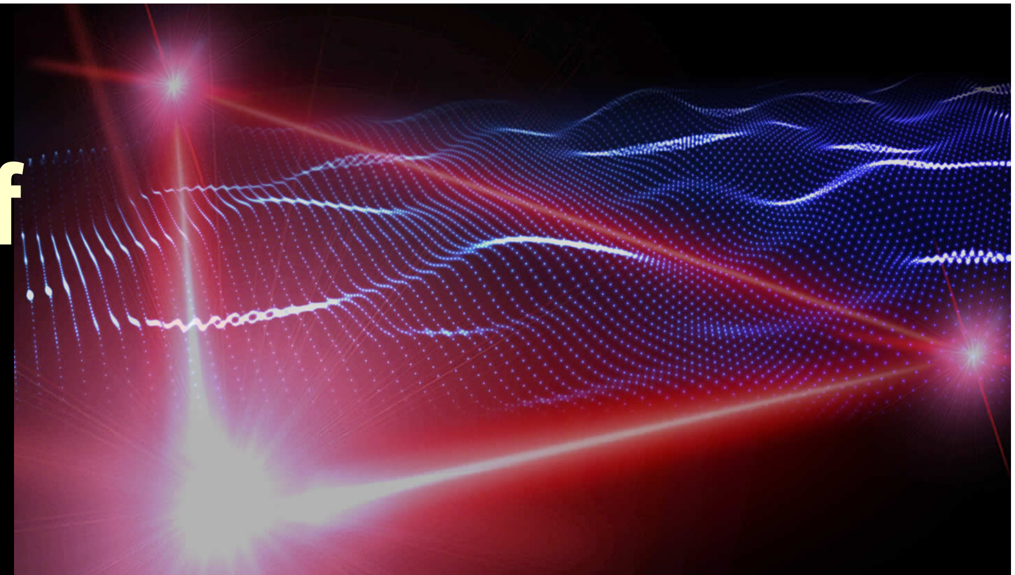
Future Observations of Compact Object Populations with Athena and LISA



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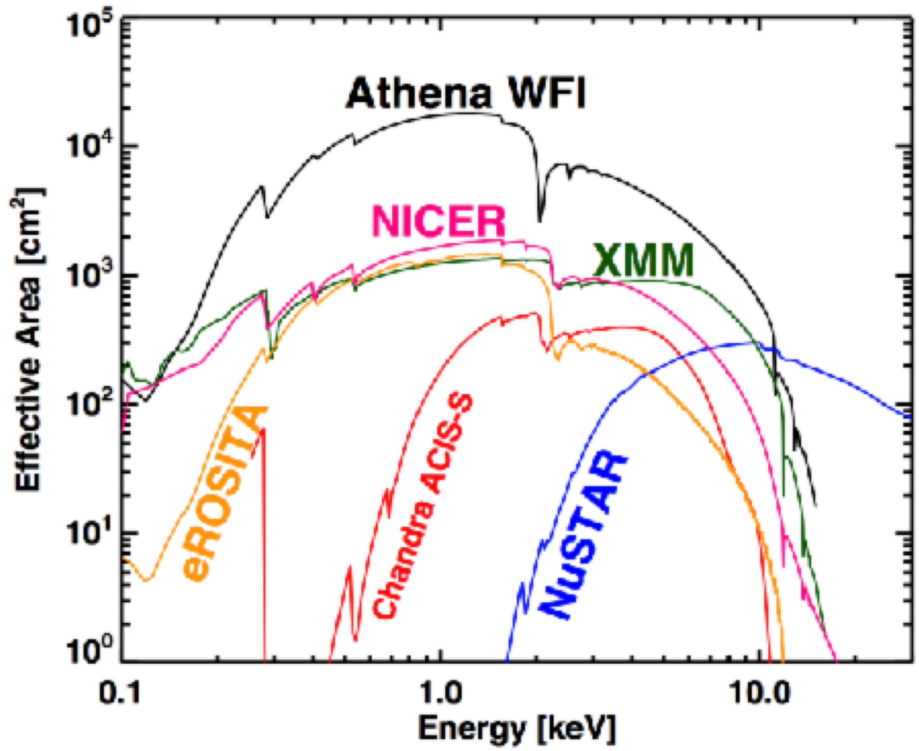
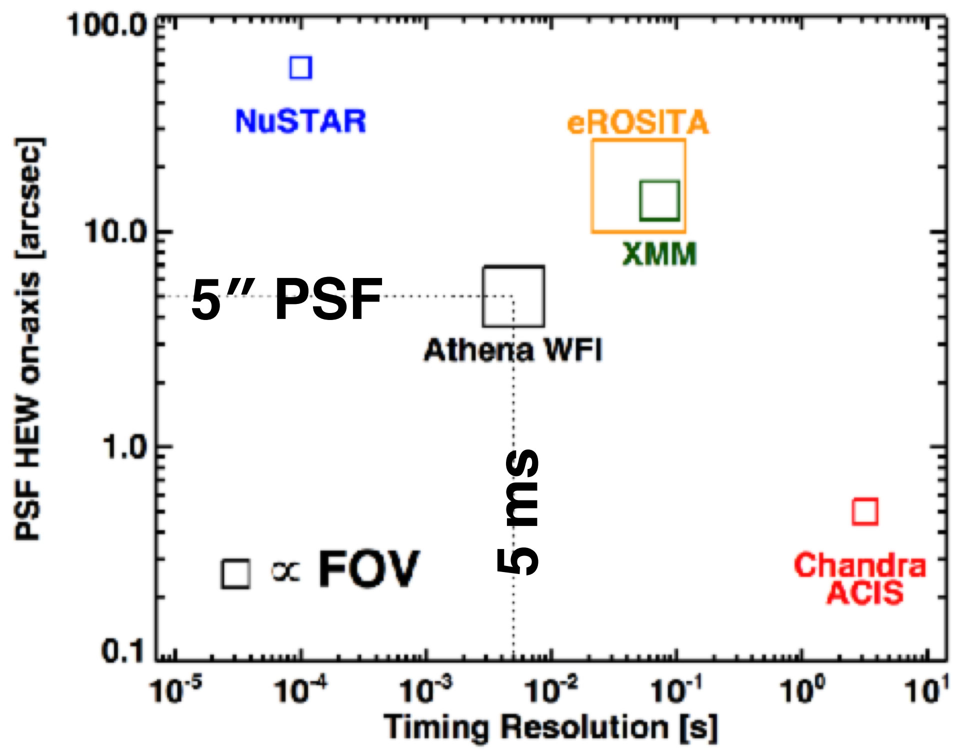
Athena Wide Field Imager

Ann Hornschemeier
Chandra Science Workshop on
Accretion in Stellar Systems

Athena WFI capabilities
40' x 40' FOV, 5" PSF,
1.4 m^2 eff. area, 5 ms timing





Key science questions, Athena WFI observations of nearby galaxies

- What is the prevalence of super-Eddington accreting pulsars and how does this fit into compact object evolution scenarios?
- What are the progenitor paths for the massive compact objects being found by e.g., LIGO/Virgo?
- What is the role of SN kicks in dynamical evolution of NS and BH populations?

UNDERSTANDING THE FORMATION OF MASSIVE STELLAR BHS:

The example of Wolf Rayet X-ray Binaries

(a rare, but important, population)

Wolf Rayet X-ray Binaries: The biggest, baddest accreting stellar-origin BHs?

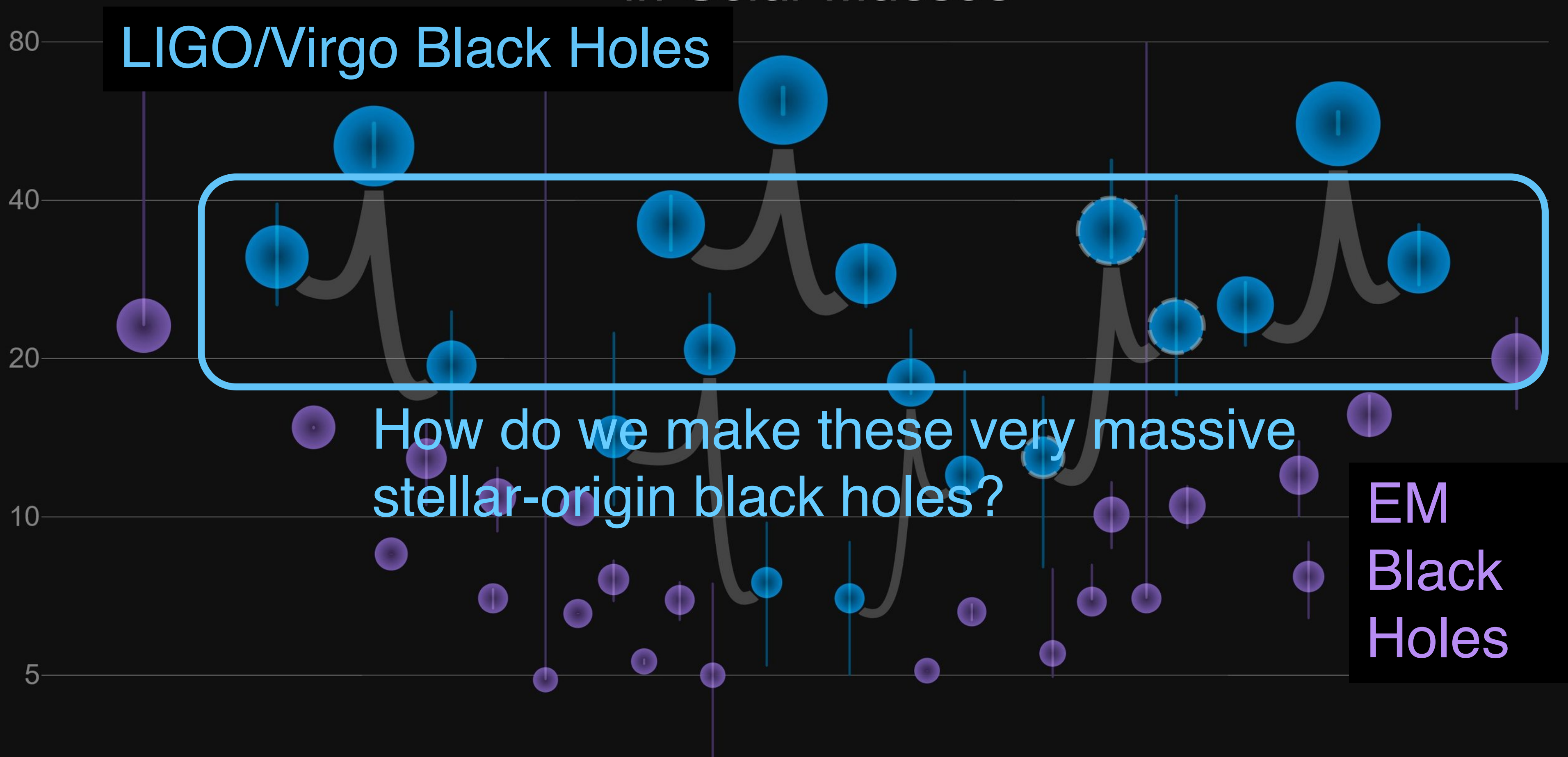

Artist's rendition of the WR XRB NGC 300 X-1

- Wolf Rayet stars are luminous, massive stars with strong stellar winds
- The orbital periods are short (most are less than a day)
- Likely only contain BH (not NS): van den Heuvel (2017)

Why might you care about a BH in a relatively tight orbit with a very massive star?

