

Very Long Baseline Interferometry (VLBI) on Earth and in Space: *the RadioAstron mission*

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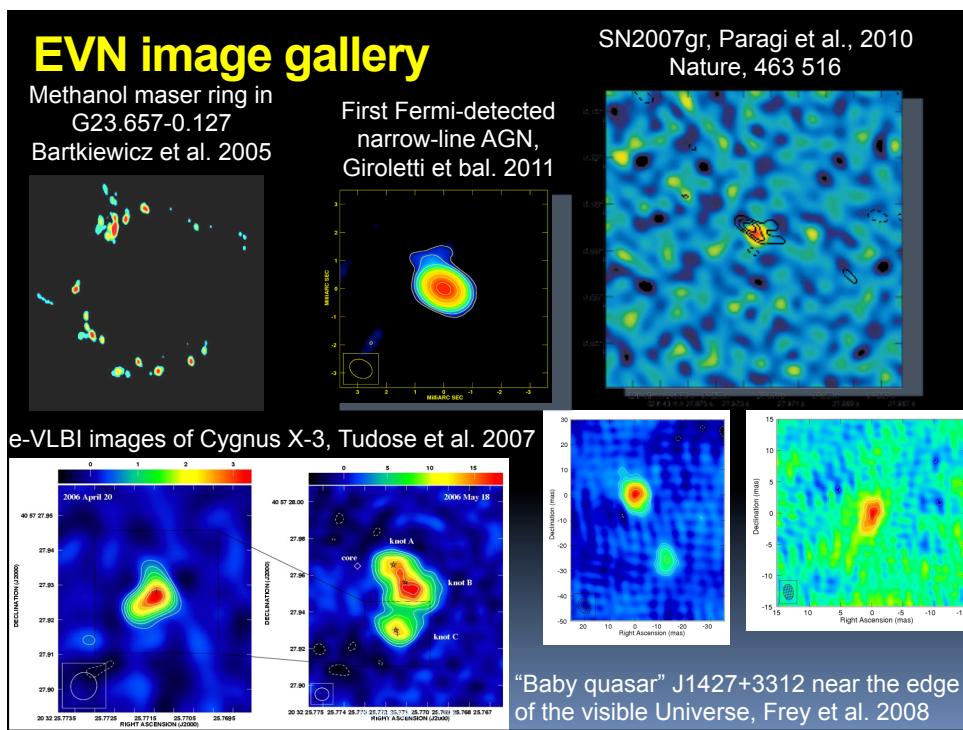
*Delft University of Technology,
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Joint Institute for VLBI in Europe

- Founded in 1993 as a central institute of the European VLBI (Very Long Baseline Interferometry) Network (EVN);
- EVN unifies 14 institutes in 12 countries;
- JIVE develops and operates the EVN Data Processor – a purpose-built digital facility (correlator), the world most advanced VLBI data processor;
- JIVE provides to the world-wide community of VLBI observers (“users”)
- JIVE staff conduct cutting edge research in astrophysics and space science

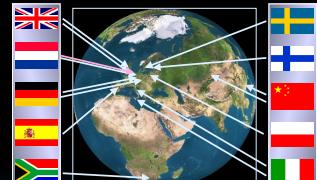
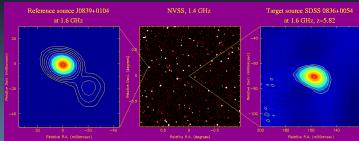
JIVE – member of NVR since 2009





JIVE: areas of expertise

- State-of-the-art data processing of (very large) data streams (~20 Gbit/s, multi Tbit/experiment)
- Operations and management of (globally) distributed networks of radio astronomy facilities
- Astrophysics and Space Science
- Management of (large) international collaborations (incl. EC FP 2-7 projects)

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JIVE: Space Science legacy

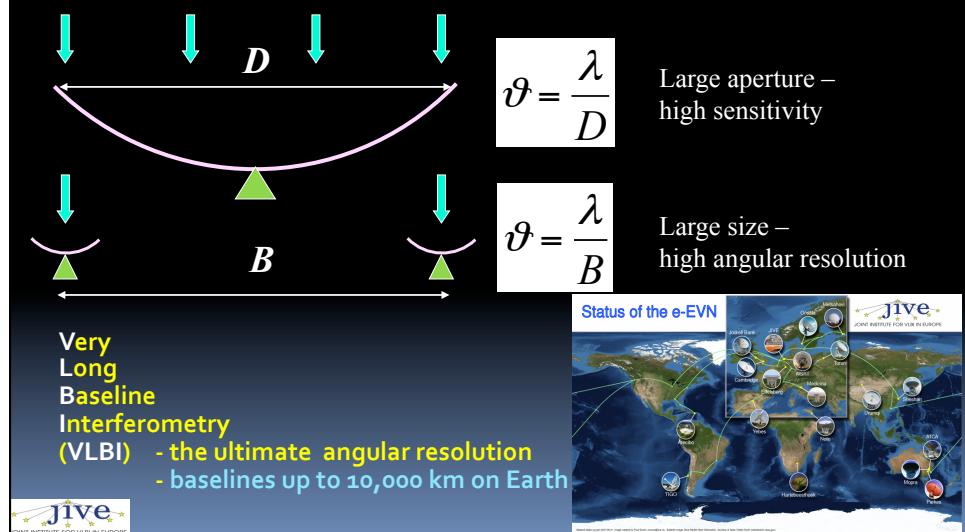
- Several Space VLBI design studies in 1990s
- Space VLBI missions VSOP (Japan, 1997-2004) and RadioAstron (2011-pt)
- VLBI tracking support to the ESA's Huygens probe 2005
- VLBI experiments with Venus Express, Mars Express, Gaia, JUICE, etc.



