The VSOP-2 (ASTRO-G) Project

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JAXA ASTRO-G Project

NAOJ VSOP-2 Office

JAXA, NAOJ, Univ. of Kagoshima, Osaka Pref. Univ.,

Hosei Univ., Yamaguchi Univ., NiCT, Hitotsubashi Univ.

International Collaborators

ASTRO-A – ASTRO-E2 (X-ray satellite)

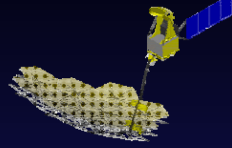
ASTRO-F (Infrared)

ASTRO-G (VSOP-2)

ASTRO-H (NeXT/Xray)

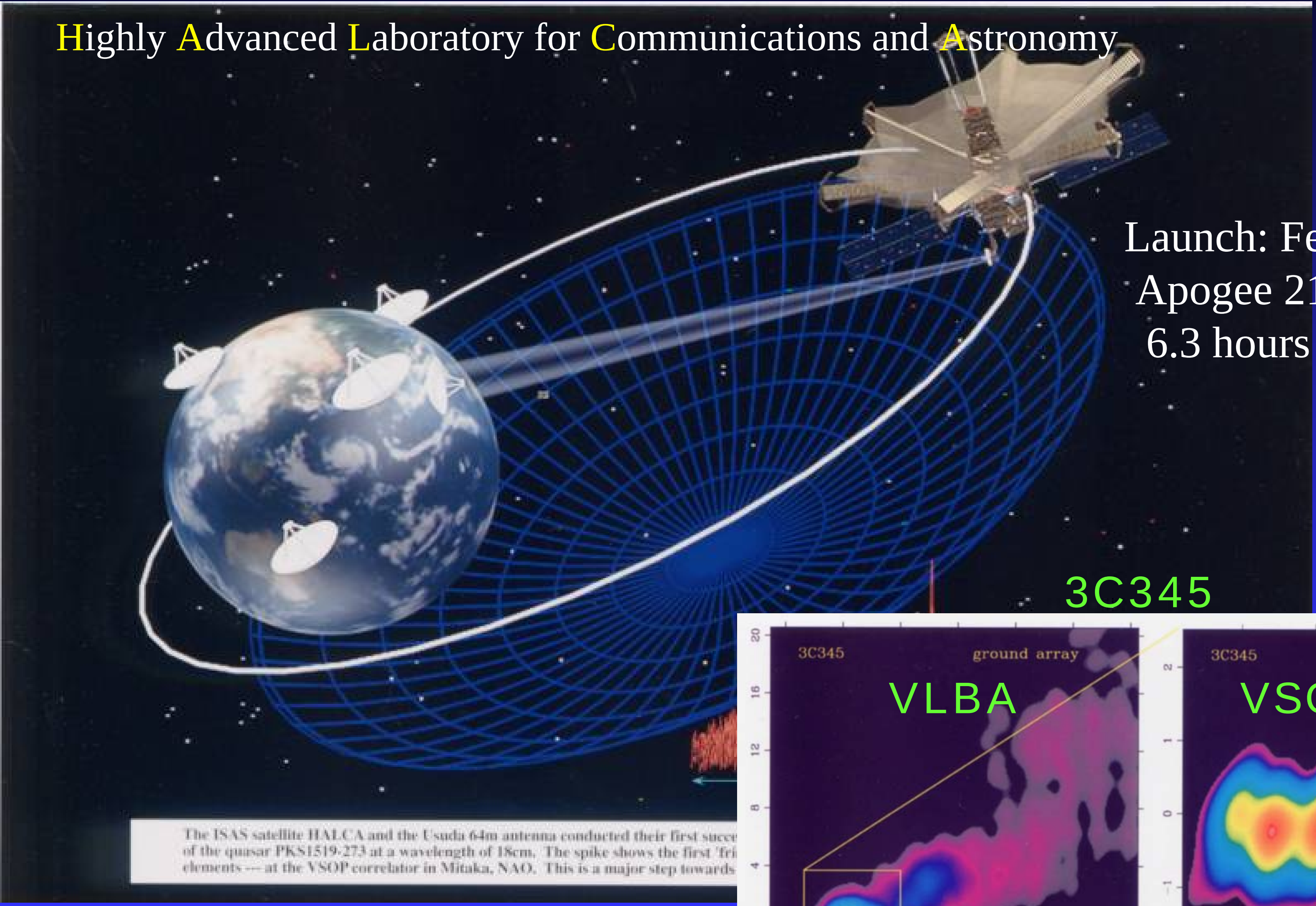
MUSES-B (VSOP-1)

MUSES-C (minor planet sample return)



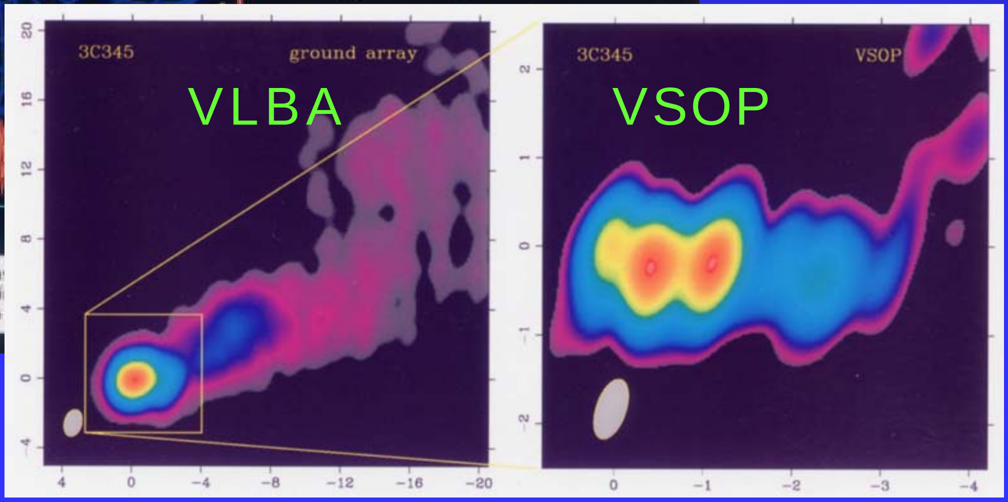
HALCA spacecraft and VSOP mission (1997-2005)

Highly Advanced Laboratory for Communications and Astronomy

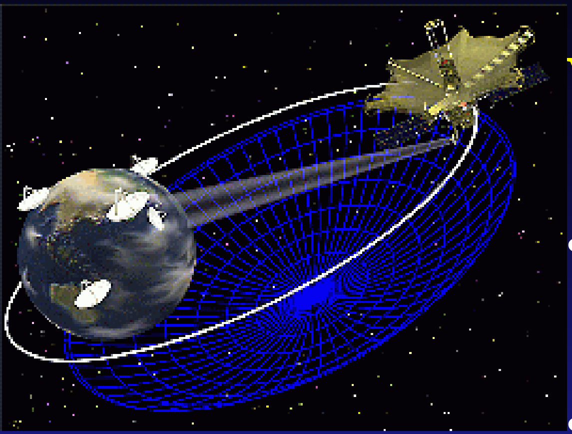


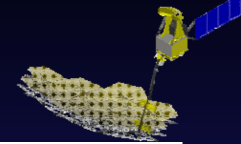
Launch: Feb. 12, 1997
Apogee 21,000km
6.3 hours orbit

3C345



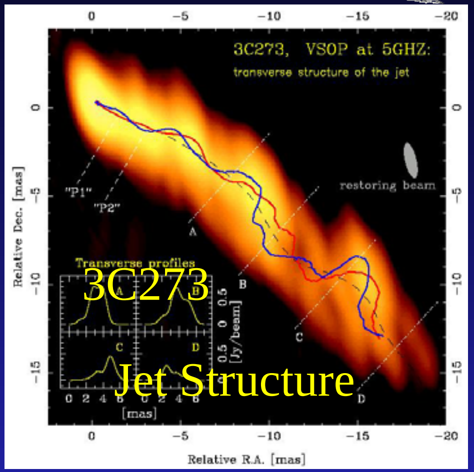
VSOP with HALCA



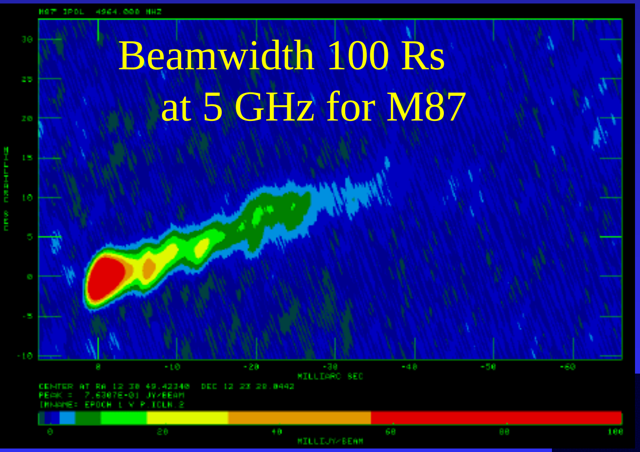


- The first space VLBI imaging mission
- Studied AGN environment and jet physics
  - Structure and kinematics of jet in AGN
  - Absorption near the core and study of torus structure
  - Existence of high brightness temperature sources

