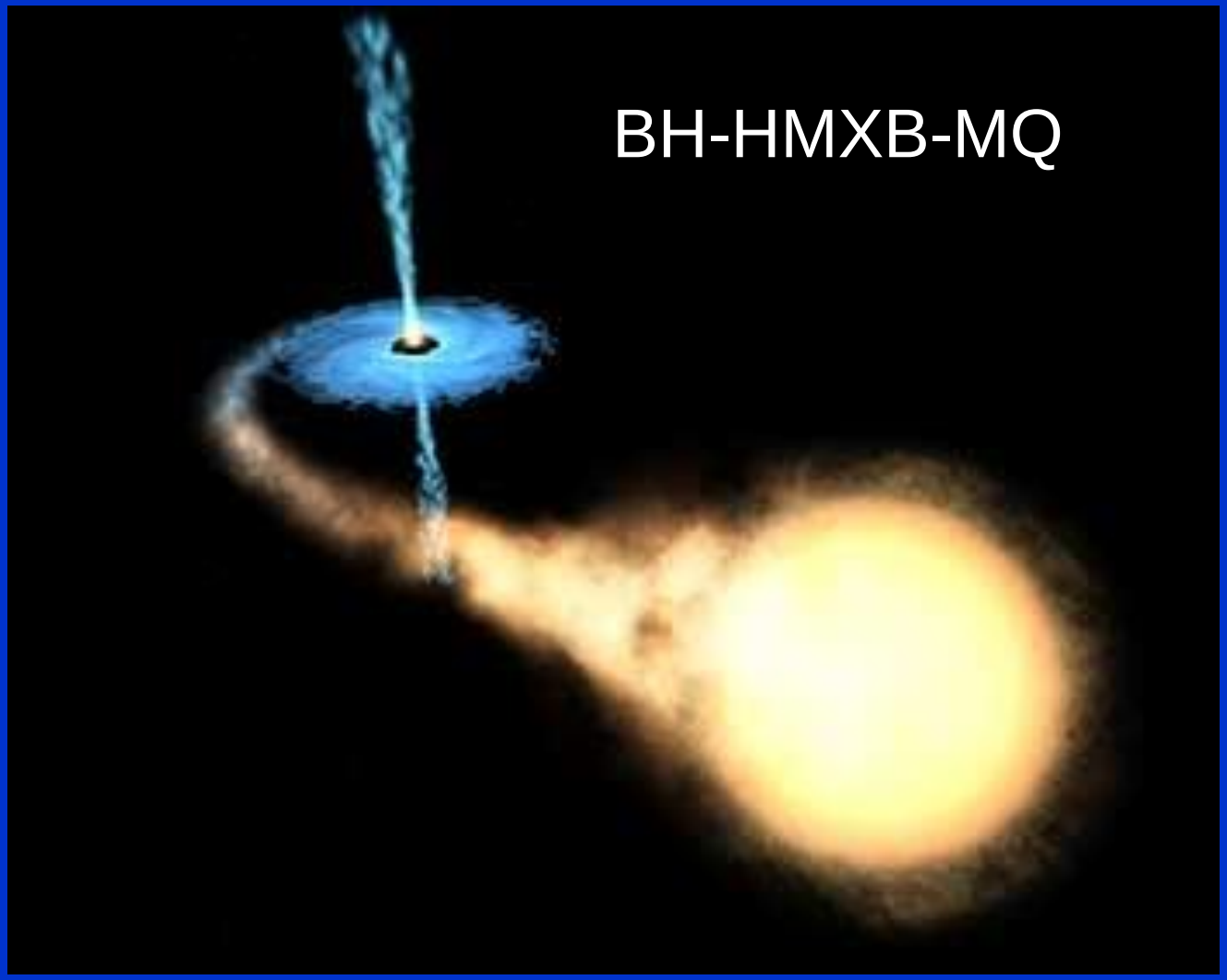
STELLAR BLACK HOLES AT COSMIC DAWN

Impact in: 1) Cosmology and 2) Gravitational Wave Astrophysics

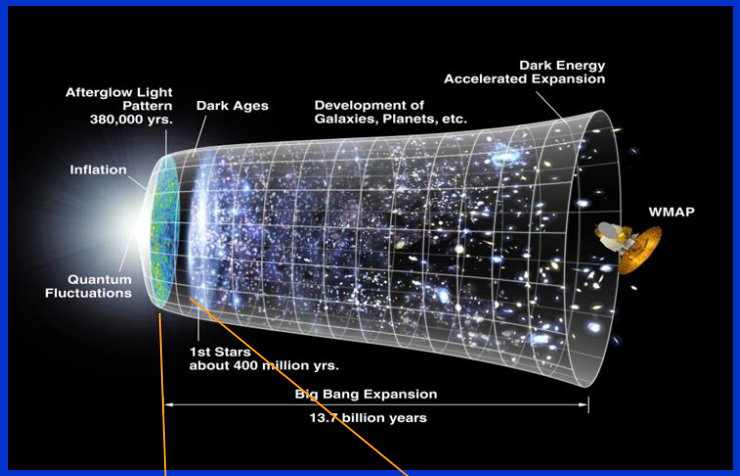
Félix Mirabel. (IAFE-Conicet-UBA-Argentina)



