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

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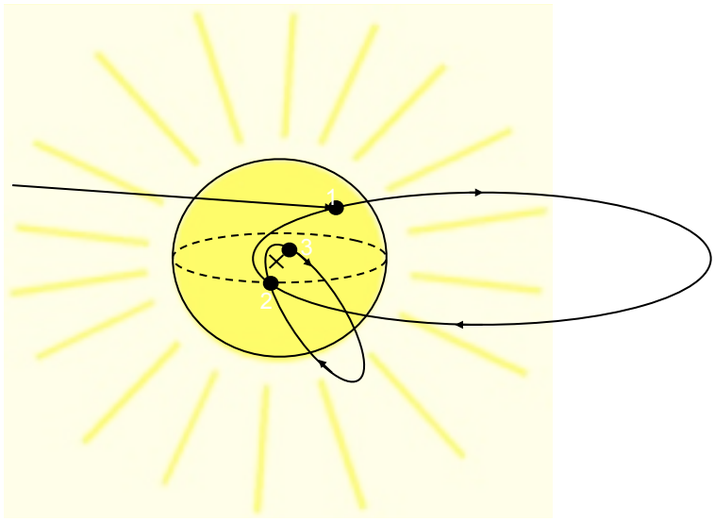
SS & Joakim Edsjö, Phys. Rev. D85 (2012) 123514, arXiv:1201.1895

DM neutrinos from the Sun/Earth

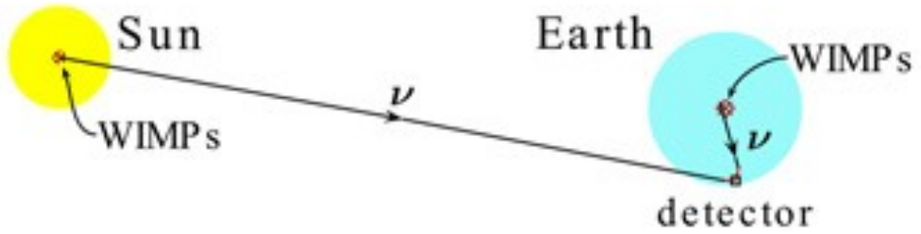
- Galactic WIMPs pass and scatter off nuclei in the Sun & Earth.



- Some become gravitationally bound in the scatter (captured), accumulate in the centers of the Sun/Earth.

- WIMPs annihilate -> neutrinos -> IceCube neutrino telescope.

- The presence of a co-rotating dark matter disc boosts the WIMP annihilation rate inside the Sun and especially the Earth (factor ~1000, Bruch et.al. 2009), see Joakim's talk.



- 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.

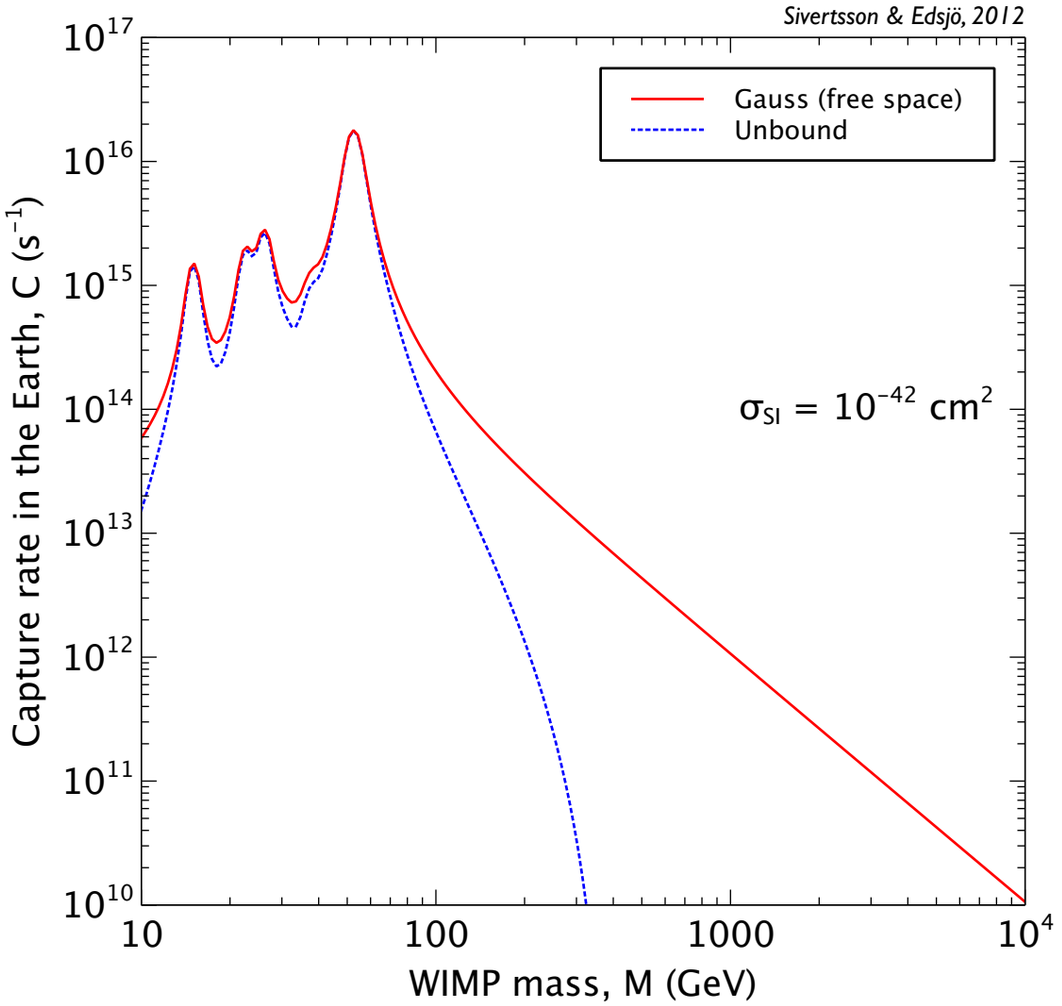
- To understand why we start with a review of how the understanding of the dark matter dynamics have evolved over the years and how this have affected the predicted WIMP capture rate in the Sun/Earth.

