Tidal disruption events

Karri Koljonen - 23/10/2023 - Astrophysics II

My path to Trondheim

2008 2009 2014 2016 Now

Research topics: Accreting compact objects (X-ray binaries, active galactic nuclei, tidal disruption events), relativistic outflows from accreting compact objects, multiwavelength astronomical observations, data analysis methods

Current project: LOoking for supermassiVE NEutron STars (PI: Manuel Linares)

Contact: karri.koljonen@ntnu.no

Tidal disruption events

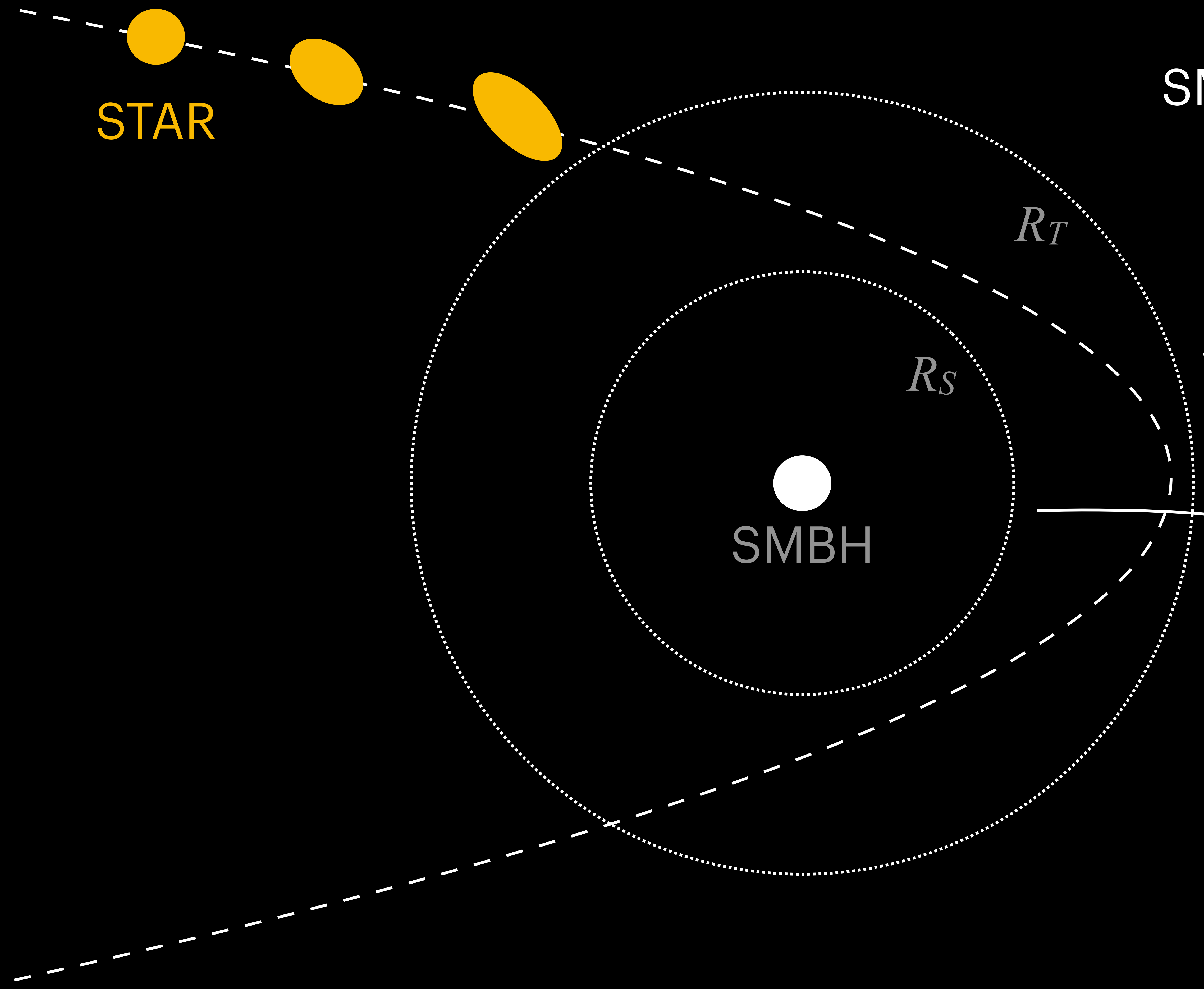
The story of an unlucky star

Tidal force:

$$F_t = \frac{2GM_{BH}R_*}{r^3}$$

Stellar gravity:

$$F_* = \frac{GM_*}{R_*^2}$$



SMBH tidal forces > binding forces of the star

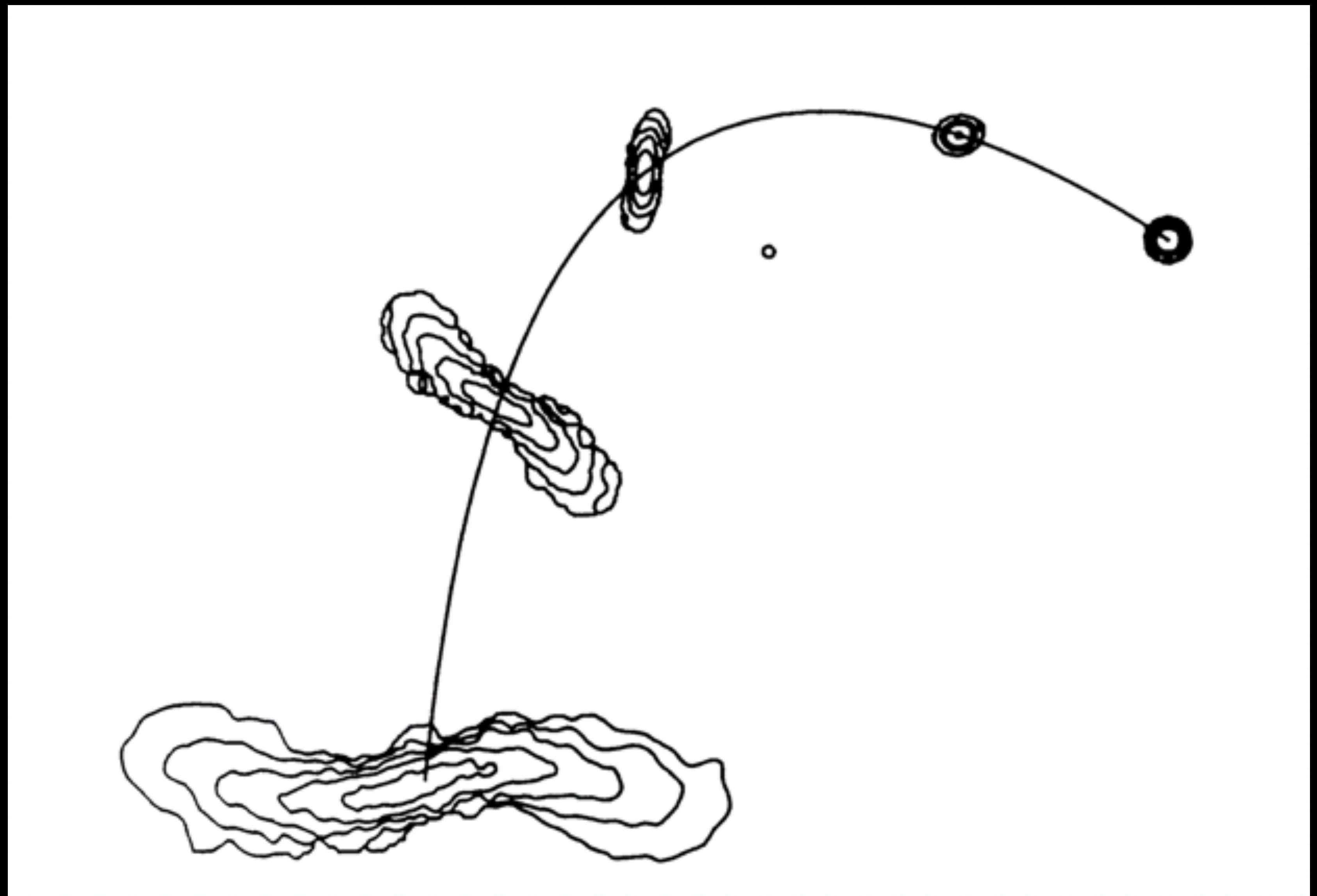
$$R_T = \left(\frac{M_{BH}}{M_*}\right)^{1/3} R_*$$

