

The Search for Dark Matter Debris

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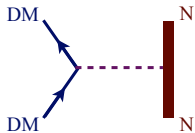
w/ D. Spergel [1105.4166], M. Kuhlen and D. Spergel [1202.0007]

Dark Matter Searches

Experimental signatures depend on local phase space

Direct Detection

Dark matter scatters off nuclei

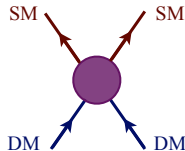


Measure recoil energy of nuclei

$$\text{Rate} \propto \int v f(v) dv$$

Astrophysical Detection

Dark matter annihilation



Detect annihilation products

$$\text{Flux} \propto \int_{\text{los}} \rho^2(r) ds$$

Direct Detection

RAVE star survey

$$v_{\text{esc}} = [498, 608] \text{ km/s}$$

$$\frac{dR}{dE_R} \propto \int_{v_{\text{min}}}^{v_{\text{esc}}} d^3v \frac{d\sigma}{dE_R} v \boxed{f(v)}$$

↑

↓ Scattering kinematics

↓ Model parameters

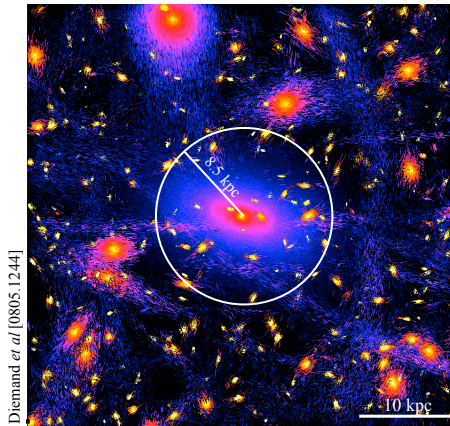
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Halo Formation

Milky Way DM halo forms as subhalos merge to form a more massive system

Incomplete merging of subhalos leaves structure in DM phase space

Phase Space Density



Stars as Tracers

The dense cores of subhalos were the site of star formation billions of years ago

These stars are tidally-stripped from subhalos as they orbit the Milky Way



Johnston *et al.* [0807.3911]

Time required for stars to exchange energy and momenta is long compared to age of the Galaxy

Therefore, kinematics of old stars encode information about their origin

Stars as Tracers

Stellar halo is a fossil record of the Galaxy's evolutionary history

Old, metal-poor stars in the halo can act as 'tracers' for dark matter

Use stellar distributions to shed light on the question:

What are the distinctive features of the local dark matter distribution?

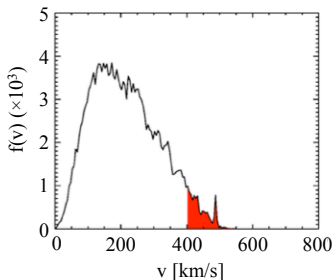
Tidal Streams

Material that has recently been stripped from infalling satellite

Spatially confined and exhibits low velocity dispersion

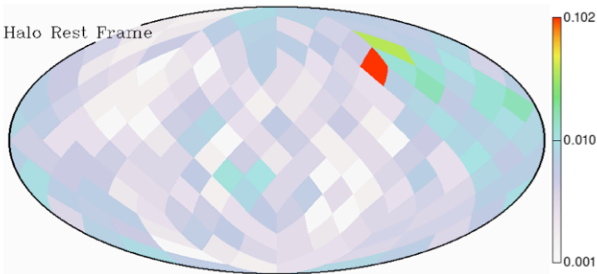
Velocity Distribution

$$f(\vec{v}) = \delta(\vec{v} - \vec{v}_{\text{stream}})$$



Skymap

$$\rho(\vec{r}) = \delta(\vec{r} - \vec{r}_{\text{stream}})$$



Tidal Streams

Material that has recently been stripped from infalling satellite

Spatially confined and exhibits low velocity dispersion

Small odds that a *single* stream dominates the local density

20% chance that a single stream will contribute 1% of local density

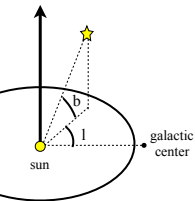
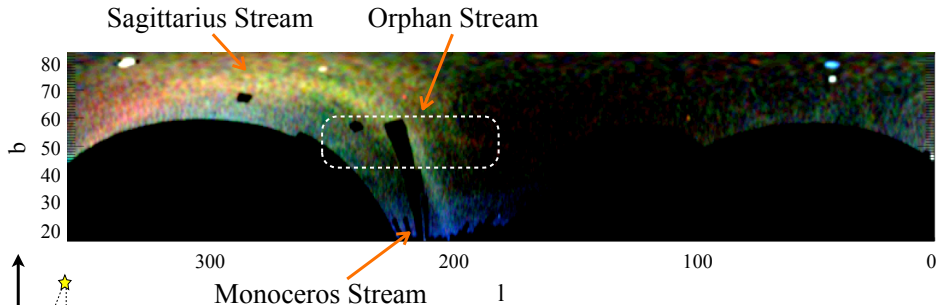
Vogelsberger and White [1002.3162]

