

Current dark matter candidates and a new model of dark matter production; Dark Big Bang

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- **Dark matter candidates**
 - Candidates and classification
 - Current model and its problems
- **Introducing a paper “Dark matter and gravitational waves from a dark big bang ” published by PRD 107,083522(2023)**

What is dark matter?

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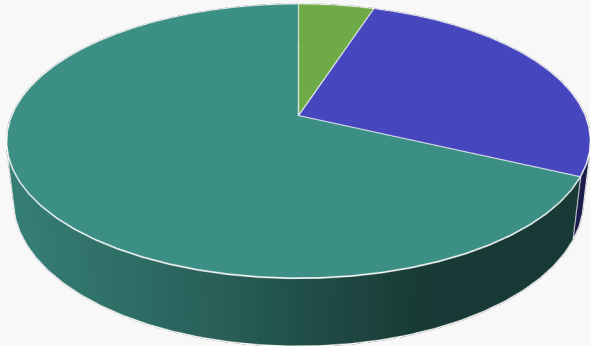
Observational results that can't be explained only by known "visible" matter

- Galaxy rotation curve
- Gravitational lens

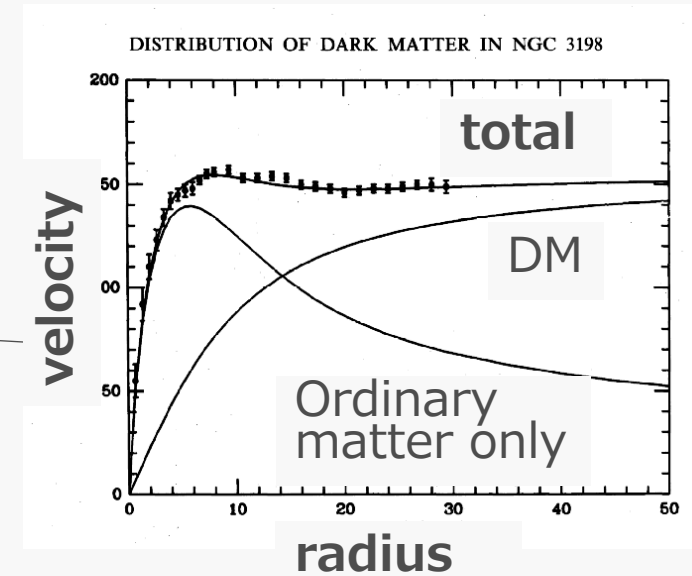


Invisible missing mass is called "Dark Matter(DM)"

composition of the universe



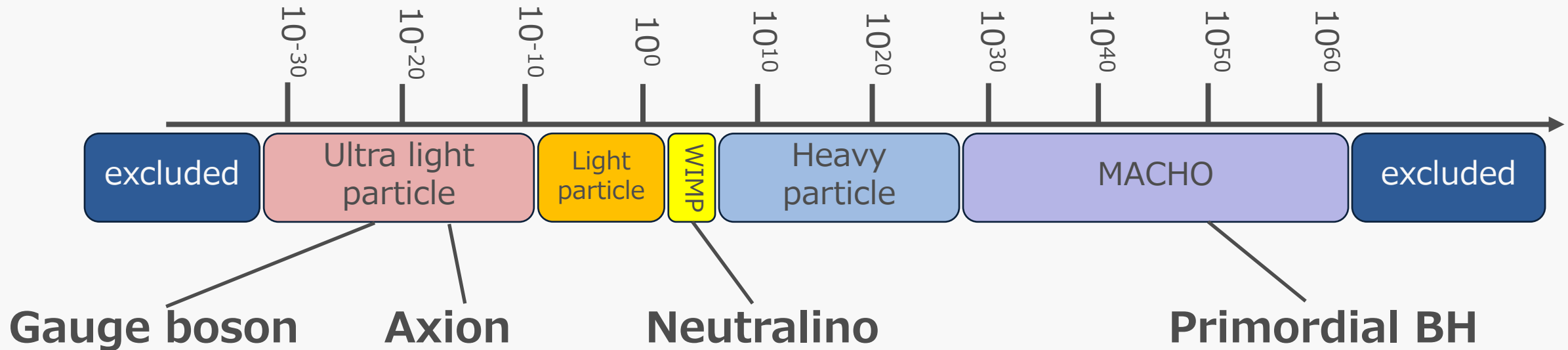
■ ordinary matter ■ dark matter ■ dark energy



