

EPS-HEP 2019, Ghent, Belgium

Yen-Hsun Lin

Nat'l Cheng Kung U, Taiwan

JHEP 08, 069 (2018)

in collaboration with

Chian-Shu Chen (Tamkang U,Taiwan)

Probing self-interacting dark matter through neutron stars

Outline

▶ **Part I:**

Historical remarks on dark matter (DM) and the necessity of self-interaction

▶ **Part II:**

Neutron star (NS) cooling and DM heating mechanisms

▶ **Part III:**

How can we deduce DM properties by observing the NS temperature

▶ **Summary**



X-ray: NASA/CXC/SAO

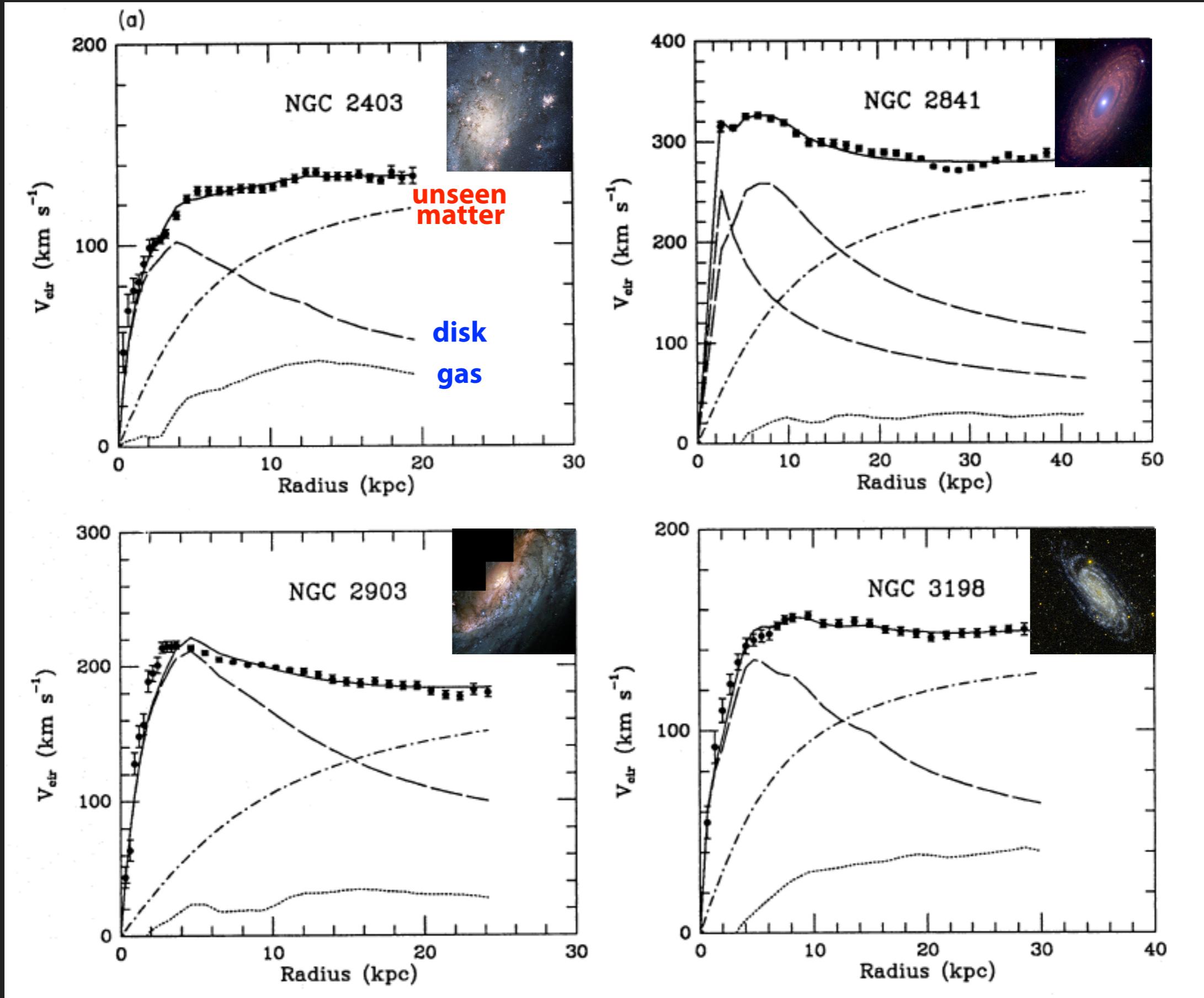
Optical: NASA/STScI

Infrared: NASA-JPL-Caltech

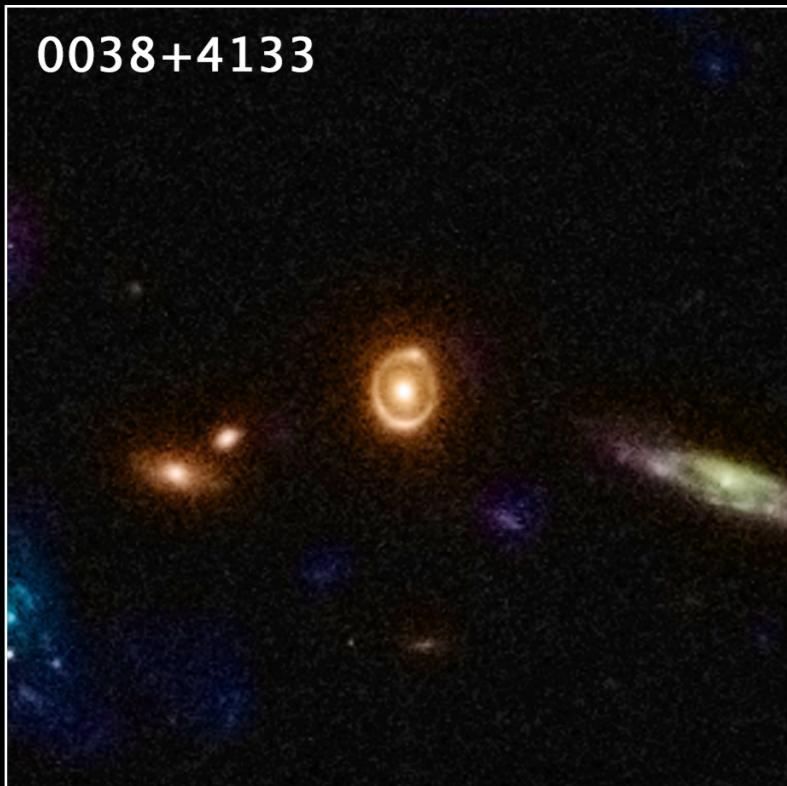
Crab Nebula

Part I

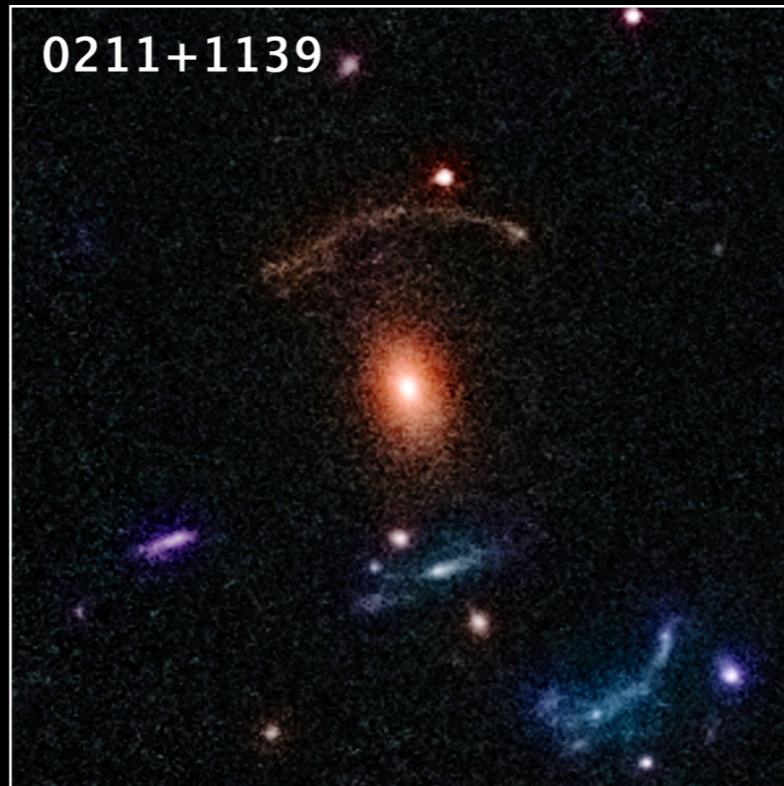
DM in the Universe



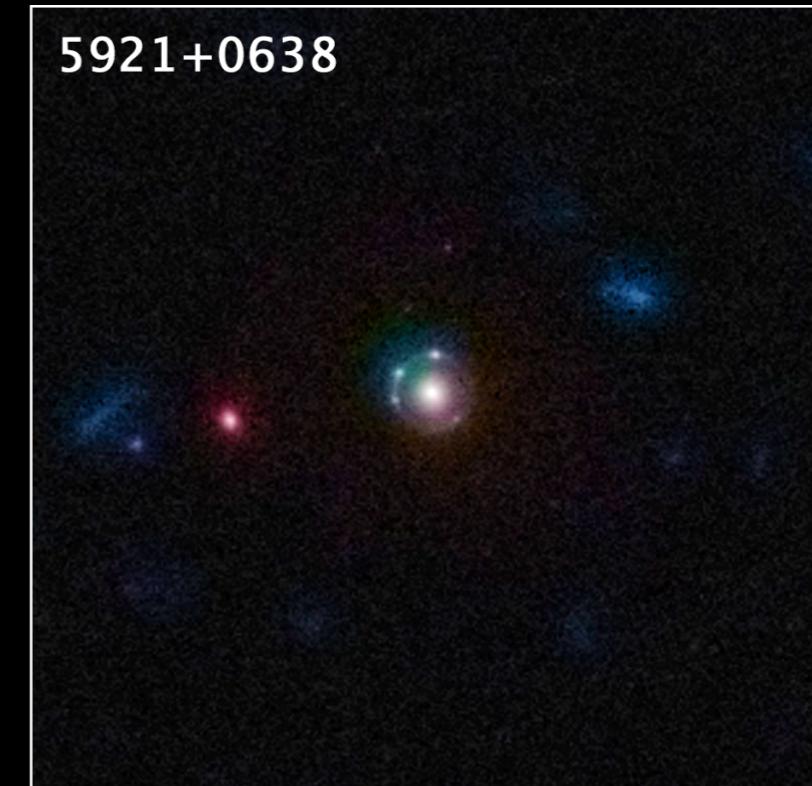
0038+4133



0211+1139



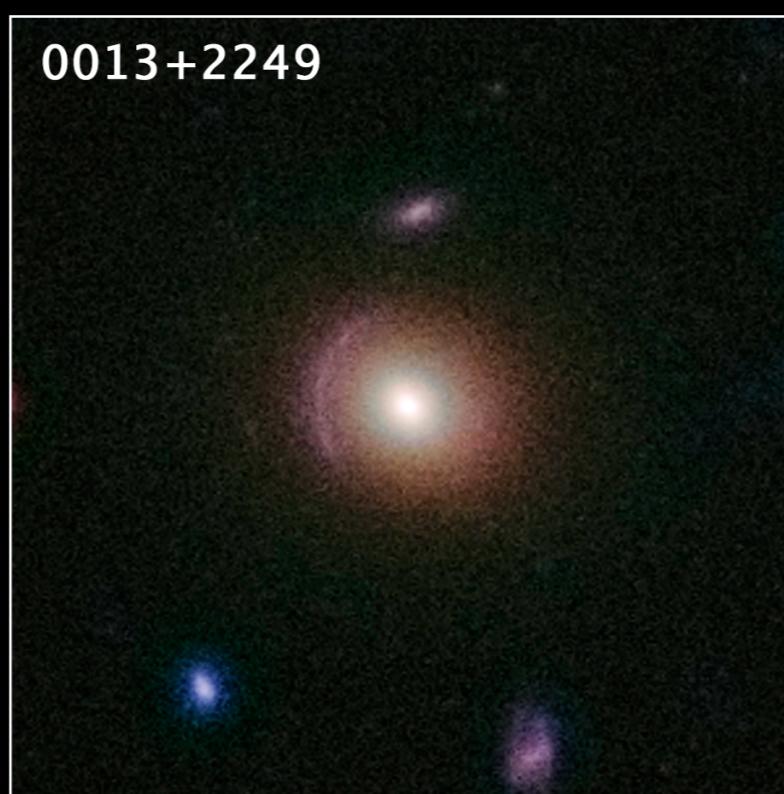
5921+0638



