Stellar/AGN photometric astronomy in the era of SDSS Phase V
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AGN: the most powerful variable sources in the Universe

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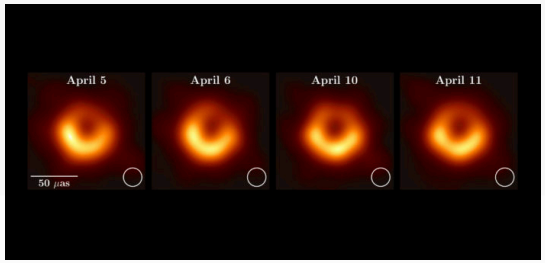
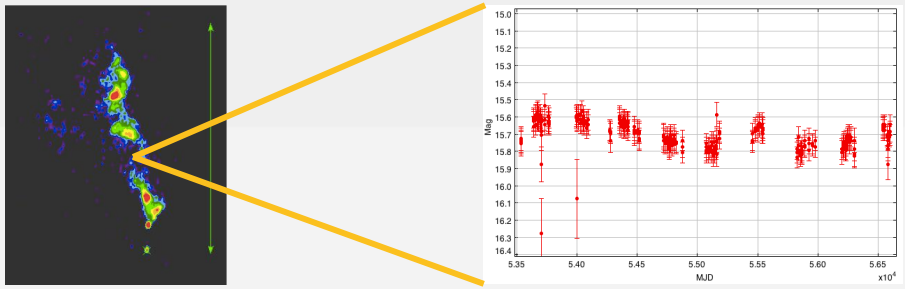


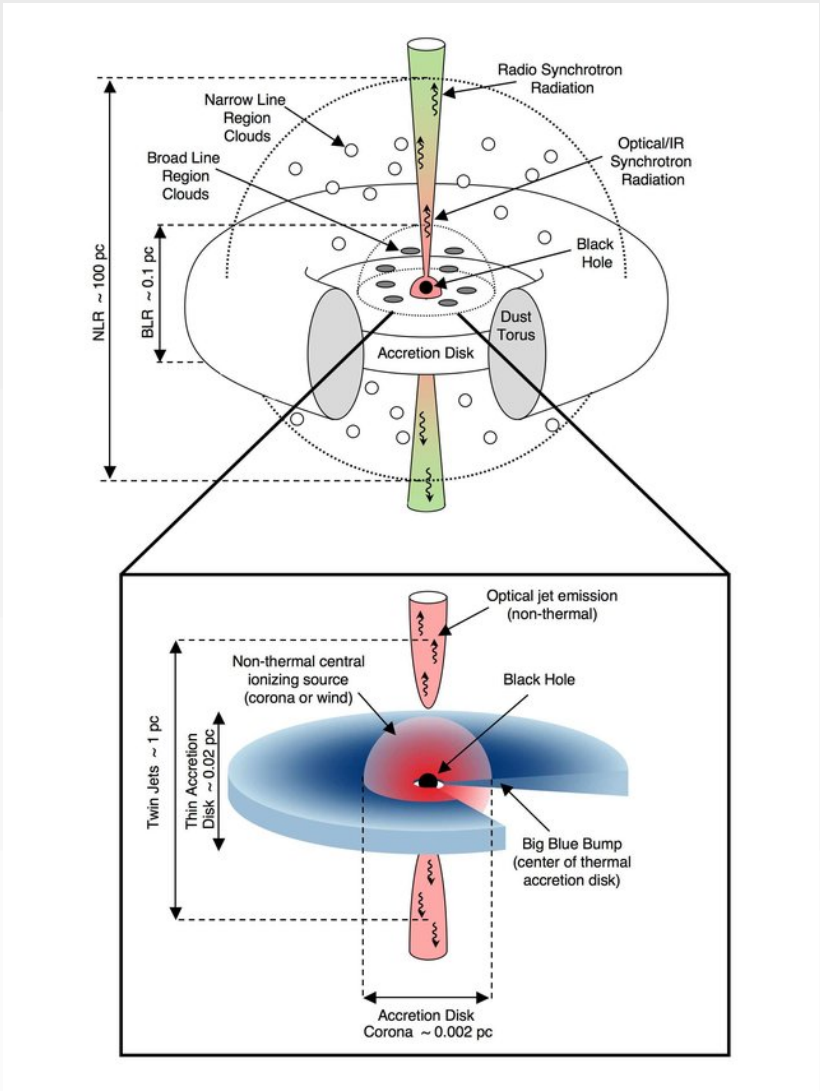
(EHT Collaboration)

Quasar variability

- First quasar identified 3C 48 – most striking feature was that the optical radiation varied

