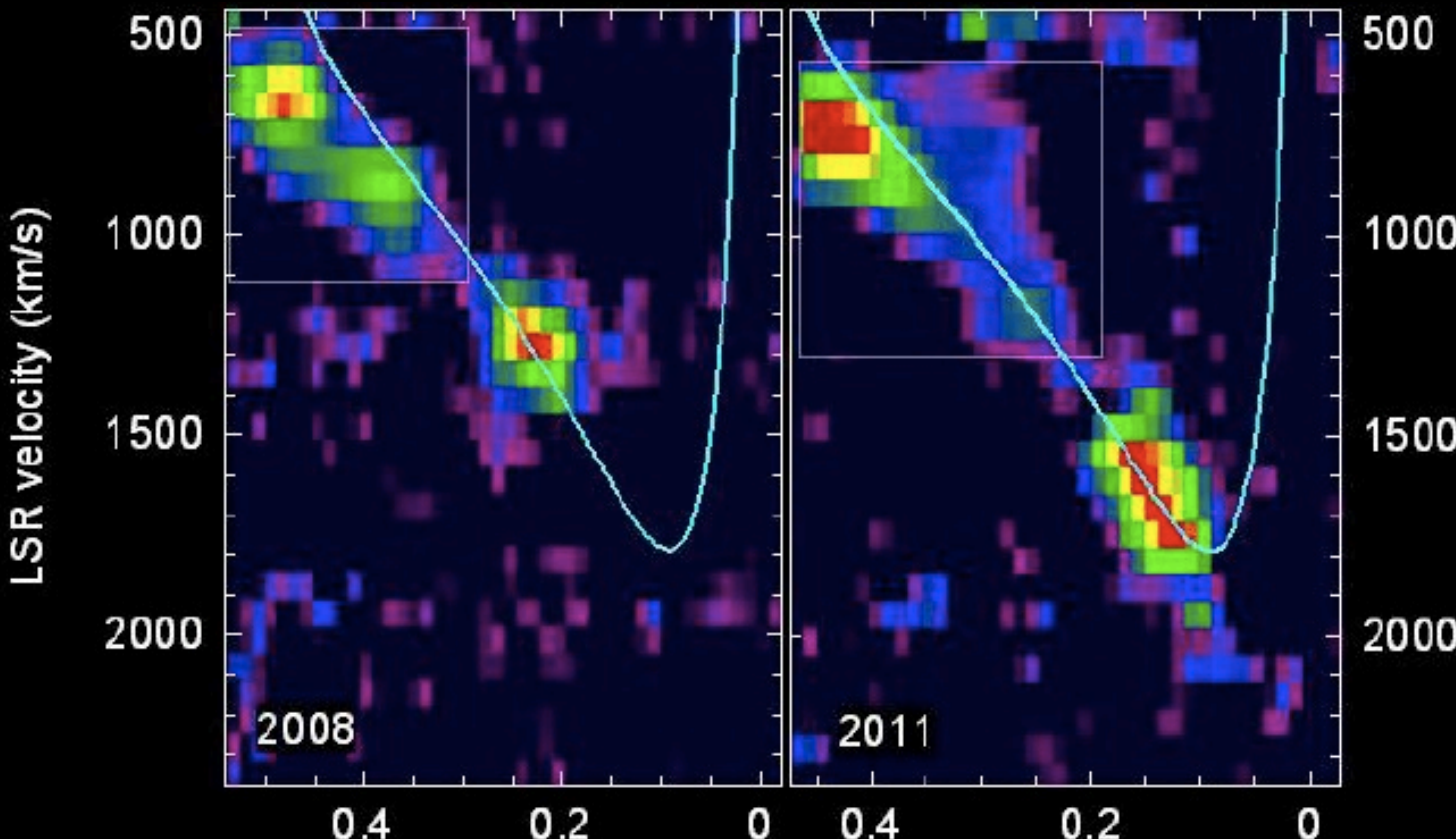
Watching a tiny gas cloud fall into the SMBH

(Gillessen et al. 2012; Nature)

Burkert, Schartmann, Alig, Gillessen, Genzel + IR Group, astroph/1201.1414




lactic Center
ernung: 0,042280 Lj
zentrum des Sternsystems
1992 Aug 19 02:28:24 UTC
Zeit angehalten
chwindigkeit: 0,00000 m/s
FOV: 28° 34' 28,8"

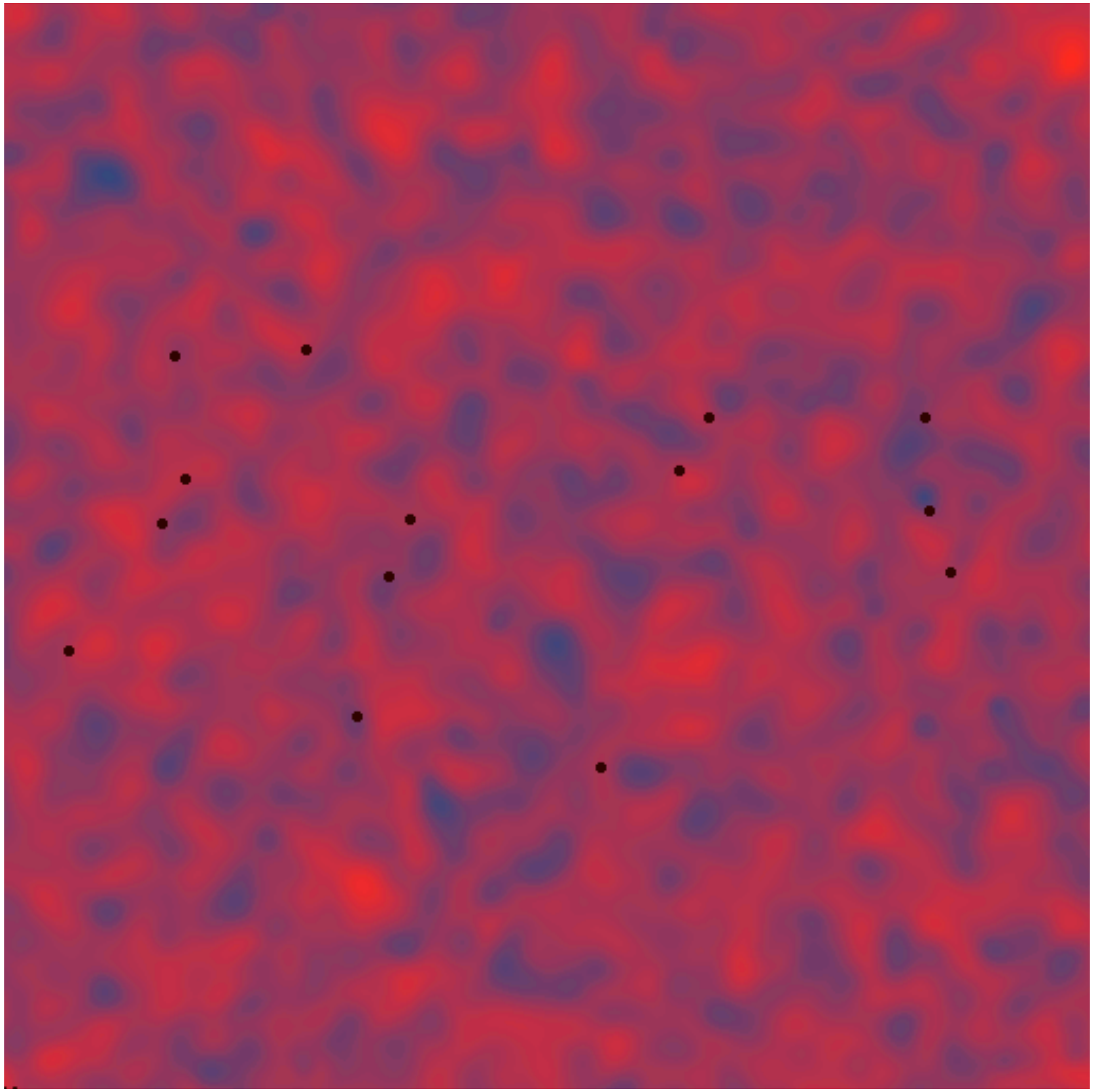
Sgr A*, a currently inactive, supermassive black hole

$$\dot{M} \leq 10^{-6} \cdot \dot{M}_{\mathrm{Eddington}}$$

- Irregular **flickering** events (Baganoff et al. 01; Genzel et al. 03)
- **X-ray echo** → **accretion event** about **100 yrs** ago (Sunyaev et al. 93, Revnivtsev et al. 06)
- **Major outburst 1-10 Myrs ago** that produced the disk of young stars (Baganoff et al. 03; Nayakshin et al. 07; Bonnell & Rice 09; Alig et al. 11)
- The **puzzle** of the **missing gas disk** (Alexander et al. 11)
- ***Chandra*:** hot, X-ray emitting gas bubble (Baganoff et al. 03)
- Quataert et al. (02,04): **shock-heated stellar winds**
- Sazanov, Sunyaev & Revnivtsev (11): X-ray emission from **late-type main sequence stars** of central stellar cusp

3d numerical simulations of stellar wind interaction

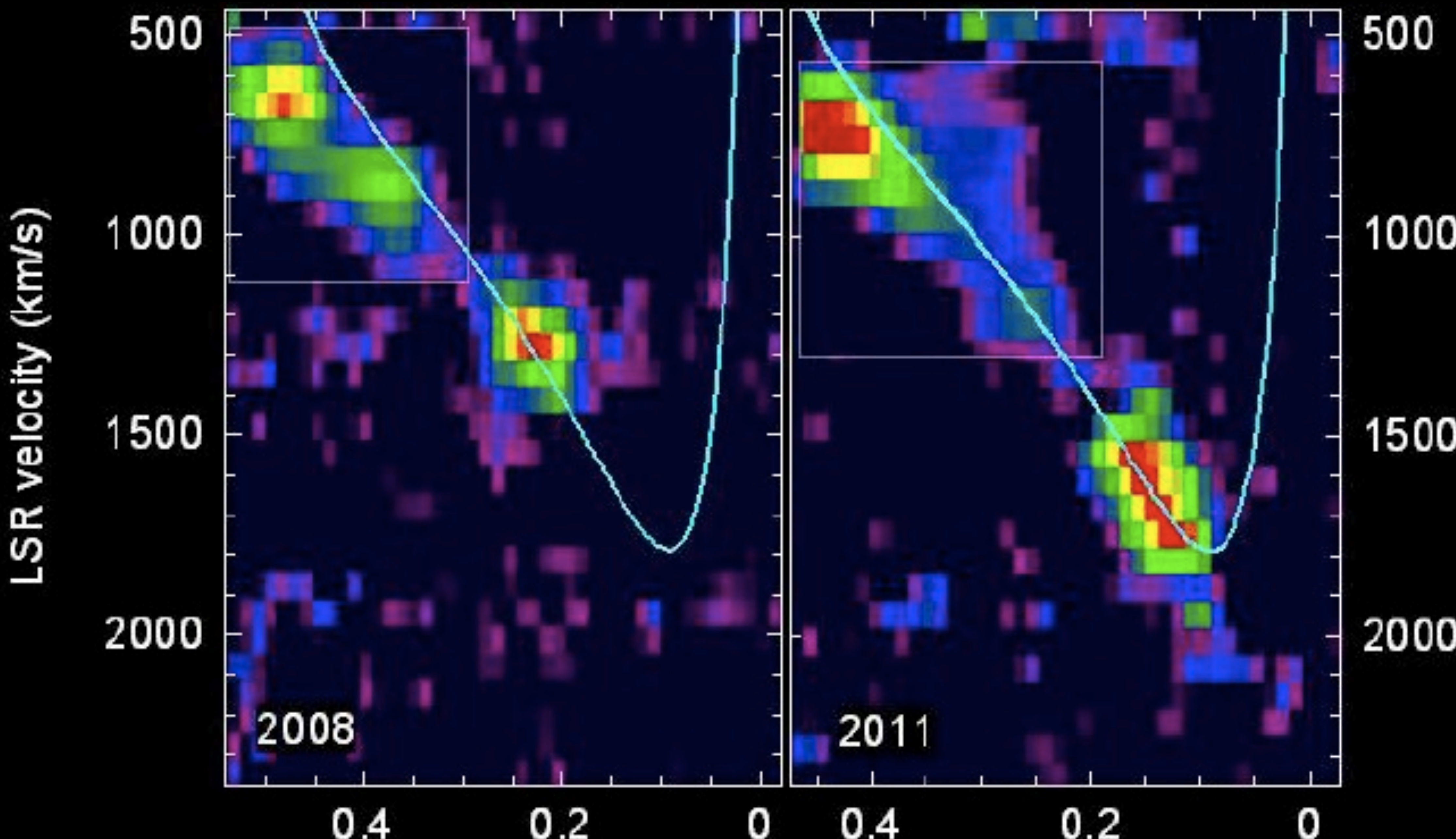
(Cuadra et al. 05, 06, 08; Nayakshin et al. 07, 08)



