ACCRETION-JET CONNECTION IN BLACK HOLES

THE ORIGIN OF STELLAR BLACK HOLES & THEIR ROLE IN THE EVOLUTION OF THE UNIVERSE

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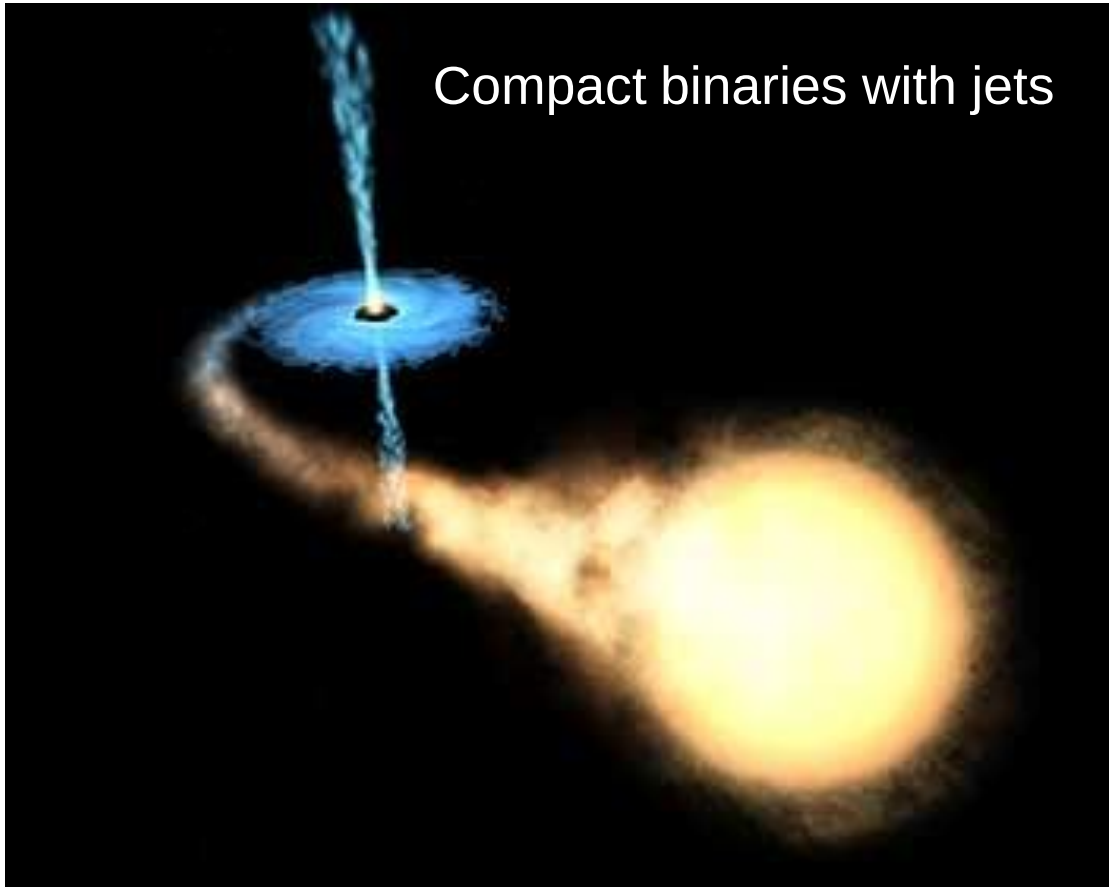
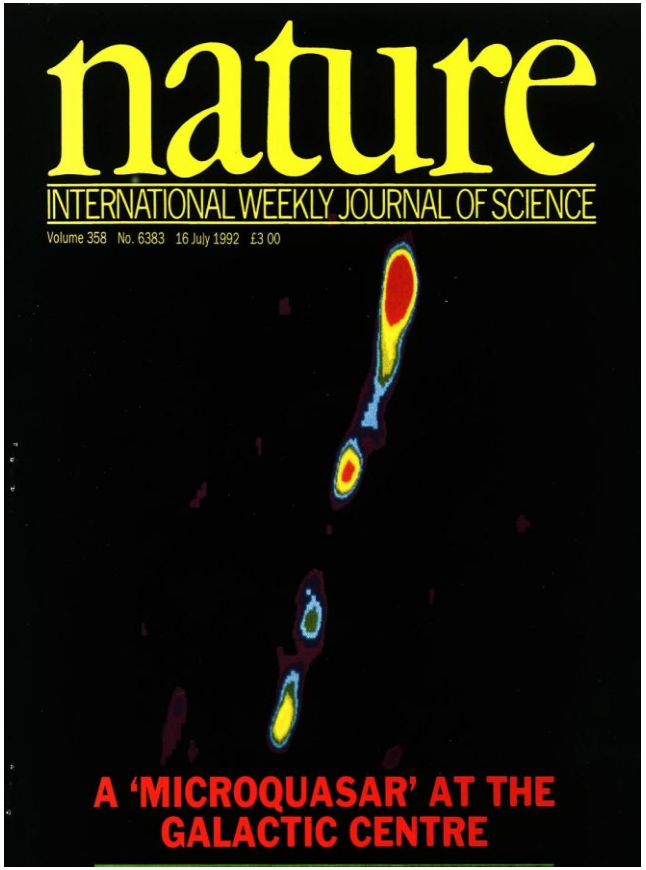
MIQROQUASARS AS LABORATORIES TO UNDERSTAND THE RELATION BETWEEN ACCRETION AND RELATIVISTIC JETS

