Indirect Detection of WIMPs

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Outline

- WIMP candidates
  – will focus on the neutralino in the MSSM
- Ways to search indirectly for WIMPs
- Direct detection versus neutrino telescopes
- Recent developments in Earth rates (gravitational diffusion revisited)
- Comparison of future searches

Many groups work on this, e.g.

- Ellis, Falk, Olive, Santoso, Spanos et al.
- Bottino, Donato, Fornengo, Scopel et al.
- Baer, Belyaev, Krupovnickas, O'Farrill, Tata et al.
- Silk, Bertone, Hooper, et al.
- Nezri, Orloff, et al.
- Roszkowski, Nihei, Ruiz de Austri, et al.
- Bergström, Baltz, Edsjö, Gondolo, Ullio, Schelke et al.
- ...

The neutralino as a WIMP

Will focus on the neutralino in the MSSM as a dark matter WIMP candidate.

The neutralino:

$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

The neutralino can be the lightest supersymmetric particle (LSP). If R-partity is conserved, it is stable.

The gaugino fraction

$$Z_g = |N_{11}|^2 + |N_{12}|^2$$

Calculational flowchart

1. Select model parameters
2. Calculate masses etc
3. Check accelerator constraints
4. Calculate the relic density $\Omega_\chi h^2$
5. Check if the relic density is cosmologically OK
6. Calculate fluxes, rates, etc

Calculation done with DarkSUSY

DarkSUSY 4.1 available on
www.physto.se/~edsjo/darksusy
astro-ph/0406204

The relic density

$$\Omega_\chi h^2 = 0.103^{+0.020}_{-0.022}$$

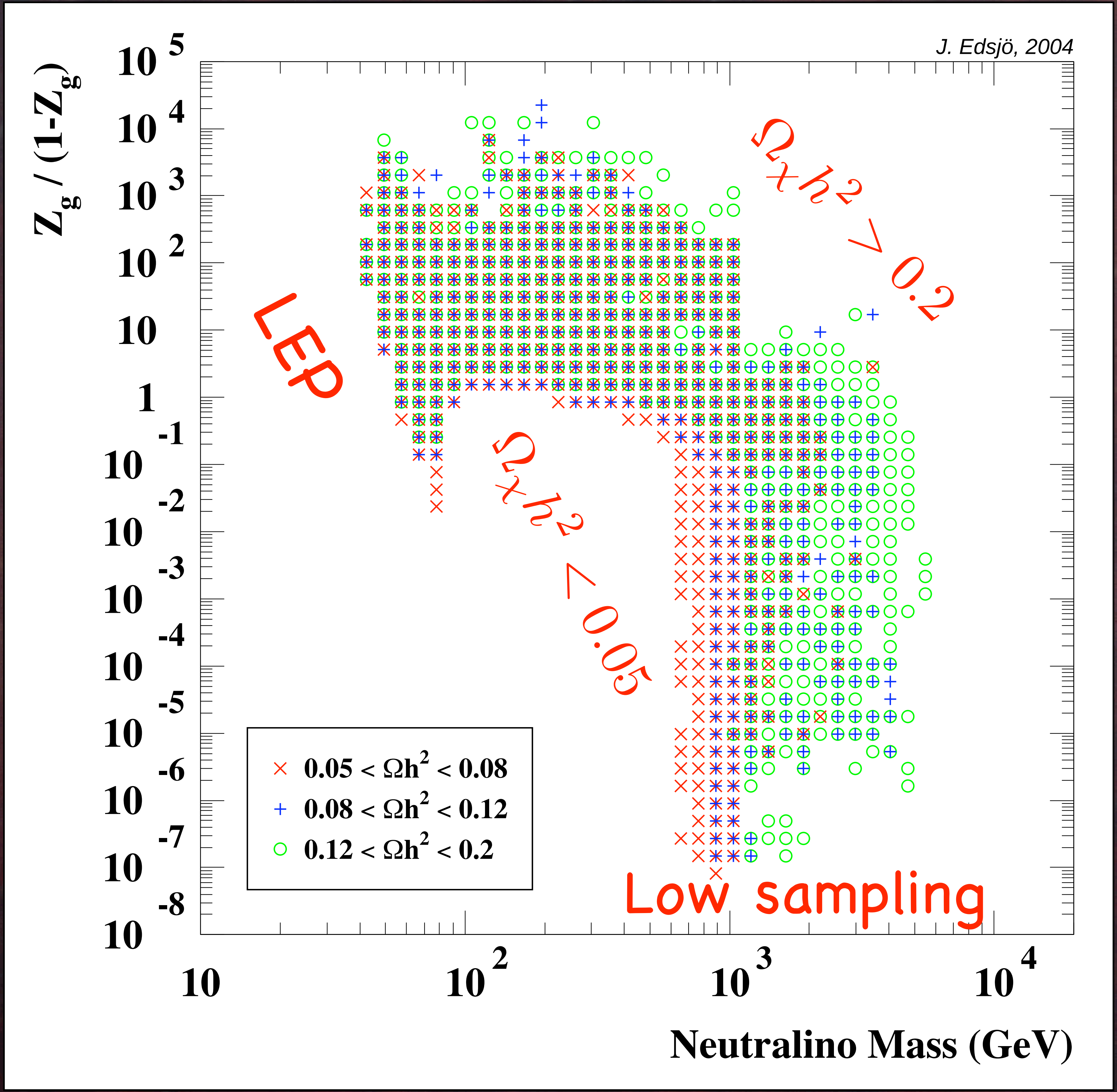
from WMAP+SDSS
M.Tegmark et al., astro-ph/0310723

The $m_\chi - Z_g$ parameter space

Gaugino

Mixed

Higgsino



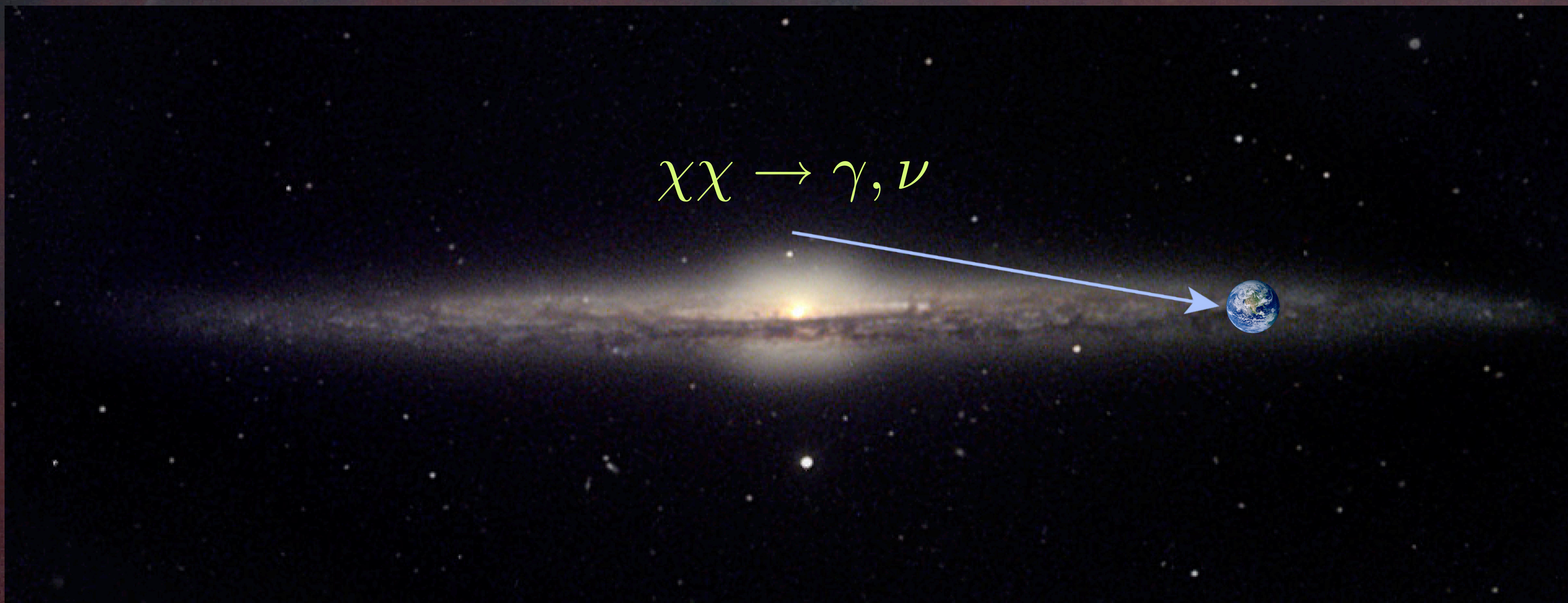
In this and the coming plots, sfermion coannihilations are not included in the relic density calculation (yet).

WIMP search strategies

- Direct detection ← Use CDMS @ Soudan to constrain our models
- Indirect detection:
  - neutrinos from the Earth/Sun ← Focus on these
  - antiprotons from the galactic halo
  - antideuterons from the galactic halo ← Use these to constrain our models (future)
  - positrons from the galactic halo
  - gamma rays from the galactic halo ← Use these to constrain our models (future)
  - gamma rays from external galaxies/halos
  - synchrotron radiation from the galactic center / galaxy clusters
  - ...

Annihilation in the halo

Neutral annihilation products

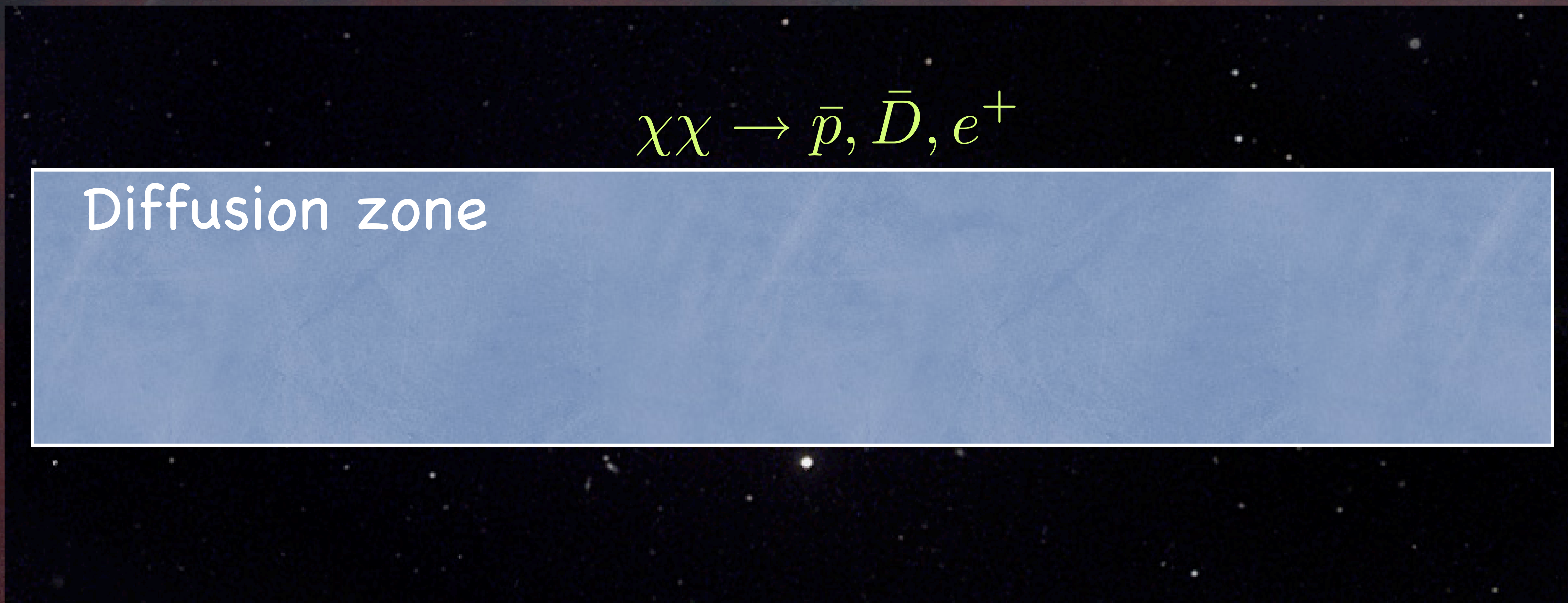


- Gamma rays can be searched for with Air Cherenkov Telescopes (ACTs) or GLAST.
- Signal depends strongly on the halo profile,

