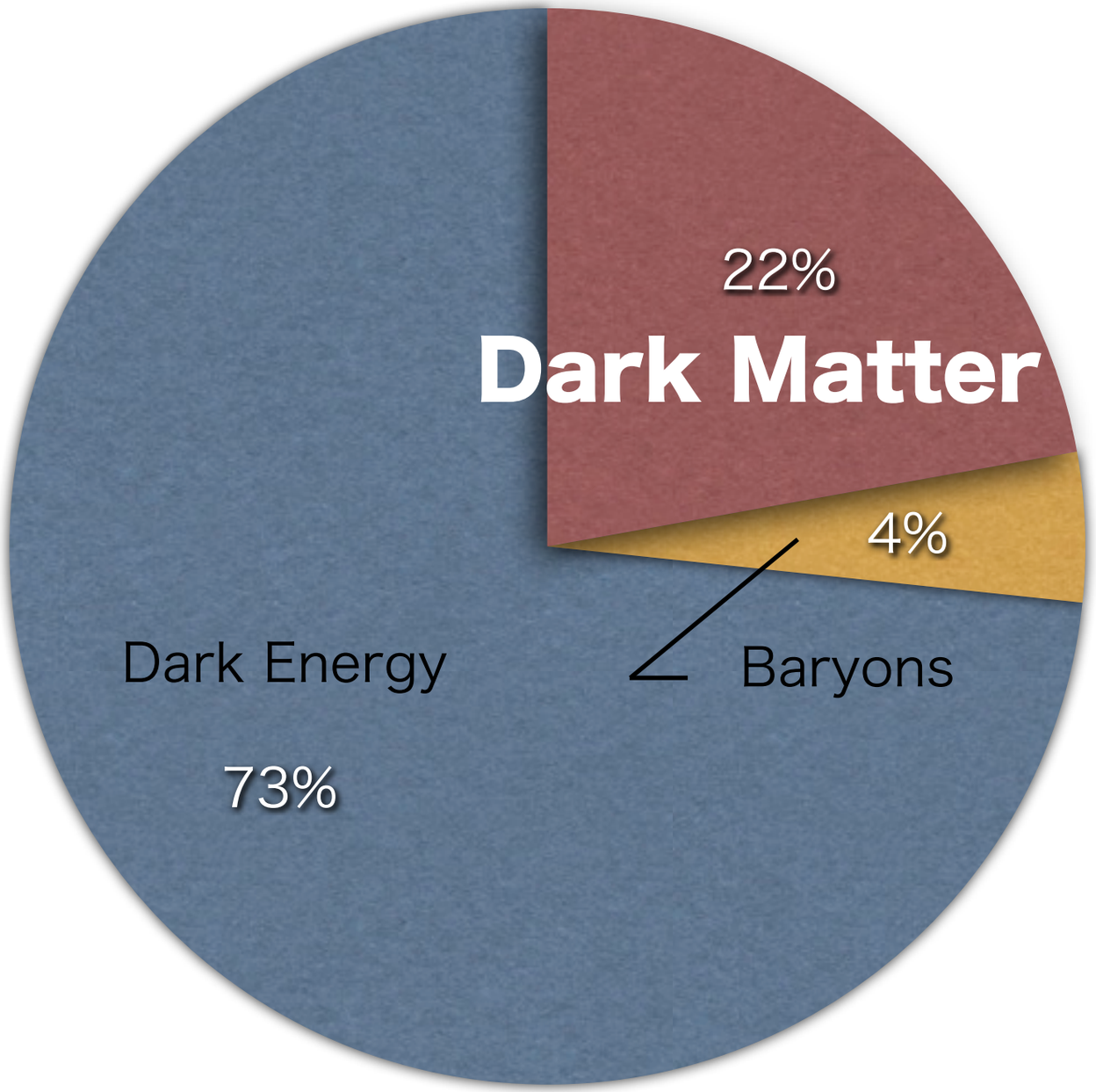
2011/9/27　JGRG21

Constraints on Particle Dark Matter Models by the Presence of Primordial Black Holes

Ryo Saito (YITP)
with S. Matsumoto, S. Shirai, T. Yanagida

Dark Matter

Non-relativistic matter in the Universe is almost non-baryonic, and dark (non-luminous).



What is dark matter?

WIMPs (as thermal relics)

