FORMATION OF STELLAR BLACK HOLES

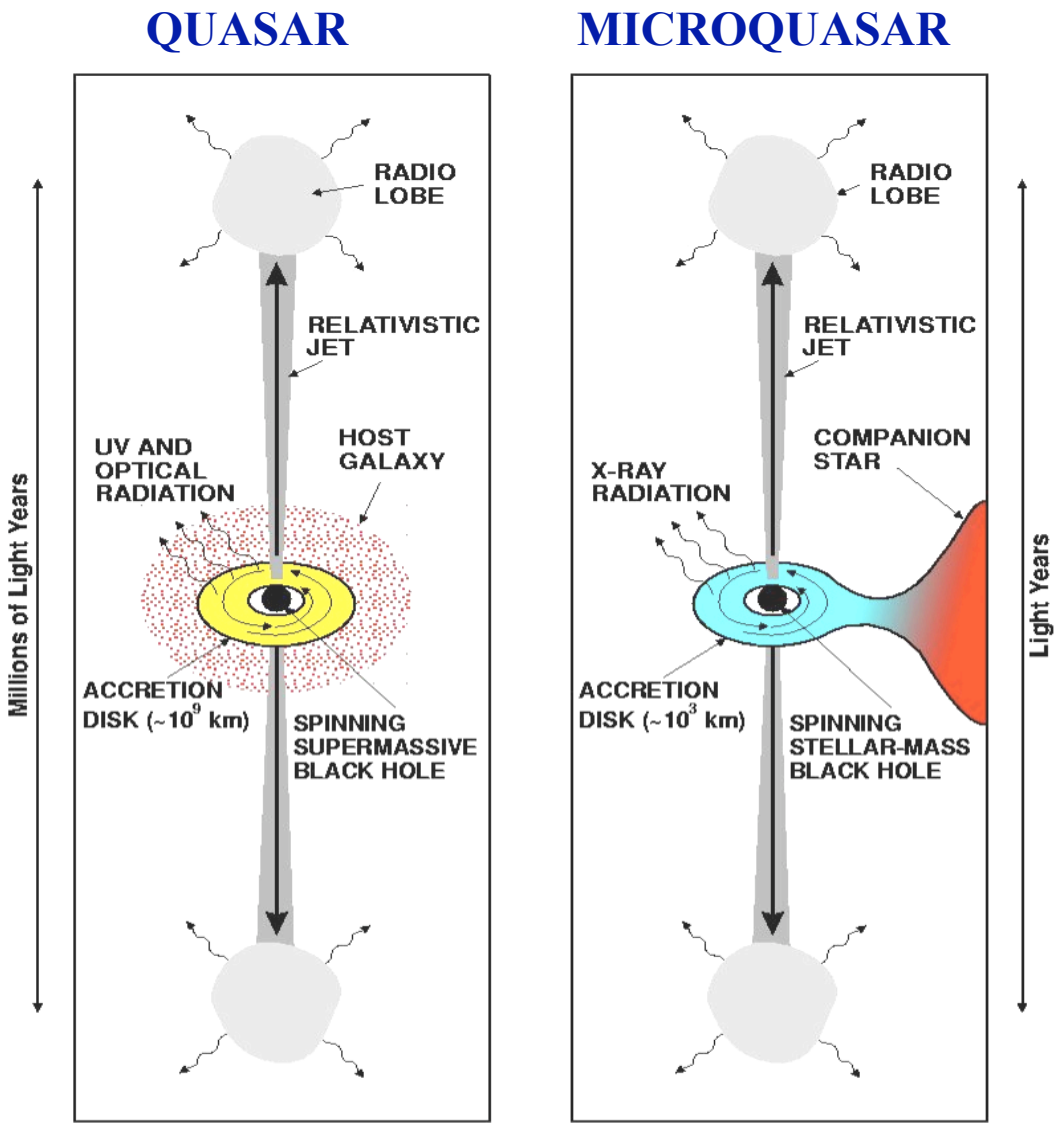
&

ACCRETION - JET COUPLING

Félix Mirabel

CEA – Saclay (France) & Conicet (Argentina)

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)

Waited era of space astronomy

For a given accretion rate:

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

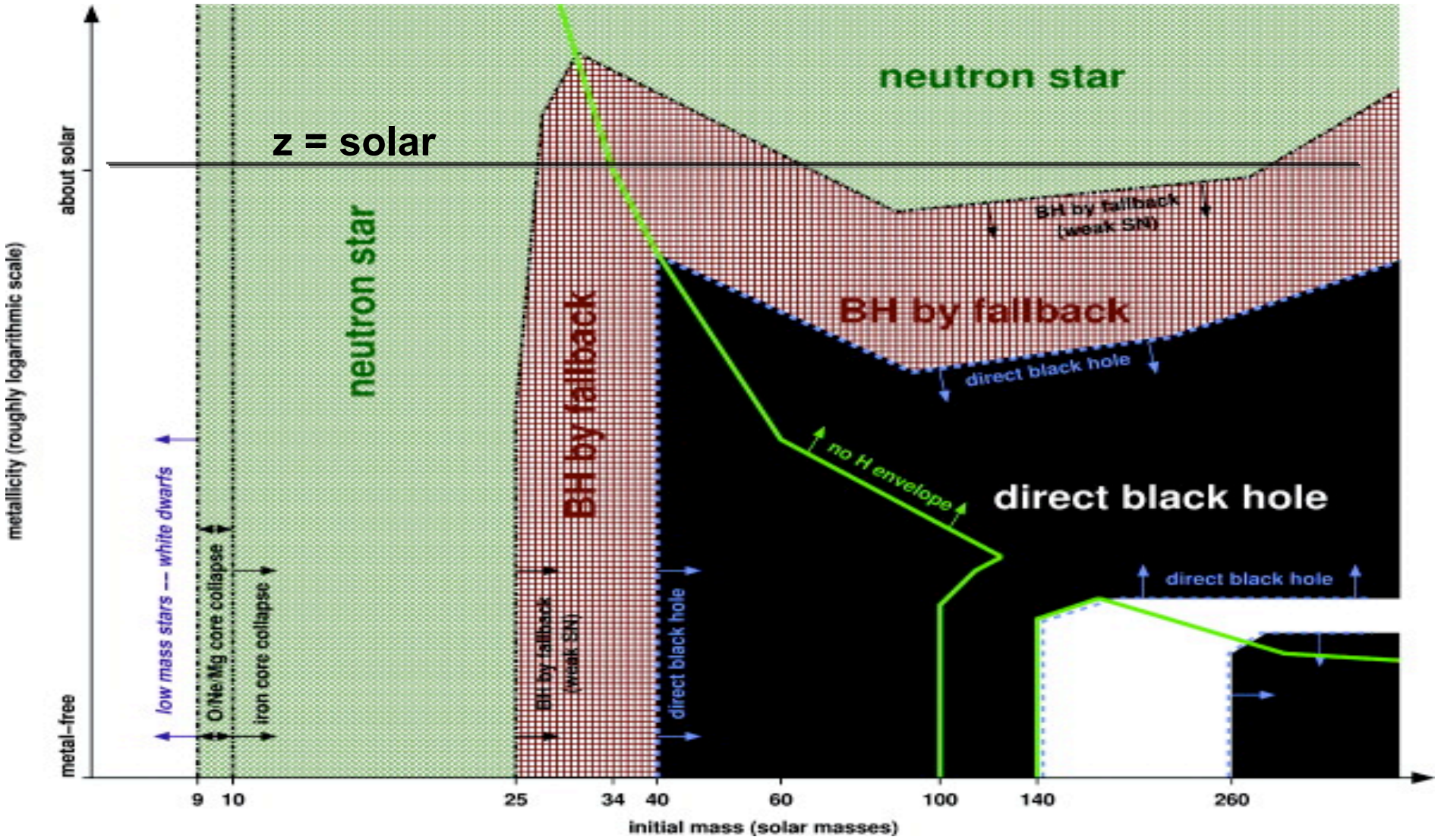
$$\varphi \; \alpha \; M_{BH}^{-1} \; ; \; B \; \alpha \; M_{BH}^{-1/2}$$

