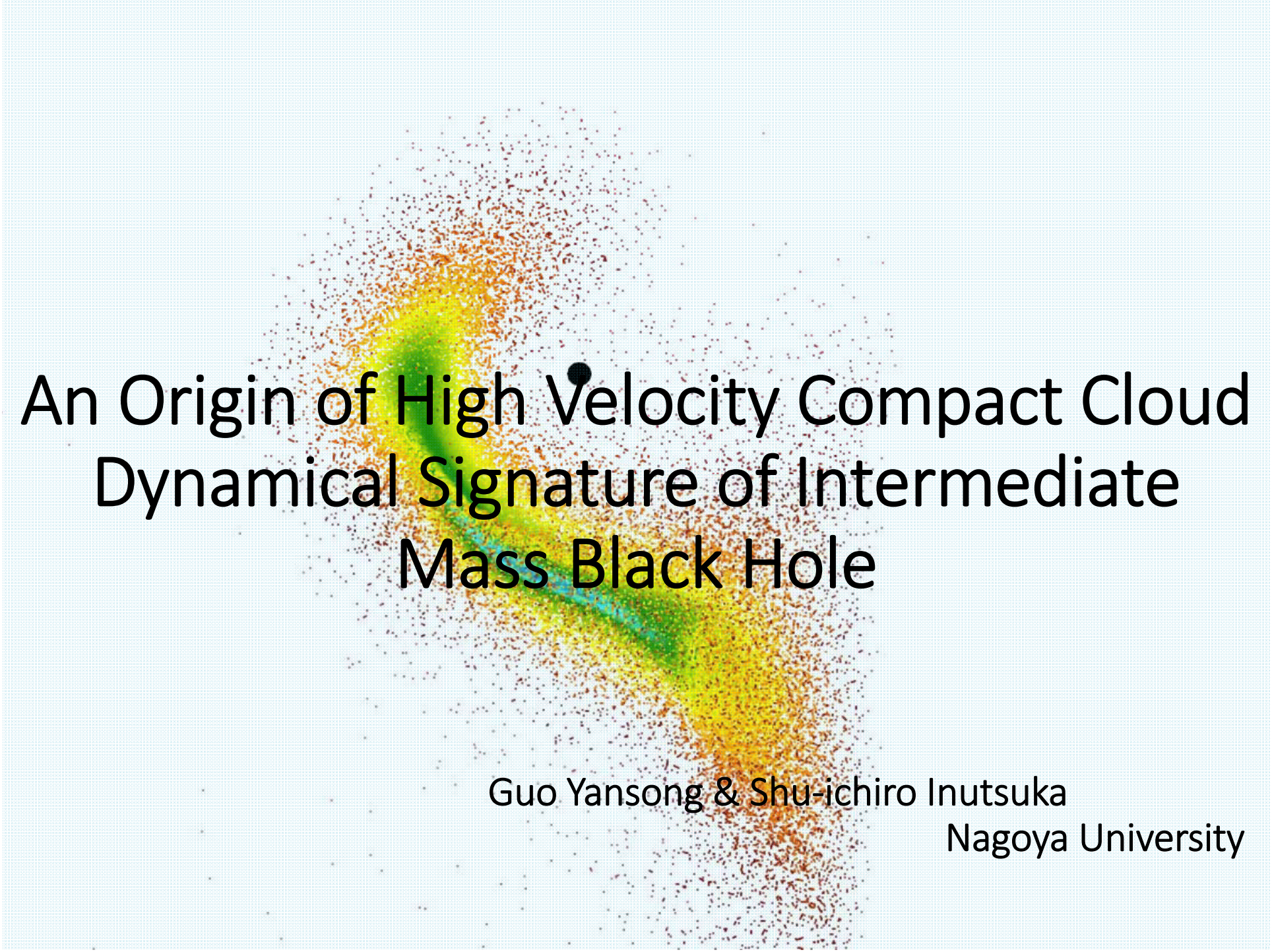


An Origin of High Velocity Compact Cloud Dynamical Signature of Intermediate Mass Black Hole

Guo Yansong & Shu-ichiro Inutsuka
Nagoya University

New Evidence of IMBH(Oka et al. 2016)