Event horizon

$$R_S = 2GM_{BH}/c^2$$

$$R_T \gtrsim R_S \,, \text{for } M_{BH} \lesssim 10^8\, M_\odot$$

Tidal disruption events
The story of an unlucky star



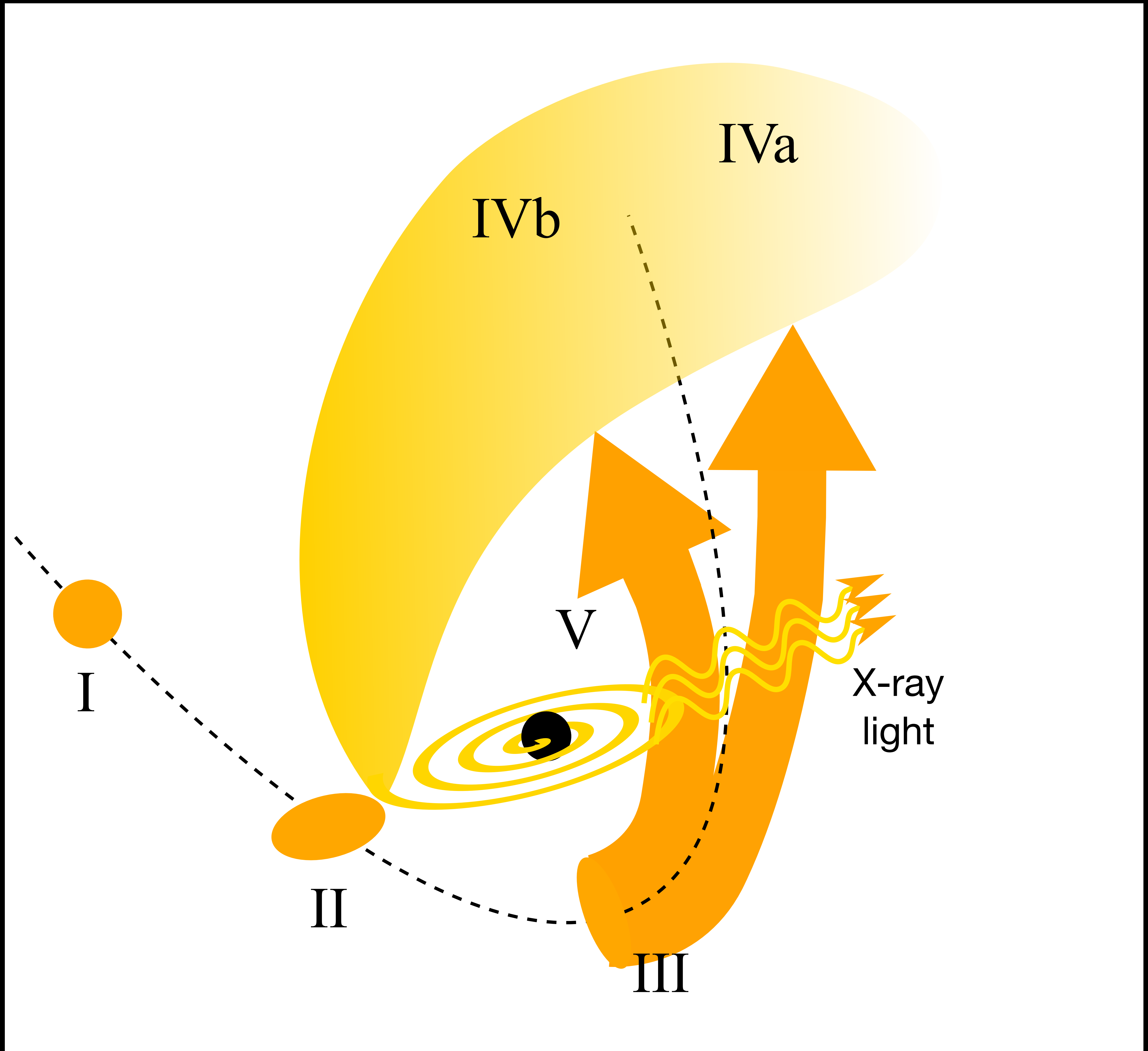
Evans & Kochanek (1989)

Credit: NASA's Goddard Space Flight Center/Chris Smith (USRA/GESTAR)

Tidal disruption events

The story of an unlucky star

- Assuming parabolic orbit for the star (total orbital energy is zero)
- Velocity asymmetries at the pericenter: half of the disrupted matter have bound orbits while the other half has unbound orbits
- The bound matter eventually returns towards the black hole



Tidal disruption events

The story of an unlucky star

- What is the infall rate of the bound matter?

$$\frac{dm}{dt} = \frac{dm}{de}\frac{de}{dt}$$

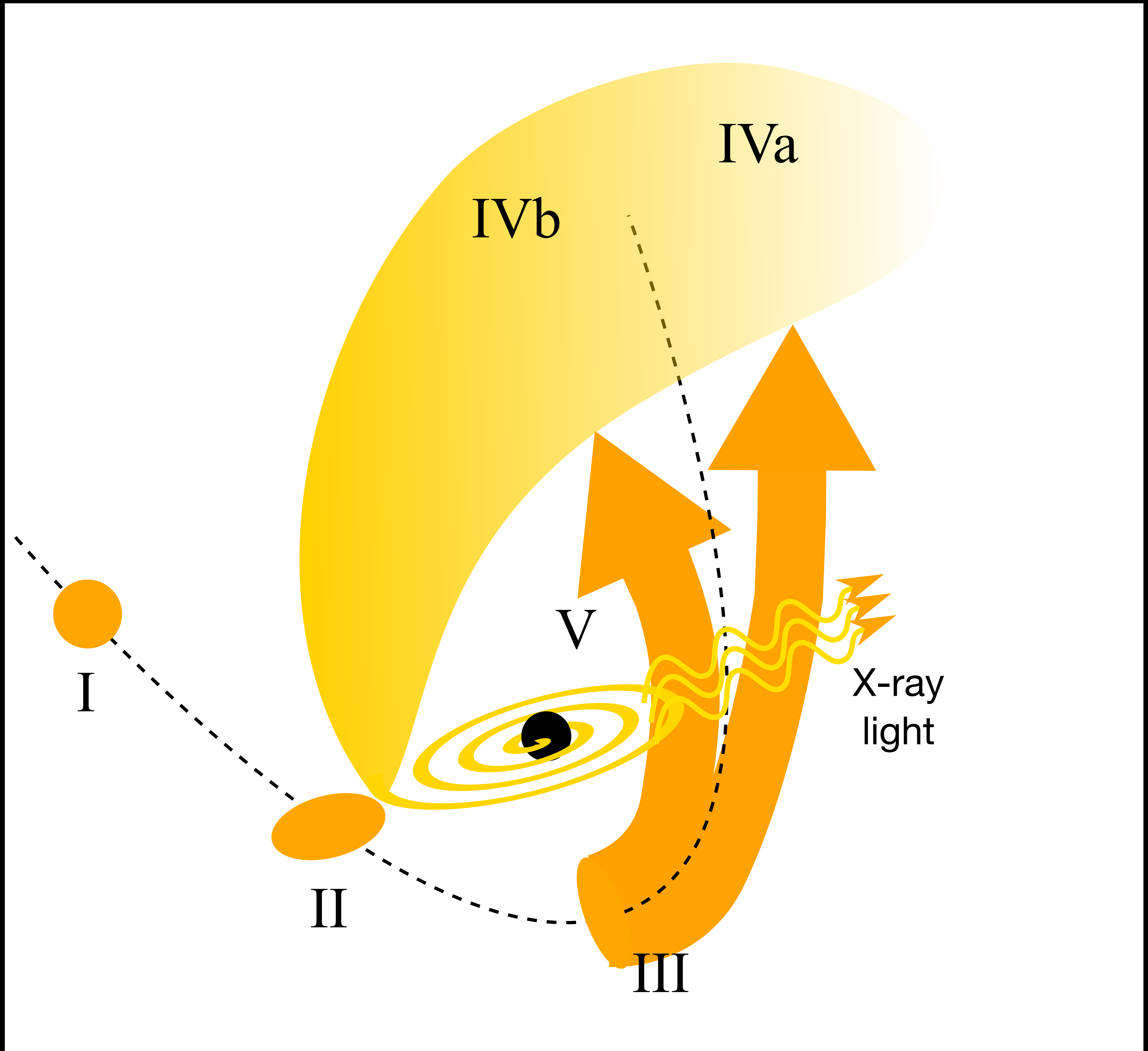
- Specific energy of a Keplerian orbit:

$$e = -\frac{GM}{2a} \propto t^{-2/3}$$

$$t = 2\pi\left(\frac{a^3}{GM}\right)^{1/2} \Longrightarrow a = \left[GM\left(\frac{t}{2\pi}\right)^2\right]^{1/3} \propto t^{2/3}$$

- Assuming flat distribution of mass with specific energy ($dm/de = \text{constant}$):