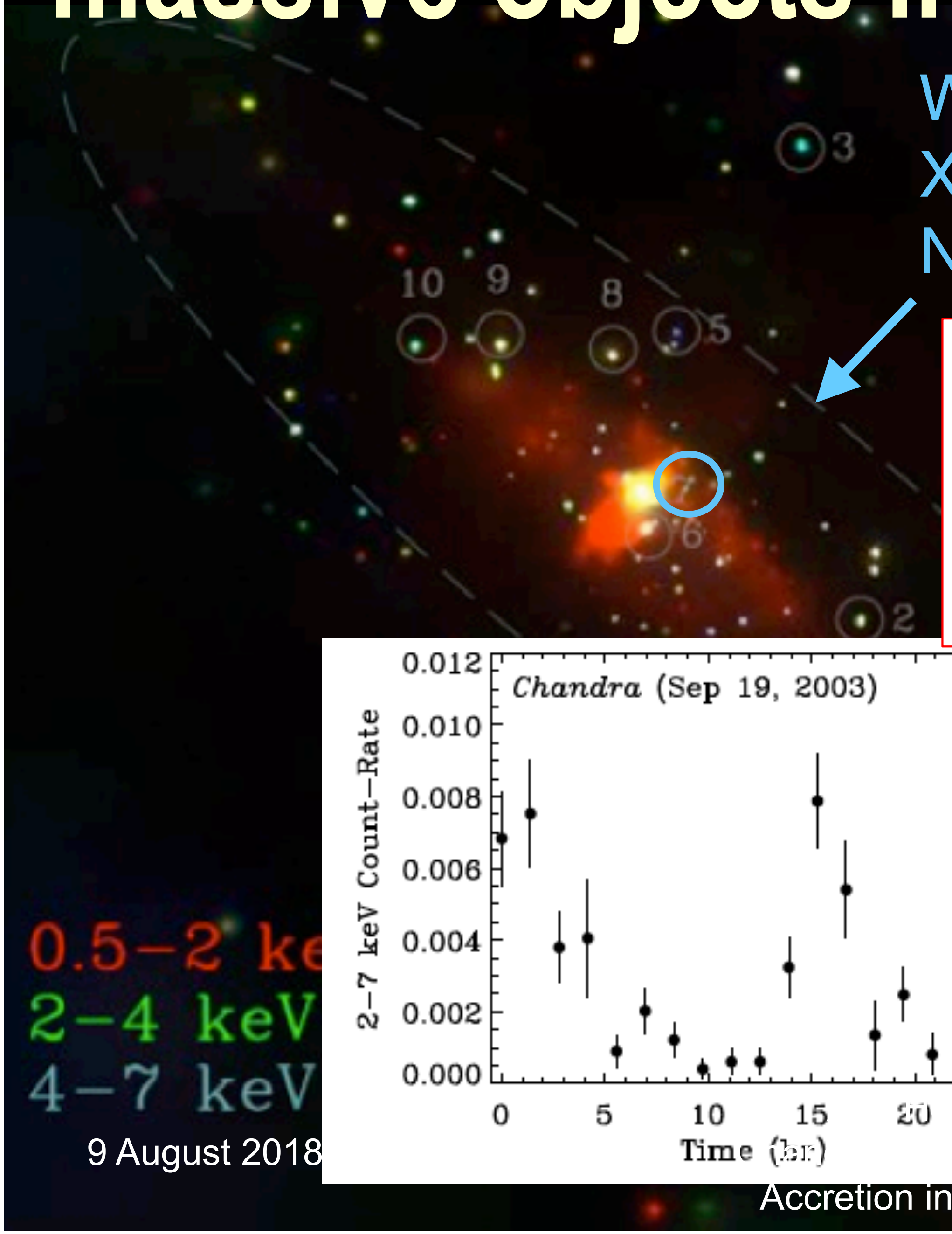
Masses in the Stellar Graveyard

in Solar Masses

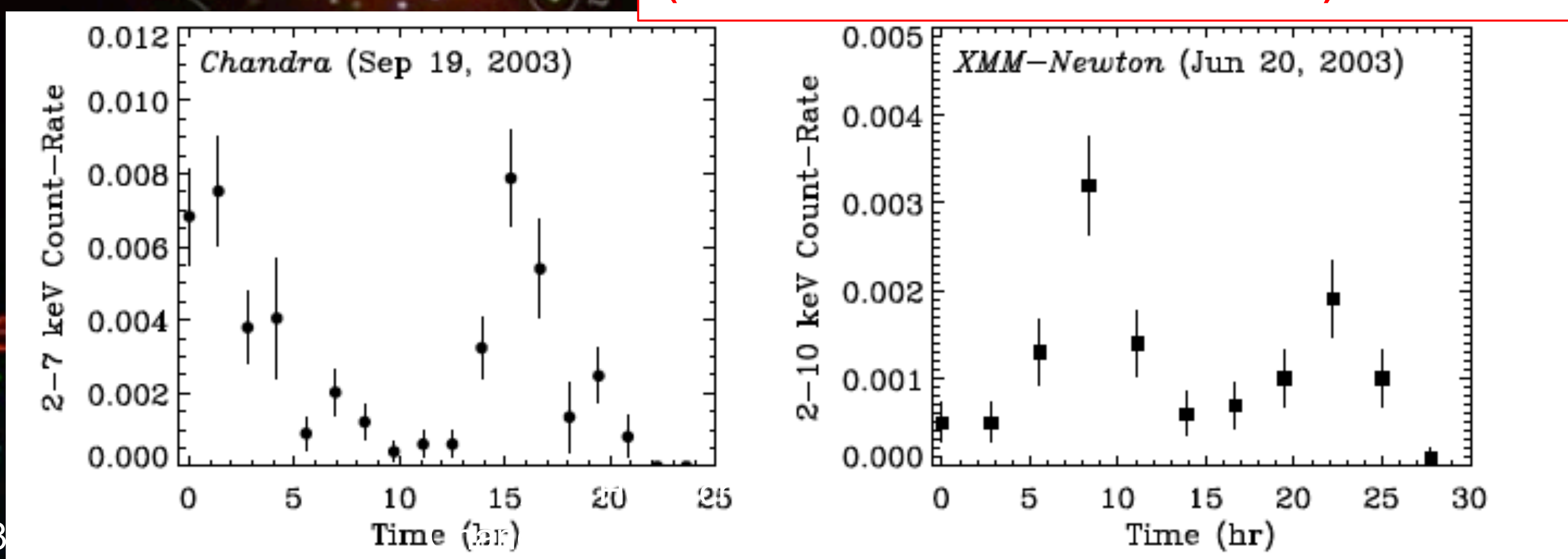


Time domain discovery space: massive objects in tight orbits

We noticed a highly variable X-ray source in our 2012 NuSTAR-Chandra campaign

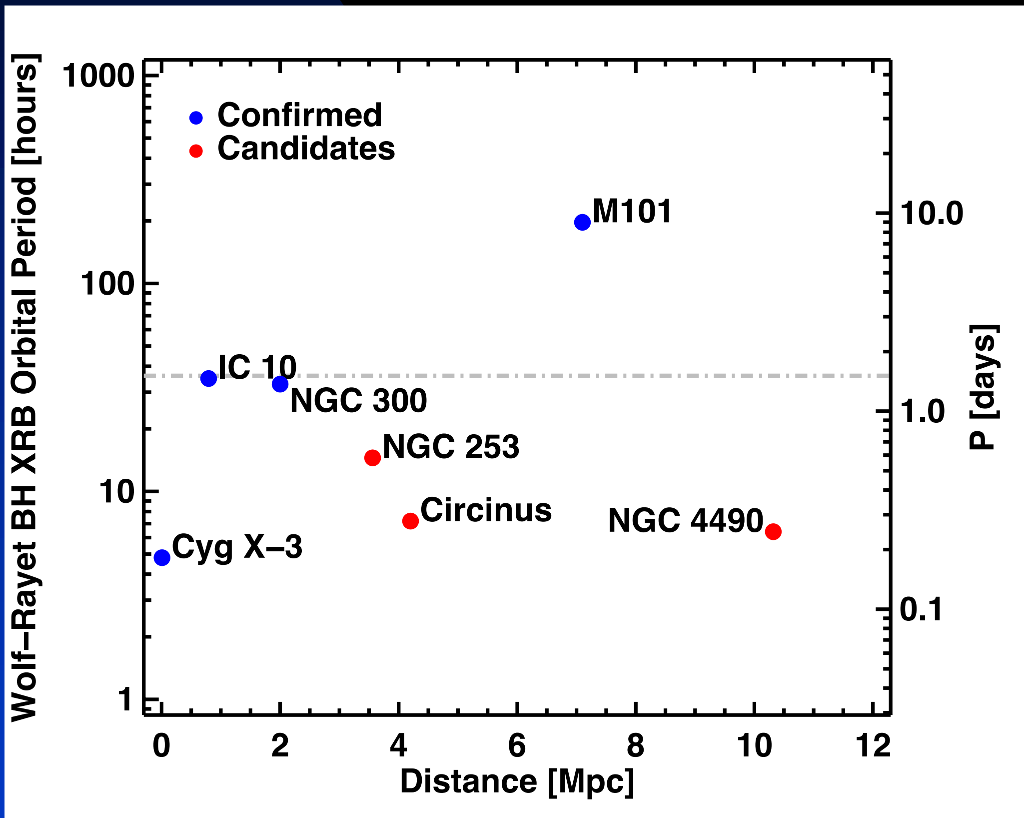


Using archival Chandra data
From observation 9 years prior:
Periodicity of ~14-15 hours
(Maccarone et al. 2014)



WR XRBs are rare! (but important)

Only six examples known!



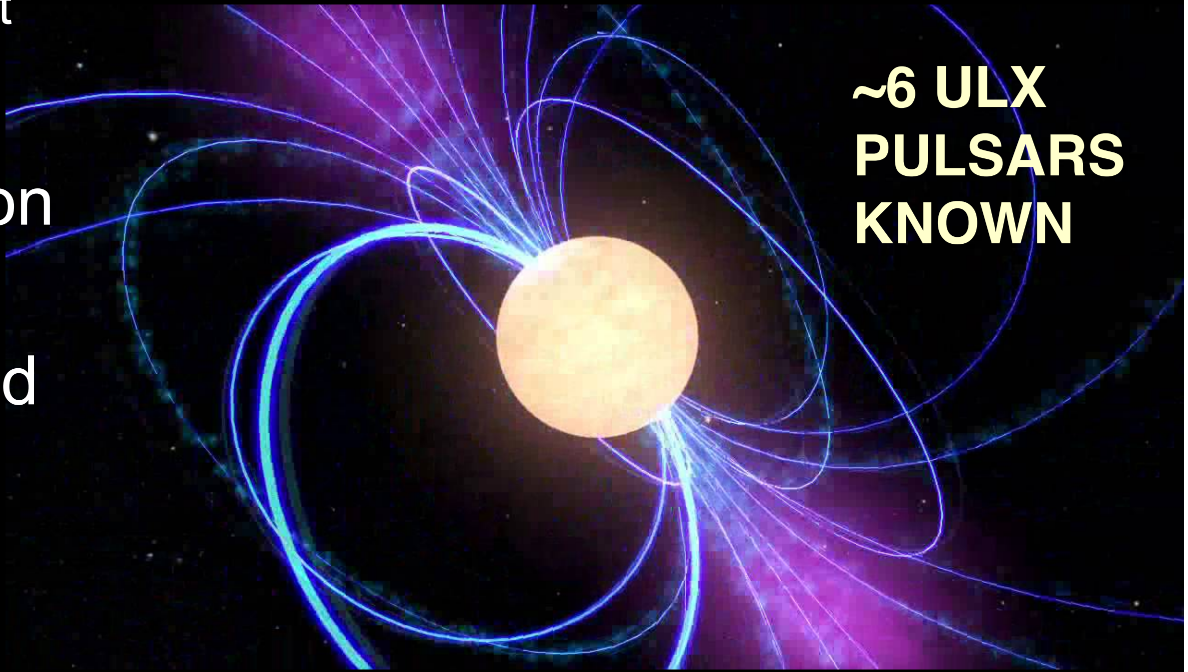
- Few HMXBs survive to the WR XRB phase: unstable mass transfer in the Common Envelope phase?
  (e.g., Munoz et al. 2015, van den Huevel et al. 2017)
- This single source (the NGC 253 WR XRB) implies Advanced LIGO detection rates up to ~10 per year (Maccarone et al. 2014)

SUPER-EDDINGTON ACCRETION ONTO PULSARS:

How prevalent is this? How does this fit with the rest of the pulsar population?

