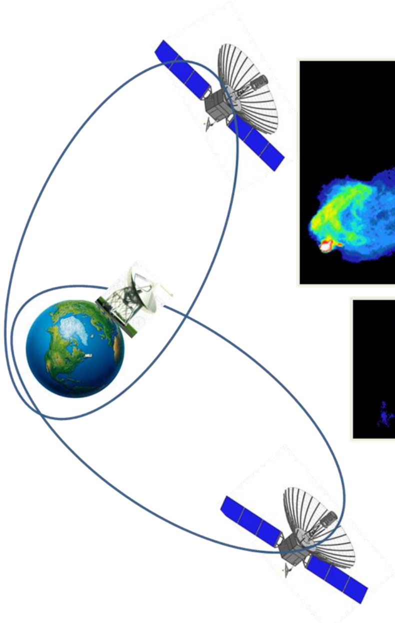
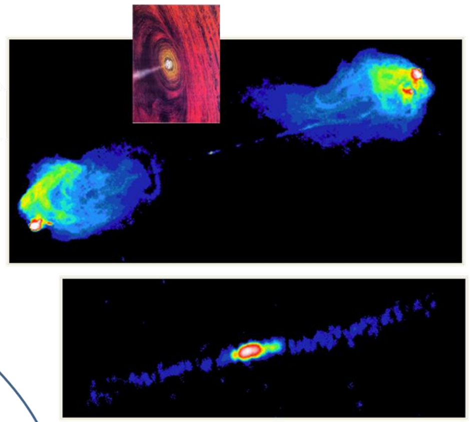
Status of the Chinese Space Millimeter-Wavelength VLBI Array Planning





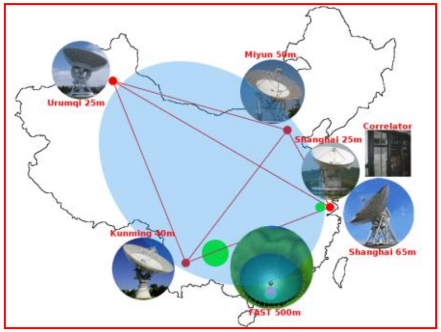
----Uncovering the Secrets of Super Massive Black Holes and Active Galactic Nuclei

Xiaoyu HONG,
Zhiqiang SHEN, Qinghui LIU, Tao AN et al

Shanghai Astronomical Observatory(SHAO), CAS
May. 19, 2014，
3rd China-US workshop, Green Bank

1. Brief introduction of the project

- *Reported in the 2nd Sino-US workshop and ISSI-BJ workshop*
- **SHAO: the development of VLBI, and cm radio astronomy;**
  - □ 1970s：VLBI Network Concept
  - □ 1980s：Shanghai 25m
  - □ 1990s；Urumqi 25m
  - ● Join EVN, IVS and VSOP Obs.
  - □ 2000s；Beijing（60m） and Kunming（40m）
  - ● (CVN：5 Ant. + correlator) join the tracking for CE(1.2.3)
  - ● MK5B, CDAS, eVLBI
  - □ 2010s Tianma(65m), FAST (500m)
  - □ 2020s ??? 2030？？？
  - □ QTT，Space VLBI？Northern hemisphere SKA at cm??



1.2 Space Science Projects in CAS

- The Chinese Academy of Sciences (CAS) leads the Strategic Pioneer Program to Space science programs. (2011-2015)
  - The Hard X-ray Modulation Telescope (HXMT, 2015),
  - The Quantum Experiments on Space Scales (QUESS, 2015),
  - The Dark Matter Particle Explorer (DAMPE, 2015)

- The for the project from 2015 to 2020, there are 8 candidates:
- The first batch background research （4 projects）for the next generation of Chinese space science missions, which includes the Space Millimeter VLBI Array (SMVA) was selected for further study in 2011 and start at 2012;
- Magnetosphere – Ionosphere – Thermosphere Coupling Exploration (MIT)
- Solar Polar Orbit Radio Telescope (SPORT)
- X-ray Timing and Polarization mission (XTP)
- Space Millimeter VLBI Array (SMVA)
- The second batch （another 4 projects）was selected in 2013 and started in 2014.

1.3 A proposal of SVLBI in China

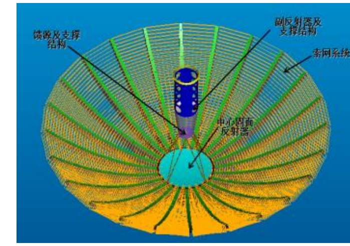
- We worked out a proposal for China space VLBI
  - Stage 1: Long-mm-wavelength Space VLBI Array, with the potential start in 2015 and launch in 2020
    - two 10m space telescopes,
    - highest frequency 43GHz,
    - to realize 20uas resolution and good (u,v) coverage together with ground radio telescopes for imaging
  - Stage 2: Mm-wavelength Space VLBI Array (3x12-15m, 86 GHz) in 2021-2025
  - Stage 3: submm Space VLBI Array (3-4 12-15m, sub-mm) after 2026

➢ Space Scientific Projects in CAS

- In 2012, the project for pre-study of space VLBI array was approved by the CAS as a "Background Prototype Research" .
- Uncovering the Secrets of Super Massive Black Holes and Active Galactic Nuclei with capability of high resolution for imaging
- The goal is to complete the overall design of the first space VLBI array. To work out several key engineering and technical problems as well as science cases, from 2012 to 2015.
- There was an interim evaluation in April, 2014.

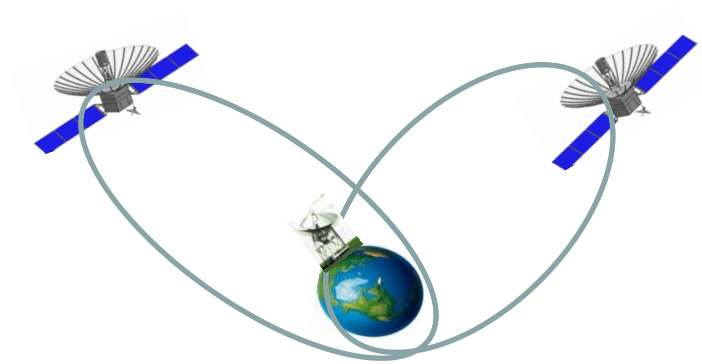
2. Main concepts of the SVLBI proposal

2.1 Two 10m space antennas



To improve Orbital Design

- Obtain good (uv) coverage for major observing targets



- Preliminary scheme

  Two Satellites (10m antenne)

  - Apogee 60000 km
  - Perigee 1200 km
  - Inclination Angle 28.5 deg
  - Angle between two orbital planes ~120 deg
- Achieve good (uv) coverage at 2-dimention – a critical requirement for imaging
- accomplish imaging within an/several orbital periods

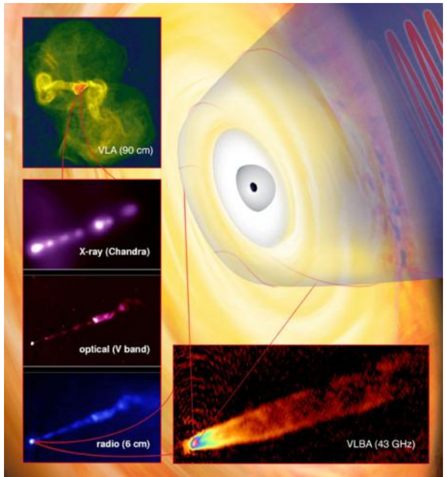
2. Main concepts of the SVLBI proposal

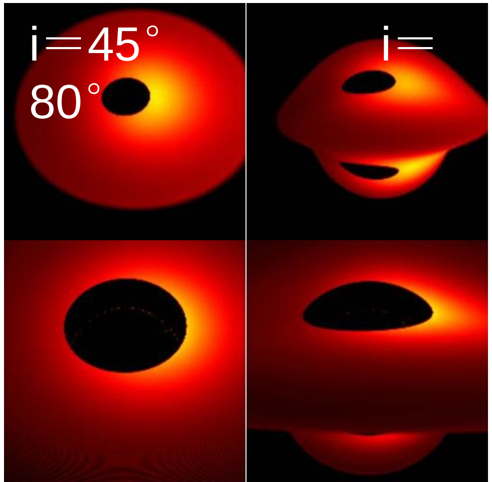
2.2 The Scientific goals:

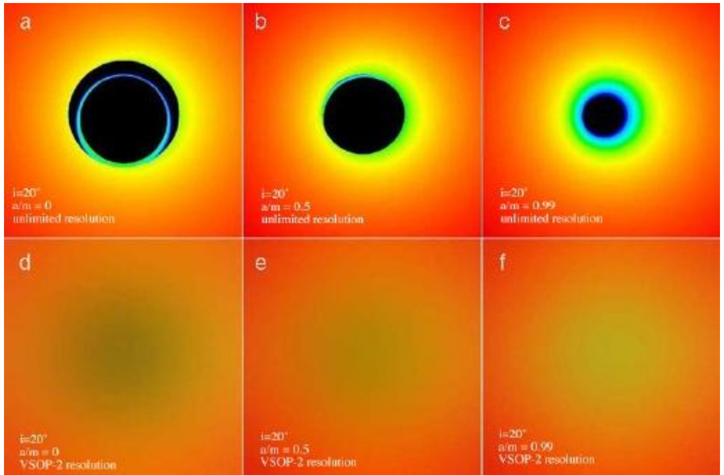
- Focusing on some important scientific questions which will help us to understand the Universe better
- Imaging Super massive Black Holes, Active Galactic Nucleic and compact radio sources with high resolution
- Key Science Goals
  - Supermassive Black Hole (SMBH) – M87
  - Supermassive Black Hole (SMBH) – Megamasers
  - Jets in Active Galactic Nuclei (AGN)
  - Formation and Evolution of Massive Stars

Key Sciences to be addressed

- **Super-massive Black Hole(SMBH)**
  - Utilizing the space-ground baselines, mapping the emission structure surrounding SMBHs. The elliptical galaxy M87 will be studied in detail.
  - At 43GHz, resolution of 20μas, mapping the closest massive BH in the heart of M87, directly detection and imaging of BH shadow.



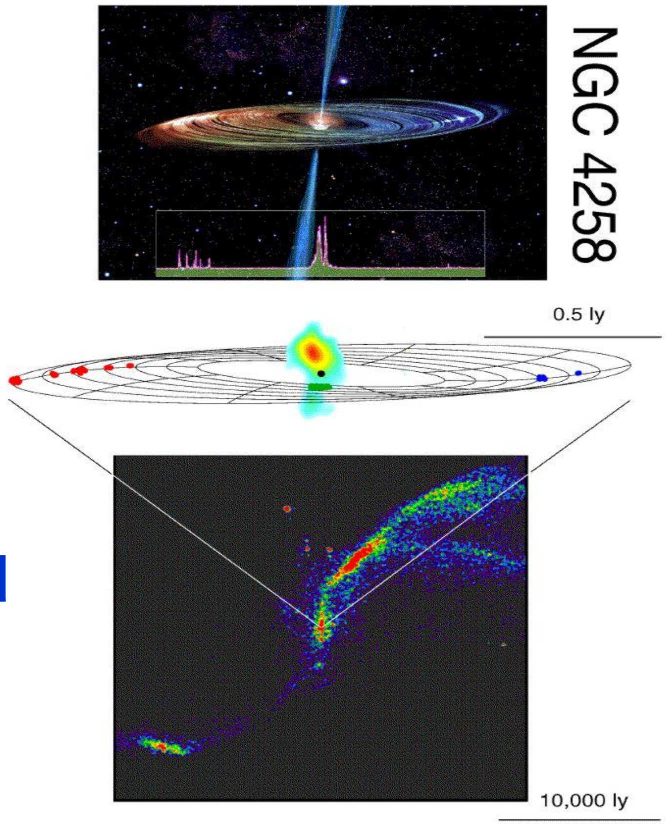




Name	Other Name	D [Mpc]	M_{BH} [10^8 $\mathrm{M}_\odot$]	θ_g [μas]	$S_{15\mathrm{GHz}}$ [mJy]	Remarks
NGC 3031	M 81	3.63	0.7	0.93	164.8	
NGC 3627	....	6.6	0.9	0.27	2.9	
NGC 3998	....	21.6	5.8	0.53	85	S at 5 GHz
NGC 4143	....	17	3.7	0.44	10	
NGC 4261	....	35.1	7.5	0.43	6230	S at 8.4 GHz
NGC 4278	....	9.7	2.8	0.57	89.7	
NGC 4374	M 84	18.4	16	1.74	183.7	
NGC 4486	M 87	16.8	32	3.81	2835.7	
NGC 4552	....	16.8	3.7	0.43	58.6	
NGC 4594	M 104	20	2.7	0.27	86.6	S at 8.4 GHz
NGC 5128	Cen A	4.2	2.4	2.96	2500	S at 8.4 GHz
IC 1459	PKS 2254 – 367	27	25	1.85	1000	S at 8.4 GHz
Sgr A*	....	0.008	0.04	6.50	1030	S at 8.4 GHz

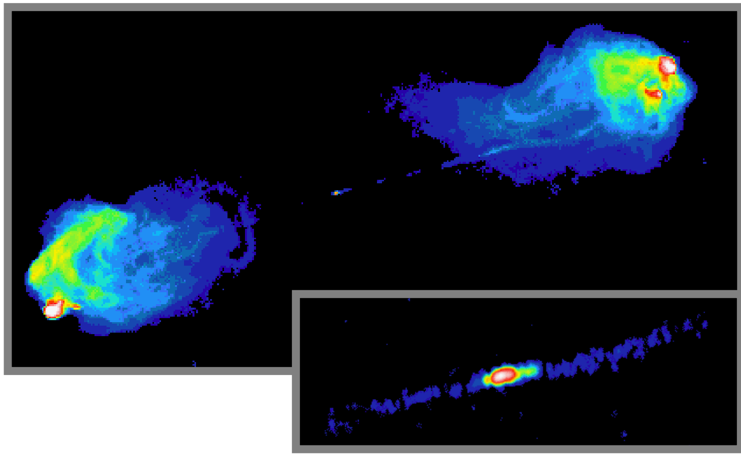
Key Sciences to be addressed

- **Super-massive Black Hole (SMBH)**
  - **Imaging extra-galactic water mega-masers which lie in accretion disks orbiting SMBHs to reveal the disk structure and dynamics, and then to determine the SMBH masses.**



Key Sciences to be addressed

- **Jets in Active Galactic Nuclei (AGN)**
  - Probe a range of angular scales, enabling a detailed study of morphology, kinematics, and emission in extragalactic jets.
  - Formation, acceleration, collimation of the relativistic jets
  - Internal structure of jets
  - Polarization structure



Key Sciences to be addressed

Formation & Evolution of Massive Stars

- **Observing star-forming accretion disks and outflows traced by masers**
  - ***H2O at 22 GHz***

    On scales of 1-10 AUs, the gas kinematics can be probed by H2O masers using the Space VLBI Array.
  - ***SiO at 43 GHz***

    Imaging these bright and compact sources at 43 GHz allows investigation of a number of key scientific topics in late stellar evolution.
- **Again, sensitivity is an issue**
- **Deep exploration of maser physics in extreme situations**

2. Main concepts of the SVLBI proposal

2.3 Frequencies considered:

- The traditional observed bands in ground VLBI: P, L, S, C, X, Ku, K, Q, W,
- VSOP; L, C, K
- RadioAstron: L, C, and K

- Since VSOP and RadioAstron have had good results from L and C band, we are considering other bands (higher frequencies) for new results . So X, K, Q are under considered.

