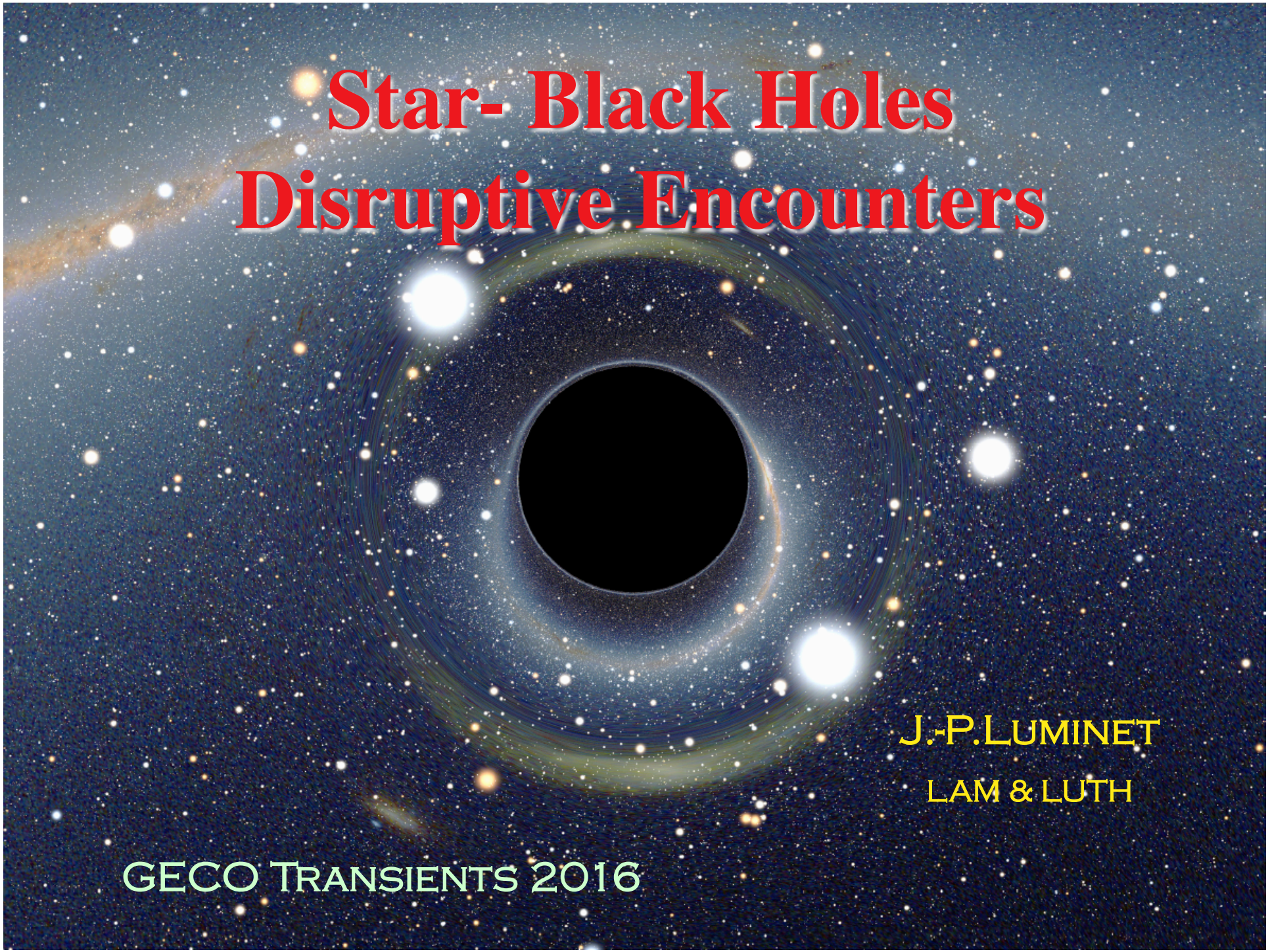

Star- Black Holes
Disruptive Encounters
J.-P.Luminet
LAM & LUTH
GECO Transients 2016