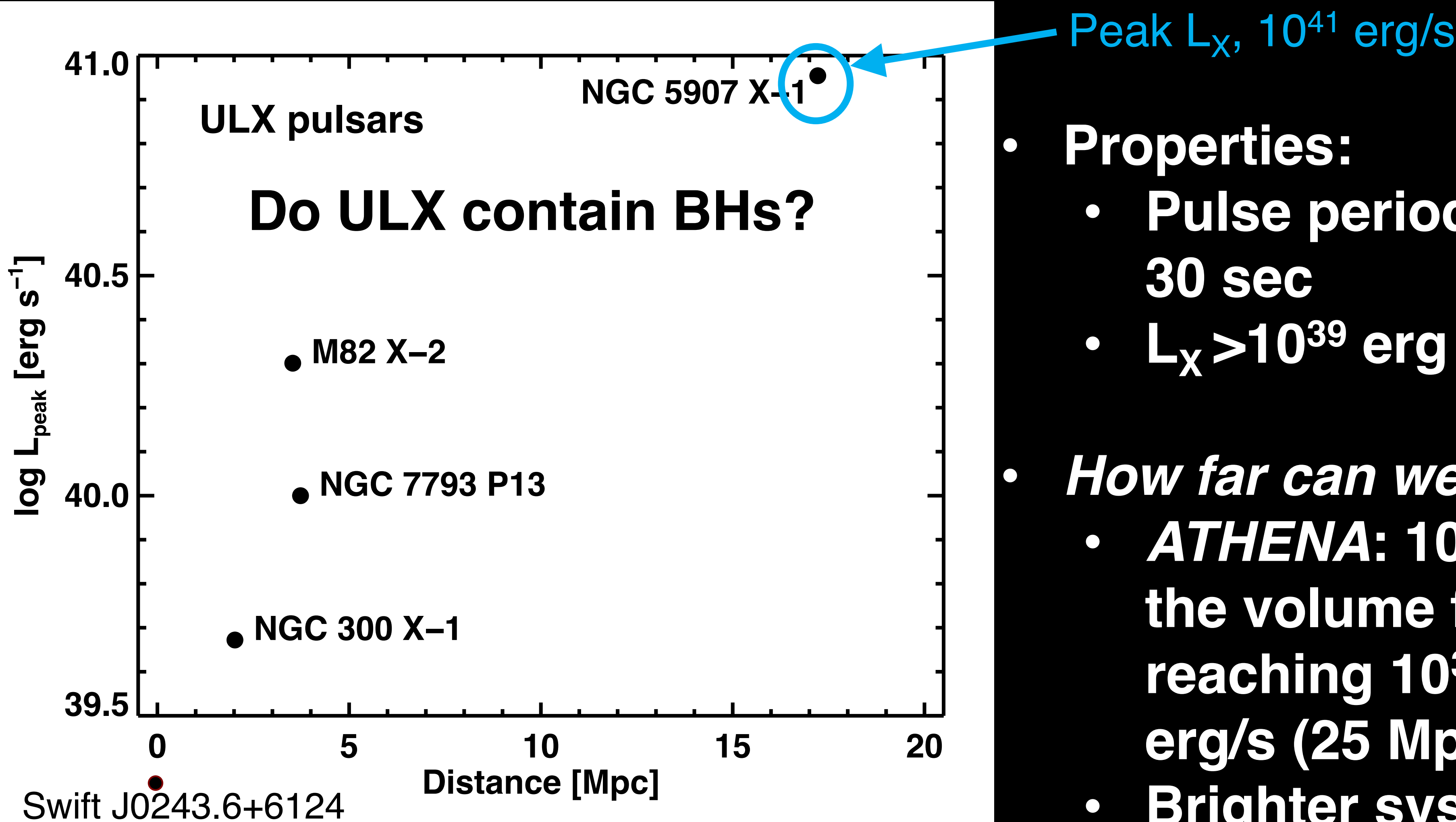
ULX pulsars, a major challenge to our understanding of accretion

- **ULX PULSARS**
  (Bachetti et al. 2014, Feurst et al. 2016, Israel et al. 2017, Kosec et al. 2018, Brightman et al. 2018; Carpano et al. 2018)
  Up to 500 times Eddington limit for a 1.4 $M_{\odot}$ NS
- Athena WFI time-resolved spectroscopy: separate the (pulsed) accretion column from the (non-pulsed) accretion flow beyond the magnetosophere



~6 ULX PULSARS KNOWN

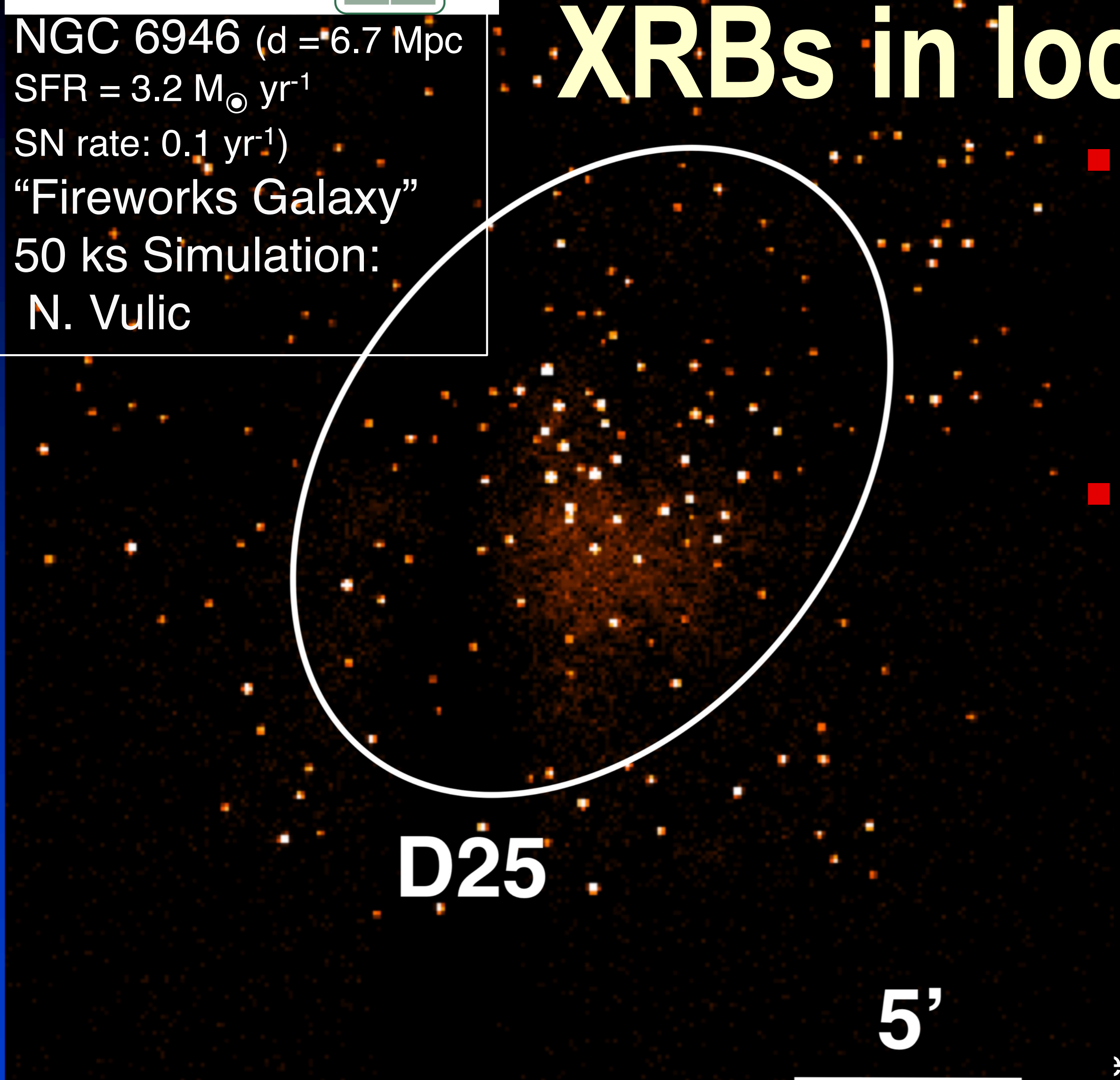
ULX Pulsars: NS at 500x > L_{EDD}!



