RadioAstron: AGN Tb survey

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SVLBI baseline ~ 350,000 km
GRTs involved in the survey

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

**Single-dish:**
- RATAN-600 (Russia);
- ATCA (Australia);
- WSRT (the Netherlands);
- Urumqi (China);
- Effelsberg (Germany);
- Oven Valley (USA);
- GBT (USA).
The brightness temperature inverse-Compton limit

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 $10^{11.5} \text{ K}$ is confirmed by previous studies if Doppler boosting is involved. VLBI kinematics estimates a typical Doppler boosting to be $\sim 10$. RadioAstron survey probes values up to about $10^{16} \text{ K}$.

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

![Histogram of observed temperature](image1)

![Distribution of temperature](image2)
AGN survey results: detection statistics

Sample: ~250 strong AGN
Correlated and post-processed to date: 2000 experiments, significant detections are found for 160 AGNs in 700 experiments at 18 and/or 6 and/or 1.3 cm up to 350,000 km.
The highest resolution: 0235+164 & OJ287 at 1.3 cm, 15 Earth diameters, about 14 µas. Not an absolute record any more...
Summary: typical Tb one order of magnitude higher than what was previously known.

L-band
Total number of experiments: 1385
Sources detected: 122 out of 236

C-band
Total number of experiments: 1884
Sources detected: 145 out of 241

K-band
Total number of experiments: 632
Sources detected: 34 out of 138
RadioAstron core brightness temperature: $2 - 4 \cdot 10^{13}$ 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 $10^{11.5}$ K.

Note: Gomez et al. (2016) got similar Tb values for the core of BL Lac from RA 1.3 cm imaging.
Direct $T_b$ estimates:
median $\sim 10^{13}$ K
max $\sim > 10^{14}$ K
$T_b$ lower limit

No component flux density assumed, only direct RadioAstron measurements are used following an approach suggested by Lobanov (2015).
Where does the high Tb comes from?
We use the RadioAstron imaging (Gomez et al.)

Core: <10 µas, >2×10^{13} K
How to generate high brightness temperature

✓ Very high Doppler boosting with typical $\delta \sim 100$ – VLBI kinematics does not confirm it.
Typical observed VLBI kinematics does not reflect 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? $\gamma$-ray photon flux is not high enough but radio photons could be upscattered to lower energies and increase uv / x-ray flux.

✓ Relativistic protons or coherent processes.
Requires very efficient acceleration and high magnetic field. Many problems.
**Discovery of the scattering sub-structure**

**PSR 0329+25**

RadioAstron

Scattering disk: 3.6 mas

Popov et al. (2016)

See for details the poster by Andrianov.

- Modeling of the scattering substructure effect for AGN at RadioAstron baselines (Johnson et al. 2016): expected at 1% level at 18 and 6 cm, does not affect results significantly.
- Should be taken into account even for EHT SgrA* start observations.
- A new promising tool to reconstruct the background source true image.

\[ \lambda = 18 \text{ cm} \]
Summary

- About 160 AGNs are detected at RadioAstron baselines. Typical brightness of their cores is on the level of $10^{13}$ K and extends to more than $10^{14}$ K.

- Typical Doppler factors of a hundred or an efficient acceleration mechanism parsecs away from the core is required to explain it.

- Particles energy should dominate, equipartition does not seem to survive.

- Scattering sub-structure is discovered, affects and helps observations of pulsars, AGNs, SgrA*, interstellar medium.
Thank you
Refractive Substructure and RadioAstron

Typical angular broadening is 30 μas
Nominal Resolution of RadioAstron is up to ~35 μas

Johnson & Gwinn (2015)