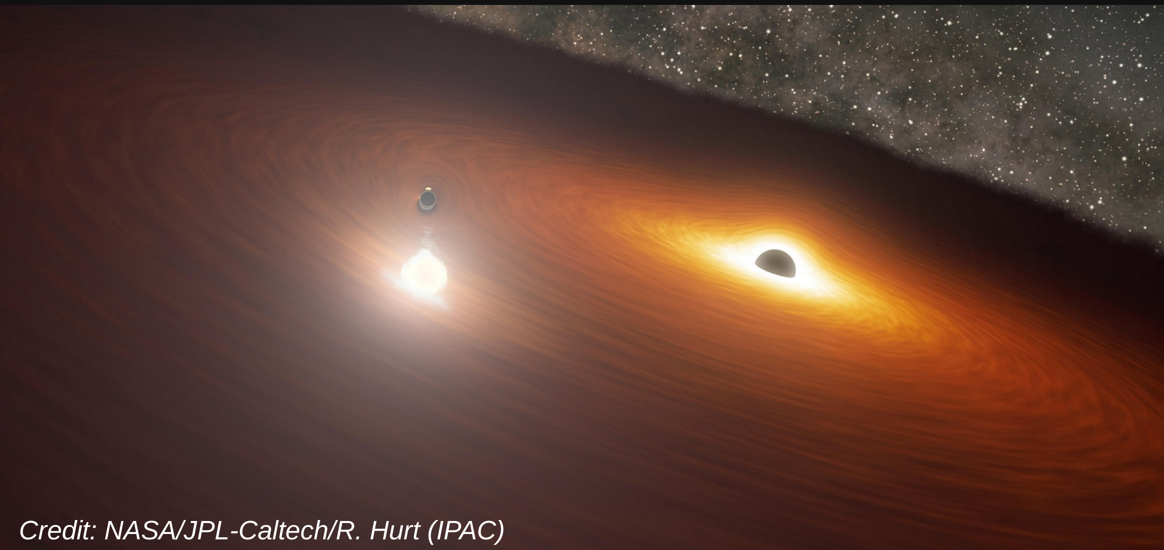
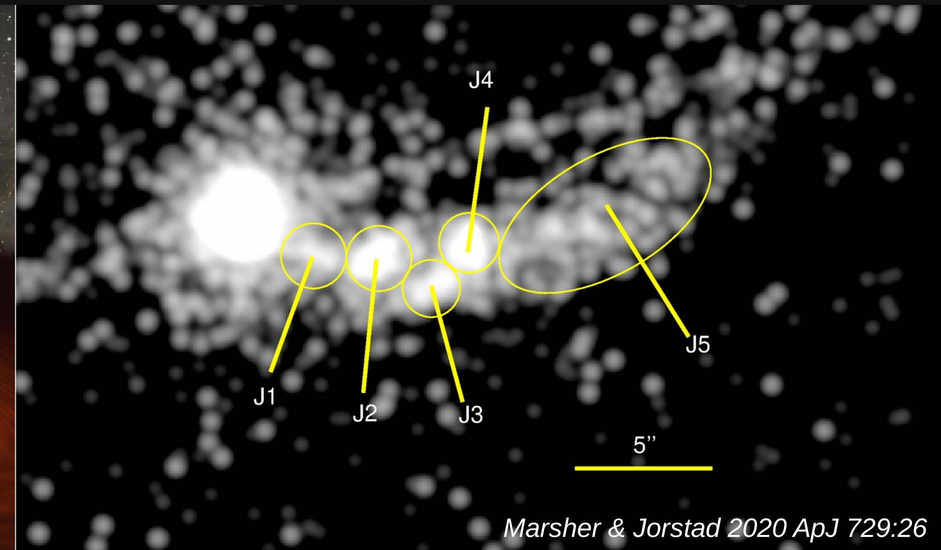
A multiwavelength look at the 2017 flare of OJ 287





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on behalf of the VERITAS collaboration

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Gamma 2022 Conference
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VERITAS

A bit of background

- **OJ 287:** IBL blazar at redshift z = 0.306
- Started showing strong signs of activity in UV/X-ray from mid 2016 (*Grupe et al. Atel 9629, 2016*)
- VERITAS observed it for months until a large X-ray flare happened in Feb. 2017 → led to its first VHE detection (*Mukherjee et al., Atel 10051,2017*).
- Preliminary results of the VERITAS campaign shown at ICRC 2017 (*O'Brien 35th ICRC Proc. 2017*)

What did happen in OJ 287 in Feb 2017?
→ Complex event from a complex target, aka 'The Rosetta stone of blazars'
(Title firstly used by L. O. Takalo (1994))

To attempt a reply, we need to review the following aspects of OJ 287:

- SMBH binary system
- Strong jet precession
- Complex radio-VLBI jet kinematics
- Mpc X-ray extended jet
- 'Orphan-like' flares