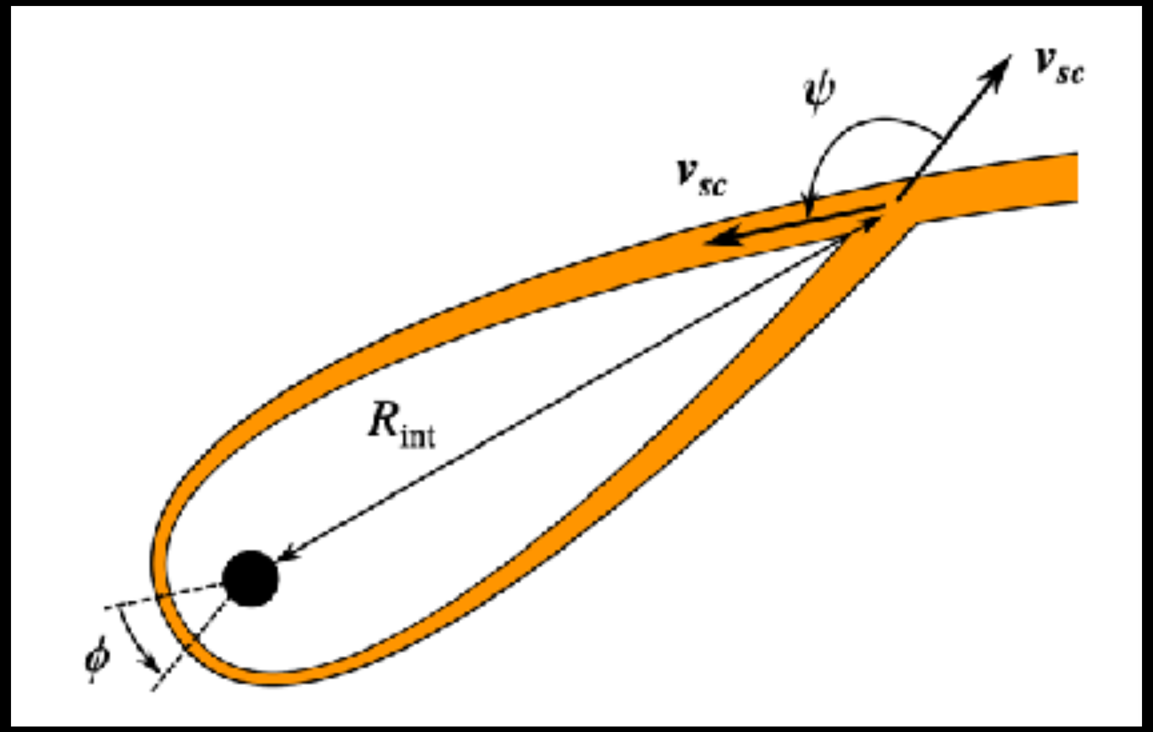
$$\boxed{\frac{dm}{dt} \propto t^{-5/3}}$$

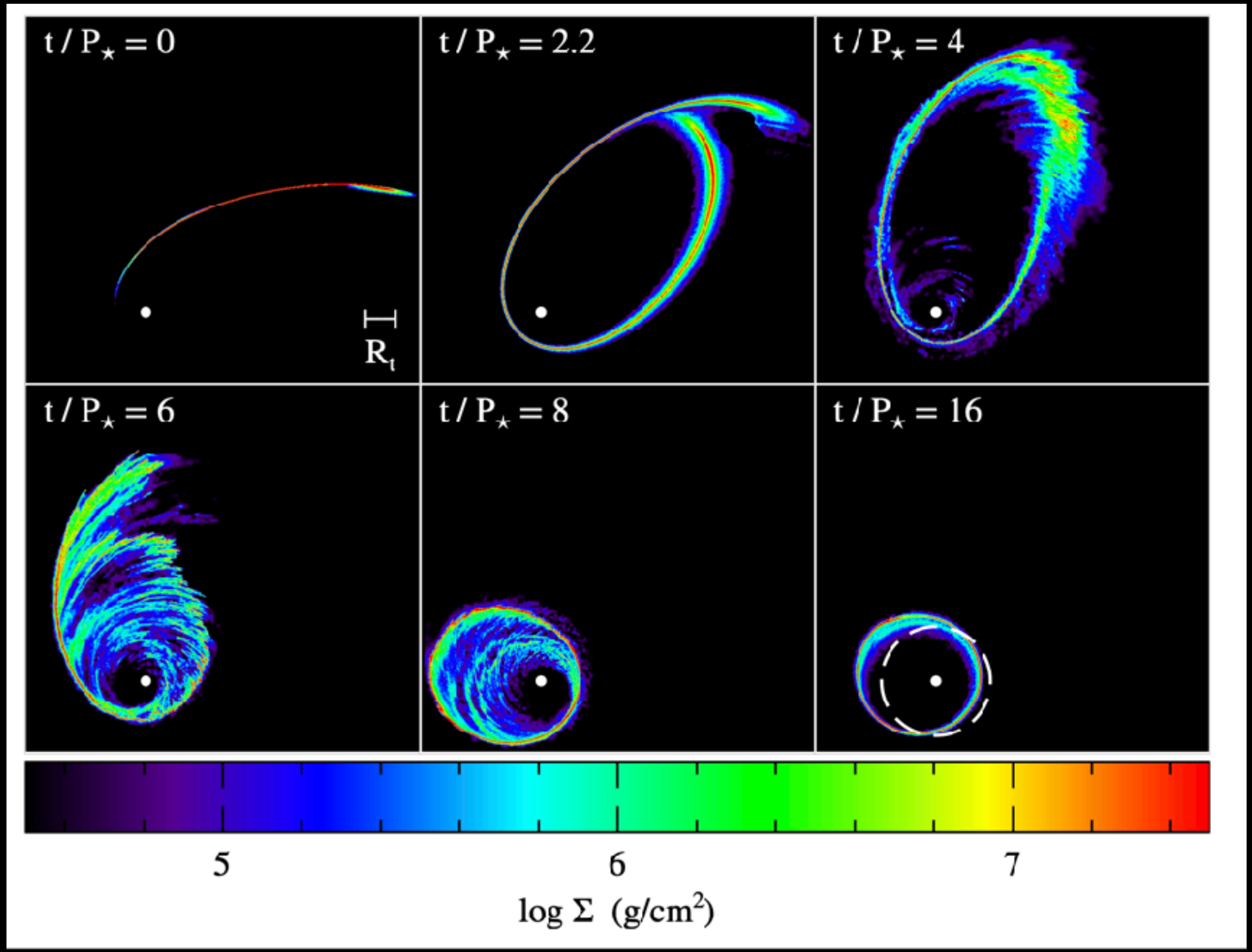


Tidal disruption events

The formation of an accretion disk

- After disruption the stellar matter evolves into an elongated structure/stream.
- How this stellar stream evolves and forms an accretion disk around the black hole is a much-discussed topic:
  - Energy dissipation through shocks:
    - Compression shock at the pericenter.
    - Stream collision through relativistic apsidal precession.

