Imprints of dark stars in the 21-cm signal

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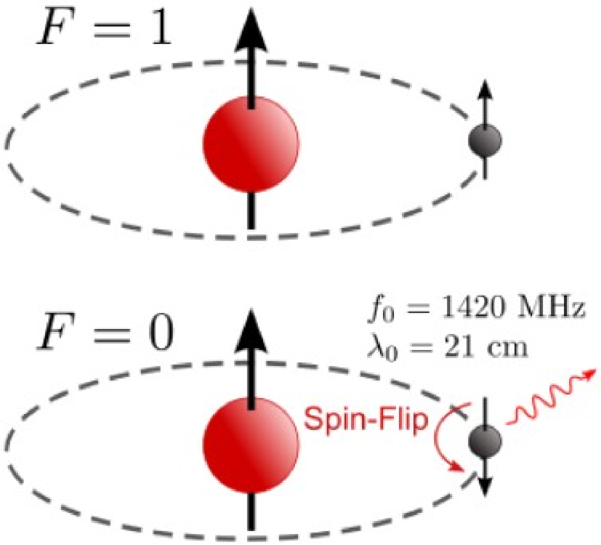
Introduction

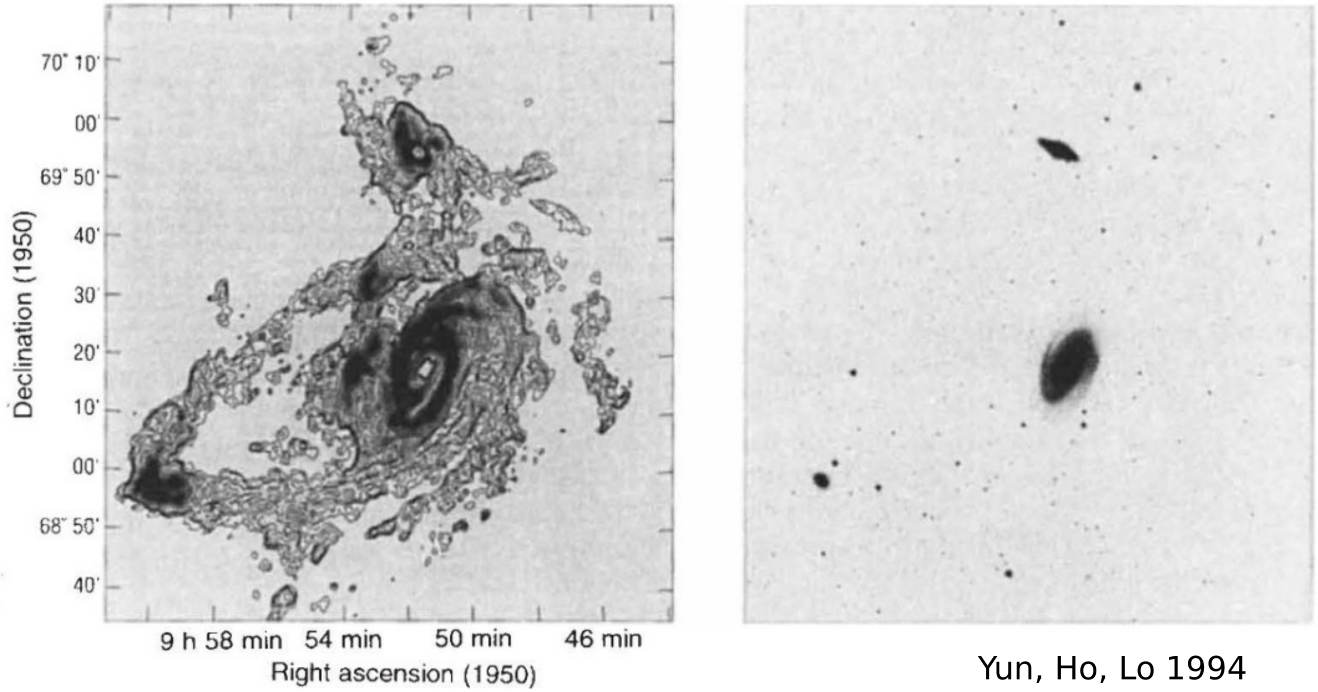
21-cm signal

What is the 21-cm line?



21-cm line photons are emitted from the hyperfine structure transition of neutral hydrogen

