# RadioAstron

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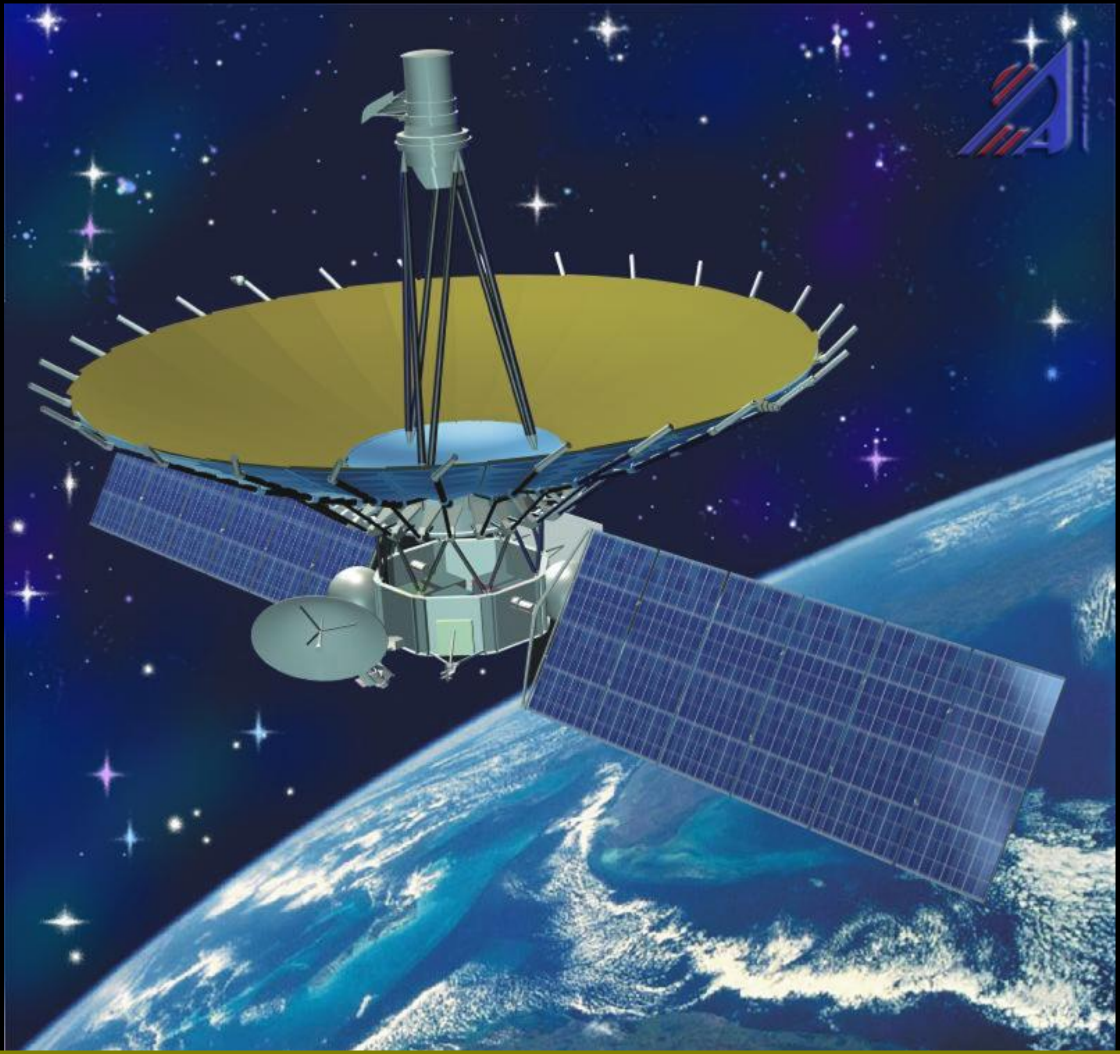
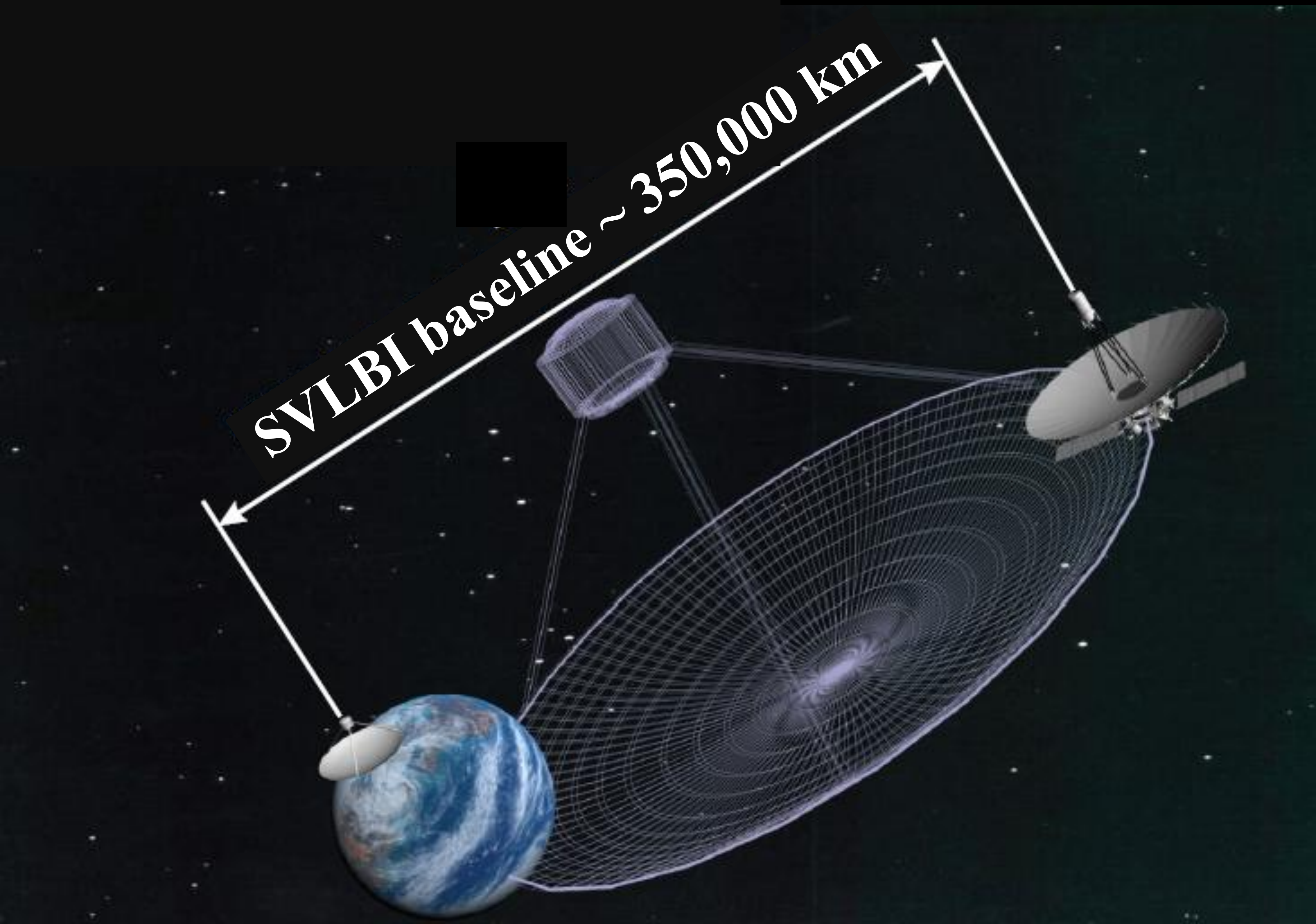
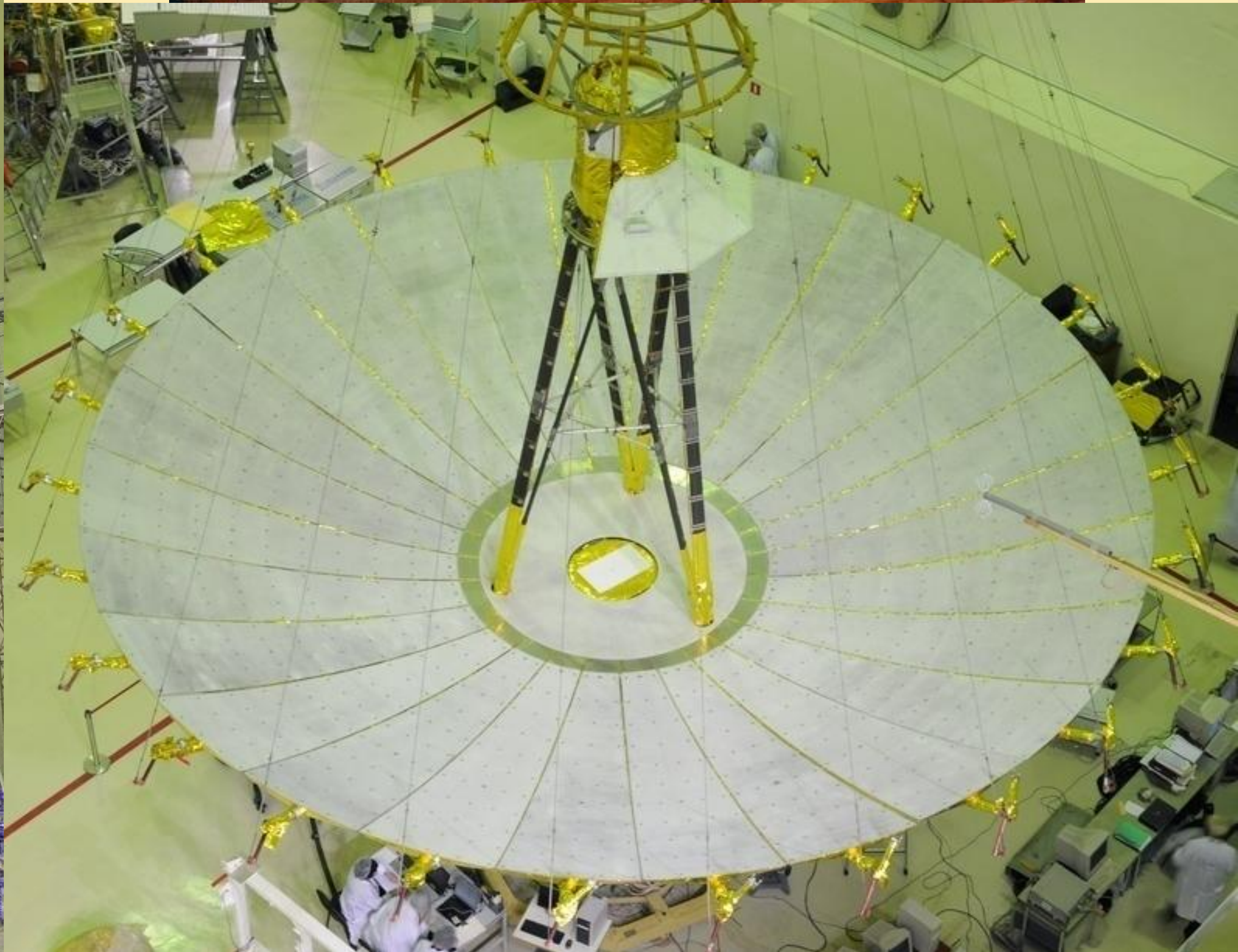


# The Biggest Radio Telescope:



# Launch in 2011



# General information and current status

- ✓ Space radio telescope: 10-m; launched in 2011.
- ✓ Frequency bands: 0.3, 1.6, 5, 22 (18-25) GHz.
- ✓ Apogee ~350,000 km.
- ✓ Tracking station: Pushchino, Russia; Green Bank, USA. Bit rate: 128 Mbps coming from space.
- ✓ Two methods of time synchronization: on-board (open loop at 8 and 15 GHz) and ground (closed loop at 7, 8, and15 GHz) hydrogen maser.
- ✓ Software correlators: ASC, DiFX-Bonn, JIVE SFXC.
- ✓ GRTs: up to 40 around the world.
- ✓ Open assess since 2013.
- ✓ Main science areas: quasars and nearby AGNs, pulsars, masers, scattering, gravitational redshift.

