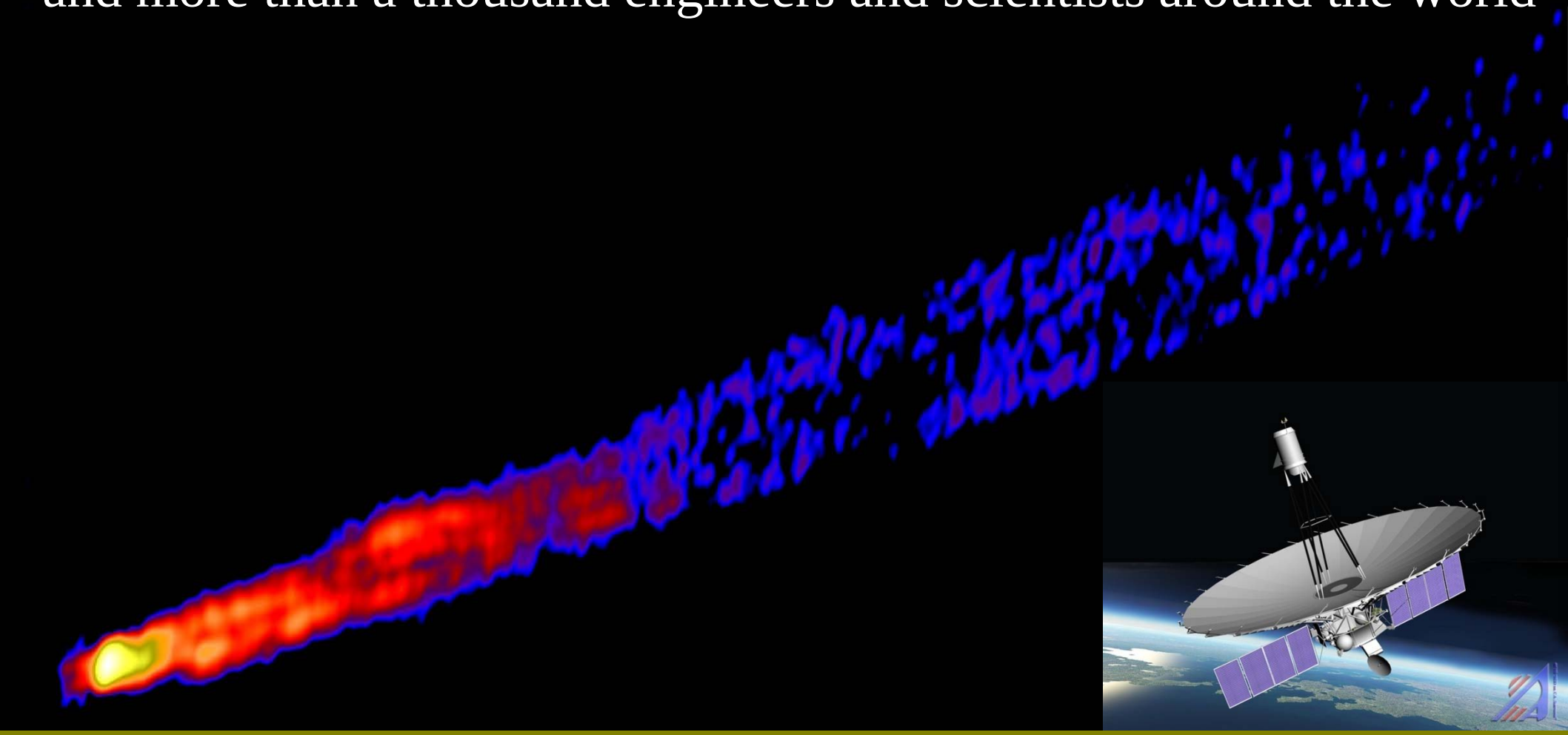
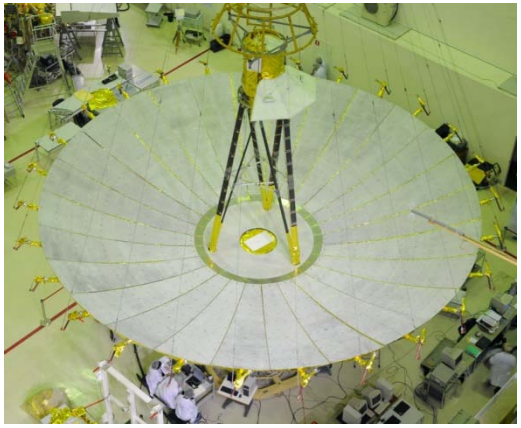
RadioAstron early AGN results

Yuri Kovalev
Astro Space Center of Lebedev Physical Institute, Moscow
and more than a thousand engineers and scientists around the world