$$\Phi \propto \int_{\text{line of sight}} \rho^2 dl$$

Annihilation in the halo

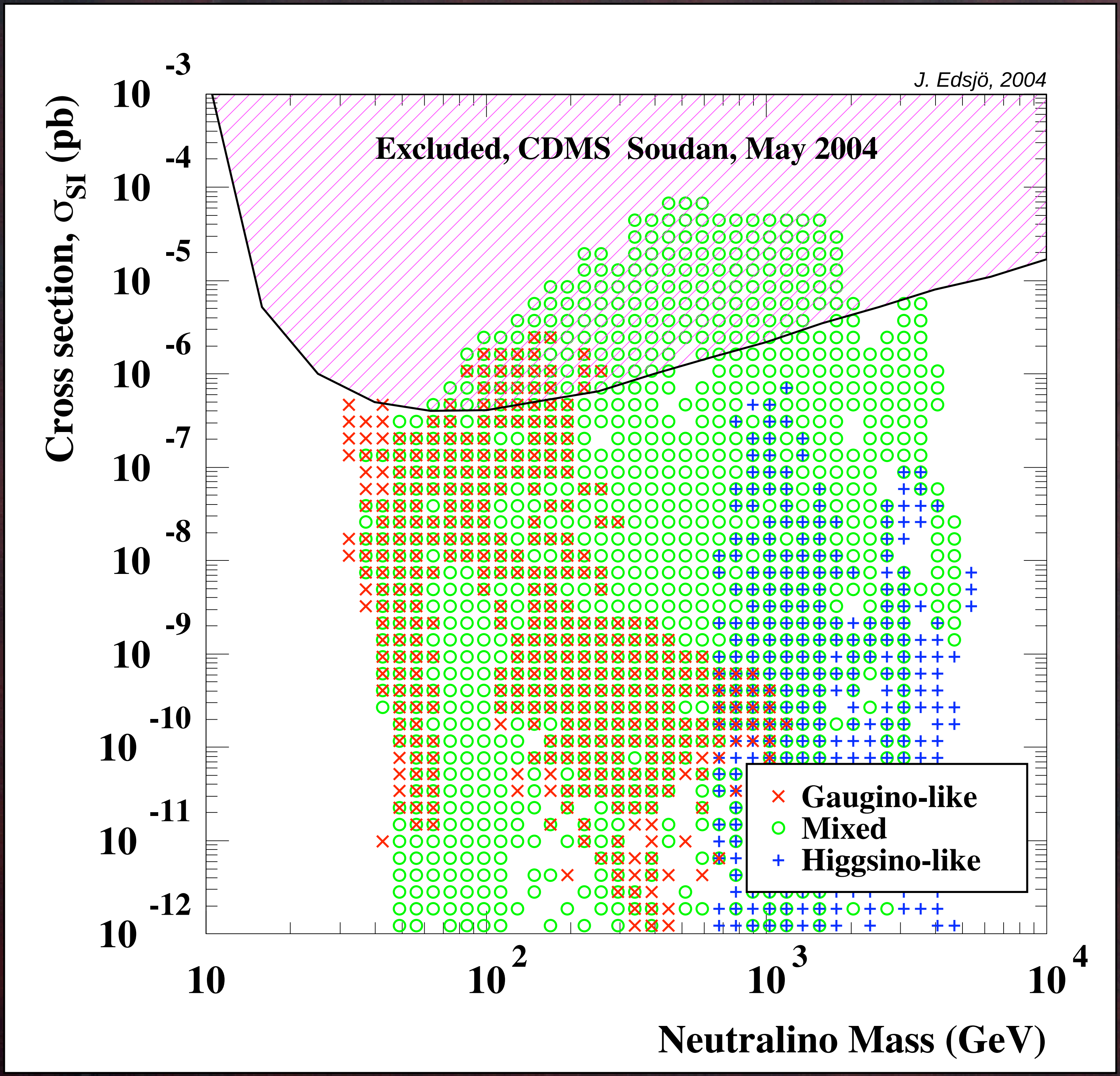
Charged annihilation products



- Diffusion of charged particles. Diffusion model with parameters fixed from studies of conventional cosmic rays (especially unstable isotopes).
- Current detectors are e.g. HEAT, Caprice and BESS. Future detectors are e.g. AMS, Pamela and GAPS.

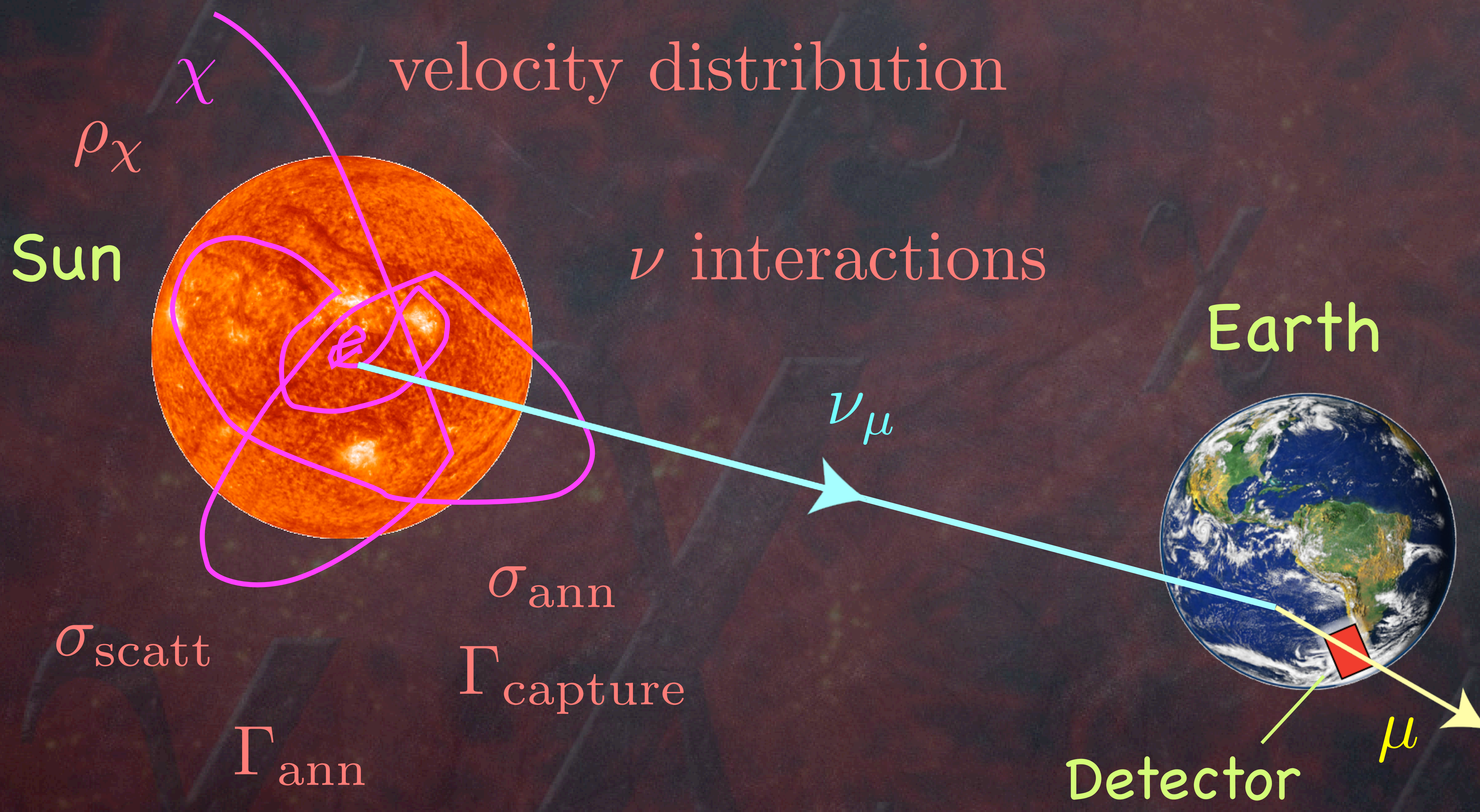
Direct detection

current limits



- CDMS @ Soudan, astro-ph/0405033
- Direct detection experiments have really started to explore the MSSM parameter space!

Neutralino Capture



Silk, Olive and Srednicki '85
Gaisser, Steigman & Tilav '86

Freese '86
Krauss, Srednicki & Wilczek '86
Gaisser, Steigman & Tilav '86

Neutrino Telescopes

Capture

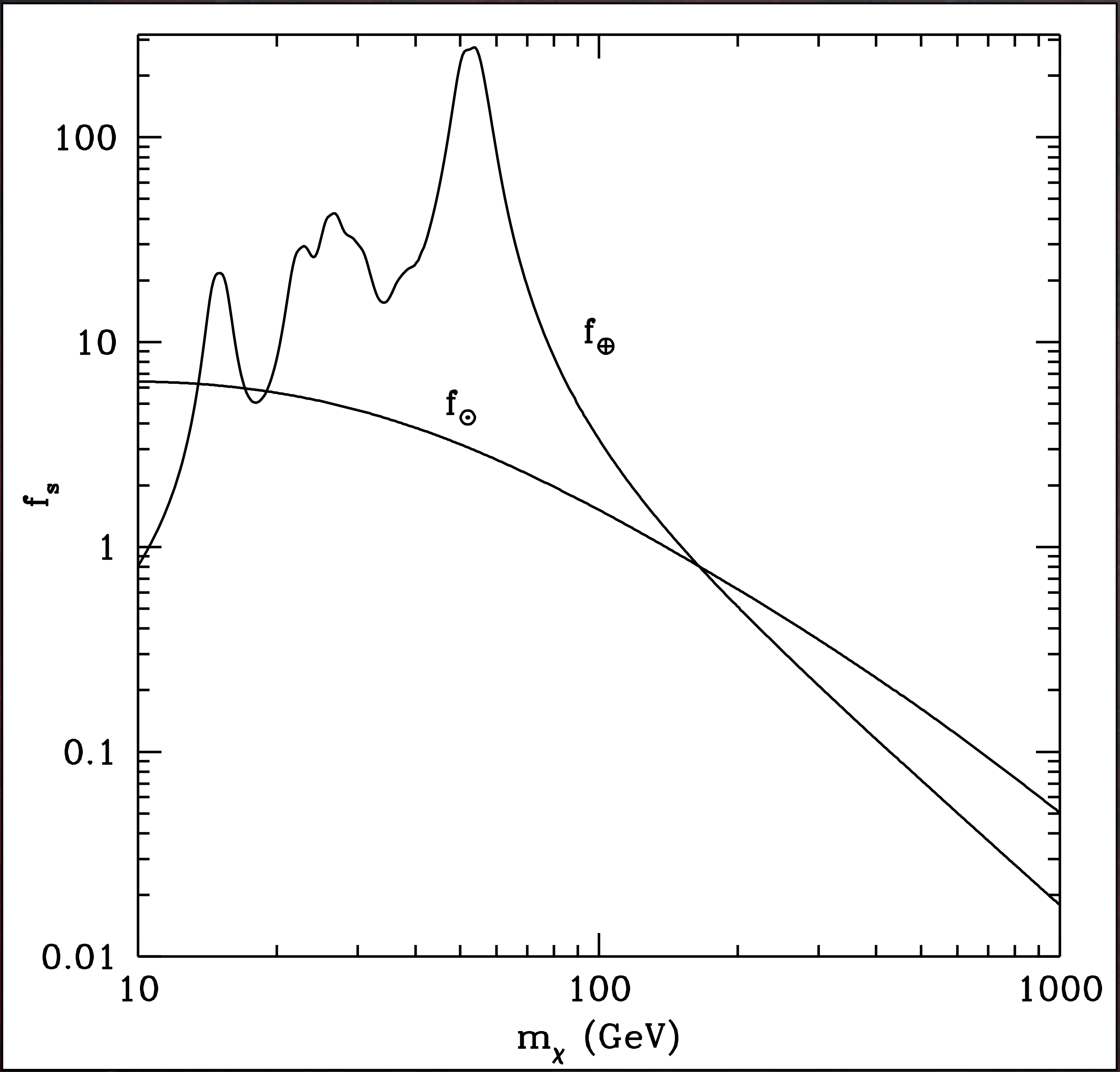


Figure from Jungman, Kamionkowski and Griest

Capture in Sun

- Mostly on Hydrogen
- Both spin-independent and spin-dependent scattering

Capture in Earth

- Mostly on Iron
- Essentially only spin-independent scattering
- Resonant scattering when mass matches element in Earth
- Capture from WIMPs bound in the solar system

Review of capture rate calculations

- 1985: Press & Spergel, ApJ 296 (1985) 679:
  Capture in the Sun

- 1987: Gould, ApJ 321 (1987) 571:
  Refined Press & Spergel's calculation for the Earth.

