FORMATION OF BLACK HOLES BY IMPLOSION

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From the properties of the fossils of massive stars can we infer whether they finished as energetic SNe or silently ?

Are there observations that support the theoretical prediction of black hole formation with no SNe ?

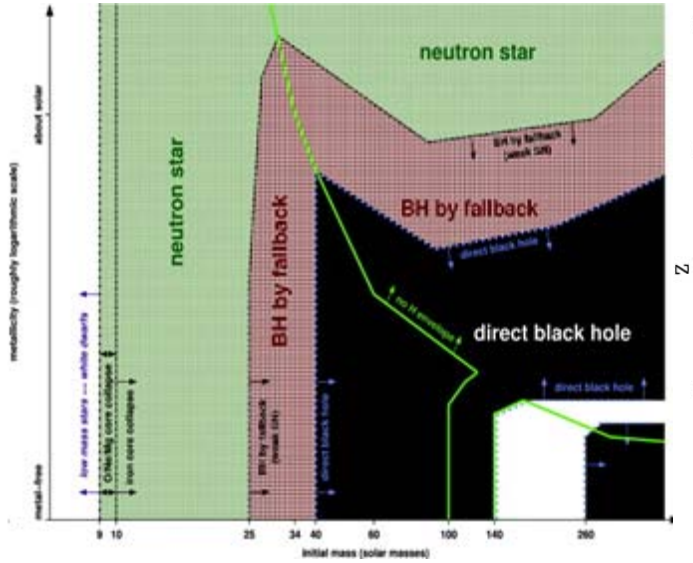
It is difficult to prove the “inexistence”…

Plan of the talk:

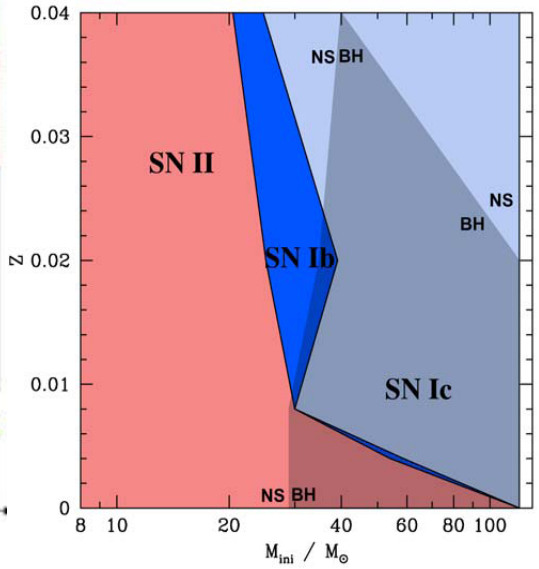
- Review the predictions from theoretical models
- Review observations of neutron stars and black holes that support direct formation of black holes
- The formation of black hole binaries depends on the SFR of the host galaxy and Z of the progenitor
- Cosmological implications

MODELS FOR THE COLLAPSE OF SINGLE MASSIVE STARS

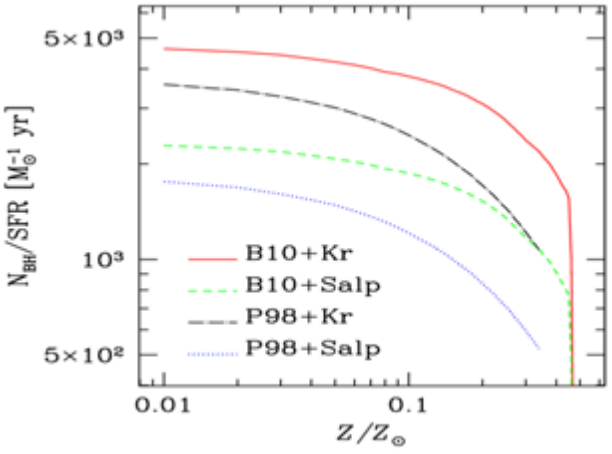
Heger et al. (2003)
with no rotation



Georgy et al (2009)
with rotation



Mapelli et al. (2010)
Number of expected massive BHs per galaxy normalized to the SFR as a function of Z