Characteristic distances

Accretion radius

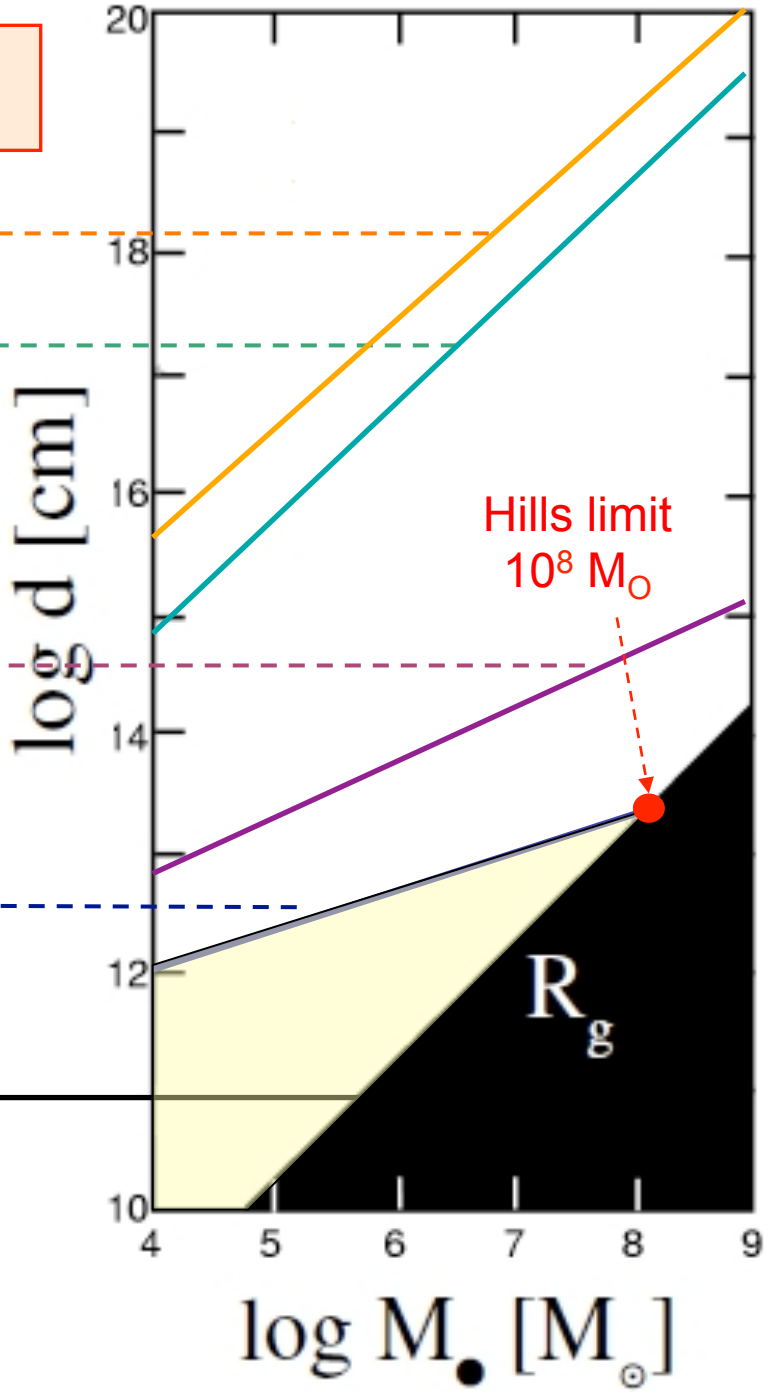
Collision radius

Ablation radius

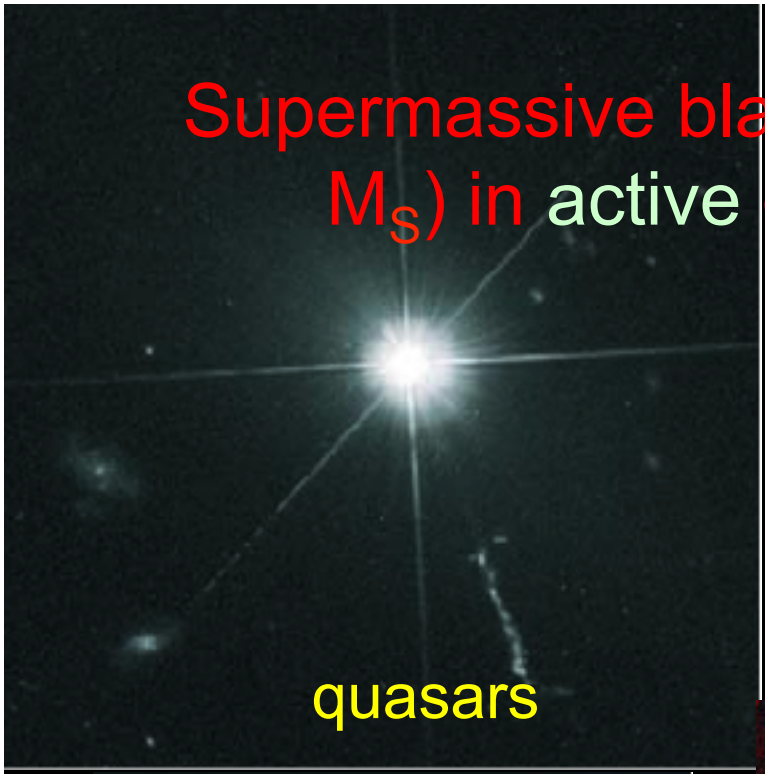
Tidal radius

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

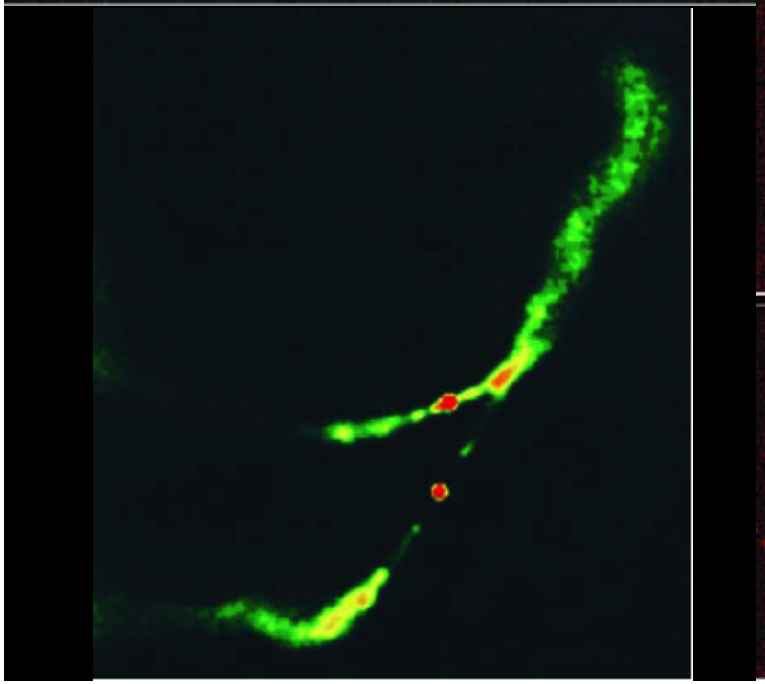
BH's gravitational radius

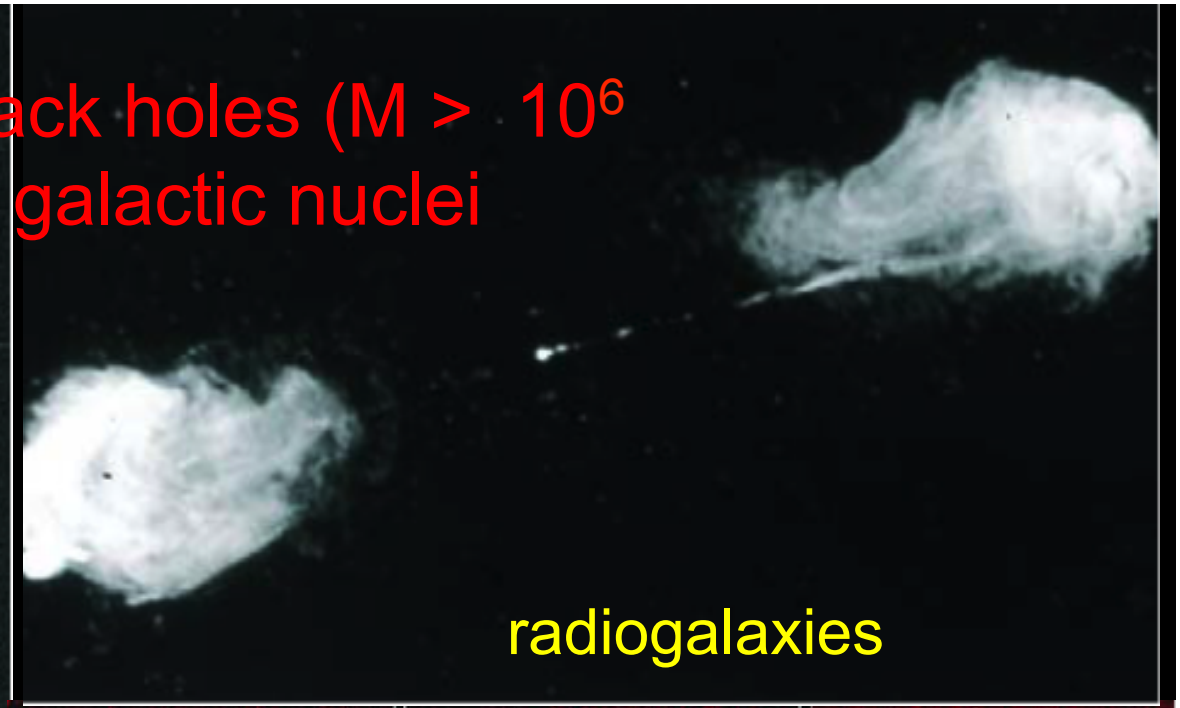


Supermassive black holes ($M > 10^6 M_S$) in active galactic nuclei

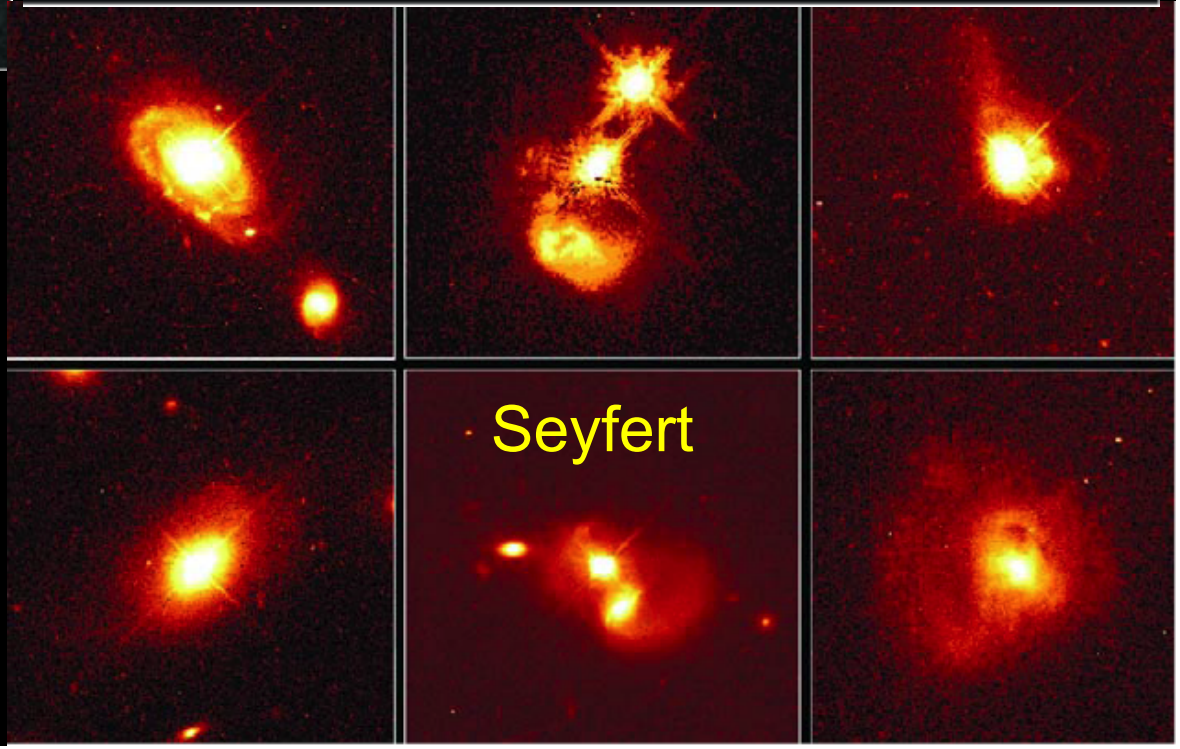


quasars



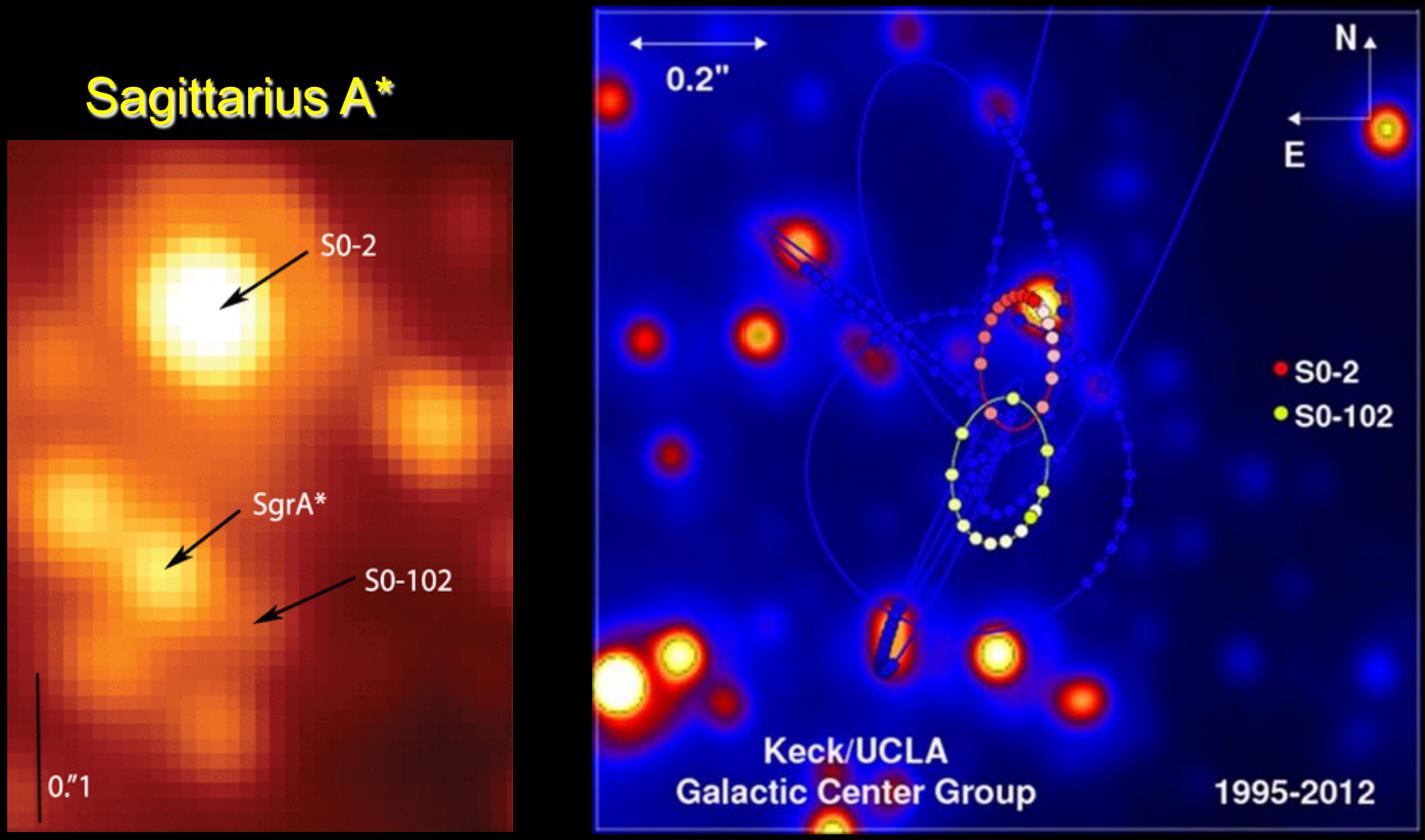


radiogalaxies



Seyfert

Massive black holes ($M \sim 10^6 M_S$) in quiescent galactic nuclei



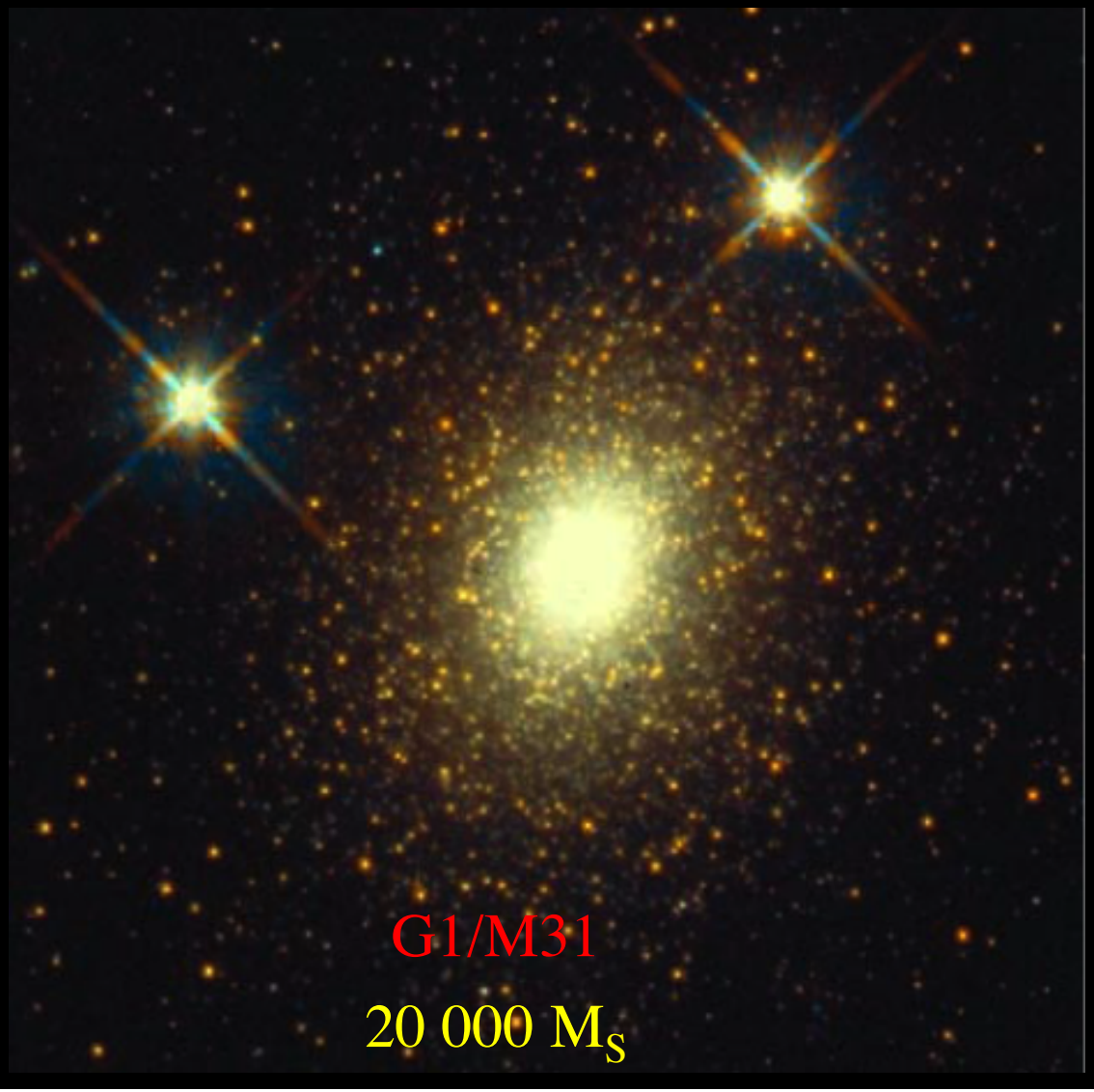
$M \quad 4 \times 10^6 M_S)$

Intermediate mass black holes ($10^3 < M < 10^6\ M_S$)

