Is the future of particle and astroparticle physics really at high energy?

MeV DM : astro-ph/0208458
LDM Models : hep-ph/0305261
DM & 511 keV: astro-ph/0309686
DM & ν: hep-ph/0612

Outline

1. Detection of a 511 keV line
2. Possible sources (which 511 keV sources?)
3. (MeV) dark matter
4. Link with neutrino masses
5. Are we sure that new physics is at high energy?

1. Detection of a 511 keV line

First detection

THE ASTROPHYSICAL JOURNAL, 172:L -L7, 1972 February 15

THE SPECTRUM OF LOW-ENERGY GAMMA RADIATION FROM THE GALACTIC-CENTER REGION

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Received 1971 October 22; revised 1971 December 22

ABSTRACT

A balloon-altitude observation was conducted 1970 November 25, of the galactic-center region, at energies between 23 and 930 keV. The radiation detected from the 24° FWHM area of Sagittarius during the 7-hour observation has a differential photon number spectrum that may be approximated by a power law with a spectral index of 2.37 ± 0.05; this is in satisfactory accord wit[illegible] previously by others at low energies. In addition, the evidence for a spectral feat[illegible]re at 0.5 MeV is presented and discussed.

FLUX detection

THE ASTROPHYSICAL JOURNAL, 225: L11–L4, 1978 October 1

DETECTION OF 511 keV POSITRON ANNIHILATION RADIATION FROM THE GALACTIC CENTER DIRECTION*

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Received 1978 June 7; accepted 1978 July 6

ABSTRACT

A balloon-borne germanium γ-ray telescope was flown over Alice Springs, Australia, in an attempt to detect spectral features from the galactic center (GC) direction. A 511 keV positron annihilation line was detected at a flux level of $(1.22 \pm 0.22) \times 10^{-3}$ photons s^{-1} cm^{-2}. Suggestive evidence for the detection of the three-photon positronium (Ps) continuum is presented. A brief discussion of the possible origin of the positrons is given.

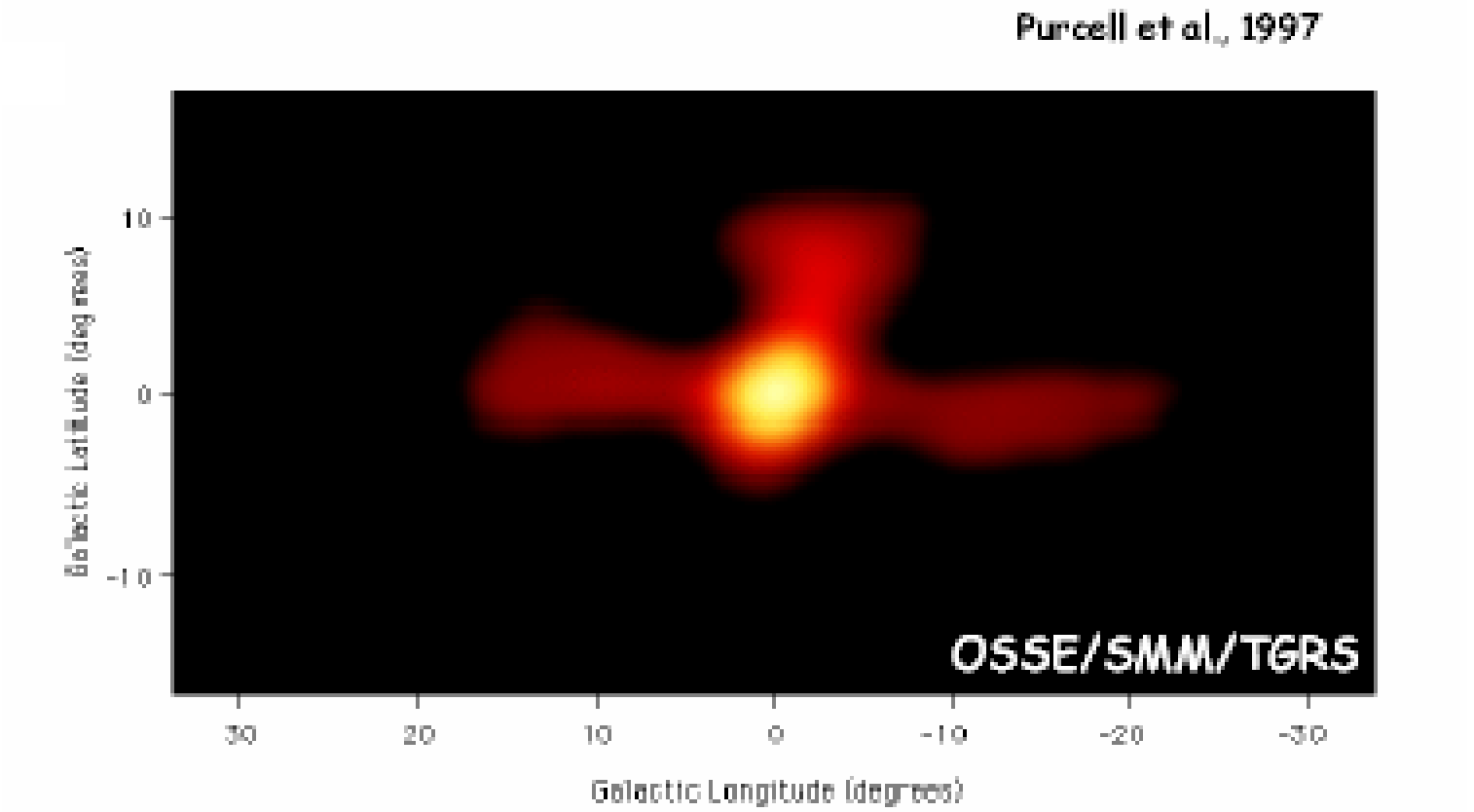
Subject headings: galaxies: Milky Way — gamma rays: general

