# TeV $\gamma$-rays from Dark Matter annihilations


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F. F., astro-ph/0505414


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# Outline

The Galactic Centre at TeV energies

Indirect detection of DM

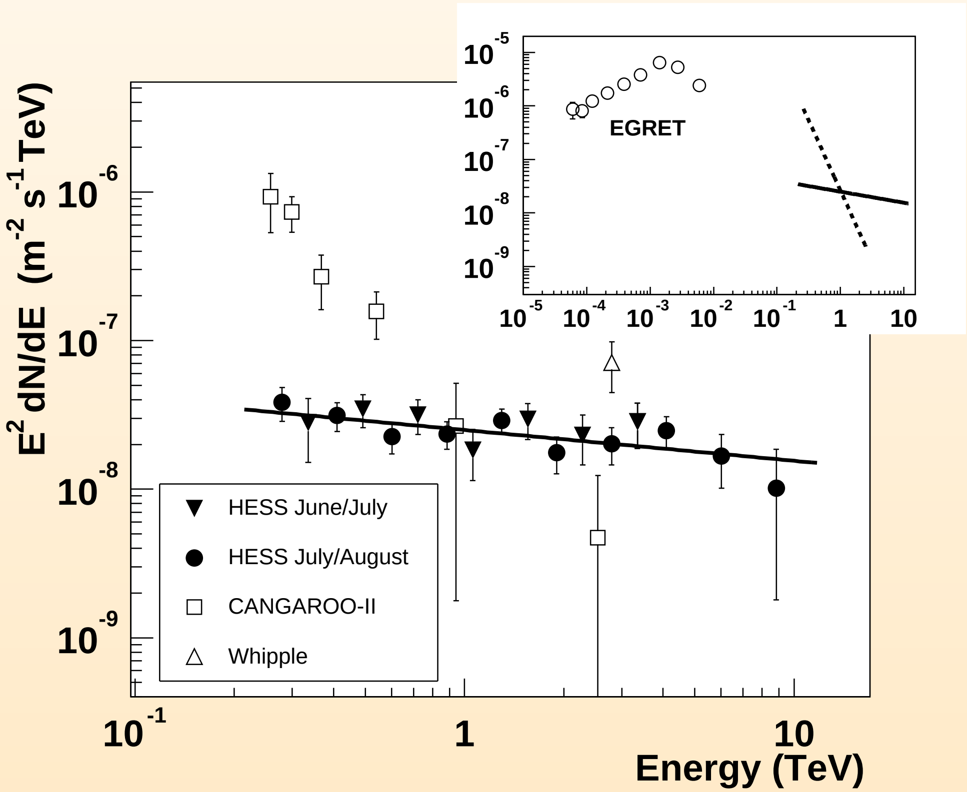
Gamma-rays from dwarf spheroidals

Conclusions

# The Galactic Centre at TeV energies

Gamma-ray observations of the GC region have been made in several energy ranges employing a wide variety of techniques:

- Satellites like EGRET surveyed the MeV – GeV region
- ACTs have, so far, seen emission from the central region above $\sim$ 100 GeV

