Testing 130 GeV gamma-ray line with Fermi-LAT data

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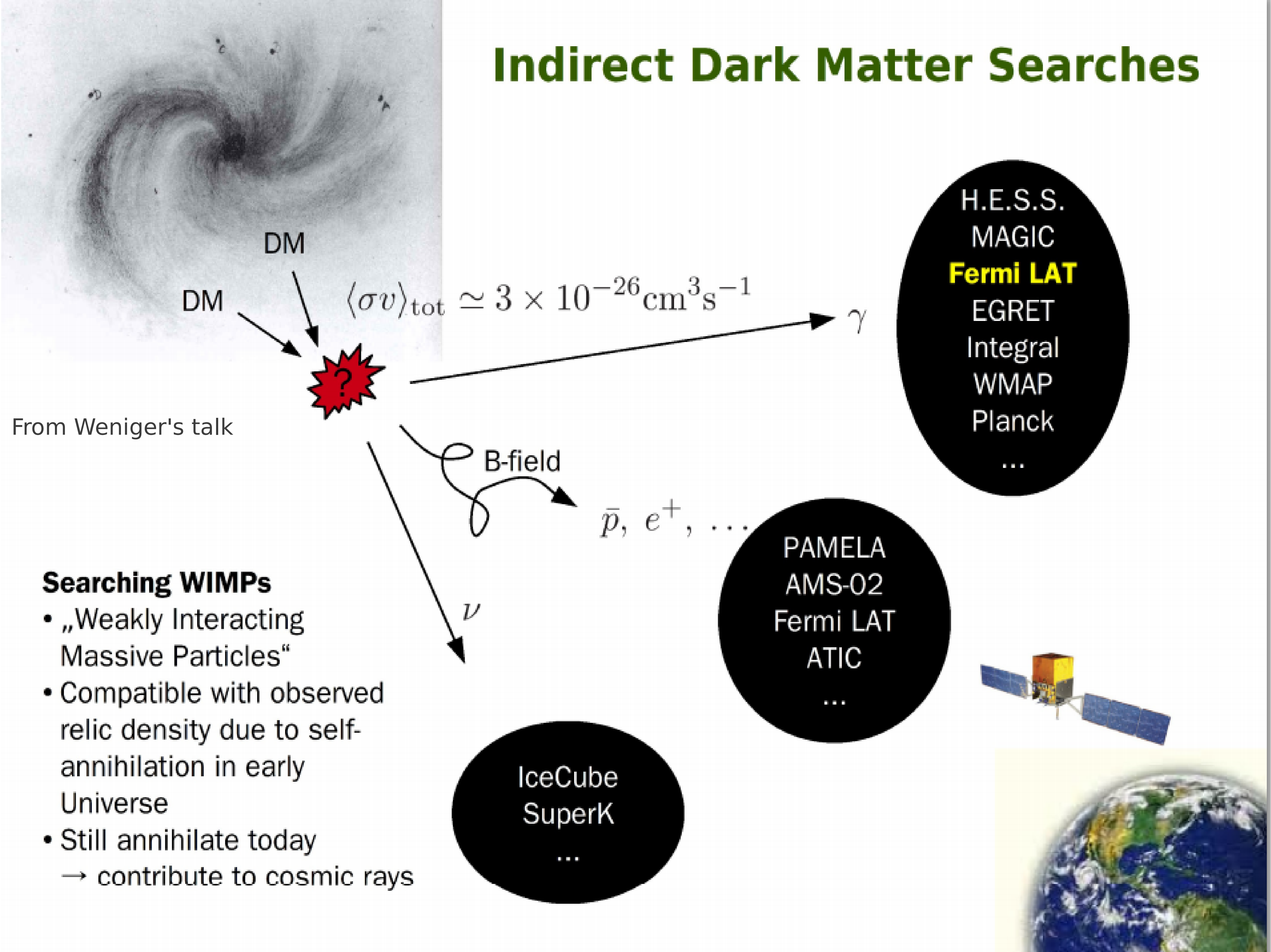
Based on arXiv 1208.0267 and work in progress
with Qiang Yuan, Pengfei Yin, Xiaojun Bi and Xuelei Chen

Indirect Dark Matter Searches



From Weniger's talk

Searching WIMPs

- „Weakly Interacting Massive Particles“
- Compatible with observed relic density due to self-annihilation in early Universe
- Still annihilate today → contribute to cosmic rays

The Gamma-Ray Signal

From weniger's talk

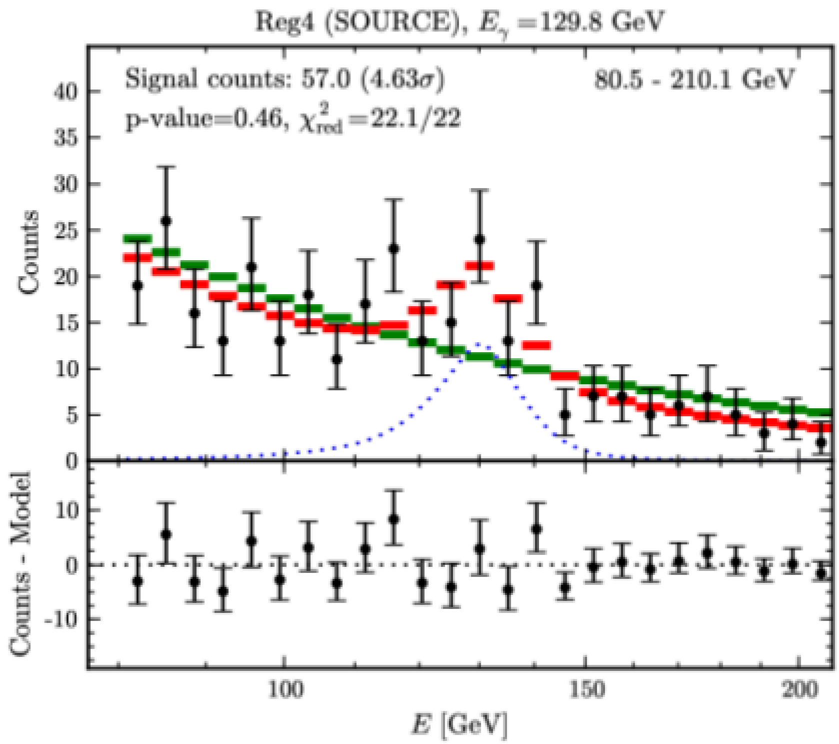
The gamma-ray flux from dark matter annihilation at energy E in direction Ω:

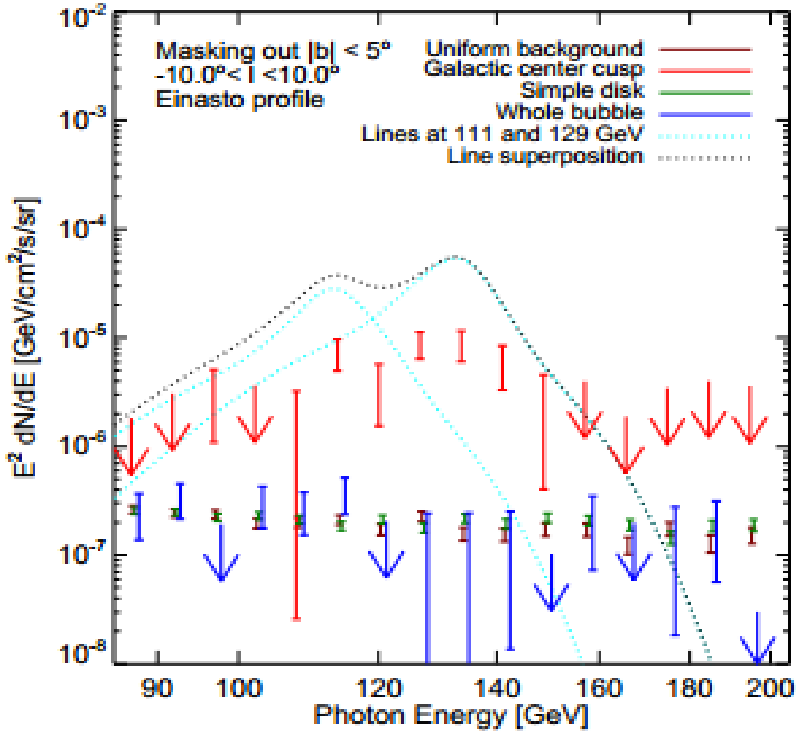
$$\frac{dJ_{\mathrm{ann.}}}{d\Omega dE} = \frac{\langle \sigma v \rangle}{8\pi m_{\mathrm{dm}}^2} \frac{dN}{dE} \times \int_{\mathrm{l.o.s.}} ds\ \rho(\vec{r}[s,\Omega])^2$$

„Particle Physics Factor“ → Characteristic **Energy Spectrum**

„Astrophysics Factor“ → Characteristic **Spatial Dependence**

TENTATIVE GAMMA RAY LINE(S) SIGNAL



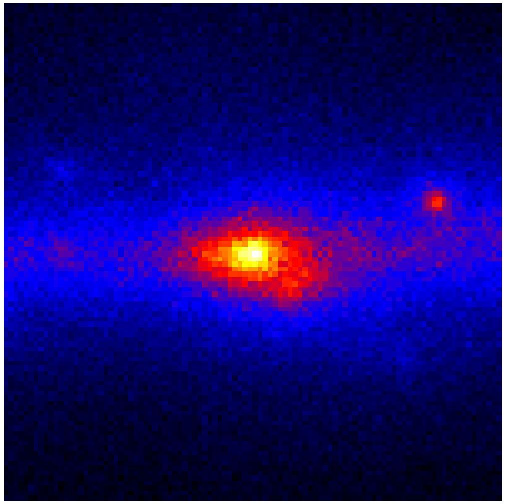


- Bringmann et. al. (arXiv: 1203.1312) found an extra emission around 130 GeV in the Galactic Center which could be the Internal Bremsstrahlung Signatures from Dark Matter Annihilation.
- Weniger (arXiv:1204.2797) showed this could be a gamma ray line signal which would be the ’smoking gun’ signiture for dark matter indirect detection.
- Tempel et. al. (arXiv: 1205.1045) found that the spatial distribution of this tentative dark matter annihilation signal has no correlation with the shape of Fermi Bubble, and also a displacement of this extra emission from the galactic center.
- Su and Finkbeiner (arXiv: 1206.1616) confirmed the signal is concentrated in the galactic center and the displacement, and also there could be another line in the spectra.

CONTINUOUS GAMMA-RAY EMISSION FROM THE INNER GALAXY

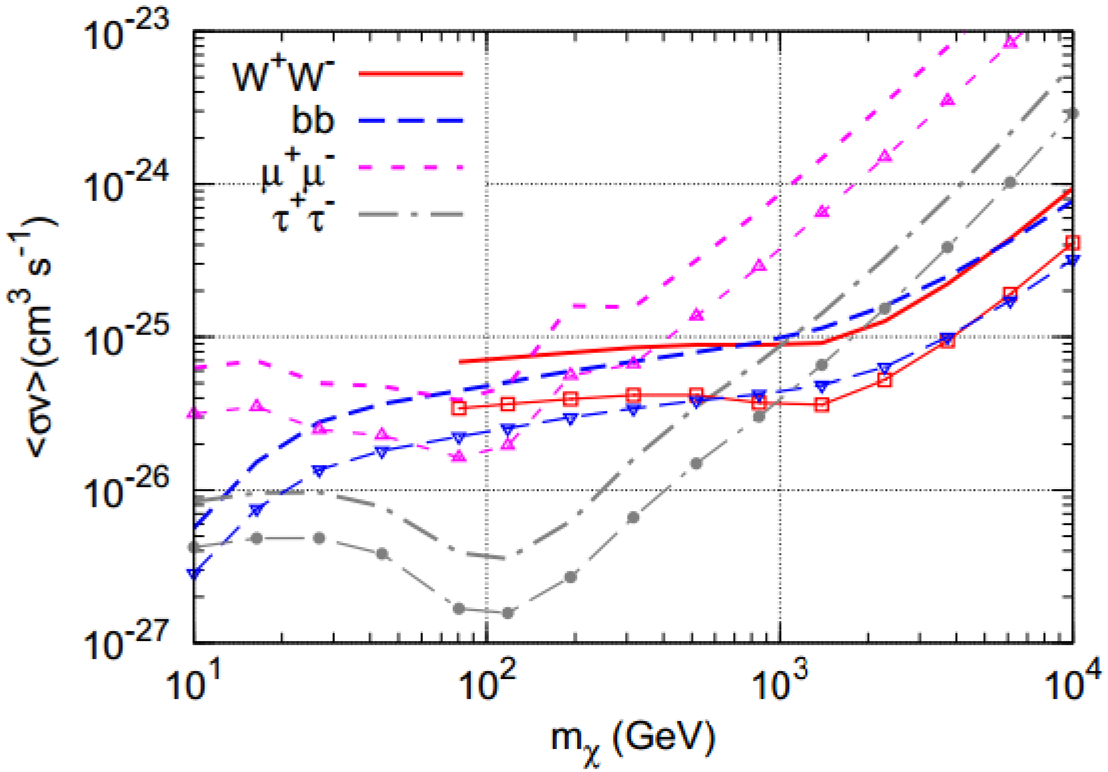
- Dark matter may be easier to annihilate into the charged particles at the tree level, then these annihilation products may induce significant continuous γ-ray flux.
- We use the Fermi data from the inner Galaxy, because of its high dark matter density, to place limits on the DM annihilation cross section.