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Radio interferometry: a one-slide tutorial

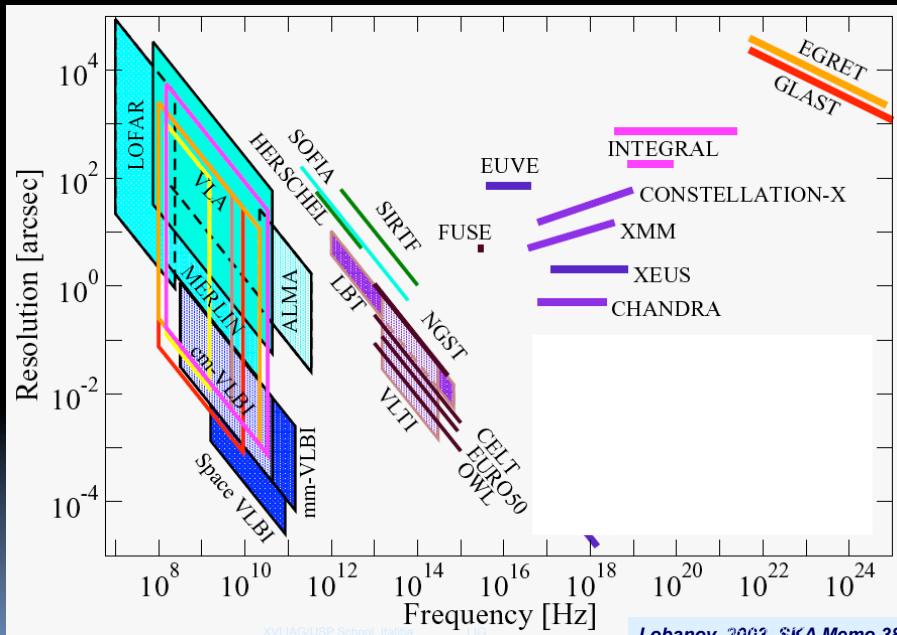
- Michelson & Young, 1890's: measurements of stars' diameters
- Synthesis of large apertures (*by poor and curious people*)

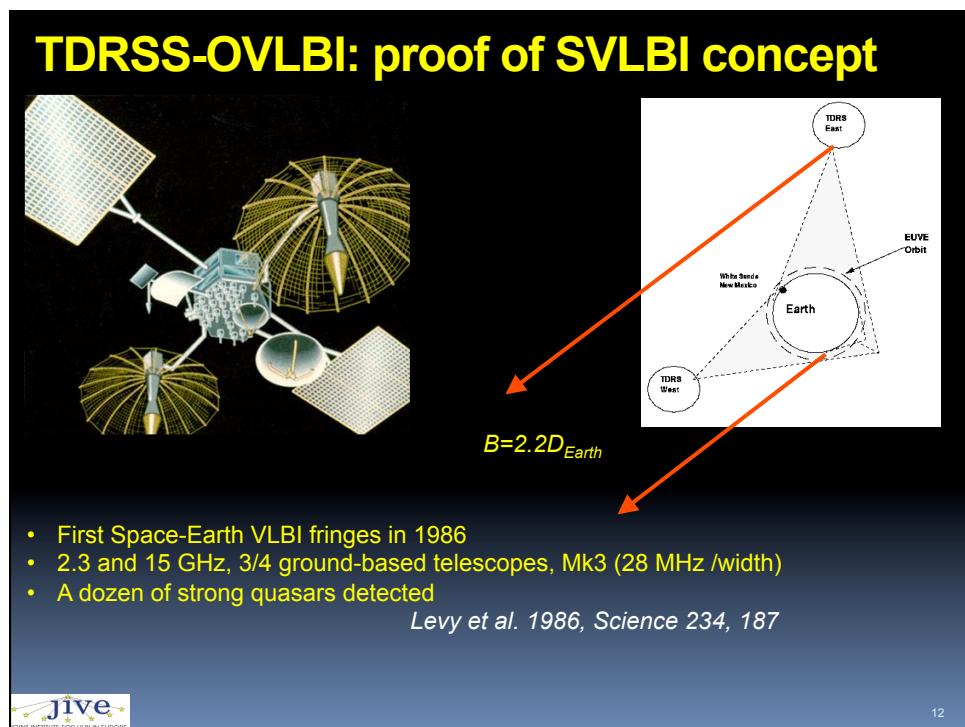
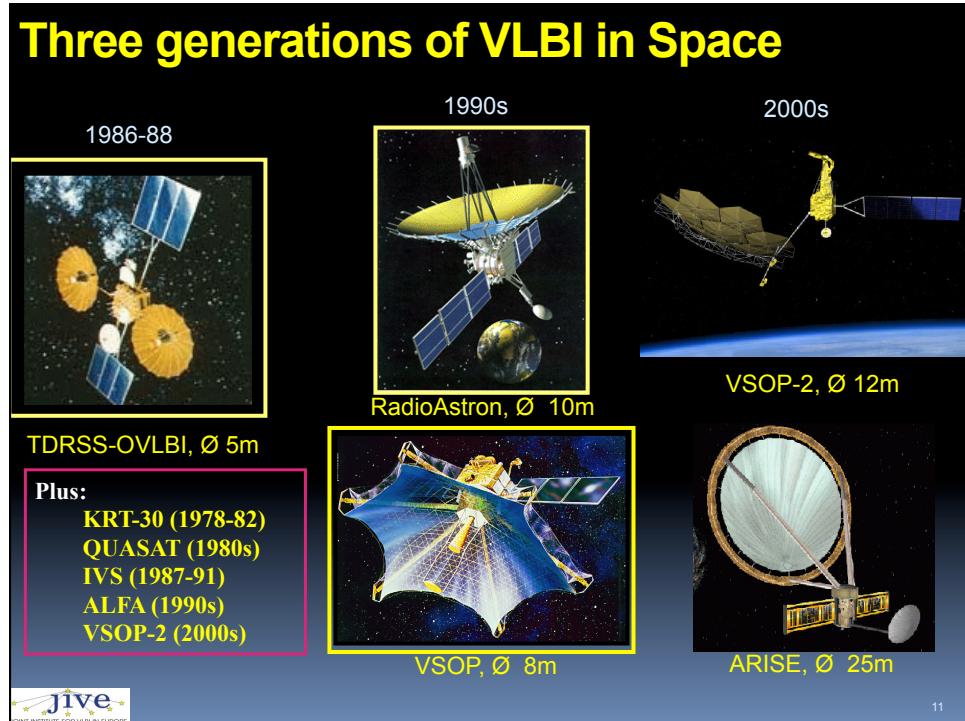


Why VLBI in Space?

