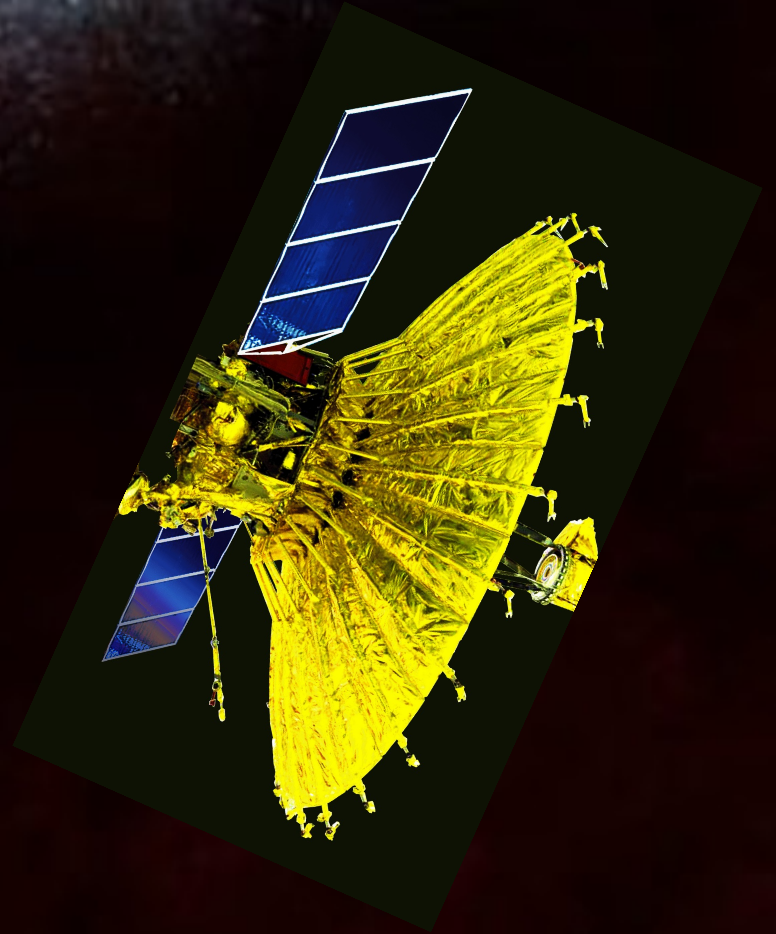
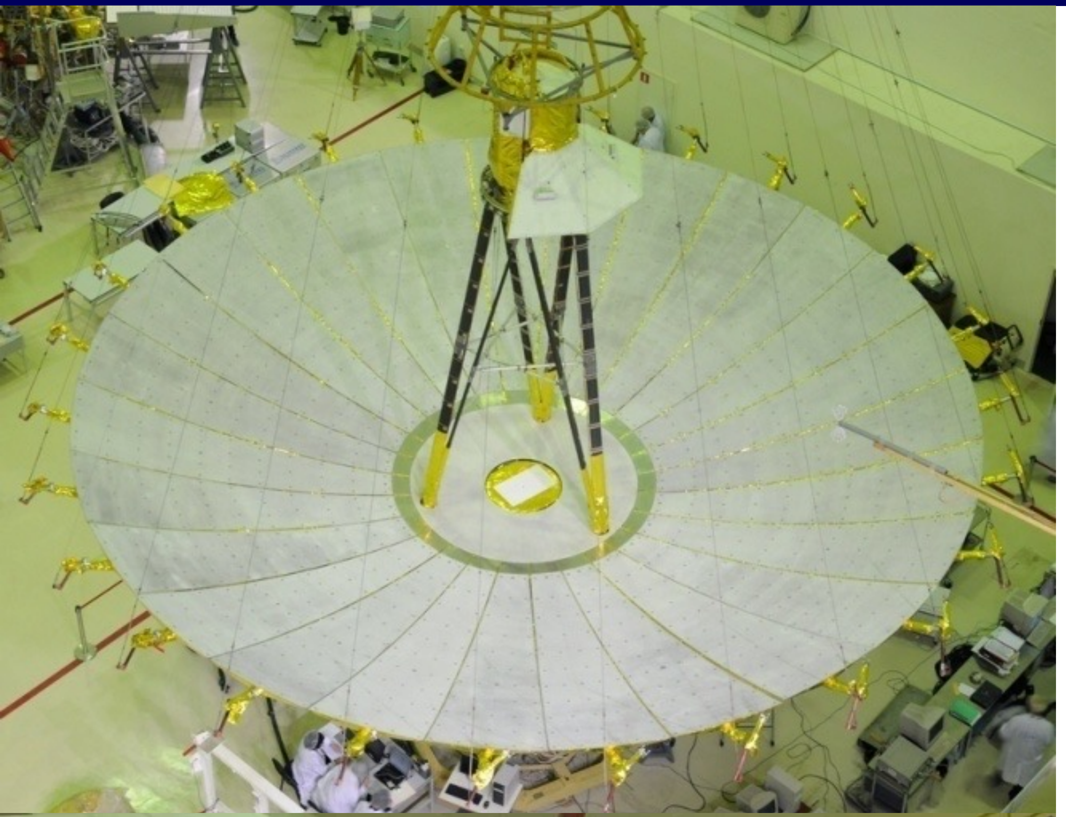
RadioAstron: scientific highlights



Yuri Kovalev (MPIfR and LPI)

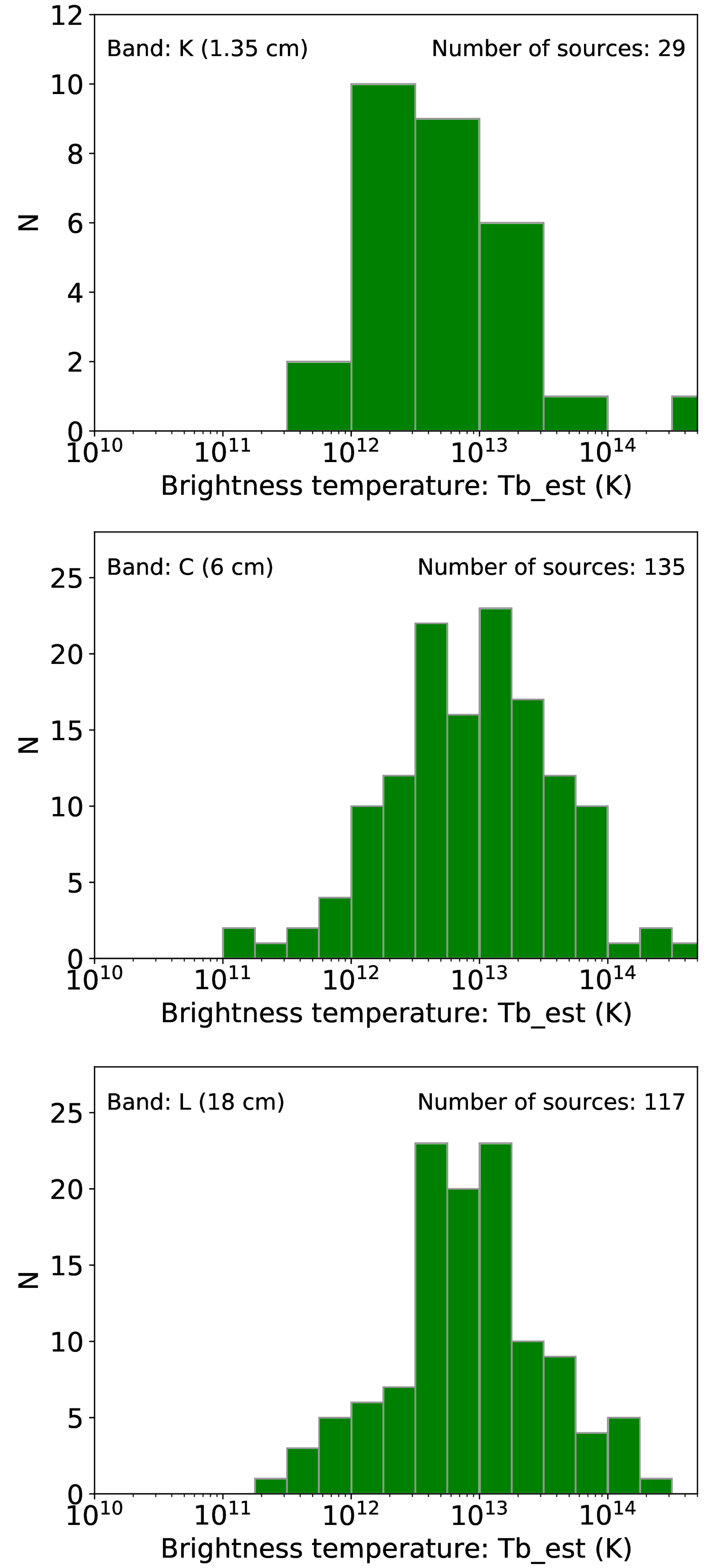
ngSVLBI-3 workshop, 17 October 2022

RadioAstron: general information



✓ Space radio telescope: 10-m; launched in 2011.
✓ Frequency bands: **0.3, 1.6, 5, 22 (18-25) GHz** with **polarization** capability.
✓ **Dual-band** observing capability.
✓ Apogee **350,000 km**. Resolution up to 8 μas (mega maser NGC4258).
✓ **Real time tracking** station: Pushchino, Russia; Green Bank, USA. Bit rate from space: 128 Mbps. Ground based: 256 Mbps.
✓ **Two methods of time synchronization**: space and ground-based H-masers.
✓ **Software correlators**: ASC, DiFX-Bonn, JIVE SFXC.
✓ GRTs: up to 58 around the world.
✓ Open assess since 2013.
✓ Raw data are stored for re-analysis. 4 PB collected.
✓ **Main science areas**: quasars and nearby AGNs, pulsars, masers, scattering, gravitational redshift. About 270 targets observed.
✓ Communication lost on Jan 10, 2019, after 7.5 years of operations. Expected lifetime: 3 years.
The mission has officially ended in May 2019.
✓ **Scheduling limitations**: solar and thermal constraints, by the tracking stations, availability of GRTs (Jauncey talk), and 1.3 cm weather.

RadioAstron survey completed:
AGN cores at unprecedented angular resolution



- 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 survey is finished. Out of 248 observed AGNs 164 were detected in about 1/3 of segments at 18 or 6 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.
- Extreme brightness of AGN cores is discovered. AGN cores are found to be at least 10 times brighter than predicted and observed before.

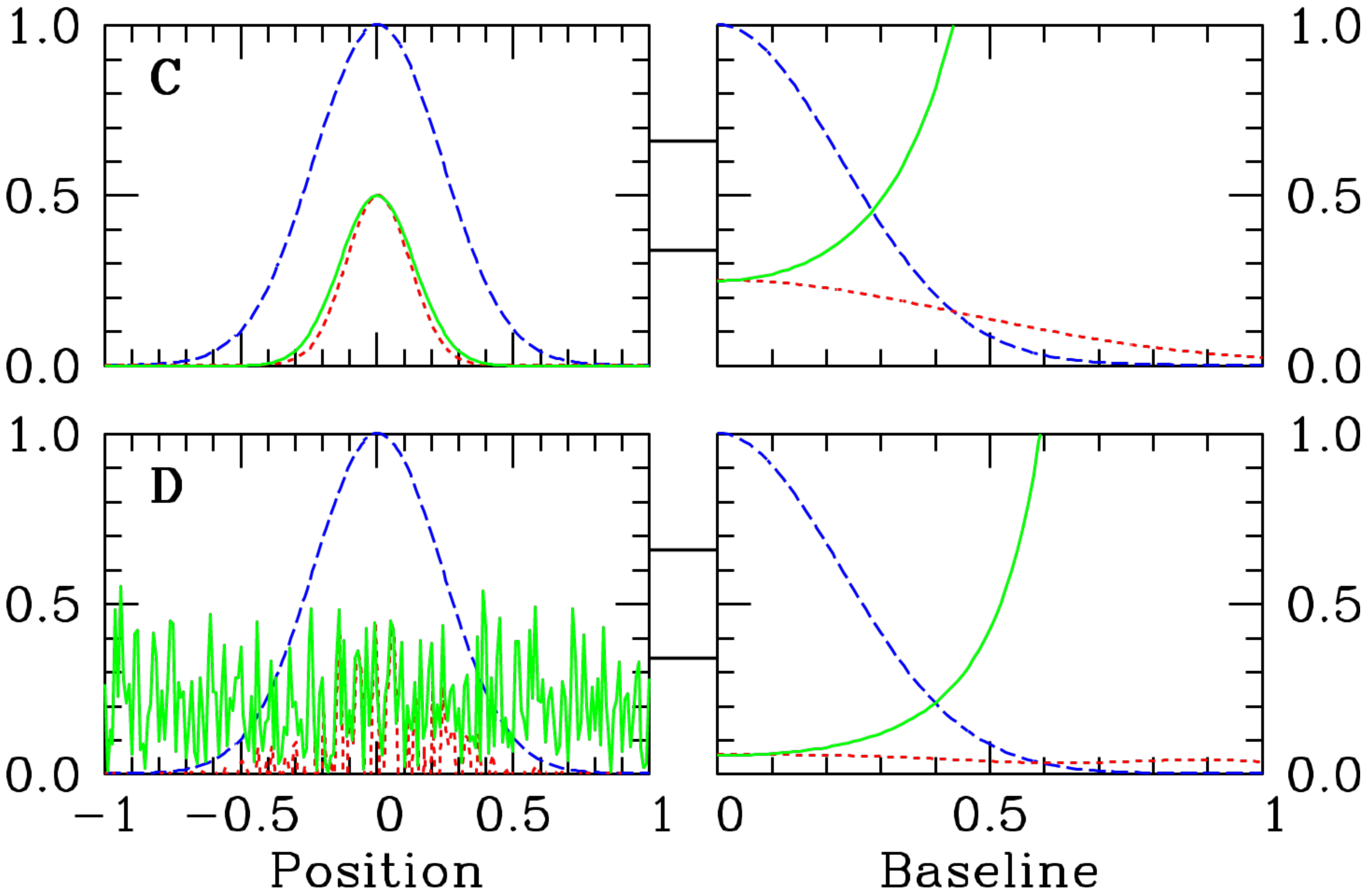
- Options: extreme Doppler boosting (??), Compton catastrophe during flares, re-acceleration parsecs away from the nucleus (magnetic reconnection?), synchrotron emission of relativistic protons.

