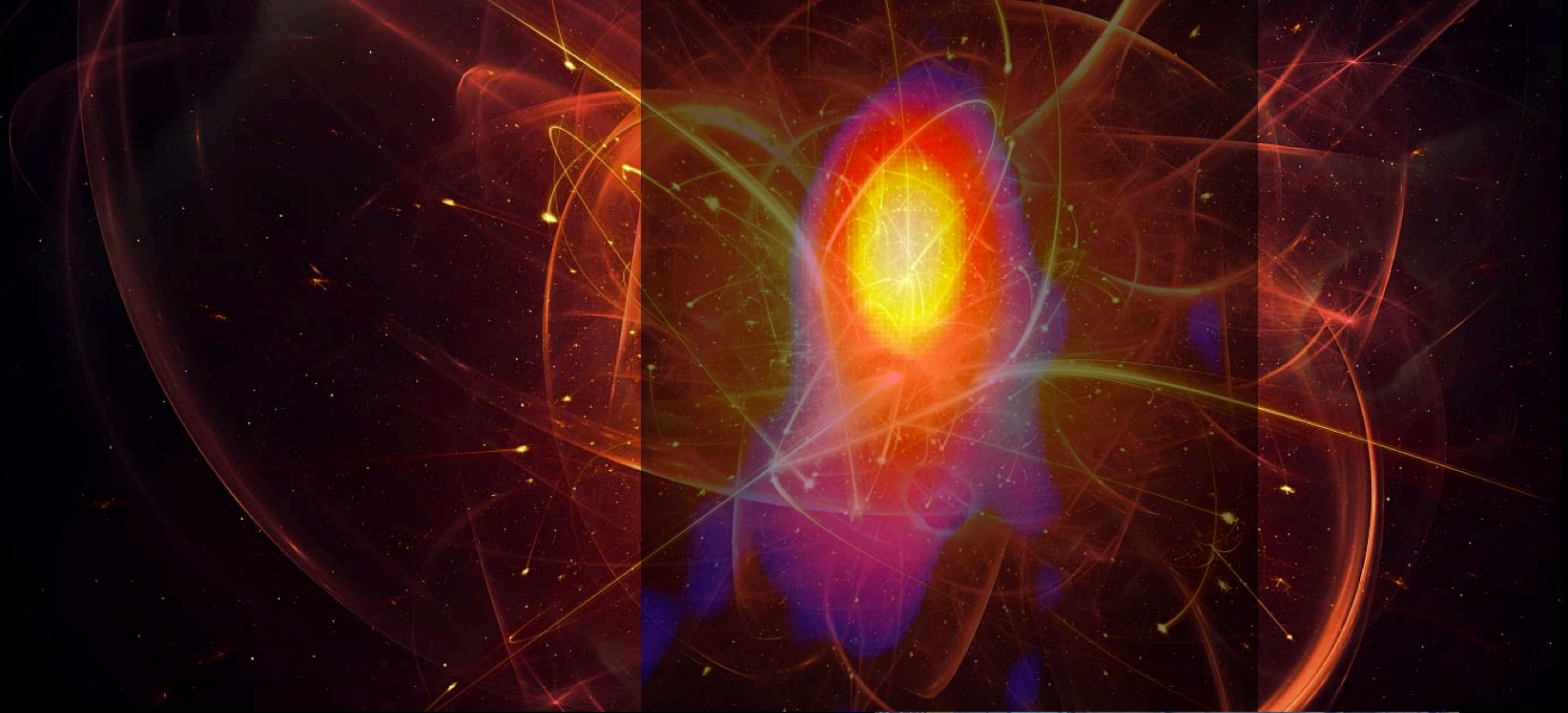


Cosmic Collider:

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



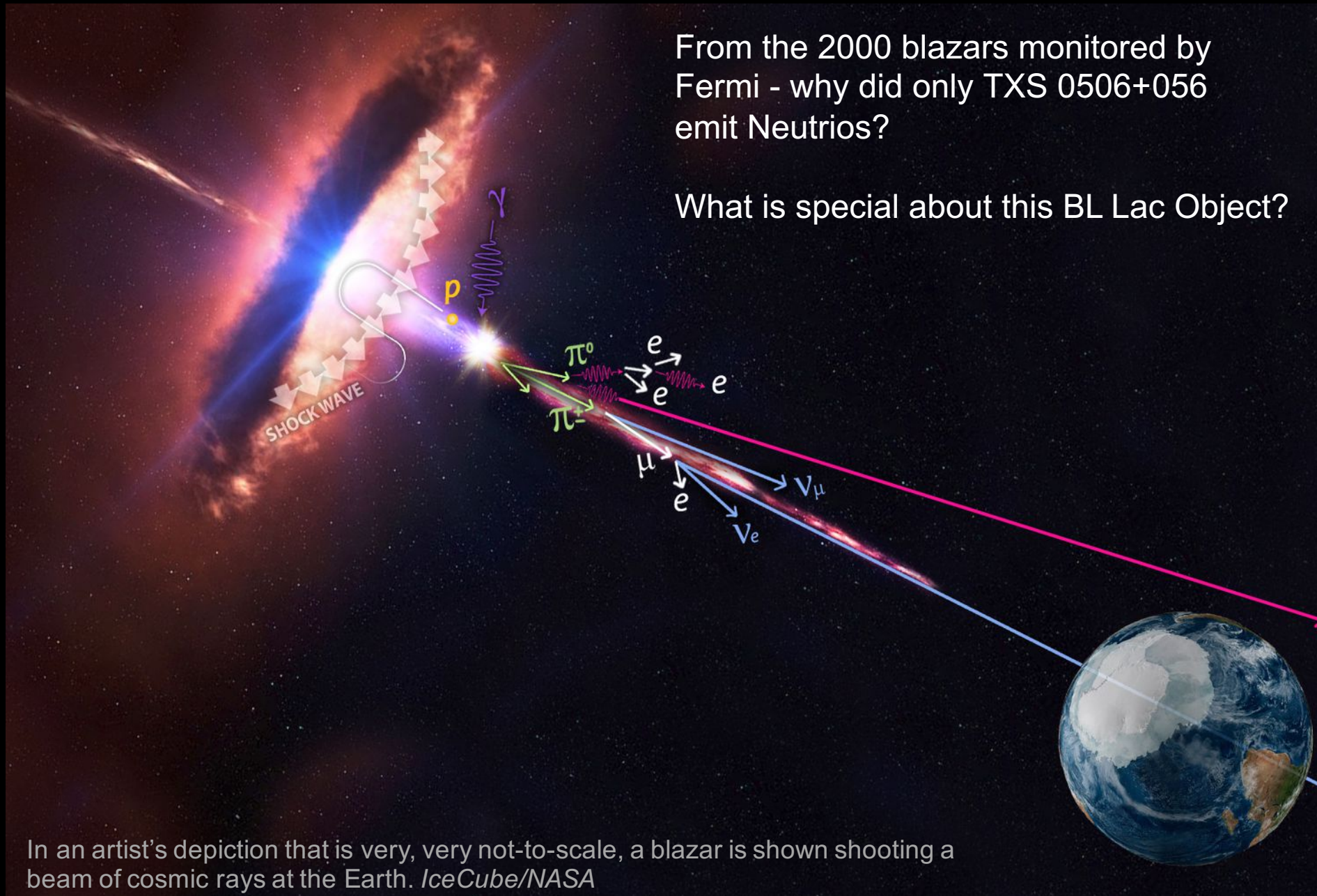
PD Dr. Silke Britzen

Max-Planck-Institut
für
Radioastronomie



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

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*

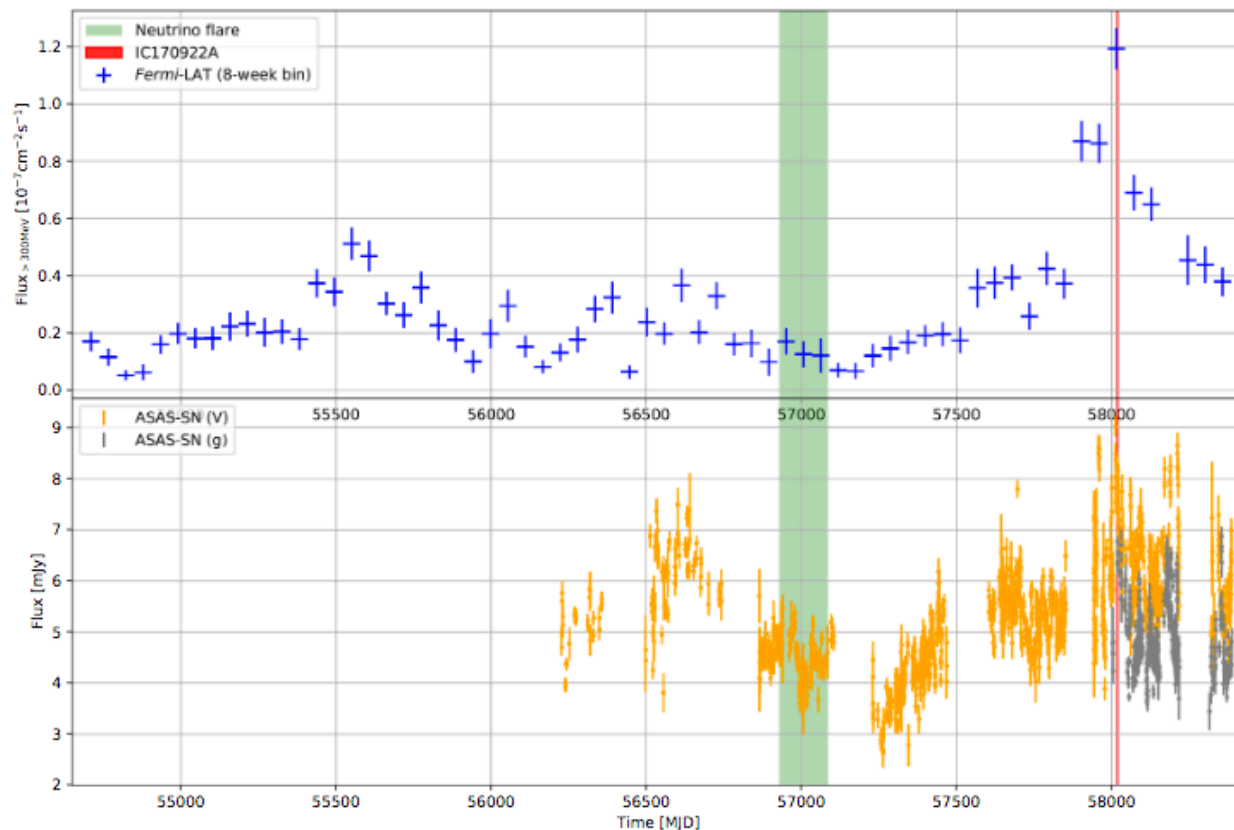


Figure 1. Top: *Fermi*-LAT light curve (photon flux integrated above 300 MeV) of TXS 0506+056 since mission start using 8-weeks binning. Bottom: Optical light curve from ASAS-SN in the V (yellow) and γ -ray (gray) bands. The green shaded area indicates the time interval of the neutrino flare while the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