Used in radio astronomy due to abundance of HI

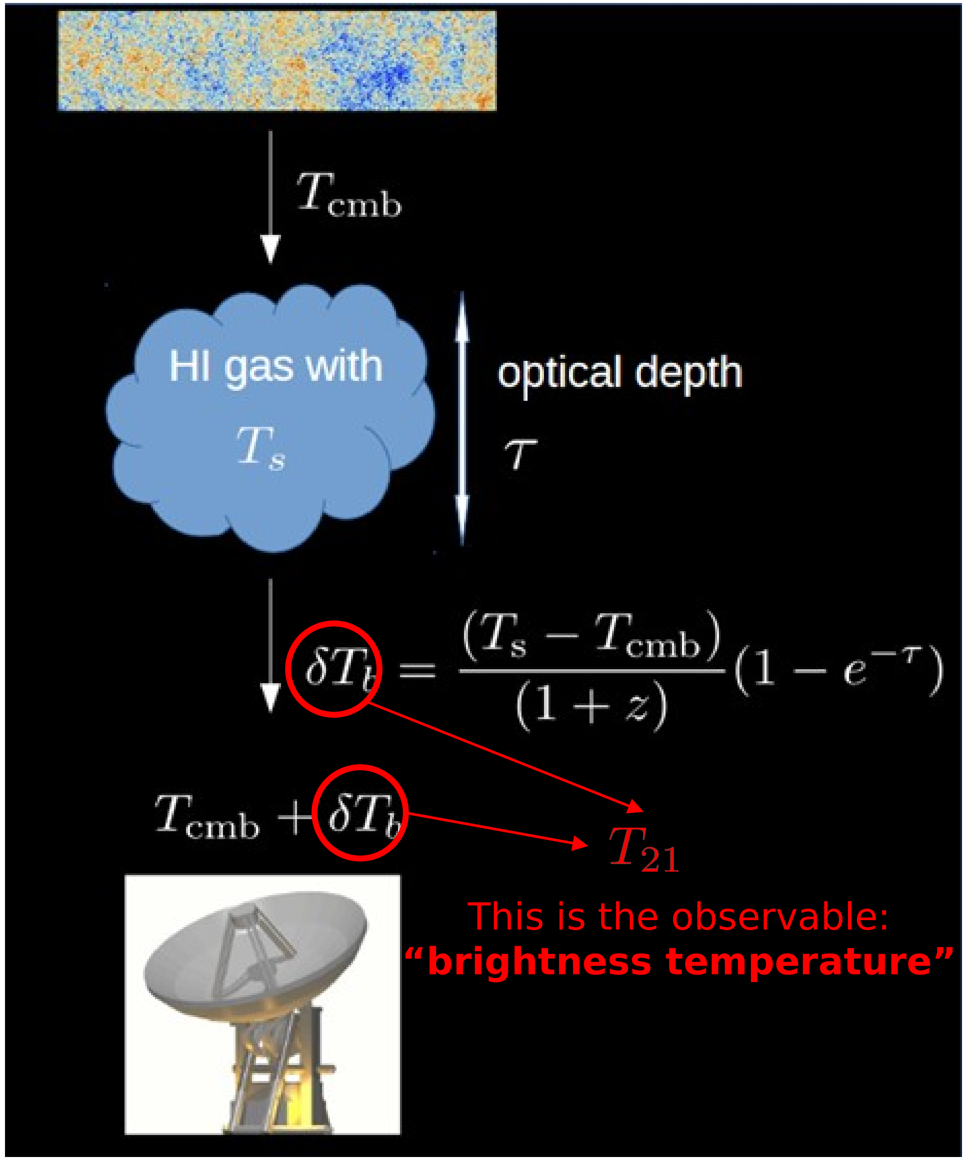


Yun, Ho, Lo 1994

The relative abundance of the hydrogen states defines the **"spin temperature"**.

$$\frac{n_1}{n_0} = \frac{g_1}{g_0} e^{-\frac{E_{21}}{k_B T_s}} \sim 3\left(1 - \frac{E_{21}}{k_B T_s}\right)$$

