Dark Solar Wind

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BSM particles from the Sun

BSM particles from the Sun

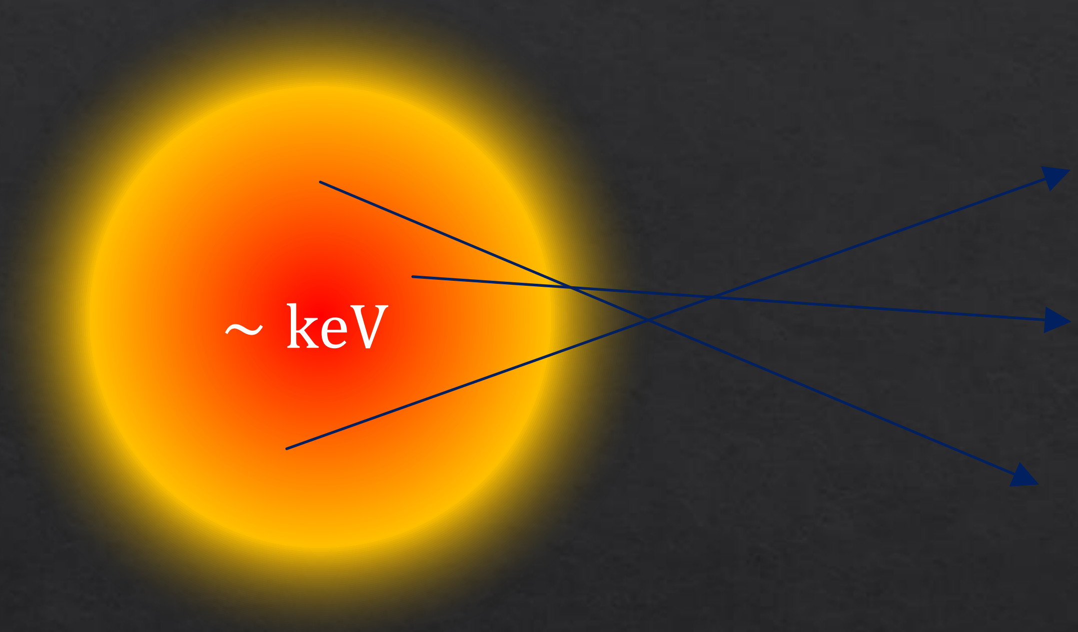
Maximum energy flux on Earth limited by **red giant energy loss**

$$\frac{10^{-2} L_\odot}{4\pi \ \mathrm{AU}^2} \sim 10^{-4} \frac{\mathrm{GeV}}{\mathrm{cm}^3}$$

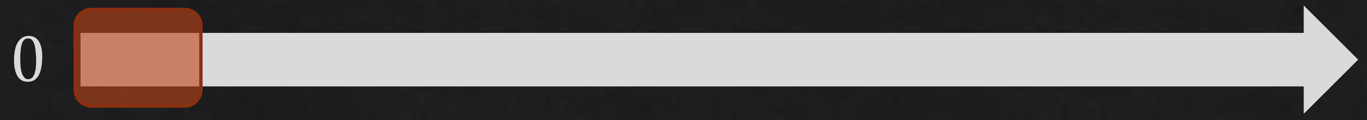
Comparable to local DM energy flux $\rho_{\mathrm{DM}} v_{\mathrm{DM}}$