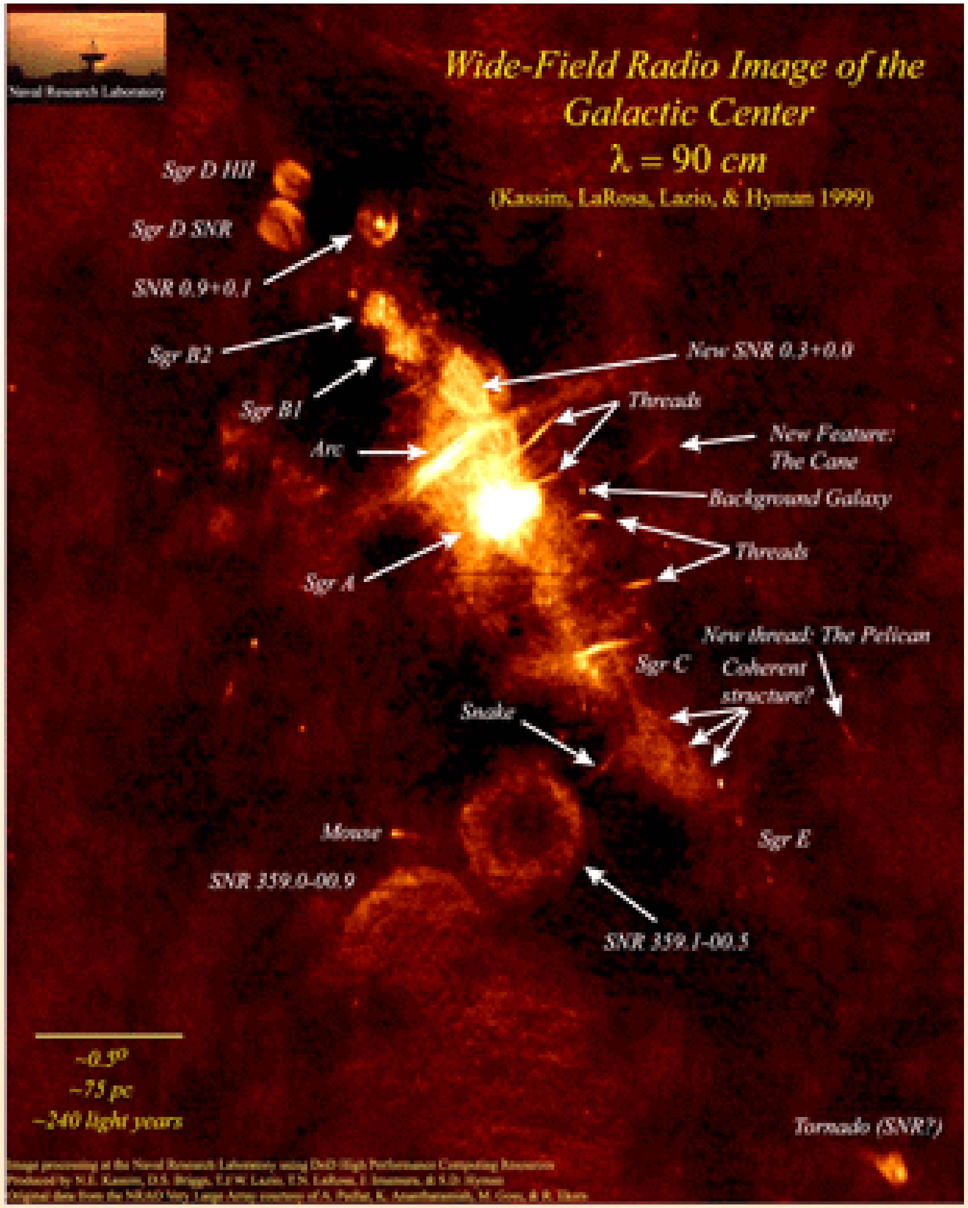


# Sources of TeV radiation

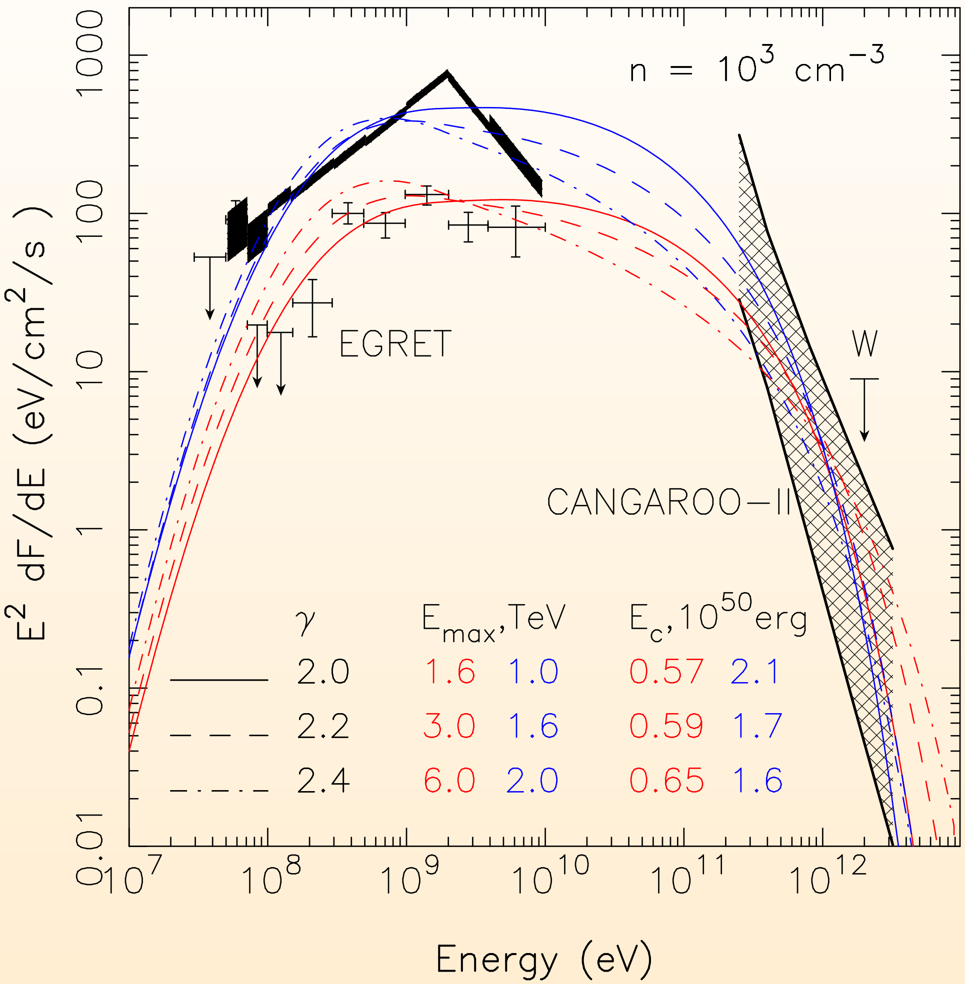
The Galactic center is a complex and rich region. Its most notable inhabitant is a $2.6 \times 10^6 M_\odot$ black hole, coincident with the radio source Sgr A$^*$.

Additionally, the region may contain massive X-ray binaries emitting relativistic plasma jets (microquasars) capable of producing high-energy $\gamma$-rays by either hadronic ($\pi^0$ production) or leptonic (inverse Compton) processes. The region could also contain Supernova Remnants (SNRs) which are widely believed to be the source of Galactic cosmic rays.

