RadioAstron AGN survey

Yuri Kovalev on behalf of the survey team
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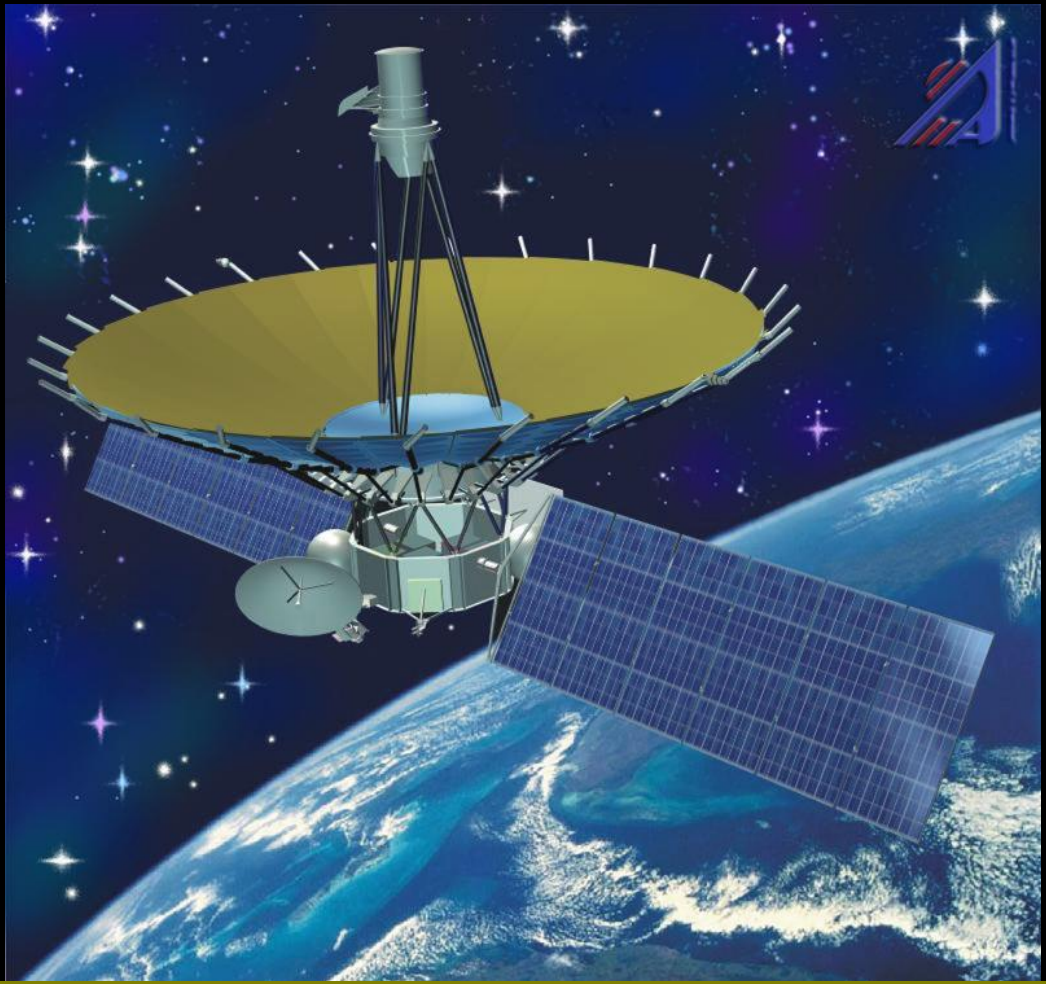

RadioAstron AGN survey: the team

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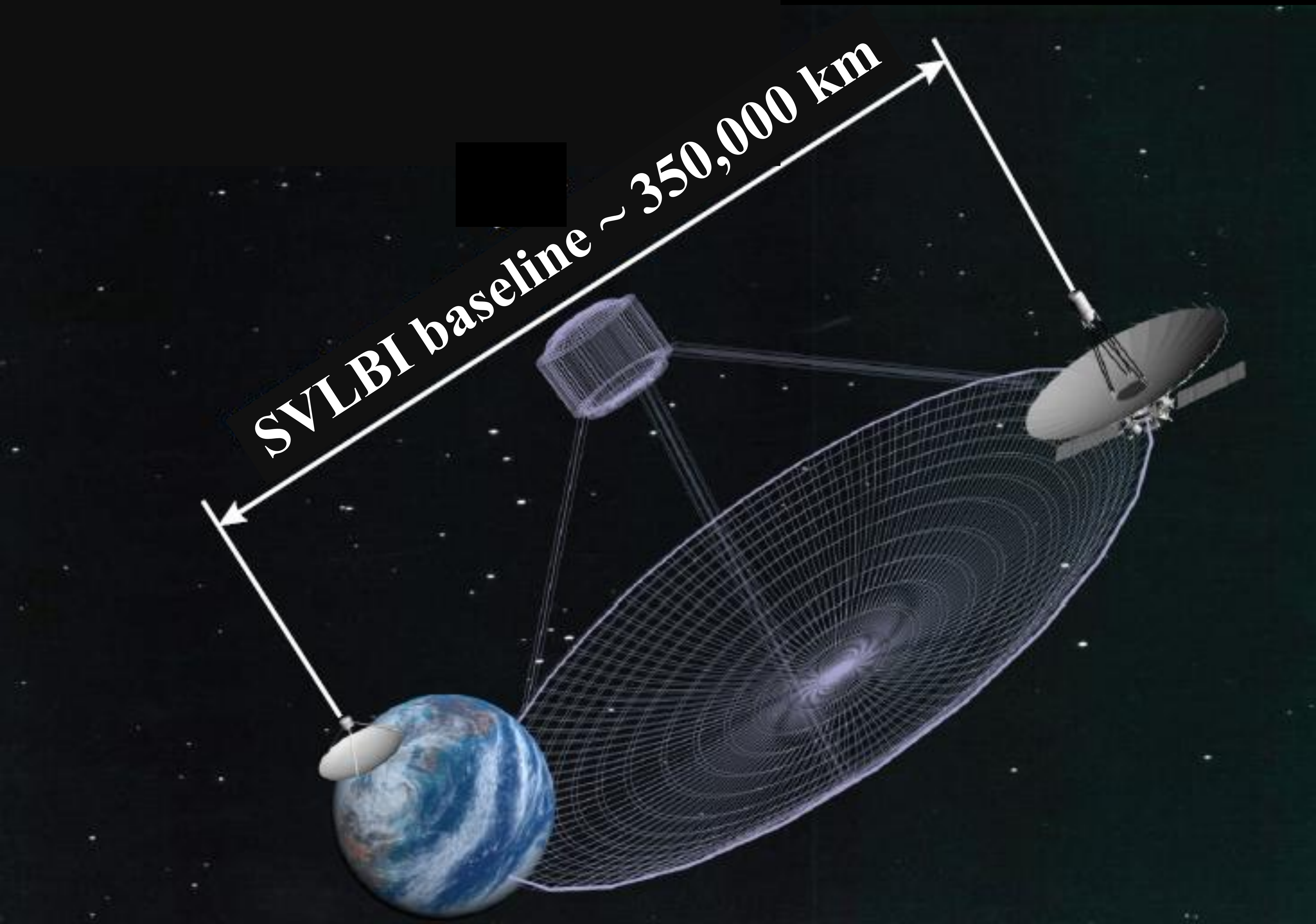
The Biggest Radio Telescope:



