MICROQUSARS

Félix Mirabel

CEA-Saclay-France & Conicet-Argentina

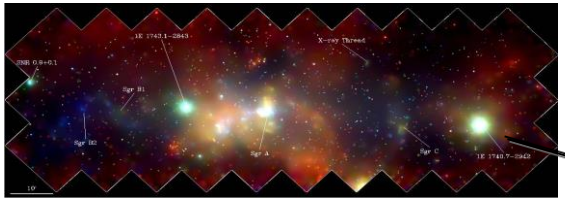
- **High energy astrophysics**
- **Cosmology (in cosmic re-ionization epoch)**
- **Gravitational wave astrophysics (in formation of StBHs)**

A "MICROQUASAR" AT THE GALACTIC CENTRE REGION

Mirabel, Rodríguez, et al. (1992)

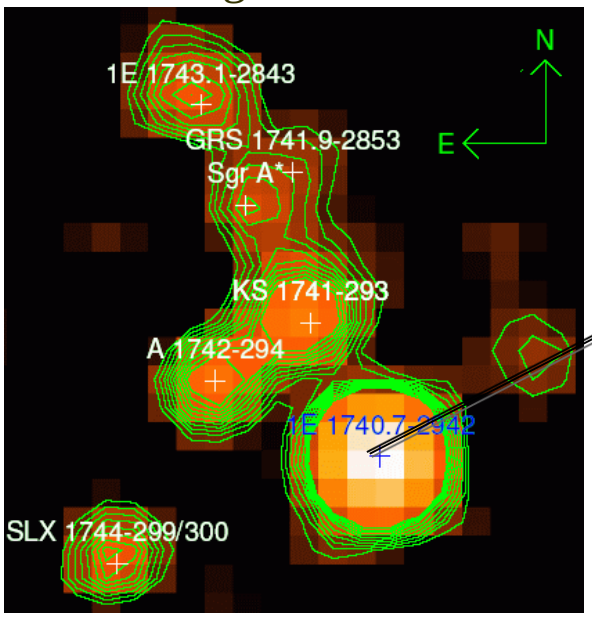
A multi-λ approach revealed the radio and IR counterparts…