# Sources of TeV radiation



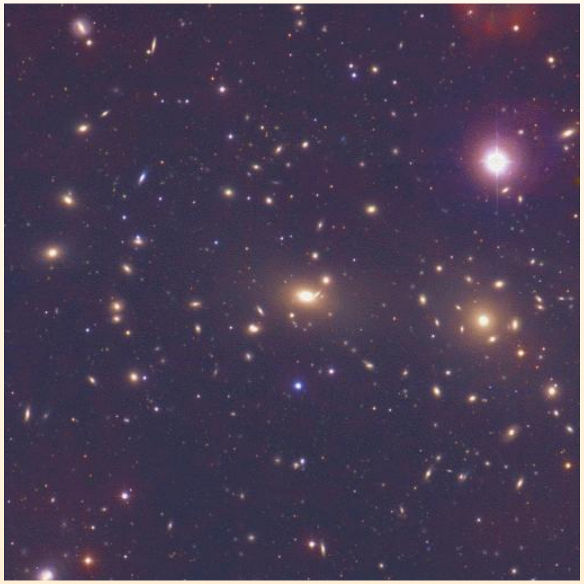
# Astrophysical model fit

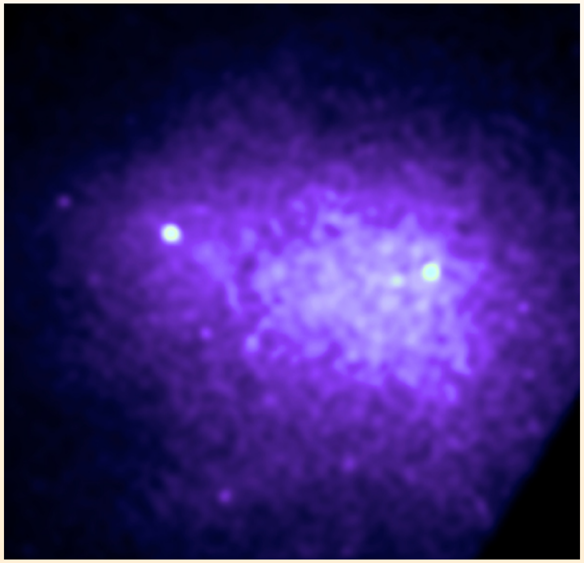



Or maybe we are seeing the effects of the Dark Matter in the GC?

# Where can we find the DM?

The first evidence for the existence of Dark Matter was found by Zwicky in 1933, who concluded that almost all of the Coma cluster ($\sim Mpc$) mass is in the form of some invisible dark matter.





Ostriker et al. and Einasto et al. pointed out, back in 1974, the need for large amounts of dark matter around isolated galaxies ($\sim Kpc$).

# Where can we find the DM?

Models of structure formation require the presence of cold, non-relativistic, dark matter (CDM) for the primordial fluctuations to grow into the galaxies that we see nowadays. The success of Big Bang Nucleosynthesis implies that most of it is non-baryonic.

Analyses of the dynamics of both individual galaxies and clusters of galaxies, as well as recent measurements of the Hubble diagram for distant Type Ia supernovae and the degree-scale anisotropy of the cosmic microwave background radiation (CMB) constraint the cosmological abundance of Dark Matter to be

$$\Omega_{cdm} h^2 = 0.094 - 0.129 \; (2\sigma)$$

Despite this extensive body of evidence in favor of cold, non-baryonic, dark matter, its identity remains elusive.

# Indirect signals from DM

There are plenty of candidates motivated by Particle Physics. Most of them were introduced to solve problems unrelated to Cosmology.

The foremost candidate is a weakly interacting massive particle (e.g. LSP), that would have naturally the right relic density.

However, there are many possibilities with widely different masses. Usually, the DM particles would give indirect signals (if any) at energies comparable to their mass:

- $1-100 MeV$ (qed scale) scalars could explain the $511 KeV$ line seen by INTEGRAL
- $0.1-10 TeV$ (electroweak scale) could explain the $\gamma$-ray emission seen by satellites and ACT
- $10^{12-13} GeV$ (hidden scale) particles could be at the origin of the UHECRs

# Indirect signals from DM

The flux of $\gamma$-rays observed from the GC, if due to dark matter annihilation, is given by:

$$\frac{d\Phi_\gamma(\psi, E_\gamma)}{dE_\gamma} = \langle \sigma v \rangle \frac{dN_\gamma}{dE_\gamma} \frac{1}{4\pi M_X^2} \int_{los} dl(\psi)\ \rho^2(r).$$

- The energy dependence is determined solely by the particle physics model.
- Both astrophysics and particle physics modulate the intensity. Spatial variations are due to different density distributions.