21 cm line observation



Observe 21 cm line with CMB as background

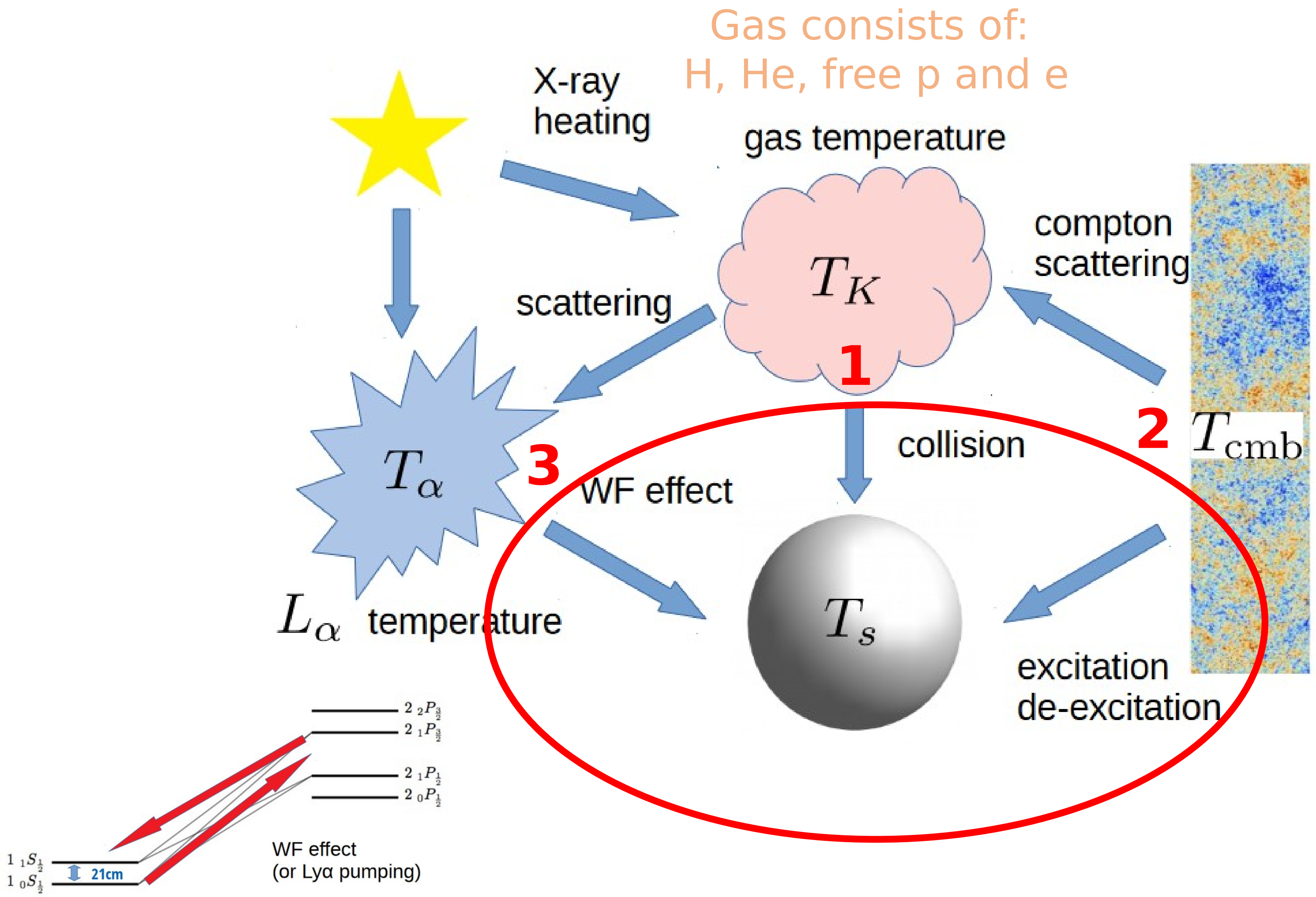
$T_s > T_{\rm CMB}$ Emission

$T_s < T_{\rm CMB}$ Absorption

21 cm line observations:

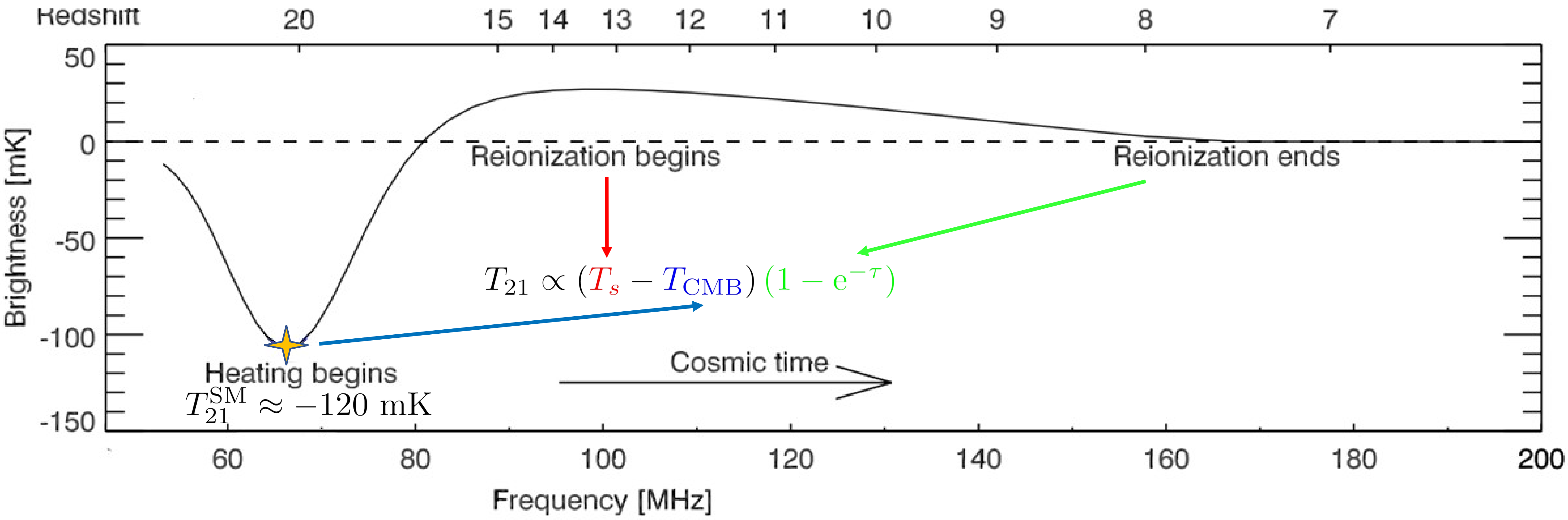
- Constrain properties of the intergalactic medium (IGM) and can shed light on structure formation.
- Provide a means to observe the Universe at different redshifts (reionization).

