Jet precession & Supermassive binary black holes

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Very Long Baseline Interferometry

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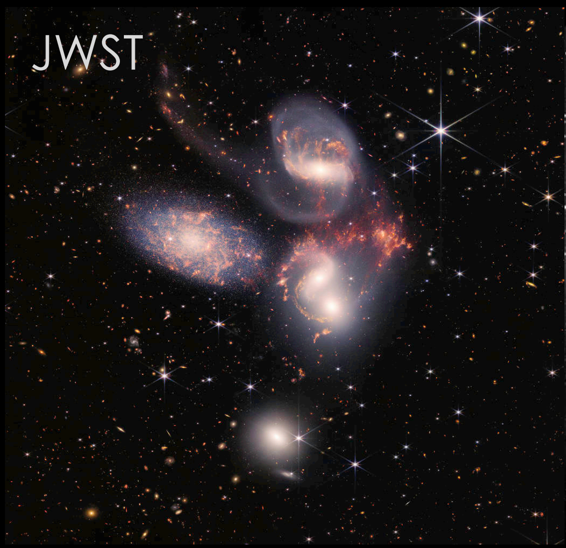
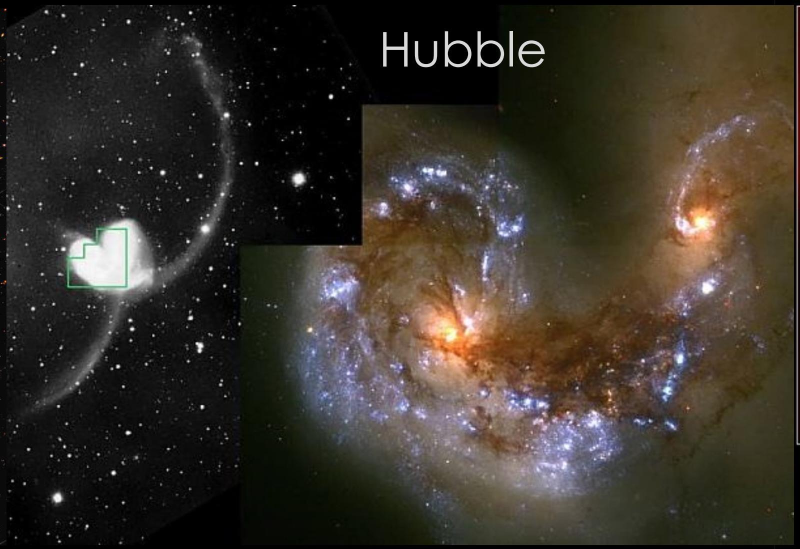
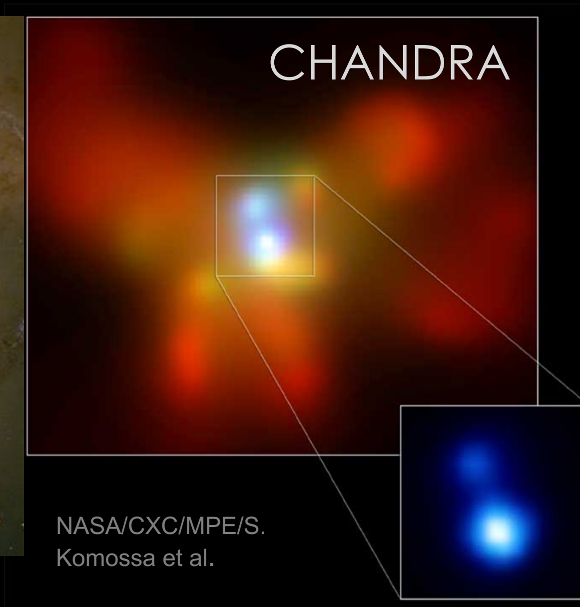
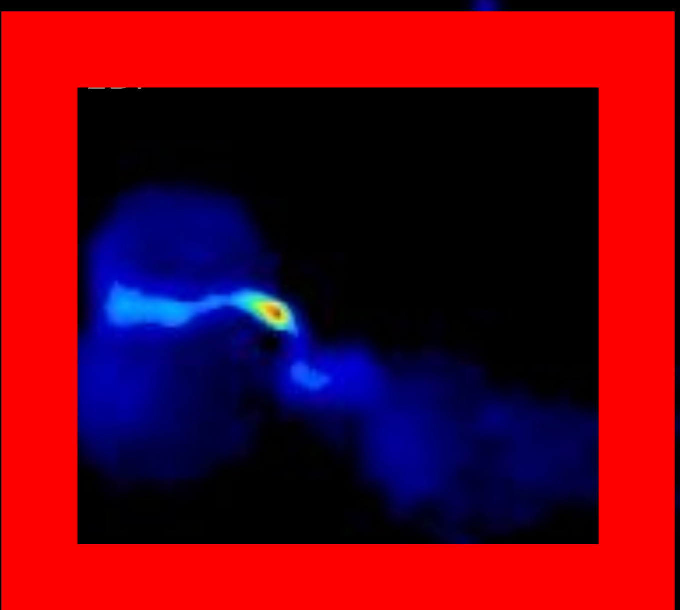
Supermassive binary black holes have to be there

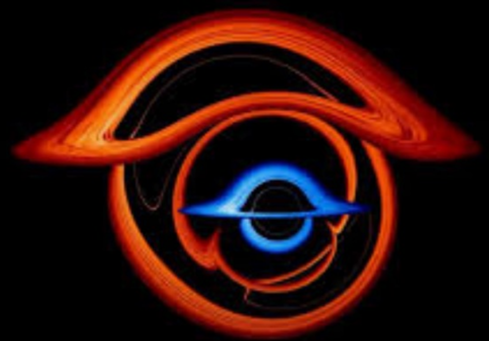




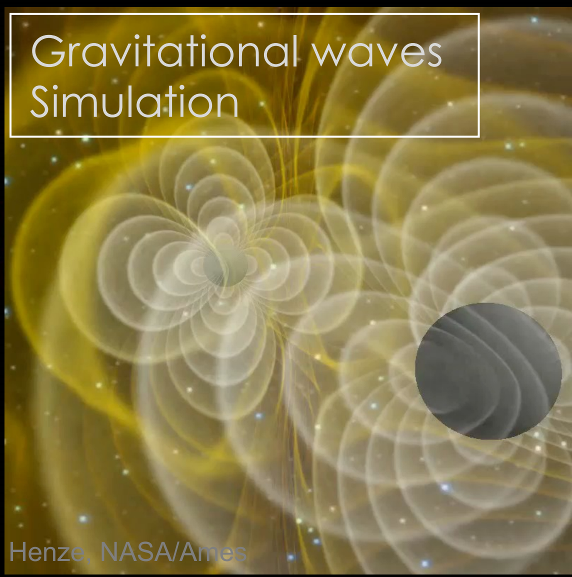




Simulation

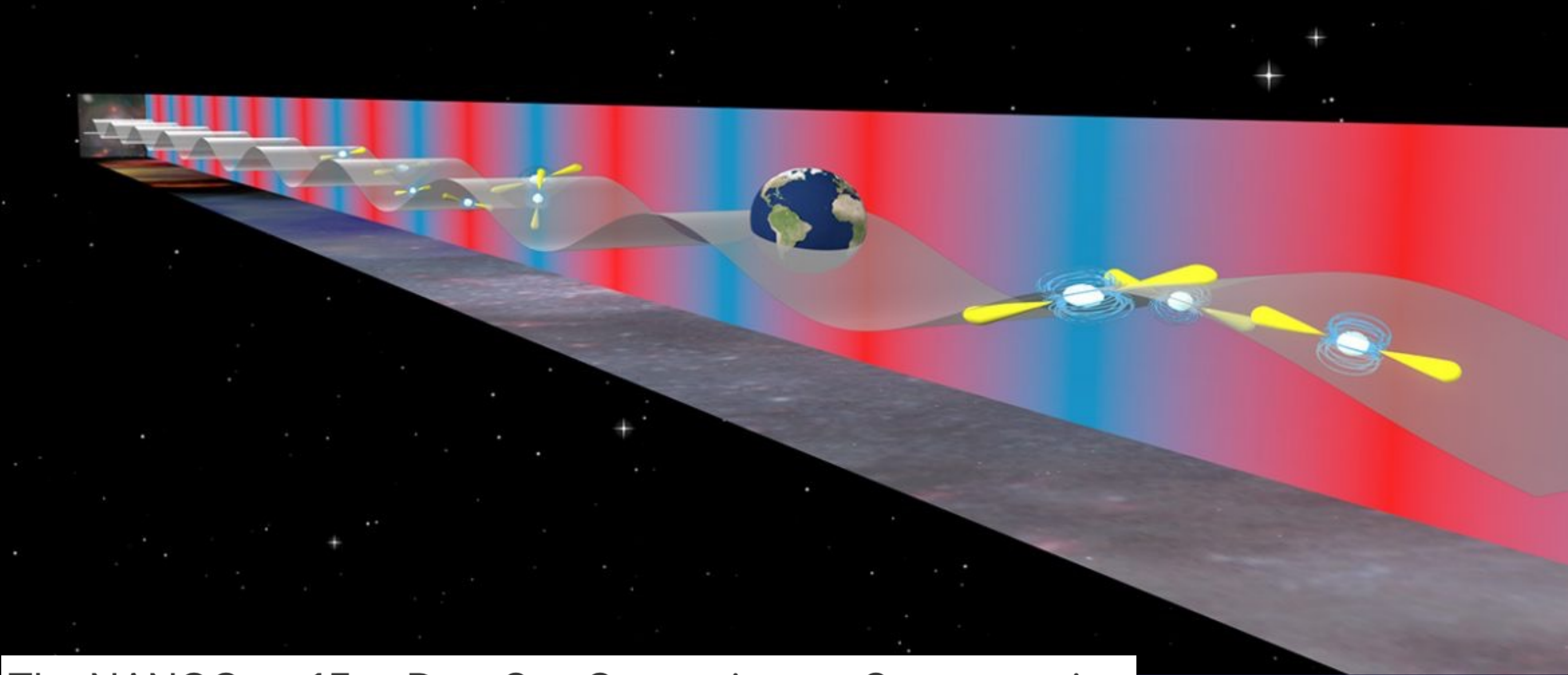


Schnittman / NASA



North American Nanohertz Observatory for Gravitational Waves
A National Science Foundation Physics Frontiers Center