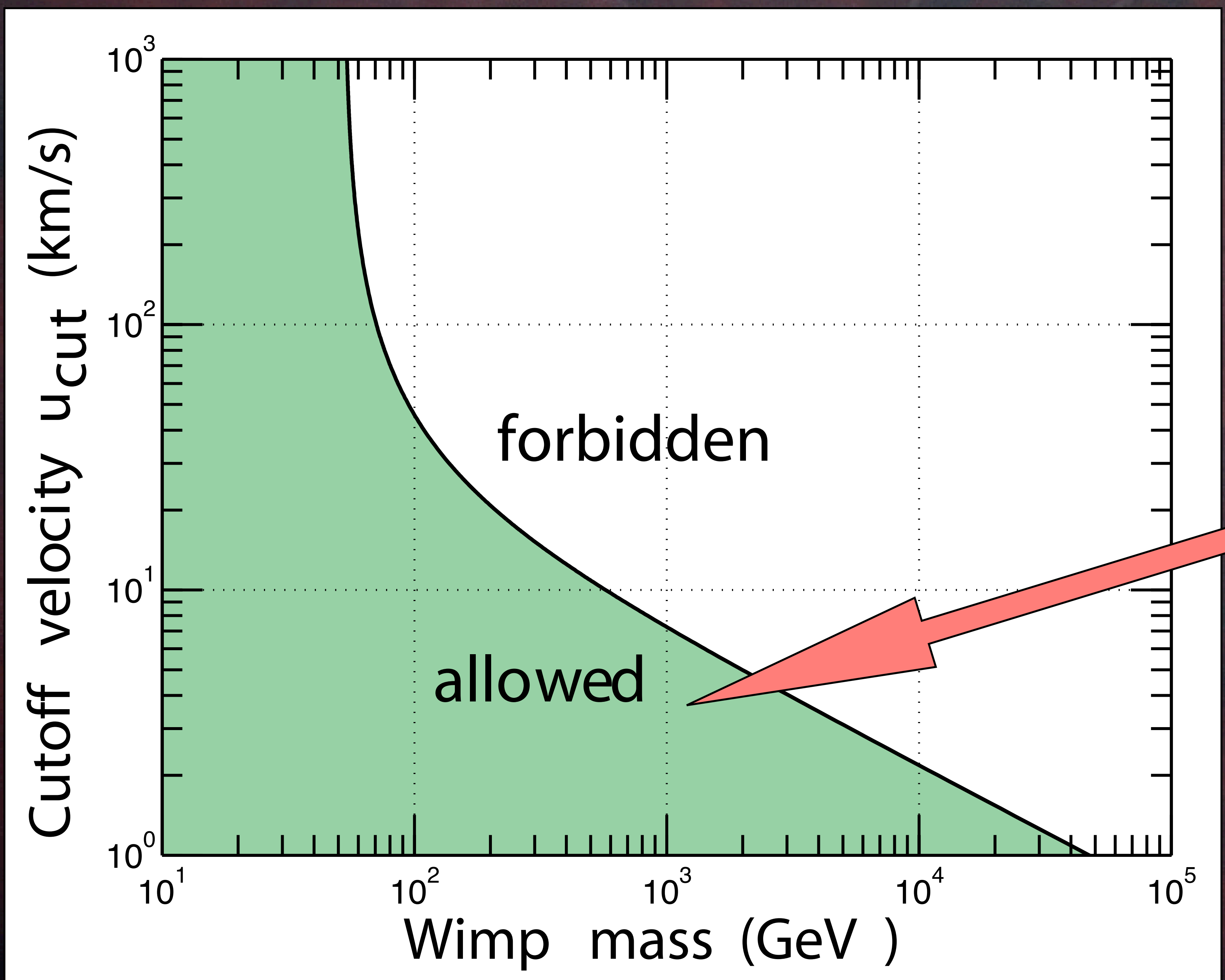
- 1988: Gould, ApJ 328 (1988) 919:
  Pointed out that the Earth cannot capture efficiently from the halo since the Earth is deep within the potential well of the Sun ($v_{esc} \approx 42$ km/s)

- 1991: Gould, ApJ 368 (1991) 610:
  WIMPs will diffuse around in the solar system due to gravitational scattering off the planets. Net result is that the velocity distribution at Earth is approximately as if the Earth was in free space, i.e. the 1987 expressions are still valid.

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

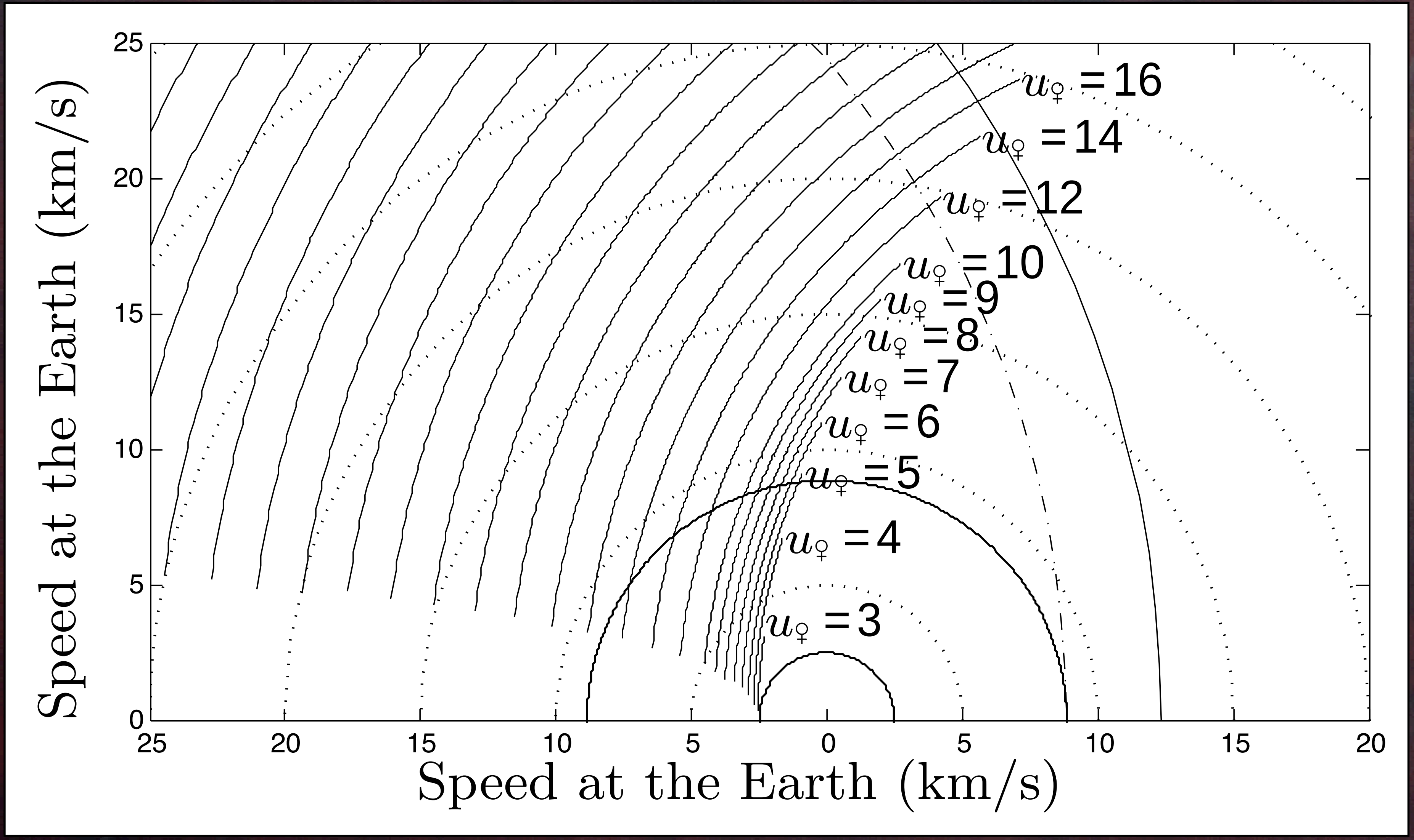


Capture on Fe most important.

For a given lowest velocity of the velocity distribution, we can only capture WIMPs up to a maximal mass.

Diffusion effects of the planets

- Gravitational scattering off one planet causes diffusion along spheres of constant velocity with respect to that planet.
- When seen from another planet's frame, the velocity can have changed.



The net effect is that Venus and Jupiter diffuse to velocities down to 2.5 km/s

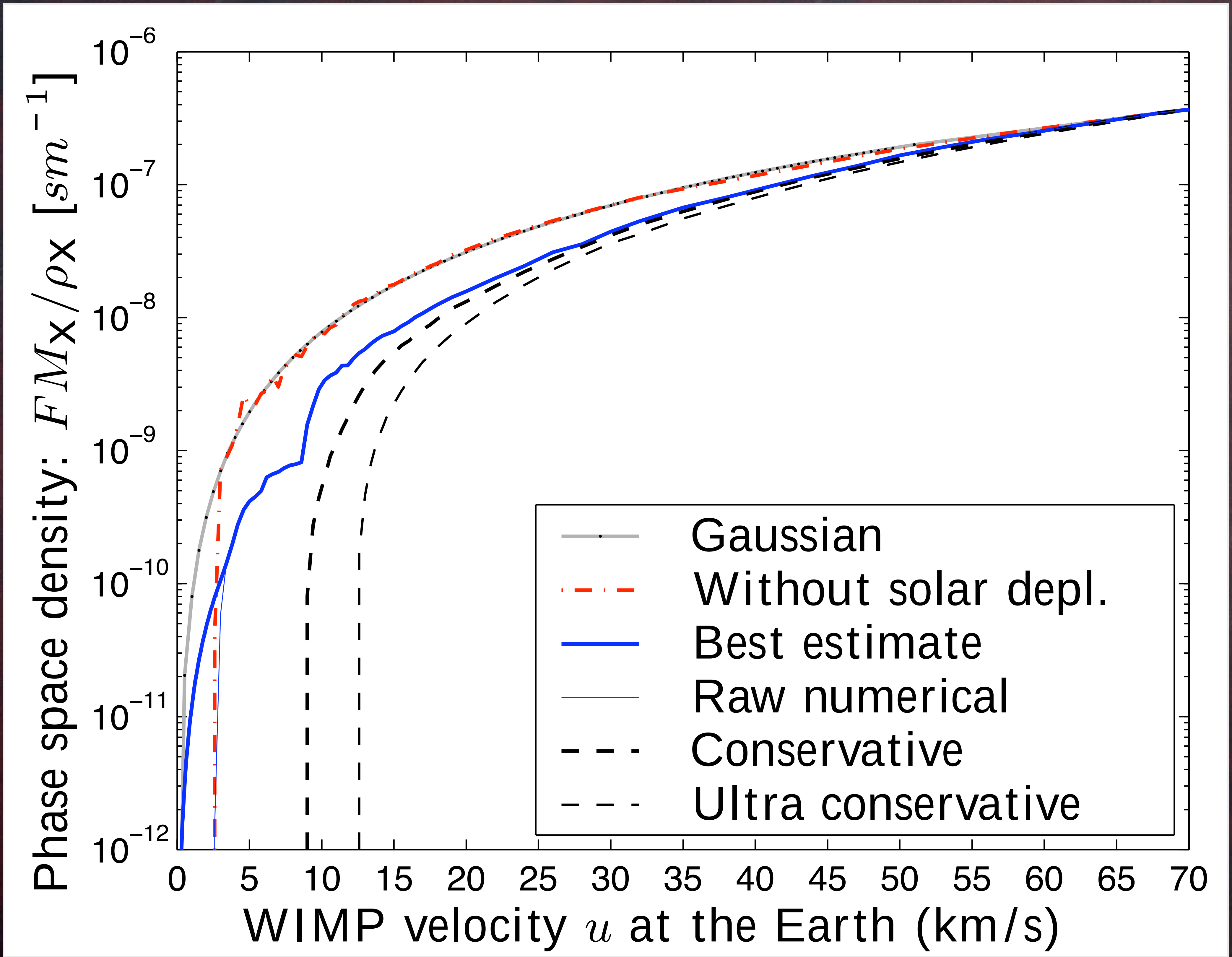
The velocity distribution at Earth is 'as in free space'

