Chinese Outlook for Space VLBI

Tao An
on behalf of Space VLBI team
Shanghai Astronomical Observatory

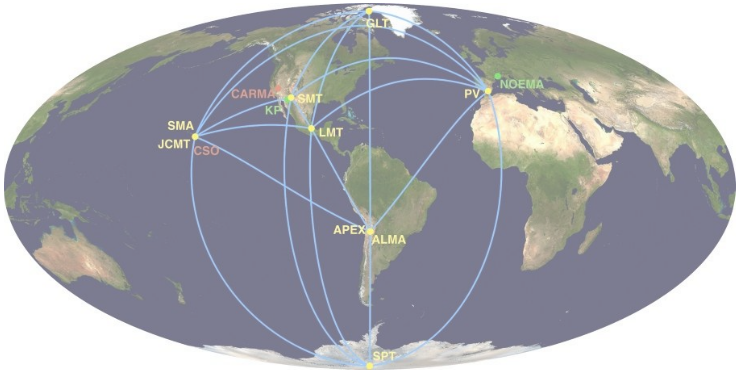
Next Generation Space VLBI workshop, 2022 Oct 17-19

Outline

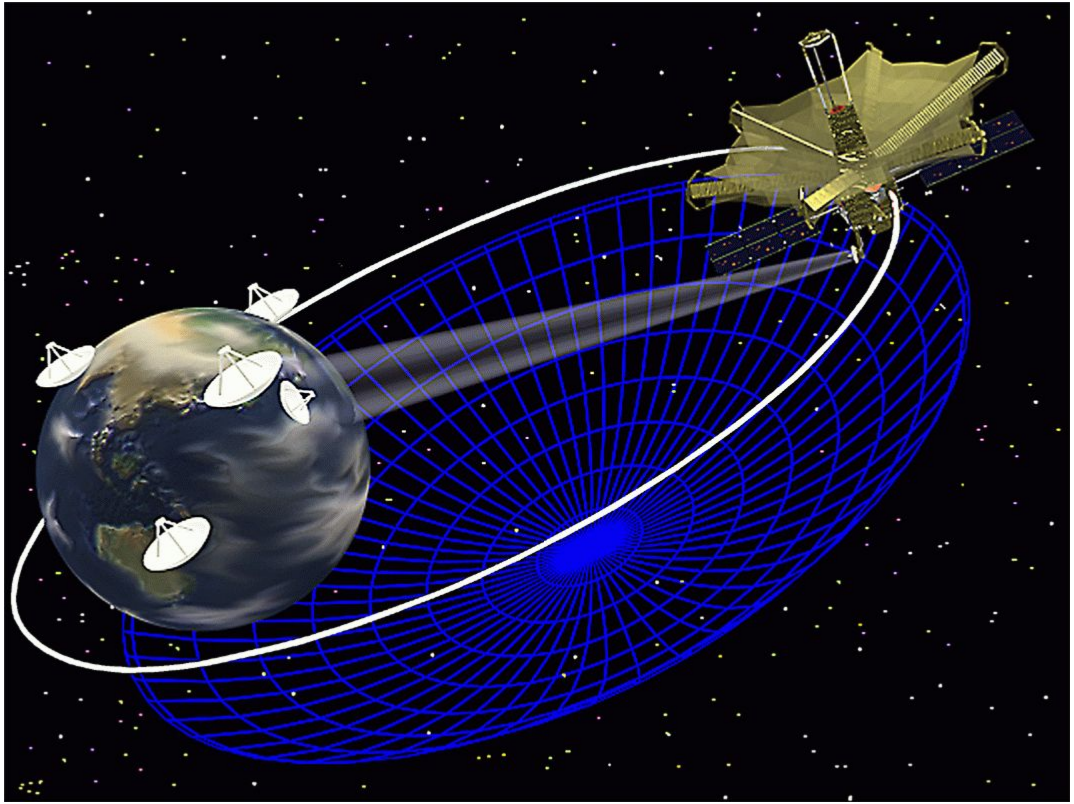
- SMVA: Space mm-wavelength VLBI Array
- **SLRO: Space Low-frequency Radio Observatory**
- LOVEX: Lunar Orbit VLBI EXperiment
- SERA: Space Extendable Radio-telescope Array

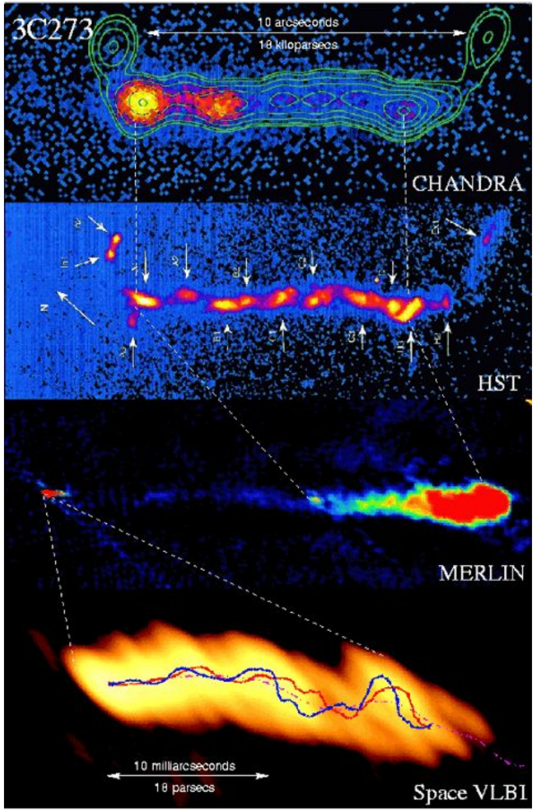
Refe: An, T., X. Hong, W. Zheng, S. Ye, Z. Qian and Space VLBI Team, Space very long baseline interferometry in China, 2020, Advances in Space Research, 65, 850 https://arxiv.org/abs/1901.07796

VLBI: from Ground to Space



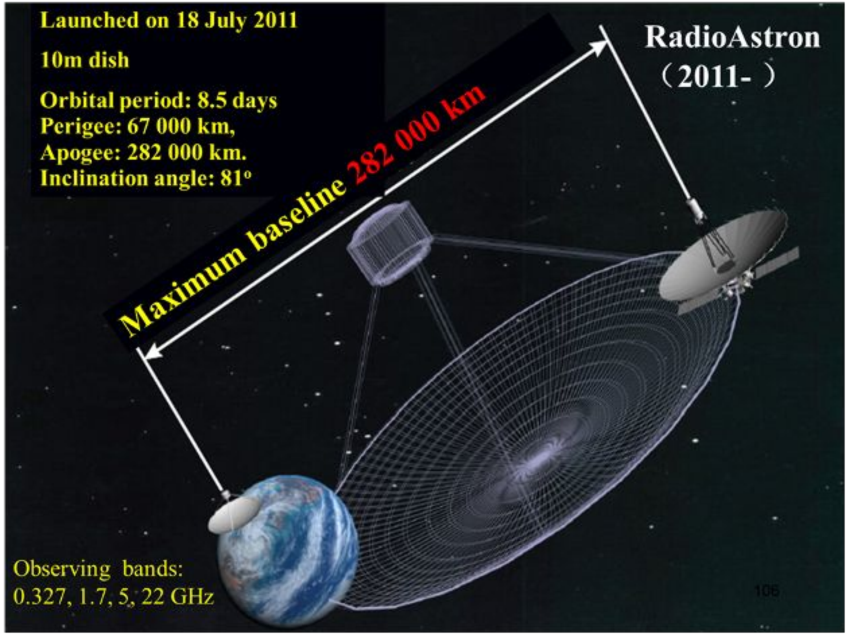
VSOP - first Space VLBI of scientific operation

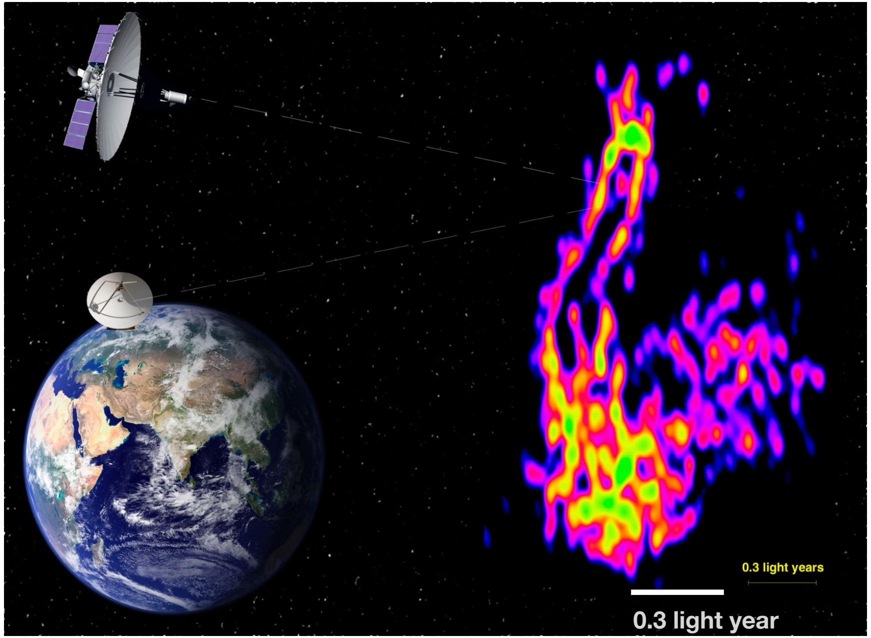




IAA Award to VSOP Team

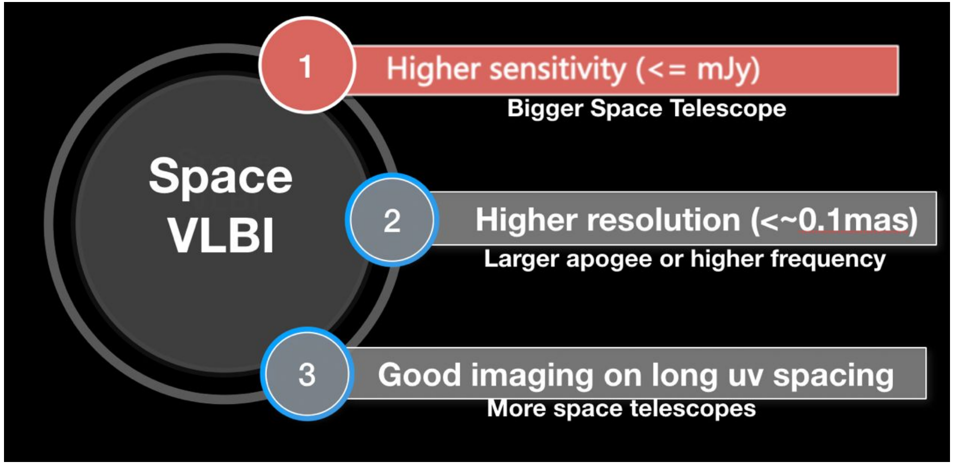
RadioAstron: a Guinness World Record of resolution