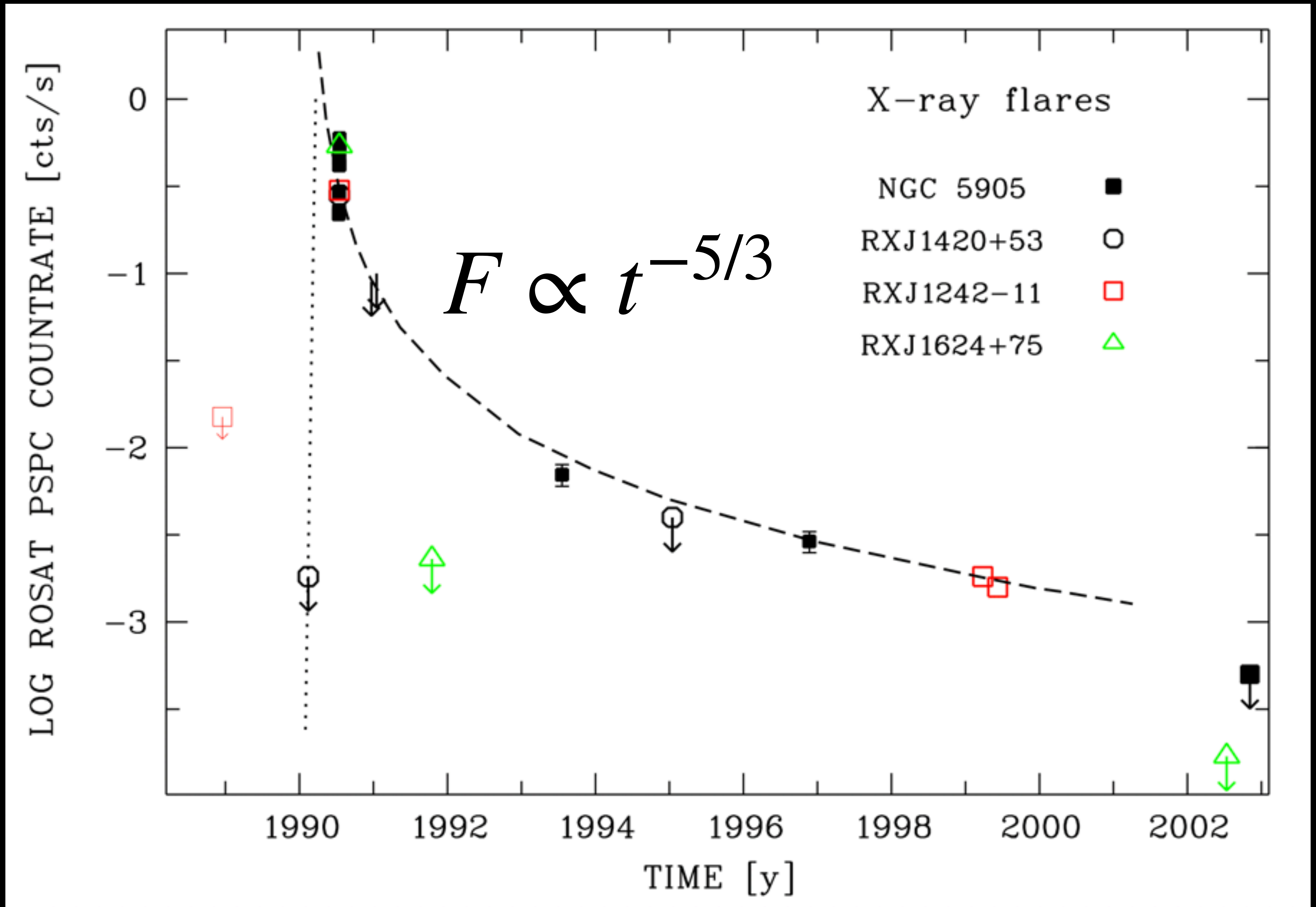




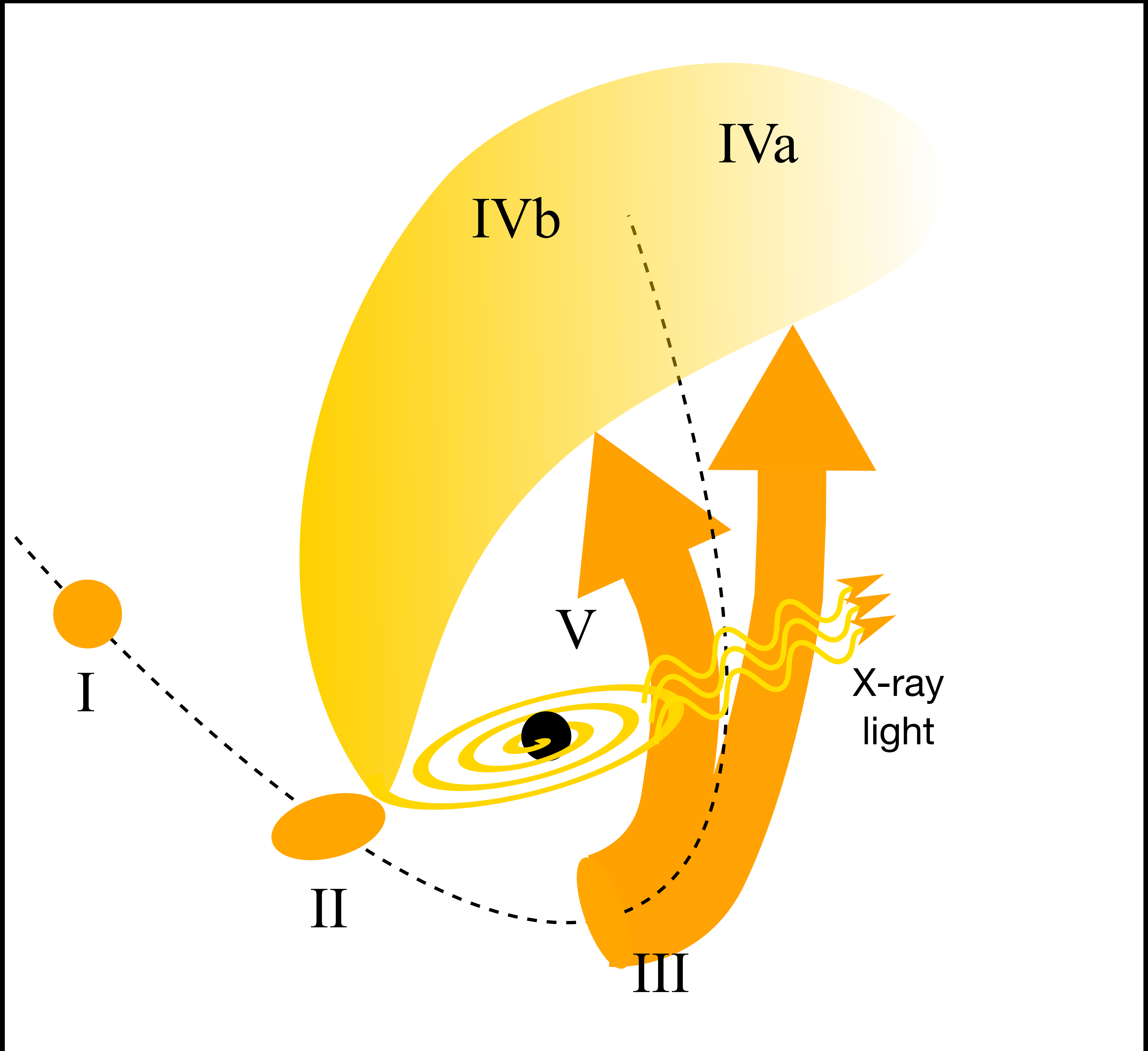
Bonnerot 2017

Tidal disruption events

The formation of an accretion disk



Komossa & Bade 1999; Komossa 2004



Tidal disruption events

How luminous the TDEs can get?

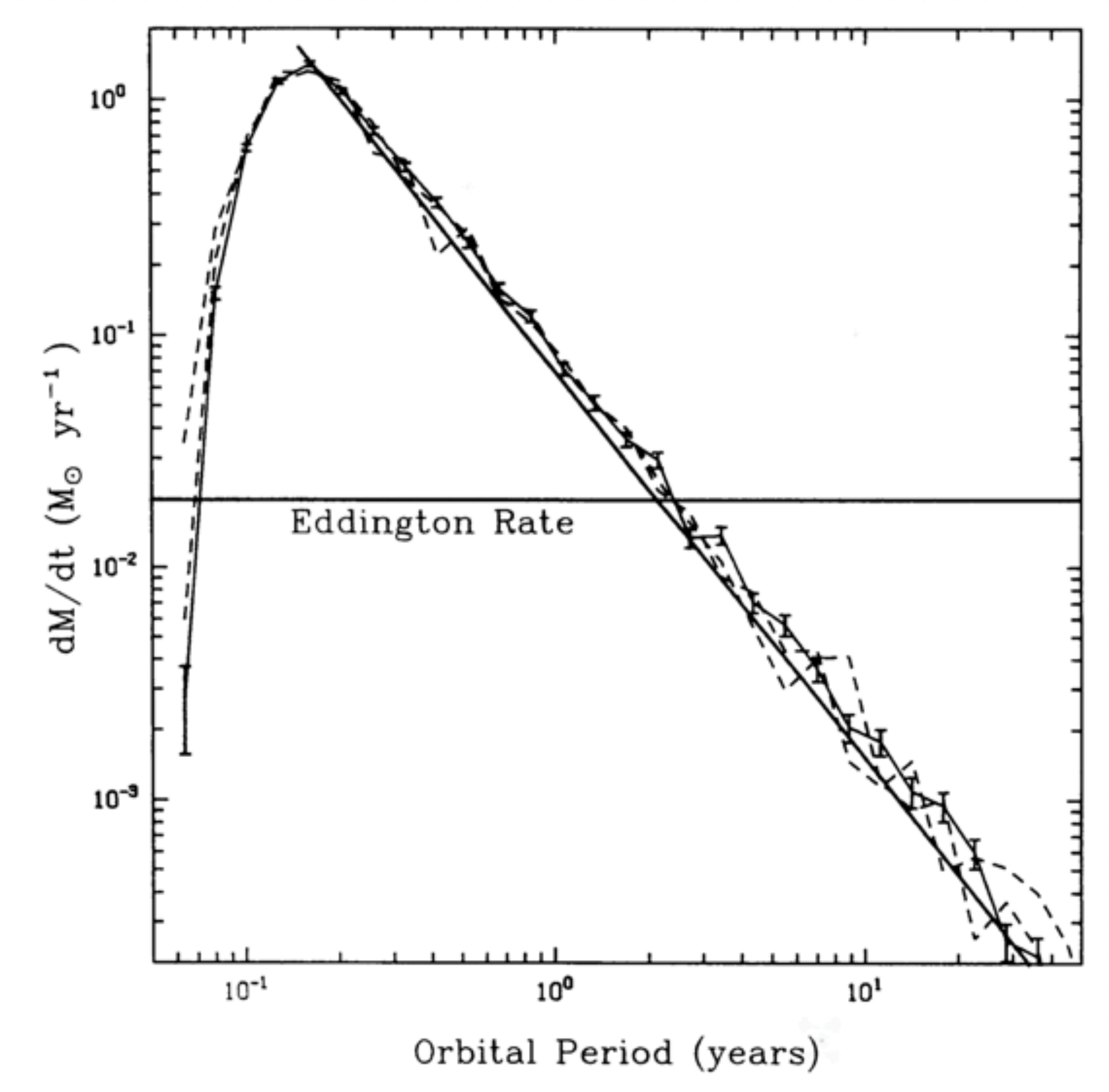
- Peak mass accretion rate according to simulations by Evans & Kochanek (1989):

$$\sim 1.4\left(\frac{R_p}{R_t}\right)^{-3}\left(\frac{R_*}{R_\odot}\right)^{-3/2}\left(\frac{M_*}{M_\odot}\right)^{2}\left(\frac{M_{BH}}{10^6 M_\odot}\right)^{-2/3} M_\odot\,\mathrm{year}^{-1}$$

