Illuminating Massive Black Holes with White Dwarfs

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in collaboration with:

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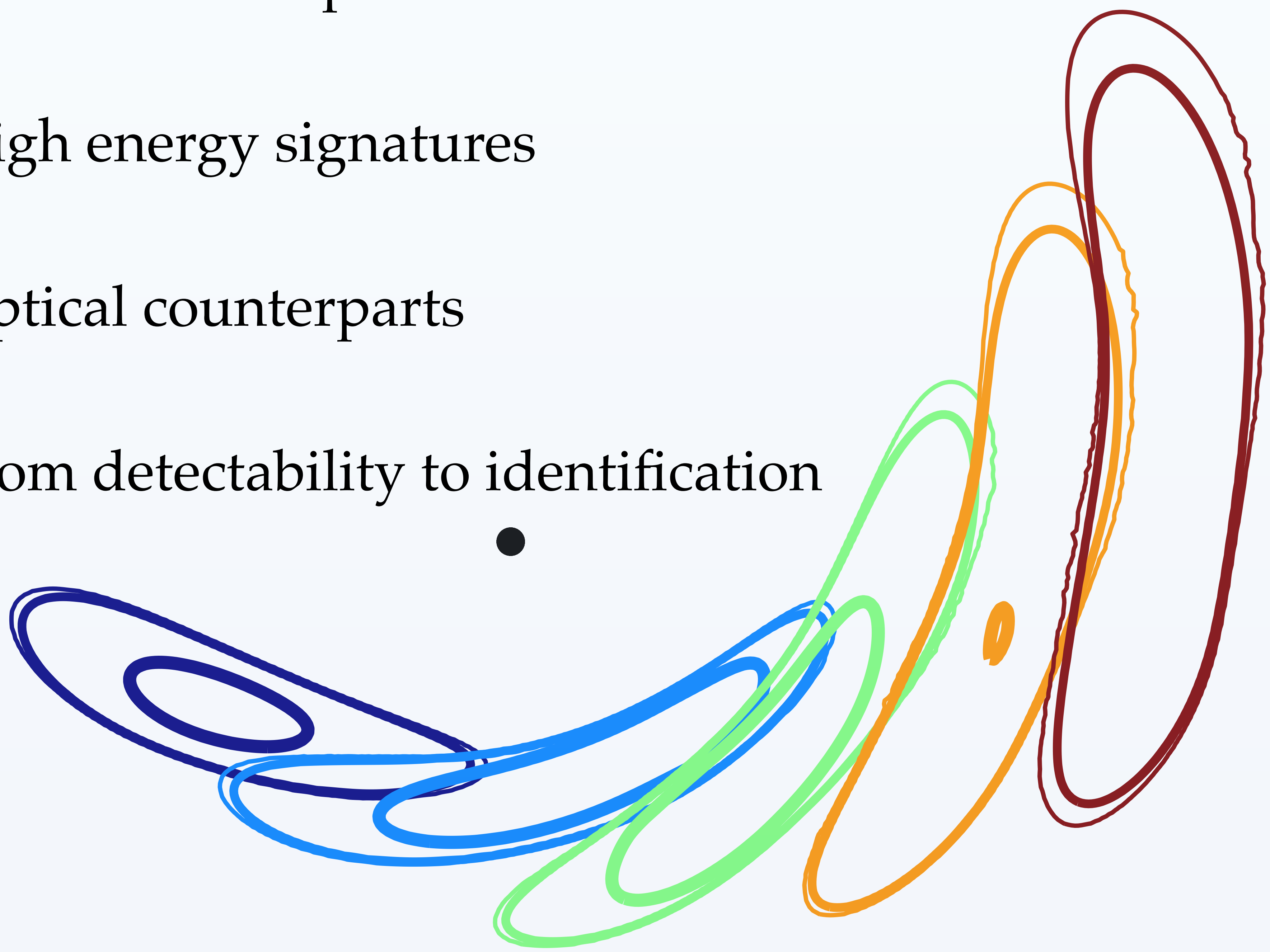
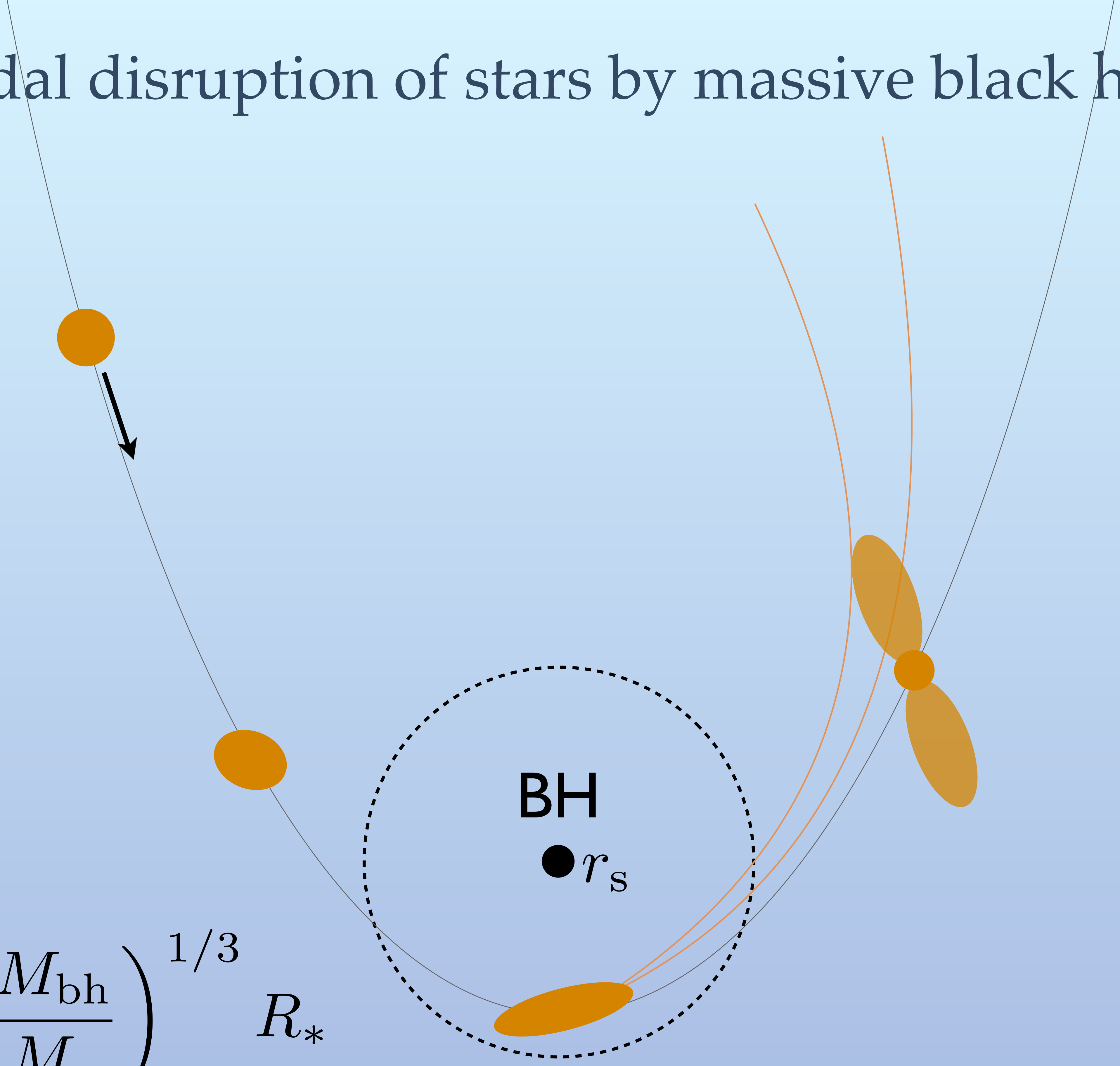
Outline

- WD tidal disruption
- High energy signatures
- Optical counterparts
- From detectability to identification



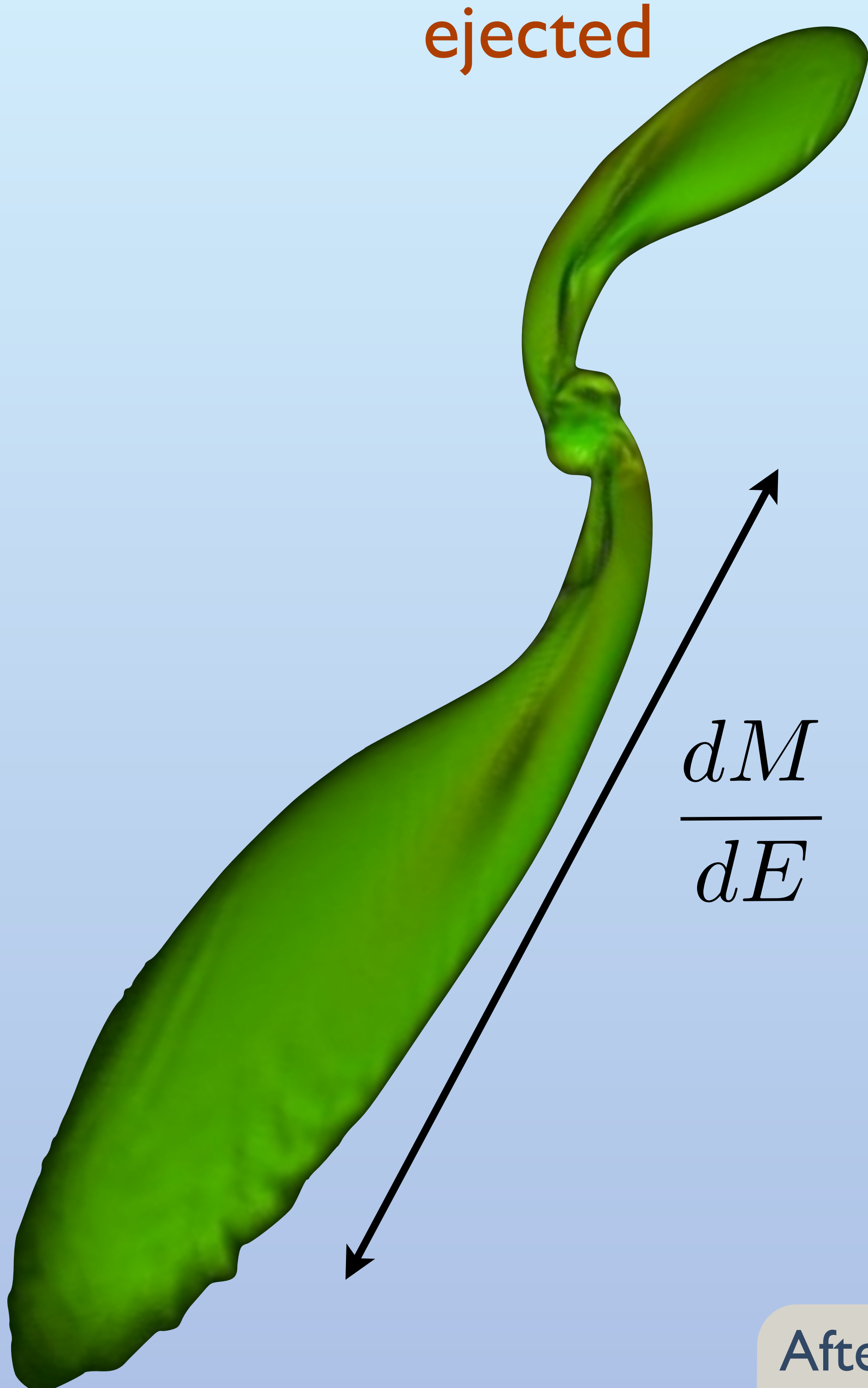
This talk builds on the work of: (Rosswog+ 2008,2009), (Clausen+ 2011), (Haas+ 2012), (Scherbakov+ 2013), (Cheng+ 2013,2014), (Jonker+2013)
…. and yesterday's talk by Thomas Wevers

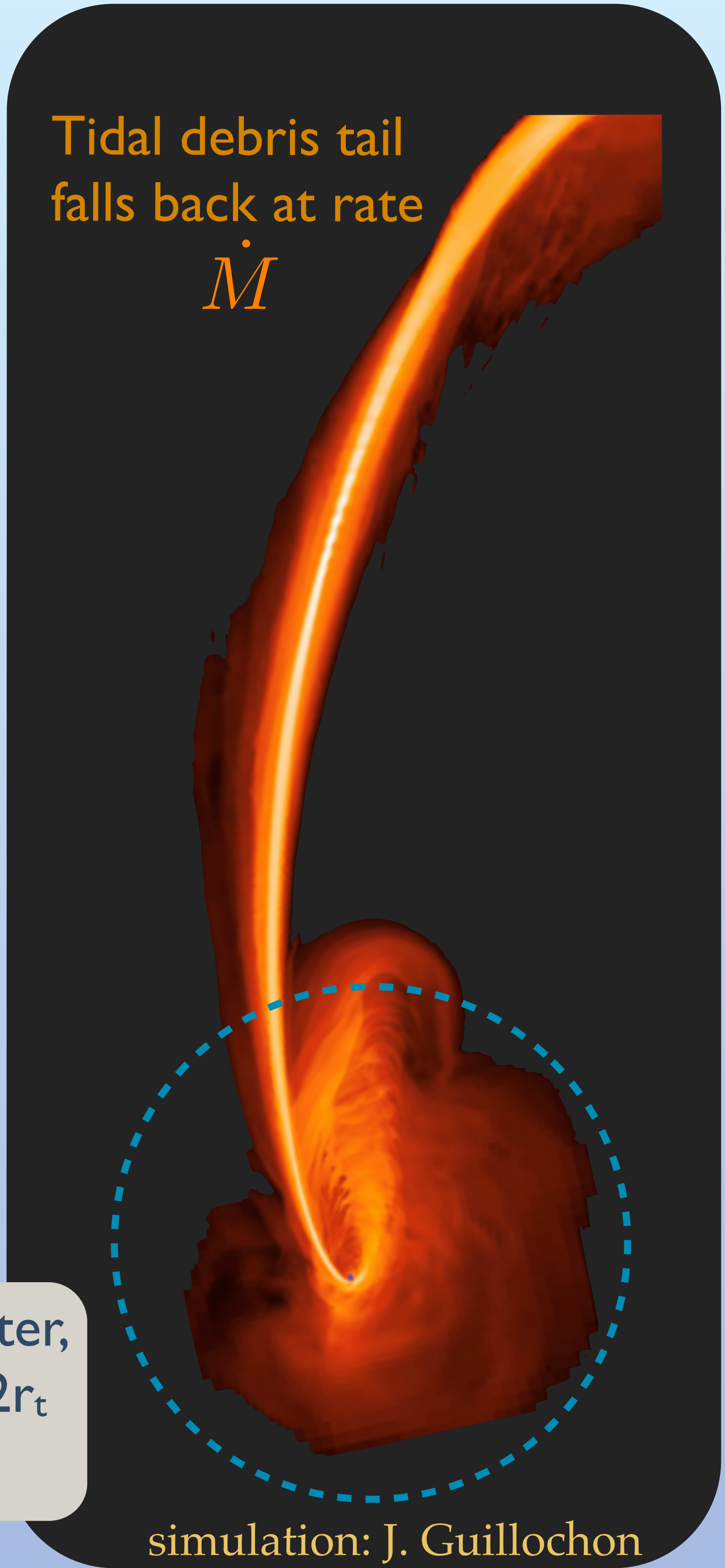
Tidal disruption of stars by massive black holes



