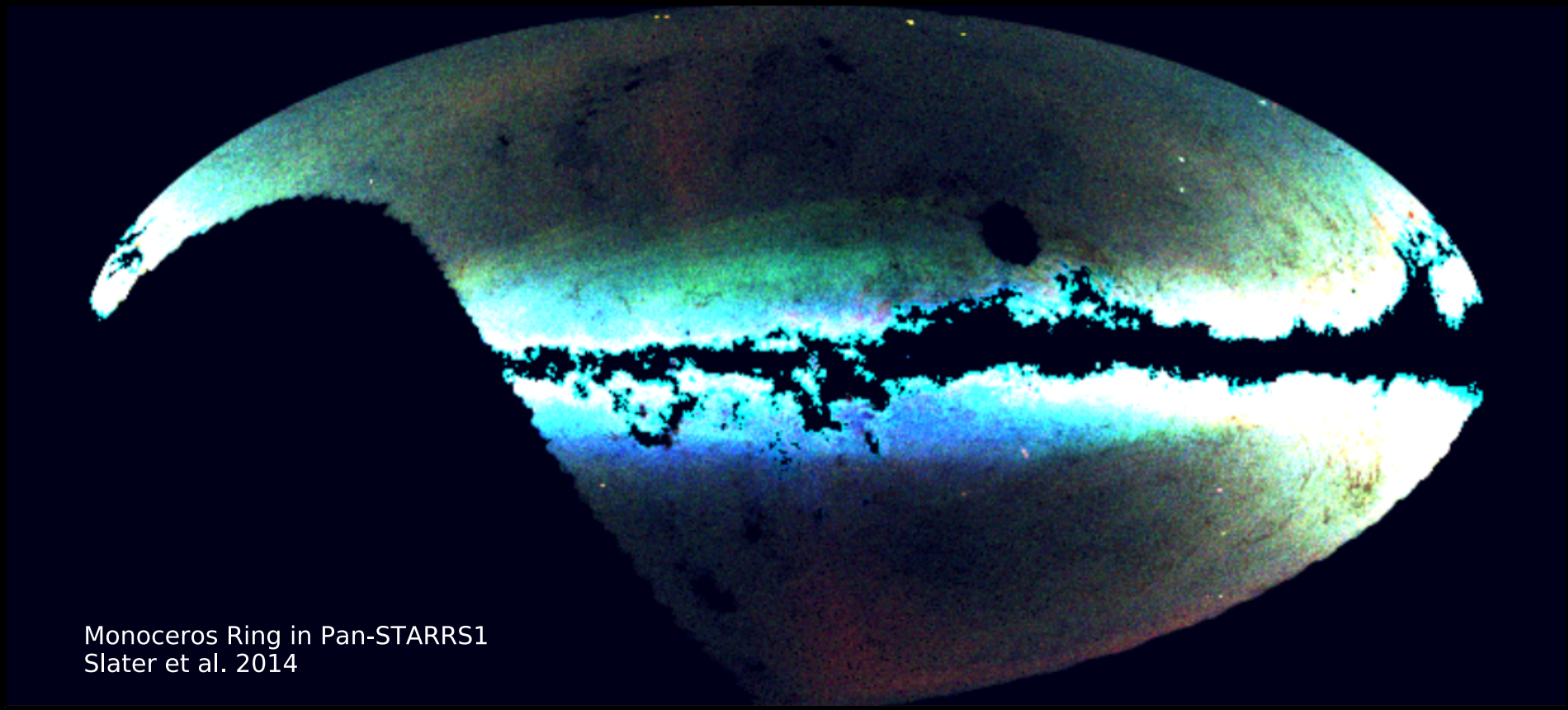
Halo Structure and Direct Detection



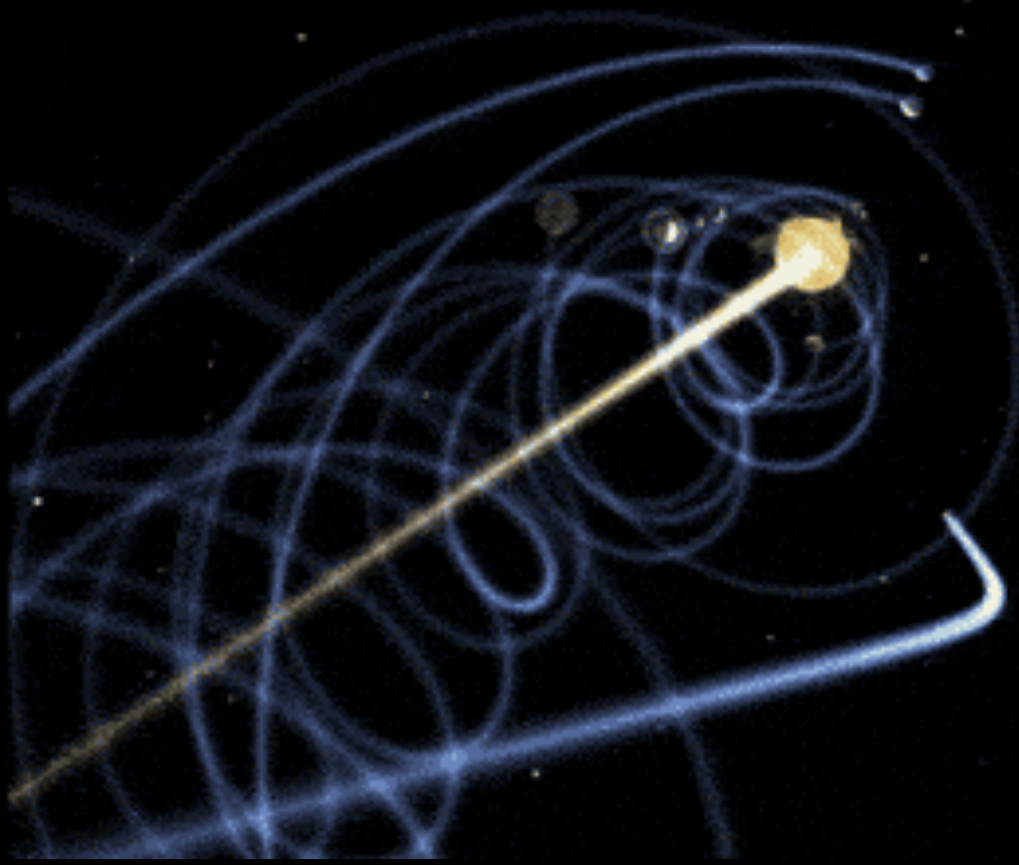
Monoceros Ring in Pan-STARRS1
Slater et al. 2014

Annika Peter

The Ohio State University

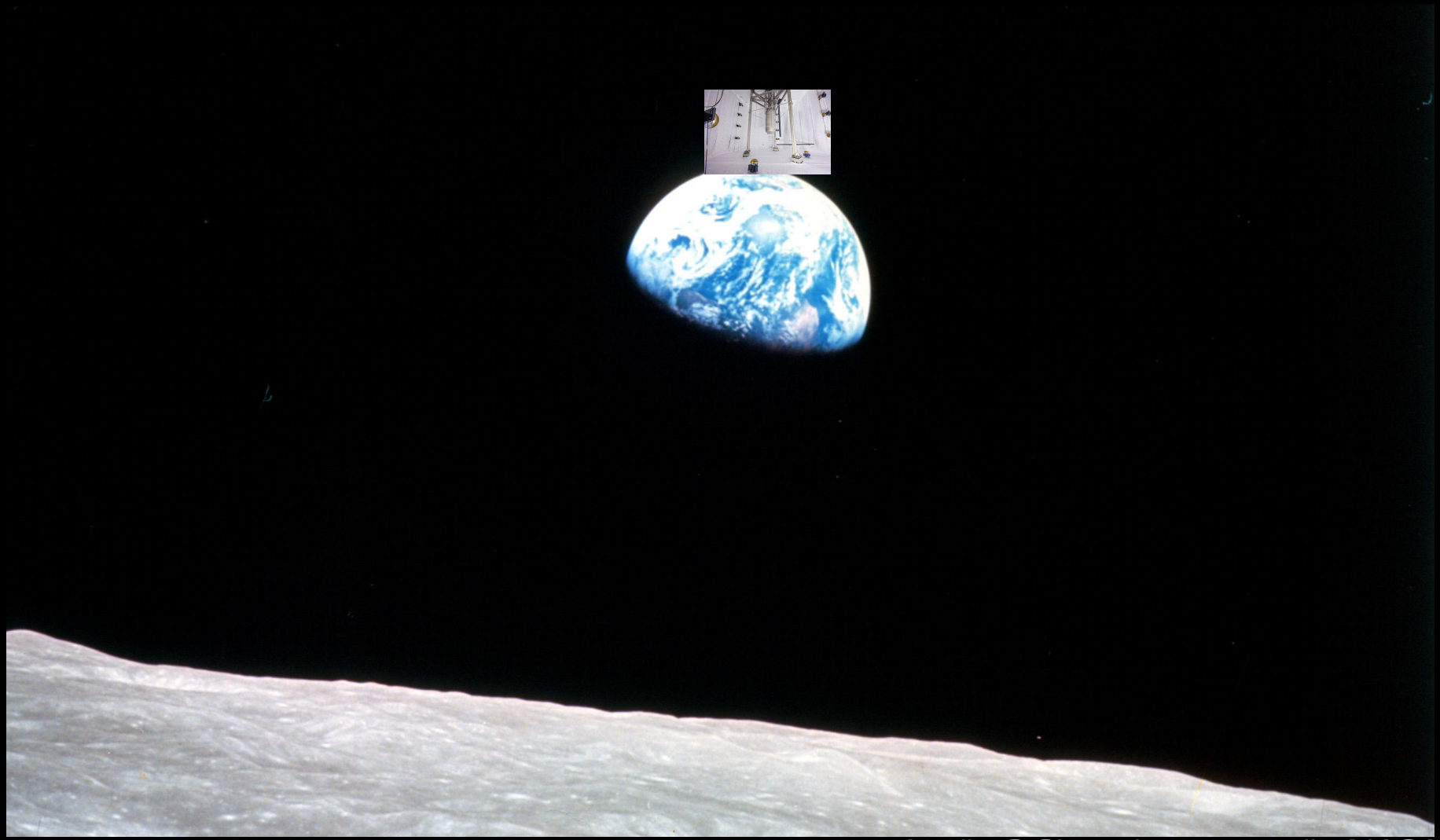
“you revolve around me
as we fly around the galaxy”