Impact on experiments depends on dark matter properties

Field of Streams

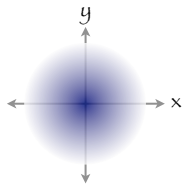
Abundance of substructure observed in star surveys

Spatial overdensities indicate presence of stellar streams

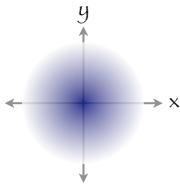


A Spectrum of Possibilities

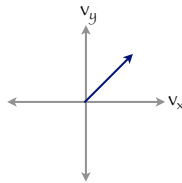
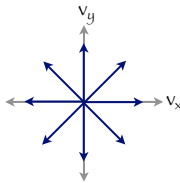
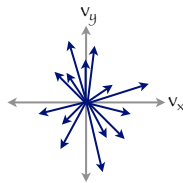
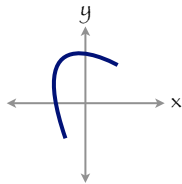
Maxwell-Boltzmann



Debris Flows



Streams



Fully Virialized



Not Virialized

Locating the Debris

Searched for distinctive features in Via Lactea-II,
with a focus on tidal debris

A particle is labeled as “debris” if it was bound at some $z > 0$,
but is no longer bound to a subhalo today

Via Lactea-II

High-resolution N-body simulation
of the Milky Way

Only dark matter; no baryons

20047 subhalos identified today and
evolutionary tracks available

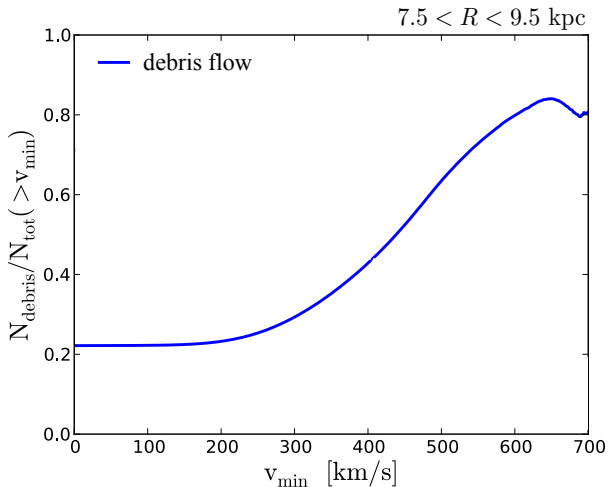


Properties of Debris

Spatially-homogenous in the inner halo

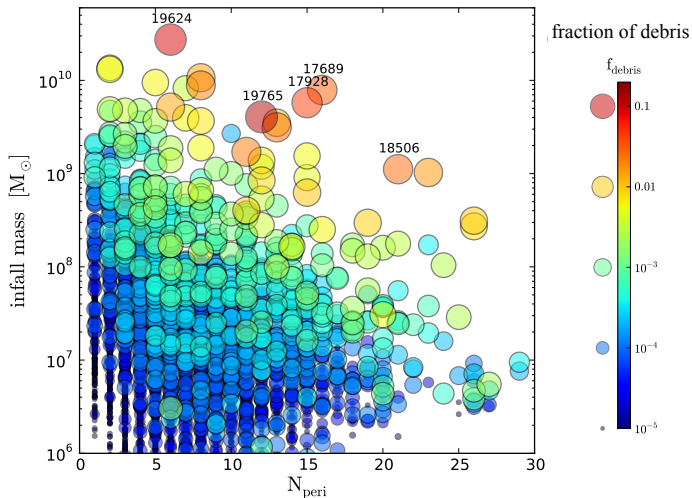
Properties of Debris

Comprises majority of high-velocity particles in the Milky Way



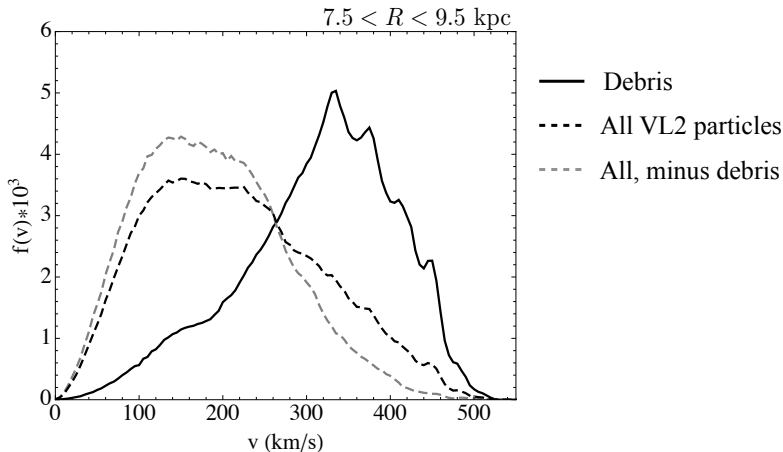
Properties of Debris

Arises from the most massive subhalos falling into MW that make numerous pericenter passages



