Understanding the growth of supermassive black holes through tidal disruption events

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How do supermassive black holes (SMBH) form ?

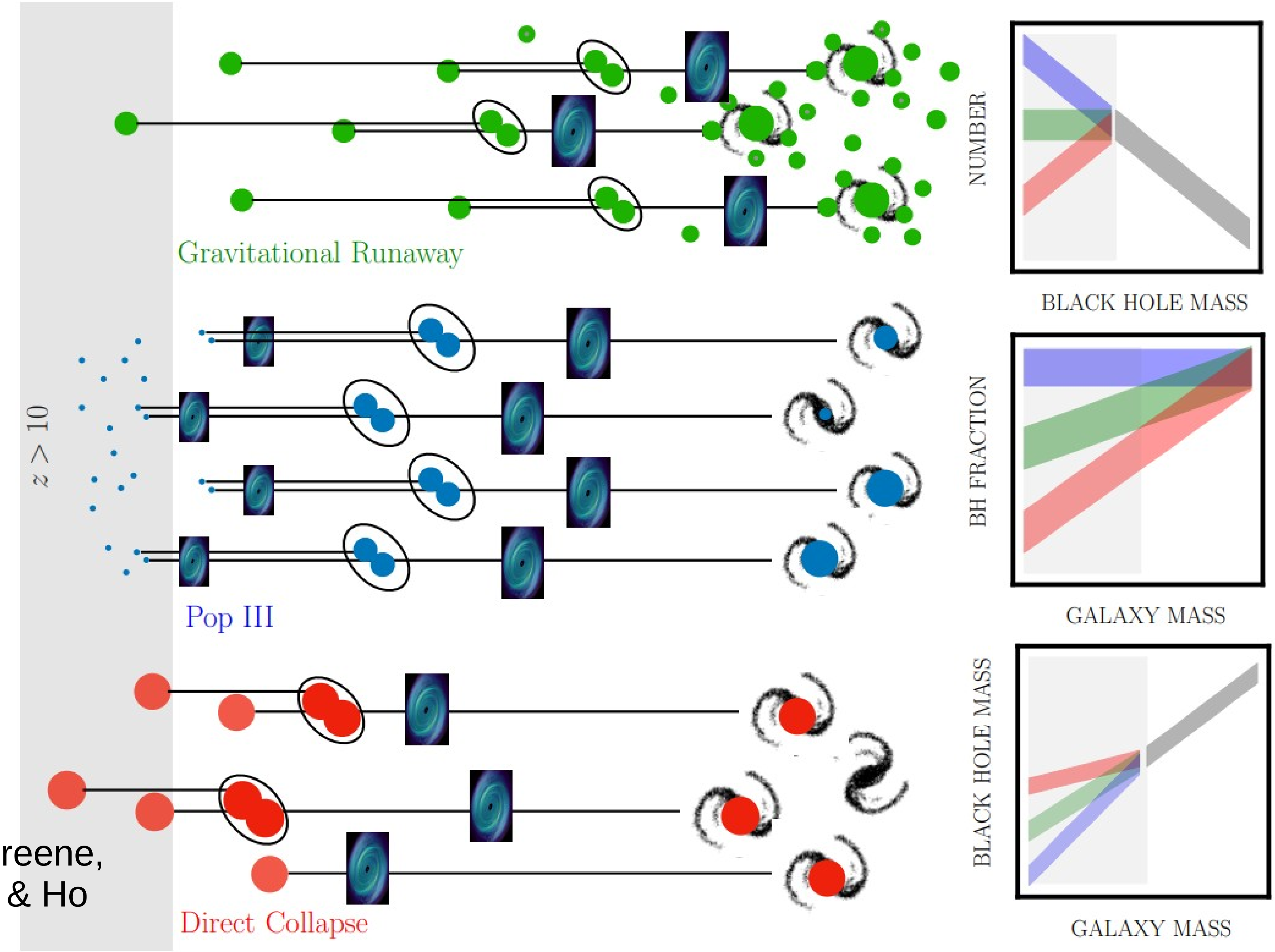
Stellar mass black holes (~3-100 $M_\odot$) form at the end of the lives of massive stars or from the coalescence of neutron stars

But supermassive black holes can not form in the same way

Accretion onto a stellar mass black hole, even at the maximal rate (Eddington limit), difficult to explain a population of black holes of ~10^9 $M_\odot$ at z>7 (e.g. z~7.1 e.g. Mortlock et al. 2011, or 8x10^8 $M_\odot$ at z=7.54, Bañados et al. 2018)

Require more massive « seeds » and/or super-Eddington accretion to form supermassive black holes (e.g. Volonteri, 2012; Volonteri, Silk & Dubus, 2015)

Evolution from seeds to supermassive black holes



From Greene, Strader & Ho (2020)

Natalie Webb
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How do supermassive black holes form ?