DM makes up nearly 30% of the universe, so it is important in the formation of galaxies

- **Astrophysical DM** ←can't explain all dark matter
 - **MACHO: Massive Astrophysical Compact Halo Object**
Ex)BH, WD, NS, BD
- **Particle DM** ←mainly discussed
 - **WIMPs: Weakly Interacting Massive Particles**
Introduced with SUSY
 - **Axion**
Solve the Strong CP problem
 - **Gauge boson**
Install new gauge symmetry
 - **⋮**

Mass of DM (GeV)



Classification of particle dark matter

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- **Thermal relic particle**

- **Hot DM**

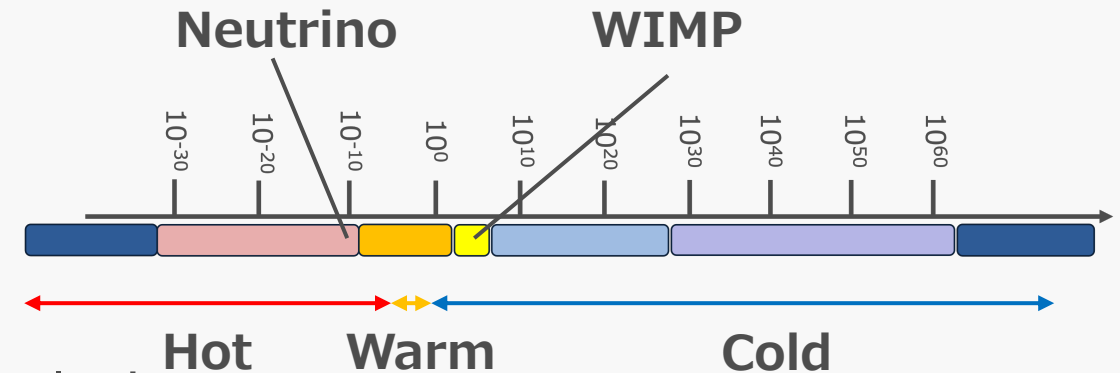
- relativistic speed, can't make galaxies
Ex)neutrino

- **Cold DM**

- Nonrelativistic speed, successfully makes galaxies
Ex)WIMPs

- **Warm DM**

- Intermediate speed, successfully makes galaxies
Ex)gravitino



※only about thermal relic
Non thermal relic needs to
be considered individually

- **Non thermal relic particle**

- Ex)Axion, Gauge boson; cold DM

Λ CDM model is the standard model(SM)

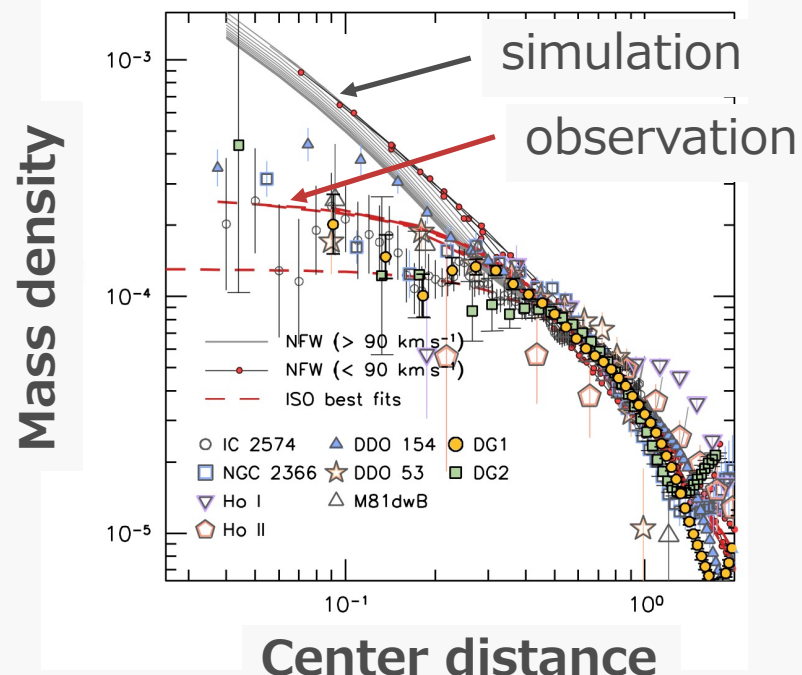
Cold DM model with cosmological constant Λ