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 10^{-14} s/s for six years. Currently switched to the closed loop mode, also highly stable.

Many participating ground radio telescopes

<u>VLBI:</u>

Kvazar network: Sv, Bd, Zc (Russia);
Kalyazin (Russia);
Evpatoriya (Ukraine);
Effelsberg (Germany);
WSRT (the Netherlands);
Torun (Poland);
Medicina, Noto, Sardinia (Italy);
Yebes (Spain);
Jodrell Bank 1 & 2 (UK);
Robledo (Spain);
Usuda (Japan);
Shanghai 25 & 64, Urumqi (China);
VLA, GBT, Arecibo (USA);
HartRAO (South Africa);
LBA.

<u>Single-dish:</u>

RATAN-600 (Russia);
ATCA (Australia);
WSRT (the Netherlands);
Urumqi (China);
Effelsberg (Germany);
Oven Valley (USA);
GBT (USA).

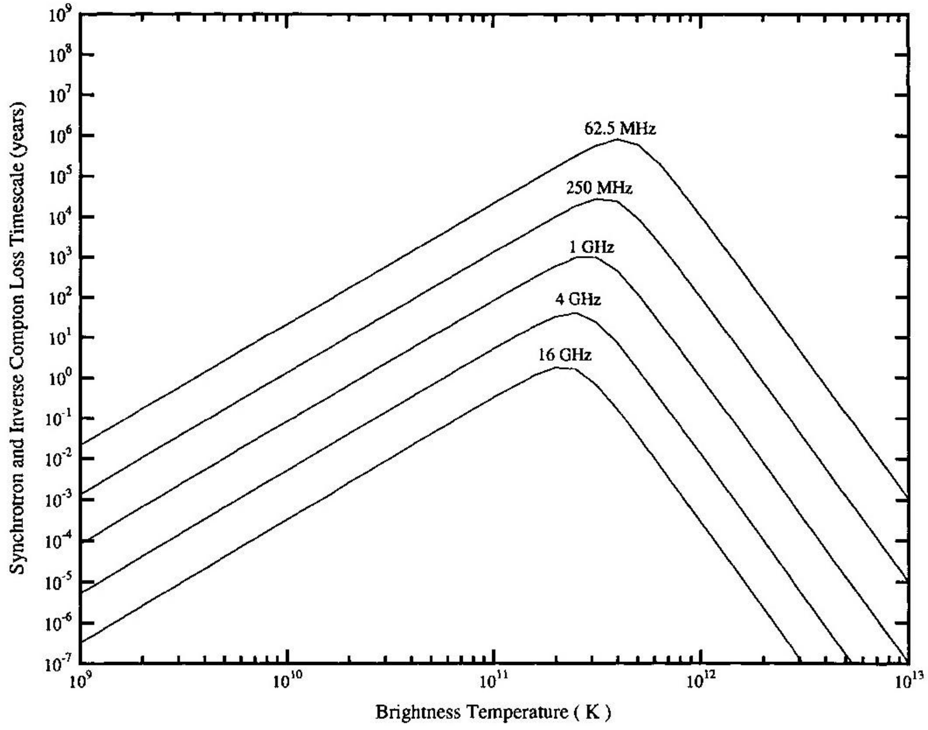
RadioAstron AGN survey: main goal

The goal:

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

- Estimate brightness temperature of most compact structure(s) in the AGN jet base,
- Test the predicted inverse-Compton limit ($10^{11.5}$ K for electrons) boosted by Doppler.

We overcome the Earth-based T_b limit. This can not be done by going to higher frequencies on the ground; only Space VLBI. Critical to test emission mechanism.