OSSE: 3 components

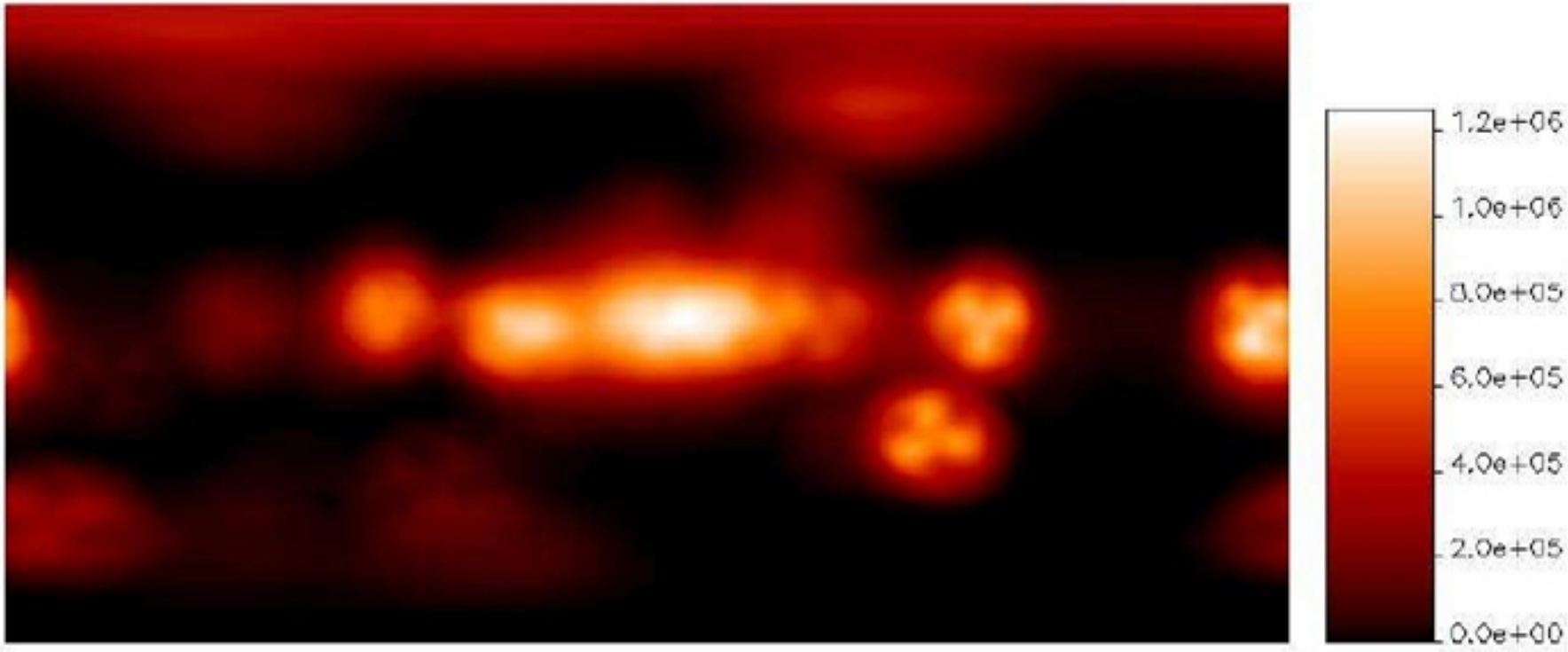
Disk

Bulge

Positive latitude Enhancement



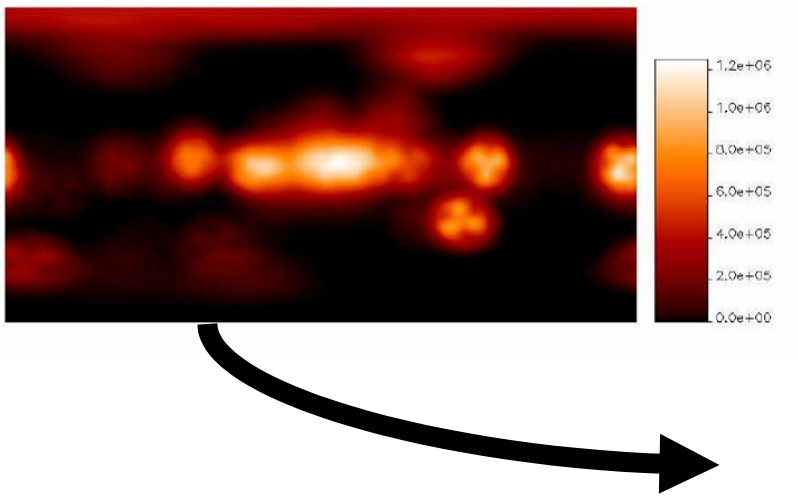
INTEGRAL/SPI (before):