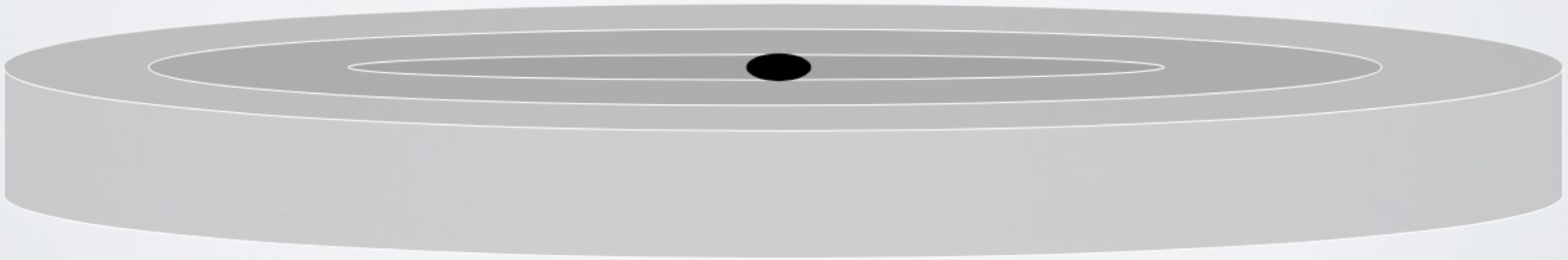


- Physical origin of photometric variability in optical/UV is unclear:
  - Instabilities in the accretion disk
  - Supernovae
  - Microlensing
  - Stellar collisions
  - Thermal fluctuations from magnetic turbulence



Physical timescales in AGN

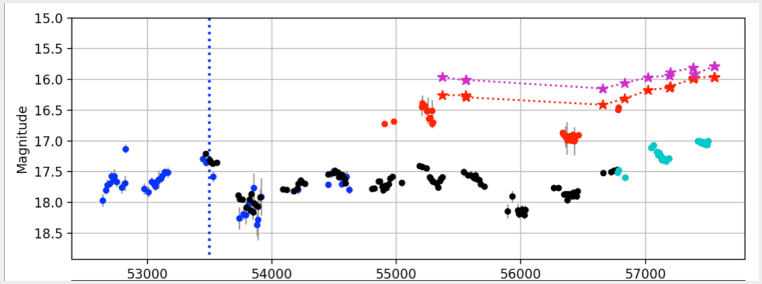
	Accretion Disk	Broad Line Region
Viscous ("radial drift")	10,000 yr	-
Light travel	Hours	Days
Dynamical	Days	Years
Thermal	Days-years	-

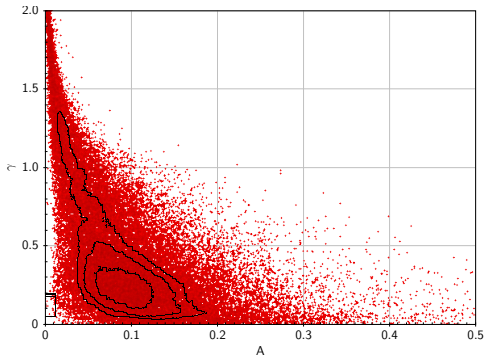


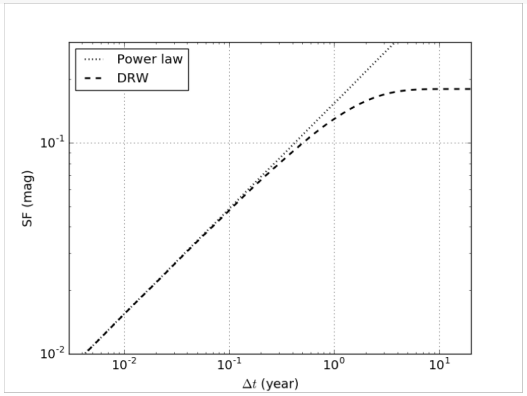
(C. MacLeod)