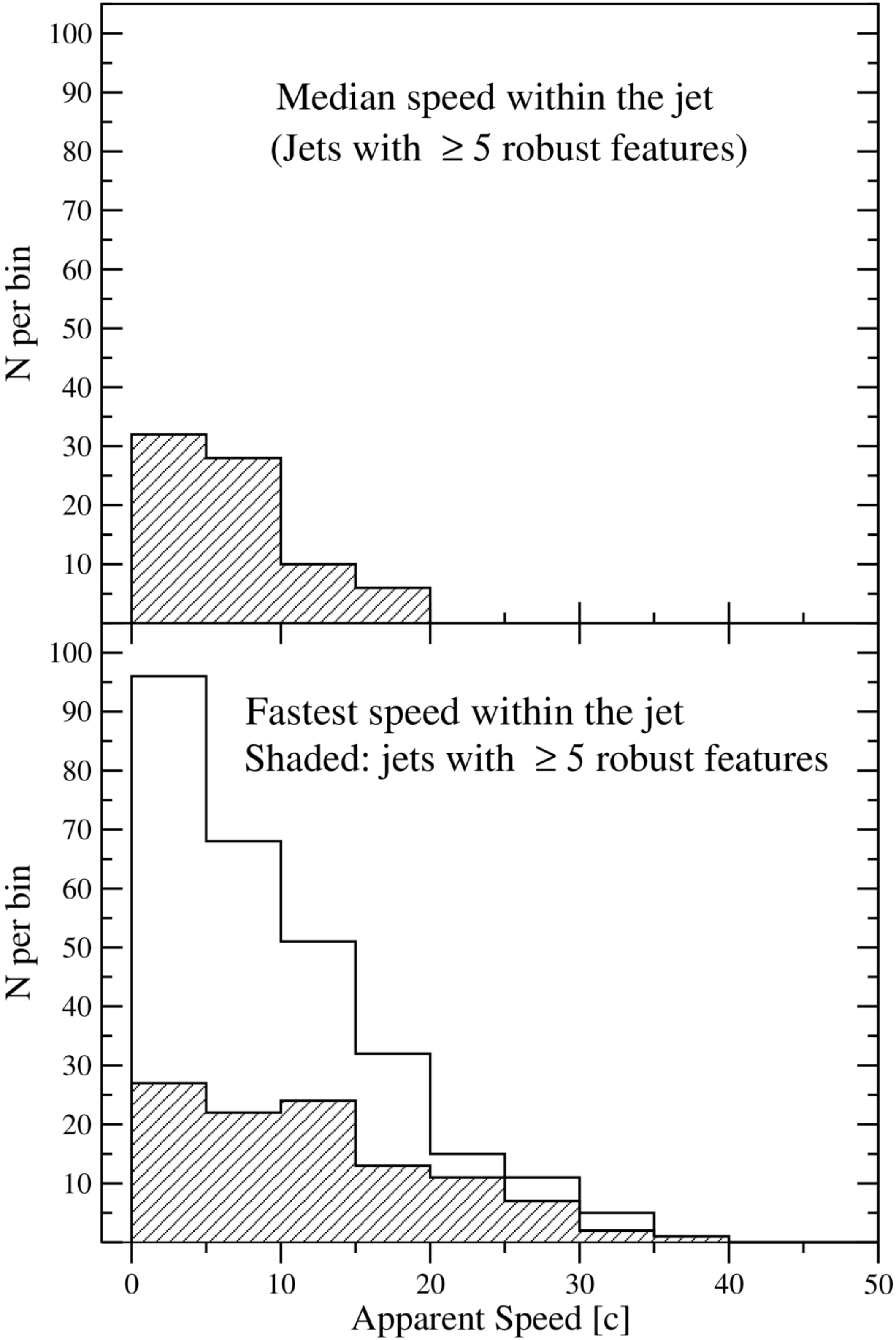


Readhead (1994)

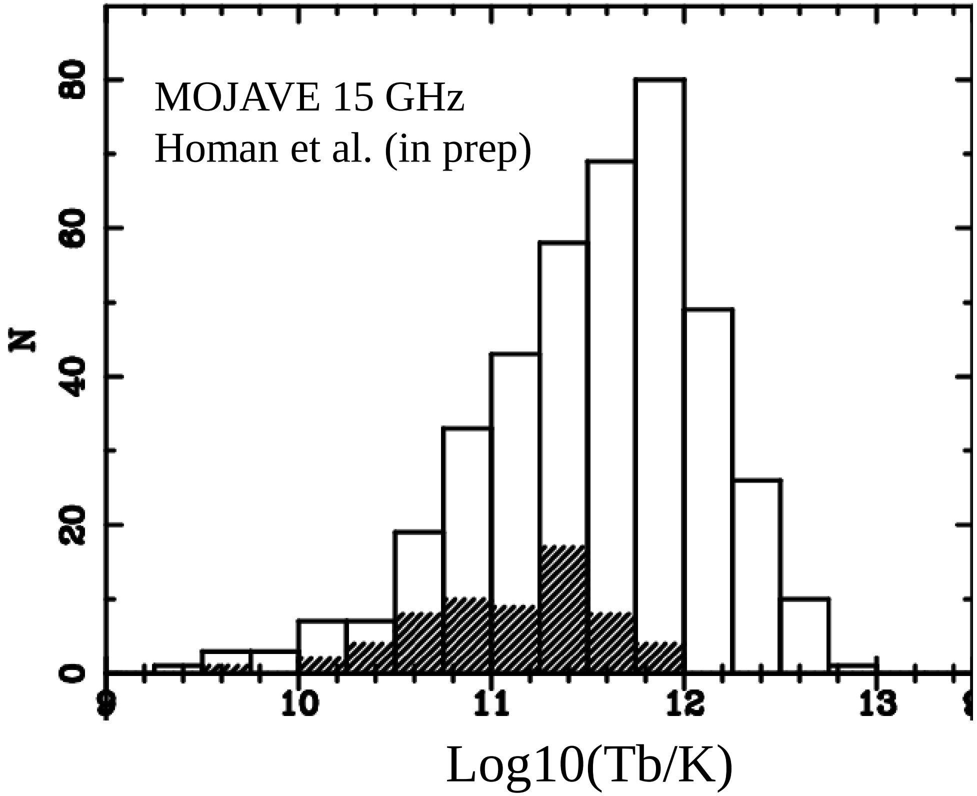
The most recent MOJAVE VLBI kinematics data

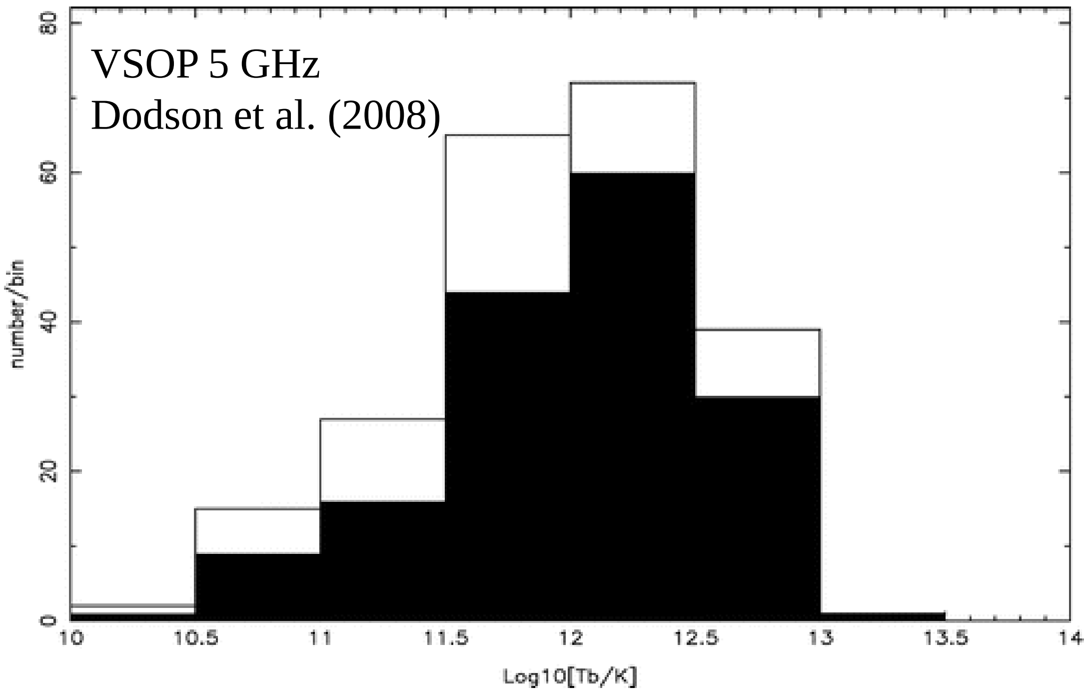
Typical Doppler and Lorentz factors for the MOJAVE sample most of which is also observed by RadioAstron: about or less than 10.