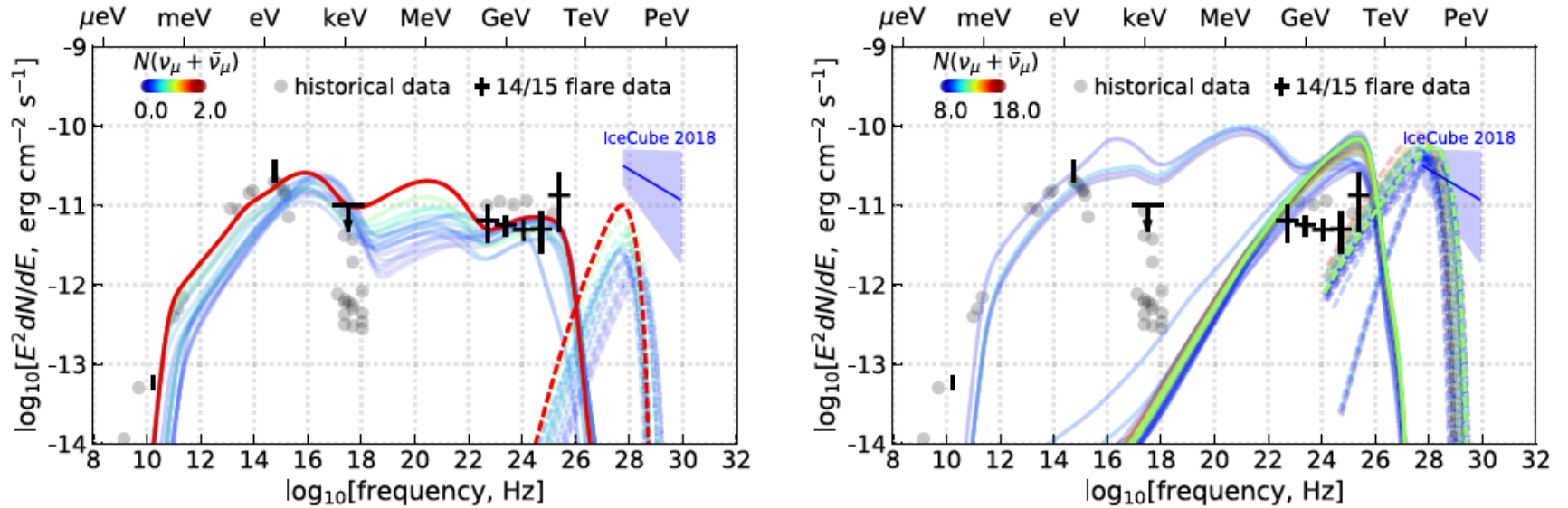


Figure 1. Spectral energy distributions (SEDs) and muon neutrino fluxes predicted by the one-zone hadronic model, compared to the single-flavor flux derived by IceCube (Aartsen et al. 2018b). In the left panel, the parameter sets optimized to describe the SED in agreement with observations fail to explain 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 flare (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 $\gamma\gamma$ 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.

together with:

C. Fendt², M. Böttcher³, F. Jaron^{1,4}, I.N. Pashchenko⁵, A. Araudo⁶,
V. Karas⁶, and O. Kurtanidze⁷

¹ Max-Planck-Institut für Radioastronomie, Bonn, Germany

² Max-Planck-Institut für Astronomie, Heidelberg, Germany

³ Centre for Space Research, North-West University, South Africa

⁴ Institute of Geodesy and Geoinformation, University of Bonn, Germany

⁵ Astro Space Center, Lebedev Physical Institute, Russian Academy of Sciences

⁶ Astronomical Institute, Academy of Sciences, Prague, Czech Republic

⁷ Abastumani Observatory, Mt. Kanobili, Abastumani, Georgia

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., subm. to ApJ:

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)

$z=0.3365\pm0.0010$ (Paiano et al. 2018)

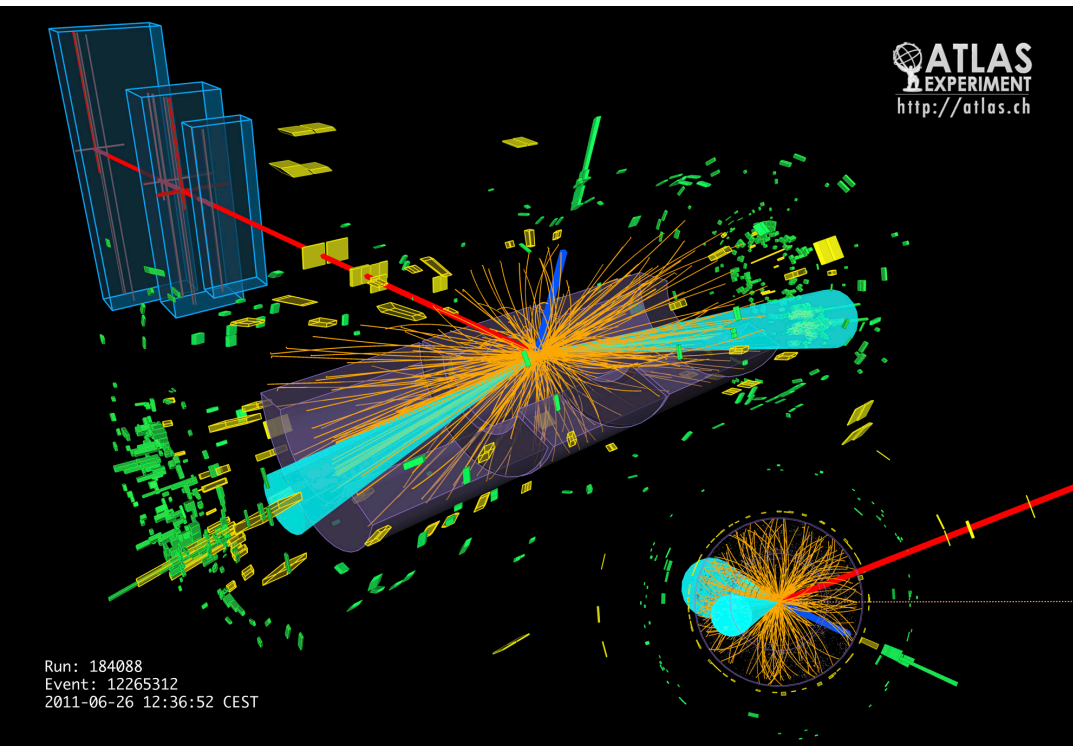
BL Lac Object



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

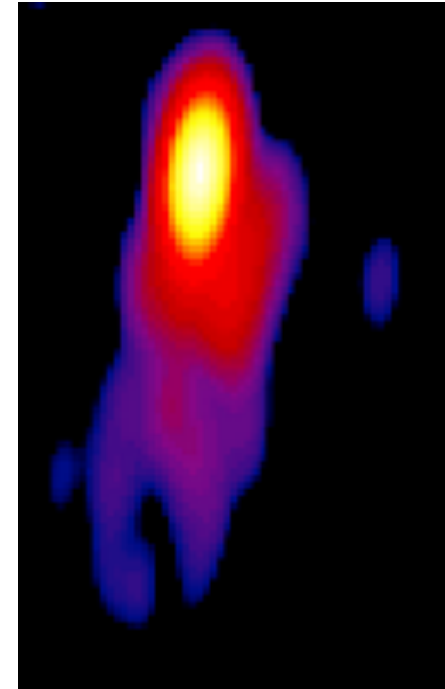
<https://www.physics.purdue.edu/MOJAVE/>