The dark matter capture rate

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

- For a WIMP to be captured it must scatter to a velocity below the local escape velocity. Easier for slow moving WIMPs and if the WIMP and target nucleus are similar in mass.

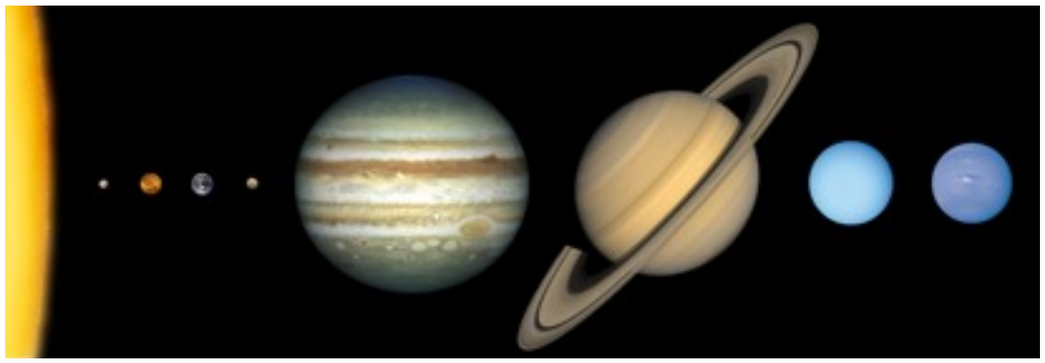
- Galactic WIMPs passing the Earth are accelerated by the Sun, unables the Earth to capture heavy WIMPs (blue dotted line), Gould 1988.



The Solar System has planets

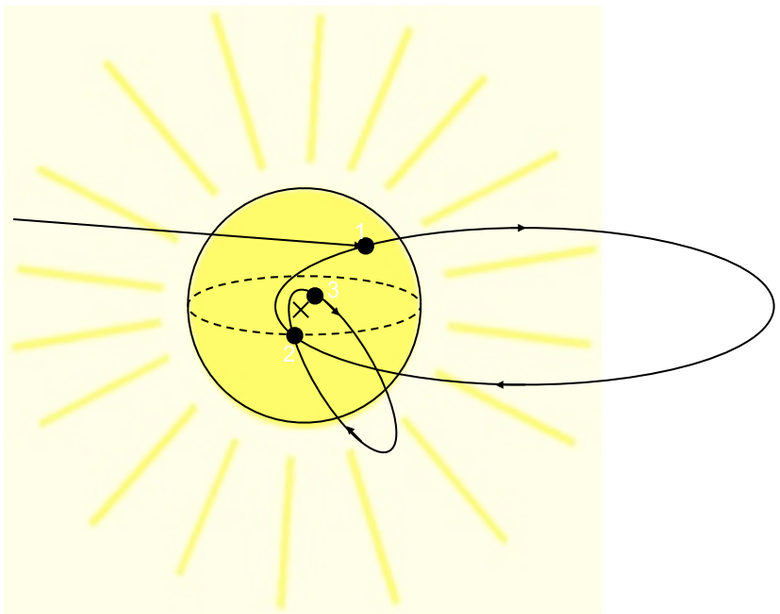
- Planetary interaction give gravitational slingshots, altering the WIMP velocity relative the Sun.

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



- Throws in WIMPs from the Galactic halo.

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



- Jupiter also disturbs WIMPs which the Sun has captured.