Probes **different theory space** and **more directly**

BSM particles from the Sun

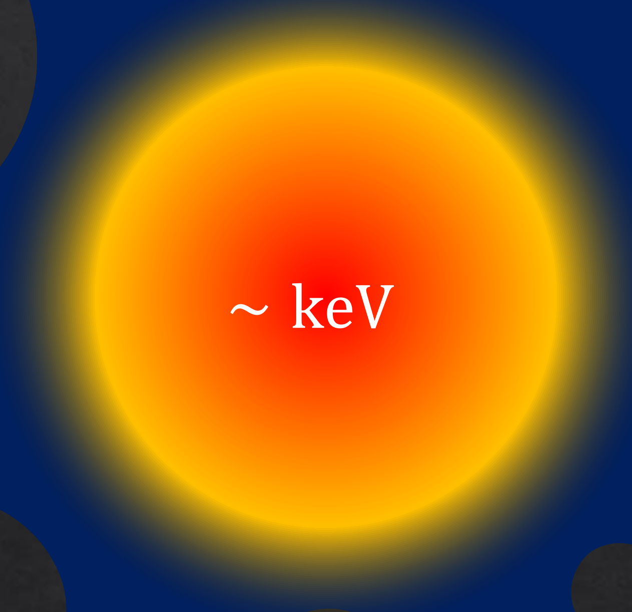


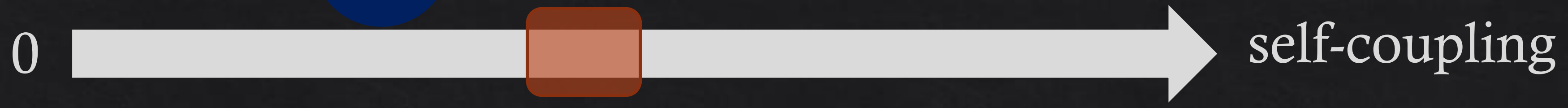
Free streaming



BSM particles from the Sun

Nasty phase space





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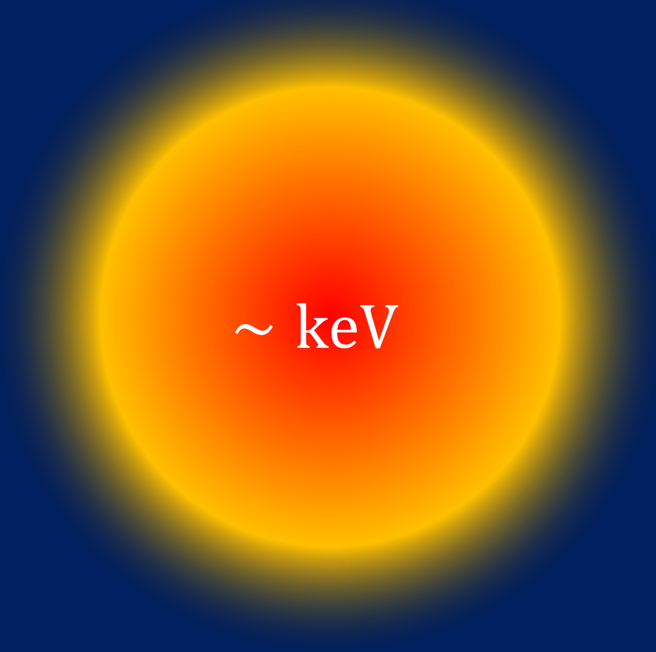

Self-thermalization
Admits **model-independent** description
Predictive
Different and interesting outcomes

Two outcomes from thermalization

1. Denser and Less Energetic

   Before thermalization $n \ll E^3$. After thermalization $n \sim T^3 \sim E^3$ (naively)

2. Fluid Dynamics

   Mean free path ~ (coupling)$^{\#} T^{-1}$ = **microscopic**

   Thermal pressure leads to **relativistic bulk velocities**, $\gamma(1\text{ AU}) \approx 900$ (for light MCPs)

   Boosted thermal distribution: $n \sim \gamma \tilde{T}^3$, $E \sim \gamma \tilde{T}$

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Boosted thermal distribution: $n \sim \gamma \tilde{T}^3$, $E \sim \gamma \tilde{T}$

Overall: n increased by *at least* 10^3
E decreased by *at least* 10^3
compared to the free-streaming case

Fluid Dynamics

$$\frac{1}{r^2}\partial_r\left[r^2\gamma^2 v(\tilde{\rho}+\tilde{p})\right]=\dot{Q}$$

$$\frac{1}{r^2}\partial_r\left[r^2\gamma^2 v^2(\tilde{\rho}+\tilde{p})\right]=-\partial_r\tilde{p}$$

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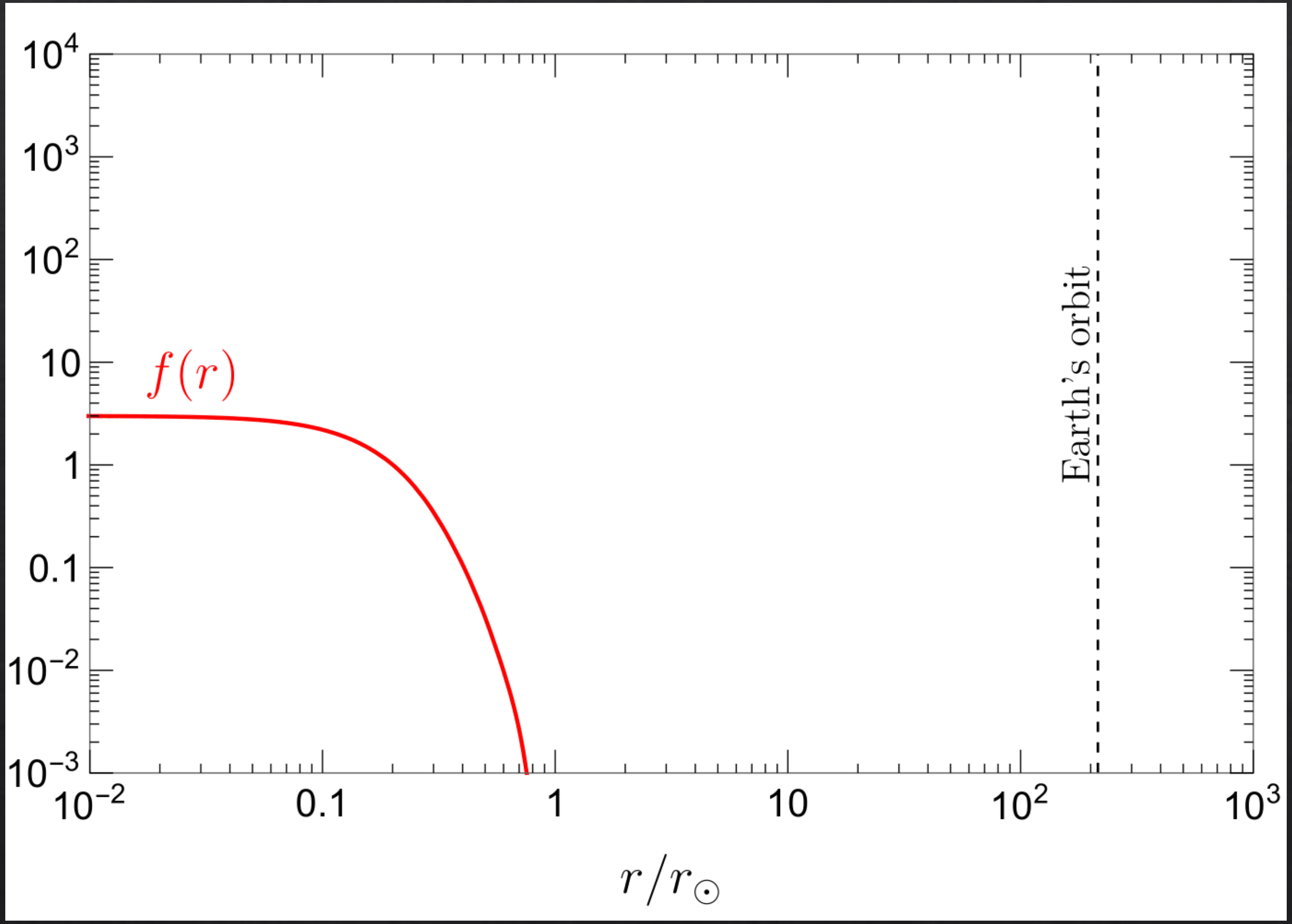
$$p = \rho/3$$

