天文学正在发现

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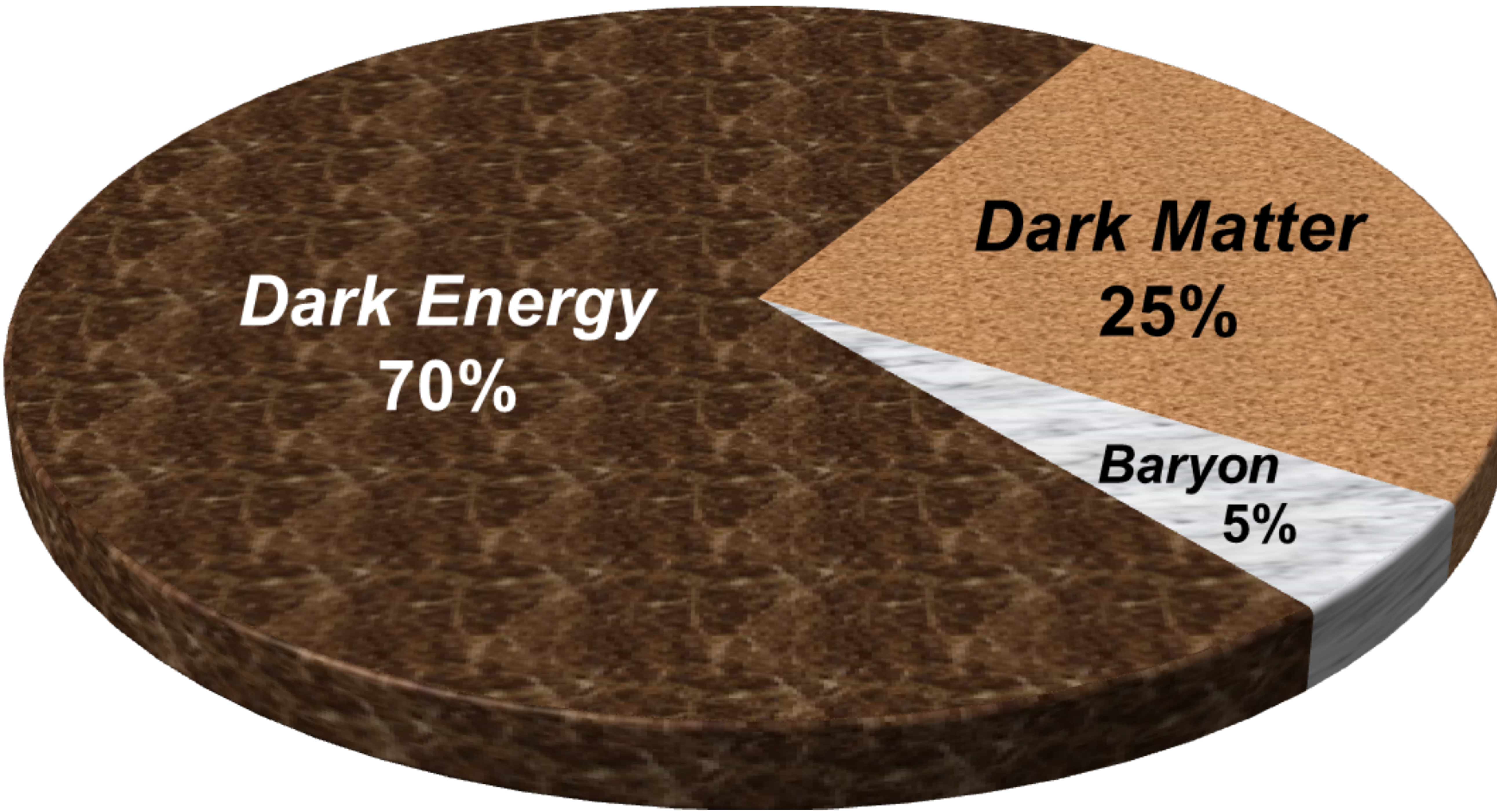
outline

1. 膨胀宇宙的发现
2. 暗物质的发现
3. 暗能量的发现
4. 宇宙微波背景辐射的发现
5. 中微子的发现
6. 引力波的发现
7. 脉冲星的发现
8. 宇宙第一缕曙光的“发现”

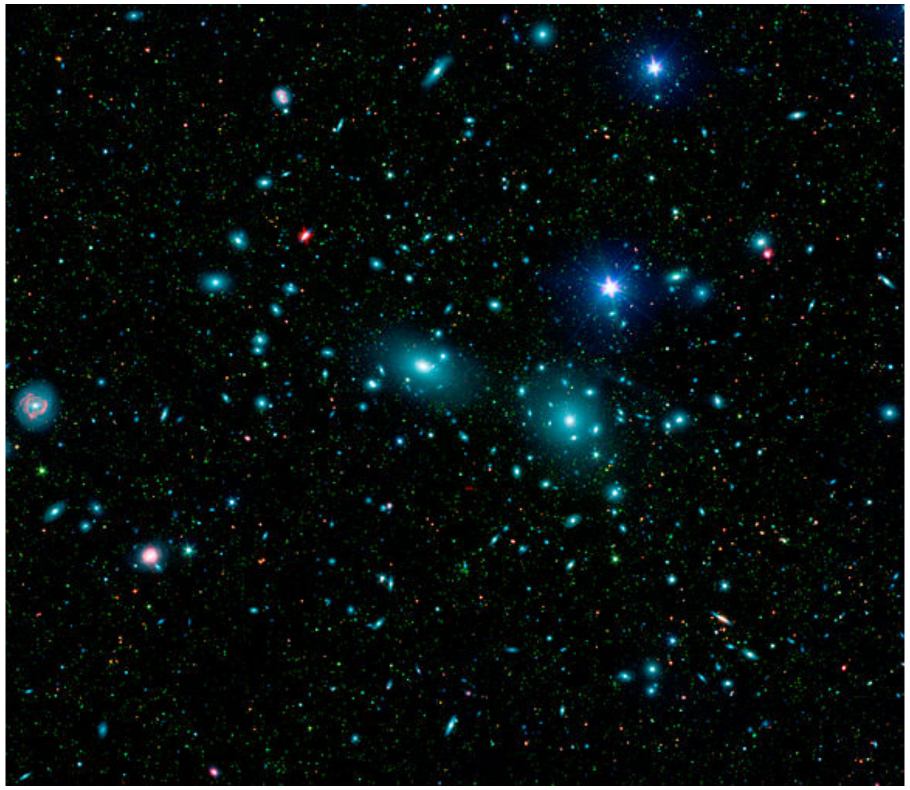

Dark Energy
70%
Dark Matter
25%
Baryon
5%

The “Missing Mass” Problem

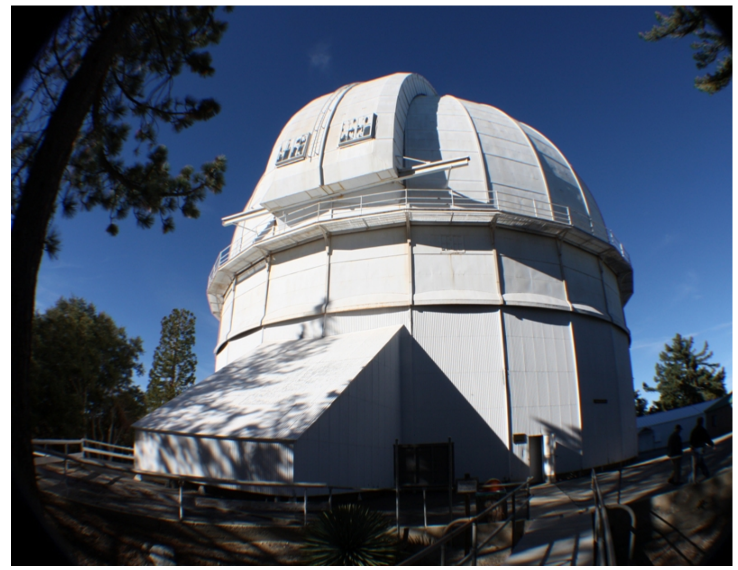
- In 1933, Zwicky was studying galaxies and he estimated their total mass by measuring their brightness
- Then, he used a different method of measuring the mass, and came up with a number 400x his estimate
- Nobody did anything about it