IMPACT OF BH-HMXBs IN COSMOLOGY

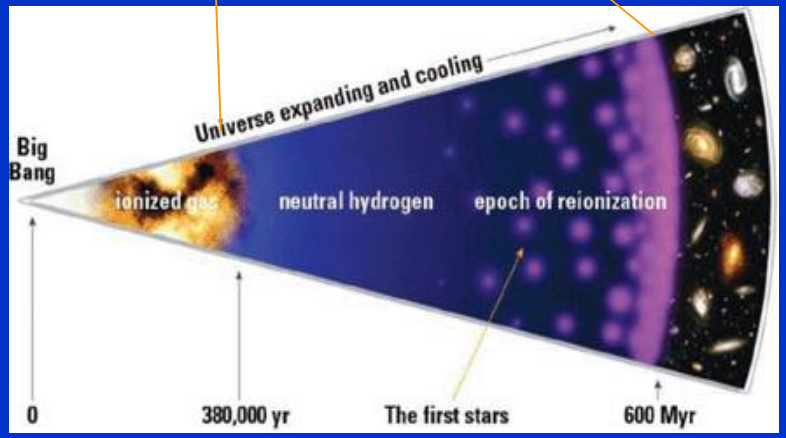
THE DARK AGES & THE ERA OF REIONIZATION

"First light in the universe": one of the main frontiers in Cosmology



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

Cold phase of the IGM from 4×10^4 up to 10^9 yrs



BH-HMXBs, the fossils of Pop III stars, preheat the ISM

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

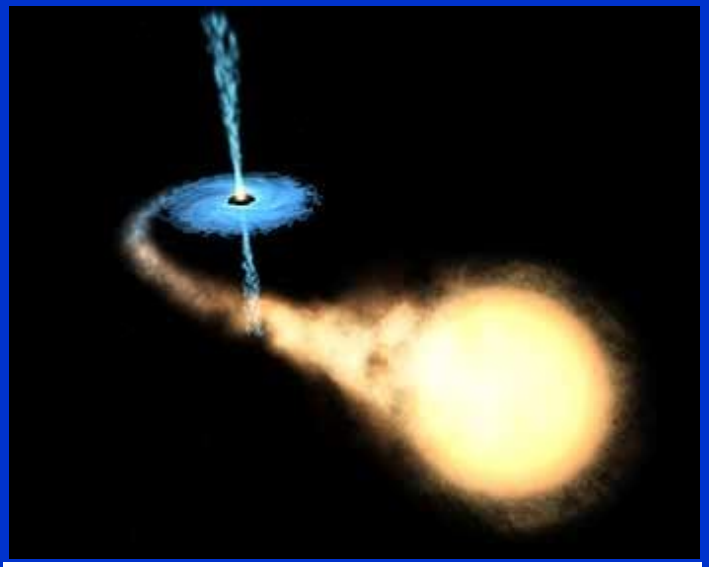
OBSERVATIONAL GROUNDS

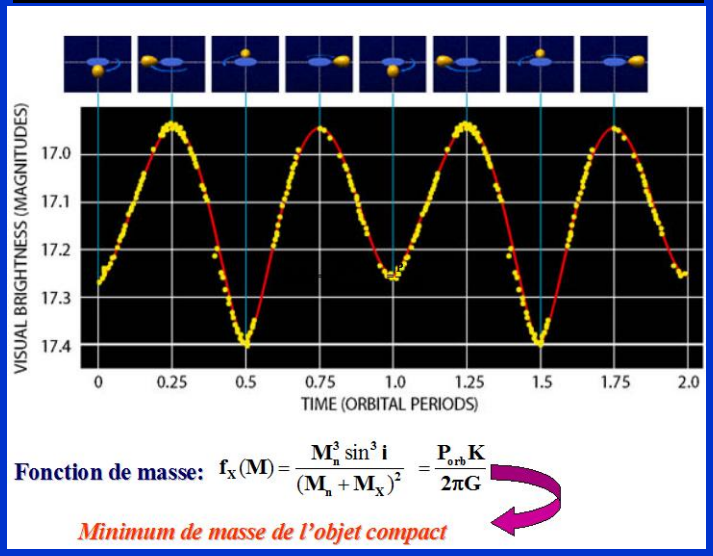
- **BHs FORM WITH NO ENERGETIC SNe⇒BHs & DONOR REMAIN BOUND**
  Mirabel & Rodrigues, Science 2003; Mirabel+ Nature 2008
- **MOST ULXs & LGRBs ARE HOSTED IN LOW Z-HIGH-SSFR GALAXIES**
  Feng & Soria,2011;LeFloc'h,Duc,Mirabel;2003;Fruchter+ Nature, 2006; Perley+ 2014
- **IN LOW Z GALAXIES Lx/SFR IS LARGER 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 $L_{2\text{-}10\ keV}$ (HMXB)/SFR α $(1 + z)$

BLACK HOLES OF STELLAR ORIGIN

Identified by X-rays





IN BINARY SYSTEMS:

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

40 known in binaries and
30 additional candidates

- **Estimated total population in the Galaxy: ~ 300 millones**
  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 $4 \times 10^6\ M_\odot$ in Sgr A***
- **StBHs in the MW are dormant**

Because massive stars with low Z end as black holes by direct collapse

THE COSMIC EVOLUTION OF METALLICITY
$\Rightarrow$ A COSMIC EVOLUTION OF BH-HMXBs

- **THE FRACTION OF BLACK HOLES/NEUTRON STARS**
- **THE FRACTION OF BINARY/SINGLE BLACK HOLES**

SHOULD INCREASE WITH REDSHIFT

Beyond the theoretical uncertainties (e.g. mixing due to rotation in Pop III stars), the observations in the Local Universe support this hypothesis

BH-HMXBs IN COSMOLOGY

"Stellar black holes at the dawn of the universe"

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

⇒ A smoother end of the cosmic reionization

- **BH-HMXBs (sources of hard X-rays) were formed prolifically at cosmic dawn.**
- **In that work only considered the hard X-ray feedback of BH-HMXBs of Pop III-II**

BH-HMXBs also are Microquasars!