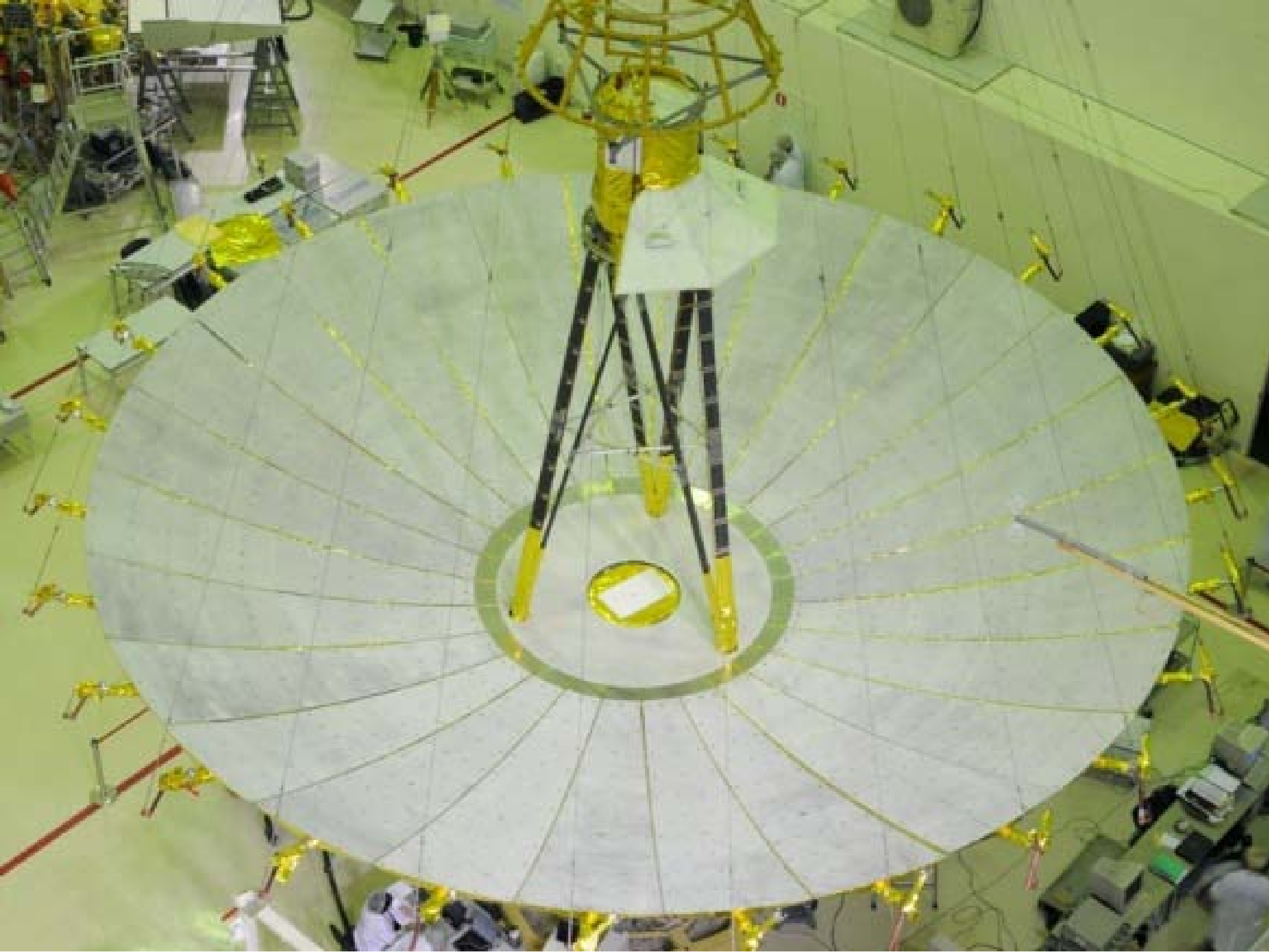
After 30 years: Spektr-R is in Space



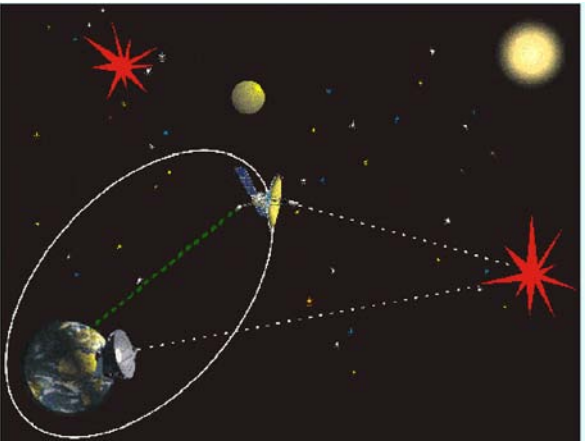
Assembled together:
SRT+Bus (early 2011)

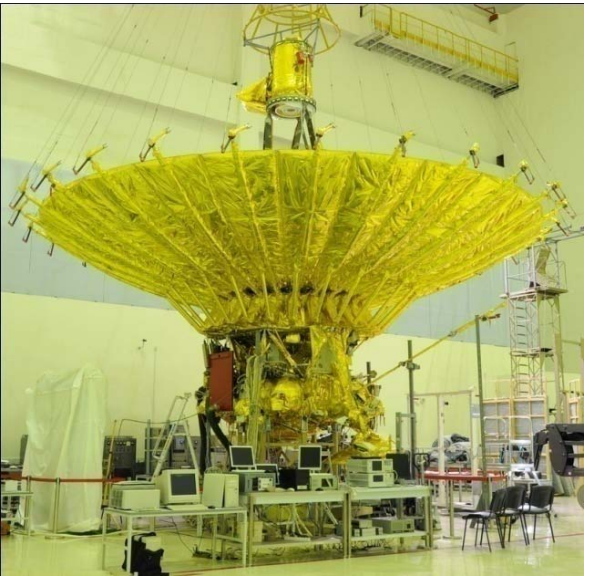
Tested
and packed

Launched on July 18, 2011
unfurled on July 23, 2011



RadioAstron: general information



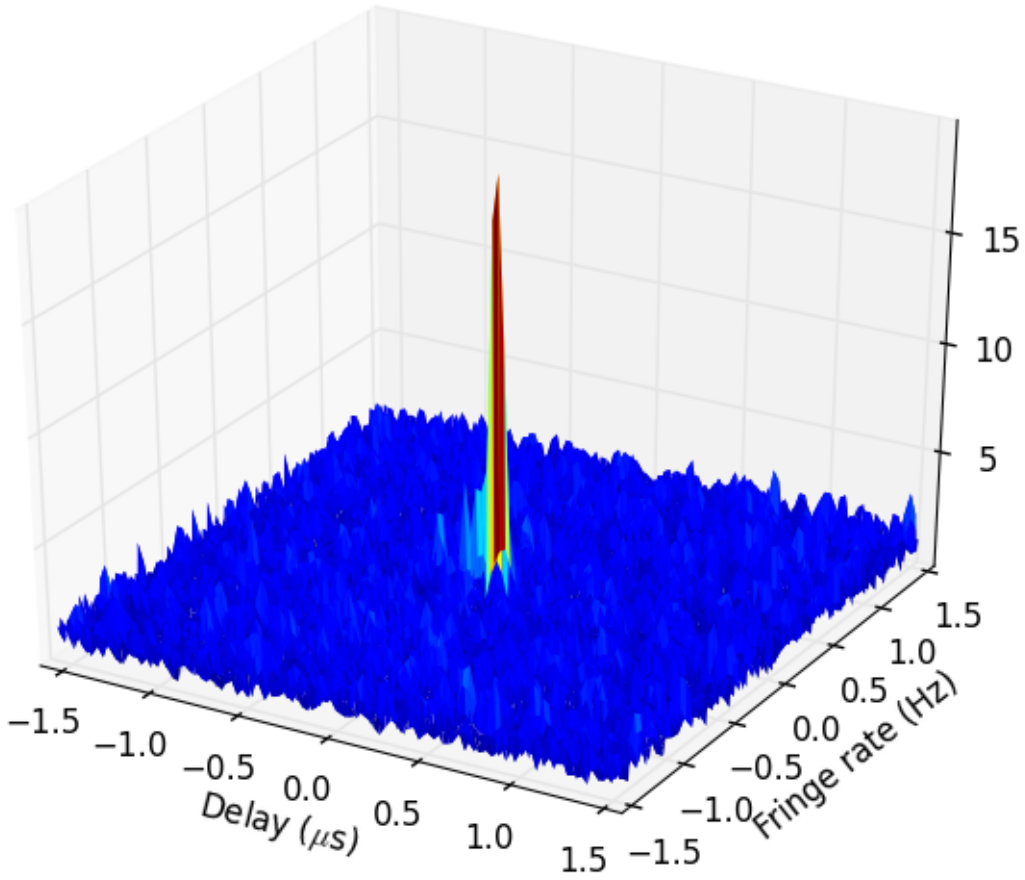


- ✓ Space radio telescope: 10 meters diameter
- ✓ Frequency bands: 0.3, 1.6, 5, 22 (18-25) GHz
- ✓ Highest resolution (at 1.3 cm): ~7 μas.
- ✓ Orbit: gravitationally perturbed by Moon, perigee ≥ 10,000 km, apogee ~300,000 km, ~9 days period
- ✓ Five methods of orbit measurements including Doppler measurements, laser ranging, VLBI.
- ✓ Required accuracy of the orbit reconstructon: distance 500 m, velocity 2 cm/s.
- ✓ Expected lifetime: 5 years (general estimate)
- ✓ Control stations: Ussurijsk, Bear Lakes.
- ✓ Tracking station: Pushchino, Russia; USA (43-m in Green Bank) and South Africa ─ expected.
- ✓ Bitrate: 128 Mbps coming from space.
- ✓ Two methods of time synchronization: on-board and ground hydrogen maser.
- ✓ Software correlators: ASC, DiFX-Bonn, JIVE SFXC.