后发座

The **Coma Cluster** (**Abell 1656**) is a large cluster of galaxies that contains over 1,000 identified galaxies

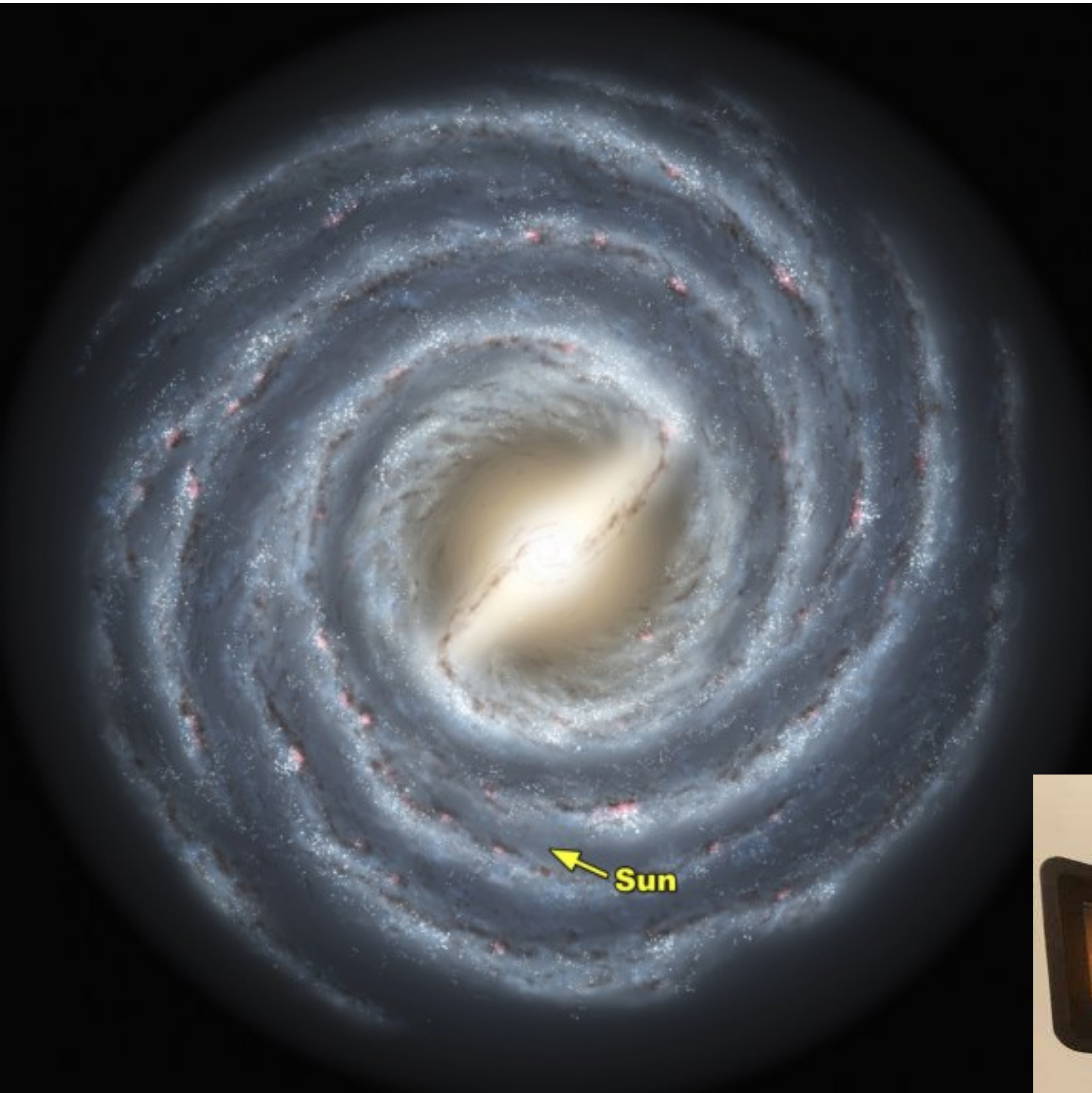


Zwicky used to call other astronomers at the Mount Wilson observatory "Spherical bastards". Why spherical? “Because they were bastards, when looked at from any side".

