Cosmic Collider:
IceCube neutrino generated in a precessing jet-jet interaction in TXS 0506+056?

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From the 2000 blazars monitored by Fermi - why did only TXS 0506+056 emit Neutrios?

What is special about this BL Lac Object?

In an artist’s depiction that is very, very not-to-scale, a blazar is shown shooting a beam of cosmic rays at the Earth. *IceCube/NASA*

Reimer et al. ApJ, in press

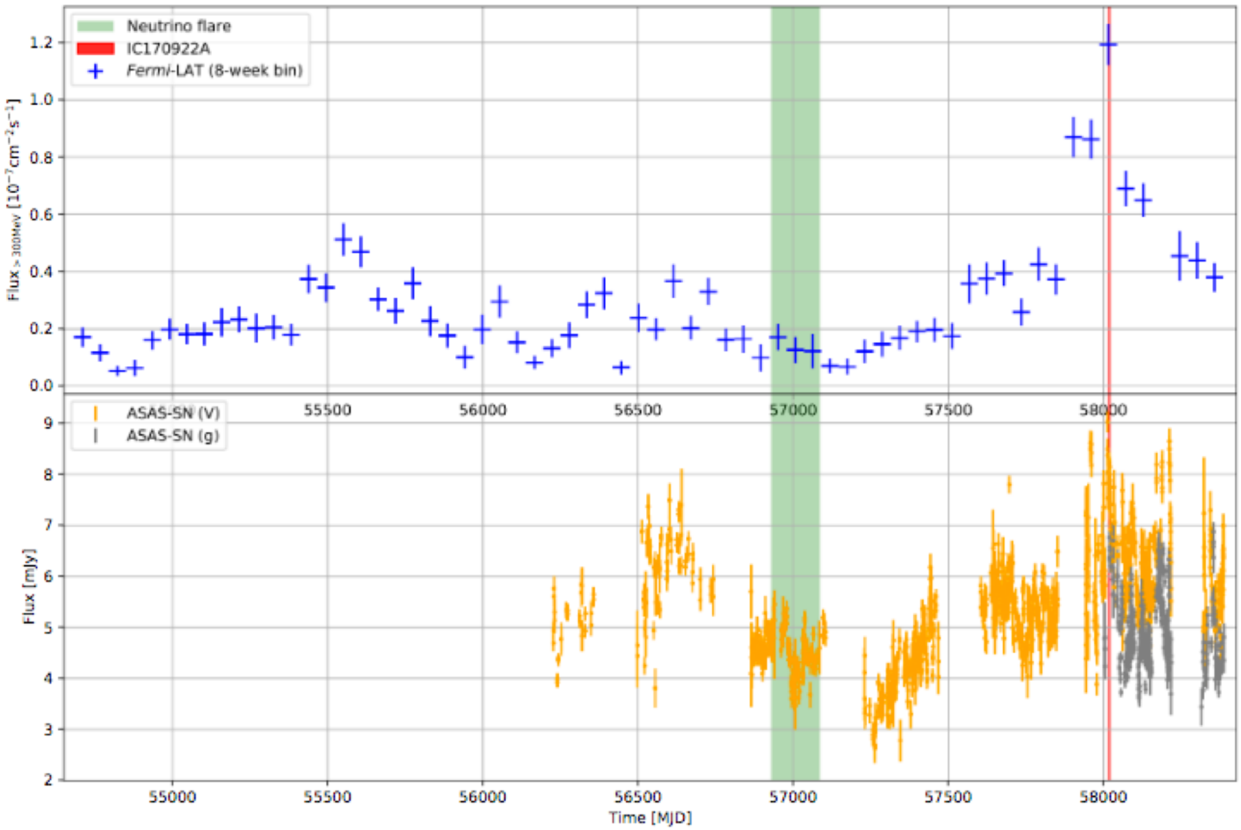

Figure 1. Top: *Fermi*-LAT light curve (photon flux integrated above 300 MeV) of TXS 0506+056 since mission start using 8-weeks binning. Bottom: Optical light curve from ASAS-SN in the V (yellow) and γ-ray (gray) bands. The green shaded area indicates the time interval of the neutrino flare while the red line corresponds to the detection time of the IceCube-EHE-170922A event.

a scenario where Compton-driven cascades develop in the stationary soft-X-ray photon target which photo-hadronically produced the observed neutrinos appears feasible with required proton kinetic jet powers near the Eddington limit. The source is then found to produce neutrinos inefficiently, and emits GeV photons significantly below the observed *Fermi*-LAT-flux. Hence, the neutrinos and the bulk of the gamma rays observed in 2014/2015 from TXS 0506+056 cannot have been initiated by the same process.

