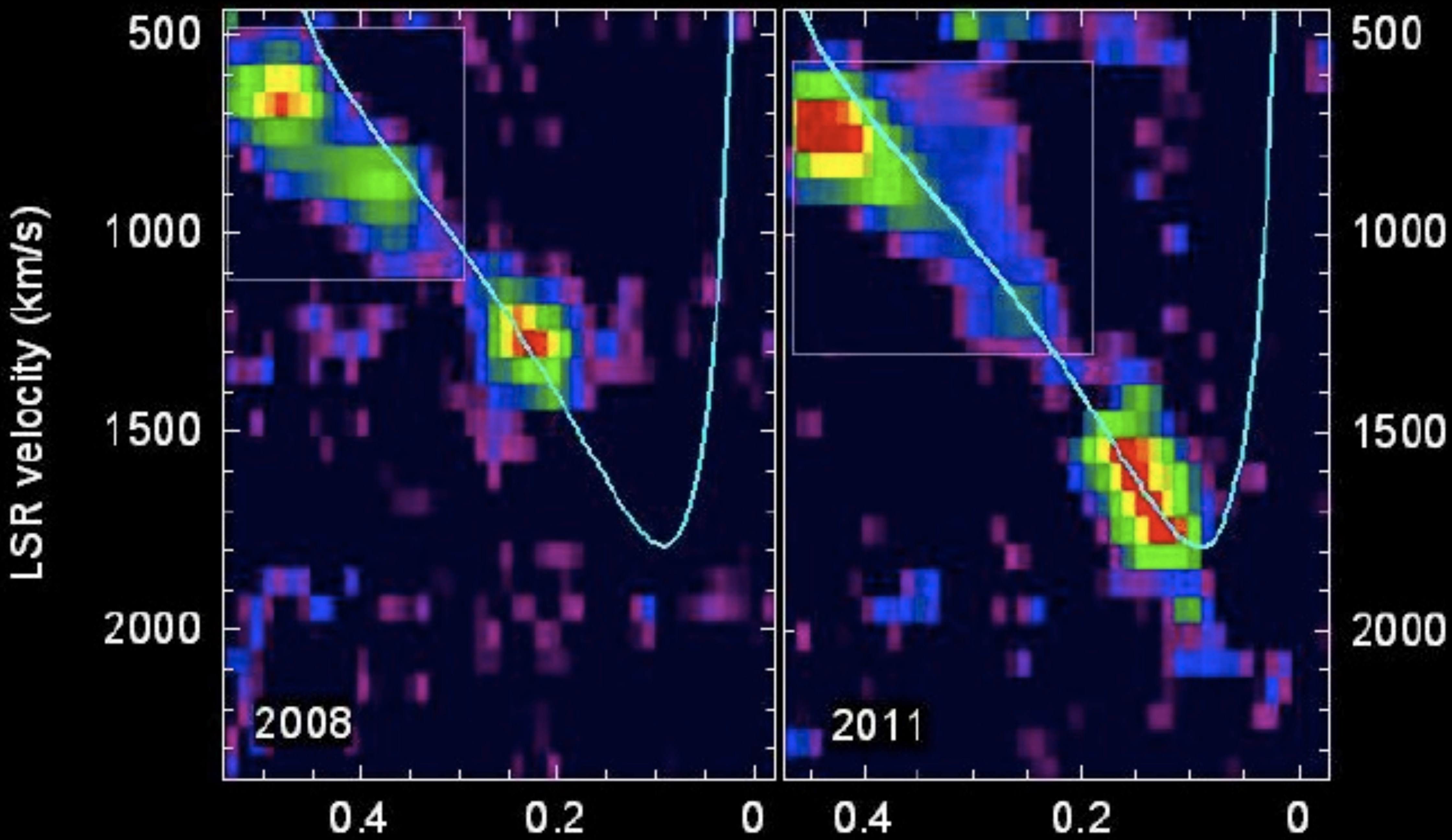
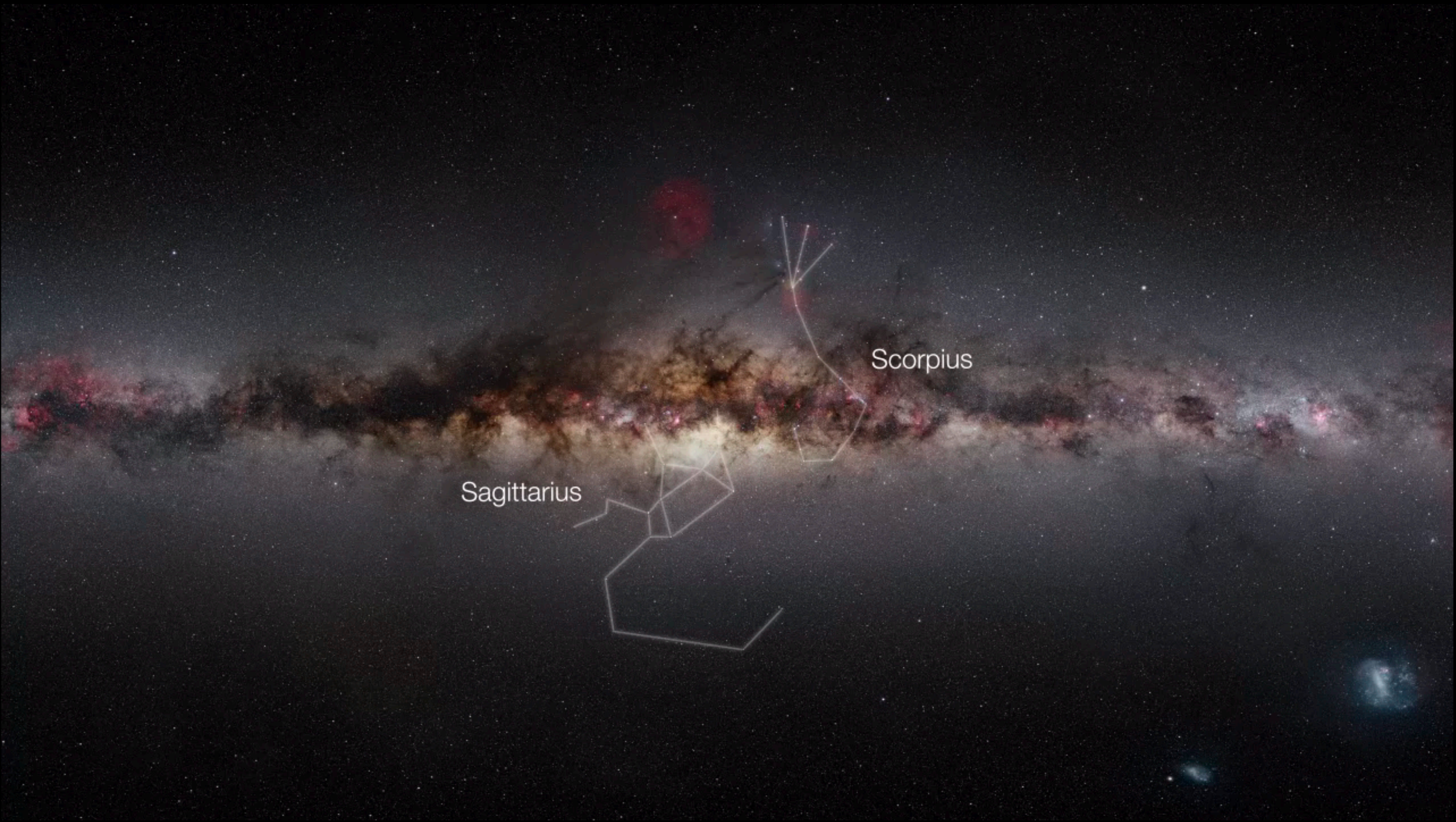
Watching a tiny gas cloud fall into the SMBH

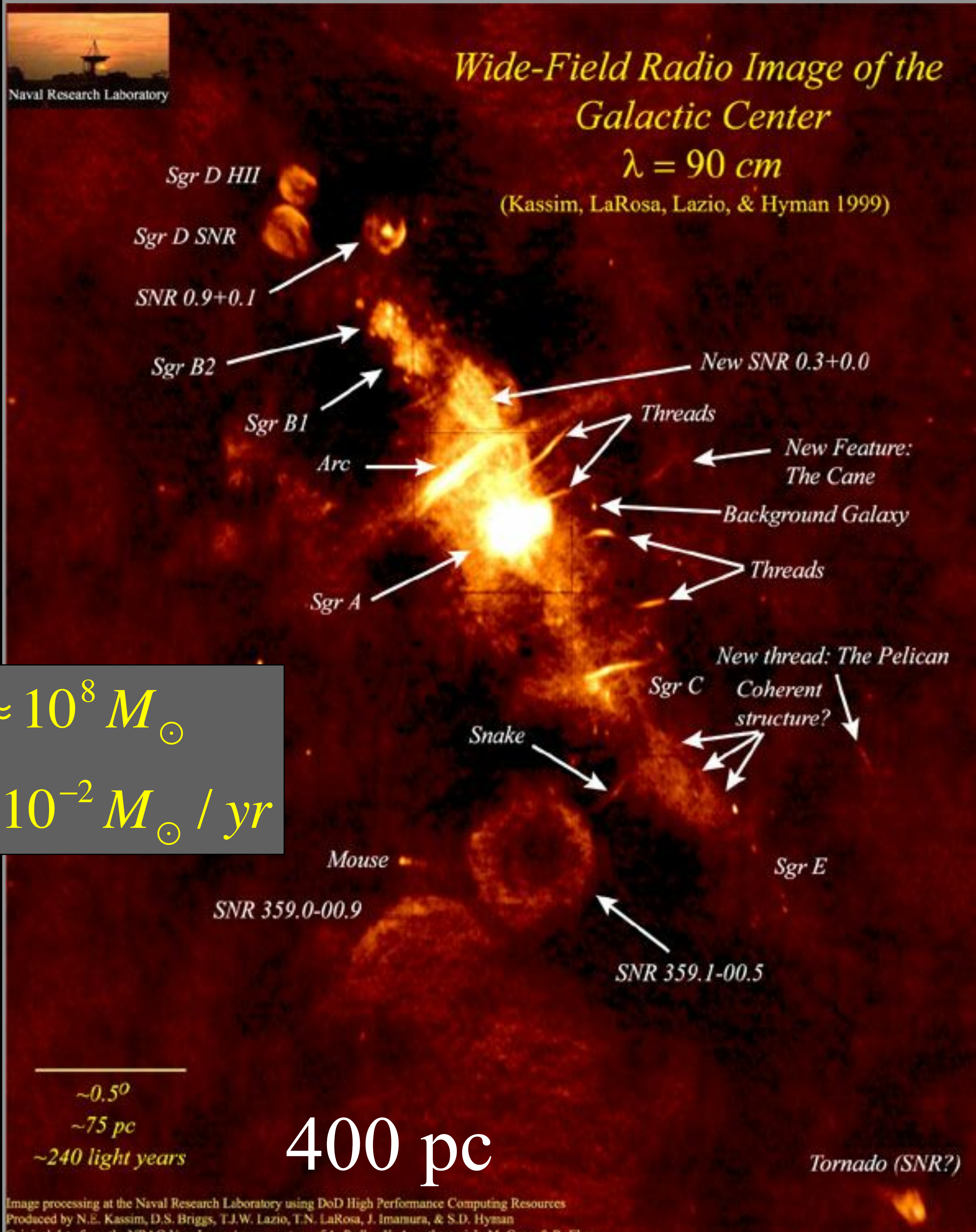
Burkert, Schartmann, Ballone, Alig, Gillessen,
Genzel + IR Group



Gillessen + 2012; Burkert + 2012; Schartmann + 2012

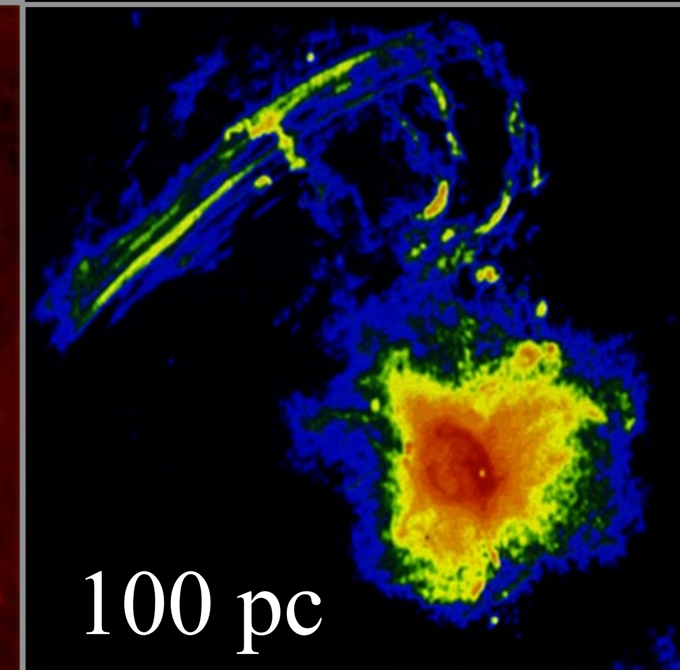
Gillessen et al. 2012, Nature 481, 51; Burkert et al. astro-ph/1201.1414

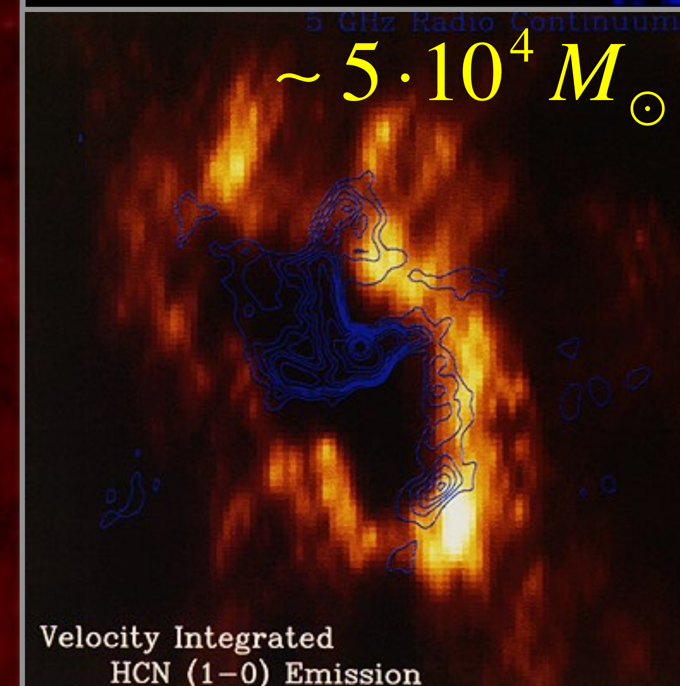

Scorpius
Sagittarius

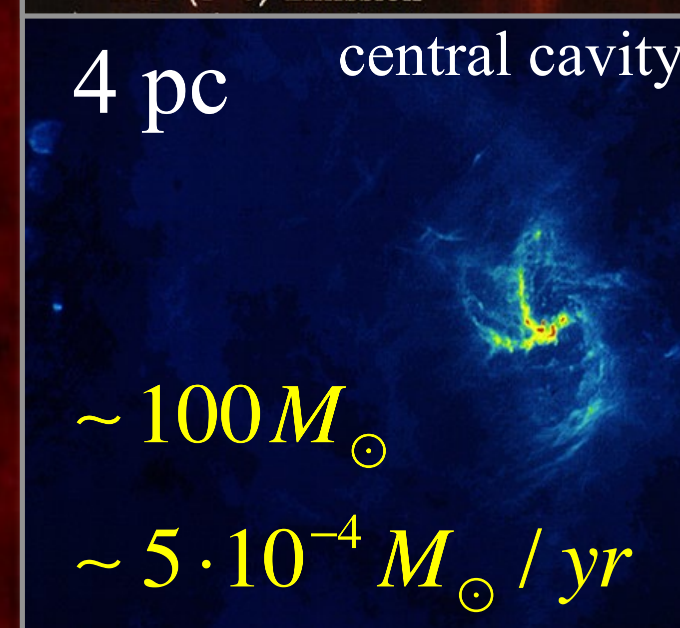


$M_g \approx 10^8 M_\odot$

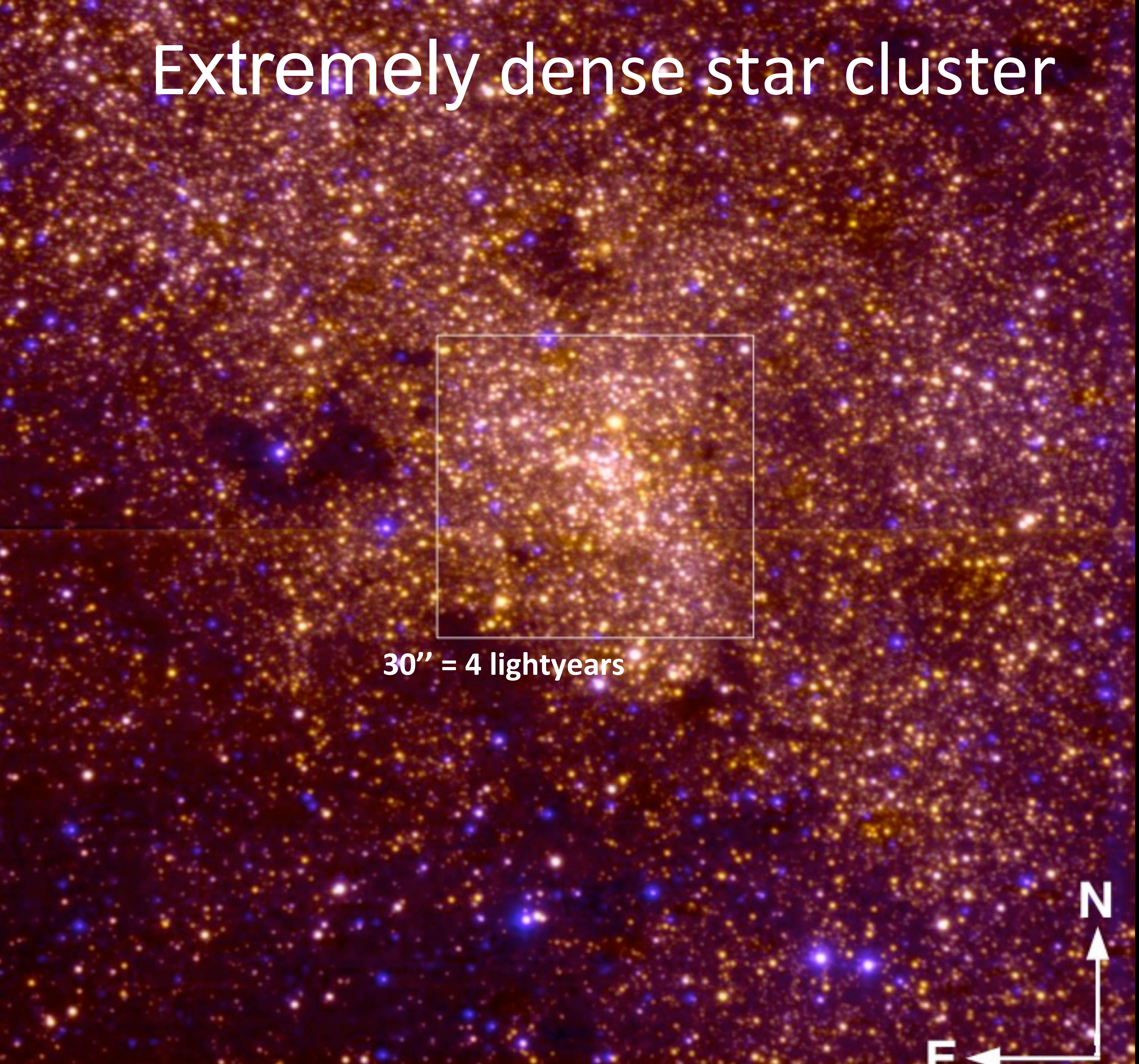
$\dot{M} \approx 10^{-2} M_\odot / yr$





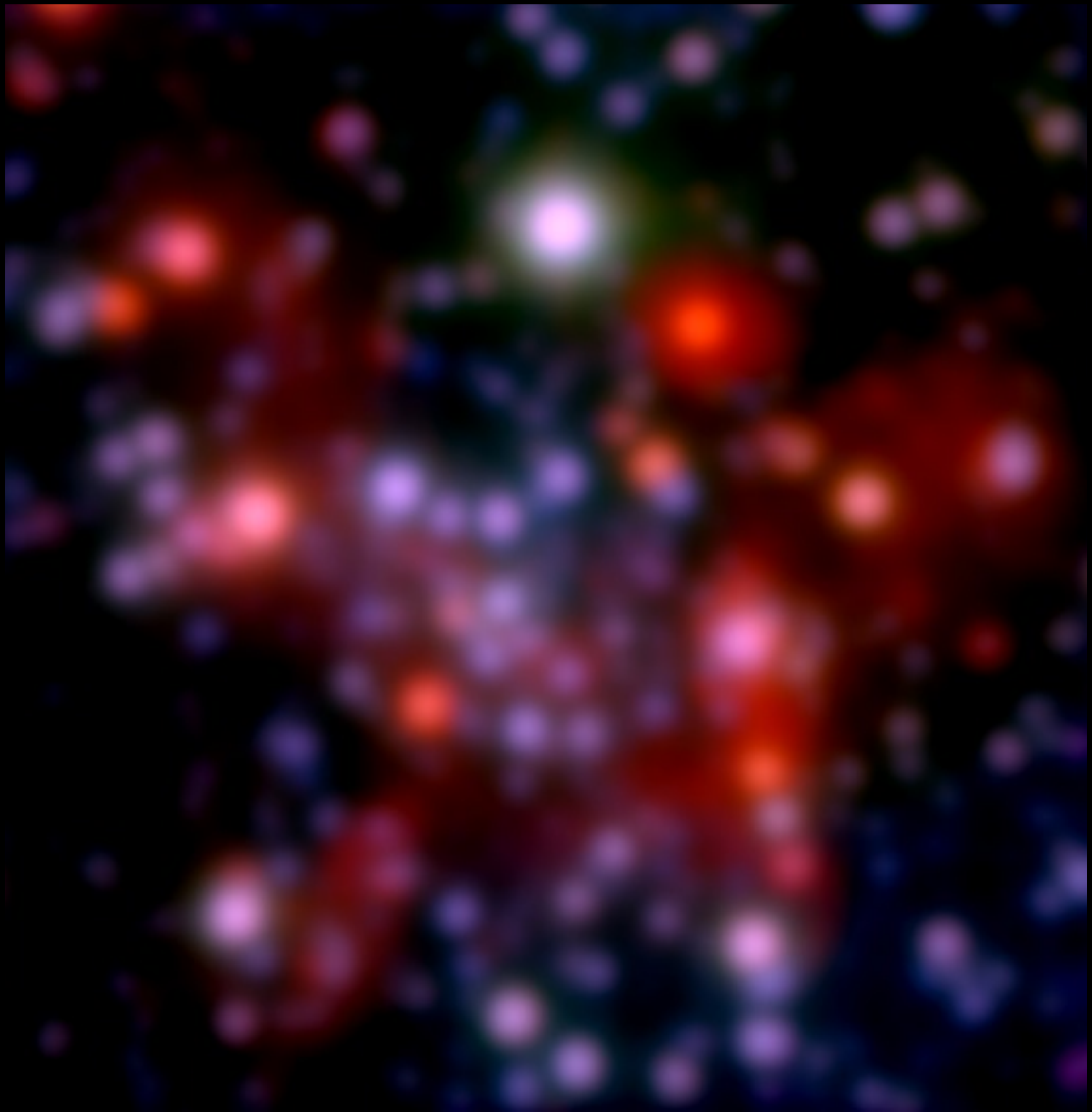


Extremely dense star cluster

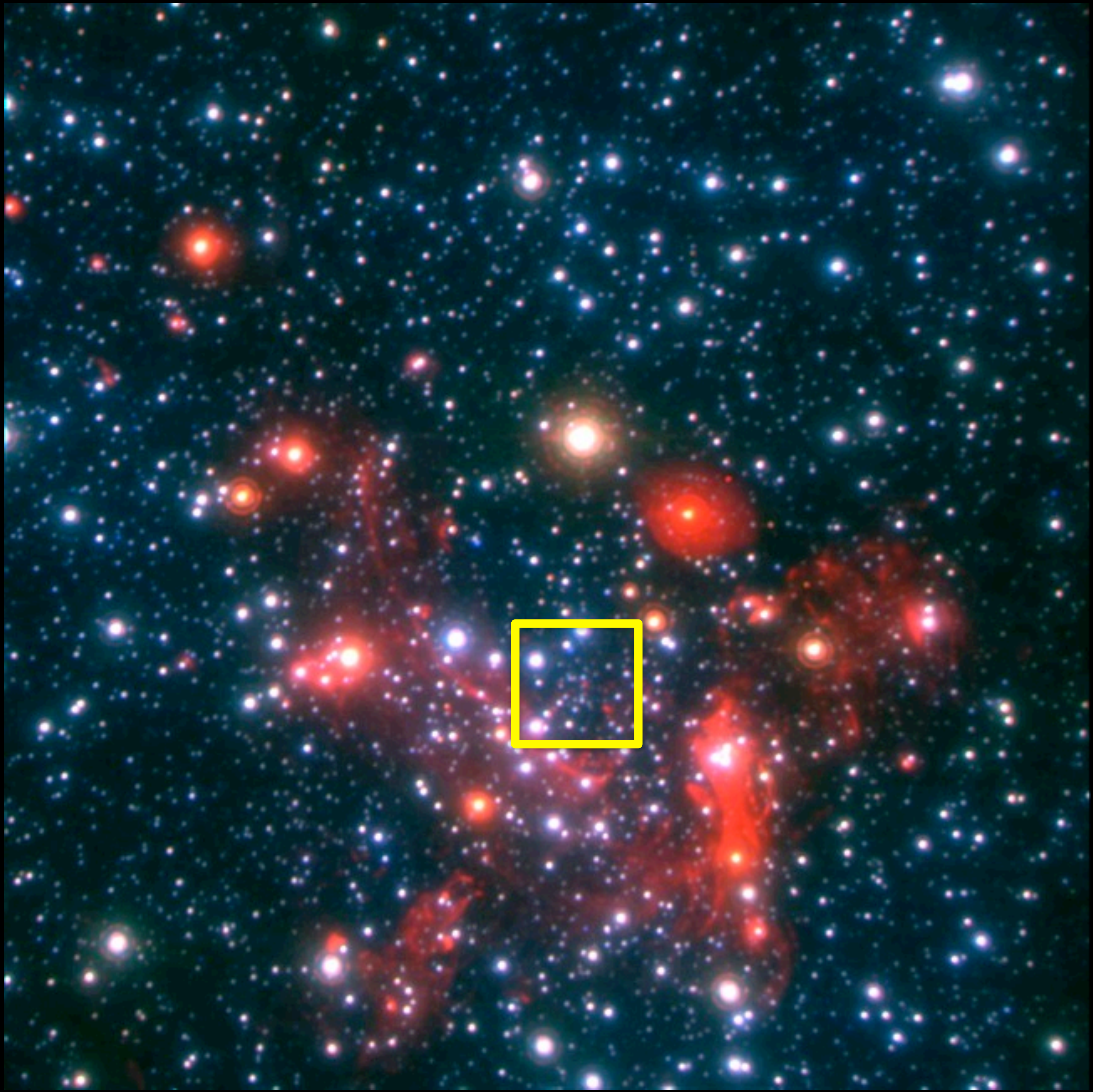


Schödel+ 2006
(ISAAC, VLT)