The latter might have an interesting connection to high energy neutrino association with radio blazars. We need to understand jet acceleration better, need to image both cores and jets.

Polarization at long SVLBI projections

Stokes I
Linear P
Fractional p

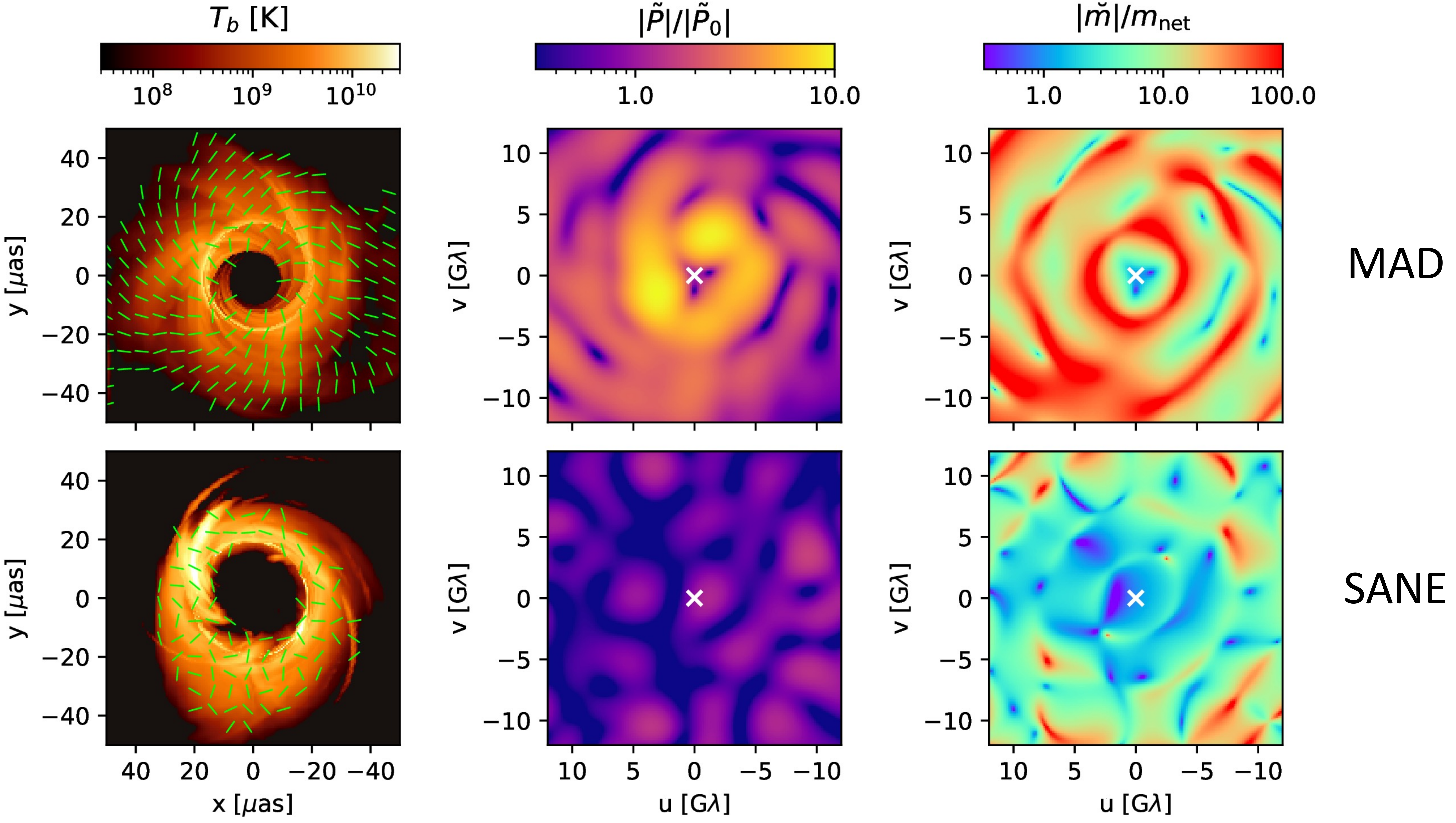
Johnson et al. (2015)

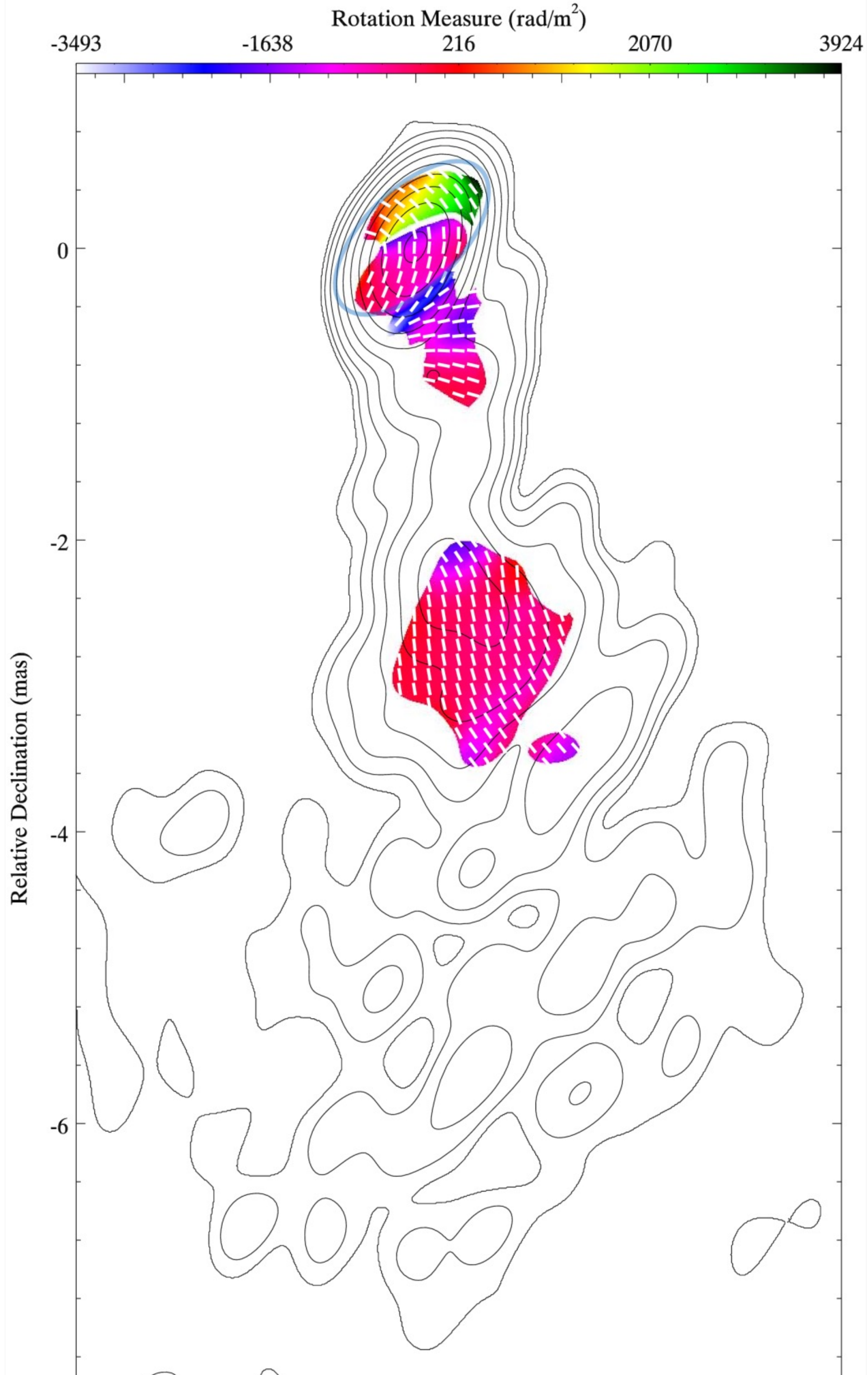


Fractional correlated linear polarization is found to rise dramatically with projected very long baseline in quasar cores: 3C279 is here again together with about dozen other blazars. Highly ordered magnetic field in a single or multiple very compact regions within the core can explain the data.

Modeling polarization at long spacings

Ricarte+22 (in prep).





BL Lacertae: polarization imaging at 1.3 cm

Numerical 3D RMHD simulations managed to model RadioAstron RM gradient results if toroidal magnetic field is assumed for the jet base.

More on polarization: talk by Gabuzda.