in globular clusters

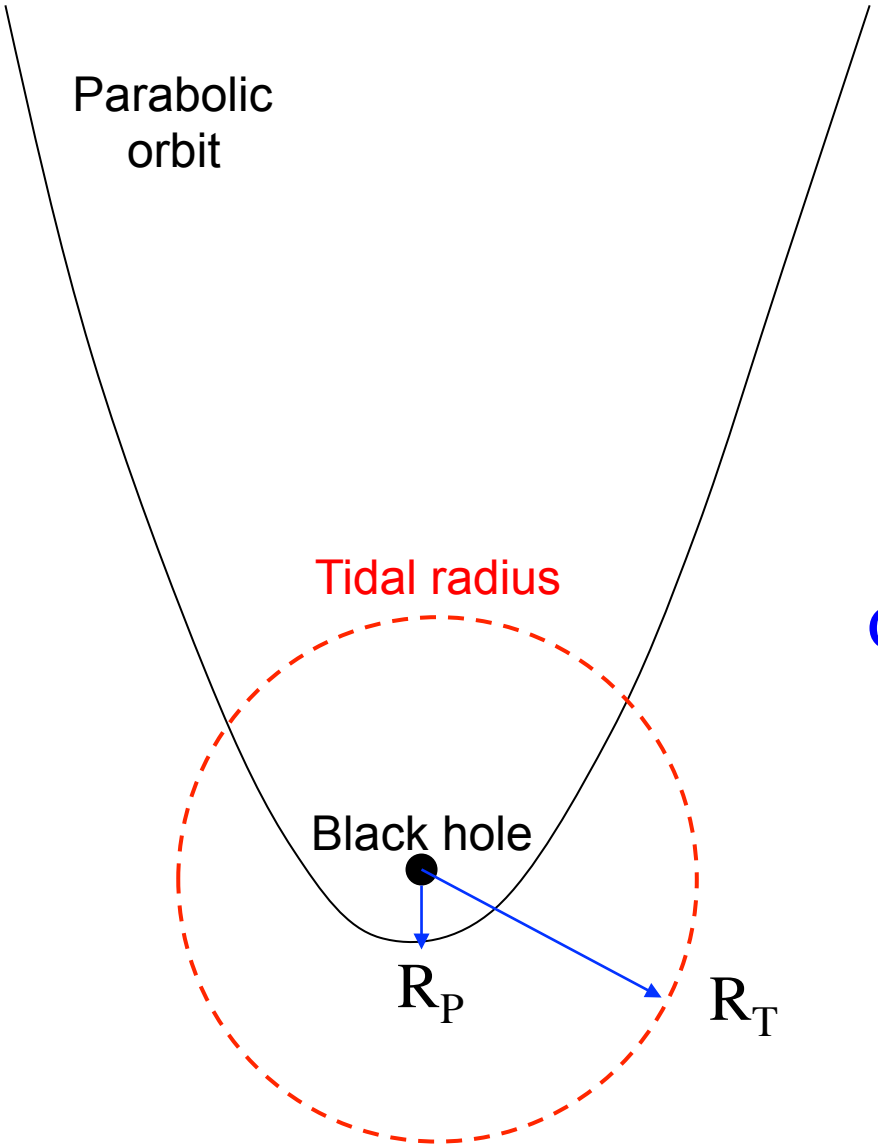
M15

4000 M_S



G1/M31

20 000 M_S



Crucial parameter :

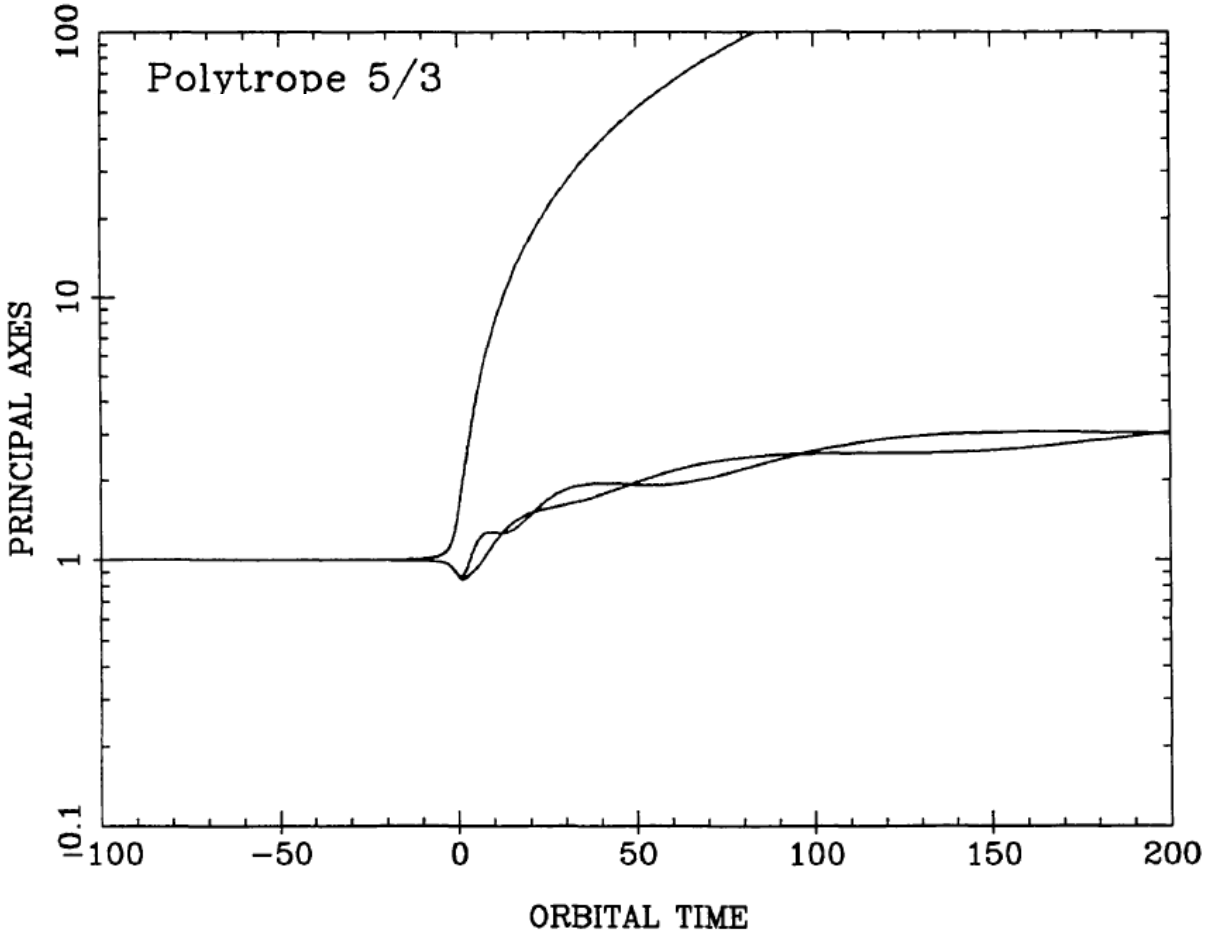
the penetration factor

Carter & Luminet (*Nature*, 1982)

$$\beta \equiv \frac{R_T}{R_p}$$

Slight penetration ($\beta \sim 1$) in the tidal radius

Disruption process in the ellipsoidal model
(Luminet & Carter, 1986)

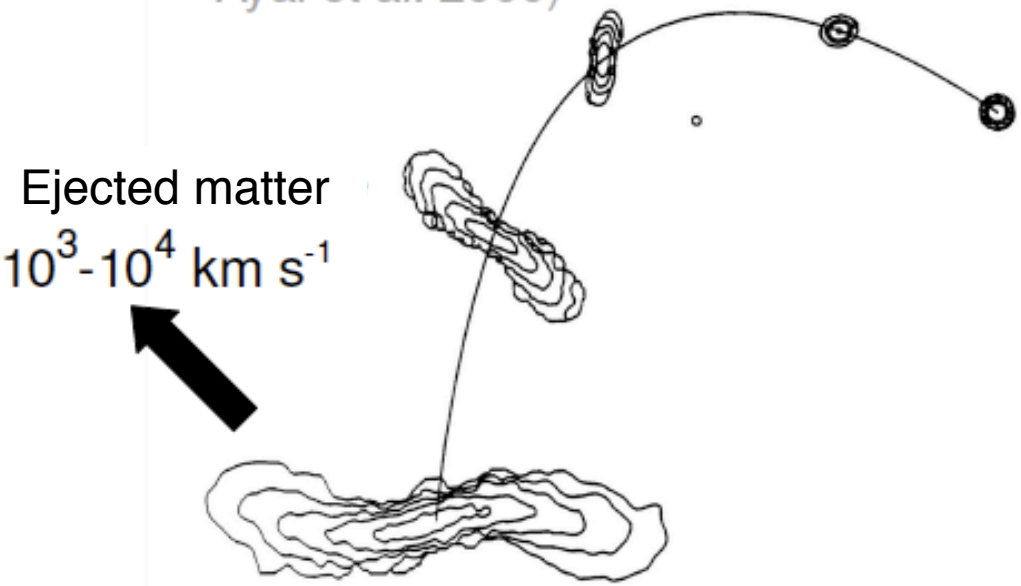


« cigar-like »
configuration after leaving the tidal radius

Disruption process reproduced by

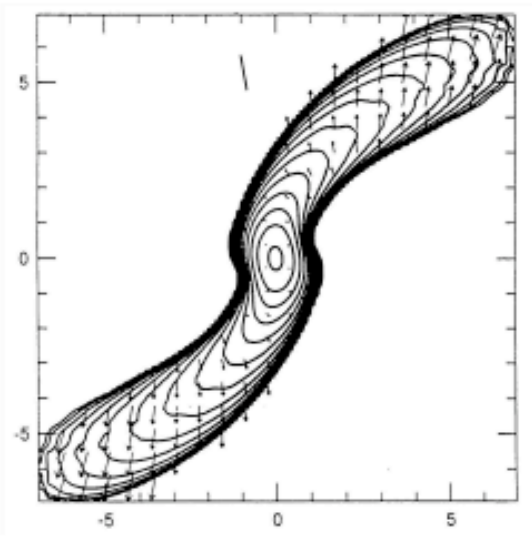
hydrodynamical simulations

(e.g. Nolthenius & Katz 1982; Evans & Kochanek 1989; Laguna et al. 1993; Khokhlov et al. 1993; Frolov et al. 1994; Fulbright 1995; Diener et al. 1997; Ayal et al. 2000)



« cigar-like » configuration after leaving the tidal radius

(Evans & Kochanek 1989)