# The energy of the photons

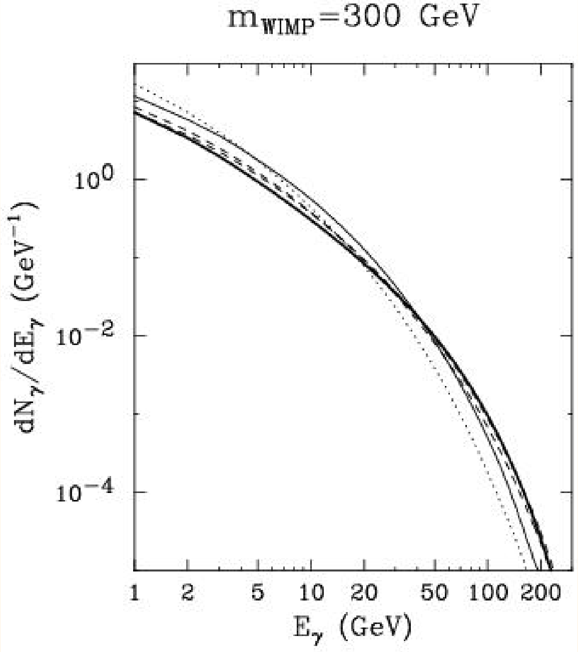
Annihilations of dark matter particles can produce $\gamma$-rays in several ways:

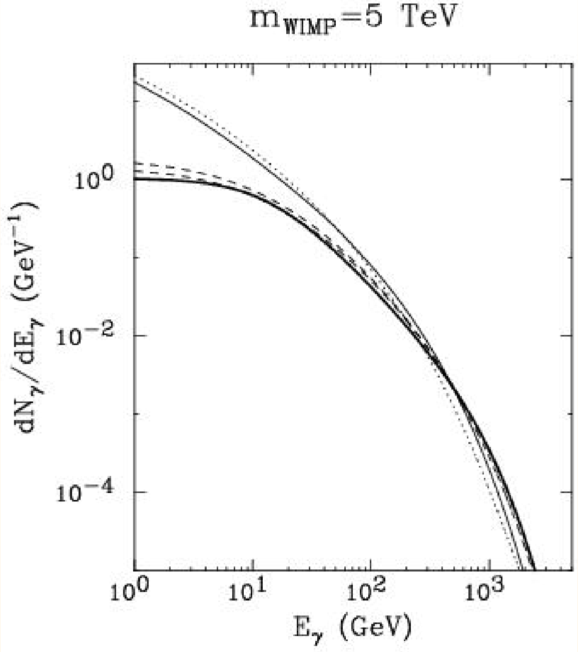
- A continuum of $\gamma$-rays results from the hadronization and decay of $\pi^0$'s generated in the cascading of annihilation products.
- Monoenergetic $\gamma$-ray lines are produced as dark matter particles annihilate via the modes $XX \to \gamma\gamma$ and $XX \to \gamma Z$.

A good fit to the continuum spectrum obtained by fragmentation Monte Carlo codes is provided by:

$$\frac{dN_\gamma}{dE_\gamma} \simeq \frac{0.73}{M_X} \frac{e^{-7.76 E_\gamma / M_X}}{(E_\gamma/M_X)^{1.5} + 0.00014}$$

