Title: 5th forces and astrophysical probes

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Collection: School on Table-Top Experiments for Fundamental Physics

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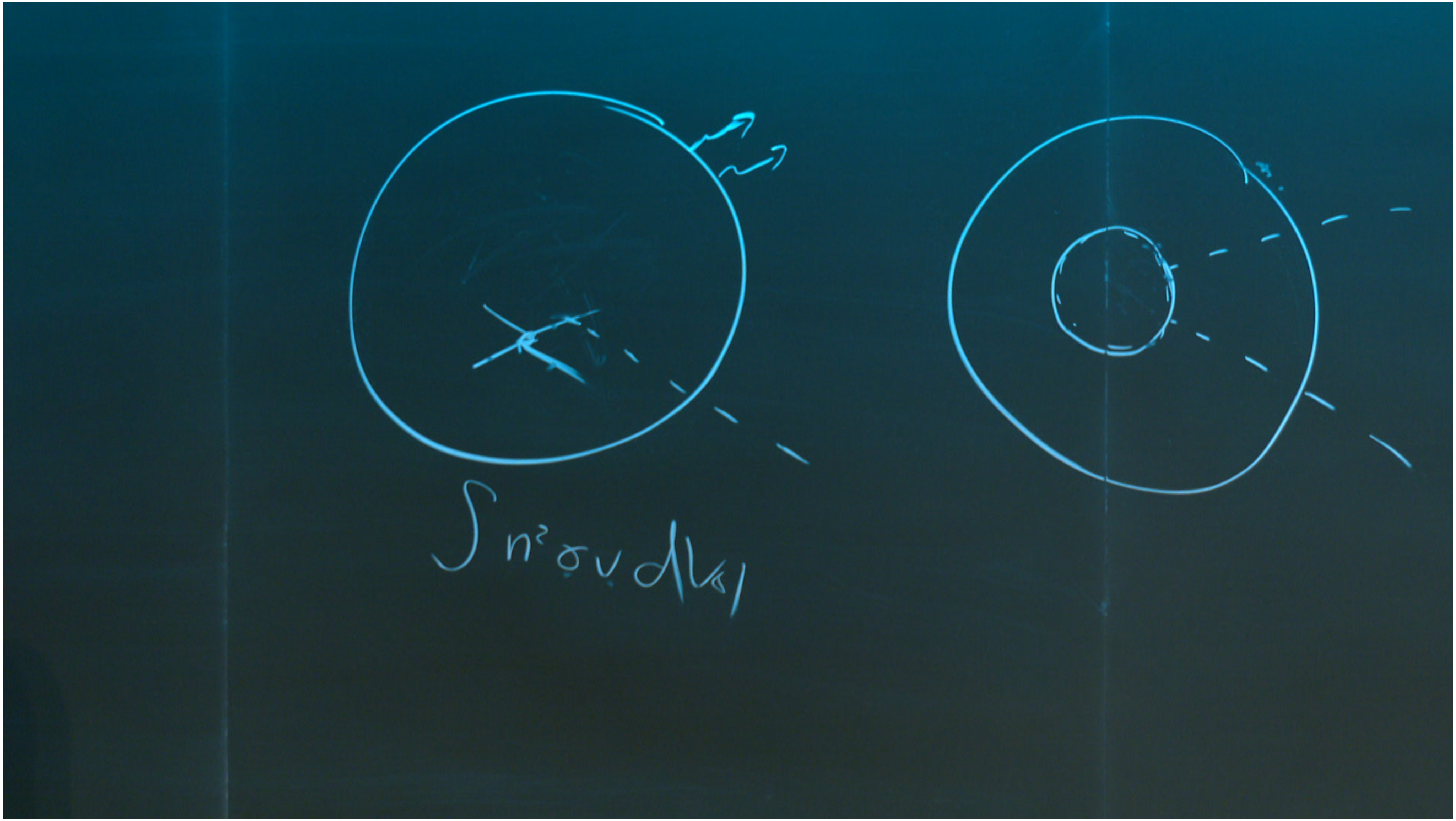
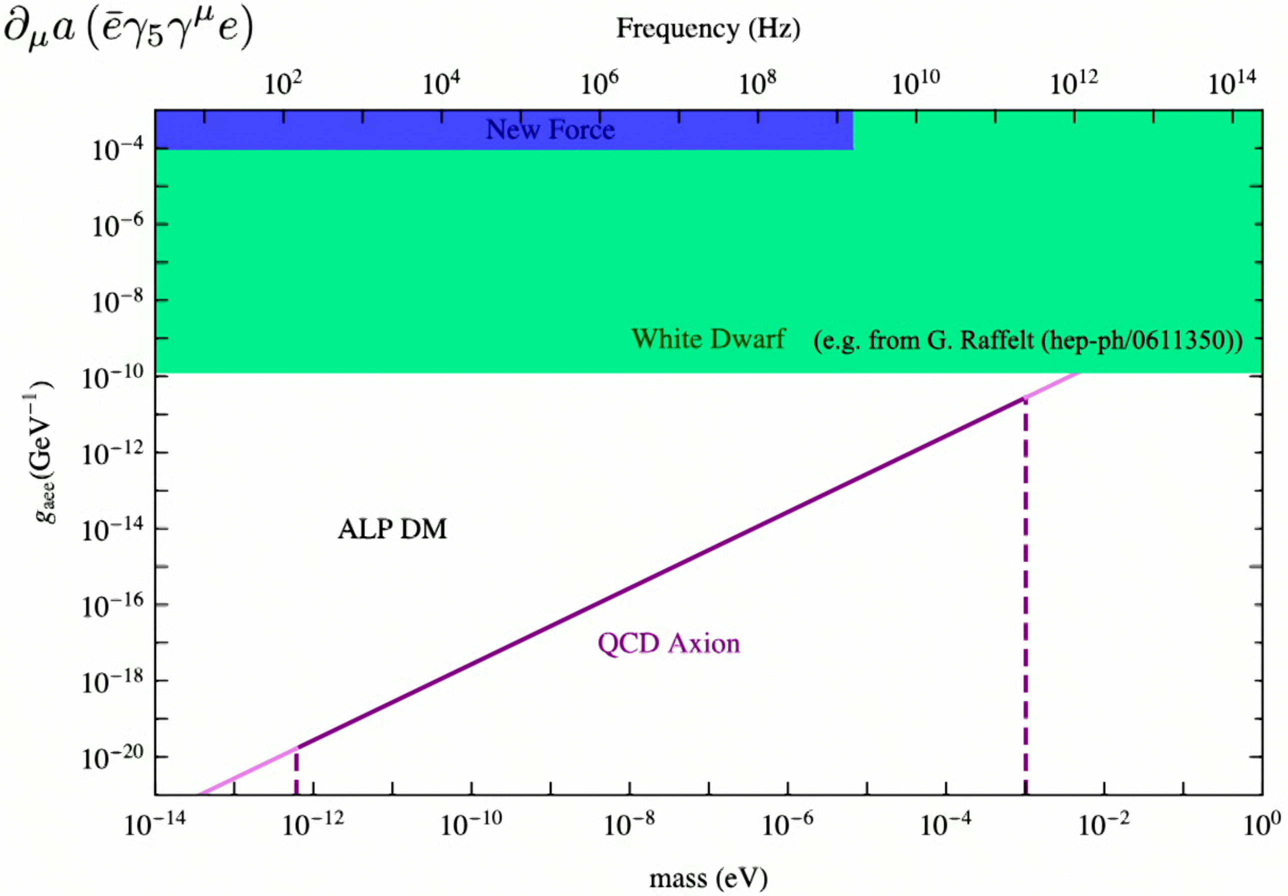
Astrophysical Probes