- ... Because THERE ARE celestial radio sources out there THAT DO NEED a sharper radio view!
- ... and “we do this not because it is easy, but because it is hard...” (*J.F. Kennedy, announcing, no, not the first Space VLBI mission, but rather the US intention to put a man on the Moon, 1961*)

Best (imaging) angular resolution across EM spectrum





VSOP/HALCA antenna deployment test



VSOP/HALCA launch 12 February 1997



VLBI beyond the Earth diameter: VSOP mission
ISAS, Japan + world-wide collaboration (1997 – 2005)

Angular resolution:

$$\theta \approx \lambda/B$$

Ground-based VLBI: $\lambda = 6 \text{ cm}; B = 10000 \text{ km} \Rightarrow \theta \approx 1.5 \text{ mas}$

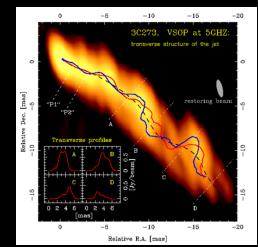
VSOP: $\lambda = 6 \text{ cm}; B = 30000 \text{ km} \Rightarrow \theta \approx 0.5 \text{ mas}$

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VSOP mission legacy

- High quality, high resolution images of several “famous” sources (*e.g. 3C273, Lobanov & Zensus, 2001*)
- Several surprisingly compact galactic OH masers (*Slysh et al. 1999*)
- Correlation between structural and other properties of flat-spectrum AGN (*Lister et al. 2001*)
- The highest lower limit of $T_B = 5.8 \times 10^{13} K$ (*Frey et al. 2000*)
- Statistics of sub-mas structures in AGN based on the VSOP Survey (*Horiuchi et al. 2004*)



Total of ~700 observations conducted

Link to results: <http://www.vsop.isas.ac.jp/>



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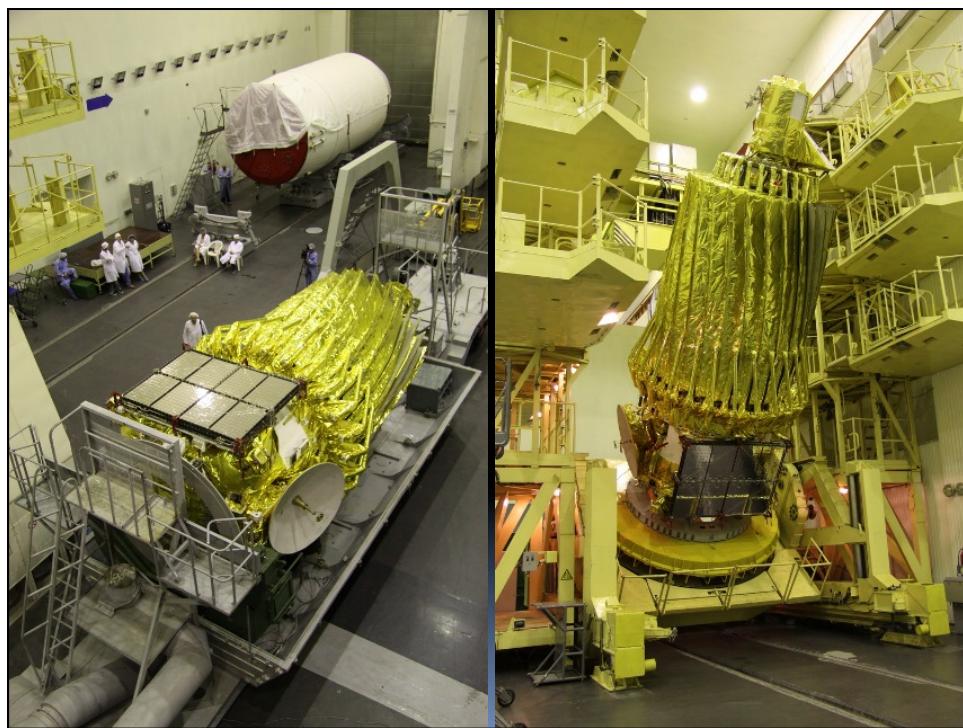
RadioAstron – Spektr-R

- 10-m antenna
- 0327, 1.6, 5 and 22 GHz
- Dual-polarization
- 128 Mbps (Ku-band)
- 2 on-board H-masers
- Apogee (initial) – 343,000 km
- Data reception – Pushchino Green Bank



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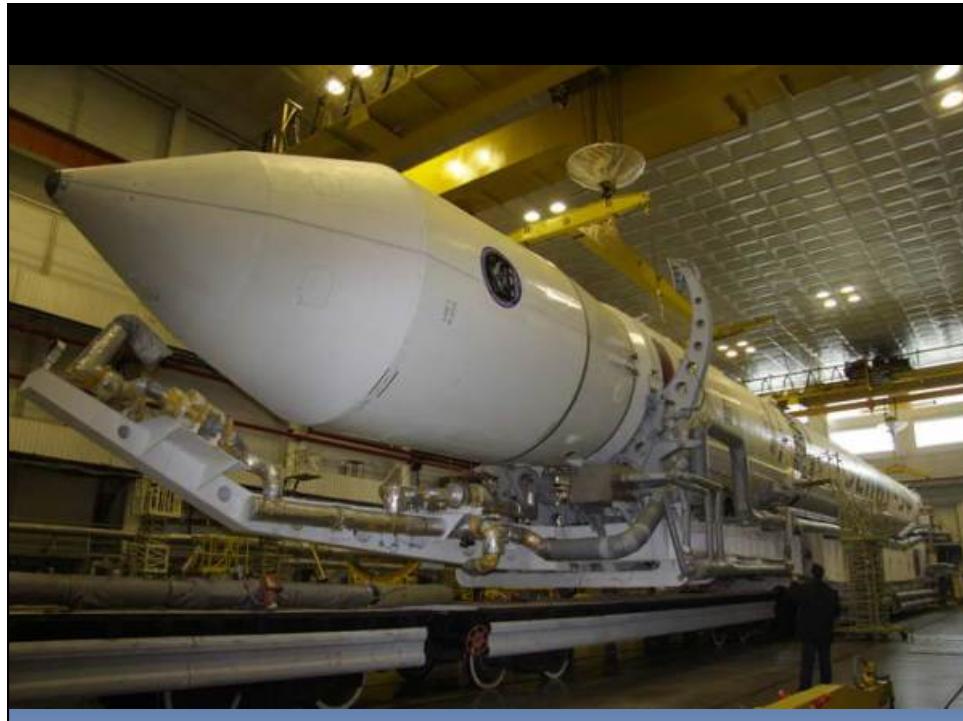
17/05/2014

