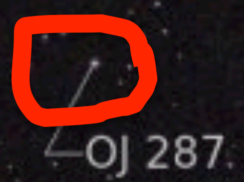
OJ 287: Deciphering the "Rosetta Stone of blazars☀"

☀Takalo 1994

Silke Britzen, MPIfR, Bonn

in cooperation with:
C. Fendt[2], G. Witzel[3], S.J. Qian[4], I. Pashchenko[5], O. Kurtanidze[6,7],
M. Zajacek[1,8,10], G. Martinez[3], V. Karas[8], M. Aller[9], H. Aller[9],
A. Eckart[1,10], K. Nilsson[11], P. Arevalo[12], J. Cuadra[13], M. Subroweit[10],
and A. Witzel[1]



1 MPIfR, Bonn
2 MPIA, Heidelberg
3 UCLA, Department of Physics and Astronomy, LA, USA
4 Beijing Observatory, China
5 Astro Space Center, Lebedev Physical Institute, Russian Academy of Sciences
6 Abastumani Observatory, Mt Kanobili, 0301 Abastumani, Georgia
7 Engelhardt Astronomical Observatory, Kazan Federal University, Tatarstan, Russia
8 Astronomical Institute, Academy of Sciences, Prague, Czech Republic
9 University of Michigan, USA
10 I. Physikalisches Institut der Universität zu Köln
11 Tuorla Observatory, Department of Physics and Astronomy, University of Turku, 20500, Turku, Finland
12 Instituto de Física y Astronomía, Facultad de Ciencias, Universidad de Valparaíso, Gran Bretaña No. 1111, Playa Ancha, 2360102 Valparaíso, Chile
13 Instituto de Astrofísica, Pontificia Universidad Cato □lica de Chile, 782-0436 Santiago, Chile

- NED knows about 1092 references to OJ287

Valtonen, M
Marscher, A
Jorstad, S
Nilsson, K
Agudo, I
Kidger, M
Krichbaum, T
Takalo, L
Zensus, J
Gomez, J
Sillanpaa, A
Gabuzda, D
Lehto, H
Aller, M
Hudec, R
Larionov, V
Smith, P

Zola, S
de Diego, J
Aller, H
Lahteenmaki, A
Fuhrmann, L
Heidt, J
Pursimo, T
Xie, G
Angelakis, E
Baliyan, K
Gopakumar, A
Sadakane, K
Ciprini, S

Drozdz, M
Gurwell, M
Mikkola, S
Berdyugin, A
Britzen, S
Sievers, A
Thum, C
Tornikoski, M
Witzel, A
Fan, J
Gazeas, K
Gonzalez-Perez, J
Hagen-Thorn, V
Kurtanidze, O
Molina, S

Nestoras, I
Ogloza, W
Poyner, G
Readhead, A
Ros, E
Wardle, J
Zhang, X
Casadio, C
Ganesh, S
Jermak, H
Lindfors, E
Siwak, M
Ungerechts, H
Basta, M
Blinov, D

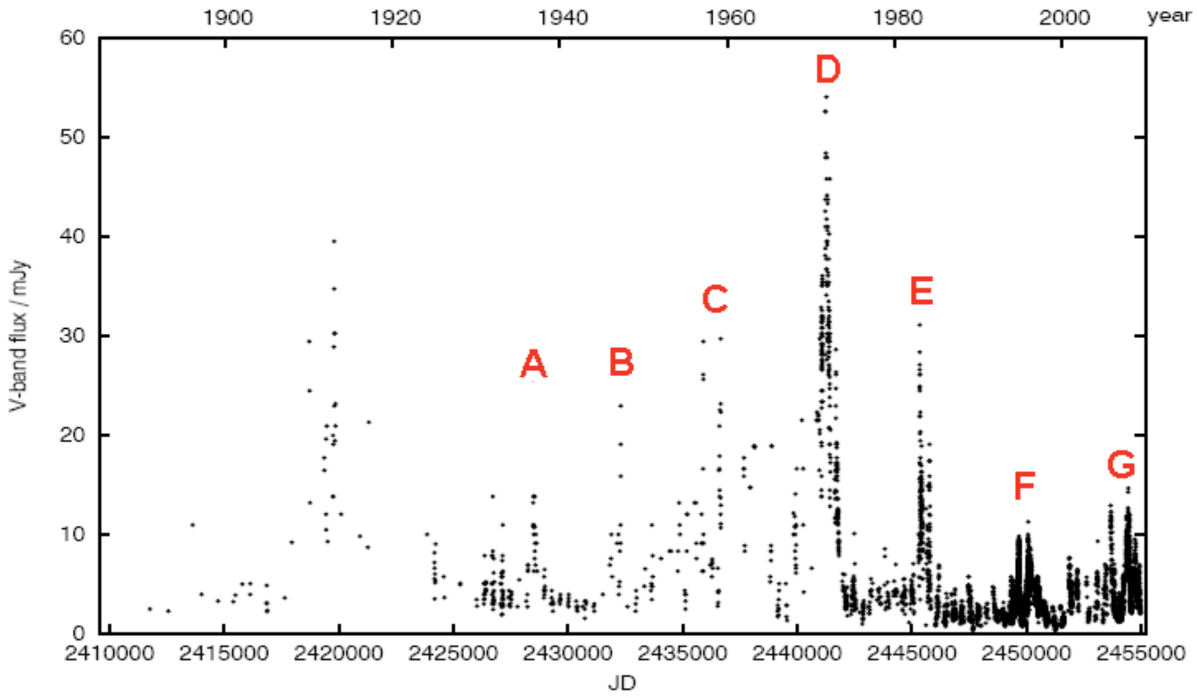
Cawthorne, T
Hobbs, G
Hodgson, J
Kovalev, Y
Liu, F
Liu, X
Manchester, R
Matsumoto, K
Provencal, J
Qian, S
Reichart, D
Reinthal, R
Wiik, K
Burke-Spolaor, S
Chavushyan, V

Dalessio, J
Debski, B
Dultzin-Hacyan, D
Erdem, A
Giommi, P
Karamanavis, V
Lobanov, A
Marti-Vidal, I
Morozova, D
Myserlis, I
Pavlidou, V
Pearson, T
Pihajoki, P

OJ287 – some facts

- Active Galactic Nucleus (AGN) = Active supermassive black hole
  - low-synchrotron peaked (LSP) BL Lac Object – we might look right into the jet
- redshift: 0.306 (Stickel et al. 1989)
- it's variable – also a TeV-emitter
- highly polarized, both at optical and radio wavelengths. The degree of linear polarization and its position angle change with time scales of hours

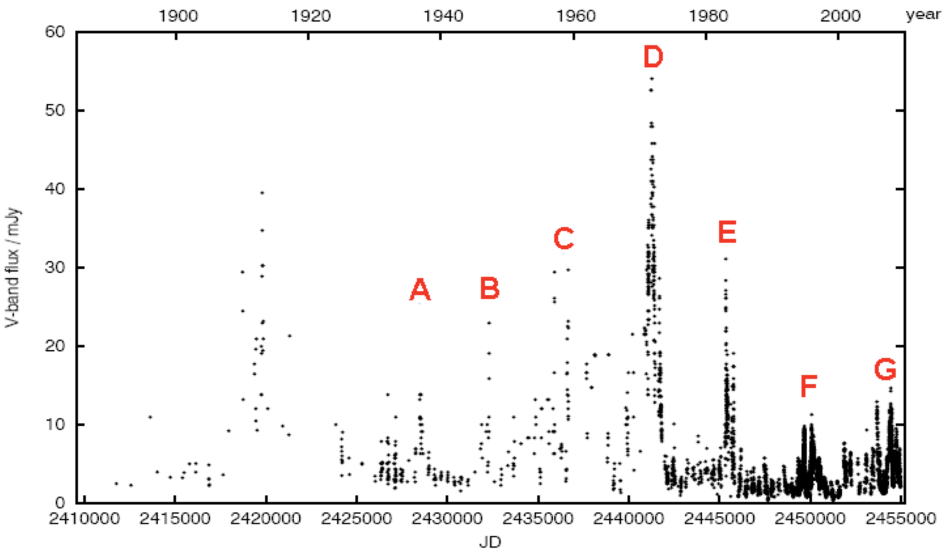
Fig.1 The observations of the brightness of OJ287 from late 1800's until today.

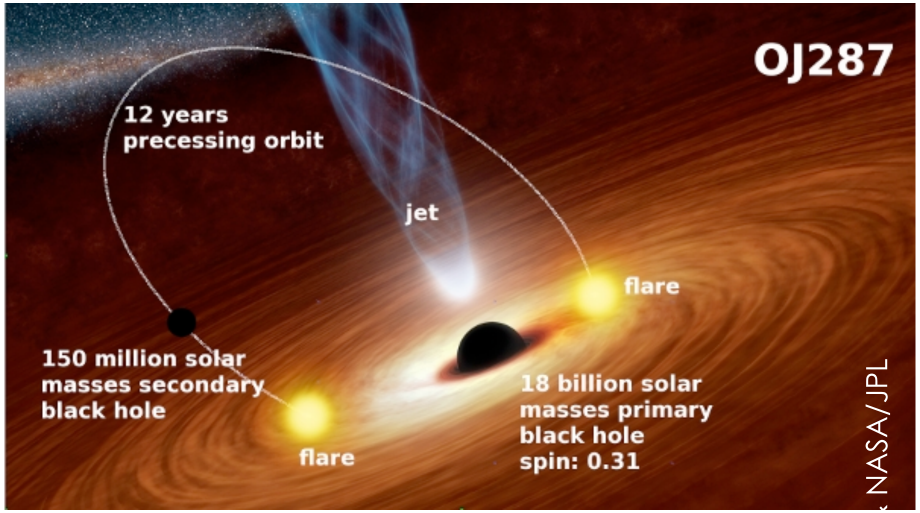


Historic:
A light-curve observed in the optical V band since **1890** shows repeated outbursts at
~ **11.65 yr** intervals
(Sillanpää et al. 1988)

How to explain the optical variability?

