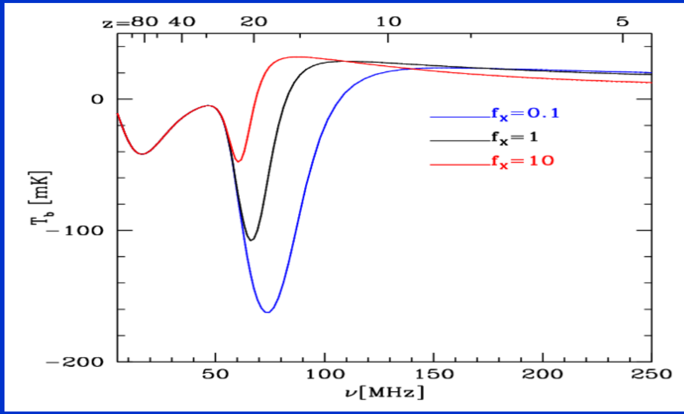
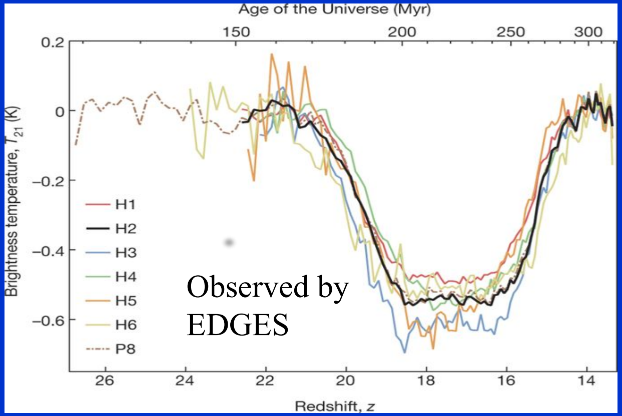
STELLAR BLACK HOLES AT COSMIC DAWN

Félix Mirabel (CEA-Paris-Saclay & CONICET-UBA)

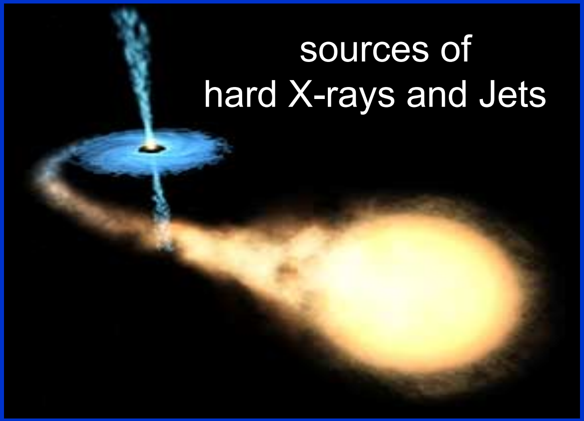
Mirabel+ AA & N&V in Nature (2011)



Bowman+ (Nature 2018)



BH-HMXB-MQs of POP III

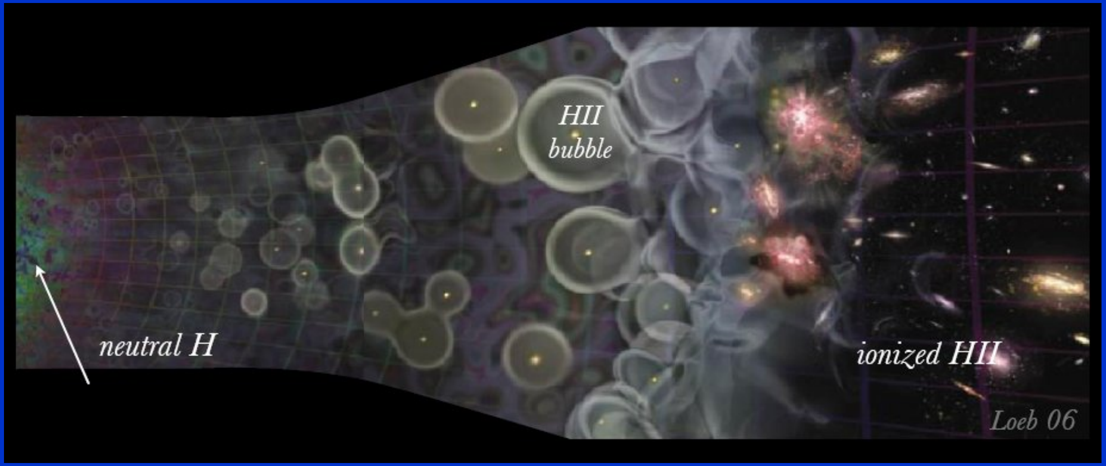


CAN POP III BH-HMXB-MQs ACCOUNT FOR THE TENTATIVE EDGES DETECTION OF λ21cm HI ABSORPTION AT z~17?

Mirabel (2019): Review at IAU Symp. 346 arXiv#1902.00511

Until 2011 the heating & reionization sources of the IGM are the UVs from Pop III/II stars & soft X-rays from SNe…which are absorbed by high dense HI

THE « SWISS CHEESE » MODEL ⇒ A PATCHY STRUCTURE



"Stellar black holes at the dawn of the universe"

Mirabel, Diskra, Loeb, Laurent, Pritchard; A&A & N&V by Haiman in Nature (2011)

- **BH-HMXB-MQs FORMED PROLIFICALLY AS REMNANTS OF POP-III STARS**
-
- **HARD X-RAYS FROM POP-III BH-HMXBs PRE-HEATED THE IGM**

⇒A smoother end of cosmic reionization

ASTROPHYSICAL GROUNDS FOR A PROLIFIC FORMATION OF BH-HMXBs AT COSMIC DAWN

THEORETICAL GROUNDS

- **MOST POP III & II STARS WERE FORMED AS MULTIPLE SYSTEMS**
  Turk+Science 2009; Krumholz+ Science 2009; Clark+ Science 2011; Stacy+…etc.
- **STARS OF LOW Z WITH M > 20 $M_{\odot}$ END AS BHs BY DIRECT COLLAPSE**
  Fryer,1999;Heger+2003;Georgy+2009;Woosley+2008;Nomoto+2010;Linden,Kalogera+2011