CONTINUOUS GAMMA-RAY EMISSION FROM THE INNER GALAXY



- We use the 3.7 years Fermi-LAT data in the region-of-interest (ROI) of a $10^\circ \times 10^\circ$ box centered around the GC.
- We assume the dark matter distribution is NFW profile or Einasto profile.
- We take the DM substructures into account.
- For the DM annihilation we discuss W^+W^-, $b\bar{b}$, $\mu^+\mu^-$ and $\tau^+\tau^-$ final states.

CONTINUOUS GAMMA-RAY EMISSION FROM THE INNER GALAXY



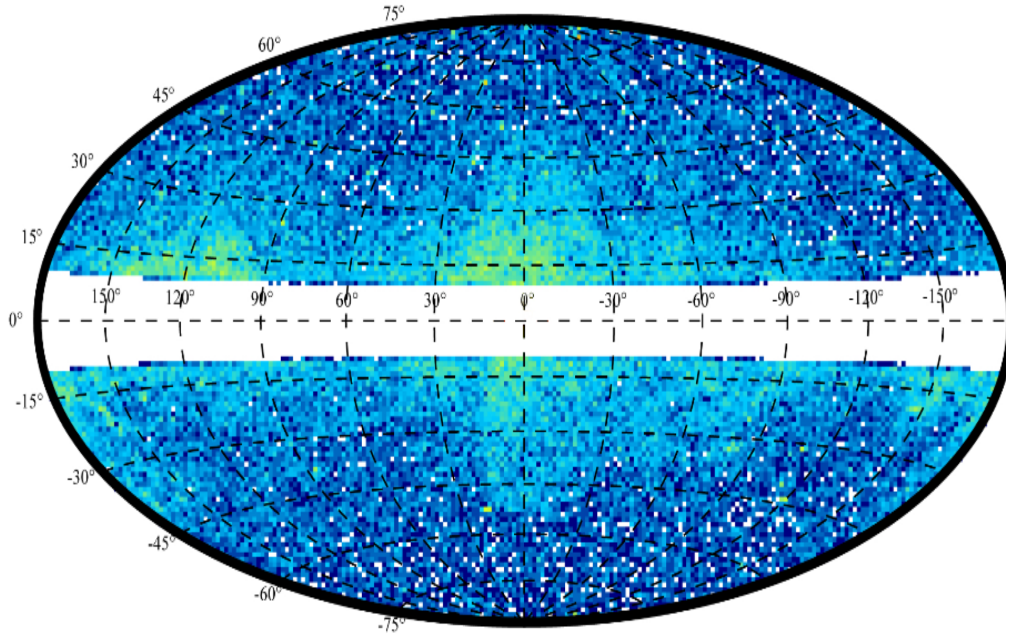
- For dark matter mass around 130 GeV, the continuous cross section can only be larger by a factor of $1.2 - 30$ compared with the cross section to gamma-gamma.
- These constraints suggest the charged particles in the loop have to be heavier than the DM particle so that the tree level process into the charged particles is forbidden.

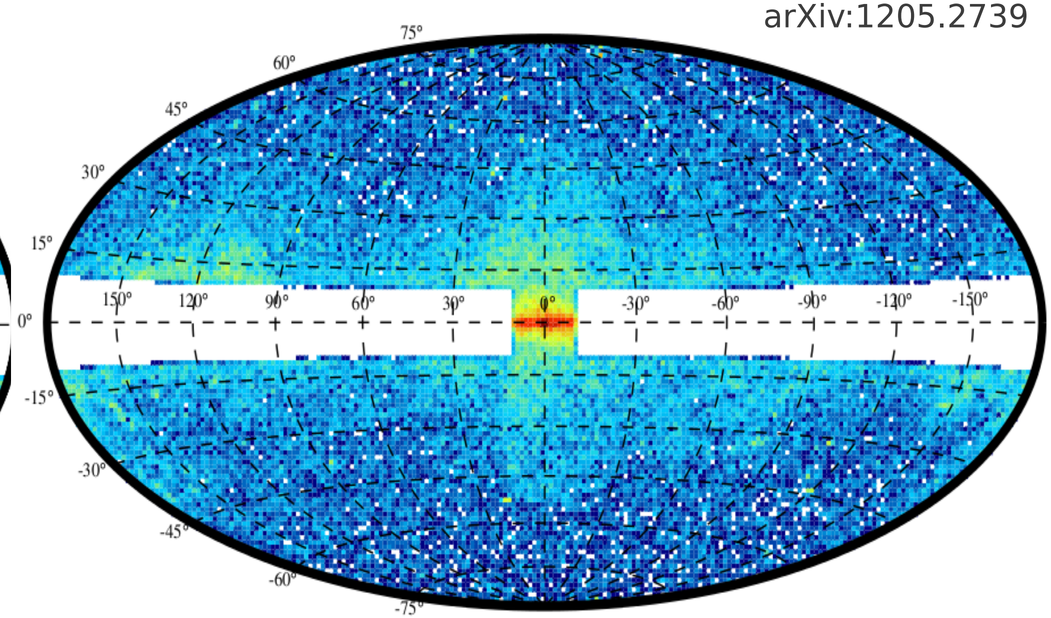
LINE EMISSION FROM THE GALACTIC HALO

- The search for the line emission in the Galactic halo should be of great importance, especially in case that there might be significant contribution from DM substructures as shown by cold DM simulations.
- We choose two sky region, $|b| > 10^\circ$ (Reg. I) and $|b| > 10^\circ$ plus $|l| \leq 10^\circ$, $|b| \leq 10^\circ$ (Reg. II)
- We use spectrum analysis, ignoring the spatial information, to search the gamma-ray line signal.

