Ultraluminous X-ray pulsars: spin-evolution and super-orbital modulation during super-Eddington accretion

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A shift of the ULX paradigm

Before: intermediate mass black holes accreting at sub-Eddington rates

After: ULXs can host NS accreting at super-Eddington rates

Bachetti+ 2014; Fürst+ 2016
Israel+ 2017 ...

L > 10^{39} erg/s

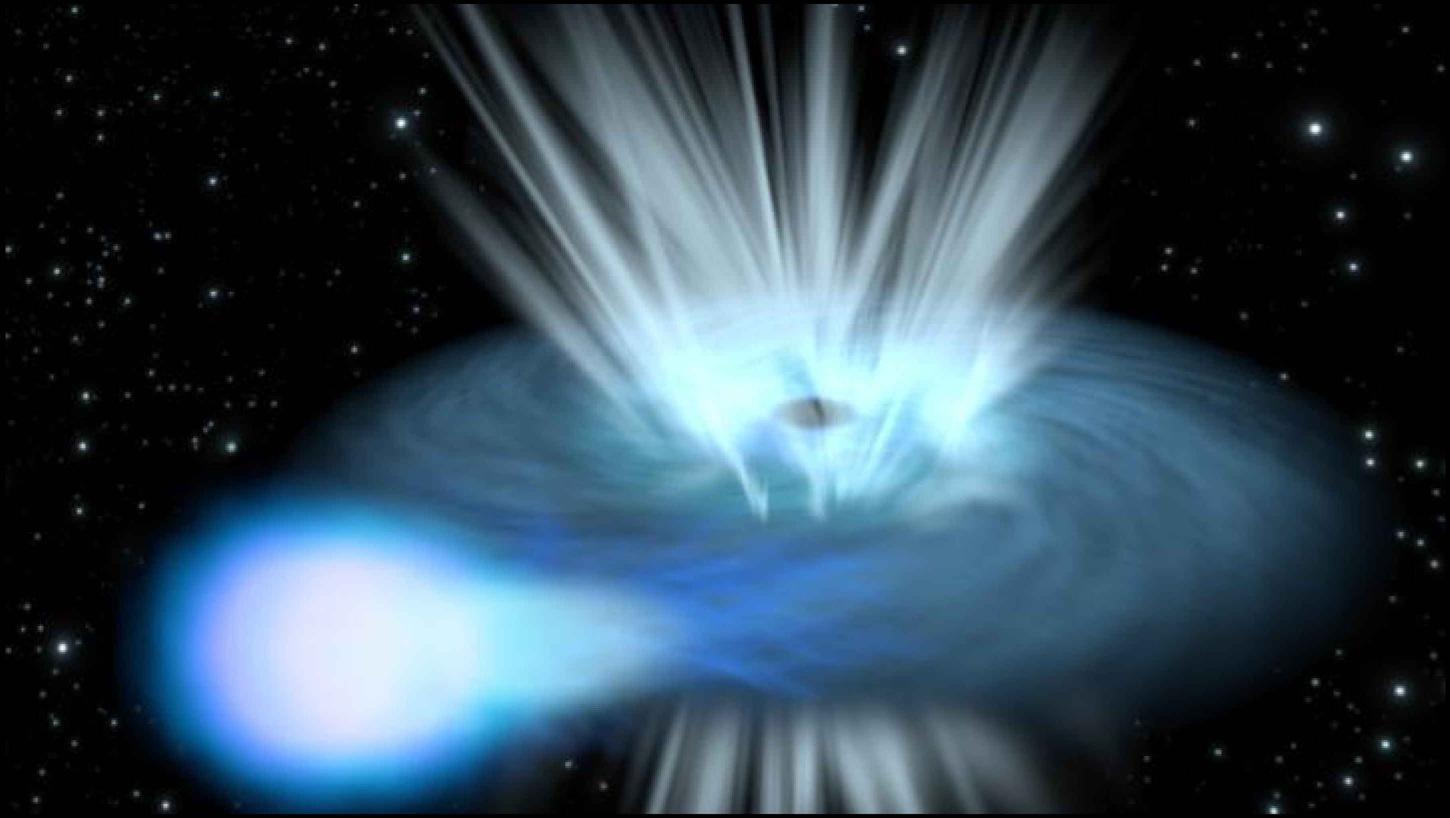
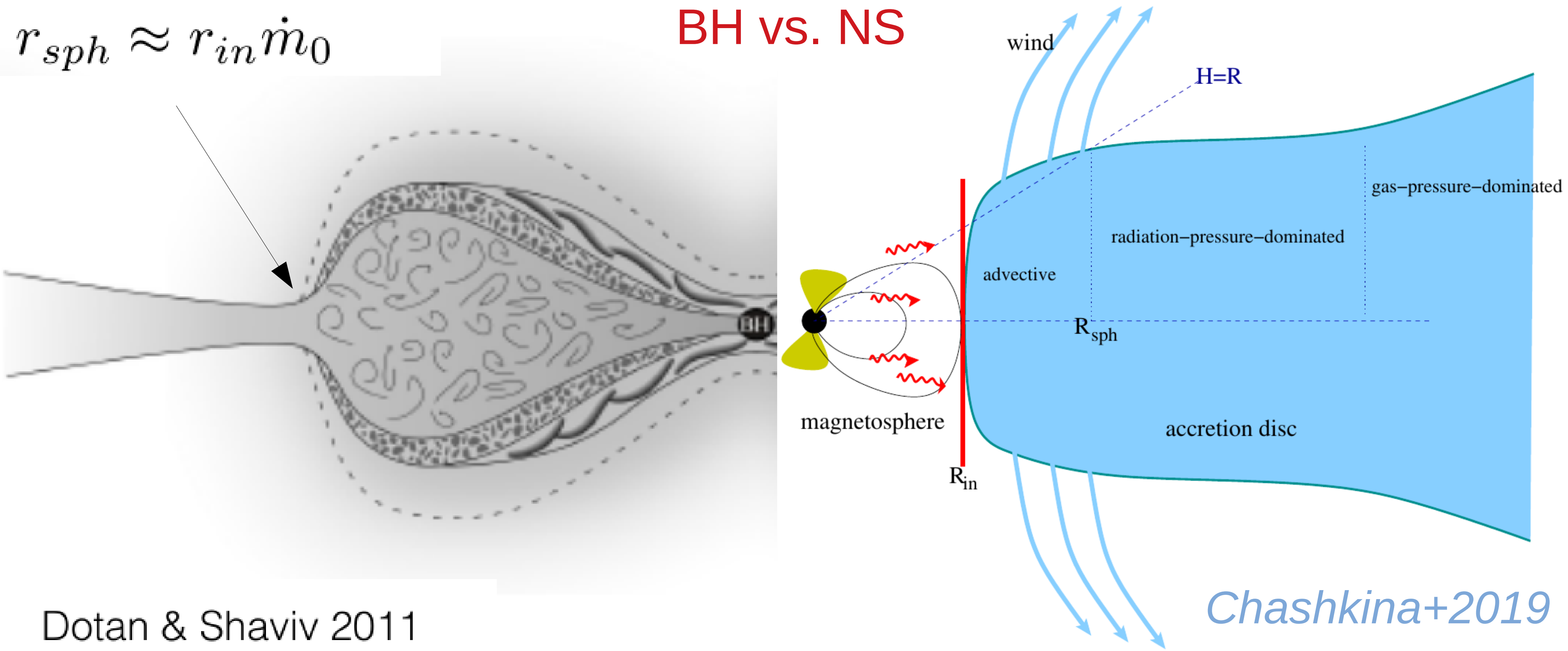