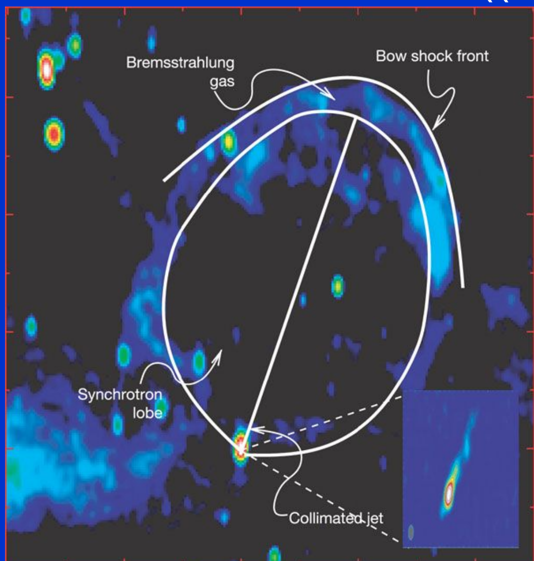
OBSERVATIONAL GROUNDS

- **BHs FORM WITH NO ENERGETIC SNe⇒BHs & DONORS REMAIN BOUND**
  Mirabel & Rodrigues, Science 2003; Mirabel+ Nature 2008
- **MOST ULXs & LGRBs ARE HOSTED IN LOW Z-HIGH-SSFR GALAXIES**
  Feng & Soria,2011;LeFloc'h,Duc,Mirabel;2003;Fruchter+ Nature, 2006; Perley+ 2014
- **IN LOW Z GALAXIES Lx/SFR IS LARGER THAN IN MAIN-S GALAXIES**
  Thuan+ 2004; Kaaret+ 2014; Brobry+ 2018; Douna, Pellizza & Mirabel + 2015, 2018
- **Lx/SFR EVOLUTION WITH z IS DRIVEN BY Z EVOLUTION IN HMXBs**
  Fragos+2012; Basu-Zych+2012; Lehmer, Basu-Zych, Mineo et al. (2016)
  up to z~2.5 $L_{2\text{-}10\ \mathrm{keV}}$ (HMXB)/SFR α (1 + z)
- **THE LARGE BH MASSES & MERGER RATES FOUND BY GWs** (LIGO-Virgo Coll.)

BH-HMXB-MQs IN THE GALAXY

Cygnus X-1

Gallo+ Nature 200((5

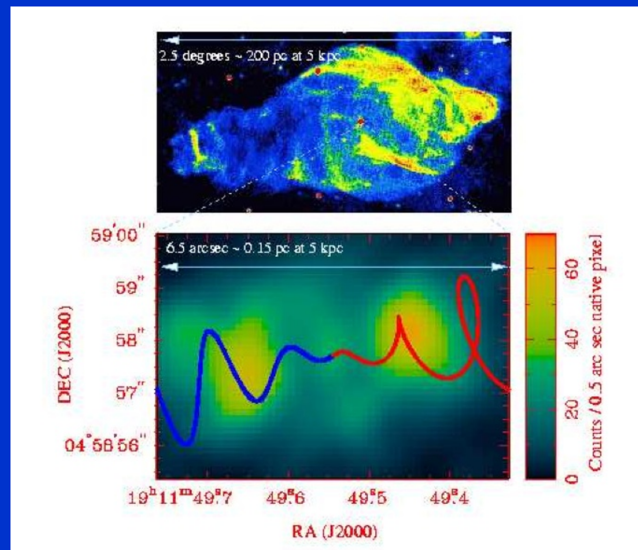


$10^{36} < P_{jet} < 10^{37}$ erg s^{-1}

Total energy ~ 10^{48} erg

SS 433

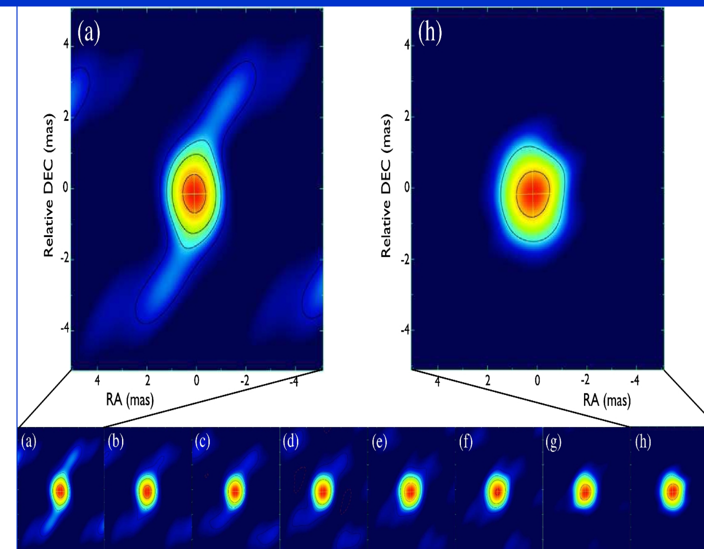
Dubner+; Rupen+ …



Jet power of ~10^{39} erg s^{-1}

Cygnus X-3

Ergon+ 2017



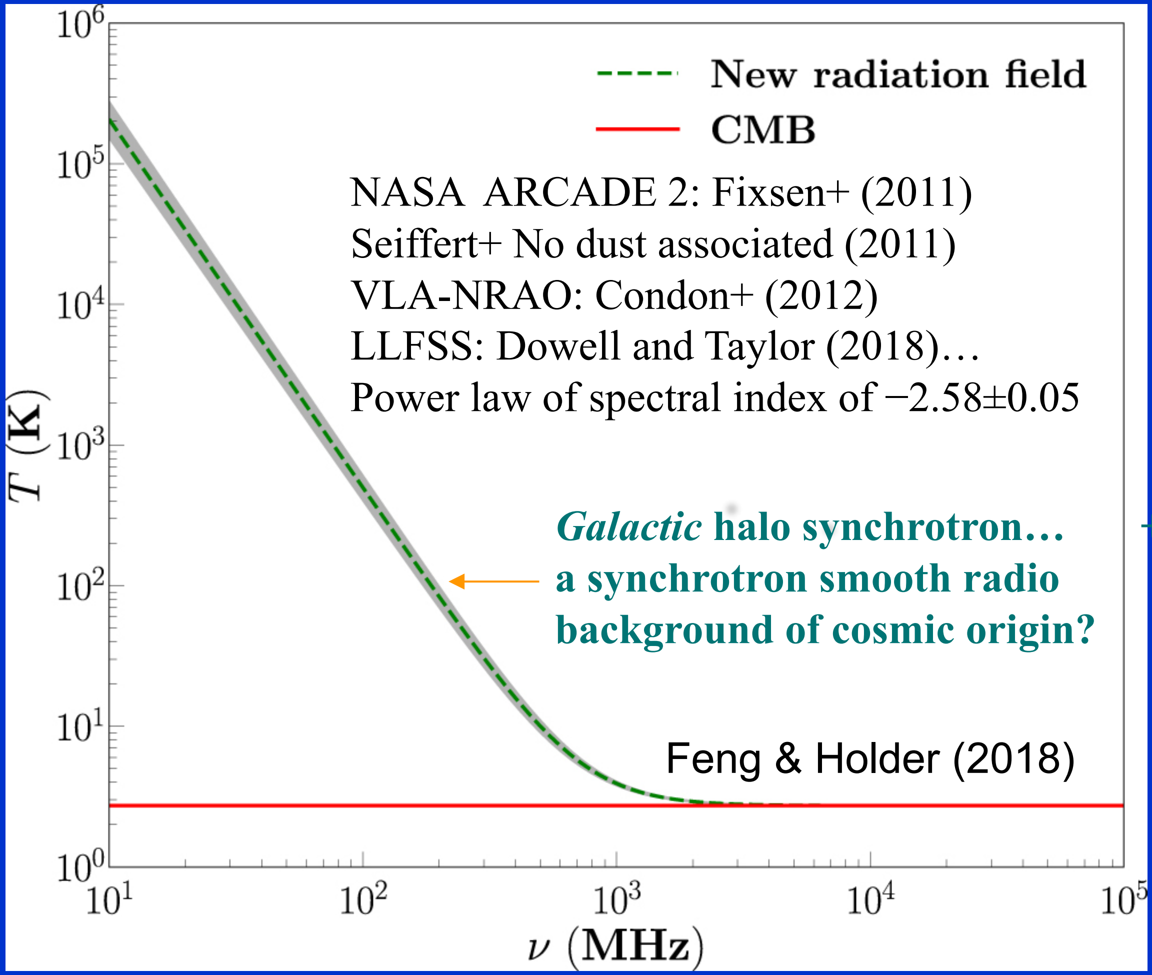
Giant radio flares of 10-50 Jy.

