Stuff that Happens in Astrophysics if the Dark Matter is Light

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[arXiv:1208.4602]
[arXiv:1203.6617]
[arXiv:1110.5919]

RAPID COMMUNICATIONS

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Asymmetric dark matter may alter the evolution of very low-mass stars and brown dwarfs

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We study energy transport by asymmetric dark matter (ADM) in very low-mass stars and brown dwarfs. Our motivation is to explore astrophysical signatures of ADM, which may not otherwise be amenable to indirect dark matter searches. In viable models, the additional cooling of low-mass stellar cores can alter stellar properties. ADM with mass $4 \lesssim M_x/\mathrm{GeV} \lesssim 10$ and a spin-dependent (spin-independent) cross section of $\sigma_p^{SD} \sim 10^{-37}$ cm^2 ($\sigma_p^{SI} \sim 10^{-40}$ cm^2) increases the minimum mass of main sequence hydrogen burning, partly determining whether or not the object is a star at all. Similar ADM candidates reduce the luminosities of low-mass stars and accelerate the cooling of brown dwarfs. Such light dark matter is of interest given results from the DAMA and CoGeNT dark matter searches. We discuss possibilities for observing dark matter effects in stars and exploiting these effects to constrain dark matter candidates.

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Dark matter direct search rates in simulations of the Milky Way and Sagittarius stream

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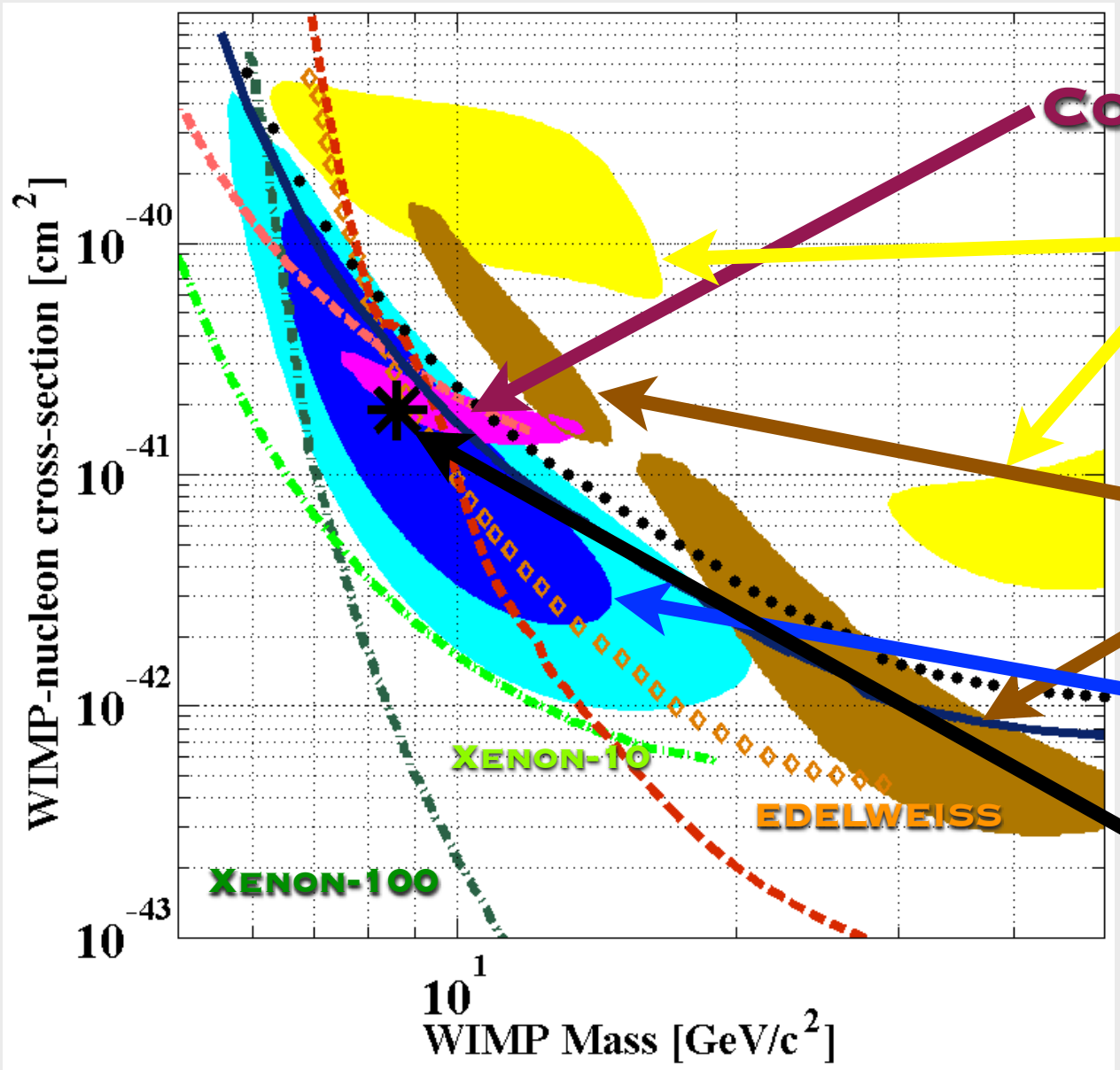
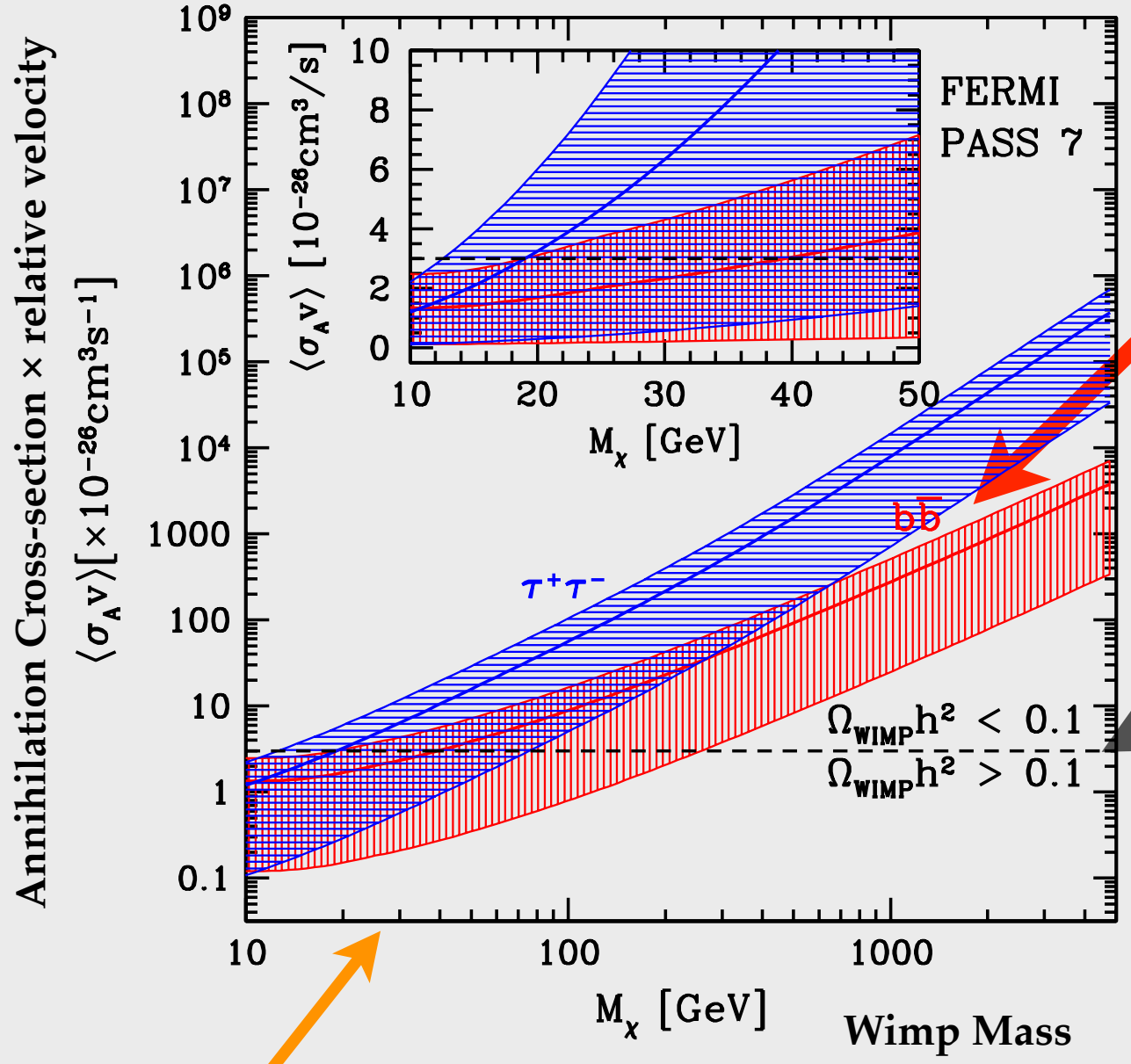
Abstract. We analyze self-consistent N-body simulations of the Milky Way disk and the

Direct Detection

CDMS Collaboration [arXiv:1304.4279]