Image credit: ESA - C. Carreau

Inside Spherization Radius: Change in disk structure & Mass Loss

$r_{sph} \approx r_{in} \dot{m}_0$

BH vs. NS



Dotan & Shaviv 2011

Chashkina+2019

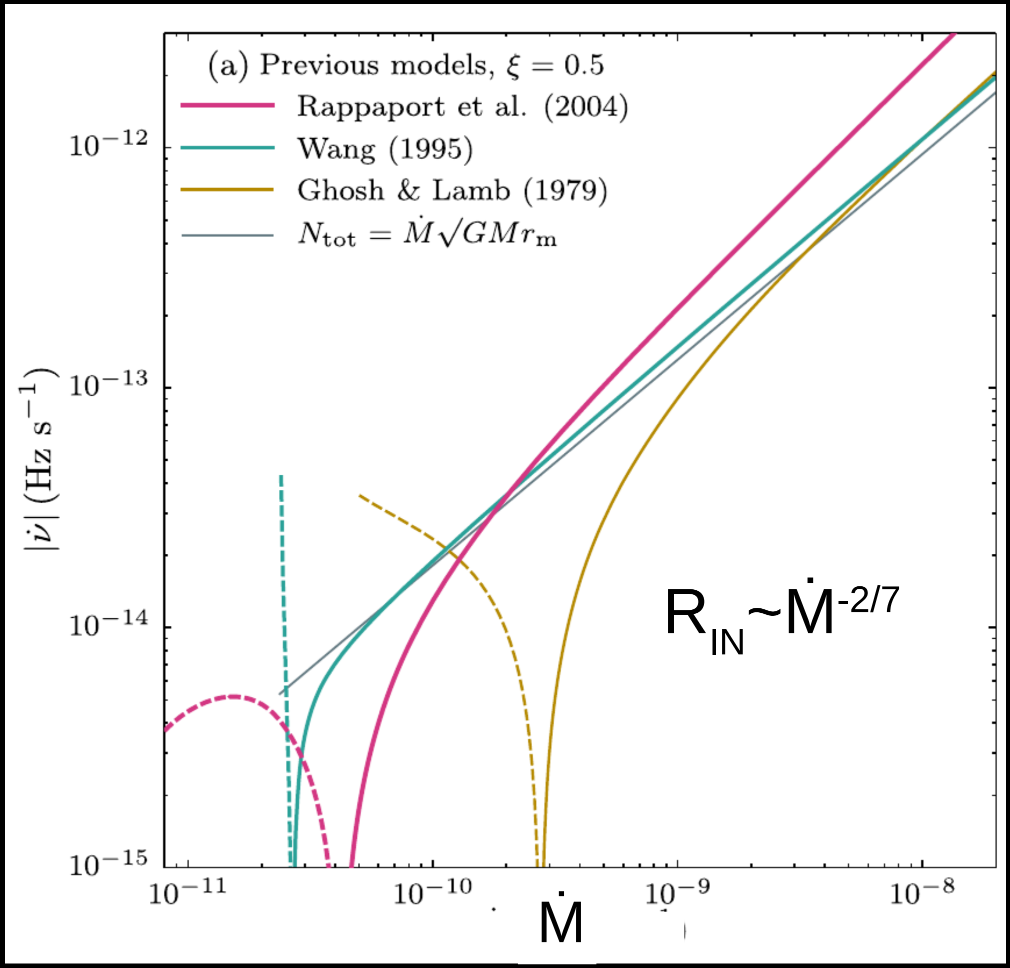
$$\dot{M}(R) \simeq \frac{R}{R_{\rm sph}} \dot{M}_{\rm Edd}$$

e.g.
Shakura & Sunyaev 1973

Outflows see:
Poutanen+ 2007
Abolmasov+ 2009

Accretion and torque transfer

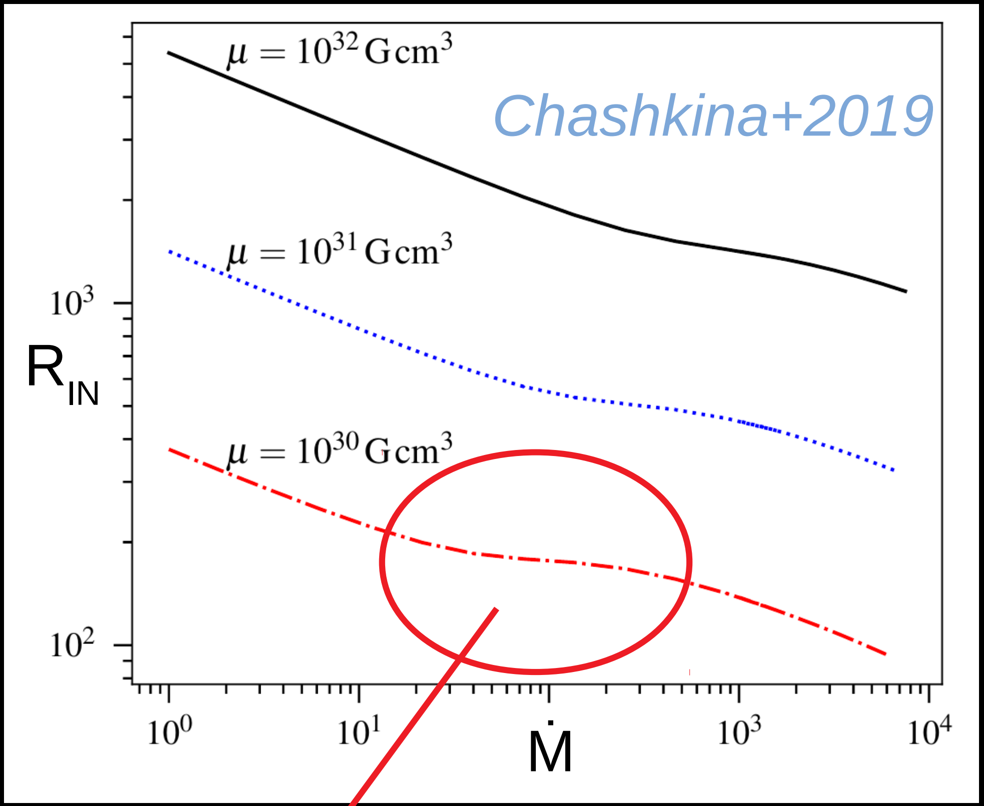
Spin change due to accretion -> Provides information for $\dot{M}$