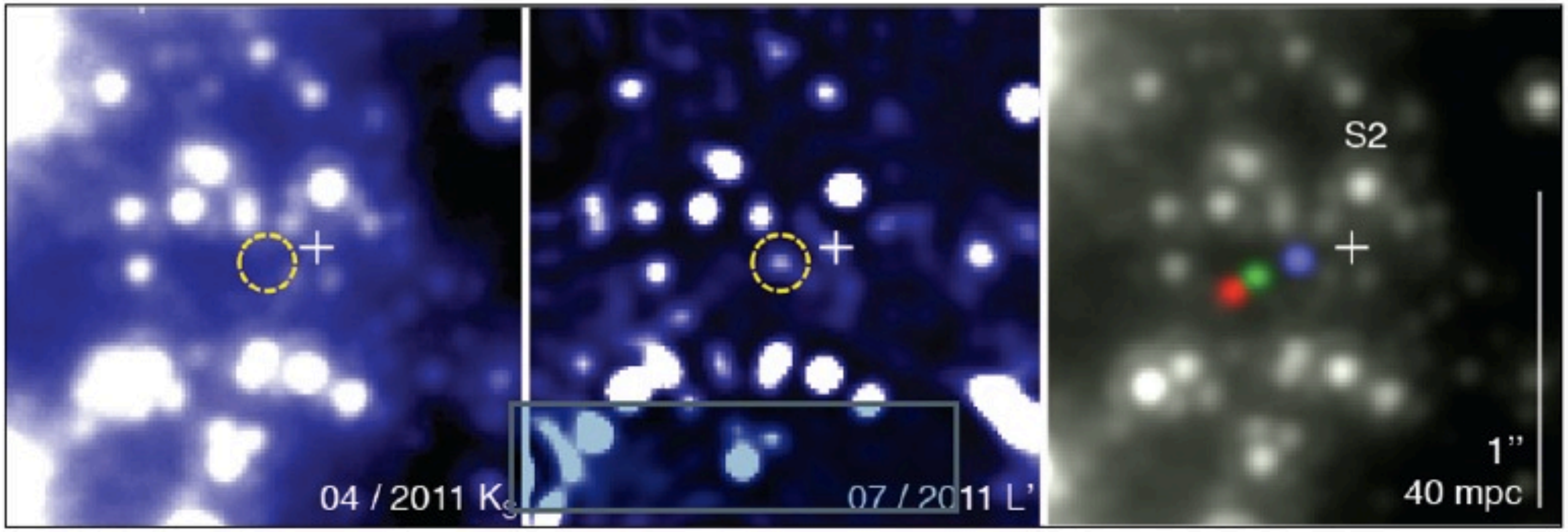
J. Cuadra

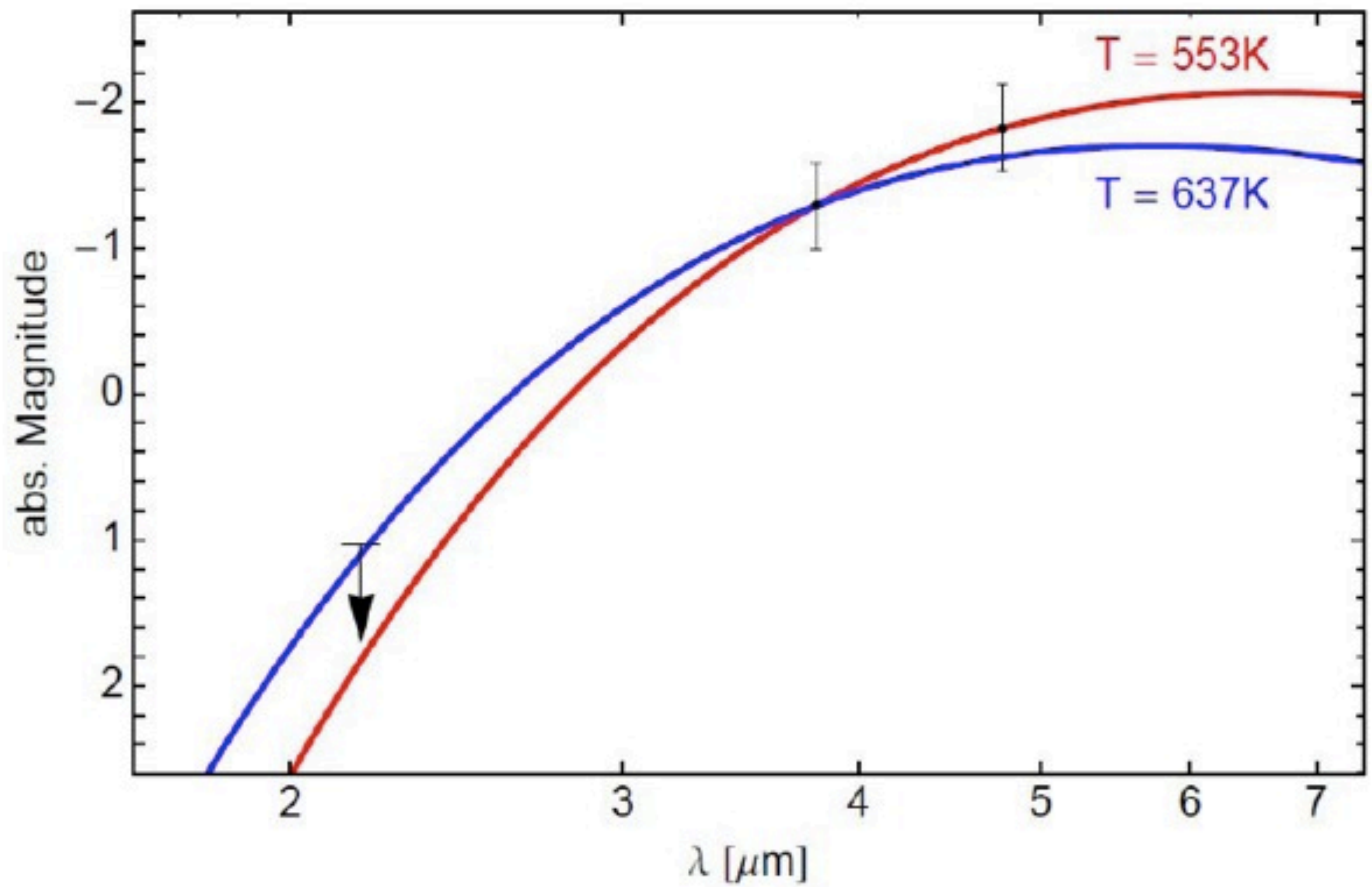
Watching a tiny gas cloud (G2) fall into the SMBH

(Gillessen et al. 2012; Nature 481, 51)

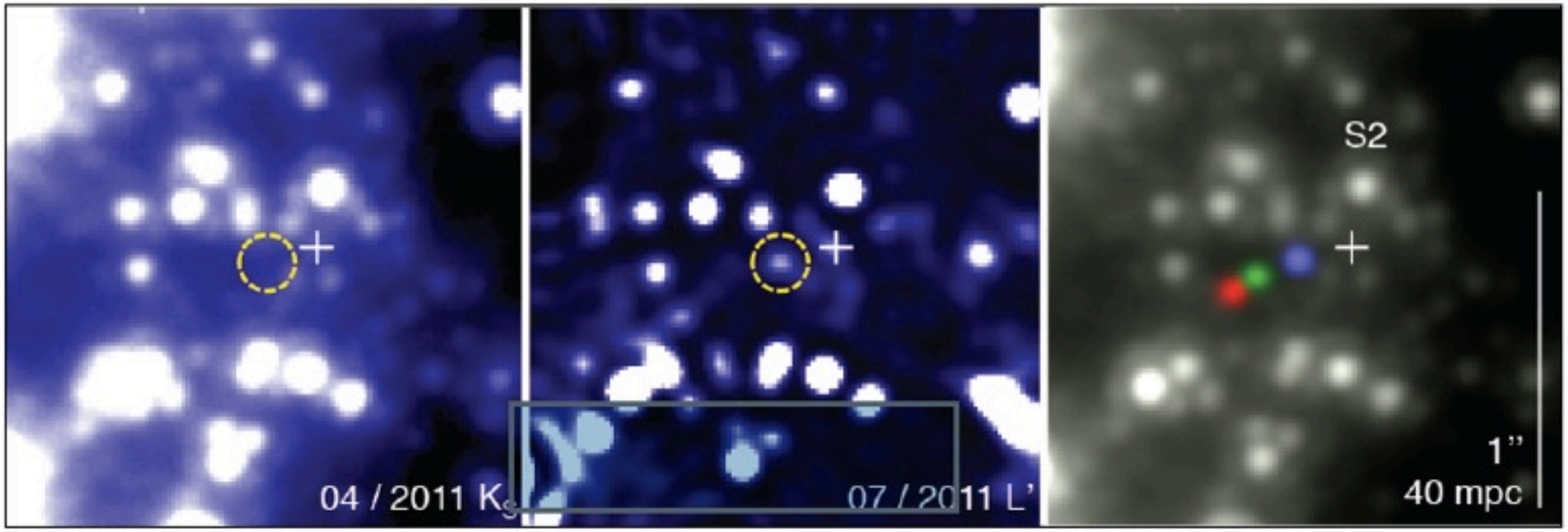


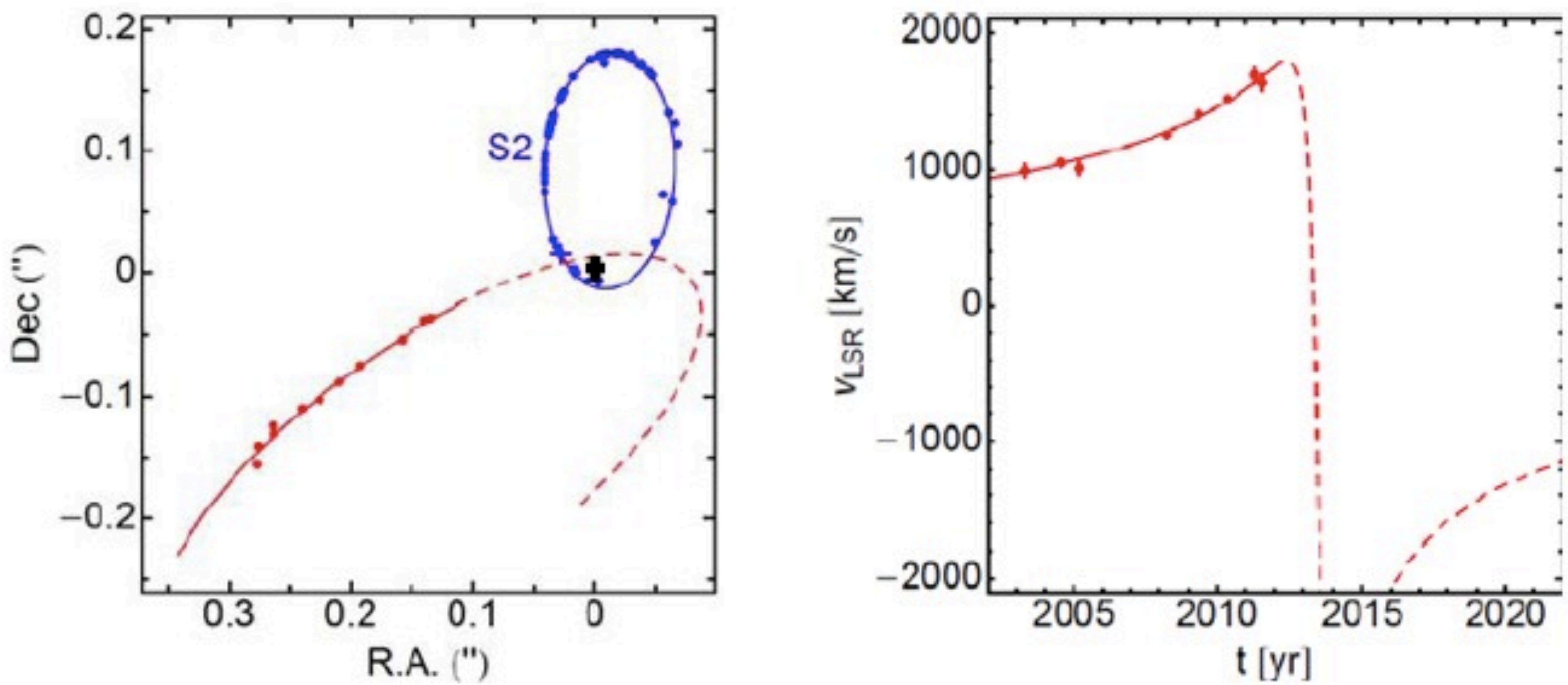
Clenet et al. (2005): extended dusty structure (G1) near Sgr A*



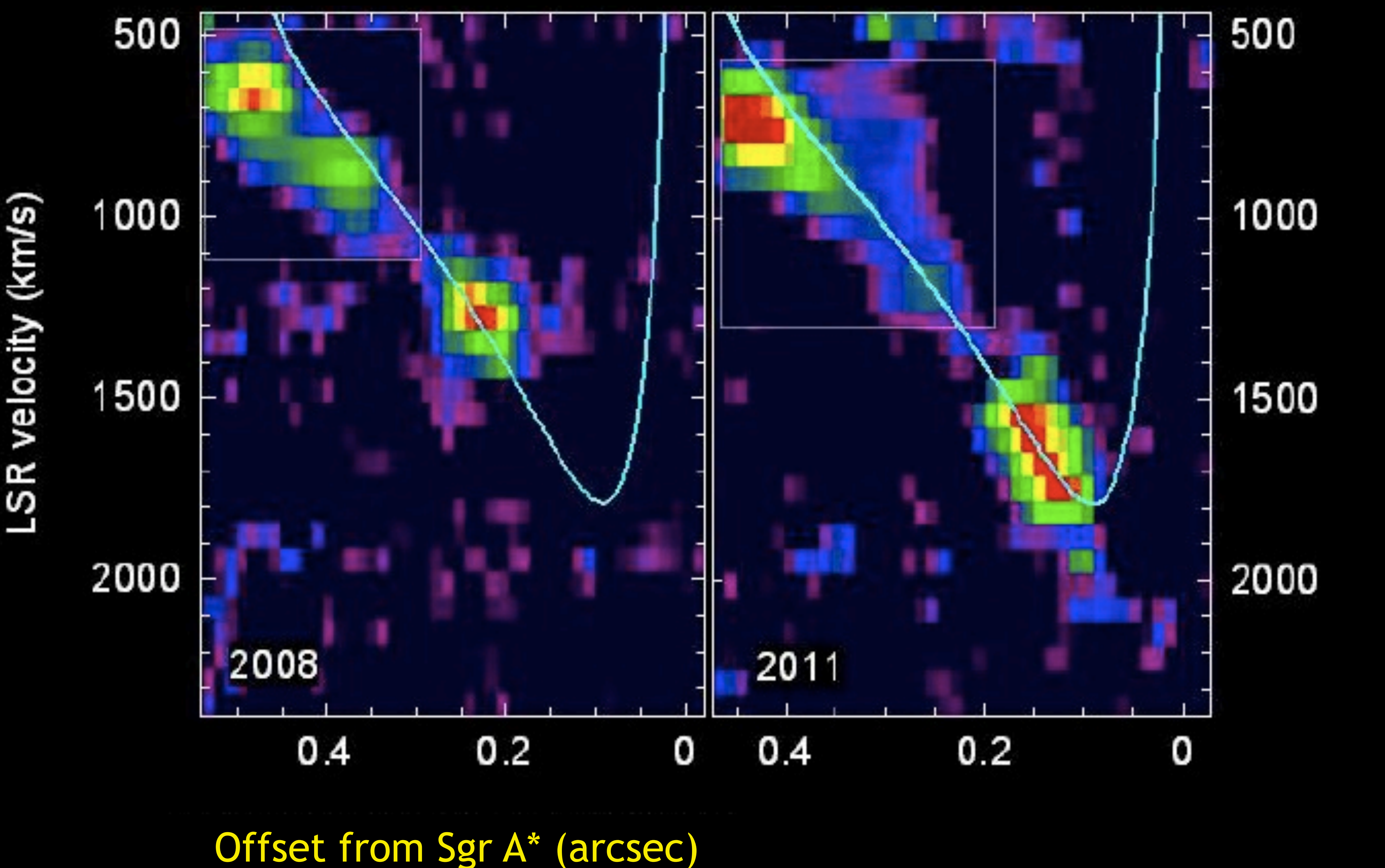


- Rapidly moving object seen in all **L** and **M** band images since 2002 but **not** in **shorter wavelengths: cold** object with **dust of T=600 K**





- Rapidly moving object seen in all **L** and **M** band images since 2002 but **not** in **shorter wavelengths: cold** object with **dust of T=600 K**
- Brγ and **He I** emission: **dusty, ionized, optically thin gas cloud**



LSR velocity (km/s)
500
1000
1500
2000
2008
2011
0.4
0.2
0
Offset from Sgr A* (arcsec)

Observed properties

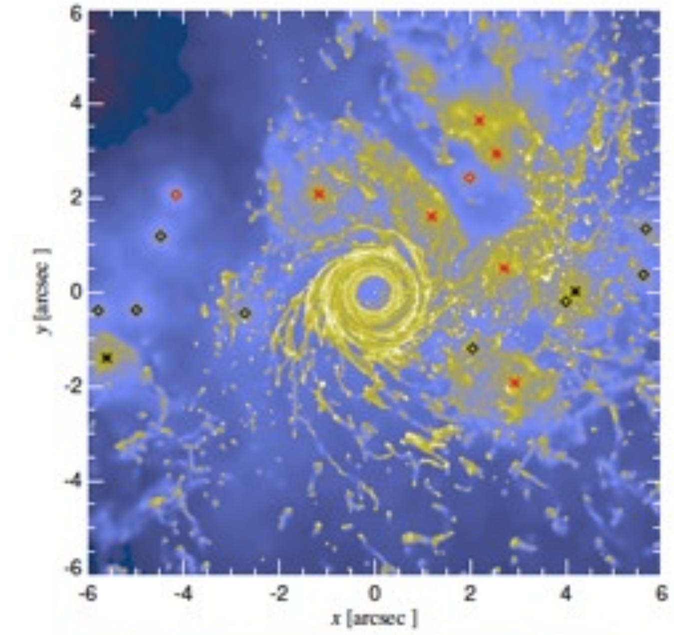
parameters of Keplerian orbit around $4.31 \times 10^6\ M_\odot$ black hole	$M_c \approx 1.7 \cdot 10^{28}\, g$ $R_{c,eff} \approx 2 \cdot 10^{15}\, cm$
semi-major axis a	521 ± 28 milli-arcsec $7.1 \cdot 10^{16}\, cm$
eccentricity e	0.9384 ± 0.0066
$R_{apo} = 1.26 \cdot 10^{17} \mathrm{cm}$ $R_{2011} = 1.6 \cdot 10^{16} \mathrm{cm}$ $R_{peri} = 4 \cdot 10^{15} \mathrm{cm}$	$L_{Br\gamma} \approx 1.7 \cdot 10^{-3}\ L_\odot$ $n_{cloud} \approx 3 \cdot 10^5 \left(\frac{2 \cdot 10^{15} \mathrm{cm}}{R_{c,eff}} \right)^{-\frac{3}{2}} \mathrm{cm}^{-3}$
peri-bothron distance from black hole r_{peri}	$4 \pm 0.3 \times 10^{15} \mathrm{cm} = 3140\ R_S$
orbital period t_o	137 ± 11 years