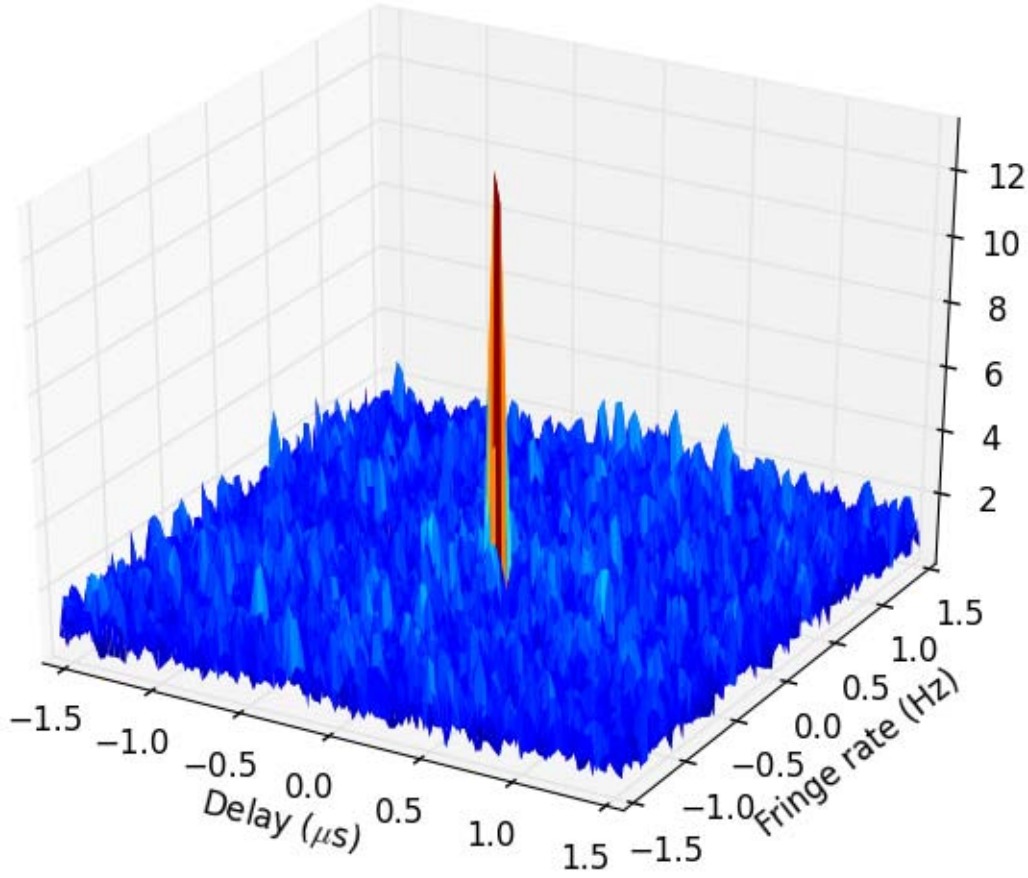
K-band: lucky ending of a long story

Quasar 2013+370, 0.25 ED, 1 min integration time

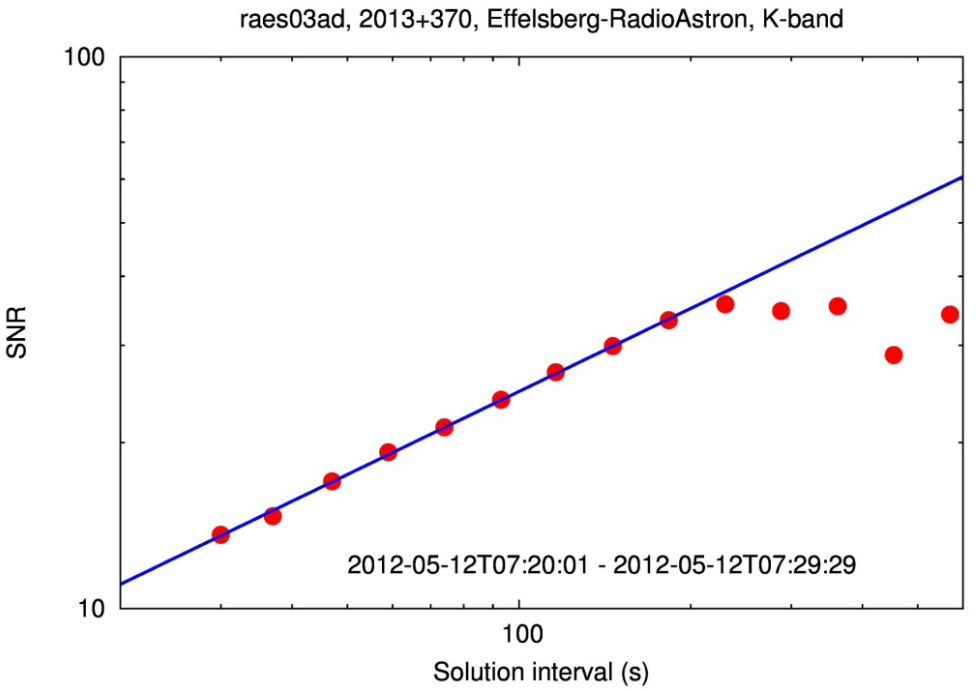
C-band: SRT-WSRT



K-band: SRT-Eff

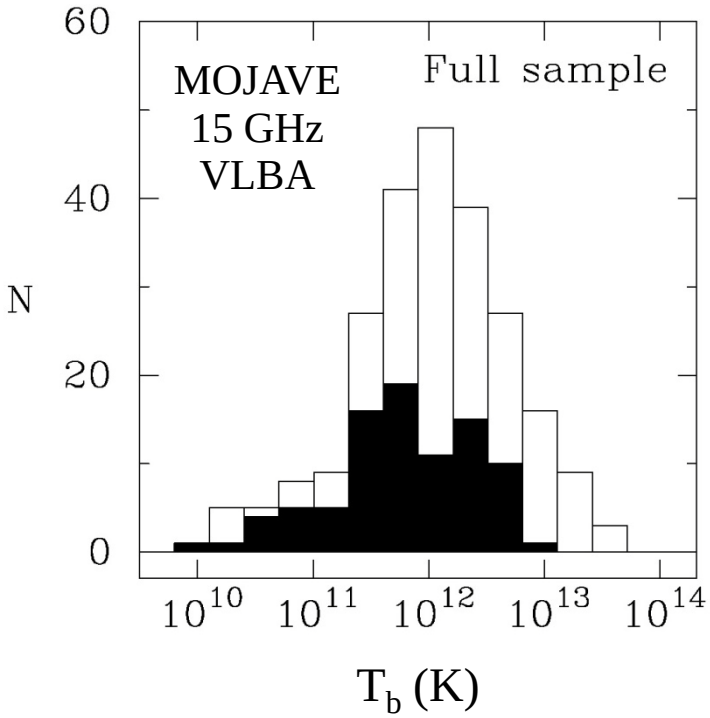


The hydrogen maser was turned on and reports to work properly for already >1.5 years



RadioAstron AGN survey early science

SVLBI core size, brightness temperature, beaming, ISM



Ground-based VLBI, 2 cm:
Median $T_b = 10^{12}$ K, maxTb (limit) $=5 \cdot 10^{13}$ K.
VSOP 6 cm results are similar.

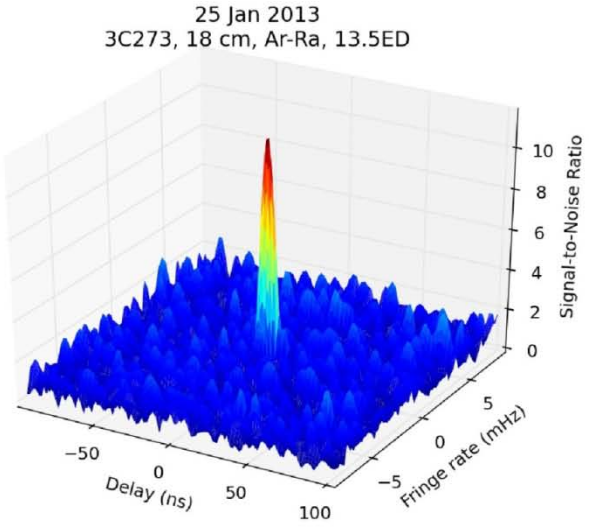
The inverse-Compton limit is confirmed if Doppler boosting is involved. And we know from VLBI kinematics measurements (Lorentz factors up to 50 are estimated) that jet emission it is indeed boosted.
But! Many lower limits on T_b…

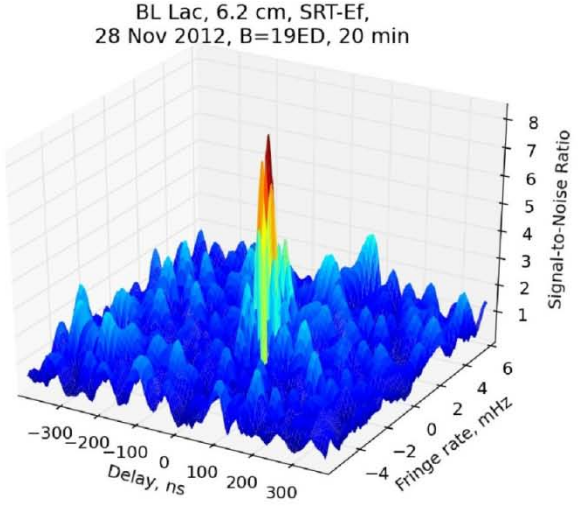
RadioAstron AGN fringe survey: estimate correlated flux density, size, brightness temperature of most compact structure(s) in the AGN jet base. Test the IC limit boosted by Doppler. Overcome the Earth-based Tb limit. This can not be done by going to higher frequencies on the ground. Critical to test emission mechanism. Introduce or "kill" exotic models (coherent processes, proton synchrotron radiation, etc.).