- **WIMPs (Weakly Interacting Massive Particles)**

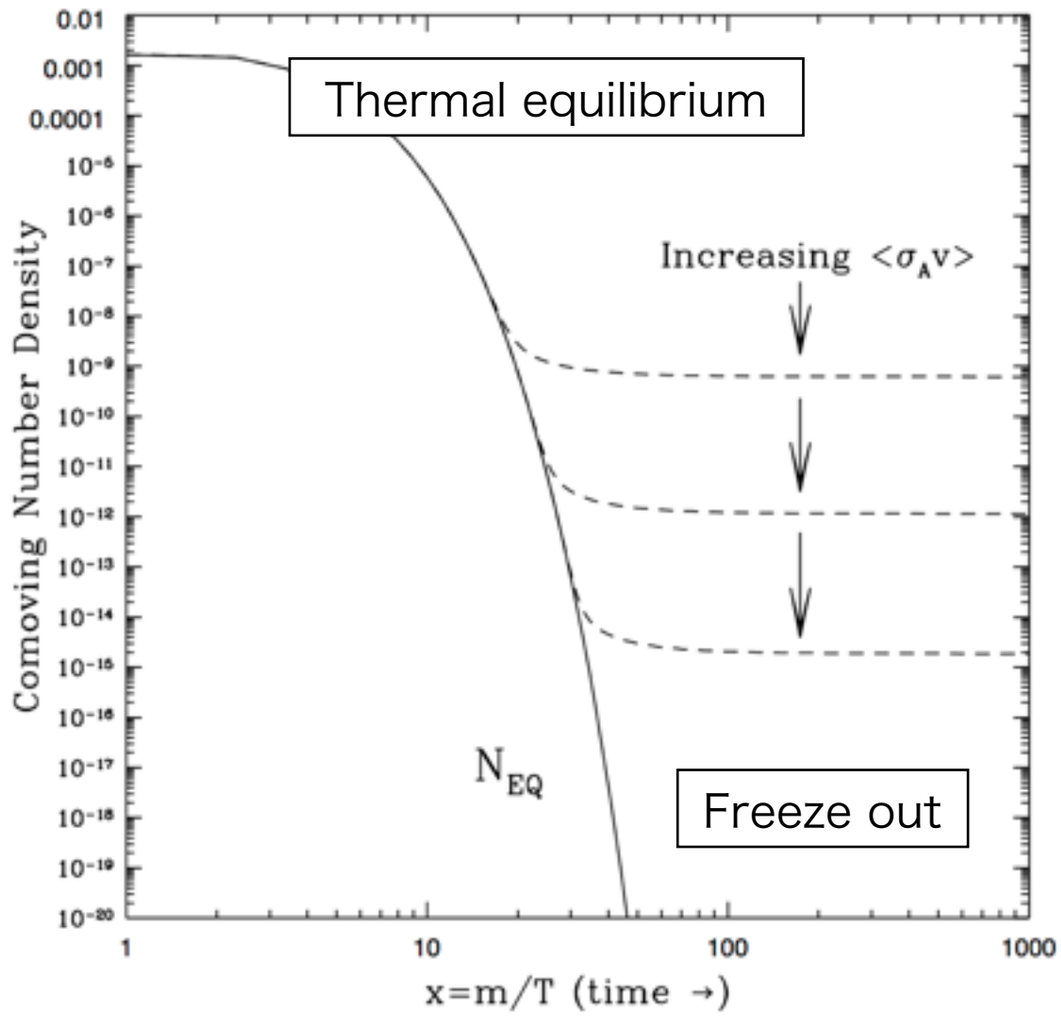
  Particles with weak-scale mass (10GeV-TeV) and cross sections.

e.g. Neutralino = neutral gaugino (wino + bino) + higgsino (in supersymmetric SM)

WIMP abundance in the thermal relic scenario

$$\Omega_{\rm WIMP} = \Omega_{\rm CDM} \left(\frac{\langle \sigma_{\rm A} v \rangle}{3 \times 10^{-26} {\rm cm}^3/{\rm s}} \right)^{-1}$$

The abundance is determined by annihilation cross sections.



WIMPs (as thermal relics)

But some models predict smaller abundance of DM-candidate particles.

(e.g. wino-like, higgsino-like neutralino)

$$\Omega_{\mathrm{CDM}} > \Omega_{\mathrm{WIMP}}$$

another scenario? or component?