torque transfer standard models

Ghosh & Lamb 1979, Wang 1995

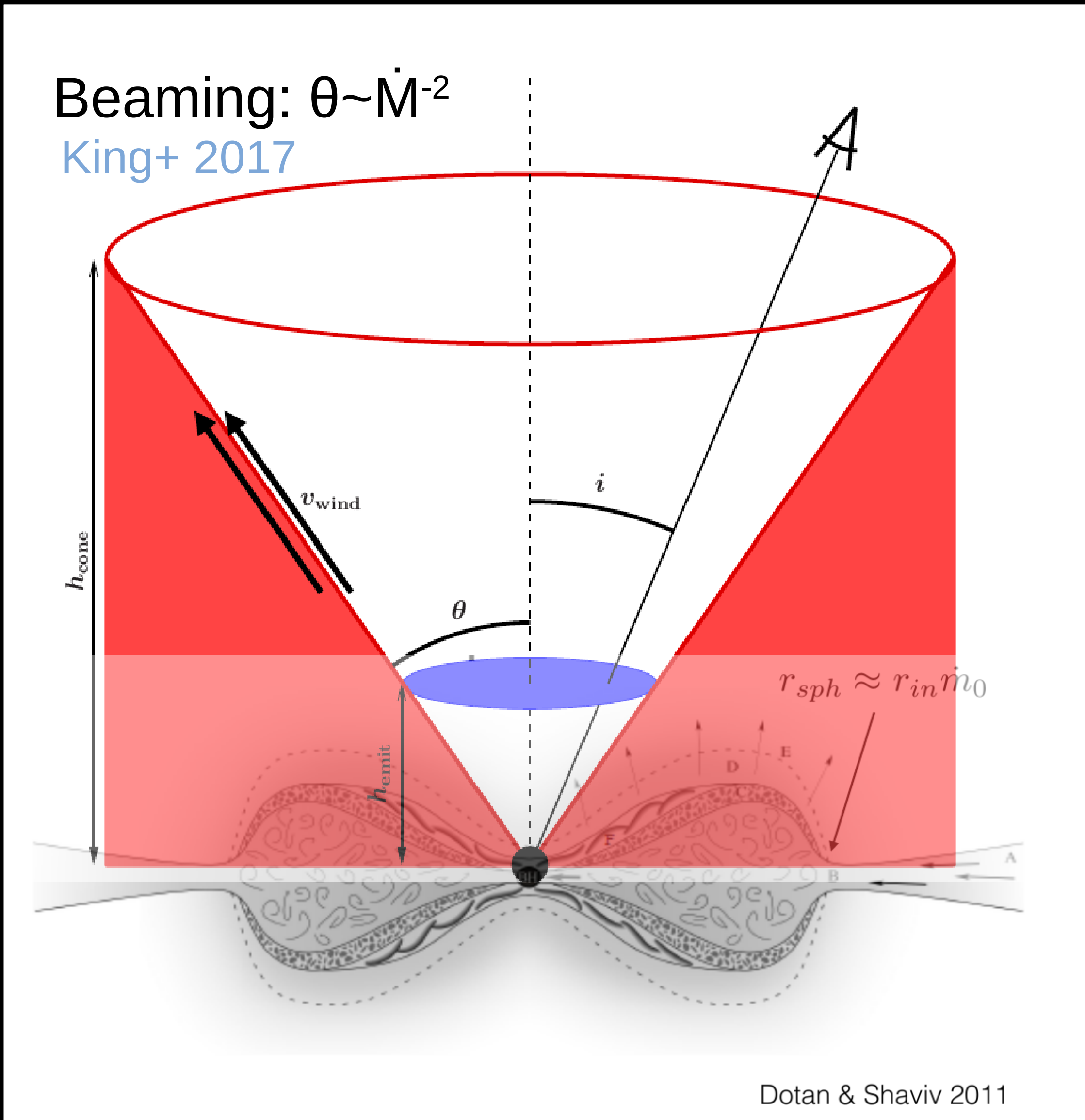
Parfrey+ 2016



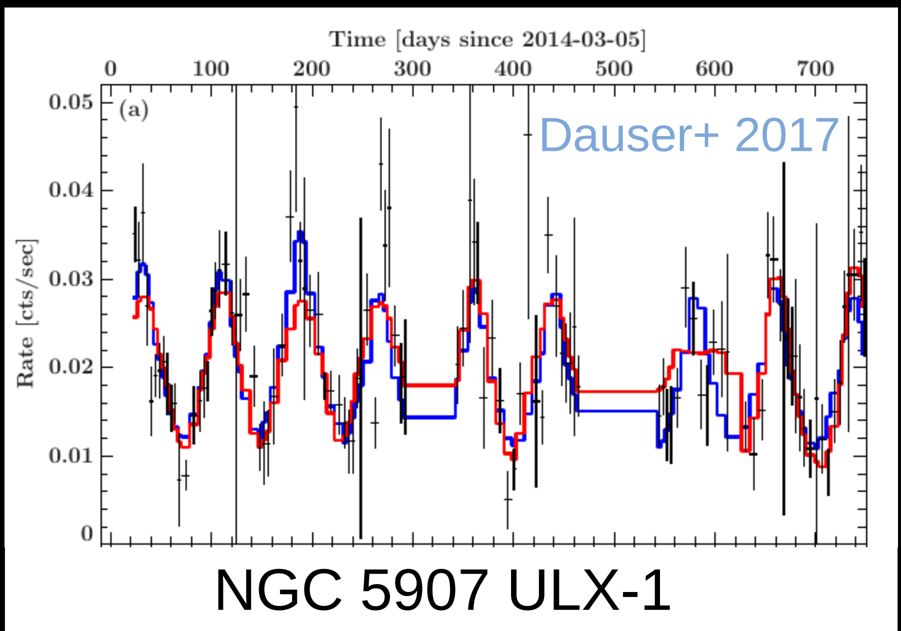
Close to Eddington rate:

Disk inner R insensitive to changes in $\dot{M}$

Long-term variability – Super-orbital period



Disk precession
or
Propeller transition?

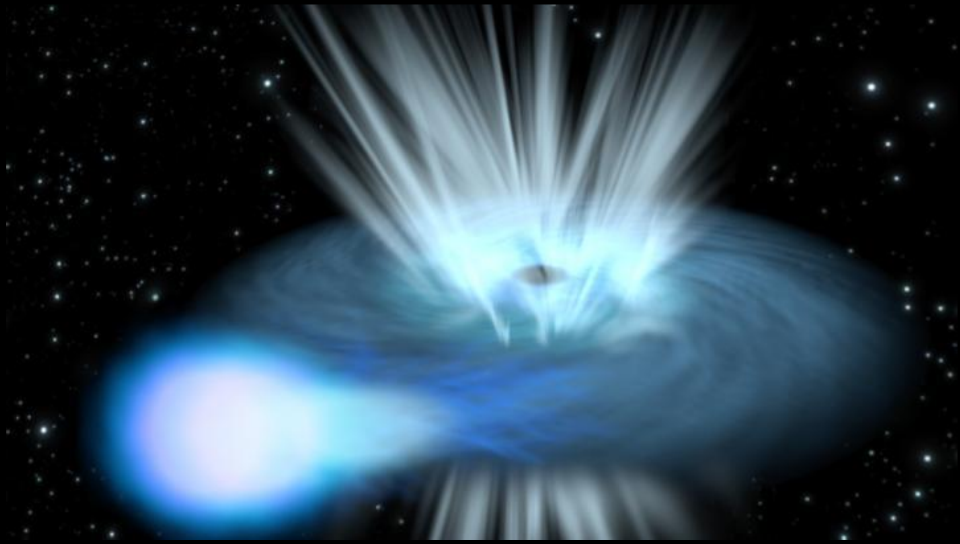


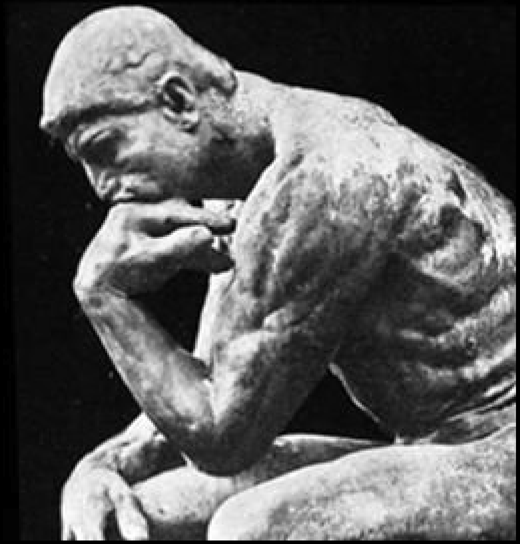
What causes precession?

Lense-Thirring: Middleton+ 2018

New puzzles to solve!