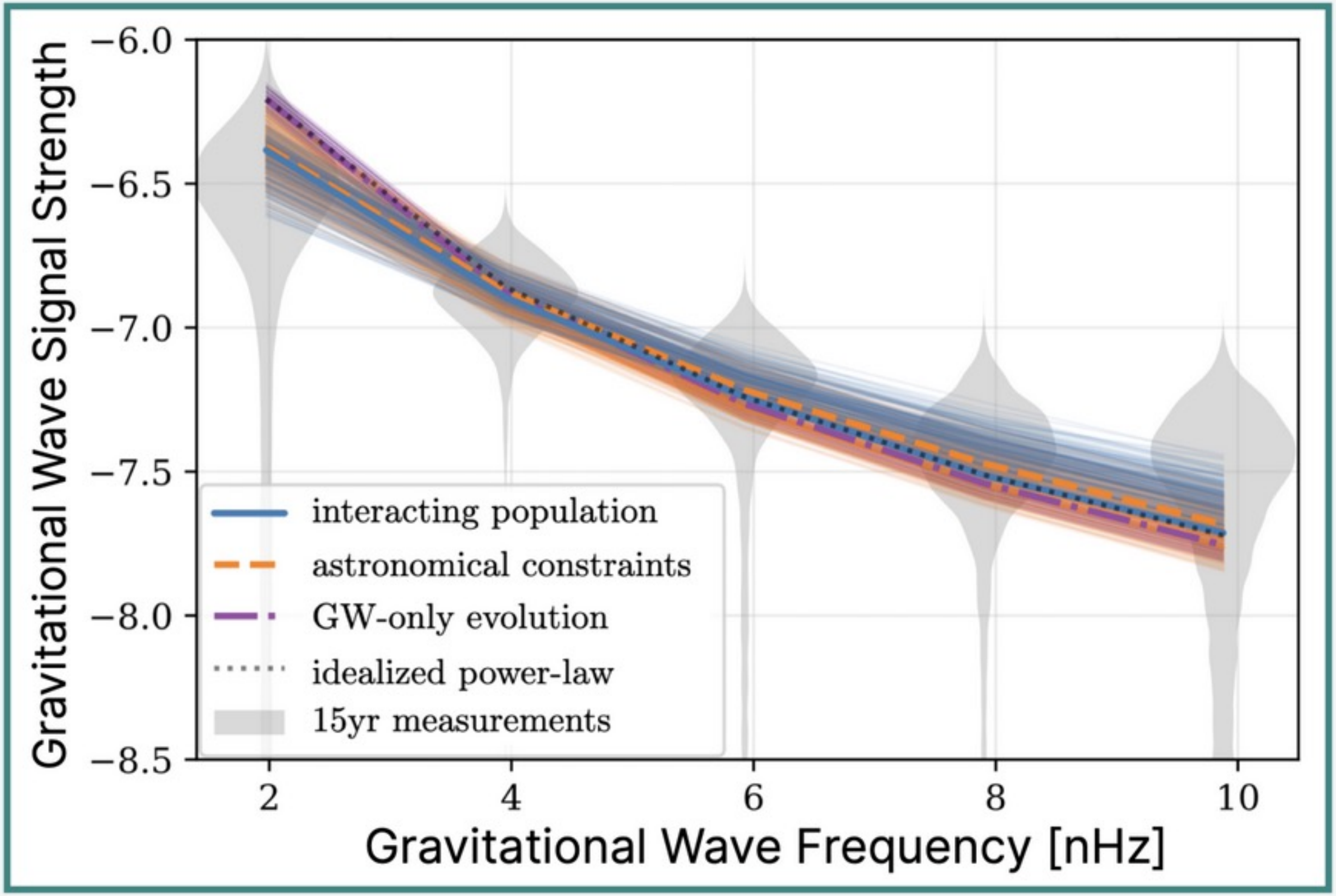
NANOGrav (the North American Nanohertz Observatory for Gravitational Waves)



The NANOGrav 15 yr Data Set: Constraints on Supermassive Black Hole Binaries from the Gravitational-wave Background

Gabriella Agazie *et al* 2023 *ApJL* **952** L37

.... supermassive binary black holes either have to happen ***more frequently***, or are ***heavier*** than expected.



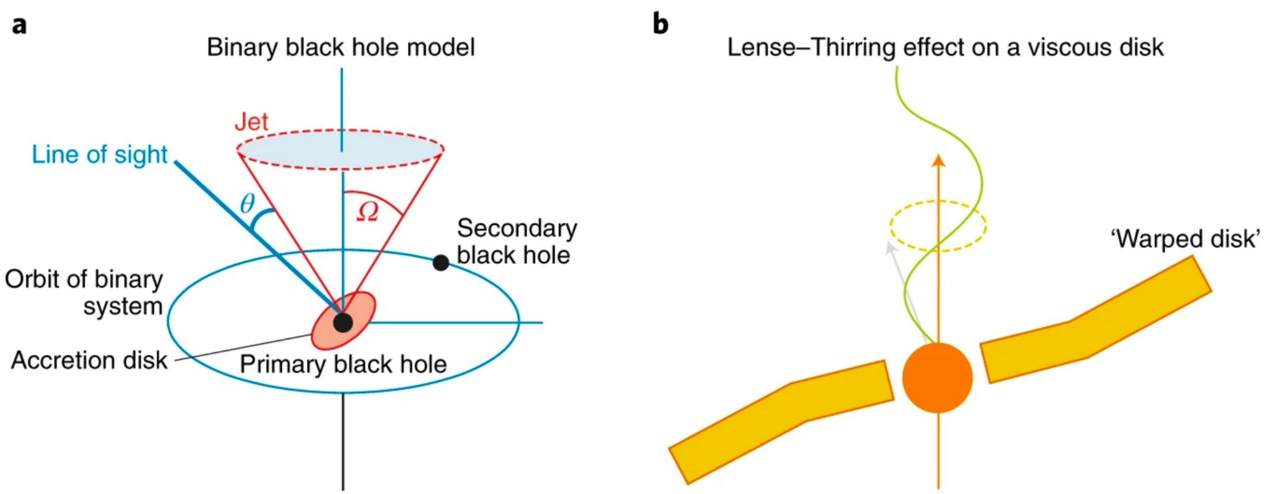
Simulated populations of supermassive black hole binaries accurately reproduce the signal detected by NANOGrav. We compare the observed characteristics of the gravitational-wave (GW) background detected by NANOGrav, shown as grey "violins," with the best-fitting theoretical GW spectra from SMBH binary population models (colored lines). We show three different types of simulated populations, all of which are able to accurately match the data. The bestfitting populations (blue) require more than just gravitational waves: the binaries must be interacting with their host galaxies at higher frequencies than typically expected.

https://nanograv.org/15yr/Summary/Interpret

Precessing blazar-jets hint at binary black hole nature

- Jet precession has been found and modeled:
  - e.g., 3C 279 (Abraham & Carrara 1998), 3C 273 (Abraham & Romero 1999), **PKS 0735+178** (Britzen+ 2010), 2200+420 (BL Lac, Caproni et al. 2013), PG 1553+113 (Caproni+ 2017), 3C 345 (Caproni & Abraham 2004), 3C 120 (Caproni & Abraham 2004), 1308+326 (Britzen+ 2017), 3C 84 (Dunn+2006, Britzen+ 2019), **TXS 0506+056** (Britzen+ 2019, Becker Tjus+ 2022, Jaroschewski+ 2023), **PKS 1502+106** (Britzen+ 2021), J1048+743 (Kun+2020, 2024), and many more.
  - and **OJ 287** (e.g., Sillanpää+1988; Valtonen+2016, Britzen+2018, Britzen+2023)

IceCube neutrino(s)

