Constraining Spins of Black Holes When they Disrupt Stars

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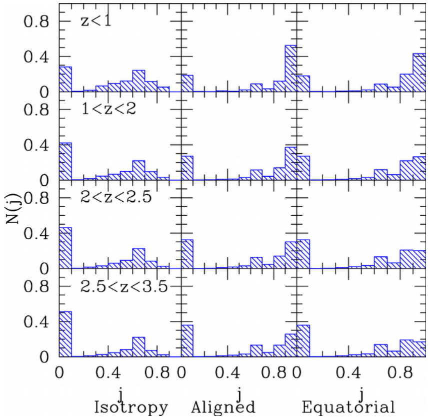
Pasham et al. 2018, submitted

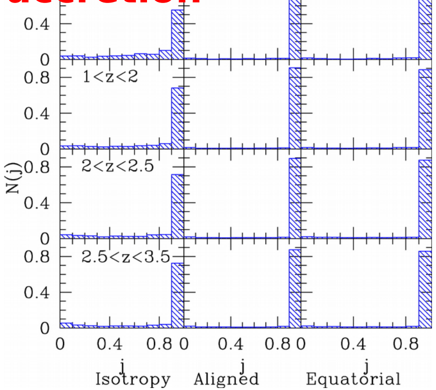
Motivation

- Black holes only have two parameters: mass and spin
- Black holes somehow regulate galaxy evolution
- Evolution of supermassive black holes will tell us about how galaxies evolve