A. Gould, ApJ 368 (1991) 610, J. Lundberg & J. Edsjö, PRD69 (2004) 123505.

Possible problems: solar capture

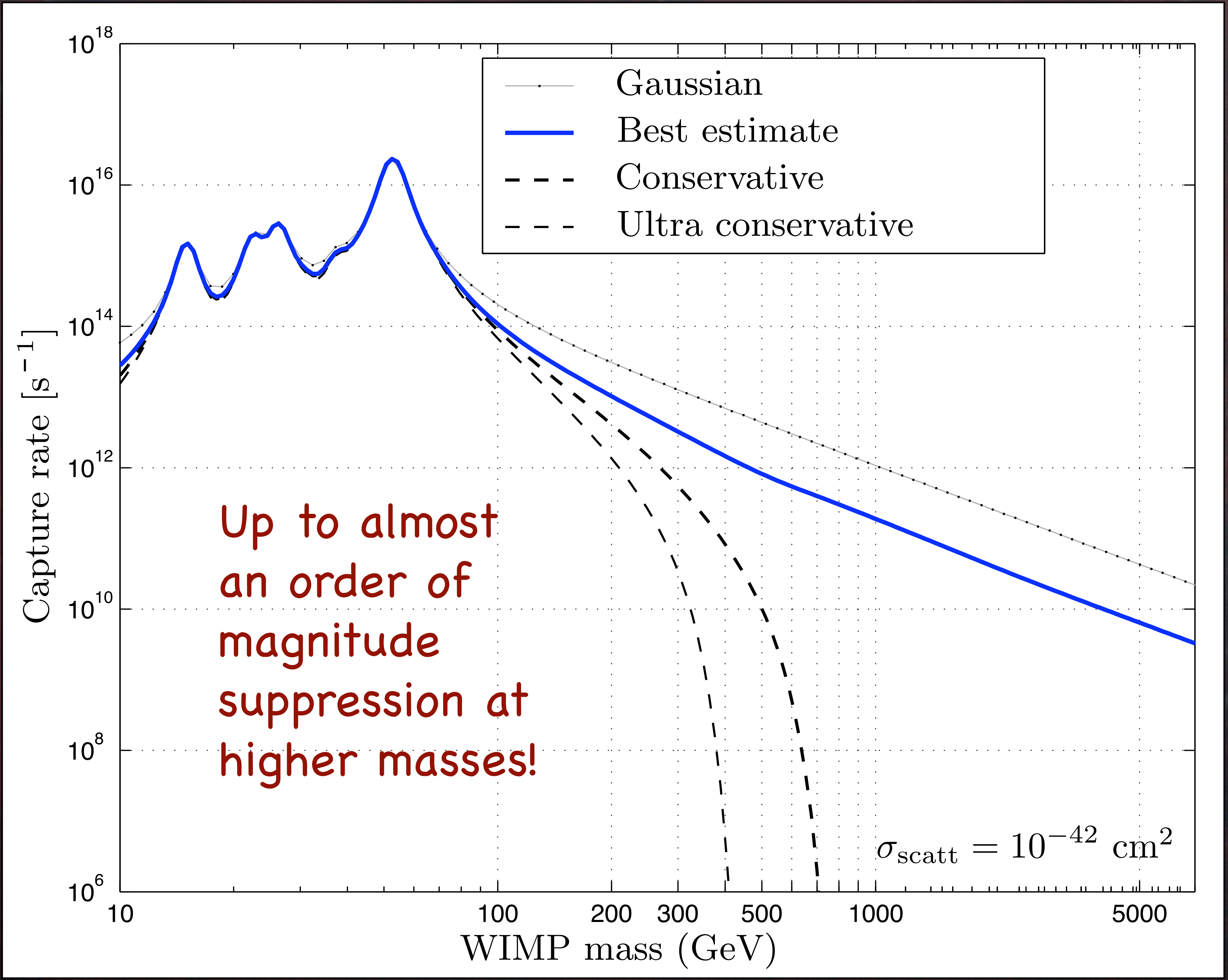
- 1994: Farinella et al, Nature 371 (1994) 314:
  Simulations of asteroids thrown out of the asteroid belt showed that they were typically forced into the Sun in less than $2 \cdot 10^6$ years.
- 2001: Gould and Alam, ApJ 549 (2001) 72:
  If Farinella's results hold for general WIMP orbits, the bound WIMPs in the solar system could be depleted.
- 2004: J. Lundberg and J. Edsjö, PRD69 (2004) 123505:
  Numerical simulation of WIMP orbits to find out if this is the case.

Velocity distribution at Earth

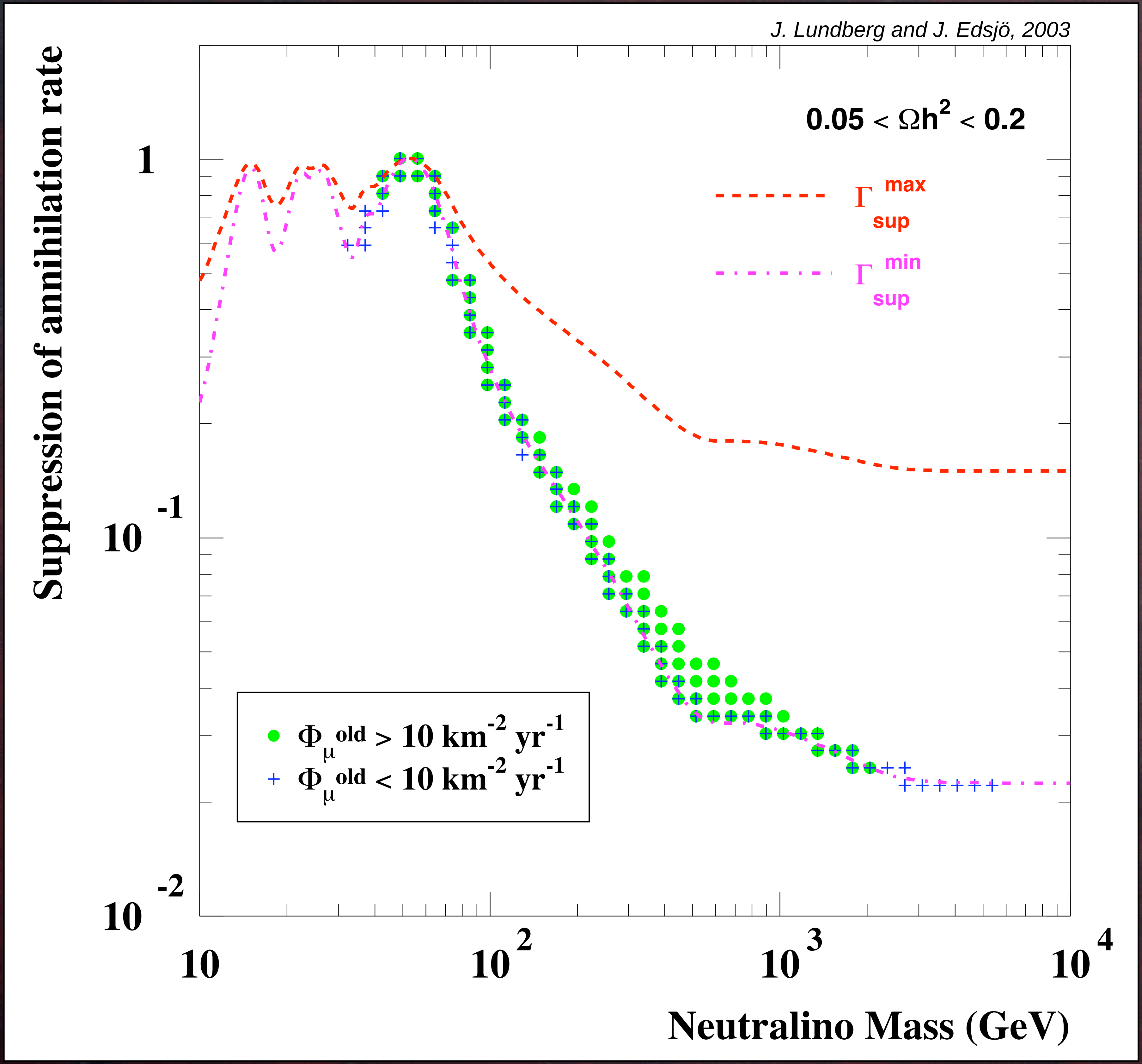


- Without solar capture, Gould's results of 'capture as in free space' are confirmed.
- Including solar capture, we get a significant suppression at low velocities, not as bad as initially thought, but still significant