LHC @ Geneva: Collider on earth



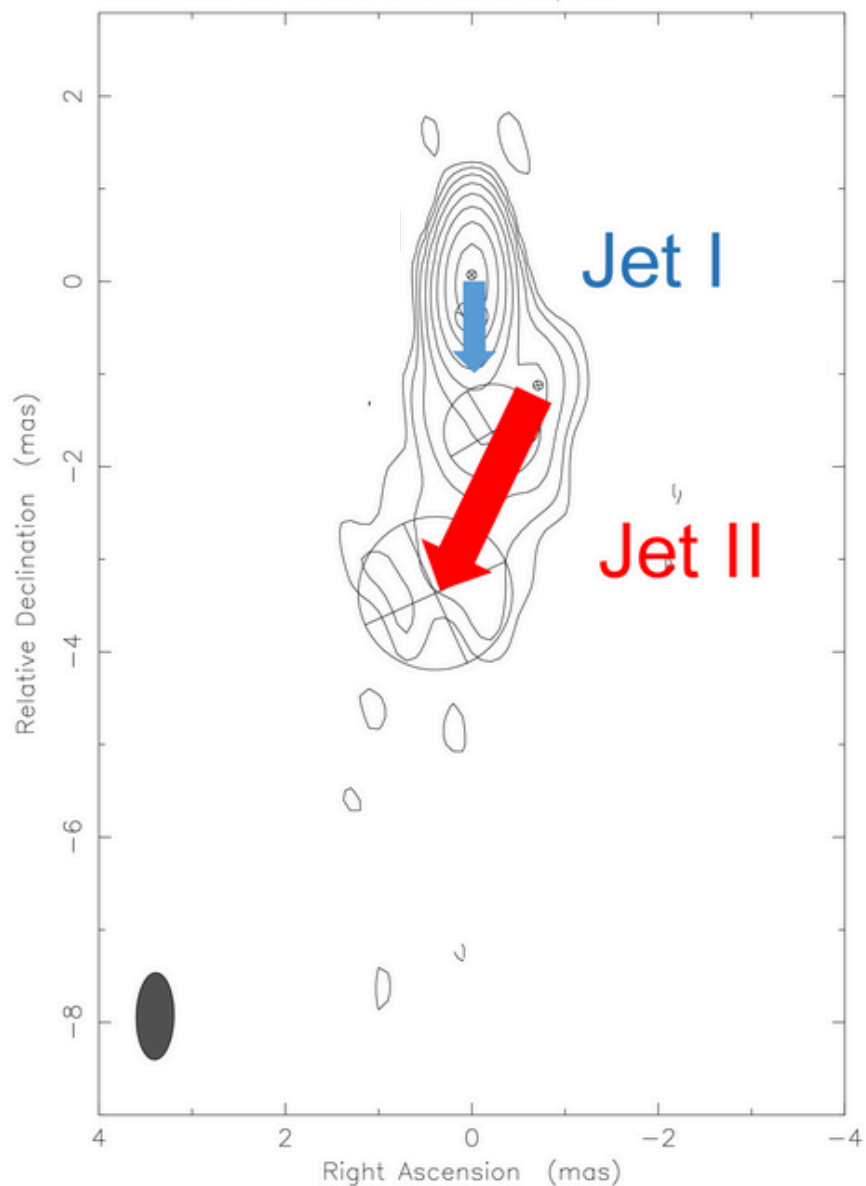
Graphical representation of one of the collision events used in obtaining the new ATLAS result, showing traces and energy deposits left by the particles flying through the ATLAS detector. They possibly originate from a Higgs boson decaying into two taus, which subsequently decay into an electron (blue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