0018+3845



0013+2249

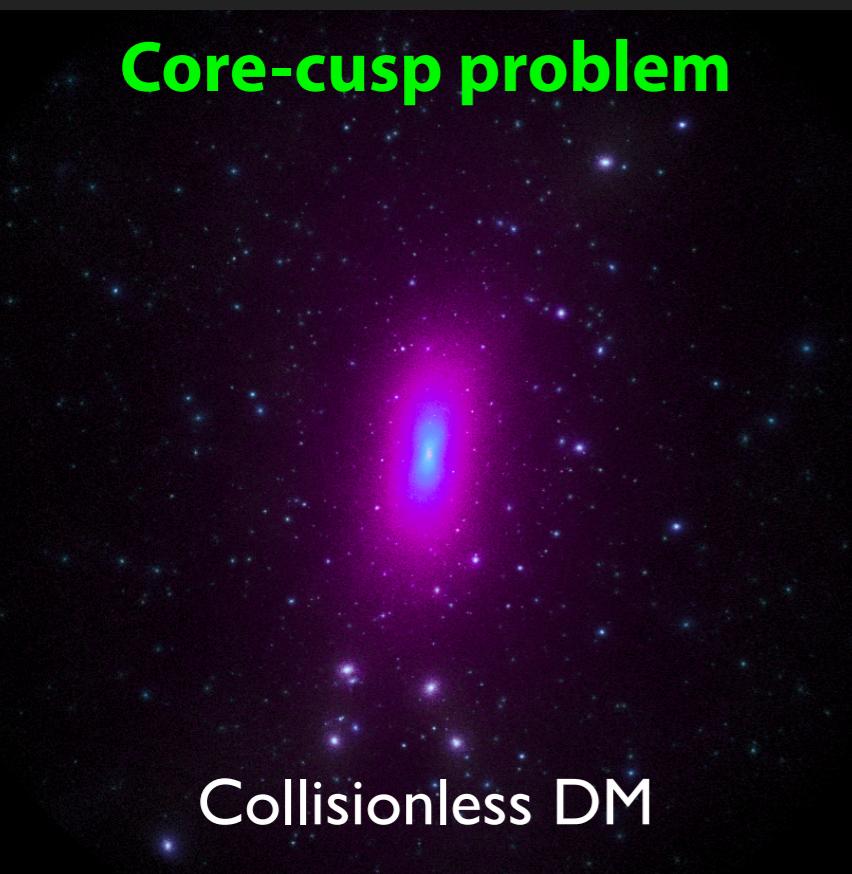


0047+5023



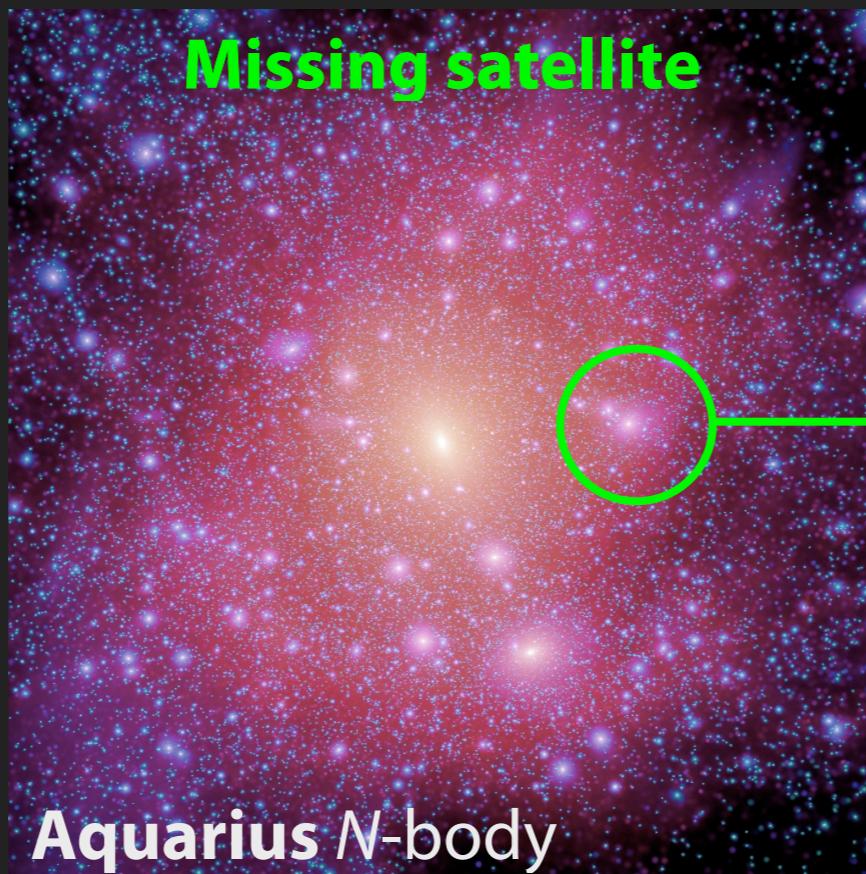
**Gravitational Lenses in the COSMOS Survey
*Hubble Space Telescope ▀ ACS/WFC***

Core-cusp problem



Collisionless DM

Missing satellite



Aquarius N-body

Too-big-to-fail

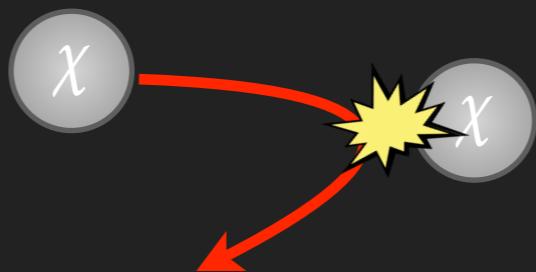


We didn't see any satellite as massive as predicted by the N -body sim.