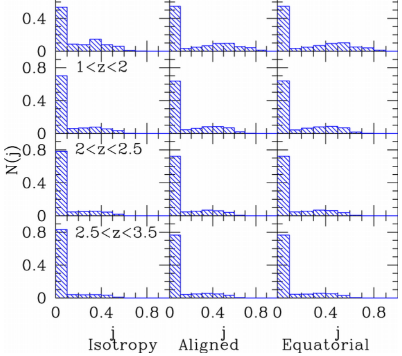
Mergers only



Mergers + steady accretion

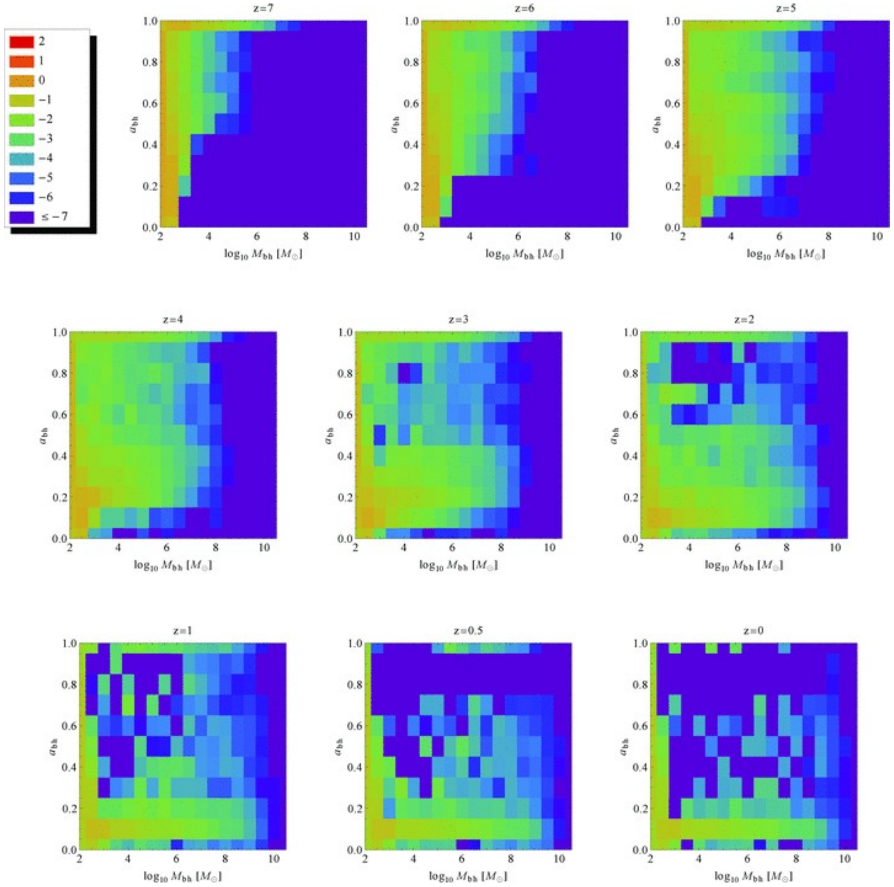


Mergers + chaotic accretion



Emanuele and Volonteri 2008; Hughes & Blandford 2002; Barausse 2012

Motivation: Ultimate goal



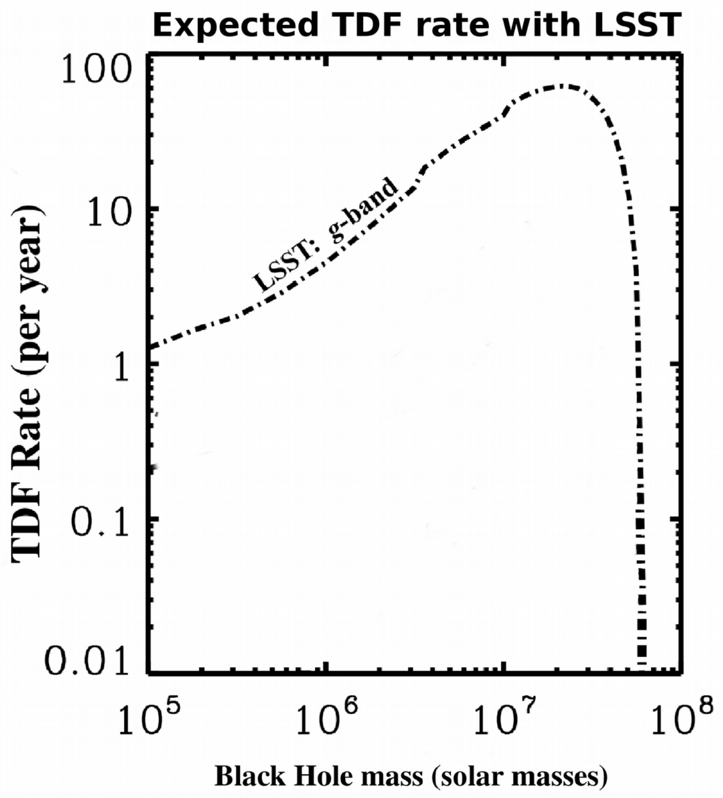
- To measure spins of hundreds of supermassive black holes at various redshifts
- Compare directly with galaxy evolution models

One way to build black hole census: Tidal disruptions flares

Barausse 2012

Tidal Disruption Flares

Tidal Disruption Flares



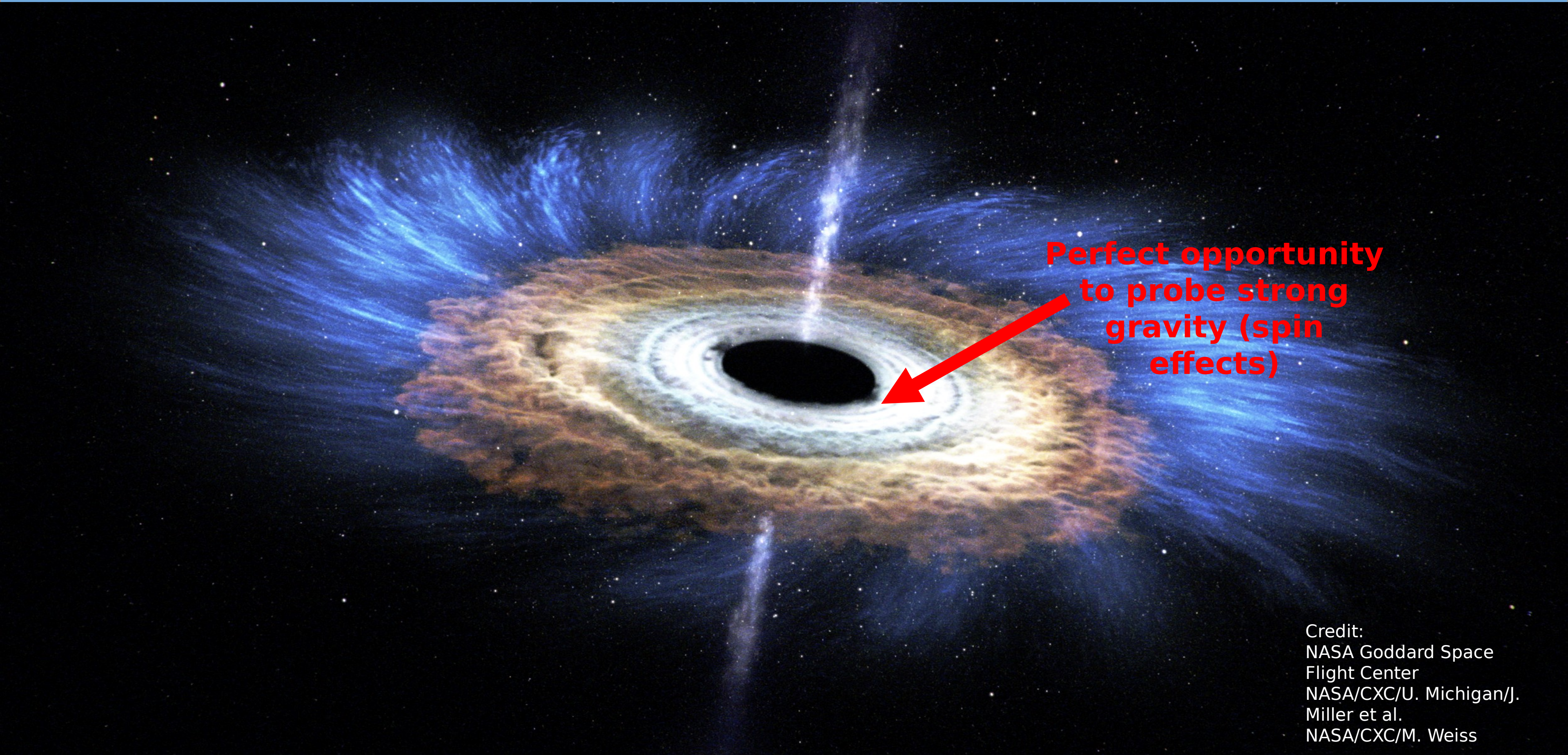
Gezari et al. 2010

- Should happen roughly once every 10^{4-5} years/galaxy
- Translates to a detection rate of 10s per year with current all-sky surveys
- With LSST this would be 100s per year
- eROSITA will boost this number