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

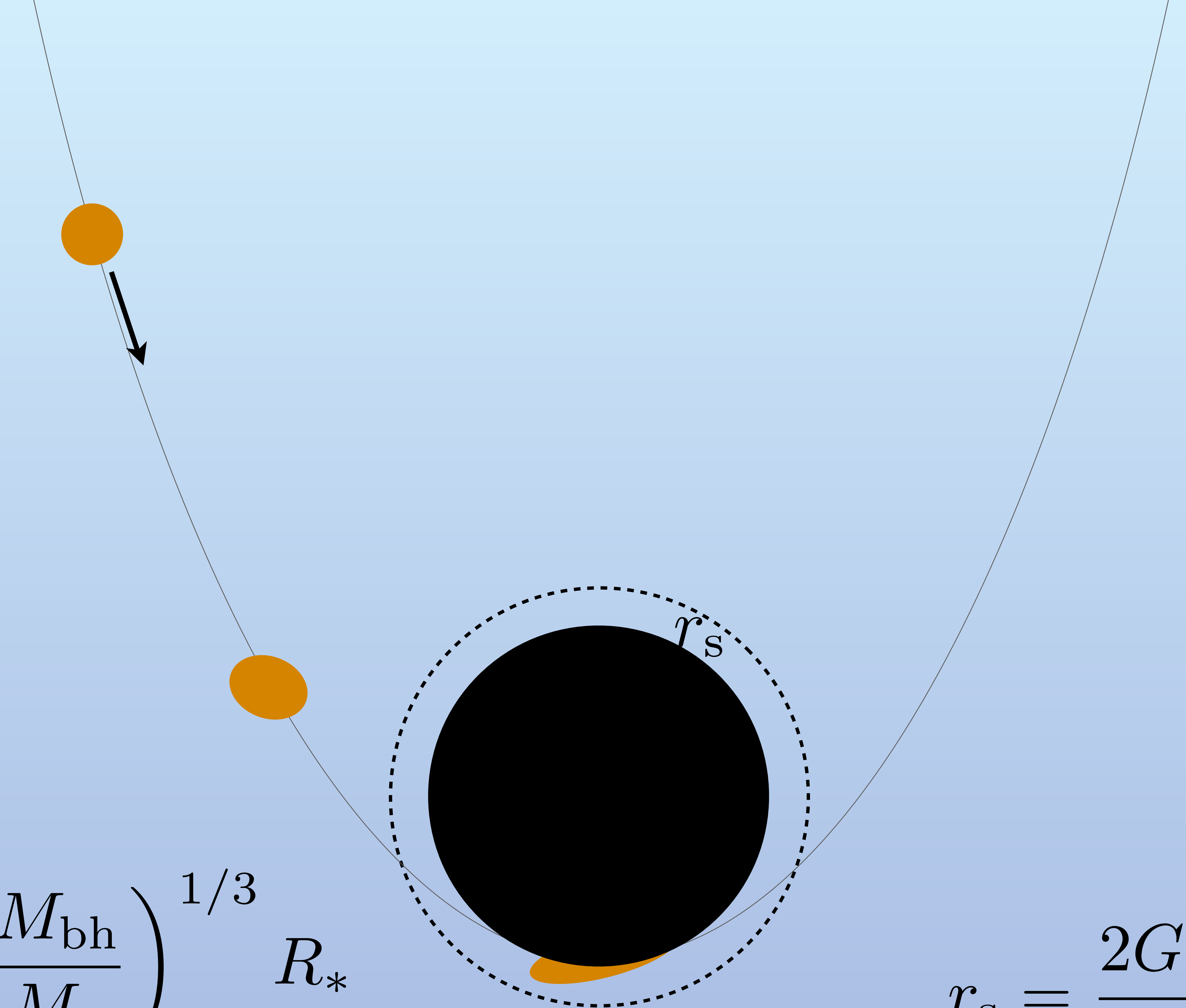
From fallback to accretion flare





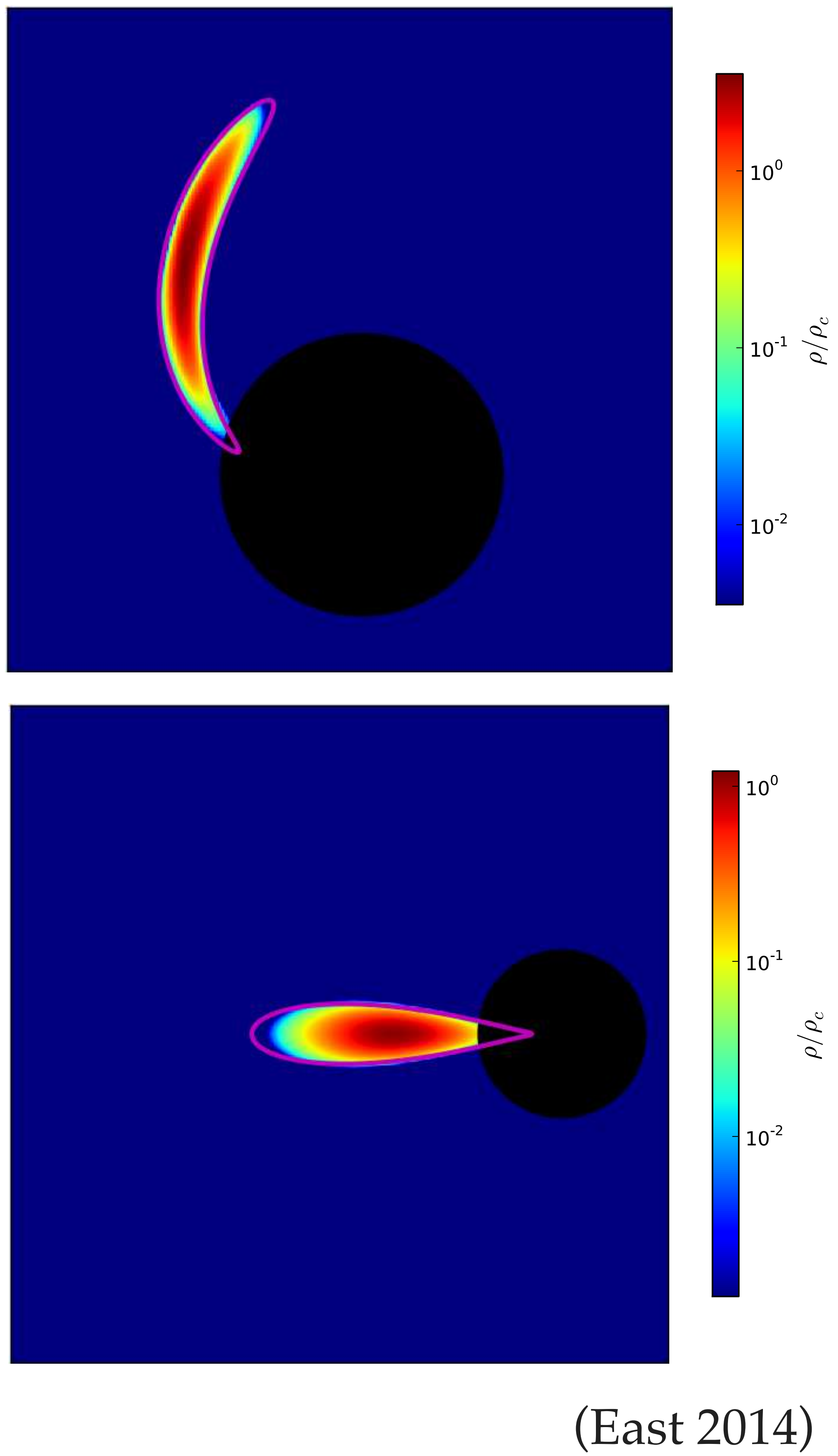
After returning to pericenter, material circularizes at ~$2r_t$ and accretes viscously.