Lister et al. (2016).



The brightness temperature inverse-Compton limit





Median T_b = 10^{12} K, max T_b =$5\cdot10^{13}$ K.

The inverse-Compton limit of 10^{12} K is confirmed if Doppler boosting is involved.

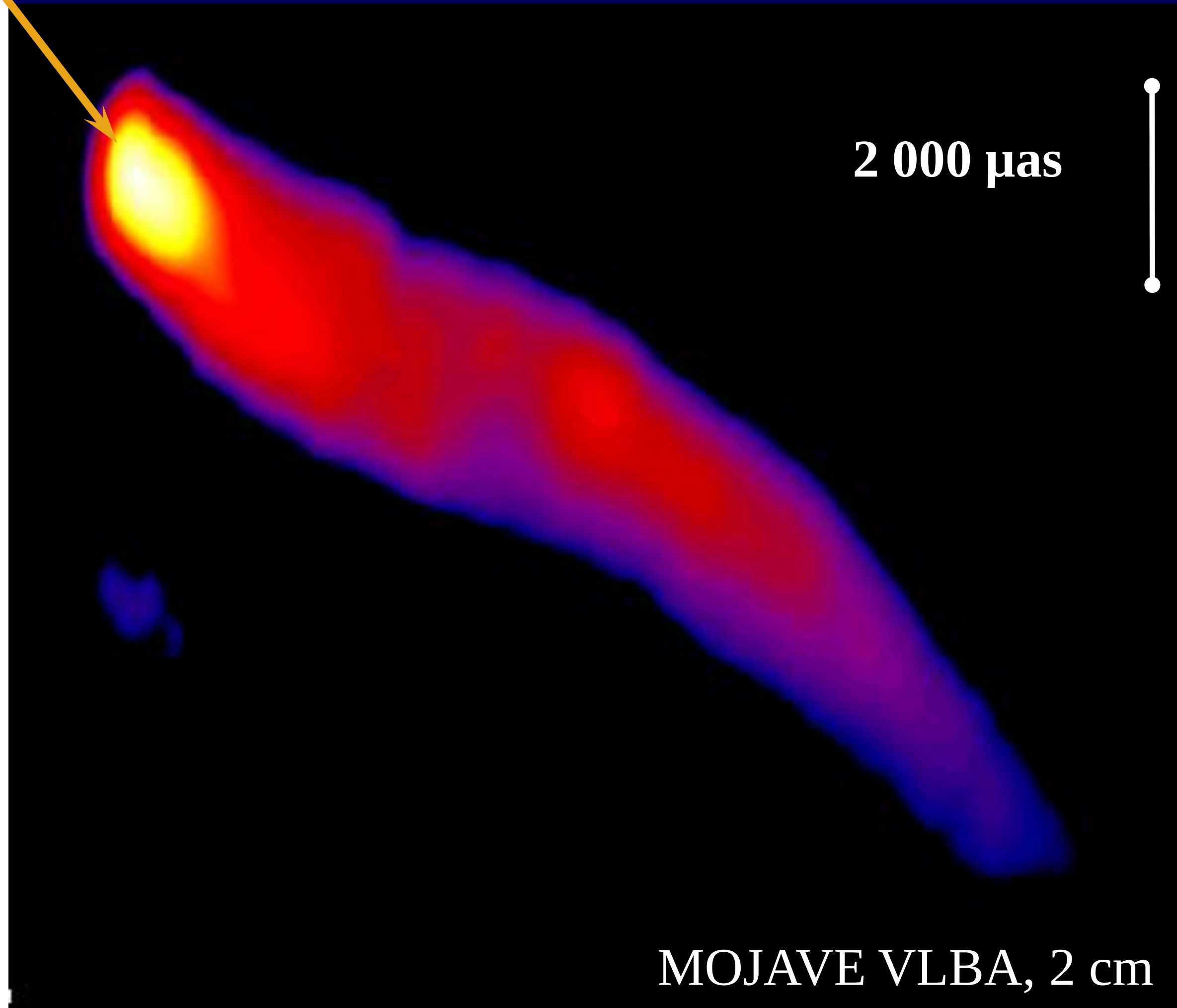
Brightness temperature survey

3C273 at 18, 6, 1.3 cm

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

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 inverse-Compton limit of $10^{11.5}$ K.

See also the talk by J.L. Gomez for Bl Lac.



Kovalev et al. (2016)

