Unusual changes in the Microquasar GRS 1915+105

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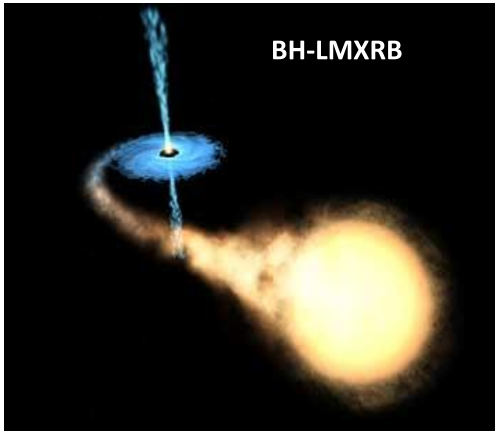
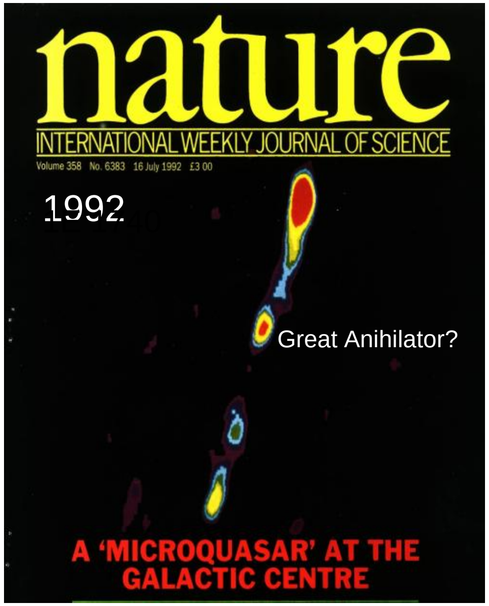


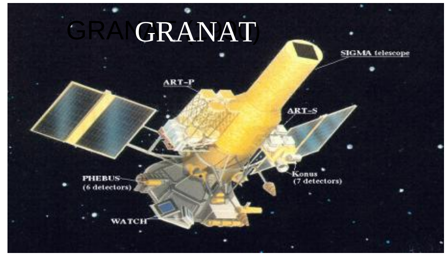
Rodríguez & Mirabel. 2025, The Astrophysical Journal 986, 108.

- Introduction to microquasars and their role in black hole physics
- Usual phenomena in GRS 1915+105 explained by Special & General Relativity
- A recent unusual change in the orientation of the jets in the year 2023, associated to
- An unusual change in the period of the sinusoidal radio flux of the compact source
- The possible unknown causes of these unusual changes in the year 2023
- Analogies between the growth of Stellar and SMBHs in the Local & Early Universe