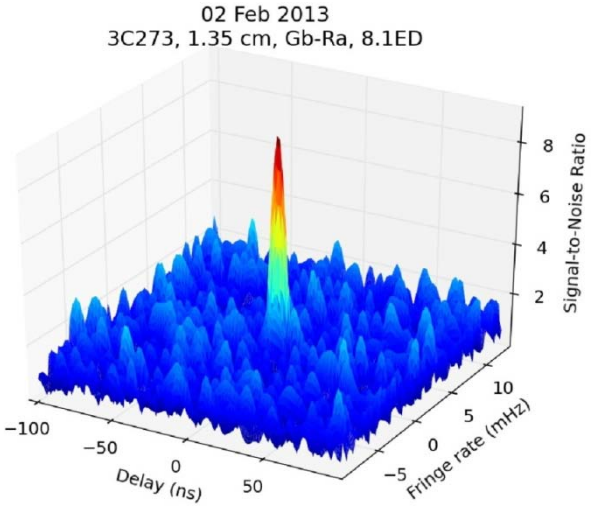
Is there anything beyond 5-10 Earth diameters (ED)?

RadioAstron AGN survey: current status

18 cm: 16.4 ED 0529+483 (RA-GBT), 14 ED 3C273 (RA-Ar); *and 92 cm*
6 cm: 19 ED BL Lac (RA-Ef) and 19 ED 0529+483 (RA-Ef);
1.3 cm: 8.1 ED, 3C273 (RA-GBT and RA-VLA).
Record breaking (formal) resolution: 27 μas.

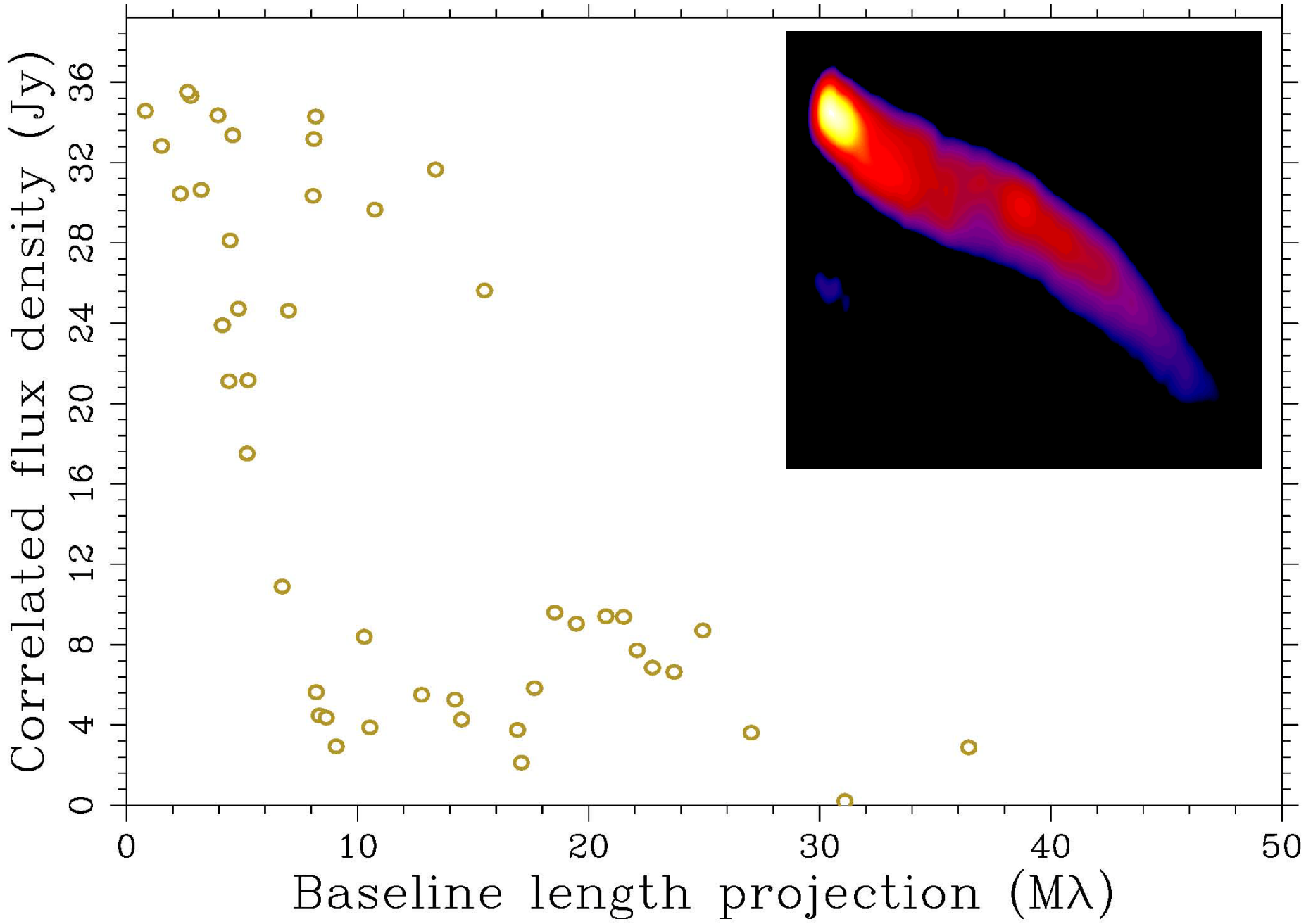






✓ Several dozen observed, many detected at long baselines. Routine fringes with all GRTs involved.
✓ Brightest AGN cores: 0529+483, 0716+714, 3C273, 3C279, 3C345, BL Lac, etc.
✓ Typical T_b so far in the range 10^{12} to $>10^{14}$ K. Requires high Doppler boosting (typical δ~10-100) if relativistic electrons.
✓ ISM does not “kill” compact emission at 6 and even 18 cm.