# Bounds from EGRET



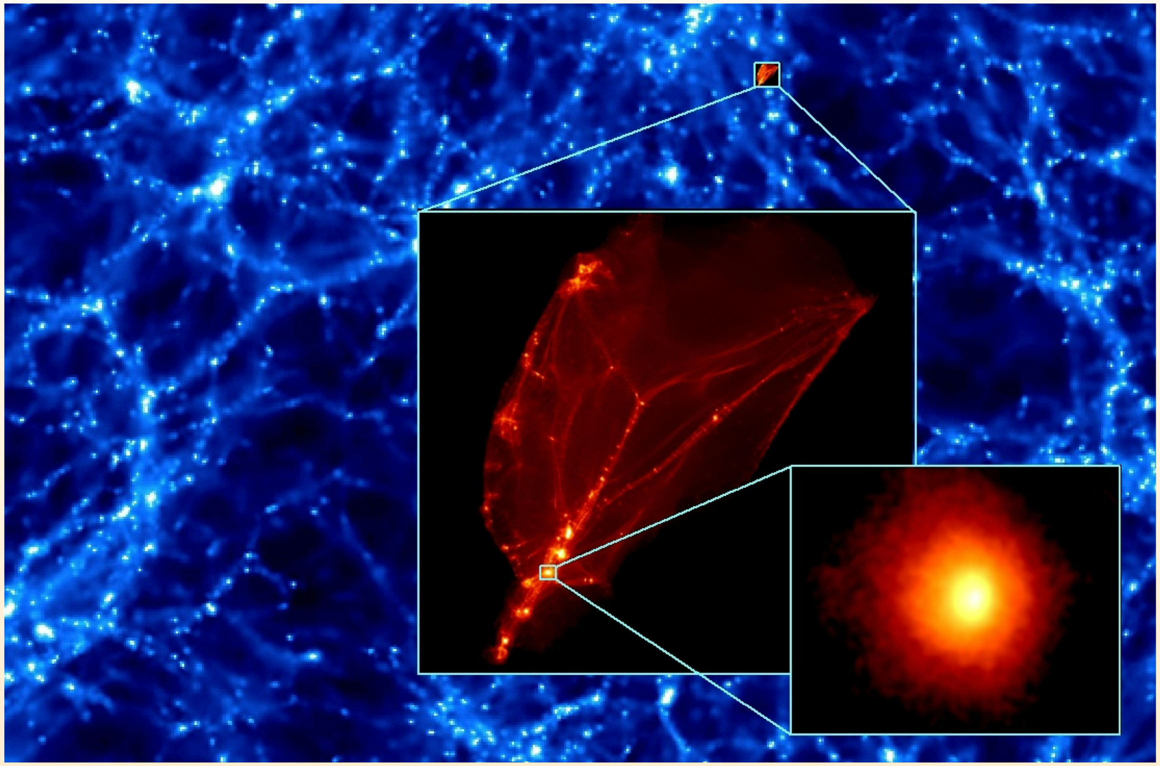




If dark matter annihilation indeed produces the TeV $\gamma$-rays observed by ACTs, then a lower energy component is expected to which EGRET (or in the future GLAST) is, in principle, sensitive.

A spectrum normalized to the Whipple observations will *violate* the EGRET bound if the particle mass is below about 3.5–4 TeV. If annihilations to modes other than gauge bosons dominate, this bound excludes masses up to about 5 TeV.

# The local distribution of DM

One can use the observed rotation of the galaxies to determine an empirical density profile of the DM distribution, or one can resort to the theoretical predictions of numerical N-body simulations.



N-body simulations usually predict cuspy profiles, but observations favour milder cored profiles. Also plenty of substructure is found in simulations.

Moore et. al. 05

# The centre of the Galaxy

The highly cusped models found by numerical simulations have suggested that the centre of the Milky Way Galaxy might be the optimum place to search for DM. Awkwardly, there is a substantial body of astrophysical evidence that the halo of the MW is not cusped at all.

