

# Repeating Nuclear Transients as Extreme-Mass Ratio Inspirals counterparts

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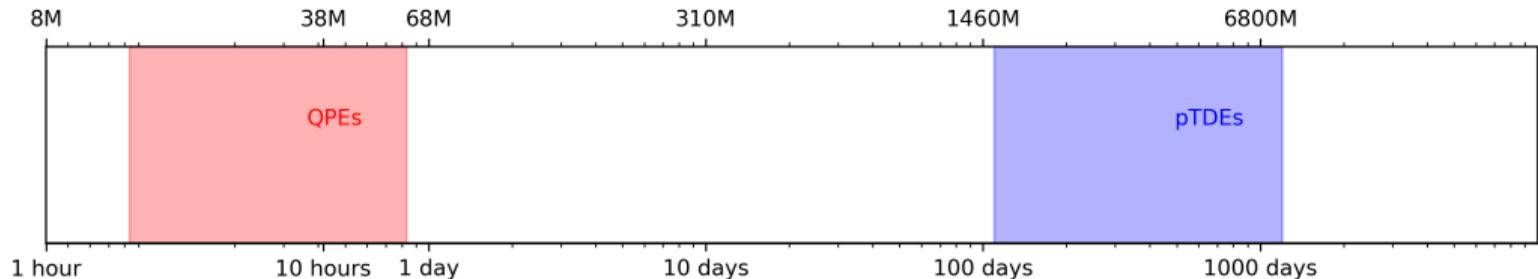
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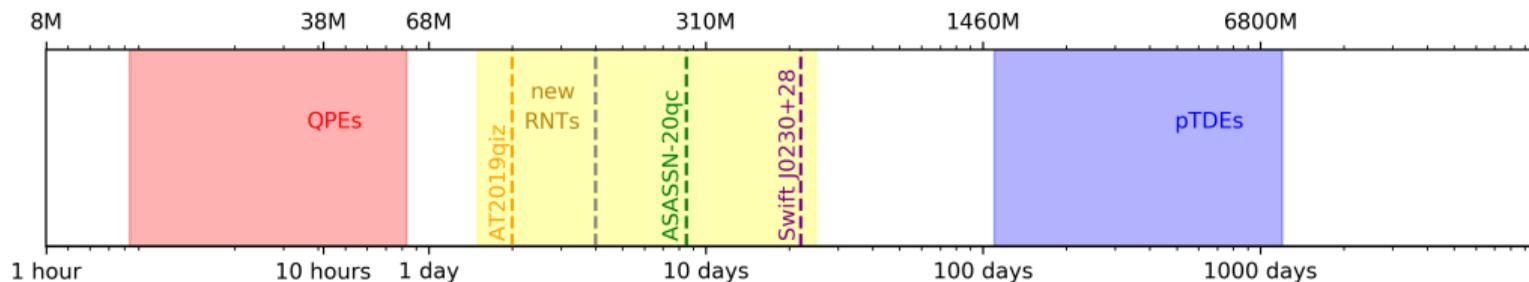
# Repeating Nuclear Transients (RNTs)

broad class of sources showing repeating bursts of activity on very different time scales

- QPEs - quasiperiodic eruptions
  - e.g. GSN 069, eRO-QPE1, eRO-QPE2, RX J1301
  - soft X-ray eruptions (amplitude  $\sim 10$ -100)
  - time scale: 2 - 20 hours
  - no variability in UV/optical band
- rpTDEs - repeating partial tidal disruption events (also known as RNTs)
  - ASASSN-14ko, AT2018fyk, eRASSt J045650.3-203750
  - strong (variable) UV/optical emission, long decay
  - time scale: months - years (110-1200 days)



