WIMP diffusion in the Solar System and the neutrino signal from the Sun and the Earth

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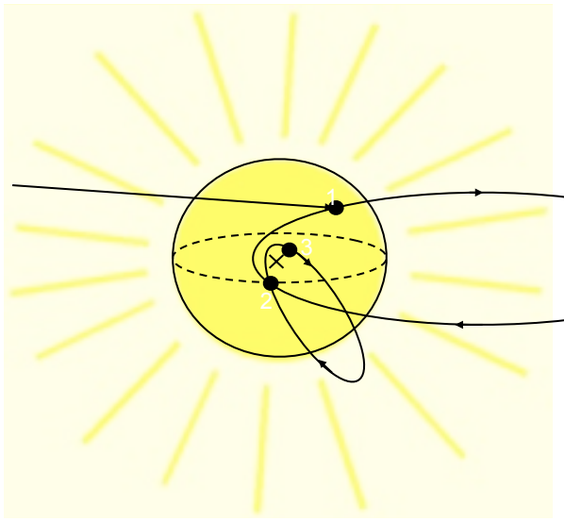
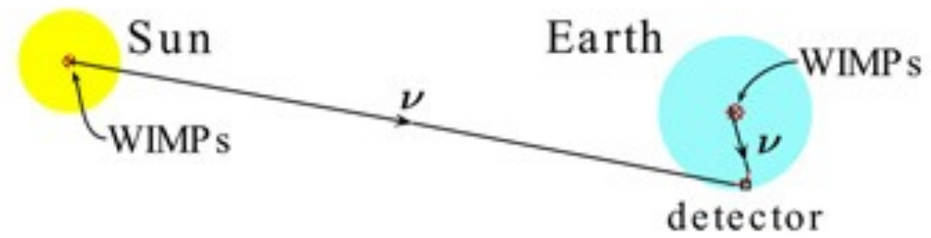
SS & Joakim Edsjö, Phys. Rev. D85 (2012) 123514

DM neutrinos from the Sun/Earth

- Galactic WIMPs pass and scatter off nuclei in the Sun & Earth.
- Some WIMPs loose enough energy to become gravitationally bound (captured) in the scatter.
- WIMPs accumulate in the centers of the Sun/Earth where they annihilate.
- WIMP annihilation -> neutrinos -> neutrino telescope, for example IceCube.
- Here we study the capture of WIMPs.



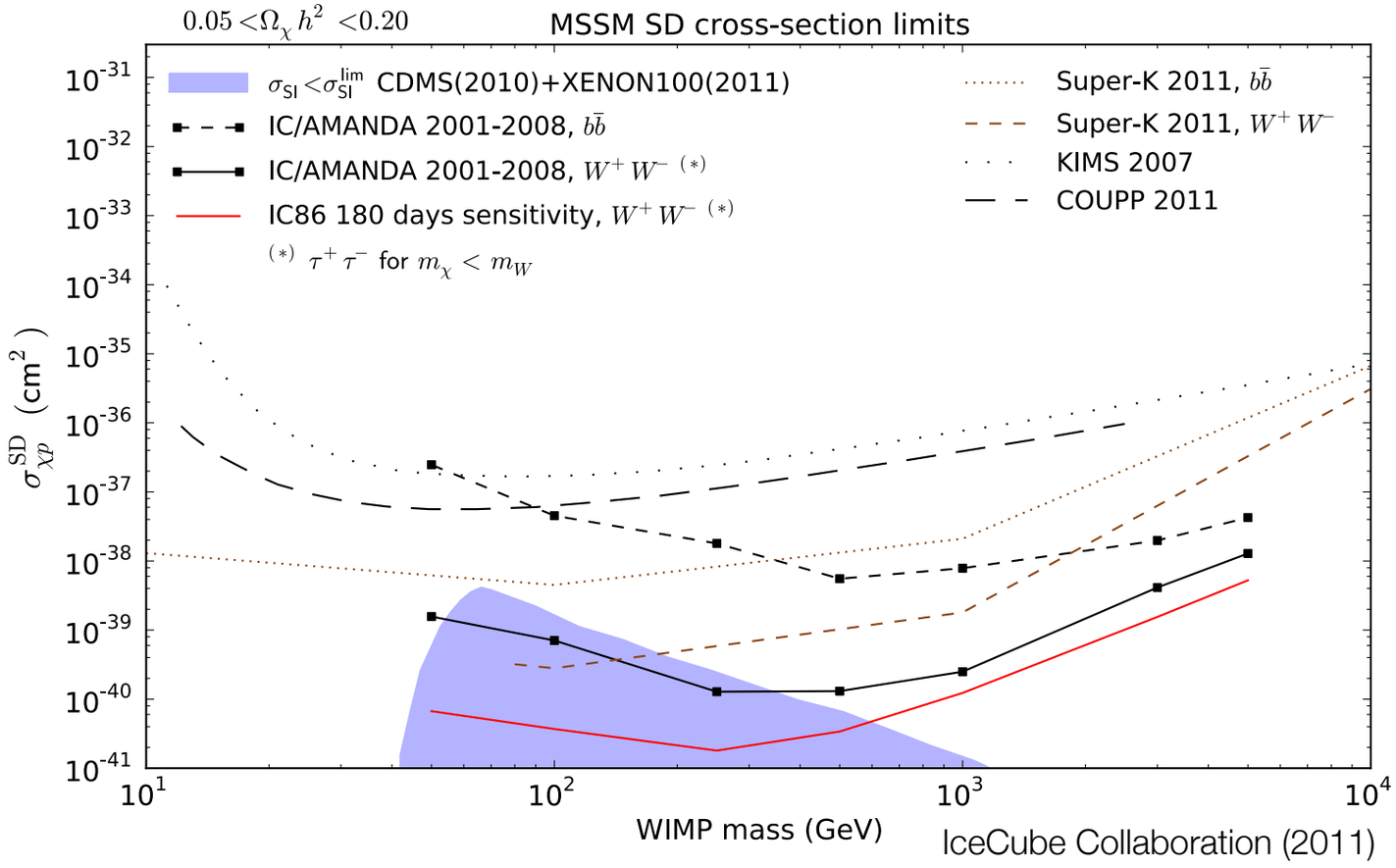


DM neutrinos from the Sun/Earth

- The non-observation of this neutrino signal from the Sun sets strong limits on the spin-dependent scatter cross section.

- The signal depends on the properties of the galactic dark matter halo.

- The presence of a co-rotating dark matter disc boosts the WIMP annihilation rate (with factor ~50 for the Sun and ~1000 for the Earth, Bruch et.al. 2009).



- The insights on the dynamics of dark matter in the Solar System presented in this talk also increases the expected WIMP capture rate, especially for the Earth.

