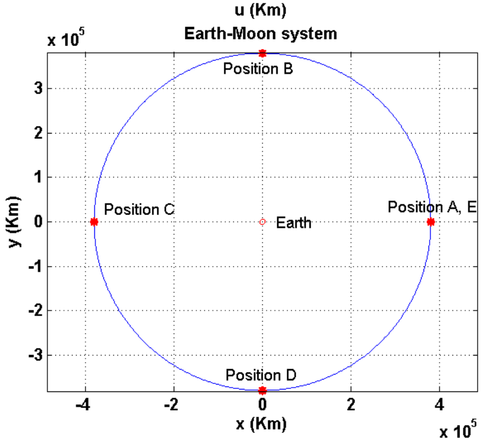


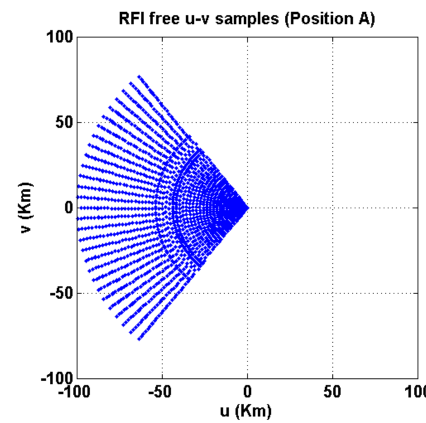
Earth-Moon system and RFI free

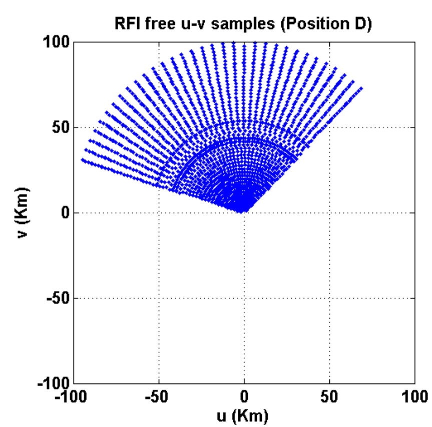


- 30% RFI free
- 60% coverage (taking into account the conjugate points)
- RFI mitigation (if works) improves the coverage