An exceptional SMBH binary system

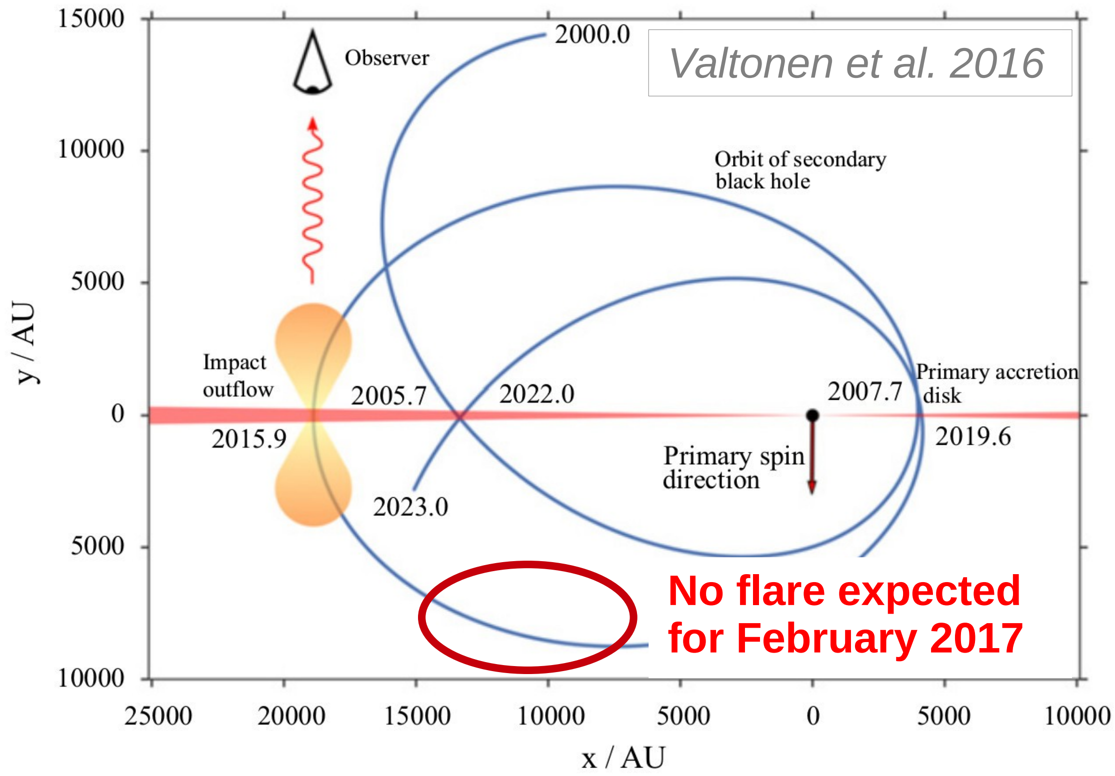
- Archival optical observations dating back to 1890 have revealed a ~12 year outburst cycle.
  (Sillanpaa et al. 1988)

- Optical variability suggests a binary system

$$\mathrm{BH}_1 = 1.8 \times 10^{10}\ M_\odot \qquad \frac{\mathrm{BH}_1}{\mathrm{BH}_2} \sim 100$$
$$\mathrm{BH}_2 = 1.3 \times 10^{8}\ M_\odot$$

(Valtonen et al. 2011)

- Definitive confirmation of a SMBH system from a flare prediction in 2019, July 31 by Spitzer.
  'the Eddington flare arrived within 4 hours of the predicted time'
  (Seppo Laine et al 2020)



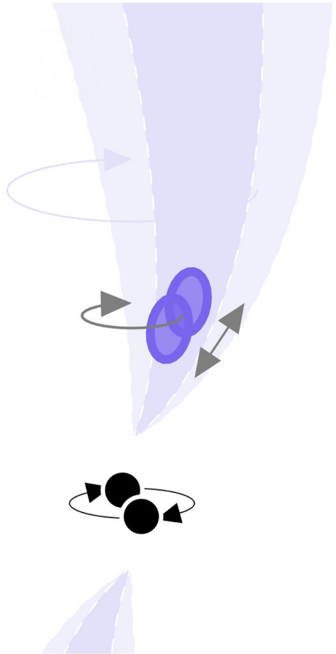
Feb. 2017 flare does not appear to be related to the secondary SMBH

Closer look at the binary SMBHs

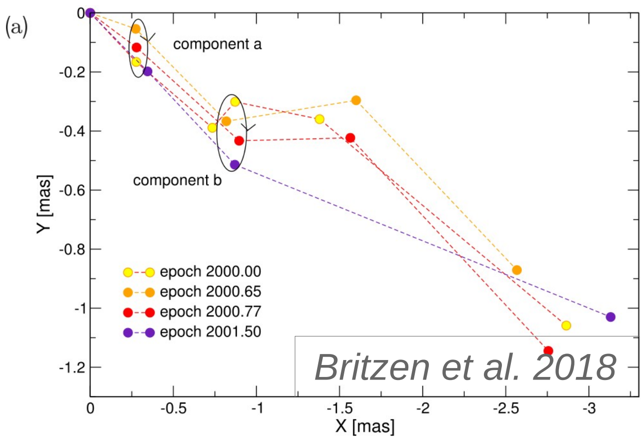
Credit: NASA/JPL-Caltech/R. Hurt (IPAC)

Jet precession

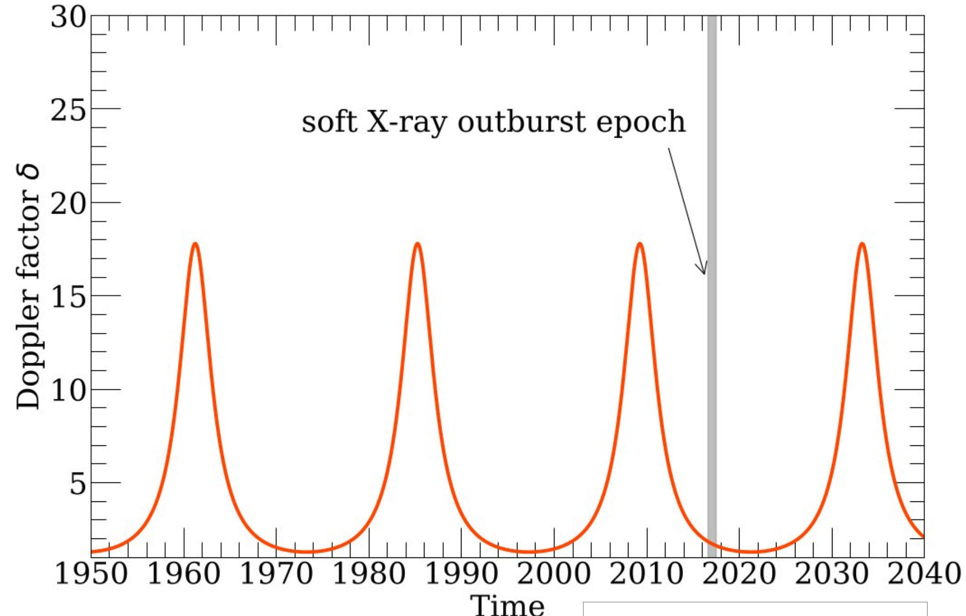
A jet precession periodicity of ∼22 yr (~ twice optical periodicity time-scale) has been deduced from radio VLBI observations *(Britzen et al. 2018).*