Earth capture rates



Earth annihilation rates



$$\Gamma_A = \frac{1}{2} C \tanh^2 \frac{t}{\tau}$$

Annihilation and capture is not in equilibrium in the Earth

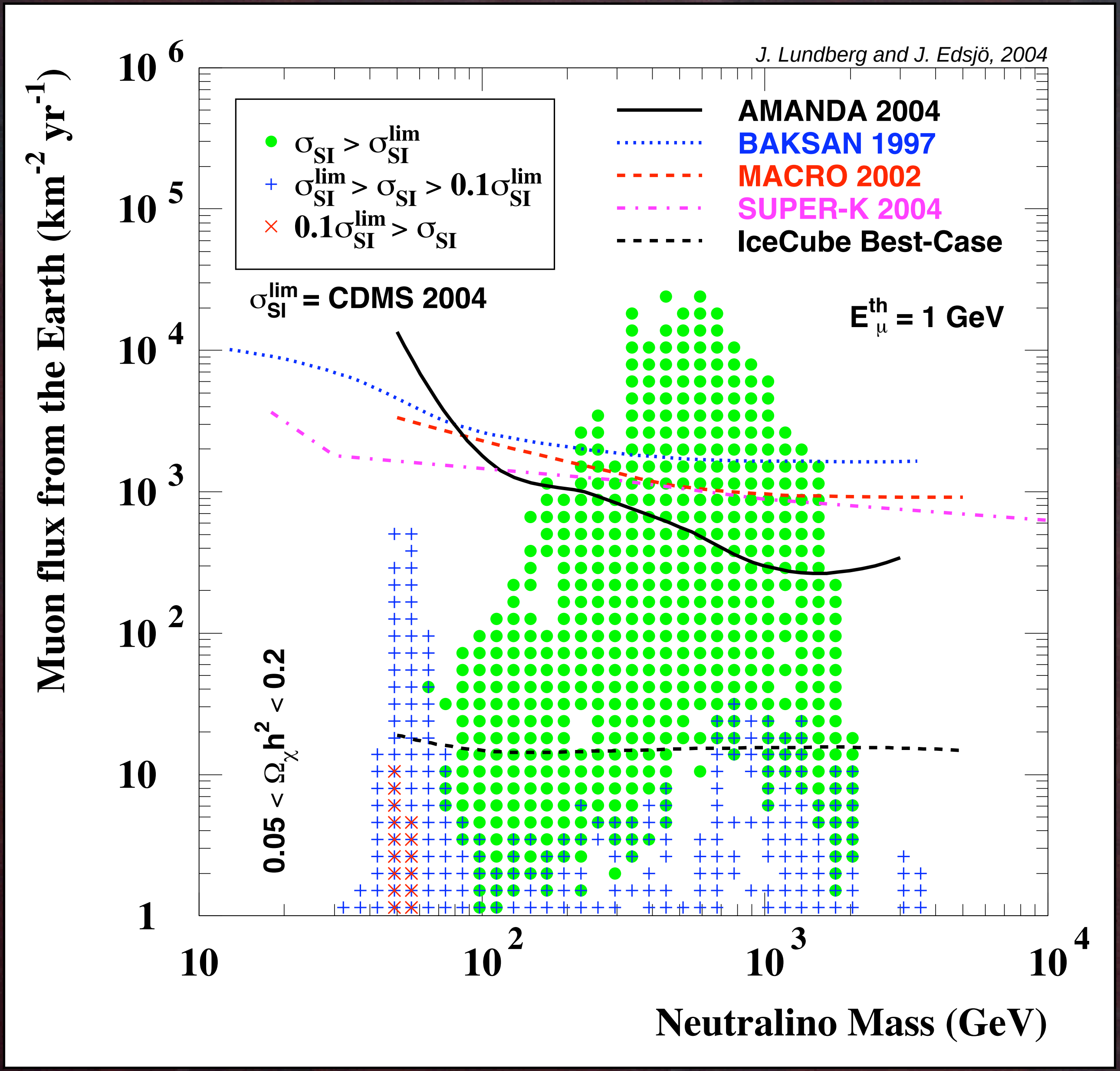
⇩

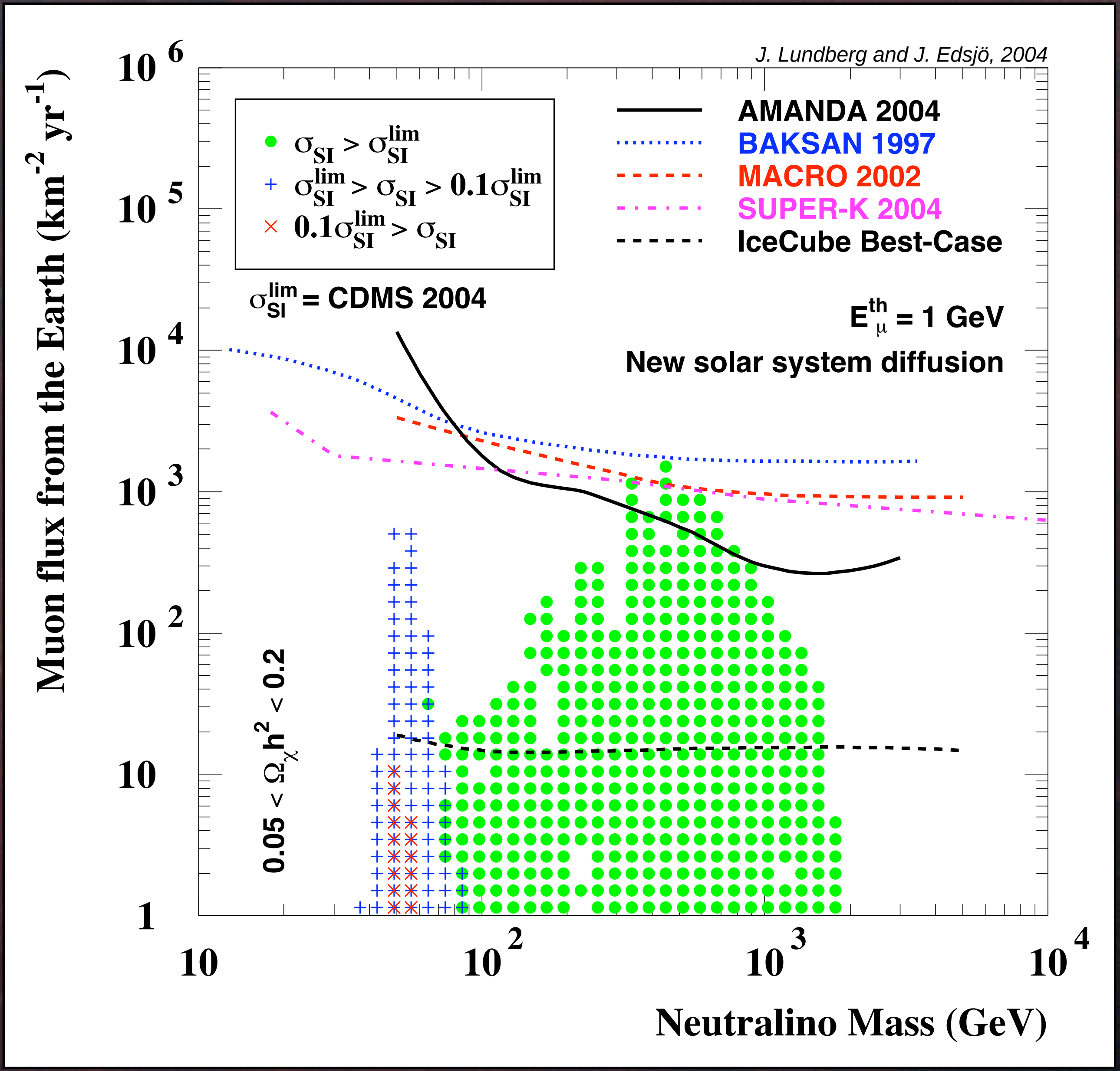
The annihilation rates are suppressed by up to almost two orders of magnitude!

Neutrino-induced muon fluxes from the Earth

Usual Gaussian approximation

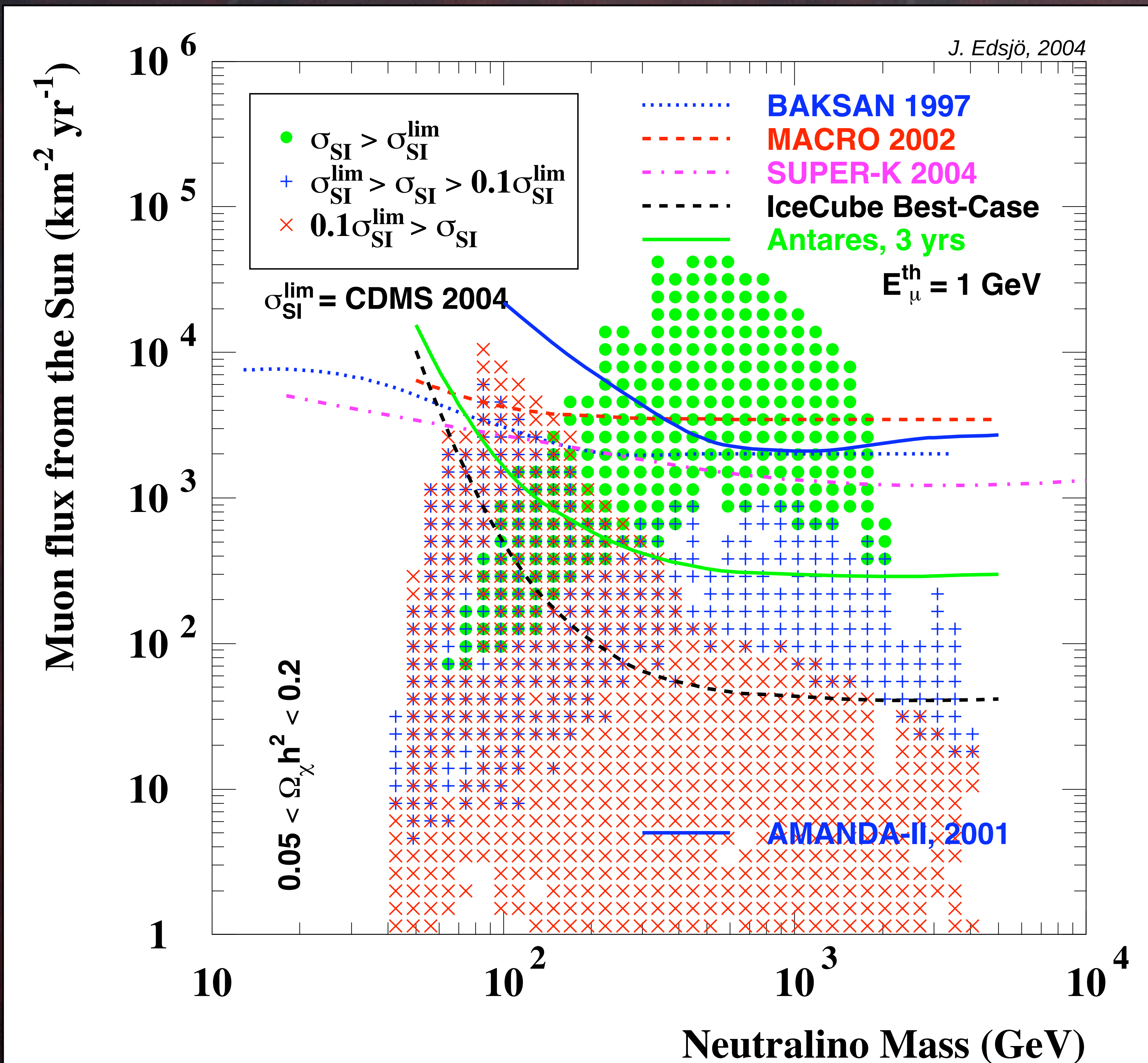
New estimate including solar capture





Maxwell-Boltzmann velocity distribution assumed.

Neutrino-induced muon fluxes from the Sun



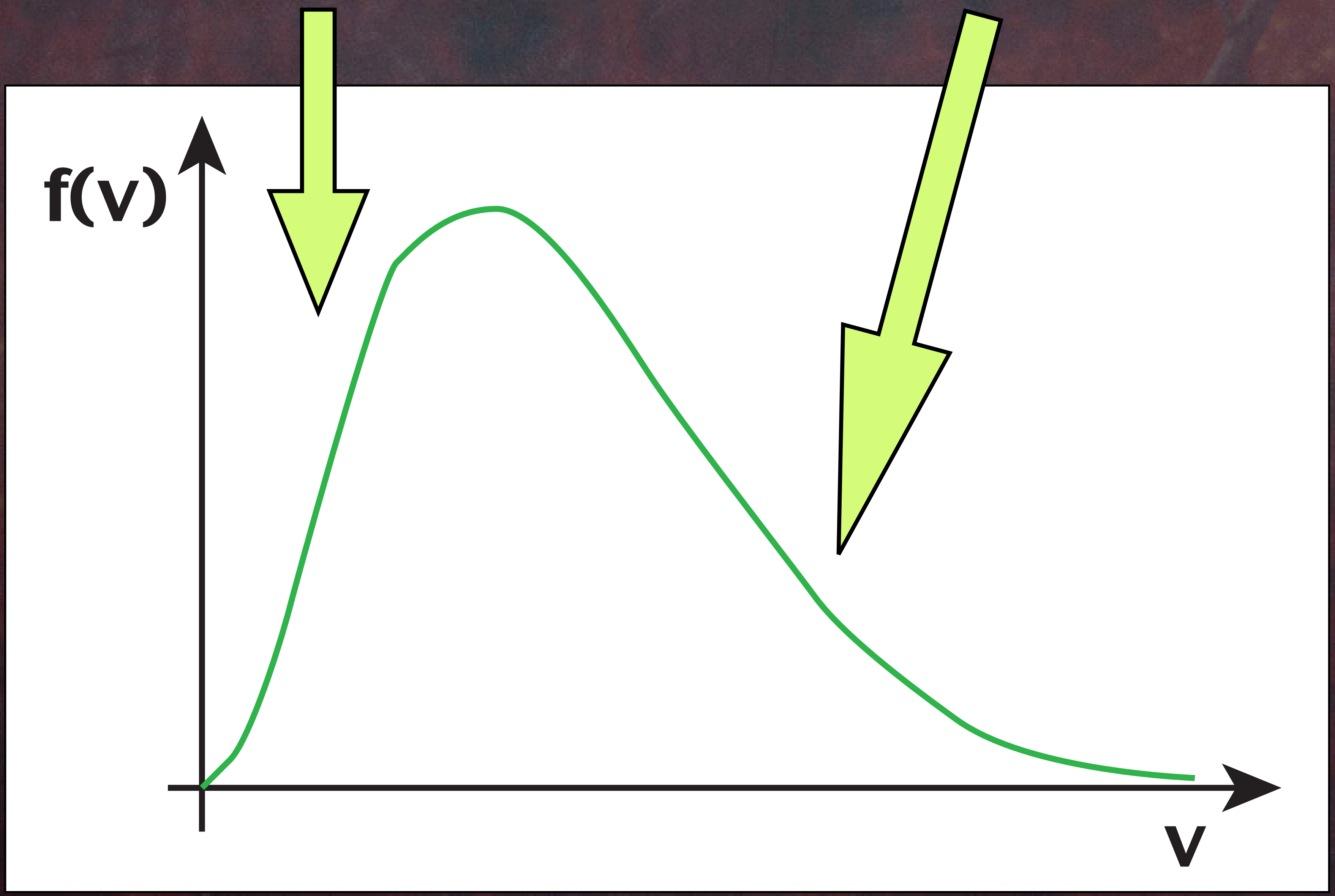
- Compared to the Earth, much better complementarity due to spin-dependent capture in the Sun.

