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Dark matter hurricane

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Topics for today

arXiv:[1807.09004]

KCL-PH-TH-2018-38

A Dark Matter Hurricane: Measuring the S1 Stream with Dark Matter Detectors

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(Dated: July 25, 2018)

The recently discovered S1 stream passes through the Solar neighbourhood on a low inclination, counter-rotating orbit. The progenitor of S1 is a dwarf galaxy with a total mass comparable to the present-day Fornax dwarf spheroidal, so the stream is expected to have a significant DM component. We compute the effects of the S1 stream on WIMP and axion detectors as a function of the density of its unmeasured dark component. In WIMP detectors the S1 stream supplies more high energy

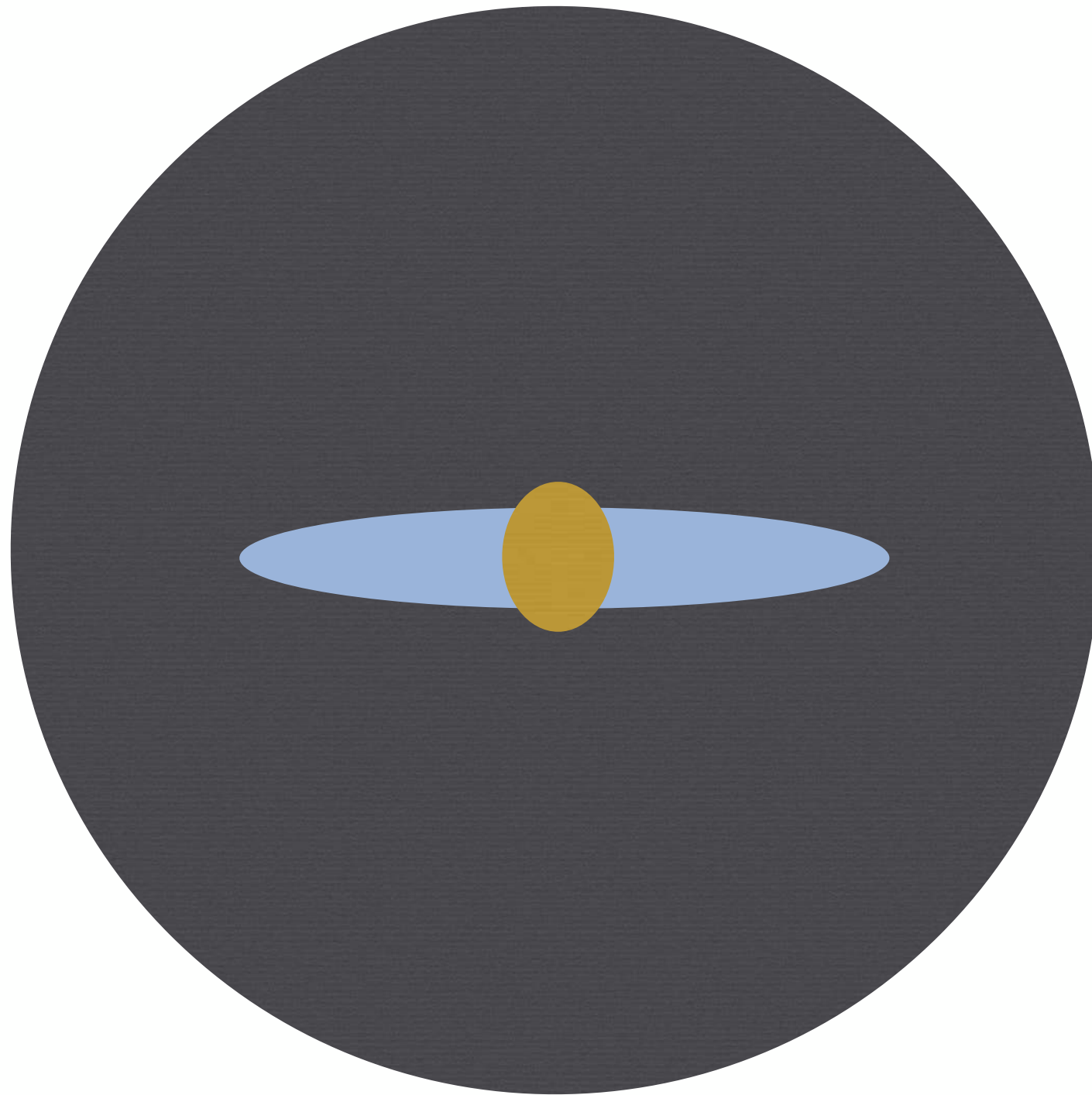
What is a stream?

What is the S1 stream?

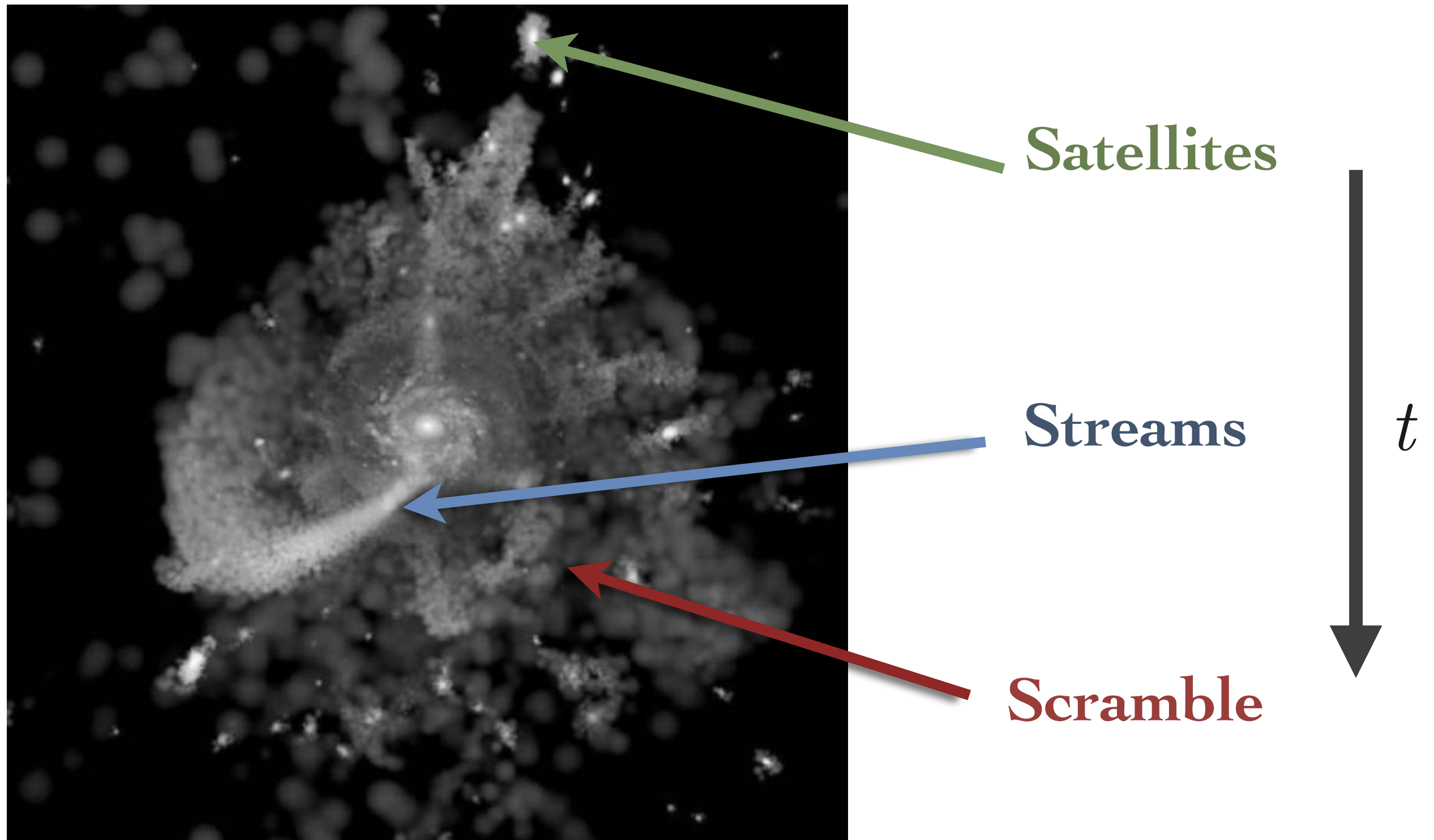
What is the impact for WIMPs?

What is the impact for axions?

A dark matter halo



A dark matter halo (really)



Importance for DM

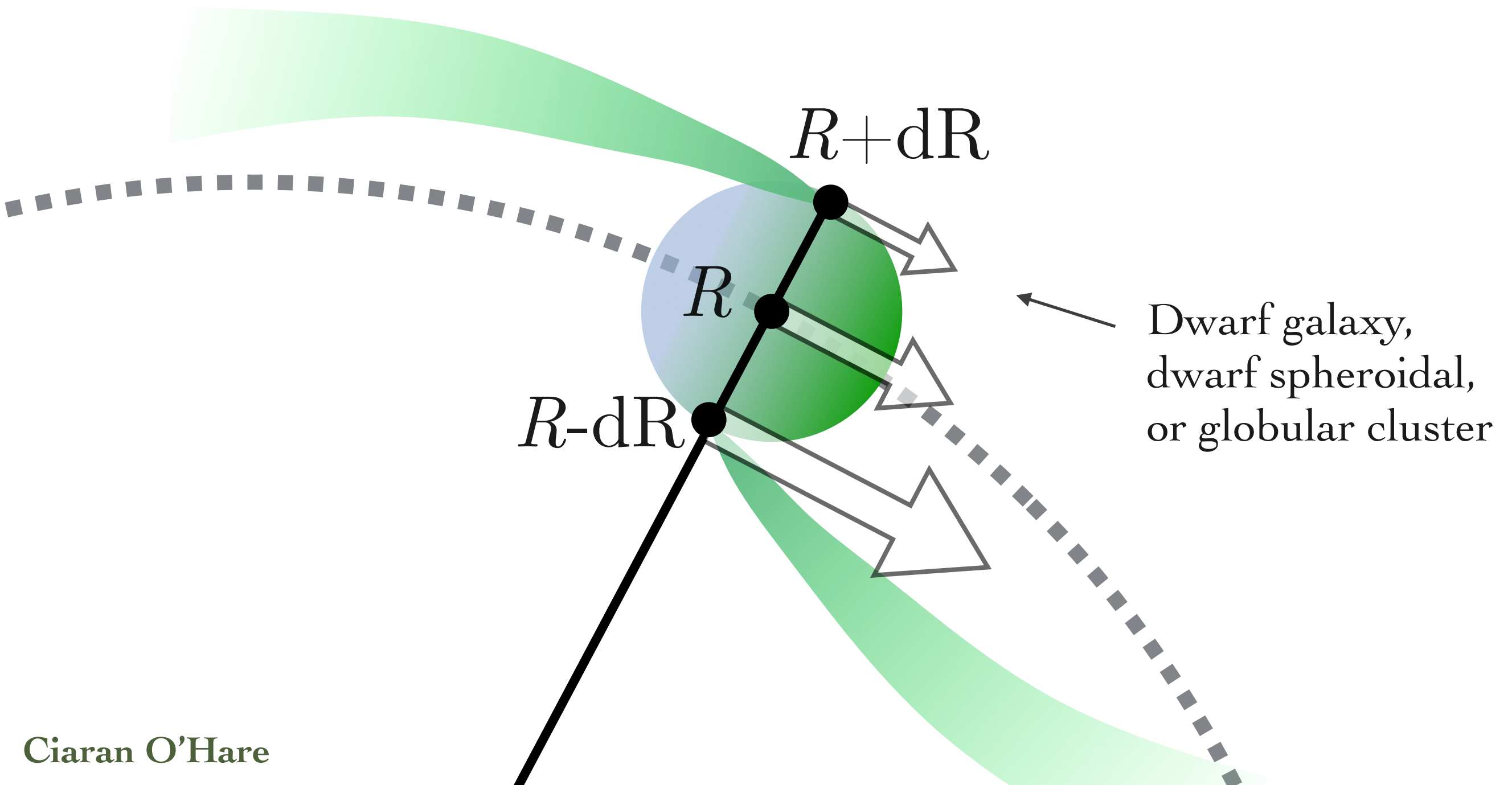
Satellites → Distinguishing warm/cold DM
→ Targets for DM annihilation or decay

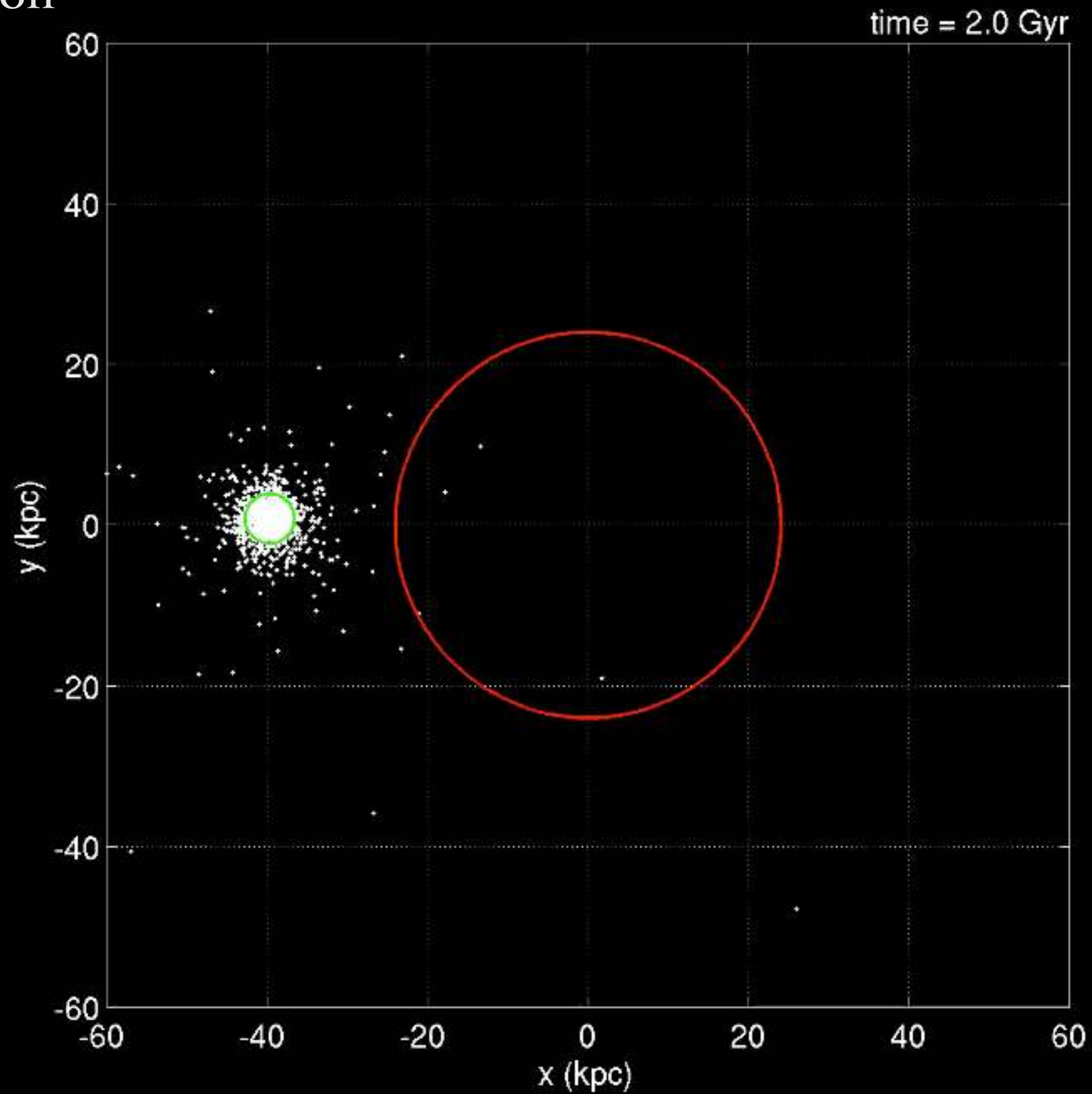
Streams → Informs about the granularity of DM halo
→ Traces the shape of MW potential
→ Can be used to constrain fuzzy DM

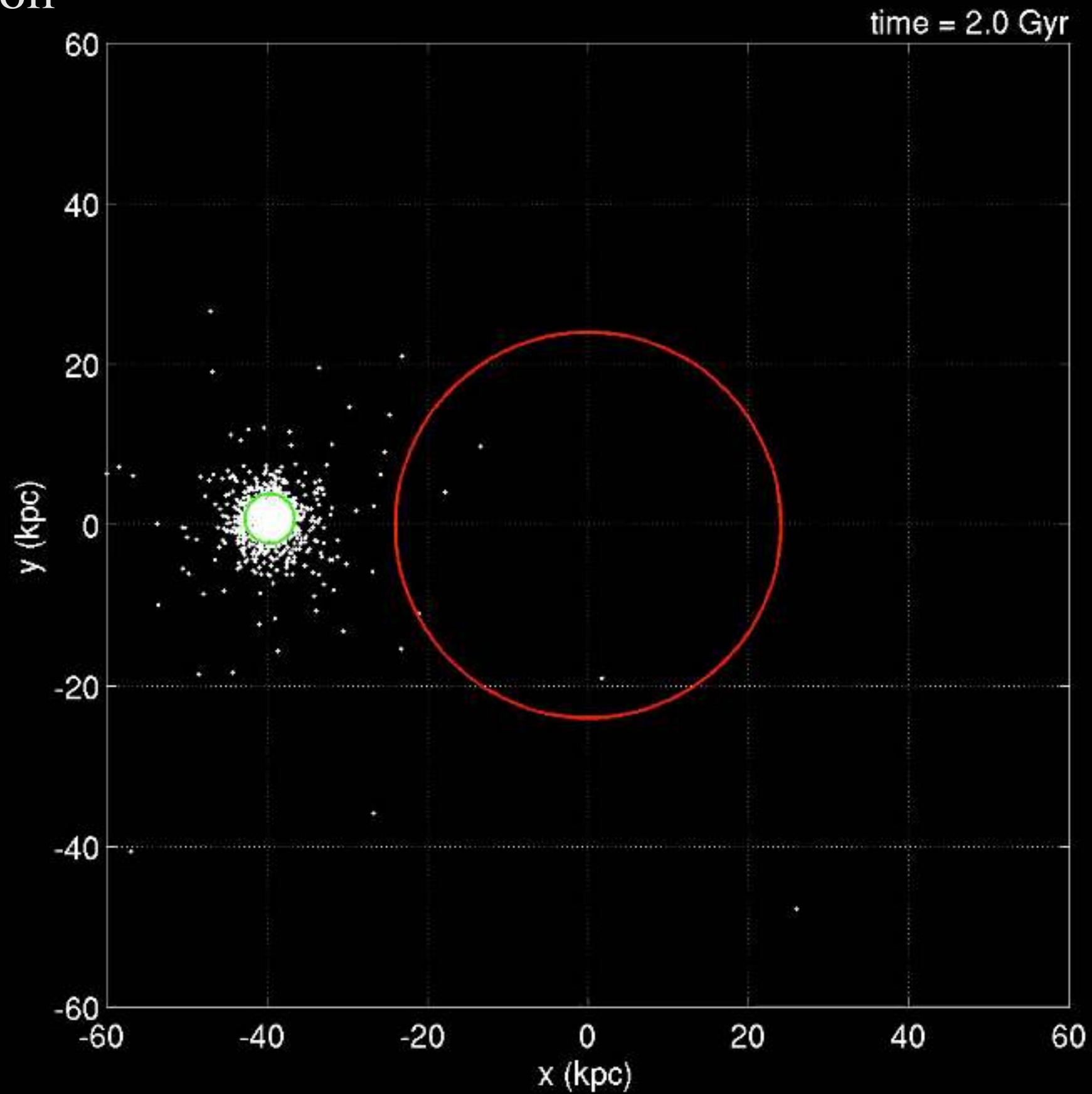
Scramble → Clumpiness of the dark matter halo
→ Crucial input for all direct DM searches

Forming tidal streams

Satellite is pulled apart when the tidal force across it overcomes its own self-gravity