RELATIVISTIC JETS IN STELAR BLACK HOLES

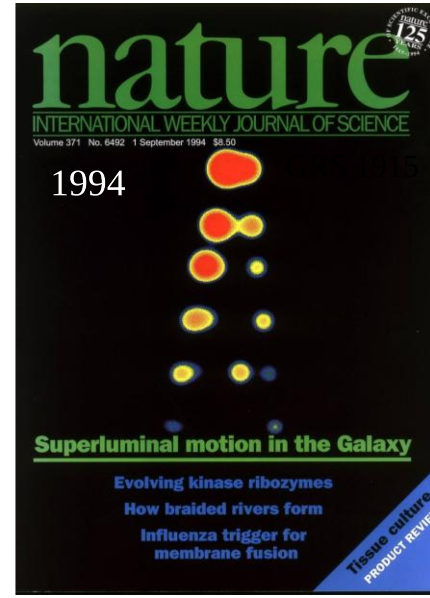
1E 1740-2942: Mirabel, **Rodríguez**+



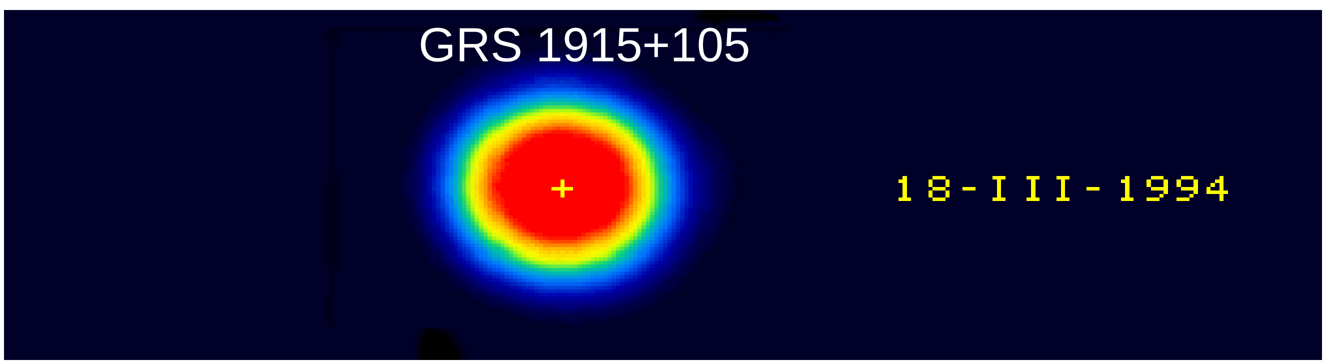


Luis F. Rodríguez

GRS 1915+105: Mirabel & Rodríguez

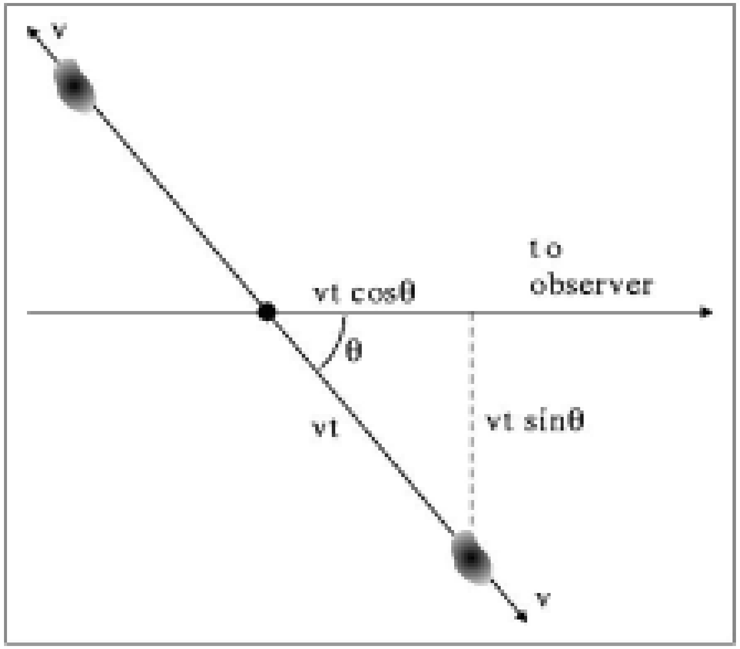


1 arc sec



- V_{app} > C: Jets with apparent super-luminal velocities
- Kinetic energy of ejecta ~ 1/3 de Moon's mass at v = 0.98c

RELATIVISTIC ABERRATION IN ANTISYMMETRIC TWIN JETS



$$\frac{S_a}{S_r} = \left(\frac{1+\beta\cos\theta}{1-\beta\cos\theta}\right)^{k-\alpha},$$

$$\mu_a = \frac{\beta\sin\theta}{(1-\beta\cos\theta)}\frac{c}{D},$$

$$\mu_r = \frac{\beta\sin\theta}{(1+\beta\cos\theta)}\frac{c}{D},$$

$$\beta\cos\theta = \frac{\mu_a-\mu_r}{\mu_a+\mu_r},$$

$$D = \frac{c\tan\theta}{2}\frac{(\mu_a-\mu_r)}{\mu_a\mu_r}.$$

Same bulk Lorentz factors as in QSOs: 2-10

$$D \le \frac{c}{\sqrt{\mu_a\mu_r}}.$$

Relativistic upper limit: D < 14 kpc

Assuming 'c' is a universal constant the jet phenomenology is clearly explain

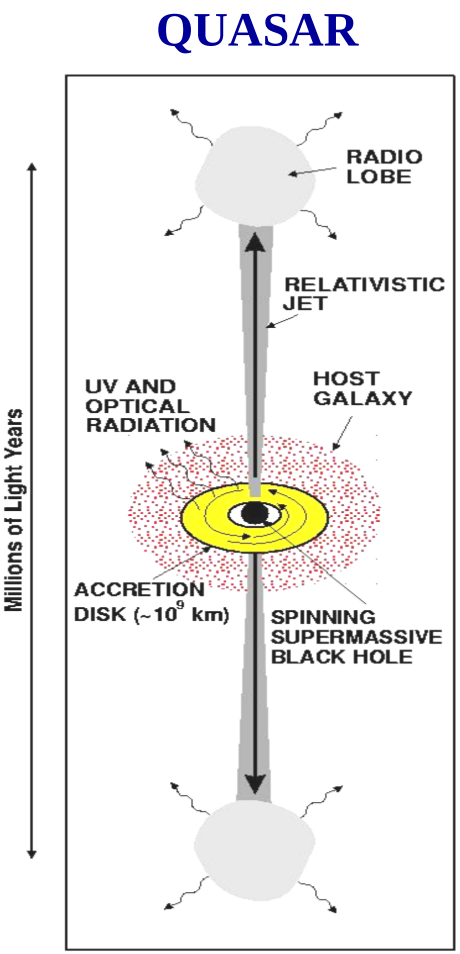
Mirabel & Rodríguez (1994)