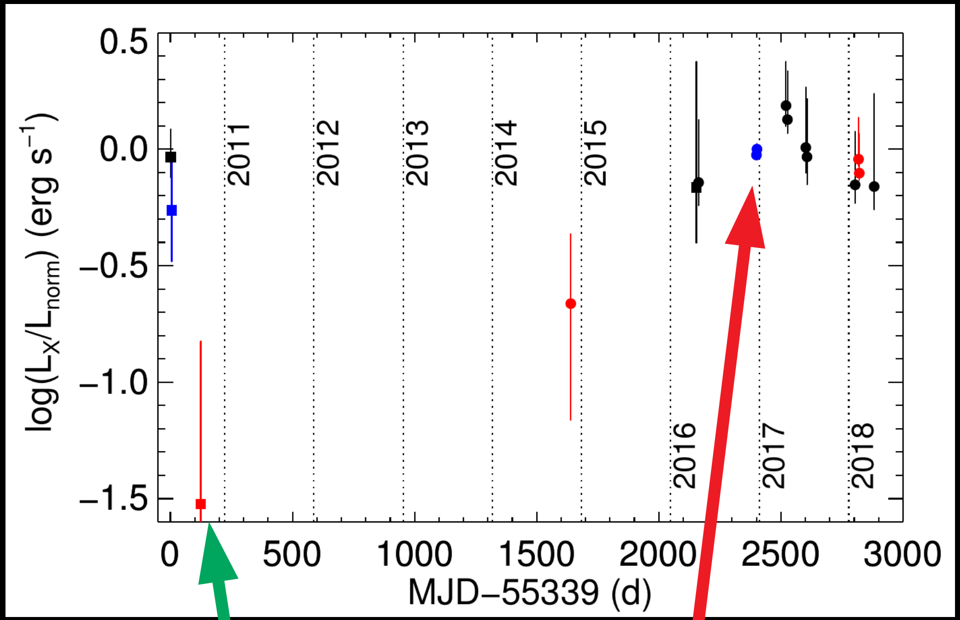
- Observed LX - Accretion:
  - ➔ Super Eddington vs beaming
- NS magnetic field:
  - ➔ Magnetar like B vs “typical” values
- Super-orbital modulation
  - ▪ What is the origin
- ▪ Study of newly discovered systems:
  - ➔ NGC 300 ULX1
  - ➔ M51 ULX-7

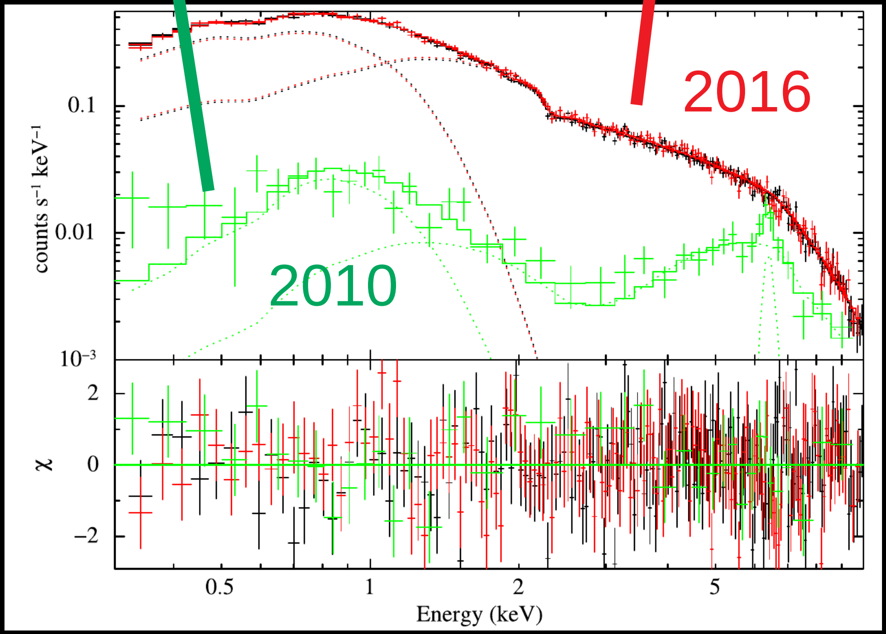




NGC 300 ULX1

From SN2010da impostor event … to a new ULX pulsar





Identified as ULXP by Carpano+ 2018

P= 31 s (Nov 2016)

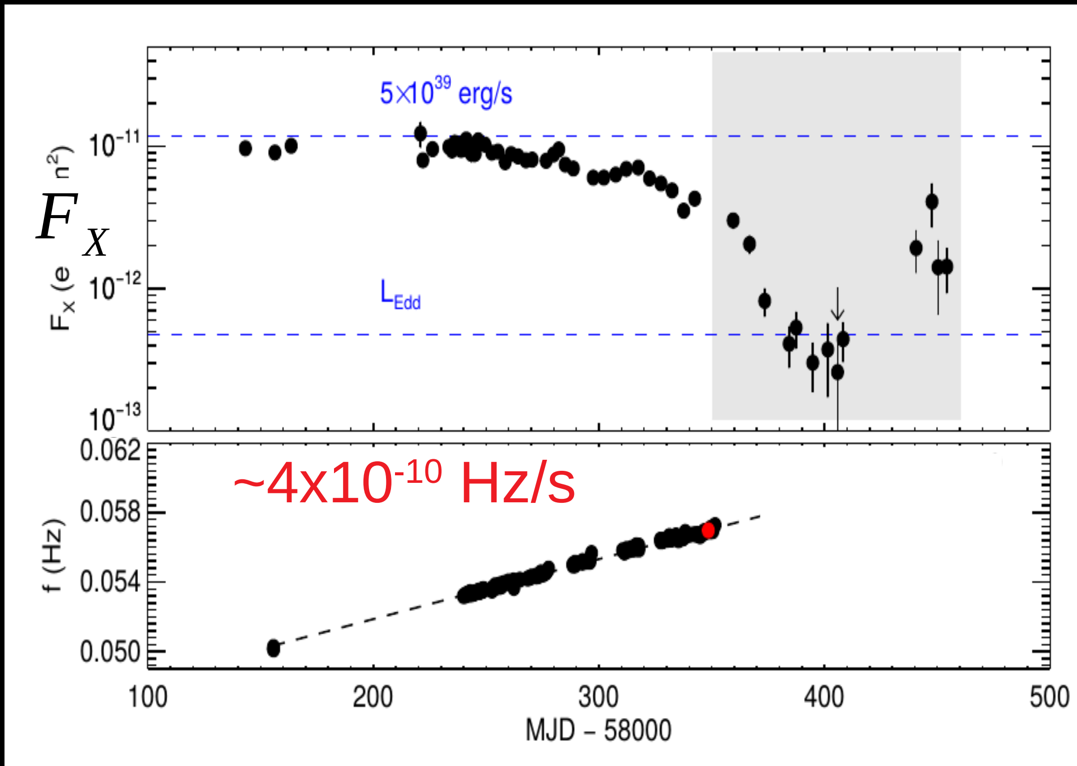
L_x~4.7x10[39] erg/s (0.3-30 keV)

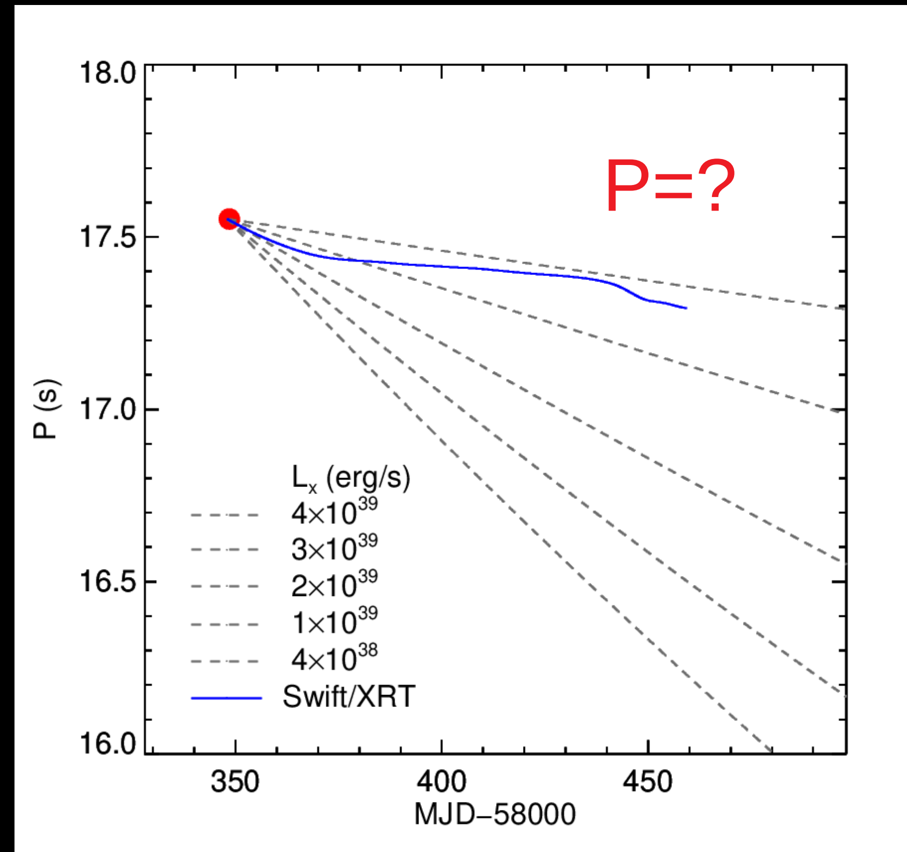
Flux modulation can be attributed to variable absorption.