Gomez+16

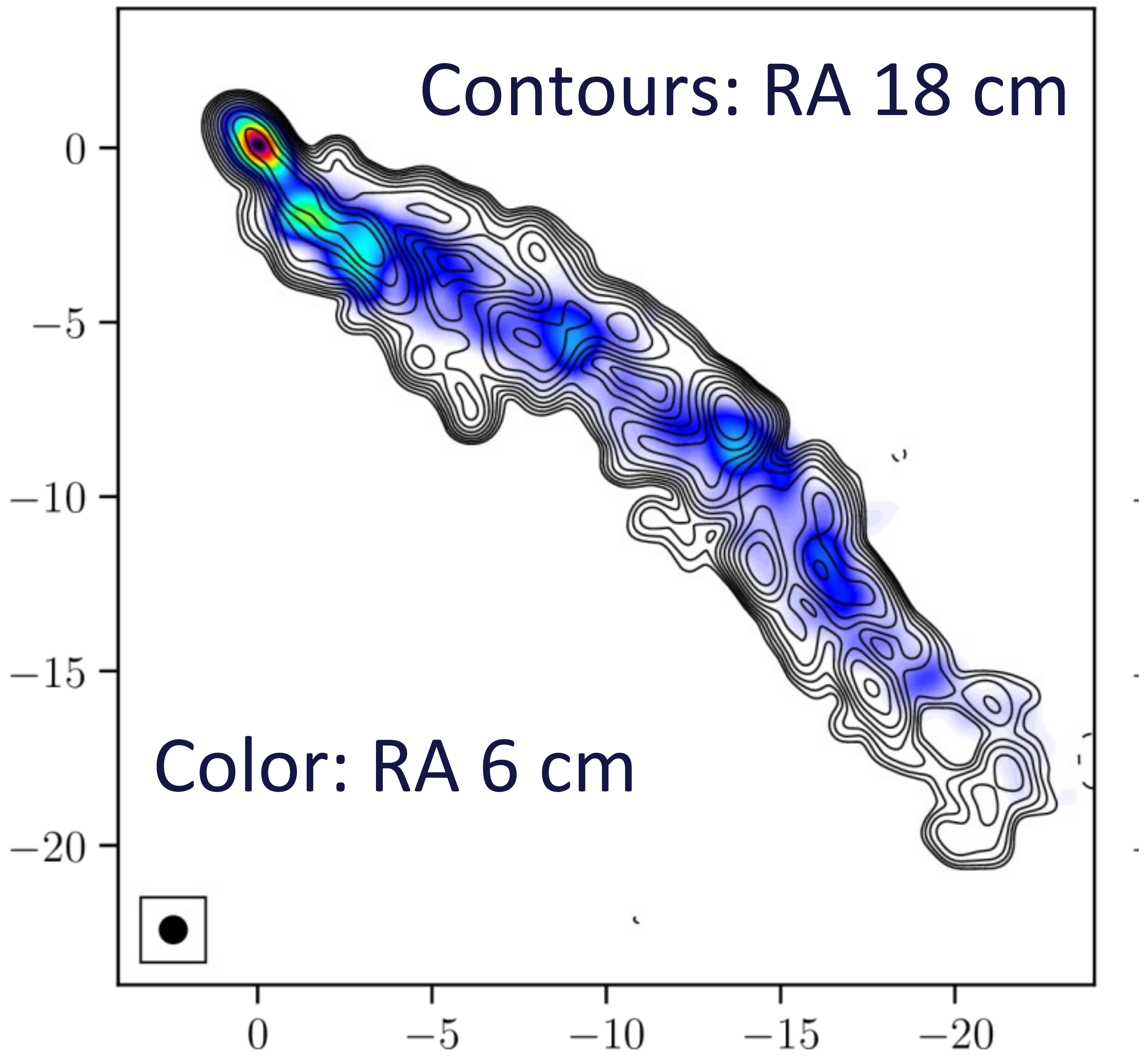
Observations of OJ287 at K-band

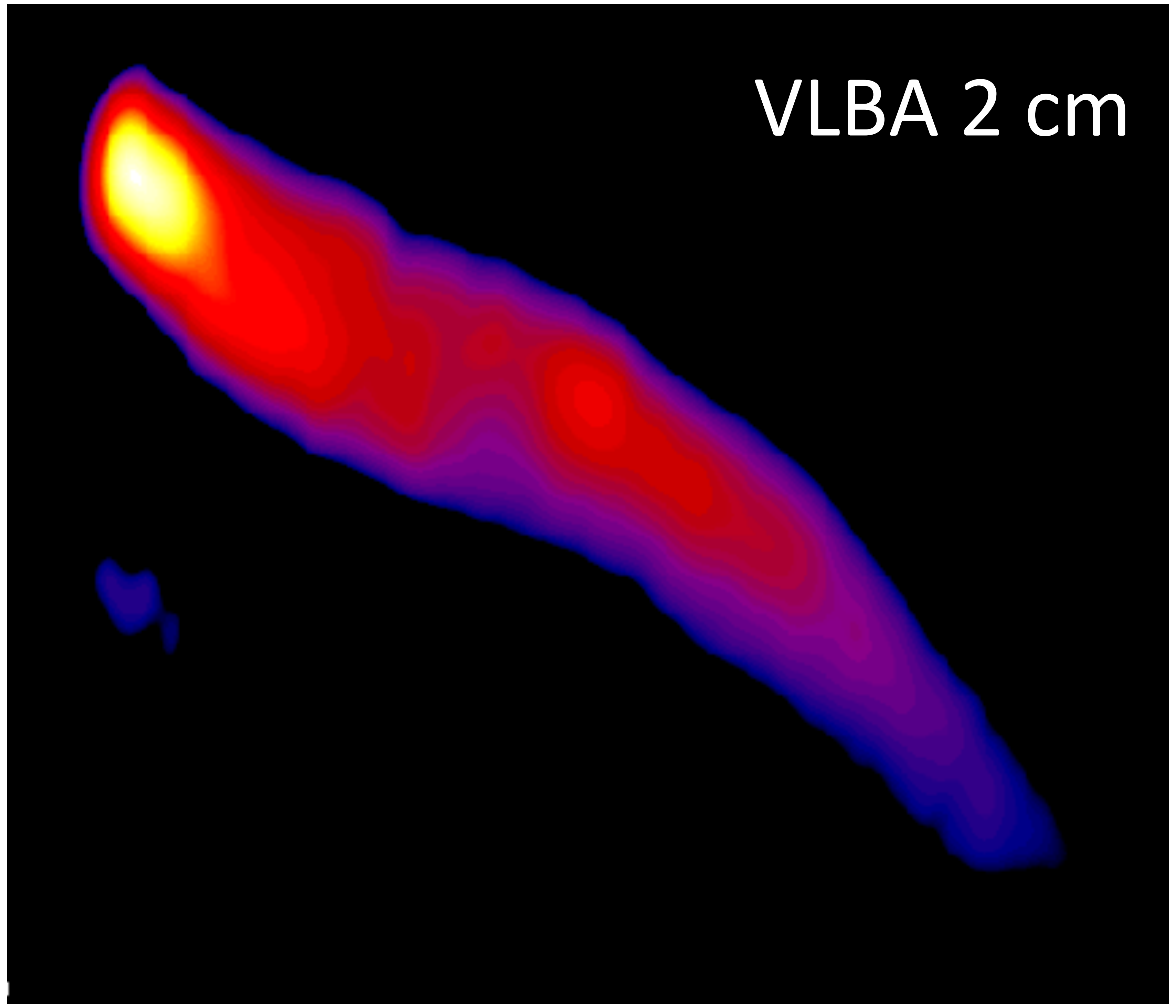
RadioAstron "Polarization" Key Science Program

The helical jet structure as well as the innermost swing rotation are in qualitative agreement with supermassive binary black hole model.

Gomez+22

Extreme jet stratification in 3C273



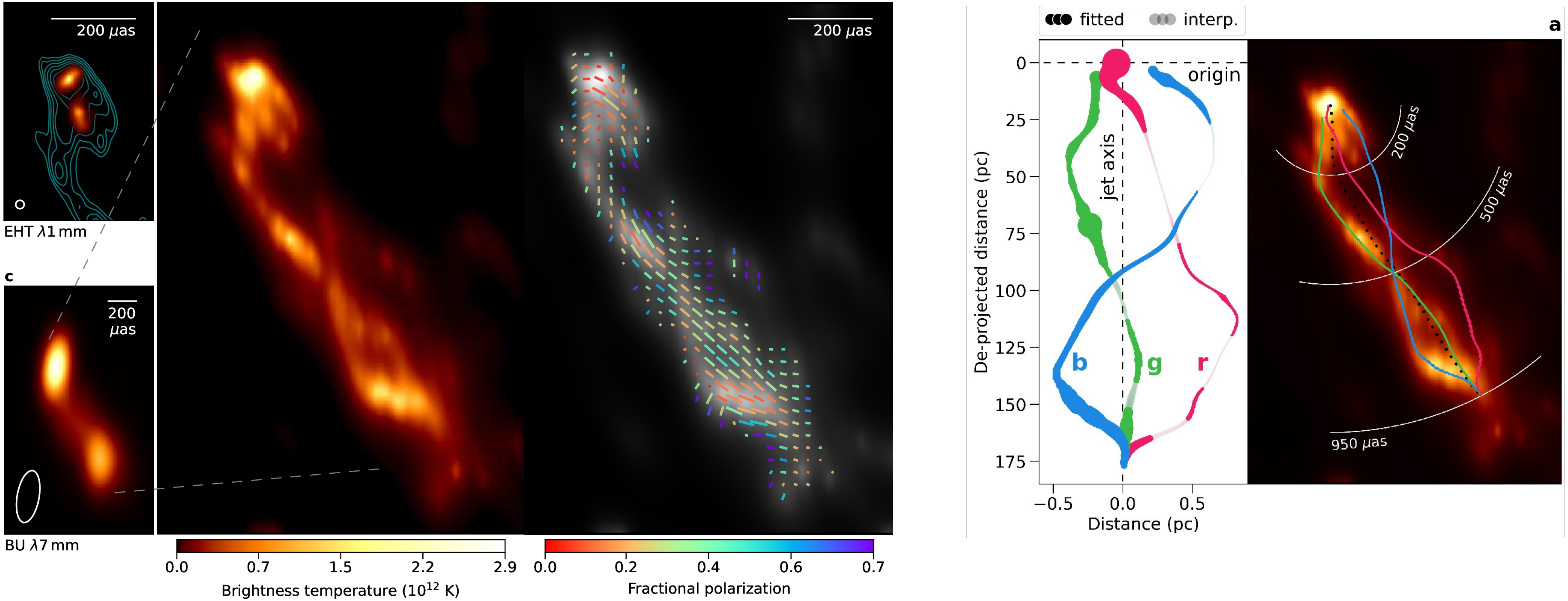


3C273 jet shows a clear edge brightening at 18 cm and at the same time a bright spine at 6 cm.

- ➢ Extreme plasma stratification and strong Doppler boosting gradient? Not enough.
- ➢ A steep energy density or opacity gradient related to helical magnetic field structure.

Bruni+21

Plasma instability in 3C279



Filamentary structures in the jet of 3C279 produced by Kelvin–Helmholtz instabilities which are threaded by a helical magnetic field.