Problems of Λ CDM model

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- Small scale problems (<1 Mpc)

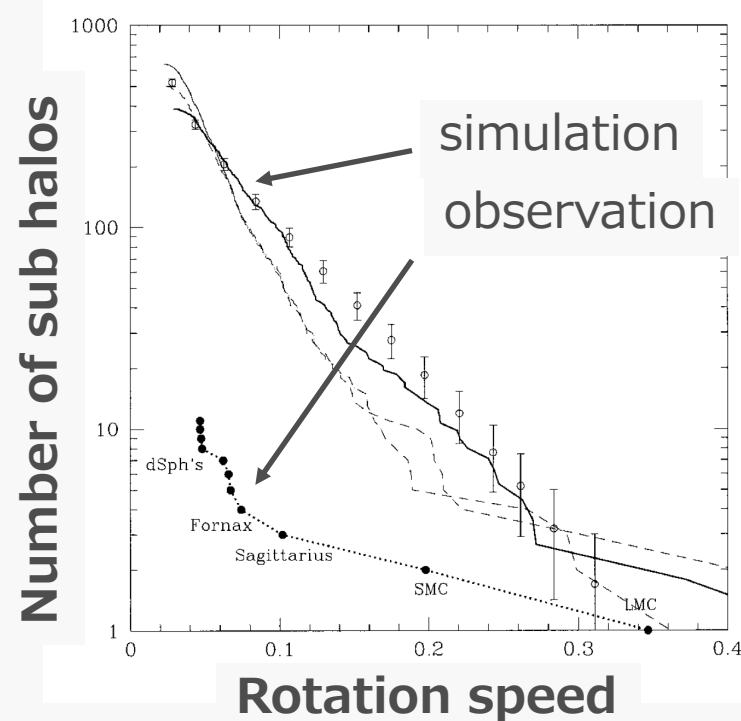
Core/cusp problem



Oh et al, 2011

Flat central density

Missing satellites problem



Moore et al, 1999

Too few sub halos

- **With SM**

- **Bryon feedback**

- Gravitational field fluctuation effects from astronomical events like SN

- **Other DM models**

- **Warm dark matter**

- Intermediate speed, collisionless damping makes small scale structure

- **Self interacting dark matter**

- elastic scattering of DM makes small scale structure

- **Fuzzy dark matter**

- $< 10^{-22} \text{eV}$, wave-like nature makes small scale structure

- Ex) Axion Like Particle

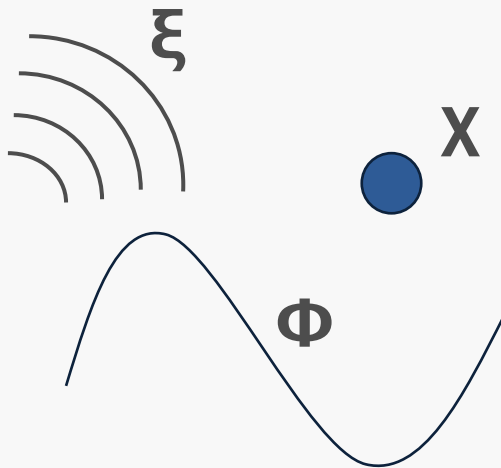
In SM, DM is produced in BBN with ordinary matters