$\int n^2 \sigma v \, d|\vec{x}|$

Limits on Axion-Electron Coupling

$g_{\rm aee}\,\partial_\mu a\,(\bar{e}\gamma_5\gamma^\mu e)$



other spin-dependent couplings similar

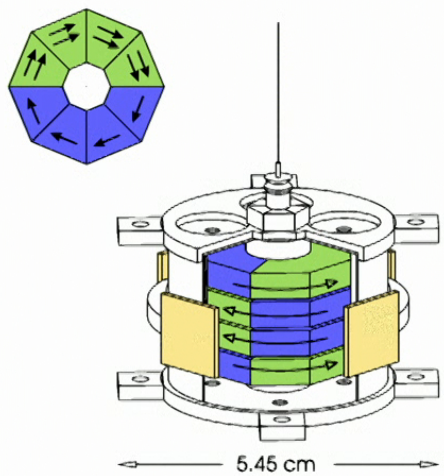
Fig from 1306.6088

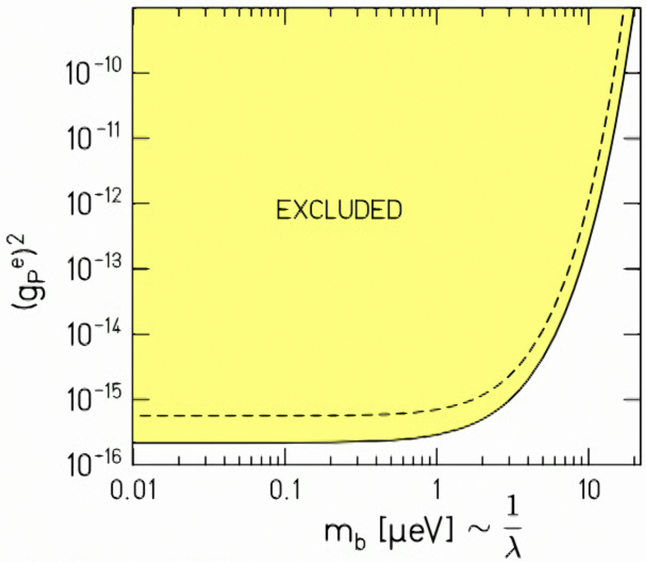
Spin-Dependent Forces

Can also search for spin-dependent forces (e.g. axion - pseudoscalar)