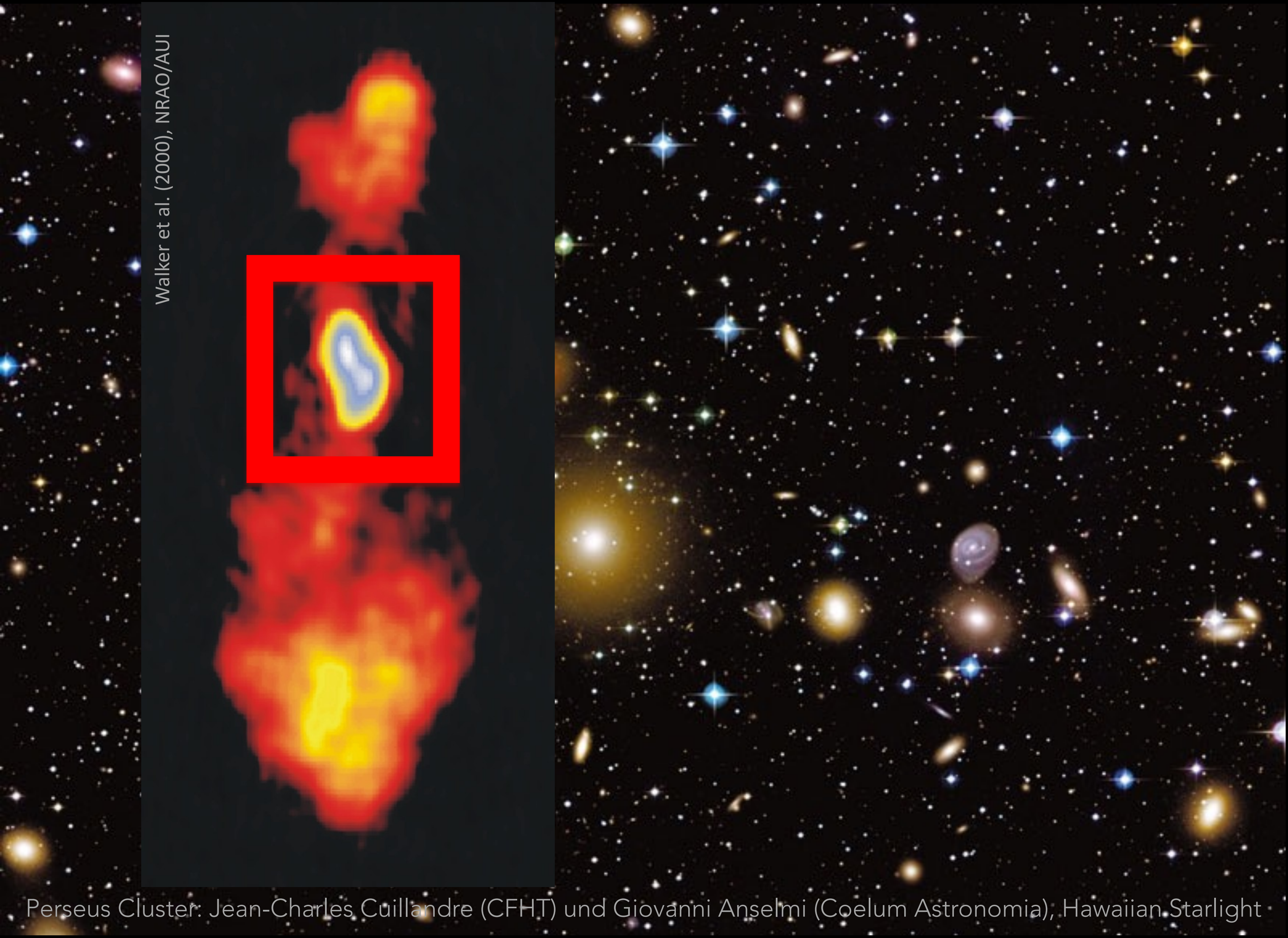


a, The orbital motion of a supermassive black hole binary leads to the precession of the jet on the surface of a cone with opening angle Ω, at an angle θ from the observer's line of sight. **b**, A misalignment of the supermassive black hole spin (orange arrow) with the accretion disk angular momentum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

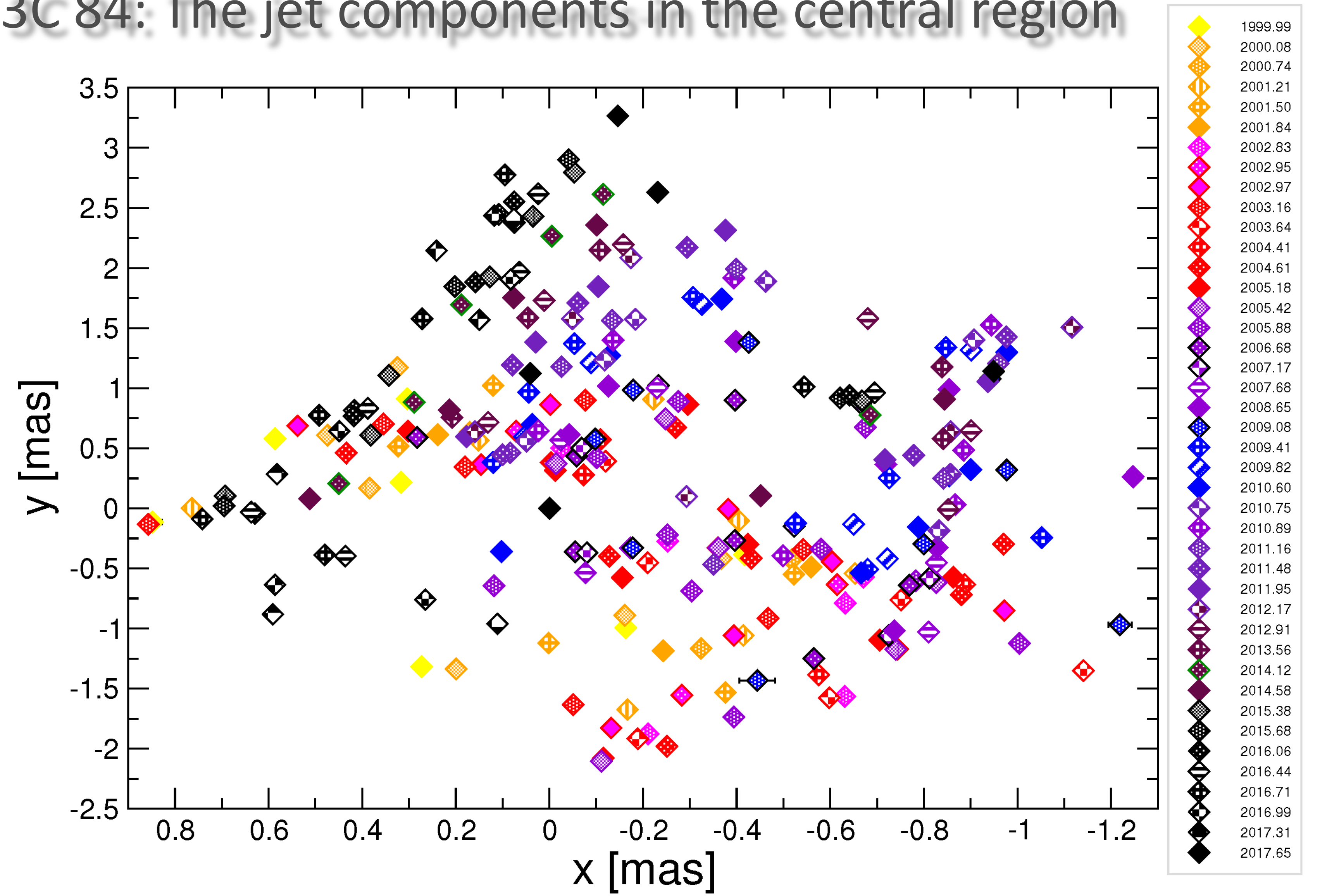
Abraham, Nature Astronomy, 2018

A precessing jet in

3C 84 (NGC 1275, Perseus A)