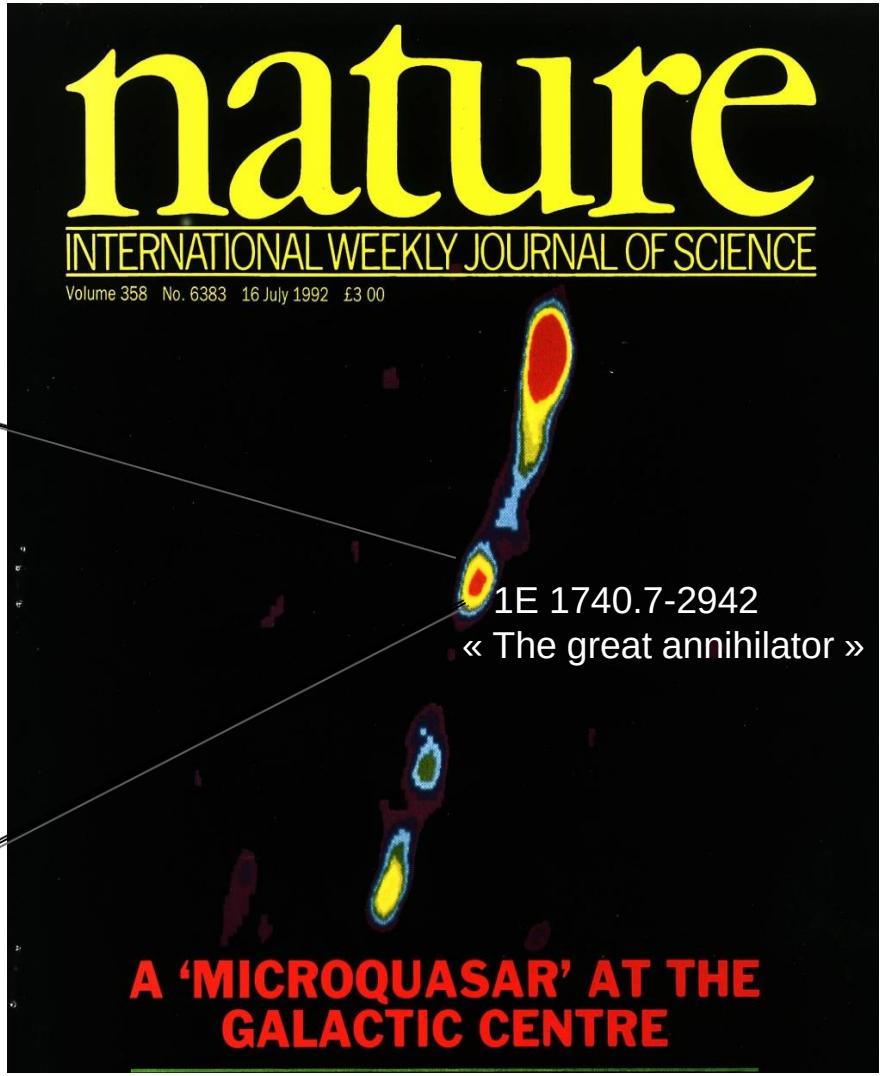
CHANDRA



Belanger et al. 2003

GRANAT..& INTEGRAL



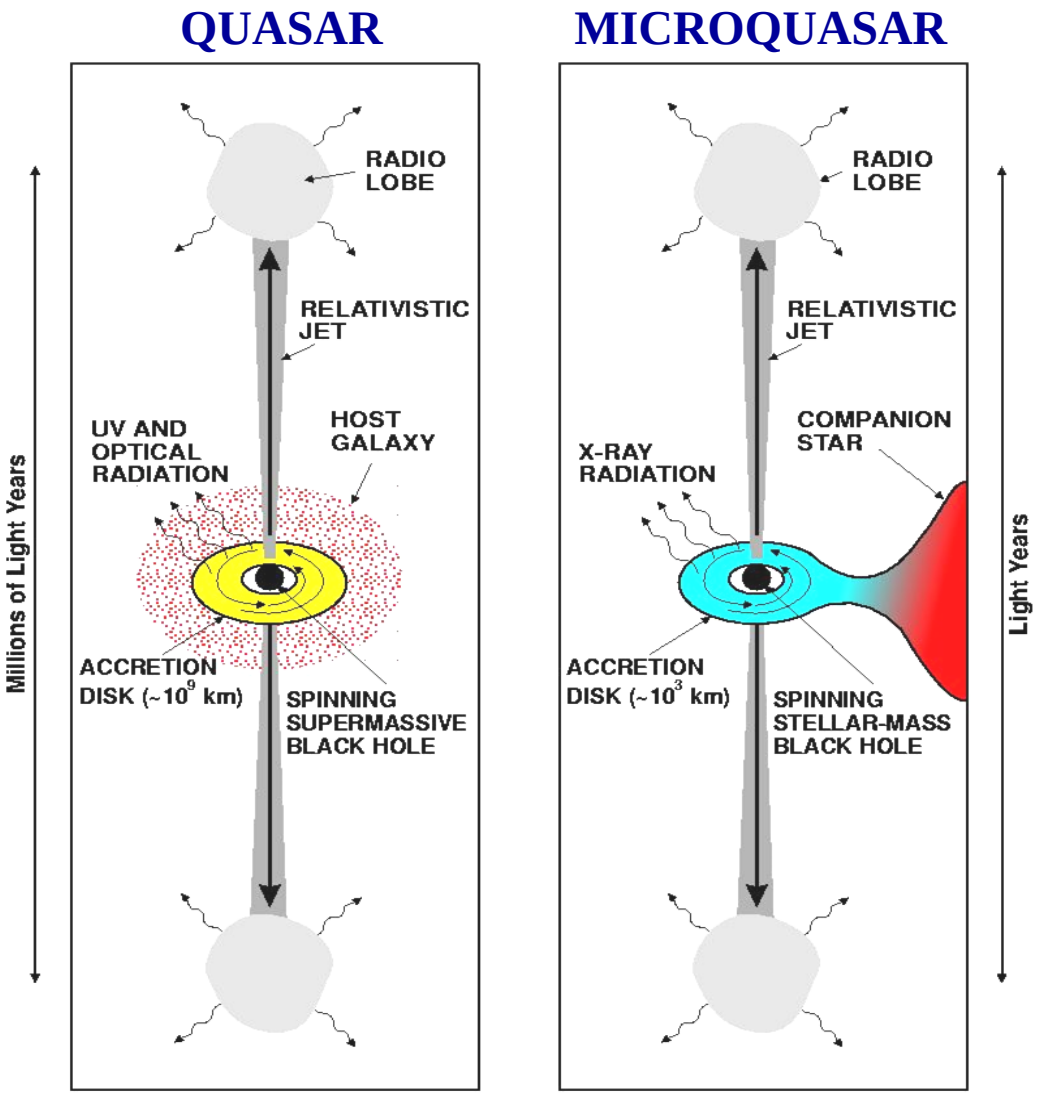


1E 1740.7-2942
« The great annihilator »

BH in a LMXB (Martí, Mirabel, Chaty 2000)

10 international meetings on μQSOs, including an IAU Symp.in BsAs (2010)

QUASAR-MICROQUASAR ANALOGY



Mirabel & Rodríguez (Nature 1998)

The scales of length and time are proportional to M_{BH}

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

Unique system of equations:

The maximum color temperature of the accretion disk is:

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

(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 2004)

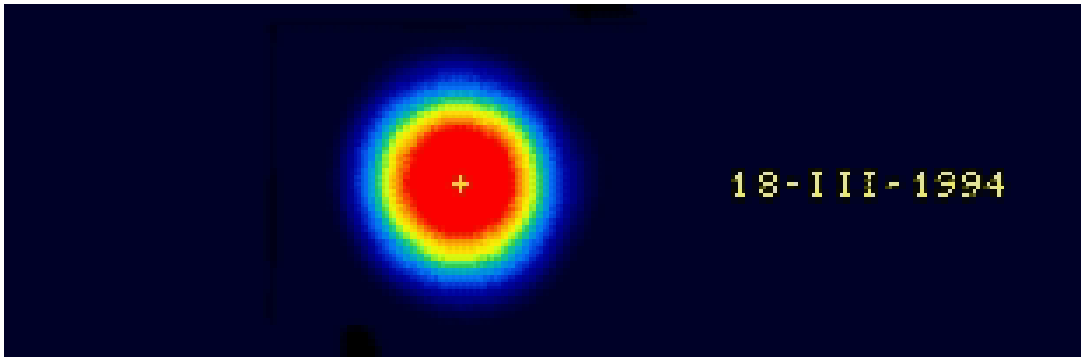
Could analogous apparent superluminal motions at those found in QSOs & Radio Galaxies also be observed in μQSOs?