TXS 0506+056: Cosmic Collider

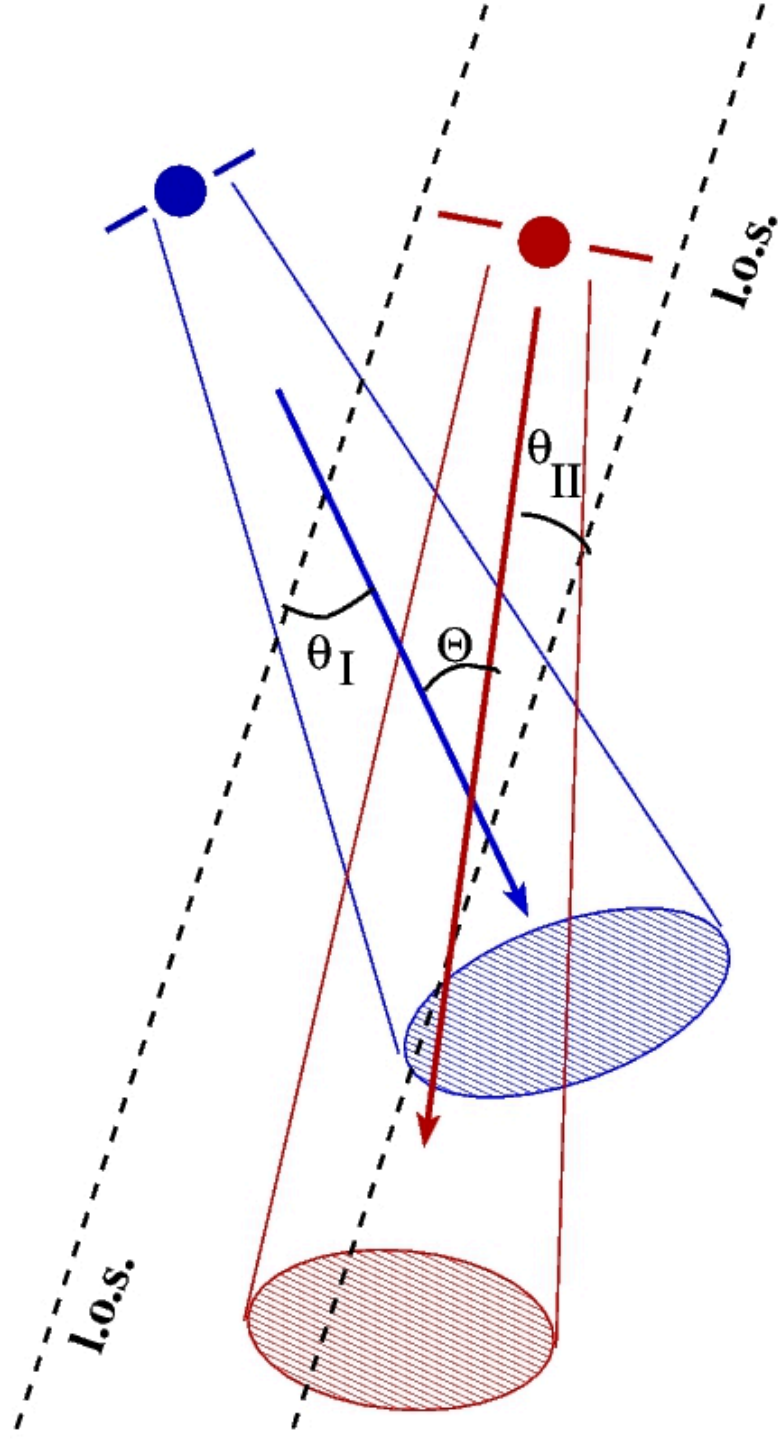


MOJAVE map
2018-04-22
15.4 GHz

Clean I map. Array: BFHKLMNOPS
0506+056 at 15.352 GHz 2015 Sep 06

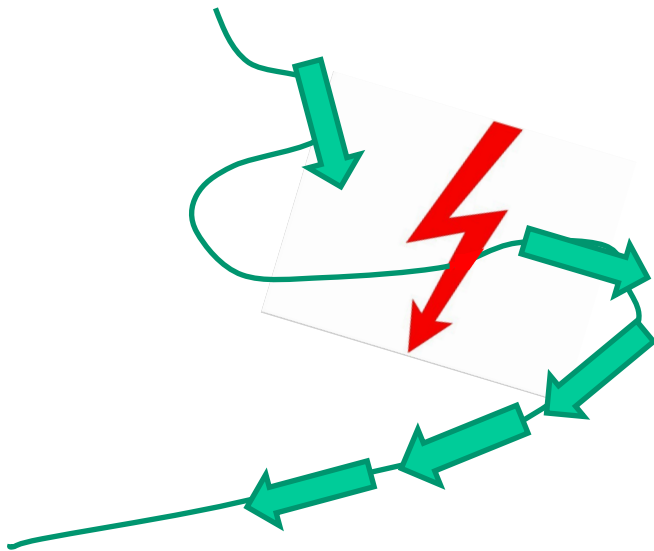


Map center: RA: 05 09 25.964, Dec: +05 41 35.334 (2000.0)
Map peak: 0.254 Jy/beam
Contours %: -0.5 0.5 1 2 4 8 16 32 64
Beam FWHM: 0.942 x 0.406 (mas) at -0.996°

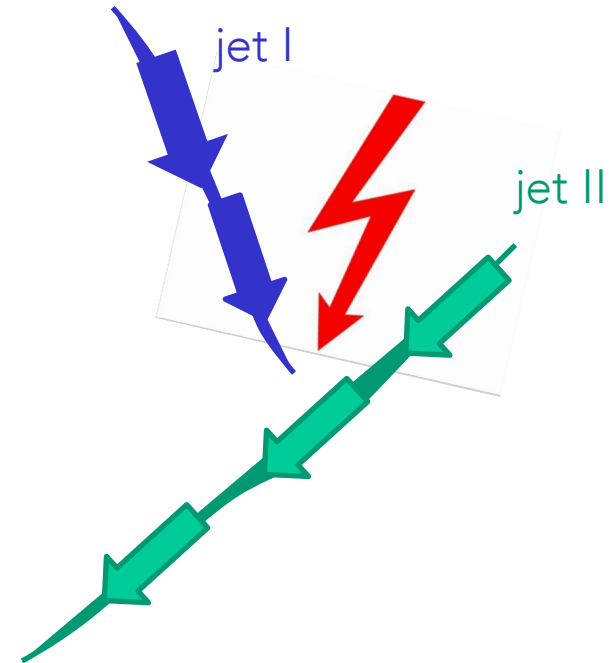


1Jet or 2Jet-scenario ?

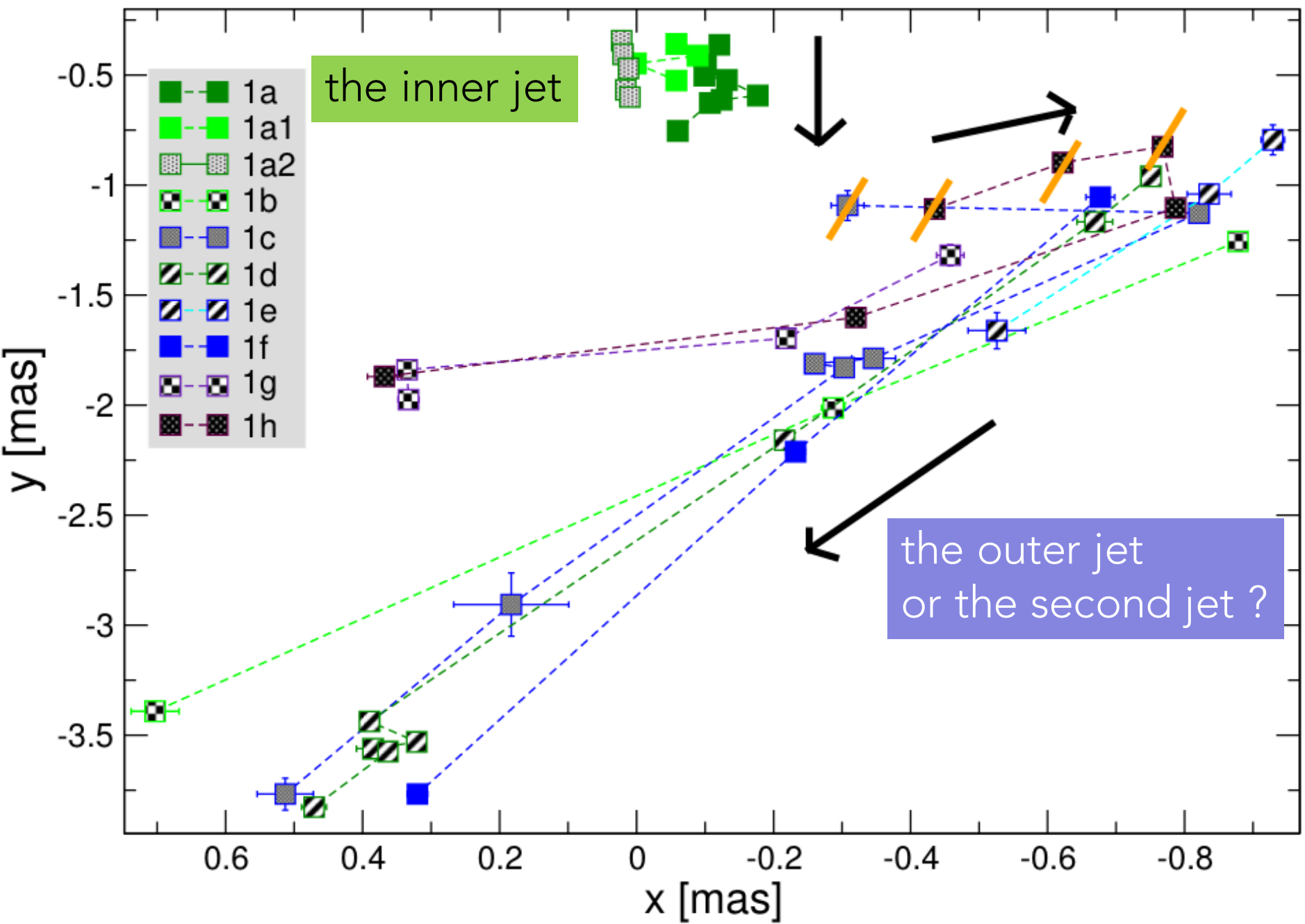
In any case: jet collision !!