(Sams, Eckart, Sunyaev, 96; Rees 04)

SIMILAR PHYSICS CLOSE TO THE BHs ON FORMATION, GROWTH & FEEDBACK

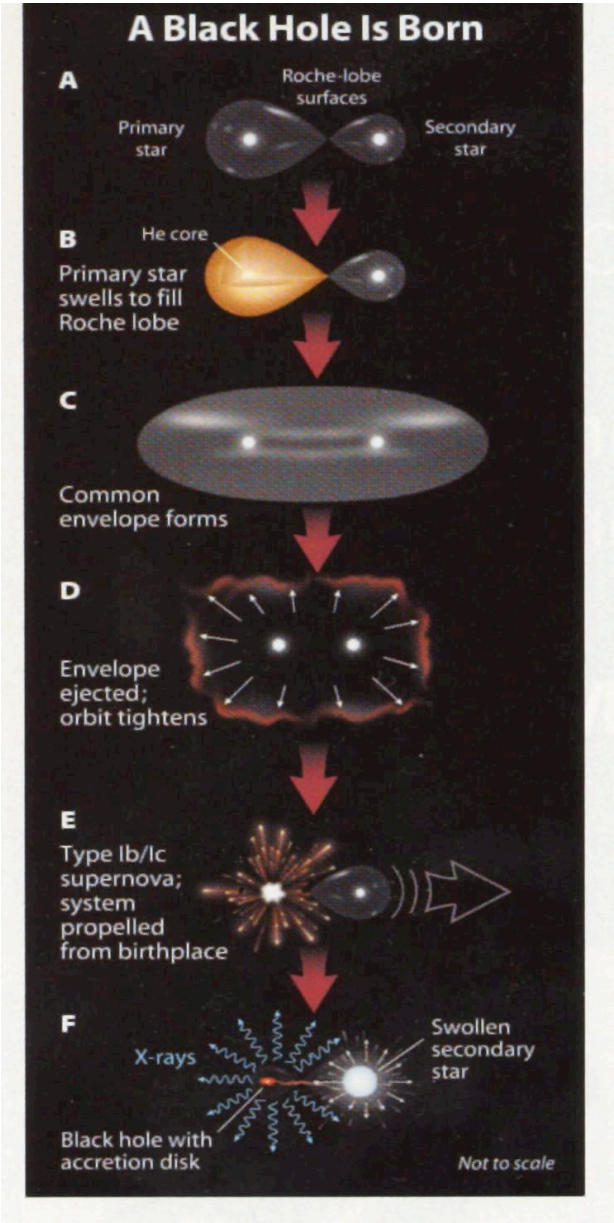
FORMATION OF STELLAR BLACK HOLES

Heger et al. (2003)



BHs also form directly in models that include rotation & binarity

THE KINEMATICS OF μQSOs ⇒ BLACK HOLES MAY FORM WITH NO ENERGETIC SNe



Mirabel & Irapuan Rodrigues (2001-2009)

Used their kinematics to test whether stellar black holes may form directly

IF THE BH BINARIES HAVE NO ANOMALOUS MOTIONS THEY MUST HAVE BEEN FORM WITH NO ENERGETIC SNe KICKS

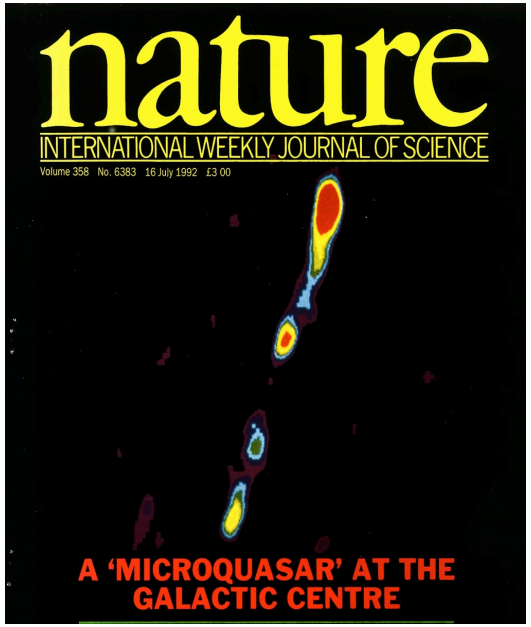
SO FAR WAS DETERMINED THE SPACE VELOCITY (KINEMATICS) OF 5 BHXRBs WITH 5-14 $M_\odot$