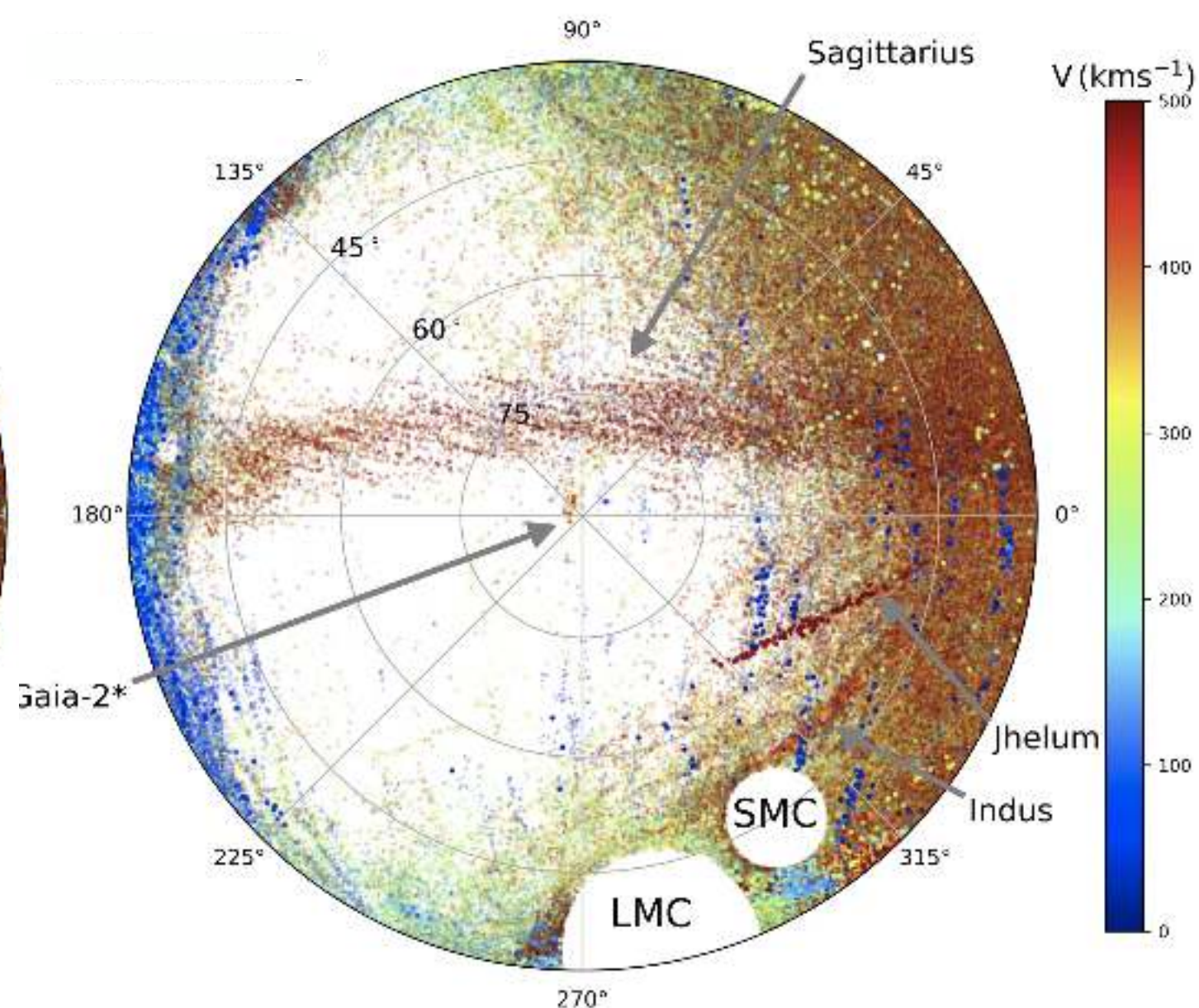
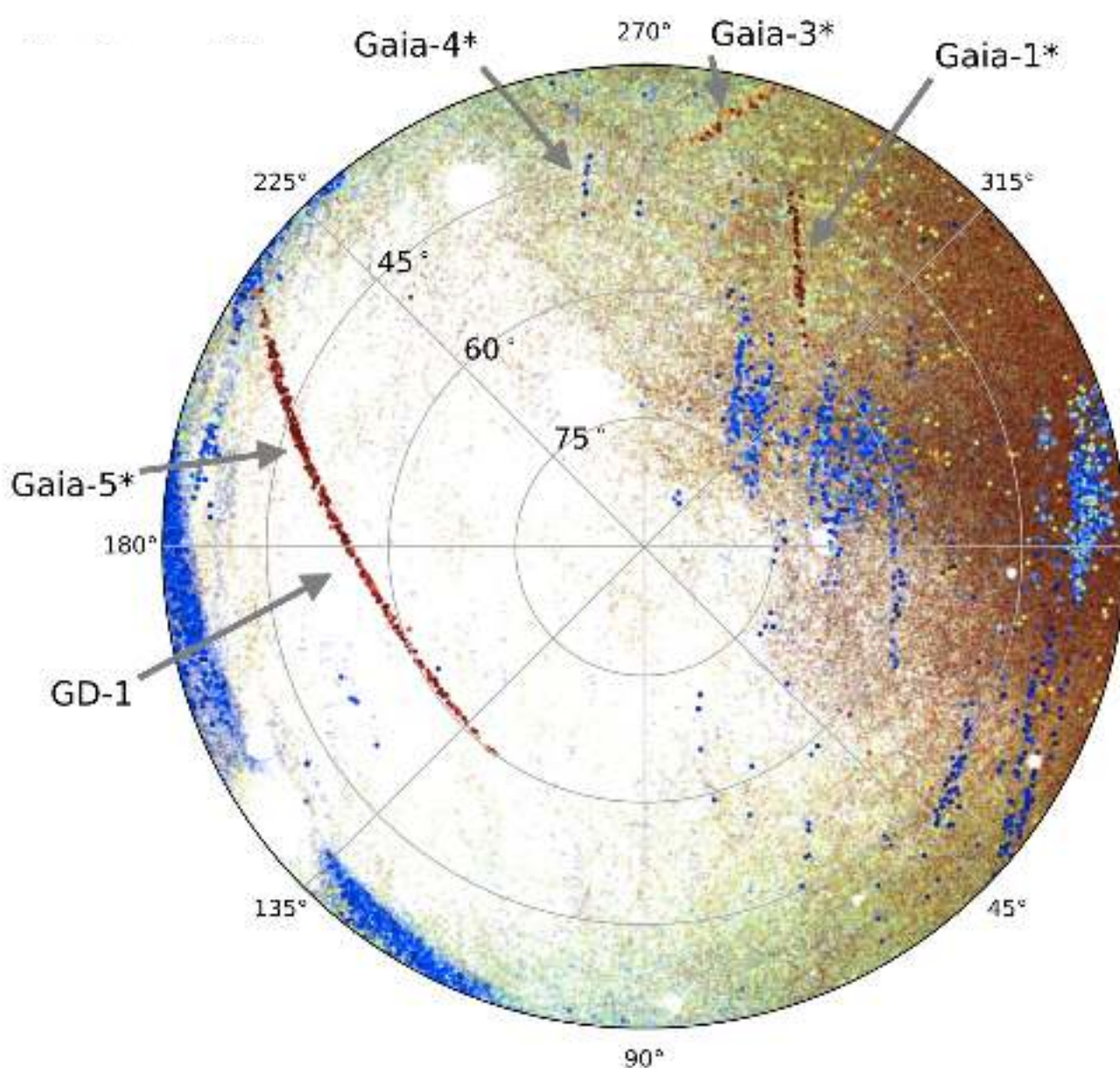




Finding streams spatially

Northern sky

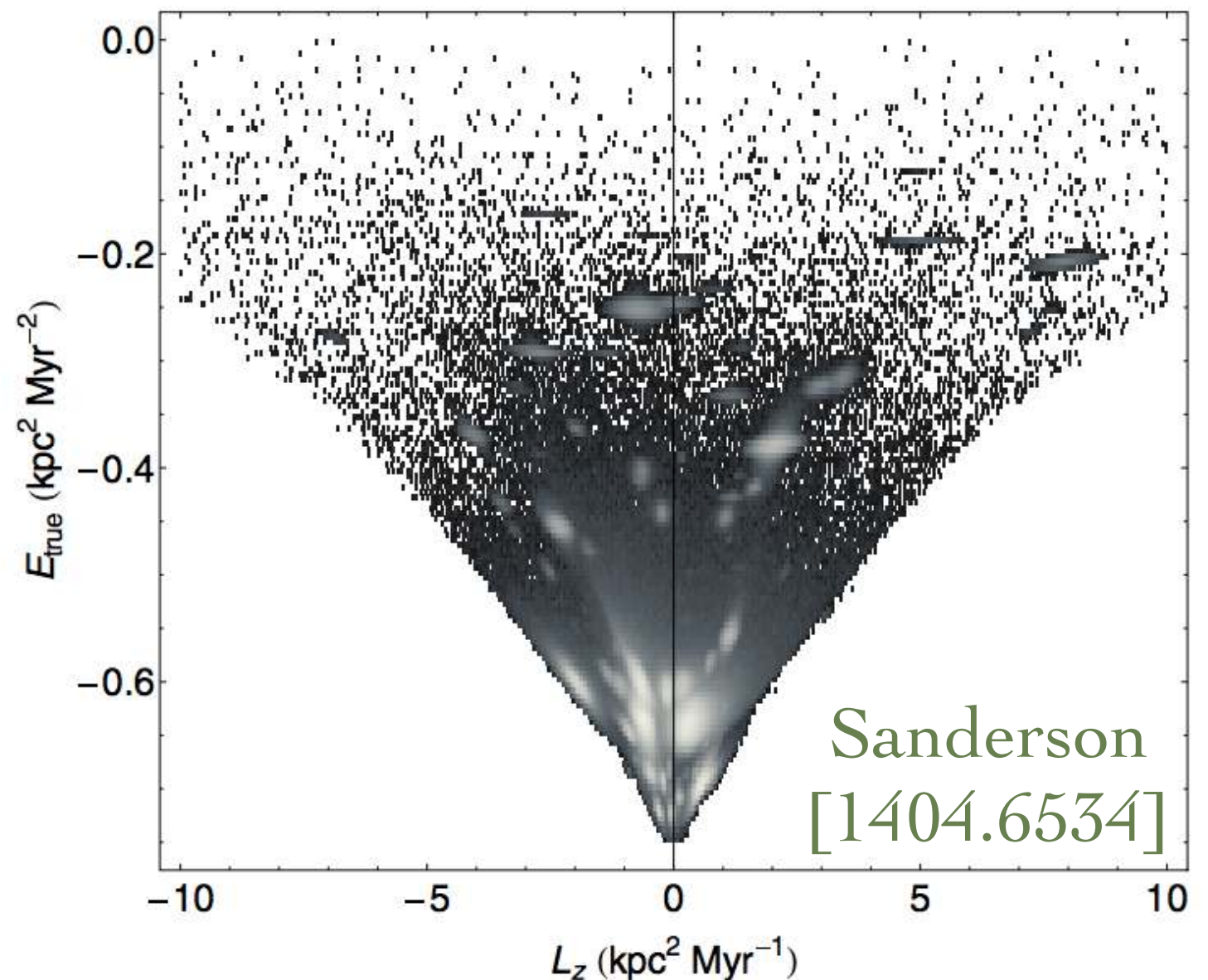
Southern sky ESA



Finding streams kinematically

“Angle-Actions” - map orbital parameters into variables that are conserved for orbits in slowly varying potentials
→ hence streams remain clustered in “action space” long after they have ceased to be visible in star counts

Computing these variables for stars requires full orbital information
→ **Need complete 6D kinematic data to find streams this way...**



Gaia

- Launched in 2013
- Will operate until ~2022
- 1.7 billion stars (1% of MW)
- Parallax+proper motion on 1.3 billion
- 20 million stars with distance precise to 1%
- 40 million stars with tangential velocity precise to < 0.5 km/s
- 7 million stars with full 6D solution (x, y, z, v_x, v_y, v_z)



Compared to predecessor, Gaia has 10,000 times more stars, over a volume 100,000 times larger, with 1000 times better accuracy

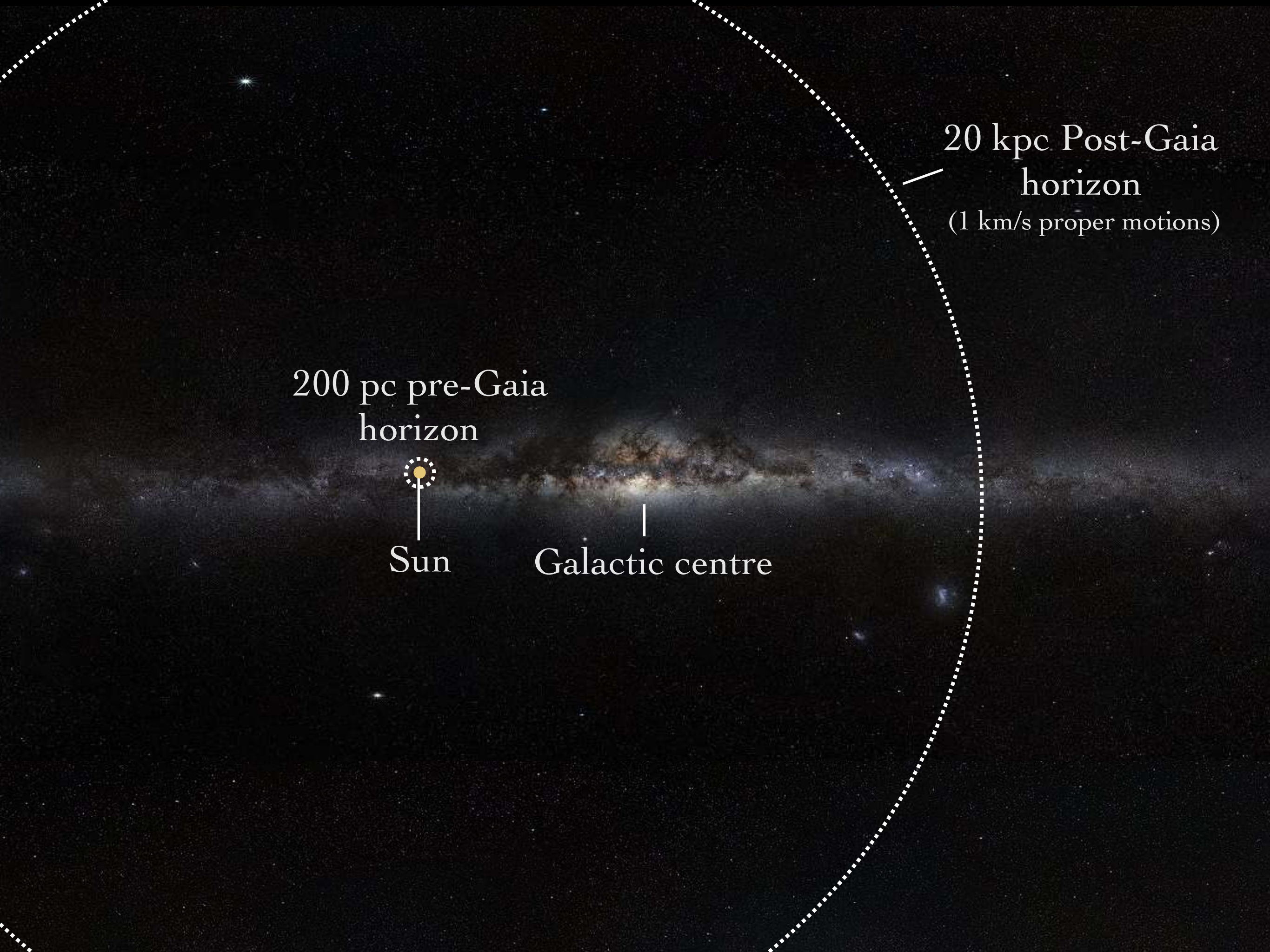
200 pc pre-Gaia
horizon



Sun



Galactic centre



200 pc pre-Gaia
horizon



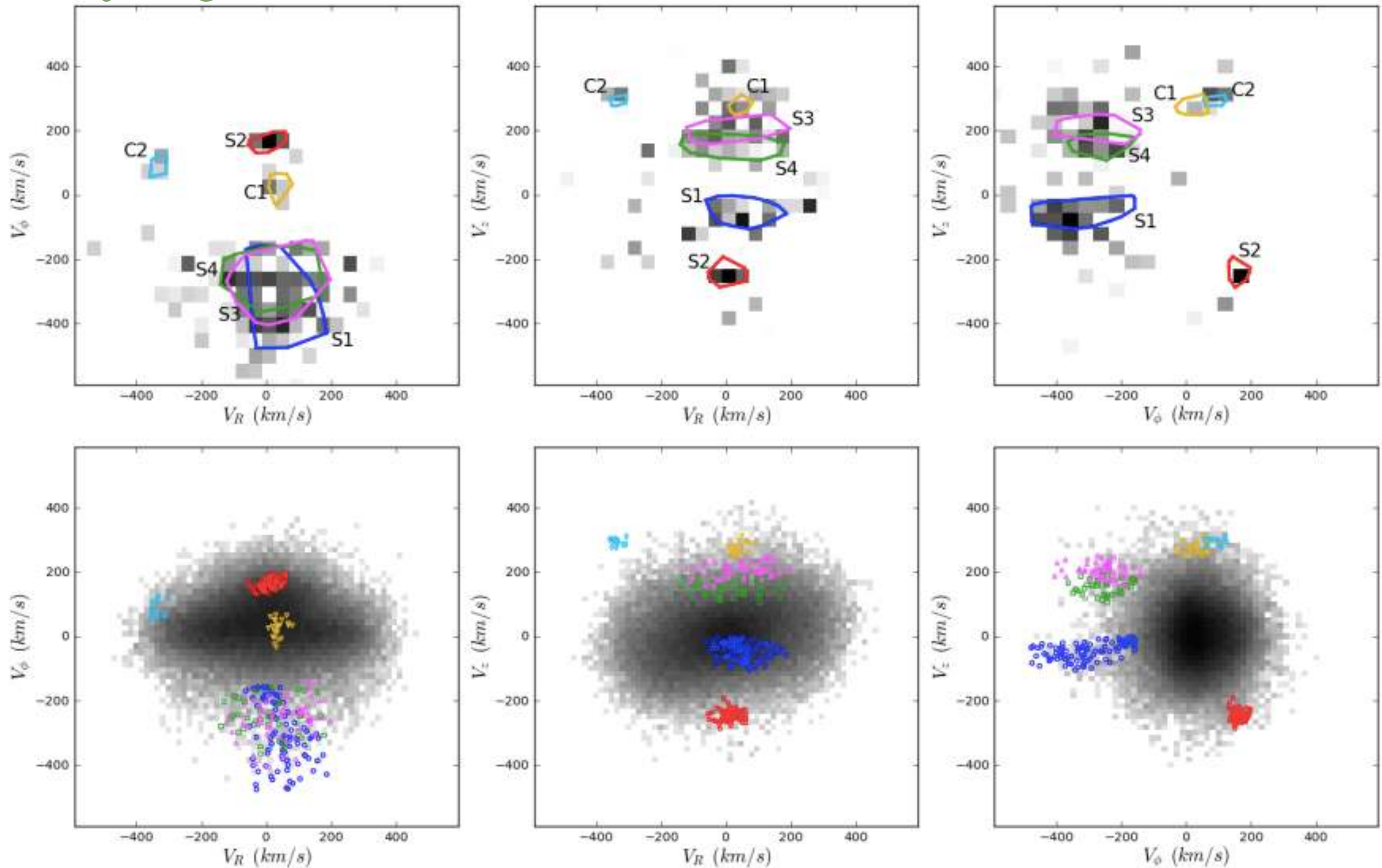
Sun

Galactic centre

20 kpc Post-Gaia
horizon
(1 km/s proper motions)

Substructure in Gaia

Myeong+ [1712.04071]

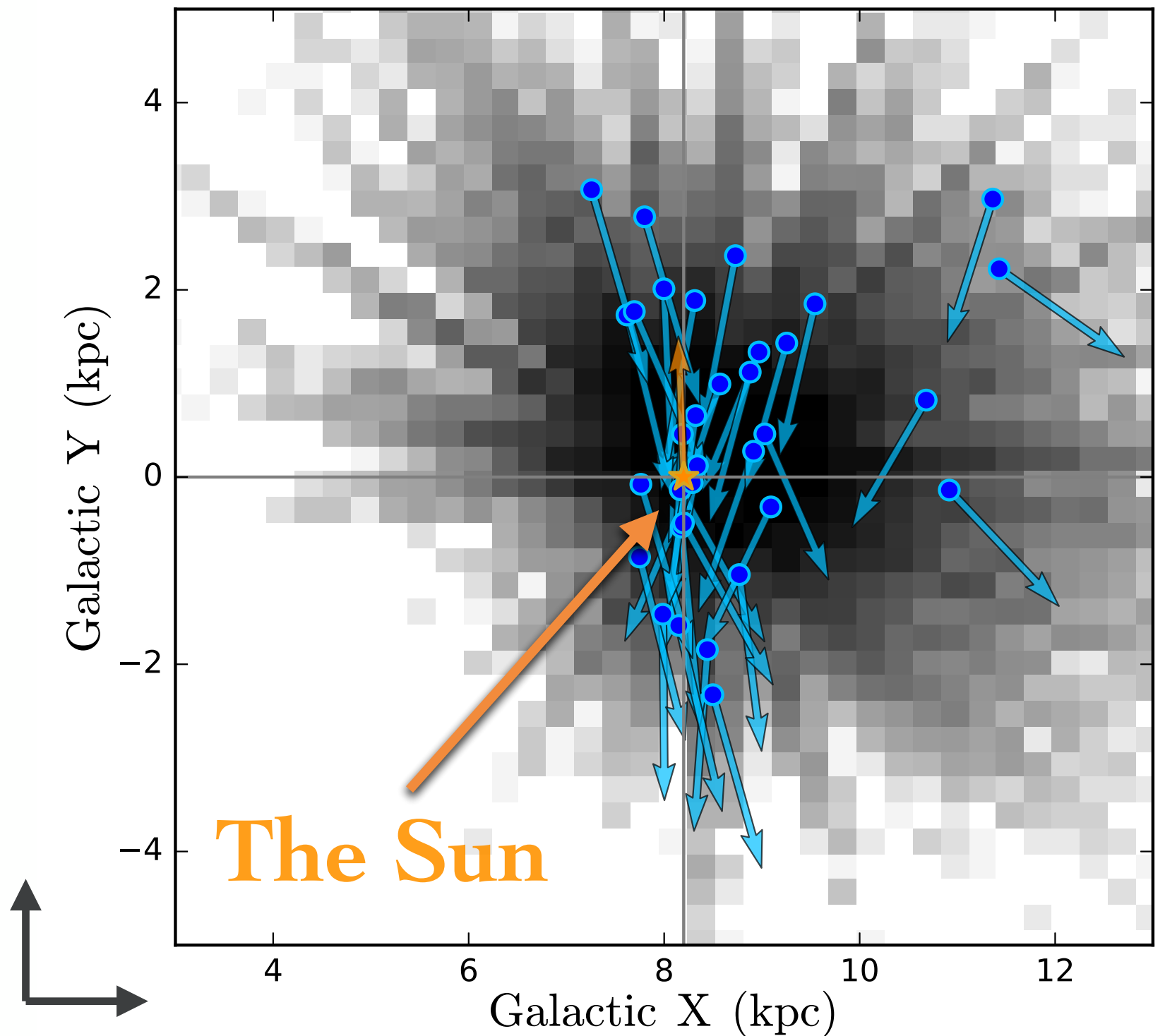


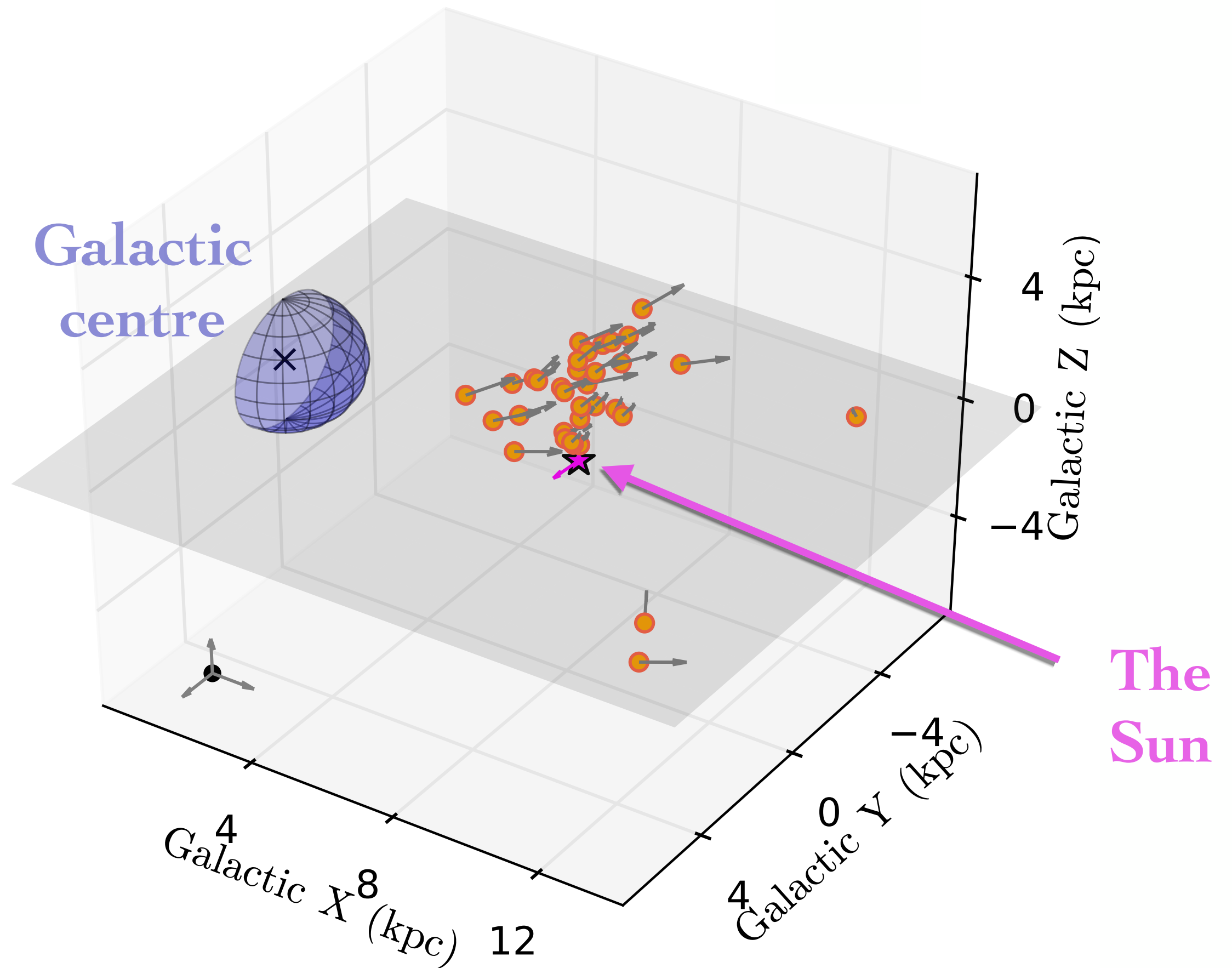
The S1 stream

S1 stream

→ Stars identified with common accretion history streaming with orbits intersecting our location

