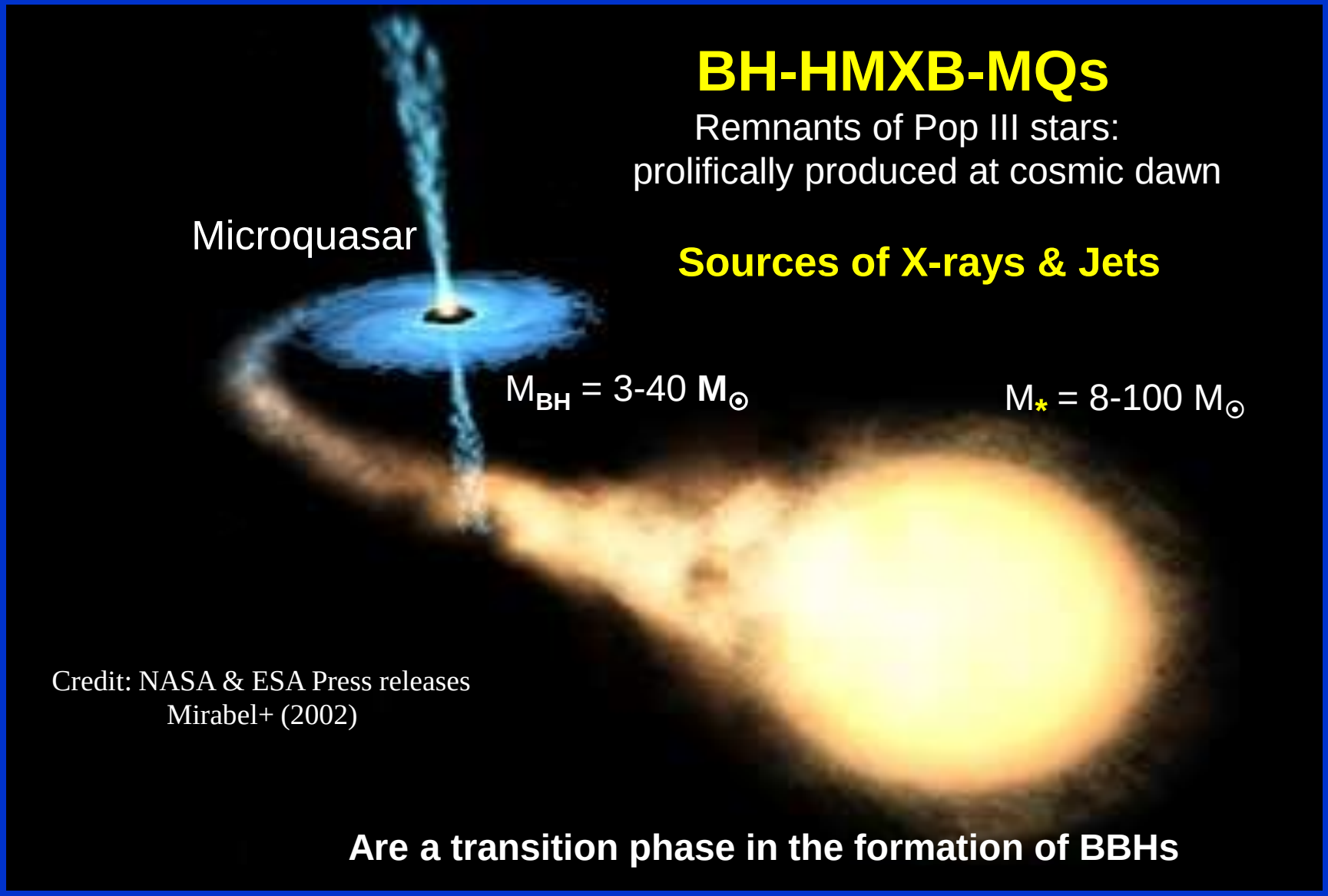
STELLAR BLACK HOLES AT COSMIC DAWN

Félix Mirabel (IAFE-Buenos Aires-Argentina & CEA-Paris-France)