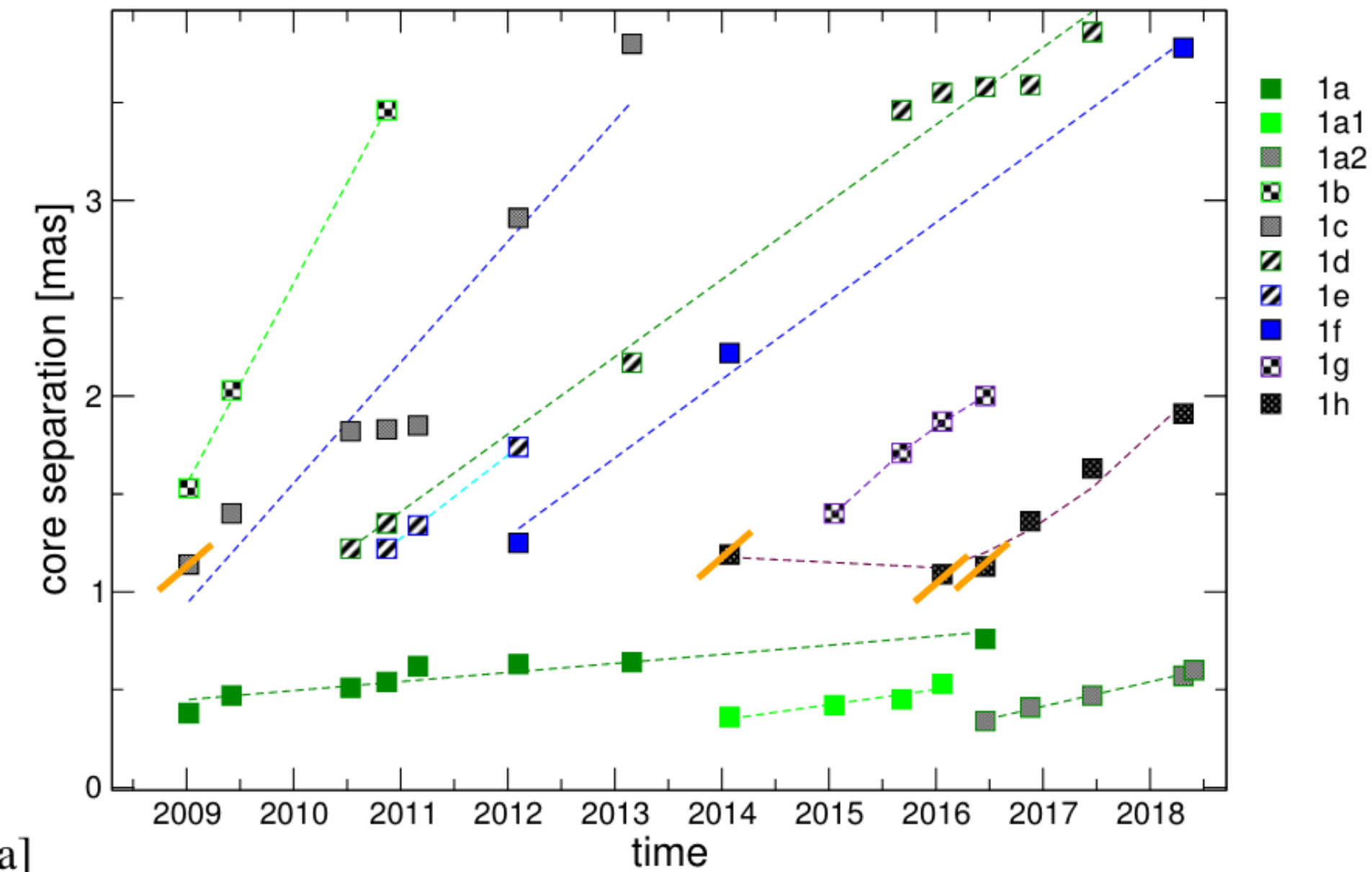
a strongly curved jet,
very special viewing angle