LINE EMISSION FROM THE GALACTIC HALO

From Fermi-LAT Collaboration arXiv:1205.2739

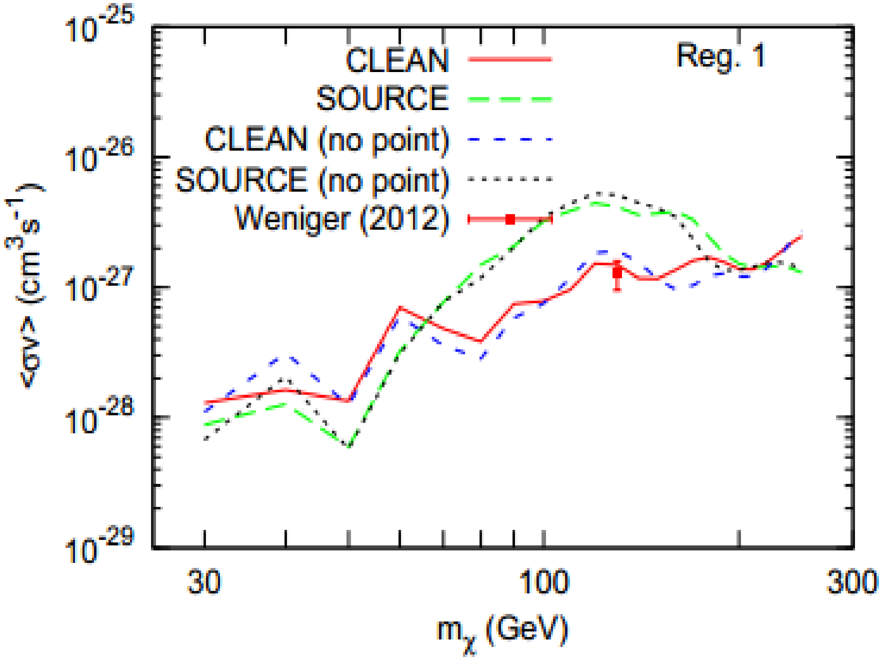


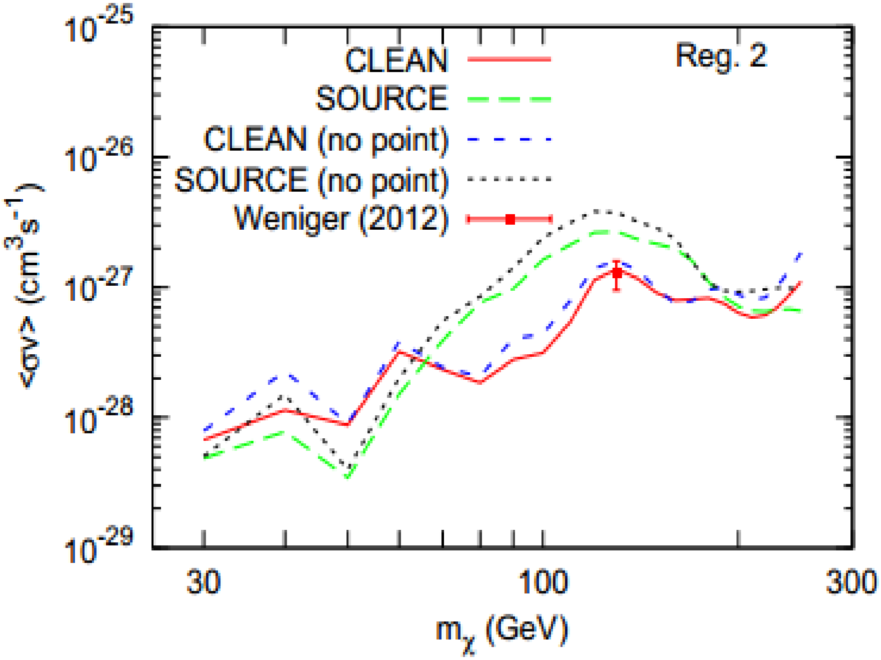


	NFW	NFW+sub	EIN	EIN+sub
Reg. 1	20.2(17.7)	43.9(38.7)	22.0(19.3)	45.8(40.3)
Reg. 2	31.4(22.5)	55.4(43.6)	42.2(27.8)	66.2(48.9)

- We assume the dark matter distribution is NFW profile or Einasto profile, and we also take the DM substructures into account.
- We mask the point source, based on the second Fermi-LAT source catalog, in this region.