3C273: ground-based 18 cm VLBI



“Correlated” fast variations of 0716+714 in radio and optical band

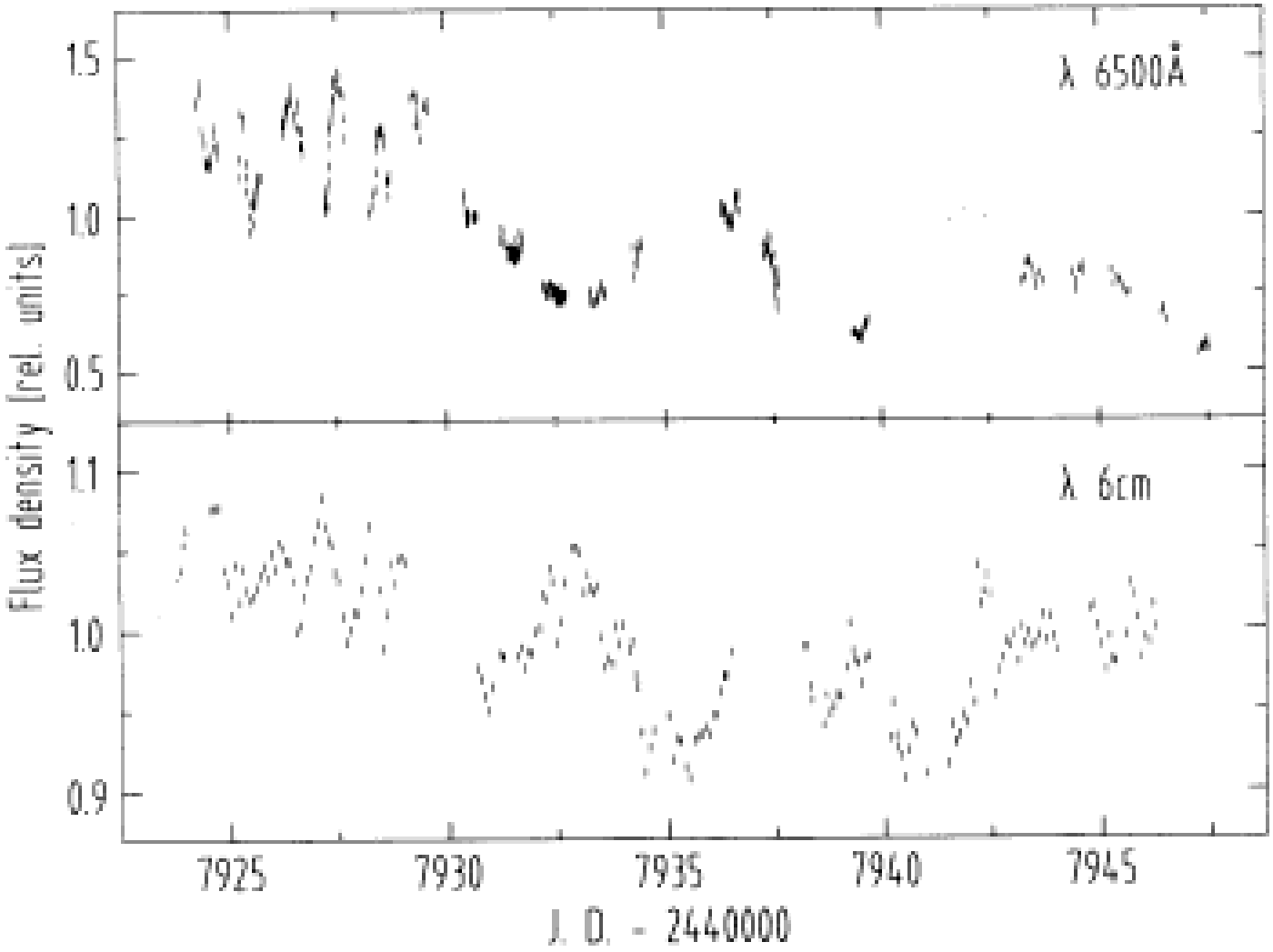


FIG. 1.—Optical (*top*) and radio (*bottom*) light curves of the BL Lacertae object 0716 + 714 (linear scales). In both light curves the mean flux density was set to 1, and fractional deviations from the mean are plotted on the *y*-axis.

Quirrenbach et al. (1991)

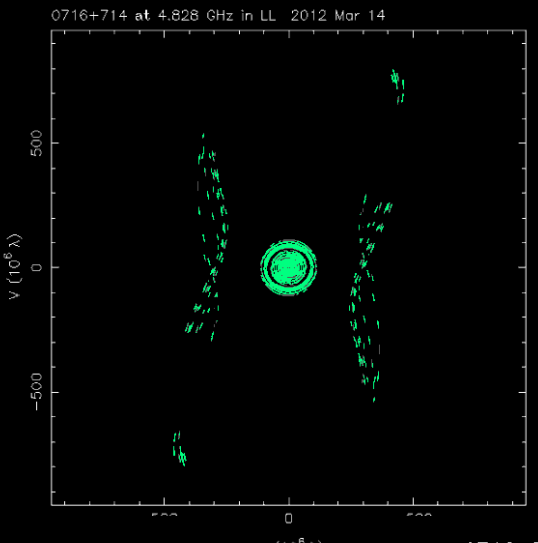
Apparent VLBI kinematics:
μ = 10-30 *c.*

Intrinsic or external mechanism of fast variations?

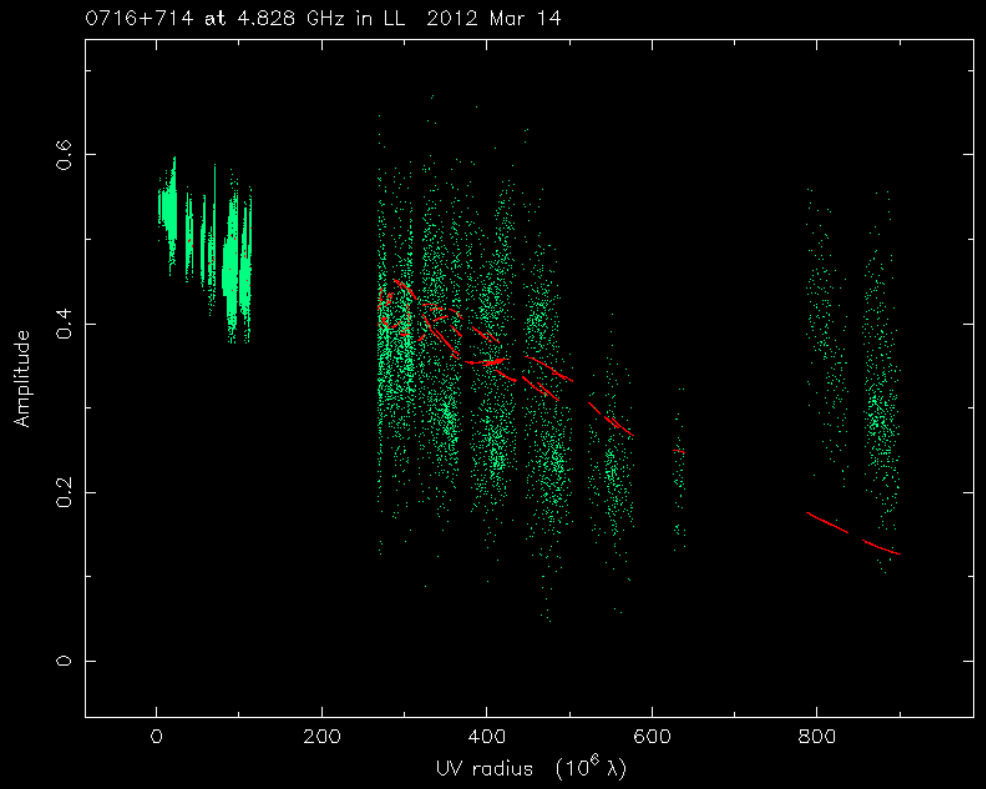
Famous IDV target 0716+714: 6 cm RadioAstron-EVN imaging

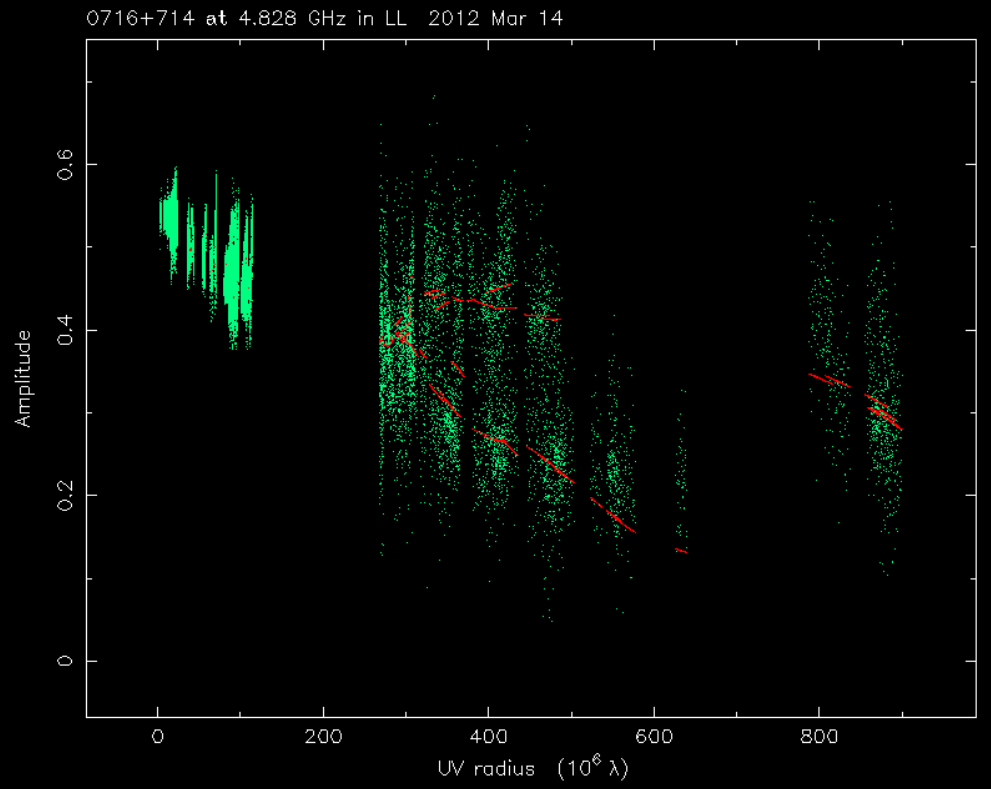
uv-coverage with SRT, Ef, Jb1, Wb, Ys, Mc, Sv, Zc, Bd, Sh, Ur