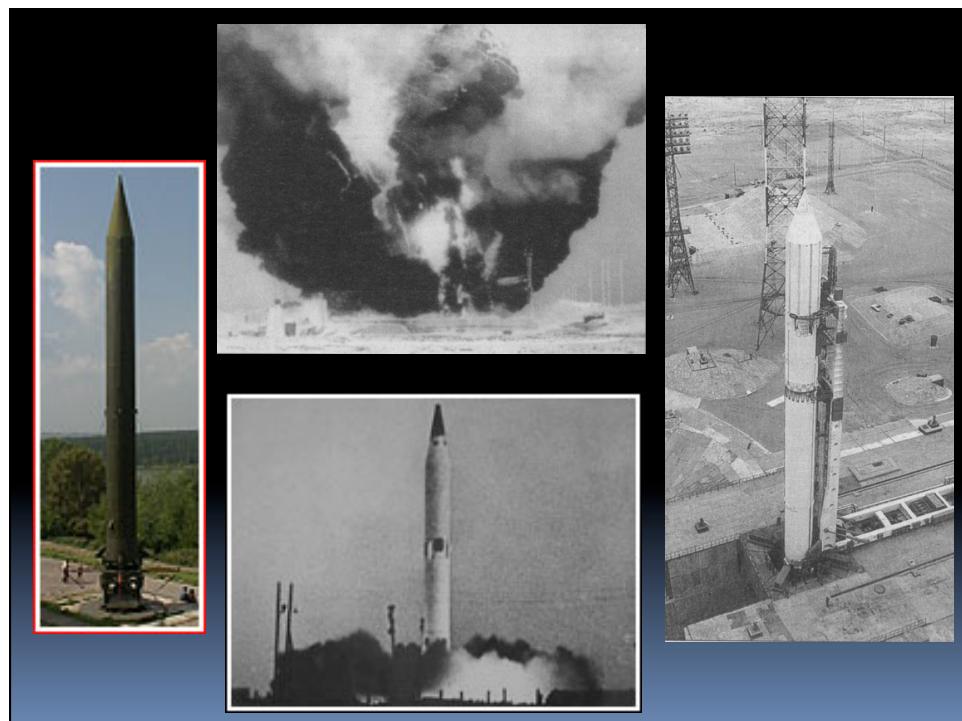
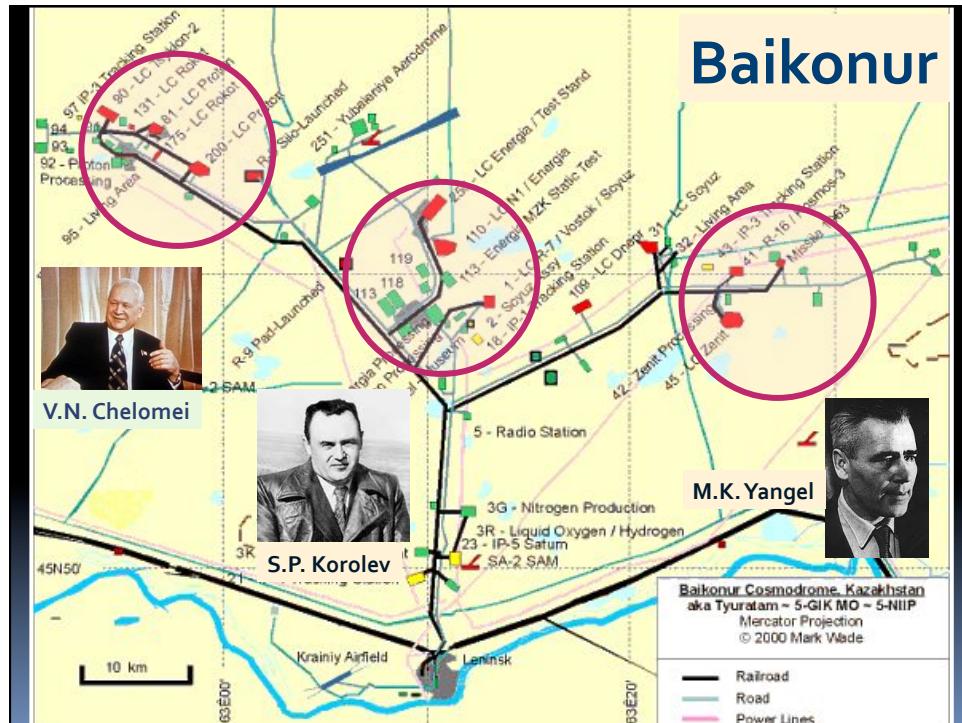




Baikonur, 24 June 2011







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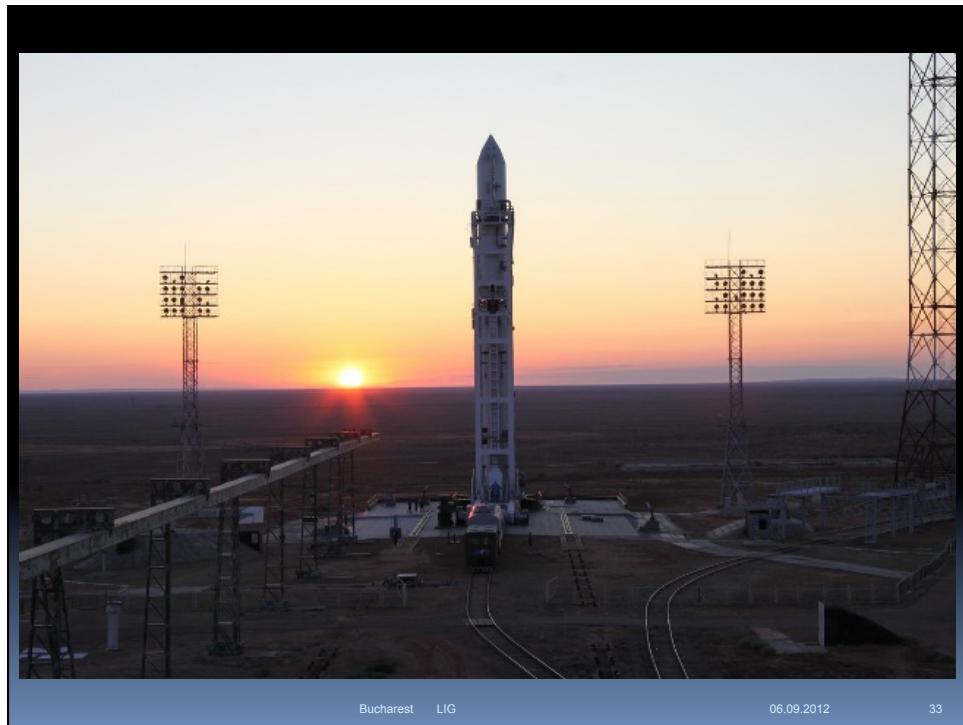
RadioAstron?