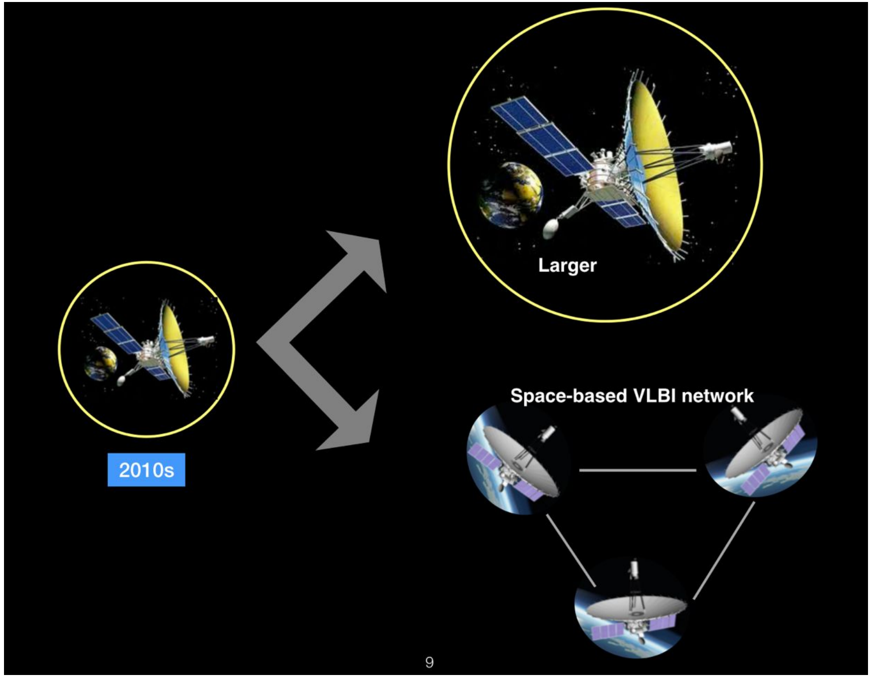




Credit: Giovannini et al. Nature Astro. (2018)
RadioAstron

Future Space VLBI





Gurvits, L. I., Space VLBI: from first ideas to operational missions, 2020, Advances in Space Research, 65, 868

proposals and plans for next-generation space VLBI: see other colleagues' talks

SMVA (2012-2015):
Space mm-wavelength VLBI Array

a step toward imaging the most compact astronomical objects

PI: Xiaoyu Hong

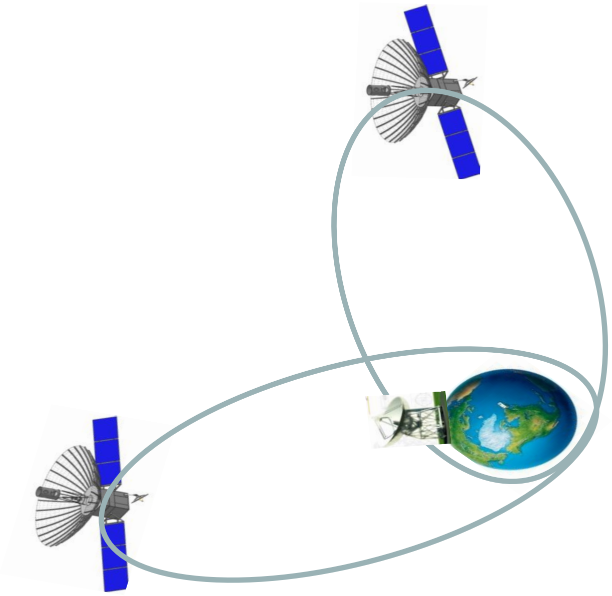
Hong, X., Z. Shen, T. An, and Q. Liu, The Chinese space Millimeter-wavelength VLBI array-A step toward imaging the most compact astronomical objects, 2014, Acta Astronautica, 102

Road map of Chinese mm-wavelength Space VLBI Array

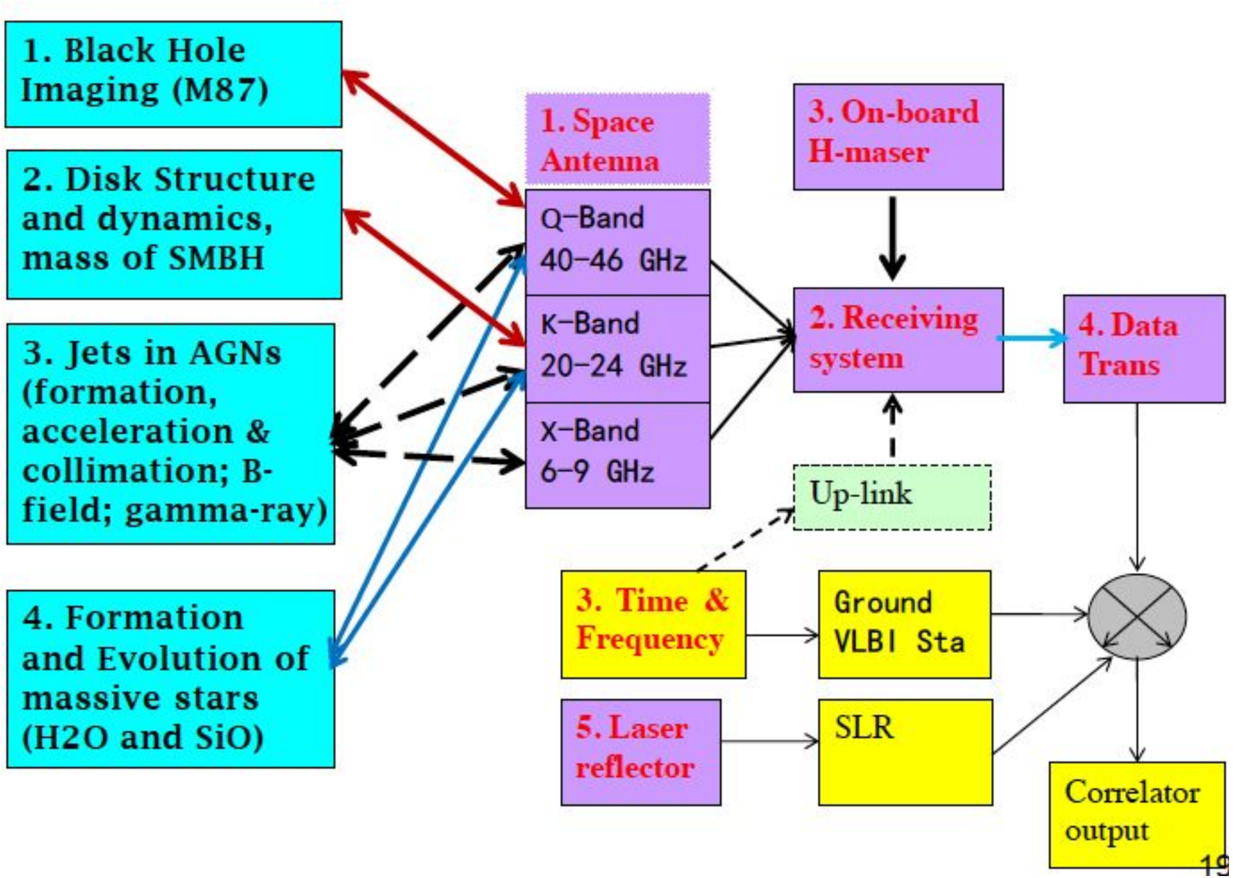
- Stage 1: Long-mm-wavelength Space VLBI Array, aim to be funded in 2016-2020
  - two 10-meter Space telescopes, highest frequency 43GHz, to realize 20uas high resolution and good uv coverage together with ground-based telescopes for imaging.
- Stage 2: Mm-wavelength Space VLBI Array, aim to be funded in 2021-2025
  - three 12-15meter mm-wavelength Space telescopes (86GHz), to achieve high resolution with ground VLBI telescopes
- Stage 3: submm Space VLBI Array, aim to be funded after 2026
  - three-four 12-15meter Submm Space telescopes to acquire ultra-high resolution, great astrophysics breakthrough

SMVA: overall design, sciences, orbit, man.

- Two Satellites (10m in diameter)
    - Apogee: 60000 km
    - Perigee: 1200 km
    - Inclination: 28.5 deg
    - angle between two orbital planes: 120^{o}
- Observing Bands:
    - X (6-9 GHz)
    - K (20-24 GHz)
    - Q (40-46 GHz)
    - Dual Polarization LCP/RCP
    - Cryogenic Rx (@22/43GHz)
- Data Rate (1.2 Gbps) or 2.4 Gbps
- Ang. Res.: 20 micro-as
- Pointing : <15”
- Life time: 3 years

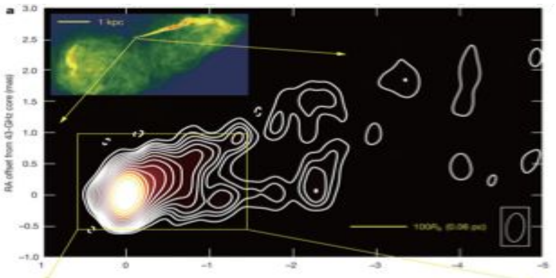


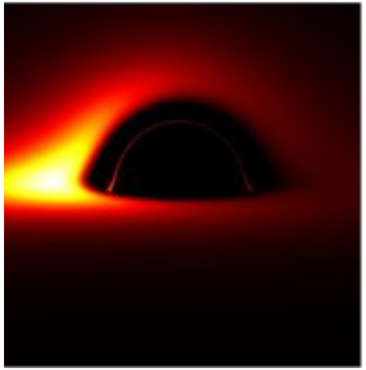
SMVA: Scientific goals and system



Three Key sciences

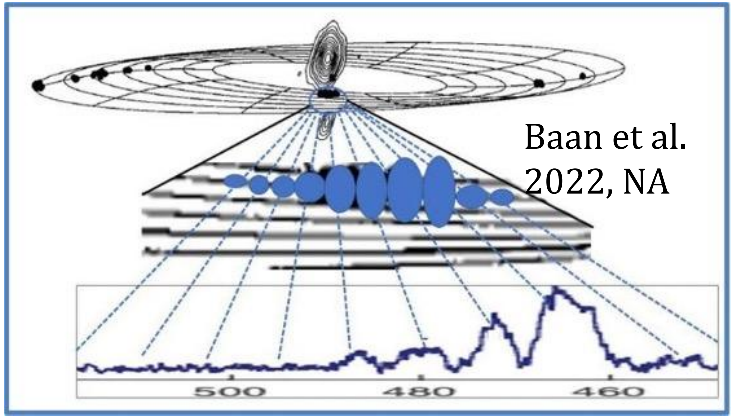
- **Portrait of SMBH**: 20μas ($4r_s$), obtaining the image of BH shadow and innermost jet