Indirect Detection

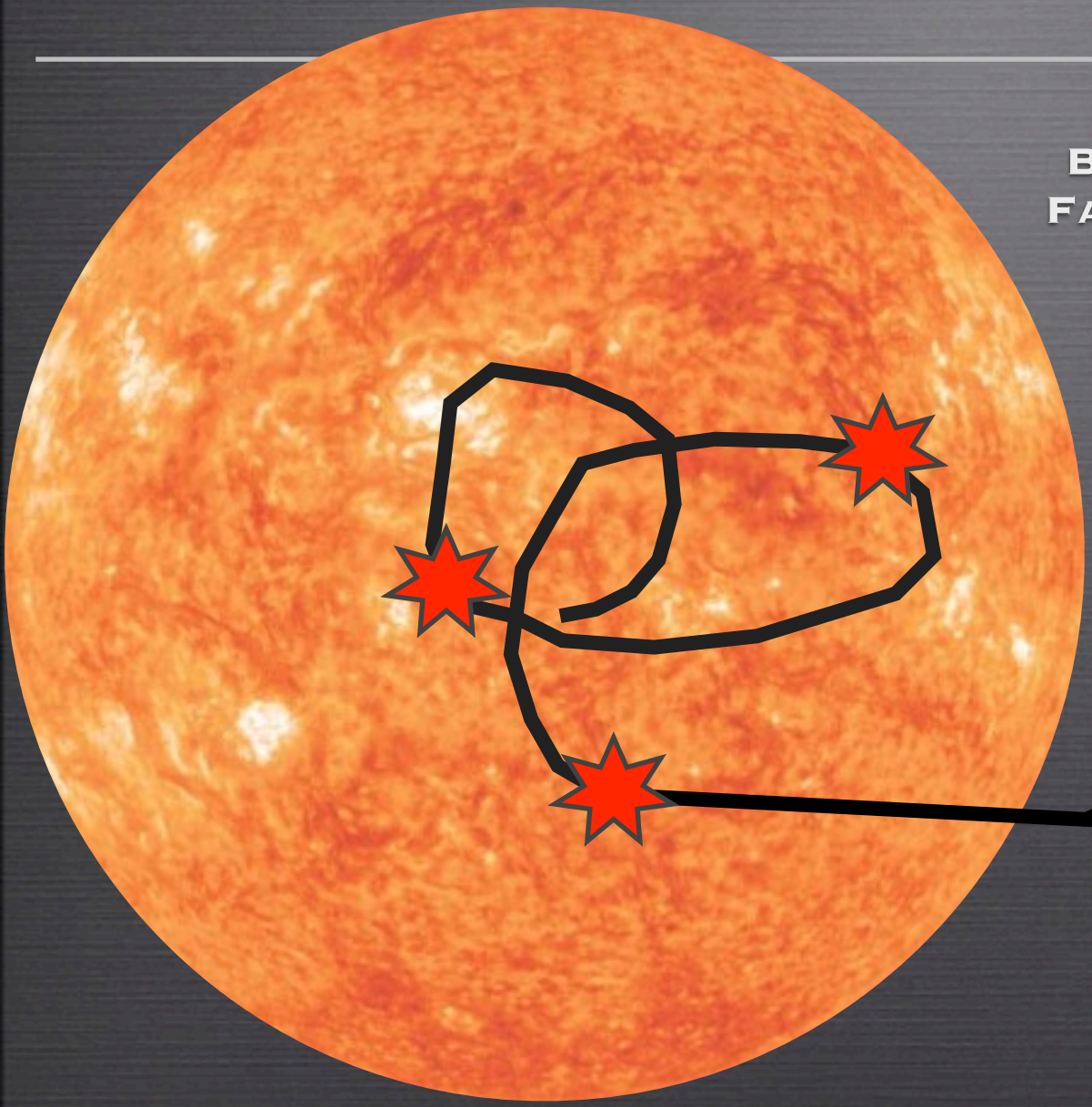


Annihilation Product

Canonical thermal WIMP cross-section that gets relic dark matter abundance correct

Geringer-Sameth & Koushiappas [arXiv:1108.2914] and Fermi collab. [arXiv:1108.3546]

Signatures of Light Dark Matter in Stars



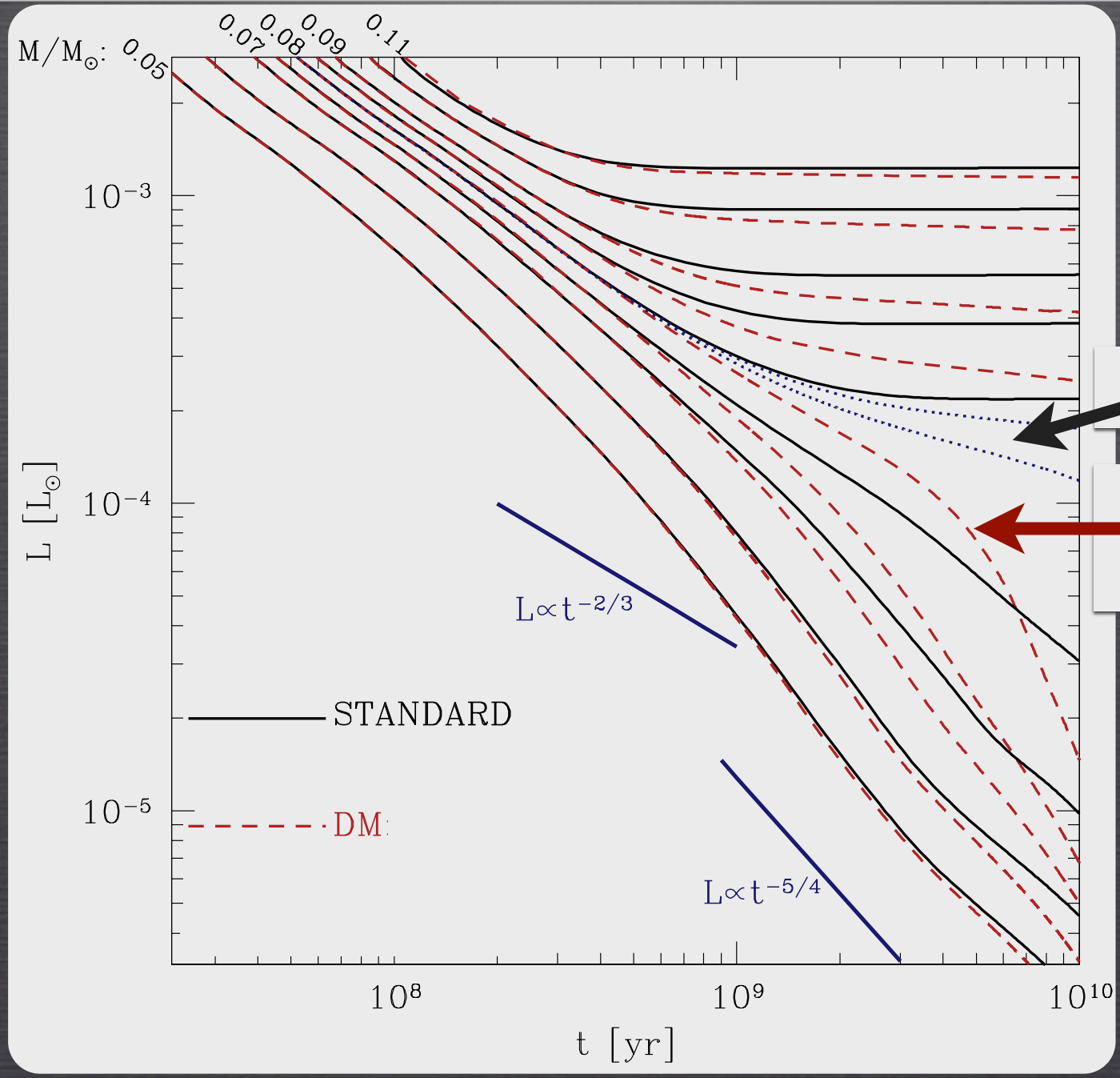
Back to Press & Spergel 1985, Faulkner & Gilliland 1985, who studied the Sun

Approaching Dark Matter Particle

Low-Mass Stars as DM Labs

1. For stars, $M \propto R$: low-mass stars capture as much DM per unit mass as the Sun!
2. $L \propto M^{3.5}$: Less energy needs to be moved around to dramatically alter the stellar structure
3. Low-mass ($\lesssim 0.2\ M_\odot$) are just hot enough to fuse hydrogen and fusion rates are VERY sensitive to core temperature.
4. Astronomical observatories are just becoming capable of taking a census of low-mass stars!