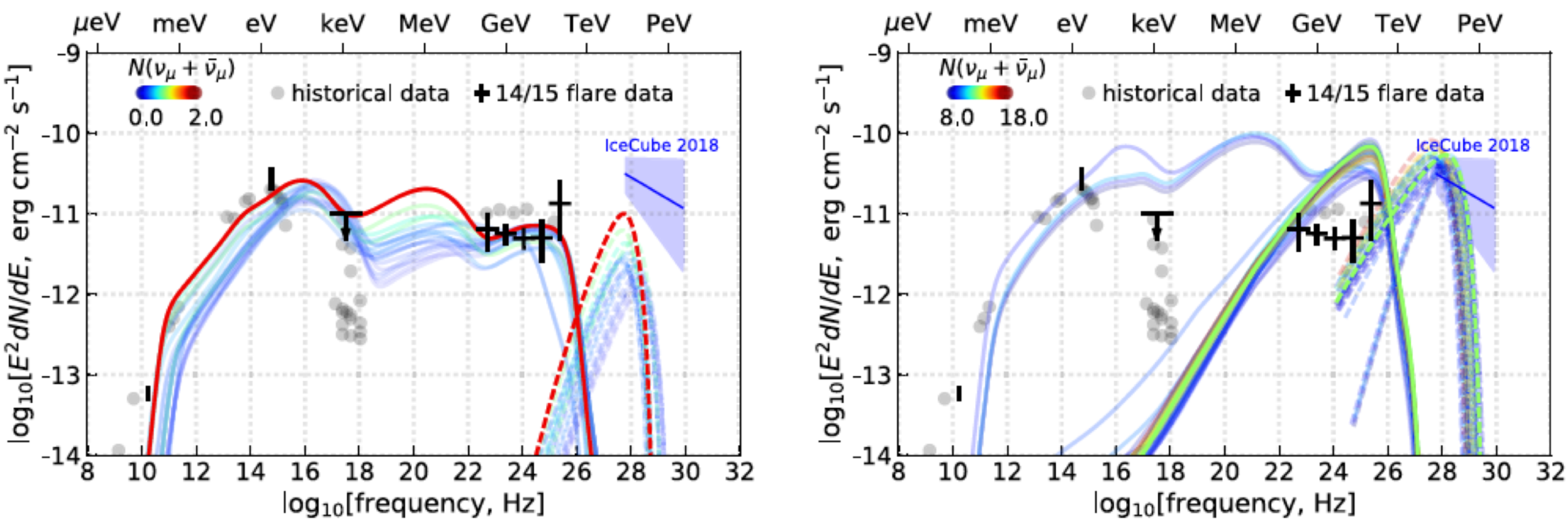

Figure 1. Spectral energy distributions (SEDs) and muon neutrino fluxes predicted by the one-zone hadronic model, compared to the single-flavor flux derived by IceCube (Aartsen et al. 2018b). In the left panel, the parameter sets optimized to describe the SED in agreement with observations fail to explain neutrino emission; in the right panel the parameter sets account for 13 ± 5 muon neutrinos in IceCube, but overshoot the multiwavelength emission. Table 1 contains the parameters for the red curve from the left panel, and the green curve from the right panel. The observations available during the historical neutrino flare are plotted in black (see the main text) and include one radio point (Padovani et al. 2018). The archival data taken during the years before 2017 from the databases of the Space Science Data Center (SSDC) and the NASA/IPAC Extragalactic Database (NED) are shown in gray.

The models compatible with the SED (left panel) produce too few neutrinos, where at most 1.8 events are expected during the duration of the neutrino fl are (red curve) . This number is limited by the X-ray constraint on the SED, which they derive from the nondetection by Swift BAT. The two bumps around the X-ray limit come from synchrotron and IC emission off $e_\pm$ that originate from γγ annihilation at higher energies, and from Bethe–Heitler pair production.

On the other hand, a compatible neutrino flux level implies an SED that is in tension with observations (right panel) . These neutrino-compatible SEDs belong to a class of models with a strong hadronic cascade.

Rodrigues et al. 2019

together with:

C. Fendt[2], M. Böttcher[3], M. Zajacek[1,4,5], F. Jaron[1,6],
I.N. Pashchenko[7], A. Araudo[8], V. Karas[8], and O. Kurtanidze[9]

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The articles:

Britzen et al., subm. to A&A
A Cosmic Collider:
IceCube neutrino generated in a precessing jet-jet interaction in TXS 0506+056?

Reimer et al., ApJ, in press:
Cascading Constraints from Neutrino Emitting Blazars: The case of TXS 0506+056
https://arxiv.org/pdf/1812.05654.pdf

pc-scale radio structure of TXS 0506+056

MOJAVE (Monitoring Of Jets in Active galactic nuclei with VLBA Experiments)

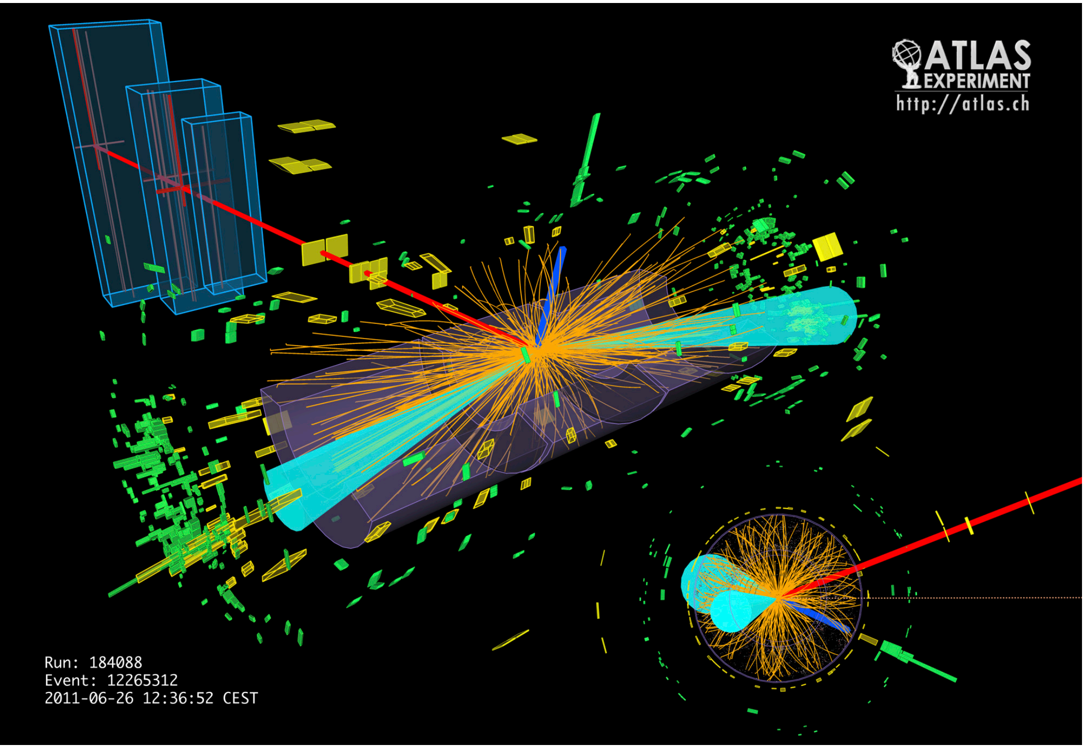
z=0.3365±0.0010 (Paiano et al. 2018)
BL Lac Object