Describing quasar photometric variability

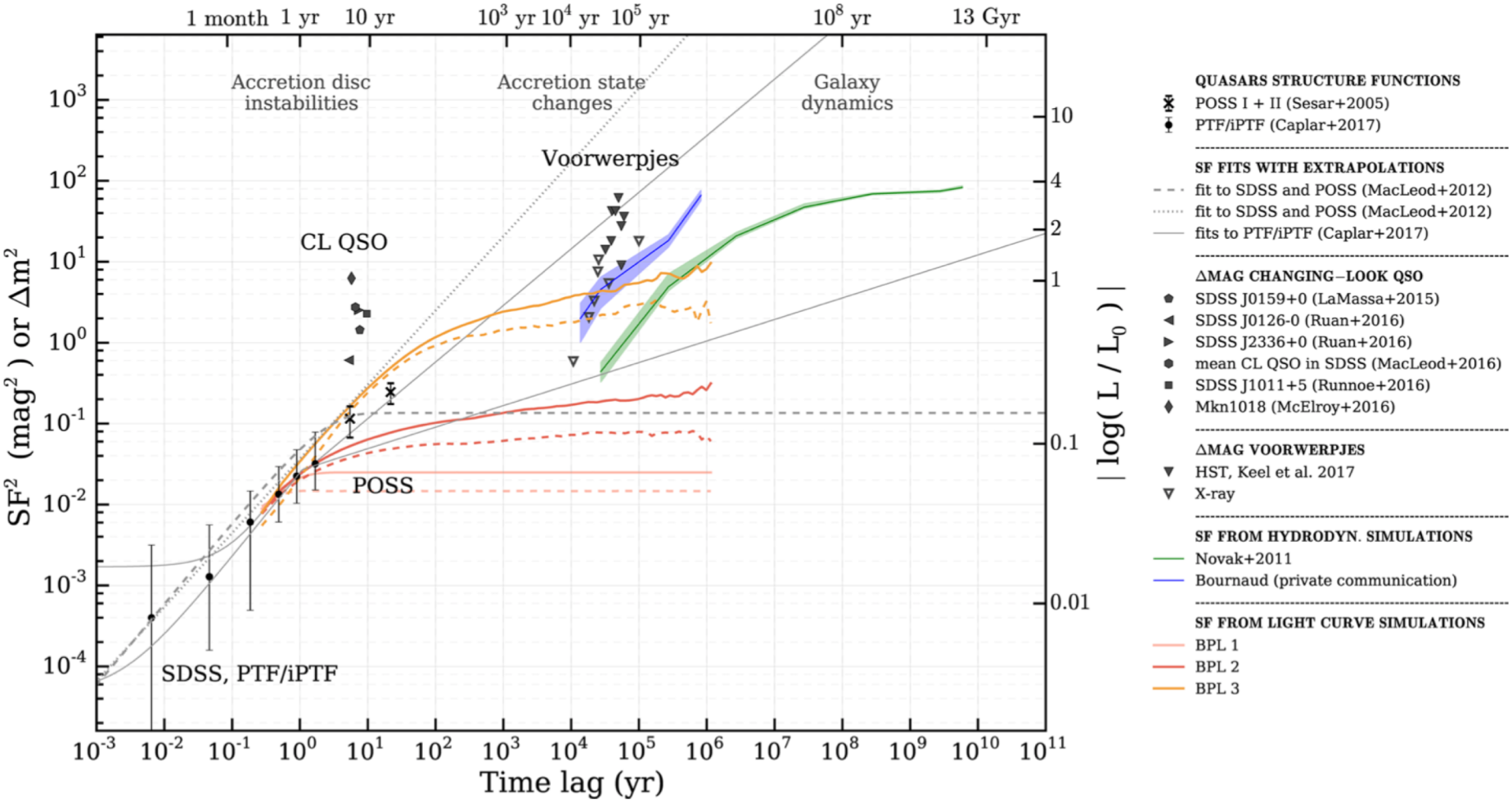
- $|\Delta m| > x$
  - DPOSS vs. SDSS (Stripe 82) vs. PS1
- Excess variability: χ^2
- Structure function
  - Variability amplitude as a function of the time lag between compared observations
  - Historic descriptor of variability and a variety of estimators
  - Not much information







Variability timescales

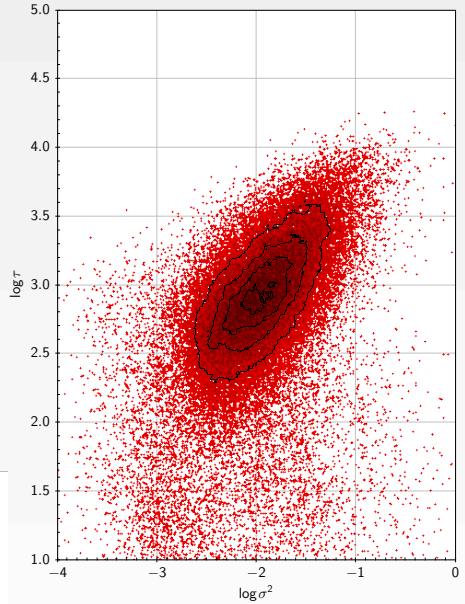


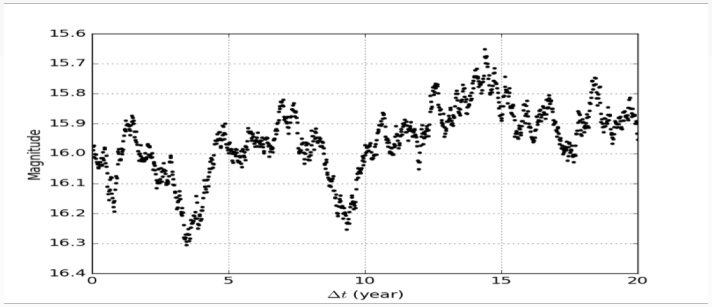
(L. Sartori)