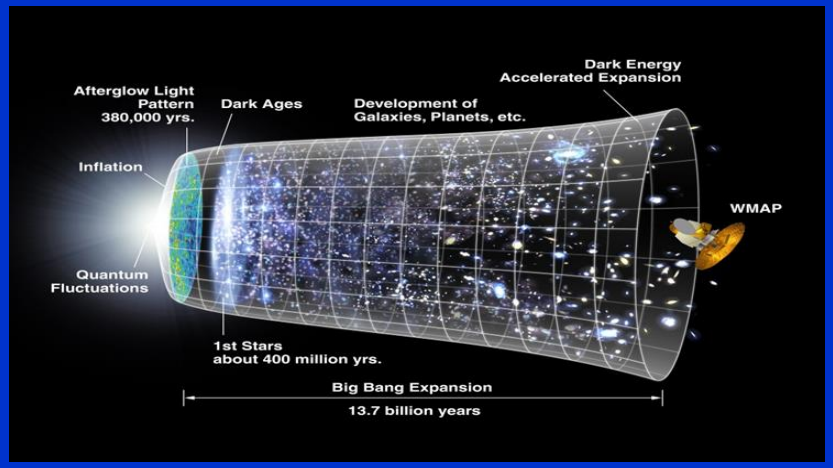


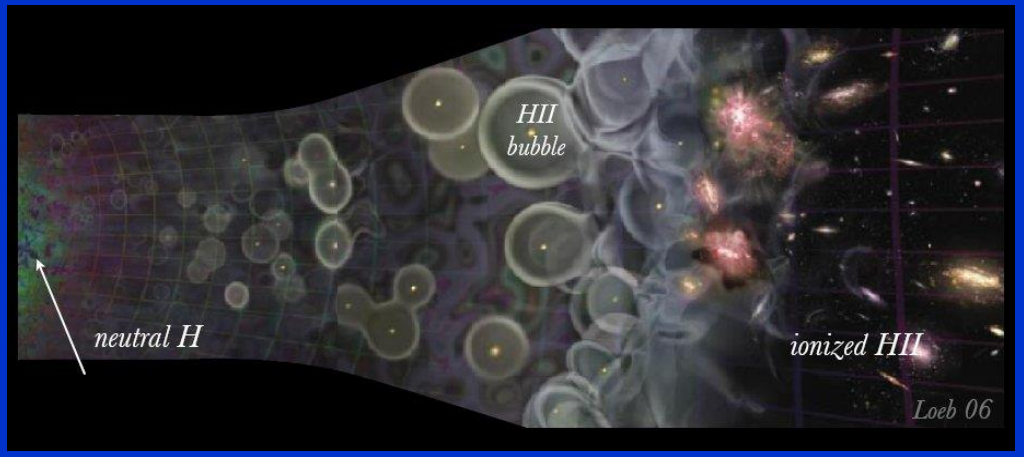
BH-HMXB-MQs IN COSMOLOGY

TRANSITION FROM THE DARK AGES TO THE ERA OF REIONIZATION

Until 2011 the agents of heating & reionization were UVs from Pop III/II stars and SNe soft X-rays

« SWISS CHEESE » MODEL ⇒ PATCHY STRUCTURE





It is proposed that BH-HMXBs were prolifically formed at cosmic dawn

Mirabel, Diskra, Loeb, Laurent and Pritchard (A&A 2011)

⇒ Hard X-Rays pre-heat the IGM before reionization is completed

⇒ A smoother end of reionization News & Views in Nature by Haiman (2011)