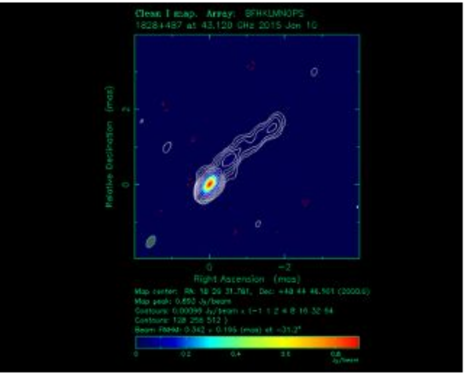


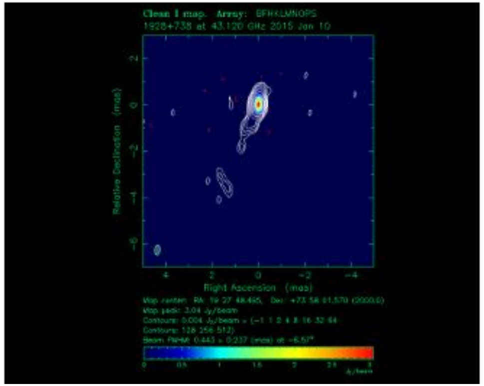
- **Accretion disk dynamics**: NGC4258

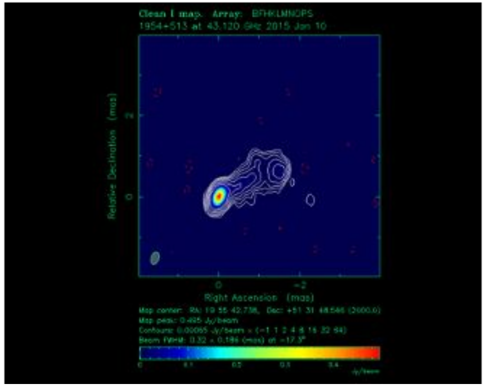
- **AGN Jet**: formation, acceleration, collimation, Internal structure, composition, origin of high-energy radiation

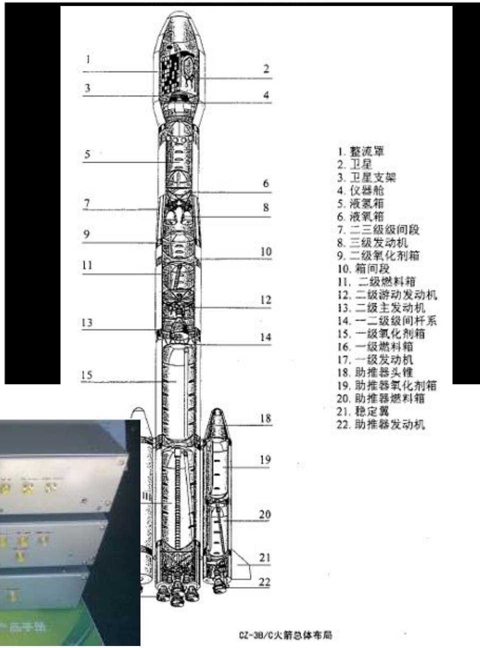


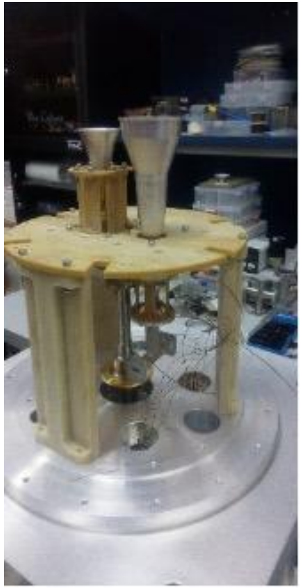
Baan et al. 2022, NA

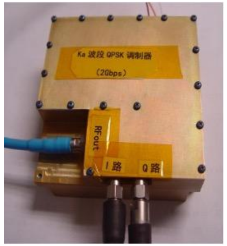

Clean I map. Array: BFHKLMNOPS
1828+487 at 43.120 GHz 2015 Jan 10
Relative Declination (mas)
Right Ascension (mas)


Clean I map. Array: BFHKLMNOPS
1928+738 at 43.120 GHz 2015 Jan 10
Relative Declination (mas)
Right Ascension (mas)


Clean I map. Array: BFHKLMNOPS
1954+513 at 43.120 GHz 2015 Jan 10
Relative Declination (mas)
Right Ascension (mas)


1. 整流罩
2. 卫星
3. 卫星支架
4. 仪器舱
5. 液氢箱
6. 液氧箱
7. 二三级级间段
8. 三级发动机
9. 二级氧化剂箱
10. 箱间段
11. 二级燃料箱
12. 二级游动发动机
13. 二级主发动机
14. 一二级级间杆系
15. 一级氧化剂箱
16. 一级燃料箱
17. 一级发动机
18. 助推器头锥
19. 助推器氧化剂箱
20. 助推器燃料箱
21. 稳定翼
22. 助推器发动机
CZ-3B/C火箭总体布局




Ka 波段 QPSK 调制器
(2Gbps)
RFout
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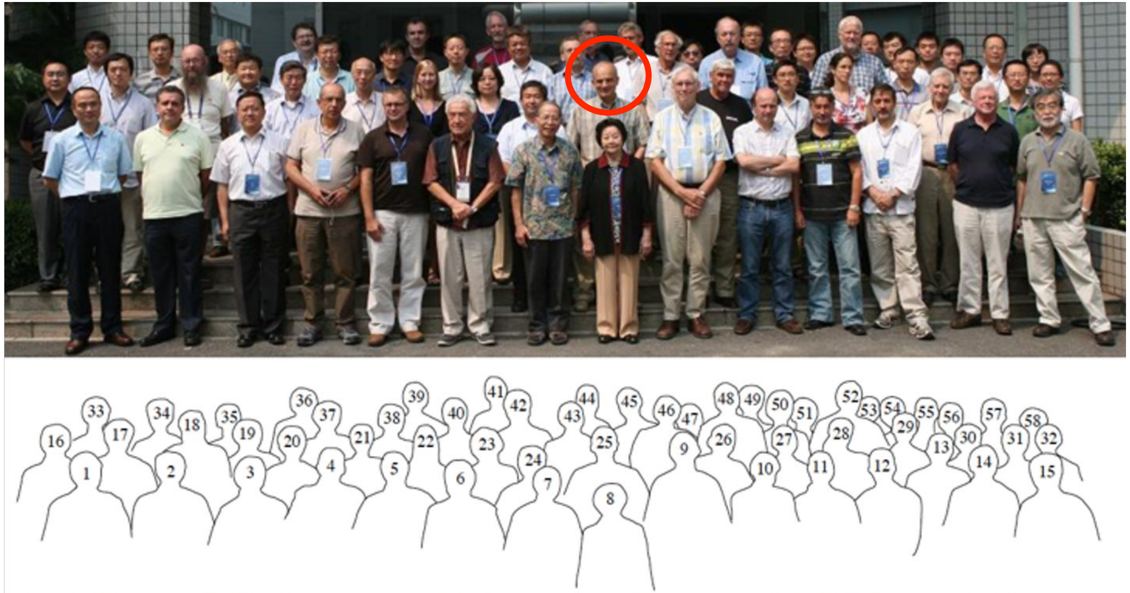
Q 路