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

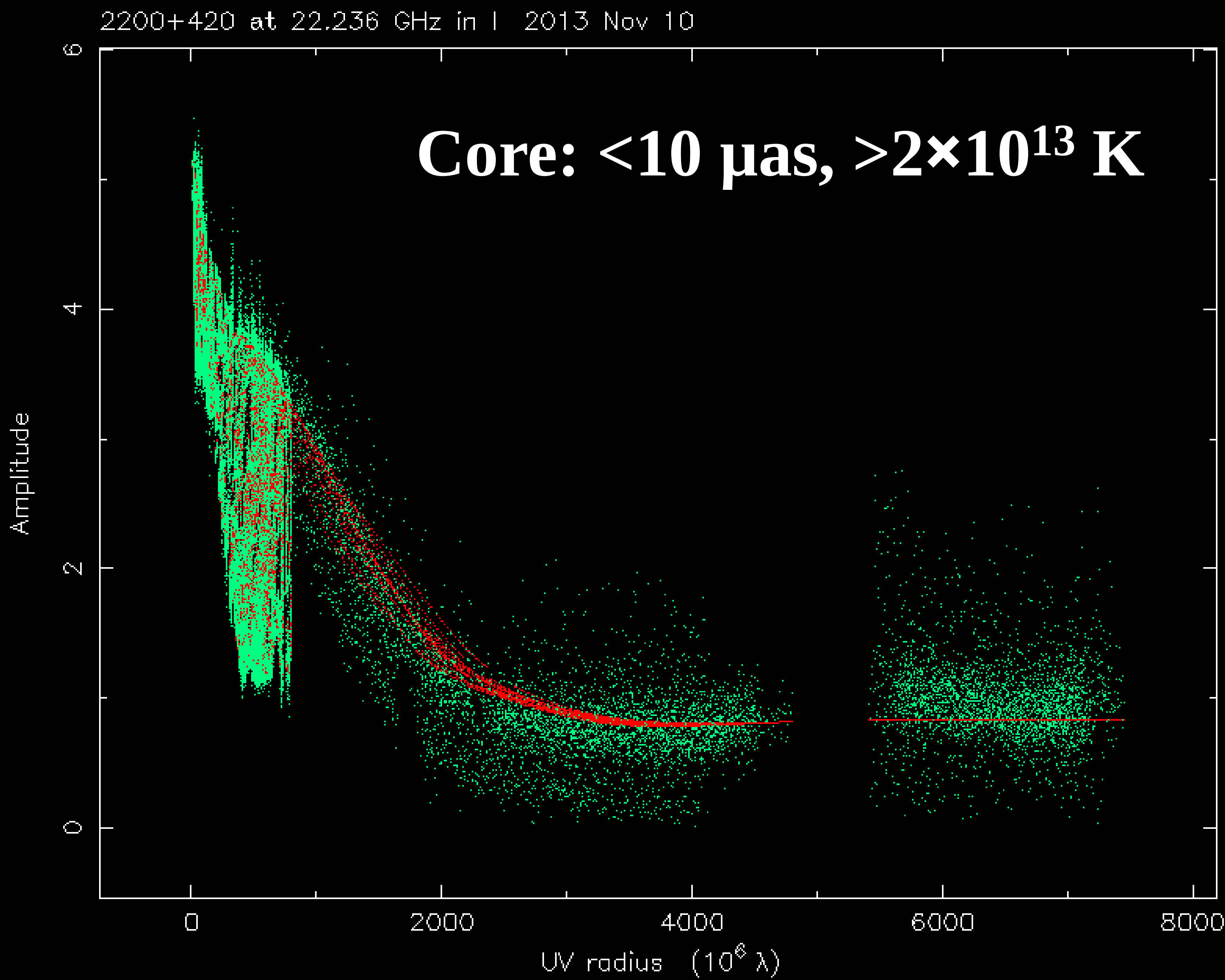
The survey is finished.

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.

Why does RadioAstron deliver higher Tb?

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



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?

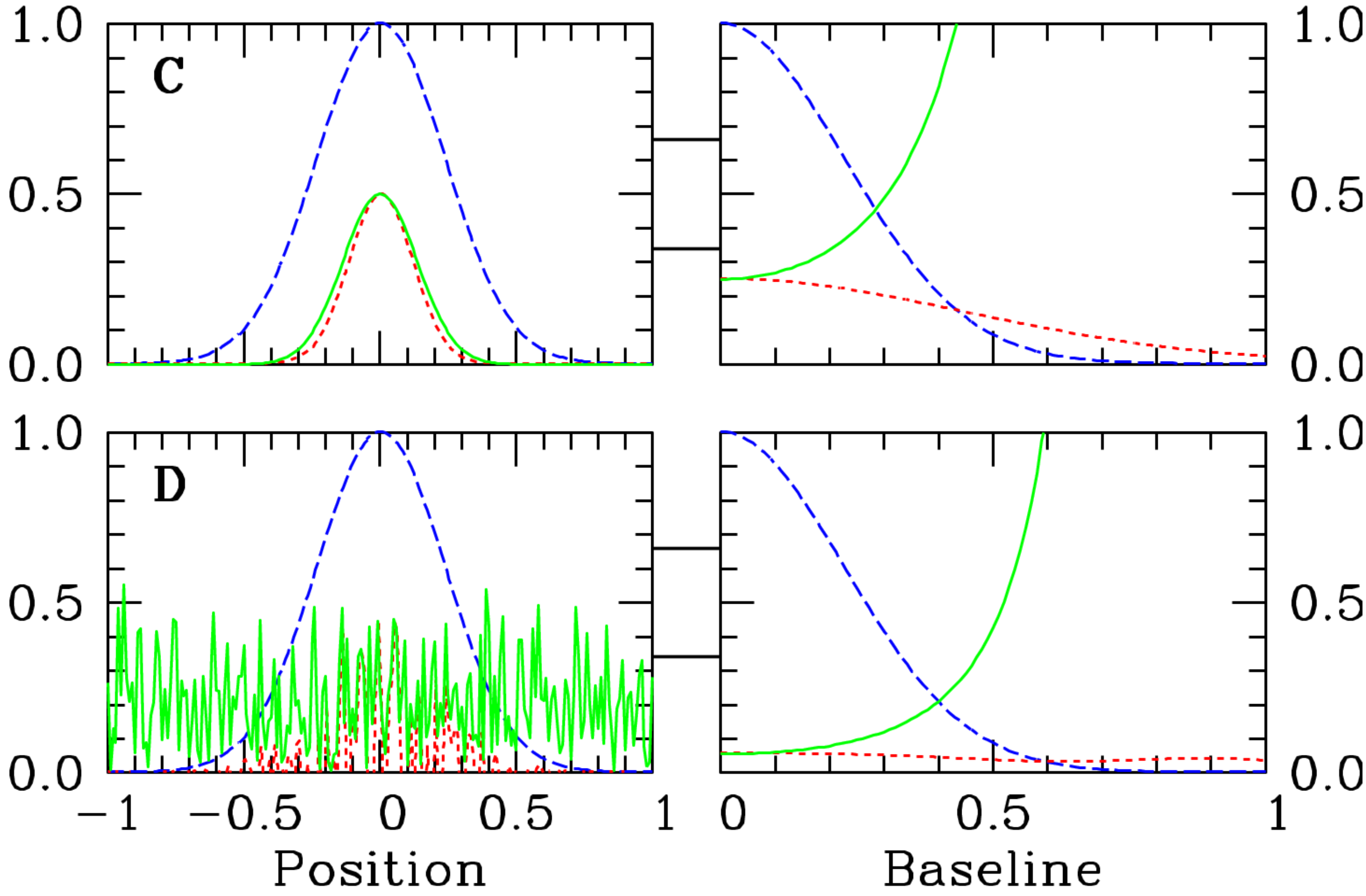
✓ Continuously "excited" core being most of the time at the inverse-Compton limit or continuous re-acceleration several parsecs away from the core.

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 x-ray flux.

✓ Relativistic protons or coherent processes.