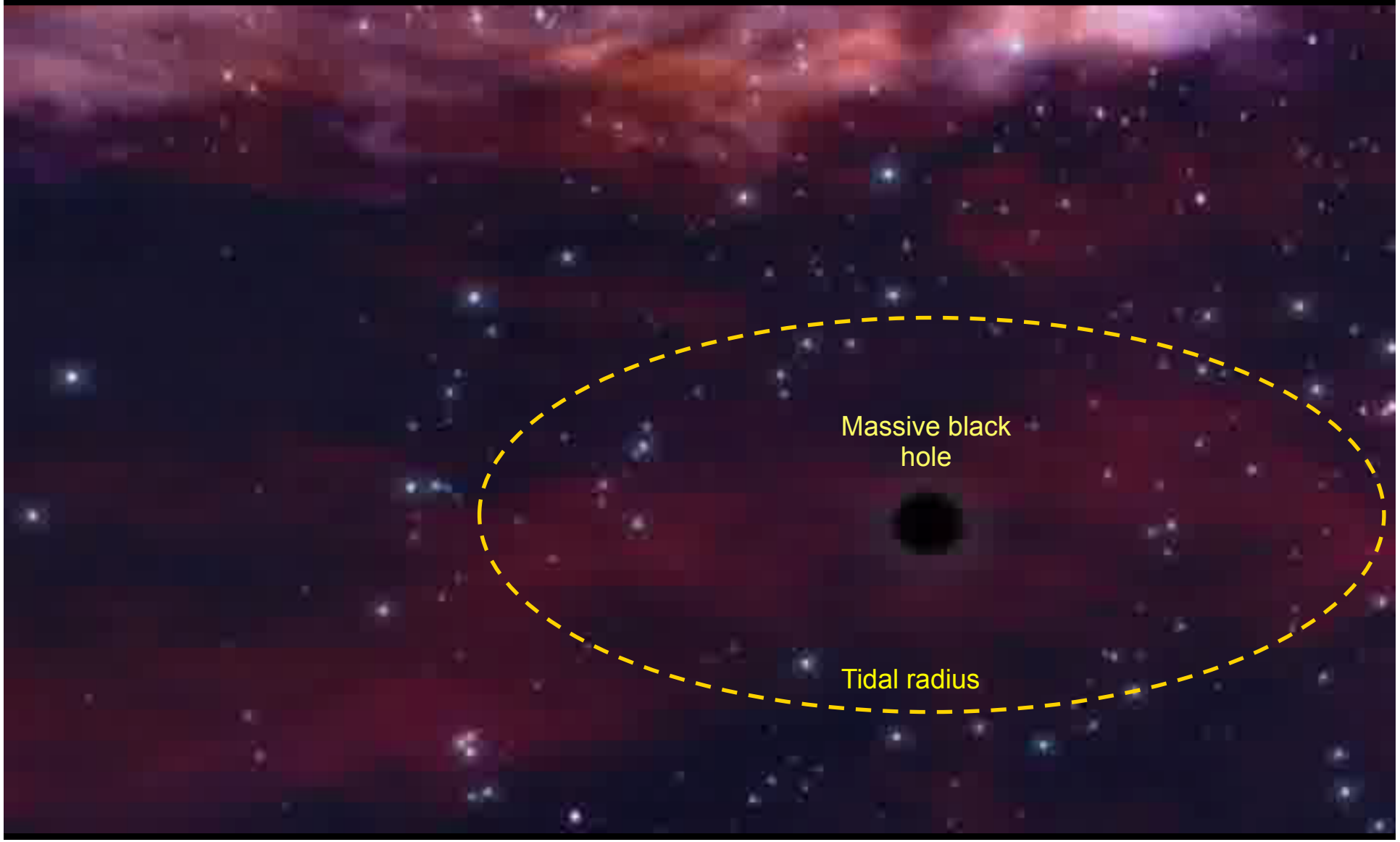


« S-like » configuration at the periastron

(Frolov et al. 1994)

Accretion of stellar debris (50%) ➔ Tidal Flares

Lidskii & Ozernoy (1979), Rees (1988)



X-UV-optical luminous flares

Detection (Chandra, Galex, Pan-starrs…) of flares from (non active) galactic nuclei

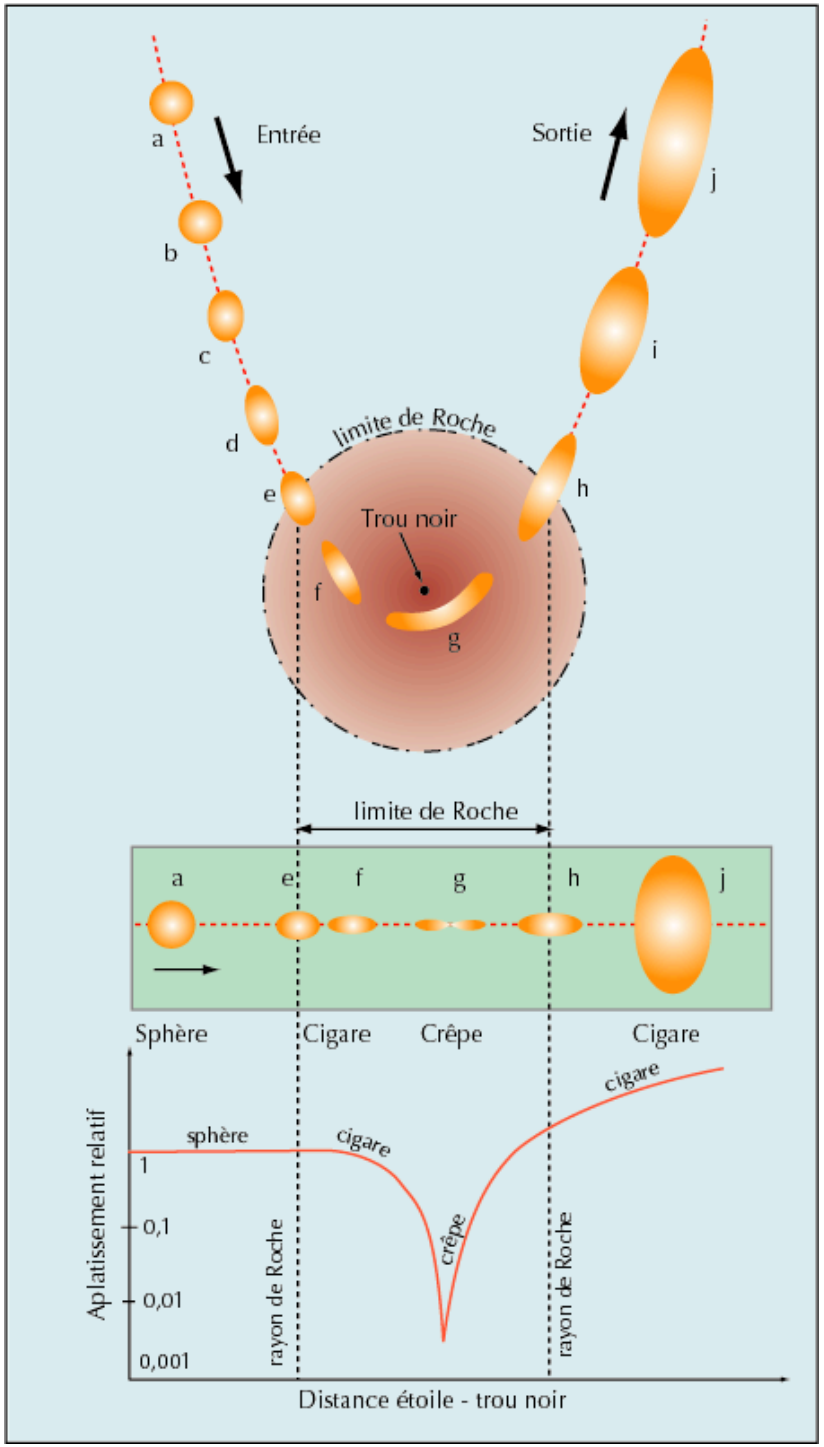
(Komossa *et al*., Saxton *et al*. , Esquej *et al*., Gezari *et al*., etc.)

« Relativistic » Tidal Flares

Detection (Swift) of hard-X flares (L_x ~10^{47} ergs)

(Zauderer et al. 2011, Cenko et al. 2012)

⟹ Relativistic jets from tidal ejecta ?

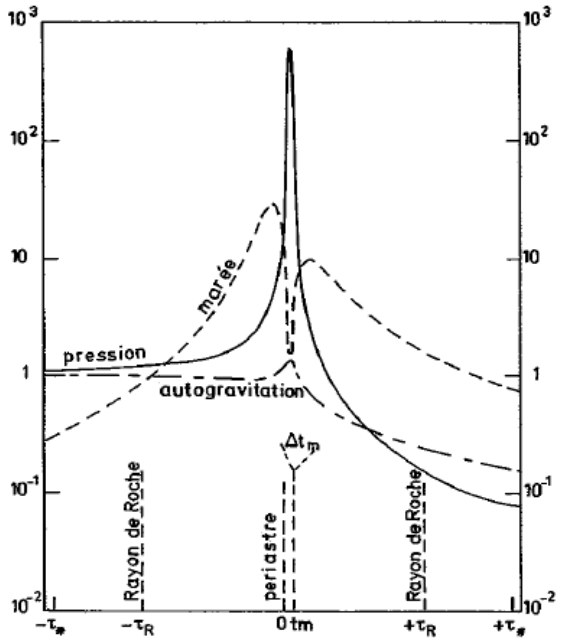


The Pancake Effect

(Carter & Luminet, *Nature*, 1982)

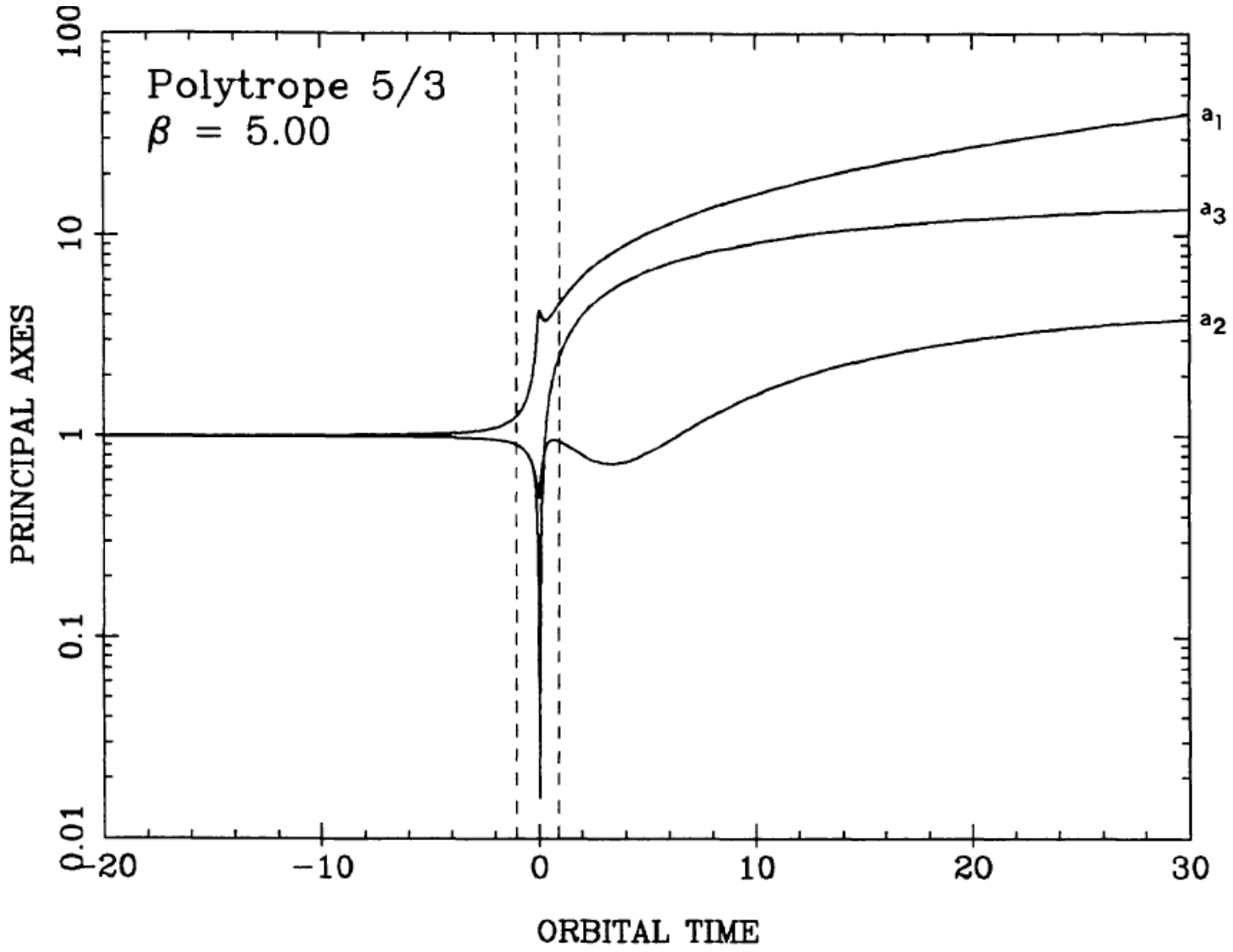
Fixed compressive principal direction of the tidal tensor in the « vertical » direction ==>

deep penetration ($\beta > 3$)



Deep penetration ($\beta > 3$) in the tidal radius

Disruption process in the ellipsoidal model
(Luminet & Carter, 1986)



Explosive stellar disruption ?