—Kids Learning Tube, “The Sun”



http://infinity-imagined.tumblr.com/

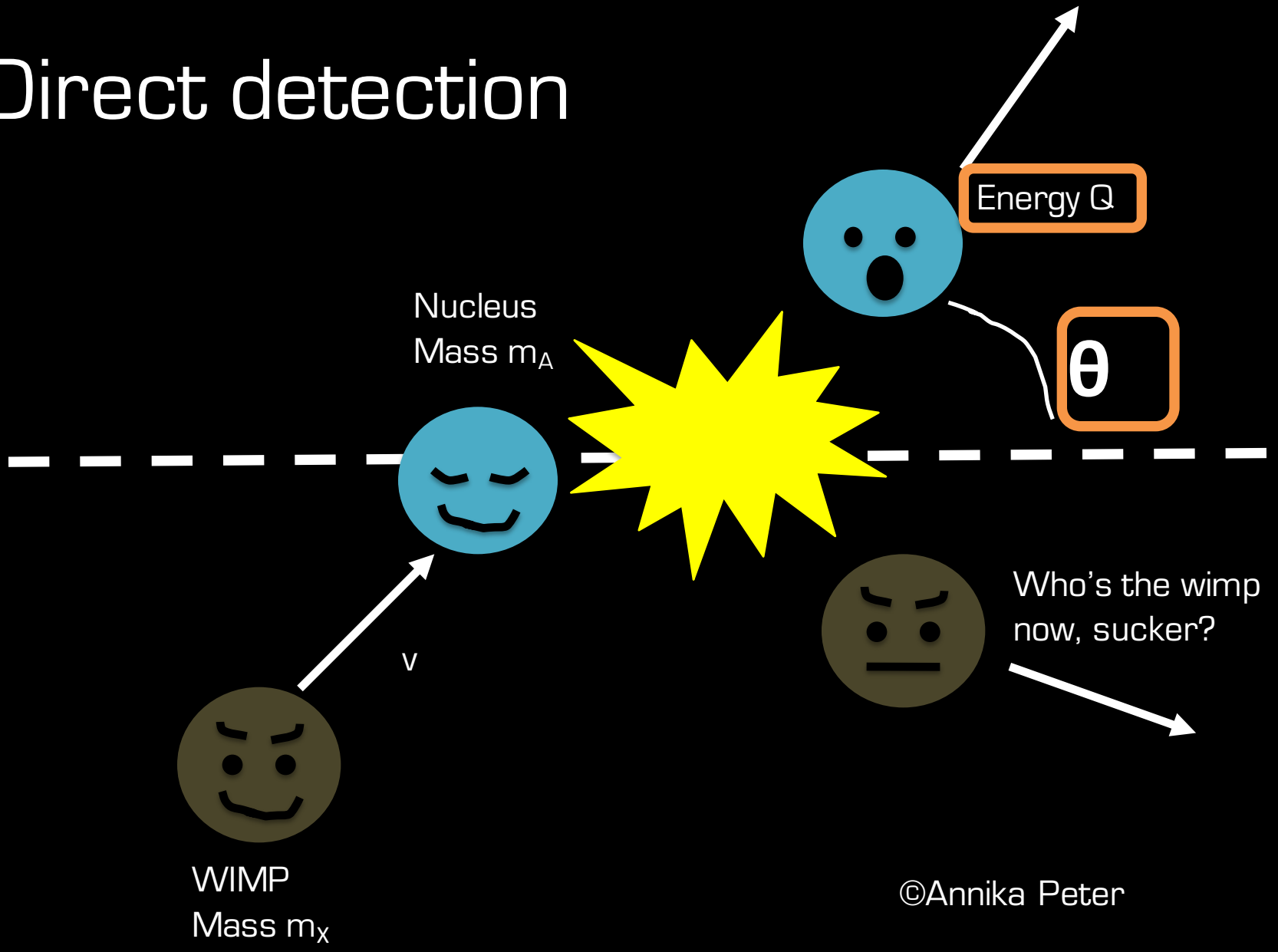
Direct detection



Apollo 8 Shot. Image credit: NASA

Image credit: LUX collaboration

Direct detection



Rates

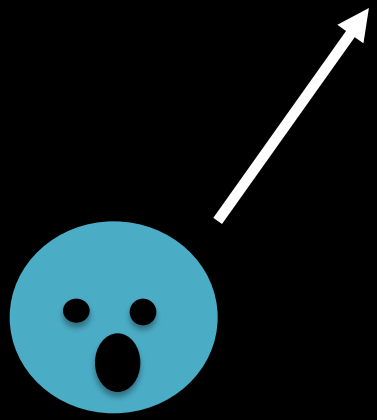
$$\frac{dR}{dQ} \propto \int_{v_{cut}}^{v_{esc}} d^3v f(r,v) v \frac{d\sigma}{dQ}, v_{cut} = \sqrt{\frac{m_A Q}{2\mu^2}}$$

If elastic

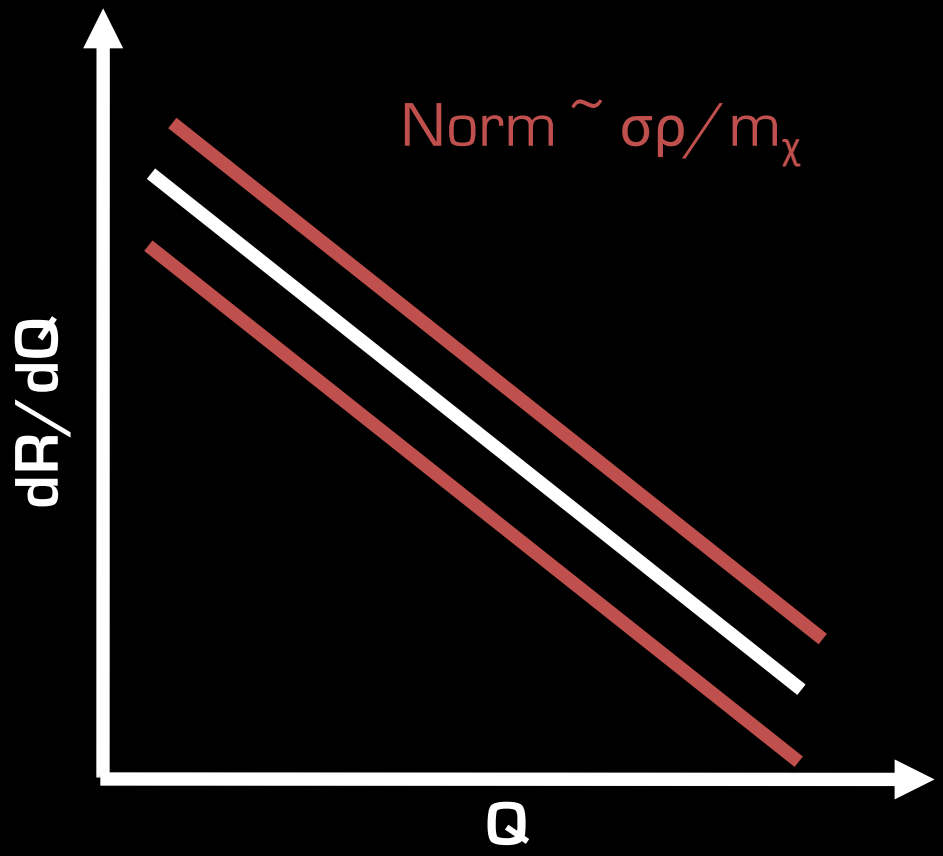
≈pf(v, t)

Includes motion of Sun and Earth

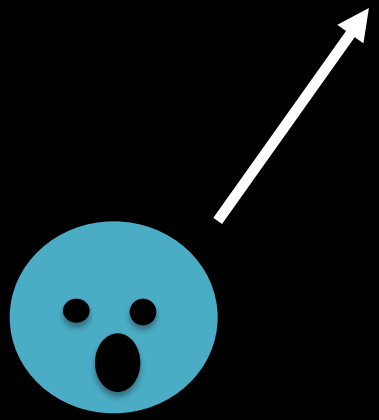
Rates: ρ



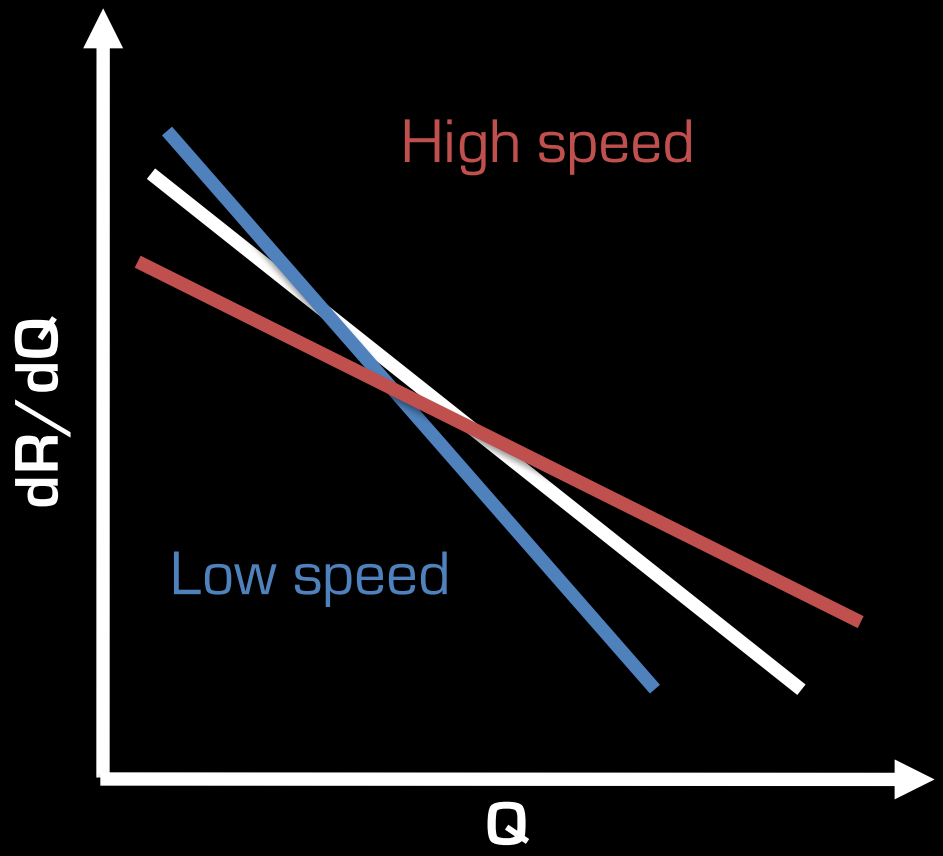
Energy Q



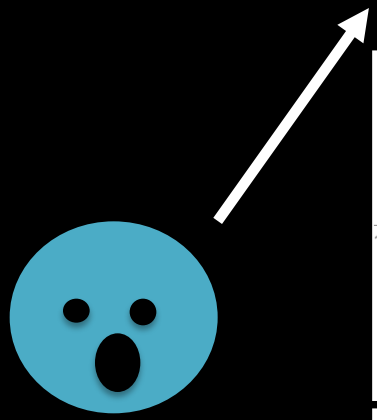
Rates: f(v)