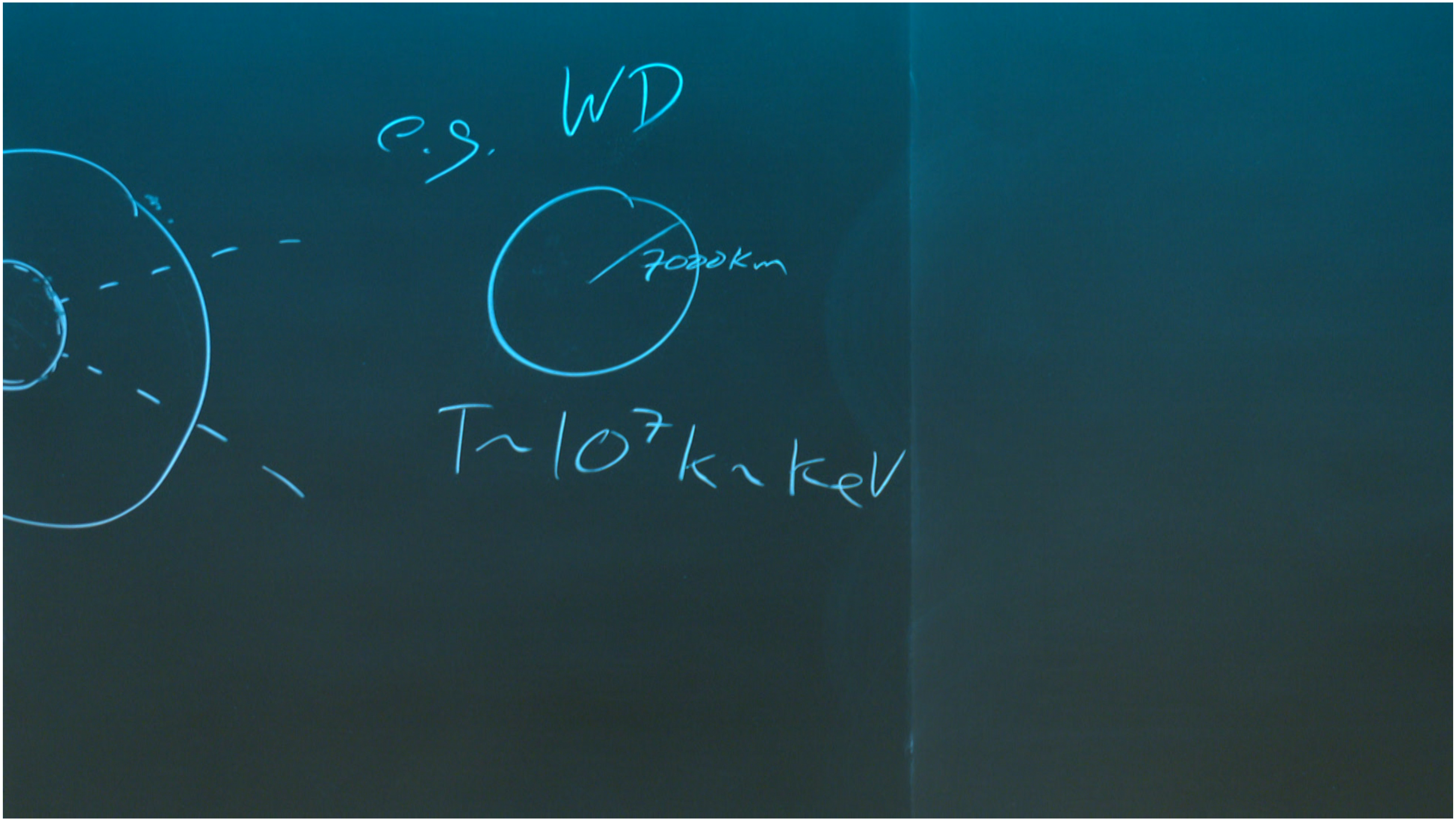
Automatically distinguishable from gravity

detect e.g. with spin-polarized torsion pendulum

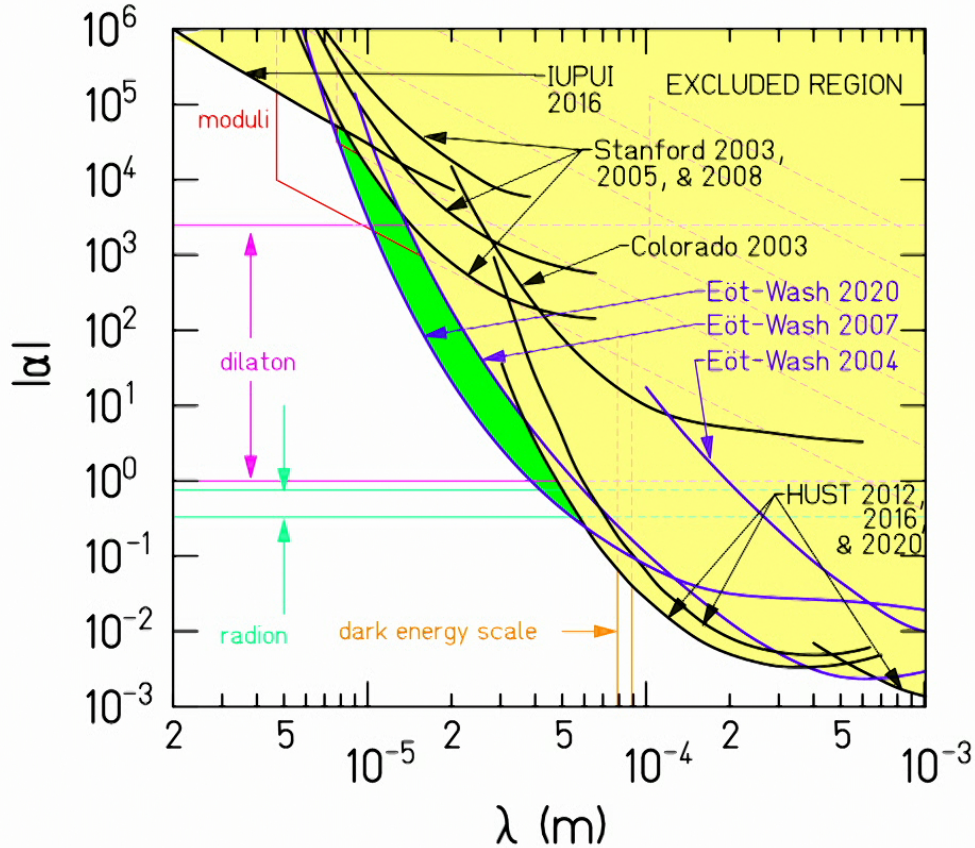




Heckel, Terrano, & Adelberger (2013)


e.g. WD
7000km
T~10^7 K ~ keV

Limits on short-range forces



From Eot-Wash: Lee, Adelberger, Cook, Fleischer, & Heckel (2020)

