Neutrinos from dark matter annihilations in the Sun and the Earth

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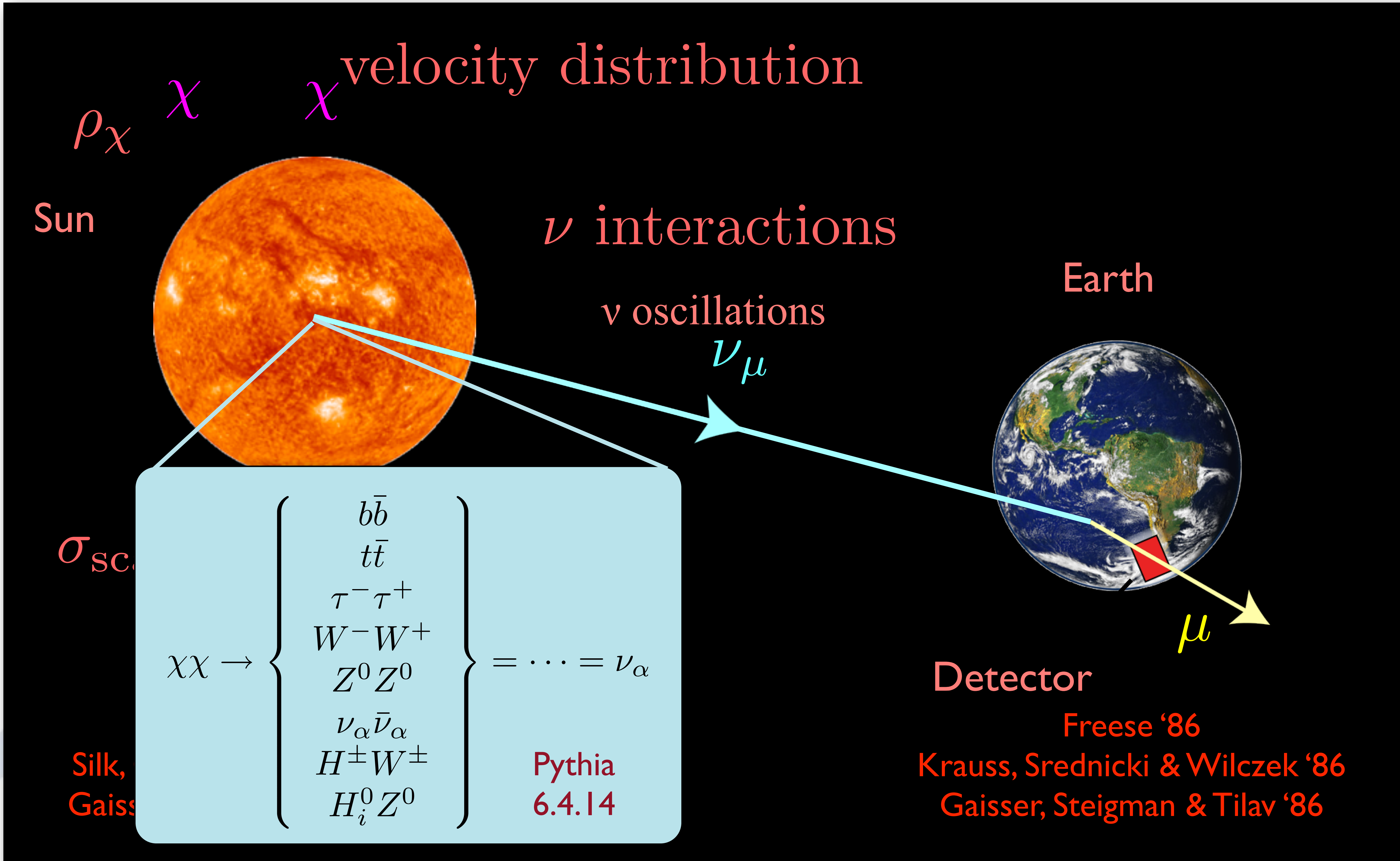
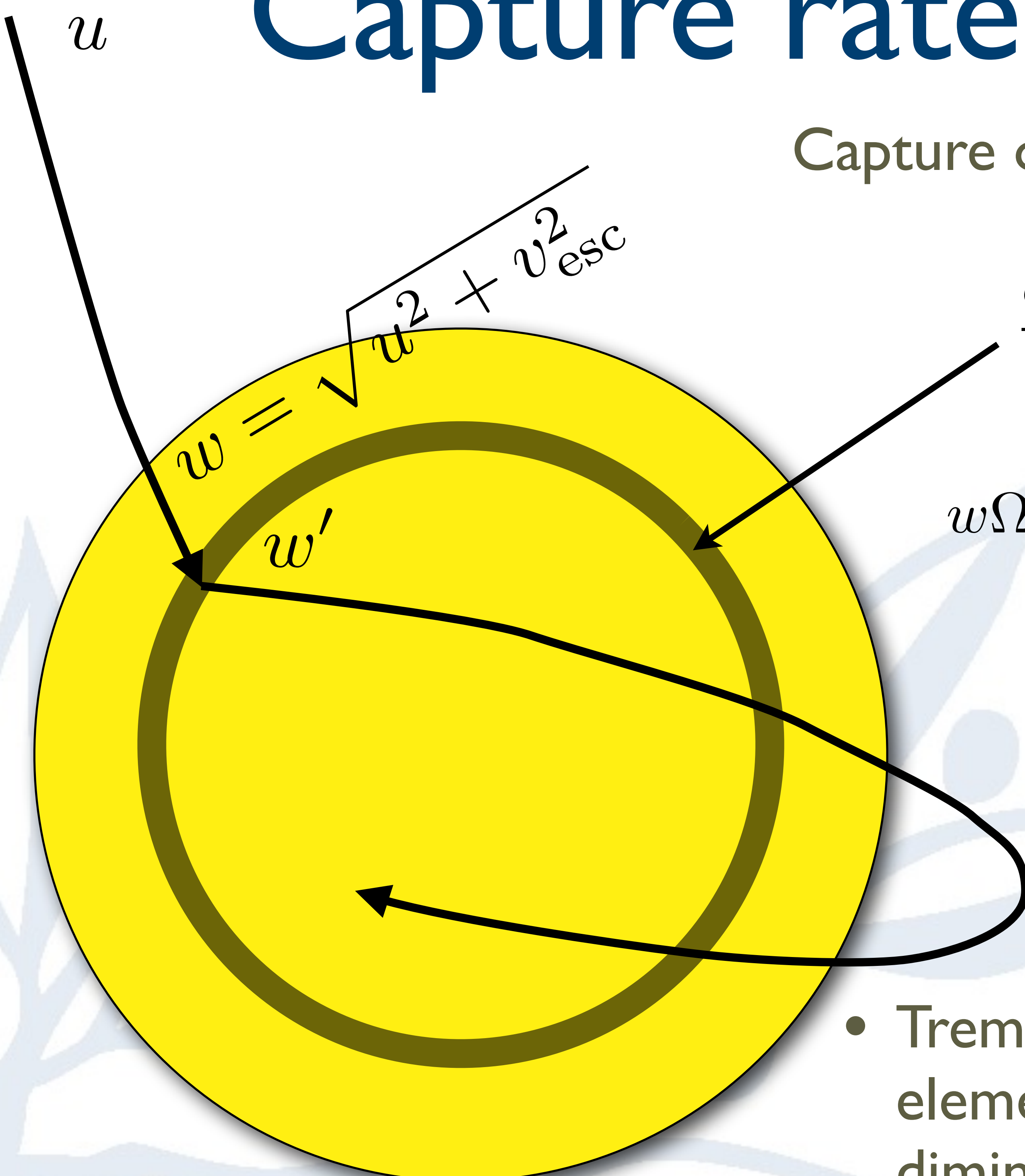
WIMP Capture



Capture rate calculation



Capture on element i in volume element

$$\frac{dC_i}{dV} = \int_0^{u_{max}} \mathrm{d}u \frac{f(u)}{u} w\Omega_{v,i}(w),$$

$$w\Omega_{v,i} \propto \sigma_{\chi i} n_i(r) P(w' < v_{\rm esc})[\text{FF suppr.}]$$

$\sim A^2$ $\sim A^2$

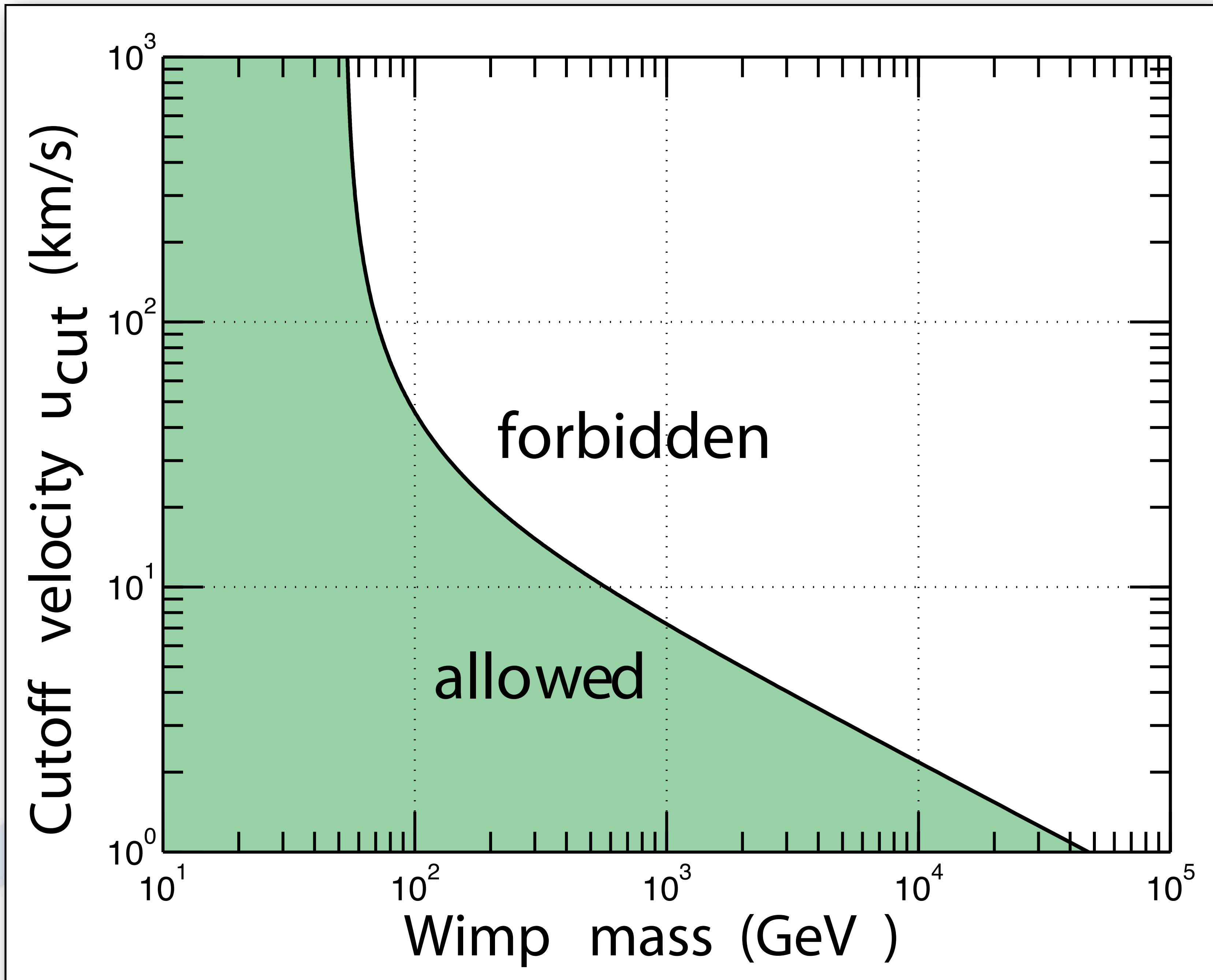
$\sim A^4$ A=atomic number

- Tremendous enhancements for heavy elements in the Sun. The form factor diminishes it somewhat though by reducing the first A^2.
- Low velocity WIMPs are easier to capture.

Earth Capture

Why are low velocities needed?

- Capture can only occur when a WIMP scatters off a nucleus to a velocity less than the escape velocity



For capture on Fe, we can only capture WIMPs if the velocity is lower than

$$u_{\rm cut} = 2\frac{\sqrt{M_\chi M_{Fe}}}{M_\chi - M_{Fe}} v_{\rm esc}$$

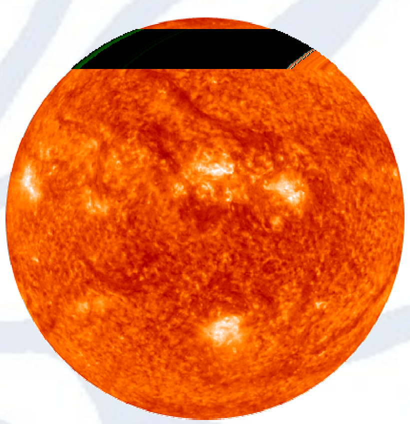
or, alternatively, for a given lowest velocity, we can only capture WIMPs up to a maximal mass.