The central 20’’: Seeing limited

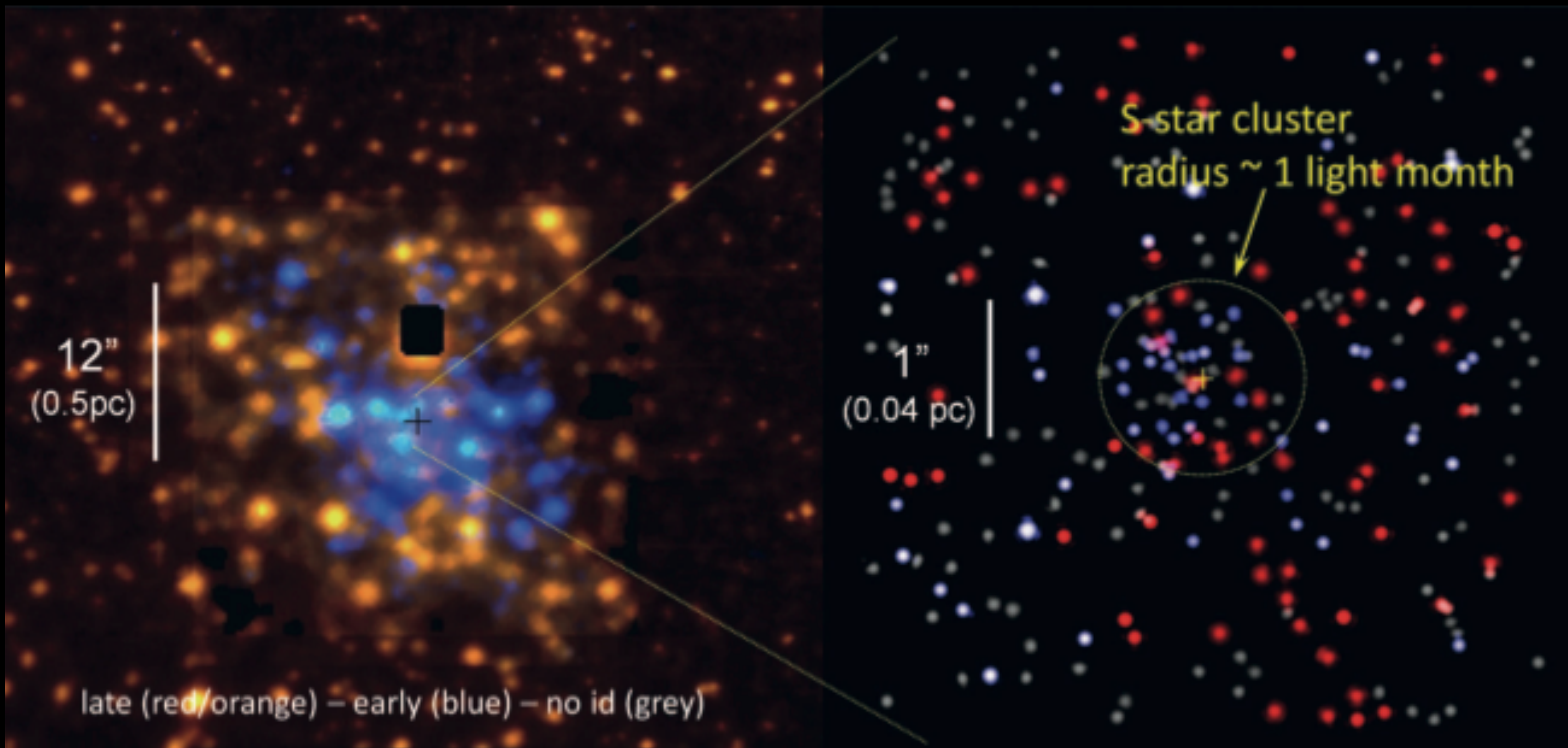


Adaptive Optics



NACO,
HKL color composite

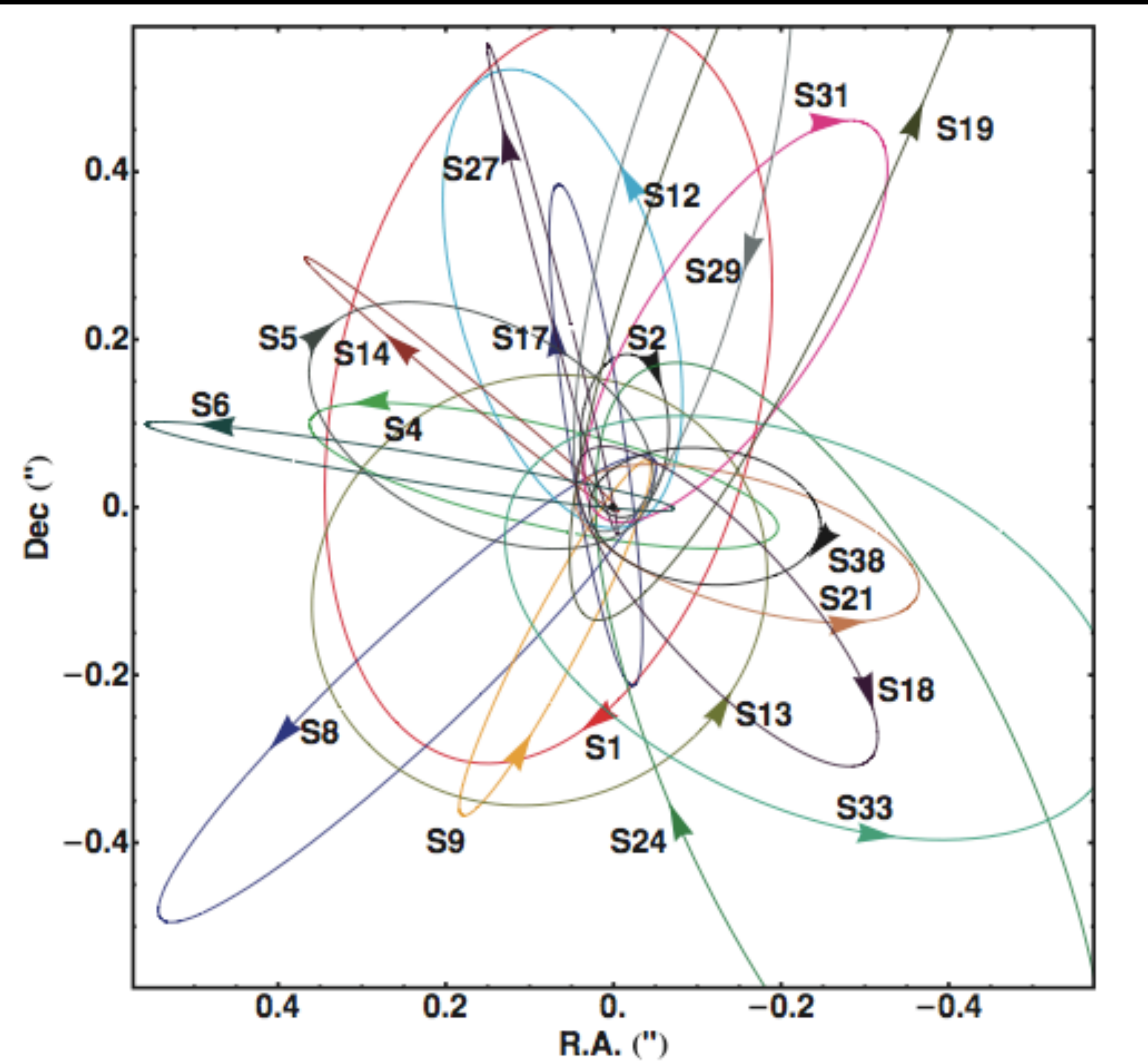
Cluster of old stars and S-star cluster

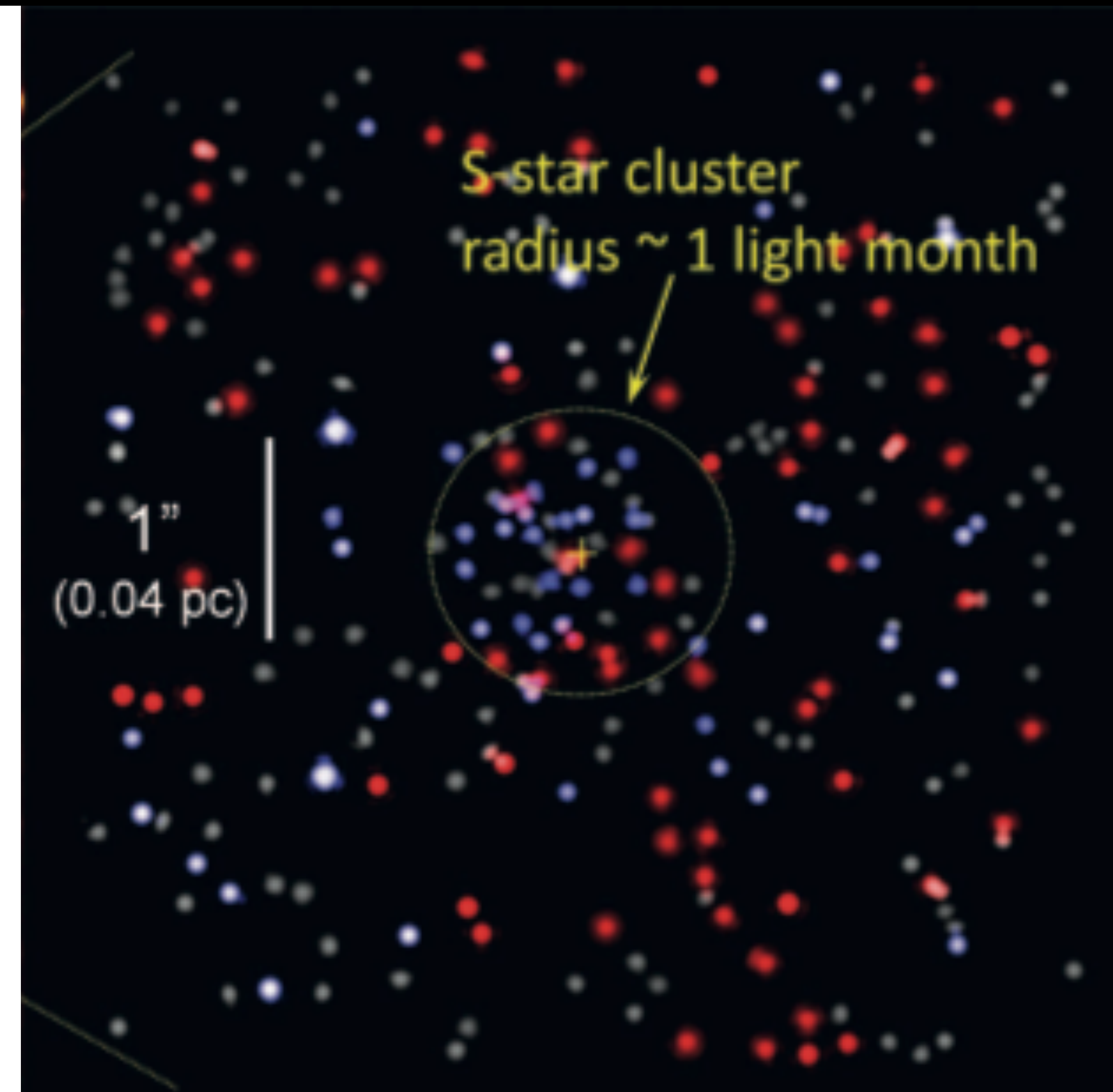


Distribution of late-type stars (red)
and early type stars (blue)

Genzel et al. 2010

Cluster of old stars and S-star cluster

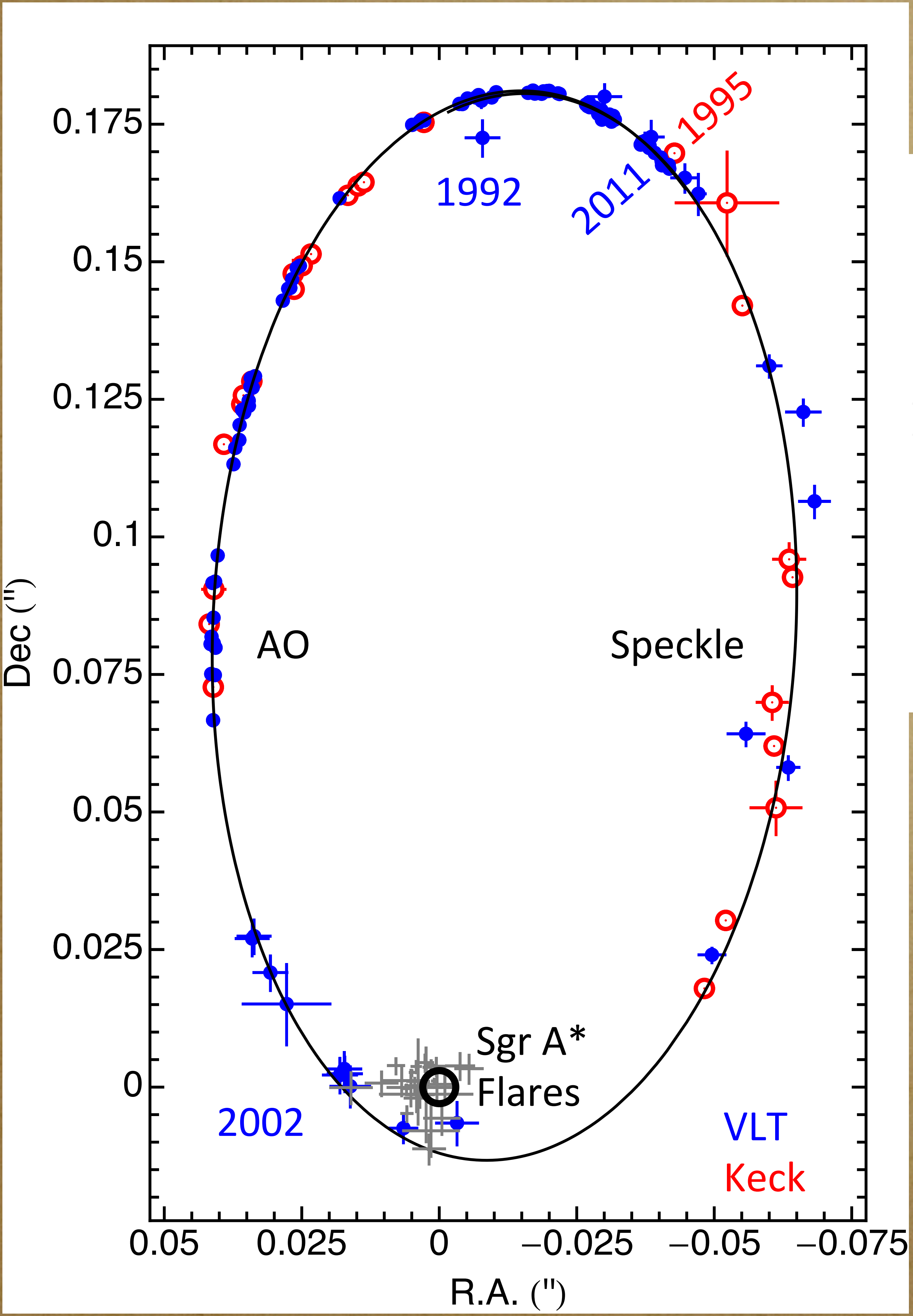


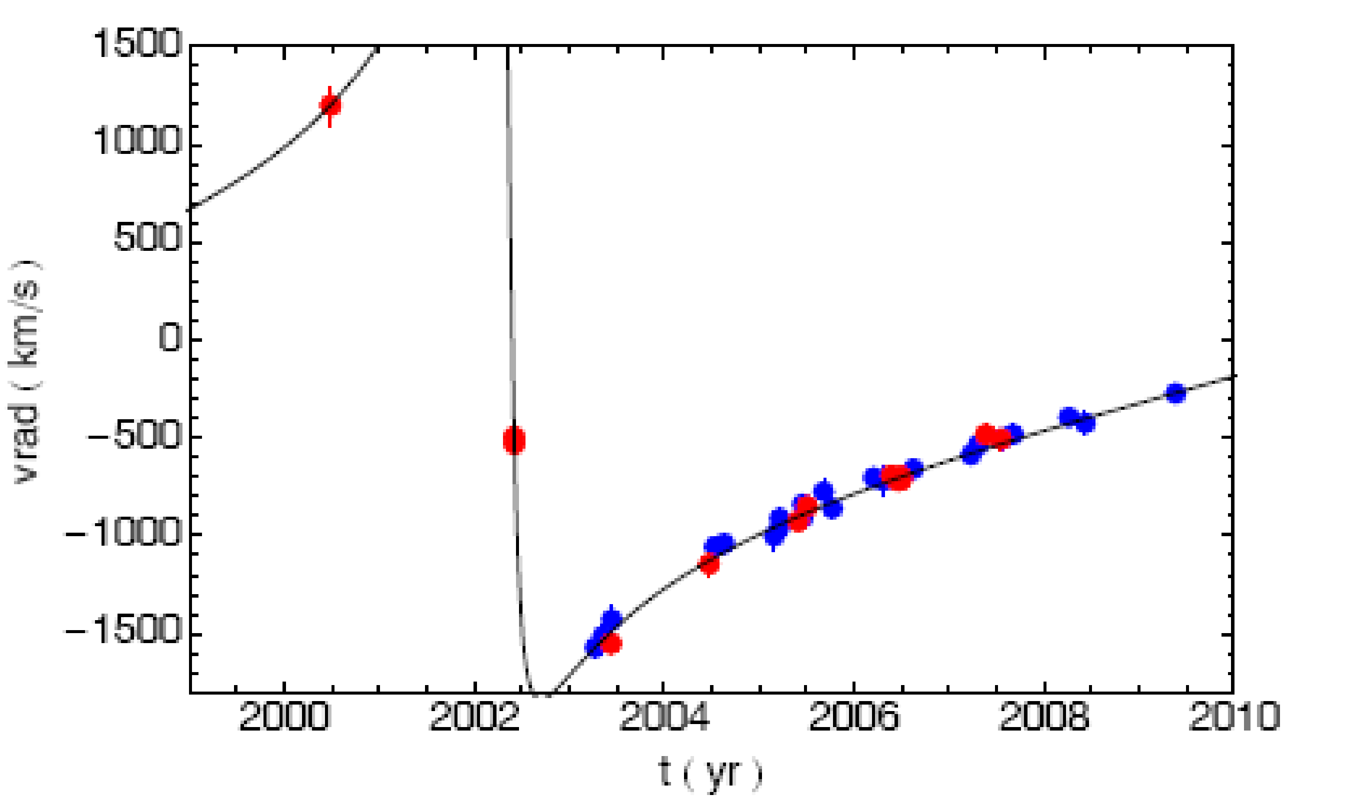


spherical cluster of young stars

Genzel et al. 2010

Keplerian Orbit



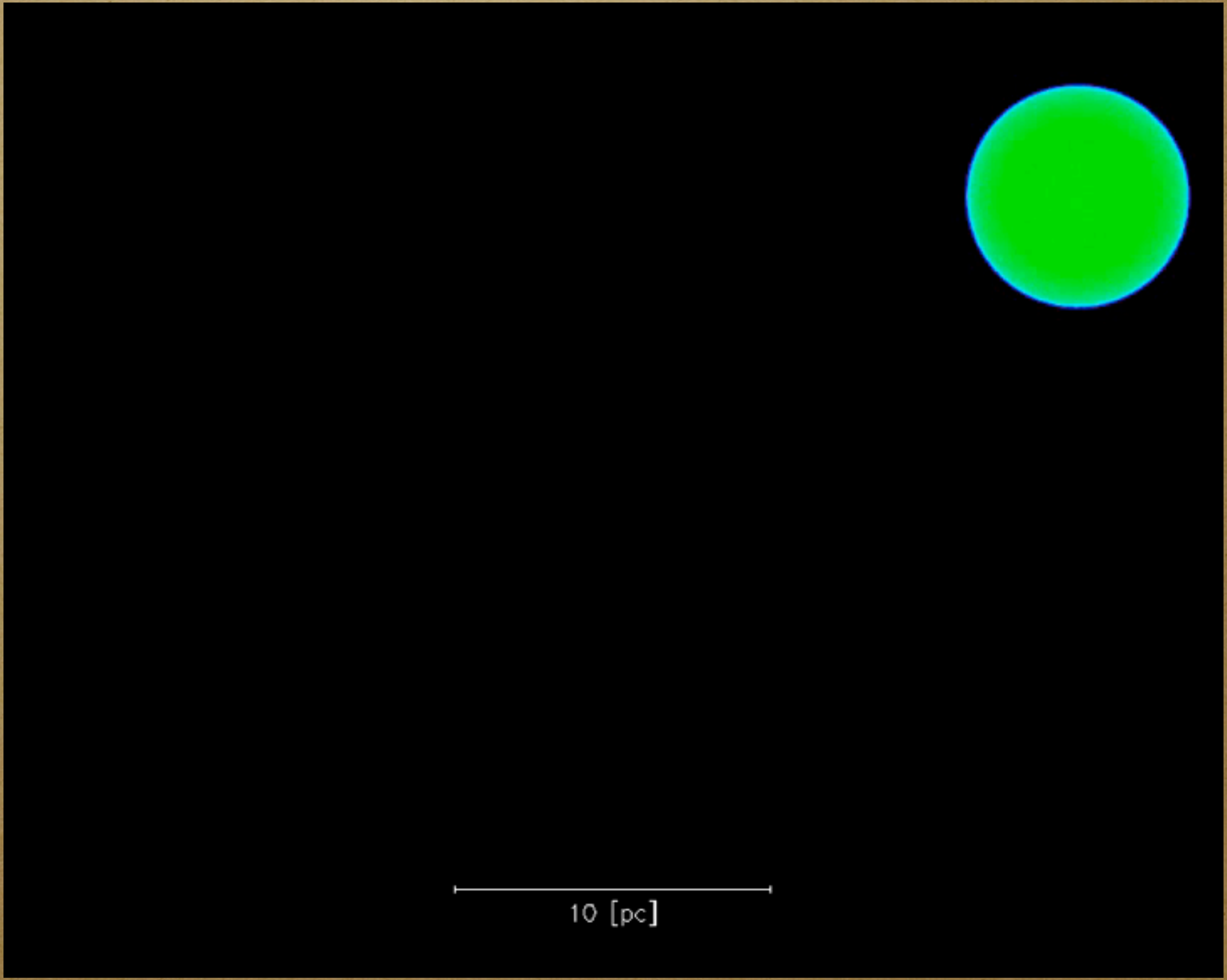


$$M_\bullet = 4.3 \pm 0.35 \cdot 10^6 M_\odot$$

Schödel et al. 2002, 2003, Ghez et al. 2003, 2005, 2008, Gillessen et al. 2009a,b, Genzel et al. 2010