- ✓ Extended by Roscosmos until the end of 2019.
- ✓ Recent orbit correction has happened successfully.
- ✓ Onboard hydrogen maser has provided required stability on the level of $10^{-14}$ s/s for six years. Currently switching to the closed loop mode.

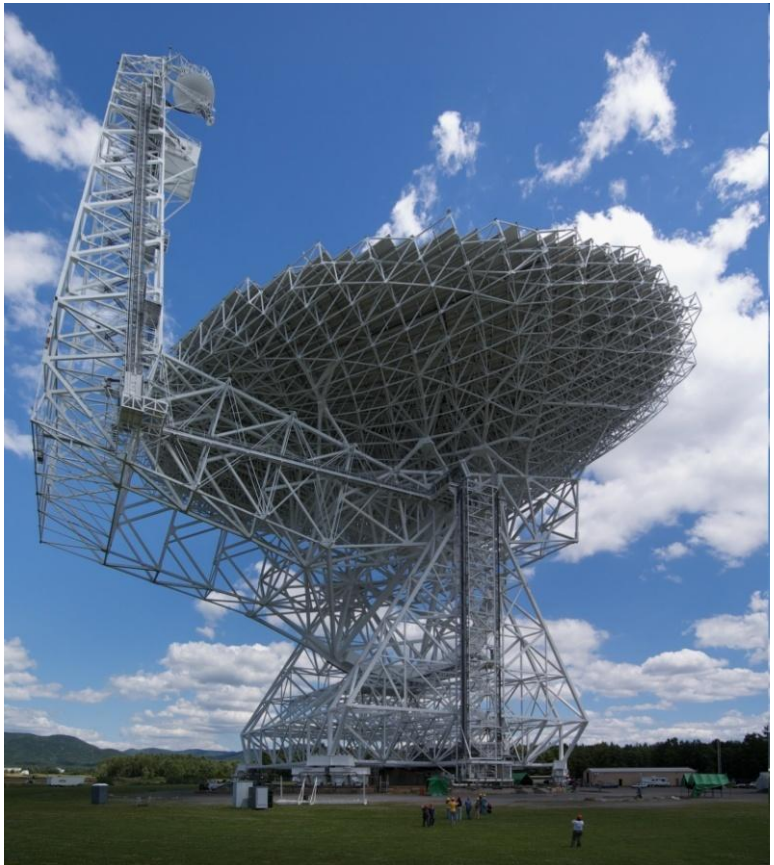
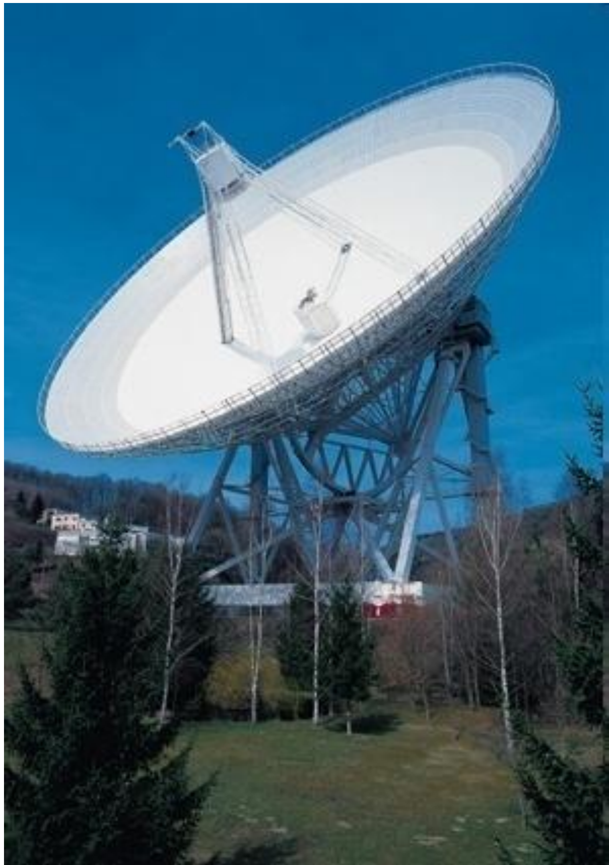
# Ground stations: more that 40 telescopes

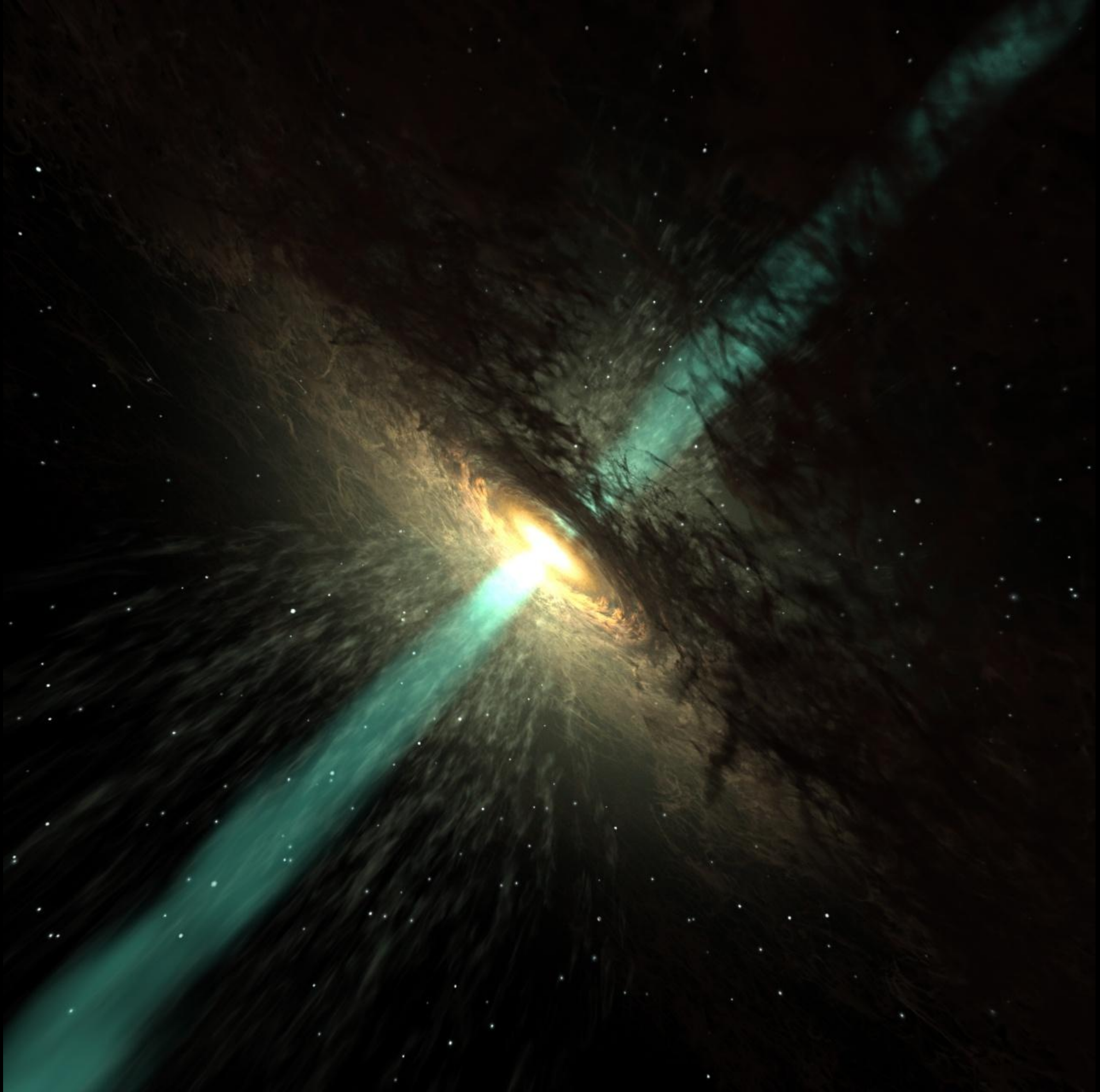
***Russian Quasar network, telescopes from Europe, USA, South Africa, Australia, China, Korea, Japan, etc.***