Energy Q



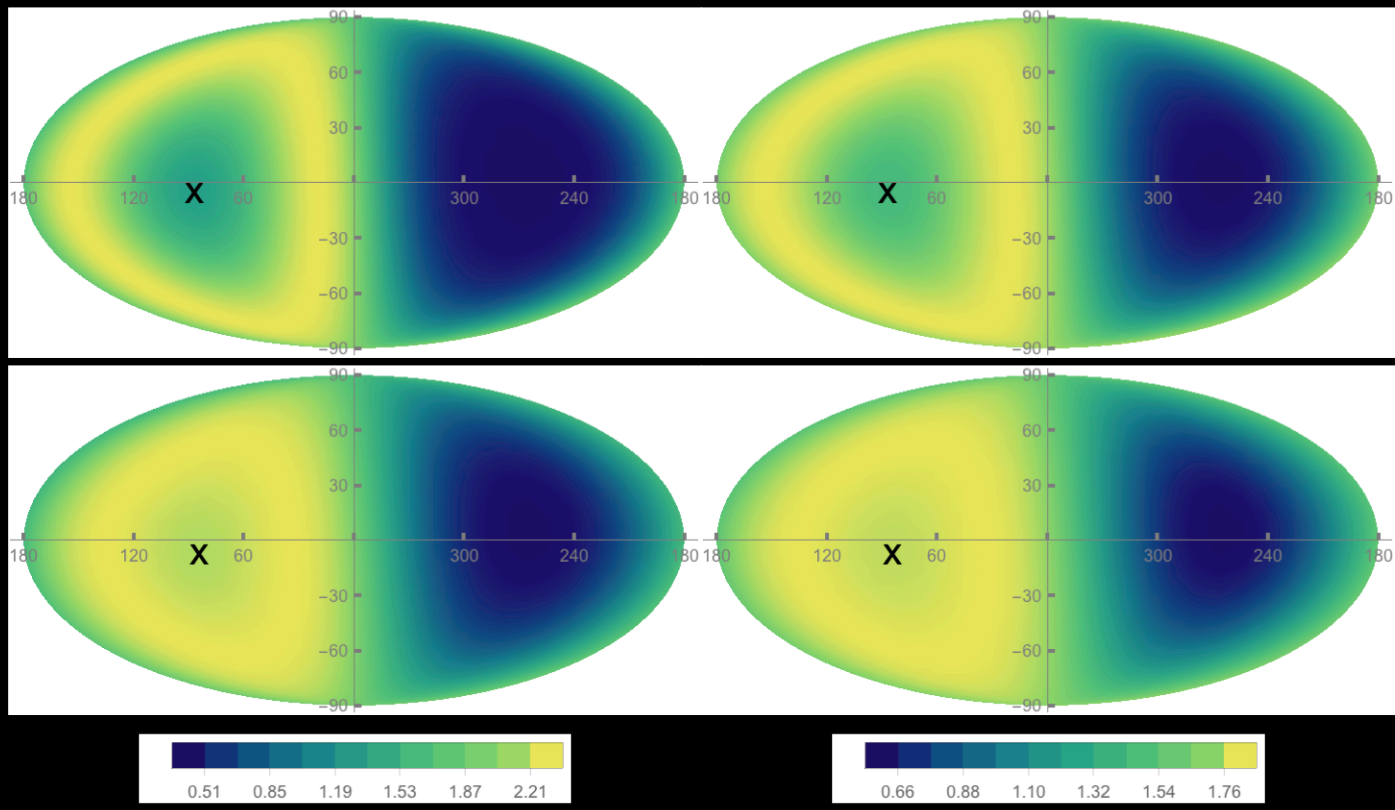
Rates: angular



Low dispersion

High dispersion

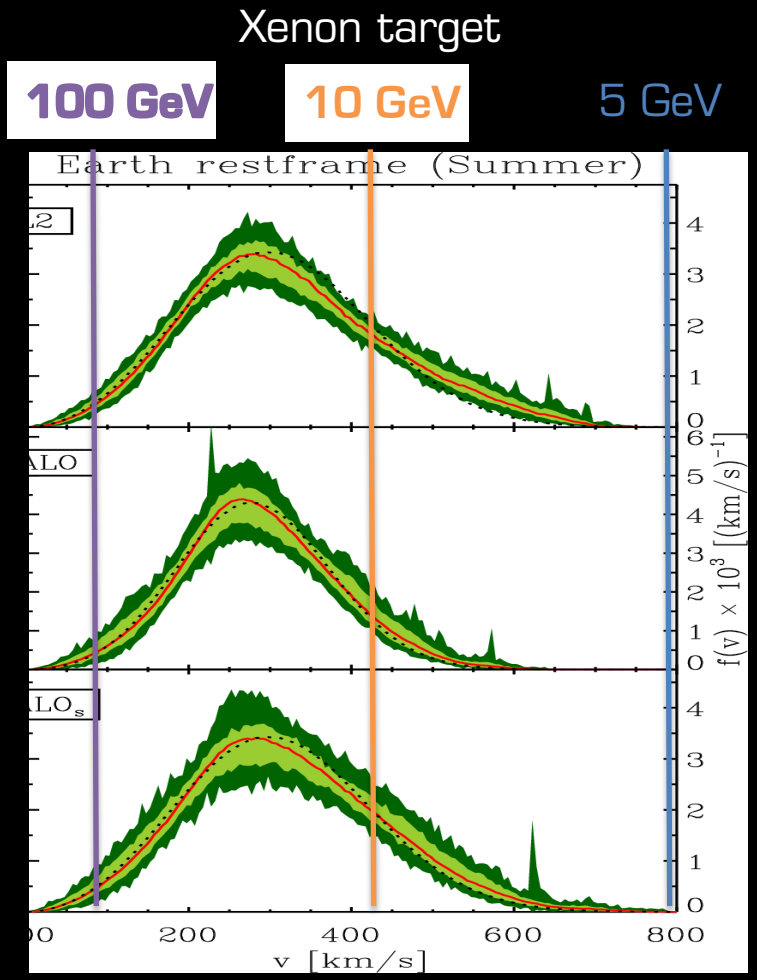
Low LSR



Mayet+ 2016

Why is this an issue?

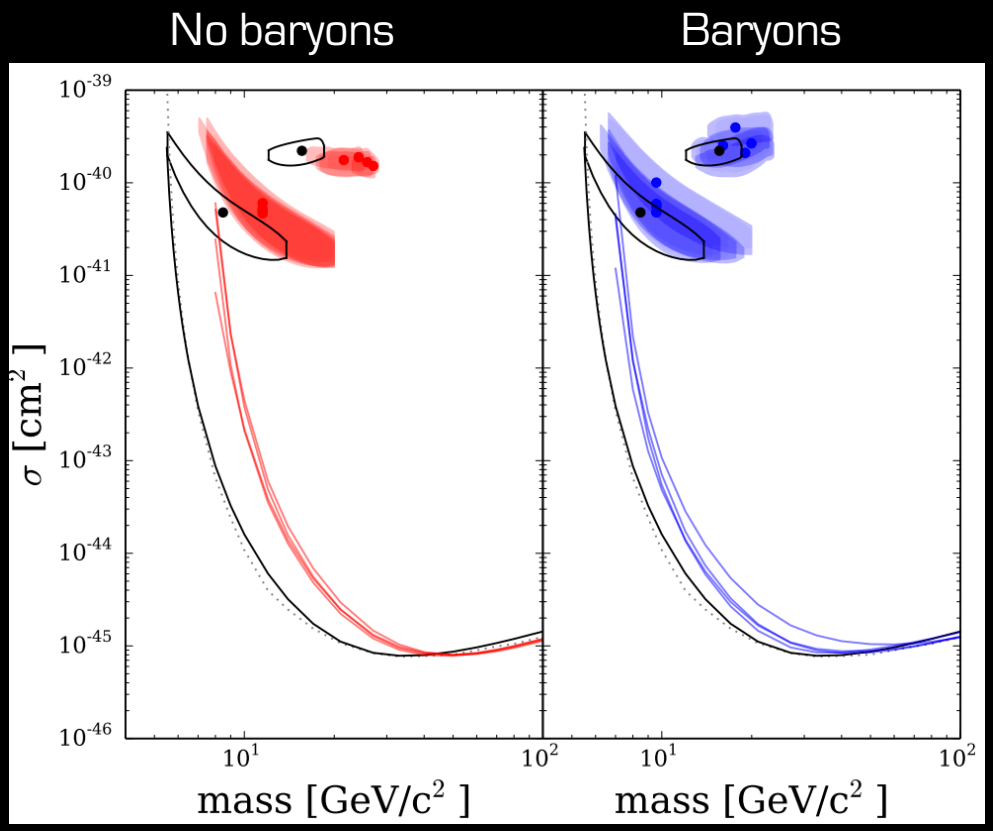
- Incorrect inference of particle properties.
- Internecine wars about detection vs. non-detection.



Kuhlen+ 2010

Why is this an issue?

- Incorrect inference of particle properties.
- Internecine wars about detection vs. non-detection.



Sloane+ 2016

The program

Uncertainty

1. ρ
2. f(v,t)—halo reference frame
3. Solar motion

Solution

1. Self-calibration
2. Beating neutrinos

NB: I will focus on time-independent direct detection & directional detection. Some of the uncertainties are worse for annual modulation.

Uncertainty

1. ρ

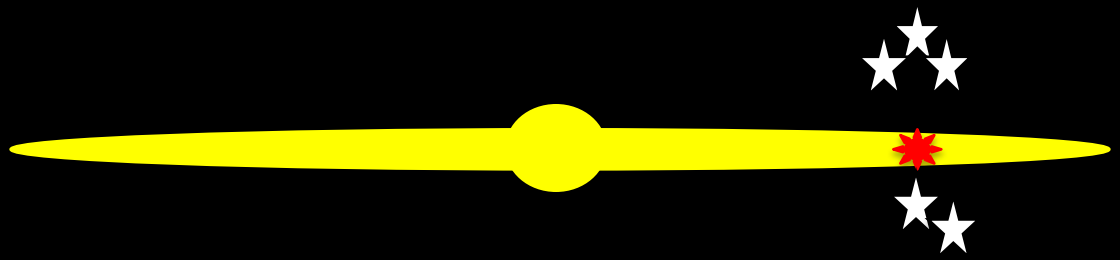
“A long time ago,

in a galaxy (not so) far away…”

(we’ve been arguing since Kapteyn in the 1920’s…)