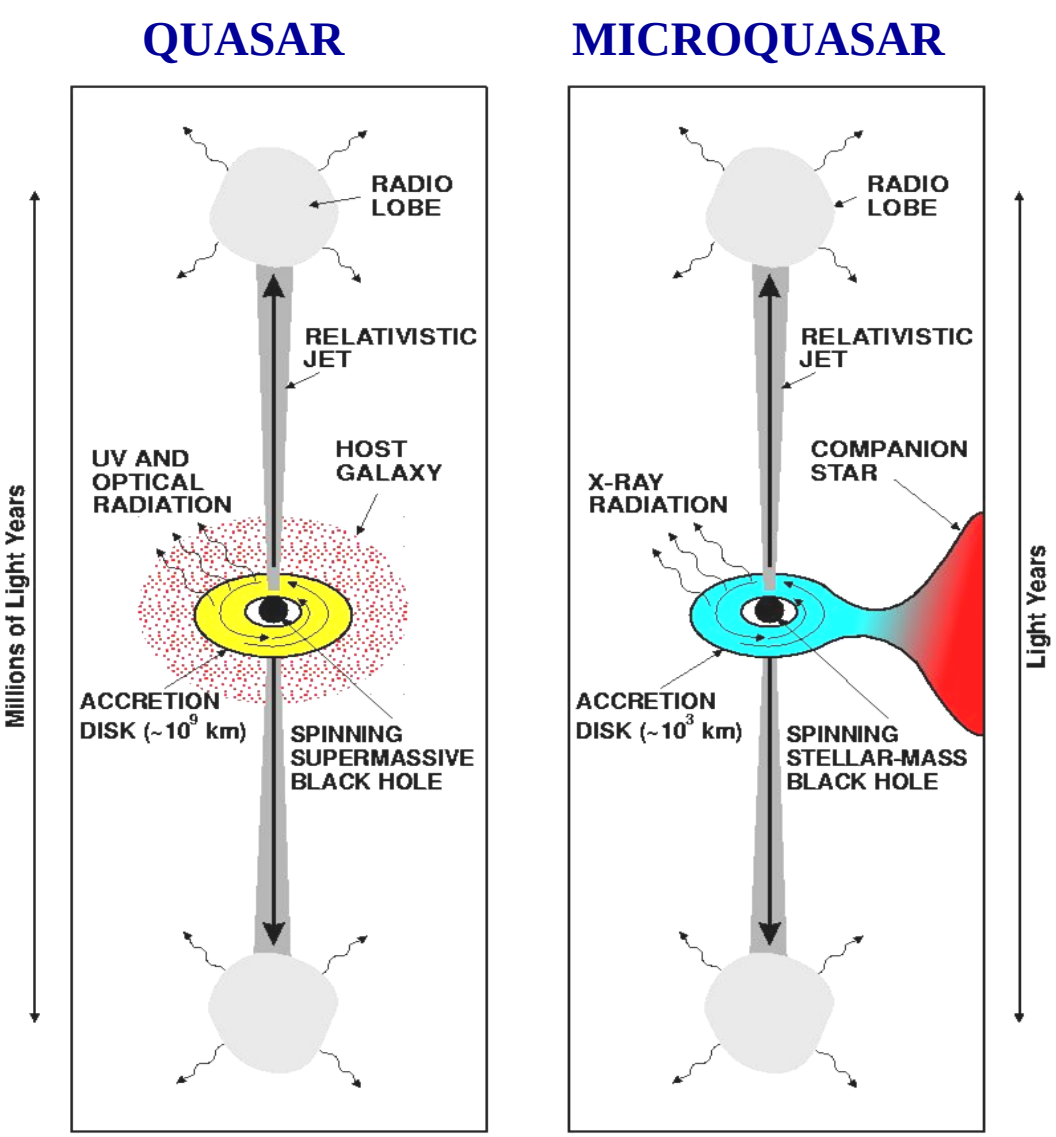
Mirabel, Rodríguez et al. 1992





Since their discovery there have been seven International workshops

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)

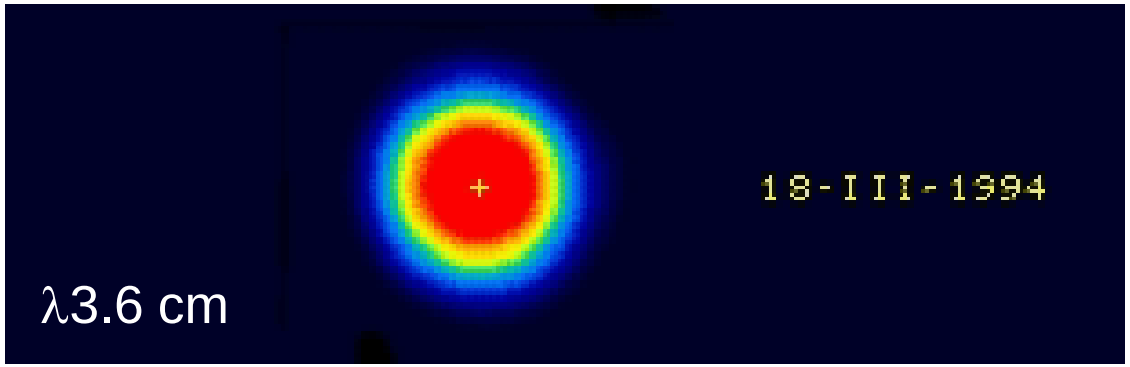
APPARENT SUPERLUMINAL MOTIONS IN μQSOs AS IN QSOs ?

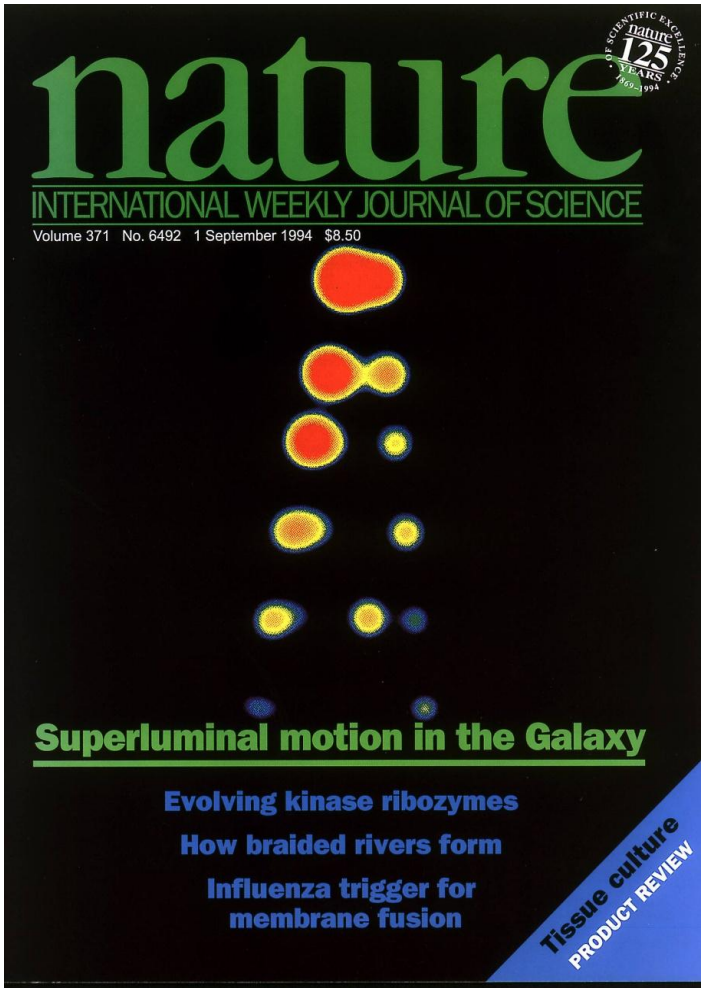
SUPERLUMINAL EJECTION IN A μQSO

Mirabel & Rodriguez, 1994

GRS 1915+105: A BH of 14 $M_\odot$ + 1 $M_\odot$ red giant

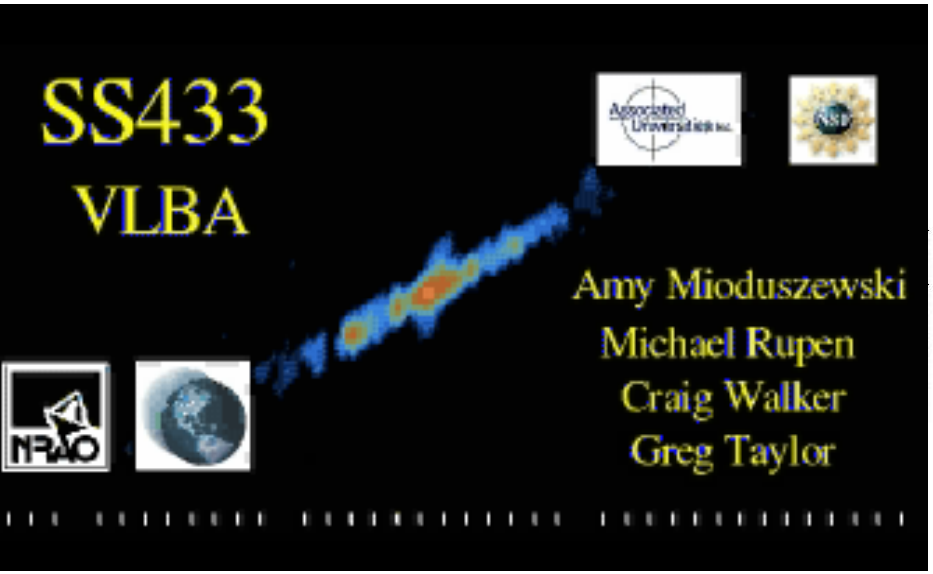
- "At the time of a sudden drop of the hard X-rays…"
- "The particles (corona/inner disk) are blown away…"
- "Jets have a very large kinetic energy…Moon @ >.9c"