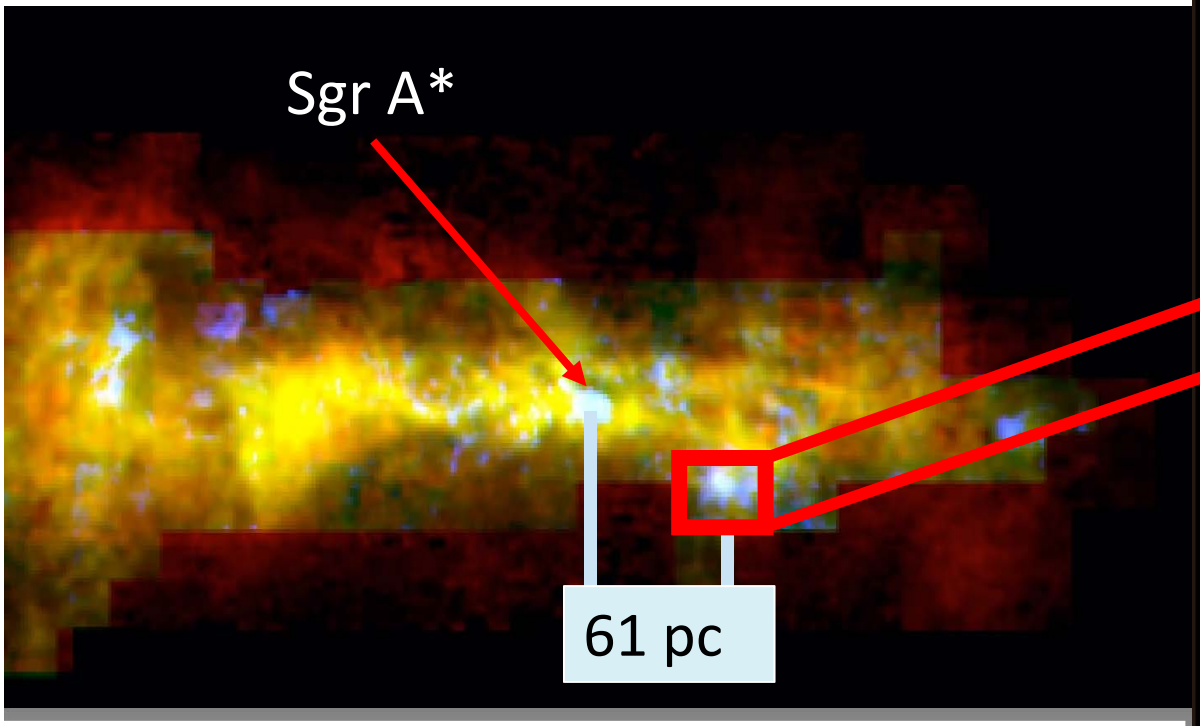
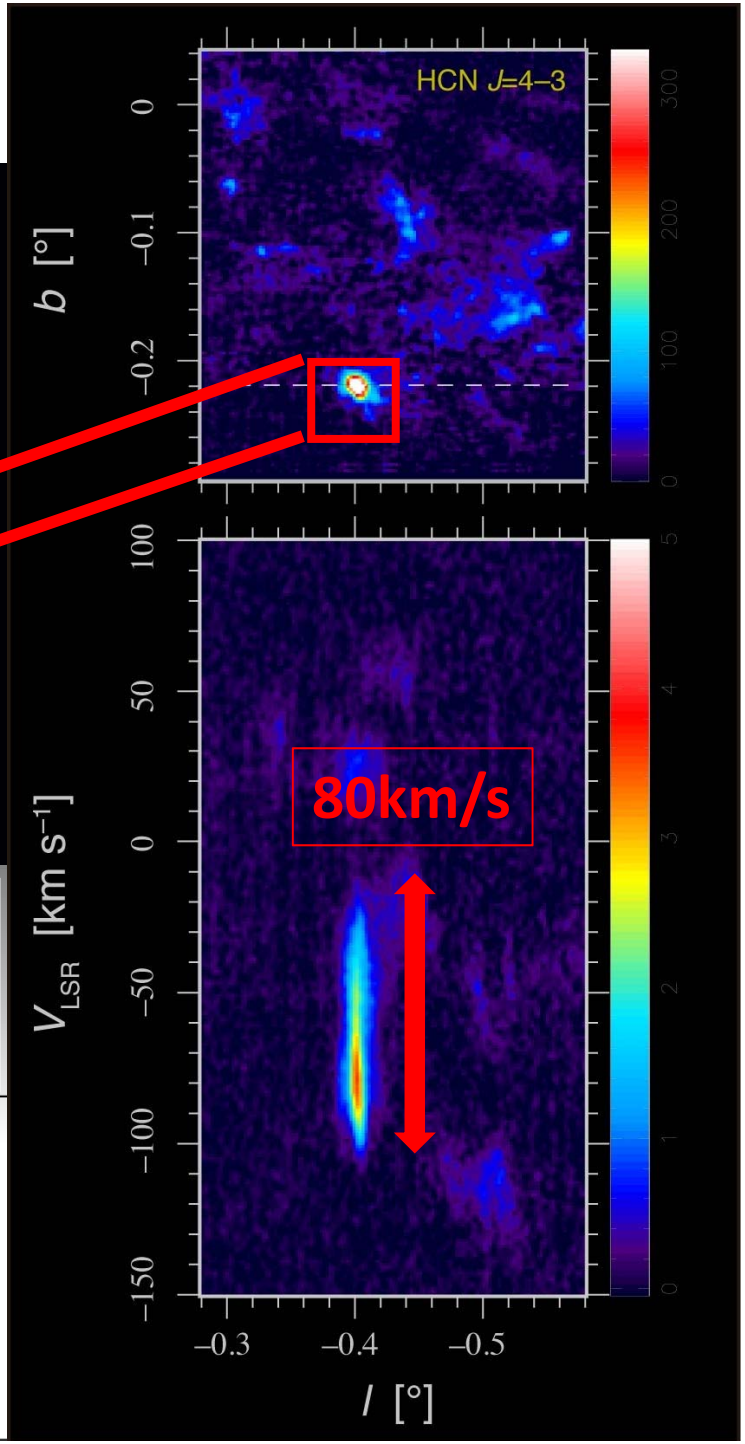


Image taken from Oka et al. 2016



Colors:

Red: Intensity of CO J = 1–0 line

Yellow: Intensity of CO J = 3-2 line

Blue : Intensity ratio of CO J = 3–2/J = 1–0

How to Explain the High Velocity Dispersion?

Typical Molecular sound speed: ~ 0.2 km/s ⟷ 80 km/s

1.Cloud–Cloud Collision : Energy is 10~100 smaller than HVCC

2.Bipolar emission: Energy is 10~100 times smaller than HVCC

3.SNR: No X-ray/non-thermal emission!

All of the above scenarios have **difficulties.**(Tanaka et al. 2014)

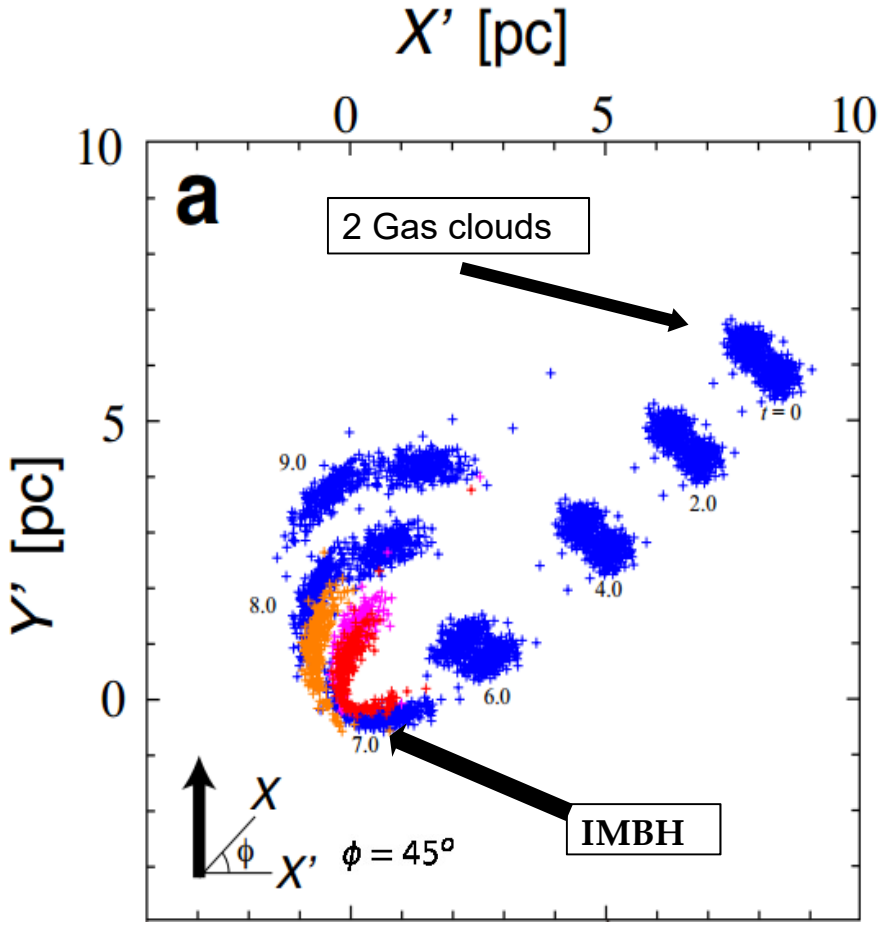
4.**Scattering by Gravitational Source :**