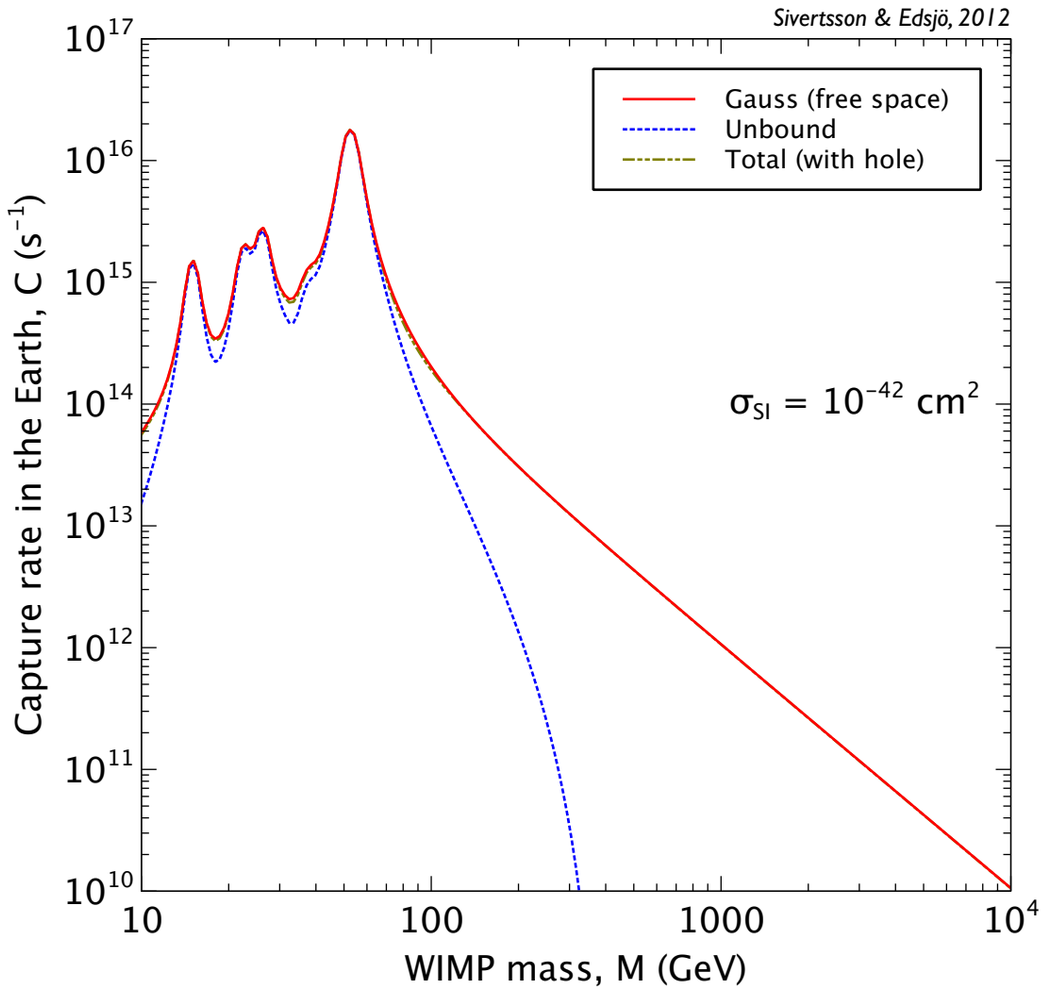
Liouville's theorem

- 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.

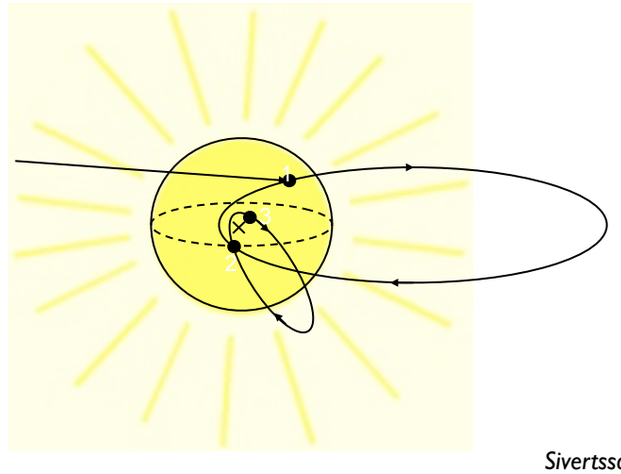
- Gould 1991: Earth's WIMP capture rate can be calculated as if the Earth were alone in the Galaxy.
  (Liouville's theorem + efficient mixing)

- Hence a return to the original prediction.



Solar and Jupiter depletion

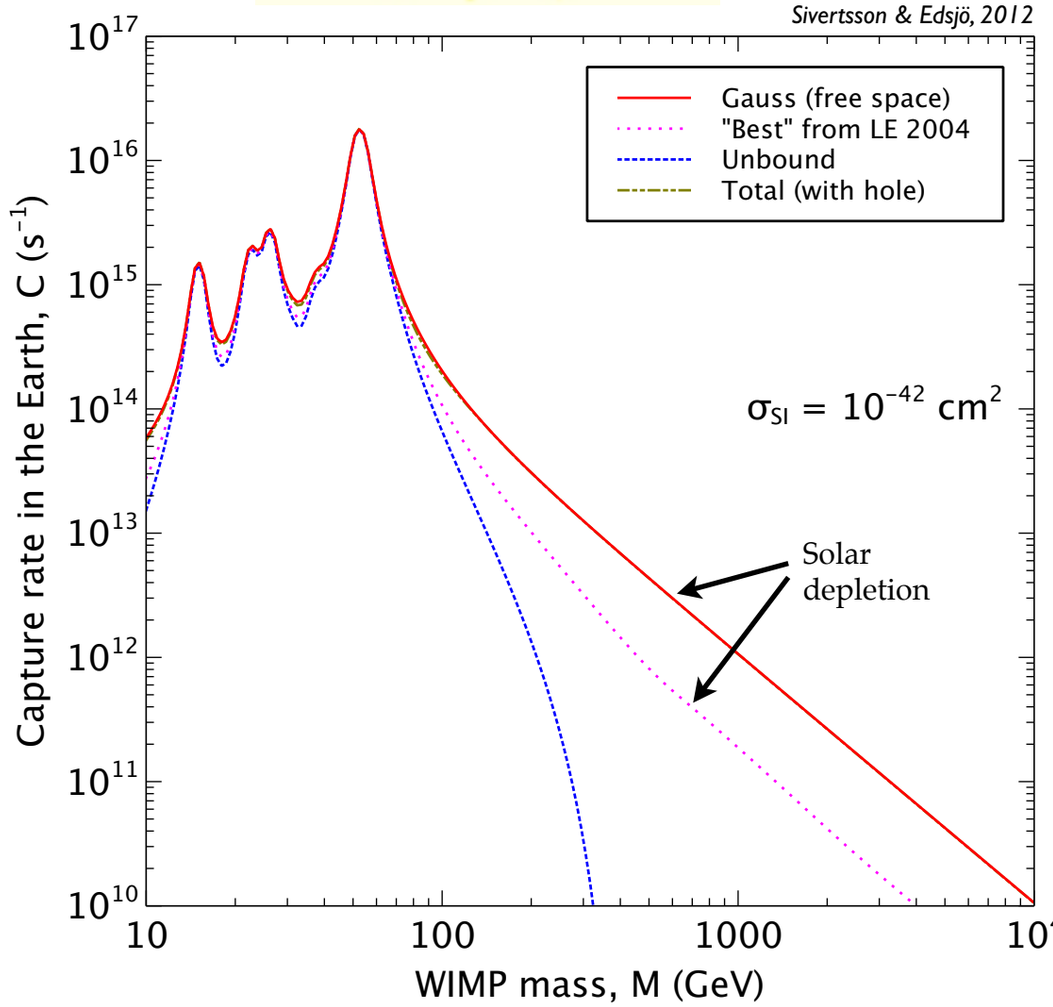
- **Jupiter depletion** (Peter 2009):
  All WIMPs captured by the Sun that reach Jupiter will be thrown away by Jupiter before scattering in the Sun again.