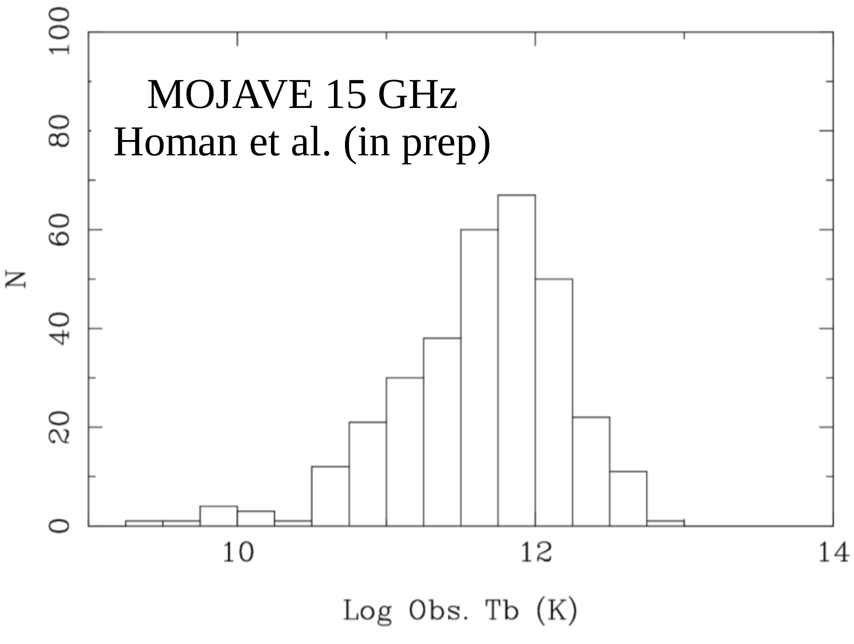
# Brightness of Active Galactic Nuclei

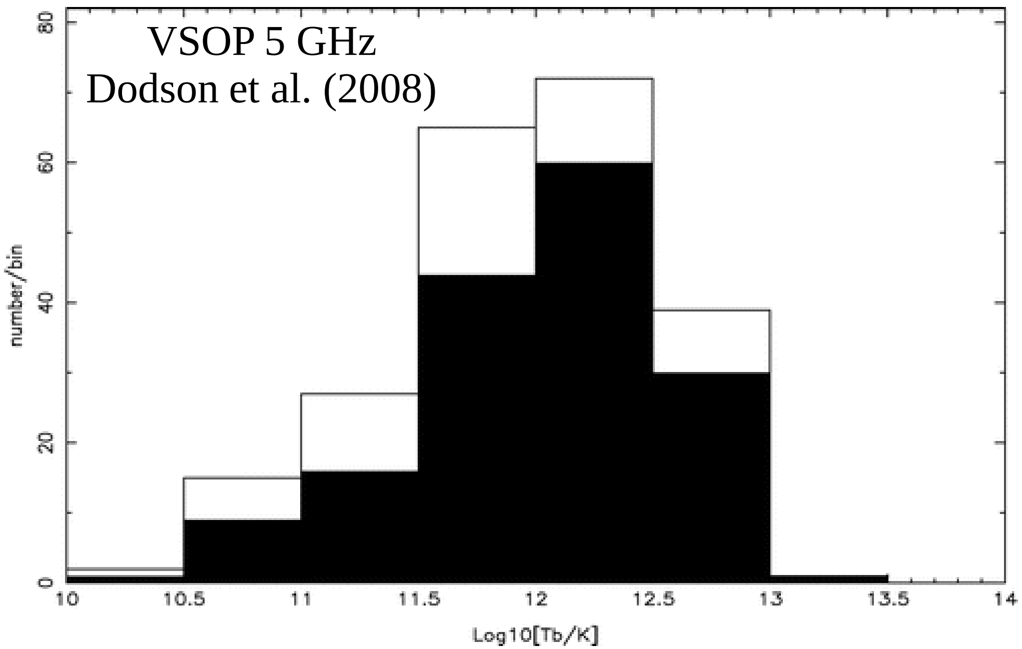
**The RadioAstron AGN Tb survey goal:**

**Measure and study brightness temperature of AGN cores in order to better understand physics of their emission while taking interstellar scattering into consideration.**

The inverse-Compton limit of $10^{11.5}$ K is confirmed by previous studies if Doppler boosting is involved. VLBI kinematics estimates a typical Doppler boosting to be ~10. RadioAstron survey probes values up to about $10^{16}$ K.

*Median $T_b = 10^{12}$ K, max $T_b = 5 \cdot 10^{13}$ K.*



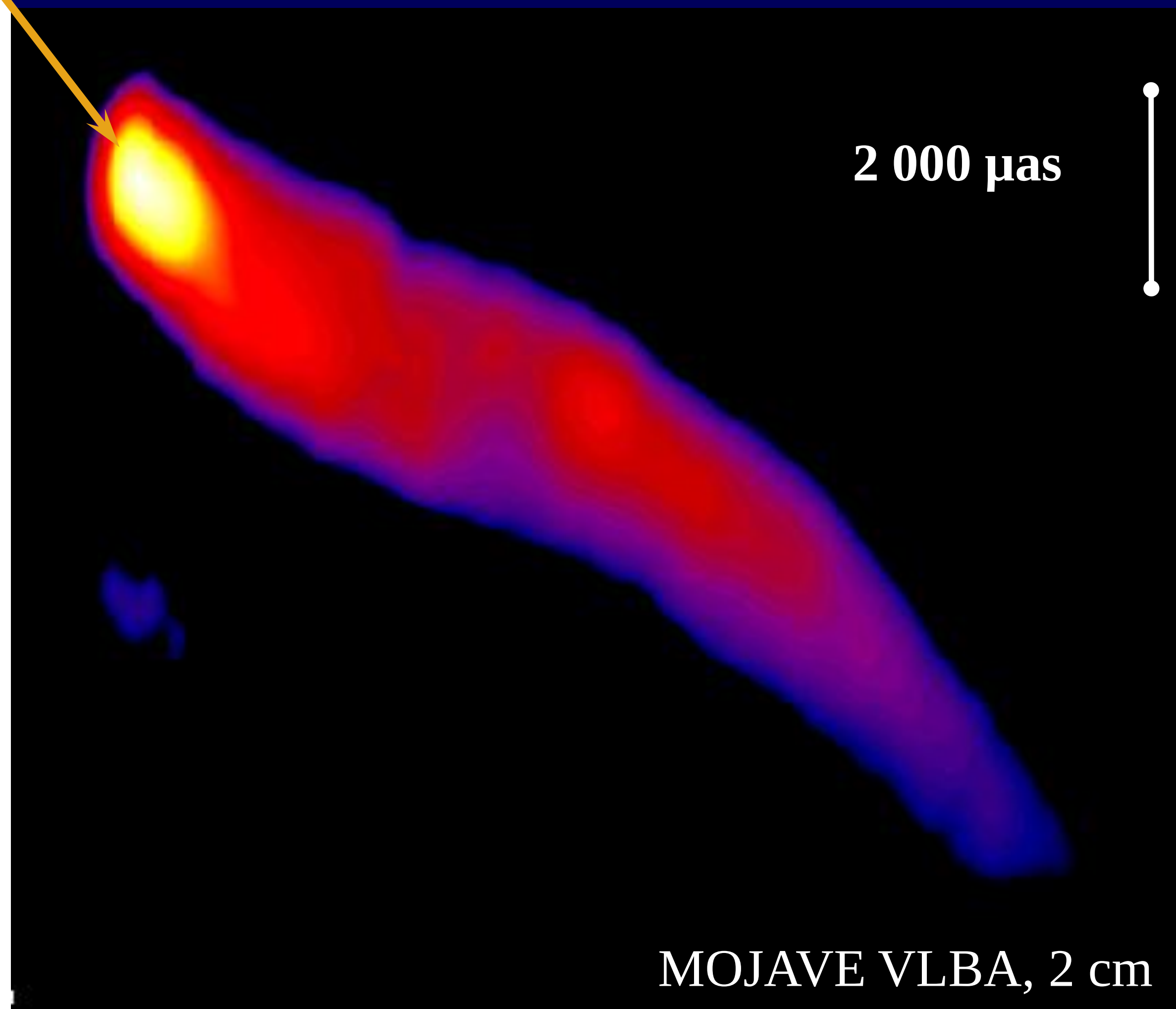



**RadioAstron core brightness temperature: 2-4·$10^{13}$ K.**

*Brightness temperature survey*

# 3C273 at 18, 6, 1.3 cm

The Doppler factor about or less than 13 (Jorstad et al. 2005, Savolainen et al. 2010) is not high enough to get the brightness temperature down to the predicted KelPau inverse-Compton limit of $10^{11.5}$ K.



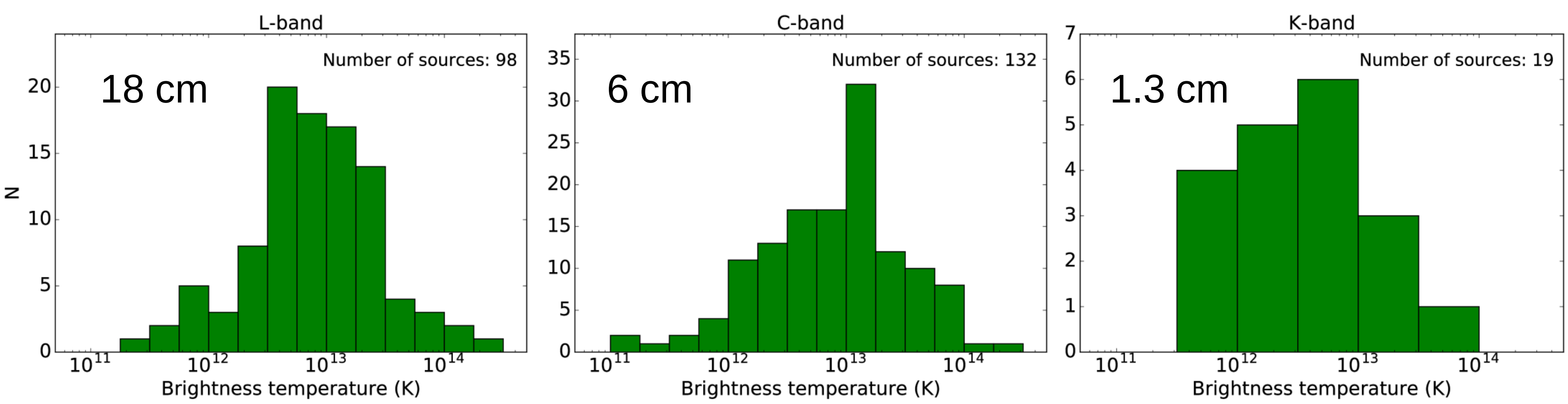

Kovalev et al. (2016)

# Direct $T_b$ estimates: AGN survey completed
## *median ~$10^{13}$ K, max ~> $10^{14}$ K*

Out of 248 observed AGNs 164 were detected in about 1/3 of segments at 18 and/or 6 and/or 1.3 cm up to the longest projected spacing of 350,000 km. Highest formal resolution is achieved for 0235+164, OJ287, 3C279 at about 10 μas.

**AGN cores are found to be at least 10 times brighter than predicted and observed before.**

Possible scenarios: higher boosting then estimated, efficient re-acceleration (magnetic reconnection), coherent processes or relativistic protons.




Kovalev et al.

# How to generate high brightness temperature

✓ Very high Doppler boosting with *typical* δ~100 – VLBI kinematics does not confirm it.