Galactic plane





S1 stream: what we know so far

Galactic velocity: $\mathbf{v}_{\text{str}} = (8.6, -286.7, -67.9) \text{ km s}^{-1}$

→ Stream on a strongly retrograde orbit, so DM impacts us at high velocity $\sim 500 \text{ km/s}$

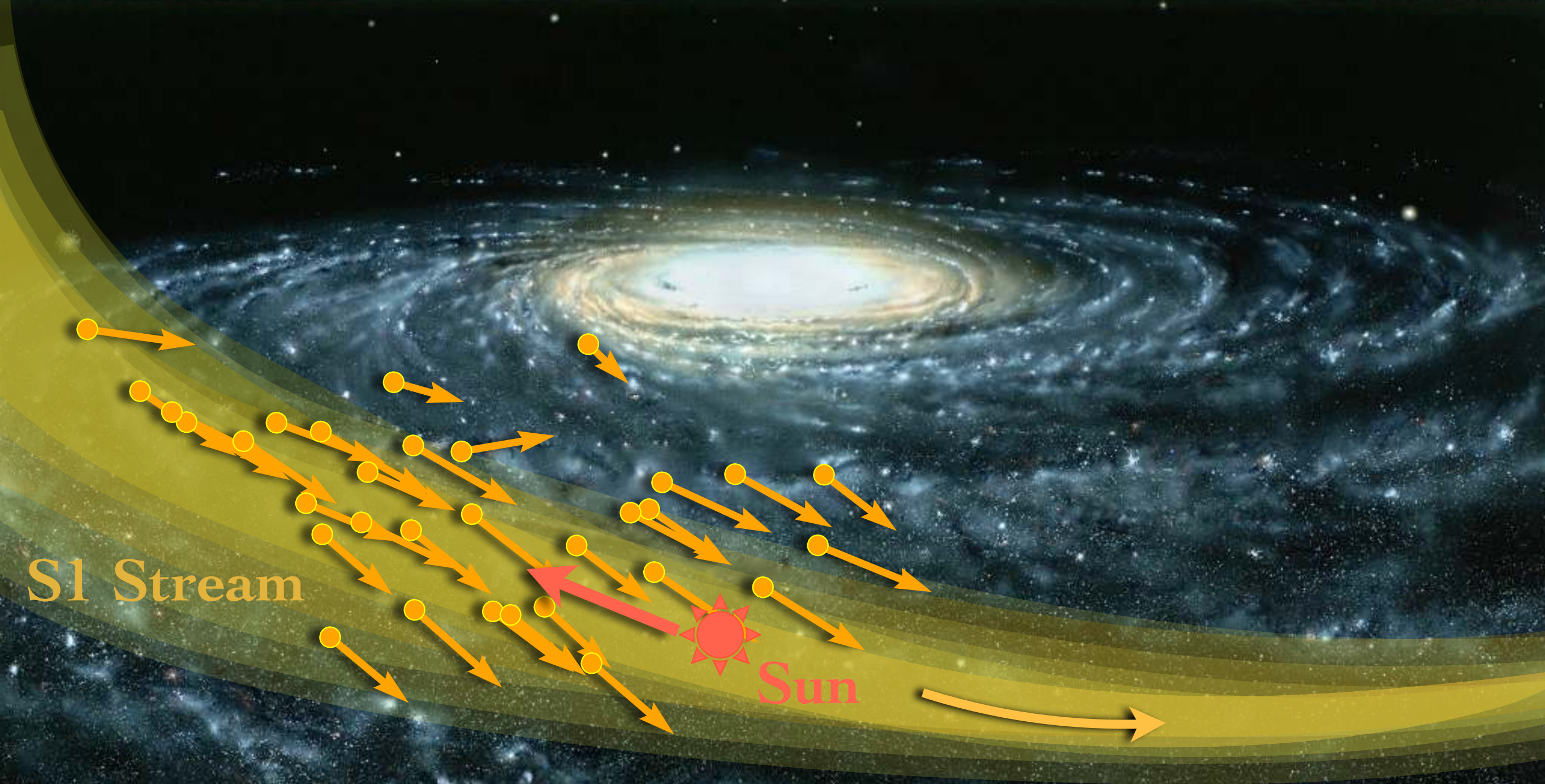
Velocity dispersion: $\sigma_{\text{str}} = 46 \text{ km s}^{-1}$

→ Suggests a dwarf spheroidal origin, around the mass of the present day Fornax satellite galaxy accreted over 8-10 billion years

Dark matter content: $0 + \epsilon < \rho_{\text{str}} < 0.55 \text{ GeV cm}^{-3}$

→ Upper bound: is *probably* the local DM density probed over length scales smaller than the stream

→ Lower bound: Progenitor very likely had dark matter but other than that we cannot say, must remain agnostic



S1 stream impacting the solar system at high speeds
Dark matter wind → A dark matter hurricane?



Home / News / A 'dark matter hurricane' is storming past Earth

A 'dark matter hurricane' is storming past

And it could help scientist detect the strange substance.

 **EXPRESS**

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News Science

Dark matter hurricane to hit Earth with speeds of up to 310 miles per SECOND

BBC

Menú

NEWS | MUNDO

Noticias Hay Festival América Latina Internacional Economía Tecnología Ciencia S

Qué es el "huracán de materia oscura" en el que se encuentra la Vía Láctea y qué permitirá saber sobre uno de los mayores misterios de la ciencia

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'Dark matter hurricane' blowing at 310 miles per SECOND is on a collision course with Earth and may finally offer proof the mysterious material exists

A Dark Matter "Hurricane" Is Blowing Past The Earth Right Now

SPACE / NOV 15, 2018 / NIKOS DIMITRIS FAKOTAKIS / 0 COMMENT

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PHYSICS

So What's Going on With That 'Hurricane of Dark Matter?'



Ryan F. Mandelbaum

11/14/18 12:10pm • Filed to: DARK MATTER ▾



67.1K



17



4





Urgent: "Scientist "Claim Dark Matter Hurricane" Is Coming

28,497 views

701 62 SHARE SAVE ...



Paul Begley ✓
Published on Nov 14, 2018

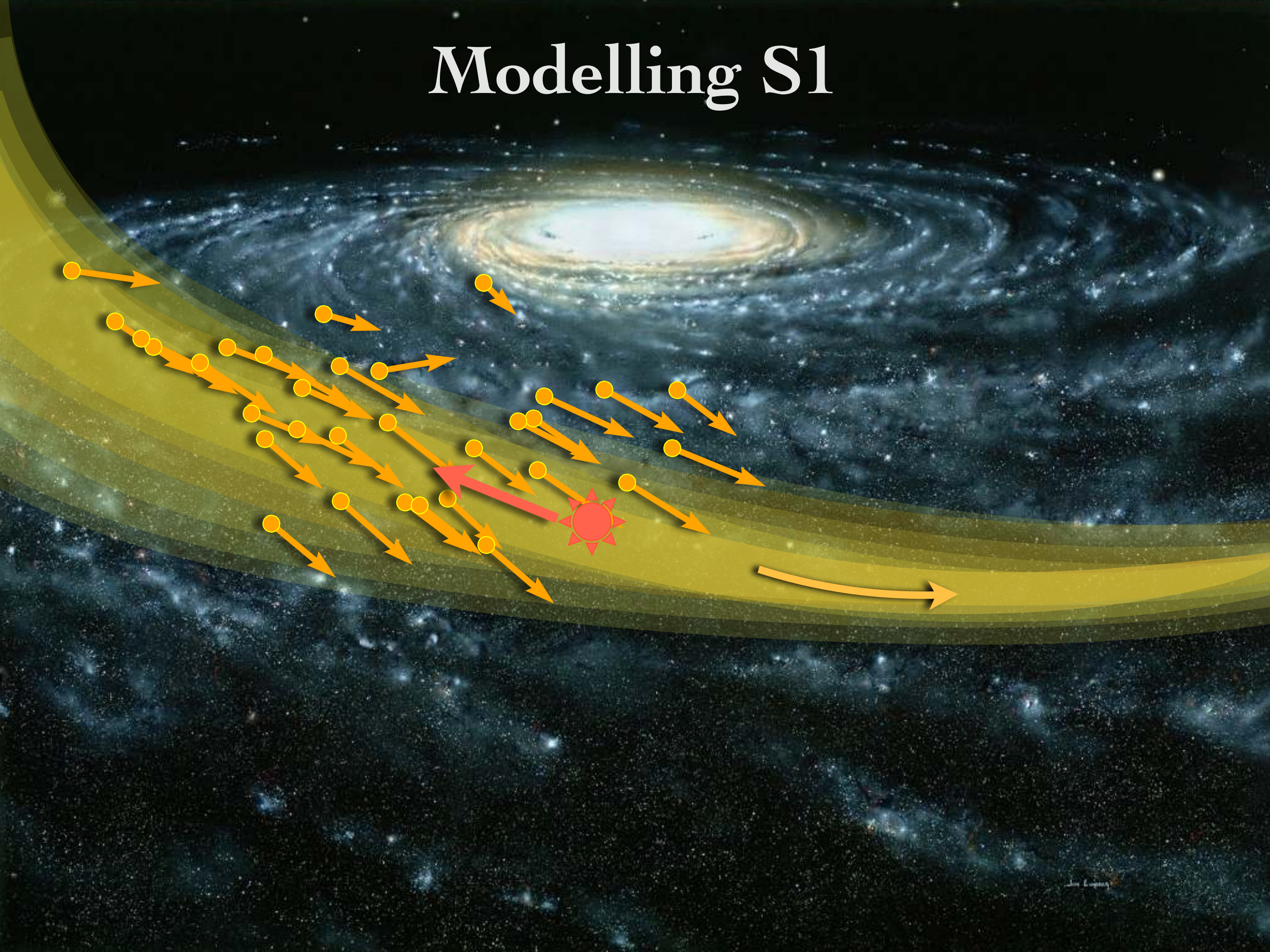
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Approaching dark matter hurricane will collide with earth, predict scientists

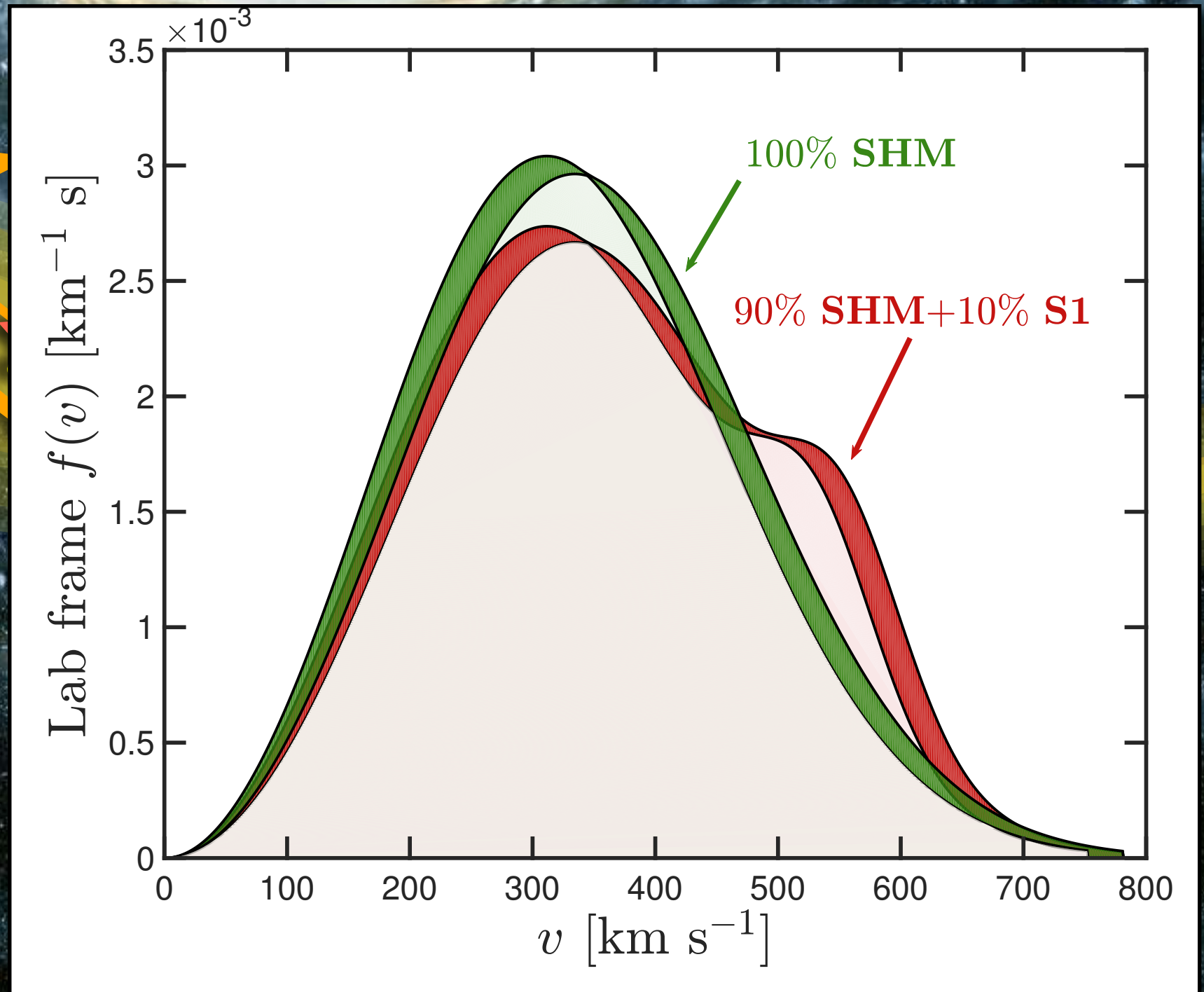
- Conspiracy theorists believe that the dark matter hurricane will result in an imminent apocalypse on earth.