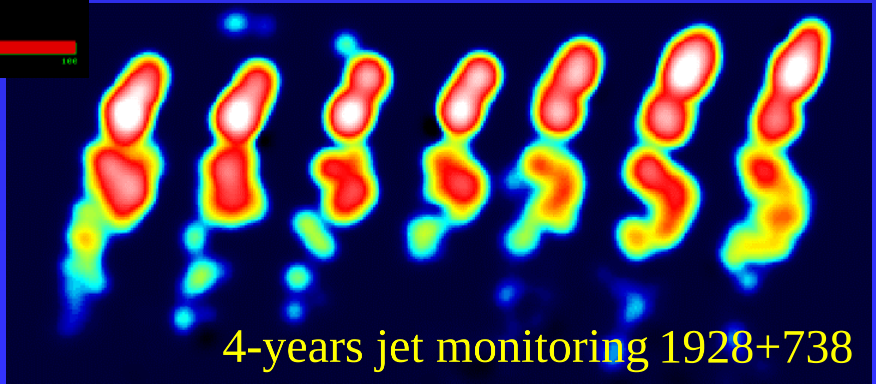
Also Pulsars, X-ray binaries, OH masers



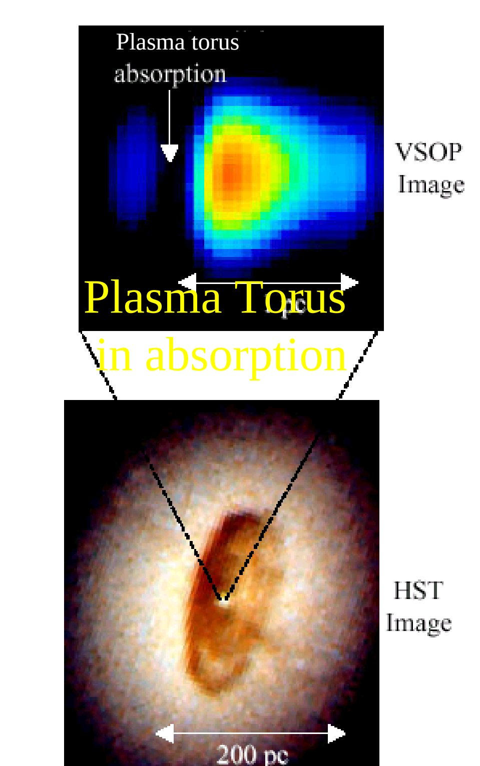
3C273 Jet Structure



Beamwidth 100 Rs at 5 GHz for M87



4-years jet monitoring 1928+738



Plasma Torus in absorption

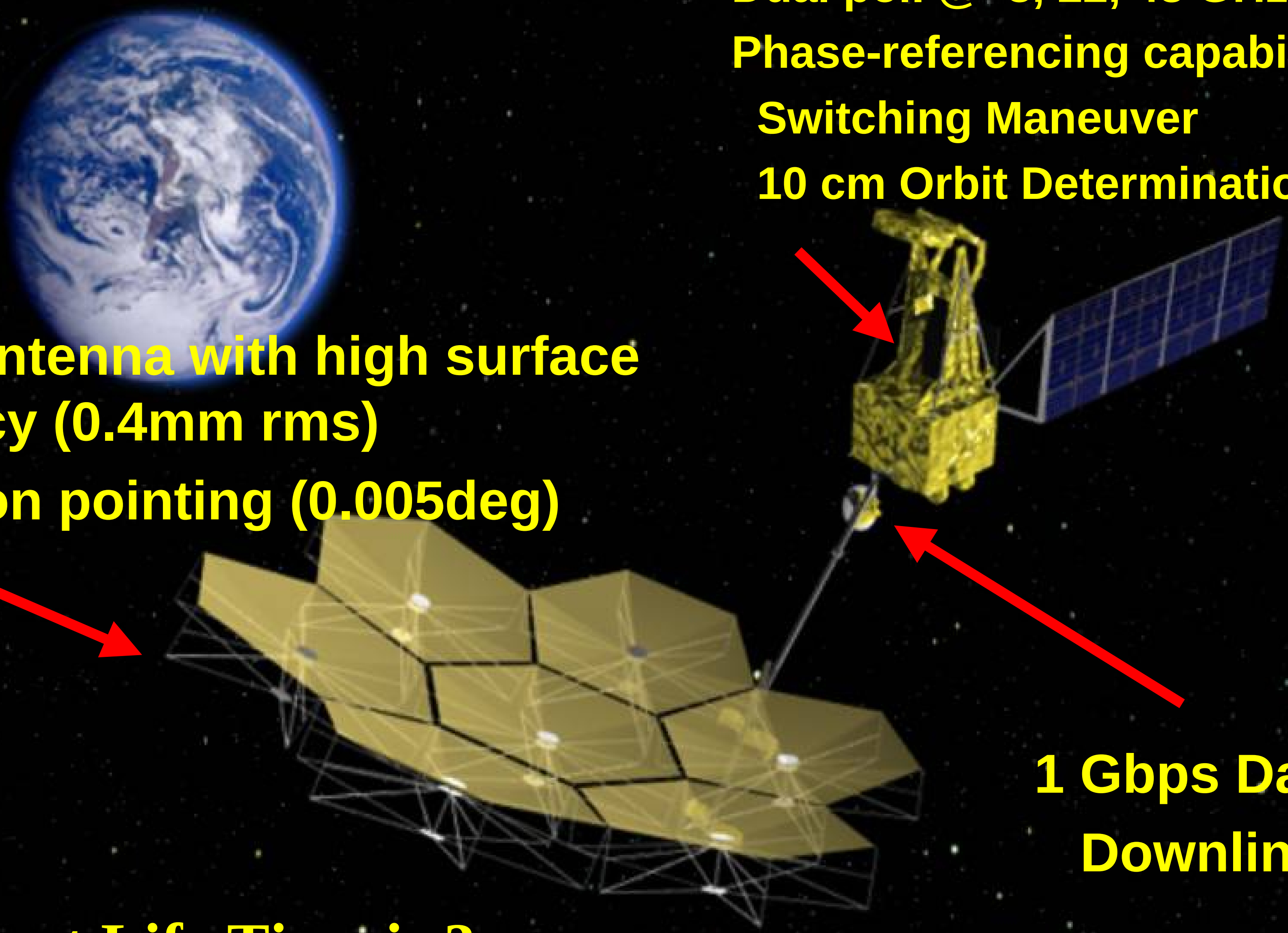
VSOP-2 (ASTRO-G) Mission

Dual pol. @ 8, 22, 43 GHz

Phase-referencing capability

Switching Maneuver

10 cm Orbit Determination



9.3 m Antenna with high surface accuracy (0.4mm rms)

precision pointing (0.005deg)

1 Gbps Data Downlink

Target Life Time is 3 years.

Specifications for ASTRO-G

Orbit :

Apogee 25,000 km

Perigee 1,000 km

Inclination 31deg

Period 7.5 hours

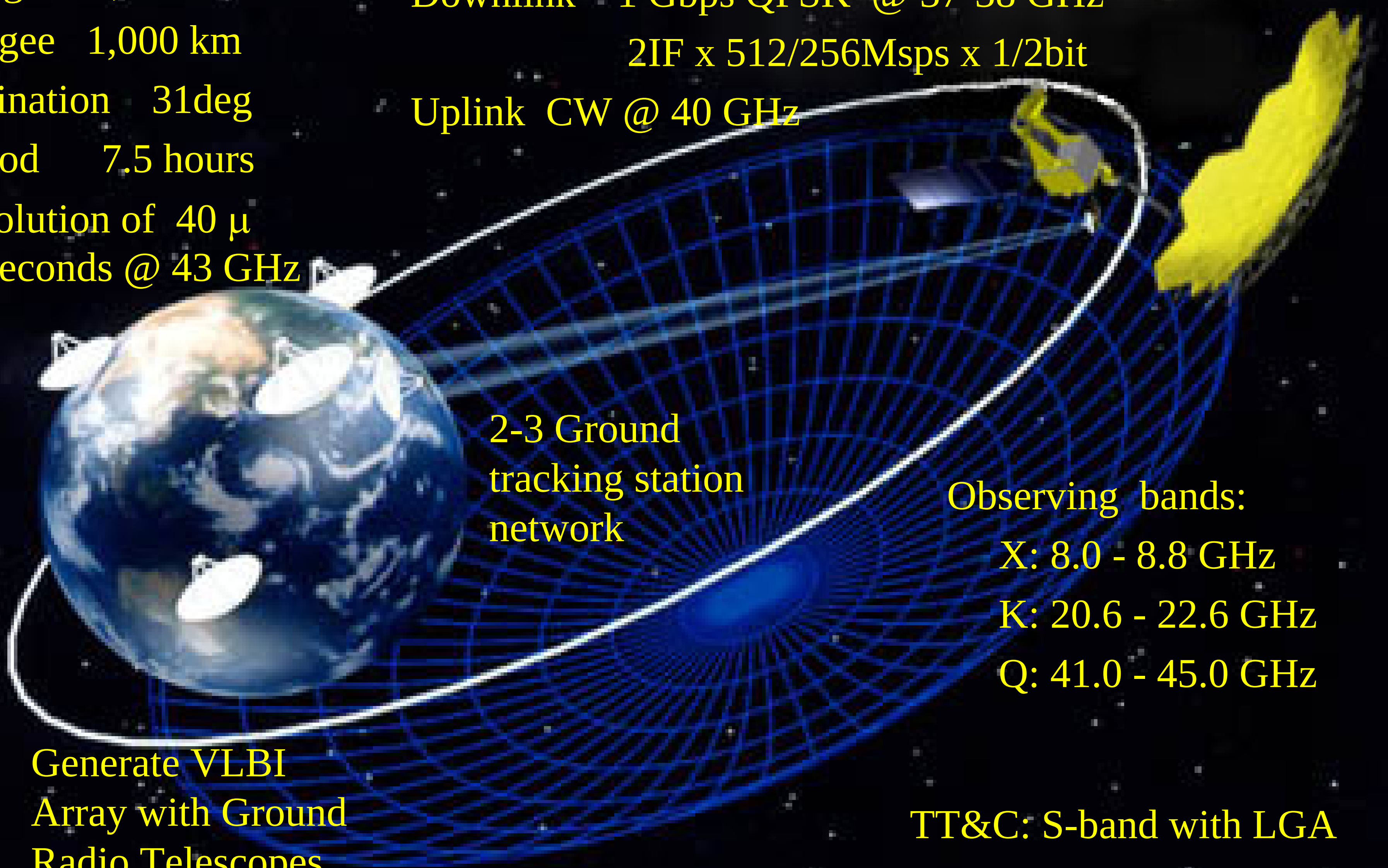
Resolution of 40 μ arcseconds @ 43 GHz

Phase Link & Data Transmission:

Downlink 1 Gbps QPSK @ 37-38 GHz

2IF x 512/256Msps x 1/2bit

Uplink CW @ 40 GHz



2-3 Ground tracking station network

Observing bands:

X: 8.0 - 8.8 GHz

K: 20.6 - 22.6 GHz

Q: 41.0 - 45.0 GHz

Generate VLBI Array with Ground Radio Telescopes.

TT&C: S-band with LGA

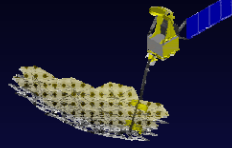
Rocket & Orbit

- **Launch Rocket is H2A**
  - Launch epoch; Summer, 2012
  - Single or Shared Launch is not decided now.

- **ASTRO-G Orbit (HALCA)**
  - Apogee Height: 25,000 km (21,300 km)
  - Perigee Height: 1,000 km (560 km)
  - Inclination 31° (31°)
  - Orbit Period 7.5 hours (6.3 h)

- **Resolution of 40 m arcseconds @ 43 GHz**

Comparison of ASTRO-G/VSOP-2 and HALCA/VSOP



Higher Resolution

- More information on fine structure and magnetic field from AGN jets and cores
  - Higher resolution with polarization capability. At 43 GHz.

Higher sensitivity

- With 2 polarization, 8 times wider bandwidth (continuum sources)
- Cooled receivers for 22 & 43 GHz

High agility attitude control system for fast switching

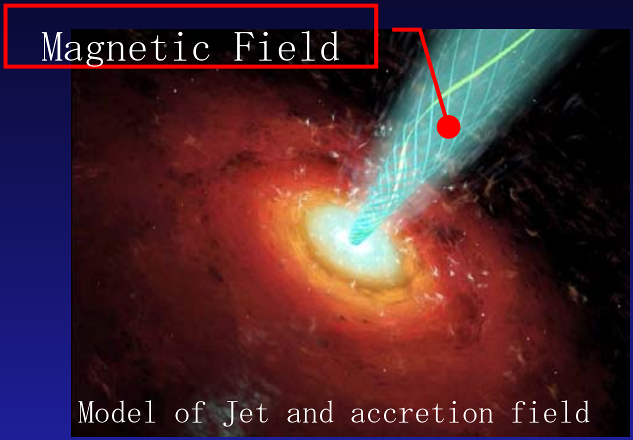
- Improved calibration capability (ASTRO-G can observe calibrators, HALCA could not)
- Phase-referencing observations enabled

  Allows weaker source detection by extending integration time and astrometry observations