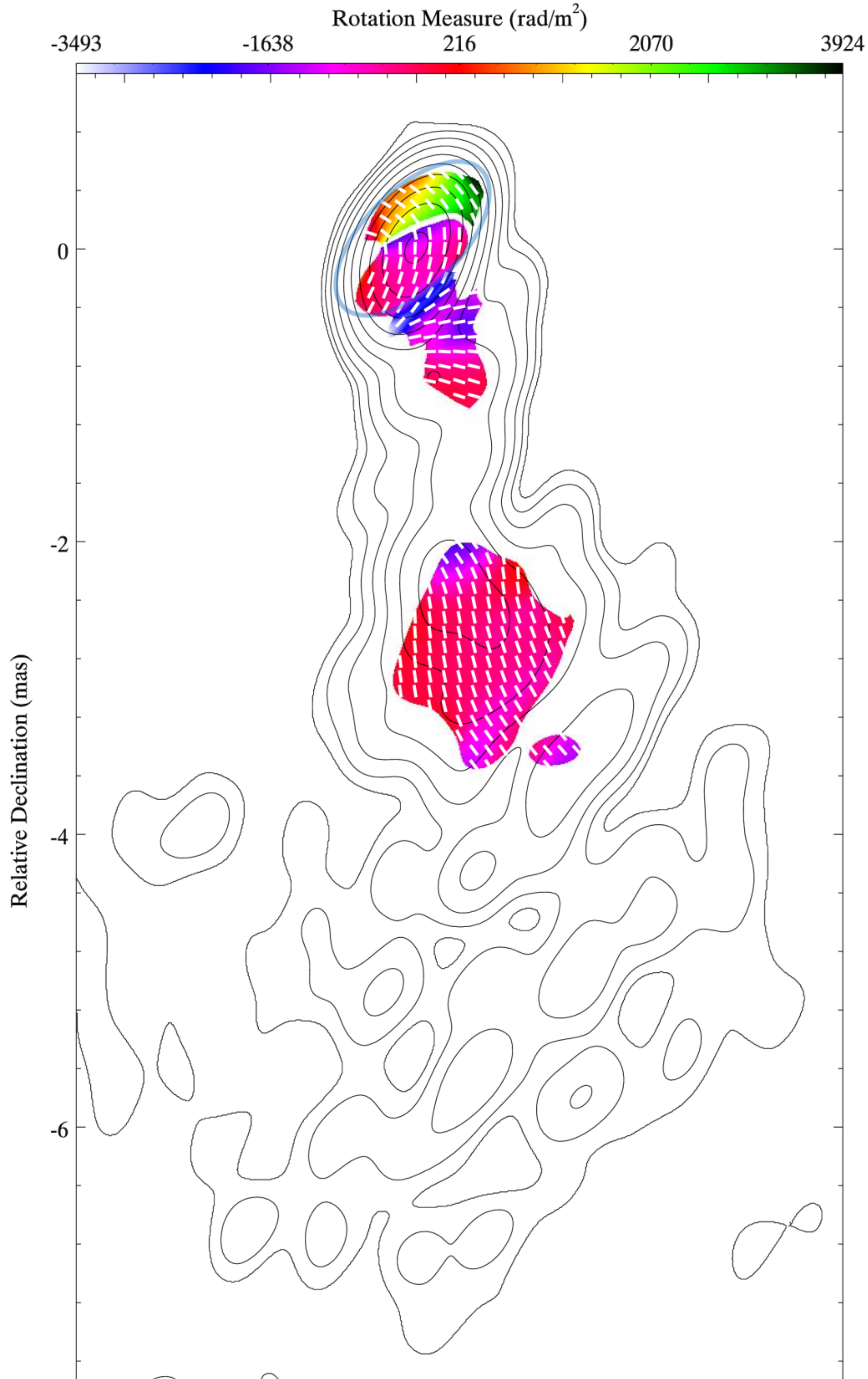
Typical observed VLBI kinematics does not reflects the plasma bulk motion in many cases?

✓ Continuously "excited" core being most of the time at the inverse-Compton limit or continuous re-acceleration several parsecs away from the core.

How? Flares do not happen all the time. Magnetic reconnection? Shocks? γ-ray photon flux is not high enough but radio photons could be up-scattered to lower energies and increase uv / x-ray flux.

✓ Relativistic protons or coherent processes.

Requires very efficient acceleration and high magnetic field. Many problems.



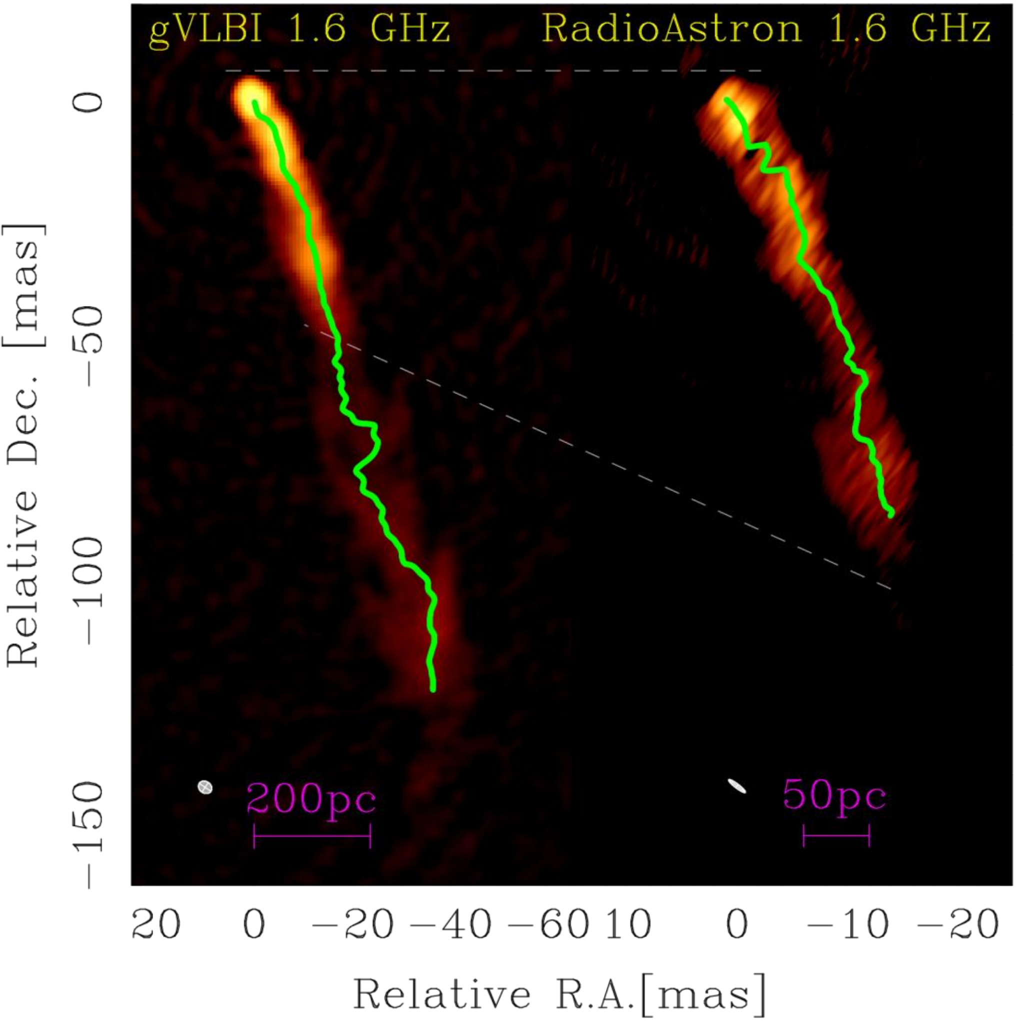

# BL Lacertae:
## Faraday rotation 15-43 GHz

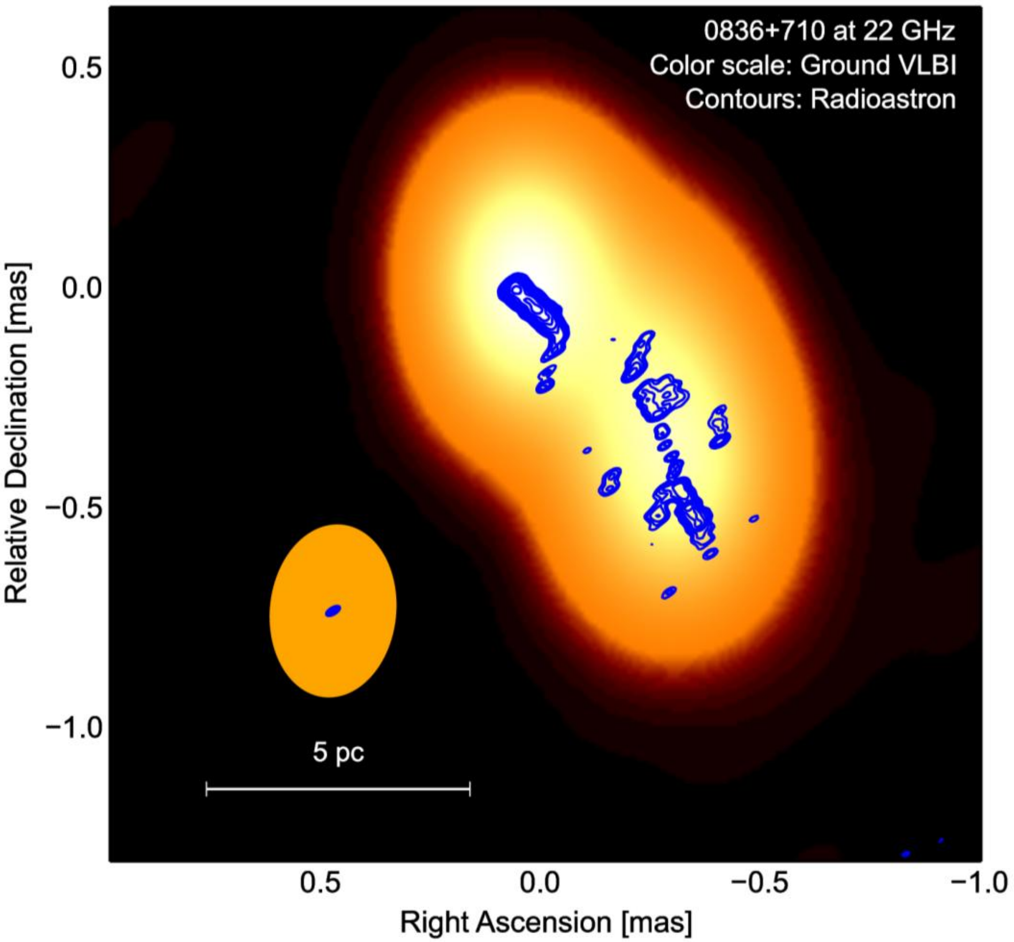
Gomez et al. (2016) observed RM gradient around the core region, its distribution is consistent with RMHD simulations of jets with a helical magnetic field.