Paradox of youth
1992 Aug 19 02:28:24 UTC
Zeit angehalten
chwindigkeit: 0,00000 m/s
FOV: 28° 34' 28,8"

Disk of young stars formed by collision of a molecular cloud with the black hole



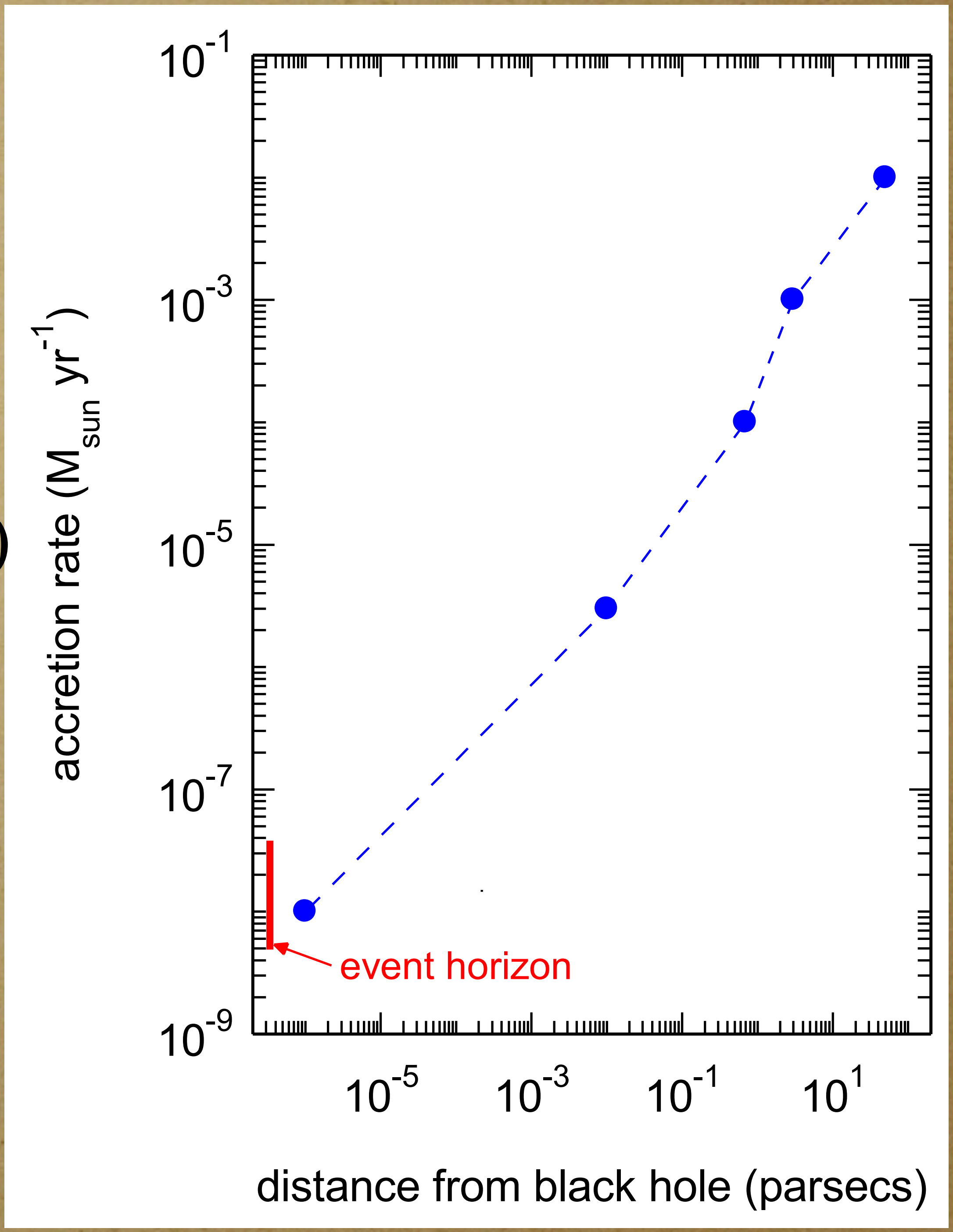
$$M_{\rm cloud} = 10^5\,M_\odot$$
$$R_{\rm cloud} = 3.5\,{\rm pc}$$

Alig et al. 2011

Sgr A*, a currently inactive, supermassive black hole

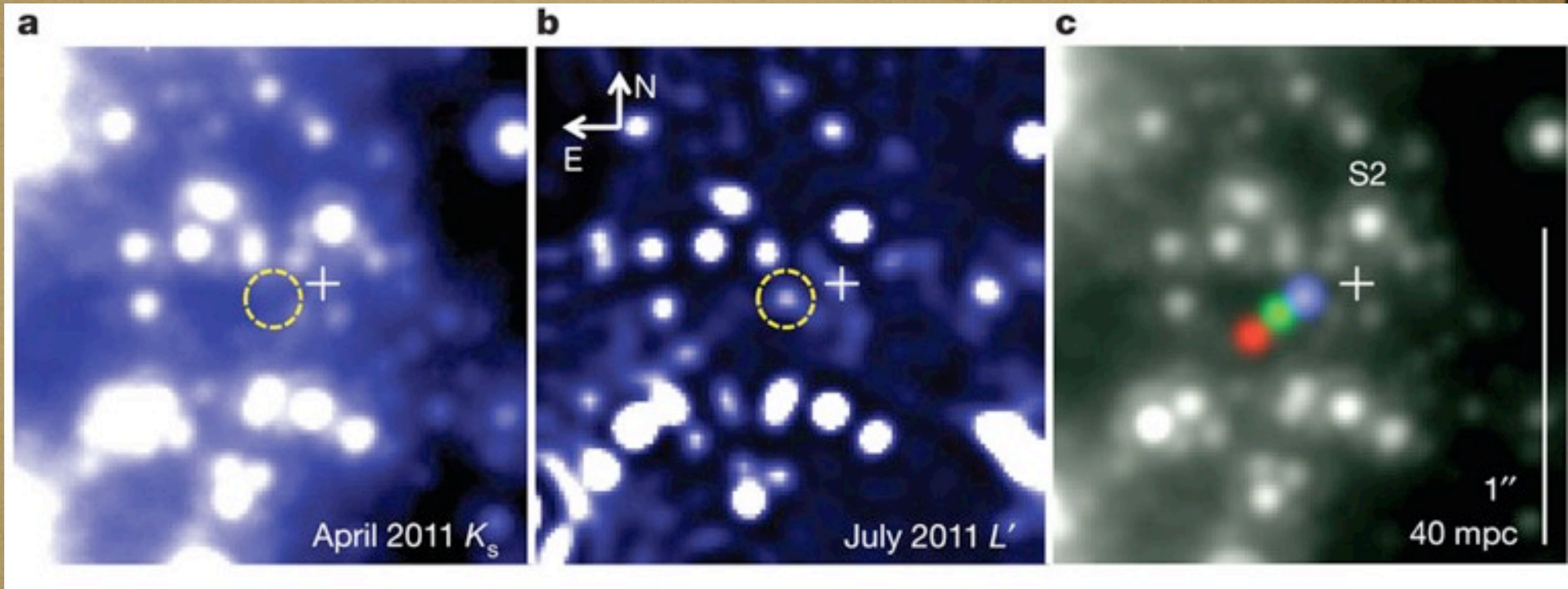
$$\dot{M} \leq 10^{-6} \cdot \dot{M}_{Eddington}$$

- 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 formed 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**



Observations of the gas cloud G2

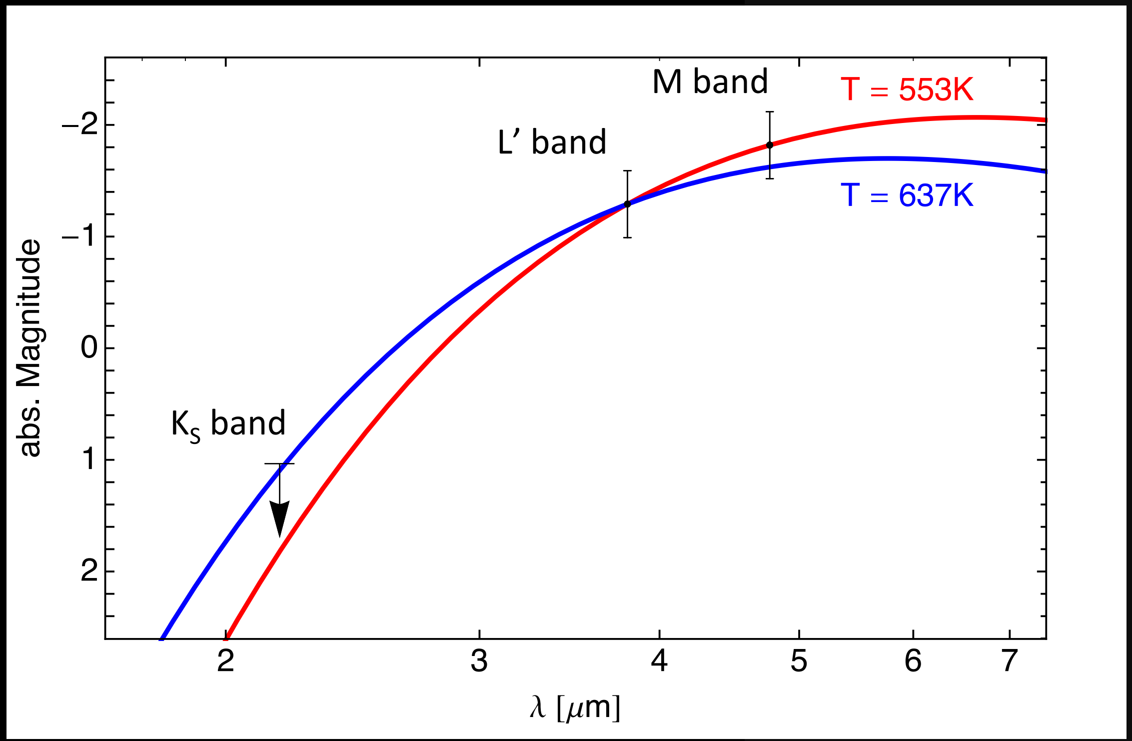
Gillessen+ 2012

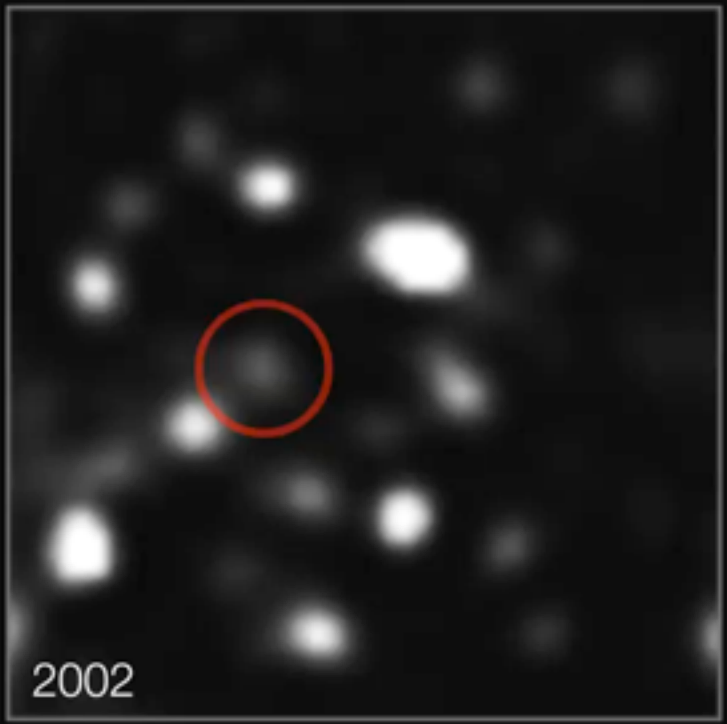


visible in L-band (3.8 micron), but not K-band (2.2 micron)

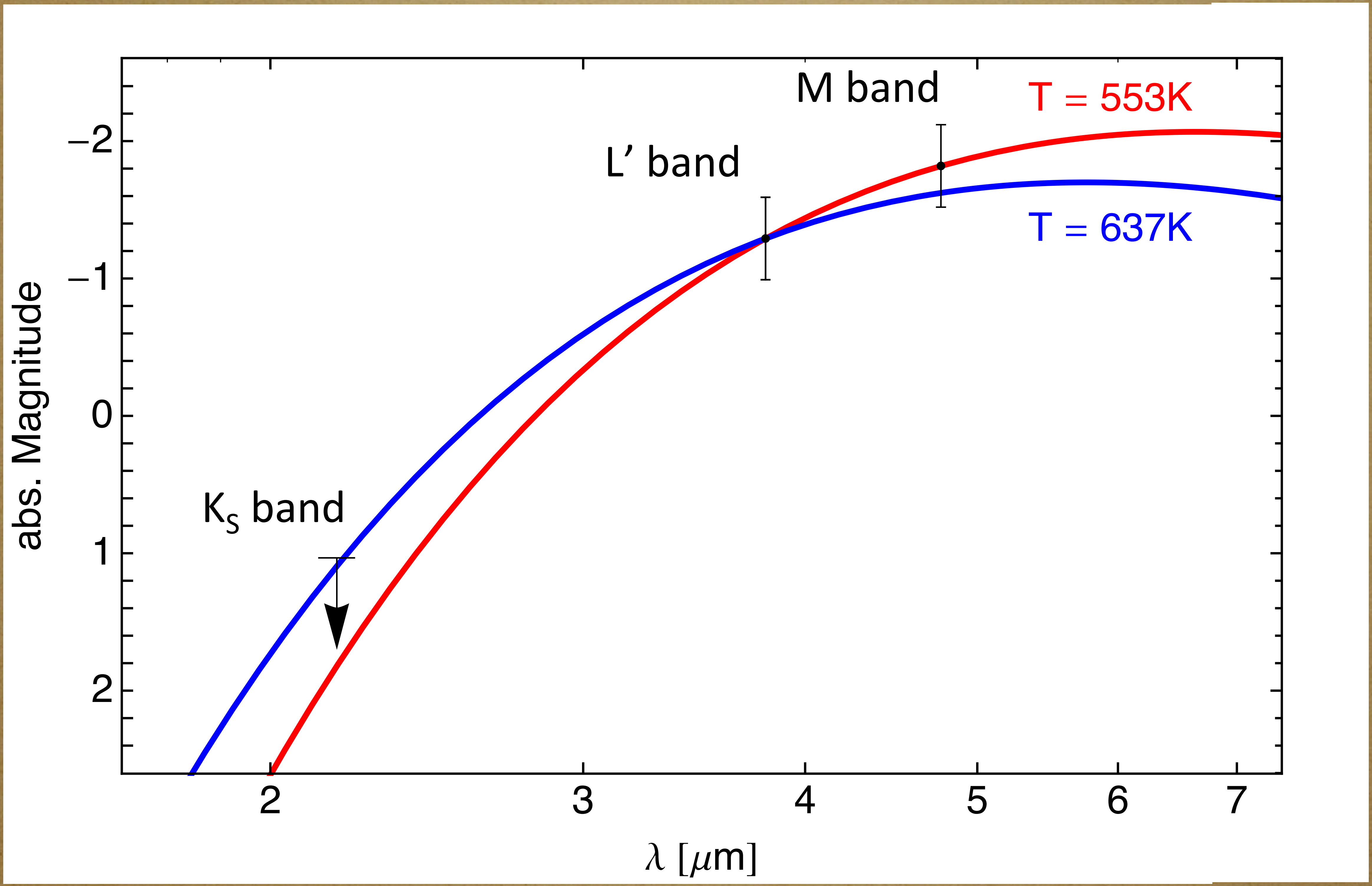
not a typical B-star, but a dusty ionized gas cloud

$$L_{Br\gamma} = 1.7 \cdot 10^{-3} L_\odot$$



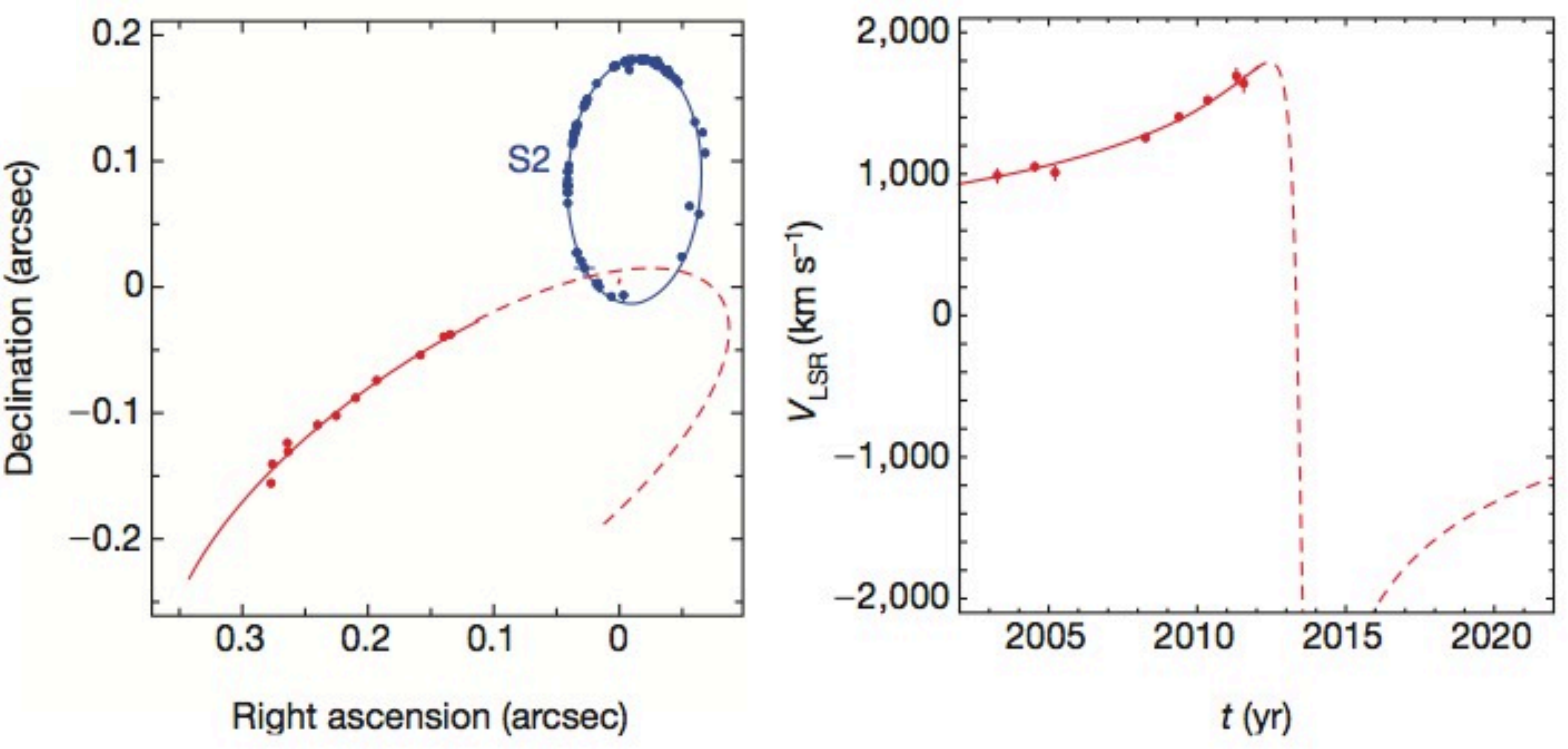


ESO/MPE/L. Calçada

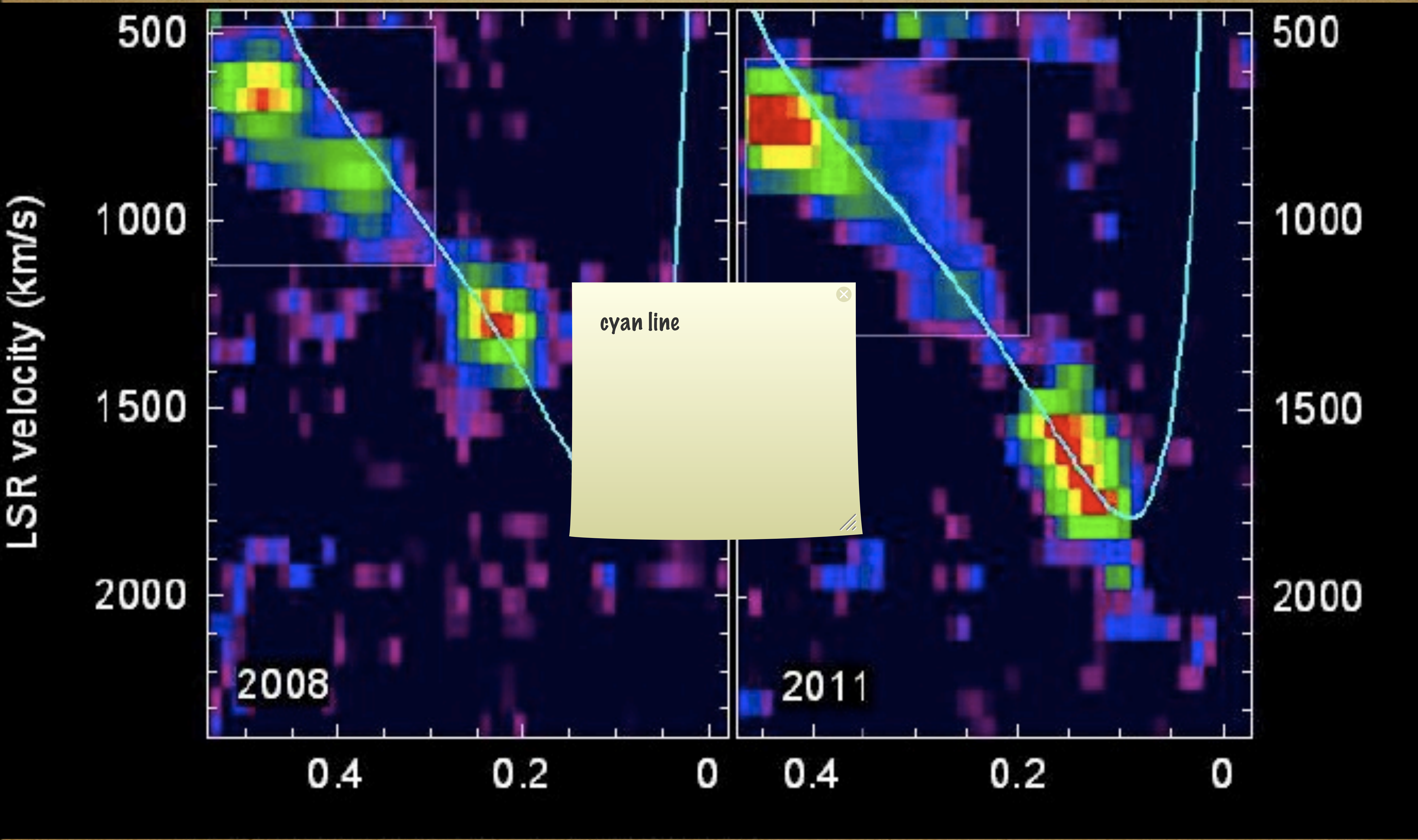


G2 is fully ionized by UV radiation from young massive stars in the GC

The cloud's orbit is well-constrained



$Br\ \gamma$ line emission



Offset from Sgr A* (arcsec)

G2's mass
(case B recombination)

$$Br\text{-}\gamma \text{ luminosity: } L_{Br\gamma} = \frac{4\pi}{3}\gamma_{Br\gamma} n_e^2 R^3 = 1.7\cdot 10^{-3} L_\odot$$

$$\rightarrow \; n_e = 2.6\cdot 10^5\, cm^{-3} R_{1.5\cdot 10^{15}\,cm}^{-3/2} T_{e,10^4\,K}^{0.54}$$

$$M = \frac{4\pi}{3}\mu n_e R^3 = 1.7\cdot 10^{28}\, g\; R_{1.5\cdot 10^{15}\,cm}^{3/2} T_{e,10^4\,K}^{0.54}$$

Mass: 3 Earth mass ⟶ not self-gravitating

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

Pericentre passage: Soon and close

	Gillessen et al. 2012	New fit
semi major axis (mas)	521 ± 28	666 ± 39
eccentricity	0.9384 ± 0.0066	0.9664 ± 0.0026
inclination [°]	106.55 ± 0.88	109.48 ± 0.81
position angle of ascending node [°]	101.5 ± 1.1	95.8 ± 1.1
longitude of periastron [°]	109.59 ± 0.78	108.50 ± 0.74
epoch of periastron [yr]	2013.51 ± 0.04	2013.69 ± 0.04
orbital period [yr]	137 ± 11	198 ± 18
pericenter distance [R_S]	3100	2200