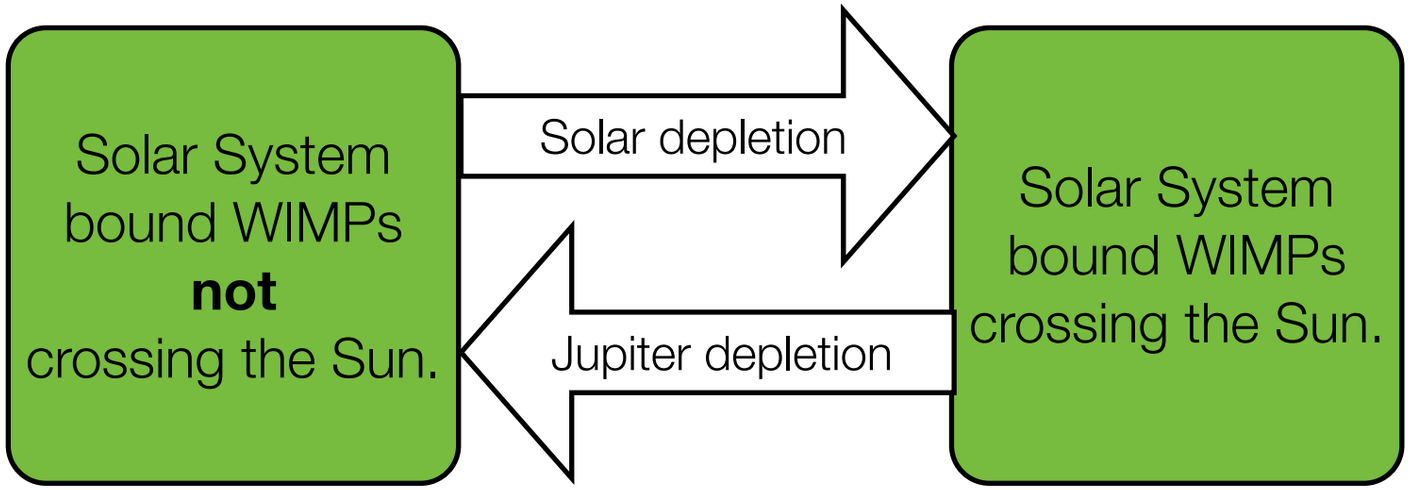
- Substantially reduces the Solar capture rate for heavy WIMPs (above ~10 TeV) which scatter spin-dependently.

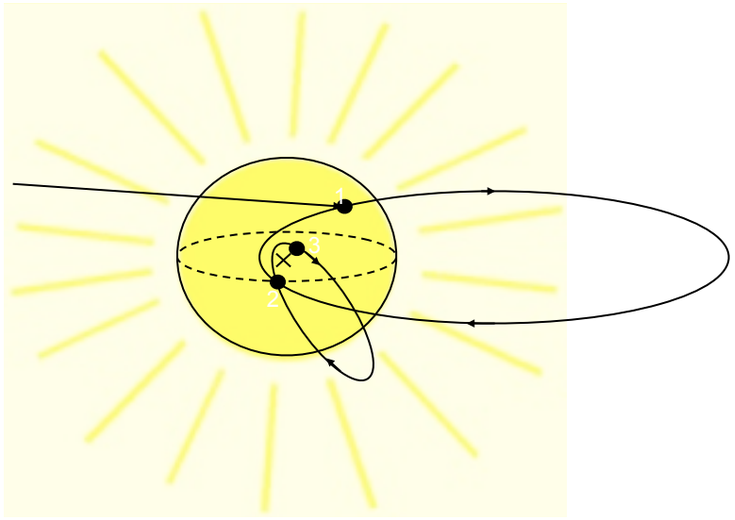
- **Solar depletion**:
  Earth passing WIMPs bound to the Solar System are efficiently driven into the Sun by Solar System resonances, (Farinella et.al. 1994 for asteroids).

- Lundberg & Edsjö 2004 simulated solar depletion numerically (pink dotted line).



That was the review, what's new?