Adapted from Gattano et al, 2020



Britzen et al. 2018

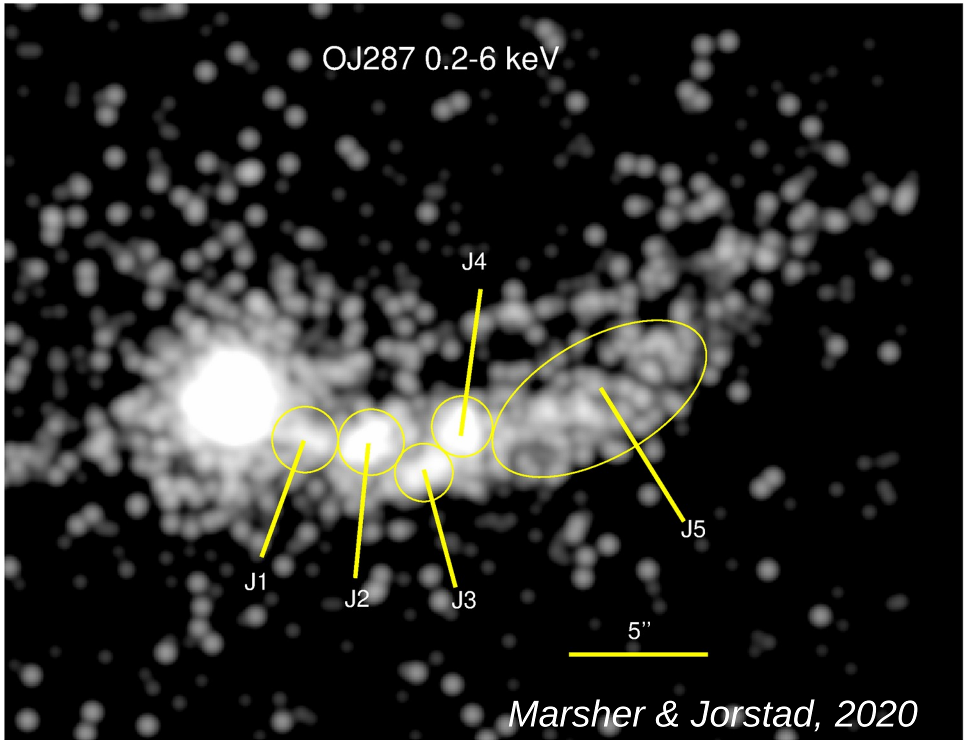


Huang et al. 2021

Feb. 2017 flare does not appear to be related to the jet precession

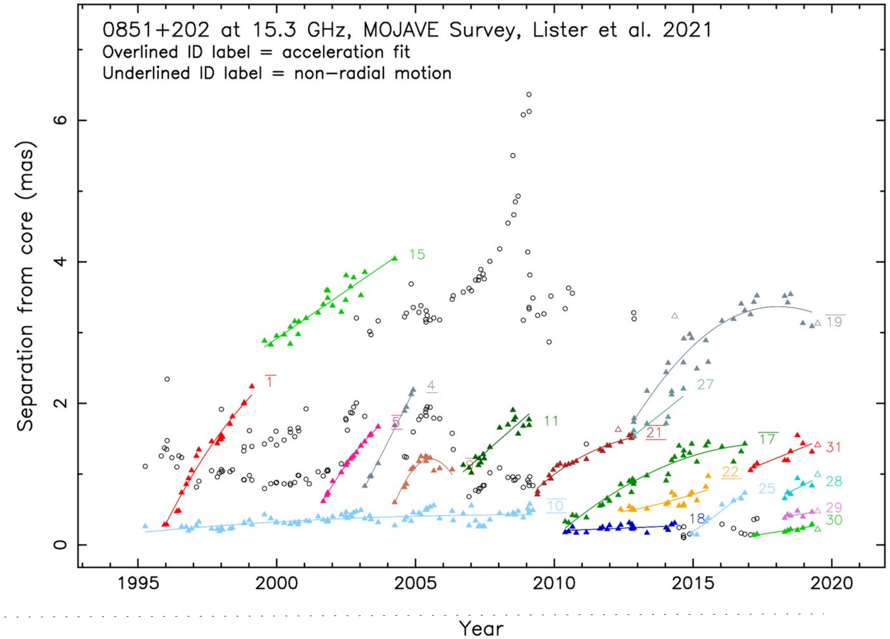
Large scale X-ray jet

- X-ray extended jets mostly seen in FSRQs, and in some LBLs/IBLs : http://hea-www.harvard.edu/XJET/
- Total deprojected jet size >~ 1 Mpc
- Size of X-ray knots ~ [2 – 13] kpc
→ Apparently inconsistent with the variability of ~1 day observed during Feb 2017

