Searching for DM with stars

Dark matter
- WIMP. (cold)
- Fuzzy DM. (ϕ), cold E.g. axions.
  Ultra-light field ($m \sim 10^{-15} - 10^{-22}$ eV)

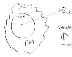
$\partial_t \gg \partial_x$

$(\Box - m^2)\phi = 0 \Rightarrow \ddot{\phi} + m^2 = 0 \quad \cdot \frac{1}{H}$

solution: $\boxed{\phi \propto \cos(mt)}$ Coherent oscillation

$G_{\mu\nu} = 8\pi G T^{(\phi)}_{\mu\nu}$

$\boxed{\begin{matrix} \rho_\phi = \text{const} \\ P \propto \cos mt \end{matrix}}$



Weak field.

$\Phi_{total}(\bar{x},t) = \Phi_N(x) + \frac{\pi G \rho_{DM}}{m^2}\cos(mt')$

$[t' \simeq t + \bar{v}_{rel}\bar{x}]$

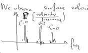
$= \Phi_N + \delta\Phi(t) \leftarrow$ How this can be observed?

Stellar oscillations

convective zone
radiative zone
70% $R_\odot$

- Excitation: Turbulence.
- Observed ~3000 frequencies, $l = 0, \ldots, O(200)$ degree.

We observe surface velocity amplitudes.



$V^2_{surface} = V^2_{turbulence} + \boxed{V^2_{DM}}$

$\rho = \rho(r) + \delta\rho(\bar{r},t)$

$\bar{r} = \bar{r}_0 + \bar{\xi} \qquad \bar{\xi}/r_0 \ll 1$

} Stellar oscillations Equilibrium $\to$ Perturb $\to$ Oscillation spectrum

$$\ddot{\bar{\xi}} + 2\eta\dot{\bar{\xi}} + \underbrace{\hat{\mathcal{L}}(\partial^2)}_{\text{"mass" term}}\bar{\xi} = \bar{F} = \bar{F}_{turb} + \bar{F}_{DM}$$

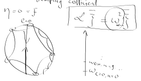
damping coefficient

forcing.

$\eta = 0 = F$

$\boxed{\mathcal{L}\bar{\xi} = \omega^2_{nlm}\bar{\xi}}$

$\bar{\xi} \propto \bar{\xi}_{nlm}(r) e^{-i\omega_{nlm} t}$



$\mathcal{L}\bar{\xi} = \omega^2\bar{\xi}$

$H\psi = E_n\psi$

$\bar{\xi} = \sum_{nlm}\bar{\xi}_{nlm}(\bar{r})e^{-i\omega_{nlm}t}$: Standing wave $\Rightarrow$ oscillation spectrum $\omega_{\ldots}$

$\bar{\xi} = \sum_{nlm} A_{nlm}(t)\,\bar{\xi}(\bar{x})e^{-i\omega_{nlm}t}$

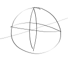
$$\frac{\partial A_{nlm}(t)}{\partial t} + \eta A_{nlm}(t) \propto \frac{1}{\omega_{nlm} I_{nlm}} e^{i\omega_{nlm}t}\int d^3x\, \bar{\xi}^*_{nlm}\,\Phi_{DM}(\bar{x},t)$$

$$\Phi_{DM} \sim \frac{G w \rho_{DM}}{m^2}\,\bar{v}_{rel}\cdot\bar{r}\,\sin(mt) + O(v/c)$$

$|\bar{v}|\cdot|\bar{r}|\cdot\cos\theta \propto Y^{m=0}_{l=1}$

$\frac{\partial A_{nlm}}{\partial t} + \eta A_{nlm} \boxed{\propto \frac{1}{\omega_{nlm} I_{nlm}}\cdot\delta_{l=1}}\,\delta_{m=0}$

DM excites the $l=1$ modes in the star (acoustic)



spherical symm. $\to$ axis symmetry $l=1$

$$V^{nlm}_{surface} \simeq \omega_{nlm}\cdot\langle|A_{nlm}(t)|^2\rangle \qquad \langle|A(t)|^2\rangle = \frac{1}{T}\int_0^T dt\,|A_{nlm}|^2$$

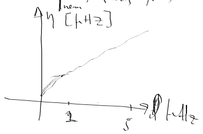
$$V^{DM}_{surface} = 10^{-8}\times\left(\frac{\rho_{DM}}{0.42\,\text{GeV/cm}^3}\right)\times\left(\frac{v_{rel}}{220\,\text{km/sec}}\right)\times\left(\frac{150\,\mu\text{Hz}}{m}\right) \times\left(\frac{10^{-6}\,\mu\text{Hz}}{\eta_{nlm}}\right)\times\left(\text{form factor} \sim 0.5\right)\left(\frac{\text{cm}}{\text{sec}}\right)^2 = 10^{-8}\left(\frac{\text{cm}}{\text{sec}}\right)^2$$

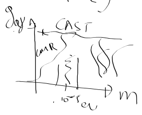
$\omega_{l=1,n=0}$

$V^2_{surf} \simeq \underbrace{V^2_{turb}}_{} + V^{2\,DM}_{surf}$

1 - 10 cm/sec

$\eta \propto g^{-0.3}\cdot \boxed{T_{eff}^{10.8}}$





$\left(\frac{G\rho_{DM}}{m}\right)$ sin

$r_{DM} > R_\odot$

$\partial_x \ll \partial_t$

Conclusions:

- DM (fuzzy) can excite stellar oscillation.
- Red giants can act as good candidates

arXiv: Saksteina Seltas 2023