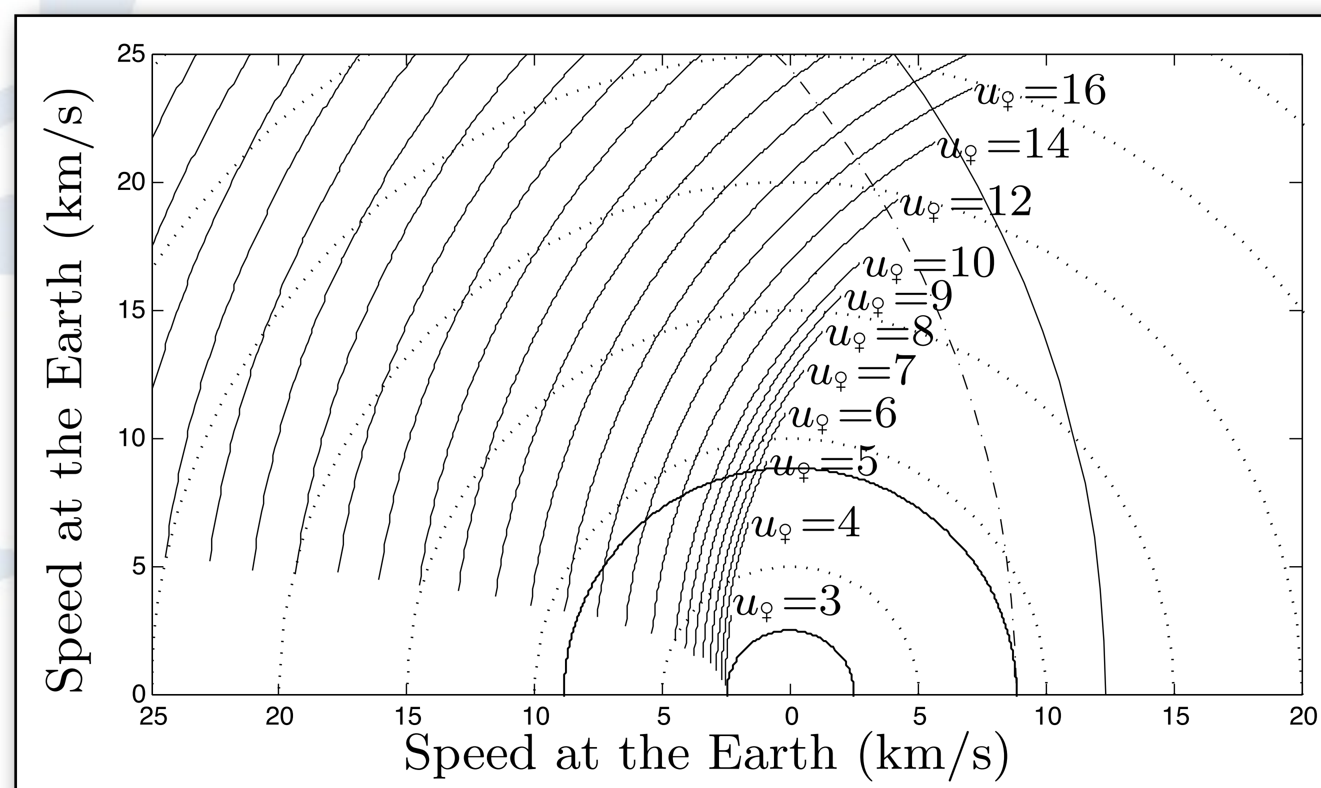
DM diffusion in the solar system

- DM particles are affected by the Sun and the planets (gravitational diffusion) in the course of being captured.
- See Gould '91, Lundberg & Edsjö '04, Peter '09 and Sivertsson & Edsjö '12 for more details

Diffusion by planets, e.g. Jupiter

- In **Jupiter**'s frame of reference: w=w'
- In the **Sun**'s frame of reference, w'≠w (since Jupiter is moving) and it could happen that w'<v_{esc}, i.e. that the WIMP is now gravitationally bound to the solar system.





Gould diffusion '91

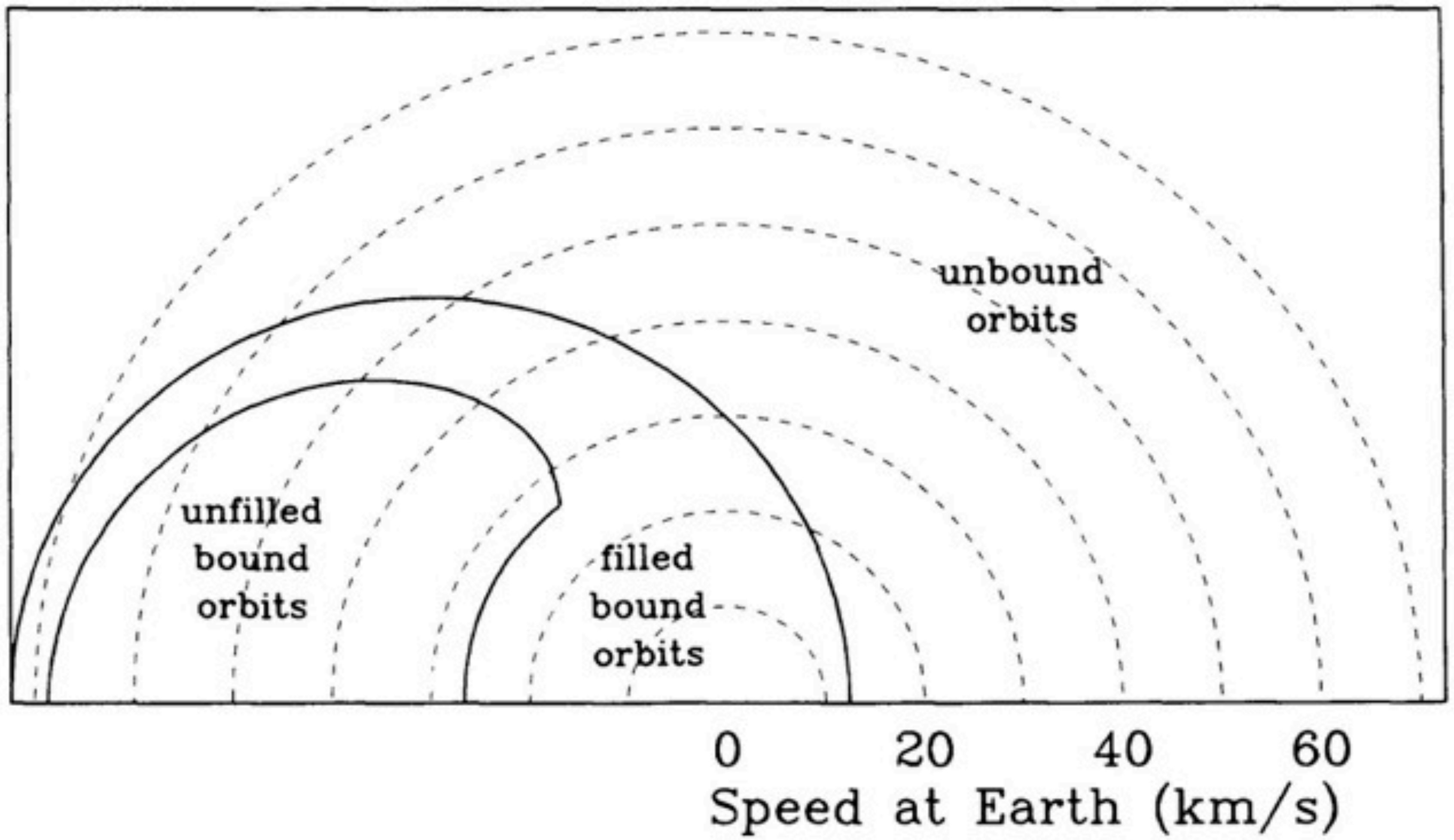
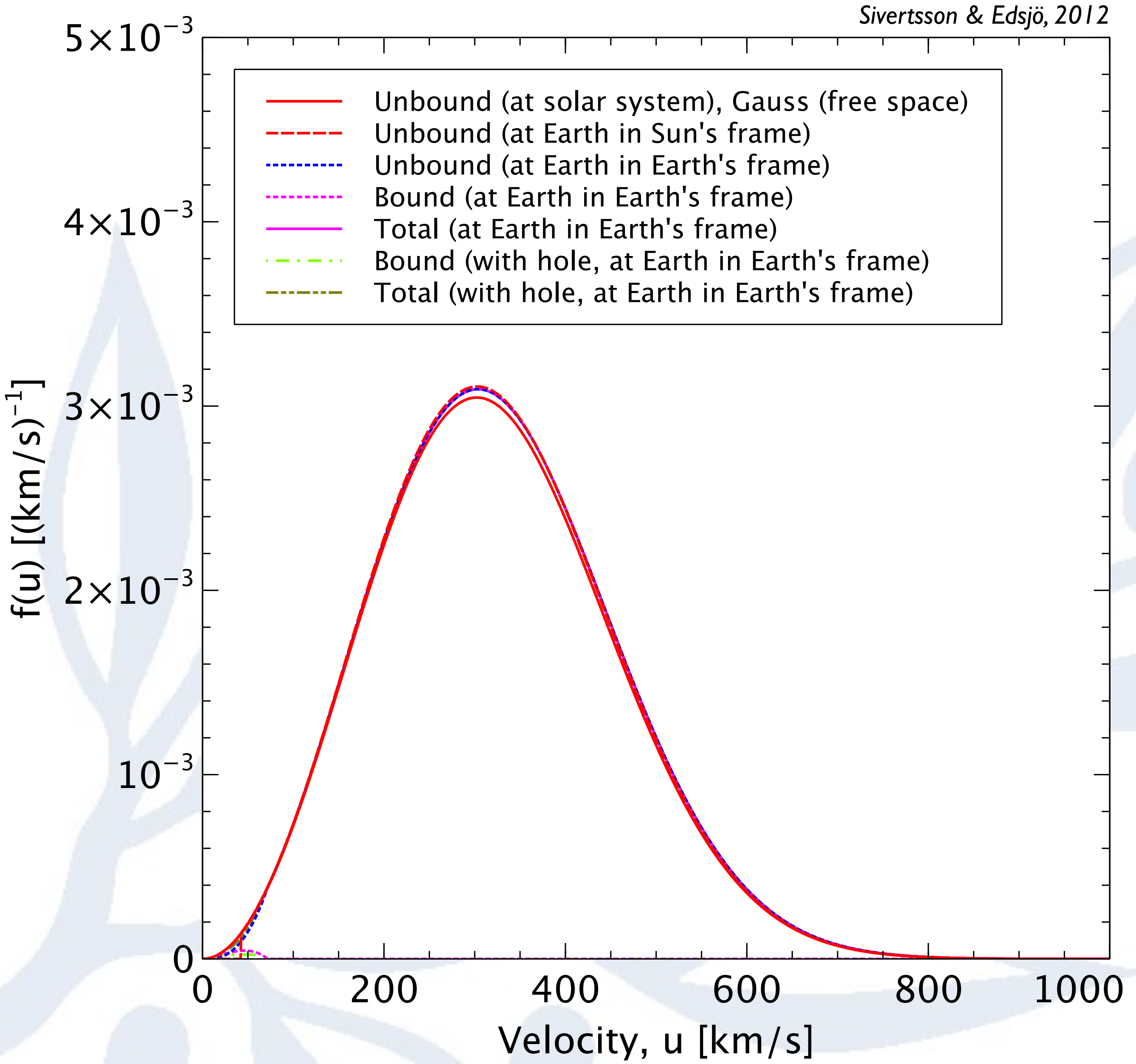
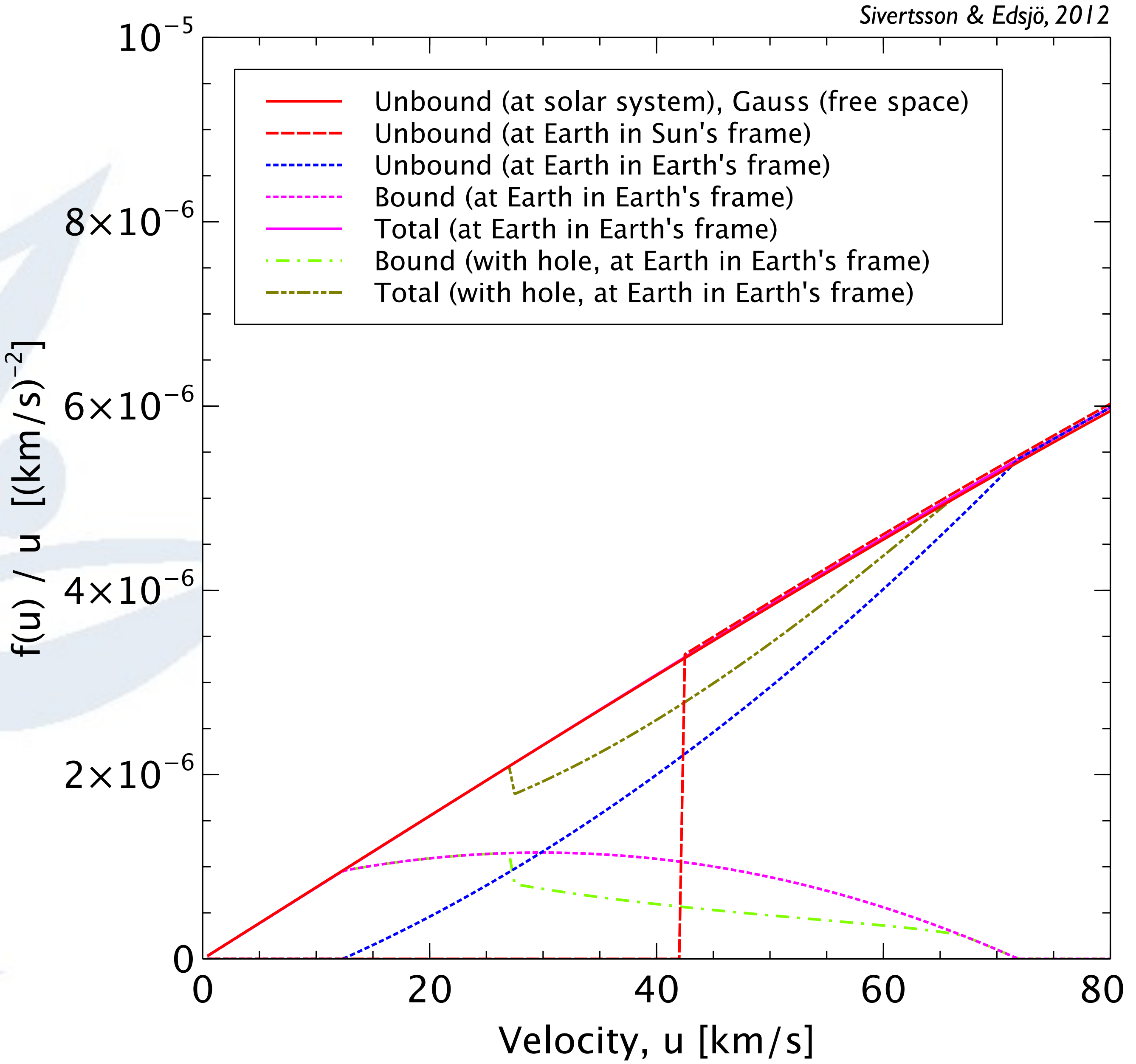