Space VLBI forum, 2013 Sep 16-18, Beijing

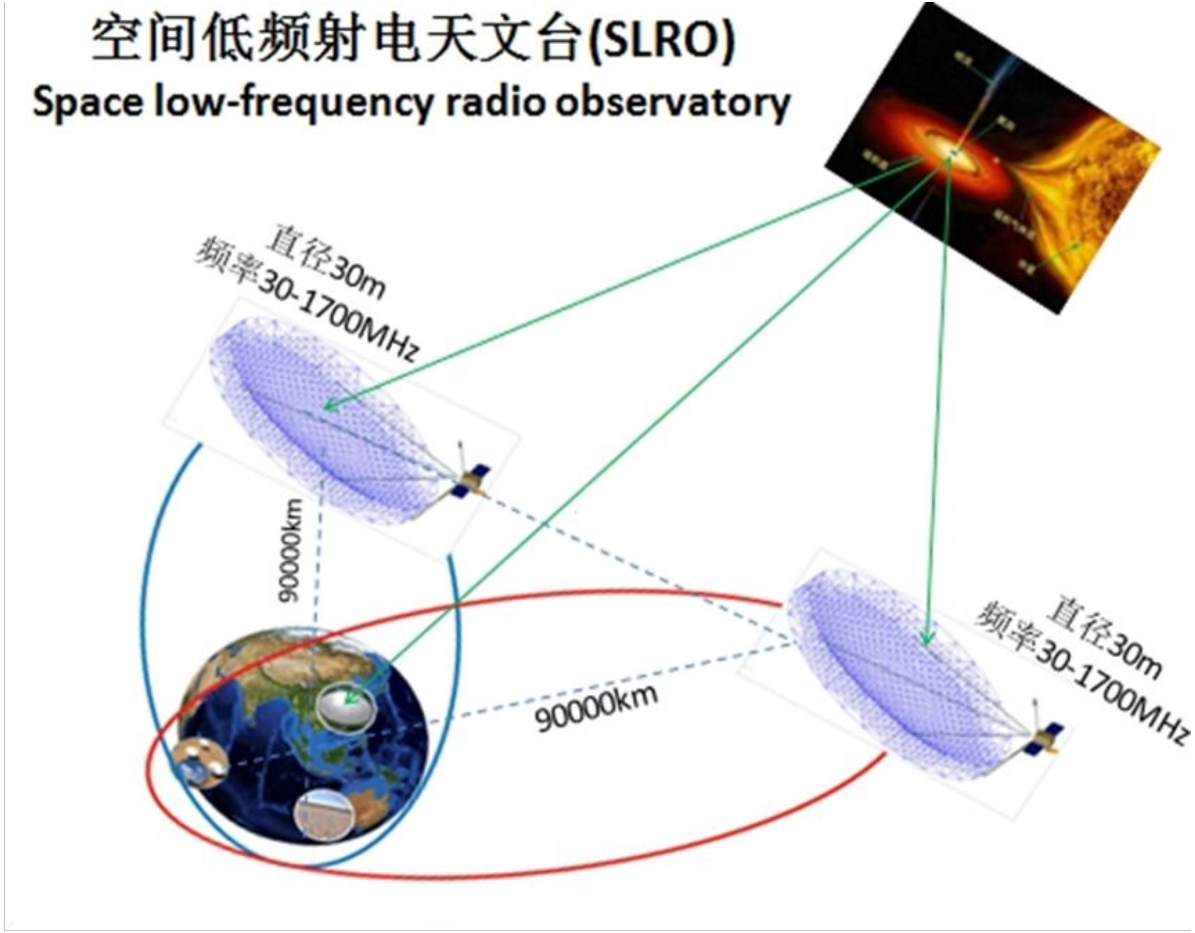


1. X.-Y. Hong
2. R. Bachiller
3. J. Wu
4. G. Giovannini
5. J. A. Zensus
6. G. Setti
7. H. Hirabayashi
8. S.-H. Ye
9. J. M. Moran
10. P. Charlot
11. M. A. Garrett
12. A. K. Tzioumis
13. N. S. Kardashev
14. R. S. Booth
15. M. Inoue
16. B. Li
17. Z.-Q. Shen
18. E. Valtaoja
19. D.-G. Roh
20. D.-R. Jiang
21. Z.-H. Qian
22. T. Hovatta
23. J.-H. Zheng
24. Y. Murata
25. L. I. Gurvits
26. D. L. Jauncey
27. J. Tao
28. S. Boehm
29. X.-P. Wan
30. F.-C. Shu
31. J. Yang
32. F. Wu
33. K. Wajima
34. D. Chen
35. M. Shao
36. K. M. Menten
37. X. Liu
38. J.-S. Kim
39. A. J. Beasley
40. D. Li
41. A. R. Taylor
42. Q.-H. Liu
43. A. Gusev
44. V. Pankonin
45. H. Falcke
46. K. I. Kellermann
47. L.-W. Fung
48. K. J. Johnston
49. S. Cao
50. Y.-C. Minh
51. Z. Cui
52. W. Baan
53. Y. Huang
54. T. An
55. P. Lv
56. L.-J. Chen
57. X.-Z. Zhang
58. H.-Y. Zhang

SLRO:
Space Low-frequency Radio Observatory

Contact: Weimin Zheng, Tao An

An et al. 空间科学, A cosmic microscope to probe the Universe from Present to Cosmic Dawn - dual-element low-frequency space VLBI observatory (arXiv:1808.10636)


空间低频射电天文台(SLRO)
Space low-frequency radio observatory
直径30m
频率30-1700MHz
90000km
直径30m
频率30-1700MHz
90000km

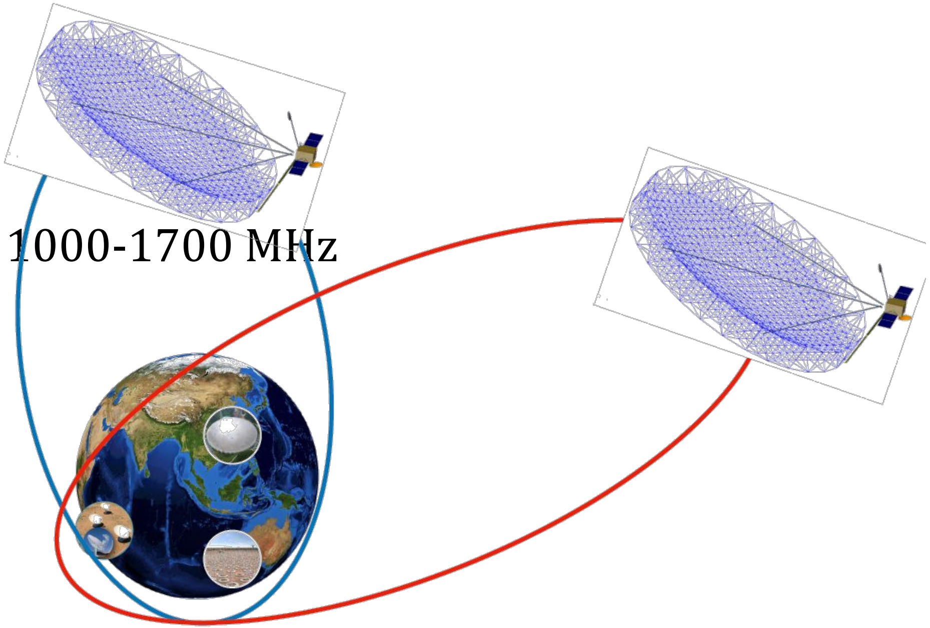
GOAL: Space VLBI in FAST & SKA era - ‘microscope’ probing the Universe from nearby exoplanets to SMBHs in Cosmic Dawn

2020-

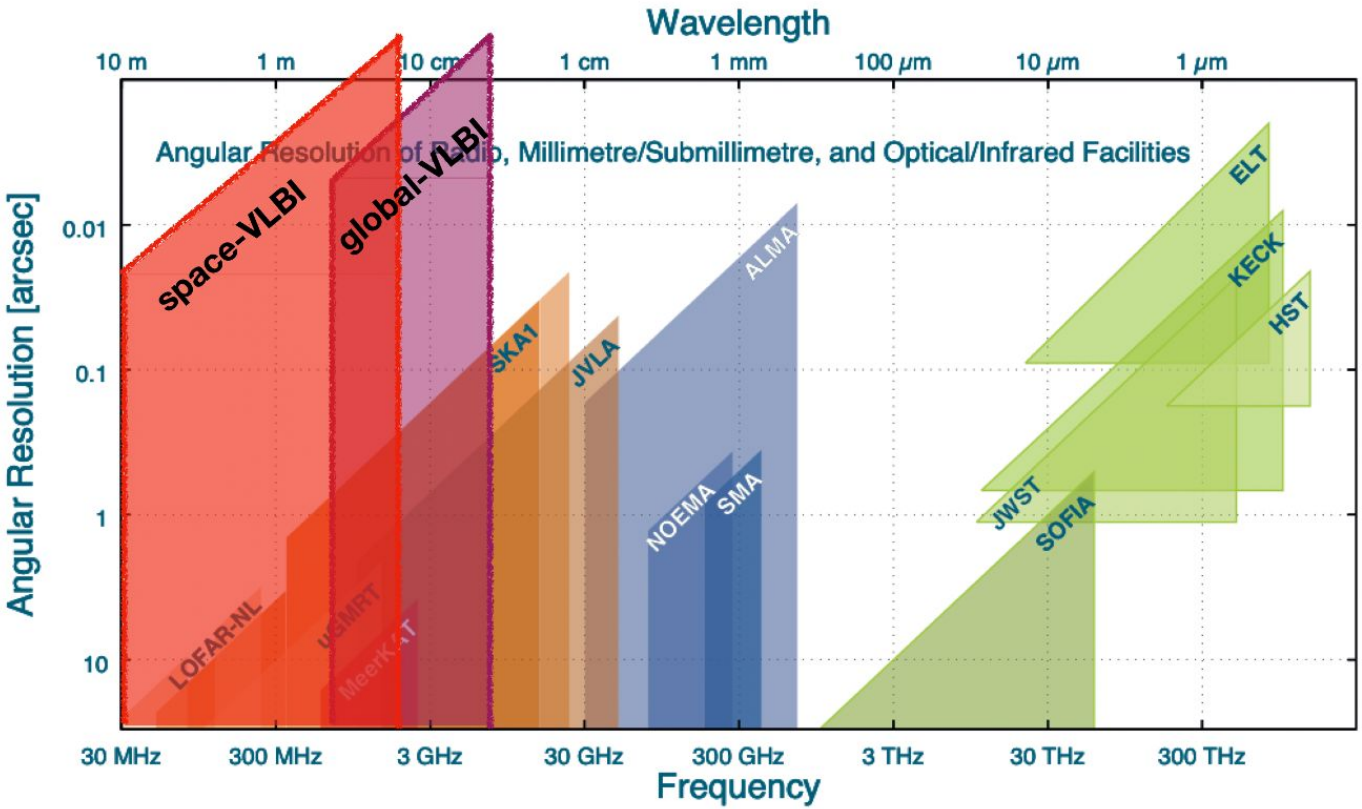
2028-

Mission Concept

- Space Antenna: two 30m
- Orbit:
  - 90000x2000 km, 148.5^{o}
- Frequency Bands:
  - 30-120, 30-170, 10-350, 580-1150, 1000-1700 MHz
- Weight: 1.5 Ton/satellite
- Resolution:
  - 8 mas (80MHz)
  - 2 mas (300 MHz)
  - 0.3 mas (1.5GHz)
- Sensitivity
  - Baseline sensitivity: sub-mJy (10min)
  - Image sensitivity: micro-Jy/beam (1h, 1.5GHz)



New Physics New Phenomena



Flexible operation modes

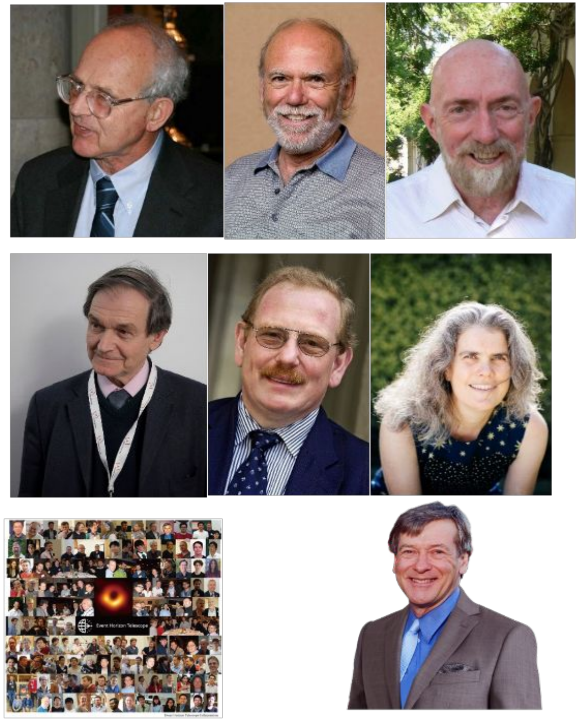
1. **Space-ground VLBI**
   - Unprecedented Super VLBI network consists of twin space-based VLBI Stations + ground large telescopes (SKA1, FAST, Arecibo, Effelsberg, Green Bank, GMRT, QTT......)
   - New electromagnetic spectrum window (30 - 300MHz), unexplored for space VLBI
2. **Space-space VLBI (single baseline)**
   - Unique space-based VLBI, long integration time, fast response of super-burst of OH masers, auroral radiation from extrasolar systems, and other transients
3. **Space-based single dish**
   - HI intensity mapping, EoR total power spectrum, ...

