Flaring up of the Compact Cloud G2 during the Close Encounter with Sgr A* in 2013 Summer

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arXiv:1212.0349 ← Today!!

http://v1.jmlab.jp/~saitoh/G2/

Contents

LETTER

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A gas cloud on its way towards the supermassive black hole at the Galactic Centre

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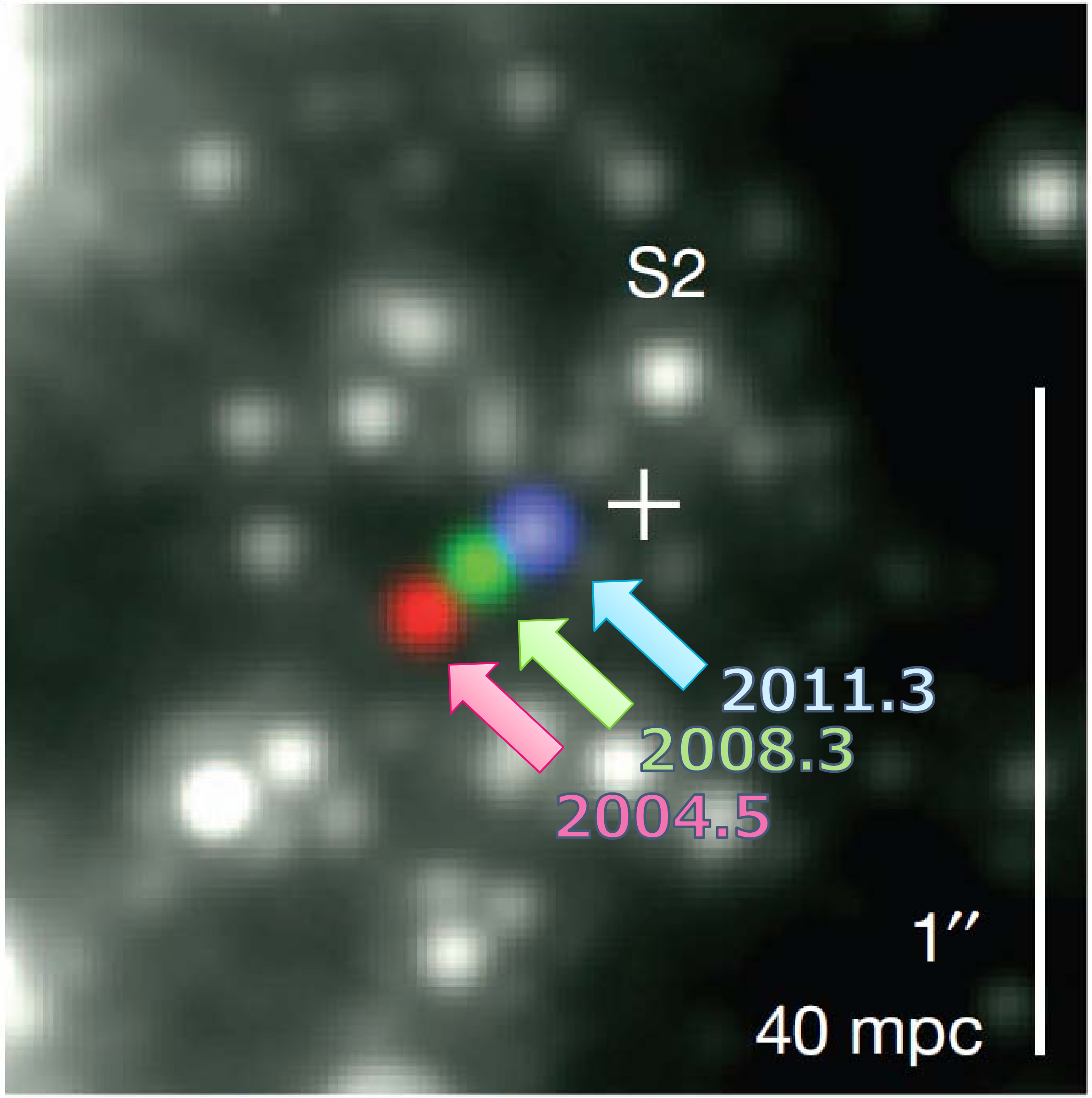
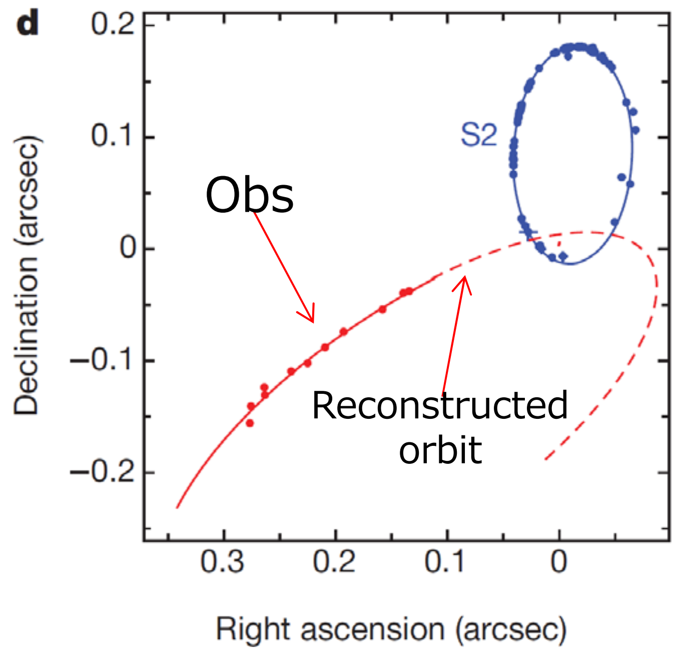
Measurements of stellar orbits[1–3] provide compelling evidence[4,5] that the compact radio source Sagittarius A* at the Galactic Centre is a black hole four million times the mass of the Sun. With the exception of modest X-ray and infrared flares[6,7], Sgr A* is surprisingly faint, suggesting that the accretion rate and radiation efficiency near the event horizon are currently very low[3,8]. Here we report the presence of a dense gas cloud approximately three times the mass of Earth that is falling into the accretion zone of Sgr A*. Our observations tightly constrain the cloud's orbit to be highly eccentric, with an innermost radius of approach of only ~3,100 times the event horizon that will be reached in 2013. Over the past three years the cloud has begun to disrupt, probably mainly through tidal shearing arising from the black hole's gravitational force. The cloud's dynamic evolution and radiation in the next few years will probe the properties of the accretion flow and the feeding processes of the supermassive black hole. The kilo-electronvolt X-ray emission of Sgr A* may brighten significantly when the cloud reaches pericentre. There may also be a giant radiation flare several years from now if the cloud breaks up and its fragments feed gas into the central accretion zone.

- 3 Earth mass cloud was found in the Galactic center
- Rperi~270 au/Tperi~ 2013 Summer
- Giant radiation flare would be observed due to the mass accretion onto the Sgr A*