High accuracy navigation using onboard GPSR and SLR

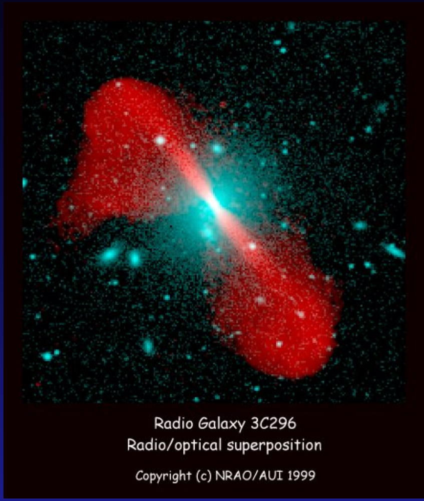
Required for phase-referencing

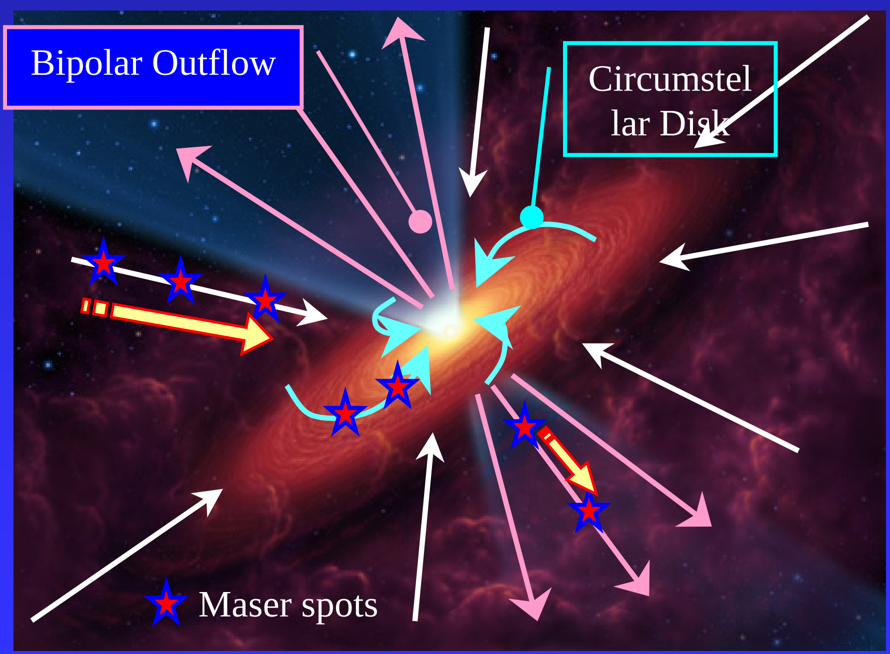
ASTRO-G Science Goals

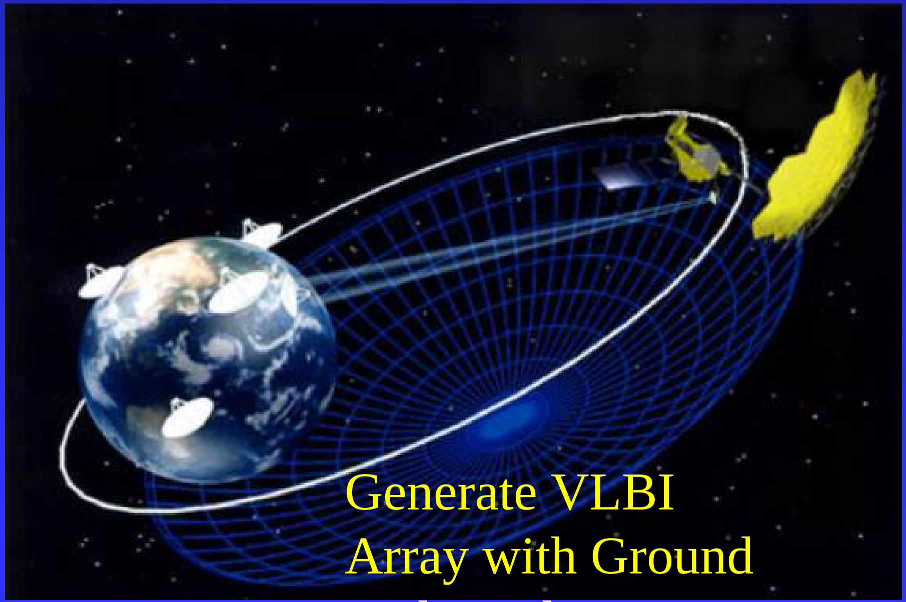


Marscher et al., Wolfgang Steffen, Cosmovision, NRAO/AUI/NSF

- Imaging of Accretion disks around black holes
- Imaging of Jets from the accretion disks, with the polarization Information.
- Imaging of YSOs & Masers

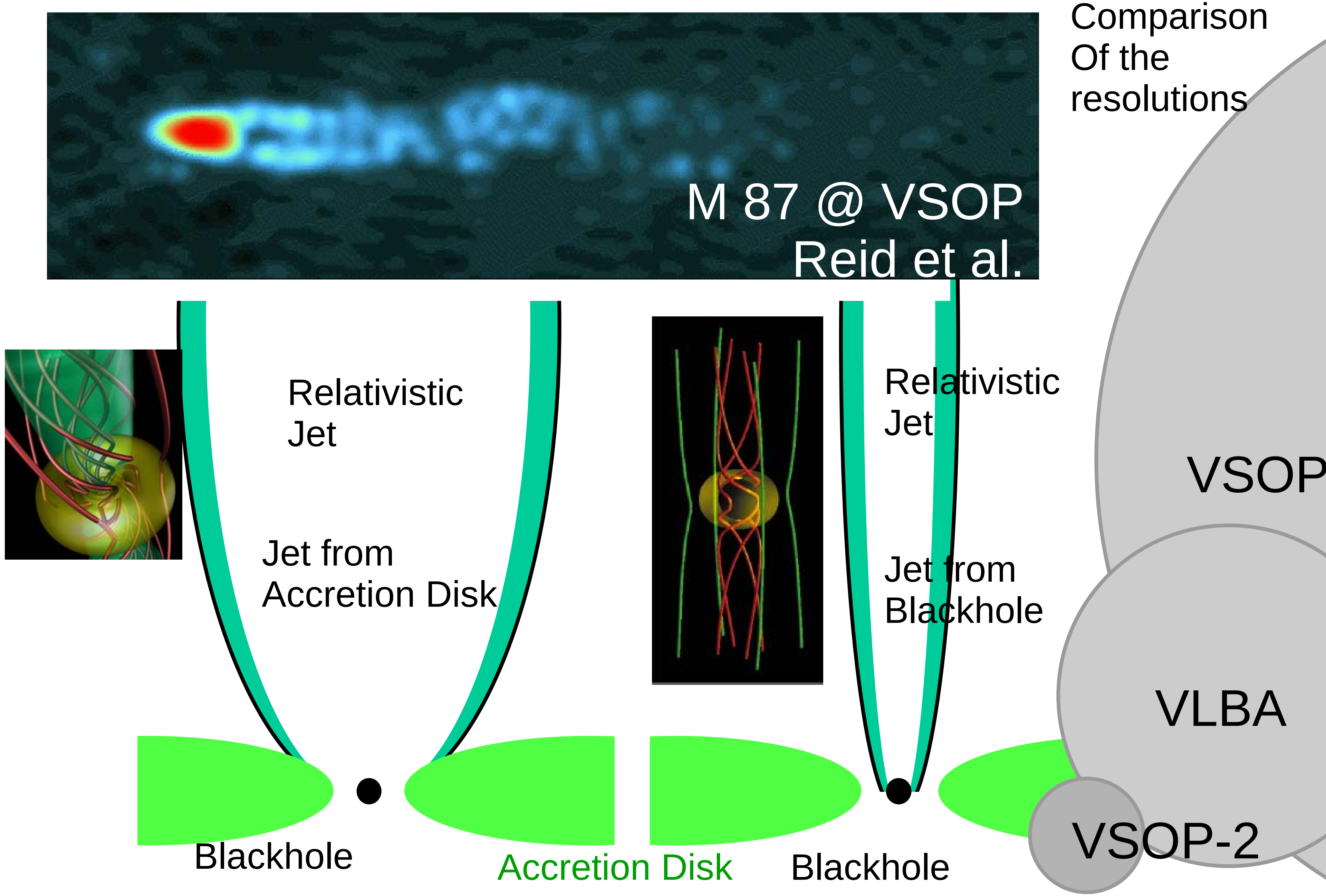


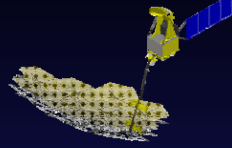




Generate VLBI Array with Ground Radio Telescopes.

ASTRO-G Can see the root of the relativistic Jets





Current Status of ASTRO-G

System Definition Review 19 Mar. 2007

Review For Project Starting at HQ of JAXA 5 Apr, 2007

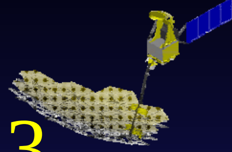
PROJECT Official START 1 Jul, 2007

Preliminary Design Review (PDR) for subsystems has started June,2008.

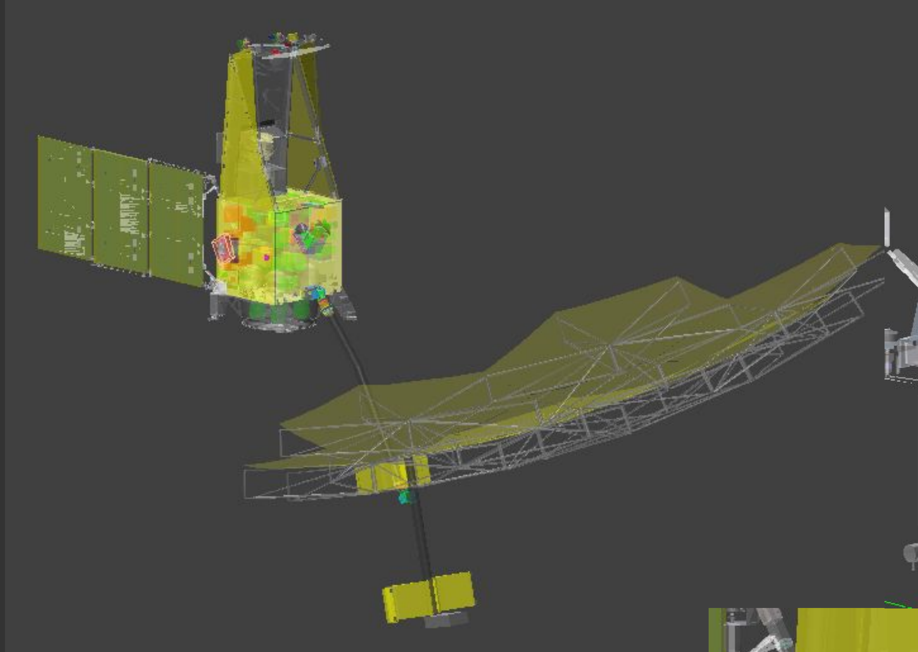
Government committee review before the development of ASTRO-G: June – July, 2008

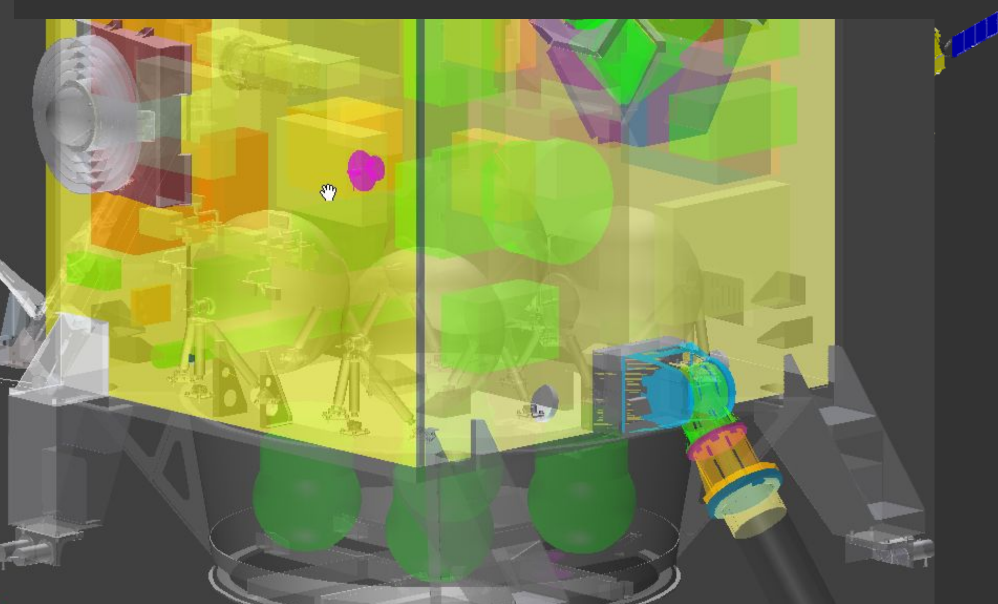
All PDR process are expected to finish March 2009