WIMPs (as thermal relics) + PBHs

But some models predict smaller abundance of DM-candidate particles.

(e.g. wino-like, higgsino-like neutralino)

$$\Omega_{\mathrm{CDM}} \overset{?}{=} \Omega_{\mathrm{WIMP}} + \Omega_{\mathrm{PBH}}$$

another scenario? or component?

+ Black Holes (Primordial black holes) ?

Primordial Black Holes

- **PBHs (Primordial Black Holes)**

  Black holes produced in the early Universe (radiation-dominated era)
  by phase transitions or gravitational collapse of primordial density fluctuations.

Wide range of mass

from the Planck mass to masses much larger than the solar mass.

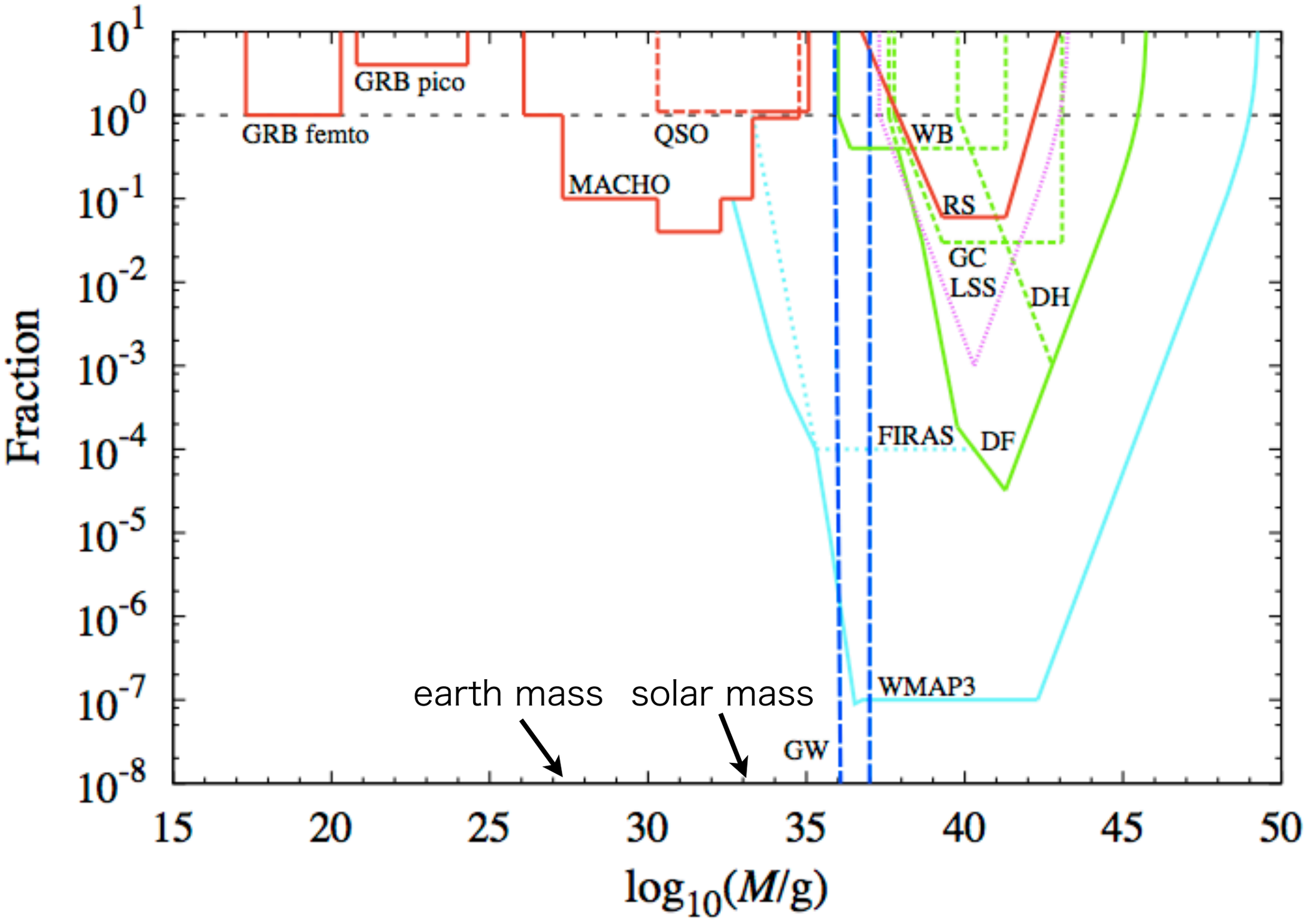
But: Hawking radiation → PBH dark matter cannot be too light.