INTEGRAL:

International Gamma-Ray Astrophysics Laboratory
SPI is the spectrometer on board of INTEGRAL

SPI image after reconstruction:



The 10deg region is contained in the galactic bulge!

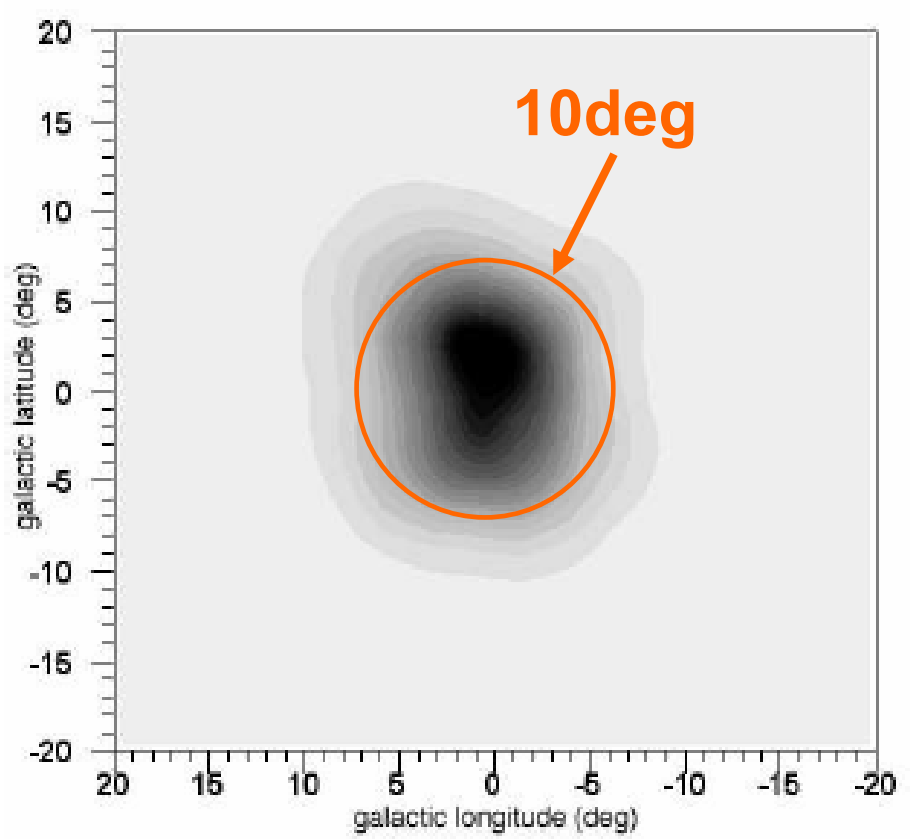


Fig. 3. Simulated 511 keV gamma-ray line intensity map based on an azimuthally symmetric gaussian model of 10° FWHM centred at $l = 0°$ and $b = 0°$.