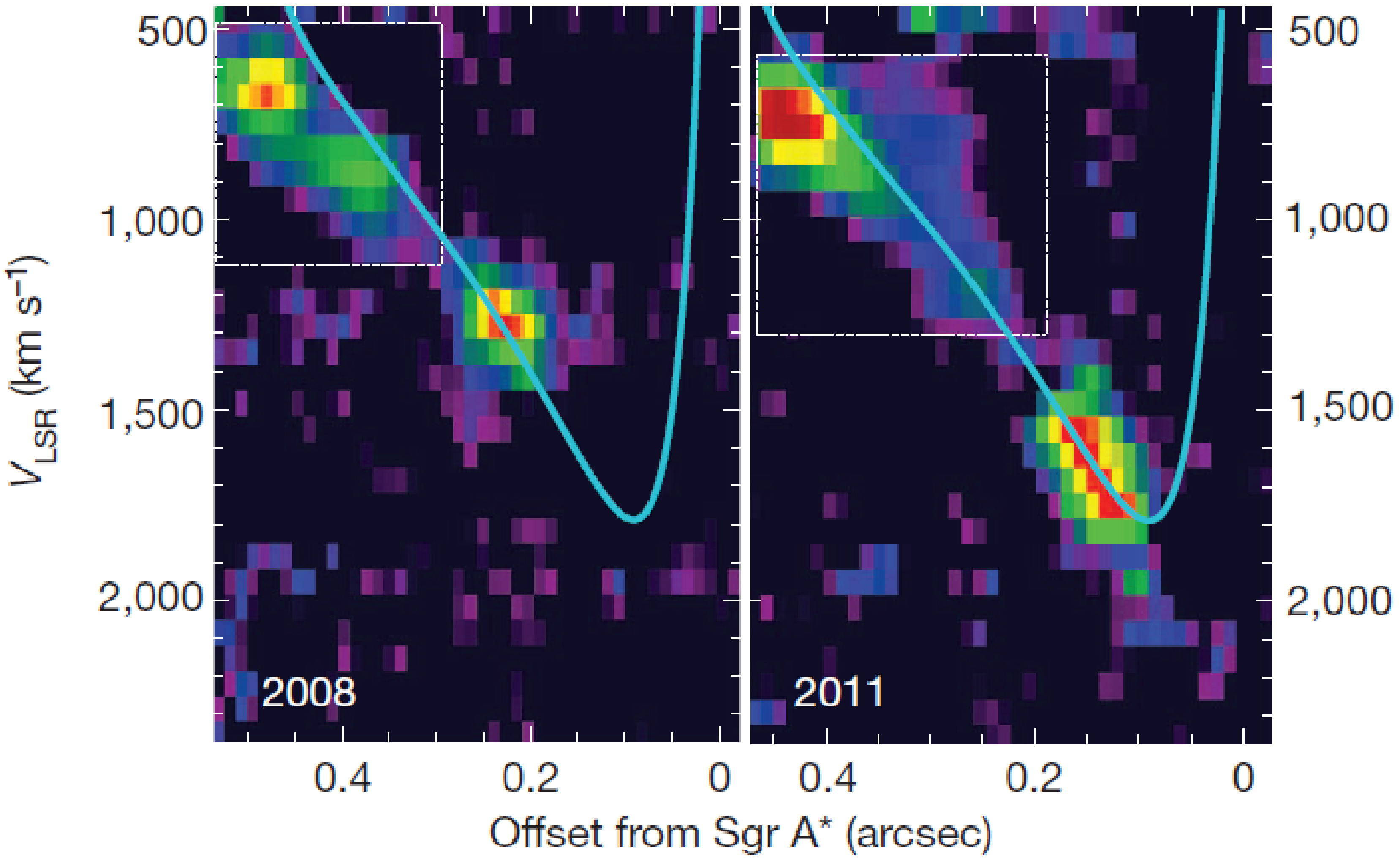
IR band images by VLT





Gillessen et al. 2012

P-V diagrams



- Elongated structure has been observed

Gillessen et al. 2012

Cloud's and orbital properties

- Mass : **~3 earth mass**
- Effective Radius:~15mas **~125 AU**

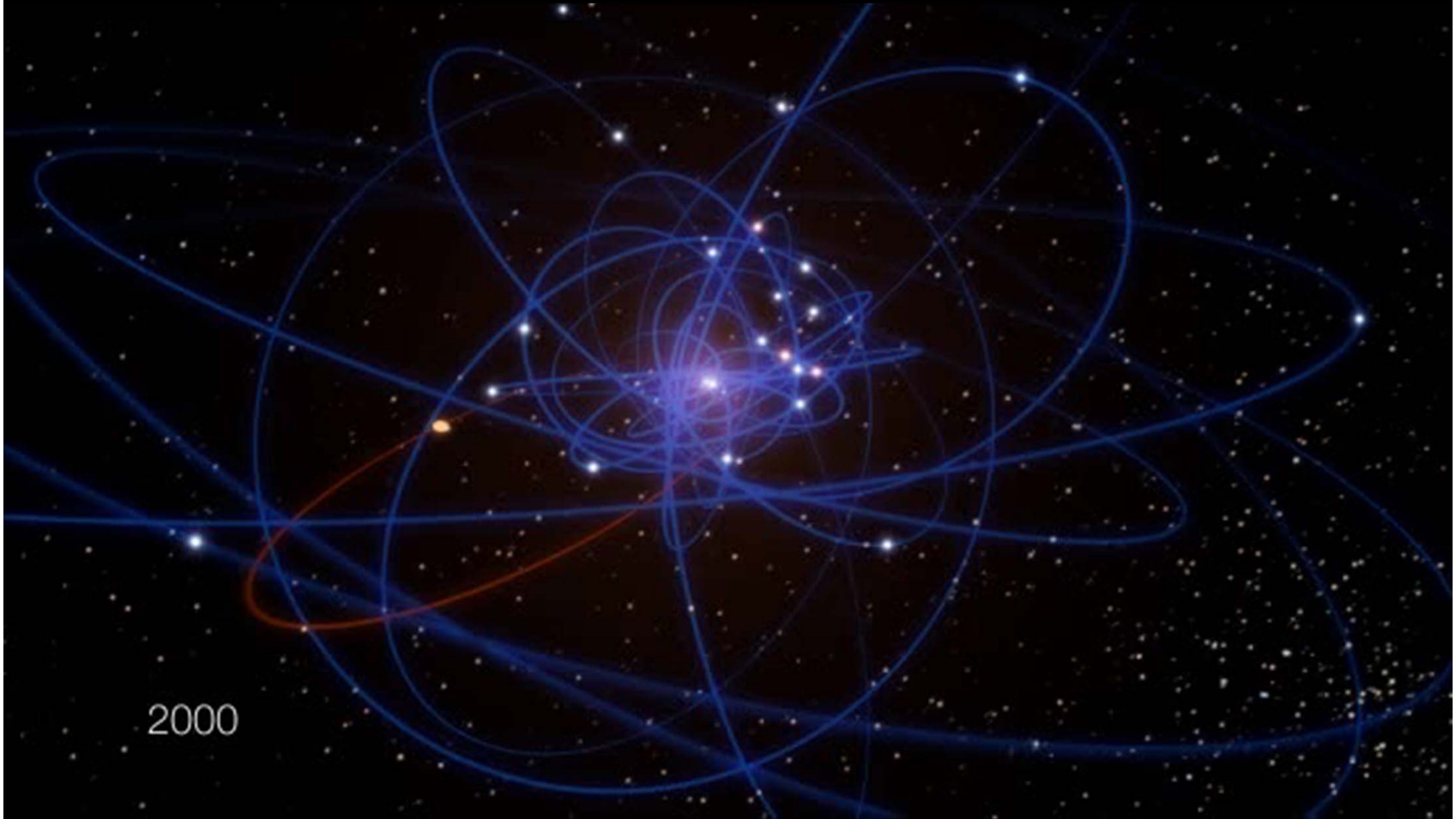
Table 1 | Orbit parameters of the infalling cloud

Parameters of Keplerian orbit around the $4.31 \times 10^6 M_\odot$ black hole at $R_0 = 8.33$ kpc	Best-fitting value
Semi-major axis, *a*	521 ± 28 mas
Eccentricity, *e*	0.9384 ± 0.0066
Inclination of ascending node, *i*	106.55 ± 0.88 deg
Position angle of ascending node, *Ω*	101.5 ± 1.1 deg
Longitude of pericentre, *ω*	109.59 ± 0.78 deg
Time of pericentre, t_{peri}	2013.51 ± 0.035
Pericentre distance from black hole, r_{peri}	$4.0 \pm 0.3 \times 10^{15}$ cm = 3,140R_S
Orbital period, t_o	137 ± 11 years

Summary of Obs

- **Three earth mass** cloud, G2, was found in the Galactic center, which is approaching the Sgr A* and will be pass **the pericenter (~270 au)** in **2013 summer**.
- Interaction with the ambient hot gas may induce the destruction of G2 by KH/RT instabilities, resulting in *the enhancement of the activity in the Sgr A*.*
- **Attractive Event!**
  - **35** citations (4 Dec 2012)