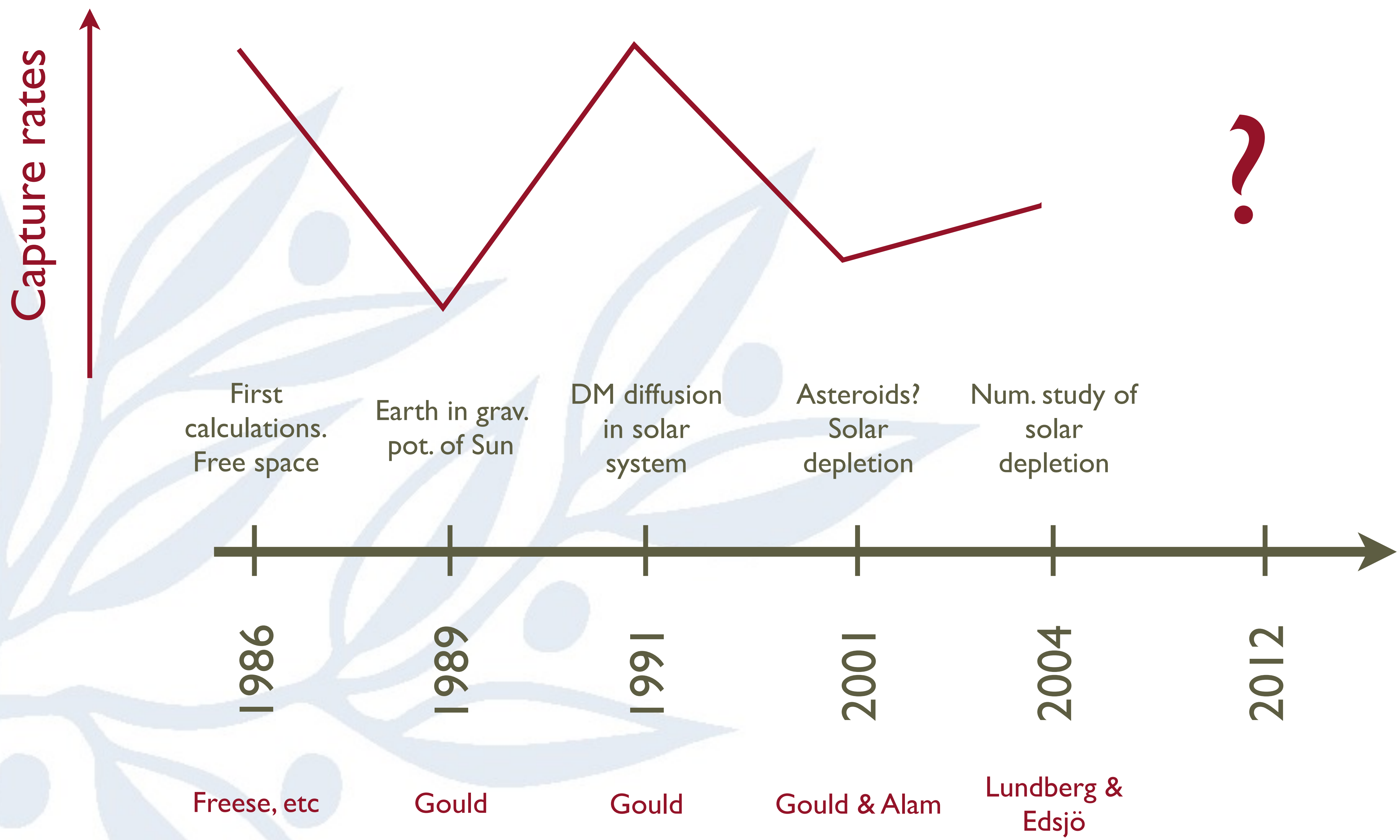
FIG. 3.—Bound and unbound low-velocity WIMPs. Dashed semicircles are curves of constant speed relative to the Earth. The solid semicircle delimits the bound from the unbound orbits, and the solid contour encloses the region of orbits which remain empty over an Earth lifetime. Note that for any given "cutoff velocity," the phase space inside the corresponding semicircle is mostly populated.

Velocity distributions





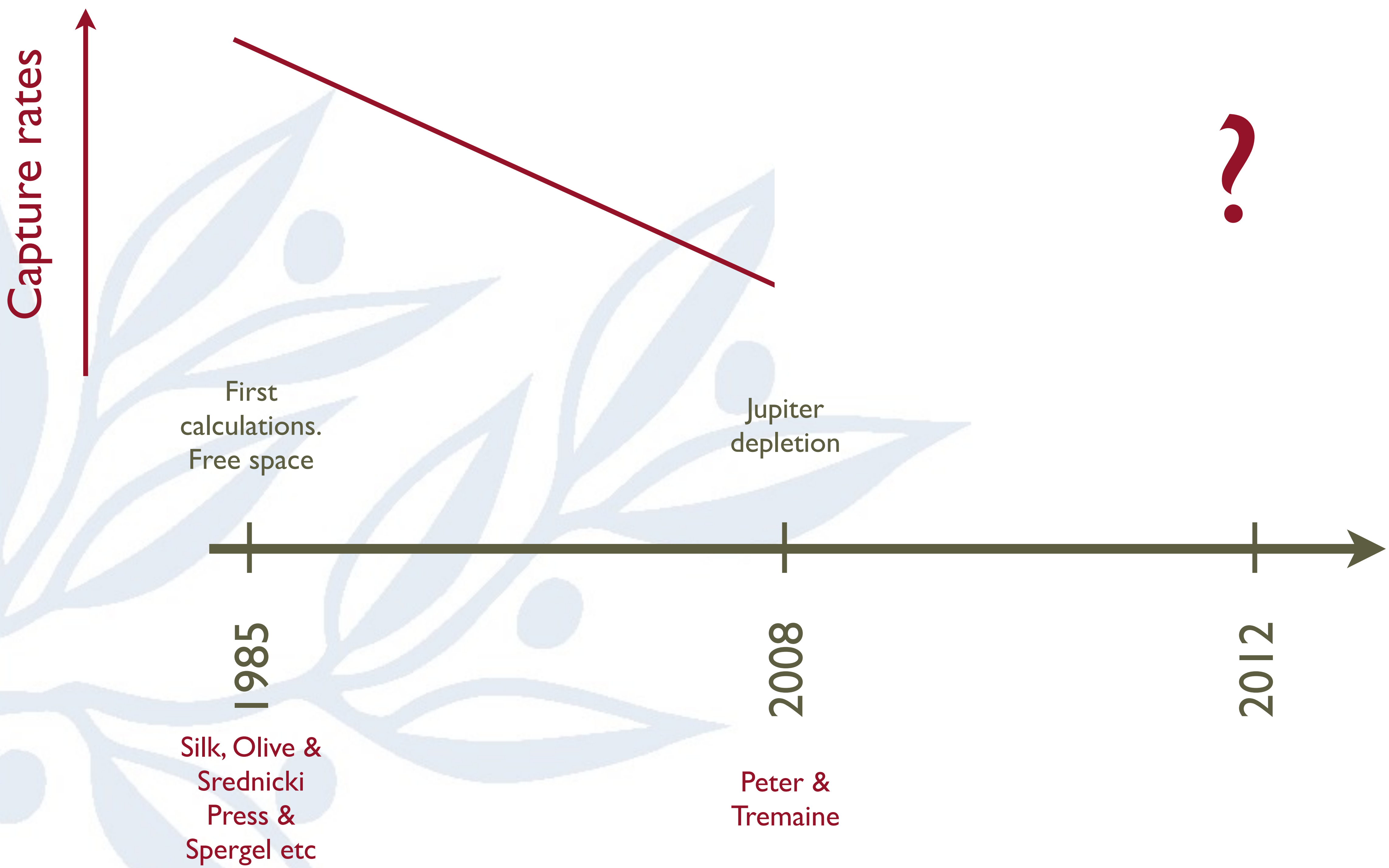
History of Earth capture



Jupiter effects on solar capture

- Traditionally, if a WIMP scatters to below the escape velocity (at that point in the Sun), it is considered captured.
- Peter & Tremaine showed that if the WIMP after its first scatter reaches out to Jupiter, Jupiter can disturb the orbit so that it no longer passes through the Sun and eventually gets thrown out of the solar system.
- They found that this reduces the solar capture rate, especially for heavy WIMPs

History of Sun capture



New analytical treatment
(supported by numerical simulations)

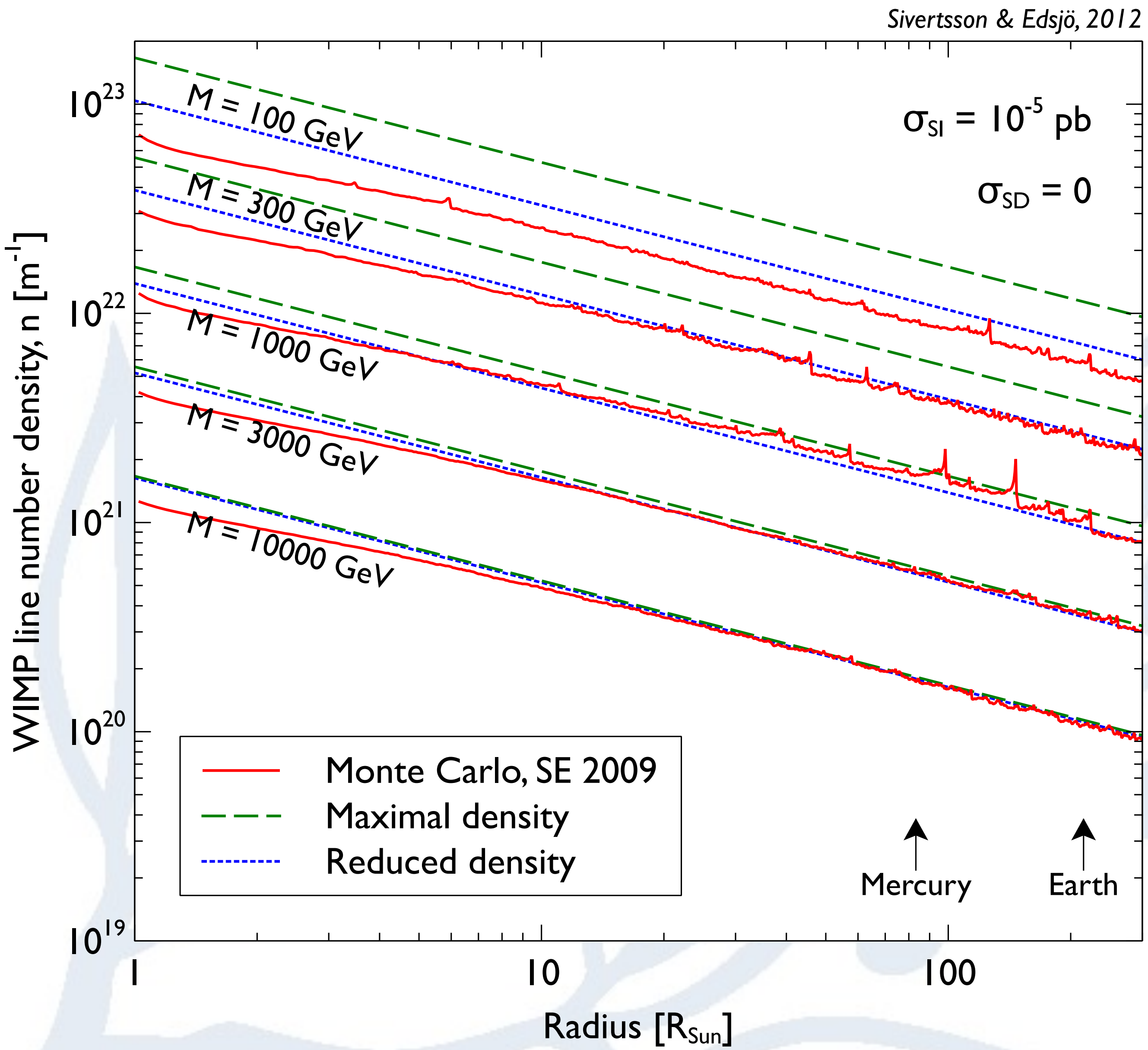
- New insight:

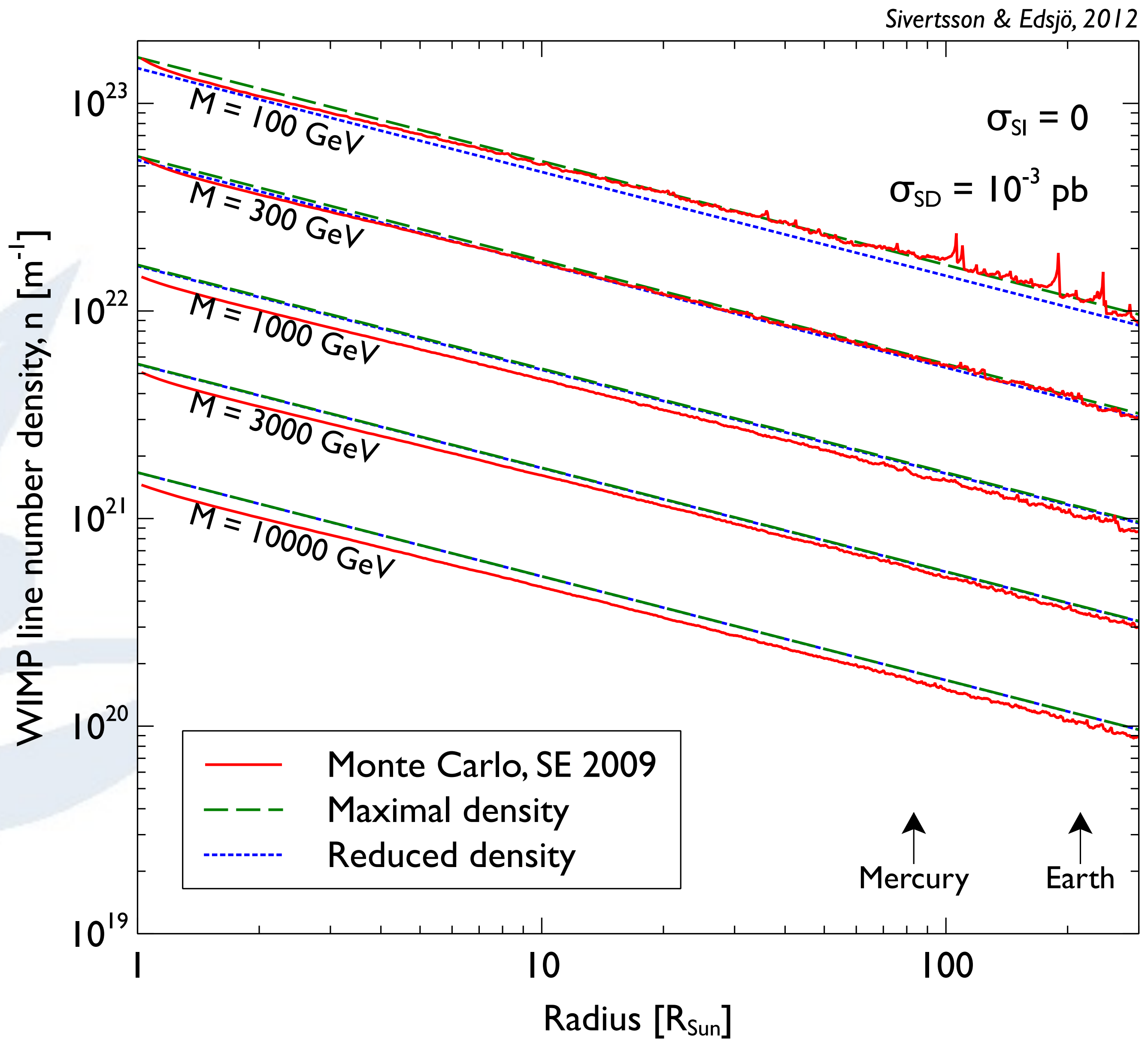
  WIMP scatterings in the Sun from the galactic halo approximately follows Liouville's theorem, meaning that the phase space density of bound WIMPs in this population matches the density from the gravitationally diffused WIMPs