3. The structure of the system

"Space VLBI Array Phase 1"

1. System Designing
   - Sciences
   - Techniques

2. Satellite Platform
   - Designing
   - Pointing
   - Downlink

3. Space antenna
   - 10m
   - 43GHz

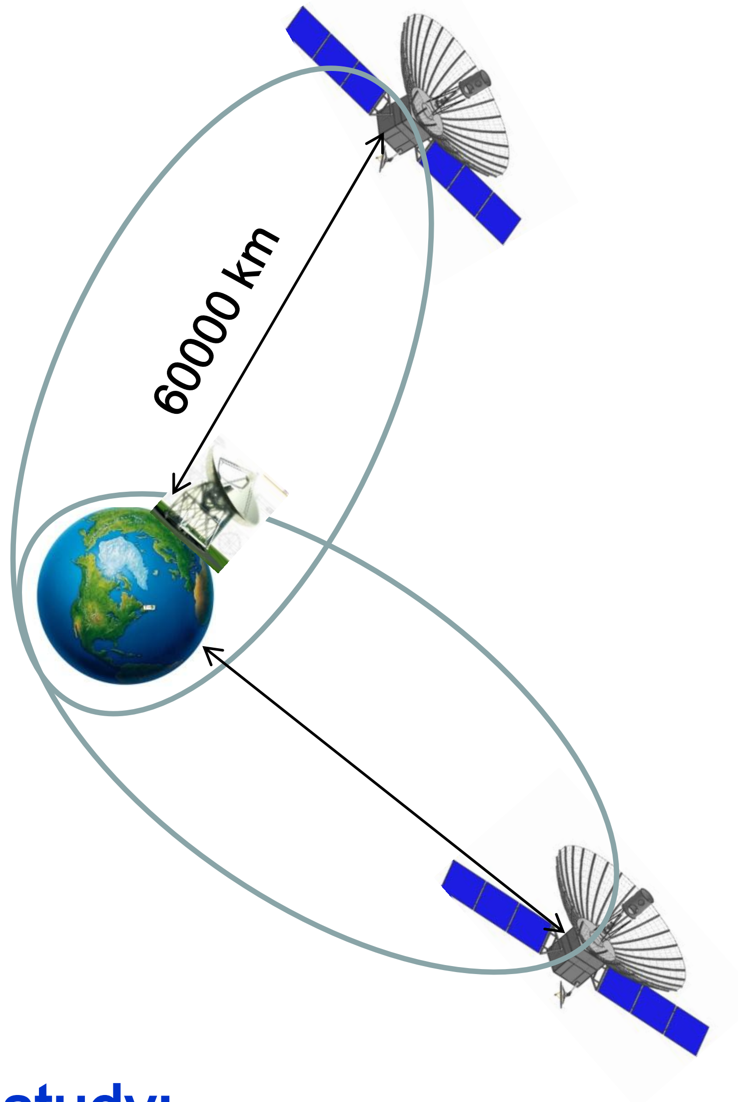
4. Astronomical Payload
   - receivers
   - recording sys.
   - time & freq. (H-maser) …

4. Some international meetings

- Learnt a lot from the international colleagues
- Realized such project is a really challenging both at Sciences and technology.
- It should be strongly supported by international collaboration.
- It will be a very expensive project

5、The Progress --system design

- Two satellite
  apogee 60000 km
  perigee 1200 km
  inclination 28.5 deg
- Observation band:
  X（6-9）/K（20-24）
  /Q（40-46）GHz
  LCP/RCP
  Cooled receiver（22/43GHz)
- Date rate: 1-2 Gbps
- Resolution： 20 μarc（@43GHz）
- Schedule: 2012-2016 key technique study;



5、The Progress --system design

- Strong scientific goal
- Orbiters design with good (u,v) coverage for sciences
- Orbiters determination with USB+VLBI and SLR
  - No phase referencing model is considered this moment, It is possible at low orbit priod.
- Down link date rate (1.2 – 2.4 Gbps), need ground station support.
- Time and frequency (Both uplink and Space H masers are considered this moment)

Scientific goals

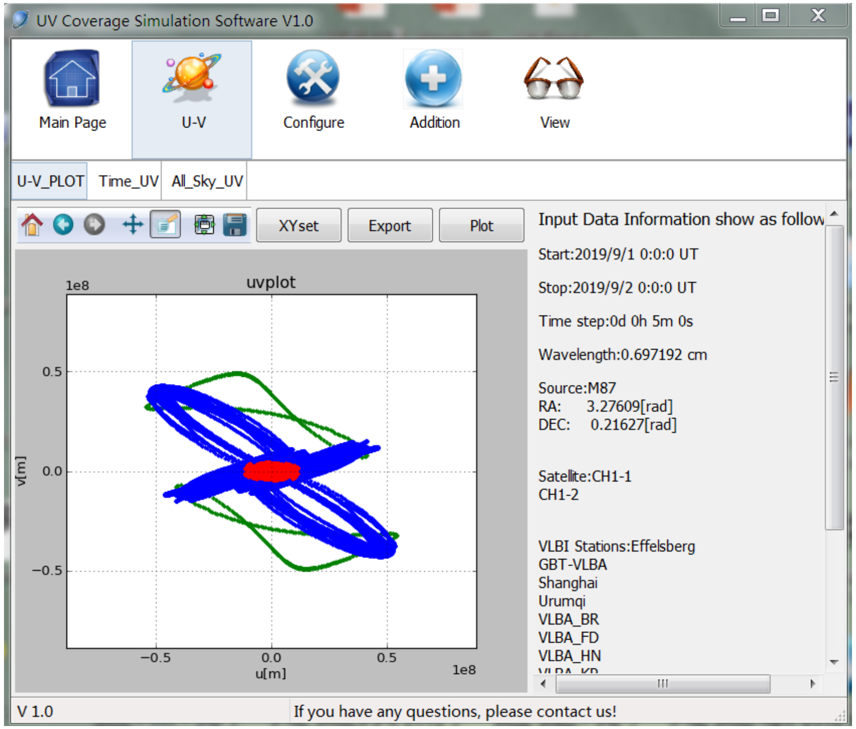
- SMBHs (e.g., M87);
  - BH shadows?   Challenge
- Masers
  (not many source can be detected)
- Jets in AGN
  - Structure
  - Launching
  - Magnetic structure
  - High Energy connection
  - Jets in x-ray binaries
- Formation and evolution of massive stars
  (the importance and the feasibility?)

Scientific goals

- Suggested to have L band

- Pulsars
- ISM - Intraday variability
- Transients
- Gravity

➢ Developing a software to plot uv for two space antenne.