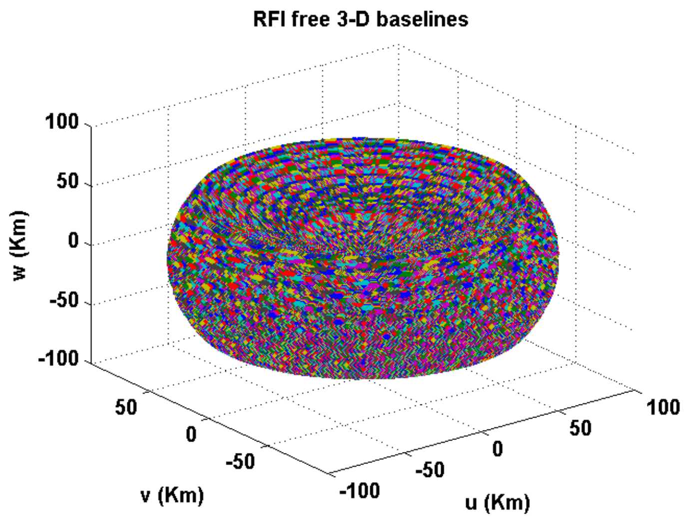


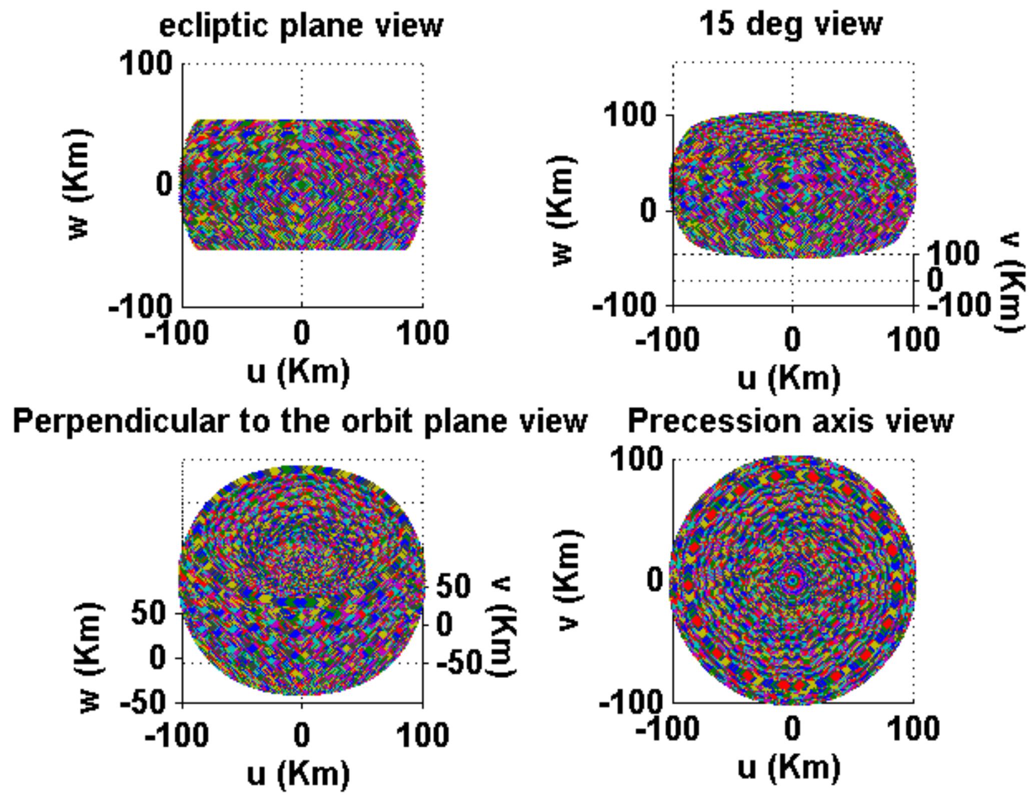




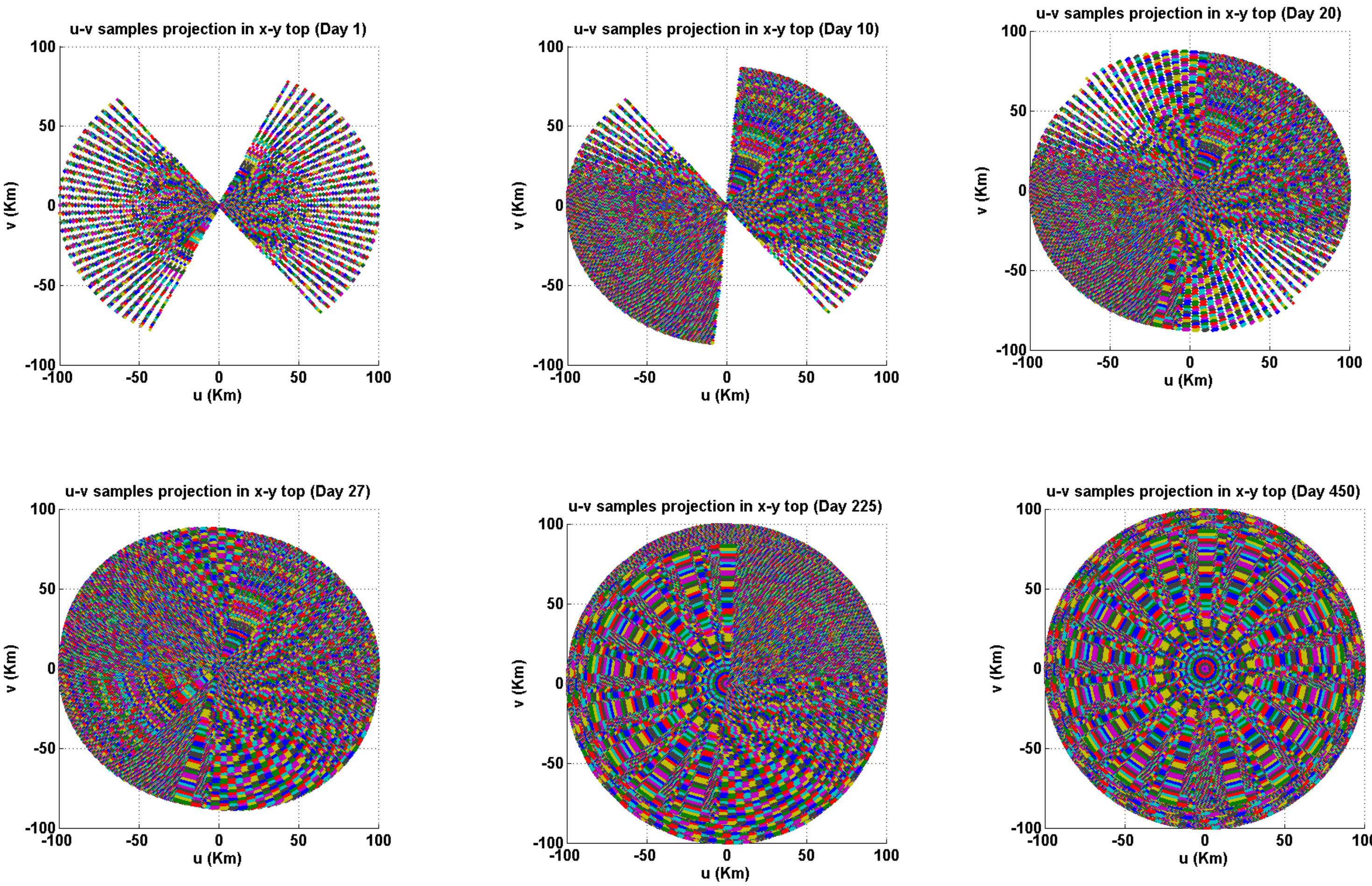


RFI free + precession

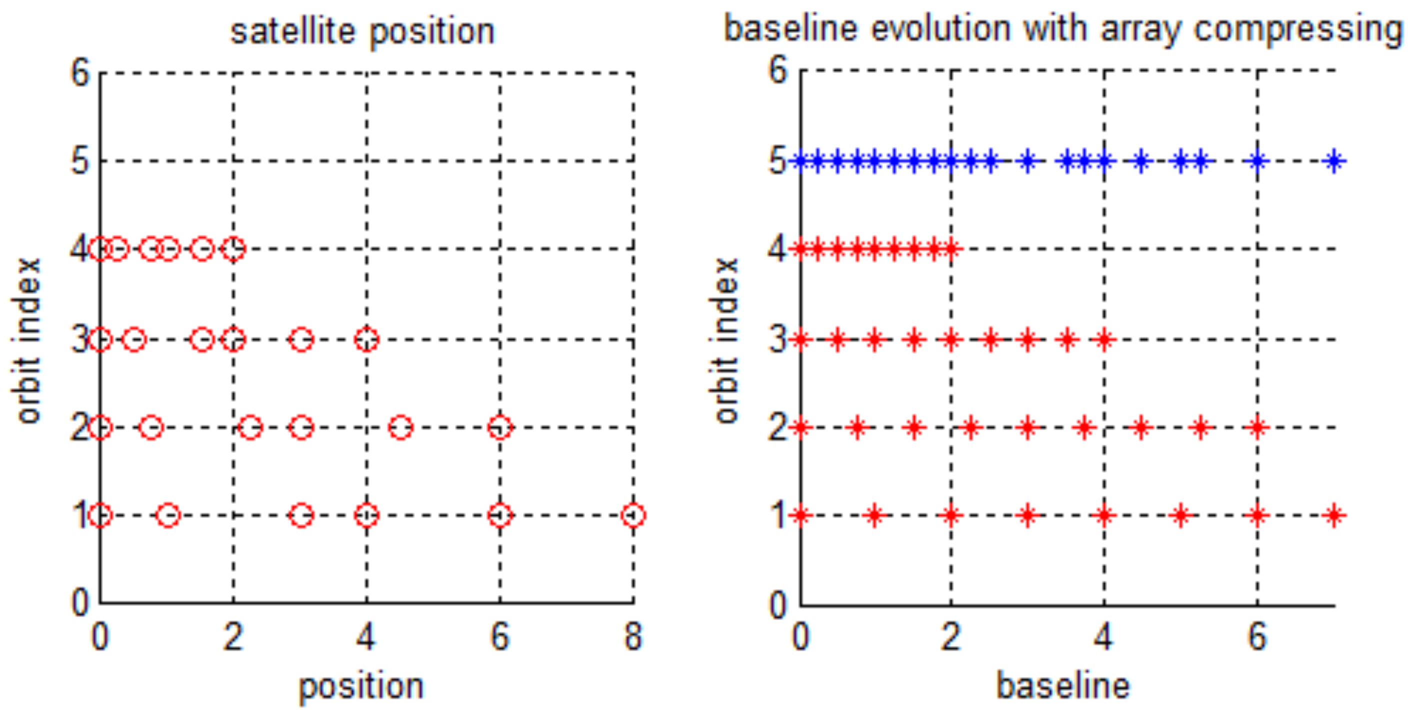




RFI free + Moon blockage + precession



Make denser coverage in UV plane

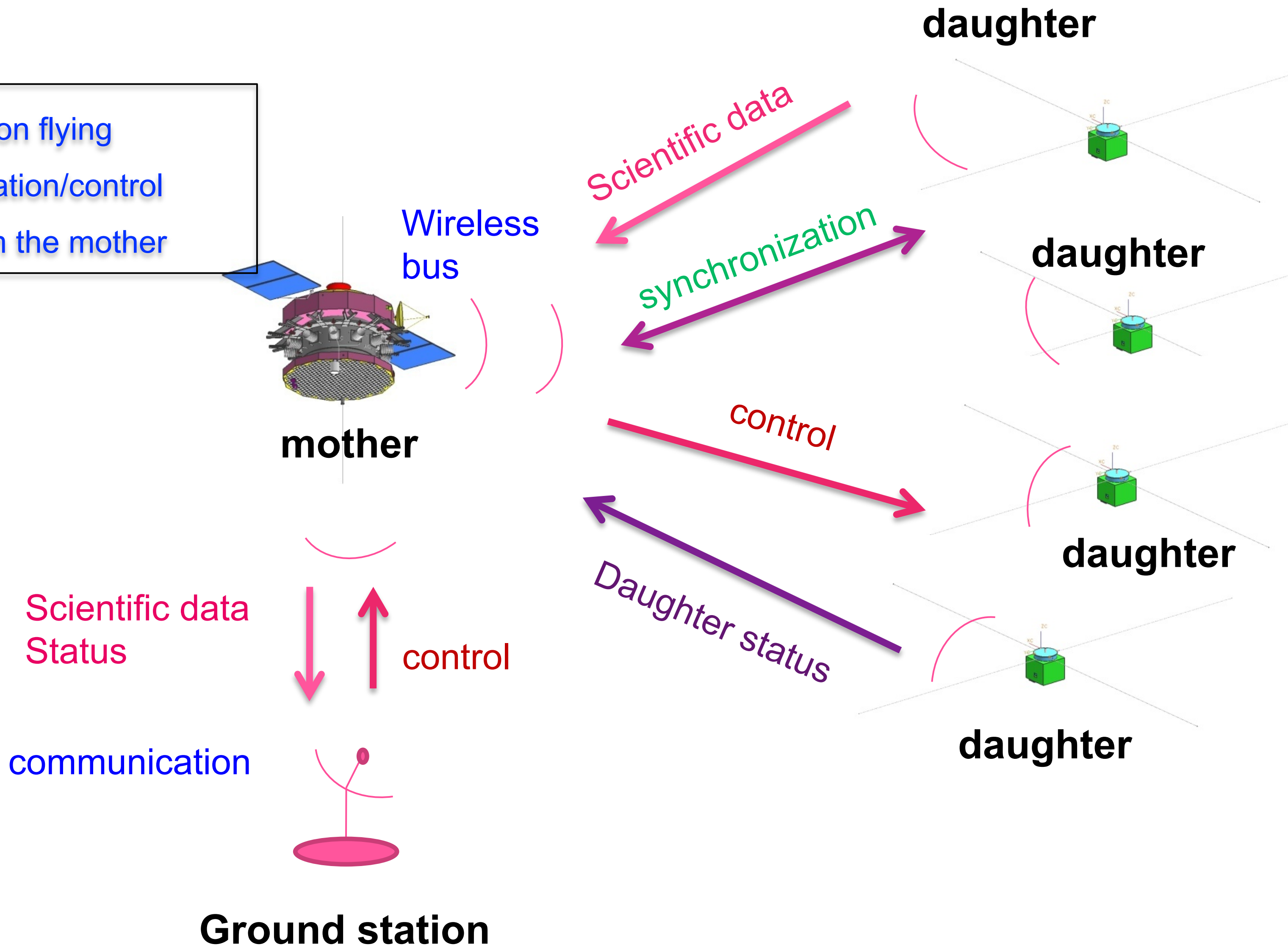


Advantages:

- ✓ Easy change the baseline in a linear array
- ✓ Dense and controllable coverage
- ✓ Image quality is improving orbit by orbit

Mission concept

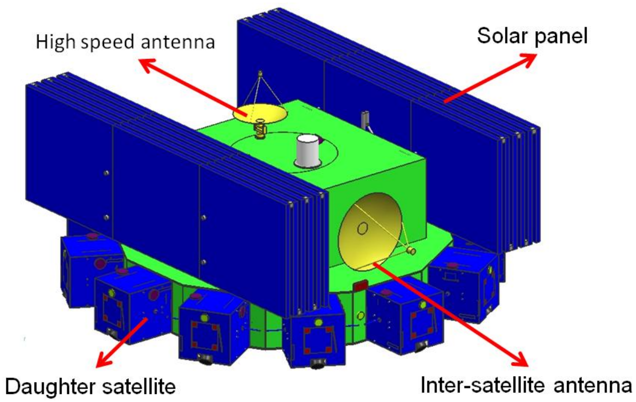
- Linear formation flying