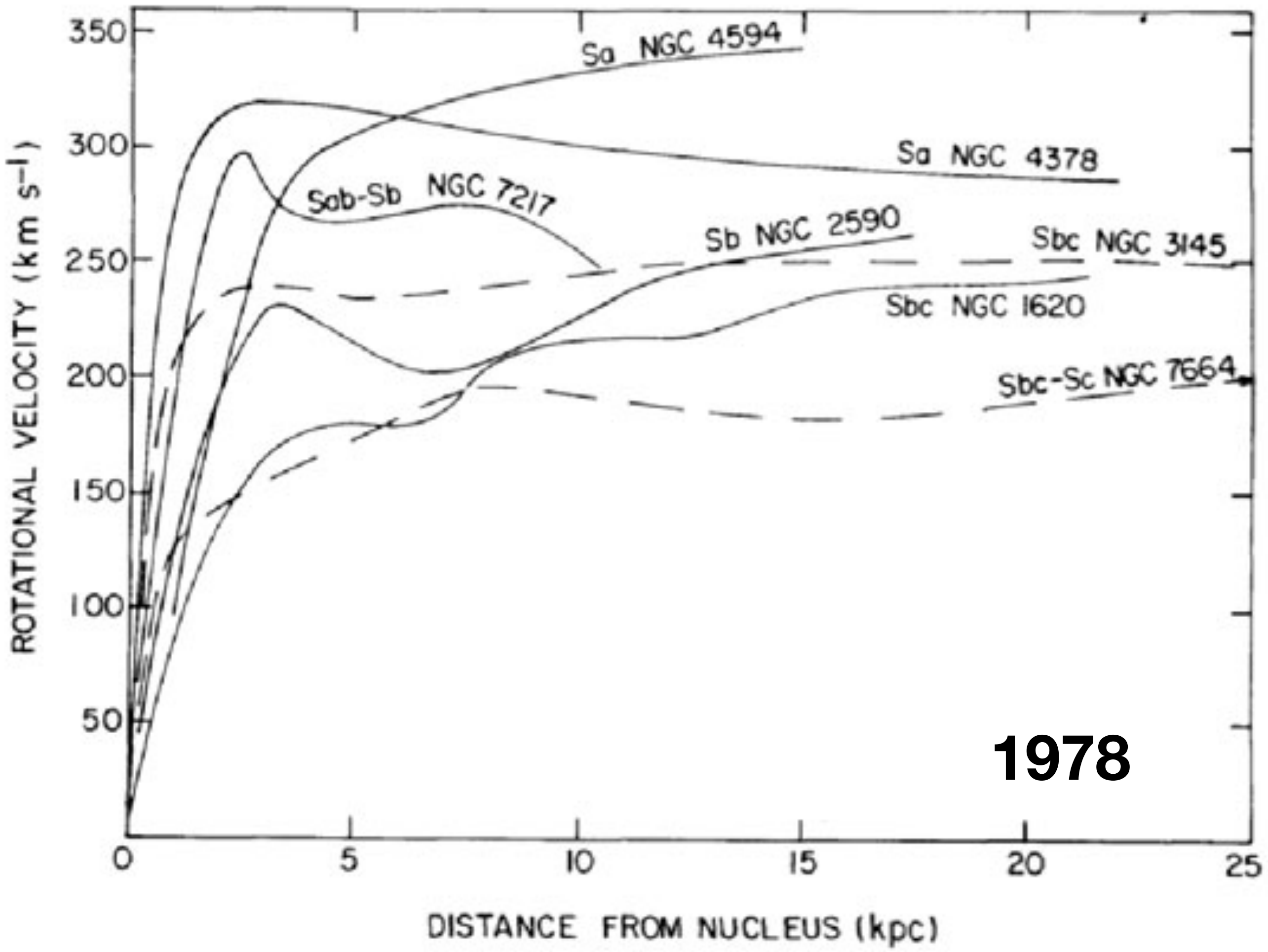


The Zwicky's were once inviting some graduate students for dinner. As the group was ringing the door bell, Zwicki's wife Dorothea opened and called into the house without intending to joke: "Fritz, the bastards are here!".

During an observation night at the Mount Wilson, when the turbulences of the air were disturbing, Zwicky has told his assistant to shoot with the gun into the turbulent air. His hope was that the bullet would smooth the turbulences. The gun was indeed shot but the turbulences stayed... This story illustrates that Zwicky was ready to try unusual ways for solutions.