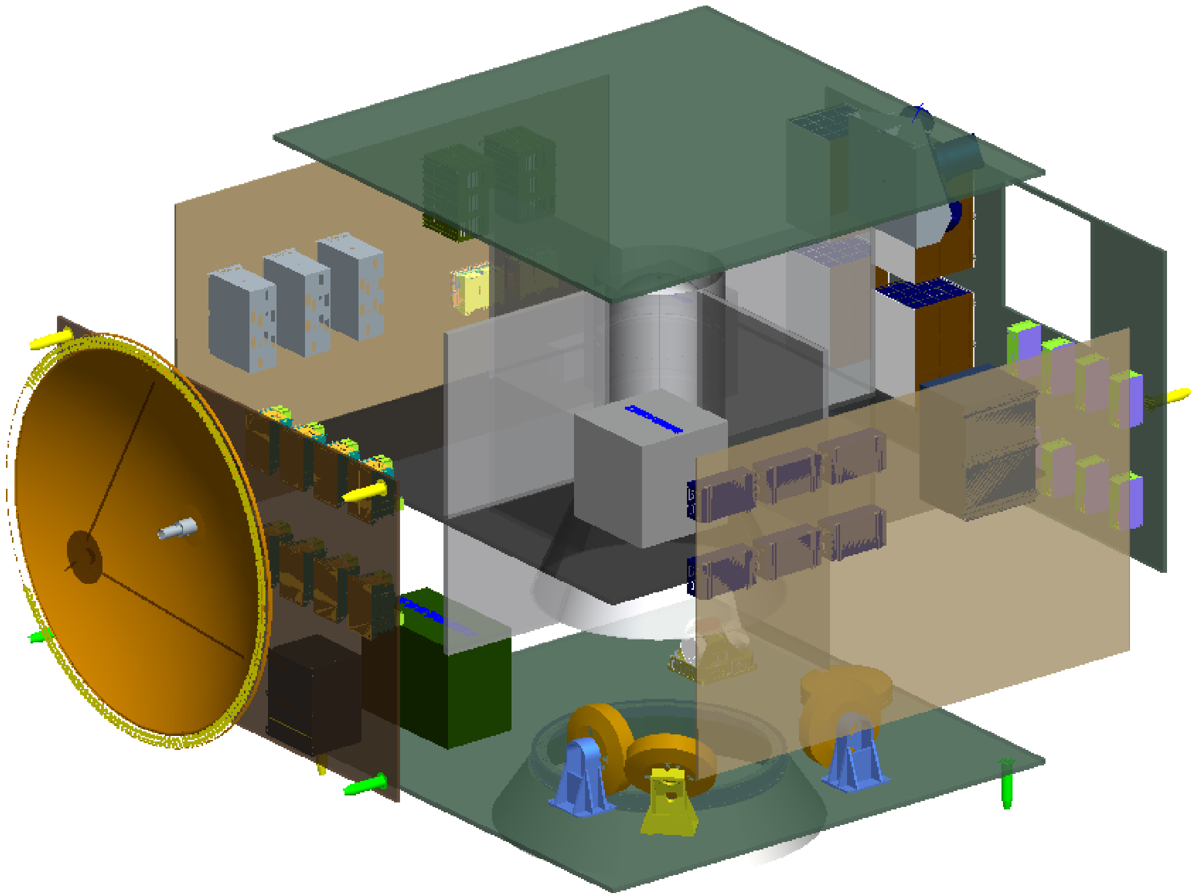


- **If the apogees of the two satellites are deferent by 5000km, the uv coverage will much better.**

	Satellite 1	Satellite 2
Apogee	60000 km	55000 km
Perigee	1200 km	1200km
Inclination Angle	28.5 deg	28.5 deg

Satellite Platform

- Pointing is very important



5、The Progress --payload

payload	Item	Specification
Space Antenna	Aperture	10m
	Freq./Efficiency	X： 6-9GHz; ≥60%
		K： 20-24GHz; ≥50%
		Q： 40-46GHz; ≥40%
	Surface Error	≤ 0.4mm(RMS)
	Mass	≤400Kg
Astronomical Receiving System	Type	K/Q: cryogenic, X: room temp.
	Polarization	LCP/RCP
	Bandwidth	512/256/128MHz, 1/2bit
Time/freq. Standard System	Stability	3×10^{-12}（1s），3×10^{-13}（10s），3×10^{-14}（100s）
	Method	Onboard H-maser, Ref. signal trans. System

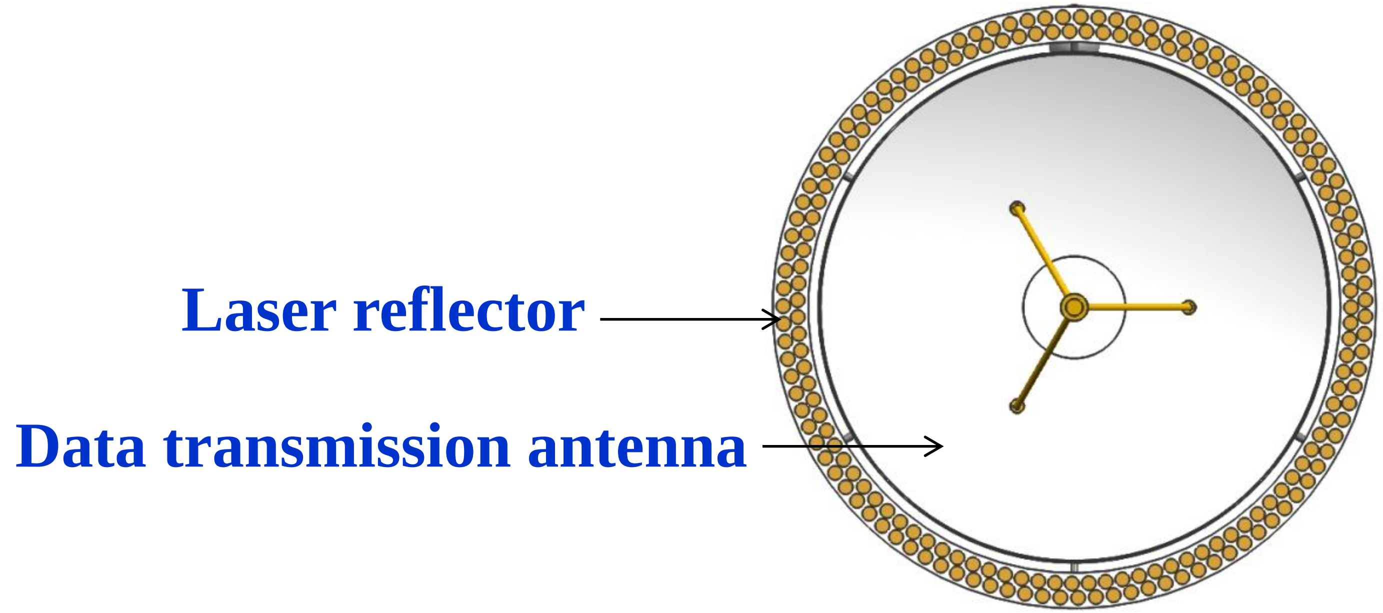
Payload Consideration

payload	Specification
High-rate data transmission system	Band : Ka Antenna 1.5m Modulation: QPSK/8PSK/16APSK Coding: RS or LDPC Rate: >1.2Gbps
Laser Reflector	Effective reflection area: 1650 cm^2 Field: ±15° Precision of Laser Ranging: 5cm

