Radio and Gamma-ray loud Narrow-Line Seyfert 1

galaxies in the spotlight

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With

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What are Narrow-Line Seyfert 1 Galaxies?

Narrow-line Seyfert 1 (NLS1) galaxies are a particular class of AGN with:

- ✘ small width of their broad optical emission lines [FWHM(H_β) < 2000 km/s; Osterbrock & Pogge 1985] → Low BH masses (10^6–10^8 $M_\odot$)
- ✘ super-strong iron (Fe II) emission complexes
- ✘ rapid X-ray variability → BLR and accretion disk are directly visible
- ✘ near-Eddington accretion rates (L/L_{Edd} ratios between 0.1–1) [Boroson & Green 1992]
- ✘ super-soft X-ray spectra and
- ✘ other intriguing multi-wavelength properties [review by Komossa 2008]

- ✘ A small fraction of them is radio-loud, launching relativistic jets, and γ-ray detected with Fermi [Komossa et al. 2006; Abdo et al. 2009a, b]

A Source of New Insights

These few sources are exceptional because they show blazar-like observational attributes such as:

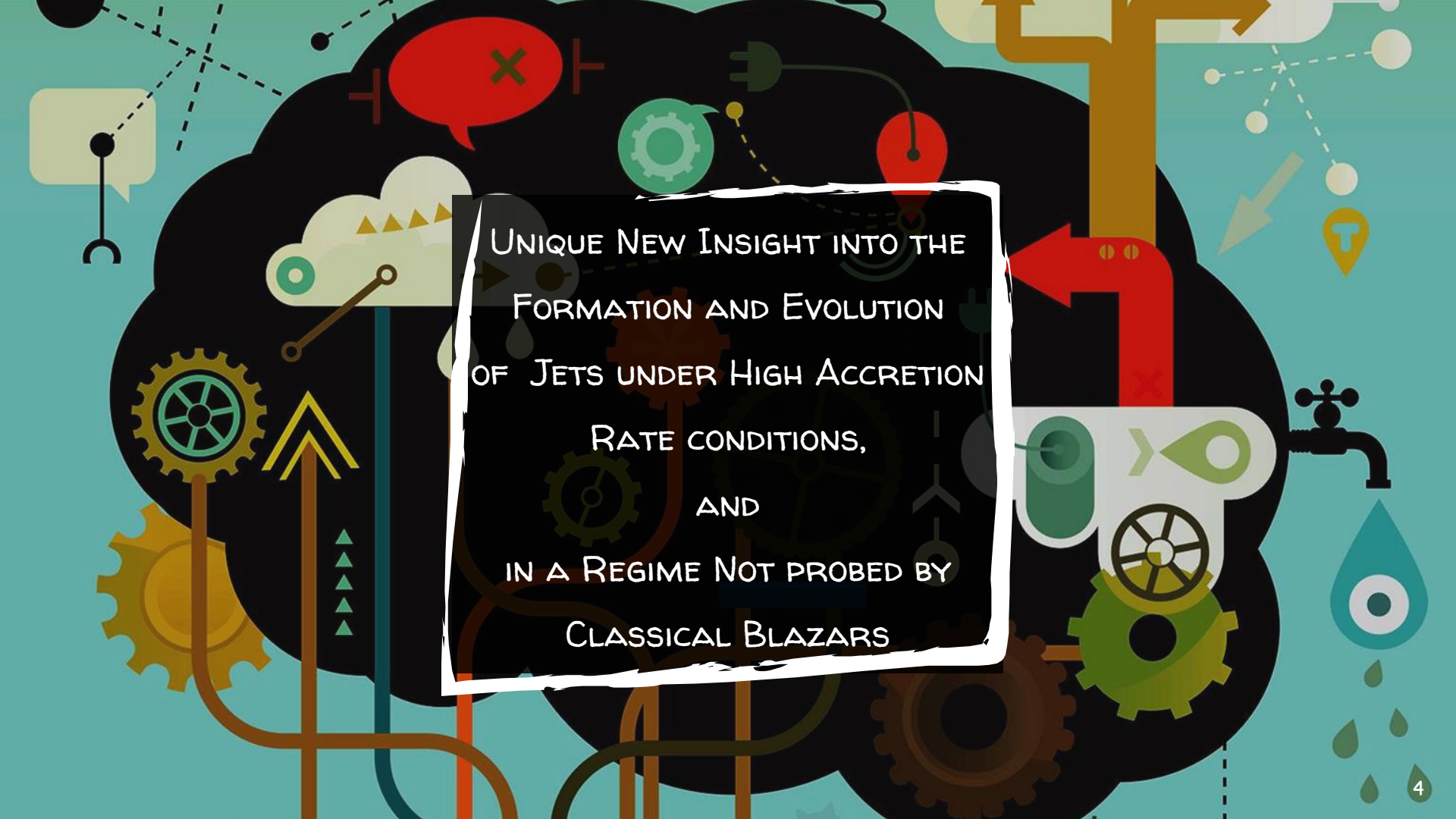
- ✘ Radio-loudness and flat radio spectra
- ✘ High brightness temperatures (reported 10^{10} up to 10^{14} K) [D'Ammando et al. 2013, Angelakis et al. 2015, Fuhrmann et al. 2016]
- ✘ Doppler boosting
- ✘ gamma-ray emission and
- ✘ one-sided relativistic jets