Damped random walk (DRW/OU)

$$dX(t) = -\frac{1}{\tau}X(t)dt + \sigma\sqrt{dt}\varepsilon(t) + bdt \quad \tau,\sigma,t > 0$$

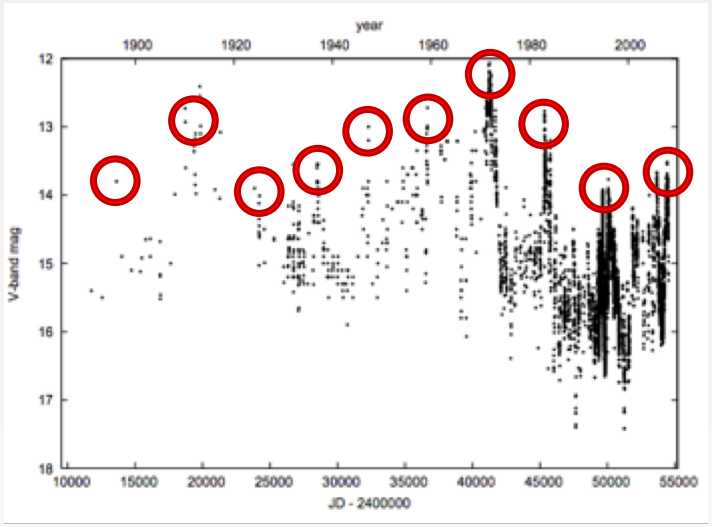
- Characterized by variability amplitude σ and timescale τ
- Basis for stochastic models of variability
- Deviations noted (e.g., Mushotzky 2011, Zu et al. 2013, Graham et al. 2014)
- Degenerate model – can be best fit for a non-DRW process (Kozlowski 2016)
- Need a baseline $\gtrsim 10\tau$ to recover τ

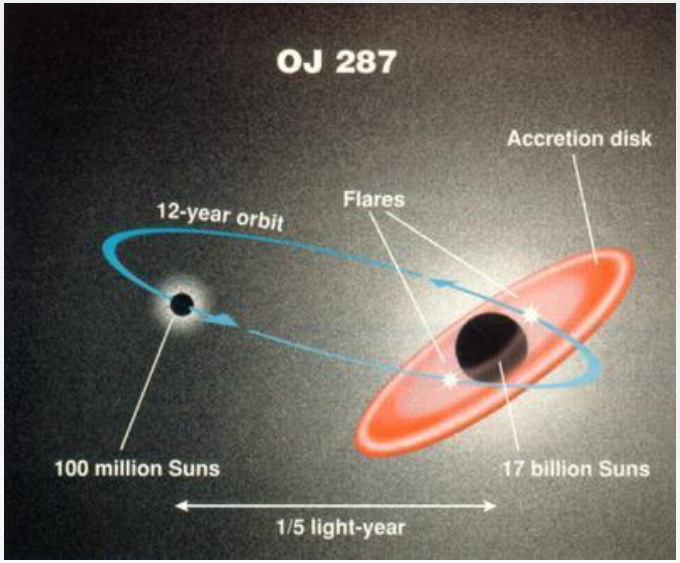


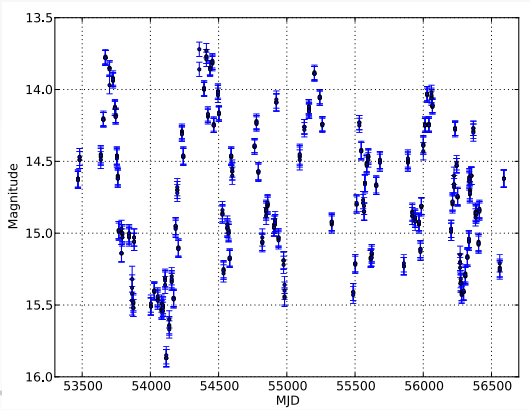


Are there periodic quasars?