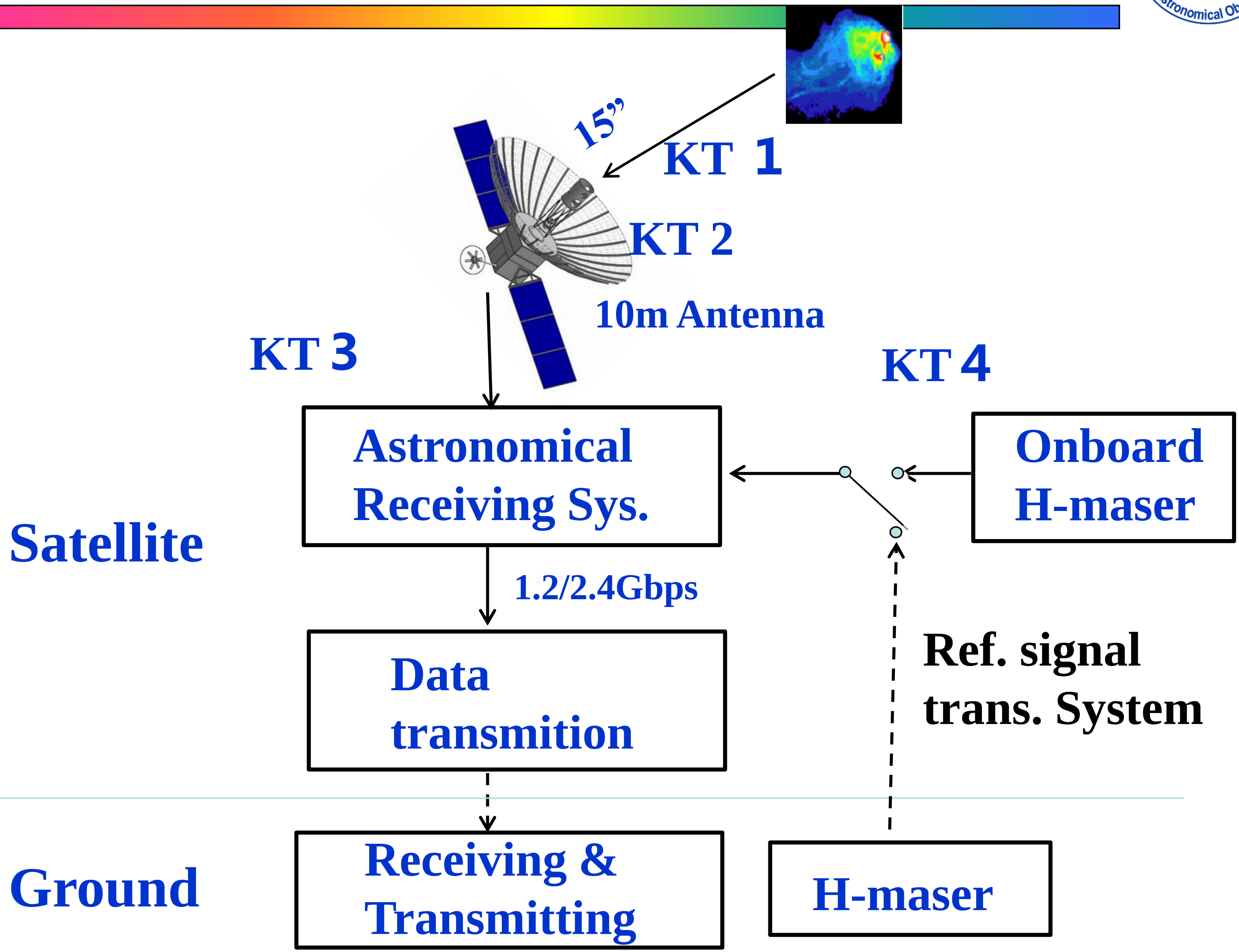
Technique Requirement

Preliminary consideration: CZ-3C rocket, maximal allowed weight is 3.2 ton,

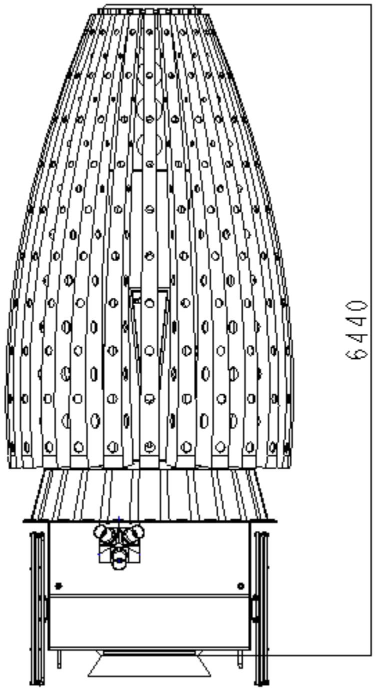
- **Orbit determination accuracy : 200m at apogee, 30m at perigee for engineering**
- **USB+VLBI; USB+SLR, Satellite tracking accuracy 20 m for sciences.**



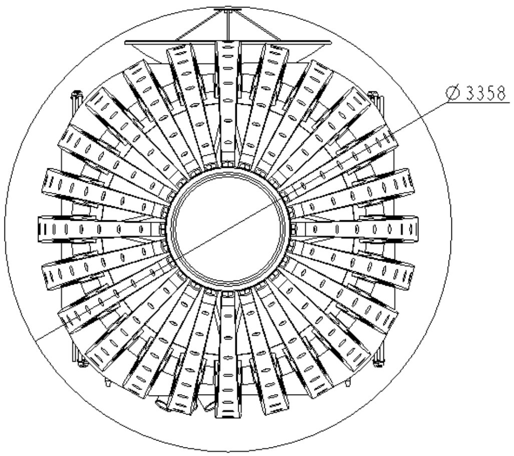
Key Techniques



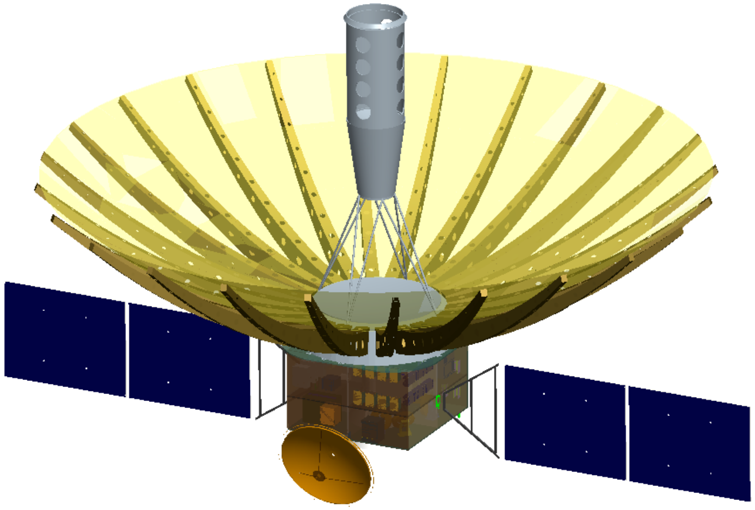
KT1: Satellite configuration and layout



Side view



Top view



Side view

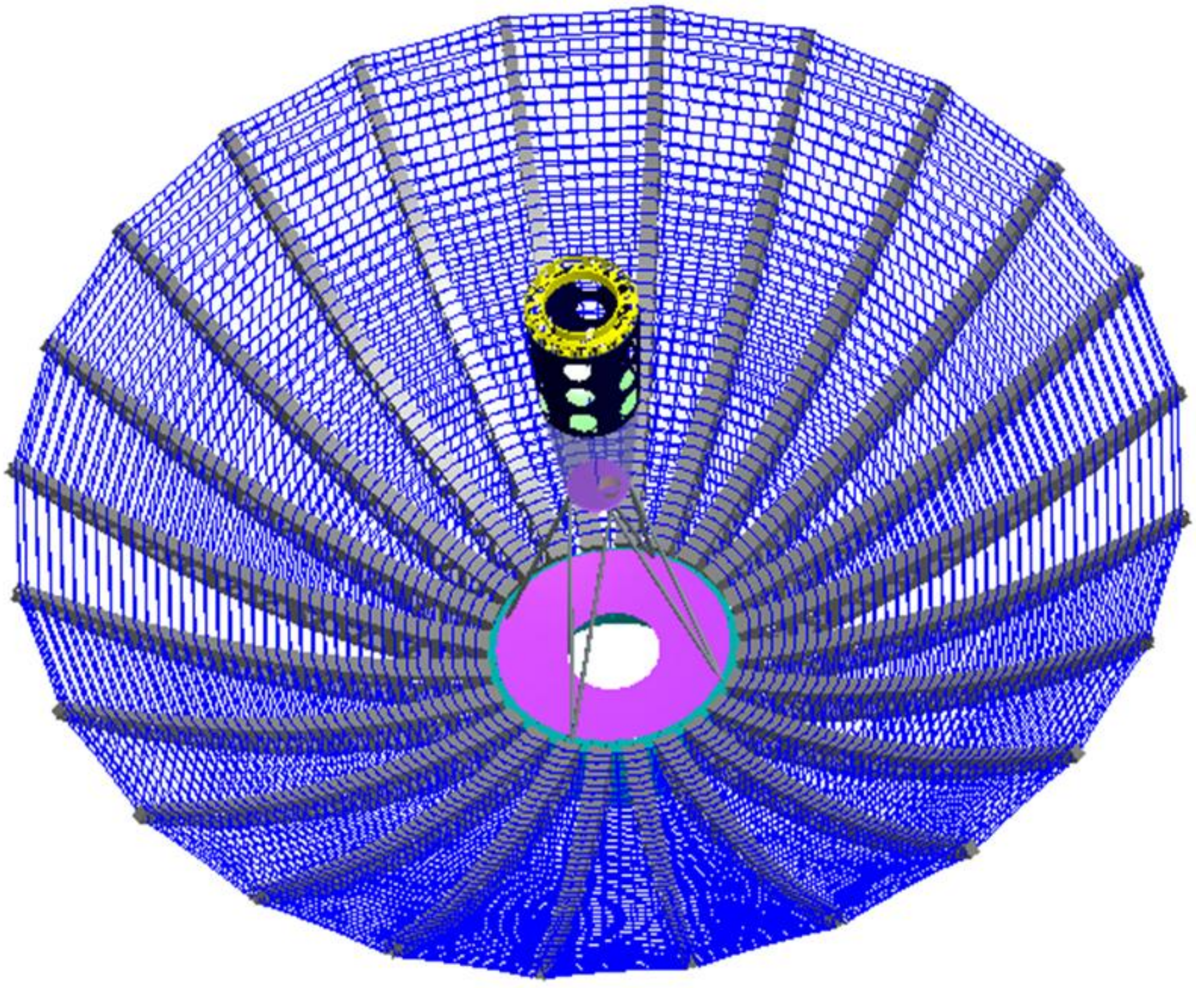
KT2: On-board antenna

24 sectors

inside panel
+outside net.