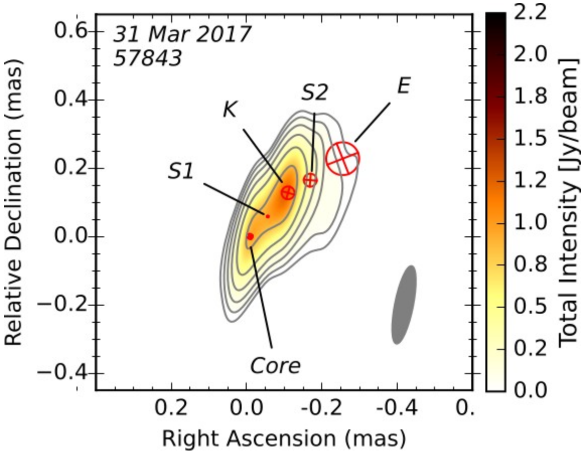


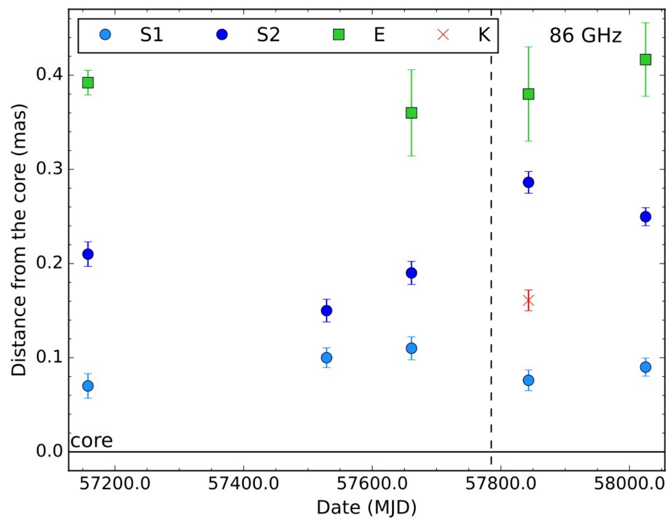
Radio VLBI jet kinematics, new insights

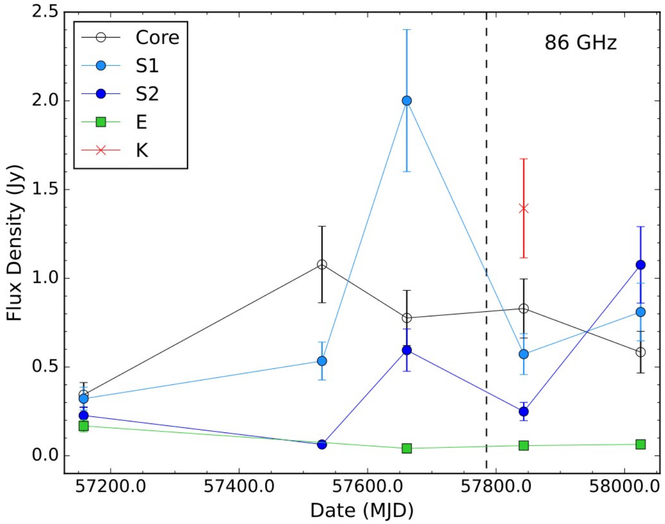
- Very complex kinematics:
  Quasi-stationary-knots, moving knots, accelerations, non-radial motions,…
- GMVA campaign at 86GHz taken in 2015-2017 shows the emergence of a new component K just after the Feb 2017 outburst
  (Lico et al. 2022)



GMVA results





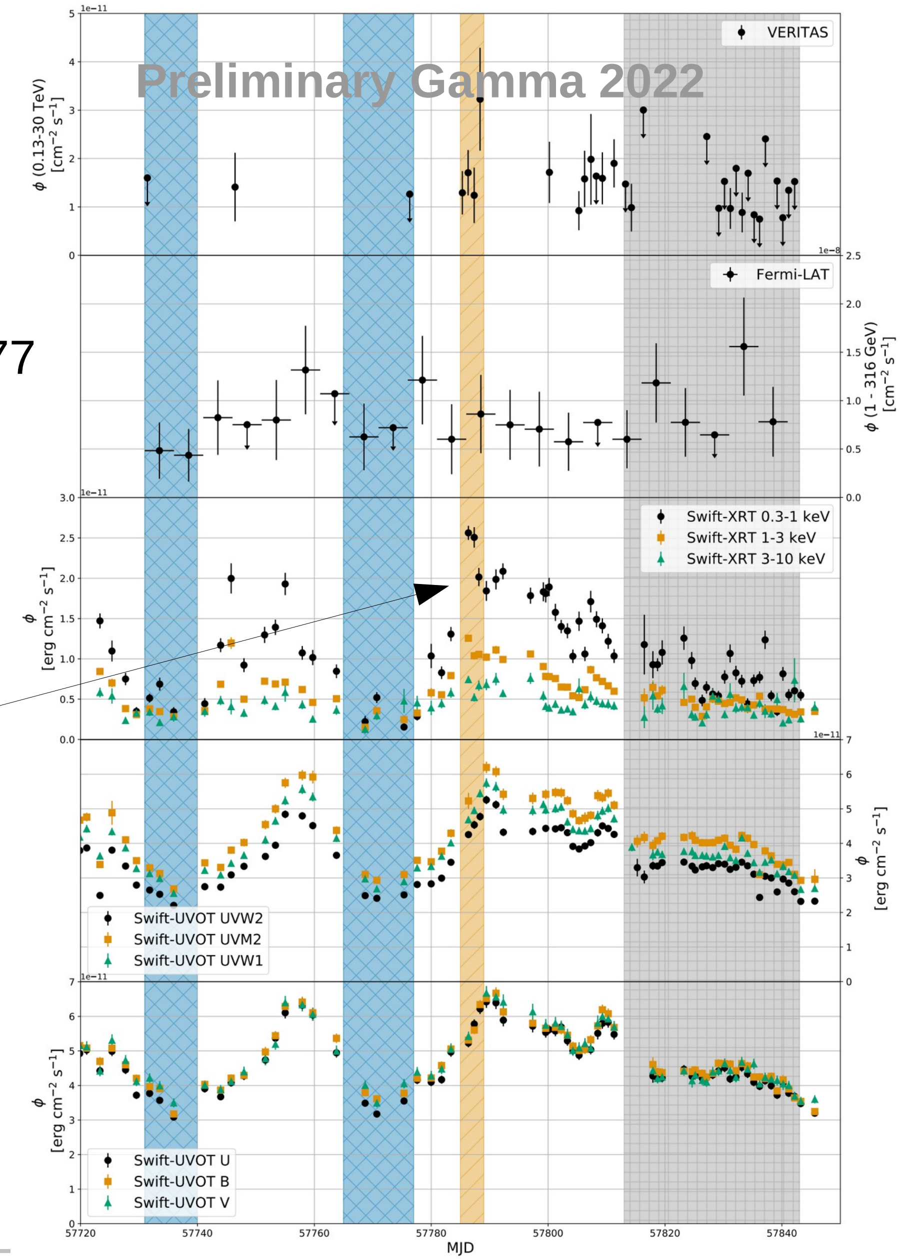


Multiwavelength lightcurve

We defined three states of activity to investigate and build MWL SEDs

- **Low state:** MJD 57731-57740 & MJD57765-57777
- **Flare:** MJD 57785-57789
- **Post-flare:** MJD 57813-57843

