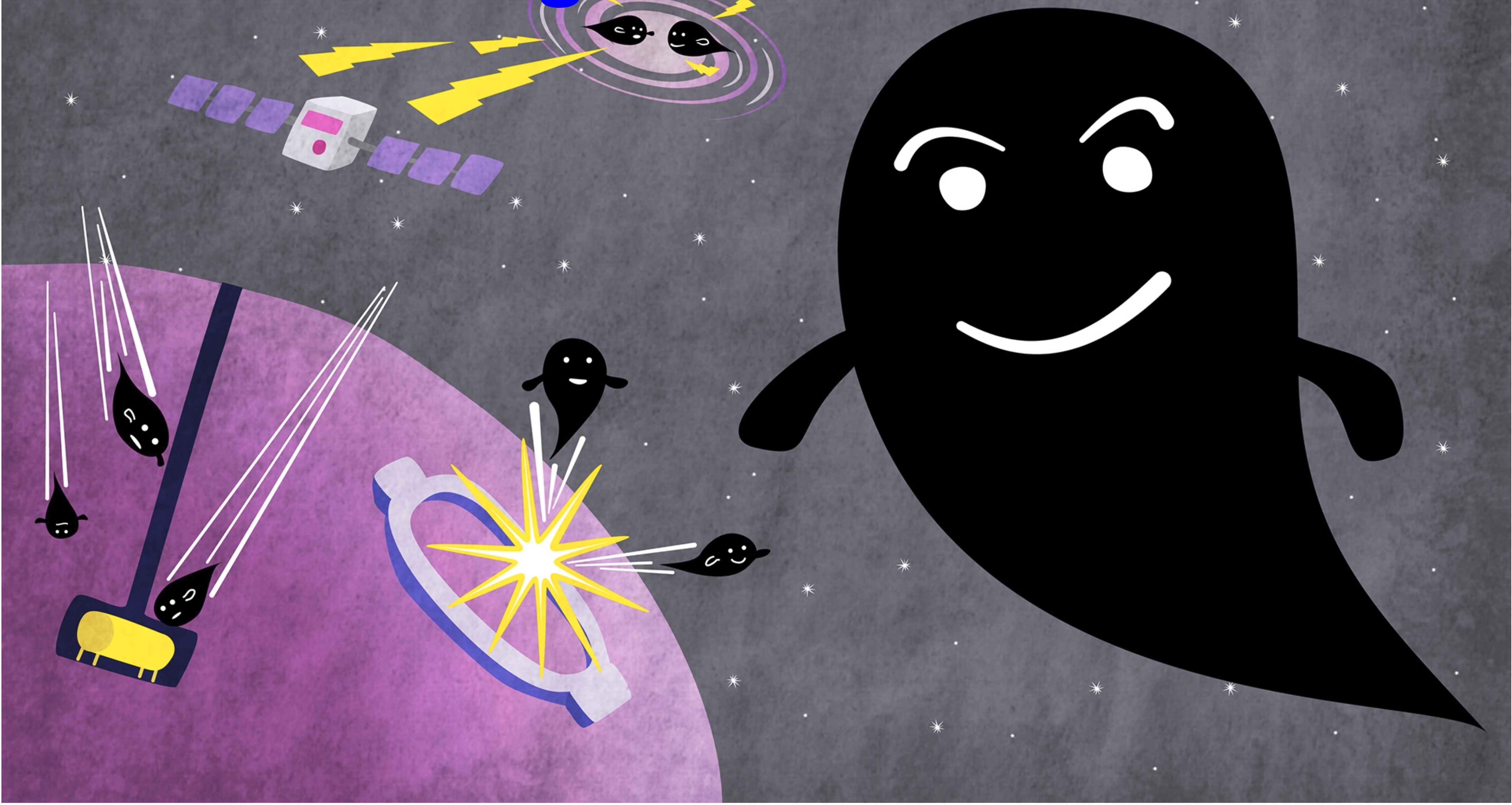
Multi-messenger dark matter searches



Marco Regis

(Torino)