Tidal disruption of stars by massive black holes

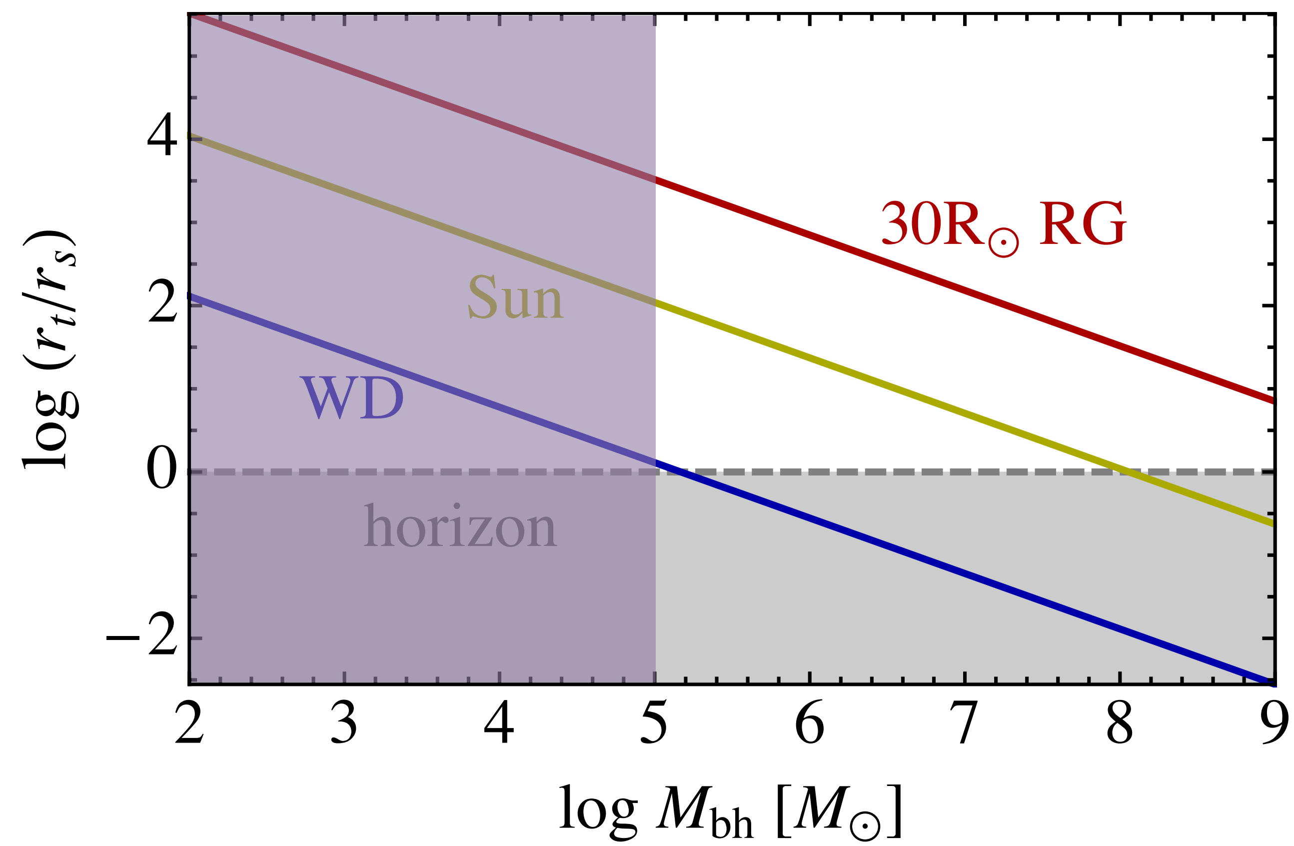


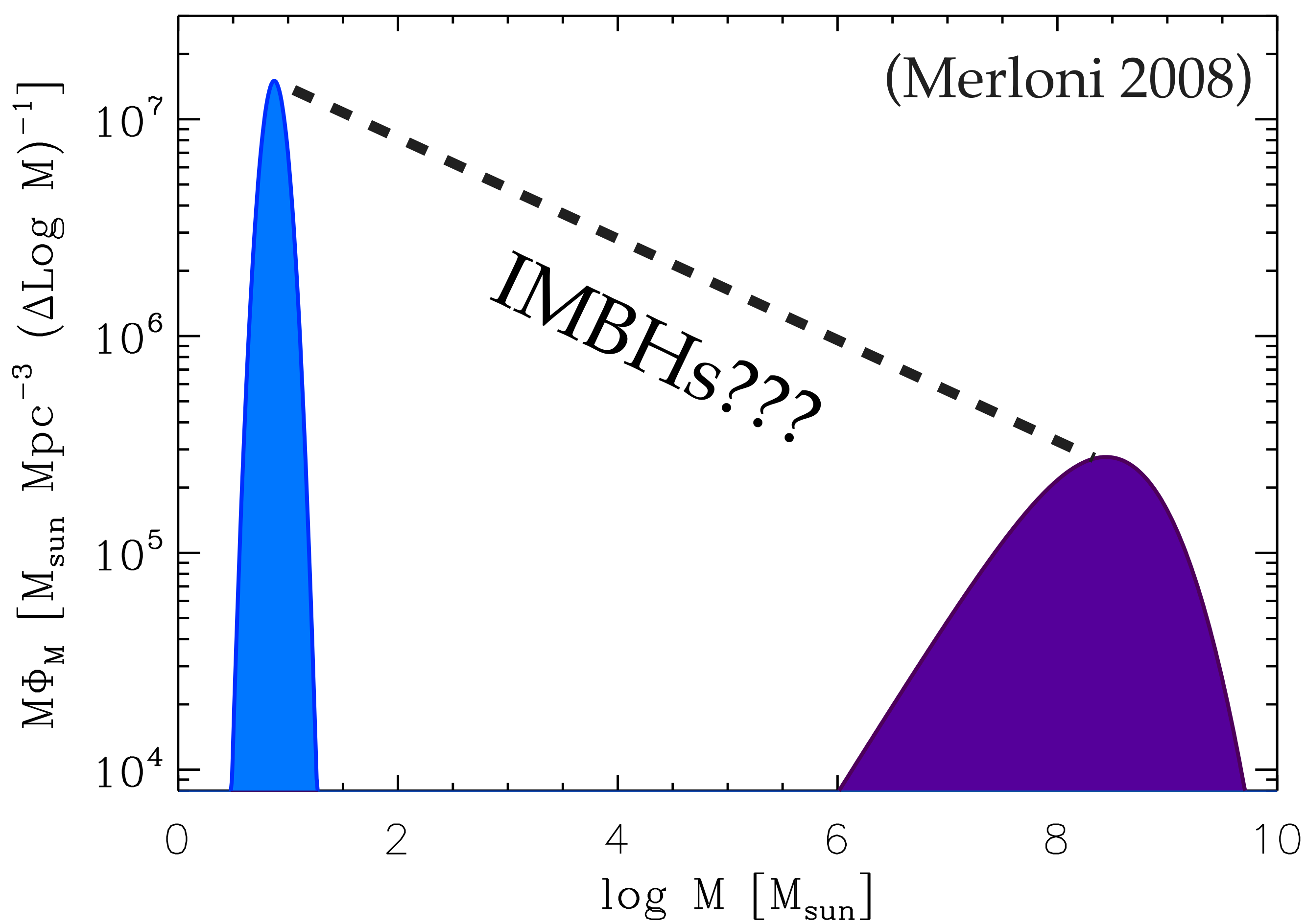
$$r_{\mathrm{t}} = \left(\frac{M_{\mathrm{bh}}}{M_*}\right)^{1/3} R_*$$

$$r_{\mathrm{s}} = \frac{2GM_{\mathrm{bh}}}{c^2}$$

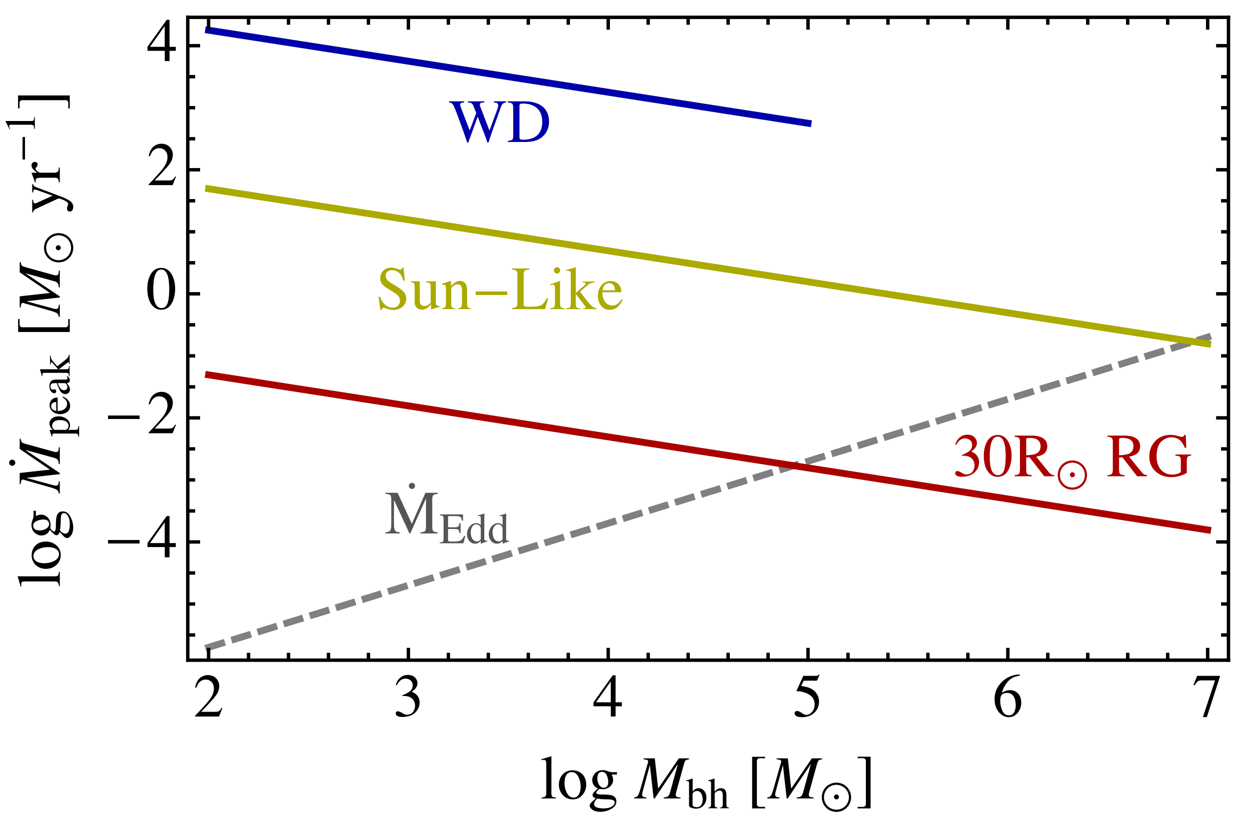


Direct swallowing of star by BH





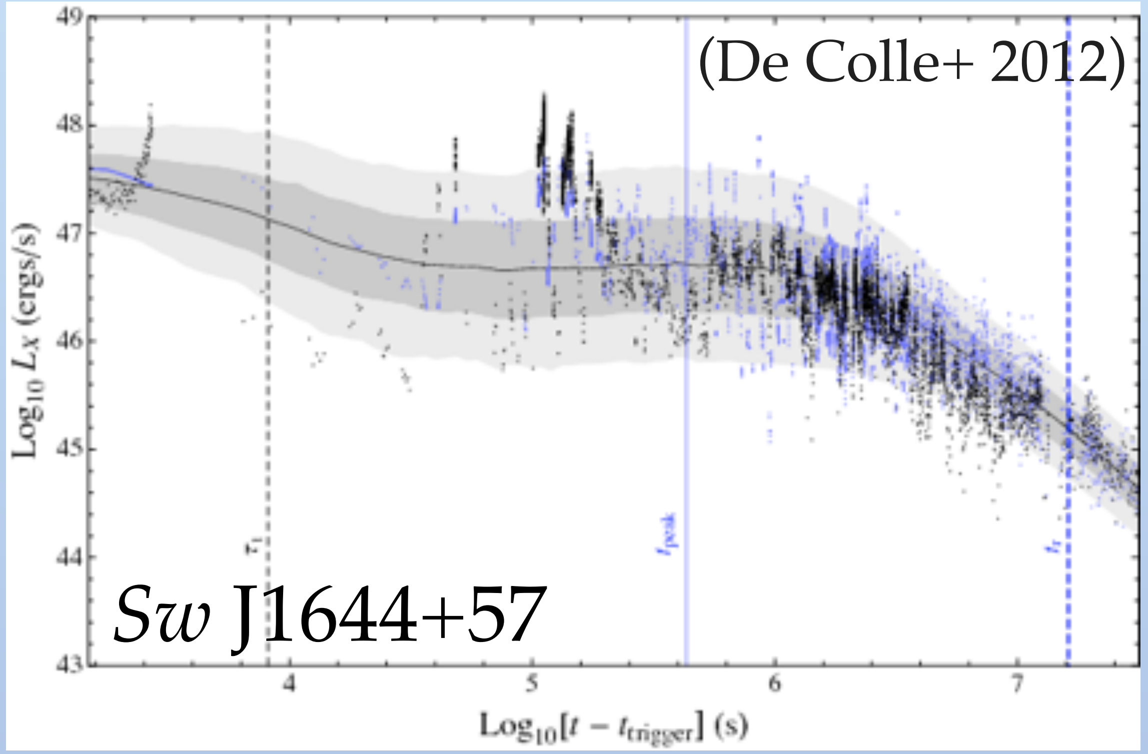
High energy disruption signatures



The peak feeding rate in WD disruptions greatly exceeds the Eddington mass accretion rate, and that of MS TDEs:

$$\dot{M}_{\rm peak} \propto M_{\rm bh}^{-1/2} M_*^2 R_*^{-3/2}$$

These highly super-Edd. accretion flows can launch relativistic outflows which greatly outshine thermal accretion-disk emission