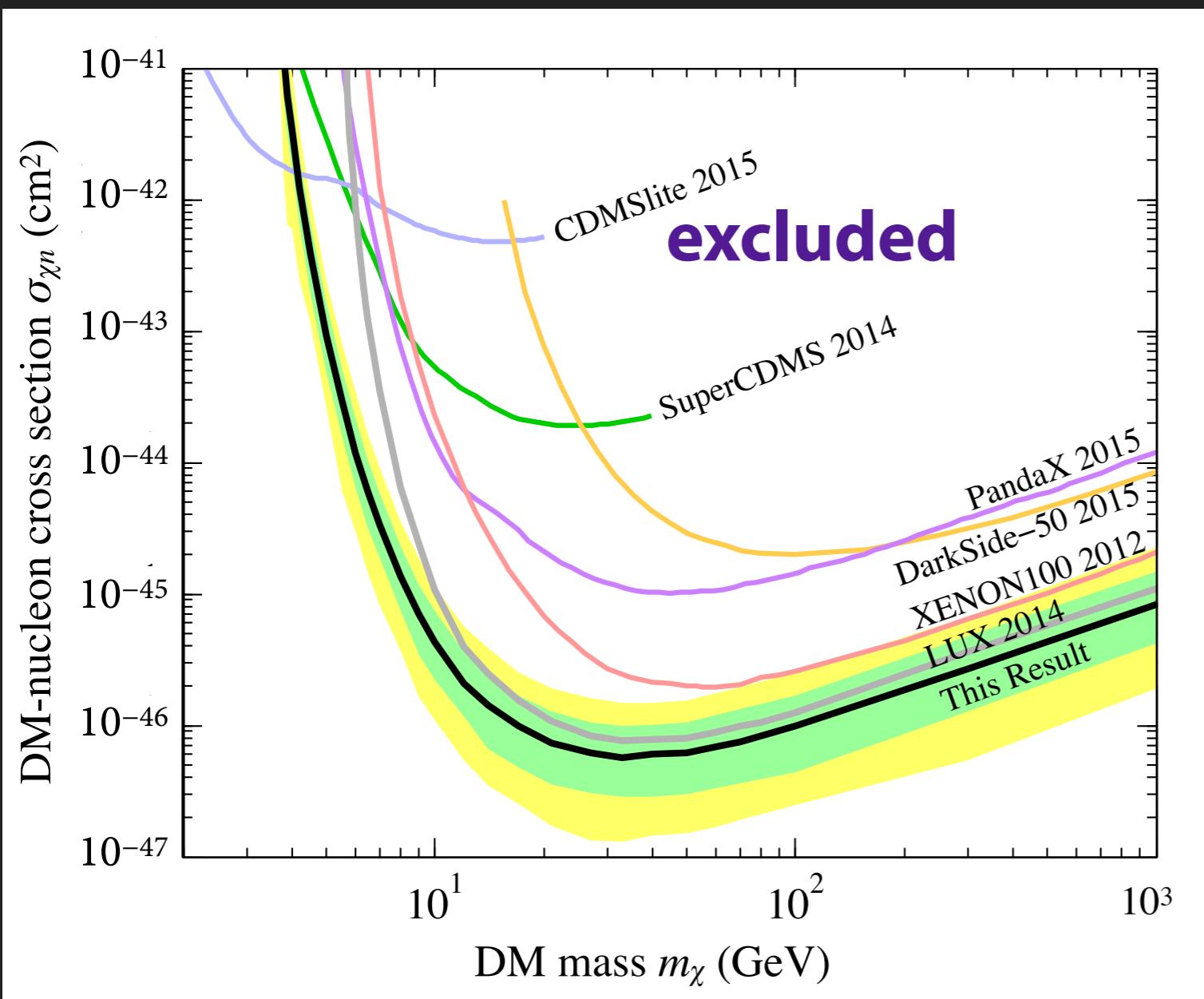
To alleviate these small-scale problems:

DM self-interaction is introduced

$$10^{-25} \frac{\text{cm}^2}{\text{GeV}} \leq \frac{\sigma_{\chi\chi}}{m_\chi} \leq 10^{-23} \frac{\text{cm}^2}{\text{GeV}}$$



Constraints from DM direct searches



- Most stringent result yields at $m_\chi \approx 30$ GeV and $\sigma_{\chi n} \approx 7 \times 10^{-47}$ cm²
- We will probe a more smaller $\sigma_{\chi n}$ in the later discussion