UNIVERSITÀ DEGLI STUDI DI TORINO

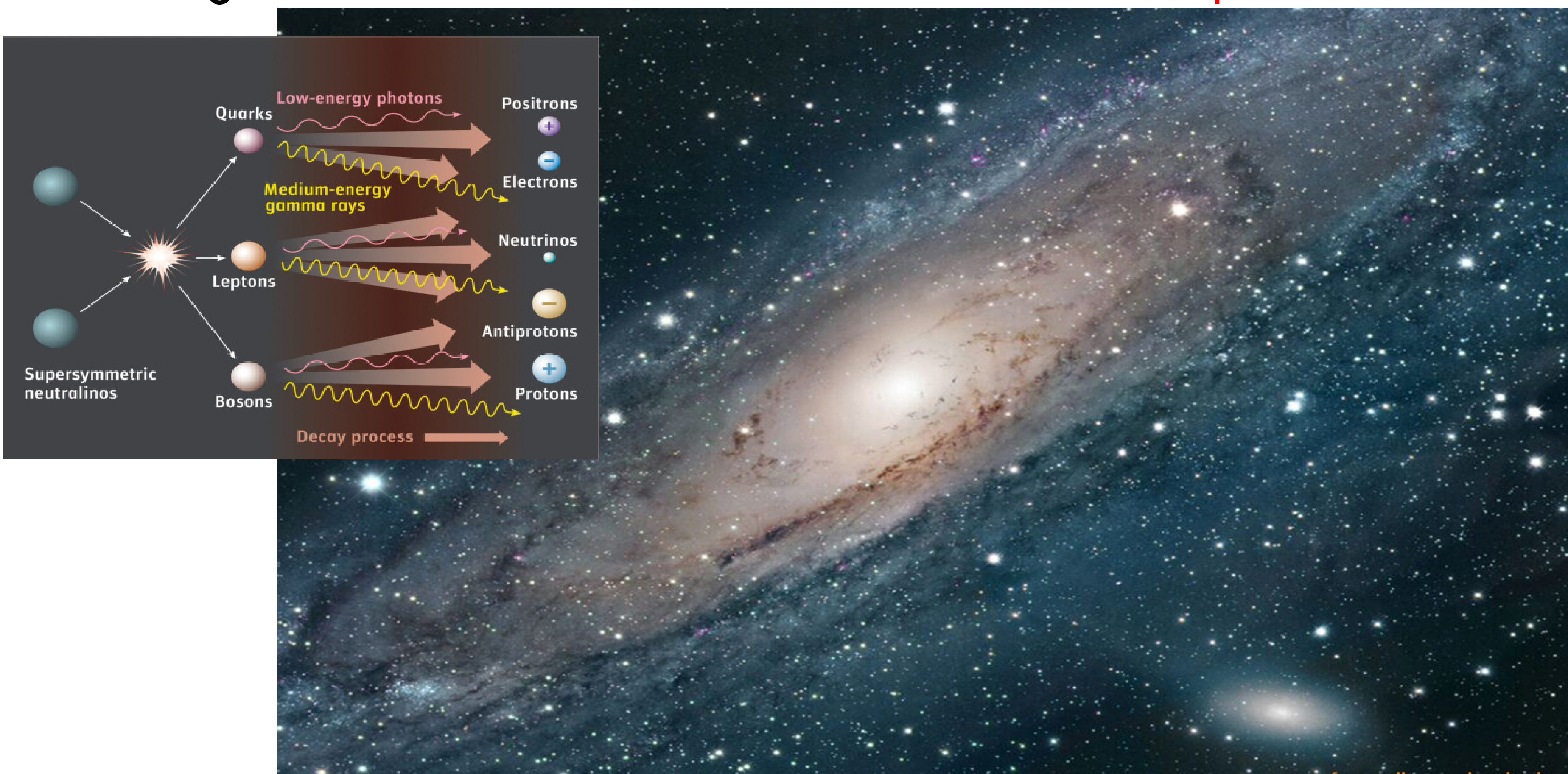
INFN Istituto Nazionale di Fisica Nucleare