$M_{BH} = \frac{r v_{rot}^{2}}{G}$ gives "Gravity Source" $\sim 10^{5} M_{sun} @ 0.1\mathrm{pc}$

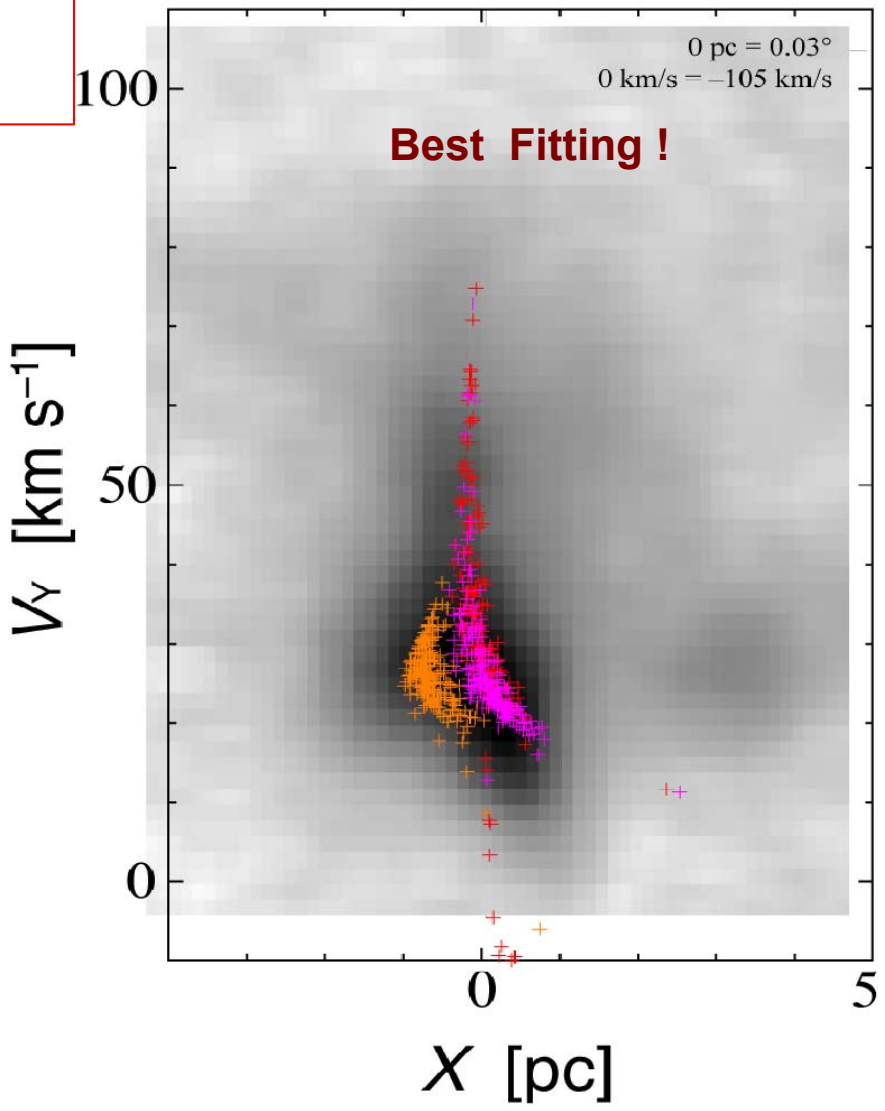
IMBH!

(Oka et al.2016) Simple Test Particle Simulation

- Only considering gravity from IMBH
- No self-gravity
- No hydrodynamic effects



(Image taken from Oka et al. 2016)



Possible Diagnostics

However , tidal force creates a strong shock wave!
If tidal heating dissociates all the molecules,
this scenario would not work!
Remember we are observing molecular lines!

I. Tidal Compression — 5000 yrs

↓

II. Gas Heating/Shock wave — Estimated Mach number ~10

↓

III. Molecular dissociation/recombination: — 2000 yrs

Therefore, we need

- **full hydrodynamic treatment with self-gravity**
- **radiative heating/cooling and chemistry**

Governing Equations

$$\rho = \mu m_H n$$

Density and Number density

$$\frac{d\rho}{dt} = -\rho \nabla \cdot \vec{v}$$

Continuity Equation

$$\frac{d\vec{v}}{dt} = -\frac{1}{\rho}\nabla P + \nabla \int dx'^3 \frac{G\rho(x')}{|\vec{x} - \vec{x}'|} + \frac{GM_{BH}\vec{r}}{r^3}$$

EOM

$$\frac{d\epsilon}{dt} = -\frac{P}{\rho}\nabla \cdot \vec{v} + \Gamma - \Lambda$$