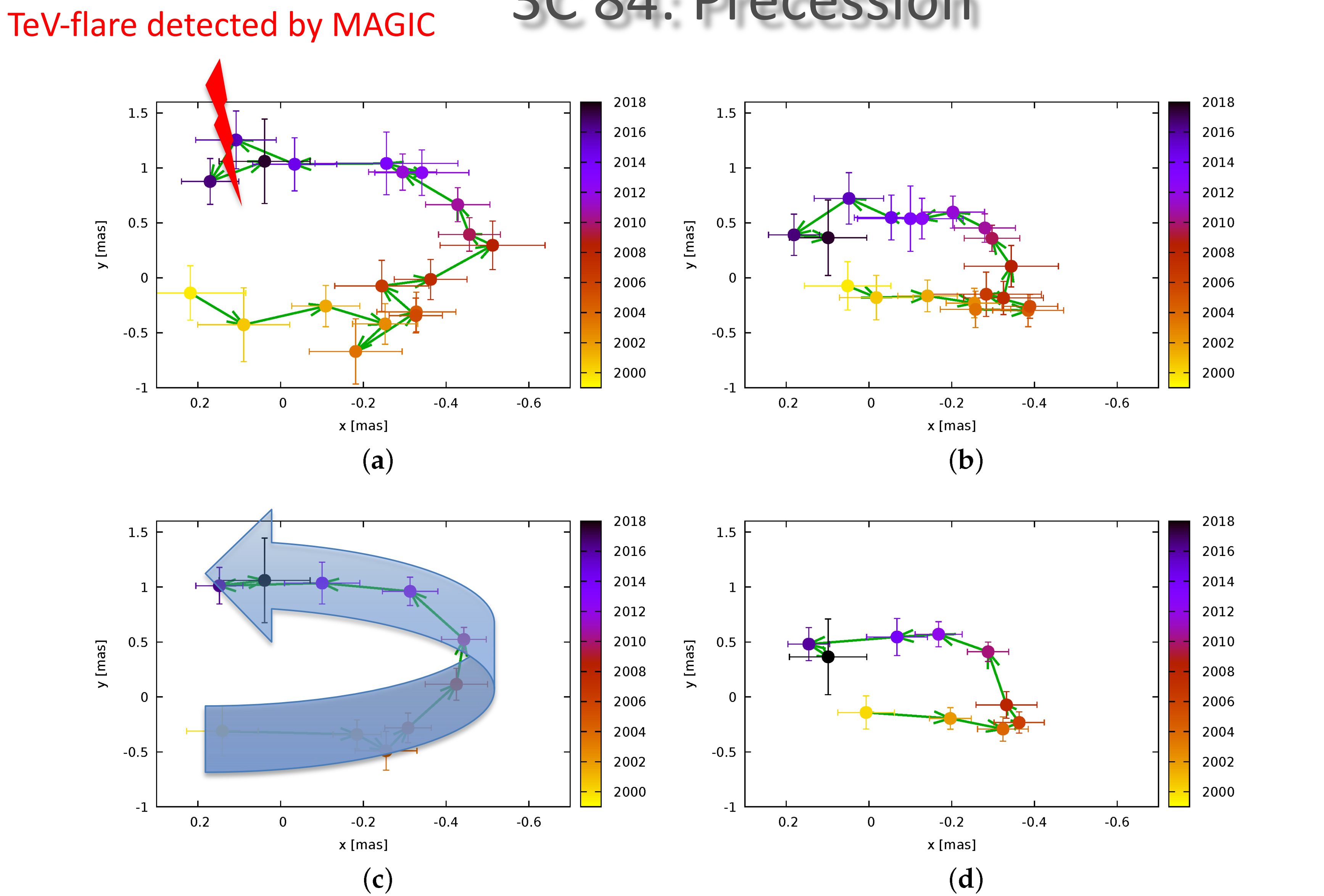

Walker et al. (2000), NRAO/AUI
Perseus Cluster: Jean-Charles Cuillandre (CFHT) und Giovanni Anselmi (Coelum Astronomia), Hawaiian Starlight

3C 84: The jet components in the central region



Britzen et al., *Galaxies* **2019**, *7*(3), 72

3C 84: Precession



(a) Average values for the data in yearly intervals. The green arrows indicate the direction of the precessing motion. (b) The same relation as in (a) but averaged over two years in time.

(b) (c) Flux-density weighted average values in yearly intervals and averaged in two years in (d).

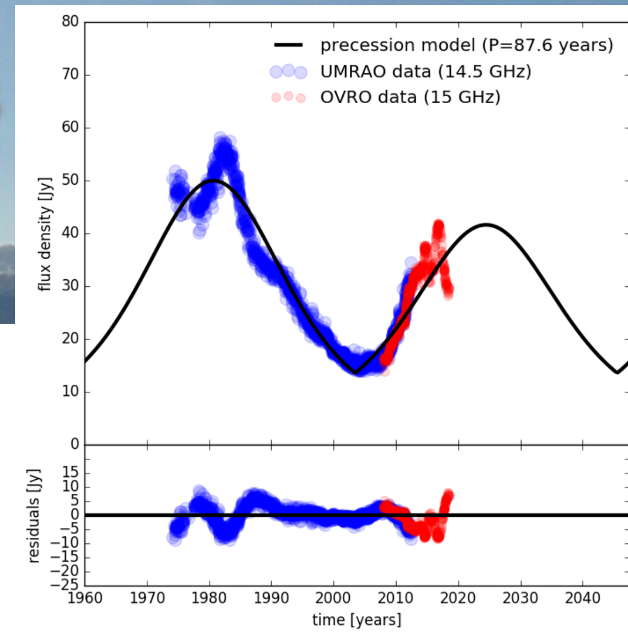
Precession explains Brightness variations

VLBA data provide evidence for precession of the central radio structure of 3C 84.

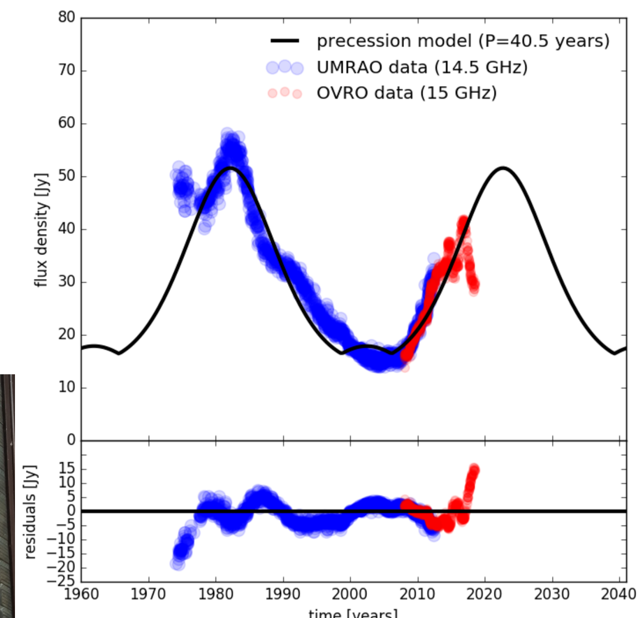
Fitting a precession model to the single-dish radio data (OVRO + UMRAO, 15 GHz) provides evidence for precession as well.

Going back to the archival data: maps from 40yrs ago show similar morphology – further evidence for precession

3C 84 is **precessing** with a **time-scale of about 40 yrs**

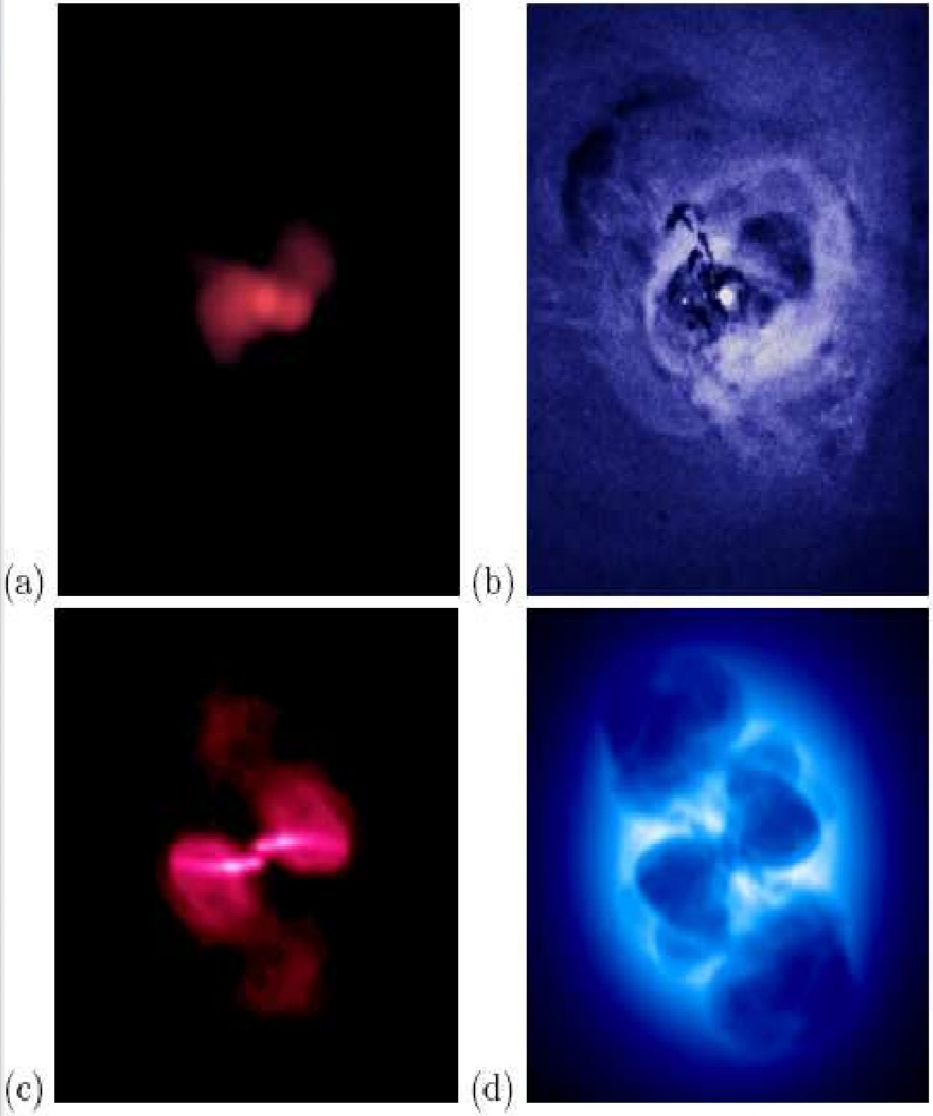


(a)



(b)

Britzen et al., *Galaxies* **2019**, *7*(3), 72



Further support for Precession in 3C 84 based on modeling X-ray data

Precession in 3C 84 has been claimed before by several authors based on simulations (e.g., Dunn et al., 2006; Falceta-Goncalves et al., 2010) to explain the Chandra observations of the X-ray cavities (e.g., Fabian et al., 2011).