Indirect detection

Annihilations or decays of DM particles

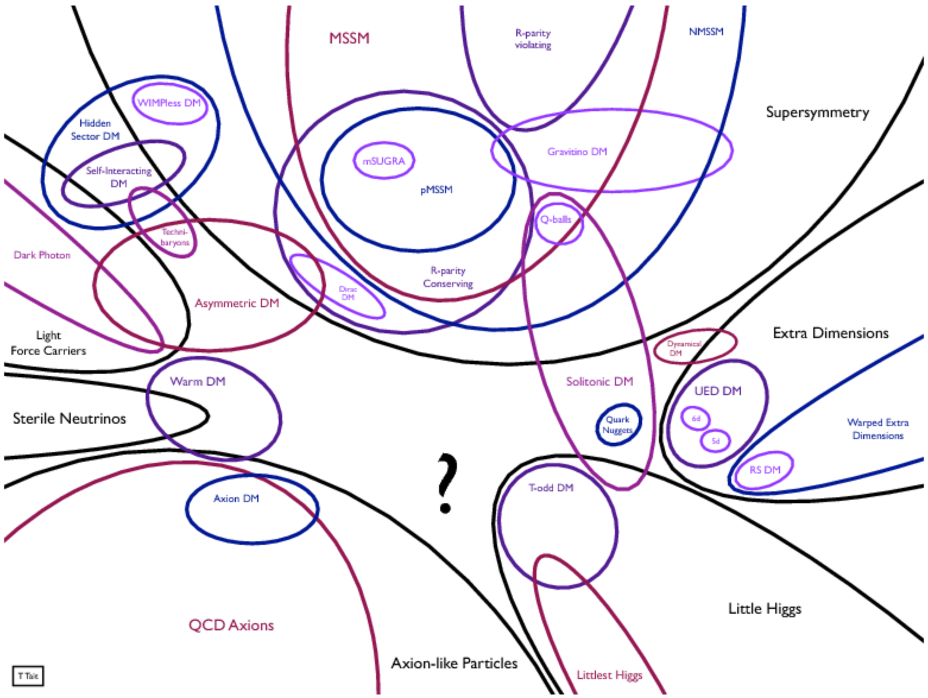
in astrophysical objects

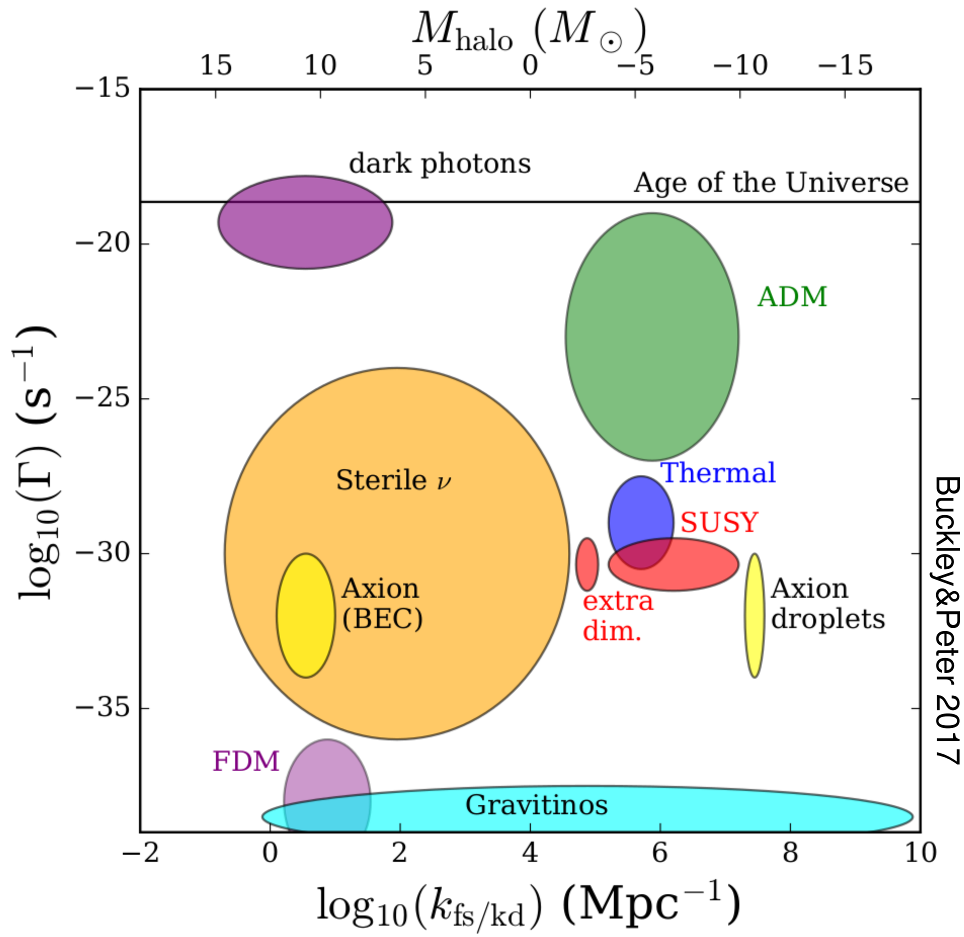
generate fluxes of “standard” detectable particles.



Energy of the process set by the **DM mass**

Particle DM candidates





SOURCE FUNCTION

Annihilating DM $$Q_i^a(r,E) = \langle \sigma_a v \rangle \, \frac{\rho(r)^2}{2\, M_\chi^2} \, \frac{dN_i}{dE}(E)$$

Decaying DM $$Q_i^d(r,E) = \Gamma_d \, \frac{\rho(r)}{M_\chi} \, \frac{dN_i}{dE}(E)$$

