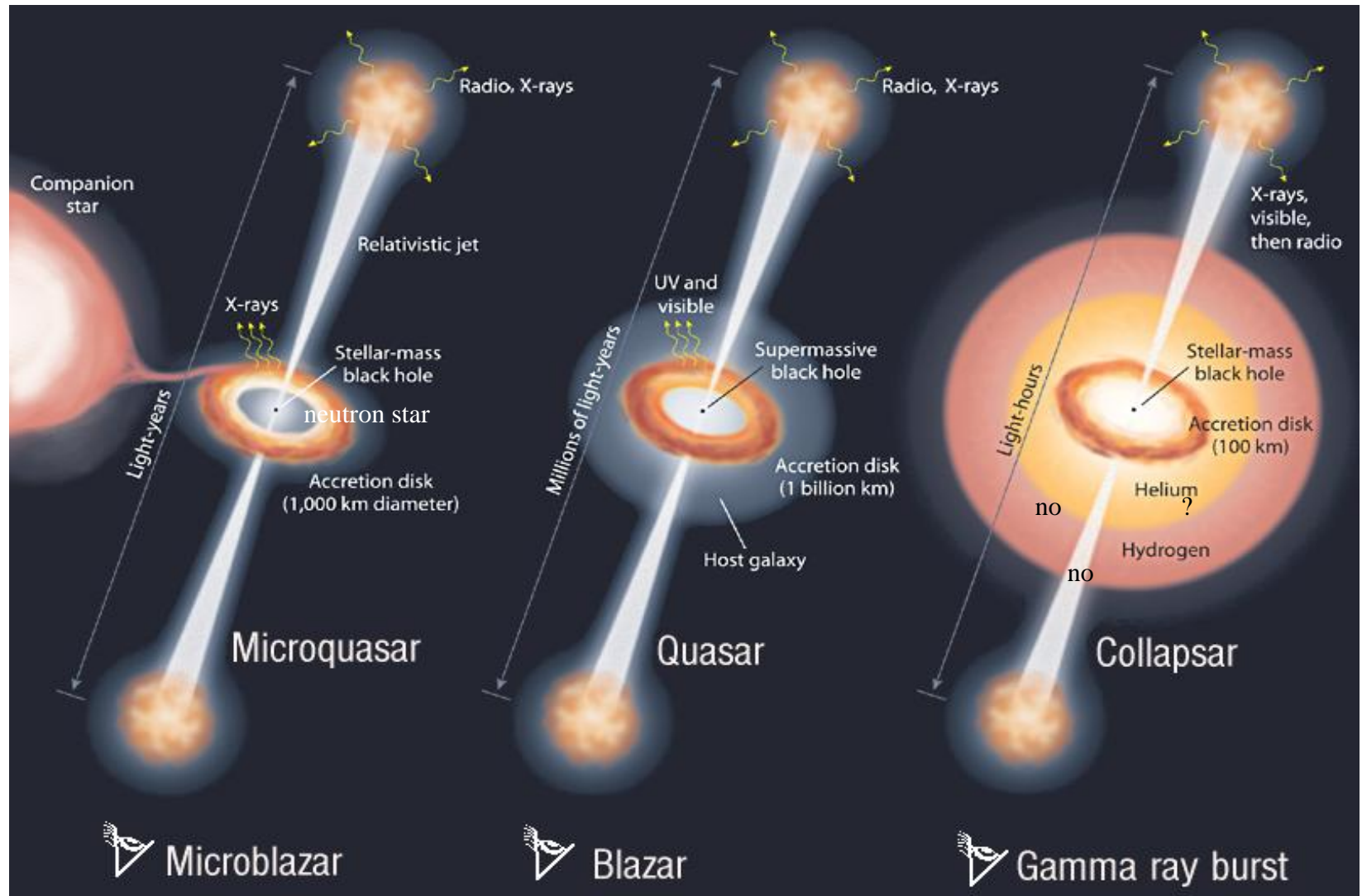


# QSO - $\mu$ QSO - GRB ANALOGY

HAVE THE SAME 3 BASIC INGREDIENTS (M. & Luis Rodriguez, S&T 2002)



**AN UNIVERSAL MAGNETO-HYDRODYNAMIC MECHANISM FOR JETS ?**

# GAMMA-RAY BURSTS

- **THE MOST ENERGETIC EXPLOSIONS IN THE UNIVERSE.**
- **WERE A MYSTERY FOR MORE THAN THREE DECADES UNTIL MULTIWAVELENGTH APPROACH OF A GRB DETECTED BY Beppo-SAX LEAD TO THE DISCOVERY OF OPTICAL AND IR AFTERGLOWS (van Paradijs)**
- **ARE RARE FINAL STAGES OF STELLAR EVOLUTION**
- **TWO TYPES: SHORT ( $<1\text{sec}$ ) AND LONG DURATION ( $>1\text{s}$ )**

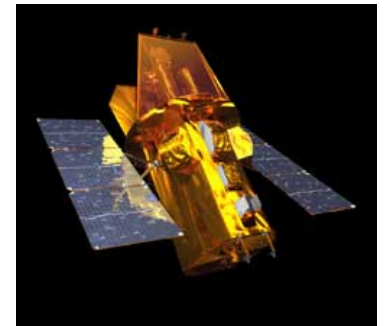
# GAMMA-RAY BURSTS OF SHORT DURATION

Duration < 1 second

Origin of GRBs of short duration: Double NS Mergers?--Still speculative



- SWIFT launched in November 20, 2004
- Associated to early type galaxies at  $z < 0.5$  (Nature)
- LIGO-LISA Connection for gravitational waves