Fuentes+22, see talk by Gomez

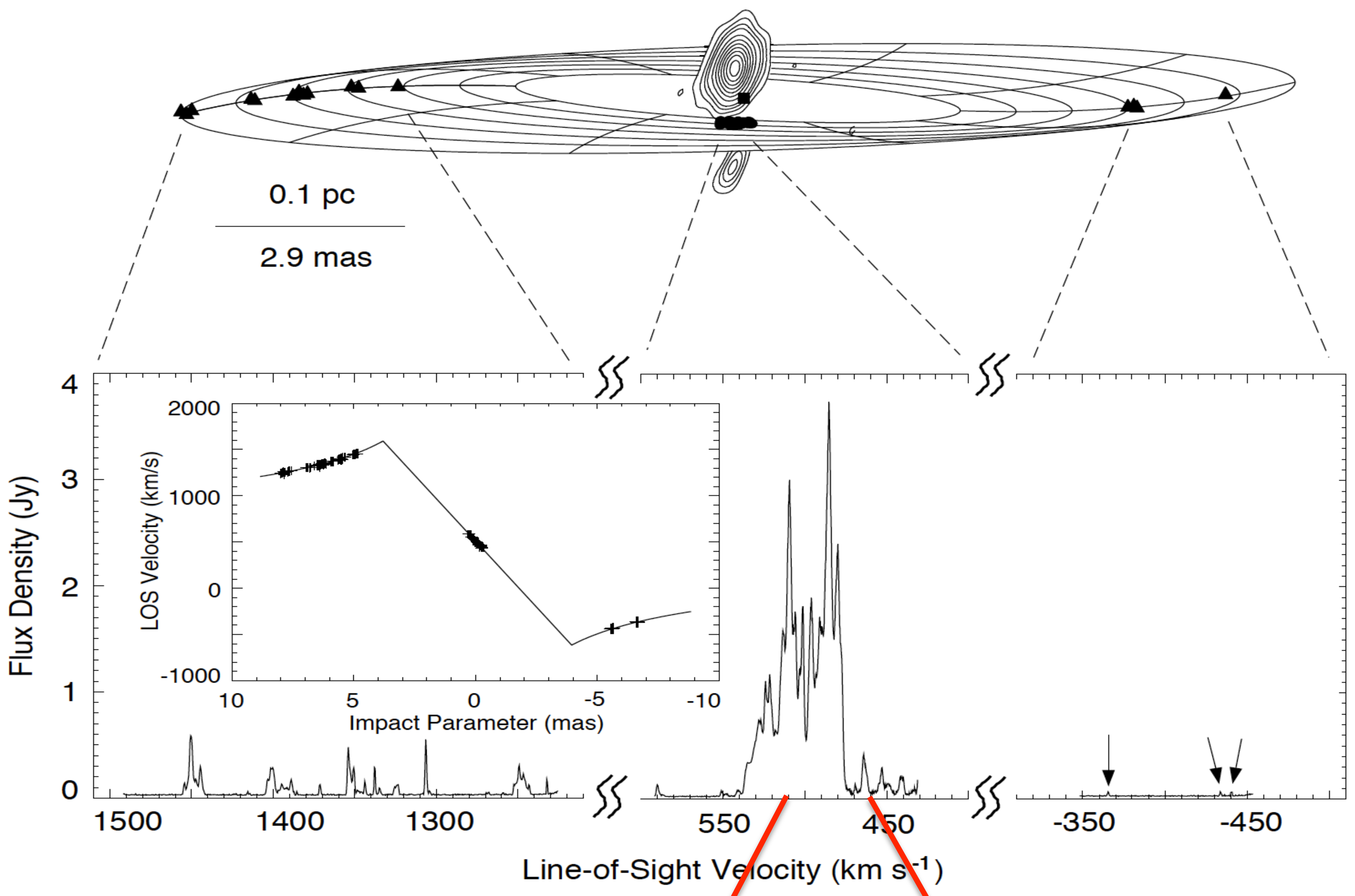
Extragalactic H_2O masers: 1.3 cm

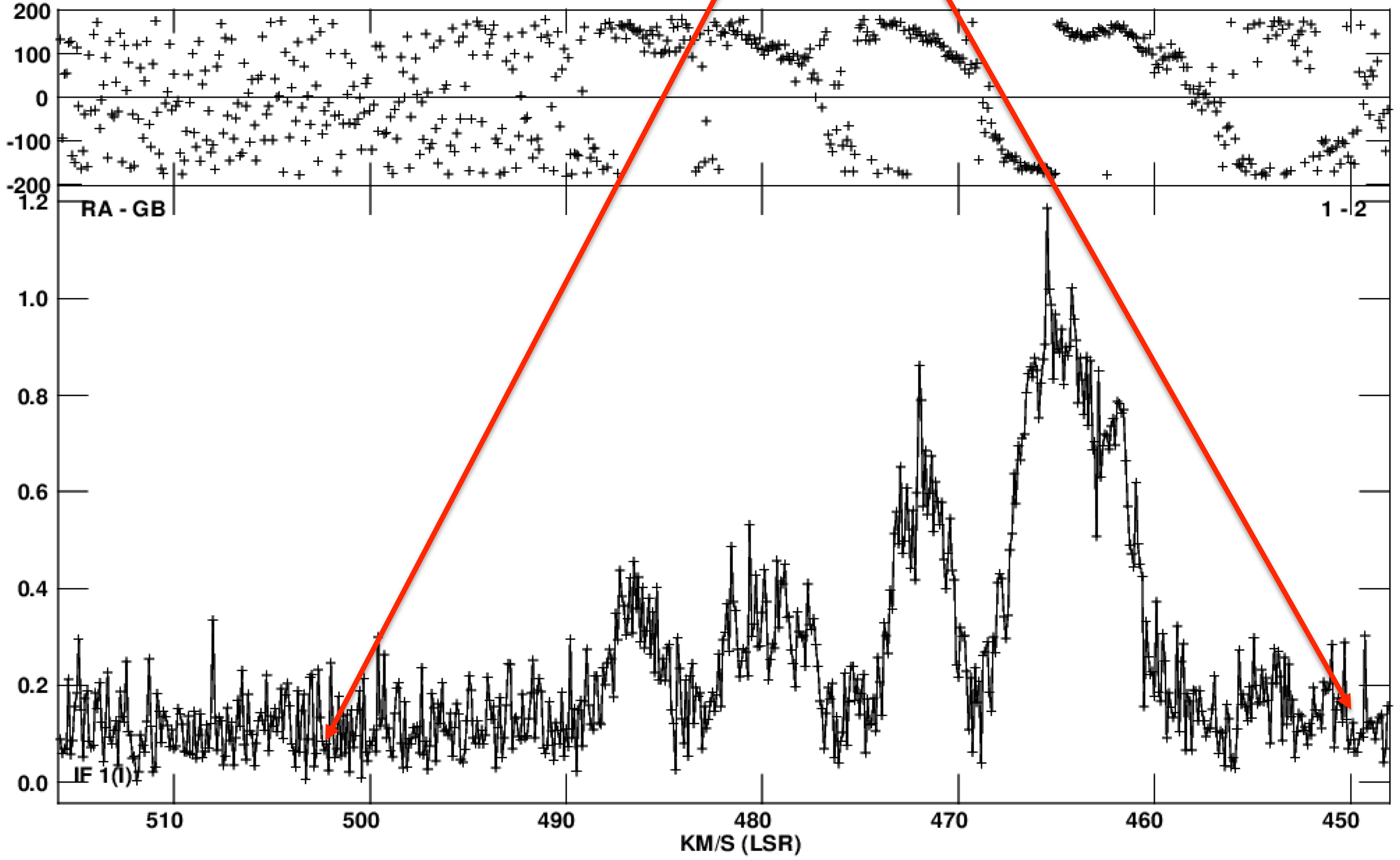
RadioAstron has found ultra-compact regions of maser emission in the accretion disk of the galaxy NGC4258:
detection at projected baseline of 26 Earth diameters, 8 μas.

Individual components are probably unresolved (≤3 μas), need higher angular resolution.
Star forming regions?

Thickness of accretion disk is about 10 μas.

Constraints kinematics and dynamics of the accretion disk.