- VLBA observations at 15 GHz
- 16 epochs between Jan. 2009 and March 2018
- fitting Gaussian components
- detailed analysis of the jet kinematics

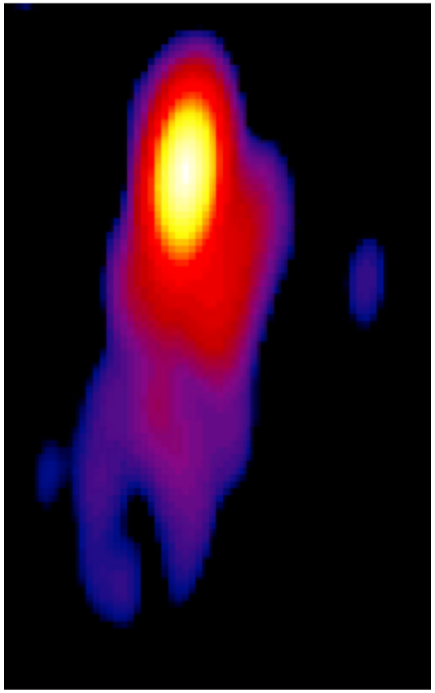
https://www.physics.purdue.edu/MOJAVE/

LHC @ Geneva: Collider on earth

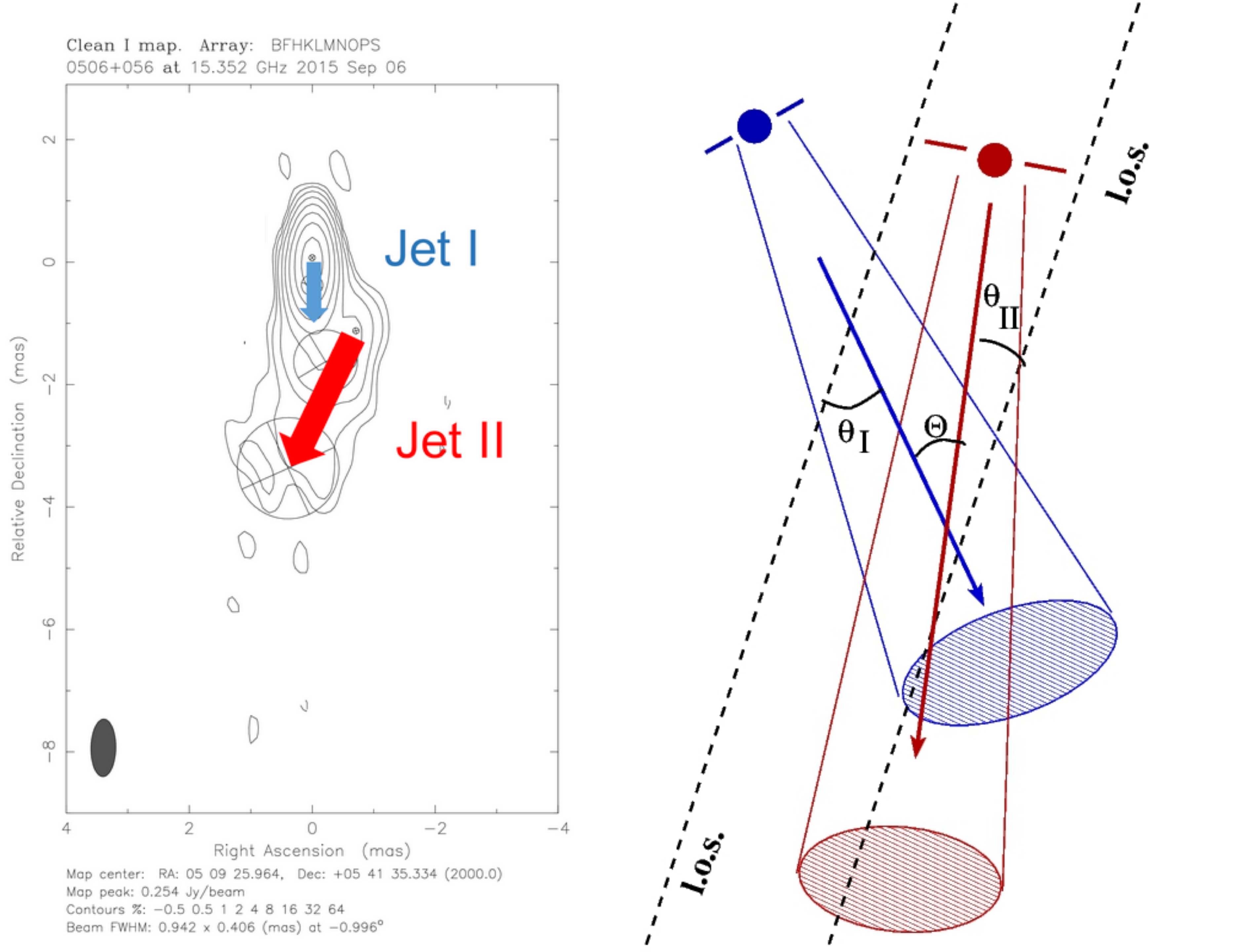
TXS 0506+056: Cosmic Collider



Graphical representation of one of the collision events used in obtaining the new ATLAS result, showing traces and energy deposits left by the particles flying through the ATLAS detector. They possibly originate from a Higgs boson decaying into two taus, which subsequently decay into an electron (blue line) and a muon (red line).