$$M_{\rm PBH} > 10^{15}\ {\rm g}$$

Constraints on the PBH abundance

PBH fraction to CDM

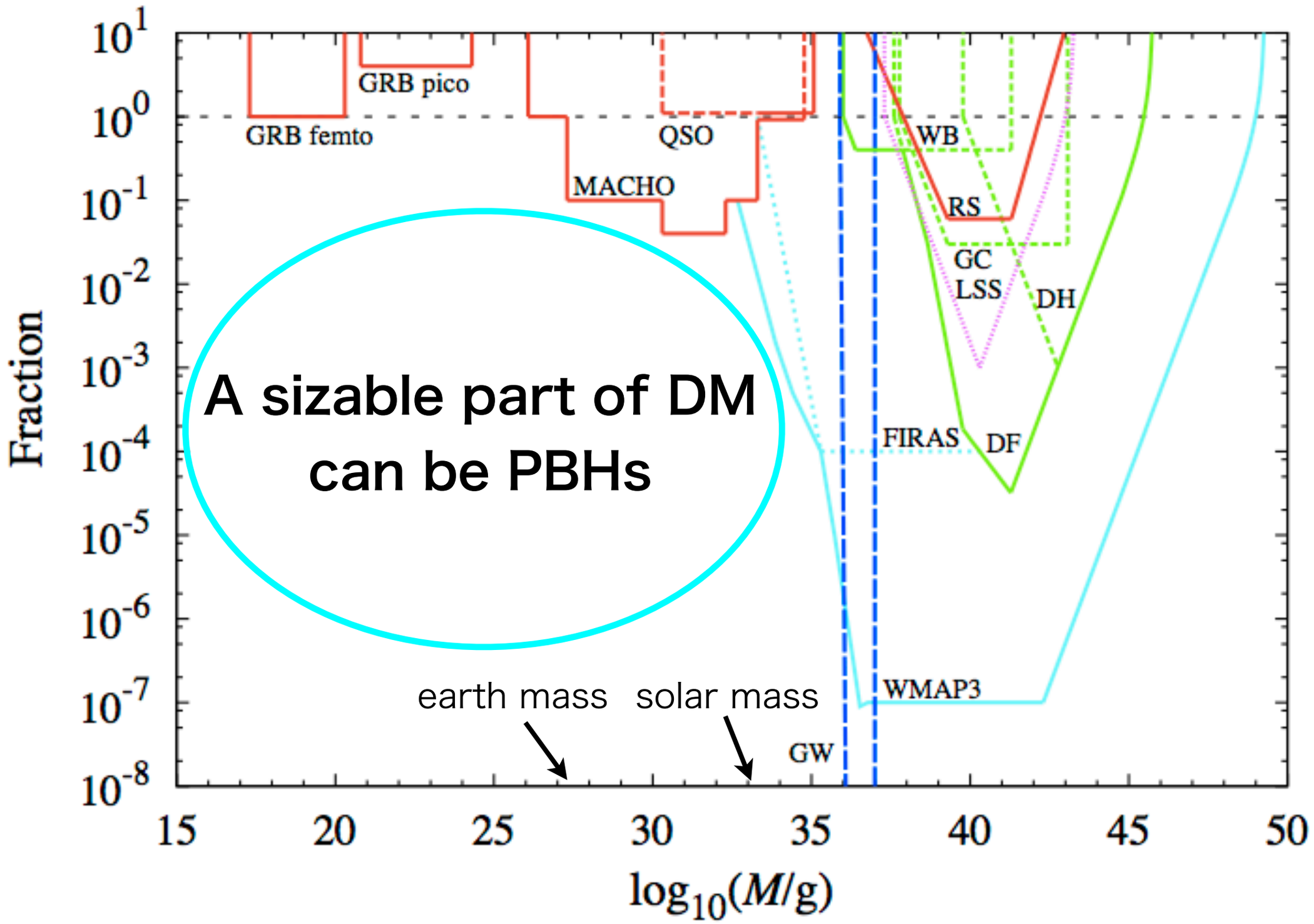
Carr, Kohri, Sendouda, & Yokoyama 09



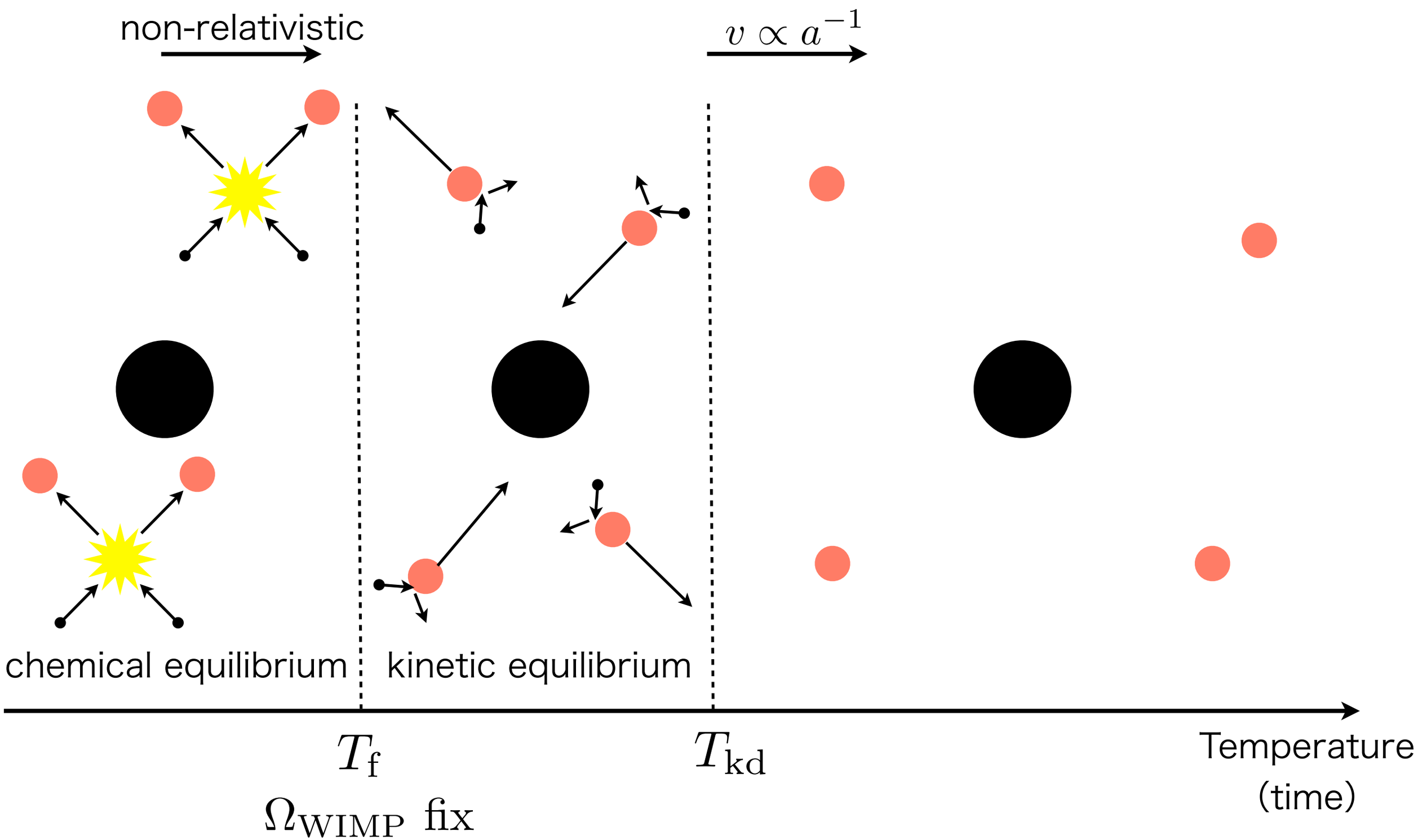
Constraints on the PBH abundance

PBH fraction to CDM

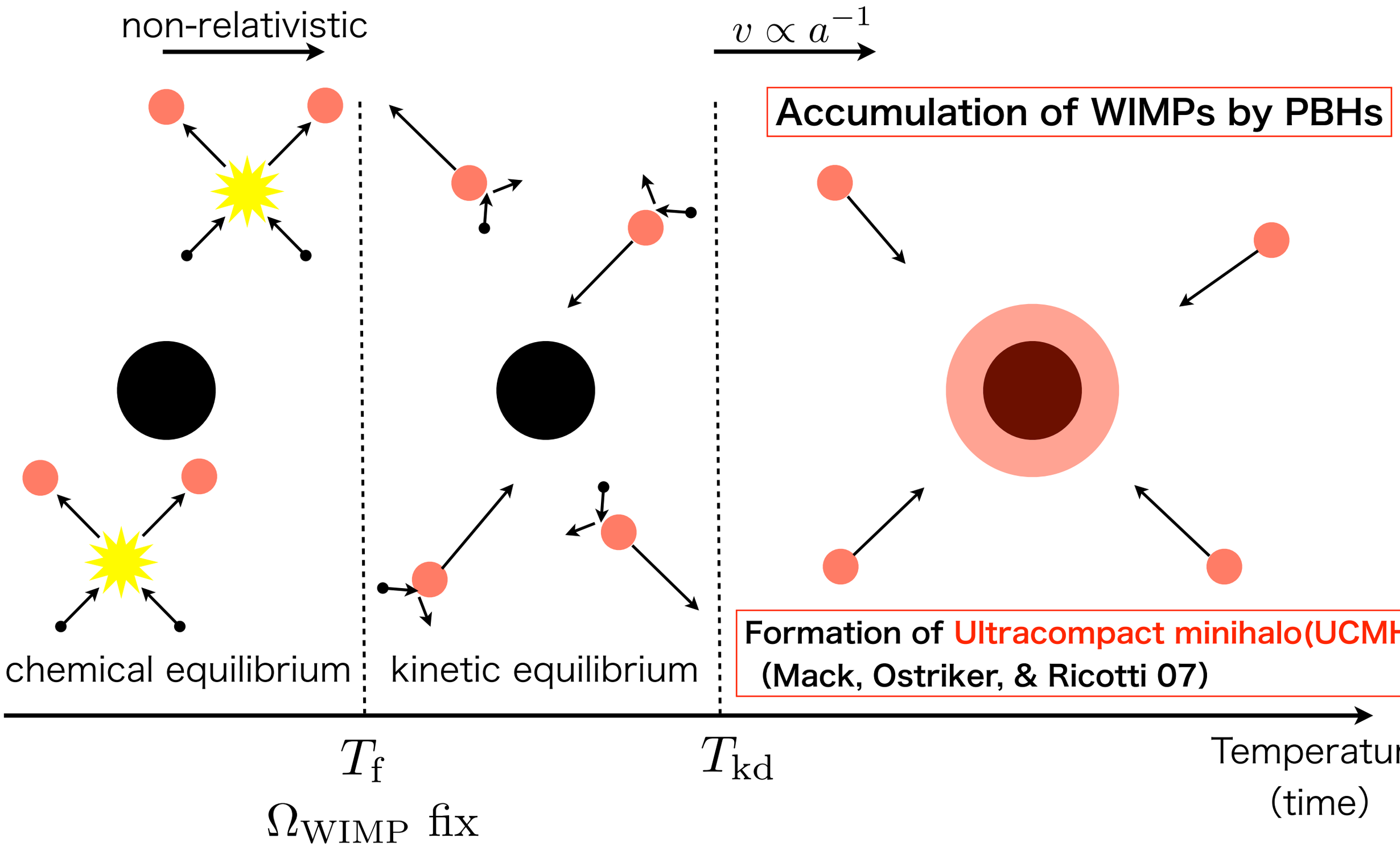
Carr, Kohri, Sendouda, & Yokoyama 09



History of WIMPs+PBHs



History of WIMPs+PBHs



History of WIMPs+PBHs

non-relativistic

$v \propto a^{-1}$

Accumulation of WIMPs by PBHs

m_{WIMP}

M_{PBH}

chemical equilibrium

kinetic equilibr

Formation of Ultracompact minihalo(UCMH)

Scattering cross sections (with ν, e)