Exceptions to Astro Bounds

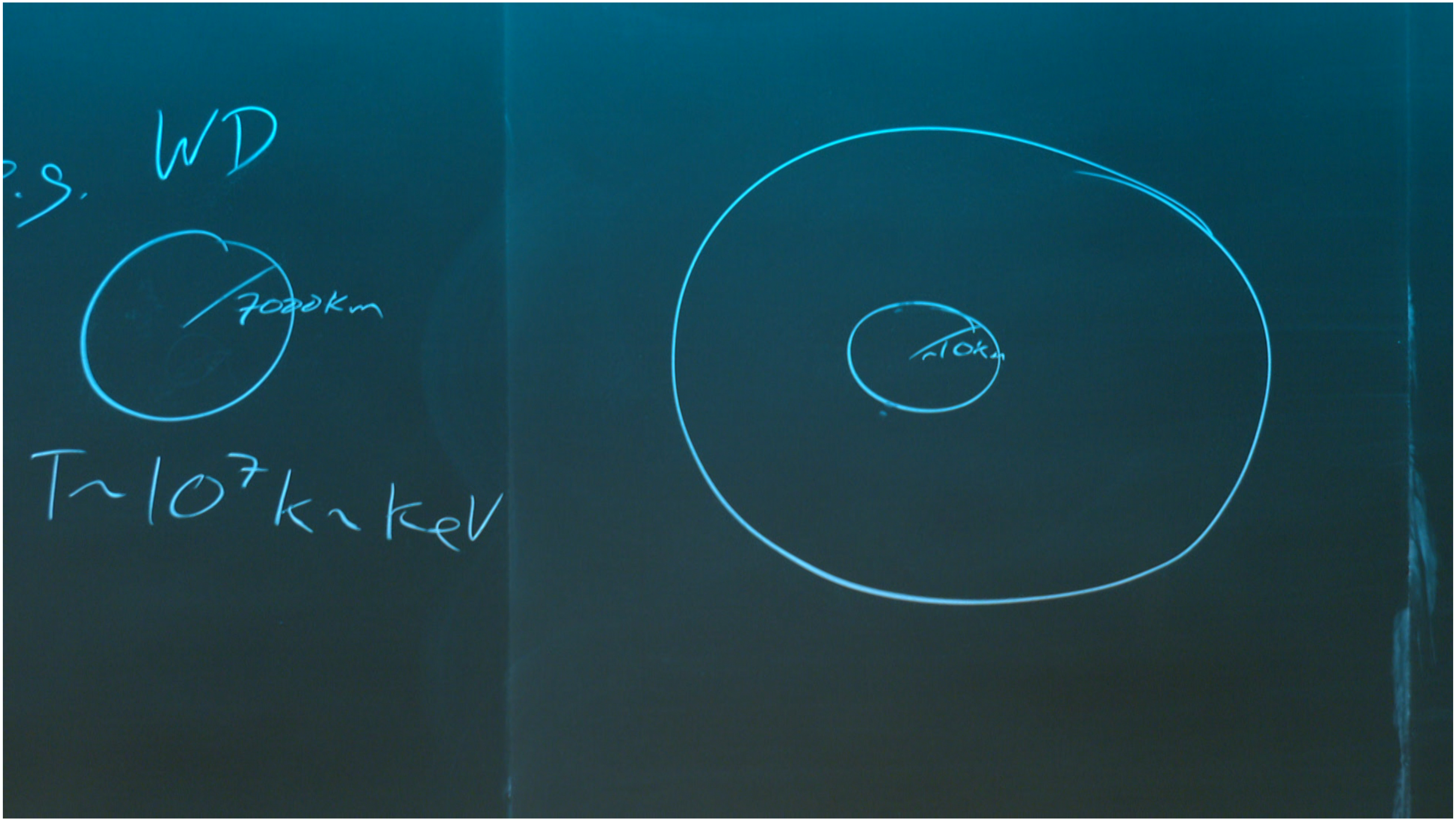
Can make models to evade astro bounds in some cases, though challenging due to general thermo/entropy arguments

- Coupling could be smaller in stellar environment, e.g. density dependent (see Masso + Redondo (2006))
- Mass could be density dependent, increases in star so above temperature and can't be produced (see DeRocco, PWG, Rajendran (2020))

Generally difficult: finely-tuned, or carefully chosen parameters or complicated models

SN1987A

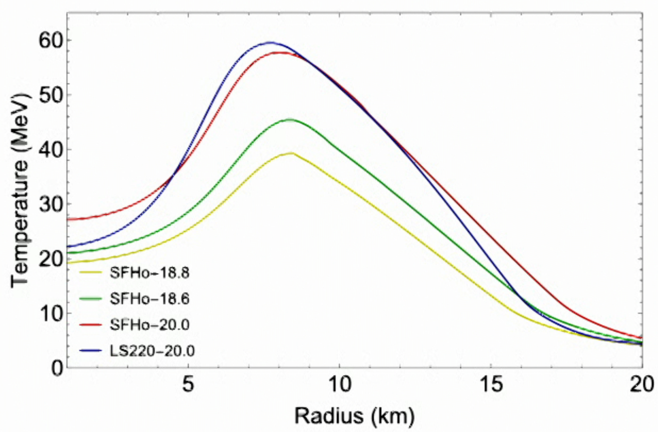
Emission from SN1987A places some of the tightest limits on many new types of particles/couplings (see e.g. Raffelt (1990))