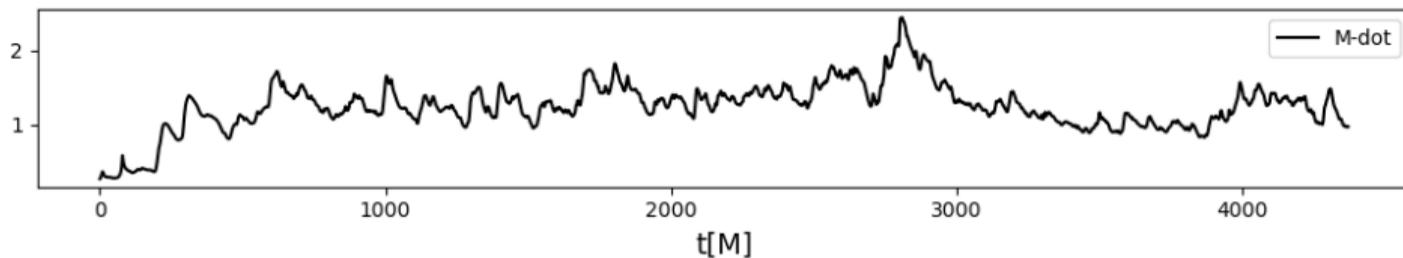
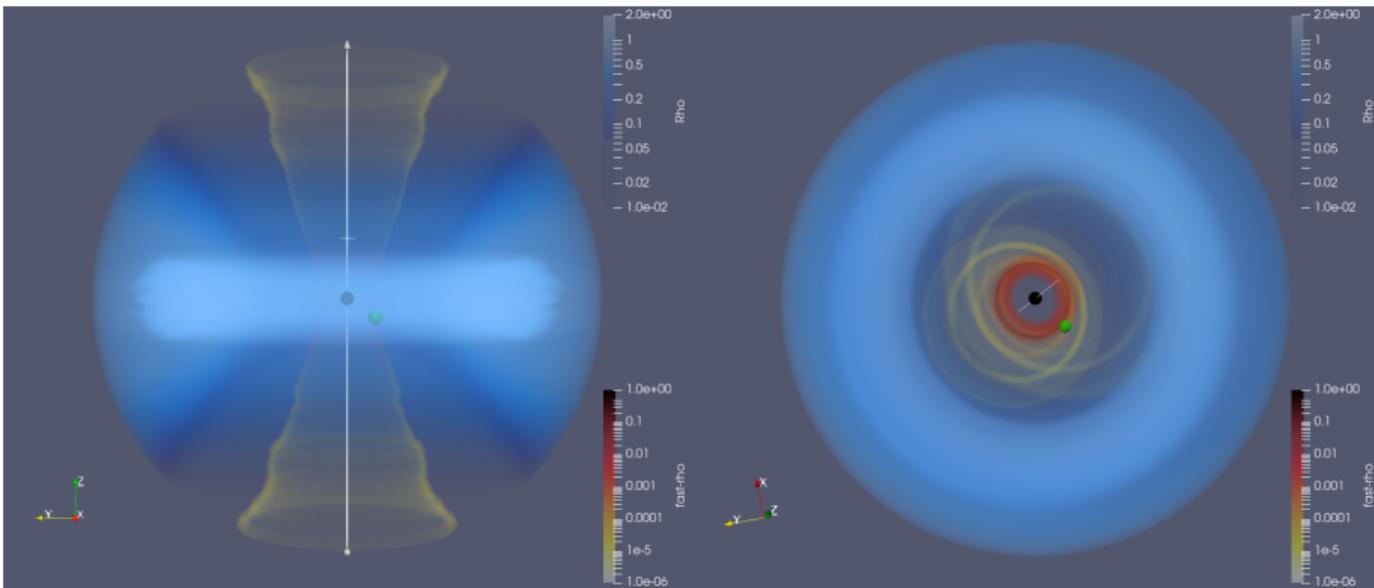
- ASASSN-20qc: QPOuts - quasiperiodic ultra-fast outflows (**Pasham+24, Sci. Adv.**)
  - no periodicity in soft X-rays/UV/optical
  - quasiperiodic absorption events in X-rays with 8.5 days period  $\Rightarrow$  outflow with  $\sim 0.3c$
- Swift J0230+28: large (200x) X-ray flares (**Guolo+24, Nat. Astron.**)
  - 22-day period - between QPEs and pTDEs
  - no UV/optical variability, slightly slower rise, much lower luminosity, but large amplitude
  - very low accretion rate in quiescence
- AT2019qiz: TDE + QPE/QPOuts (2 day period) after 4 years (**Nicholl+24, Nature**)
- QPE source with 4 days period (not published yet)