Annihilation cross sections

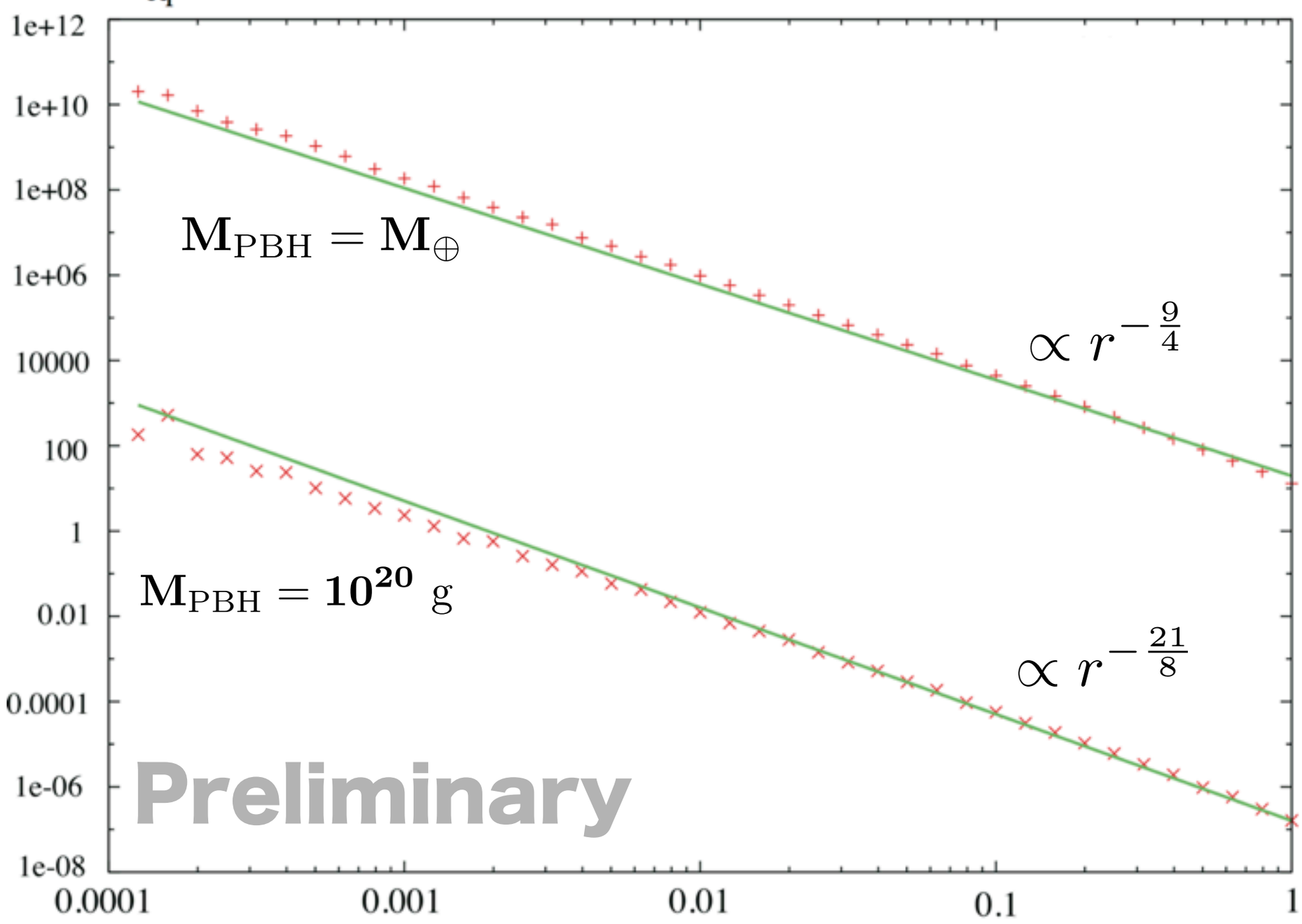
T_{kd}

Temperature
(time)

Ω_{WIMP} fix

Density Profiles of WIMPs

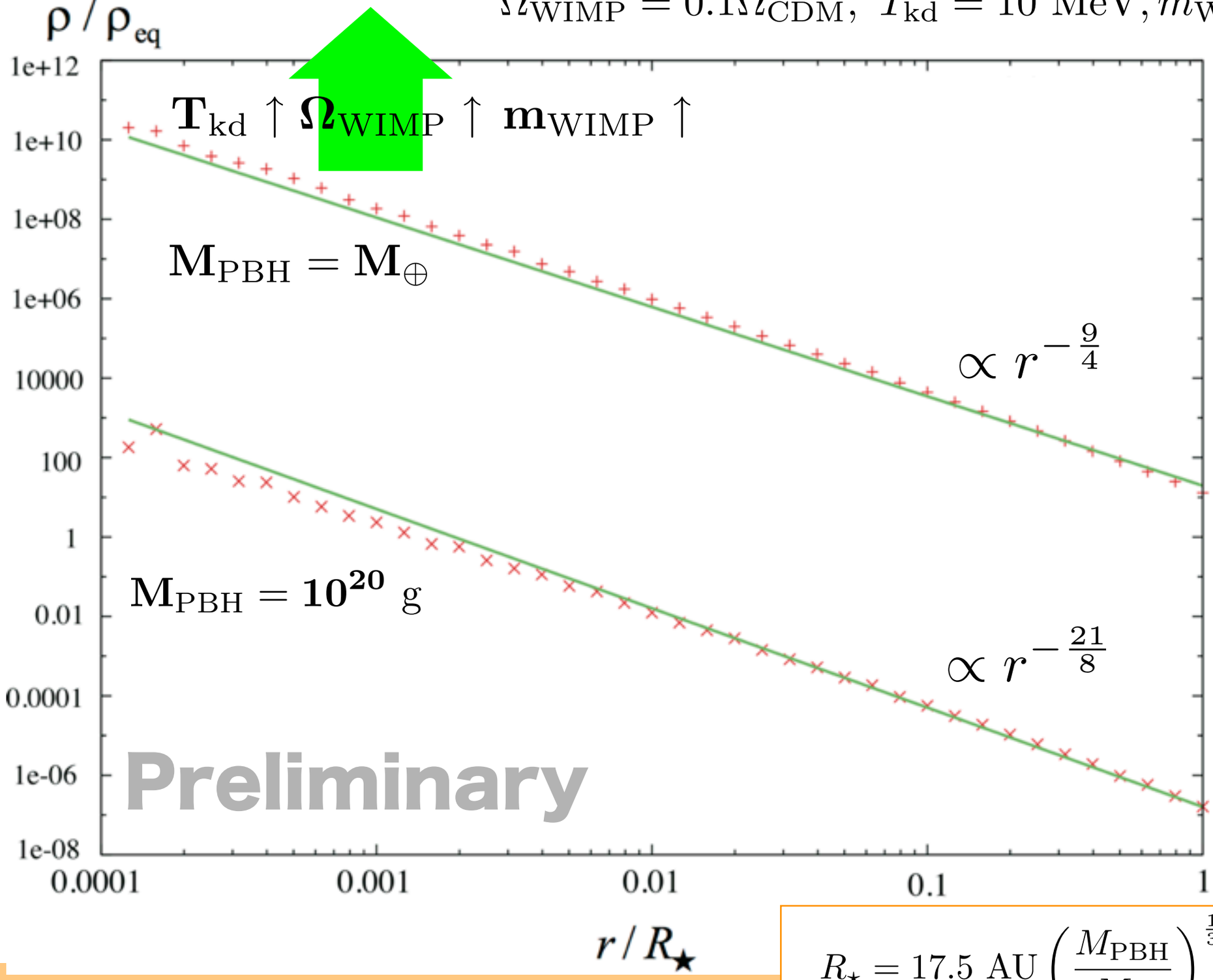
$$\Omega_{\rm WIMP} = 0.1\Omega_{\rm CDM},\ T_{\rm kd} = 10\ {\rm MeV}, m_{\rm WIMP} = 100\ {\rm GeV}$$



$$R_\star = 17.5\ {\rm AU} \left(\frac{M_{\rm PBH}}{M_\oplus}\right)^{\frac{1}{3}}$$