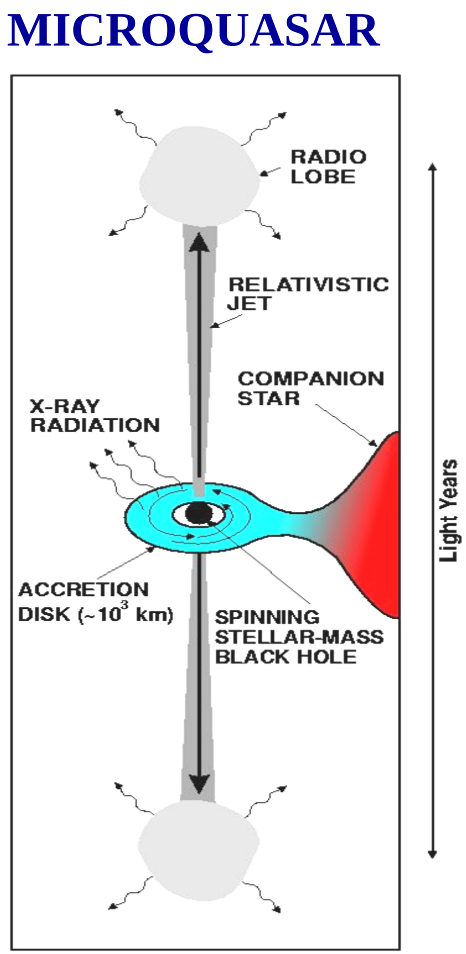
Einstein with experimental physicists and observational astronomers

The experiment of Michelson–Morley in1887 found no difference between the speed of light in different directions of movement; Nobel prize 1907

After Hubble's discovery of the expansion of the universe in 1929, Einstein abandoned the hypothesis of a cosmological constant.

ANALOGY BETWEEN QUASARS & MICROQUASARS





Mirabel & Rodríguez (Nature, 1998)

The scales of space & time are:

$$R_{sh} = 2GM_{BH}/c^2 \; ; \; \Delta T \; \alpha \; M_{BH}$$

A unique system of equations

The maximum brightness temperature of the accretion disk:

$$T_{col} \; \alpha \; (M/10M_{\odot})^{-1/4}$$

(Shakura & Sunyaev, 1976)

For a given accretion rate:

$$L_{Bol} \; \alpha \; M_{BH} \; ; \; l_{jet} \; \alpha \; M_{BH} \; ;$$

$$\varphi \; \alpha \; M_{BH}^{-1} \; ; \; B \; \alpha \; M_{BH}^{-1/2}$$

(Sams, Eckart & Sunyaev 96; Rees 04)

Sinergy of SMBHs & MQs is needed to disentangle the physics of astrophysical BHs

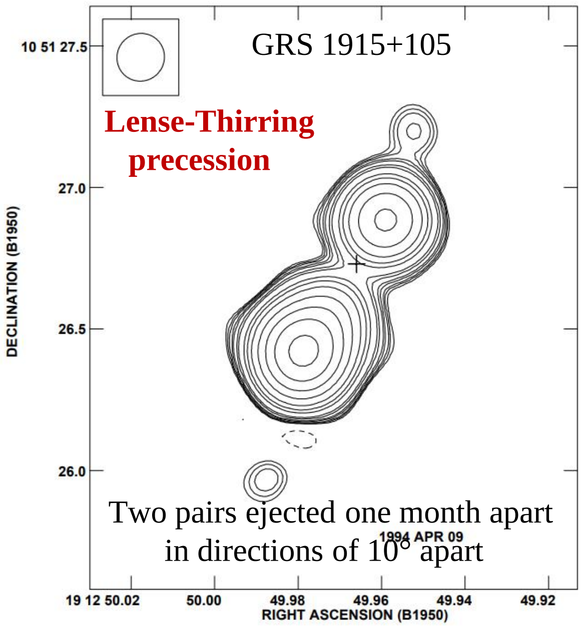
The spatial structures in SMBHs are in R_{Sh} scales (e.g. accretion disk in M87 with EHT).

The time variabilities in MQs are in human scales (e.g. periods of sinusoidal fluxes in BH-XRBs).

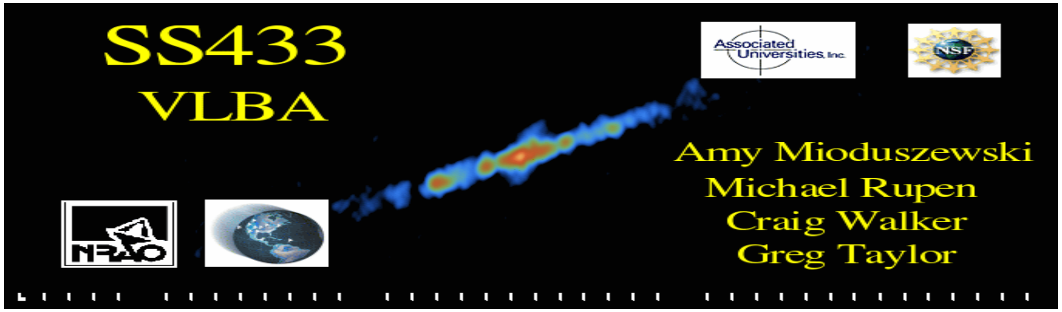
If the jets are parallel to the disk spin, the jets reveal the changes in inner accretion disks

Smooth and continuous changes in the jet axis of BH-LMXBs of up to ~ 10° by GR effects

Rodríguez & Mirabel 1999



If BH-spin and orbital angular momenta are not aligned, the Lense–Thirring mechanism causes relativistic torques on the disk. Then the BH-spin lines the disk with its spin (Bardeen-Petterson effect).



V_{jets} ~ 0.25c

Early in the lifetime of BH-LMXBs, accretion torques over times ~ 10^6–10^8 yr may bring the BH spin into alignment with the orbital plane, but in systems older than 4x10^9 yr old as GRS 1915+105, the accretion disk spin aligns with the BH-spin.