Promising times for tidal disruption flares

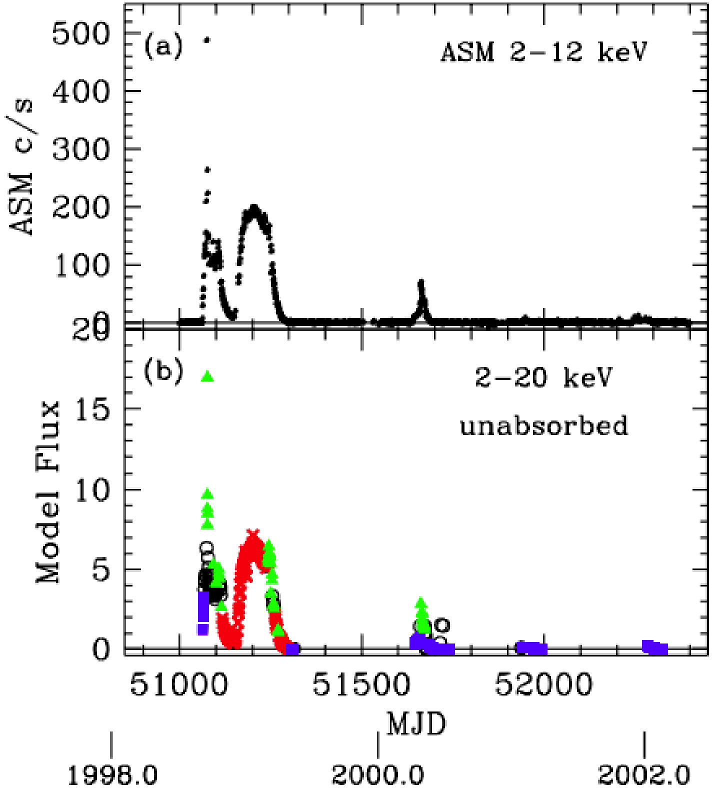
Wang et al., 2012, van Velzen and Farrar, 2014 ..

Tidal Disruption Flares



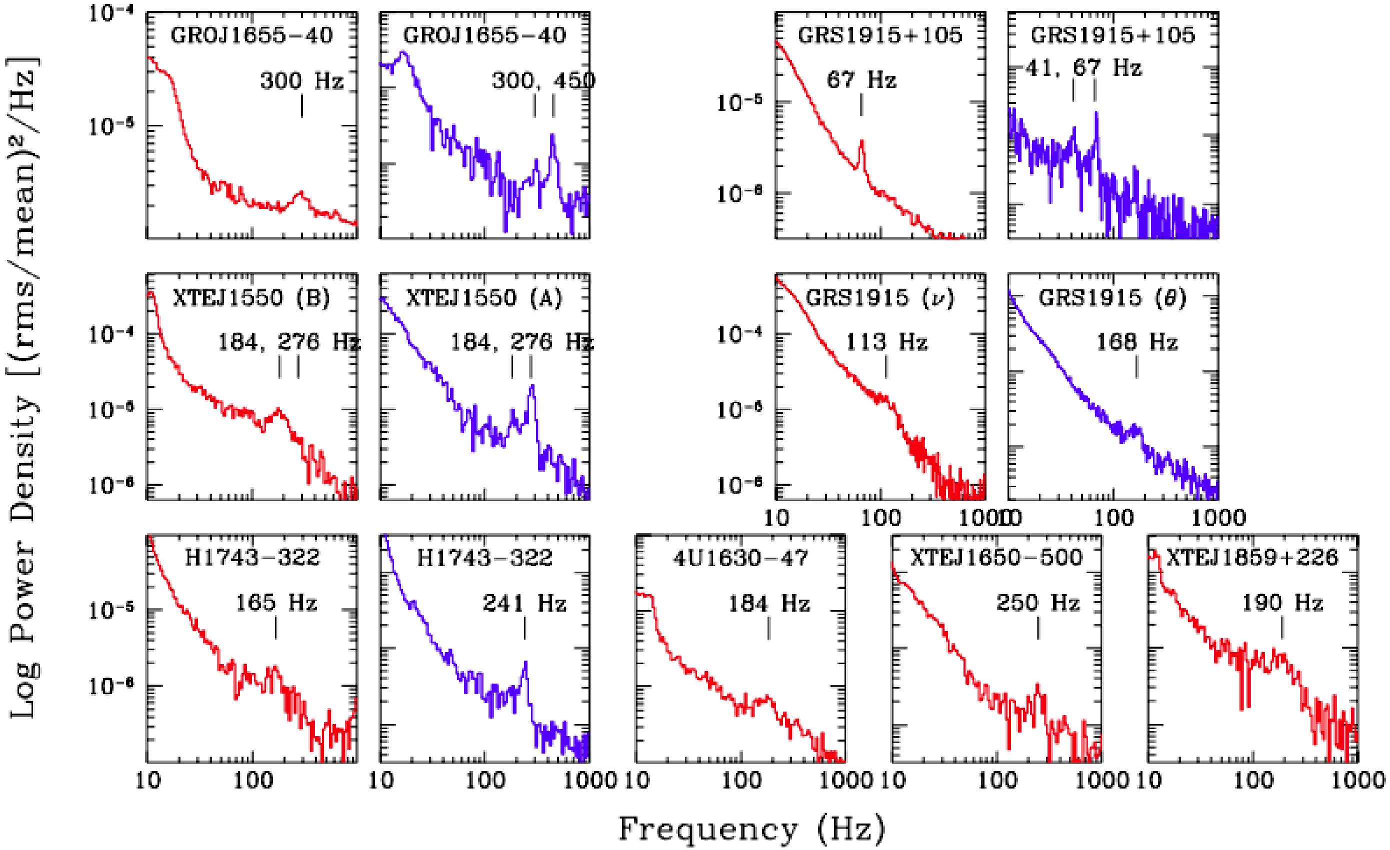
Credit:
NASA Goddard Space Flight Center
NASA/CXC/U. Michigan/J. Miller et al.
NASA/CXC/M. Weiss