- Compression and heating strongly dependent from the penetration factor

Maximum values for an ideal gas with polytropic index 5/3 :

(Carter & Luminet 1983; Luminet & Carter 1986)

$$\rho^{m}_{\star} \approx \beta^{2/(\gamma-1)} \rho_{\star} \qquad \gamma = 5/3 \qquad \approx 10^{6}\ \mathrm{g\ cm^{-3}}$$

$$T^{m}_{\star} \approx \beta^{2} T_{\star} \qquad \beta \geq 10 \qquad \approx 10^{9}\ \mathrm{K}$$

$$\Delta t^{m}_{\star} \approx \beta^{-(\gamma+1)/(\gamma-1)} \tau_{\star} \qquad \approx 0.1\ \mathrm{s}$$

- ✔ Conditions required for explosive thermonuclear reactions

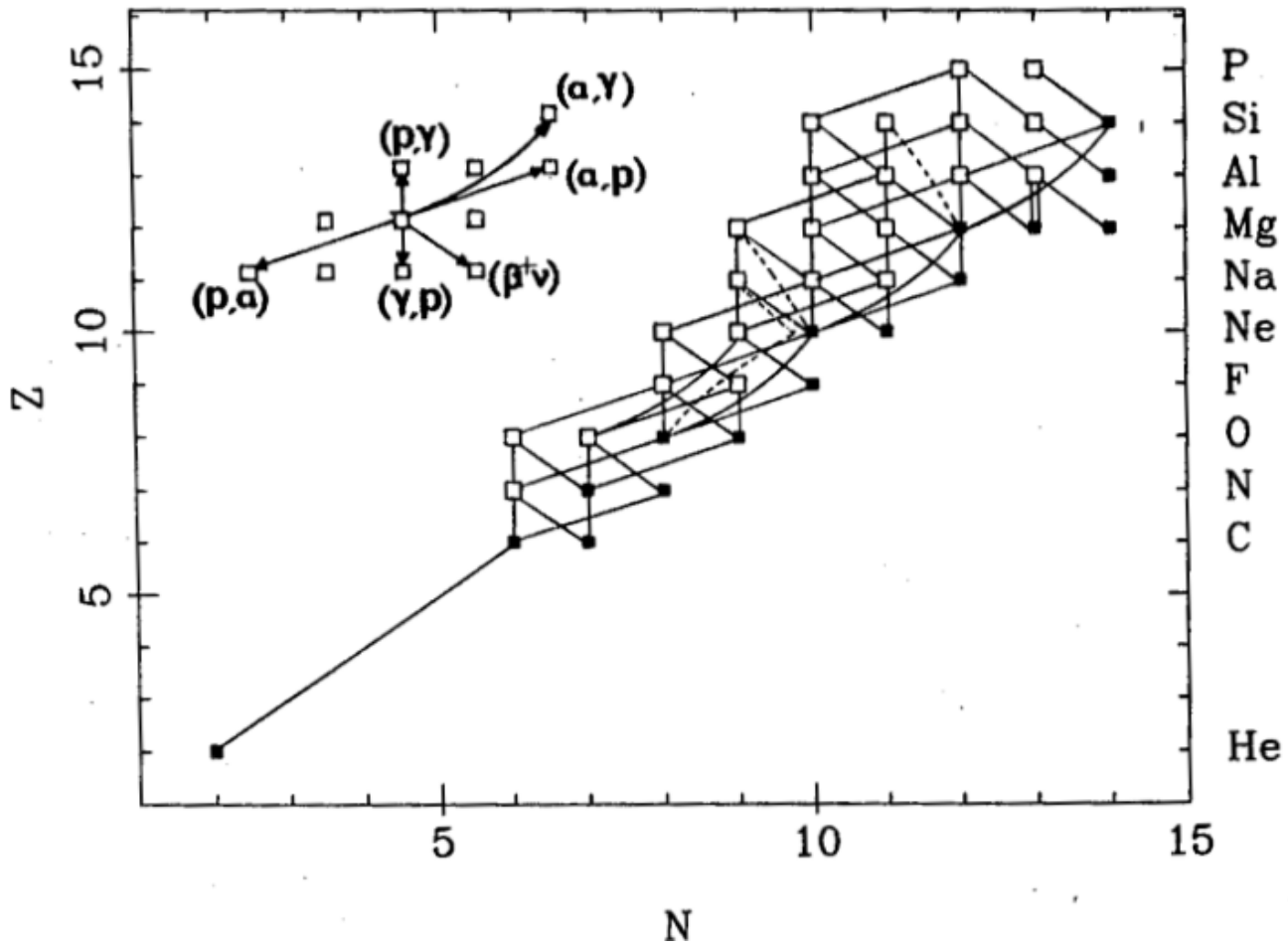
Nuclear flow in pancake stars

Luminet & Pichon 1989a

Temperature > 10^8-10^9 K

Density > 10^5-10^6 g/cc

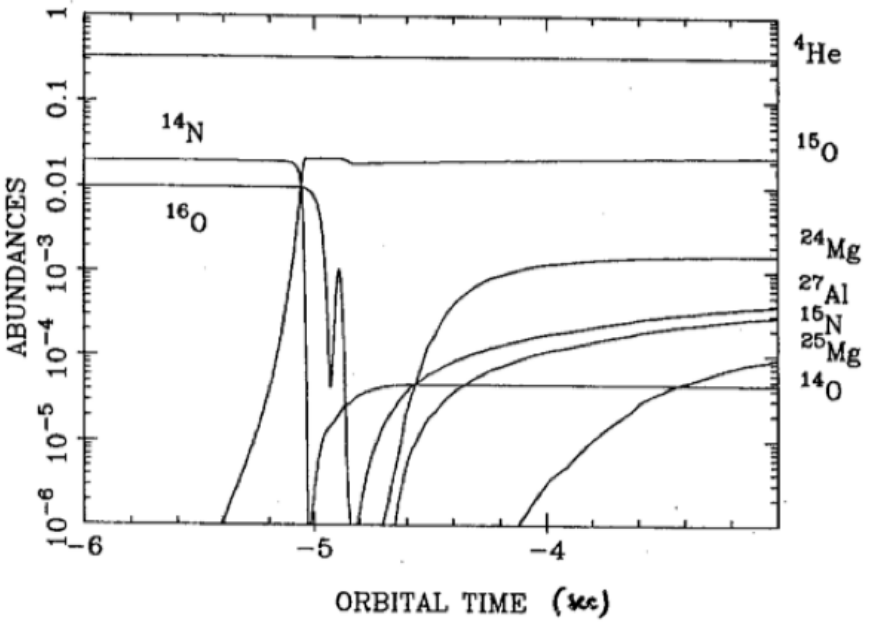
Timescale < 1 sec

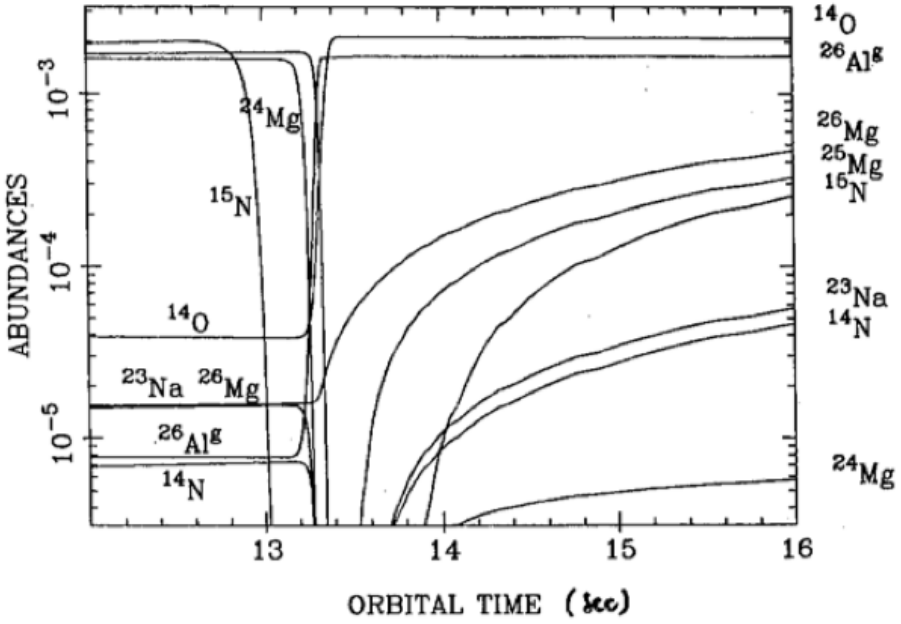


Alpha/proton capture process

Pancake nucleosynthesis

$M_{bh} = 10^5 M_S / M_* = 1 M_S$ / Penetration factor $\beta=15$





1rst pancake

2nd pancake

Luminet & Pichon 1989

Detonation of degenerate stars

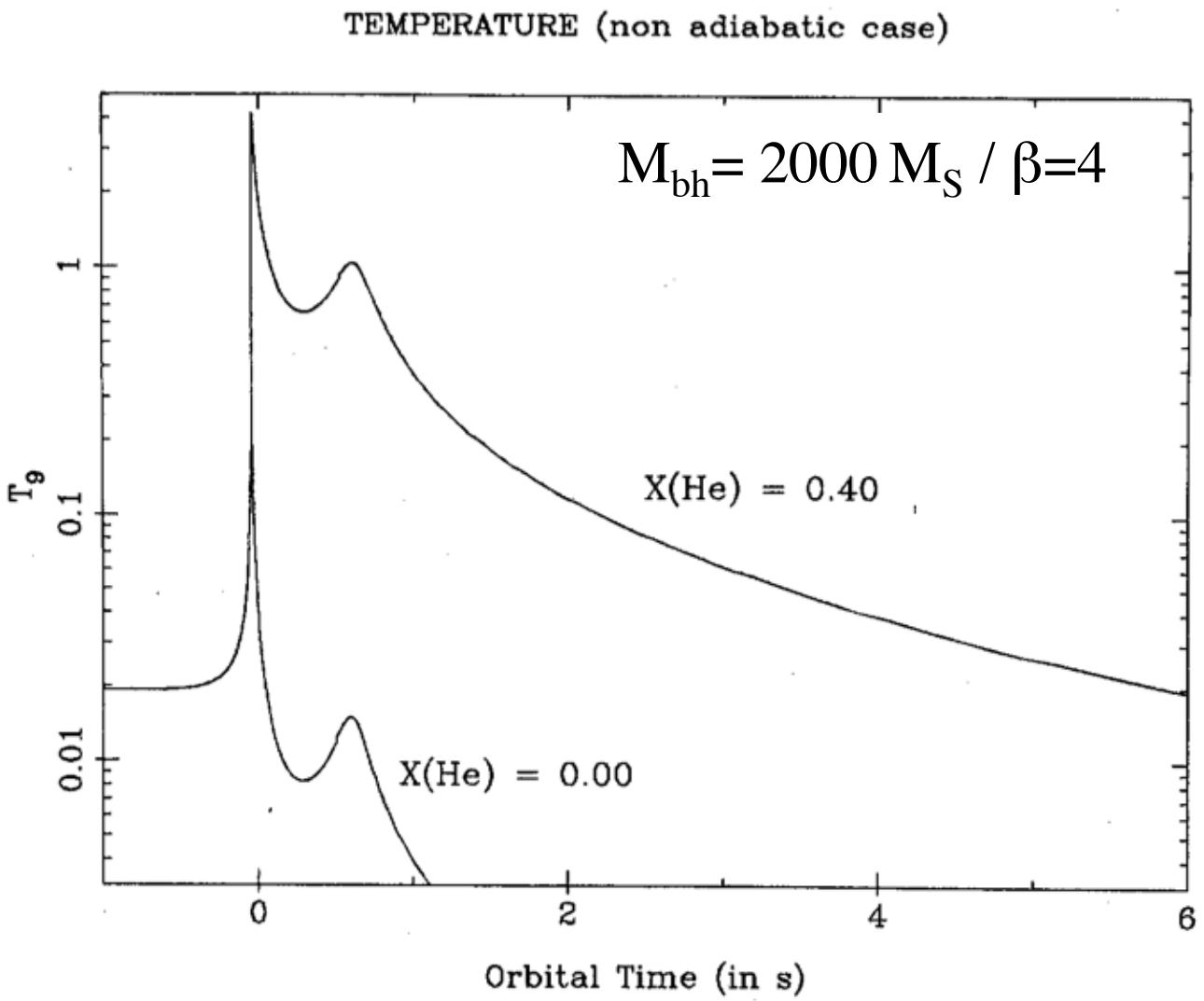
- C-O WD :