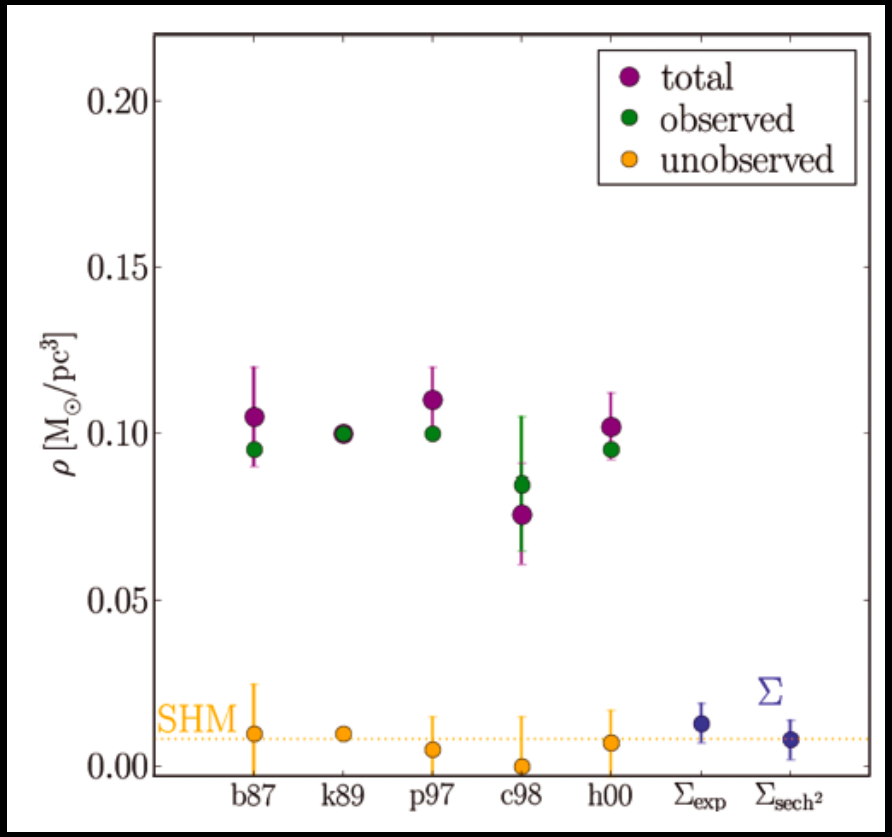
1. ρ

Dark matter



Equilibrium solution from stellar motion

Summary: Garbari+ 2011



K dwarfs (to 1.1 kpc) Hipparcos stars (to 200 pc)

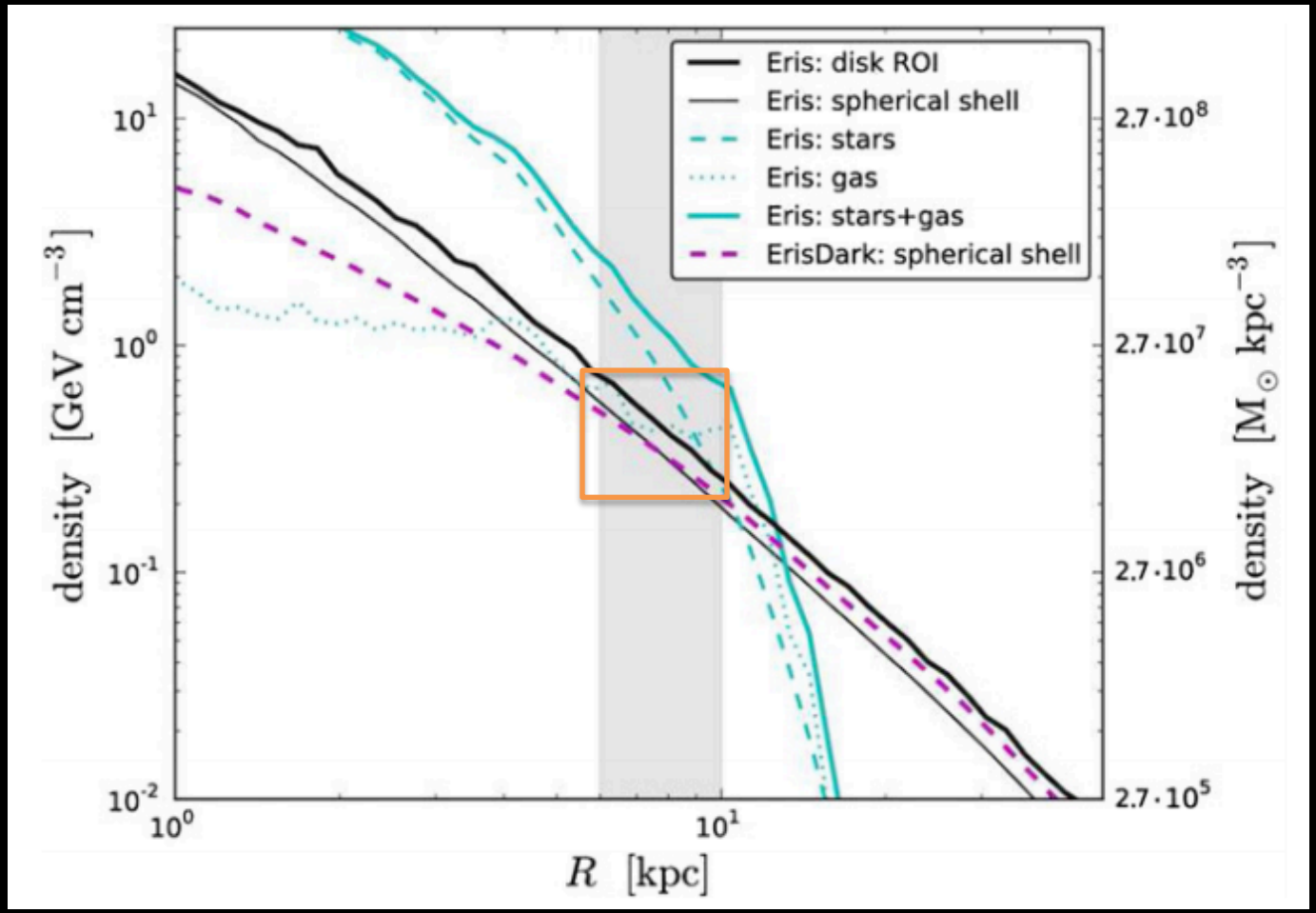
Most recent, interesting, and presaging more:

Bovy & Rix 2013

Global modeling: Iocco et al. 2015, McMillan (several)

0.008 $M_\odot/pc^3$ (0.3 GeV/cm^3)

Simulations



Pillepich+ 2014

2. f(v,t)

“From there to here,

here to there,

funny things are everywhere.”

-- Dr. Seuss, ***One Fish, Two Fish, Red Fish, Blue Fish***

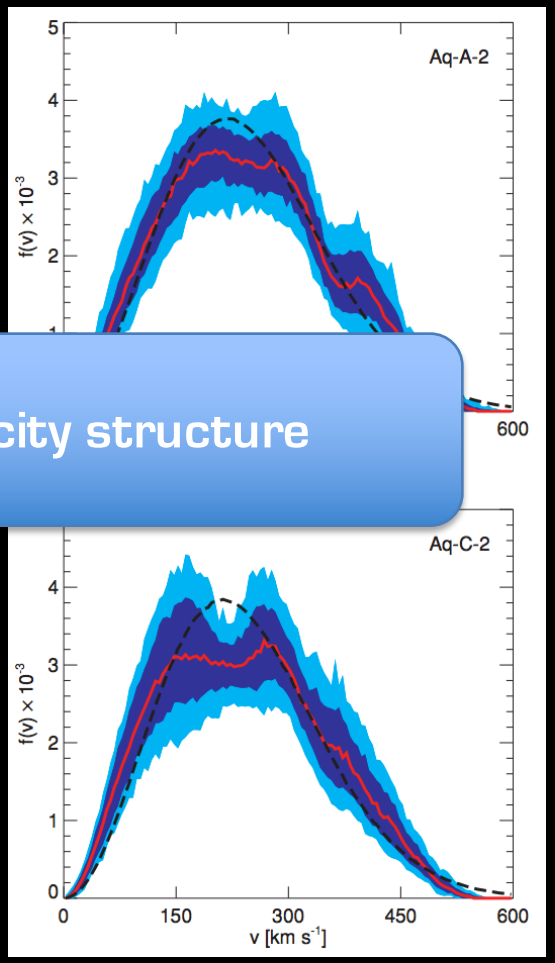
f(v,t)

Redbubble.com

- Singular isothermal sphere
- Isotropic velocity distribution

- You got yourself a Gaussian-distributed “Standard Halo Model” (SHM)