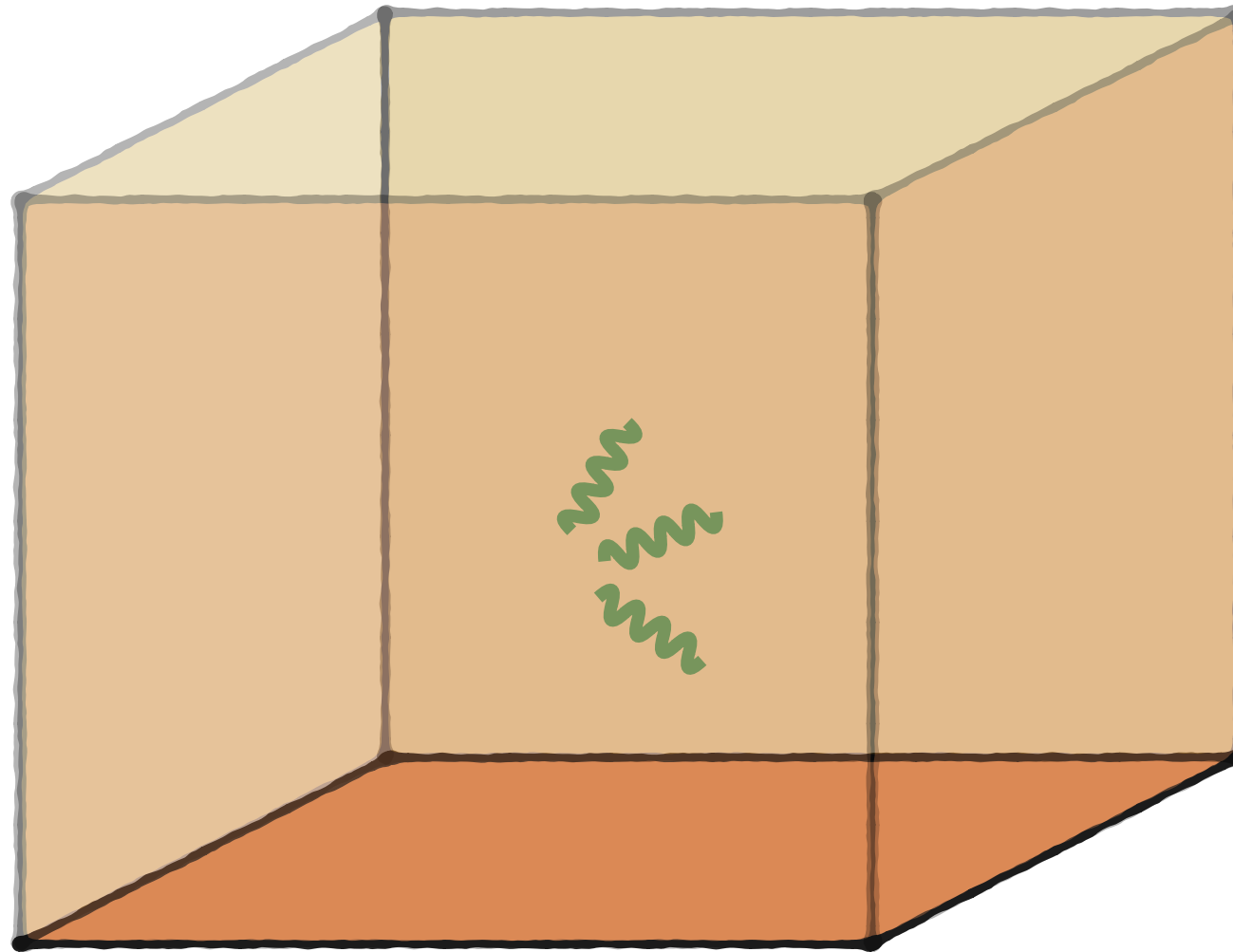
Modelling S1



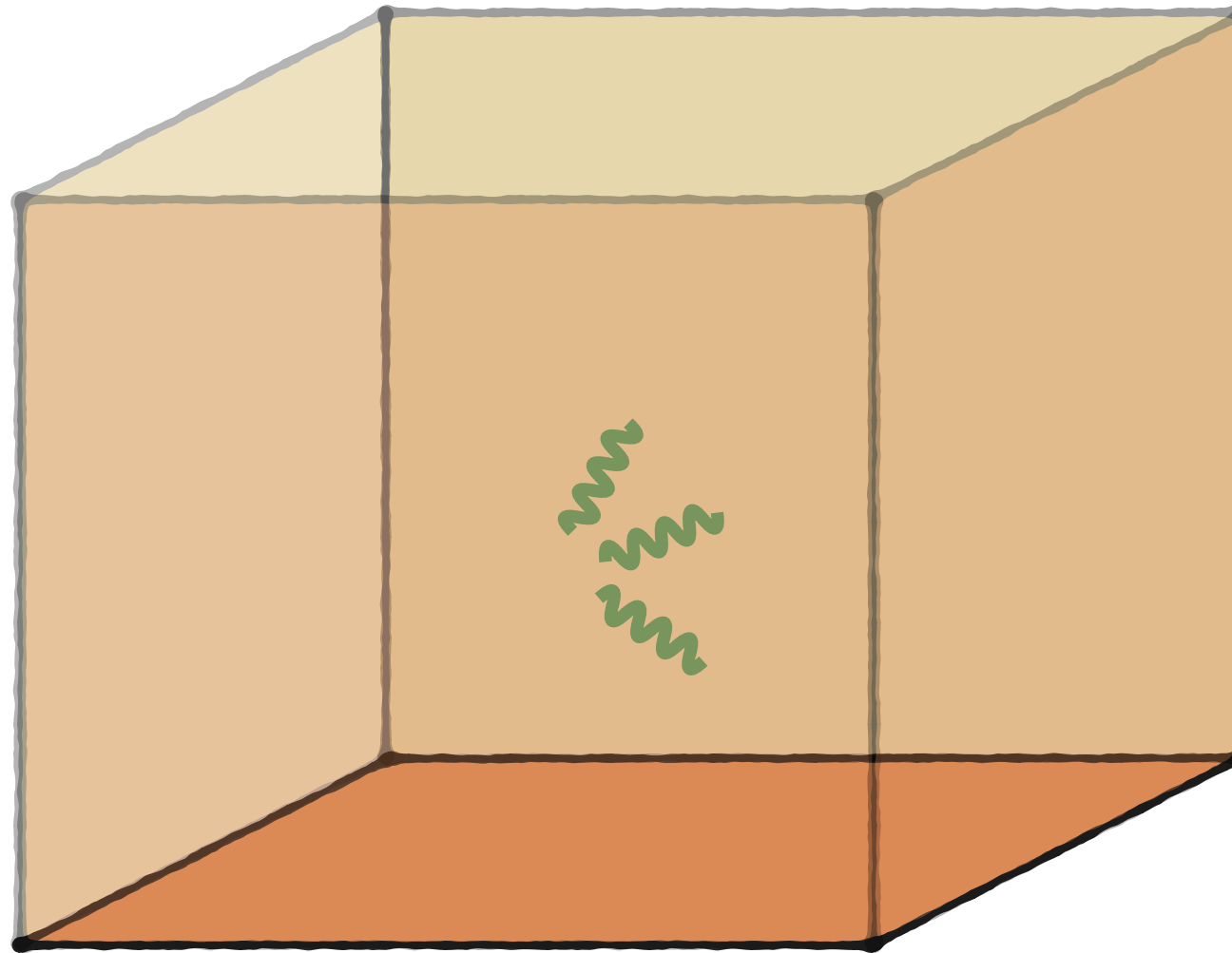
Modelling S1



How to build a WIMP detector

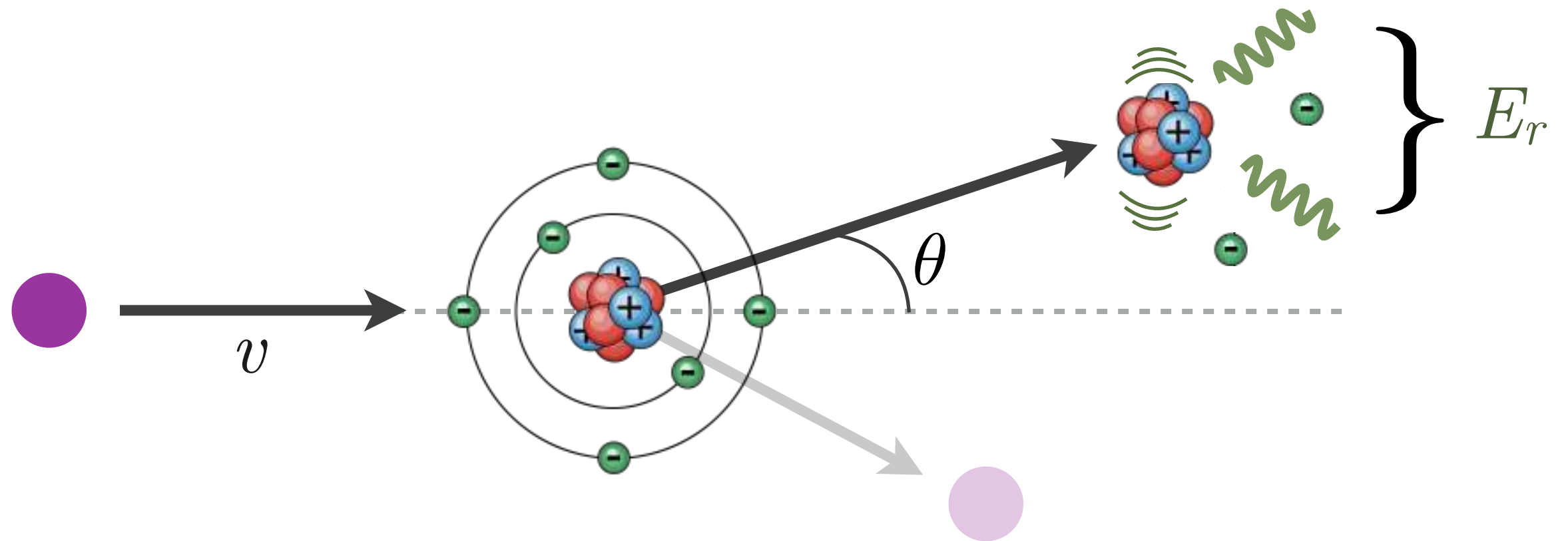


How to build a WIMP detector



Make a very quiet box

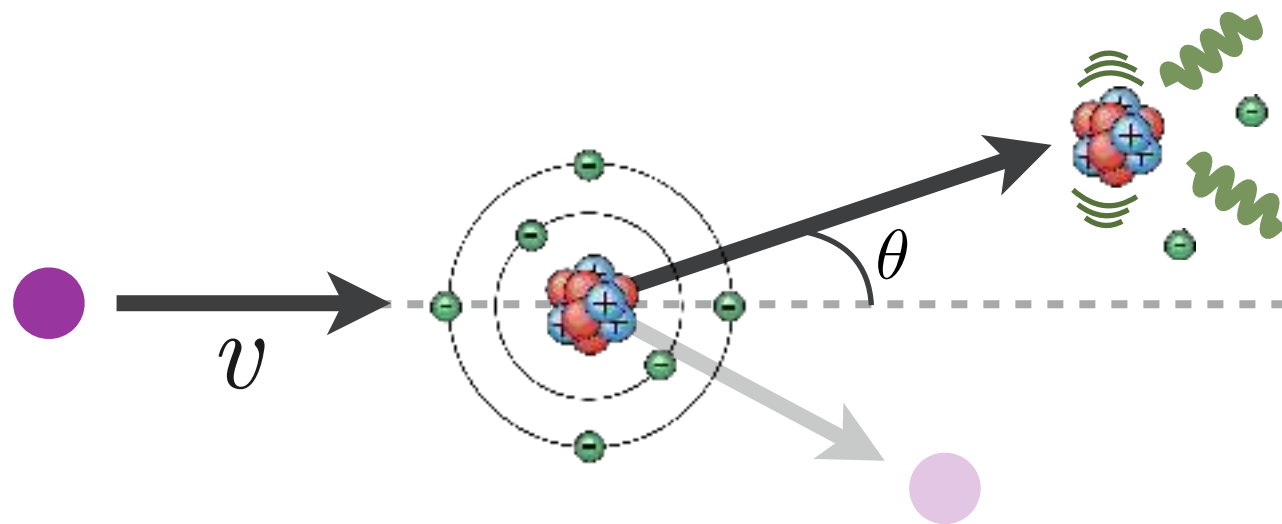
WIMP direct detection



$$\text{“Signal”} \propto E_r = \frac{2m_N m_\chi^2}{(m_N + m_\chi)^2} v^2 \cos^2 \theta$$

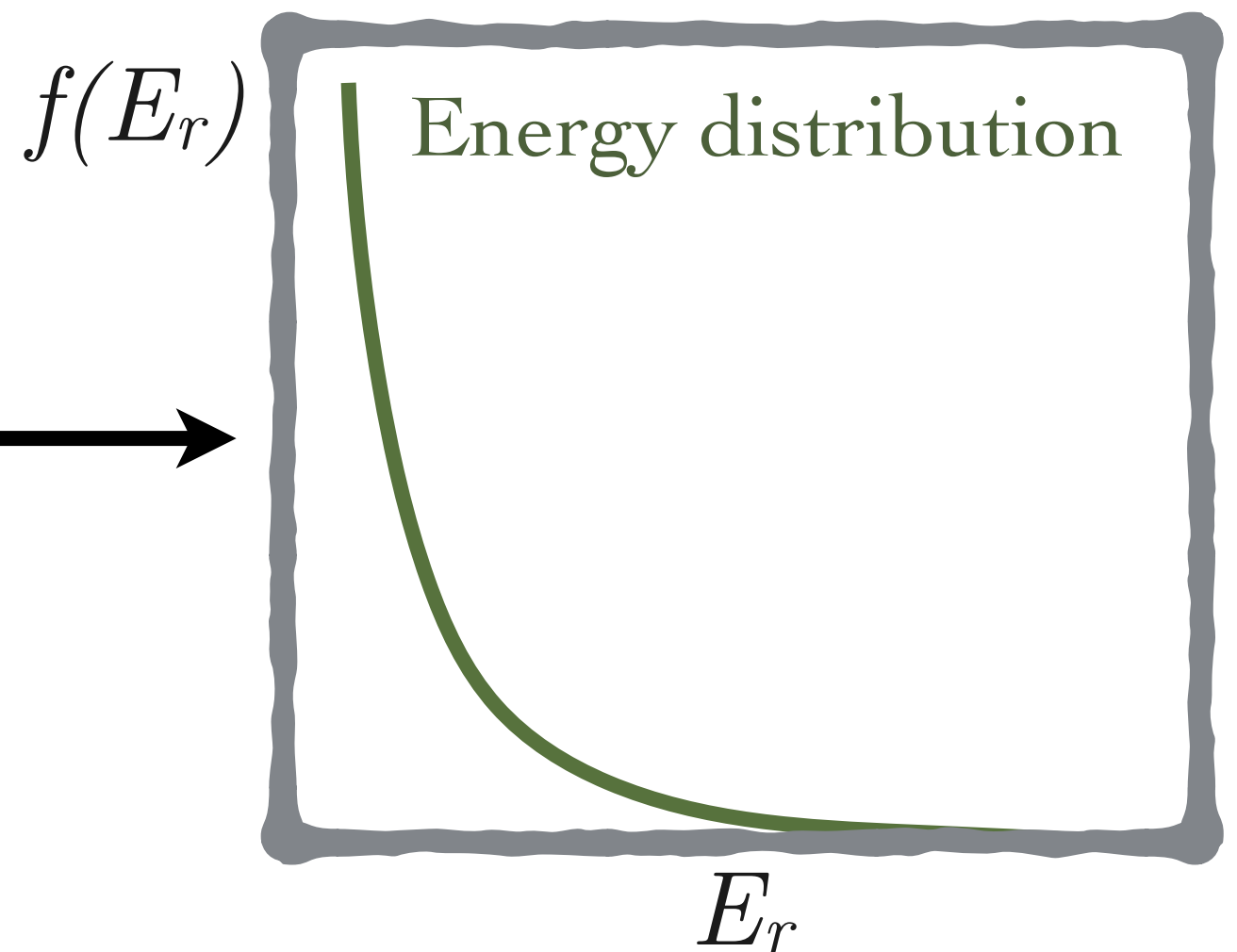
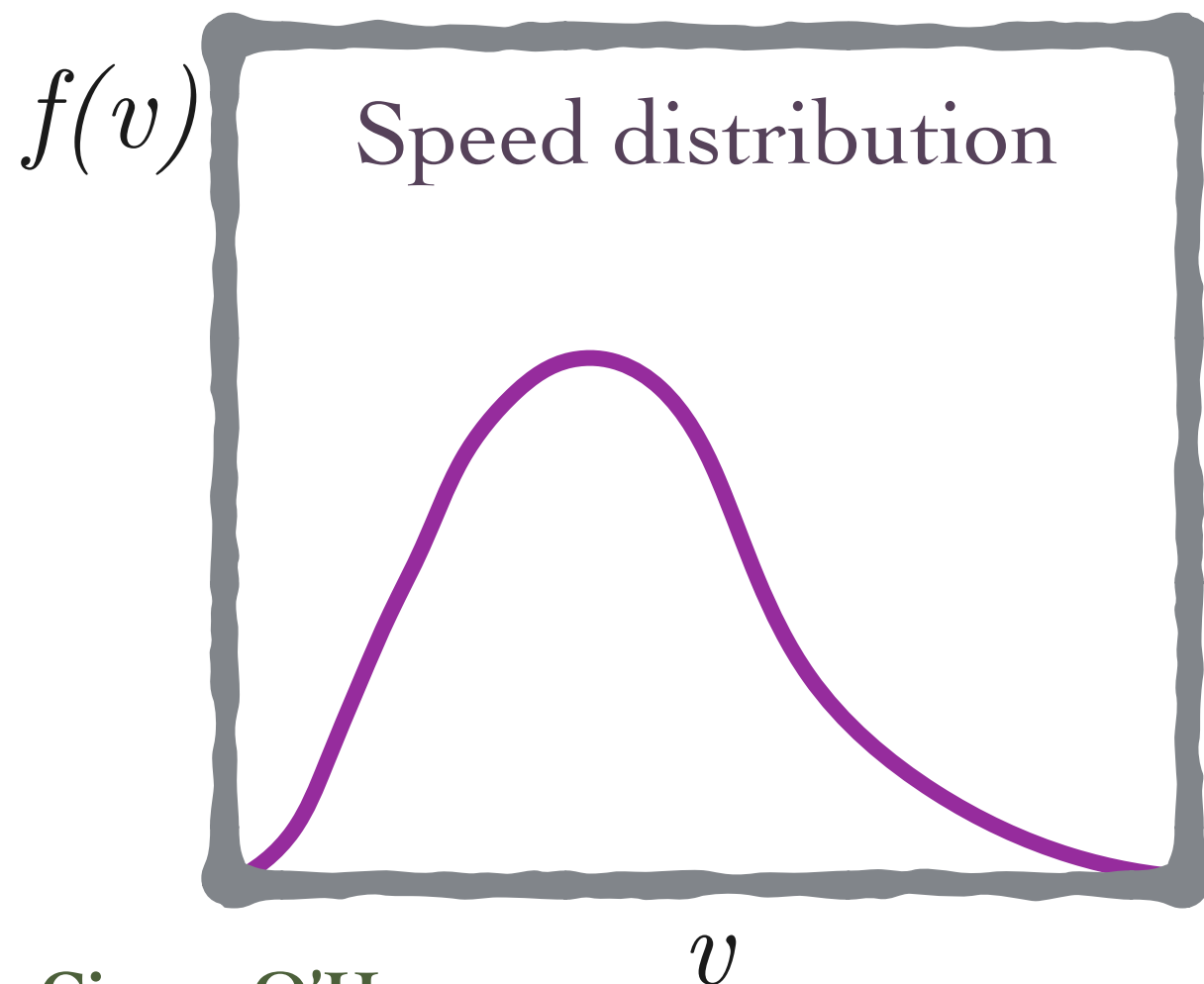
m_N = Nucleus mass
 m_χ = WIMP mass

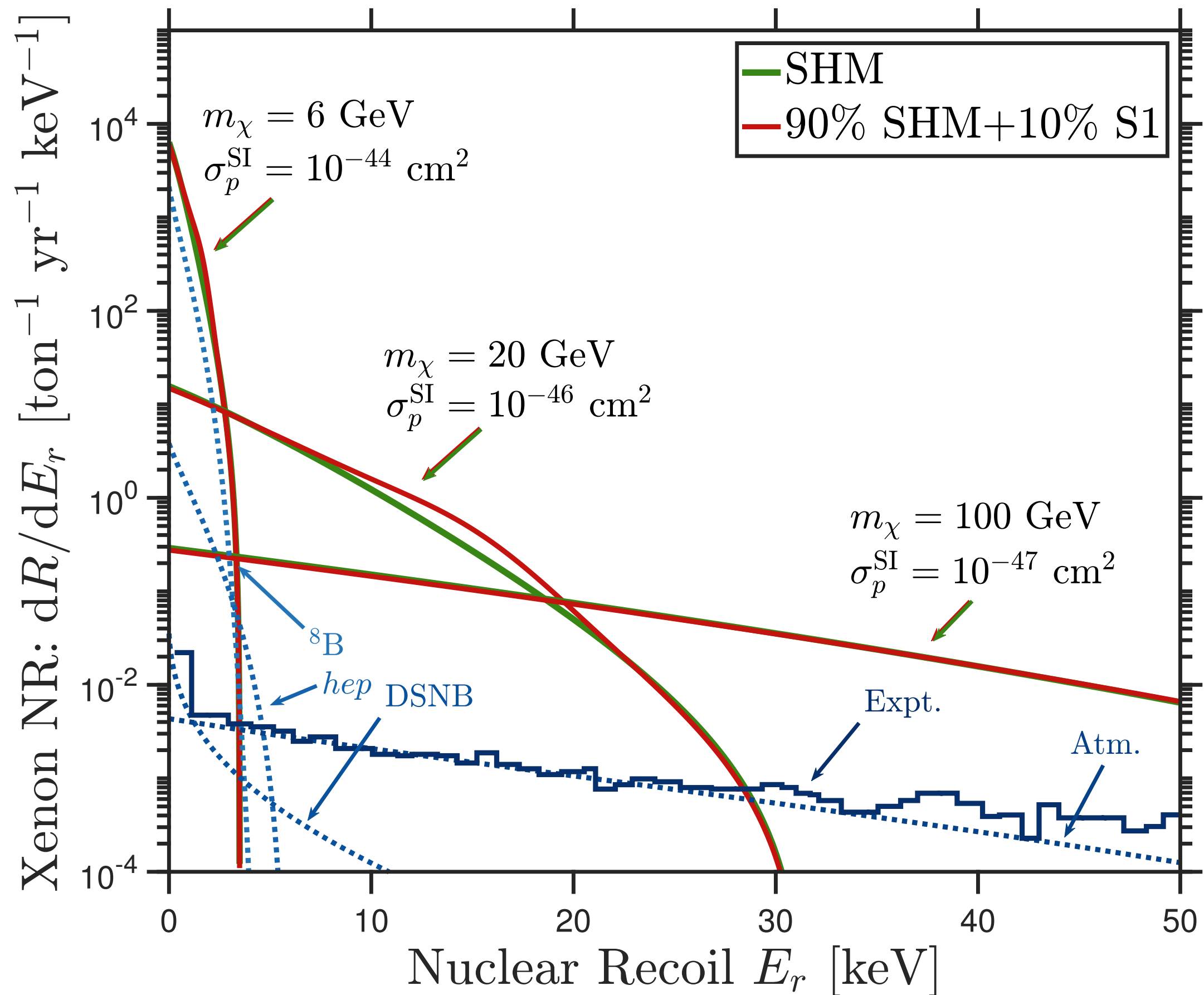
WIMP direct detection



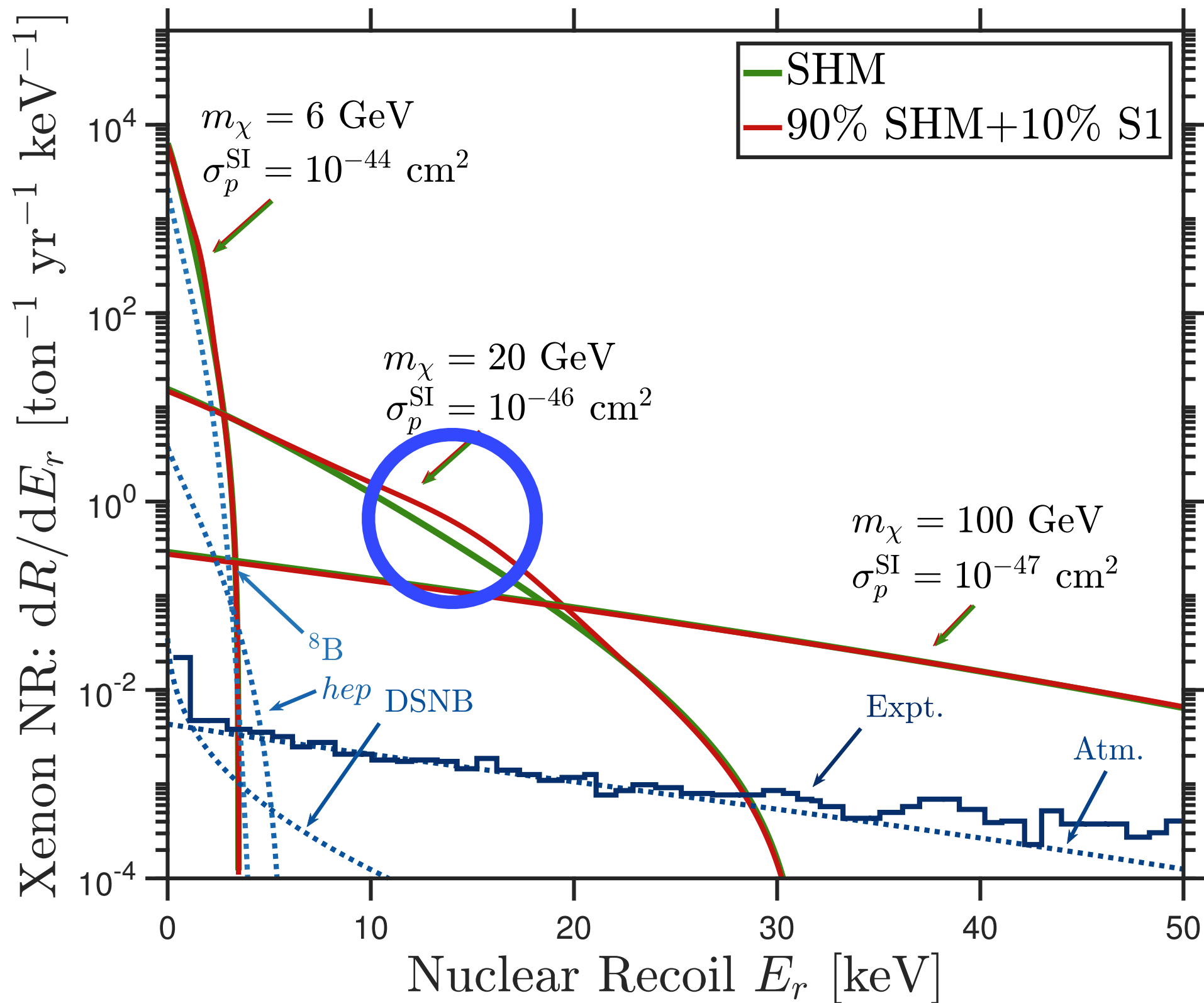
Angle not measurable so
for a given speed:

$$E_r \in \left[0, v^2 \frac{2m_N m_\chi^2}{(m_N + m_\chi)^2} \right]$$





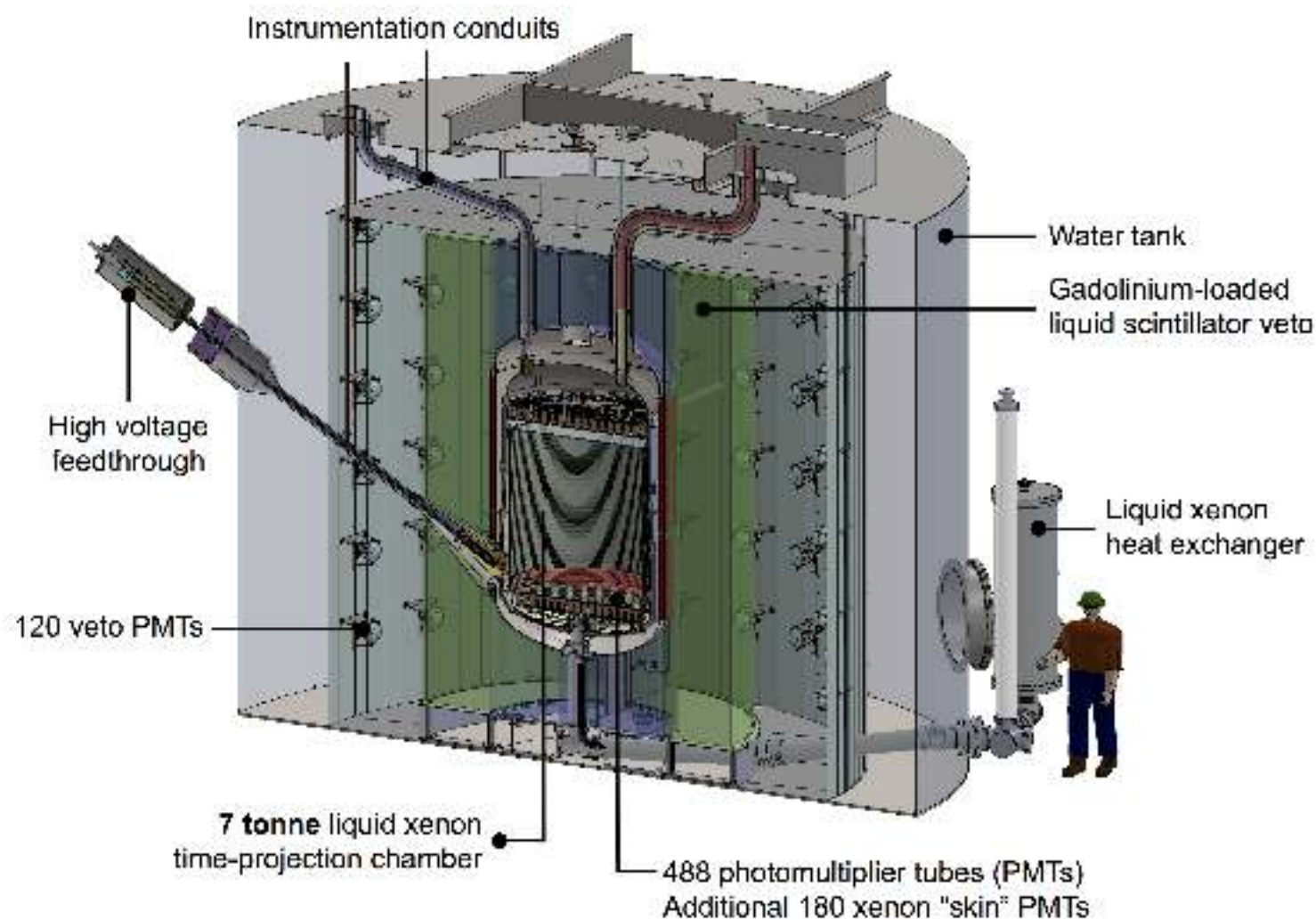
Q: How strong does the hurricane need to be to detect it in an experiment?