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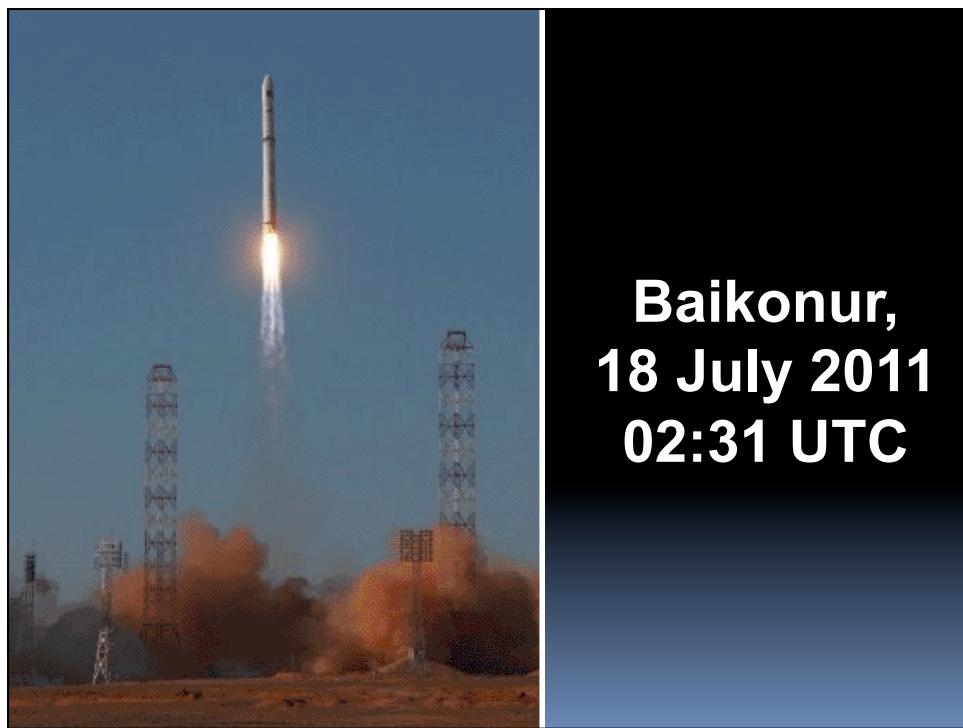
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Bucharest LIG

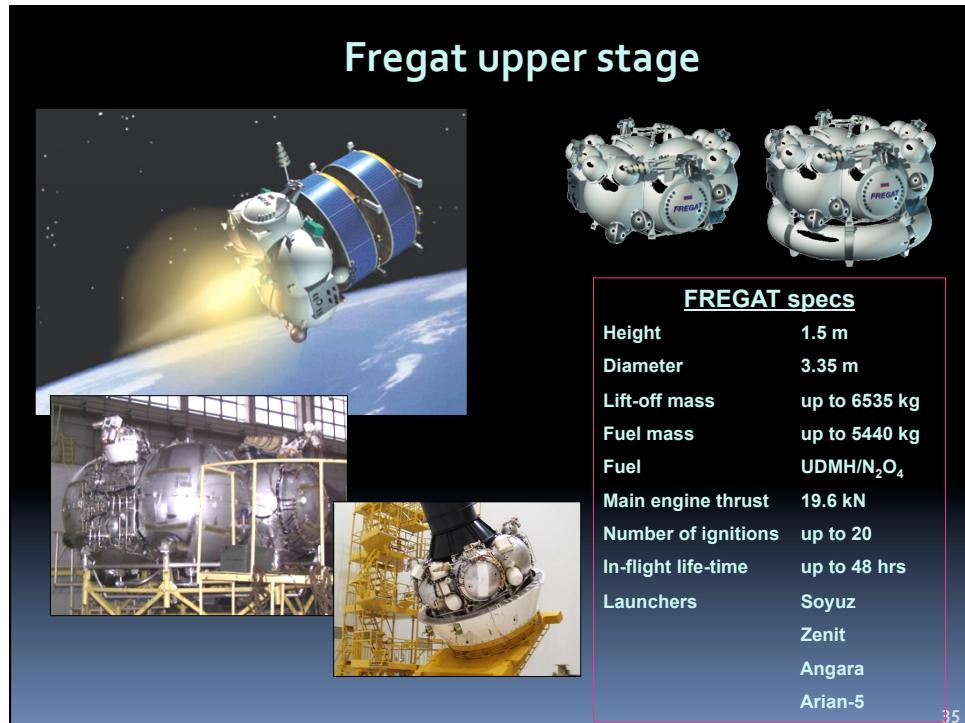
06.09.2012

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**Baikonur,
18 July 2011
02:31 UTC**