ESO animation



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SIMULATIONS OF THE ORIGIN AND FATE OF THE GALACTIC CENTER CLOUD G2

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ABSTRACT

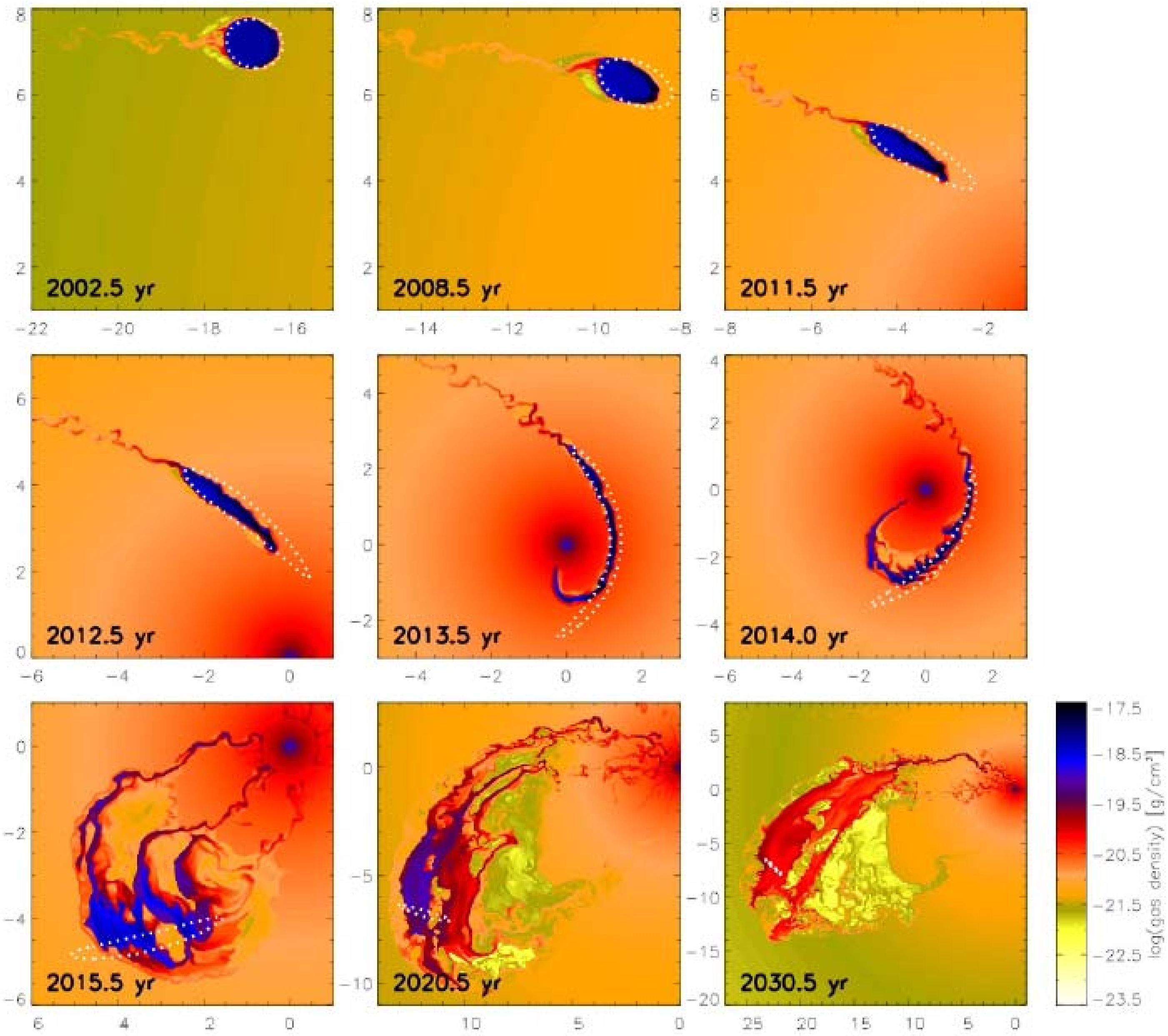
We investigate the origin and fate of the recently discovered gas cloud G2 close to the Galactic center. Our hydrodynamical simulations focusing on the dynamical evolution of the cloud in combination with currently available observations favor two scenarios: a *Compact Cloud* which started around the year 1995 and a *Spherical Shell* of gas, with an apocenter distance within the disk(s) of young stars and a radius of a few times the size of the Compact Cloud. The former is able to explain the detected signal of G2 in the position–velocity (PV) diagram of the Brγ emission of the year 2008.5 and 2011.5 data. The latter can account for both G2's signal as well as the fainter extended tail-like structure G2t seen at larger distances from the black hole and smaller velocities. In contrast, gas stripped from a compact cloud by hydrodynamical interactions is not able to explain the location of the detected G2t emission in the observed PV diagrams. This favors the *Spherical Shell Scenario* and might be a severe problem for the Compact Cloud as well as the so-called *Compact Source Scenario*. From these first idealized simulations, we expect a roughly constant feeding of the supermassive black hole through a nozzle-like structure over a long period, starting shortly after the closest approach in 2013.51 for the Compact Cloud. If the matter accretes in the hot accretion mode, we do not expect a significant boost of the current activity of Sgr A* for the Compact Cloud model, but a boost of the average infrared and X-ray luminosity by roughly a factor of 80 for the Spherical Shell Scenario with order of magnitude variations on a timescale of a few months. Assuming that a part of the gas is accreted in cold disk mode, even higher boost factors can be reached. The near-future evolution of the cloud will be a sensitive probe of the conditions of the gas distribution in the milli-parsec environment of the massive black hole in the Galactic center.

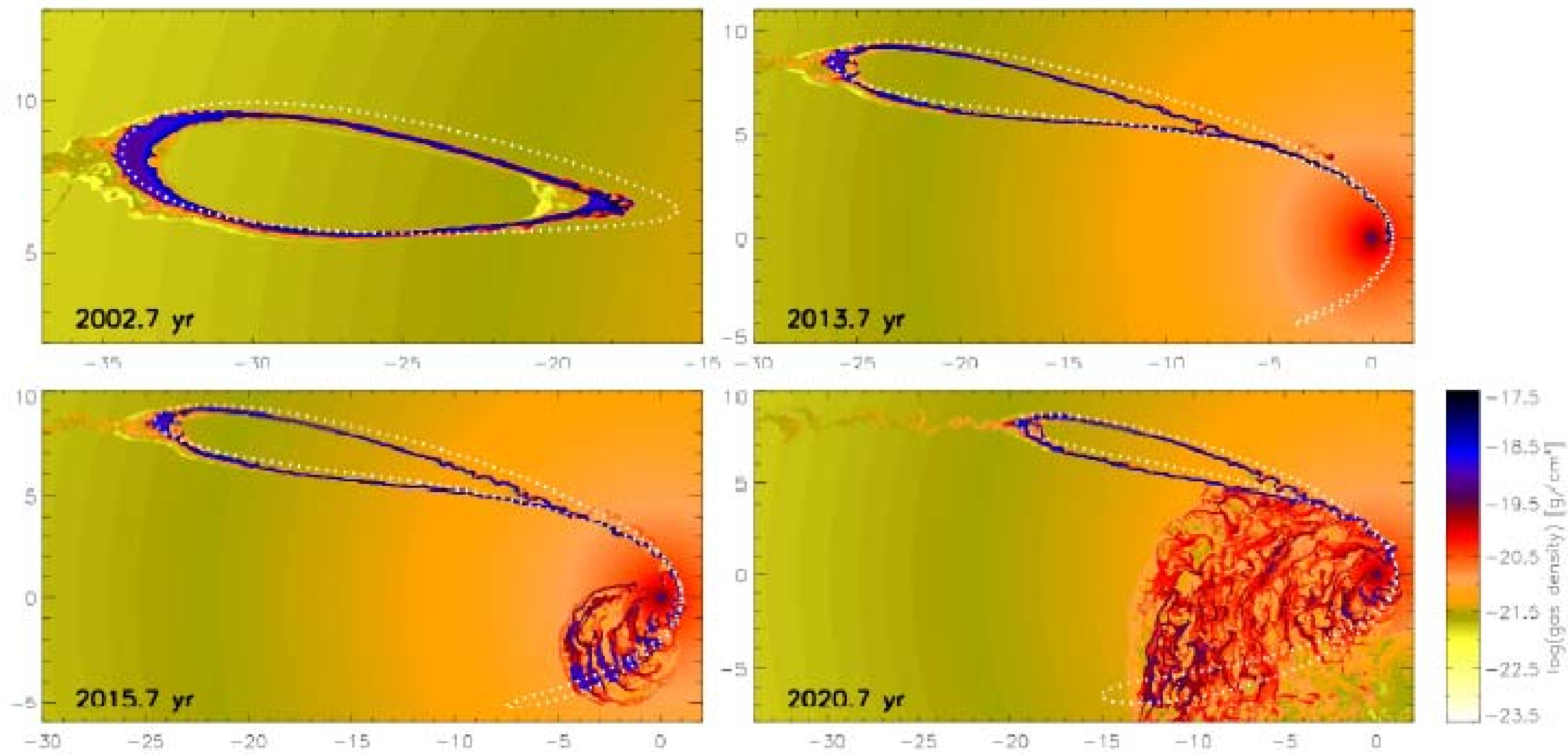
Key words: accretion, accretion disks – black hole physics – Galaxy: center – ISM: clouds

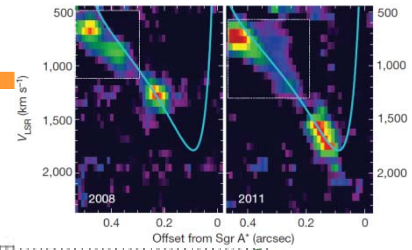
Online-only material: color figures

Simulation

- 2D, PLUTO(AMR)
- 2 scenarios
  1. Compact cloud scenario
  2. Spherical shell cloud scenario
- EOS : Isothermal
- Hot ambient gas surrounding the Sgr A*
  - Radiatively Inefficient Accretion Flow (RIAF)
    - Density/Temperature profile:~1/r (Yuan+2003)
  - Profiles are (almost) fixed.