Energy Flux

$$\#\,\gamma^2 v\,\tilde{T}^4 = \frac{L_\chi}{4\pi r^2}$$

Fluid Dynamics



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Bulk Velocity

$$\frac{d \ln v}{d \ln r} = \left(\frac{1/3 + v^2}{1/3 - v^2}\right)\left[f(r) - \frac{2(1 - v^2)}{1 + 3v^2}\right]$$

$$f(r) = \frac{\dot{Q} r^3}{\int_0^r \dot{Q} r'^2 dr'}$$

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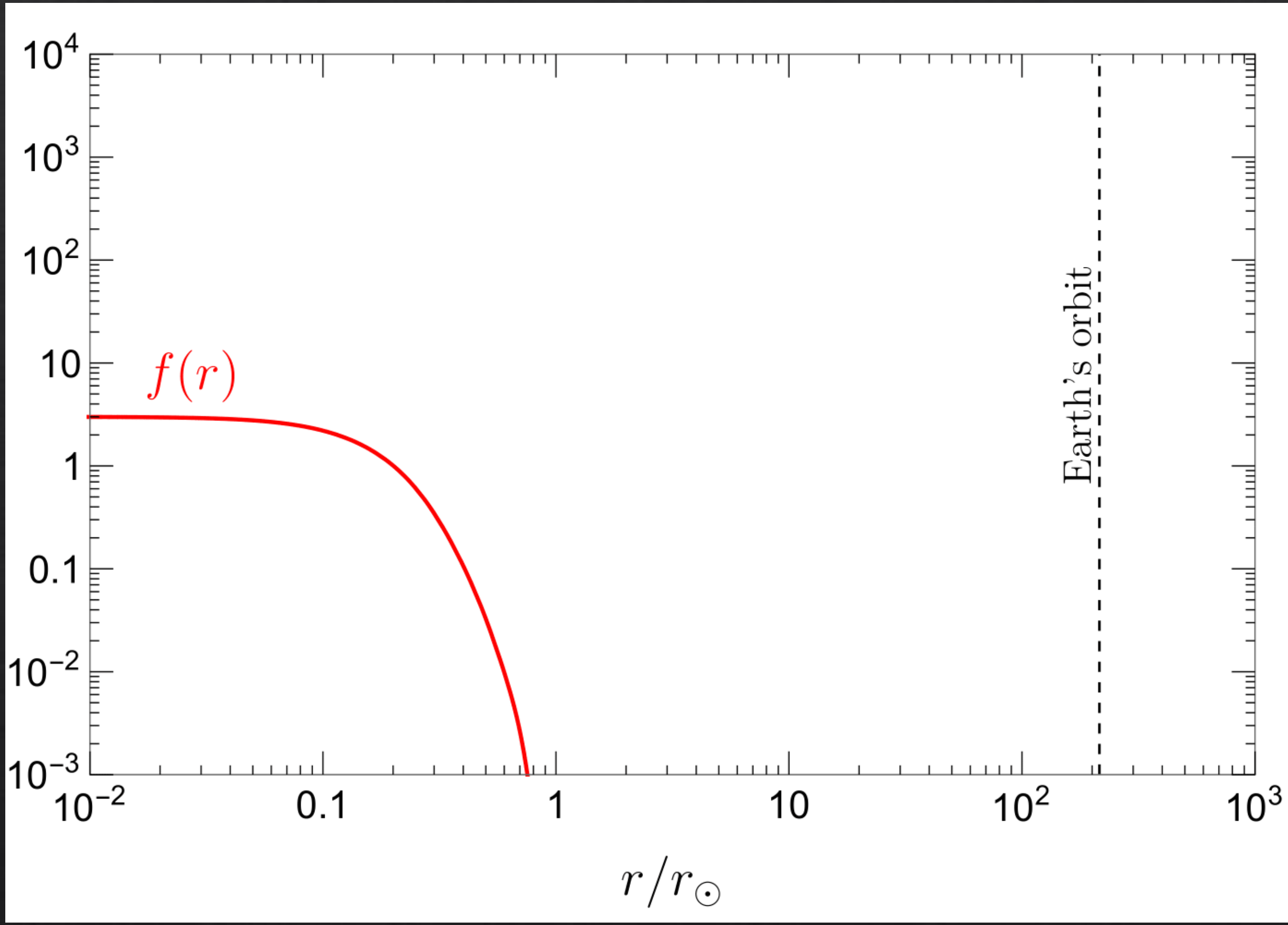