# GAMMA-RAY BURSTS OF LONG DURATION

Associated to more distant starbursting galaxies up to  $z = 6.4$

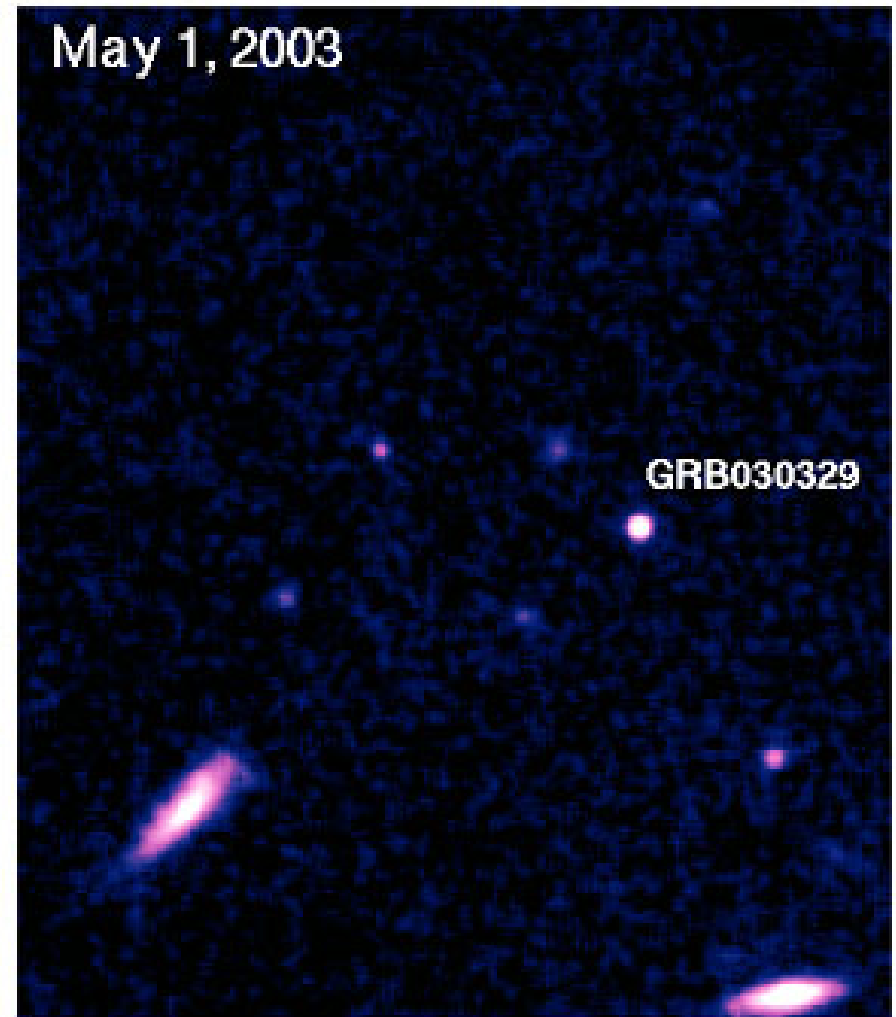
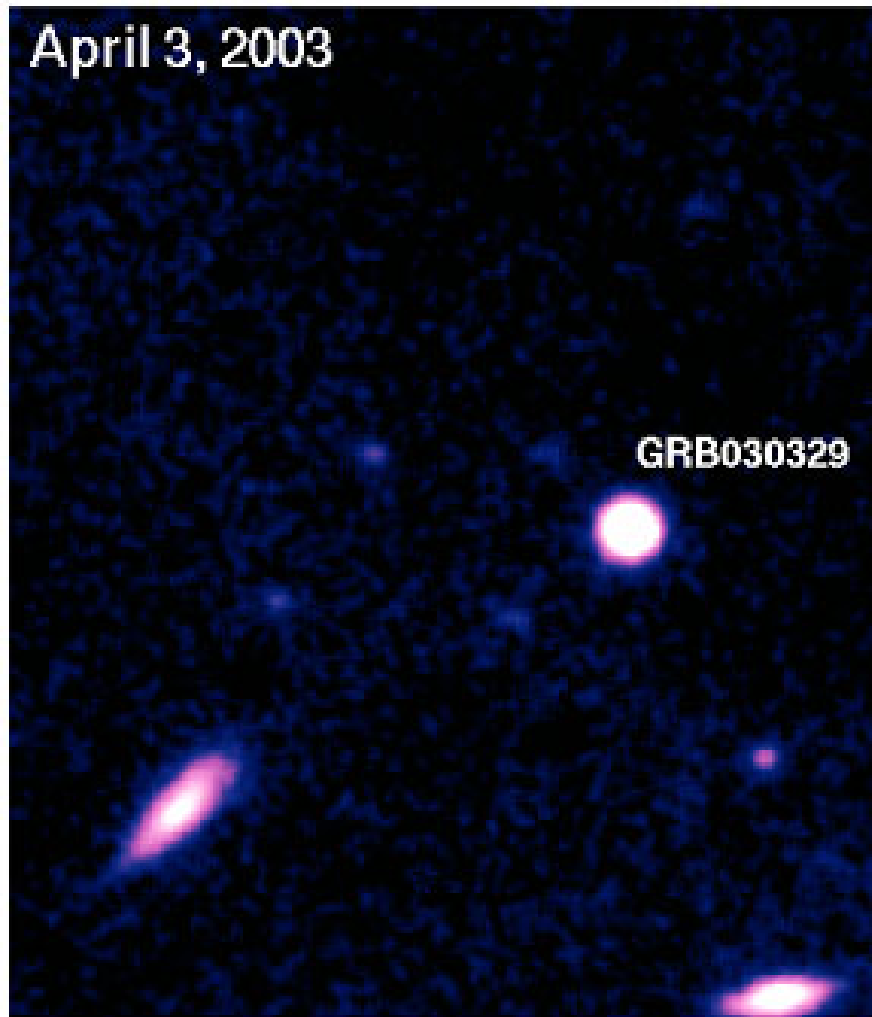
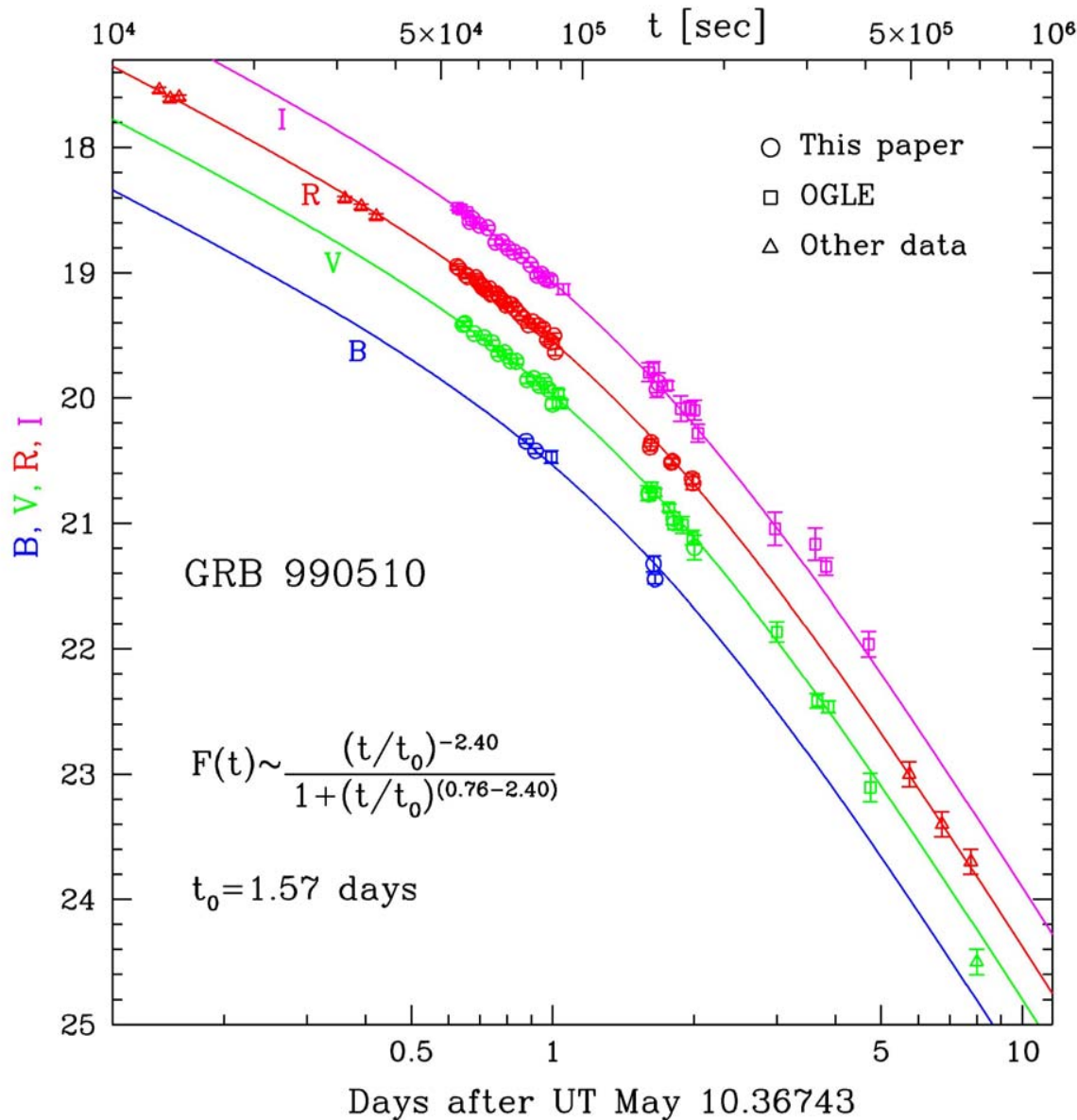