2002.5 yr
2008.5 yr
2011.5 yr
2012.5 yr
2013.5 yr
2014.0 yr
2015.5 yr
2020.5 yr
2030.5 yr
log(gas density) [g/cm³]
-17.5
-18.5
-19.5
-20.5
-21.5
-22.5
-23.5


2002.7 yr
2013.7 yr
2015.7 yr
2020.7 yr
log(gas density) [g/cm^3]



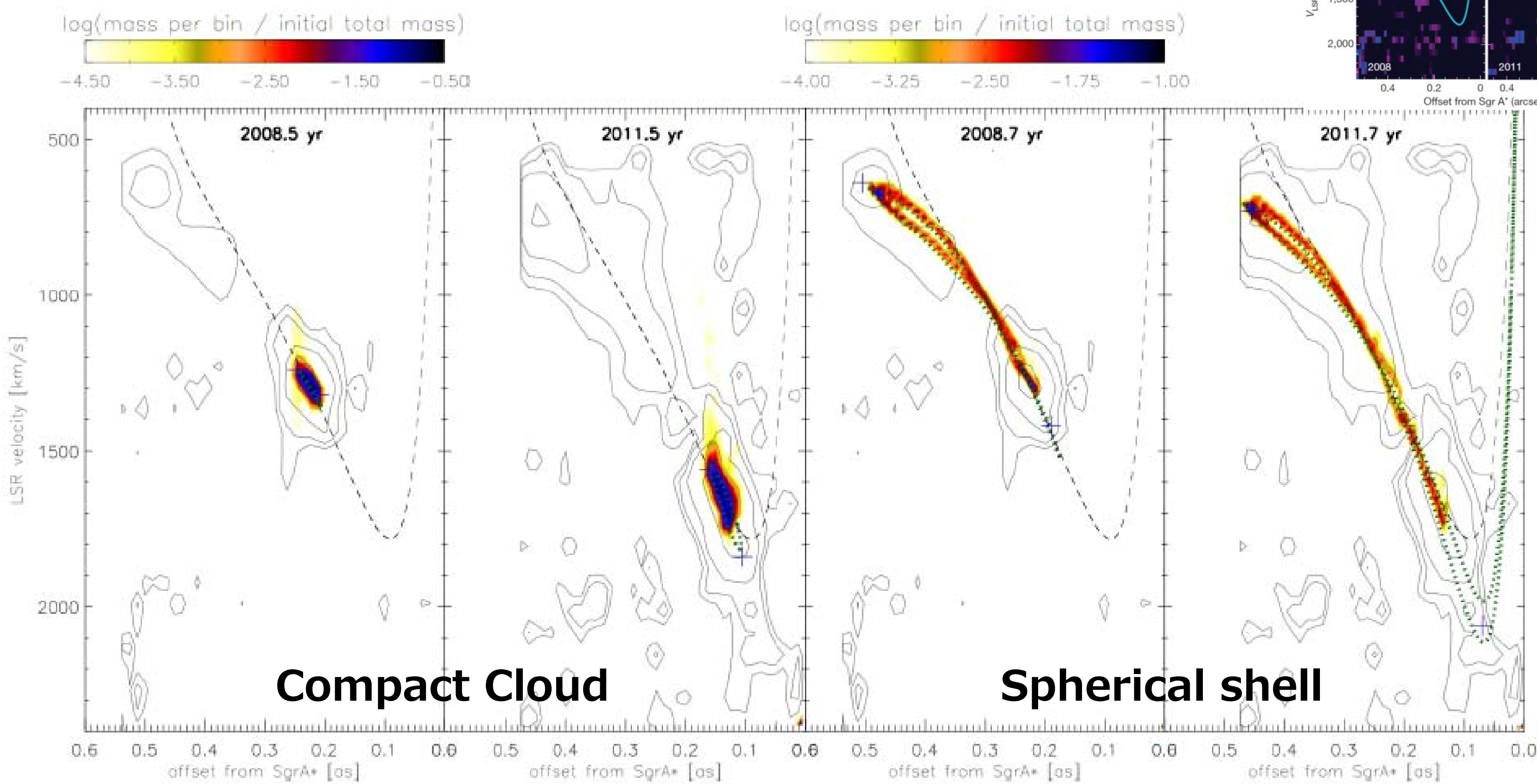


Figure 10. Comparison of the position-velocity diagrams for the simulations CC01 (left panels) and SS01 (right panels) with observations (background contours). The distance to Sgr A* – projected on the sky – is plotted against the line-of-sight velocity. The colored contours display a mass histogram, relative to the total initial mass of the respective cloud model. The dashed line represents the evolutionary path of a test particle in the center of the cloud on the orbit of G2 with the parameters given in Table 1 for a full orbital revolution. The green dotted lines show the result of the test particle simulation.

- Spherical shell model can explain the p-v diagram much well.

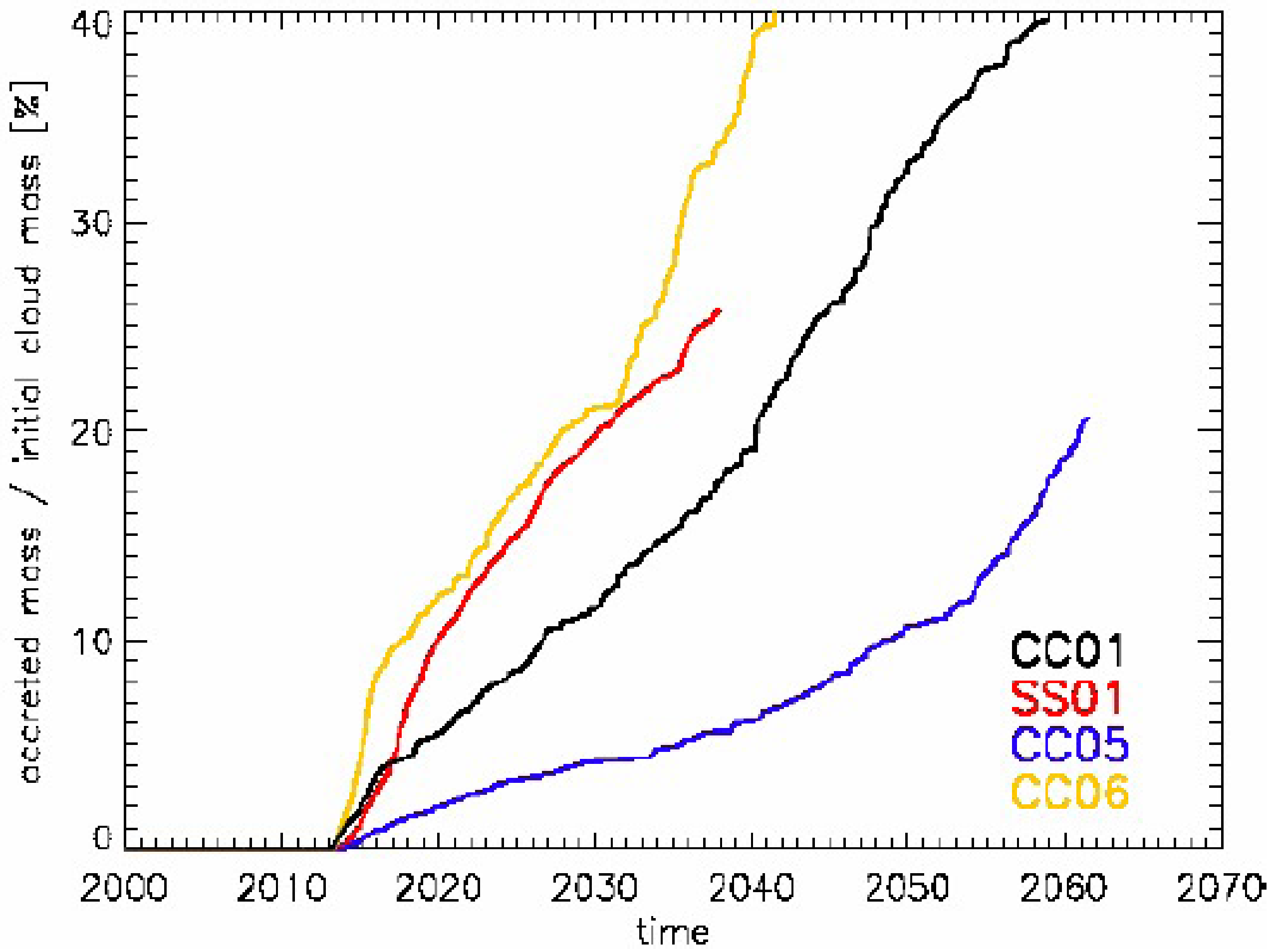


Figure 7. Accreted cloud mass of the models discussed in this paper relative to their initial cloud masses. See Table 2 for more details on the simulations.