Without significant accretion/ recoil through encounters, some « seeds » will remain today

Finding these seeds/intermediate mass black holes (IMBH) and determining their mass will prove their existence and indicate where they reside

This data can be used for simulations to understand the early Universe

Few IMBH known today

Future observations will access high redshift IMBH allowing us to discern between seeding mechanisms

Where should we look for intermediate mass black holes?

In the centres of low mass galaxies

In the outskirts of galaxies/galaxy clusters

In stellar clusters

(In Ultra Luminous X-ray Sources, ULXs)

But intermediate mass black holes (IMBH) are often accreting very little and therefore are very faint and difficult to detect

Detect when they go through a period of high accretion

Identify faint/low mass galaxies which may house IMBH

Search for signatures of low level accretion (compact jets)

4XMM-DR11

3 Feb. 2000–17 Dec. 2020 Released : 18th August 2021

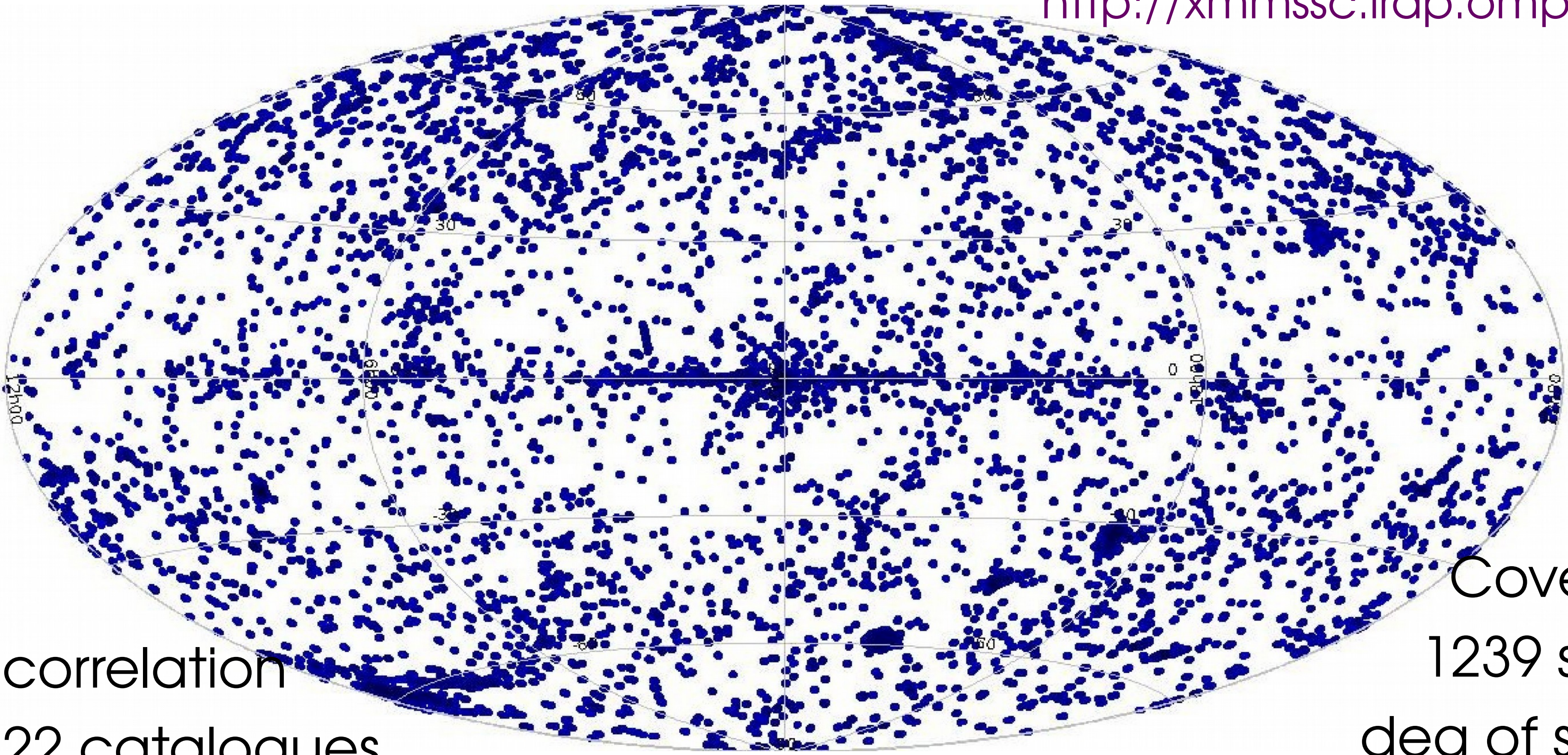
895415 detections, 602543 unique sources - detected up to 80 times

288282 (36%) sources with spectra and lightcurves

112084 extended sources

Webb, et al. (2020)

http://xmmssc.irap.omp.eu



Cross correlation with 222 catalogues

Covers 1239 sq. deg of sky

Tidal disruption events (TDEs)

Detecting TDEs allows us to find massive black holes normally too faint to detect

Tidal radius inside black hole (BH) event horizon for $M > 10^8 M_\odot$

Observe TDE from lower mass BHs + (super-)Eddington accretion

Could help understand the growth of supermassive black holes (SMBH)

$1.7\pm^{2.85}_{1.27}$ x10^{-4} TDE per galaxy per yr (Hung et al., 2018)

Open questions concerning tidal disruption events

Have TDEs played an important role in SMBH growth ?
- rate of TDEs
- mass accretion rate (sub/super-Eddington) & mass accreted
- what is physical mechanism behind super-Eddington accretion ?