- **Properties:**
  - **Pulse periods ~1-30 sec**
  - **$L_X > 10^{39}$ erg s^{-1}**
- ***How far can we go?***
  - ***ATHENA*: 100X the volume for reaching 10^{39} erg/s (25 Mpc)**
  - **Brighter systems to much larger distances (>250 Mpc)**

5 confirmed, 1 candidate (M51)

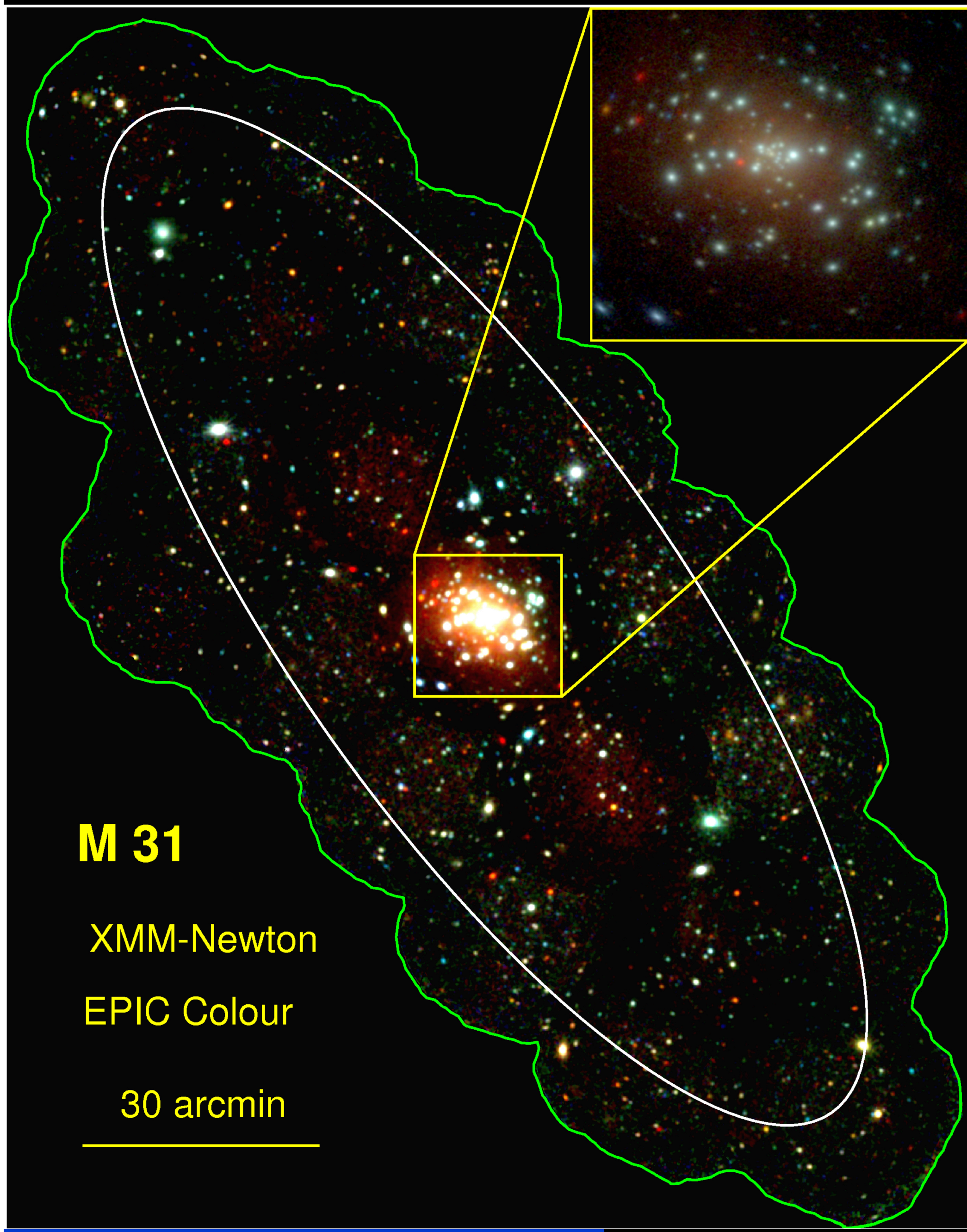
Athena WFI: Time domain studies of XRBs in local galaxies

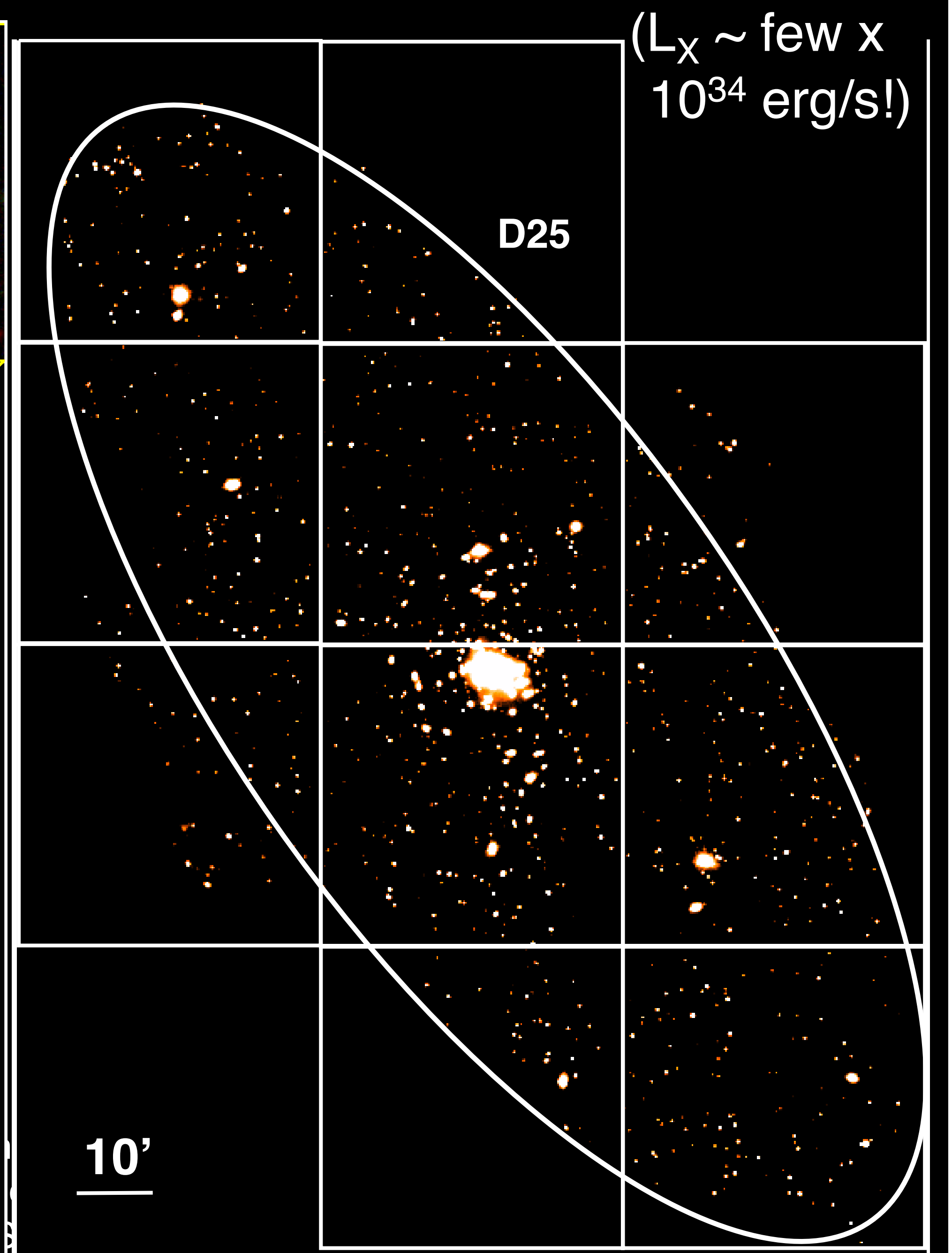


- **TIMING CAPABILITY:** (~5 ms timing resolution) -
  → young, ULX pulsars (0.4-30 s pulse periods) easily found and/or verified
- **SURVEY POWER** (collecting area × solid angle)
  → period measurements to search for e.g., WR XRBs
  → HMXB orbital periods also means constraint on compact object masses

M31 *XMM* survey (Stiele et al. 2011) ~100 ks x ~20 pointings

M31 *ATHENA* WFI simulation 10 ks x 10 pointings

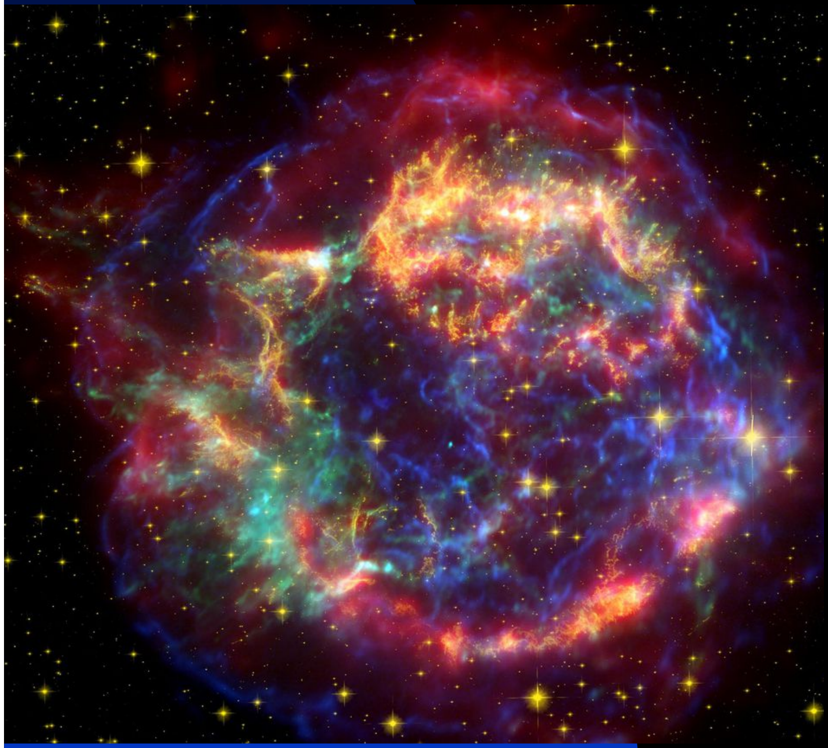




SUPERNOVA KICKS:

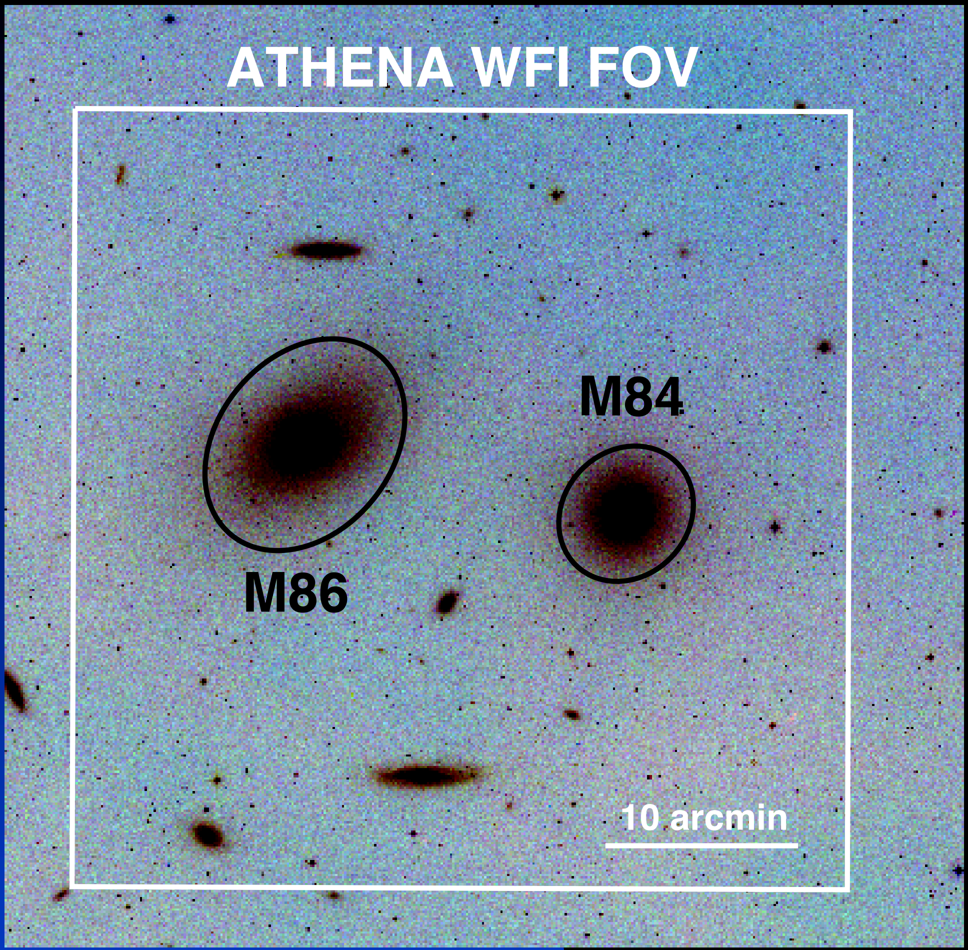
The dynamical evolution of LMXB systems

Supernova Kicks inferred from LMXB distribution



- Asymmetry in mass ejection and/or neutrino emission can lead to SN kicks
- Suggestive evidence, centered on NS:
  - Excess LMXBs in ellipticals found with Chandra at $L_X < 10^{38}$ erg/s (Zhang, Gilfanov & Bogdan 2013)
  - Intracluster LMXBs found in Virgo (3.5σ result, Hou et al. 2017)
- Stellar mass BH SN kicks?
  - Large natal kicks for BHs possible (Repetto et al., 2012; Repetto & Nelemans, 2015)
  - BH-LMXBs, as transients, less luminous on average (e.g. Wiktorowicz et al. 2014; Corral-Santana et al. 2016; Belloni & Motta, 2016).