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 BH-HMXBs**
  Fragos+2012; Basu-Zych+2012; Lehmer, Basu-Zych, Mineo+ (2016); Fornasini+ (2019)…

up to z~2.5 $L_{2\text{-}10\ keV}$ (HMXB)/SFR α $(1 + z)$

Several additional observational evidences reported in 2018-2020

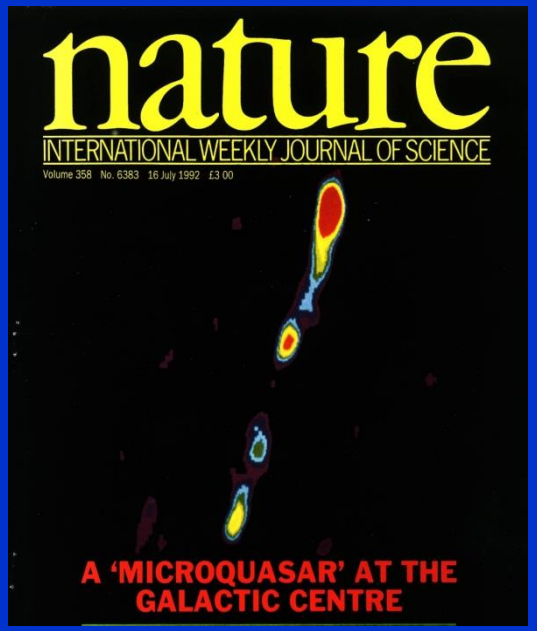
SYNCHROTRON JETS IN BH-XRB-MQs

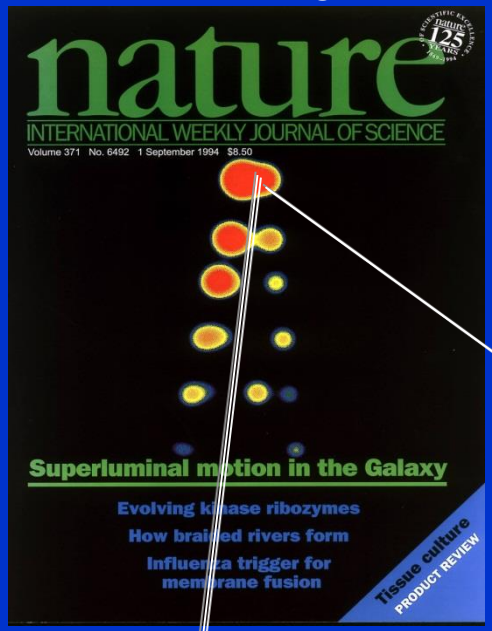
Mirabel, Rodríguez+1992

Mirabel & Rodríguez 1994

Luis F. Rodríguez

VLA λ3.6 cm





STEADY JETS

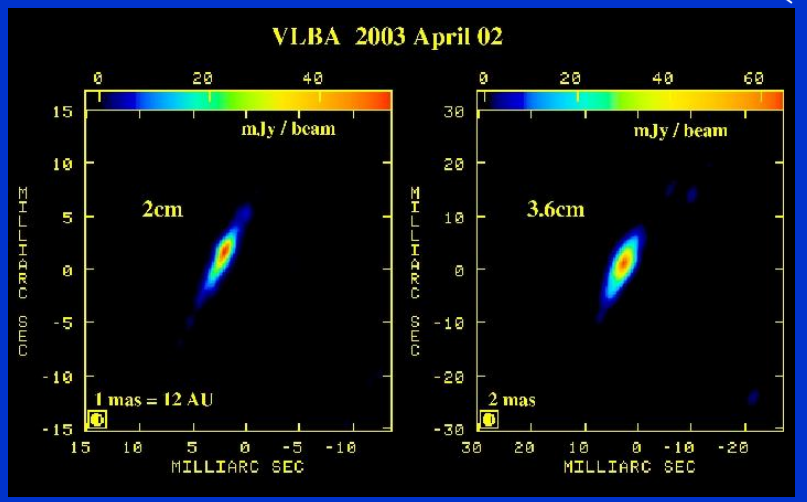
TRANSIENT JETS

COMPACT JETS

Dhawan, Mirabel, Rodríguez (2007)