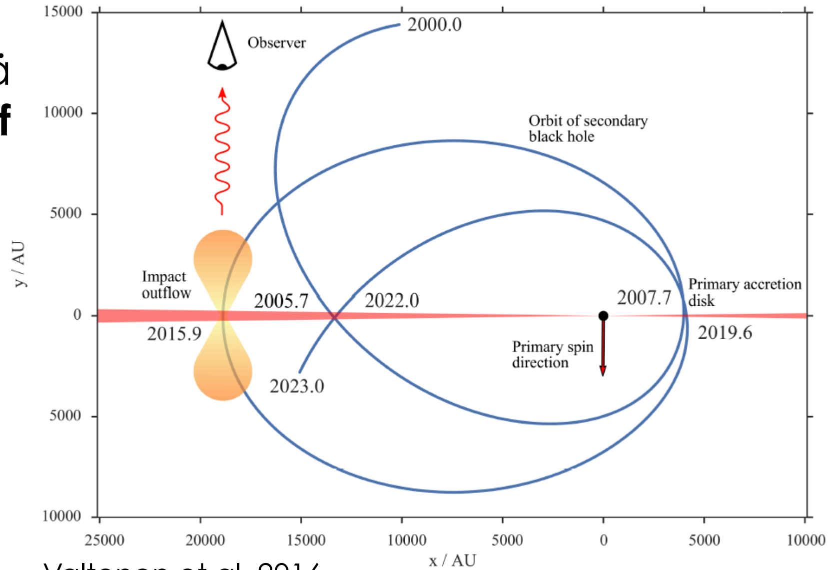
Fig.1 The observations of the brightness of OJ287 from late 1800's until today.





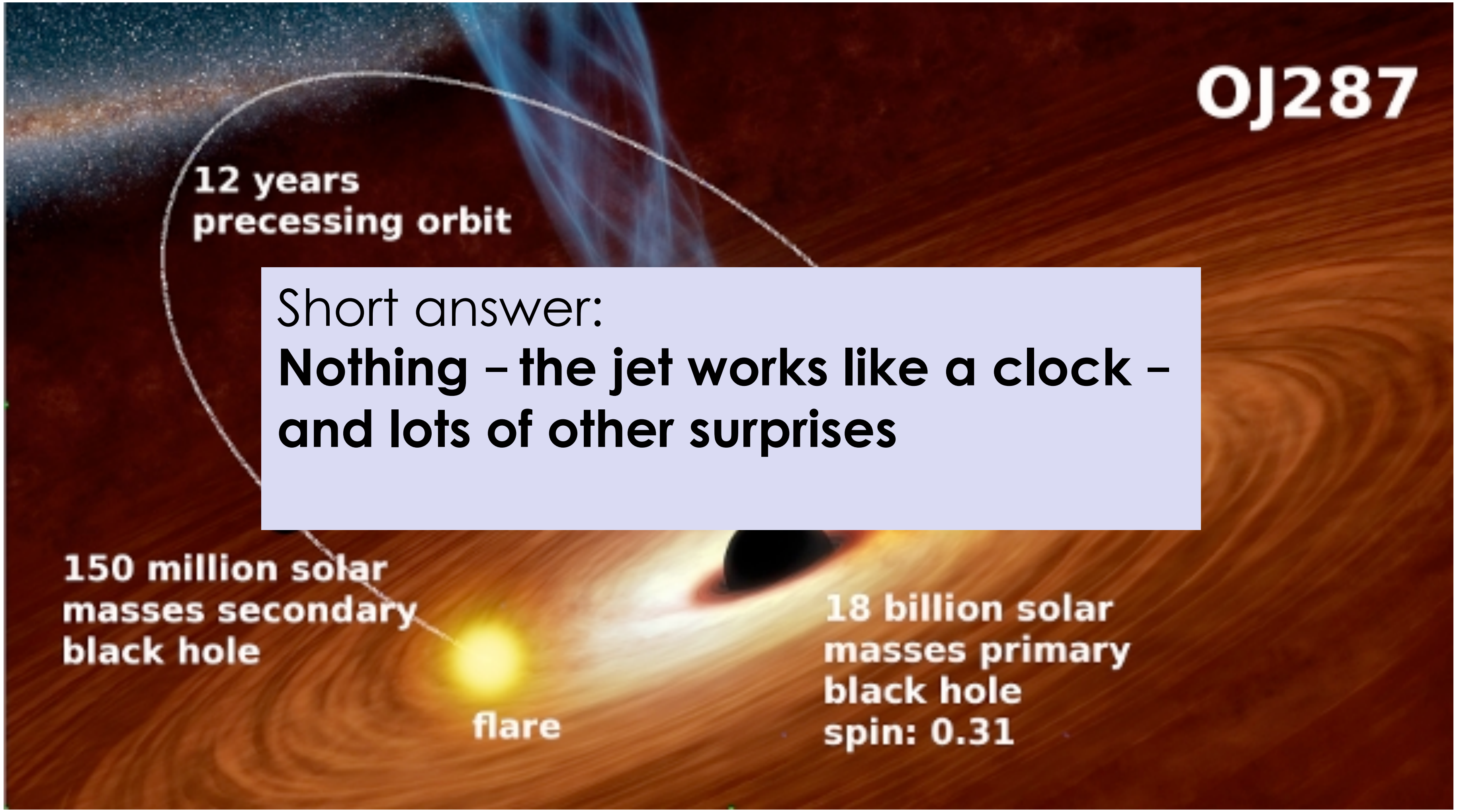
Since the light curve during an outburst resembles the pattern of inflow of gas from an accretion disk to a supermassive black hole in a tidal perturbation, Sillanpää et al. (1988) proposed that OJ287 is a **binary pair of supermassive black holes** with an orbital period of 9 yr in the rest frame of OJ287.

Lehto & Valtonen (1996) explain the substructure inside the major outbursts with a model in which **a smaller black hole crosses the accretion disk of a larger black hole during the binary orbit** of the black holes about each other.



Valtonen et al. 2016

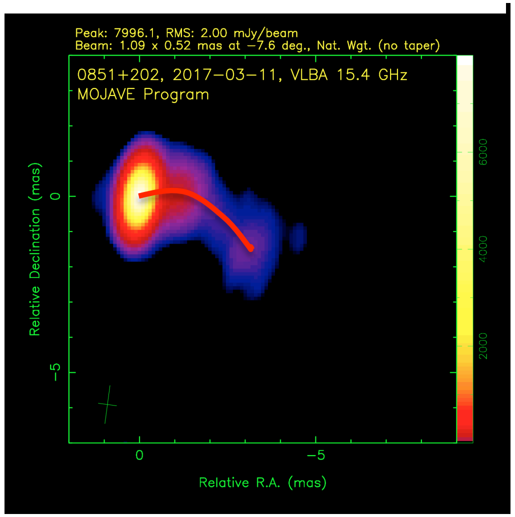
With the disturbance of the accretion disk – what happens to the radio jet?



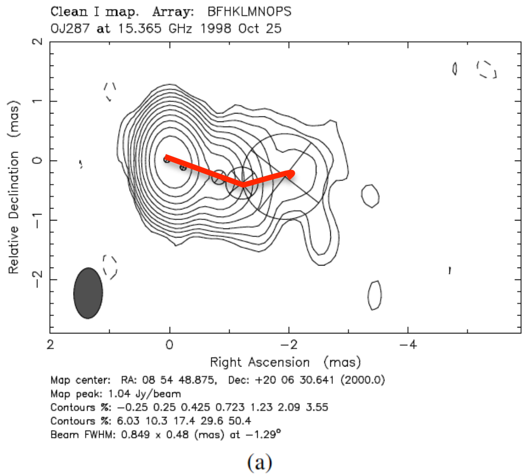
Short answer:
Nothing – the jet works like a clock – and lots of other surprises

Radio Interferometry – the jet data

- we re-analyzed **120 VLBA** data sets (Apr. 1995 – Apr. 2017) obtained at 15 GHz within the **MOJAVE** (**M**onitoring **O**f **J**ets in **A**ctive galactic nuclei with **V**LBA **E**xperiments) survey
- http://www.physics.purdue.edu/astro/MOJAVE/index.html