Quite unusual flare happening mostly in soft X-ray



Hint for multiple components:
Correlation VERITAS / Hard-Xray ~2.3 sigma
Correlation VERITAS / Soft-Xray ~3.8 sigma

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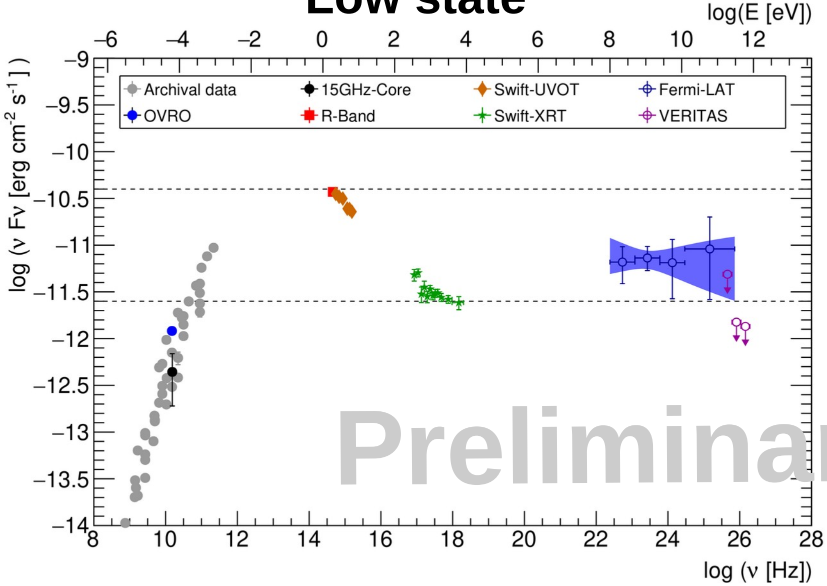
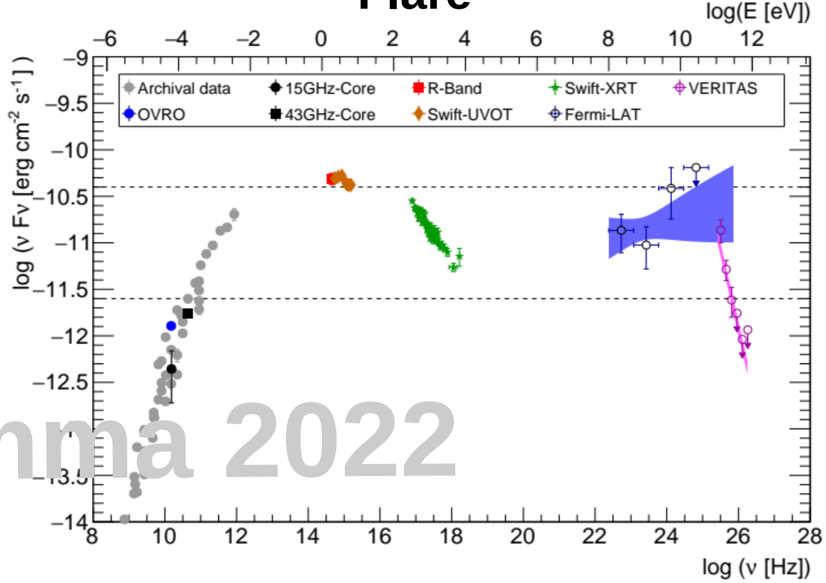
O. Hervet
Gamma 2022, July 2022