- Central correlation/control
- Downlink from the mother

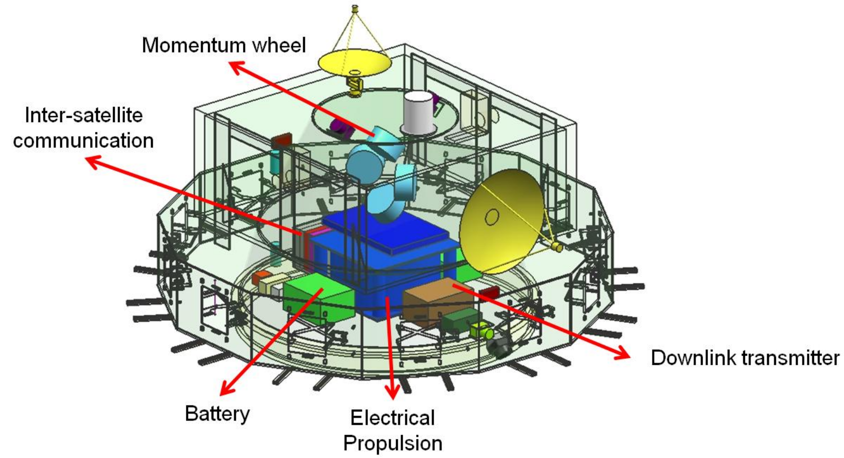


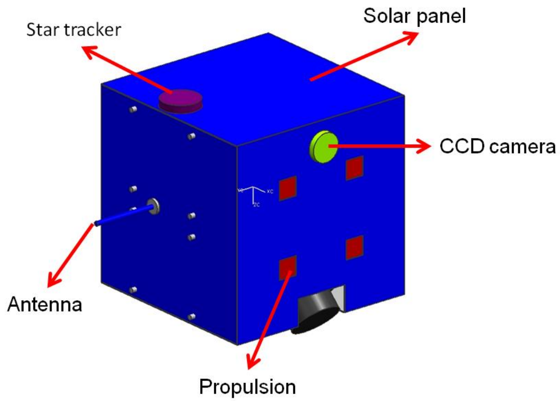
Mission concept

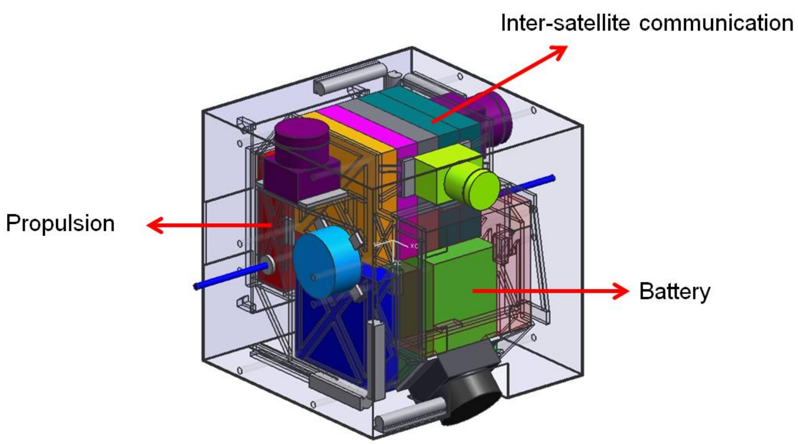
Baselines change from 100km to 100m within 5 days needs
15g cold gas for 12 satellites maneuver

Satellite

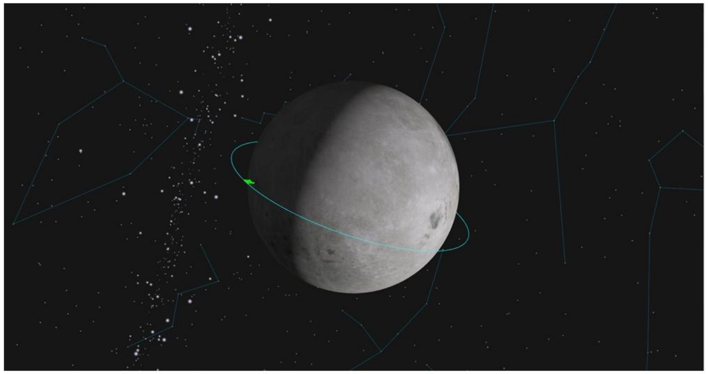

High speed antenna
Solar panel
Daughter satellite
Inter-satellite antenna

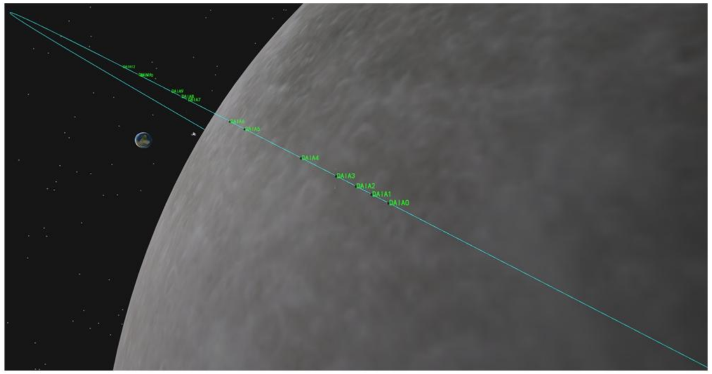

Momentum wheel
Inter-satellite communication
Downlink transmitter
Battery
Electrical Propulsion