- Will affect both Earth and Sun capture rates

Sivertsson & Edsjö, arXiv: 1201:1895, PRD to appear

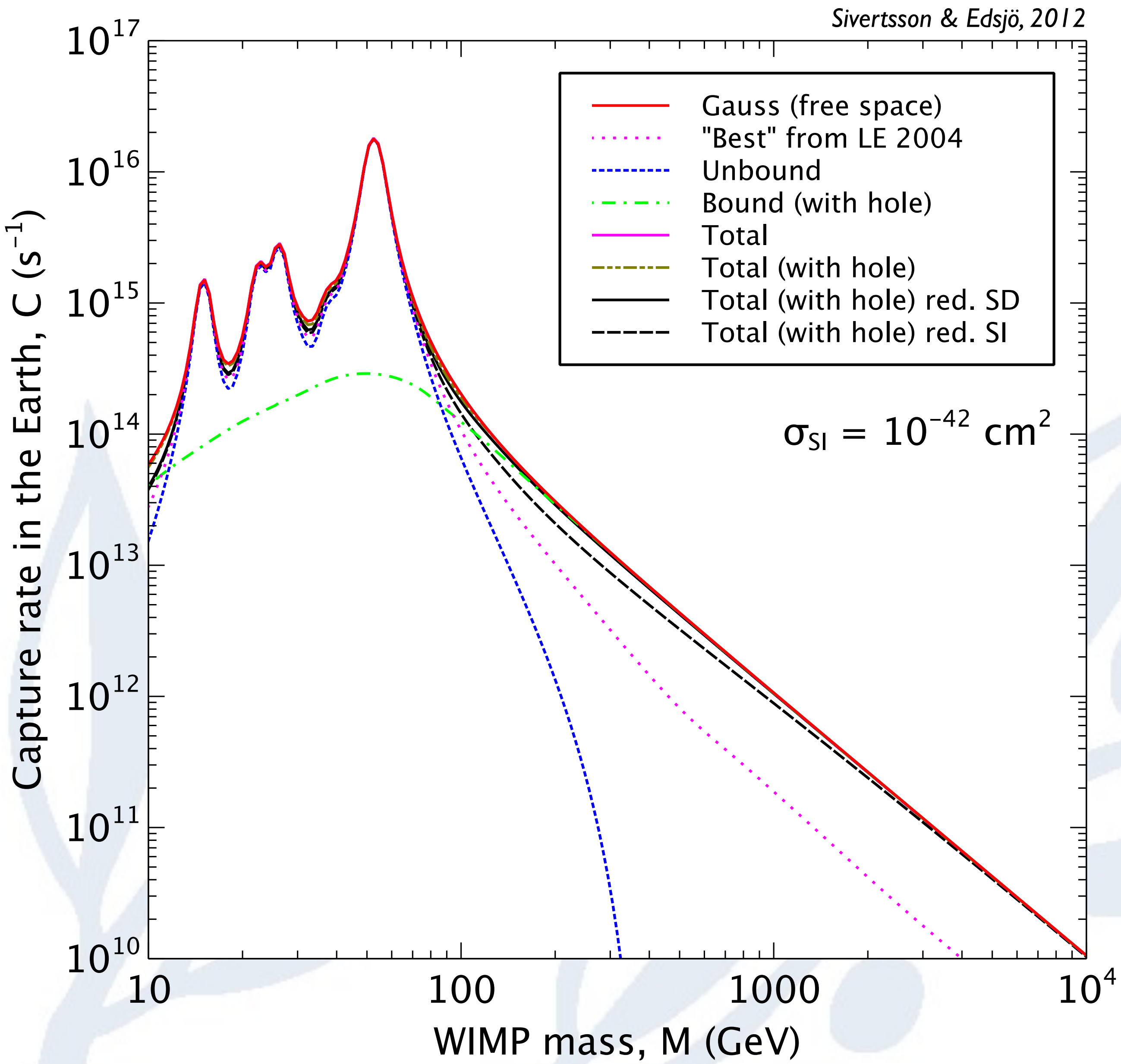
Densities from weak capture in the Sun

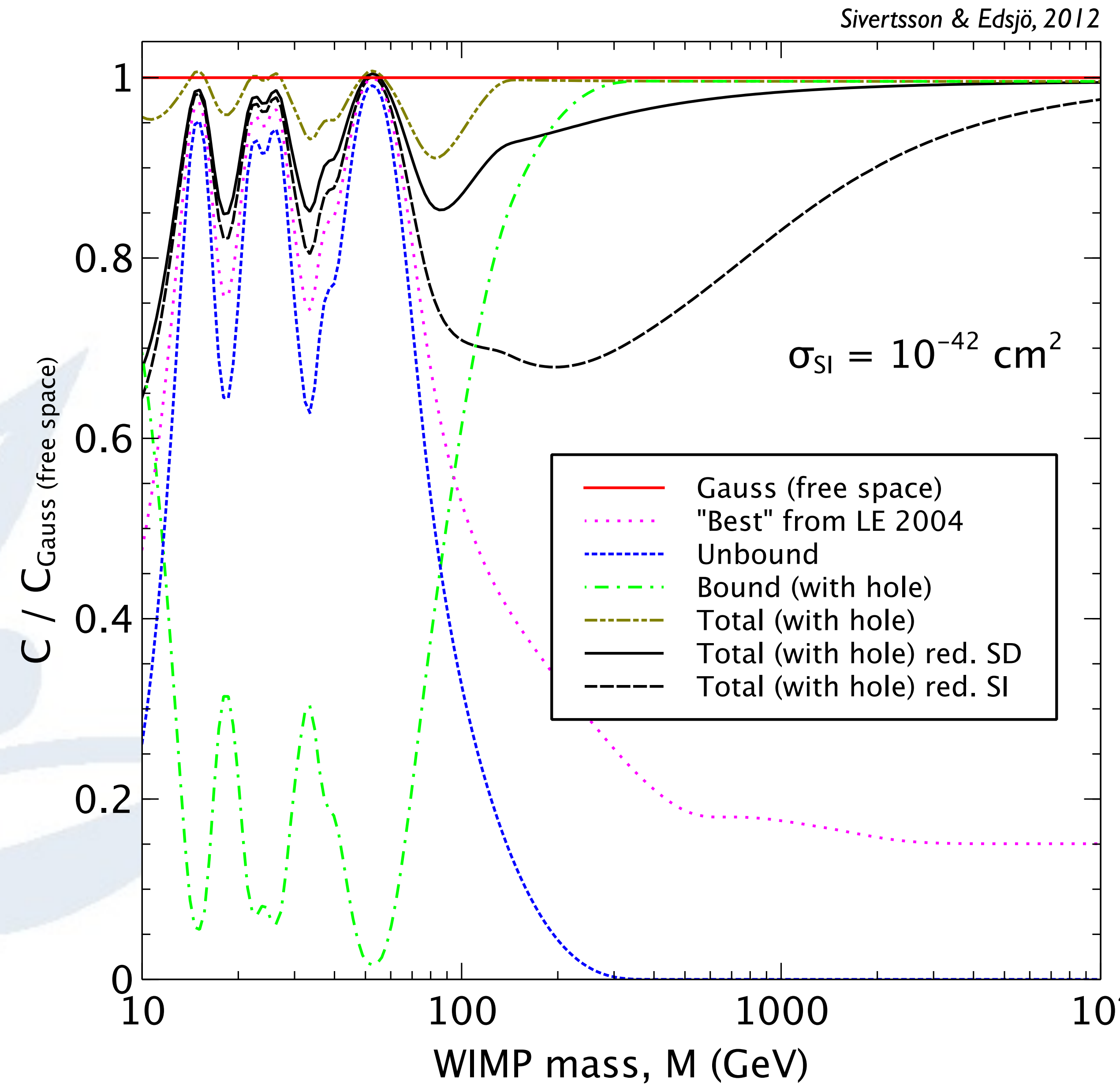




For a standard Gaussian distribution

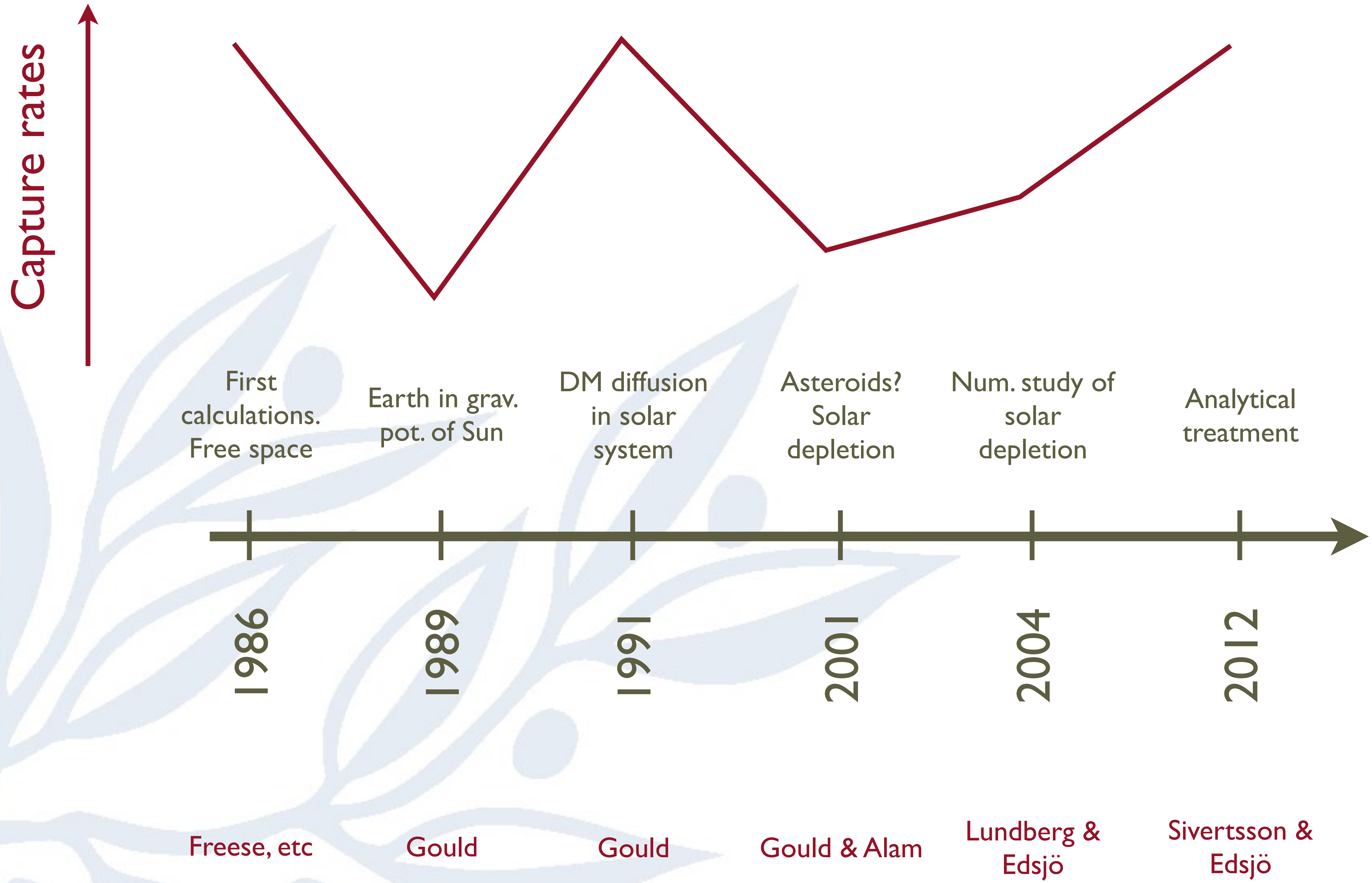
Capture rates in the Earth





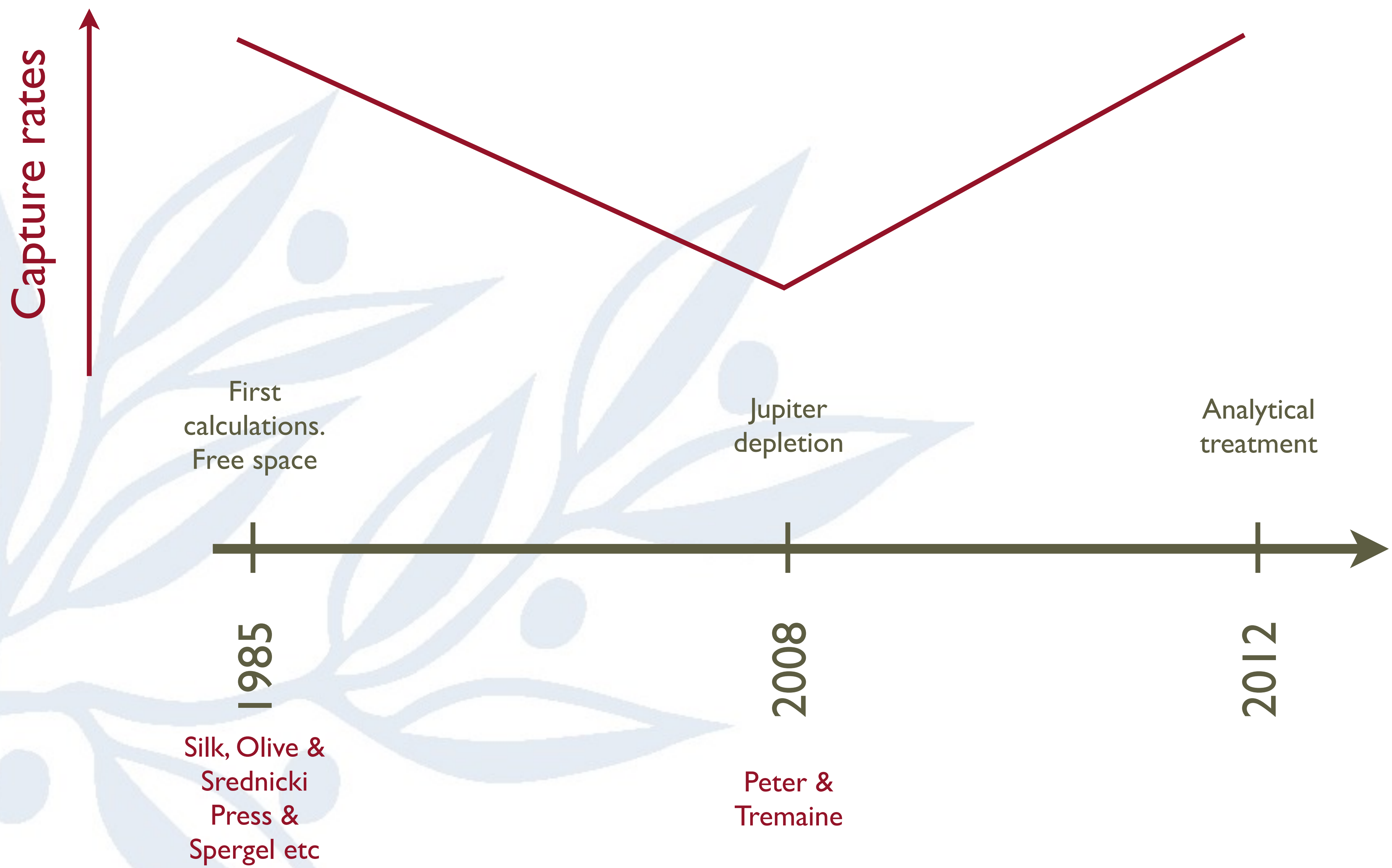
The reduced curves indicate how much the densities at most can be reduced (for a Gaussian) due to weak capture sampling the whole velocity distribution and not only the low-velocity part as gravitational diffusion does.

History of Earth capture



Also: Damour-Krauss population cannot exist