LINE EMISSION FROM THE GALACTIC HALO



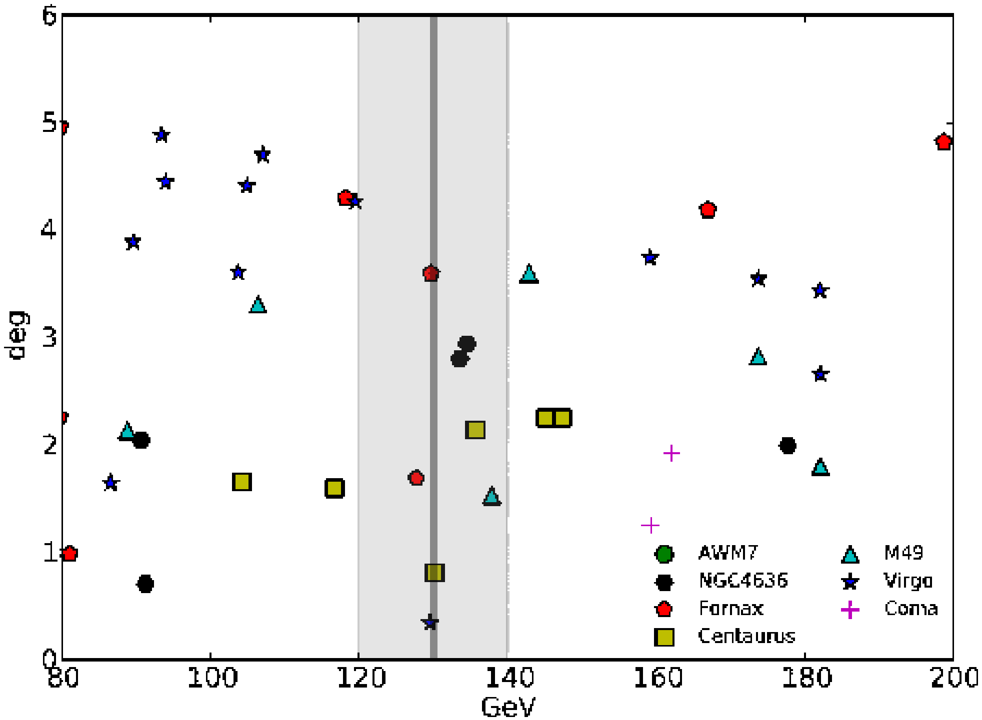


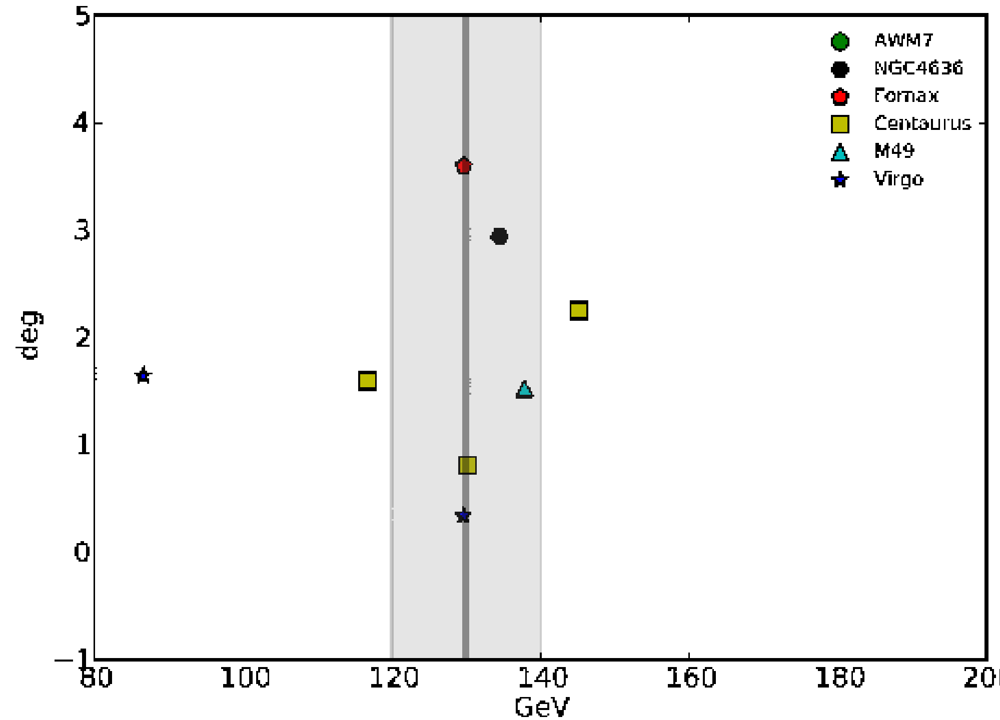
- No line emission from the Galactic halo is found in the Fermi data
- The “CLEAN” results of Reg. 2 are consistent with that derived by Fermi-LAT collaboration, in which two-year Pass 6 “ULTRACLEAN” data are used.
- For the“CLEAN” data we can only conclude that the present constraints from the Milky Way halo observations of the line-like emission are marginally consistent with that from the inner Galaxy if explaining it with DM annihilation.

LINE EMISSION FROM GALAXY CLUSTERS

- Seven clusters, Fornax, AWM7, M49, NGC4636, Centaurus, Coma and Virgo are chosen as our targets.
- We consider the effect of dark matter substructures, which could boost the J-factor to a factor of 1000.
- We treat these targets as extended sources.