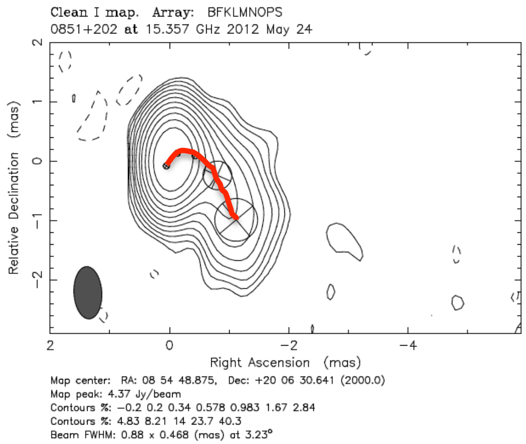


2017

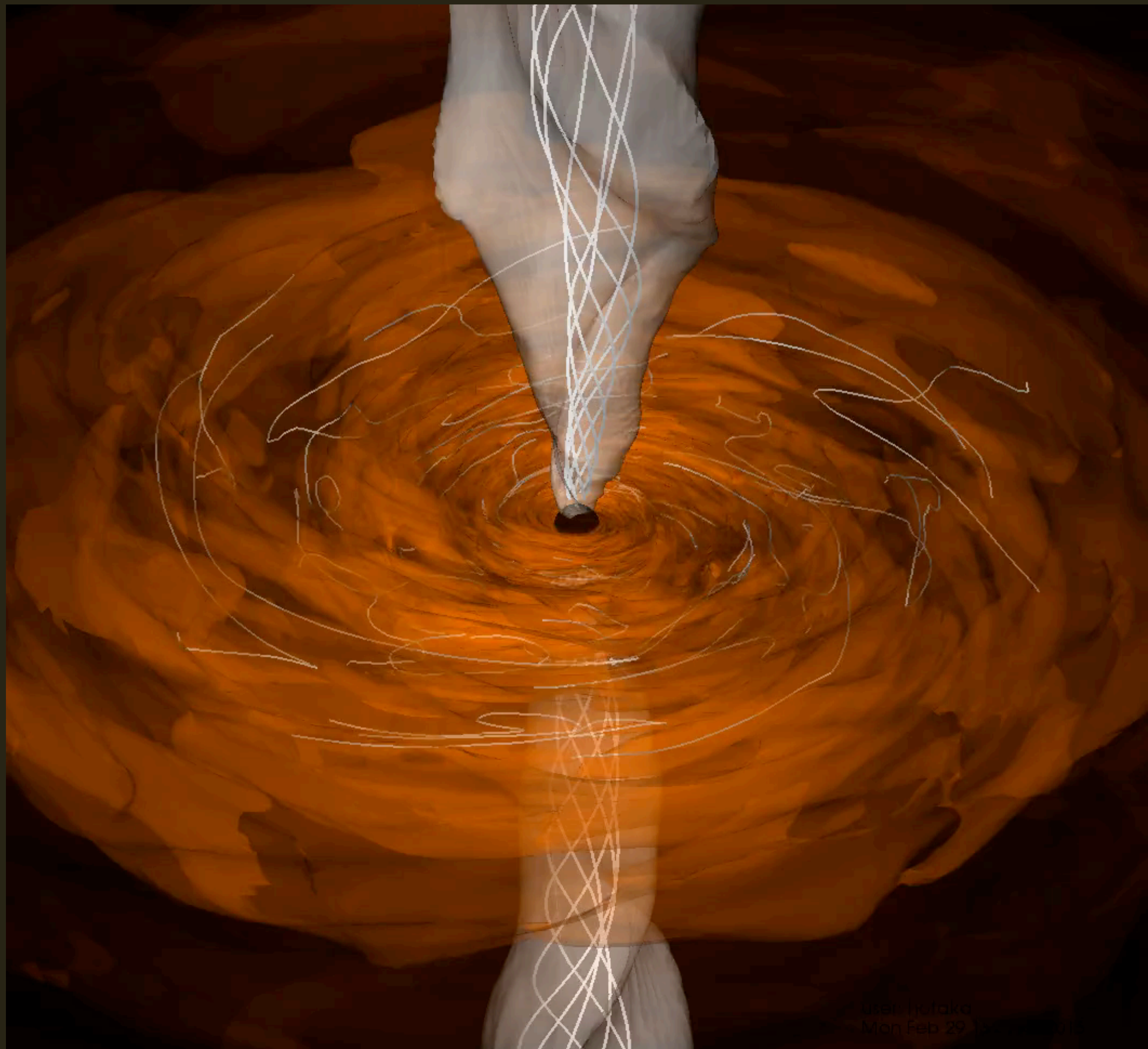


1998

Something is going on …



2012



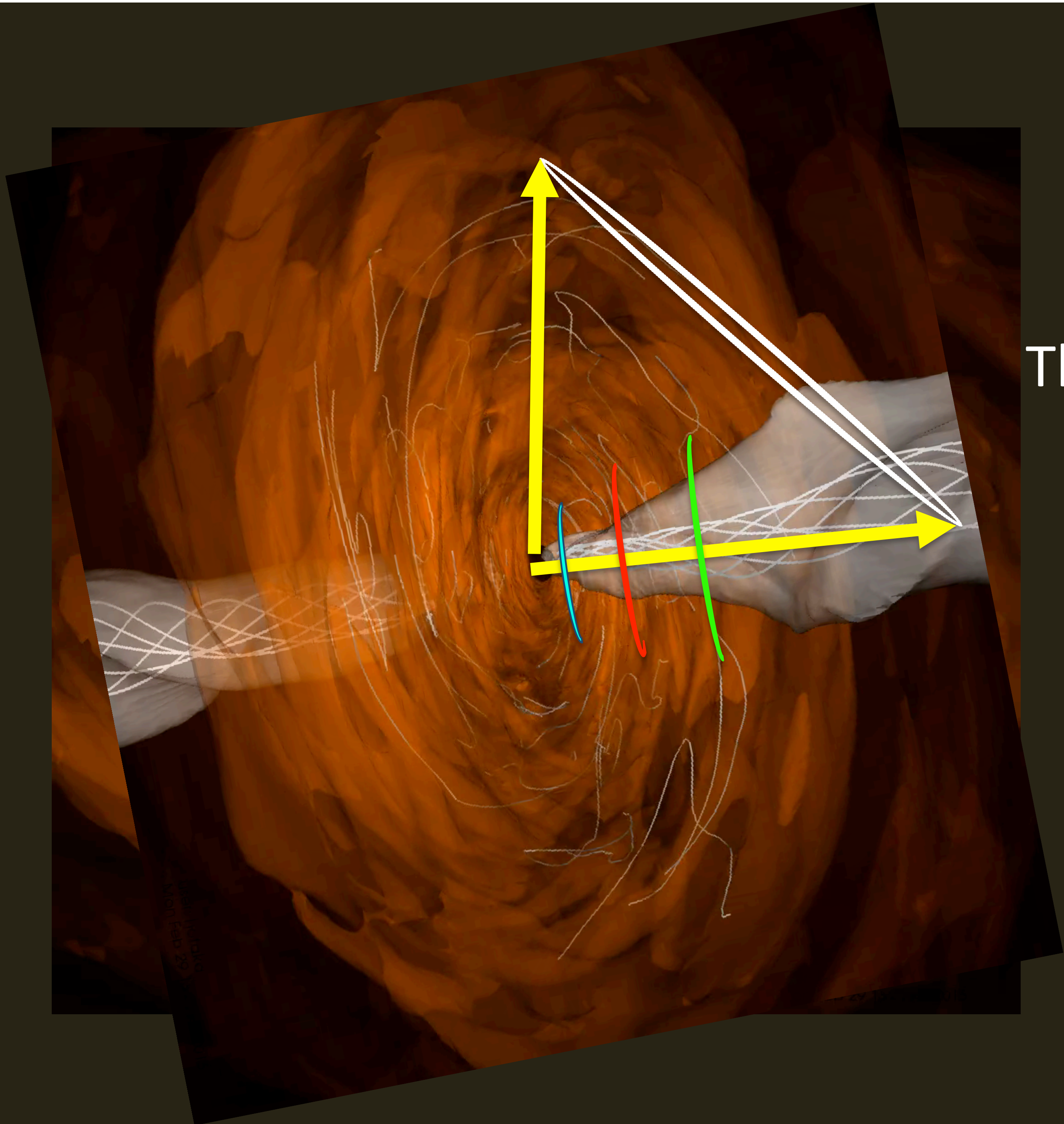
General Relativistic Magnetohydrodynamics (GRMHD) simulation of a black hole accretion disk.

The gas is orbiting around the central black hole and slowly moving toward it.

The disk is highly turbulent and seeded with the entangled magnetic field lines, shown by the white lines.

The jet structure is highlighted with the white contour surface.

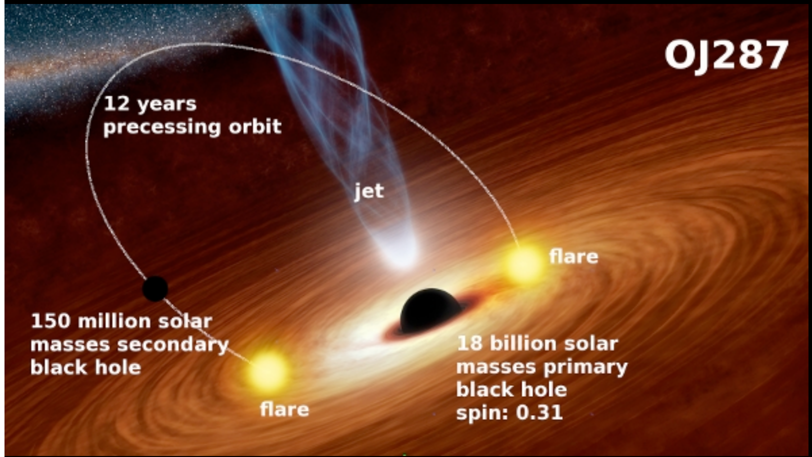
Credit: Hotaka Shiokawa



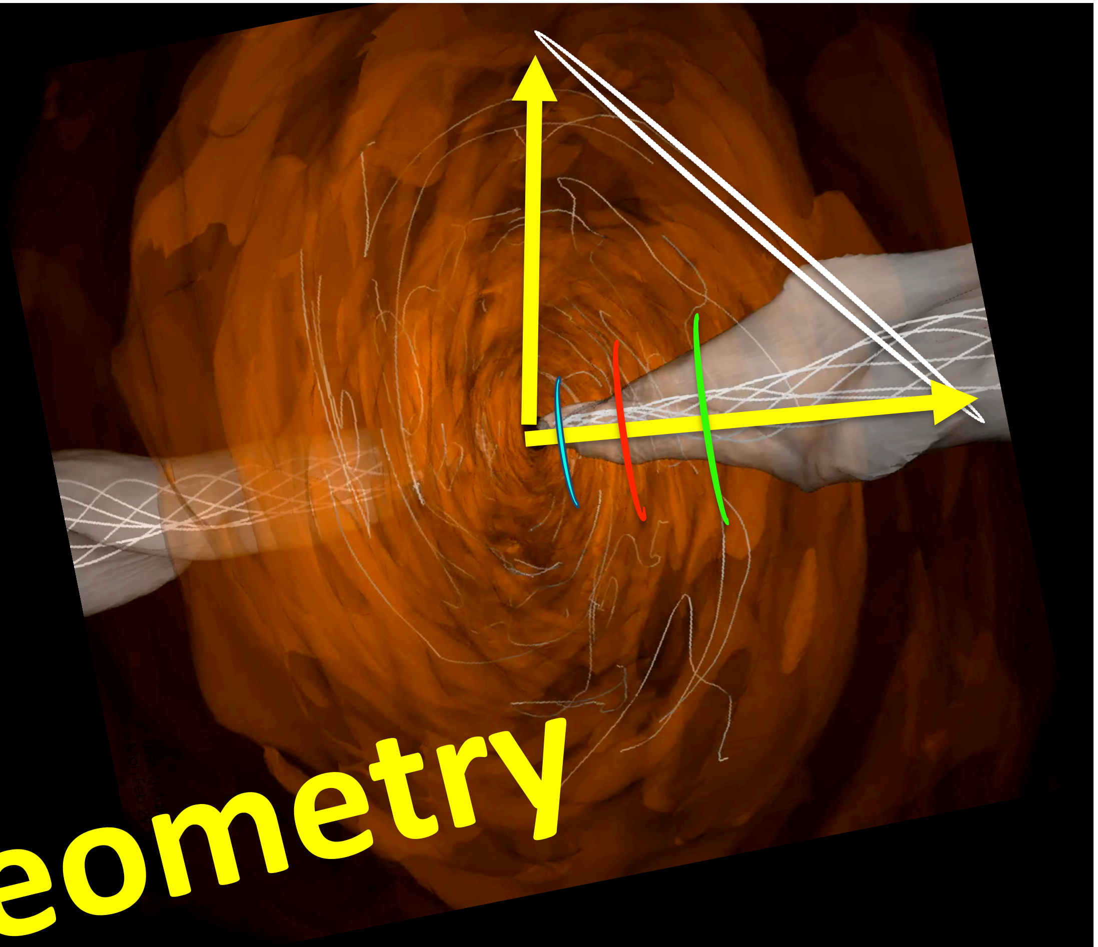
The jet is precessing –
on a time scale
of the optical
variability !

just a sketch - no simulation - not to scale

Previous



Valtonen et al. (e.g., 2016)