Several studies probing gravity with stellar-mass black hole outbursts



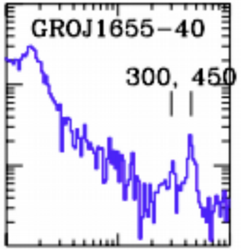
Remillard et al. 2006

X-ray High-Frequency Quasi-periodic Oscillations (QPOs)



Remillard et al. 2006

Stellar-mass black hole High-frequency QPOs



- Timescale ∼ 0.01 seconds (FAST)--Millisecon
- Stable in frequency for a given black hole (to change in luminosity)
- Sometimes come in integral pairs of 3:2 frequency ratio

Stellar-mass black hole High-frequency QPOs

1) For a 10 solar mass black hole, 100s of Hz corresponds to Keplerian/orbital frequency at ISCO!

2) Stable frequency —> associated with something fundamental

Origin: Very close to the black hole where dynamics are dictated by black hole's mass and spin

High-frequency QPOs have been used to measure spins of stellar-mass black holes!

Motta et al. 2014, Franchini, Motta, Lodato et al. 2017

Can we detect similar stable oscillations in TDFs?

To constrain disrupting black holes spins

ASASSN-14li:

A Promising X-ray bright TDF Candidate discovered by ASASSN survey in Nov. 2014!

Holoien et al. 2016, van Velzen et al. 2016, Miller et al. 2015, Pasham et al. 2017, Brown et al. 2017, Alexander et al. 2016, Prieto et al 2016, Krolik 2016, Cenko et al. 2016, Romero-Canizales et al. 2016 ….

ASASSN-14li: X-rays from inner accretion flow

- Interestingly, the X-ray energy spectrum is thermal with a black body temperature of roughly 60 eV!

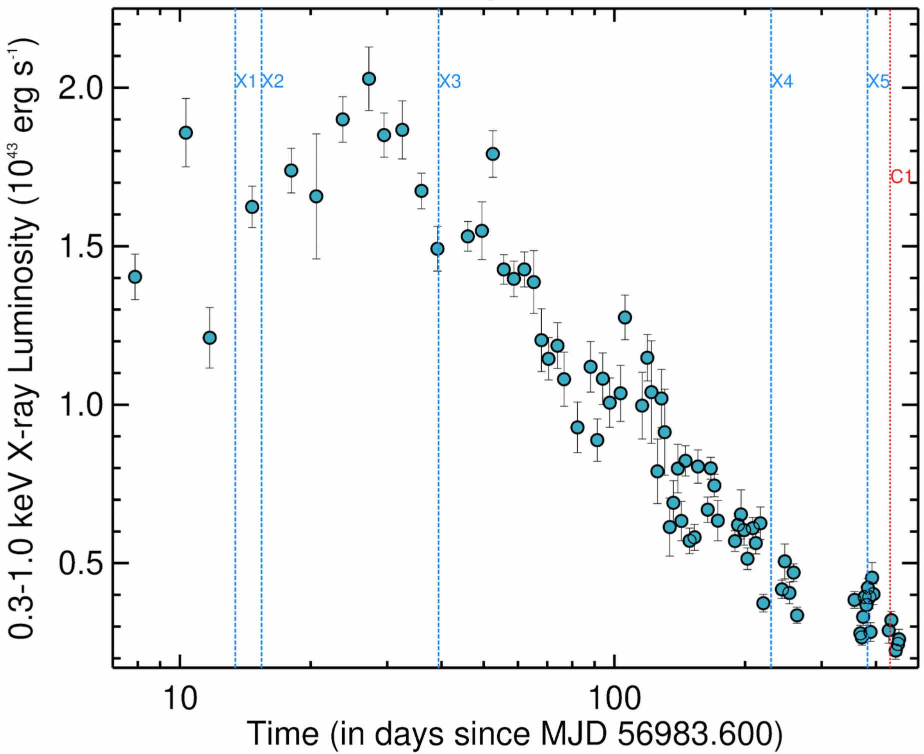
- The implied size of the X-ray photosphere from a blackbody model is $\sim 10^{12}$ cm → $\sim$ ISCO for a 10^6 $M_\odot$ black hole

- X-rays are very likely from the innermost regions of the accretion flow!