Simulations: Dark matter only



SHM a bad fit; diversity in velocity structure

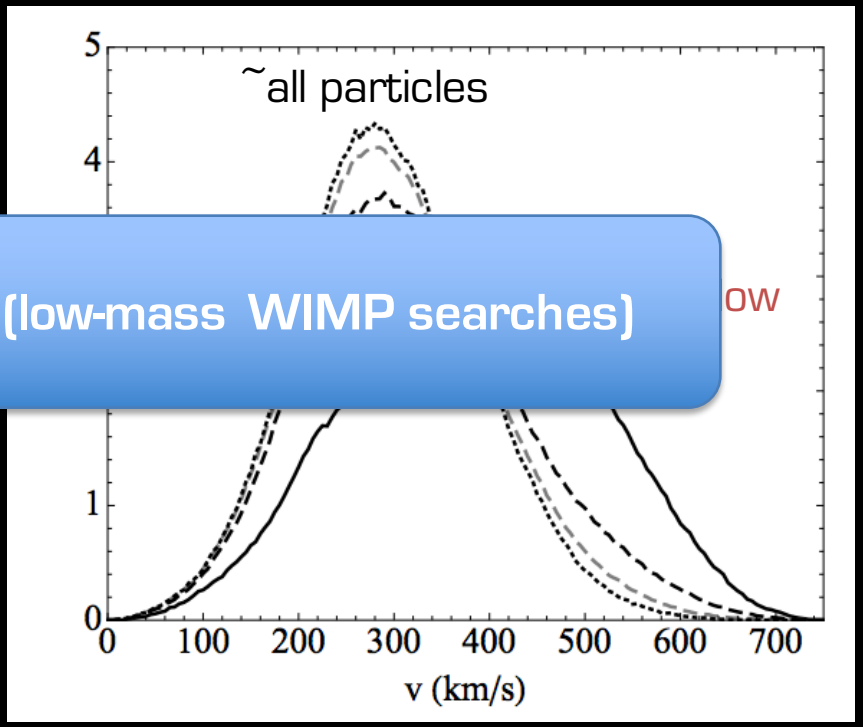
Springel+ 2008

Vogelsberger+ 2009

Simulations: debris flows

Springel+ 2008

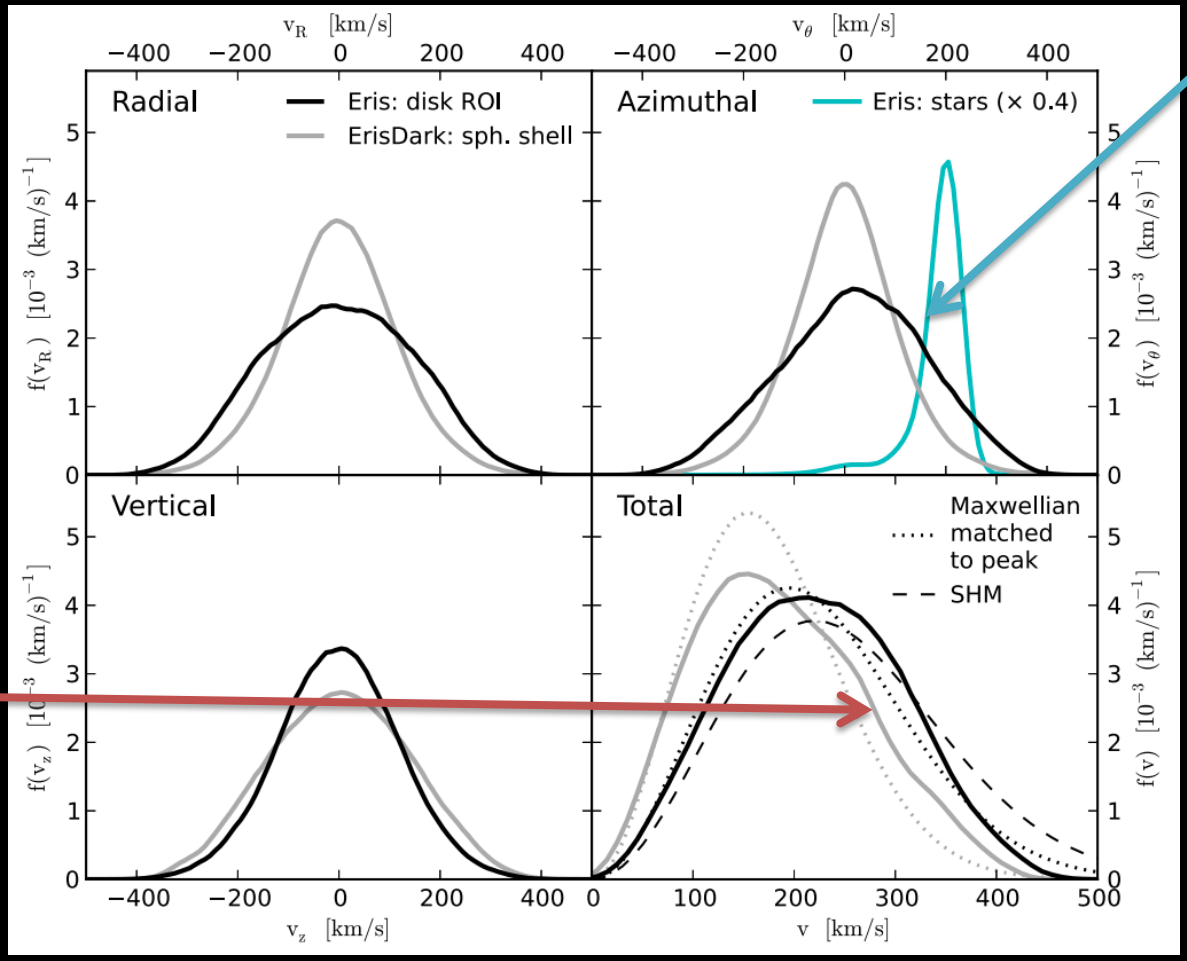
Earth frame



Kuhlen, Lisanti & Spergel 2012

Bad news for high-speed tail (low-mass WIMP searches)

Simulations: baryons

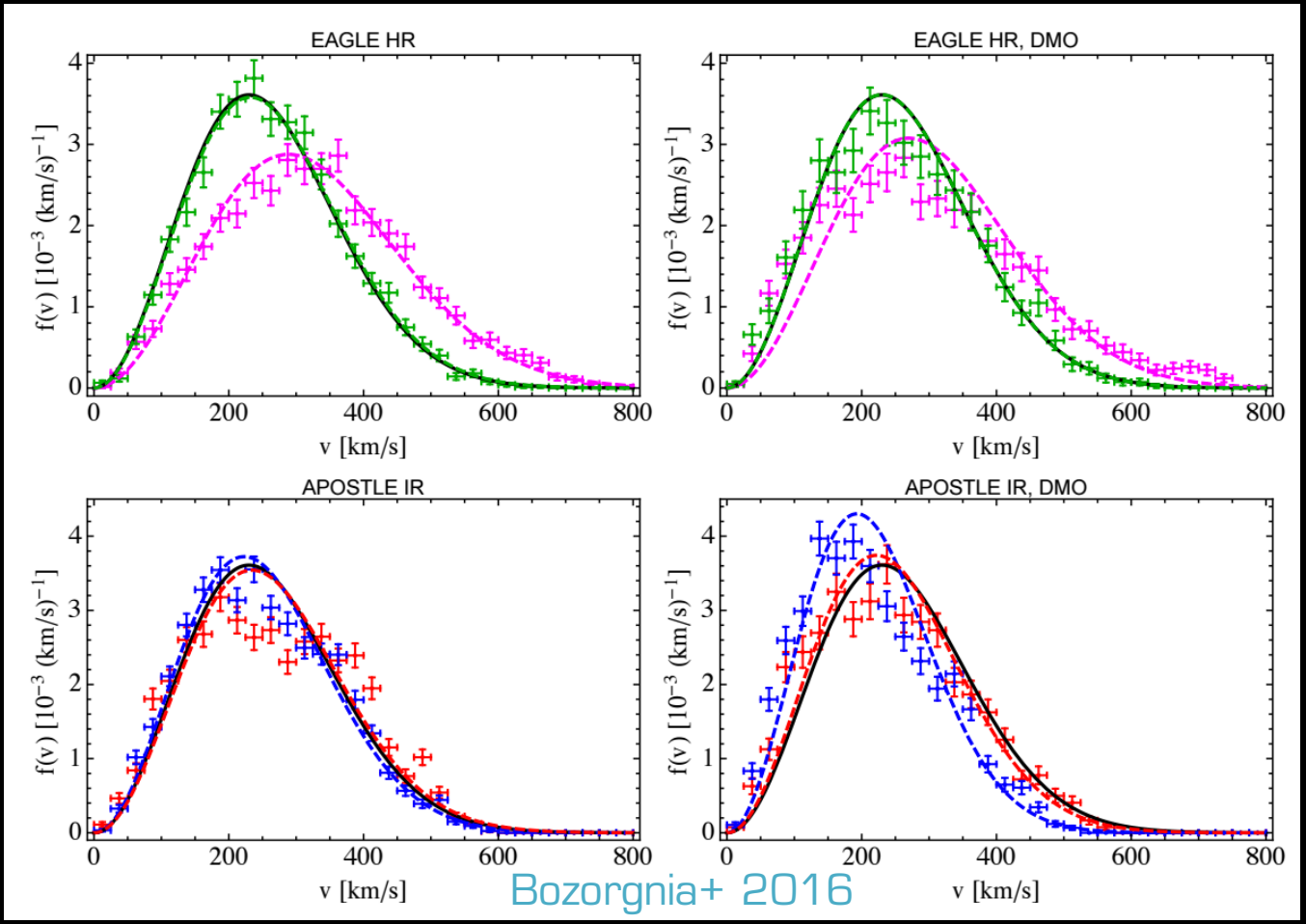


Dark disk?

SHM: not so bad except out in tail.

Pillepich+ 2014

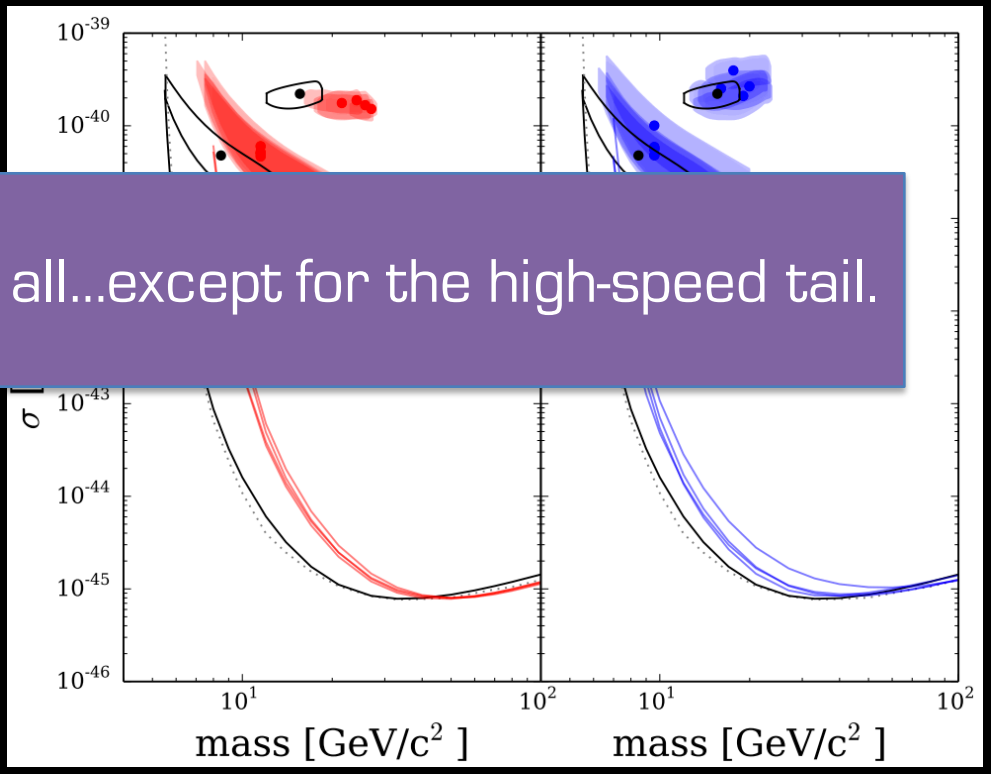
Simulations: baryons



Bozorgnia+ 2016

See also: Kelso+ 2016, Sloane+ 2016

Simulations: baryons



SHM maybe not so bad after all...except for the high-speed tail.