Mean Jet power of 10^{37} erg s^{-1}

BUT BH-HMXB-MQs OF POP III WERE MORE NUMEROUS AND MORE POWERFUL RADIO SOURCES THAN TODAY (Sotomayor & Romero 2019)

Is there a Smooth Synchrotron **Cosmic Radio Background (CRB)?**

ARCADE 2 reported an additional low frequency smooth radio background of possible cosmic origin



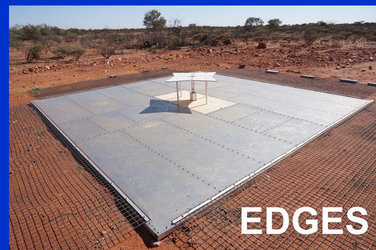
SOME OF THIS POSSIBLE ADDITIONAL SYNCHROTRON RADIO EMISSION MAY COME FROM BH-HMXB-MQs OF POP III

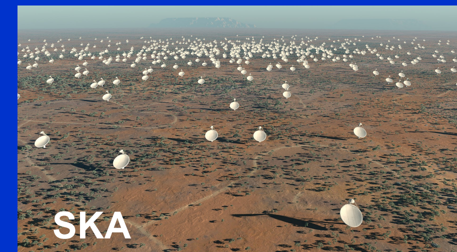
TOMOGRAPHY OF HI IN THE EARLY UNIVERSE

Experiments to Detect the Global EoR Signature
e.g. DARE, EDGES, LEDA

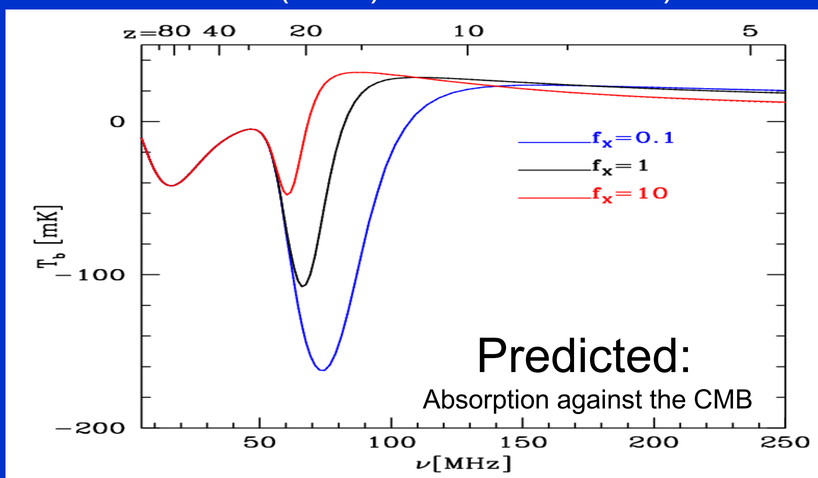
Interferometers for fluctuation measurements
e.g. LOFAR, SKA, HERA

EDGES: Two low-band instruments, each of which has a dipole antenna pointed to the zenith and observing a single polarization

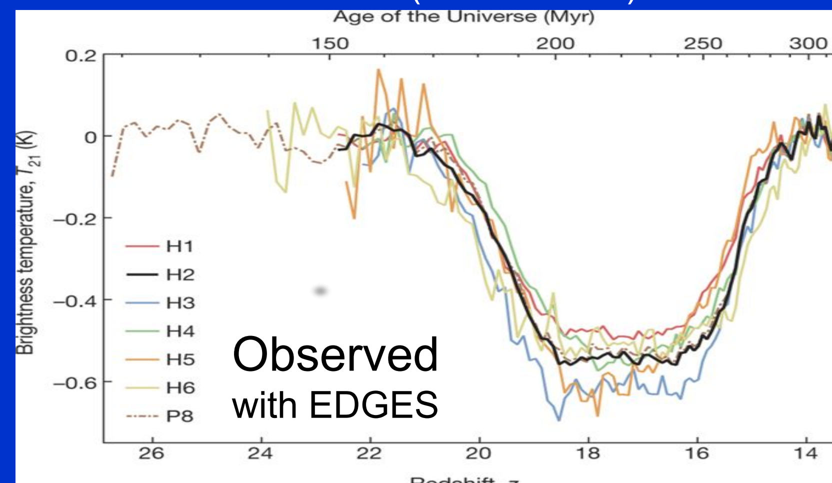




Mirabel+ (2011) + N&V in Nature)



Bowman+ (Nature 2018)



- Absorption at z~17 during 170-270 Myrs, consistent with fx<0.1, but ~3 times larger amplitude & bottom flat
- Extra amplitude absorption due to cooling by interaction of dark matter with baryons (e.g. Barkana+ Nature)?

$\delta T_b \propto \{1 - (T_{CMB} + T_{rad})/T_s\}$; $F_{boost} \sim 1 + T_{rad}/T_{CMB}$ (Feng & Holder; Ewall-Wice+ 2018)

T_{rad} MAY COME FROM POP III RADIO LOUD BH-HMXB-MQs

CONCLUSION

If the EDGES absorption is confirmed:

- It would be evidence of a large population of BH-HMXB-MQs of Pop III at cosmic dawn, and therefore **an indirect evidence of stars of Pop III**

- BH-HMXB-MQs of Pop-III would be **formed before the appearance of SNe, neutron stars, and large quantities of dust.**

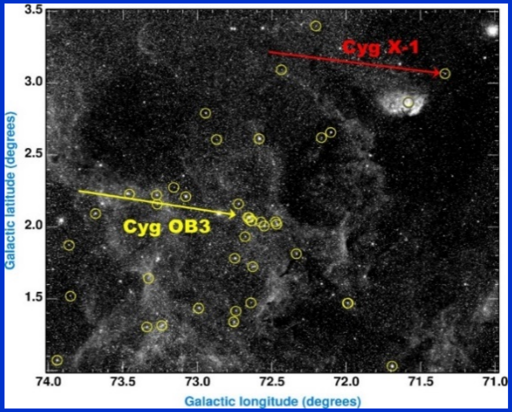
- $f_x < 0.1 \Rightarrow$ column densities of $N_H > 5 \times 10^{23}$ cm^{-2} $\Rightarrow$ **the UVs and soft X-rays are absorbed, but are transparent for the radio emission**

Mirabel (2017): New Astronomy Reviews
Mirabel (2019): Review at IAU Symposium 346 (arXiv#1902.00511)

NEXT STEP: From the CRB to account for the amplitude of the λ21cm HI absorption at z~17 estimate the properties and numbers of POP III stars.
Problem: Inverse Compton of the MQ jets on the CMB photons at z~17…