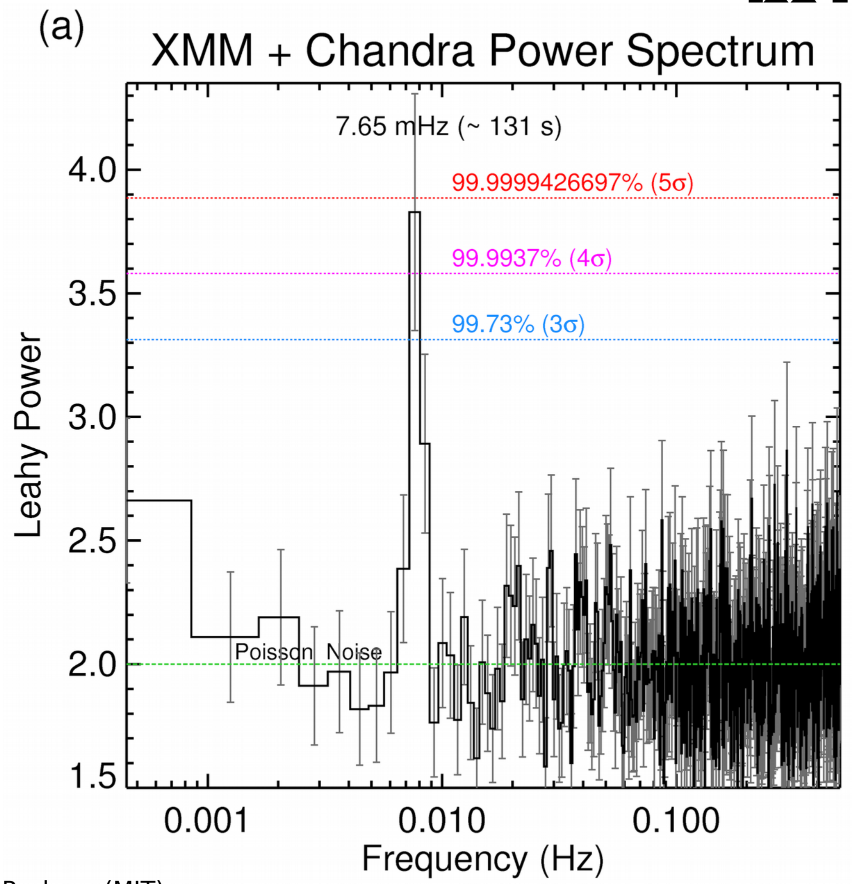
Search for stable QPOs in ASASSN-14li

Holoien et al. 2016, Miller et al. 2015, Pasham & van Velzen 2018, Brown et al. 2017, Krolik 2016 ...

ASASSN-14li's long-term evolution in



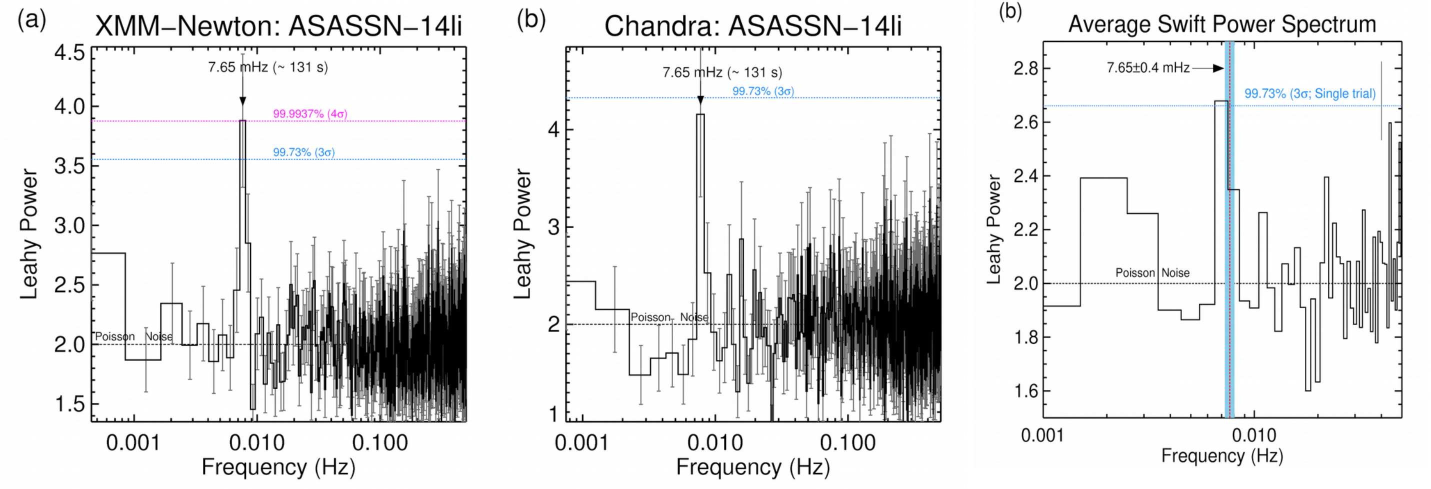
A very stable, very loud QPO at 7.65 mHz



- The signal is stable for over 500,000 cycles!
- The fractional rms amplitude at late times is 40%
- The signal is fairly narrow (coherence = 16±6)
- **Stable → tied to something fundamental (mass and spin)**

