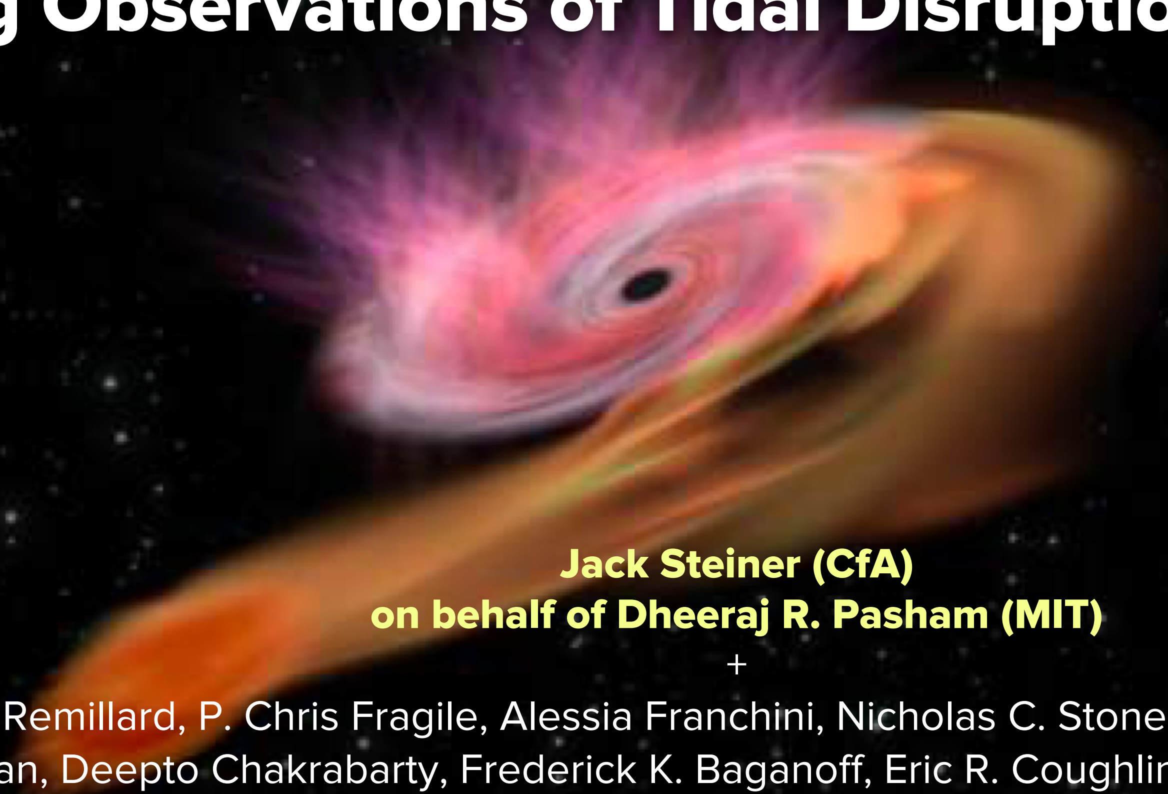
Spins of Supermassive Black Holes with X-ray Timing Observations of Tidal Disruption Events



Jack Steiner (CfA)
on behalf of Dheeraj R. Pasham (MIT)
+
Ronald A. Remillard, P. Chris Fragile, Alessia Franchini, Nicholas C. Stone, Giuseppe Lodato, Jeroen Homan, Deepto Chakrabarty, Frederick K. Baganoff, Eric R. Coughlin, Nishanth R. Pasham

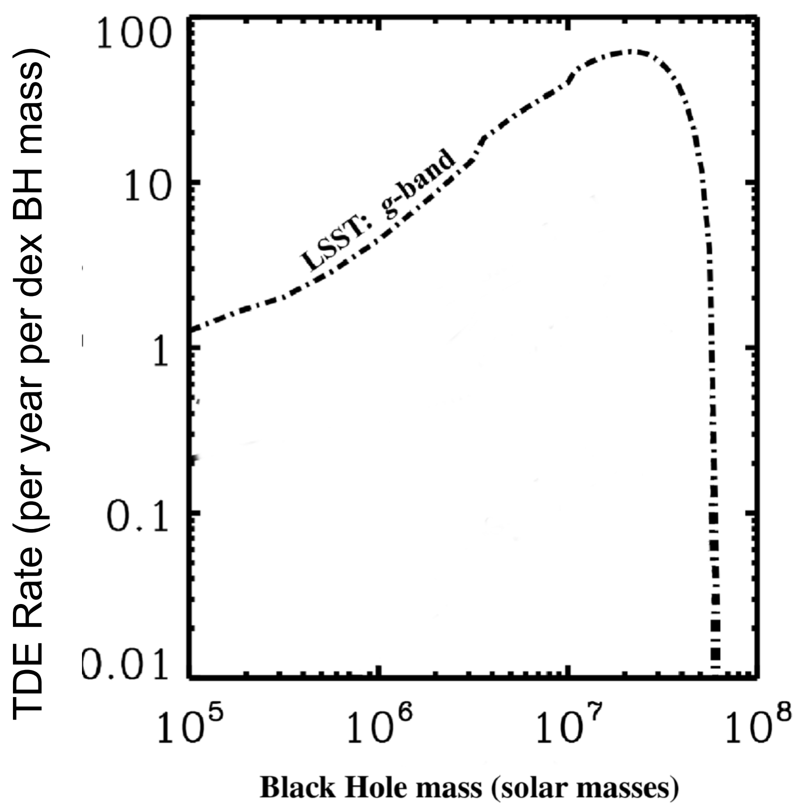
Pasham et al. 2019, Science, 363, 6426

Tidal Disruption Events (TDEs)