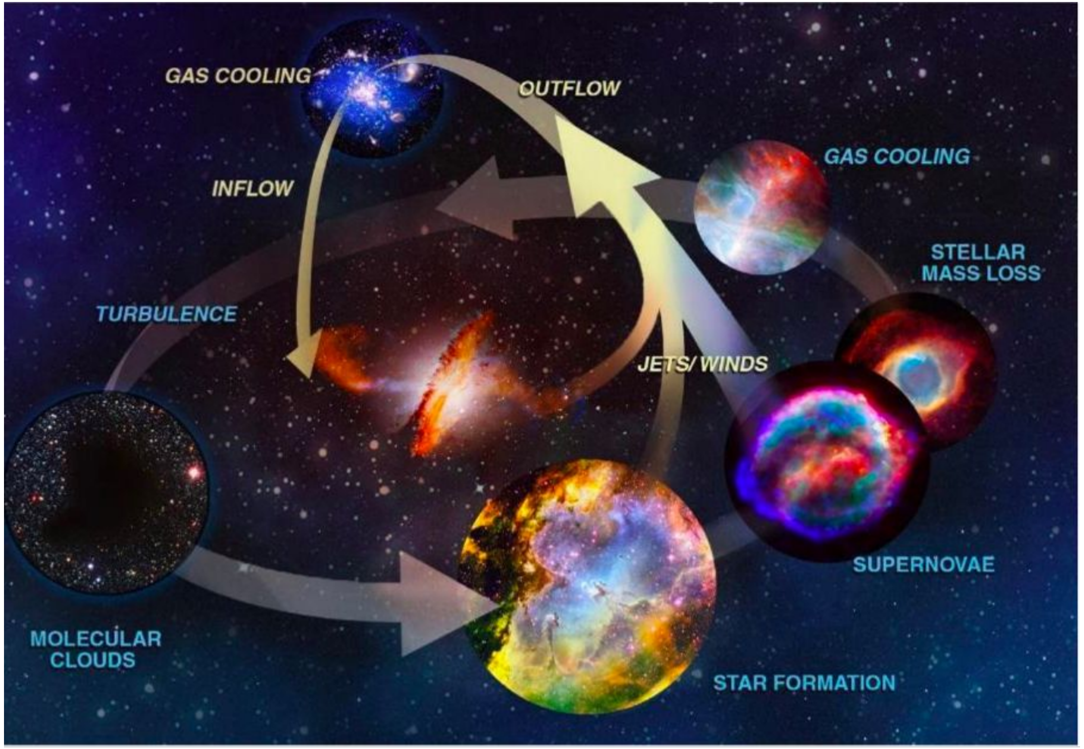
Scientific Goals

- **Black holes and outflows**: outflows from different-masses systems, in different cosmic era; first-generation SMBHs; intermediate-mass BHs, wind and large-aperture outflows, corona
- **Exoplanets**: VLBI astrometry; VLBI polarimetry; dynamic spectrum
- **Dark energy**: redshift 0.1-1 HI large-scale structure
- Investigating uas celestial reference frame
- understanding the nature of dark matter by detecting axion signals.
- Precise calibrations of star formation rates in galaxies.
- Obtaining high-precision positions of FRBs

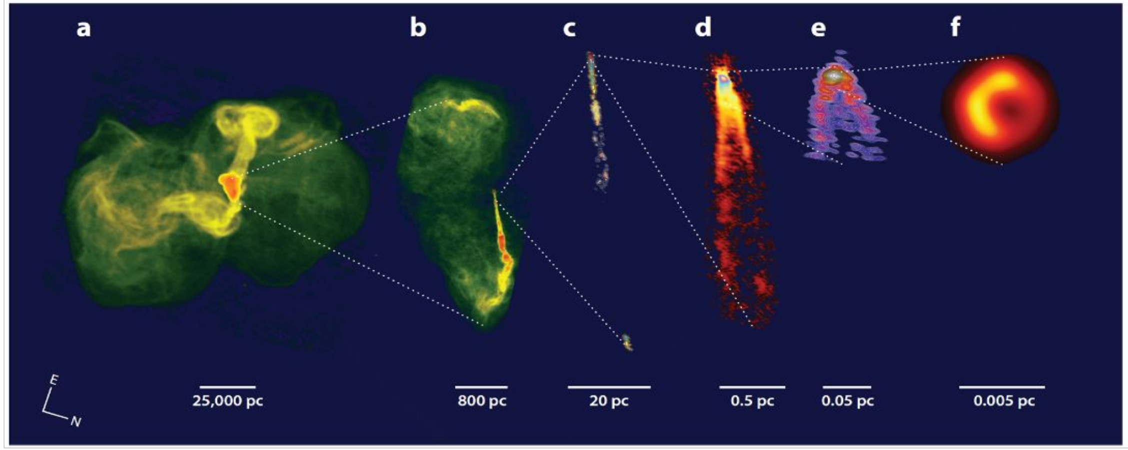
BHs and outflows

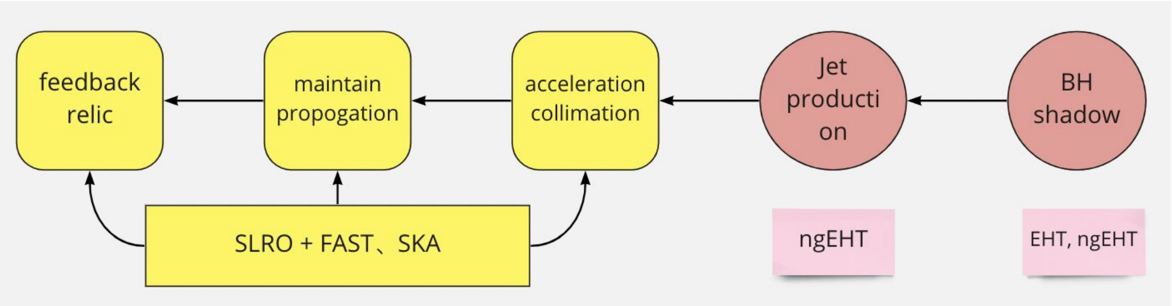
Black hole outflows affect the cosmic ecosystem and its evolution
Outflows are a new scientific breakthrough after black holes





BHs and outflows





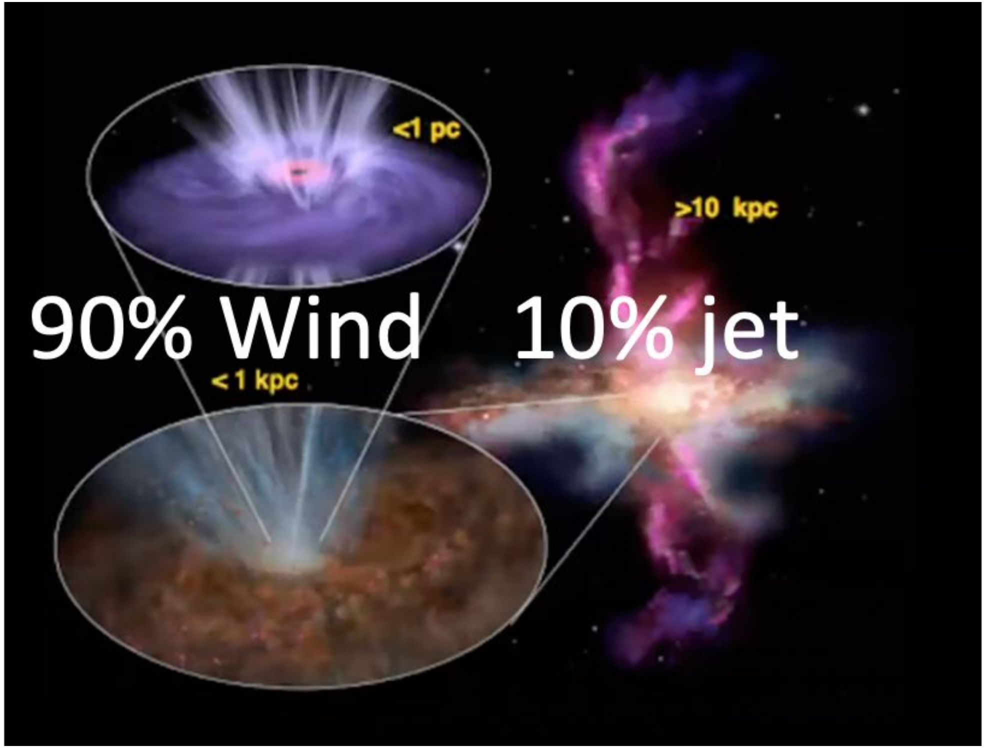
Q: jet production, collimation and acceleration; how black hole outflows affect the ecosystem of the Univesre

S: Imaging the BH and outflow with high resolution

A: VLBI is the unique tool

G: a maojr breakthrough in the study of jet physics

BH and outflow



- The origin of the winds, which constitute the vast majority of the AGN, remains an open question.
- Need low frequency, high sensitivity
- Space low-frequency VLBI will solve the geometry of accretion disk wind, initial energy, coupling with the dynamical structure of the nuclear region
- Solve the outflow problem of 90% of the population in AGN

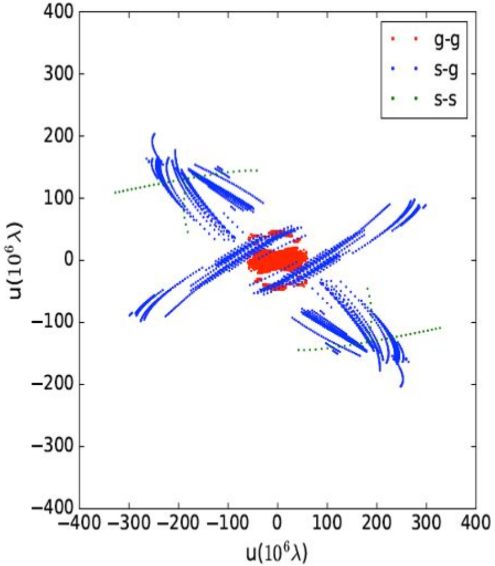
Exoplanet

Vedantham etal.(2020)