Equation of energy

$$P = (\gamma - 1)\rho\epsilon$$

Equation of state

$$\frac{dn_i}{dt} = C_i - Dn_i$$

Chemistry network

$$where \;\; i \; represents \, [H^+, H, H_2, C^+, CO, e^-]$$

Radiative Cooling, Heating, & Chemistry Network

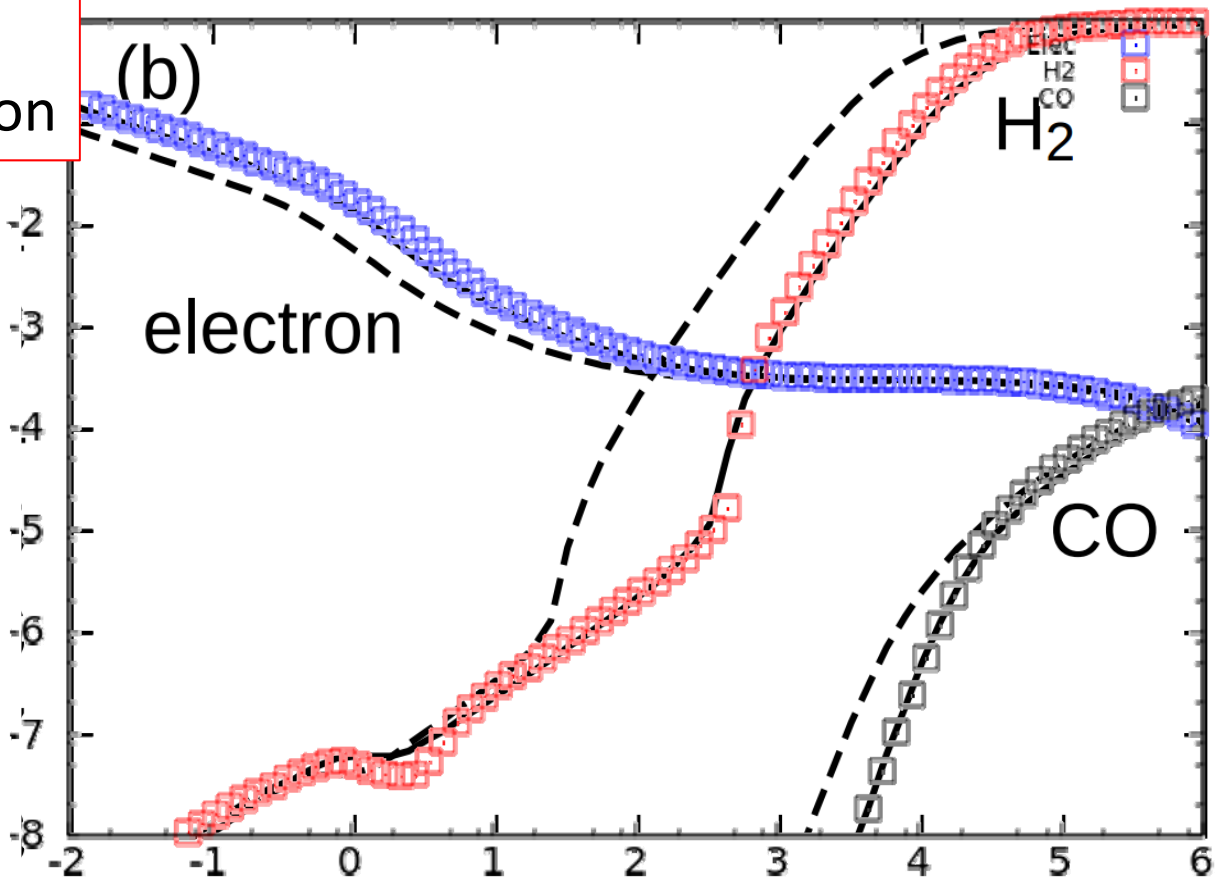
Heating effects:

1. Photoelectric heating
2. Cosmic rays/X-rays
3. H2 formation/destruction

Cooling effects:

1. Line emission: H, CII, O,H2,CO
2. Atomic and molecular collisions with dust grains

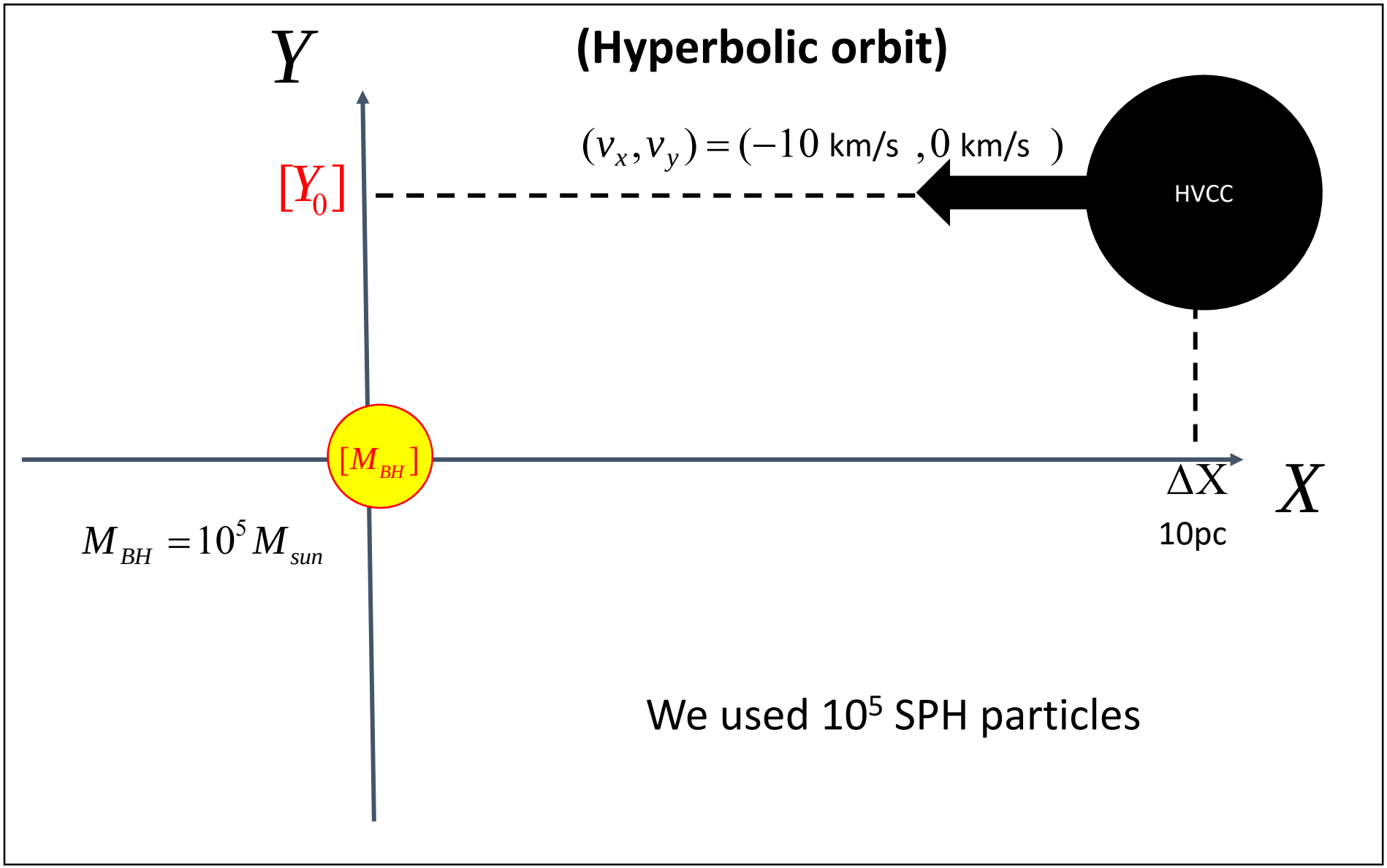
Relative Abundances

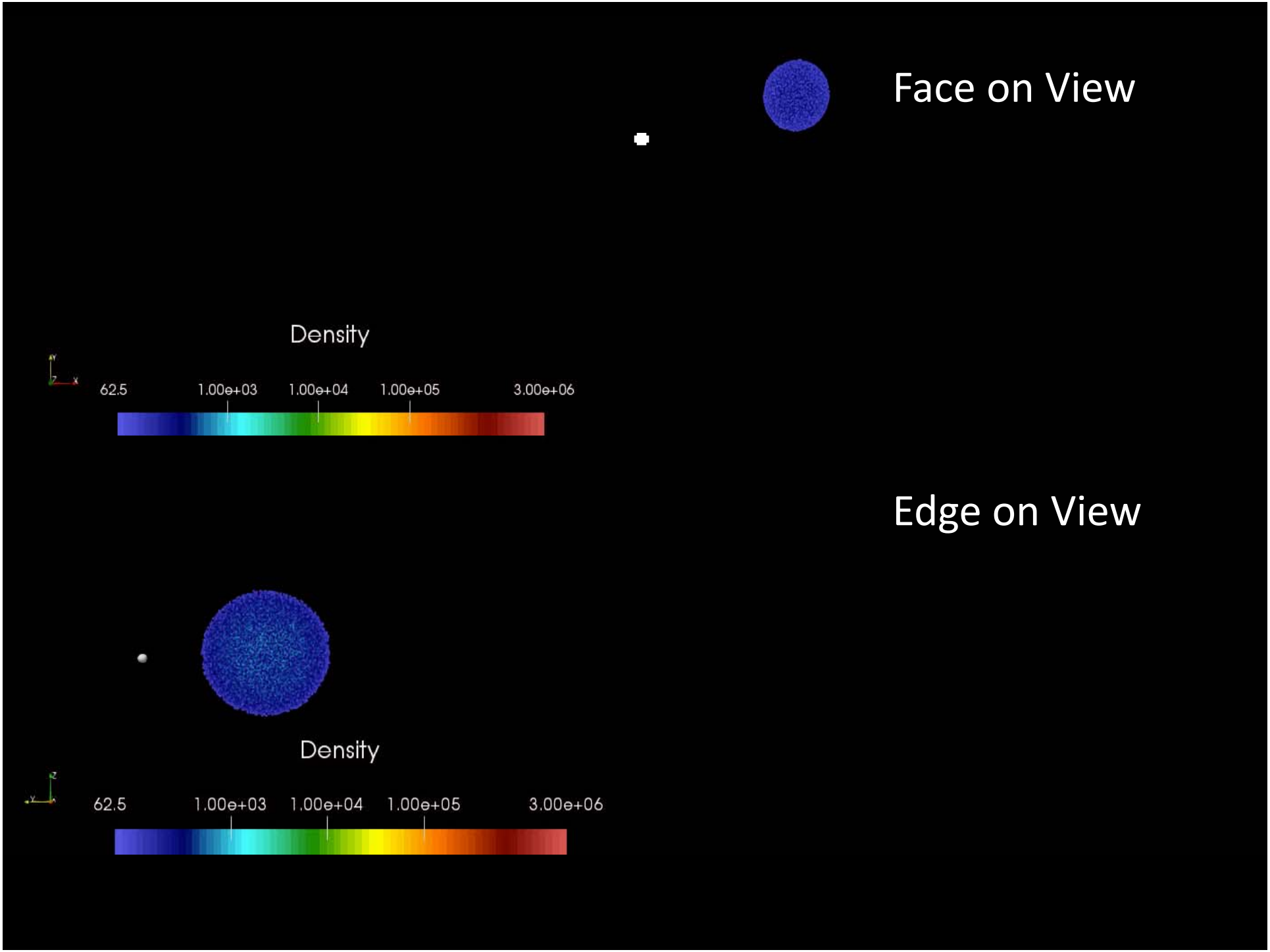


Result of our numerical code