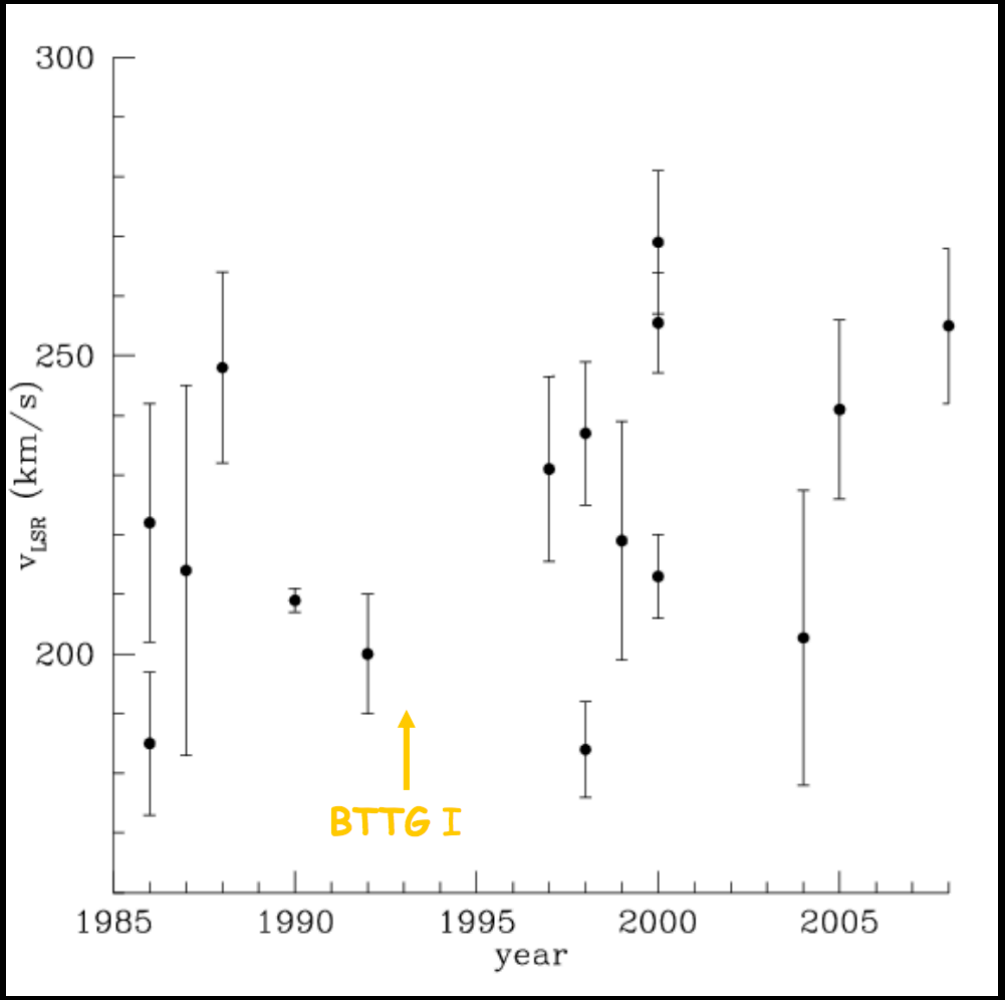
Sloane+ 2016

3. Solar motion

“Here comes the Sun,
Here comes the Sun.”
–The Beatles

Biggest uncertainty: LSR & solar motion

See: Reid+ 2014, Bovy+ 2012,2013
Schoenrich & Binney 2010



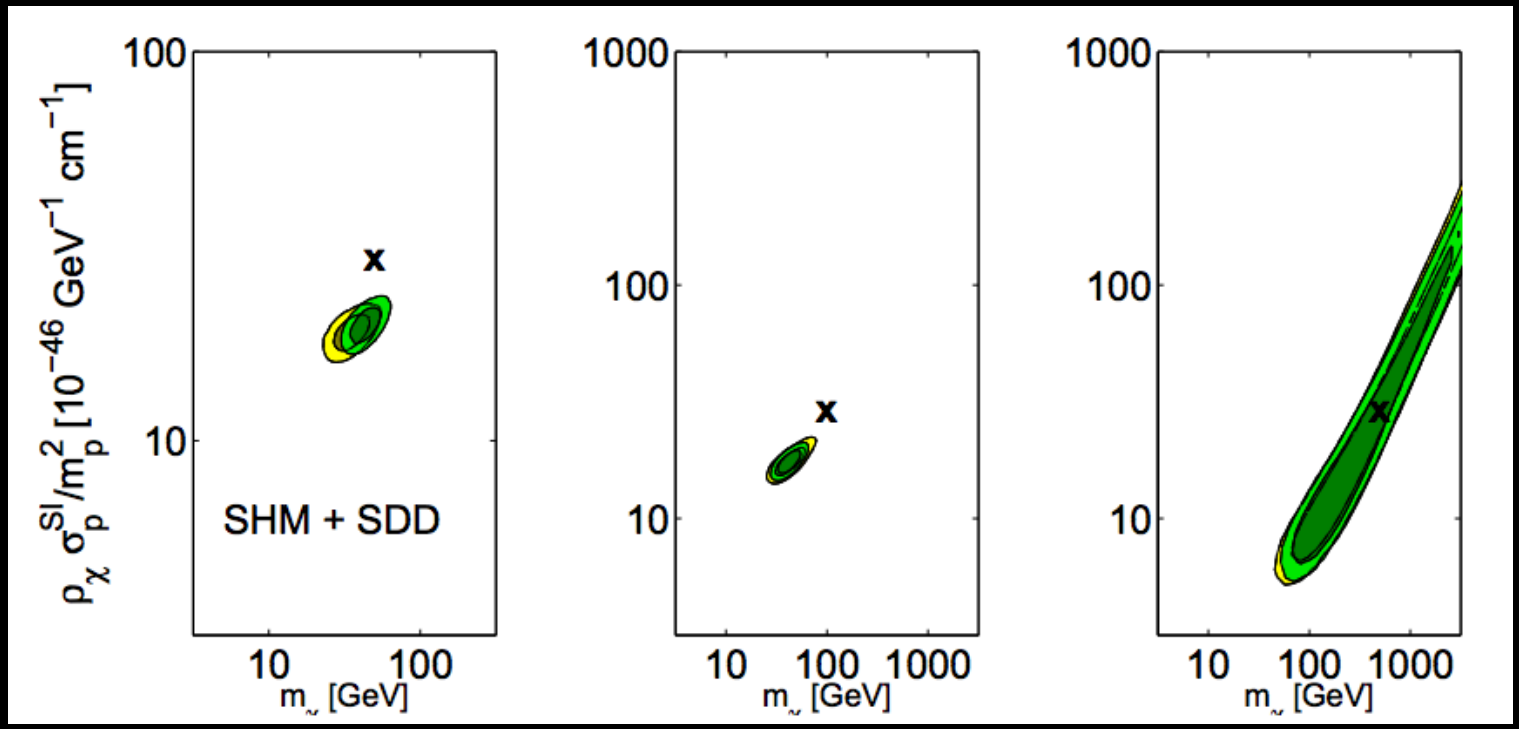
Tremaine, "Back to the Galaxy II" conference, 2008

Solution

(Not going to talk about halo-independent methods for now.)

1. Self-calibration (WIMP astronomy!)

Modeling your known unknowns.



Peter 2011

More parameters for MultiNest

Go from:

$(m_X, \rho, \sigma_{SI}, \sigma_{SD}...)$

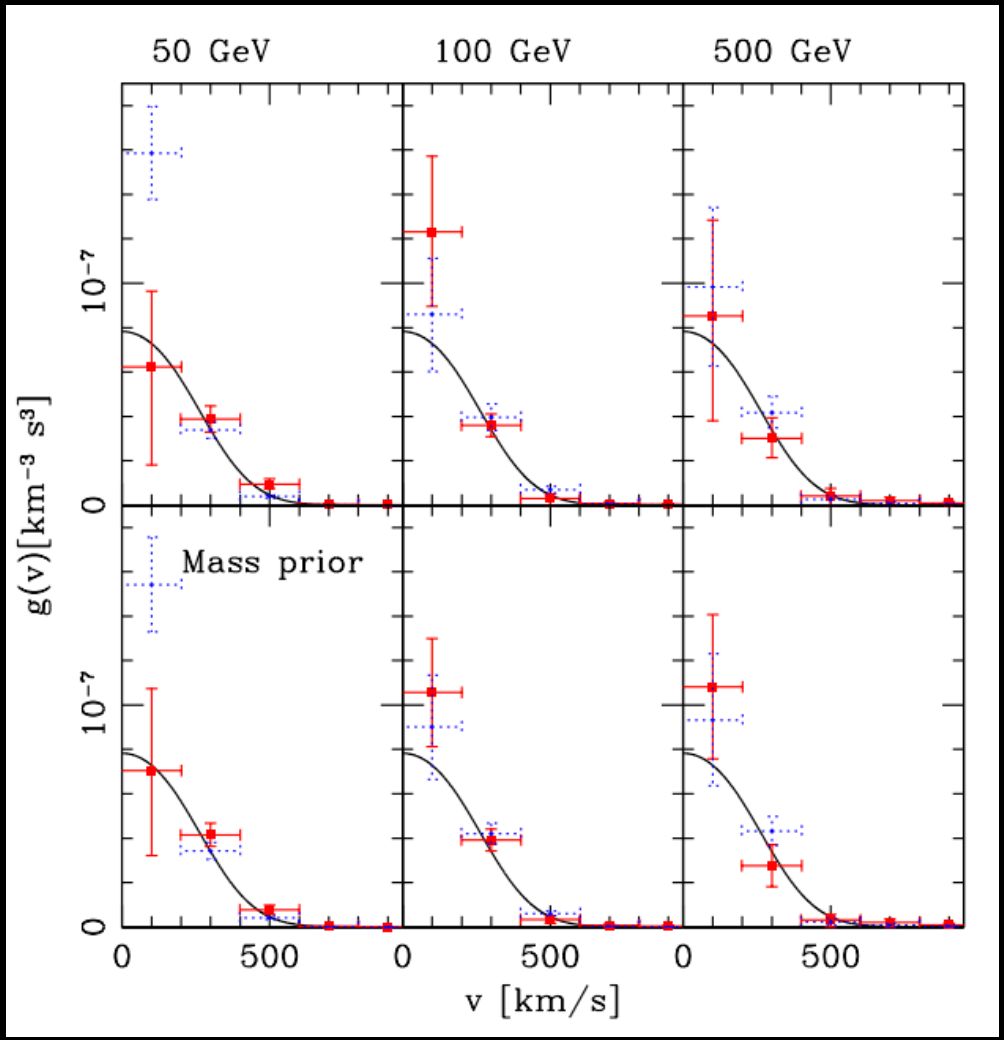
To

$(m_X, \rho, \{\sigma_i\}, \{f_j(v)\})$

CRITICAL ELEMENT:

Need several different targets (break degeneracy w/mass)