Exoplanet

Curiel et al. (2020)

uv coverage



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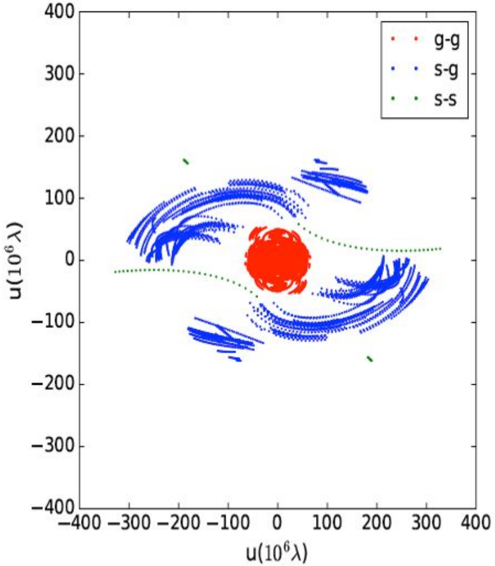

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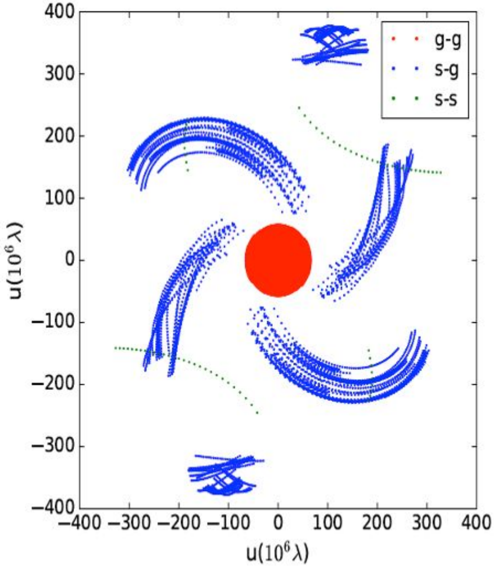

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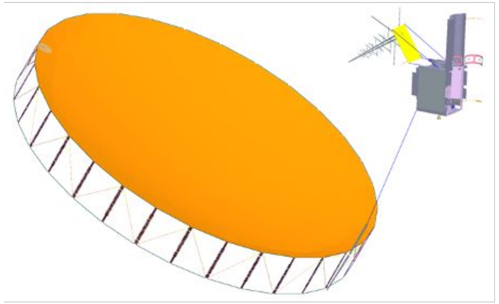
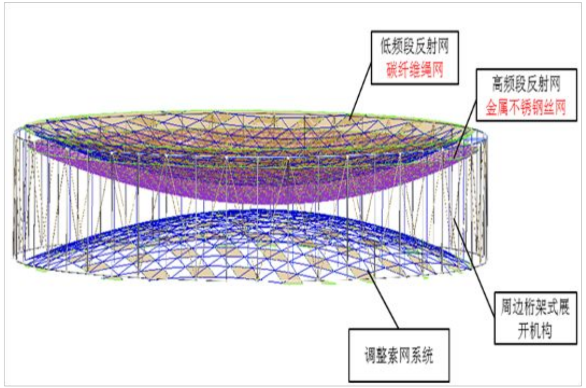
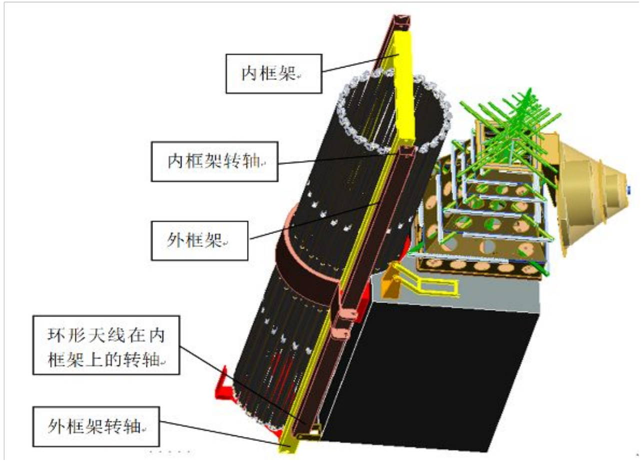
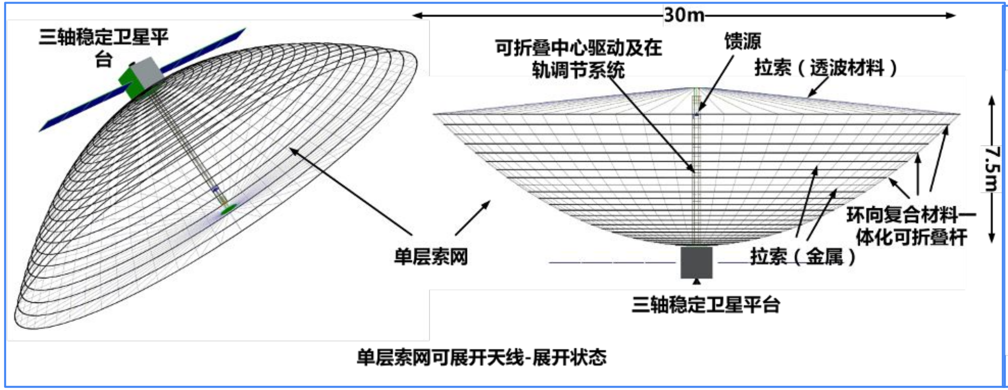
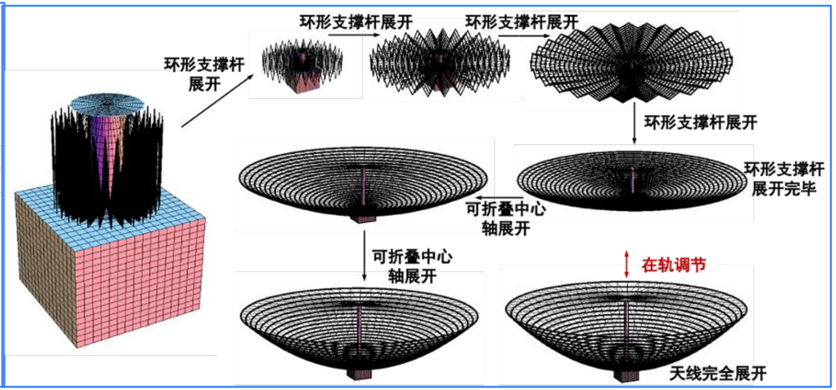
Space antenna and feed



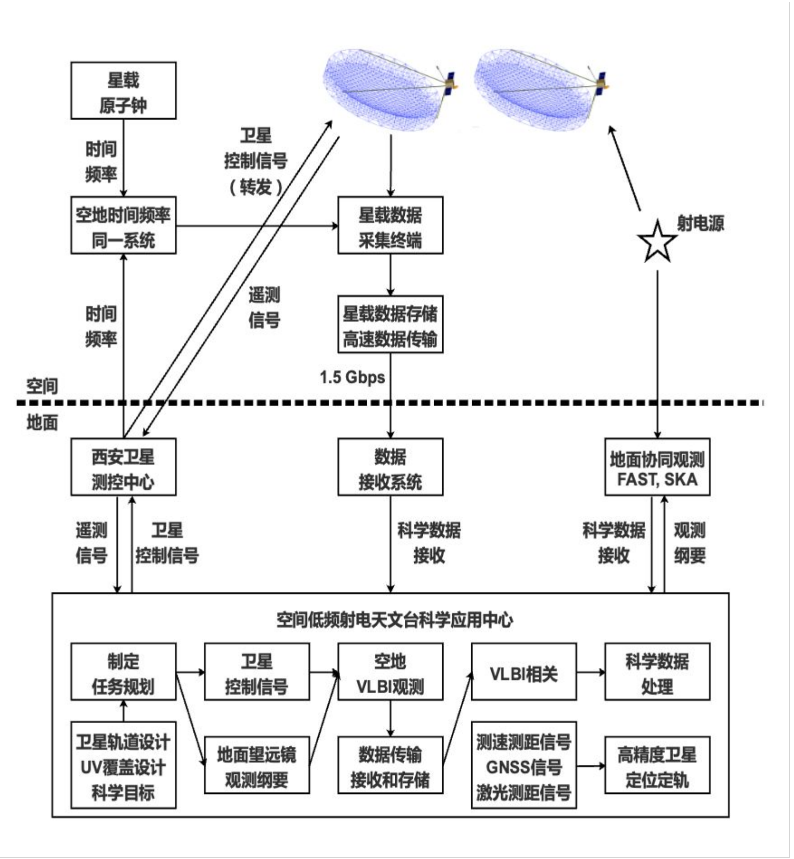


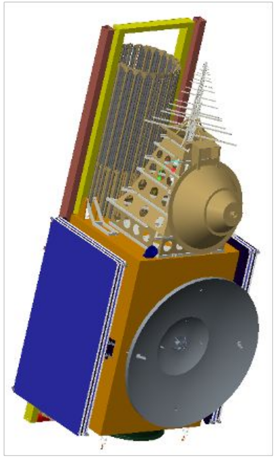


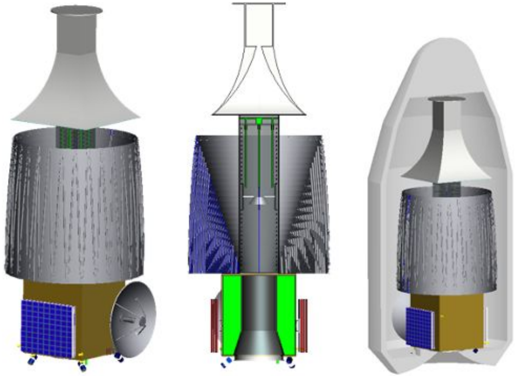




Overall scheme







Roadmap

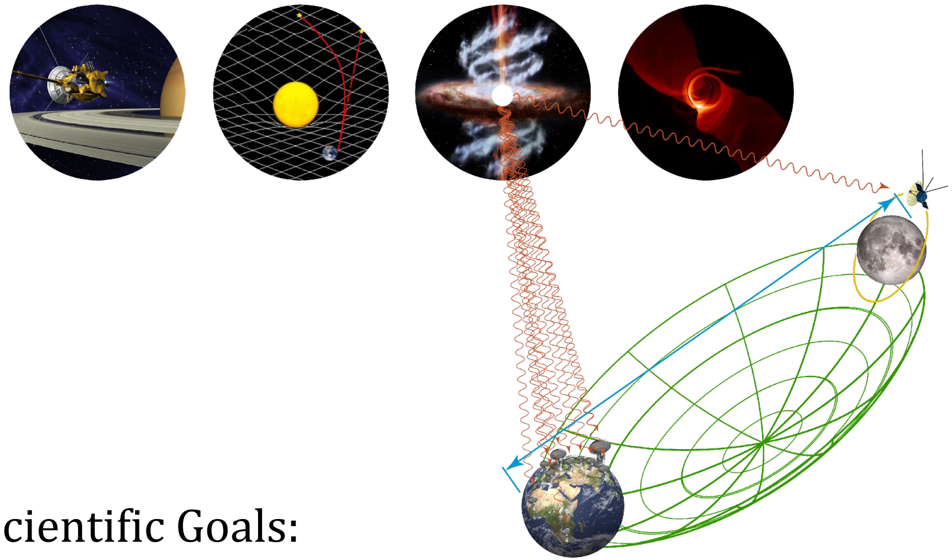
- Prototyping
  - 2022-2205, scientific objectives, key techniques, overall scheme, main prototypes
- Engineering
  - 5 years after funded.
  - first 3 years: launch first satellite
  - last 2 years: launch second satellite
- Operation
  - >8years lifetime