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Boundary Conditions

$v = 0$ at $r = 0$

$\tilde{T} = 0$ at $r \to \infty$

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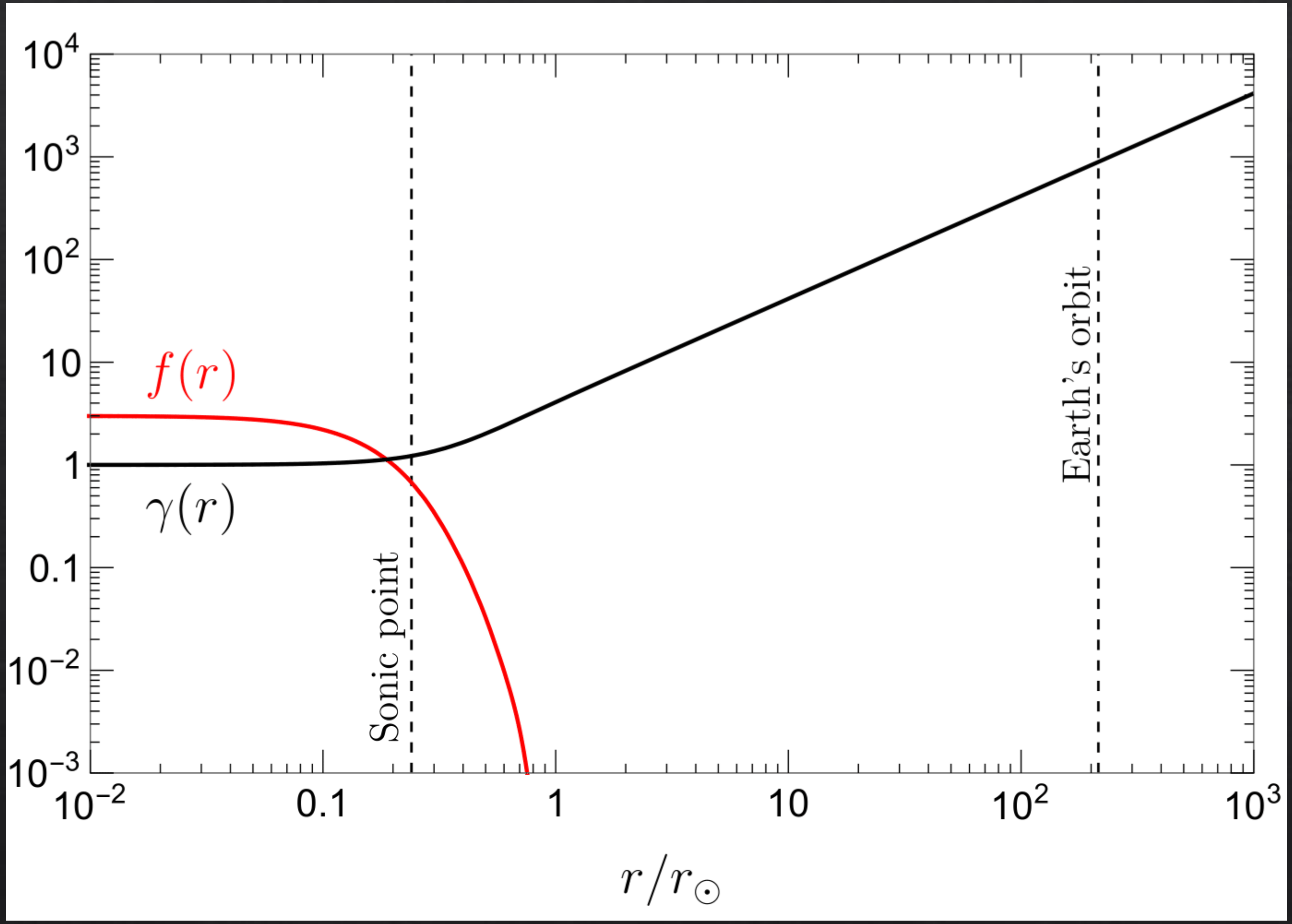

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Transonic Solution

analogous to **Parker's solar wind**, asymptotes to "fireball" solution $\gamma \propto r/r_{\mathrm{sonic}}$ at $r \gg r_{\mathrm{sonic}} = 0.2r_\odot$

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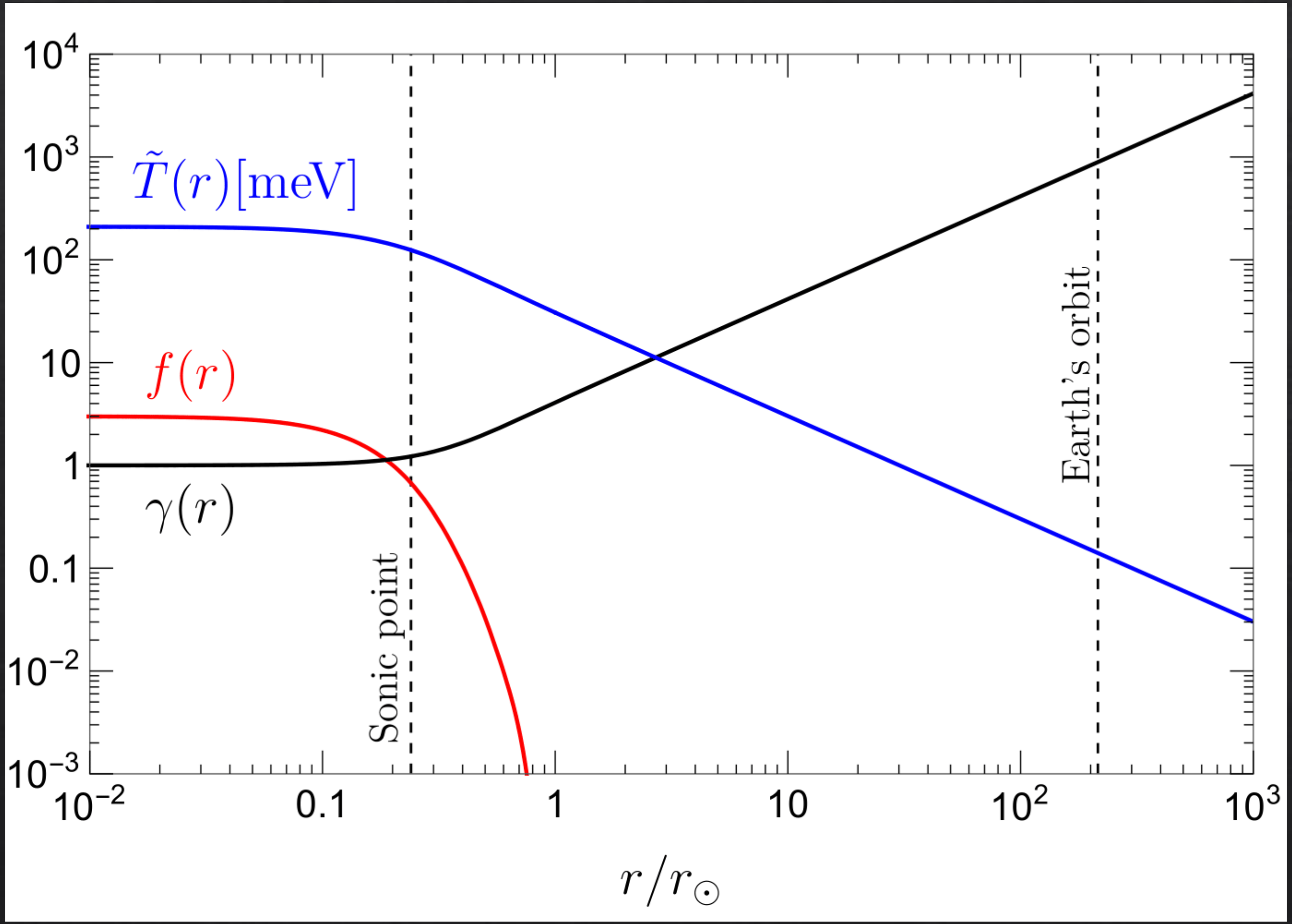