Requires very efficient acceleration and high magnetic field. Many problems. High magnetic field is not seen at cm wavelengths.

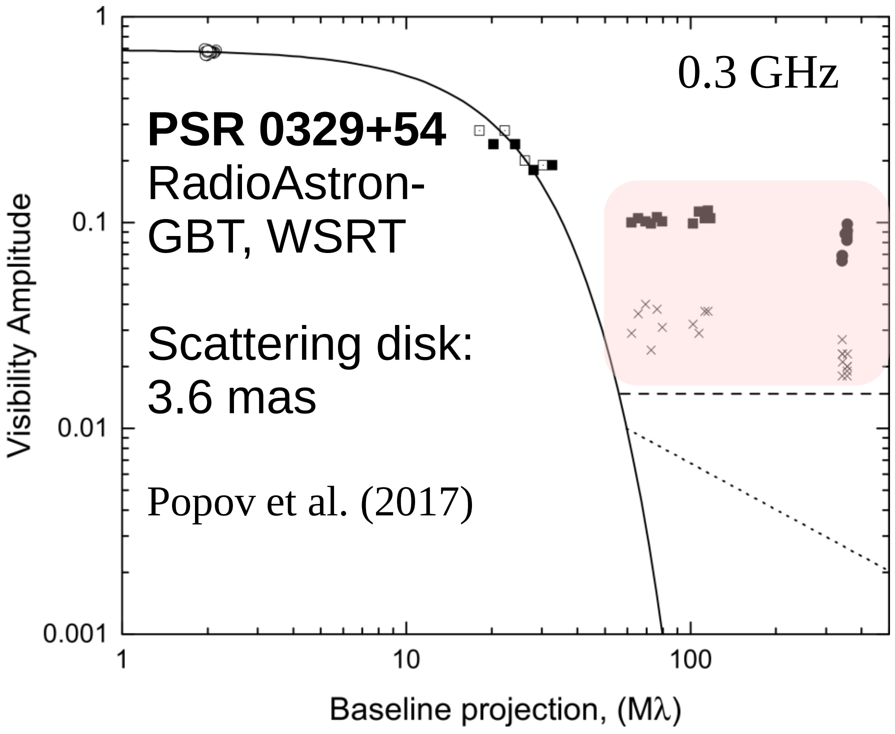
Polarization at long SVLBI projections

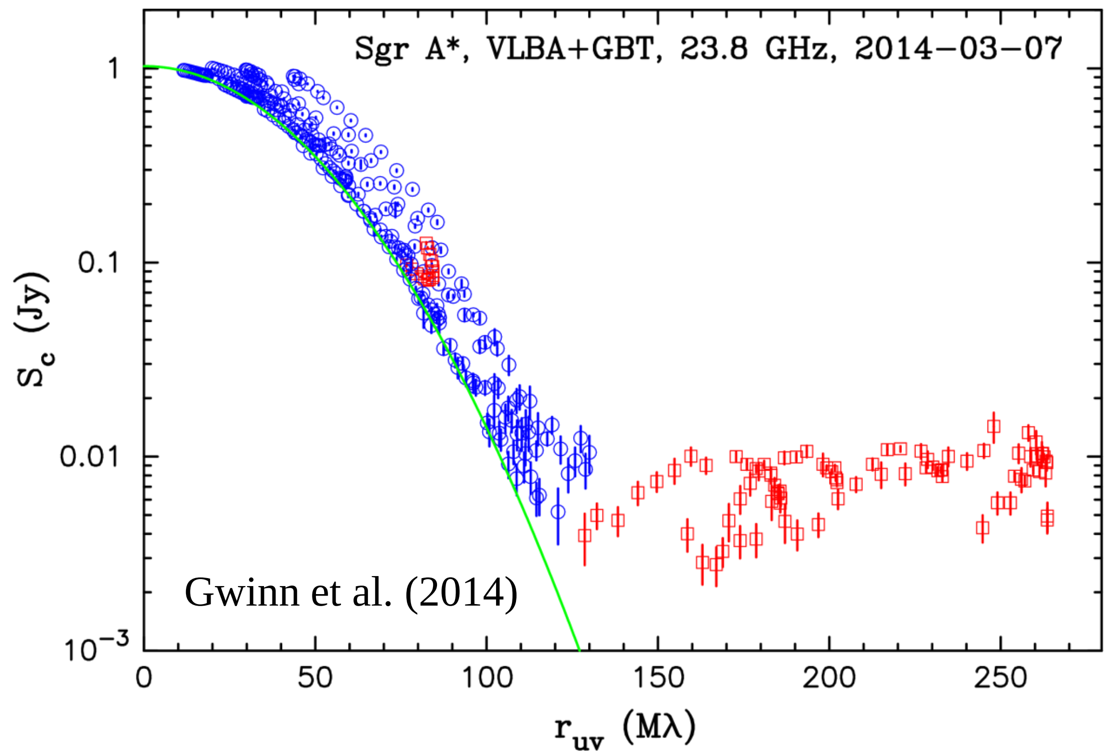


Johnson et al. (2015)

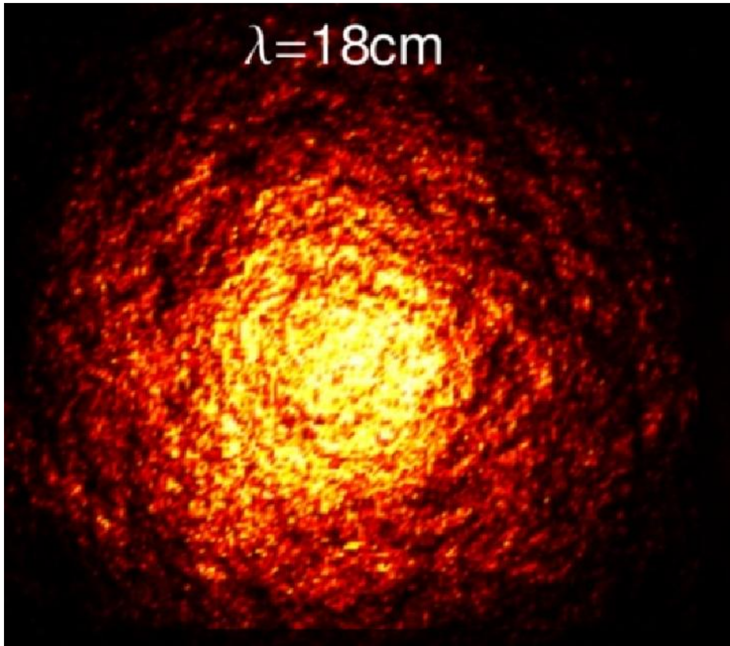
Fractional correlated linear polarization is found to rise dramatically with projected very long baseline in quasar cores. Highly ordered magnetic field in a single or multiple very compact regions within the core can explain the data.