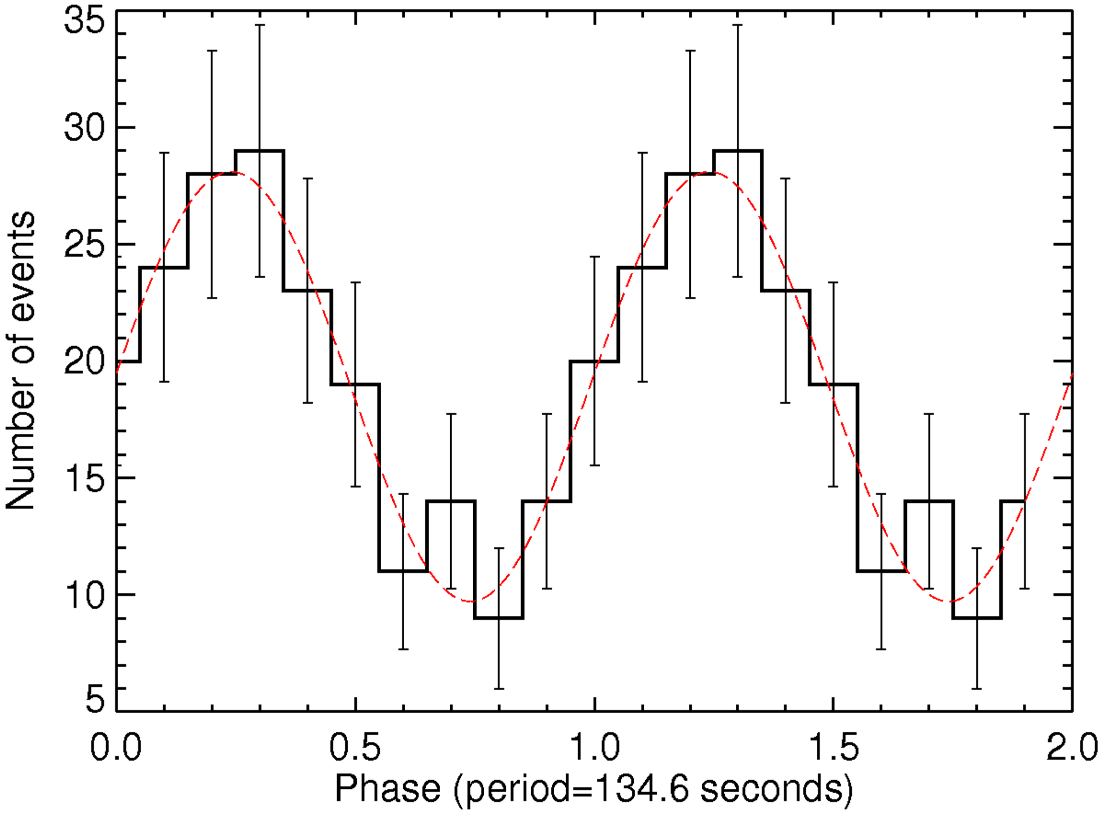
A very stable, very loud QPO at 7.65 mHz