Image of Afterglow of GRB 030329  
(VLT + FORS)

# GAMMA-RAY BURSTS ARE JETS



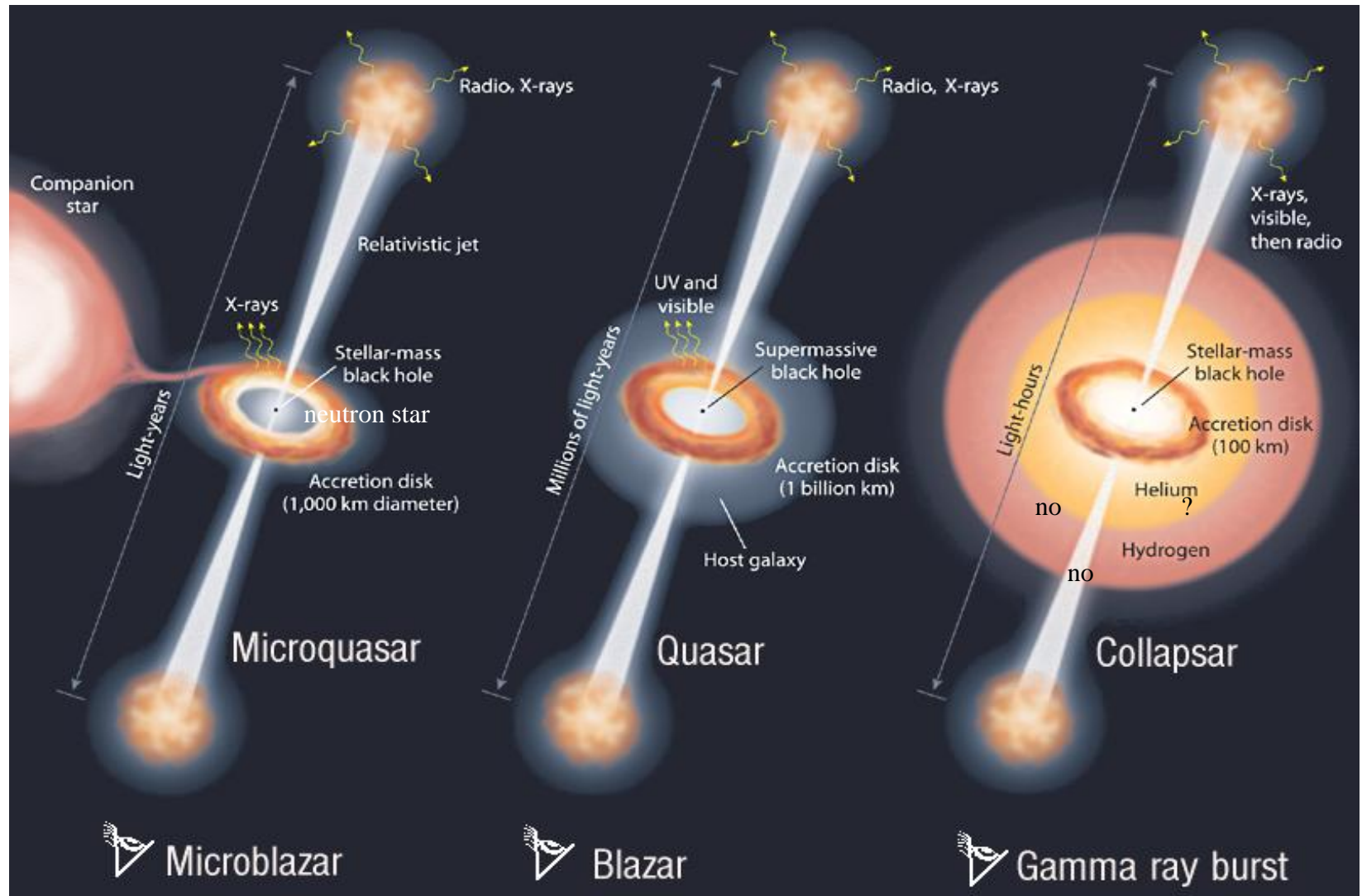
- Beaming and true energy
- Energy in Jets:  
opening angle  $< 10^\circ$
- Reduces required  
Gamma Energy from  
E 54 to E 51 ergs  
(=Supernova-like)