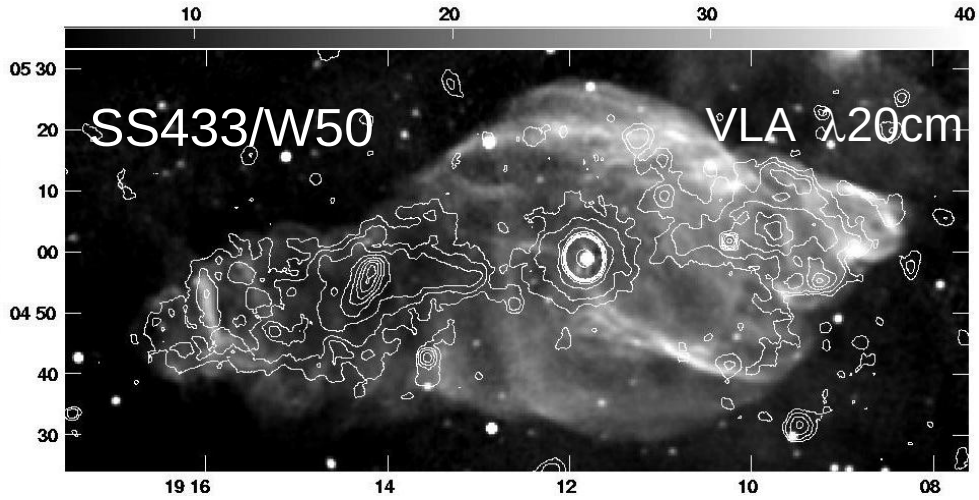
The asymmetries are explained as due to relativistic aberration in twin jets

POWERFUL DARK JETS FROM BLACK HOLES



1arcsec

Radio (Dubner et al); X-rays: (Brinkmann et al)



1^{o} = 60 pc

- **ATOMIC NUCLEI MOVING AT 0.26c ⇒**
- **MECHANICAL LUMINOSITY > 10^{39} erg/sec**
- **NON RADIATIVE JETS = "DARK" JETS**
- **>50% OF THE ENERGY IS NOT RADIATED**

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

HIGH ENERGY EMISSION FROM μQSOs

MICROBLAZARS: **due to relativistic beaming:** $\Delta t \propto 1/2\gamma^2$; $I \propto 8\gamma^3$

e.g. **If** $\gamma = 5$, $\Theta < 10^o \Rightarrow \Delta t < 1/50$ **and** $\Delta I > 10^3$ (Mirabel & Rodríguez, ARAA 1999)

SHOULD APPEAR AS SOURCES WITH FAST & LARGE VARIATIONS OF FLUX

$\Rightarrow$ **DIFFICULT TO FIND & DIFFICULT TO FOLLOW**

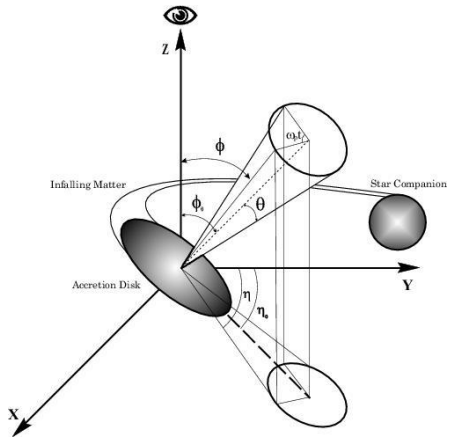
DUE TO PHYSICAL INTERACTIONS IN THE JETS:

LEPTONIC:Inverse Compton up-scattering of stellar photons in HMXBs

Kauffman Bernadó, Romero & Mirabel (A&A 2002)

HADRONIC: From windy microquasars

Romero, Torres, Kaufman Bernadó, Mirabel (A&A 2003)



Have μQSOs been detected by Cherenkov telescopes, Fermi, Agile…?

GeV & TeV PHOTONS FROM COMPACT BINARIES

•**VHE (>100 GeV)** from LS 5039, PSR B1259-63, LSI +61 303 & **Cyg X-1 (?)**

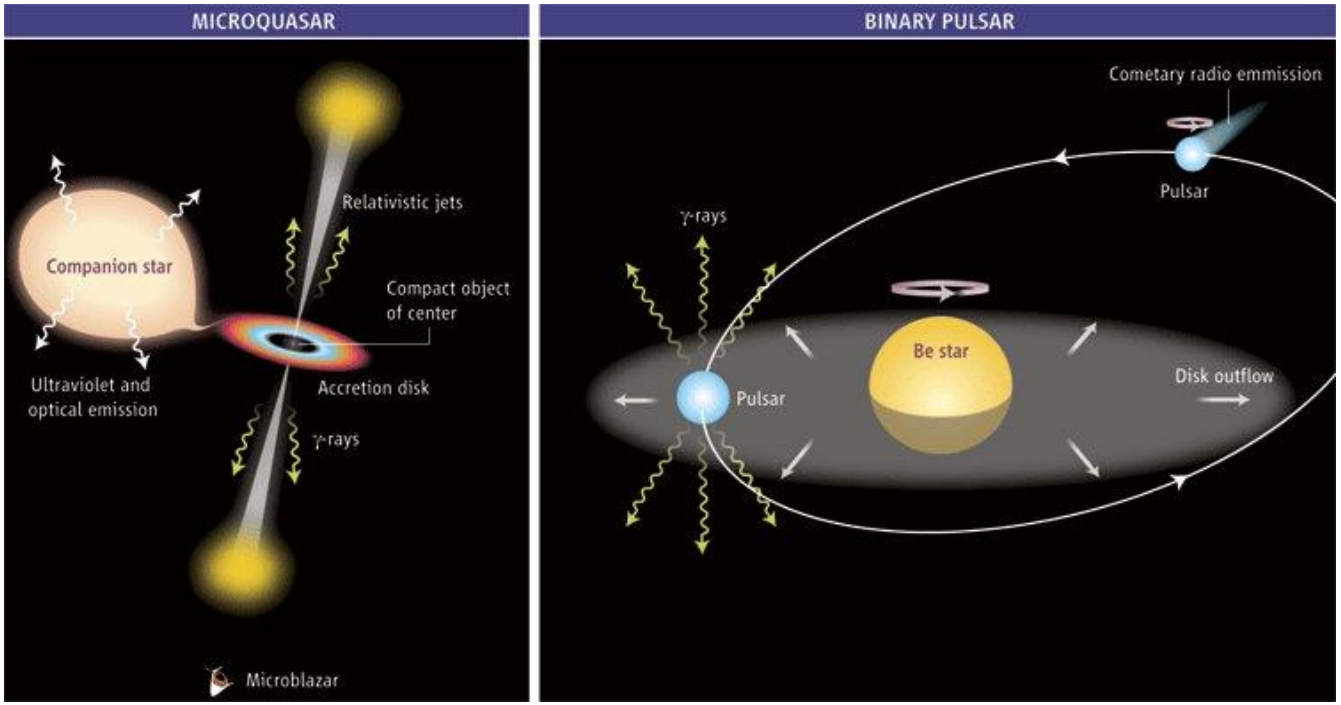
Mirabel (Science, 2006)

Cyg X-1

&

Cyg X-3

?



PSR B1259-63

&

LSI +61 303

LS 5039

?