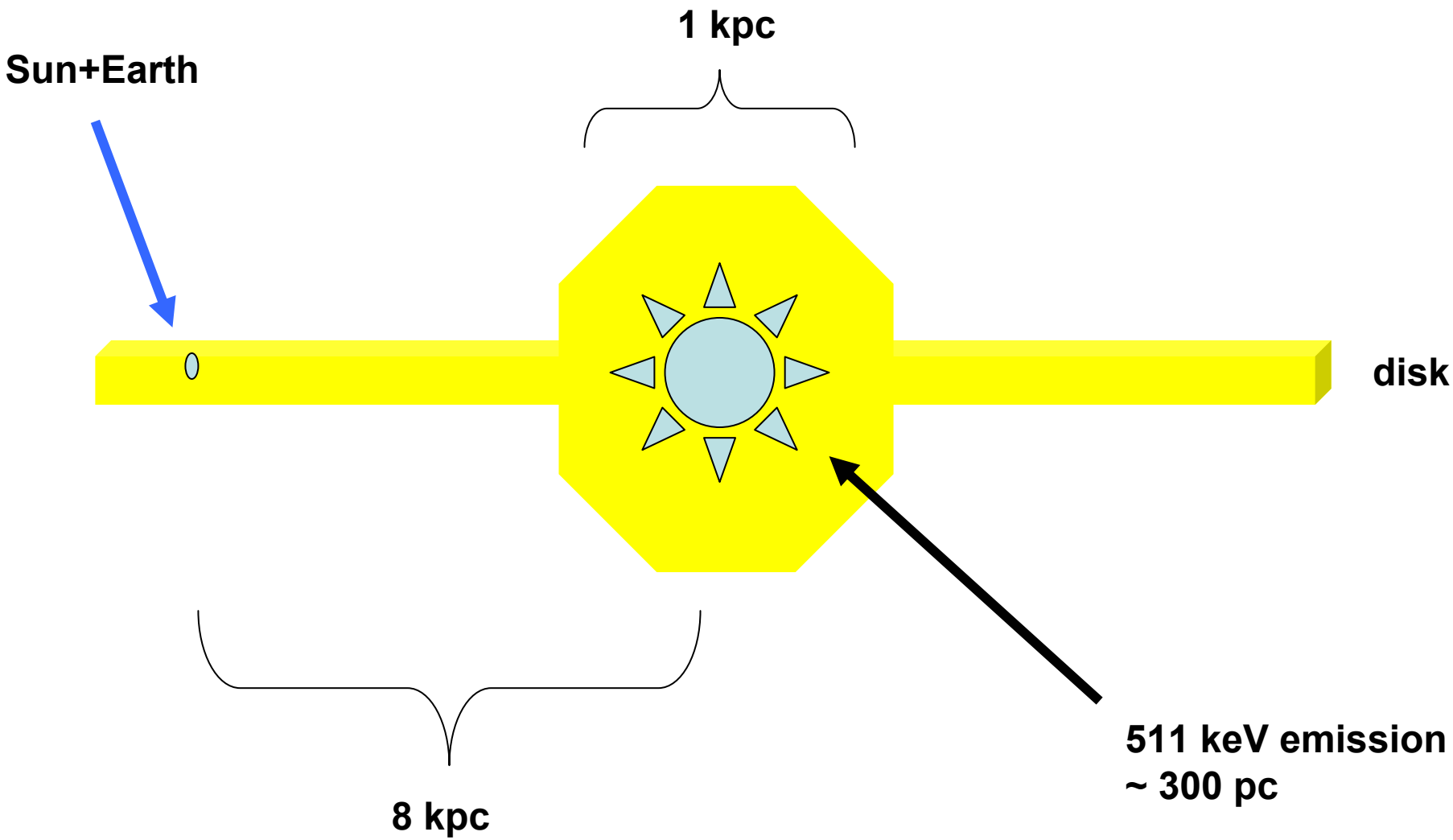
What does the 511 keV observation teach us?

1. There are low energy positrons,
   i.e. anti-matter, in our galaxy!

2. Most of the positrons are located in the bulge

(Bulge-to-Disk: B/D>0.4-0.8)

A simplistic view:



2. possible sources of positrons?

Astrophysical sources

- Stars
  - ✓ SNe (Co 56)
  - ✓ SNII (Al26, Ti 44)
  - ✓ WR (Al 26)
- Compact sources
  - ✓ Pulsars
  - ✓ Black holes
  - ✓ Low Mass Binaries
- Cosmic rays
  - ✓ p-anti p -> positrons
  - ✓ Radioactive isotopes

Slide (courtesy P. Jean)

Standard astrophysical sources

**

Most of well-know astrophysical sources have a

too low

disk/bulge ratio

**

They are excluded!

Remaining astrophysical candidates

Old galactic population or exotic solution

SNIa

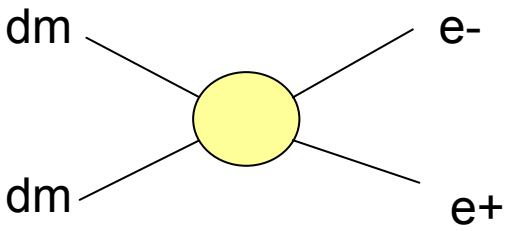
Need a large escape fraction and
an explosion rate significant to maintain
a steady flux

LMBX **(Low Mass X-ray Binaries)**

Need the electrons to escape from the
disk and migrate to the bulge

3. (MeV) Dark Matter

How can LDM explain the 511 keV line?