Star tracker
Solar panel
CCD camera
Antenna
Propulsion

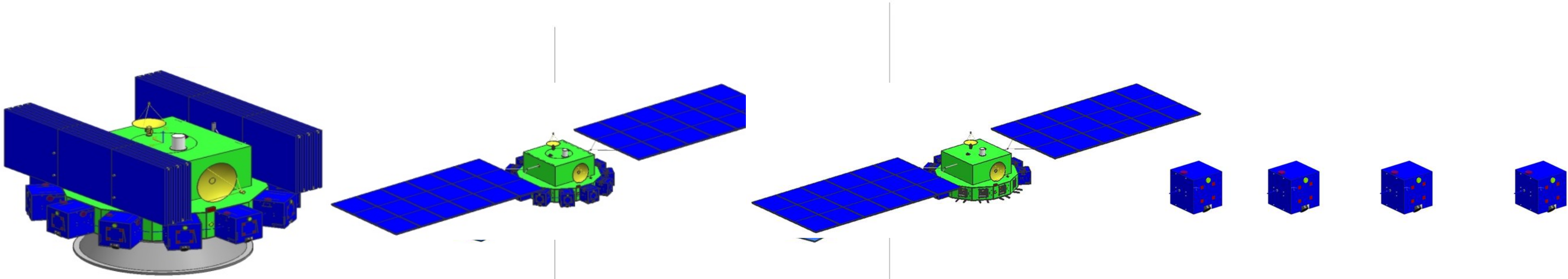

Inter-satellite communication
Propulsion
Battery

Mission Concept





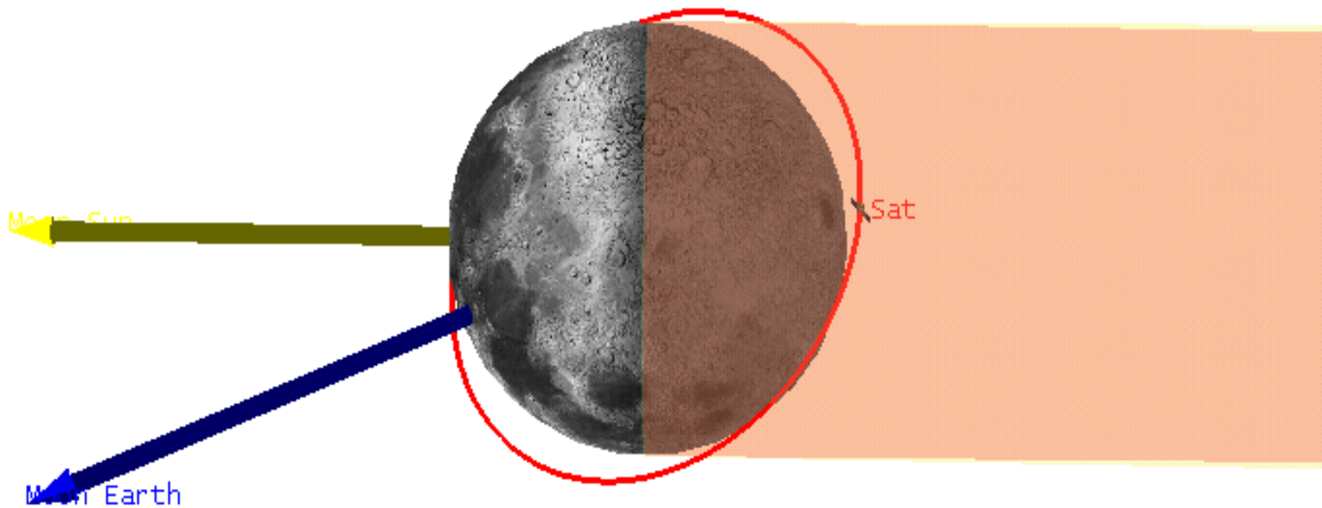
- 300km lunar orbit
- Linear formation flying.
- Active formation control
- Baselines coverage from 100km to 10m.



1. Satellites launch configuration.
2. Configuration in the transfer orbit from the Earth to the Moon.
3. Formation establishment.

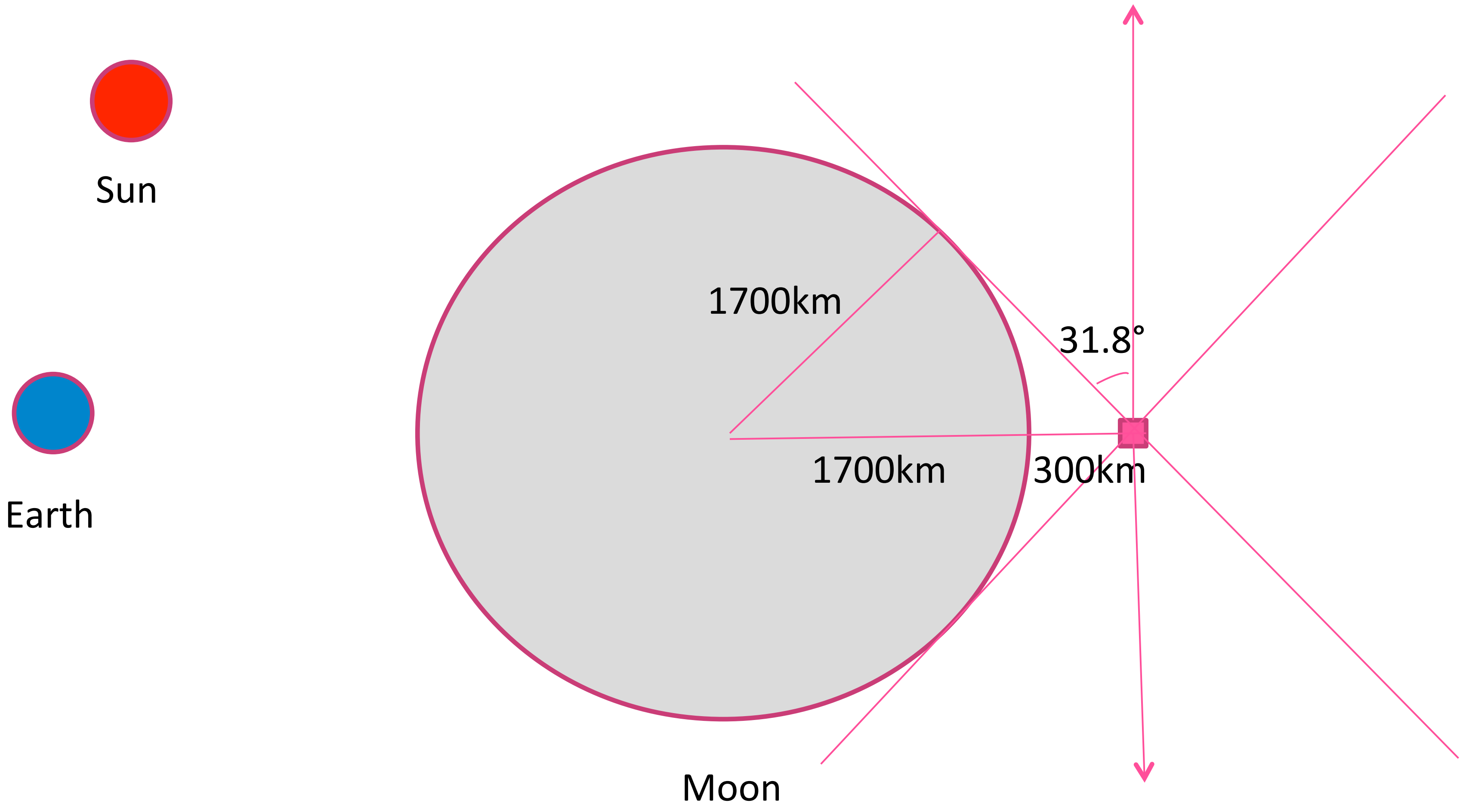
Target orbit analysis

- Perfect RFI free
- 1 or more strong sources will be blocked time to time, enabling diverse comparisons
- Orbit is stable, no crash will be happened
- Easier to avoid satellites collision