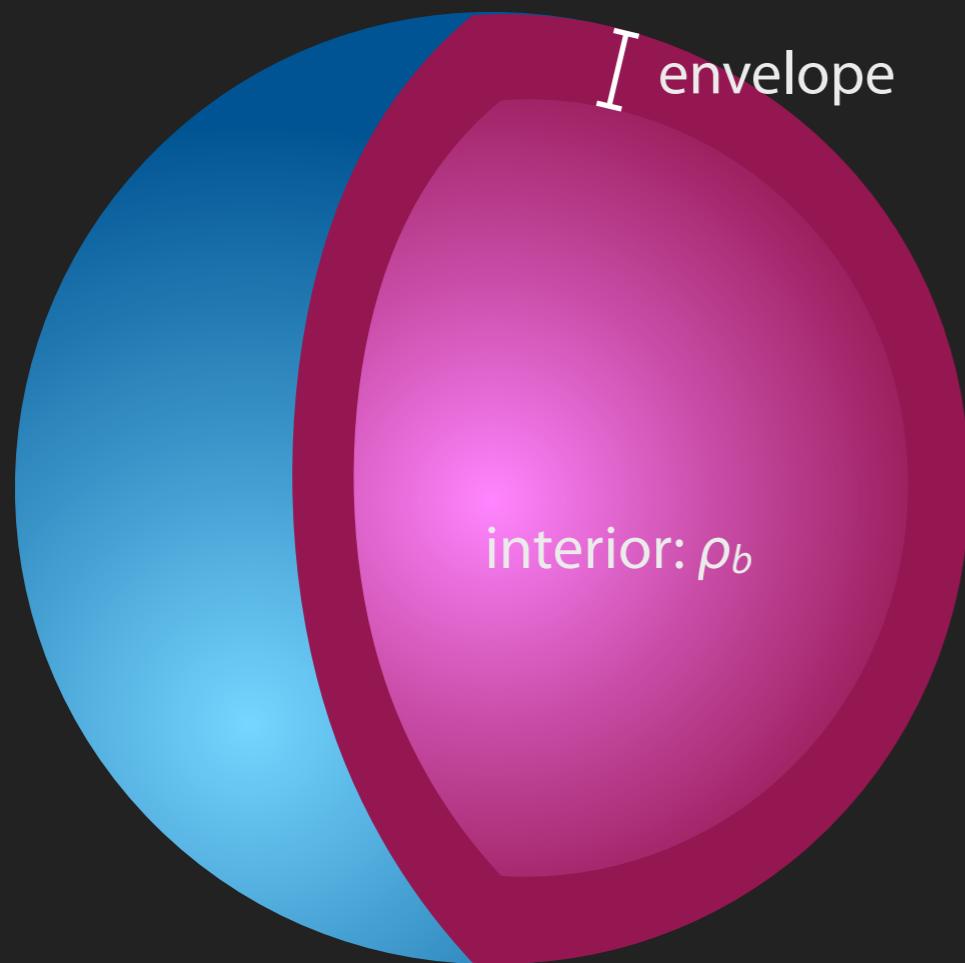
S. A. Malik *et al.*, *Phys. Dark Univ.* **9-10**, 51 (2015)
O. Buchmueller *et al.*, *JHEP* 01, **037** (2015)
J. Aalbers *et al.* [DARWIN], *JCAP* **11**, 017 (2016)
D. S. Akerib *et al.* [LUX] *PRL* **118**, 021303 (2017)
C. Amole *et al.* [PICO], *PRL* **118**, 251301 (2017)
E. Aprile *et al.* [XENON] *PRL* **119**, 181301 (2017)



Part II

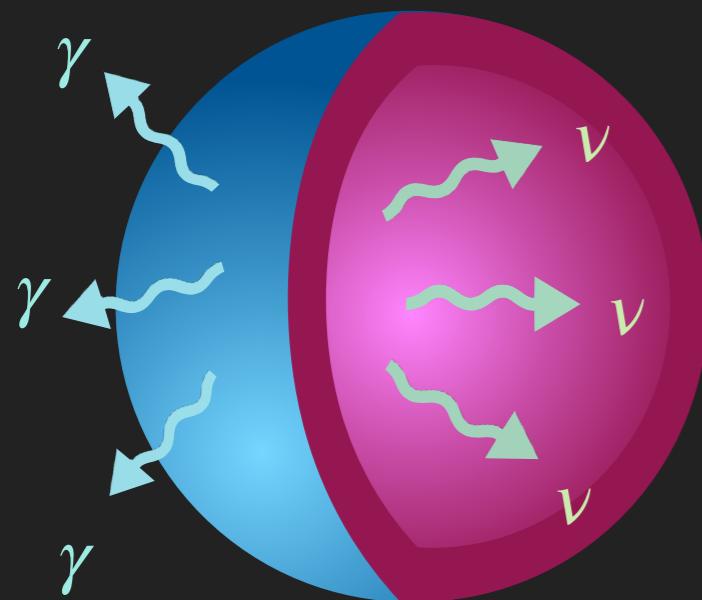
**NS cooling,
heating and
DM capture**

A simple NS model



- Age $t_{\text{NS}} \gtrsim 2$ Gyr (old) & isolated
- Near the Sun (< 10 pc)
- Non-rotating
- $M \sim 1.44M_{\odot}$ and $R \sim 10.6$ km
- Two-layers:
 - A thin envelope
 - Interior with average baryonic density $\bar{\rho}_b \simeq 10^{13} \text{ g cm}^{-3}$

NS cooling



- ▶ Two cooling effects:

- Neutrino emission

$$L_\nu \approx 1.9 \times 10^{23} \left(\frac{T_{\text{NS}}}{10^7 \text{ K}} \right)^8 \text{ erg s}^{-1}$$