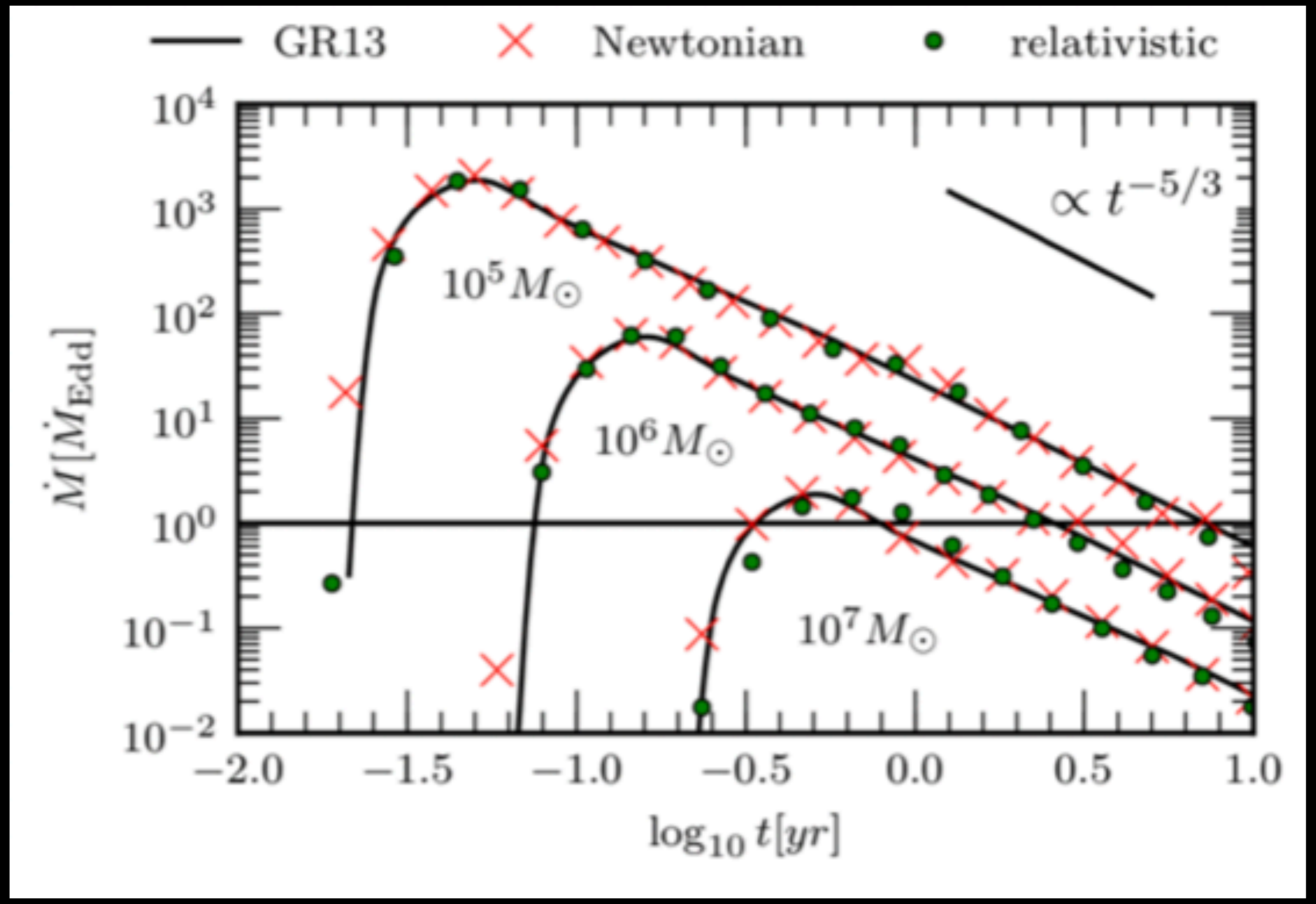
- In terms of Eddington luminosity (hydrostatic equilibrium):

$$(dm/dt)_{\mathrm{Edd}} = \frac{L_{\mathrm{Edd}}}{\epsilon c^2} \qquad L_{\mathrm{Edd}} = \frac{4\pi G M_{BH} c}{\kappa} \approx 10^{38}\left(\frac{M_{BH}}{M_\odot}\right)\mathrm{erg\,s^{-1}}$$

$$(dm/dt)_{\mathrm{Edd}} \approx 10^{-2}\left(\frac{M_{BH}}{10^6\,M_\odot}\right) M_\odot\,\mathrm{year}^{-1}$$