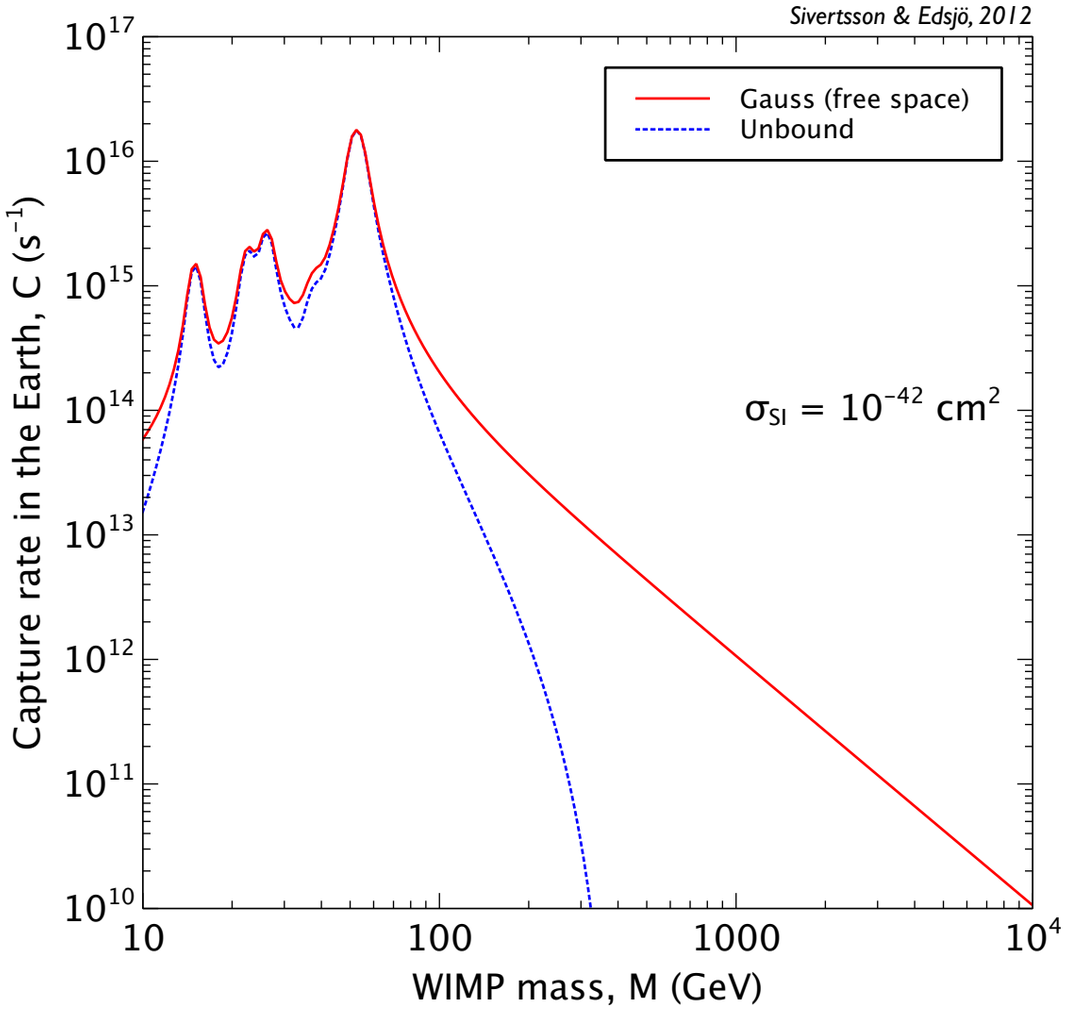
- First a short review.

WIMP capture rate by the Earth

- Early calculations of the capture rates treated the Earth as alone in free space (red line), e.g. Press & Spergel 1985.

- Resonance peaks due to the larger energy loss in the scatter if the WIMP and target nucleus are similar in mass.

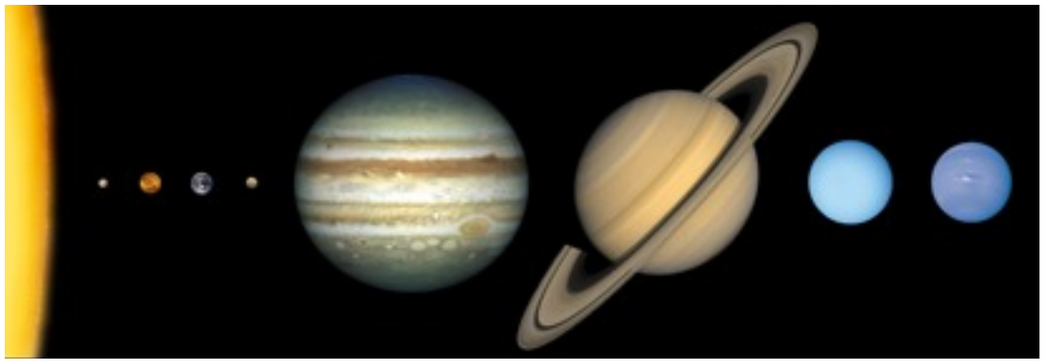
- Galactic WIMPs passing the Earth have however also been accelerated by falling towards the Sun.
  -Unables the Earth to capture heavy WIMPs (blue dotted line), Gould 1988.



WIMP diffusion via gravitational interactions

- Planetary interaction give gravitational slingshots, altering the WIMP velocity relative the Sun.

- Especially Jupiter (mass: 318 Earth masses) does this quite efficiently.



- Gravitationally diffuses WIMPs between the galactic halo and the Solar System.

- Generates a WIMP population bound to the Solar System from which the Earth can capture WIMPs.