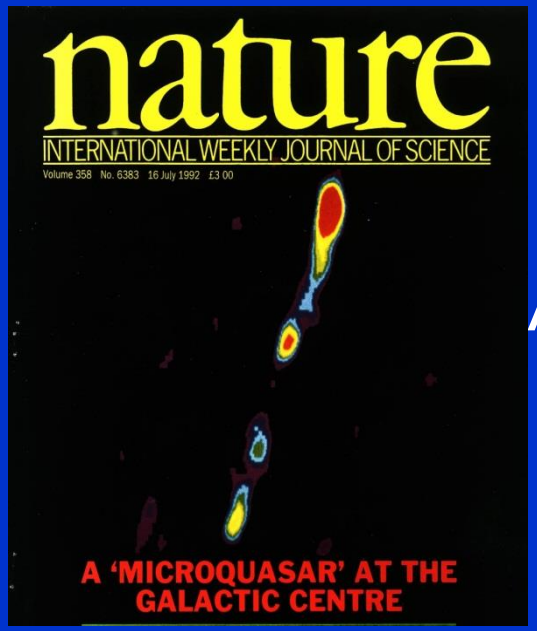
e.g. Cyg X-1; Cyg X-3, SS 433…

If BH-HMXBs were prolifically formed at cosmic dawn:

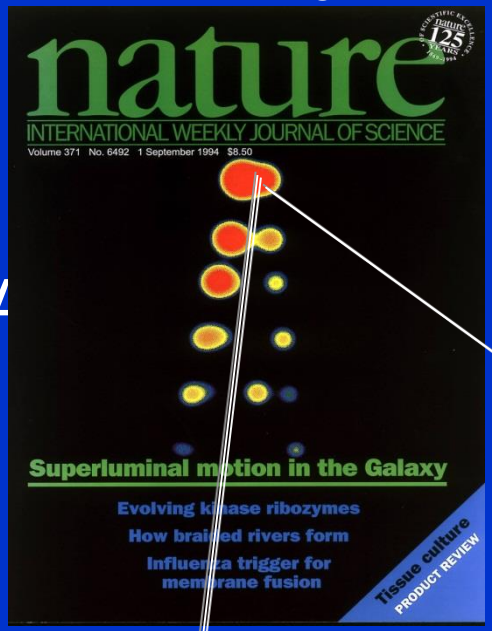
BH-HMXB-MQs of Pop III should have produced a Smooth Synchrotron Cosmic Radio Background (CRB) which may account for the tentative detection by EDGES…

SYNCHROTRON JETS IN BH-XRB-MQs

Mirabel, Rodríguez+1992



Mirabel & Rodríguez 1994



STEADY JETS

TRANSIENT JETS

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

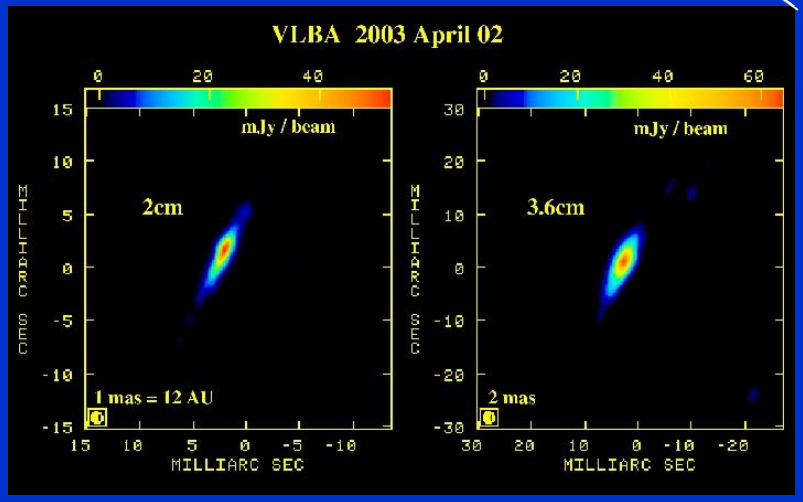
COMPACT JETS

USED TO DETERMINE PROPER MOTIONS

(with VLBI to get sub-miliarc sec precision)