SUPERLUMINAL EJECTION IN A μQSO

- GRS 1915+105 (discovered with GRANAT Sunyaev+ 1993)
- 0.5 $M_\odot$ red giant orbiting a 10 $M_\odot$ BH (Greiner+ Nature 2000)

Luis F. Rodríguez

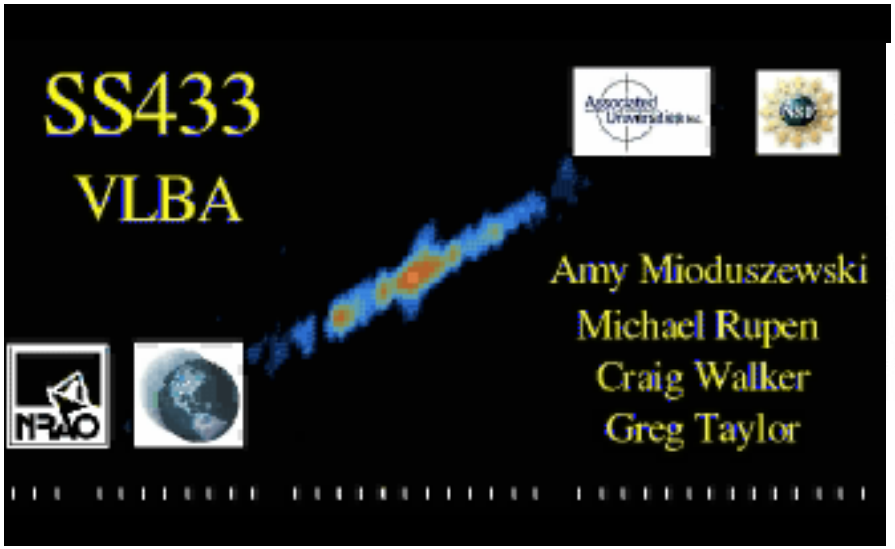
1 arcsec



Mirabel & Rodríguez, 1994

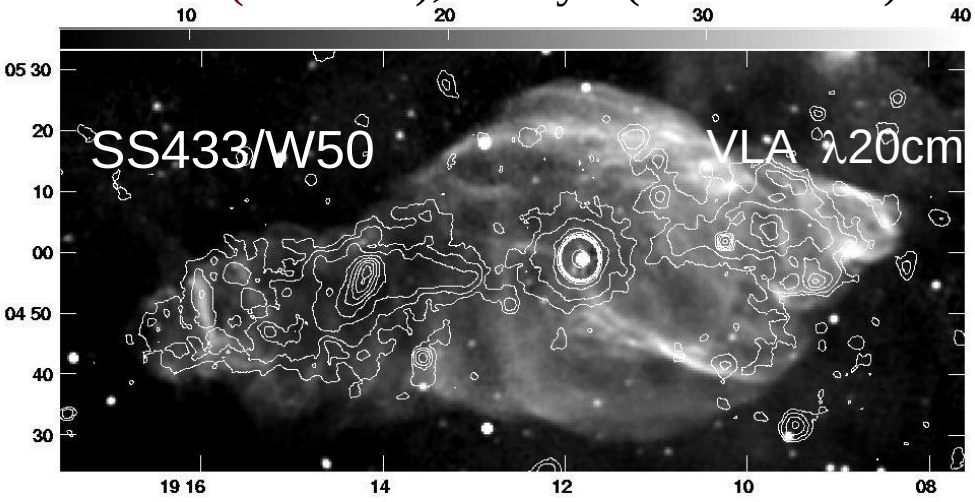
- V_{app} > C Jets have apparent superluminal motions
- K_{ejecta} = 3x10^{46} erg = 1/3 M_{Moon} at 0.95c assuming 1 p^+/e^- and γ_{int} of e^- = 10^3
- Jet at 70˚ of line of sight. No detection at HE (.1-10 GeV) & VHE (.1-100 TeV)

POWERFUL DARK JETS FROM BLACK HOLES



1arcsec

Radio (Dubner+); X-rays: (Brinkmann+)