AGN survey data in turn has shown that observed fractional polarization increases with increasing resolution, formally, even up to more than 100%. This is a clear indication of existence of highly polarized extremely compact features with highly ordered magnetic field within the jet.

# Quasar 0836+710 at 18 and 1.3 cm

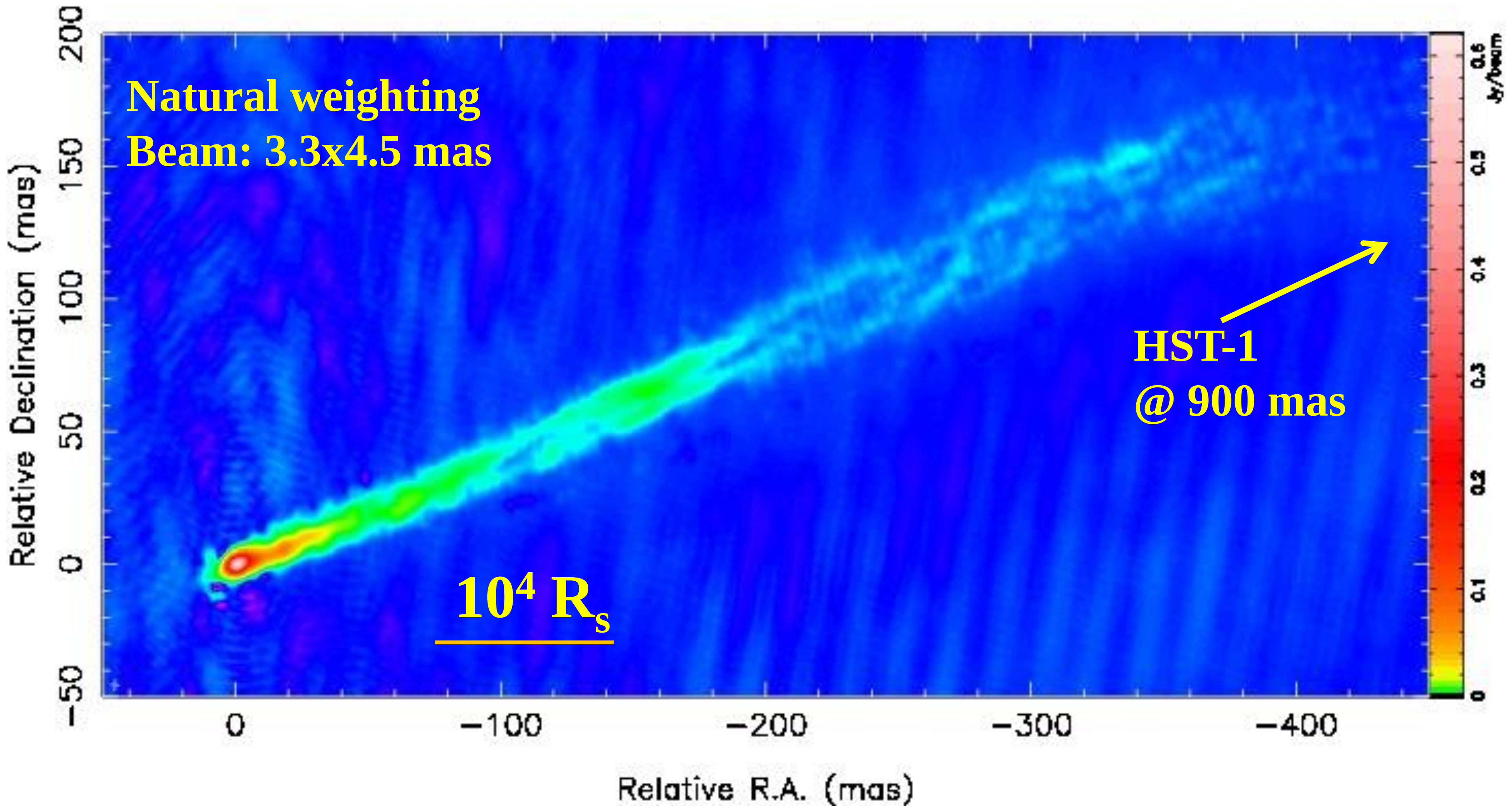
***Plasma instability and internal jet structure***



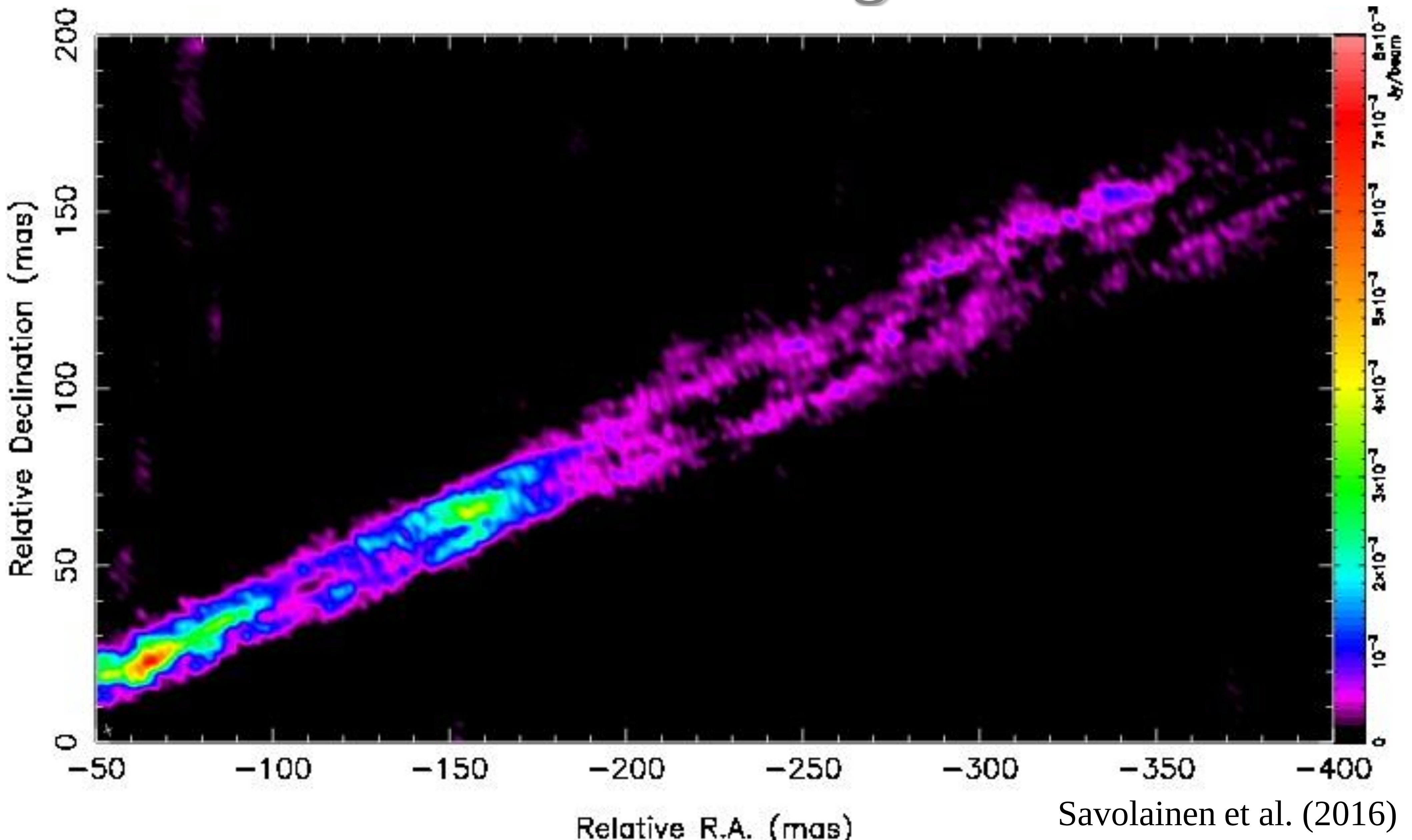




RadioAstron – global VLBI
Vega-Garcia et al.