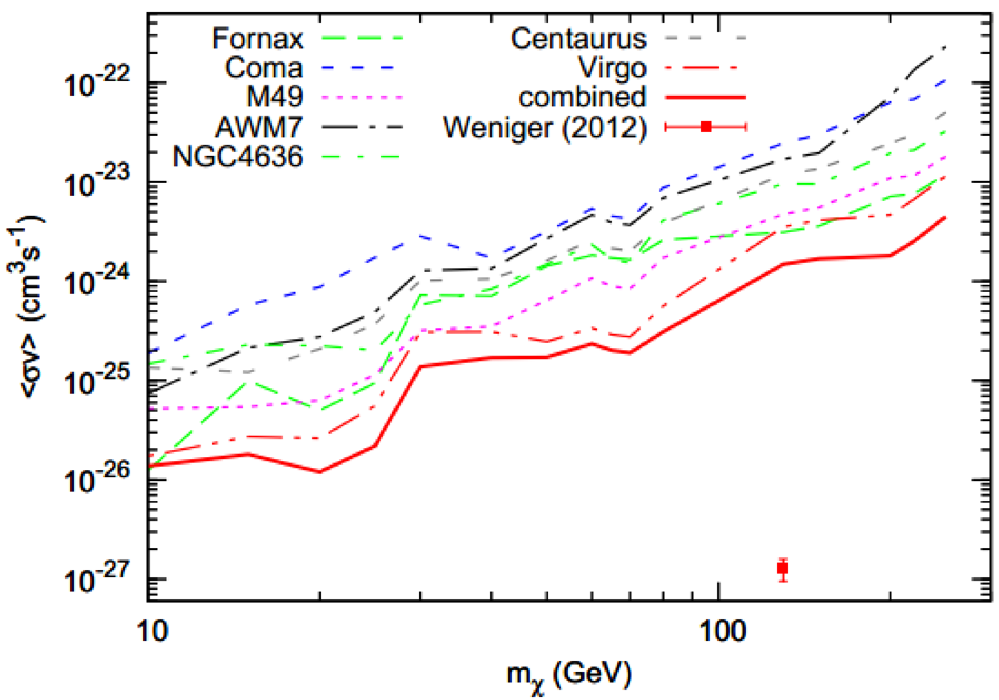
LINE EMISSION FROM GALAXY CLUSTERS

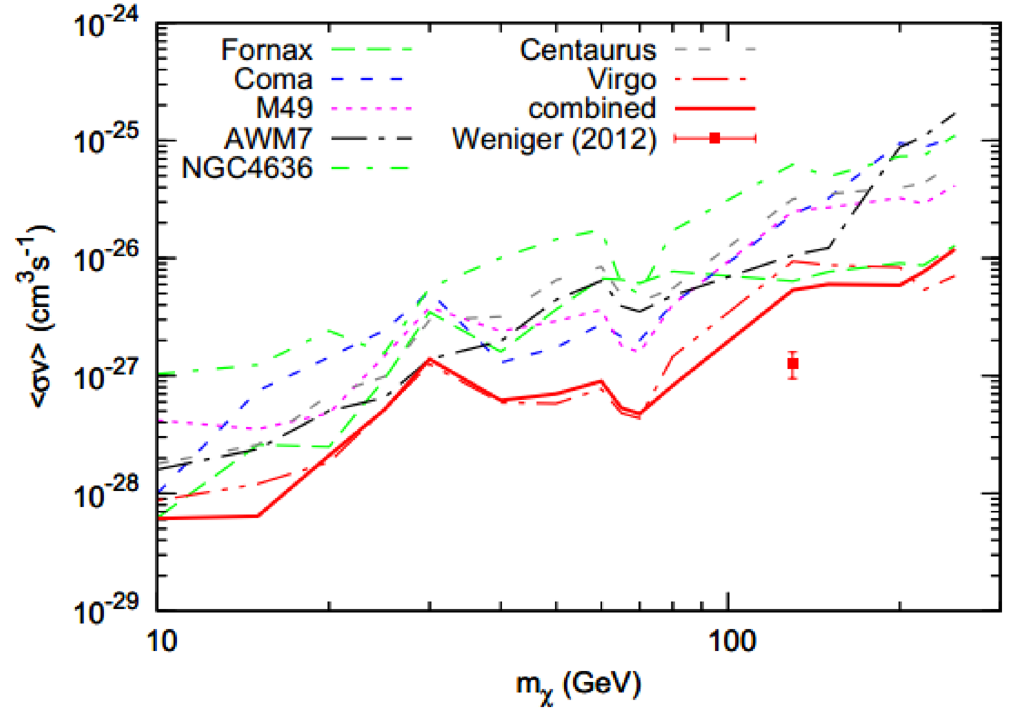




- Above plots show the individual photons with arrival directions within the virial radius of these clusters.
- It is interesting to find that for the “CLEAN” events, photons with energies between 120 and 140 GeV are more abundant than nearby energy ranges.

LINE EMISSION FROM GALAXY CLUSTERS





- Through likelihood fitting, we didn't find significant extra emission from dark matter annihilation to gamma-ray line.
- The constraints from galaxy clusters are quite weak and are still consistent with the DM interpretation of the inner Galaxy line emission, even for the case with significant substructure boost.

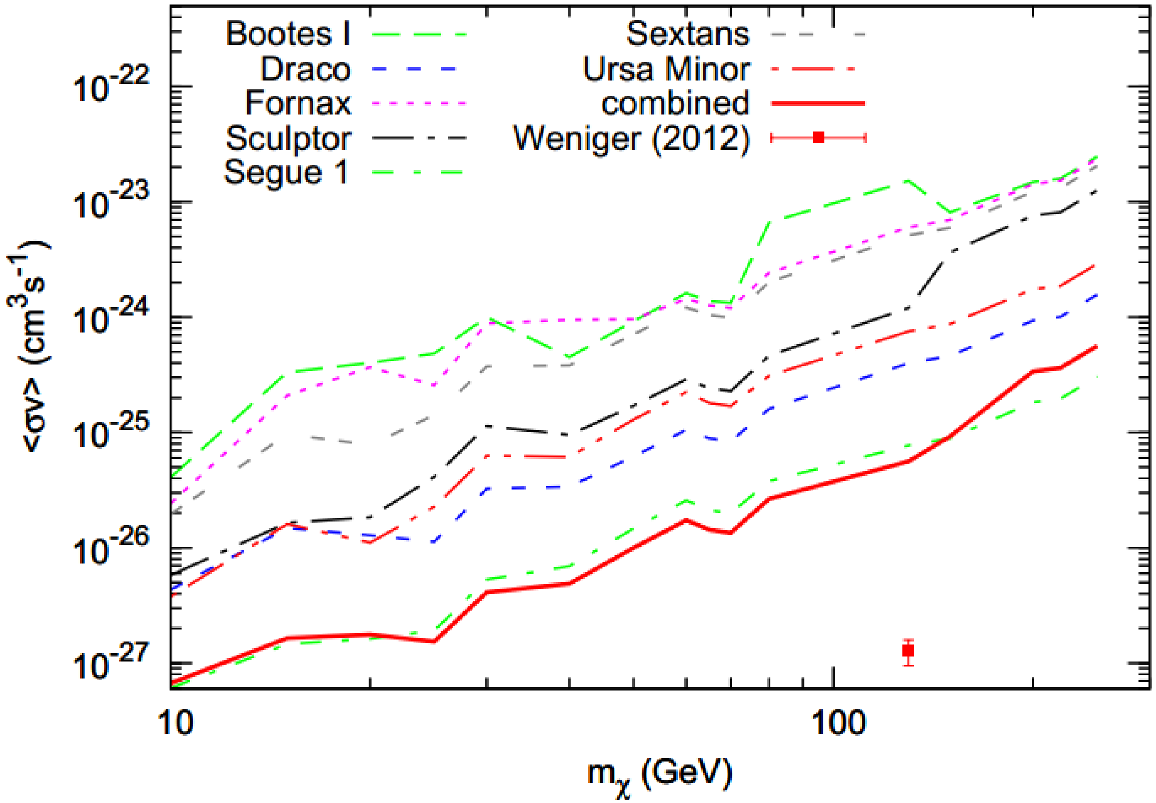
LINE EMISSION FROM DWARF GALAXIES

Name	l	b	d	$\overline{\log_{10}(J)}$	σ	ref.
	deg.	deg.	kpc	$\log_{10}[\mathrm{GeV^2cm^{-5}}]$		
Bootes I	358.08	69.62	60	17.7	0.34	[15]
Carina	260.11	−22.22	101	18.0	0.13	[16]
Coma Berenices	241.9	83.6	44	19.0	0.37	[17]
Draco	86.37	34.72	80	18.8	0.13	[16]
Fornax	237.1	−65.7	138	17.7	0.23	[16]
Sculptor	287.15	−83.16	80	18.4	0.13	[16]
Segue 1	220.48	50.42	23	19.6	0.53	[18]
Sextans	243.4	42.2	86	17.8	0.23	[16]
Ursa Major II	152.46	37.44	32	19.6	0.40	[17]
Ursa Minor	104.95	44.80	66	18.5	0.18	[16]