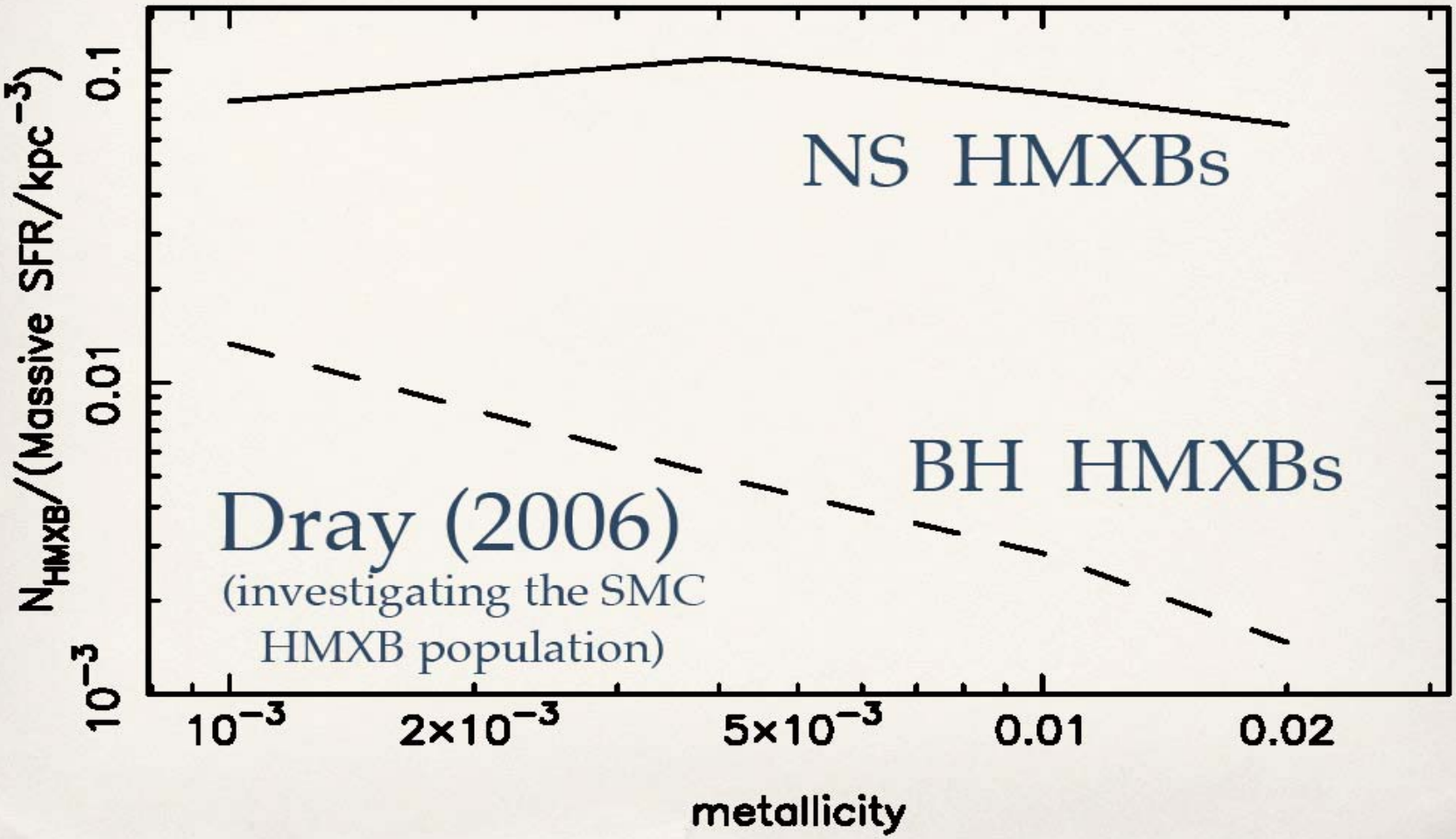


- **Low metal progenitors may form BHs by implosion** (Fryer, 1999)
- **There is a threshold effect: BHs form with $Z < 0.5\ Z_{\odot}$**

But the destiny of massive stars also depends on magnetism & **binarity**

FORMATION OF BH HMXBs AS A FUNCTION OF SFR & Z

For early studies of BH-binary Z-dependence, see Belczynski et al. (2004) & Dray (2006)



In the context of current models:

- THE MASS OF STELLAR BLACK HOLES
- THE FRACTION OF BLACK HOLES / NEUTRON STARS
- THE FRACTION OF BINARY / SOLITARY BLACK HOLES

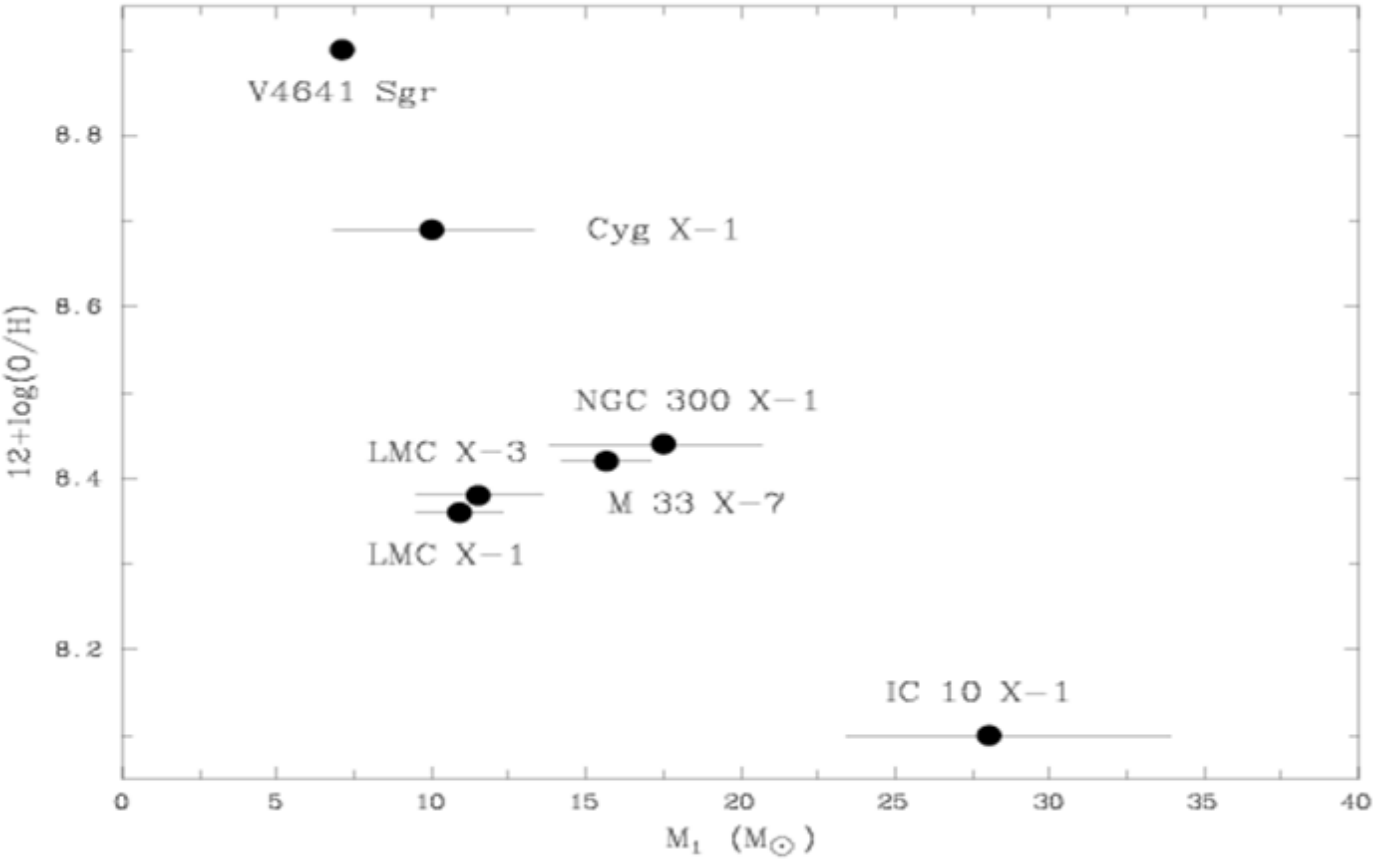
SHOULD INCREASE WITH THE SFR OF THE HOSTS & DECREASING METALLICITY OF THE PROGENITORS:

Because the fraction of binary systems that remain bound increases, from a theoretical point of view one expects that

THE FRACTION OF BLACK HOLE HIGH MASS X-RAY BINARIES SHOULD INCREASE WITH THE SFR OF THE HOST GALAXIES AND DECREASING METALLICITY OF THE PROGENITORS

THE MASS OF BHs IN HMXBs SEEMS TO BE A DECREASING FUNCTION OF METALLICITY

Masses determined dynamically (Crowther et al. 2010)