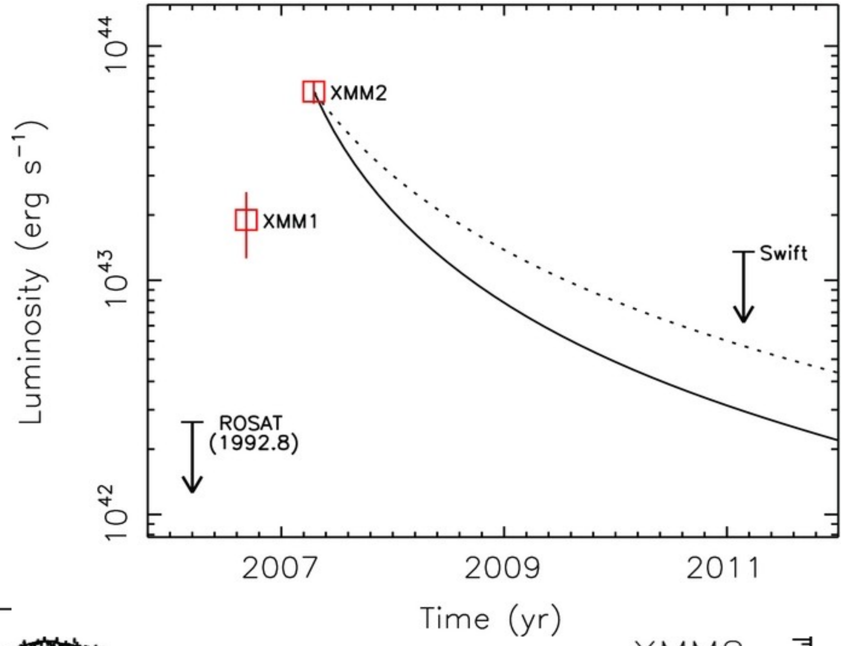
Why is outburst duration so variable?
- maybe linked to accreted star mass
- or inefficient circularisation of debris stream, so high fallback

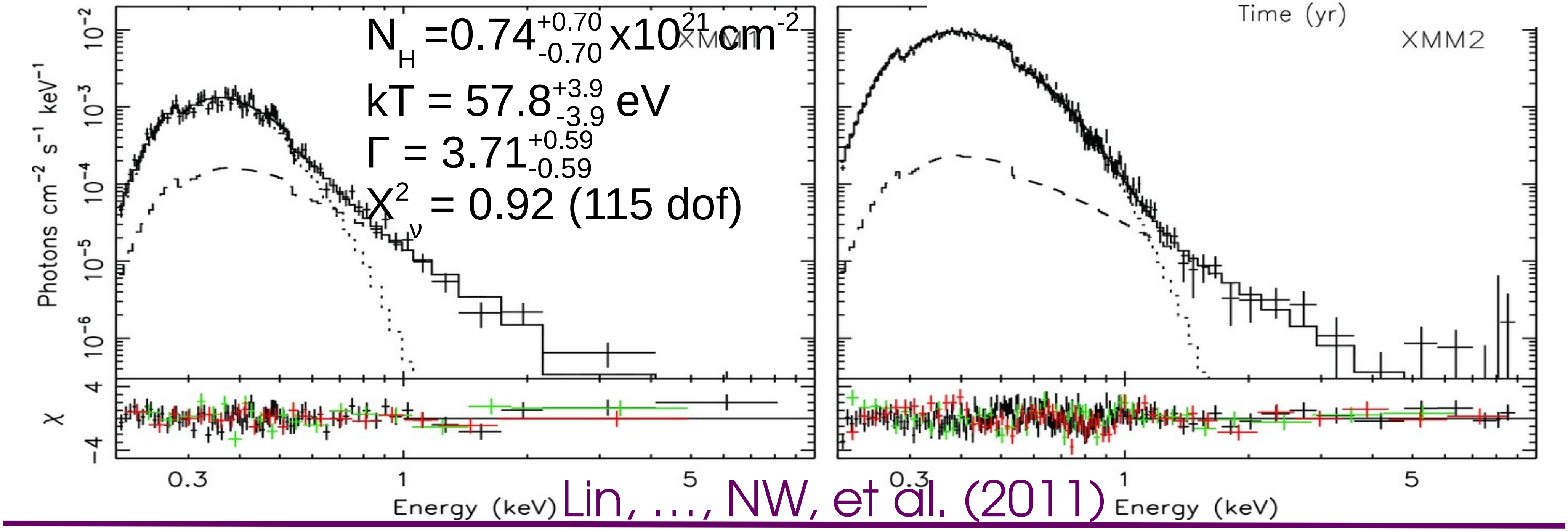
Why do some TDEs have hard spectra instead of thermal spectra?
- possibly due to jets (e.g. Auchettl et al. 2017)
- or e.g. shocks in accretion flows (Hryniewicz & Walter 2016)