Evolution



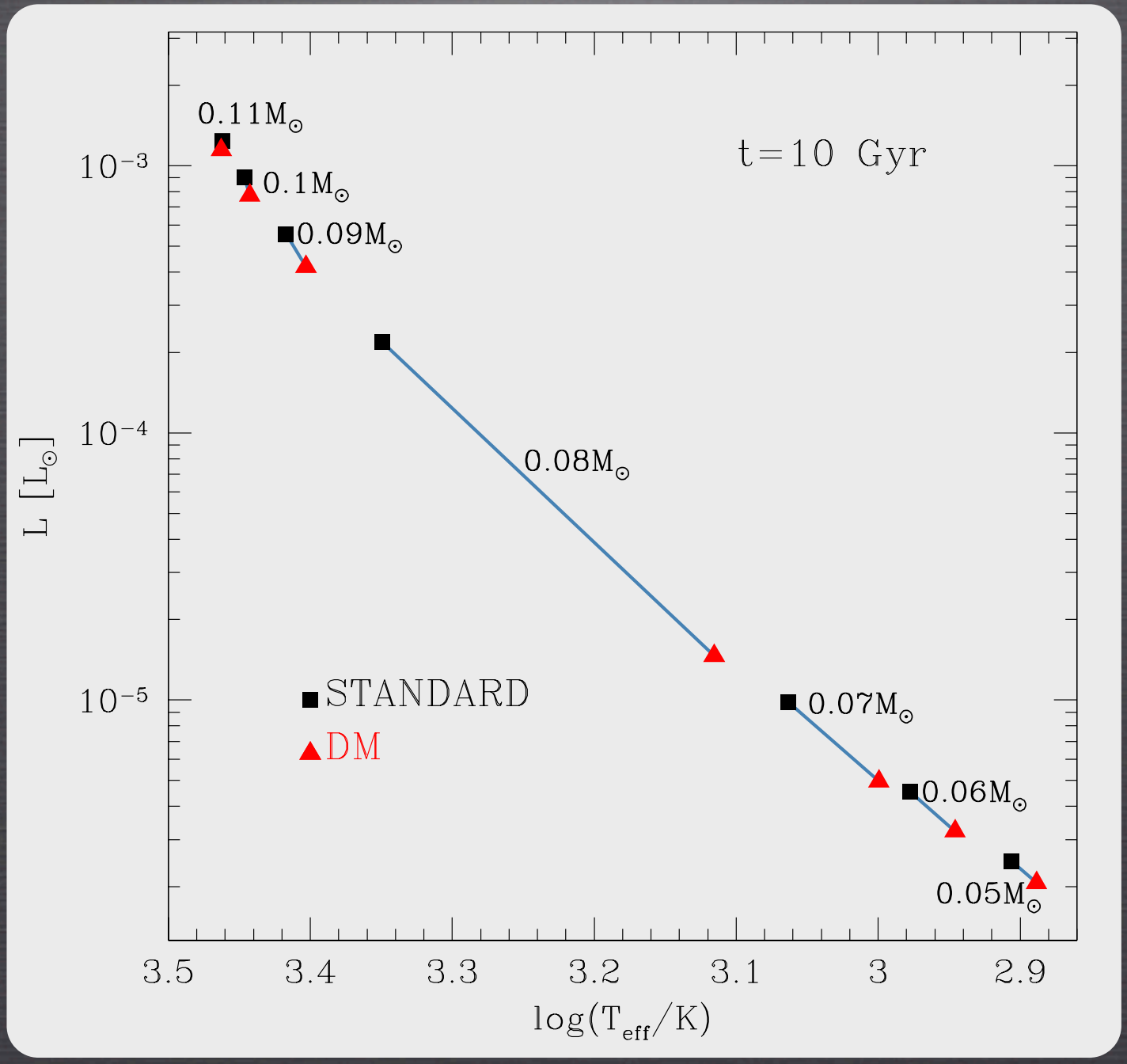
Locally

Dwarf Galaxies

Luminosity [Solar Luminosities]

Time [Years]

Evolution



Luminosity [Solar Luminosities]

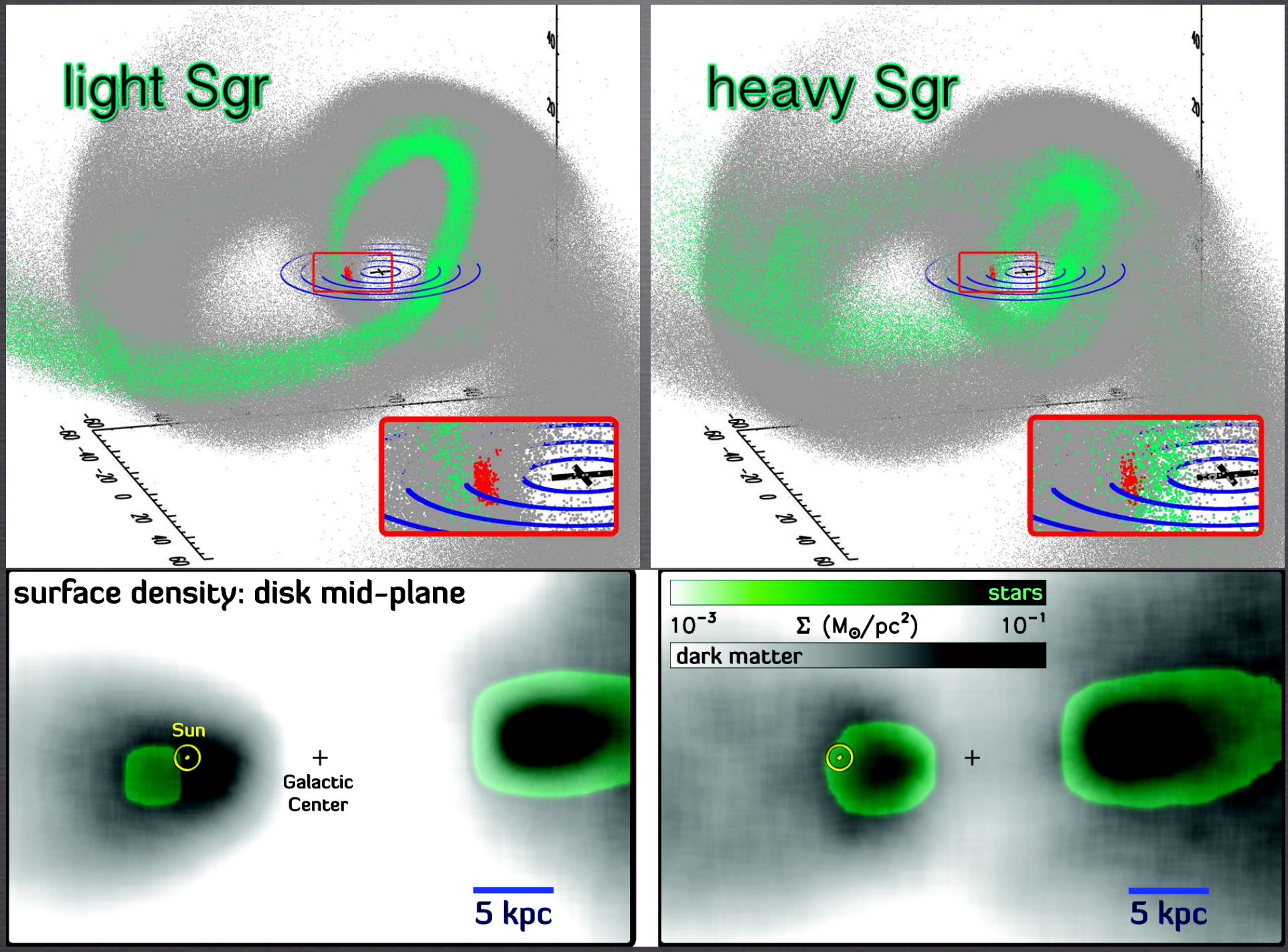
Surface Temperature [K]

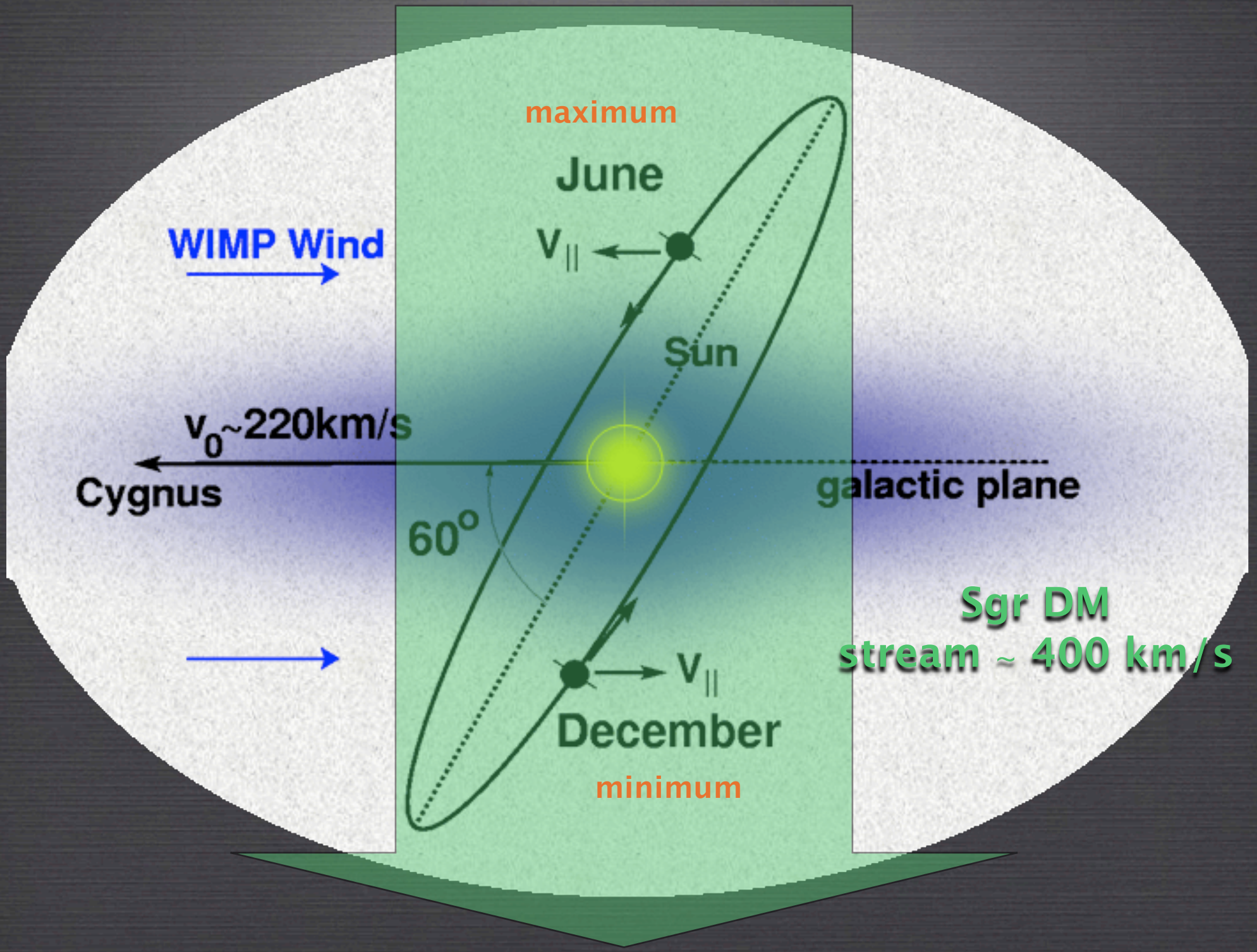
Direct Detection:

Dark Matter from the Sagittarius Stream

e.g., Freese et al. 2004, Savage et al. 2006, Kuhlen et al. 2011;
Purcell, Zentner, Wang 2012 ⟵ THIS RESULT

The Sun is in the Sagittarius DM Stream




maximum
June
WIMP Wind
$v_{||}$
Sun
v_0~220km/s
Cygnus
galactic plane
60°
Sgr DM
stream ~ 400 km/s
$v_{||}$
December
minimum

The SGR Stream

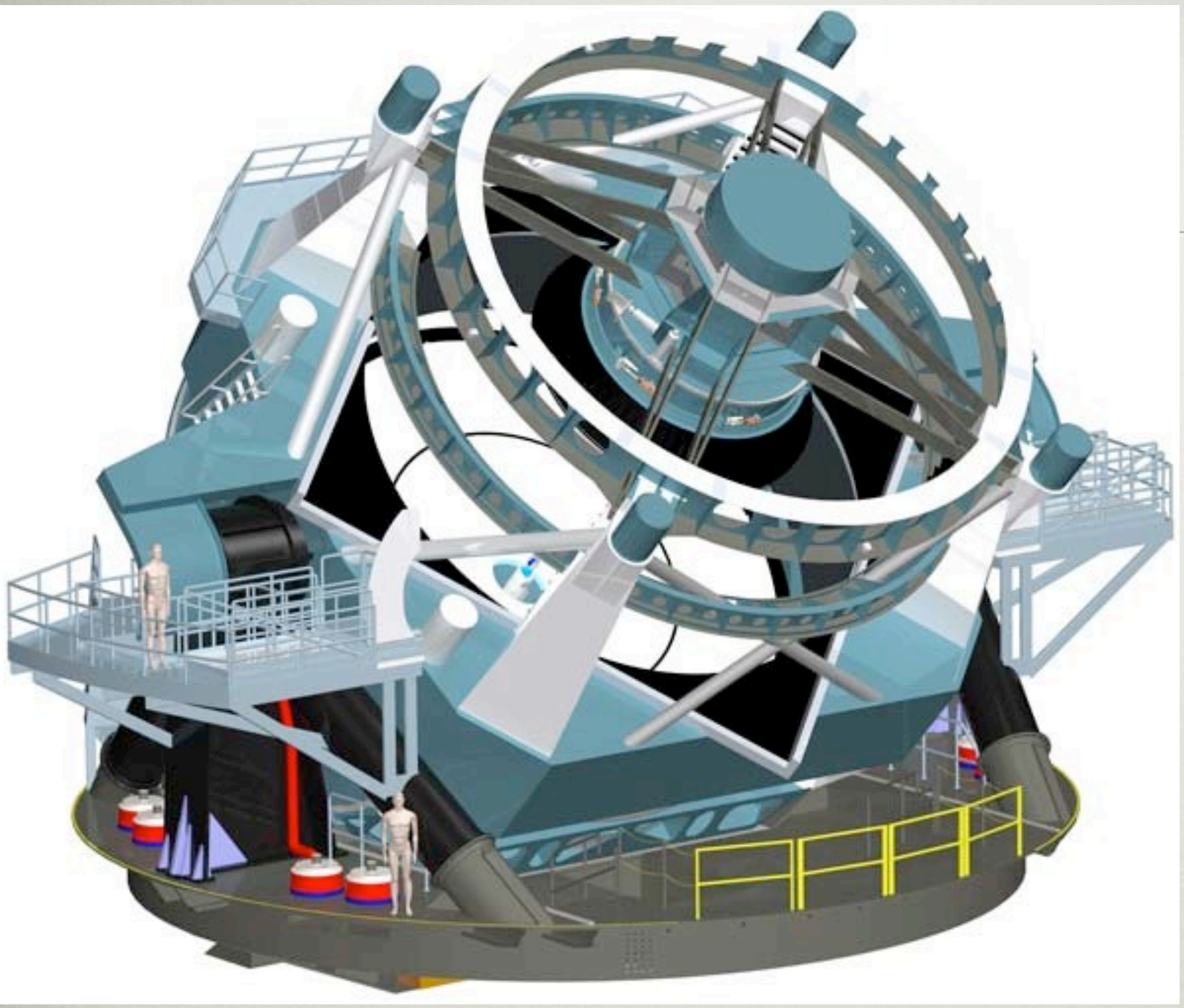
- The SGR Stream likely "Impacts" the Solar System.
- The SGR Stream Particles are all high-velocity
- The SGR Stream Particles are out of phase from the general solar system signal.

The SGR stream induces ...

- ~20-40% higher event rates compared to halo alone.
- a decreased Annual modulation amplitude by as much as a factor of ~2
- A shift in the peak of the annual modulation signal as much as ~20 days
- Lower energy of phase-reversal of Annual modulation signal by ~ 0.2 keV_{NR}

Conclusions

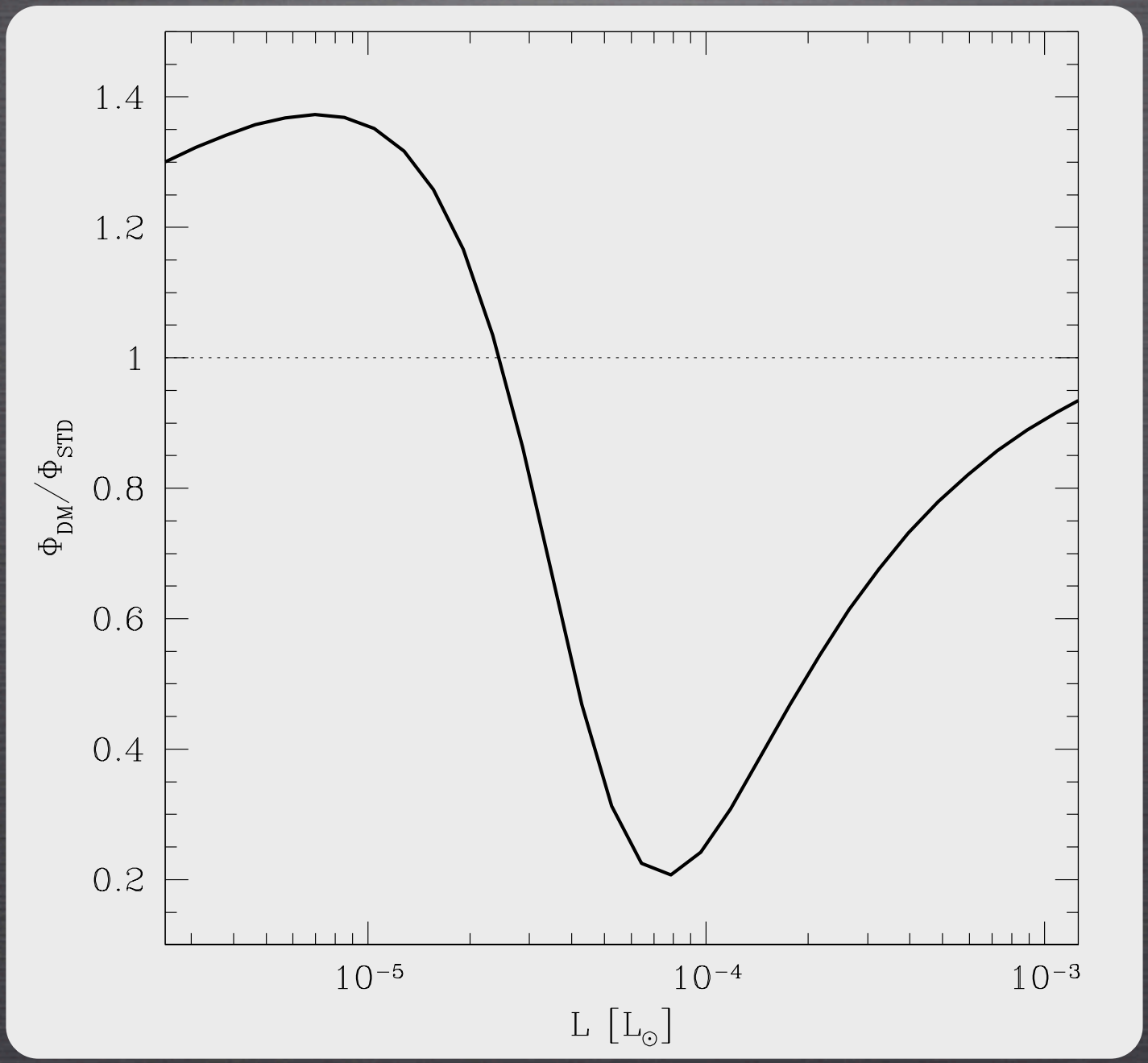
- Low-mass Dark Matter Particles ($\lesssim$ 20 GeV) may alter low-mass Stellar Evolution
  - Significantly lower stellar luminosities at fixed mass, particularly in dwarf galaxies
- Low-mass Dark Matter Particles can have direct search signatures significantly altered due to SGR Stream dark matter near the Sun.