Energy generation negligible

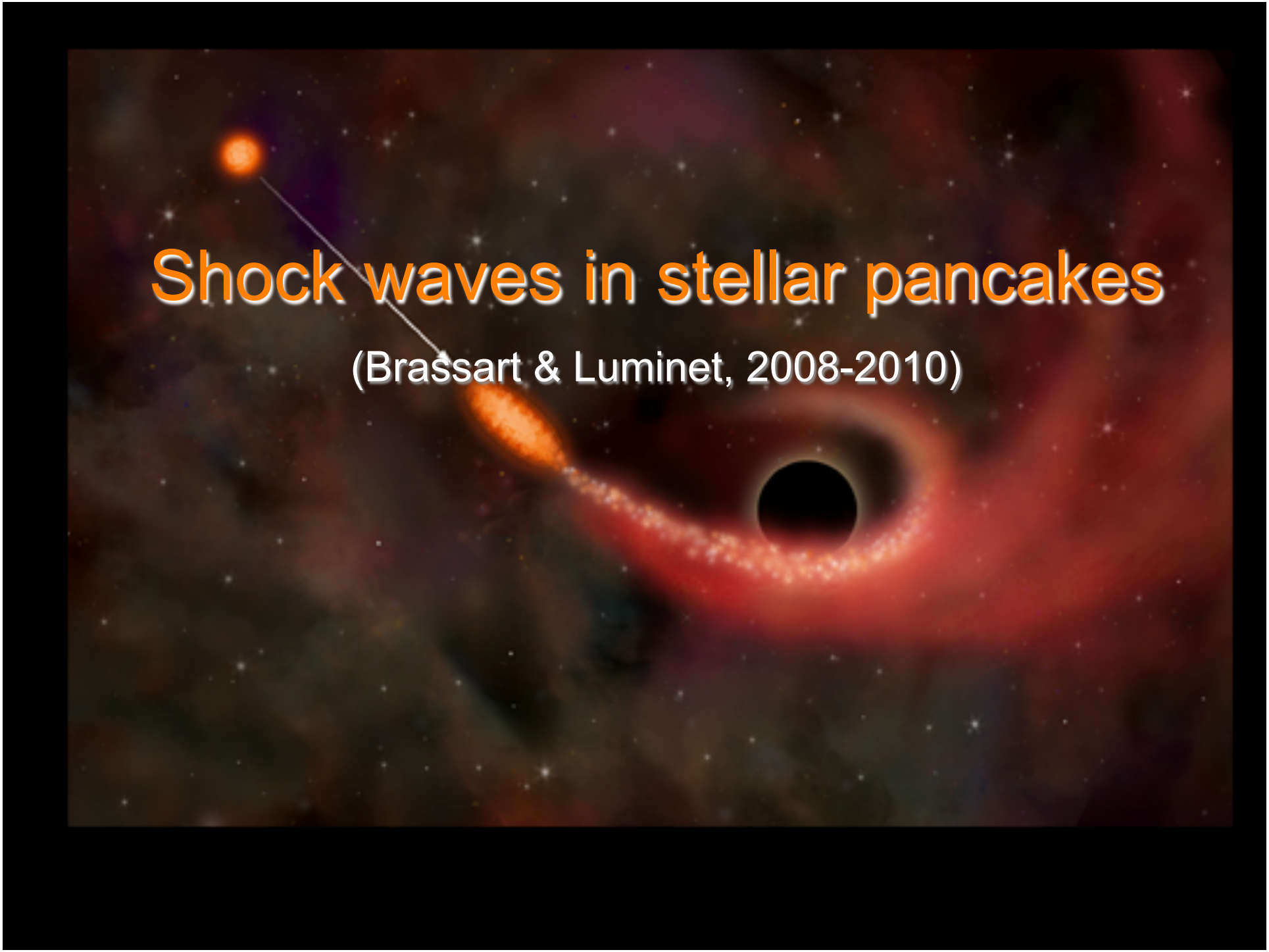
- He star :

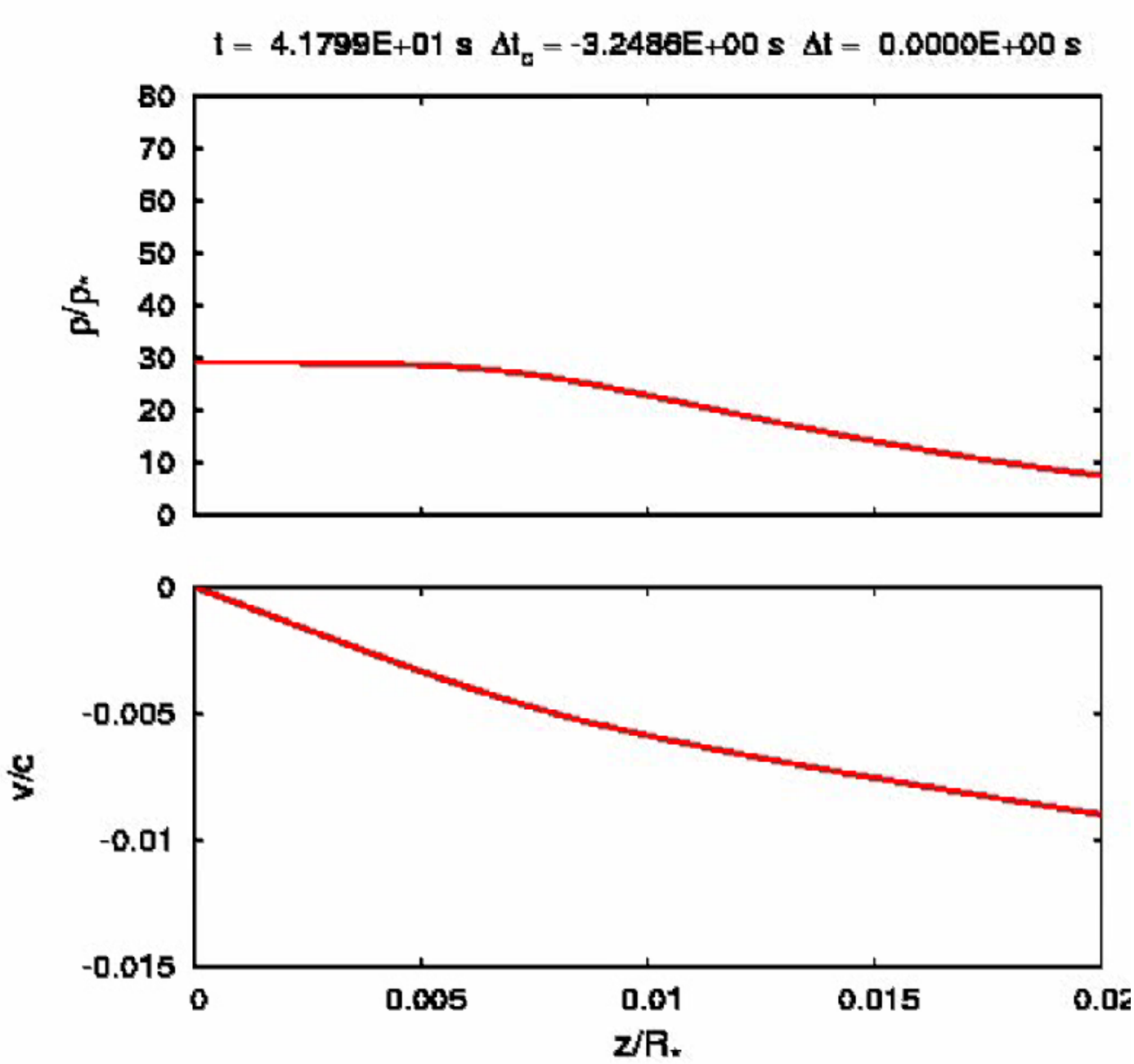
α-p capture process

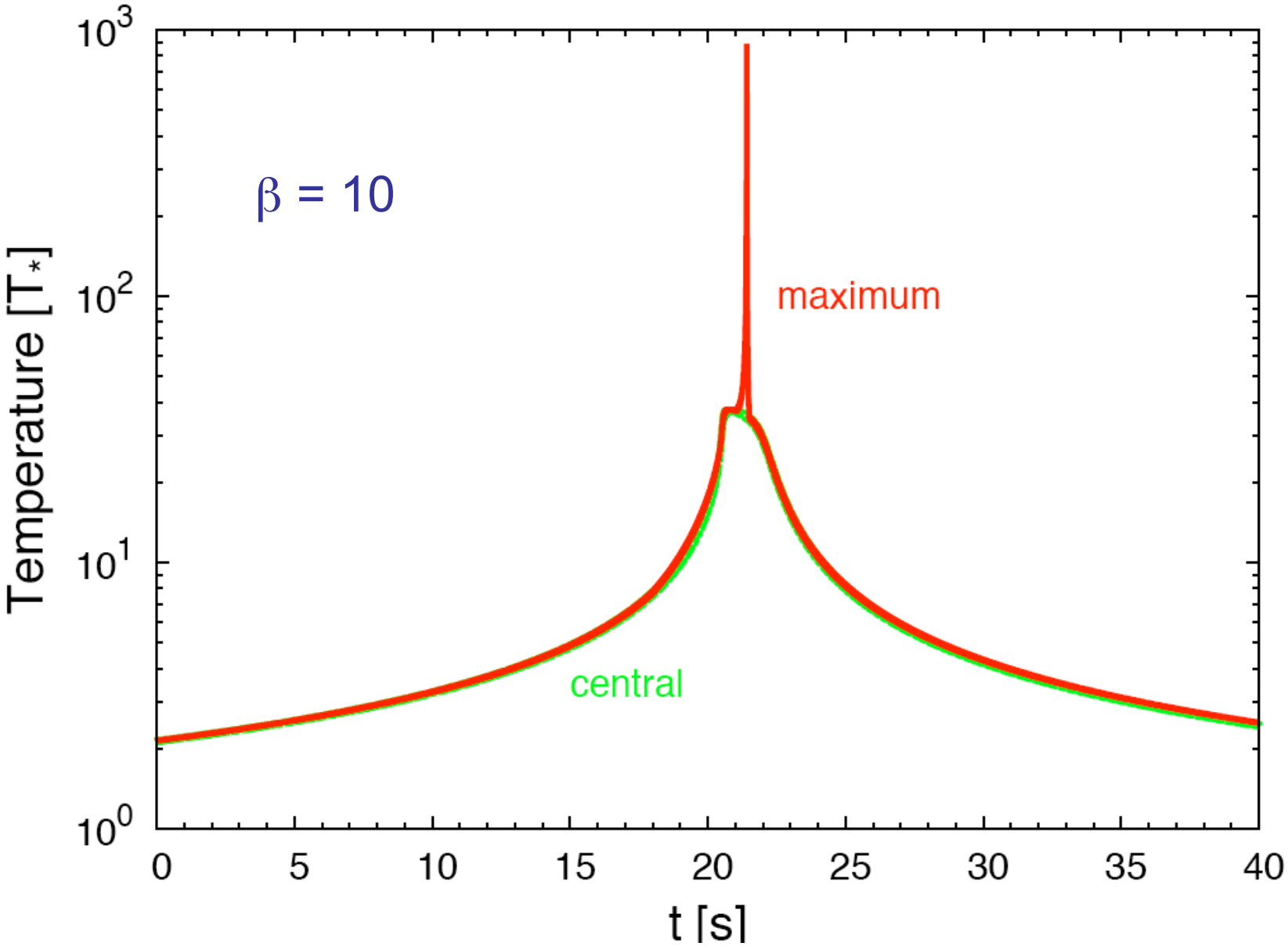
Energy generation (10^{50} ergs)