Why are some TDEs detected at some wavelengths and not others?
- possibly from reprocessing of X-ray emission from the disc
- or from shocks between the debris streams as they collide
- or a combination of both
- or due to viewing angle, obscuration by dust, or something else

XMM-Newton tidal disruption events

- Coincident with centre of IC 4765-f01-1504 at z=0.0353
- Galaxy inactive
- Modelling the disc with kerrbb ⇒ $M_{BH} \sim 6 \times 10^4 - 4 \times 10^6\, M_\odot$





$N_H = 0.74^{+0.70}_{-0.70} \times 10^{21}$ cm^{-2}

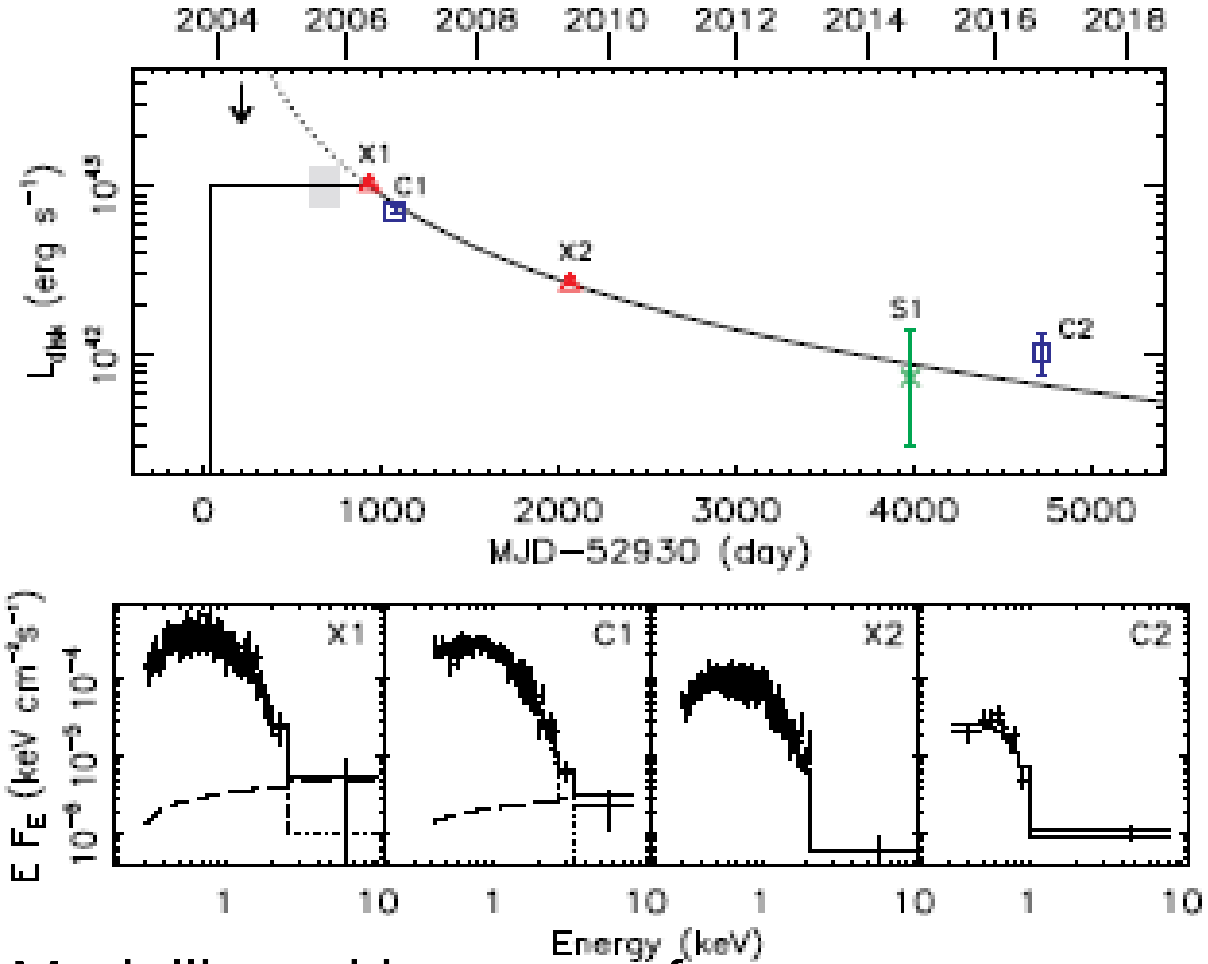
$kT = 57.8^{+3.9}_{-3.9}$ eV

$\Gamma = 3.71^{+0.59}_{-0.59}$

$\chi^2_\nu = 0.92$ (115 dof)