Density Profiles of WIMPs

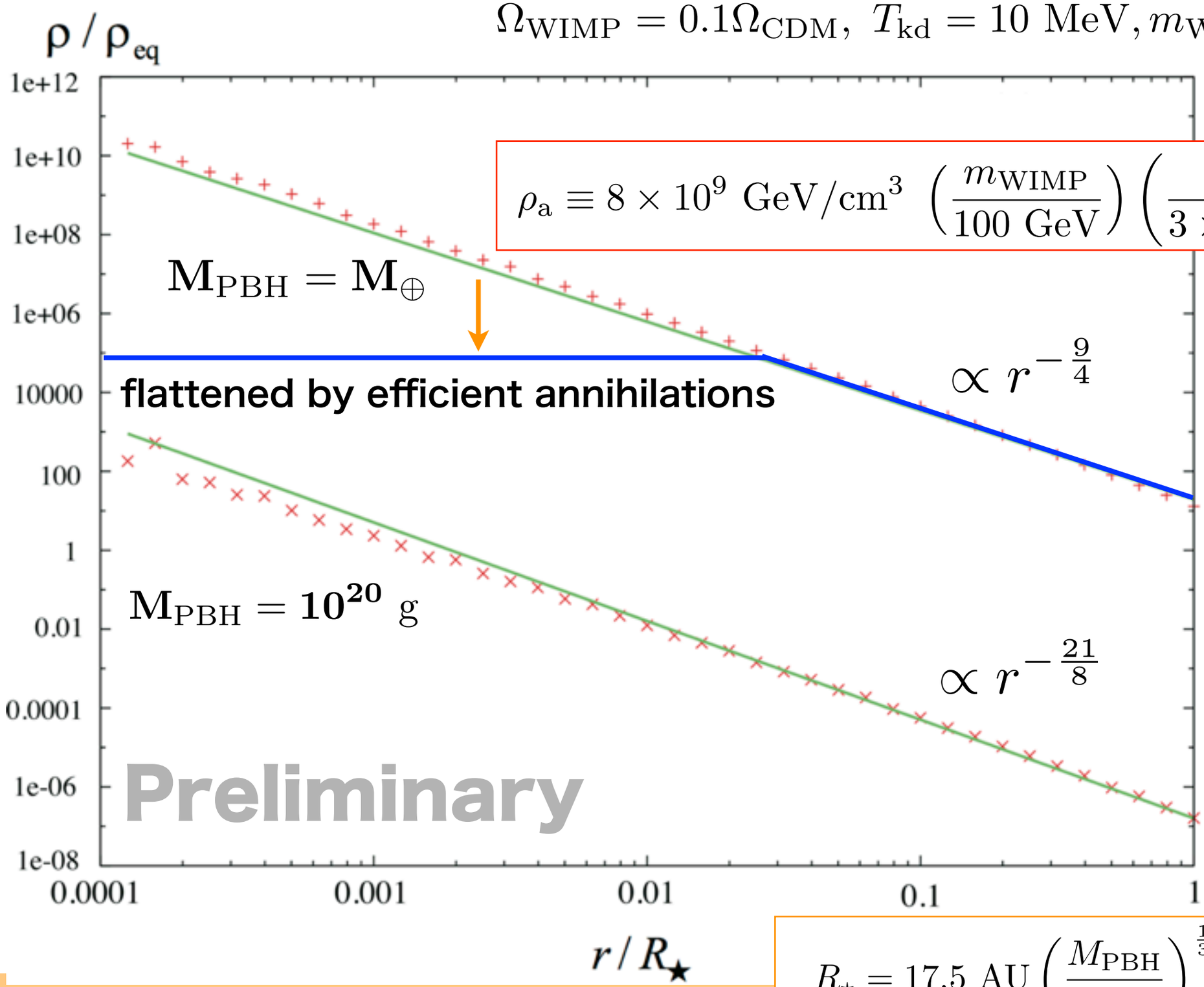
$\Omega_{\rm WIMP} = 0.1\Omega_{\rm CDM},\ T_{\rm kd} = 10\ {\rm MeV}, m_{\rm WIMP} = 100\ {\rm GeV}$



$$R_\star = 17.5\ {\rm AU} \left(\frac{M_{\rm PBH}}{M_\oplus}\right)^{\frac{1}{3}}$$

Density Profiles of WIMPs

$$\Omega_{\rm WIMP} = 0.1\Omega_{\rm CDM},\ T_{\rm kd} = 10\ {\rm MeV}, m_{\rm WIMP} = 100\ {\rm GeV}$$



$$\rho_{\rm a} \equiv 8\times10^{9}\ {\rm GeV/cm^3}\left(\frac{m_{\rm WIMP}}{100\ {\rm GeV}}\right)\left(\frac{\langle\sigma_{\rm A}v\rangle}{3\times10^{-26}\ {\rm cm^3/s}}\right)^{-1}$$

$$R_\star = 17.5\ {\rm AU}\left(\frac{M_{\rm PBH}}{M_\oplus}\right)^{\frac{1}{3}}$$

UCMHs as Gamma-ray Sources

WIMP annihilation rate is proportional to $n^2_{\rm WIMP}$

→ The WIMP annihilation rate is much larger than that of surroundings.