Luminet & Pichon 1989b

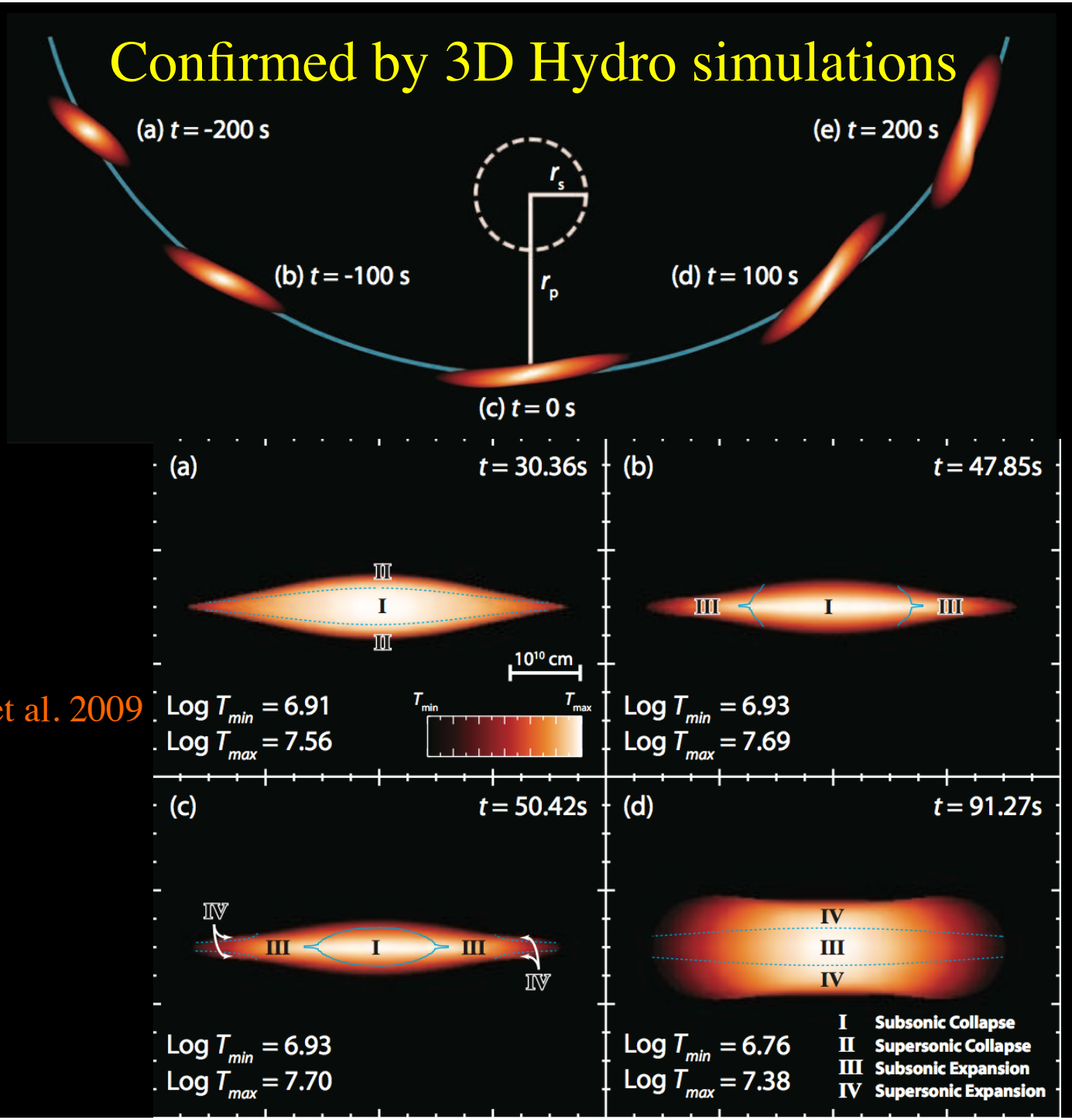

Shock waves in stellar pancakes
(Brassart & Luminet, 2008-2010)


t = 4.1799E+01 s Δt_c = -3.2486E+00 s Δt = 0.0000E+00 s
80
70
60
50
40
30
20
10
0
ρ/ρ*
0
-0.005
-0.01
-0.015
v/c
0
0.005
0.01
0.015
0.02
z/R*



Shock-driven maximum temperature

Confirmed by 3D Hydro simulations

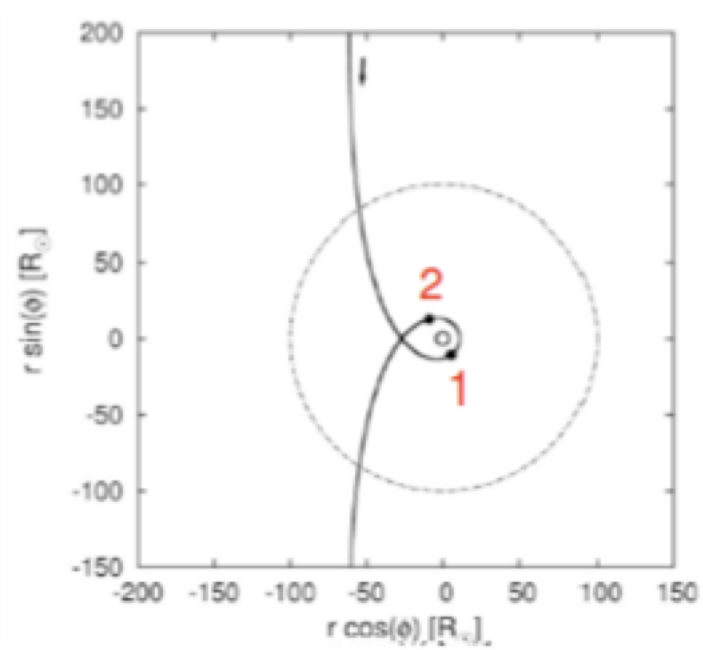


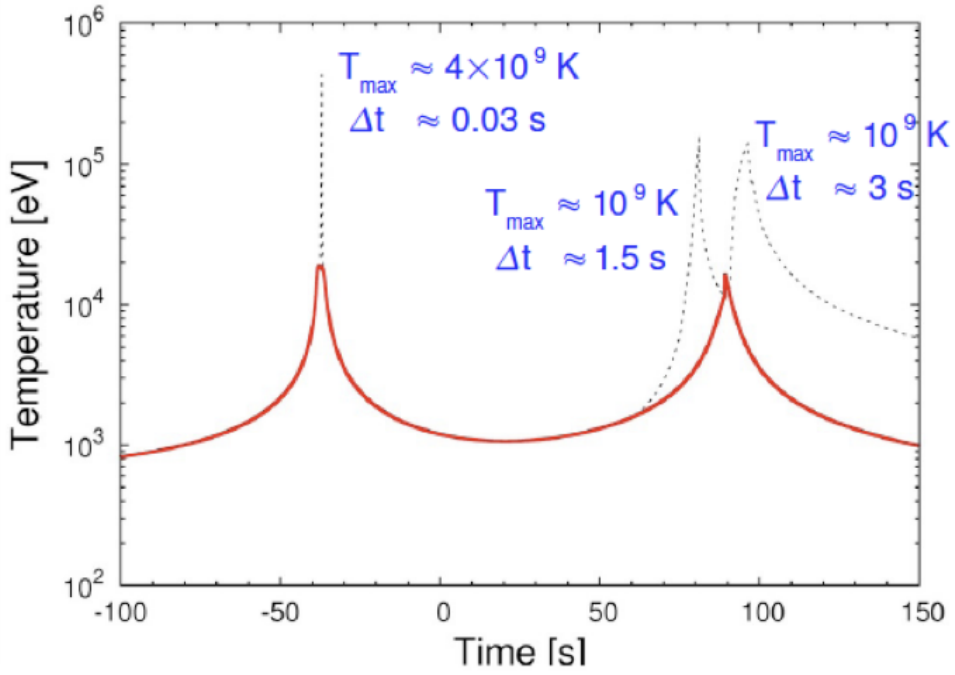
Guillochon et al. 2009

Relativistic tidal field

Luminet & Marck, 1985 Brassart & Luminet, 2011

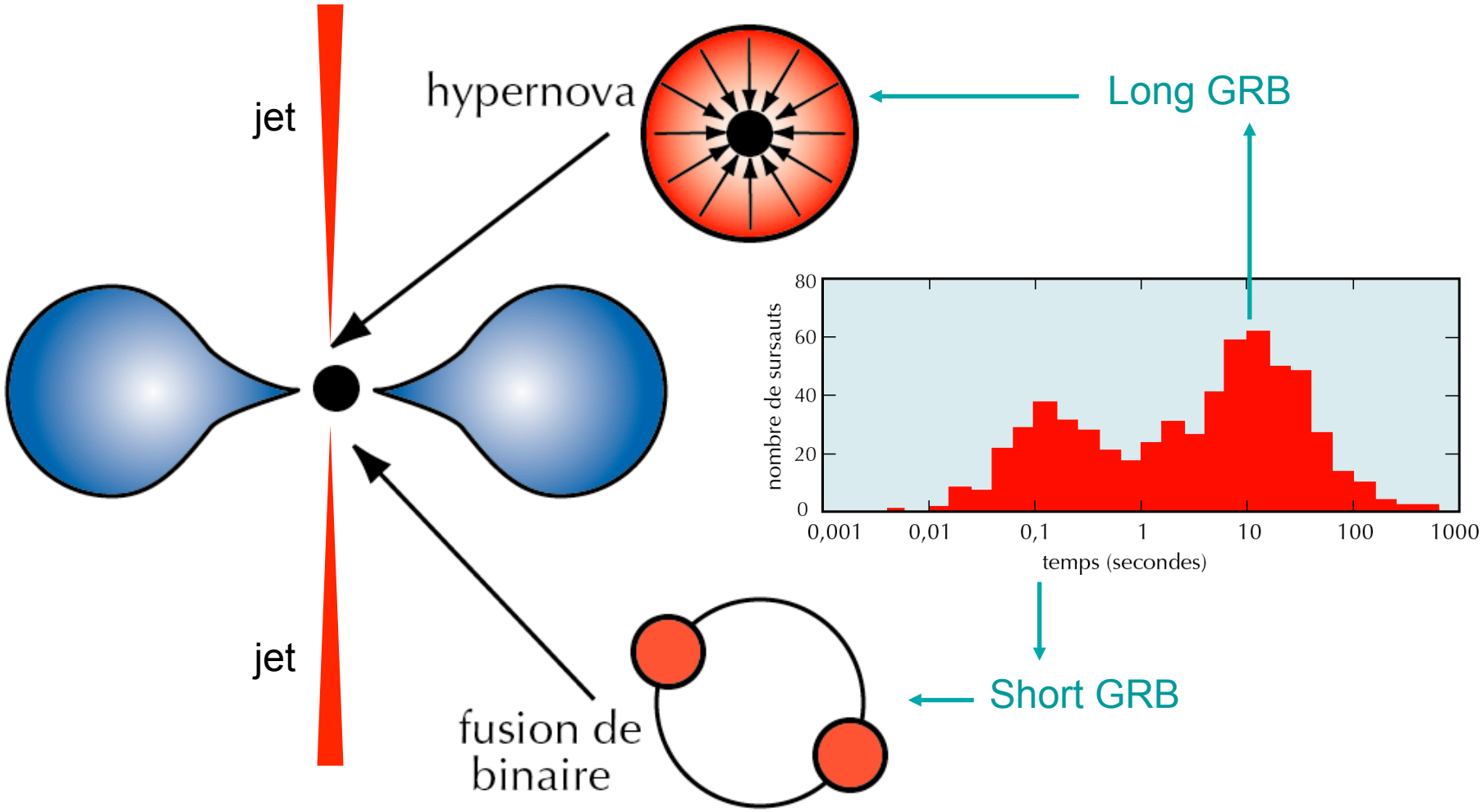
Double point inside the tidal radius ⟹ Several compressions