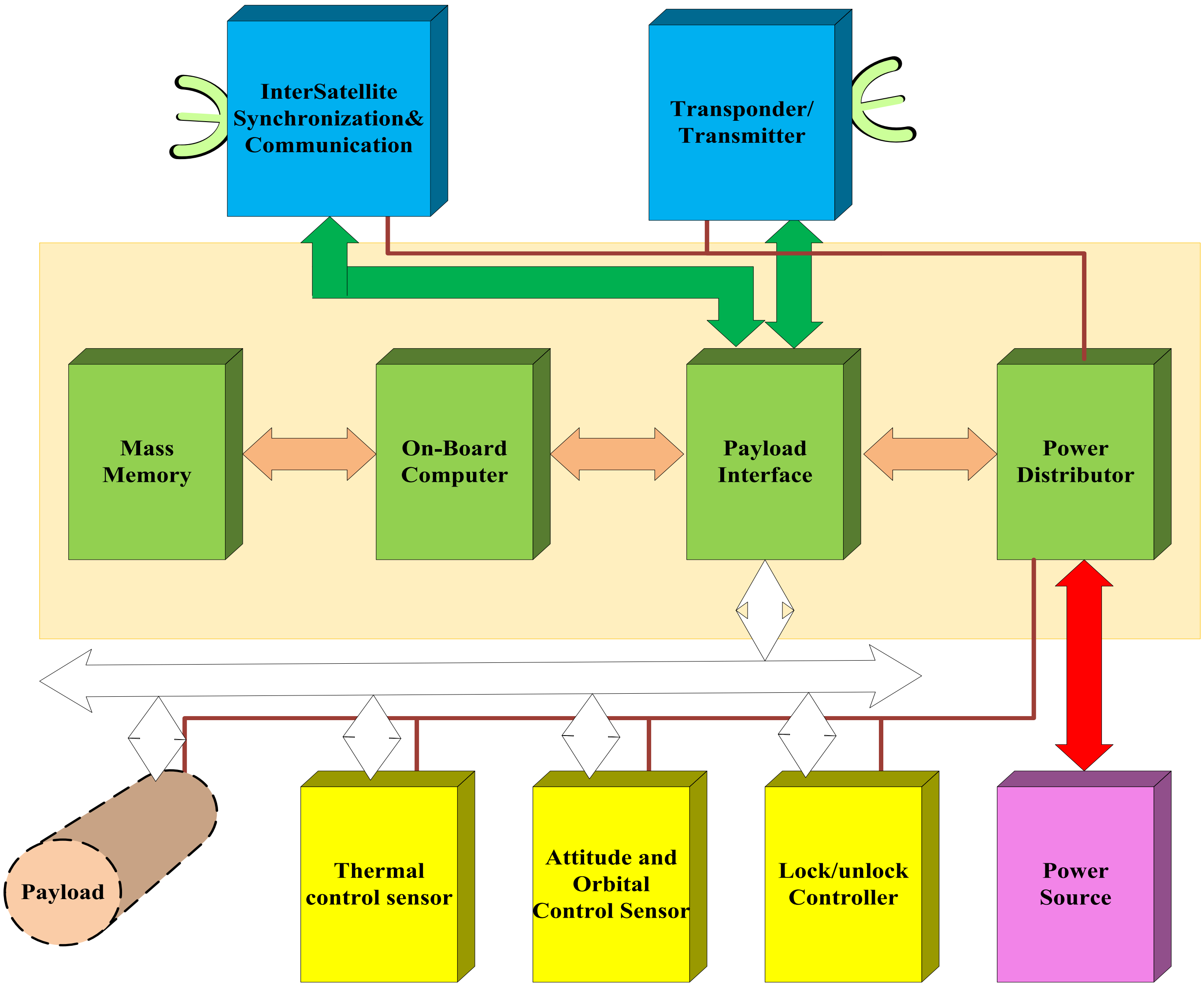


Orbit altitude: 300km
Sun/Earth free: 30%

Antenna field of view

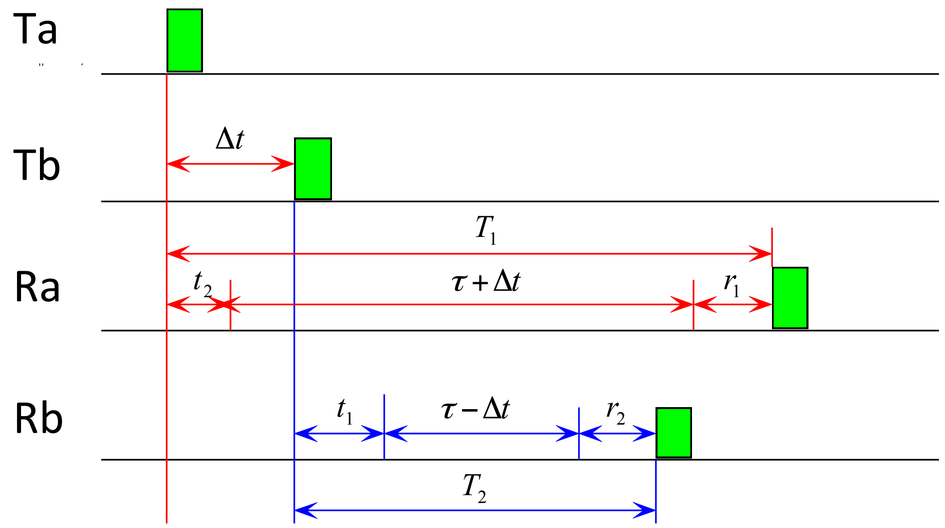


Integrated Electronic Subsystem(IES)



Communication, Ranging and Time Synchronization

Ranging Precision under Current Link Situation: 2cm



Time Synchronization

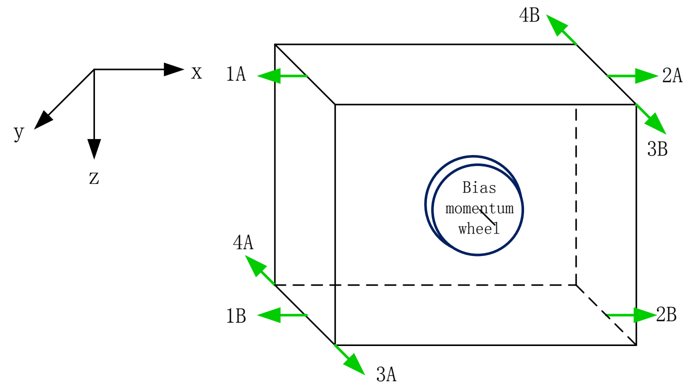
Dual One-way Ranging，DOR

$$D = \frac{1}{2} \cdot [(T_1 + T_2) - (t_1 + t_2) - (r_1 + r_2)] \cdot c$$

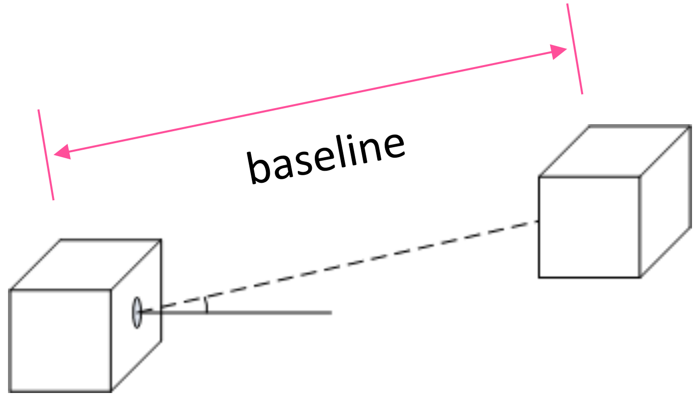
$$\Delta t = \frac{1}{2} \cdot [(T_1 - T_2) - (t_2 - t_1) - (r_1 - r_2)]$$

Attitude control and baseline determination

- Mother sat
  - 1 orbit control thruster, 12 attitude control thrusters and 4 momentum wheels.
- Daughter cubesat
  - 1 bias momentum wheel and 8 attitude control thruster.