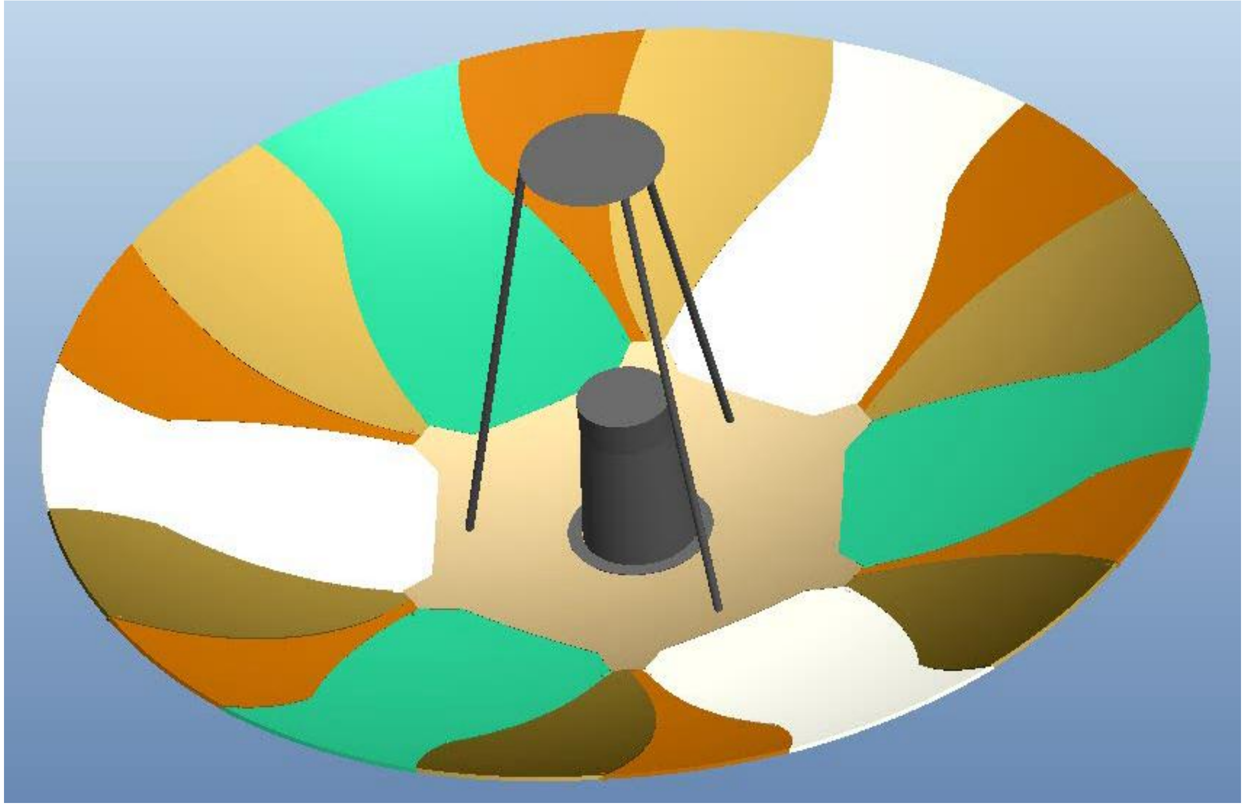
Double mesh,

and surface can
be adjusted at
6000 points



KT2: On-board antenna

Sunflower Solid surface antenna

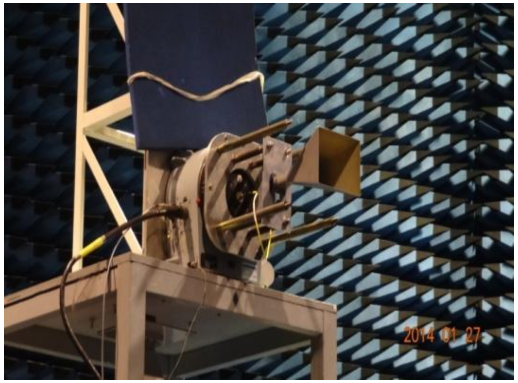


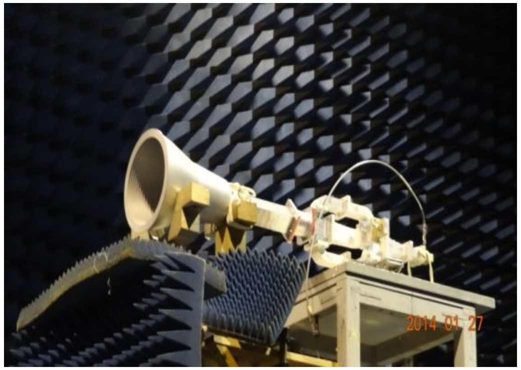
KT2: Feed horn

K/Q-band light-wall horn

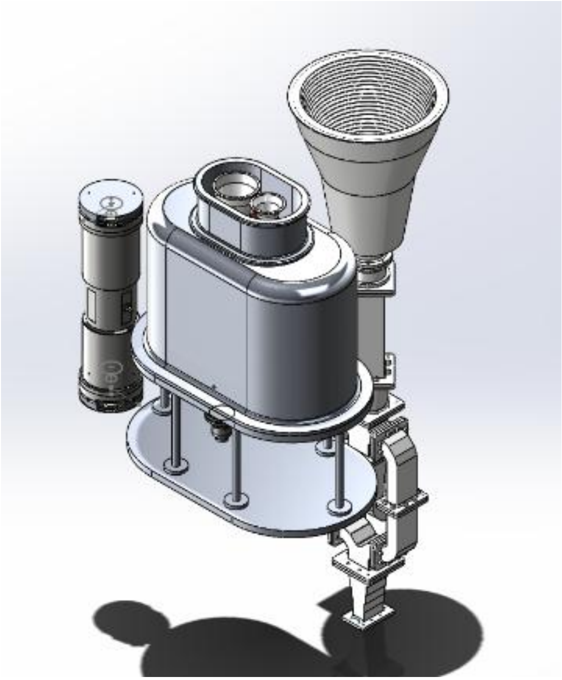