Multi-pancake effect and X/γ bursts

Modelisation of Gamma-Ray Bursts



• GRB 060614 (long ~100 s) without SN remnant : disruption of a WD by an intermediate mass BH ?
(Lu et al. 2008)

• A new class of γ-ray bursts from stellar disruptions by IMBH ? (Gao et al., 2010)

From a total of 328 Swift GRBs with accurate measured durations and without SN association, 25 GRBs satisfying the criteria for GRB060614-type bursts…

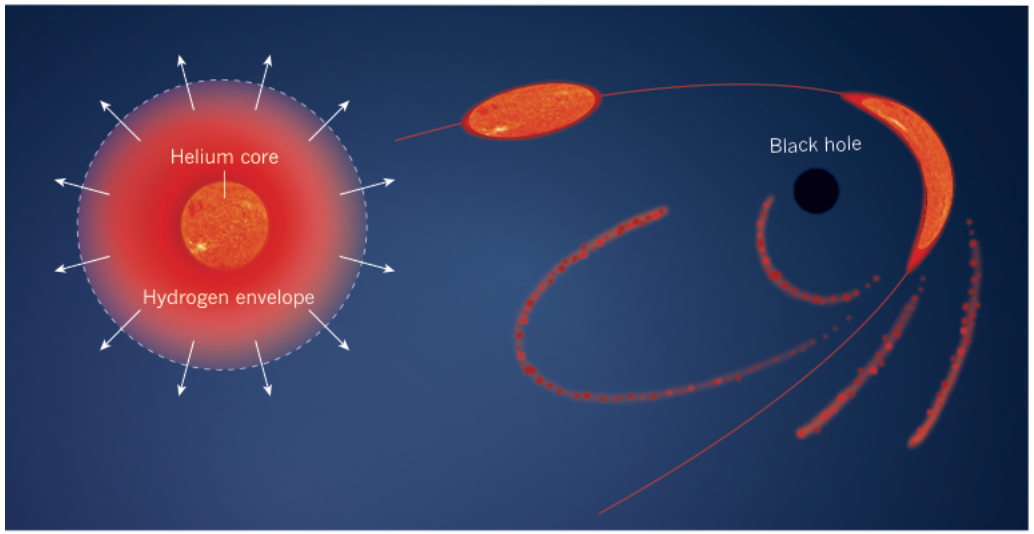
Recent hydro models …

• 3D simulations coupling hydrodynamics and nuclear network (Rosswog et al., 2008, Guillochon et al., 2011):

Confirm the occurrence of tidally induced supernovae

• Red giants / BH interactions (Mac Leod et al., 2012):

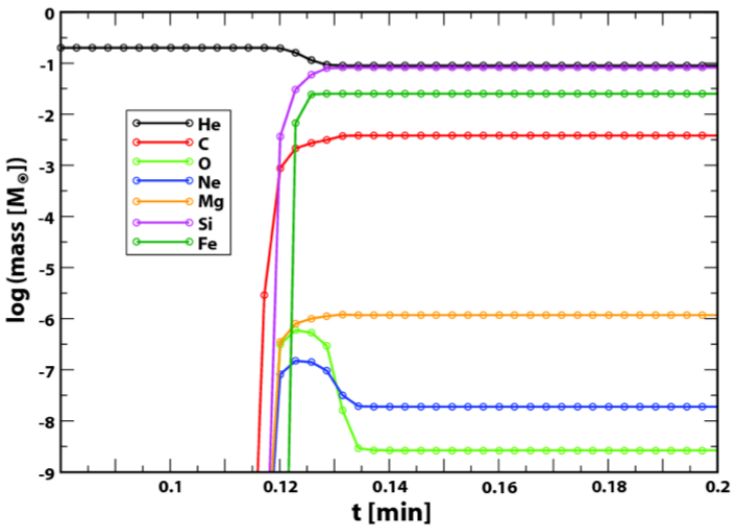
Tidal stripping of atmosphere



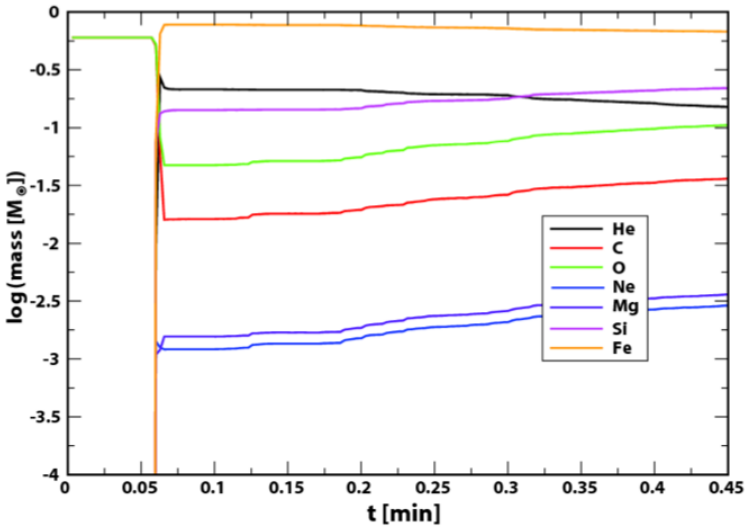
White dwarfs / IMBH strong encounters

Rosswog et al. 2010, Hass et al. 2012

Confirm nuclear ignition



0.2 M_S WD/1000 M_S BH, β=4



1.4 M_S WD/500 M_S BH, β=4

Number of disruption events:

Wang & Merritt (2004), Tal (2005)
BH binaries : Chen et al (2009)

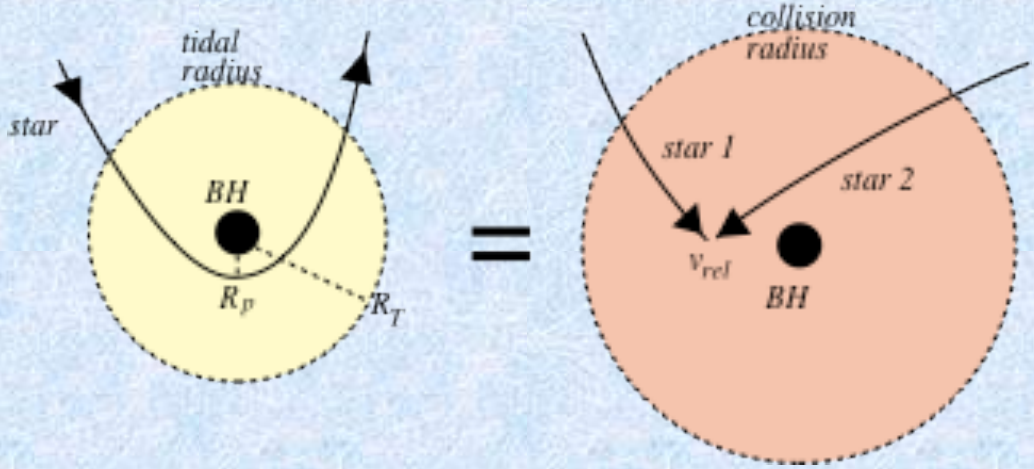
$$N \approx 10^{-5}\,\beta^{-1}\,/\,year\,/\,galaxy$$

$$\Longrightarrow \quad N(z<0.8) \approx 10^{4}\,\beta^{-1}\,/\,year$$

UV/X/gamma-ray flares

Analogy with stellar collisions

Around a 10^9 M_S black hole, the typical collisional velocities are > 5000 km/s within a distance 0.1 pc from the black hole



$\beta = R_T/R_p$ ⟵ crushing factor ⟶ $\beta = v_{coll}/v^*$

Massive BH (10^4 - 10^8 M_S)

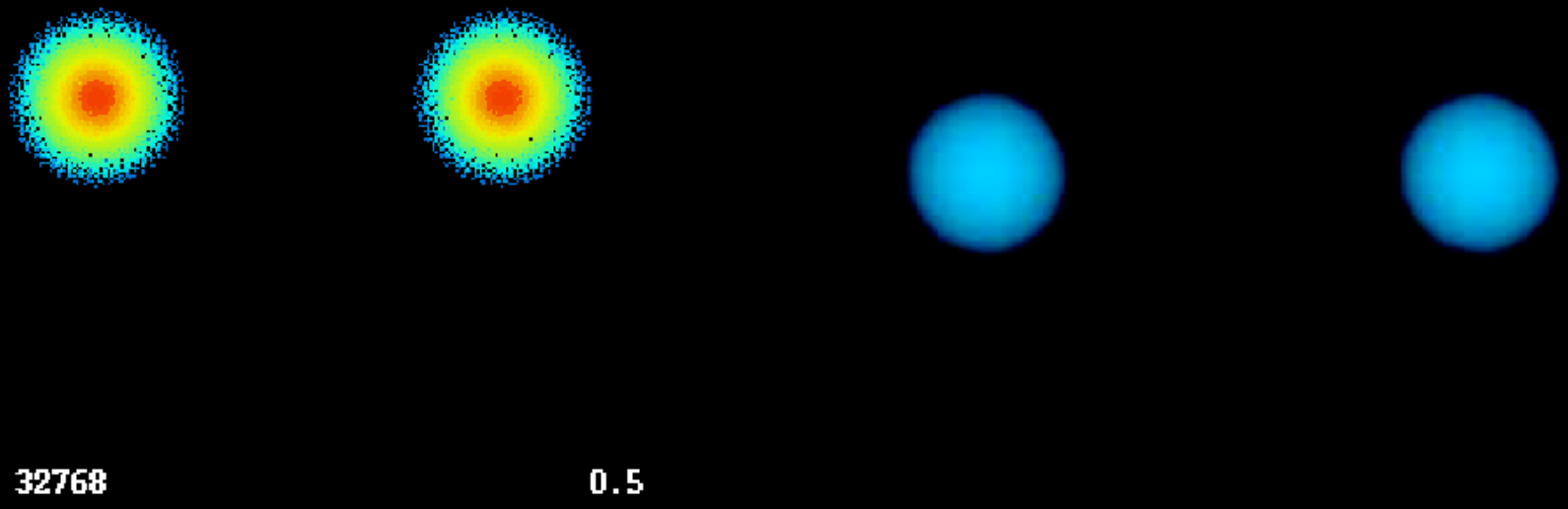
Glob. Clusters, GN, Seyfert

Supermassive BH > 10^8 M_S

Quasars, Giant elliptical …

$\beta > 1$: disruption / $\beta > 5$: pancake effect

High velocity head-on collisions, polytropes 5/3



Makino, 1999

Barnes, 2003


The End