Broadband SEDs

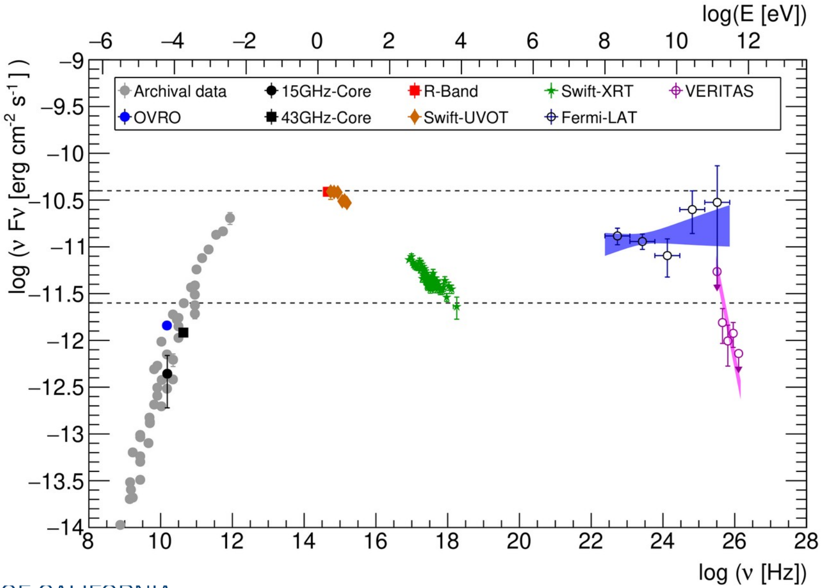
Low state



Flare

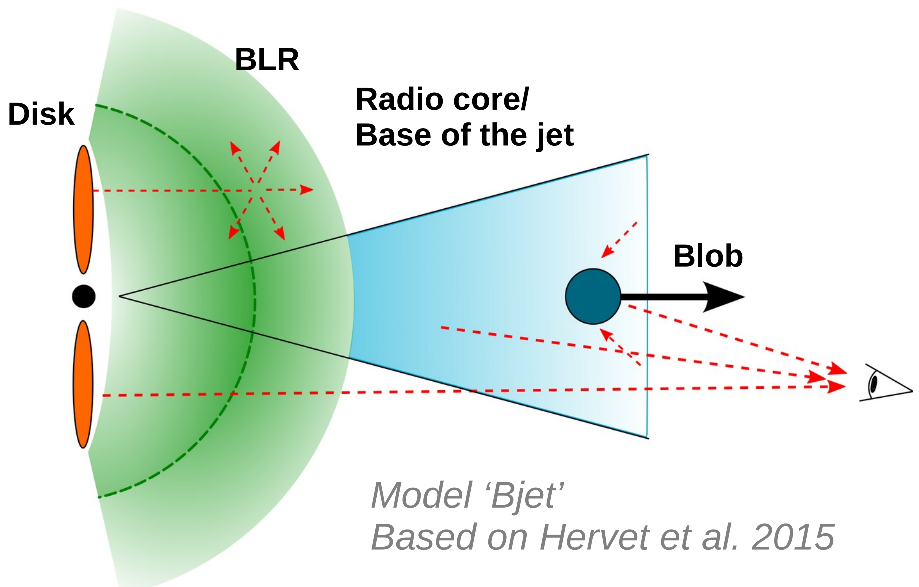


Post-flare

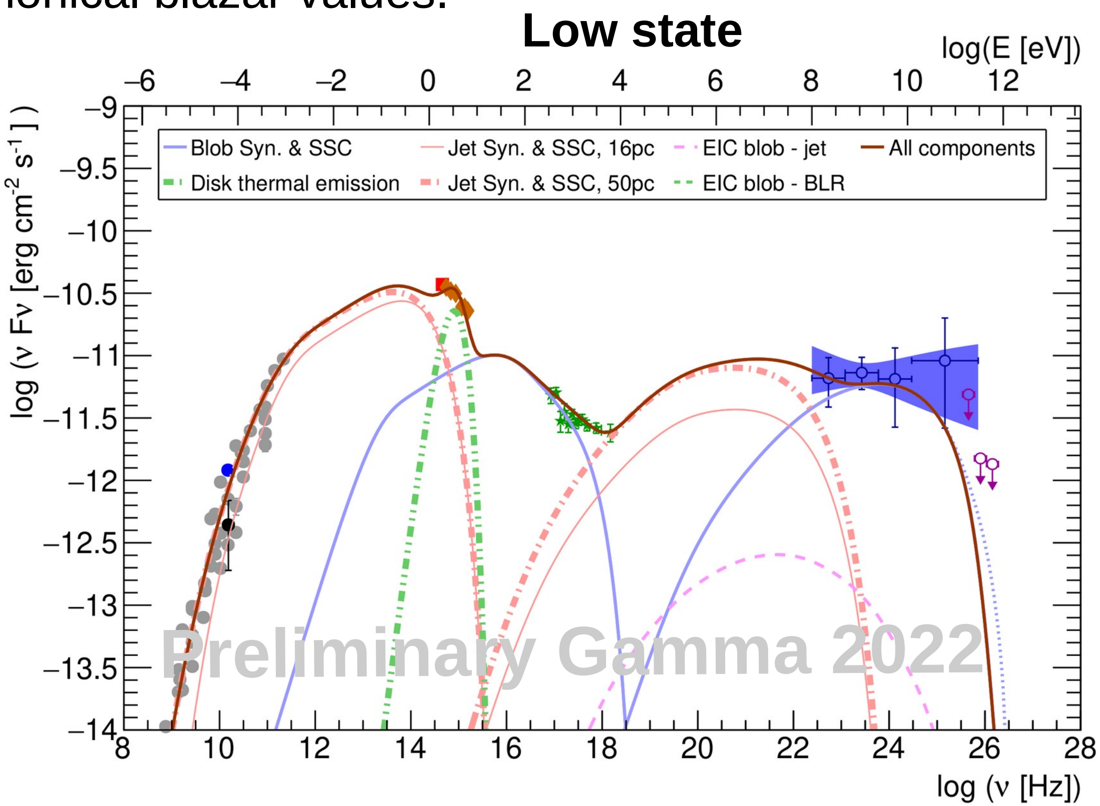


Broadband modeling – *Blob in jet*

- Doppler factor and angle with the line of sight deduced from fastest motions in radio VLBI jet *(Hervet et al. 2016)*
- Minimal variability ~ 1day
- The size of the jet base is adjusted to match the observed radio core extension, with its flux constrained by radio core observations at 22GHz and 43GHz.
- The modeling parameters are within canonical blazar values.