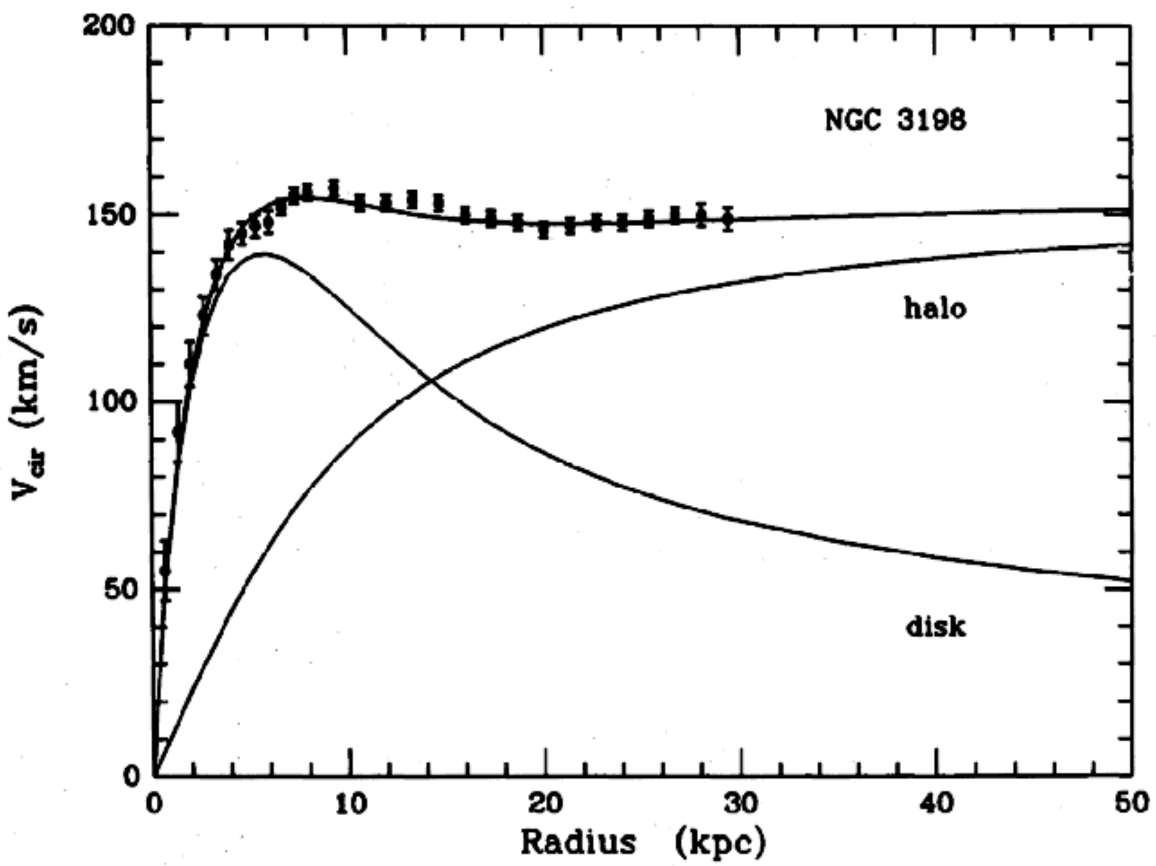

Sun

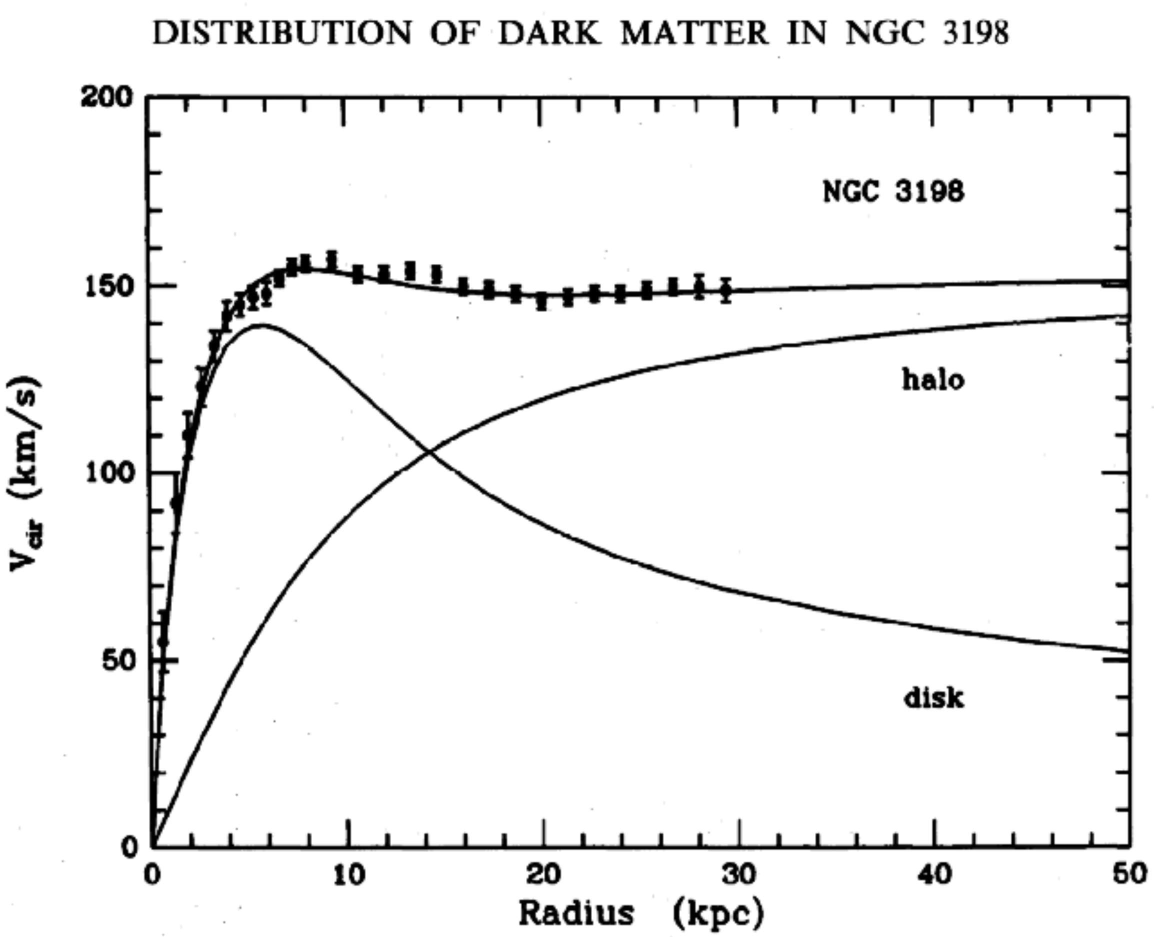

8
G124
上海虹桥站
→北京南站
复兴号

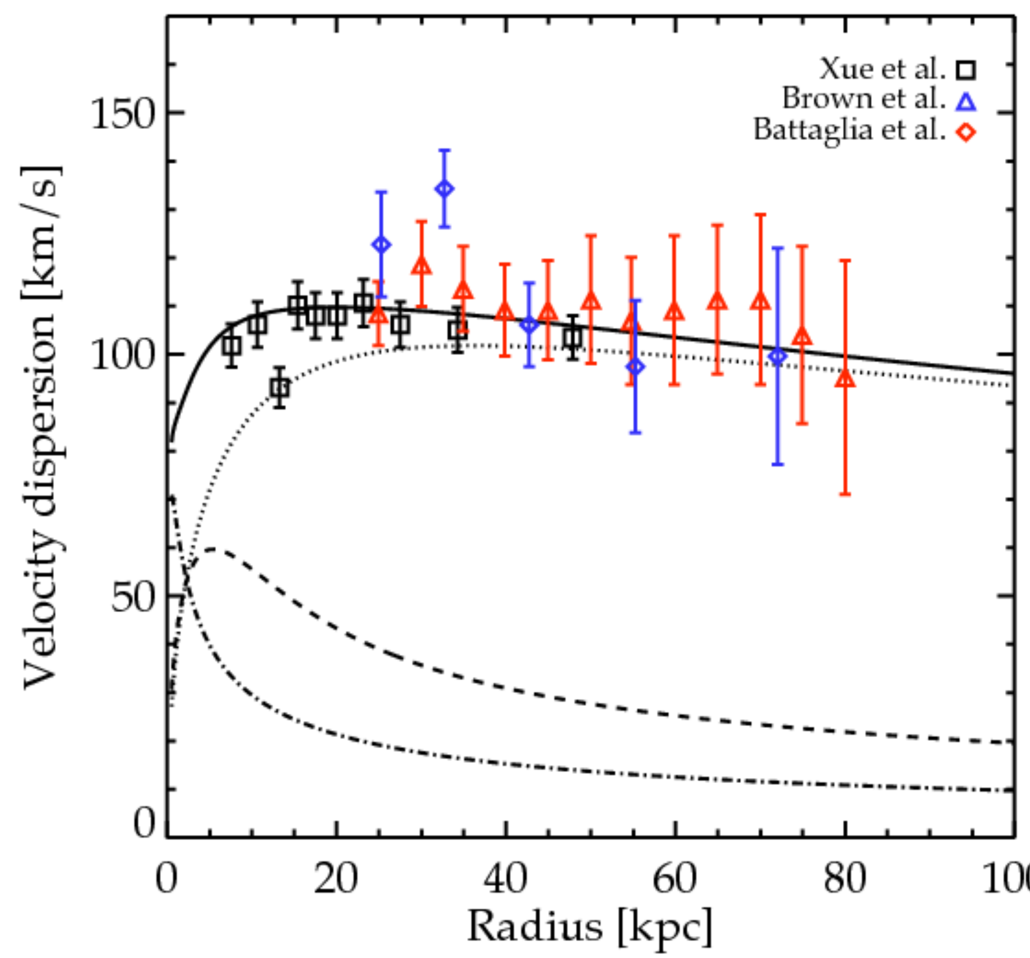


Vera Rubin

DISTRIBUTION OF DARK MATTER IN NGC 3198

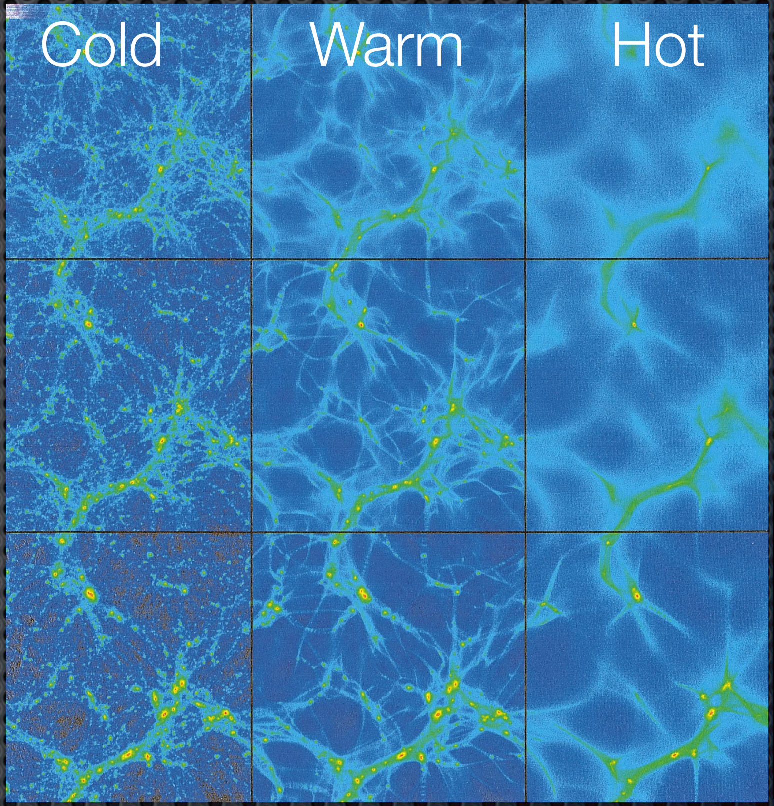



DISTRIBUTION OF DARK MATTER IN NGC 3198
NGC 3198
halo
disk
V_{cir} (km/s)
Radius (kpc)
0
50
100
150
200
0
10
20
30
40
50

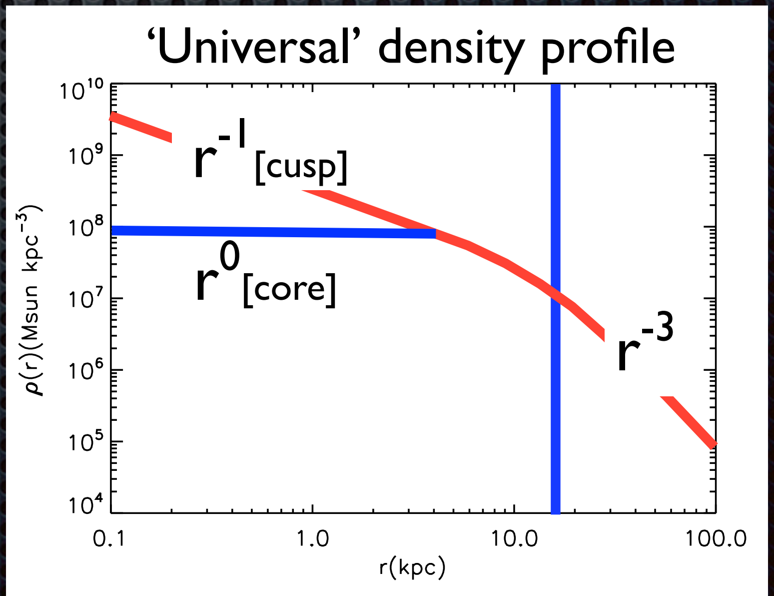

Xue et al.
Brown et al.
Battaglia et al.
Velocity dispersion [km/s]
Radius [kpc]
0
50
100
150
0
20
40
60
80
100

What do we know about dark matter?