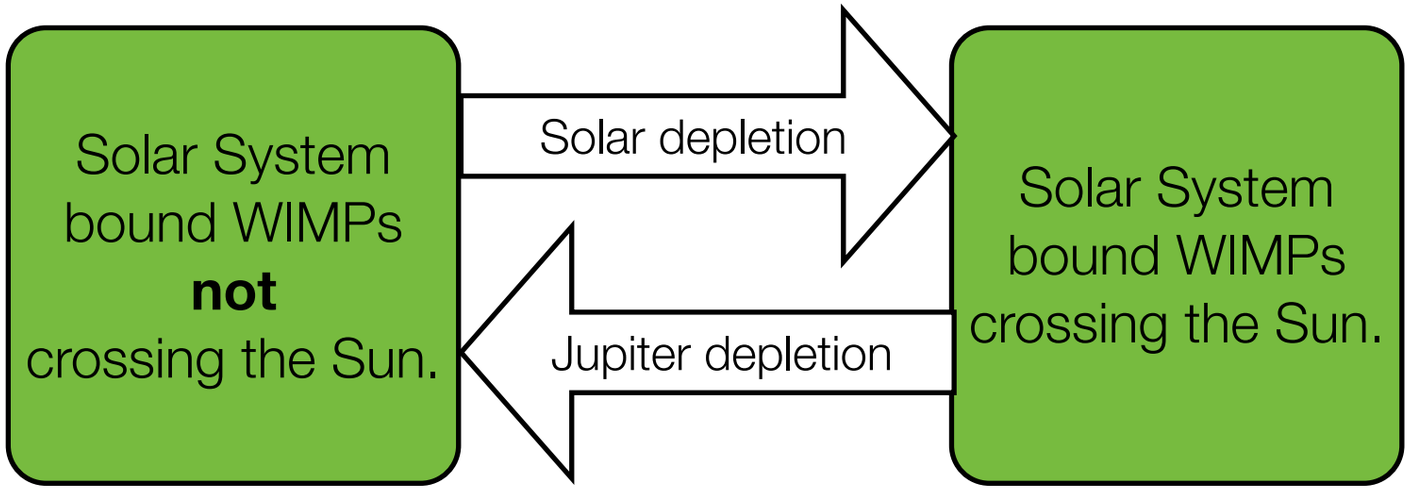




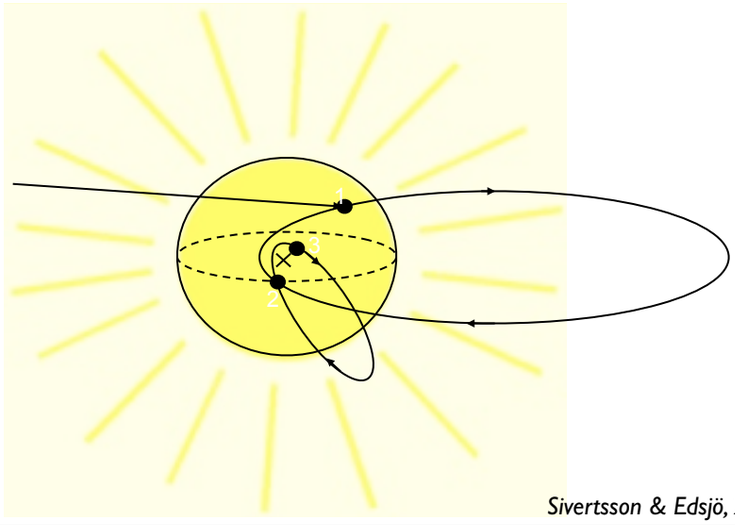
- Gravitational diffusion between two populations, in which direction is the net effect?

- Which has the largest phase space density?

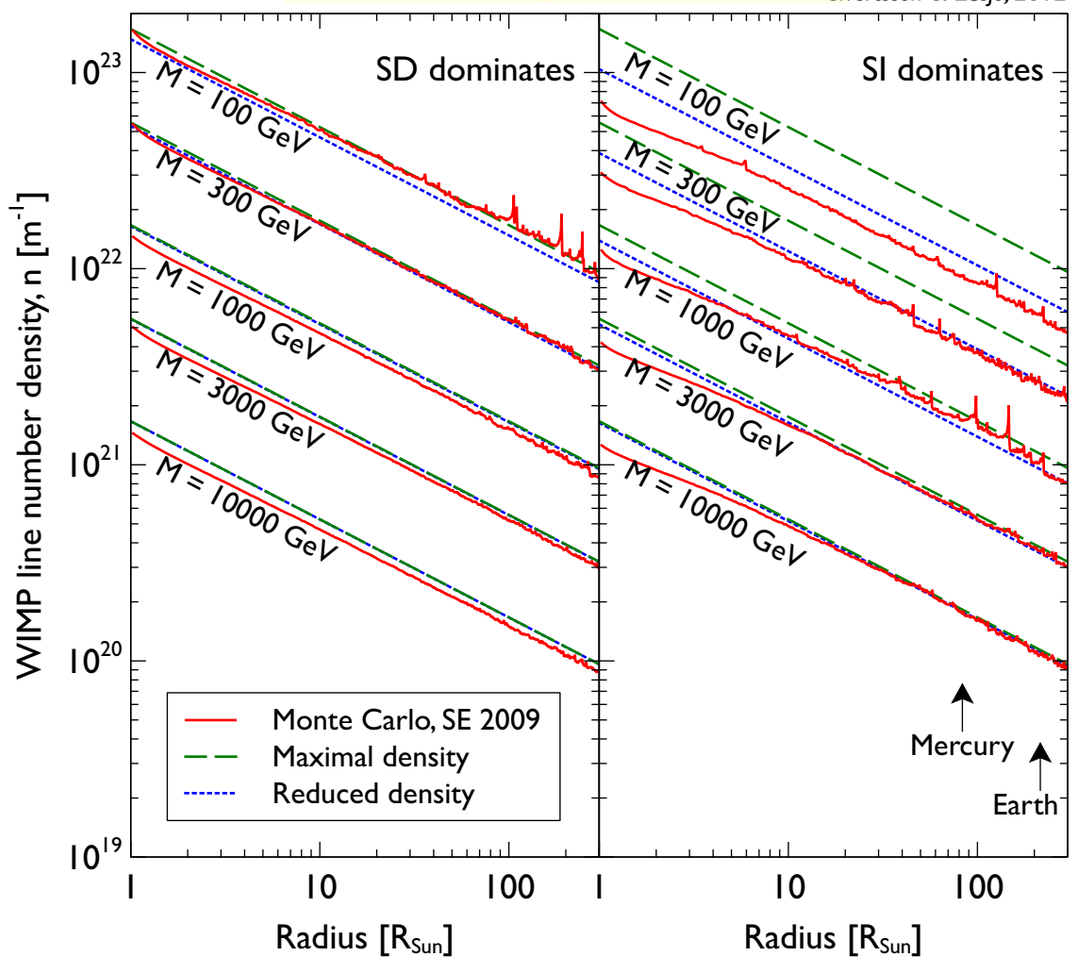
That was the review, what's new?