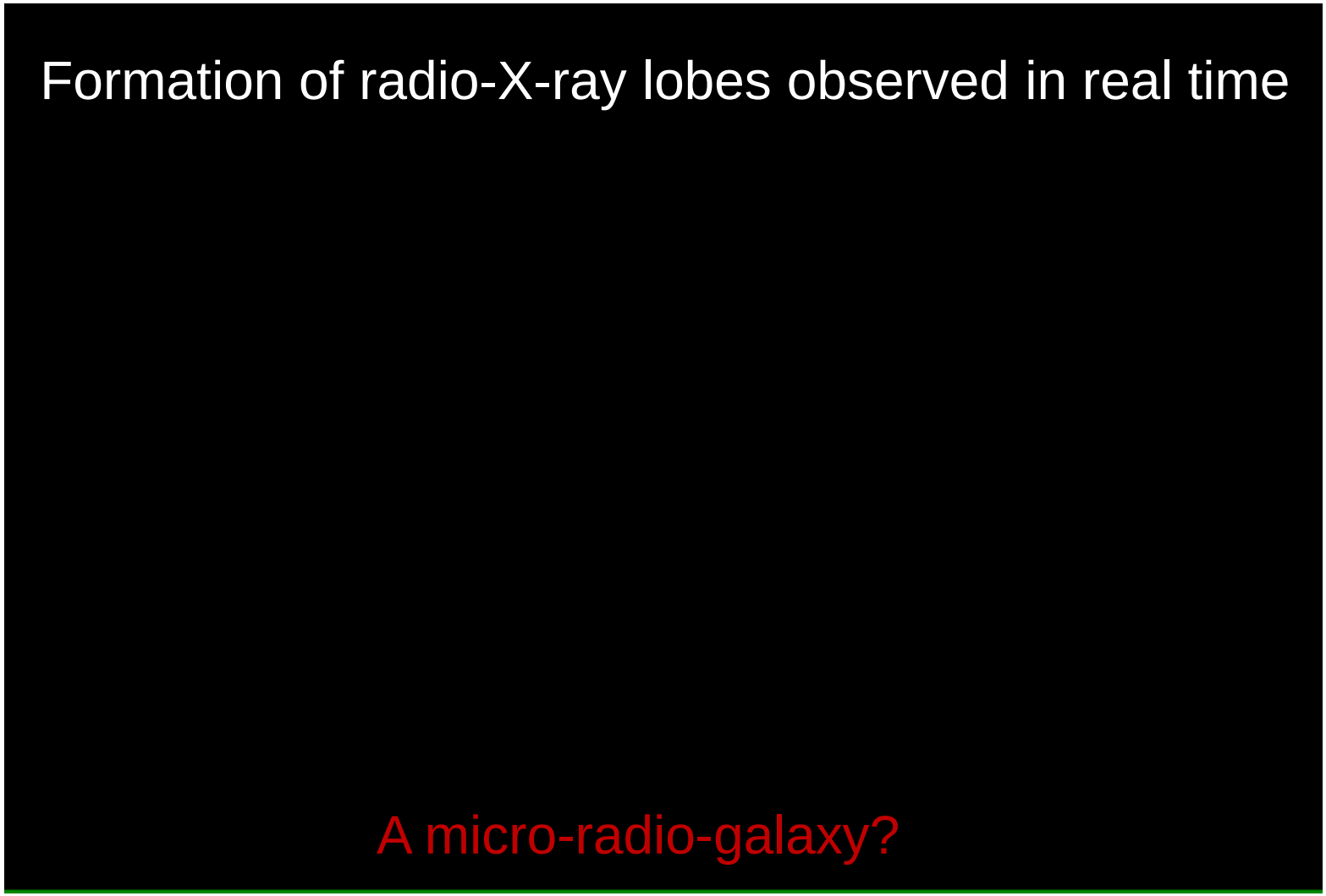


1º = 60 pc

- Atomic nuclei moving at 0.26c ⇒ Lmech > 10^{39} erg/sec
- Non radiative jets (>50% of energy is not radiated ⇒ **"DARK JETS"**
- Fermi detects a maximum @ 250 MeV with extension up to 800 MeV (Bordas+ 2015)
- HAWC detects VHE emission from the lobes (Sandoval+ 2018)
- MAGIC placed constraints on the particle acceleration fraction at the inner jet regions and on the physics of the jet/medium interactions. (Ahnen+ 2017)

MOVING X-RAY JETS IN μQSOs

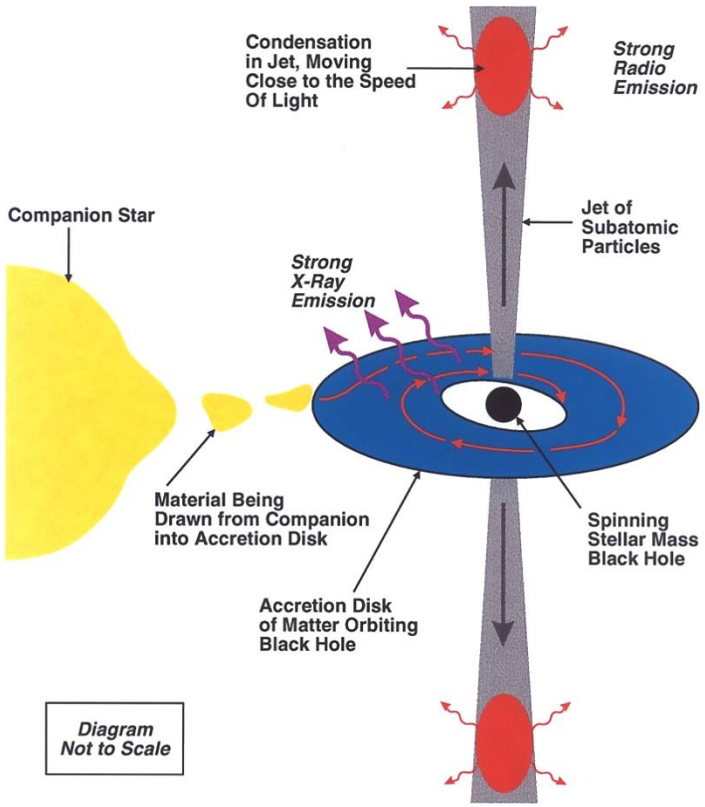
μQSOs XTE J1550-564 & H1743–322 (Corbel+ Science 2002, 2005)