Dynamical Evolution of LMXBs: Supernova Kicks?

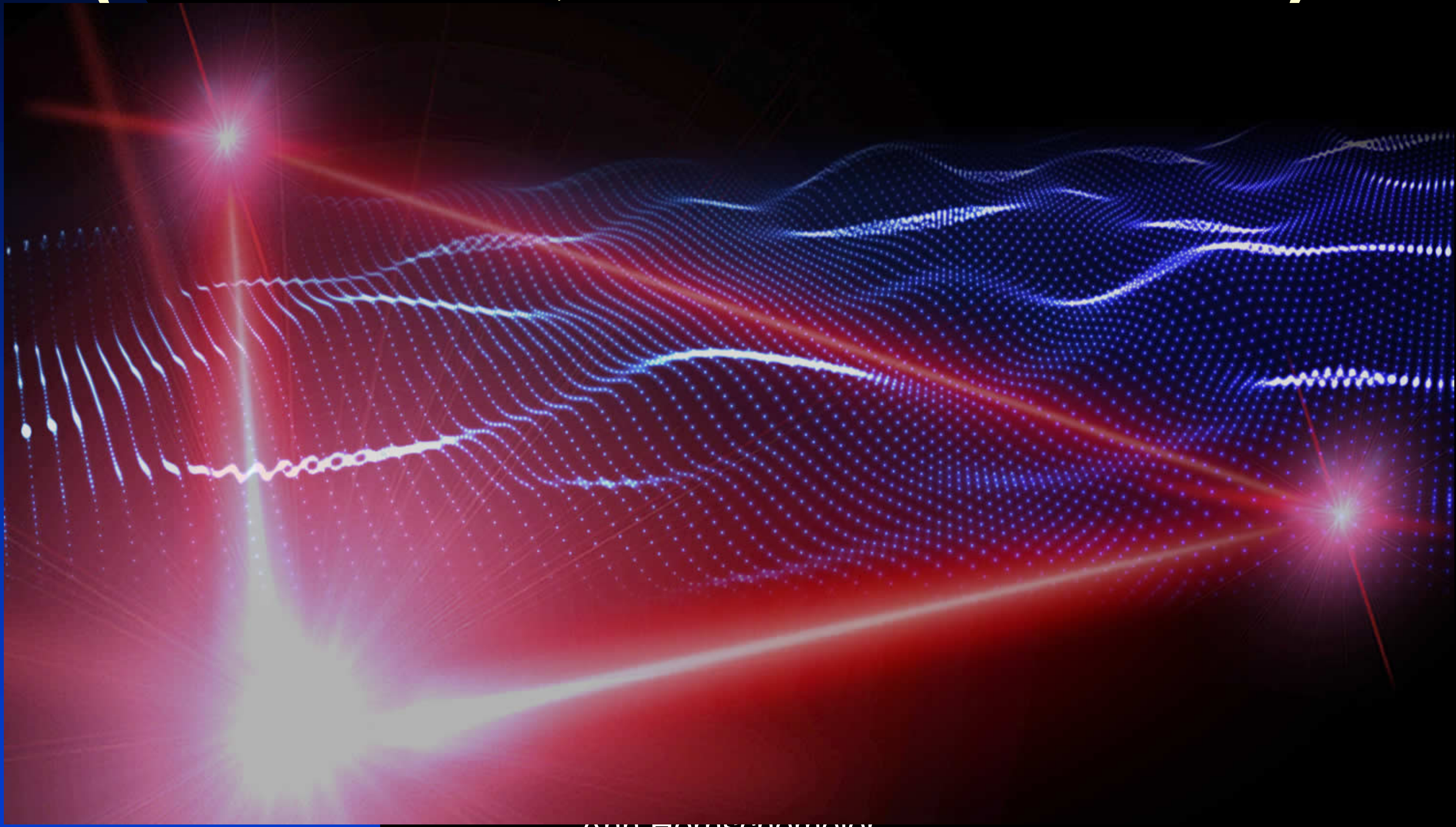


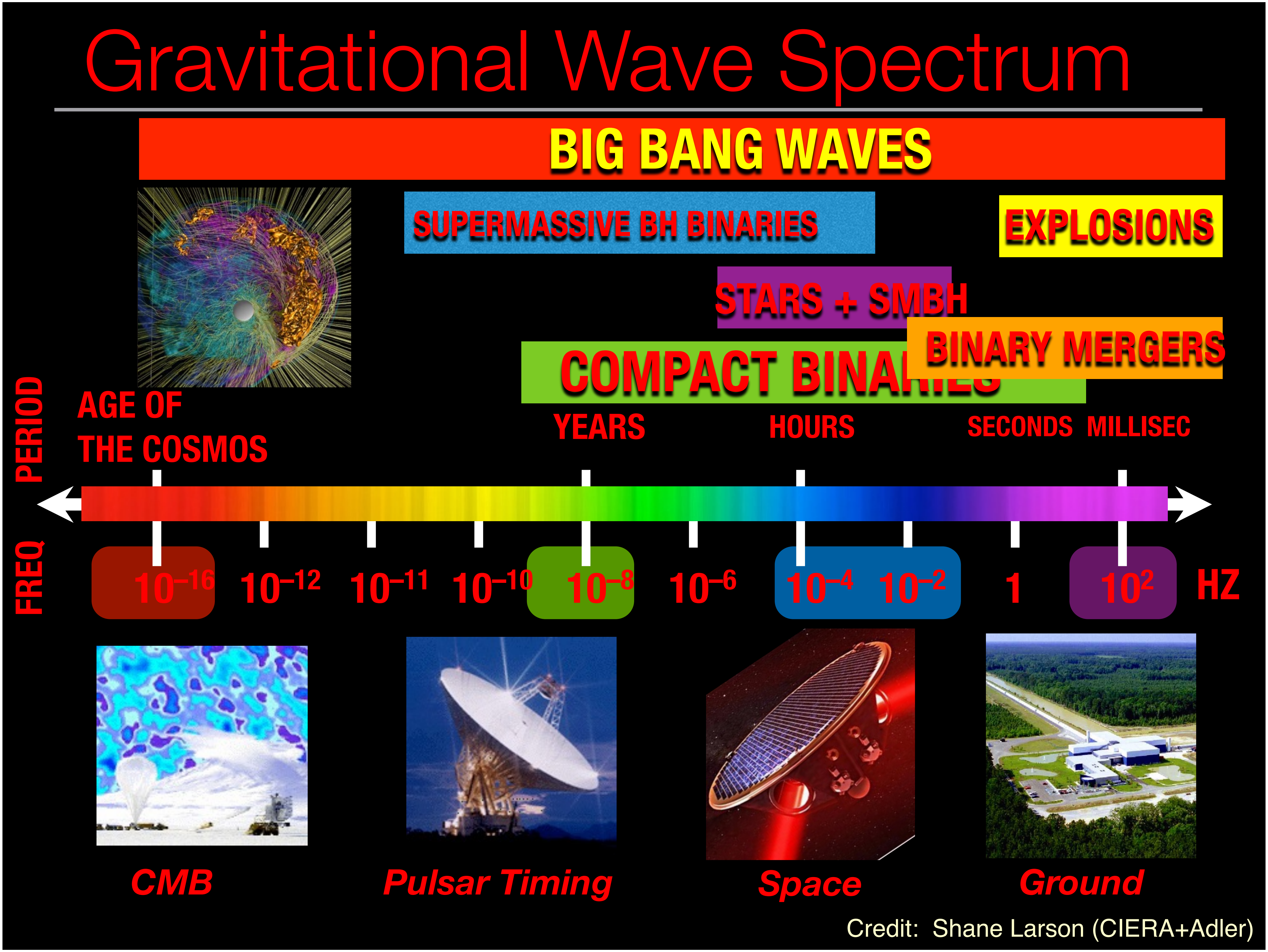
WFI FOV permits efficient/sensitive measurement of LMXBs in galaxy outskirts to required low-L_X~10^{37} erg s^{-1}