(Galama et al.1999; Frail et al.2001)



# QSO - $\mu$ QSO - GRB ANALOGY

HAVE THE SAME 3 BASIC INGREDIENTS (M. & Luis Rodriguez, S&T 2002)



**AN UNIVERSAL MAGNETO-HYDRODYNAMIC MECHANISM FOR JETS ?**

# **GAMMA-RAY BURSTS OF LONG DURATION MARK THE BIRTH OF BLACK HOLES AT COSMIC DISTANCES**

A cosmic jet, depicted as a bright yellow and orange cone of light, extends diagonally across the frame. At its base is a small, intense orange-yellow point source. The background is a dark, reddish-brown nebula with some blue and purple hues. The jet appears to be moving away from the point source, creating a sense of depth and direction.

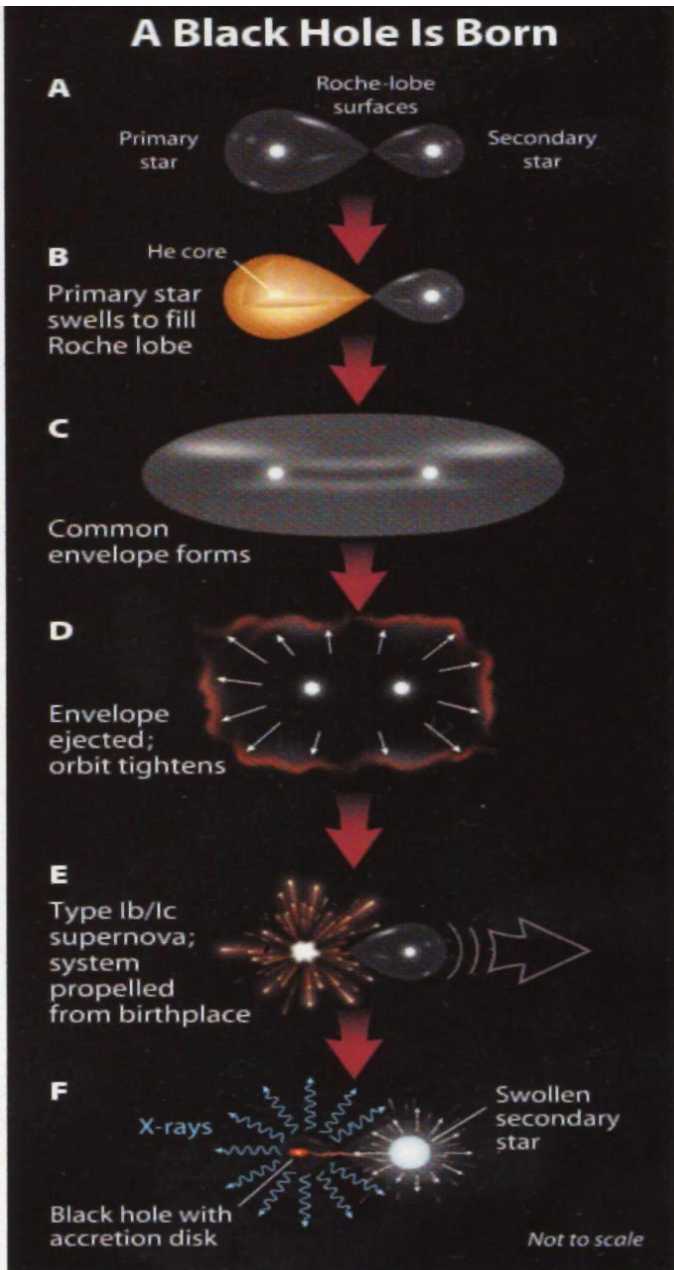
**Association with JETS, SN Ic & GRB @  $Z=6.4 \Rightarrow$**

**PROGENITORS OF GRB's ARE MASSIVE BINARIES**

**$\Rightarrow$  SOME  $\mu$ QSOs ARE FOSSILS OF GRBs  $\Rightarrow$**

**KINEMATICS AS PROBES OF BH FORMATION**

# HOW ARE BLACK HOLE BINARIES FORM ?



THERE ARE THEORETICAL MODELS

e.g. Fryer & Kalogera ; Woosley & Heger (2002)

BUT FEW OBSERVATIONS !