Indirect detection channels

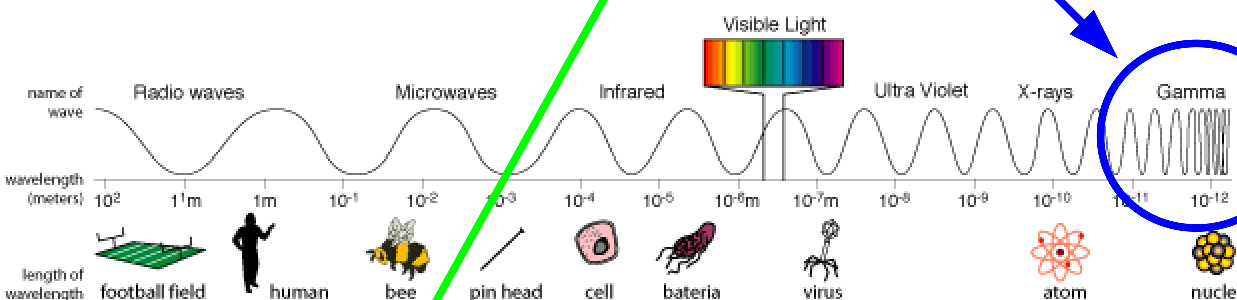
WIMPs are a primary source of

high-energy charged cosmic-rays,

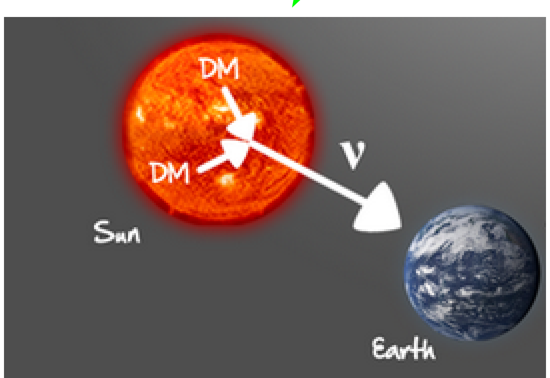
gamma-rays

and

