Ultra-close tidal disruptions of white dwarfs by IMBHs

Haas et al. 2011, ApJ submitted, arXiv:1201.4389

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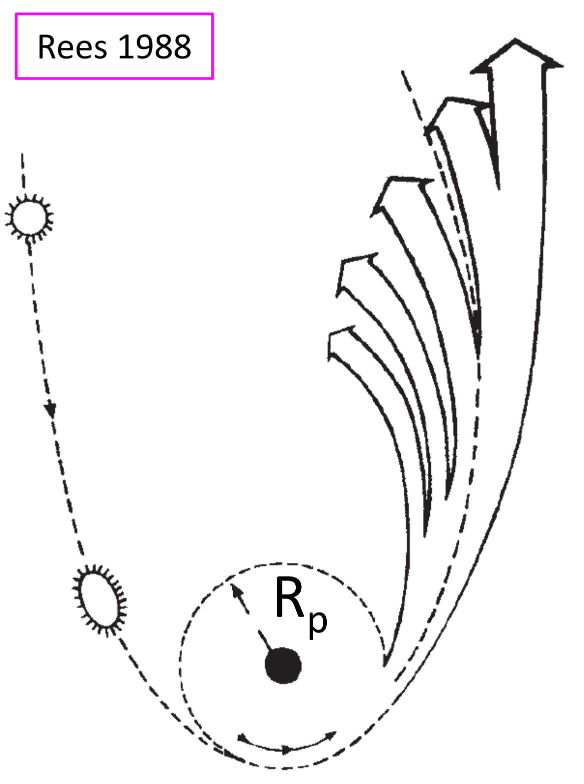
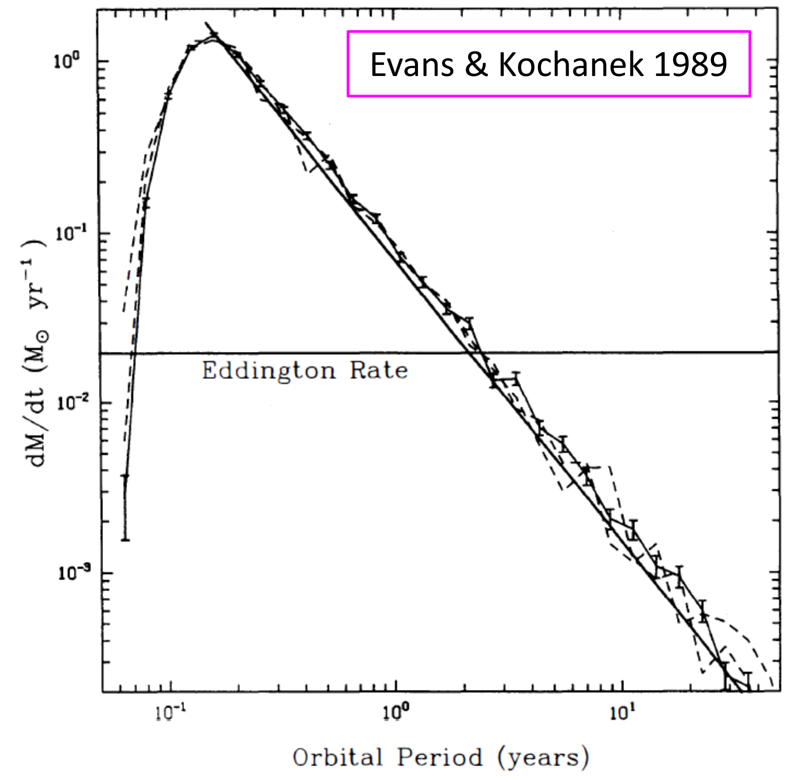
"Normal" tidal disruptions