But

With non-blazar physical properties:

- ✘ 2 orders of magnitude lower BH masses
- ✘ high accretion rates

- ✘ Represent young AGN rapidly growing their BHs? → Clues for accretion physics and AGN evolution at low z
- ✘ Orientation effects? → Important for accurate BH masses, applying scaling relations, and in case of flat BLRs
- ✘ The issue of hosts: Do spirals harbor relativistic jets?


Unique New Insight into the
Formation and Evolution
of Jets under High Accretion
Rate conditions,
and
in a Regime Not probed by
Classical Blazars

Overview

1. Our NLS1 galaxies radio monitoring program
2. The curious case of RX J2314.9+2243
3. Very-long-baseline interferometry (VLBI) monitoring of 1H 0323+342

The NLS1 galaxies Monitoring program

Identity of the Program

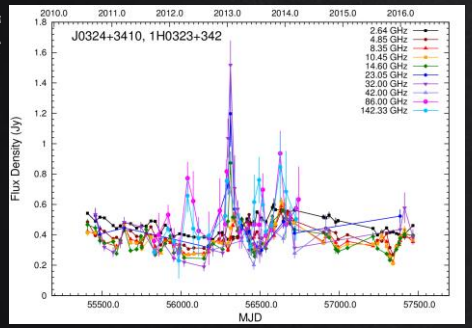
- ✘ The most comprehensive (longest duration & most frequencies) monitoring of 4 RL and GL NLS1 galaxies at cm and mm radio bands
- ✘ Includes the nearest RL gamma-ray emitting NLS1 1H 0323+342 (z=0.02; Zhou et al. 2007) and the most distant one currenlty known SDSS J1222+0413 (z~1, Yao et al. 2015)
- ✘ Monthly monitoring
- ✘ Data at 2.6, 4.8, 8.4, 10, 15, 23, 32, 43, 86, and 142 GHz (10 bands) spanning 5 years
- ✘ Effort is ongoing and the sample is expanded with 3 additional sources

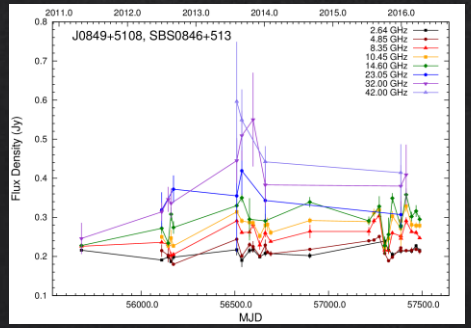
1H 0323+342
SBS 0846+513
PMN J0948+0022
PKS 1502+036
FBQS J1644+2619
SDSS J122222.55+041315.7
B3 1441+476