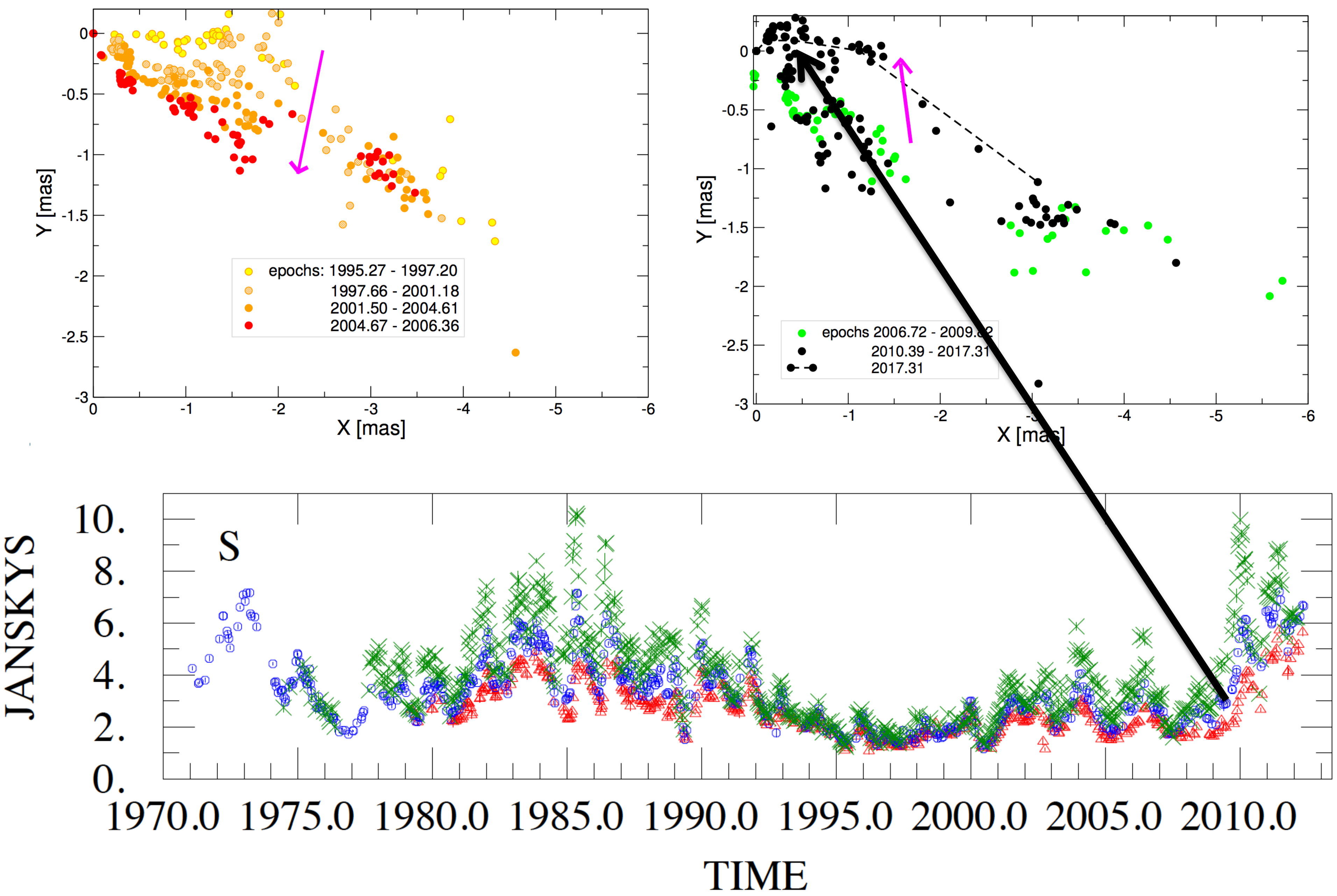
NEW – it‘s all geometry

Britzen et al. subm. MNRAS

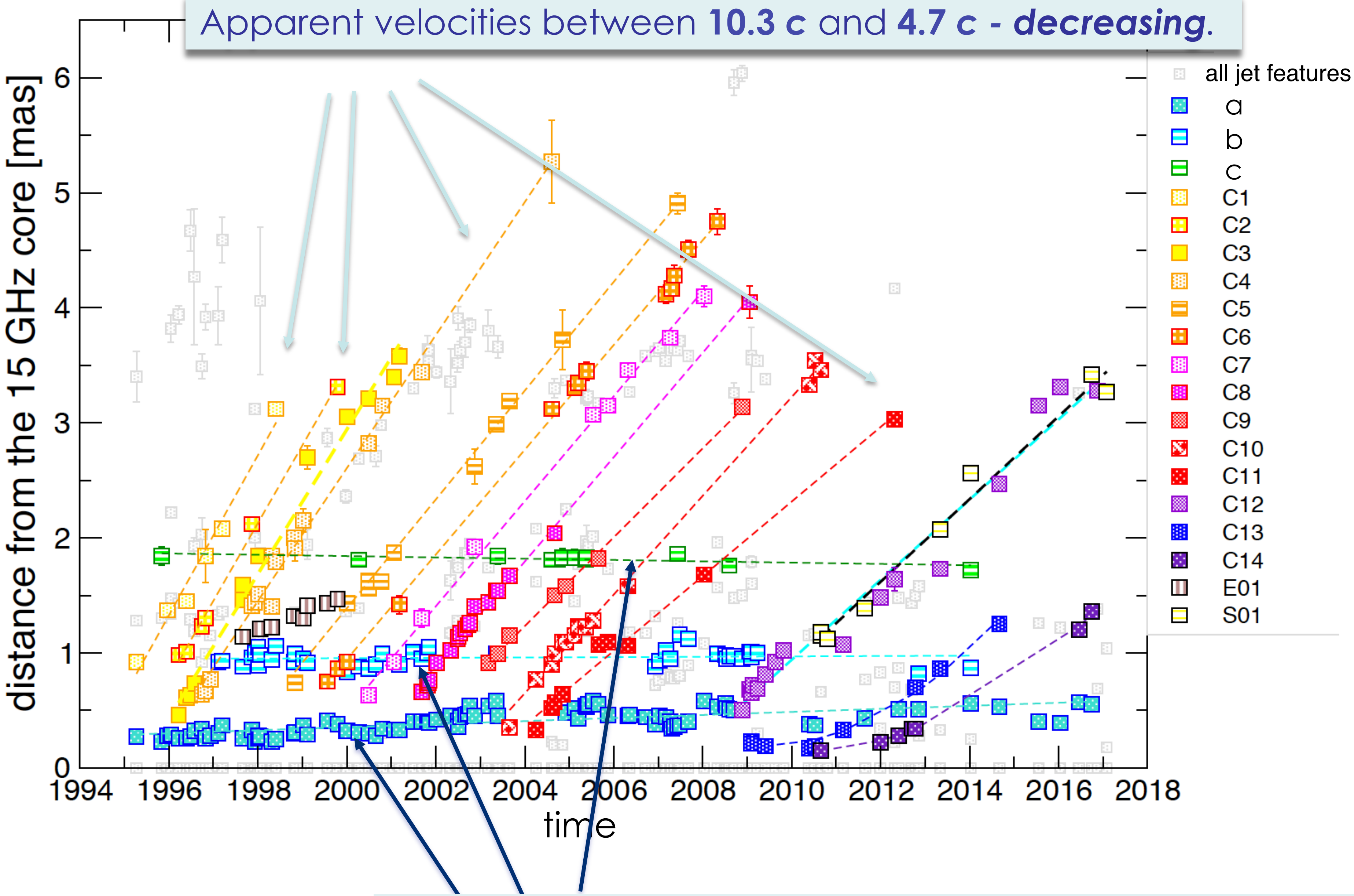
optical + radio variability seems to be of geometric origin

jet precession + jet rotation (nutation) –
due to viewing angle changes + Doppler beaming

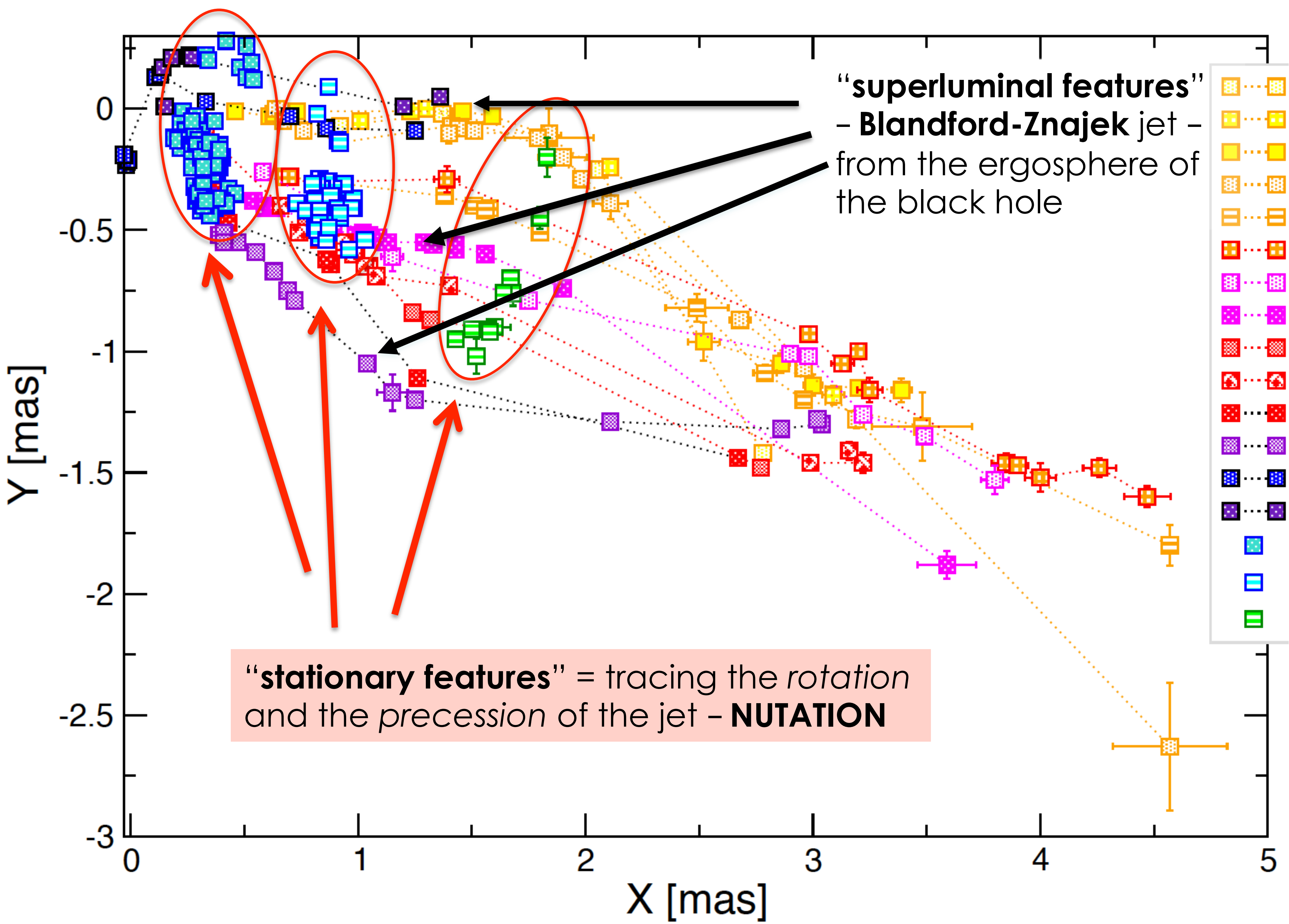
The jet is wandering in the sky - Precession



Apparent velocities between **10.3 c** and **4.7 c** - ***decreasing***.