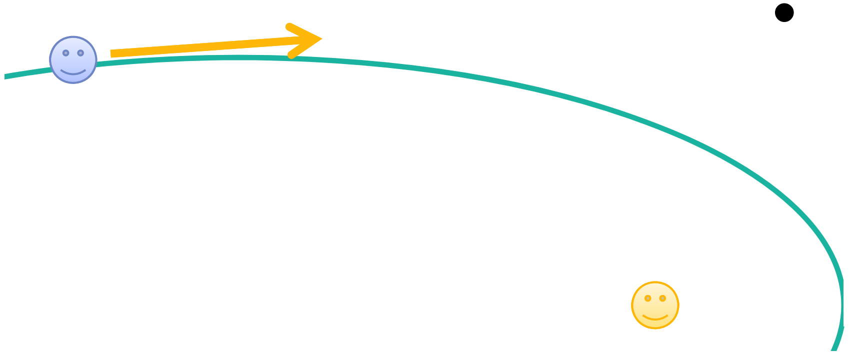
- If ~0.1 M_{earth} falls into the Sgr A* and it releases 10 % of its grav. energy, the released energy is ~10^{48}erg
- ~10^{39}erg/s: if we assume 10 years as the duration time.
- However, if we adopt the typical the eff. of RIAF ~ 10^{-6}, ~10^{33} erg/s.

Q

- Is **2D approximation** good for this system?
  - Tidal force in the vertical direction to the orbital plan was excluded.
  - Since the V_{peri}~5000km/s, the compression energy will be enormous even if only several % of V_{peri} can be used.
- Here, we investigate the effects of three-dimensionality.
  - We adopt the compact cloud scenario, and do not care details in the formation process of cloud.

3D Simulation Setup

- N-body/SPH simulations of the system with the cloud, hot ambient and Sgr A*.
  - Gravity, hydrodynamics and radiative cooling w/Optically thin
- 3D uniform density cloud
  - $3M_{Earth}$, Radius 125AU
- Orbital parameter : Gillessen+2012
  - Pericenter passage: A.D. 2013.5
- Since A.D. 1995 to A.D. 2033



- hot ambient profile

$$\rho_{\rm hot}(r) = 1.7\times 10^{-21} f_{\rm hot}\left(\frac{1.0\times 10^{16}{\rm cm}}{r}\right) {\rm g\ cm^{-3}}$$

$$T(r) = 2.1\times 10^{8}\left(\frac{1.0\times 10^{16}{\rm cm}}{r}\right) {\rm K},$$

Run parameters

Table 3: Particle Information

Component	Number of particles	Mass of particles	Softening length
Cloud (Run 1)	1×10^6	$3 \times 10^{-6}\ M_\oplus$	0.43 au
Cloud (Run 2)	3×10^5	$1 \times 10^{-5}\ M_\oplus$	0.65 au
Cloud (Run 3)	10^7	$3 \times 10^{-7}\ M_\oplus$	0.20 au
Hot gas (Run 1)	1×10^7	$2.8 \times 10^{-5}\ M_\oplus$	0.92 au
Hot gas (Run 2)	3×10^6	$9.4 \times 10^{-5}\ M_\oplus$	0.63 au
Hot gas (Run 3)	N/A	N/A	N/A
SMBH (Run 1,2,3)	1	$4.31 \times 10^6\ M_\odot$	10 au

Table 2: Values of $f_{\rm hot}$

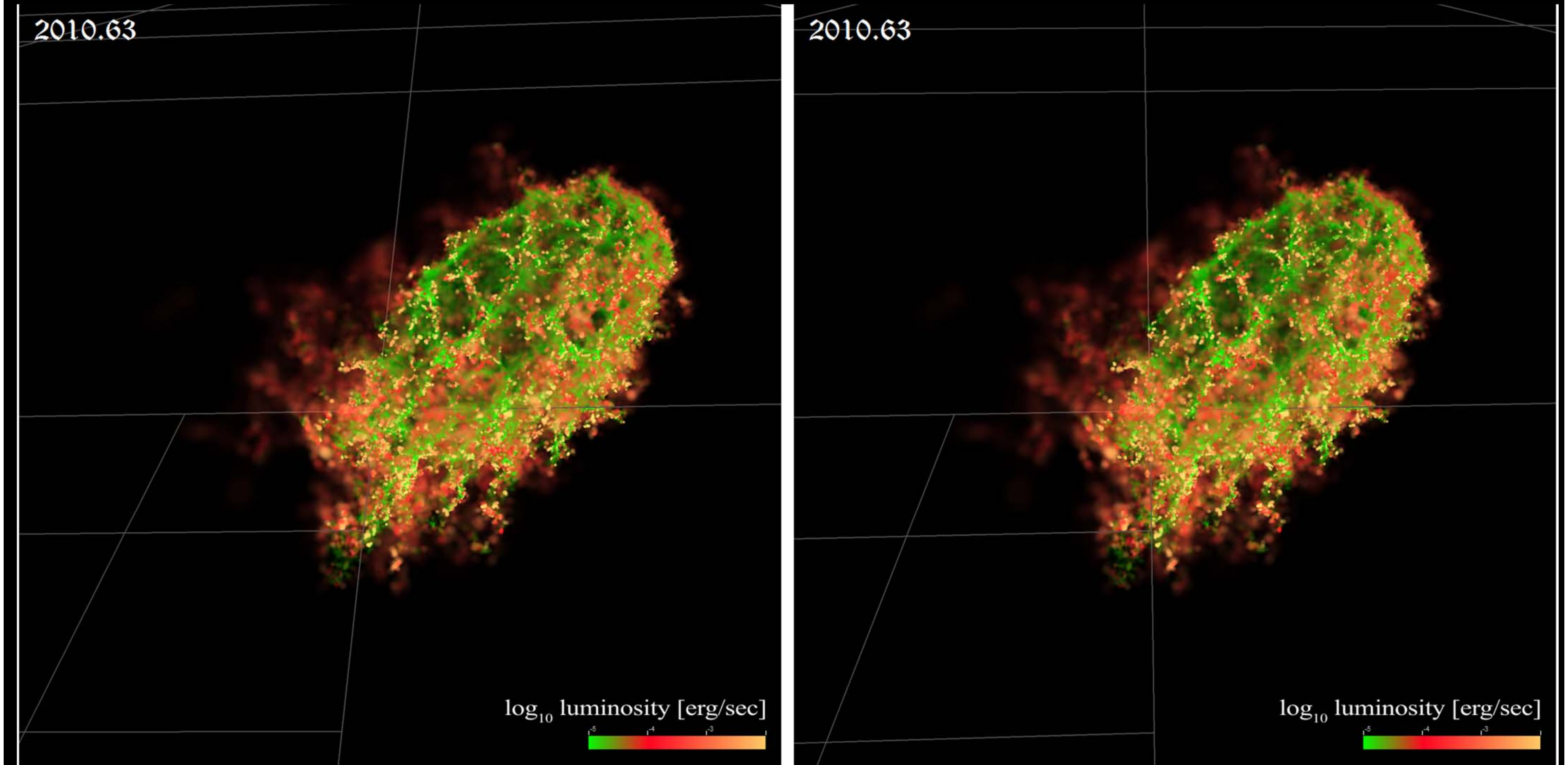
Run name	$f_{\rm hot}$
Run 1	1
Run 2	0.1
Run 3	0

Note that $M_\odot = 1.989 \times 10^{33}$ g, $M_\oplus = 5.972 \times 10^{27}$ g, and $\mathrm{au} = 1.496 \times 10^{13}$ cm.