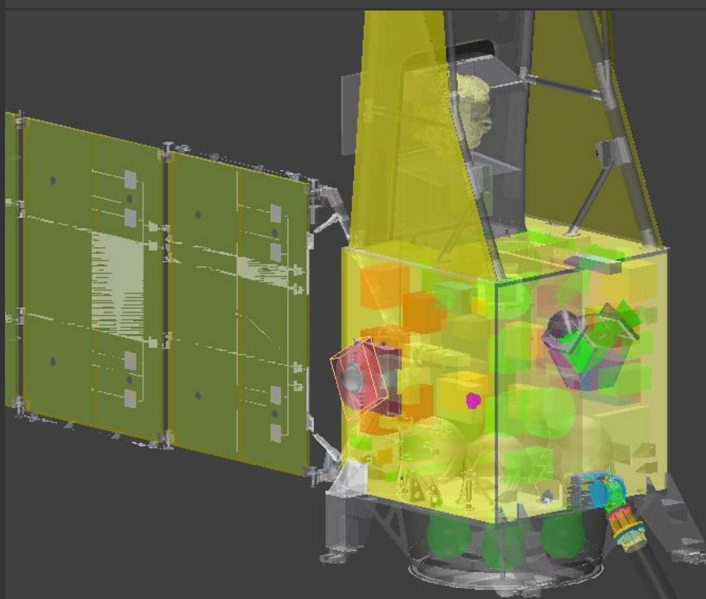
ASTRO-G Development schedule **Launch Jan/Feb 2013**

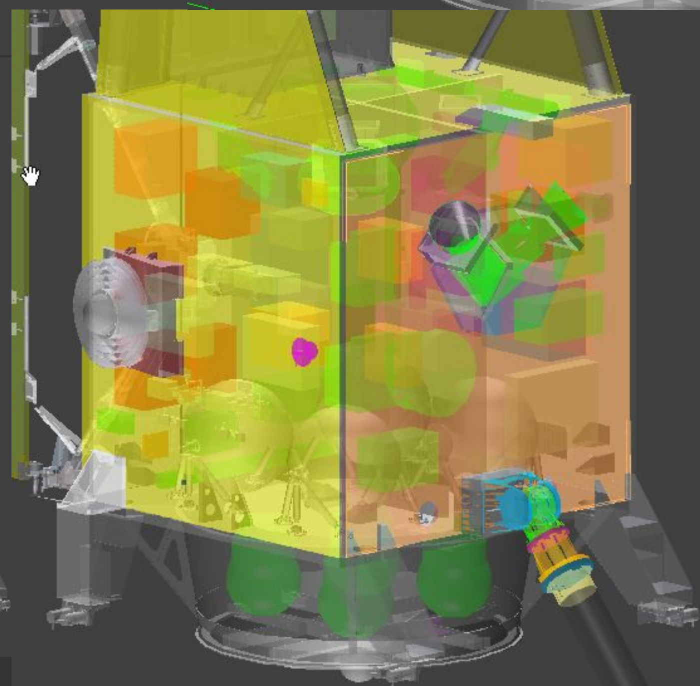


Financial Year (Apr-Mar)	2000～2005	2006	2007	2008	2009	2010	2011	2012～
Spacecraft Development Phase	Concept Pre Phase -A	Design Phase -A	Basic Design Phase -B △ Project starts	Basic Design	Detailed D. Phase -C	Manufacture and Test Phase -D	Manufacture and Test	Operation Phase -E Launch
Events	Selection of the science mission in ISAS NEXT (X) Solarsail (Jupiter)	Approval of project preparation △ Reviews △Budget Request	△System I/F Fixed Design of PFM Structure Antenna, Obs.system Attitude control system △SAC review	△ △SAC review	△ PDR △	△ CDR △	△	△ Review **More than 3 years operation**
Tracking Stations			Ground Tracking Stations Usuda	Ground Tracking Stations Usuda	Ground Tracking Stations International	Ground Tracking Stations International		
Ground Radio Telescopes.					Developments	Developments	Op. Test	





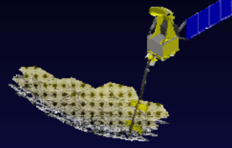




Check the system Design

Structure
Thermal Control
Deformation
Endurance of
Vibration
Radiation
Mass budget
Center of Mass
Inertia
Attitude Control
Power budget
etc

Expected Performance of ASTRO-G Based on the basic design, and BBM tests.



Freq.	resolution	SEFD	7- σ detection with VLBA
8 GHz	205 μ as	6100 Jy	32 mJy
22 GHz	75 μ as	3600 Jy	72 mJy
43 GHz	38 μ as	7550 Jy	188 mJy

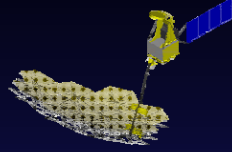
Assumption

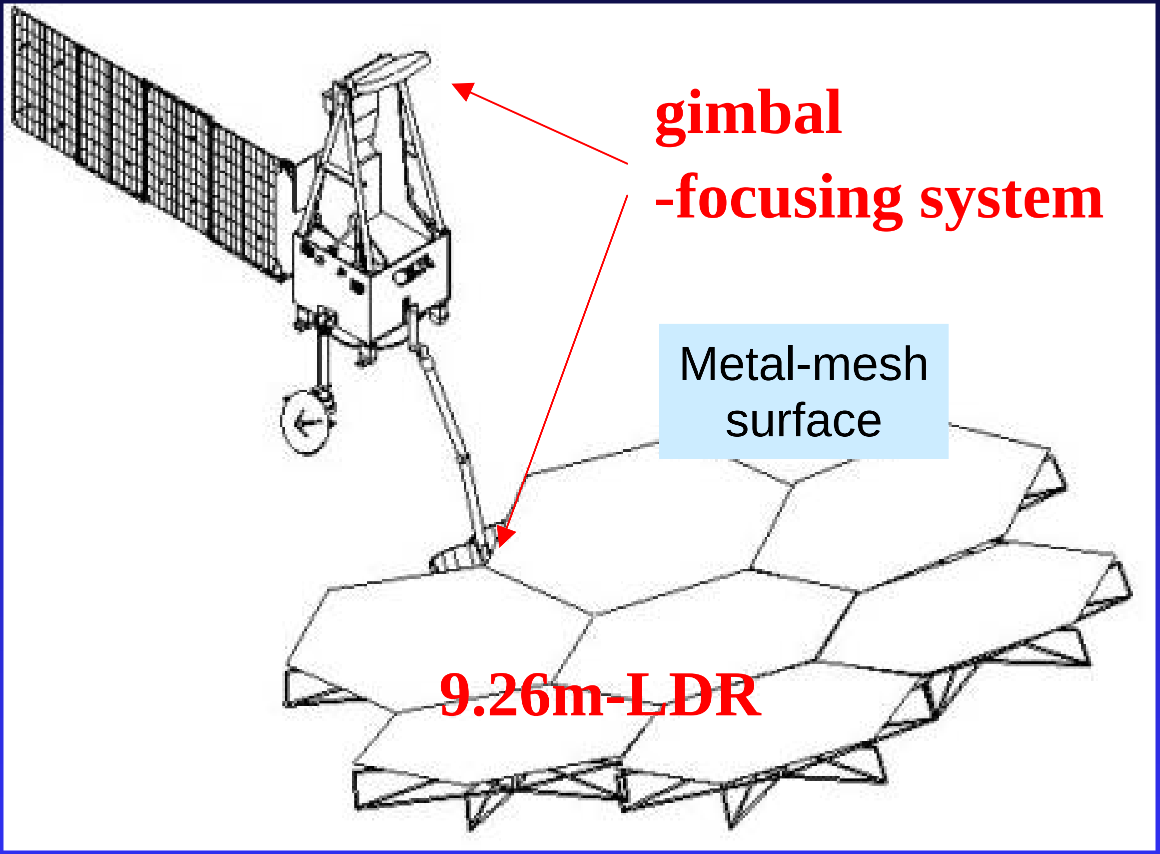
- SEFD=2kTsys/Ae
- Bandwidth for VSOP-2, 128 MHz /2bit or 256 MHz/1bit.

(Tsuboi et al. 2007 VSOP-2 Symposium @ Sagamihara)

ASTRO-G LDR

(Large Deployable Antenna)





9.26-m LDR

Deployable offset Cassegrain antenna with module structures

Light weight 200 kg

Mesh as Surface of LDR

We also used Mesh as Surface of LDR for HALCA.

High surfece accuracy

r.m.s < 0.4 mm

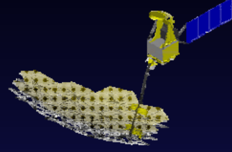
Observing Frequecny

1.6, 5,(22)=>8,22,43 GHz

Gimbal -focusing system

Mission lifetime 3 years

Astro-G antenna performance based on the basic design



Band (GHz)	Xf (mm)	Yf (mm)	Zf (mm)	Tilt (deg)	Gain (dBi)	η_0	X-pol. (dB)	mesh surface η_S	deformation $\exp(-(4\pi\varepsilon/\lambda)^2)$ (ε=0.4mm)	Expected aperture eff. η_A
8.0–8.8	0	-170	138	3	56.7	0.64	-27.8	1?	0.98	0.60 (0.38 at 5GHz)
20.6–22.6	39.4	0	48	0	65.1	0.68	-32.9	1?	0.88	0.59
41.0–45.0	20.5	0	36	0	71.2	0.69	-35.6	0.87	0.61	0.36

Blue numbers :HALCA

aperture efficiency $\eta_A = \eta_0 \, \eta_S \exp(-(4\pi\varepsilon/\lambda)^2)$

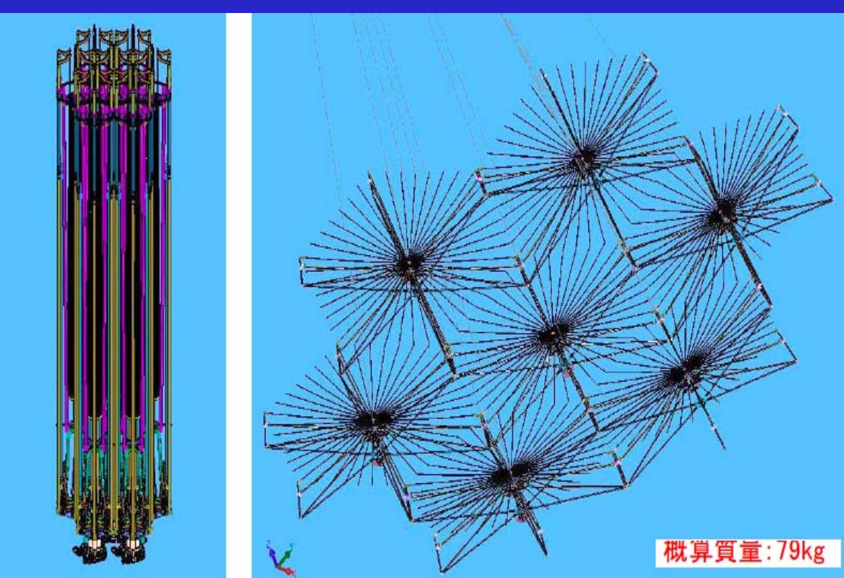
η_0 is depended on aperture illumination.