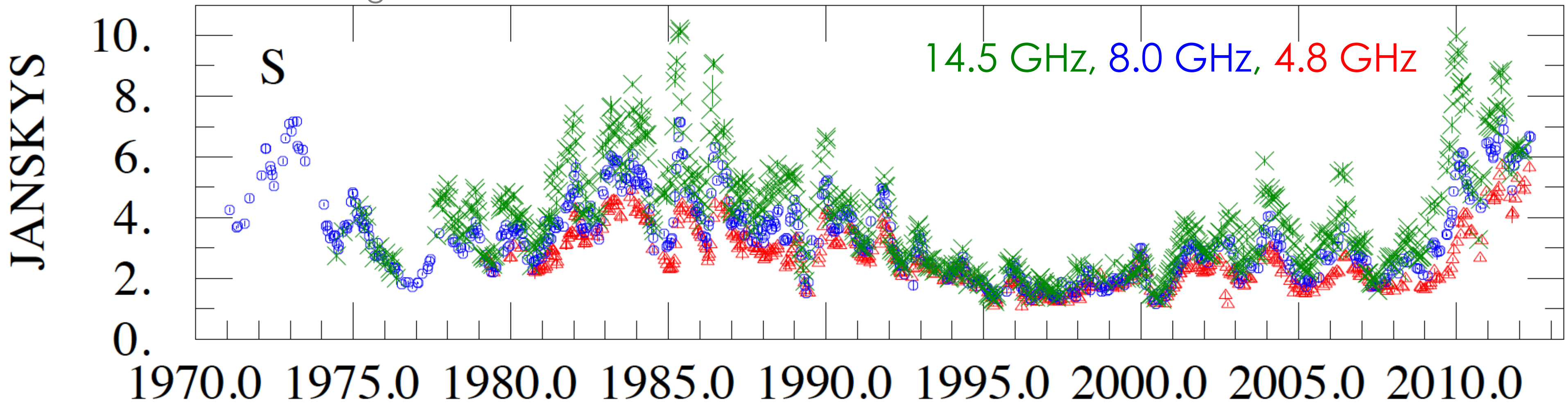
Stationary jet features: almost **no** motion in jet direction.

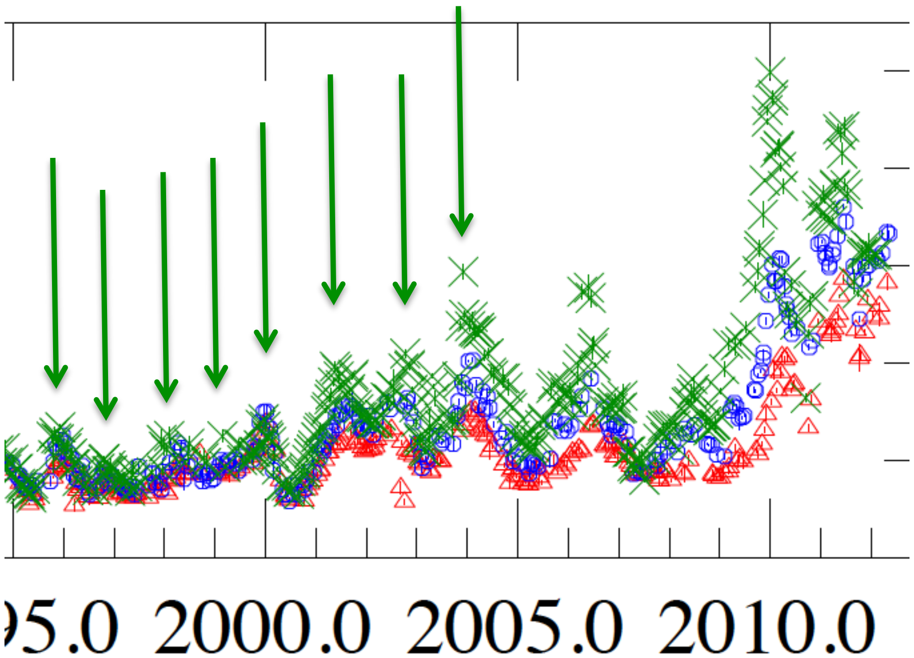


"superluminal features"
– Blandford-Znajek jet –
from the ergosphere of
the black hole
"stationary features" = tracing the rotation
and the precession of the jet – NUTATION
Y [mas]
X [mas]
0
-0.5
-1
-1.5
-2
-2.5
-3
0
1
2
3
4
5

Radio Light-curve **long-term variability** = **Jet precession**

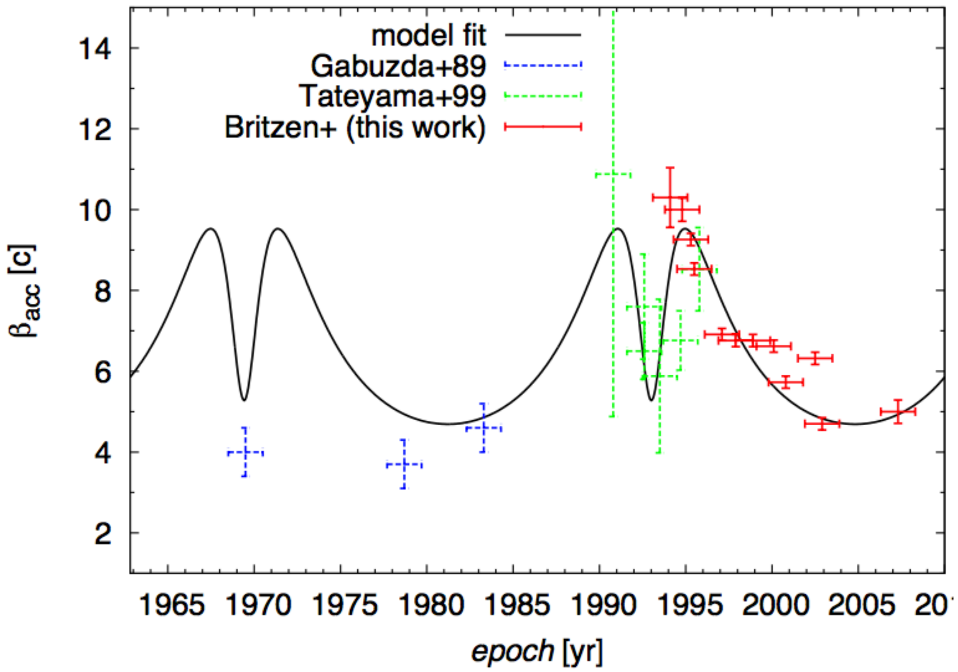
UMRAO, single-dish



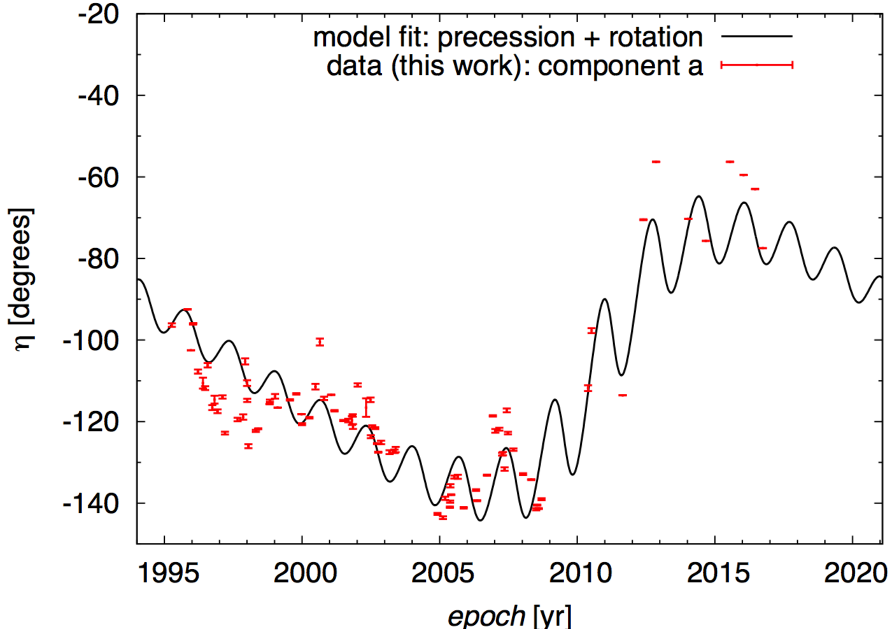


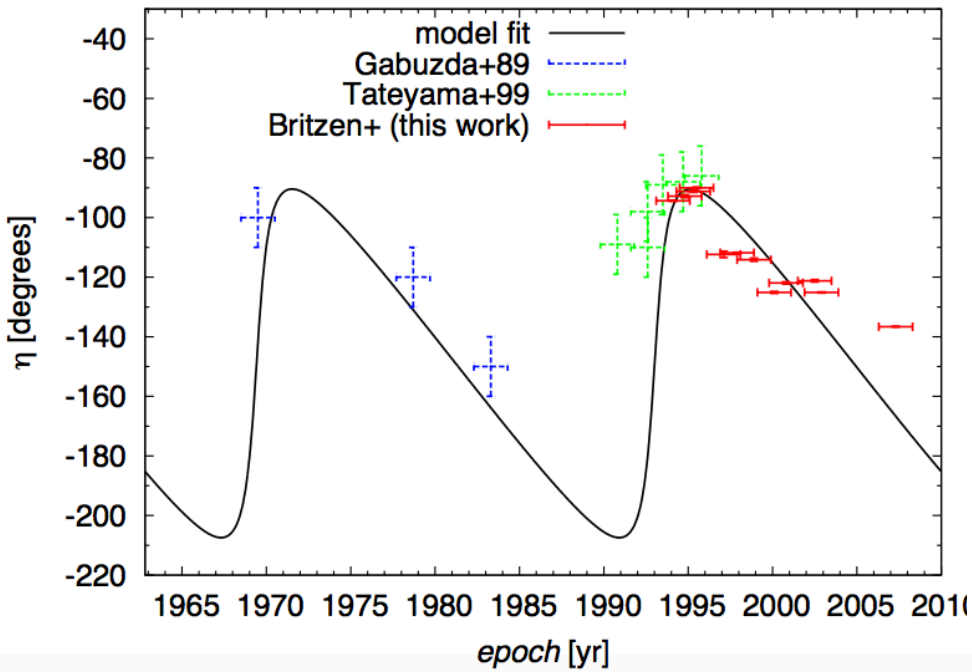
short-term variability
in the 15 GHz light-curve
originates in the
jet nutation

It's all geometry.