What determines the spin temperature? (Standard model)



21-cm signal

Pritchard, Loeb 2012



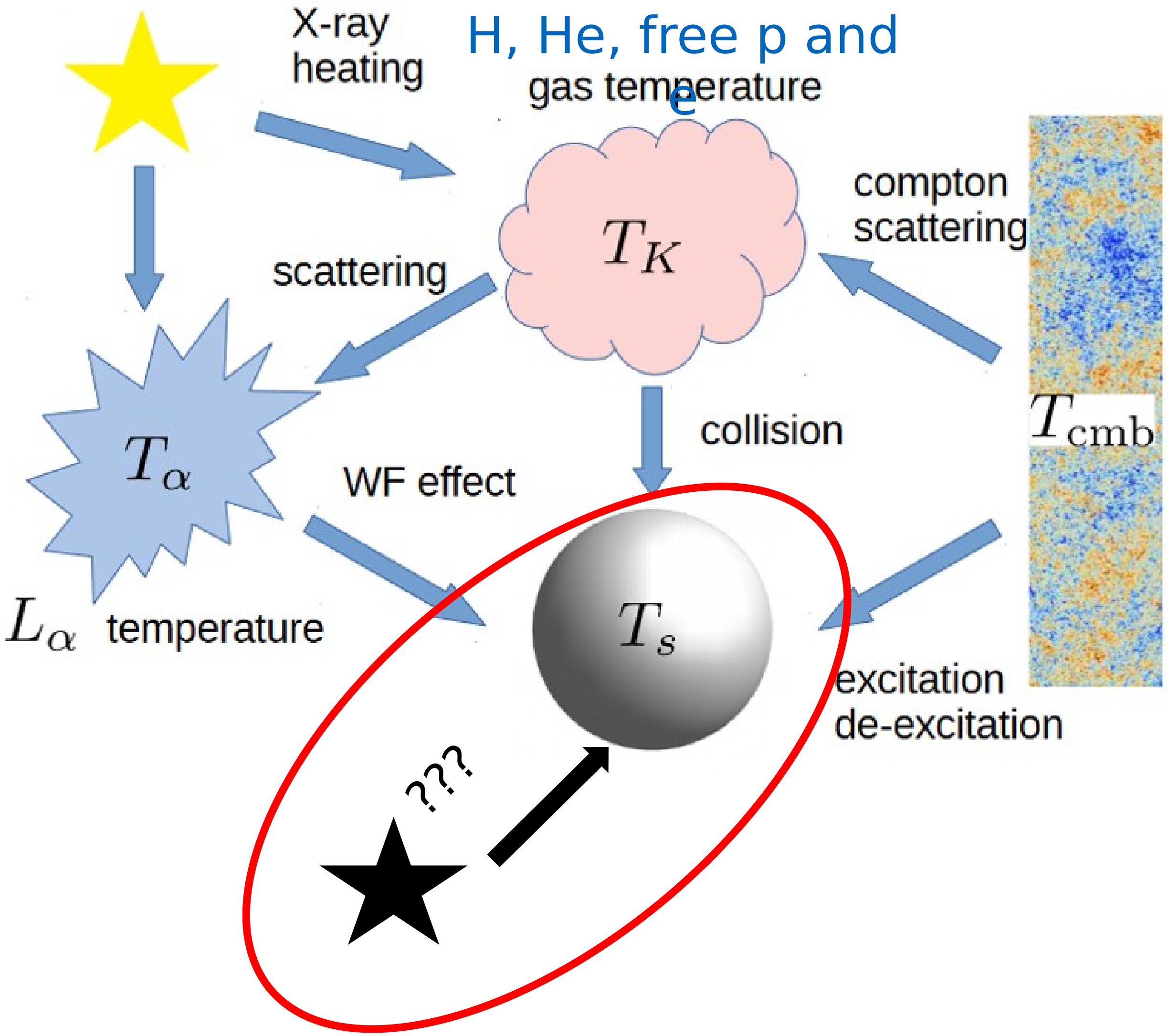
Our idea

Could **dark stars** modify the spin temperature and consequently the amount of H?

Questions to address:

1. What are dark stars?
2. How do they inject energy?
3. What are the consequences on the 21-cm signal and reionization?

Gas consists of:
H, He, free p and e



1. What are dark stars?

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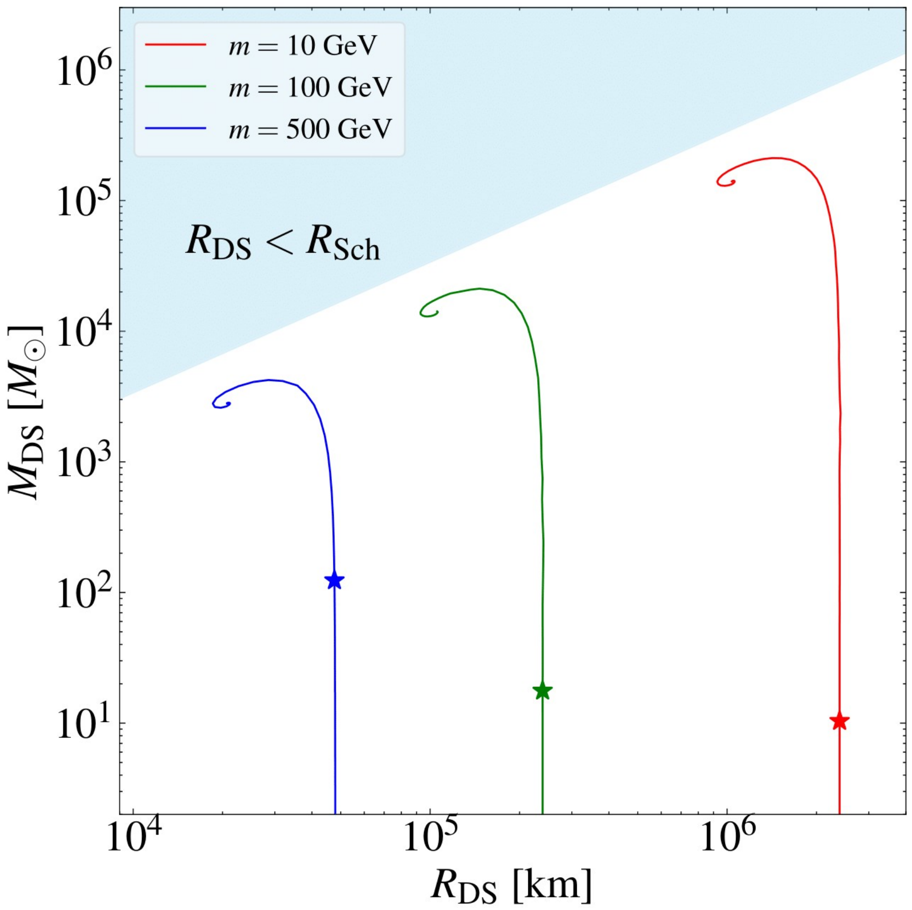
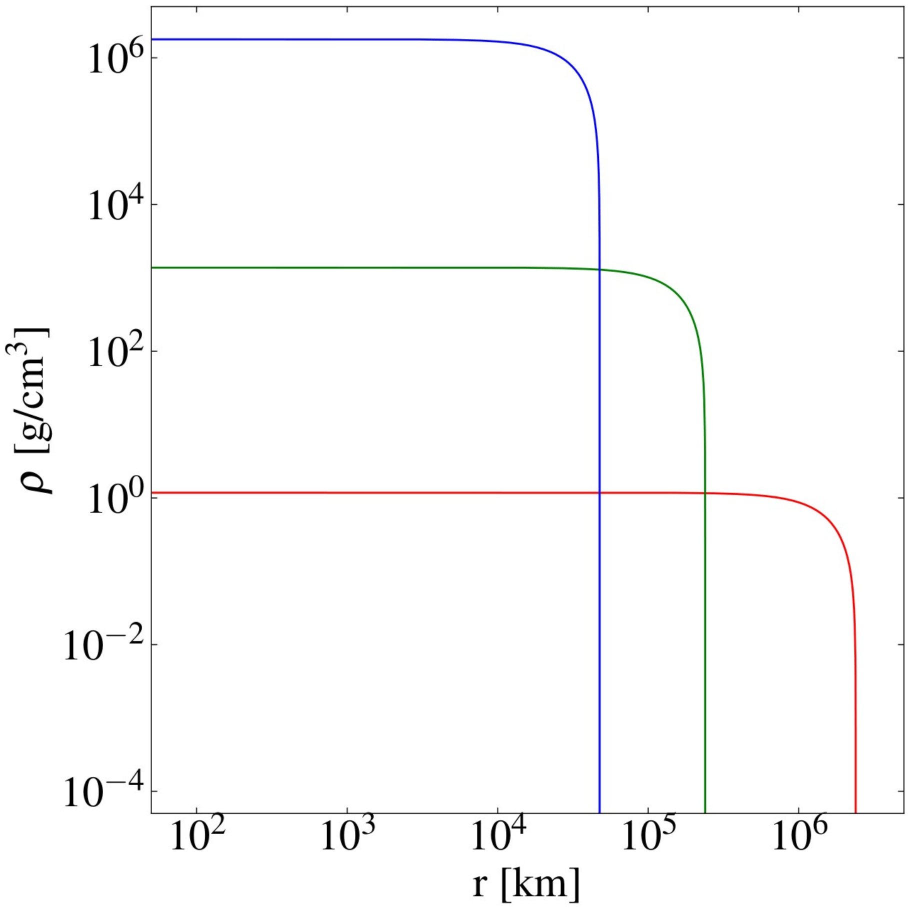
Self-interacting particle dark matter (DM) can form compact objects, the so-called **“dark stars” (DS).**

- **“Dark electron”**, subdominant component of DM (<1%).
- Interaction mediated by the analogous, massive **“dark photon”**.
- Structure of the DS depends on particle masses and the strength of the self-interaction.





How do dark stars form?