e+ lose energy

e+ form positronium with
e- present in the medium

Positronium decays

Para-positronium

2 γ

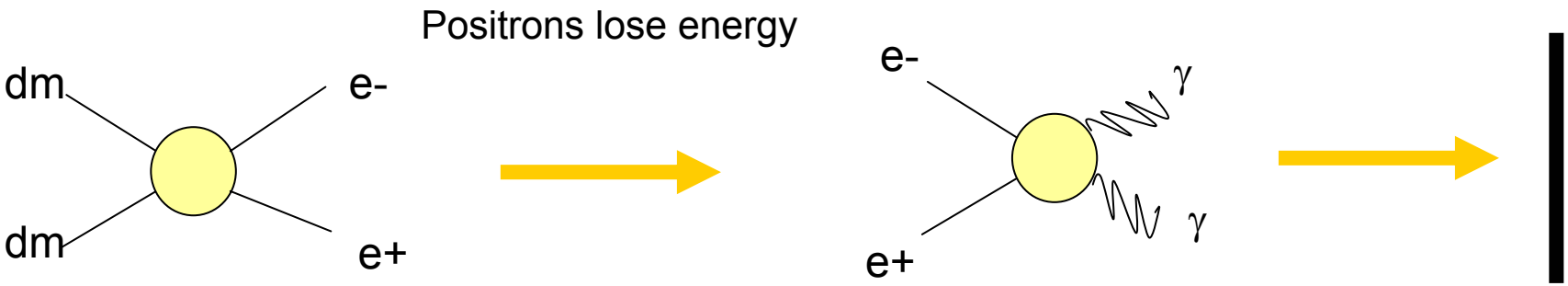
Monochromatic with 511 keV

Ortho-positronium

3 γ

continuum

511 keV line



Expectations

511 keV line emission:

* The more dark matter annihilates, the more it produces positrons.

The positron emission should follow the DM energy density distribution

[i.e. it should mostly happen in the region where DM is the most ``concentrated'']

*The positron emission should have the same spatial distribution than Dark matter

dark matter is spatially distributed in a sphere surrounding the galactic disk.

The positrons (and hence the 511 keV line) emission should be spherical.

The positron flux

* **Depends on the DM annihilation rate.**

* **It should be maximal where the DM energy density is maximal.**

Why thinking about MeV DM?

1) Natural solution as it was already proposed in the context of:

- *Structure formation*

MeV DM is one example of *Weakly Interacting Massive Particle* which does not have a CDM-like matter power spectrum (P(k) or CMB spectrum)!

- *Relic density*

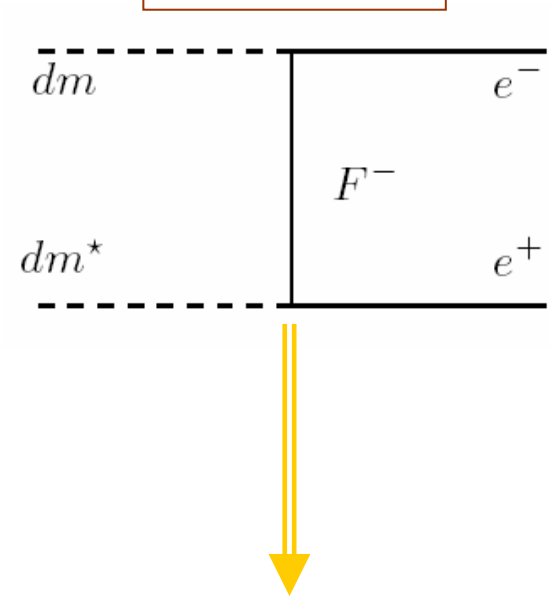
Escape Lee-Weinberg limit. The annihialtion cross section is not too small.

2) The model is very much constrained; there is no freedom.

Predictivity!!!

Model with 1 or 2 interaction(s)

$\sigma v \sim v^0$

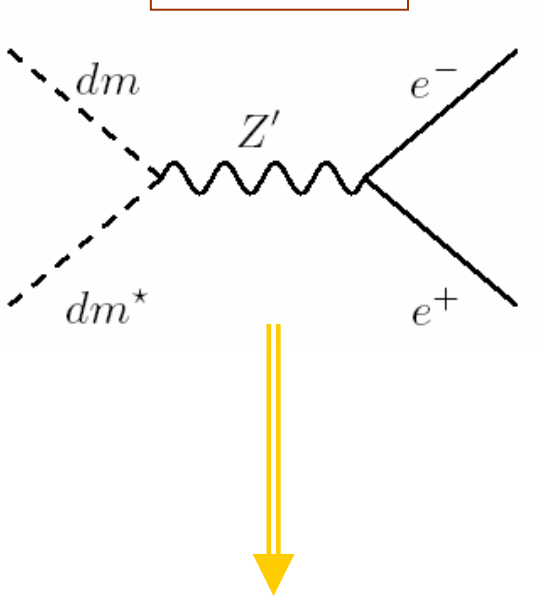


Relic density OK

but

too many gamma rays

$\sigma v \sim v^2$



Relic density OK

AND

Not too many gamma rays

Can LDM fit the morphology of the emission?