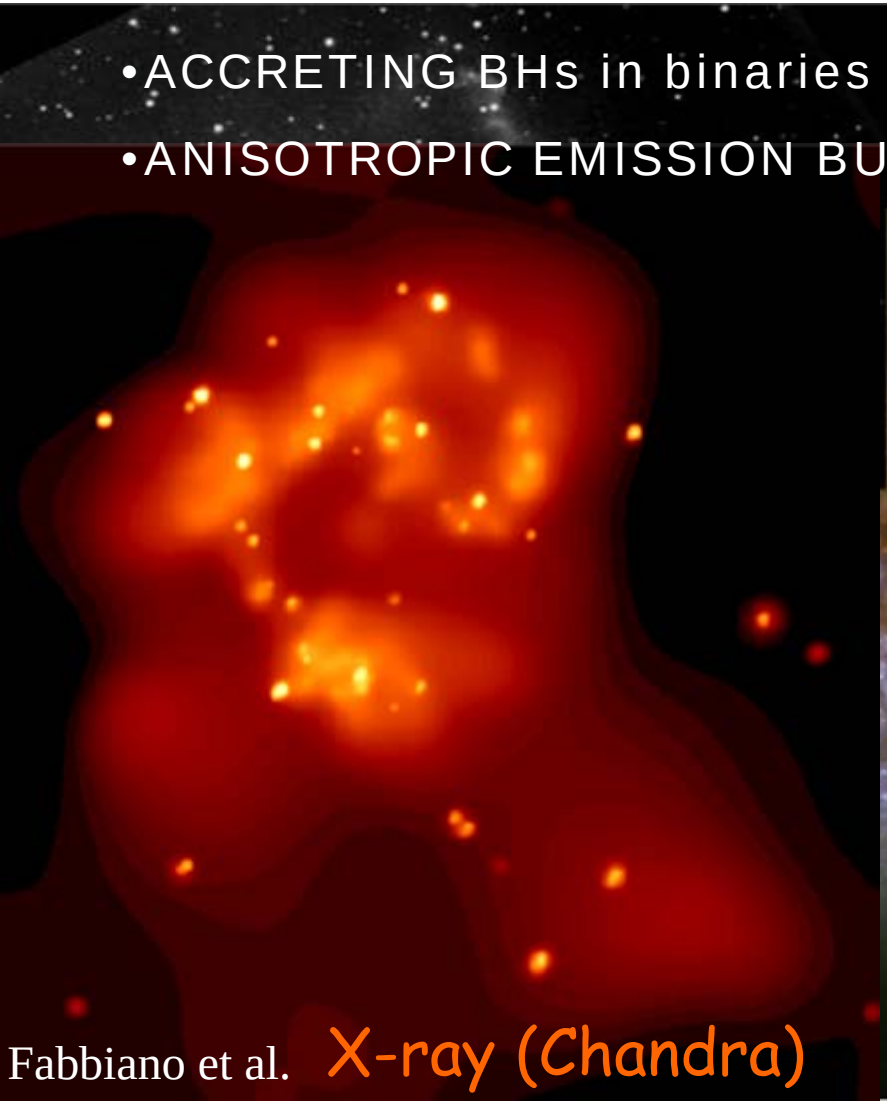
The stellar BHs in M 33 X-7, NGC 300 X-1, IC 10 X-1 have $M_{BH} > 15\ M_{\odot}$ whereas in the Galaxy and M 31 no stellar BH with $M_{BH} > 14\ M_{\odot}$ is known

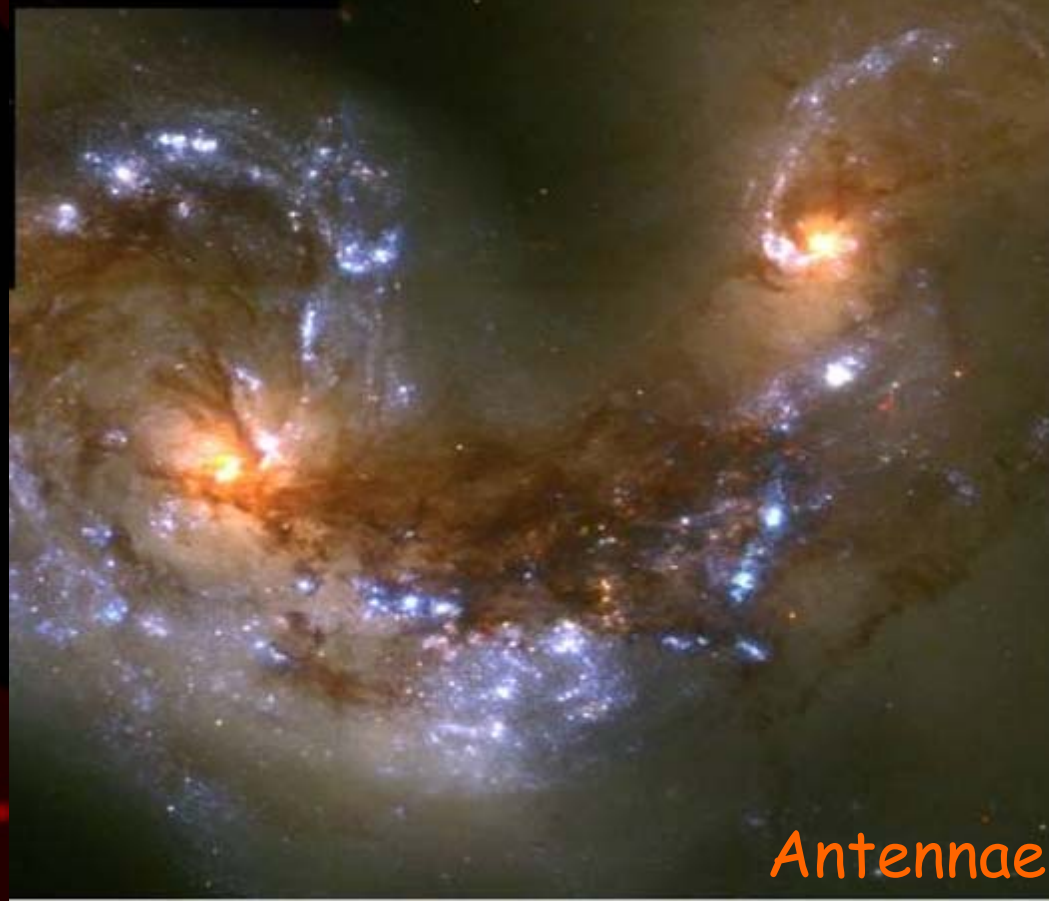
Does the new dynamic mass for NGC 1313 X-2 reveal another black hole of large stellar mass ?