# Virgo A jet
18 cm

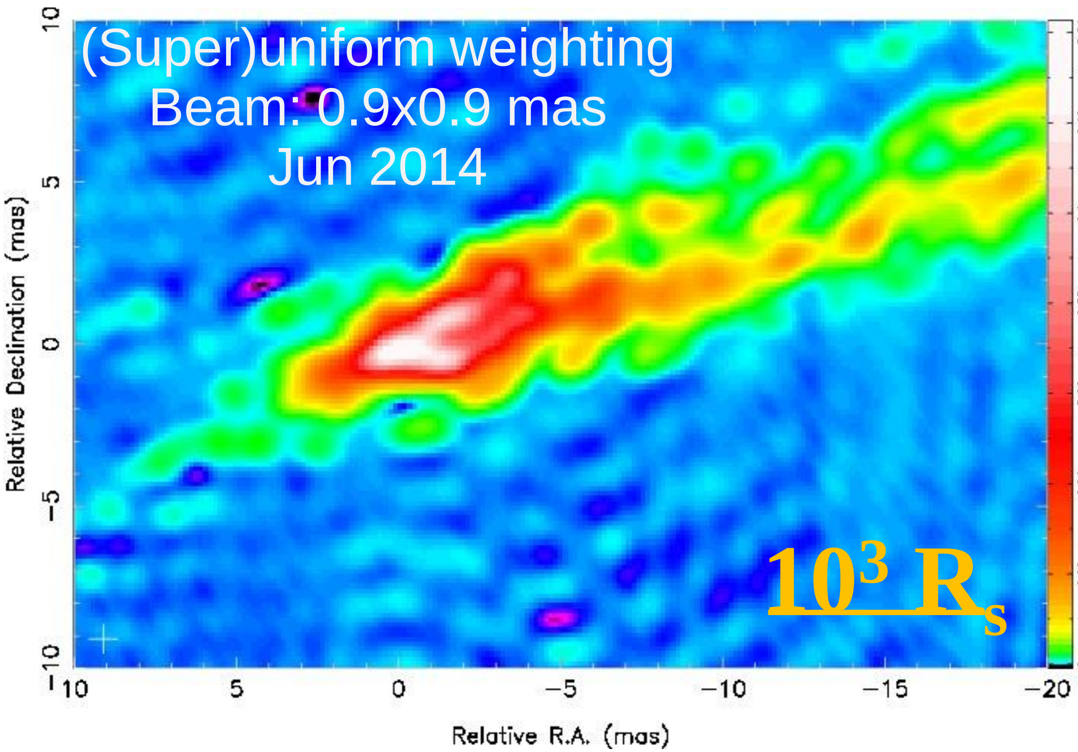


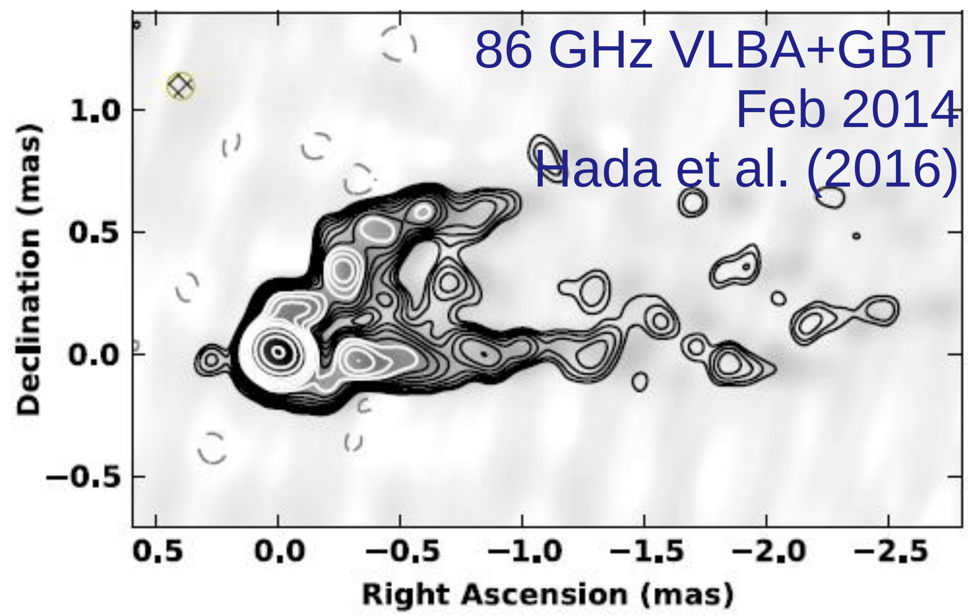
# Virgo A at 18cm
# – including RadioAstron

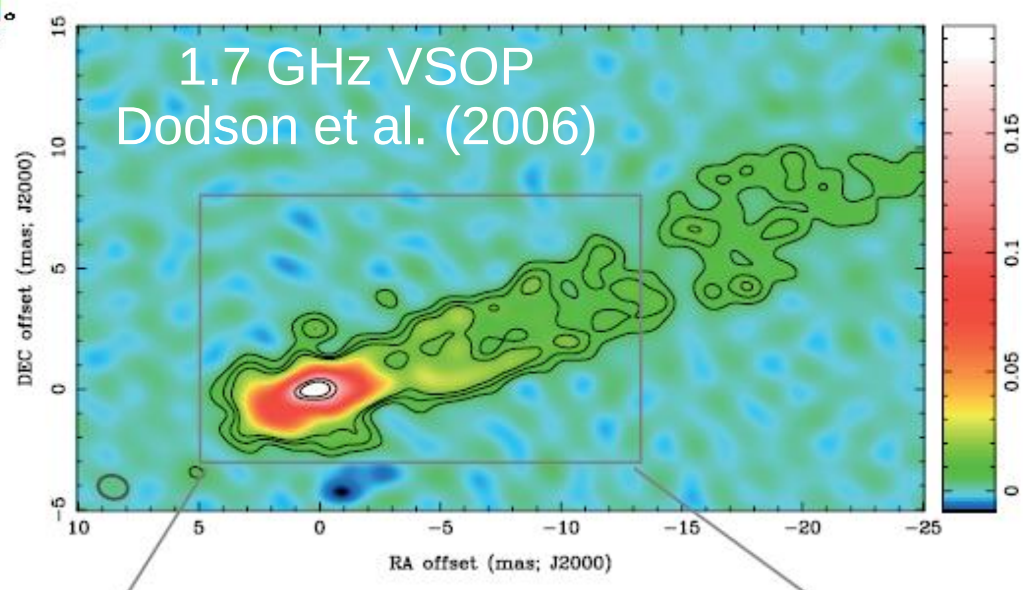



Savolainen et al. (2016)

# Virgo A at 18cm – core region

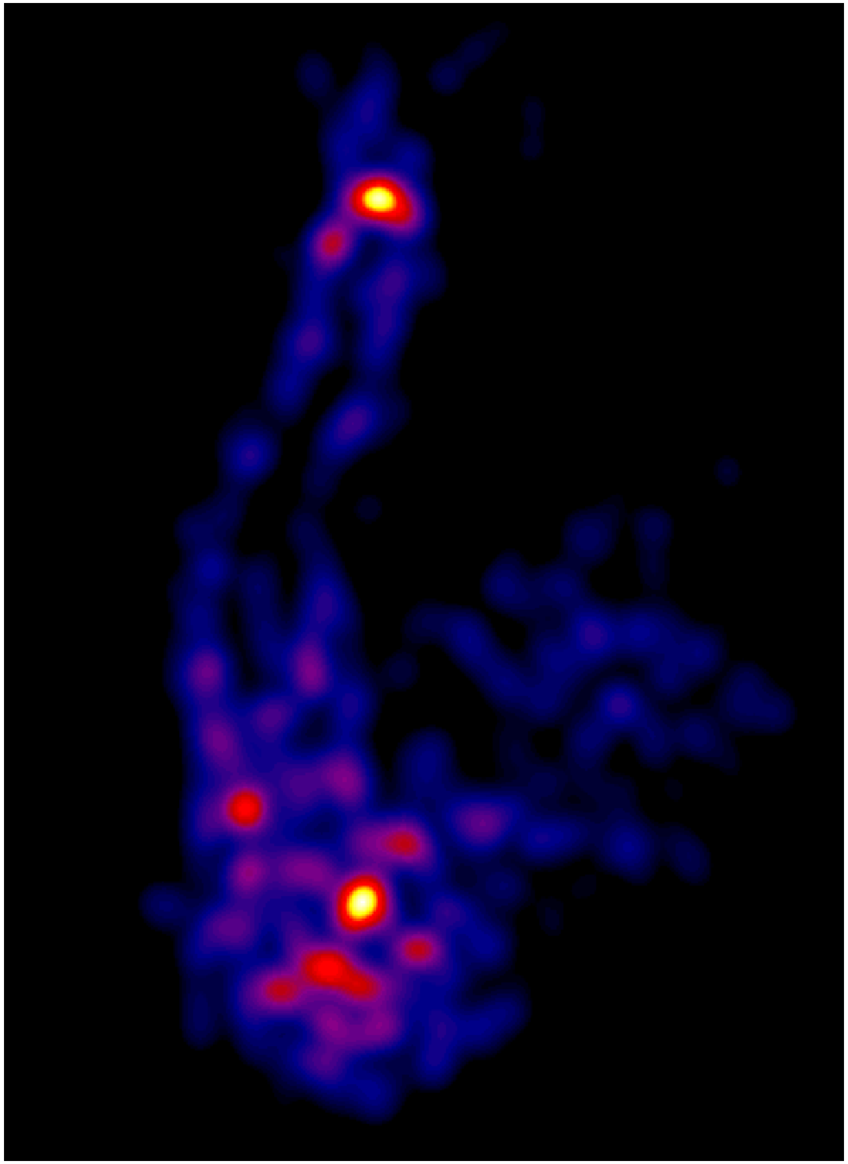


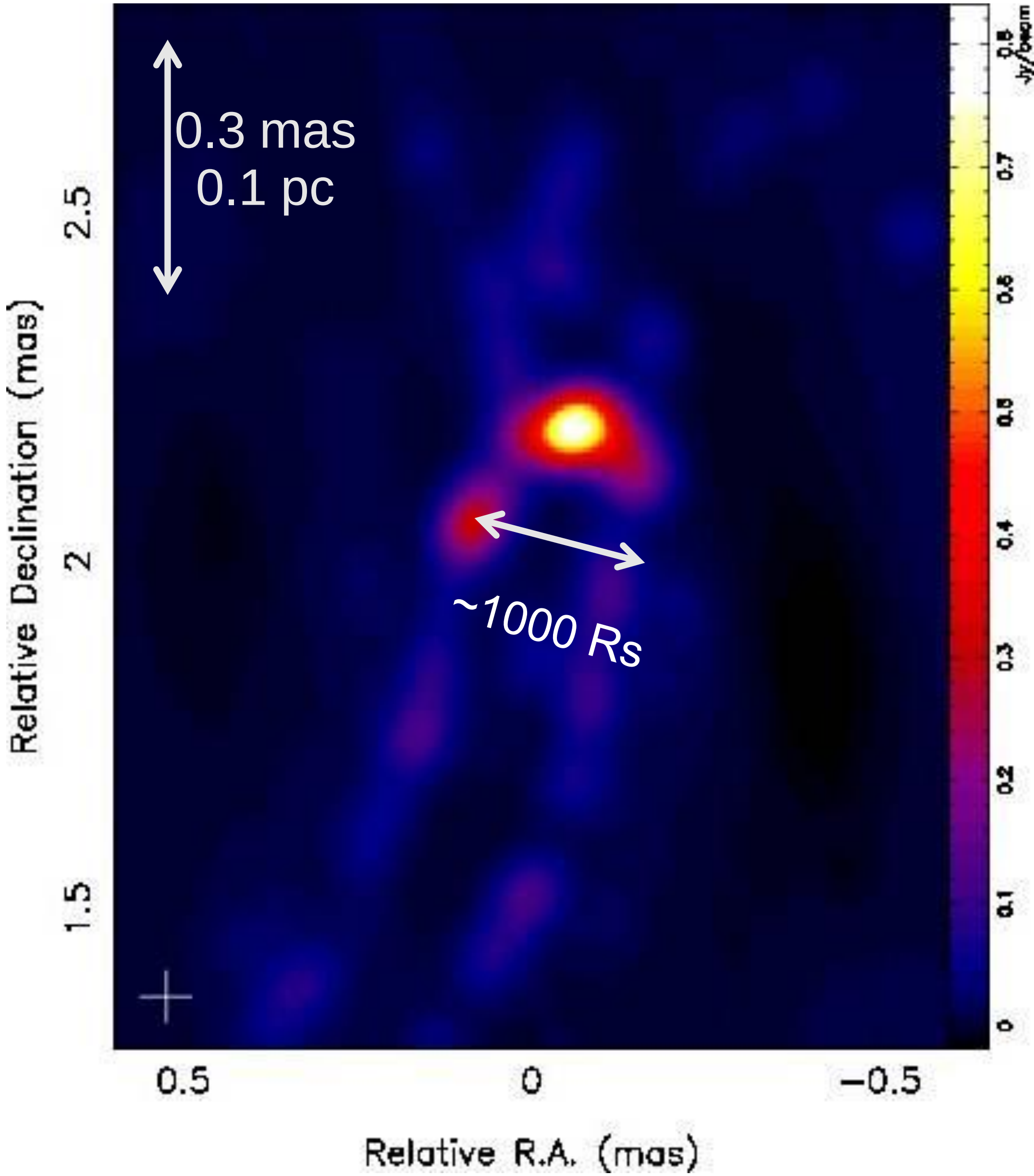




- ✓ Edge-brightened core structure visible at both 1.7 GHz RadioAstron and 86 GHz VLBA+GBT images
- ✓ Counter-jet is visible
- ✓ Low-intensity emission around the conical core – sheath?
  Width ~ 5mas ~ 700 $R_S$