LOVEX:
Lunar Orbit VLBI EXperiment

Contact: Xiaoyu Hong

LOVEX: Lunar Orbit VLBI EXperiment

- **A sharpest view to the radio sky**
- 4.2m radio dish around the Moon
- Working at X-band
- Wideband receiver: 512MHz
- No atmospheres

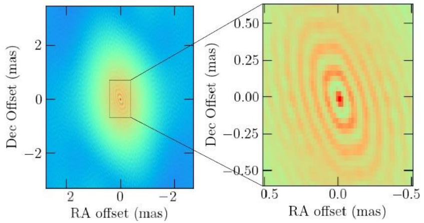


Space VLBI Project	LOVEX	VSOP	RAstron
Size (m)	4.2	8	10
Frequency (GHz)	8	1.6/4.9 /22	0.3/1.6/5 /22
Max. baseline (ED)	33	3	28
Bandwidth (MHz)	512	64	32

Scientific Goals:

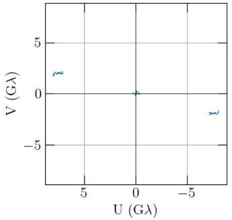
- High resolution structure of jet base
- Constraint the orbit of deep space satellites
- Measure the size of jet base and brightness temperature

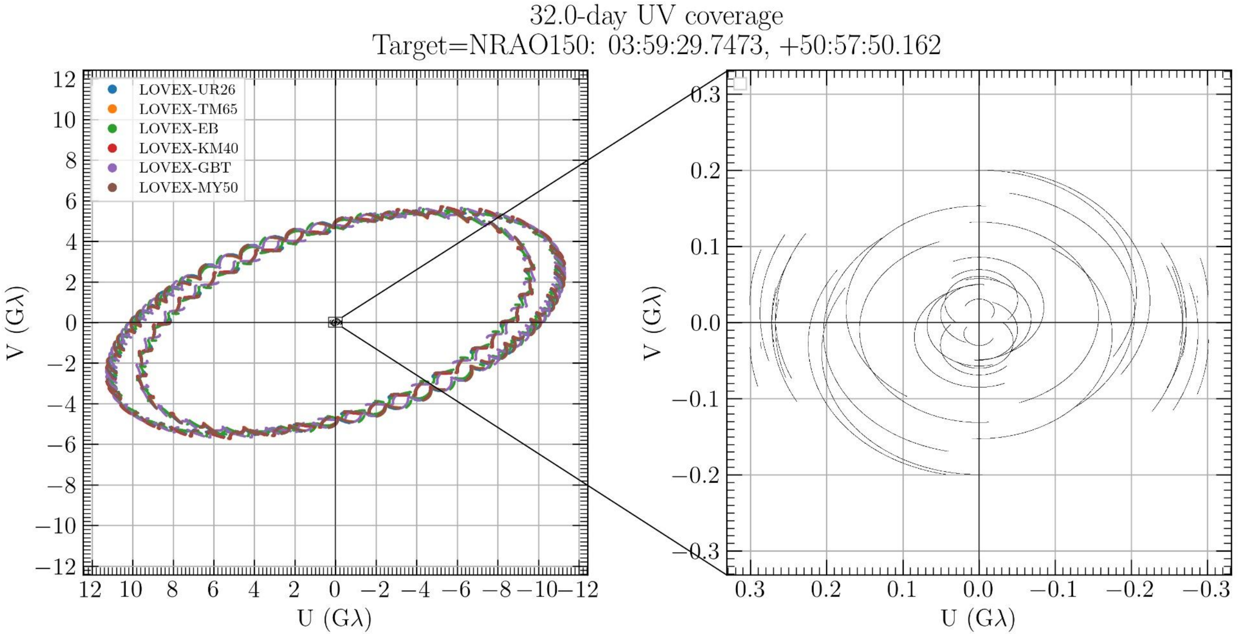
LOVEX: Lunar Orbit VLBI EXperiment

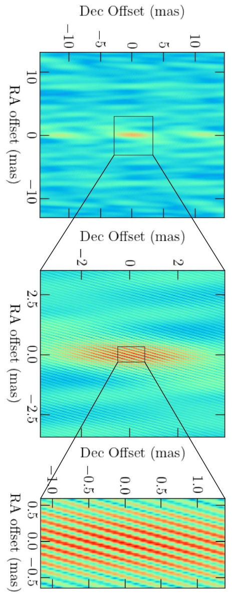


UV coverage and beam pattern for high and low declination sources

Resolution: <10μas

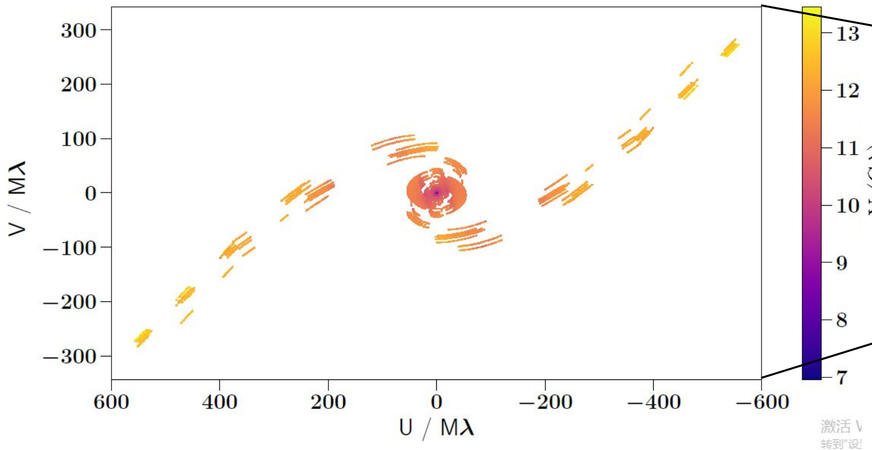




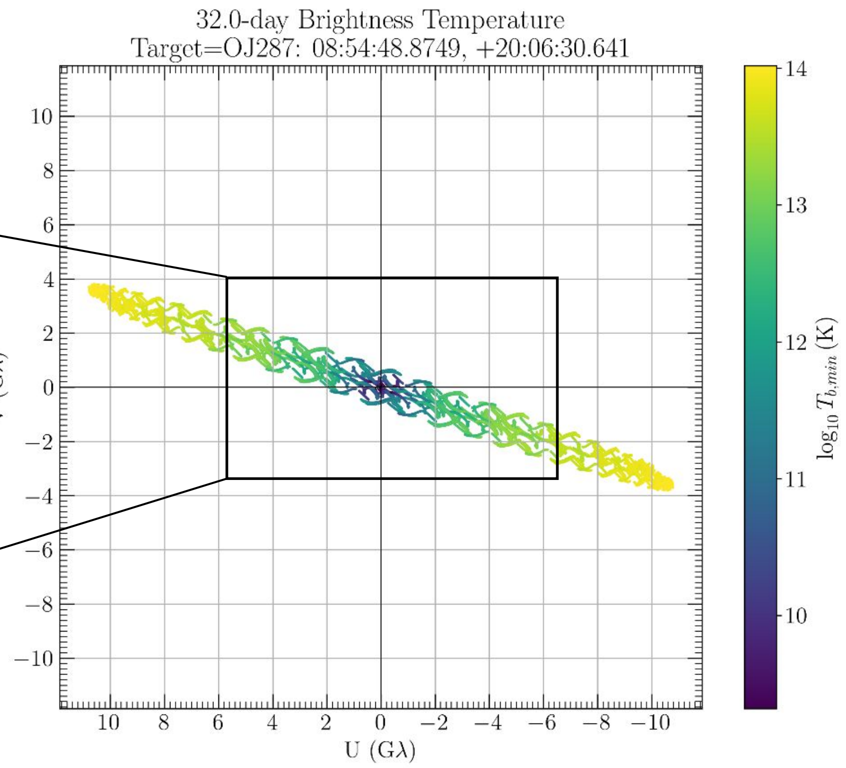


LOVEX: Lunar Orbit VLBI EXperiment

Invers Compton limit : $10^{11.5}$ K
Ground based VLBI : 10^{11} - 10^{12} K
RadioAstron: 10^{12} - 10^{13} K
LOVEX: 10^{13} - 10^{14} K



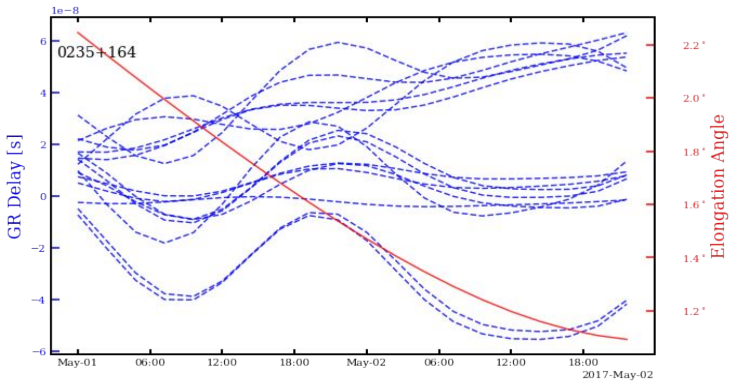
RadioAstron

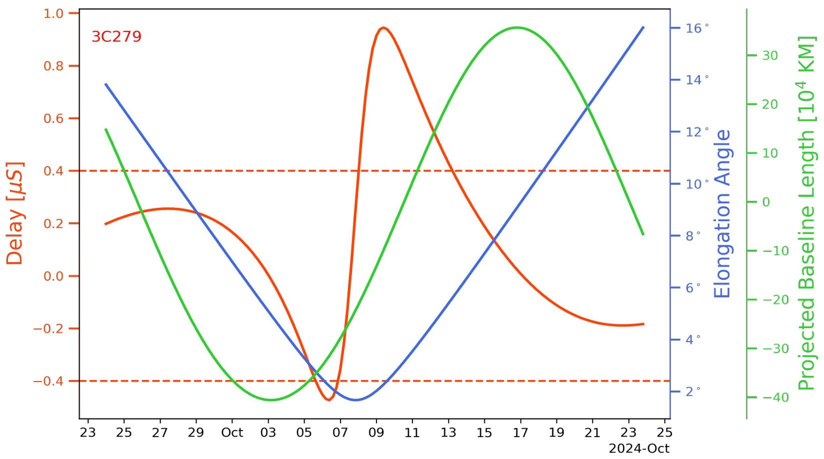


LOVEX

LOVEX: Lunar Orbit VLBI EXperiment

Geodetic science:
Precision of geodetic measurements: 90~700 ps
Projected baseline length：0~38 10^4 KM
Outstanding for the testing of general relativtivity
Contribute to deep space orbit determination





SERA:

Space Extendable Radio-telescope Array

Contact: Bo Zhang

SERA: Space Extendable Radio-telescope Array

Ground:

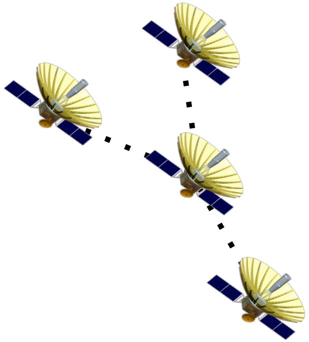
Single large → **Array**

Space:

Single telescope → **Array?**

Assembling in space?