THE OCCURRENCE RATE OF ULXs PER UNIT GALAXY MASS IN STARBURST GALAXIES IS A DECREASING FUNCTION OF THE METALLICITY OF THE HOST GALAXY

e.g. Zampieri & Roberts (2009)

- ACCRETING BHs in binaries with $M_{BH} > 30\ M_{\odot}$ (Pakull et al. 2002)
- ANISOTROPIC EMISSION BUT NOT BEAMED (King et al. 2001)

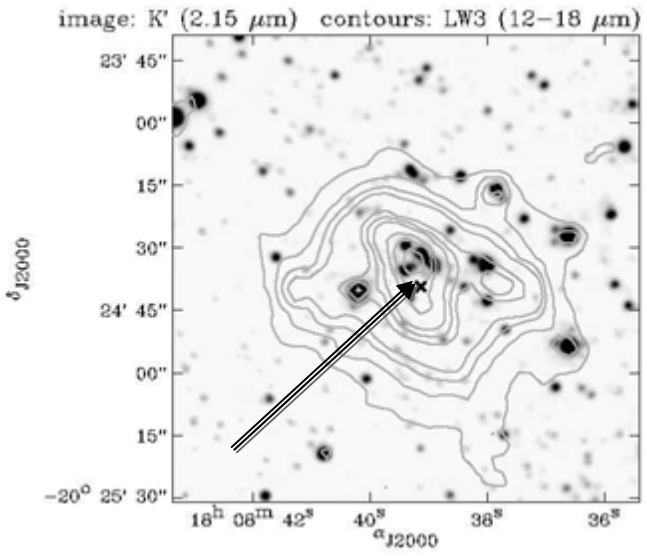




SGRs and AXPs (young neutron stars) found in clusters of massive stars

SGR 1806-20

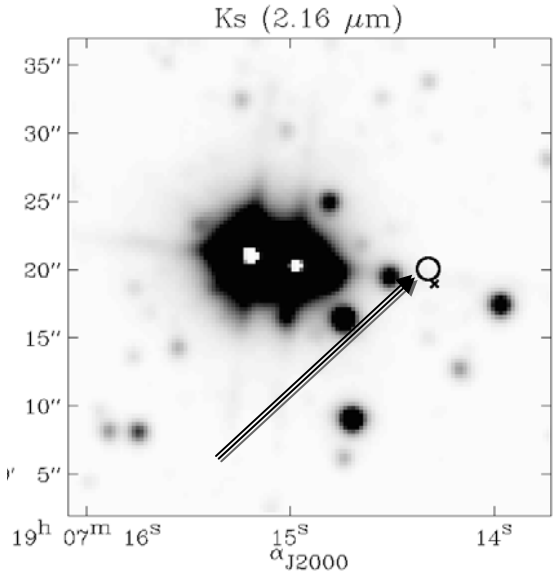
Mirabel et al. (1999)



$M_{prog} > 40\ M_{\odot}$

SGR 1900+14

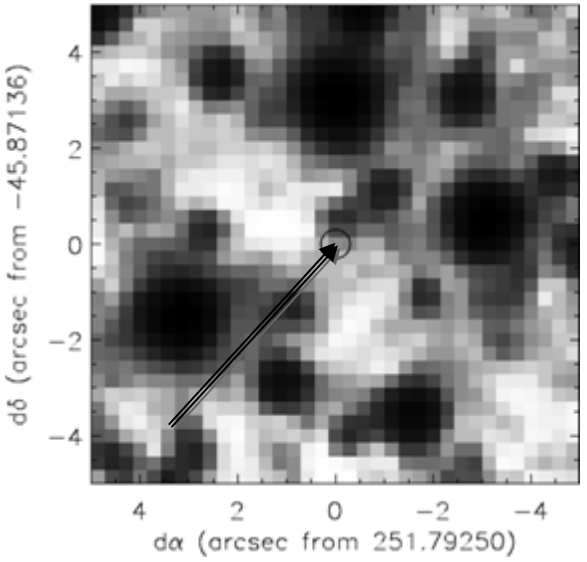
Vrba et al. (2000)