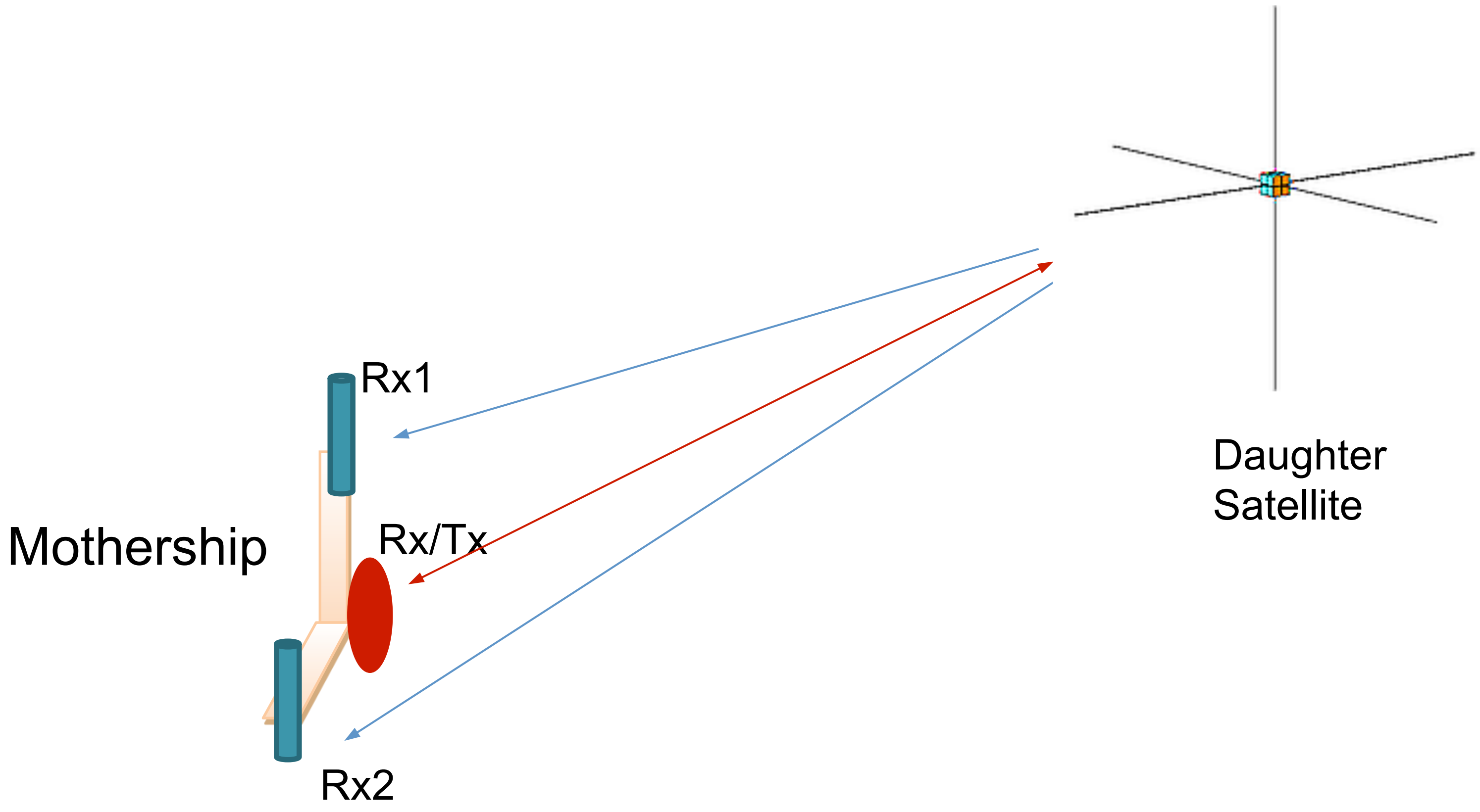


Attitude control



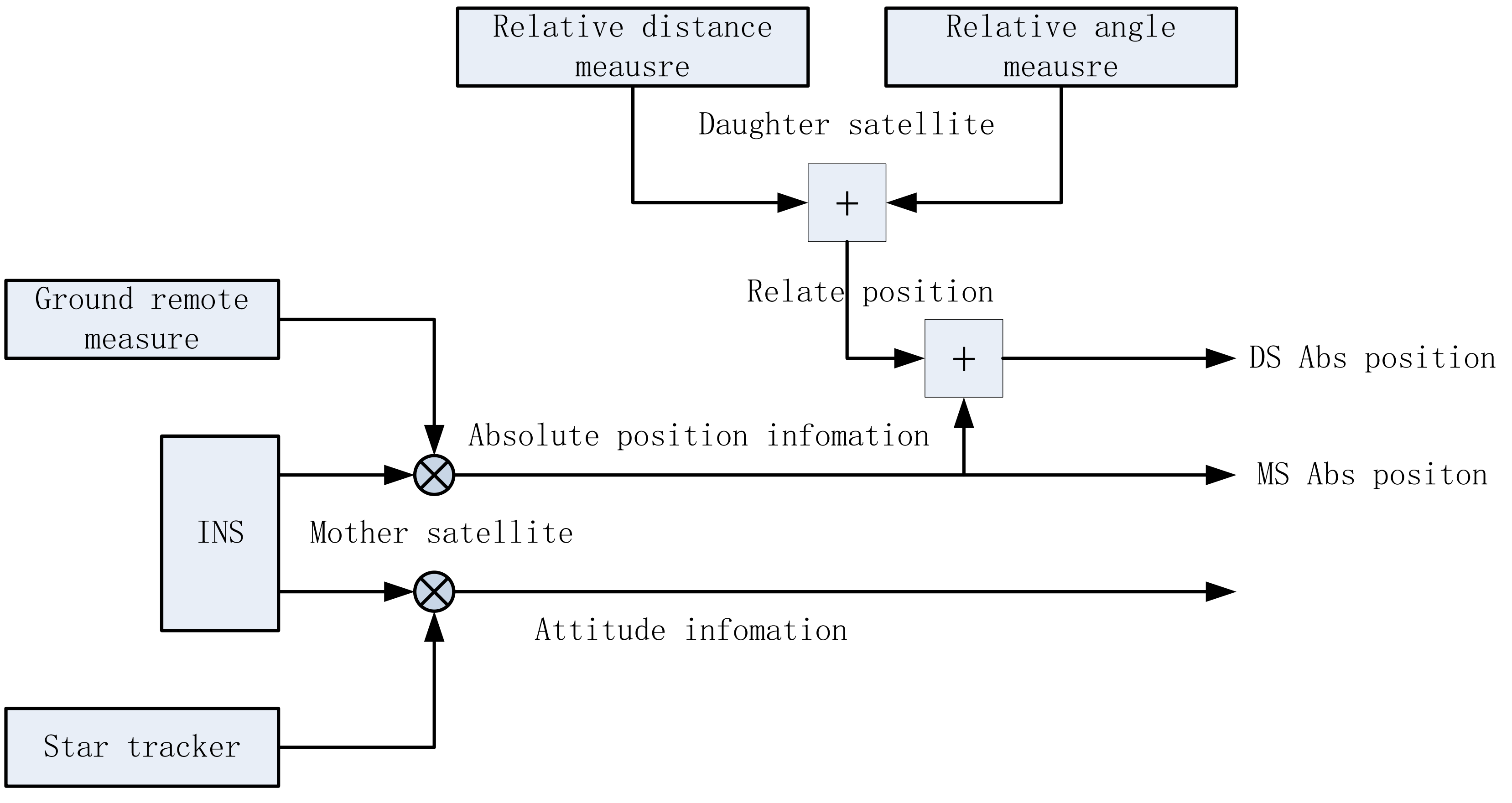
baseline determination
CCD camera of 0.01°angular resolution