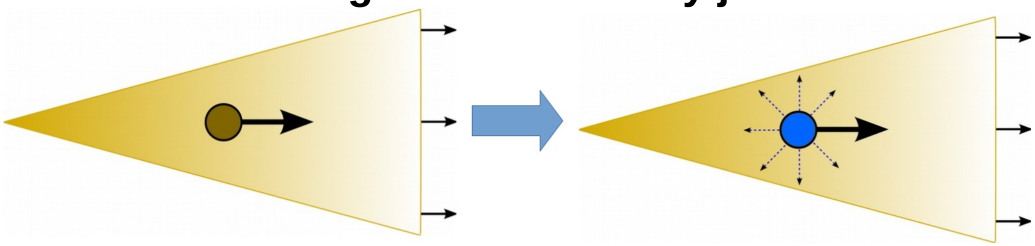


Model 'Bjet'
Based on Hervet et al. 2015

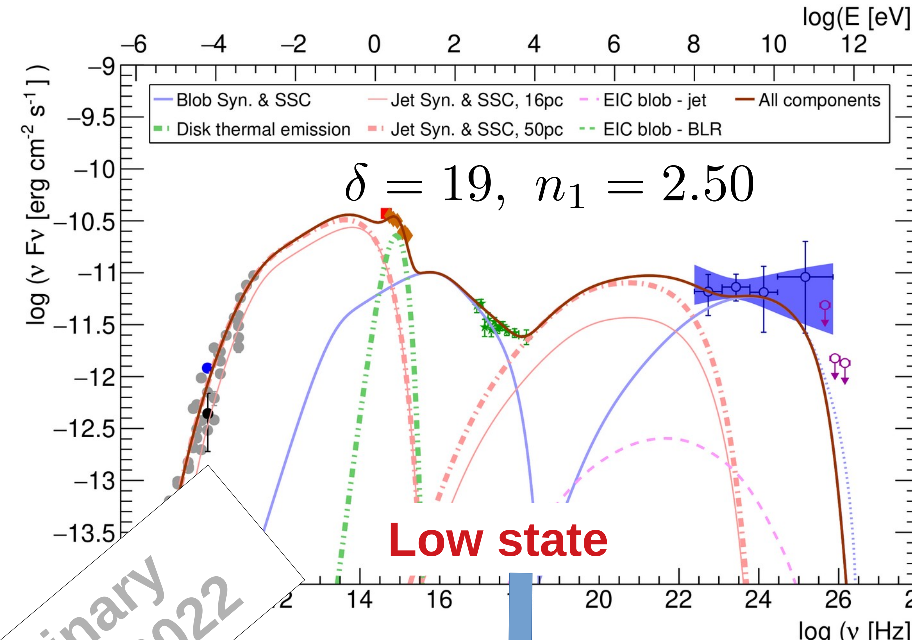


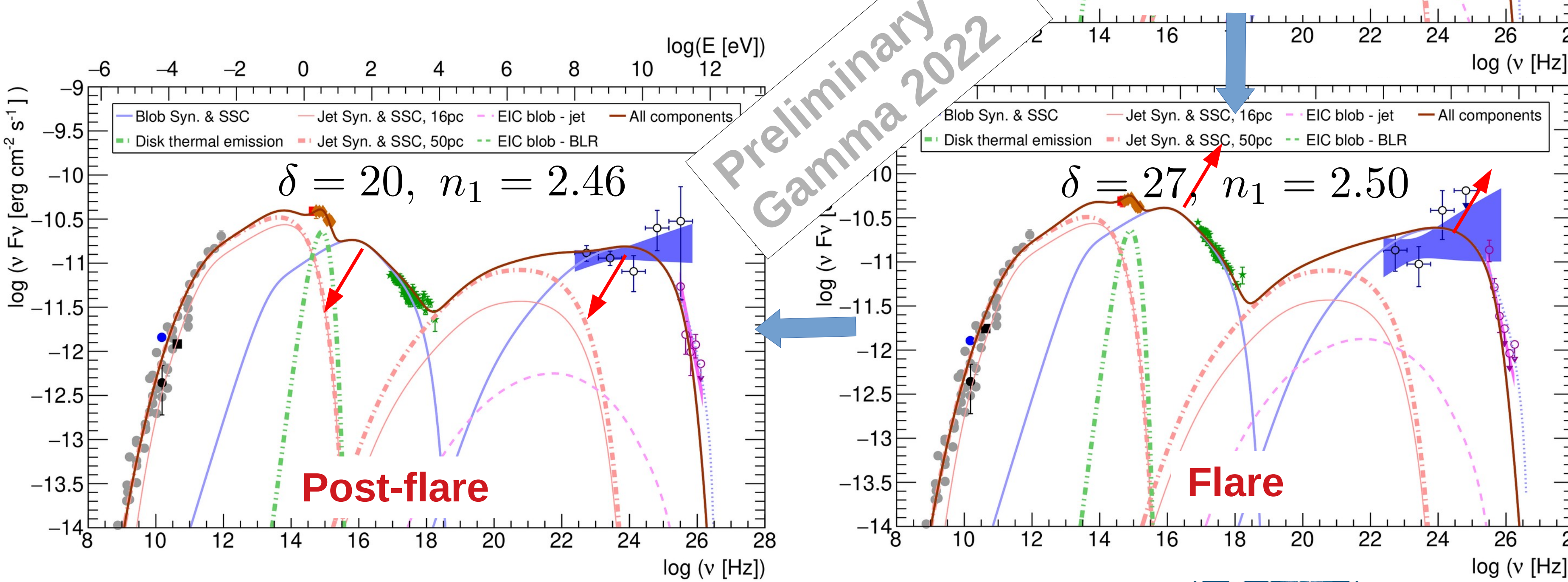
Broadband modeling – *three states*

A flaring blob in a steady jet



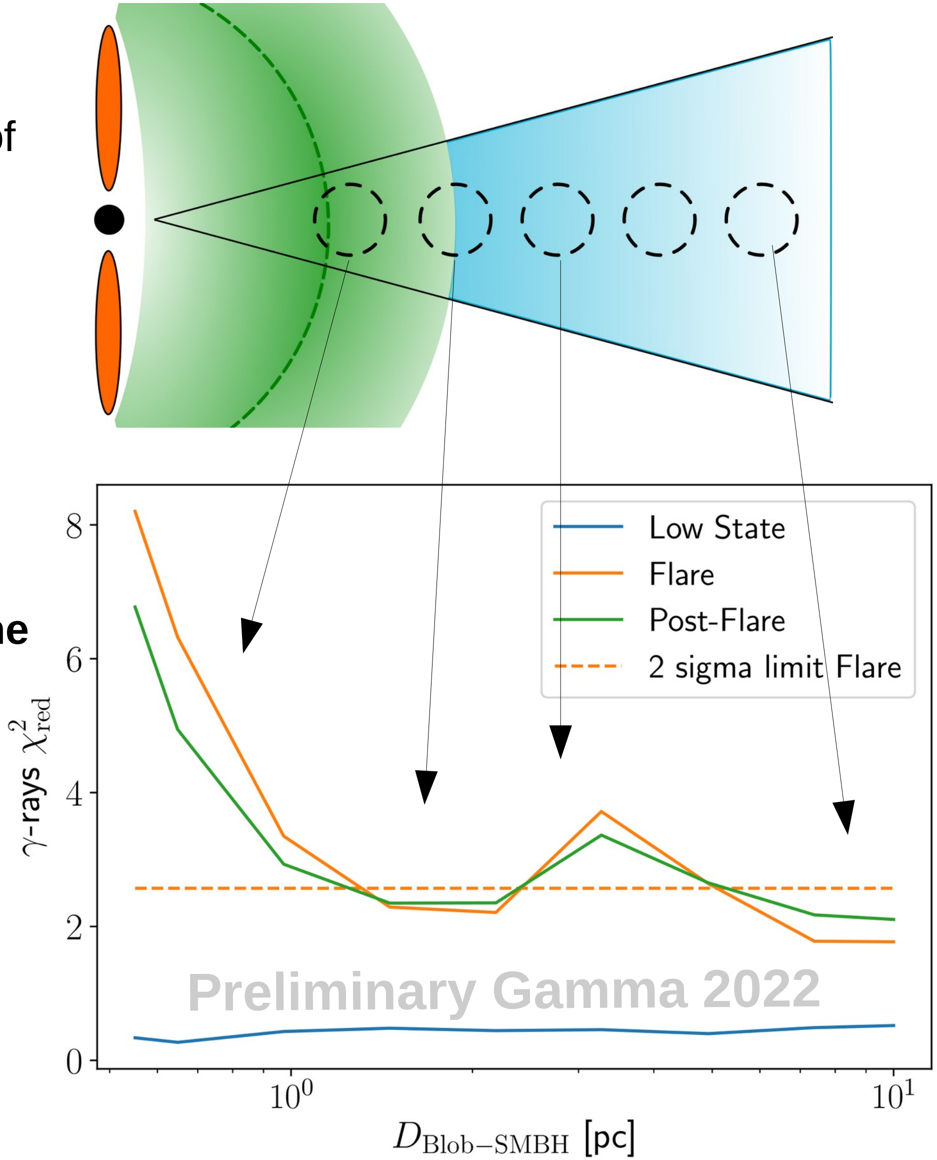
The observed variability can be reduced to two parameters: the **Doppler factor δ** and at smaller extent, the first index n1 of a broken power law particle distribution