Pulsar wind model (Dhawan et al. 2006) or **μQSO jets in non μblazar sources ?**
(Albert et al. Science, 2008; Kaufman-Bernadó & Massi, A&A 2009)

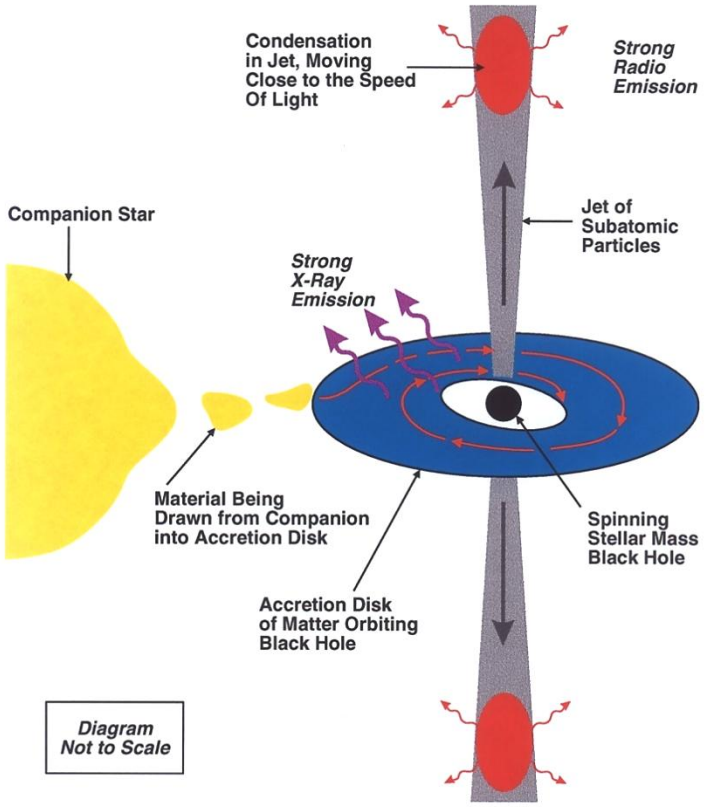
TeV intraday variability from M87 (Aharonian et al. Science, 2006)

Fermi & Agile detect GeV photons from a HMXB microquasar (submitted)

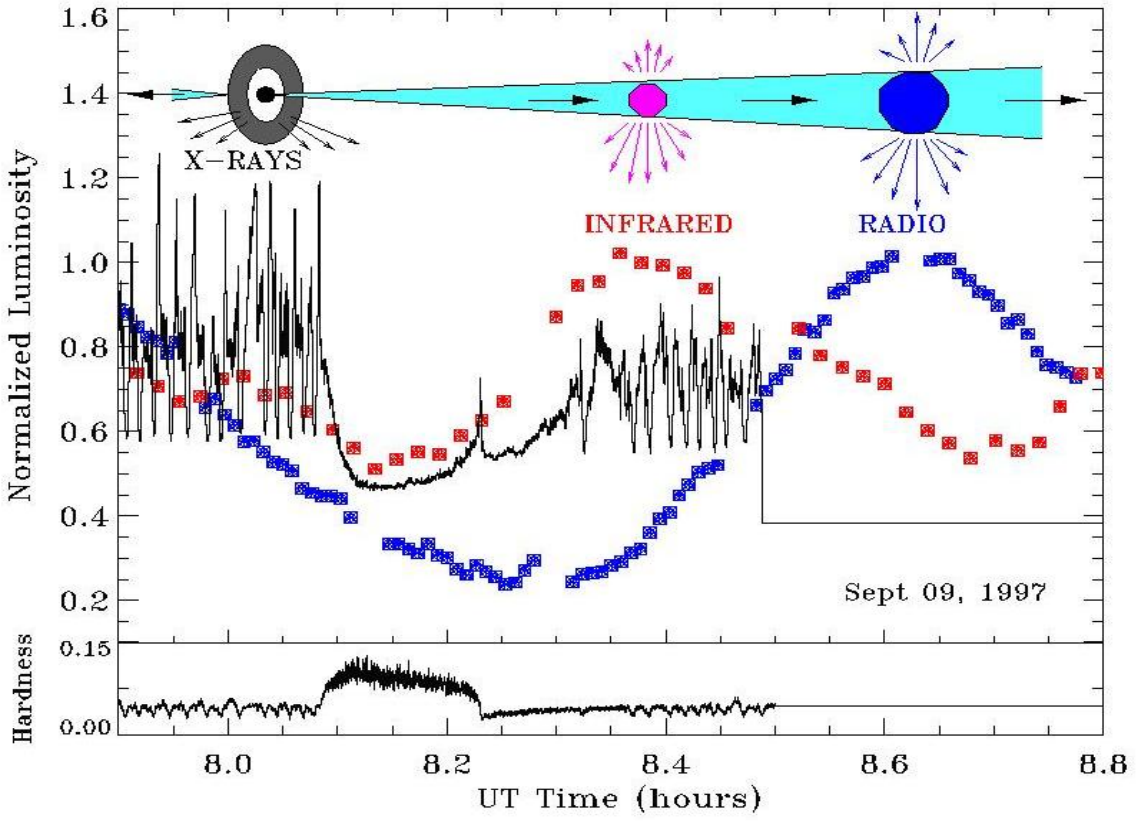
ACCRETION–JET CONNECTION

$\Delta T \propto M_{BH}$

1 hr = 30 yr in SgrA*



GRS 1915+ 105 (Mirabel et al. 1998)



- ABSCENCE OF EVIDENCE FOR A MATERIAL SURFACE IN A M_{BH} =14 $M_{\odot}$
- THE ONSET OF THE JET IS AT THE TIME OF A X-RAY "SPIKE"
- SUDDEN REFILL OF THE DISK & SHOCK THROUGH COMPACT JET

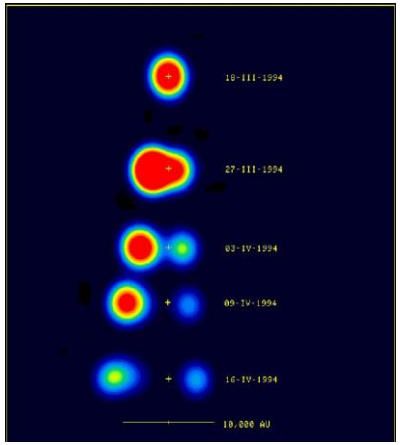
DISK-JET COUPLING IN BLACK HOLES

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

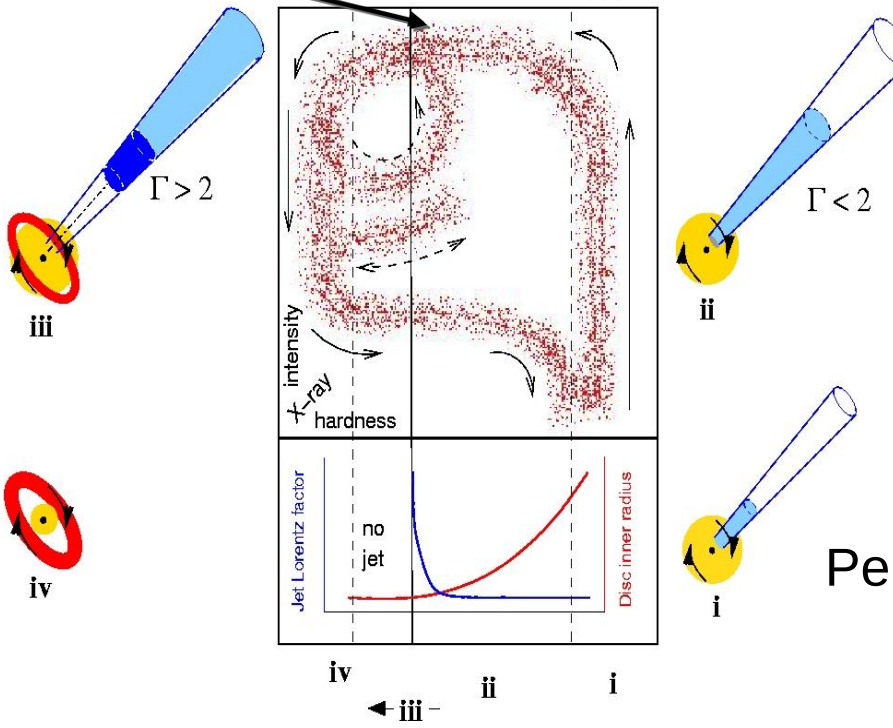
Fender, Belloni, Gallo (2006)