In other words: How big does this bump need to be for the experiment to tell the difference?

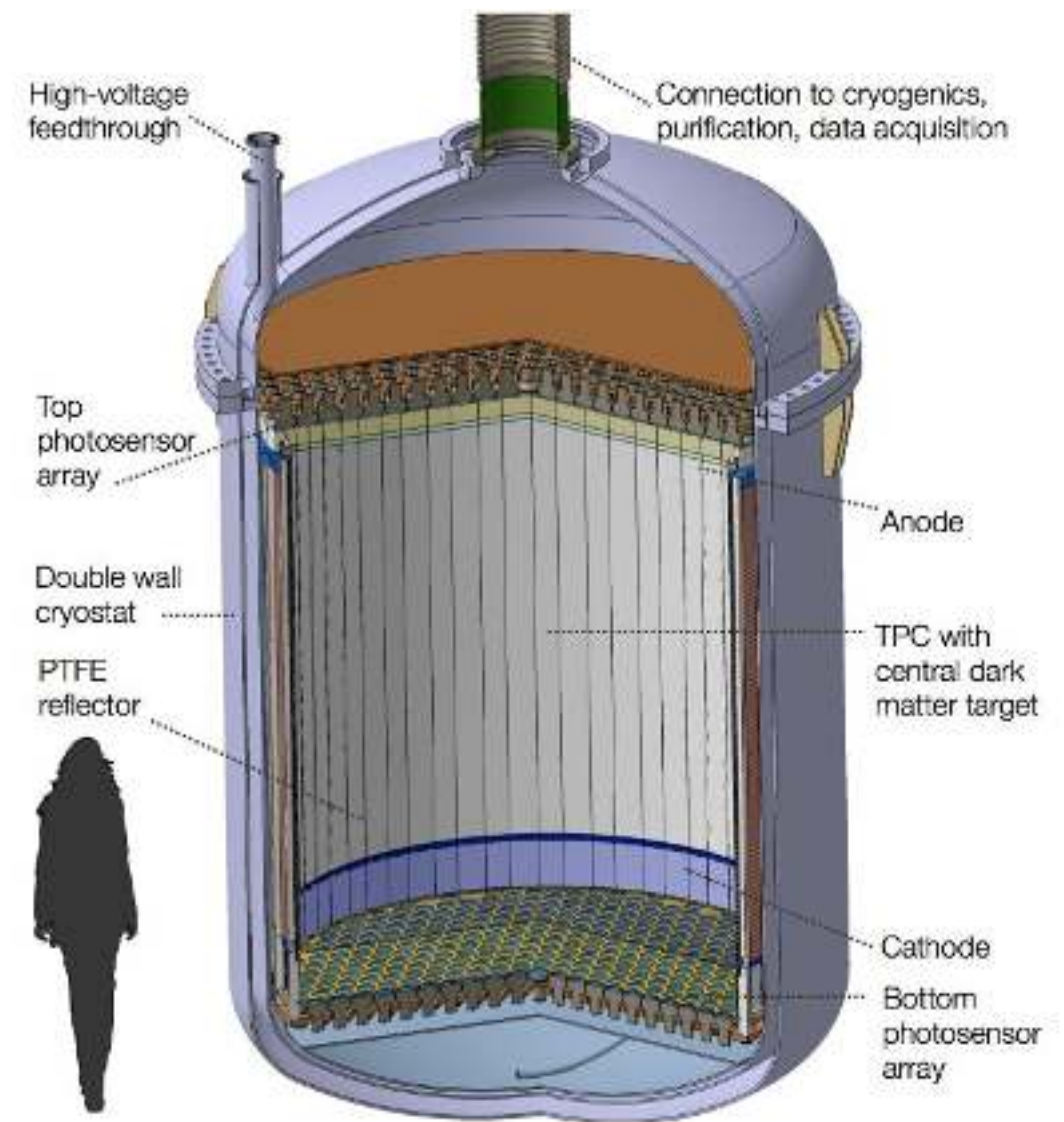
Liquid Xe time projection chambers

LZ



Target mass: 5.6 tons

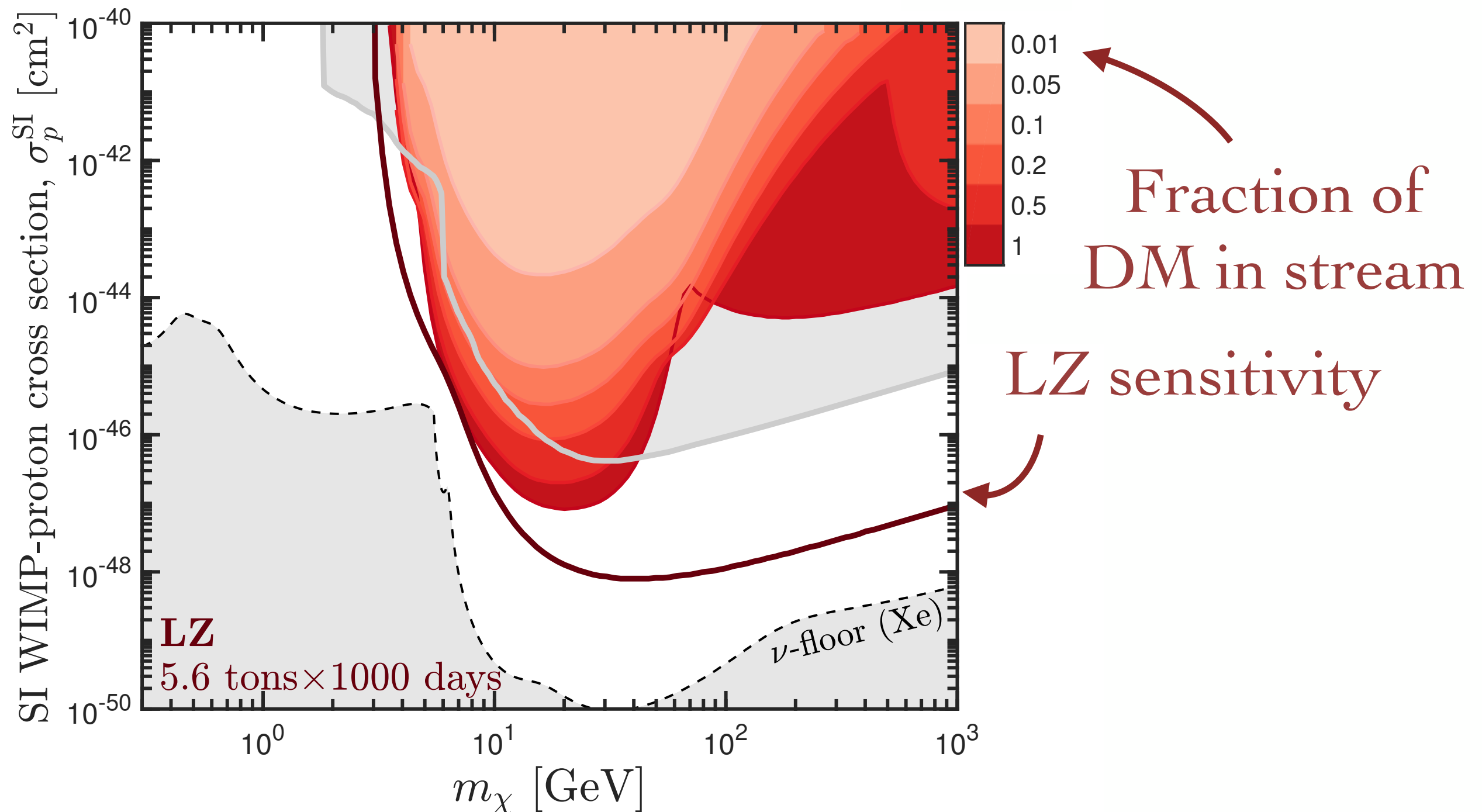
DARWIN



Target mass: ~40 tons

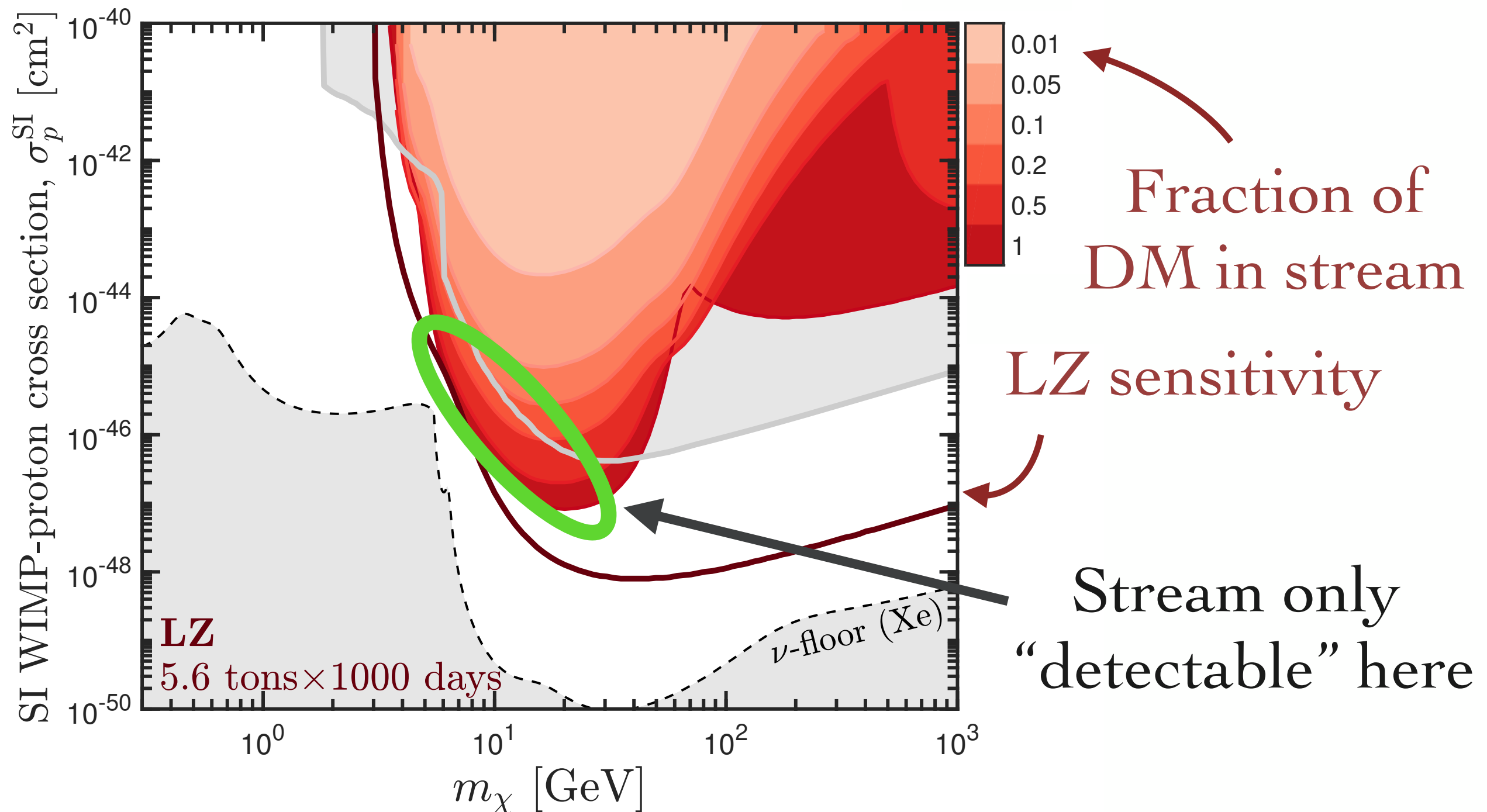
S1 in LZ

Red regions: range of WIMP masses and couplings for which the stream can be distinguished from the halo in LZ at 3 sigma



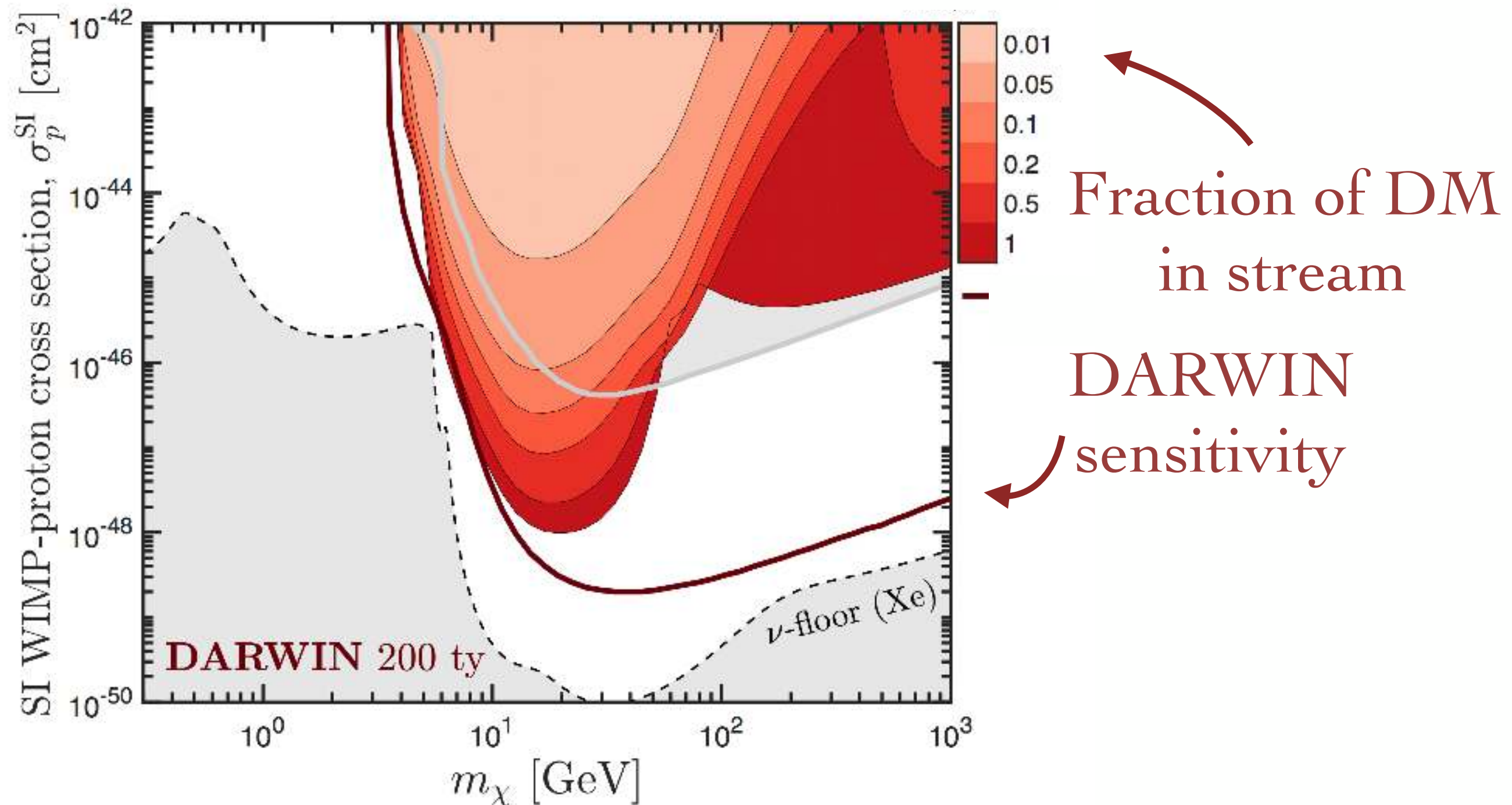
S1 in LZ

Red regions: range of WIMP masses and couplings for which the stream can be distinguished from the halo in LZ at 3 sigma

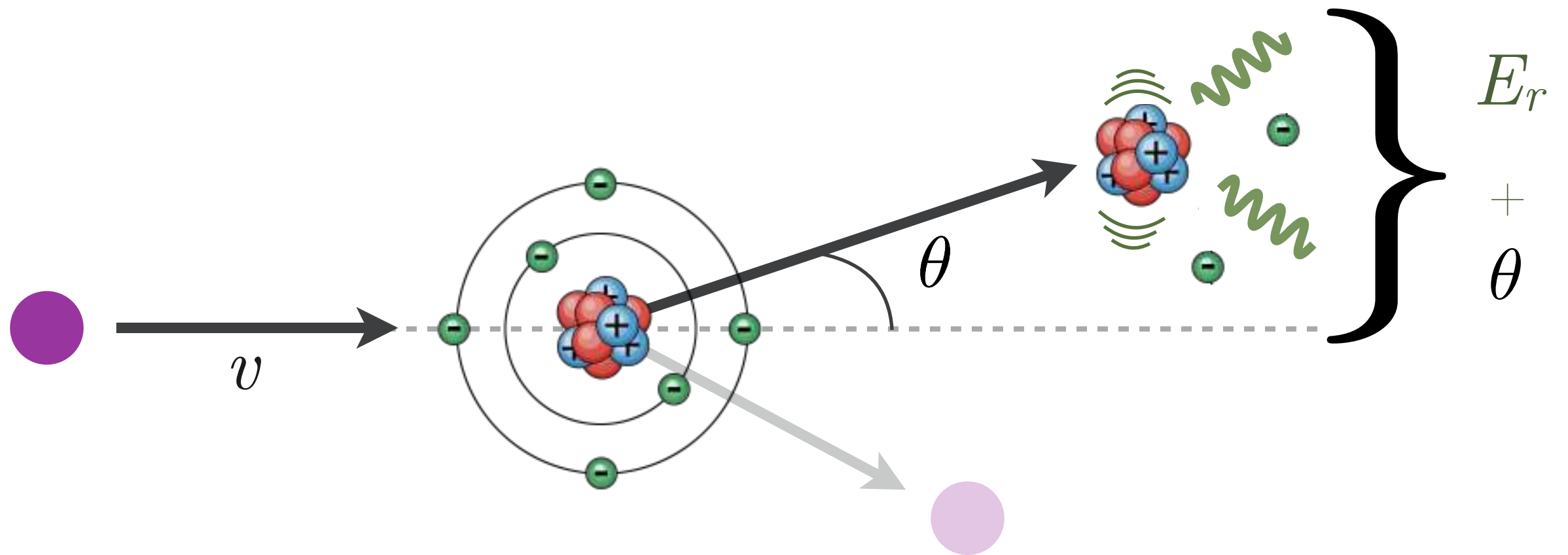


S1 in DARWIN

Red regions: range of WIMP masses and couplings for which the stream can be distinguished from the halo in DARWIN at 3 sigma