Parallel N-body/SPH code : ASURA

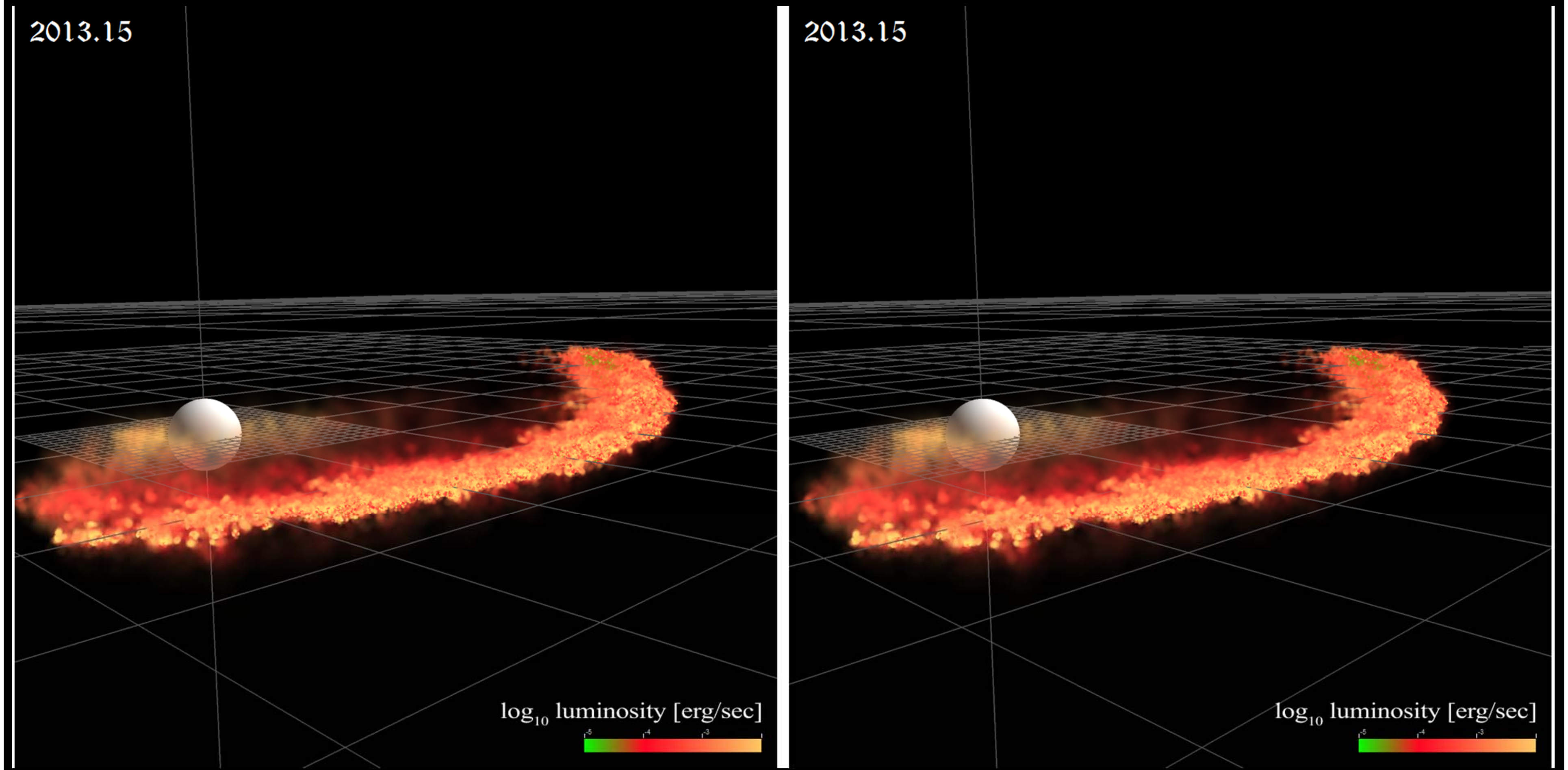
- C (C99) + MPI
- Domain decomp.:Orthogonal Recursive Bisection
- Gravity: Parallel Tree+GRAPE
  - Hardware accelerators : GRAPE-5/GRAPE-6A/GRAPE-7/GRAPE-DR
  - Software accelerator : Phantom-GRAPE
    - Assembler tuned software library!!
  - Symmetrized Plummer Potential (Saitoh&Makino 2012a)
- Hydro : Density Independent SPH (Saitoh&Makino 2012b)
- Time integrator: Leap-frog
  +Individual time steps
  +Time-step limiter (Saitoh&Makino 2009)
  +FAST (Saitoh&Makino 2010)

Stereograms



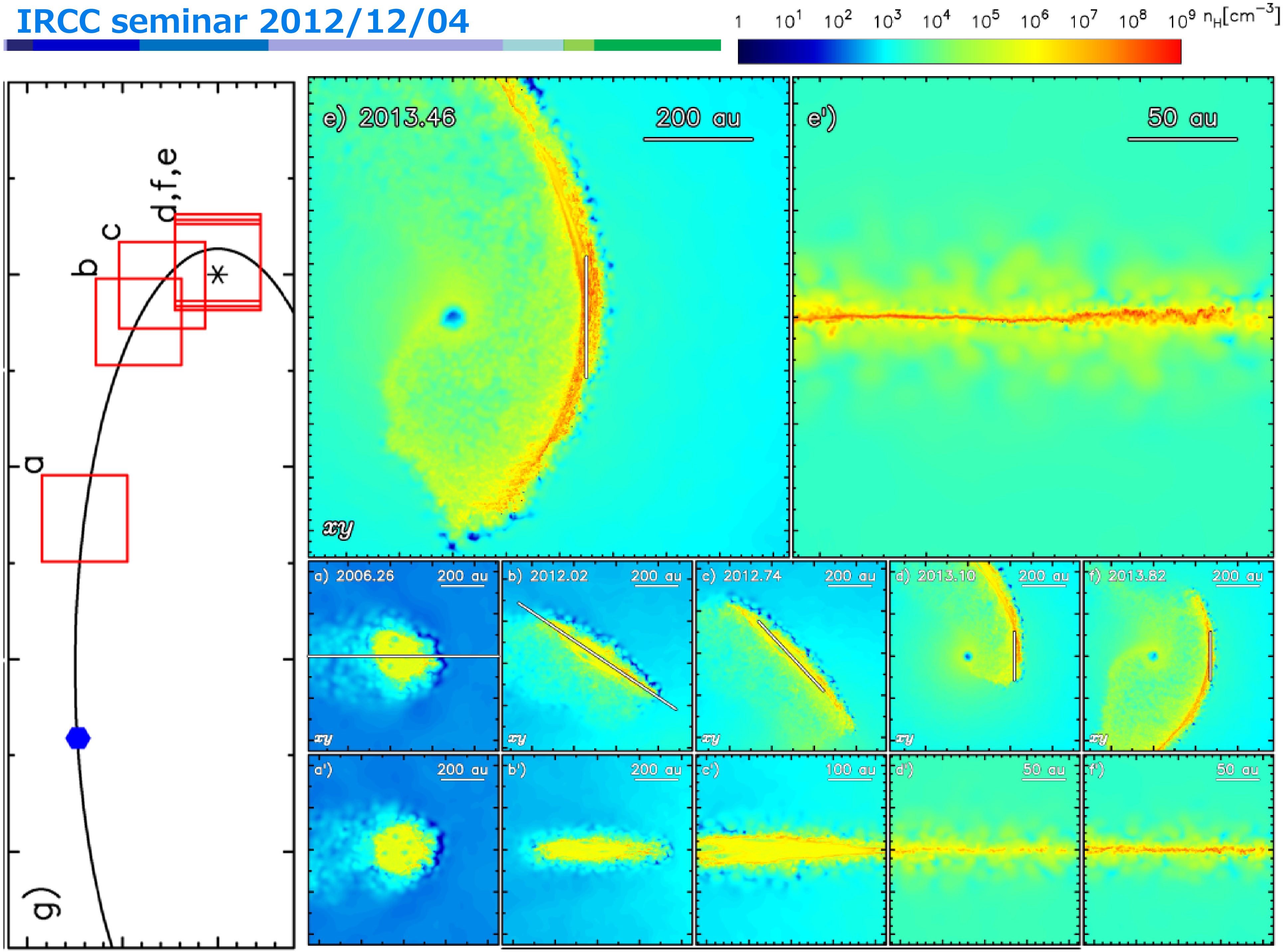
The cross-eyed view method is used.