Liouville's theorem

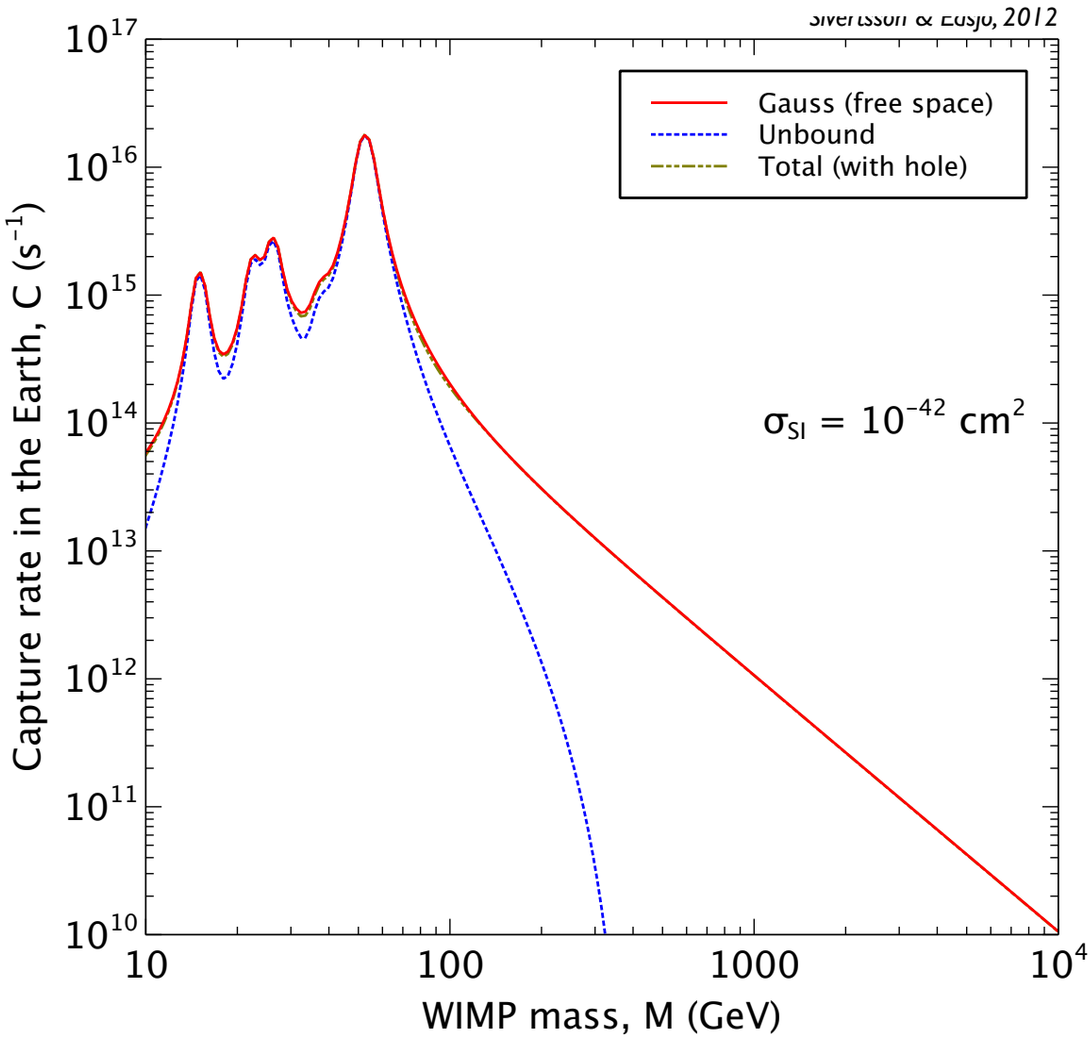
- Liouville's theorem: Gravitational diffusion preserves phase space density.

- Hence the WIMP population bound to the Solar System has same phase space density as the Galactic WIMP population.

- Gould 1991: Earth's WIMP capture rate can be calculated as if the Earth were alone in the Galaxy.
  (Liouville's theorem + efficient mixing)

- Hence essentially a return to the original prediction

- There are however more complications...

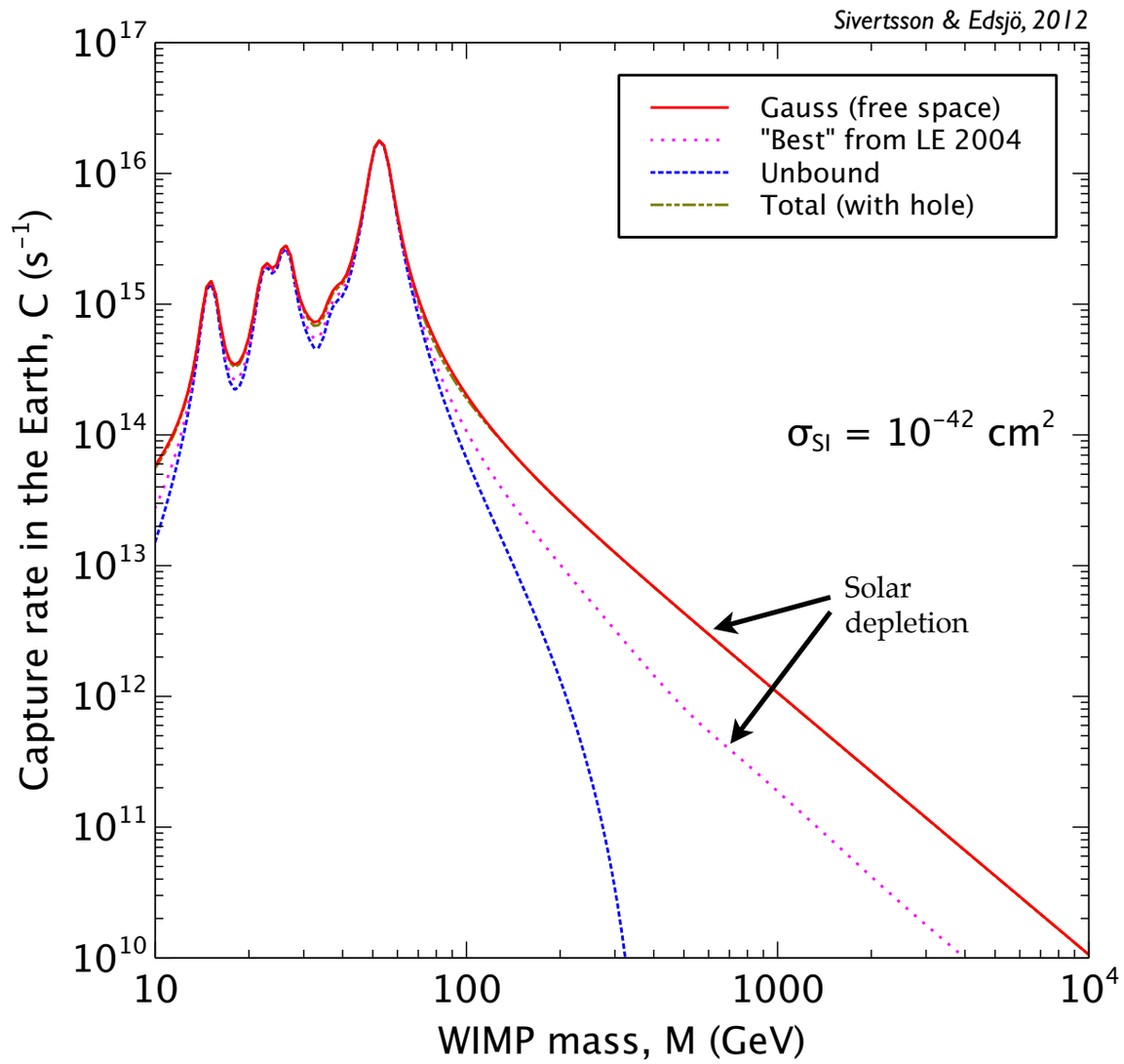


Solar depletion for the Earth

- WIMPs bound to the Solar System can also be captured by the Sun, reducing the bound WIMP population.

- Earth passing asteroids are efficiently driven into the Sun by Solar System resonances, Farinella et.al. 1994.

- **Solar depletion**
  Lundberg & Edsjö 2004 simulated solar depletion for WIMPs numerically (pink dotted line).