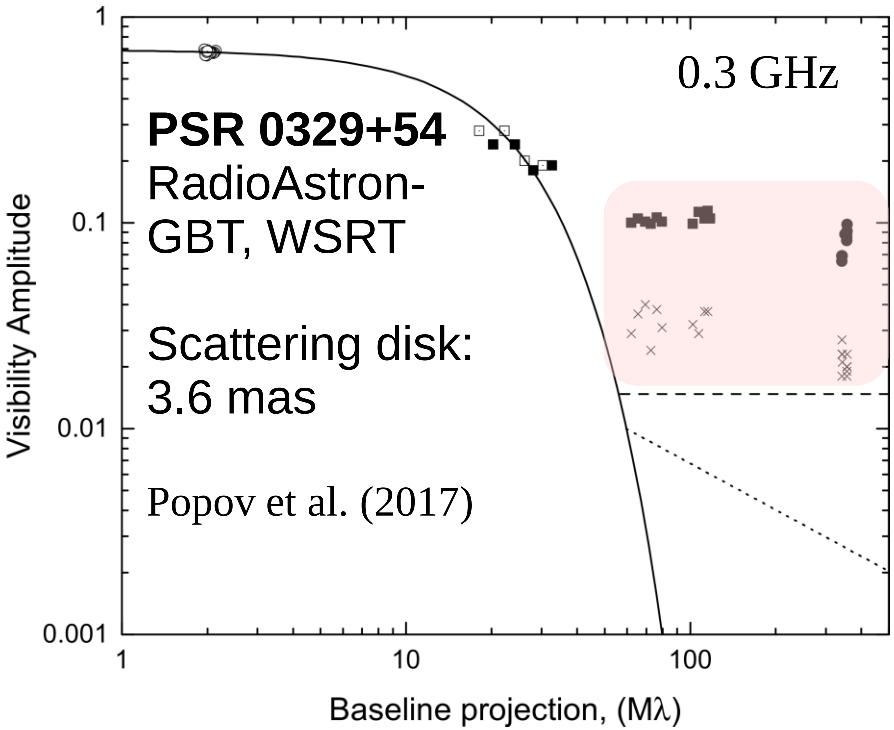
# 3C84 RadioAstron observations – 22 GHz image

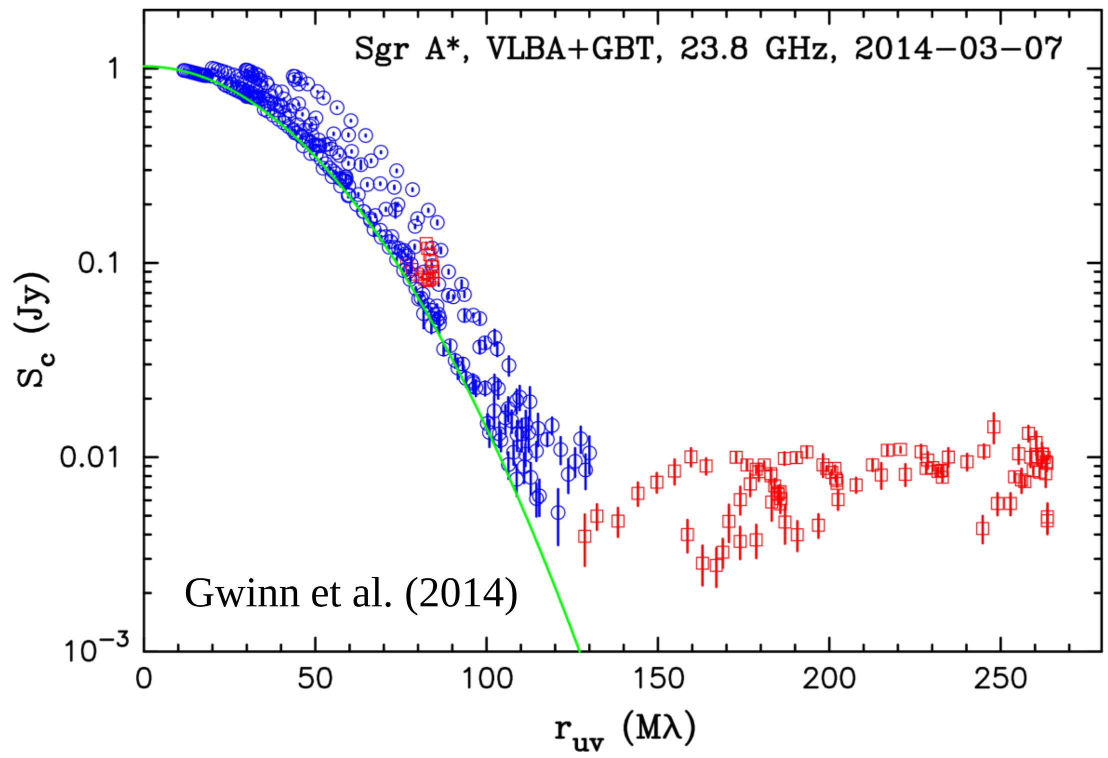


Giovannini et al., Savolainen et al.

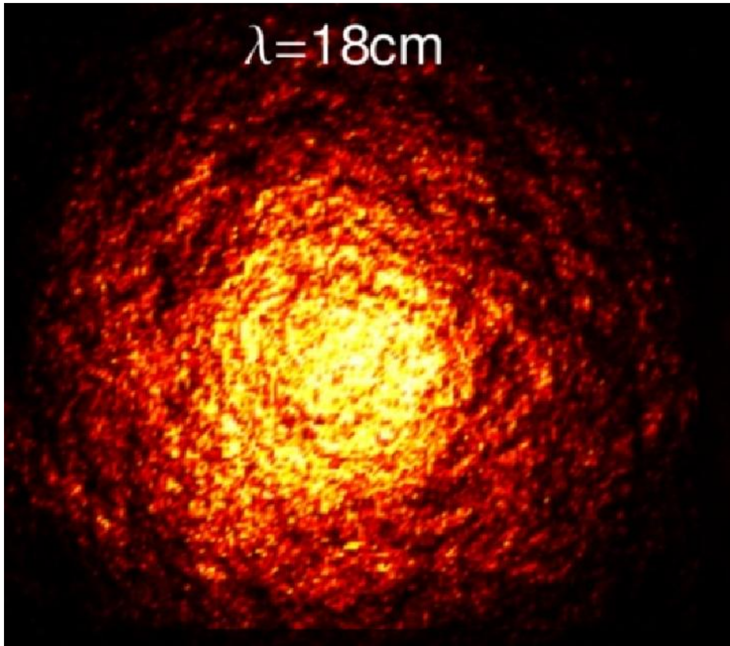


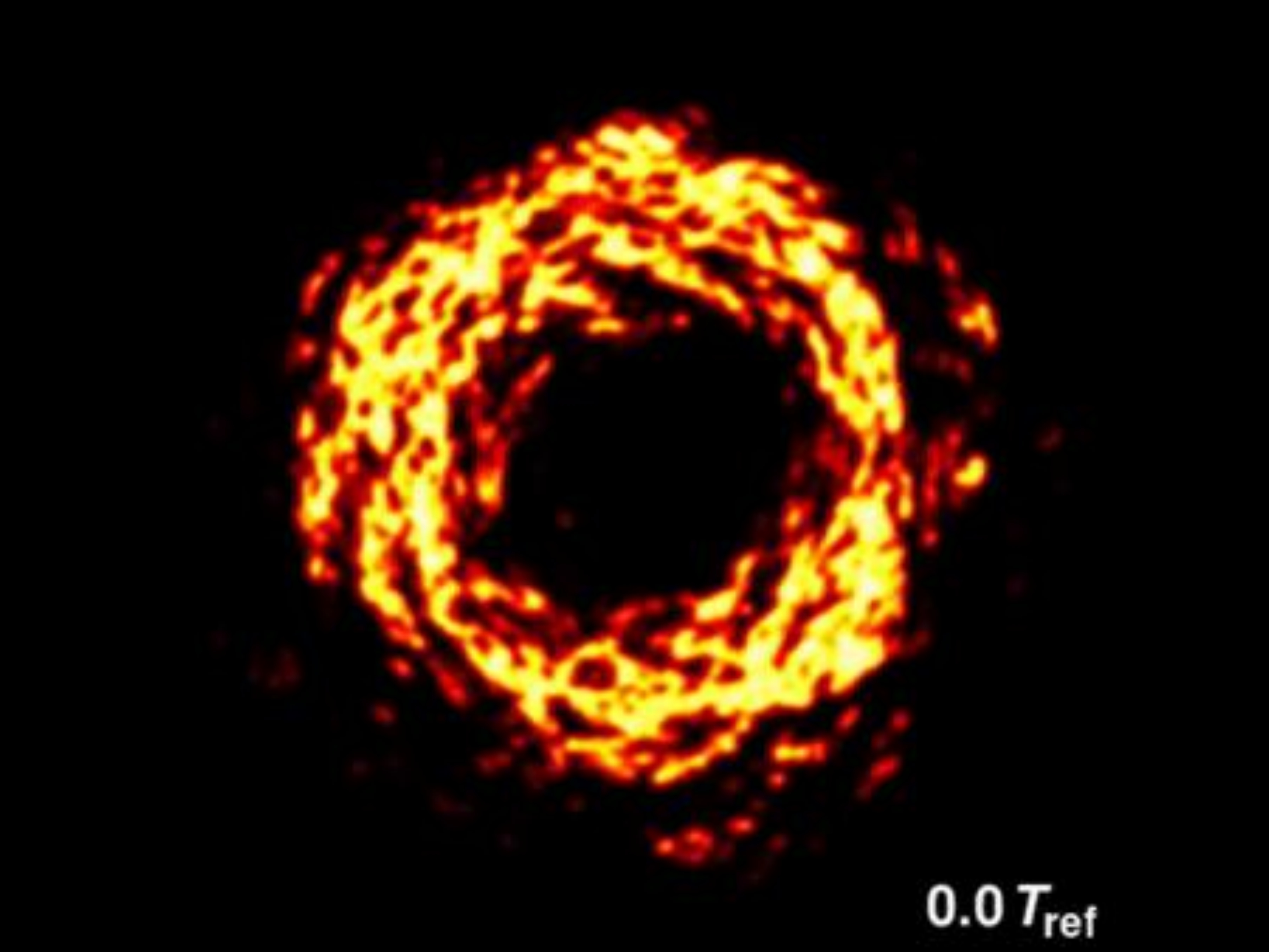
# Discovery of the scattering sub-structure