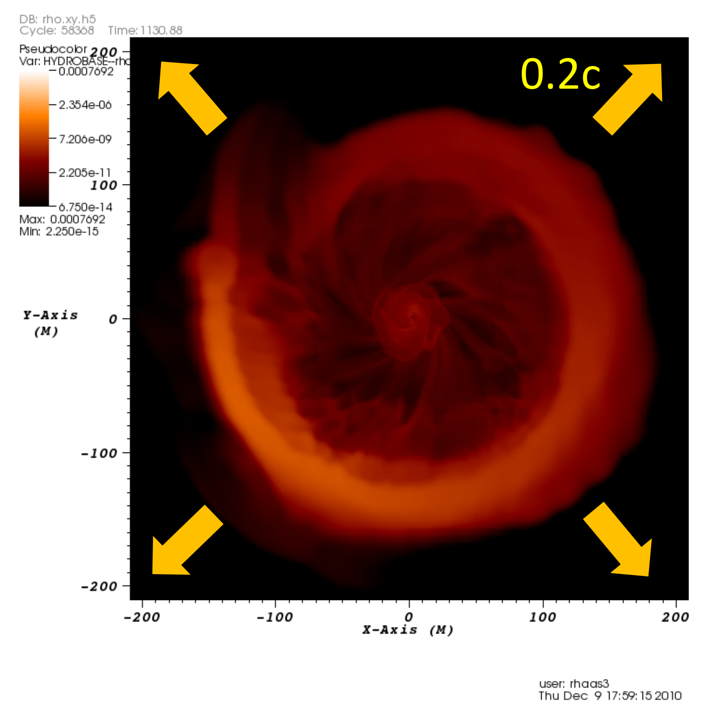
Rees 1988

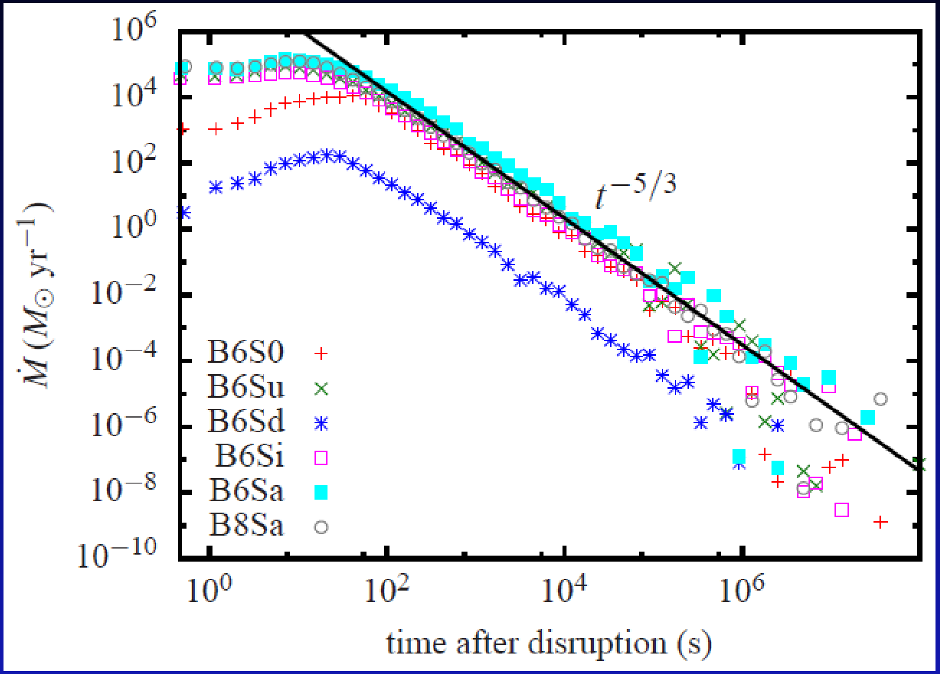


Evans & Kochanek 1989

- Pericenter distance R_p >> gravitational radius R_g
- 50% accreted, 50% expelled (parabolic orbit)
- Debris flying at low speeds in one direction
- Long delay between disruption and fallback (e.g. 2months)
- Low peak accretion rate ~ star mass/delay (e.g. $1M_{sun}$/yr)

Ultra-close tidal disruptions





Haas, Shcherbakov et al. 2011, ApJ submitted

- Pericenter distance R_p = several R_g (ultra-close) ≈ $2R_{WD}$
- Relativistic outflow speeds
- BH spin value/orientation control the disruption
- No delay + extreme accretion rate ($10^4 M_{sun}$/yr)

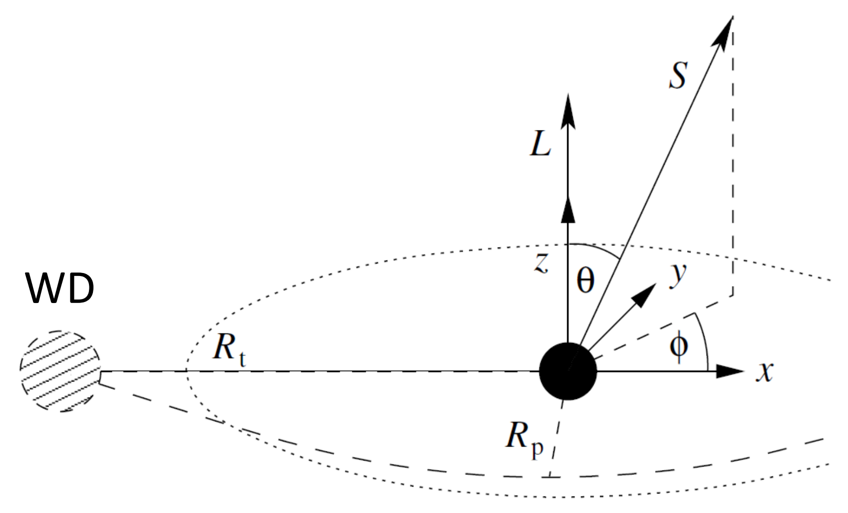
  => sudden strong flare?