A note about velocity distributions

Remember the different velocity dependencies!

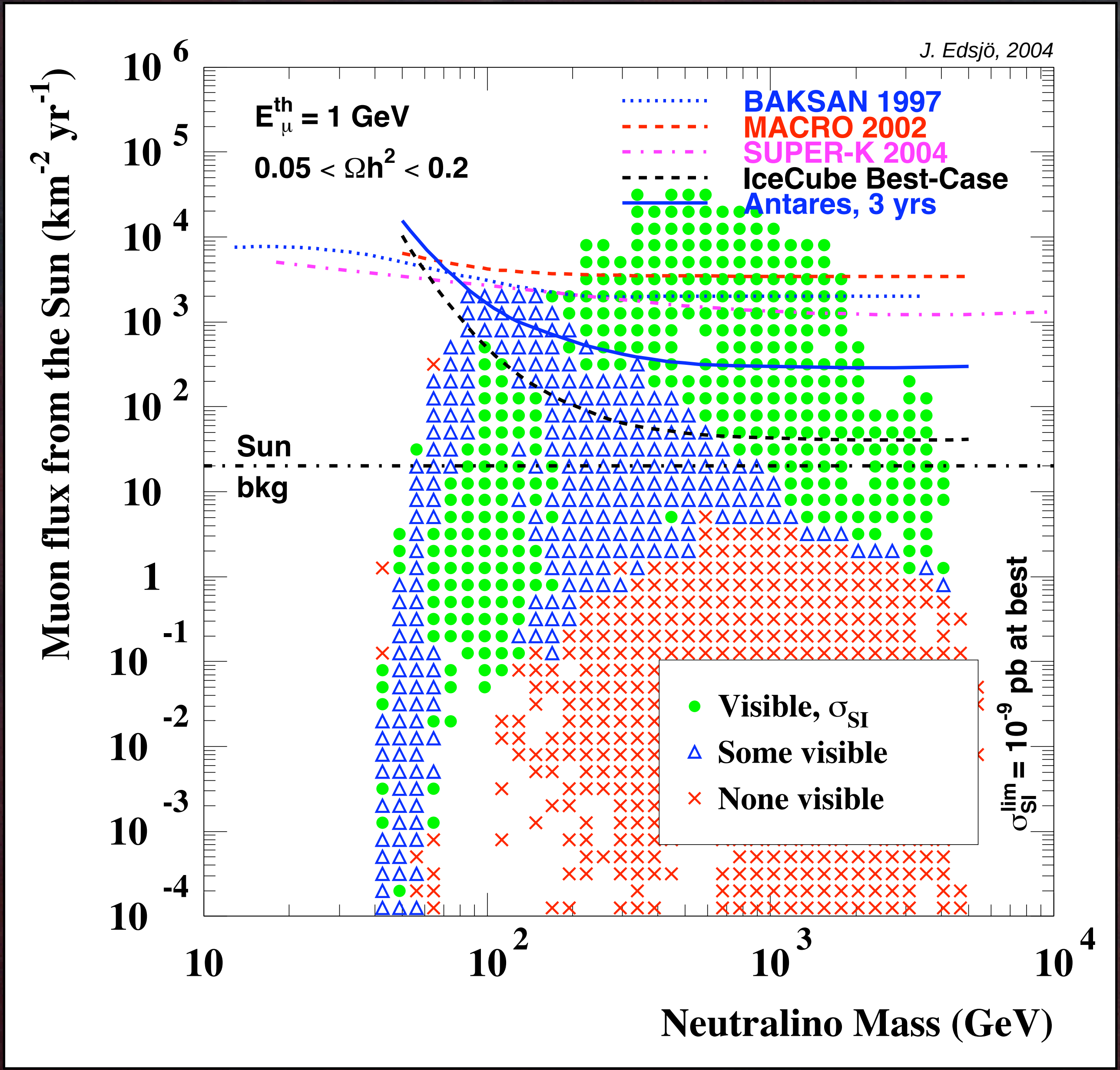
Capture sensitive to the low-velocity region

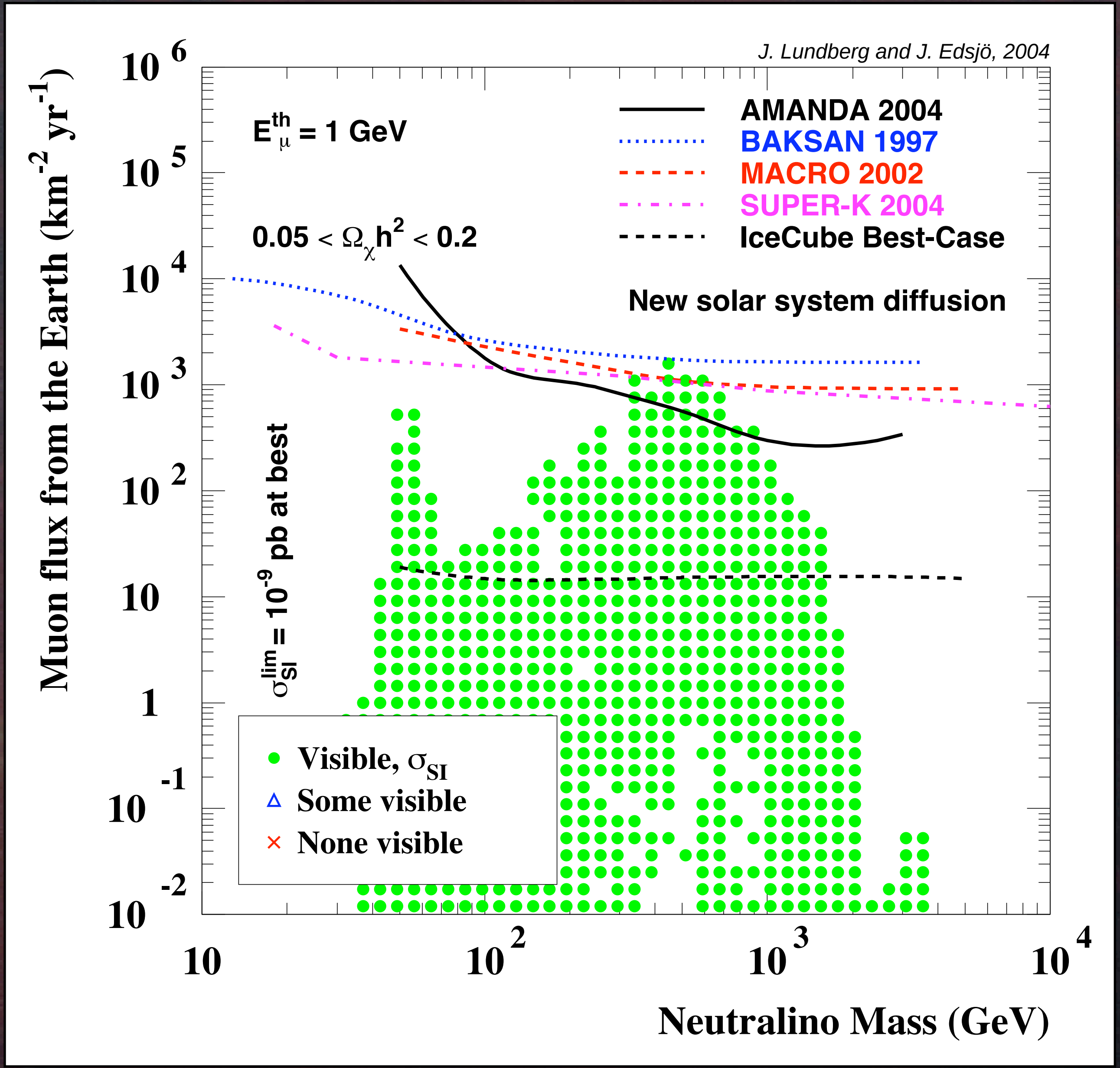
Direct detection sensitive to the high-velocity region