Cygnus X-1

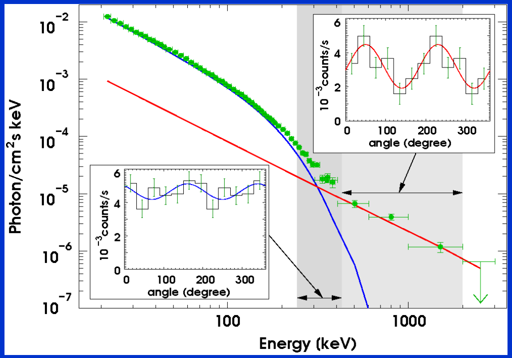
Mirabel & Rodrigues (Science 2003)



D= 1.86 ± 0.1 kpc ; M_{BH} = 14.8 ± 1.0 $M_{\odot}$
Donor = O9.7 Iab of 19.2 ±1.9 $M_{\odot}$
P = 5.6 days; e = 0.018 ± 0.003

THE BH IN Cyg X-1 WAS FORMED BY IMPLOSION OF A ~45 $M_{\odot}$ STAR

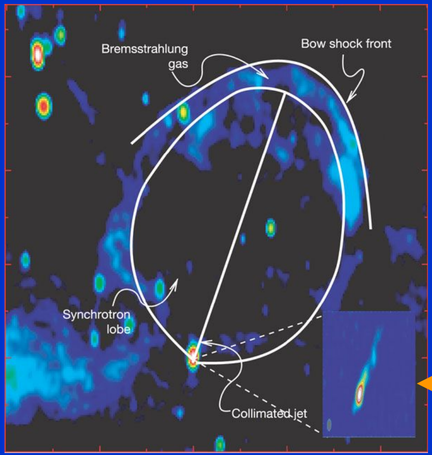
Laurent+ (Nature 2018)



Cyg X-1 IS A SOURCE OF HARD X-RAYS (UP TO ~2 MeV)

with polarized emission from synchrotron jets

Gallo+ (Nature 2005)



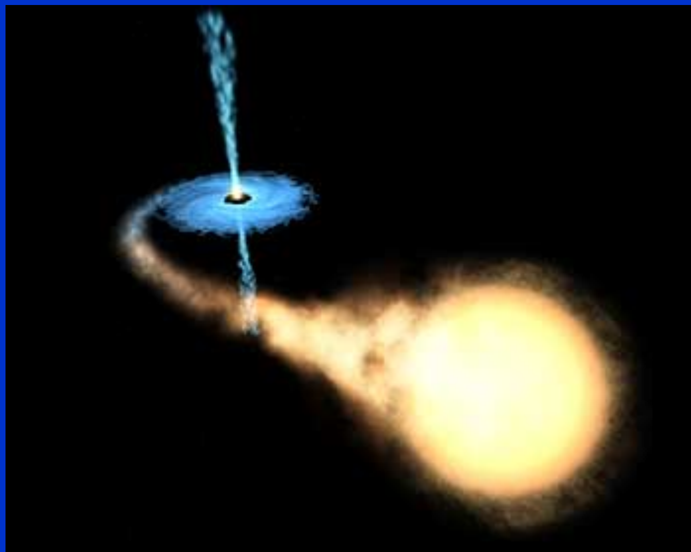
Cyg X-1 IS A SOURCE OF POWERFULL RELATIVISTIC JETS

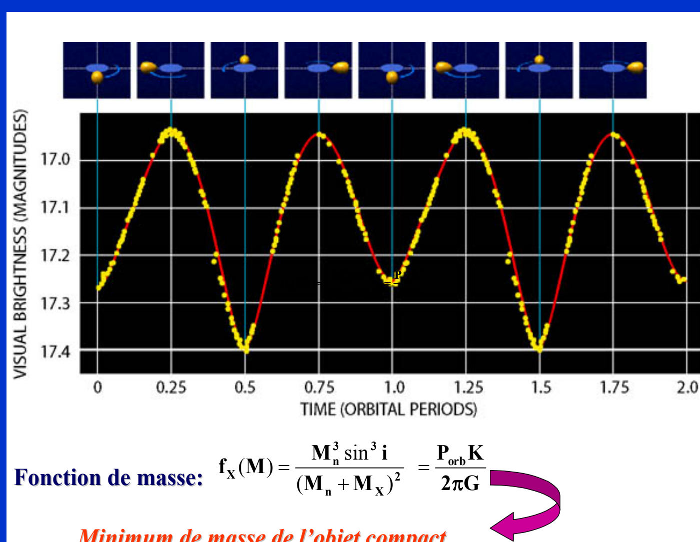
- $10^{36} < P_{jet} < 10^{37}$ erg s^{-1}
- Total energy ~ 10^{48} erg

compact jet

STELLAR BLACK HOLES IN THE GALAXY

Black holes identified by X-rays





IN BINARY SYSTEMS:

$M > 3\ M_\odot \Rightarrow$ BLACK HOLE

~50 known in binaries plus
~30 additional candidates

- **Estimated total population in the Galaxy: ~300 millions**
  Brown & Bethe (1994); Timmes, Woosley, Weaver (1996)

- Assuming ~10 $M_\odot$ this form of dark matter of baryonic origin would be **~4% of the total mass of the baryonic matter in the Galaxy**

- **Its mass is ~10^3 times the mass of the BH of $4\times10^6\ M_\odot$ in Sgr A***

- **Most stellar BHs in the Galaxy are presently in quiescence (dormant)!**

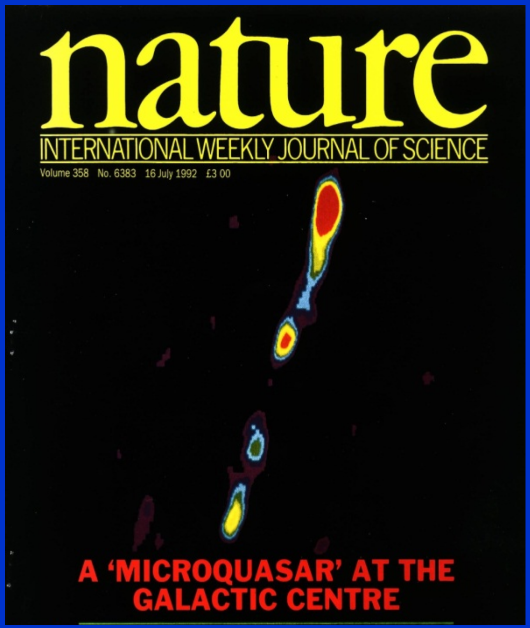
SYNCHROTRON JETS IN BH-XRB-MQs

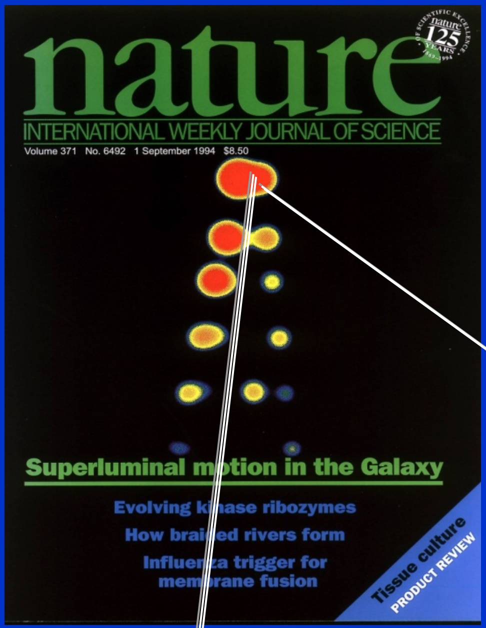
Mirabel, Rodríguez+1992

Mirabel & Rodríguez 1994

with VLA

STEADY JETS


nature
INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
Volume 358 No. 6383 16 July 1992 £3 00
A 'MICROQUASAR' AT THE GALACTIC CENTRE


nature
INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
Volume 371 No. 6492 1 September 1994 $8.50
Superluminal motion in the Galaxy
Evolving kinase ribozymes
How braided rivers form
Influenza trigger for membrane fusion
Tissue culture
PRODUCT REVIEW