Oscillation see by all three X-ray telescopes separately:
XMM, Chandra and Swift

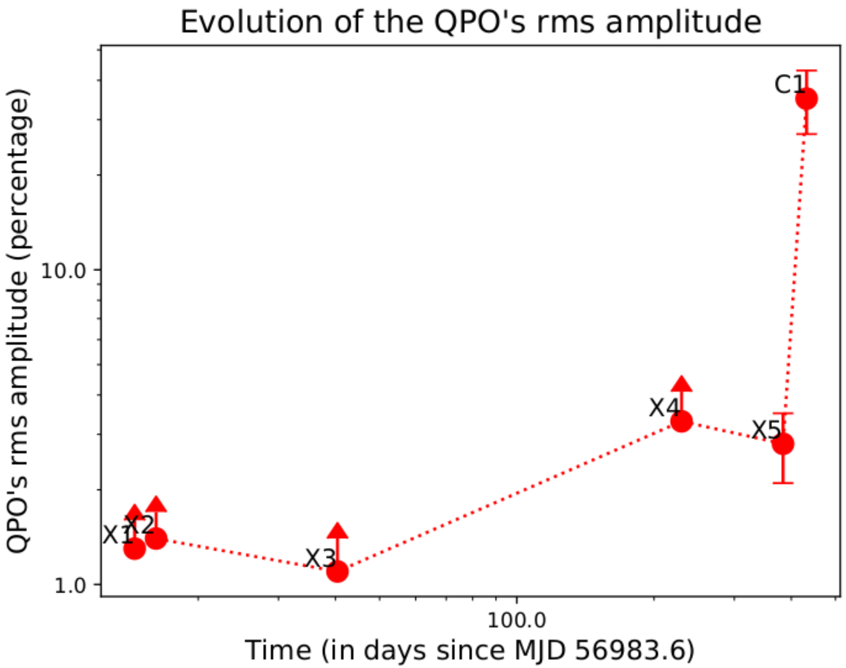


Pasham et al. 2018,

Folded Chandra light curve

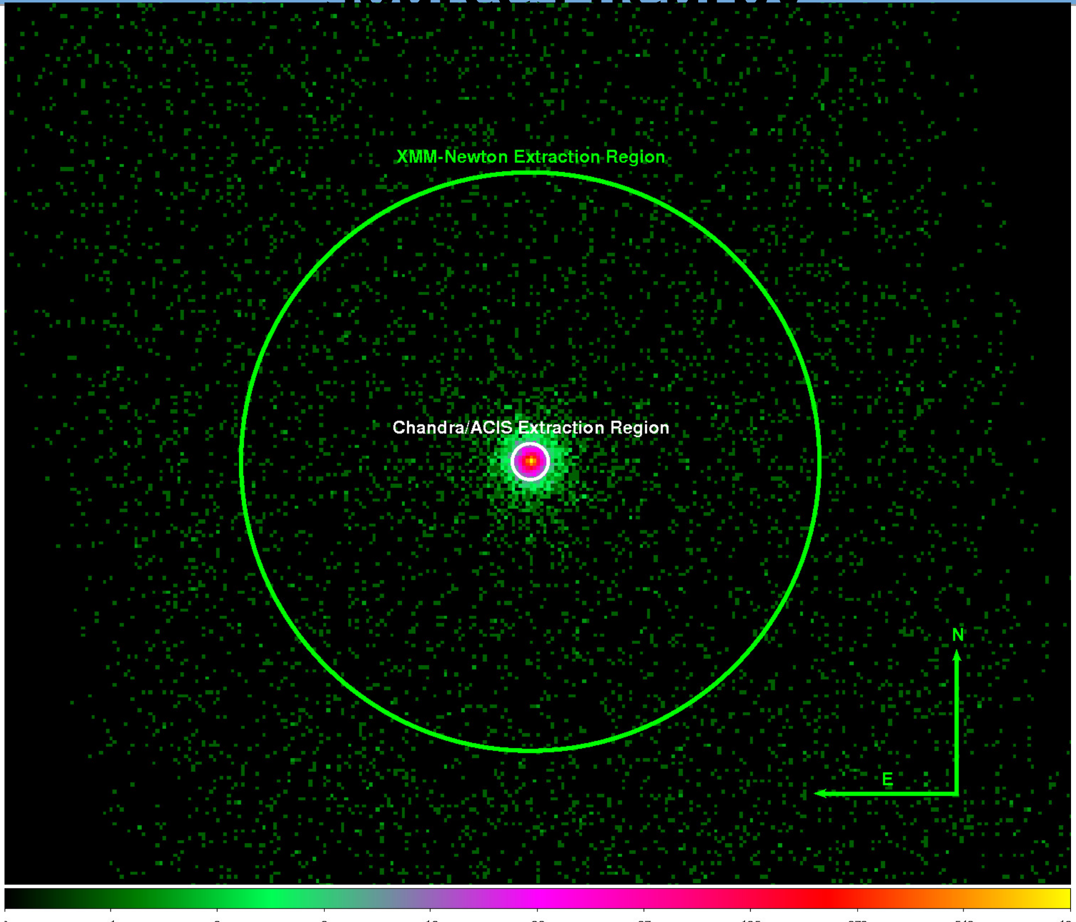


QPO strength evolution is bizarre!



- **Fractional rms appears to increase as source begins to dim**
- **Only lower limits at early times**

Chandra high-resolution image shows NO contaminating sources nearby



Unlikely to be a pulsar!

- Very large optical/UV and radio photospheres compared to a neutron star size
- ULX pulsar?
  - then it would still be 1400 brighter than the brightest known ULX pulsar. Also, ULX pulsars get into their ULX state for only brief periods of time NOT like a years long flare.
  - Soft x-ray spectrum is unlike any ULX pulsar. Because all X-ray bright jets show hard x-rays, if ASASSN-14li’s x-ray emission were highly beamed one would expect hard x-rays to be present
- Foreground pulsar? Only < 3% chance probability of coincidence with a background galaxy
- More importantly, ASASSN-14li’s multiwavelength properties are unlike any neutron star outburst and are all similar to many previously known TDEs.

So, the QPO is from the TDF!

We have a sense of what the disrupting black hole mass is from the M-σ, M-L
(host galaxy scaling relations; consistent with TDEFit)
Mass: $10^{5.8\text{-}7.1}\ M_{\odot}$

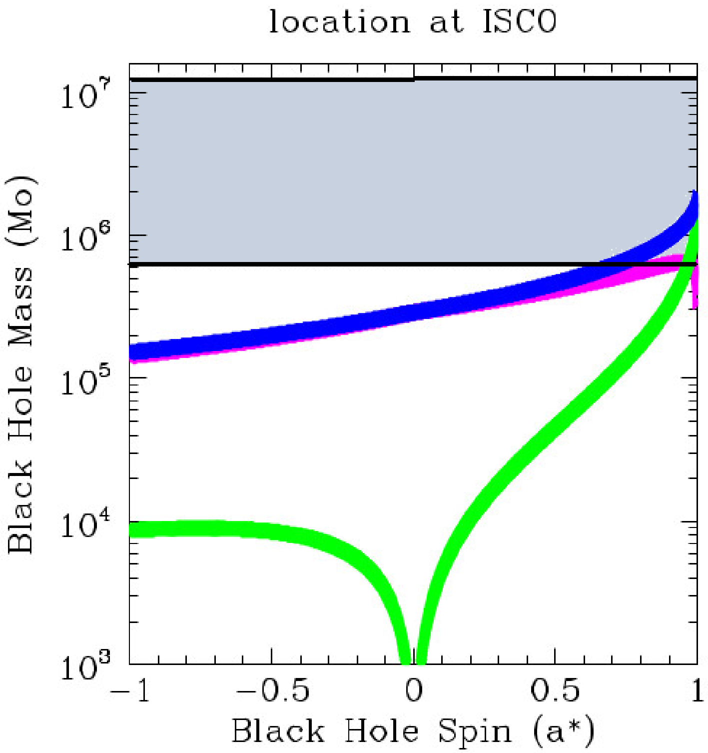
Can we constrain the black hole's spin?

Wevers et al. 2017, Holoien et al. 2016, Miller et al. 2015, van Velzen et al. 2018 …

Tidal Disruption Flares to constrain black hole spin

Constraining the spin of the black hole

a TDF



Assuming the black hole mass from M-σ, M-L, and James Guillochon's TDEfit, the only spin solution is

a* > 0.7

Pasham et al. 2018,

Tip of the iceberg?

Many TDFs expected in next decade

Even if a fraction have X-rays we would have 10s of systems

Where do we go from here?