- OJ 287 shows a pair of outburst peaks every 12.2 years for at least the last century







The physics of a SMBH binary merger

Stage I (> 1pc)

- SMBHs dissipate angular momentum through dynamical friction with surrounding stars

Stage II (0.01 – 1pc)

- Stalled phase due to stellar depletion (~10^6 – 10^7 yrs)

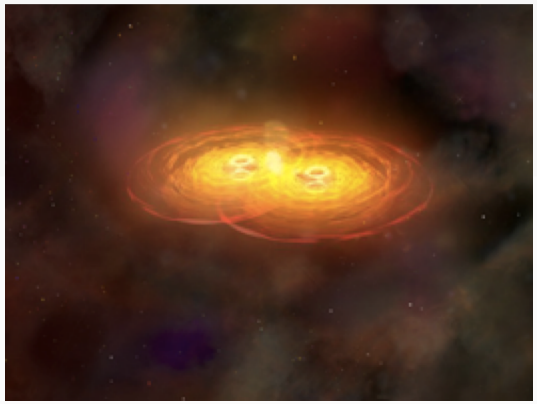
Stage III (< 0.01pc)

- Orbital angular momentum lost by gravitational radiation

Stage IV

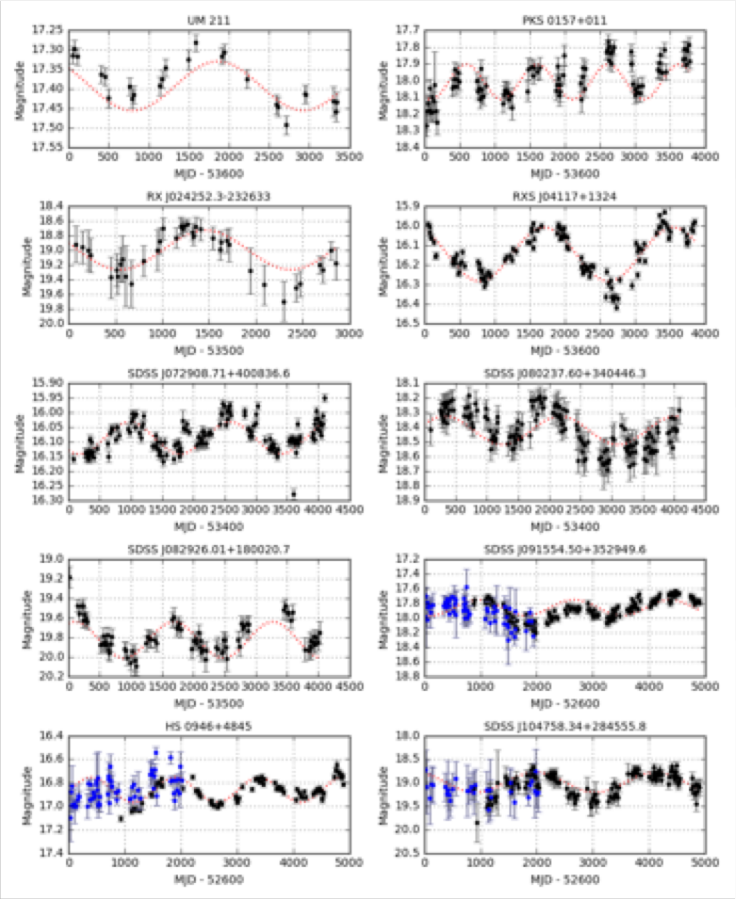
- Coalescence and recoil

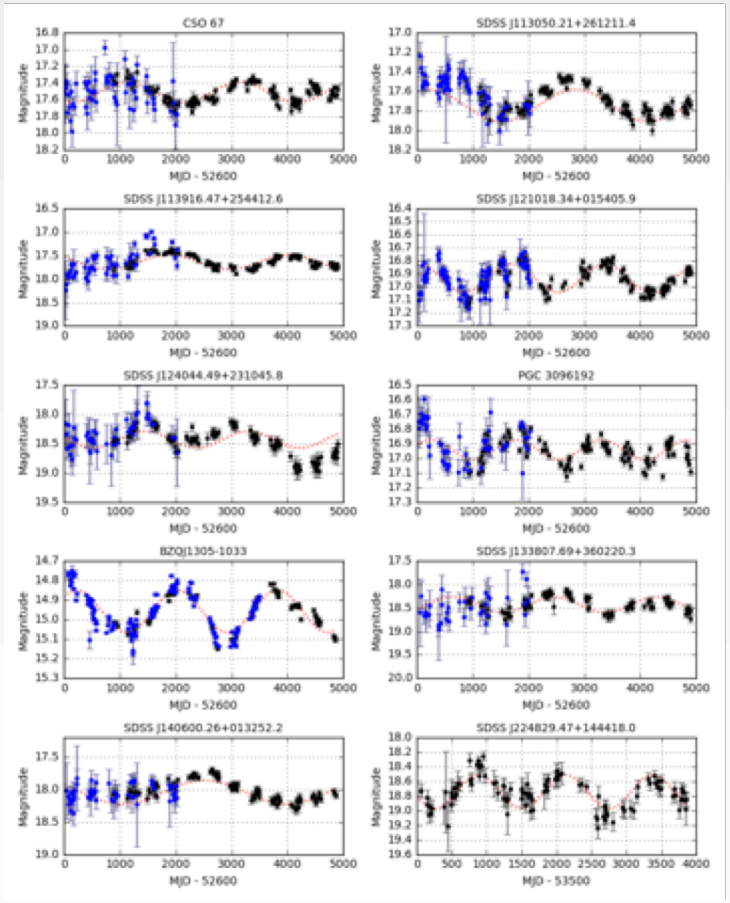
- The “final parsec” problem
- Subparsec systems are not resolvable
- PTA and potential LISA sources