Numerical simulations

MayaKranc code (GaTech)

- based on Cactus framework
- numerical GR
- ideal hydro
- Carpet AMR (adaptive mesh)

- No magnetic field
- No radiation
- No nuclear reactions



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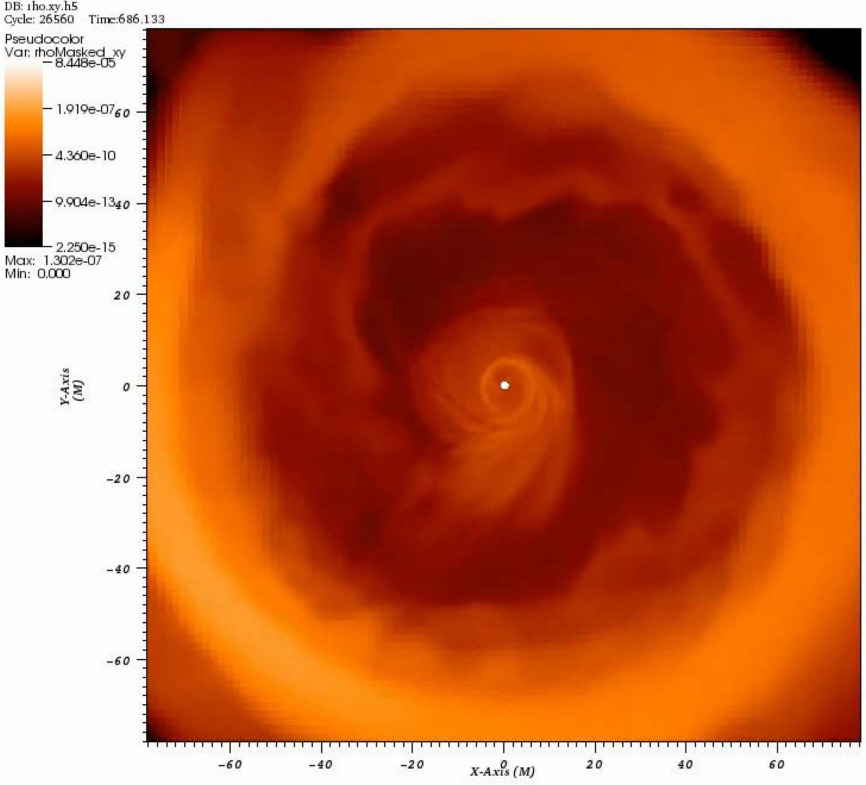
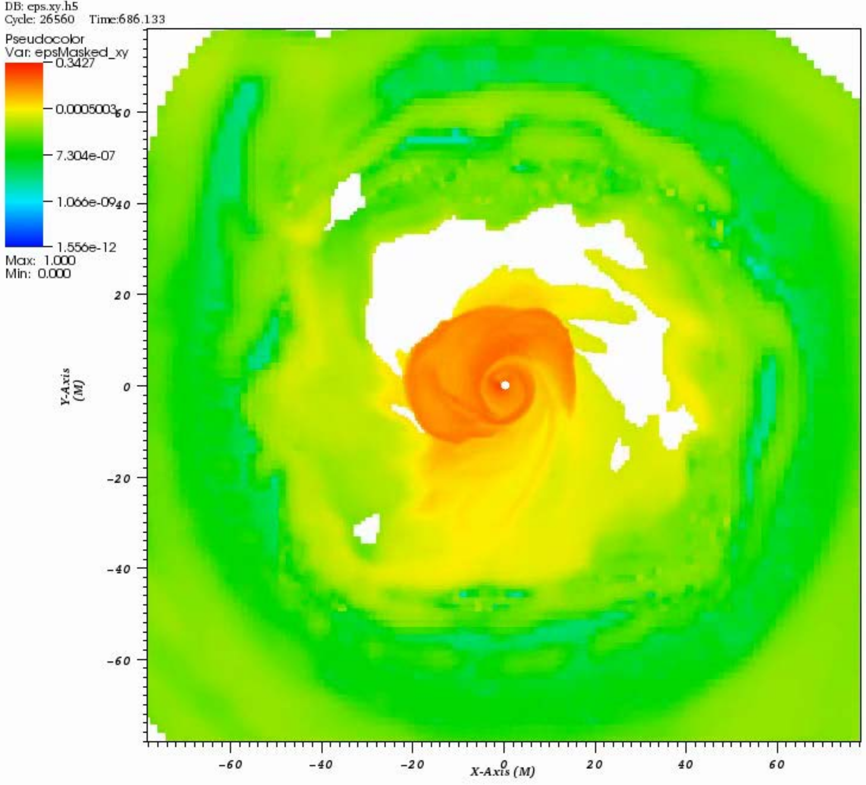
Simulate IMBH ($10^3 M_{sun}$) + white dwarf ($1 M_{sun}$)
for 6s of real time (≈20 orbits)
and extrapolate to 10years