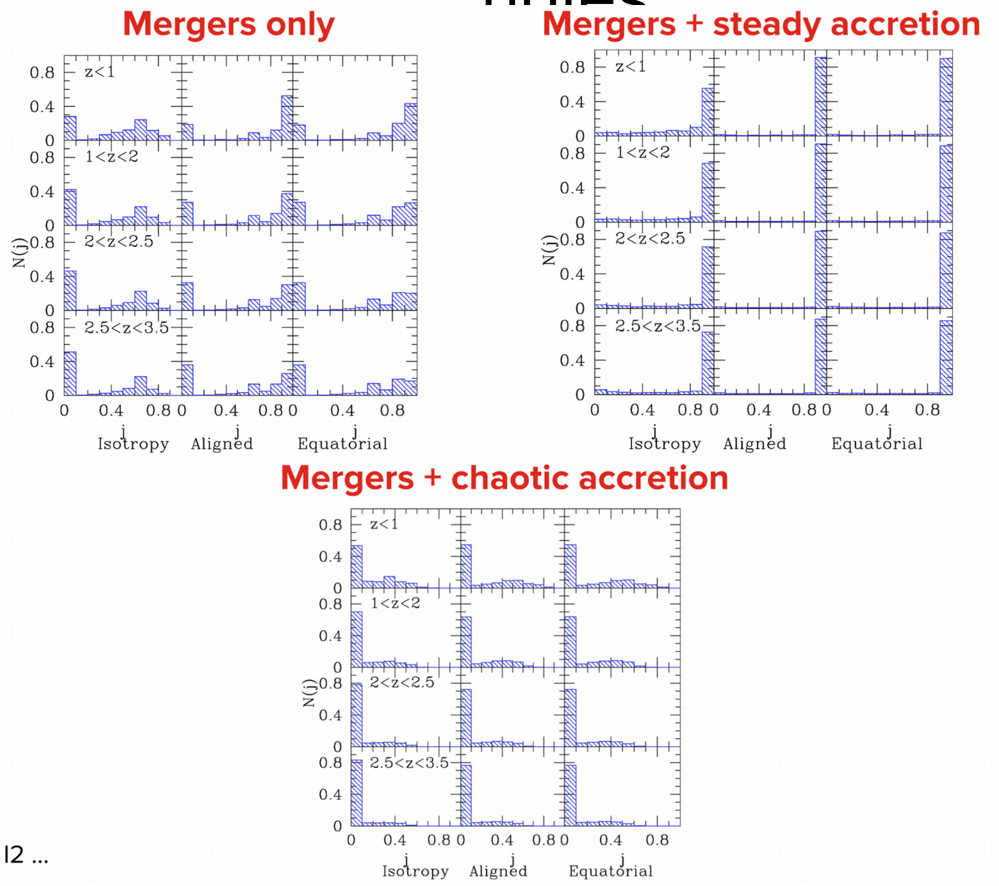
ASASSN-14li is a quintessential TDF!

Maybe several TDFs exhibit these QPOs!
(missed because no follow-up?)

Jetted TDF SwJ1644+57 also have a QPO

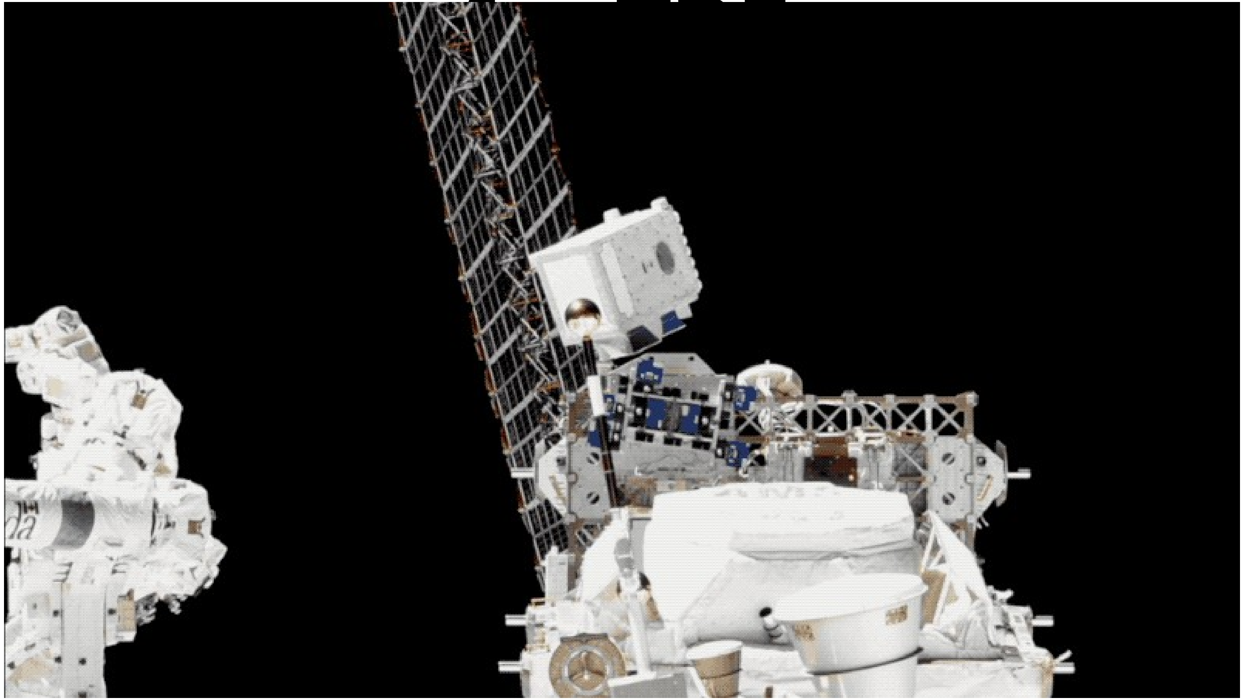
Can constrain TDF masses and spins in large numbers?

Could constrain the spins of large number of black holes



I2 …

Where do we go from here? … NICER



Thank you!