X-band corrugated horn

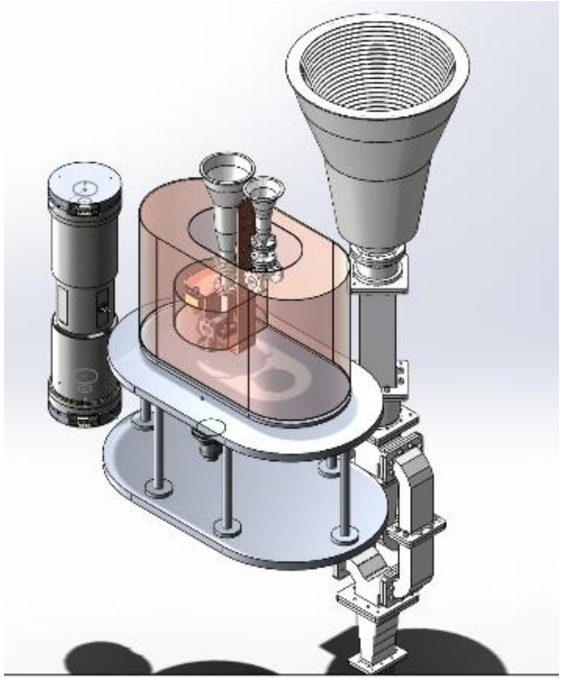
Horn test

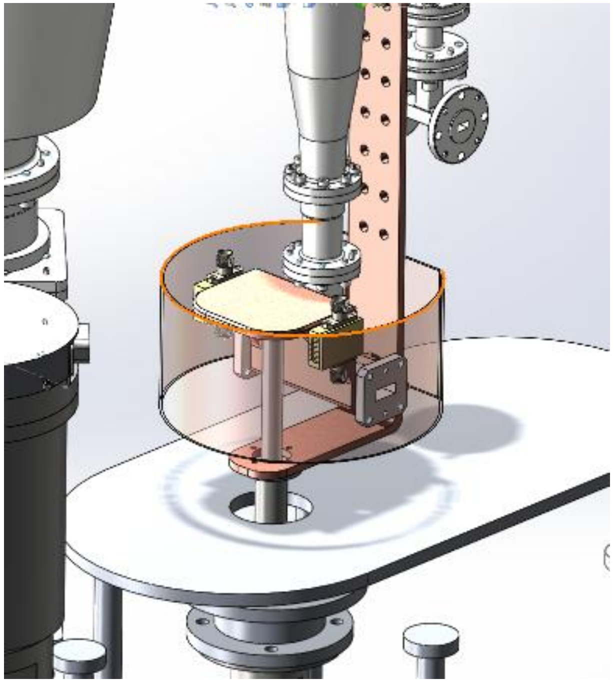




KT3 Cooler receiver and DBBC

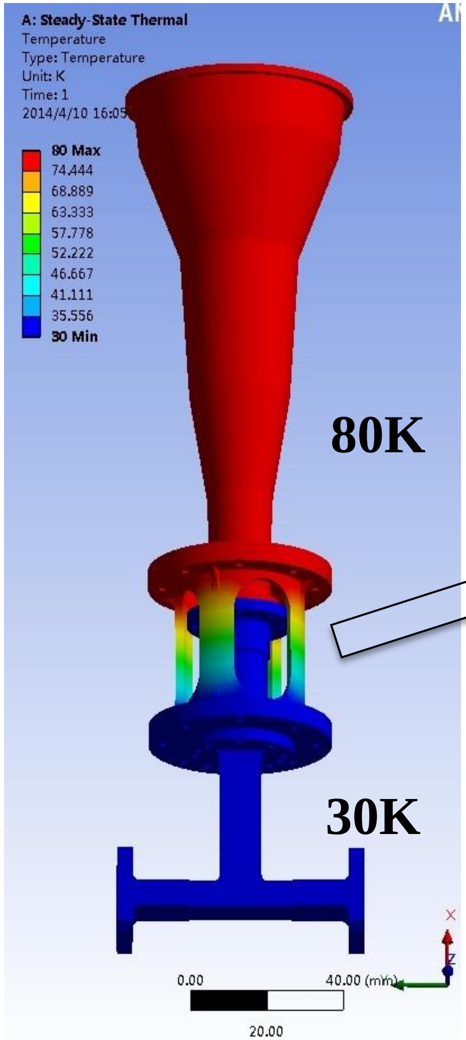




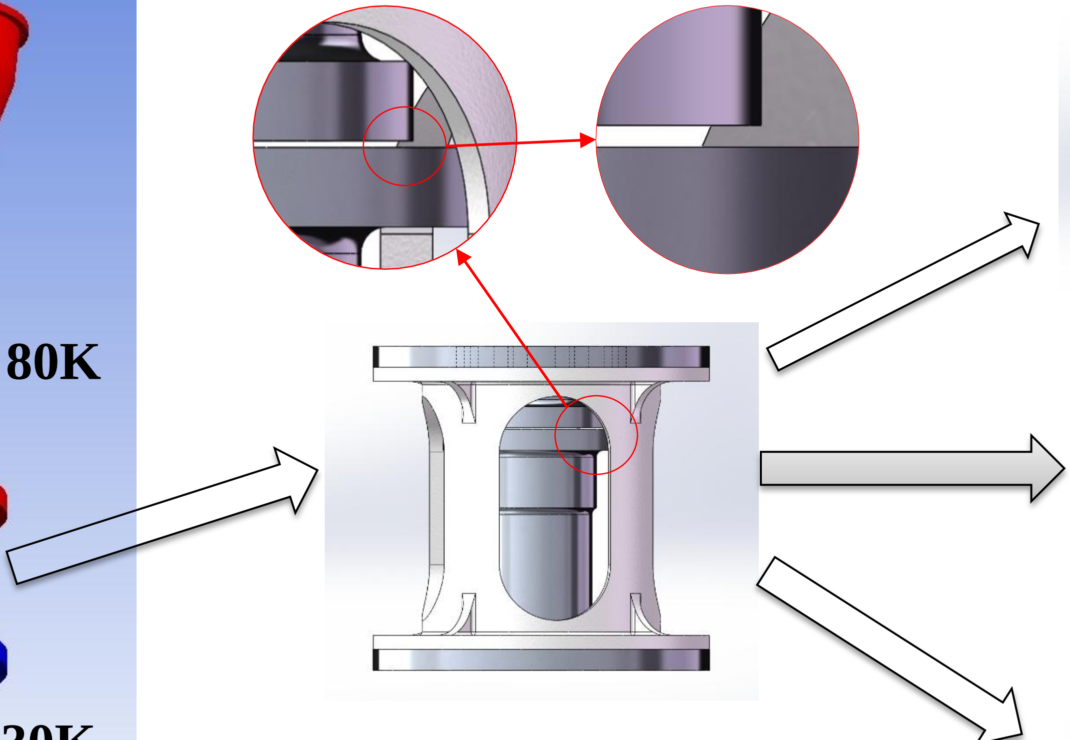


X/K/Q band receiver. Key tech: design of refrigeration and heat insulation under small cold capacity