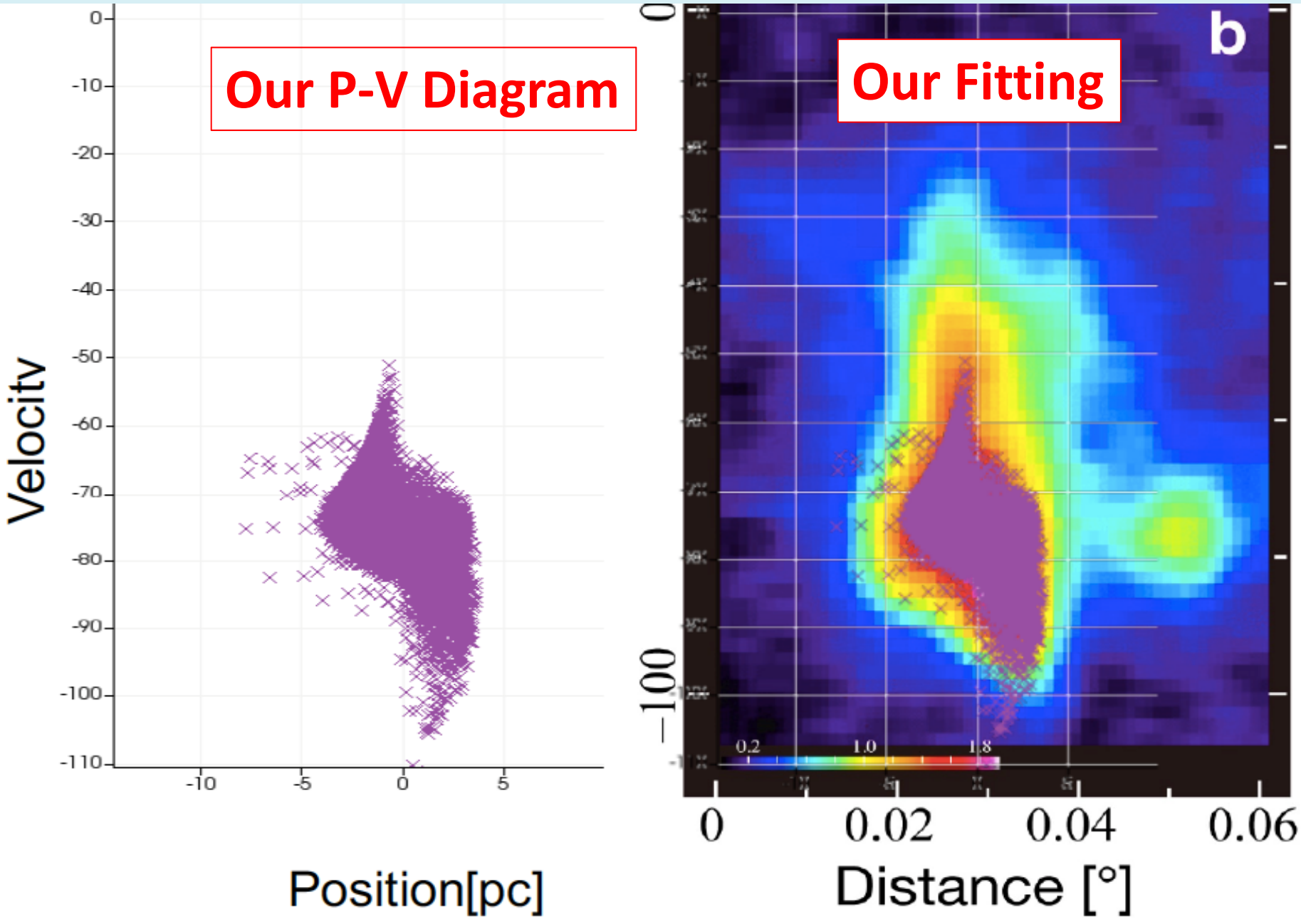
(Koyama & Inutsuka 2000)

Simulation setup

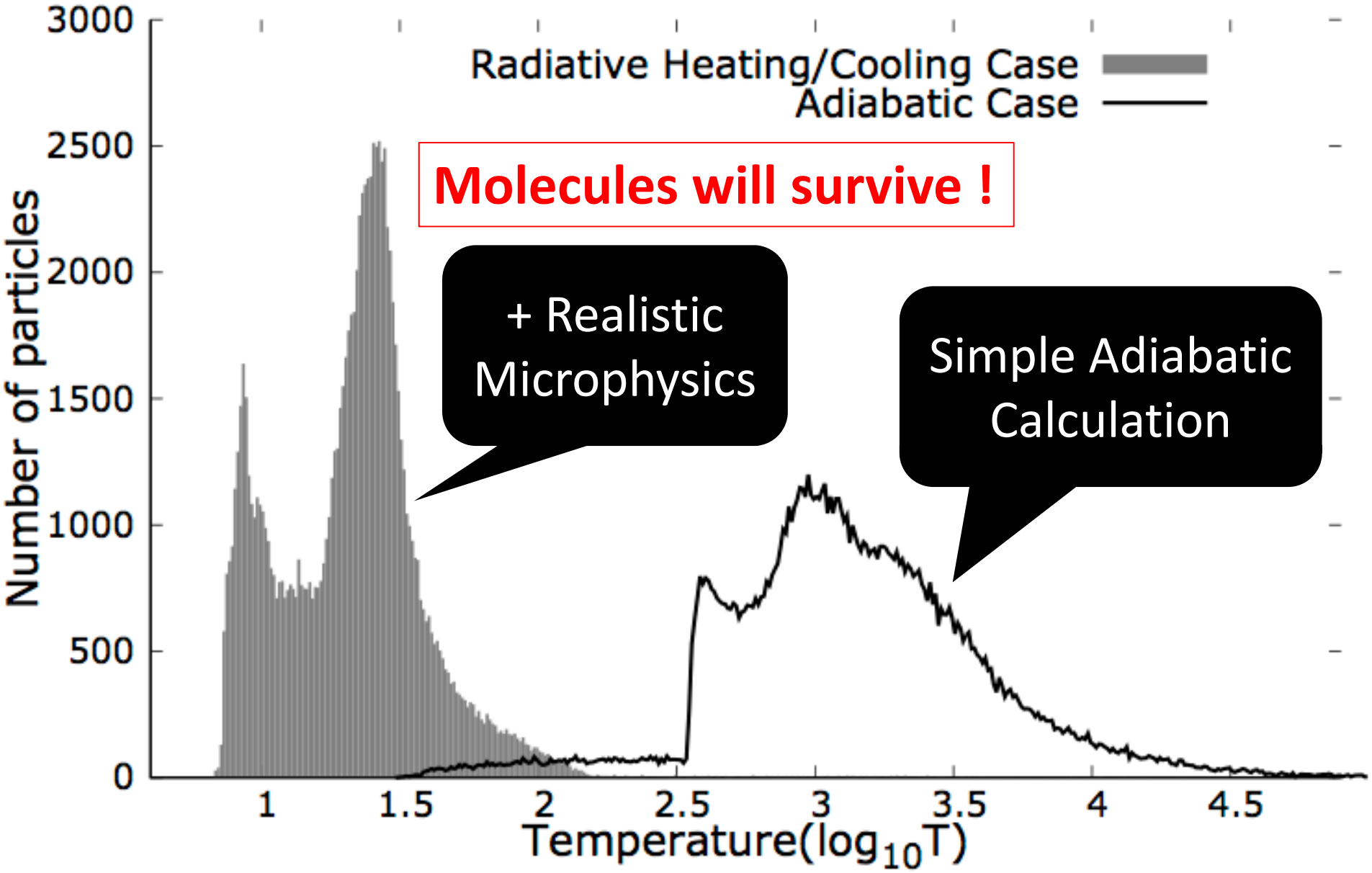



Face on View
Density
62.5
1.00e+03
1.00e+04
1.00e+05
3.00e+06
Edge on View
Density
62.5
1.00e+03
1.00e+04
1.00e+05
3.00e+06