$M_{prog} > 25\ M_{\odot}$

AXP 1647-45

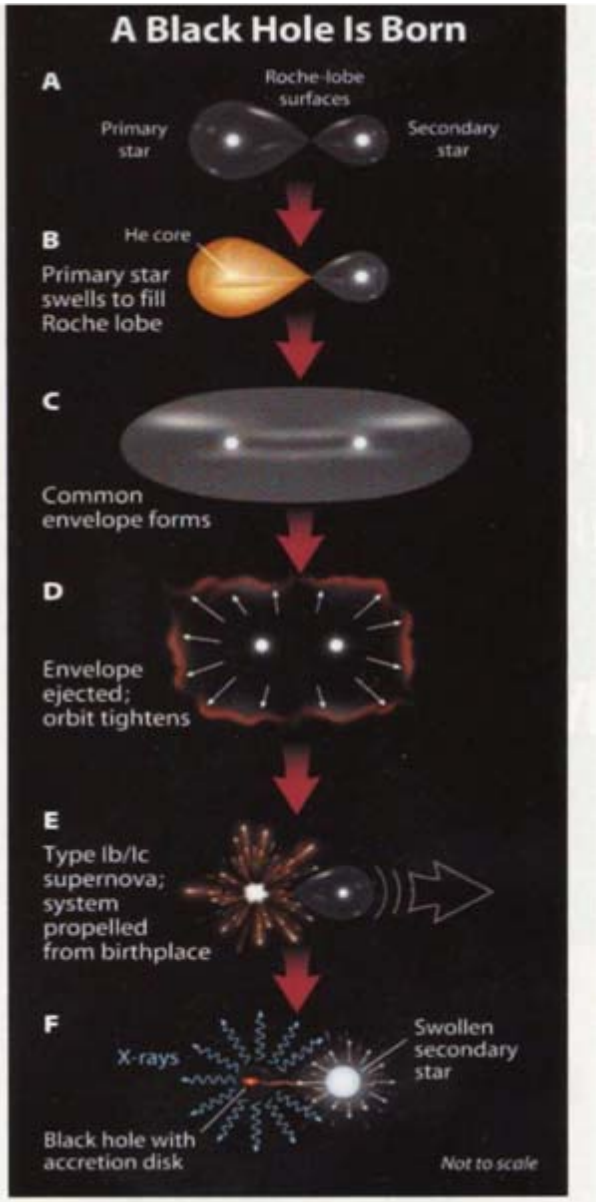
Muno et al. (2006)
in Westerlung 1



$M_{prog} > 40\ M_{\odot}$

MASSIVE STARS OF HIGH METALLICITY END AS NEUTRON STARS RATHER THAN BLACK HOLES

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

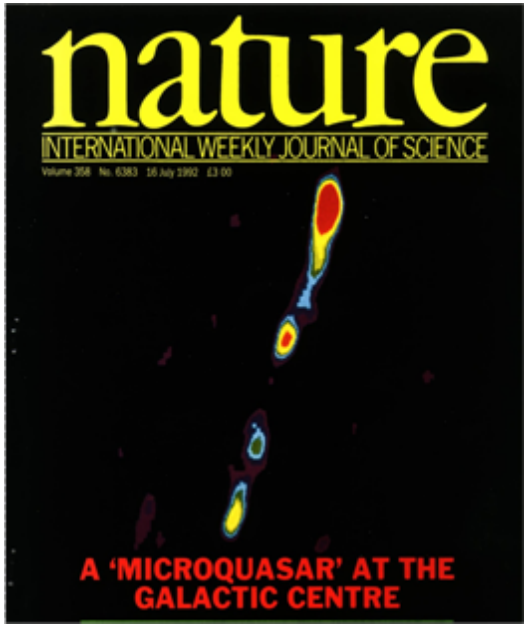
IF THE BH BINARIES HAVE NO ANOMALOUS MOTIONS THEY MUST HAVE BEEN FORM WITH NO ENERGETIC SNe KICKS

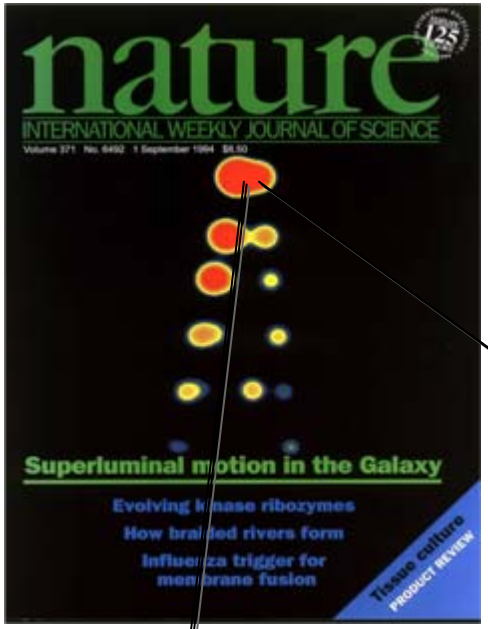
SO FAR DETERMINED THE SPACE VELOCITY (KINEMATICS) FOR 5 BHXRBs WITH 5-14 $\mathbf{M}_{\odot}$

JETS IN MICROQUASARS

Mirabel et al. (1992) Mirabel & Rodríguez (1994)

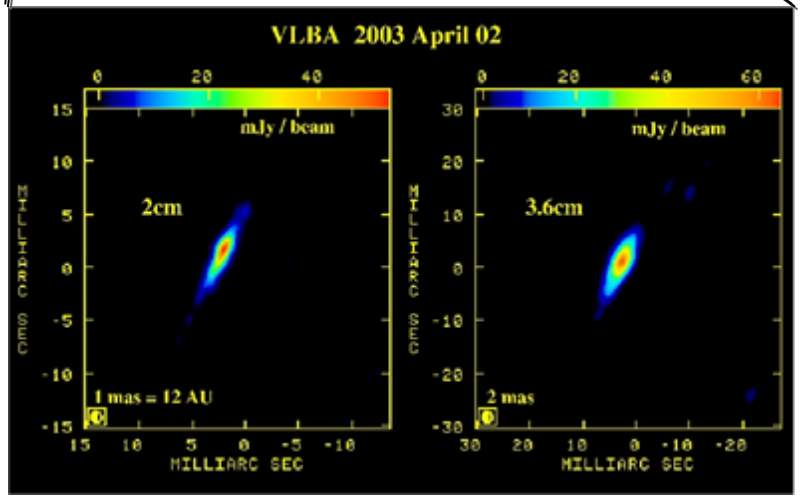
STEADY JETS





TRANSIENT JETS

Dhawan, Mirabel, Rodríguez (2007)



COMPACT JETS

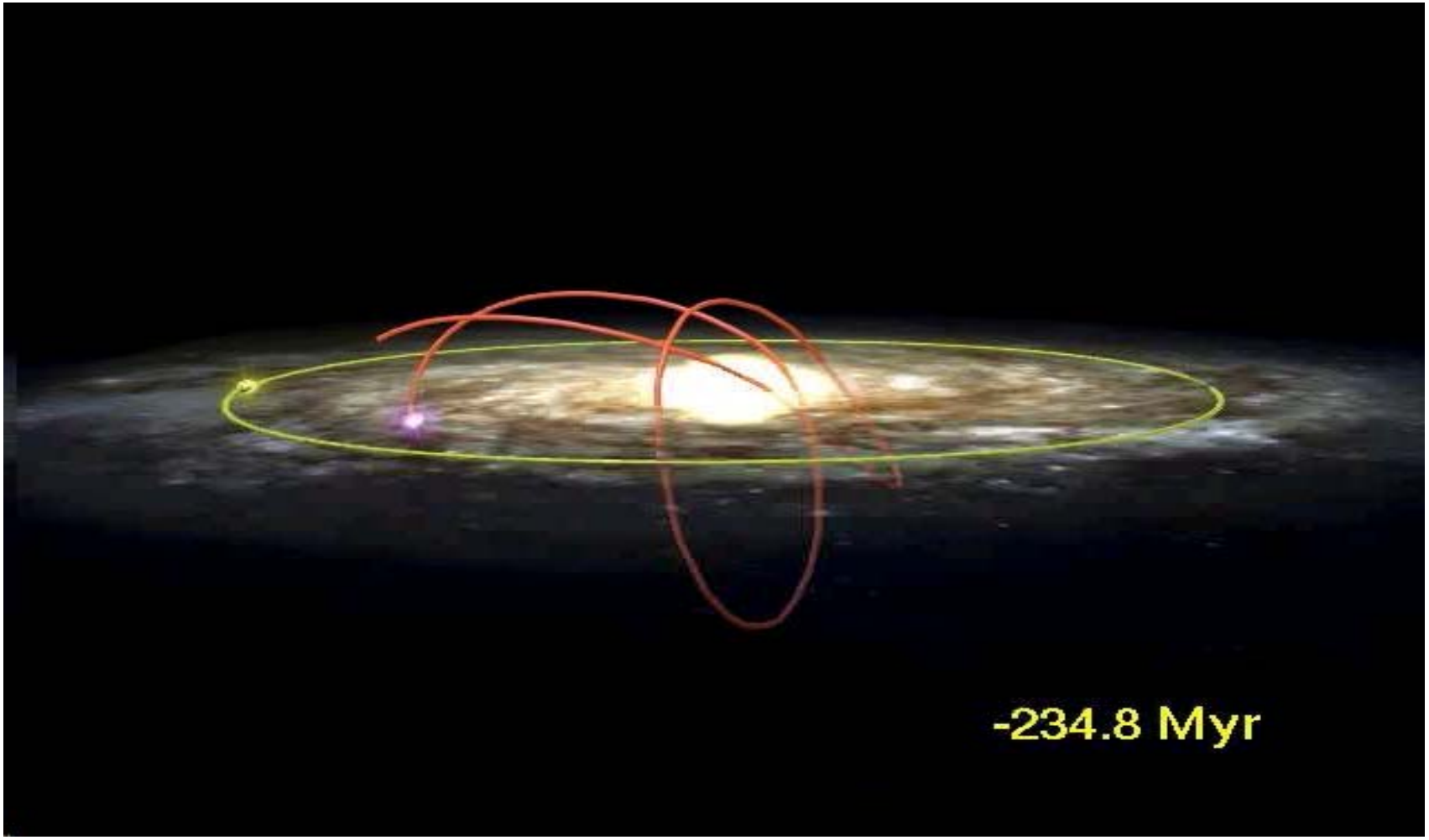
In low hard state. Size ~ 100 AU. Same PA