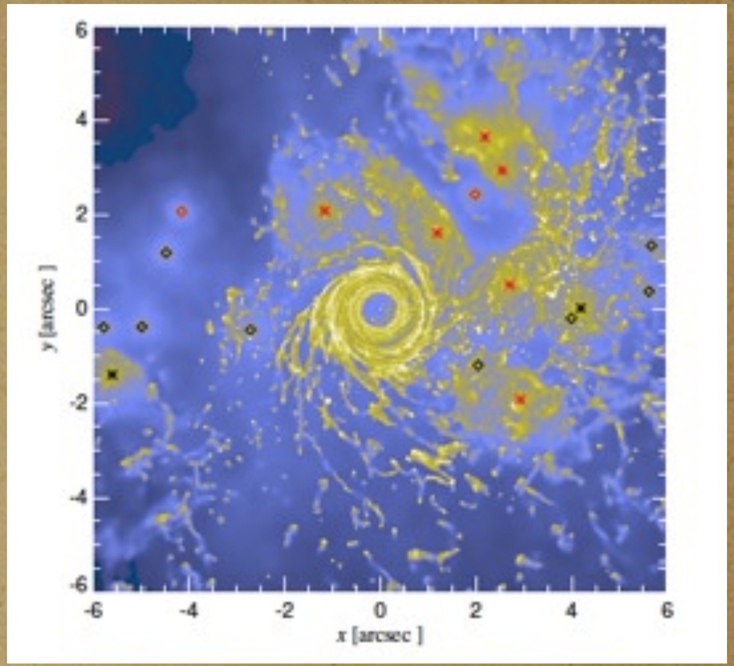
S2 (2002, 2018): 1500 R_S

S14 (2000): 1000 R_S

A great challenge for theorists and (magneto) hydrodynamical simulations

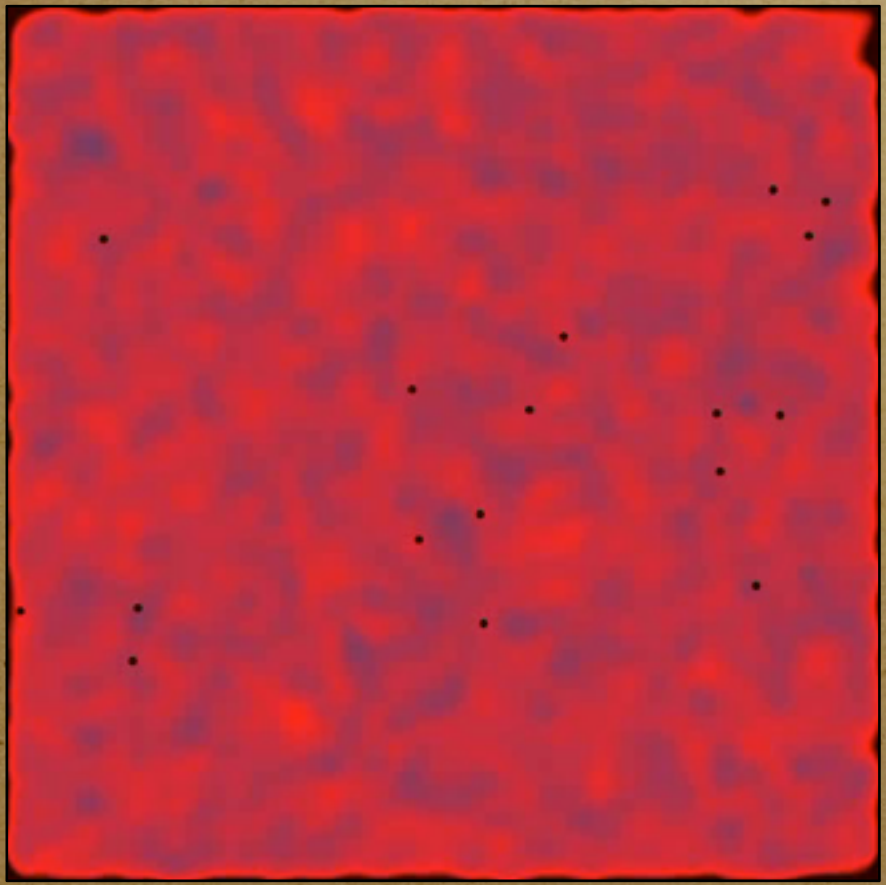
- Origin of **physical cloud properties (mass, density, radius)**
- Origin of **orbital parameters**
- **How did it form?**
- **Where will it go?**
- **Are there more clouds, waiting to be discovered?**
- **Will the central SMBH become active soon?**

Formation Scenarios

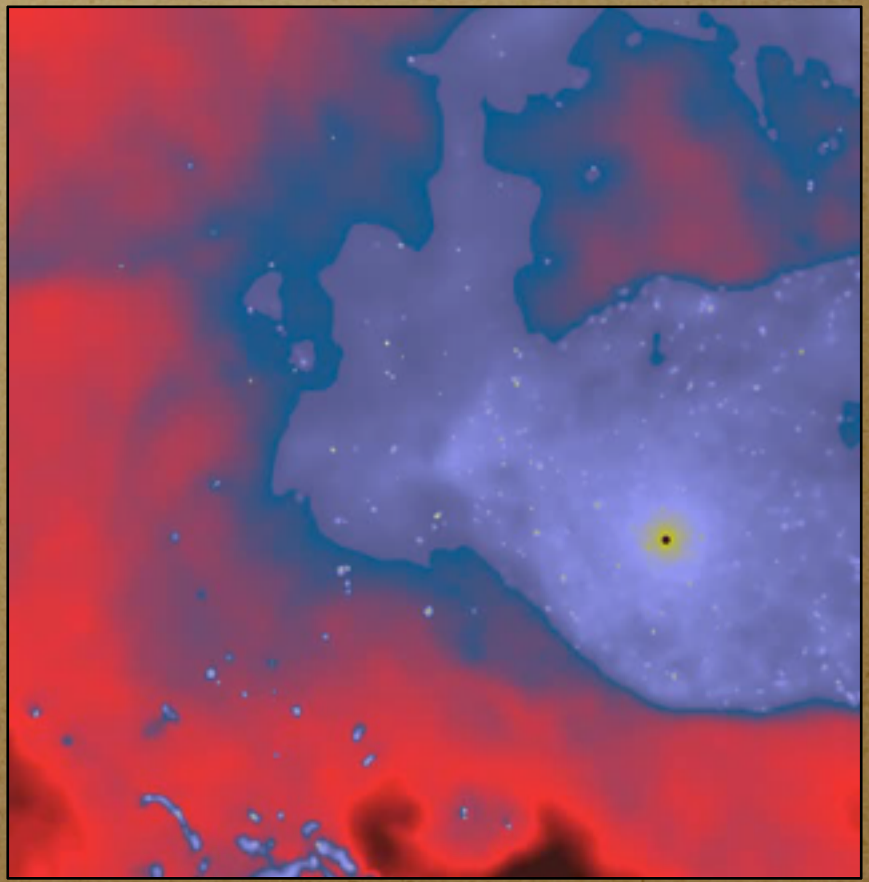


Cloud scenario:

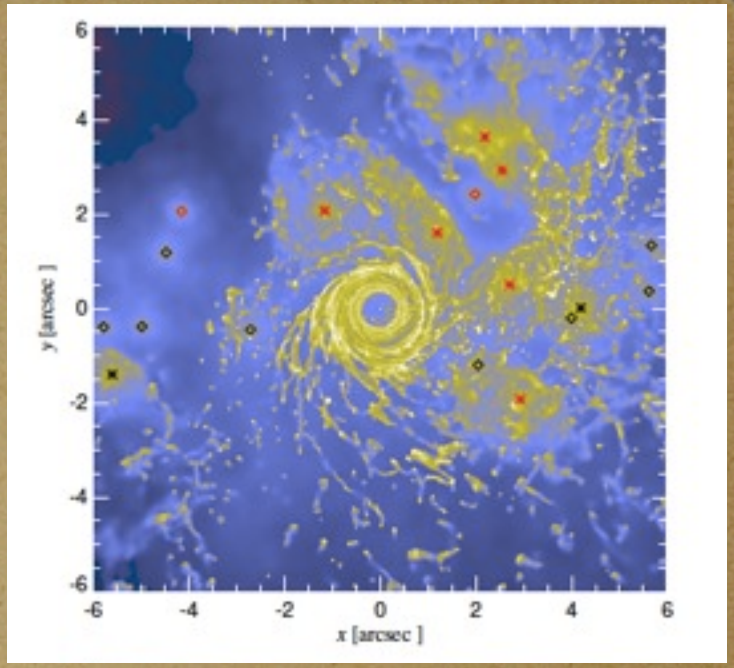
- **Cooling timescale** of hot gas too long.
- **Shocked stellar winds** in disk of massive stars (Cuadra et al.)
- First time approach (frequent process)



Cuadra et al. 2006



Formation Scenarios



Cloud scenario:

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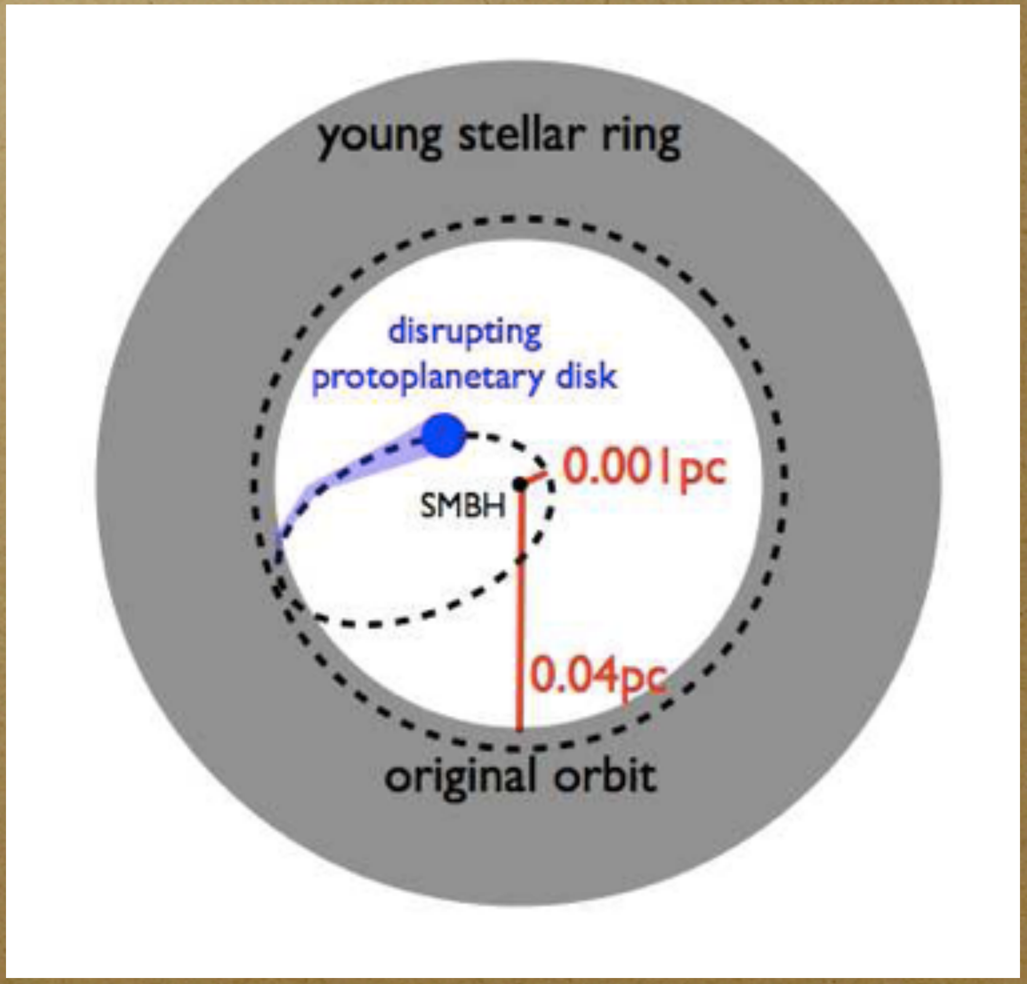
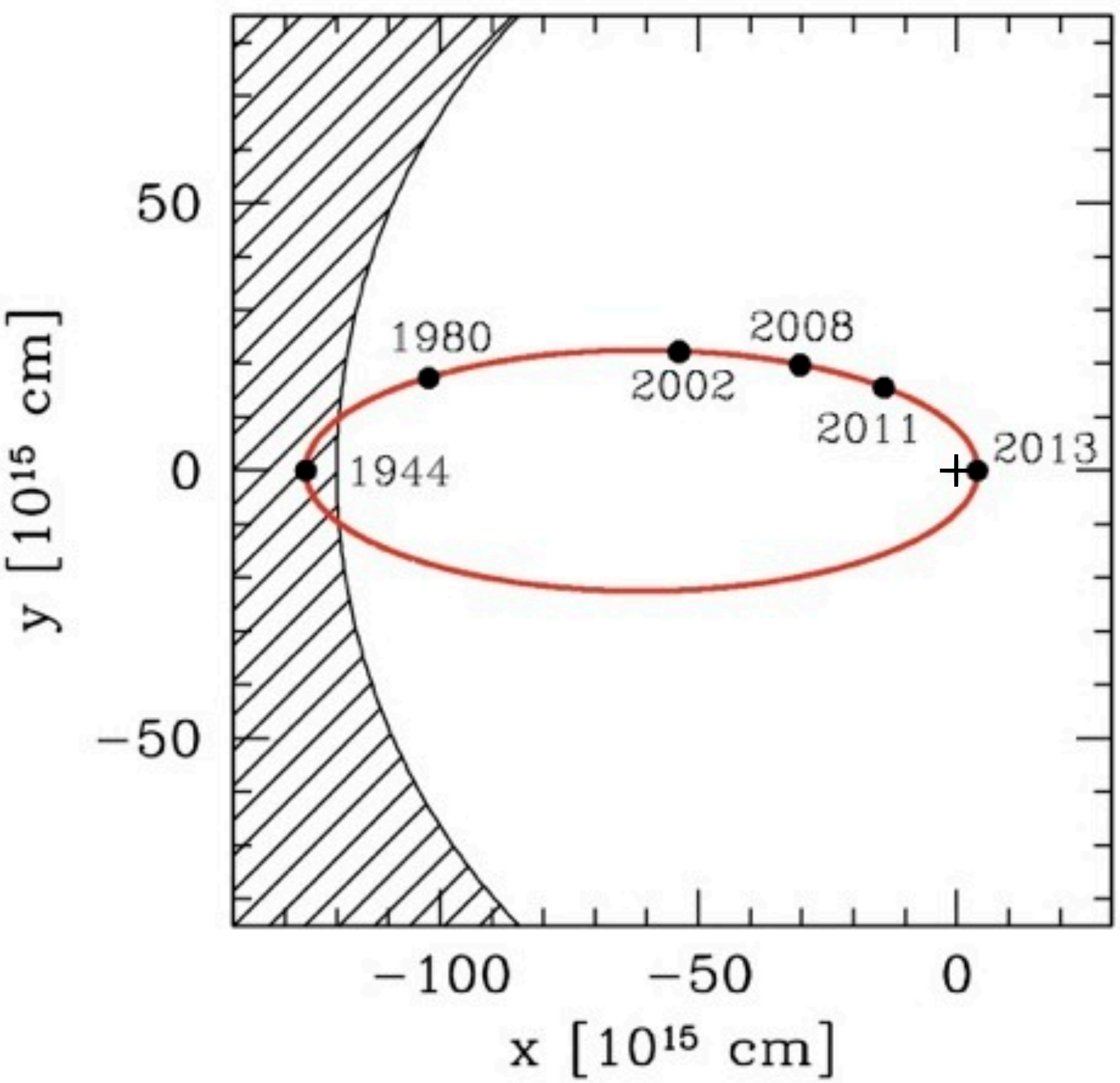
Compact source scenario

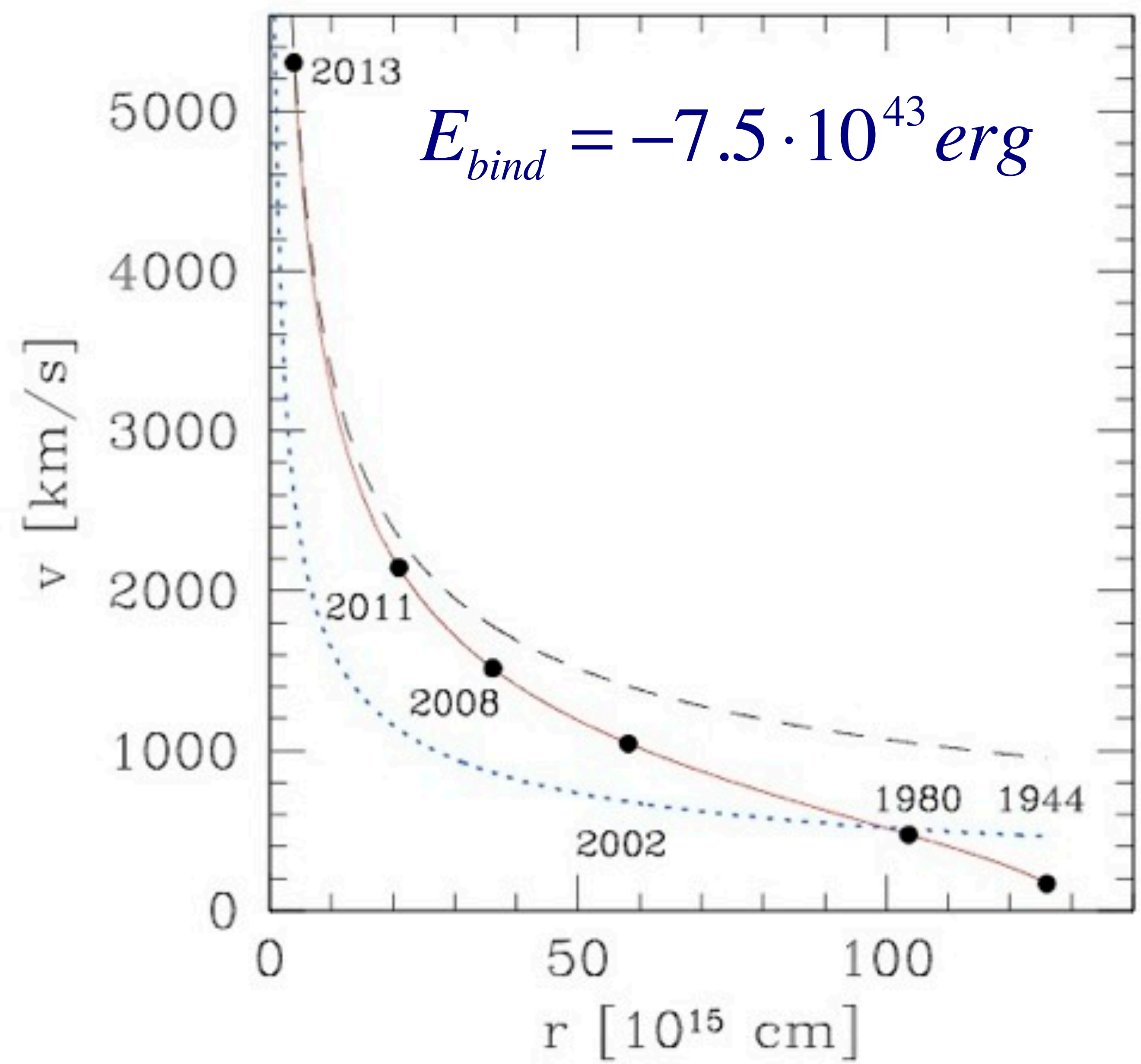
(Murray-Clay & Loeb 12)

- Gas atmosphere of an **invisible central source** (protoplanetary disk)



Orbital properties





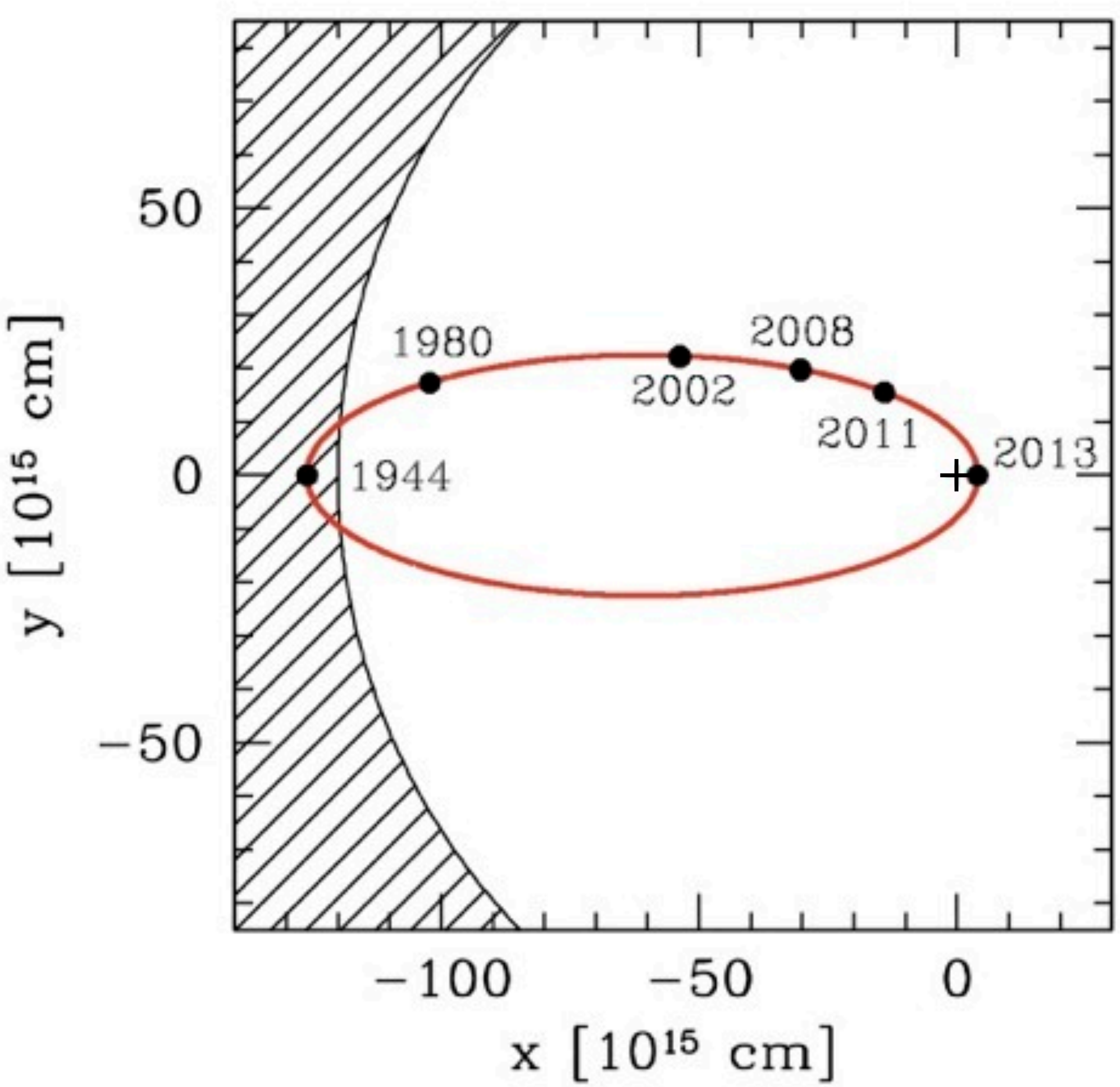
$$T_{hot} \approx 2.1 \cdot 10^{8} \left(\frac{16.8 \cdot 10^{15}\,\mathrm{cm}}{r} \right) \mathrm{K}$$