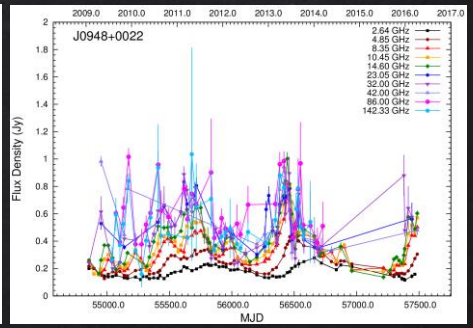
Angelakis et al. 2015

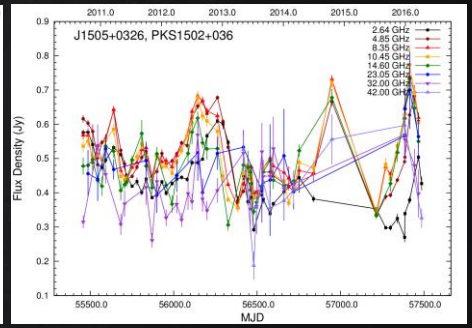
Monitoring with the Effelsberg 100-m & the IRAM 30-m telescopes

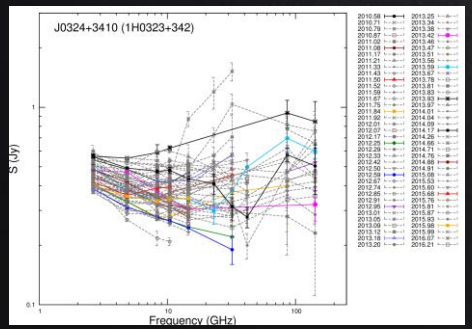
Data: Light Curves and Spectra

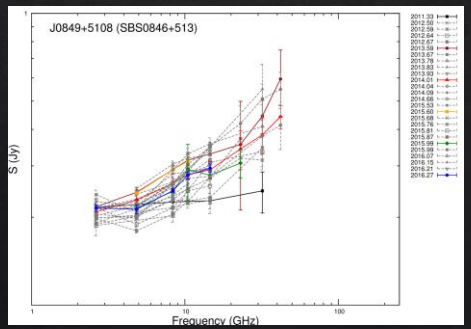


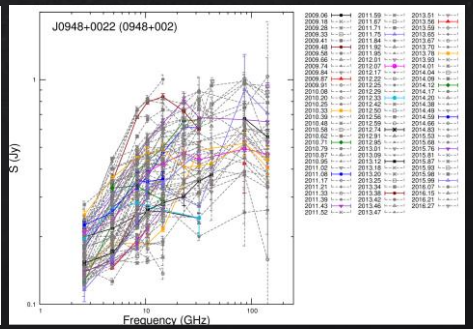


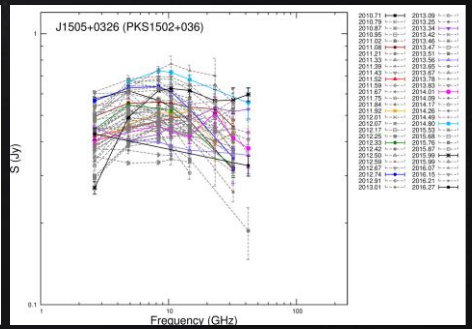








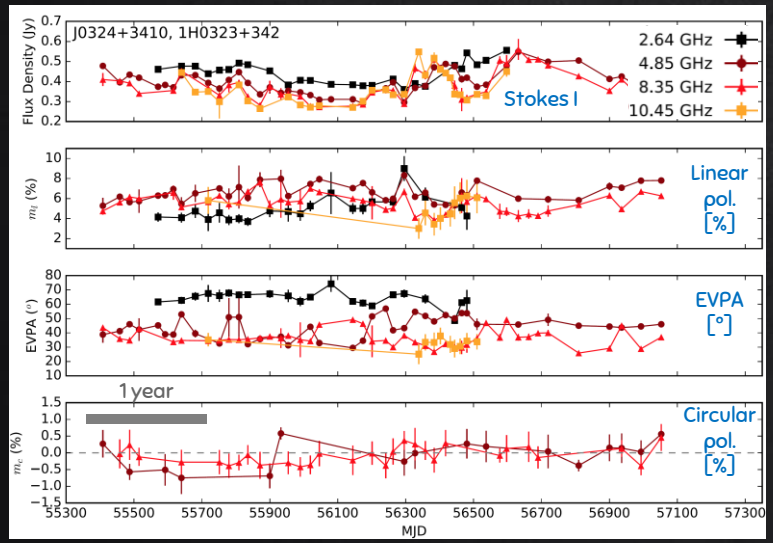




Angelakis et al. 2015

Polarimetry of NLS1 galaxies

1H0323+342



Radio polarization

- ✘ At 4 bands from 2.6 to 10.5 GHz
- ✘ Most sources at undetectable levels

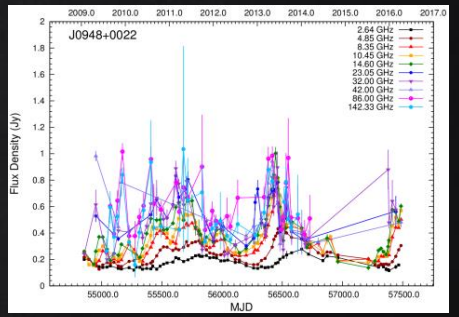
- ✘ Only 1H 0323+342 shows ~3–9% of linear pol. High compared to other AGN (Myserlis 2015, PhD Thesis, Univ. Cologne)
- ✘ EVPA almost perpendicular to the jet, so projected magnetic field is parallel to the jet axis

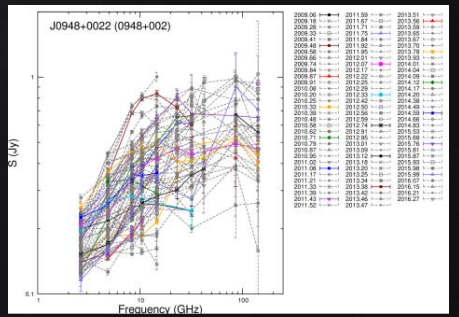
R-band polarization

- ✘ With the RoboPol instrument (Pavlidou et al. 2014)
- ✘ Mean fractional pol. from <1% up to 20%

Monitoring Results

- ✘ Rapid flaring more prominent at higher frequencies,