In X-ray low hard state. Size ~ 100 AU

with VLBA at λ3.6 cm sub-miliarc sec

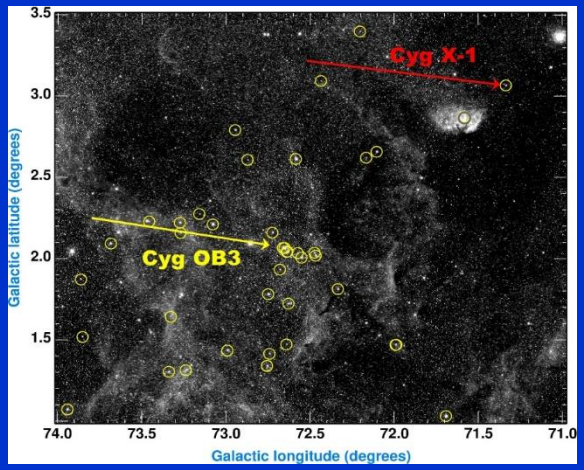


3 well studied BH-HMXBs: Cyg X-1, Cyg X-3, SS 433...

Cygnus X-1

Irapuan Rodrigues

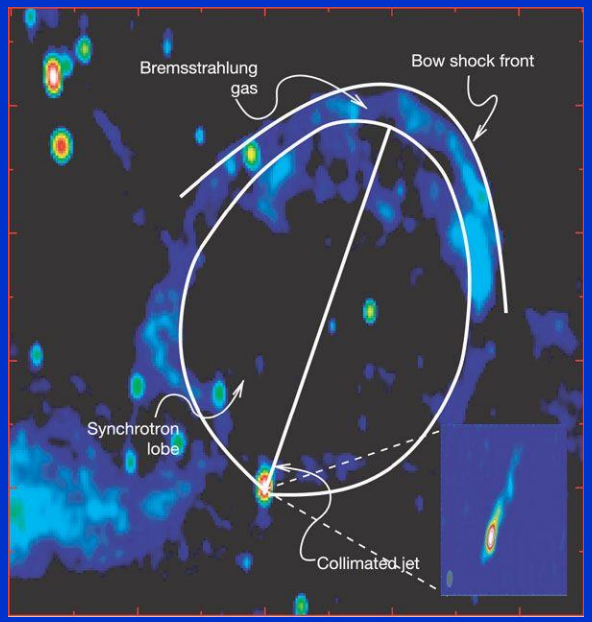
Mirabel & Rodrigues (Science 2003)



D = 1.86 ± 0.1 kpc
M_{BH} = 14.8 ± 1.0 $M_\odot$
Donor = O9.7 lab of 19.2 ±1.9 $M_\odot$
P = 5.6 days; e = 0.018 ± 0.003
Progenitor mass was ~40 ±5 $M_\odot$

THE BH IN Cyg X-1 WAS FORMED IN THE DARK

Gallo+ (Nature 2005)