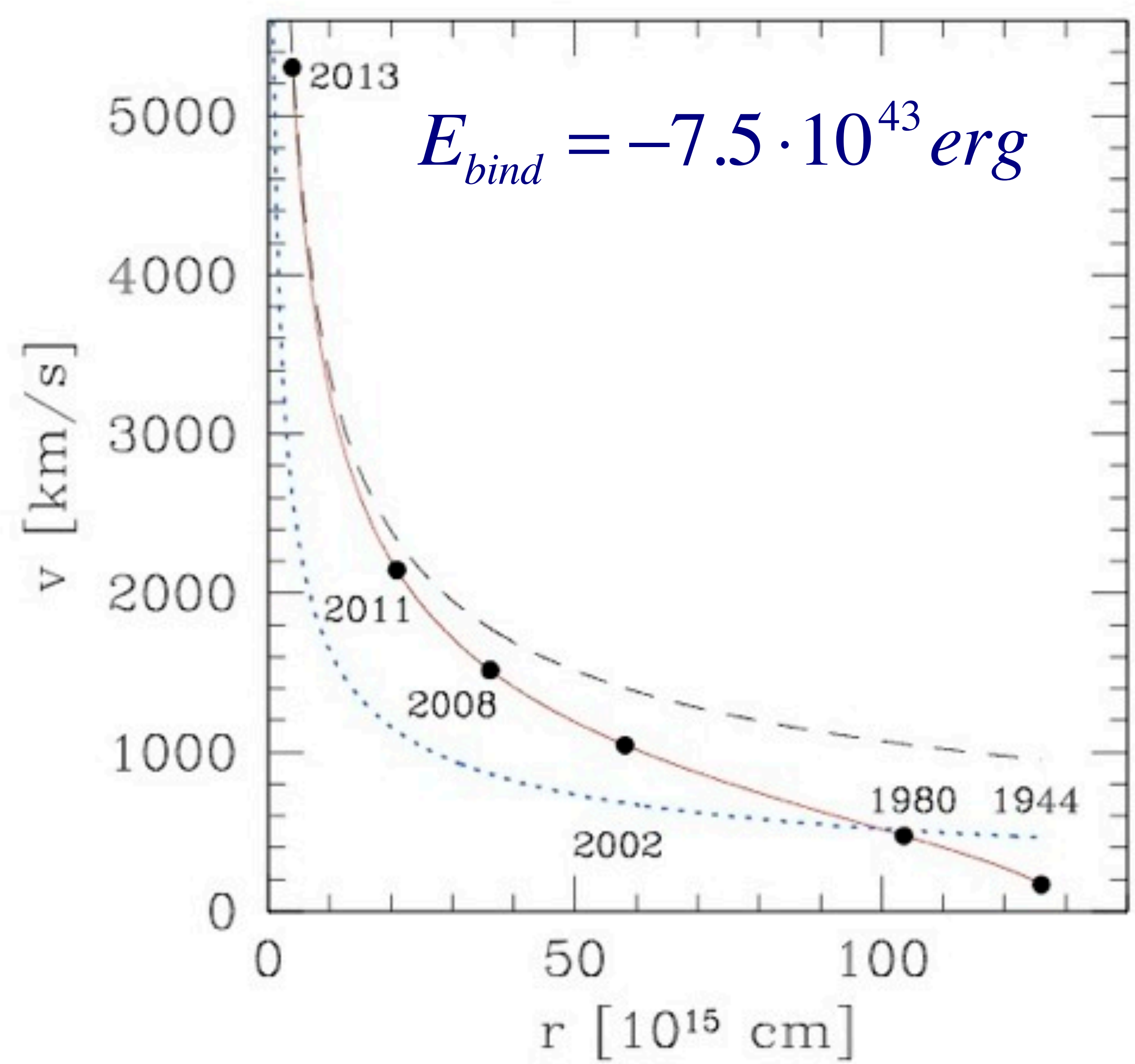
$$\rho_{hot} \approx 9.0 \cdot 10^{-22} \left(\frac{16.8 \cdot 10^{15}\,\mathrm{cm}}{r} \right) \frac{\mathrm{g}}{\mathrm{cm}^{3}}$$