Falceta-Gonçalves et al., 2010

Fig. 4.— a) 328 MHz VLA radio map credit NRAO/VLA/G.Taylor, b) credit: NASA/CXC/IoA/A.Fabian, c) temperature integrated along the line of sight normalized by its maximum and d) emission measure normalized by its maximum value. Panels c and d correspond to the projection of the mentioned quantities along a line of sight inclined 40◦ with respect to the total angular momentum of the system. The synthetic maps shown were zoomed to better fit the observations. In both cases the total length of the image is 70kpc in each direction.

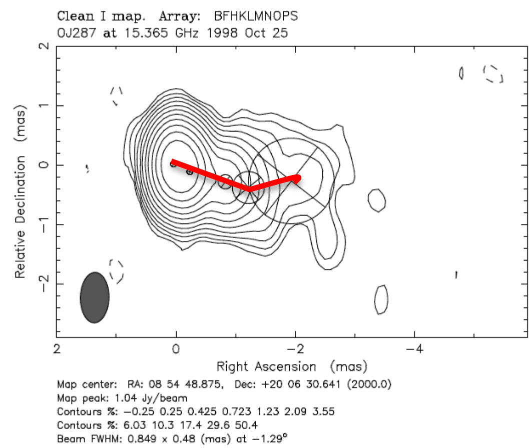
Another precessing jet in

OJ 287

The most promising candidate for a supermassive binary black hole

OJ 287 – the jet data

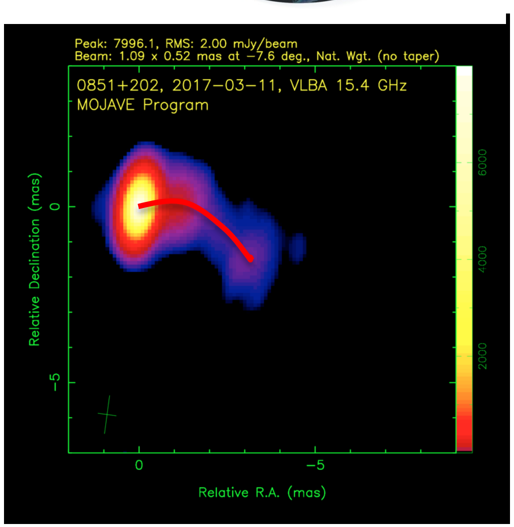
- we re-analyzed **120 VLBA** data sets (Apr. 1995 – Apr. 2017) obtained at 15 GHz within the **MOJAVE** (**M**onitoring **O**f **J**ets in **A**ctive galactic nuclei with **V**LBA **E**xperiments) survey
- http://www.physics.purdue.edu/astro/MOJAVE/index.html



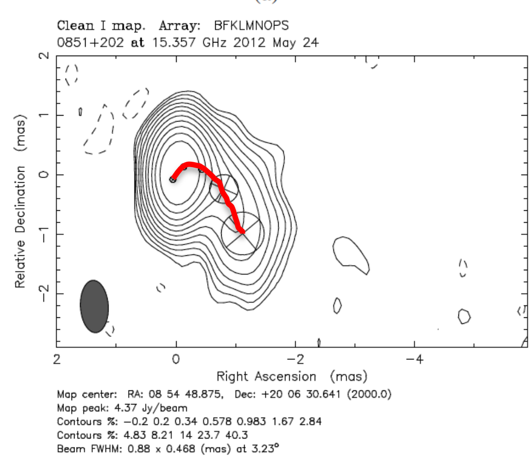
(a)