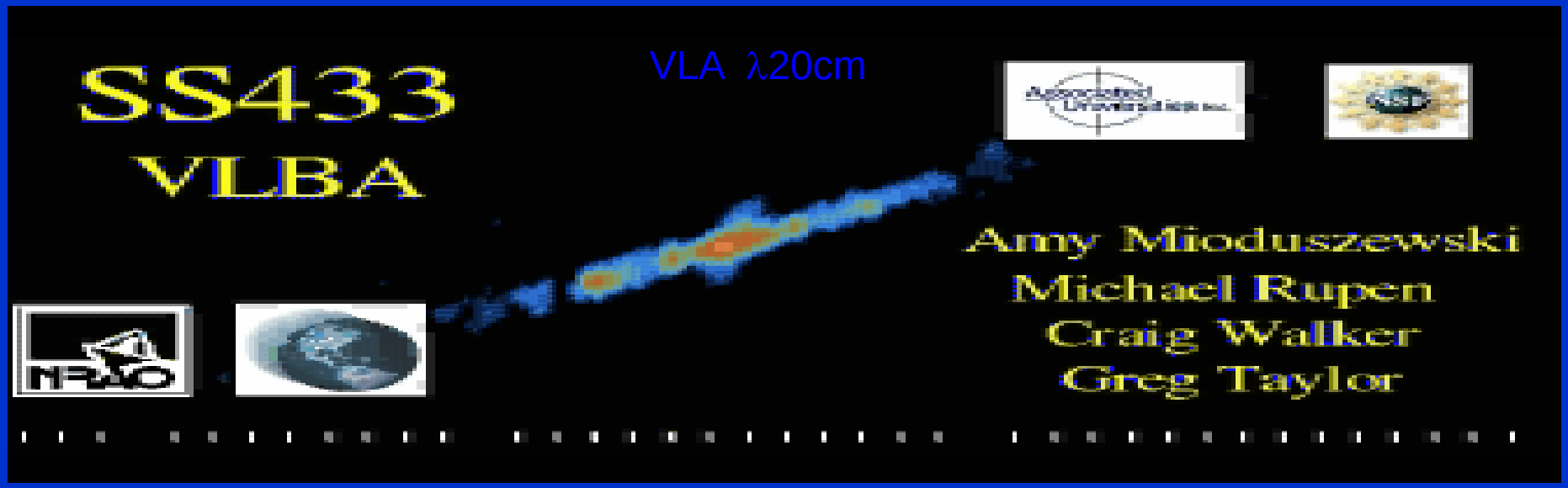


compact jet

- **Cyg X-1 IS A SOURCE**
- **OF POWERFULL JETS**
- $10^{36} < P_{jet} < 10^{37}$ erg s^{-1}
- Total energy ~ 10^{48} erg

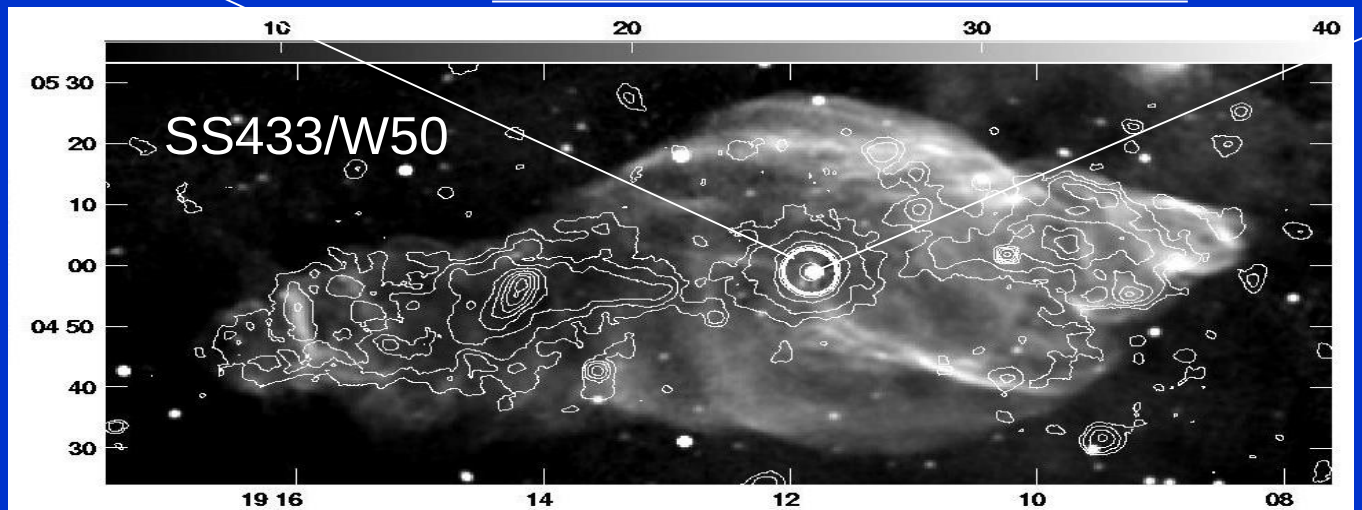
>70% Polarized at 400-keV to 2 MeV
Laurent+ (Science 2011)
Jerome Rodriguez+ (ApJ 2015)