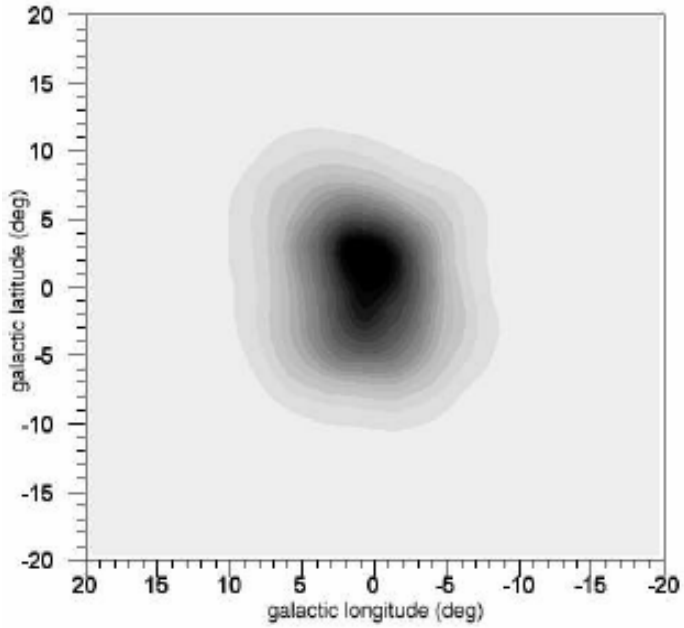


Fig. 3. Simulated 511 keV gamma-ray line intensity map based on an azimuthally symmetric gaussian model of 10° FWHM centred at $l = 0°$ and $b = 0°$.

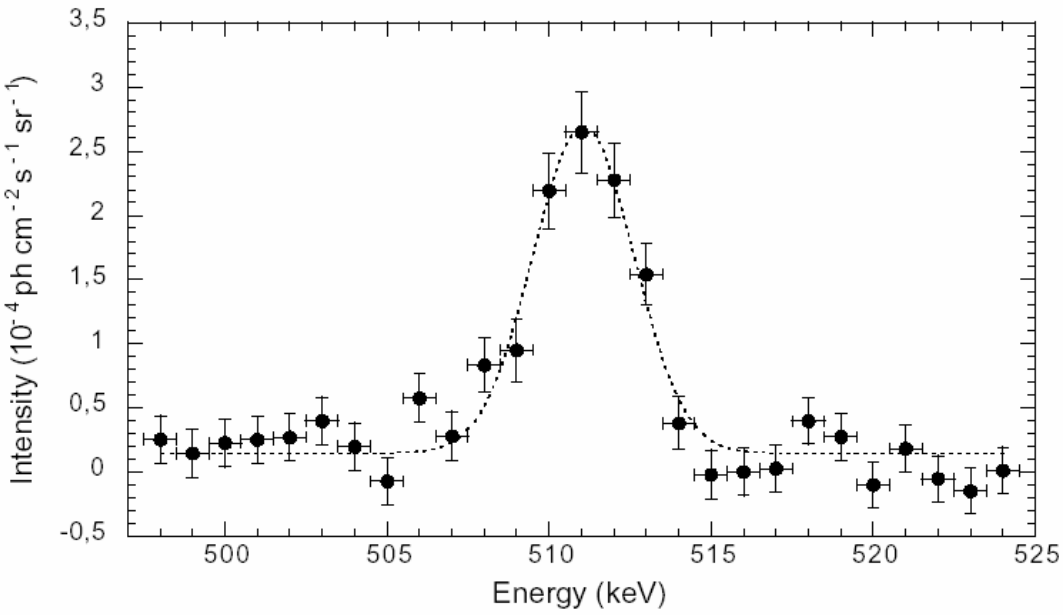


Fig. 3. 511 keV flux spectrum obtained using a gaussian centred on the GC with a FWHM of 10°.

FLUX ~ 10^{-3} ph/cm^2/s

YES!!

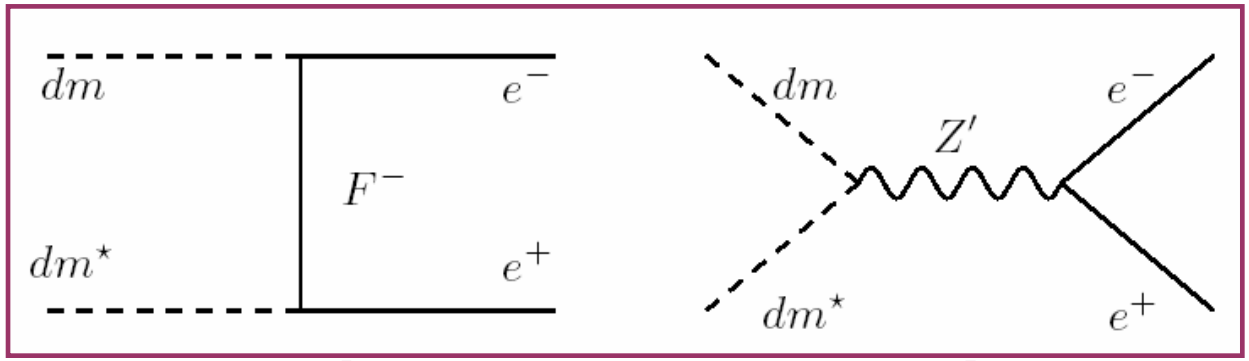
Several Fits

(CB, D. Hooper, J. Silk, M. Casse, J. Paul 2004;

CB, Y. Ascasibar 2005;