Discovery of the scattering sub-structure



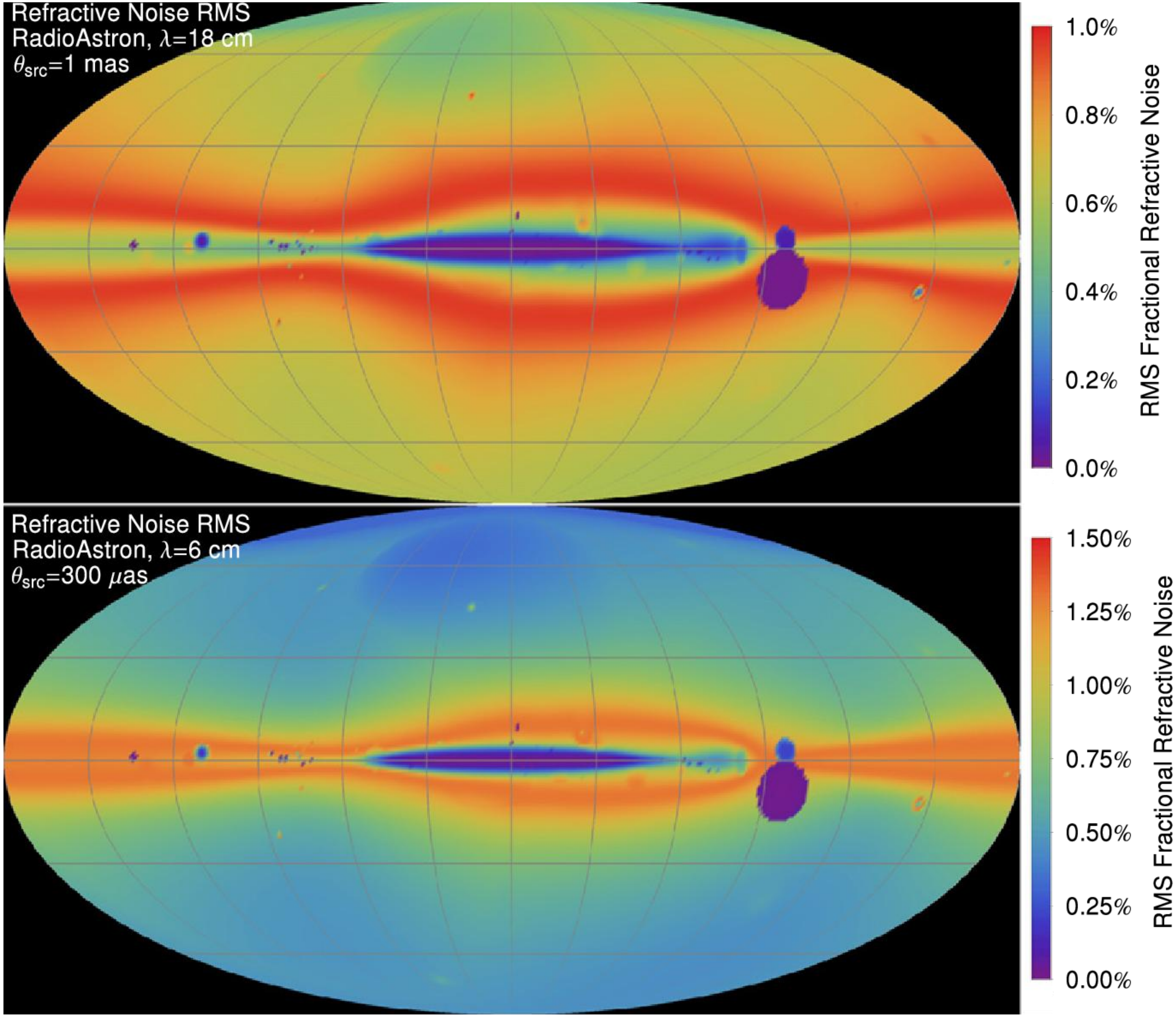


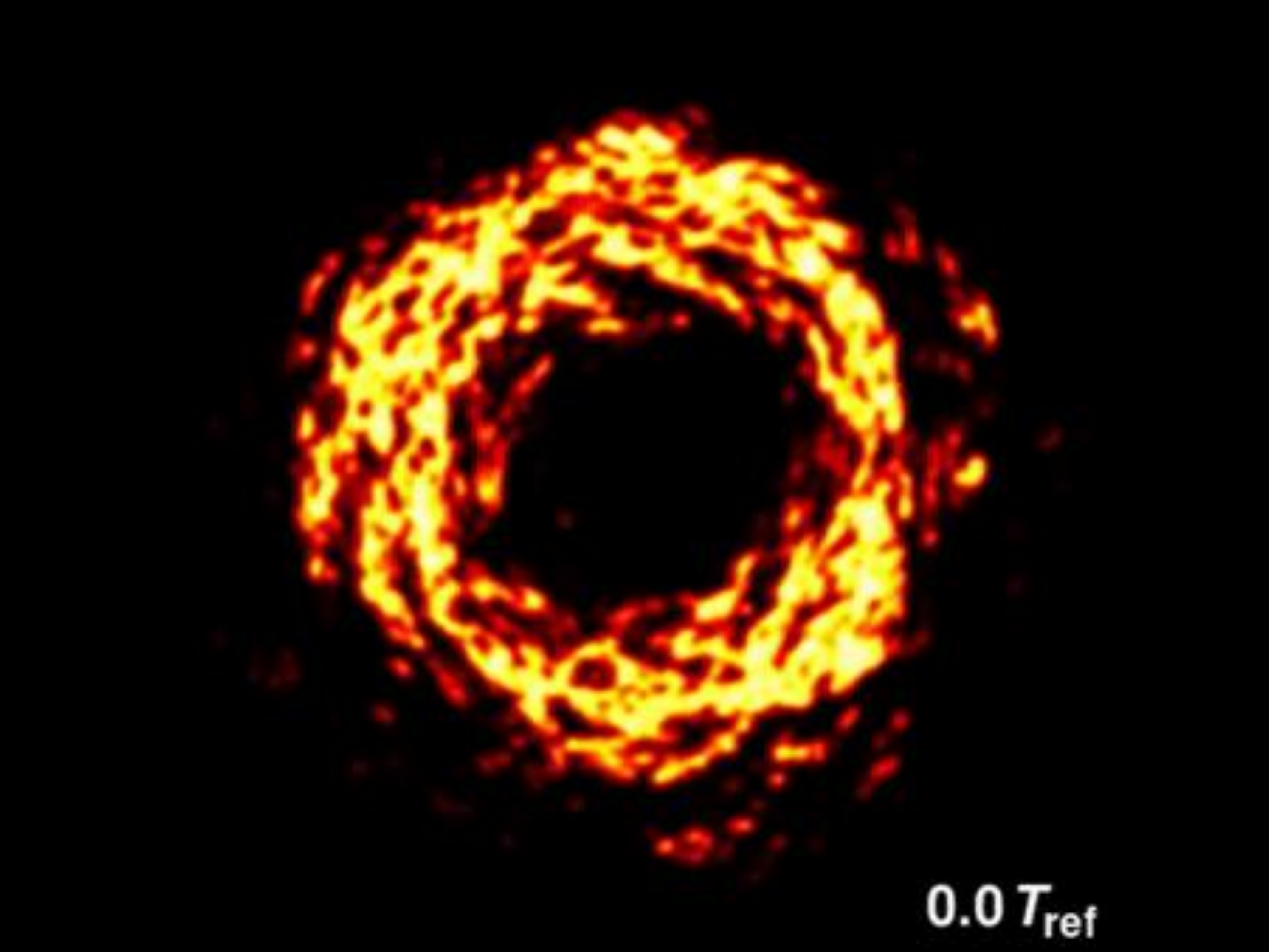
- A tool to probe turbulent interstellar medium.
- Must be taken into account by RadioAstron and Event Horizon Telescope.
- A new promising tool to reconstruct the true image of observed background target.