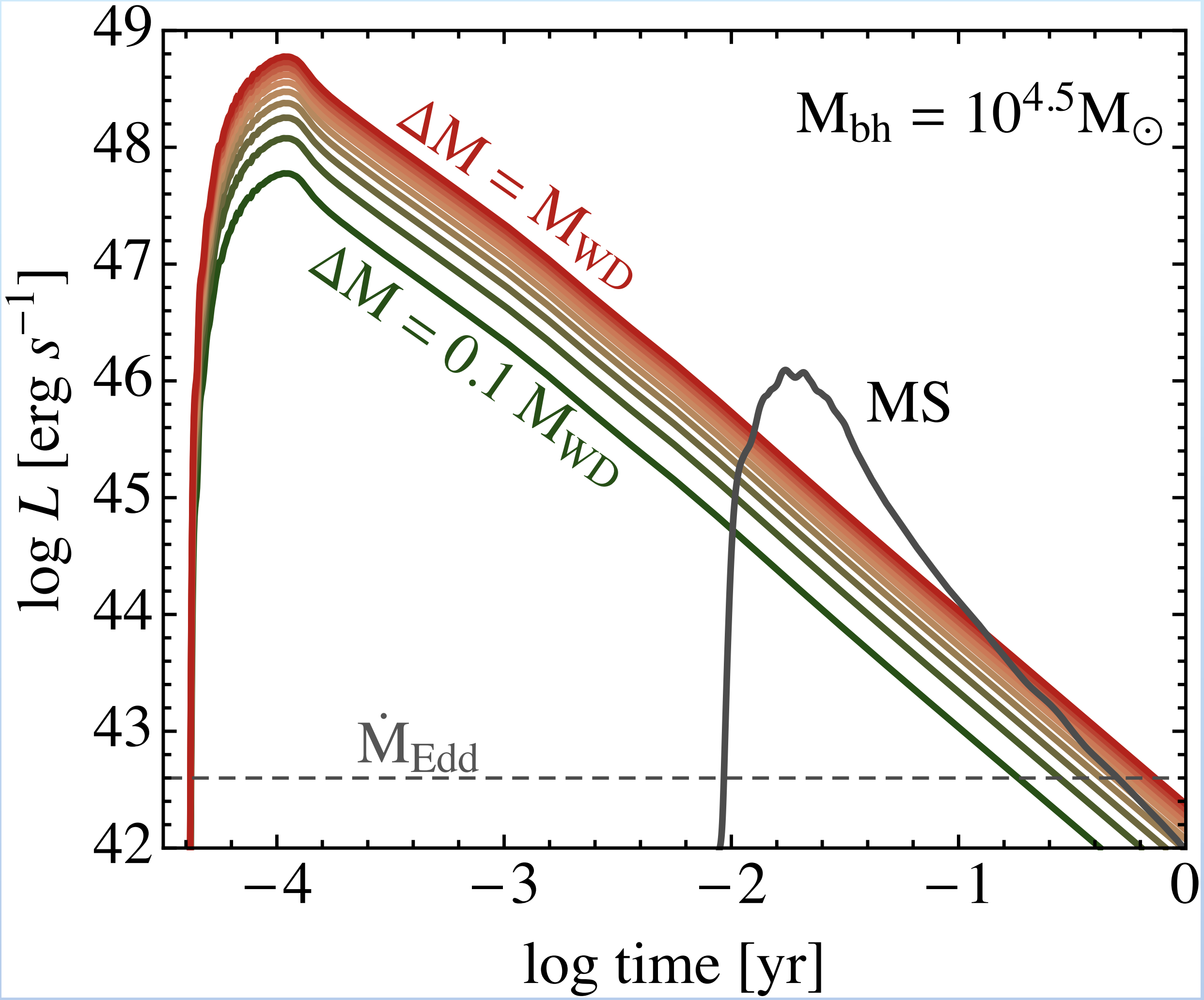
$$P_{\rm jet} = \epsilon \dot{M} c^2$$

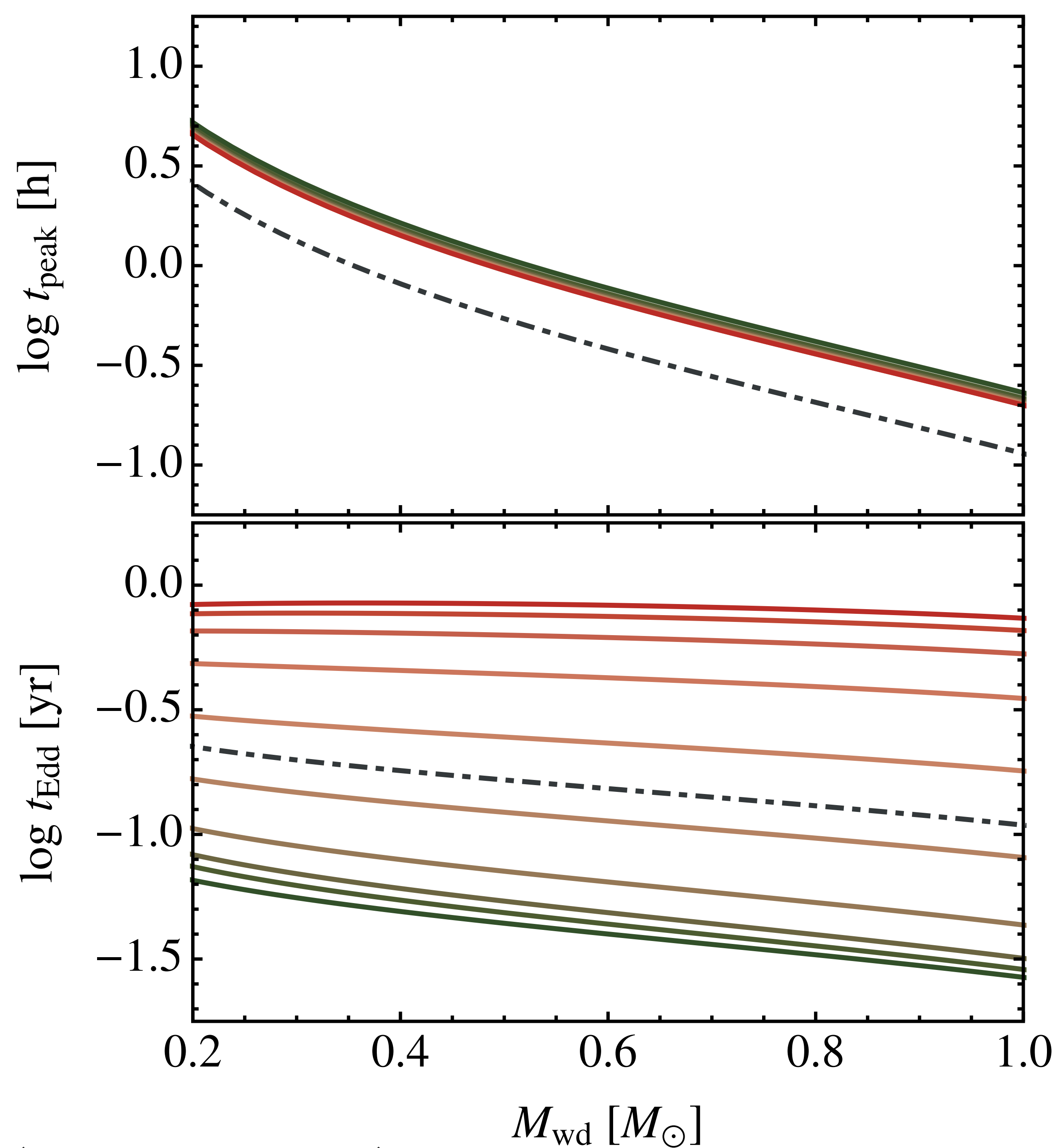
$$\gg \epsilon \dot{M}_{\rm Edd} c^2$$

(e.g. yesterday's talk by A. Sadowski)

High energy disruption signatures

observer along the jet axis:





(MacLeod+ 2014)

$$M_{\rm bh} = 10^{4.5} M_\odot :$$

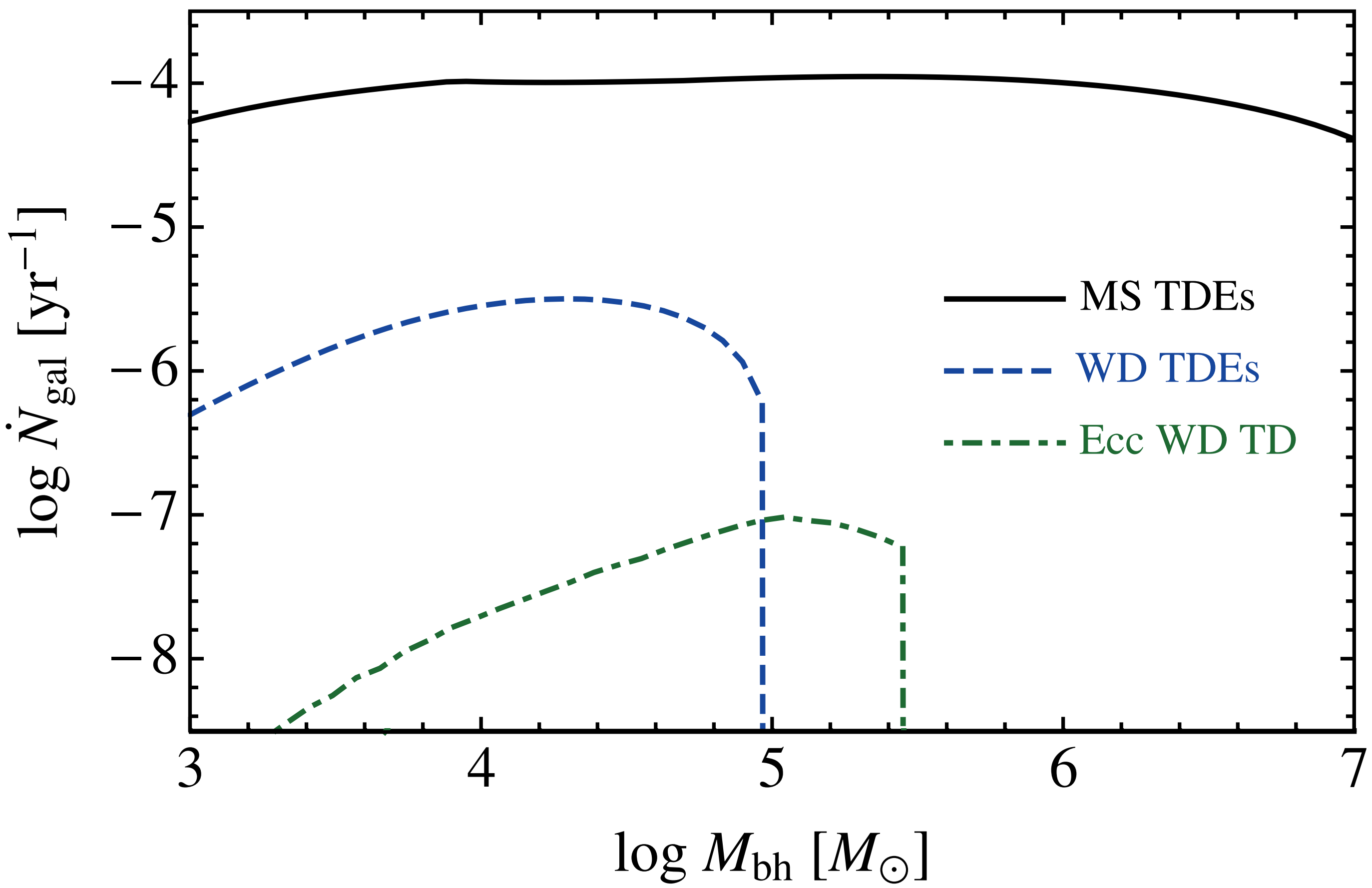
$$L_{\rm peak} \approx 10^{48}\ {\rm ergs}^{-1}$$

$$t_{\rm peak} \approx 1\ {\rm h}$$

$$t_{\rm Edd} \approx 3\ {\rm months}$$

High energy disruption & detection rates

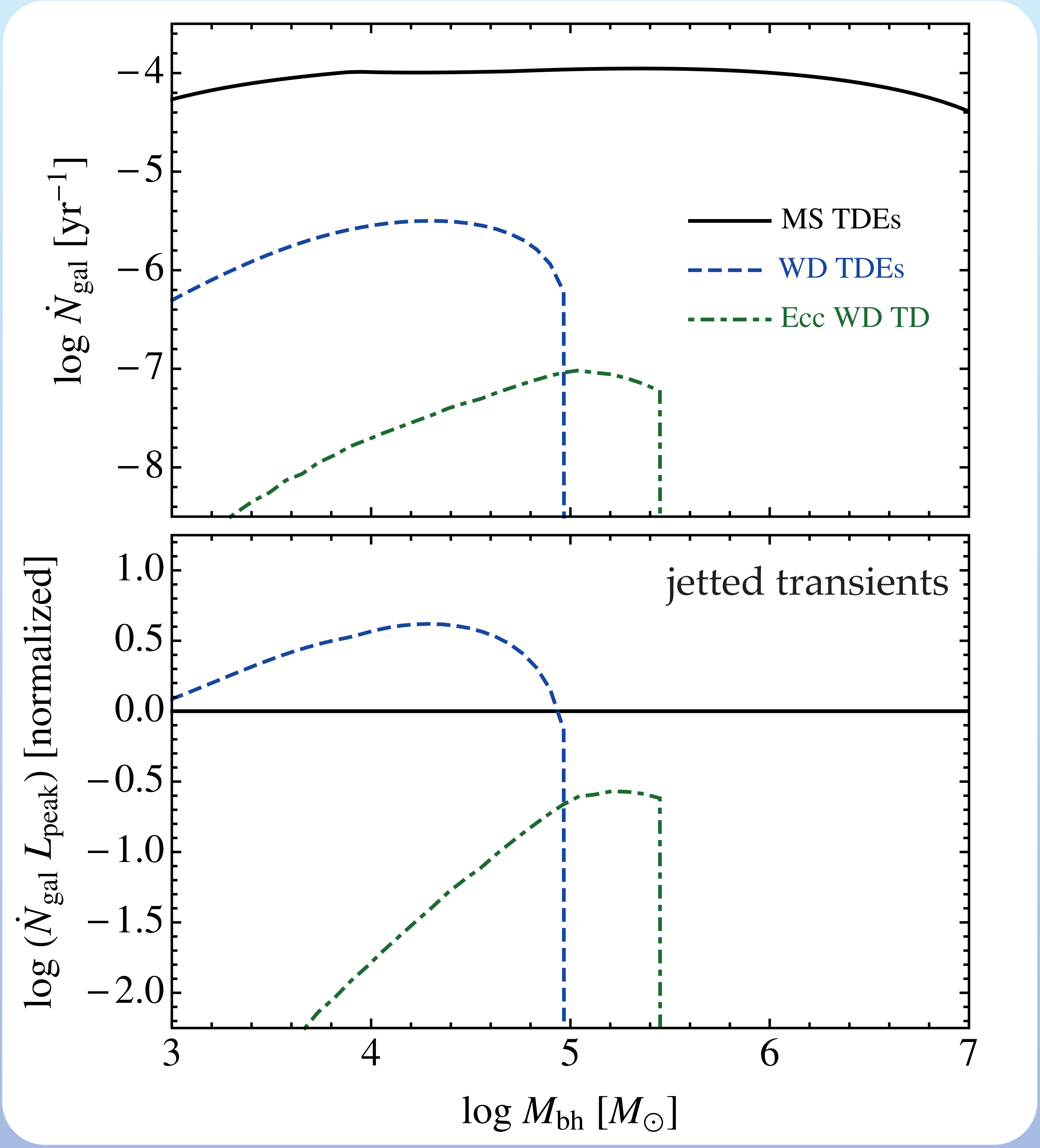
(Given extrapolation of Mbh-sigma relaition…)



WD disruptions are a factor of ~100x less common than their main sequence counterparts.

(MacLeod+ 2014)

High energy disruption & detection rates

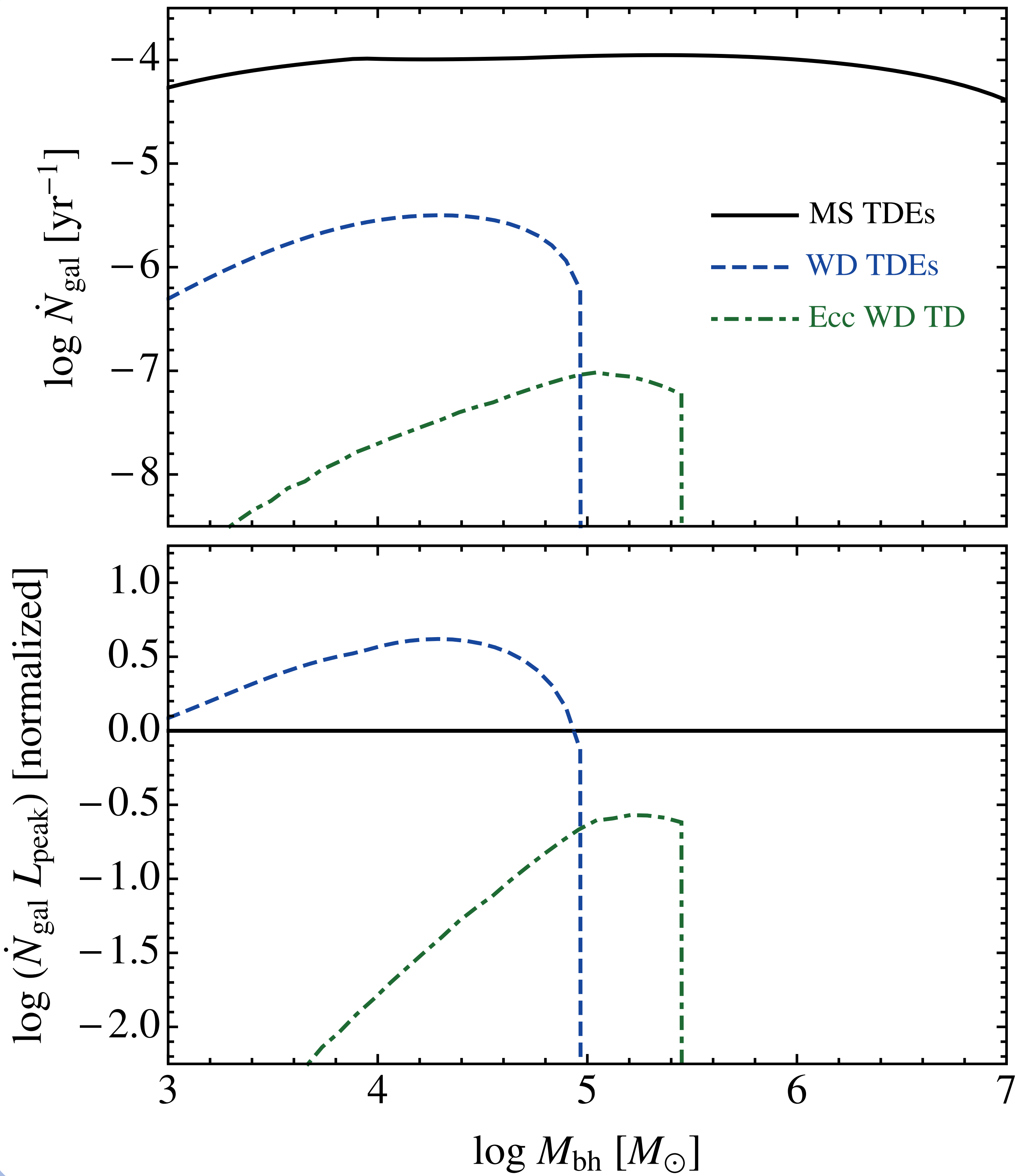


WD disruptions are a factor of ~100x less common than their main sequence counterparts.