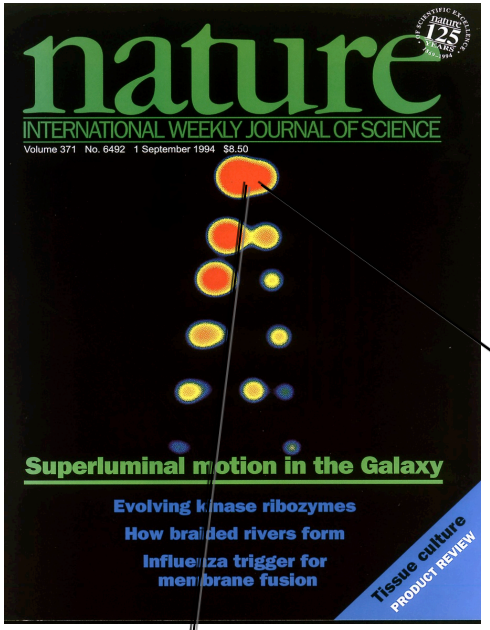
JETS IN MICROQUASARS

Mirabel et al. (1992)

Mirabel & Rodríguez (1994)

STEADY JETS





TRANSIENT JETS

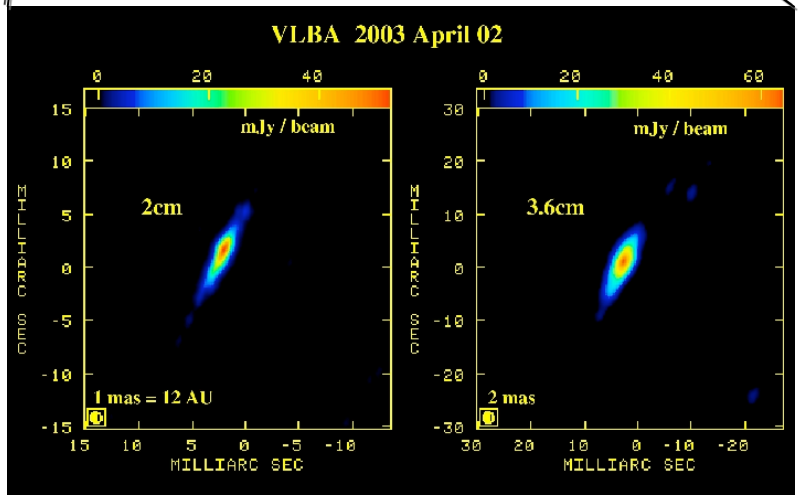
COMPACT JETS

In low hard state. Size ~ 100 AU. Same PA

USED TO DETERMINE PROPER MOTIONS

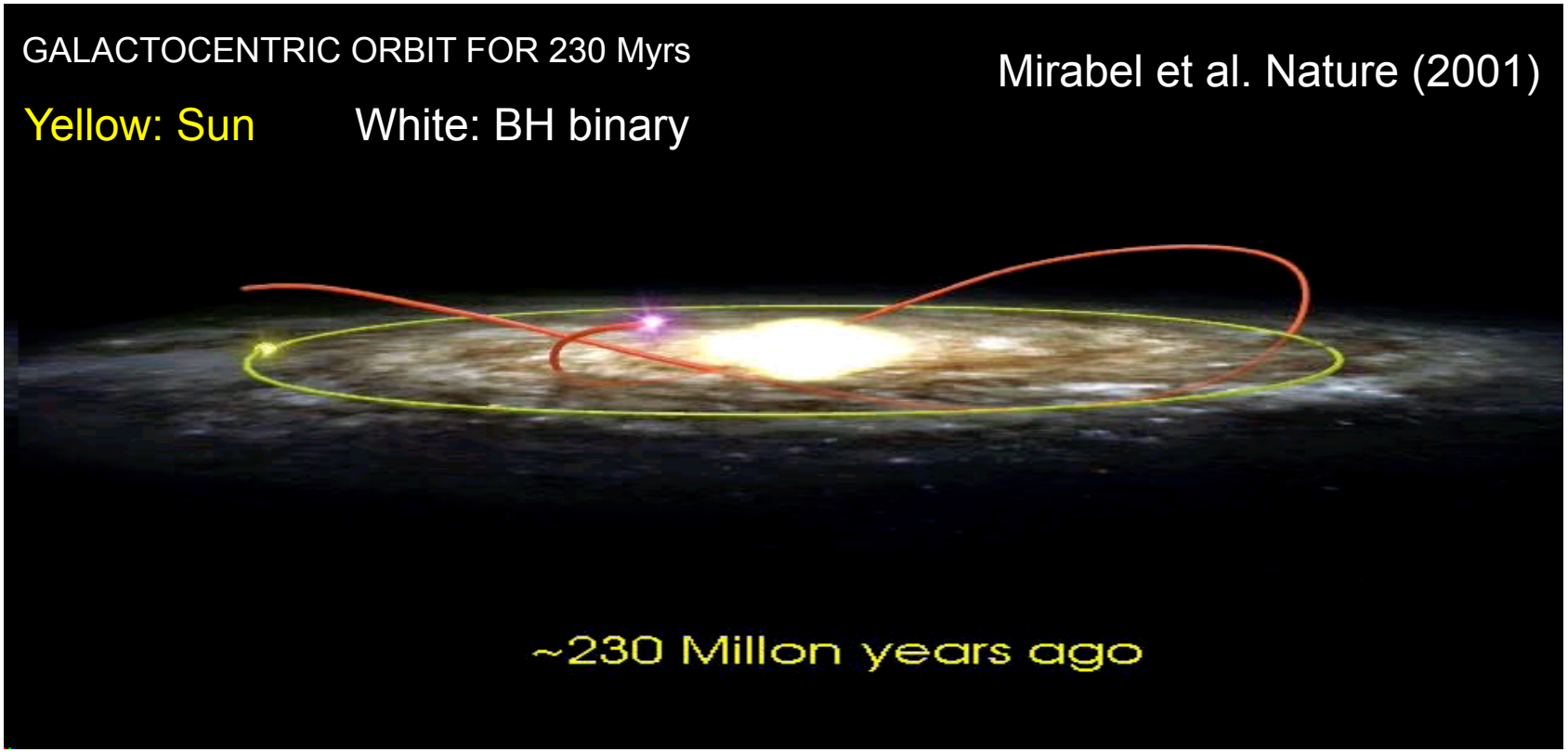
(with VLBI to get sub-miliarc sec precision)

Dhawan,Mirabel,Rodríguez (2007)