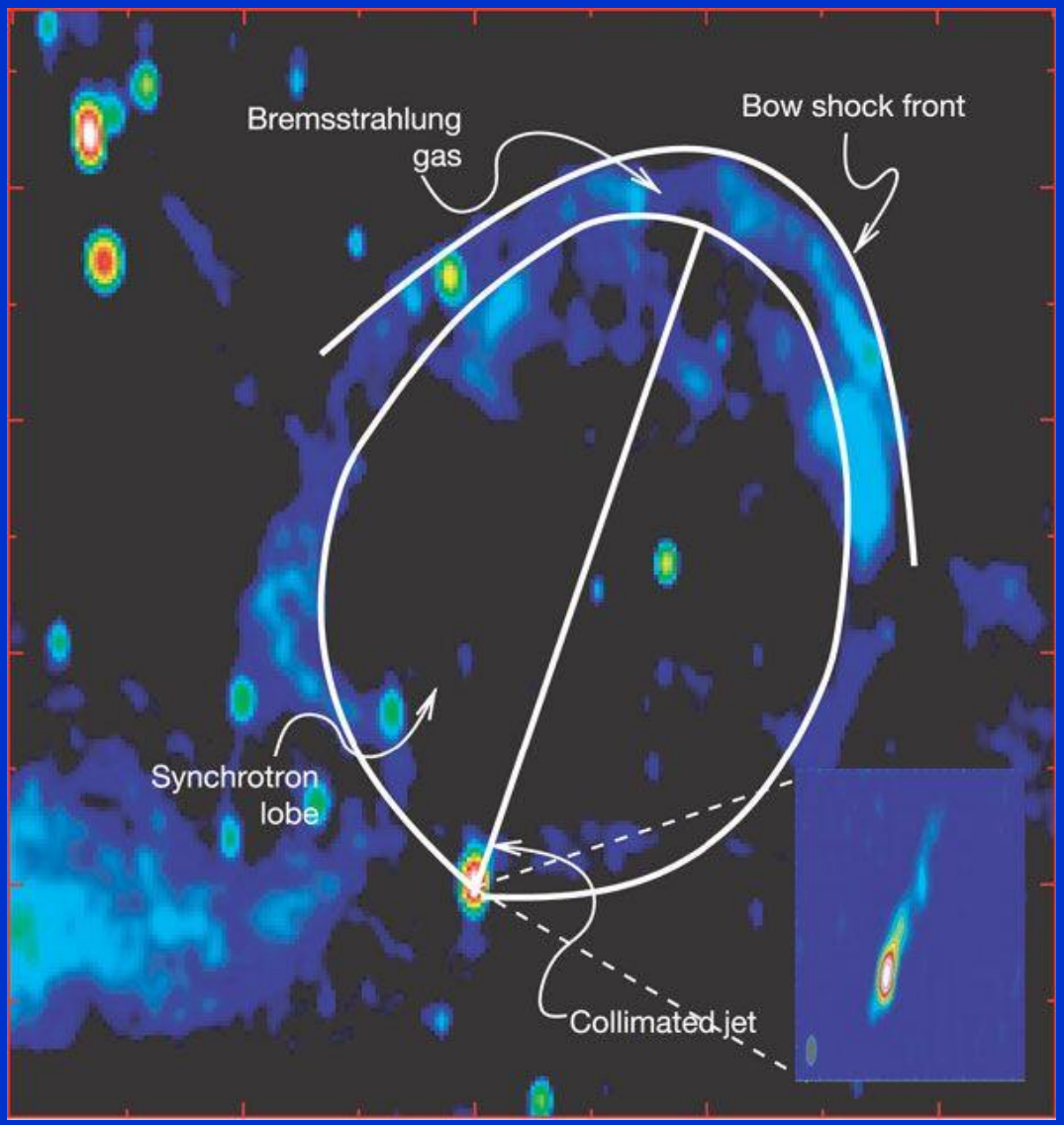
λ3.6 cm

Dhawan, Mirabel, Rodríguez (2007)



Cygnus X-1

Gallo+ (Nature 2005)