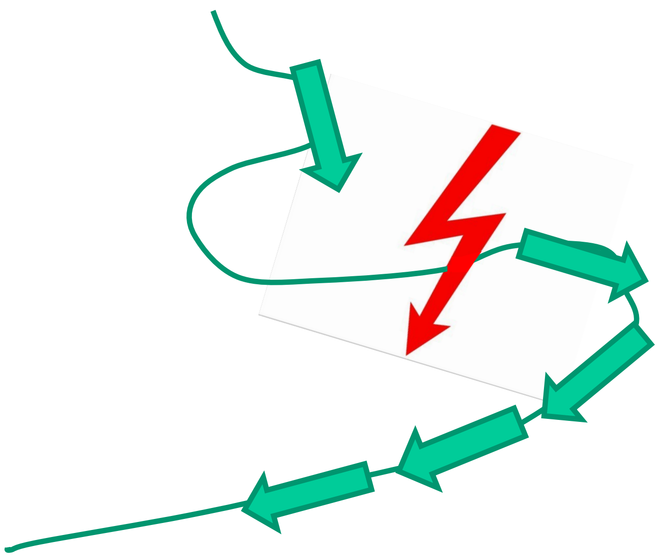
MOJAVE map
2018-04-22
15.4 GHz



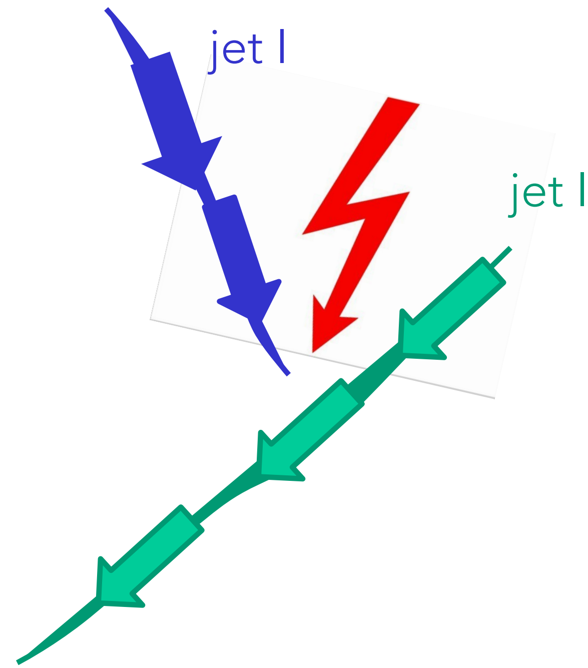
Clean I map. Array: BFHKLMNOPS
0506+056 at 15.352 GHz 2015 Sep 06
Relative Declination (mas)
Right Ascension (mas)
2
0
−2
−4
−6
−8
4
2
0
−2
−4
Jet I
Jet II
Map center: RA: 05 09 25.964, Dec: +05 41 35.334 (2000.0)
Map peak: 0.254 Jy/beam
Contours %: −0.5 0.5 1 2 4 8 16 32 64
Beam FWHM: 0.942 x 0.406 (mas) at −0.996°
l.o.s.
l.o.s.
θ_{II}
θ_I
Θ

1Jet or 2Jet-scenario ?

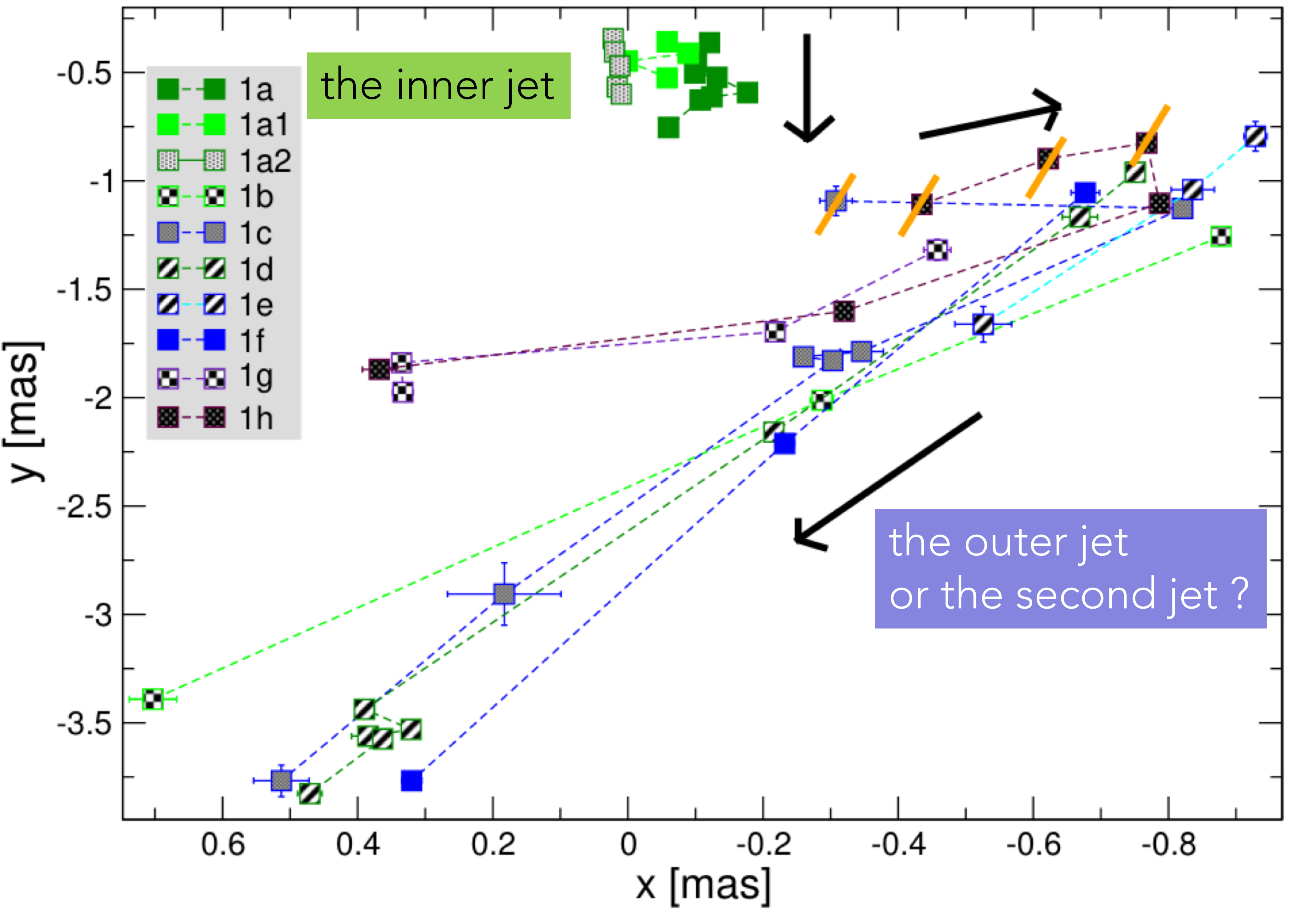
In any case: jet collision !!