TRANSIENT JETS

Dhawan, Mirabel, Rodríguez (2007)

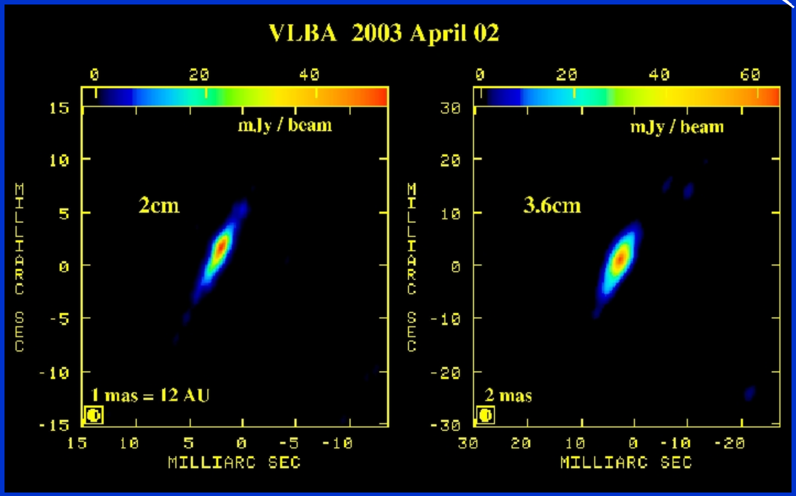
In low hard state. Size ~ 100 AU. Same PA

COMPACT JETS

TO DETERMINE PARALAXES & PROPER MOTIONS

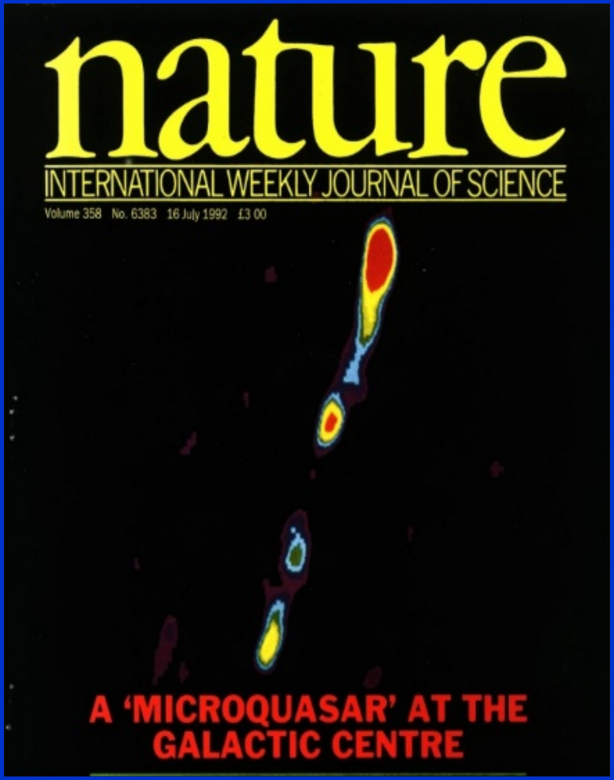
(with VLBI to get sub-miliarc sec precision)

with VLBA at λ3.6 cm



BH-HMXBs ARE MICROQUASARS

Mirabel, Rodríguez+ 1992



STEADY JETS

Mirabel & Rodríguez 1994

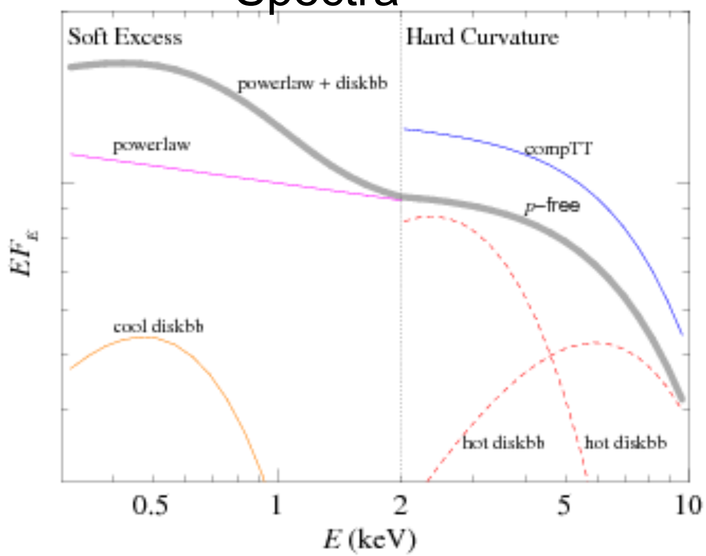
TRANSIENT JETS

SOURCES OF POWERFUL SYNCHROTRON JETS

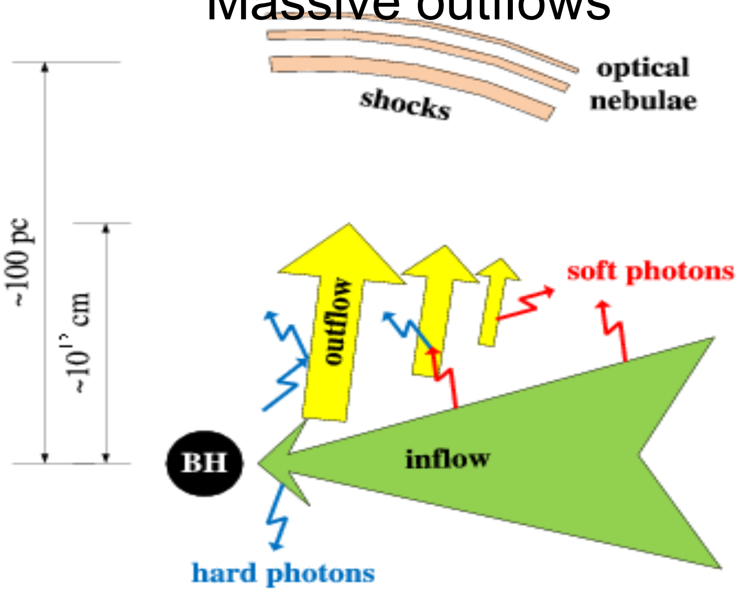
BH-HMXBs IN LOW METAL-STAR-FORMING GALAXIES

From Feng & Soria (2011)