D= 1.86 ± 0.1 kpc

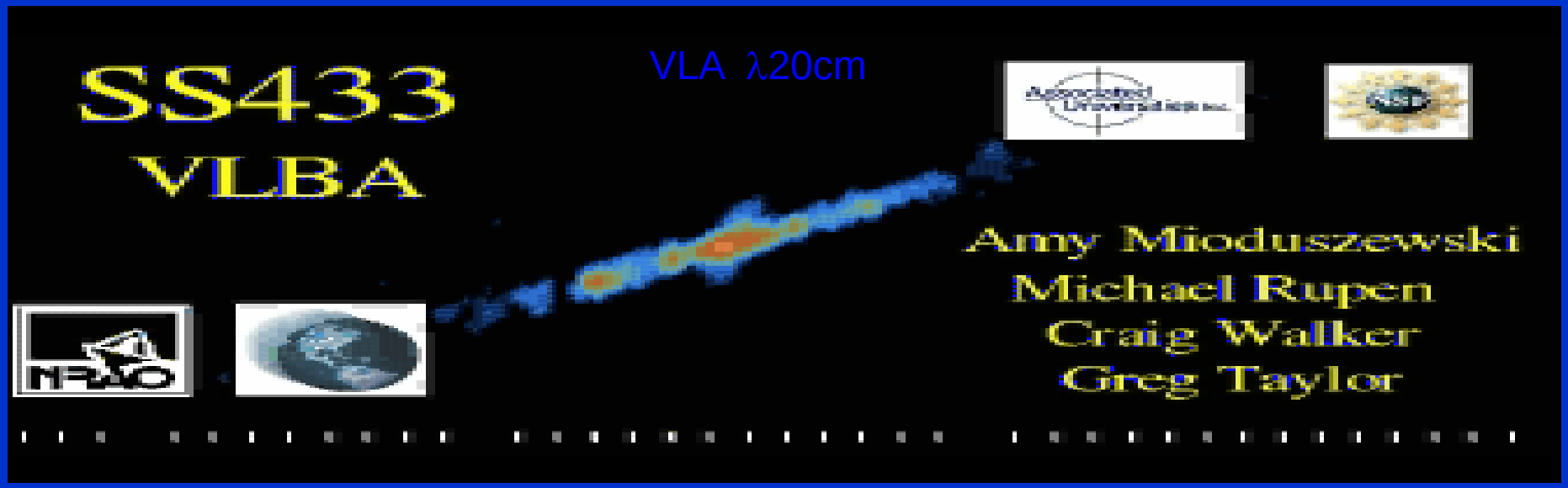
M_{BH} = 14.8 ± 1.0 $M_{\odot}$

Donor = O9.7 lab of 19.2 ±1.9 $M_{\odot}$

P = 5.6 days; e = 0.018 ± 0.003

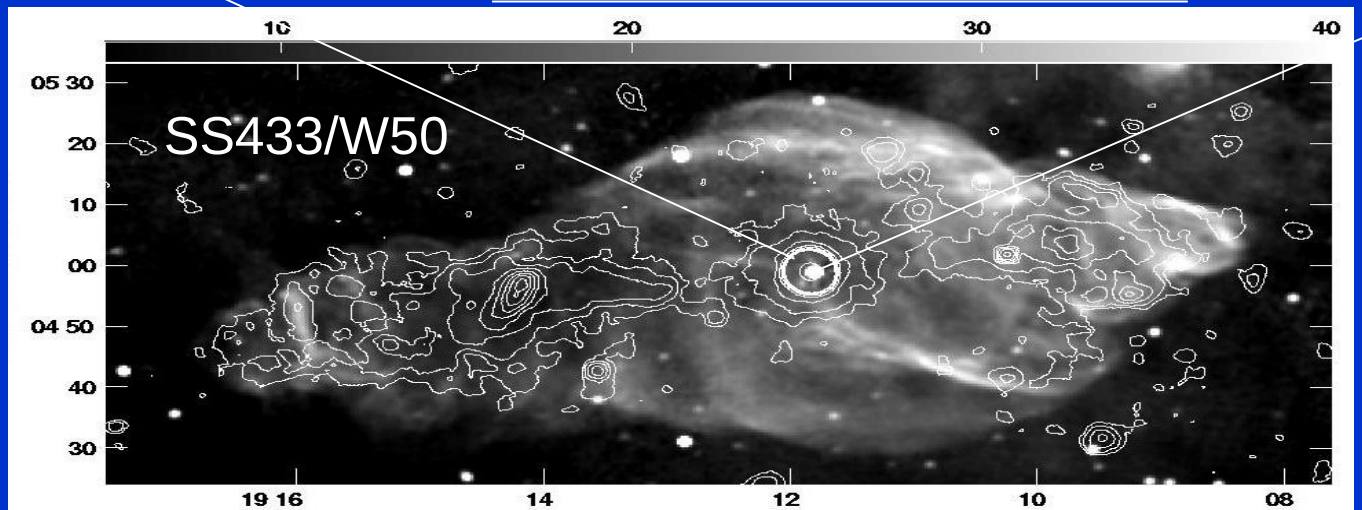
- $10^{36} < P_{jet} < 10^{37}$ erg s^{-1}
- Total energy ~ 10^{48} erg

STELLAR BHs PRODUCE POWERFUL JETS



1arcsec

$1^o = 60$ pc



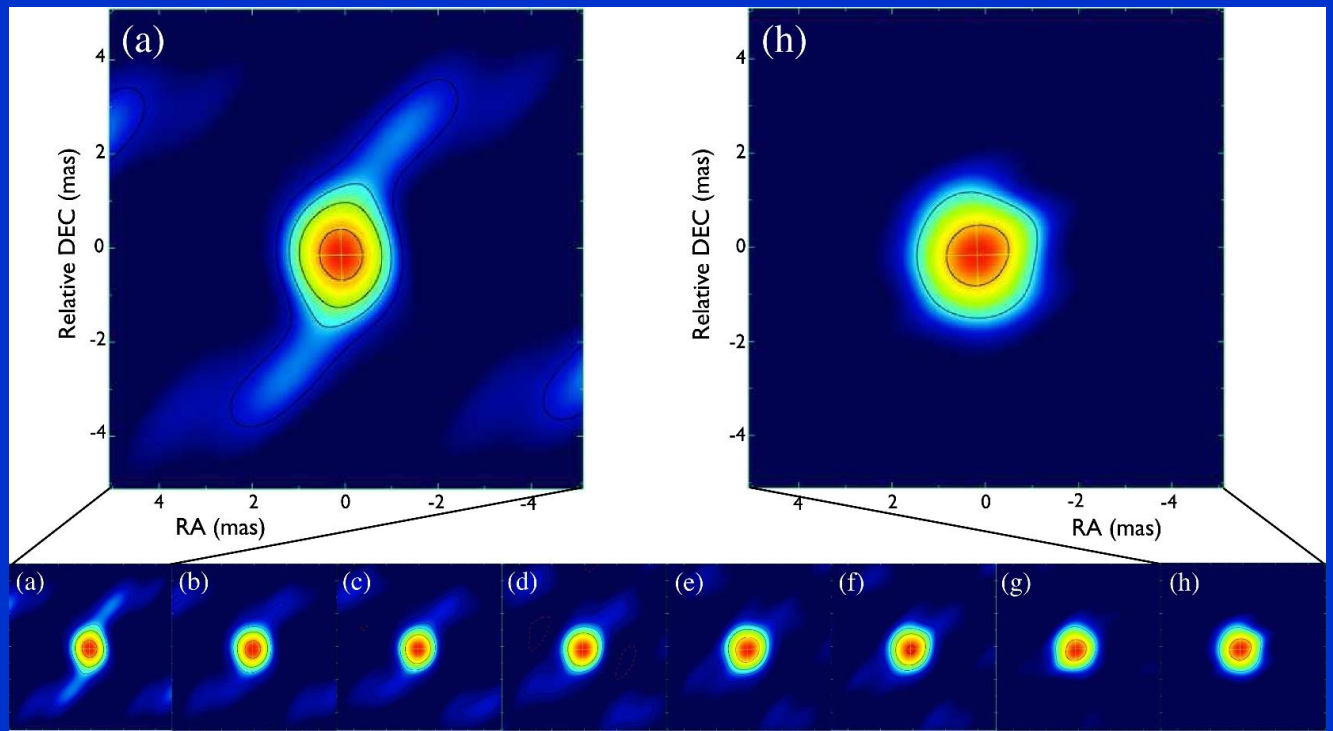
Radio (Dubner+)