a strongly curved jet,
very special viewing angle

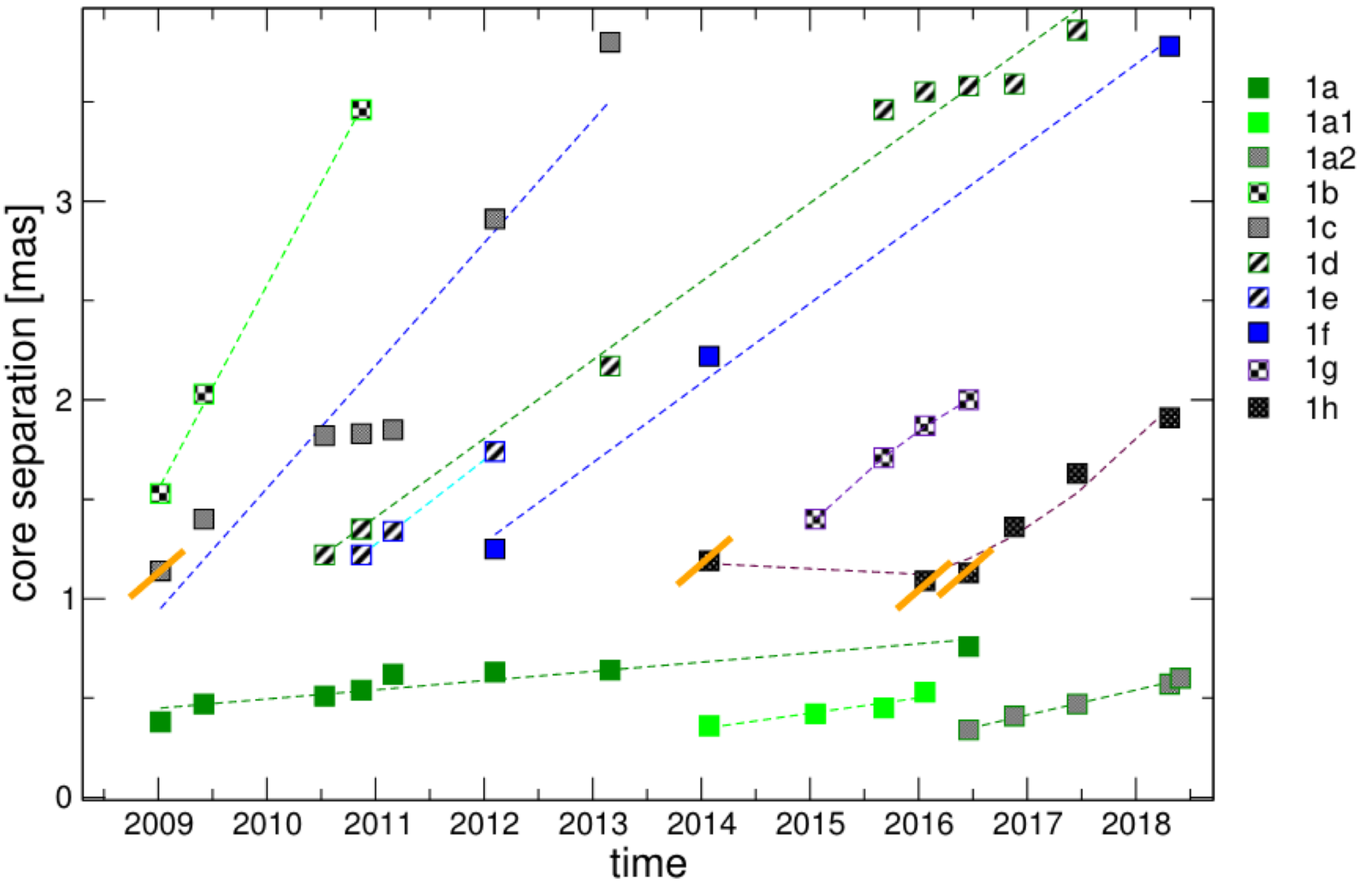


2 jets on a collision-course



the inner jet
the outer jet
or the second jet ?
1a
1a1
1a2
1b
1c
1d
1e
1f
1g
1h
y [mas]
x [mas]
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8

Apparent speeds



a]