History of Sun capture



Summary of diffusion

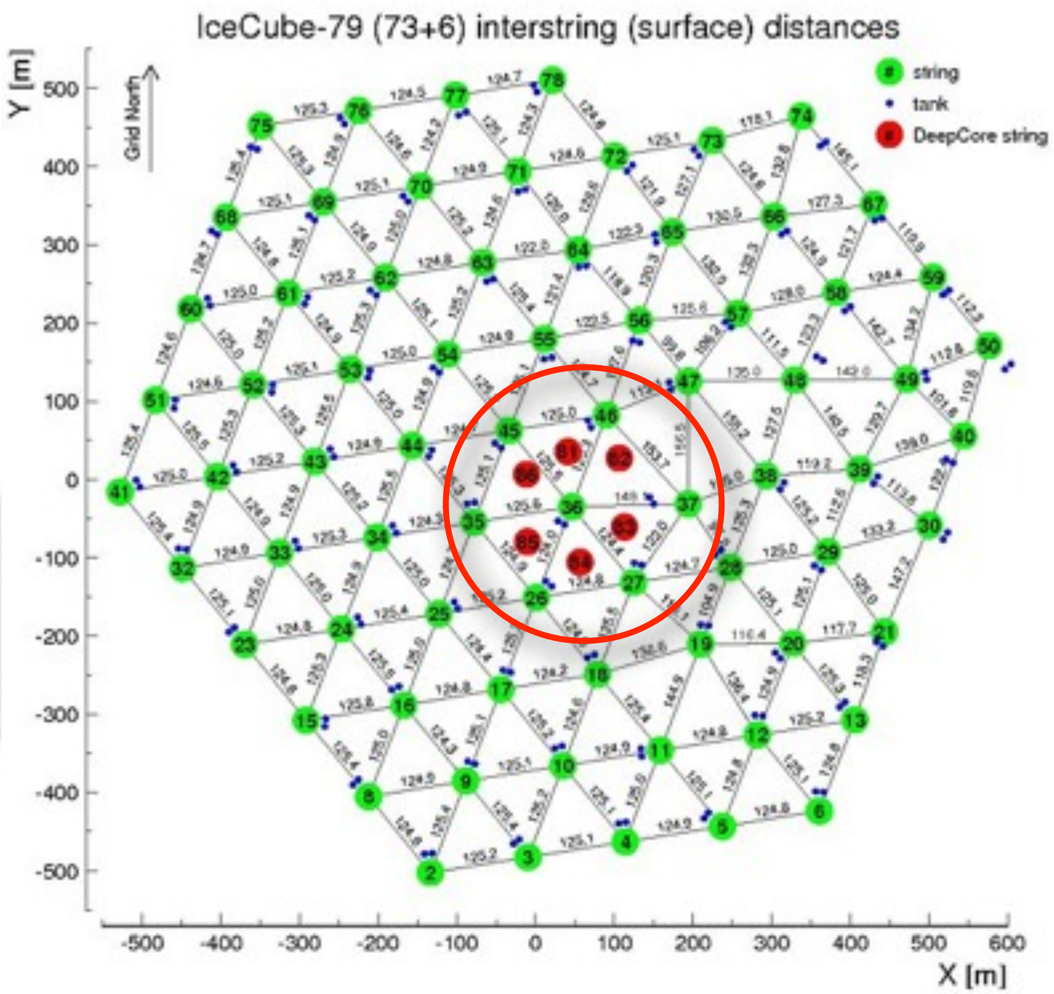
- Jupiter depletion (for the Sun) not important. The depleted WIMPs are refilled from the halo
- Solar depletion (for the Earth) not important. The depleted WIMPs are refilled from scatterings of halo WIMPs in the Sun.
- Simple approximations as if Sun/Earth in free space (à la Gould '91) roughly OK.

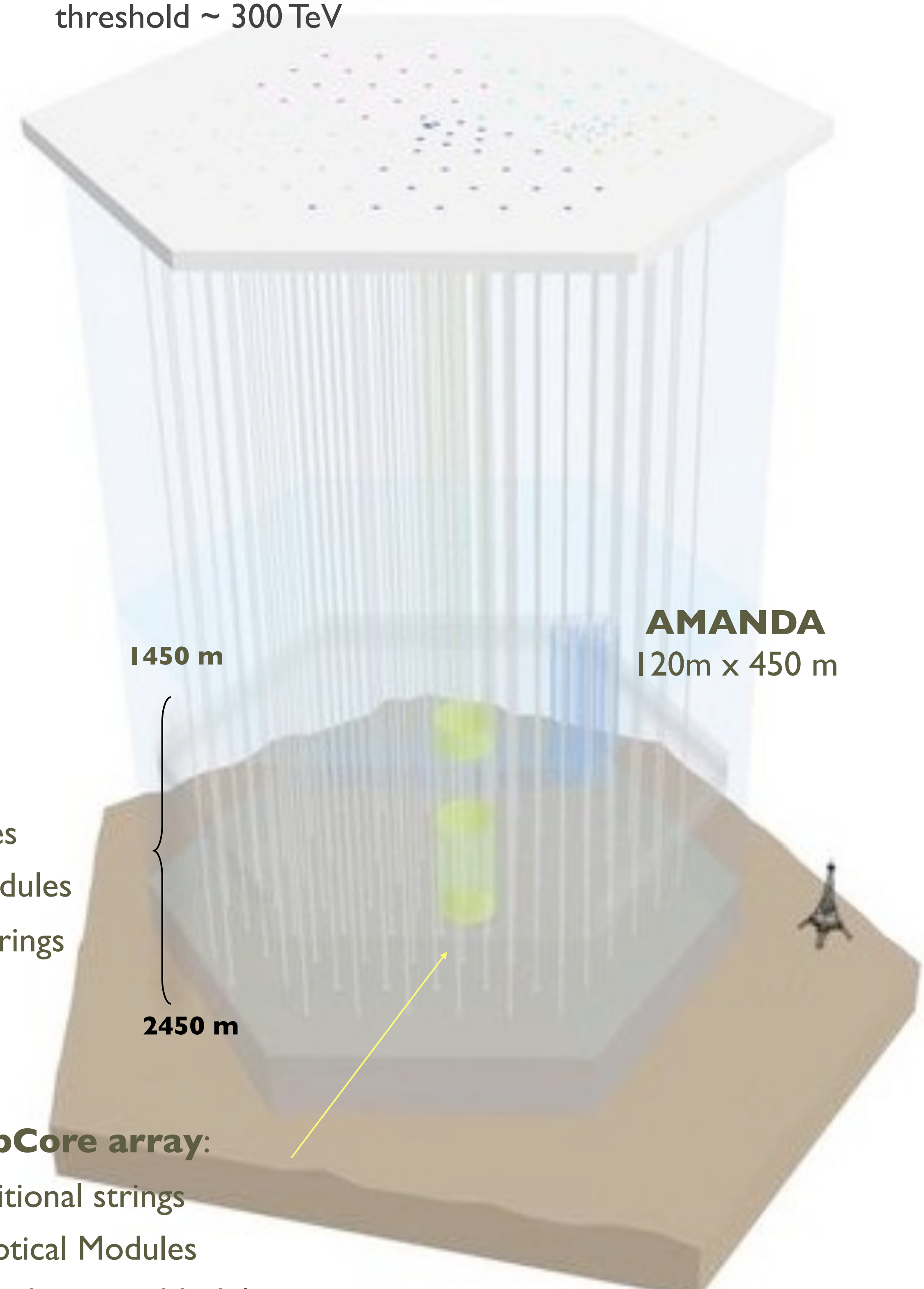
The IceCube Detector

IceTop: Air shower detector

80 stations/2 tanks each

threshold ~ 300 TeV





AMANDA

120m x 450 m

InIce array:

80 Strings

60 Optical Modules

17 m between Modules

125 m between Strings

DeepCore array:

6 additional strings

60 Optical Modules

7/10 m between Modules

72 m between Strings

IceCube complete - Dec 18 2010

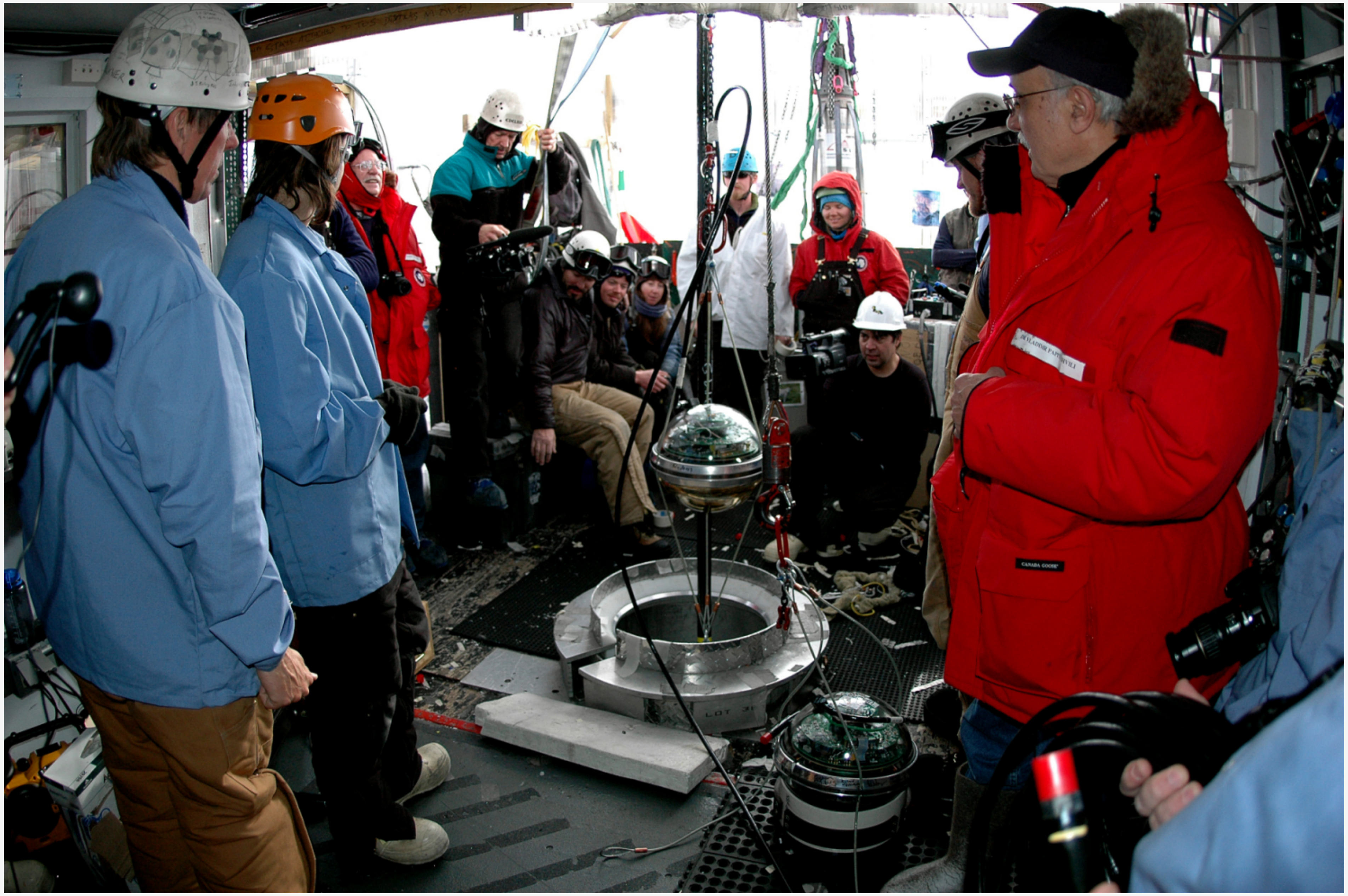
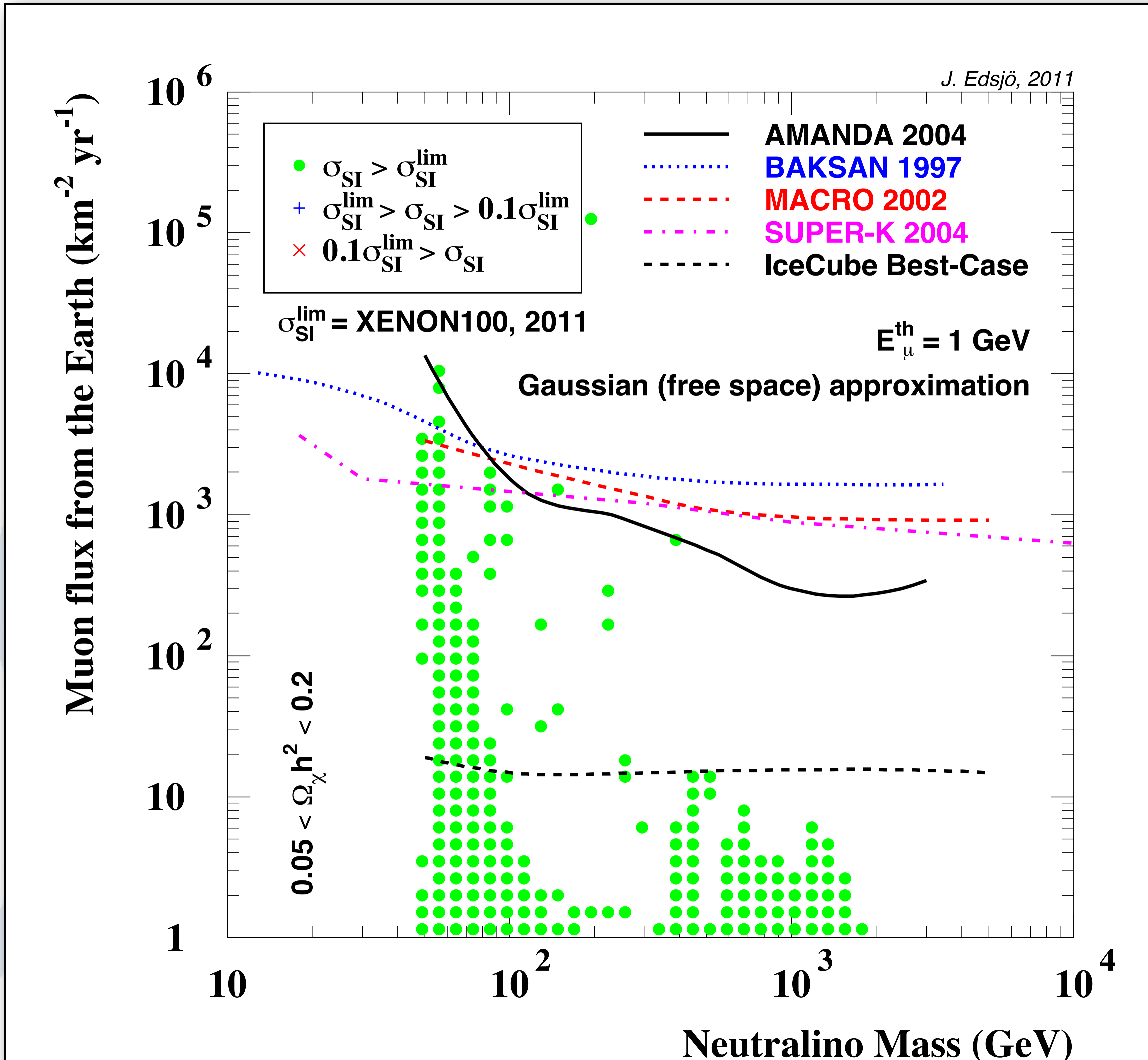


Photo: P. Rejcek, NSF

IceCube collaboration 33 institutions worldwide w. ~250 scientists

Neutrino-induced muon fluxes from the Earth

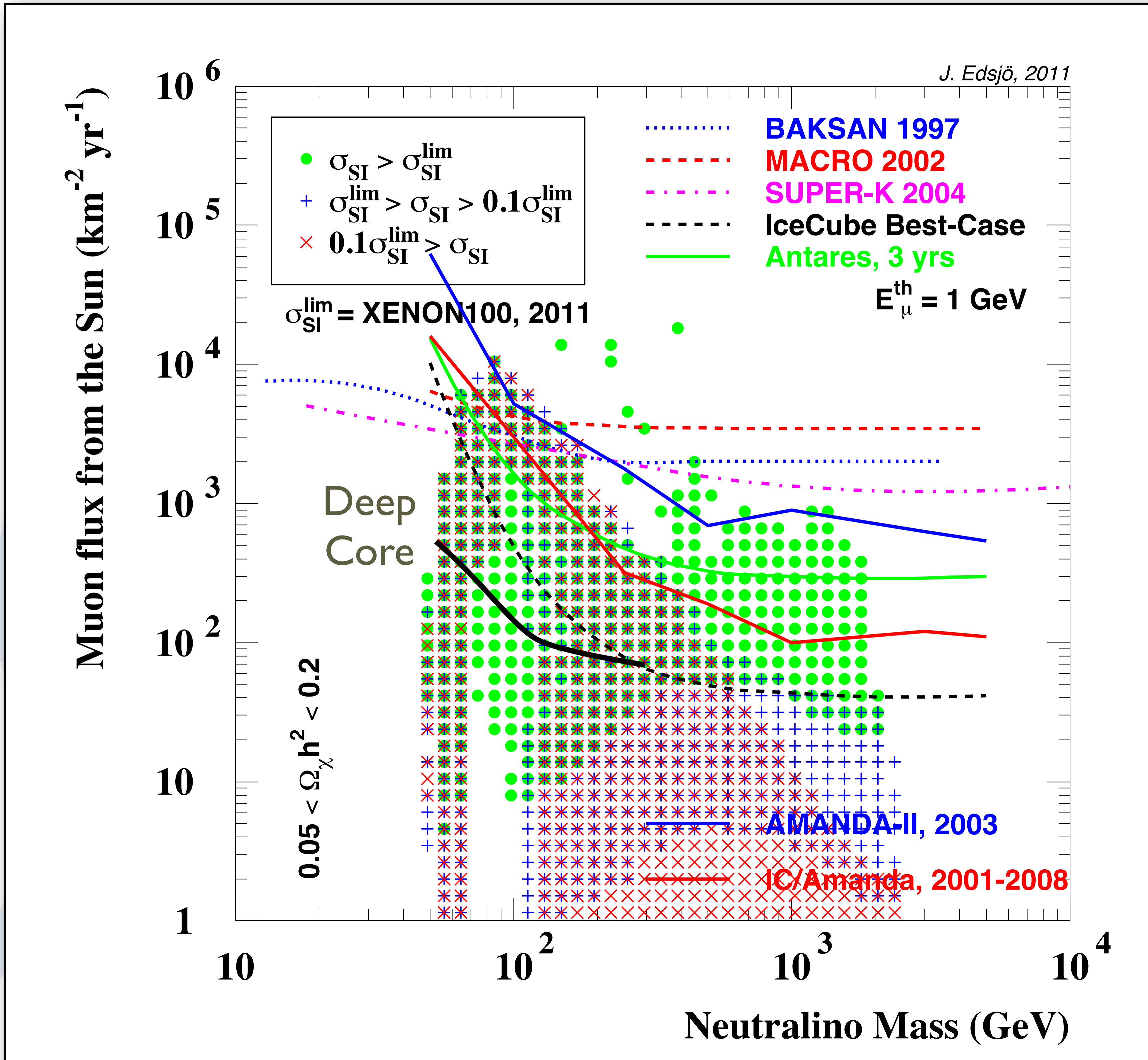


- Direct detection and the neutrino signal from the Earth are both sensitive to the spin-independent scattering cross section

- Large correlation

Dark disk not included

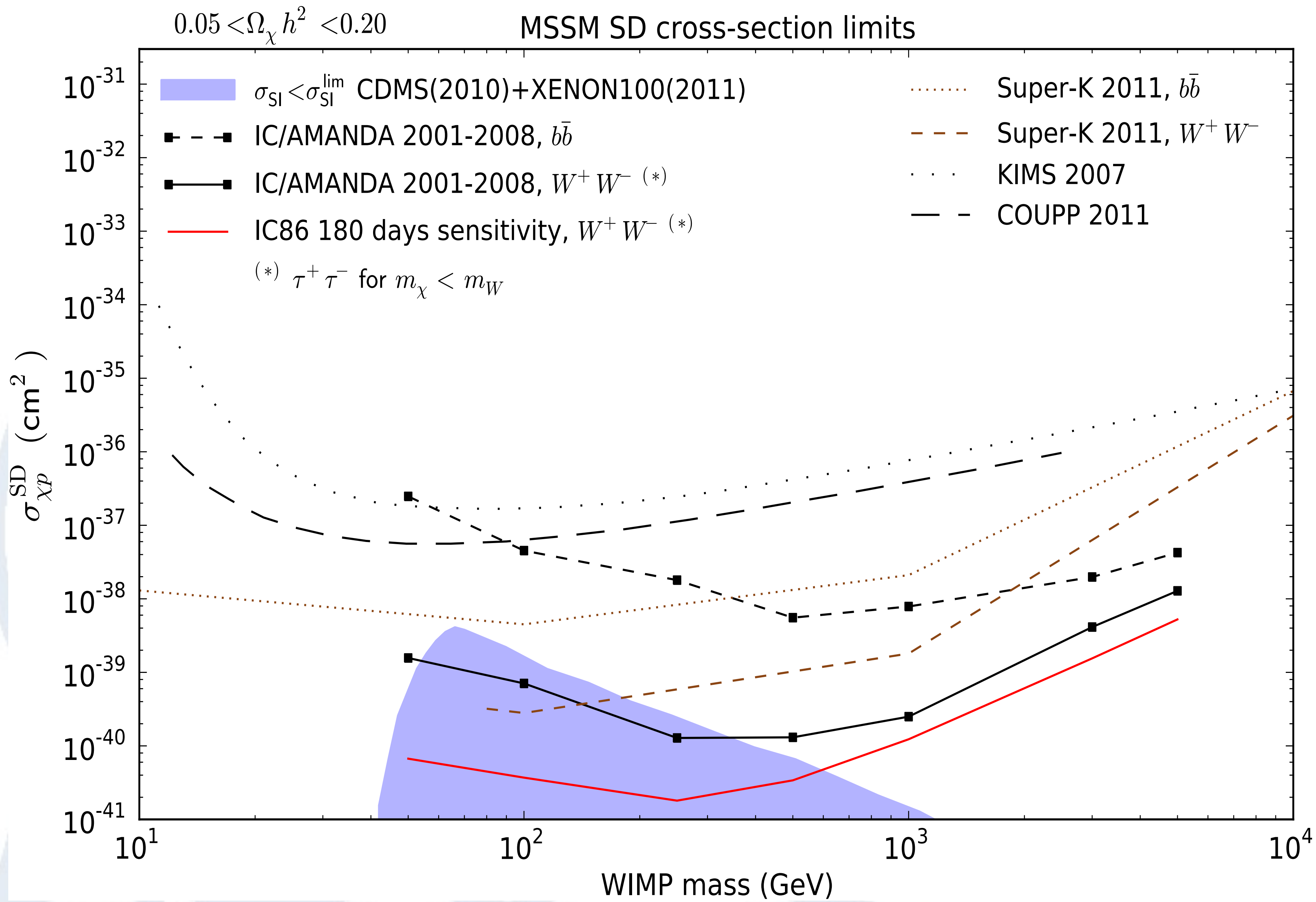
Neutrino-induced muon fluxes from the Sun



- Compared to the Earth, much better complementarity due to spin-dependent capture in the Sun.

Dark disk not included

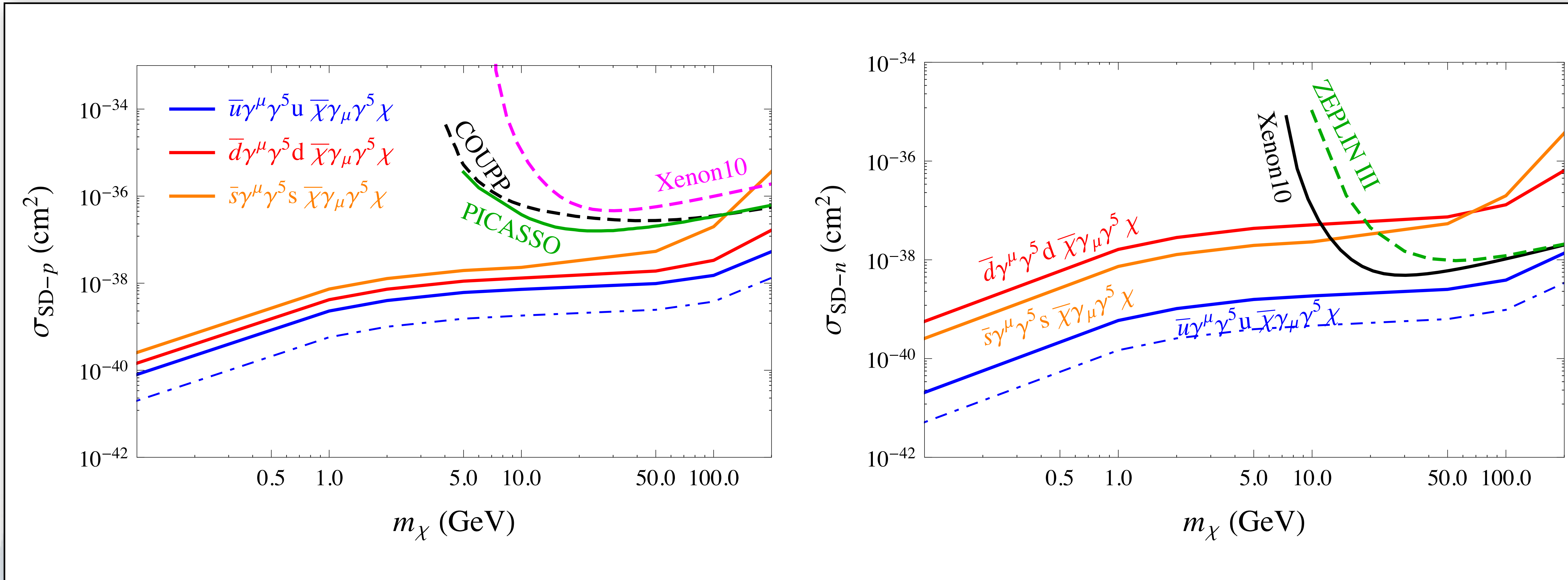
Complementarity between neutrino detectors and direct detection