- So far, we mostly have “negative” information (constraints from astrophysics and searches for new particles):
  - No colour charge
  - No electric charge
  - No strong self-interaction
- Stable, or very long-lived
- *Not a particle in the Standard Model of particle physics*



Bode et al. 2001

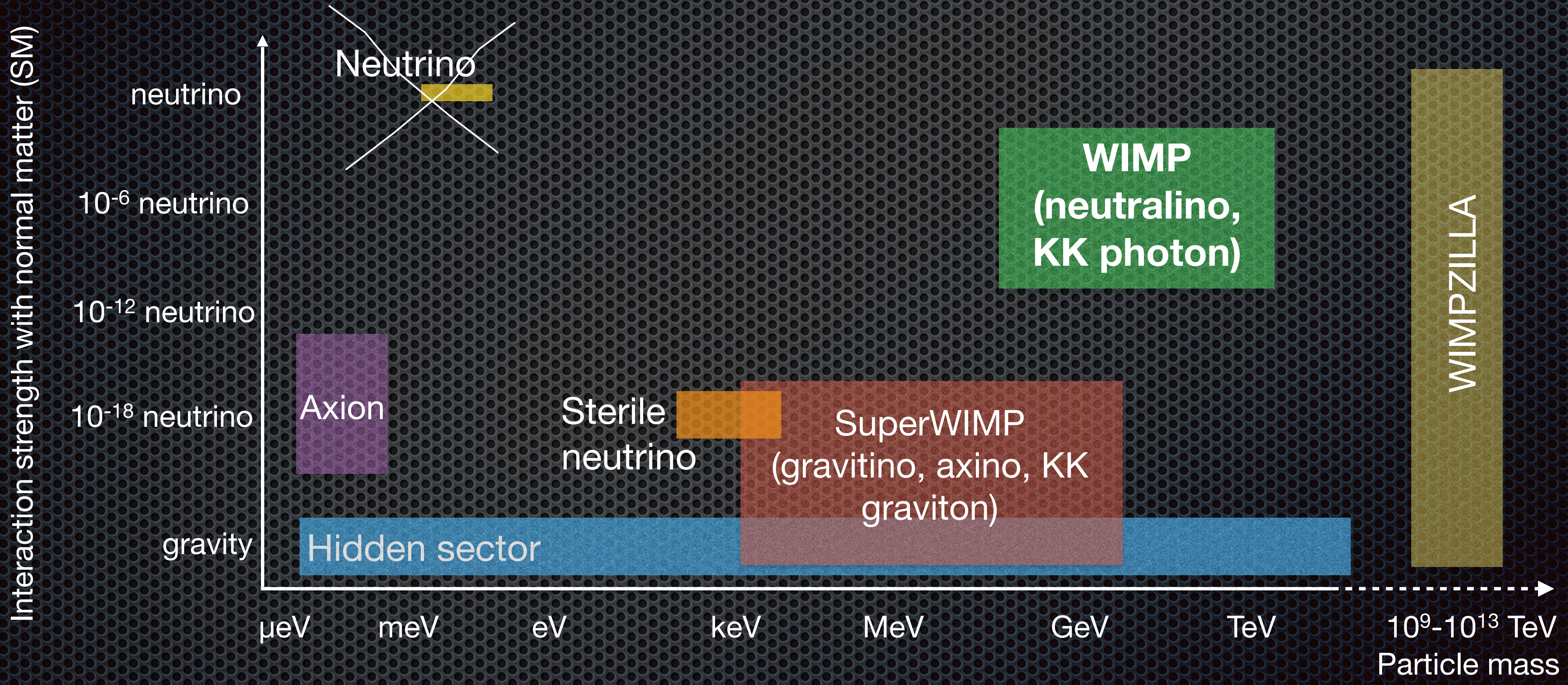


Navarro, Frenk & White 1996

Probing dark matter through gravity

What do we know about dark matter?

- The mass and cross section range span many orders of magnitude
- *Strong guidance from theorists to us experimentalists*



I will mostly focus on axions and WIMPs

WIMP, Axion, MACHO

WIMP (Weakly Interacting Massive Particle)

WIMPs: in thermal equilibrium in the early Universe, freeze-out when annihilation rate drops below expansion rate and $M_{WIMP} > \approx T$ ('cold')

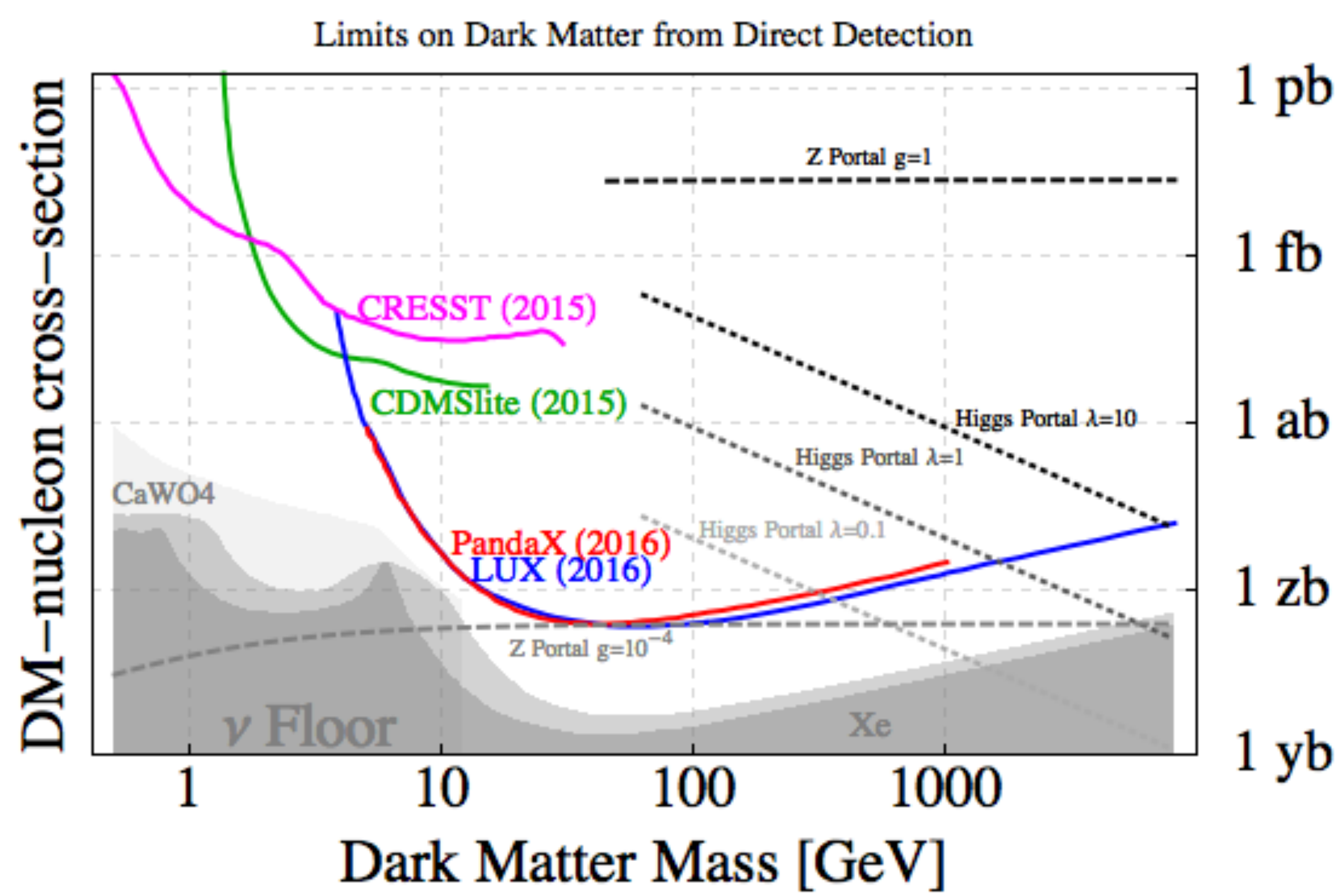
Their relic density can account for the dark matter if the *annihilation cross section is weak* (~ picobarn range)