Flares lasting months to years

Expected rates of TDEs in the coming years

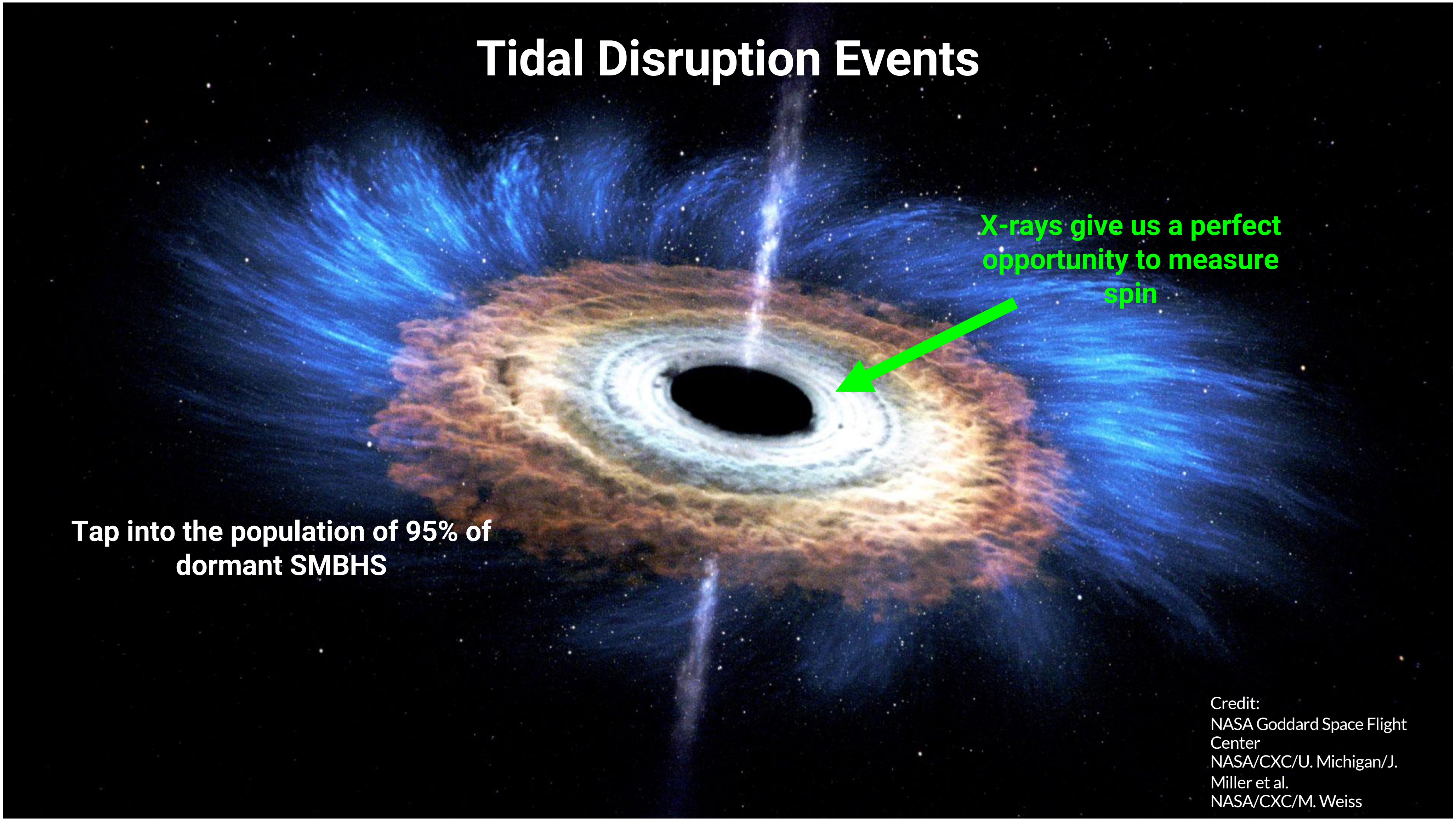
LSST prediction



- once every 10^{4-5} years/galaxy
- A few dozen per year with current all-sky surveys
- With LSST: 100s per year
- **eROSITA will detect several 100s in X-rays in 4 years**

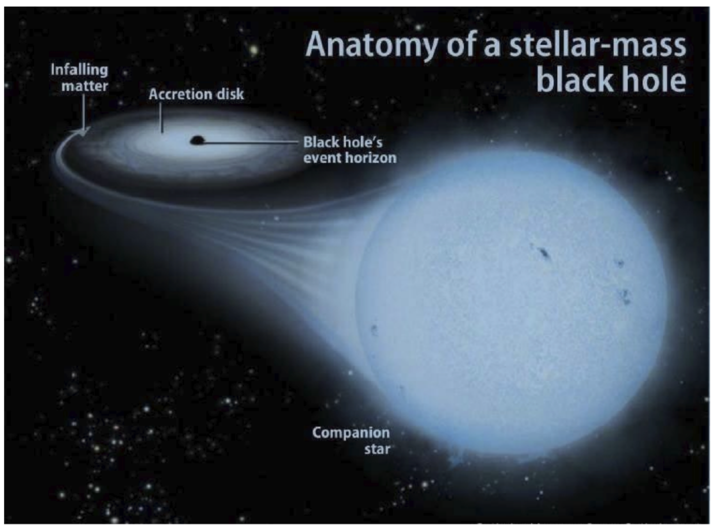
Promising times for tidal disruption events