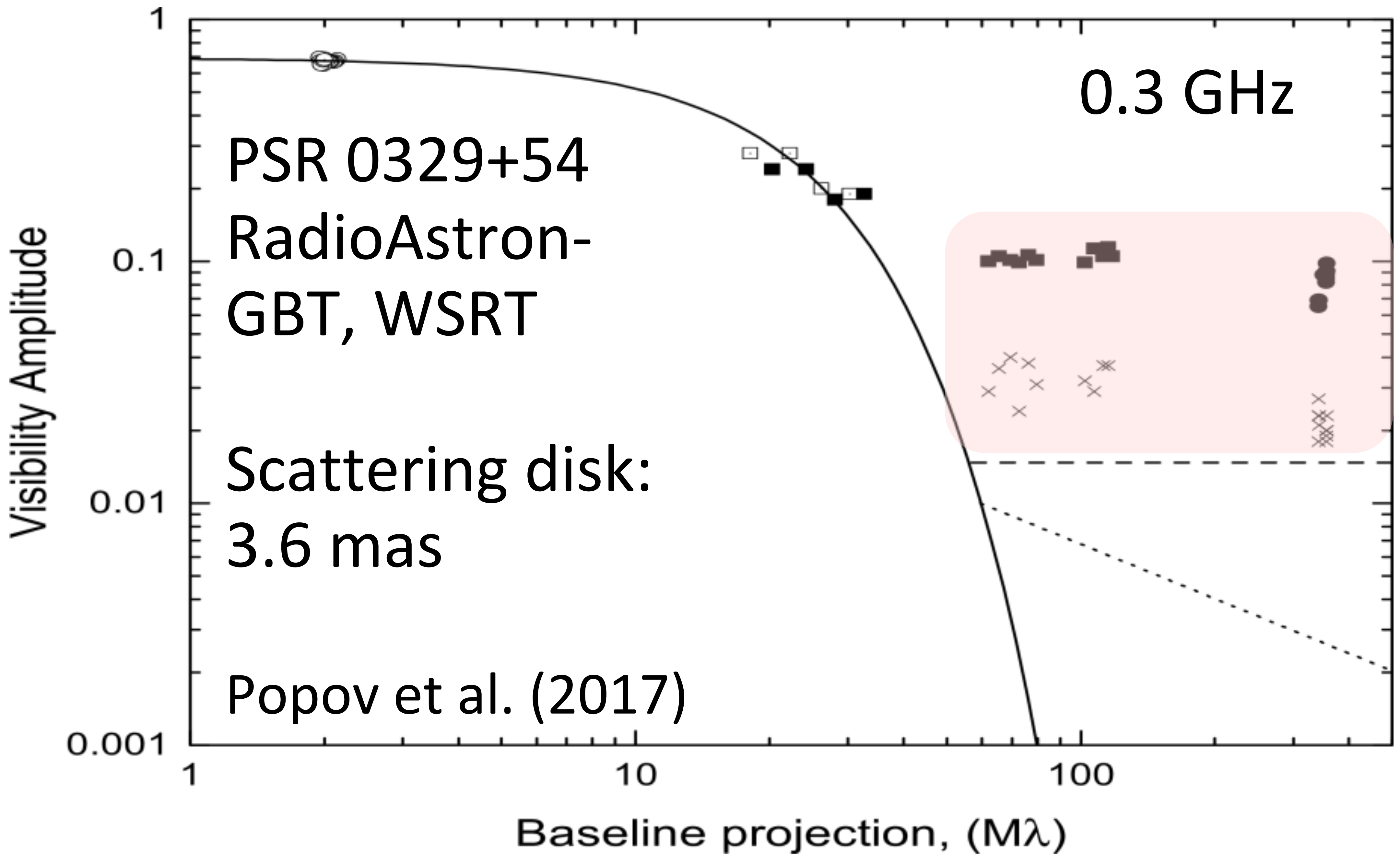


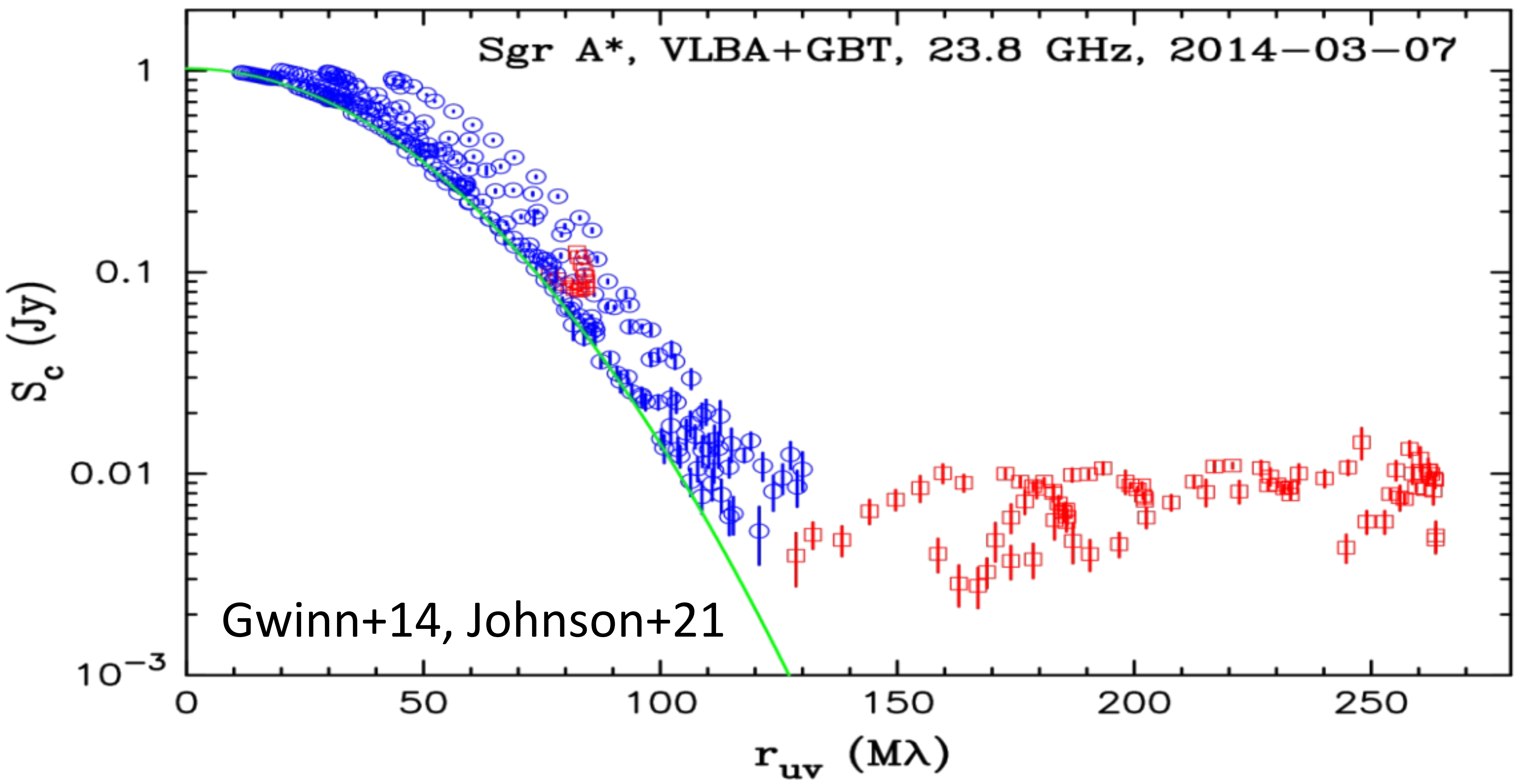


Baan+2

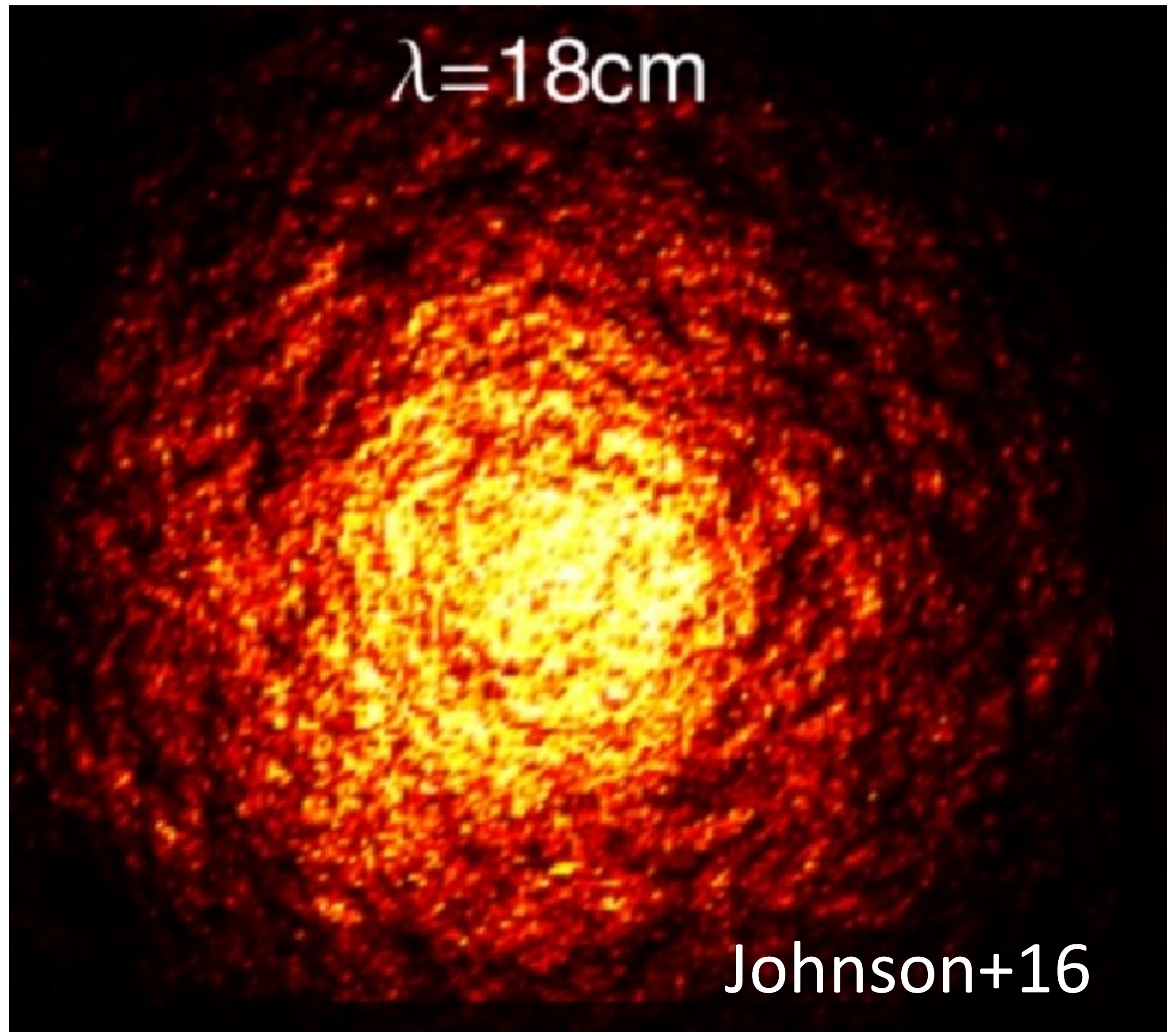
See talk by Bayandina for details.

Discovery of the scattering sub-structure



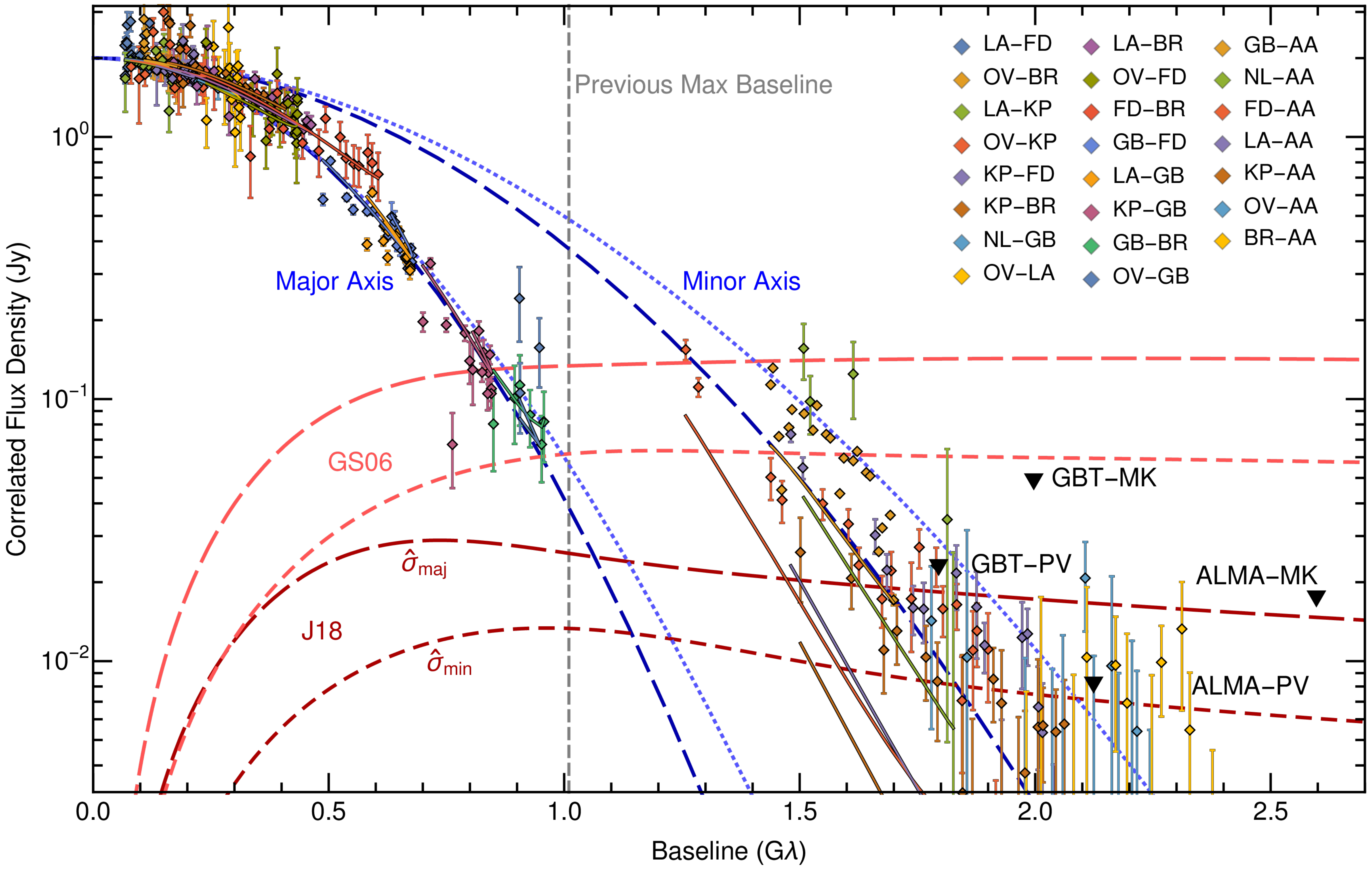


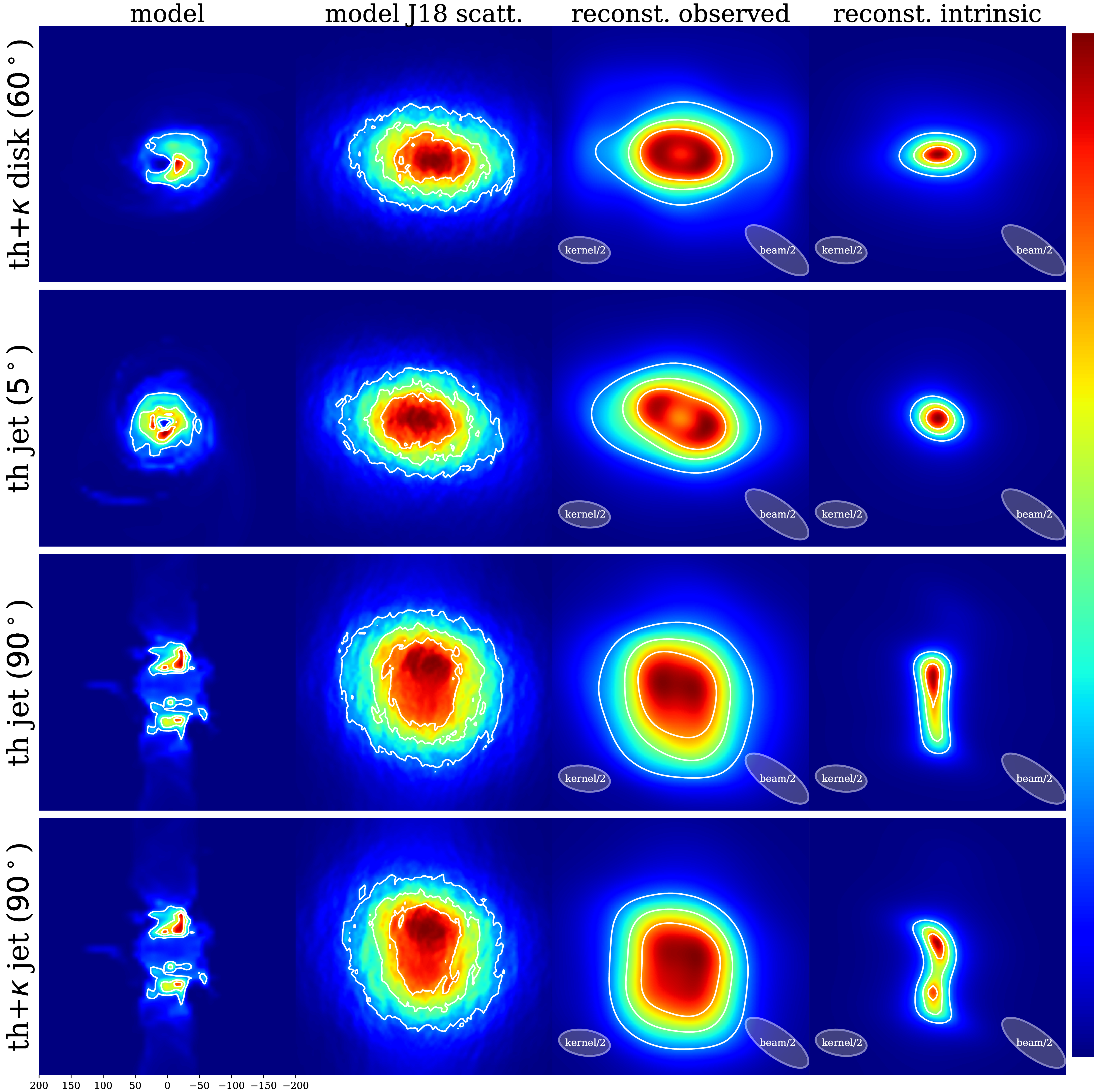
- A tool to probe turbulent interstellar medium.
- Should be taken into account by high resolution VLBI experiments, important for SgrA* even at high frequencies (Johnson+18).
- A new promising tool to reconstruct the true image of observed background target.



See the talk by Gwinn for details.

3 mm SgrA* ground VLBI results: scattering



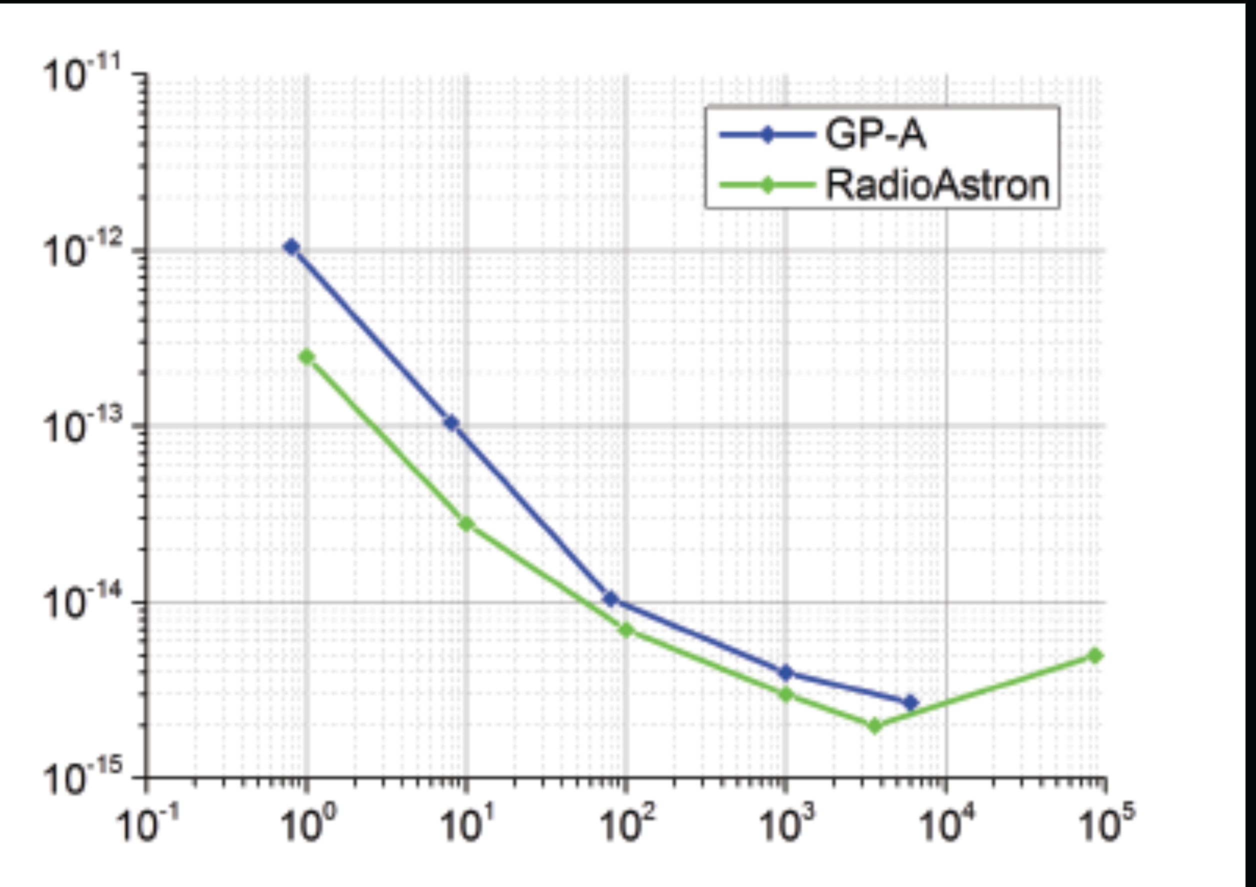


And this was indeed done for SgrA* at 3 mm.