Location of the emission zone

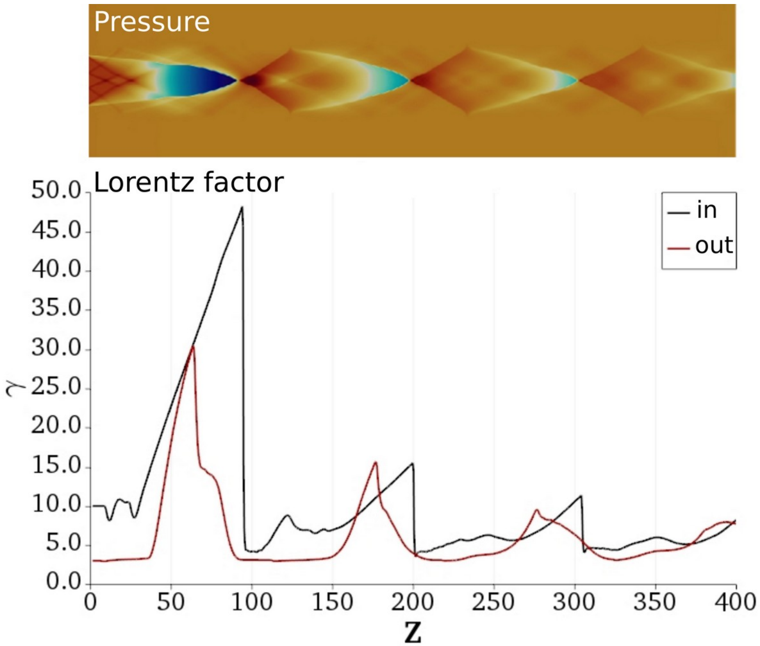
- Estimation of the reduced Chi2 of the model on Fermi+VERITAS spectra changing only the distance of the blob from the SMBH (1 free parameter)
- The flare state SED is the one providing the most constraint on the location of the emission zone
- Dashed orange line show the 2-sigma limit of the a given distance being worse than the best one (for the flare state SED)
- The data favors a model with low photon-photon opacity and weak external IC → **likely downsteam the BLR and the radio core (>~ 6pc)**
- Only 1 free parameter here, so the result is **very-strongly** model dependant and cannot be seen as hard evidence of the blob's distance



A strong shock in the 1rst radio knot?

- Recent observations of a brightening of the 1st radio knot (S1) before the Feb 2017 flare, and a new radio knot downstream afterwards strongly suggests a flare happening in S1 (~10pc from the core)
- Our multi-zone model favours an emission zone downstream of the radio core
- Our model suggests that most of the variability can be explained by an abrupt change of the blob's Doppler factor (19 → 27)

This effect is actually expected when considering S1 as a strong recollimation shock



Top: 2D pressure profile of a 2-flow jet with a strong first recollimation shock. Bottom: associated Lorentz factor of the inner (in) and outer (out) jets. *Adapted from Hervet et al. 2017*

Outlook

Besides the binary system and the jet precession, OJ 287 shares several features with other known TeV IBLs/LBLs such as:

- an hybrid VLBI jet kinematics *(Hervet et al. 2016)*
- an X-ray extended jet (e.g. Ap Lib)
- flares happening mostly in X-ray and VHE (e.g. BL Lac, VER J0521+211)

IBLs/LBLs are slowly making their way in becoming a fundamental distinct blazar class, not just along a smooth continuum between HBLs and FSRQs
(e.g. Hervet et al. 2017)

Thanks !

Annex – model parameters

Parameter	Low state	Flare	Post-flare	Unit
θ	2.0	–	–	deg
Blob				
δ	**19**	**27**	**20**	
$N_e^{(1)}$	2.0×10^5	–	–	cm^{-3}
n_1	**2.50**	–	**2.46**	–
n_2	3.8	–	–	–
γ_{min}	1.0×10^3	–	–	–
γ_{max}	1.9×10^5	–	–	–
γ_{brk}	2.3×10^4	–	–	–
B	2.5×10^{-1}	–	–	G
R	1.75×10^{16}	–	–	cm
$D_{BH}{}^*$	8.0	–	–	pc
Nucleus				
L_{disk}	7.0×10^{45}	–	–	erg s^{-1}
T_{disk}	1.3×10^4	–	–	K
Jet				
δ	8	–	–	
$N_e^{(1)}$	3.0×10^4	–	–	cm^{-3}
n	2.5	–	–	–
γ_{min}	2.5×10^2	–	–	–
γ_{max}	1.0×10^4	–	–	–
B_1	2.0×10^{-1}	–	–	G
R_1	7.5×10^{16}	–	–	cm
L^*	5.0×10^1	–	–	pc
$\alpha/2^*$	5.1×10^{-1}	–	–	deg

* *Host galaxy frame.*