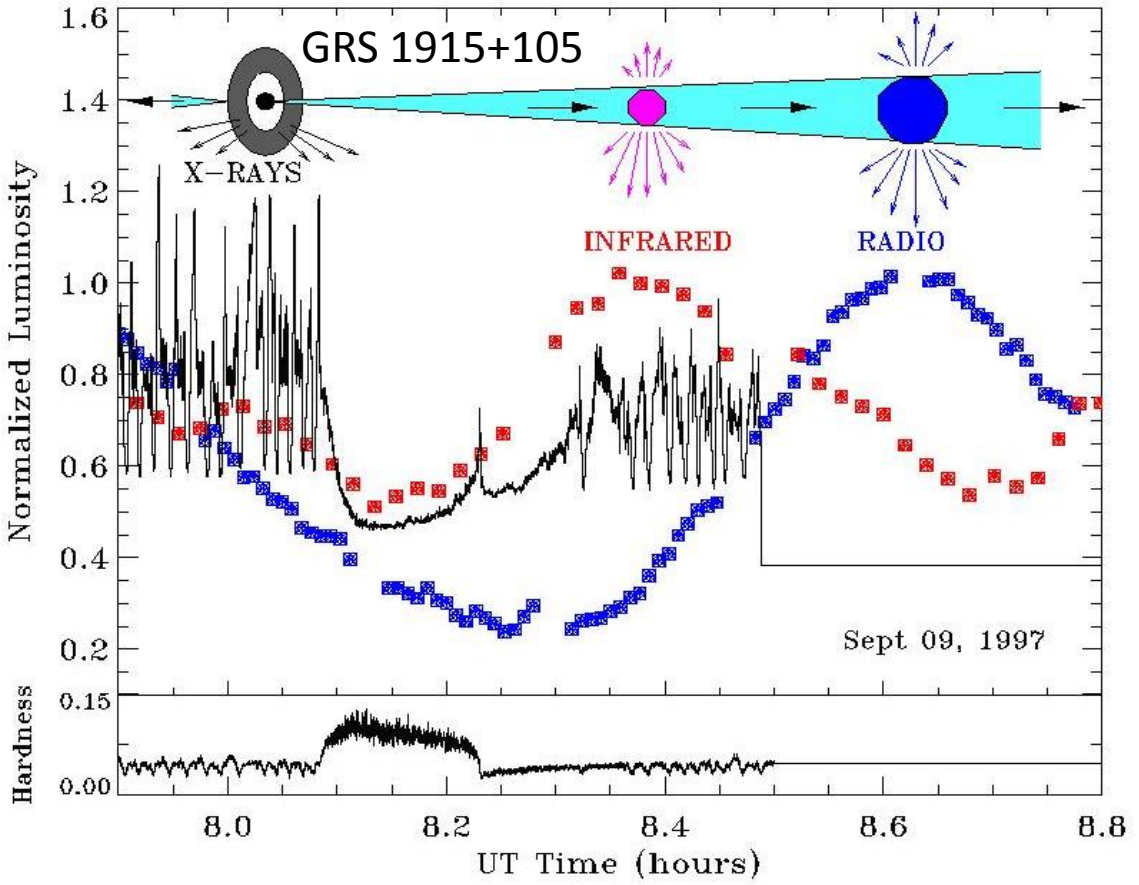
X-rays are produced by synchrotron ⇒ electrons accelerated to TeV energies

ACCRETION – JET CONNECTION

$\Delta T \propto M_{BH}$



Mirabel+ (Nature 1998)



- DROP OF X-RAYS⇒MATTER MAY GO THROUGH THE HORIZON OF BH
- AFTER 5m A SPIKE MARKS THE ONSET OF A JET SEEN IN THE IR…

NO BURST ⇒ COMPACT OBJECT WITH NO MATERIAL SURFACE

DISK-JET COUPLING IN BLACK HOLES

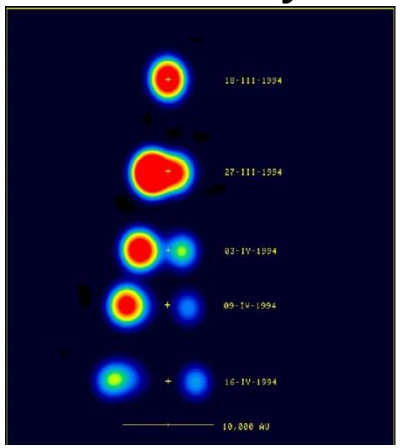
Transition between radiative efficient/radiative inefficient accretion

Fender, Belloni & Gallo (2006)

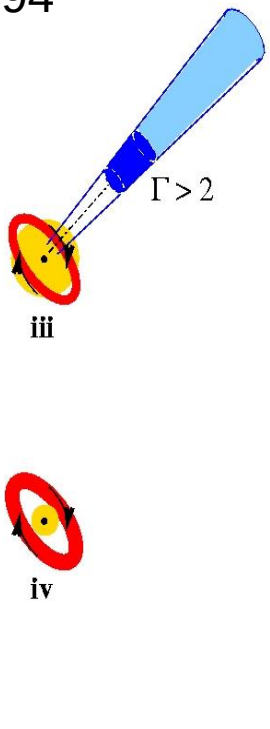
Outburst with rapid transition from hard to soft X-ray state

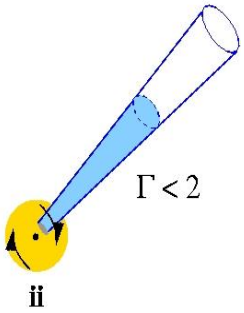
Mirabel & Rodríguez 1994

Soft X-rays



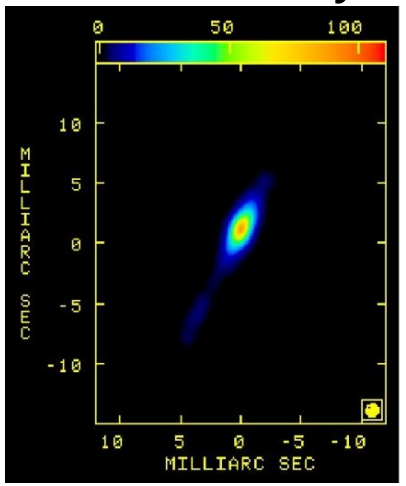
Transient, optically thin radio jets: $\Gamma > 2$