USED TO DETERMINE PROPER MOTIONS

(with VLBI to get sub-miliarc sec precision)

THE GALACTIC TRIP OF SCORPIUS X-1

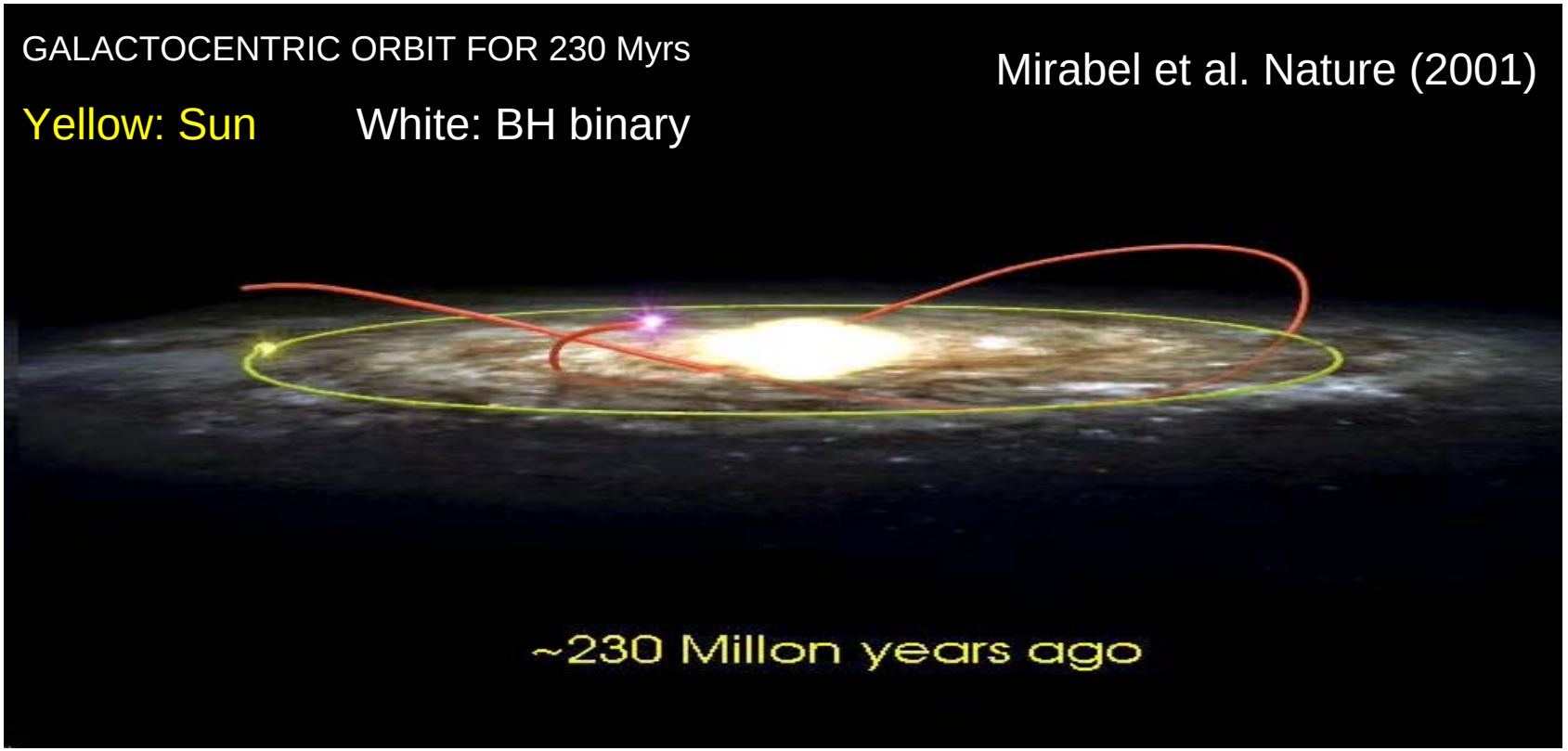
Parallax $\Rightarrow$ the best determined space velocity (Mirabel & Rodrigues, 2003)