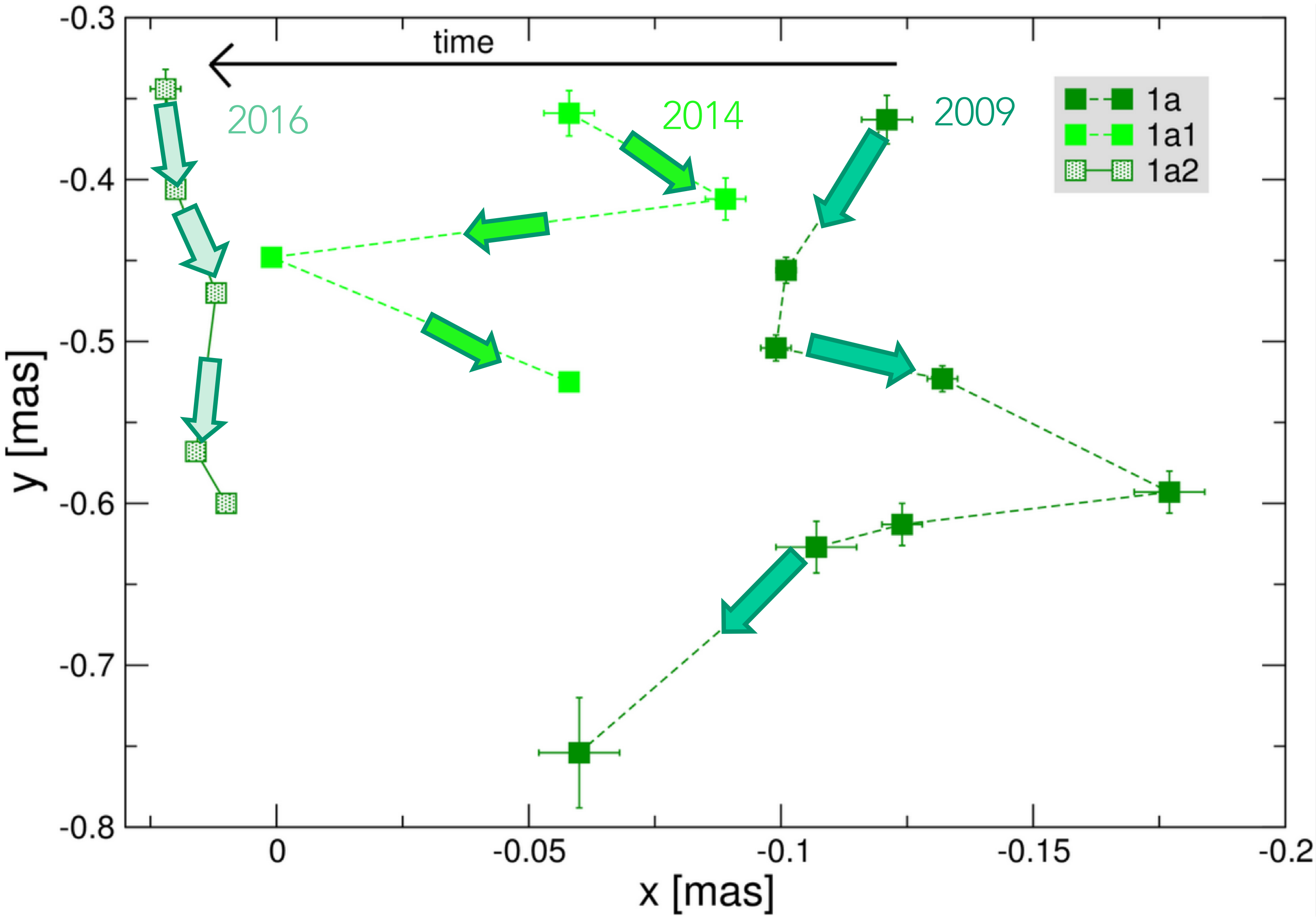
Apparent speeds

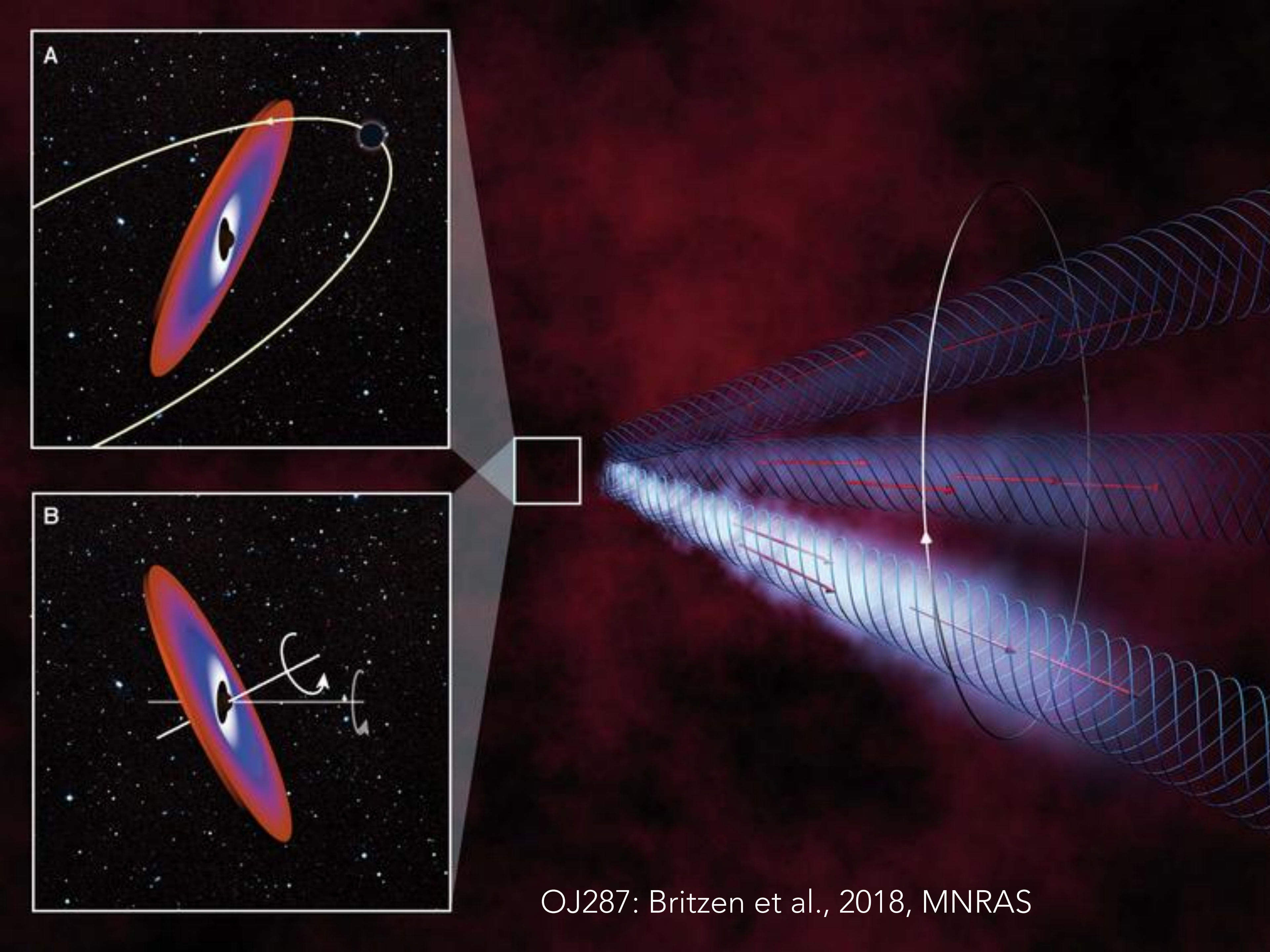
Jet	Jet feature	μ [mas yr^{-1}]	β_{app} [c]	est. time of ejection	η [°]
Jet I	**1a**	0.05±0.01	0.81±0.17	1999.31	-161.57
Jet I	**1a1**	0.08±0.02	1.29±0.32	2009.48	-170.82
Jet I	**1a2**	0.13±0.01	2.10±0.16	2013.74	176.30
Jet I/II	**1b**	1.03±0.05	16.67±0.81		
Jet II	**1c**	0.67±0.10	10.84±1.62		
Jet I/II	**1d**	0.40±0.02	6.47±0.32		
Jet I/II	**1e**	0.42±0.01	6.80±0.16		
Jet I/II	**1f**	0.40±0.03	6.47±0.49		
Jet I/II	**1g**	0.43±0.03	6.96±0.49		
Jet II	**1h**	0.38±0.04	6.15±0.65		