Lin, …, NW, et al. (2011)

Low mass tidal disruption events



Lin, …, NW, et al. Nature Astronomy (2018)

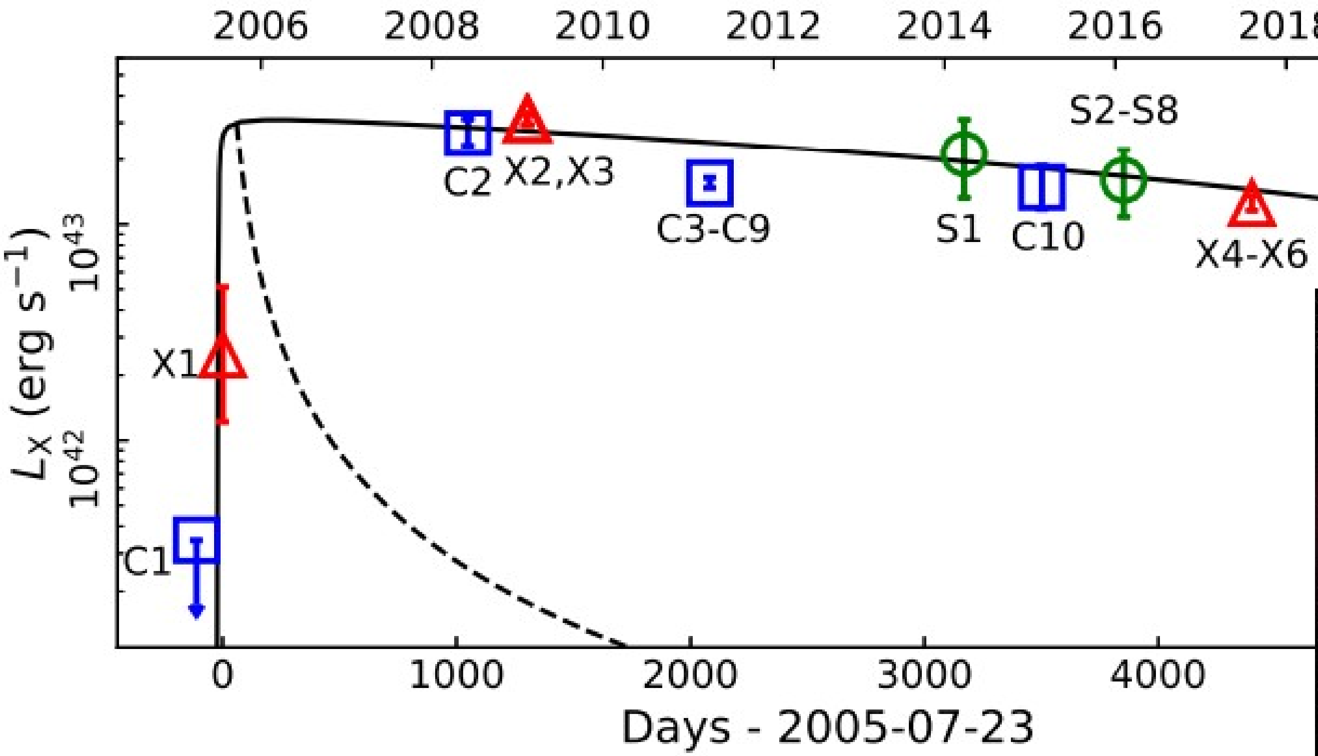
Modelling with *optxagnf* :

0.92 < a_* (spin) < 1.0 (D_L=247 Mpc)

$5.3 \times 10^4 M_\odot$ < mass < $1.2 \times 10^5 M_\odot$

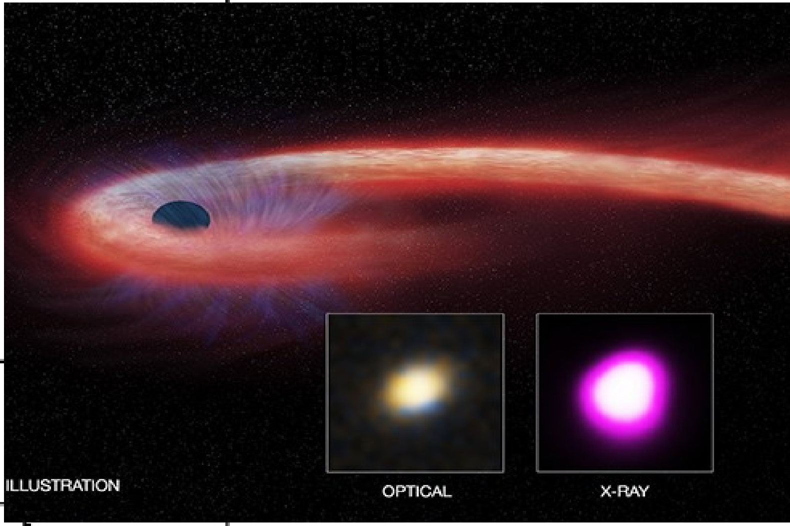
$7.1 \times 10^4 M_\odot$ (Chen & Shen 2018)