Narayan + 2012:
Non-thermal radio synchrotron emission from bow shock

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

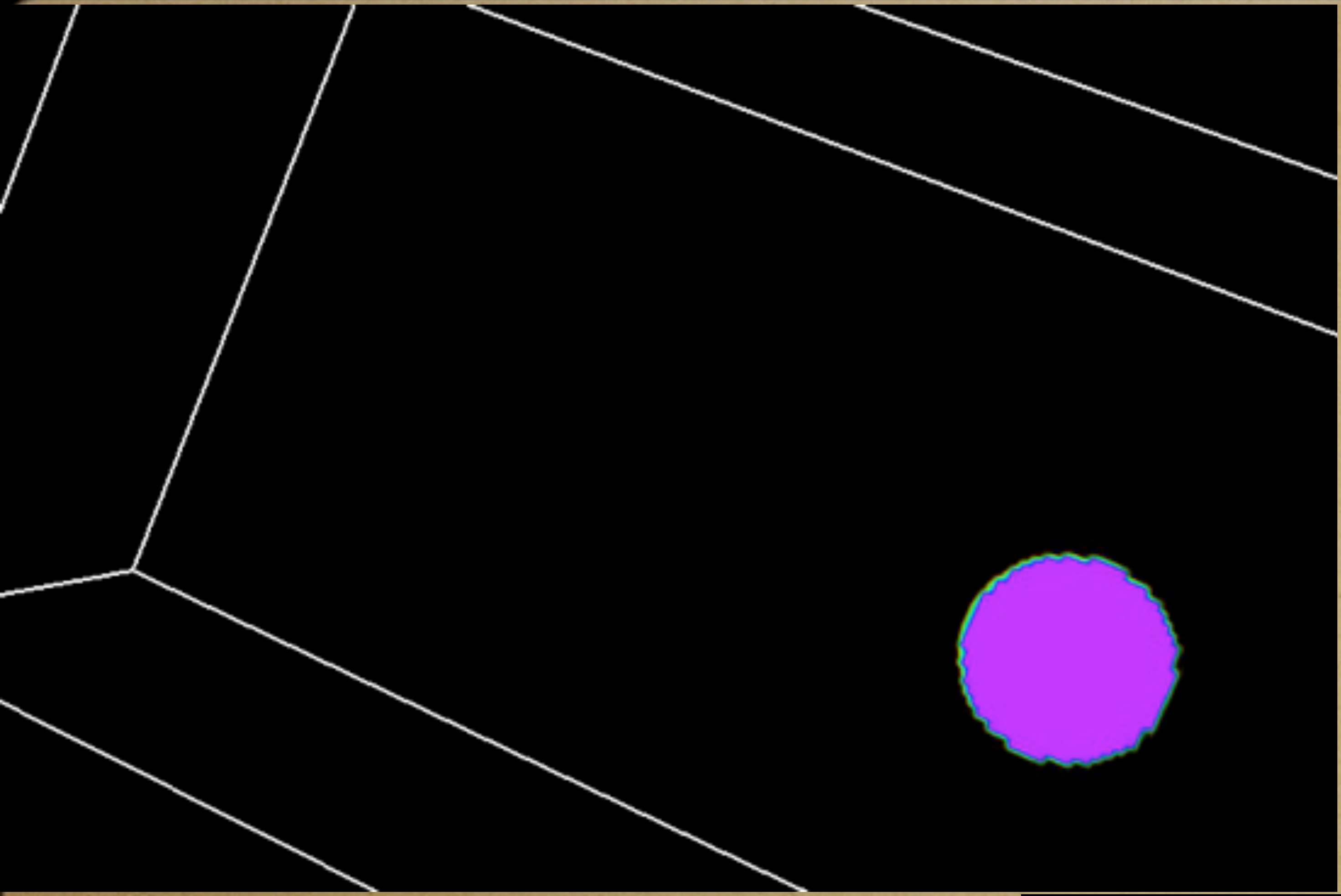
Orbital properties





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

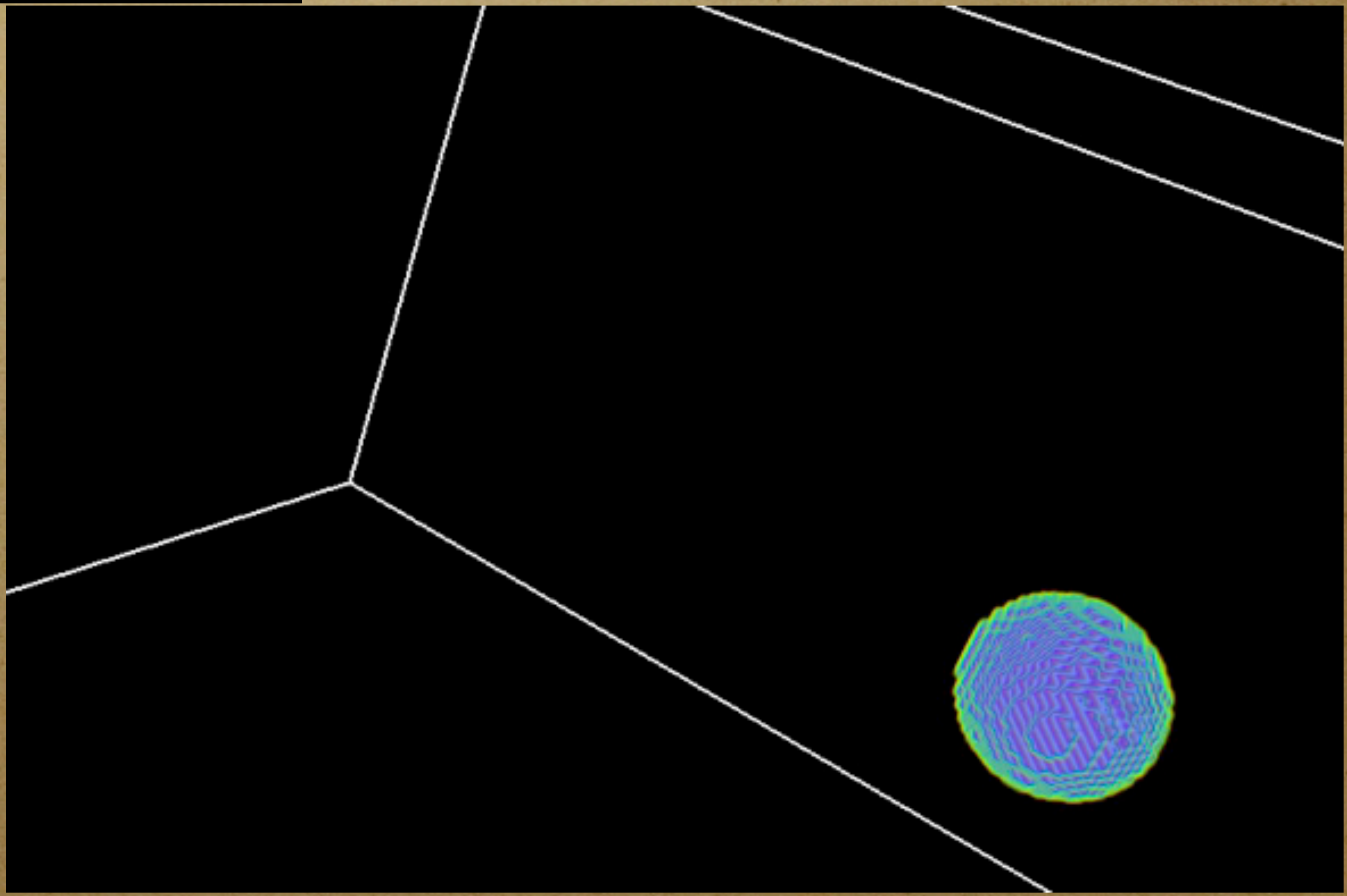
Ram pressure flattening and back flow

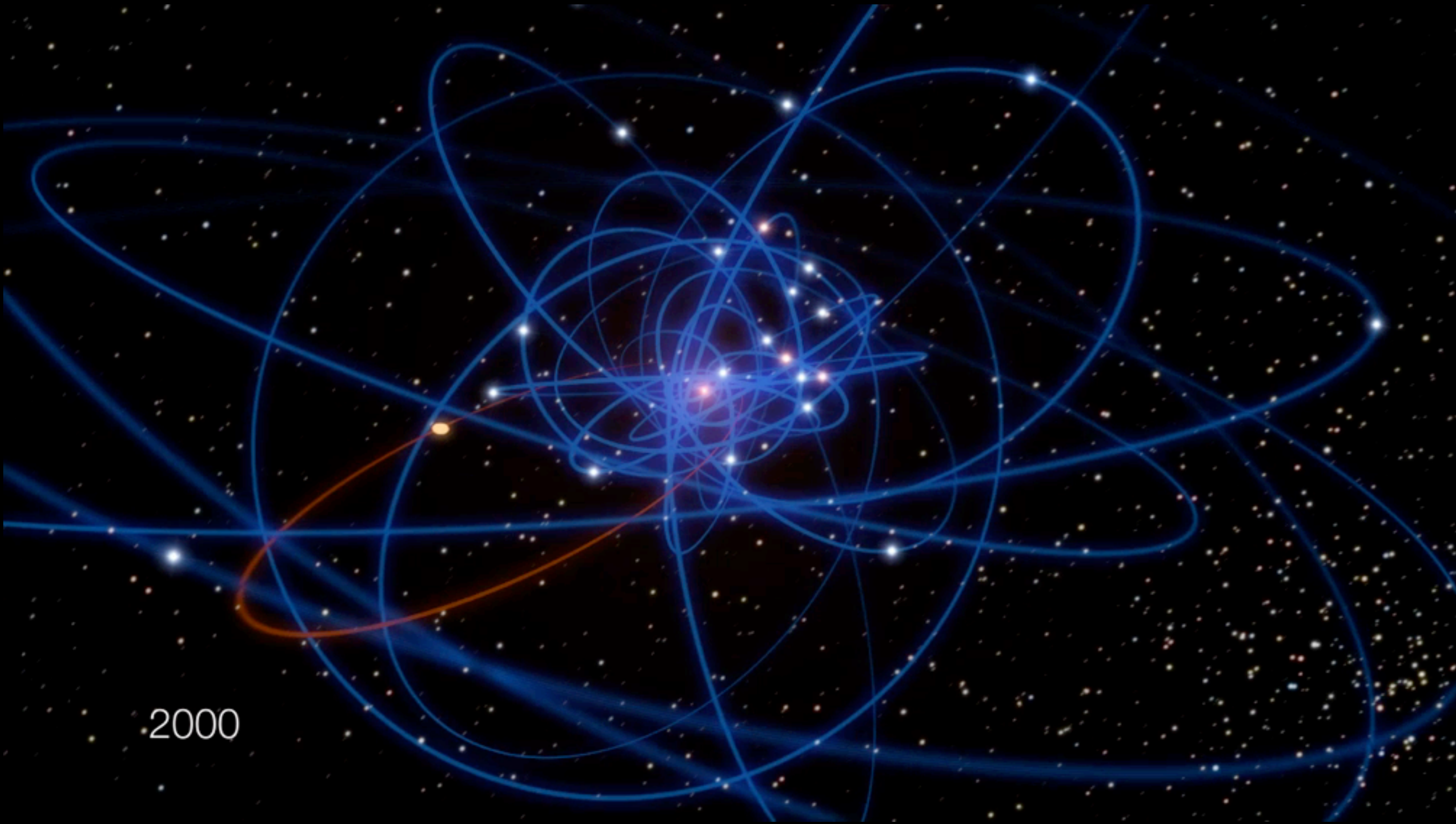


3d-simulation

2d-cut

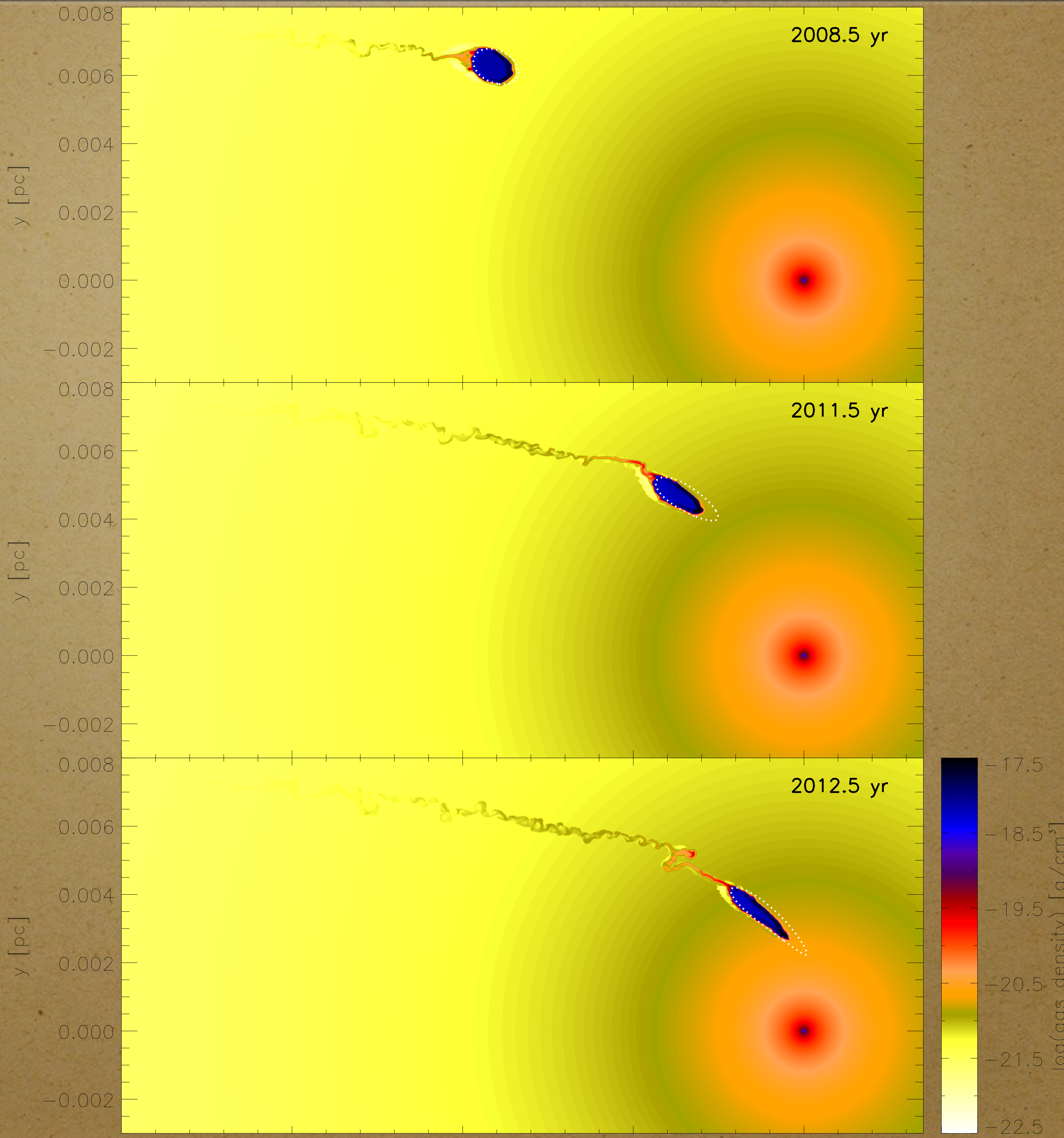
visualised with Vapor

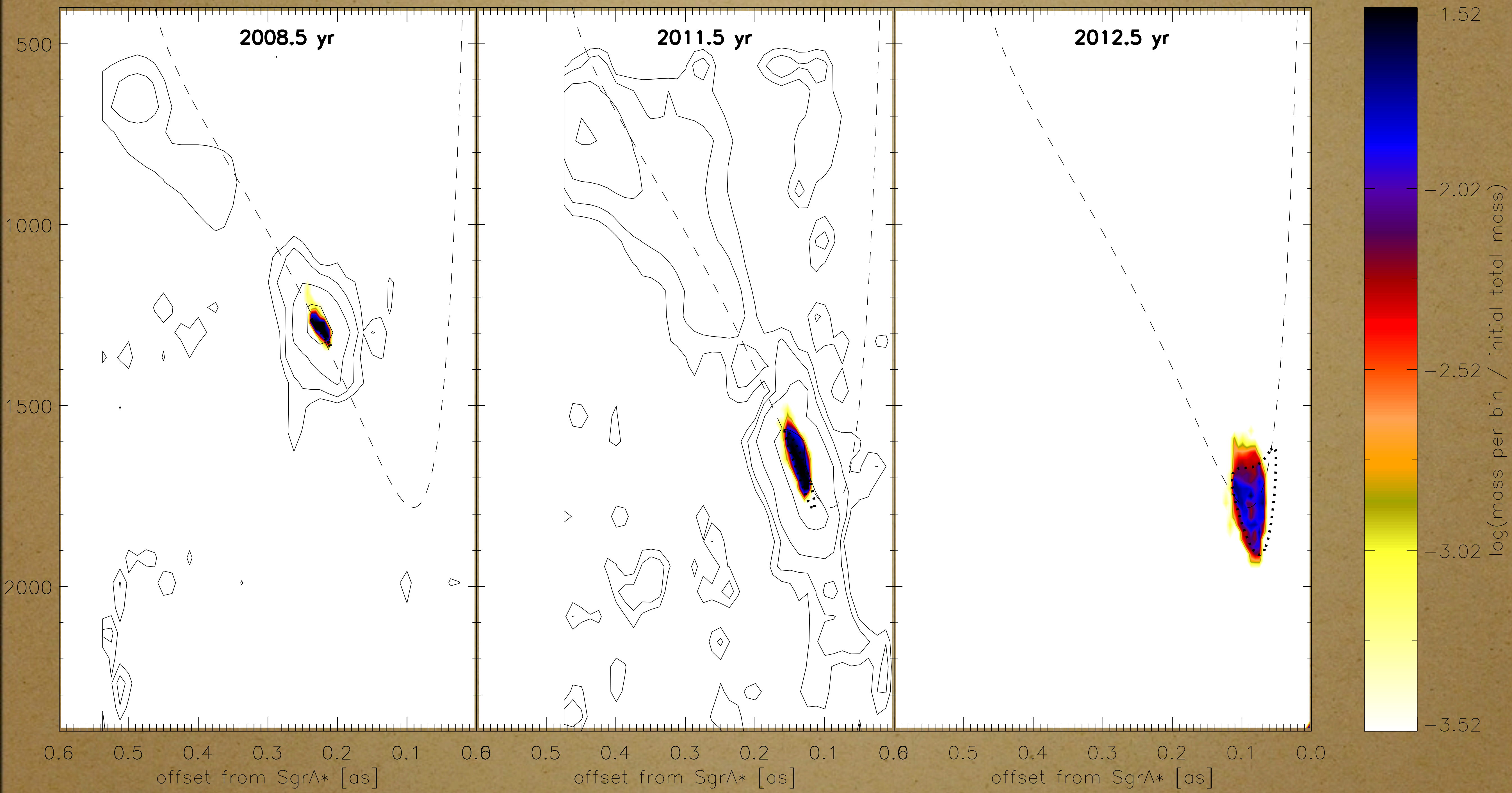



2000

In situ model

Formation in 1995

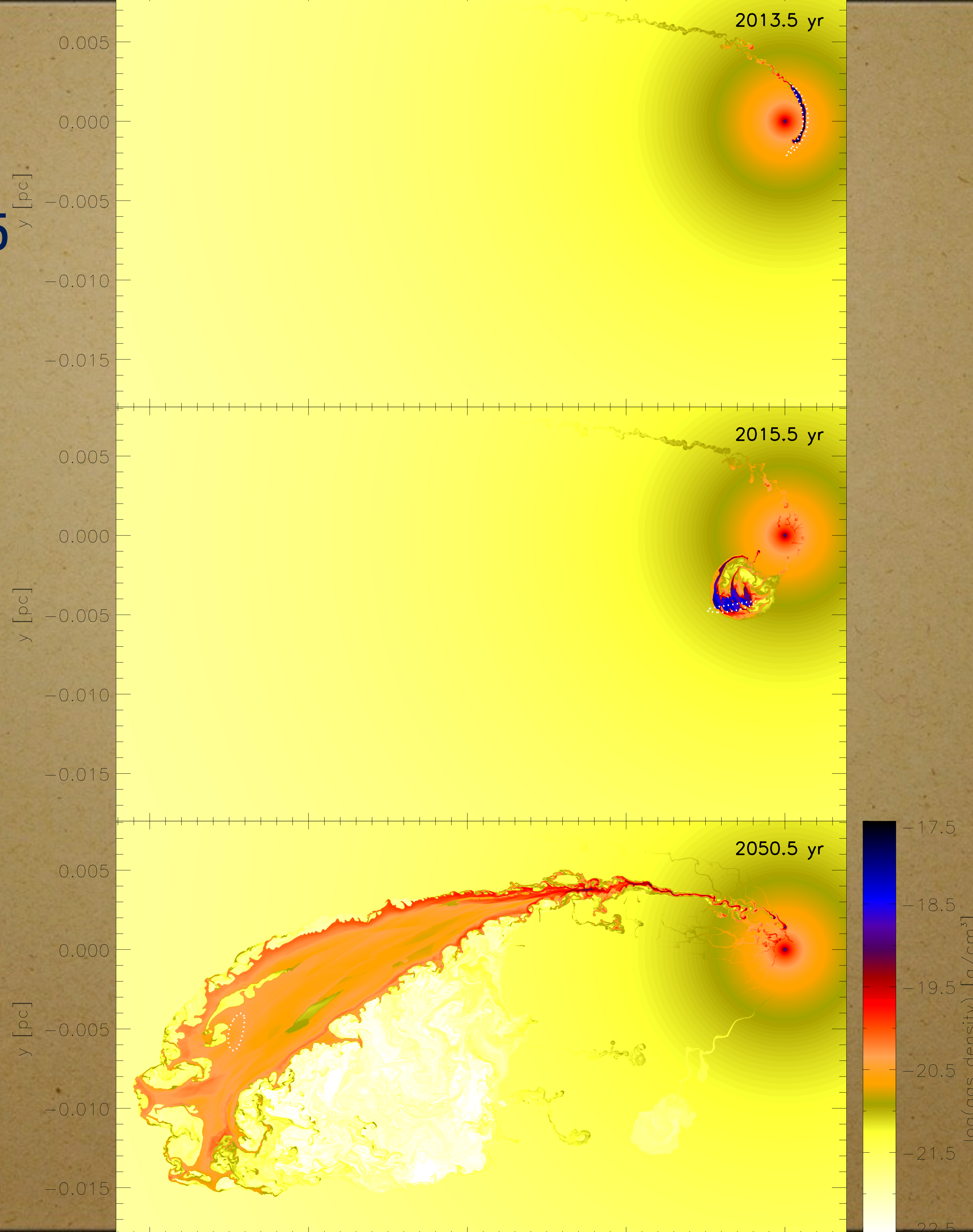




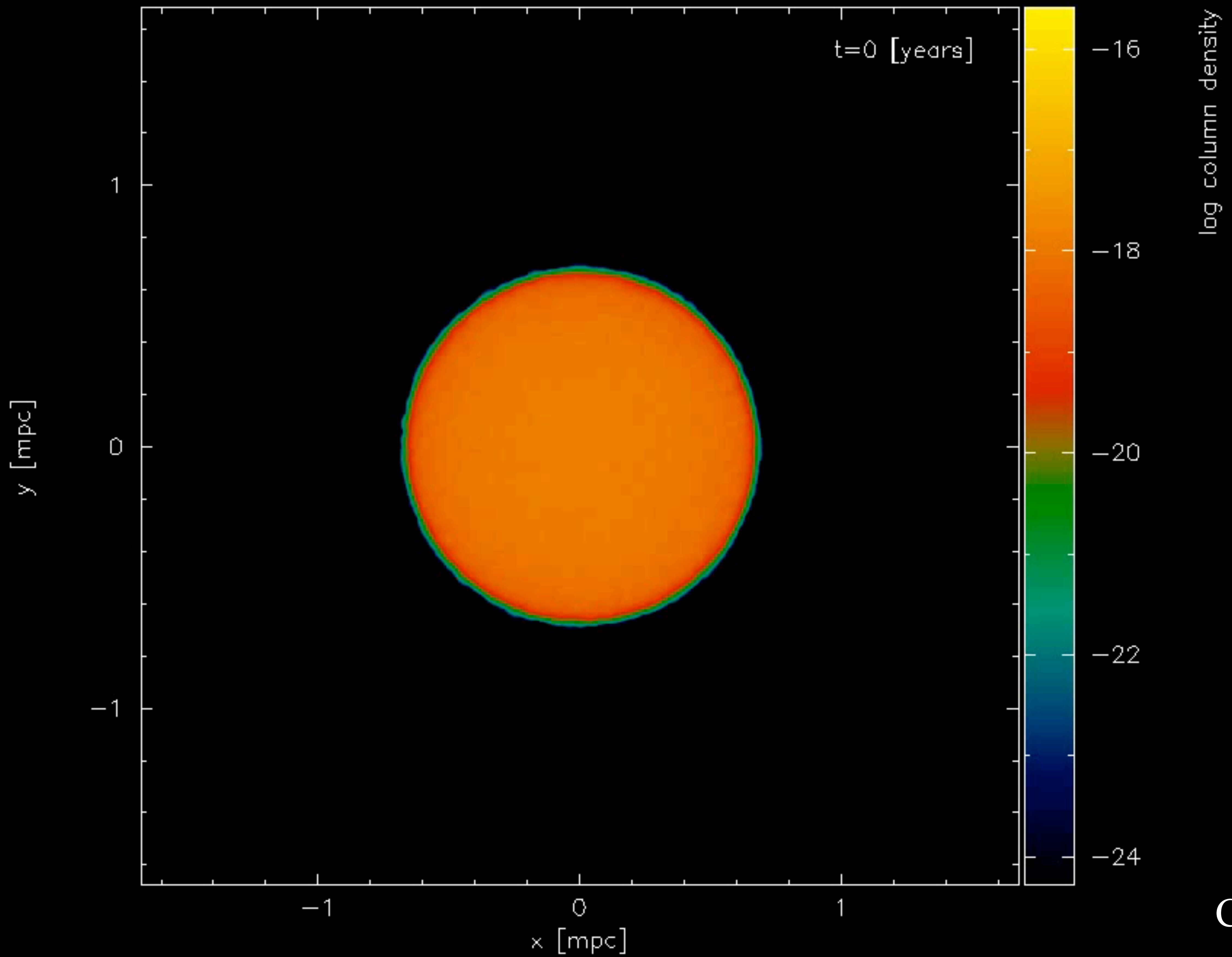
Could G2 have formed in 1995?

In situ model

Formation in 1995

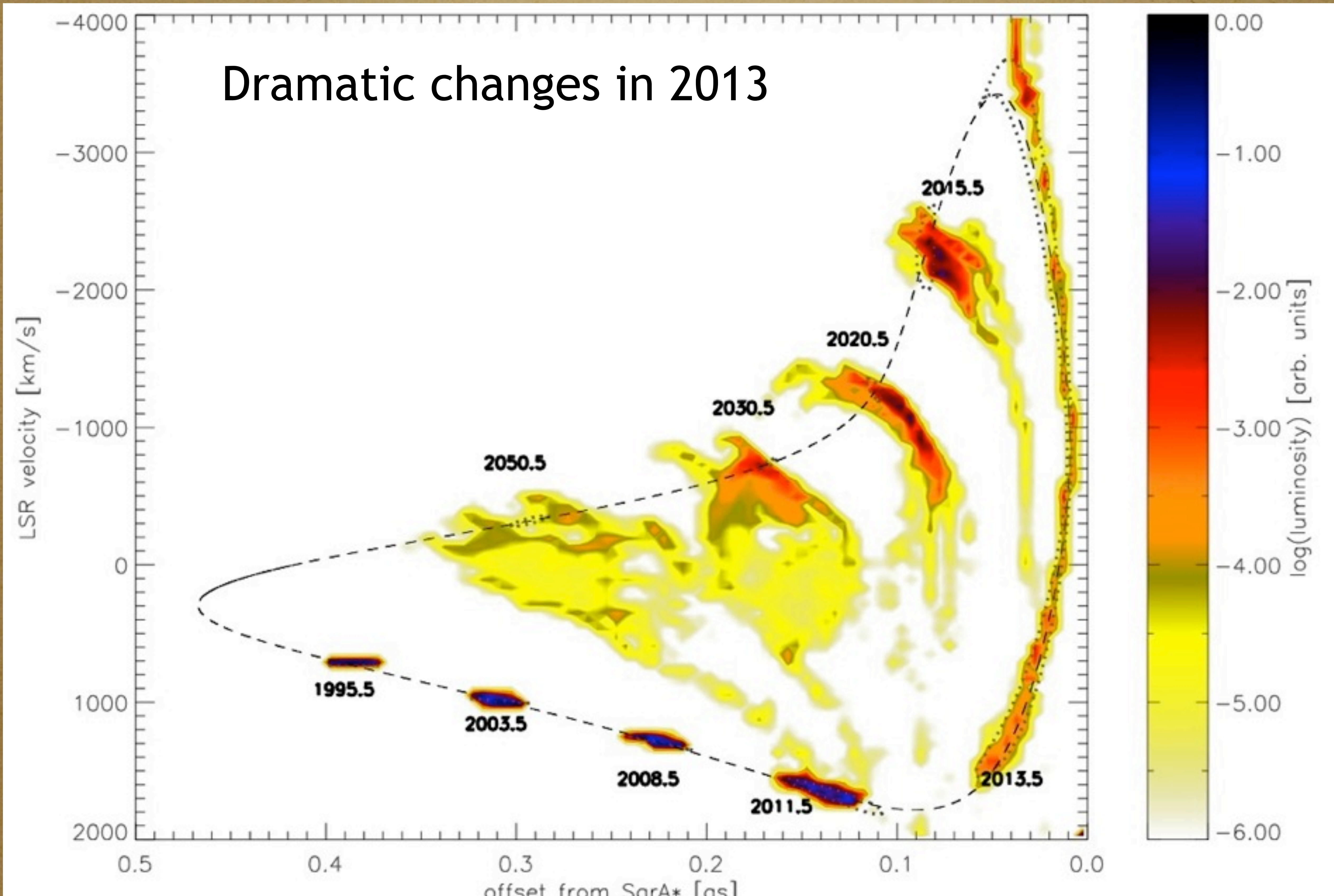


Forget about SPH :-((

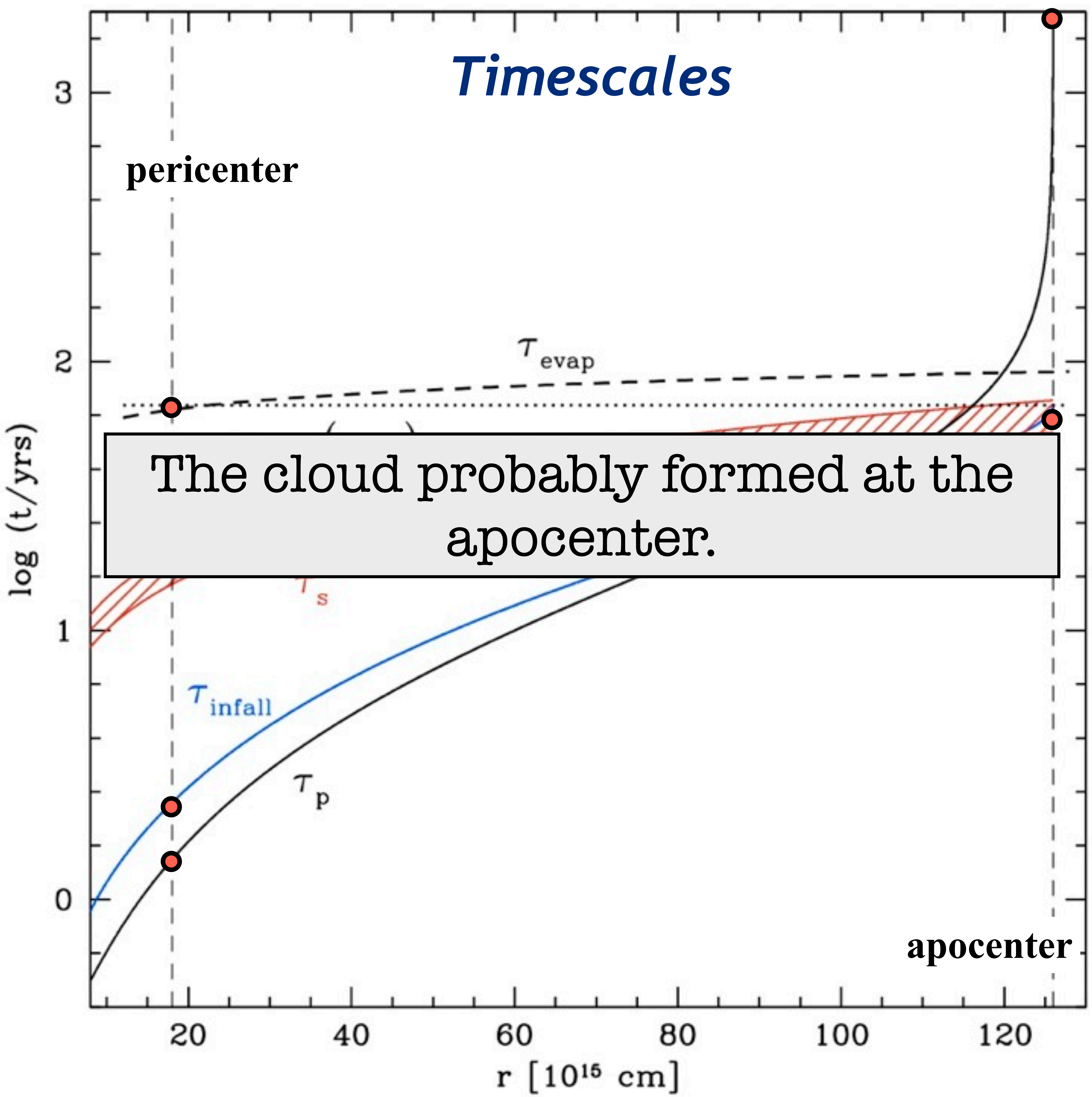


C. Alig

position-velocity diagram

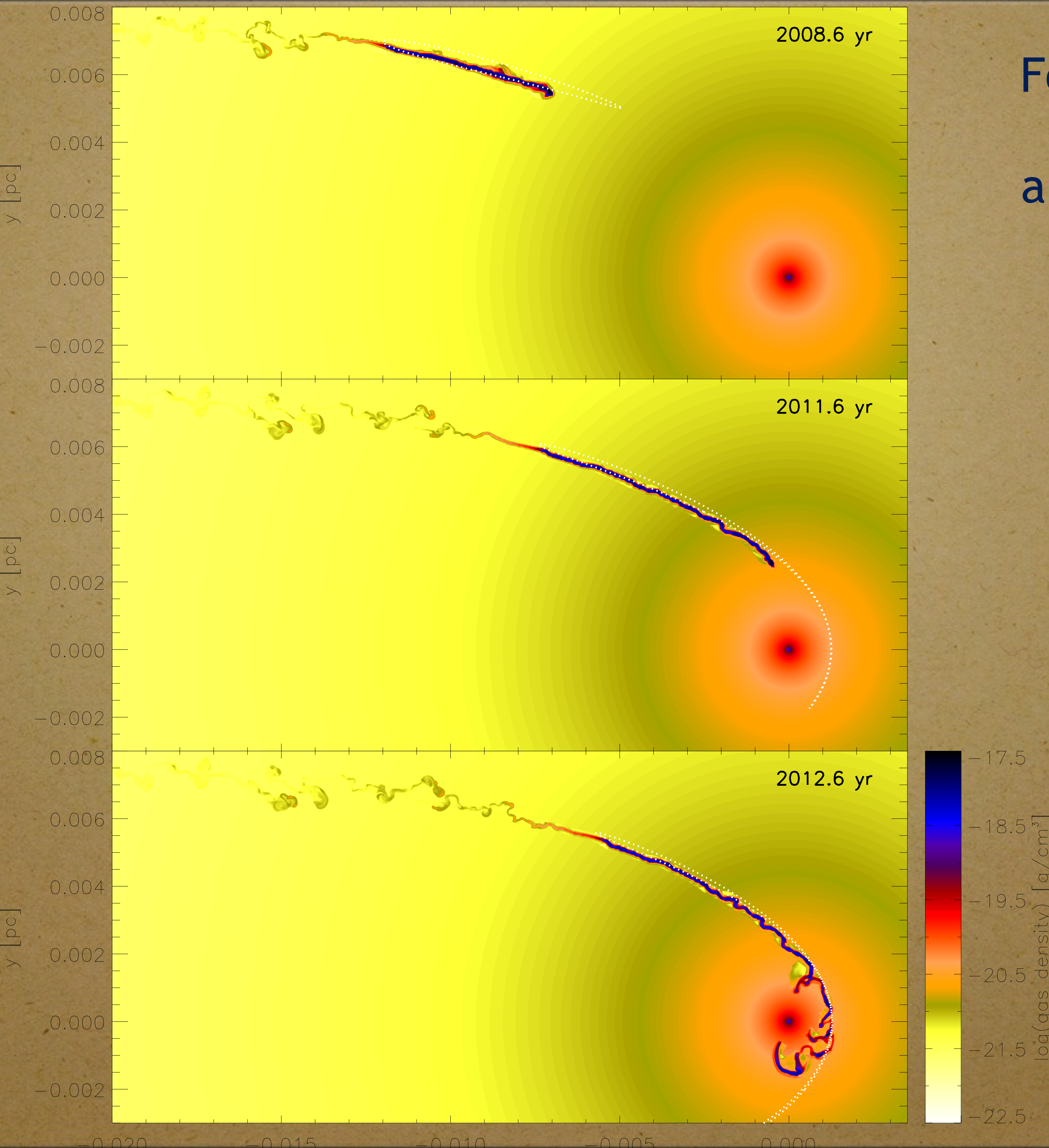


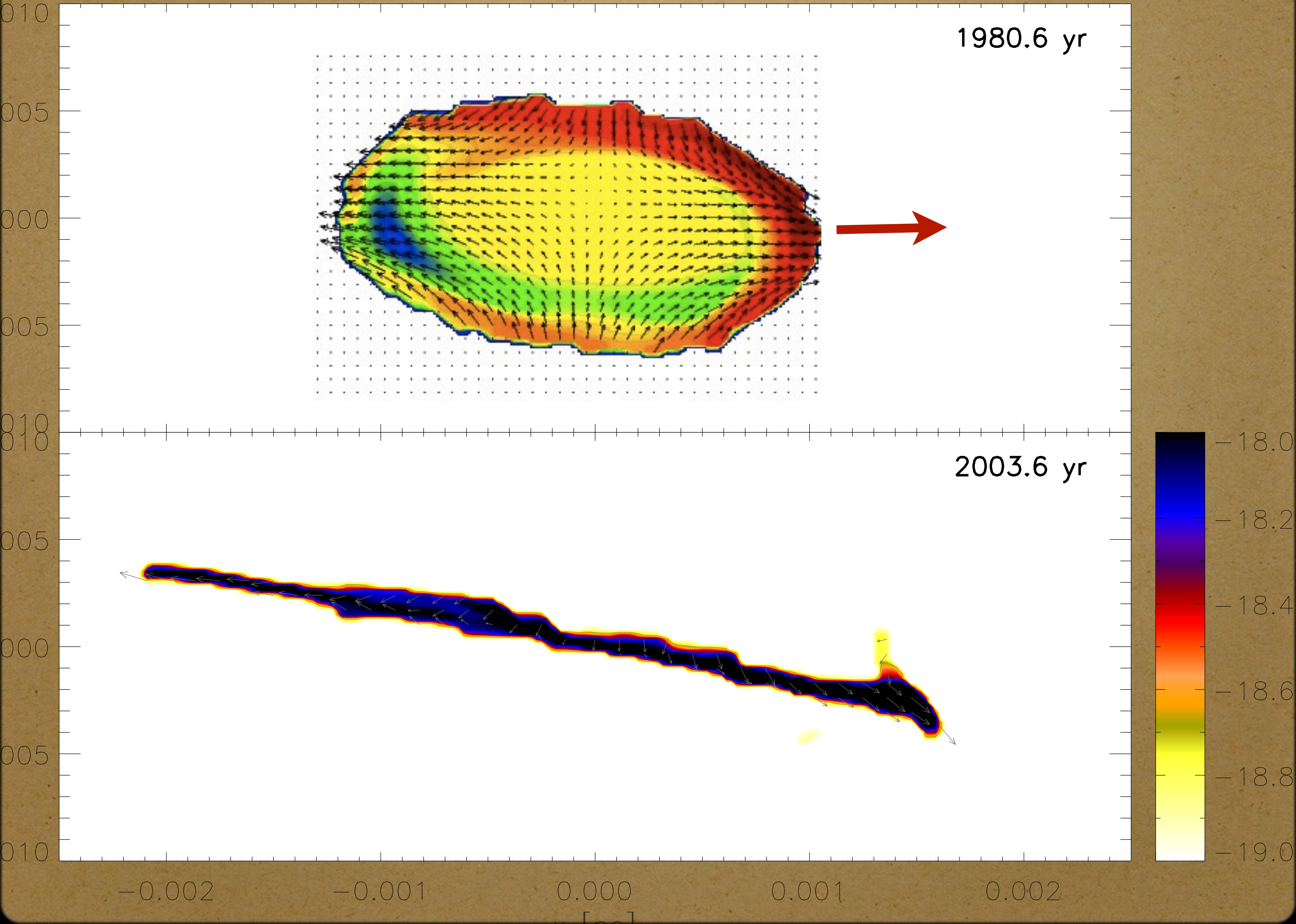
Timescales



The cloud probably formed at the apocenter.

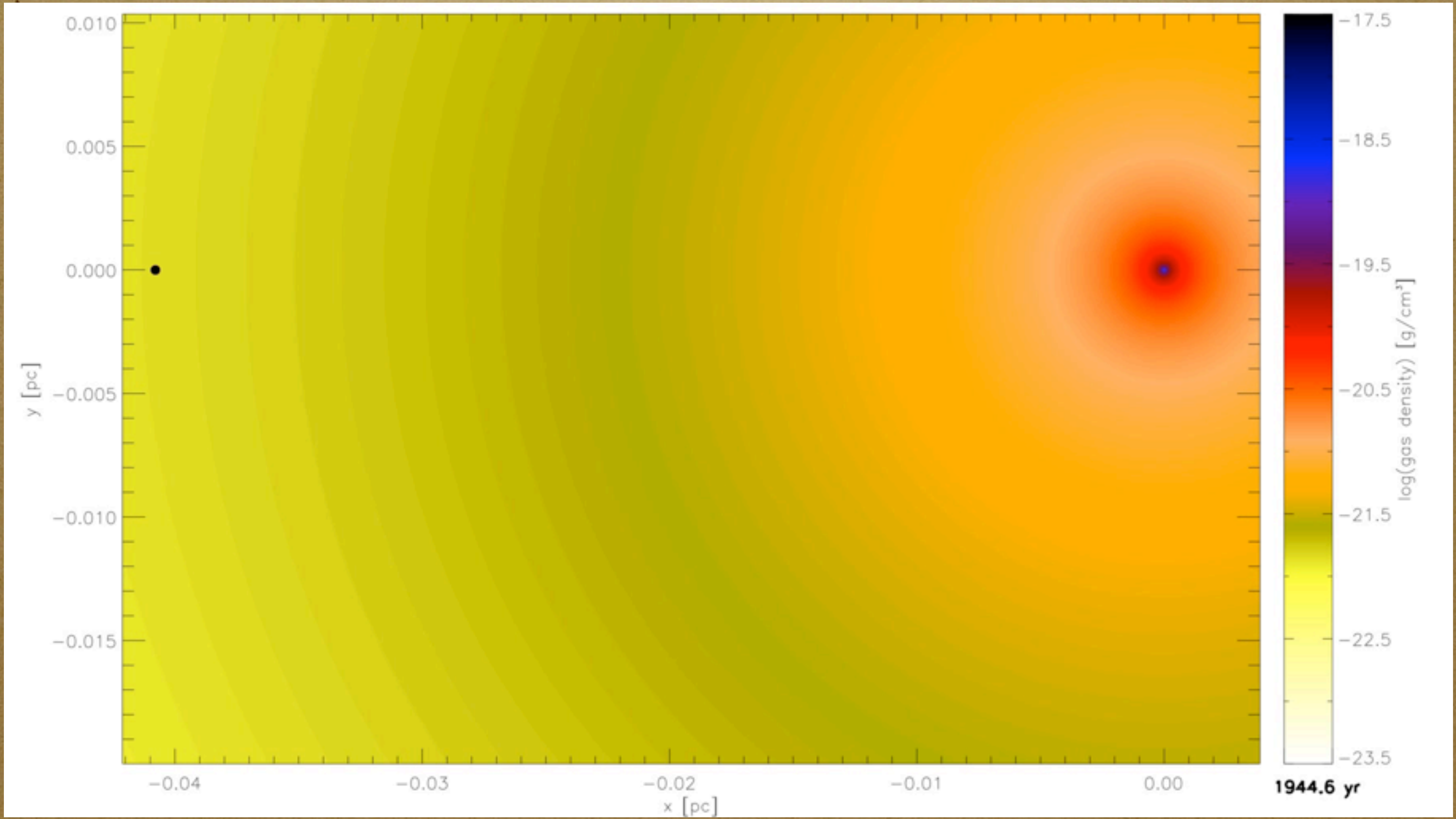
Formation at apocenter



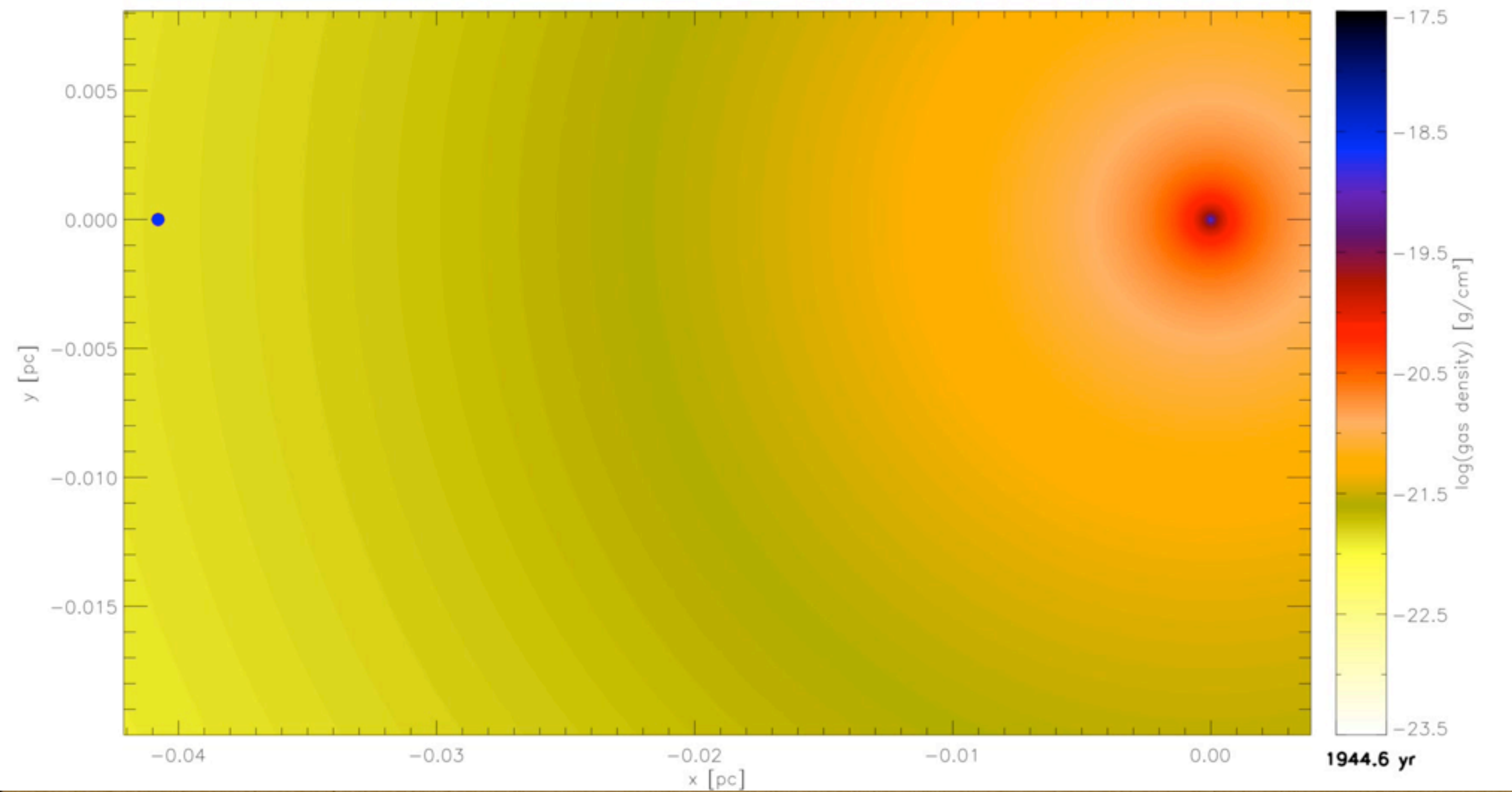

1980.6 yr
2003.6 yr
−0.002
−0.001
0.000
0.001
0.002
−18.0
−18.2
−18.4
−18.6
−18.8
−19.0