M. & I. Rodrigues (2001-05) used the kinematics of  $\mu$ QSOs to find out:

- BIRTH PLACE & NATURE OF THE PROGENITOR STARS
- WHETHER THE PROGENITOR STAR ALWAYS EXPLODES AS AN ENERGETIC SUPERNOVAE



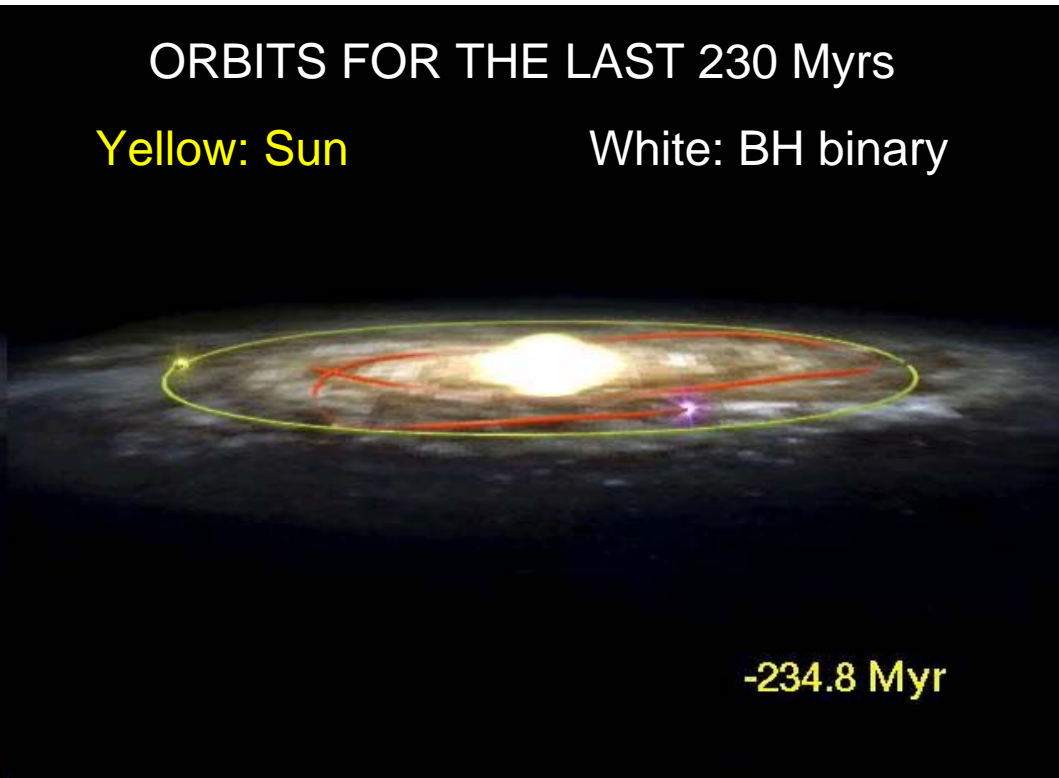
# RUNAWAY BLACK HOLE

**GRO J1655-40**       $M_{\text{BH}} \sim 4 M_{\odot}$

ORBITS FOR THE LAST 230 Myrs

Yellow: Sun

White: BH binary



**A LIKELY FOSSIL OF A GRBs  
FORMED IN AN HYPER-NOVA**  
(Israelian et al. Nature 2001)

Mirabel, Irapuan Rodrigues et al.  
(A&A 395, 595, 2002)