TWO RUNAWAY BLACK HOLES

XTE J1118+480 M_{BH}~ 6 $M_\odot$ M_*~0.4 $M_\odot$ kpc; Vp=145-210 km/s

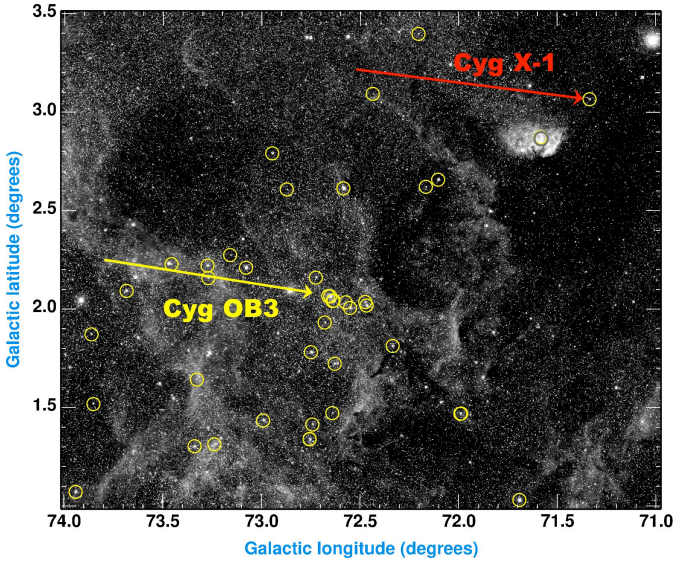


GRO J1655-40: Fossil of a HPN (Israelian et al. Nature 1999)

M_{BH} ~ 5 $M_\odot$ M_*~2 $M_\odot$;D=1-3 kpc; V_p=112+/-18 km/s (Mirabel et al. 2002)

THE TWO BHs WITH 5-6 $M_\odot$ EJECTED FROM THEIR BIRTH PLACE (BY NATAL SNe ?)

BHs WITH > 10 $M_\odot$ FORM DIRECTLY



Mirabel & Rodrigues (Science, 2003)

Cyg X-1

Vp < 9 +/- 2 km/s ⇒ < 1 $M_\odot$ ejected in SN

Otherwise it would have been shot out from the parent stellar association

GRS 1915+105

(Dhawan, Mirabel & Rodríguez, 2001)

M_{BH} ~ 14+/-4 M⊙; M*~1.2 $M_\odot$; D=9+/-2 kpc: **Vp= 50-80 km/s & W = 7+/-3 km/s**

V404 Cyg

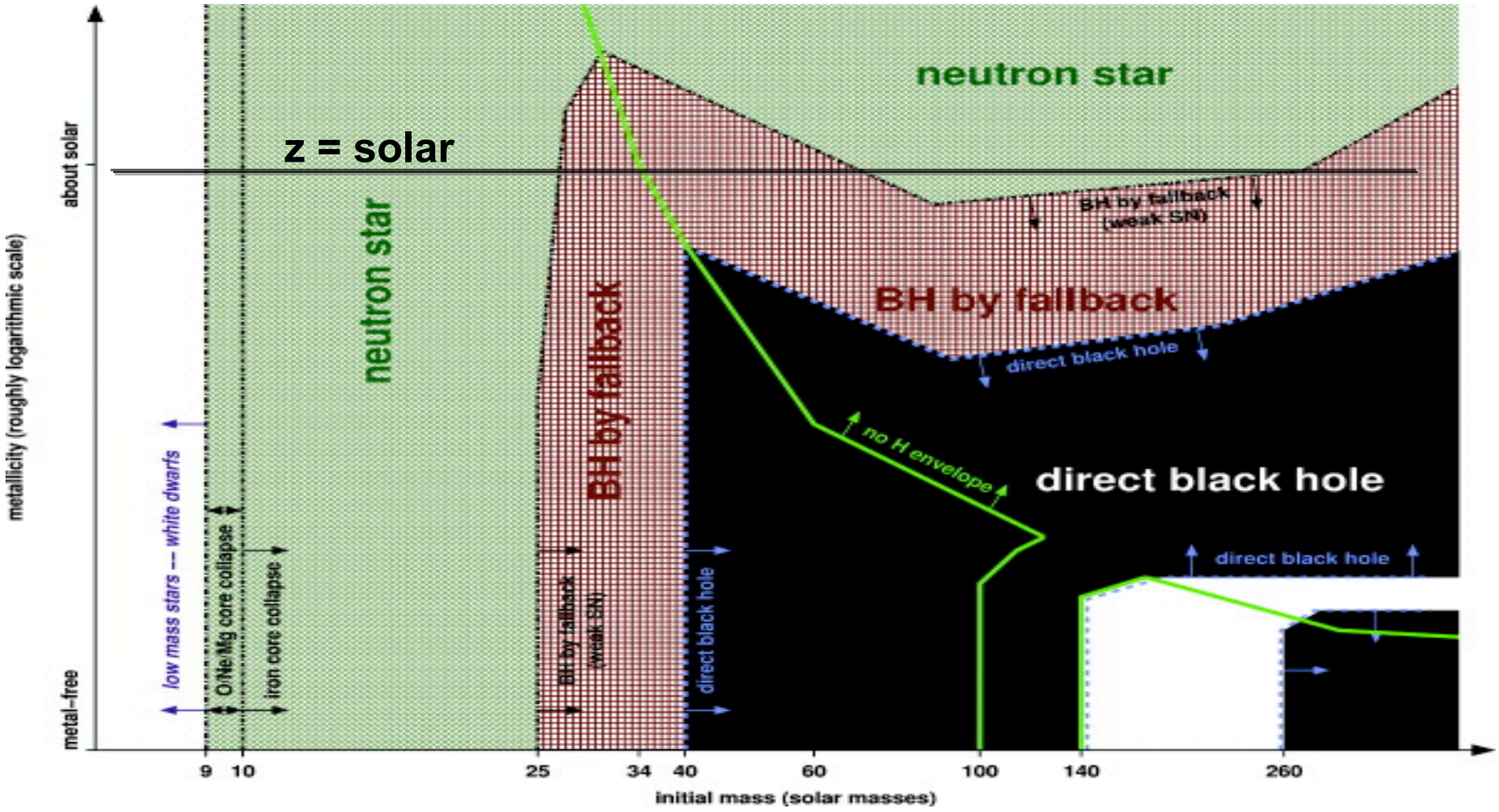
(Miller-Jones, Jonker, Nelemans et al., 2009)

M_{BH}~12+/-2 $M_\odot$; M*~0.7 $M_\odot$; D=4+/-2 kpc: **Vp= 45-100 km/s & W = 0.2+/-3 km/s**