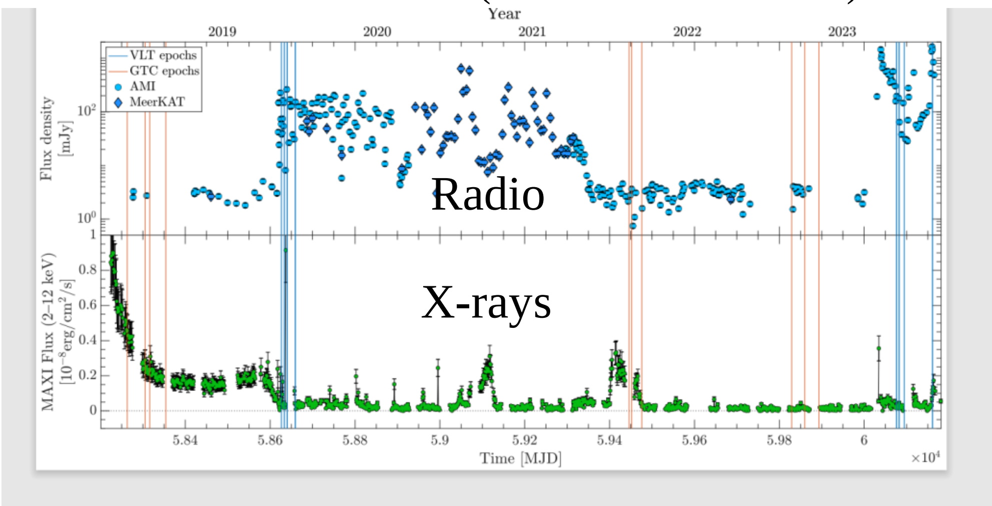
The misalignment of the disk respect to the **BH spin induces relativistic torques** (Lense–Thirring effect) on the disk, causing the disk to precess at early times.

but according to the Bardeen-Petterson efect

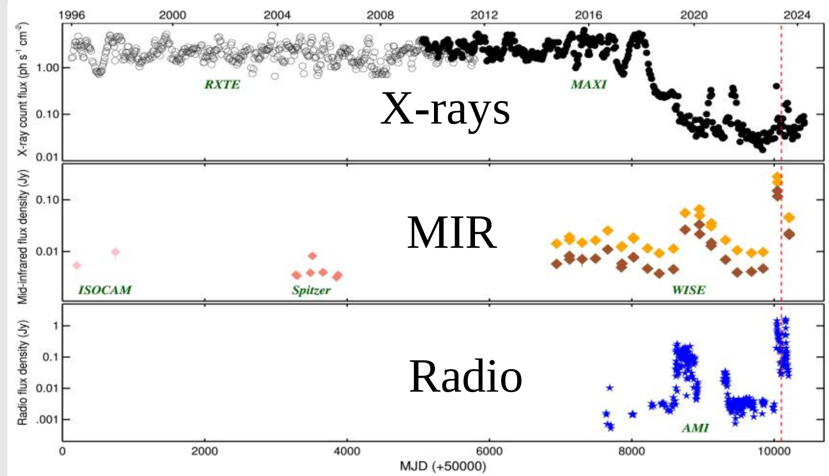
Most BH spin axes in BH-LMXBs are not tilted or tilted by < 10° (Fragos+ 2010)

In early 2018 GRS 1915+105 initiated a transition to a X-ray obscured but luminous Radio & MIR stage

Radio at 15 GHz (Sánchez-Sierras + 2023)



JWST-MIR (Gandhi+ 2025)



- Since 1994 the X-ray and radio activity are correlated. But in 2018 the source initiates a decline in X-rays reaching an “obscure X-ray” state due to intrinsic obscuration, probably due to Compton-thick absorption due to enshrouding by very high neutral gas densities. However, between ~mid-2019’s to ~mid 2021’s, it shows a stage of high radio flux with obscured X-rays, re-initiating this stage in 2023.

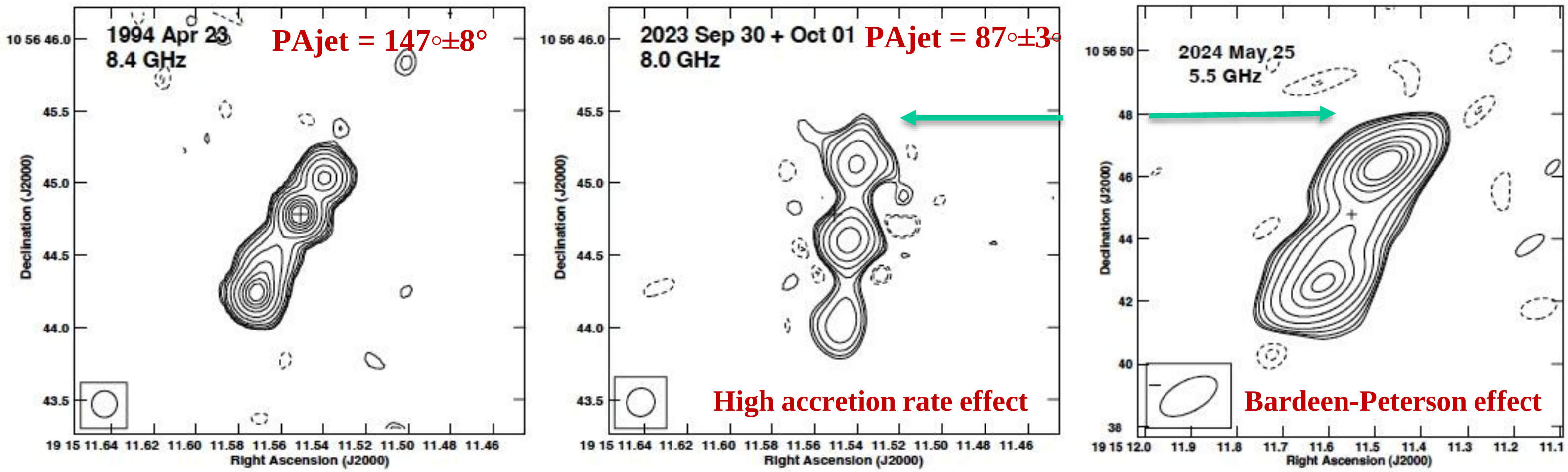
- **JWST detect in June 2023 a MIR flux > 10 times all previous values** (Gandhi+ 2025).