- ✘ Strong spectral evolution (consistent with the shock-in-jet scenario)
- ✘ Moderate variability brightness temperatures (& associated Doppler factors no higher than ~10) → (only) mildly relativistic jets
- ✘ Behaviour overall consistent with blazars, except lower powers, lower jet speeds
- ✘ Radio-loud NLS1 galaxies extent the blazar phenomenon into a previously unexplored parameter regime





Angelakis et al. 2015

The curious case of RX J2314.9+2243

Identity of RX J2314.9+2243

- ✘ Radio-loud NLS1, R=10–20 (z=0.17; Komossa et al. 2006)
- ✘ Close to Eddington accretion rate with BH mass $8 \cdot 10^7 M_\odot$

- ✘ Marginal gamma-ray detection (Foschini et al., priv. com.)

But

- ✘ Steep radio spectrum, a=–0.76, first measured with Effelsberg (Komossa et al. 2015), and confirmed by our follow-up monitoring

Freq. [GHz]	Flux density with Effelsberg 100-m [mJy]			
	2013 July 7	2013 Feb. 3	2013 Feb. 9	2013 July 23
2.6	12 ± 2	...	14 ± 3	...
4.8	9 ± 2	7 ± 1	7 ± 1	7 ± 2
8.4	5 ± 1	5 ± 1	5 ± 1	5 ± 1
10.5	<17	...	...	...
43	<56	...	...	...

