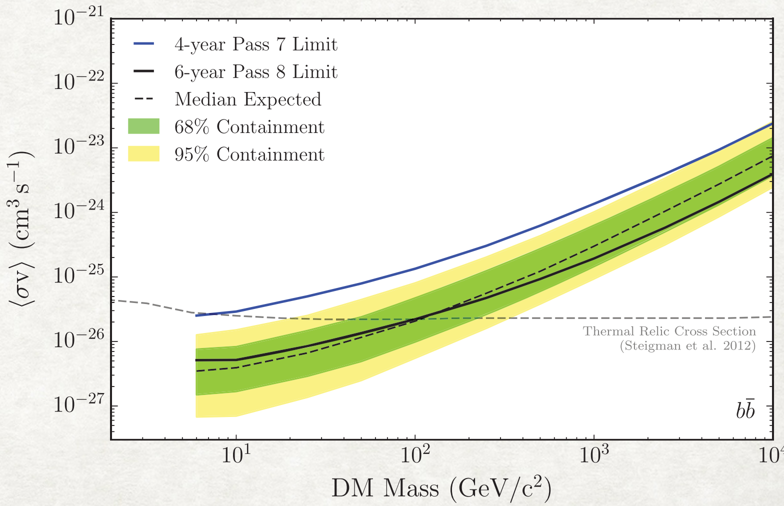
# JEANS EQUATION SOLVER USING ML

Kohei Hayashi (Ichinoseki College) Sung Hak Lim(Rutgers), Mihoko Nojiri (KEK)

- Motivation
- Dwarf Spheroidal Galaxy (dSph, small galaxy, old stellar population with little dust.
- The center must contains dark matter and good place to look for dark matter pair annihilation.
- Central density of dark matter (J factor)
- set limit on dark matter interaction or dark matter interactions



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The Jeans equation: basics partial differential equation to estimate the gravitational potential  from the stellar system.

Spherical Jeans equation

$$\frac{d(\nu\sigma_r^2)}{dr} + \frac{2\beta}{r}\nu\sigma_r^2 = -\nu\frac{d\Phi}{dr}, \quad \beta(r) = 1 - \frac{\sigma_\theta^2 + \sigma_\phi^2}{2\sigma_r^2},$$

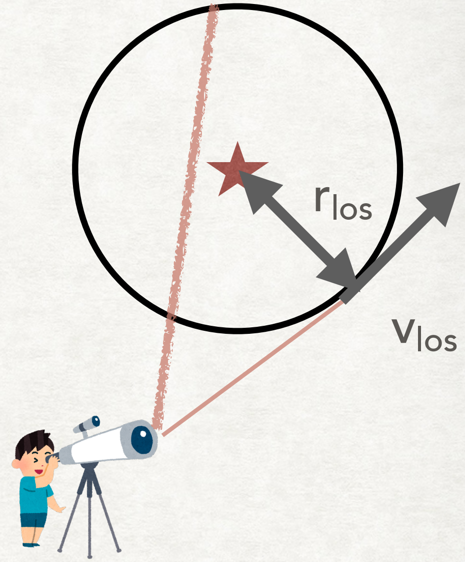
$$\frac{d\Phi}{dr} = \frac{GM_<(r)}{r^2}$$

Number density of stars: $\nu(r)$
Variance of the velocity: $\sigma_r(r)$ $\sigma_\theta(r)$ $\sigma_\phi(r)$
Potential: $\Phi(r)$

If we know the star position and velocity distribution ($x$, $y$, $z$, $v_r$, $v_\theta$, $v_\phi$) , we can infer the total mass distribution in the system.

# DARK MATTER DENSITY ESTIMATION

Star information is limited (x,y, z, vr, vθ, vϕ)→ (x, y, vlos)
(los=line of sight)




There is analytical solution connecting los distribution to 6D coordinate under some assumptions. Information of 6D distribution is there, but not easy to handle.

Ex

$$\nu(r) = -\frac{1}{\pi}\int_r^\infty \frac{d\tilde{\nu}}{dr_{\rm los}} \frac{dr_{\rm los}}{\sqrt{r_{\rm los}^2 - r^2}}$$

The dark matter density (gravitational potential) is infered from observation by template study. Namely, set of (the potential Φ and star profile) is compare with the data, and best solution is obtained.

generated star distribution ⇄data (MCMC study)

Profile of dark matter density
→ γ (singularity at the center) →dark matter signature from dSph

$$\rho_{\rm DM}^{\rm Zhao}(r) = \frac{\rho_s}{(r/r_s)^\gamma \times [1 + (r/r_s)^\alpha]^{(\beta-\gamma)/\alpha}}$$

# OUR PROPOSAL

•Create the star phase space distribution consistent to the data using normalizing flow.

(New treatment of model that impose spherical symmetry and boundary condition without introducing penalty term to the loss function --to be reported )

•Use Jeans equation to obtain M(r) from the model

•Fit using 1000 stars from GAIA Challenge Dataset reproduce the assumed density profile ( stellar distribution -generalized Plummer model , DM density distribution NFW)

•Error estimate based of bootstrapping of the sample star looks reasonable

•More consistency check needed (varying β(r), fit region, even smaller sample, non-spherical)

Include Observational effect