A great challenge for theorists and (magneto) hydrodynamical simulations

(Burkert et al. 2011a, Schartmann et al 2011a)

- Origin of **physical cloud properties (mass, density, radius)**
- Origin of **orbital parameters**
- **How did it form?**
- **Where will it go?**
- **Are there more clouds, waiting to be discovered?**
- **Will the central SMBH become active soon?**

Formation Scenarios



Diffuse cloud scenario:

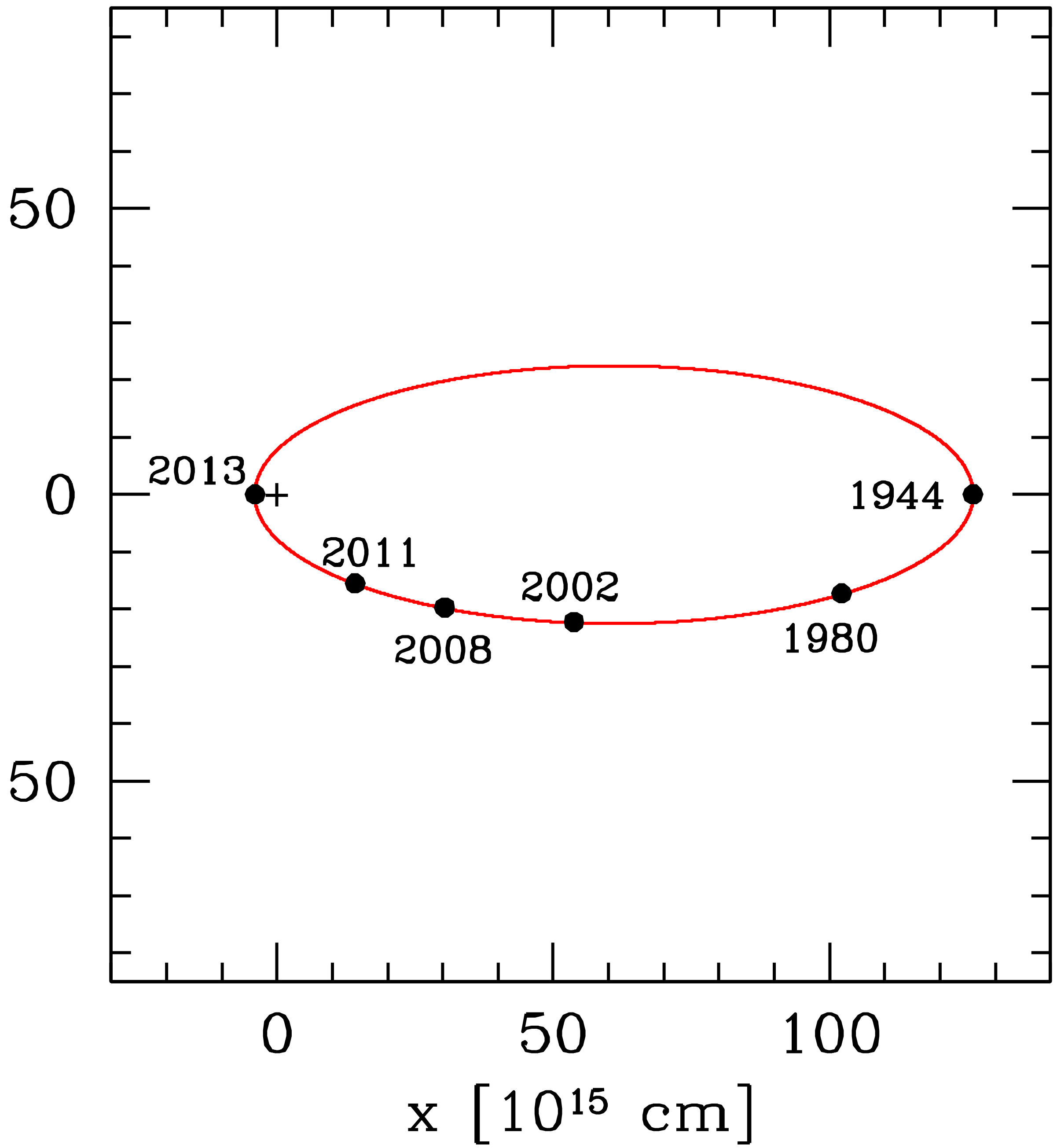
- **Cooling timescale** of hot gas too long.
- **Shocked stellar winds** in disk of massive stars (Cuadra et al.)
- First time approach (frequent process)

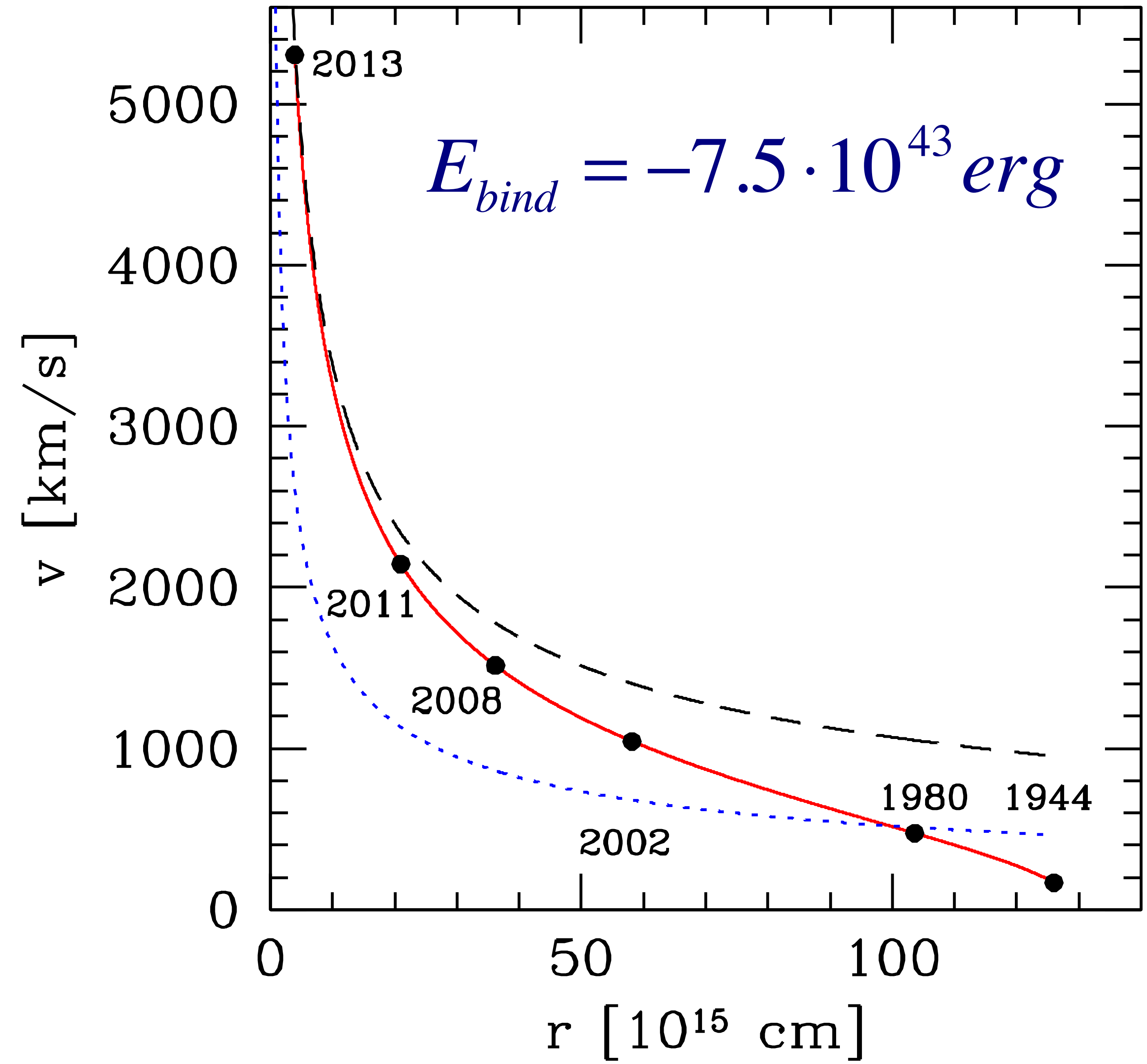
Compact source scenario (Murray-Clay & Loeb 12)

- Gas atmosphere of an **invisible central source** (planetary nebula, evaporating star or planet, protoplanetary disk)
- On this orbit for **many orbital periods**

$$T_{source} \geq 10^{4.6} K \quad \text{and} \quad L_{source} \leq 10^{3.7} L_{\odot} \quad \text{or very cold}$$

Orbital properties



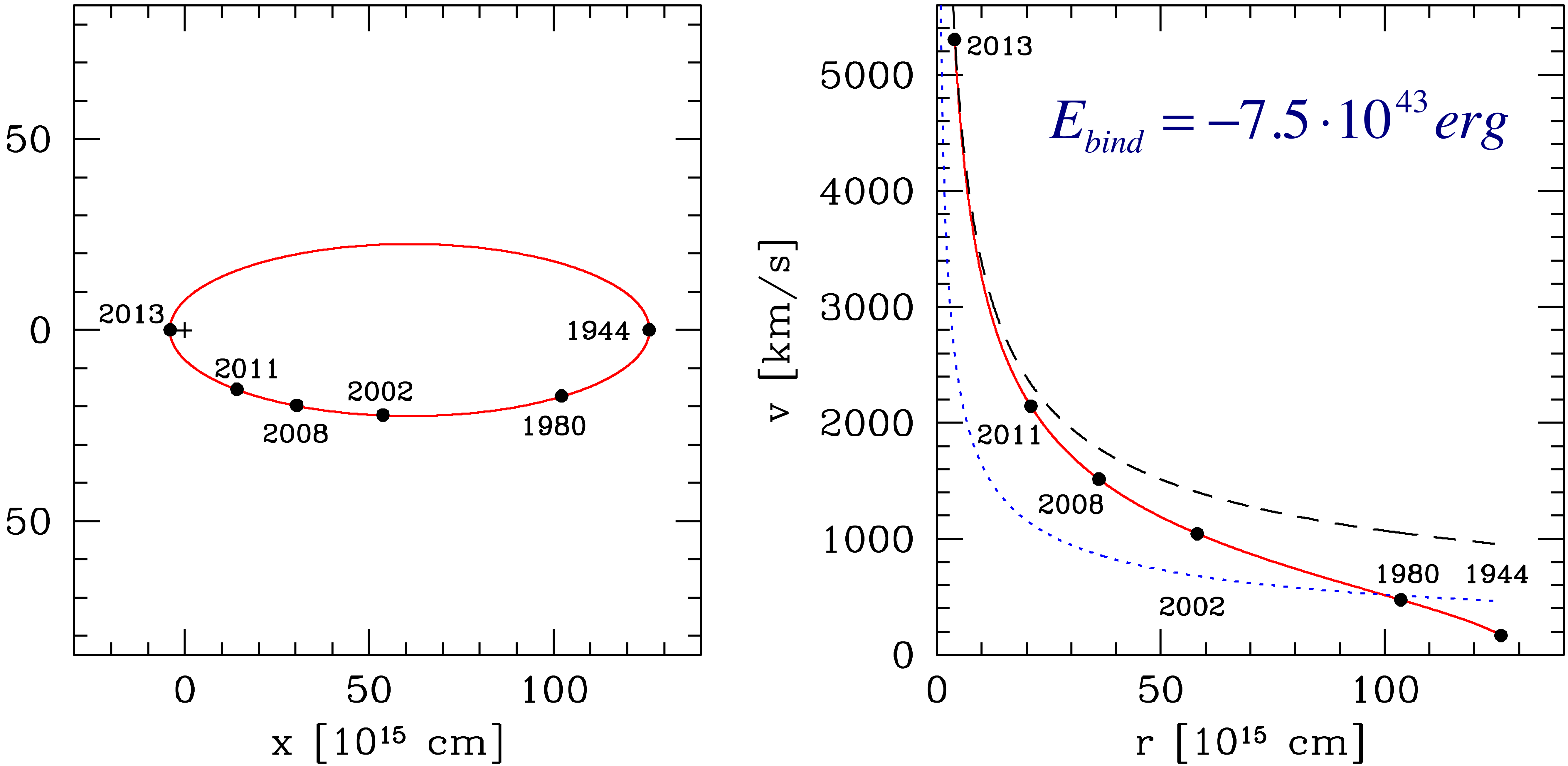


$$T_{hot} \approx 2.1 \cdot 10^{8} \left(\frac{16.8 \cdot 10^{15}\,\mathrm{cm}}{r} \right) \mathrm{K}$$

$$\rho_{hot} \approx 9.0 \cdot 10^{-22} \left(\frac{16.8 \cdot 10^{15}\,\mathrm{cm}}{r} \right) \frac{\mathrm{g}}{\mathrm{cm}^{3}}$$

(Yuan et al. 03; Xu et al. 06)

Where did the cloud come from?