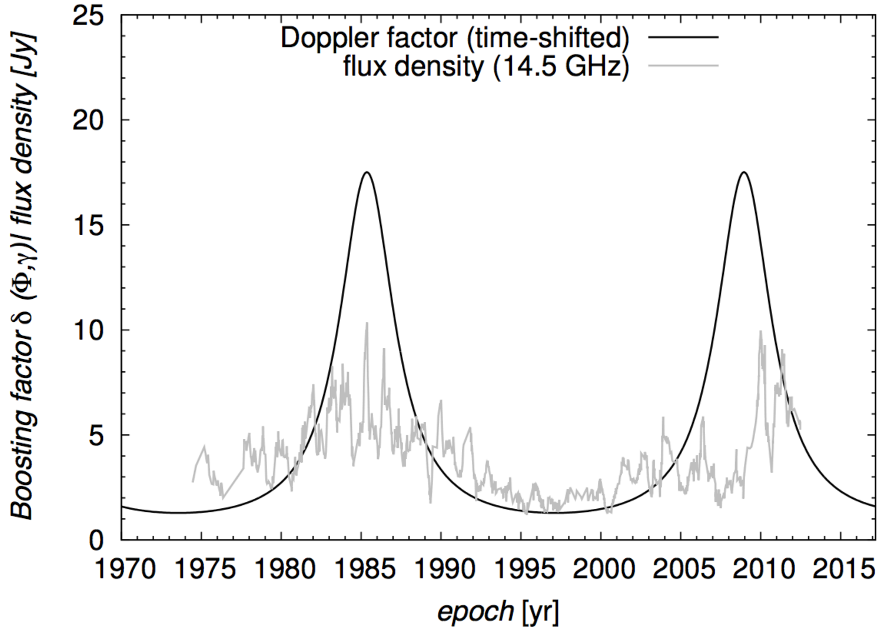

model fit
Gabuzda+89
Tateyama+99
Britzen+ (this work)
β_{acc} [c]
epoch [yr]

a]


model fit: precession + rotation
data (this work): component a
η [degrees]
epoch [yr]


model fit
Gabuzda+89
Tateyama+99
Britzen+ (this work)
η [degrees]
epoch [yr]

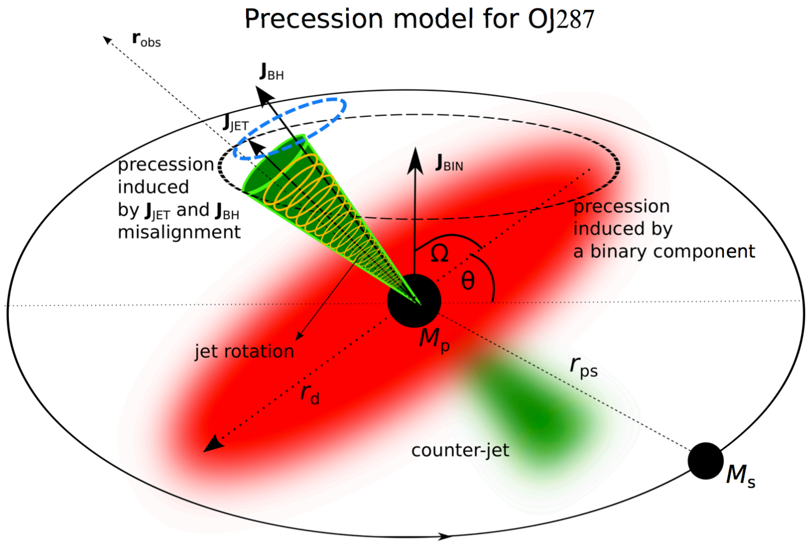
b]

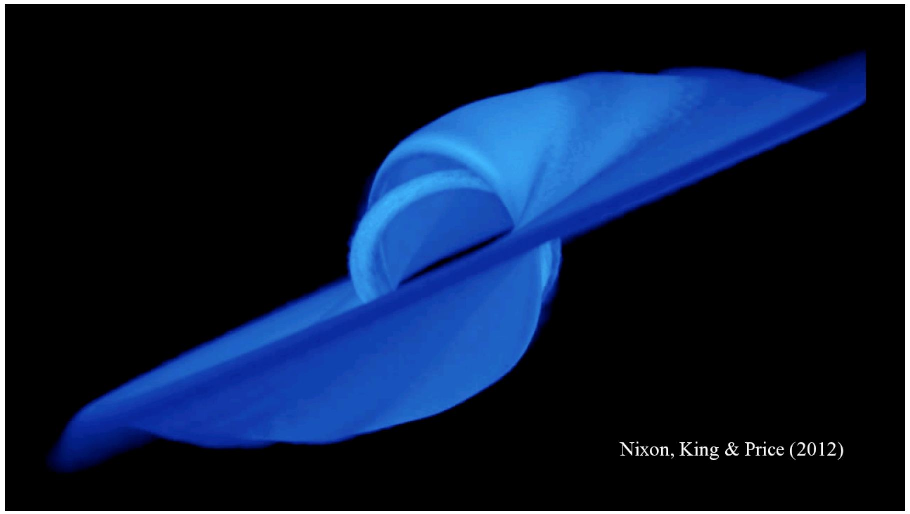

Doppler factor (time-shifted)
flux density (14.5 GHz)
Boosting factor δ (Φ,γ)/ flux density [Jy]
epoch [yr]

Binary or not a Binary?

We suggest that the optical emission is produced by the synchrotron mechanism (e.g. Abraham 2000) and is thus related to the jet radiation. *Disturbances of an accretion disk caused by a plunging black hole do not seem necessary to explain the observed variability.*

We find that although the binary black hole model does not seem necessary to explain the observed variability, a **binary model (e.g., Katz 1997) seems to be required to explain the time scale of the precessing motion**. Lense-Thirring precession (e.g., Pringle 1997) explains the time scales as well. Hereby we have considered binary black holes with a primary mass of 10^8 (Heidt et al. 1999) and 10^{10} solar masses (Valtonen model).

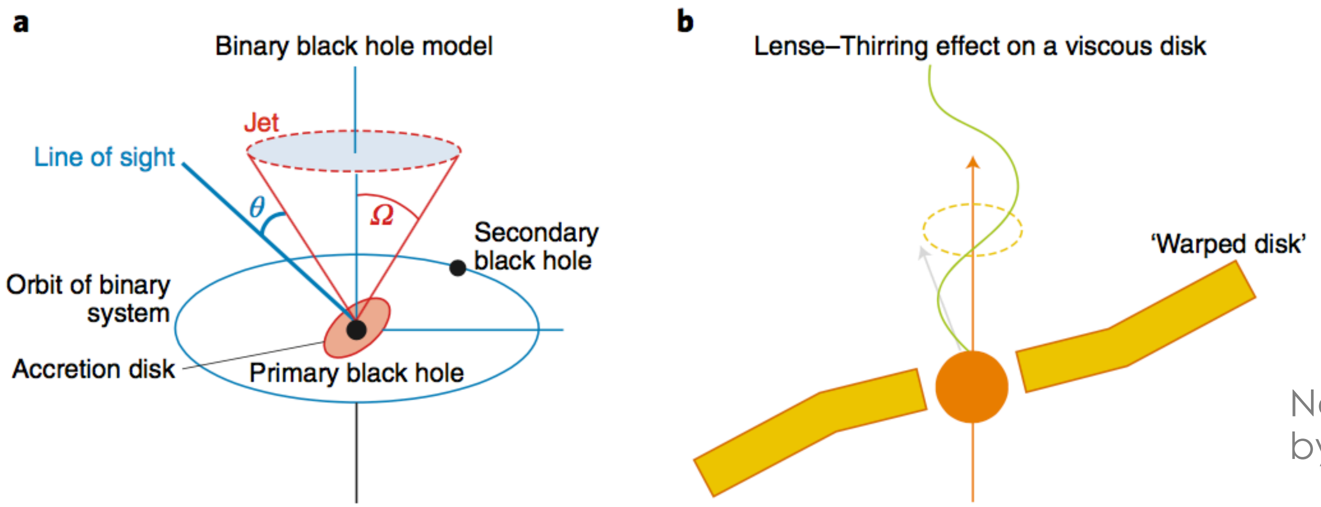




Binary or not a Binary?

We suggest that the optical emission is produced by the synchrotron mechanism (e.g. Abraham 2000) and is thus related to the jet radiation. *Disturbances of an accretion disk caused by a plunging black hole do not seem necessary to explain the observed variability.*

We find that although the binary black hole model does not seem necessary to explain the observed variability, a **binary model (e.g., Katz 1997) seems to be required to explain the time scale of the precessing motion**. Lense-Thirring precession (e.g., Pringle 1997) explains the time scales as well. Hereby we have considered binary black holes with a primary mass of 10^8 (Heidt et al. 1999) and 10^{10} solar masses (Valtonen model).