Dhawan, Mirabel, Rodríguez (2005)

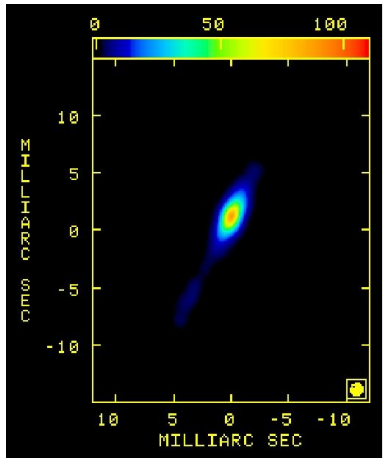
Soft X-rays



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



Low-hard X-rays

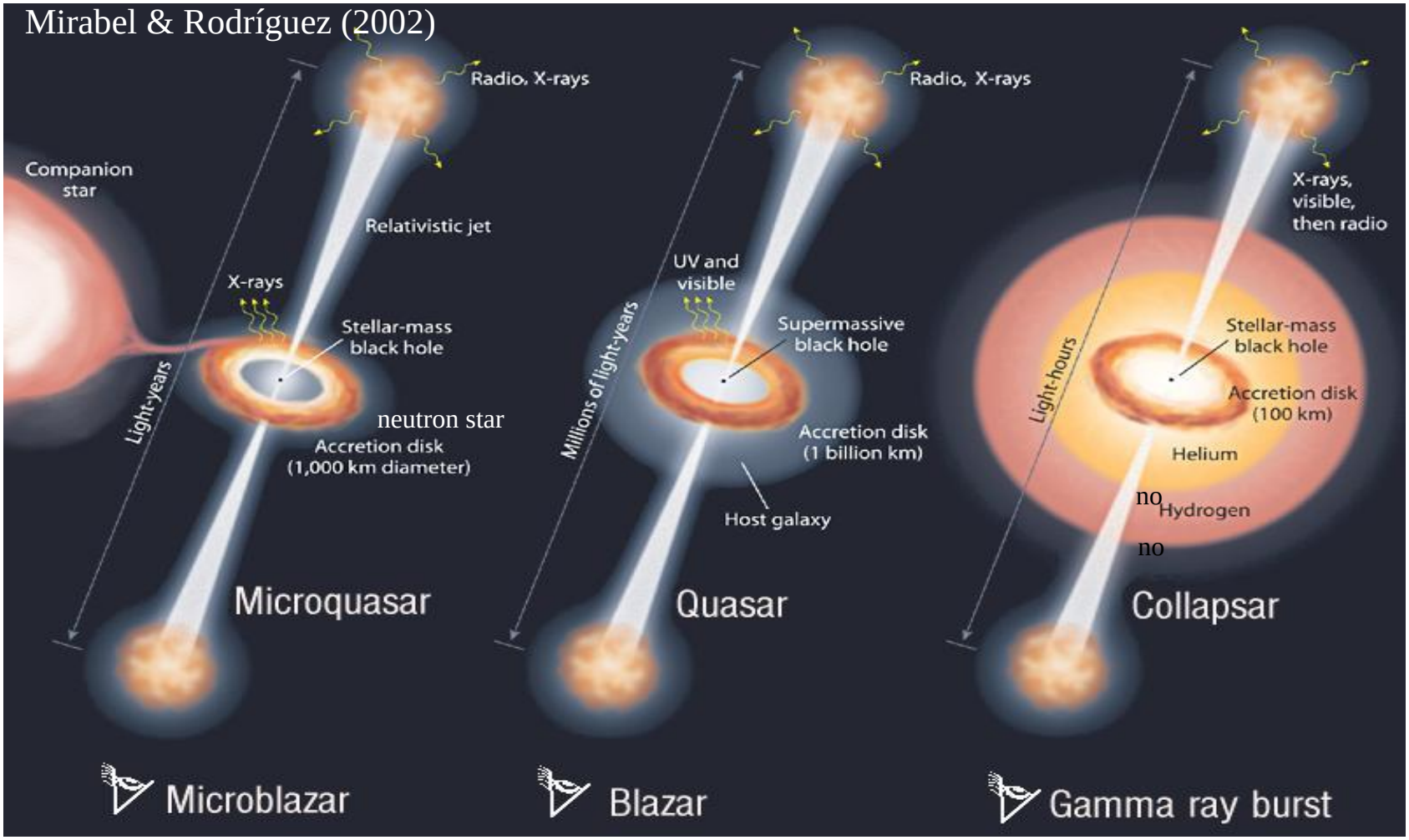


Persistent, flat spectrum radio source: $\Gamma < 2$

- **The transient radio jets are produced by internal shocks**
- **Disk-jet coupling also observed in QSOs** (Marscher et al Nature 2004)
- **How are BH binary states related to AGN types ?** (Köerding et al.)