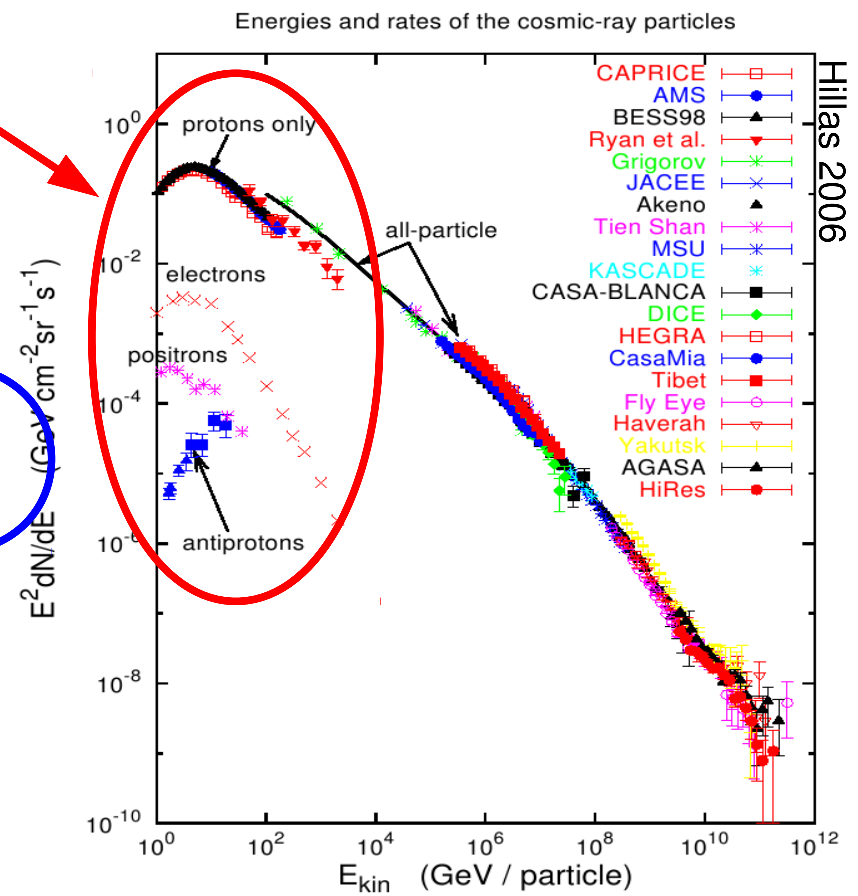
neutrinos



NASA image

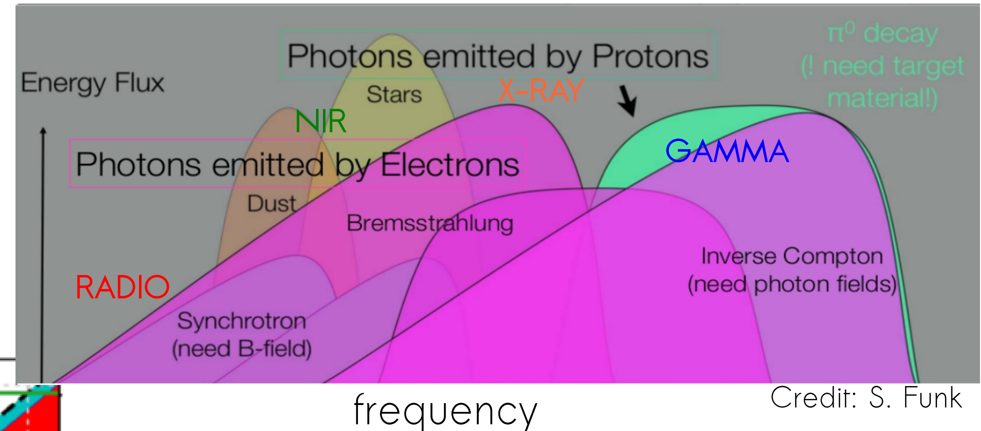


Plus radiative emission in the radio, X and gamma bands from WIMP induced e^+-e^-