Mirabel+ 2005

Low-hard X-rays



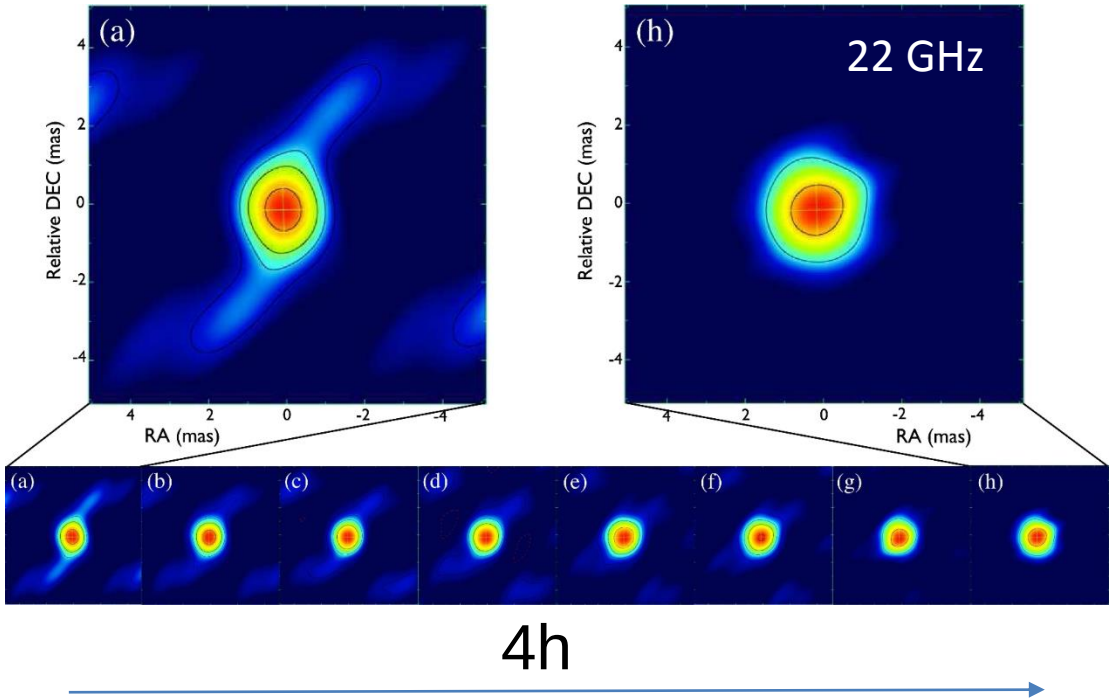
Persistent, flat spectrum radio source: $\Gamma < 2$

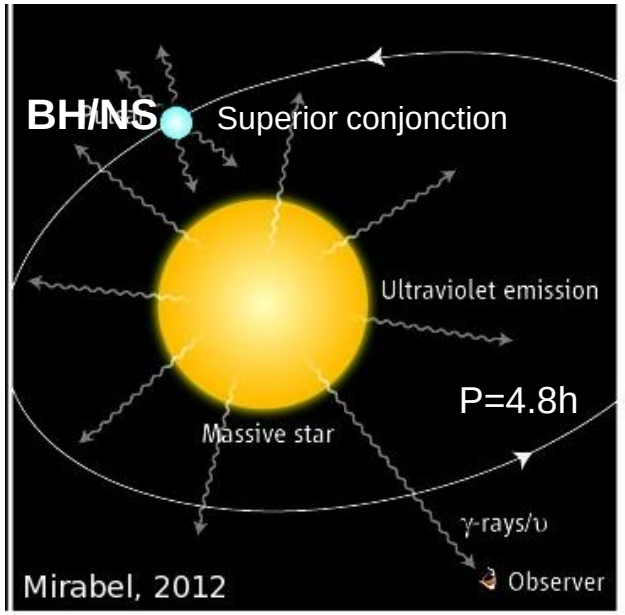
- Are the transient radio jets produced by internal shocks? (as in GRBs?)
- Disk-jet coupling also observed in QSOs (e.g. 3C 120 Marscher+ Nature 2002)

γ-RAY FLARES FROM THE μQSO Cyg X-3

Detected by **FERMI & AGILE** when the compact source is behind the WR star

Egron et al. (2018, EVLBI)





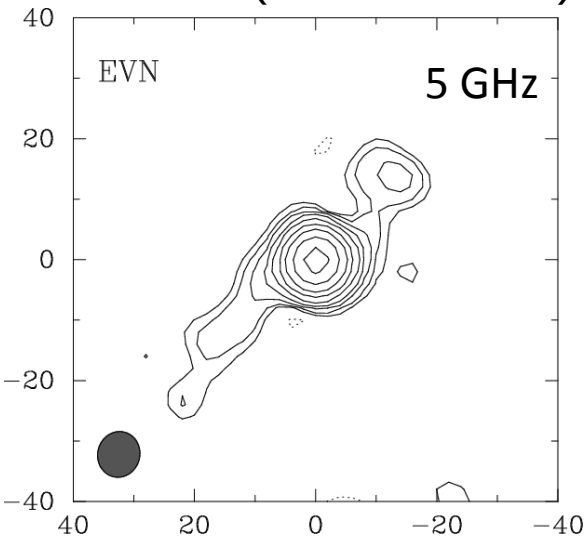
- γ–rays **produced by inverse Compton on stellar UVs or by hadronic interactions, modulated with the orbital motion and geometry respect to the observer.**