(e.g. C/O WD, tidal ratio R_t/R_p=6, spin a=0.6, tilted spin axis)

Movies “from above”: aligned spin



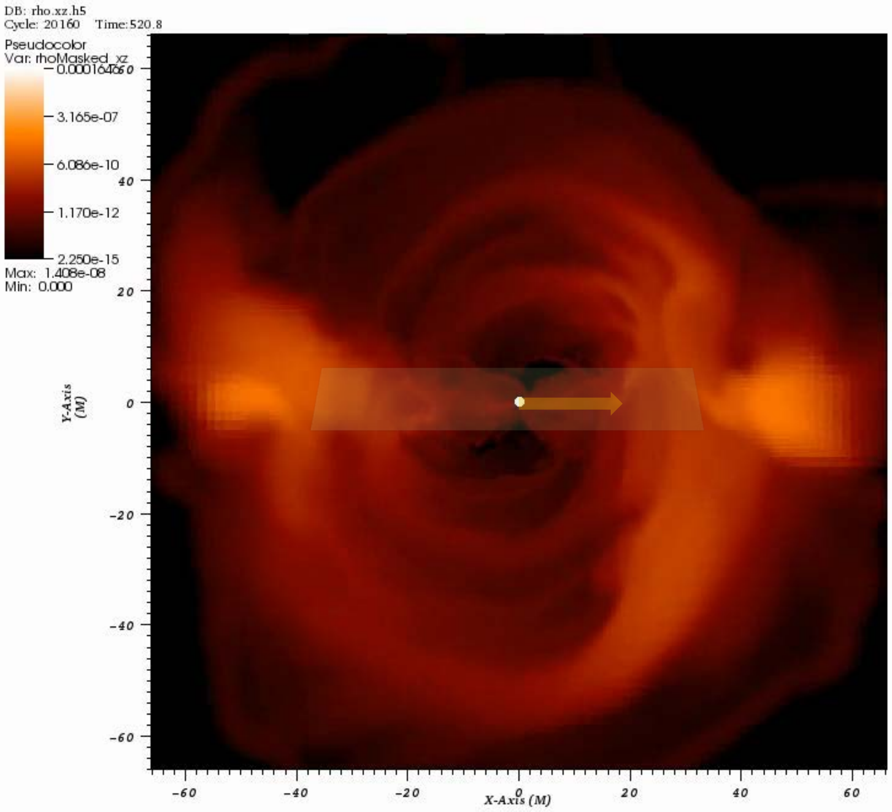
Density (white – highest)