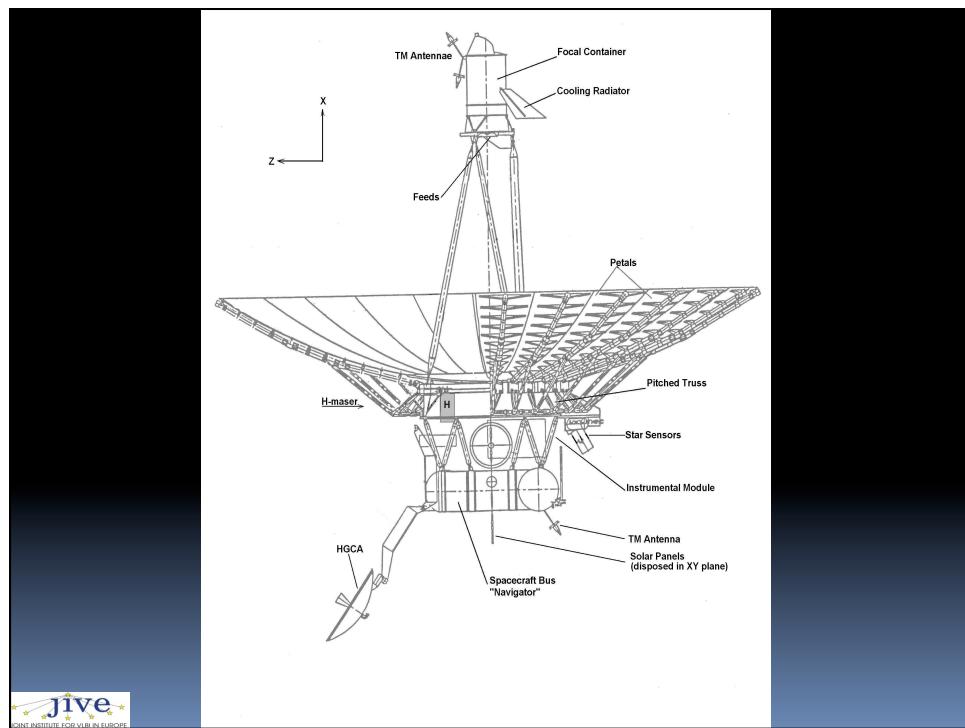
Fregat upper stage

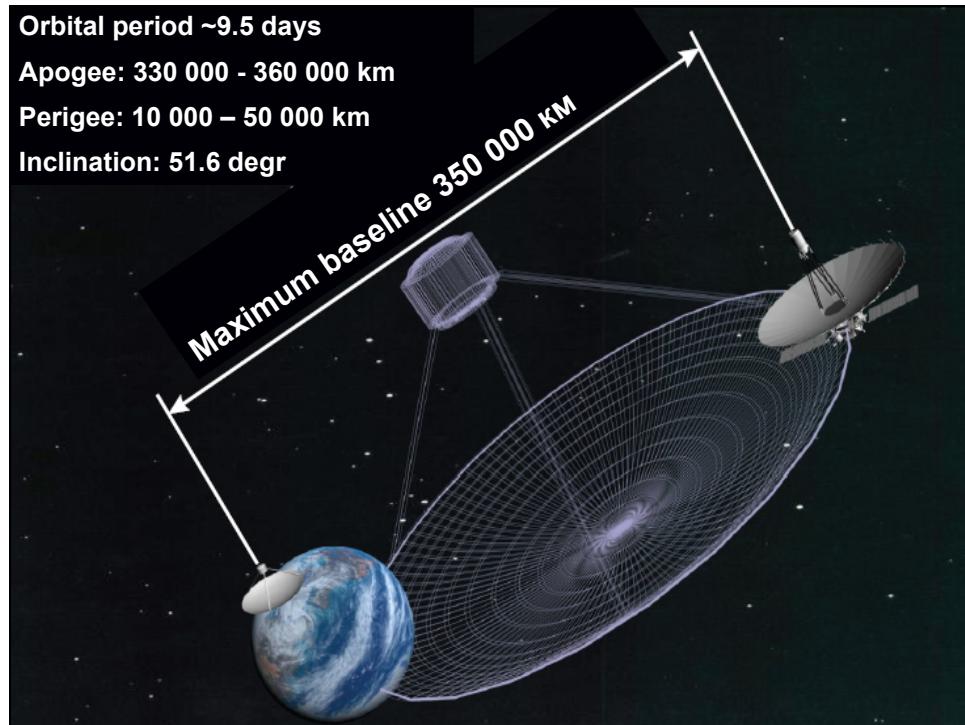


The slide features several images of the Fregat upper stage. At the top left is a photograph of the stage in space, showing its blue cylindrical body and white spherical upper section with a visible engine plume. To the right are two views of the stage's spherical upper section: one from the side and another from above, both with the word "FREGAT" printed on them. Below these are two smaller images: one showing the stage integrated into a larger rocket structure on a launch pad, and another showing it being prepared on a yellow mobile service tower.

FREGAT specs	
Height	1.5 m
Diameter	3.35 m
Lift-off mass	up to 6535 kg
Fuel mass	up to 5440 kg
Fuel	UDMH/N ₂ O ₄
Main engine thrust	19.6 kN
Number of ignitions	up to 20
In-flight life-time	up to 48 hrs
Launchers	Soyuz Zenit Angara Arian-5

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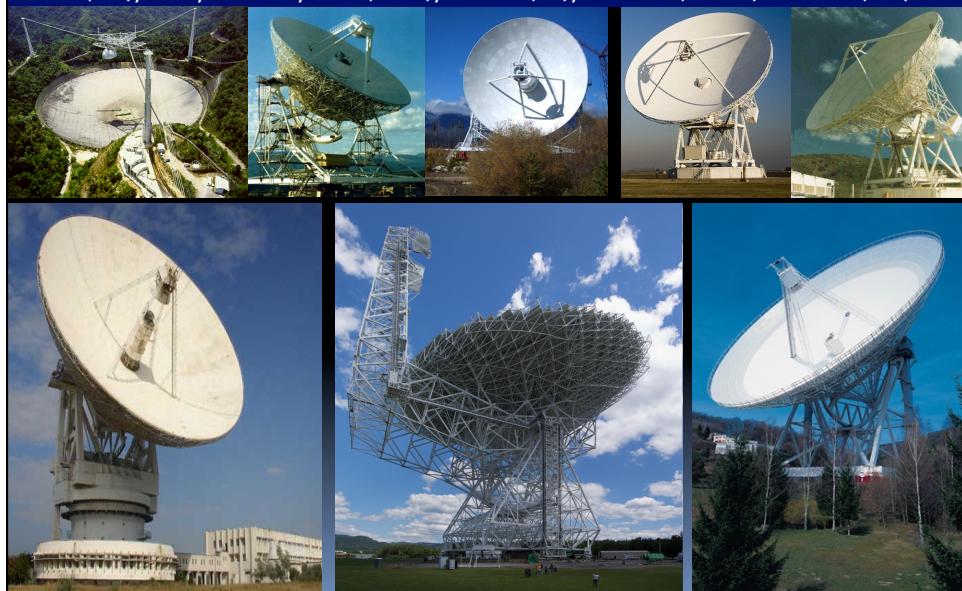


RadioAstron mission observing system

Spectral band [GHz]	P 0.320- 0.328 92	L 1.636- 1.692 18	C 4.804- 4.860 6.2	K 18.372- 25.132 1.19-1.63
IF bandwidth (dual-pol) [MHz]	2 x 4	2 x 32	2 x 32	2 x 32
Minimum fringe spacing on baseline 300 000 km [μas]	580	113	39	7.5 - 10
Total flux densit/ polarisation flux density sensitivity, 1σ [mJy] (GBT, 5 min total and 3 hrs polarisation)	33 / 7	3 / 0.7	5 / 0.7	13 / 1.7