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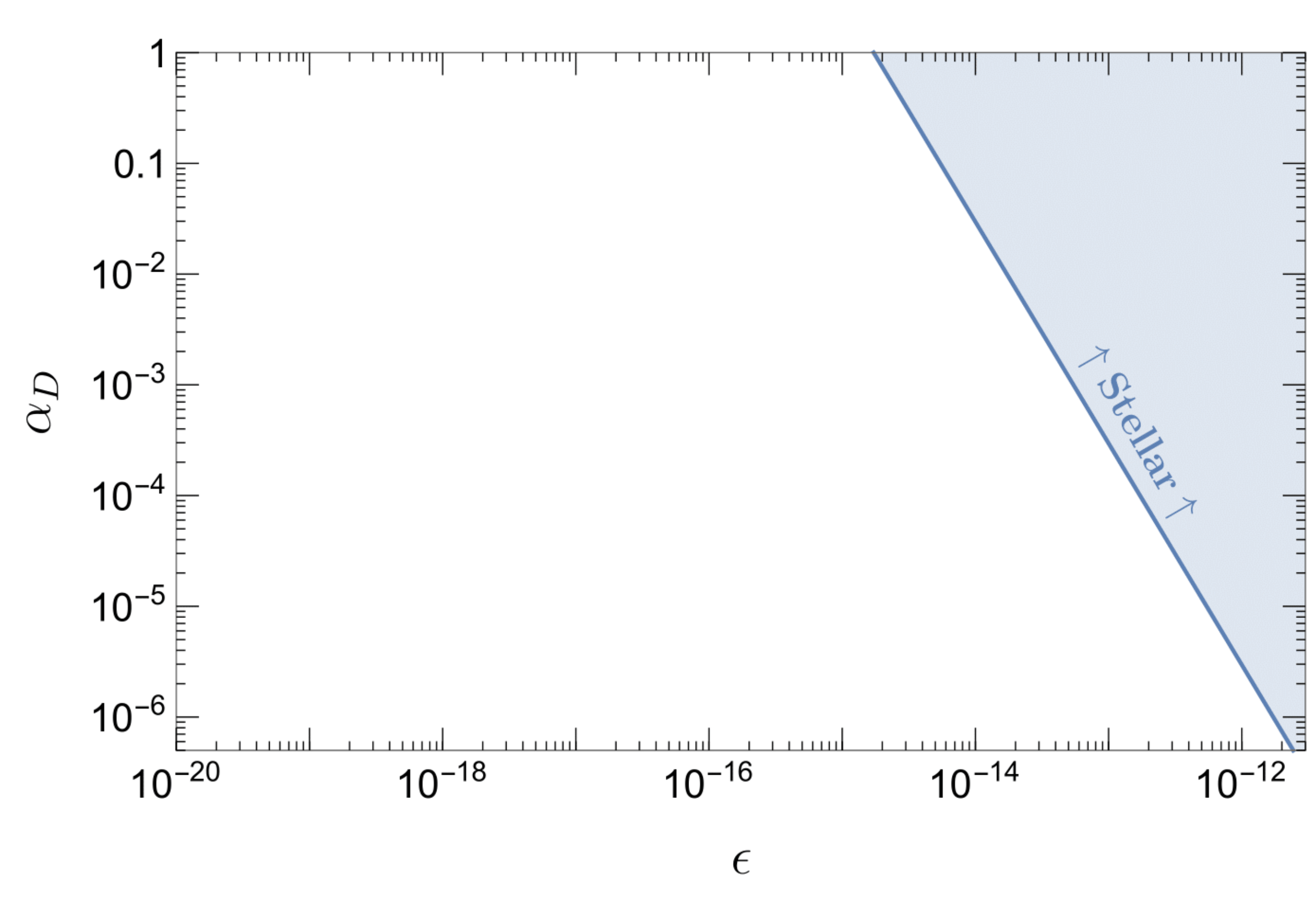
Millicharged Particles