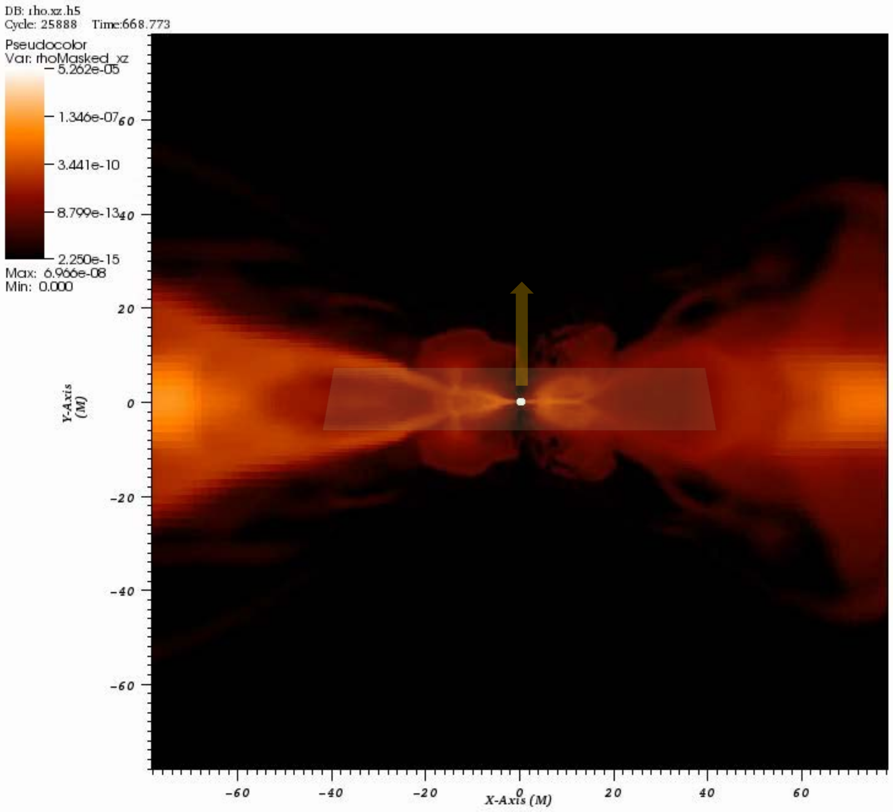
Temperature (red – highest)

Fallback disk has radius ~30M(≈4R_p)

Disruptions in edge-on view



misaligned spin (in disruption plane)



spin aligned w/ angular momentum

pericenter distance R_p=7R_g; tidal radius R_T=40R_g; spin0.6

Debris obscure inner fallback disk
for realistic misaligned spins

Effect of spin/orientation

pericenter distance $R_p = 7R_g$; tidal radius $R_T = 40R_g$; spins 0, 0.6

	Run	f_{acc}	f_{unb}	
spin 0	B6S0	68%	19%	most plunges; small fallback disk
aligned spin 0.6	B6Su	$< 1\%$	60%	non plunges; larger fallback disk
anti-aligned spin 0.6	B6Sd	$> 99\%$	$< 0.5\%$	all plunges; non escapes; no fallback
spin in disruption plane	B6Si	65%	22%	similar to non-spinning?!

f_{acc} – plunges during first 6s (≈20 orbits)
f_{unb} – total unbound fraction
$(1 – f_{acc} – f_{unb})$ – fallback fraction: from t=6s till t=∞

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BH spin/orientation strongly influence an ultra-close disruption

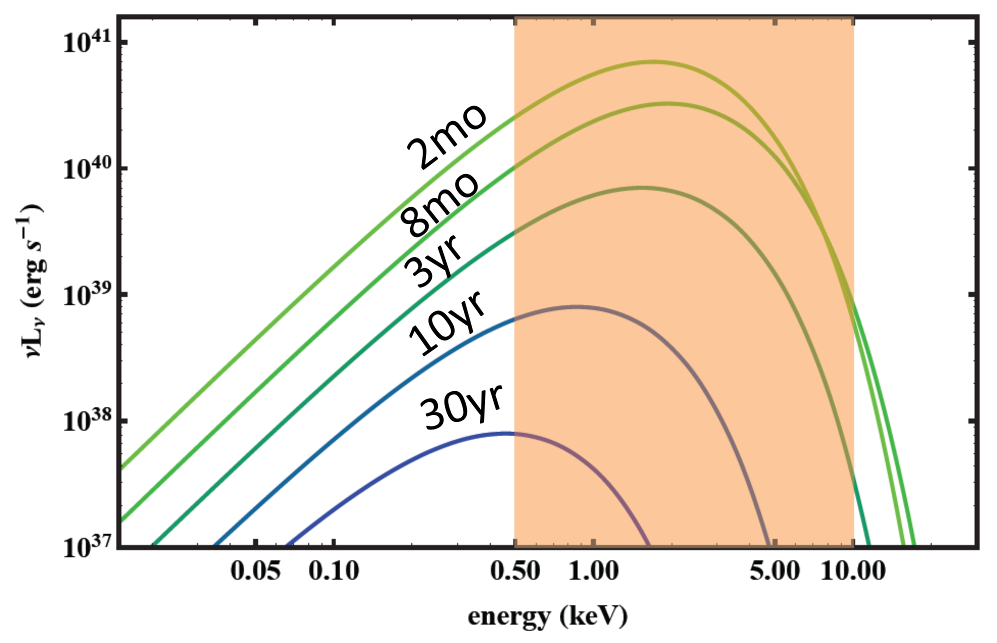
Spectrum of fallback disk

Slim disk model:

trapped photons

Abramowicz et al. 1988

$\dot{M} \sim t^{-5/3}$

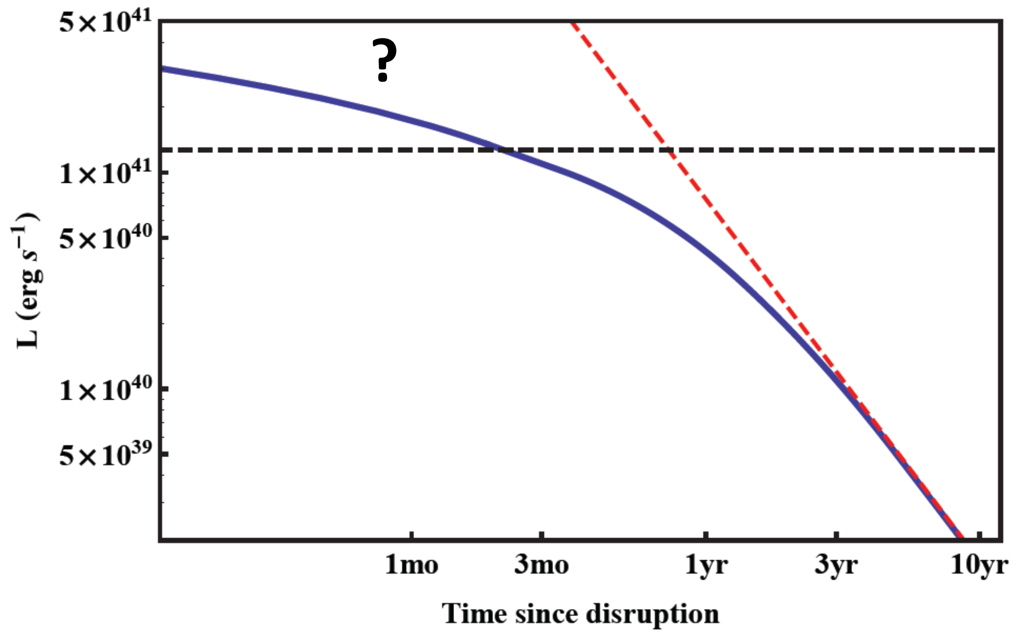


tidal ratio R_t/R_p=6, aligned spin a=0.6

Spectral features

- soft X-rays
- softer at late times

Luminosity of fallback disk



tidal ratio R_t/R_p=6,   aligned spin a=0.6

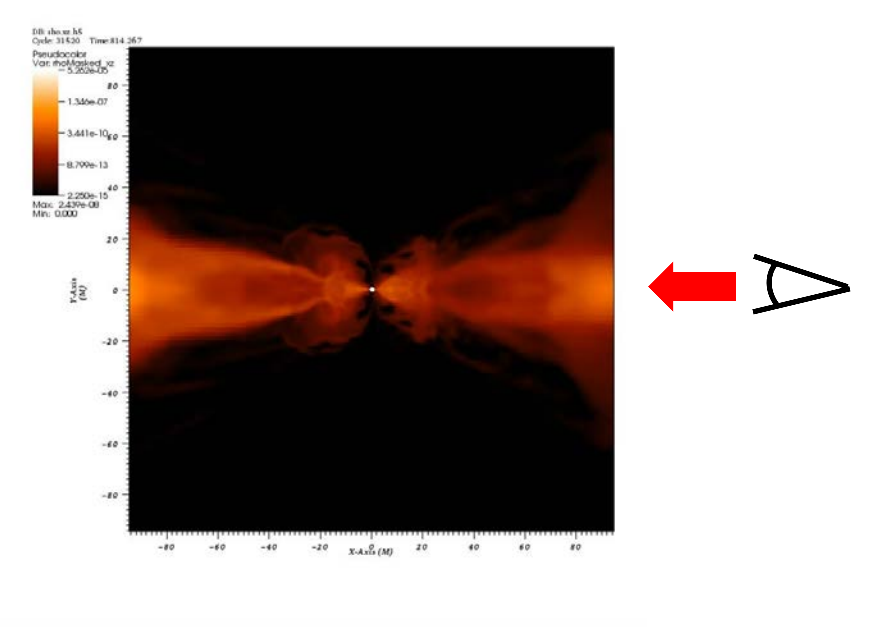
Lightcurve features

- Eddington-limited at t<1yr, sub-Eddington afterwards (no outflow assumed)
- Luminosity approaches $L=0.05\dot{M}c^2$ at late times: slim disk → thin disk