QSO - μQSOs - GRB

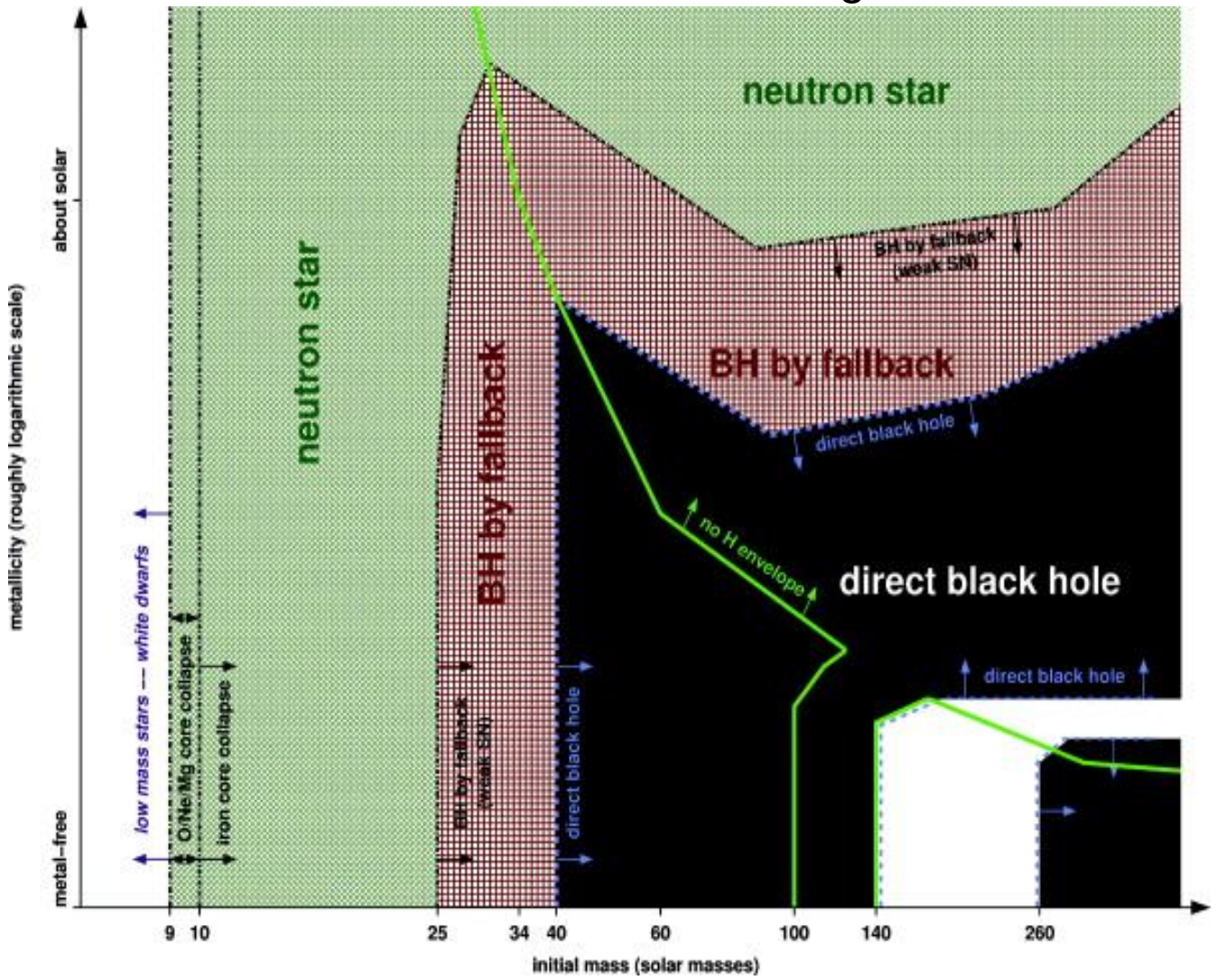
HAVE THE SAME 3 BASIC INGREEDIENTS



- AN UNIVERSAL ACCRETION - JET CONNECTION IN BLACK HOLES ?
- AN UNIVERSAL MAGNETO-HYDRODYNAMIC MECHANISM FOR JETS ?

FORMATION OF STELLAR BLACK HOLES

Heger et al. 2003

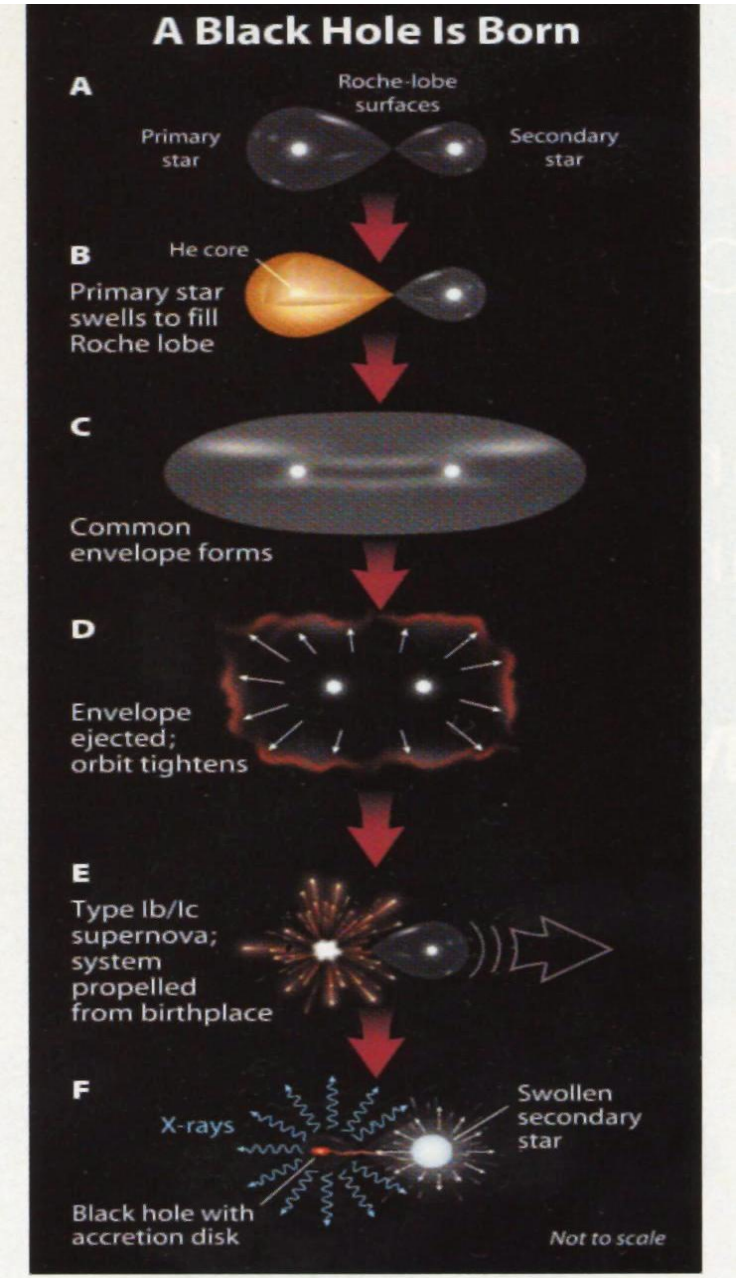


Direct collapse depends on:

- Metal content
- Mass of the core
- Angular momentum

Can this model be tested observationally ?

HOW ARE FORM BLACK HOLE BINARIES ?



CORE COLLAPSE MODELS:

(Fryer & Kalogera ; Woosley & Heger; Nomoto et al.)

BUT FEW OBSERVATIONS TO TESTS

USE THE KINEMATICS OF μQSOs TO TEST CORE COLLAPSE MODELS:

FUNCTION ON THE MASS OF BH ?

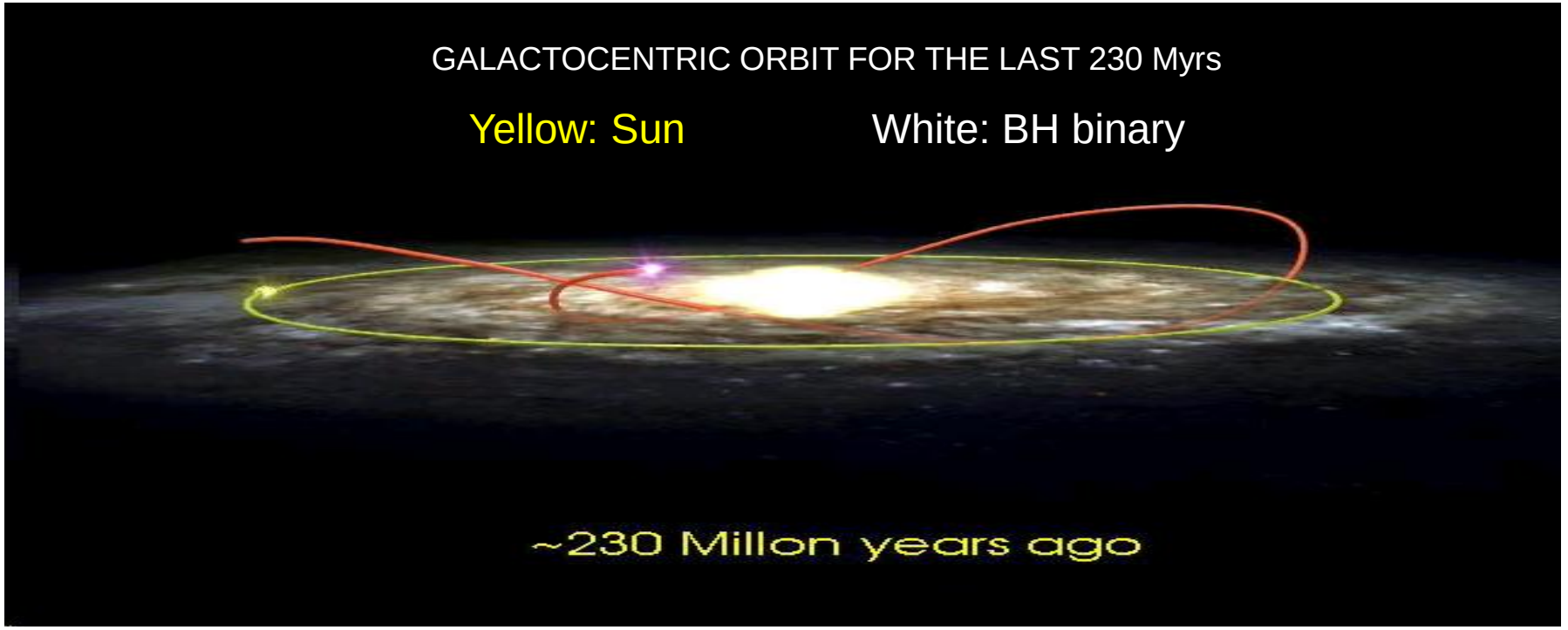
Mirabel & Irapuan Rodrigues (2001-2009)