- Scattering screen properties studied.
- Characteristics of the unscattered image reconstructed.

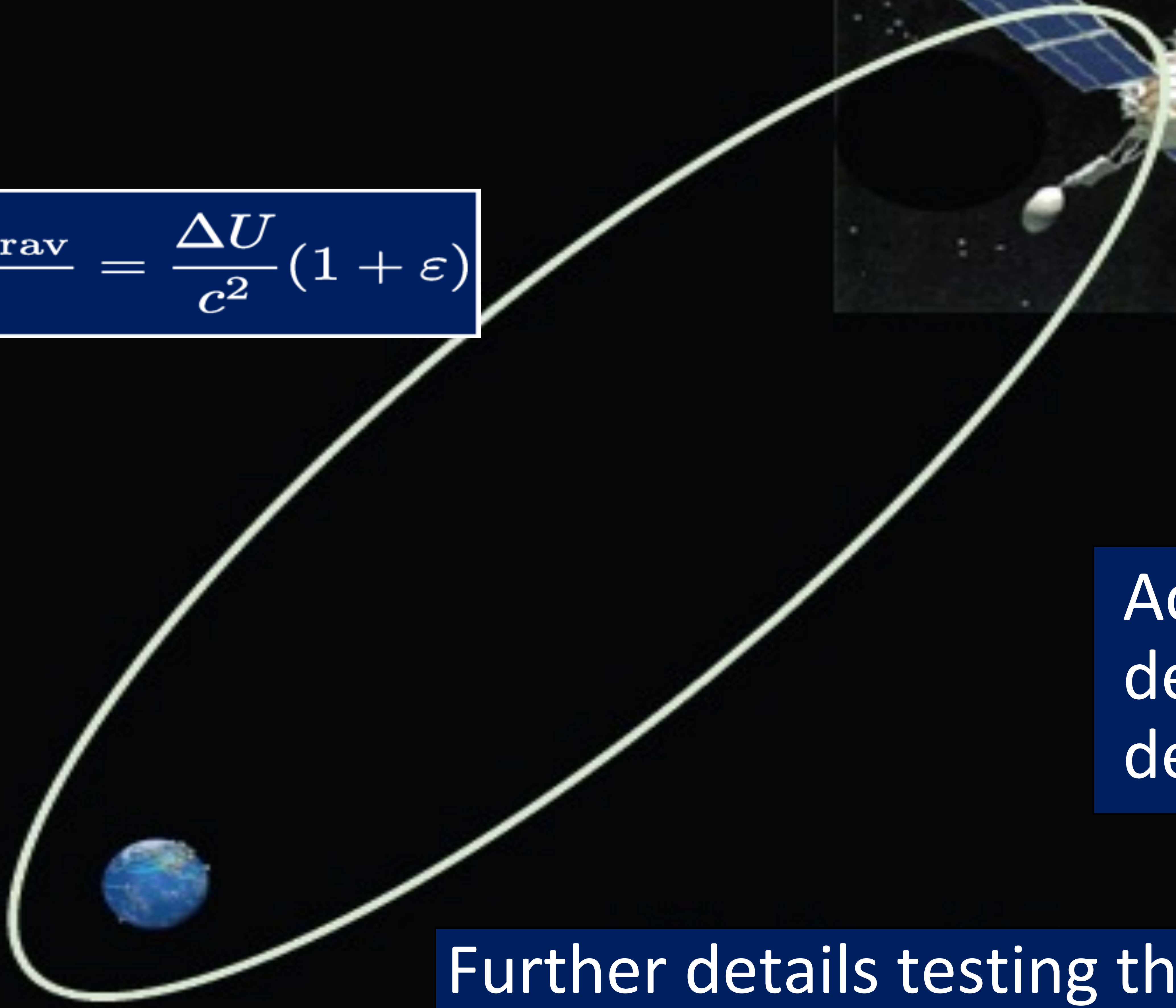
Issaoun+19

Probing gravitational redshift for potentially most sensitive test of general relativity



RA: Better H-maser stability:
$\sigma_y = 2\times10^{-15}$ at 1 hr

$$\frac{\Delta f_{\rm grav}}{f} = \frac{\Delta U}{c^2}(1+\varepsilon)$$



H-clock-2

Accuracy:
de = 2×10^{-5} expected
de ~ 10^{-4} currently

H-clock-1

Further details testing the equivalence principle:
Method: Litvinov+2018, Phys. Lett. A 382, 2192
Prelim. results: Nunes+2020, Adv. Sp. Res 65, 790
See the talk by Bartel.

SVLBI science prospects: my take

CM SVLBI:

brightness temperature and scattering science, plasma instability studies. Better availability of ground instruments, higher SNR.

MM SVLBI:

BH demographics, the n=1,2 rings, acceleration and collimation studies. High energy neutrino production: where and how?

Polarization:

"Magical" properties: insight into core physics at very high resolution.

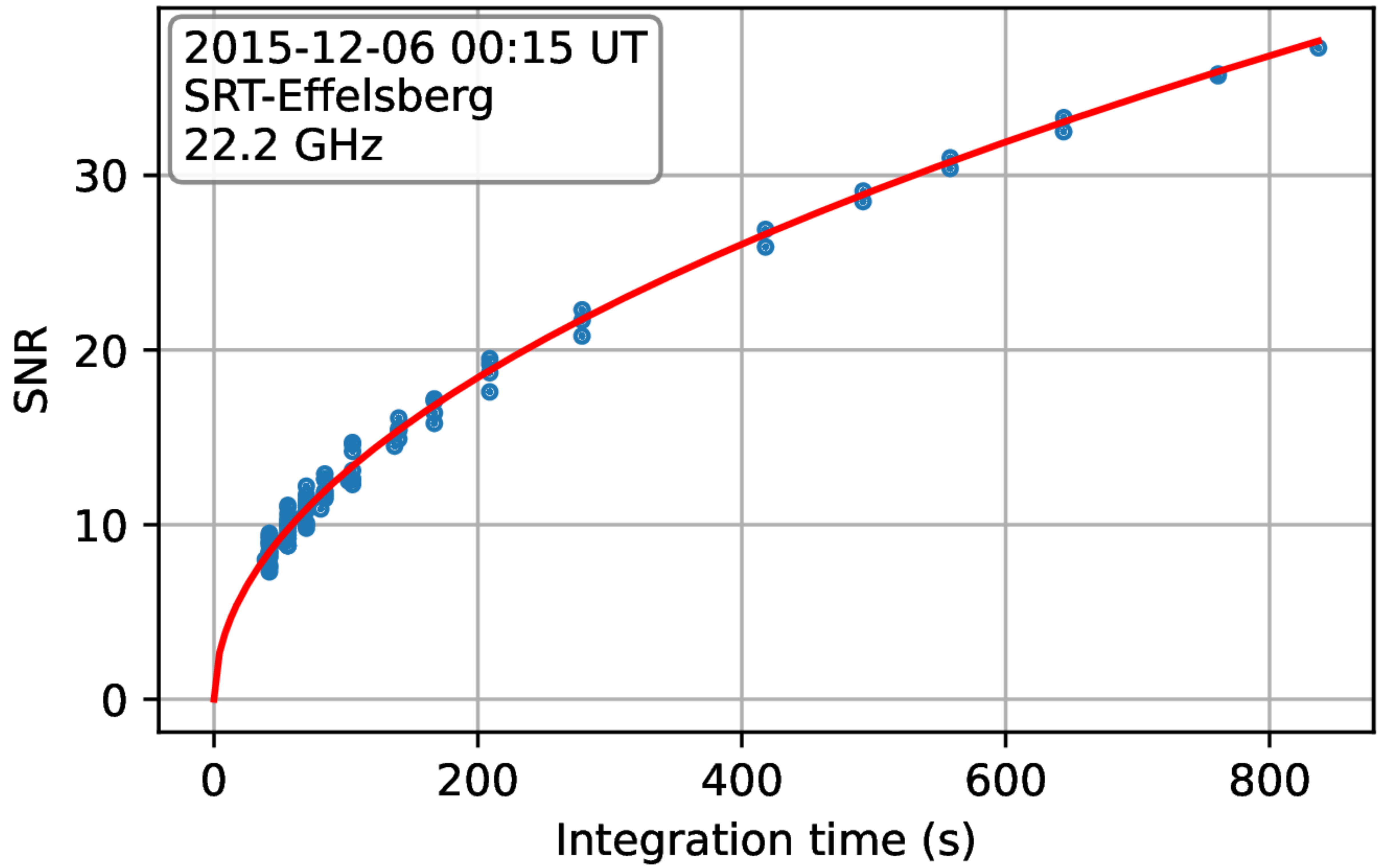
Multi-frequency ground and ground-space:

Faraday RM, magnetic field, spectral indexes, modeling. Also: improves uv-coverage, SNR and significance due to phase-transfer (talk by Rioha).

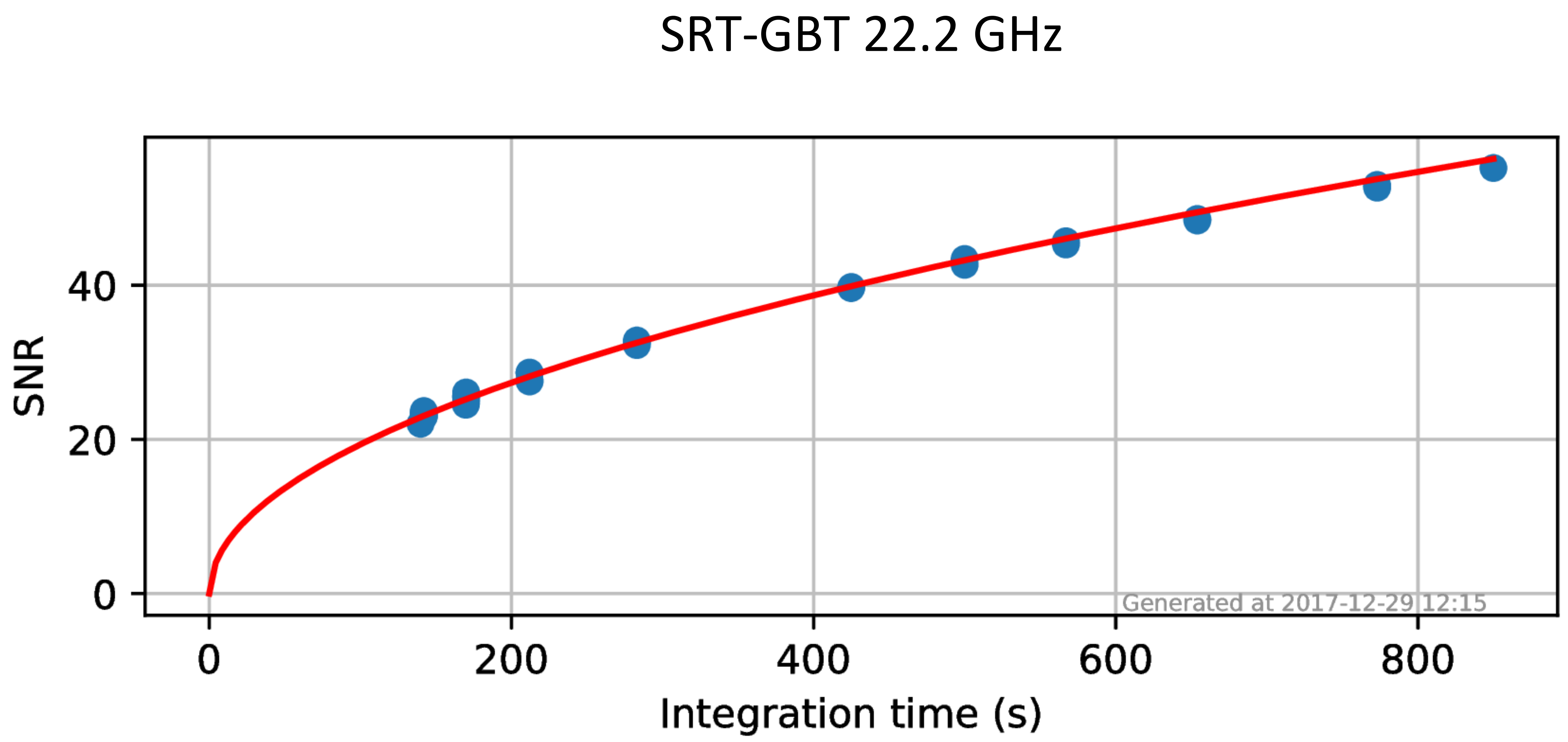

Thank you

Results of coherence tests: 1.3 cm

Open loop (space H-maser)