It is likely that the cloud started around 1944 at the apocenter

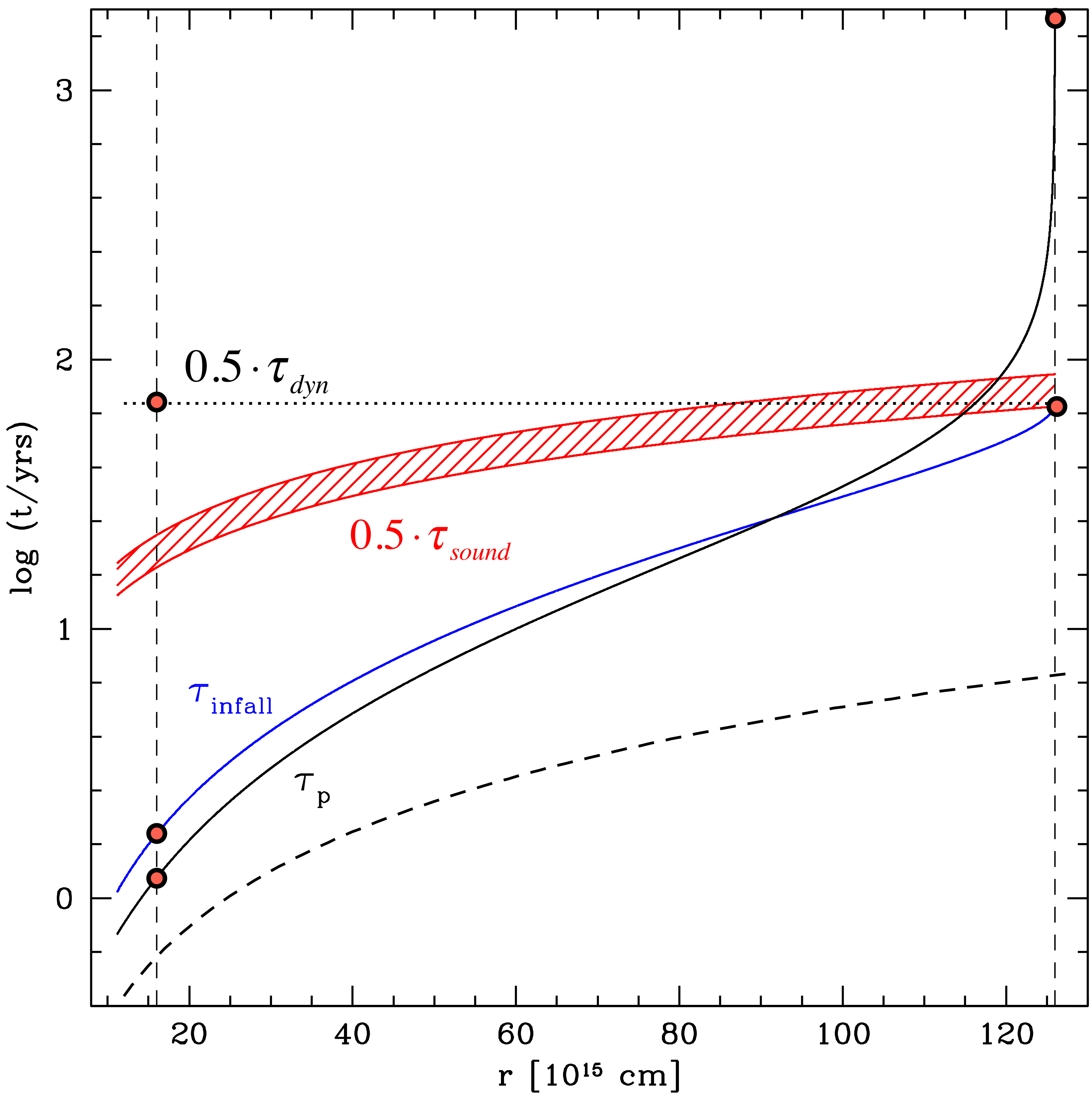
Cloud evaporation ?

(Cowie & McKee 1977)

- **Cloud evaporation** in the highly saturated limit $\lambda = 10 - 100 R_{cloud}$:

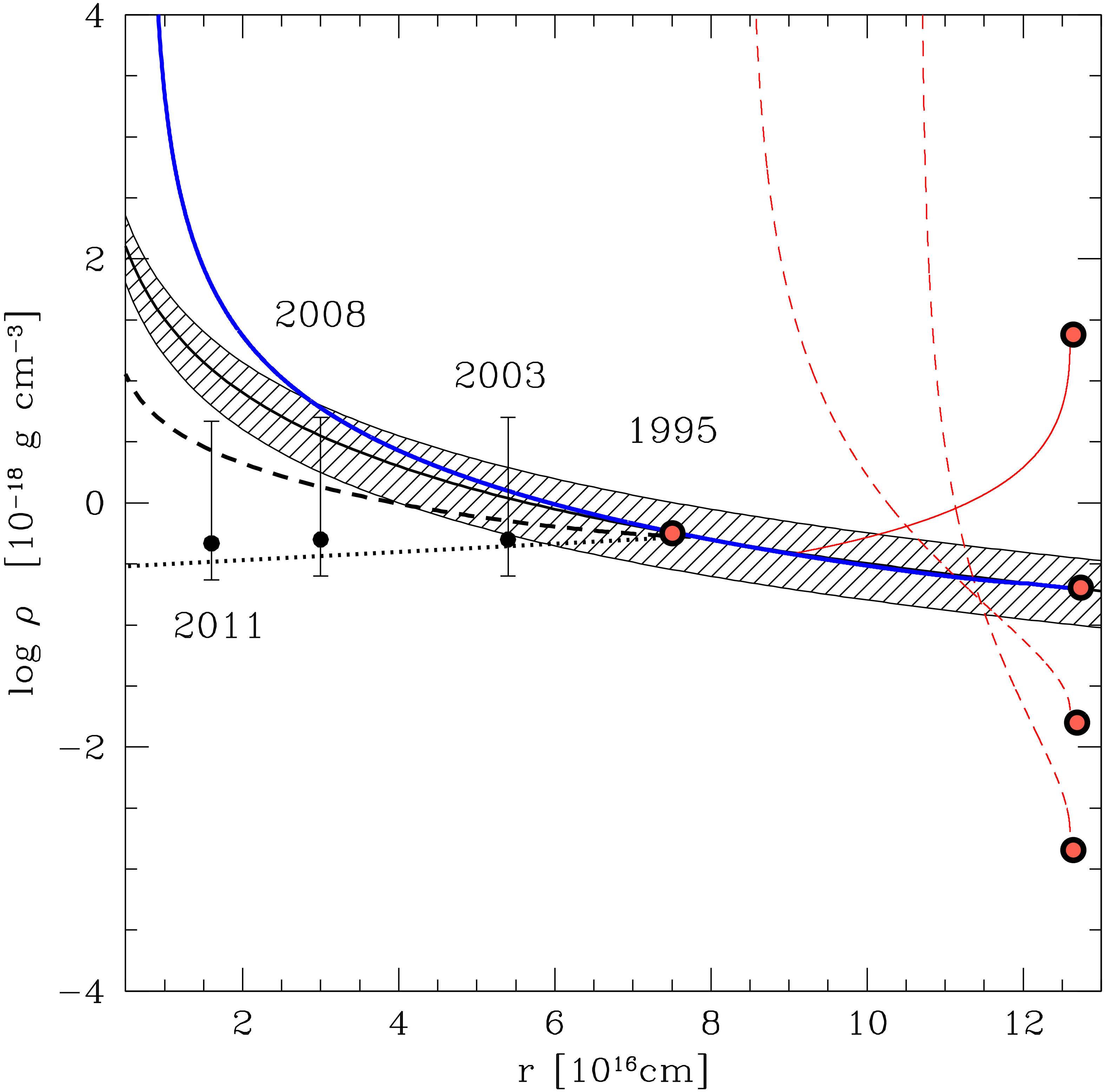
$$\tau_{evap} = \tau_{dyn} \left(\frac{r}{10^{16} cm} \right)^{1/6} \left(\frac{M_{cloud}}{M_{G2}} \right)^{1/3}$$

- **Infall of a rare massive object?**
- **Efficient evaporation as soon as cloud breaks up.**



$0.5 \cdot \tau_{dyn}$
$0.5 \cdot \tau_{sound}$
τ_{infall}
τ_p
log (t/yrs)
r [10^{15} cm]
0
1
2
3
20
40
60
80
100
120

Initial conditions



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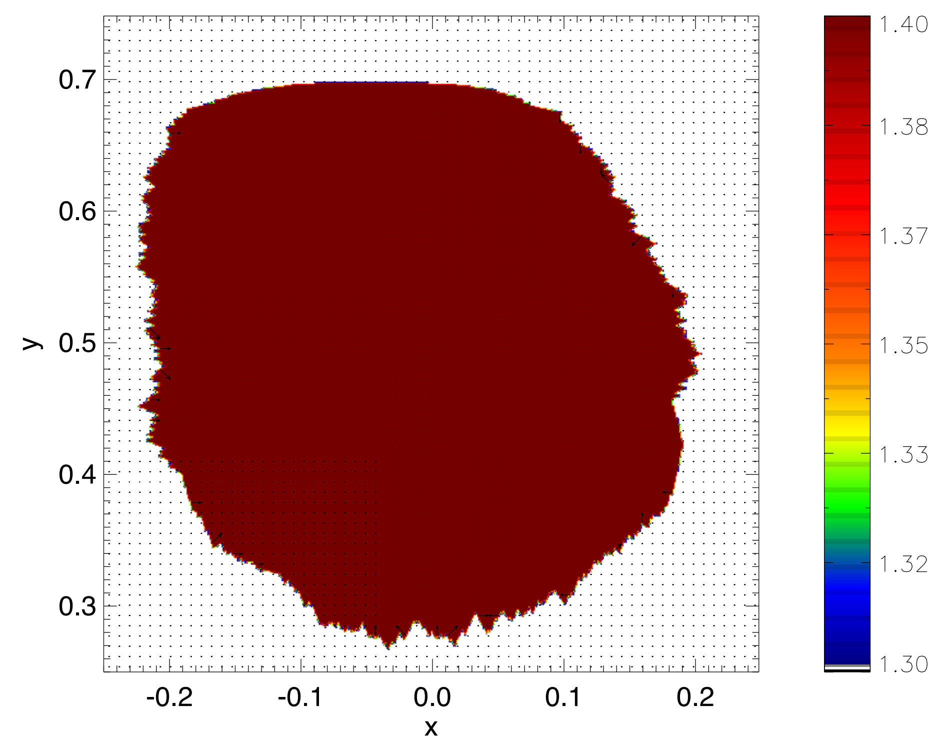
(Yuan et al. 03; Xu et al. 06)



(Klein, McKee & Colella 94; Murray & Lin 04)

The cloud probably started in pressure equilibrium with the surrounding.

$$T_{hot} \approx 2.1 \cdot 10^{8} \left(\frac{16.8 \cdot 10^{15}\,\mathrm{cm}}{r} \right) \mathrm{K}$$

$$\rho_{hot} \approx 9.0 \cdot 10^{-22} \left(\frac{16.8 \cdot 10^{15}\,\mathrm{cm}}{r} \right) \frac{\mathrm{g}}{\mathrm{cm}^3}$$

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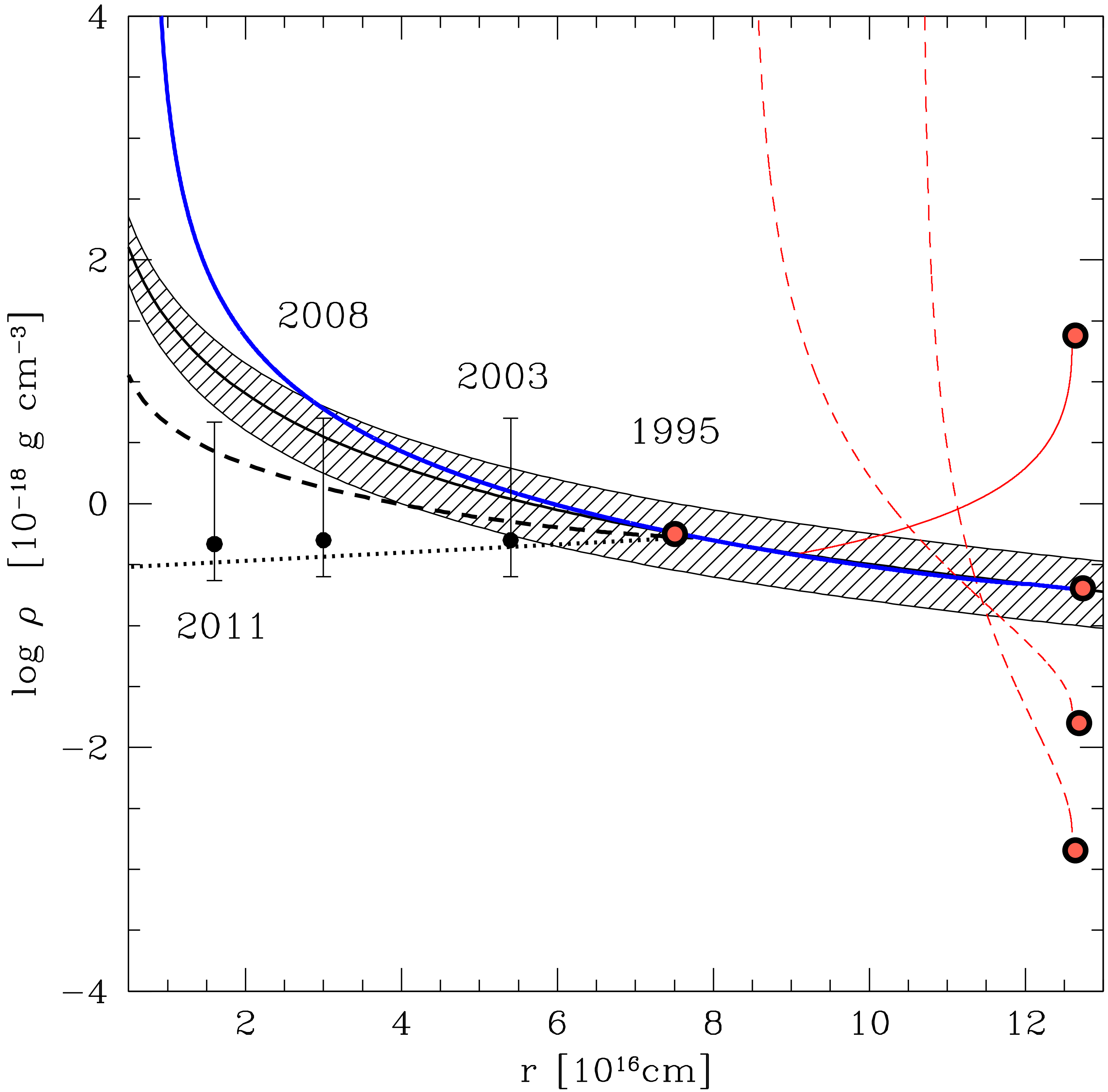