$$\Omega_\chi h^2 \simeq 3 \times 10^{-27}\mathrm{cm}^3\mathrm{s}^{-1} \frac{1}{\langle \sigma_A v \rangle}$$

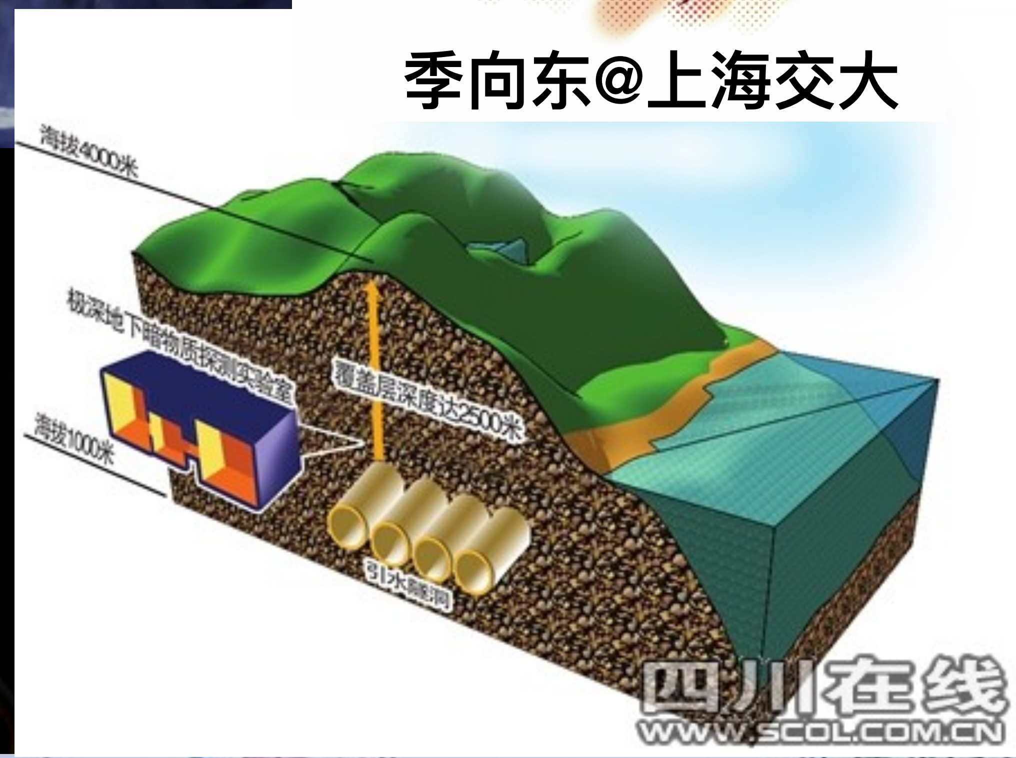
$$\Omega_\chi h^2 = \Omega_{\mathrm{cdm}} h^2 \simeq 0.1143 \quad \Rightarrow \langle \sigma v \rangle \simeq 3 \times 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}$$