Proper motion with HST +  
radial velocity from ground

**RUNAWAY VELOCITY  $\sim 120$  km/s**

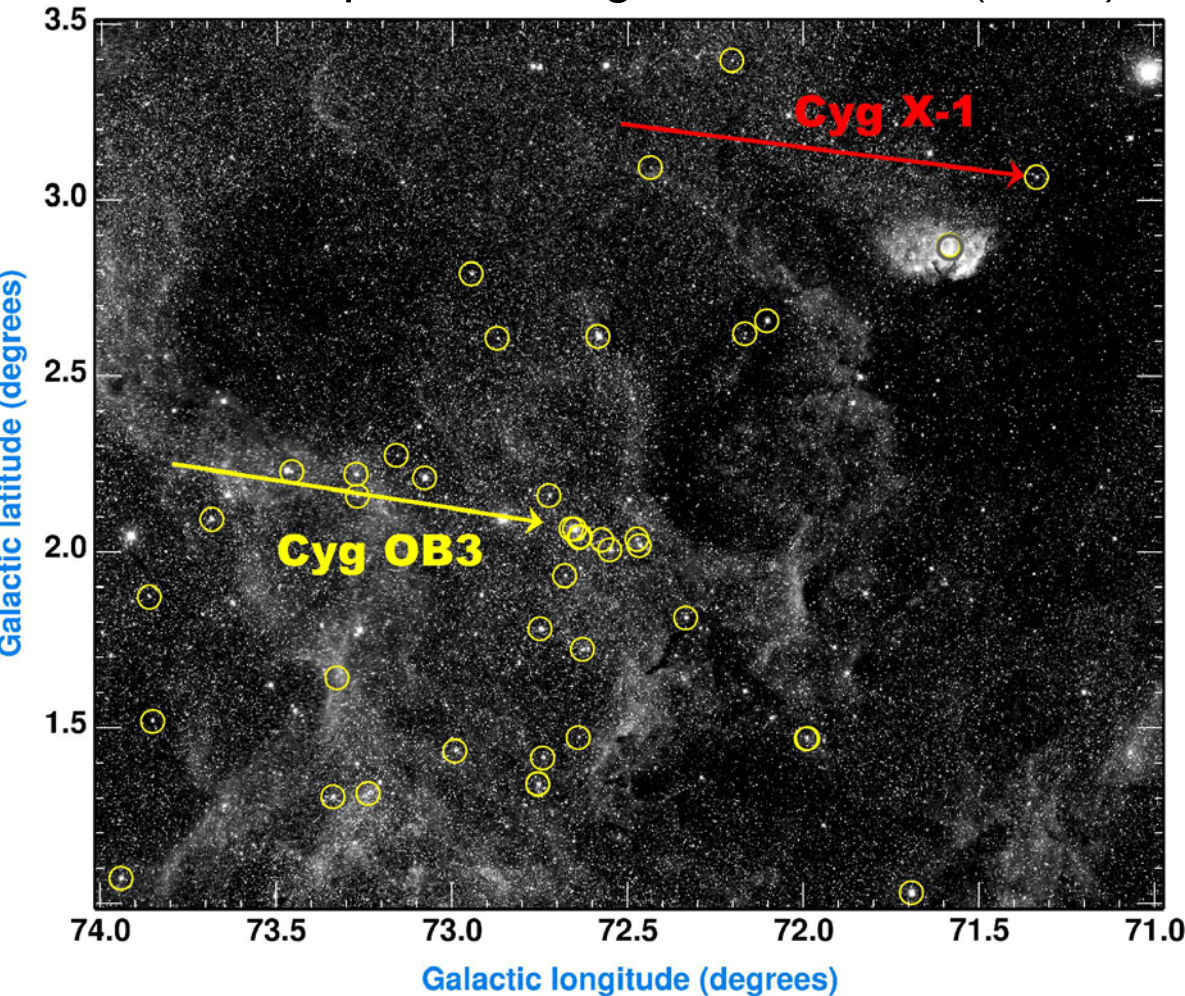
**MOMENTUM =  $550 M_{\odot}$  km/s**

as in runaway neutron stars

# LOW-MASS BLACK HOLE FORM IN A LUMINOUS SUPERNOVA

# THE $\sim 10 M_{\odot}$ BLACK HOLE IN Cyg X-1 WAS BORN IN THE DARK

M. & Irapuan Rodrigues, Science (2003)



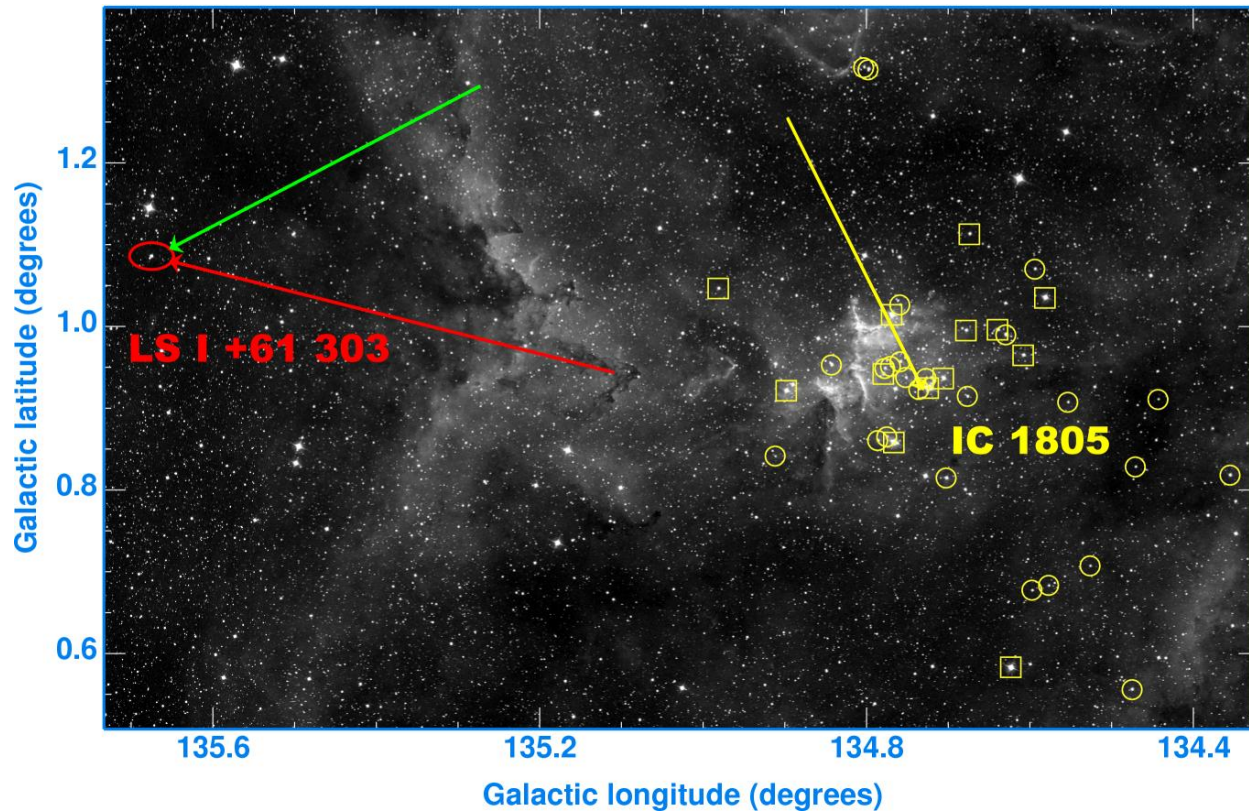
$$V < 9 \pm 2 \text{ km/s} \Rightarrow$$

$< 1 M_{\odot}$  ejected in SN

Otherwise it would have  
been shot out from the  
parent association of  
massive stars

## MASSIVE STELLAR BH FORM PROMPTLY

# A $\mu$ QSO SHOT OUT FROM A CLUSTER



Using an approach called  
“Virtual Astronomy”

Mirabel, I. Rodrigues & Lu  
(A&A, 422, L29, 2004)