SO FAR HAVE BEEN DETERMINED THE KINEMATICS OF 5 BHs WITH MASSES IN THE RANGE OF 4-14 $M_\odot$

TWO RUNAWAY BLACK HOLES

XTE J1118+480 M_{BH}~7 $M_\odot$ M_*~0.4 $M_\odot$ kpc; **Vp=145-210 km/s**

(Mirabel et al. Nature, 2001)



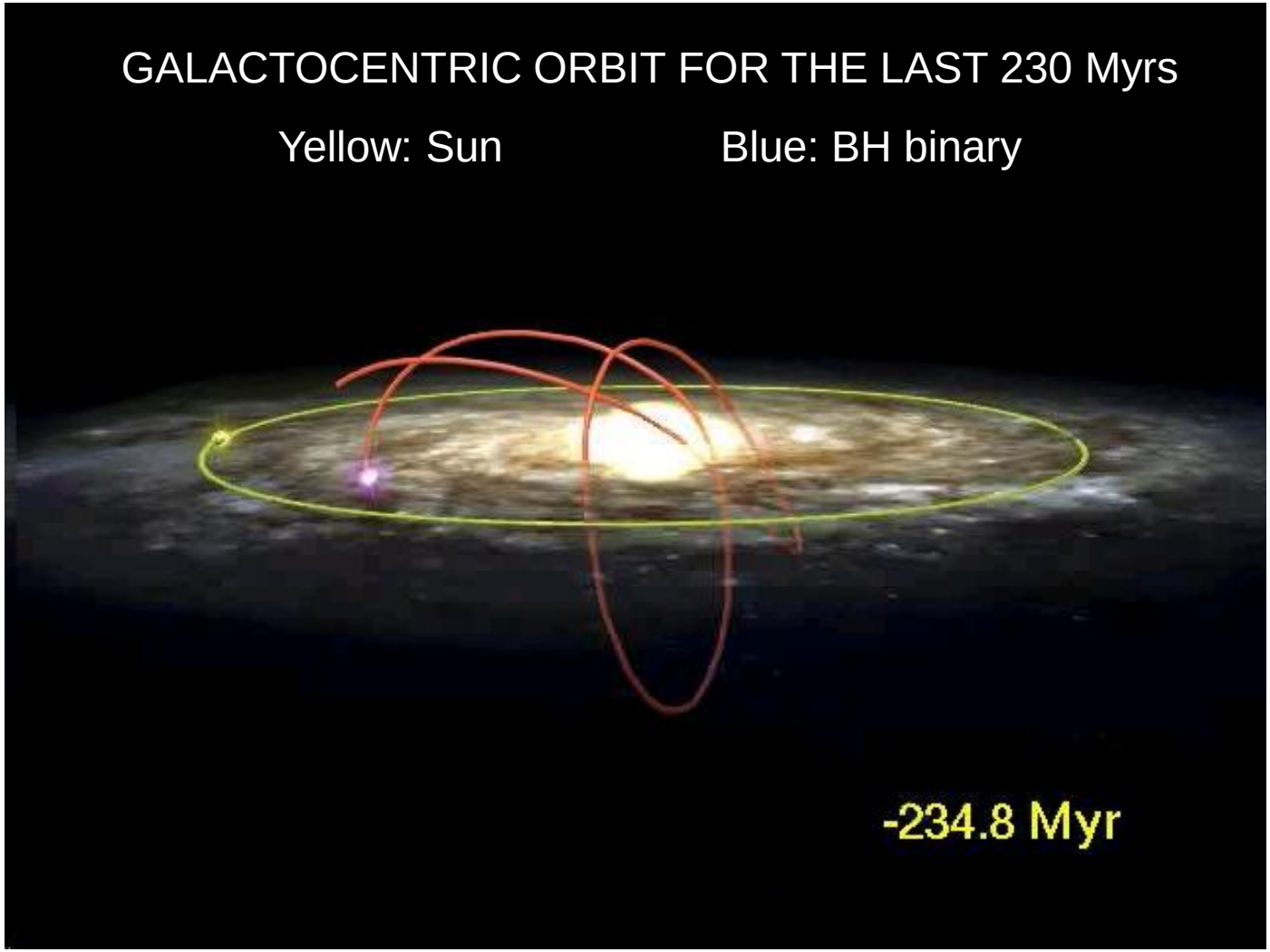
GRO J1655-40 M_{BH}~5 $M_\odot$ M_*~2 $M_\odot$;D=1-3 kpc; **V_p=112+/-18 km/s**

(Mirabel et al. A&A 2002)