Periodic quasars

- Graham et al. (2015a, b) identified 111 quasars with statistically significant periodicity (over stochastic models)



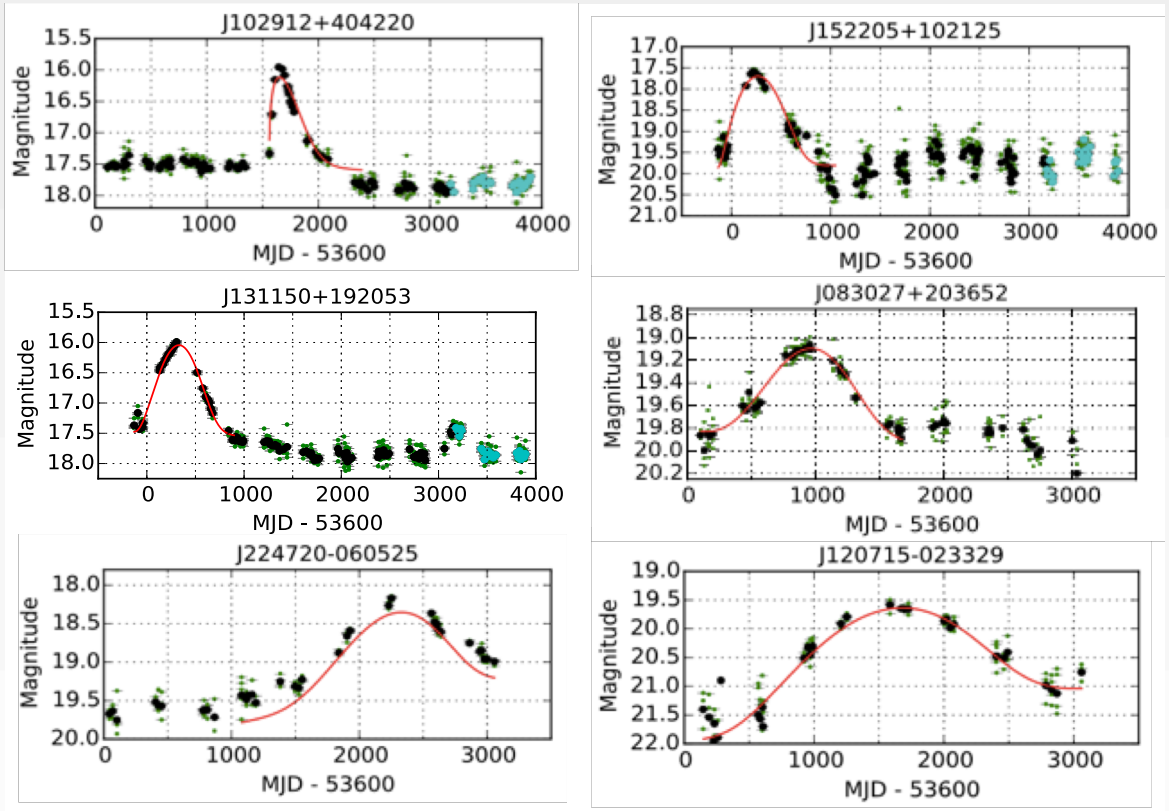


(Updated data Graham et al., in prep)

Major flares

A sample of 51 AGN with a significant flaring event inconsistent with DRW behavior