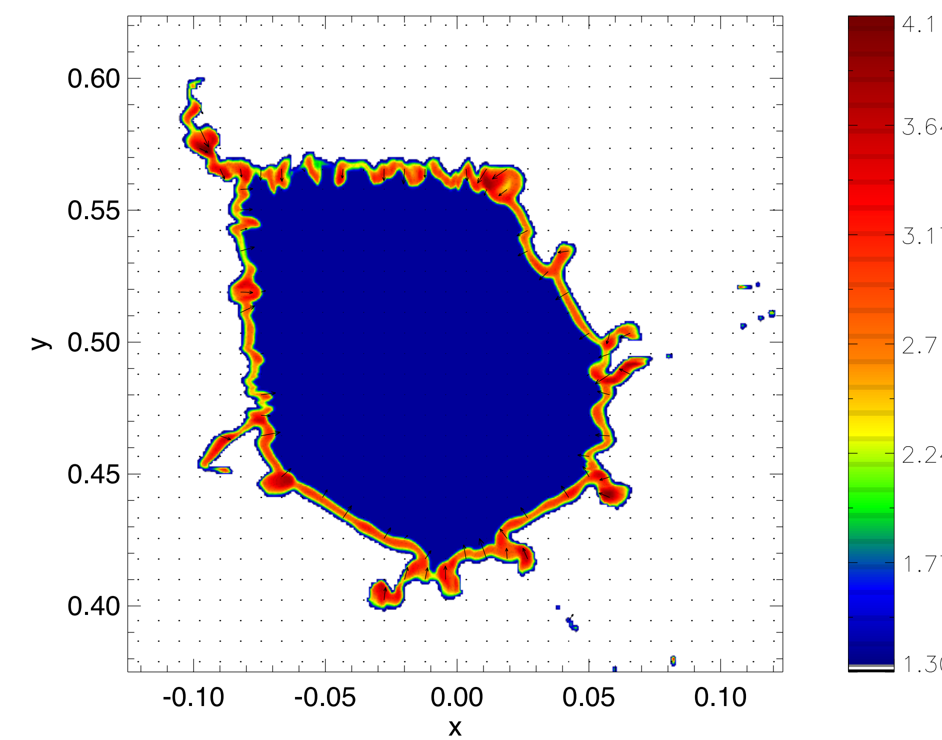

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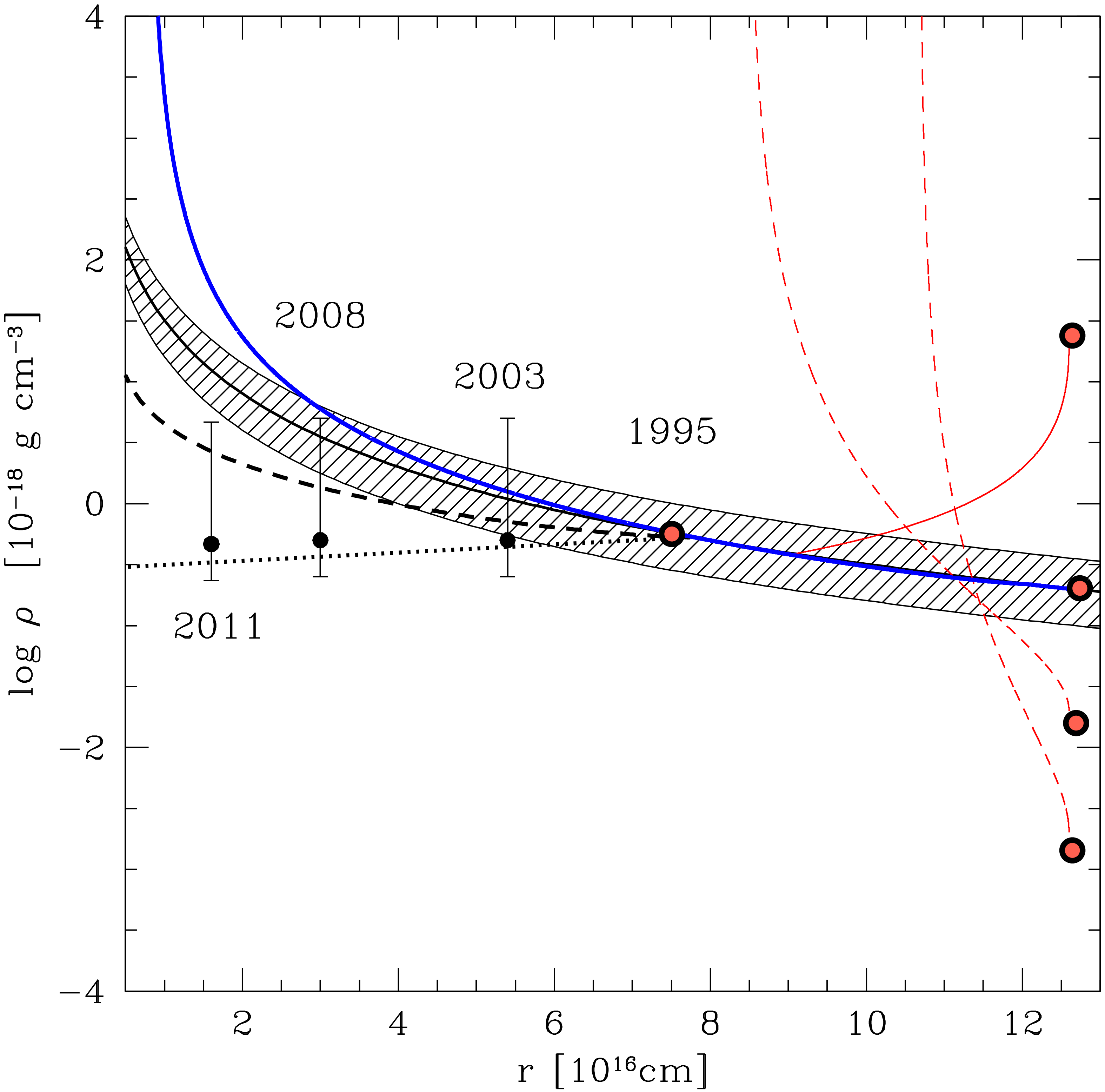

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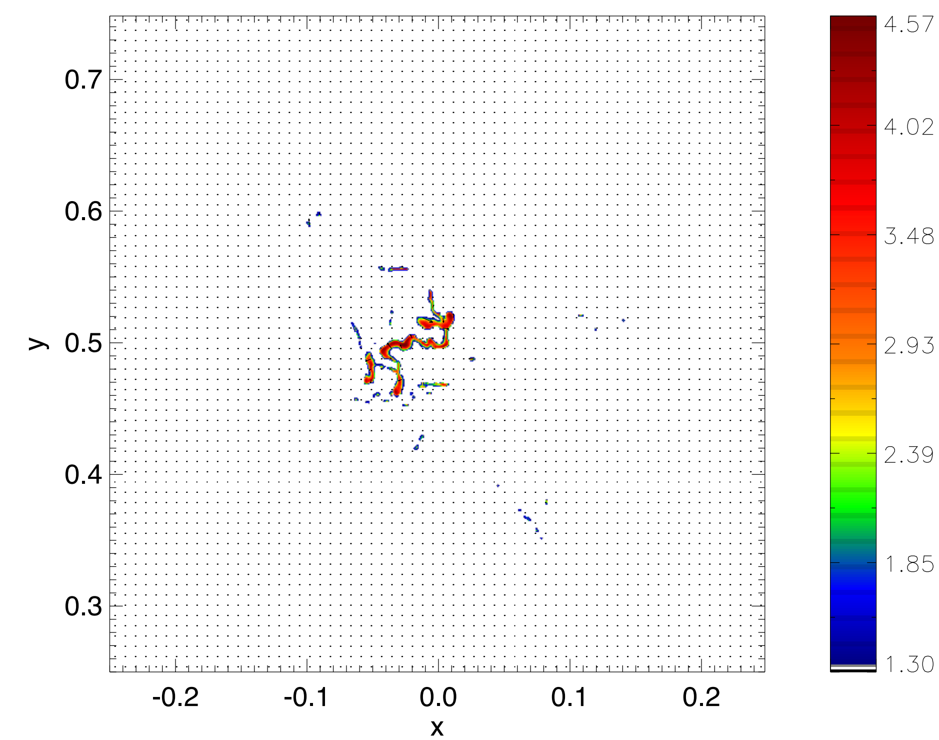