Over-pressured cloud

CC03: cloud starting at apocenter with over-pressure

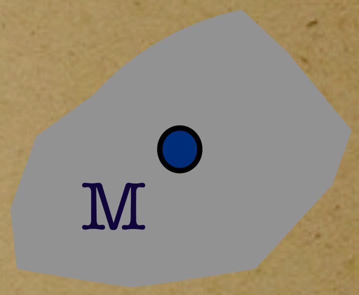


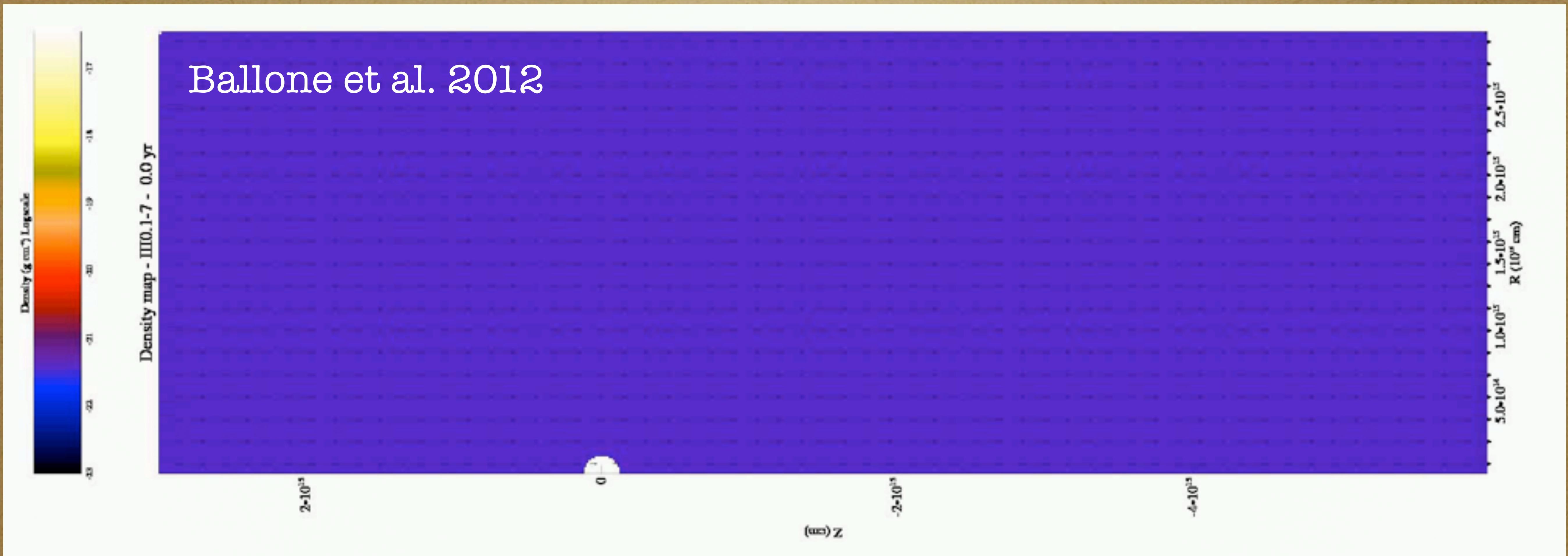
Small cloud scenario: $M_{G2} \approx 10^{27} g$



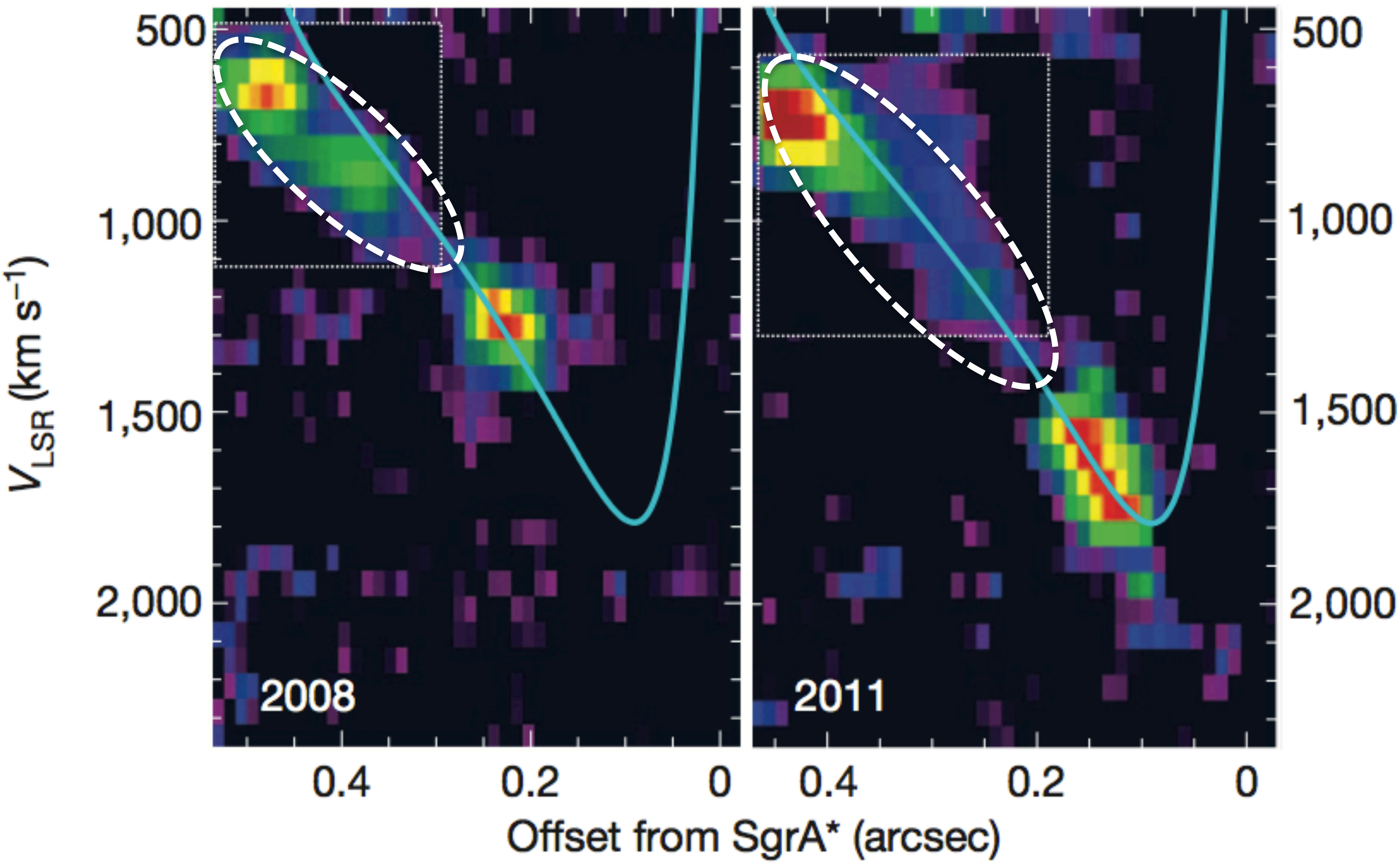
Origin of G2: compact source scenario

(Murray-Clay & Loeb 12)

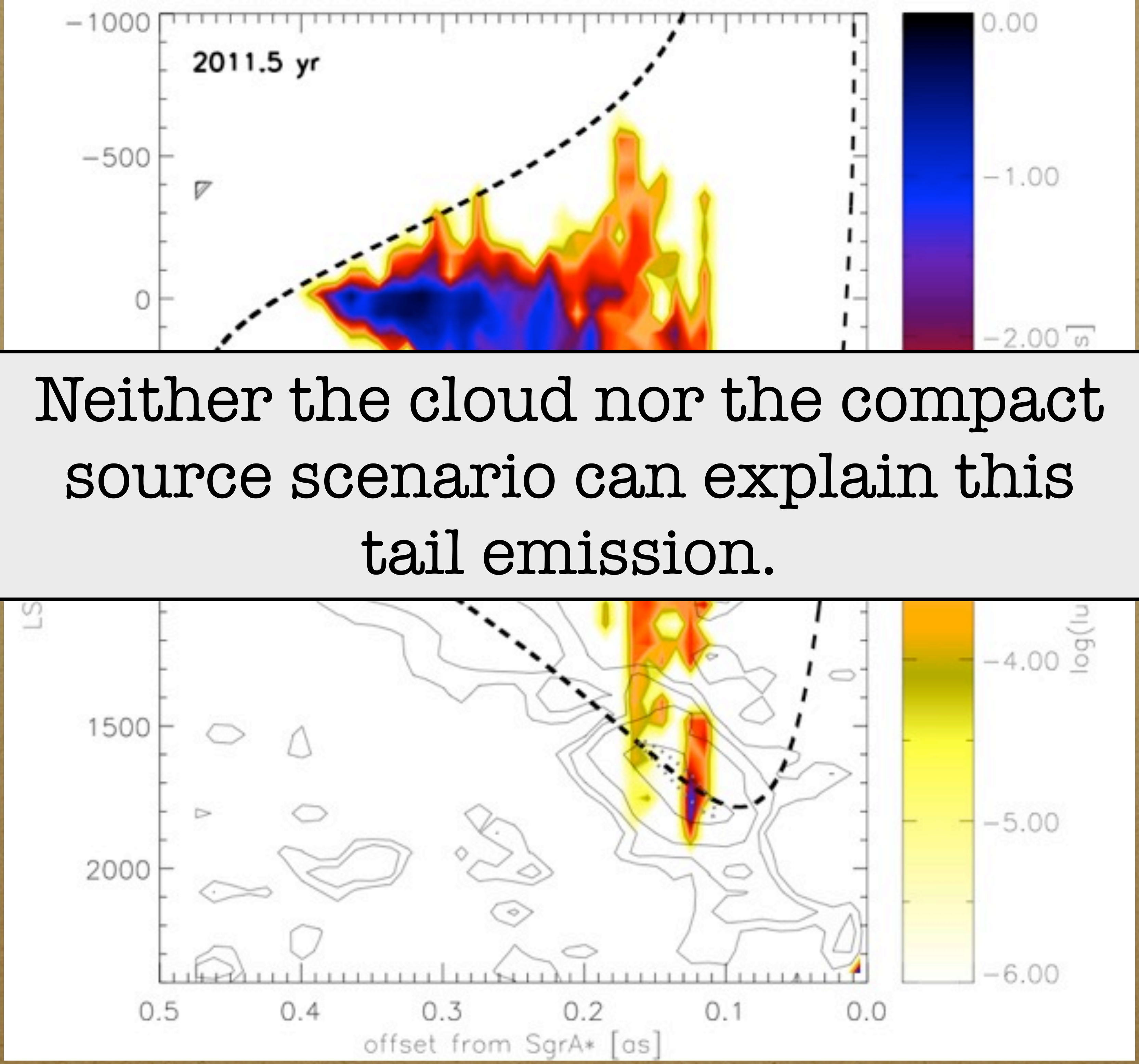




A tail of emission is seen in the data



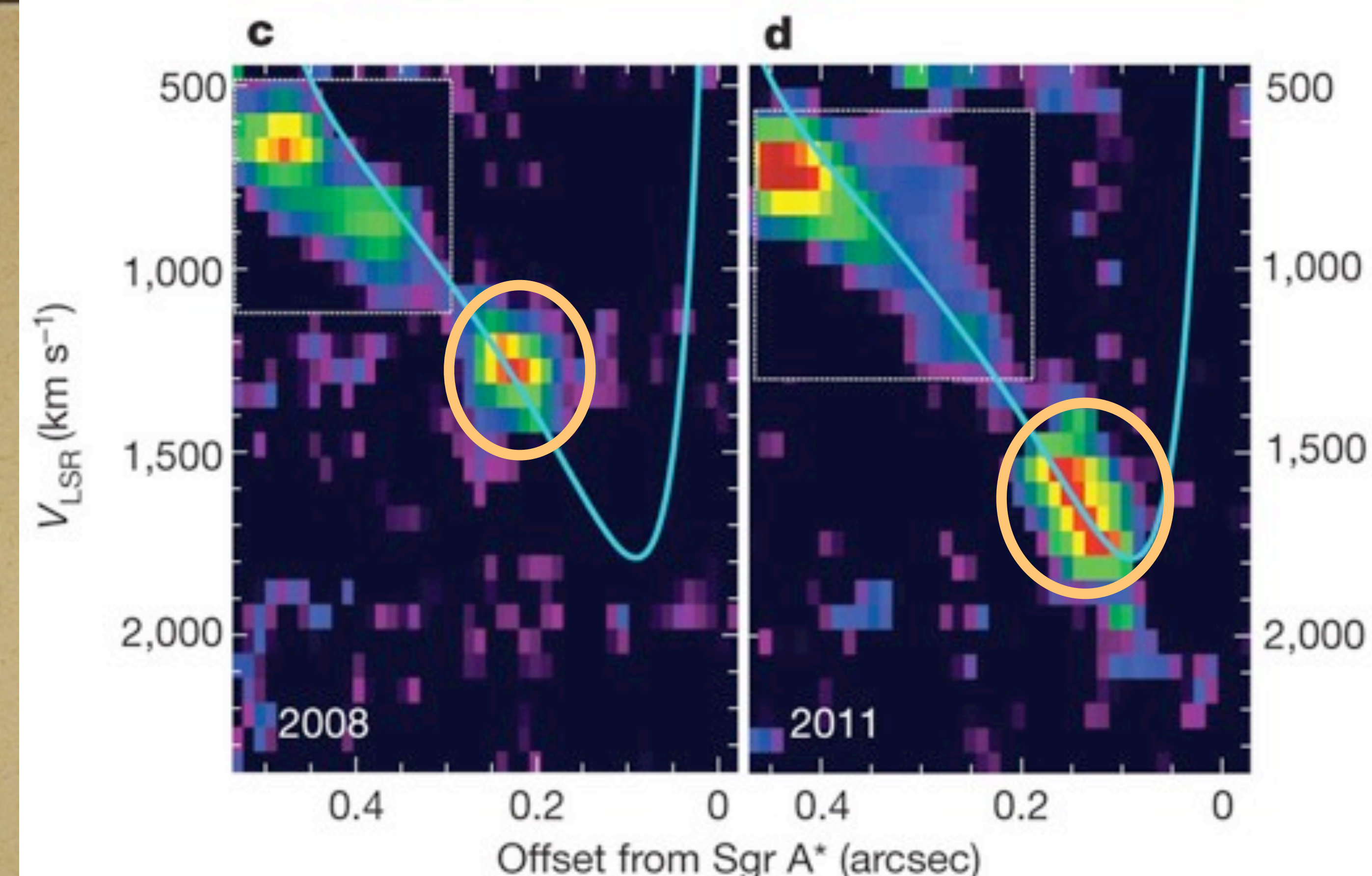
Stripped material would be slower than orbital velocity

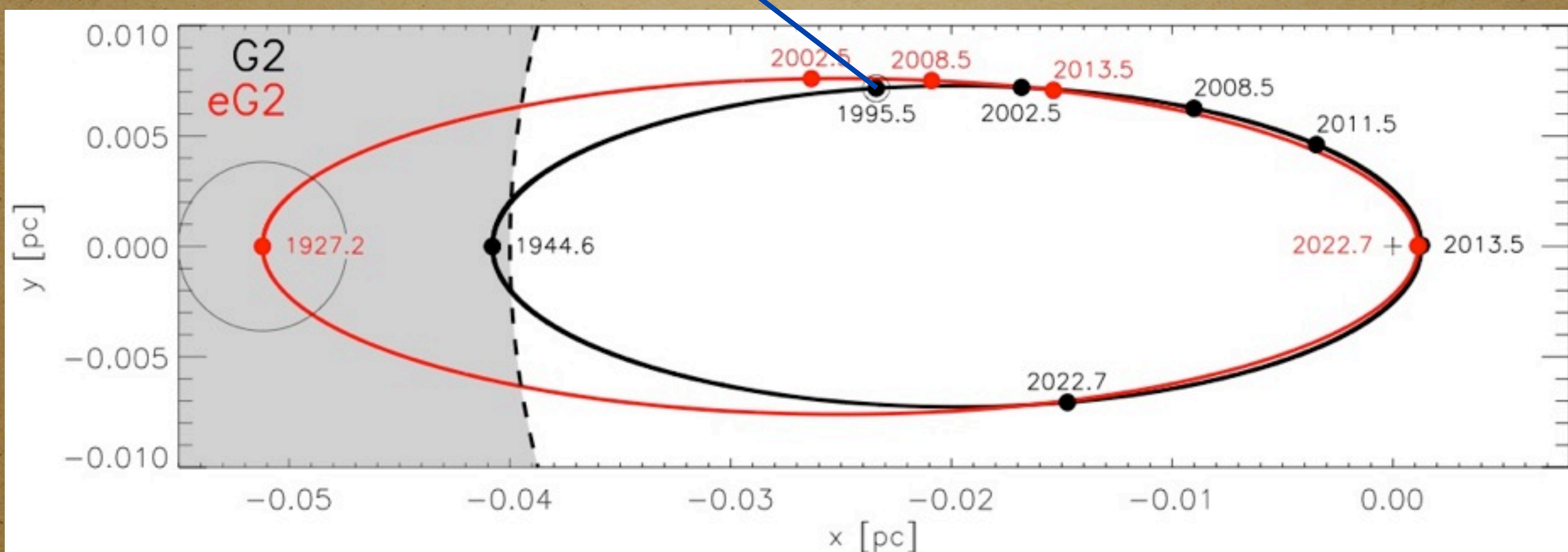


Neither the cloud nor the compact source scenario can explain this tail emission.