LSST/Euclid

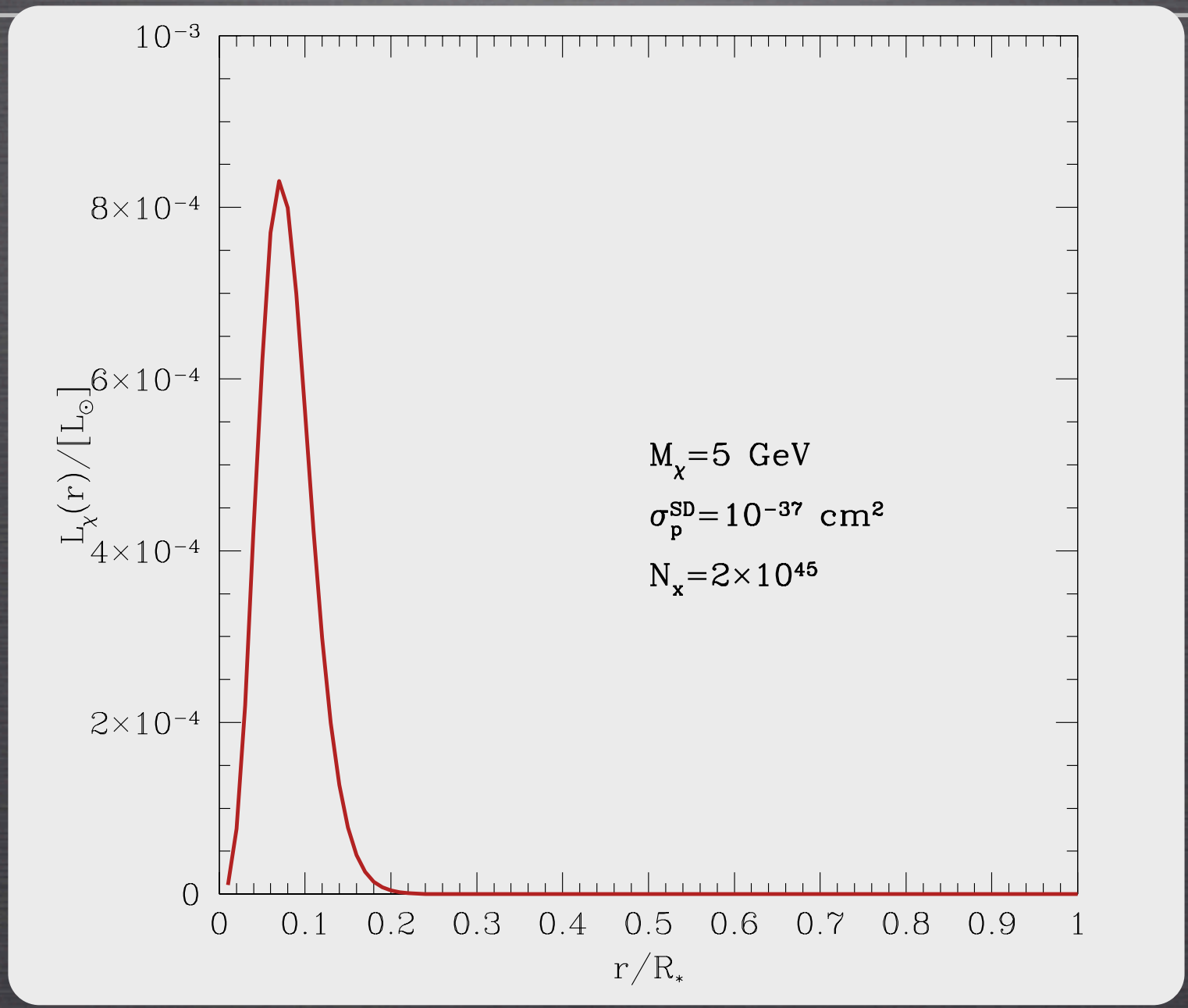
Abundances

Number of stars relative to standard model

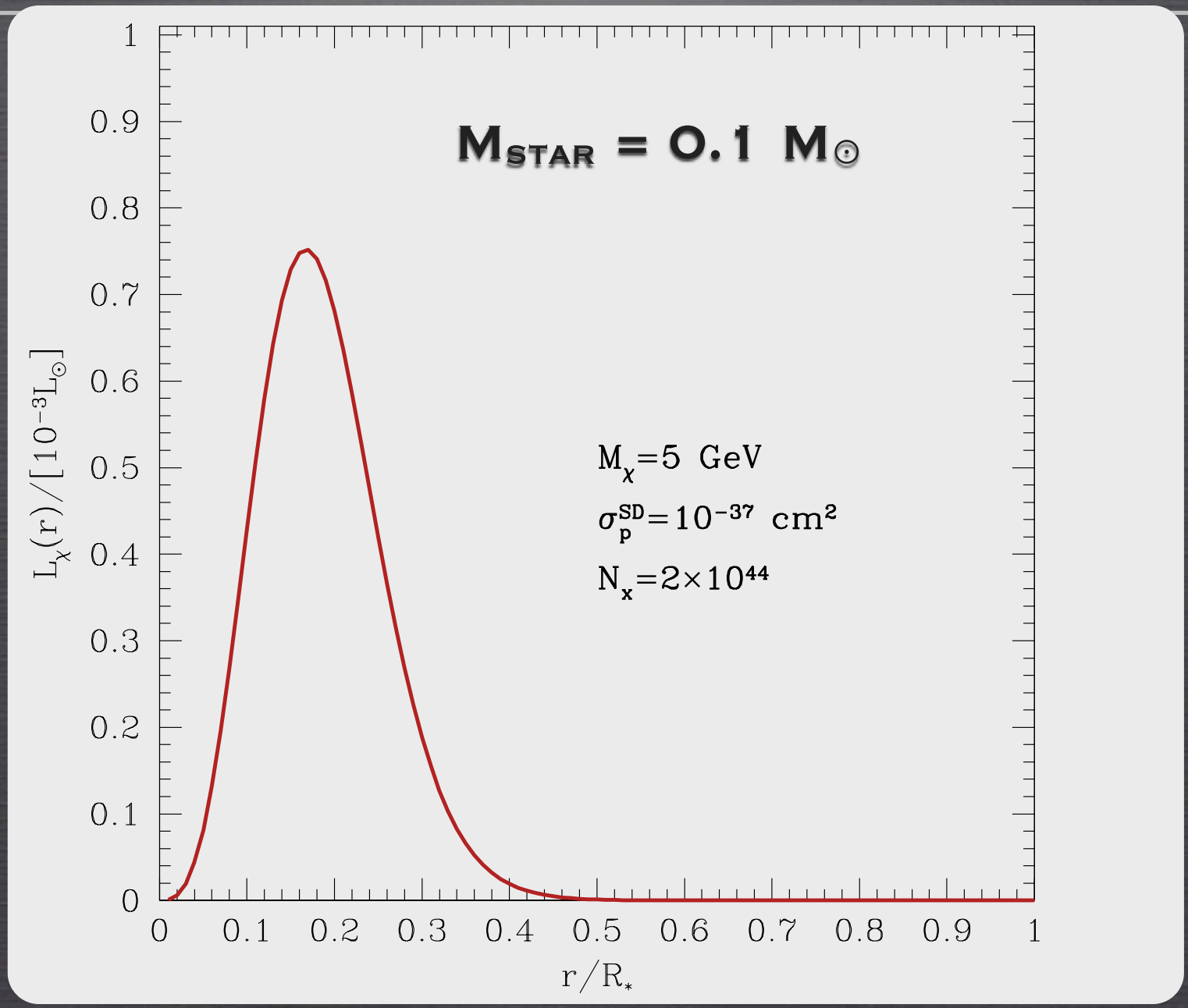


Luminosity [Solar Luminosities]

In the Sun


Luminosity Transported by Dark Matter through surface at R
10^{-3}
8×10^{-4}
6×10^{-4}
4×10^{-4}
2×10^{-4}
0
$L_\chi(r)/[L_\odot]$
M_χ=5 GeV
$\sigma_p^{SD}=10^{-37}$ cm^2
$N_x=2\times10^{45}$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
r/R_*
Radial Position, in units of stellar radius