Large Deployable Antennas (1/2)
-ETS-VIII Deployment Mechanism-

Module-type offset-Cassegrain antenna

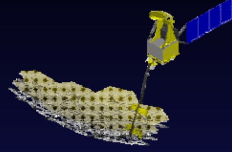
ETS-VIII (2006) deployment mechanism

Seven Modules (Stow / Deployment)

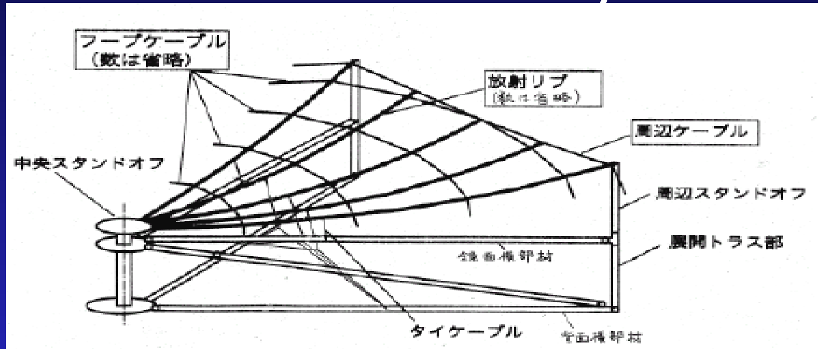


Deployment Test of ETS-VIII

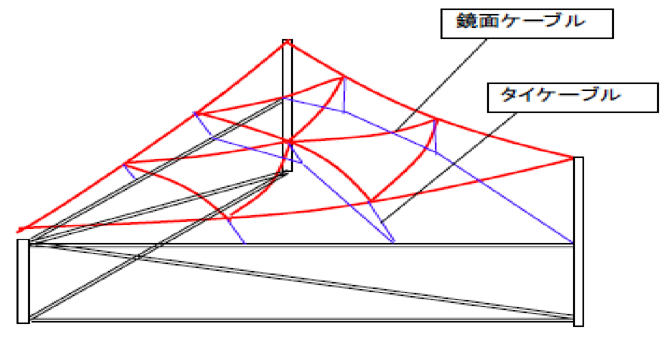
Large Deployable Antennas (2/2)



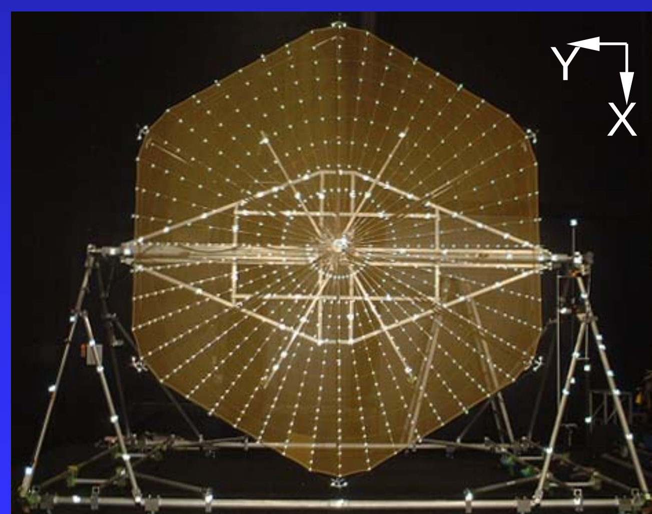
Improve Surface accuracy (0.4mmrms)
ETS-VIII 2GHz, ASTRO-G 43GHz



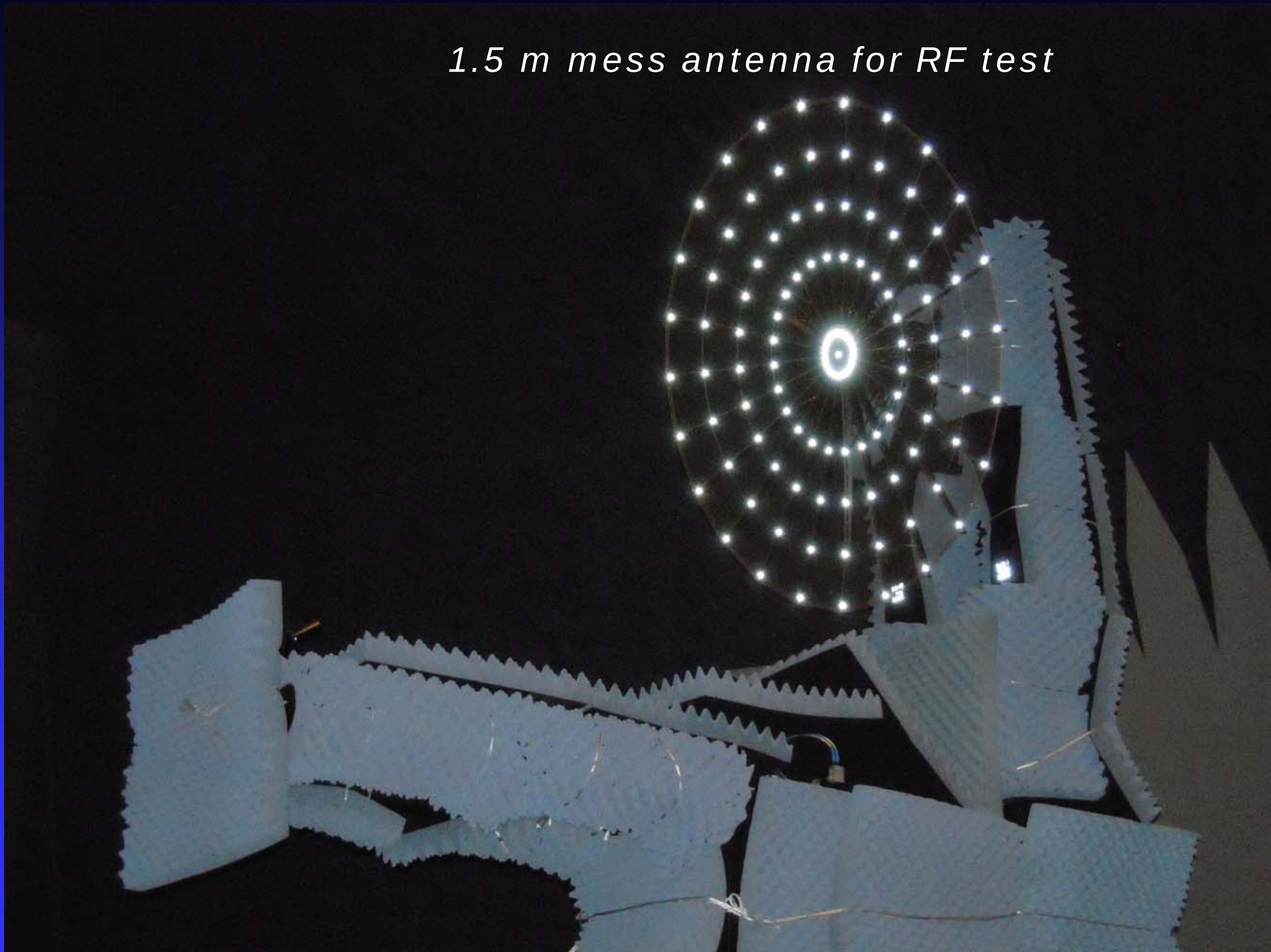
Azimuthal Hoop Cable & Radial Rib.



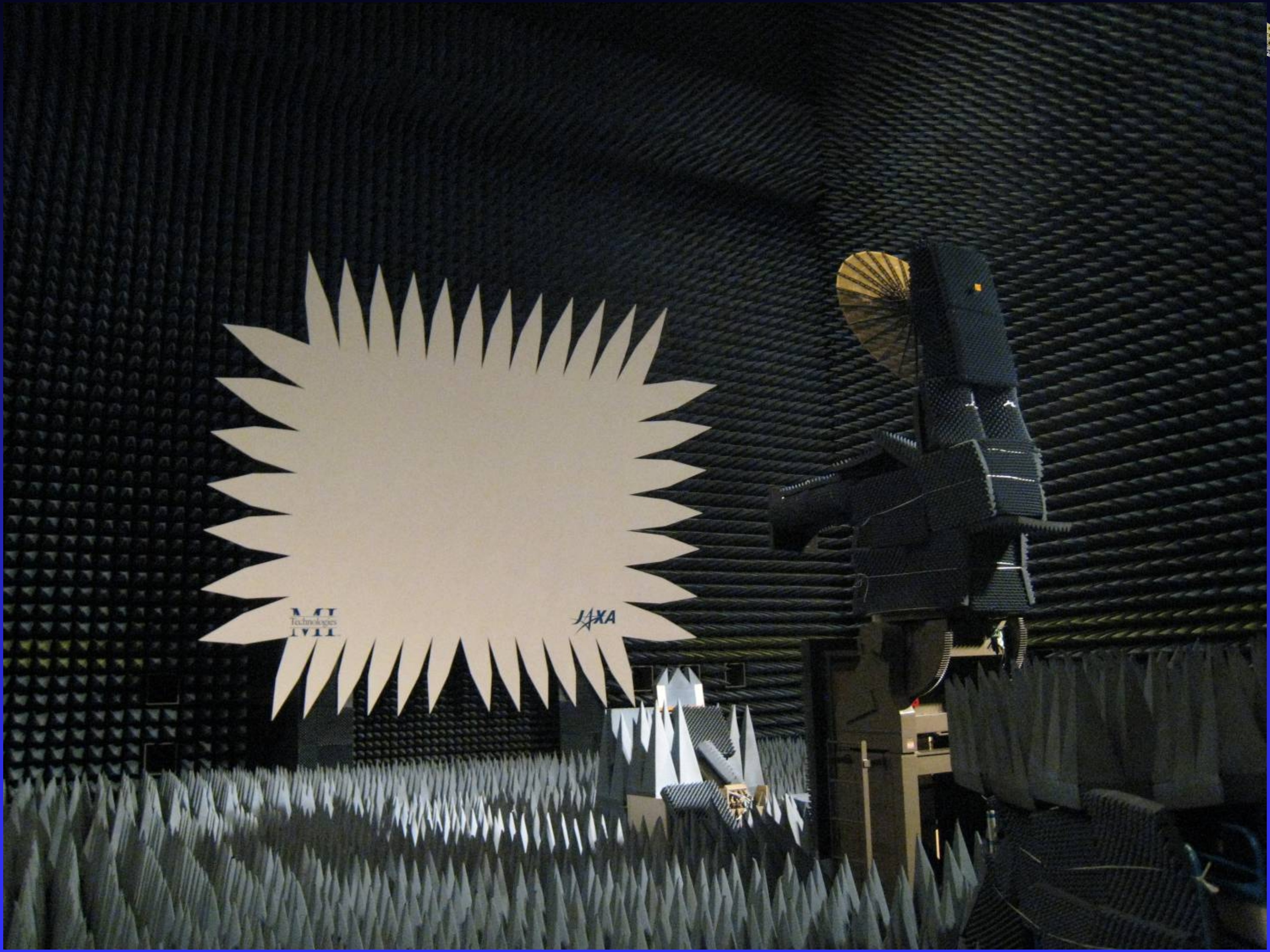
Cable Network



Development Module (2003)