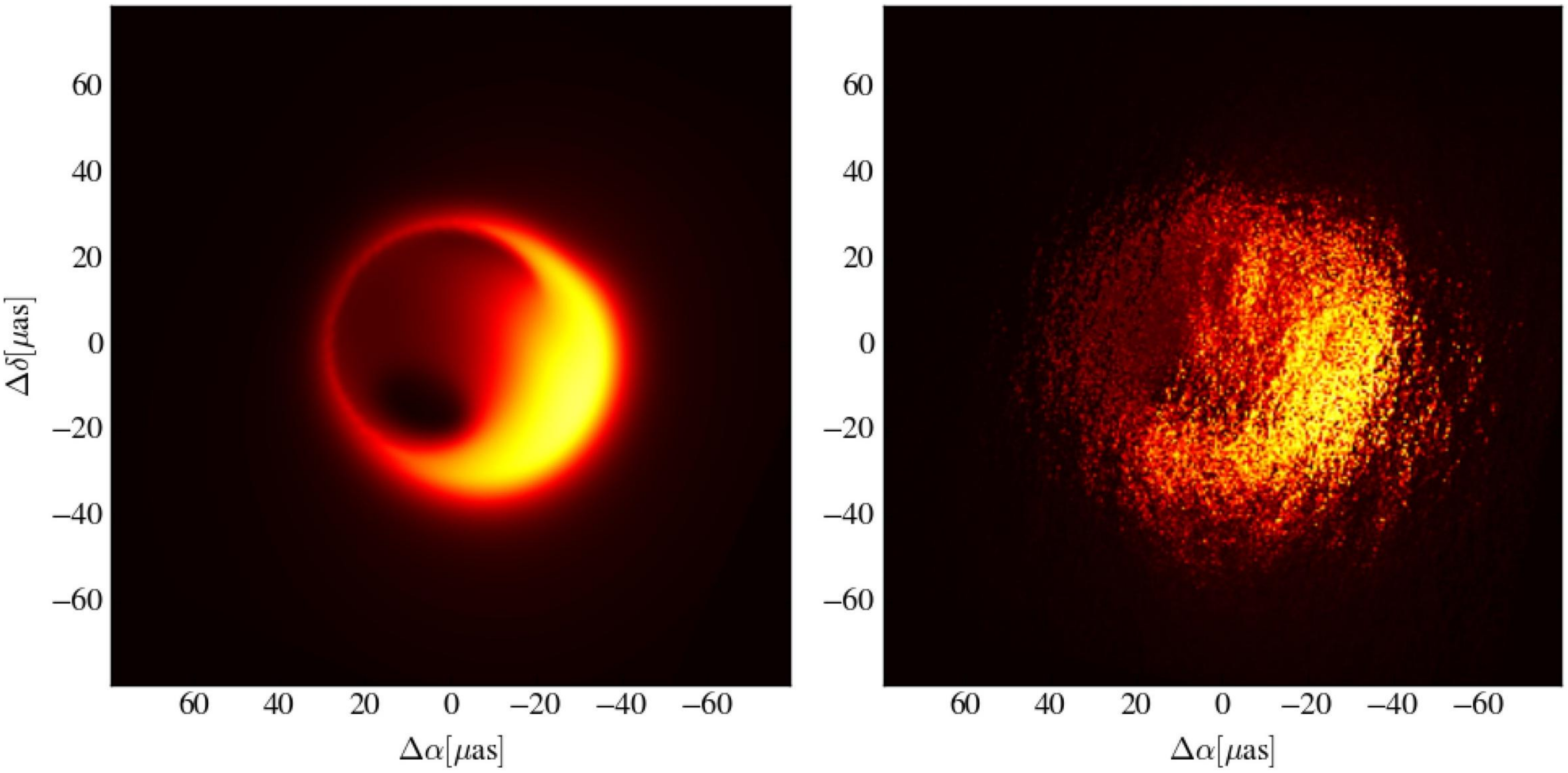
Modeling the sub-structure contribution

Johnson & Gwinn (2015)




$0.0\ T_{ref}$

SgrA* black hole shadow model



Broderick et al. (2016)

Summary

- AGN cores appear in RadioAstron observations as bright as 10^{12}-10^{14} K, at least about 10 times brighter than what was known before. In the same time, no 10^{15}-10^{16} K values are found within our conservative method of measurements.

- No apparent explanation why this could be the case. Equipartition between particles and magnetic field does not seem to be typical in blazar cores.

- Even more compact regions with highly ordered magnetic field are found in polarization. Indication of magnetic re-connection?

- The discovered scattering sub-structure is our friend and enemy: ISM versus true source structure.

THANK YOU