Properties of Debris

Debris speeds peaked at ~ 340 km/s in Galactic frame



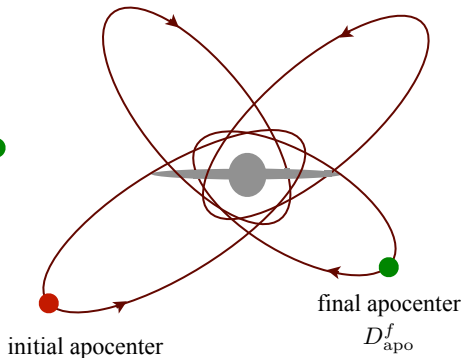
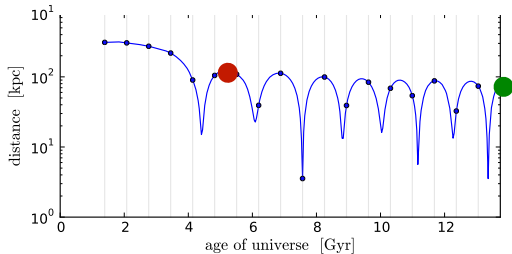
Speeds

Characteristic speed of debris flow is a consequence of energy conservation

$$v^2(8.5 \text{ kpc}) - v^2(D_{\text{apo}}^f) = 2 \left[\Phi(8.5 \text{ kpc}) - \Phi(D_{\text{apo}}^f) \right]$$

$$v(8.5 \text{ kpc}) \simeq 370 \text{ km/s}$$

Example Subhalo



Direct Detection

Local velocity distribution of dark matter affects scattering rate

$$\frac{dR}{dE_R} = n_{\text{dm}} \left\langle v \frac{d\sigma}{dE_R} \right\rangle \propto \int_{v_{\text{min}}}^{v_{\text{esc}}} d^3v \frac{d\sigma}{dE_R} v f(v)$$

Typical assumption is that $f(v)$ is Maxwell-Boltzmann
 \Rightarrow leads to exponentially-falling scattering rate

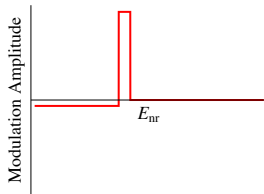
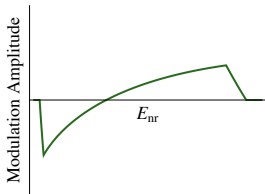
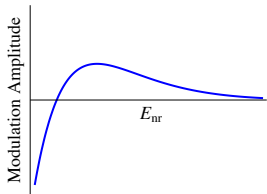
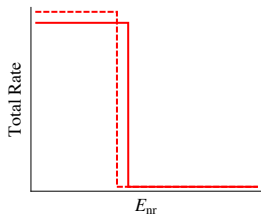
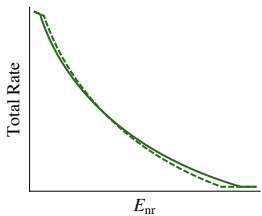
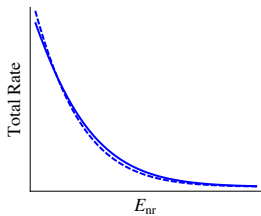
How does this change for debris flows?

A Spectrum of Possibilities

Smooth Halo

Debris Flows

Streams



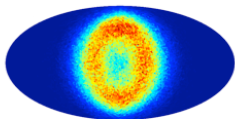
Fully Virialized ←—————→ Not Virialized

Directional Detection

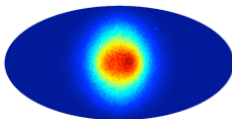
Debris flows broaden distribution of incidence directions and change location of “hotspot”

Mollweide projections for distribution of incidence directions

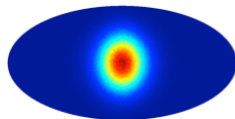
$350 < v < 500$ km/s



Debris

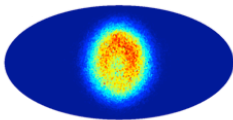


MB+Debris

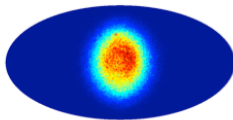


Maxwell-Boltzmann

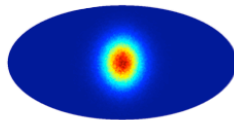
$v > 500$ km/s



Debris



MB+Debris



Maxwell-Boltzmann

Stellar Debris Flow

Kuhlen, ML, Madau, Rashkov, Spergel [in progress]

Presence of stellar streams strongly suggests that stellar debris flow should also be present and potentially detectable

Look for stars in large areas of the sky that exhibit distinct velocity behavior, but no distinct spatial structure

(for example, with GAIA or SEGUE)

An orthogonal approach to dark matter searches that complements direct detection experiments

Conclusions

Wealth of dark matter structure in the solar neighborhood

Debris flows offer unique way to search for dark matter:
Direct detection and star surveys provide orthogonal detection possibilities

Discovery would tell us a lot about the local halo:
Significant fraction is unvirialized and retains distinctive phase-space features

Substructure is a fossil record of the MW's merging history:
“Build-up” the merger history of the halo and test the Λ CDM picture

Questions?