

# Stellar Wakes from Dark Matter Subhalos

MB, J. Kopp, B. Safdi, C-L. Wu  
arXiv:1711.03554 (accepted by PRL)

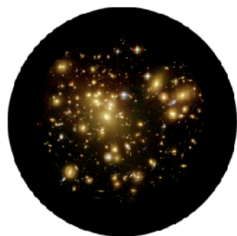
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# Dark Matter Halos

Galaxy Cluster

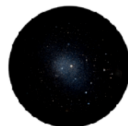


Not shown to scale!

Spiral Galaxy



Dwarf Galaxy



Empty



Empty



Empty



Empty



you may want to

cut here 

$10^7 - 10^8 M_{\odot}$

Jethwa et al 2017

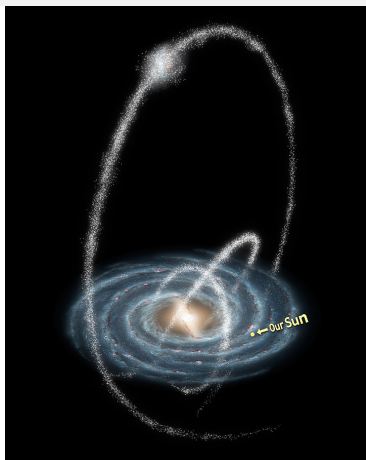
# Dark Matter Subhalos

- Spectrum of DM subhalos predicted by  $\Lambda$ CDM
- Drastic deviations between different models (in particular warm/fuzzy/self-interacting DM)
- Invaluable targets for indirect DM searches

But:

How to find something that is dark?

# Perturbing Stellar Streams

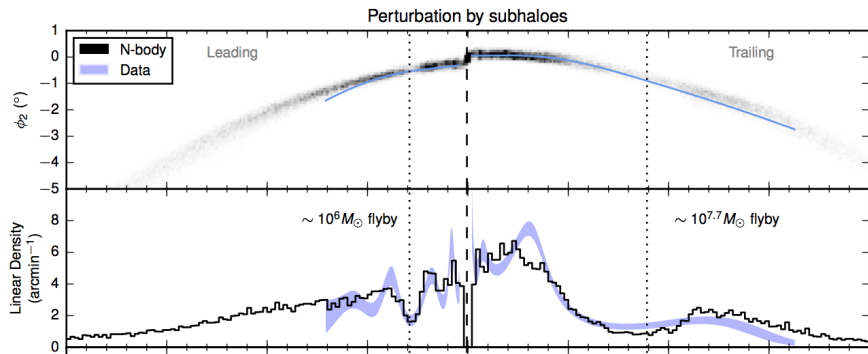


NASA/JPL-Caltech/R. Hurt (SSC/Caltech)

Method 1: Subhalo is passing through a stellar stream

# Perturbing Stellar Streams

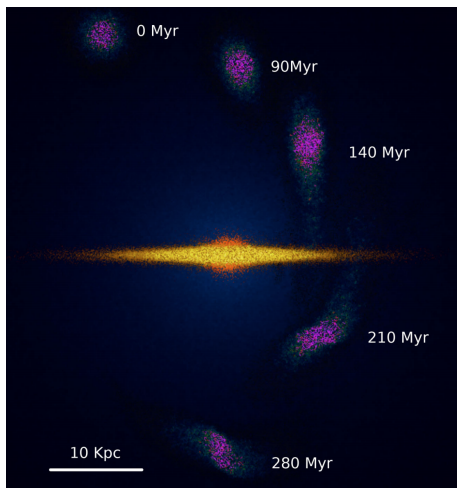
Gaps in the Pal 5 stream might be due to DM subhalos:



Erkal et al. 2017

# Perturbing the MW disk

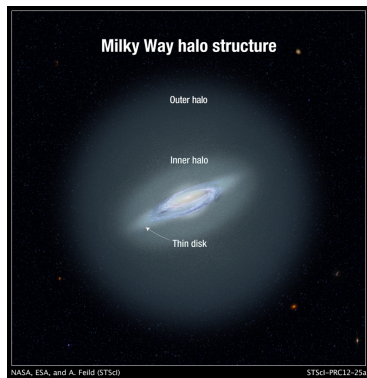
Subhalos can also leave a trace in the vertical velocity of disk stars:



Feldmann et al. 2014

# Perturbing MW Halo Stars → Stellar Wakes

This work: Perturbation to the luminous MW halo

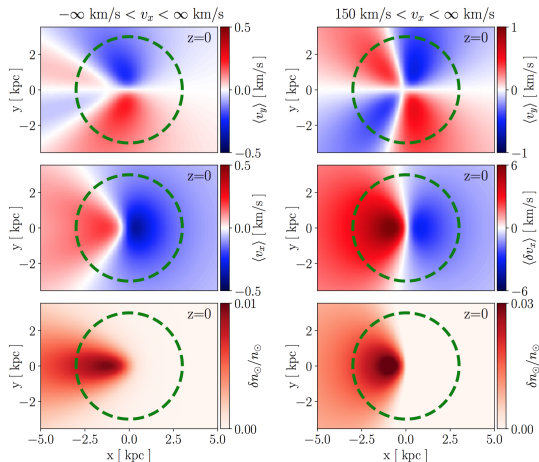


Big advantage: We can tell exactly where the subhalo is  
→ follow-up studies possible!