BHs with M_{BH} < 7 $M_\odot$ form with natal SNe; by implosion if M_{BH} > 10 $M_\odot$

FORMATION OF STELLAR BLACK HOLES

Heger, Wosley, et al. (2003)

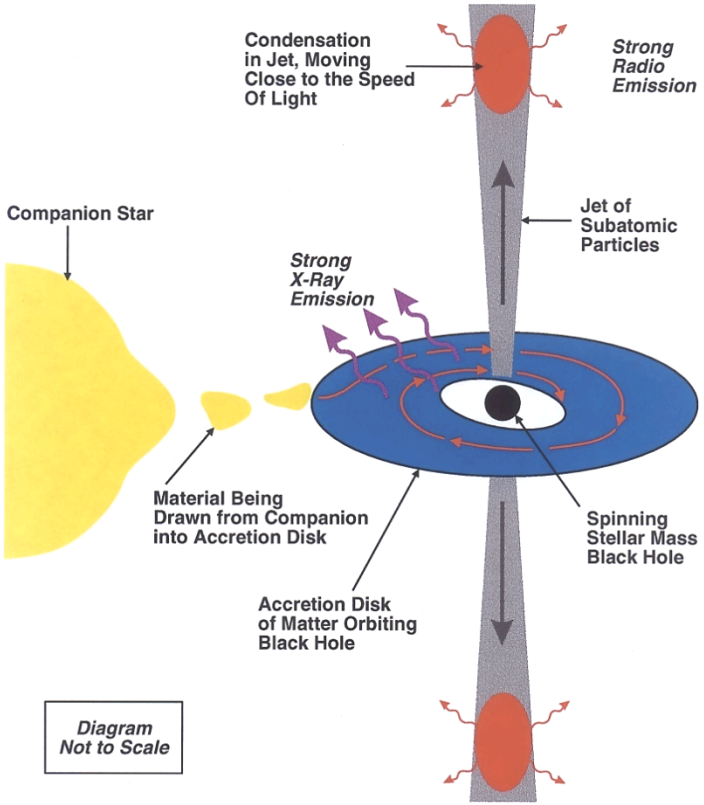


Cosmological implications (Power+ 2009;Mirabel+ 2010)

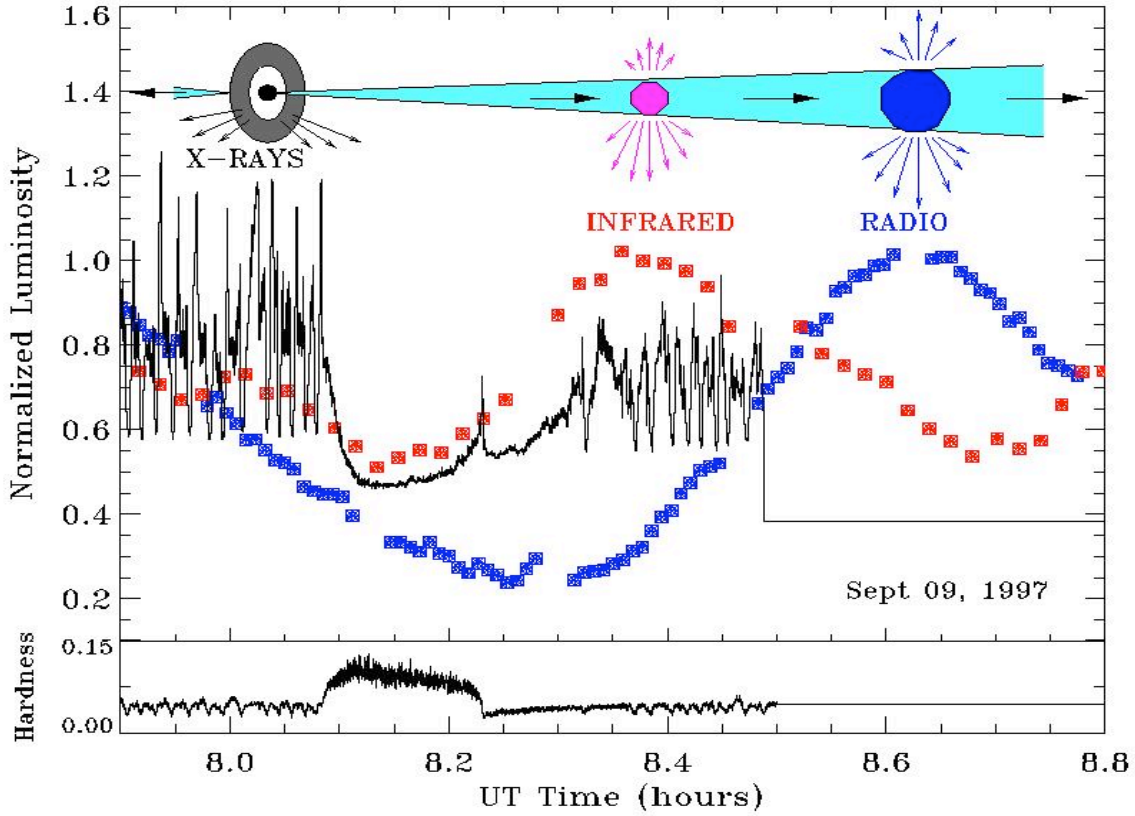
ACCRETION-JET COUPLING IN STELLAR BLACK HOLES

$\Delta T \propto M_{BH}$

1 hr = 30 yr in SgrA*



GRS 1915+ 105 (Mirabel et al. 1998)



- **THE X-RAY RADIATING PLASMA DISAPPEARS ⇒ ACCRETION ON BH ?**
- **SAME TIME DELAYS IN PLASMA EJECTED FROM Sgr A*** (Yusef-Zadeh)
- **ANALOGOUS X-RAY/RADIO COUPLING IN 3C 120** (Marscher+ Nature 2004)

UNIVERSAL DISK-JET COUPLING IN BLACK HOLES

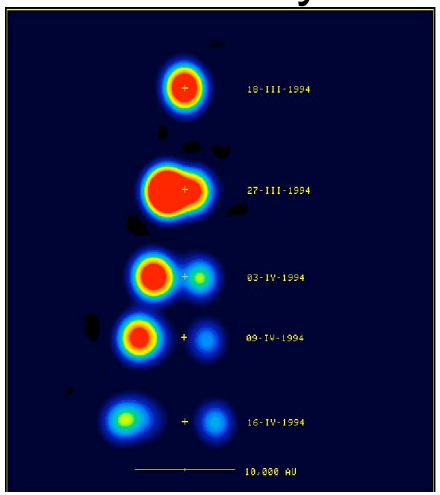
Fender, Belloni & Gallo (2006)