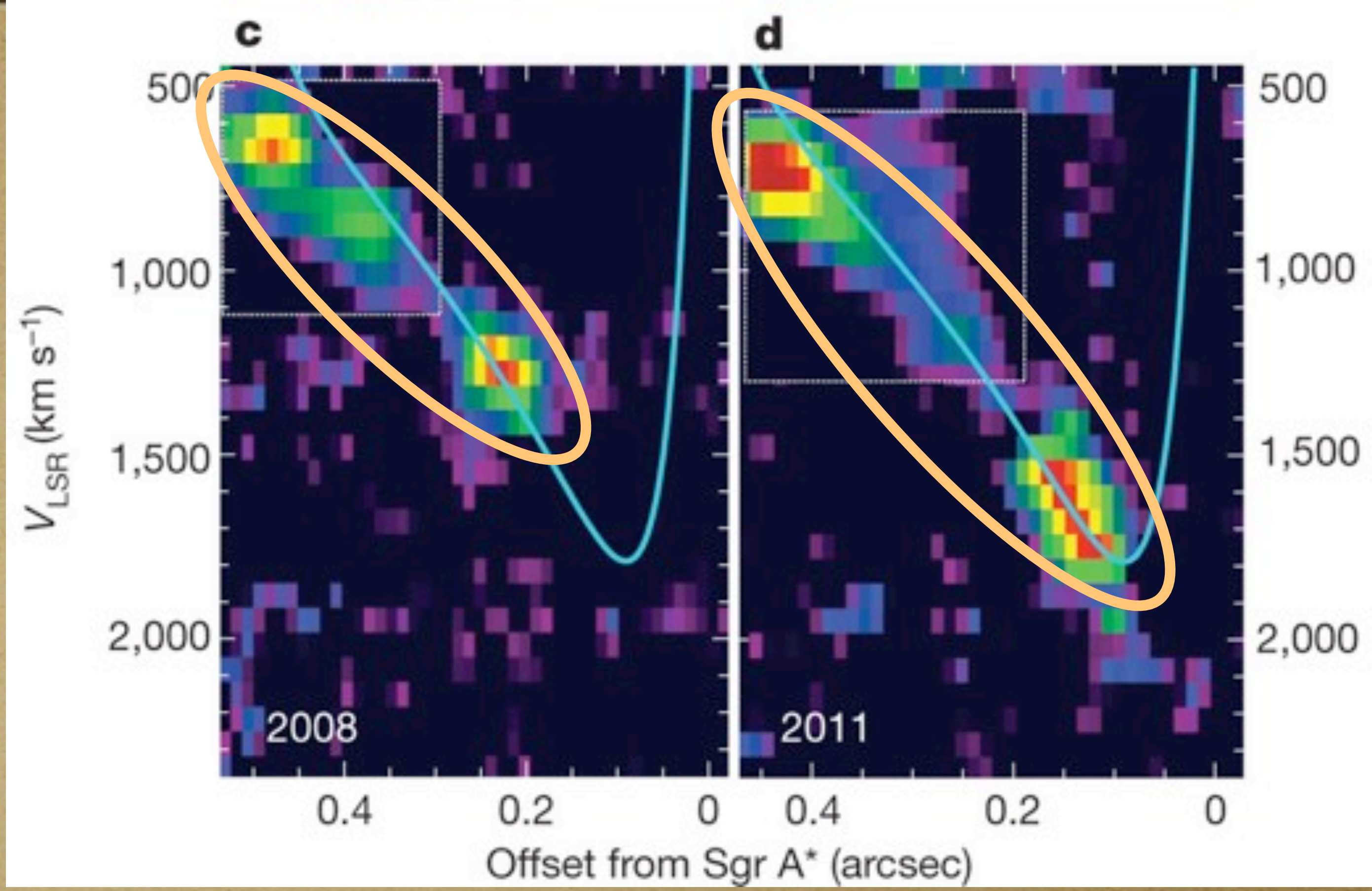
2 basic models

A) Compact Cloud

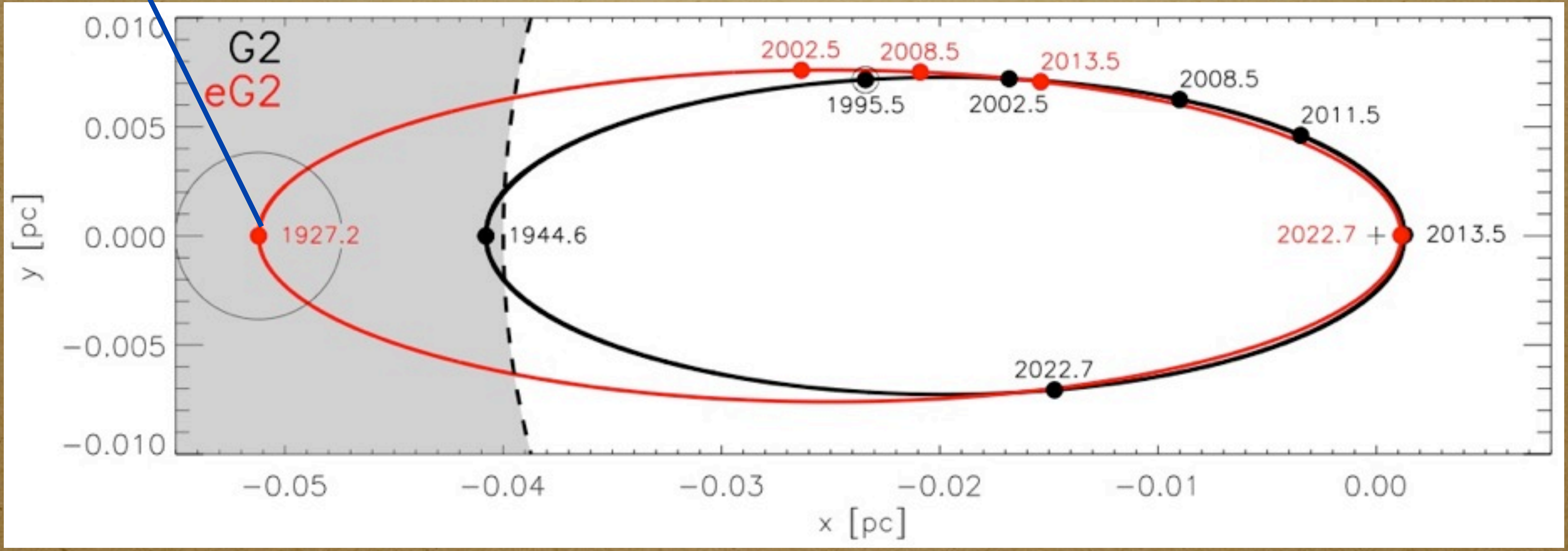




2 basic models

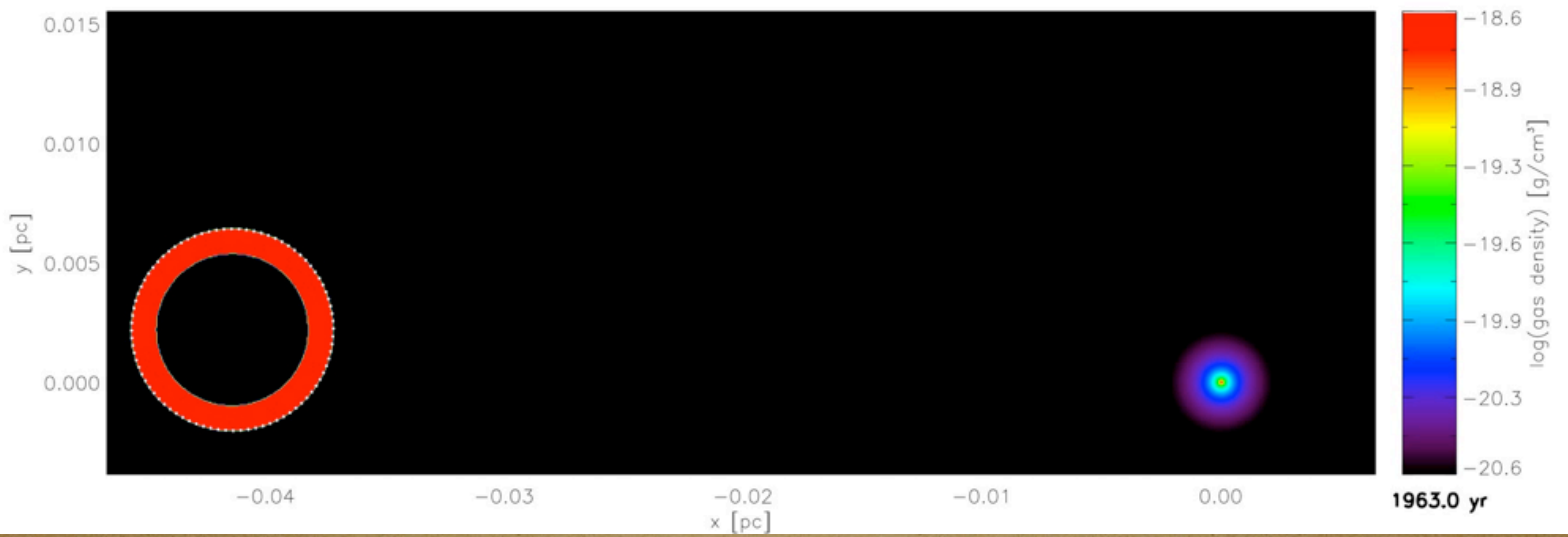


B) Spherical Shell

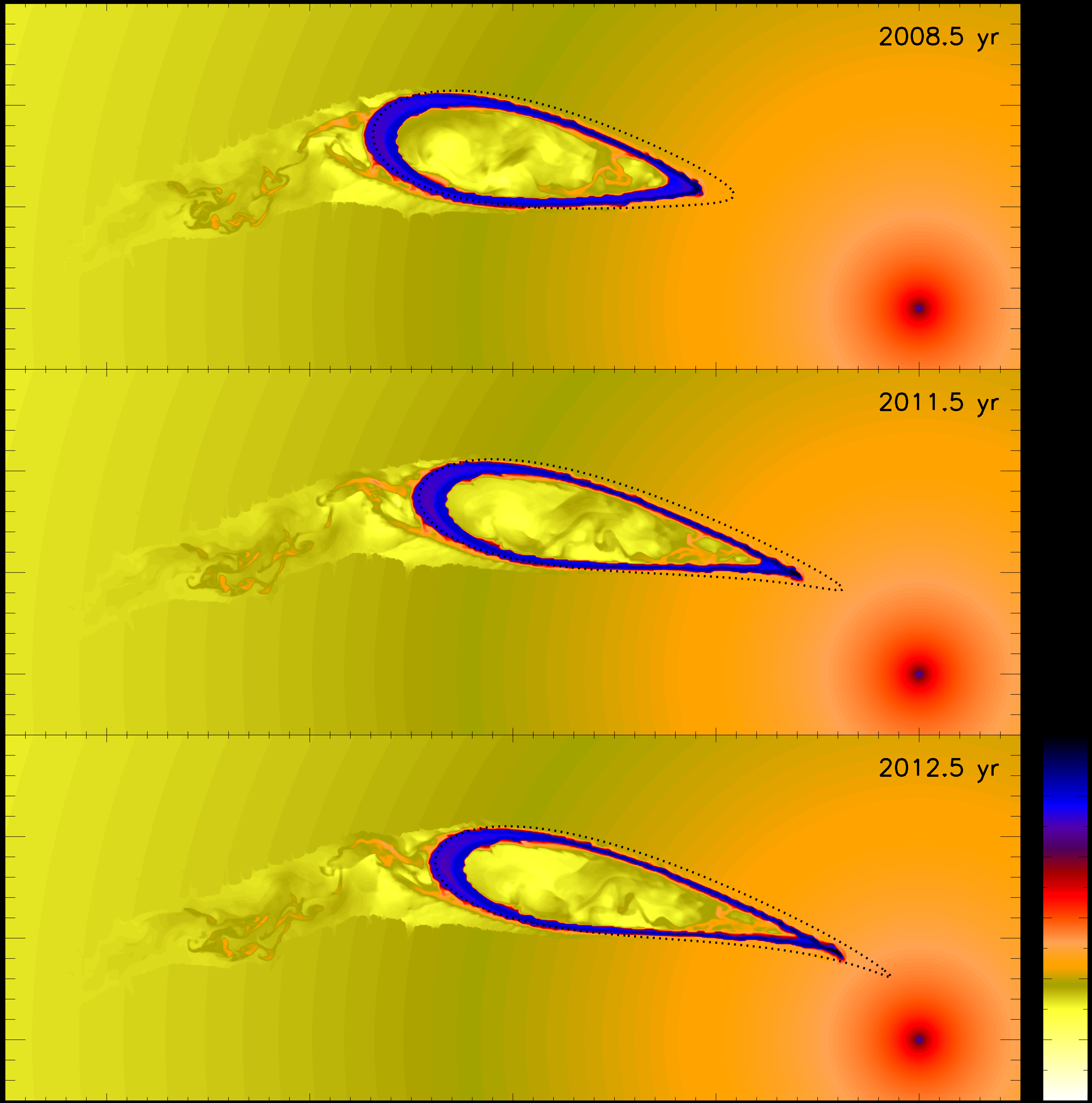


test particle simulations → 2 best-fit models

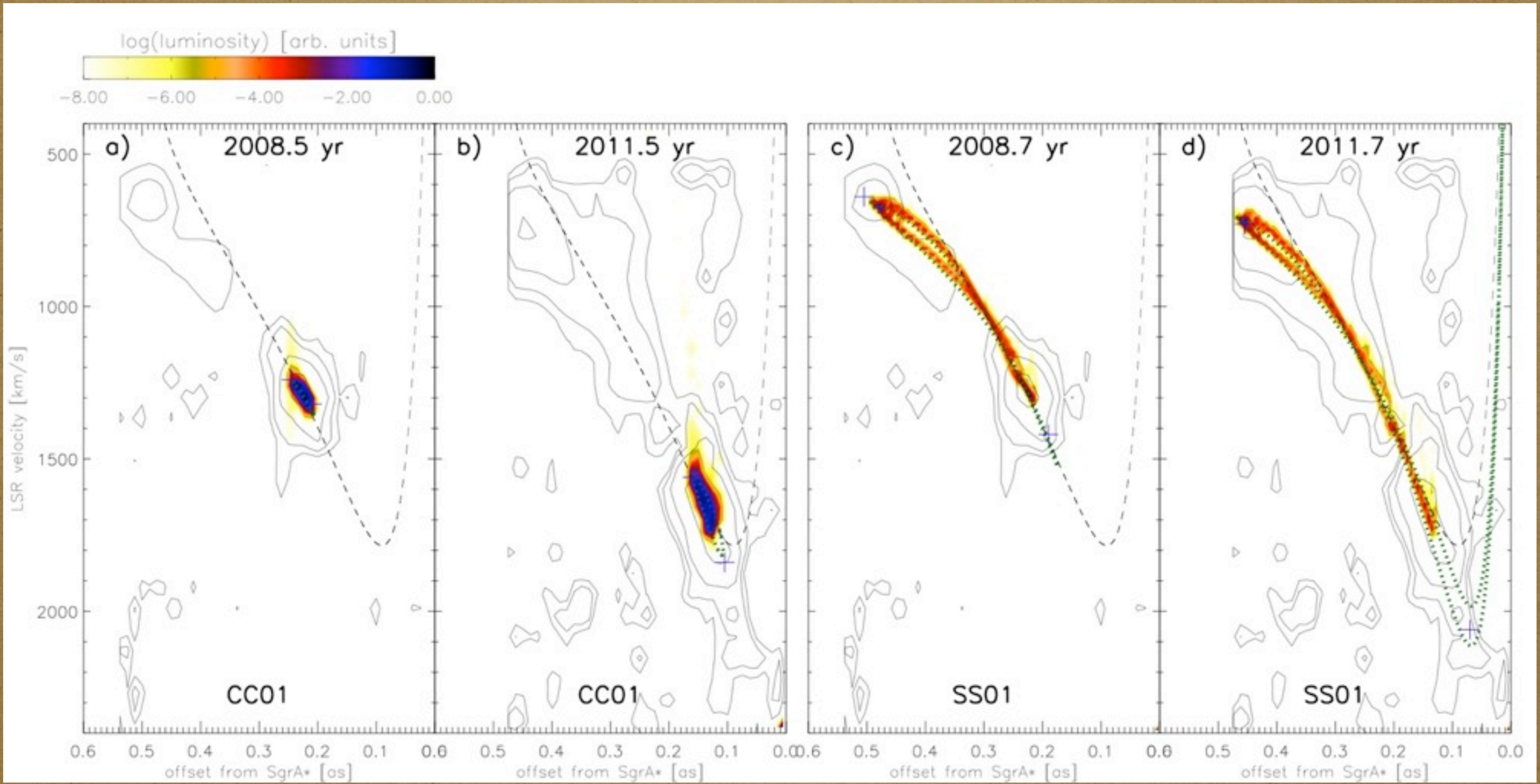
Evidence for a shell-like geometry?



Burkert et al. 2012; Schartmann et al. 2012.


2008.5 yr
2011.5 yr
2012.5 yr

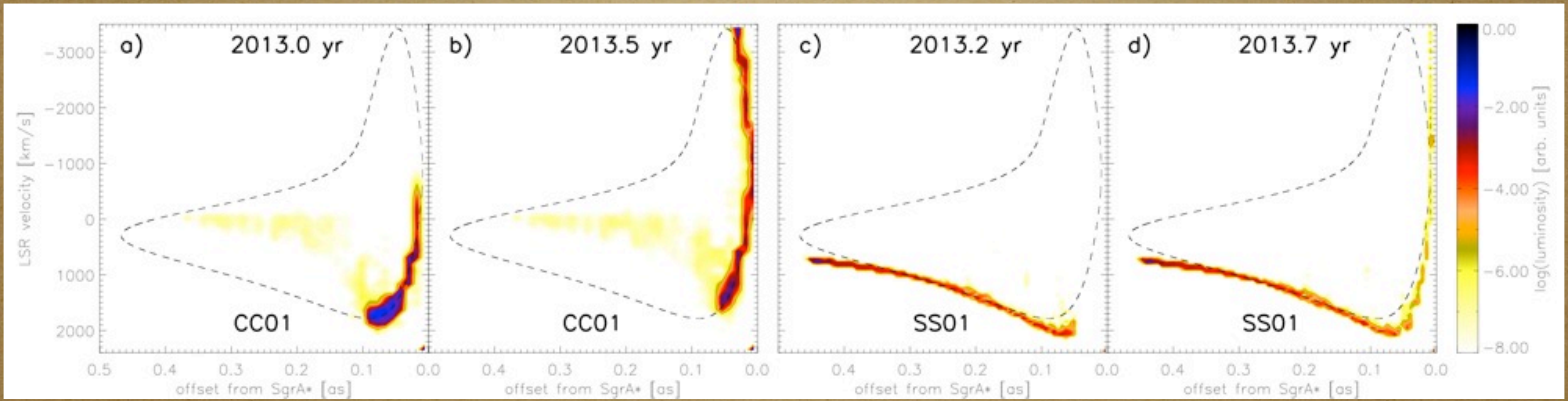
CC01 SS01



Comparison with available observations

data from Gillessen et al. 2012

CC01 SS01

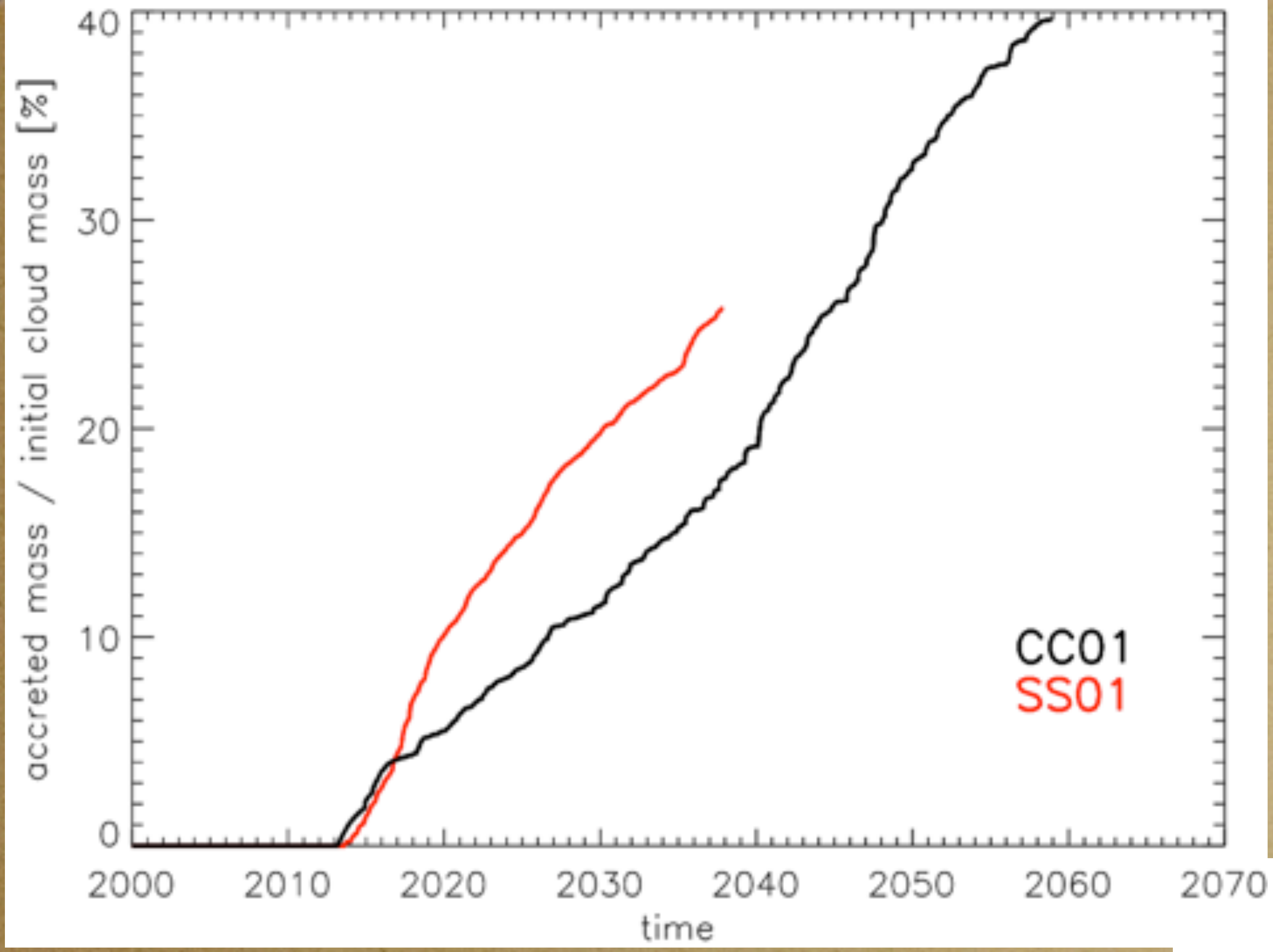


Predictions of future observations

Future of G2

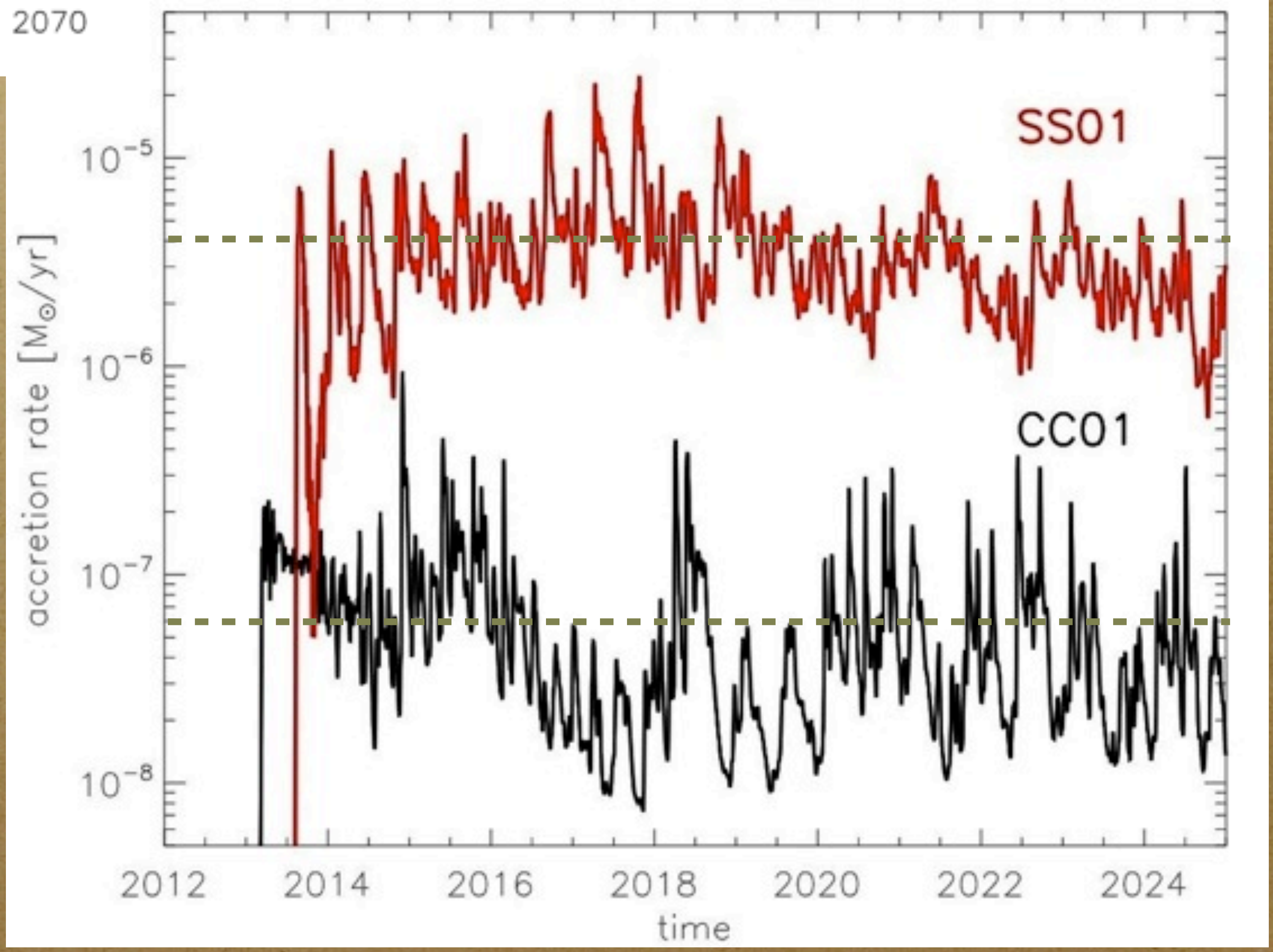
Comparison to observations

X-ray and IR flux



mass transfer through inner boundary

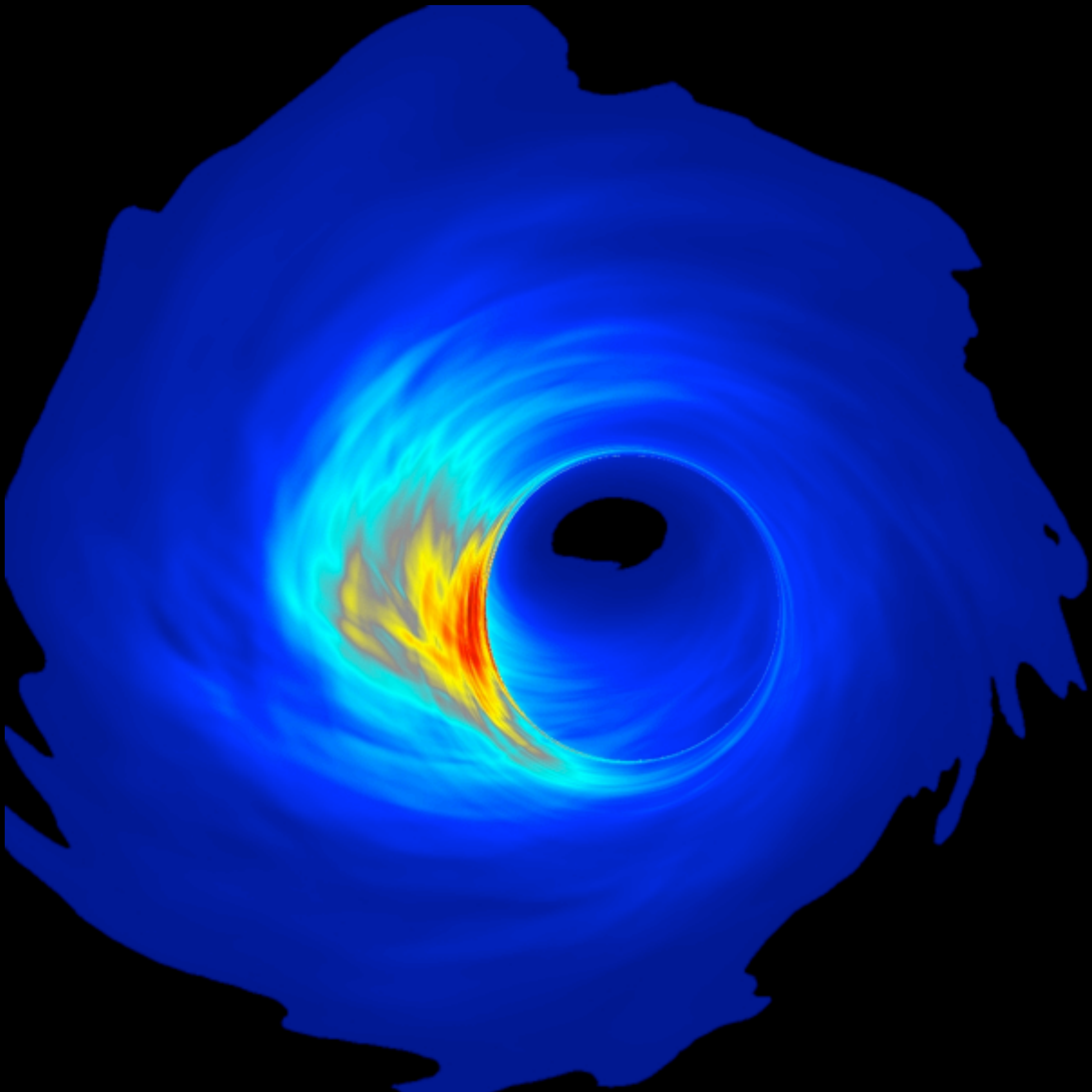
mass accretion rate through inner boundary



X-ray quiescent: 2.d33 erg/s
CC01: no boost
SS01: 20 x

IR quiescent: 7.d33 erg/s
CC01: no boost
SS01: 70 x

Missing: Interaction with Accretion Flow



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*