But their beamed emission is ~1000x more luminous

(MacLeod+ 2014)

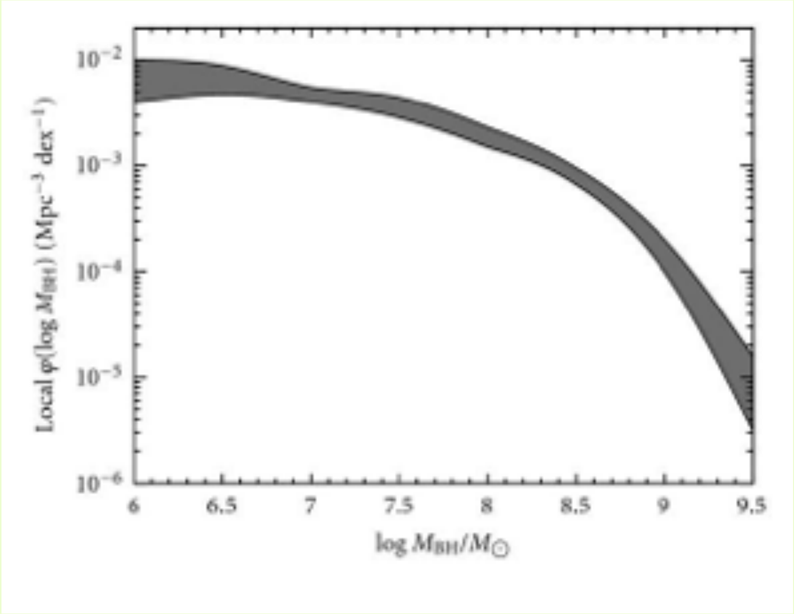
High energy disruption & detection rates



Detection with *Swift*

$$\dot{N}_{\rm gal} \sim 10^{-6}\ {\rm yr}^{-1}$$

$$n_{\rm gal} \approx 10^{7}\ Gpc^{-3}$$



$$z < 1 :$$

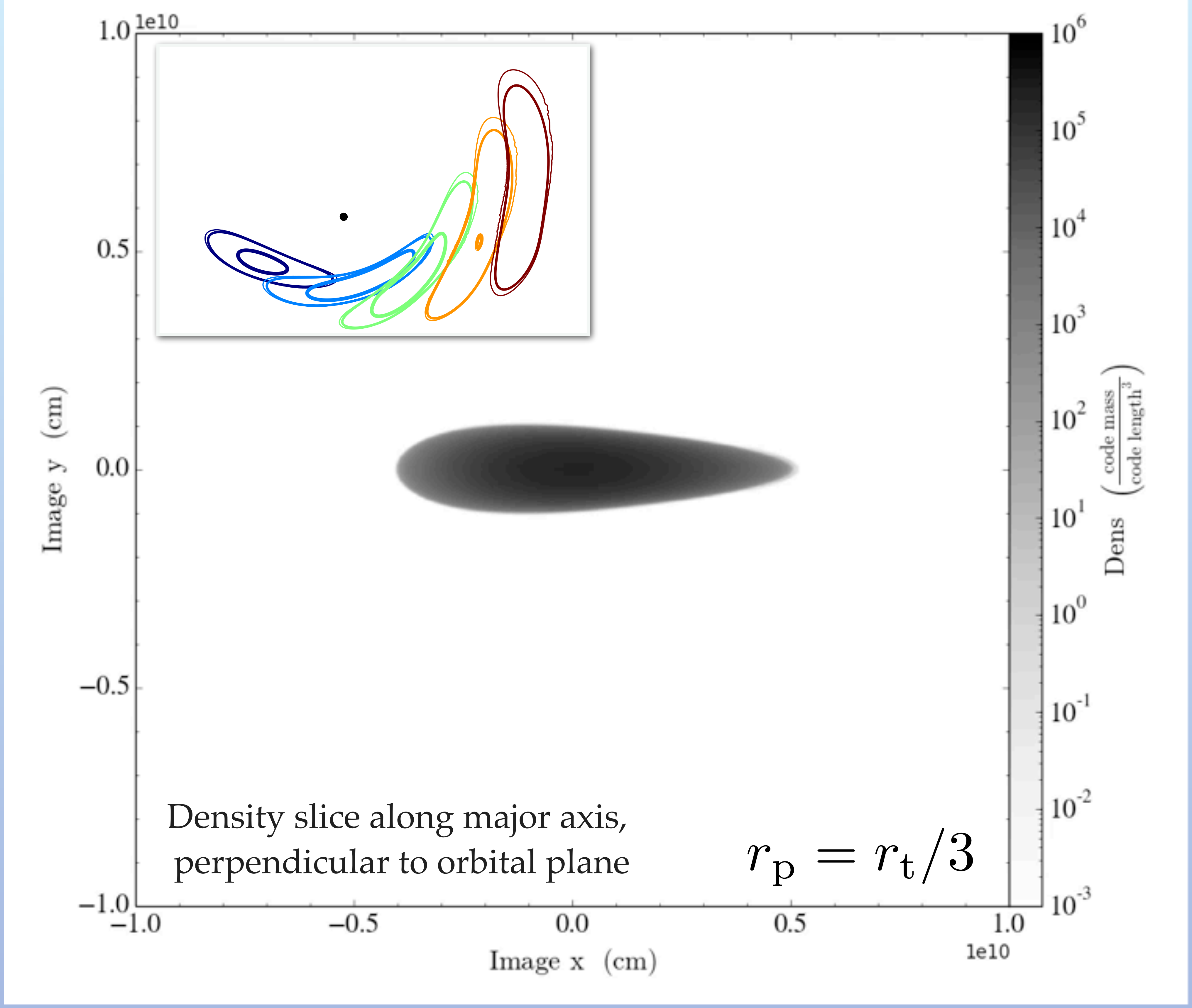
$$\dot{N}_{swift} \approx 1500 f_{\rm beam} f_{\rm MBH}\ {\rm yr}^{-1}$$

$$\sim 15\ {\rm yr}^{-1}$$

$$(f_{\rm beam} = f_{\rm MBH} = 0.1)$$

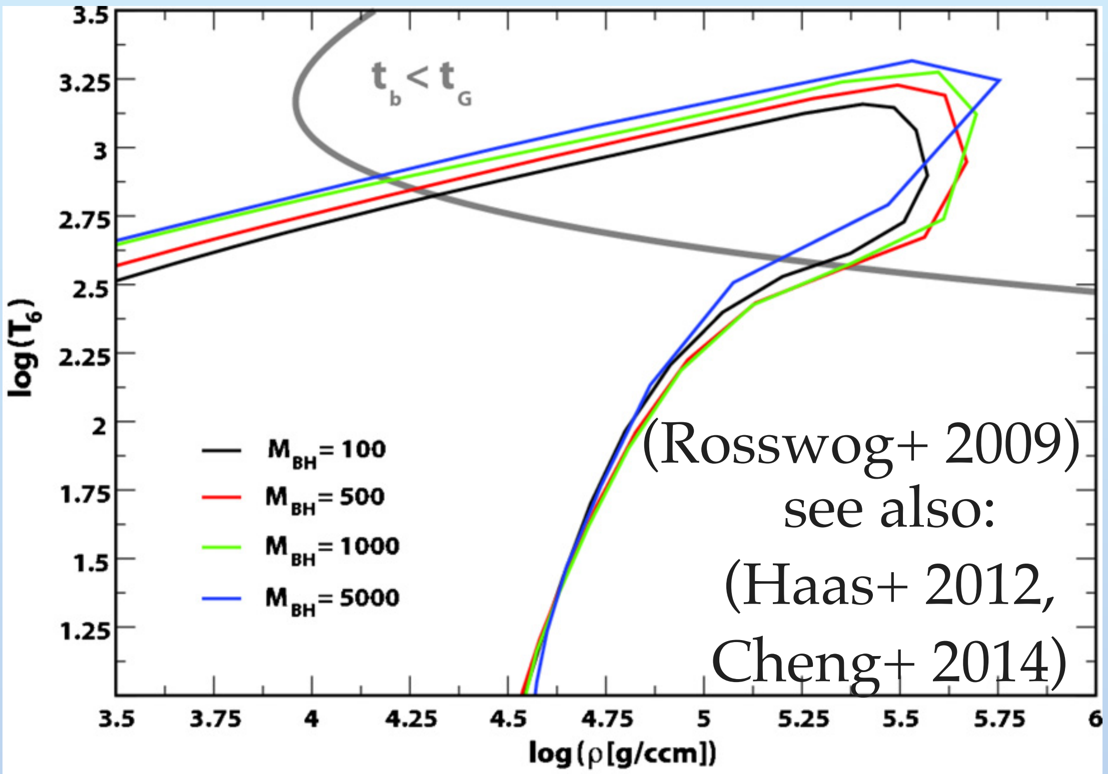
Optical counterpart: thermonuclear transient