&

- **116 days after the JWST observations we observed unusual changes in the radio jets.**

Comparing the radio observations of GRS 1915+105 during three decades (1994-2024) we find that in the year 2023 occurred an

Unusual Change in the Radio Jets during a X-ray obscure stage of GRS 1915+105



Jet images by us from NRAO archive data of project 23B-314 (PI: Motta+)

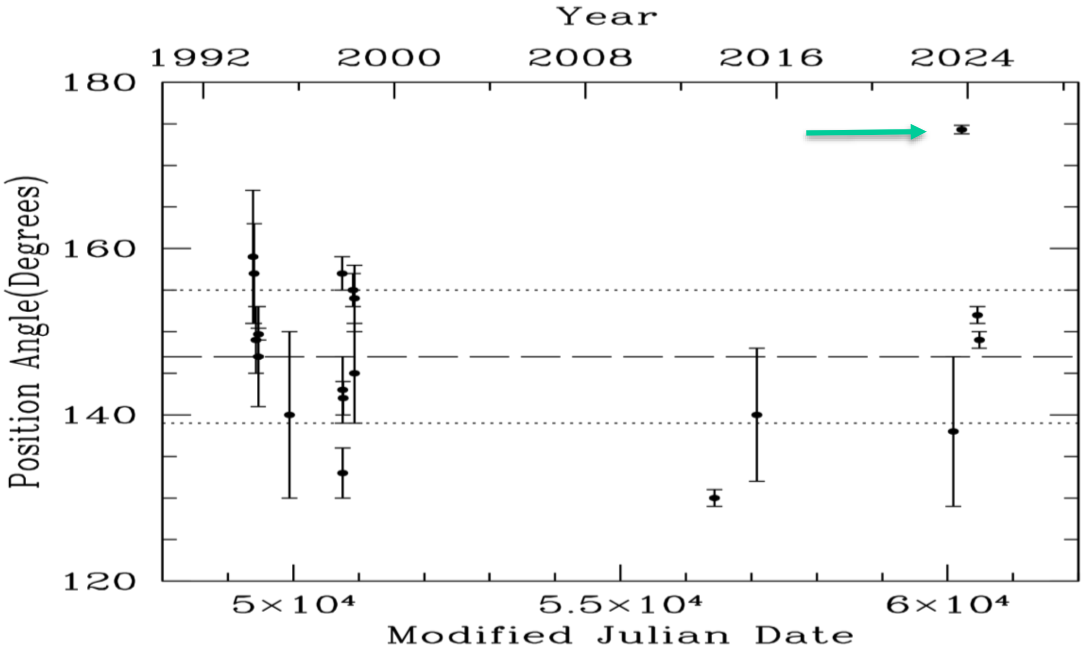
The position angle of the bipolar ejecta in the plane of the sky during the X-ray obscure stage increased counterclockwise by **$24^{\circ} \pm 3^{\circ}$.** The inclination angle of the southern jet with respect to the line of sight, estimated from the proper motions of the approaching and receding jets was **$70^{\circ} \pm 2^{\circ}$** in 1994, The inclination angle of the flow respect to the line of sight increased **by $17^{\circ} \pm 1^{\circ}$.** Therefore,

In 2023 the jets became inclined respect to the line of sight to $87^{\circ} \pm 3^{\circ}$, the plane of accretion flow becoming within $3^{\circ} \pm 3^{\circ}$ of the line of sight.

In 2023 the total angular change of jet orientation was $\Delta\phi T = 30^{\circ} \pm 2^{\circ}$.

This is one of the factors that explain the X-ray-obscure but MIR-bright state in that epoch.