2 jets on a collision-course



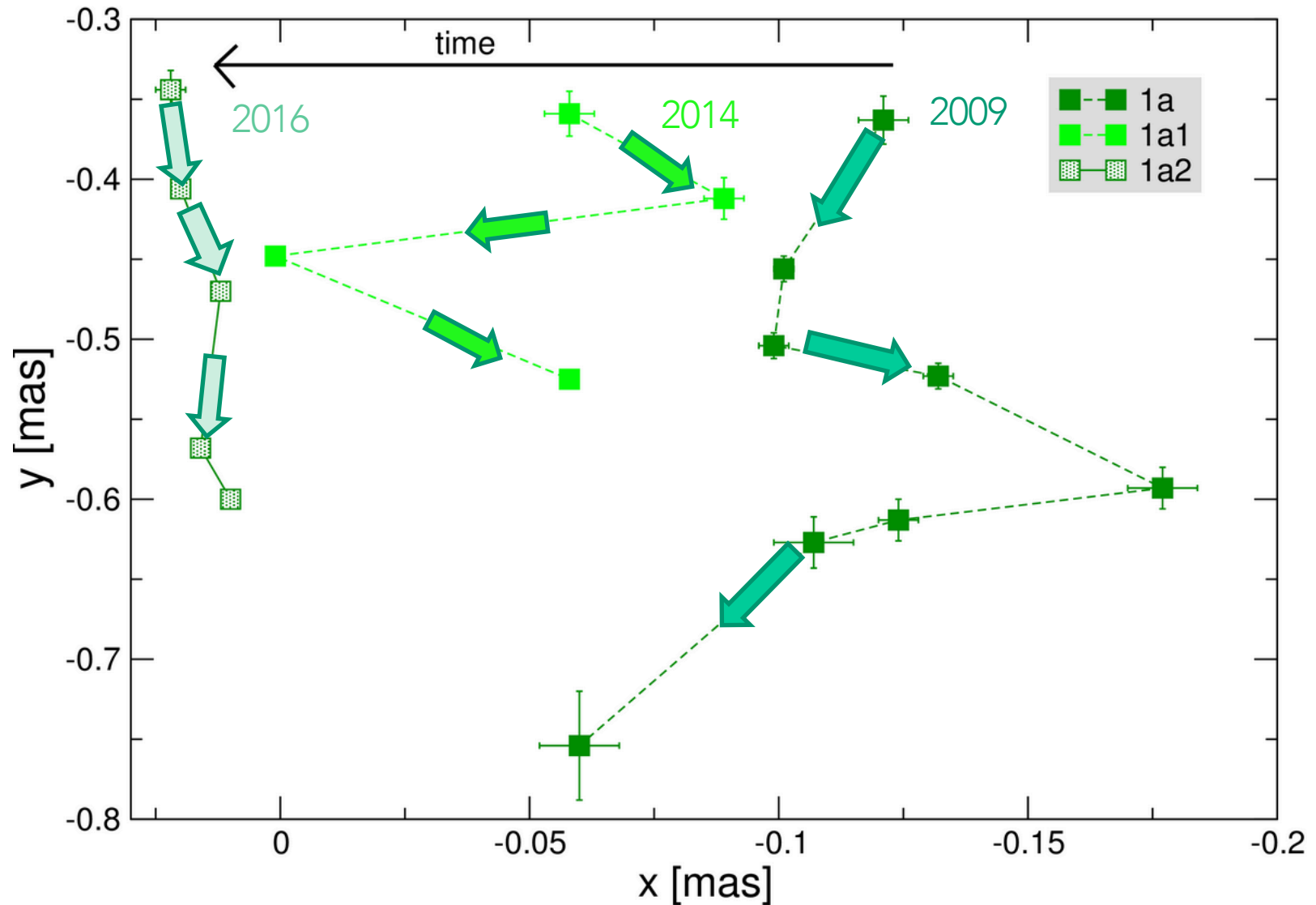
Apparent speeds

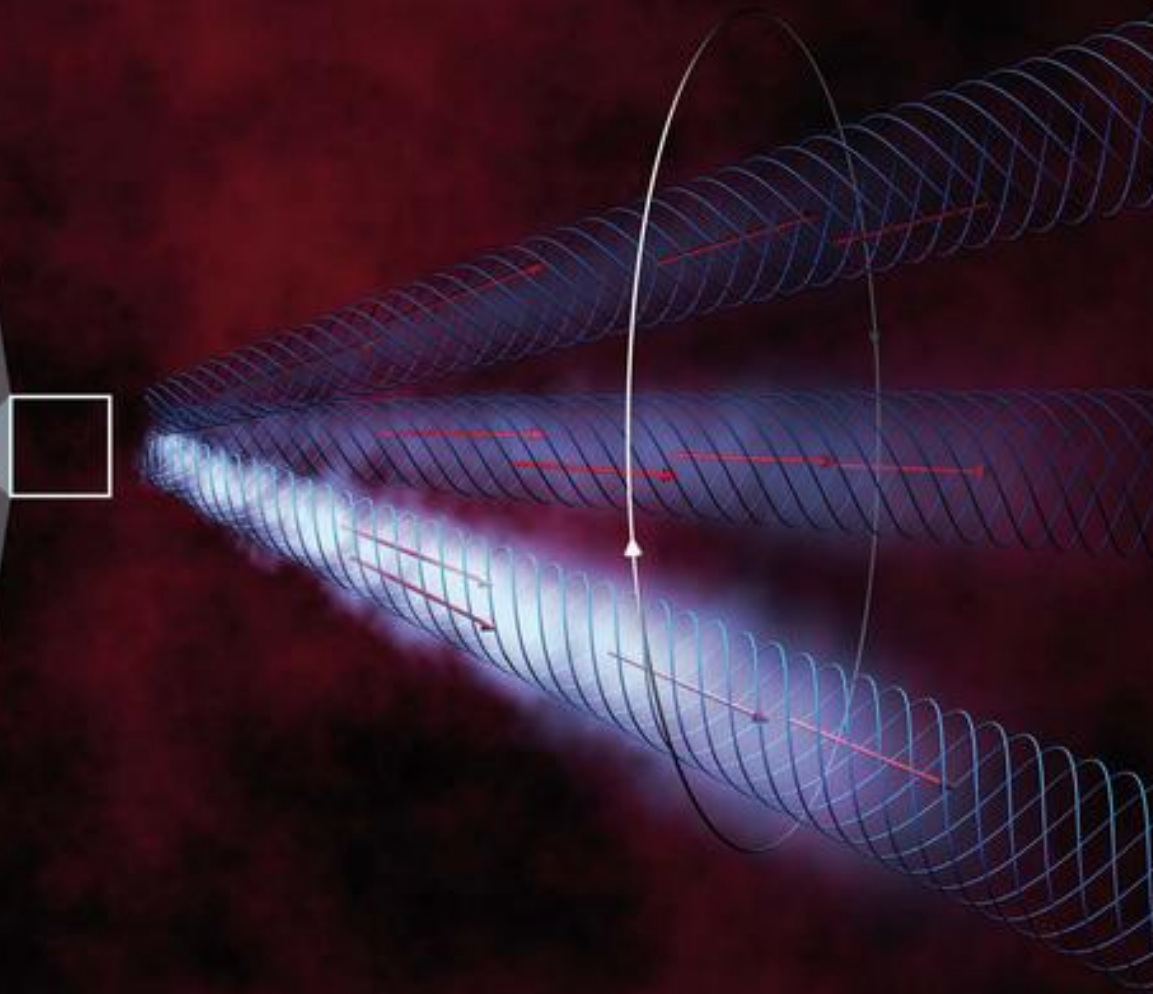
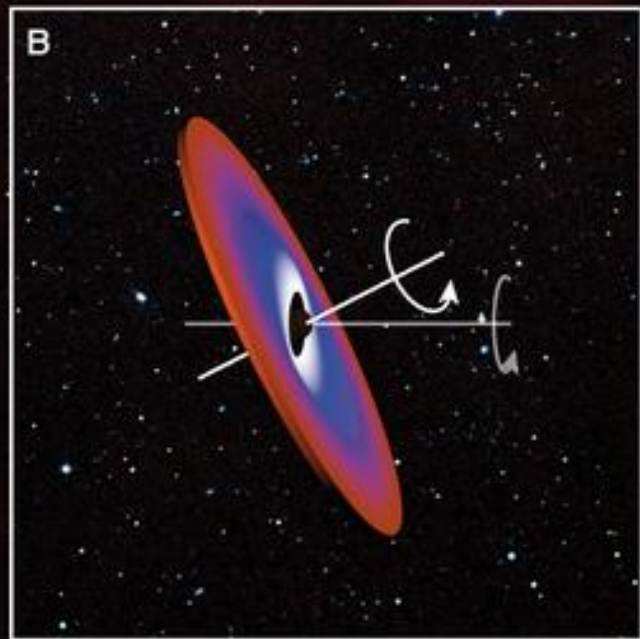