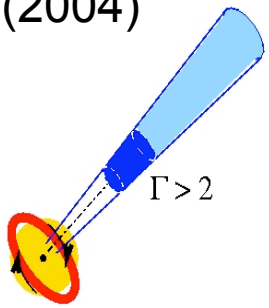
Outburst with rapid transition from hard to soft X-ray state

GRS 1915+105

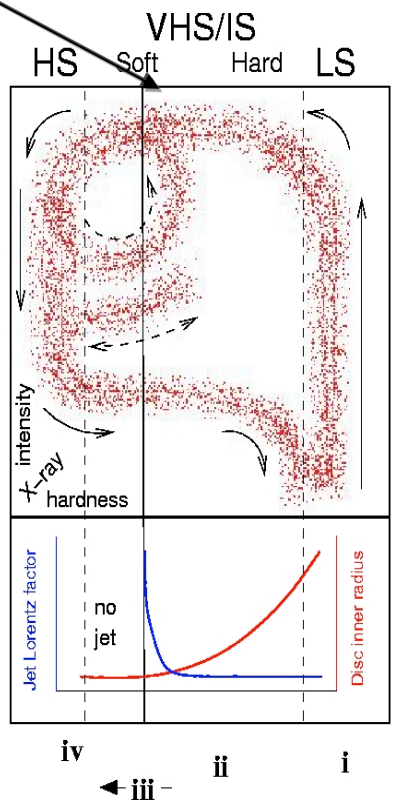
Mirabel & Rodríguez (2004)

Soft X-rays

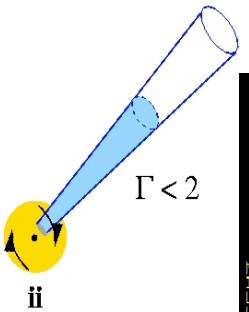


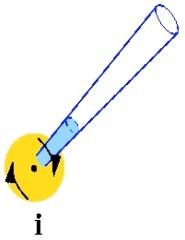


Transient, optically thin radio jets: $\Gamma > 2$

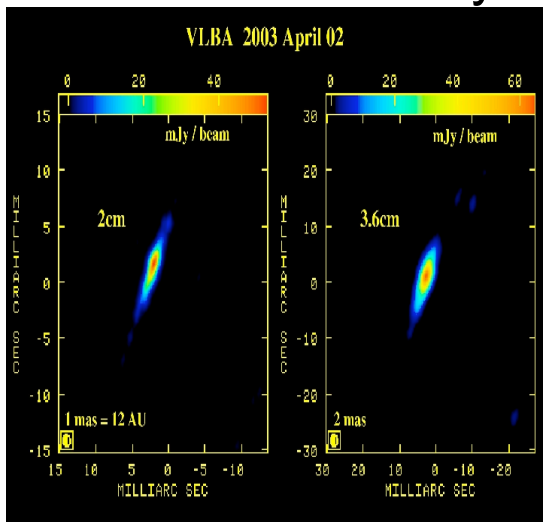


Dhawan,Mirabel,Rodríguez (2005)