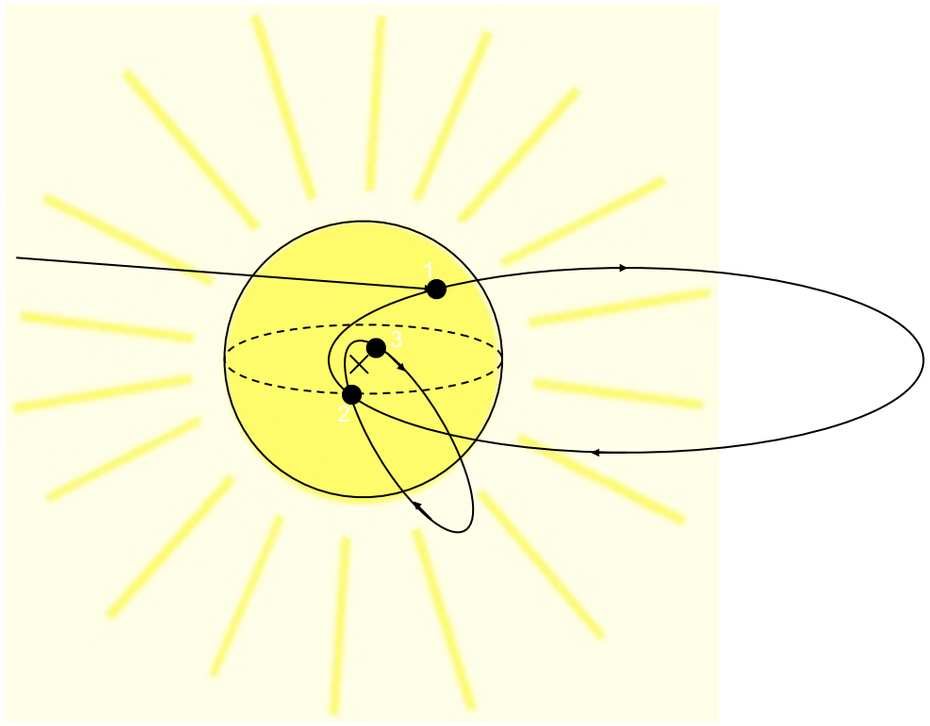


Jupiter depletion for the Sun

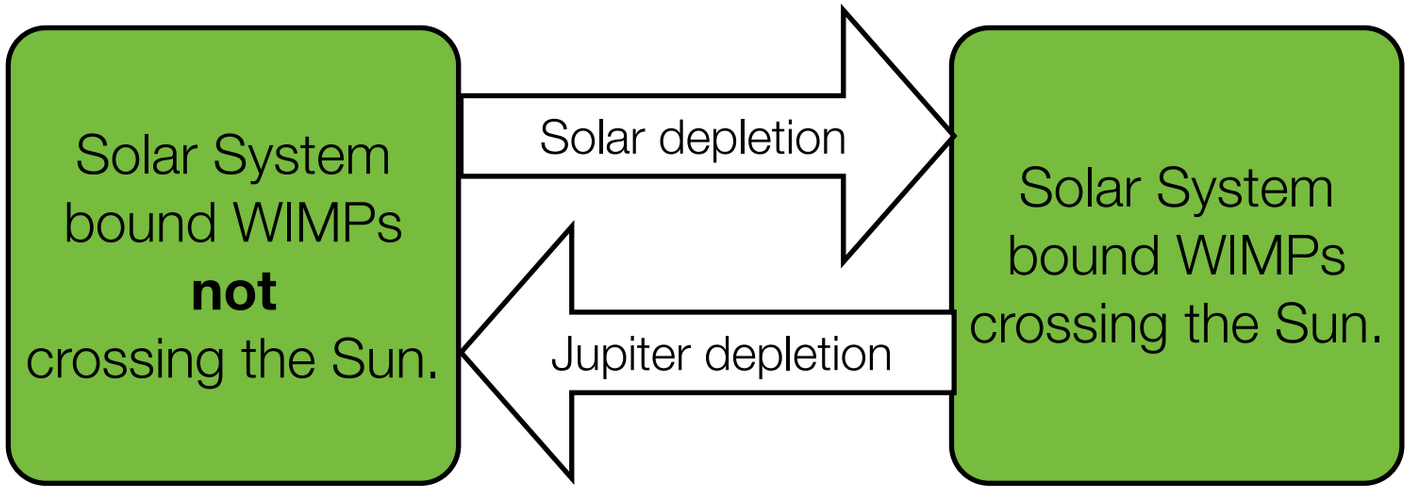
- Solar WIMP capture can be treated as if the Sun has no planets, except for...

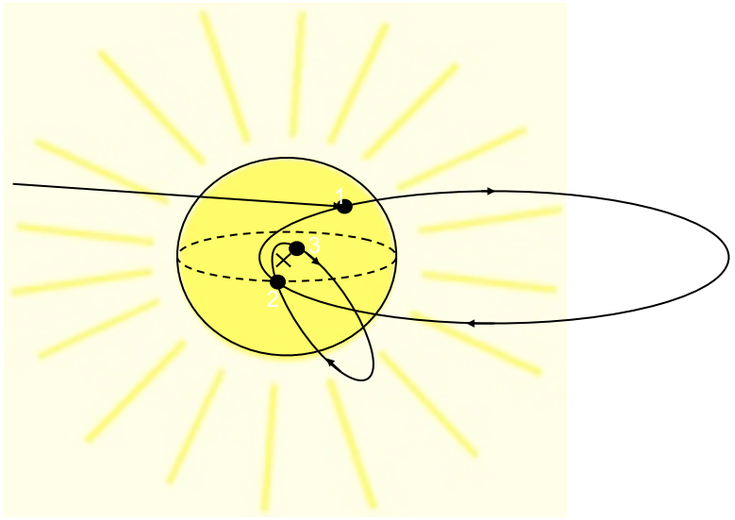
- Jupiter depletion (Peter 2009):
  All WIMPs captured by the Sun that reach Jupiter will be thrown away by Jupiter before having time to scatter again in the Sun.

- Substantially reduces the Solar capture rate for heavy WIMPs (above ~10 TeV) which scatter spin-dependently.



That was the review, what's new?