Constant luminosity → constant efficiency
t<1yr t>1yr

Fallback disk can be obscured

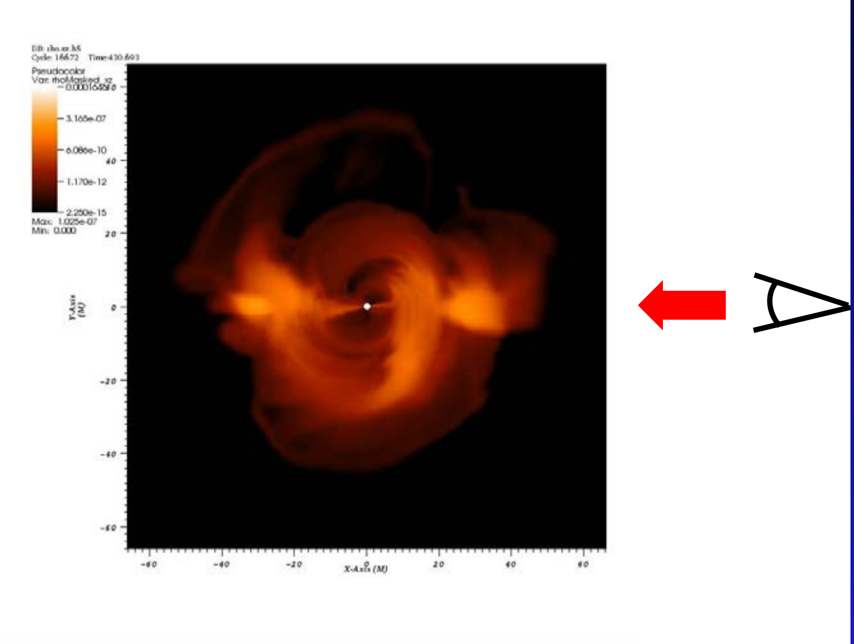
By itself – edge-on view



Thick disks are often viewed edge-on

Softer spectrum, slightly lower L

By outflowing debris



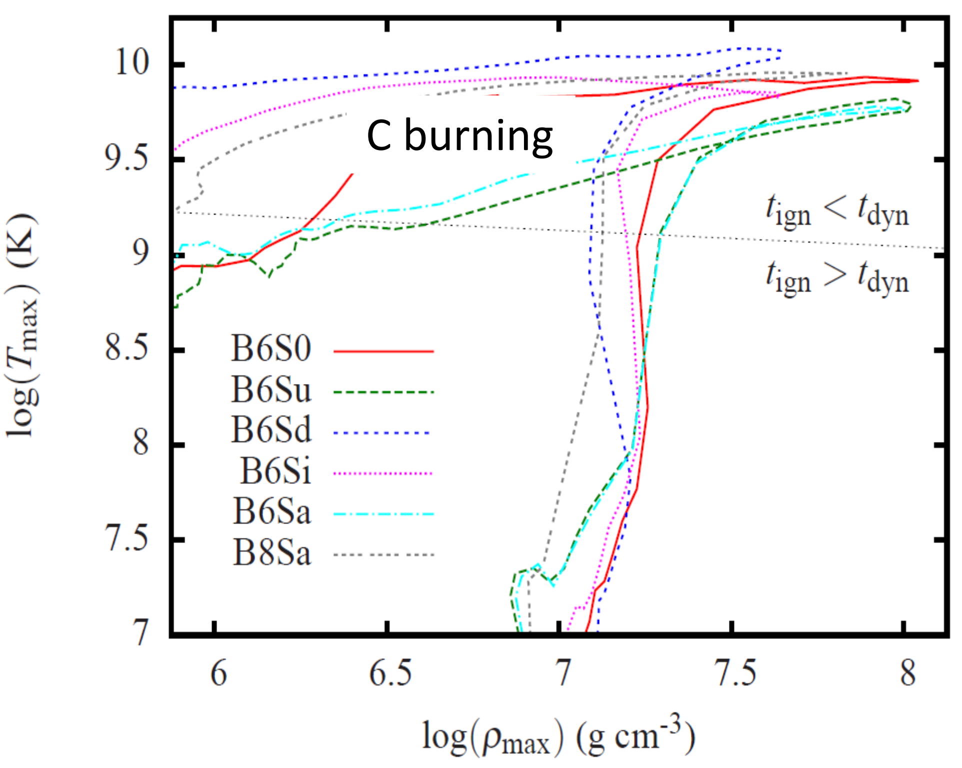
Ultra-close disruptions
with misaligned spins