Continuum spectrum is not variable? Koliopanos+ 2019

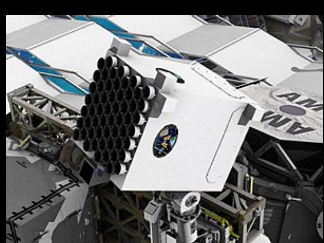
Constant $\dot{M}$?

NGC 300 ULX1: 2018 monitoring

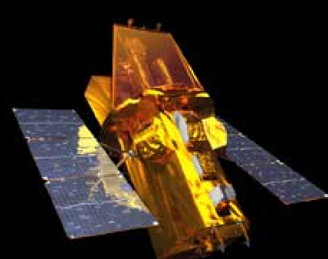




Spin: NICER



Flux: Swift/XRT



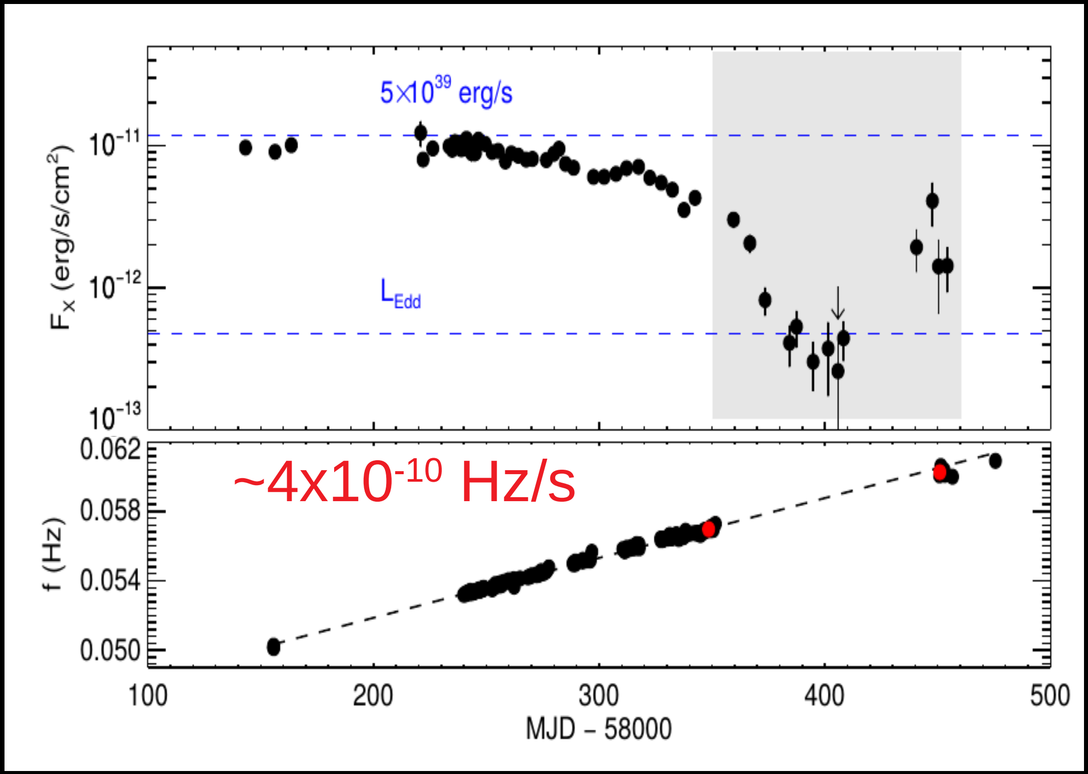
Predicted P for different $\dot{M}$

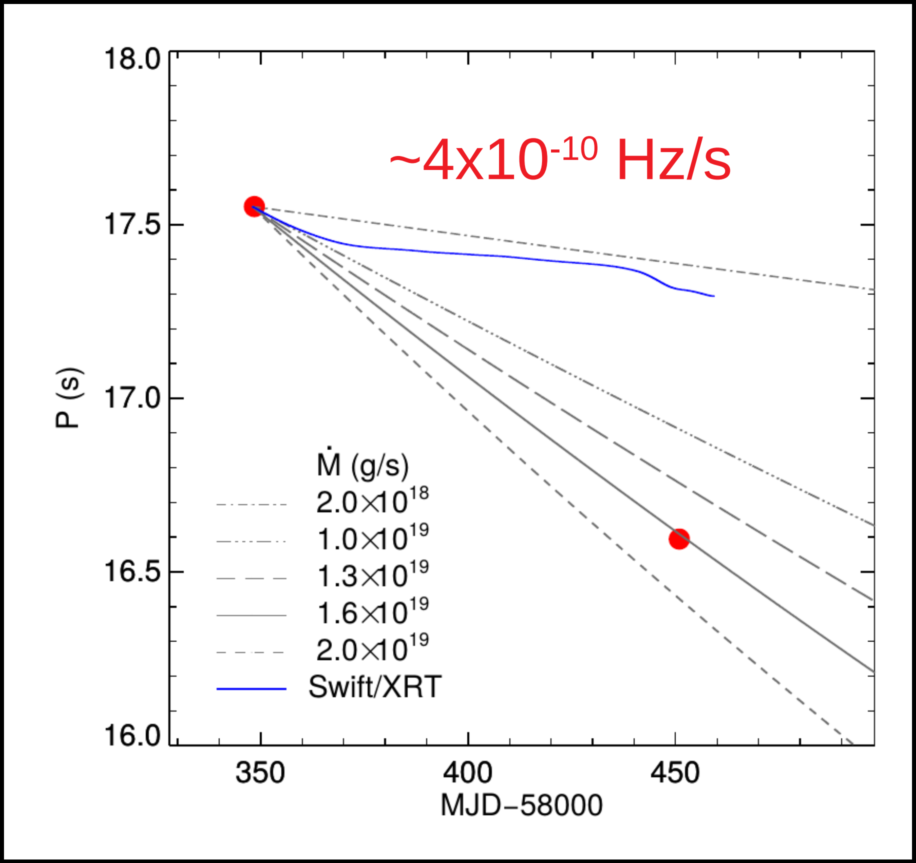
A) Changes in $\dot{M}$?

B) Changes in absorption ?