inner jet (1a, 1a1, 1a2)

outer jet (1d, 1e, 1f, 1g, 1h)

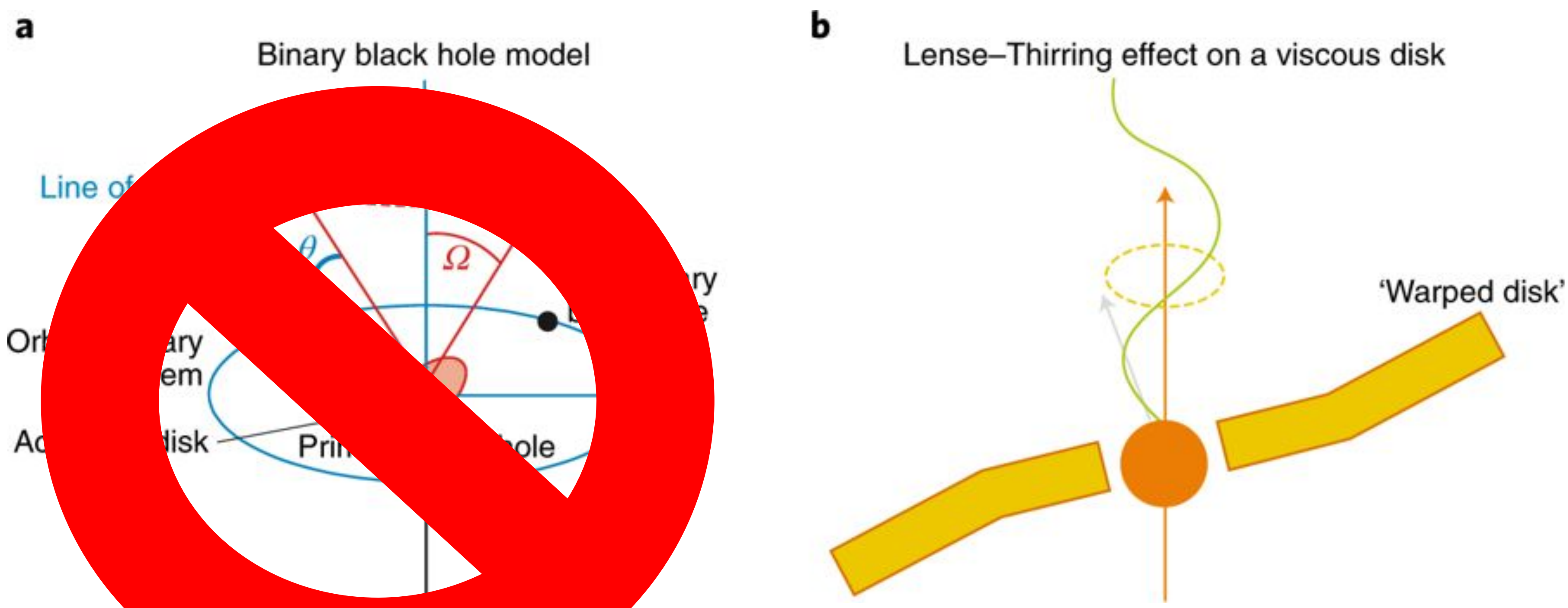
The inner part of the jet – evidence for precession





OJ287: Britzen et al., 2018, MNRAS

Jet precession – TXS 0506+056 in good company



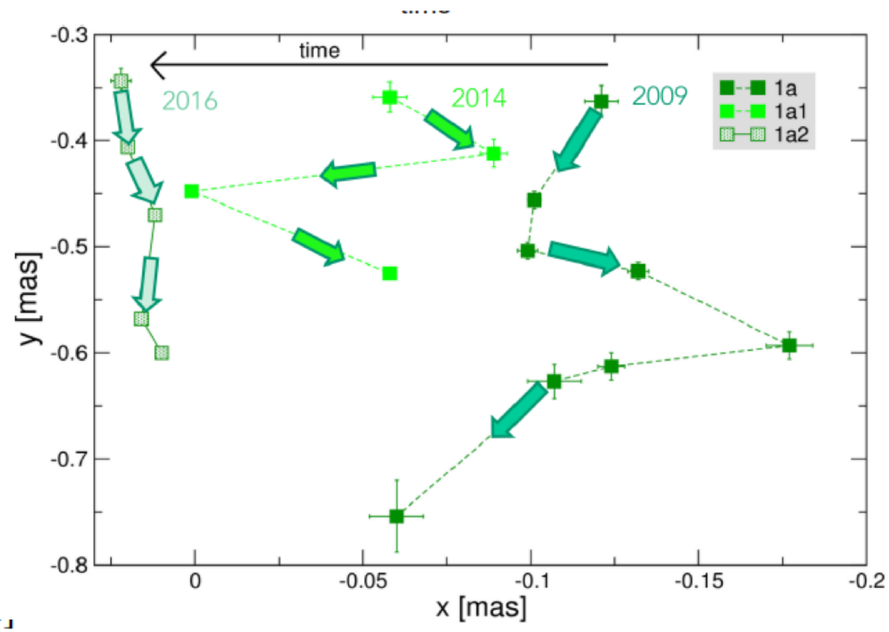
a, The orbital m[illegible]ck hole binary leads to the precession of the jet on the surface of a cone with opening angle Ω, at an [illegible] the observer's line of sight. **b**, A misalignment of the supermassive black hole spin (orange arrow) with the accretion disk angular momentum (grey arrow) leads to the Lense–Thirring effect and the precession of the relativistic jet (green line).