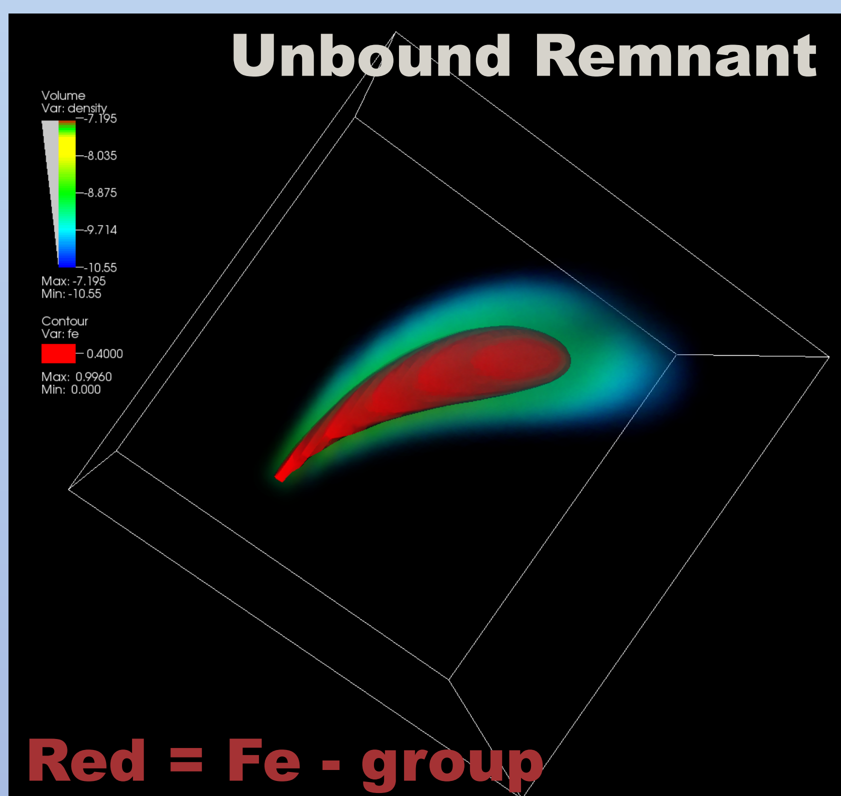
Hydrodynamics of WD compression



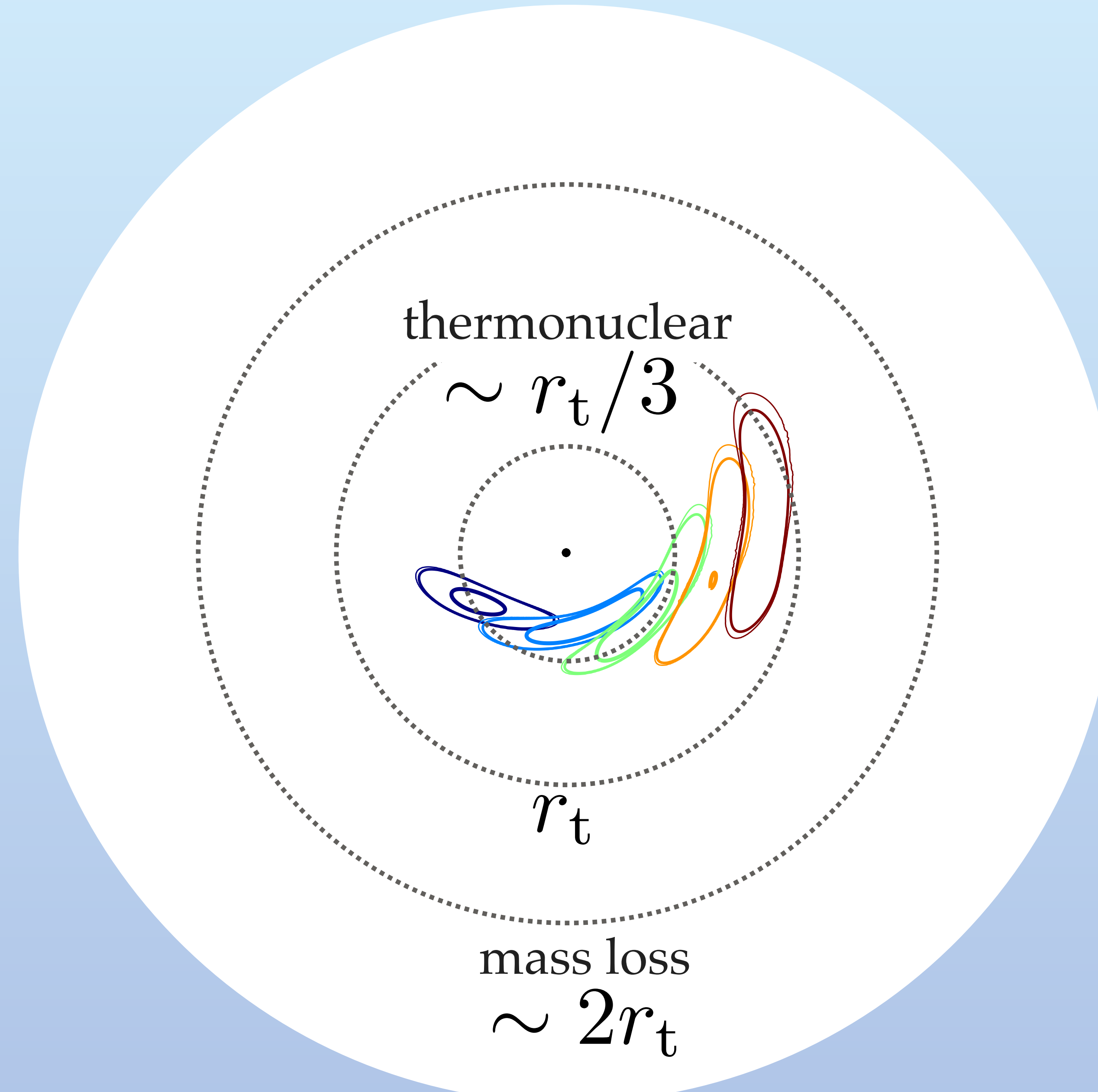
Optical counterpart: thermonuclear transient

Ignition





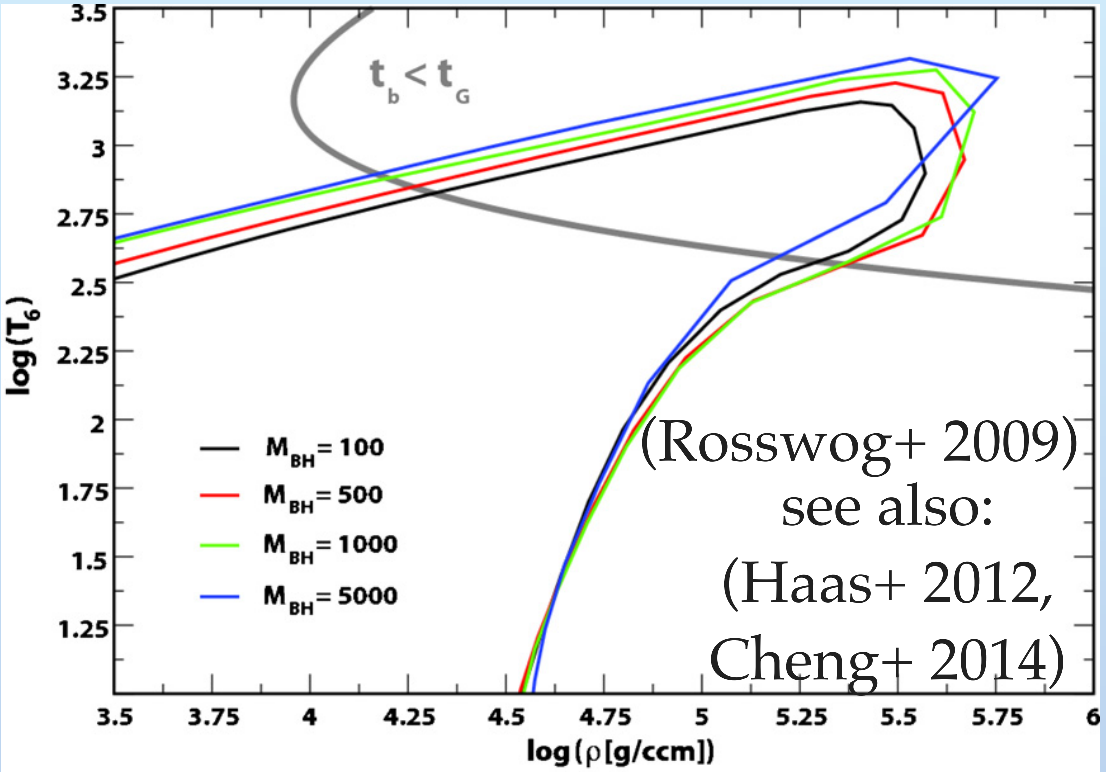
How often?

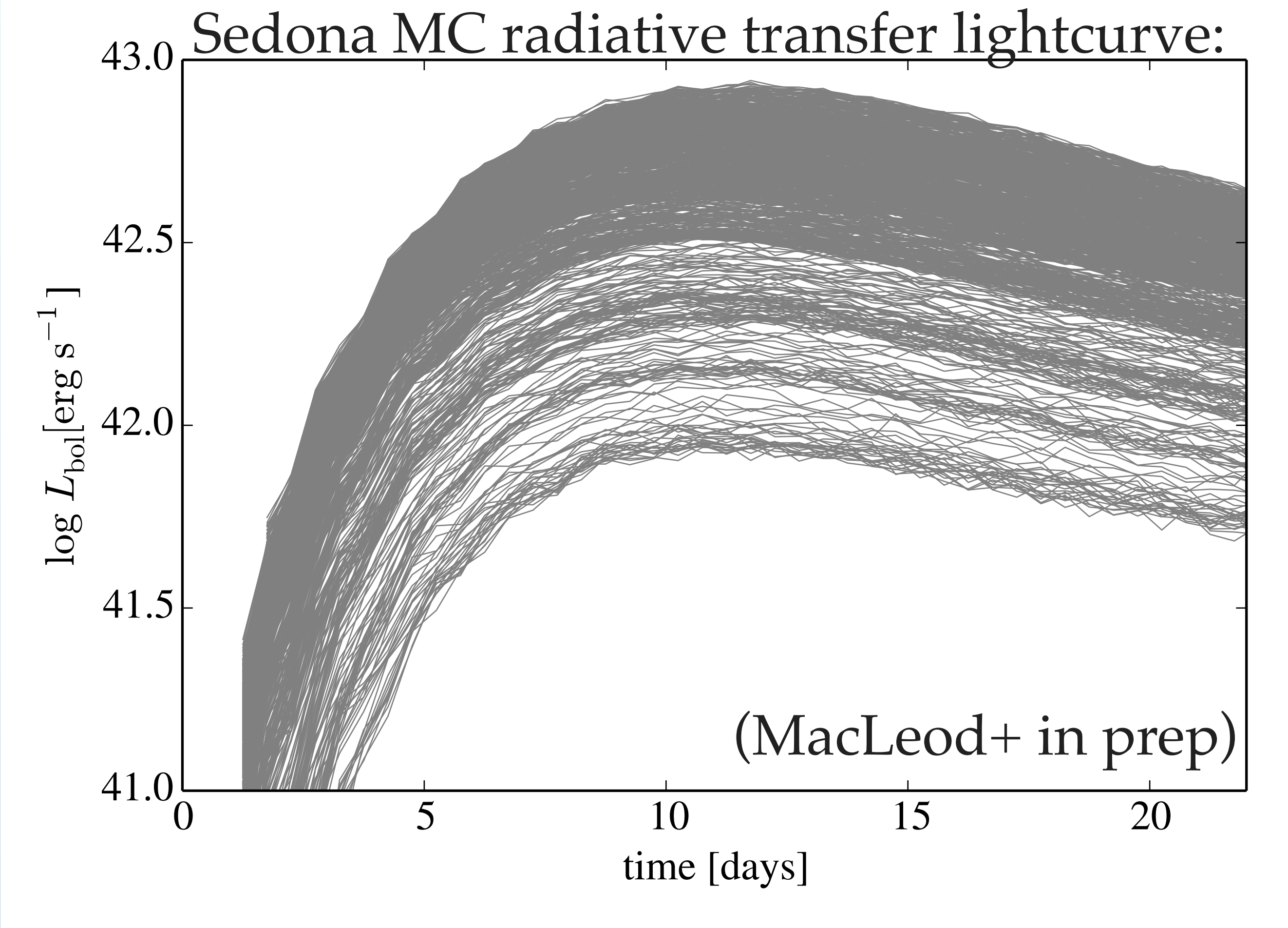


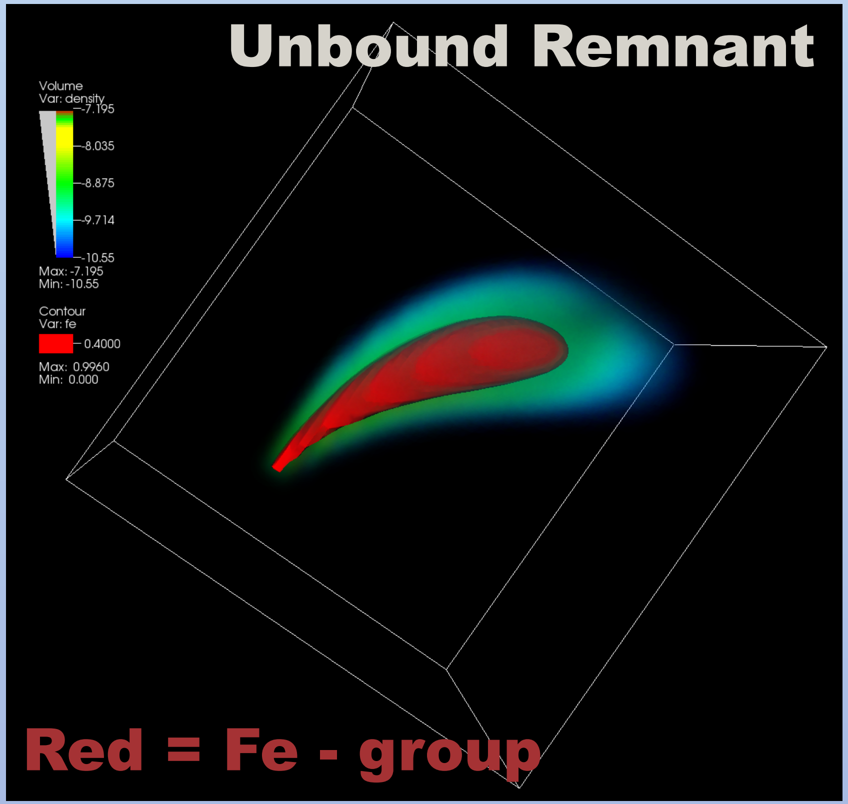
Thermonuclear fraction ~1/6 of events

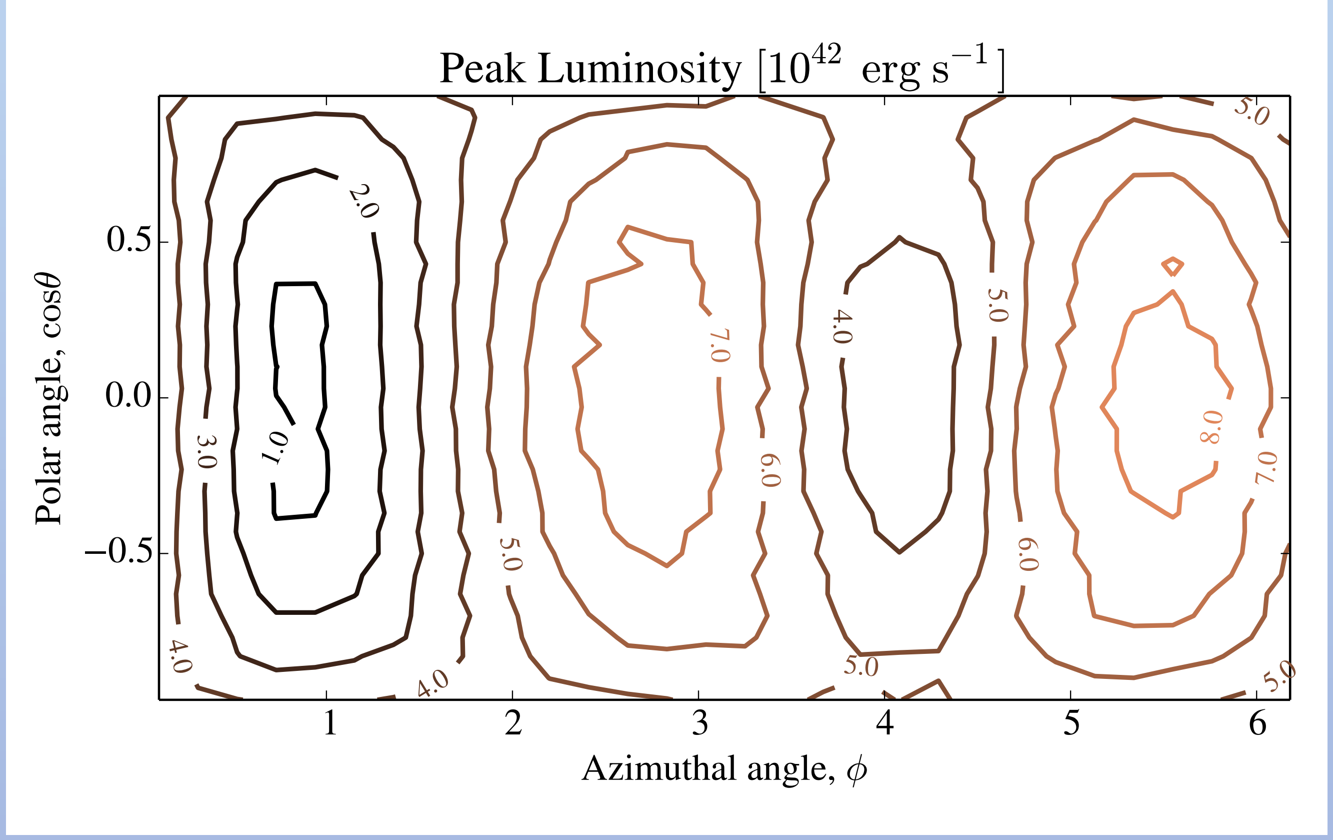
Optical counterpart: thermonuclear transient