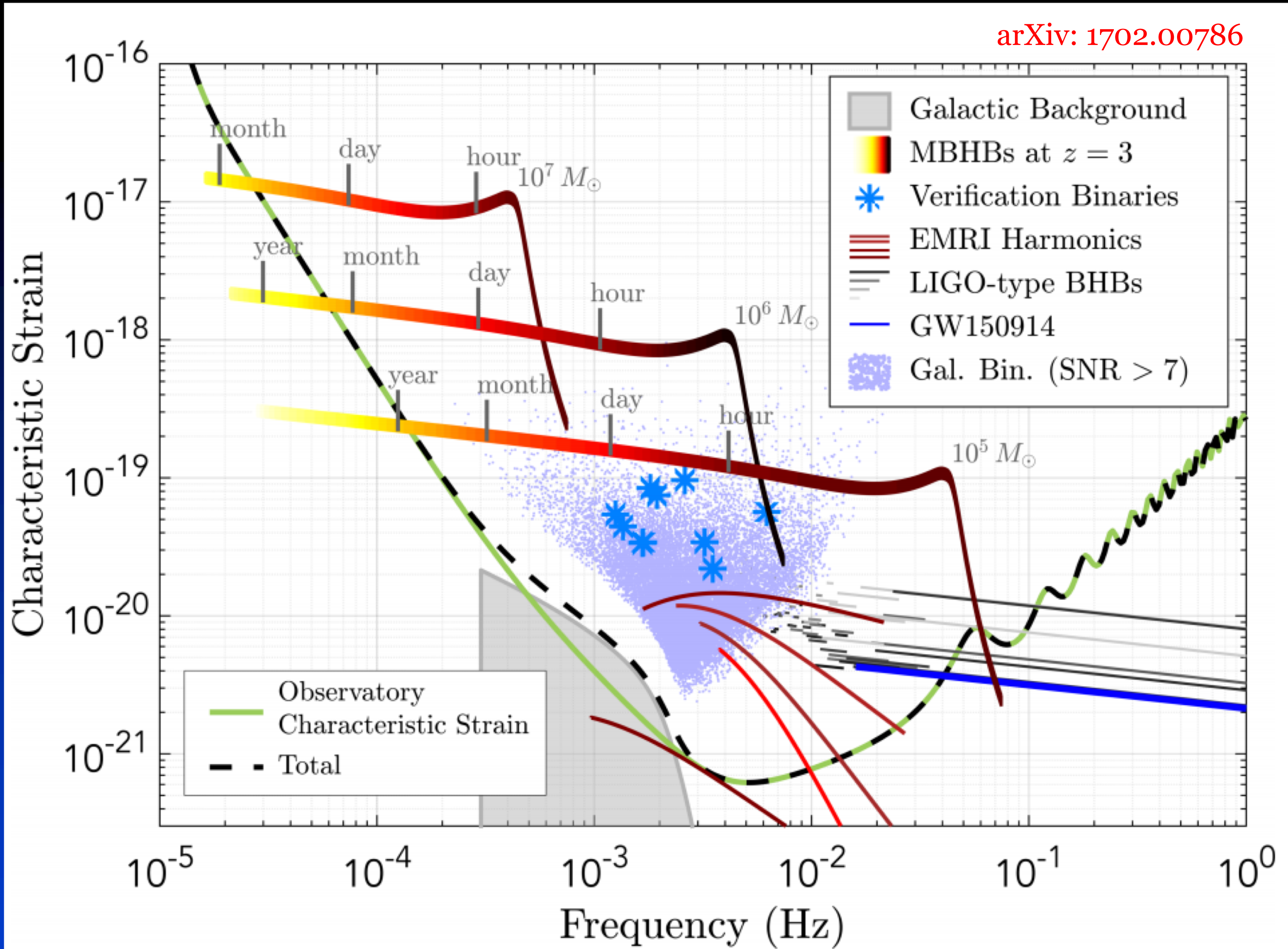
WFI t_{exp}=10 ks

Example: M84 and M86 in Virgo: can reach L_X = 1 x 10^{37} erg/s for both galaxies in 10 ks

LISA studies of accreting compact object populations (K. Breivik, CIERA → CITA)

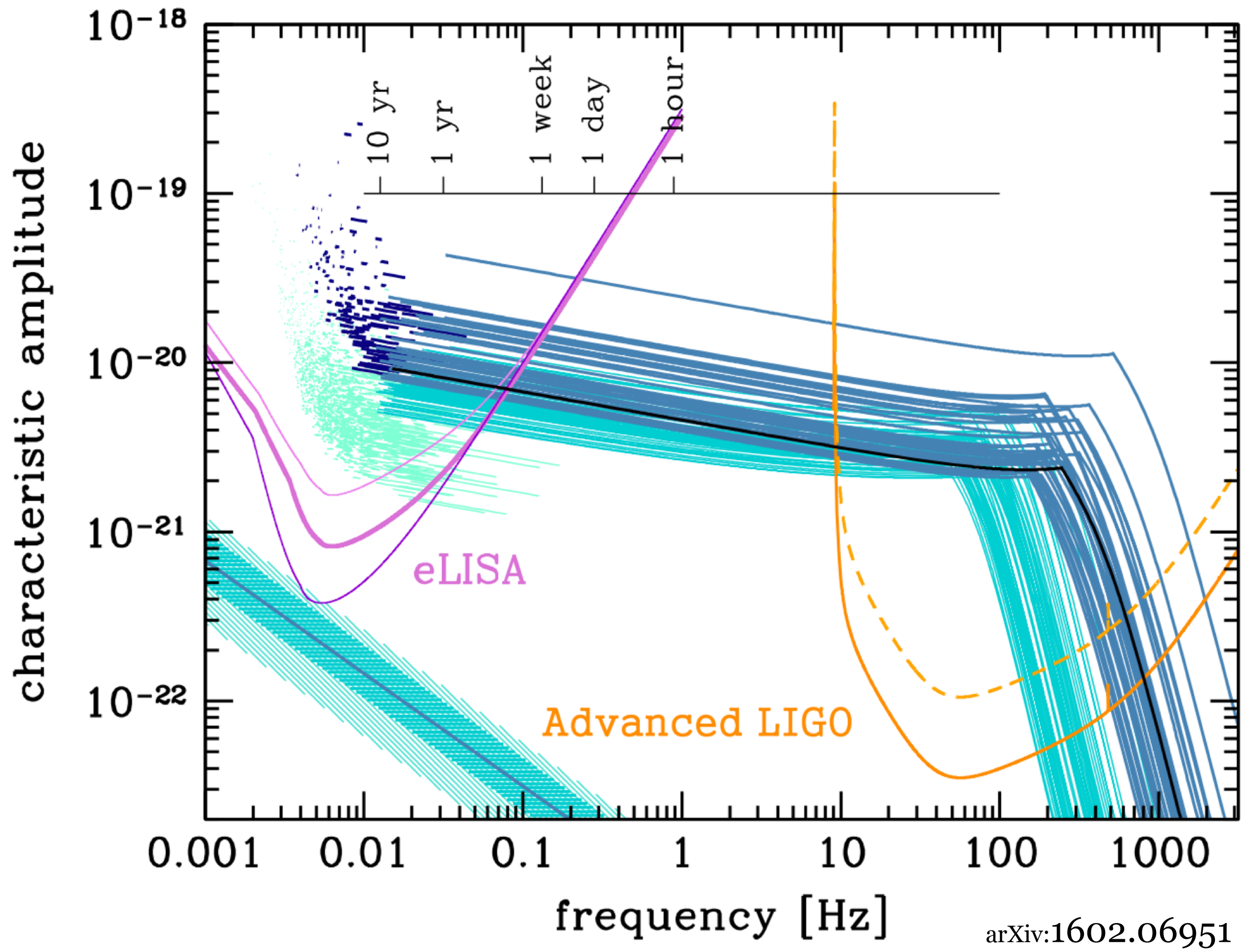



Gravitational Wave Spectrum
BIG BANG WAVES
SUPERMASSIVE BH BINARIES
EXPLOSIONS
STARS + SMBH
BINARY MERGERS
COMPACT BINARIES
PERIOD
AGE OF THE COSMOS
YEARS
HOURS
SECONDS
MILLISEC
FREQ
10^-16
10^-12
10^-11
10^-10
10^-8
10^-6
10^-4
10^-2
1
10^2
HZ
CMB
Pulsar Timing
Space
Ground
Credit: Shane Larson (CIERA+Adler)



The LISA science case… in one plot!!

LISA could observe *thousands* of black holes based on LIGO rates



arXiv:1602.06951

<u>Sesana 2016</u>

Hundreds with merger time below 10 years

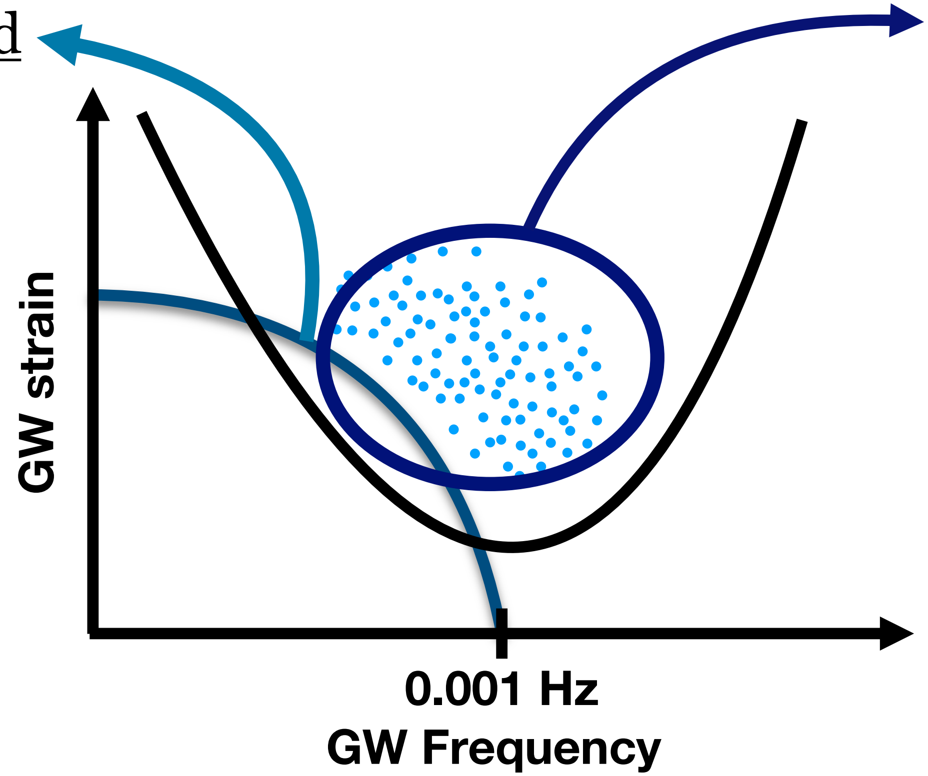
Predicted mergers with ~sec accuracy!

10^7 compact binaries observable by LISA

(courtesy of K. Breivik, Northwestern)

<u>Galactic Foreground</u>

- *Millions* of systems
- Multiple systems with the same frequency make an irreducible astrophysical foreground



<u>Resolved binaries</u>

- 10,000 systems
- **Every binary**: chirp mass, orbital period, eccentricity, inclination
- **Chirping binaries**: distance, orbital period evolution

<u>What can we do with all of this?</u>

Foreground:

Evolutionary pathways of bulk population
(e.g. Kopparapu & Tohline 2007)

Probe Galactic structure

Resolved:

Constrains interacting binaries including mass transfer & tides
(e.g. Breivik et al. 2017)

Connect to XRB populations

Measuring distances with LISA

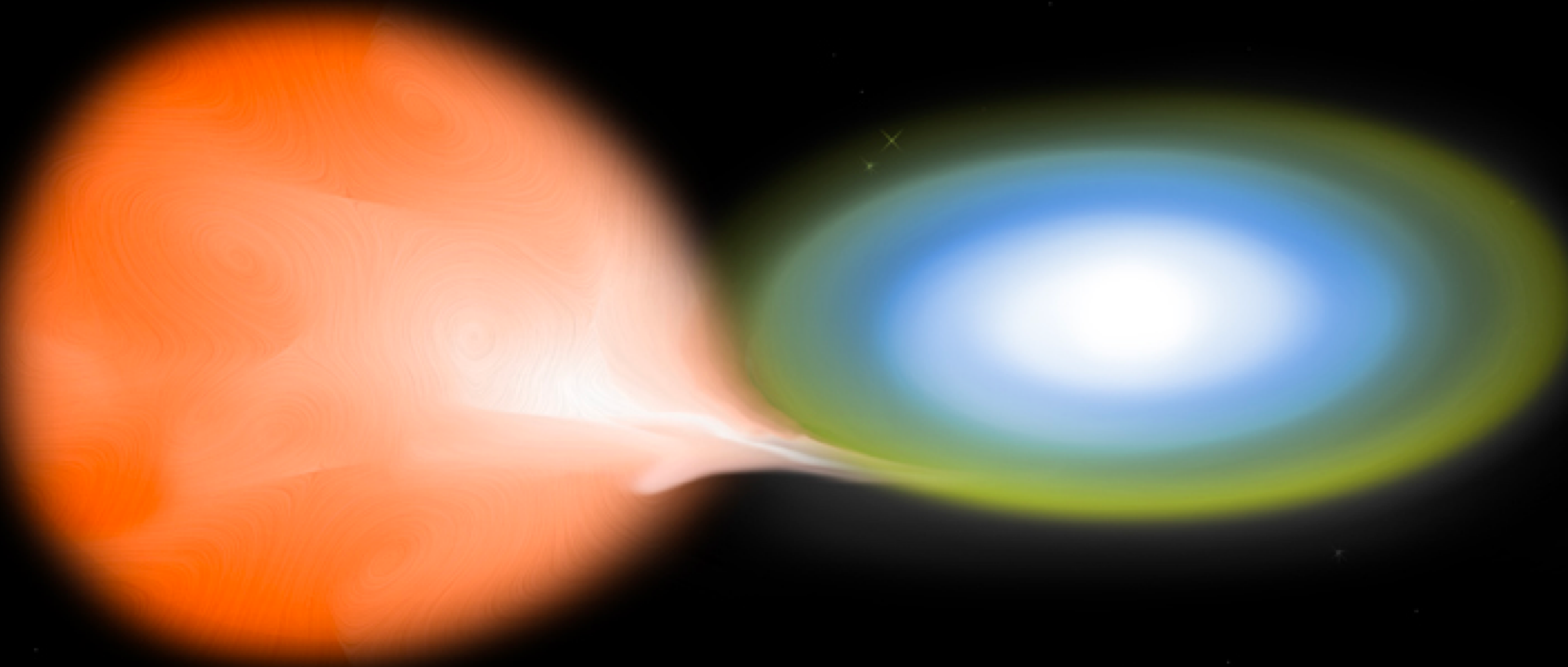
Every binary: $h_o \propto \mathcal{M}_c^{5/3} f_{\rm GW}^{2/3} D^{-1}$