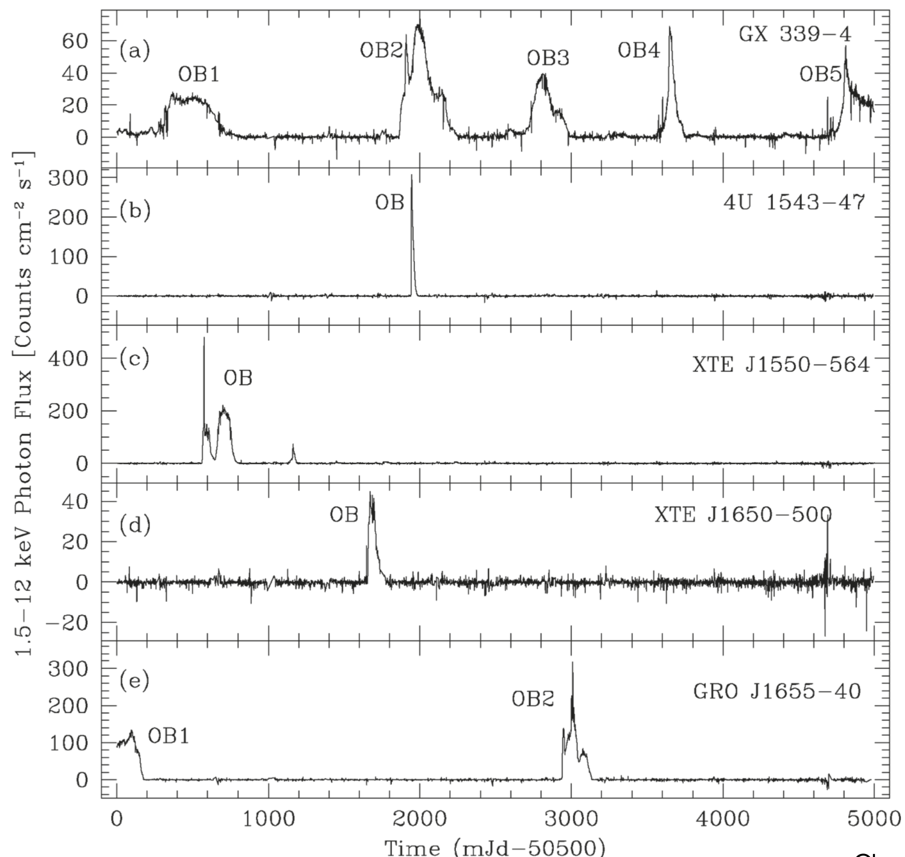
Strubbe & Quataert 2009, Wang et al., 2012, van Velzen and Farrar, 2014


Tidal Disruption Events
X-rays give us a perfect opportunity to measure spin
Tap into the population of 95% of dormant SMBHS
Credit:
NASA Goddard Space Flight Center
NASA/CXC/U. Michigan/J. Miller et al.
NASA/CXC/M. Weiss

Anchor: 30+ years of lessons from stellar-mass black hole outbursts

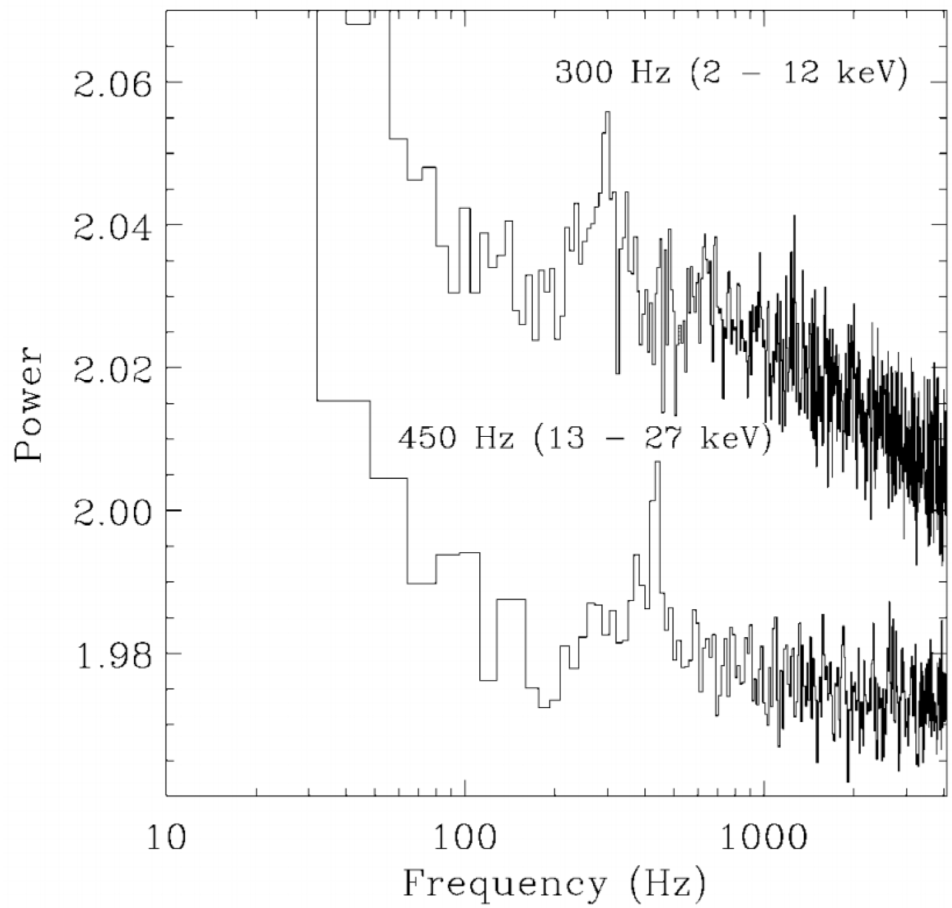
Stellar-mass black holes exhibit (in)frequent outbursts