Nature: news & views
by Zulema Abraham

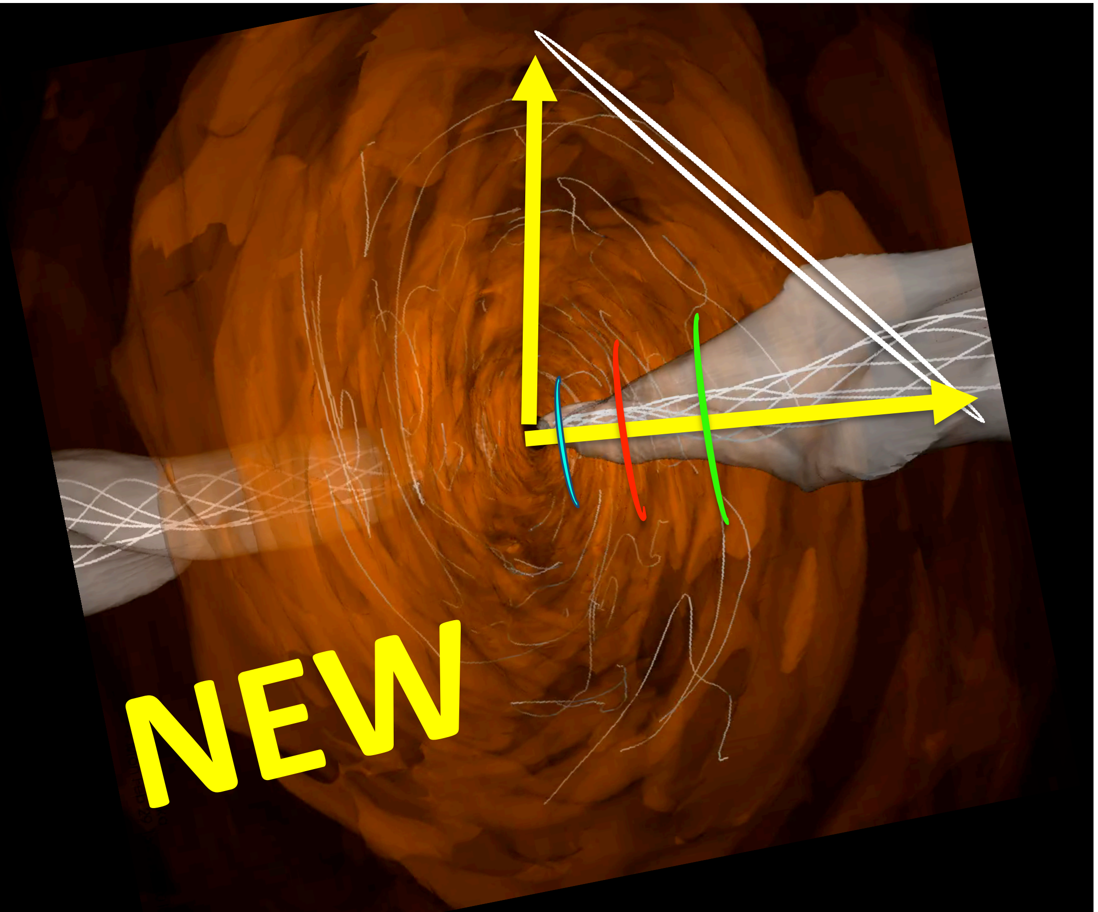
Fig. 1 | Potential geometries for the active nucleus of OJ 287. a, The orbital motion of a supermassive black hole binary leads to the precession of the jet on the surface of a cone with opening angle Ω, at an angle θ from the observer's line of sight. **b**, A misalignment of the supermassive black 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).

Britzen et al. 2018MNRAS.tmp..975B

Nature: News & Views
by Zulema Abraham

Jet precession in binary black holes

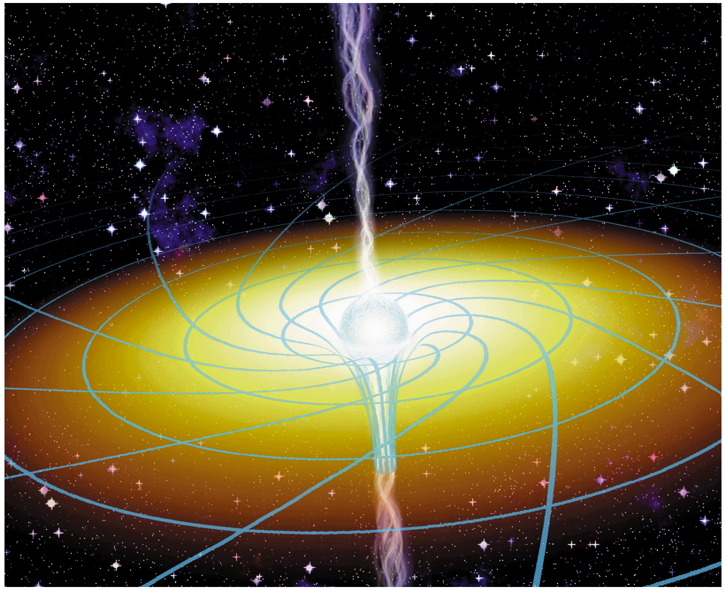
Thanks a lot for your attention !

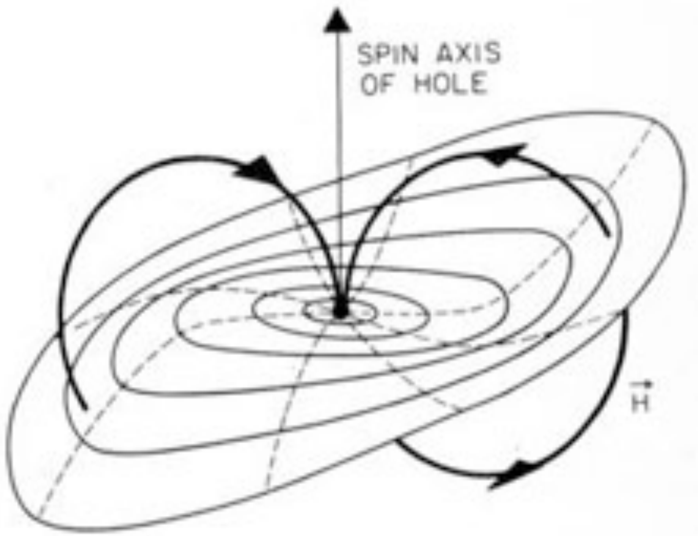


explains:

- VLBI jet morphology
- stability of the jet – works like a clock
- long-term radio variability: jet precession
- short-term radio variability: jet nutation
- optical emission– Synchrotron emission and related to jet emission
- Periodic Doppler beaming due to viewing angle changes – it‘s all geometry!

Lense-Thirring / Frame dragging





A gaseous accretion disk that is tilted with respect to a spinning black hole will experience Lense–Thirring precession.

Because the precession rate varies with distance from the black hole, the disk will "wrap up", until viscosity forces the gas into a new plane, aligned with the black hole's spin axis – the Bardeen-Petterson effect (1975).

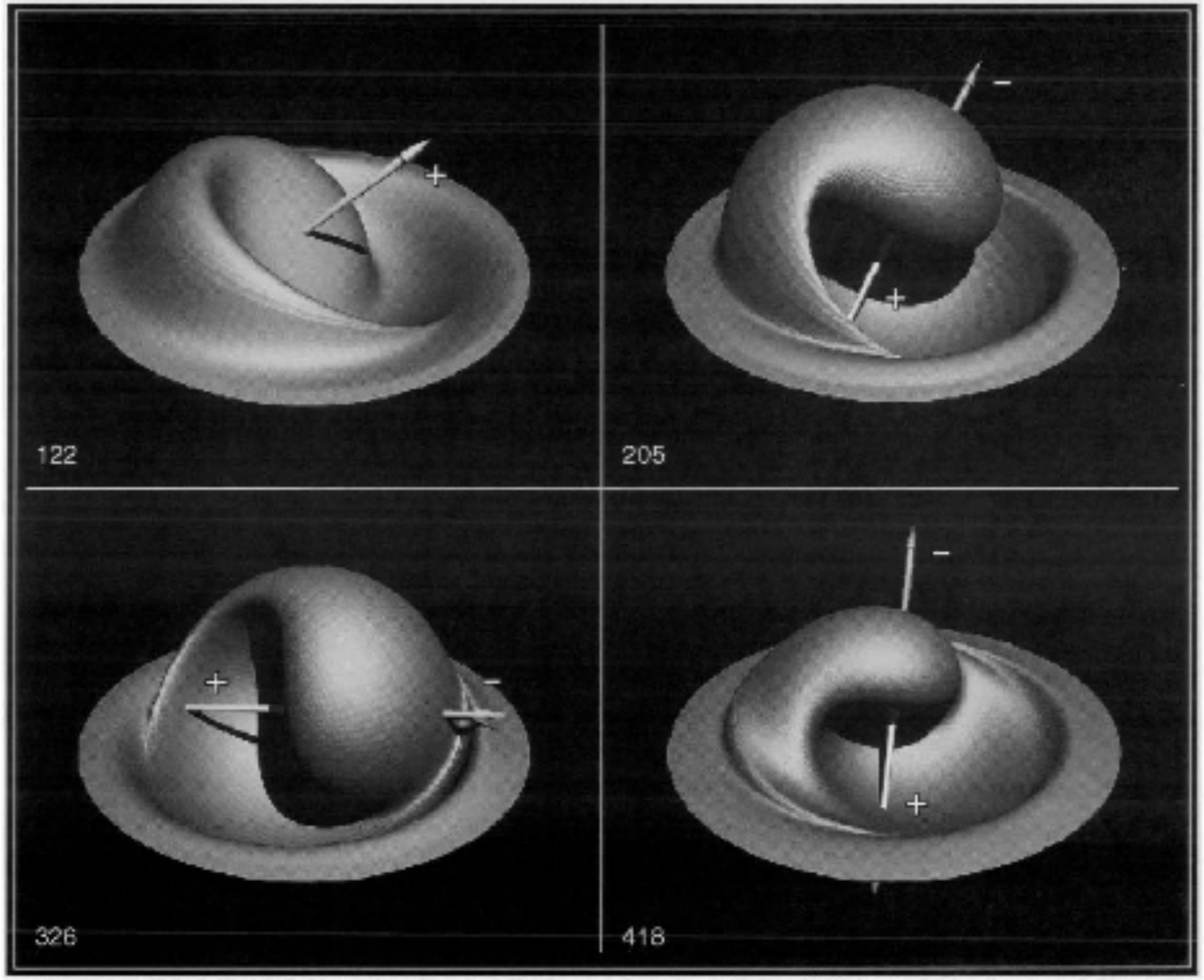
Mon. Not. R. Astron. Soc. **292,** 136–147 (1997)

Self-induced warping of accretion discs: non-linear evolution and application to AGN