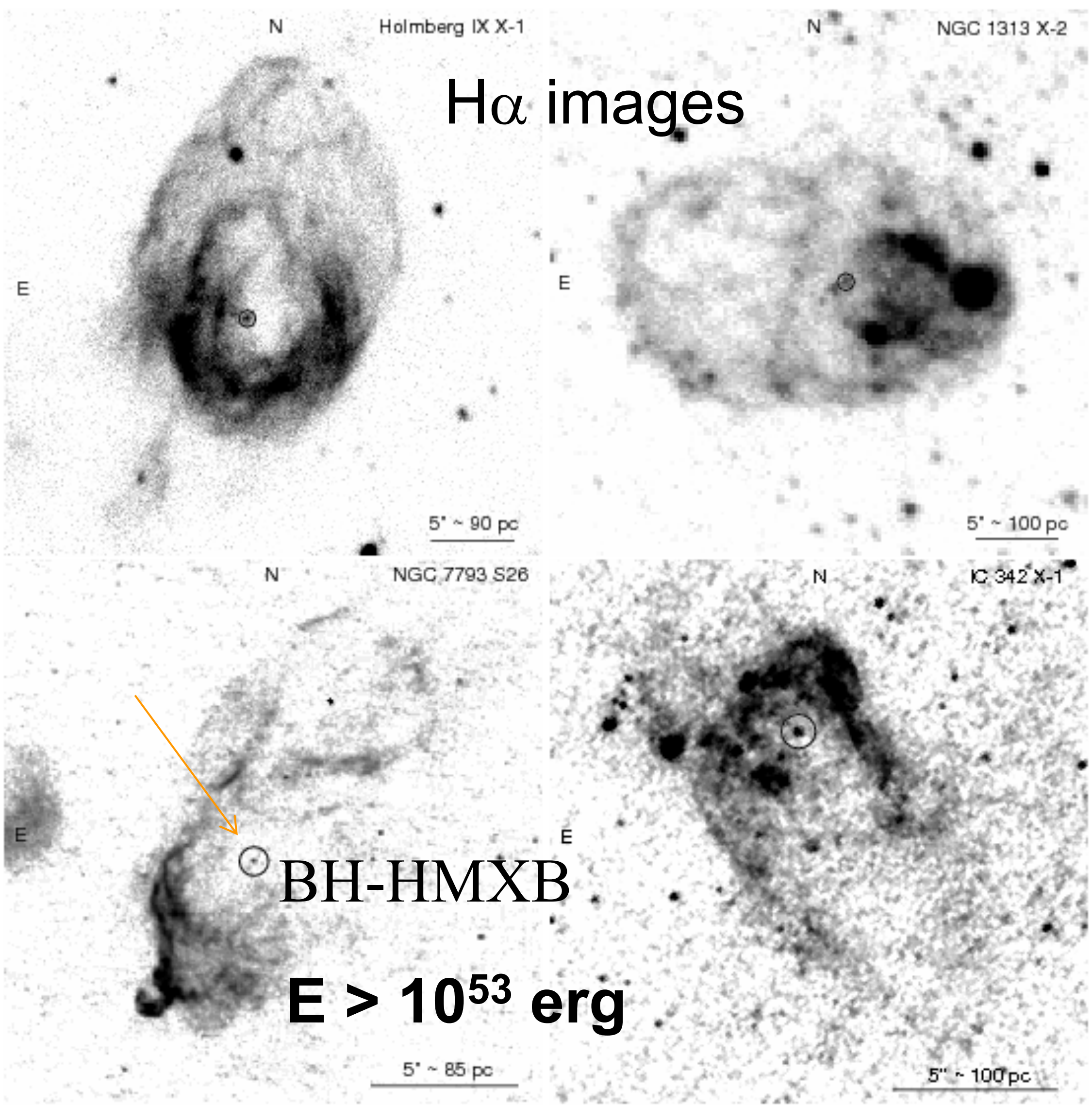
Spectra



Massive outflows



shock & photonionized bubbles of > 100 pc size

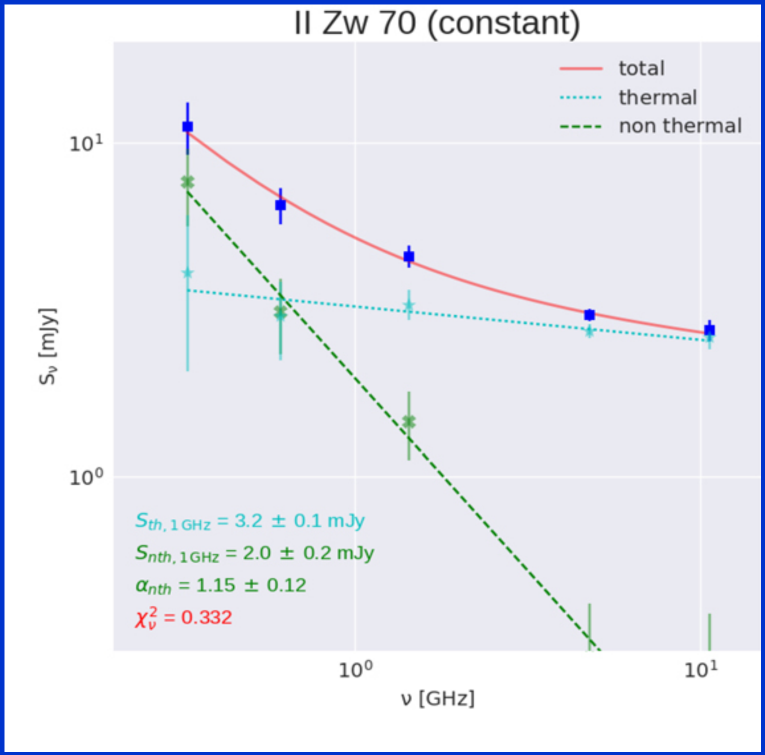


RADIO SYNCHROTRON SPECTRA IN DWARF STAR FORMING GALAXIES OF LOW Z

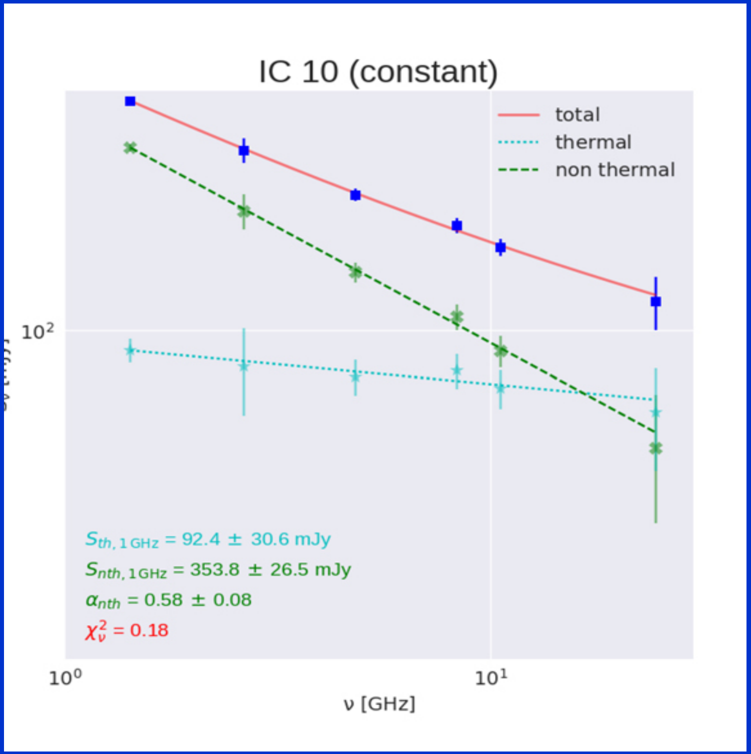
Klein, Lisenfeld and Verley (2018)