## Small Mass Ratio Inspirals (SMRIs) in RNTs?

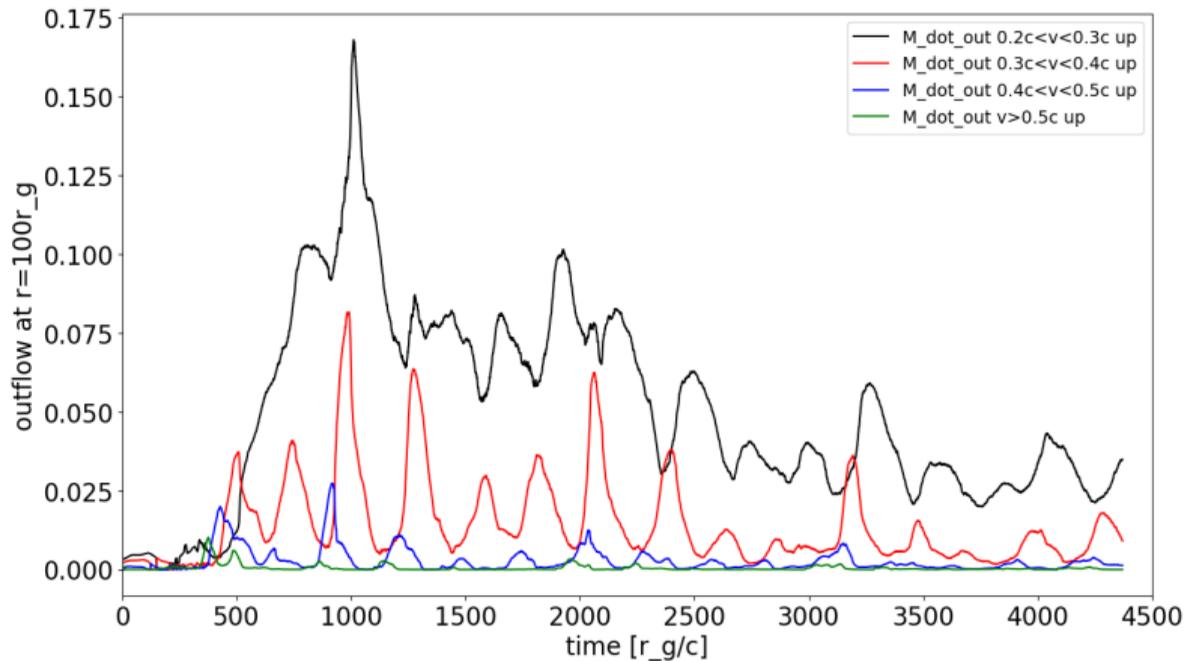
- SMRI = EMRI & IMRI = close binary system
  - primary = supermassive black hole (SMBH) - mass  $M$
  - secondary ( $m \lesssim 10^{-2}M$ ) loses angular momentum and energy (GW,HD) and spirals towards final plunge into SMBH → potential source of GW signal for LISA
- during SMRI secondary repeatedly transits through accretion flow onto SMBH ⇒ perturbation of accretion disc/ADAF
- for certain parameters the orbit can be altered by surrounding matter
- secondary = BH ⇒ possible small accretion disc and jet
- secondary = star ⇒ shocks in the atmosphere, Roche lobe overflow, (partial) tidal disruption (→ no final SMRI)
- secondary = NS ⇒ boundary layer, strong magnetic field
- ⇒ multiwavelength variability on different time scales ⇒ observable consequences (?) ⇒ manifestation as RNTs in electromagnetic spectrum?

- Simulations of repeating transits of secondary object through accretion disc on SMBH
- open source code package for GRMHD computations HARMPI
- ideal MHD, no radiation transfer  $\rightarrow$  advection dominated accretion flows (ADAF)
- initial conditions: large thick torus up to 500M (Witzany & Jefremov, 2018) + poloidal magnetic field  $\Rightarrow$  MRI
- perturber added into evolved torus (quasistationary state)
- stellar structure not considered  $\rightarrow$  rigid body
- no feedback from the accretion flow on the star trajectory  $\rightarrow$  motion along geodesics (Kerr background) or computation of GW-driven inspiral
- gas inside the perturber volume (influence radius  $\mathcal{R}$ ) is forced to move with it
- we are looking at the properties of the perturbed gas



$$\gamma_{\text{threshold}} = 1.02 \Leftrightarrow v > 0.2c, \text{ orbit: } 10 - 14.7M, e = 0.19, i = 65.5^\circ, P_r = 370M, P_\theta = 273M, P_\phi = 270M$$

- no significant signal in the accretion rate
- outflow launched by the secondary (measured at  $r = 100r_g$  in four velocity bins):



orbit:

$$r \in (10, 14.7)M$$

$$e = 0.19$$

$$i = 65.5^\circ$$

$$P_r = 370M$$

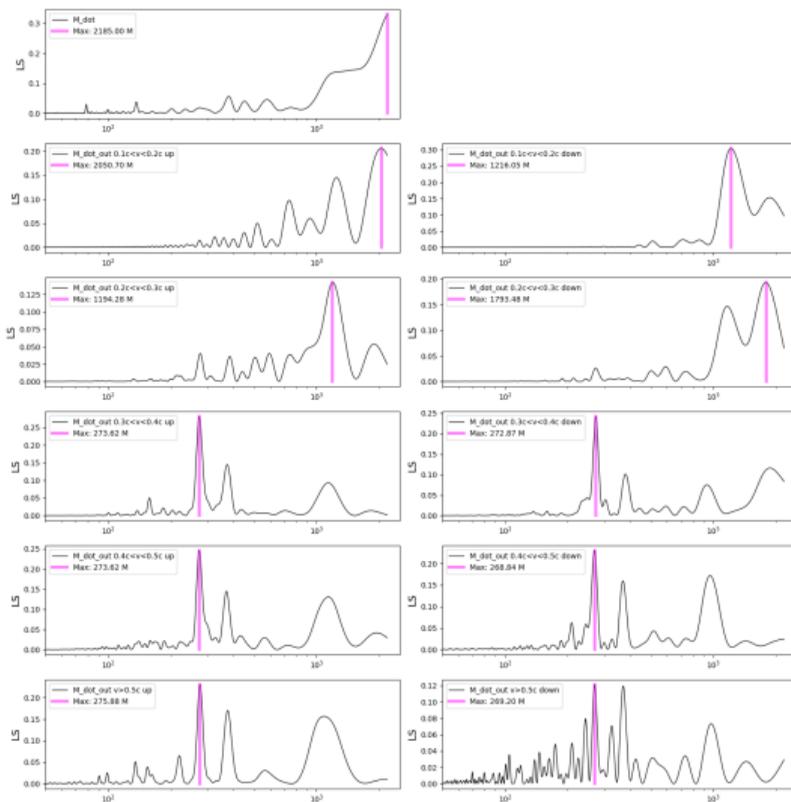
$$P_\theta = 273M$$

$$P_\phi = 270M$$

$$\mathcal{R} = 2M$$

- Good model to explain ASSAN-20qc: no modulation in continuum, strong signal in outflow band - corresponds to blue-shifted absorption line OVIII ( $\sim 0.7\text{keV}$ )

# Lomb-Scargle periodograms

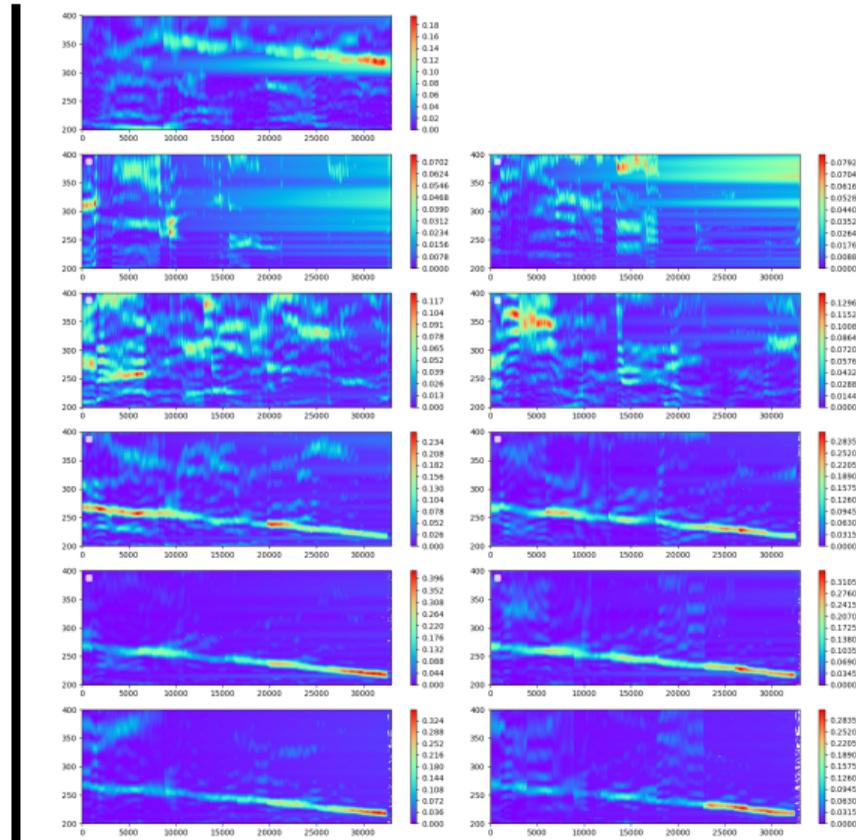
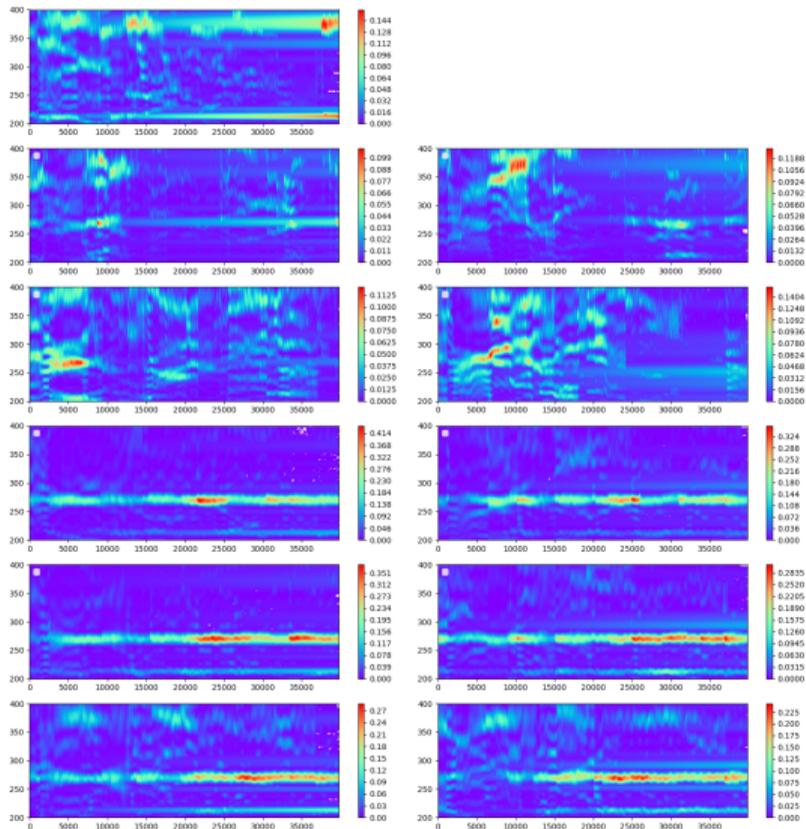