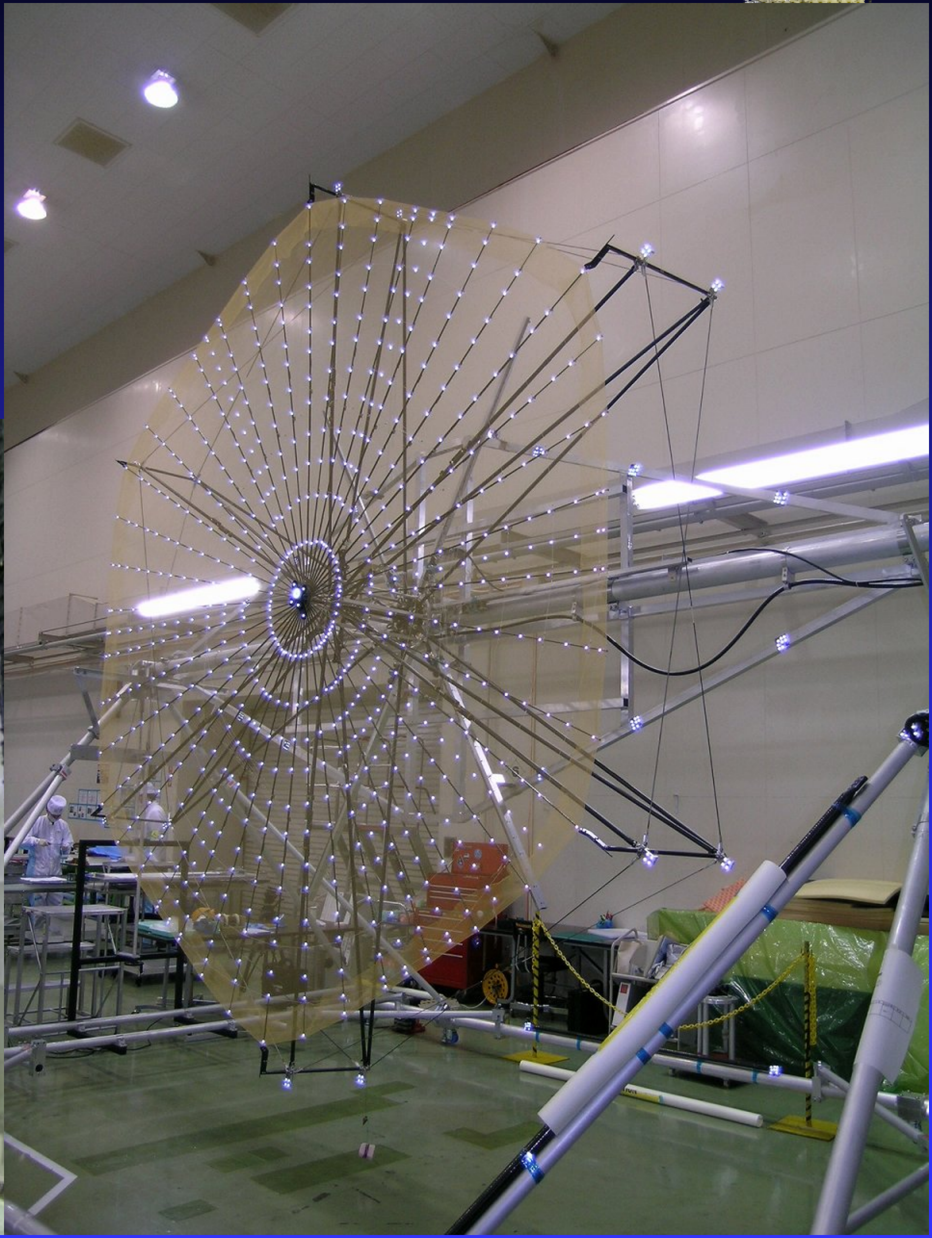


1.5 m mess antenna for RF test

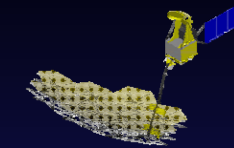


Radio Quiet Room in JAXA
Compact range system
(September 2008)

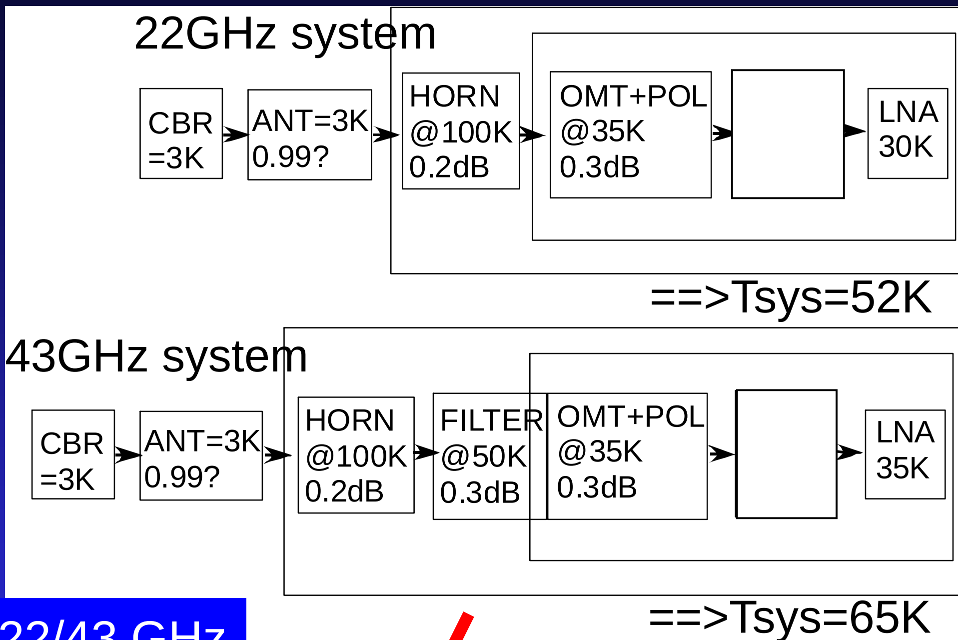
Thermal/Vacuum Test for a module Of LDR (Aug. – Sept. 2008)

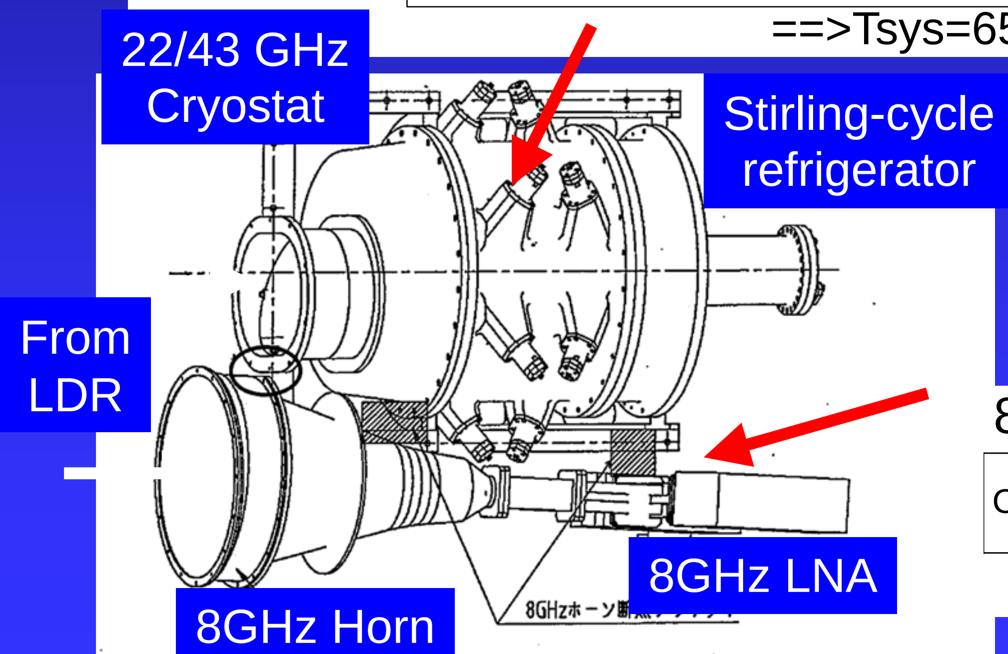


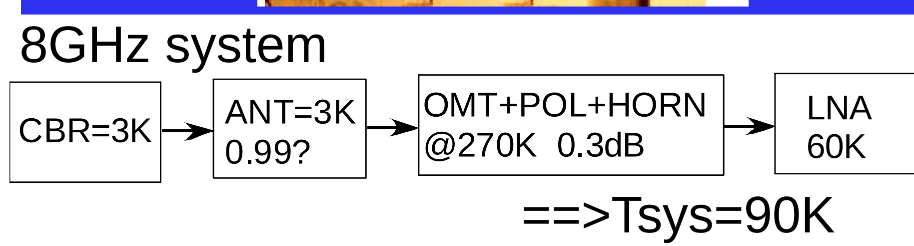
Receiver System

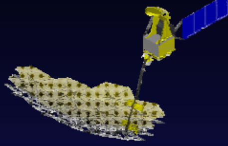


- Dual Circular Polarization Feed
- Cooled LNA at 22/43 GHz
- LNA at 8 GHz at -20 C (passive)

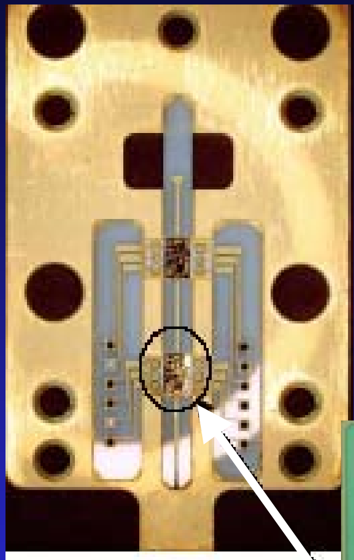






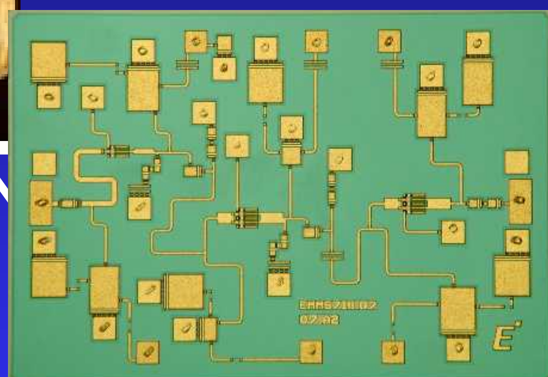


ASTRO-G 22/43 GHz LNA



LNA

Dedicated
GaAs MMIC



Low noise <20K (K) <25K(Q)
High gain > 30dB
Light weight <100g
High reliability
Radiation Hard >100kRad
&
Unconditionally Stable

Receivers at 22 and 43 GHz
cryogenically cooled to 30 K.

present status of LNA

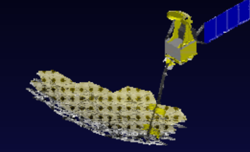
20 K at 22 GHz at BBM done

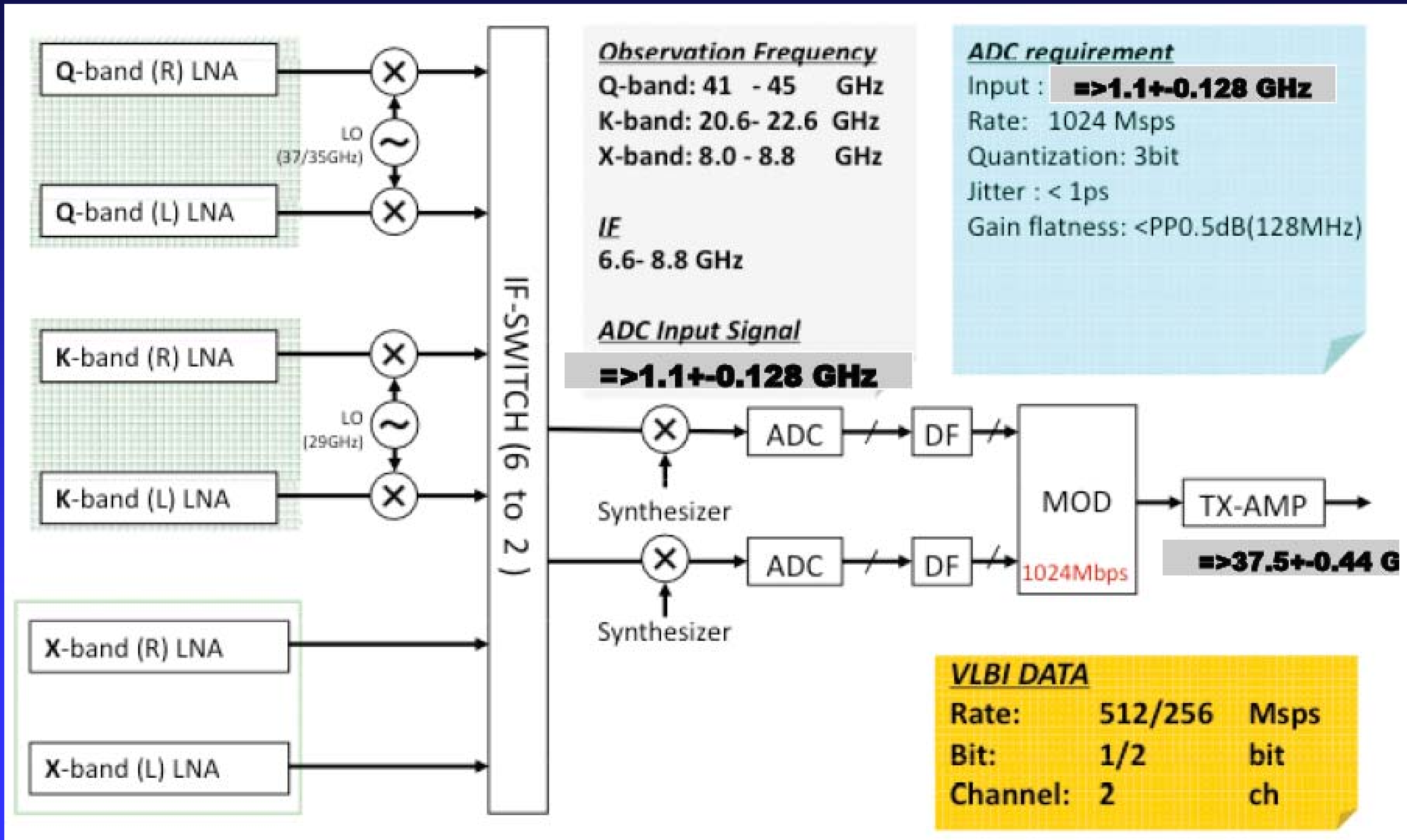
35 K at 43 GHz at BBM done

MMIC in EM will be product until Oct. 2008

ASTRO-G Observing System

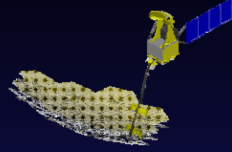
Engineering Model test will start 2Q of 2009