- 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!
- 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?

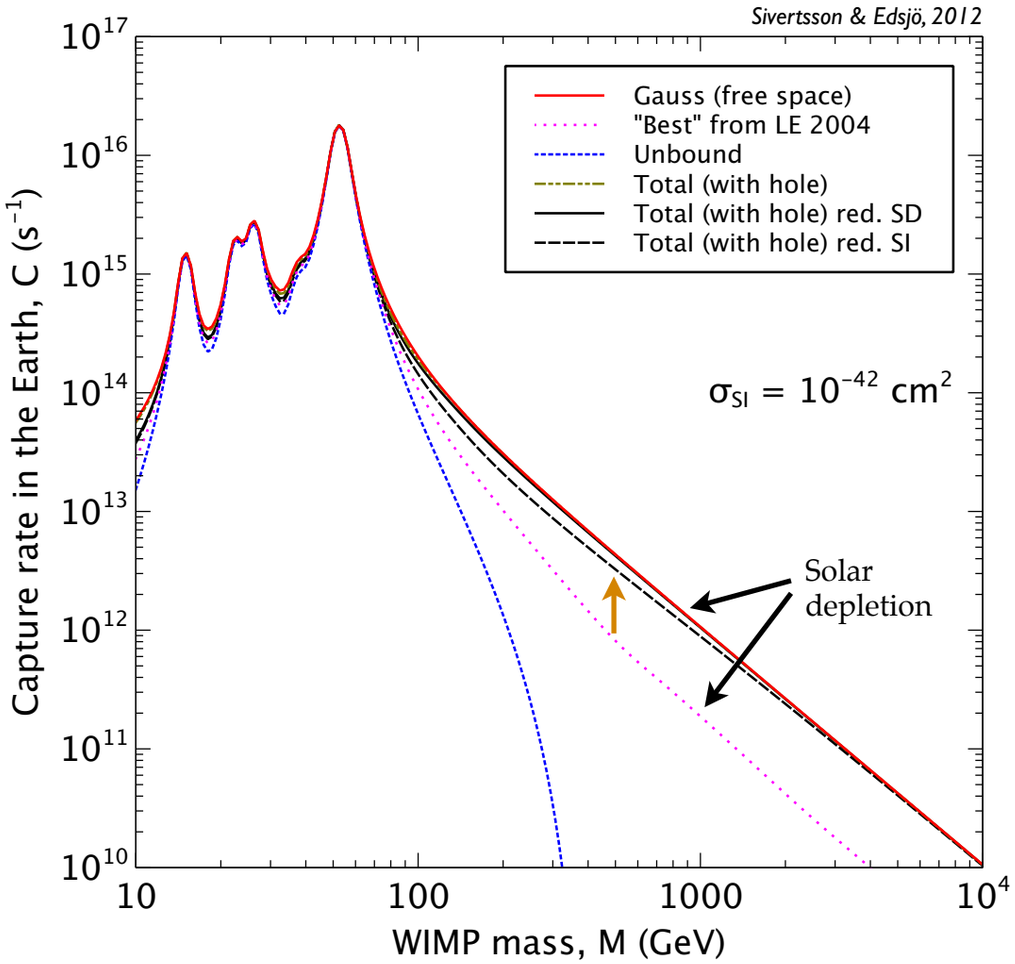
- Liouville's theorem (stating that a process preserves phase space density) is generically not applicable to nucleon scatters. However, planet reaching WIMPs scattering in the Sun turn out to approximately fulfill the conditions for Liouville's theorem.