EVOLUTION of JETS POSITION ANGLES DURING THREE DECADES



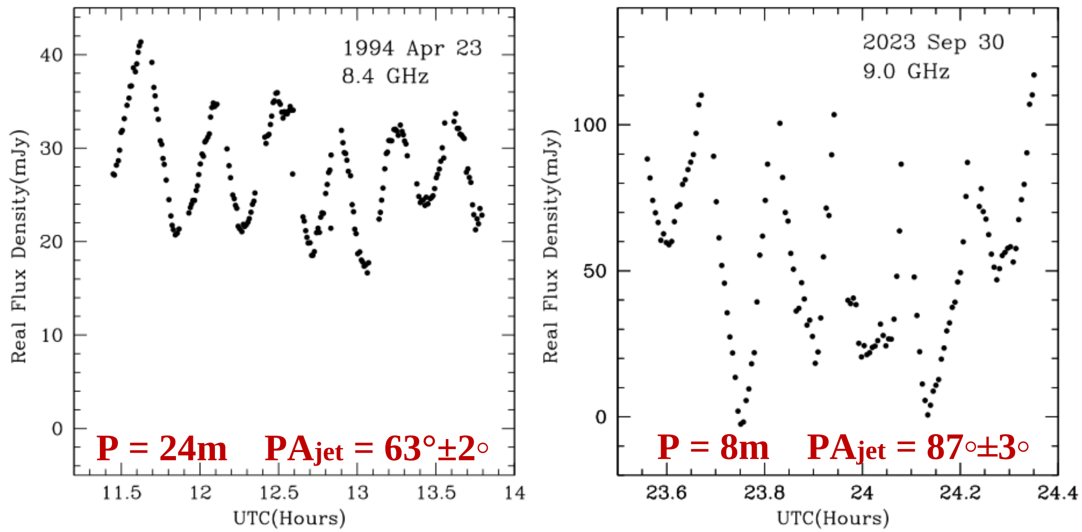
The dashed line indicates the weighted mean for all the points, with the exception of the 2023 Sep 30+Oct 01 data. The weighted ±1 − σ range is indicated by the dotted lines.

The position angle between 1994 and 2018 is 147◦ ± 8◦. **That of 2023 differs by 3.4σ from that mean and lasted about a year or less.** This differs from the smooth and continuous changes in the jet axis by Lense-Thirring precession of typical ∼ 10◦, traced by dotted lines.

The 2024 return to historical values confirmes the Bardeen-Petterson effect & indicates that:

The unusual orientation of the jets in 2023 is due to a transient event in the orientation y/o shape of an enhanced inflow, and not a change in the BH-spin

An unusual decrease in the period of quasi-sinusoidal oscillations



- **If compact jets are perpendicular to accretion plane, their oscillations trace those of the accretion plane.**

The oscillations with P=24m in 1994 decreased to P=8m in 2023, but the MIR & radio fluxes increased.

- **The opacity of synchrotron radiation goes as the frequency $\nu^{(-3.3)}$.** When the accretion plane is aligned with the line of sight, the synchrotron radiation of the accretion flow can self-occult causing a dip in the flux, and giving maximum flux when the plane of accretion is maximally misaligned (Fig. 3b).

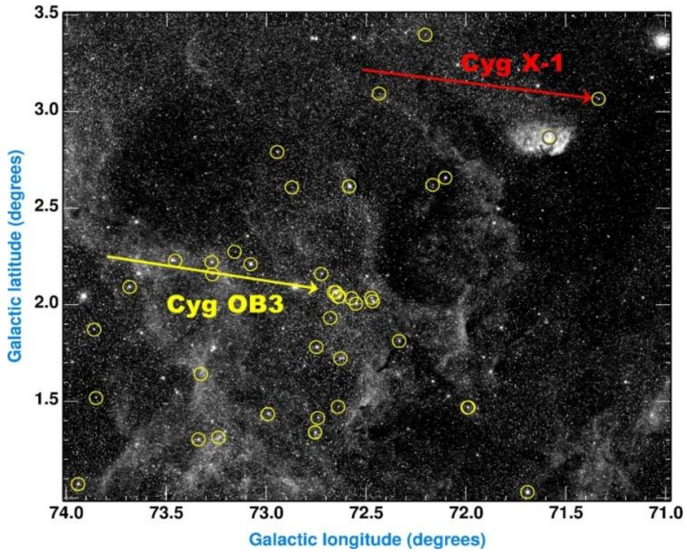
Assuming the disk preserves its circular shape, from Kepler's law the radius decreased by 48%...

This Imply an increase of accretion rate by a factor ~4.3, consistent with the deep X-ray obscuration, and high radio and MIR fluxes in that epoch.

What could be the cause of this unusually enhanced accretion flow remains an open question

Most Stellar BHs form by direct collapse with no energetic SN kicks

Mirabel & Rodrigues (Science, 2003)