SYNCHROTRON JETS IN SS 433



1arcsec

$1^o = 60$ pc



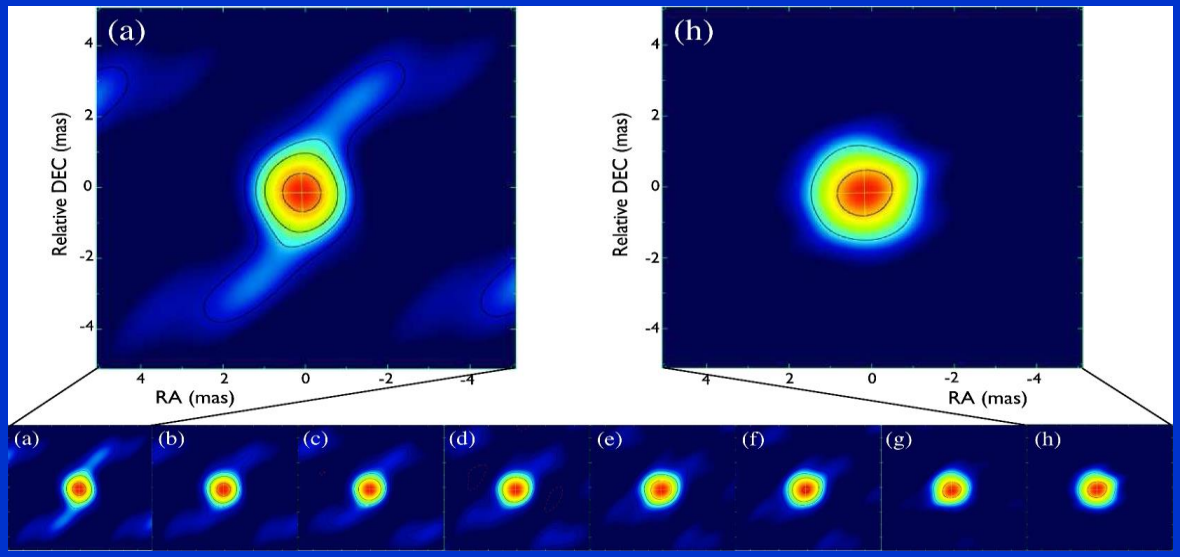
Radio:
(Dubner, Goss, Mirabel)

X-rays
(Brinkmann +)

COMPACT JETS IN Cyg 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
- **Giant radio flares of 10-50 Jy**
- Detected in gamma-rays with AGILE (Nature) & Fermi (Science)