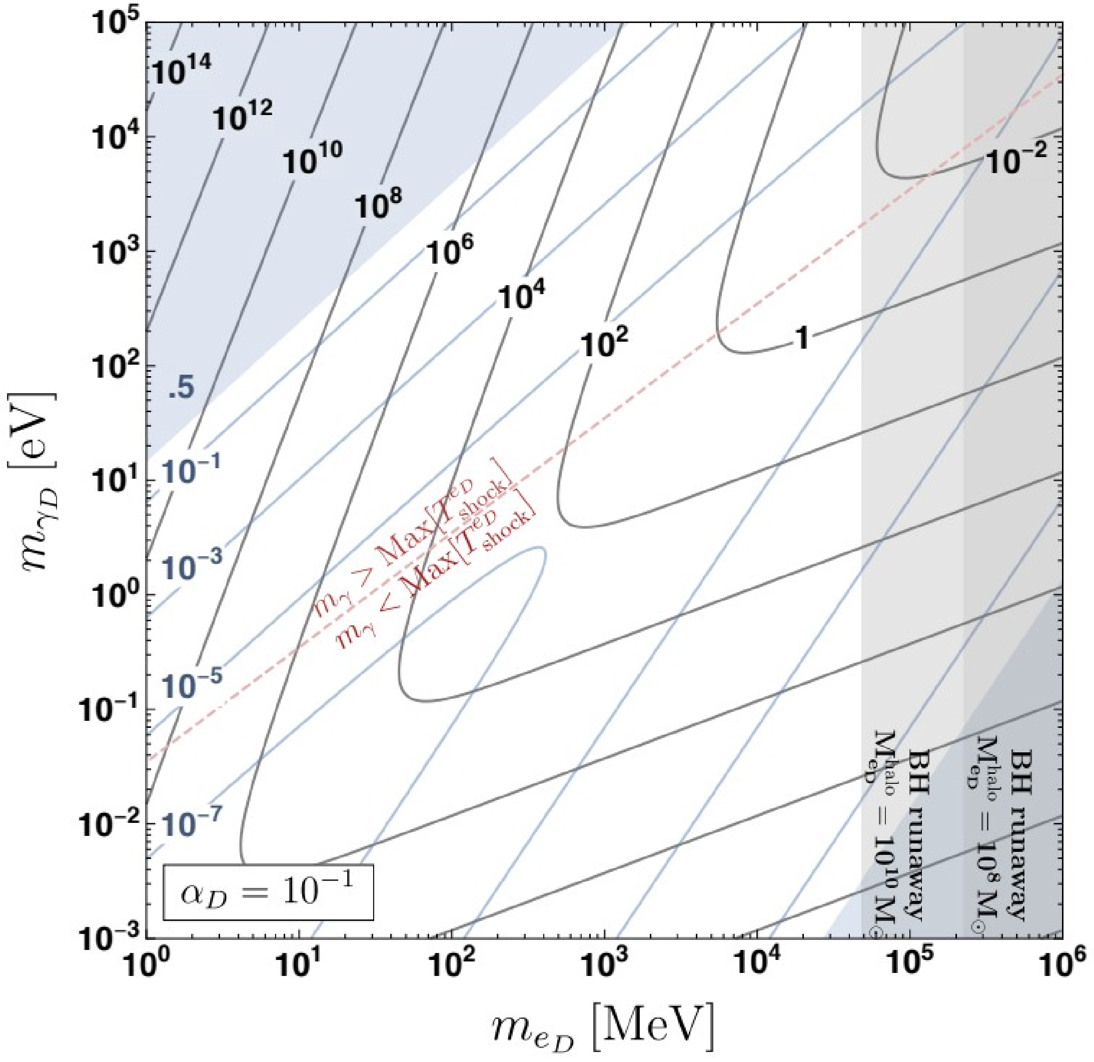
Density perturbation in early Universe grows. DM halo forms, dark electron component forms a **“clump”.**

Gravitational instabilities will force the clump to **compactify**.

The clump can collapse further only if there is an efficient mechanism that can **evacuate energy** from the system (radiation).

Dark photon emission (bremsstrahlung) will result in a contraction of the clump. Eventually it will lead to **fragmentation** of the clump into dark stars.