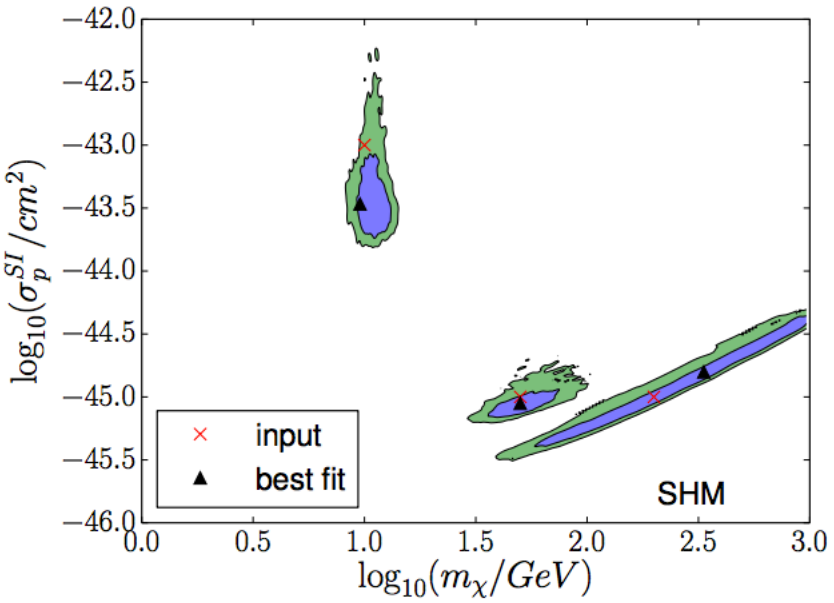
Parametrizations

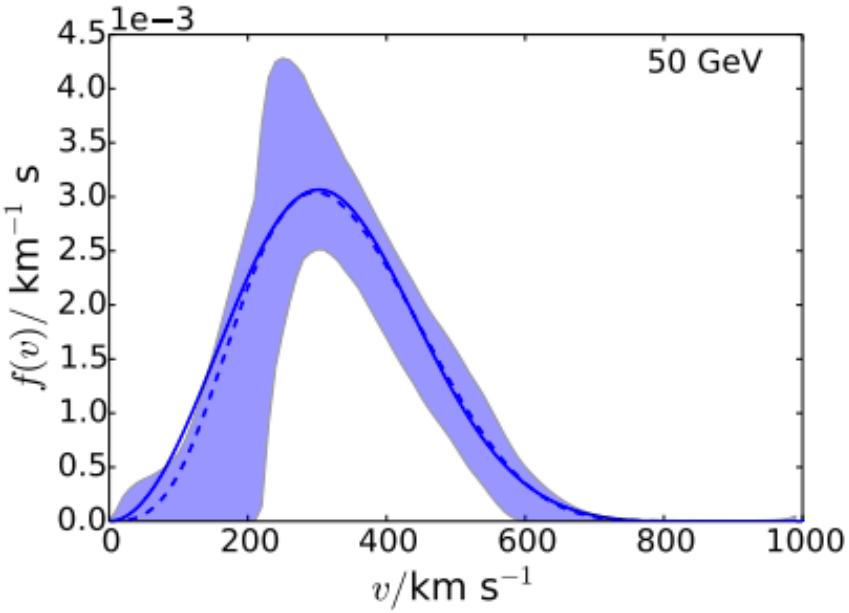


Step functions (Peter 2011)