Ground-based segment:

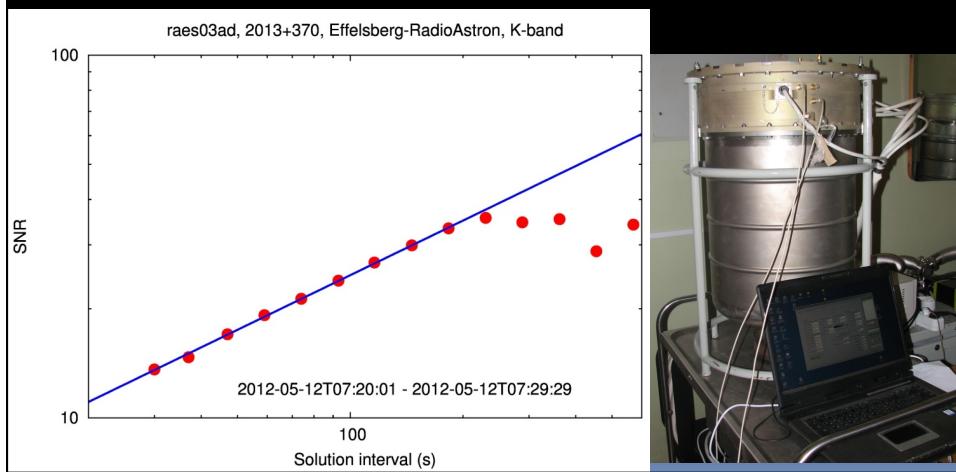
KVAZAR (Russia), Evpatoria (Ukraine), Effelsberg (DE), Medicina (IT), Yebes (ES), WSRT (NL), GBT, Arecibo, VLA (USA), Usuda (JP), Tianma (China). Parkes (AU) etc.

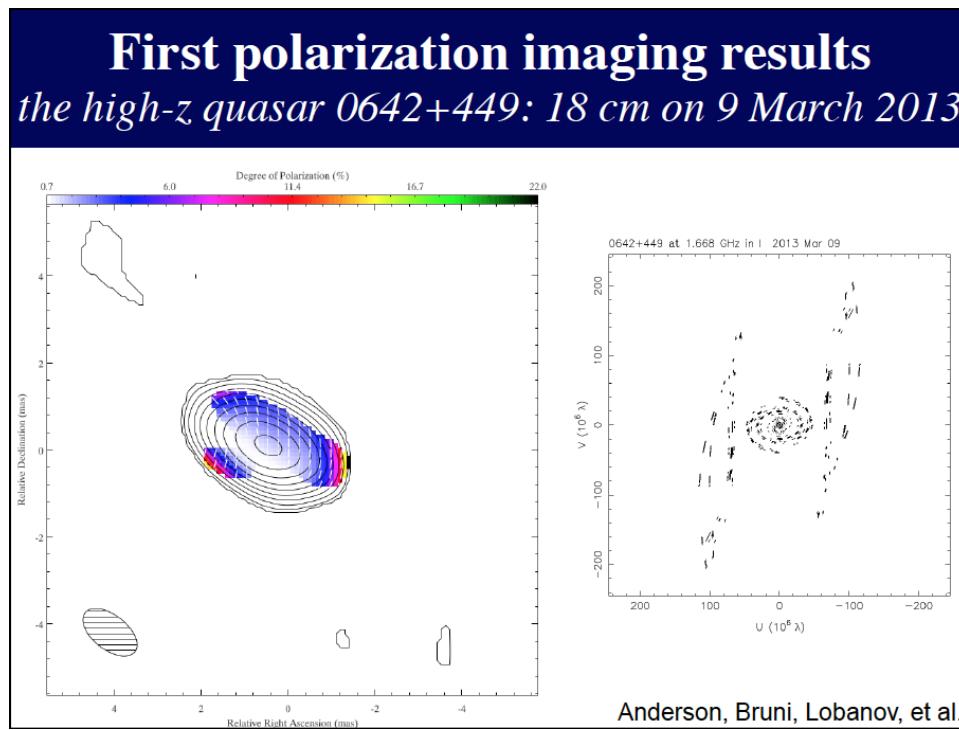
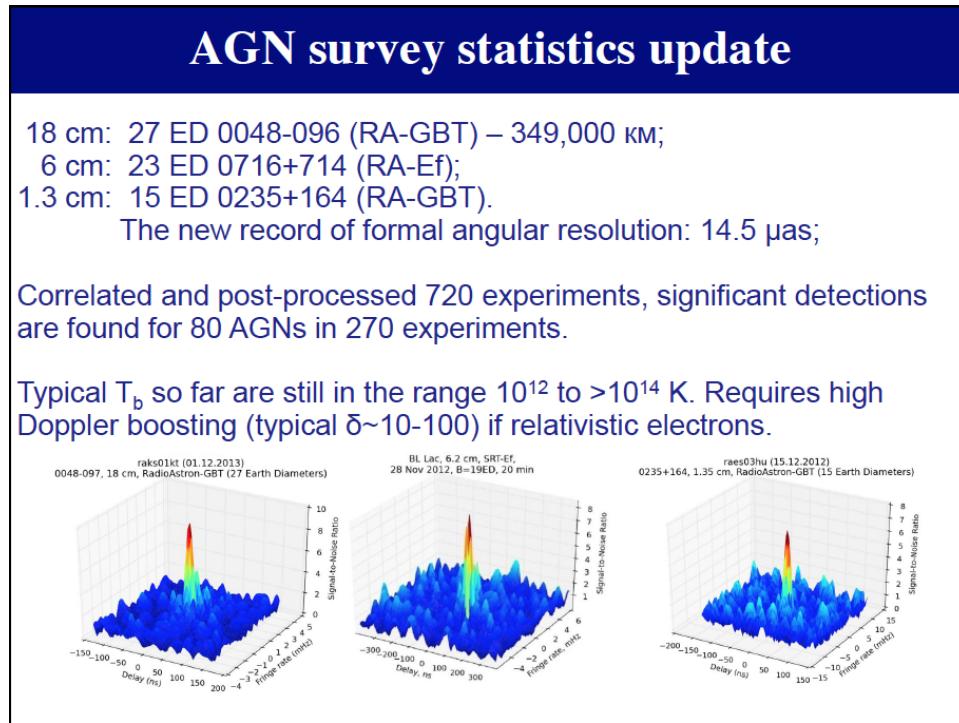


Российский бортовой активный водородный стандарт успешно работает на орбите уже > 2.5 лет!