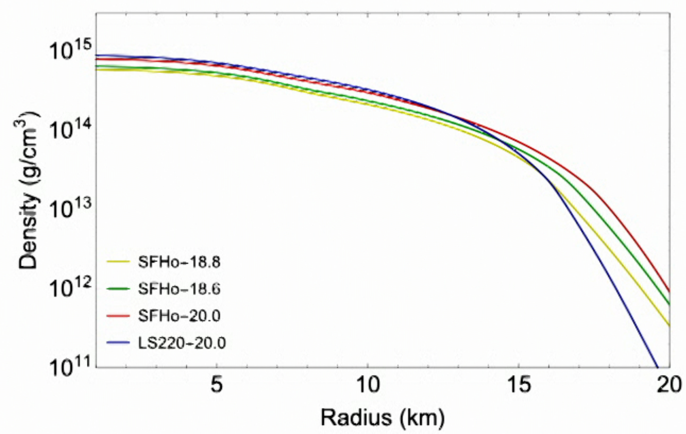

WD
7000km
T~10^7 K ~ keV
~10km

SN1987A

Emission from SN1987A places some of the tightest limits on many new types of particles/couplings (see e.g. Raffelt (1990))

At 1 s post-bounce:

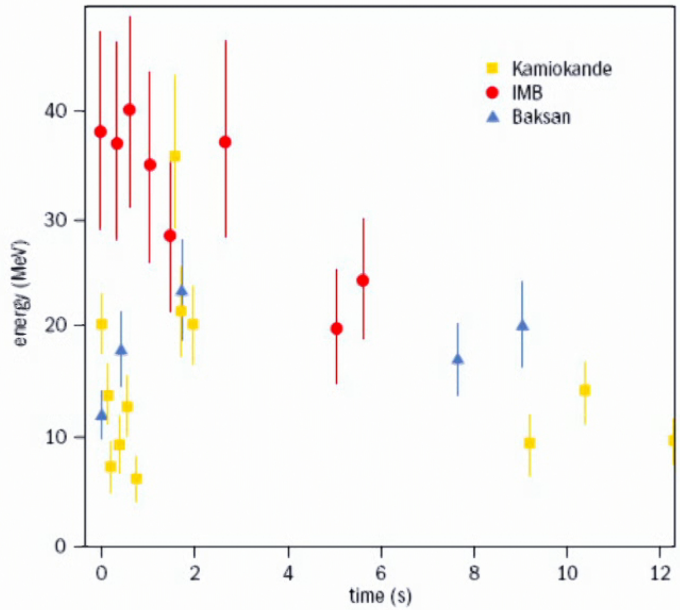




Figs from Bollig, DeRocco, PWG, Janka (2021)

Neutrinos from SN1987A

Detected neutrinos from SN1987A, burst lasted ~ 10 s

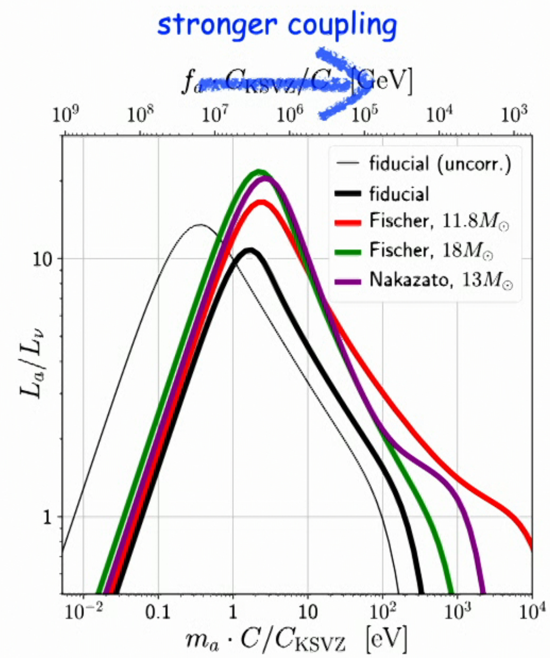


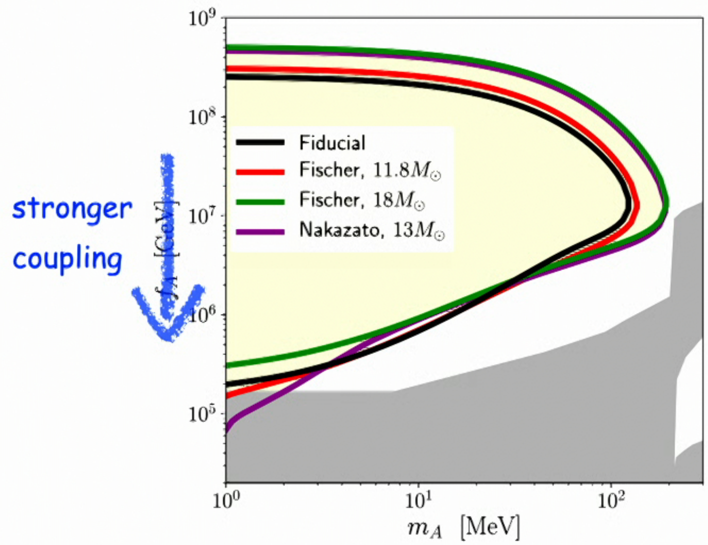
Limits from SN1987A

e.g. see Chang, Essig, & McDermott (2018) for limits on axions, dark sectors, MCPs

New particle luminosity is: $$L_{A'} = \int_0^{R_\nu} dV \int \frac{d^3\vec{k}}{2\omega(2\pi)^3} e^{-\tau(\omega,r)} \omega \Gamma_{\rm br}(\omega, r)$$