ASTRO-G VLBI Link Station

High Gain Antenna
Diameter: 80cm



ASTRO-G

Ground system manufacture based on common designfinished 1Q of 2009

Phase Transfer Uplink
Frequency 40 GHz
No Modulation
TX-Power 100mW

VLBI Data Downlink
Frequency 37-38 GHz
Bit Rate 1 Gbps
Modulation QPSK
TX-Power 25 W

Ground Link Station
Diameter >10m
Over 3 stations

H Maser

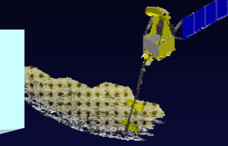
Data Storage

Phase Comparison

Data Storage
Capacity 4 TB / 8 hours

Precision Oribt Determination

Laser Reflectors



BBM of Corner Cube Reflectors (put on the side of Ka Link antenna)

ASTRO-G
25,000x1,000km

Laser Ranging

Ground Laser Stations

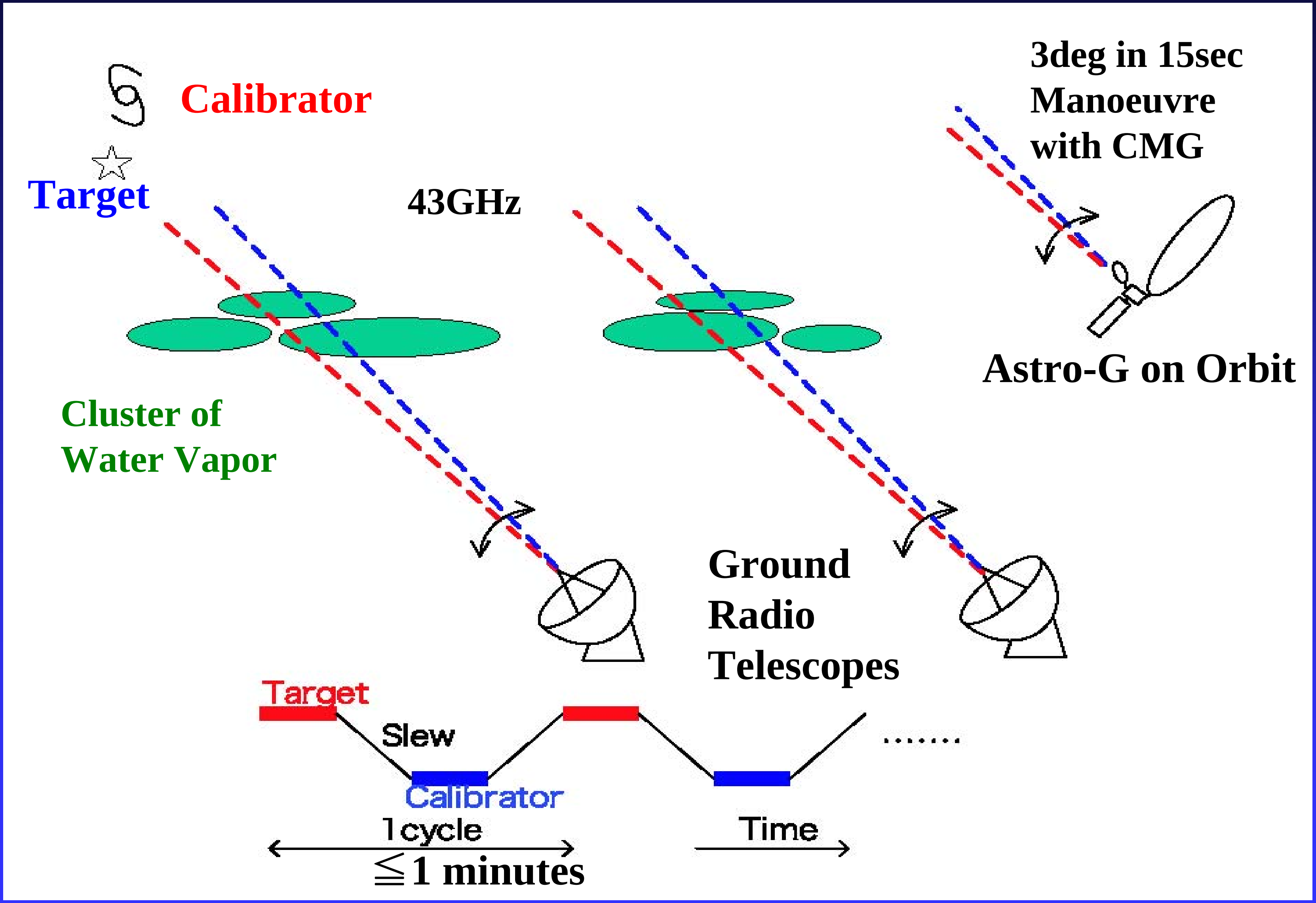
GPS
20,000km

GPS

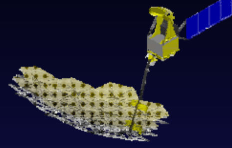
Position Accuracy
_<10 cm_

1,2 GPS Sats @ Apogee.
Many GPS Sats @ Perigee

Fast Switching Observation



VSOP-2 international collaborations



- VSOP-2 collaboration

  Based on VSOP type collaboration

  – Tracking stations (1 JAXA, 1 US, 1 Europe)

    Compatibility test at early 2011

  – GRT(Ground Radio Telescope)'s and Correlater (GVWG)
    - E-ASIA Collaborations: GRT, Correlater, Receiver ?
    - EVN, SKA, VLBA, Australia, Asia…

      GRT test observation at 2011.

      Pre-launch survey

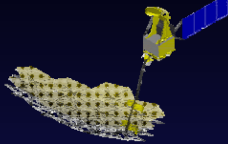
  – Navigation

  – On-borad instruments (Not in VSOP)
    - GPSR, LNA

  – Simulator, AIPS(++?) update.

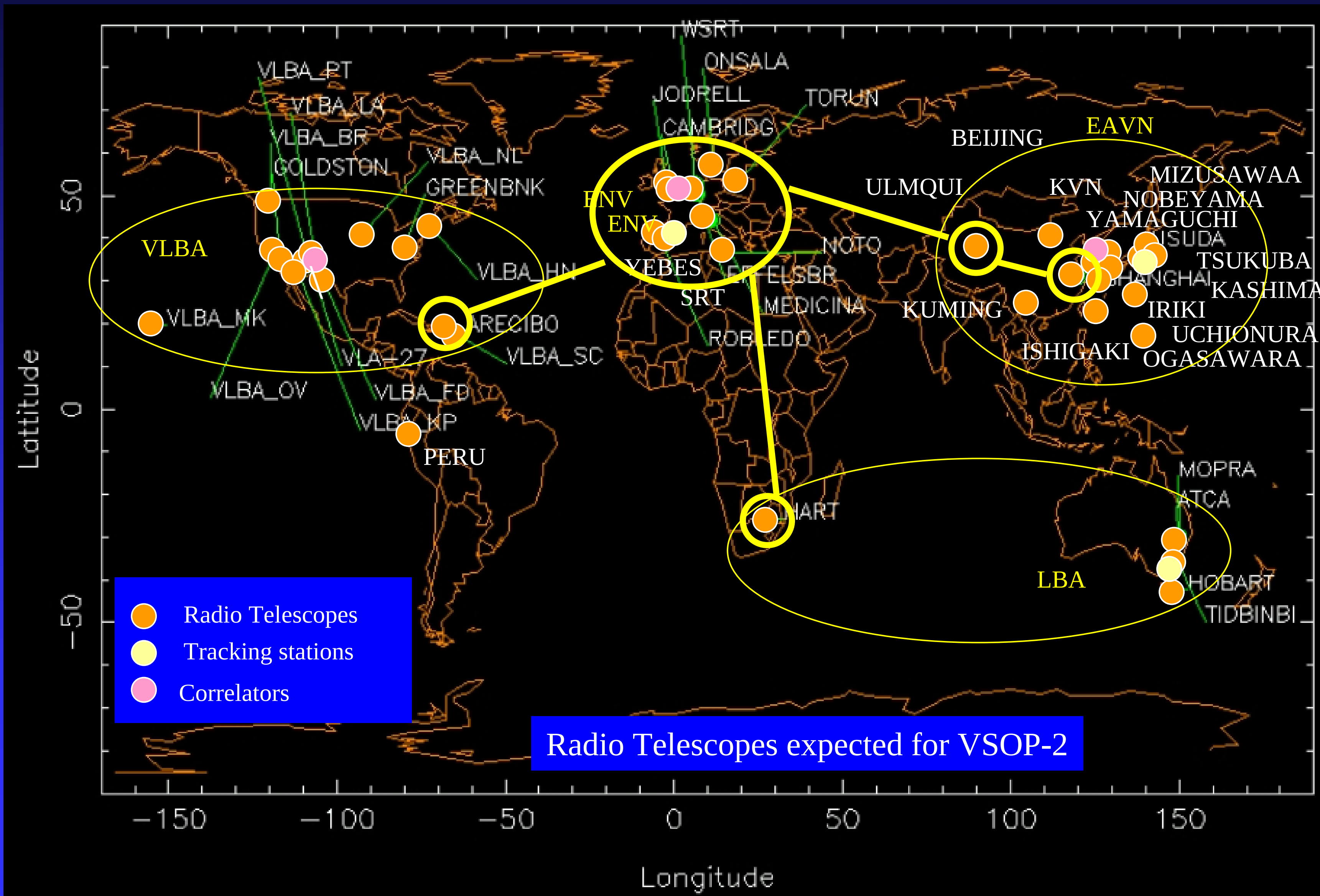
  – Forming International WG.

  – International Science Team (Survey etc..)