$V \sim 27 \text{ km/s} \Rightarrow \sim 2 M_{\odot}$  were blown away

Linear momentum =  $430 M_{\odot} \text{ km/s}$ , as in runaway neutron stars

THE RELATIVISTIC STAR IN LSI +61 303 WAS BORN  
< 2 Myr AGO IN AN ASYMMETRIC SN EXPULSION

POSSIBLE COUNTERPART OF A GAMMA-RAY SOURCE



# A BLACK HOLE FORMED ~7 BILLIONS YEARS AGO IN THE GALACTIC HALO

GALACTOCENTRIC ORBIT FOR THE LAST 230 Myrs

Yellow: Sun

White: BH binary



~230 Million years ago

M. & Irapuan Rodrigues,  
Nature 2001

XTE J1118+480

$M_{\text{BH}} = 9 M_{\odot}$

$l=158^{\circ}$   $b=+62^{\circ}$ ;  $D=1.9$  kpc

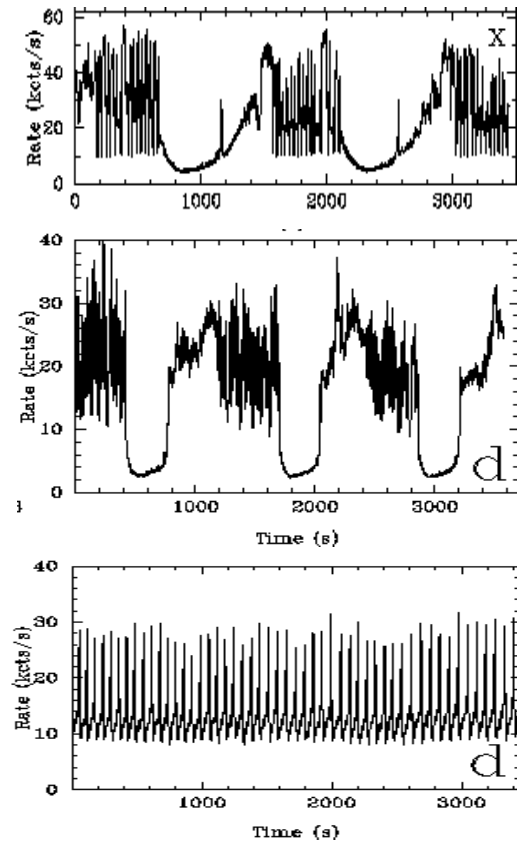
GALACTIC ARCHEOLOGY  
OF MASSIVE STARS

PROBABLY ONE OF THE SEVERAL MILLIONS BHs  
THAT ESCAPED FROM GLOBULAR CLUSTERS

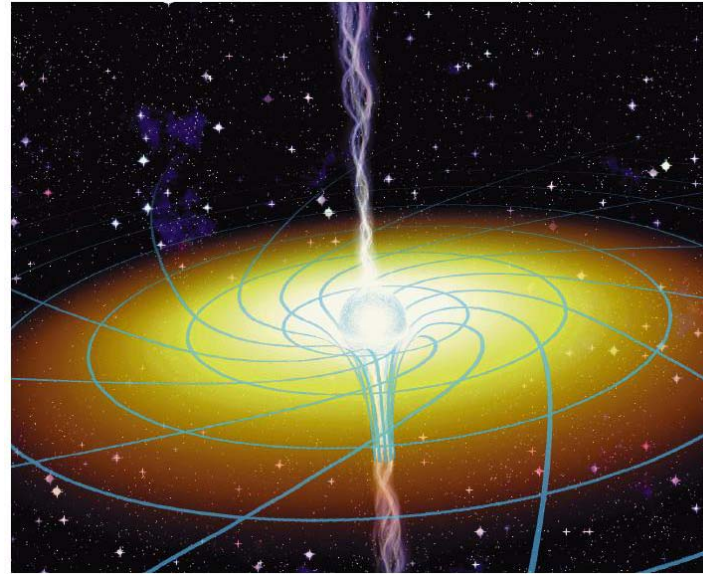


# QPOs AND GENERAL RELATIVITY

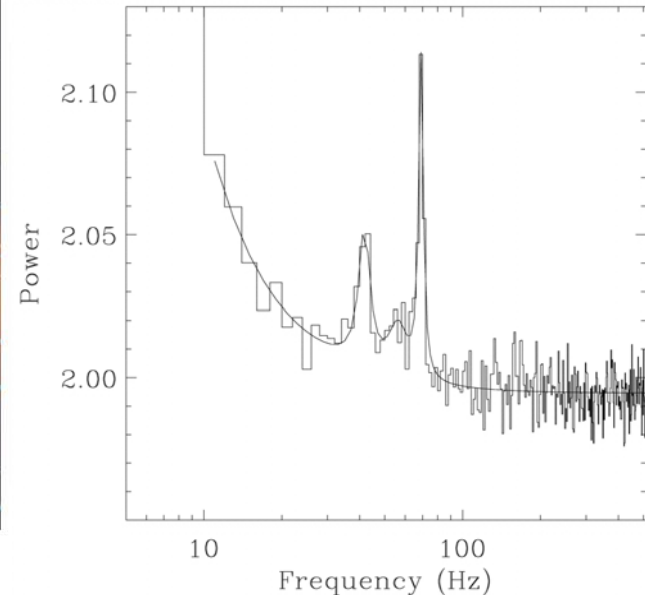
## XTE & INDIAN SAT.



Jerome Rodriguez et al.



## GRS 1915+105 (Strohmayer)



- High frequency QPOs (e.g. 40 & 67 Hz repeat in GRS)
- This 3:2 ratio now found in 4 BHXBs (Remillard et al.)  $\Rightarrow$

must depend on fundamental properties of black hole

$v_{\max} = f(M_{\text{BH}}, \text{Spin}) \Rightarrow$  DETERMINE THE SPIN OF BLACK HOLES