Jet precession in binary black holes

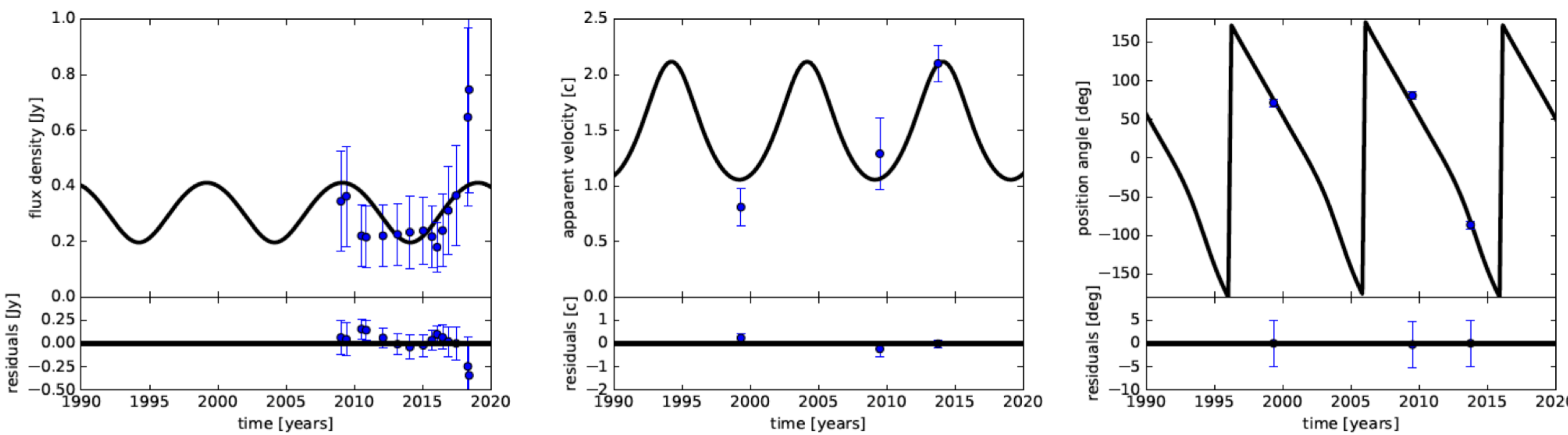
Zulema Abraham

Nature Astronomy **2**, 443–444 (2018)

Evidence for Lense-Thirring precession



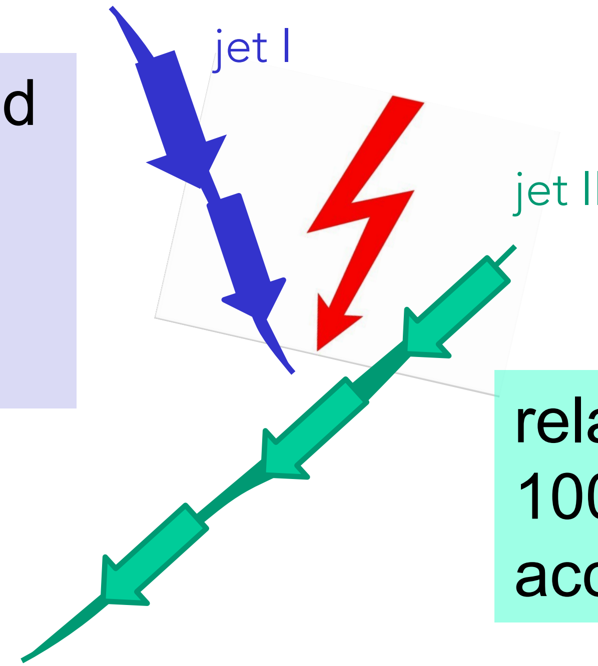
The paths of the three innermost jet components. Arrows indicate the direction of motion. The jet seems to be precessing - - Lense-Thirring effect may explain it.



Model of the bulk jet precession fitted to the TXS 0506+056 data. We performed a simultaneous least-square fitting to the flux-density of core I, apparent velocities, and position angles of jet I.

Photo-hadronic interactions in the jet(s) of TXS 0506+056

synchrotron photon field (X-rays) of jet I acts as target photon field for pγ pion production



relativistic protons in the 100 TeV-10 PeV range accelerated in jet II

As detailed in Reimer et al. (2018), such a dense target photon field will ensure that photo-pion induced pair cascades will be strongly in the Compton-supported regime, in which case the intrinsic γγ opacity is so high that any emerging γ-ray flux is far below the observed *Fermi*-LAT flux from TXS 0506+056, even in quiescence (as during the 2014-2015 neutrino flare).

for details see Britzen et al., subm. to A&A

In case the Neutrinos come from TXS 0506+056:

- based on a detailed analysis of more than 9 yrs of VLBA data, we find evidence for jet-jet collision in TXS 0506+056
- a special viewing angle and precession provided the ingredients for photo-hadronic neutrino production in 2014/15 and September 2017
- the neutrinos and the bulk of the gamma rays observed in 2014/15 from TXS 0506+056 cannot have been initiated by the same process – we provide a viable scenario with the collision !

Thanks for your attention !!