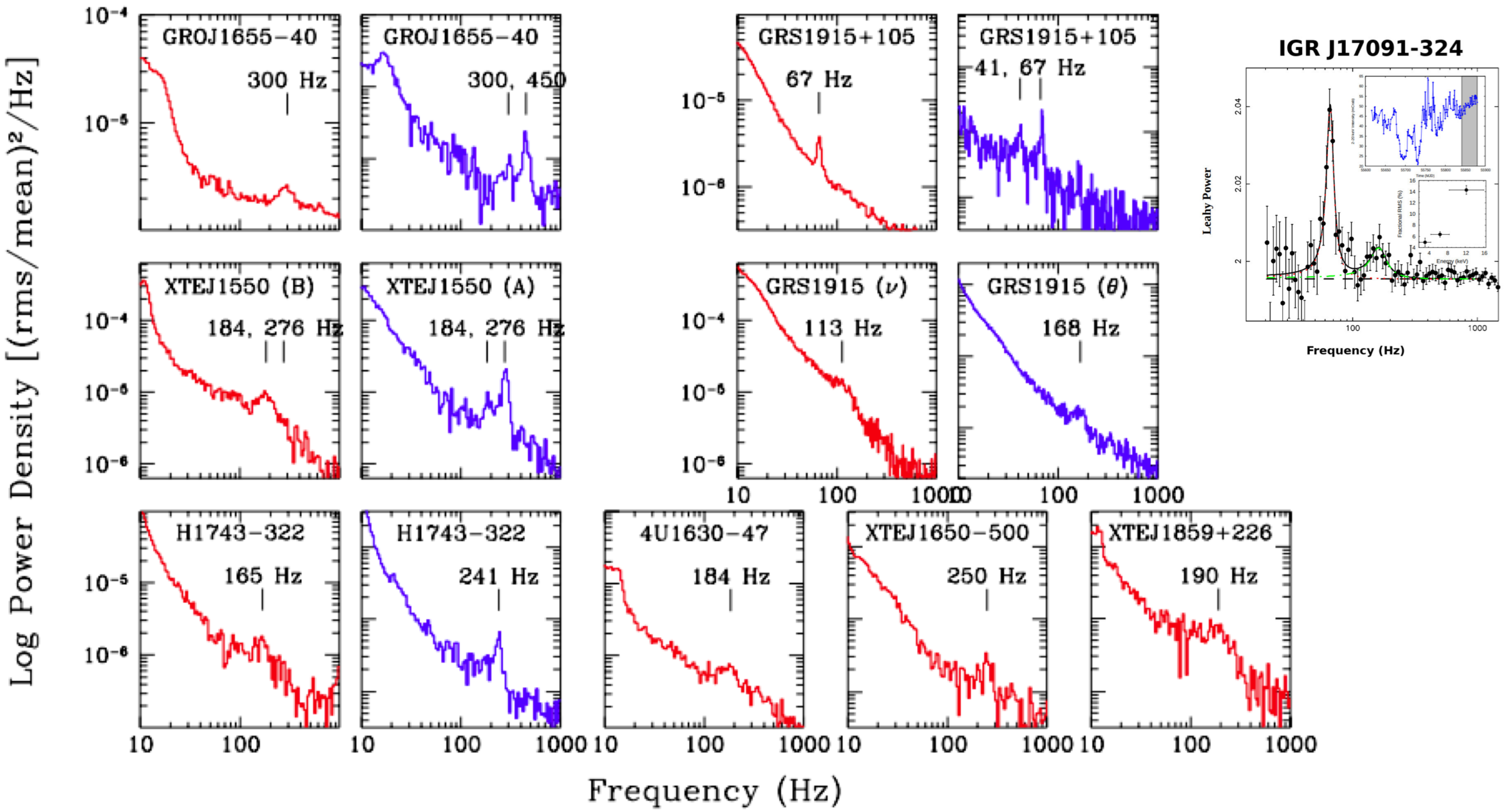
Ghosh and Chakrabarti 2018

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



Strohmayer 2001

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



Remillard et al. 2006, Altamirano and Belloni 2012

Stellar-mass black hole High-frequency QPOs

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

Belloni, Bhattacharya et al. 2019

Stellar-mass black hole High-frequency QPOs

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

2) Stable frequency —> associated with something fundamental

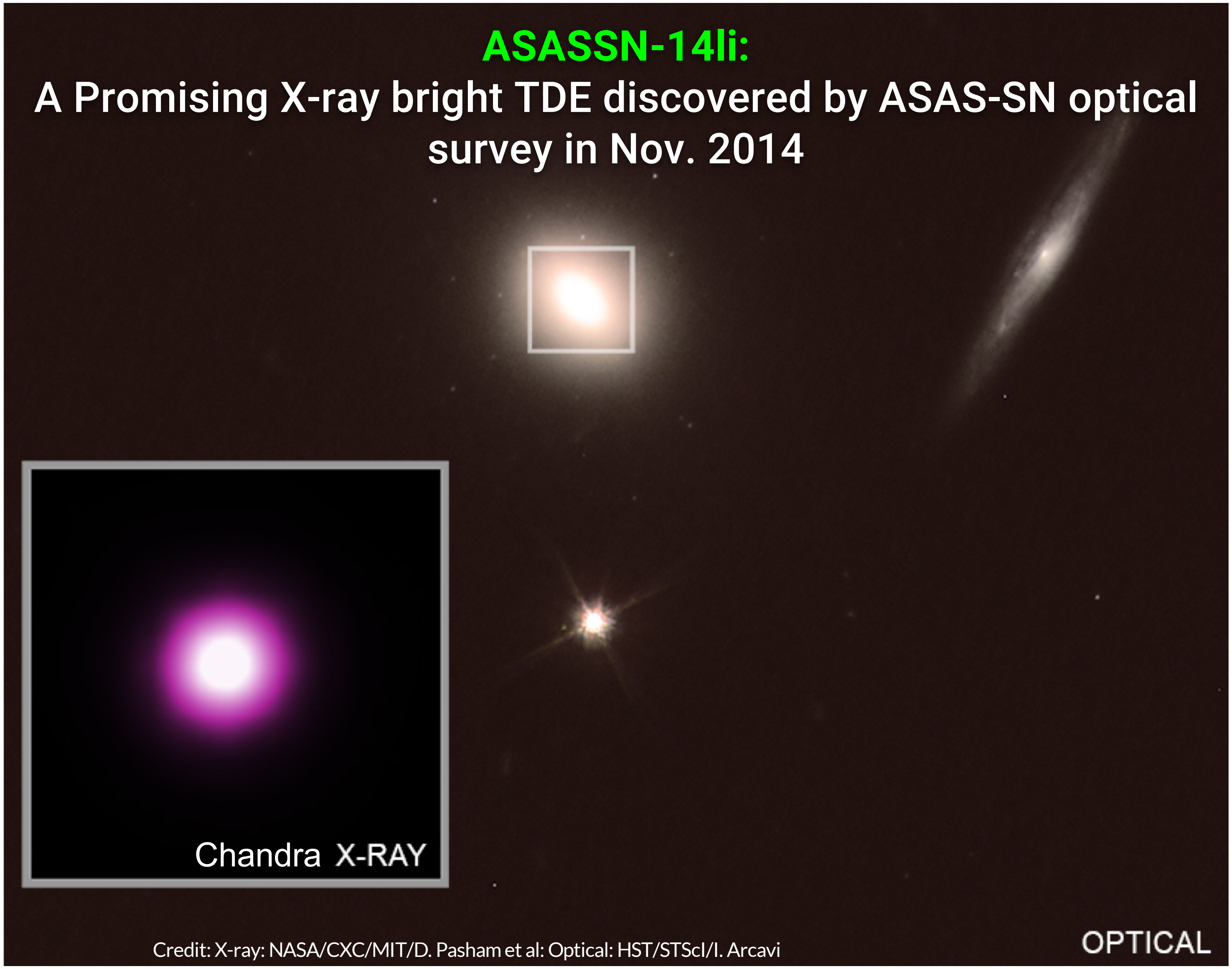
Origin: Very close to the black hole where dynamics are dictated by black hole's mass and spin