X-rays (Brinkmann +)

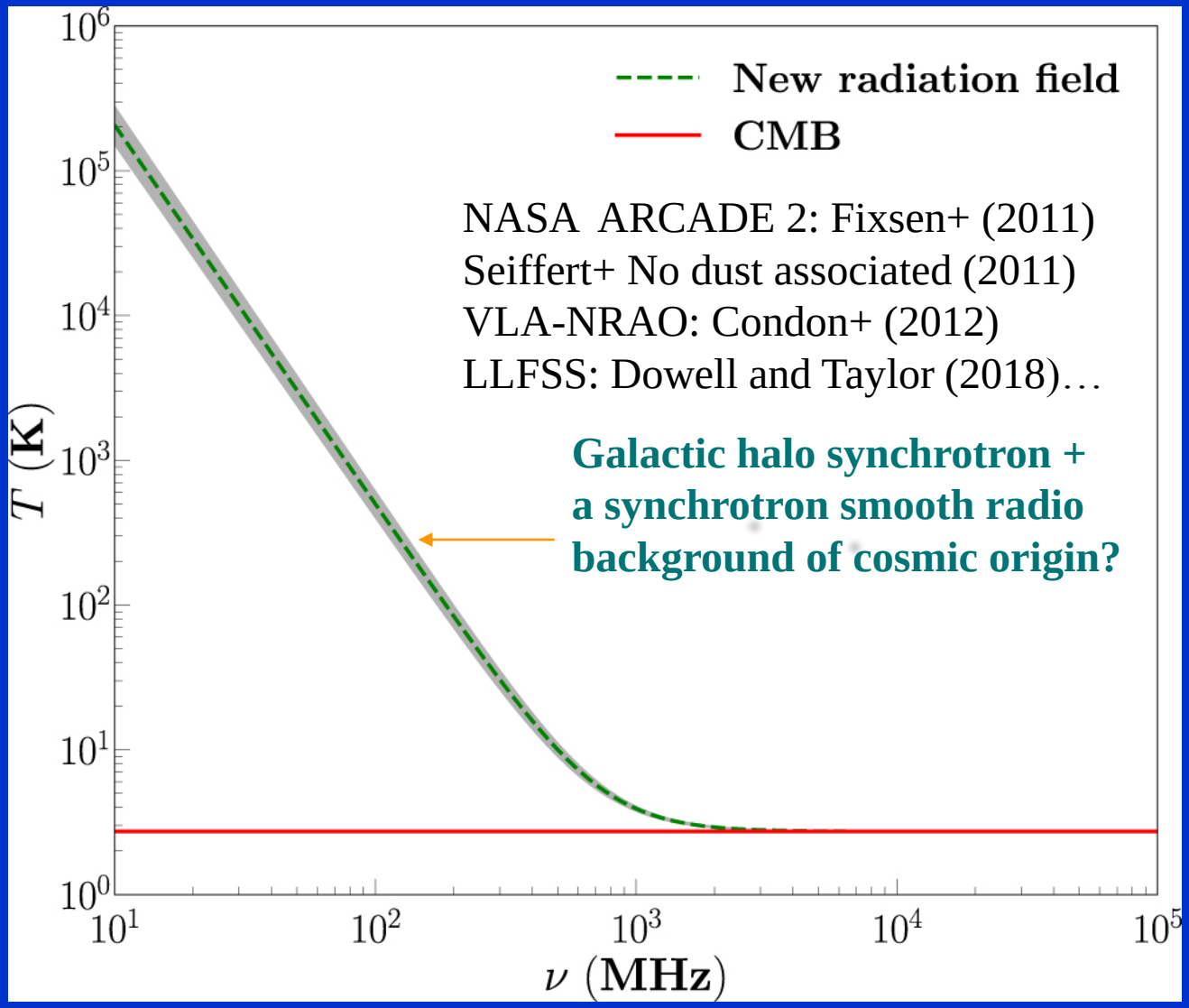
Cygnus X-3

- 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
- **Giant radio flares of 10-50 Jy**
- Detected in gamma-rays with AGILE

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



ARCADE 2 experiment reports an additional low frequency background radiation of possible cosmic origin (Fixsen 2011)