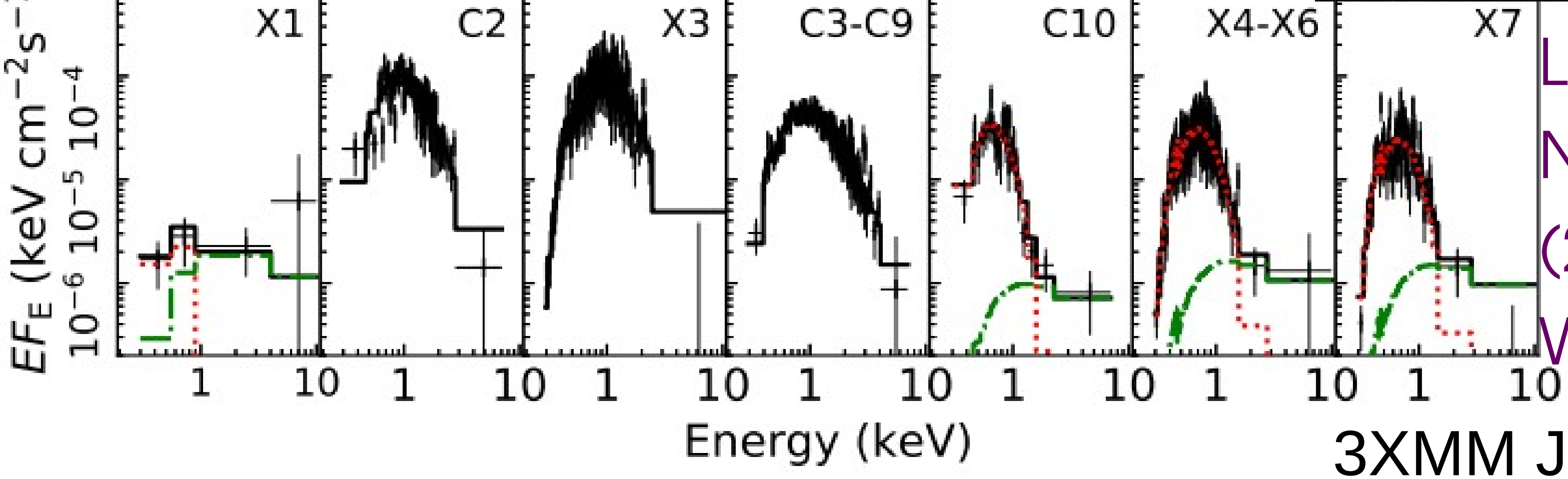
Extreme tidal disruption event



0.75M$_\odot$ star

Disrupted by a (2.2-7.6)x10^5 M$_\odot$

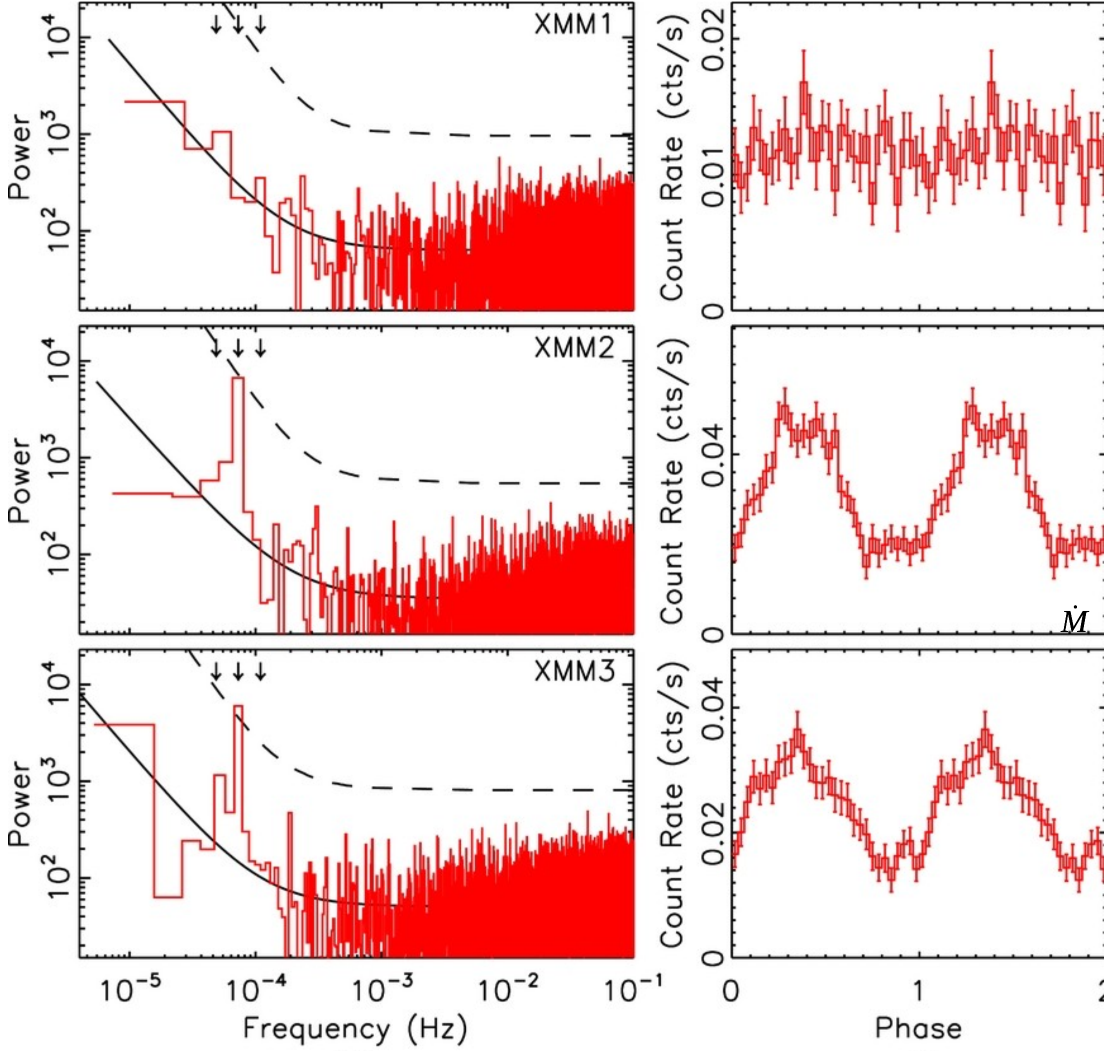




Lin, …, NW, et al. Nature Astronomy (2017); Lin, Godet, Webb et al. (2022)

3XMM J150052.0+015452

Variable tidal disruption events



3.8 hr period from galaxy J1231+11