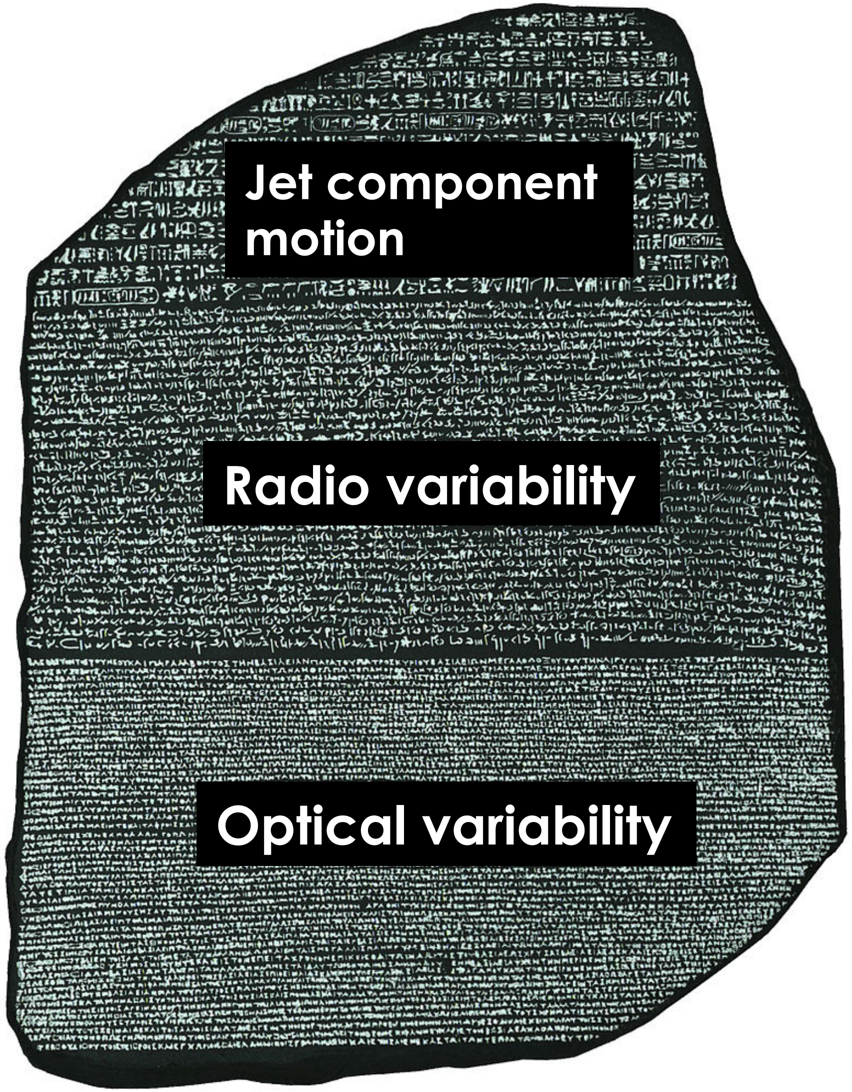
An instability in the disc could warp the disc and cause the observed precession

J. E. Pringle

Institute of Astronomy, Madingley Road, Cambridge CB3 0HA



OJ287 – the Rosetta stone of blazars (Leo Takalo, 1994)

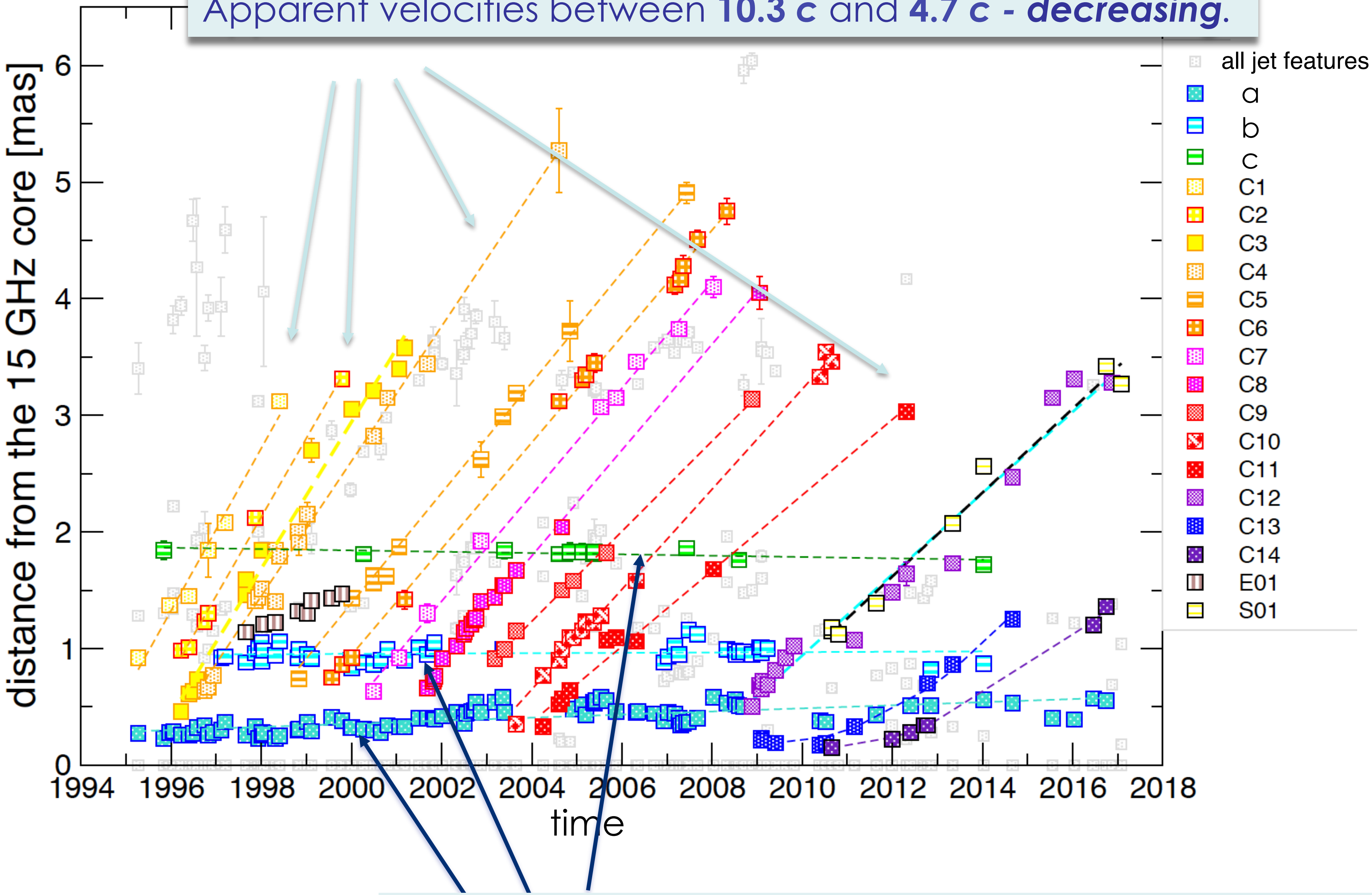


A granodiorite stele, found in 1799, inscribed with **three versions** of a decree issued at Memphis, Egypt in 196 BC during the Ptolemaic dynasty on behalf of King Ptolemy V.

The top and middle texts are in Ancient Egyptian using hieroglyphic script and Demotic script, respectively, while the bottom is in Ancient Greek. <u>As the decree is the same (with some minor differences) in all three versions, the Rosetta Stone proved to be the key to deciphering Egyptian hieroglyphs.</u>

Major advances in the decoding were recognition that the stone offered three versions of the same text (1799).

Apparent velocities between **10.3 c** and **4.7 c** - ***decreasing***.



Stationary jet features: almost **no** motion in jet direction.

Jet Feature	μ [mas/year]	β_{app} [c]	θ °
a	0.013±0.001	0.191±0.015	
b	0.001±0.002	0.015±0.029	
c	-0.006±0.002	-0.088±0.029	
C1	0.70±0.05	10.30±0.74	5.5±0.4
C2	0.68±0.02	10.00±0.29	5.7±0.2
C3	0.63±0.02	9.26±0.29	6.2±0.2
C4	0.58±0.01	8.53±0.15	6.7±0.1
C5	0.47±0.01	6.91±0.15	8.2±0.2
C6	0.46±0.01	6.76±0.15	8.4±0.2
C7	0.46±0.01	6.76±0.15	8.4±0.2
C8	0.45±0.01	6.62±0.15	8.6±0.2
C9	0.39±0.01	5.73±0.15	9.9±0.3
C10	0.43±0.01	6.32±0.15	9.0±0.2
C11	0.32±0.01	4.70±0.15	12.0±0.4
C12	0.34±0.02	5.00±0.29	11.3±0.7
S01	0.36±0.02	5.29±0.29	10.7±0.6

apparent speeds decreasing

viewing angle increasing

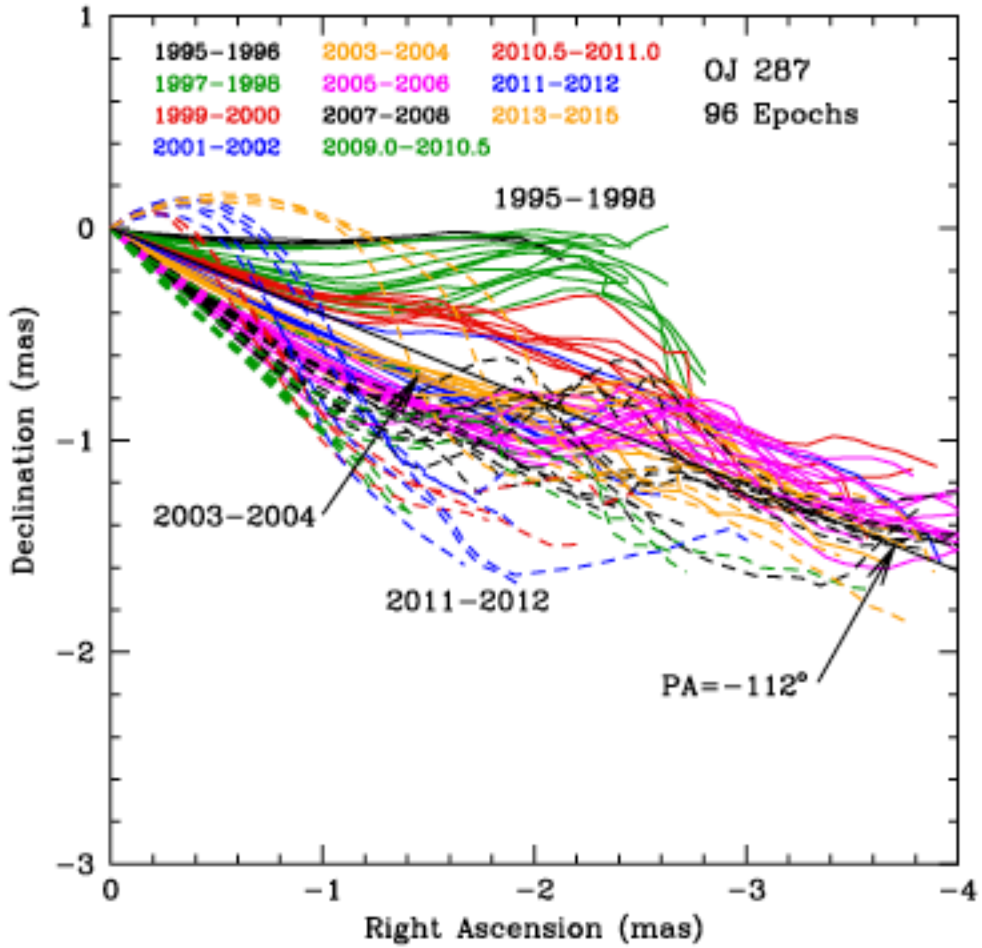


Figure 2. Ridgelines for 96 epochs. The years are grouped by color as shown; the first set has solid lines and the second set of colors has dashed lines.