 $\dot{M}$ 
 $\dot{M}_{\text{out}}$ 
 $0.1c < v < 0.2c$ 
 $0.2c < v < 0.3c$ 
 $0.3c < v < 0.4c$ 
 $0.4c < v < 0.5c$ 
 $v > 0.5c$ 

orbit:  $10 - 14.7M$ ,  $e = 0.19$ ,  $i = 65.5^\circ$ ,  $P_r = 370M$ ,  $P_\theta = 273M$ ,  $P_\phi = 270M$ ,  $\mathcal{R} = 2M$

(2D run) Kerr orbit

versus

IMRI ( $m/M = 10^{-2}$ )



## Different flavours of RNTs in SMRI model

- RNTs show different features - QPE in X-rays, QPOuts, variability in UV/optical, TDEs
- Is there a common model for these system? And if yes, how to incorporate all these distinct features into one model?
- SMRI model offers a variety of realizations:
  - orbit of secondary - inclined or embedded in the disc - production of outflowing blobs
    - circular or elliptic - interchanging pattern of recurrence times, 1x or 2x per orbit
    - reaching close to inner edge of accretion flow - effect on accretion rate
  - size of secondary - strength of outflow compared with accretion rate
    - size of shock bubble (radiation), strength of density waves
  - nature of secondary - BH - able to quietly produce outflows (?)
    - contribution of the secondary accretion disc and jet – orientation matters
  - star - supply of matter (e.g. Roche lobe overflow)
    - shocks in stellar atmosphere - source of radiation
    - reaching towards (2x) tidal radius? - (p)TDE signature
  - NS - boundary layer and strong magnetic field - anything can happen here 😊

- GRMHD simulations of repetitive star transits through ADAF:
  - ingoing/outgoing density waves in the accretion flow
  - outgoing relativistic blobs along the torus/funnel boundary
  - influence on the matter distribution
  - changes of the accretion rate (drops and peaks) - but rather small effect in 3D
  - quasiperiodic features in outflowing rate – may be connected with orbital period
- broad discussion in **Suková+21, ApJ, 917, 43**
- ASASSN-20qc – QPOuts from LLAGN (**Pasham+24, Sci. Adv. 10 (13)**)  
- outflow strength  $\rightarrow \mathcal{R} \sim 3M \Rightarrow$  **IMBH** ( $10^3 - 10^4 M_{\odot}$ )!
- possible model for ultra-long QPE Swift J0230+28 (details on different models in **Guolo+24, Nat. Astron. 8 (3)**)
- shows possible observable EM traces of SMRI  
 $\Rightarrow$  multimessenger astronomy for SMRI, help to observe SMRI with LISA (?)

**Thank you for your attention!**