Evans & Kochanek 1989



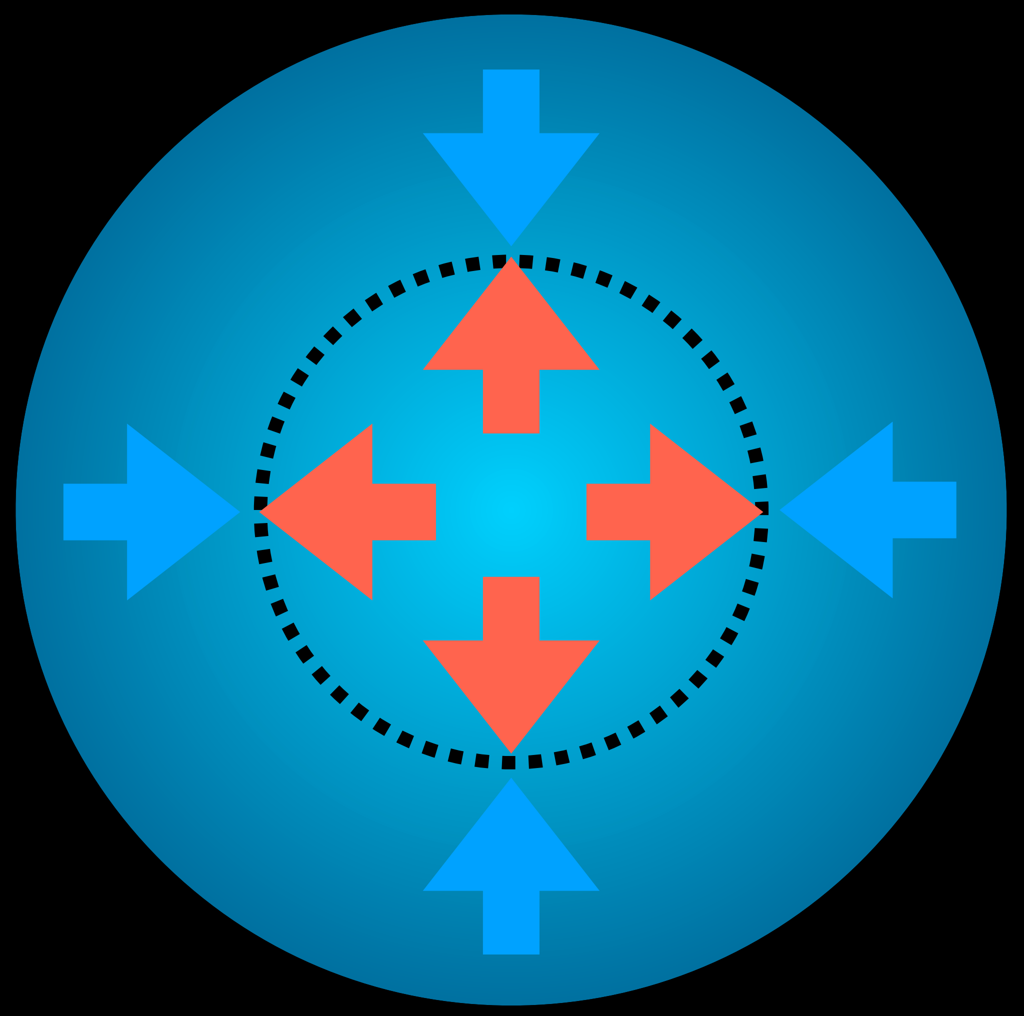
Stone et al. 2015

Tidal disruption events

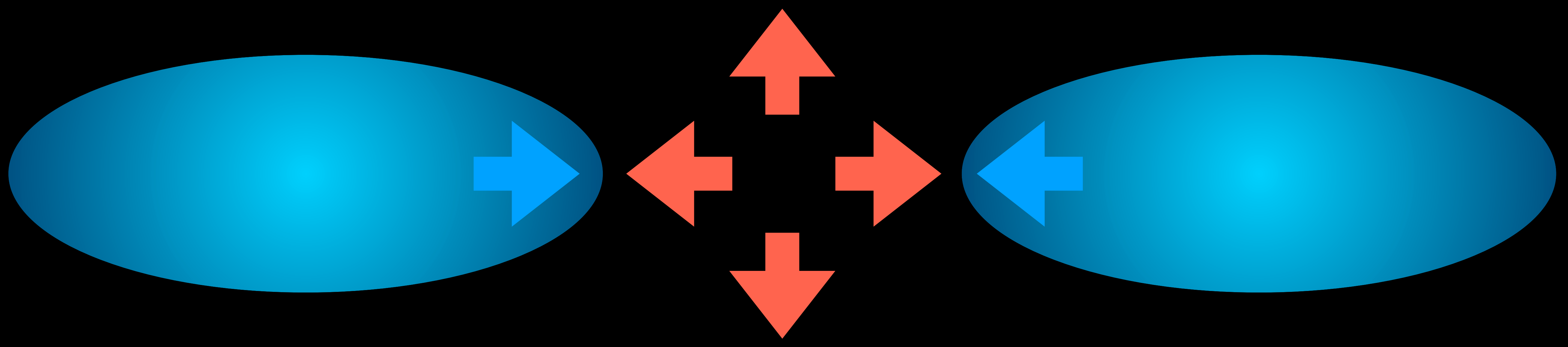
Super-Edddington accretion

- How can TDEs accrete matter at so high accretion rates?

Star



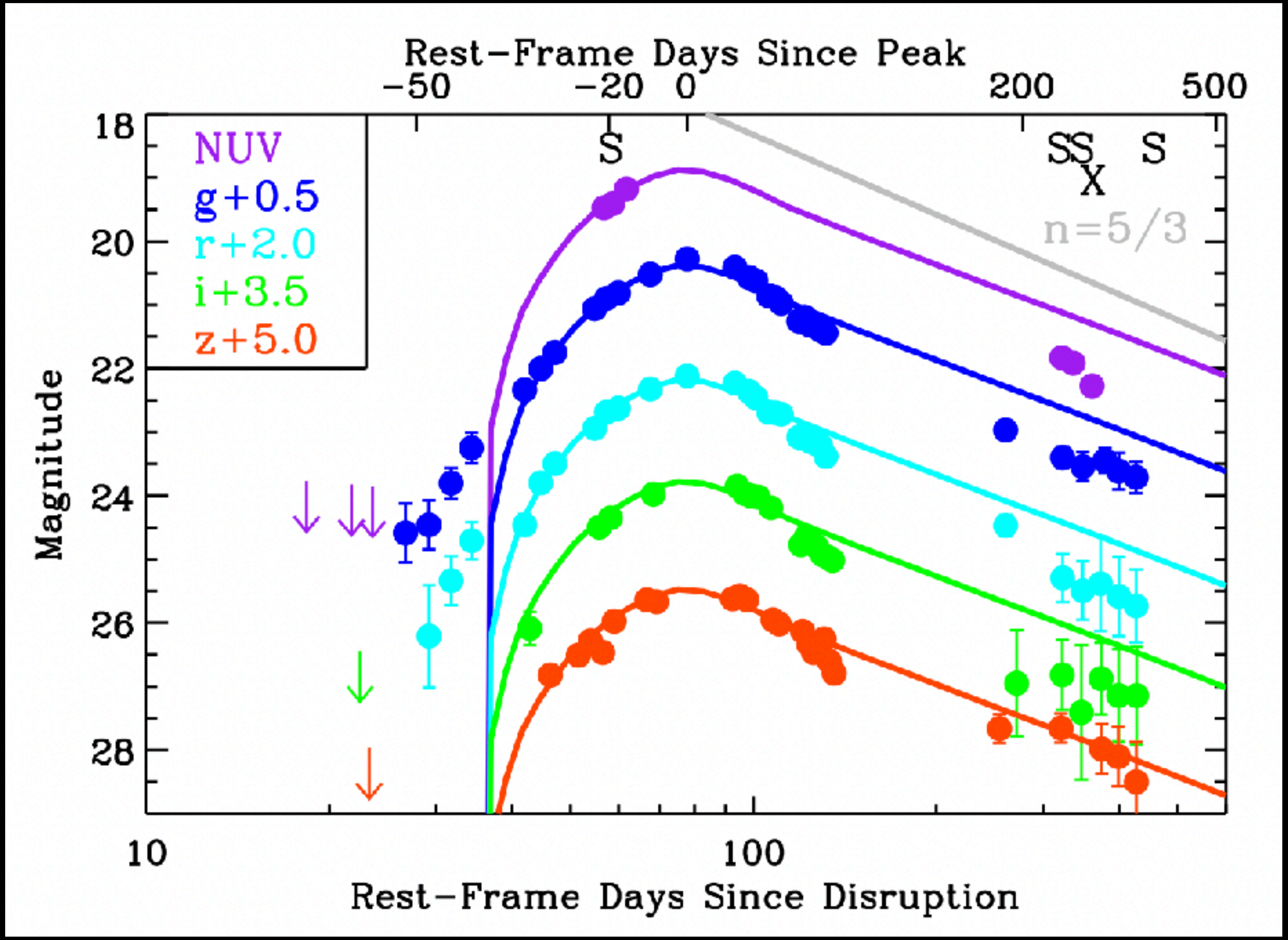
Accretion disk



Tidal disruption events

Optical TDEs

- Surprising "optical" TDE (Gezari+12)
- Located at galaxy centres
- Not as hot as accretion disk (~few 10^4 K)
- Two orders of magnitude larger radii (~10^{15} cm)

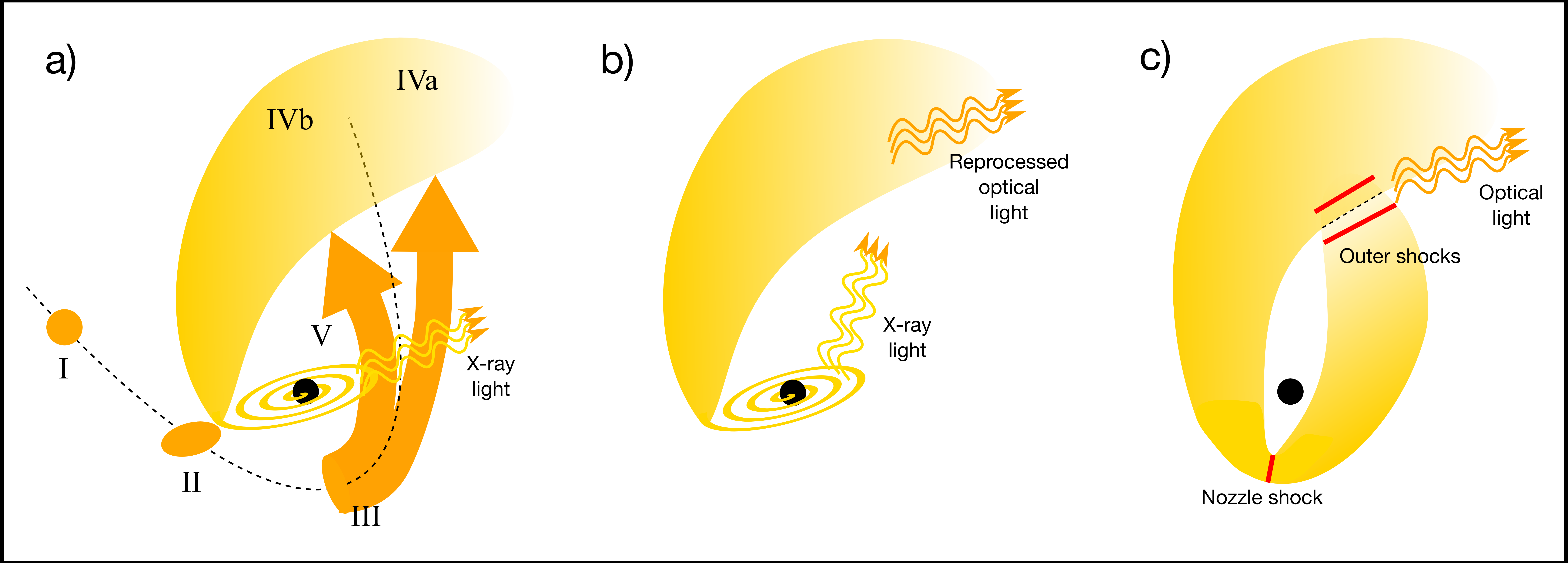


Gezari+12

Tidal disruption events

Optical TDEs

- Origin of the optical emission is unclear
- The accretion disk emission could be obscured (B) or accretion disk formation could be delayed (C)