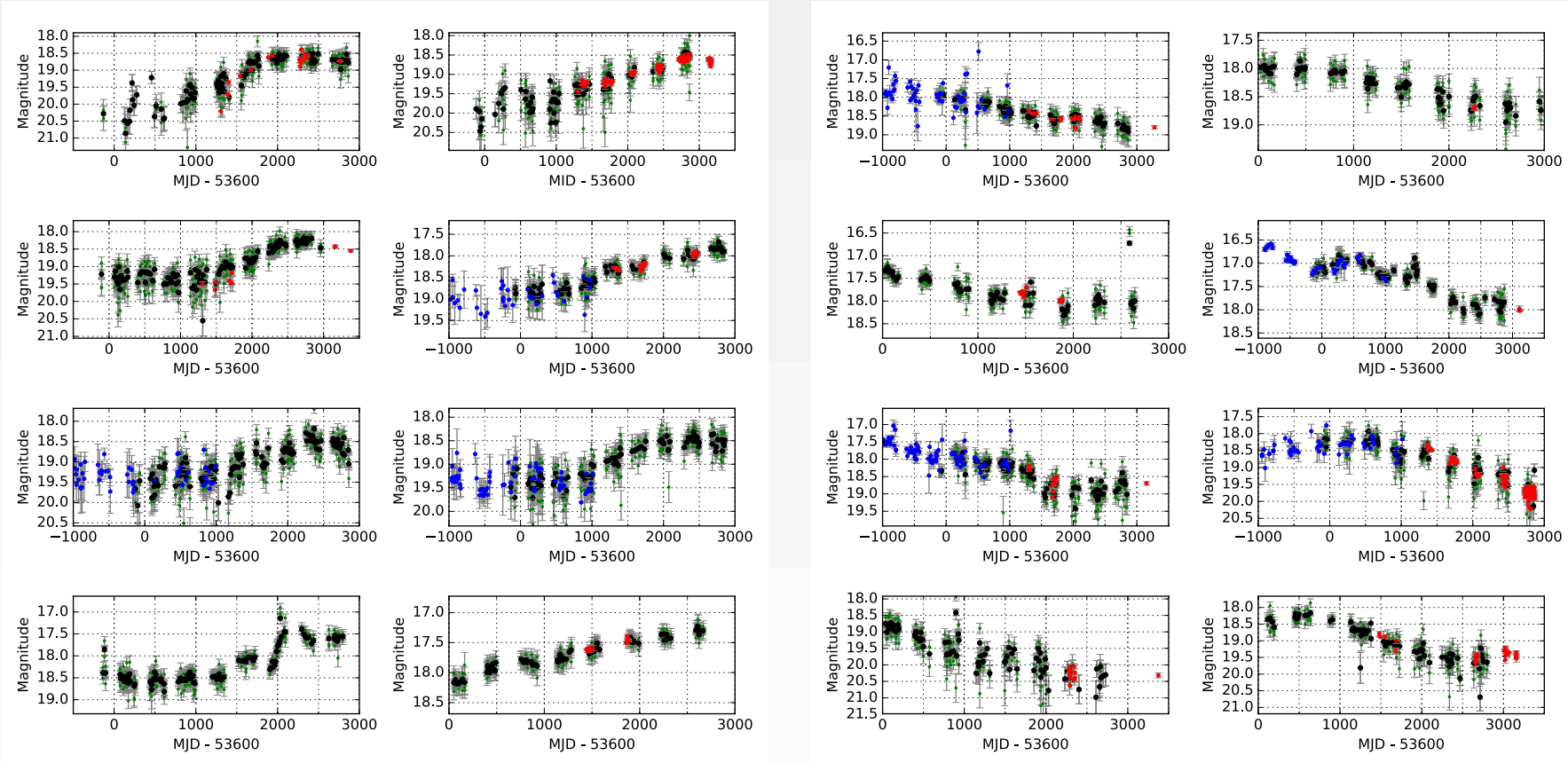
- Microlensing
- SLSN-II
- Slow TDEs
- SMBH merger in disk



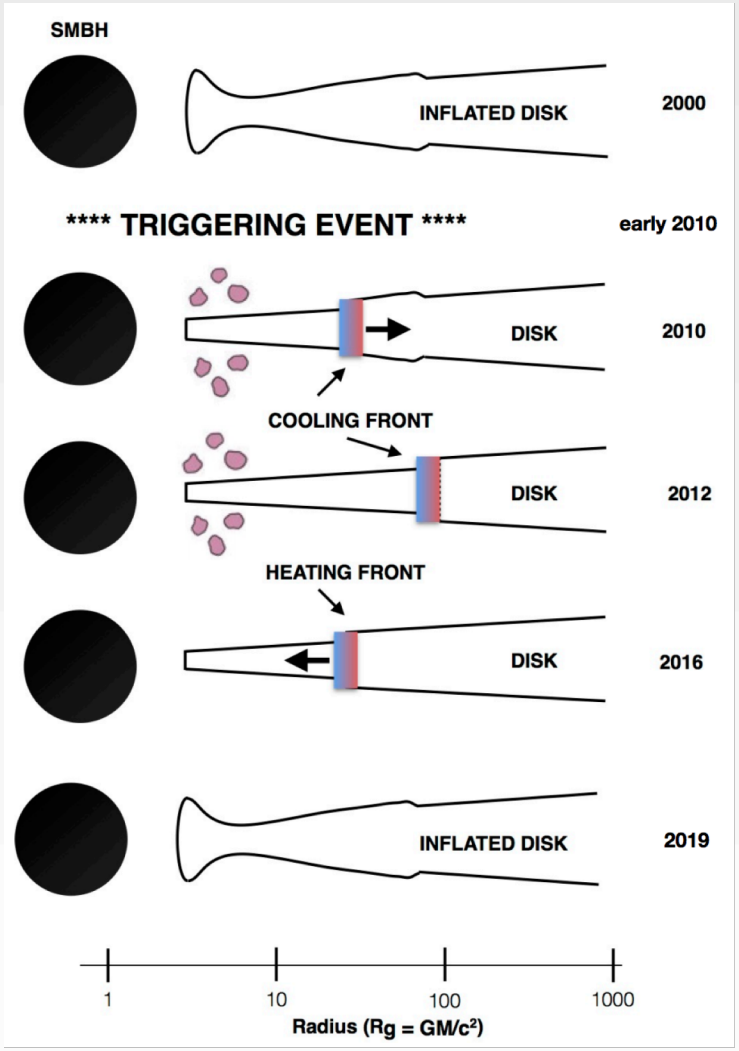
(Graham et al. 2017)