SCORPIUS X-1 WAS SHOT OUT FROM THE GALACTIC BULGE OR SCAPED FROM A GLOBULAR CLUSTER

TWO RUNAWAY BLACK HOLES

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



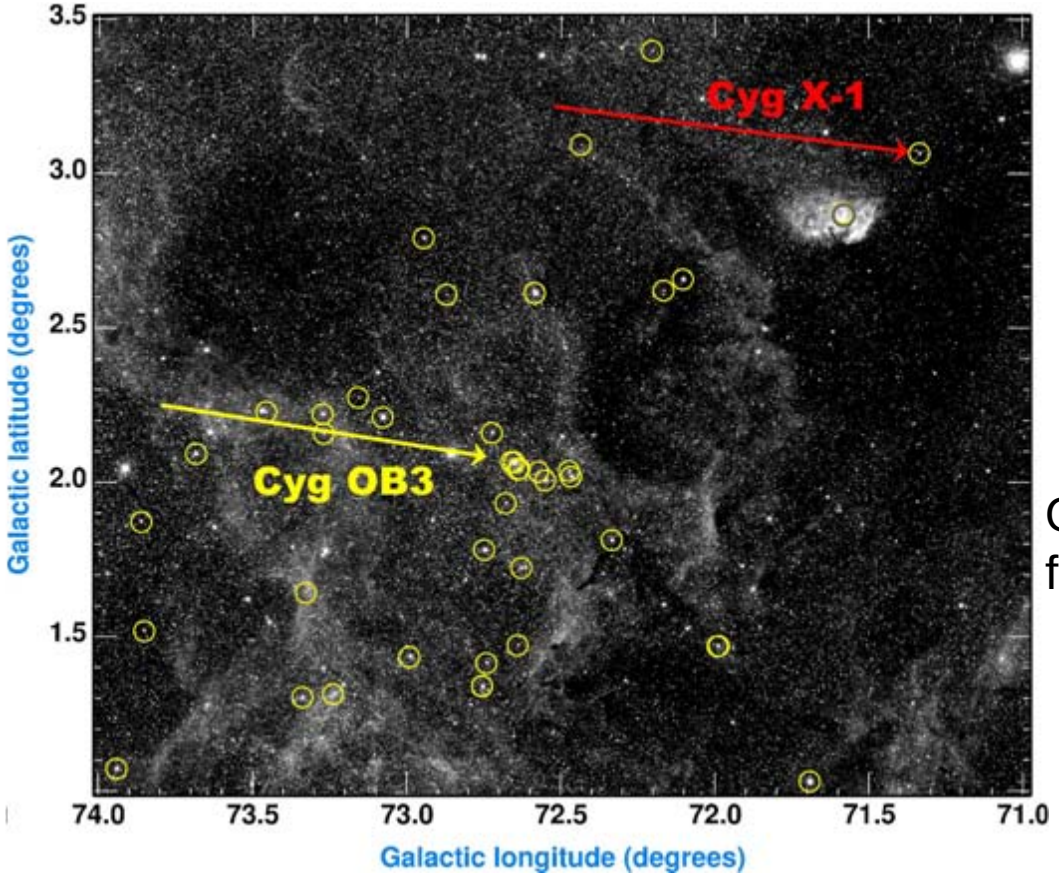
GRO J1655-40: Fossil of a HPN (Israelian et al. Nature 1999)

M_{BH}~5-7 $M_\odot$ M_*~2 $M_\odot$;D=1-3 kpc; V_p=112+/-18 km/s (Mirabel et al. 2002)

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

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 & L.F. 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, THE PECULIAR VELOCITY DISPERSION OF PULSARS SHOW THAT KICKS HAVE NO PREFERENTIAL DIRECTION.

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

THE THREE GALACTIC BHs WITH M_{BH}>10 $M_\odot$ HAVE BEEN FORM DIRECTLY OR WITH FAINT SNe

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

Other possible indications of direct black hole formation

1) No high mass progenitors < 18 $M_{\odot}$ in core collapse SNe (Smartt, this meeting)

2) Most galaxy hosts of LGRBs are small, irregular galaxies of low metallicity (Le Floc´h, Duc, Mirabel 2003; Fruchter + 2006; Savaglio + 2009).

3) CCSNe prefer higher metallicity spiral galaxy hosts than LGRBs (Graham, Fruchter et al. 2010, Svenson et al. 2010)

4) Faint core collapse SNe II with extremely low V_{exp} of the ejecta & extraordinarily low ^{56}Ni in the ejecta (Zampieri et al. 2003; Valenti et al. 2009 $\Rightarrow$ formation of black holes by implosion ?

5) No luminous SNe found associated with GRB 060505 & GRB 060614. Caveat: alternative interpretations: e.g. possibility of low ^{56}Ni production.

6) Does the rate of LGRBs increases with redshift ? Controversial issue: YES (Daigne+ 2006; Kistler+ 2009); NO (Podsiadlowski)

THE BOTOM-UP GALAXY FORMATION & THE COSMIC EVOLUTION OF METALLICITY ⇒ A COSMIC EVOLUTION OF HMBHBs

- THE MASS OF STELLAR BLACK HOLES
- THE FRACTION OF BLACK HOLES/NEUTRON STARS
- THE FRACTION OF BINARY/SINGLE BLACK HOLES

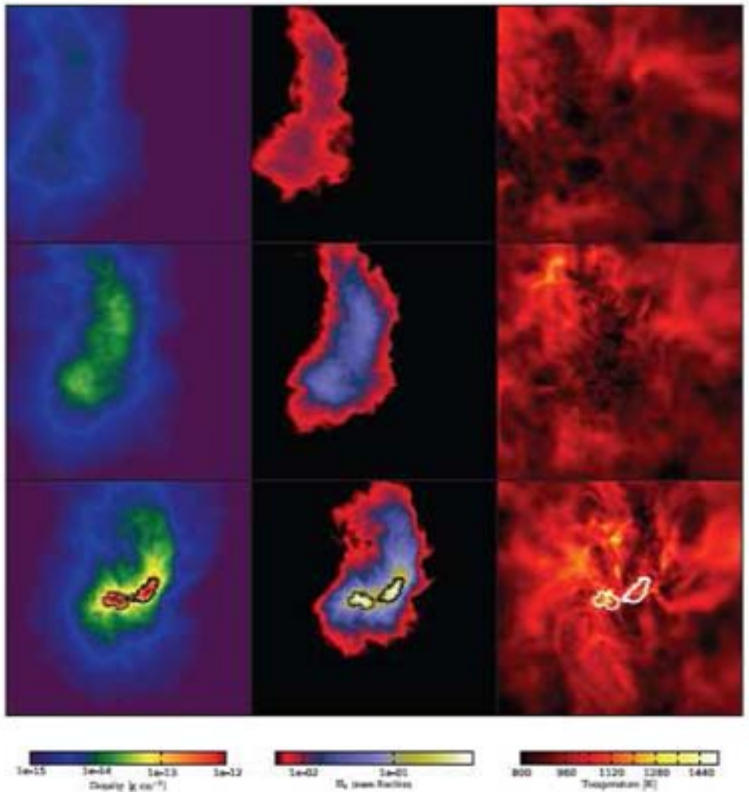
SHOULD INCREASE WITH REDSHIFT

WHAT MAY BE THE COSMOLOGICAL IMPLICATIONS OF A POPULATION OF HMBHBs (MICROQUASARS) AT HIGH z ?