1998

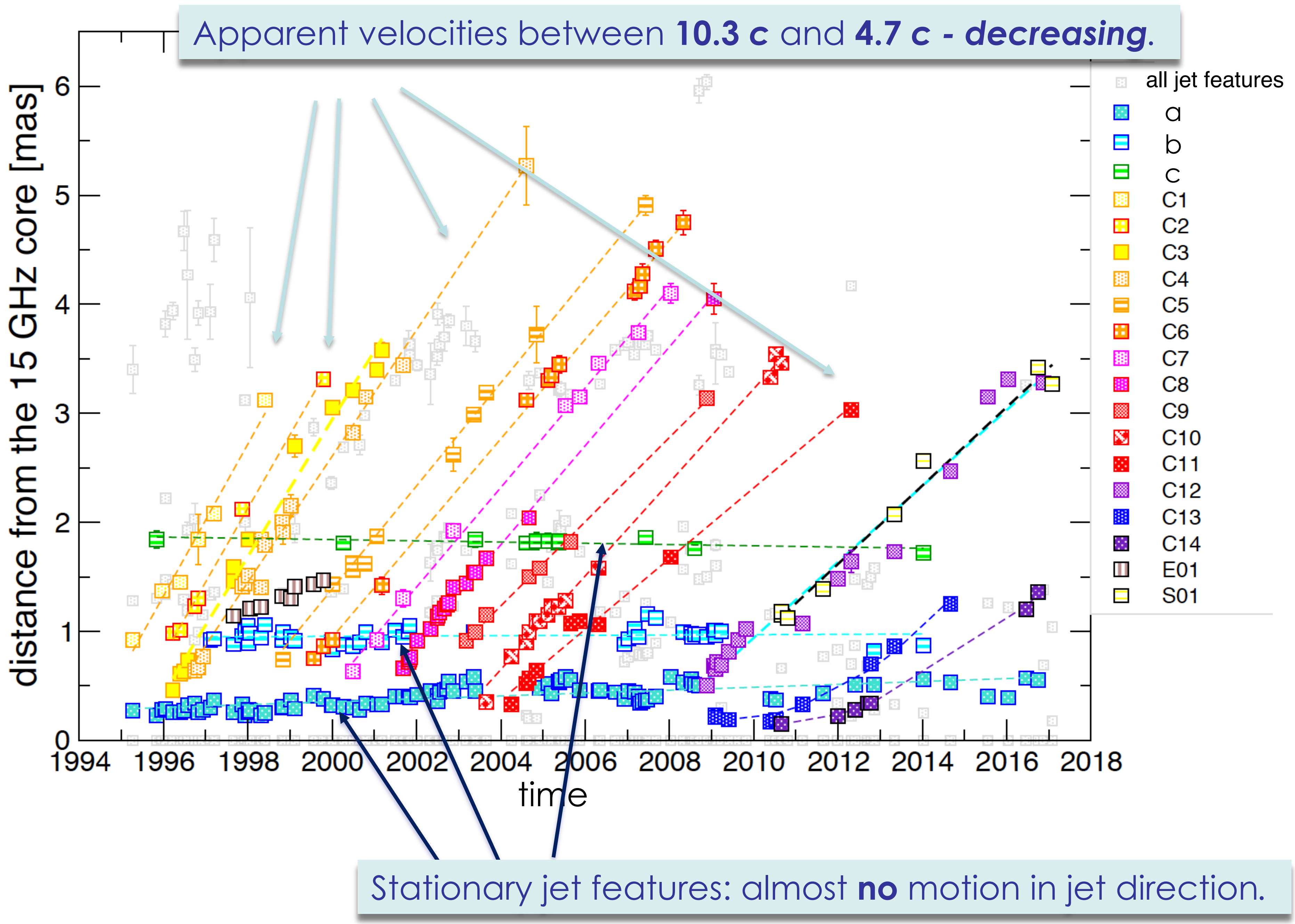
Something is going on …



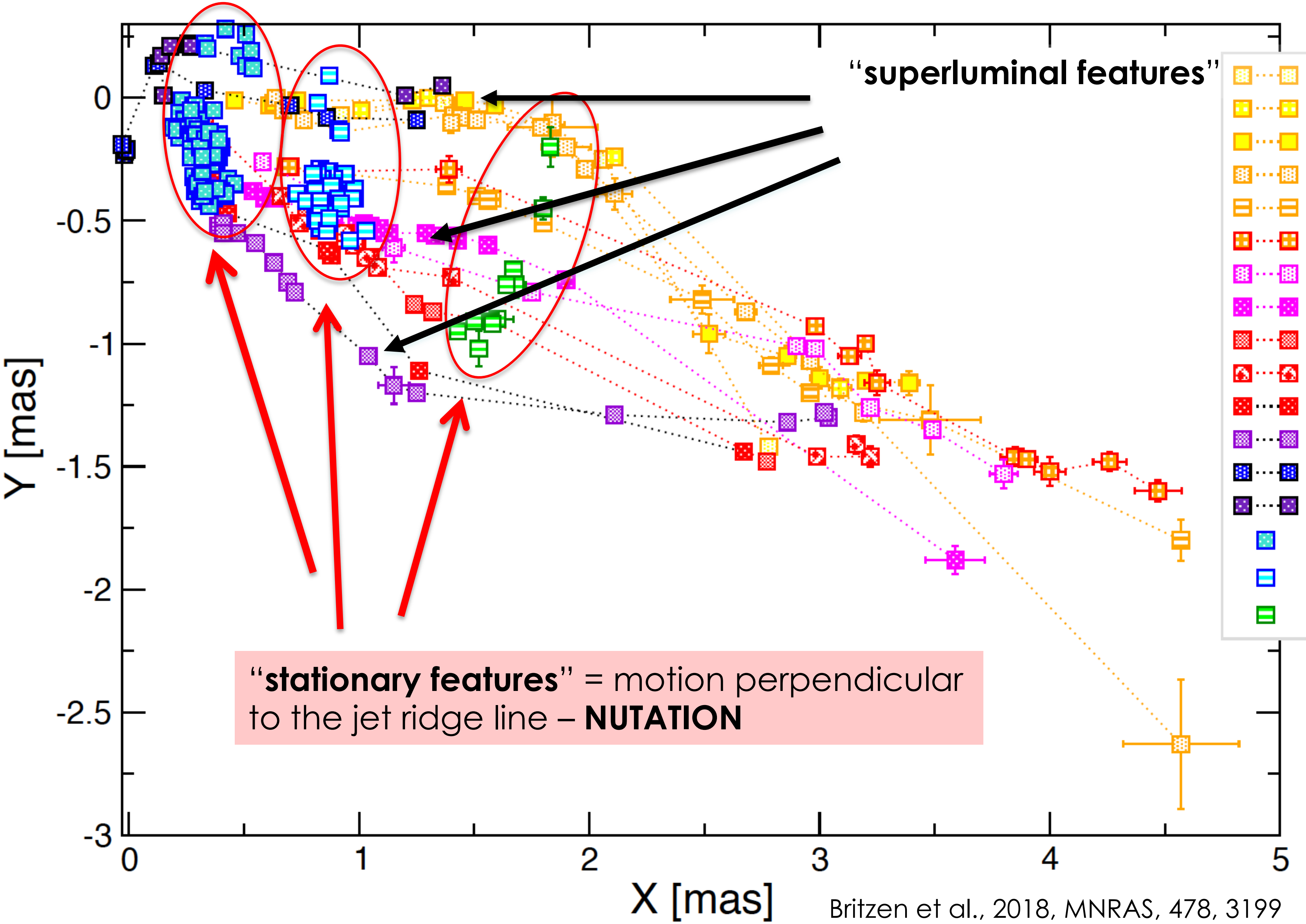
2017



2012

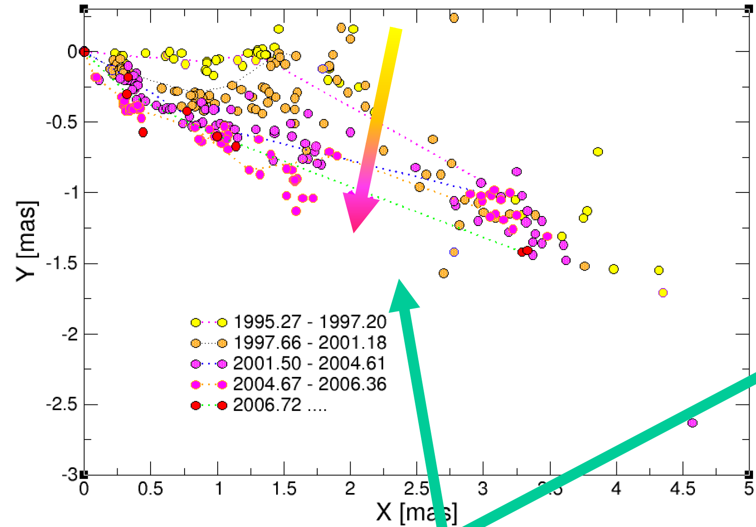


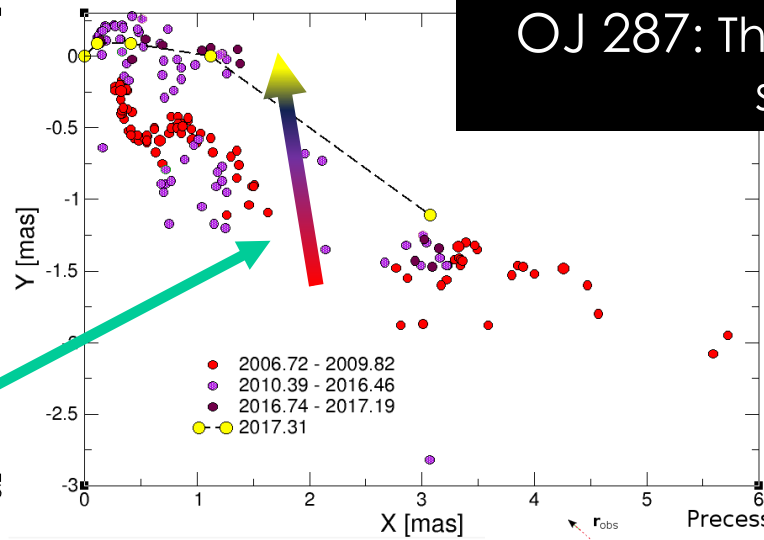
Britzen et al., 2018, MNRAS, 478, 3199



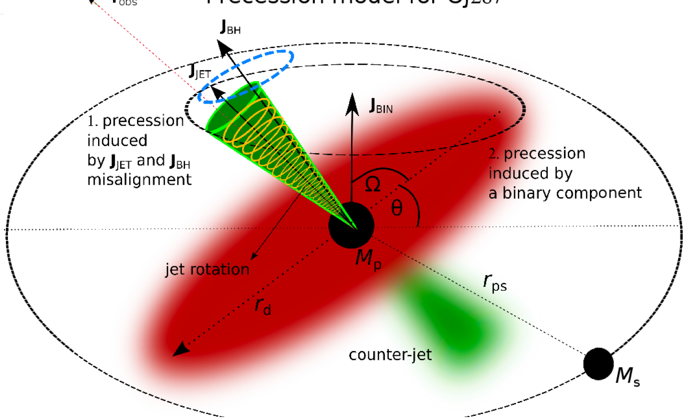
Britzen et al., 2018, MNRAS, 478, 3199

OJ 287: The deterministic showcase





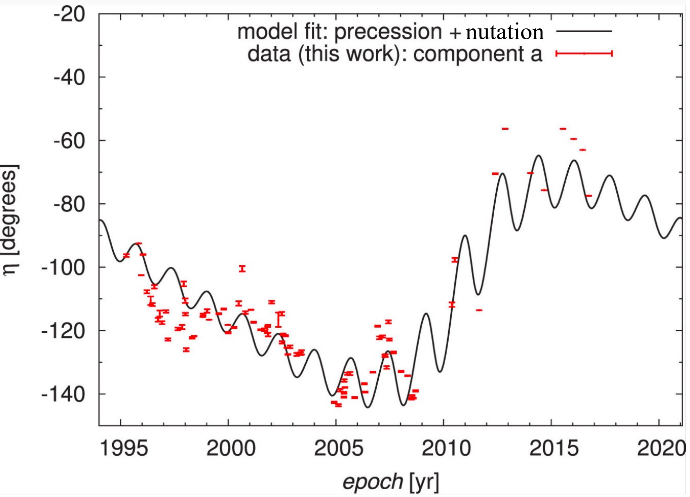
Precession model for OJ287

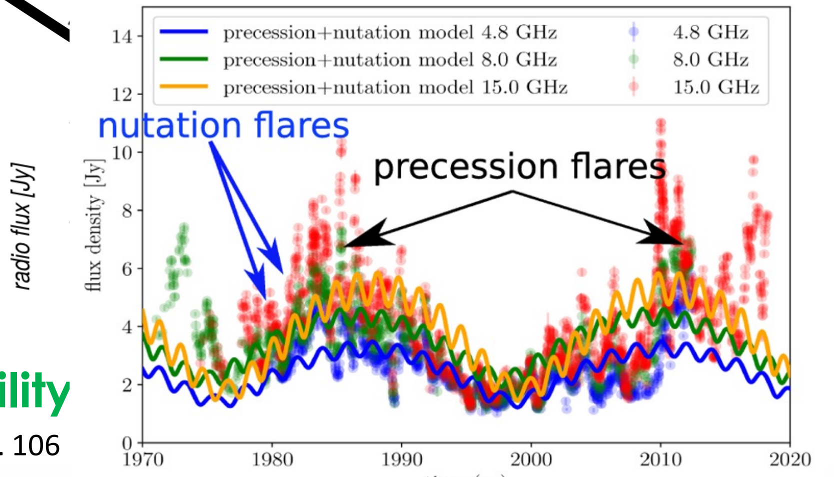


VLBI: The jet is wandering in the sky – down and up

Kinematics: so-called „stationary“ jet feature

Model: precession + nutation

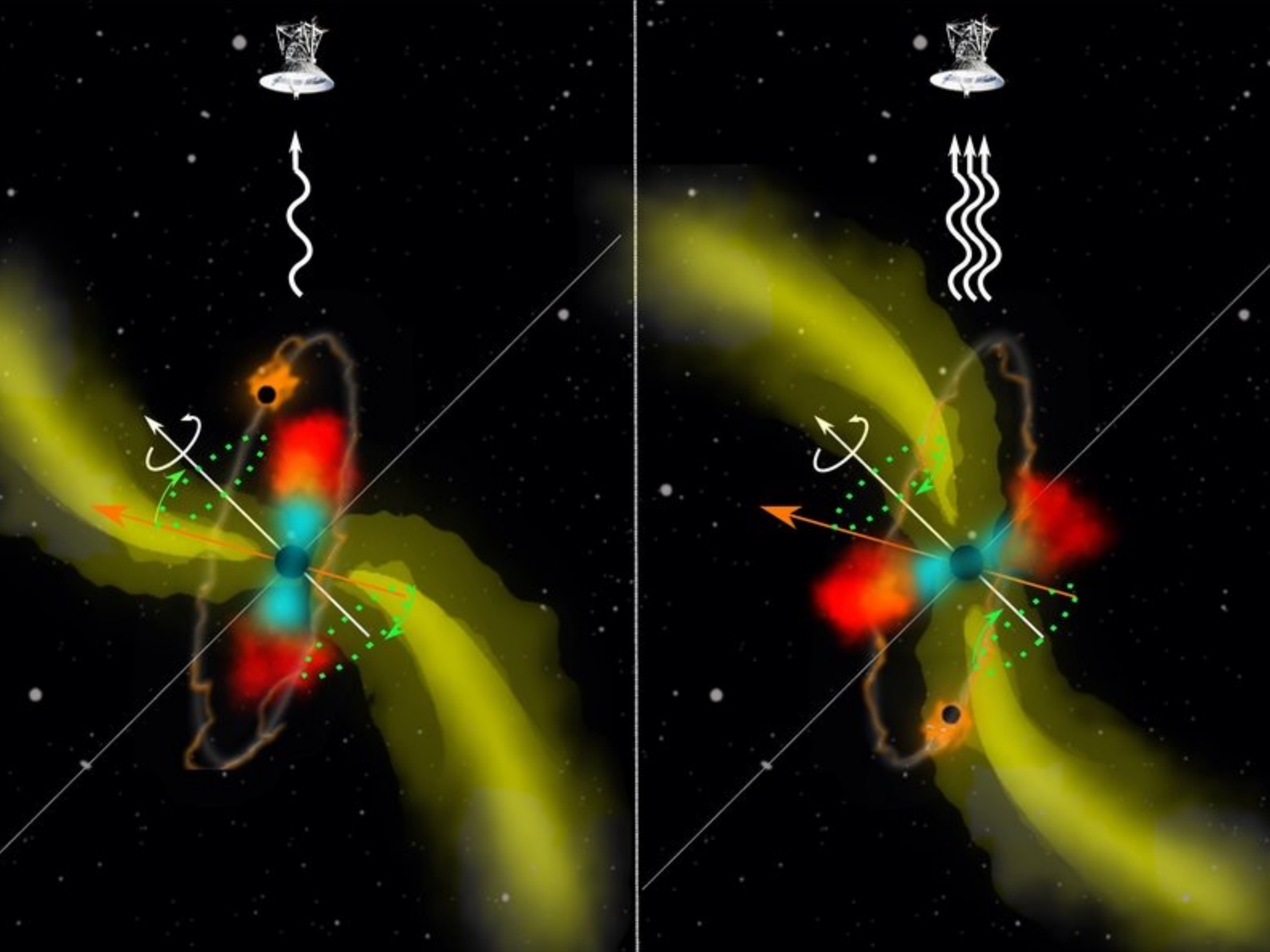




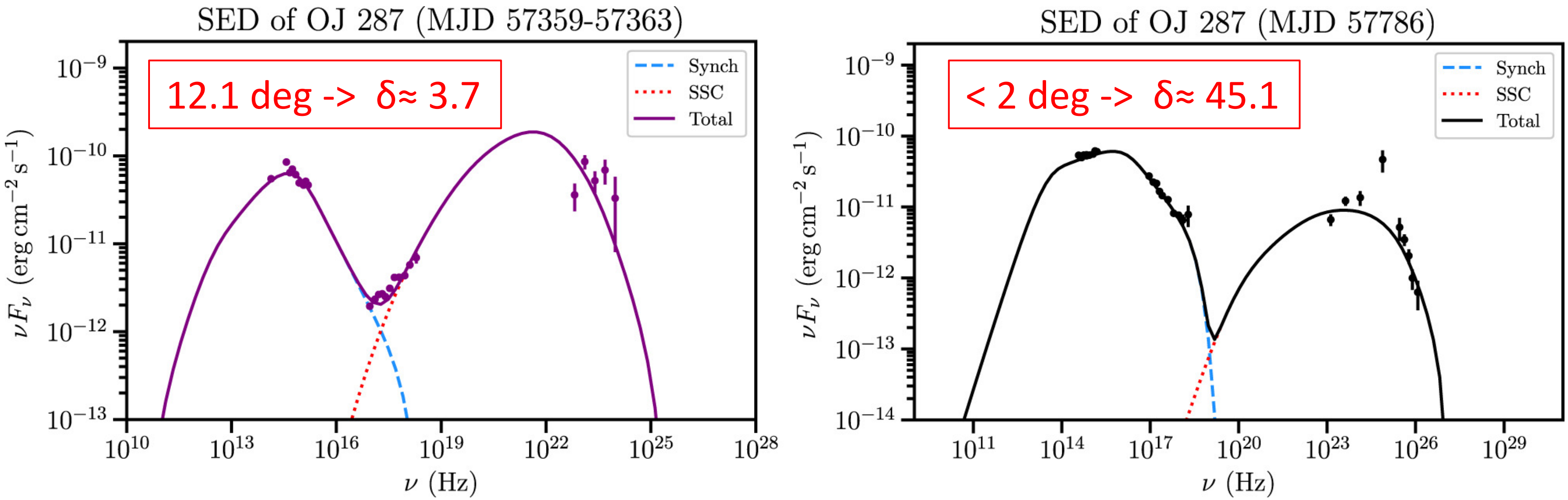
Britzen *et al*. 2018

Flux-density Variability

Britzen *et al* 2023 *ApJ* **951** 106



Same SED-model – different viewing angle



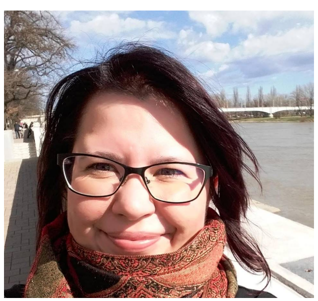


Figure 7. Pure leptonic SEDs for OJ 287 in different spectral states, where the SED points are adopted from Kushwaha (2020). Left: the blue-dashed curve shows the (self-absorbed) synchrotron, the red-dotted curve shows the SSC contribution to the total leptonic SED between MJD 57359 and 57363, which is shown by the continuous purple line. Right: the blue-dashed curve shows the (self-absorbed) synchrotron, the red-dotted curve shows the SSC contribution to the total leptonic SED at MJD 57786, which is shown by a continuous black