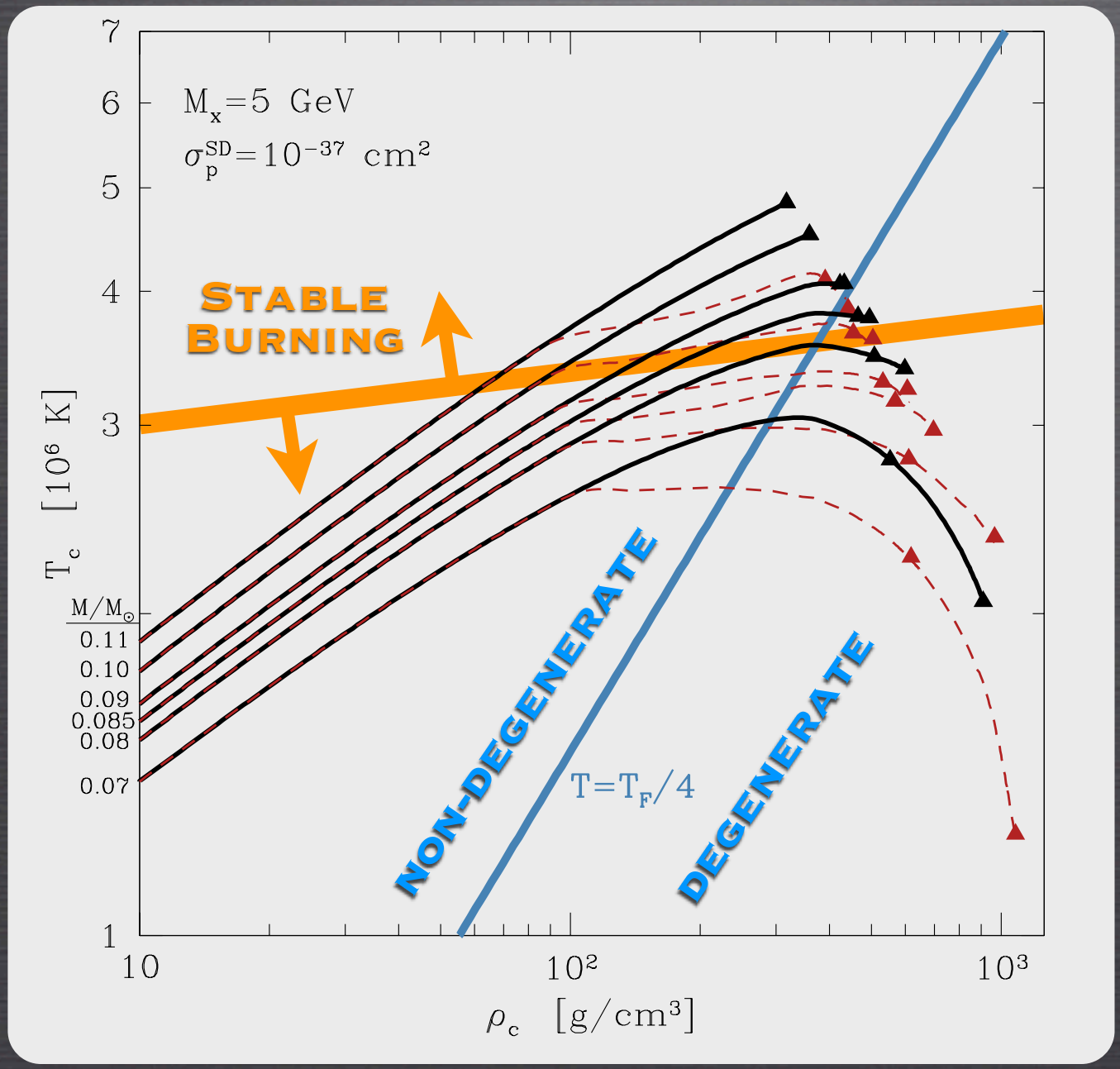
In Low-Mass Star



Luminosity Transported by Dark Matter through surface at R

Radial Position, in units of stellar radius

Core Temperature



Similar Results for $M_x \sim 7$ GeV, $\sigma^{SI} \sim 10^{-40}$ cm^2

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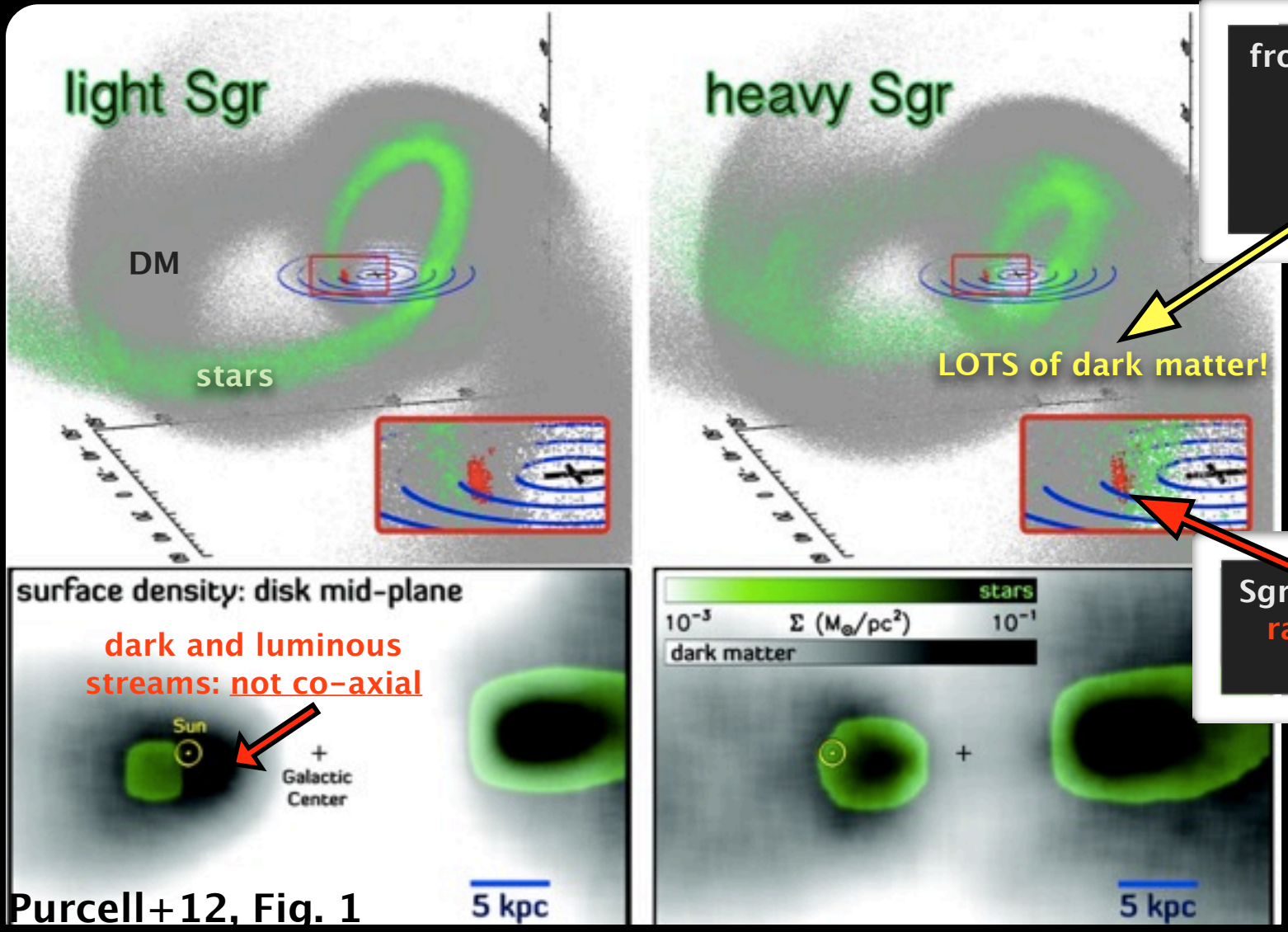
Sagittarius Debris at Earth



Purcell+12, Fig. 1

from cosmological context and kinematic reconstructions: Sgr progenitor was massive

light Sgr ≃ $10^{10.5}$ $M_\odot$

heavy Sgr ≃ 10^{11} $M_\odot$

Sgr dark matter tidal arm is raining directly onto the Earth...

...even though the stellar stream is not!

...no evidence for vertically-coherent kinematic sub-populations within ~100 pc of Sun: e.g. Helmi et al. 2006; Re Fiorentin et al. 2011

e.g. Seabroke et al. '08
Correnti et al. '10
Law & Majewski '10

ArXiv: astro-ph/1203.6617

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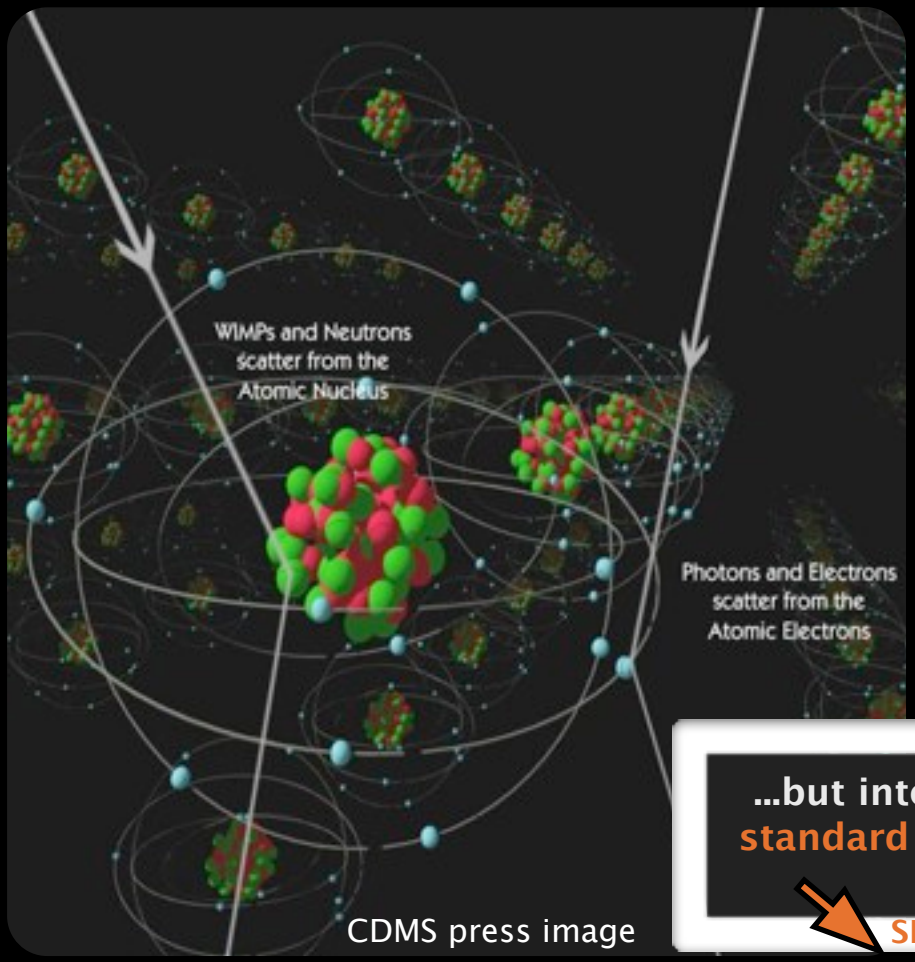
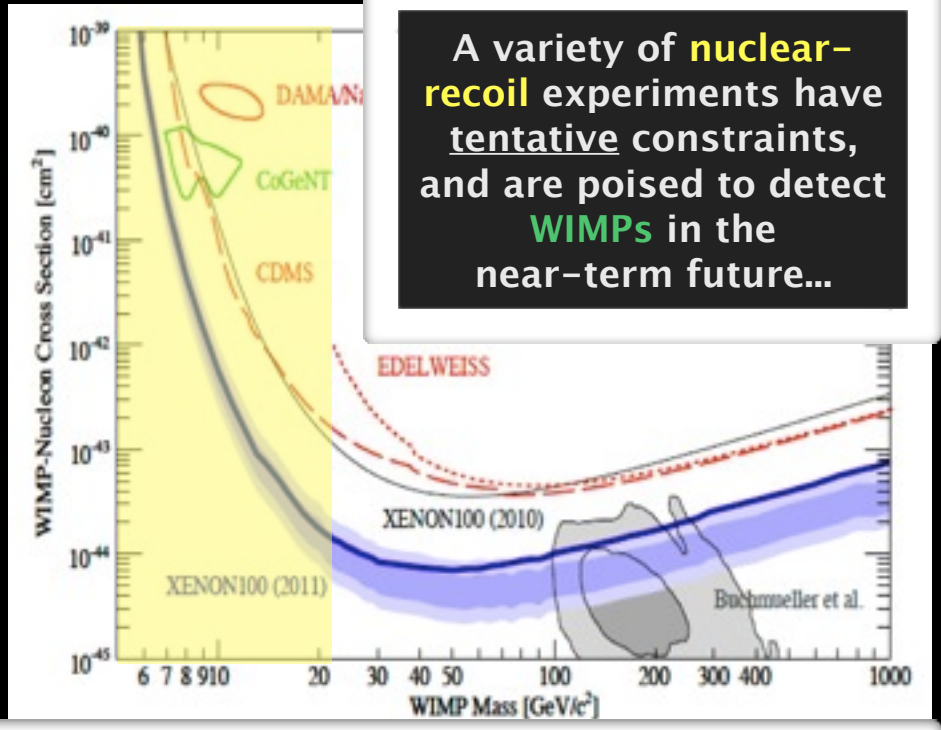
Dark Matter Direct Detection