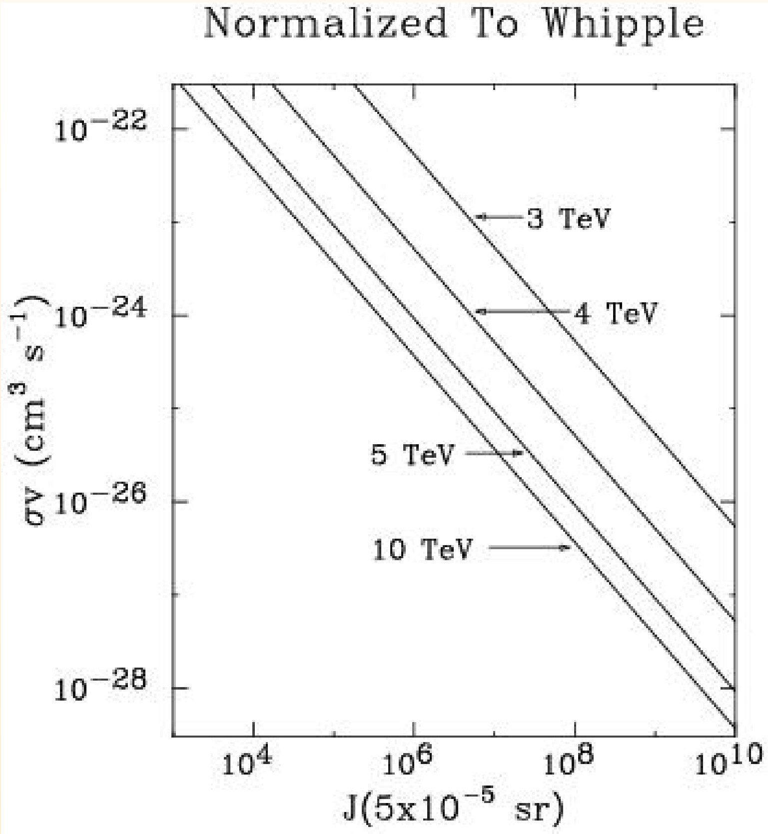
- *The pattern speed of the Galactic bar is known to be fast from hydrodynamical modelling of the motions of neutral and ionised gas. If dark matter dominates the central regions of the MW, then dynamical friction will cause it to decelerate on a few bar rotation timescales.* `Debattista & Sellwood 98, 00`
- *The microlensing optical depth towards the Galactic Centre is very high. Together with the rotation curve this tells us that lines of sight towards the Galactic Centre are not dominated by dark matter.* `Evans 00, Binney & Evans 01`

Observations suggest that bright galaxies like the MW **do not** have cusped dark haloes today. Feedback from star formation may provide a resolution with CDM theories. `Binney, Gerhard & Silk 01`

# Electroweak-scale gamma-rays caused by WIMPS

To reproduce the HESS data with DM annihilations, the WIMP should be heavy and have either a large cross section or follow a very cuspy profile.