Changing look/state quasars

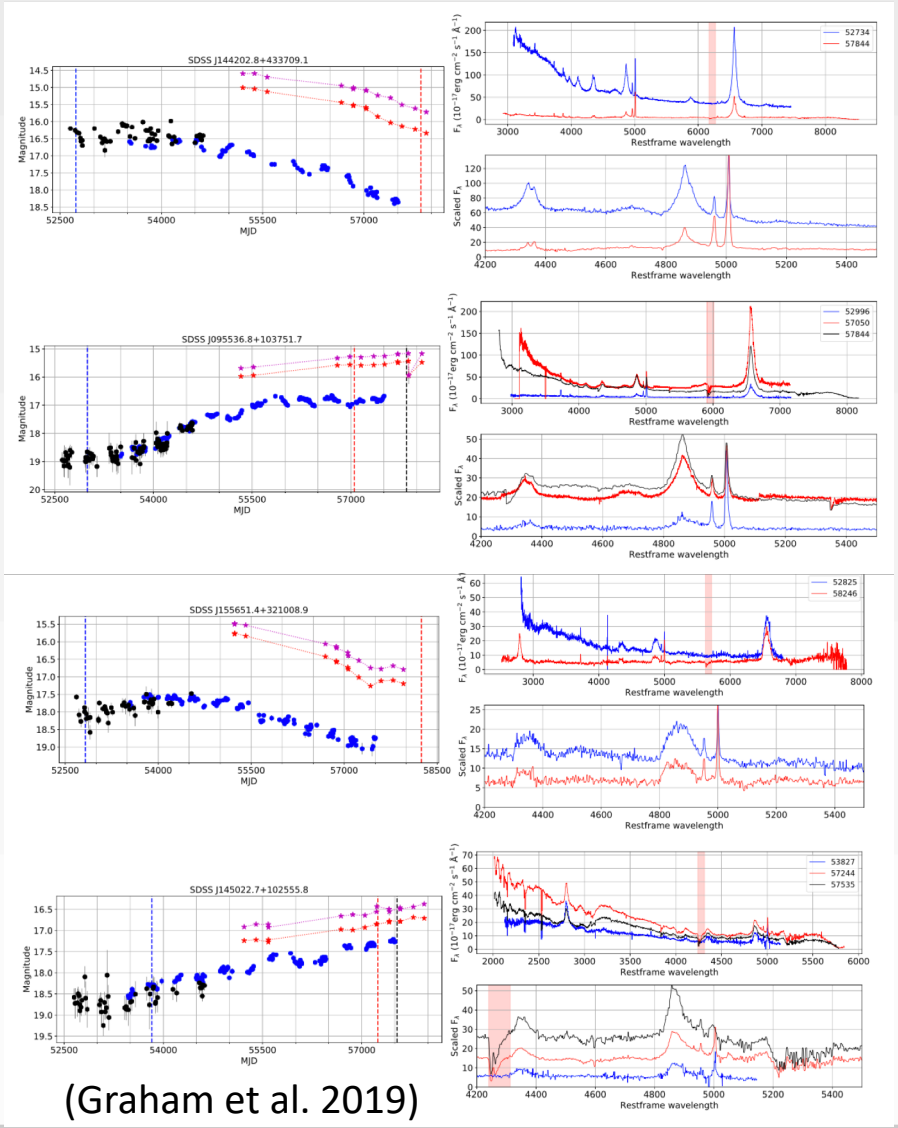
- Characterized by a smooth slow photometric rise/decline of ~1 mag over several years and some degree of spectral variability



Propagating fronts as an explanation



(Ross et al. 2018)



(Graham et al. 2019)

Variability, color, and zero motion-selected catalogs

- Feature set:
  - Variability characterizations
  - WISE colors (W1, W2, W1 – W2)
  - GAIA proper motions
- Stacking framework for ensemble classification