High-frequency QPOs have been used to measure spins of stellar-mass black holes, although which model to adopt still uncertain

e.g., Turok et al. 2005, Wagner et al. 2009, Motta et al. 2014, Franchini, Motta, Lodato et al. 2017

TDEs, to some degree are scaled-up stellar-mass black hole outbursts.

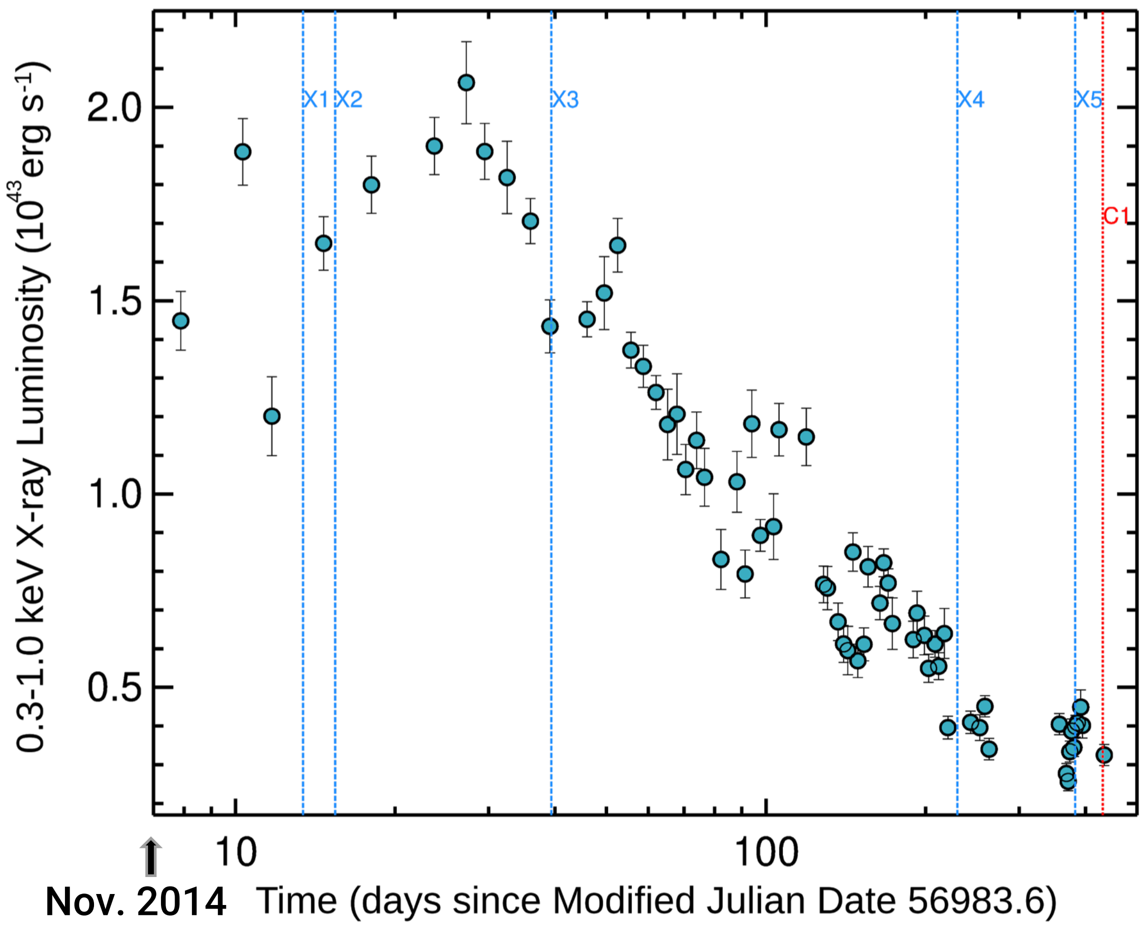
Can we detect similar stable oscillations in Tidal disruption events?
(And then possibly constrain spin?)