- **The non-detection by MAGIC is probably due to absorption in the inner region of the binary (Aleksi´c+ 2010).**

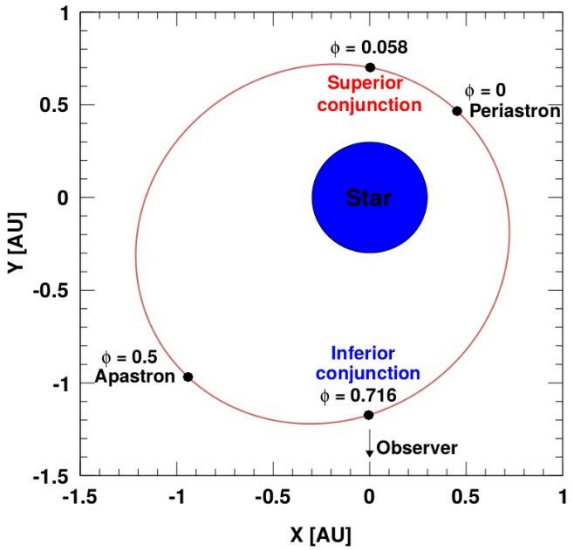
LS 5039

First “μQSQ” detected by EGRET (Paredes+ 2000) & HESS (Maraud+ 2015)

Paredes+ (Science 2000)



Maraud+ 2015



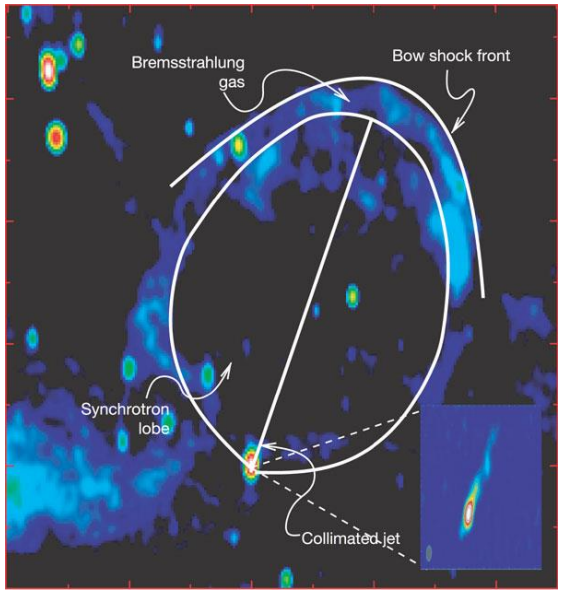
- A BH? of 3.7 ± 0.3 $M_\odot$ orbiting a 23 ± 3 $M_\odot$ star with a P~4d (Casares+ 2005)

- The X-ray and very-high-energy (VHE, > 100 GeV) fluxes display a maximum/minimum at inferior/superior conjunction, with spectra becoming respectively harder/softer, **a behavior that is completely reversed in the high-energy domain (HE, 0.1 < E < 100 GeV)…**(Maraud+ 2015)

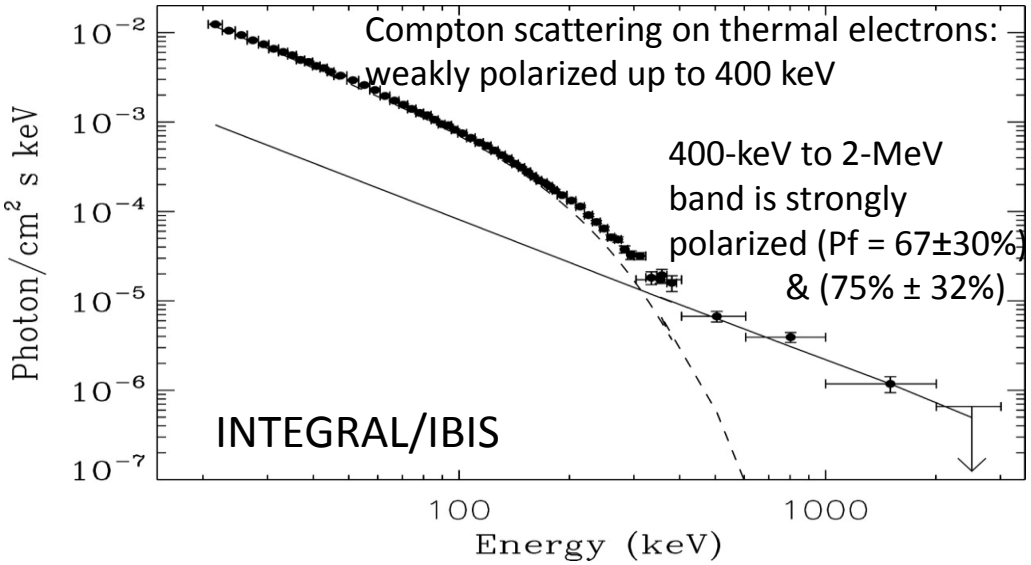
- The GeV and TeV (0.1-10^4 GeV) emission may be produced in different regions and/or by separate particle populations and physical mechanisms (Maraud+ 2015)