Parametrizations

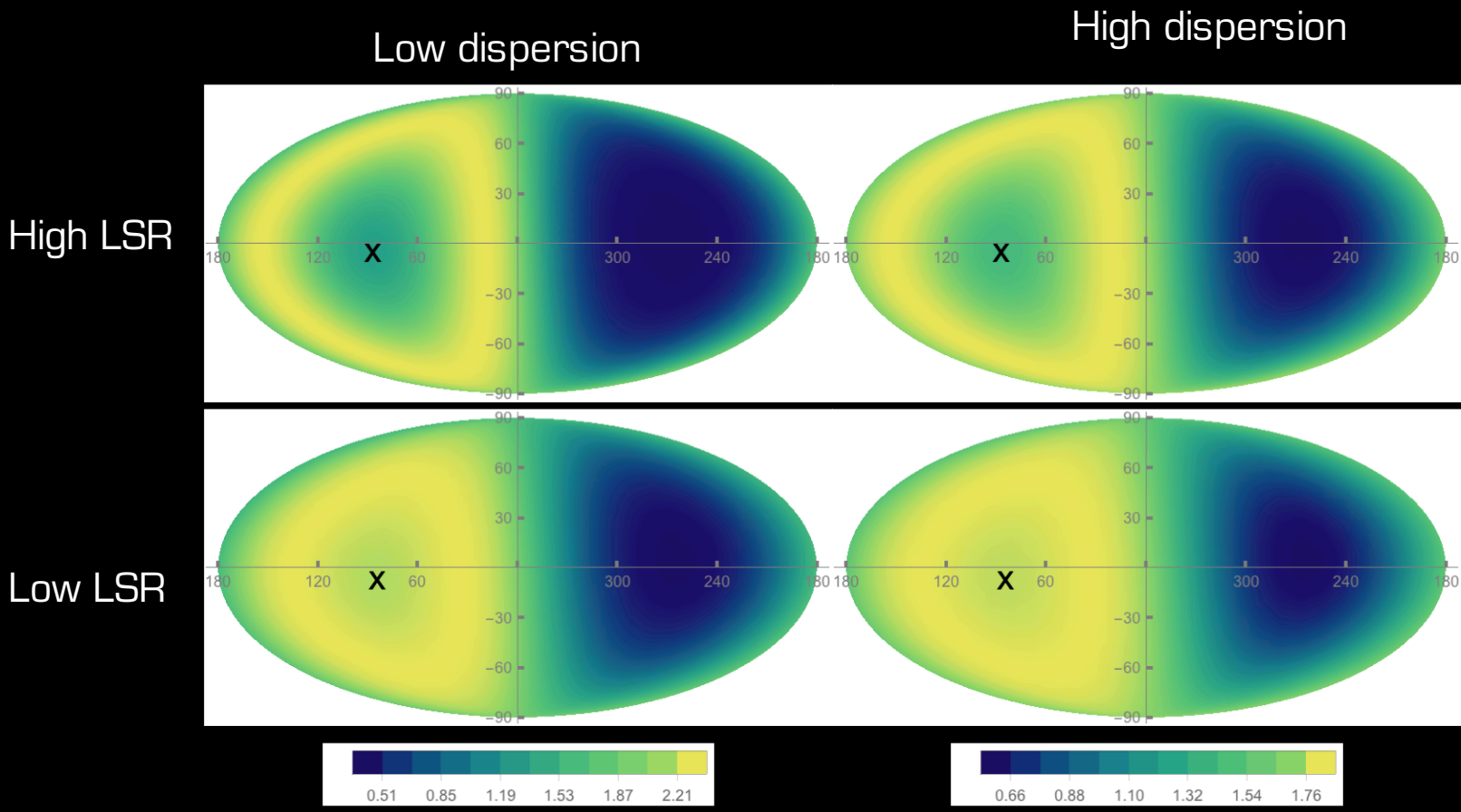
Orthogonal functions





Kavanagh & Green (several very nice papers!); plots from Peter+ 2014

Directional detection



Mayet+ 2016

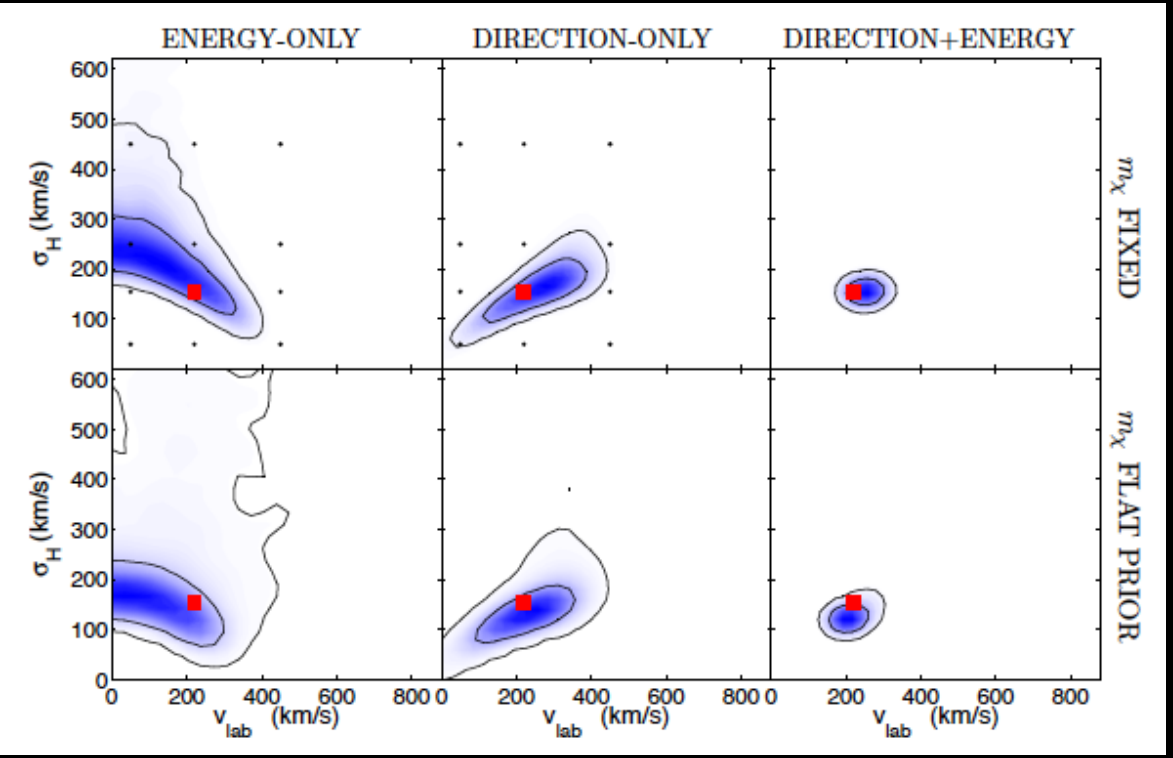
Directional detection

100 signal, 0 background events.
MIMAC-like experiment

Standard halo model input

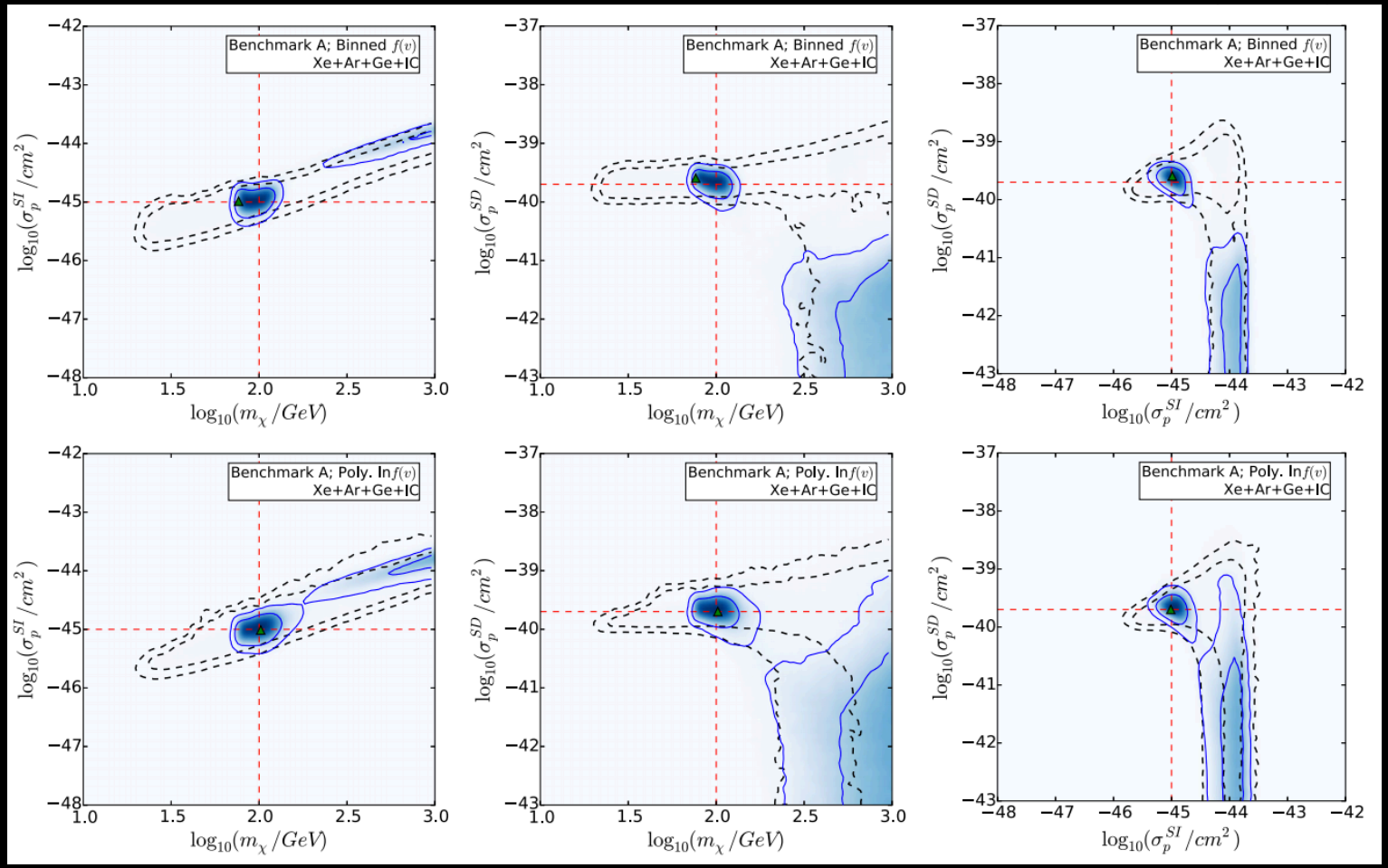
50 GeV WIMP

Fix the direction of v_{lab}



Lee & Peter 2012

Combine w/ solar WIMP searches



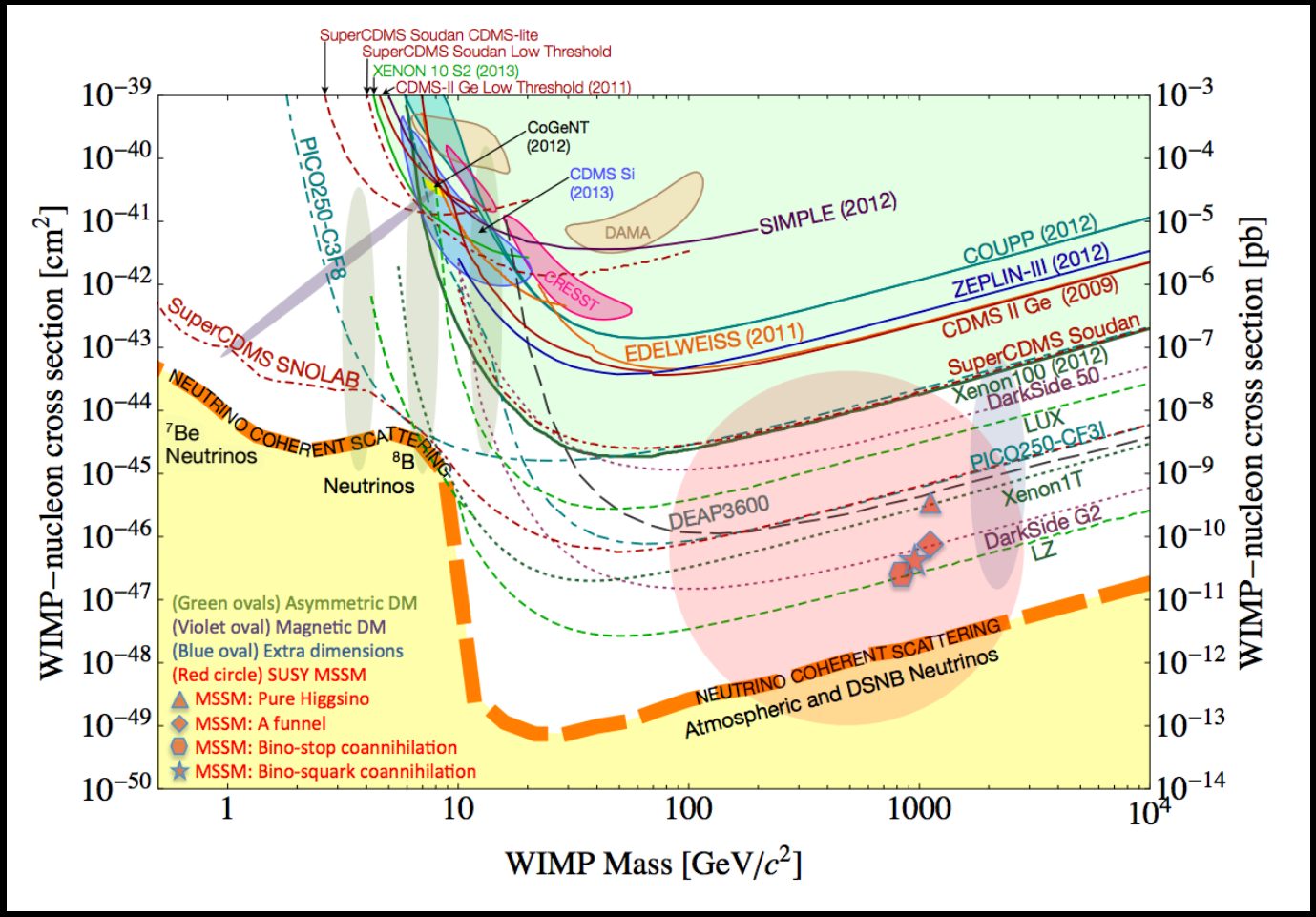
Kavanagh, Fornasa & Green 2014; see also Ferrer, Ibarra & Wild 2015

2. Beating neutrinos

“You can’t shield from neutrinos.”

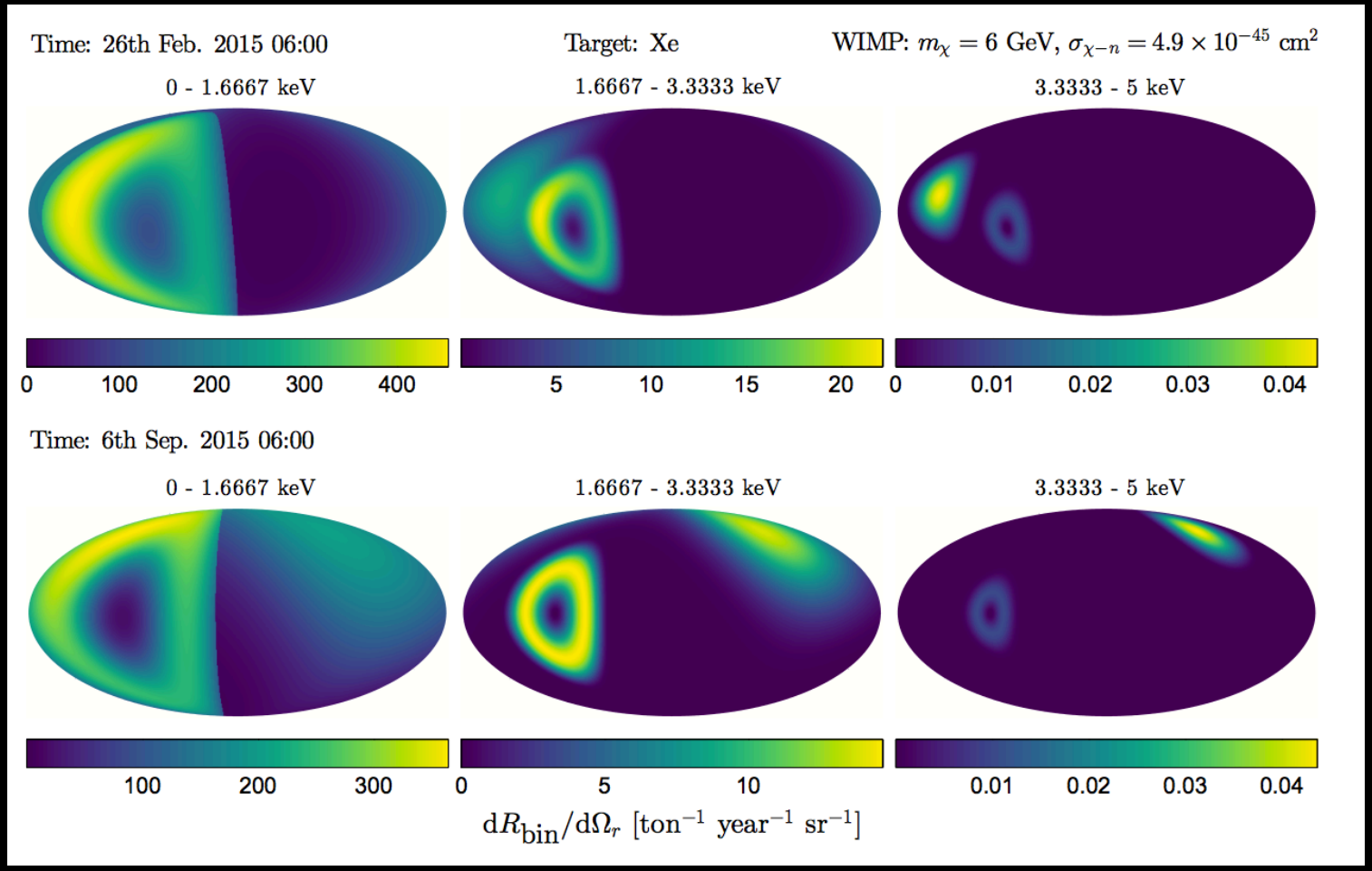
—me

“Neutrino floor”



From Cushman+ 2013, based on work by Strigari & collaborators

Beating the neutrino floor



From Mayet+ 2016 review

Conclusion

"It's better to know how to learn than to know."

---Dr. Seuss

- Data AND simulations are getting better and better.
- Parametrize your ignorance

  ---You can have your cake and eat it, too.
- **WIMP astronomy** with only ~100 events (distributed across experiments).