Komossa et al. 2015

"First steep-spectrum, gamma-emitting NLS1" galaxy, if gamma-ray detection is confirmed

(until now gamma-ray emission has been detected from flat radio spectrum NLS1s)

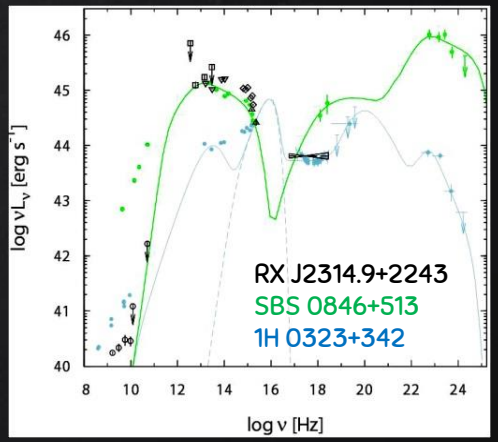
A Non-Thermal SED for RX J2314.9+2243

- ✘ Luminous IR emission
- ✘ Very steep UV spectrum, but no evidence for optical reddening/extinction beyond the Galactic value
- ✘ Flat, variable X-ray spectrum (*Swift*)
- ✘ Possible gamma-ray detection

→ SED likely dominated by non-thermal emission
(X-rays: corona; IR-UV: synchrotron)

- ✘ Very broad & blueshifted (v=1260 km/s) [OIII]5007 emission → strong outflow

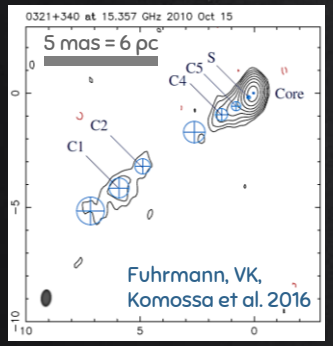
Broadband SED

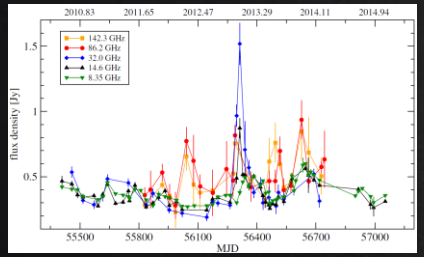


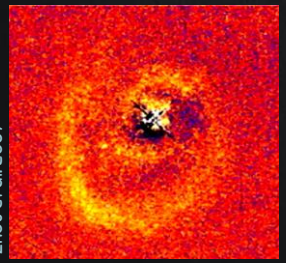
Komossa et al. 2015

Likely a case of strong AGN-induced feedback in the local universe

VLBI MONITORING OF 1H 0323+342



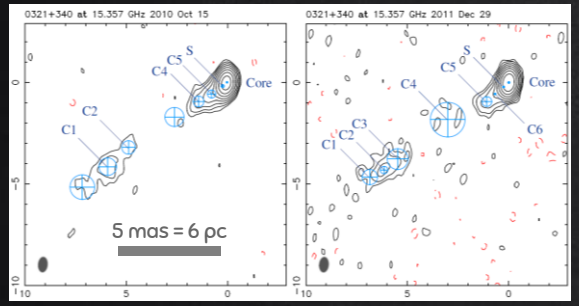


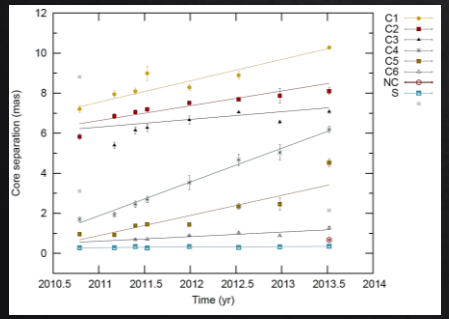


Identity of 1H 0323+342

- ✘ The most nearby radio loud (R=50) and gamma-ray emitting NLS1 (z=0.06; Zhou et al. 2007)
- ✘ High Eddington ratio of $L/L_{Edd} = 0.1$
- ✘ With low BH mass ~10^7 $M_\odot$ [Abdo et al. 2009, Paliya et al. 2014, Yao et al. 2015]
- ✘ 1H 0323+342 is highly variable at radio bands (cm to mm)
- ✘ Special case: its host galaxy is a ring galaxy or one-armed spiral, while radio-loud sources are typically hosted by ellipticals [see Zhou et al. 2007]