optical depth   production rate



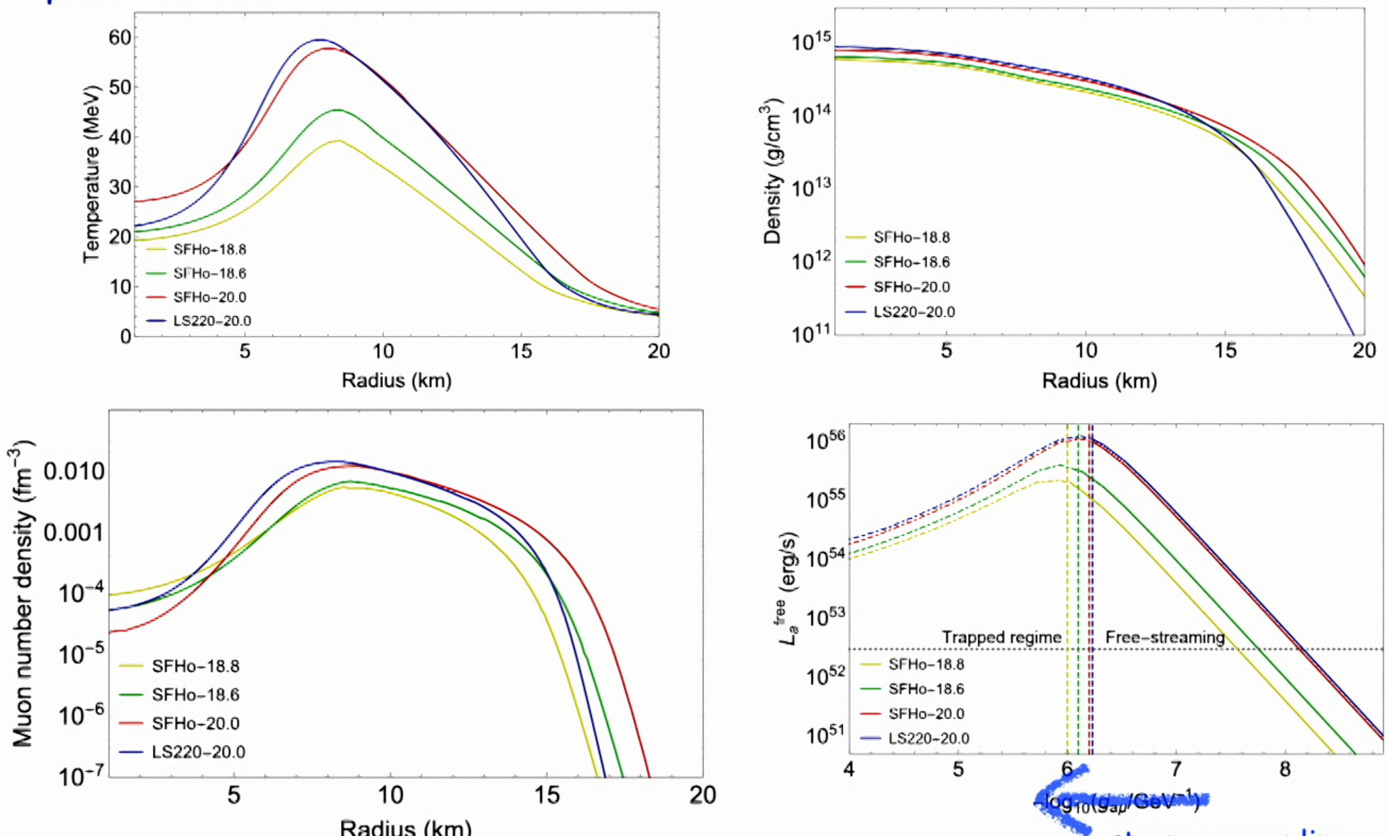


Limits on Axion-Muon Coupling from SN1987A

Supernovae even have many muons! High temperatures and chemical potentials

Bollig, DeRocco, PWG, Janka (2021) $m_\mu \approx 100\,\mathrm{MeV}$

At 1 s post-bounce:

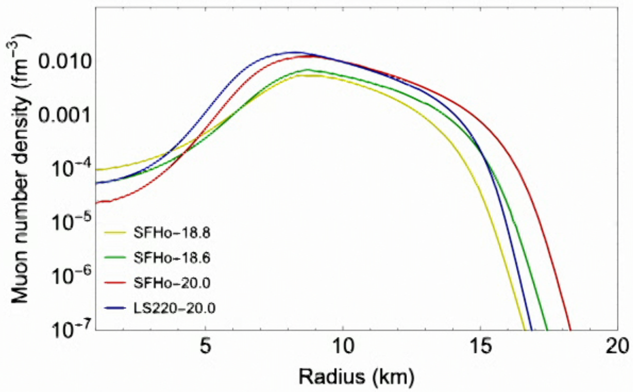


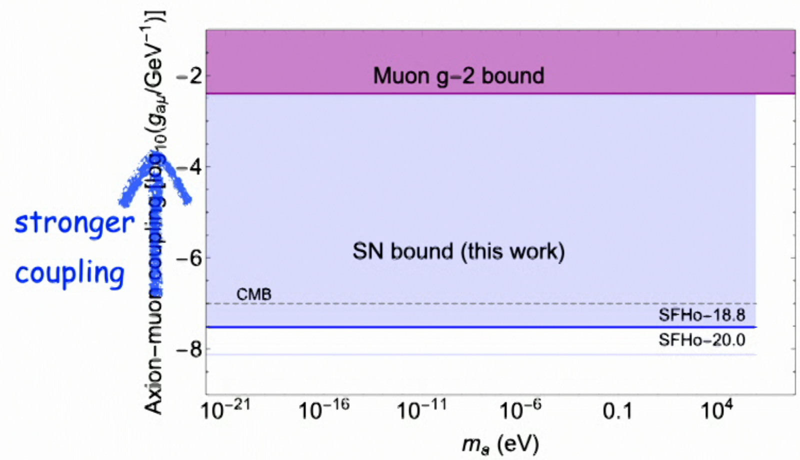
stronger coupling

Limits on Axion-Muon Coupling from SN1987A

Supernovae have many muons

Can limit a new particle coupling only to muons



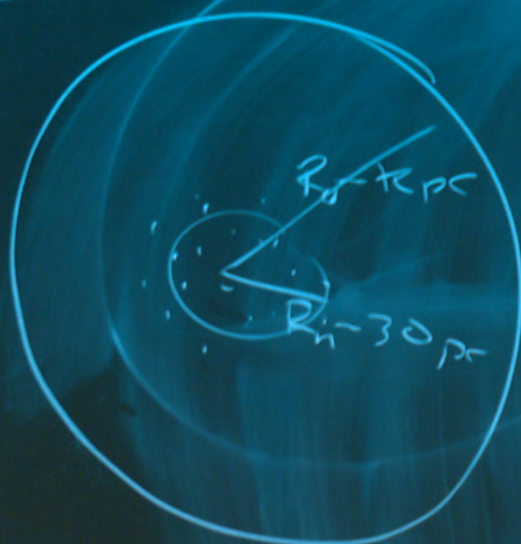


Bollig, DeRocco, PWG, Janka (2021)