- Photon emission

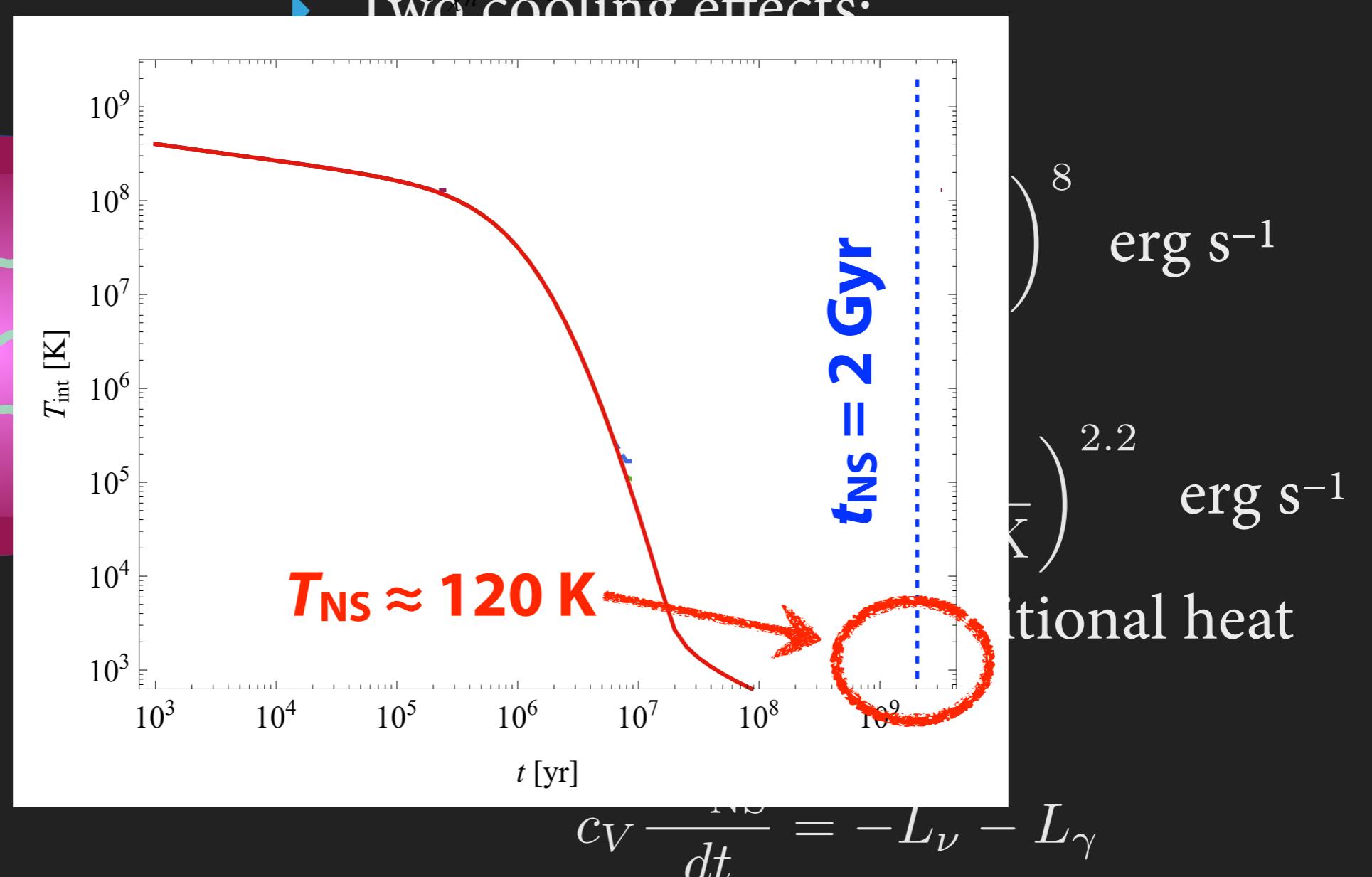
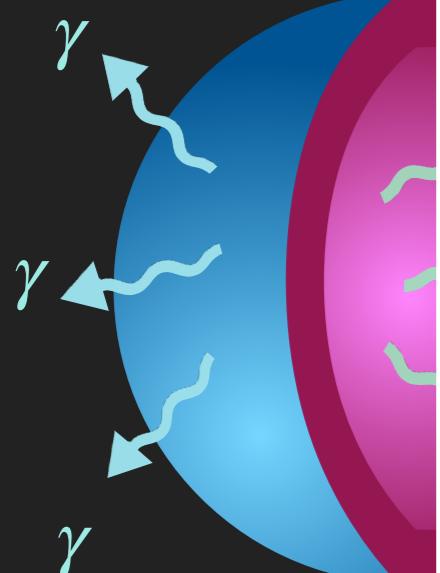
$$L_\gamma \approx 8.98 \times 10^{32} \left(\frac{T_{\text{NS}}}{10^8 \text{ K}} \right)^{2.2} \text{ erg s}^{-1}$$

- ▶ NS temperature w/o additional heat source

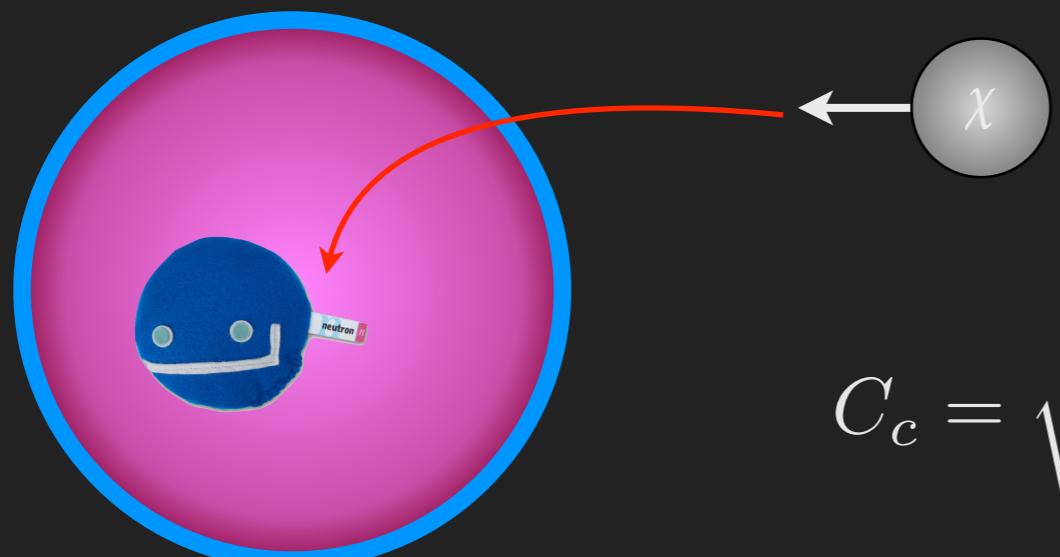
$$c_V \frac{dT_{\text{NS}}}{dt} = -L_\nu - L_\gamma$$