Radio interferometry



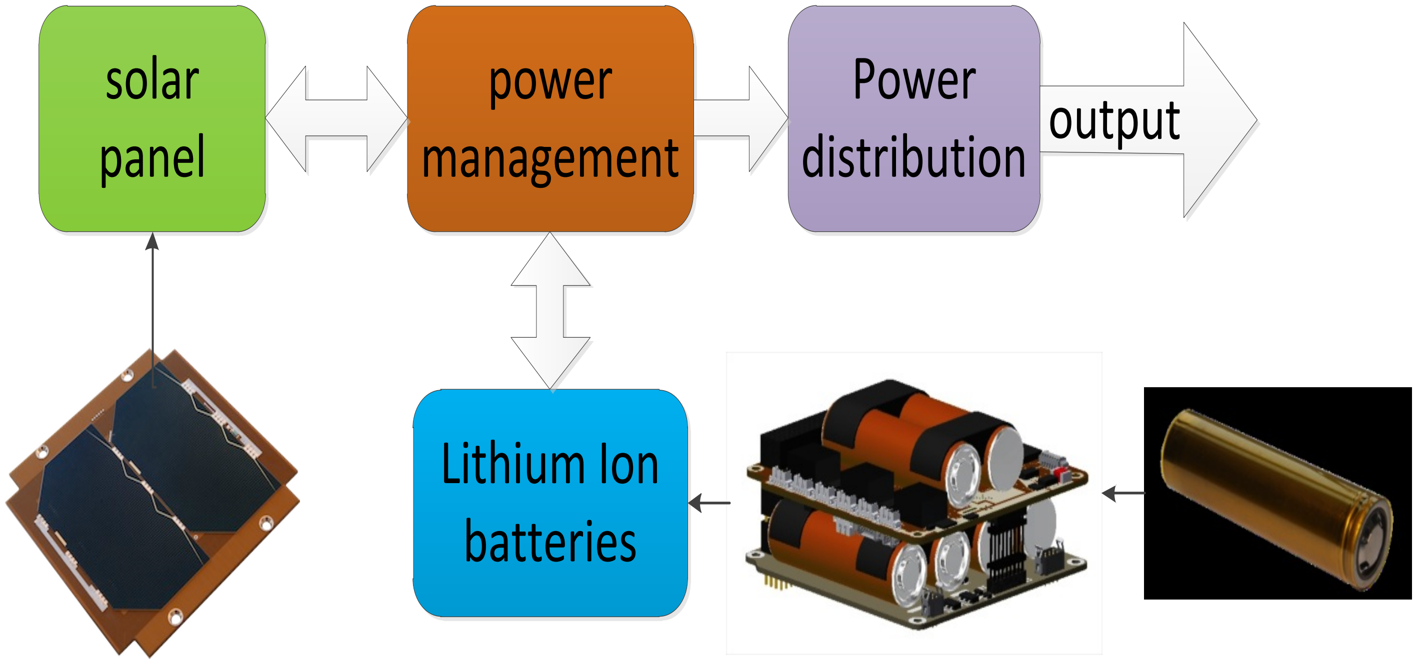
One main and two sub antennas is mounted on the Mothership. The angle of arrival (AOA) is measured by interferometry between antennas.

Navigation


Relative distance meausre
Relative angle meausre
Daughter satellite
+
Relate position
+
DS Abs position
Ground remote measure
Absolute position infomation
MS Abs positon
INS
Mother satellite
Attitude infomation
Star tracker

Power Subystem

- Power subsystem component
  - Solar panel
  - Lithium Ion batteries
  - power management and distribution system



The block diagram of power subsystem

Down link requirement

$$\tau(f) = \eta \frac{c}{f} \frac{T_0}{2\pi L}$$

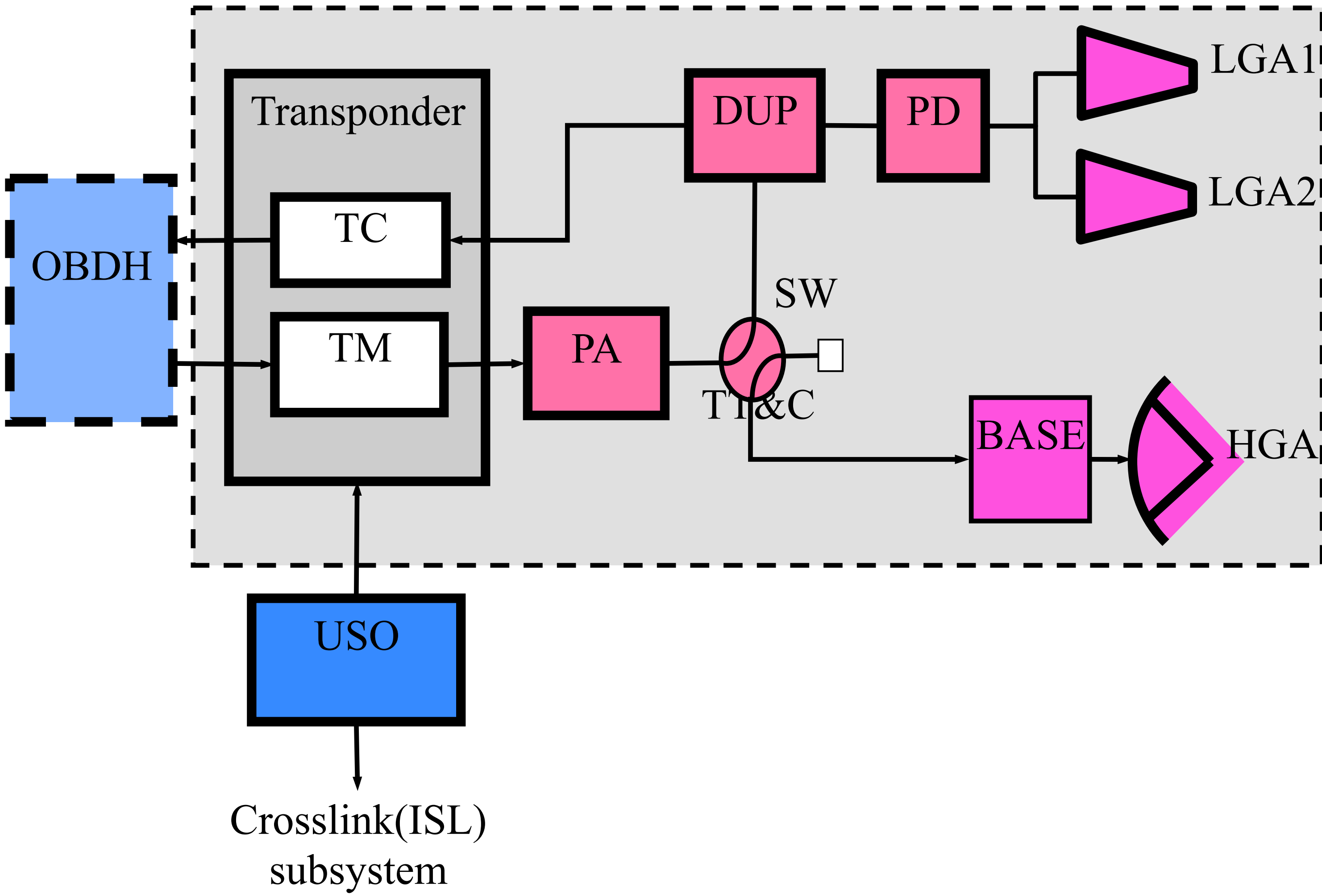
$$data\_rate_{1s} = T_{\text{rfi-free}} \sum_{f=f_0:f_m} \frac{p_n^2 \cdot W_l}{\tau(f)}$$

Assumption:

correlate 30MHz bandwidth at the same time (not possible for ISL)