Assuming that DM has only gravitational interactions with ordinary matters

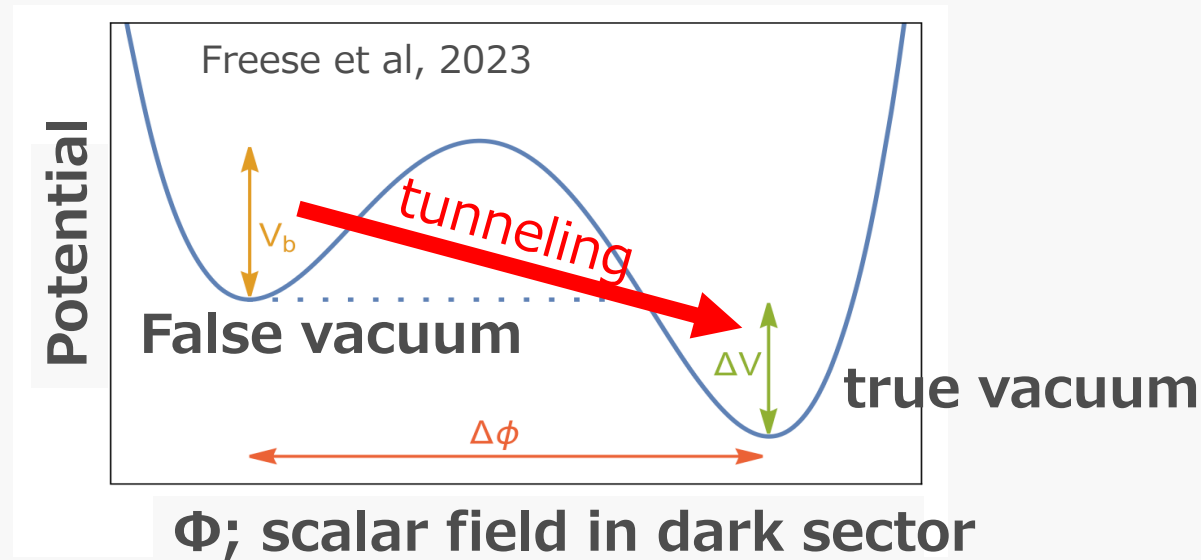
Production of DM is not confined to Big Bang

There should be **another second Big Bang** in “Dark Sector” decoupled from “Visible sector”(except gravity)



Dark sector consists of scalar field ϕ , DM particle χ (and dark radiation ξ)

- Φ in metastable false vacuum tunnels into true vacuum



- Tunneling is followed by first order phase transition “Dark Big Bang” with true vacuum bubbles
- Bubble collisions generate DM thermally or nonthermally