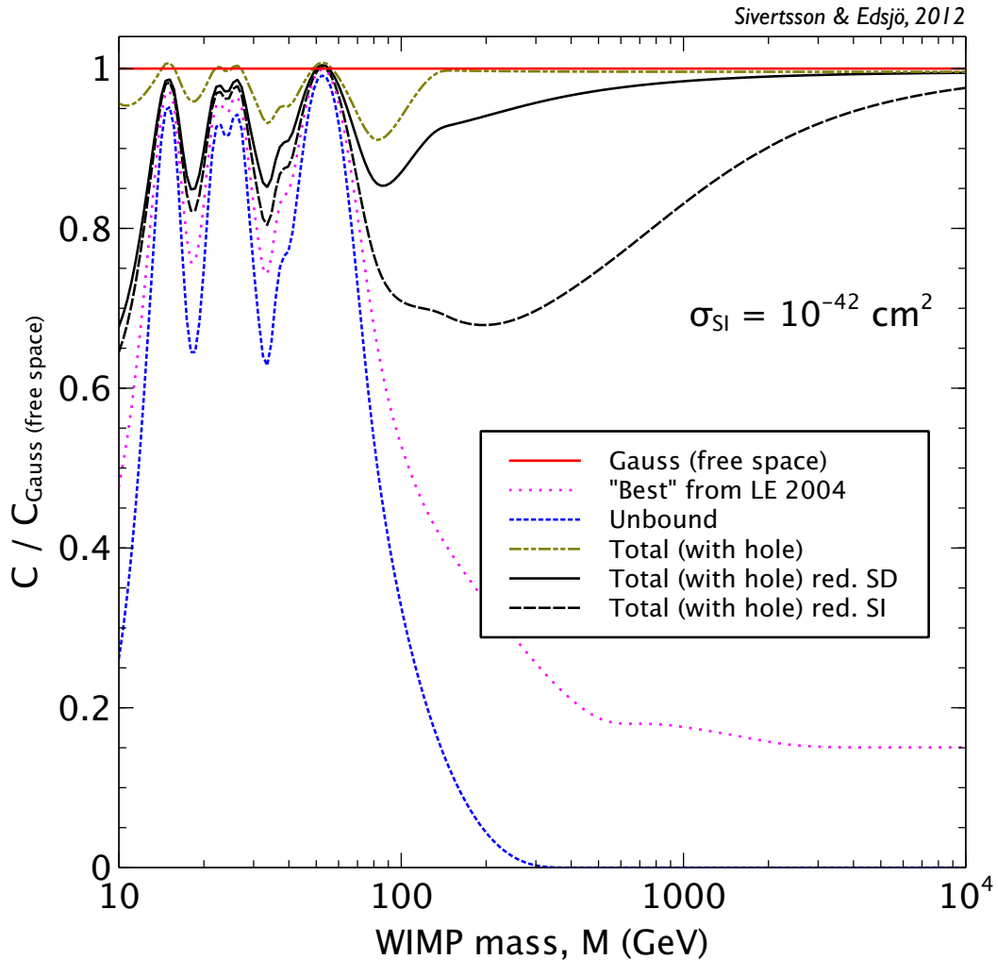
- Jupiter depletion: Cancelled by Jupiter throwing bound WIMPs into the Sun.

- 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 sling-shot 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 from conservative calculations.
  -The Earth has typically not reached equilibrium between WIMP capture and annihilation, giving a boost to the expected annihilation rate by ~10^2=10