Neutrino-induced fluxes and future direct detection limits

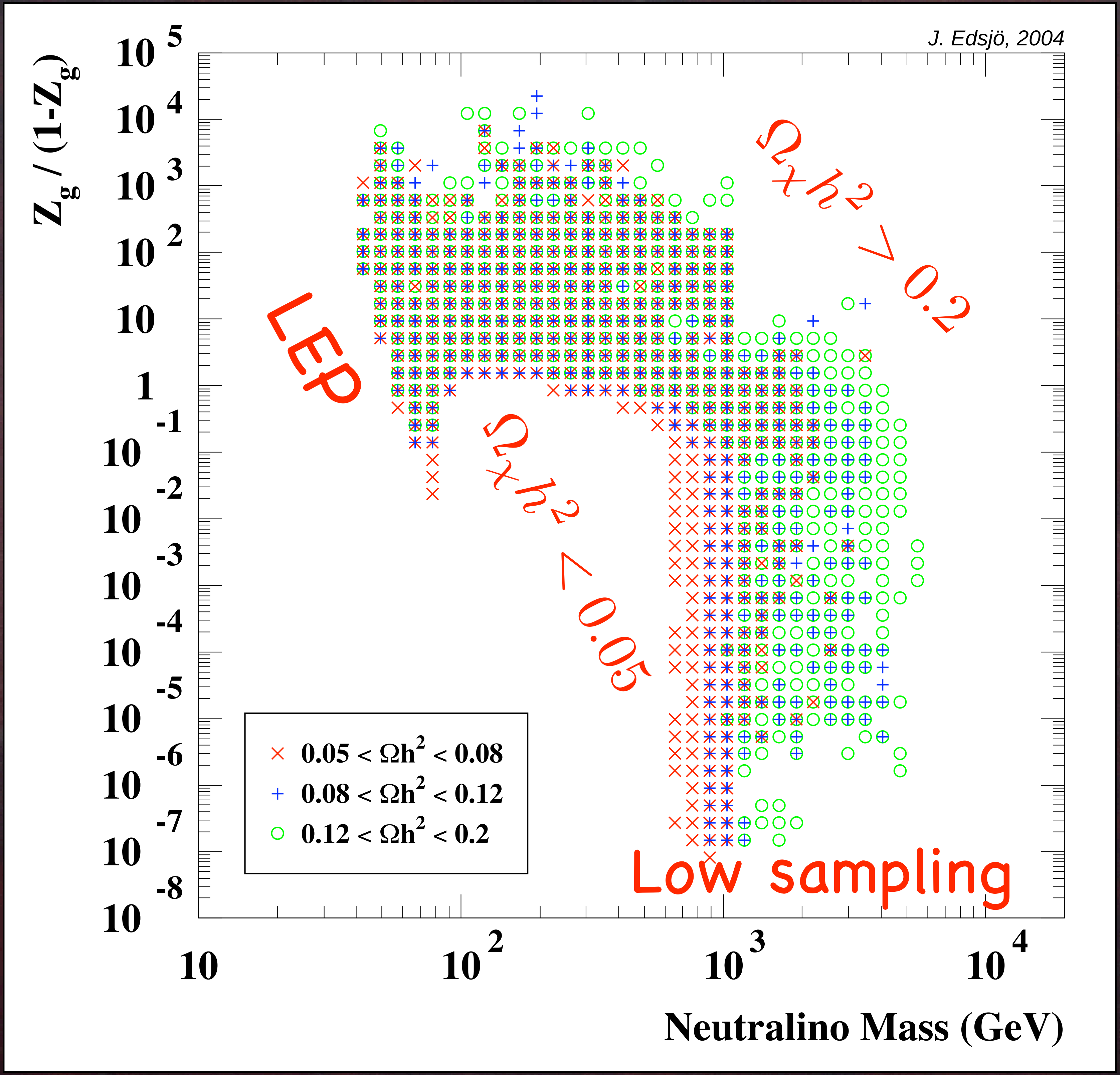
Sun Earth





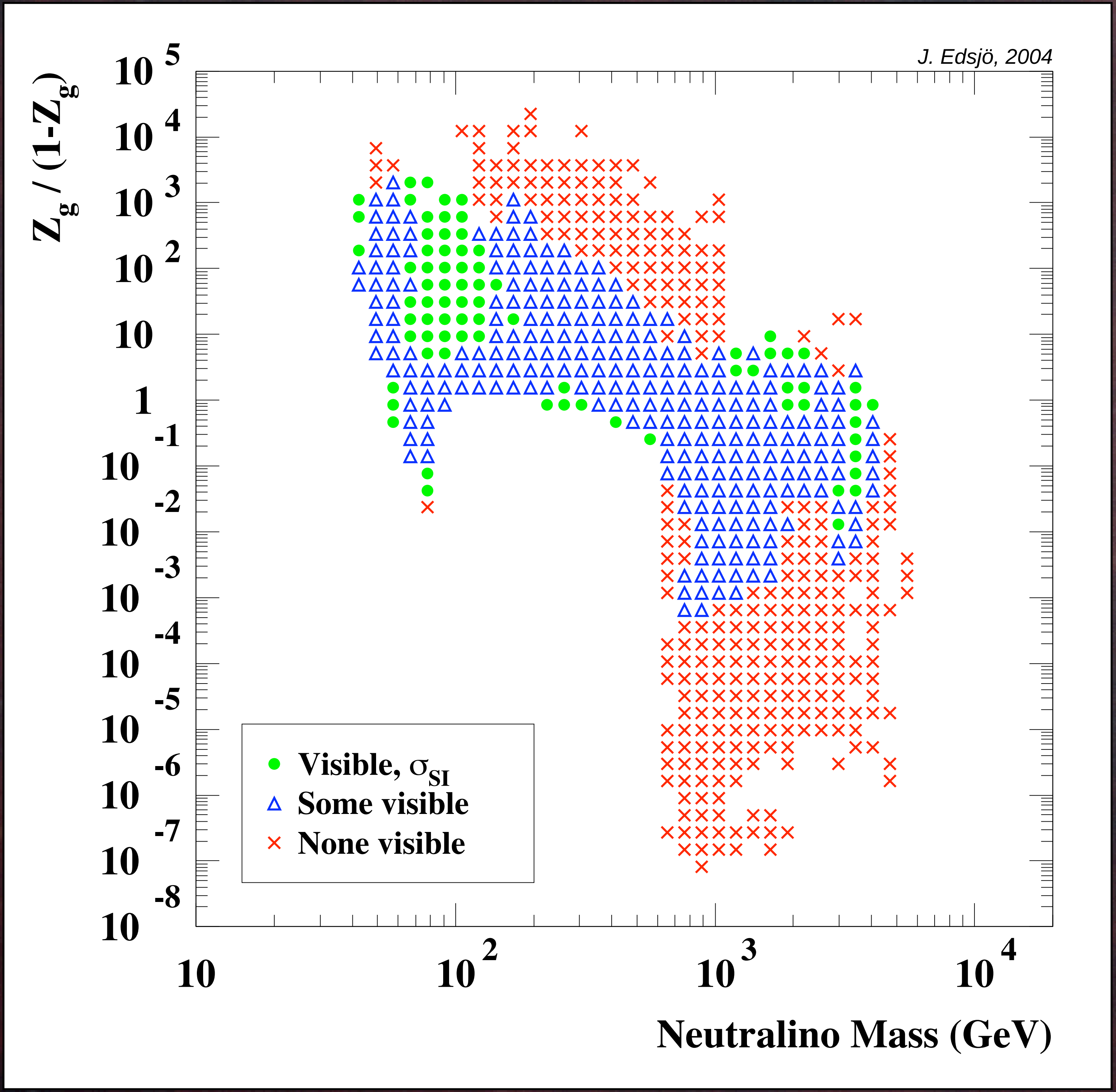
Future direct detection limit is assumed to be GENIUS/CRESST-like with a sensitivity down to 10^{-9} pb.

Comparing future searches in the $m_\chi - Z_g$ parameter space



Comparison of future searches I

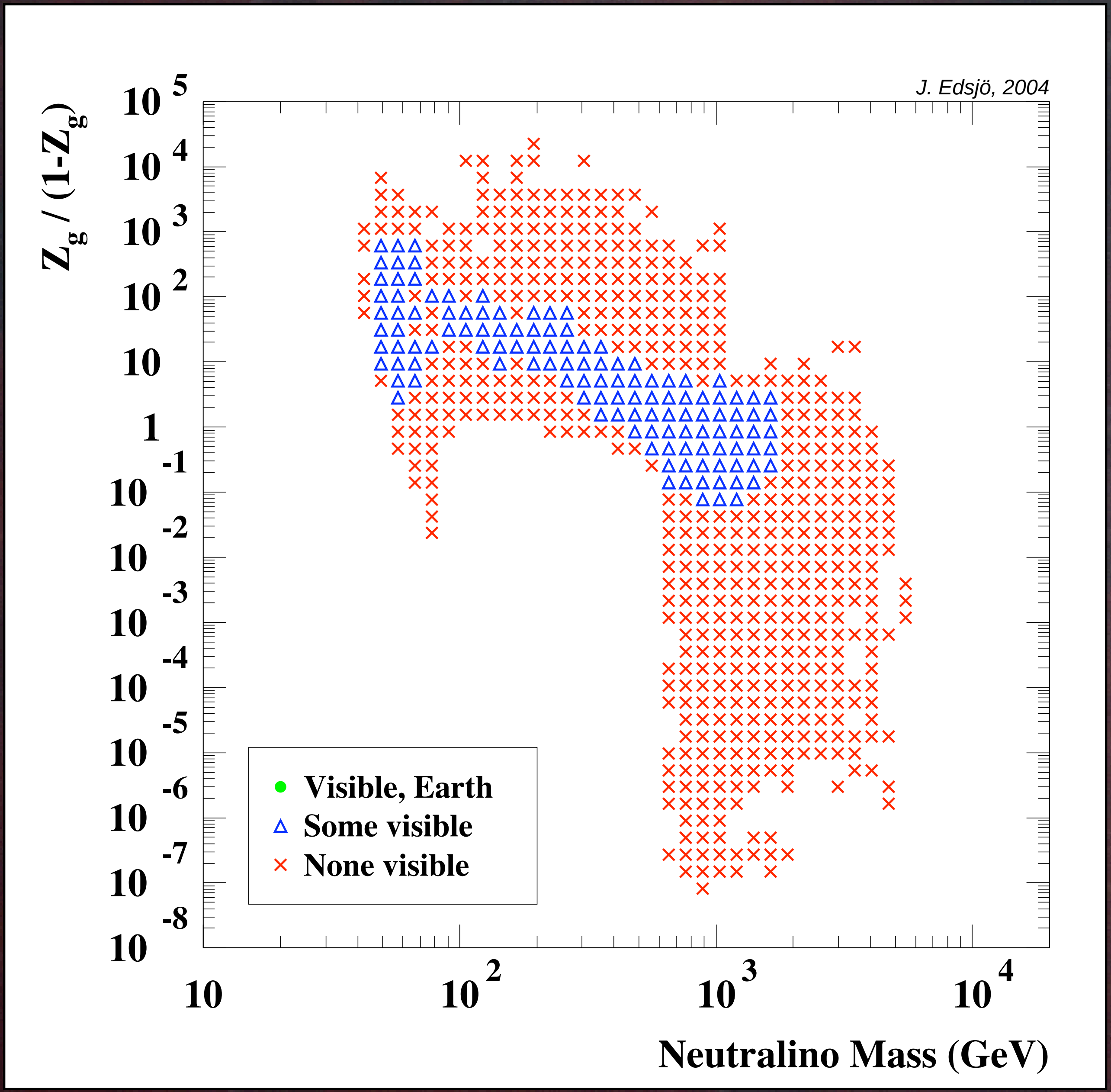
Direct detection, SI



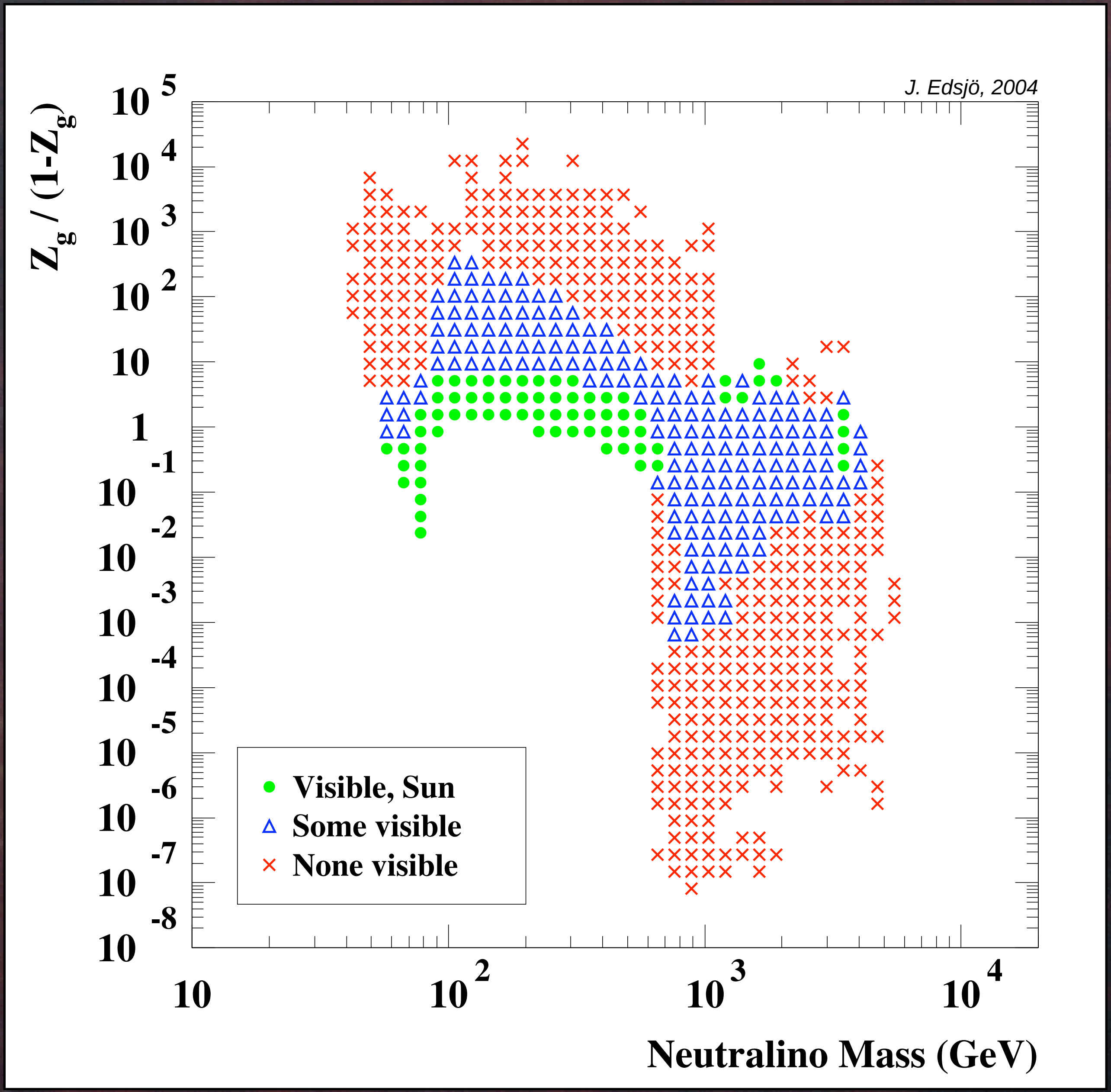
Future limit is assumed to be GENIUS/CRESST-like with a sensitivity down to 10^{-9} pb.