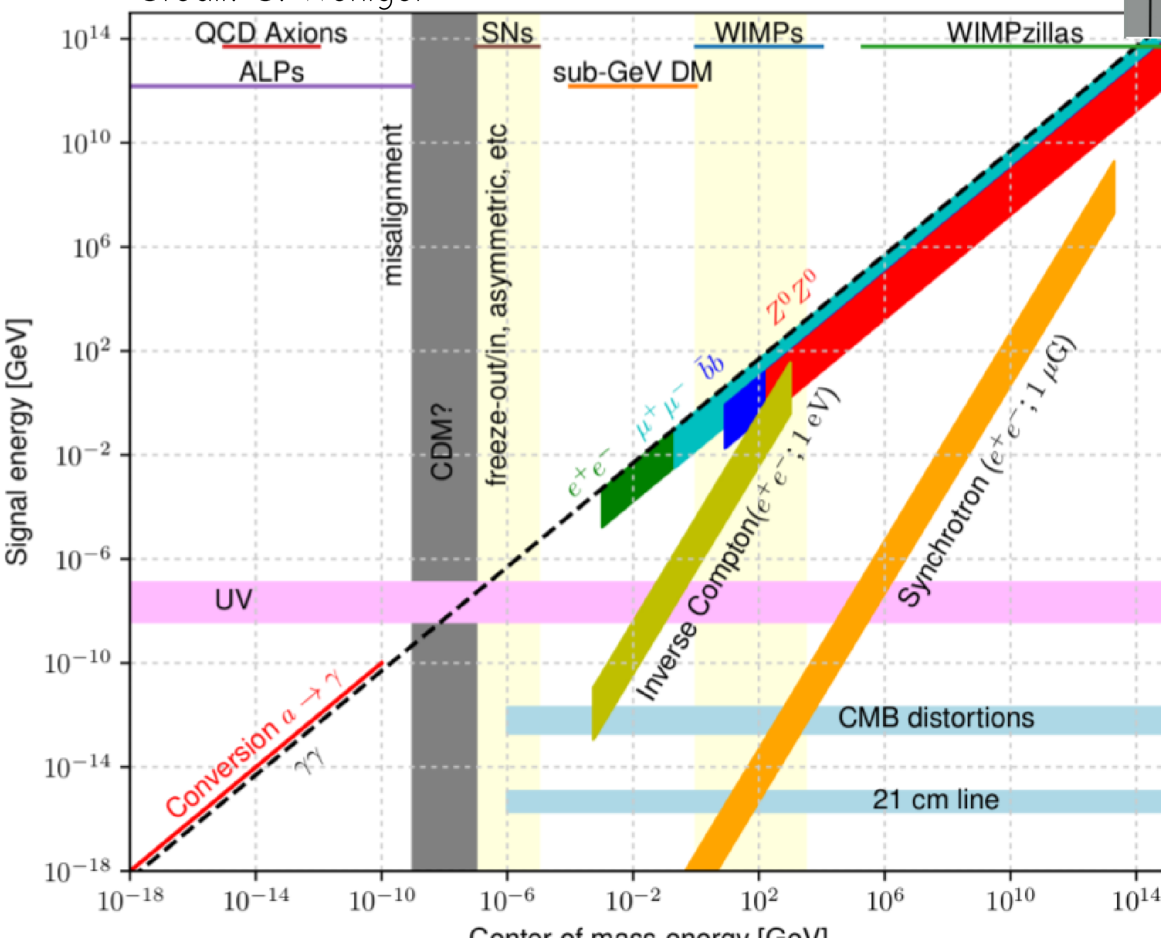
For candidates different from WIMPs other indirect signatures can arise (e.g. X-ray line for sterile neutrinos)