Apparent speeds

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	inner jet	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	outer jet		
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			

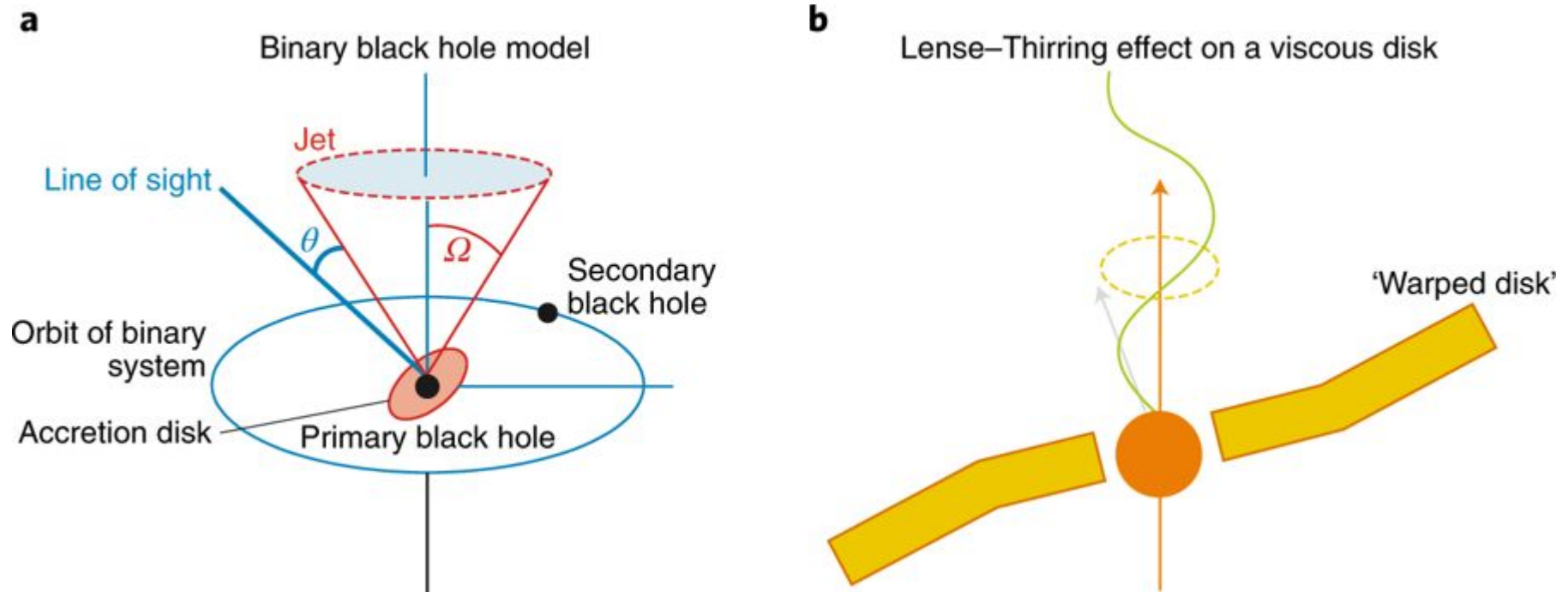
The inner part of the jet – evidence for precession





OJ287: Britzen et al., 2018, MNRAS

Jet precession – TXS 0506+056 in good company

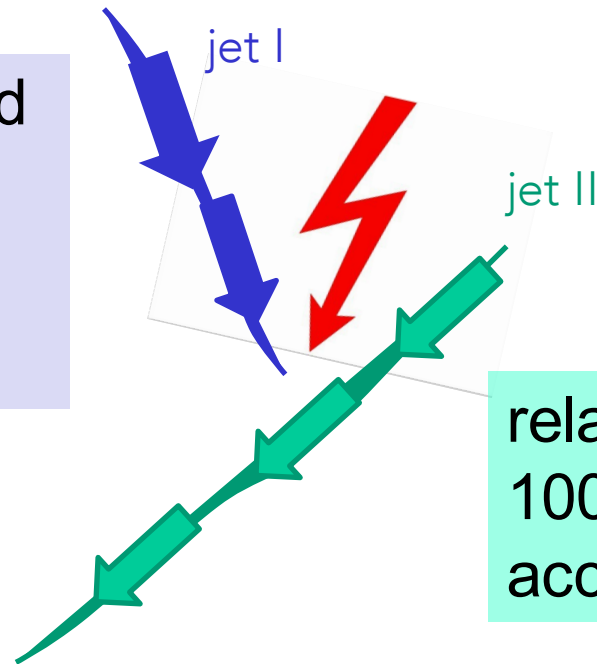


a, The orbital motion of a supermassive black hole binary leads to the precession of the jet on the surface of a cone with opening angle Ω , at an angle θ from the observer's line of sight. **b**, A misalignment of the supermassive black hole spin (orange arrow) with the accretion disk angular momentum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

Jet precession in binary black holes

Photo-hadronic interactions in the jets of TXS 0506+056

synchrotron photon field (X-rays) of jet I acts as target photon field for $p\gamma$ 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 $\gamma\gamma$ 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).

Conclusions:

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 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 !!