$S_\nu \; \alpha \; \nu^{-\alpha}$ α=0.59+/-0.20

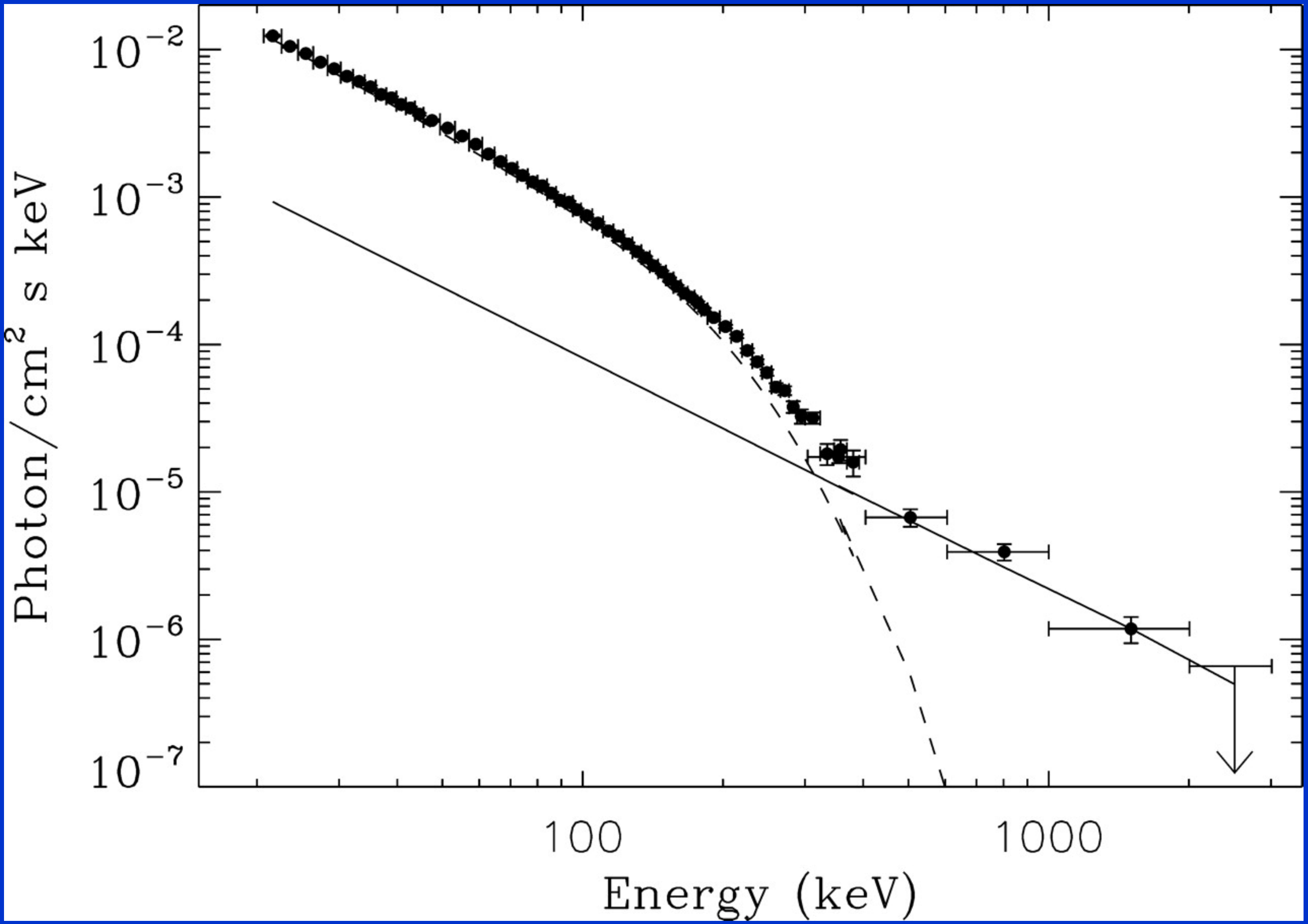
12+Log (O/H) = 7.86



12+Log (O/H) = 8.30



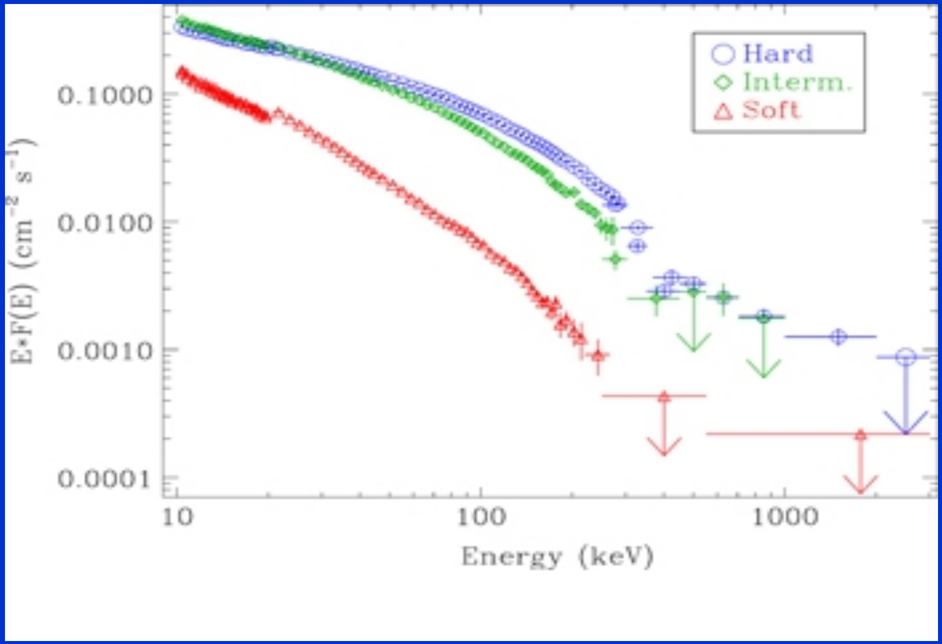
Cygnus X-1 energy spectrum as measured by the INTEGRAL/IBIS telescope and obtained with the standard IBIS spectral analysis pipeline.