P-V(Position-Velocity) Diagram Fitting

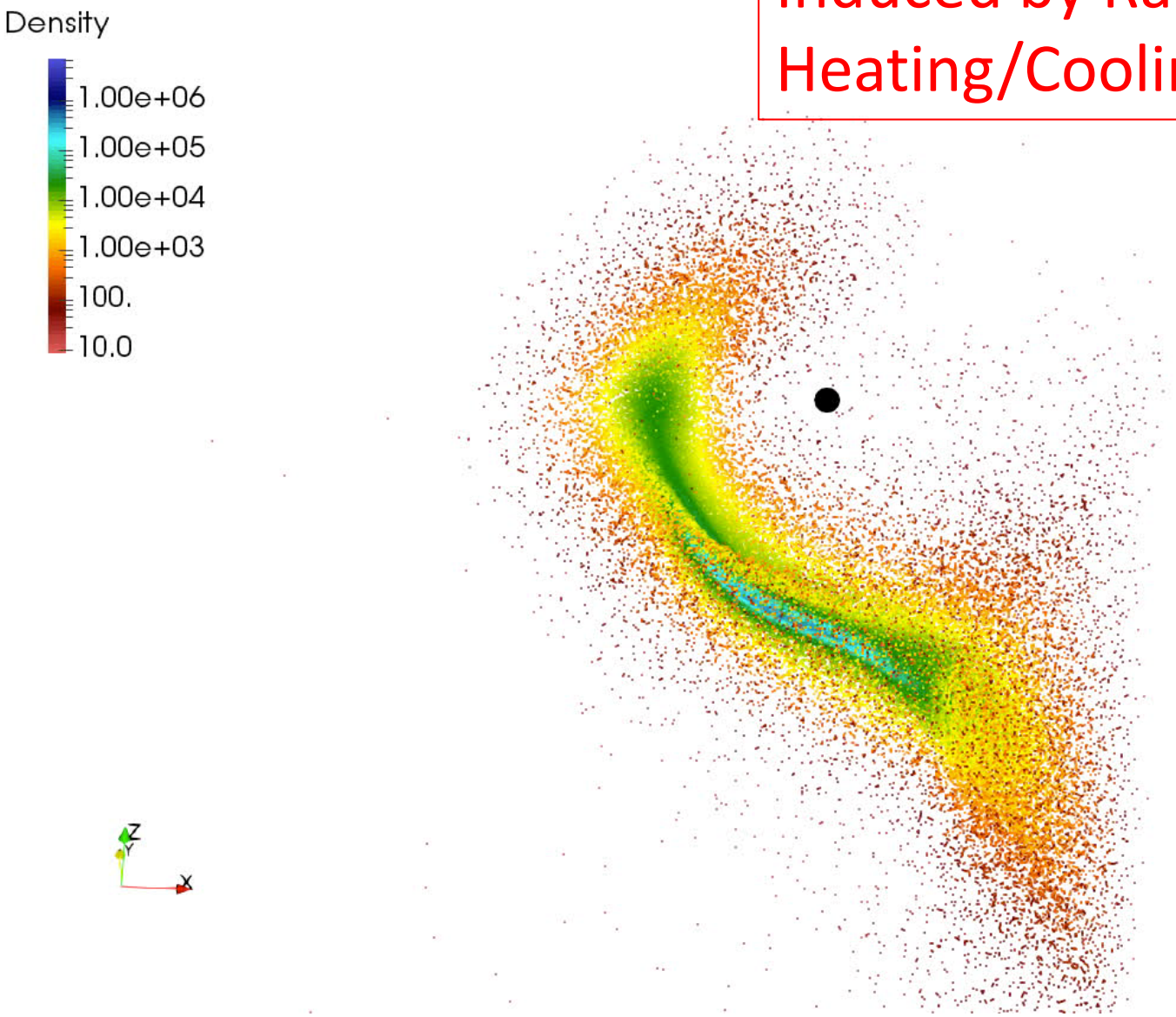


Will Molecules Survive?



“Horn Structure”

Induced by Radiative Heating/Cooling Effect



How many IMBHs in our Galaxy?

$$\sigma = \pi b^2$$

Cross section for Gravitational scattering(>100km/s)

$$f = N_{BH} n_{MC} \sigma v_{BH}$$

Frequency of HVCC events in our Galaxy

$$= 4.2 \times 10^{-16} N_{BH} \left[\frac{n_{MC}}{10^5}\right]\left[\frac{\sigma}{(\pi 2\mathrm{pc})^2}\right]\left[\frac{v_{BH}}{100\mathrm{km/s}}\right][\mathrm{s}^{-1}]$$

$$N_{obs} = t_{duration} f$$

True observed numbers of HVCC event

$$= 1.3\left[\frac{N_{BH}}{100}\right]\left[\frac{n_{MC}}{10^5}\right]\left[\frac{\sigma}{(\pi 2\mathrm{pc})^2}\right]\left[\frac{v_{BH}}{100\mathrm{km/s}}\right]\left[\frac{t_{duration}}{1\mathrm{Myr}}\right]$$

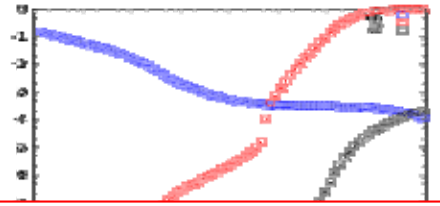
Predicted Number of IMBH in our Galaxy

$$N_{BH} = 100\left[\frac{N_{obs}}{1.3}\right]\left[\frac{n_{MC}}{10^5}\right]^{-1}\left[\frac{\sigma}{(\pi 2\mathrm{pc})^2}\right]^{-1}\left[\frac{v_{BH}}{100\mathrm{km/s}}\right]^{-1}\left[\frac{t_{duration}}{1\mathrm{Myr}}\right]^{-1}$$

Summary

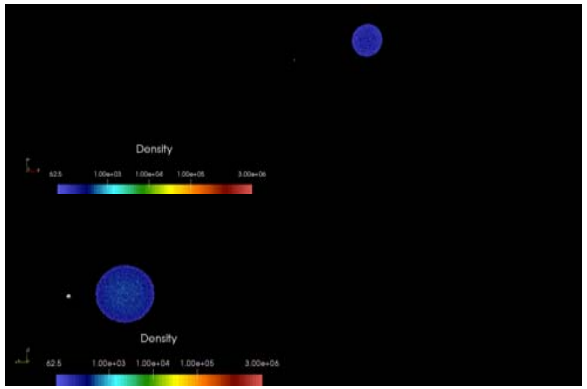
1. We developed a 3D high-resolution shock-capturing numerical code based on **Godunov SPH**. In the code We implemented realistic **radiative heating/cooling and chemical reactions**.