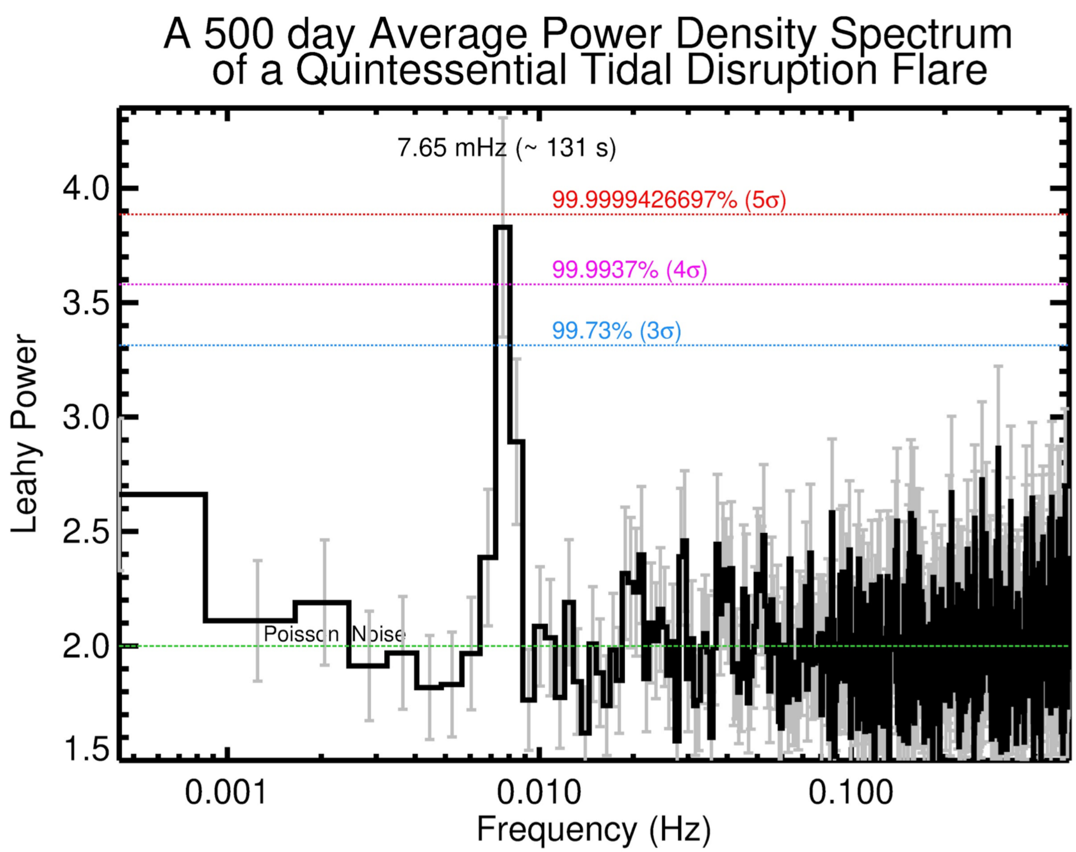
90 Mpc distant TDE
Peak $L_X \sim 10^{43}$ erg/s

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, Shappee et al. 2014 ….

ASASSN-14li's long-term evolution in X-rays with Swift



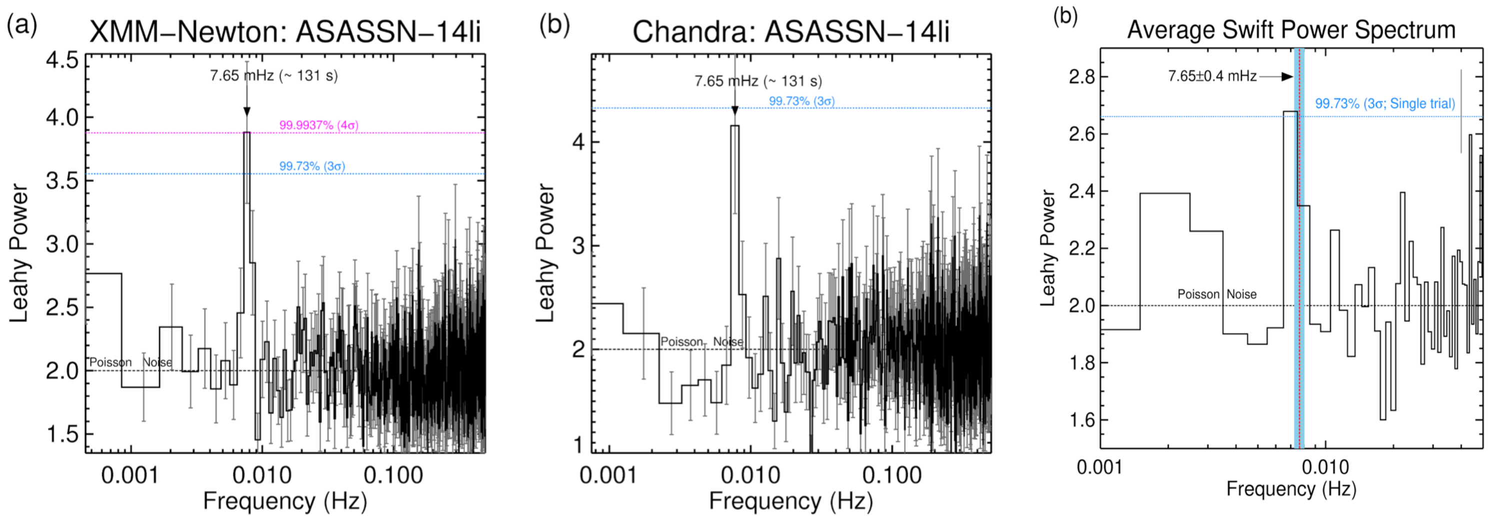
A very stable, very loud QPO at 7.65 mHz