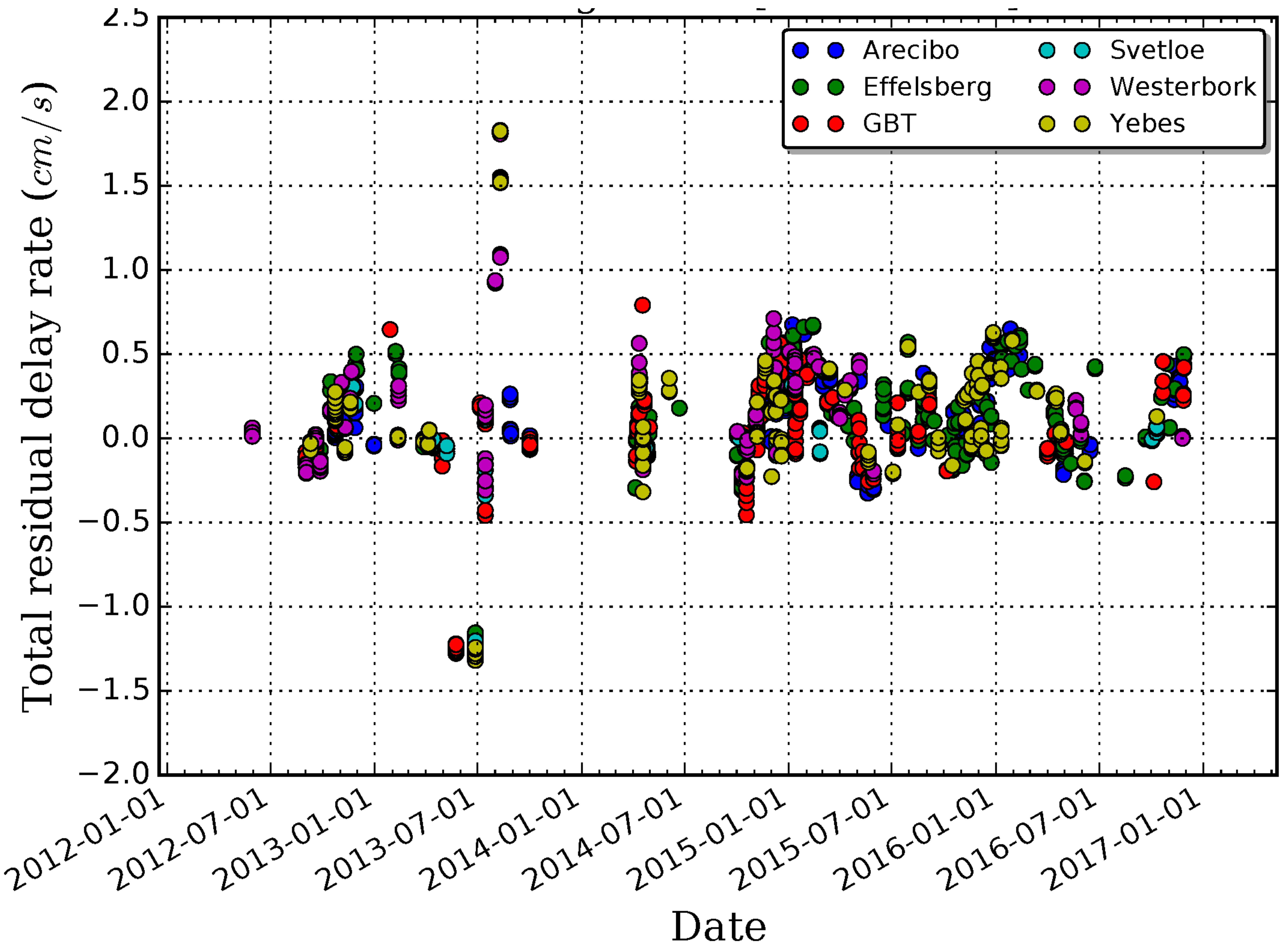


Closed loop



Under good weather conditions long coherence time can be achieved.
Only one telescope suffers being on this planet.

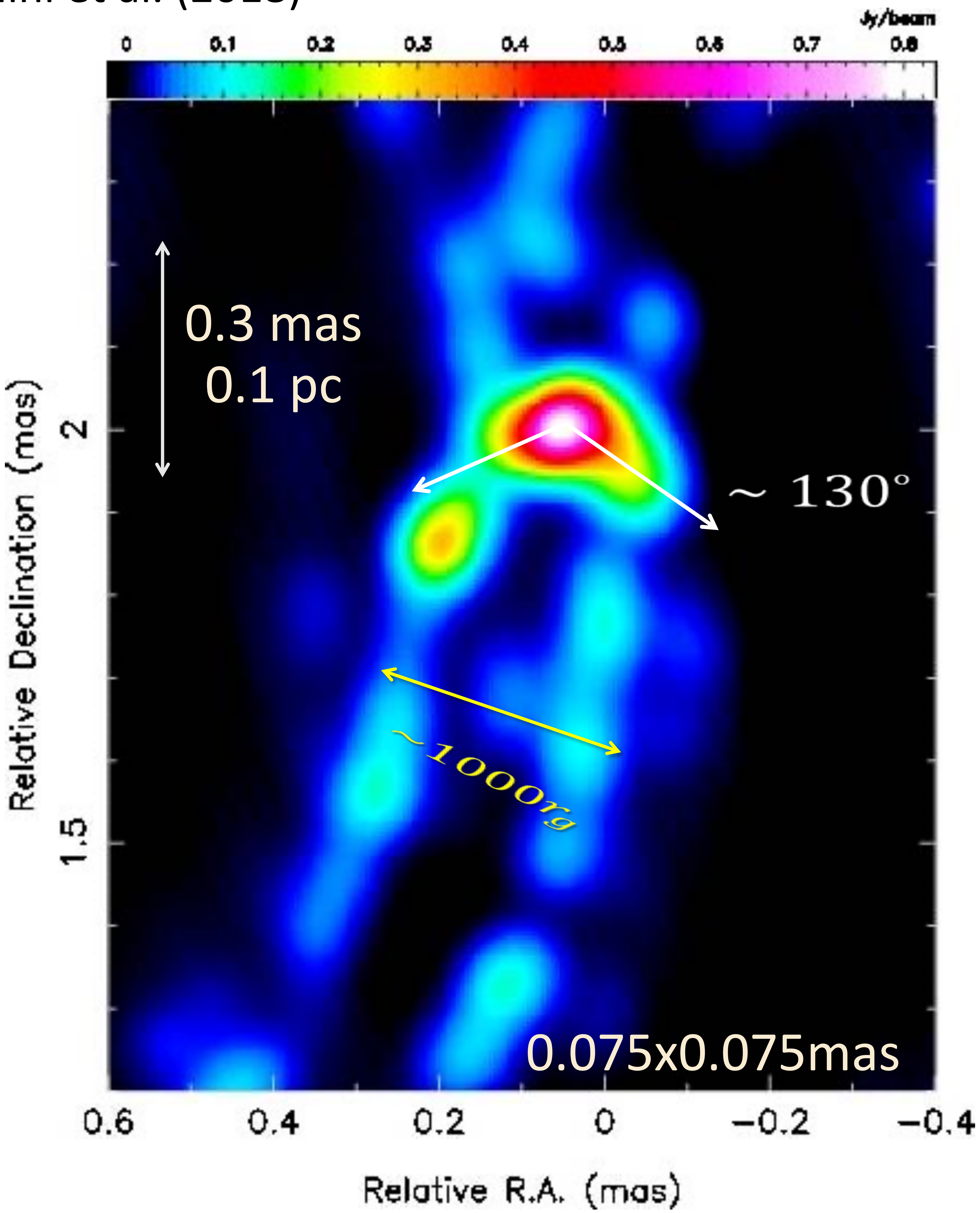
Multiple detections

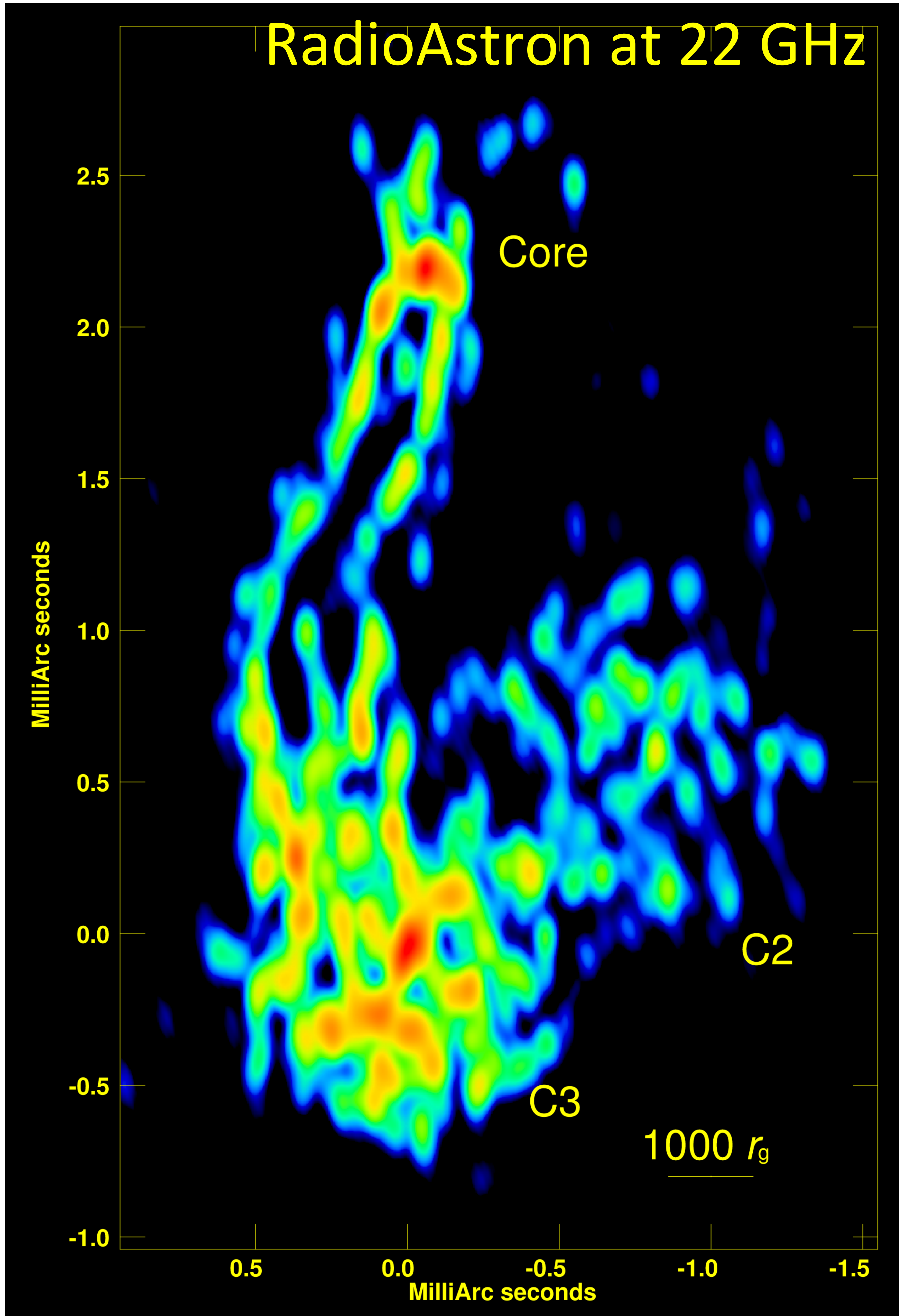


- ➢ Help to monitor and improve orbit reconstruction accuracy.
- ➢ Allow us to check significance of detections in case of low SNR for the higher frequency band.
- ➢ By monitoring the orbit reconstruction accuracy well and the overall SRT system which is not touched by our fellow engineers, we get not only detections but also firm non-detections with flux density upper limits.