TOMOGRAPHY OF HI IN THE EARLY UNIVERSE

Experiments to Detect the Global EoR Signature

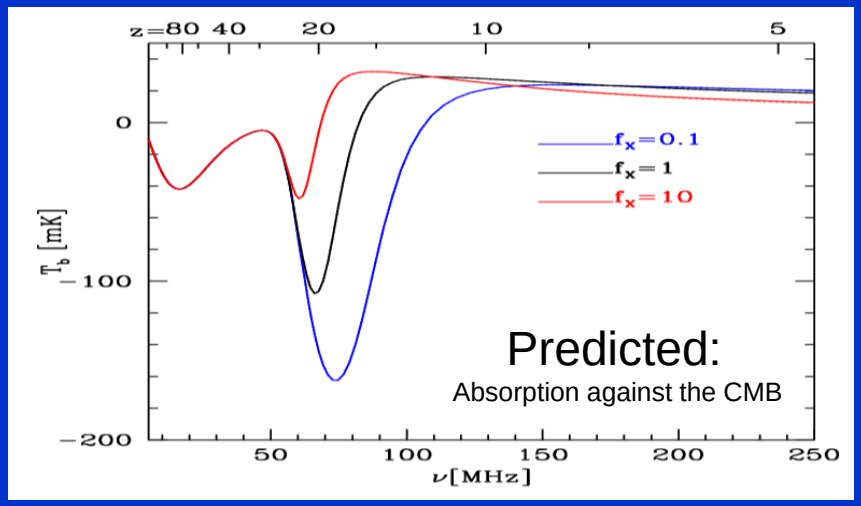
e.g. DARE, EDGES, LEDA

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

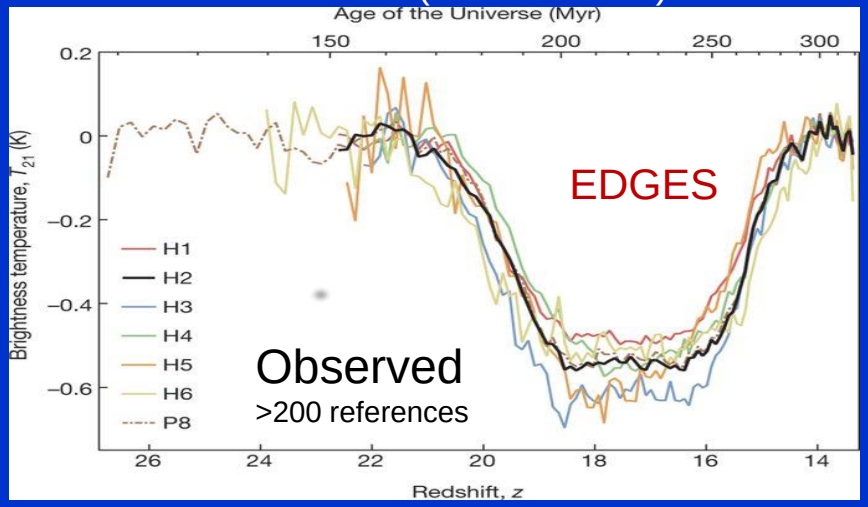
Interferometers for fluctuation measurements

e.g. LOFAR, SKA, HERA

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



Bowman+ (Nature 2018a)



- Absorption at z~17 during 200-240 Myrs, consistent with fx<0.1, but ~2-3 times larger amplitude than predicted
- Extra amplitude absorption due to cooling by interaction of dark matter with baryons by Barkana (Nature 2018)?

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

IF THE EDGES RESULT IS CONFIRMED IT MAY BE THE FIRST EVIDENCE OF BH-HMXB-MQs OF POP III

- **BH-HMXB-MQs of Pop III may be sources of a CRB (T_{rad})**

If the EDGES absorption is confirmed:

- It could 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

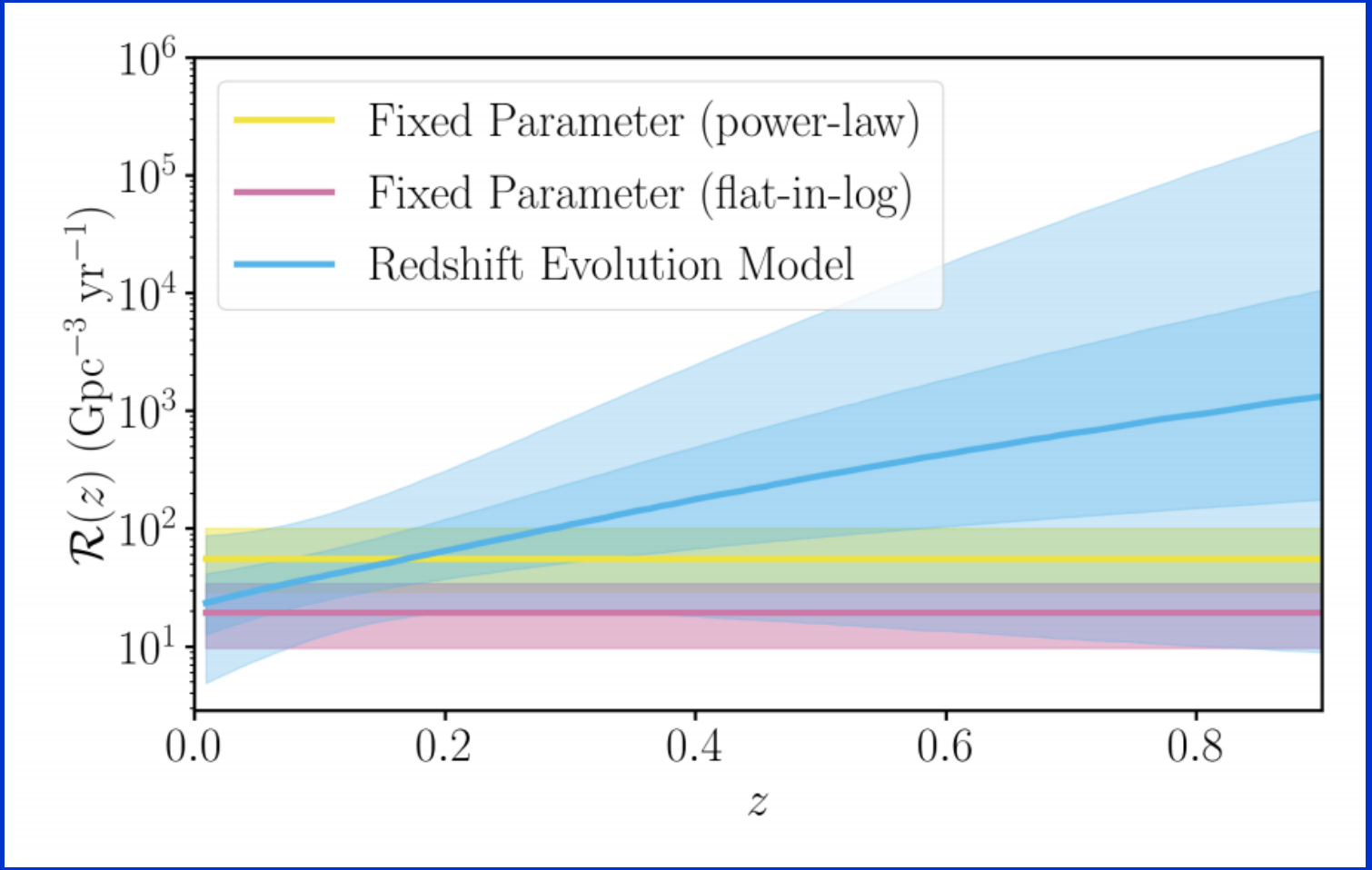
- BH-HMXB-MQs of Pop-III would be formed before the appearance of SNe, neutron stars, and large quantities of dust.