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

The End

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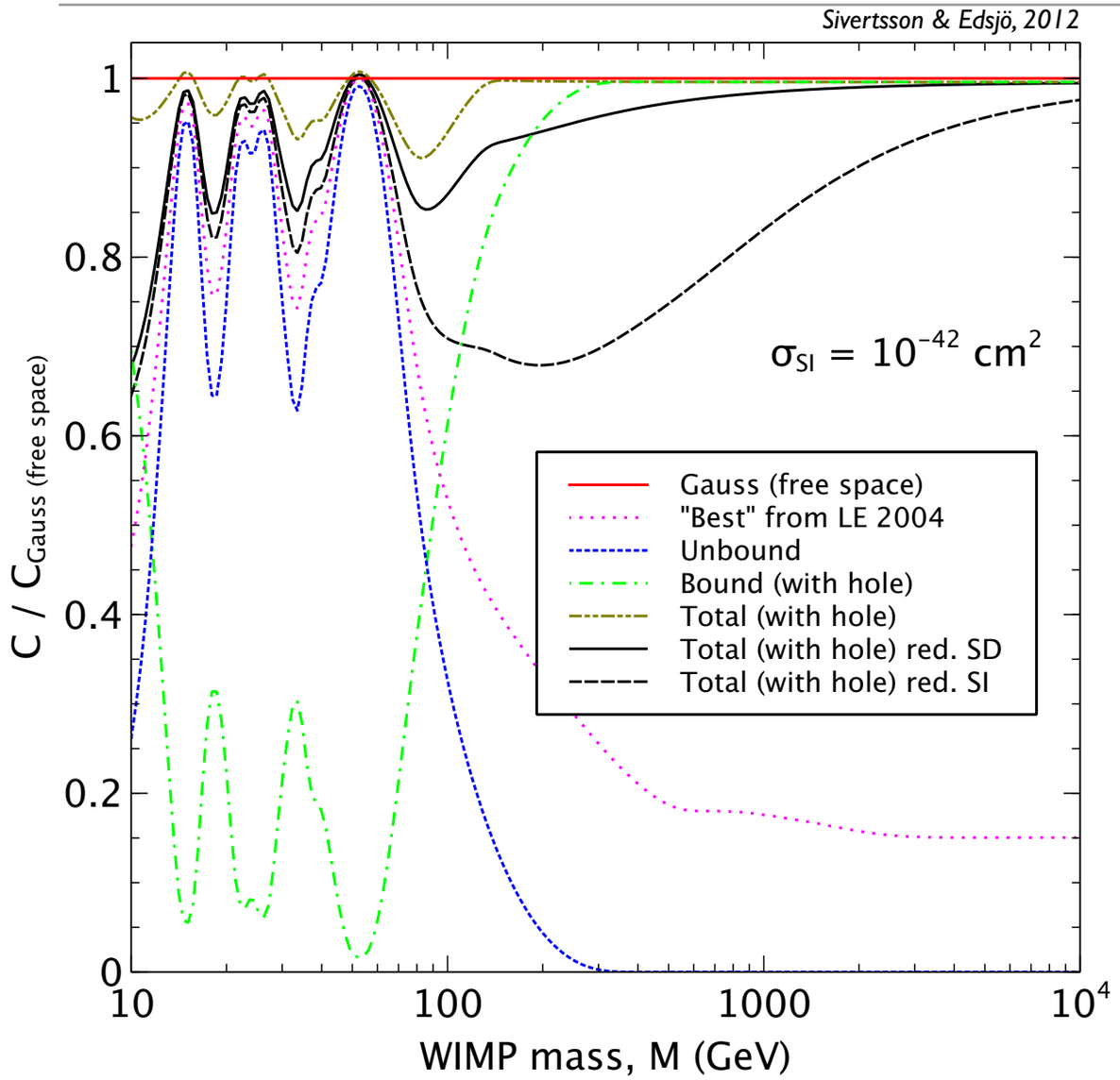
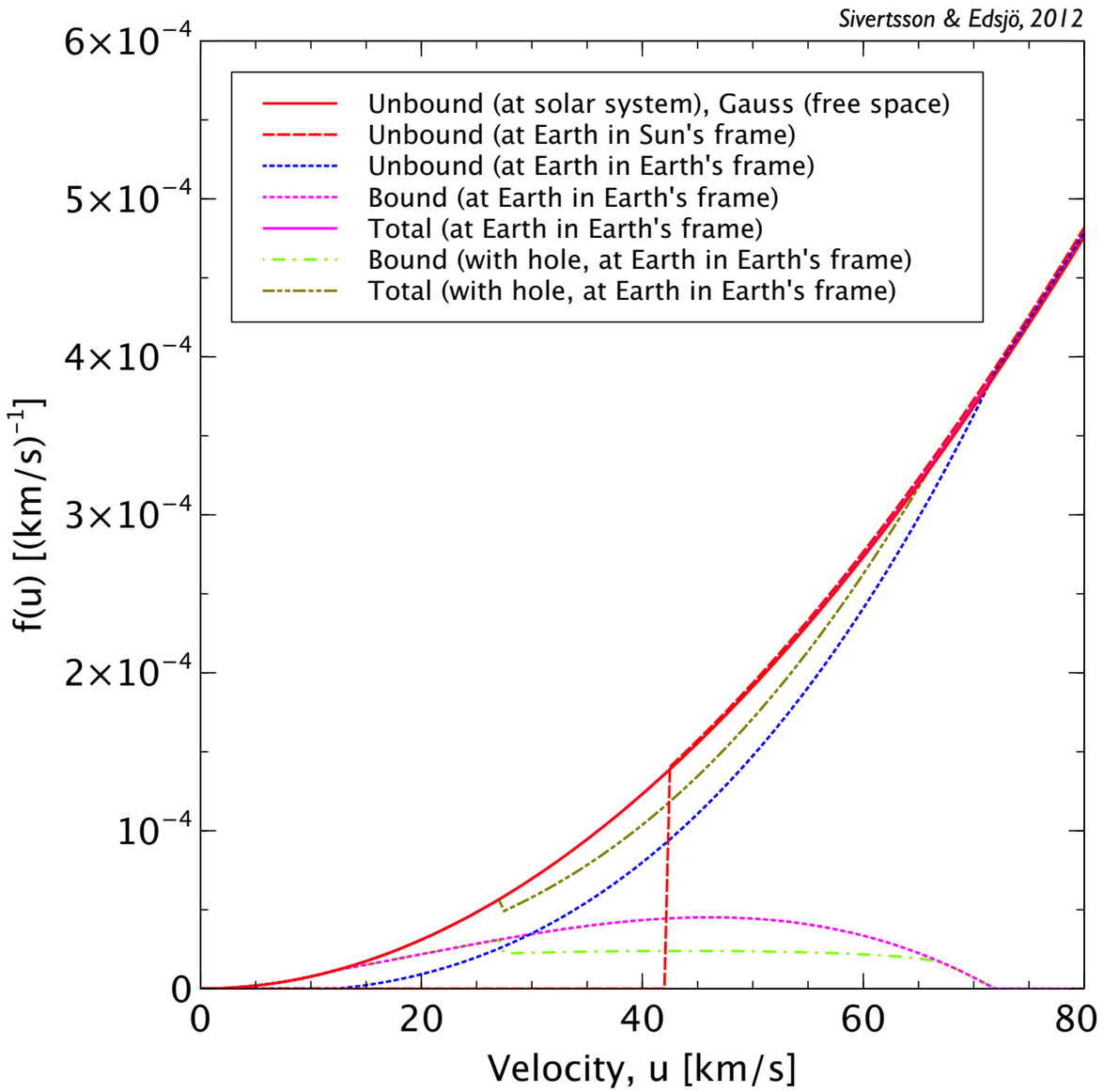
Extra


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]