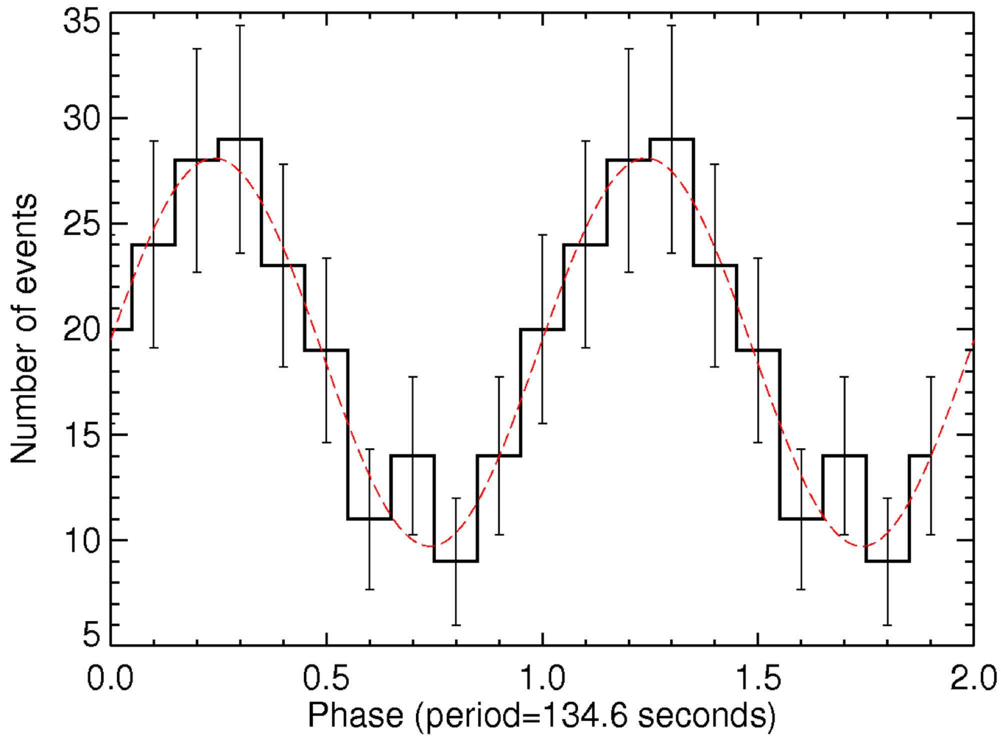
- Fractional rms amplitude≈40%
- The signal is stable over 10x range in luminosity, for over a year: 300,000 cycles!
- **Stable → tied to something fundamental (mass and spin)**

Pasham, Remillard et al. 2019, *Science*

Present in all 3 detectors … at different times



Folded Chandra light curve



Roughly 50% rms power!

The strongest BH QPO detection.

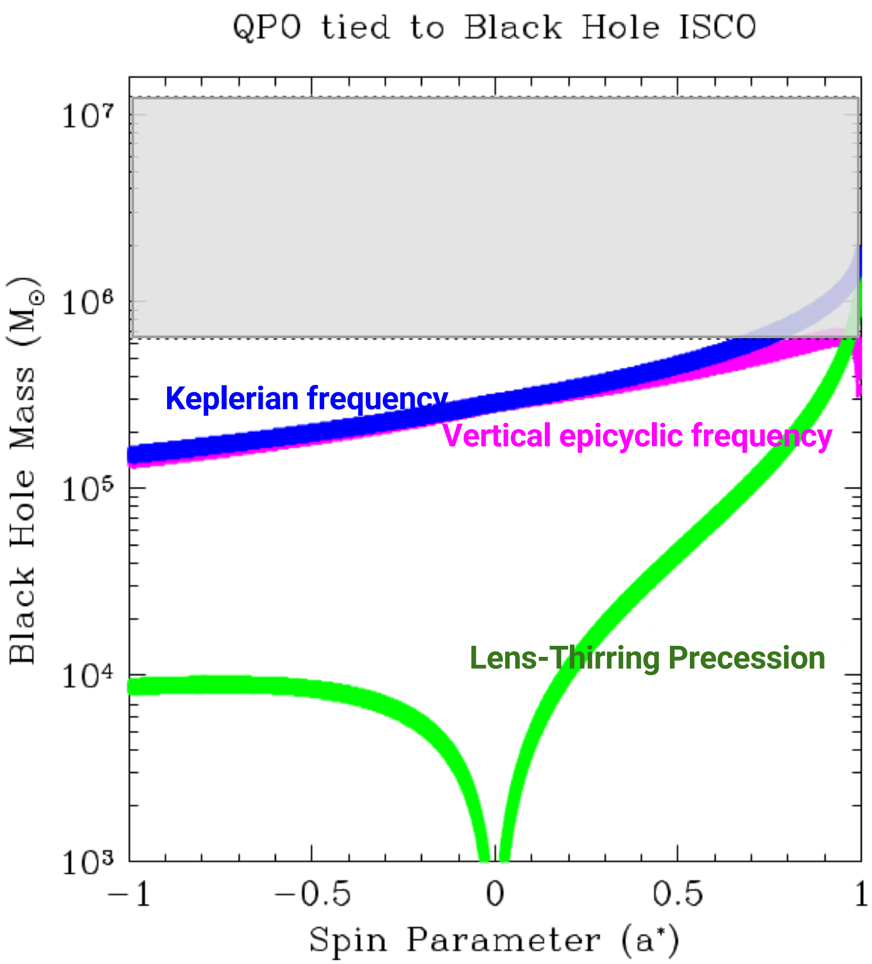
We have a sense of what the disrupting black hole mass is from the M-σ, M-L

Mass: $10^{5.8-7.1}$ $M_{\odot}$

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 …

Constraining the spin of a black hole in a TDE



Assuming the black hole mass from M-σ, M-L, the only spin solution is a* > 0.7

ISCO gives a lower limit

To an extent: Model-independent measurement!

Model popular with theorists: Lens-Thirring Precession → Maximally spinning black hole.