1. Реализовано более длительное, чем на Земле, накопление сигнала.
2. Когерентное использование всей доступной полосы.
3. Корреляция 1 бит против 2 бит.

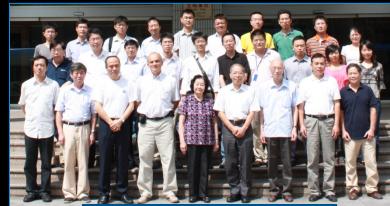
Результирующий выигрыш чувствительности интерферометра: 2 раза.



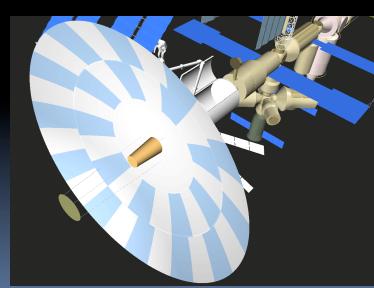
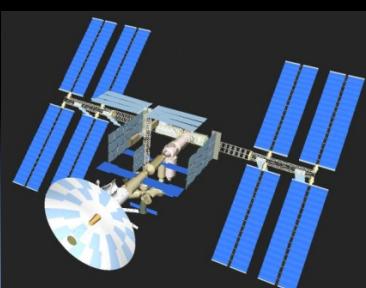


SVLBI beyond RadioAstron

- New Space VLBI initiatives
 - Chinese SVLBI project under consideration
 - New "old" ideas in Europe (wrt the ISS beyond 2020)

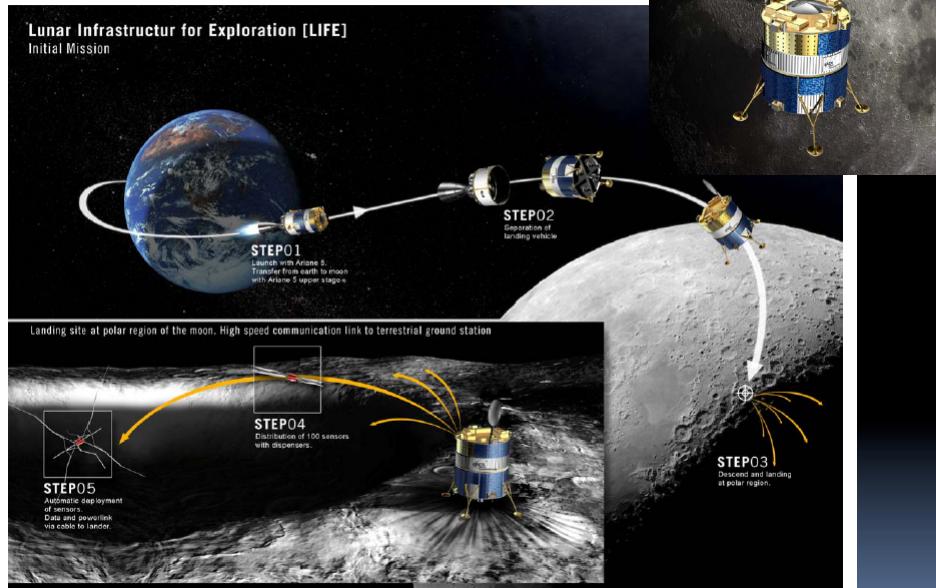


Shanghai, 2011.09.13

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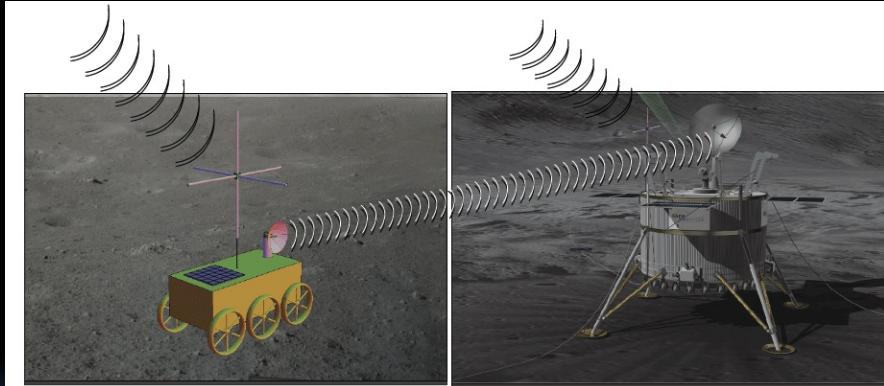
Lunar Infrastructure for Exploration (LIFE)



08.01.2013

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LRX – Basic Design



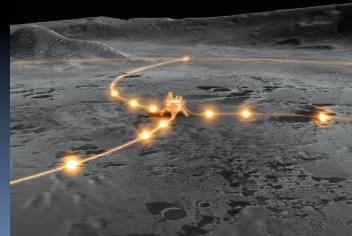
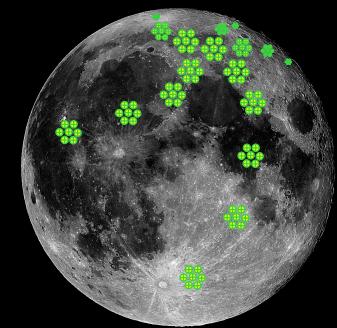
One Module: Mass ~2 kg, Power 7.5 W, Data rate: 1 Mbit/s (M:M) 2 kb/s (M:E)
(Some of these numbers are scalable with observing bandwidth)

H. Falcke

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Lunar LOFAR: distributed array of radio sensors

- First prototype phase:
 - Antennas, power, computer, communication, dispatcher
 - Weight ~ 1t (payload)
 - Needs one Ariane V launch
- Start with ~100 tripoles
- Collecting area:
 - $A_{\text{eff}} \sim 0.125 \text{ km}^2$ @ 3MHz
(17 football fields ~400 m dish)
- Separation $D = 1 \text{ km}$
 - Resolution ~1.6° (10 MHz)
- Expand with additional mission(s)
- Importance of a demonstrator – modeling underway (PhD project)



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