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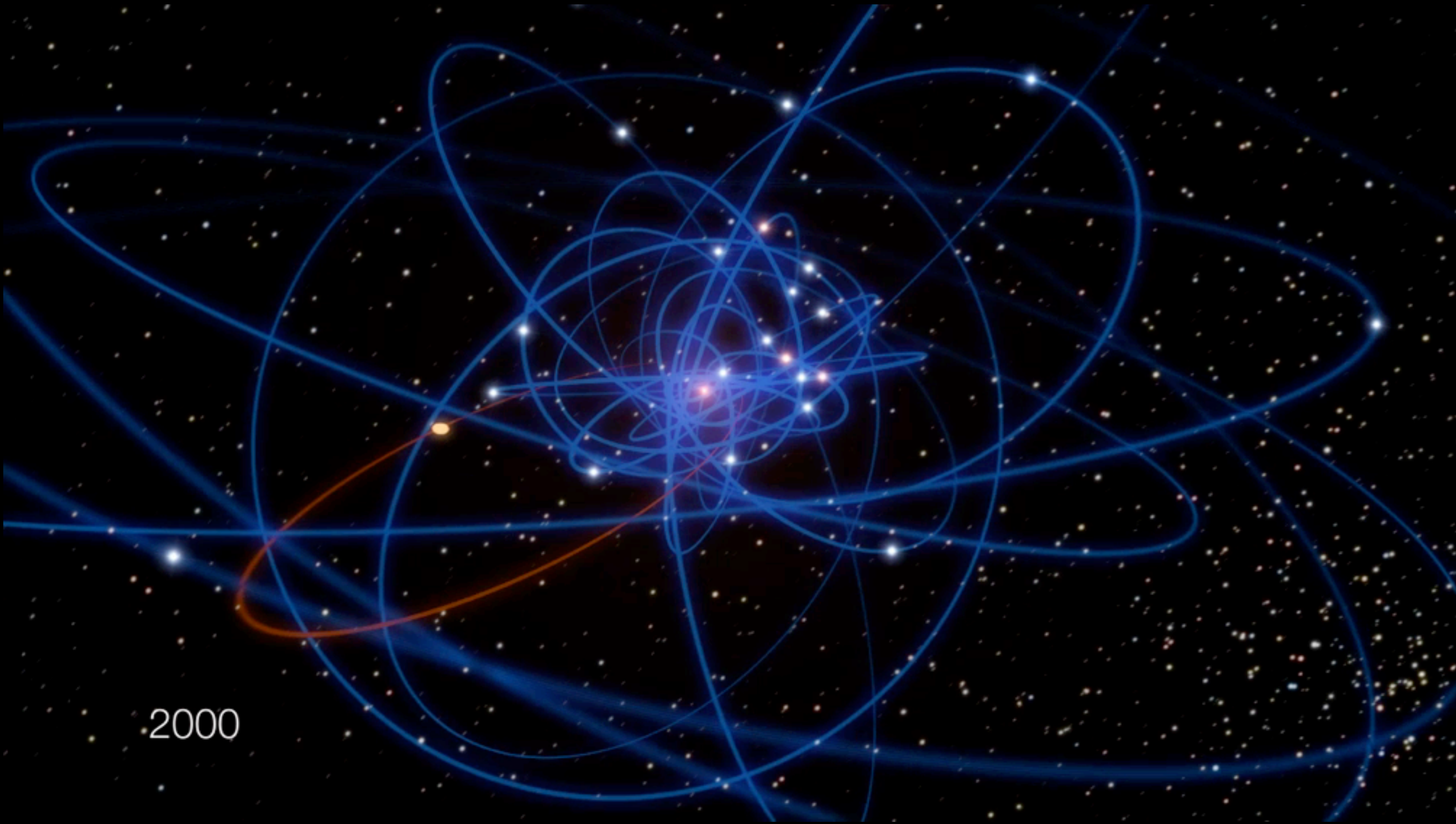
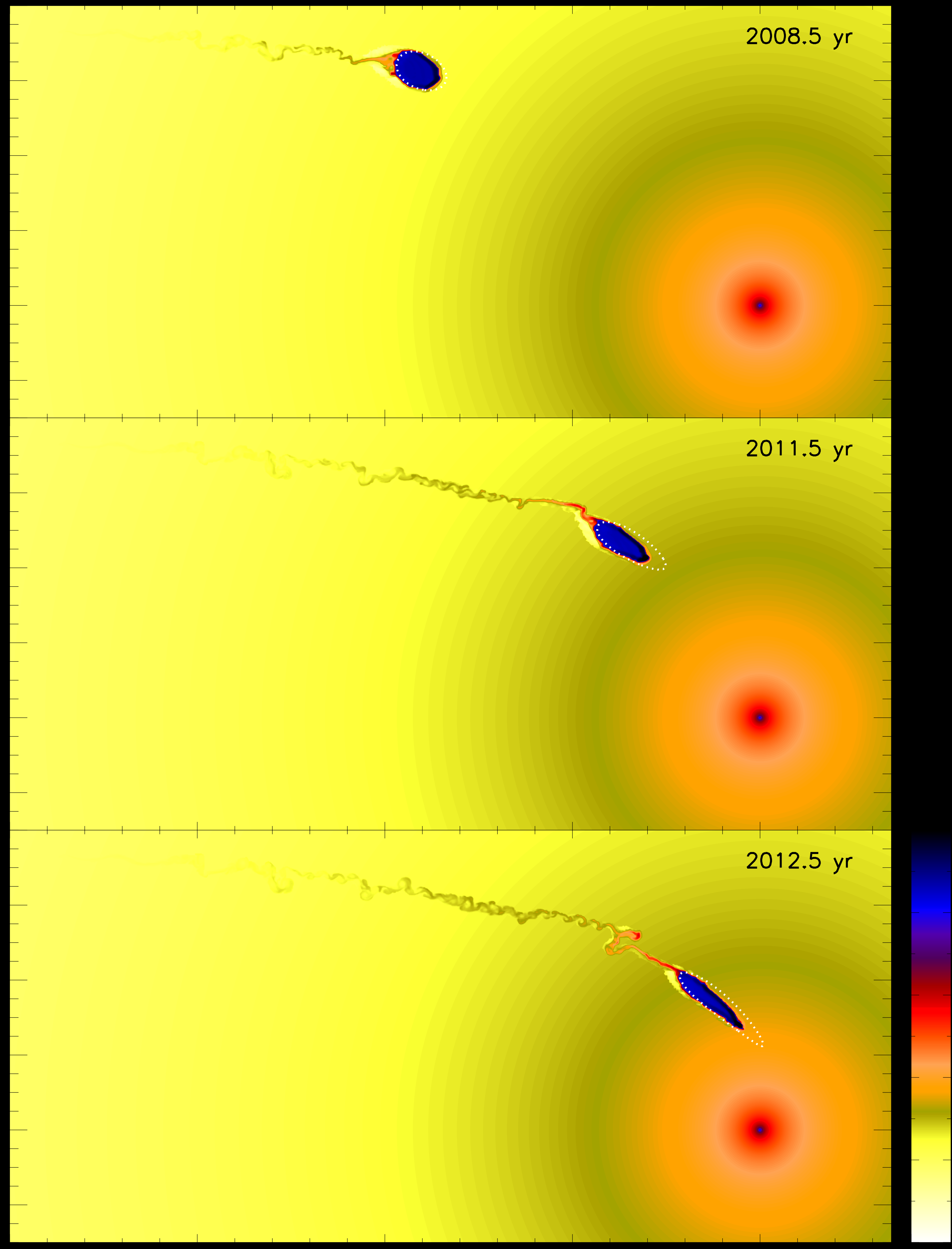
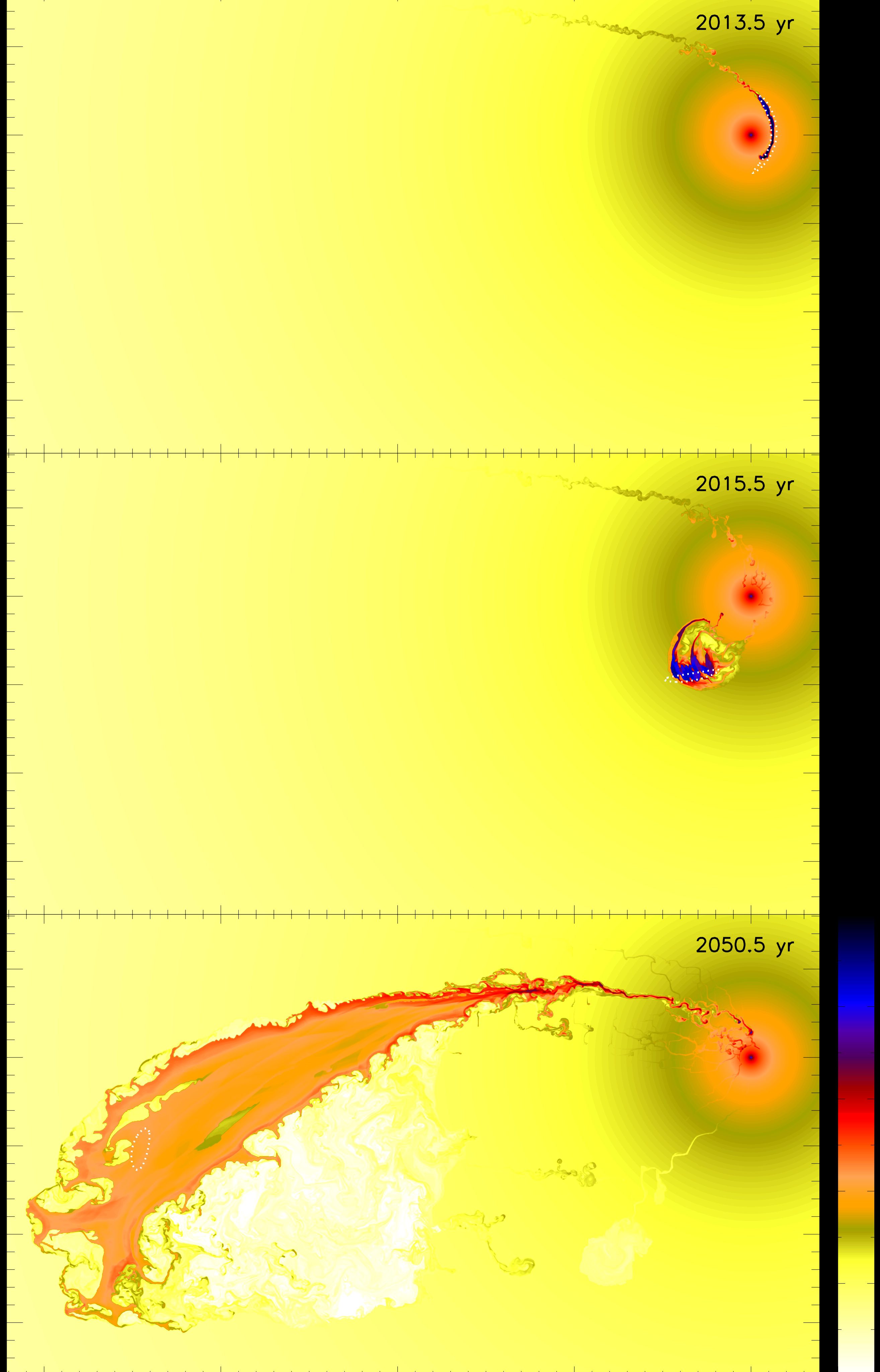
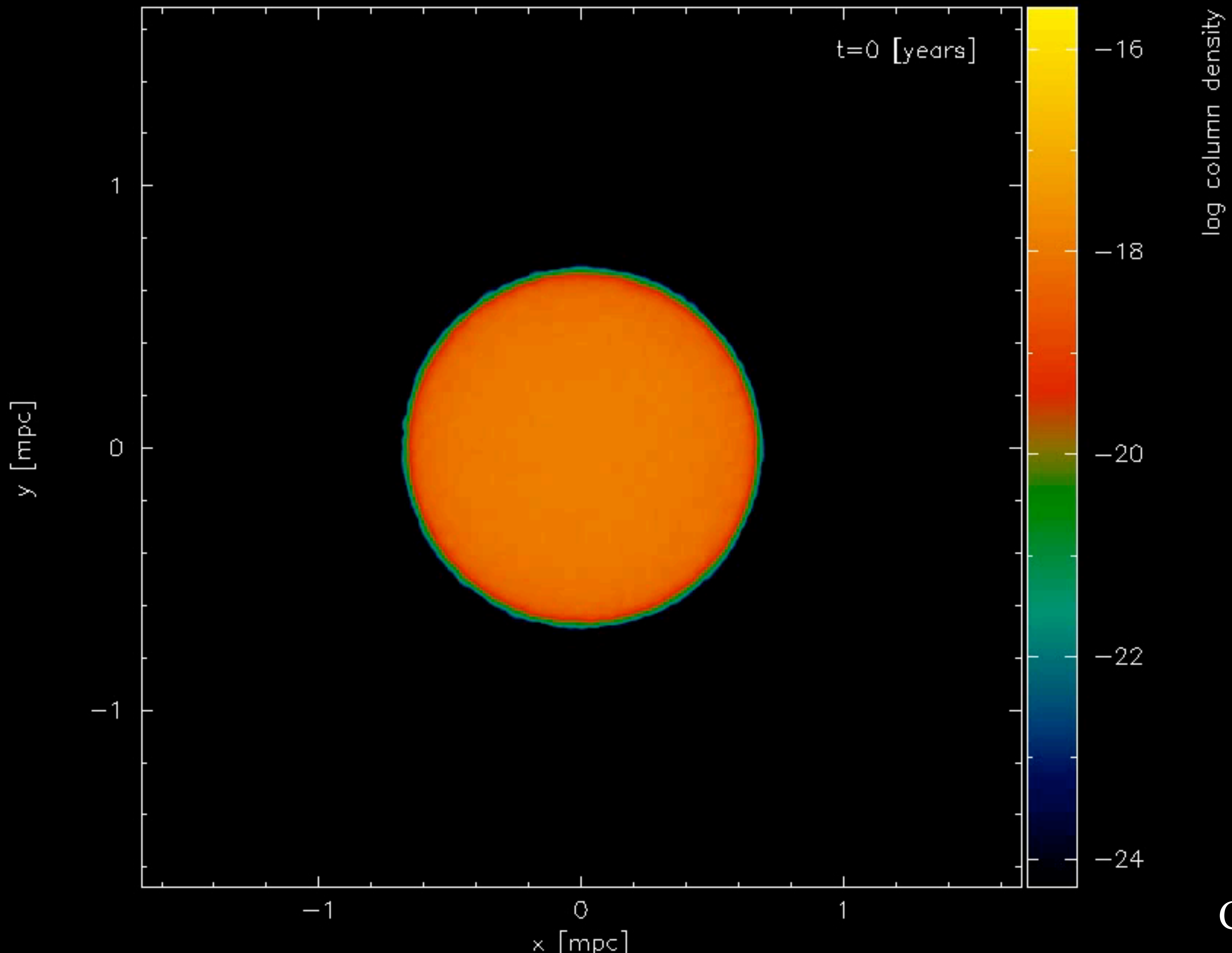