THE BLACK HOLE SPIN & DISK TEMPERATURE SUGGEST

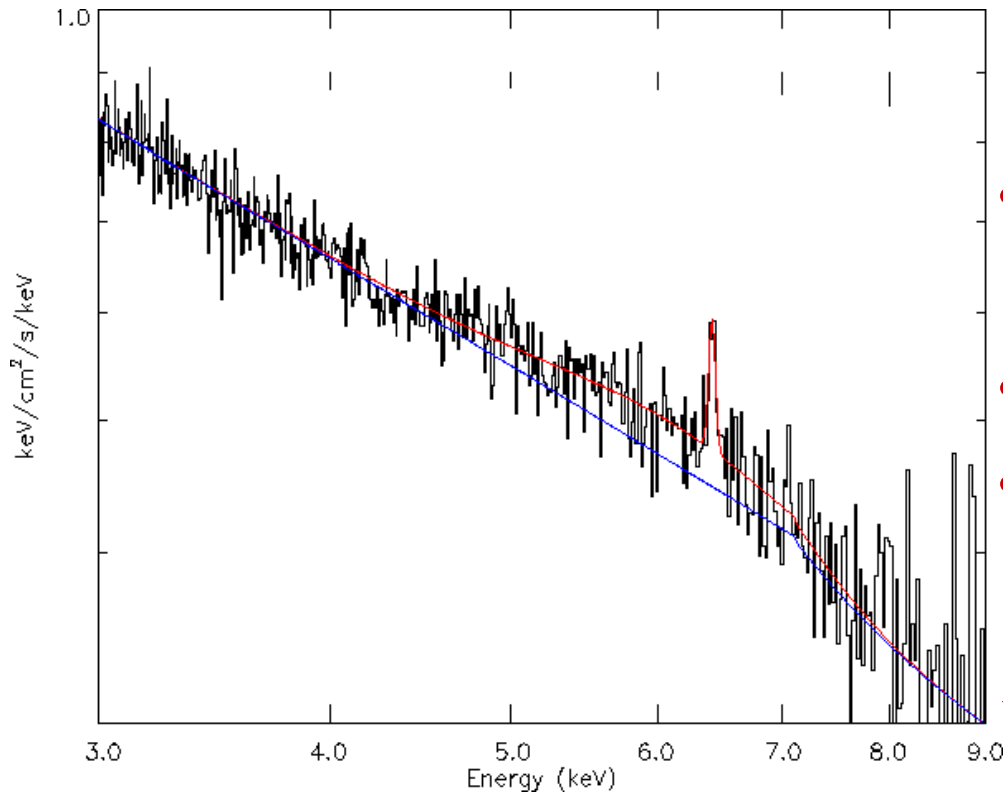
THAT JETS MAY BE POWERED BY THE BLACK HOLE SPIN

# Fe $K\alpha$ LINES IN $\mu$ QSOs

Cygnus X-1

Miller et al. (2002)

FOUND IN ~6 MICROQASARS



CHANDRA, XMM & Beppo-SAX

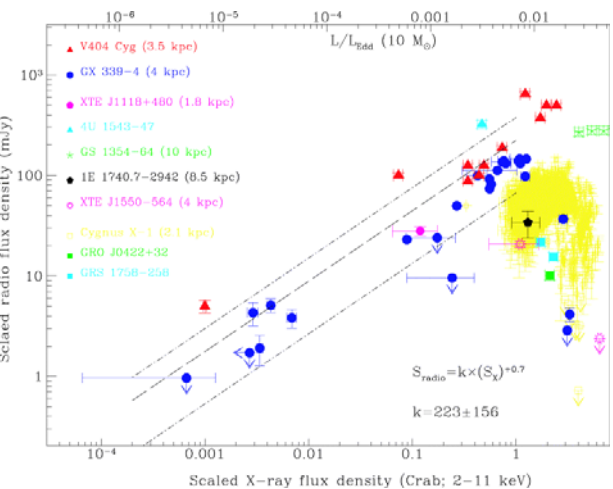
- Asymmetry: gravitational redshift, Doppler & transverse-Doppler shift
- Narrow component from outer disk ?
- Broad component from inner disk

SPINNING BLACK HOLE?

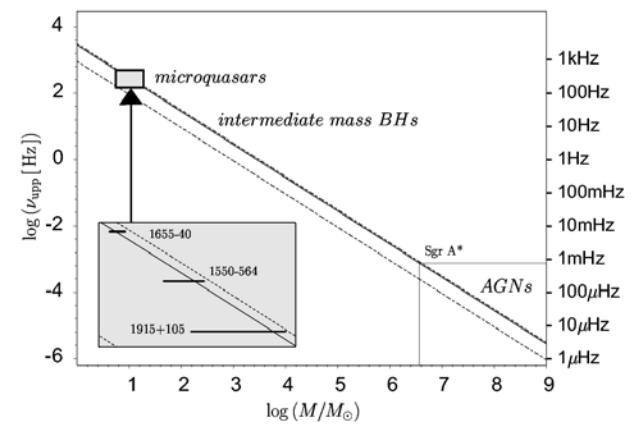
**$\mu$ QSOs MAY BE GOOD LABORATORIES TO STUDY IN SHORT TIME SCALES THE Fe  $K\alpha$  LINES AS A FUNCTION OF X-RAY STATE (e.g. GRS 1915+105)**

# IF THE EMPIRICAL CORRELATIONS

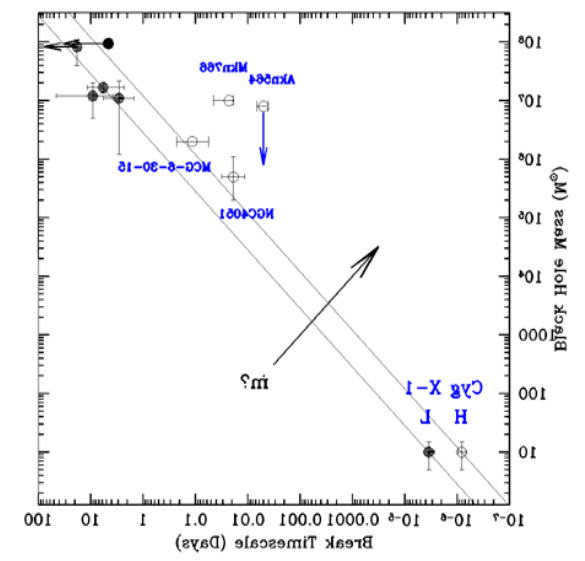
X-ray/radio/mass  
Gallo et al. 2004



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

# SUMMARY

Microquasars have provided insight into:

- **THE PHYSICS OF RELATIVISTIC JETS FROM BH's**
- **THE CONNECTION BETWEEN ACCRETION & EJECTION**
- **THE FORMATION OF STELLAR-MASS BLACK HOLES**

Microquasars could provide insight into:

- **A LARGE FRACTION OF ULXs IN NEARBY GALAXIES**
- **GRBs OF LONG DURATION IN DISTANT GALAXIES**

**BLACK HOLE ASTROPHYSICS IS TODAY IN AN ANALOGOUS SITUATION AS WAS STELLAR ASTRONOMY IN THE FIRST HALF OF LAST CENTURY, WHEN THE HR DIAGRAM WAS CONSTRUCTED FOR FIRST TIME**