CDMS press image



A variety of **nuclear-recoil** experiments have **tentative** constraints, and are poised to detect **WIMPs** in the near-term future...

...but interpretations of the event rates typically assume a **standard halo model** of the **local speed distribution of dark matter!**

SHM: isothermal halo; Maxwellian f (v)

$$\text{scattering event rate} = \frac{dR}{dE} \sim g(v) = \int_{v_{min}}^{\infty} f(v) / v$$

May 7 @ Pheno 2012

ArXiv: astro-ph/1203.6617

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Dark Matter Direct Detection

$$\frac{dR}{dE} \sim g(v)$$

ArXiv: astro-ph/1203.6617

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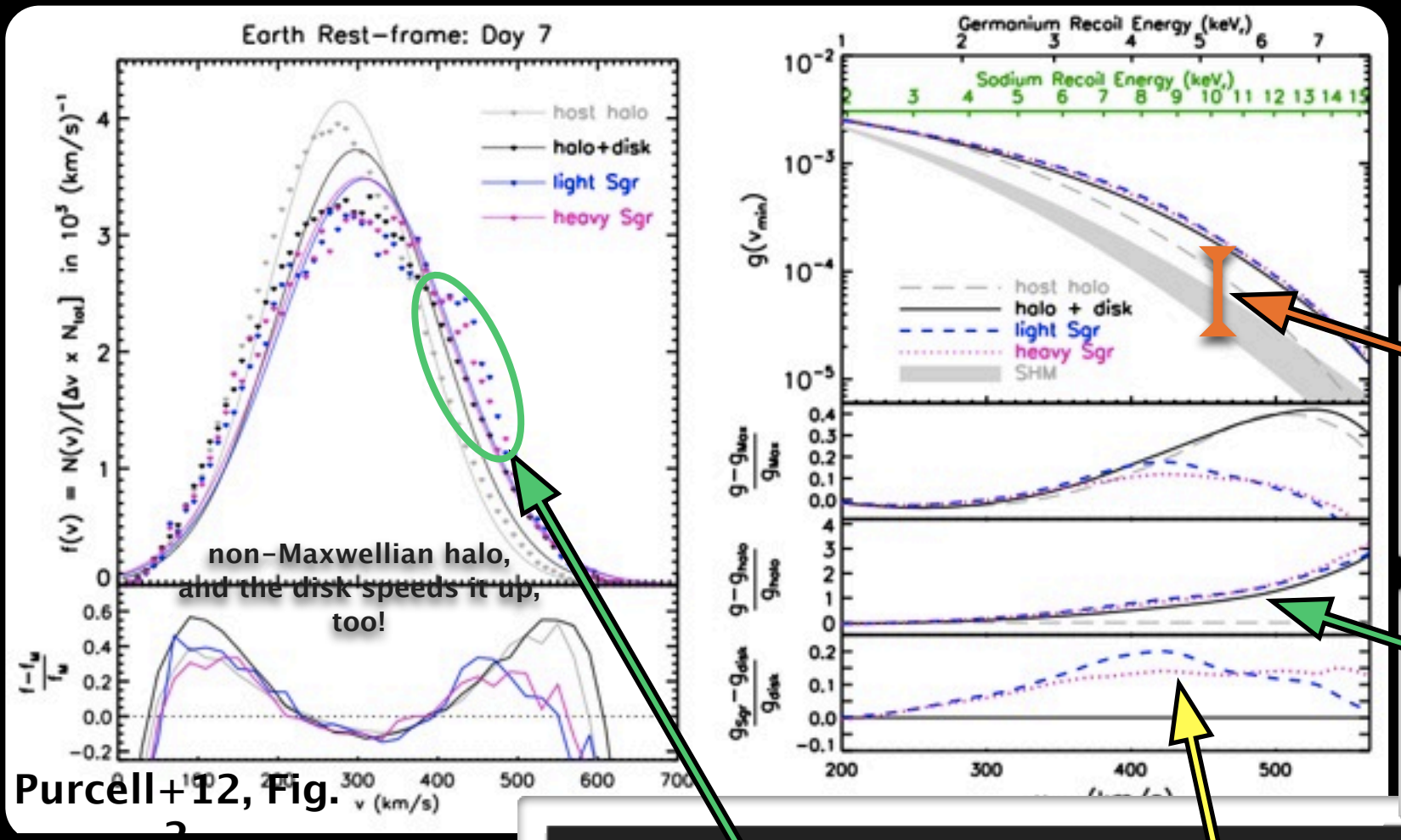
Dark Matter Direct Detection



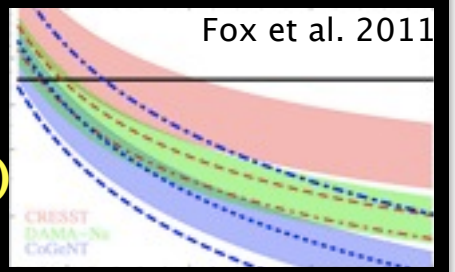
Purcell+12, Fig. 2

$$\frac{dR}{dE} \sim g(v)$$

standard halo model underestimates event-rates by a factor of >2-5!

stellar disk also boosts rates by a factor of 2 or more!

even small non-Maxwellian features can boost the event rate when integrating over the high-end of the speed distribution, so Sagittarius debris adds another ~ 10-20% (for light WIMPs)



v_{min} (km/s)

M_X (GeV/c²)