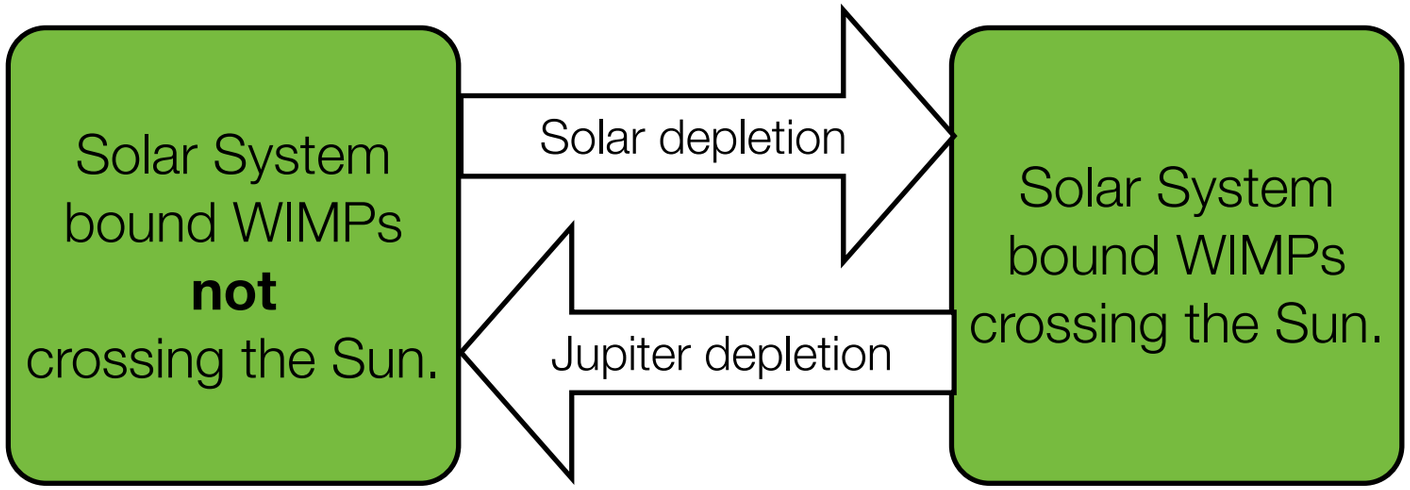




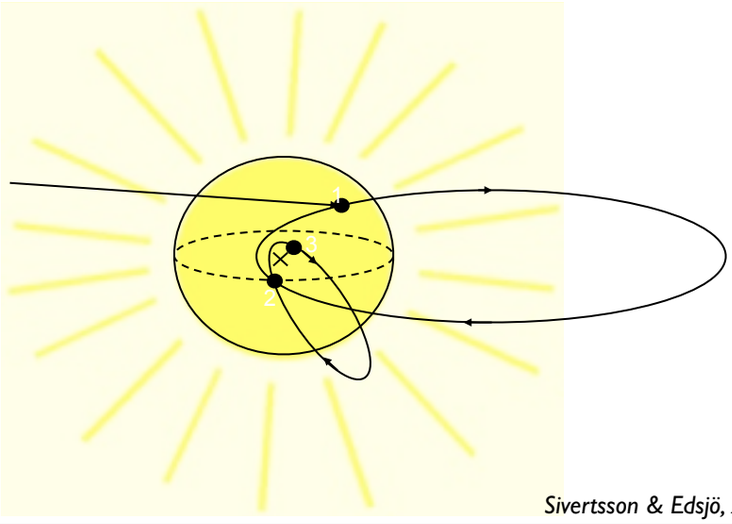
- Gravitational diffusion between two populations, in which direction is the net effect?

- Which has the largest phase space density?

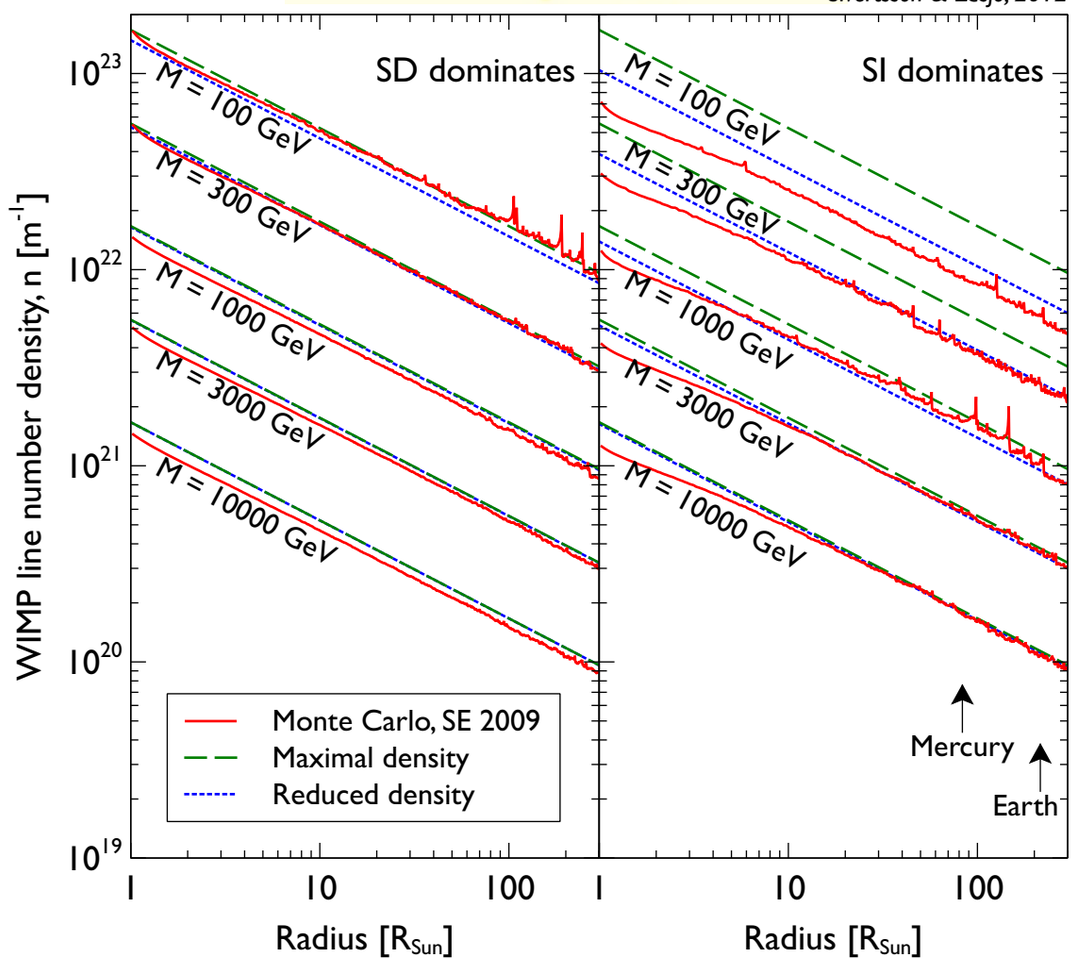
That was the review, what's new?



- Gravitational diffusion between two populations, in which direction is the net effect?
- Which has the largest phase space density?
- Phase space density turns out to be essentially the same! *(numerically verified)*
- Can approximately use Liouville's theorem also for WIMPs scattering off nuclei in the Sun!



Sivertsson & Edsjö, 2012



What happens with Jupiter and Solar depletion?