dark fine-structure constant α_D, kinetic mixing ϵ, negligible masses



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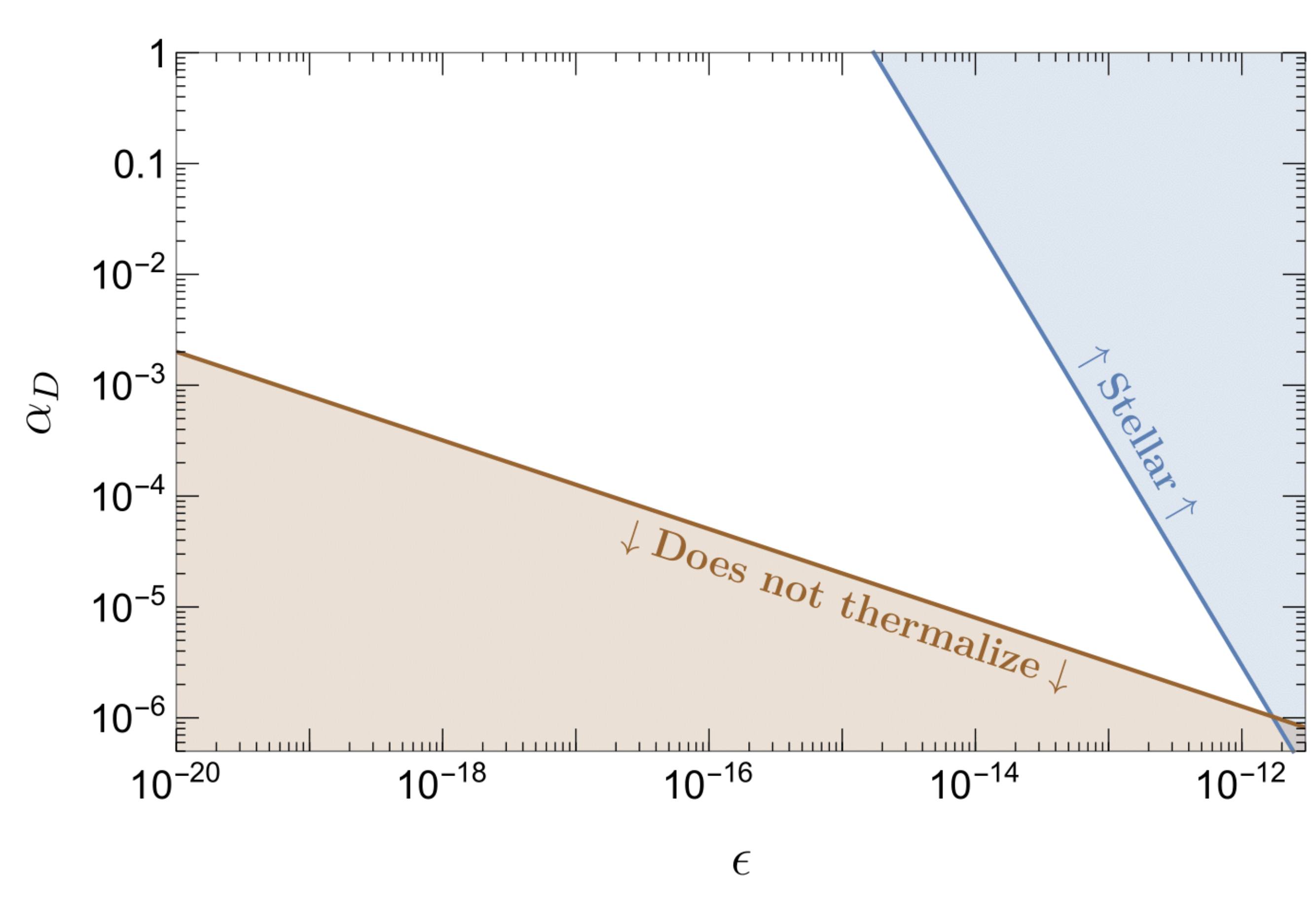

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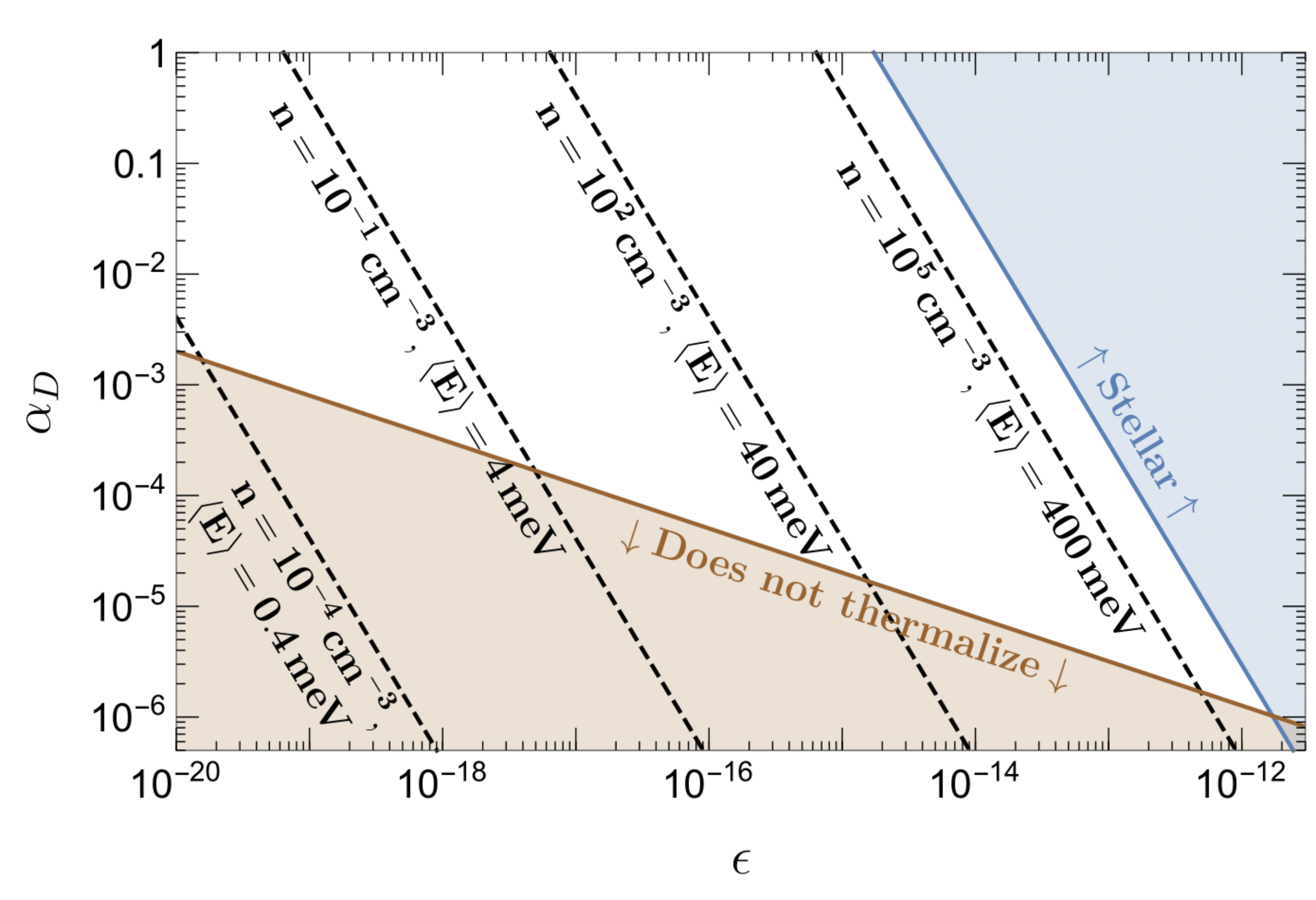