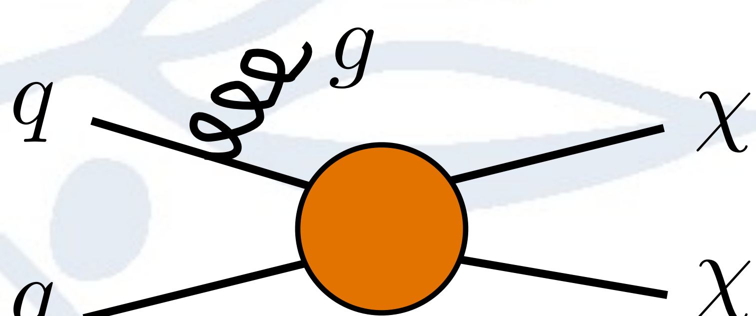
IceCube, arXiv:1112.1840
Wikström & Edsjö, arXiv:0903.2986,
see also Serpico & Bertone, arXiv:1006.3268, where relative uncertainties are studied (~factor of two)

- As neutralino capture in the Sun is very efficient for SD scattering, we can place a limit on the SD scattering cross section with neutrino telescopes
- The limits are very competitive compared to direct searches

Tevatron limits

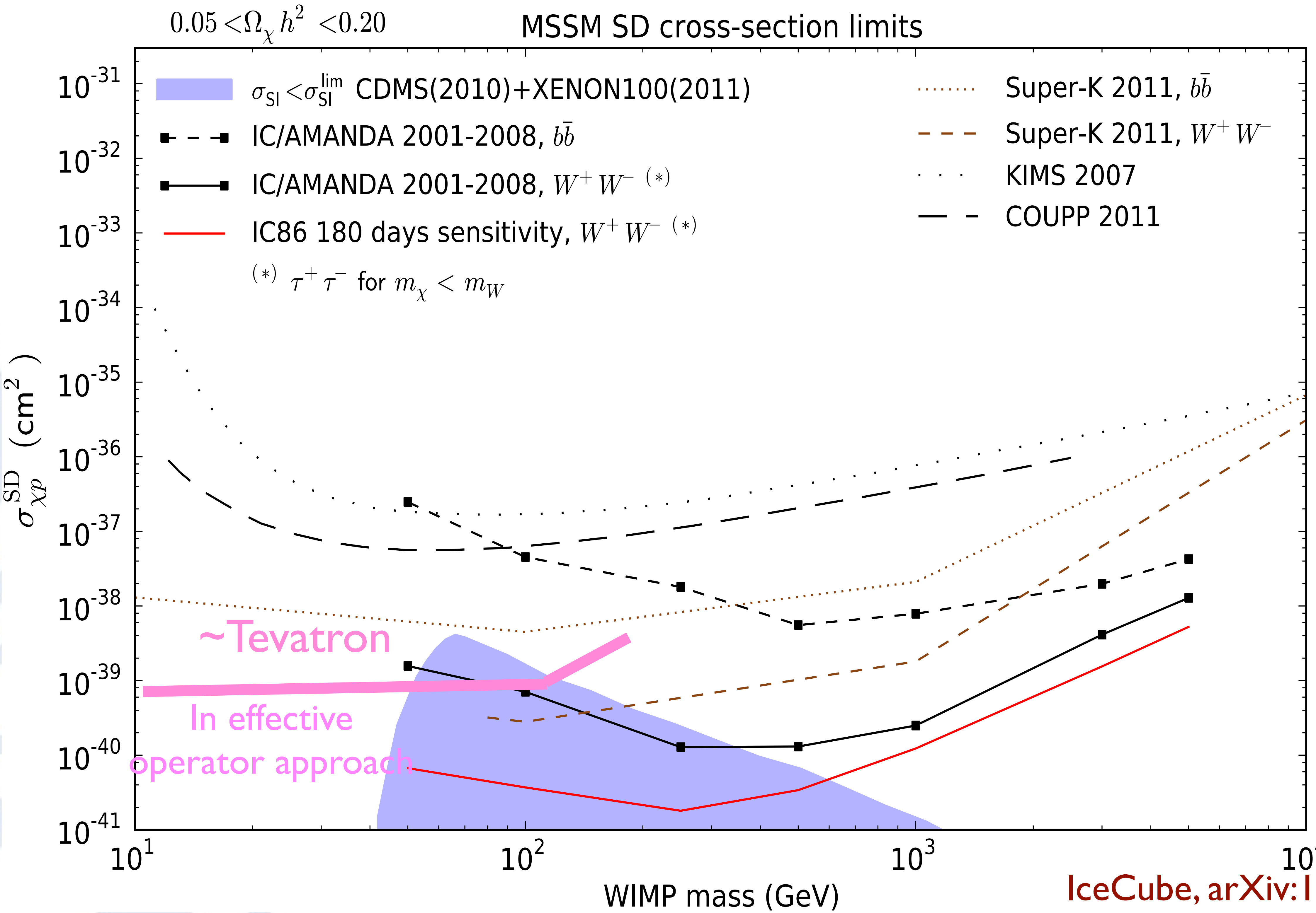


- SD scattering probes WIMP-proton(neutron) coupling. This is the same coupling that appears in p-p-colliders, for WIMP production. The experimental signature is a monojet, arising from initial state radiation



Bai, Fox & Harnik, arXiv:1005.3797.
See also Goodman et al, arXiv:1005.1286
Fox et al, arXiv:1109.4398

Complementarity between neutrino detectors, direct detection and Tevatron



IceCube, arXiv:1112.1840

Effects of dark disk

- It has been suggested (Read et al, '08) that as massive satellites fall into the Milky Way, their dark matter preferentially ends up in a dark disk, co-rotating with the stars
- If so, these dark matter particles move slowly with respect to the solar system, and are easier to capture (both by the Sun and by the solar system via gravitational diffusion) than regular halo dark matter

Dark disk model

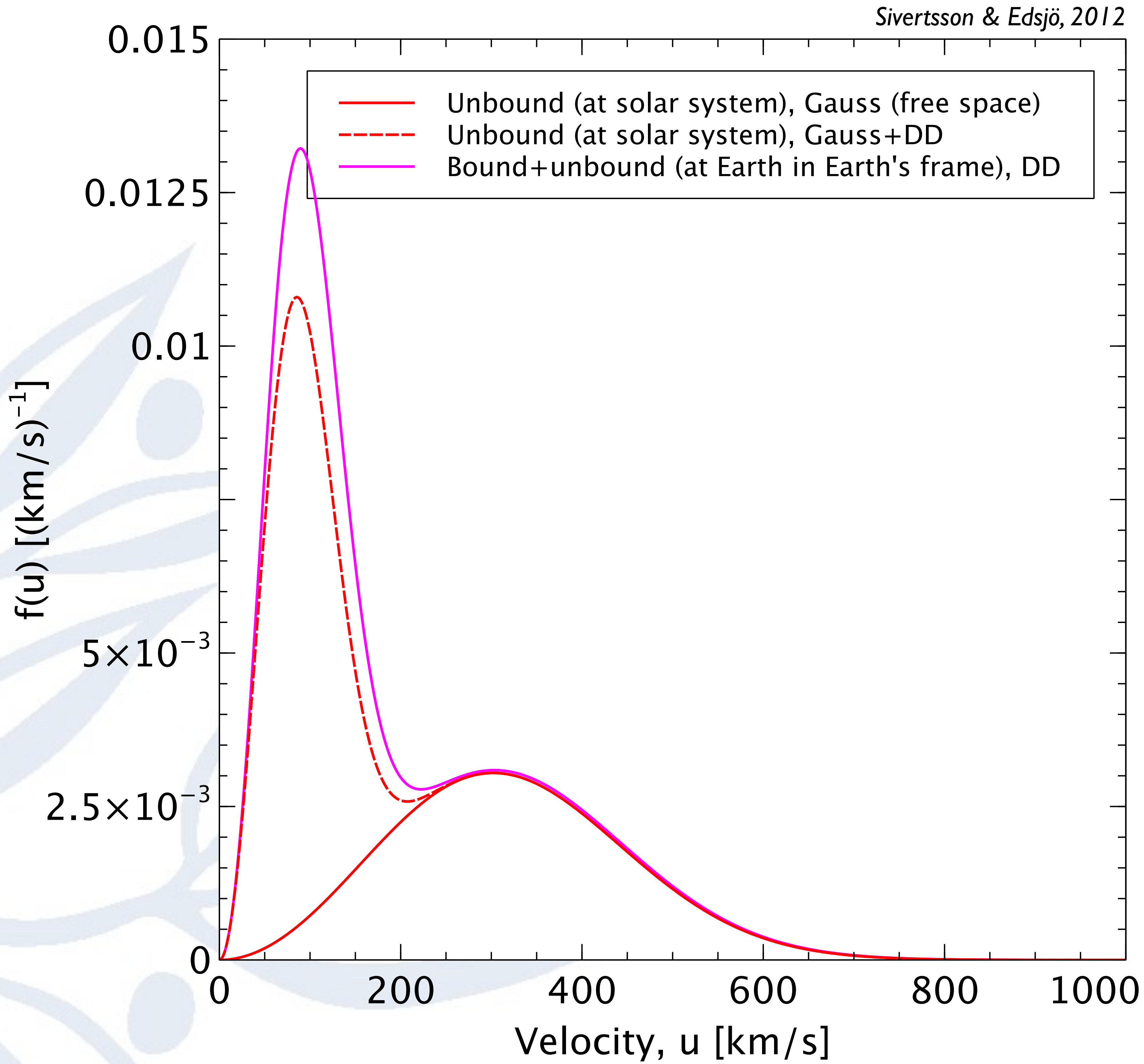
- Model the dark disk as a Gaussian (like for the smooth component)

$$f(\mathbf{u}) = \frac{1}{(2\pi\sigma^2)^{3/2}} e^{-(\mathbf{u}+\mathbf{v}_{\mathrm{lag}})^2/2\sigma^2}$$

- with σ being the velocity dispersion and v_{lag} being difference between the Sun's and the dark disk's rotational velocity

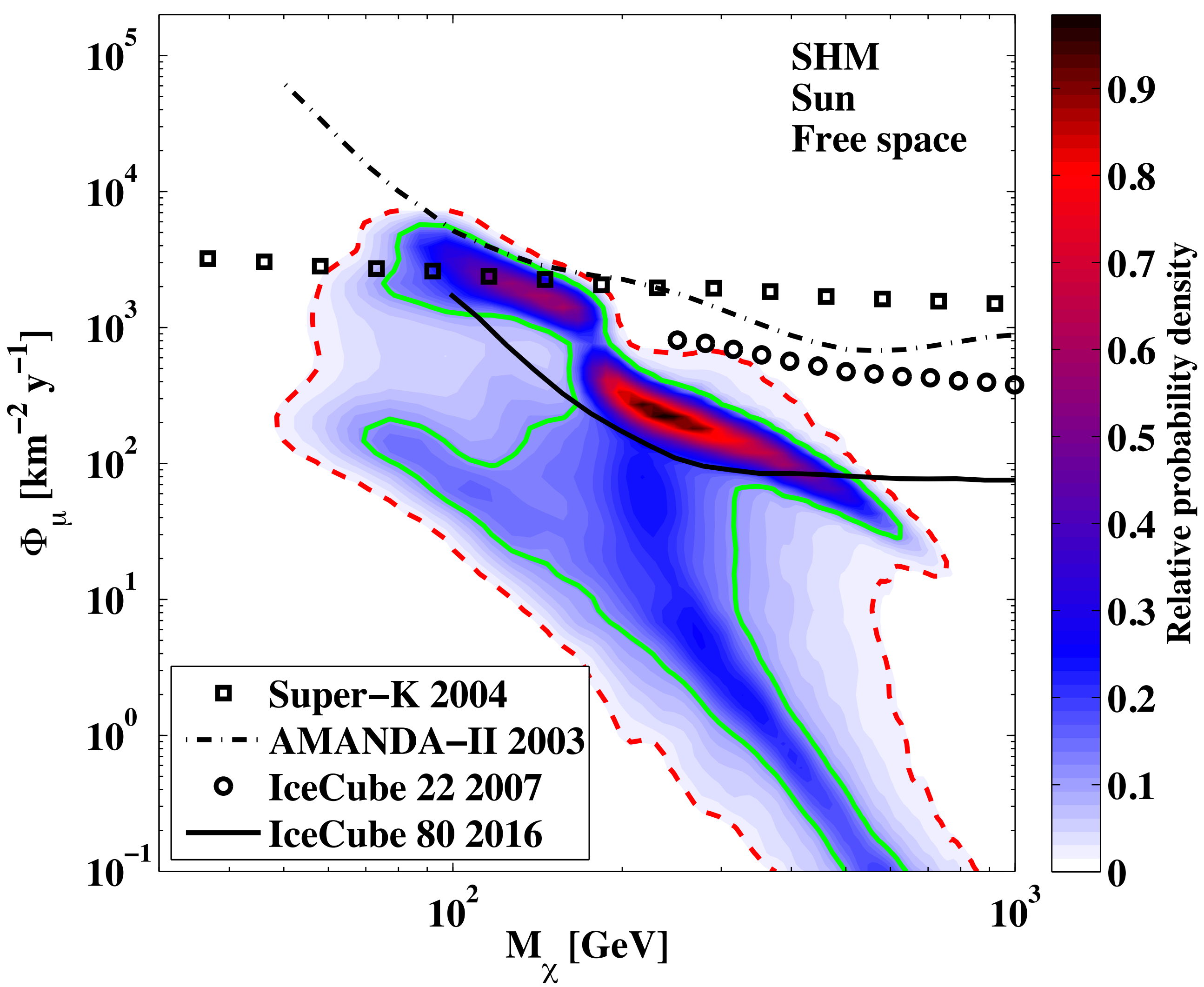
- Simple model: $\sigma = v_{lag}$ = 50 km/s, $\rho_{DD} = \rho_{smooth}$
(as in Bruch et al, arXiv:0902.4001)
(cf. σ = 156 km/s and vlag=220 km/s for the smooth halo)