Limits on PBH's from UFD

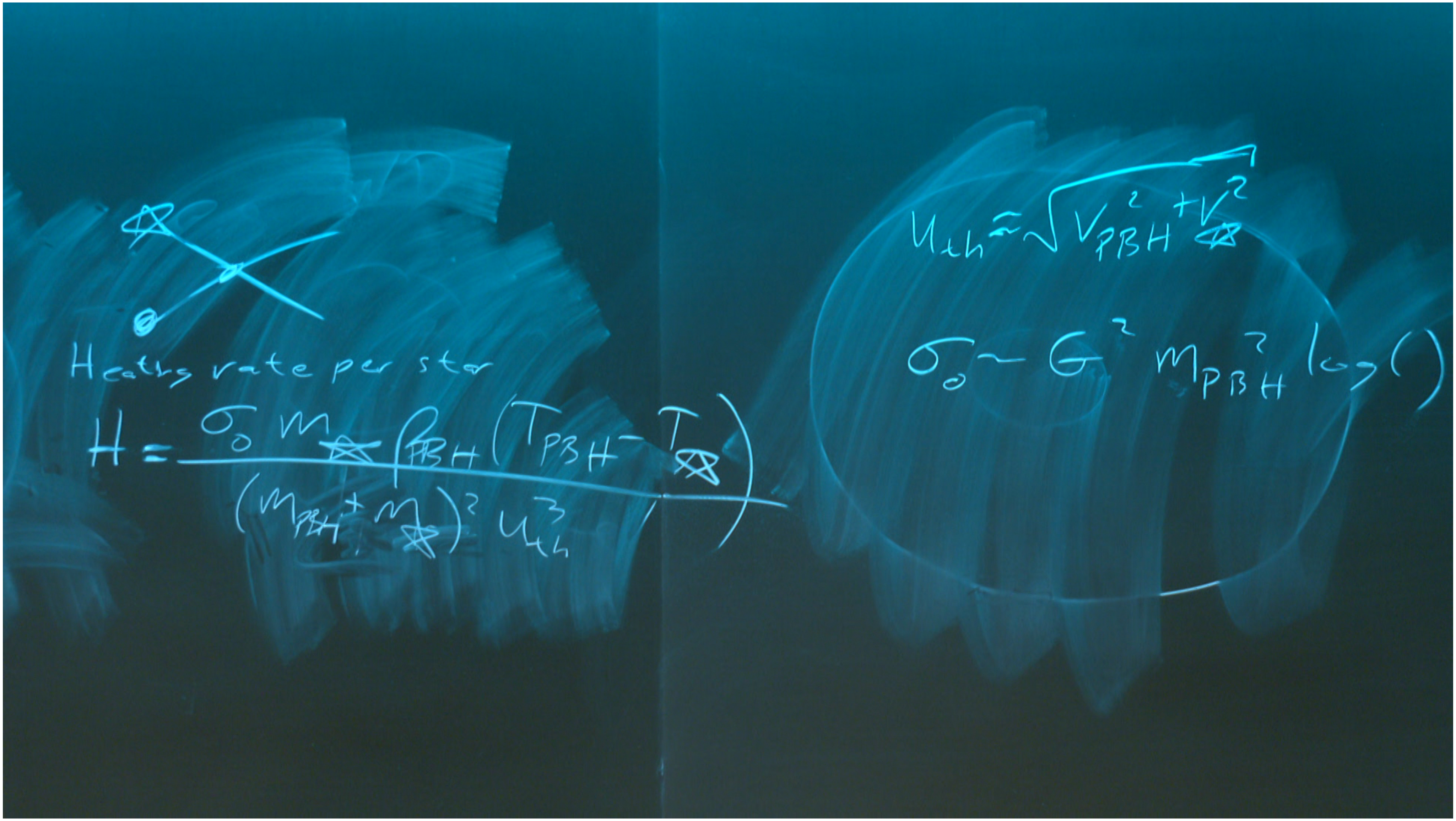
Brandt (2016)

UFD:



$$\text{"}T_{DM}\text{"} \sim \frac{1}{2} m_{PBH} V_{PBH}^2$$

$$T_{\star} \sim \frac{1}{2} m_{\star} V_{\star}^2$$


Heating rate per star
$H = \frac{\sigma_0 m_\star \rho_{PBH} (T_{PBH} - T_\star)}{(m_{PBH} + m_\star)^2 u_{th}^3}$
$u_{th} \approx \sqrt{v_{PBH}^2 + v_\star^2}$
$\sigma_0 \sim G^2 m_{PBH}^2 \log()$