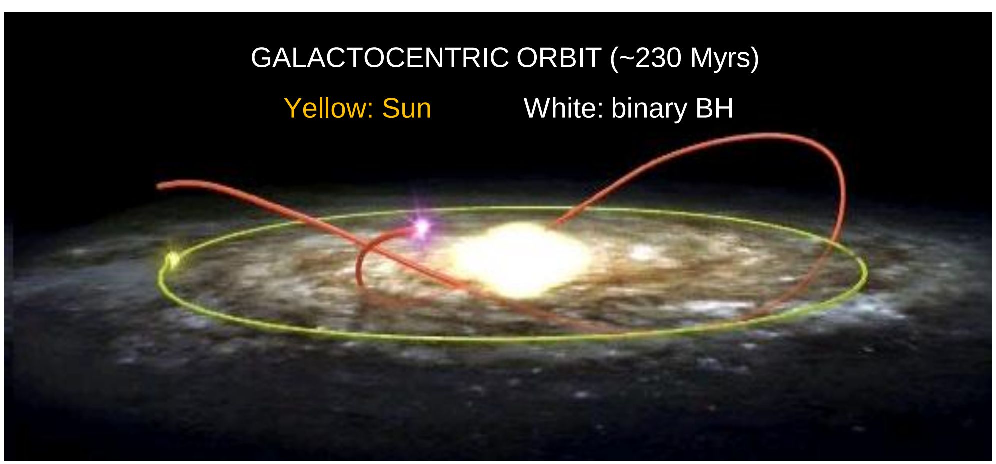
Cygnus X-1: Mbh~21 $M_\odot$; V_p< 9 ± 2 km/s ⇒ < 1 $M_\odot$ ejected by a SN

A BH-HMXB with Md ~19 $M_\odot$ & Mprog > 40 $M_\odot$ that was a Worf Rayet

GRS 1915+105: Mbh~12 $M_\odot$; V_p=22±24 km/s ⇒ Galactic diffusion

V404 Cygni: Mbh~9 $M_\odot$; V_p< 5 km/s because of a tertiary component.

Mirabel, Dhawan, Rodrigues+ (Nature 2001)



XTE J1118+480: The first BH found in the Halo

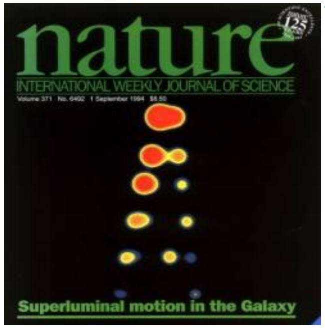
XTE J1118+480 & GRO J1655-40

ARE RUNAWAY BH-XRBs

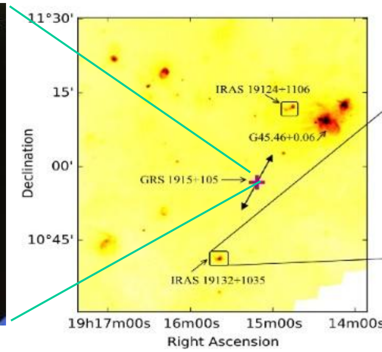
Form from isolated binaries or in dense GCs?

BH-Jets interacting with high Density Cold Gas trigger Star Formation

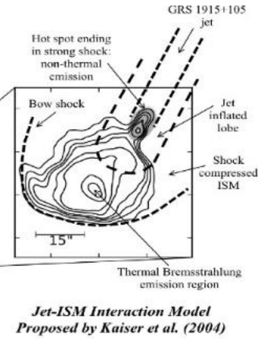
GRS 1915+105



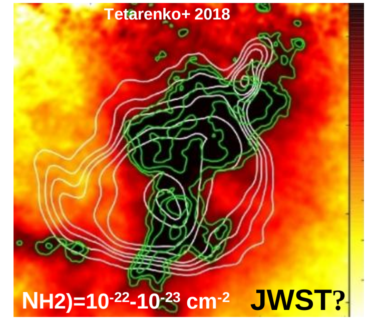
Rodriguez & Mirabel 1998



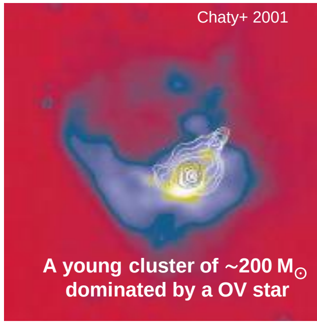
IRAS 19132+1035:



ALMA $C^{18}O$ column denity

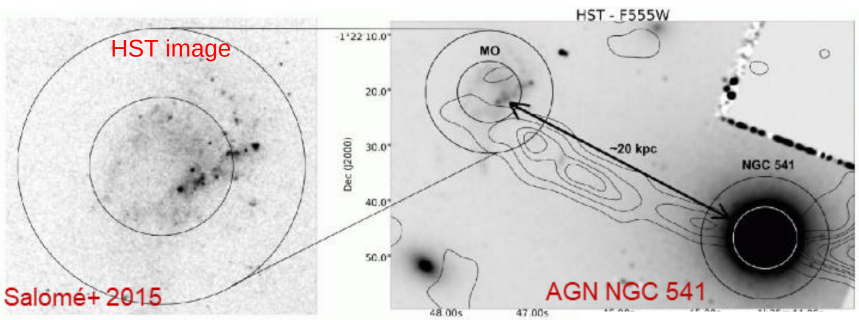


ISO 7µm & radio VLA



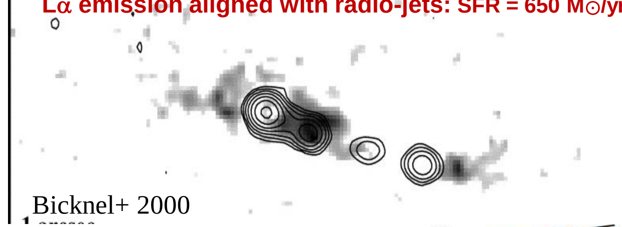
Positive BH-jet feedback

In the Local & distant Universe

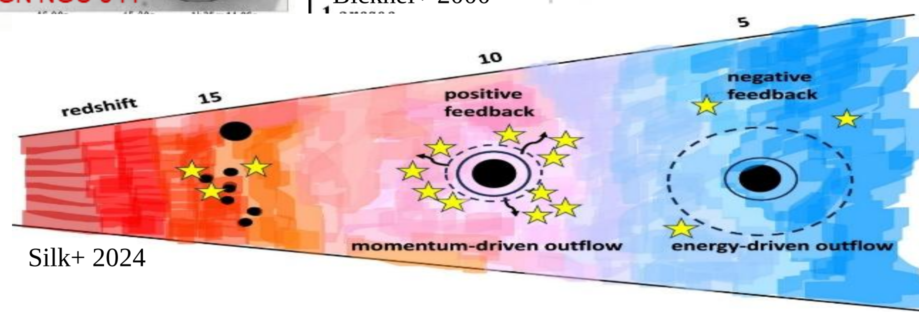


Radio galaxy 4C 41.17 at z = 3.8 (age ~1.7 Gyr)

Lα emission aligned with radio-jets: SFR = 650 M☉/yr



The diameter of the Universe evolves as 1/(1+z) and as z decreases BH feedback transient from positive to negative.

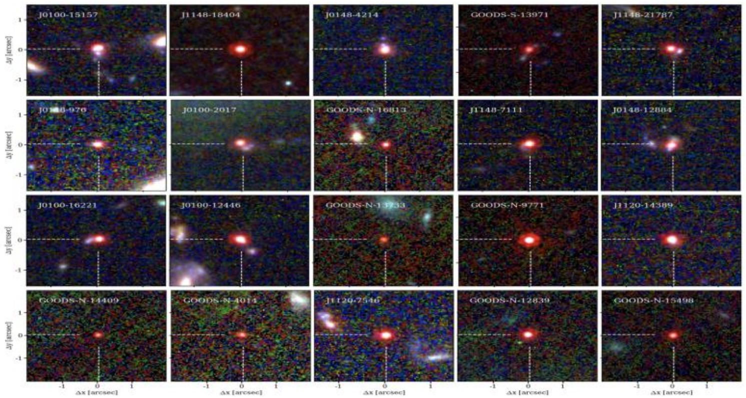


Positive feedback is rare in the Local Universe, but should be common in the Early Universe. However, direct observations of this mechanism in Early Universe remain elusive (e.g. LRDs).

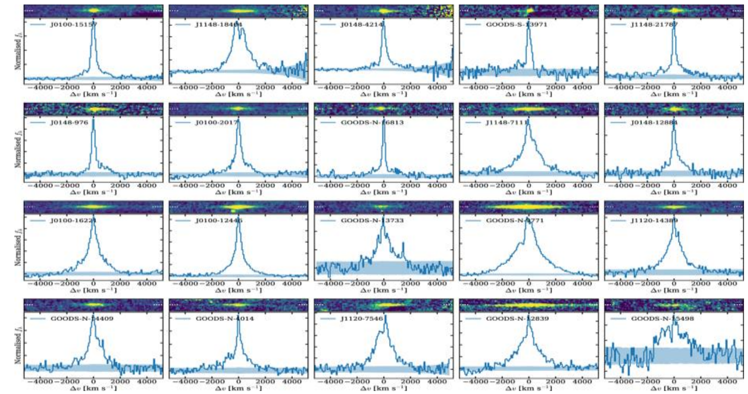
« Little Reed Dots » (LRDs) uncovered by JWST

Matthee+ 2024 now confirmed by new samples of LRDs at even higher redshifts found by several other teams

Very compact: r_e = 35pc – 150pc



Hα lines with FWHM>2000 km/s…from AGN?



LRDs

- Are very abundant at z = 4 – 10, by factors of 10-100 compared to the faint end of high-z AGN
- Have near-IR colours probably due to dust absorption
- BHs are over massive relative to stellar populations compared with Local Universe relations
- Large fractions have AGN with SMBHs of estimated $10^6 – 10^8$ $M_\odot$
- **Most LRDs are X-ray obscured as the BH in GRS 1915+105**

- **BH growth and Star Formation in Galaxies in the Early Universe is stochastic**

BHs in Microquasars may grow at high Eddington rates

GRS 1915+105: From the X-rays $N_H > 3 \times 10^{23}$ cm^{-2} (Miller+ 2019; …Motta+ 2023)

V404 Cygni: From X-rays $N_H = 1\text{–}3 \times 10^{24}$ cm^{-2} (Motta+ 2017)

Optical spectra: Hα, Hβ, HeI λ5876, λ6678, λ7065 with FWHMs ≥ 900 km s^{-1} with a Balmer decrement Hα/Hβ = 4.61 ± 0.62, the optical depth by gas and dust is very high (Rahoui+ 2016)

SMBHs in the Early Universe grow embedded in extreme gas densities

(Naidu+ 2025)

LRD BH*-1: z_{spec} = 7.7569+/-0.013

$N_H = 10^{25.8}$ cm^{-2} ; $n_H = 10^{11}$ cm^{-3}

but with a dust-free "atmosphere"

Positive BH feedback trigger the formation of first stars?