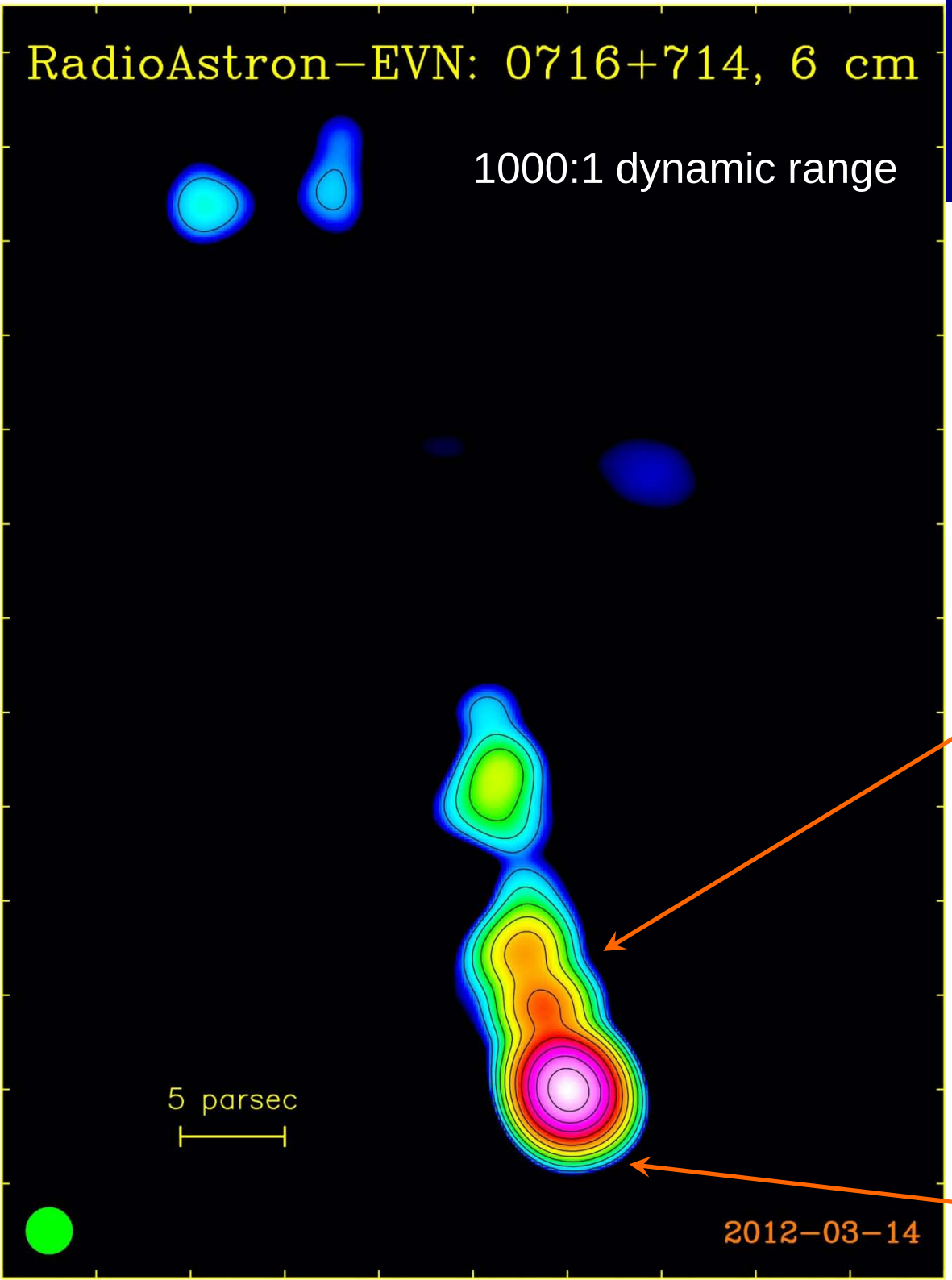
supported by VLBI PRIDE measurements of the space craft state vector



Detected up to 7 Earth diameters.
Processed at both correlators (ASC and Bonn). Results agree well.
A priori calibration in AIPS.
Hybrid imaging in difmap.





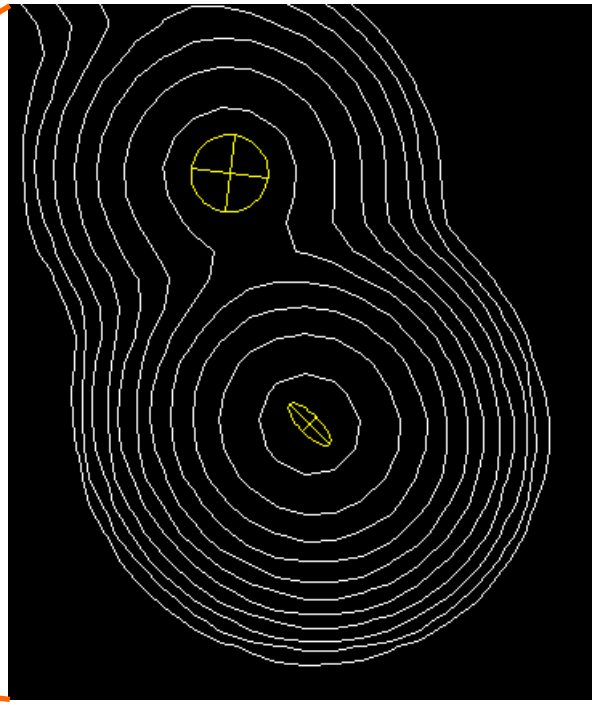


First imaging of an AGN:
0716+714, z = 0.3

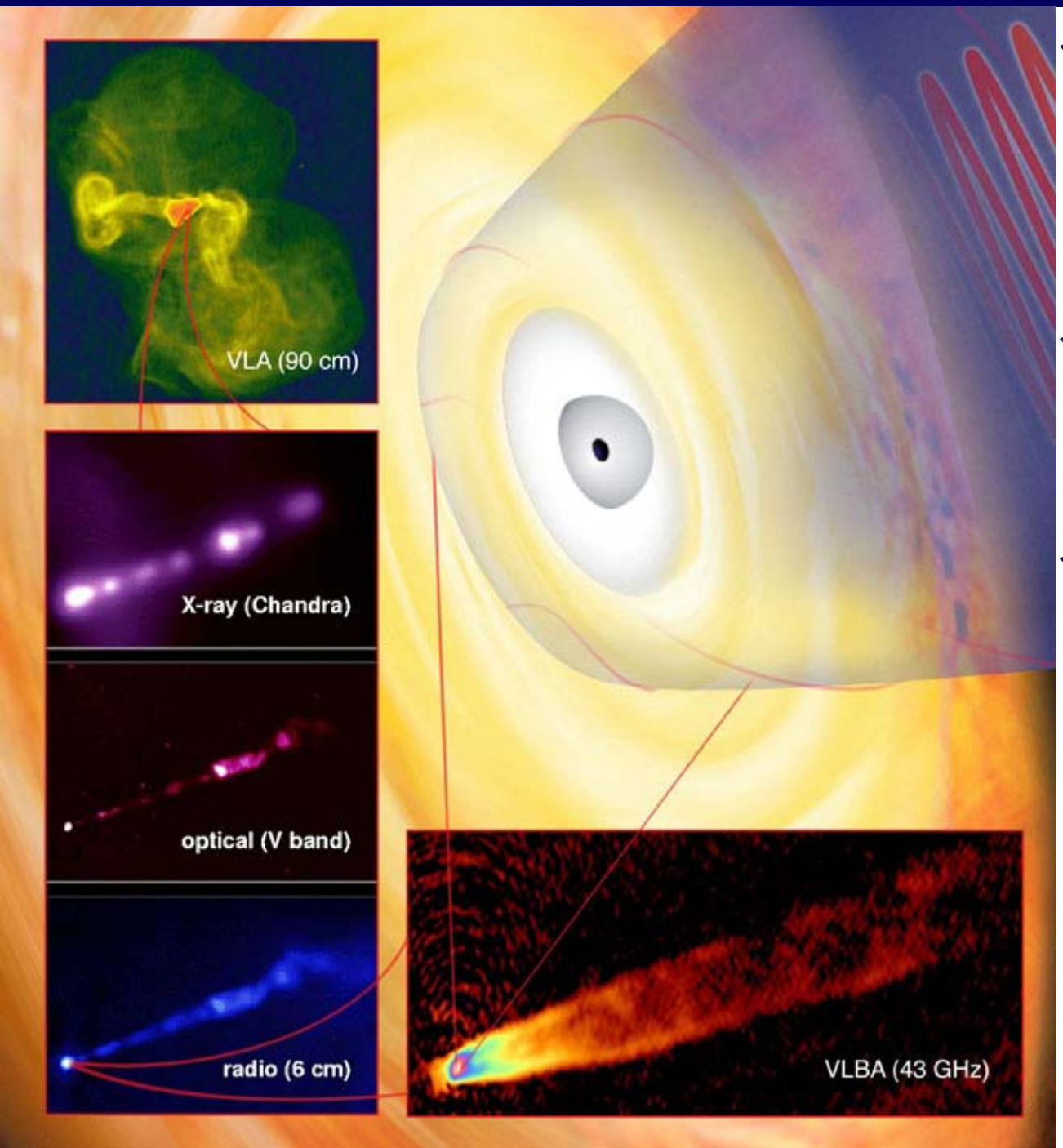
Apparent jet base width:
0.3 parsec (70 μas).