Chang, *et al.* 2018

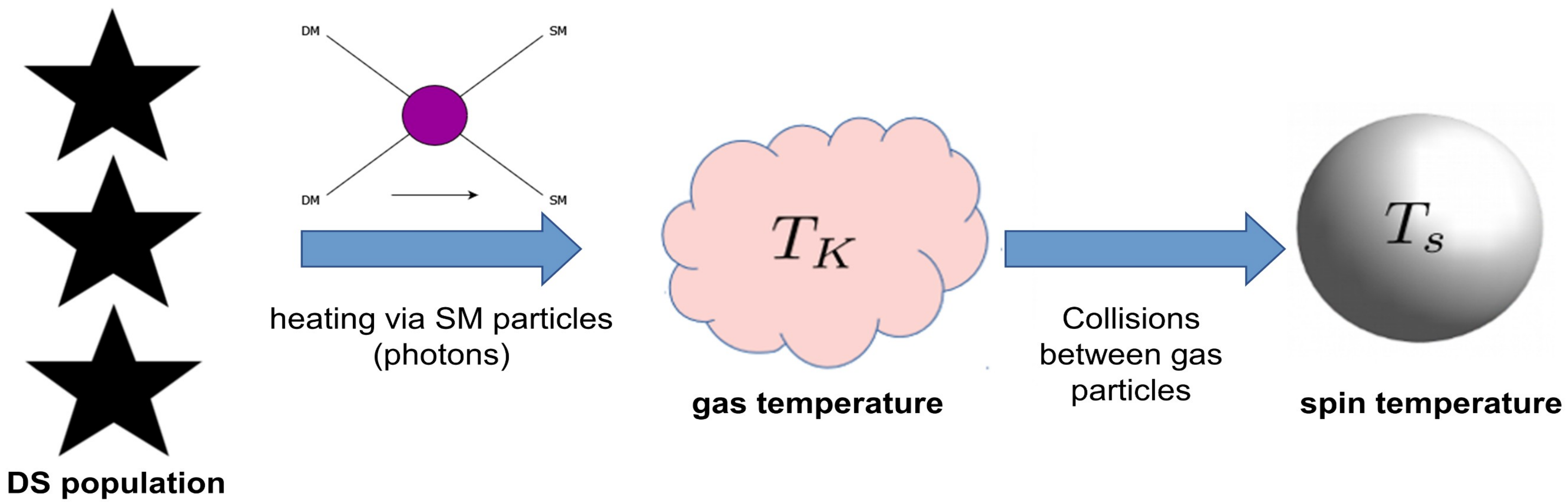


2. How do dark stars inject energy?

3. How do dark stars inject energy?

- The **high DM density** of DSs offers a unique environment to probe DM number changing processes.
- DM particles inside a DS could be **annihilating** into Standard Model particles.
- This would lead to a **luminosity:**

$$L_{\rm ann} \simeq 1.6 L_\odot \left(\frac{(\sigma v)_{\rm ann}}{10^{-44}\ {\rm cm^3\,s^{-1}}}\right)\left(\frac{R_{\rm DS}}{10^5\ {\rm km}}\right)^3\left(\frac{\rho_c}{10^3\ {\rm g\,cm^{-3}}}\right)^2\left(\frac{m}{100\ {\rm GeV}}\right)^{-1}$$



3. What are the consequences?

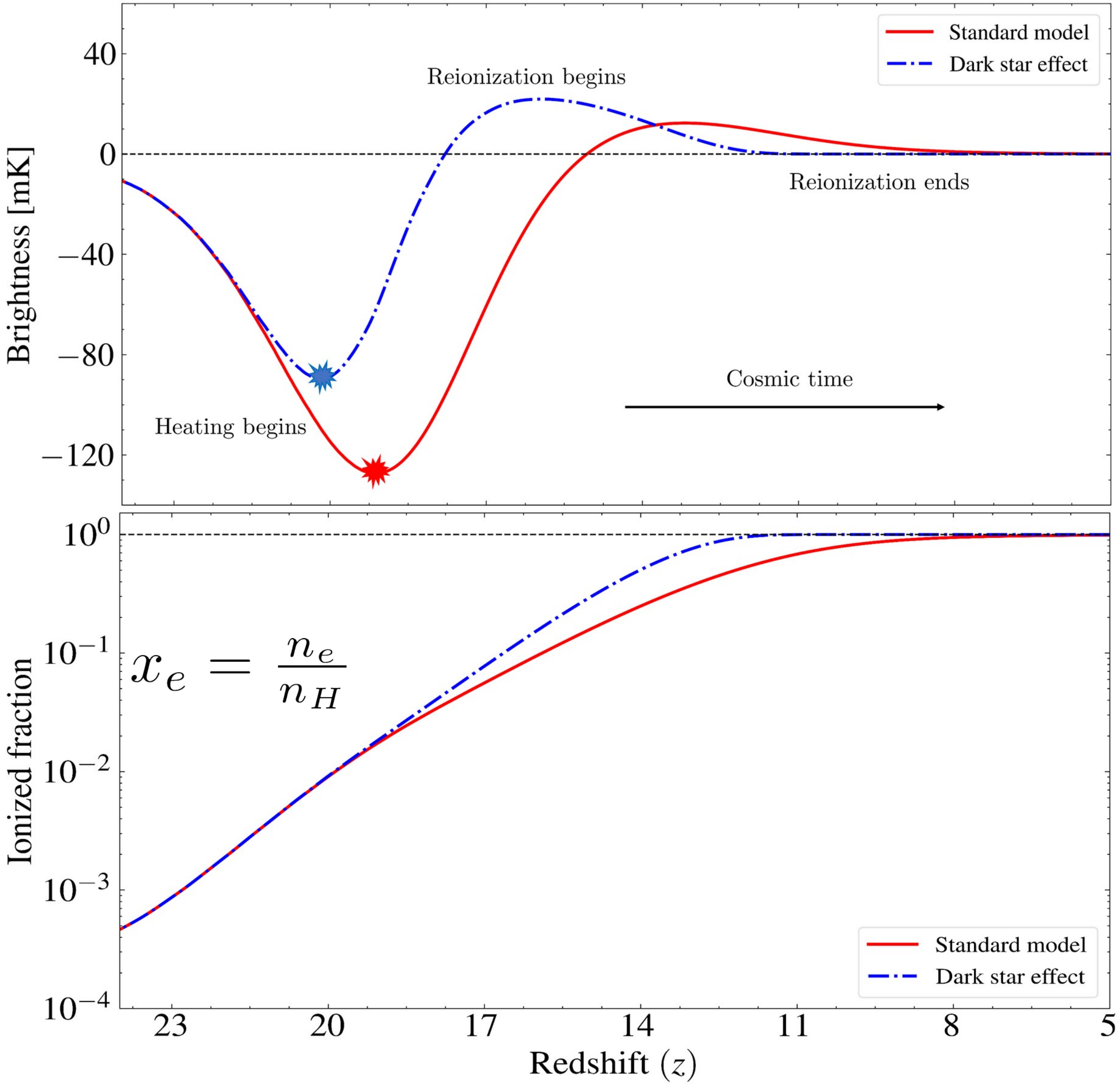
4. What are the consequences for 21-cm signal and reionization?