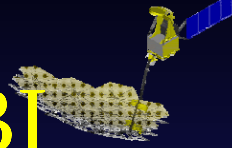


VSOP-2/ ASTRO-G

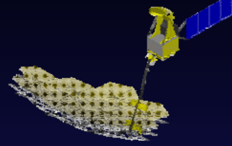
International Collaborations



European Astronomers and Space VLBI



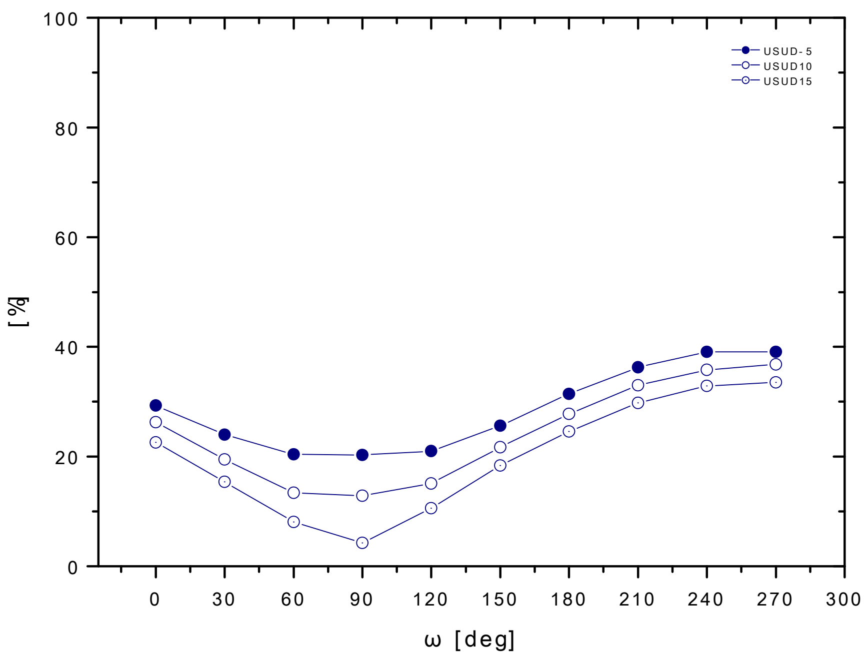
- Highly rated ESA Flexi proposal (2000) for the European segment of VSOP-2
- Significant enhancement of the VSOP-2 science via involvement of European partners:
  - Tracking station at Yebes
  - EVN data processing facility (Correlaters)
  - Co-observations with European radio telescopes
  - Scientific contributions for maximize the output of VSOP-2

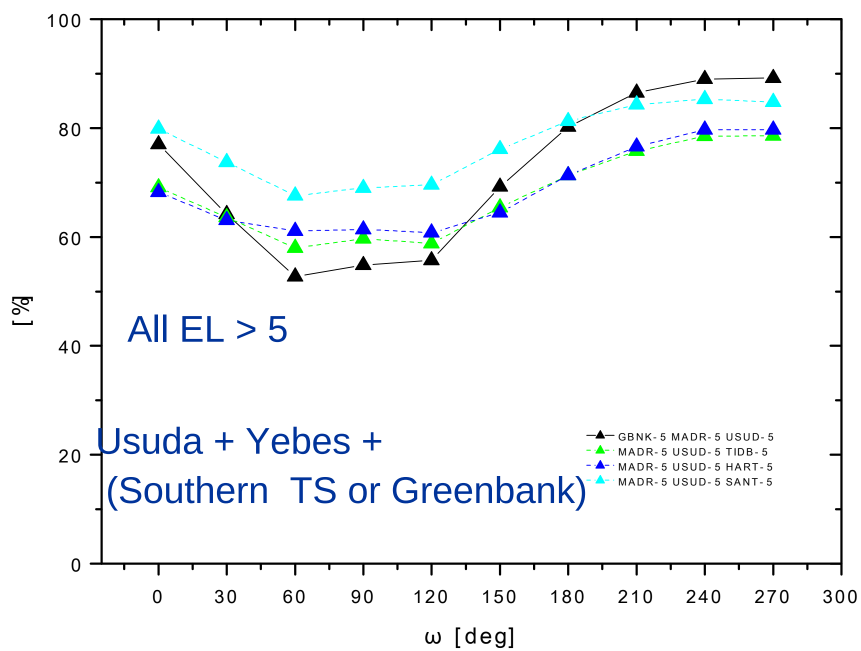


Add a tracking station for ASTRO-G

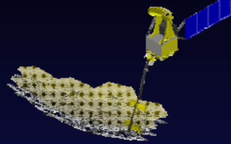
A tracking station in Europe increases VSOP-2 efficiency significantly!

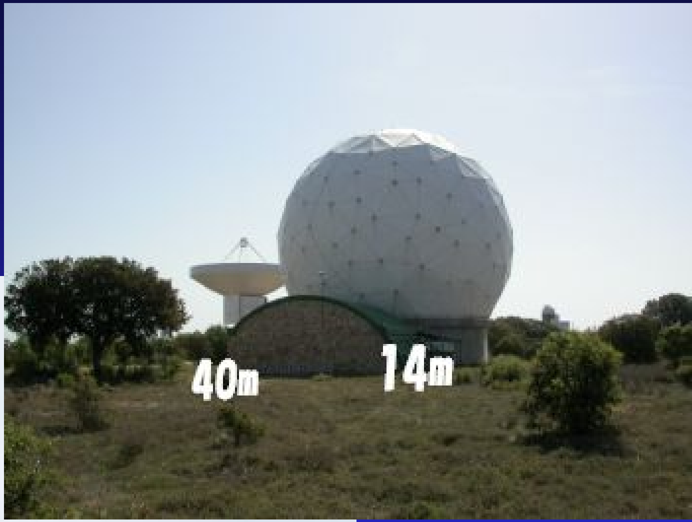
- **Usuda only (20 – 40 %)**
- **Usuda + Yebes (35 – 75 %)**
- **Usuda + Yebes + Greenbank (US) (50 – 90 %)**



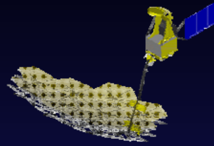


VSOP-2/Astro-G Tracking station meeting (Yebes, Spain, Feb. 19-20, 2007)





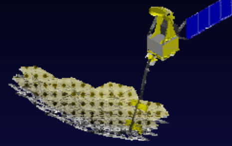
International Activities



- International meetings
  - Tracking station meetings (5 times)
    - #1 @ JPL Pasadena, Nov. 2006
    - #2 @ Yebes Spain, Feb. 2007
    - #3 @ Sagamihara, Apr. 2007
    - #4 @ Greenbank, Aug. 2007
    - #5 @ Sagamihara, Dec. 2007 “Agreed common design of the ground system”
  - Japan-U.S. KSP (Key Science Program) Meeting Oct 19-21@ Mitaka
  - VSOP-2 symposium (Dec 3-7, 2007 @ Sagamihara)
    - 135 participants. Half from outside of Japan (13 countries)

  - VSOP-2 Science Meeting (May 14-16, 2008 @ Bonn)
  - First VISC-2 Meeting (May 13, 2008 @ Bonn)

VISC-2



- **VISC-2 Formation**
  - VISC-2(VSOP-2 International Science Council)

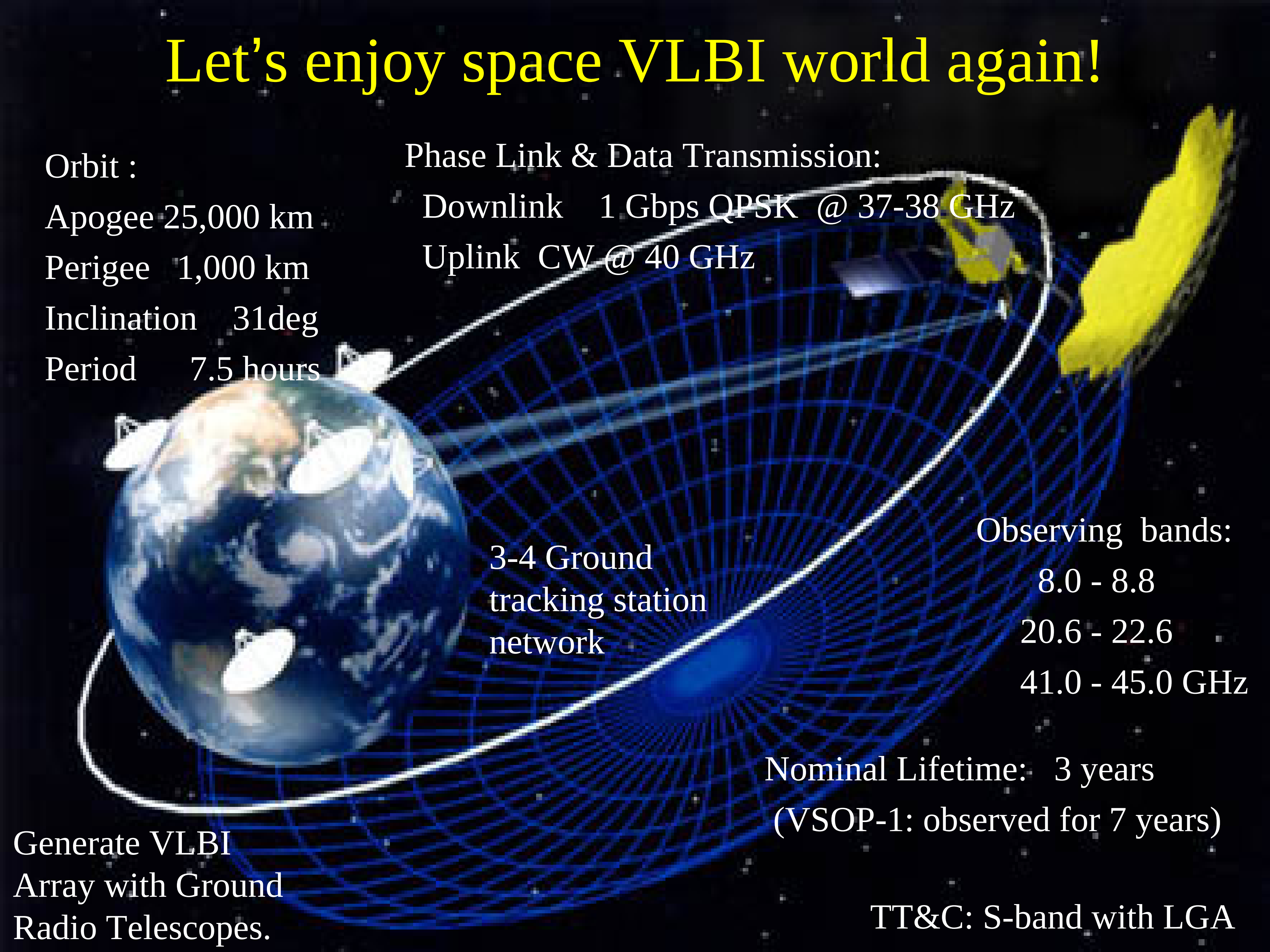
    We form VISC-2 to make consensus related to scientific operations of VSOP-2. Possible VISC-2 functions are selection of KSPs, scientific scheduling, decisions of international relations, scientific operations. (Finally decided in the first VISC-2 meeting in Bonn in May, 2008)
  - pre-meeting
    - Dec. 2007 @ Sagamihara
    - April, 2009 @Telecon
    - May, 2009 First F-F Meeting in Bonn
  - Members:
    - Ex-officio(ISAS/JAXA): H.Saito, M.Tsuboi
    - Institutional members (12):

    ISAS(1): Y.Murata (co-chair), NAOJ(1): M.Inoue, JVN(1): K.Fujisawa

    EAVN (1): H.Kobayashi, KVN/KASI (1): S.-H.Cho, NRAO(1): J.Ulvestad

    (JPL(1): D.Murphy), JIVE(1): L.Gurvits, EVN(1): A.Zensus (co-chair)

    OAN(1): R.Bachiller, ATNF(1): P.Edwards, GVWG(1): J.Romney (NRAO)
    - At-large members (3): D. Gabuzda (Univ. Collage Cork, Ireland), S.Kameno (Kagoshima Univ.), + Astrometry person (TBD)
    - VISC2 adviser (2): D.Jauncey, H.Hirabayashi
    - Liaison (1): R.Schilizzi (ISPO (International SKA Project Office))
    - Secretary(1): Y.Hagiwara (NAOJ)


Let's enjoy space VLBI world again!
Orbit :
Apogee 25,000 km
Perigee 1,000 km
Inclination 31deg
Period 7.5 hours
Phase Link & Data Transmission:
Downlink 1 Gbps QPSK @ 37-38 GHz
Uplink CW @ 40 GHz
3-4 Ground
tracking station
network
Observing bands:
8.0 - 8.8
20.6 - 22.6
41.0 - 45.0 GHz
Nominal Lifetime: 3 years
(VSOP-1: observed for 7 years)
Generate VLBI
Array with Ground
Radio Telescopes.
TT&C: S-band with LGA