Y. Ascasibar, P. Jean, CB, J. Knoldlseder 2006)

The basic model



a. SigmaV is constant

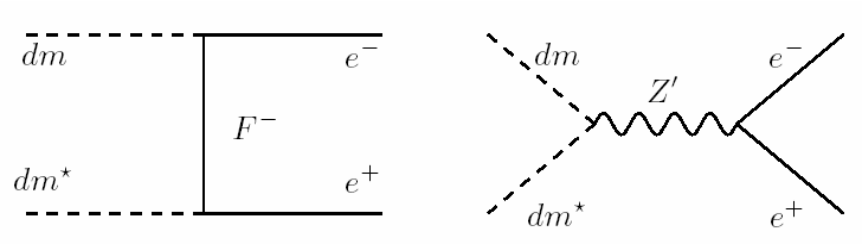
a. SigmaV depends on the DM velocity

b. Main source of 511 keV photons

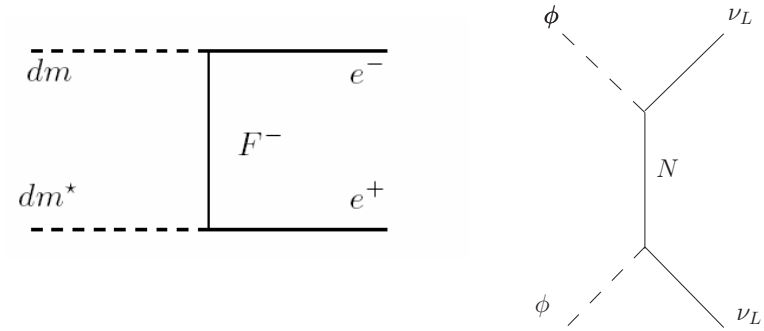
b. Responsible for the correct relic density

$$\langle \sigma v_r \rangle \approx a + bv^2 + O(v^4) \propto 2.\ 10^{-30}\ \mathrm{cm}^3/\mathrm{s}$$

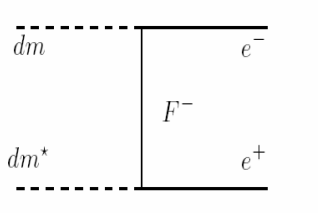
Another model!



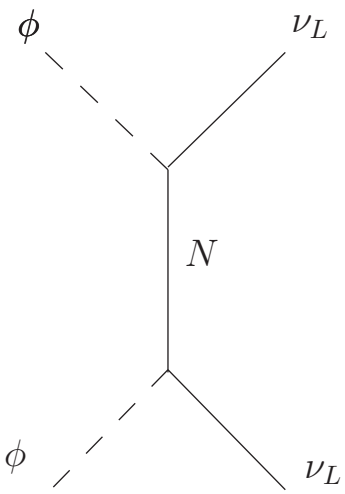
- Relic density ----- Z’
- 511 keV ----- F_e

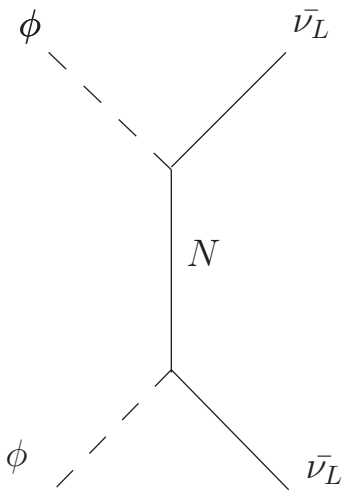


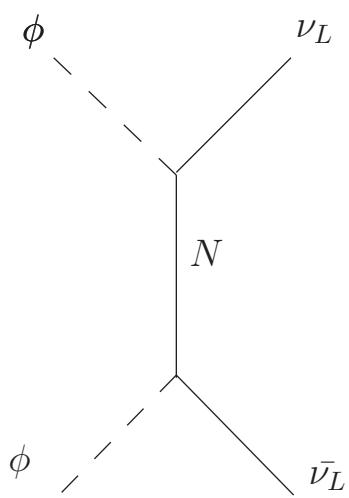
- Relic density ----- N
- 511 keV ------ F_e