THE TWO BHs WITH 5-7 $M_\odot$ WERE SHOT OUT FROM THEIR BIRTH PLACE BY ENERGETIC SNe

THE GALACTIC TRIP OF SCORPIUS X-1

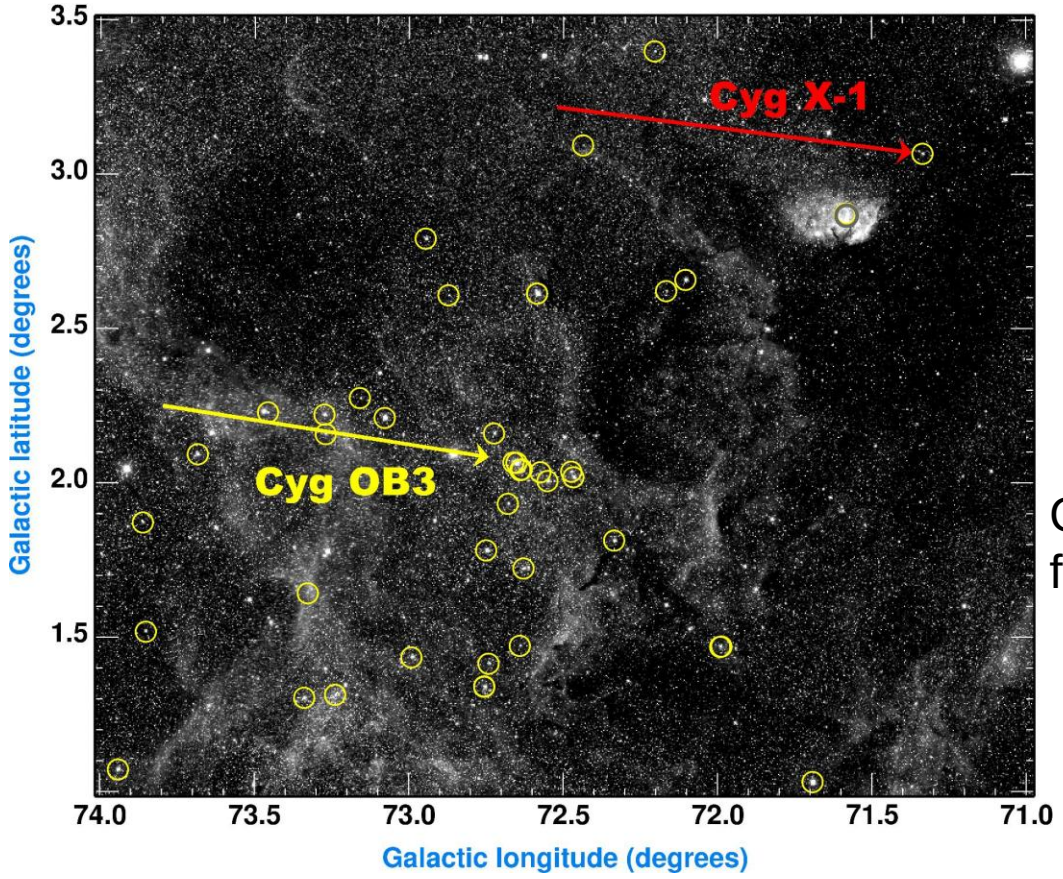
Mirabel & Rodrigues (A&A 398, L25, 2003)



SHOT OUT FROM THE BULGE OR A GLOBULAR CLUSTER

THE > 10 $M_\odot$ BLACK HOLE IN Cyg X-1 WAS BORN IN THE DARK

Mirabel & Rodrigues (Science, 2003)



V_p < 9 +/- 2 km/s $\Rightarrow$

< 1 $M_\odot$ ejected in SN

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

THE > 10 $M_\odot$ BH IN Cyg X-1 WAS FORM BY DIRECT COLLAPSE

TWO OTHER BHs WITH M > 10 $M_\odot$

- **GRS 1915+105** (Dhawan, Mirabel & Rodríguez, 2001)

  M_{BH} ~ 14+/-4 $M_\odot$; M*~1.2 $M_\odot$; D=9+/-2 kpc: **V_p= 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: **V_p= 45-100 km/s & W = 0.2+/-3 km/s**

- **THE TWO PECULIAR SPACE MOTIONS ARE DIRECTED TOWARDS THE GALACTIC CENTRE AND HAVE SMALL W COMPONENTS (V_{GC} > 10 W).**

  HOWEVER, AS SHOWN BY THE PECULIAR VELOCITY DISPERSION OF PULSARS, KICKS SHOULD HAVE NO PREFERENTIAL DIRECTION.

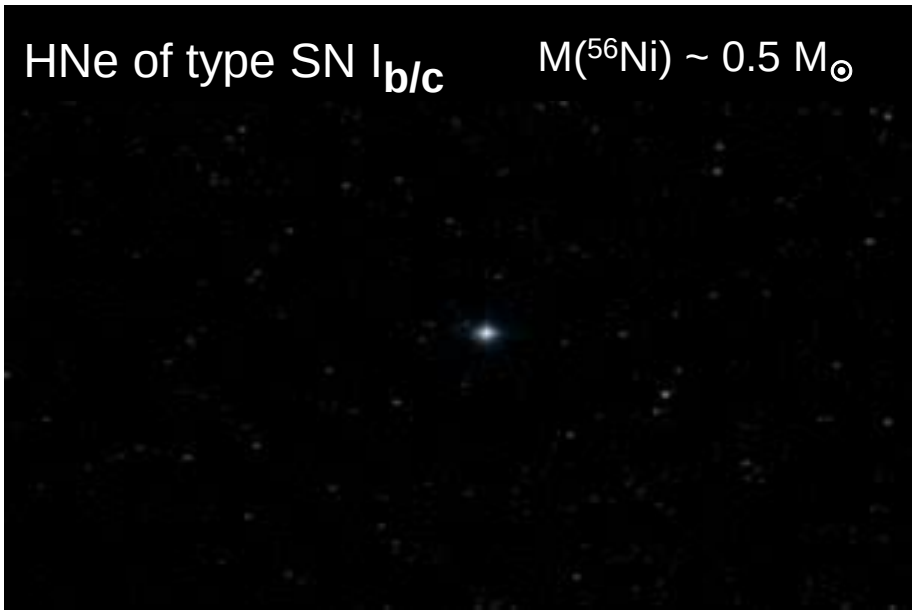
- **THE PECULIAR SPACE MOTIONS OF GRS 1915+105 AND V404 Cyg ARE CONSISTENT WITH THE GALACTIC DIFFUSION OF THE OLD STELLAR POPULATION, AND DO NOT REQUIRE ENERGETIC NATAL KICKS.**

THE THREE GALACTIC BHs WITH M_{BH} > 10 $M_\odot$ MAY HAVE BEEN FORM BY DIRECT COLLAPSE

However, this is a very small, biased, sample of the 10^8 BHs in the Galaxy

BIRTH OF STELLAR-MASS BLACK HOLES

LGRBs MARK THE BIRTH OF BHs: ASSOCIATED TO SNe $I_{b/c}$



BUT CORE COLLAPSE MAY NOT LEAD TO ENERGETIC SNe:

- **Theoretical models**: e.g. Wosley & Weaver (1995); Nomoto & Tominga (2007)
- **Two nearby LGRBs with no luminous SNe** (Della Valle +, Fynbo +, Gal-Yam +, 2006)
- **SNe of type II with $<10^{51}$ erg**; low V_{exp}; and $< 10^{-3}\ M_{\odot}$ of ^{56}Ni (e.g. Zamperi + 2003)

METAL CONTENT OF BH & NS PROGENITORS

- **Massive low metal progenitors end as massive black holes ?**
  M 33 X-7: BH of 15.65 +/- 1.45 $M_\odot$ orbiting a donor of 70 $M_\odot$ (Orosz et al. 2007)
  IC10 X-1: BH of 23-34 $M_\odot$ orbiting a WR of 35 $M_\odot$ (Prestwich et al.;Silverman 2008).

- **Hosts of LGRBs are small low metallicity galaxies** (Le Floc´h+)
  How can then be explained the existence of Cyg X-1 & SS 433 in the MW galaxy ?

- **Massive high metal progenitors end as neutron stars**
  SGR 1900+14 & SGR 1806-20: Magnetars with very massive progenitors in star clusters of > solar metal content (Mirabel et al. 1999; Watcher et al. 2008).

IN LOW METAL ENVIRONMENTS:

1) BLACK HOLE / NEUTRON STAR FRACTION INCREASES
2) FRACTION OF BINARY / SOLITARY BHs INCREASES

⇒FRACTION OF BH μQSOs INCREASES WITH Z

PRELIMINARY CONCLUSIONS FROM FEW OBSERVATIONS:

- Massive stars end as neutron stars or black holes depending on the **metal content of the progenitor**.
- Stellar black holes may form by direct or delayed collapse, namely, with & without energetic SNe, depending on the **mass of the collapsing core**.
- Multiple stellar systems will remain bound after the formation of black holes $\Rightarrow$ how important have been the x-rays from μQSOs for the reionization of the universe ? (Avi Loeb & Mirabel)