Brightness temperature:
$3 \cdot 10^{12}$ K *(but low activity state).*

In high activity state Tb increases by more than one order of magnitude.



To come soon: under correlation and/or analysis



- ✓ First RadioAstron SVLBI AGN K-band imaging
- ✓ First L-band polarization imaging
- ✓ M87 6 cm and 1.3 cm observations between 3 and 17 Earth diameters with Ar, GBT, VLA, Ef, Ys, Ev, etc.

RadioAstron Key Science Program

Open call for proposals: AO-1 (July 2013 – June 2014)

http://www.asc.rssi.ru/radioastron/ao-1/ao1.html

A transition to the open sky phase is ongoing. The ASC has announced an open call for key science program (KSP) proposals.

- ✓ Letters of Intent were submitted by 17 October 2012.
  31 received, over-subscription 4.5.

- ✓ KSP consortia organization workshop hosted by MPIfR-Bonn in December 2012, 50 participants (max).

- ✓ Full KSP proposals submitted by 8 February 2013.
  13 proposals from 200 Co-Is, 19 countries, over-subscription ~2.
  Reviewed by the RadioAstron Program Evaluation Committee.

Seven Key Science Programs selected.
Science areas covered by the accepted KSPs include active galactic nuclei (the dominating component of the KSP: survey and imaging including polarization), masers, pulsars, interstellar medium, transients.

Open Key Science program: AO-1

July 2013 – June 2014, proposals evaluation results

Rank A – excellent:

✓ Space VLBI Survey of AGN at the Highest Angular Resolutions, PI: Yuri Kovalev (ASC Lebedev, Russia)

✓ Studies of Pulsars with RadioAstron, PI: Carl Gwinn (UCSB, USA)

✓**Rank B – very good:**

✓ The nuclear structure in nearby AGN at 3-500 Schwarzschild radii resolution, PI: Tuomas Savolainen (MPIfR, Germany)

✓ Probing the innermost regions of AGN jets and their magnetic fields, PI: James Anderson (MPIfR, Germany)

✓**Rank C – good:**

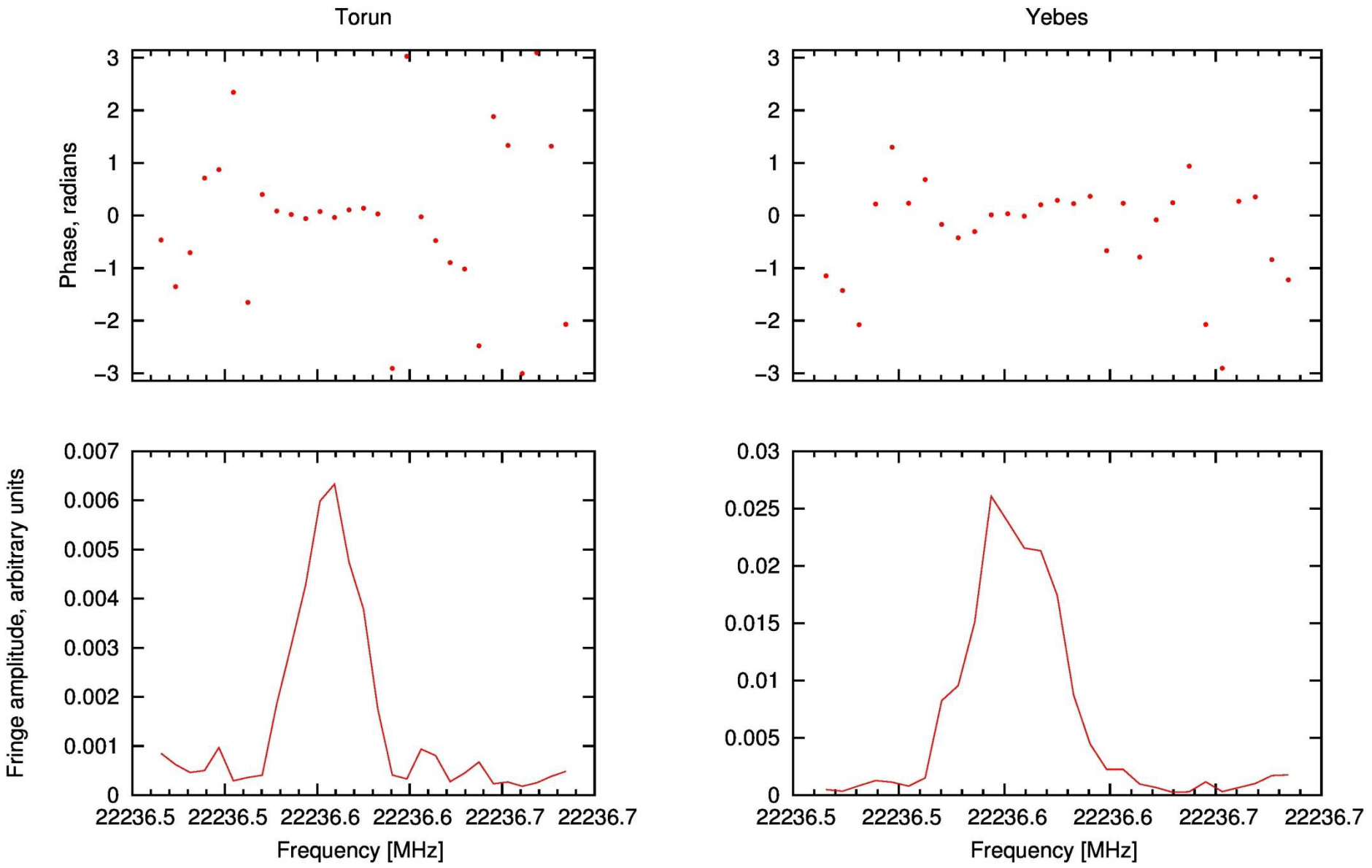
✓ Structure and physics of compact jets in AGN", PI: Manel Perucho (U. Valencia, Spain)

✓ Space-VLBI observations of radio-transients", code RA-AO1-09, PI: Kirill Sokolovsky (ASC Lebedev and SAI MSU, Russia).