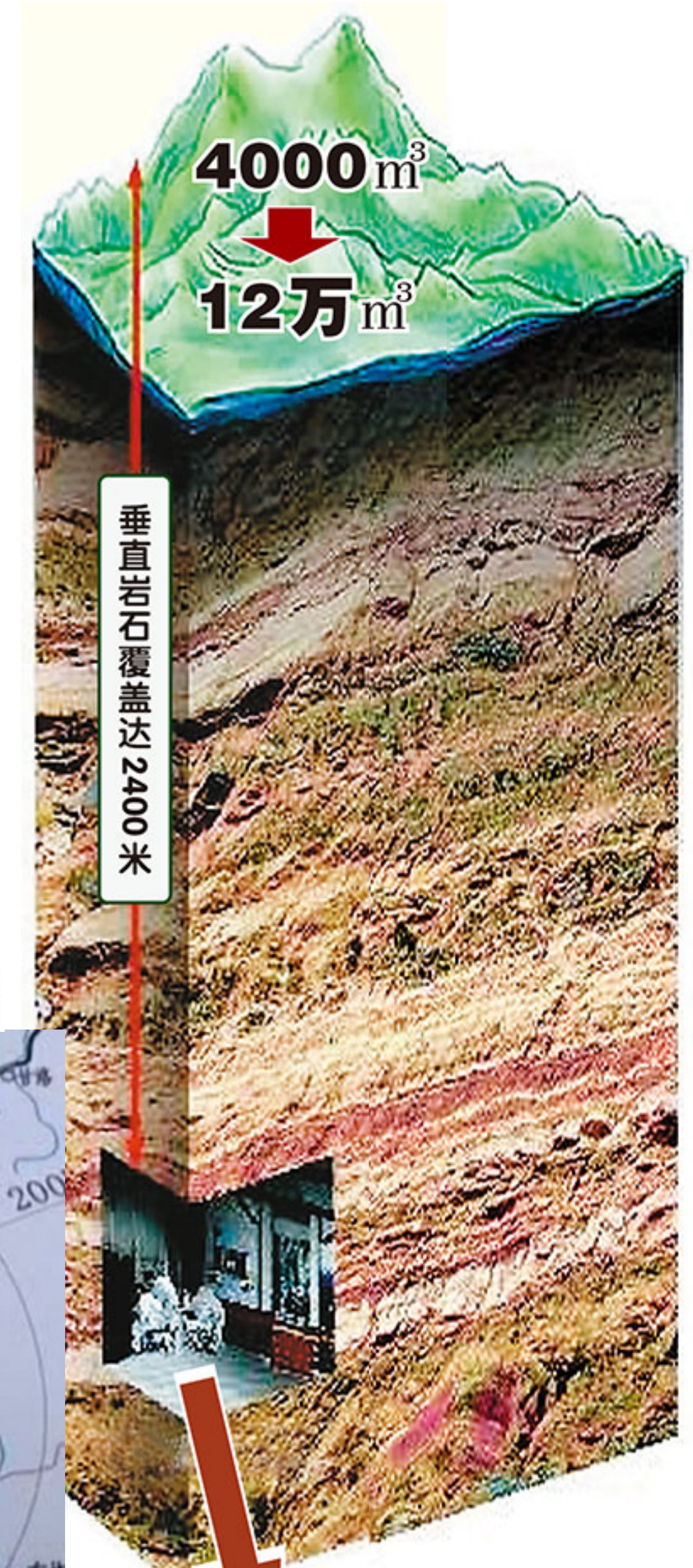
-smaller than atom

-mass range in GeV~TeV



季向东@上海交大

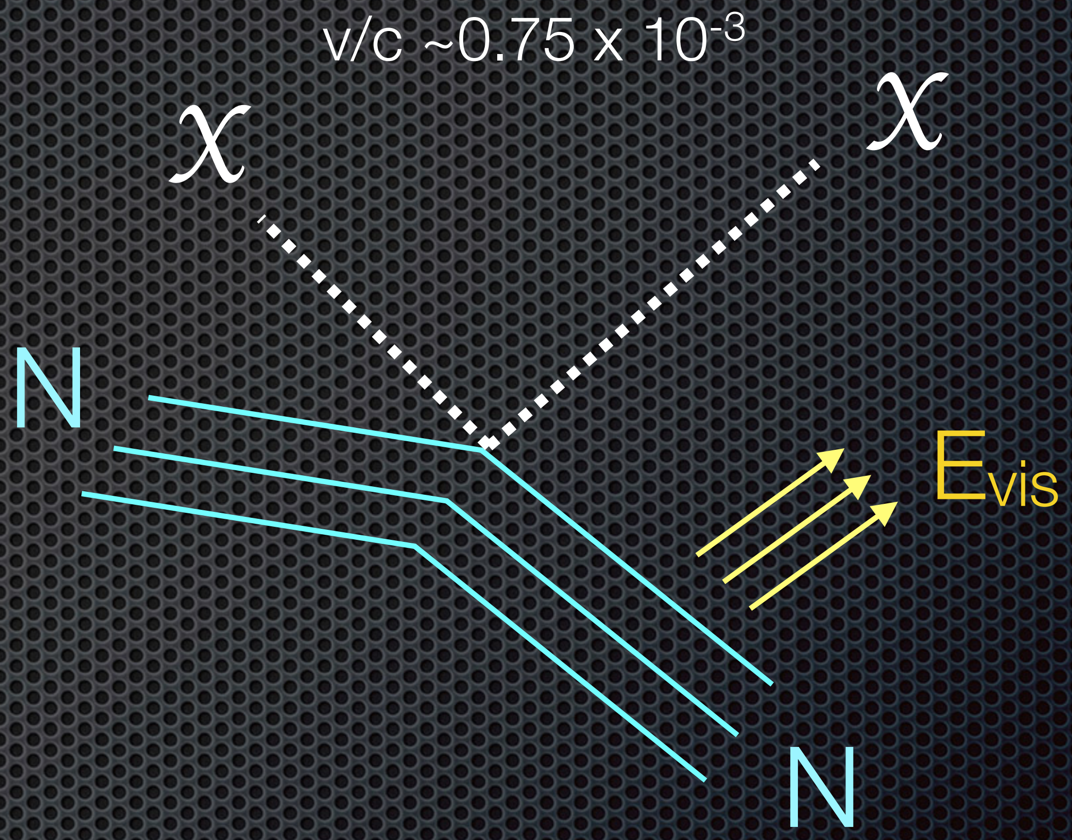


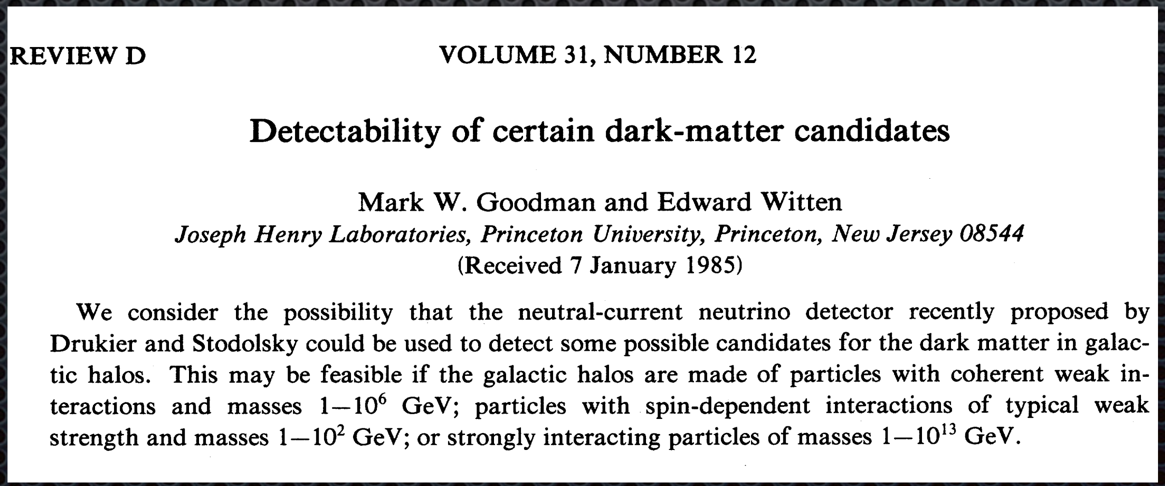


师大参与其中！

How to directly detect WIMPs in the laboratory?

- By searching for collisions of invisibles particles with atomic nuclei => E_{vis} (q ~ tens of MeV)
- Need *very low energy thresholds*
- Need *ultra-low backgrounds*, good background understanding (no “beam off” data collection mode) and discrimination
- Need *large detector masses*




REVIEW D VOLUME 31, NUMBER 12

Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses 1—10^6 GeV; particles with spin-dependent interactions of typical weak strength and masses 1—10^2 GeV; or strongly interacting particles of masses 1—10^{13} GeV.

$$E_R = \frac{q^2}{2m_N} < 30\,\mathrm{keV}$$

M. Goodman & E. Witten, 1985

Axions

- Introduced by Peccei & Quinn as a solution to the strong CP problem: a global U(1) symmetry is spontaneously broken below an energy scale f_a (originally the weak scale $f_a \approx 200$ GeV~ f_{EW})
- Weinberg & Wilczek: PQ solution implies the existence of a light pseudoscalar, the axion
- No axion detection so far; 'invisible axion' models (with arbitrary large f_a) are still viable:

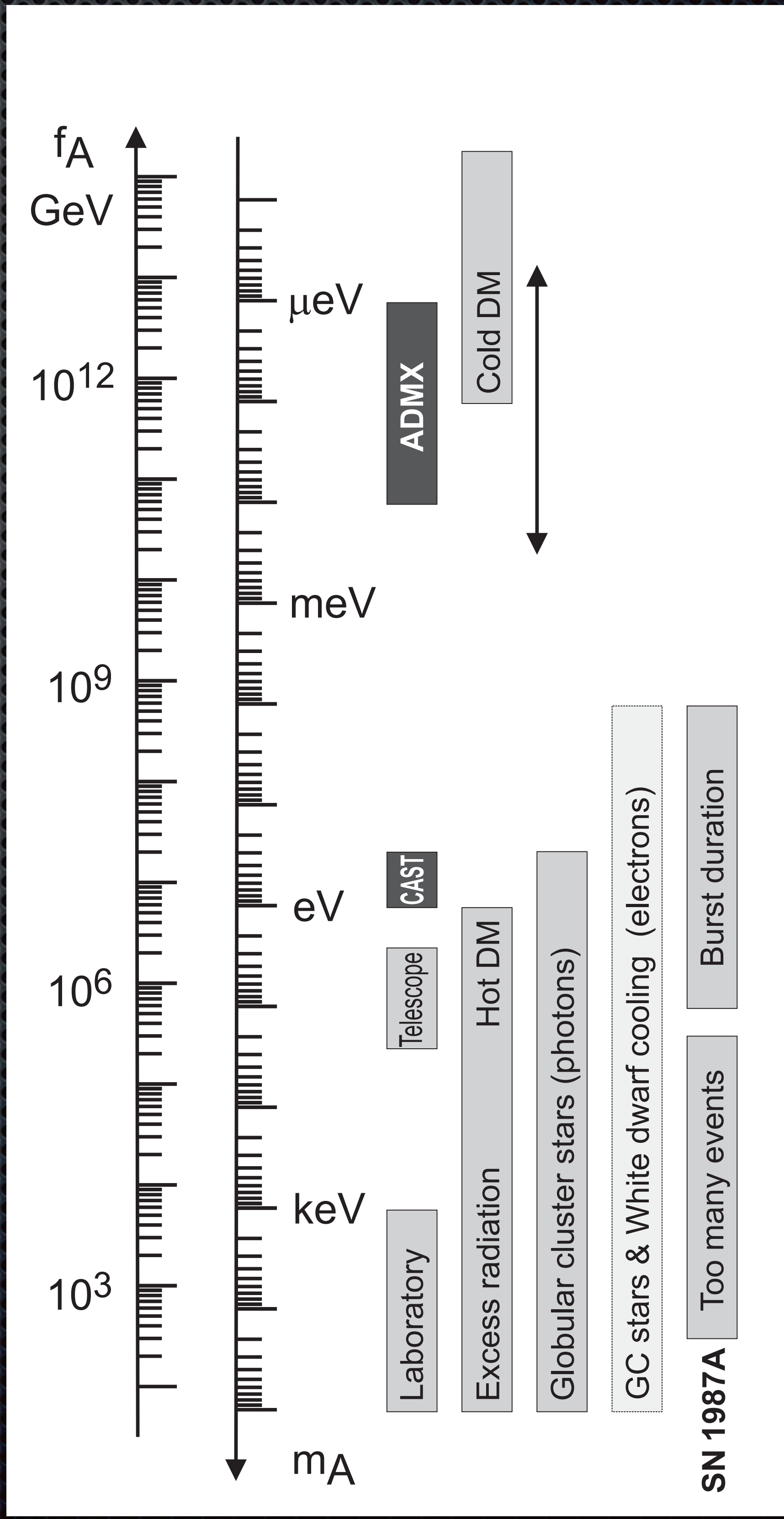
$$m_a \simeq 6 \cdot 10^{-6} \mathrm{eV} \, \frac{10^{12}\,\mathrm{GeV}}{f_a}$$

corresponds to the observed dark matter density

- Constraints from astrophysics, cosmology and laboratory searches restrict the mass of a QCD dark matter axion to:

$$\sim 1\,\mu\mathrm{eV} \leq m_a \leq 3\,\mathrm{meV}$$

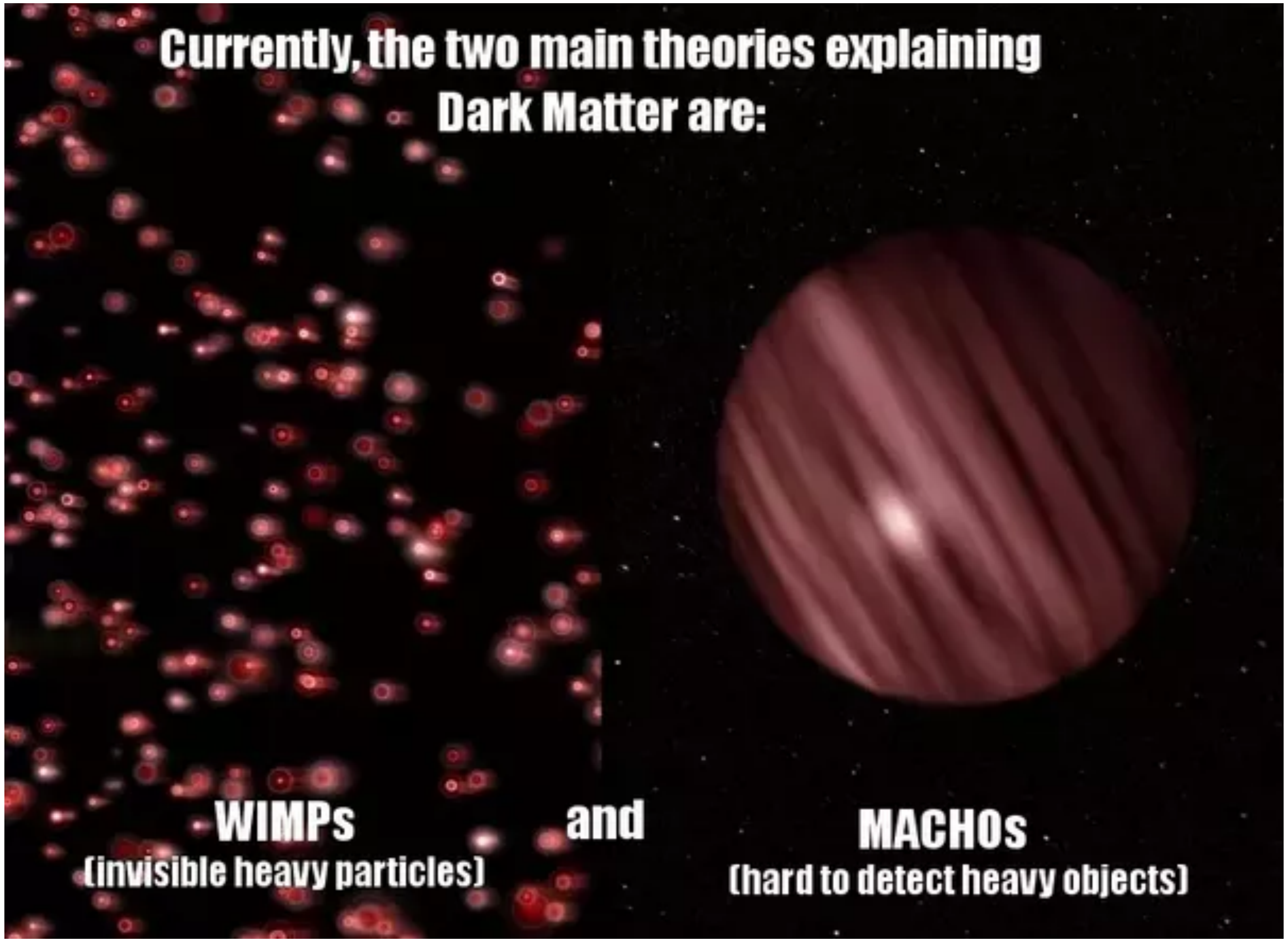
G. Raffelt & L. Rosenberg
PDG 2012



MACHO (Massive Astrophysical Compact Halo Object)

-primordial black hole $\sim 10^{-3} M_\odot$ **(Jupiter mass)**

-brown dwarf $\sim 0.08 M_\odot$ $\boxed{M_\odot \sim 10^{66} eV}$



problem-3: 暗物质都有哪些探测手段? （物理实验 / 直接探测，天文观测 / 间接探测）

problem-4: 冷 / 热 暗物质模型，在宇宙大尺度结构形成（如星系形成）过程中有何不同?