Stereograms

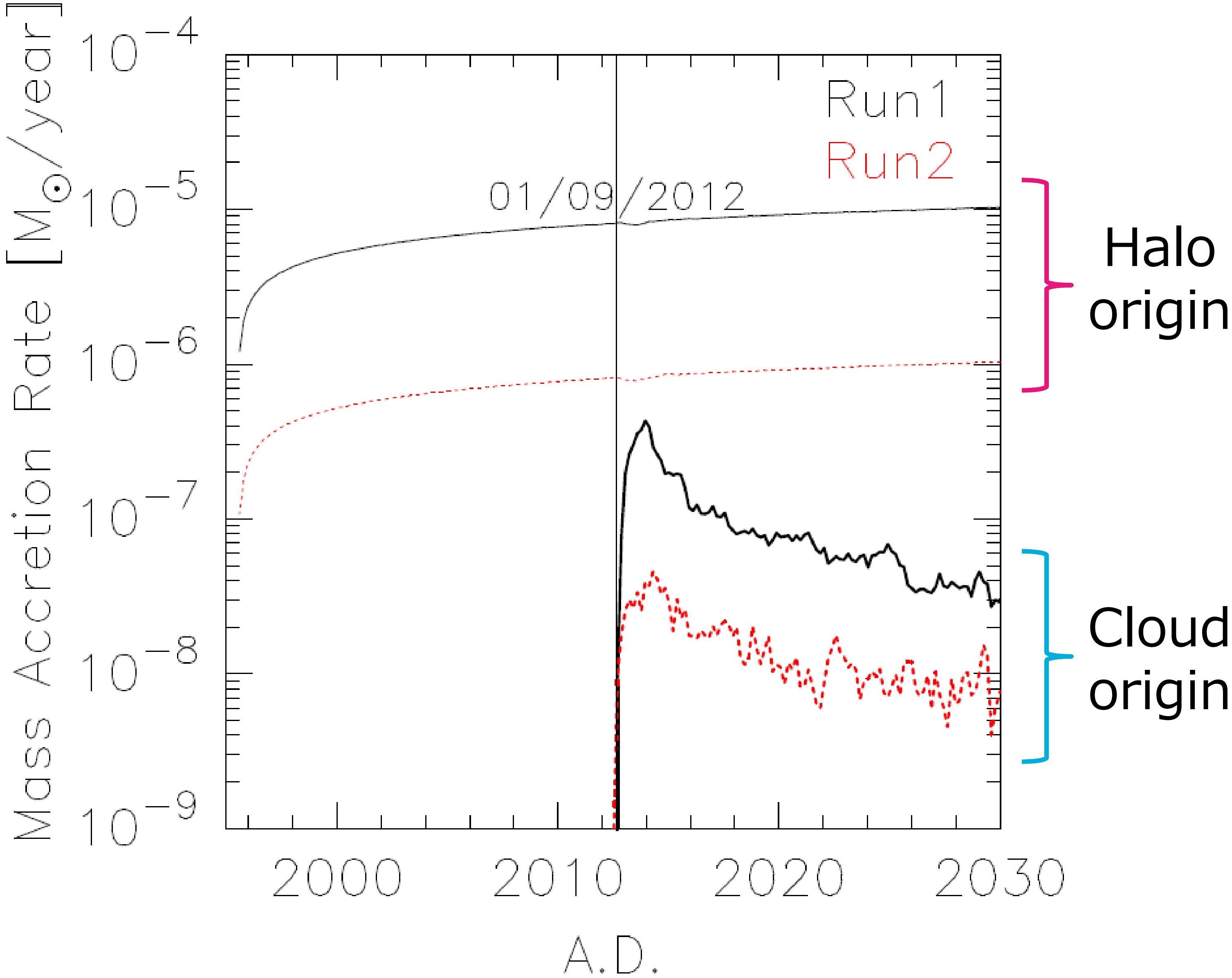


The cross-eyed view method is used.