$$\frac{(T_{PBH} - T_{*})}{\;{}^{2}\, u_{th}^{3}}$$

$$u_{th} \approx \sqrt{V_{PBH}^{2} + V_{*}^{2}}$$

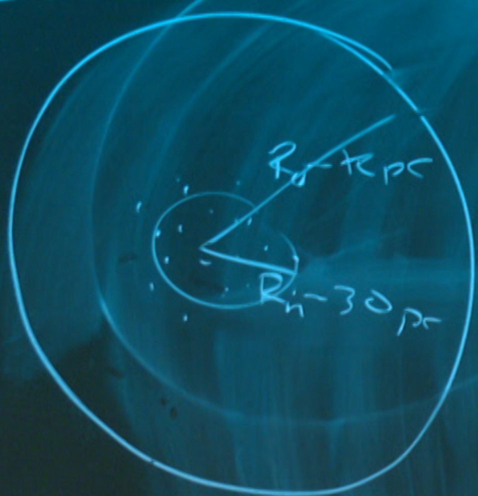
$$\sigma_0 \sim G^2 m_{PBH}^2 \log(\;)$$

$$\tau \sim \frac{H}{\left(\frac{1}{2} m_{*} V_{*}^{2}\right)} \sim \left(\frac{G^2 \rho_{PBH}\, m_{PBH}}{u_{th}^{3}} \log(\;) \frac{V_{PBH}^{2}}{V_{*}^{2}} \right)^{-1}$$

Limits on PBH's from UFD

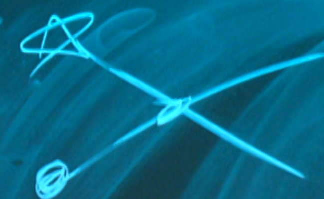
UFD: Eridanus II

Brandt (2016)



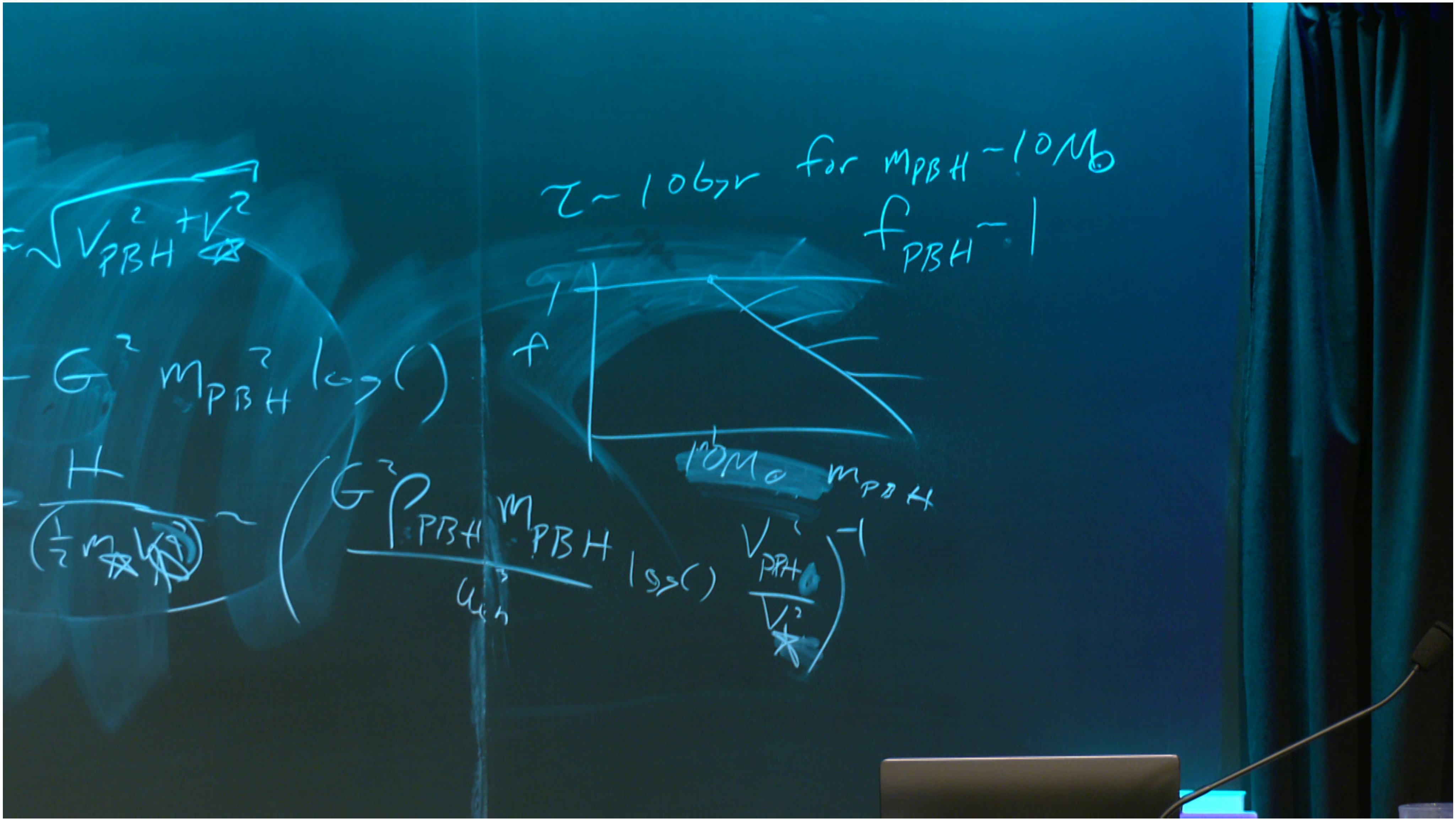
"T_{DM}" $\sim \frac{1}{2} m_{PBH} V_{PBH}^2$

$T_{\star} \sim \frac{1}{2} m_{\star} V_{\star}^2$



Heating rate per

$H = \frac{\sigma_0 m_{\star}}{(m_{PBH} + \ldots}$


τ ~ 10Gyr for m_PBH ~ 10 M_⊙
f_PBH ~ 1
10 M_⊙
m_PBH
log( )