Low-hard X-rays

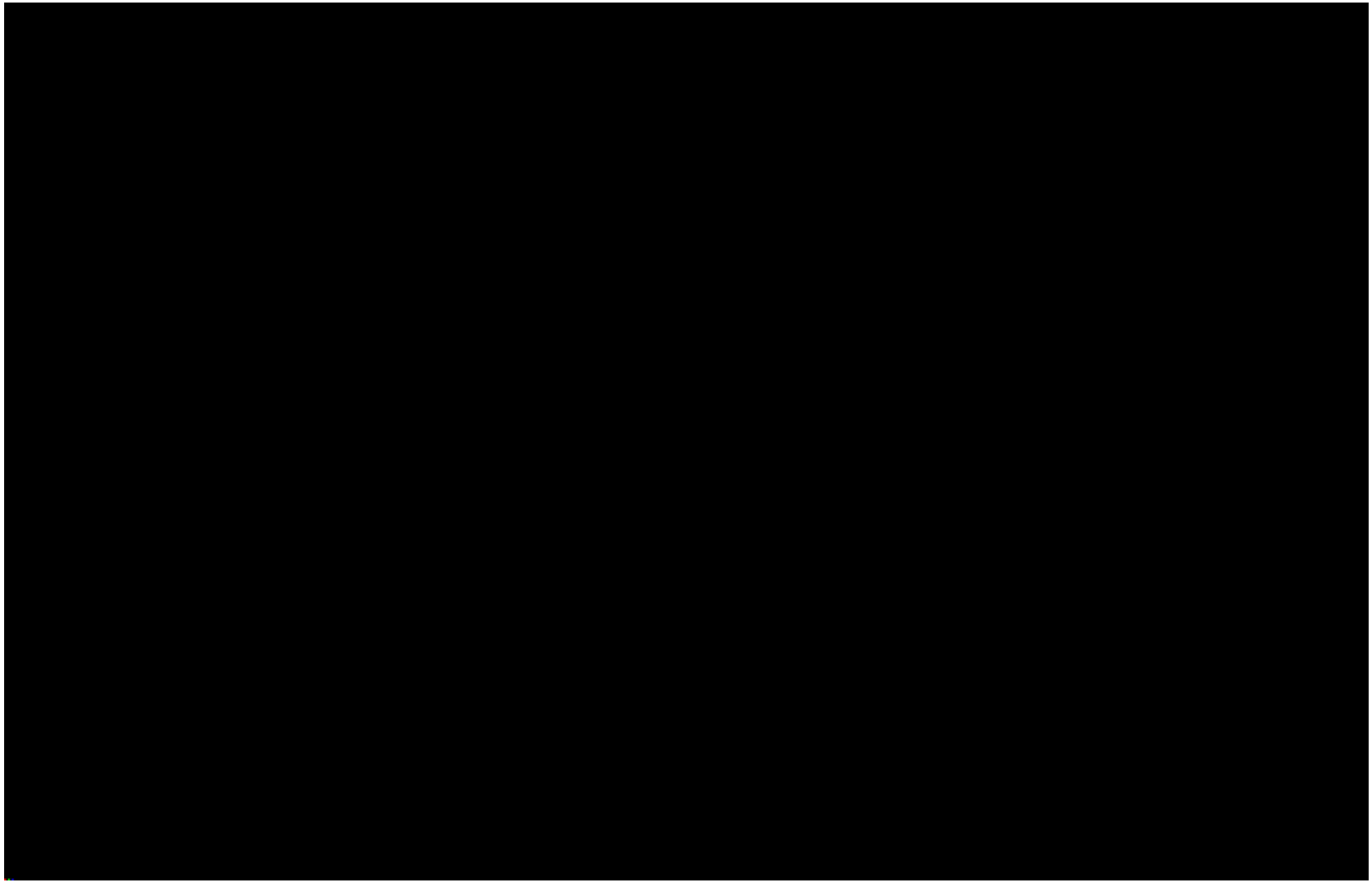


Persistent, flat spectrum radio source: $\Gamma < 2$

Transient radio jets due to internal shocks as in AGN & GRBs

MOVING X-RAY JETS IN μQSOs

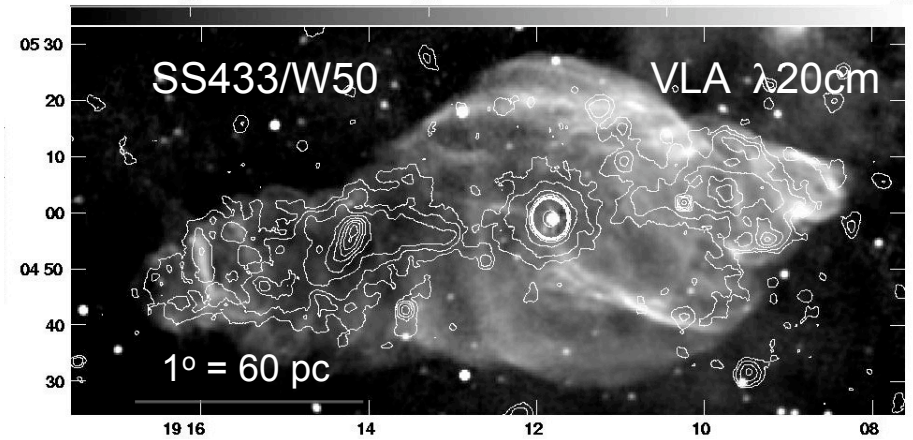
μQSOs XTE J1550-564 & H1743−322 Corbel et al. Science (2002, 2005)



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

FEEDBACK FROM JETS & WINDS

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

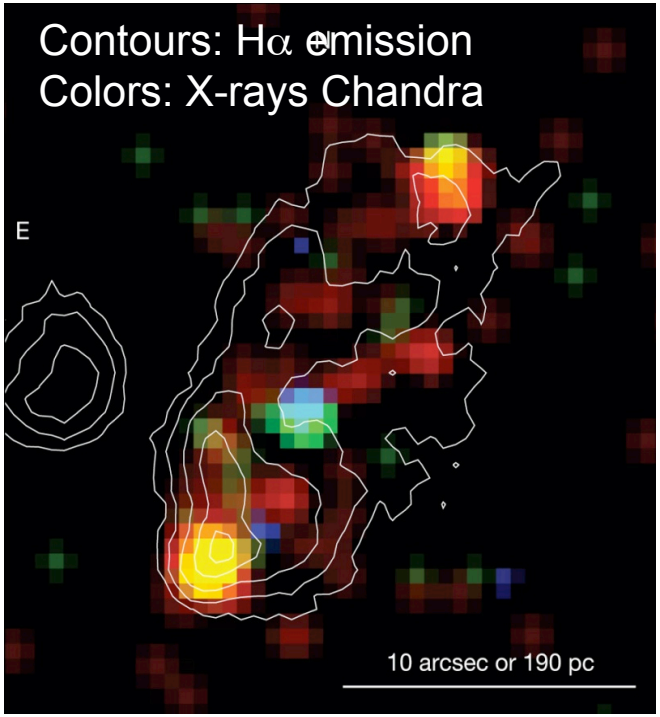


ATOMIC NUCLEI MOVING AT 0.26c ⇒

MECHANICAL LUMINOSITY > 10^{39} erg/s

NON RADIATIVE JETS = "DARK" JETS

➢50% OF THE ENERGY IS NOT RADIATED



JET INFLATED BUBBLE BY μQSO in NGC 7793

Pakull, Soria & Motch (Nature, 2010)

MECHANICAL POWER > 10^{40} erg/s

JETS~10^4 MORE POWERFUL THAN X-RAYS

ANALOGOUS TO A FRII AGN

ANISOTROPIC EMISSION (King+2001)