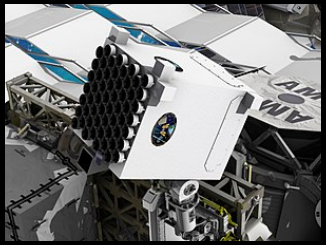
Vasilopoulos+ 2019

NGC 300 ULX1: 2018 monitoring

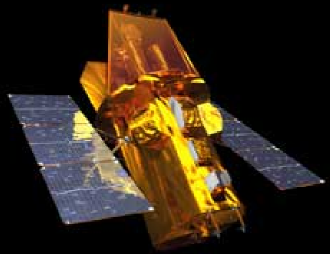




Spin: NICER



Flux: Swift/XRT



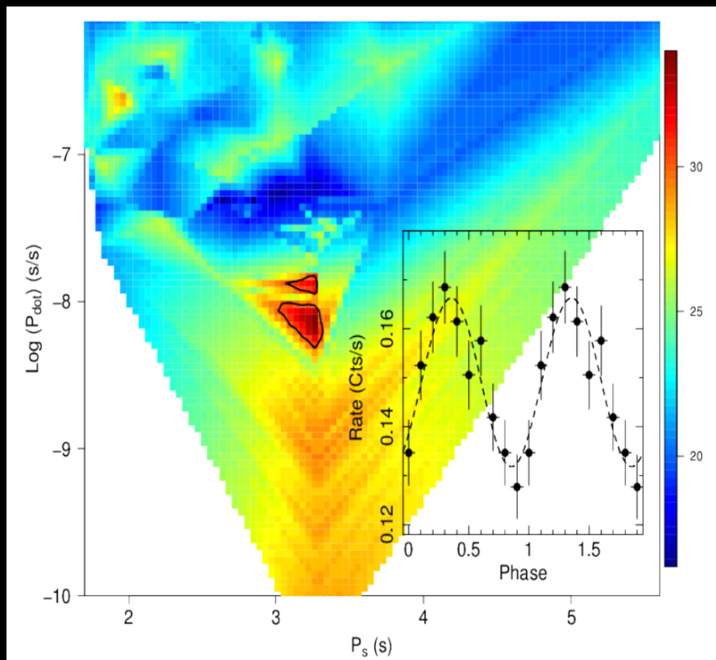
Spin evolution yields constant accretion!

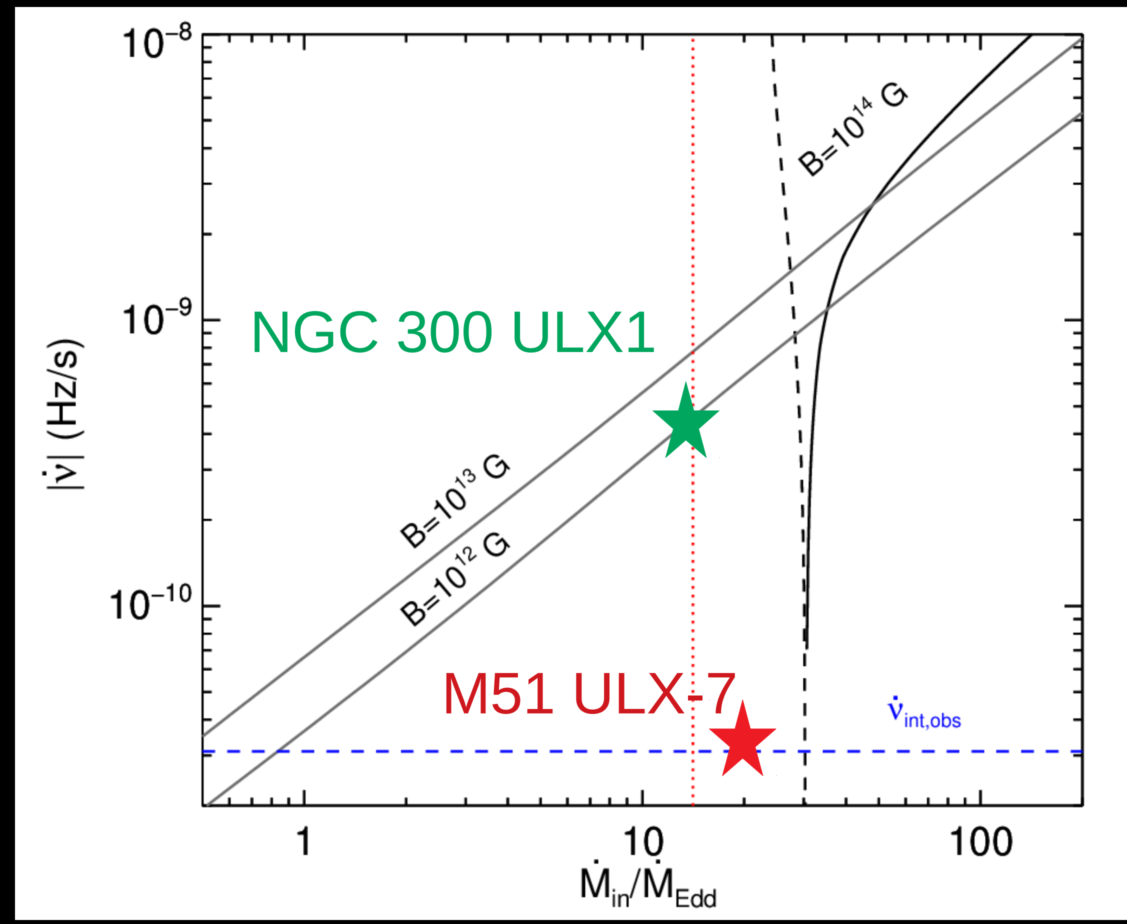
$$B = 10^{12}\ \mathrm{G}$$
$$\dot{M} = 3.2\times10^{19}\ \mathrm{g/s}\ (\sim 16\ \dot{M}_{Edd})$$

Vasilopoulos+ 2019

M51 ULX-7: spin equilibrium

Rodríguez Castillo+ 2019





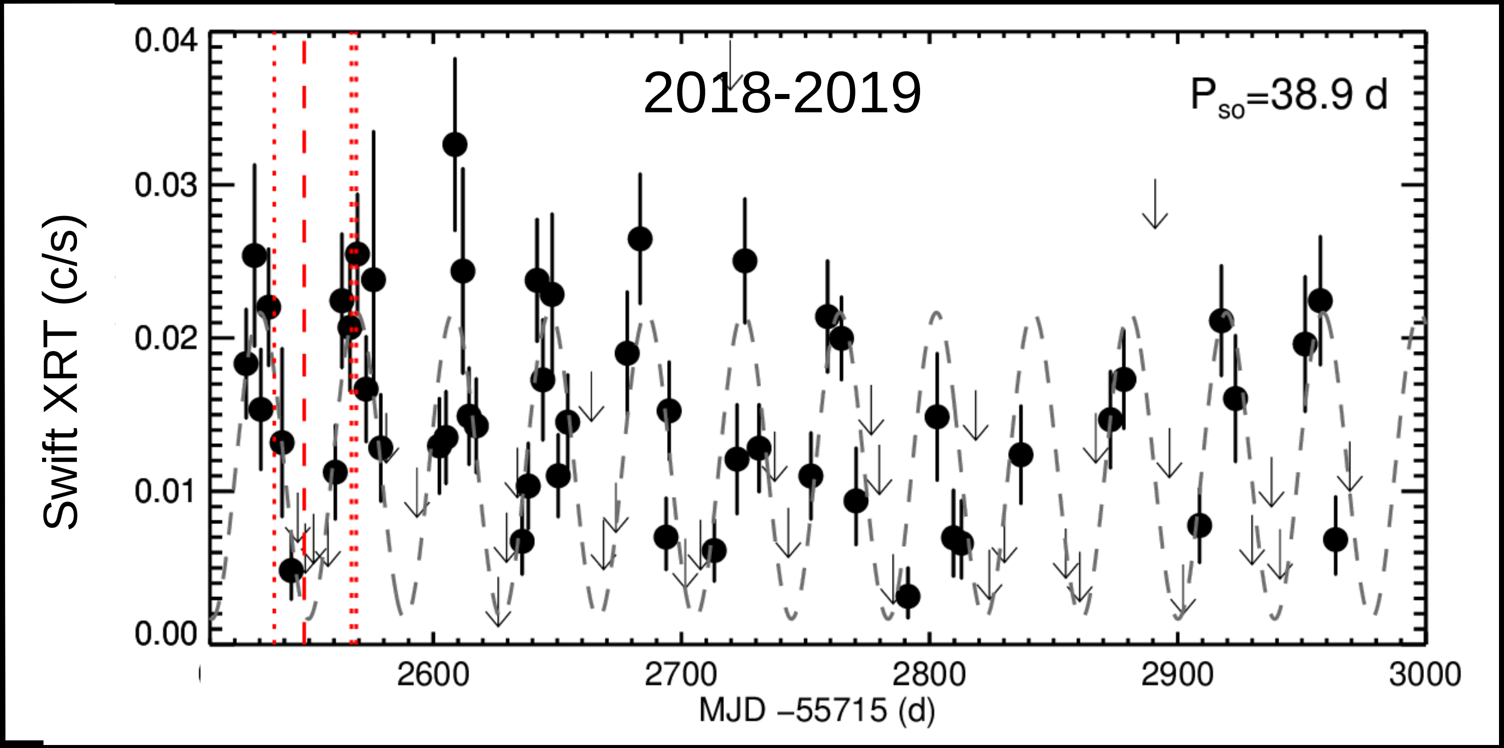
- L_x~7x10[39] erg/s (0.3-10 keV)
  ~ 2 brighter than NGC 300 ULX1
- P_{orbit} = 2 d
- P_{spin}= 2.8 s
- $\dot{P}/P^2_{spin}$~2x10^{-11} Hz/s
  ~ 20 slower than NGC 300 ULX1