Summary

- The Sun is a good source of light BSM particles
- Self-thermalization of these particles leads to very different outcomes compared to the ordinary free-streaming scenario:
  - $\gtrsim 10^3$ **denser**,
  - $\gtrsim 10^3$ **less energetic**,
  - **relativistic fluid outflow**

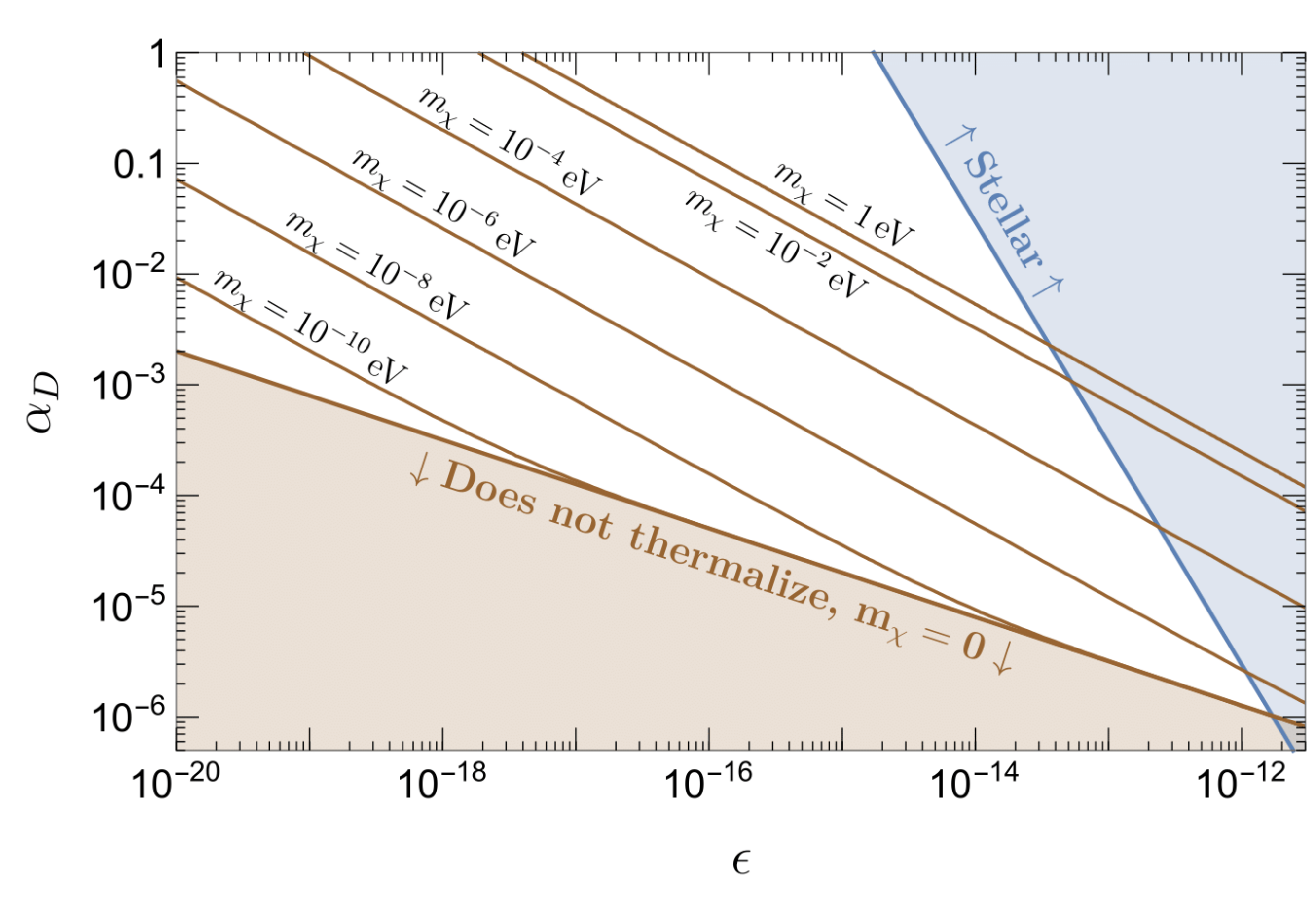
Dark Solar Wind!