Mechanisms of emission



Credit: S. Funk

Credit: C. Weniger



UHECRs

Gamma rays &
Cosmic rays

X rays

UV

Optical/IR

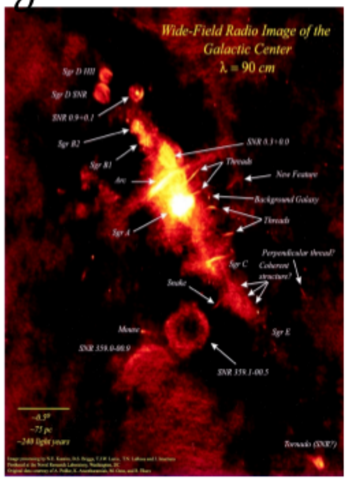
CMB

Radio

Targets

from observations...

Galactic Center

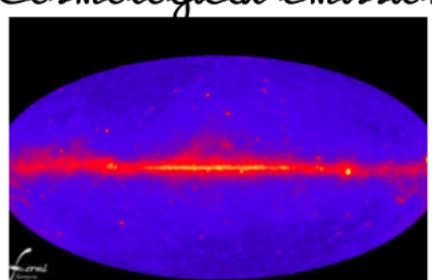


Subhalos / MW satellites

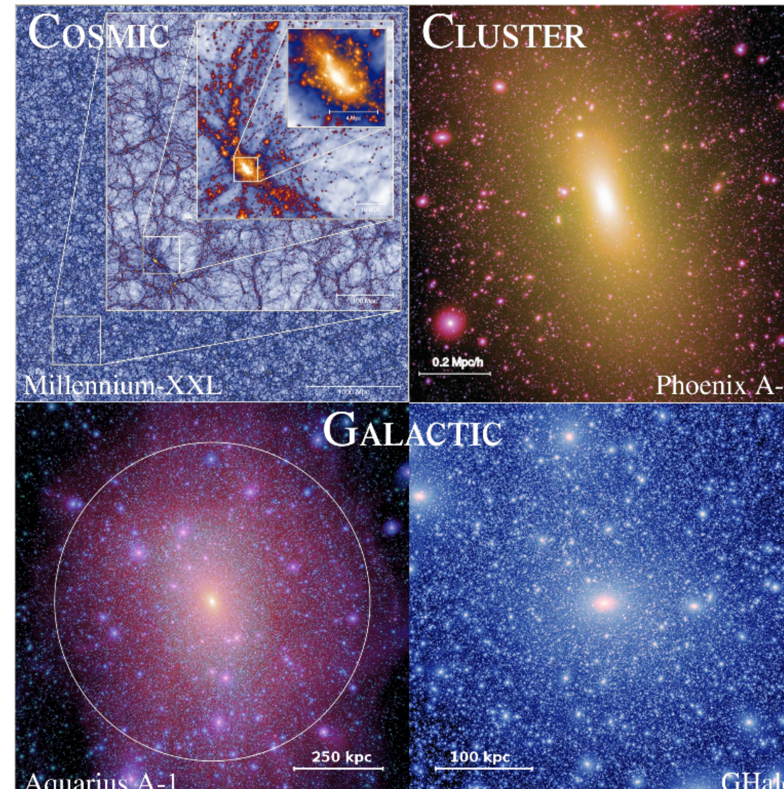
Clusters

Halo of Galaxies

Cosmological emission



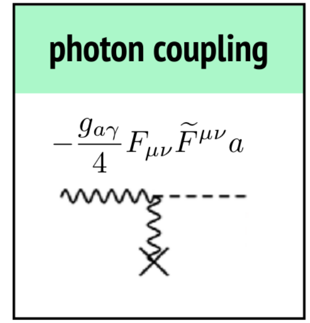
from simulations...