Comparison of future searches II

Earth



Sun

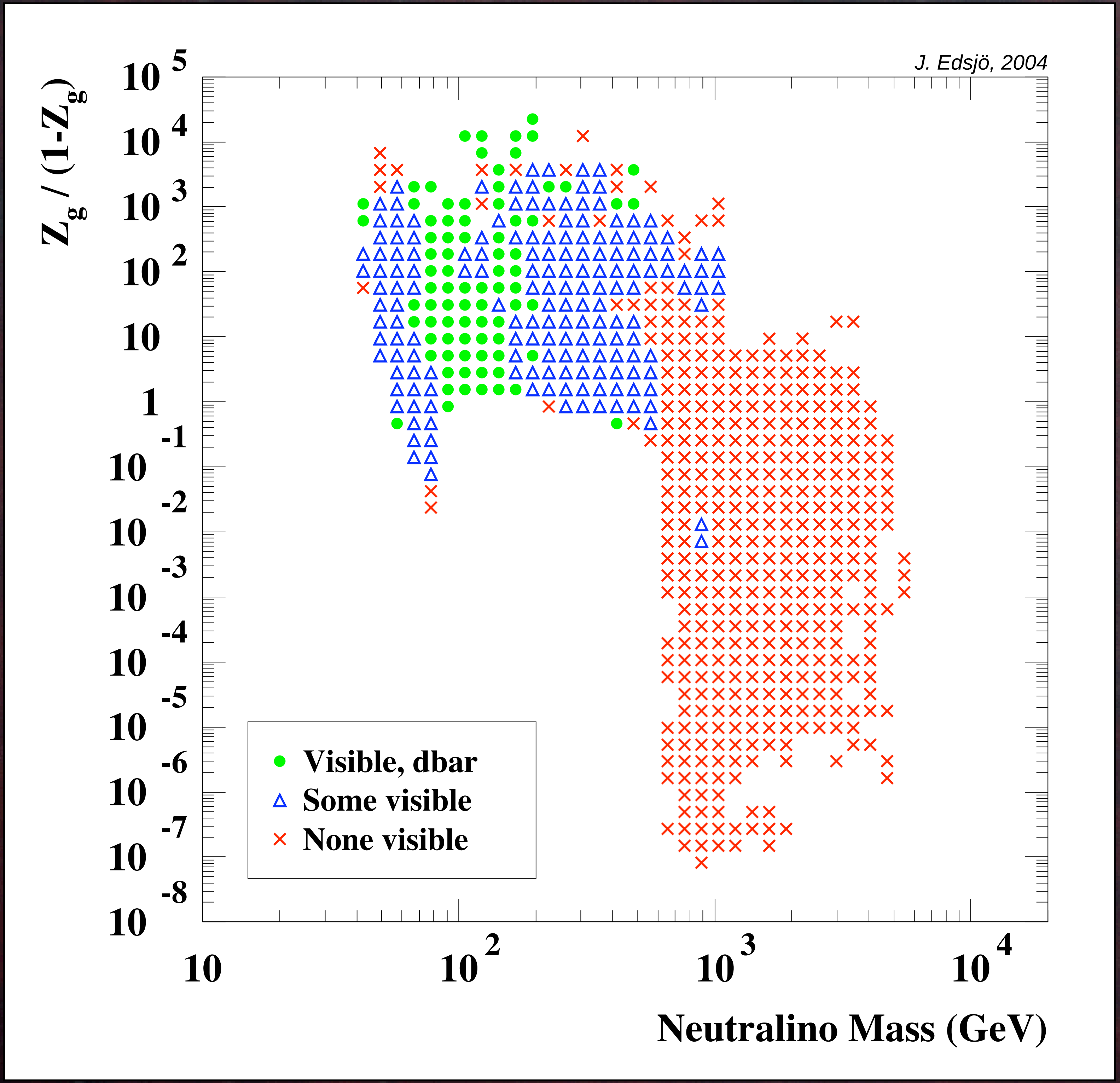


IceCube-like, 1 km^3 running for 10 years (10 years live time)

IceCube-like, 1 km^3 running for 10 years (5 years live time)

Comparison of future searches III

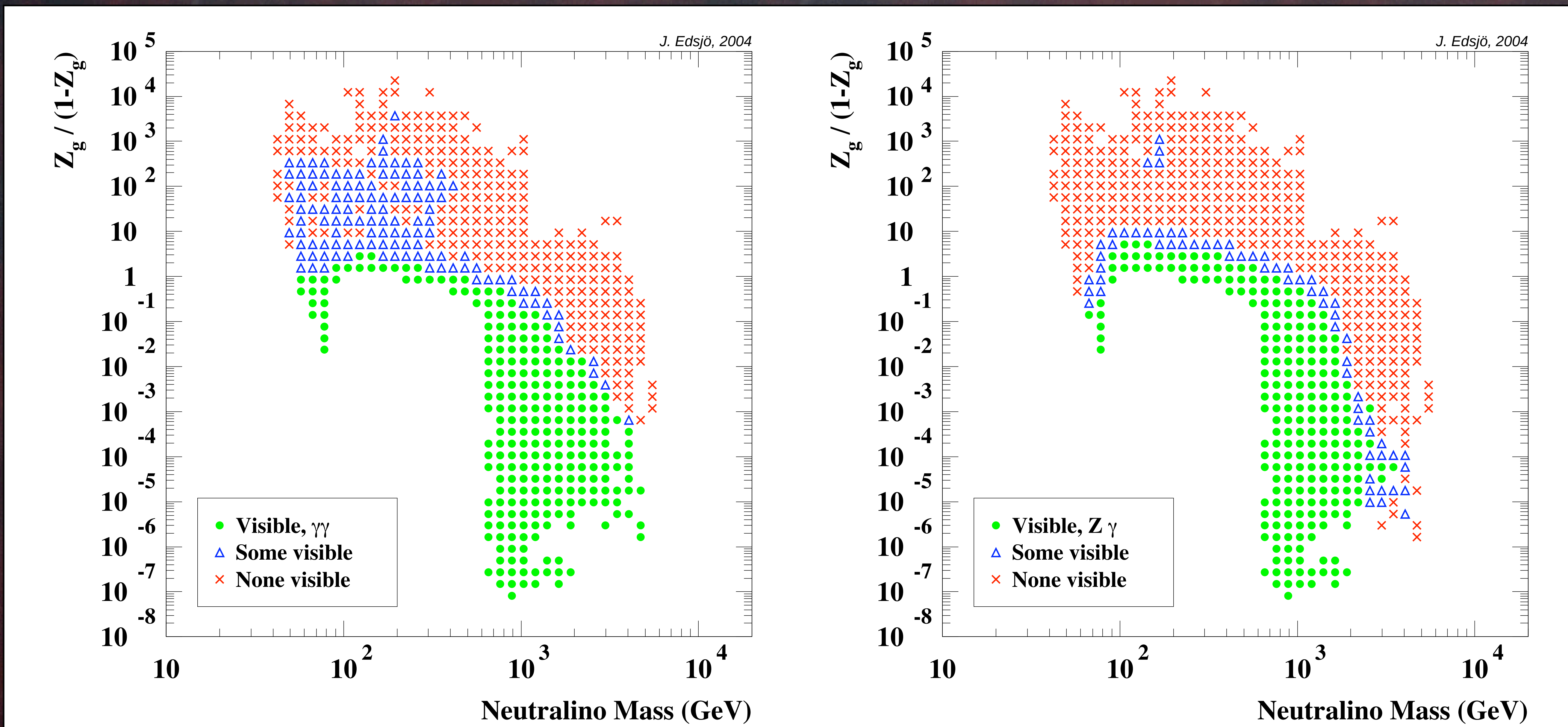
Antideuterons



- Compare with future suggested mission GAPS (Gaseous AntiParticle Spectrometer, K. Mori et al, ApJ 566 (2002) 604)
- Require at least one event (background ≈ 0) at low energies with e.g. GAPS
- Antideuteron production yields from F. Donato, N. Fornengo and P. Salati, Phys. Rev. D62 (2000) 043003.

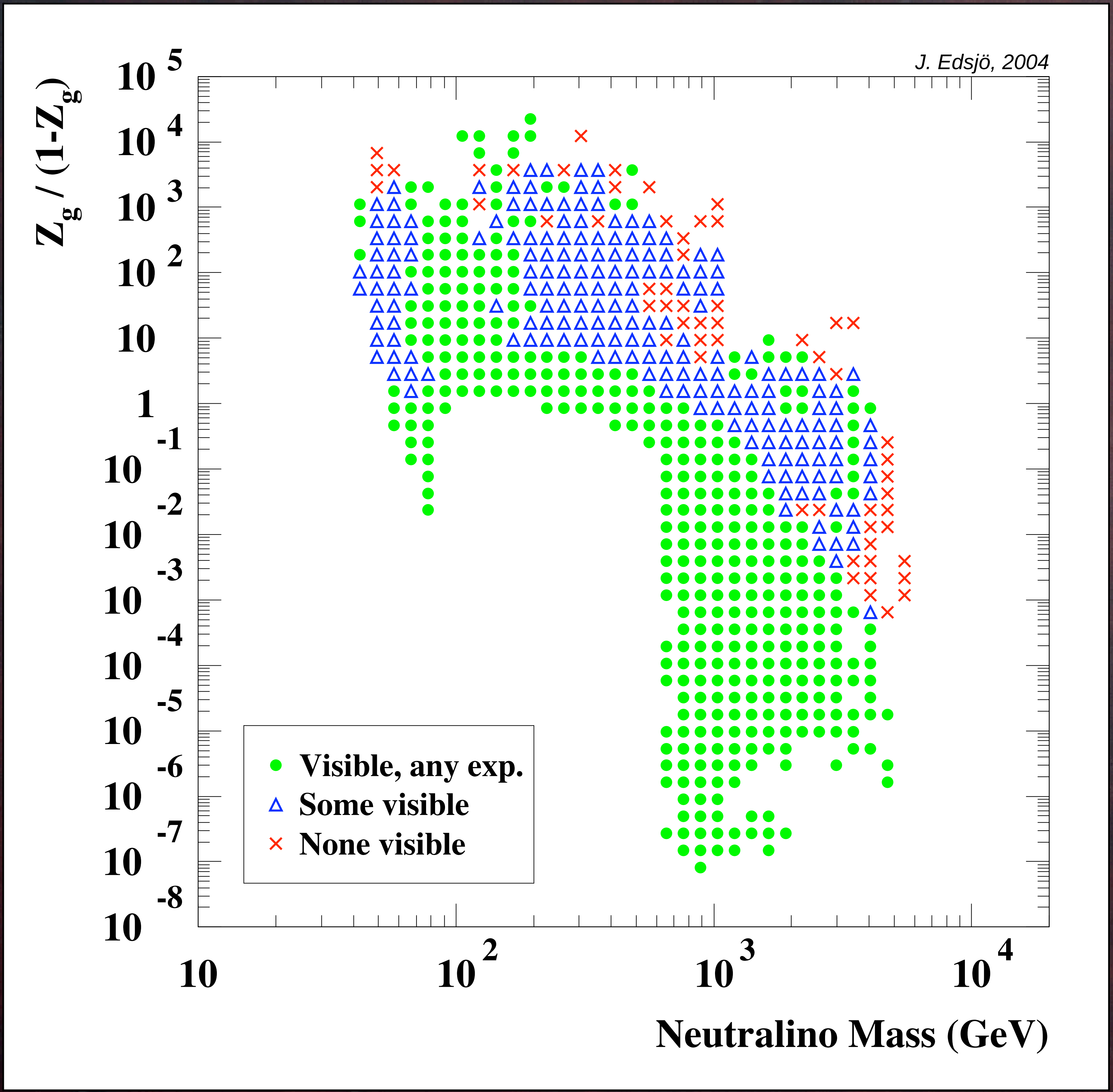
Comparison of future searches IV

γ γ　　　　　　　　Z γ



Significant signal in ACTs or GLAST towards the galactic center with a NFW profile.

Comparison of future searches V



- Large parts of the MSSM parameter space can be probed by future experiments
- The halo model is assumed to be an optimistic NFW profile.
- LHC e.g., will cut into this plane mainly from the left and top.

Conclusions

- Detection prospects of neutralinos are reasonably good.
- For 'standard' halo models, direct detection seems more promising than the neutrino-flux from the Earth, especially after including the depletion of WIMPs due to solar capture
- The neutrino-flux from the Sun is complementary to direct detection due to spin-dependent capture in the Sun
- Searching for antideuterons also seems promising.