Chirping binaries: $\dot{f}_{\rm GR} \propto f_{\rm GW}^{11/3} M_c^{5/3}$

$$D \propto \frac{h_o \dot{f}_{\rm GR}}{f_{\rm GW}^3}$$

What if $\dot{f} \neq \dot{f}_{GR}$?

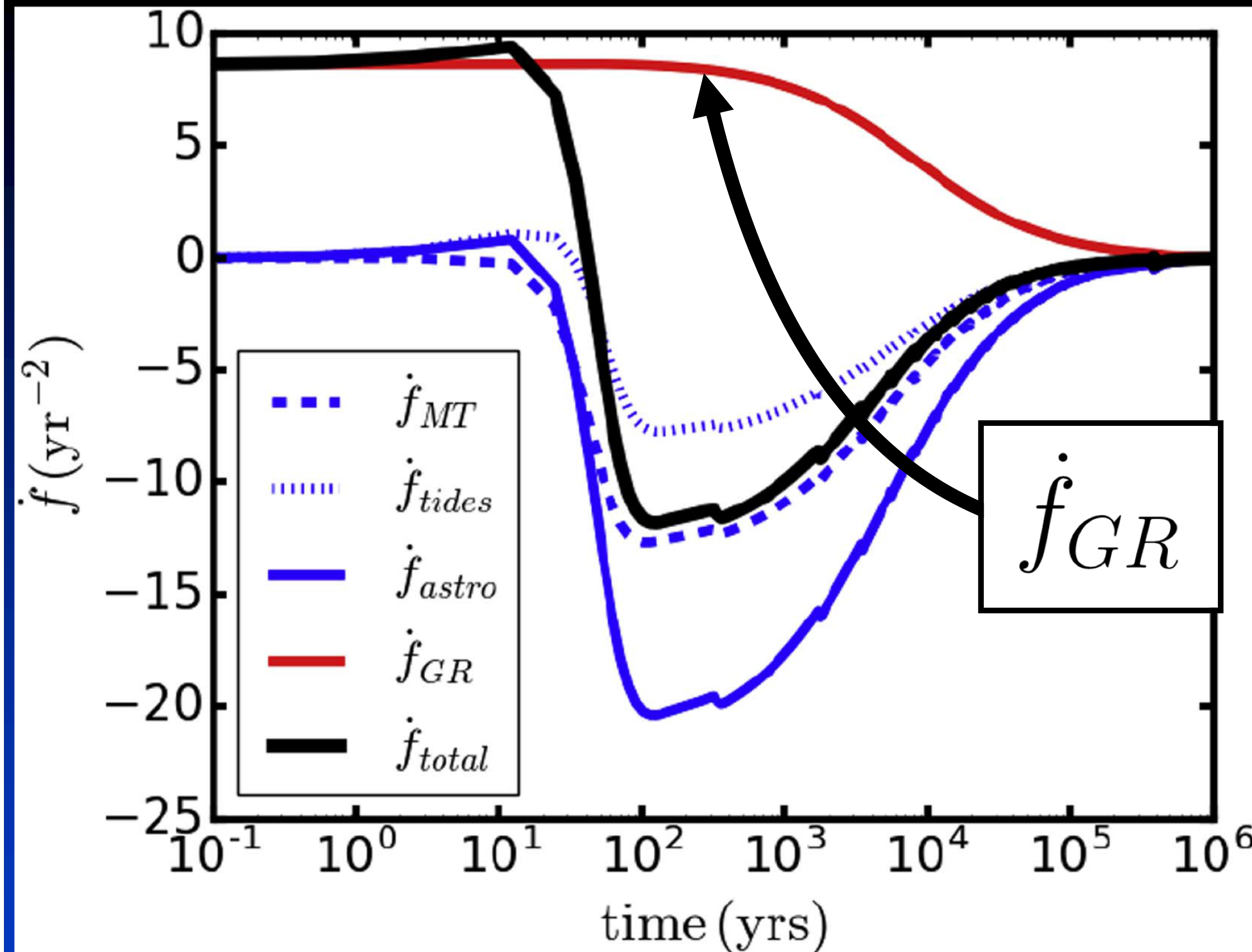
Characterizing accreting double white dwarfs



arXiv:
1707.01104
1710.08370

Katie Breivik, Kyle Kremer
Michael Bueno, Scott Coughlin
Shane Larson, Vicky Kalogera

Probing accreting double white dwarfs with LISA



$M_{accretor} = 0.5\ M_\odot$

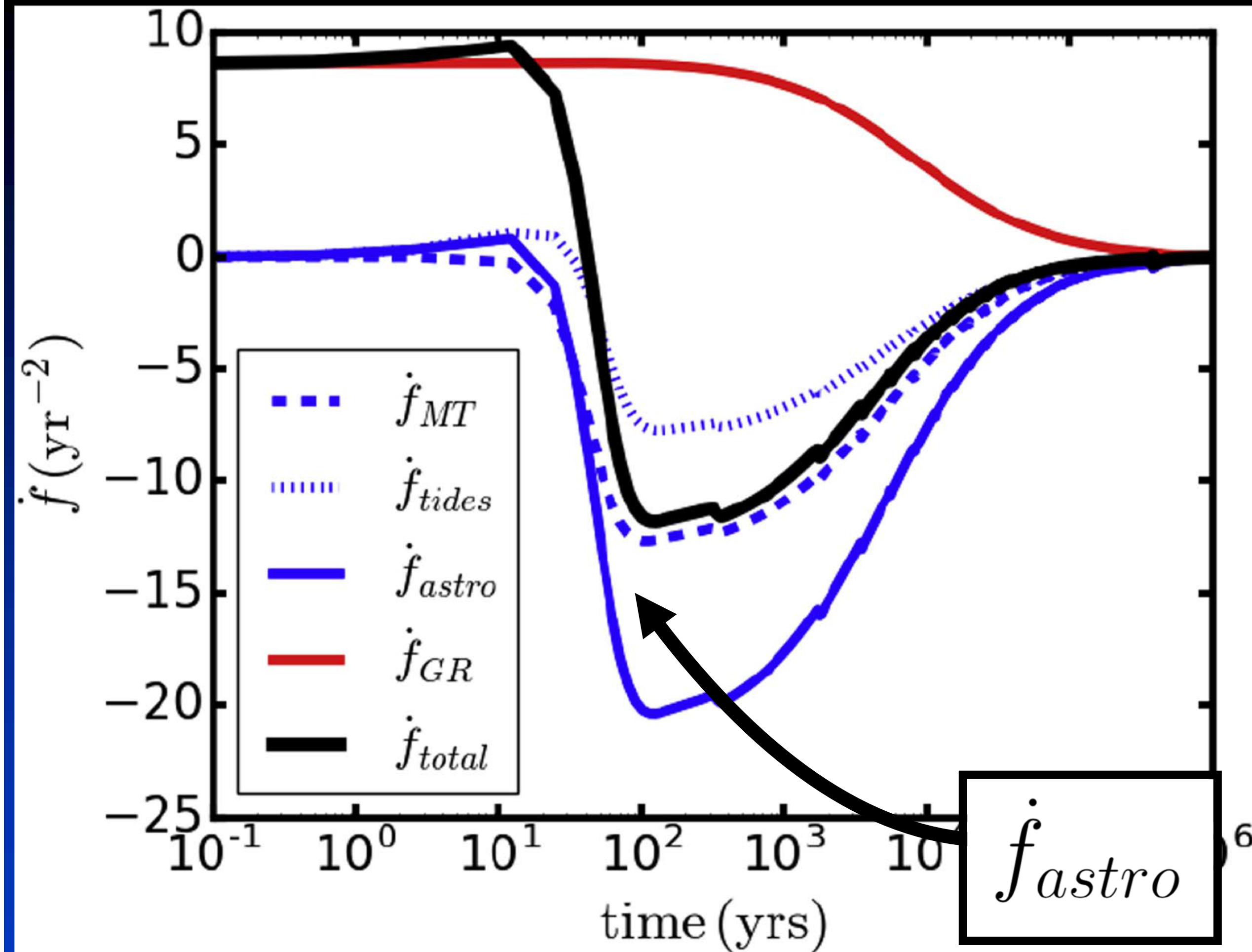
$M_{donor} = 0.25\ M_\odot$

LISA fiducial minimum chirp

$\dot{f} < -1.0$ bin/yr

Kremer et al. (2017)