Ho et al. (2011) estimate mass $\sim 10^5 M_\odot$ from narrow emisson lines

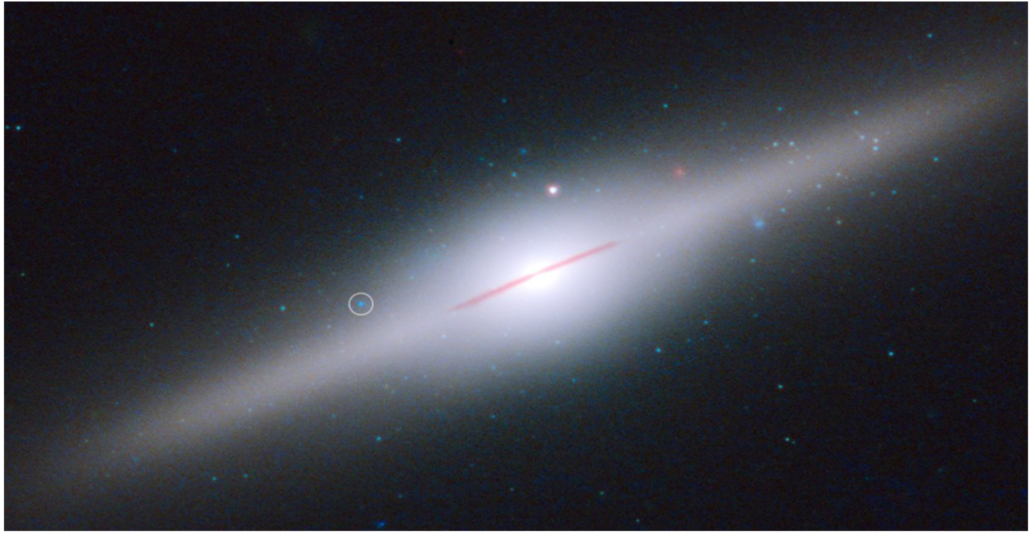
No longer detectable with Swift.

If QPO is the low frequency type, $M_{BH} < 4 \times 10^6 M_\odot$

Similar to GSN 069, no hard X-ray, strong, fast variability, no broad Hα/Hβ, UV/X-ray shows thermal disc (Lin,…,NW, et al. 2013)