From Fermi-LAT Collaboration, arXiv:1108.3546v3

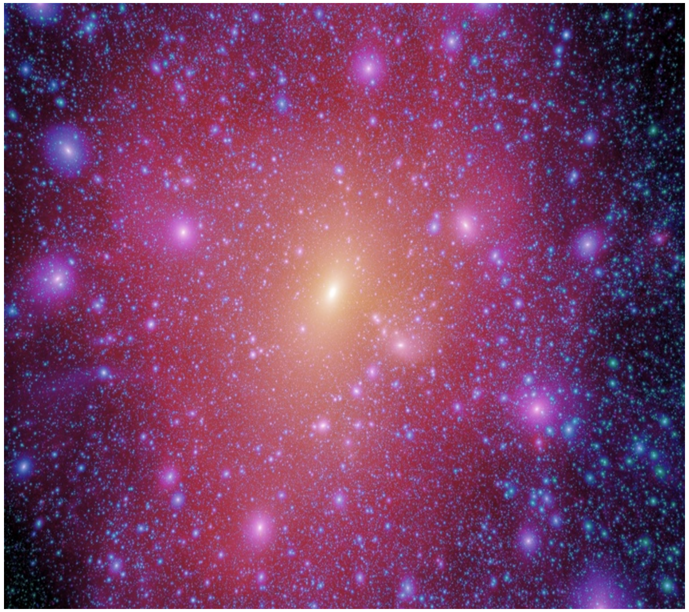
- In the work of Alex Geringer-Sameth and Savvas M. Koushiappas (arXiv:1206.0796), these authors tried to constrain line emission from dwarf galaxies.
- Here we do the likelihood fitting with point sources in the ROI and diffuse backgrounds involved, for the seek of completeness and independent check.

LINE EMISSION FROM DWARF GALAXIES



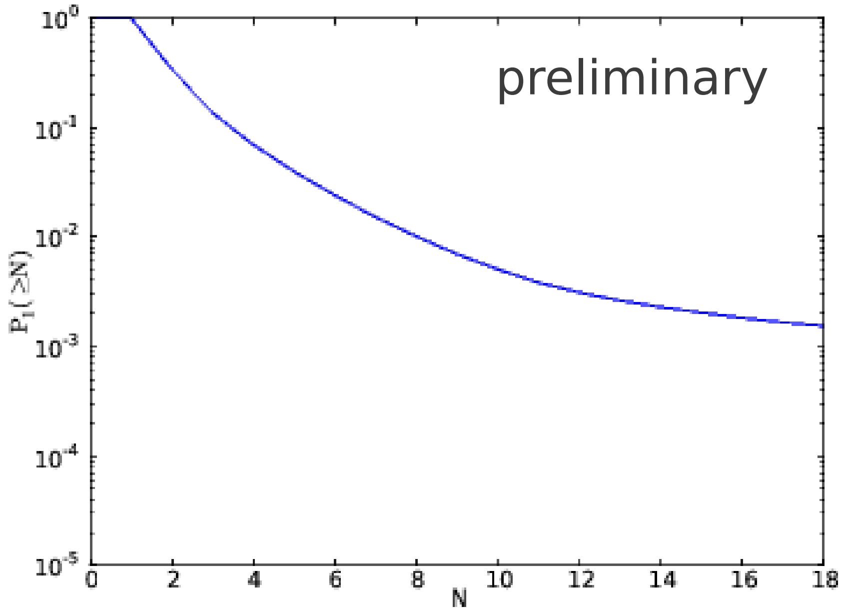
- We have found no significant γ-ray line emission in these target regions.
- We can see that the upper limits are still far away from the best fit point.
- This result is consistent with the upper limit derived in 1206.0796

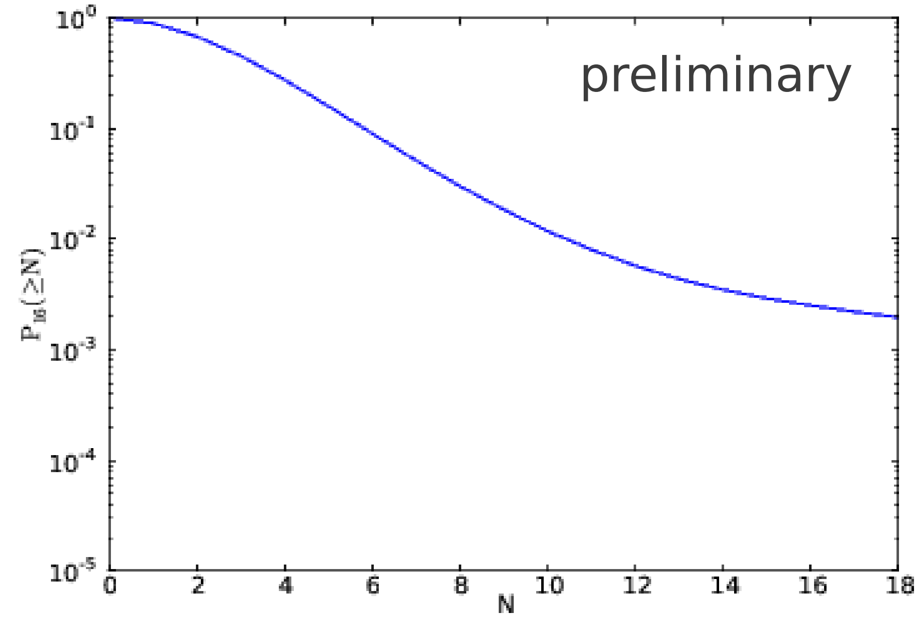
LINE EMISSION FROM SUBHALOS



- Large scale N-body cold dark matter simulations, like the Aquarius Project (arXiv: 0809.0898) show many dark matter substructures may exist in our Milky Way.
- Su and Finkbeiner (arXiv: 1207.7060) also found a tentative signal, 11 signal photons from 16 sources, from Unassociated Fermi-LAT Sources, which could be dark matter substructures in our Milky Way.