# Perturbing MW Halo Stars $\rightarrow$ Stellar Wakes



# Perturbing MW Halo Stars $\rightarrow$ Stellar Wakes



Look for patterns in the stars 6-D phase space!  
**Gaia** measures this right now!

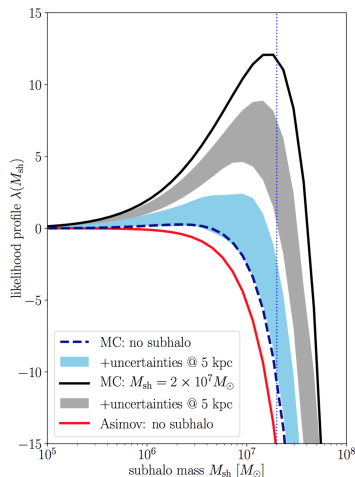
# Perturbing MW Halo Stars $\rightarrow$ Stellar Wakes

## Strategy:

- Define test statistic:  $TS = 2 \left[ \max_{\theta} \log p(\theta) - \max_{\theta} \log p(\theta) \Big|_{M_{\text{sh}}=0} \right]$
- Likelihood product over stars PS:  $p(\theta) = e^{-N_{\text{star}}} \prod_{k=1}^{\tilde{N}_{\text{star}}} f_k$
- Phase-space:  $f = f_0 + f_1$  ( $f_0 =$  Maxwell-Boltzmann,  $f_1 =$  perturbation)
- Solve Boltzmann Eq. for  $f_1$ :  $f_1 = \int_0^{\infty} \frac{du}{u^2} \vec{\nabla}_y \Phi(\vec{y}) \cdot \vec{\nabla}_v f_0(\vec{v}) \Big|_{\vec{y}=\vec{x}-\vec{v}/u}$

Here,  $\Phi$  subhalo potential, e.g  $\Phi(r) = -\frac{GM_{\text{sh}}}{\sqrt{r^2+r_s^2}}$

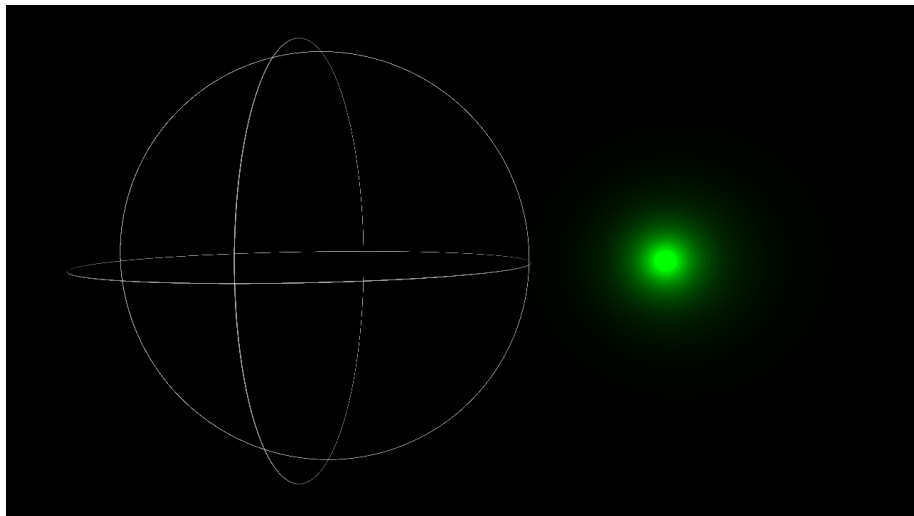
# Perturbing MW Halo Stars $\rightarrow$ Stellar Wakes



Conclusion:

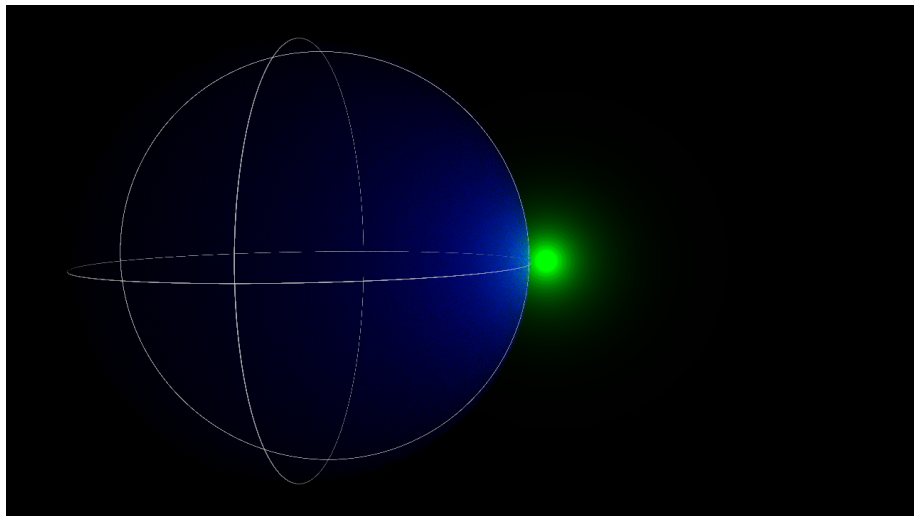
Dark matter subhalos might be found by looking at the perturbation of Milky Way halo stars!

## Perturbing MW Halo Stars $\rightarrow$ Stellar Wakes



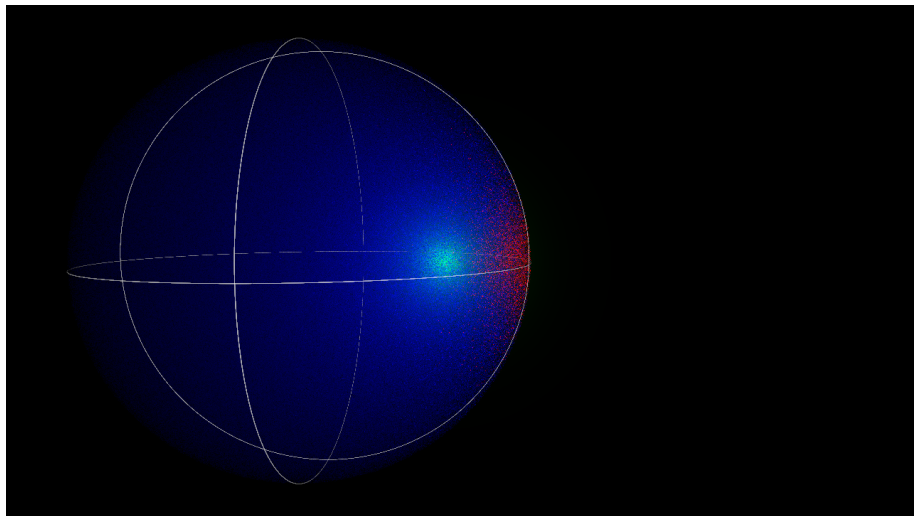
blue:  $\delta v_x > 0$ , red  $\delta v_x < 0$

## Perturbing MW Halo Stars $\rightarrow$ Stellar Wakes



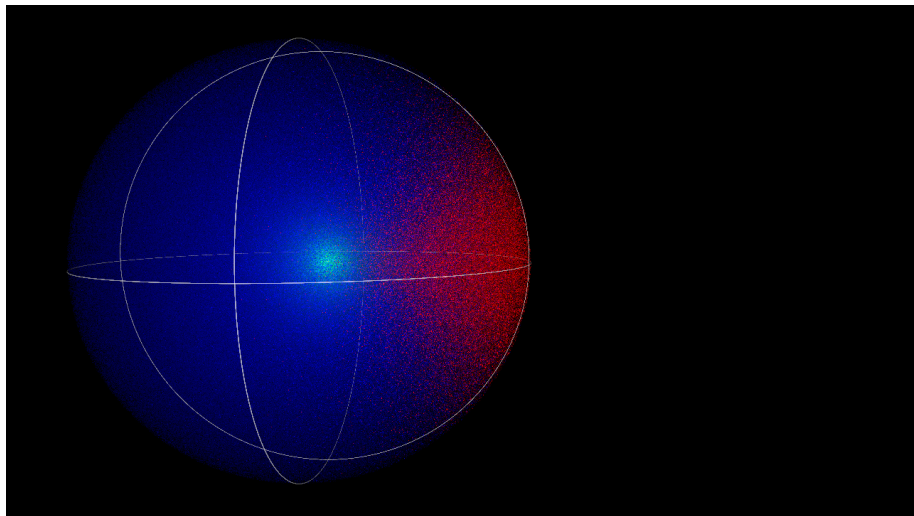
blue:  $\delta v_x > 0$ , red  $\delta v_x < 0$

# Perturbing MW Halo Stars $\rightarrow$ Stellar Wakes



blue:  $\delta v_x > 0$ , red  $\delta v_x < 0$

## Perturbing MW Halo Stars $\rightarrow$ Stellar Wakes



blue:  $\delta v_x > 0$ , red  $\delta v_x < 0$