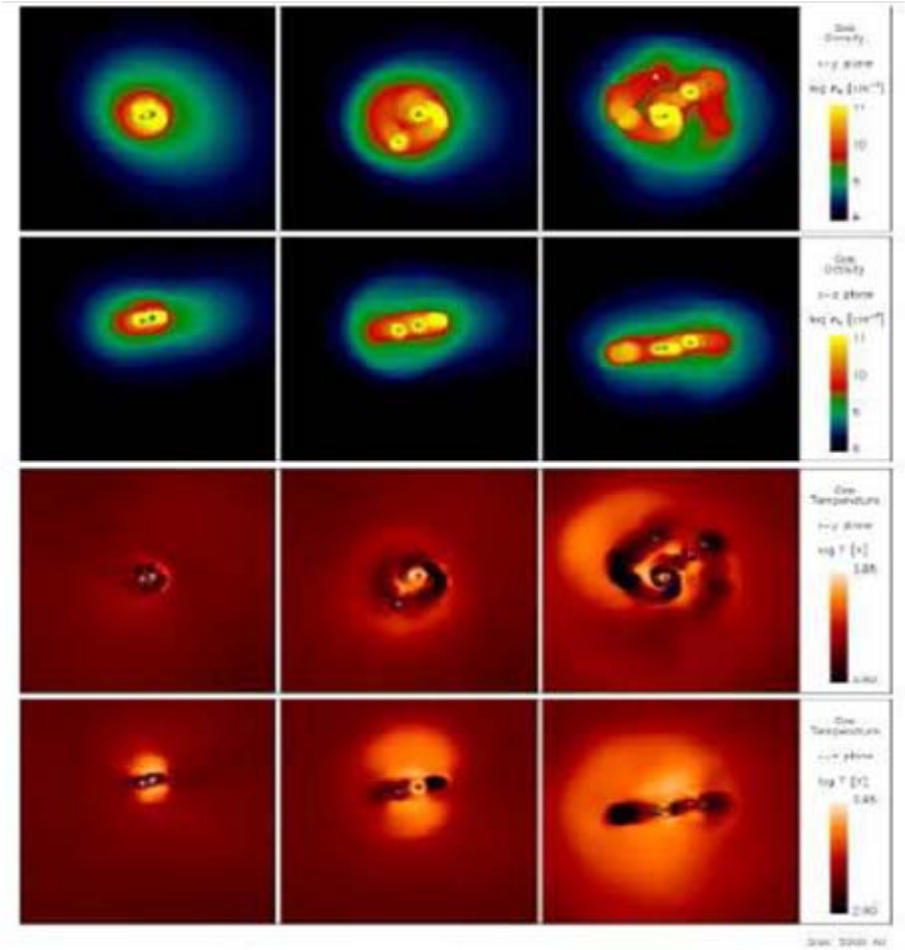
(Sunyaev in VII Microquasar workshop)

THIS IS A TIMMELY QUESTION BECAUSE…

POPULATION III BINARIES



Turk, Abel & O'Shea (Science 2009)
Krumholz et al. (Science 2009)



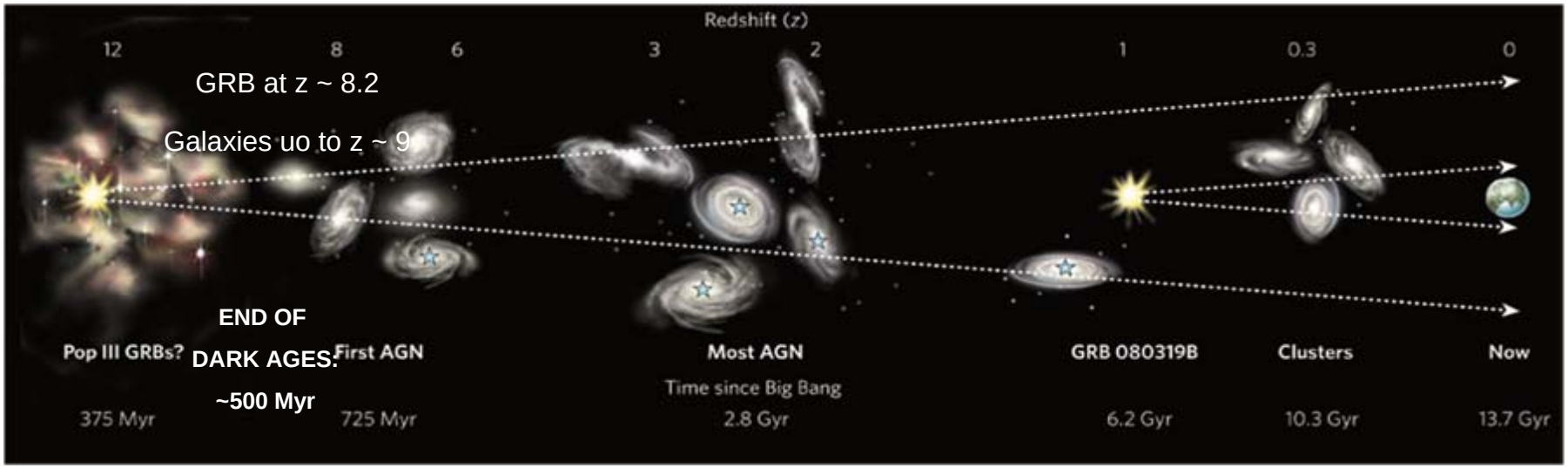
Stacy, Greif & Bromm (ApJ 2010)

Pop III stars were formed as small multiple systems dominated by binaries of a few tens of solar masses

DID BLACK HOLE BINARIES PLAY A COMPLEMENTARY ROLE TO THAT OF THEIR MASSIVE PROGENITORS AT THE END OF THE DARK AGES ?

Mirabel, Loeb, Diskra, Laurent (in progress)

From ~ 4 x 10^5 yr to < 10^9 yr after the Big Bang



Timeline of the Universe since the formation of the first stars

BESIDES BEING AN IMPORTANT SOURCE OF HEAT, BH-HMXBs MAY HAVE BEEN A COMPLEMENTARY SOURCE FOR RE-IONIZATION OF THE IGM (in progress)