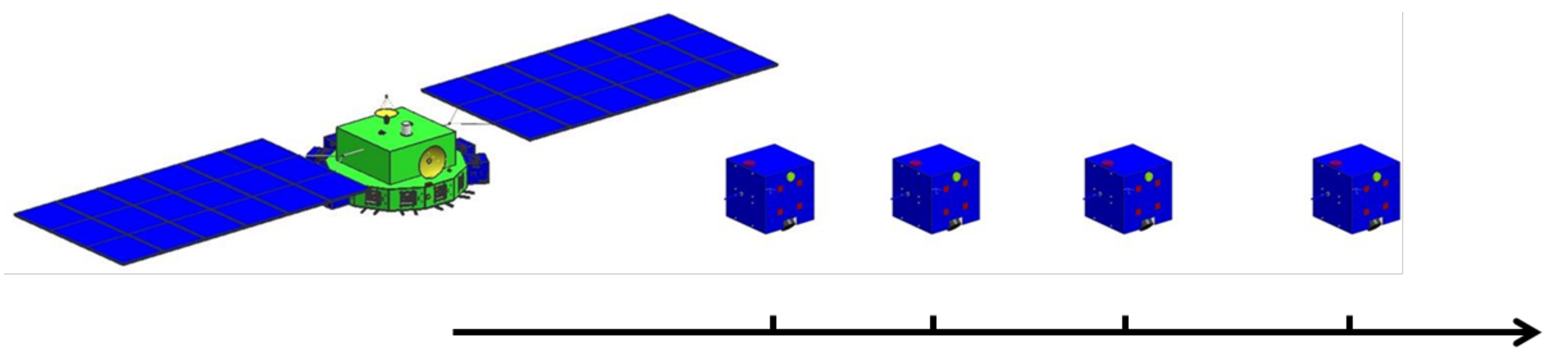
- 13.2Mbps
- 6.6Mbps (far side observation, near side download)
- High gain antenna is mandatory

TT&C Solution



In orbit calibration

- Relative amplitude calibration by cosmic background radiation
- Relative amplitude and phase calibration by calibration signal from Mother
- Absolute amplitude calibration by matched load and cosmic background
- Mothership is difficult to be used as a part of the array



High speed downlink (optional)

Phased array antenna– no moving parts

Reflector antenna- light and easier

Space engineering solution

Launch	• Launch into lunar orbit by LM-2D or Vega plus an 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	• Space-borne radio synthetic aperture radiometer with 12 nano-satellites

Preliminary specifications

Mission:

- Orbit: 300 km
- Number of satellites: 13 (1 mother + 12 daughters)
- Mass: 300kg
  - Mother: 180kg
  - Daughters: 10kg*12
- Power: 15W*12 + 1200W
- Downlink rate: <20Mbps (onboard correlation); >100 Mbps (raw data, HGA)
- Life time: 3 years

Payload

- Frequency range: 0.3 ÷ 30 MHz
- Polarization: Full-pol (circular pol)
- Antenna: Cross dipole, 2.5 m each stick
- Baseline: 100 m to 100 km
- Angular resolution: 6'@ 1 MHz, 12"@30 MHz
- Visibilities: ≈ 54K (half orbit), 59M (20 days)

Mass and Power consumption

- Mother satellite mass and power consumption

Subsystem	Subsystem Mass(kg)	Subsystem Power(W)
ADCS	3.87	6.6
Power	40.00	0.0
Propulsion	65.00	1100.0
Structure	50.00	0.0
Thermal	6.00	8.0
Communications	7.86	97.0
Payload	4.00	25.0
Data Handling	1.40	9.0
Total	**178.13**	**1229. 6**

The mass of mother satellite is 178.13kg, and power is 1229. 6W.

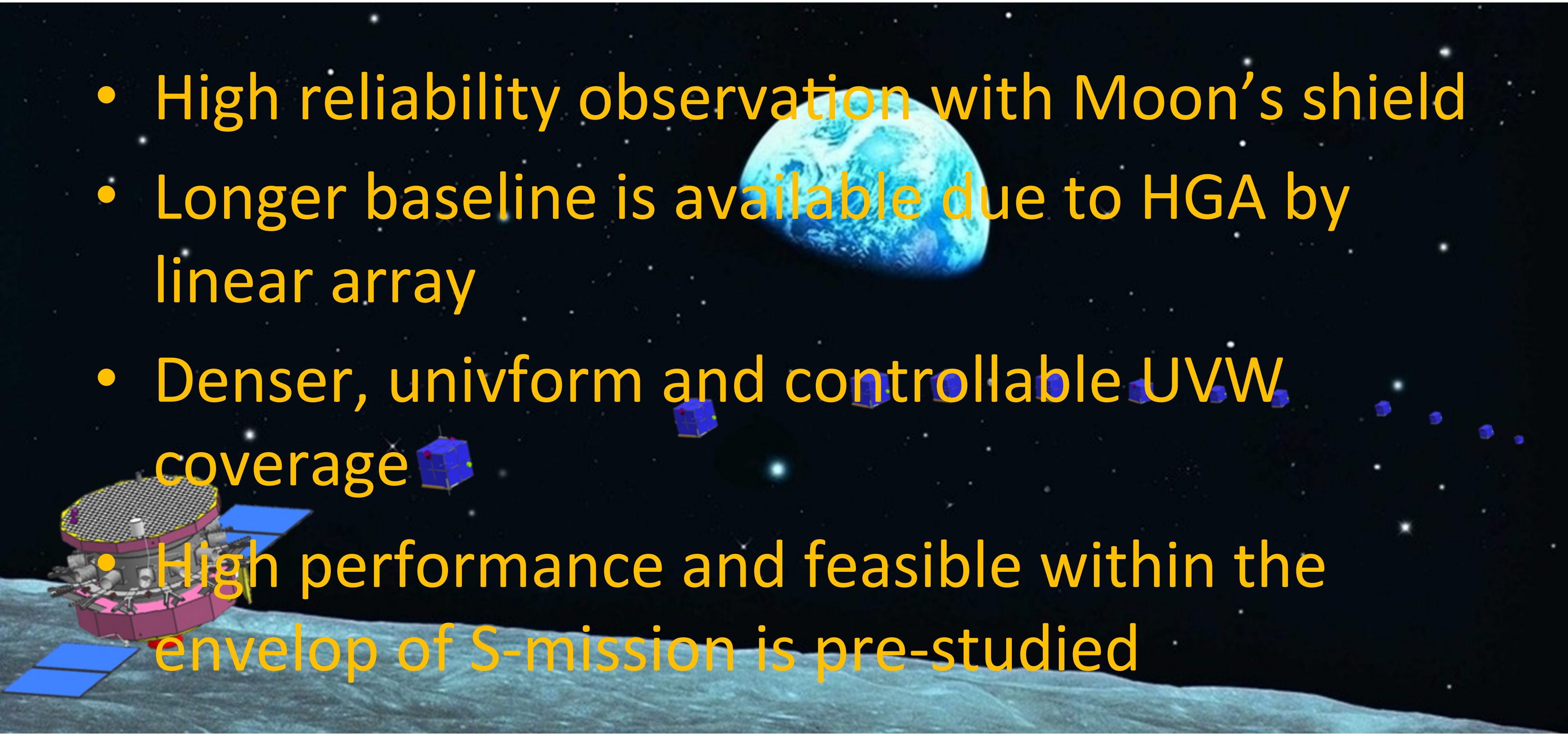
Mass and Power Consumption

- Daughter satellite mass and power

Subsystem	**Subsystem Mass(kg)**	**Subsystem Power(W)**
ADCS	1.08	2.3
Power	1.55	0.0
Propulsion	0.60	2.0
Structure	2.00	0.0
Thermal	1.00	1.0
Communications	0.50	6.0
Payload	2.00	1.5
Data Handling	0.60	3.0
Total	**9.33**	**15.8**

The mass of daughter satellite is 9.33kg, and power is 15.8W.

Summary



- High reliability observation with Moon’s shield
- Longer baseline is available due to HGA by linear array
- Denser, univform and controllable UVW coverage
- High performance and feasible within the envelop of S-mission is pre-studied