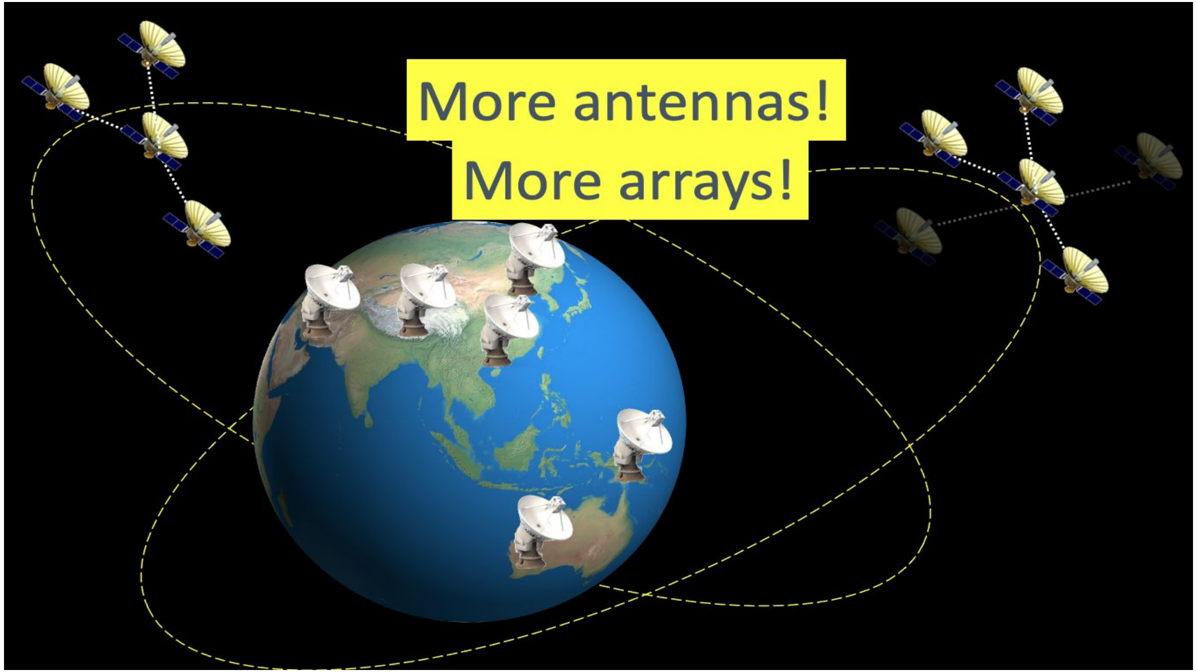
SERA concept



15m × 4
Y-shape array

SERA: Space Extendable Radio-telescope Array

1. Extendable antennas number
2. More arrays on different orbits
3. Extendable life time



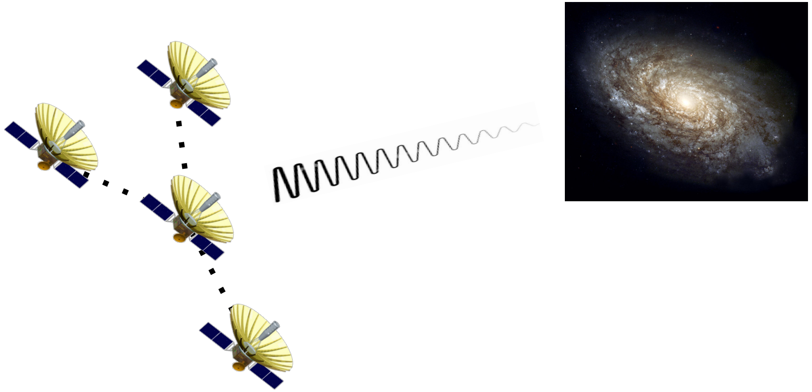
Better sensitivity!
Better resolution!
Better uv-coverage!
Larger FoV!

SERA: Space Extendable Radio-telescope Array

Telescope array/ Multi-Single dish /VLBI

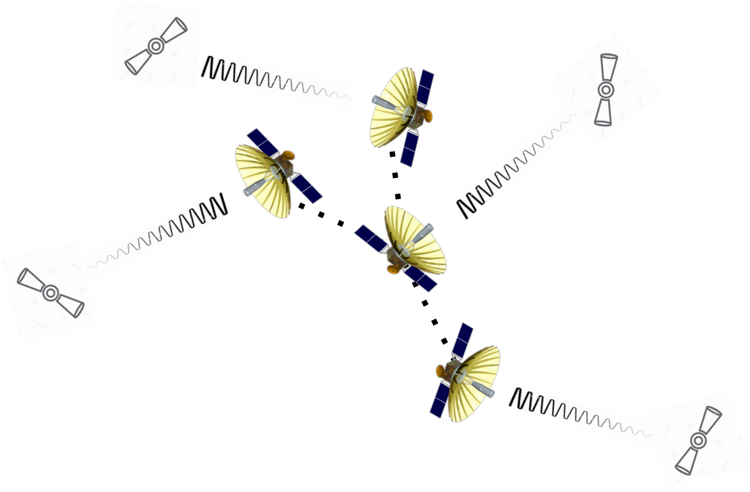
(1)Working as a stand-alone telescope array:

All time All sky



(2)Working as 4 independent telescopes:

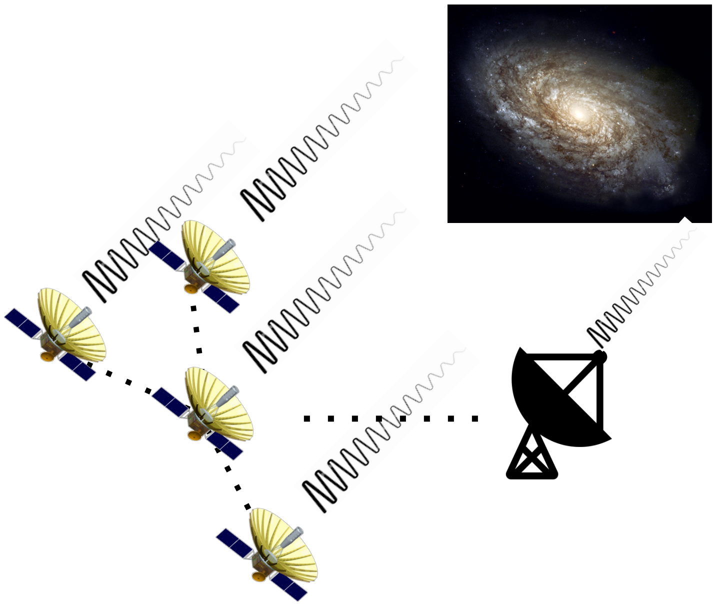
All time All sky



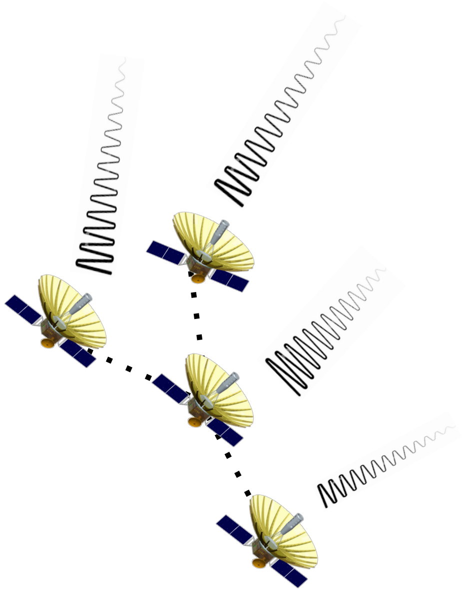
SERA: Space Extendable Radio-telescope Array

(3) Working as a VLBI element:

A: phased-up (larger baseline sensitivity)



B: multi-beam (phase-referencing)

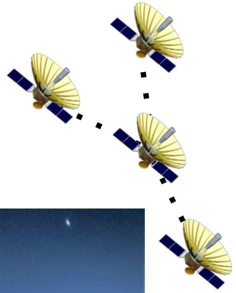


SERA: Space Extendable Radio-telescope Array

Simultaneous multi-band observation (L, C, X, Ku, K)

Parameters	SERA
Frequency coverage	1.0–6.0, 6.0–26 GHz
Reference frequency	1.6 GHz
Baseline	50,000 km
Diameter	15 m
Antenna number	4 (Y-shape, extendable)
Sensitivity (Ae/Tsys)	31.2 m^2/K
Field of View	
Resolution	0.77 mas
SEFD	88.5 Jy
Source switching speed	

SERA: Space Extendable Radio-telescope Array



Telescope array and independent telescopes

- All-sky K-band line survey (22 GHz H_2O maser, etc)
- Pulsar/Maser-based autonomous-navigation experiment
- Search for Transients and pulsar all-time all-sky

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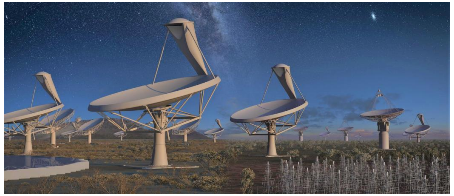

VLBI

Combining with FAST, SKA, ngVLA…, maximum baseline~ 50,000 km

- Mechansim of AGN jets
- Measuring hubble constant based on 22GHz H_2O megamaser
- Triangulating galactic star formation regions based on masers
- Measuring orbit of multiple system with ultra-compact object
- Astrometric identification of exoplanets
- Spacecraft navigation

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Space VLBI - international collaboration