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

Mirabel (2017): New Astronomy Reviews
Mirabel (2019): arXiv#1902.00511

Evolution of the BBHs merger rate with z

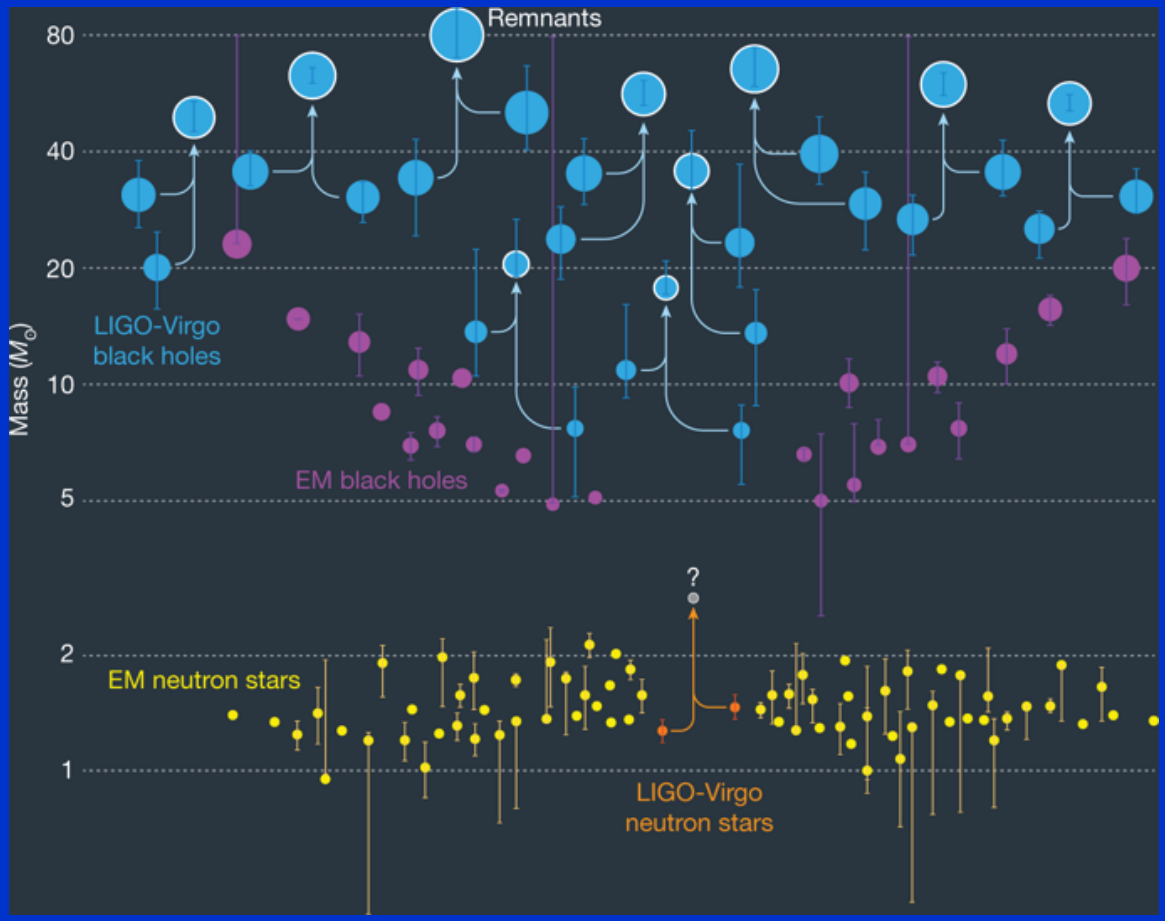
Advance LIGO-Virgo collaboration (2019)



Preliminary: Due to evolution of Z, SFR , time delay, GC formation

BBH POPULATIONS FROM LIGO-VIRGO O1 & O2

Consistent with prolific formation of stellar BHs in the early universe



M_{BH} = 7- 45 $M_\odot$; $M_{total\ BHs}$ = 19-85 $M_\odot$

Merger rates $R = 53^{+58}_{-28}$ $Gpc^{-3}\ yr^{-1}$