Directional detection of WIMPs



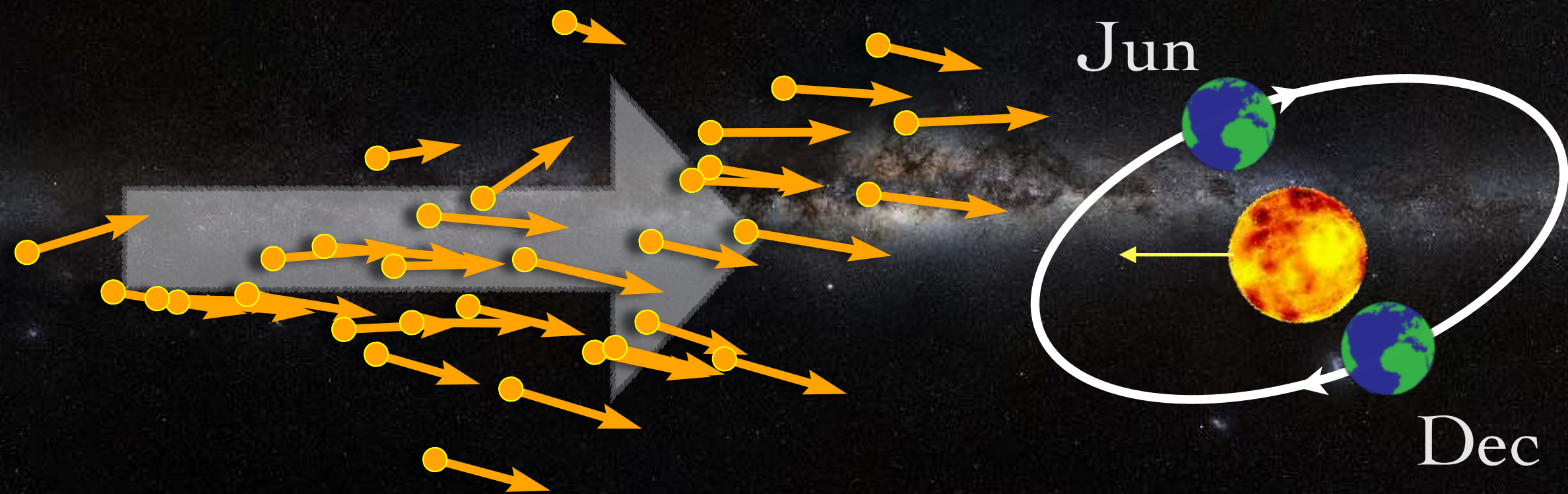
$$E_r = \frac{2m_N m_\chi^2}{(m_N + m_\chi)^2} v^2 \cos^2 \theta$$

If both energy and angle are measurable \rightarrow solve for v

Stream is counter-rotating, so will enhance
the anisotropy of the DM flux

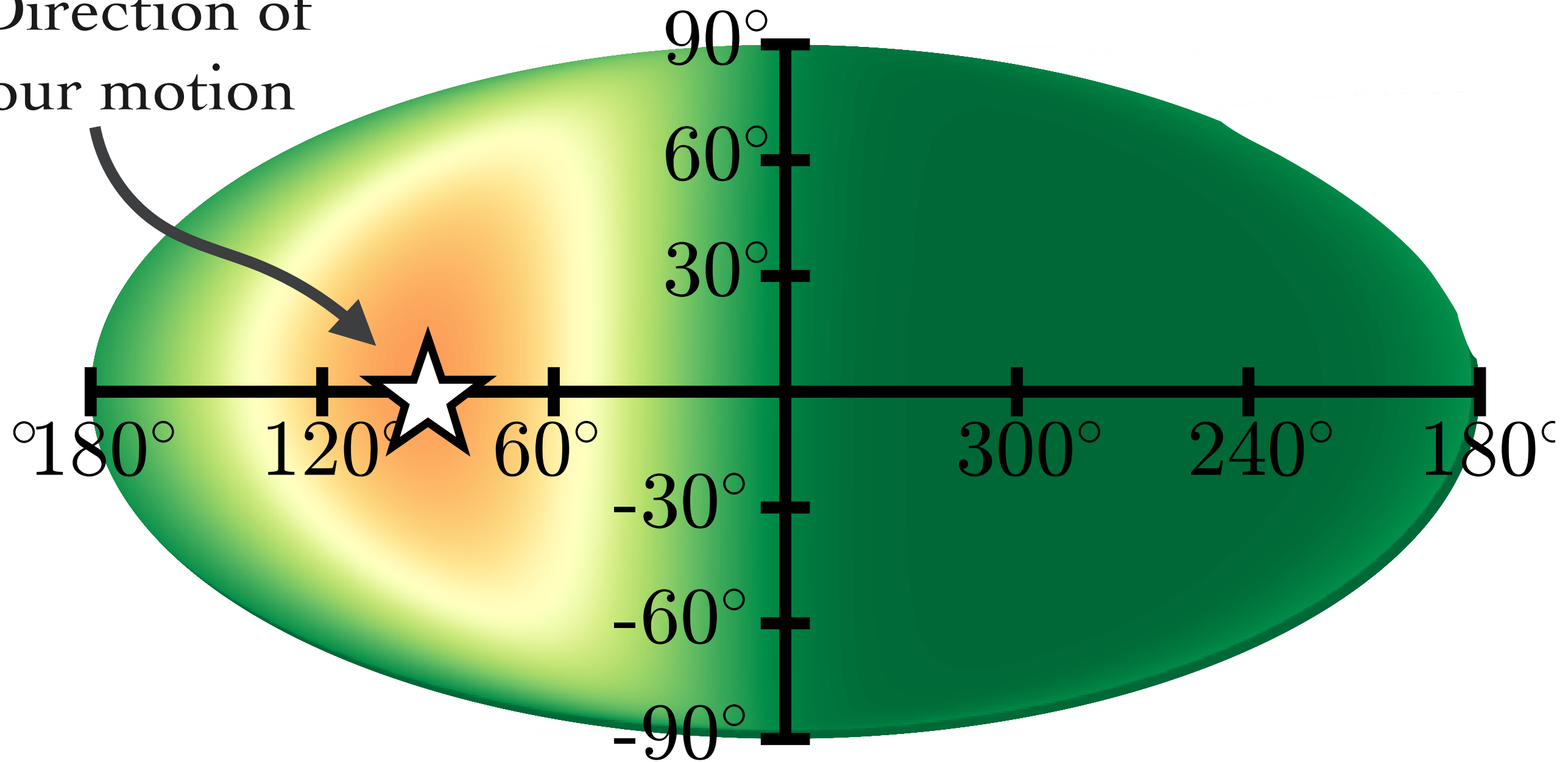


Stream is counter-rotating, so will enhance
the anisotropy of the DM flux



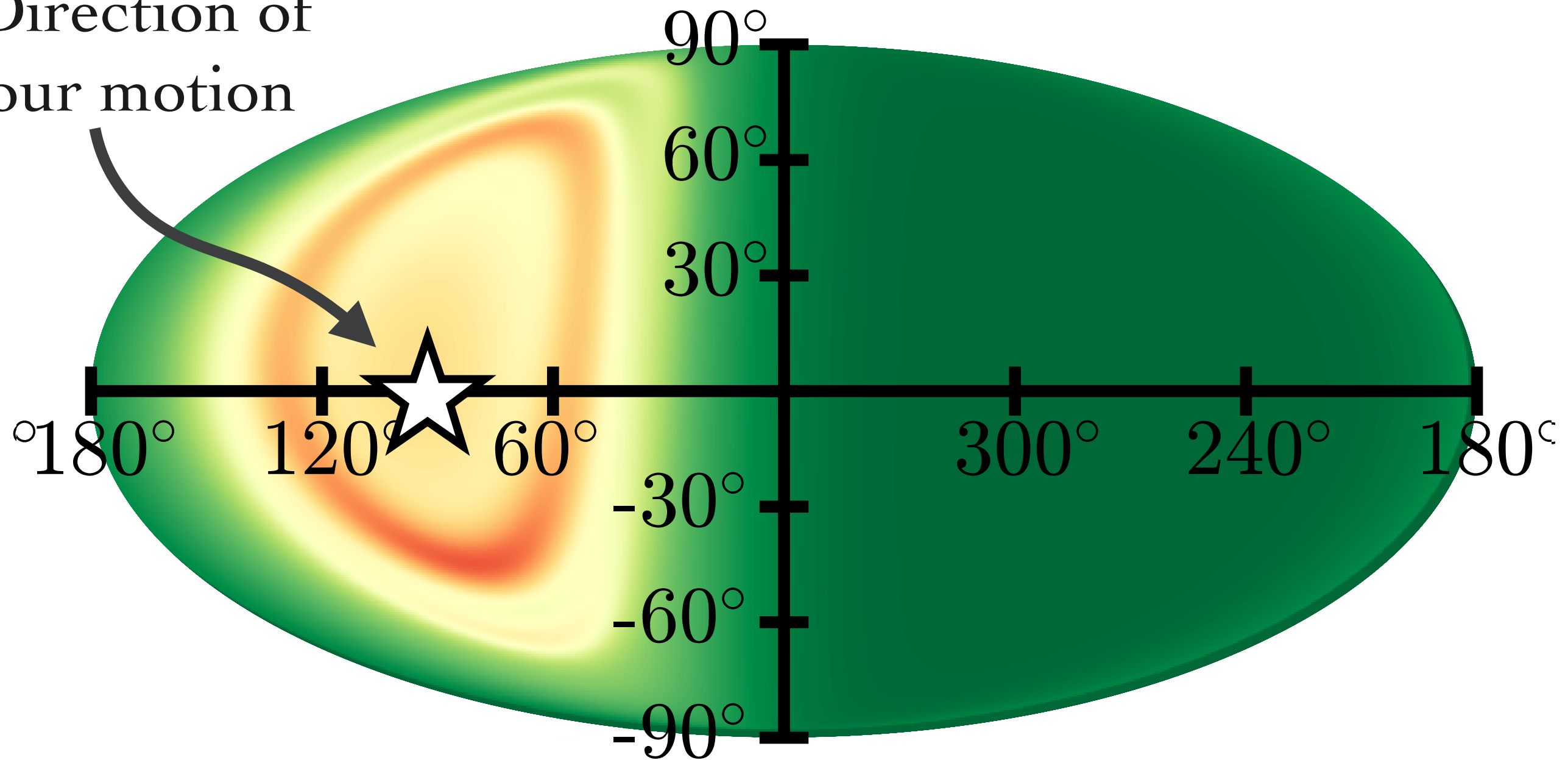
Directional detection of WIMPs

Direction of
our motion



Directional detection of WIMPs

Direction of
our motion



Halo + 10% S1

CYGNUS



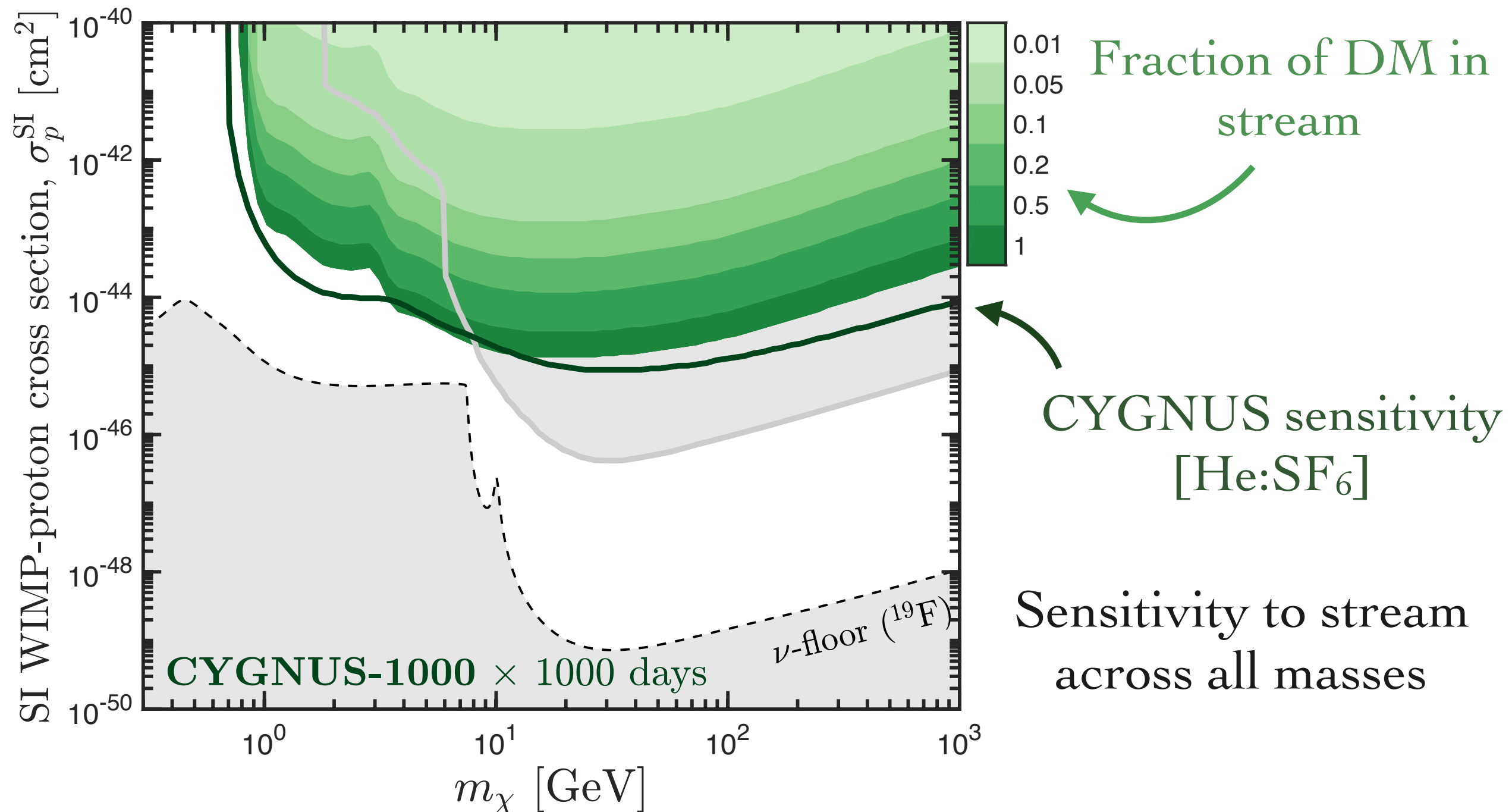
- A low pressure gas TPC
- Current plan: SF₆ at 20 torr and He at 740 torr
- Various readout technologies being compared (MWPCs, μ PIC, pixel chips, optical, micromegas)
- Main goal: circumvent the neutrino floor
- Secondary goal: study DM astrophysics
- Paper coming soon...

CYGNUS: Feasibility of a Nuclear Recoil Observatory with Directional Sensitivity to Dark Matter and Neutrinos

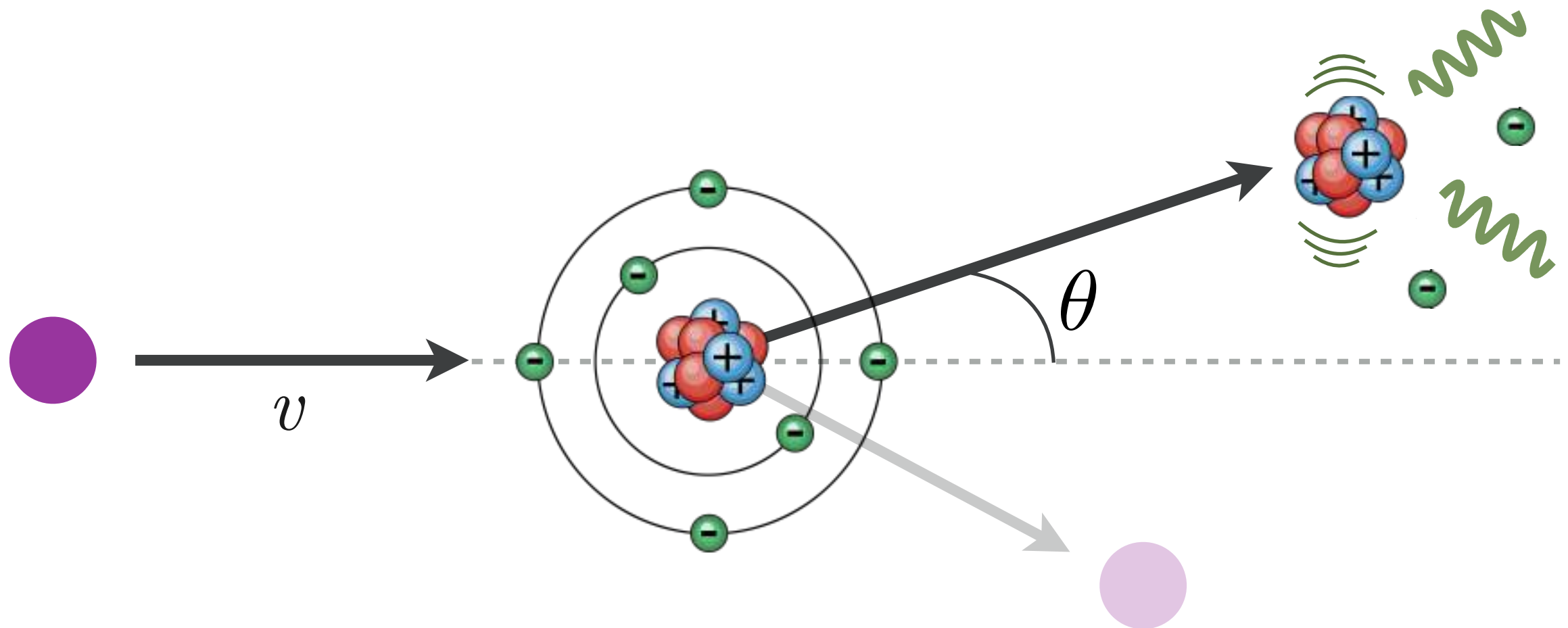
E. Baracchini,^{1,2,3} P. Barbeau,⁴ J. B. R. Battat,⁵ B. Crow,⁶ C. Deaconu,⁷ C. Eldridge,⁸
A. C. Ezeribe,⁸ D. Loomba,⁹ W. A. Lynch,⁸ K. J. Mack,¹⁰ K. Miuchi,¹¹ N. S. Phan,¹²
C. A. J. O'Hare,^{13,14} K. Scholberg,⁴ N. J. C. Spooner,⁸ T. N. Thorpe,⁶ and S. E. Vahsen⁶

S1 in CYGNUS

Green regions: range of WIMP models for which the stream can be distinguished from the halo in CYGNUS at 3 sigma

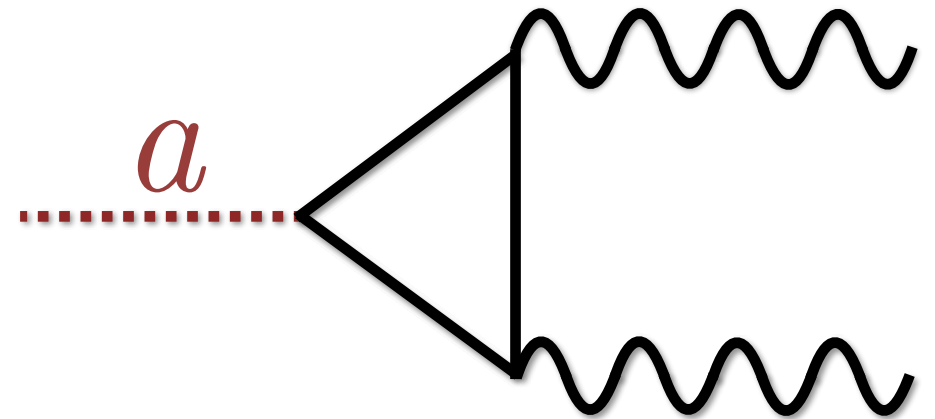


WIMP direct detection



Axion-photon coupling: $g_{a\gamma}$

$$\mathcal{L} = \frac{1}{4} g_{a\gamma} a(\mathbf{x}, t) F_{\mu\nu} \tilde{F}^{\mu\nu}$$



For QCD axion: $g_{a\gamma} \propto m_a$

$$\nabla \cdot \mathbf{E} = \rho_q - g_{a\gamma} \mathbf{B} \cdot \nabla a$$

$$\nabla \times \mathbf{B} - \dot{\mathbf{E}} = \mathbf{J} + g_{a\gamma} (\mathbf{B} \dot{a} - \mathbf{E} \times \nabla a)$$

$$\nabla \cdot \mathbf{B} = 0$$

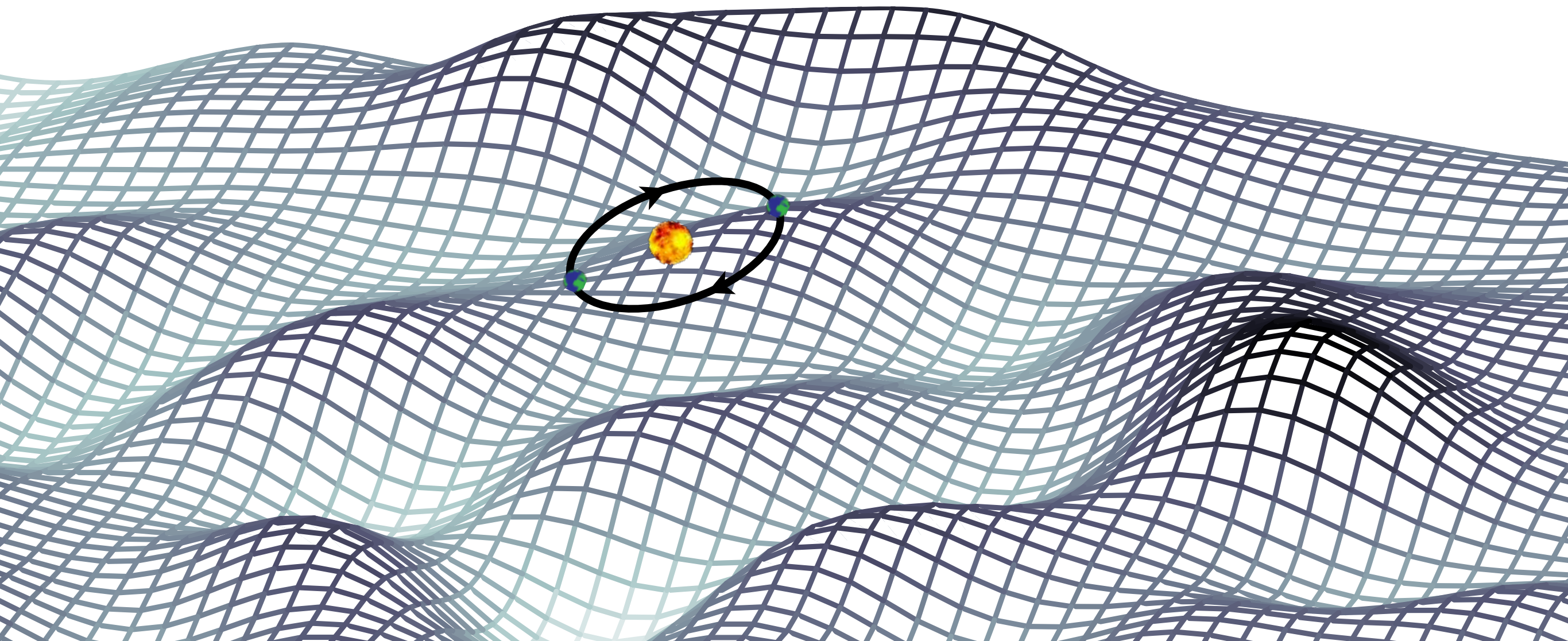
$$\nabla \times \mathbf{E} + \dot{\mathbf{B}} = 0$$

$$(\square + m_a^2) a = g_{a\gamma} \mathbf{E} \cdot \mathbf{B}$$

The local axion field

$$a(\mathbf{x}, t) \approx \frac{\sqrt{2\rho_a}}{m_a} \cos(\omega t - \mathbf{p} \cdot \mathbf{x} + \alpha)$$