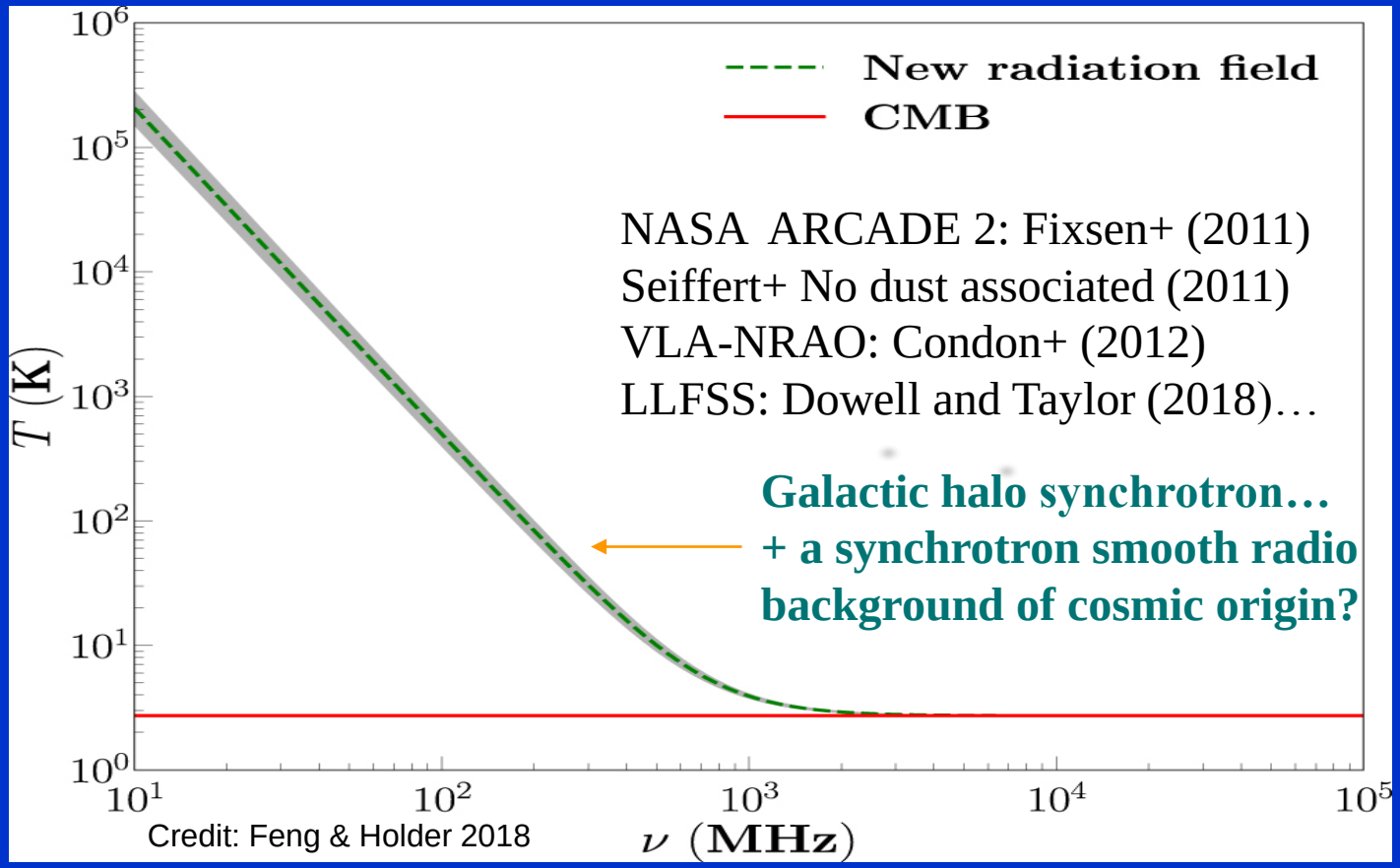
Evolution during 4h: (13.2 Jy at 7.2 GHz and 10 Jy at 18.6 GHz (Egron+ 2017)



If there are large populations of BH-HMXBs at cosmic dawn, is there any evidence of a synchrotron cosmic background?

The NASA ARCADE 2 experiment reported in 2011 an additional low frequency synchrotron background radiation of possible cosmic origin

(Fixsen+ 2011, confirmed with LLFSS by Dowell & Taylor 2018)