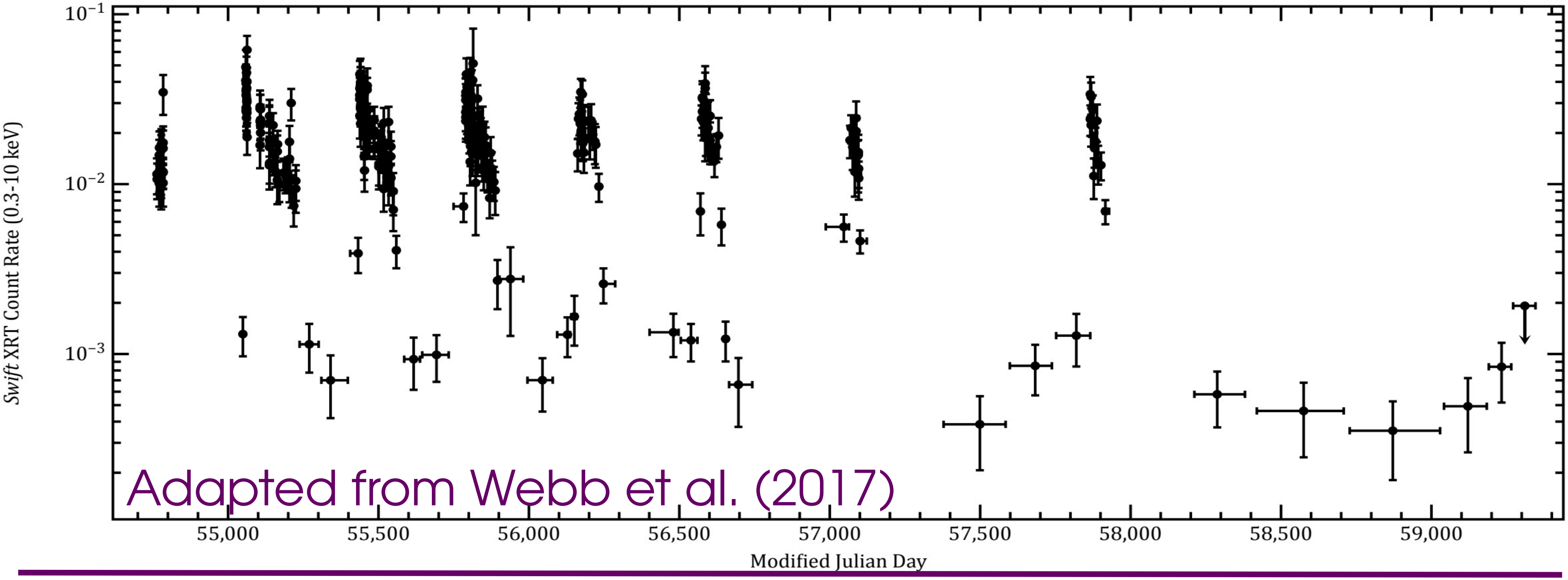
If QPEs are due to disc-instability, limit-cycle oscillations should become low-amplitude QPO, as $\dot{M}$ falls, due to shrinking size of the unstable region (Miniutti et al. 2019)

A ‘failed’ TDE (HLX-1)



HLX-1 associated with ESO 243-49 at 95 Mpc (Farrell, NW et al. 2009, Nature; Wiersema, Farrell, NW et al. 2010)

$L_{x(max)} = 1.2 \times 10^{42}$ erg s^{-1} (Godet, Barret, NW et al. 2009)



Adapted from Webb et al. (2017)

Understanding HLX-1

Black hole mass ~20000 $M_\odot$ with compact companion (Godet et al. 14)

Failed tidal disruption event (TDE) can explain HLX-1data

Possibly due to merger causing cluster star to change trajectory

Likely to be fairly common as only observed for ~30 years

Other systems likely to exist

More TDEs detected in galaxies that have undergone merger (Arcavi et al. 2014)

Are there other TDEs in XMM-Newton data ?

98 TDEs @ https://tde.space about half are detected in X-ray

Found 10 in the XMM catalogue (Lin et al – many papers)

Hundreds more expected to be hidden in XMM catalogue (Webb, 2019), but need to identify them

Require rapid follow-up observations to constrain TDE nature

Work in progress to do this (Quintin et al., in prep)

TDEs (and other transients such as gravitational wave events, γ-ray bursts, cataclysmic variables, tidal disruption events, supernovae, X-ray binary outbursts, magnetars, etc) could then be followed up in near real time

Finding IMBH in other wavelengths/multi-messengers

- Intensive automated catalogue exploitation (e.g. Chilingarian et al. 2018, 305 IMBH from fitting broad SDSS spectral lines (vel. disp.))
- eRosita – to detect (many) new TDEs
- >half of TDEs detected in optical – Rubin observatory (~5000 yr^{-1} Bricman & Gomboc 2019)
- SKA – galactic low state IMBH (Maccarone+2005, Mezcua+2013)

  – jet ejecta (à la HLX-1or Arp 299, Mattila et al. 2018)
- New transients including TDEs with SVOM (& Theseus)
- Athena – detect faint IMBH and TDEs – synergy Athena/LISA
- Gravitational wave observations with LISA/Einstein Telescope

Summary

- Finding and studying IMBH is essential for understanding the origin and evolution of SMBH
- Tidal disruption events enable us to search out (faint) IMBH
- TDEs allow us to study long term super-Eddington accretion
- QPEs may be consequence of some TDEs – which & why?
- New good IMBH candidates discovered
- HLX-1 contains a ~2 x 10^4 $M_\odot$ black hole, probably a failed TDE
- Systematic near-real time X-ray searches would reveal more IMBH
- Future observations will reveal significant populations of IMBH