Superluminal motions and Viewing Angle





Karamanavis 2015, PhD, Univ. Cologne
Fuhrmann, VK, Komossa et al. 2016
See also: Wajima et al. 2014, Angelakis et al. 2015

- ✘ Data from the MOJAVE survey at 15 GHz [Lister et al. 2009]
- ✘ On parsec scales: One-sided morphology with a prominent core and a straight jet
- ✘ Several jet components with speeds between 1 and 7c

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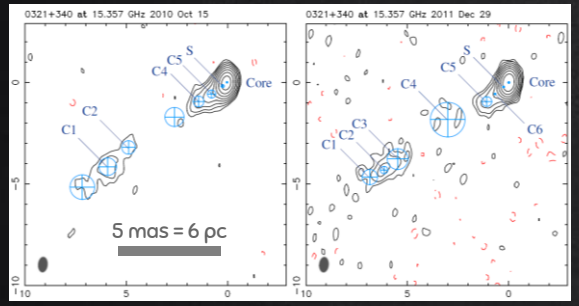

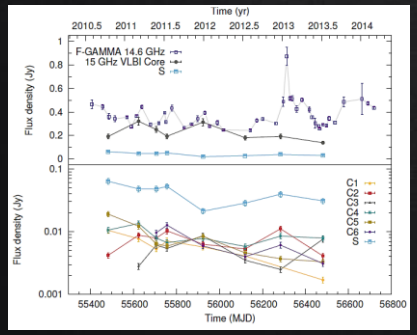

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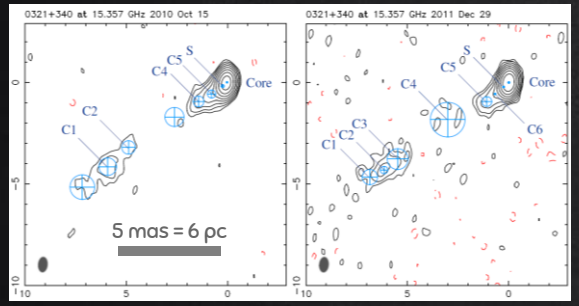
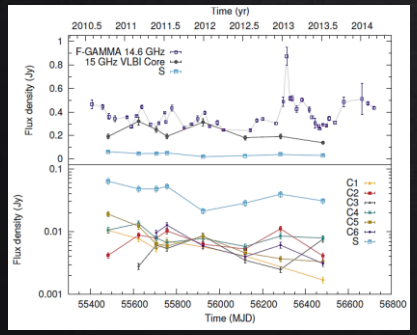
- ✘ Fast variability seen both with single-dish and VLBI
- ✘ Highest T_B of ~$6 \cdot 10^{12}$ K and Doppler factor of ~5.2

Superluminal motions and Viewing Angle





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- ✘ Viewing angle towards 1H 0323+342 of $\leq 4°–13°$
- ✘ Spin-off: viewing angle towards SBS 0846+513 of $\leq 8°–9°$
  [based on published data by D'Ammando et al. 2013]

Summary

- ✘ NLS1s are a unique source of insights into accretion and jet physics in the low BH mass and high accretion rate regime

- ✘ Radio multi-frequency and polarimetric monitoring of radio-loud and gamma-ray loud NLS1s revealed that they feature relativistic and beamed jets with moderate brightness temperatures and Doppler factors. They flare repeatedly and fast and show intense spectral evolution

- ✘ RX J2314.9+2243: A steep-spectrum source with putative gamma-ray emission, featuring a strong outflow

- ✘ 1H 0323+342: pc-scale imaging of its relativistic jet: superluminal features and viewing angle estimation – Hosted by a ring or spiral galaxy

Thank you!

Any questions?

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