Completely obscured till t~1yr,
then expanding debris become optically thin

Supernovae from tidal disruptions

If density and temperature are high enough for long enough
=> nuclear reactions / supernovae ignition

Rosswog et al. 2009



White dwarfs should explode

our work

Nuclear energy release < $0.01mc^2$

Debris dynamics + early fallback are unchanged

Disruption rates in globular clusters

Space density of globular clusters: ~ 10Mpc^{-3}

McLaughlin 1999

Brodie & Strader 2006

Event rate ~ 10^{-8}/yr/cluster (10^{3}M$_{sun}$ IMBH)

Baumgardt et al. 2004

Total ~ 100/yr within Gpc^{3} (WD-IMBH) for 1IMBH per cluster

However, L$_{X}$ ~ 10^{41}erg/s is very faint

Need very sensitive X-ray surveys (10^{-16}erg cm^{-2} s^{-1}):

WFXT

Conconi et al. 2010

Disruption of a MS star by IMBH:

Event rate ~ 10^{-7}/yr/cluster (10^{3}M$_{sun}$ IMBH)

Lasts for ~ 30 years

Baumgardt et al. 2004

Ramirez-Ruiz & Rosswog 2009

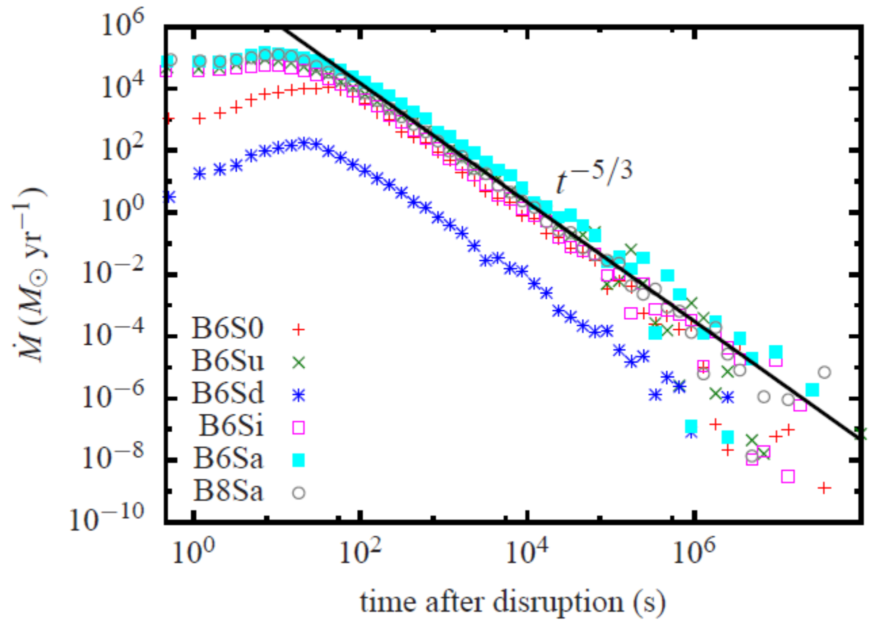
Total ~ 1 event within 30Mpc (MS-IMBH)

Candidate: ULX in NGC1399 at d=20Mpc

Irwin et al. 2010

- ❑ Optical lines from irradiated debris
- ❑ X-ray spectrum is consistent with thin disk for 10^{3}M$_{sun}$ BH
- ❑ Disruption dynamics is consistent w/ MS star + IMBH

GRB-like jets from tidal disruptions?



Blandford – Znajek process:

$$L_{\text{jet,true}} \sim 0.1\dot{M}c^2 = 6\cdot 10^{49}\,\text{erg s}^{-1}$$

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$$L_{\text{iso}} \sim 3\cdot 10^{51}\,\text{erg s}^{-1}$$

$$\text{for} \quad \theta = 15^\circ$$

✓ Event duration ~200s (long GRBs)
✓ Isotropic luminosity can reach 10^{52}erg/s
✓ Disk dynamical time 30s

Caveats:

Need 1mln times stronger regular magnetic field
(but Swift J1644+57 amplified B-field quickly?)

Conclusions

- Ultra-close disruptions is a special regime
- Spin value/orientation play major role

- IMBH+WD can make fast GRB-like transient
- t<1 yr – Super-Eddington, t>1yr – thin disk
- Disk can be obscured by debris till t~1yr
- Huge potential for SNe and GRBs