→ **Gamma-ray sources**

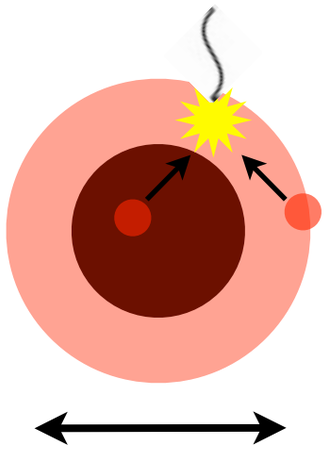
$$\Gamma \equiv \int {\rm d}^3x\ n^2_{\rm WIMP}\langle\sigma_{\rm A}v\rangle$$

$$\propto (\text{WIMP density})^2 \times (\text{UCMH volume})$$

$$\sim 10^4\ \Omega_{\rm PBH}\Gamma_{\rm background} \quad \text{(galactic)}$$

$$\sim 10^{11}\ \Omega_{\rm PBH}\Gamma_{\rm background} \quad \text{(extragalactic)}$$

$$\rho_{\rm WIMP} = O(10^{10})\rho_\odot = O(10^{15})\rho_{\rm c}$$



$$R = O(10^{-1}\ {\rm AU})\left(\frac{M_{\rm PBH}}{M_\oplus}\right)^{\frac{1}{3}}$$

Ultracompact minihalo (UCMH)

A tiny fraction of PBHs can induce a large annihilation rate.

UCMHs as Gamma-ray Sources

Signals $\simeq$ Signals from decaying DM with mass $2m_{\rm WIMP}$

It is convenient to introduce a **corresponding lifetime**

$$\tau_c \equiv \left(\frac{n_{\rm PBH}}{\rho_{\rm CDM}/2m_{\rm WIMP}} \right)^{-1} \Gamma^{-1}$$

Constraints on **decaying DM** $\rightarrow$ Constraints on **UCMHs**

PBH abundance

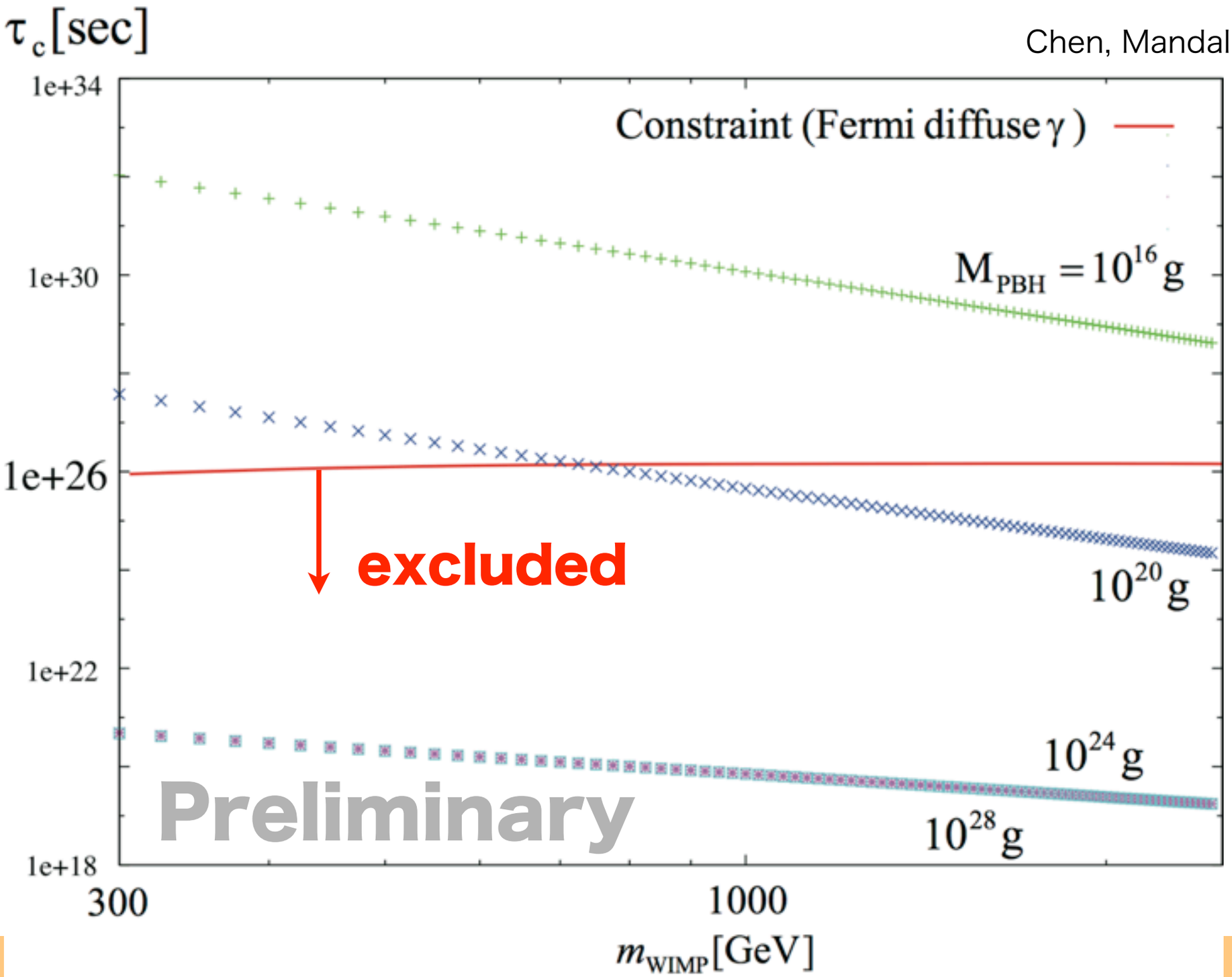
+

WIMP properties

Gamma-ray Constraints

Constraints from γ-ray observations for a model **WIMP = wino**

Chen, Mandal & Takahashi 08



Summary

・ WIMP accumulations by primordial black holes (Formation of UCMHs)

→ Constraints on WIMP+PBH DM from γ-ray observations.

Presence of a tiny amount of PBHs → Tight constraints on particle DM models

・ PBHs cannot supply a deficiency of particle DM abundance in the models.

・ If the existence of PBHs is shown (by using gravitational wave experiments, for example), the models are tightly constrained.