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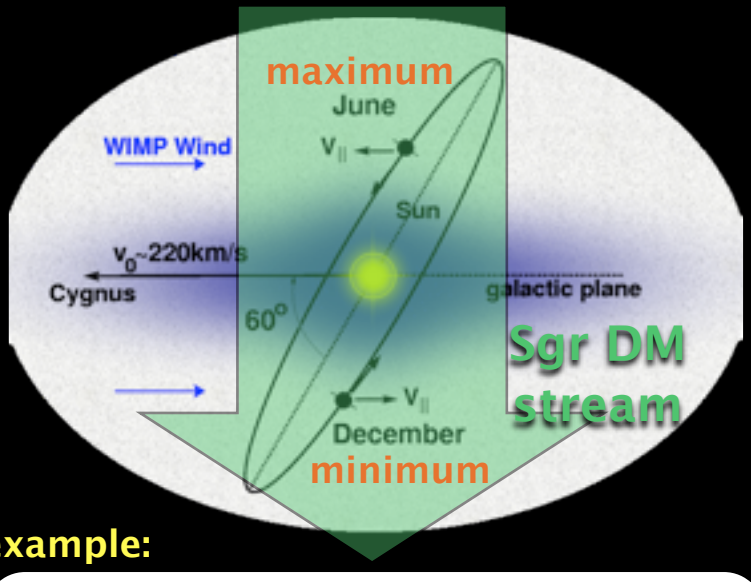
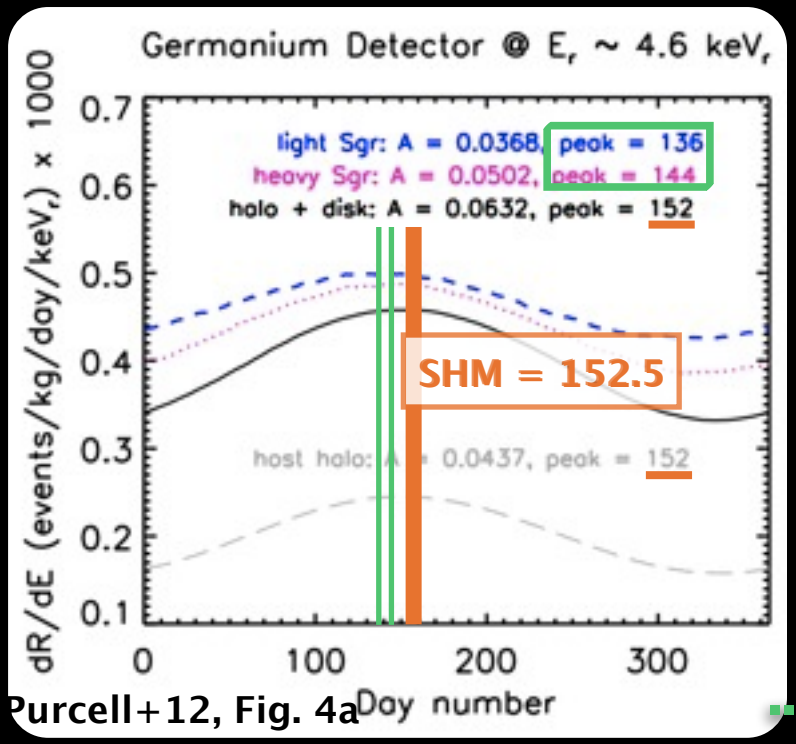
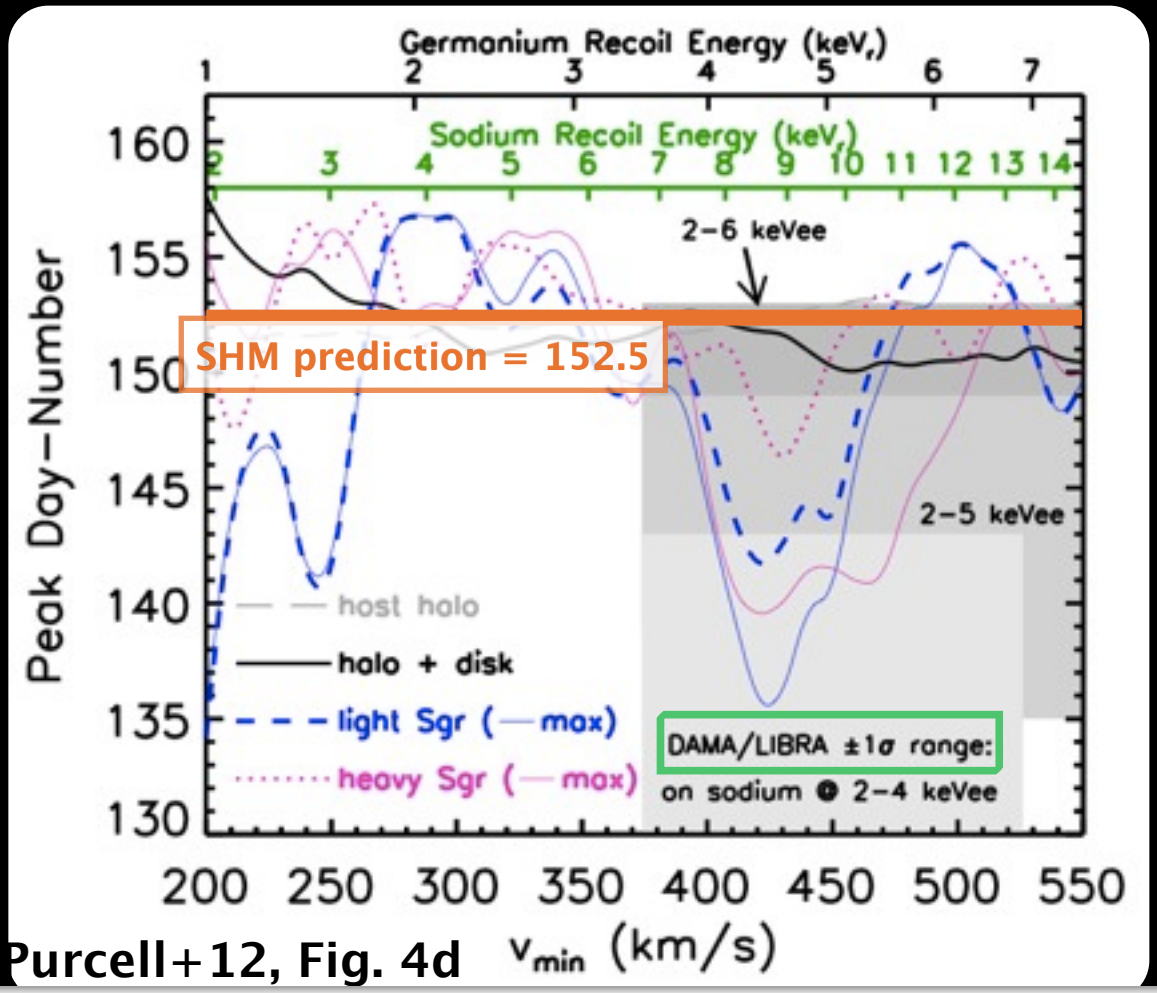
Annual Modulation: Sgr Signal?



example:



Purcell+12, Fig. 4a



Purcell+12, Fig. 4d

Only **significant** debris flows (and **not** ancient micro-streams) can drag the peak away from the SHM-predicted value by several days...

...is DAMA already "seeing" Sgr dark matter?!

ArXiv: astro-ph/1203.6617

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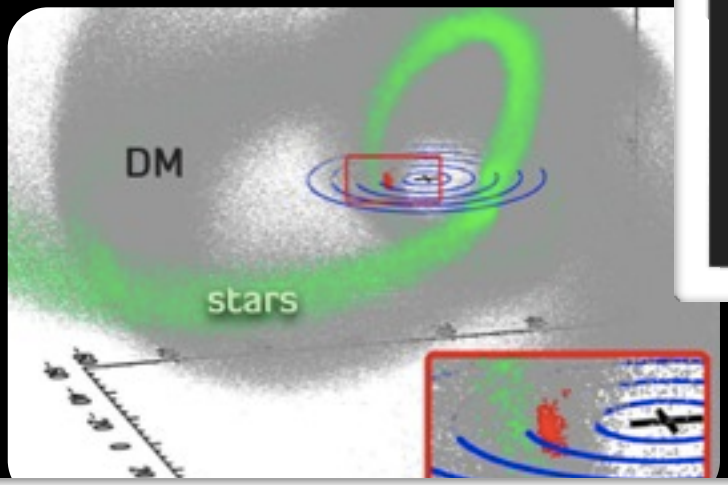
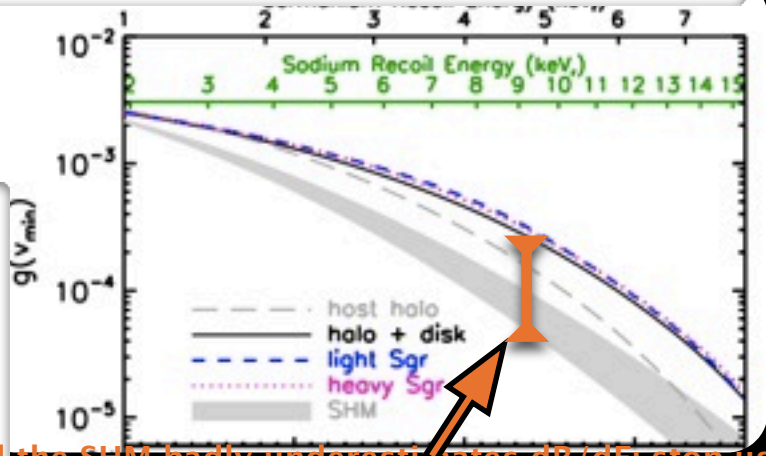
Conclusions

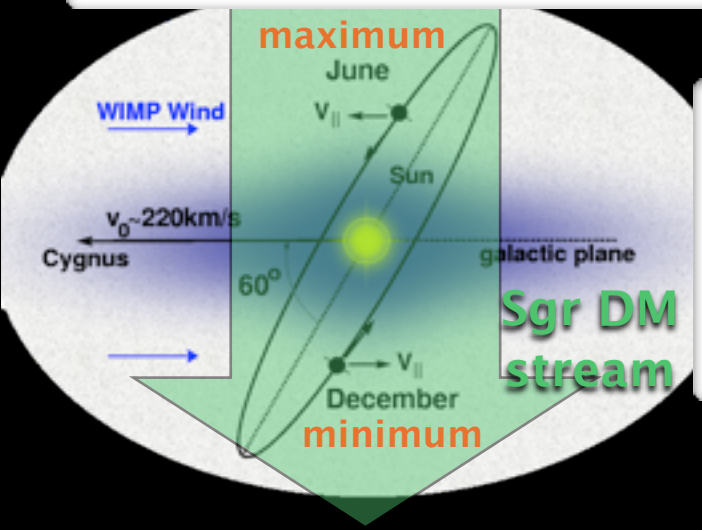


Dark matter from the disrupting Sagittarius dwarf is raining onto Earth at the solar neighborhood, and induces a ~ 10-20% boost in recoil-event rates

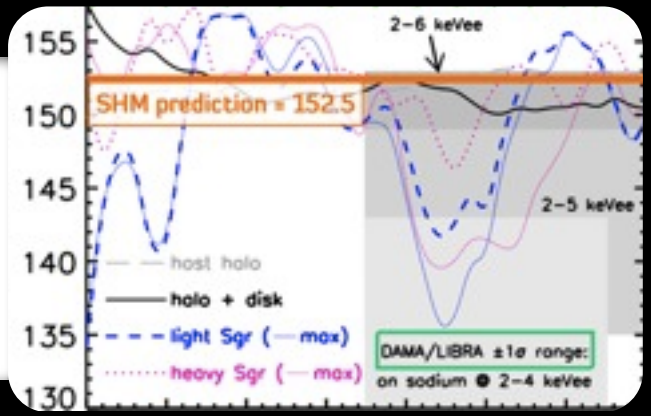


Self-consistent mapping from N-body halo rates (e.g. for VL2, Aquarius) to those predicted for same halos with realistic Galactic disks: important on factor of ~ 2 level

...and the SHM badly underestimates dR/dE: stop using it!



Coherently-moving Sgr debris changes phase of annual modulation signal by as much as ~ 10-20 days



...experiments are poised to test DAMA/LIBRA and could confirm Sgr dark matter on Earth!

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ArXiv: astro-ph/1203.6617

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