NS is M51 ULX-7 must rotate near equilibrium

B = 2-7x10^{13} G

Vasilopoulos+ 2019

M51 ULX-7: 39 d super-orbital period



NS Free Precession

Distortion of NS due to B

Misalignment of:

- Rotation axis
- Magnetic axis

$$\epsilon \propto \frac{P_{spin}}{P_{super.o}}$$

B = 3-4x10^{13} G

M51 ULX-7

P_{spin} = 2.8 s
P_{orbit} = 2 d
$P_{super.o.}$ = 39 d

$\propto$

Her X-1

P_{spin} = 1.24 s
P_{orbit} = 1.7 d
$P_{super.o.}$ = 35 d

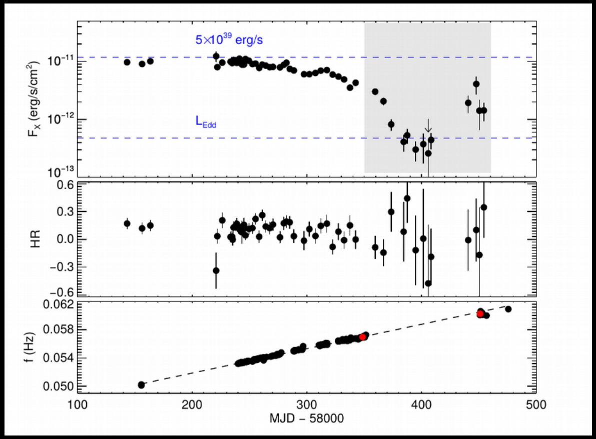
Truemper+ 1986
S.O. period due to NS free Precession

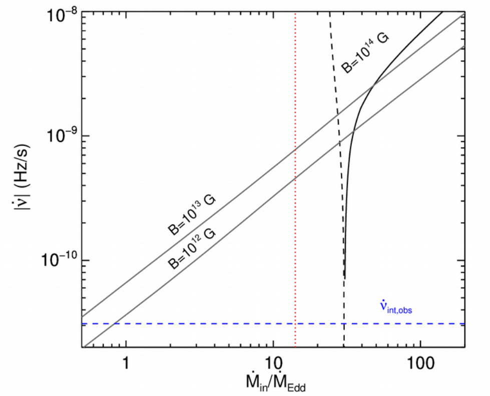
Vasilopoulos+ 2019

Summary & Conclusion

- NGC 300 ULX1
  - 2018 monitoring – Spin evolution during “off-state”
  - F_X decrease by ~50, but constant $\dot{M}$
    - “Normal” $B \sim 10^{12}$ G, no beaming

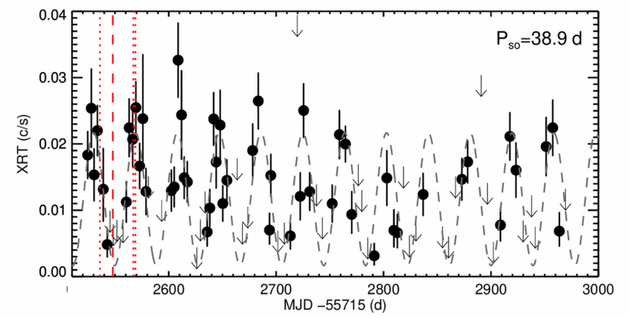
Carpano, S et al. 2018 (arXiv: 1802.10341)
Vasilopoulos, G et al. 2018 (arXiv:1811.11907)
Vasilopoulos, G et al. 2019 (arXiv:1905.03740)





- M51 ULX-7
  - NS near equilibrium: $B \sim 2\text{-}7 \times 10^{13}$ G
  - 39d super-orbital period
    if due to NS free precession -> $B \sim 3\text{-}4 \times 10^{13}$ G

Vasilopoulos, G et al. 2020 (arXiv: 1911.09670)