COOLING

NS cooling

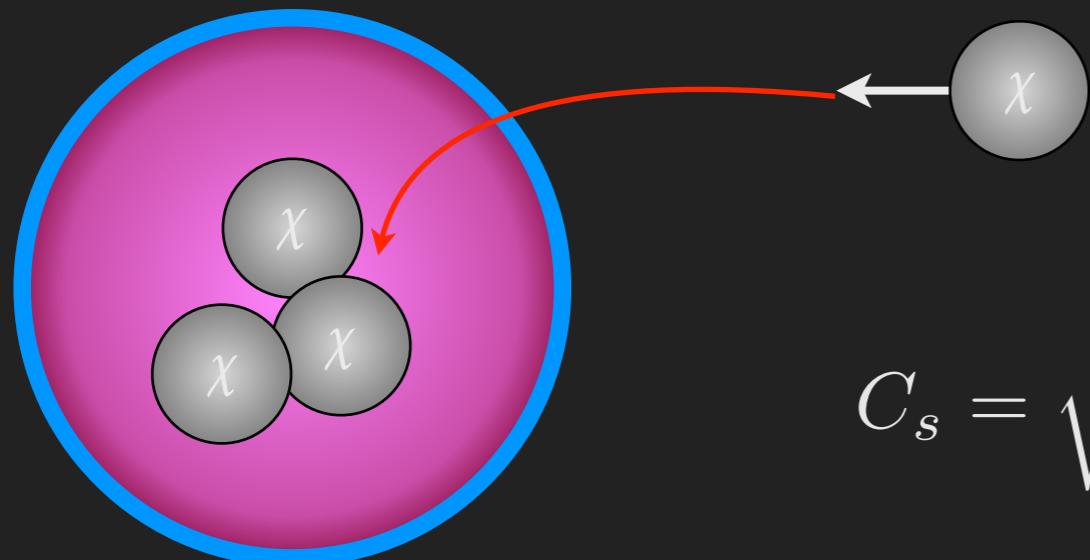


Capturing DM particles



NS capture C_c
 DM-nucleon interaction $\sigma_{\chi n}$

$$C_c = \sqrt{\frac{6}{\pi}} \frac{\rho_0}{m_\chi} \frac{v_{\text{esc}}(r)}{\bar{v}^2} \frac{\bar{v}}{1 - 2GM/R} \xi N_n \sigma_{\chi n}$$



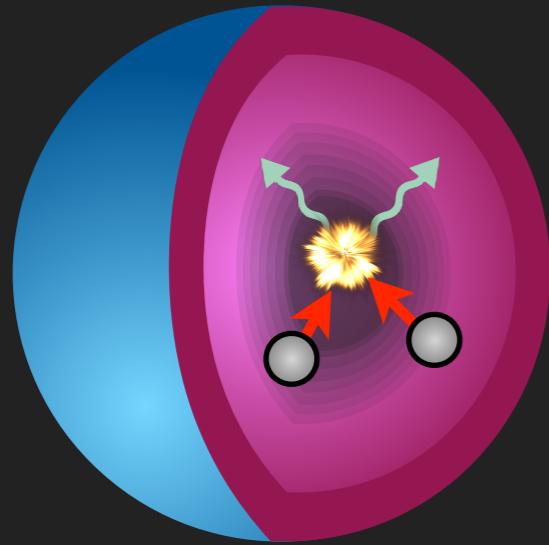
DM self-capture C_s
 DM-DM interaction $\sigma_{\chi\chi}$

$$C_s = \sqrt{\frac{3}{2}} \frac{\rho_0}{m_\chi} K(v_{\text{esc}}) \frac{1}{1 - 2GM/R} \sigma_{\chi\chi}$$

**Number of DM
particles N_χ in NS**

$$\frac{dN_\chi}{dt} = C_c + C_s N_\chi - C_a N_\chi^2$$

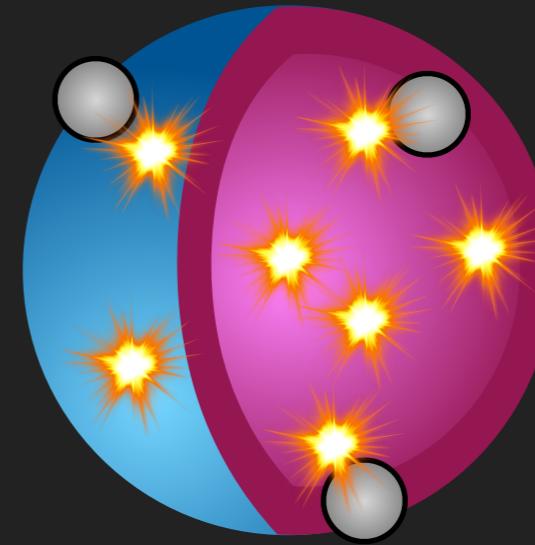
Heating effects from DM



DM annihilation

$$\mathcal{E}_\chi = 2m_\chi \times \boxed{\frac{1}{2}C_a N_\chi^2} \times f_\chi$$

ann. rate



DM kinetic heating

$$\mathcal{K}_\chi = \boxed{C_c E_s}$$

cap. rate \times energy deposition

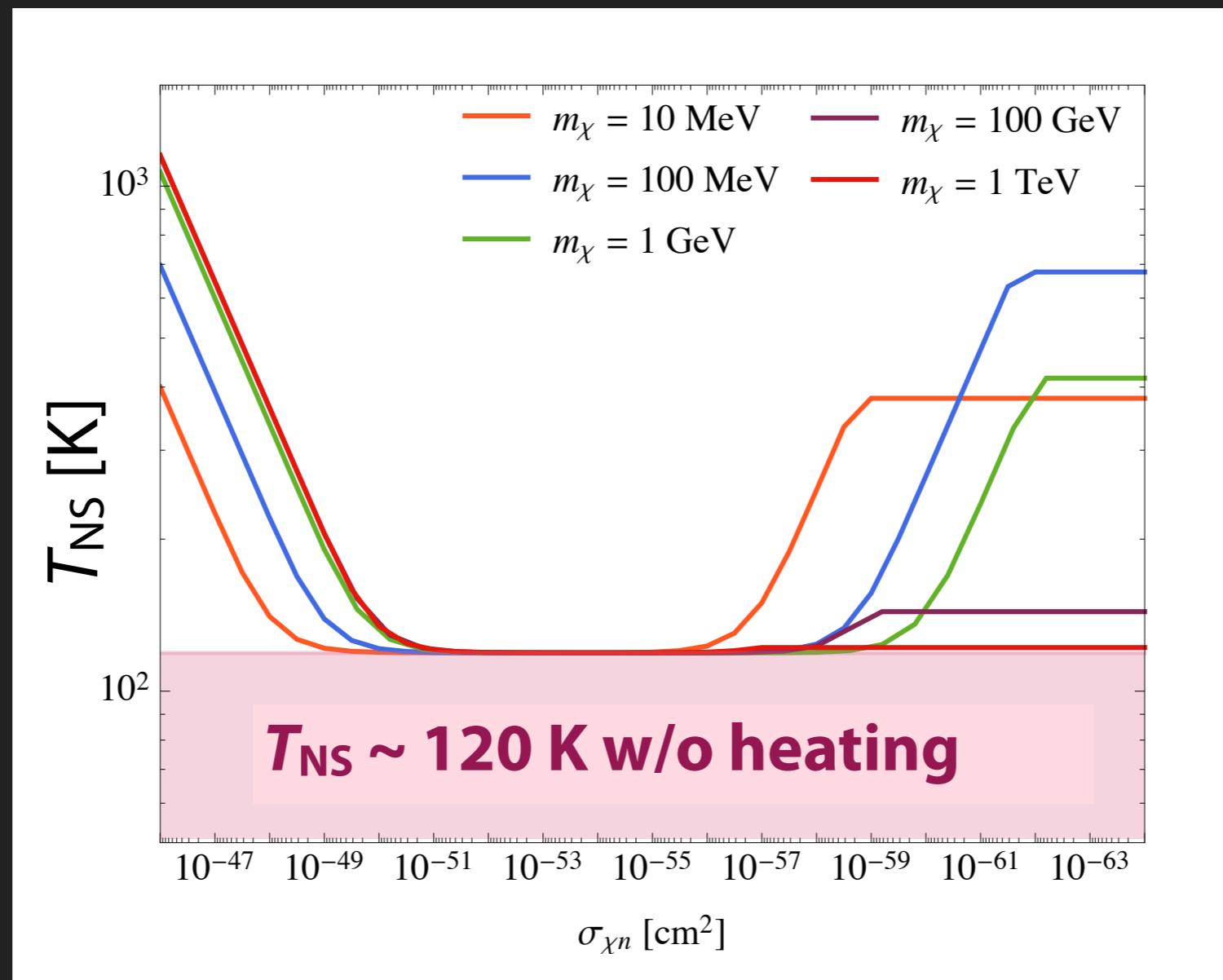
$$c_V \frac{dT_{\text{NS}}}{dt} = -L_\nu - L_\gamma + \mathcal{E}_\chi + \mathcal{K}_\chi$$