CONCLUSION

Microquasars are good laboratories to prove the physics of the

- **FORMATION (DIRECT & EXPLOSIVE)**
- **MASS GROWTH (BY ACCRETION)**
- **FEEDBACK (BY JETS & WINDS)**

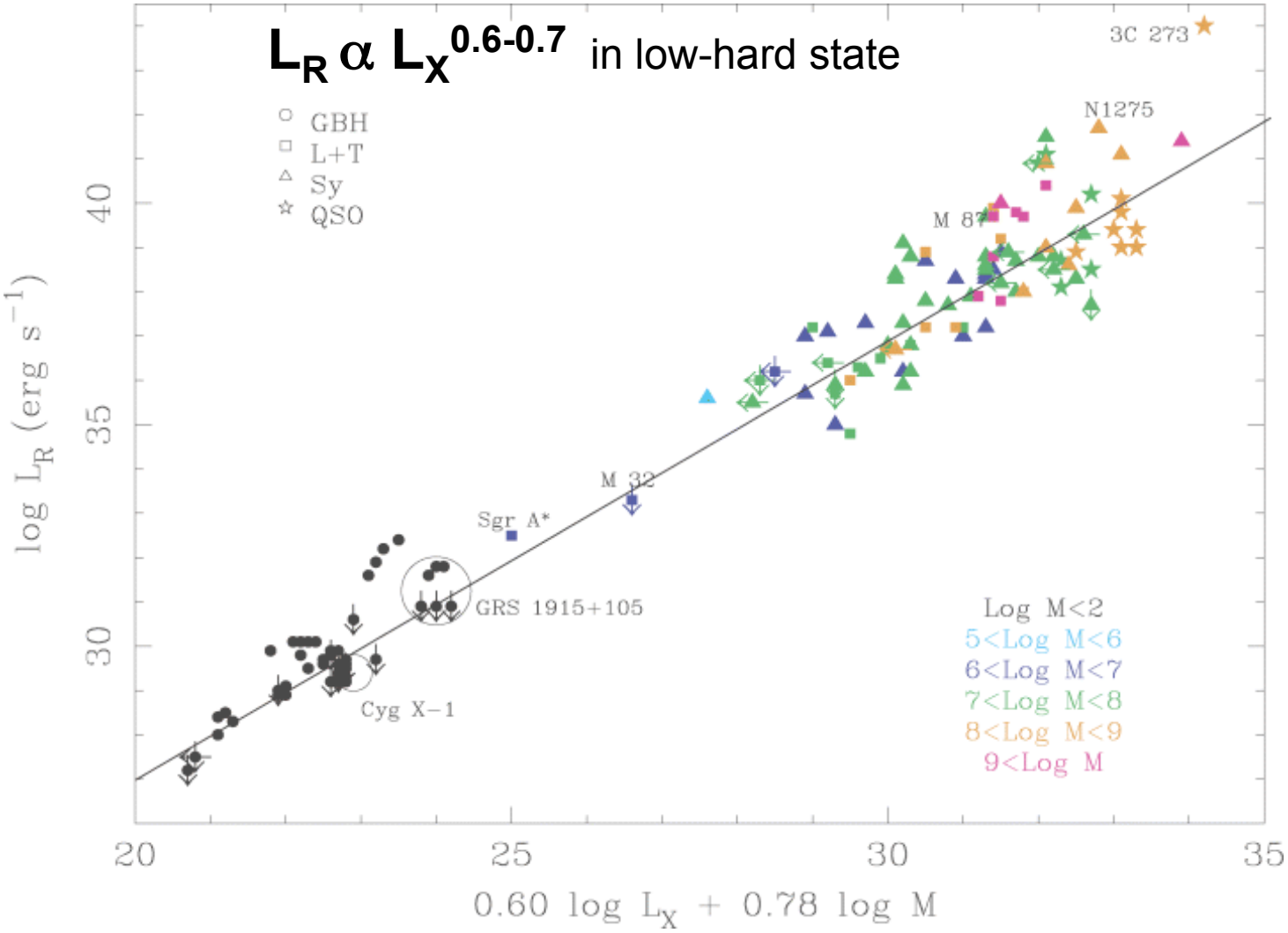
IN ASTROPHYSICAL BLACK HOLES

So far seven Microquasar International workshops.

Next as an IAU Symposium in Buenos Aires (13-17 Sept. 2010)

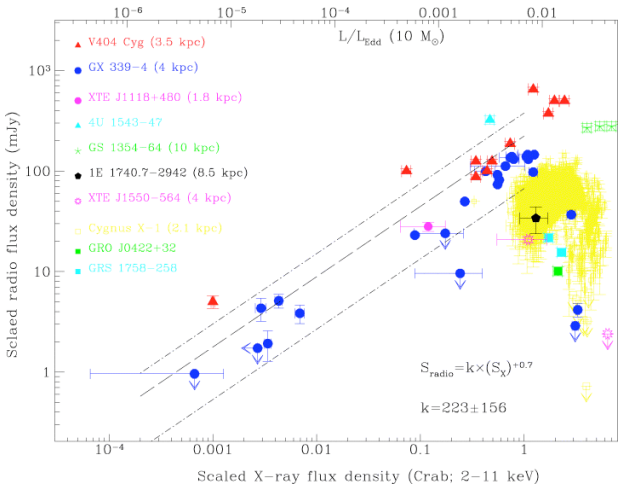
IS THERE A BLACK HOLE FUNDAMENTAL PLANE ?

(Merloni et al.) (Falke et al.) (Gallo et al.)

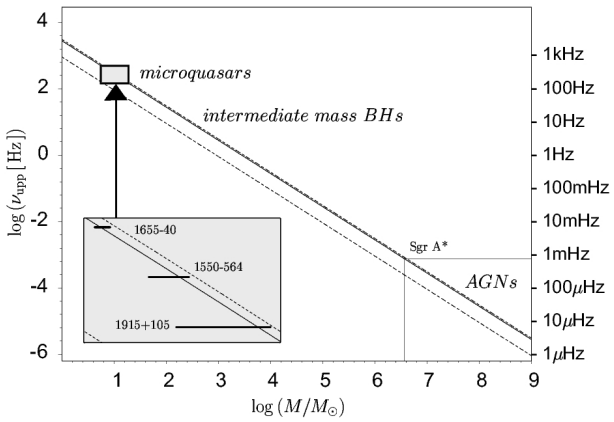


IF THE EMPIRICAL CORRELATIONS

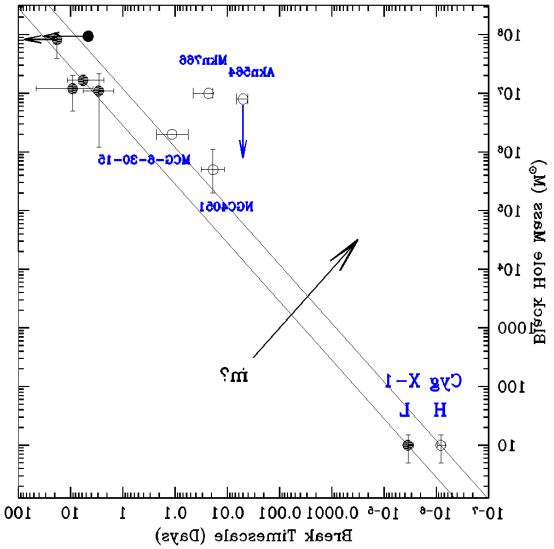
X-ray/radio/mass
Gallo et al. 2004



QPOs/mass
Abramovics, 2005



Noise-spectrum/mass
Uttley et al. 2004



BECOME MORE ROBUST, INDEPENDENTLY OF THE MODELS, THE MASS AND SPIN OF BLACK HOLES WILL BE DETERMINED

CAN WE OBTAIN OBSERVATIONAL EVIDENCES FOR THE FORMATION OF BLACK HOLES BY THE IMPLOSION OF MASSIVE STARS (WITH NO SNe) ?

It is difficult to prove observationally the direct formation (with no SNe) of stellar black holes, since one should prove the "inexistence" of SNe…

"A Survey About Nothing: Monitoring a Million Supergiants…"

From the fossils can be inferred whether massive stars finish with energetic explosions or silently

"Stellar Forensics"