Dark jet dominates the power output in the "radio quiet" μQSO Cygnus X-1

Gallo et al. (Nature 2005)



Laurent+ (Science 2011) & Rodriguez+ (2015)

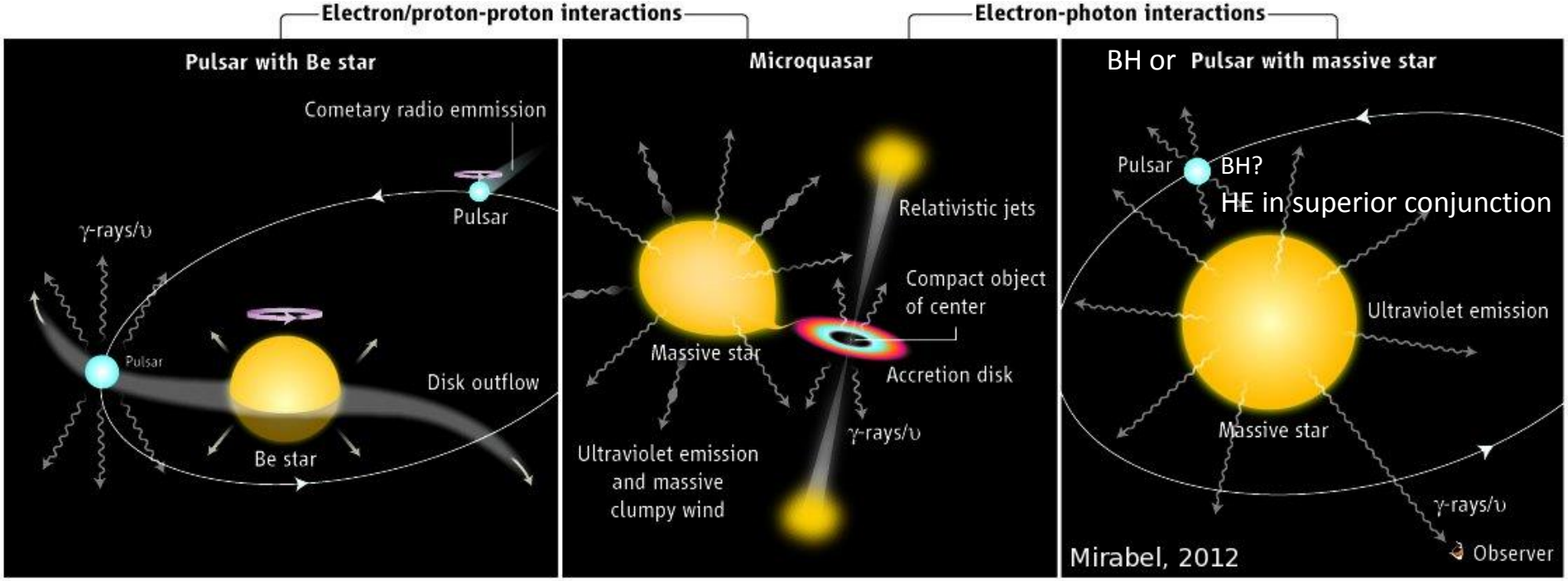


- One-sided compact jet in the low-hard X-ray state & a ring structure of 5 pc in diameter
- Cygnus X-1 dissipates the bulk of the accretion power in the form of 'dark', radioactively inefficient relativistic outflows, rather than locally in the X-ray emitting inflow.
- A MAGIC "hint" at 4.1σ coincident with flares detected by *INTEGRAL*, *Swift*/BAT and *RXTE*-ASM (Albert+2007), was not observed in more extensive observations (Ahnen+ 2017)
- The 400-keV to 2-MeV emission is synchrotron or inverse Compton emission from the jet.

COMPACT GAMMA-RAY BINARIES

Perspectives in Science (Mirabel 2006 & 2012)

HE, E>100 MeV & VHE, E>100 GeV PRODUCED BY LEPTONIC OR HADRONIC INTERACTIONS



Name	γ-ray s	Sp Type
PSR B1259-63	HE, VHE	O9.5Ve
AGL J2241+4454	HE ?	B3 IV ne+sh
HESS J0632+057	VHE	B0 Vpe
LS I+61 (BH/NS?)	HE, VHE	B0 Ve

Name	γ-ray s	Sp Type
Cyg X-3	HE	WNE([2,5])
in superior conjunction		
Cyg X-1	HE?, VHE?	O7 V

Name	γ-ray s	Sp Type
LS 5039	HE, VHE	O6.5 V((f))
1FGL J1018	HE, VHE?	O6 V((f))

- **MOST γ-RAY BINARIES ARE NSs AND BHs ORBITING MASSIVE STARS**
- **NOW THE PICTURE IS BECOMING MORE DIVERSE…**

CONCLUSION

MOST μQSOs HAVE BEEN DETECTED AS γ–RAY SOURCES WHEN:

1) They are sources of powerful radio jets

2) The compact object often has a high-mass donor star with dense winds and/or strong radiation fields, Fermi & Integral detected HE in V404 Cyg

3) The compact object typically is near superior conjunction (not in LS 5039!)

4) The jet inclination angle relative to the line of sight is small (not in SS 433!)

5) HE and VHE emission may arise in the inner jet region or in external shock regions by leptonic and/or hadronic mechanisms

6) Do μblazar events take place in the MW? (e.g. V404 Cyg & V4641 Sgr)

7) Could very high energy neutrinos be detected from μblazars?

HE = 100 MeV -10 GeV; VHE = 100 GeV - 100 TeV