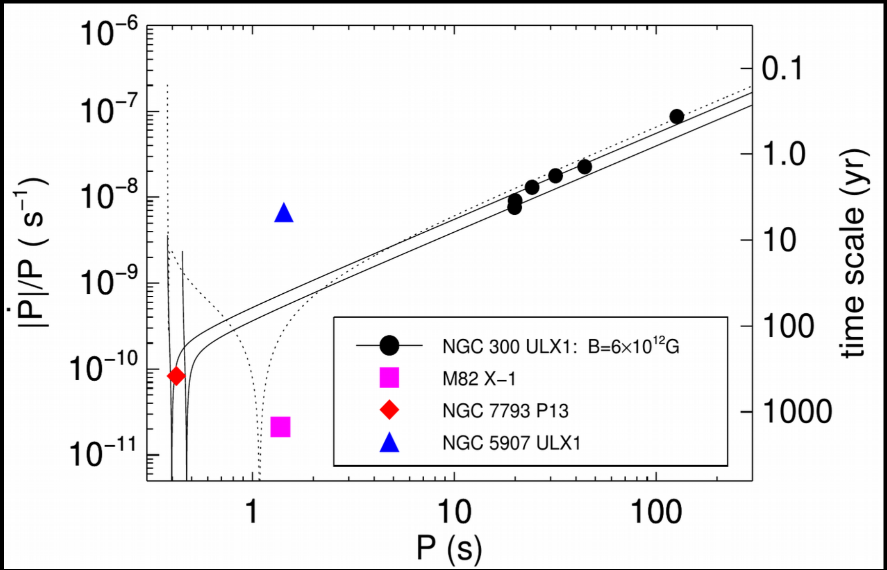
Thank You

BU slides

NGC 300 ULX1: a twist of spin

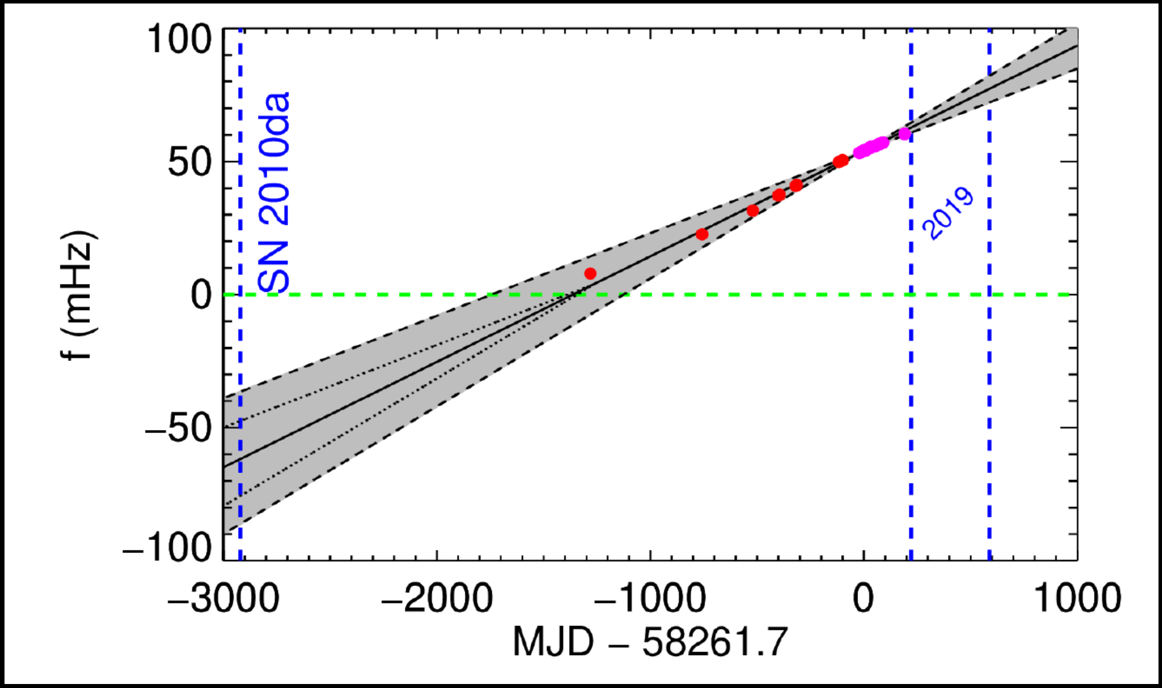
$$-\frac{\dot{P}}{P} = \frac{P}{I_{NS}\,2\pi} n(\omega_{fast})\dot{M}\sqrt{GM_{NS}R_M}$$

Wang 1995



L_X~3-5▪10^{39} erg/s , B~10^{12} G

Solve backwards in time



Implications on formation & evolution of system:

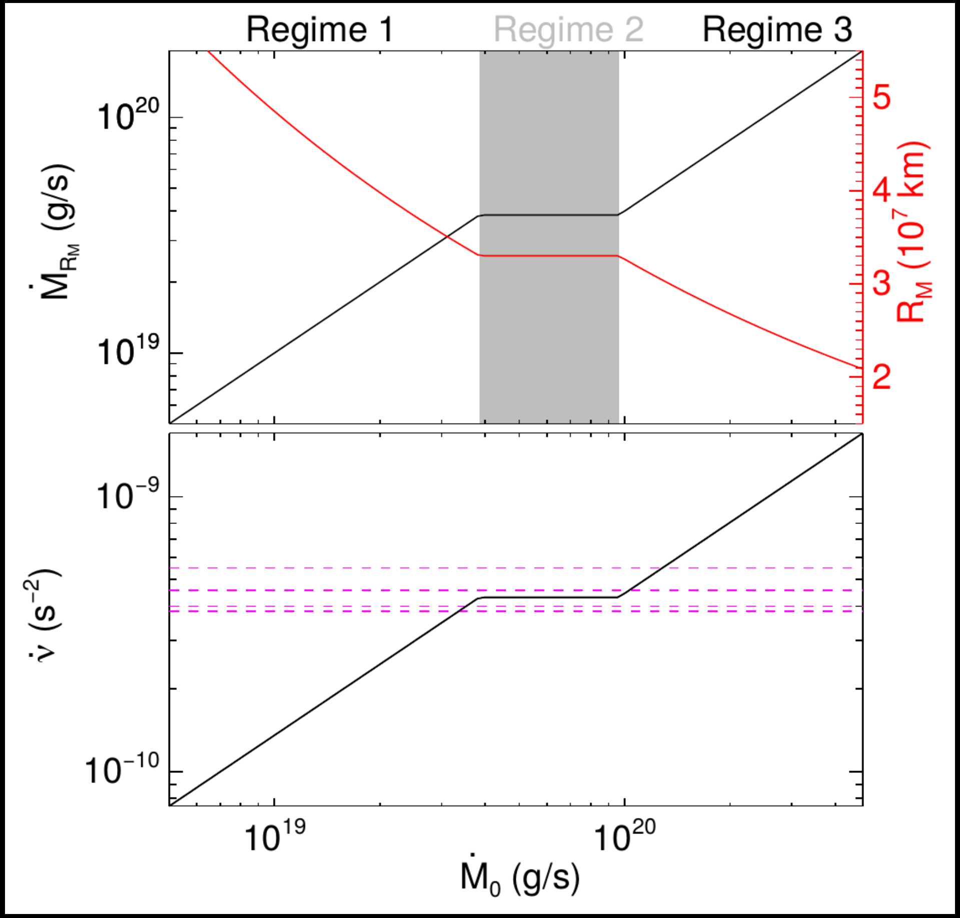
- NS – disk were initially counter-rotating
- Accretion was initially spinning-down the NS
- Accretion might have caused a NS reversal

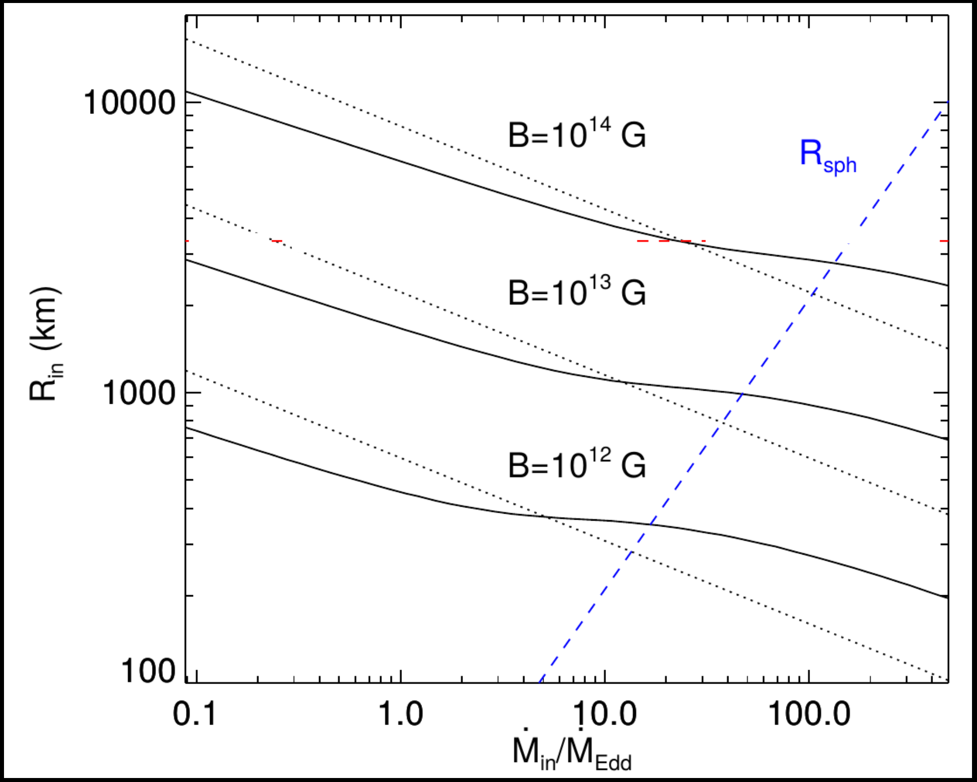
Vasilopoulos et al. 2018

ULXPs spin-up: radiation dominated

Super-Eddington:
radiation pressure dominated regime

R_{IN} *vs* $\dot{M}$





Implications for torque transfer as understood by standard models
See: Chashkina+2019, Vasilopooulos+ 2019 & 2020