Future Directions

- Detection strategies
- Neighboring parameter space
- Other models
- Other astrophysical objects
- Astrophysical consequences

Thank You

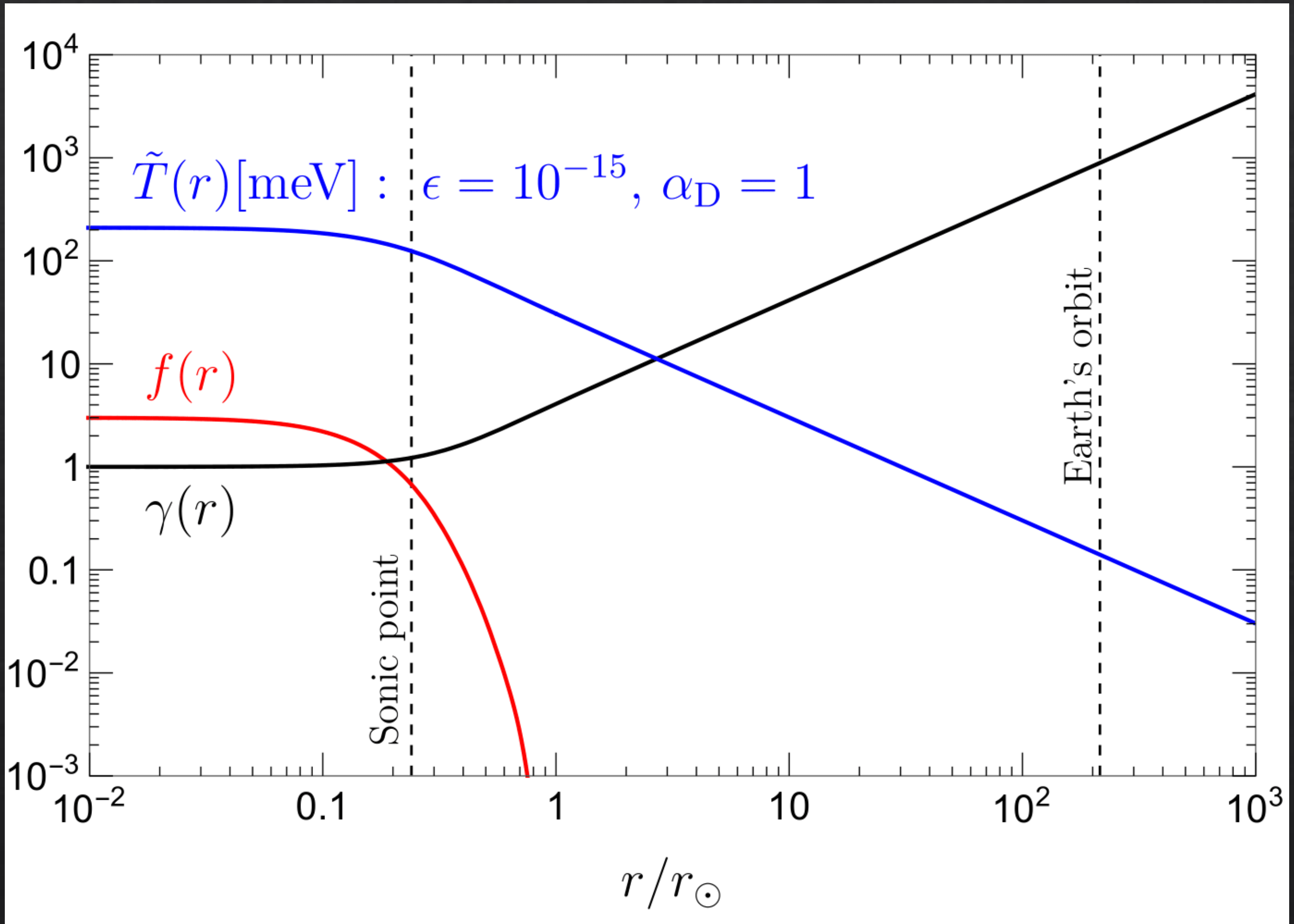
Massive Millicharged Particles



Millicharged Particle Predictions

- Bulk velocity: $\gamma(r) \approx 893\left(\frac{r}{1\ \text{AU}}\right)$
- Comoving temperature: $\tilde{T} \approx 0.1\ \text{meV}\left(\frac{\epsilon}{10^{-15}}\right)^{\frac{1}{2}}\left(\frac{\alpha_D}{1}\right)^{\frac{1}{4}}\left(\frac{r}{1\ \text{AU}}\right)^{-1}$
- Average energy: $\langle E\rangle \approx 4\gamma\tilde{T} \approx 0.5\ \text{eV}\left(\frac{\epsilon}{10^{-15}}\right)^{\frac{1}{2}}\left(\frac{\alpha_D}{1}\right)^{\frac{1}{4}}$
- Number density: $n = \frac{5\zeta(3)}{\pi^2}\gamma\tilde{T}^3 \approx 2\times 10^5\text{cm}^{-3}\left(\frac{\epsilon}{10^{-15}}\right)^{\frac{3}{2}}\left(\frac{\alpha_D}{1}\right)^{\frac{3}{4}}\left(\frac{r}{1\ \text{AU}}\right)^{-2}$

Sonic Point



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Two types of solutions:

- Subsonic: $\tilde{p}$ = finite at $r \to \infty$
- Transonic: $\tilde{p} = 0$ at $r \to \infty$

Crossing $c_s = 1/\sqrt{3}$ smoothly requires:

$[\ldots]_{v=c_s} = 0 \;\to\; r_{\text{sonic}} \approx 0.2\, r_\odot$