Ignition



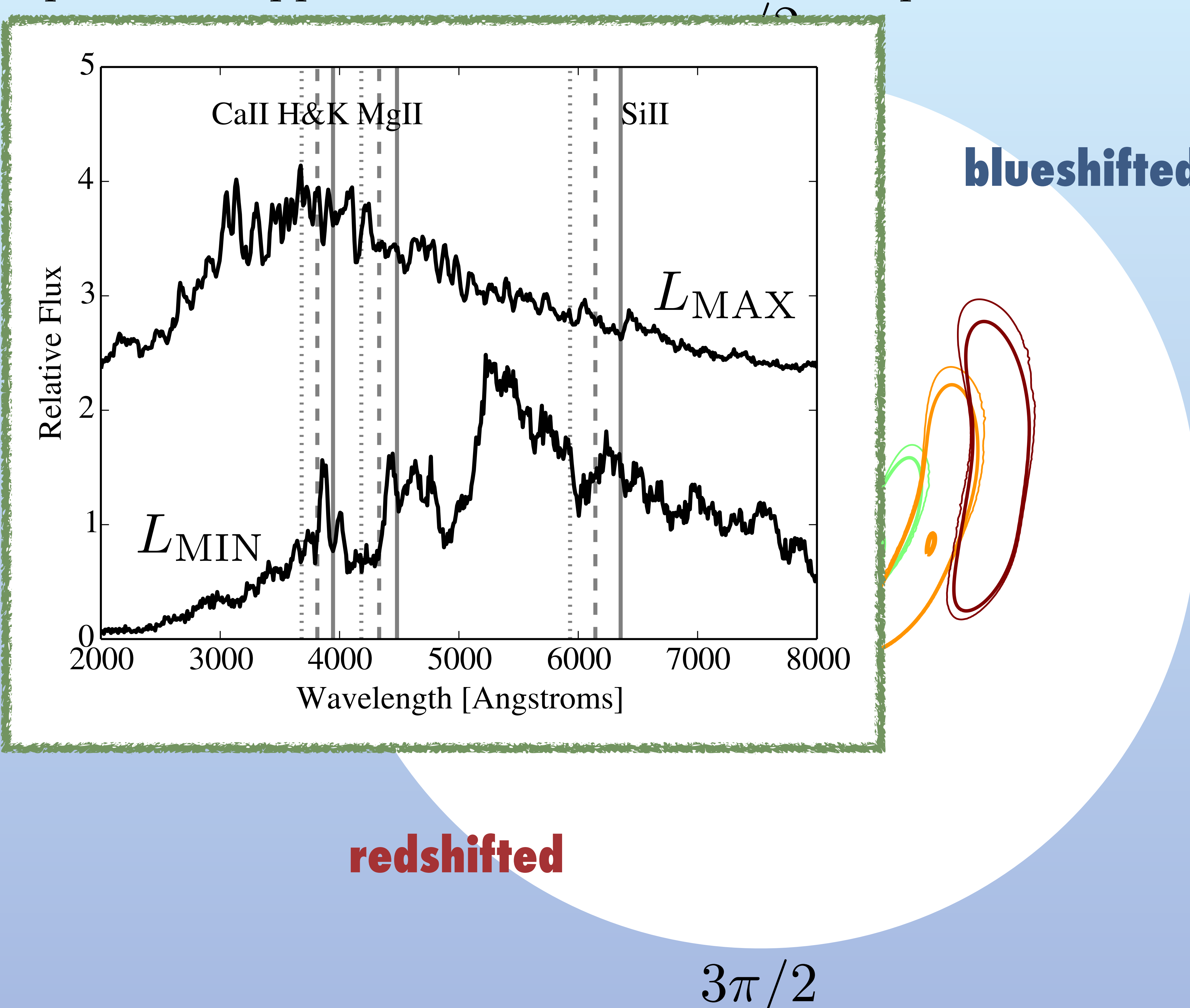






Optical counterpart: thermonuclear transient

Spectra & Doppler shifts: observer near orbital plane



optical
$L_{\rm MIN}$
(line blanketing)
red color

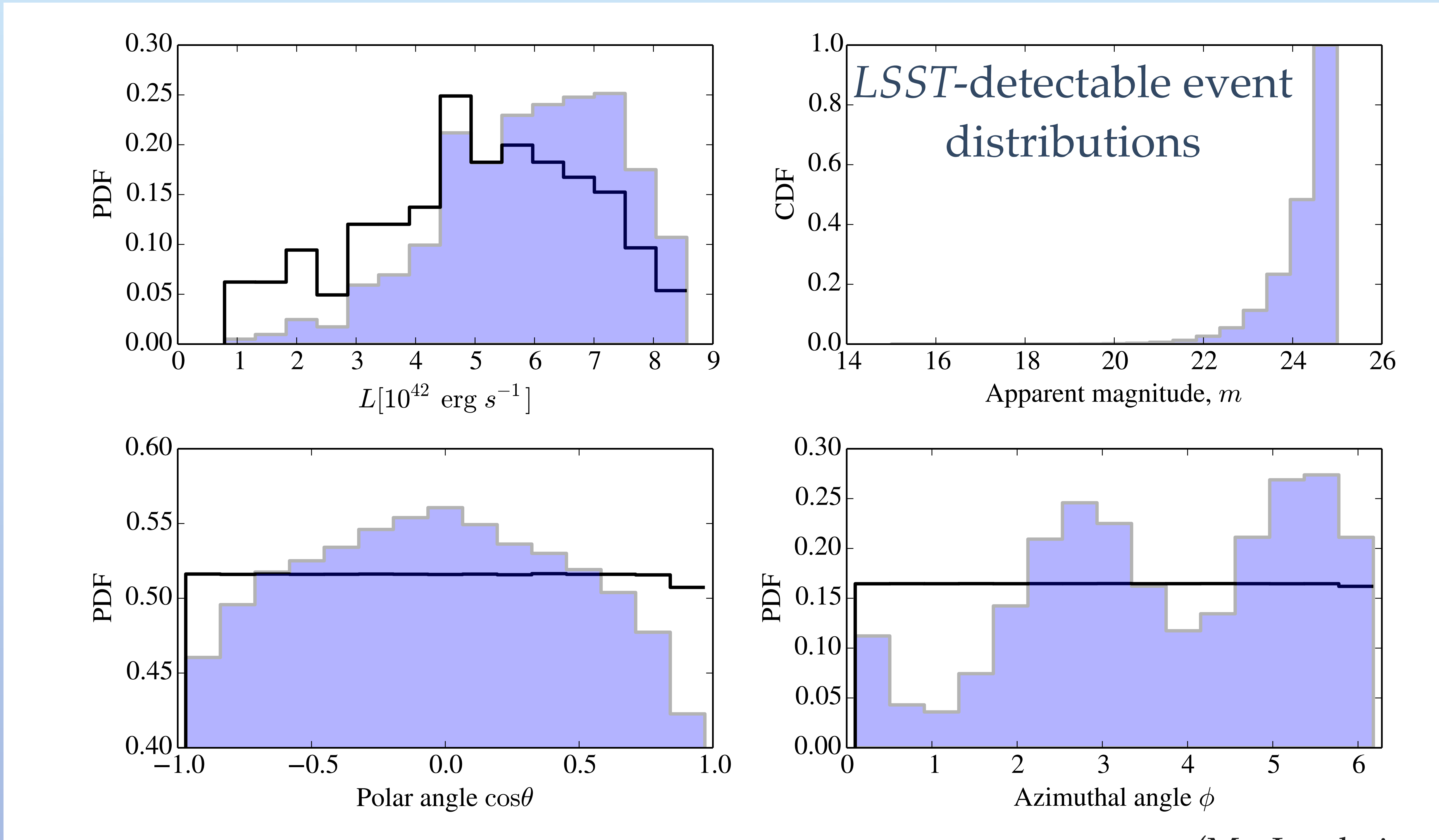
optical
$L_{\rm MAX}$
blue color

(MacLeod+ in prep)

Optical detection with *ZTF* or *LSST*

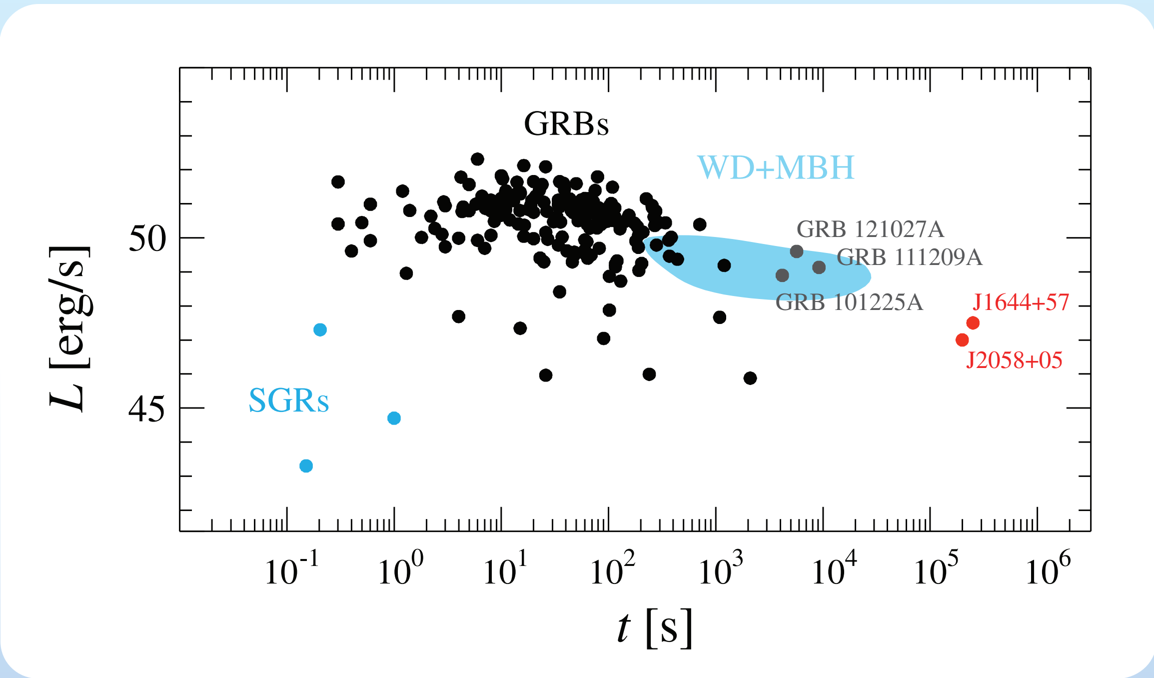
ZTF [m_{thresh}=20.5] ~ 0.5 yr $^{-1}$

LSST [m_{thresh}=25] ~ 240 yr $^{-1}$

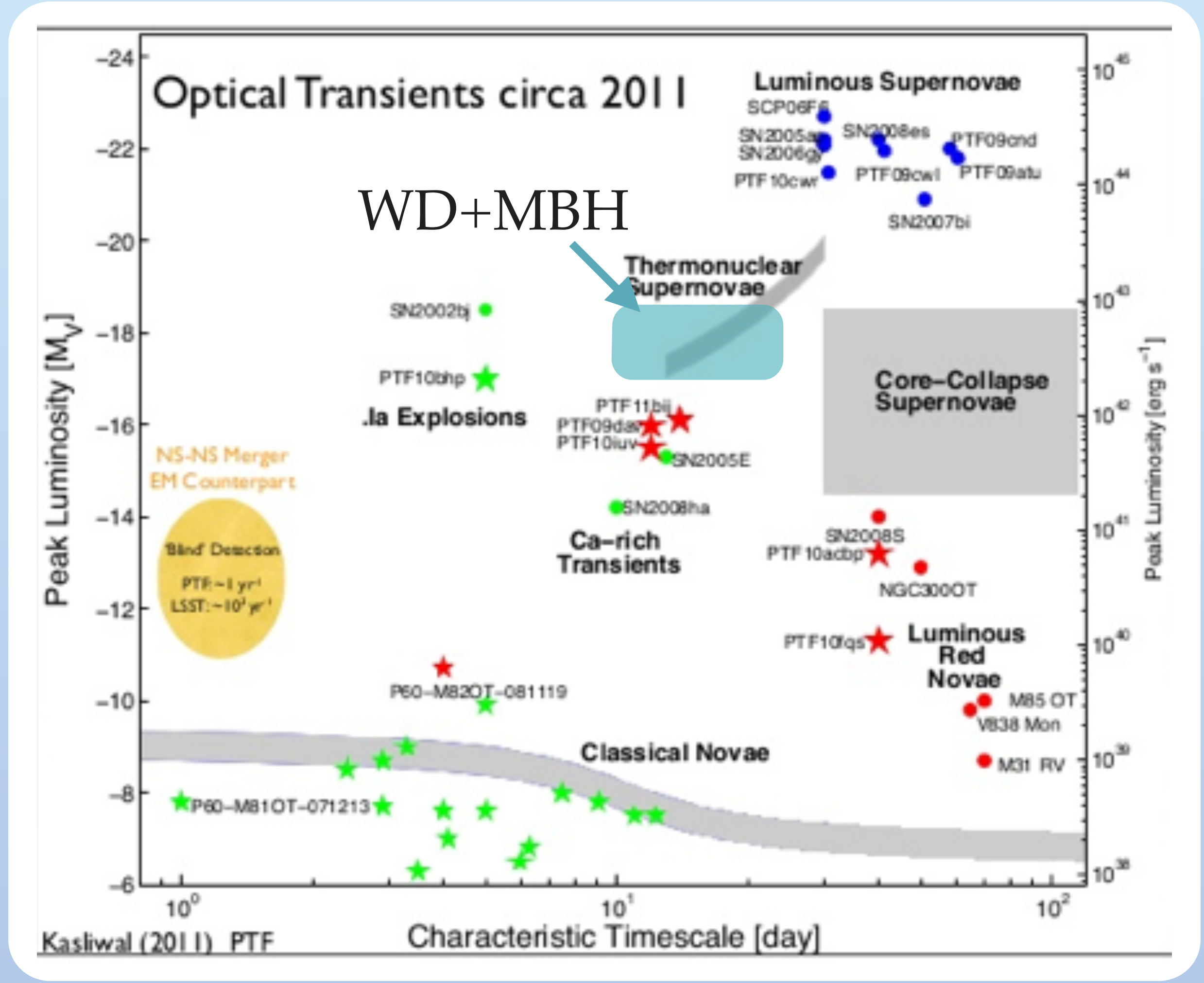


(MacLeod+ in prep)