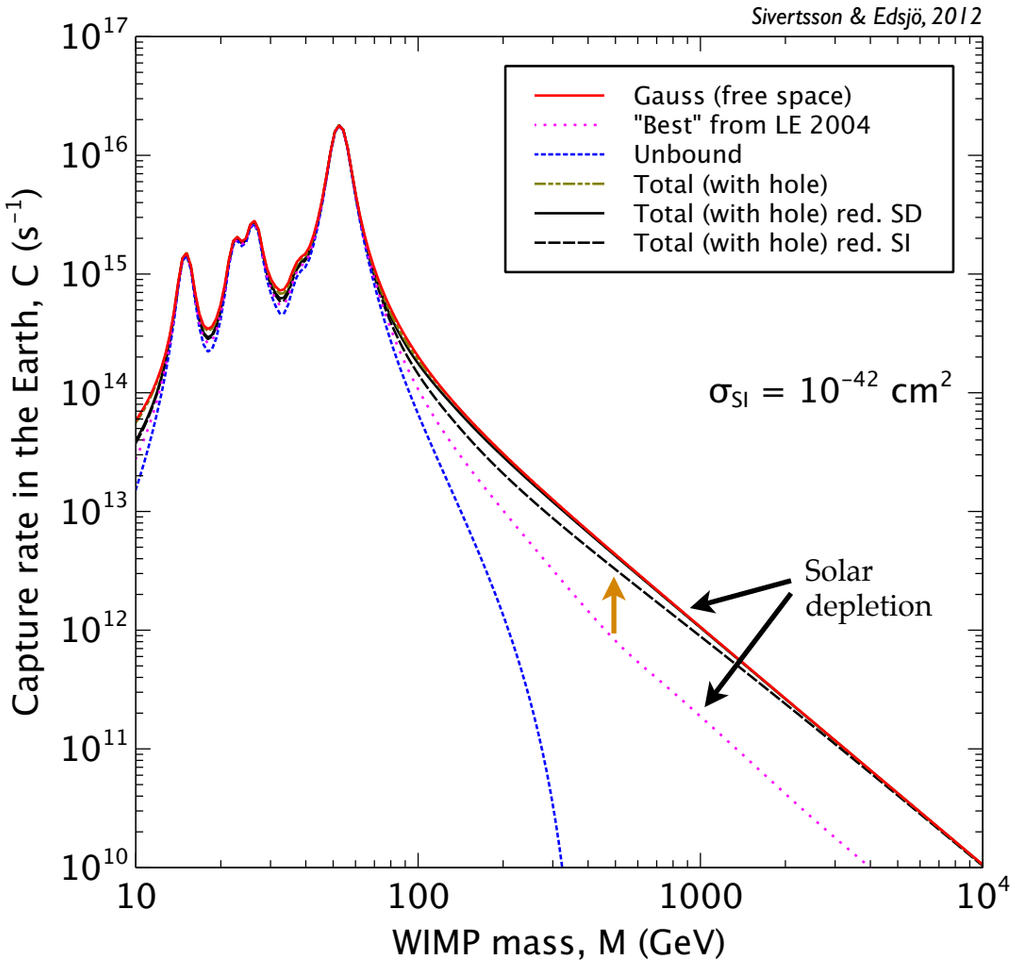
- Liouville's theorem (that phase space density is preserved) is generically not applicable to nucleon scatters. However, planet-reaching WIMPs scattering in the Sun turn out to approximately fulfill the conditions for Liouville's theorem.

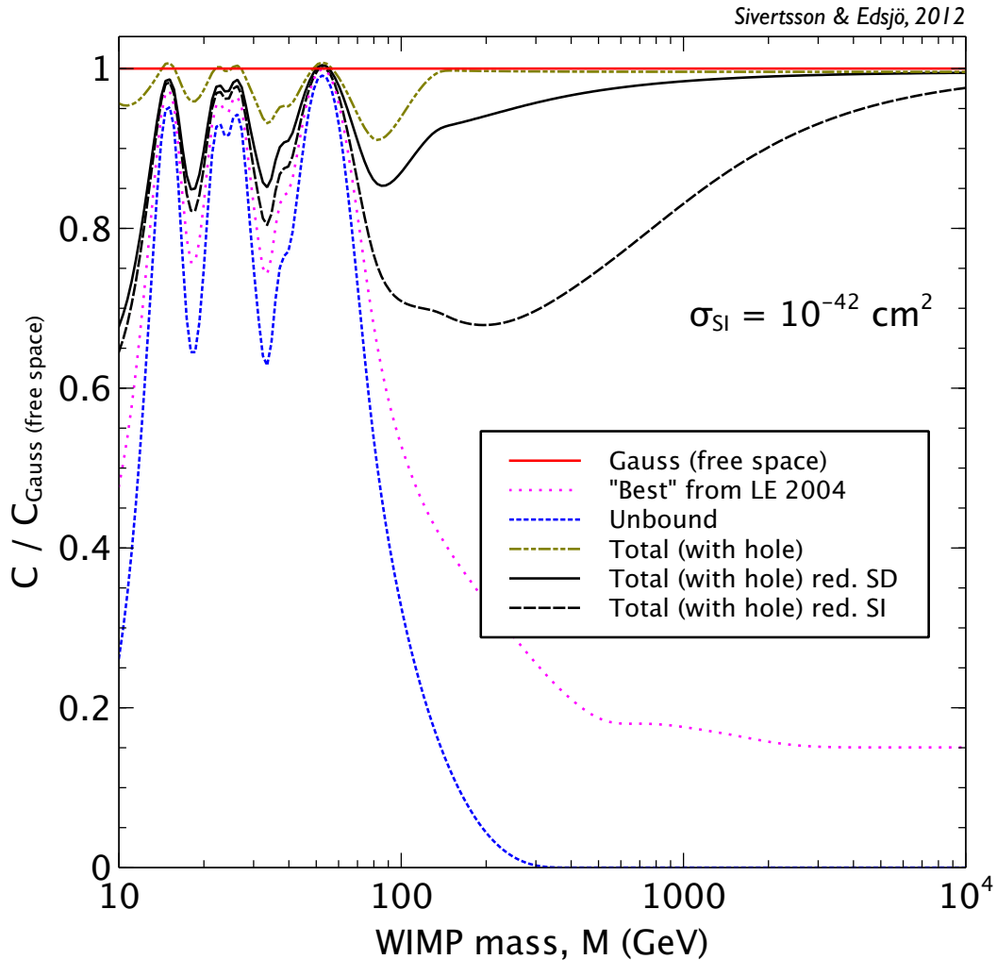
- Jupiter depletion: Cancelled by Jupiter throwing bound WIMPs into the Sun.

- Can ignore the planets when determining the Solar WIMP capture rate.

- Solar depletion: Almost completely cancelled by Solar crossing WIMPs being gravitationally perturbed.
  - The reason for the *almost* is that the galactic WIMP phase space density depends on WIMP velocity (capture via scattering and gravitational slingshot probes different galactic velocities).

What happens with Jupiter and Solar depletion?





- WIMP capture by the Earth can *almost* be treated as if the Earth were alone in the Galaxy.
  Black lines are the worst case scenarios for spin-dependent (solid) respectively spin-independent (dashed) scattering dominating in the Sun.
  -The Earth has typically not reached equilibrium between WIMP capture and annihilation, giving a boost to the expected annihilation rate by ~10^2=100.

- There is no Jupiter depletion effect on the Solar WIMP capture rate.