$$We\ considered\ 6\ spieces\ [H^+, H, H_2, C^+, CO, e^-]$$

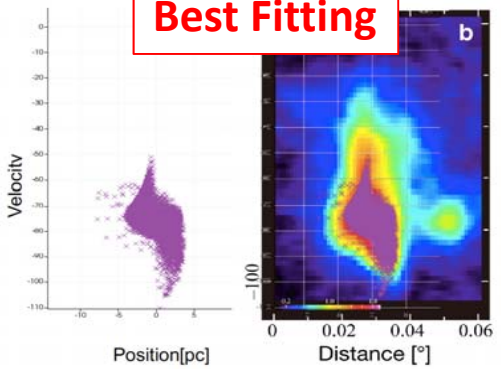


Fast O(n) Chemical Network

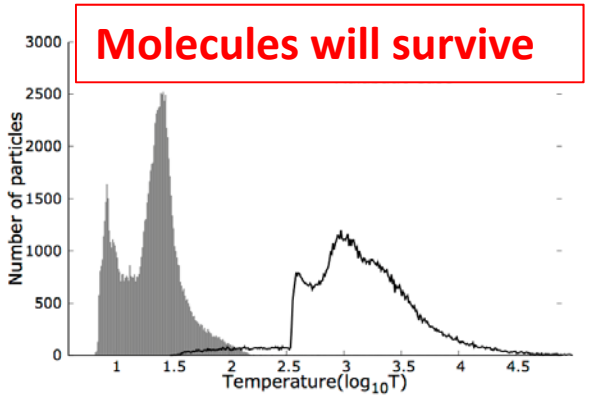
2. We performed **hydrodynamical simulations** of a molecular cloud being scattered by an intermediate mass black hole and found the case that **molecules survived**



Best Fitting

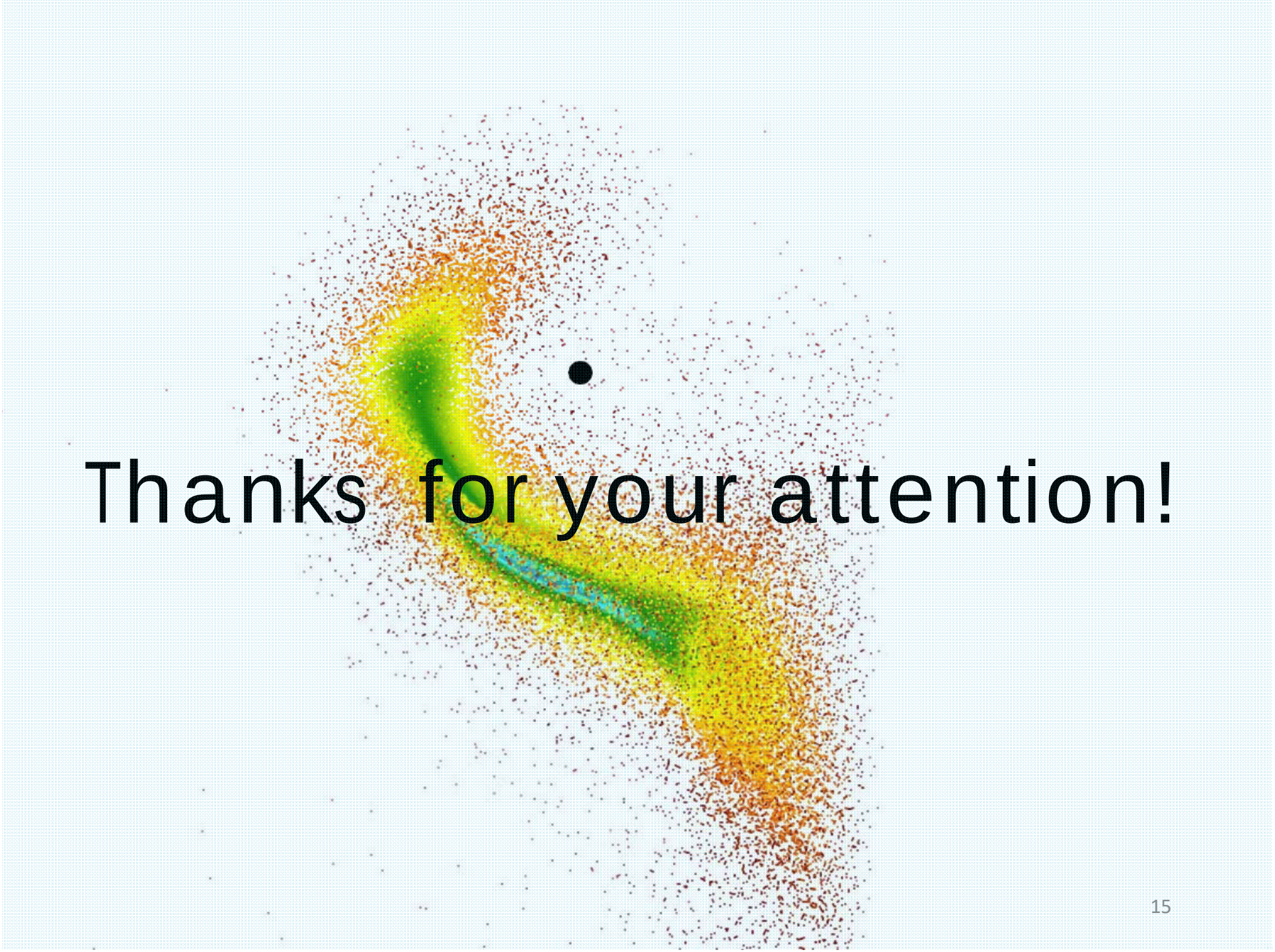


Molecules will survive



3. We formulated a method to estimate the **total number of intermediate mass black holes in our Galaxy** by the observation.

$$N_{BH} = 100\left[\frac{N_{obs}}{1.3}\right]\left[\frac{n_{MC}}{10^5}\right]^{-1}\left[\frac{\sigma}{(\pi 2\mathrm{pc})^2}\right]^{-1}\left[\frac{v_{BH}}{100\mathrm{km/s}}\right]^{-1}\left[\frac{t_{duration}}{1\mathrm{Myr}}\right]^{-1}$$



Thanks for your attention!