line. The main difference between the models applied in the figures is the viewing angle of the jet (left plot $\Phi \approx 12^\circ\!.1$, right plot $\Phi \leq 2^\circ$) and the corresponding Doppler factor (left plot $\delta \approx 3.7$, right plot $\delta \approx 45.1$).

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„in this field the observed phenomenology must lead, rather than the theory, because the detailed models that are required cannot be predicted by theory. „

S. O'Neill *et al* 2022 *ApJL* **926** L35

More results/predictions for OJ 287:

Predictions based on our precession model:

- **Mass** of primary black hole: **10^8 solar masses** (as opposed to 10^{10} by Valtonen et al.)
- **Optical flaring** caused by **precession** (and not by piercing of the accretion disk)

Absence of the predicted 2022 October outburst of OJ 287 and implications for binary SMBH scenarios

S. Komossa,[1★] D. Grupe,[2] A. Kraus,[1] M.A. Gurwell,[3] Z. Haiman,[4,5] F.K. Liu,[6,7] A. Tchekhovskoy,[8] L.C. Gallo,[9] M. Berton,[10] R. Blandford,[11] J.L. Gómez,[12] and A.G. Gonzalez[9]

The *predicted outburst was not detected*. Instead, OJ 287 was at low optical–UV emission levels, declining further into November. The *predicted thermal bremsstrahlung spectrum was not observed either*, at any epoch. Further, applying scaling relations, *we estimate a SMBH mass of OJ 287 of 10^8 $M_\odot$*.