The End

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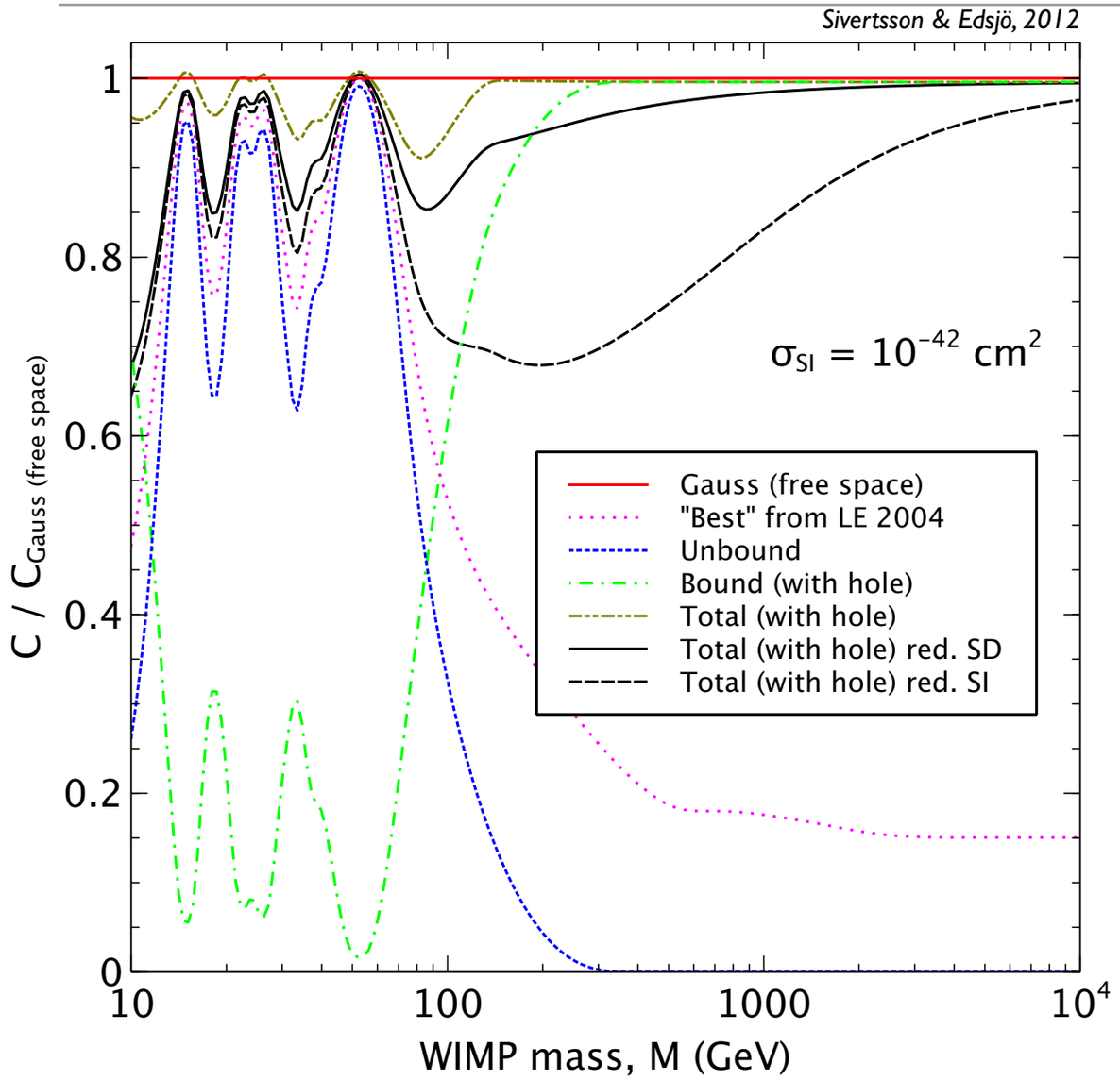
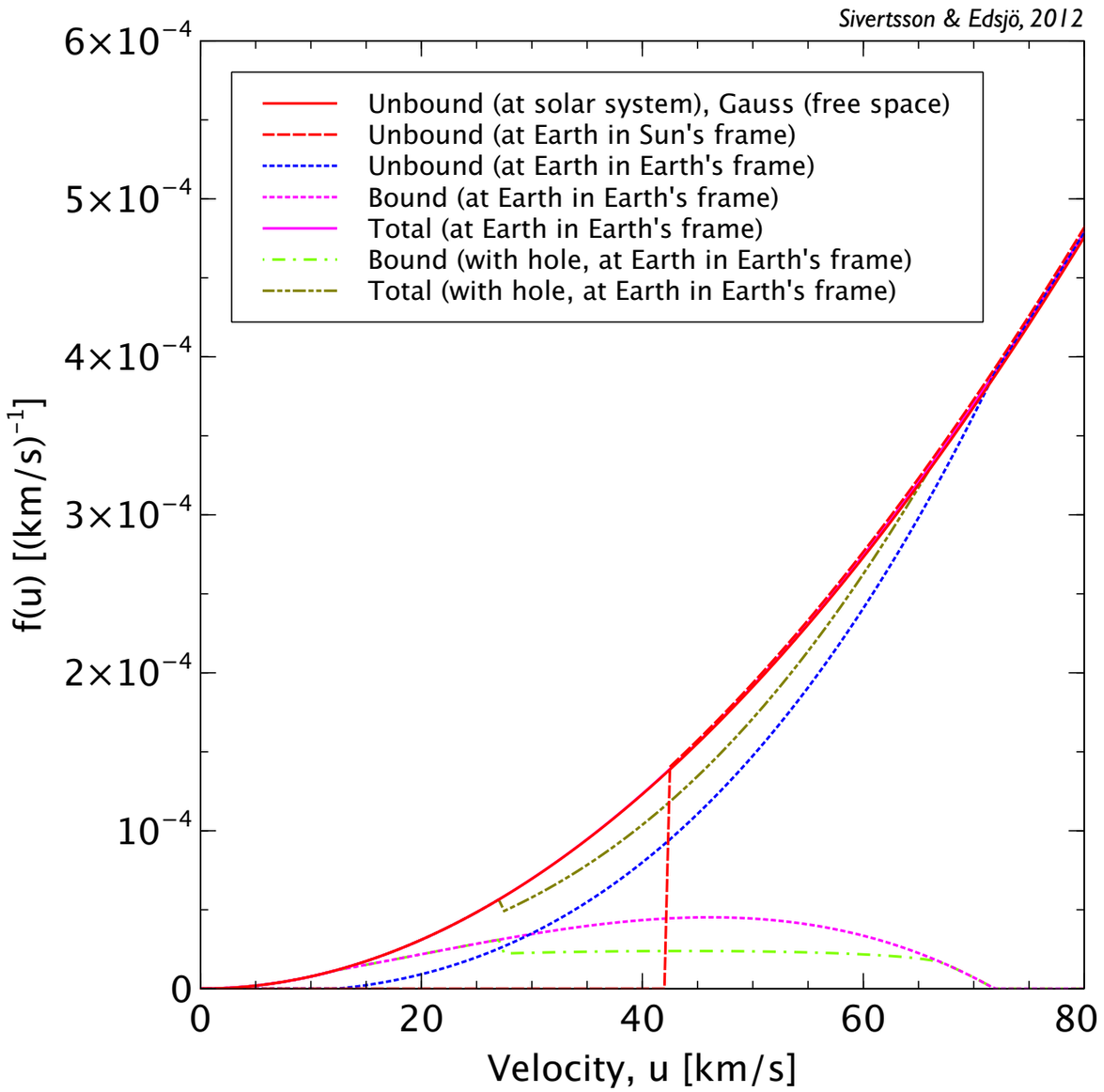
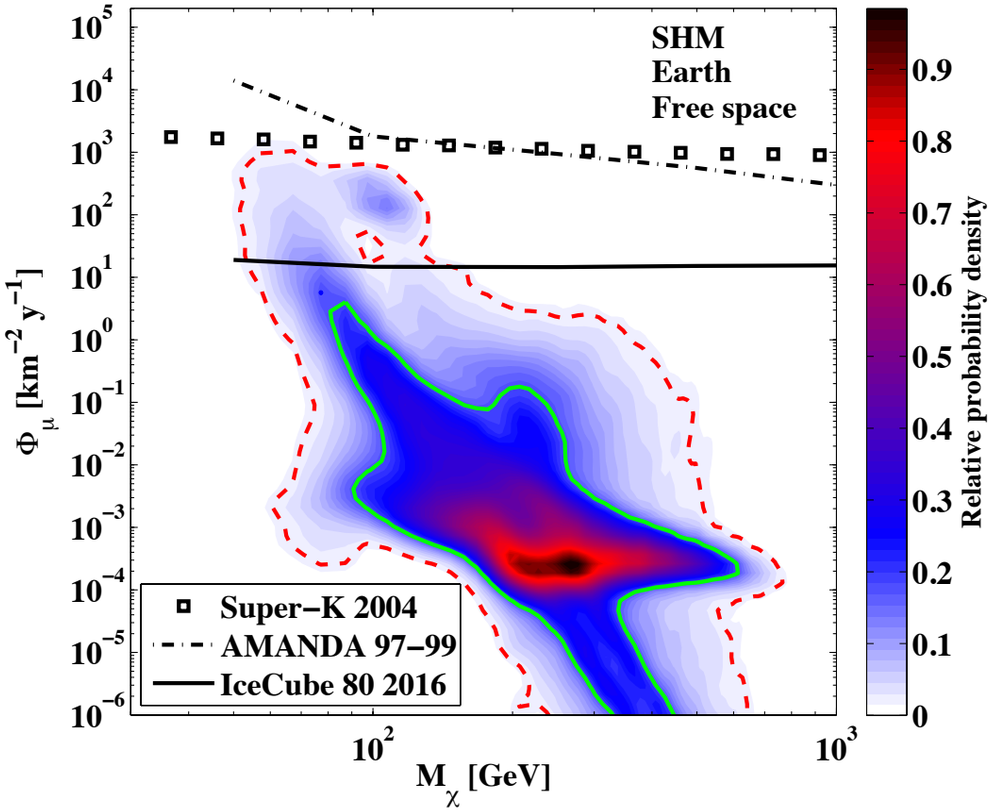
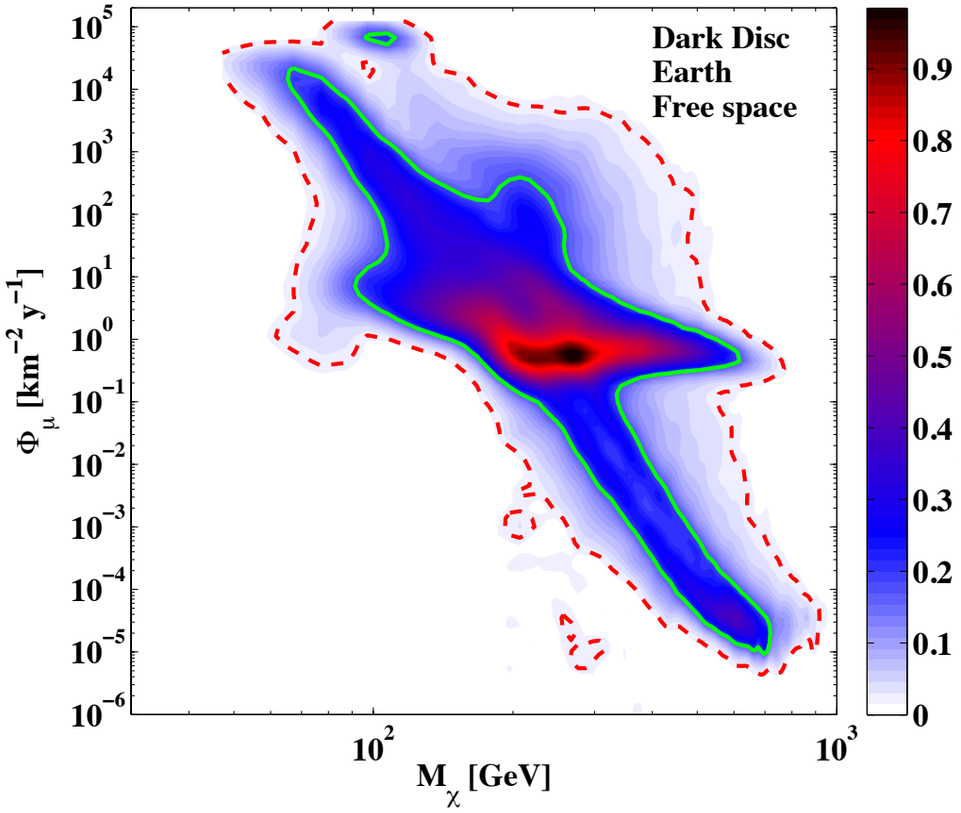
Extra


Sivertsson & Edsjö, 2012
$\sigma_{SI} = 10^{-42}$ cm^2
Gauss (free space)
"Best" from LE 2004
Unbound
Bound (with hole)
Total (with hole)
Total (with hole) red. SD
Total (with hole) red. SI
C / C$_{Gauss (free space)}$
WIMP mass, M (GeV)


Sivertsson & Edsjö, 2012
Unbound (at solar system), Gauss (free space)
Unbound (at Earth in Sun's frame)
Unbound (at Earth in Earth's frame)
Bound (at Earth in Earth's frame)
Total (at Earth in Earth's frame)
Bound (with hole, at Earth in Earth's frame)
Total (with hole, at Earth in Earth's frame)
f(u) [(km/s)$^{-1}$]
Velocity, u [km/s]

Bruch, Peter, Read, Baudis, Lake (2009)





- CMSSM models with both astrophysical and cosmological constraints (of 2009). Flat priors. (0902.4001)