Tidal disruption events

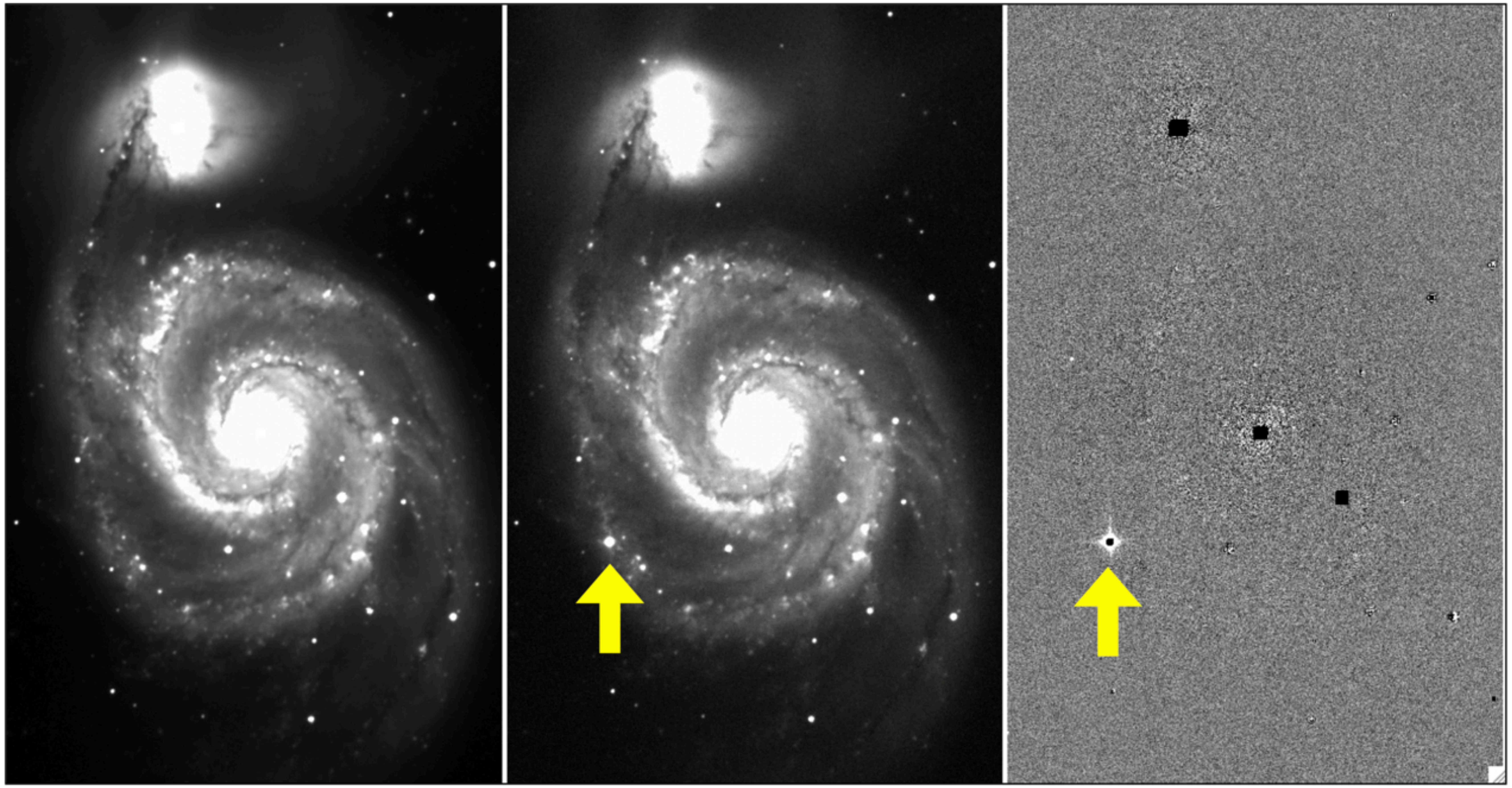
…and how to find them?

- Nuclear X-ray or optical flares
- Hot, black body spectrum (either in optical or in X-rays)
- Characteristic decay rate
- Broad emission lines (10000 km/s)
- Obvious confusions with:
    - Nuclear AGN
    - Nuclear Supernovae

Tidal disruption events

…and how to find them?

- All-sky surveys
- Small telescopes
- Differential imaging



Reference image = co-add of 20 *R* exposures (pre-outburst)

R exposure on June 19, 2011 Type IIb supernova ~ $10^9 L_\odot$

Difference image: *sci* exposure - reference

Tidal disruption events

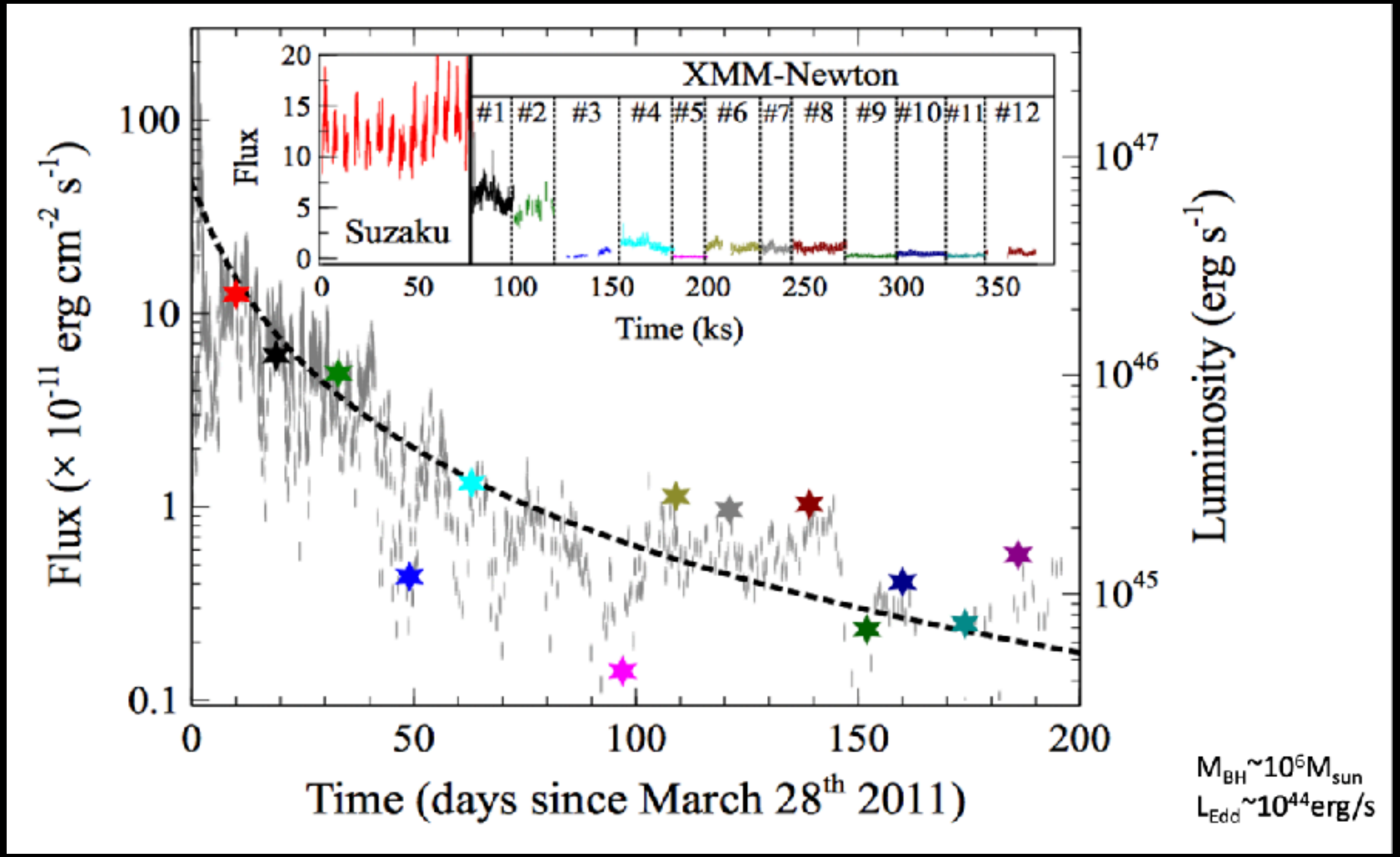
…and how to find them?