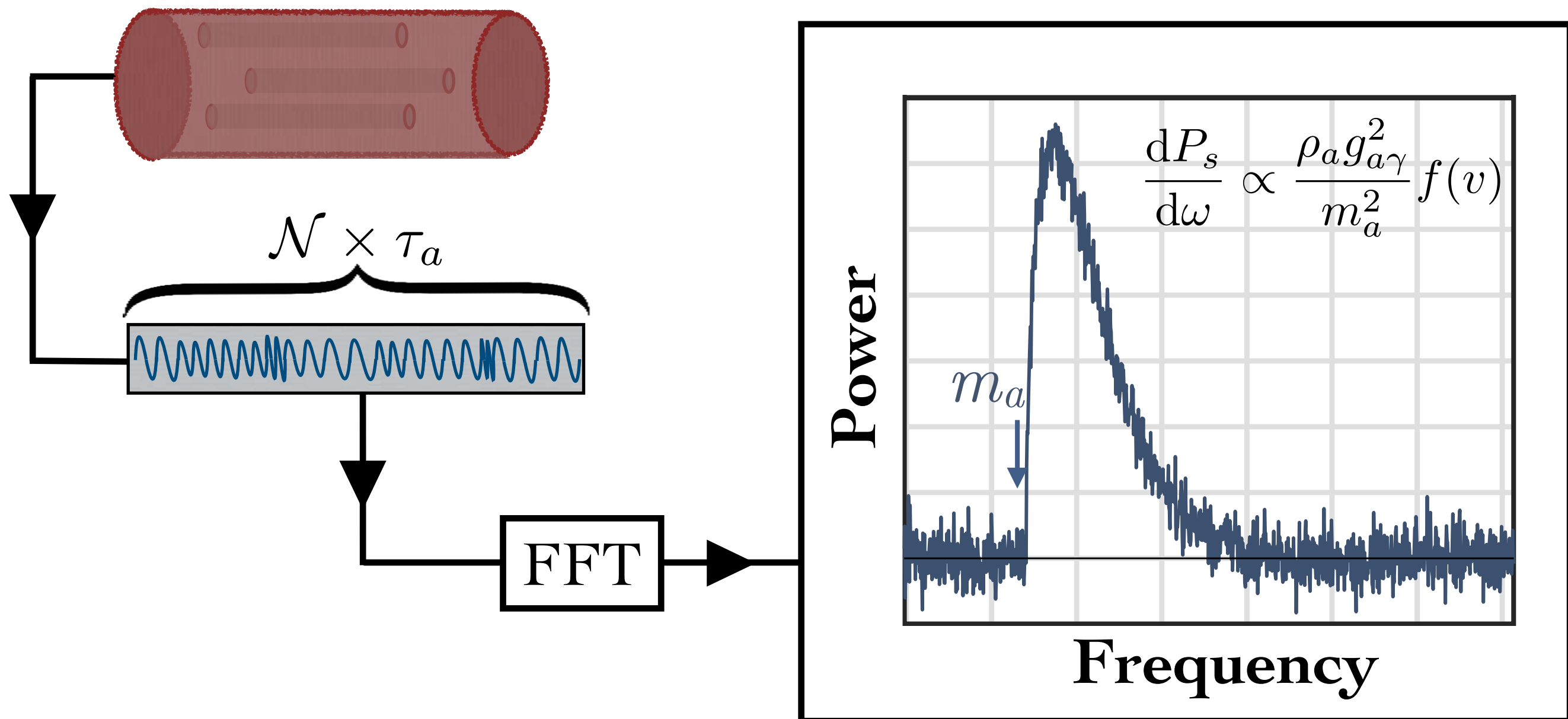
Oscillating at \sim the axion mass with coherence time $\tau \sim \frac{1}{m_a \langle v \rangle^2}$



Measuring the axion distribution

Sampling axion field over many coherence times:

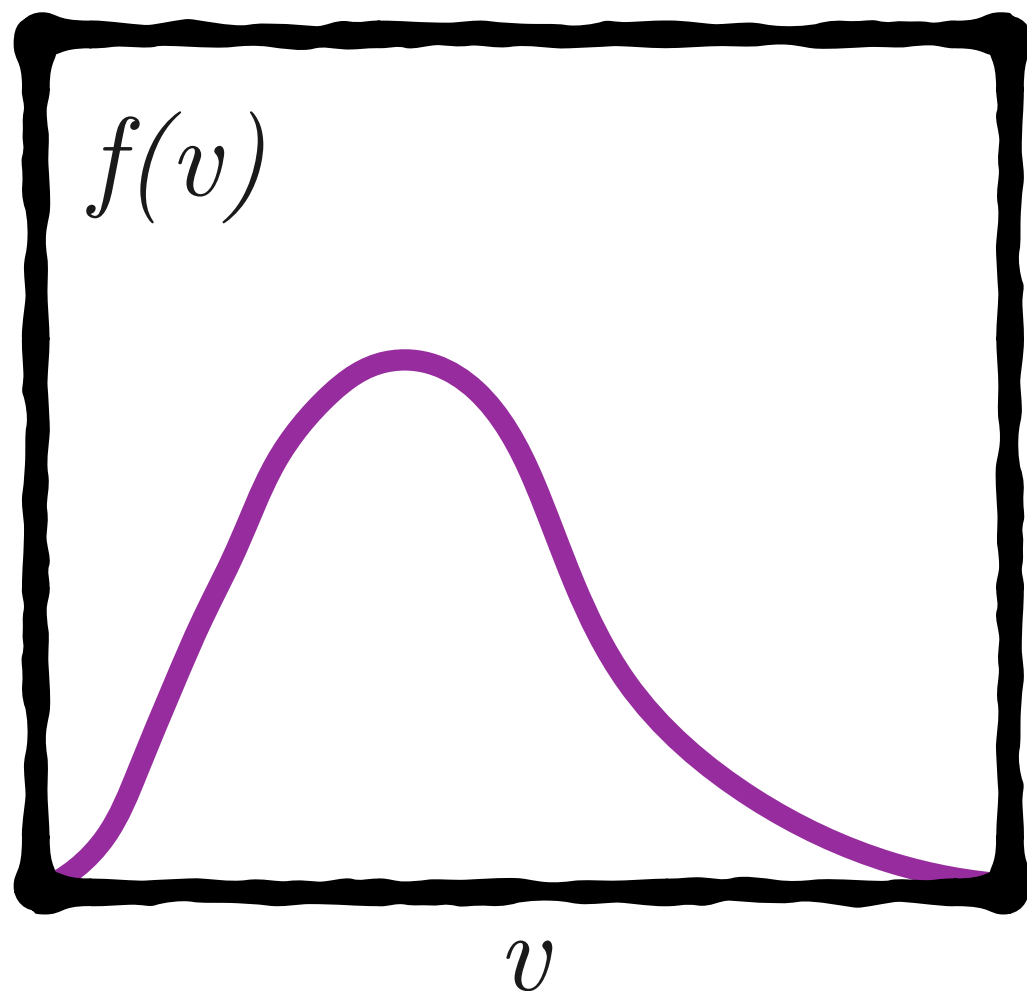
→ Power spectrum $\sim f(v)$



Measuring $f(v)$ in a haloscope

$$\omega = m_a \left(1 + \frac{v^2}{2} \right)$$

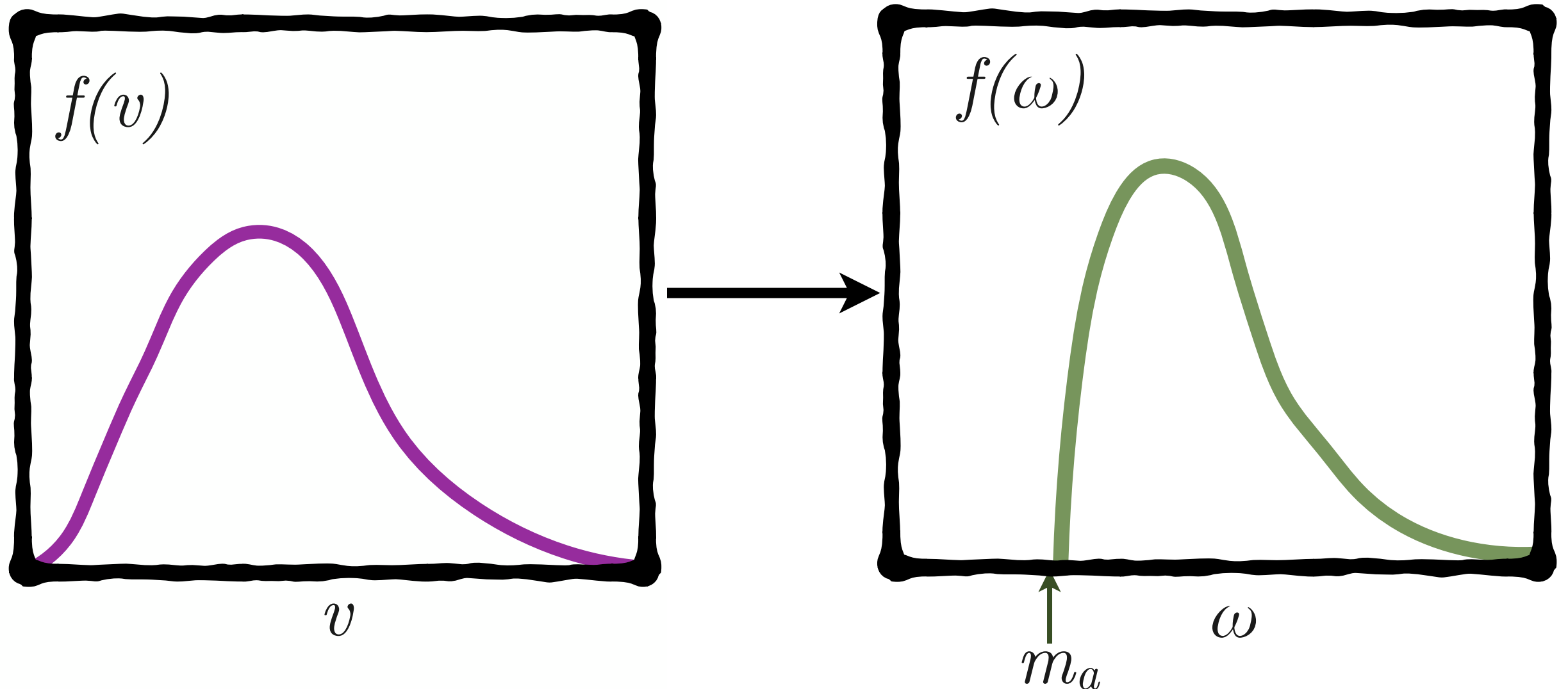
A haloscope can effectively make a direct measurement of the astrophysical speed distribution



Measuring $f(v)$ in a haloscope

$$\omega = m_a \left(1 + \frac{v^2}{2} \right)$$

A haloscope can effectively make a direct measurement of the astrophysical speed distribution

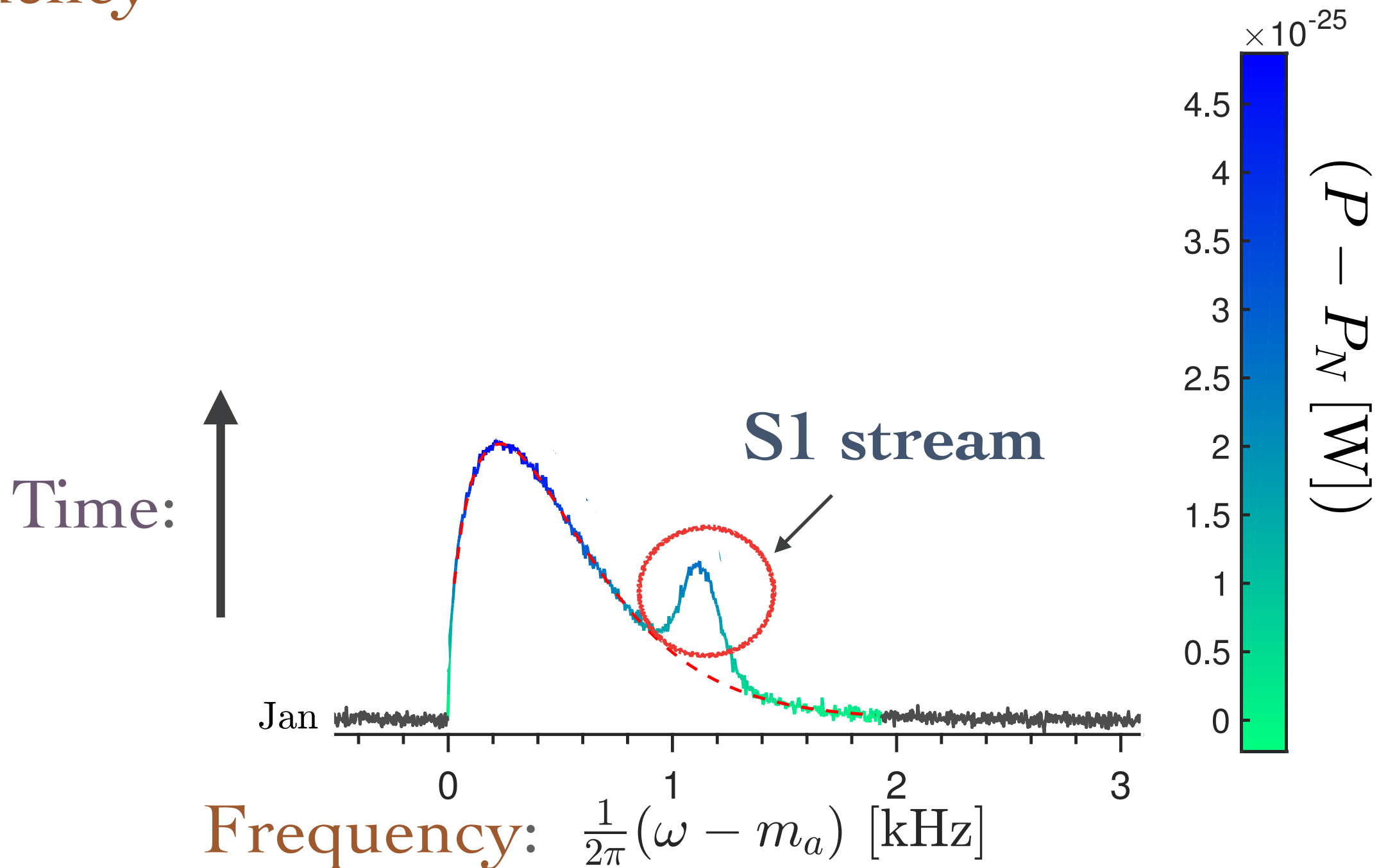


Axion haloscope:

Signal power

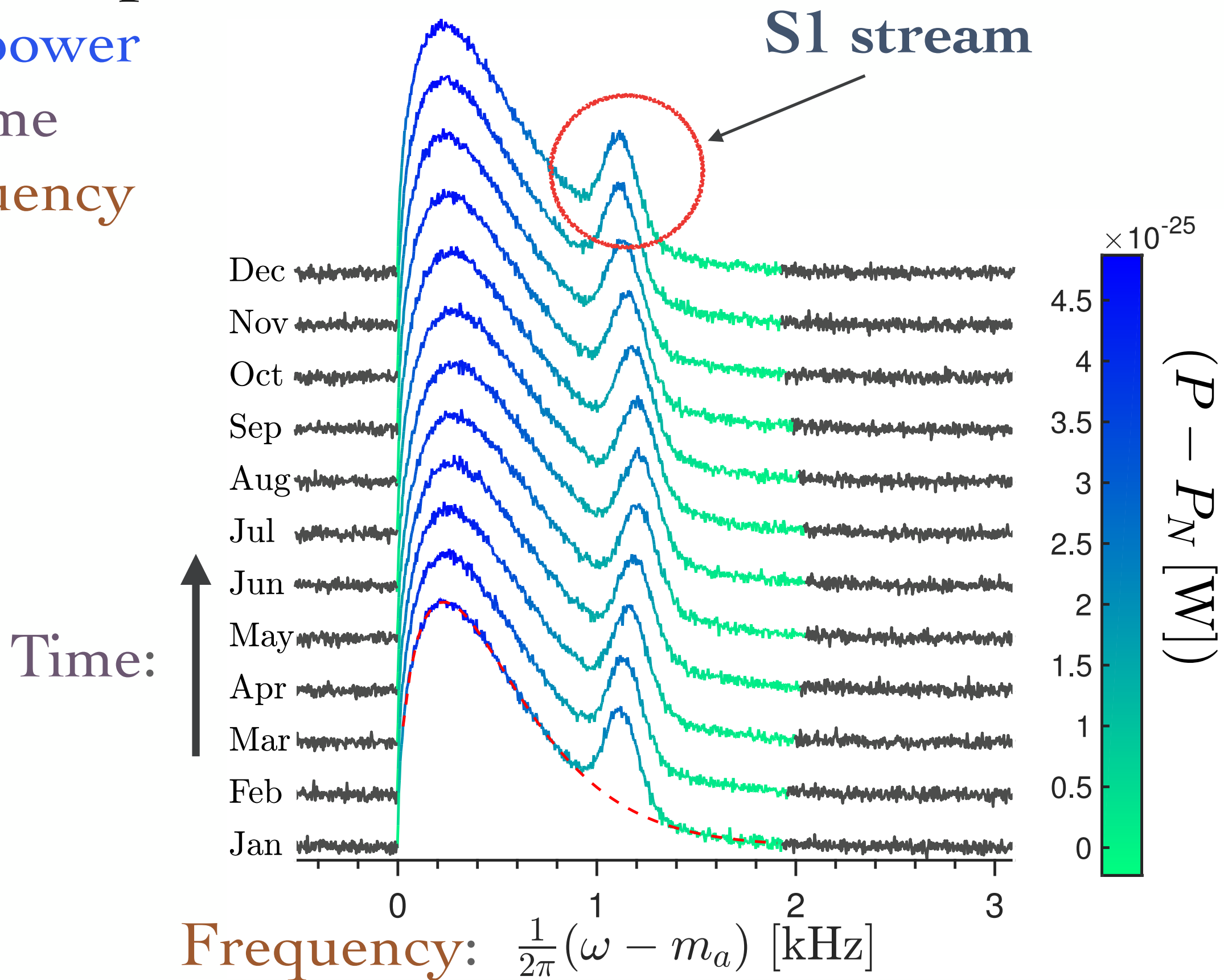
vs time

vs frequency

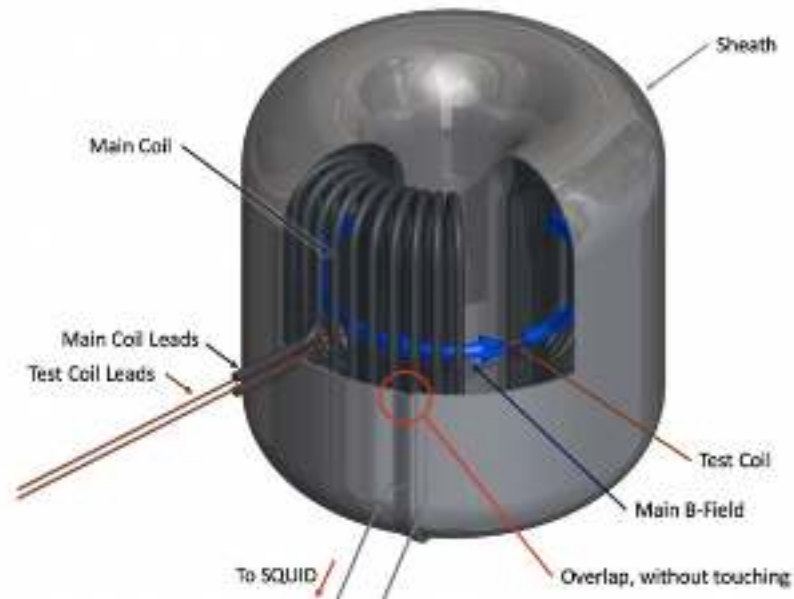


Axion haloscope:

Signal power
vs time
vs frequency



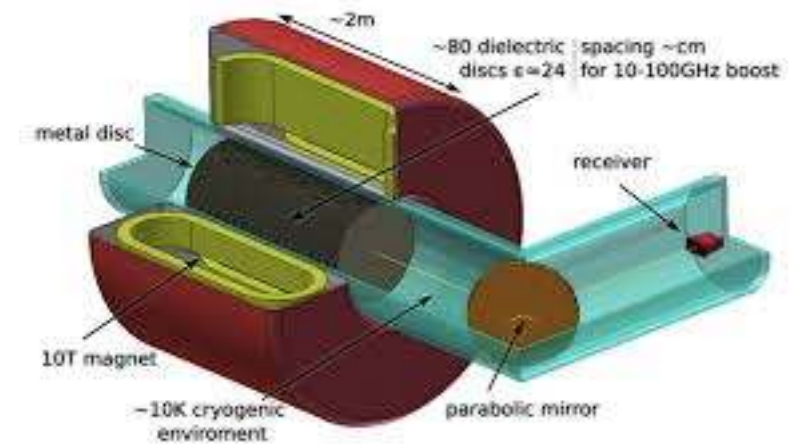
(some) Axion haloscopes



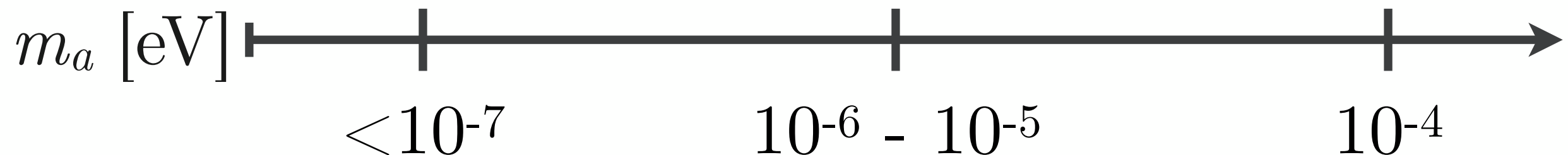
ABRACADABRA
DM-Radio
KLASH



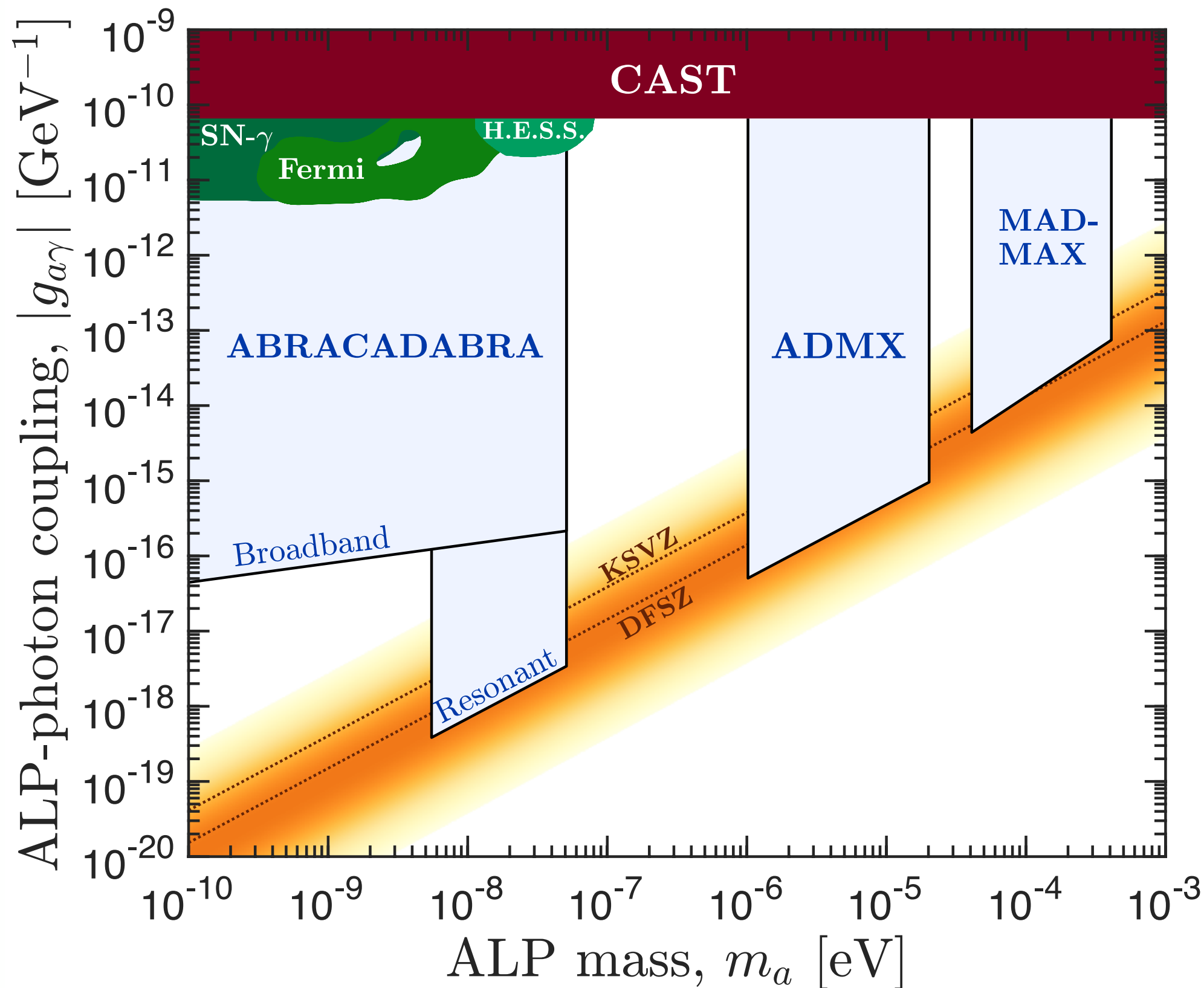
ADMX
CAPP
HAYSTAC



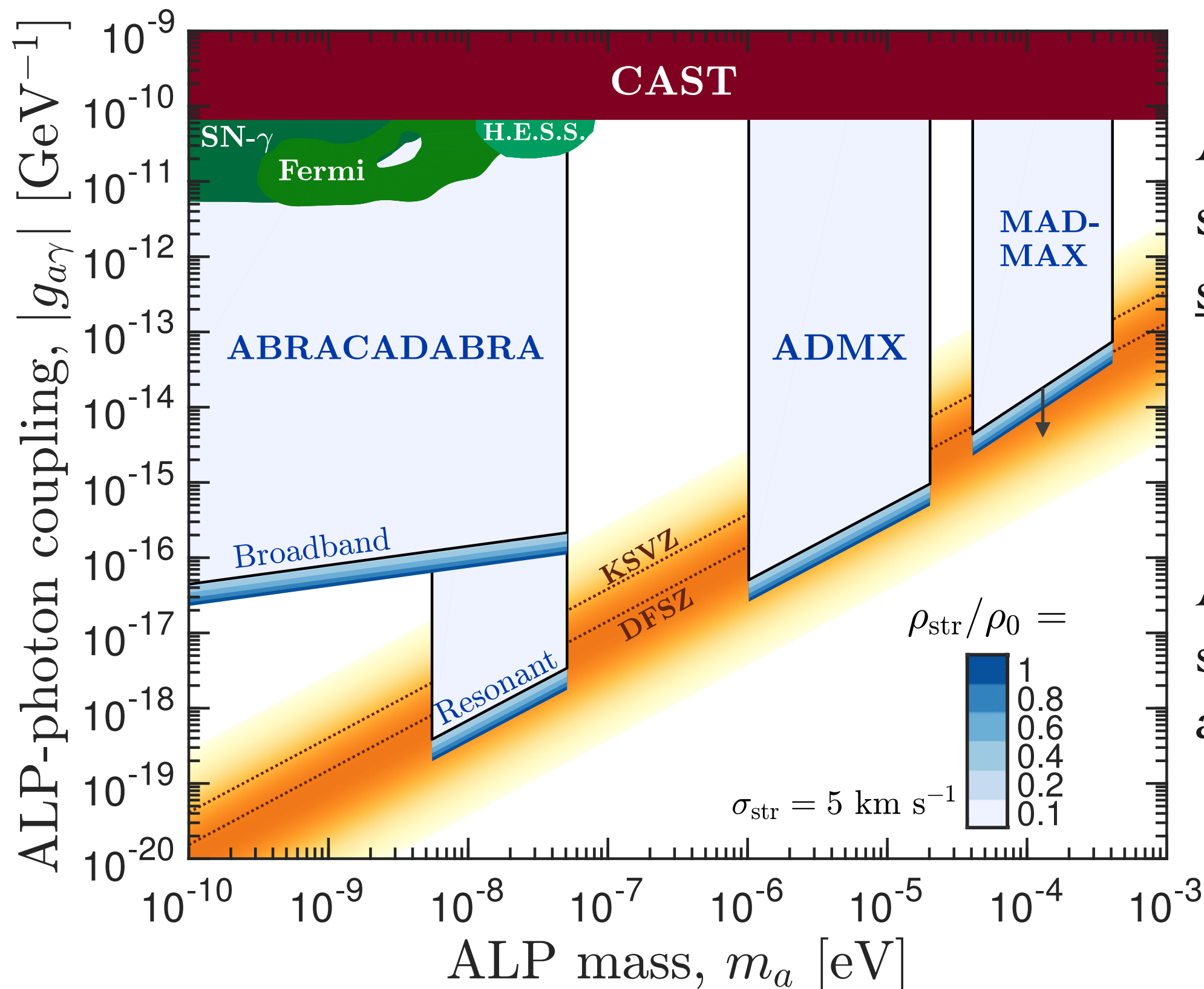
MADMAX
ORGAN
BRASS



Axion experimental projections



Impact of streams on axion searches:



Axion searches like sharp signals



A cold S1 stream improves axion sensitivity

Take home points

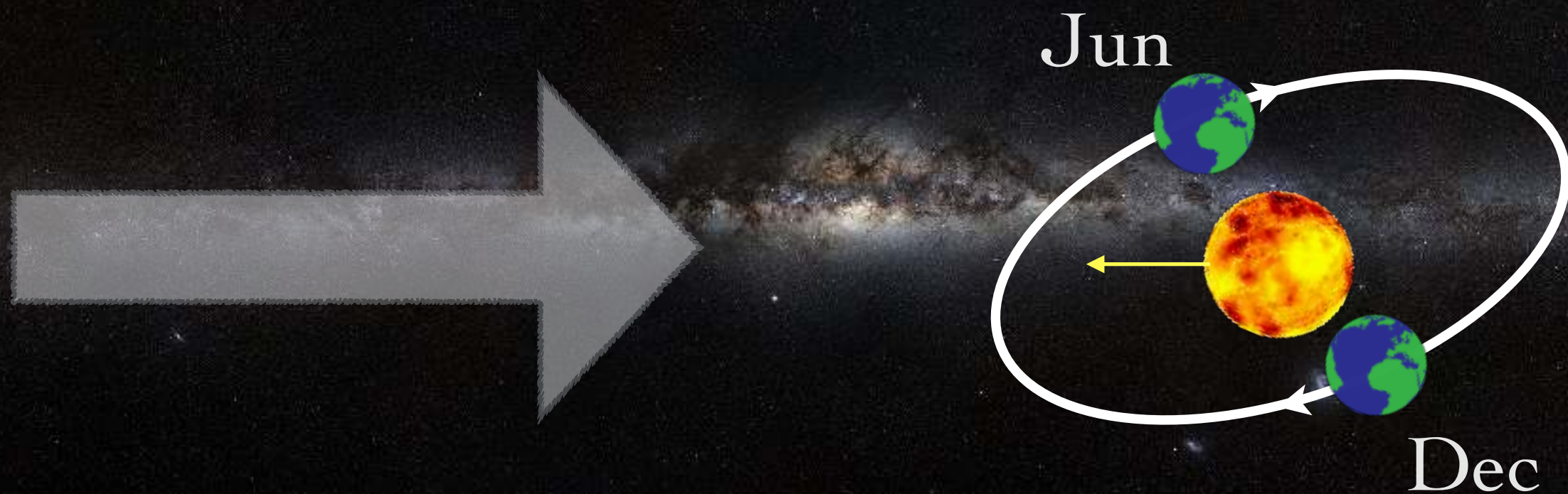
S1 stream probably bringing a hurricane of dark matter into our solar system

- Hard to detect in xenon detectors
- Easier to detect in directional detectors
- Easiest to detect in axion detectors

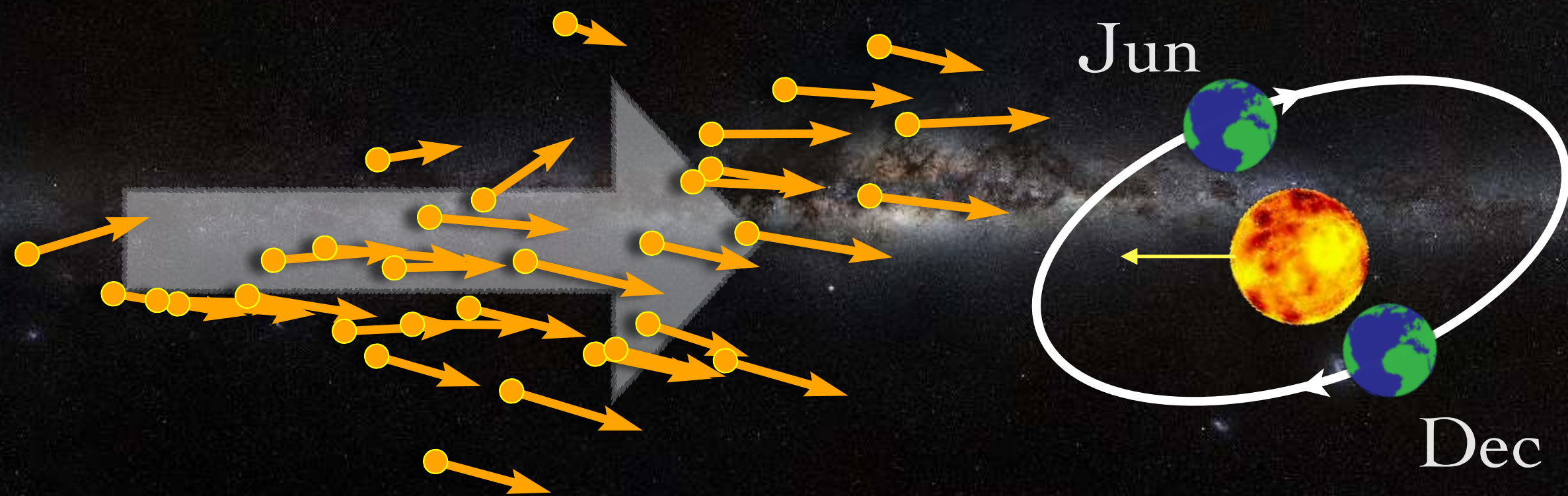
arXiv:[1807.09004]

Extras

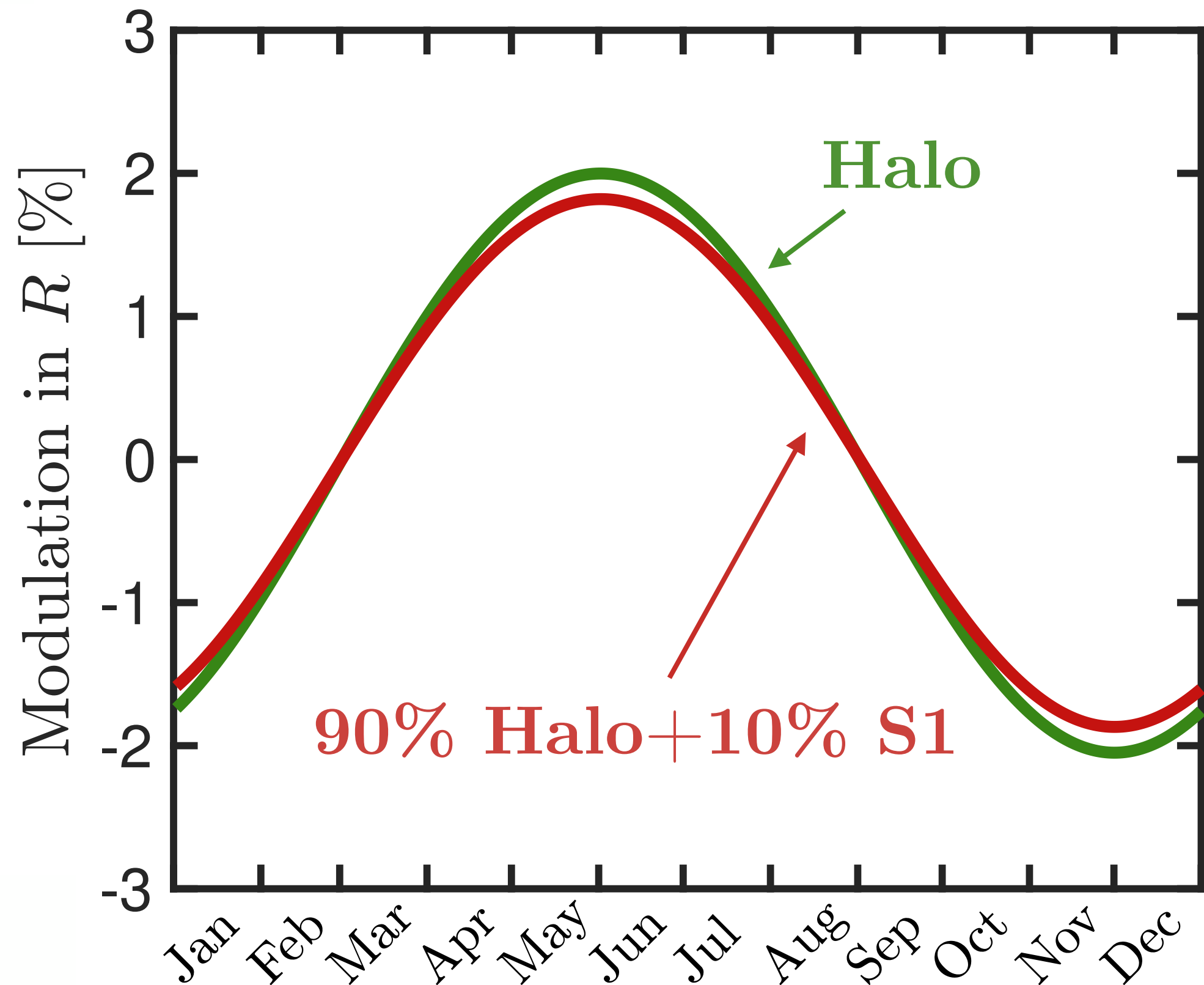
Annual modulation?



Annual modulation?



Annual modulation



The Standard Halo Model

Motivation: Simplest spherical model with asymptotically flat rotation curve

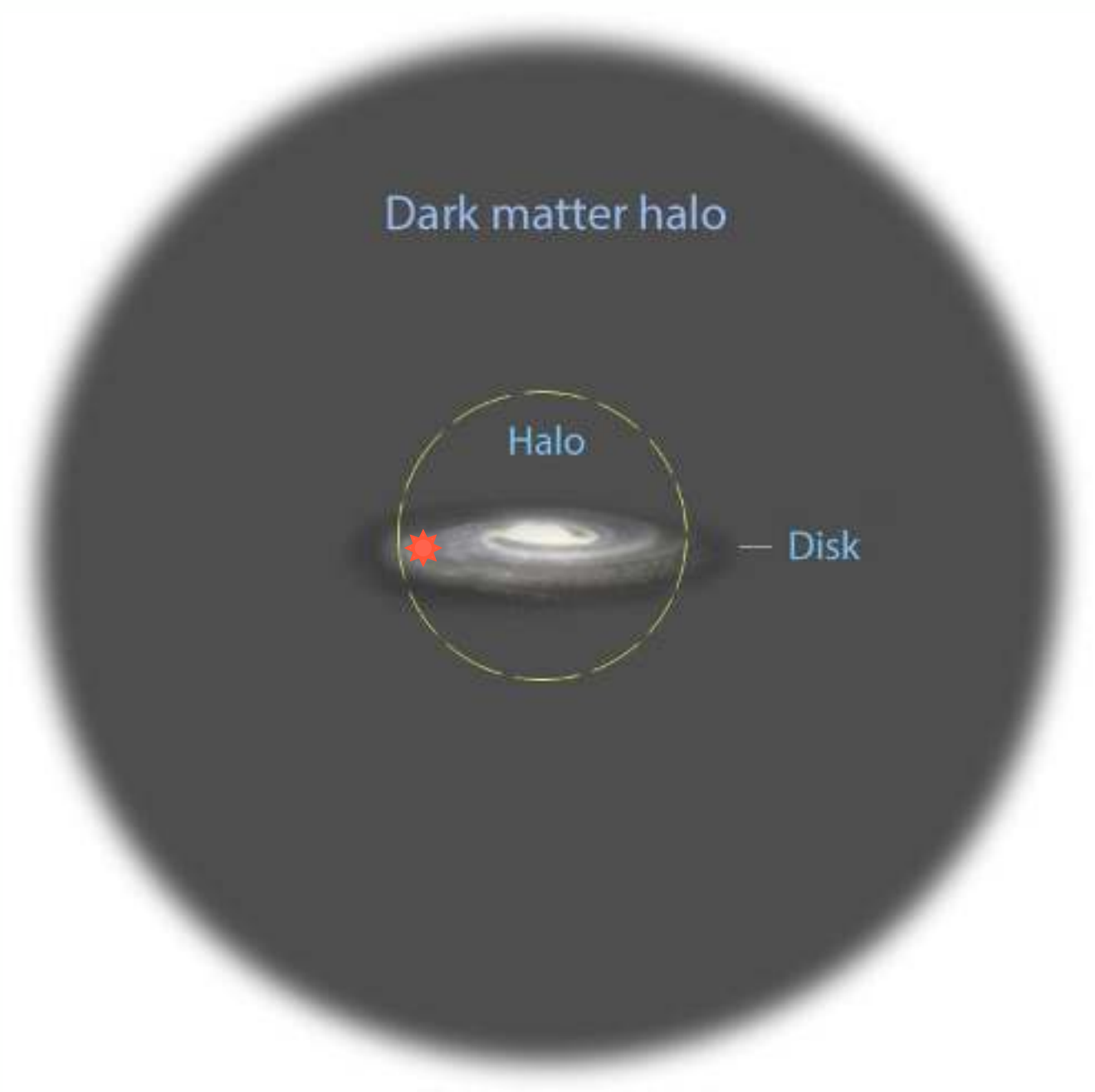
- Density $\sim 1/r^2$
- Isothermal
- Gaussian velocities
- Truncated at v_{esc}

$$f(\mathbf{v}) \sim \exp\left(-\frac{|\mathbf{v}|^2}{v_{\text{rot}}^2}\right)$$

$$\rho_{\text{dm}} = 0.3 \text{ GeV cm}^{-3}$$

$$v_{\text{rot}} = 220 \text{ km s}^{-1}$$

$$v_{\text{esc}} = 544 \text{ km s}^{-1}$$



SHM is a *standard*, i.e. it's okay for it to be wrong in certain aspects, but we should still want to refine the model with data

I) Sphericity

→ Most recent Jeans analysis with RR lyraes continue to favour a very spherical halo for the inner most 15 kpc [1806.09635]

II) Rotation speed $v_0 = v_{\text{rot}}(r = 8 \text{ kpc})$

→ Proper motion of Sgr A* → $v_0 = 233 \pm 3 \text{ km/s}$ ($\pm 1\%$ sys.) [1602.07702]

→ 23,000 APOGEE/*Gaia* red giants → $v_0 = 229 \pm 0.2 \text{ km/s}$ ($\pm 5\%$ sys.)
[1810.09466]

III) Local density

→ Recent analyses give higher values (~ 0.5) than canonical 0.3 GeV/cm^3

→ More *Gaia* analyses forthcoming, no big surprises are expected

IV) Isotropic? → Definitely not...