✓ Study of the water and hydroxyl maser properties with ultimate angular resolution", PI: Andrey Sobolev (Ural Federal U., Russia)

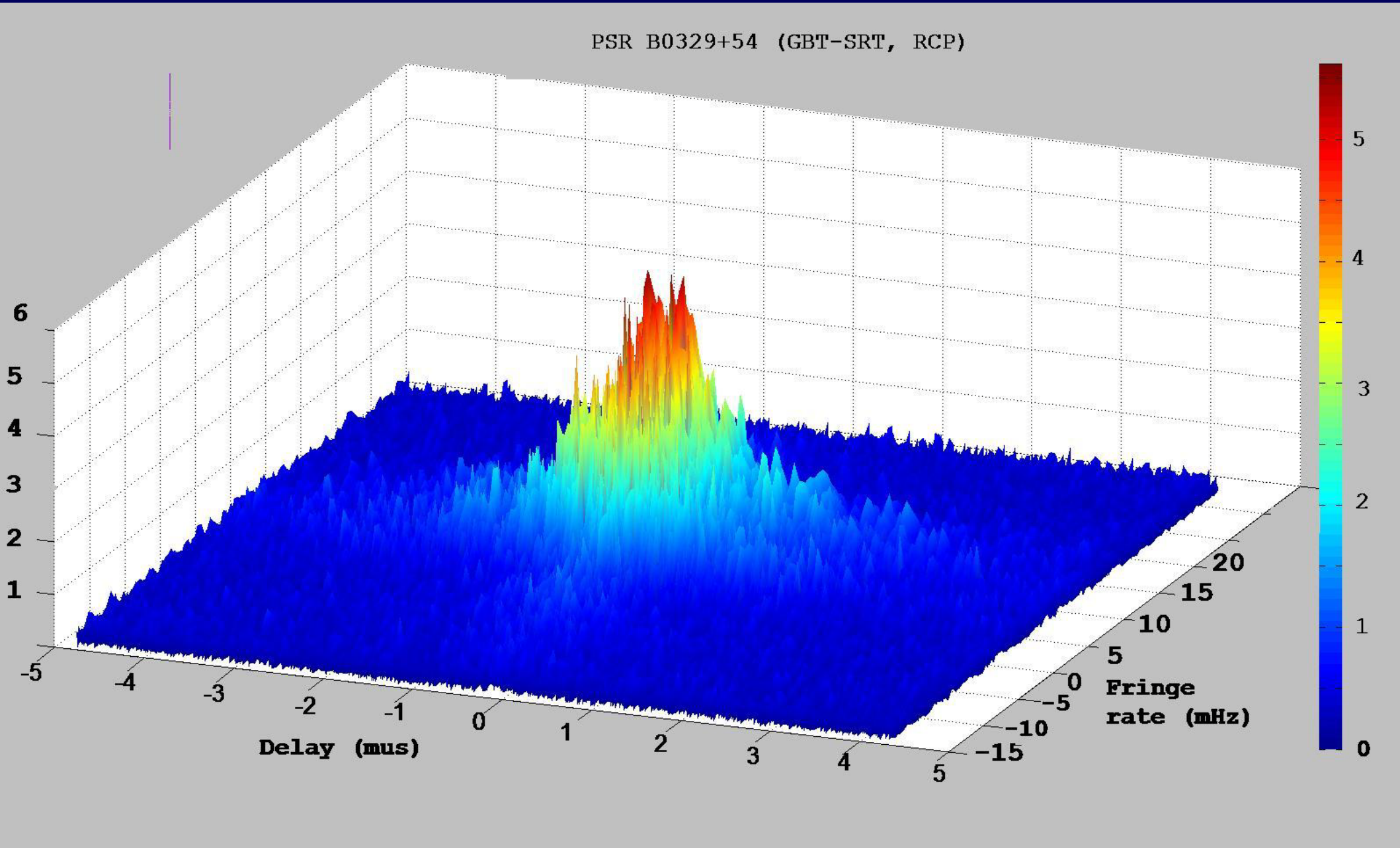
and great support by ground radio telescopes.

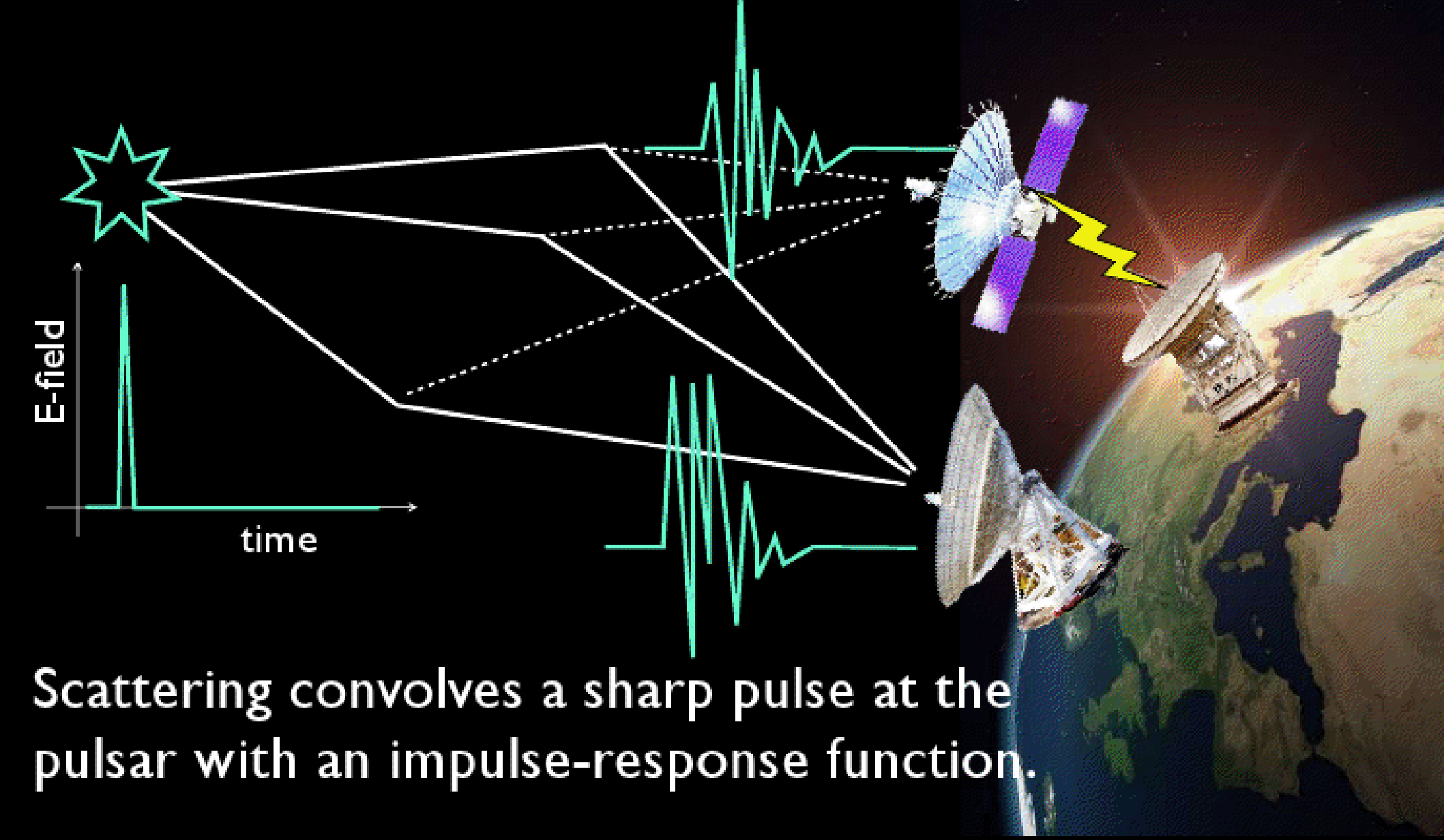
W3 IRS5: water maser, 5.4 Earth diameters Torun and Yebes !



Pulsar B0329+54: completely unexpected

SRT - GBT; 92 cm; baseline 100,000-200,000 km





Scattering convolves a sharp pulse at the pulsar with an impulse-response function.

This impulse-response function reflects reinforcement or cancellation of radiation from along different paths. Relative path lengths change with observer position.