Correlation analysis between OJ 287 radio jet observables

Q. Yuan,[1,2] M. Zhang,[1,3,4] X. Liu,[1,3,4] P.F. Jiang,[1,2] and G. I. Kokhirova[5]

We collected the archival data of blazar OJ 287 from heterogeneous very long baseline interferometry (VLBI) monitoring programs at 2.3 GHz, 8.6 GHz, 15 GHz and 43 GHz. .... The foremost findings are the correlations between the core flux density and the jet position angles on different scales, which *validated the plausible predictions of the jet with precession characteristics*.

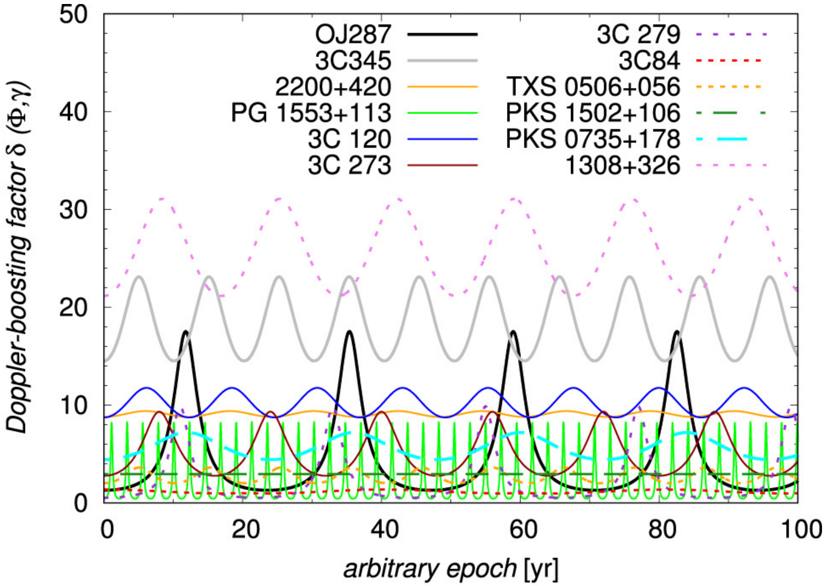
Unraveling the Innermost Jet Structure of OJ 287 with the First GMVA + ALMA Observations

Guang-Yao Zhao *et al* 2022 *ApJ* **932** 72

Our images reveal a compact and twisted jet extending along the northwest direction, with two bends within the inner 200 μas, *resembling a precessing jet in projection.*

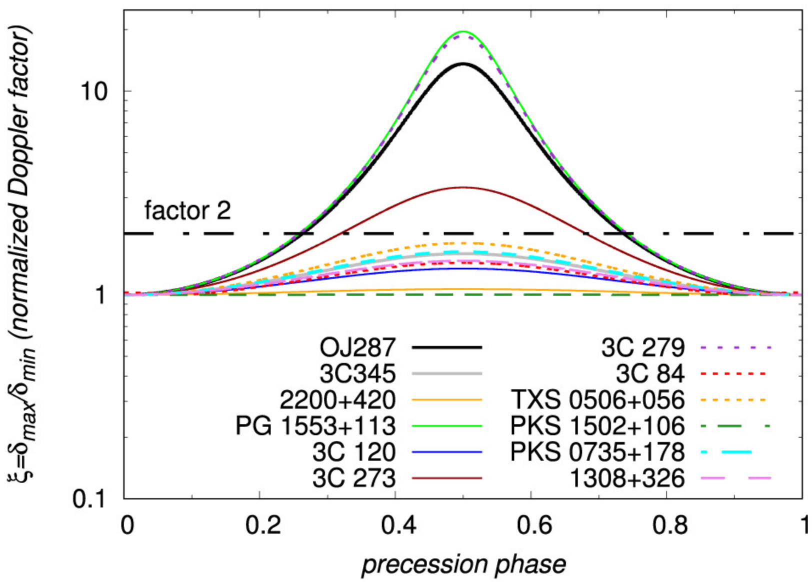
Blazar Variability: Precession-induced?

Precession model applied to 11 prominent blazars



[a]

Figure 13. (a) Shows the time-dependent Doppler boosting factor $\delta(t, \gamma, \Phi)$ for the radio galaxies studied.



[b]

In (b) the ratio of maximum to minimum Doppler factor derived for one precession phase is displayed. The dotted–dashed line denotes a ratio $\xi = 2$; most of the sources lie below this limit (8/12), while four lie above.

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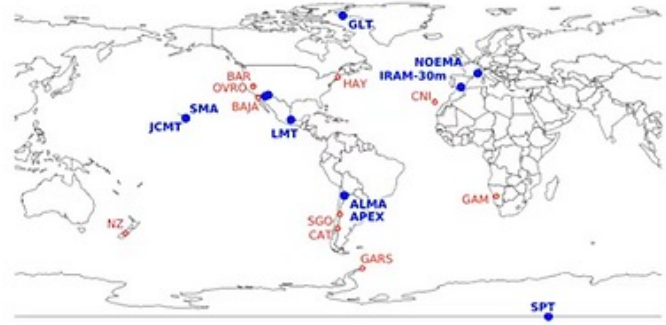
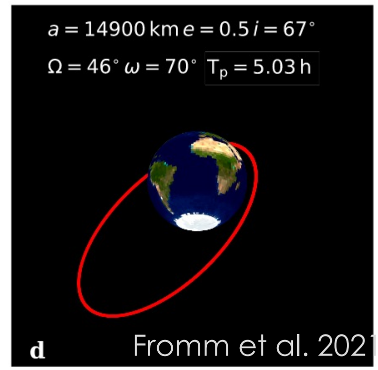
What‘s next ?

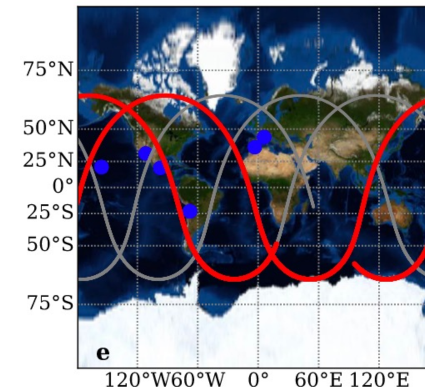
https://www.ngeht.org/

Image Credit: Ming-Tang Chen, IRAM & DiVertiCimes, Arash Roshanineshat, and Nick Conroy



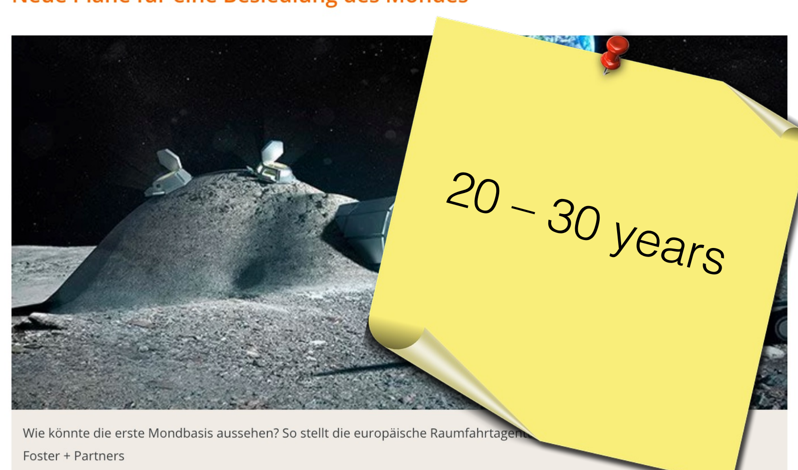
ngEHT Telescope Array Example 1





Mondbasis Alpha

Neue Pläne für eine Besiedlung des Mondes



Wie könnte die erste Mondbasis aussehen? So stellt die europäische Raumfahrtagen
Foster + Partners

Watching supermassive binary black holes dance

In this visualization, disks of bright, hot, churning gas encircle both black holes, shown in red and blue to better track the light source.
Image credit: NASA's Goddard Space Flight Center/Jeremy Schnittman and Brian P. Powell.

The animation shows two black holes: The bigger of the pair, which is about 200 million times the mass of our sun, is surrounded by red rings of hot gas called an accretion disk. Orbiting that giant is a second black hole weighing in at about half of that mass, and its gas and dust rings are illustrated in bright blue.

"Zooming into each black hole reveals multiple, increasingly distorted images of its partner,"
Jeremy Schnittman

The future

- We detect ample examples of candidate SMBBHs
- Jet precession explains:
  - light-curve variability in blazars
  - wiggled jets in blazars
  - changes of the SED in blazars

    -> Three sides of the same coin ...
- We are improving our search routine to detect the closer pairs.
- We improve the models ...
- Higher resolution observations to come (EHT, ngEHT, ngVLA)

Many thanks for your attention!