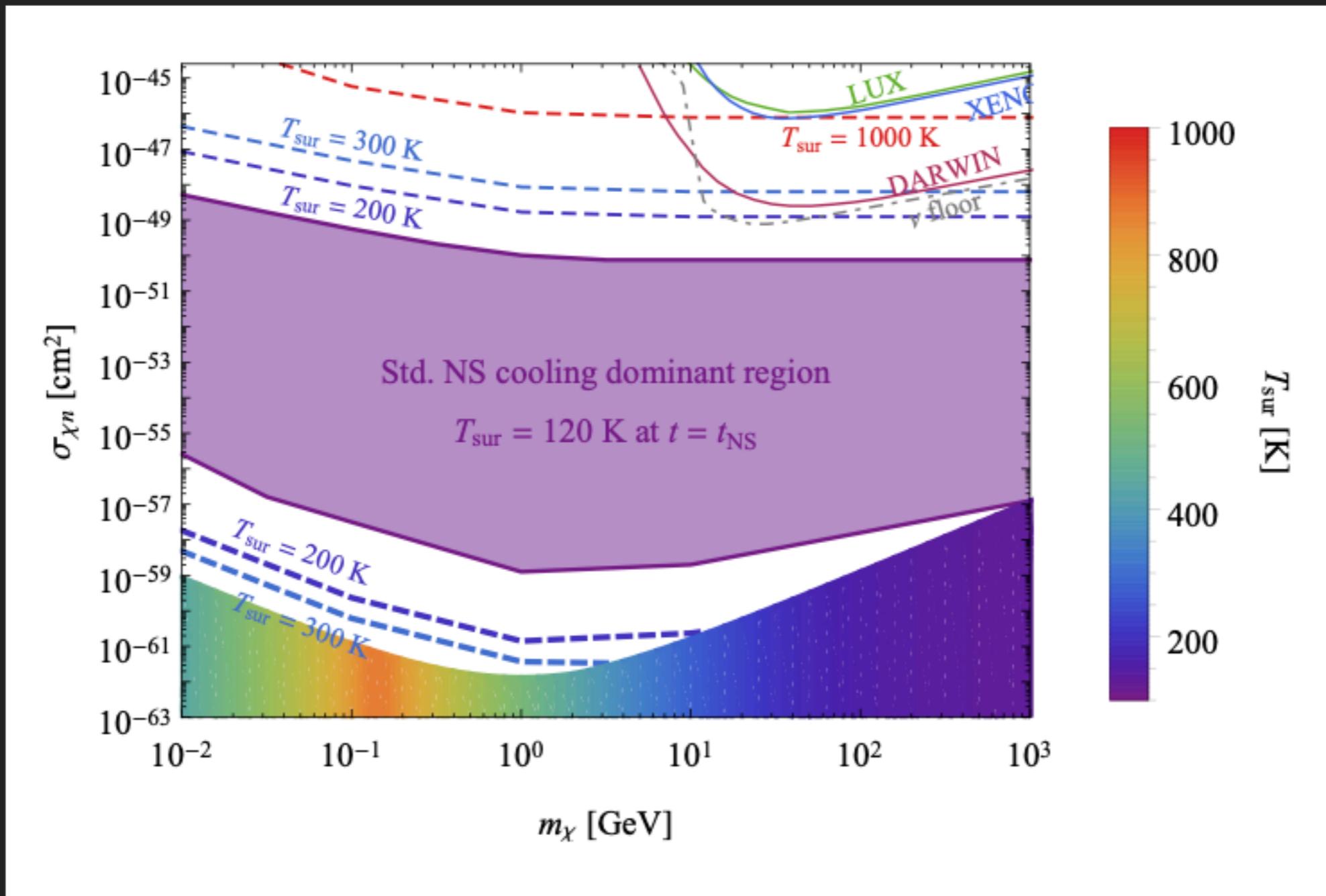
Part III

DM properties and NS tempe- rature

A 2-Gyr-old NS temperature T_{NS}



NS temp. as a complementary probe to $\sigma_{\chi n}$





Part IV

Summary

Summary

- ▶ DM self-capture plays an important role when $\sigma_{\chi n}$ is negligible
- ▶ NS will be reheated and looks like it has a relative large $\sigma_{\chi n}$
- ▶ T_{NS} ranging from 100 K to 1000 K correspond to blackbody peak wavelength $2.8 \mu\text{m} \sim 28 \mu\text{m}$: JWST, TMT and E-ELT
- ▶ T_{NS} could act as a complementary probe to $\sigma_{\chi n}$