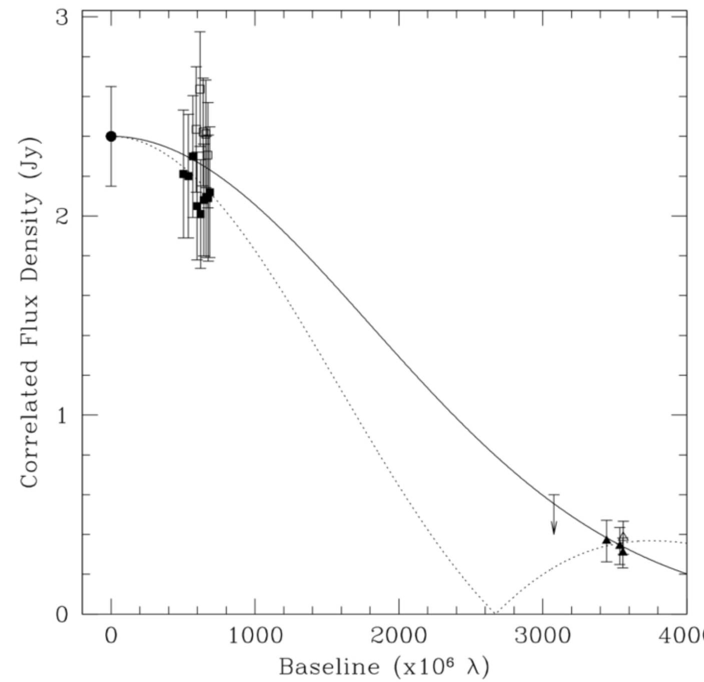

- ➢ A tool to probe turbulent interstellar medium.
- ➢ Must be taken into account by RadioAstron and Event Horizon Telescope.
- ➢ A new promising tool to reconstruct the true image of observed background target.



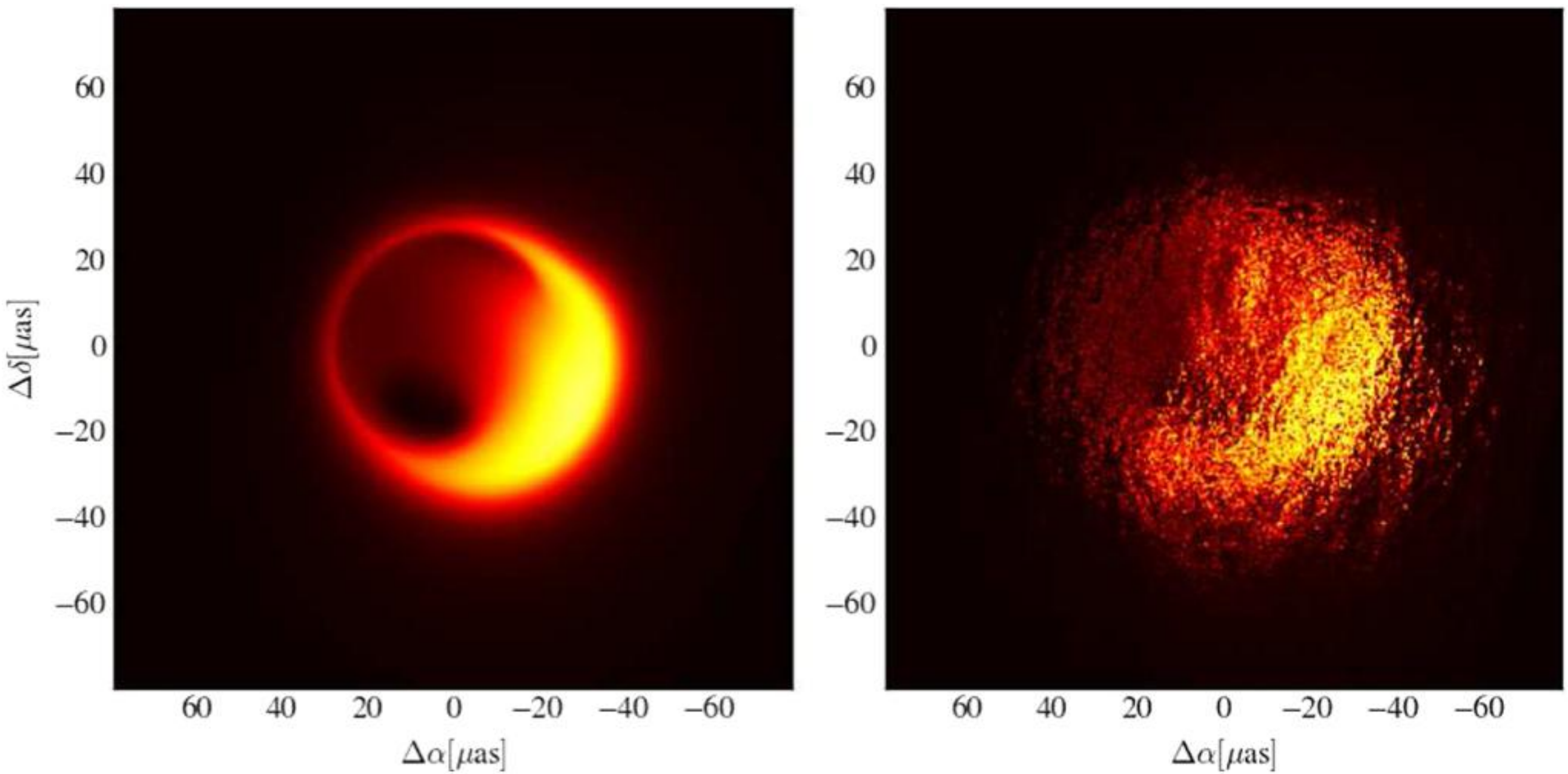

0.0 $T_{ref}$

# SgrA* at 1.3 mm

- gVLBI: no BH shadow yet.
- Indications of an asymetric structure (Fish et al. 2016)
- Scattering sub-structure should be accounted for.




Doeleman et al. (2008)

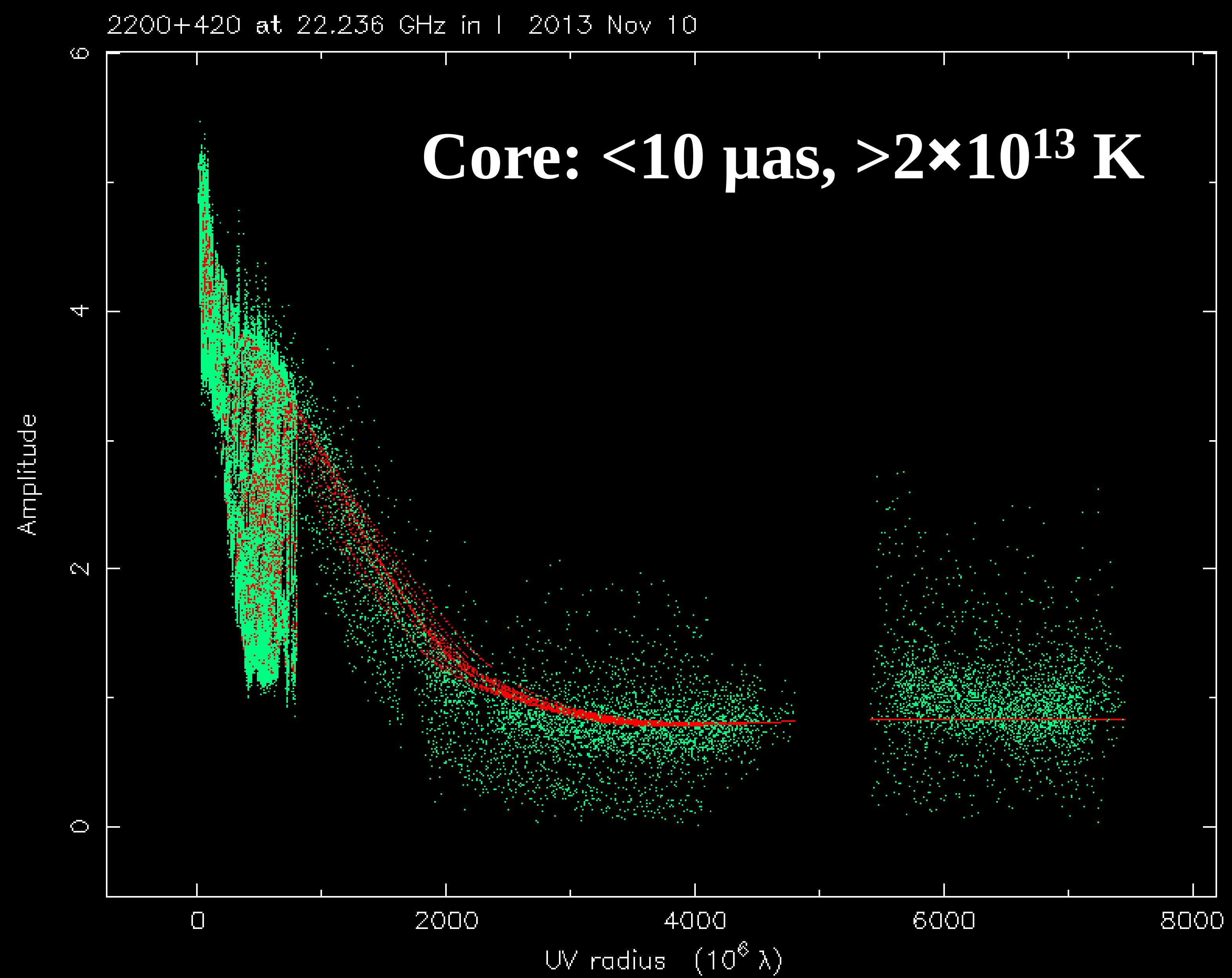



Broderick et al. (2016)

# THANK YOU

# Why does RadioAstron deliver higher Tb?

*Lets look at imaging results in details (Gomez et al., ApJ, 2016)*



# Mega-masers

Water masers in NGC4258.
Baseline: RadioAstron-GBT, 19.5 ED.
And RadioAstron-Medicina, 26.7 ED.
**Resolution about 8 μas or 60 a.u. at 7.2 Mpc! The absolute world record.**

NGC 4258 maser emission at systemic velocity (from compact nuclear disk).
Fading of powerful maser components indicates extended emission with Tb ~ $10^{12}$-$10^{13}$ K.
Many features are still unresolved - Tb > $10^{14}$ K at 8 μas.