(Schartmann et al. 2012)

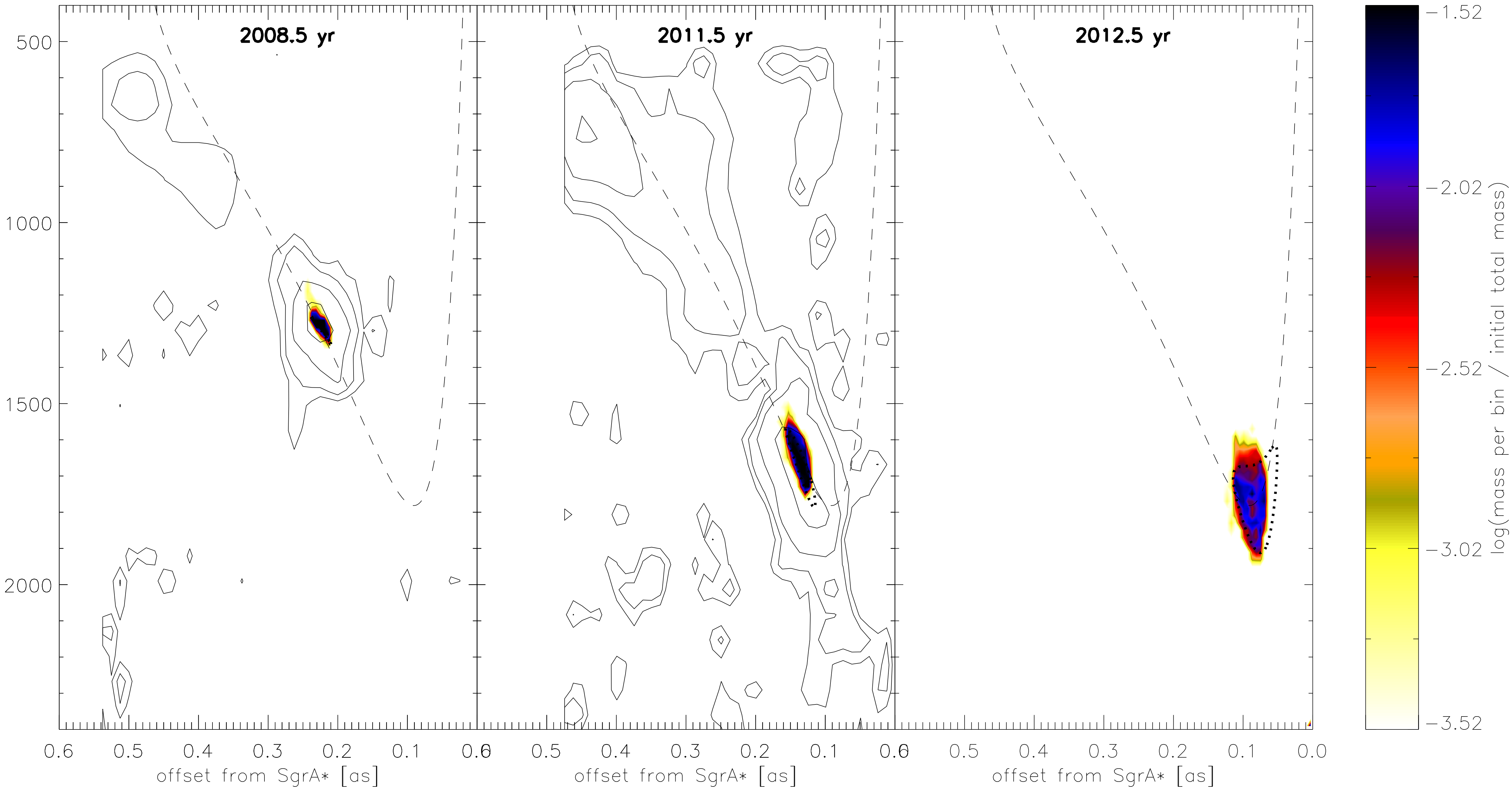

2008.5 yr
2011.5 yr
2012.5 yr


2013.5 yr
2015.5 yr
2050.5 yr

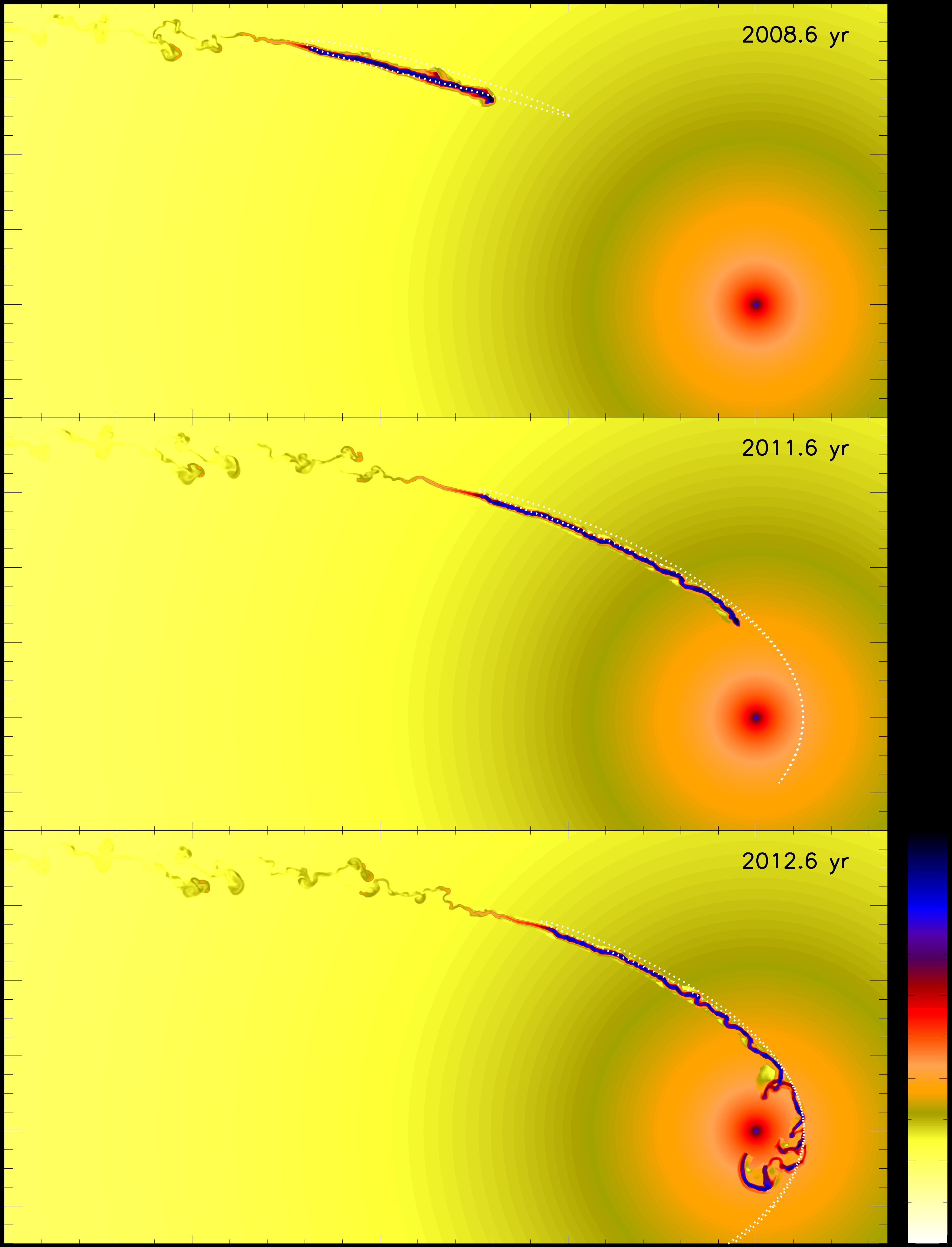
Forget about SPH :-((

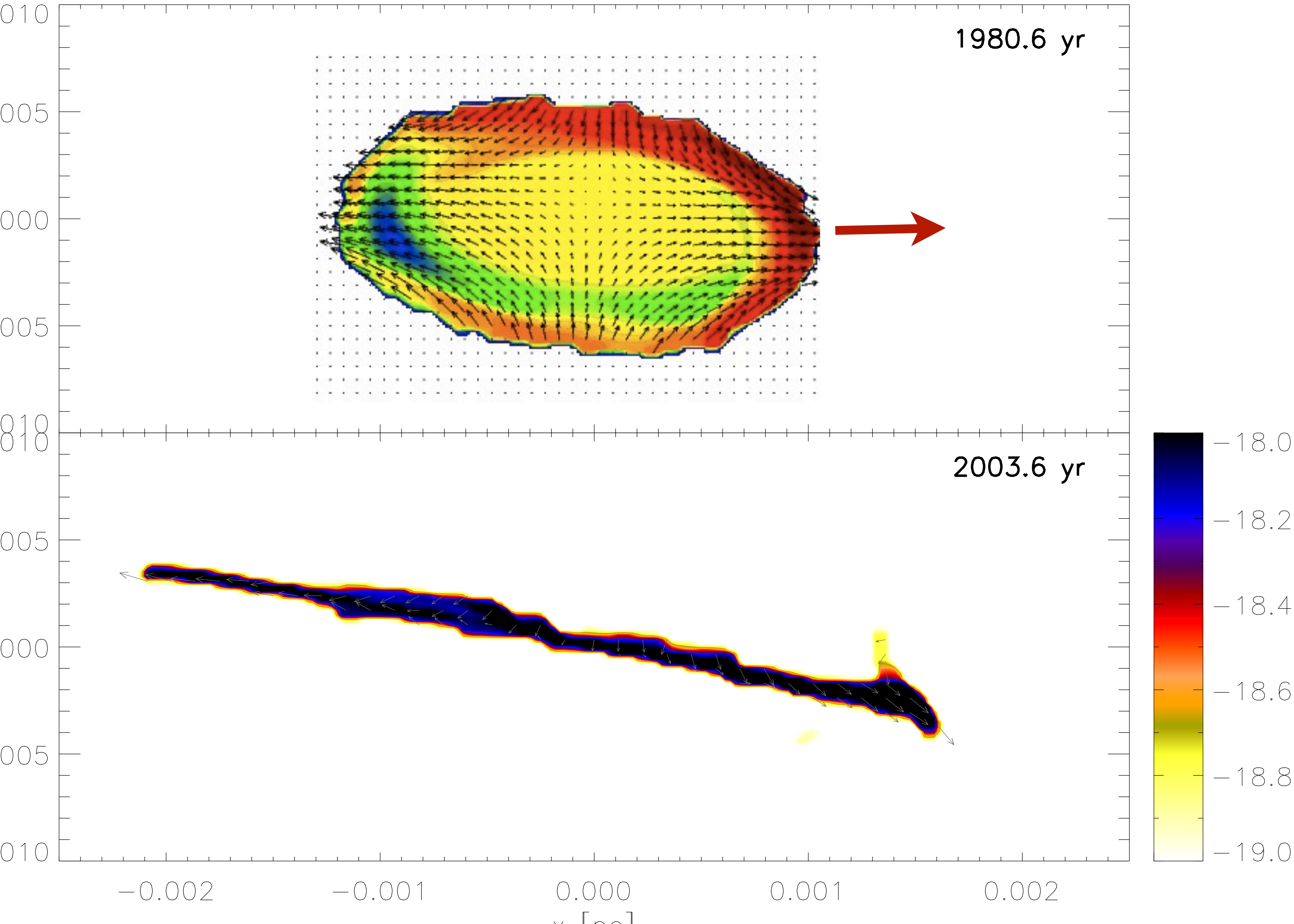


C. Alig



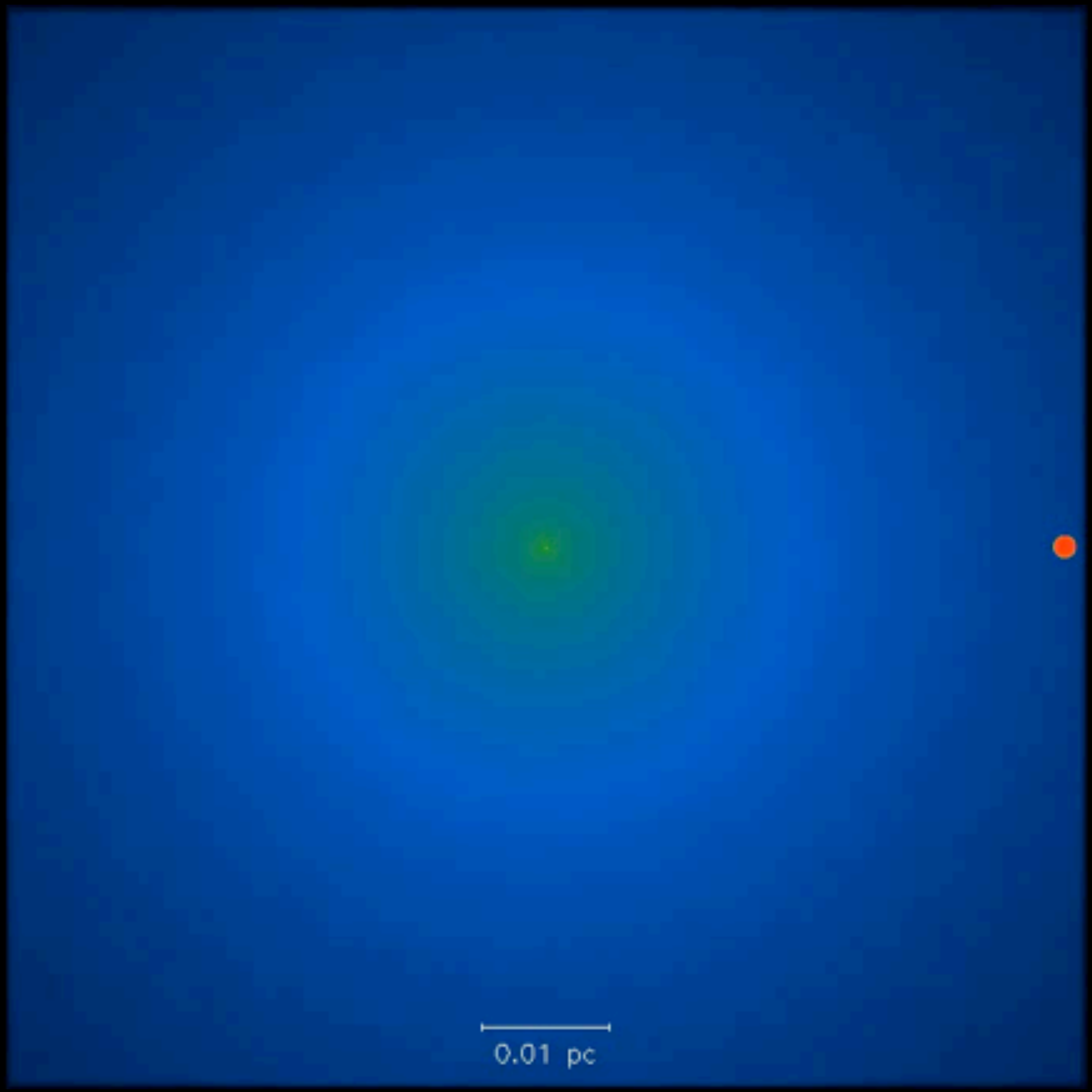
How could G2 have formed in 2000?

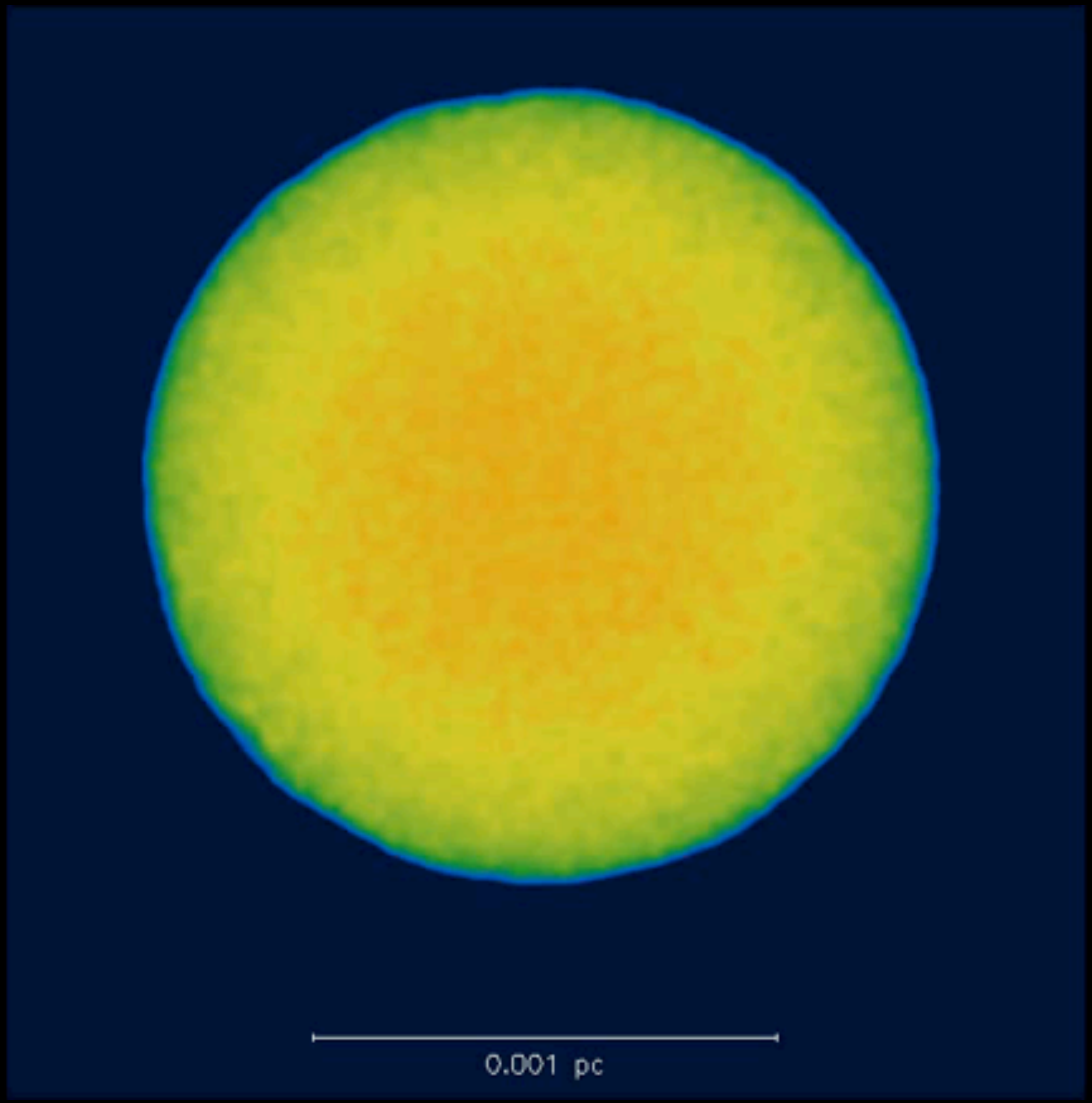

2008.6 yr
2011.6 yr
2012.6 yr



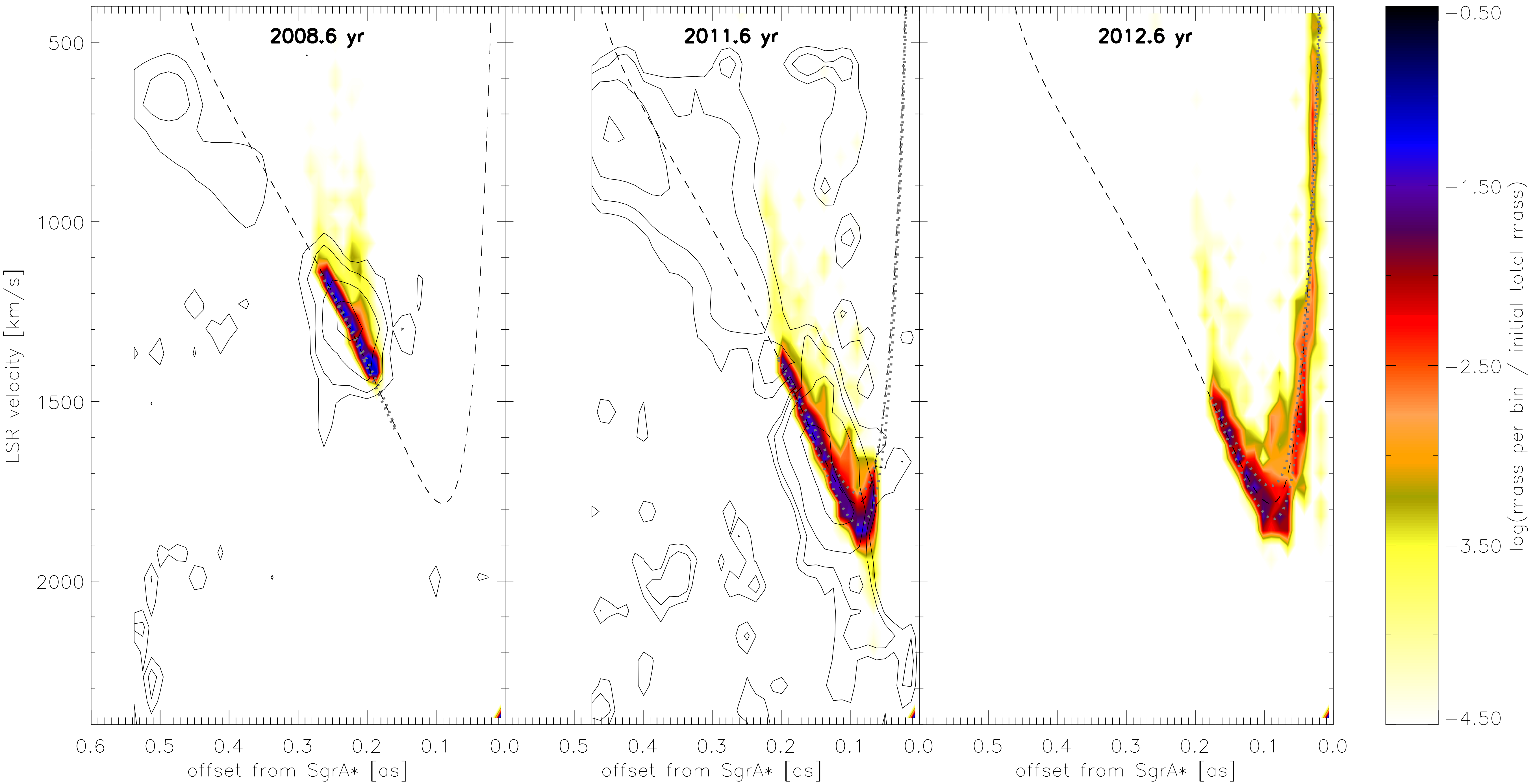
1980.6 yr
2003.6 yr
010
005
000
005
010
−0.002
−0.001
0.000
0.001
0.002
x [pc]
−18.0
−18.2
−18.4
−18.6
−18.8
−19.0