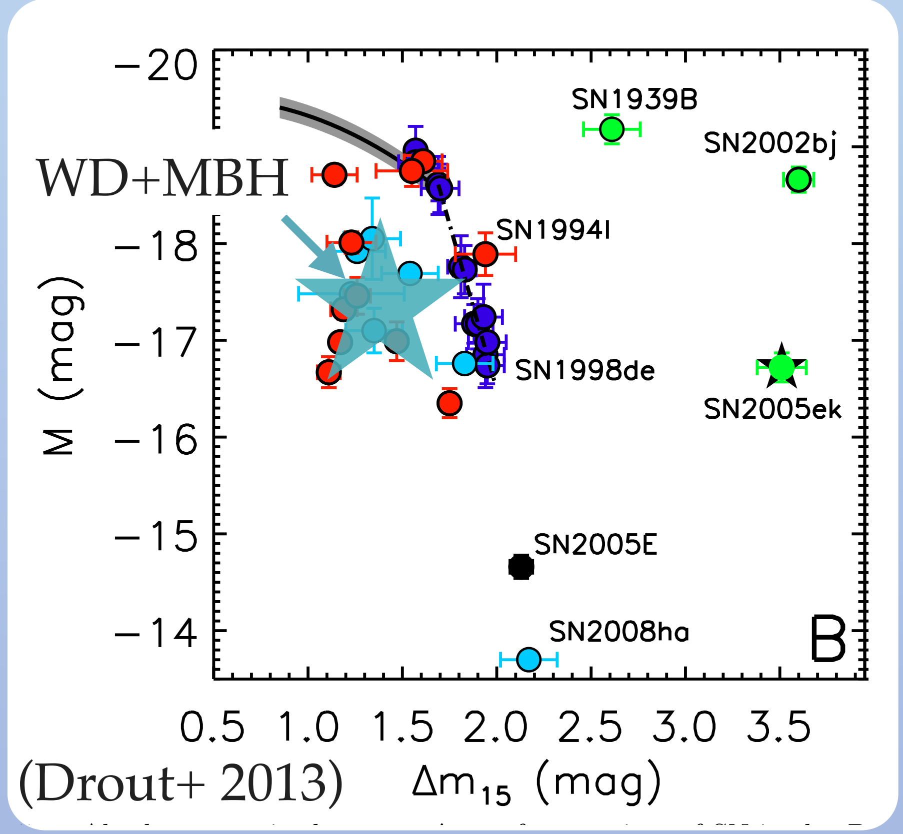
The challenge of identification



Optical transients have similar photometric properties to other thermonuclear SNe



High energy transients share phase space of emerging class of ULGRBs



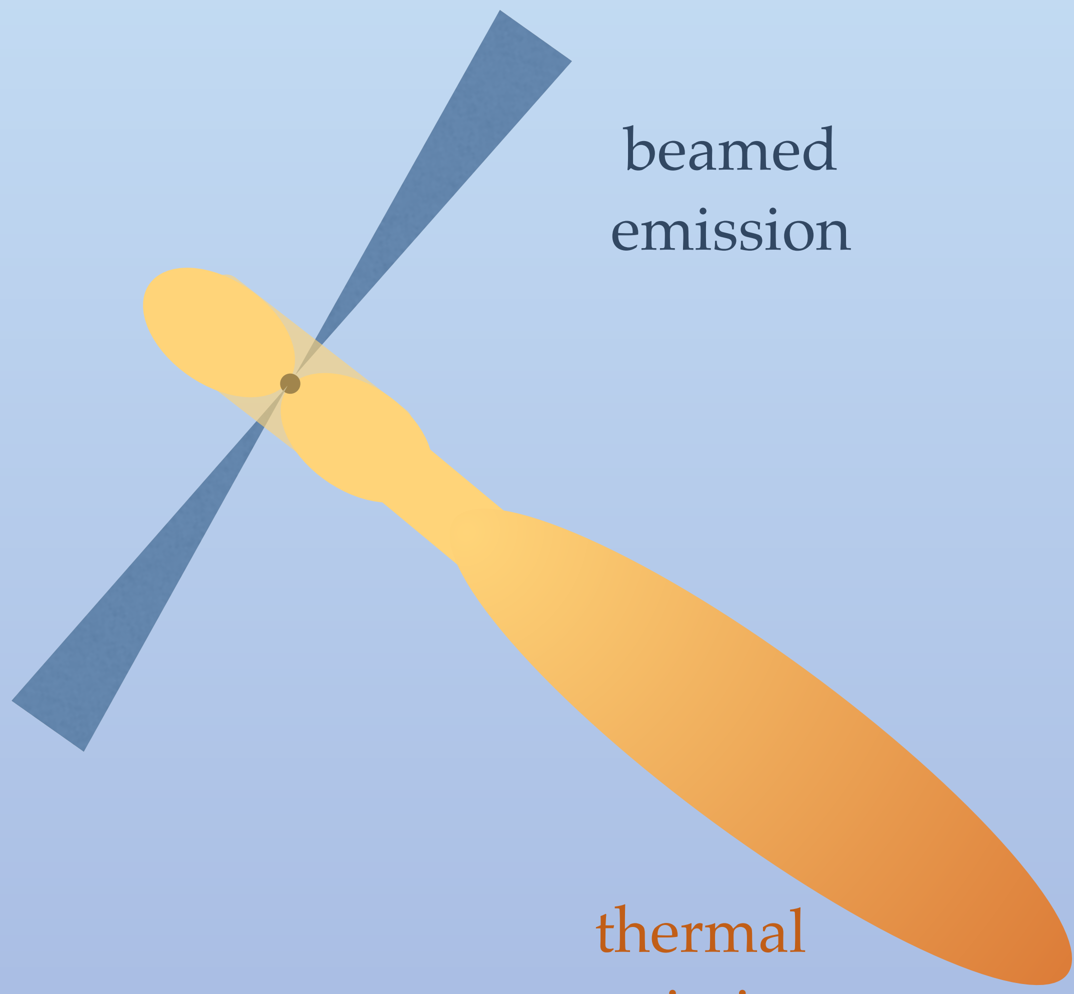
e.g. Phillips (1993) Width-Luminosity relation

Co-detection of beamed and thermonuclear transients

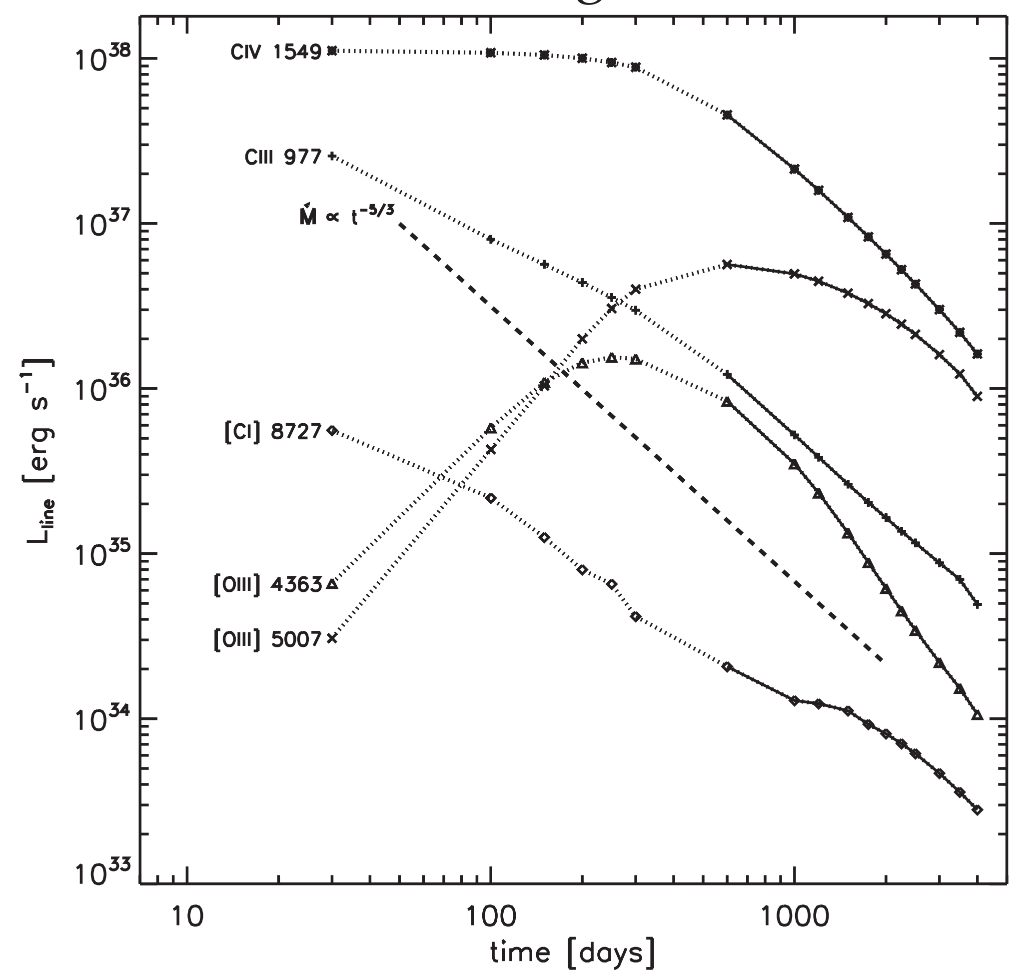
Jet + supernova

with f_{beam}=0.1,
LSST + *Swift-like*
~ 30 f_{MBH} yr $^{-1}$

detection or non-detection can constrain the MBH population & surrounding star cluster properties



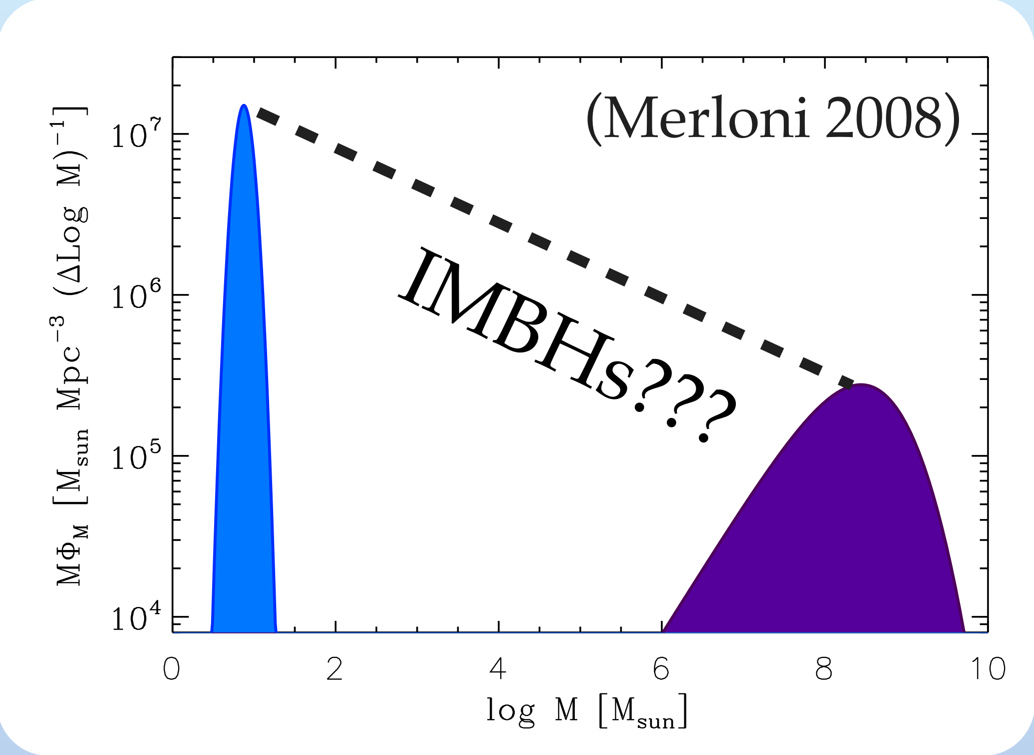
nebular emission e.g. [OIII] t~100d



(Clausen+ 2011)

Conclusions

- WD tidal disruption: an avenue to select IMBH-transients
- High energy signatures: jets & beamed emission from super-Edd feeding
- Optical counterparts: thermonuclear transients in deep encounters
- Multi-wavelength detections as an avenue to firmly identify transients



Detections *or* non-detections constrain the occurrence of MBHs <10^5 msun surrounded by dense stellar clusters.

Thank you!