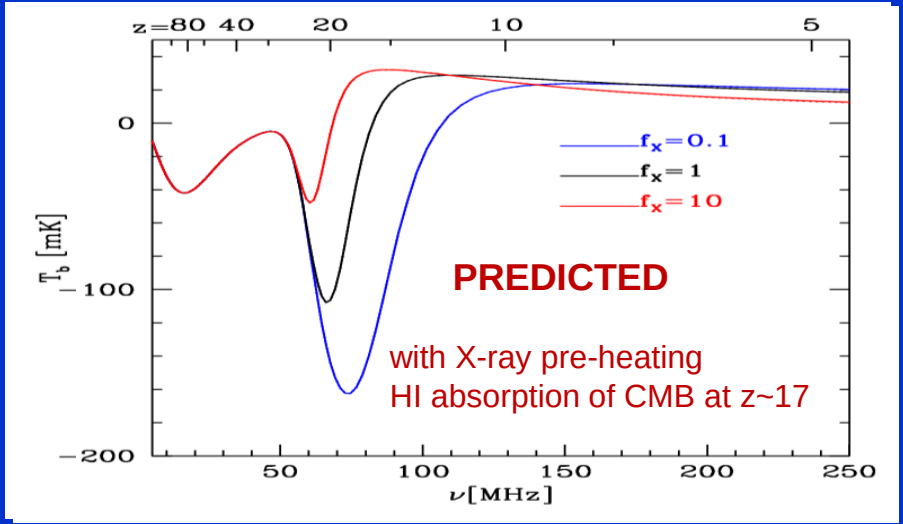
Credit: Feng & Holder 2018

COMPACT JETS FROM BH-HMXB-MQs OF POP-III MAY BE THE SOURCES OF A SYNCHROTRON COSMIC RADIO BACKGROUND

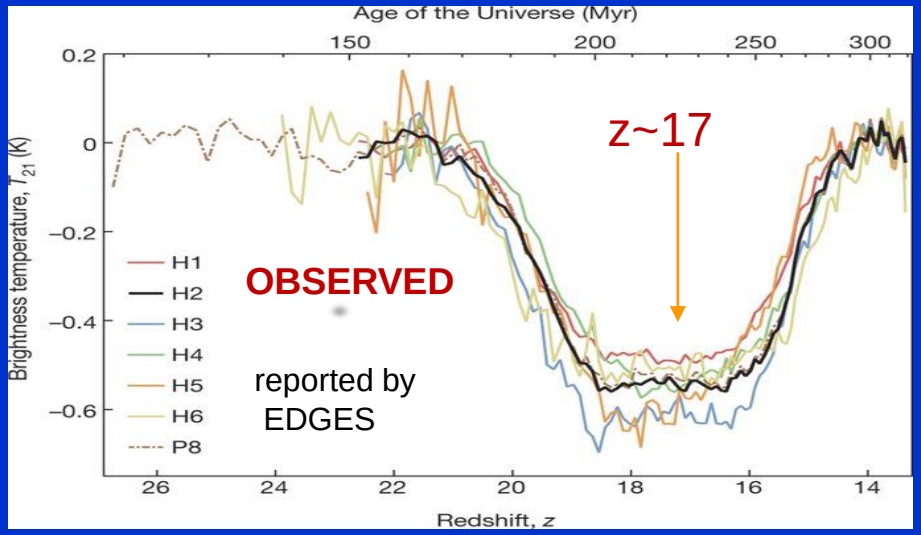
TOMOGRAPHY OF HI λ21cm LINE AT COSMIC DAWN

with experiments to Detect the Global EoR Signature (e.g. EDGES) and Interferometers (e.g. SKA)

Pritchard & Loeb (2010); Mirabel+ (2011)



Bowman+ (Nature 2018a)



If the absorption reported by EDGES is confirmed:

- Absorption at z~17 during 180-280 Myrs after the Big Bang is consistent with fx<0.1
- **However it is of 2-3 times of larger amplitude & bottom-flat instead Gaussian**

Astrophysical interpretation: $\delta T_b \propto \{1 - (T_{CMB} + T_{CRB})/T_s)\}$ (Feng & Holder 2018)

Caveat: Inverse Compton on the cosmic microwave photons takes place in the lobes but not in the compact jets, which radio emission is not affected (Zdziarski+ 2014)

CONCLUSION

The absorption reported by EDGES needs confirmation. If it is confirmed

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

- EDGES type detection may be the evidence of a large population of BH-HMXB-MQs at cosmic dawn, and therefore, **an indirect evidence of stars of Pop III**

- **RADIO EMISSION FROM BH-HMXB-MQs of Pop III MAY BE THE SMOKING GUN OF POP-III STARS**

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

e.g.: A CRB from the equivalent to that of 2×10^{15} Cyg X-1s in the 10^8 yrs of the bottom-flat absorption, could account for the $\Delta T \sim 400$ mK excess absorption reported by EDGES

(Mirabel & Laurent in progress)