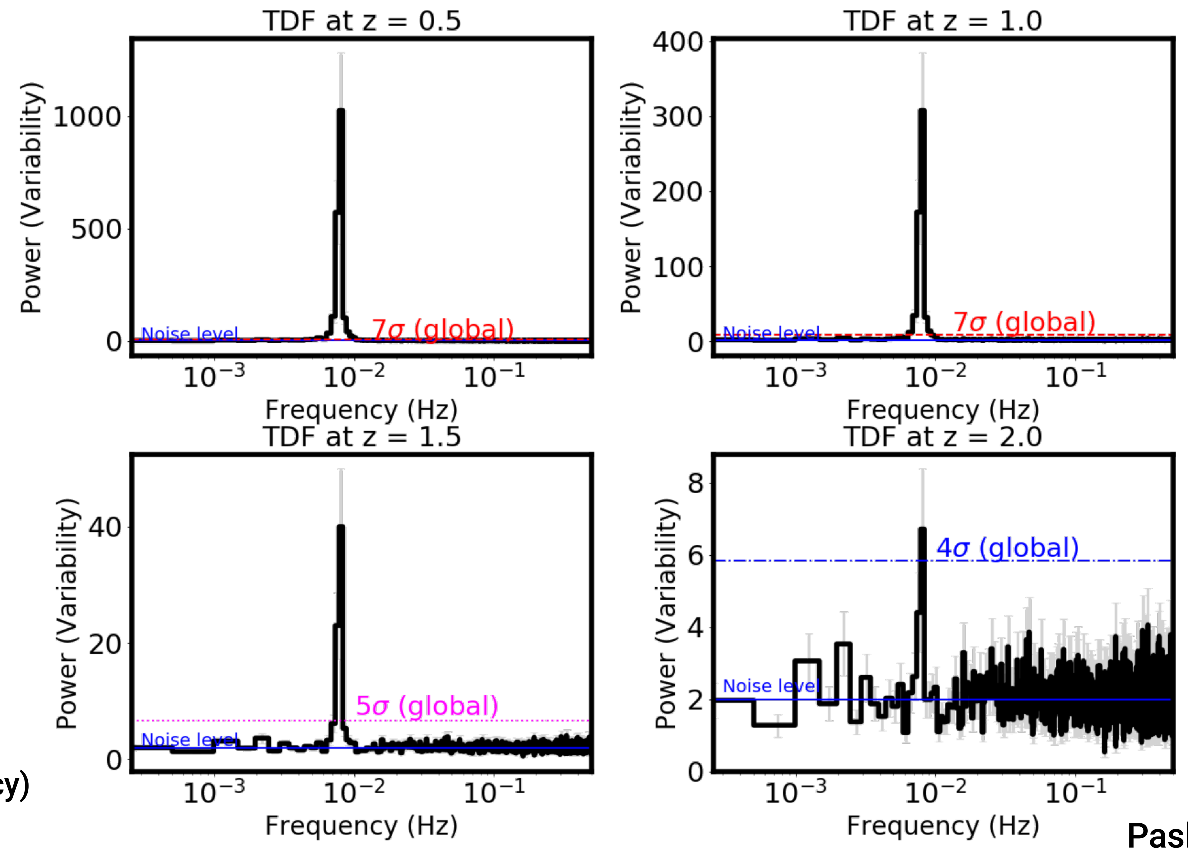
Pasham, Remillard et al. 2019, *Science*

Future: why is this important?

This opens a new method to constrain/measure spins of supermassive black holes when they disrupt stars!

Next generation X-ray telescopes: QPOs/spins out to cosmic distances!?

Simulated power spectra for ATHENA/STROBE-X class missions



Assuming fractional rms of 40%

Could detect QPOs from TDEs out to redshift of 2!!

Ignored time dilation effect of the QPO (would change frequency)

Pasham et al. 2019, White paper for 2020 decadal survey

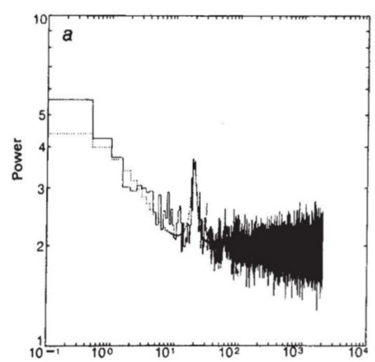
Detecting QPOs out to z=2 and constraining spins would allow us to build SMBH spin distributions at various redshifts

Takeaway message

Tidal disruption events are providing a new means to detect QPOs from supermassive black holes

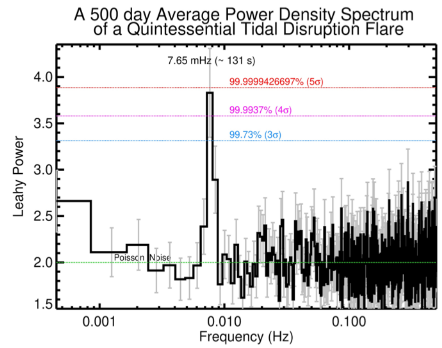
Future: New era of QPOs from cosmological distances

Past (1980s)



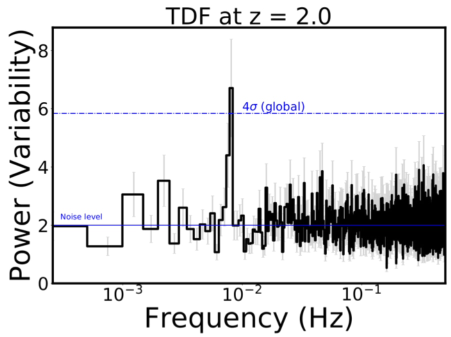
A few Kpcs

Present (2010s)



100s of Mpcs

Future (2030s)



Several Gpcs

Thank you!

In Summary …

- **We have detected an incredibly high amplitude QPO from a TDE!**
- **The QPO is stable for years**
- **Extremely soft X-ray spectrum suggests an origin from an inner accretion flow**
- **Assuming M-σ mass estimate suggests the black hole has to be fast spinning with a spin parameter > 0.7!**
- **Adopting a Lense-Thirring precession model implies an extremely fast spinning black hole**

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

Could become a tool to constrain TDE spin demographics