The **brightness temperature** depends on the spin temperature and the optical depth of the IGM.

$$T_{21} \propto (T_s - T_{\mathrm{CMB}})\,(1 - \mathrm{e}^{-\tau})$$

From both plots we notice that:

- DSs **form earlier** than other stars, so they affect the signal at larger redshifts.
- As an ensemble, they **inject more energy**, which leads to a higher maximum of the brightness temperature.
- Both effects lead to an **earlier reionization**.



Conclusions

- If a small component of DM is self-interacting, it may collapse and form **compact objects called dark stars** inside DM halos.

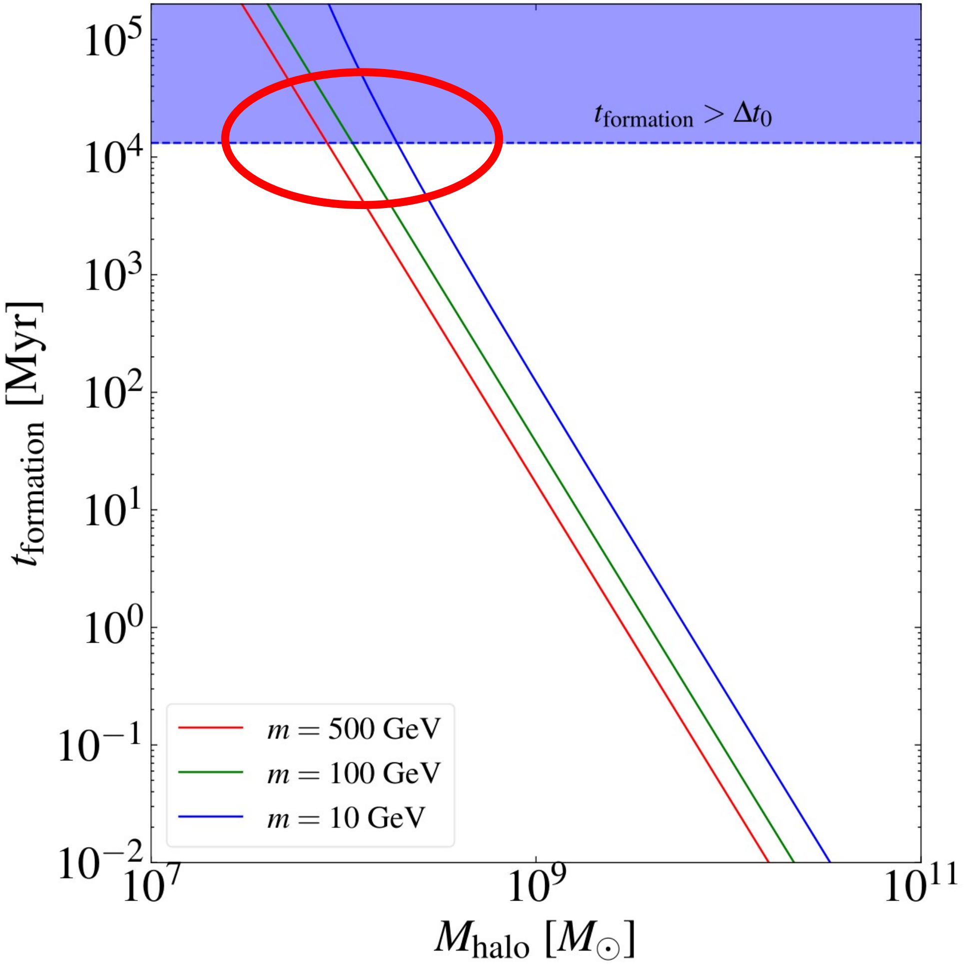
- If this component possesses **DM annihilations** to photons, the high compactness and core densities of these dark stars may produce luminosities significantly larger than those of population II and III stars.

- Dark stars can then **heat up the IGM** and induce dramatic changes in the shape and amplitude of the 21 cm signal as well as in the overall ionized fraction of hydrogen.

Thank you for your attention!

When and where are dark stars?

Halo mass influences dark star **formation timescale**



This sets **minimal halo mass**