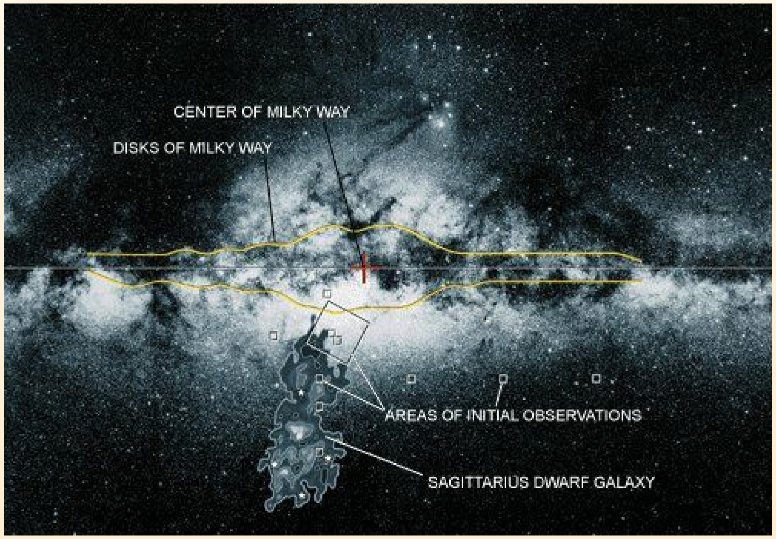
Hooper, FF, et. al. 04, Horns 04

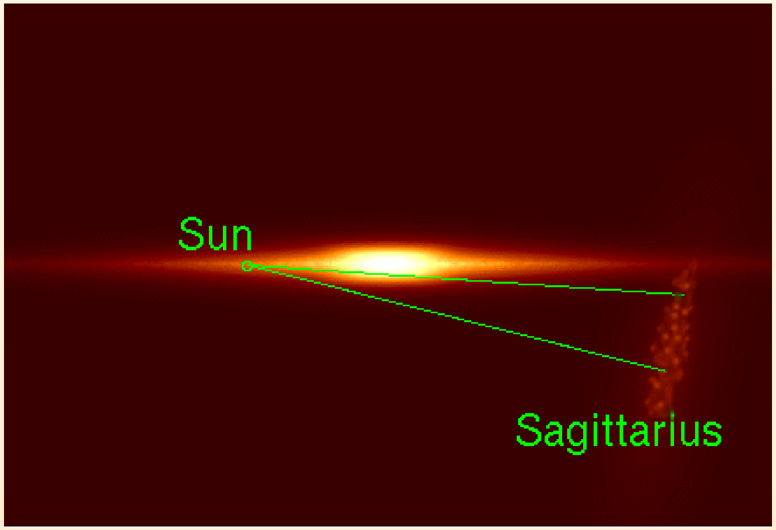



It is not natural for the neutralino to be so heavy, but stable particles from the messenger sector could do the job. Hooper and March-Russell 04

# Dwarf galaxies in our local halo

There is no observational evidence that any nearby galaxy has a cusped halo profile. Most dwarf spheroidals do not contain gas and so the structure of the dark haloes must be inferred from stellar motions. For the two nearest dSphs - Draco & Sagittarius - there is no direct evidence either for or against central cusps. Having a very large $M/L$ ratio, they offer the best prospects for constraining the LSP parameter space. `Evans, FF, Sarkar 04`




Sagittarius is the closest dwarf galaxy only $24Kpc$ away from the Sun.

# Consistency check for DM origin of $\gamma$-rays

If DM annihilations are causing (part of) the signal seen by HESS, then a similar effect from Sagittarius ensues.

$$\frac{\Phi_{ds}}{\Phi_{gb}} = \frac{\bar{J}(\Delta\Omega)_{ds}\Delta\Omega_{ds}}{\bar{J}(\Delta\Omega)_{gb}\Delta\Omega_{gb}} \sim \left(\frac{M_{ds}}{M_{gb}}\right)^2 \left(\frac{r_{gb}}{r_{ds}}\right)^3 \left(\frac{d_{gb}}{d_{ds}}\right)^2$$

Assuming a Moore profile for Sagittarius, $\overline{J_{-5}} \sim 3 \times 10^4$, a 10 TeV particle with $\sigma v_{26} \sim 1$ gives:

$$\frac{d\Phi_\gamma}{dE_\gamma}(Sag, 1TeV) \simeq 1.8 \times 10^{-9} cm^{-2} s^{-1} TeV^{-1}. \quad (1)$$

This corresponds to 10% of the flux recorded by HESS telescope from the GC at 1 TeV, well in reach of its sensitivity. Thus, once sufficient exposure in the direction of Sagittarius is attained, TeV emission from annihilating dark matter particles in Sagittarius ought to be seen.

# Conclusions

- To explain the TeV emission seen by Hess, we need a WIMP of $m \sim 10 TeV$. Possibly too heavy for being a neutralino, but particles from the messenger sector in gauge mediated SUSY models could do the job.

- Both the strenght of the signal and the angular distribution, suggesting a point like source, demand a cuspy density distribution of the DM in the central regions.

- The high mass to light ratios of the local Group dSphs makes them likely targets for DM searches. If DM illuminates the Galactic Centre, we should detect emission from Sagittarius as well.

- The point sources discovered by HESS in the GP are not, in principle, located in a dark matter dominated region, they are probably of astrophysical origin.