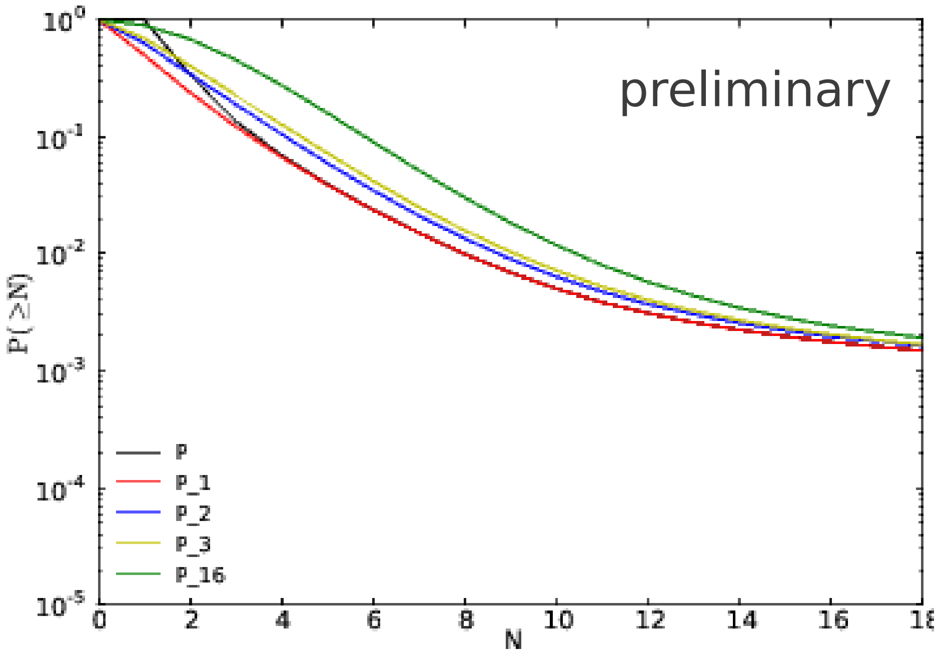
LINE EMISSION FROM SUBHALOS

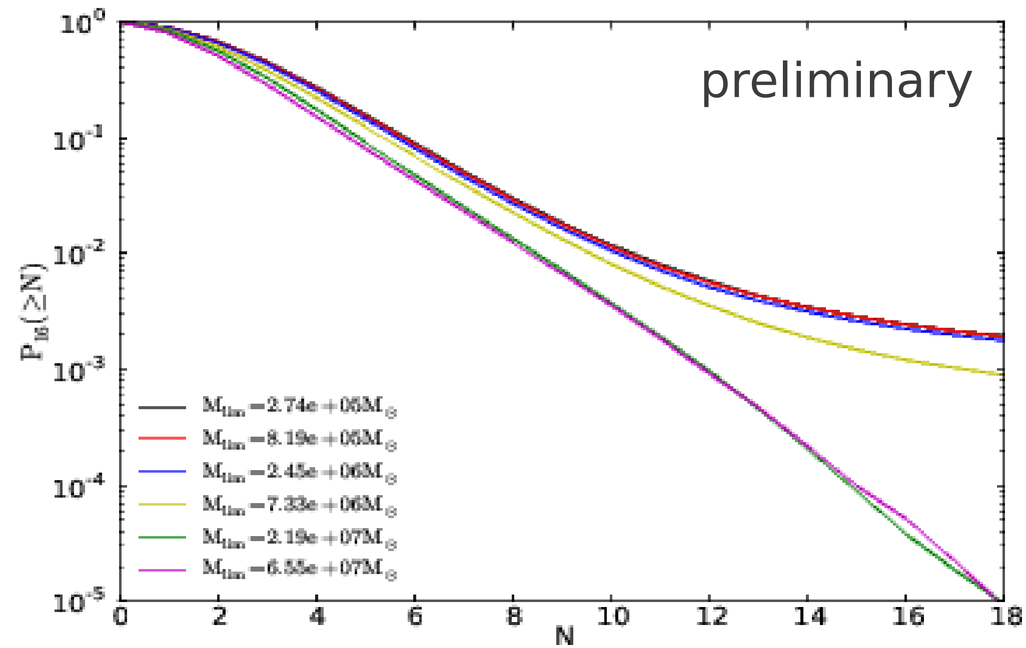




- Using the dark matter substructures configuration from Aquarius, assuming these dark matter substructures as point sources, and randomly choosing the position of the Earth, we calculate the number of photons could be detected by Fermi-LAT
- We do a Poisson Sampling by using the predicted number of photons as expected value to get the photons observed.

LINE EMISSION FROM SUBHALOS





- It seems that for large number of photons they are more likely from some brightest sources and considering more substructures will not increase the probabiliy too much for observing large number of photons
- It seems that the brightest source as mentioned above locates in the low mass end, but more low mass substructures will not increase the probability

Conclusion

- The constraints on the annihilation cross section of continuous γ-ray emission from the Galactic center are as stringent as the “natural” scale assuming thermal freeze-out of DM, and this is “unnatural” compared with the best fit cross section for gamma-gamma.
- The present constraints from the Milky Way halo observations of the line-like emission are marginally consistent with that from the inner Galaxy if explaining it with DM annihilation.
- Possible concentration of photons in $120 - 140$ GeV from nearby clusters is revealed.
- Constraints from galaxy cluster (with substructures) are marginally consistent with the DM annihilation scenario to explain the ~ 130 GeV emission, and the constraints from dwarf galaxies are weaker.
- The probability to observe dark matter annihilation photons from substructures in our Milky Way is low.

The End

Thank You!