Probing accreting double white dwarfs with LISA



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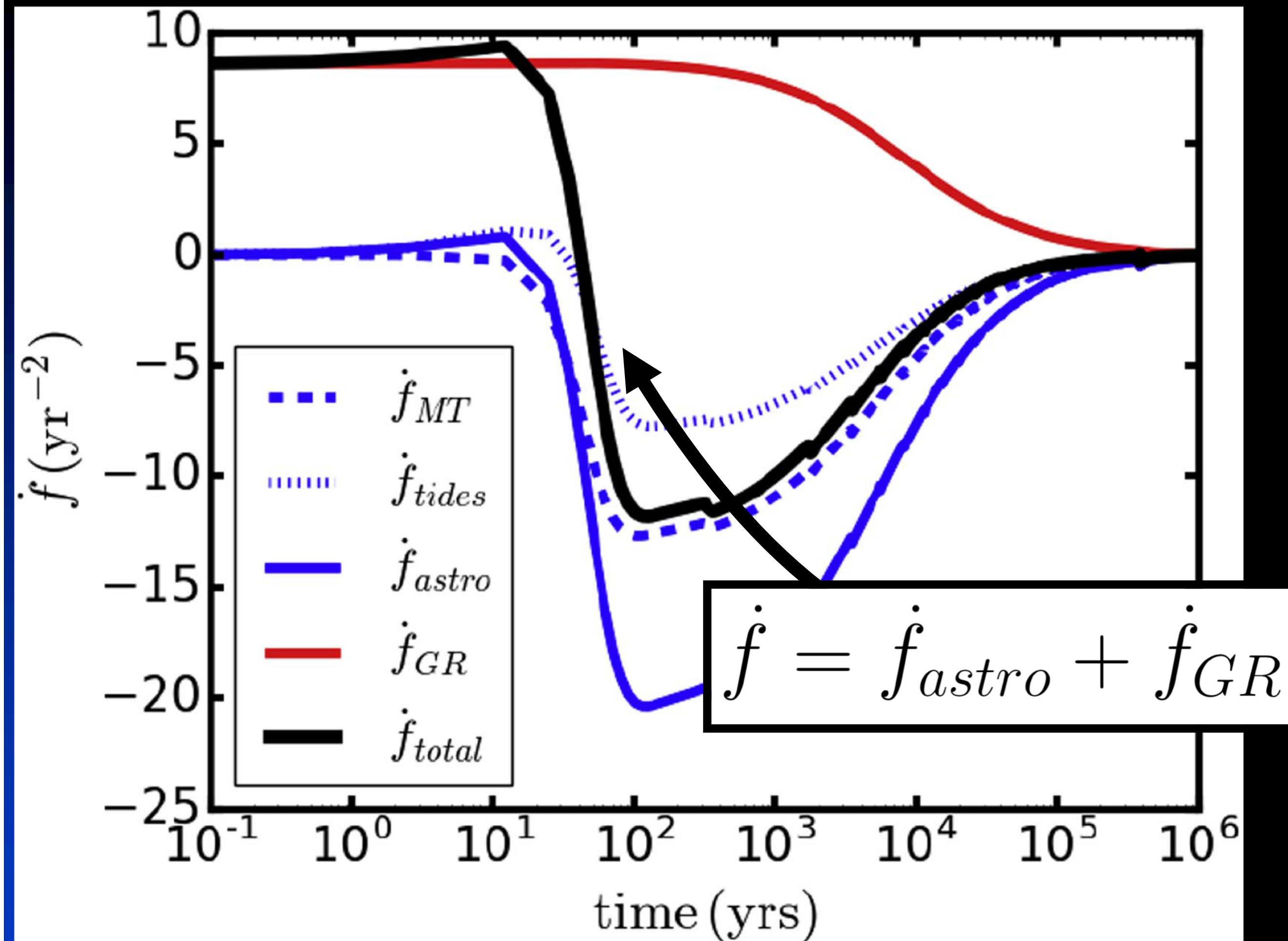

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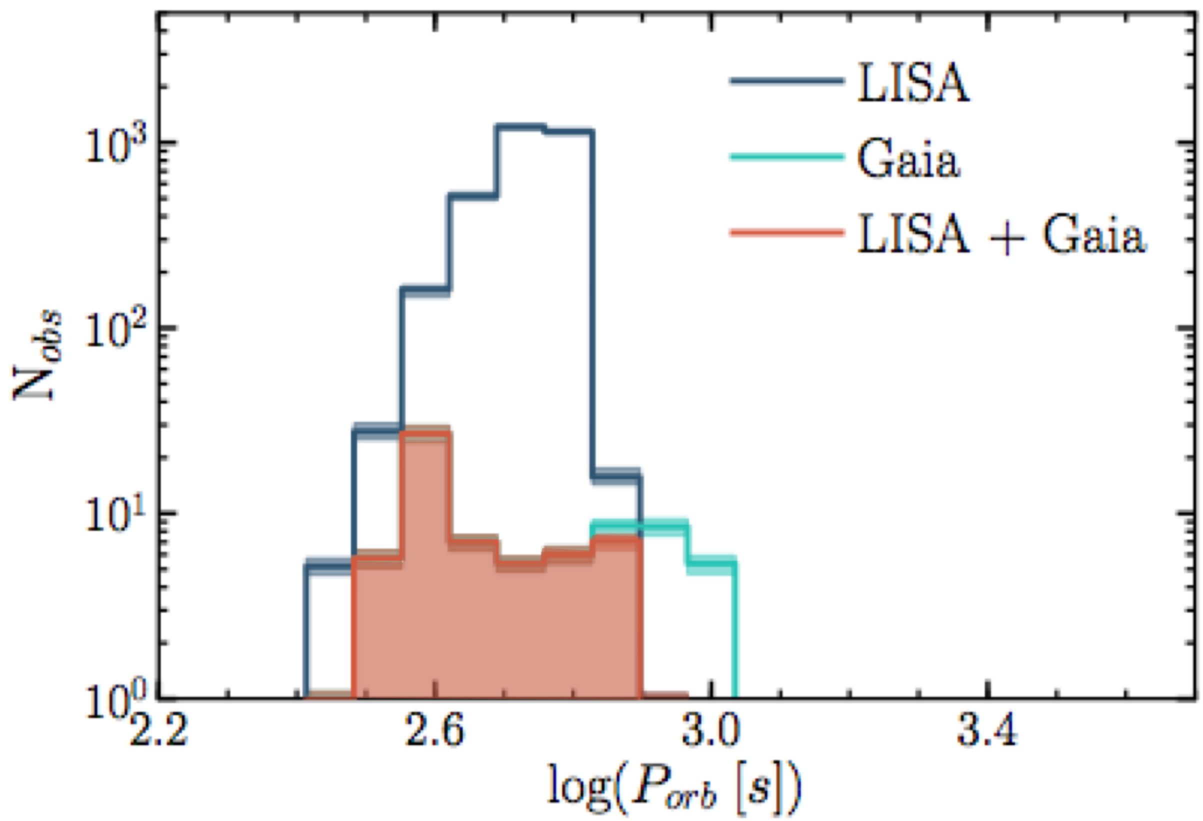
LISA fiducial minimum chirp

$\dot{f} < -1.0\ \mathrm{bin/yr}$

Kremer et al. (2017)

EM observations can help (example: Gaia)

arXiv: 1710.08370



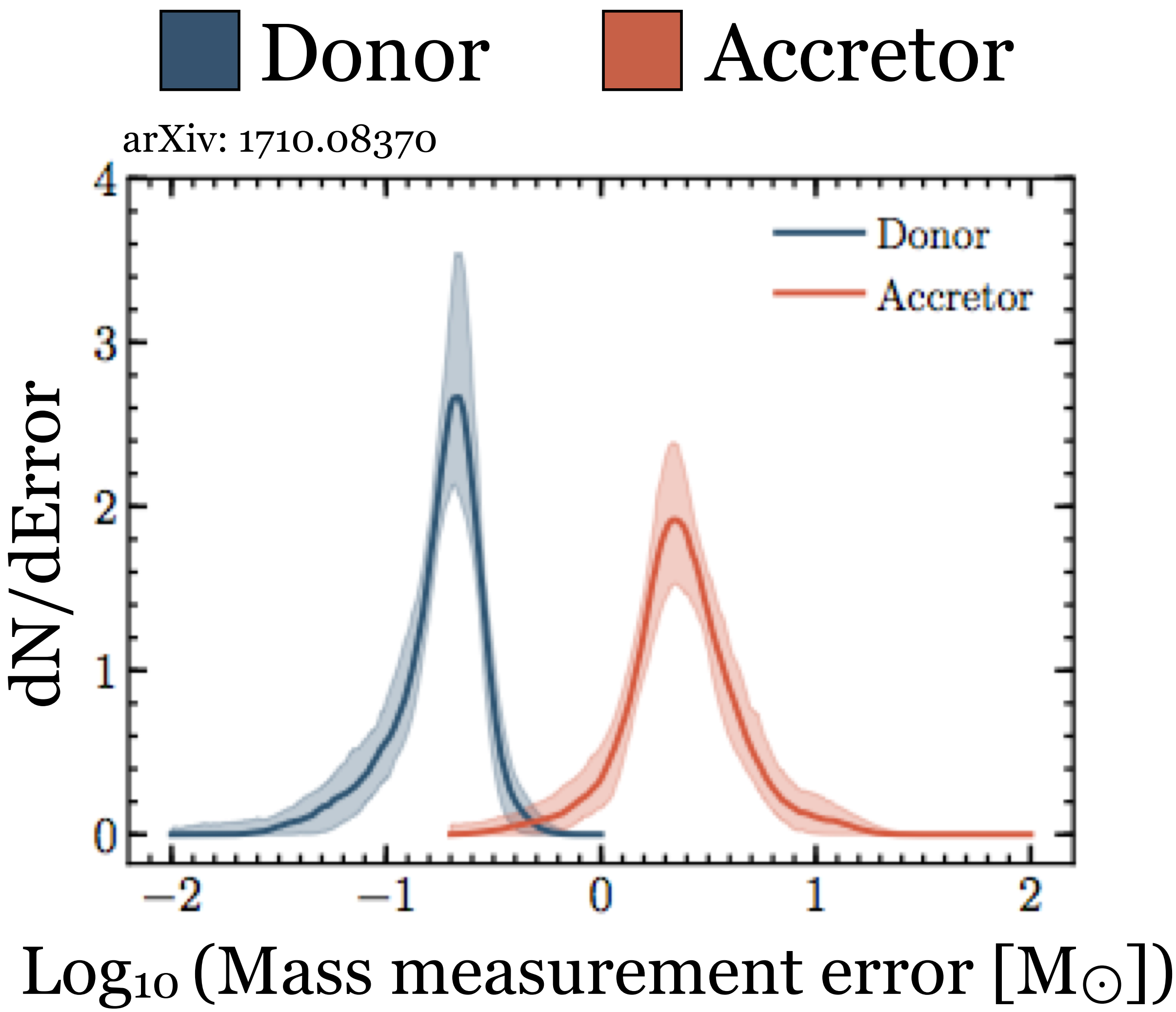
Gaia requirement

$$G < 20$$

Optical emission from Nelemans et al. 2014

~60-600 LISA + Gaia systems

LISA + EM Observatories ==
precision measurements of stellar systems



~30 DWDs with mass measurement errors:

$$\Delta M_{\rm D} < 0.1\, M_{\odot}$$

$$\Delta M_{\rm A} < 2.3\, M_{\odot}$$

Measurement errors:
Takahashi & Seto (2002)
Gaia Collaboration (2016a)

What accreting stellar systems will LISA be able to detect?

- 2700 mass-transferring white dwarf systems (among 10k expected WD binaries):
  - Working with EM constraints (GAIA and future missions) can back out component masses. Precision measurement of accretion and tides
- BH systems
  - Merger systems will be detected with orbital period sensitivity comparable to X-ray observatories

In lieu of a summary: a suggestion

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

Call to the Astronomy & Astrophysics

Community for Science White Papers

Submit in PDF via the web form that will be linked to

http://nas.edu/astro2020.html

Submissions must be made between 12:01am EST, Monday 7 January 2019 and 11:59pm Friday 18 January 2019

In preparation for the 2020 decadal survey in astronomy and astrophysics, the U.S. National Academies of Sciences, Engineering, and Medicine's Committee on Astronomy and Astrophysics (CAA) invites the community to submit white papers focusing on how our understanding of the scientific frontiers in astronomy may be advanced in 2020-2030 and beyond.

THANK YOU

Ann.Hornschemeier@nasa.gov

xraydeep.org

NASA Postdoctoral Program deadline Nov 1st:

https://npp.usra.edu/opportunities/details/?ro=18198
High Energy Galaxy Surveys