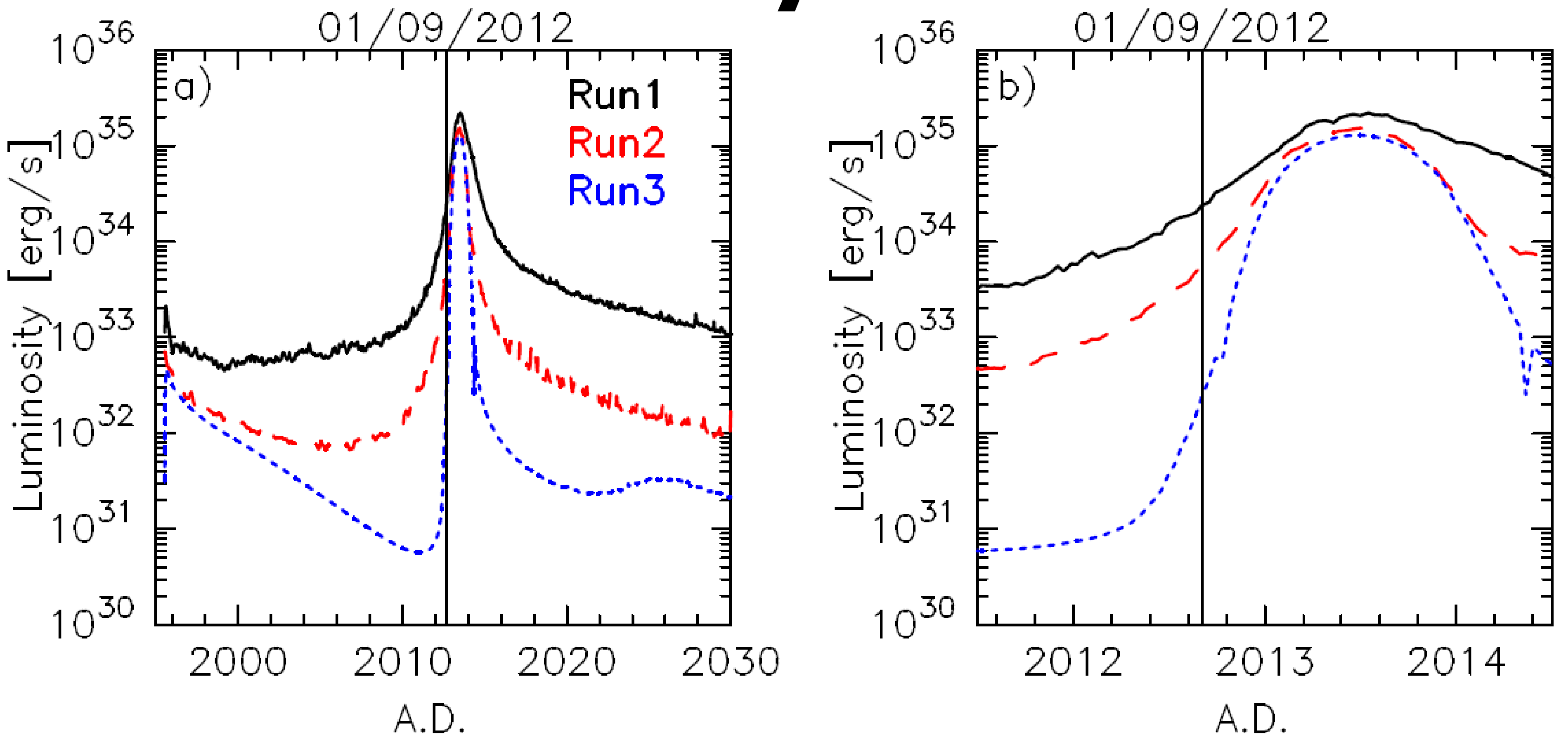
IRCC seminar 2012/12/04

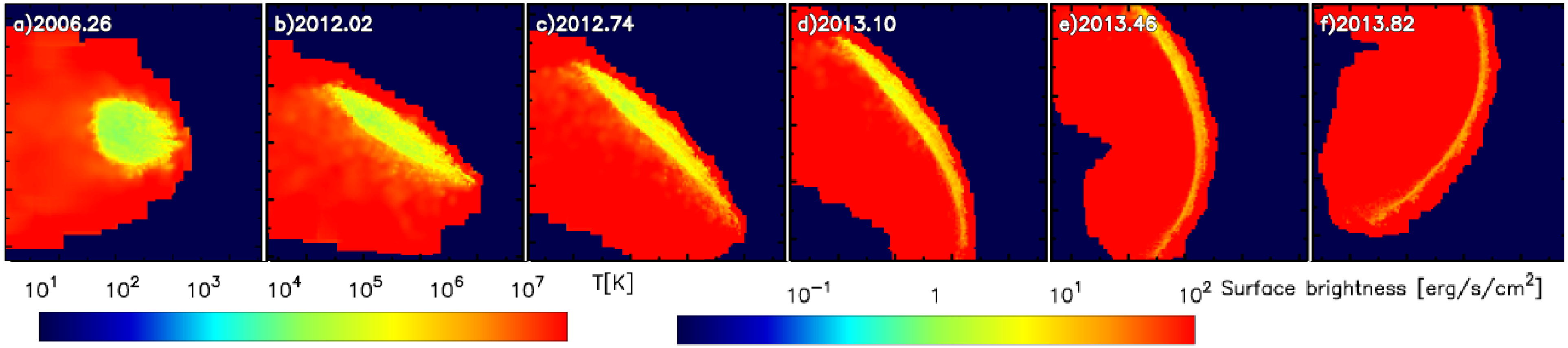


Mass accretion rate



Luminosity Evolution





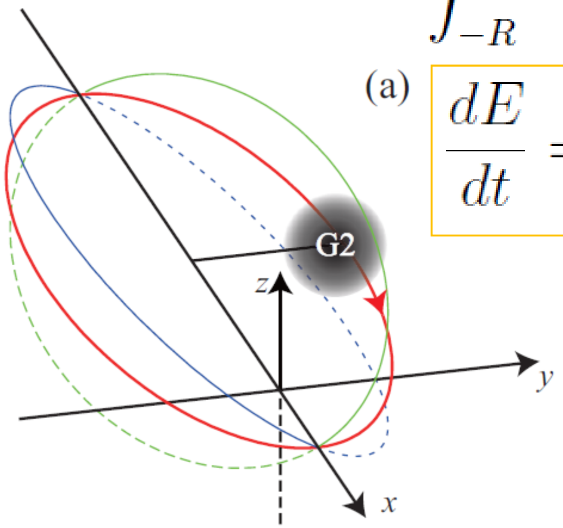
Analytic Evaluation of Luminosity

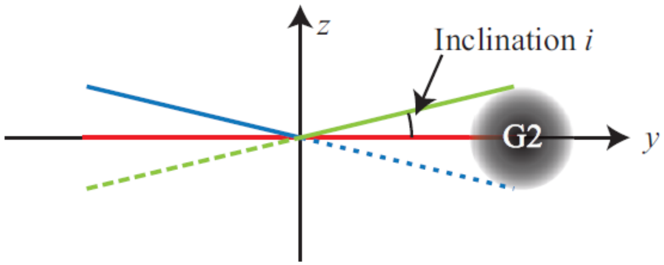
- Assume that···
  1. All elements have elliptical orbits and share the same ascending node.
  2. Cloud's radius is 125 au at the point where the semi-minor axis and orbits intersection.
  3. All energy released at the pericenter.

$$E = \int_{-R}^{R} \pi(R^2 - h^2)\rho V_z^2 dh = 3.5 \times 10^{43} \left(\frac{m}{3M_\oplus}\right)\left(\frac{R}{125\ \mathrm{AU}}\right)^2 \mathrm{erg}.$$

(a)

$$\frac{dE}{dt} = 1.1 \times 10^{36} \left(\frac{m}{3M_\oplus}\right)\left(\frac{R}{125\ \mathrm{AU}}\right)^2 \left(\frac{1\ \mathrm{year}}{\tau}\right) \mathrm{erg/s},$$





The effects of Ram pressure

- Ram pressure : $P(r) = \rho_{\rm hot}(r) v_{\rm c}(r)^2,$
- Energy/sec with a conversion factor C

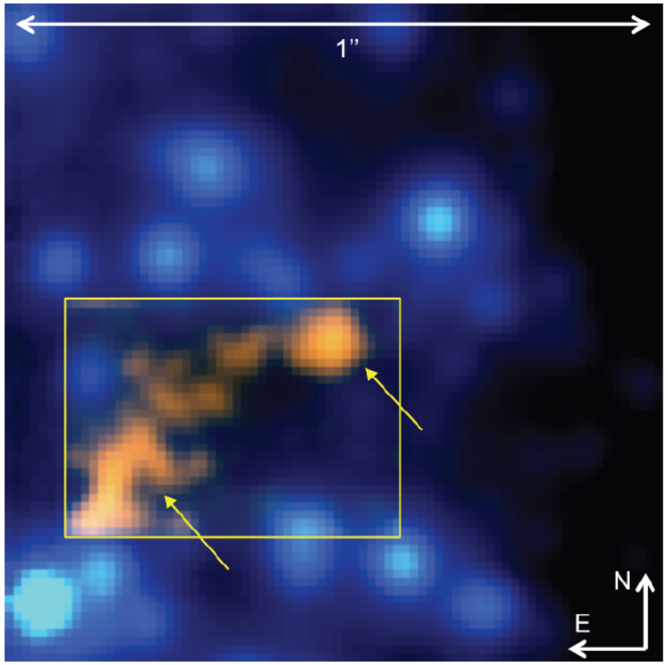
$$\frac{dE_{\rm ram}}{dt} = CP(r)\sigma_{\rm c} v_{\rm c}(r) = C\rho_{\rm hot}(r) v_{\rm c}(r)^3 \sigma_{\rm c}$$

- Substituting the hot ambient profile and orbit info. (r-v_c; Burkert+2012):

$$\frac{dE_{\rm ram}}{dt} = 7.5\times10^{33} C f_{\rm hot}\left(\frac{6\times10^{16}\ {\rm cm}}{r}\right)\left\{\left(\frac{6\times10^{16}\ {\rm cm}}{r}\right) - 0.48\right\}^{3/2}\left(\frac{\sigma_c}{\pi(125\ {\rm AU})^2}\right)\ {\rm erg\ s^{-1}}$$

1. A.D.2000,r_{2000}=6x10^{16}cm、σ=π(125AU)^2、dE/dt $\simeq 7.5\times10^{33} C f_{\rm hot}\ {\rm erg\ s^{-1}}.$
2. A.D.2013.5,$r_{2013.5}$=4x10^{15}cm,σ<1AUx40 AU=40AU^2、dE/dt $\leq 5.1\times10^{33} C f_{\rm hot}\ {\rm erg\ s^{-1}}.$

New observations of the gas cloud G2 in the Galactic Center:Gillessen+2012(arXiv:1209.2272)



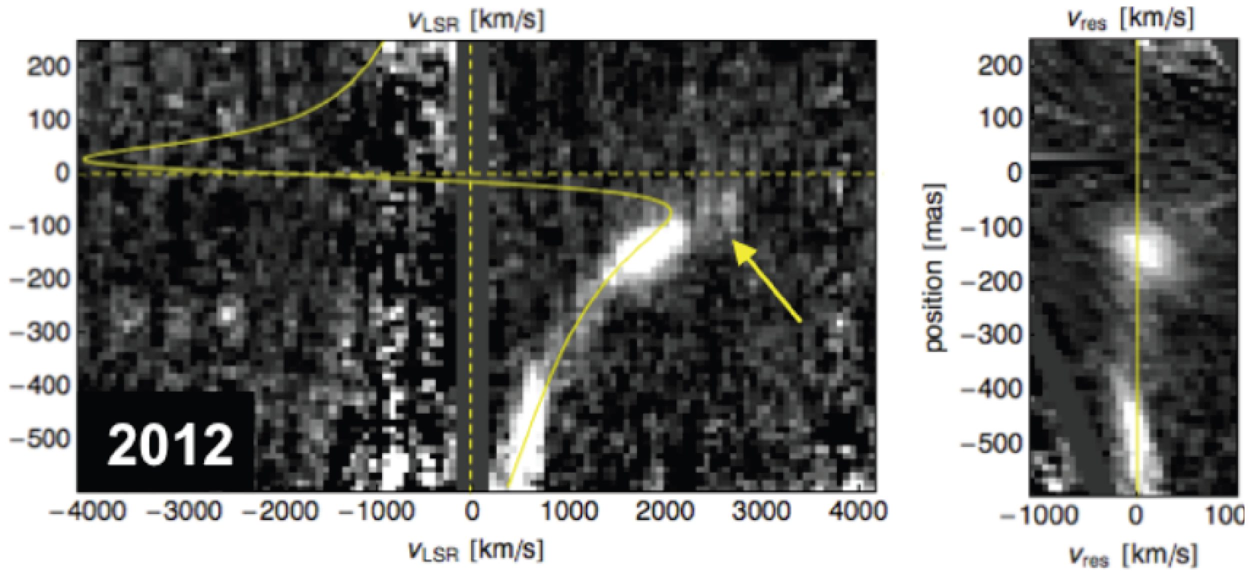


Table 2: Orbital parameters for the orbit of G2.

	Gillessen et al. 2012	Updated 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

Summary

- We performed 3D N-body/SPH simulations of the 3 M_{earth} gas cloud G2 approaching the Sgr A*.
- Due to the strong compression in the vertical direction by the tidal force, the cloud releases ~10^{35} erg/s during 2013.
  - Main source is the recombination line from the hot gas heated to ~10^4K.
  - In particular, Paschen and Brackett series (infrared-bands), which do not suffer from the dust extinction effects significantly, are good to observe.