P. Laurent et al. Science 2011;332:438-439

Figure 3 from Spectral State Dependence of the 0.4-2 MeV Polarized Emission in Cygnus X-1 Seen with INTEGRAL/IBIS, and Links with the AMI Radio Data

Jérôme Rodriguez et al. 2015 ApJ 807 17 doi:10.1088/0004-637X/807/1/17



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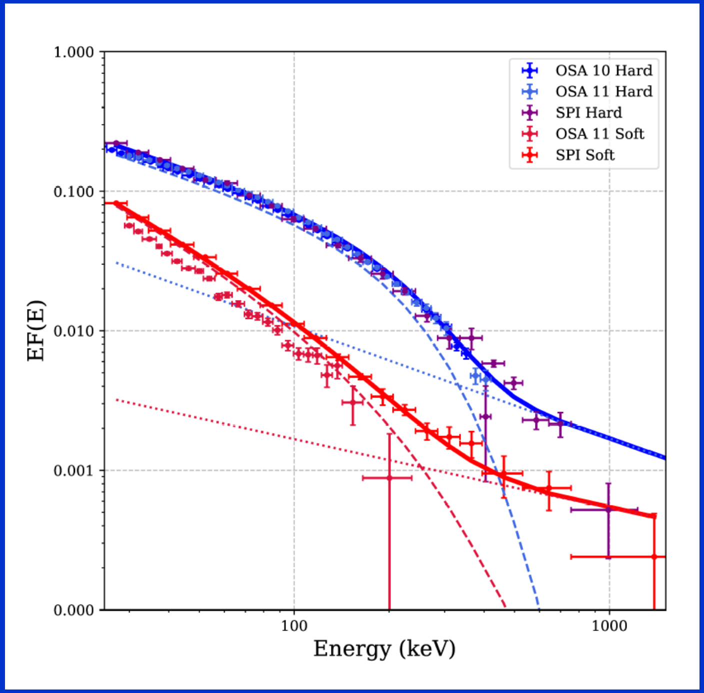
- Please remember to include the original article citation information.

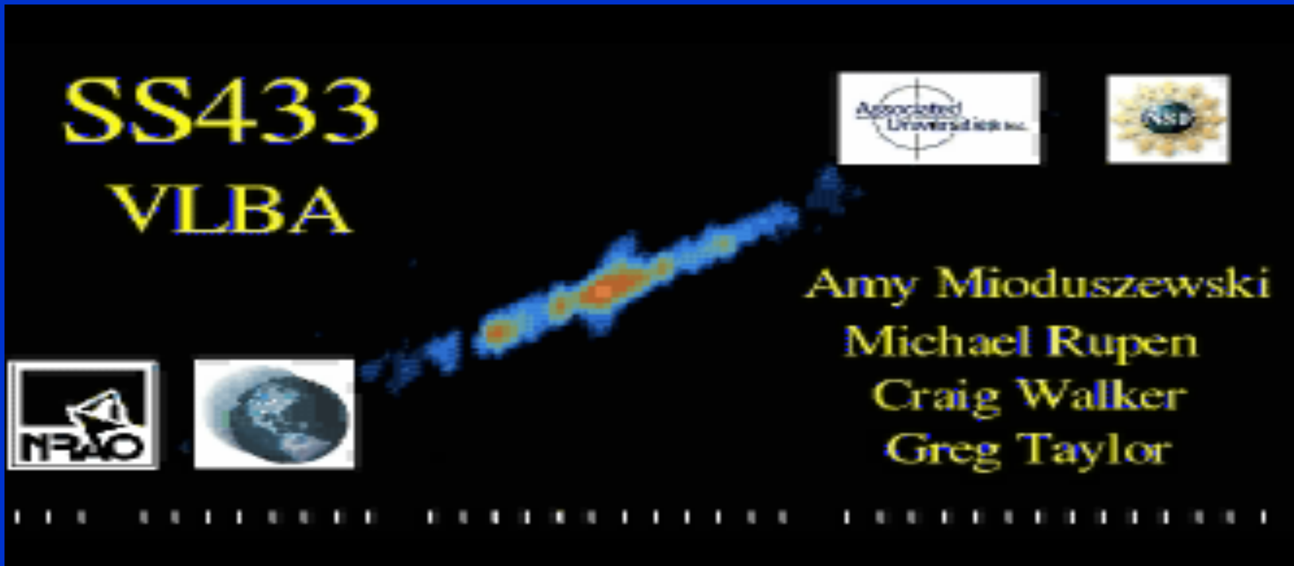
Cygnus X-1 spectra



Issu de Cangemi F. et al., 2019, proceedings of the 12th INTEGRAL conference, Geneve, 11-15 february 2019.
Spectres observés par SPI et IBIS.

Blue points and lines : hard state
Fit : comptonisation + powerlaw : kT = 55 keV, tau =0.95, alpha (PL) = -1.5
Red points and lines : soft state
Fit : cutoff PL + PL : alpha1 = -2.27 , Ecut = 273 keV, alpha2 = -1.5

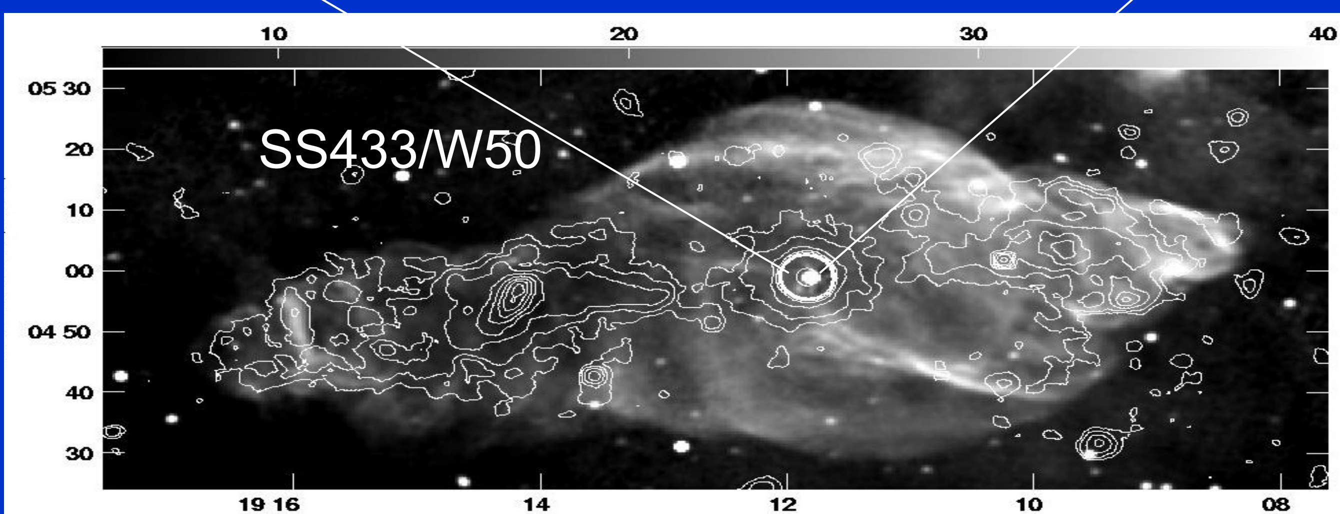
POWERFULL JETS IN SS 433



HAWAC reported detection of gamma-rays in the lobes (Nature 2019)

1 arcsec

1° = 60 pc



Radio:
(Dubner, Goss, Mirabel)

X-rays
(Brinkmann +)

Cygnus X-3

- Probably a BH wind-fed by a Wolf Rayet star
- Short orbital period: 4.8 hr, distance 7.4 kpc
- The brightest galactic X-ray binary in radio $s{-}1$

Giant radio flares of 10-50 Jy. Mean Jet power of 10^{37} erg s^{-1}

Evolution in 4h: (Egron+ 2017)