3C84: jet formation and stratification of the plasma flow

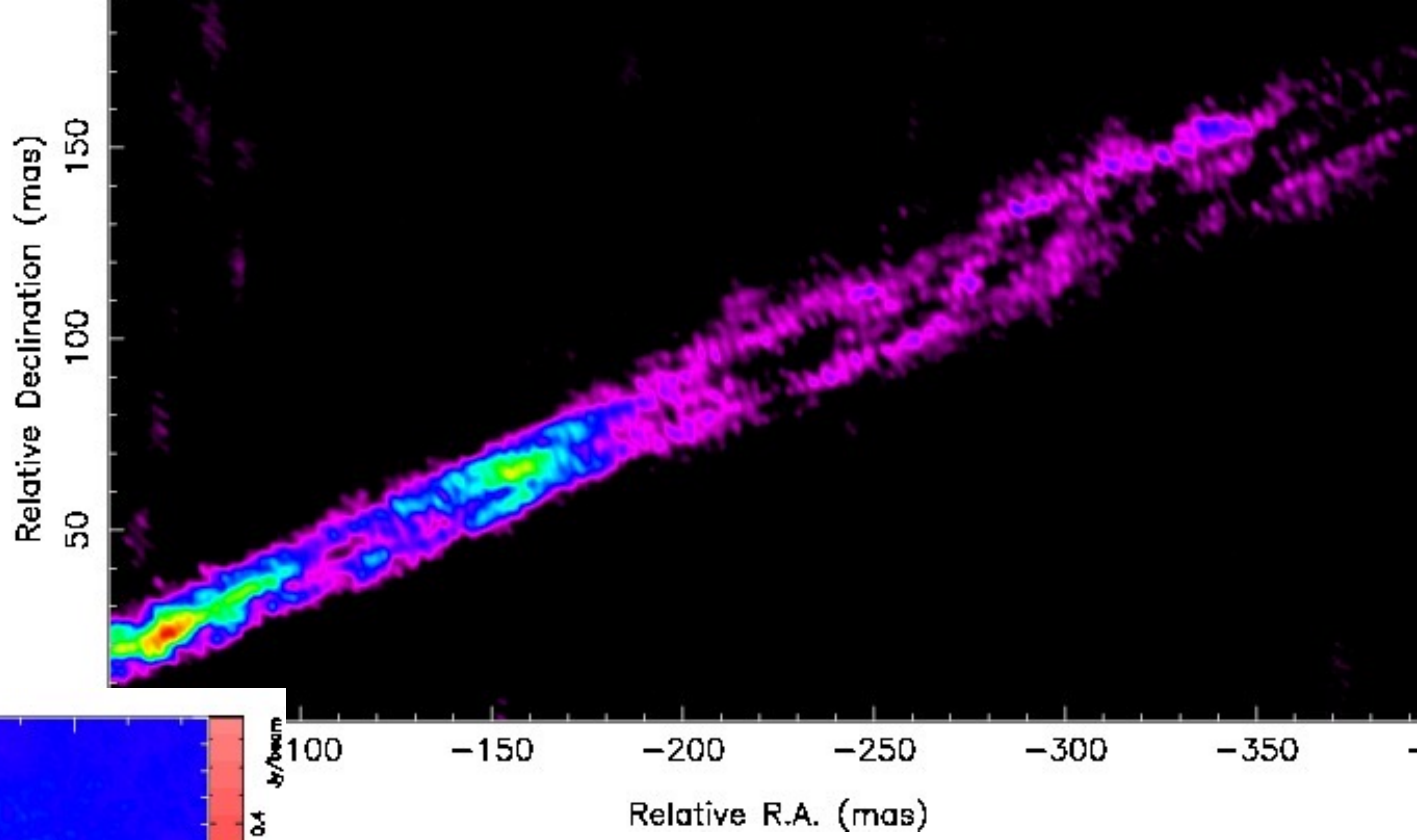
Giovannini et al. (2018)

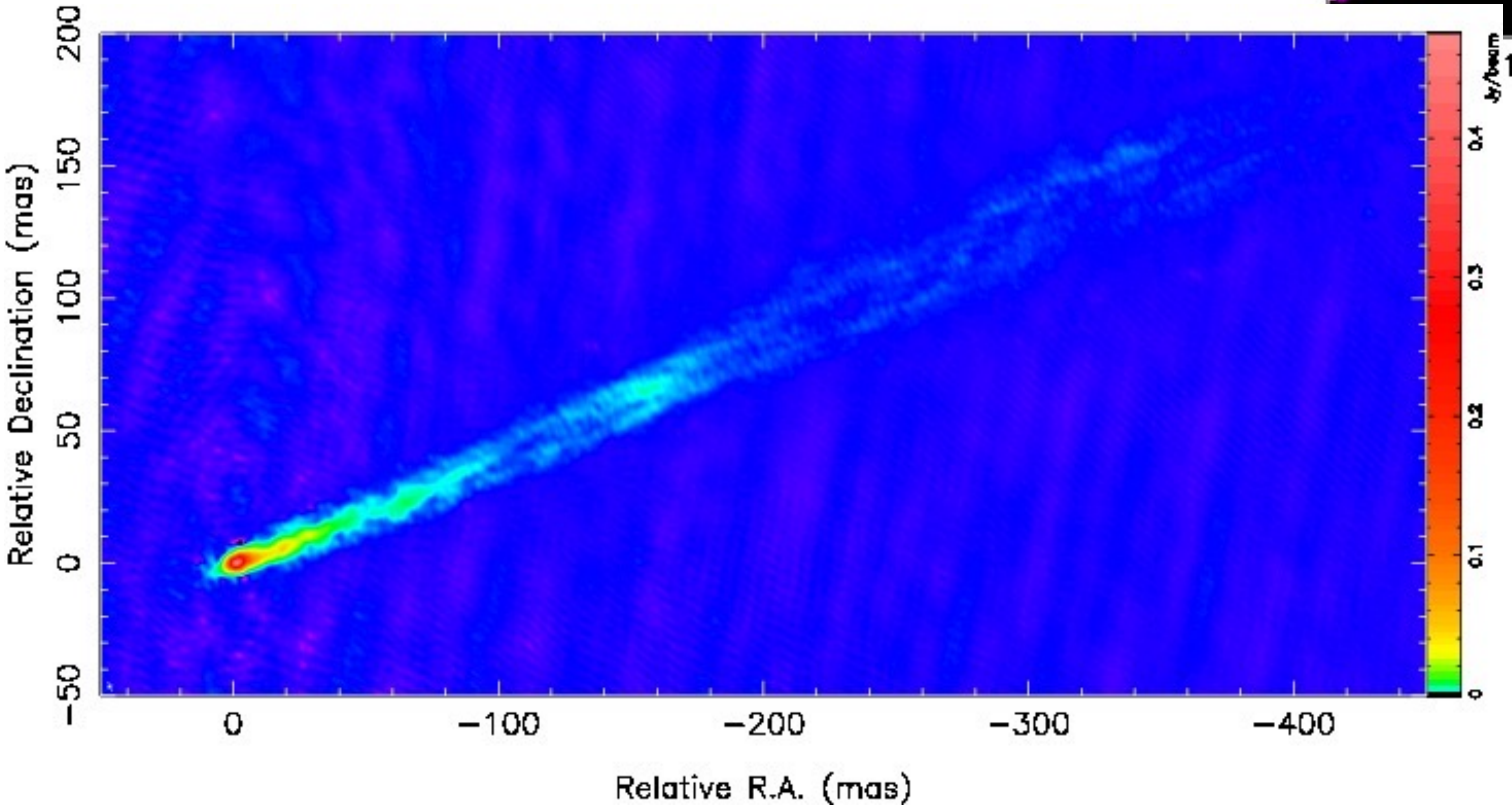




Jet in M87

RadioAstron, 18 см





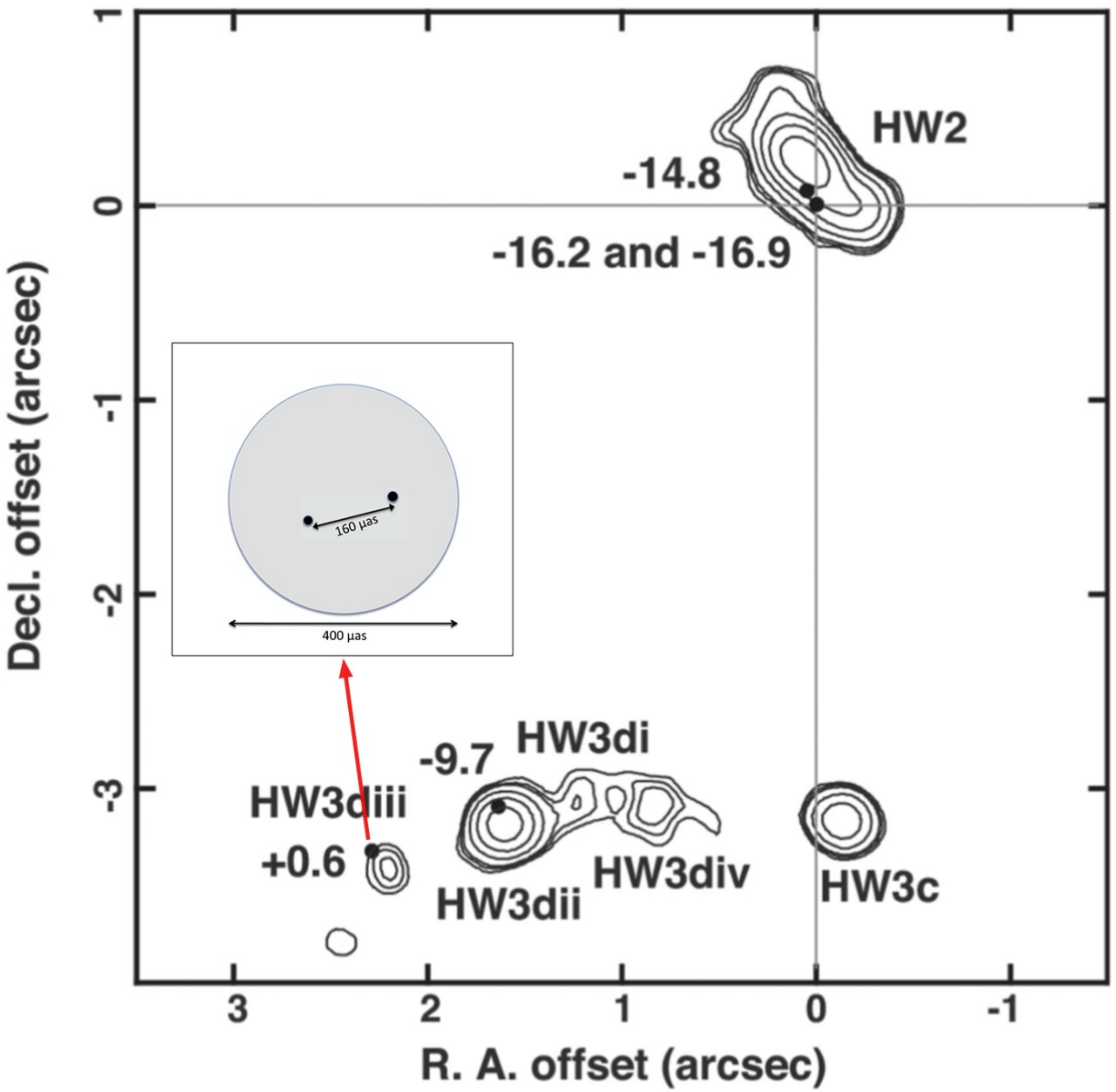
Central part is not straight.
Wiggling continues to the core.
Modeled as KH-instability
(Nikonov and Lobanov).

Savolainen et al.

Galactic H_2O masers: 1.3 cm

CepA: extremely compact sources of H_2O maser emission are found. Their size is estimated to be comparable to the size of the sun.

Results might be understood as possible turbulent von Kármán vortex street (aka Strouhal Instability).



Sobolev et al. (2018)