- **Thermal DM**

- **With dark radiation presence**

- Dark WIMP**; shows standard pair annihilation like WIMP

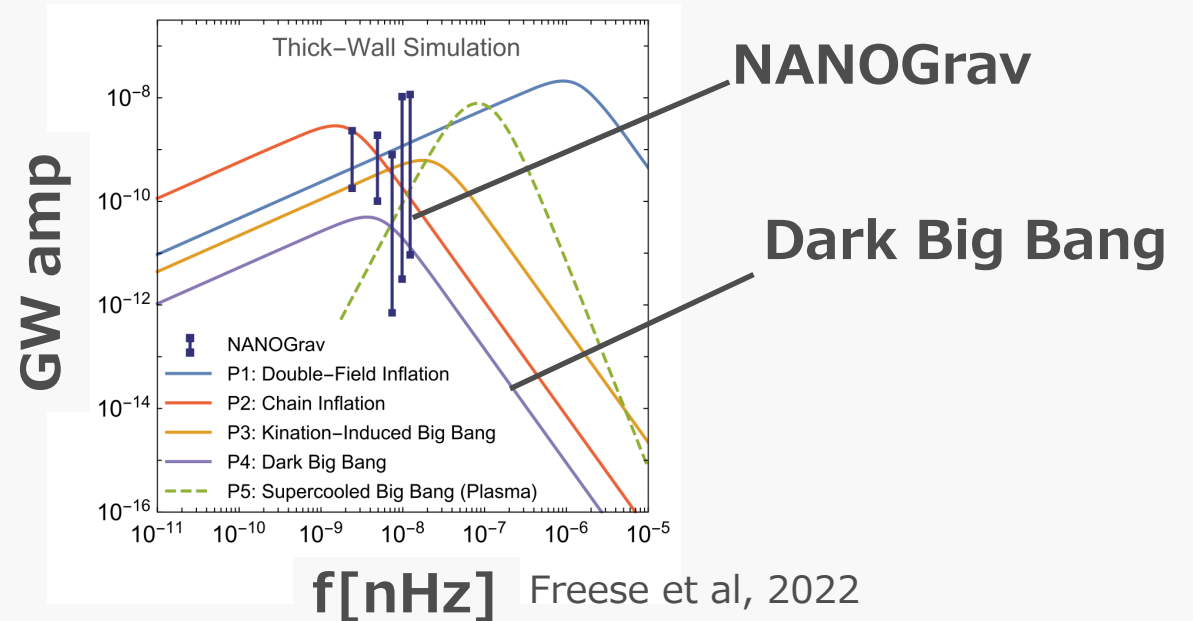
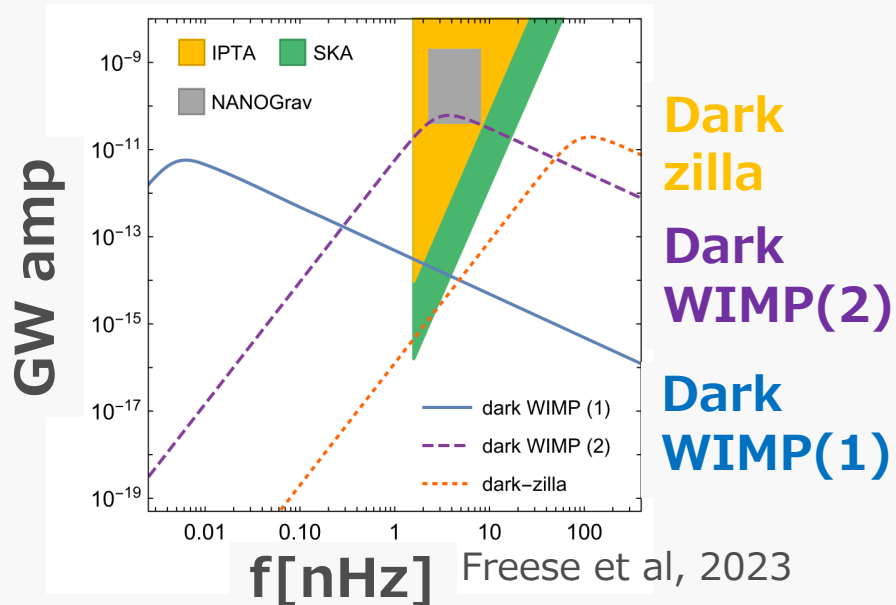
- **Without dark radiation**

- Cannibal DM**; warm and self interacting DM, cannibalizes its rest mass to keep itself warm

- **Nonthermal DM**

- **Dark zilla**; ultra heavy($\gg 10^{10}\text{GeV}$), warm DM

- DM from Dark Big Bang can't be detected directly, but nHz GW can be evidence for Dark Big Bang
- PTA has potential to catch the evidence
- NANOGrav observation is consistent with the model



- Cold dark matter is the standard model
- Other models like WD, SIDM and FDM are considered
- New DM production model Dark Big Bang suggests WD or FDM without weak interaction