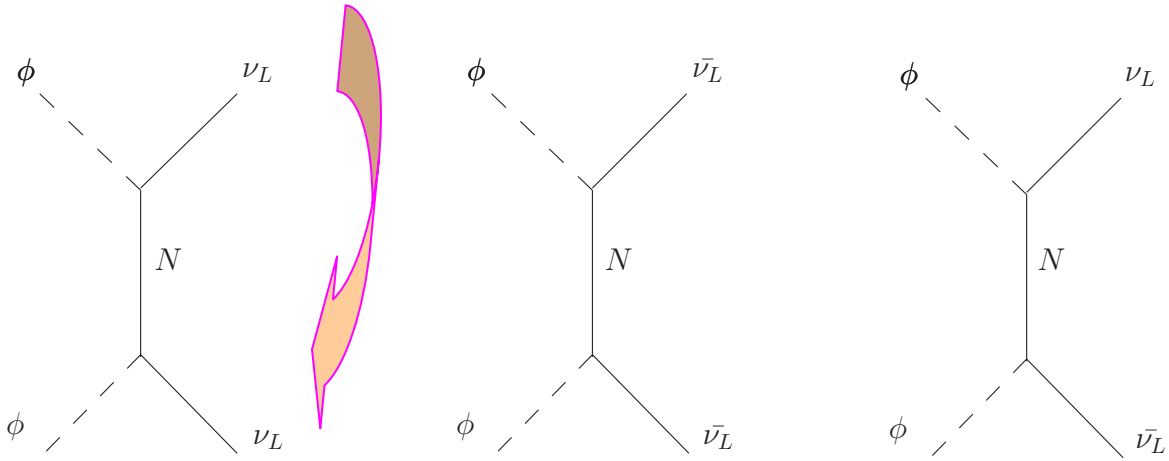
In fact 3 diagrams







4. Link with neutrino masses


ϕ
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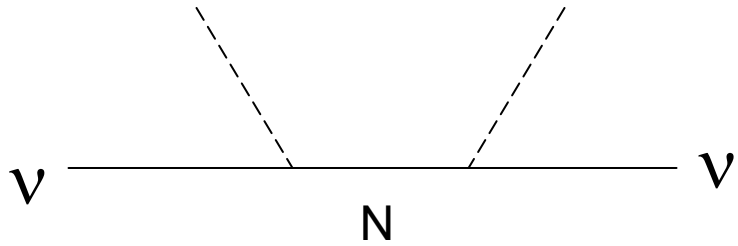
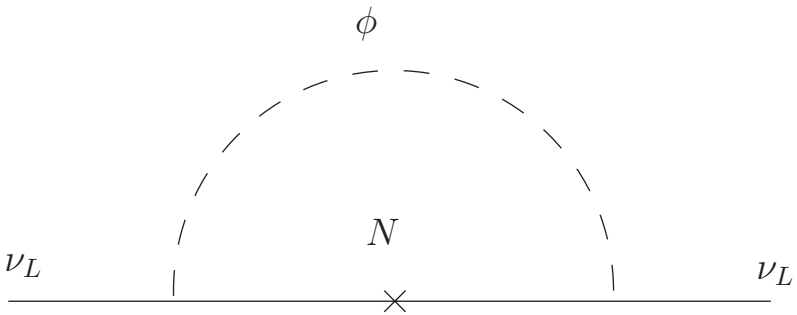

ν
ν
N


ϕ
N
ν_L
ν_L

One obtains a SIMPLE LINK between neutrino masses and the DM cross section!

$$m_\nu \cong \sqrt{\frac{\sigma v}{128\pi^3}} m_N^2 \ln\left(\frac{\Lambda^2}{m_N^2}\right)$$

* σv is well-known for the relic density (whatever the DM mass, $\sigma v \sim 10^{-26}$ cm^3/s)

* m_ν is known experimentally

Hence mN is the only free parameter

A surprising conclusion

* m_N < 10 MeV to fit neutrino data

$$m_\nu \cong \sqrt{\frac{\sigma v}{128\pi^3}} m_N^2 \ln\left(\frac{\Lambda^2}{m_N^2}\right)$$

* 1 MeV <m_{dm} < m_N

BBN stability

Hence MeV DM comes out naturally from this relationship.

5. Are we sure that new physics is at high energy?

Strong bias towards high energy physics

- Usual arguments to extend the Standard Model:

  Coupling unification
  Hierarchy problem

  Including gravity

- Theoretically:

  supersymmetry, extra-dimensions, Kaluza-Klein, little Higgs..

- Experimentally:

  no BSM events have been seen yet!

Evidence for new physics?

- Existence of dark matter

- Neutrino masses ???

Detection at low energy

- All detail in a forthcoming paper but MeV DM has definitely escaped all previous low energy experiments due to the lack of luminosity

- Perhaps a chance in BABAR/BES II…but…

Detection at high energy?

$$\frac{m_F}{100\ \mathrm{GeV}} \simeq 6 \times 10^3\ \frac{c_l\, c_r}{m_{\mathrm{MeV}}}, \qquad (20)$$

where the two couplings c_l and c_r are expected to be lower than unity (a few units at most).

For $c_l \approx c_r \approx 1$, one obtains $m_F \approx 6 - O(600)$ TeV (for $1 \lesssim m_{\mathrm{MeV}} \lesssim 100$). This is obviously out of reach for past and forthcoming colliders. However, for smaller but more realistic values of the couplings, m_F could be within the range of next colliders. According to equation (20), a mass $m_F \in [100\mathrm{GeV}, O(\mathrm{TeV})]$ would correspond to $c_l\, c_r \in 1.67 \times [10^{-4}, 10^{-3}]\, m_{\mathrm{MeV}}$. Those are not particularly

But production cross section at most 10^{-40} cm^2..

Conclusion

- MeV DM explains very well the 511 keV emission (other astrophysical sources are still hypothetic)
- Provide a natural mechanism to explain the smallness of the neutrino masses.
- Offers a very simple and quantitative link between neutrino masses and the DM relic density.
- Detection might be possible at LHC but needs experimental work!
- Had escaped low energy experiments (lack of luminosity) but it is physics at low E!
- Back to susy (snu-neutralino-nu) but needs theoretical efforts.