Dark disk velocity distributions

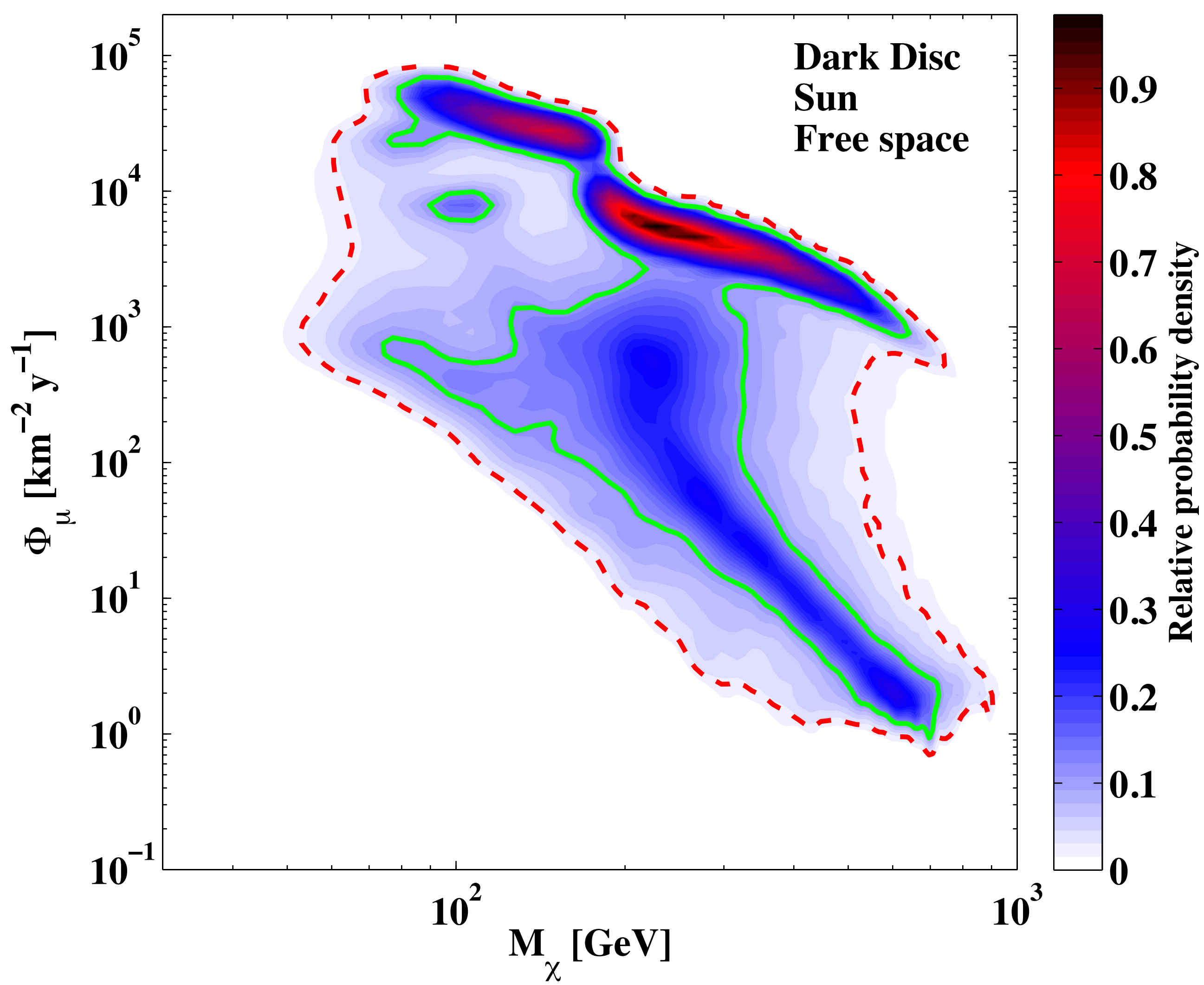


Effects on solar fluxes

Without dark disk



With dark disk

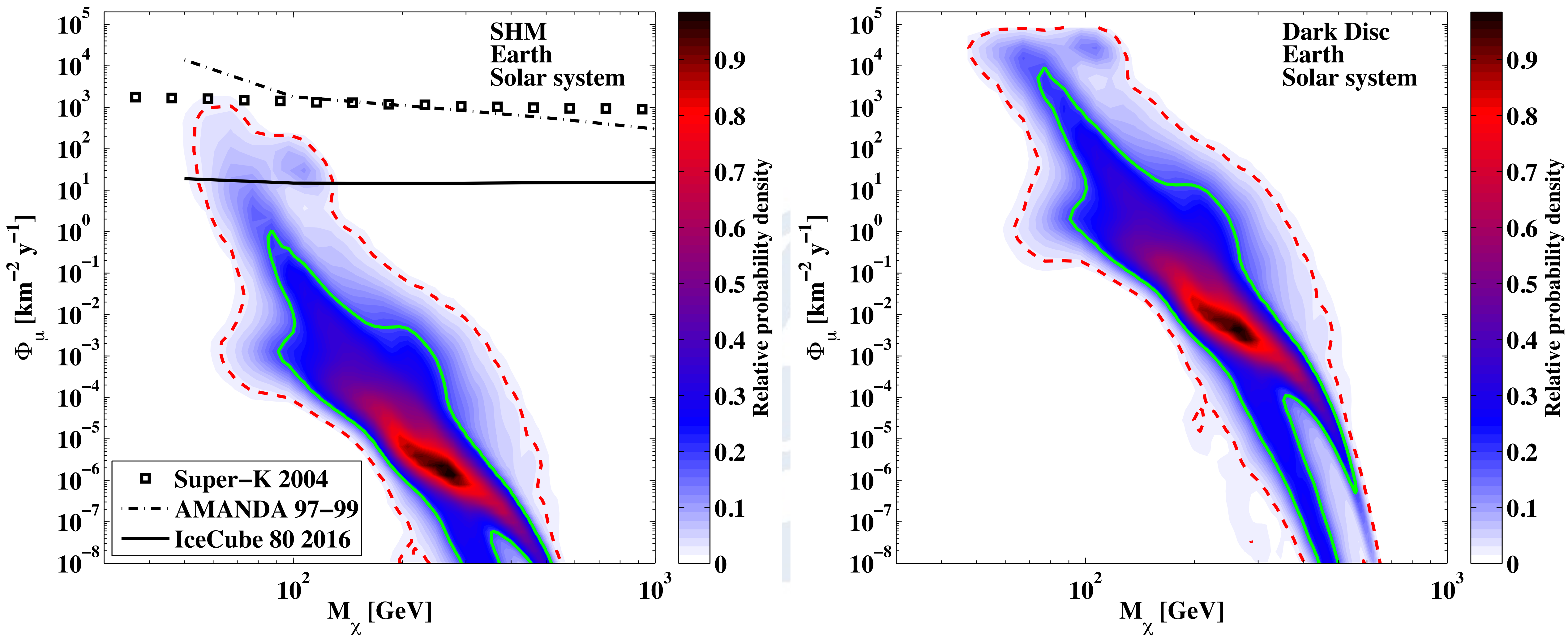


Fluxes from the Sun can be enhanced by up to one order of magnitude

Bruch et al, arXiv:0902.4001

Effects on Earth fluxes

Without dark disk	With dark disk



Fluxes from the Earth can be enhanced by up to three orders of magnitude

Bruch et al, arXiv:0902.4001

Dark disk comments

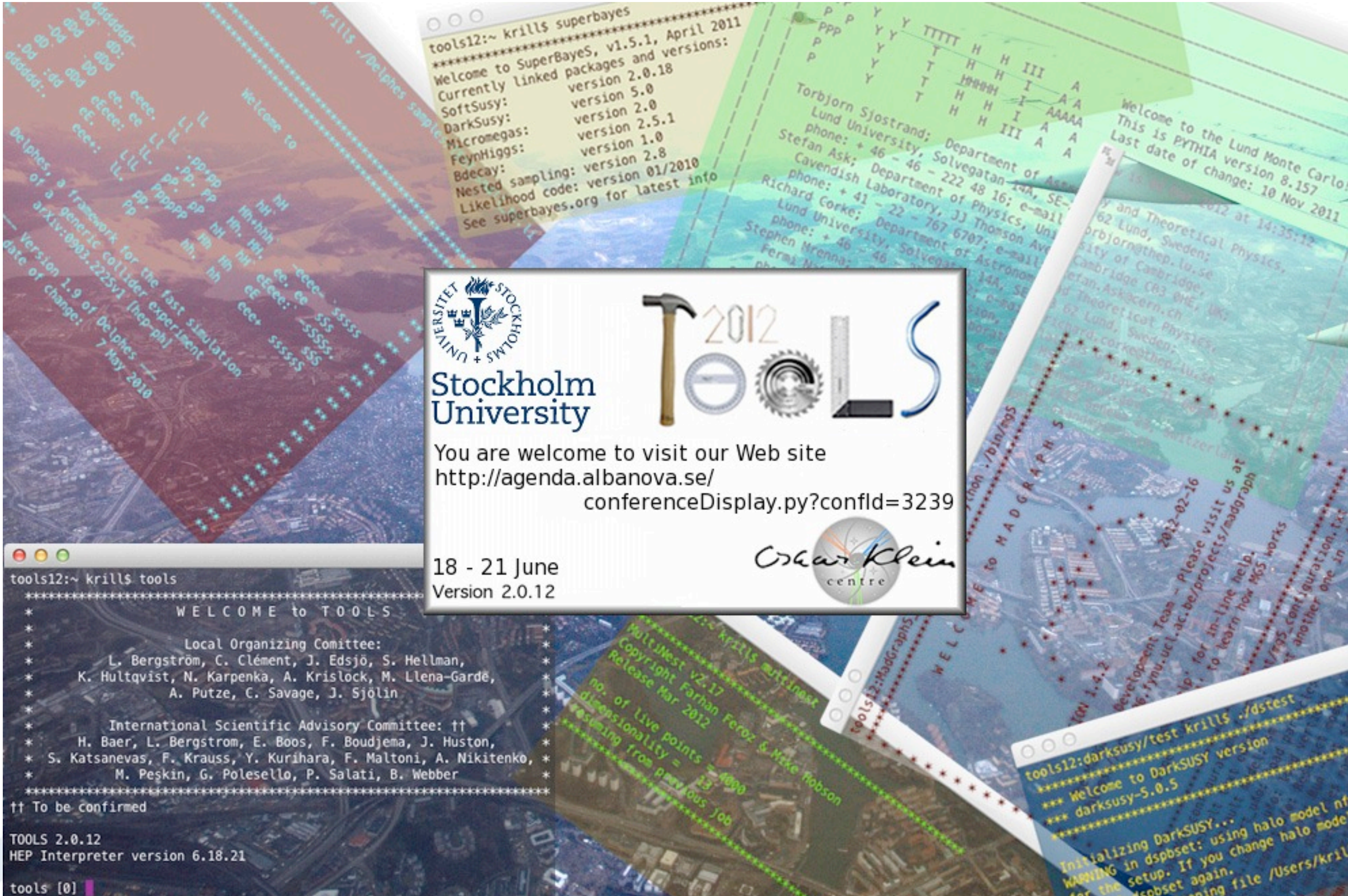
- Could give dramatic enhancements for neutrino rates from the Sun (x10) and the Earth (x1000).
- However, these enhancements depend crucially on the unknown properties of the dark disk
- Direct detection rates are not affected as much, as the dark disk gives low recoil energies, buried in the background
- Halo stars constrain the density of the disk and it seems that the density cannot be too high. (Pestaña & Eckhart, arXiv:1009.0925, Bidin et al, arXiv:1011.1289, Sanchez-Salcedo et al, 1103.4356, Bidin et al, arXiv:1204.3924)

Uncertainties with respect to direct detection

Input	Direct detection	Neutrinos from Sun	Neutrinos from Earth
Velocity distribution, f(u)	"All" velocities, for low-masses, high-velocity tail	Low velocities	Very low velocities, some solar diffusion effects
Form factor	Velocities ~200 km/s => low momentum transfer	Velocities ~1500 km/s => high momentum transfer	Velocities ~200 km/s => low momentum transfer
Local density	Sensitive to it now	Sensitive to average over last $\sim 10^8$ years	Sensitive to average over last $\sim 10^9$ years

Summary

- WIMP diffusion gets simpler when weak capture in the Sun is included. Free space approximation is quite good
- Neutrino searches (especially from the Sun) are competitive with direct detection searches
- A dark disk can enhance the neutrino signals tremendously (x10 for Sun, x1000 for Earth). Existence still uncertain though.


Stockholm University
2012
TOOLS
You are welcome to visit our Web site
http://agenda.albanova.se/
conferenceDisplay.py?confId=3239
18 - 21 June
Version 2.0.12
Oskar Klein centre
tools12:~ krill$ tools
W E L C O M E to T O O L S
Local Organizing Comittee:
L. Bergström, C. Clément, J. Edsjö, S. Hellman,
K. Hultqvist, N. Karpenka, A. Krislock, M. Llena-Garde,
A. Putze, C. Savage, J. Sjölin
International Scientific Advisory Committee: ††
H. Baer, L. Bergstrom, E. Boos, F. Boudjema, J. Huston,
S. Katsanevas, F. Krauss, Y. Kurihara, F. Maltoni, A. Nikitenko,
M. Peskin, G. Polesello, P. Salati, B. Webber
†† To be confirmed
TOOLS 2.0.12
HEP Interpreter version 6.18.21
tools [0]
tools12:~ krill$ superbayes
Welcome to SuperBayeS, v1.5.1, April 2011
Currently linked packages and versions:
SoftSusy: version 2.0.18
DarkSusy: version 5.0
Micromegas: version 2.0
FeynHiggs: version 2.5.1
Bdecay: version 1.0
Nested sampling: version 2.8
Likelihood code: version 01/2010
See superbayes.org for latest info
Welcome to the Lund Monte Carlo!
This is PYTHIA version 8.157
Last date of change: 10 Nov 2011
MultiNest v2.17
Copyright Farhan Feroz & Mike Hobson
Release Mar 2012
tools12:darksusy/test krill$ ./dstest
Welcome to DarkSUSY version
darksusy-5.0.5