KT3 Cooler receiver and DBBC



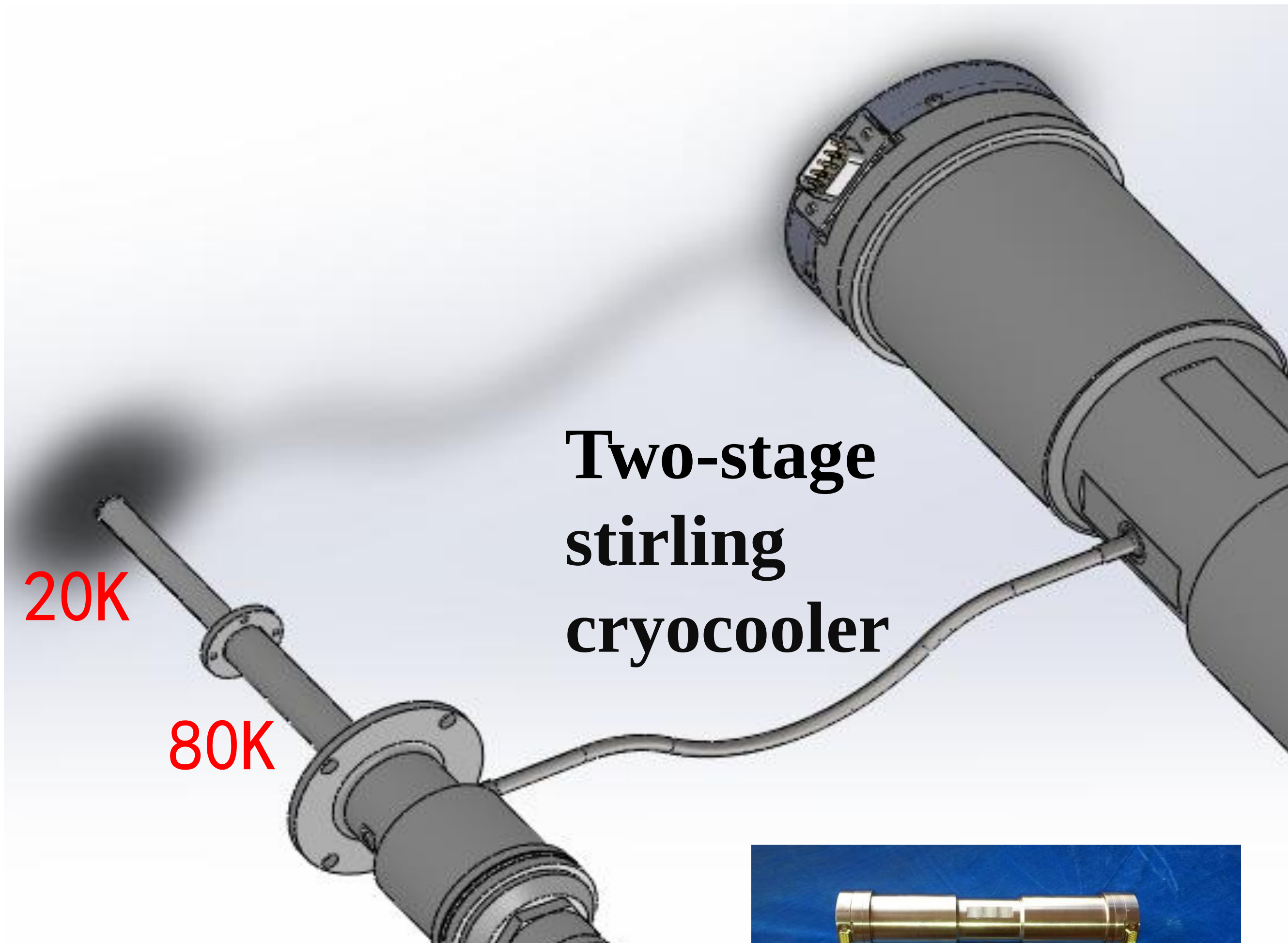
slot insulation barrel structure

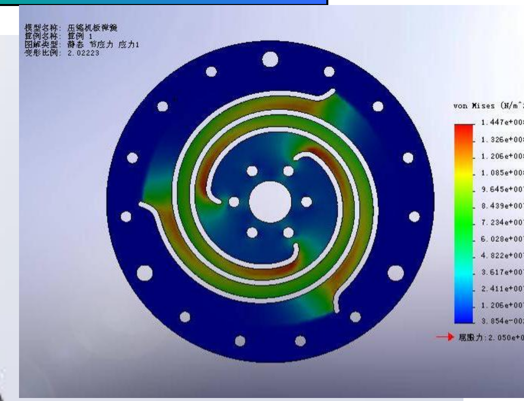


insert additional parts gap, glass fiber insulation tube

simulation results of temperature gradient

KT3 cooler receiver and DBBC





冷头板弹簧
应力分析

Two-stage
stirling
cryocooler

20K

80K

Control unit

2W@80K

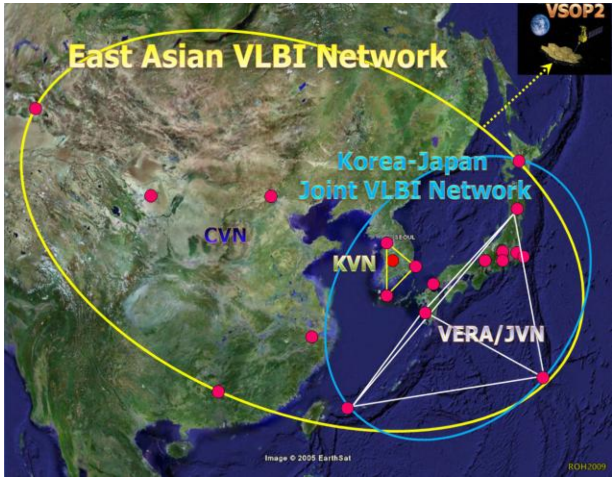
6. Next Step

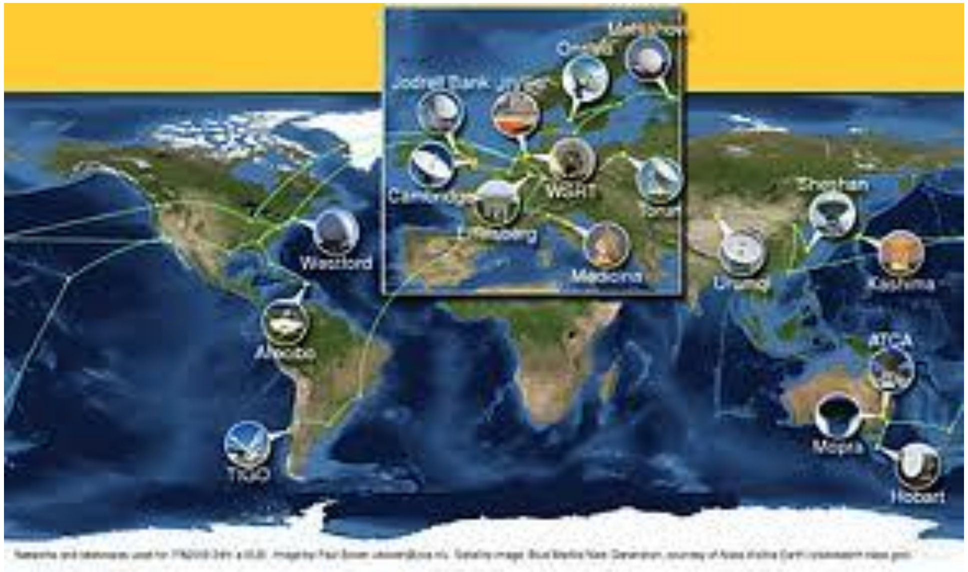
- Interim evaluation in April,
  - The progress in on the schedule as the plan.
- There is still many challenges for the project.
- Sciences:
  - more simulation studies for the imaging the shadow of M87,
  - Pre-launch VLBI survey for AGN and Maser
- Technology:
  - Antenna (prototype in 2015)
  - Pointing (not a big problem)
  - Receivers (prototype for K band in 2015)

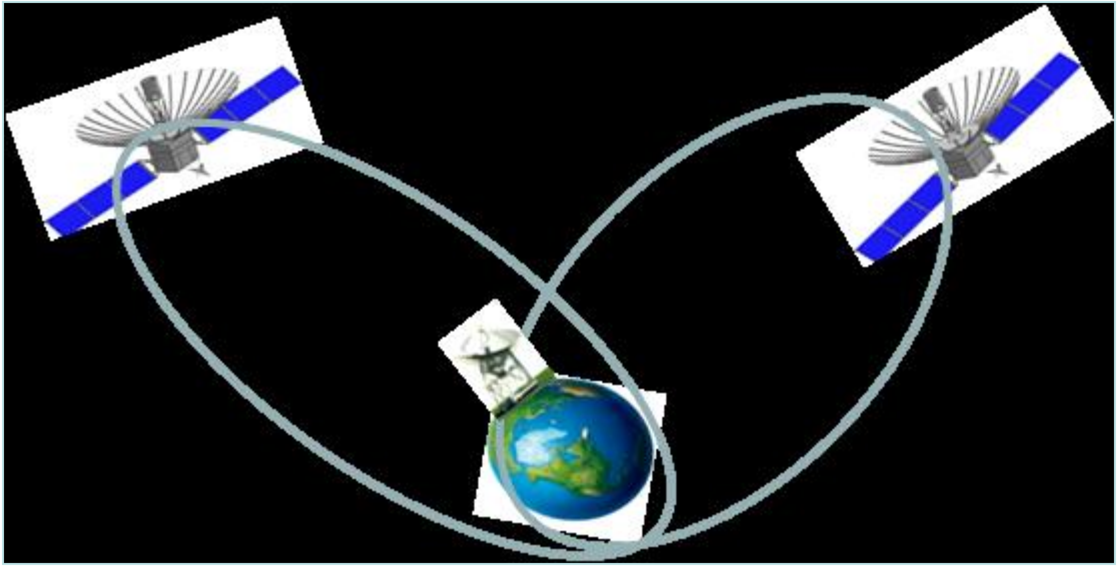
➢ International collaboration

- ☐ is very importance for Sciences,
- ☐ System Design,
- ☐ ground VLBI array

  (VLBA is very important),
- ☐ ground station (Down link)







Thank you for your attention!