- Example: ASSA-SN (All-Sky Automated Survey for SuperNovae)
- Robotic 14-cm telescopes to survey the entire visible sky nightly to about 18th magnitude
- 6 sites in Hawaii, Chile, Texas, South Africa, China
- Future is bright: Vera C. Rubin Observatory (optical), Einstein Probe (X-rays)

Tidal disruption events

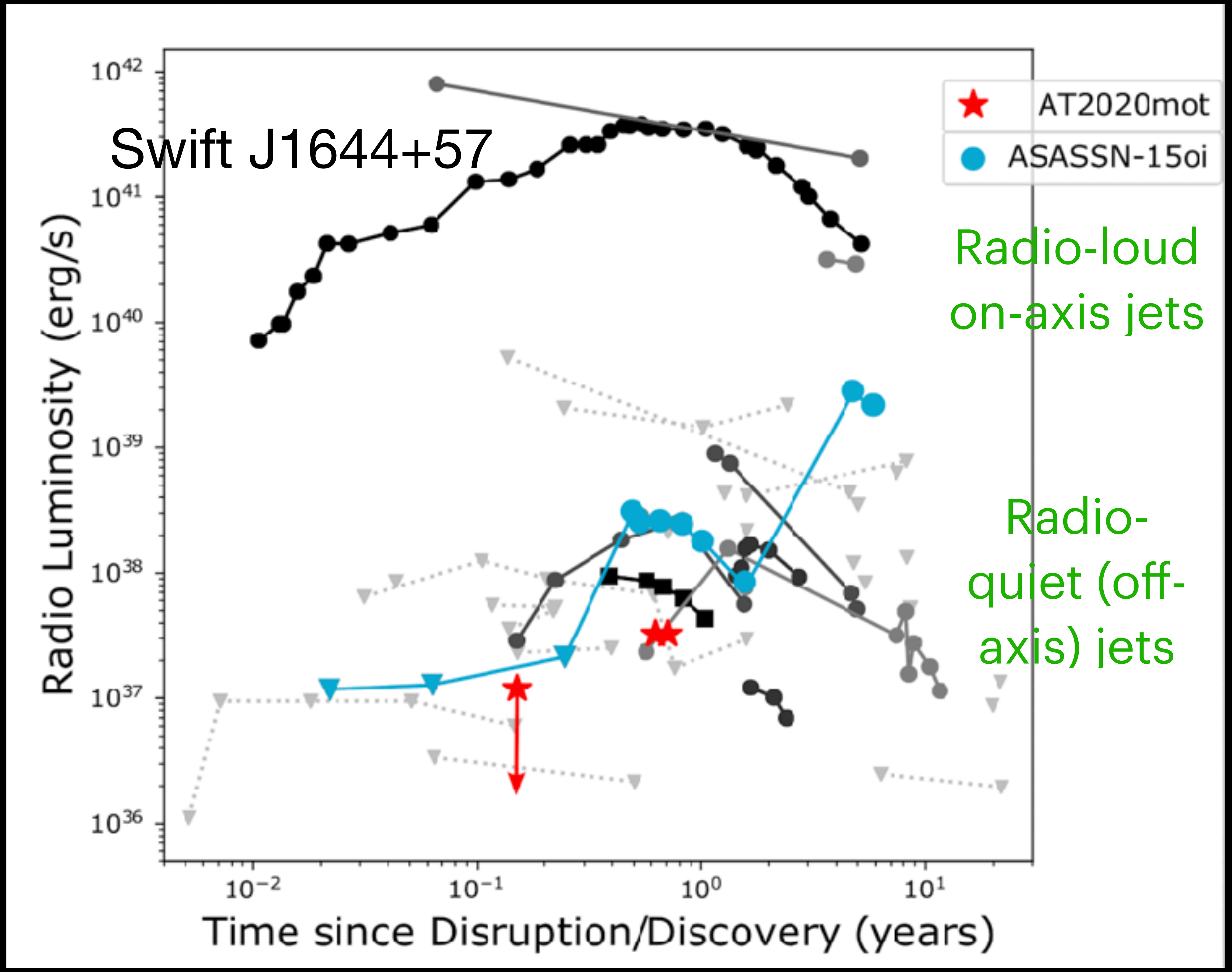
Jets

- Swift J1644+57: Extreme X-ray event, flagged as gamma-ray burst by BAT (Burst Alert Telescope) instrument onboard Swift X-ray satellite
  - Long-lived burst, fading as $\propto t^{-5/3}$
  - Peak luminosity almost $10^3 L_{\mathrm{Edd}}$
  - Brightening source of radio emission
  - The birth of a relativistic jet

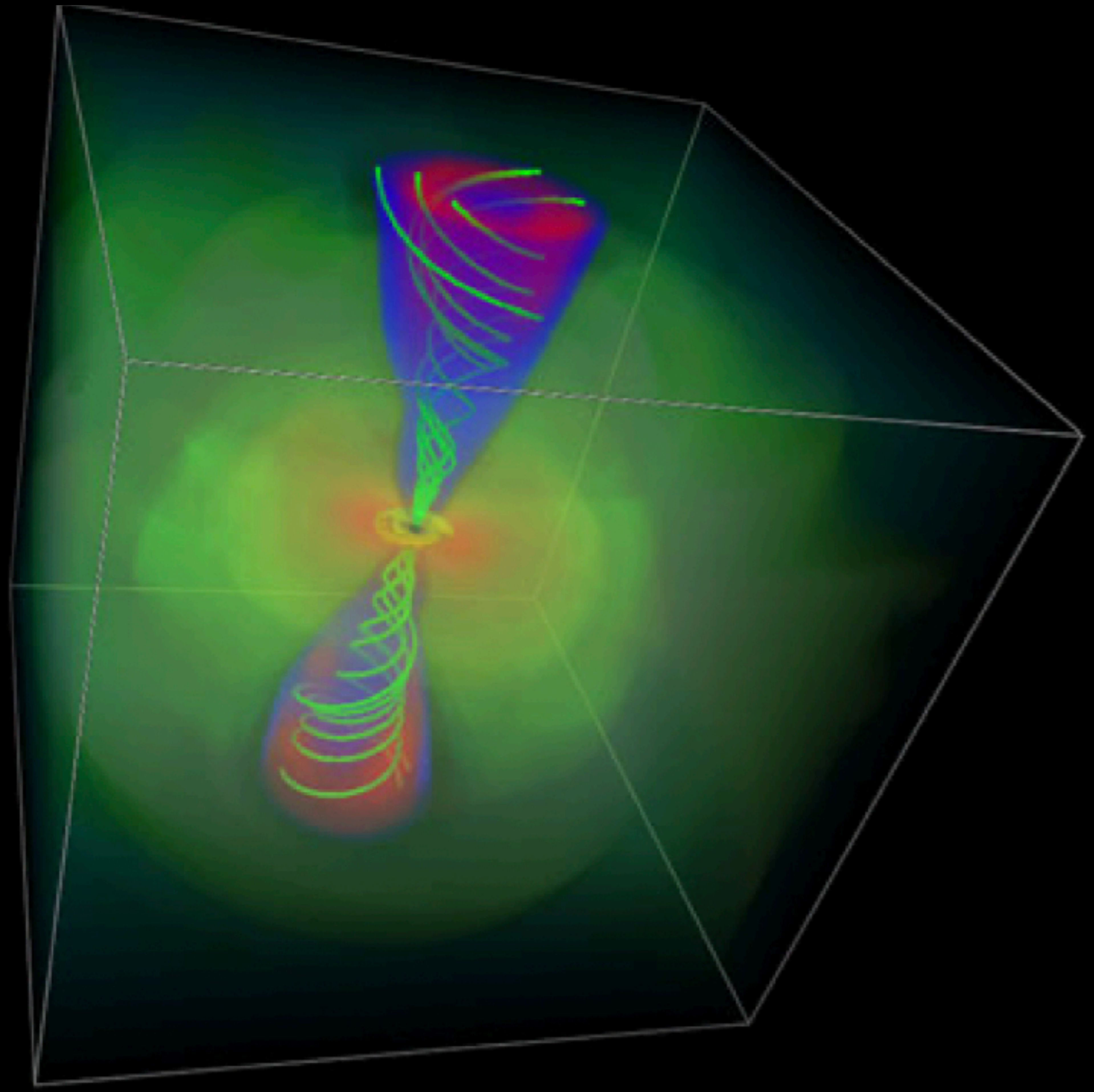


Burrows et al. (2011)

Tidal disruption events
Relativistic jets



Courtesy of K. Alexander



McKinney & Blandford 2009

Tidal disruption events

Recap

- Probes for dormant SMBHs
- Follow accretion disk and jet formation of around SMBHs in real time
- Super-Eddington accretion
  - AGN growth
- Probe the immediate environment of SMBHs