Forget about SPH :-((

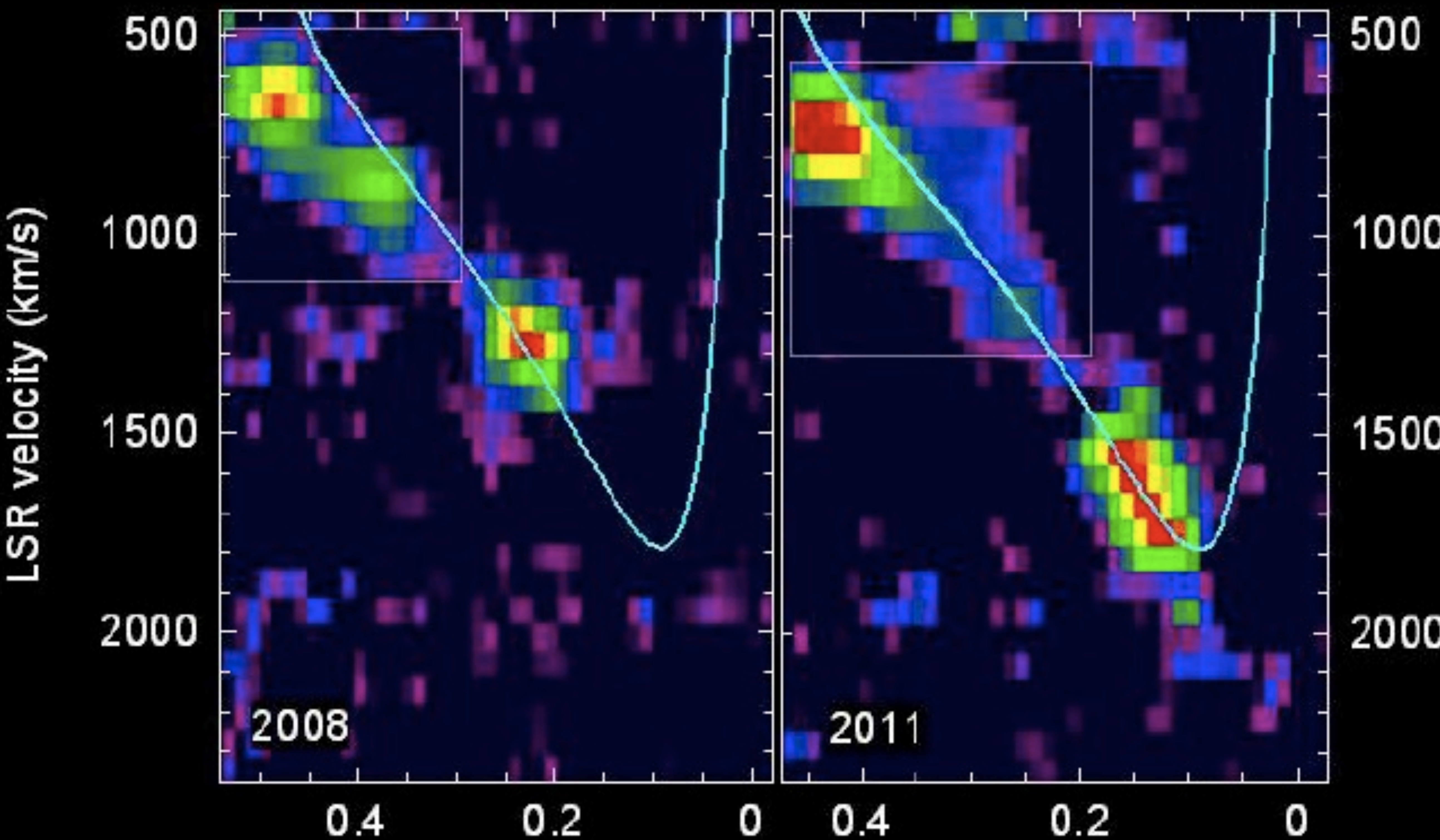




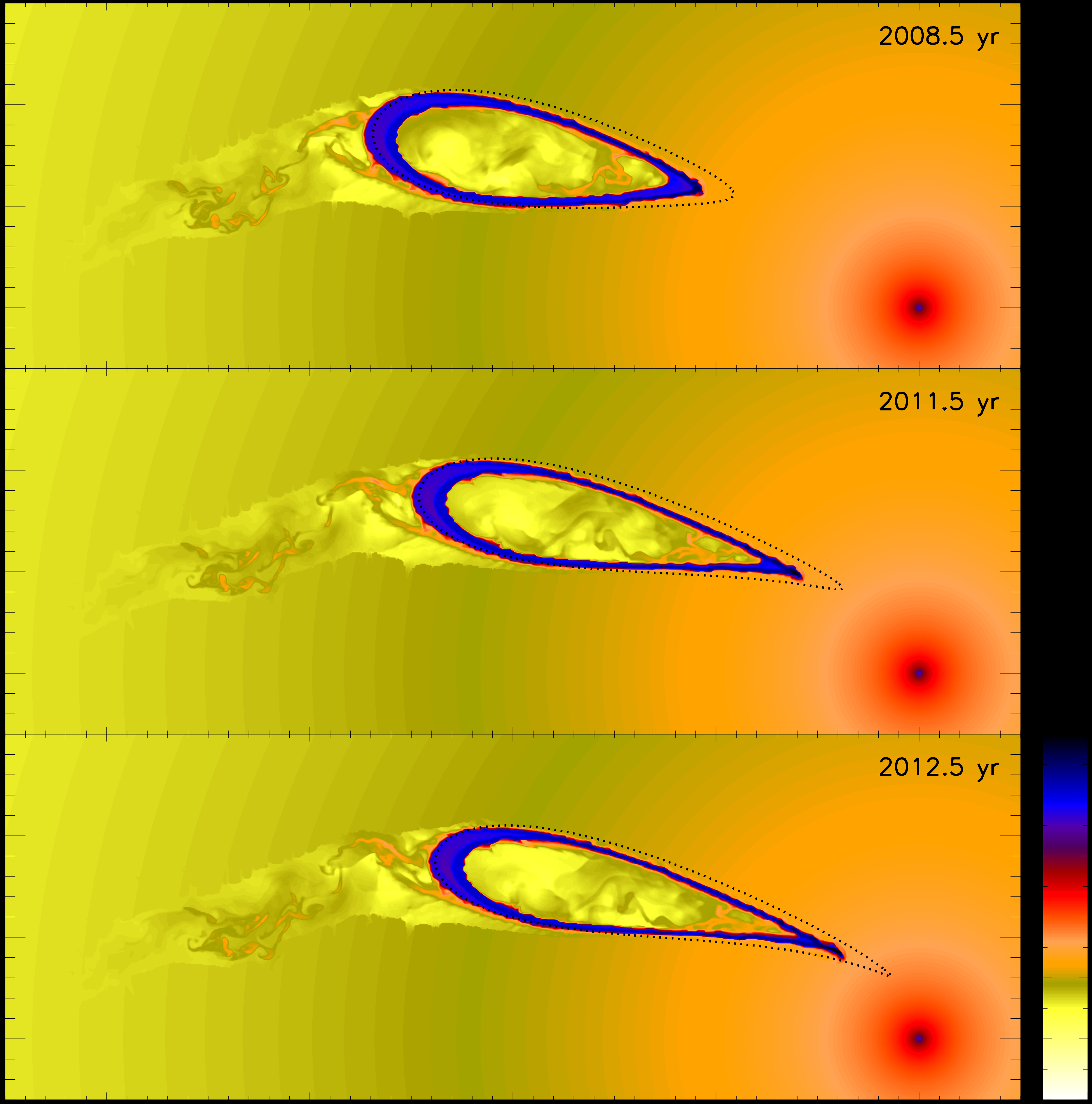
C. Alig

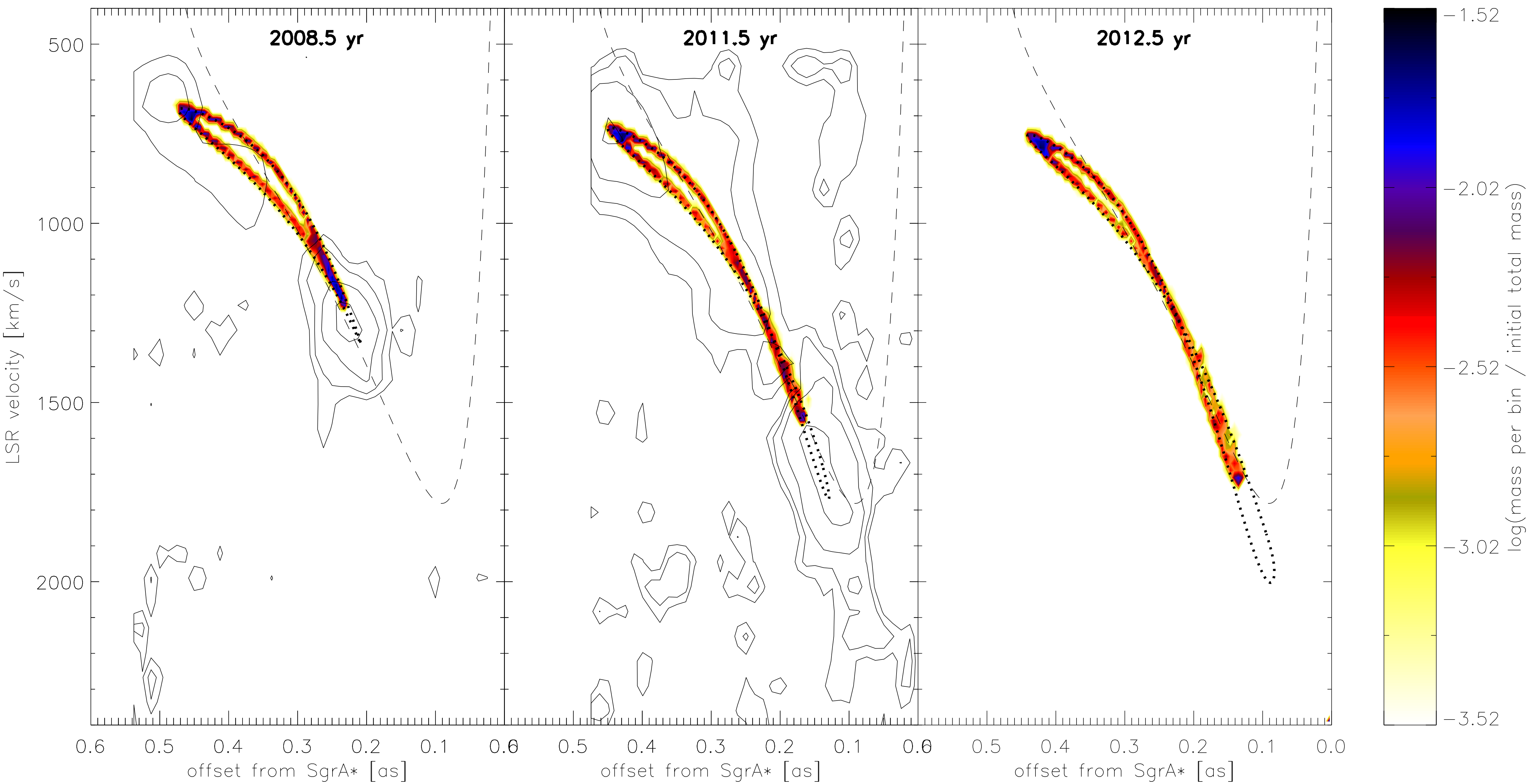


2008.6 yr
2011.6 yr
2012.6 yr
LSR velocity [km/s]
500
1000
1500
2000
0.6
0.5
0.4
0.3
0.2
0.1
0.0
offset from SgrA* [as]
offset from SgrA* [as]
offset from SgrA* [as]
log(mass per bin / initial total mass)
−0.50
−1.50
−2.50
−3.50
−4.50



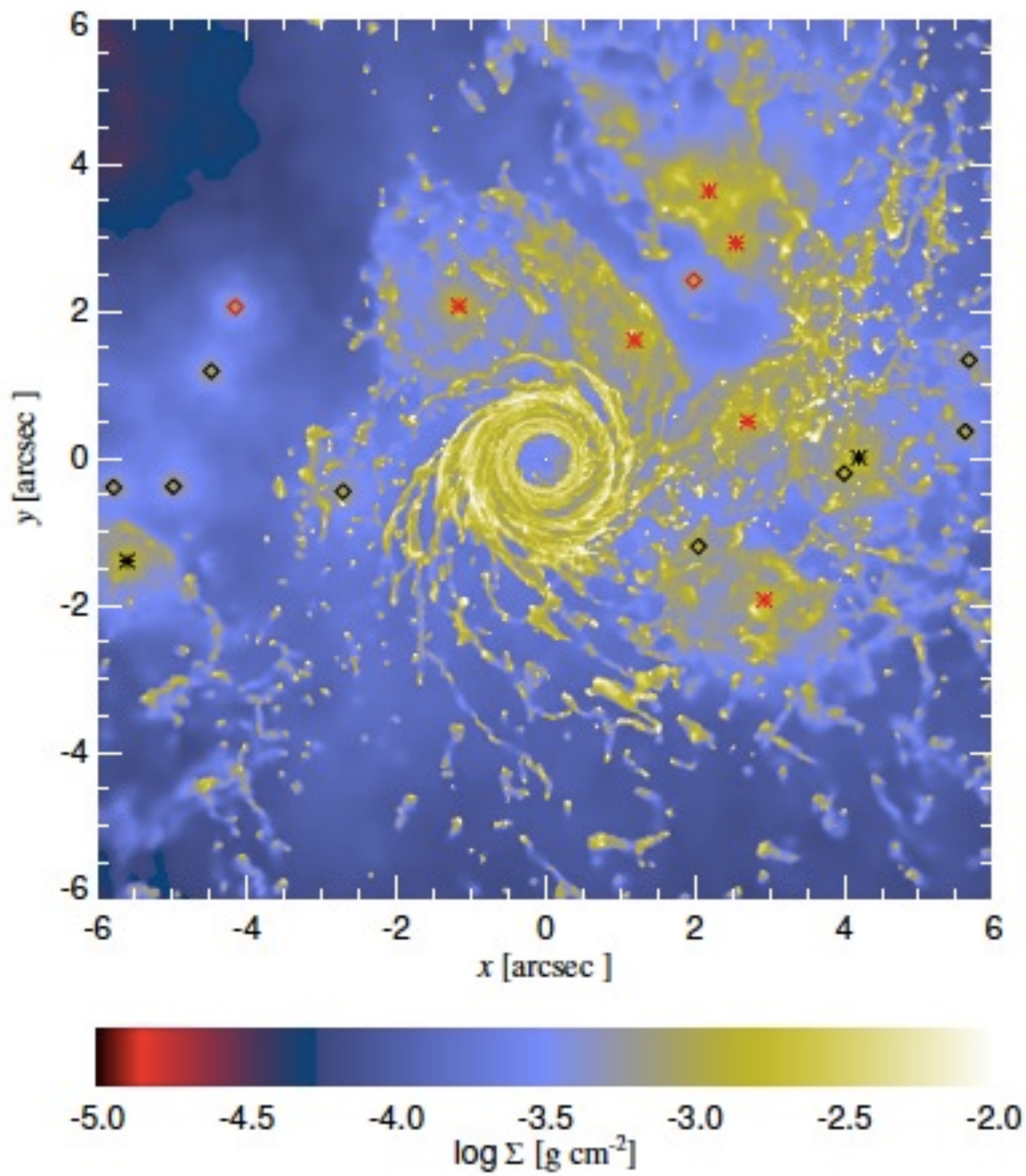
Offset from Sgr A* (arcsec)


2008.5 yr
2011.5 yr
2012.5 yr


2008.5 yr
2011.5 yr
2012.5 yr
LSR velocity [km/s]
500
1000
1500
2000
offset from SgrA* [as]
0.6
0.5
0.4
0.3
0.2
0.1
0.0
log(mass per bin / initial total mass)
-1.52
-2.02
-2.52
-3.02
-3.52

Origin of G2: diffuse cloud scenario

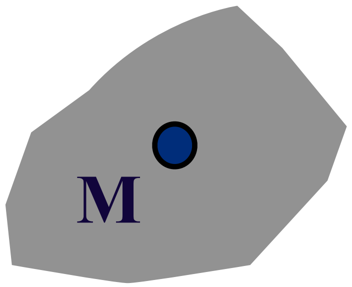
Shocked Wind debris from massive stars in the stellar disk



Cuadra et al. (07)

Origin of G2: compact source scenario

(Murray-Clay & Loeb 12)



Energy input rate:

$$\dot{E} \approx 2\pi R^2 \rho_{hot} c_{hot}^3$$

Evaporation rate:

$$\dot{M}_{evap} = 10^{14} \left(\frac{R}{10^{12}\,\mathrm{cm}} \right)^3 \left(\frac{M_\odot}{M} \right) \left(\frac{c_{hot}}{1000\,\mathrm{km/s}} \right)^3 \left(\frac{\rho_{hot}}{10^{-21}\,\mathrm{g/cm^3}} \right) \frac{\mathrm{g}}{\mathrm{s}}$$

Timescale to form G2:

$$\tau = \frac{M_{G2}}{\dot{M}_{evap}} \approx 3 \cdot 10^6\,\mathrm{yrs} \left(\frac{10^{12}\,\mathrm{cm}}{R} \right)^3 \left(\frac{M}{M_\odot} \right)$$

For $\tau \approx 100$ yrs and $M \approx 0.1 M_\odot$: $R \geq 10^{13}\,\mathrm{cm} \approx 1\,\mathrm{AU}$

Future of G2

- Tidal disruption in 2013.
- Infall of subunits into the central region around the SMBH.
- Evaporation and cooling of the hot bubble.
- We might expect a bright future of Sgr A*