Kuhlen+ 2012

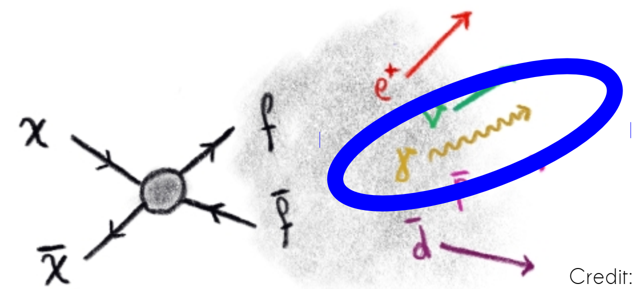
Shrinking the 4D space

Axion-like particles with decay into photon(s)



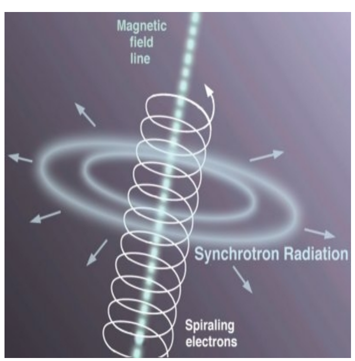
→ see talk by Javier Redondo

WIMP DM with prompt and radiative emissions



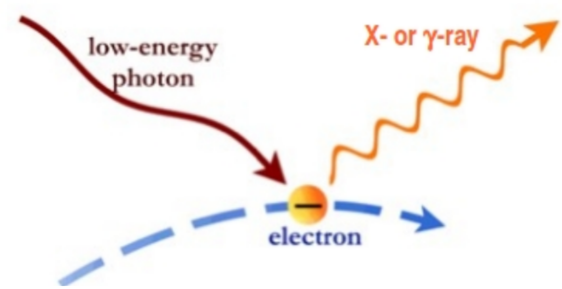
Credit: M. Korsmeier

SYNCHROTRON



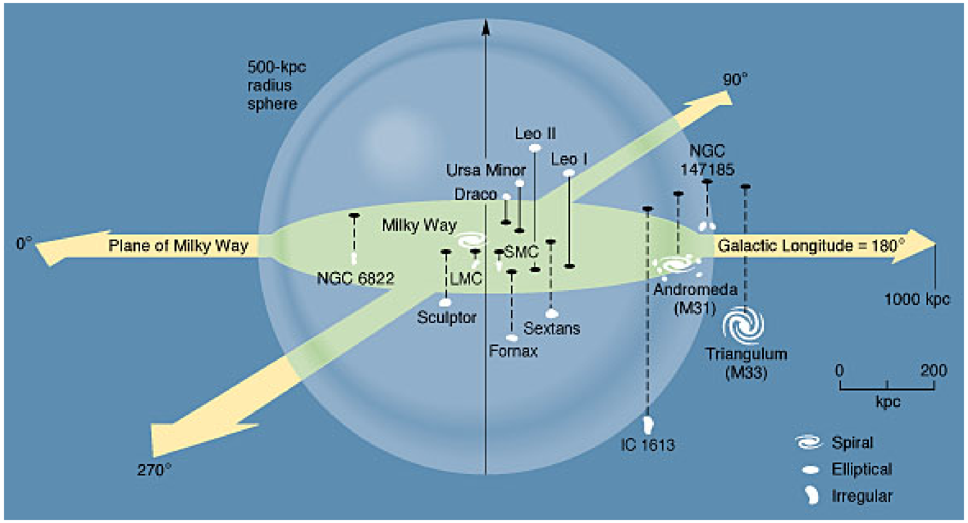
$$E \simeq 15\sqrt{\nu_{GHz}/B_{\mu G}}\ \mathbf{GeV}$$

INVERSE COMPTON

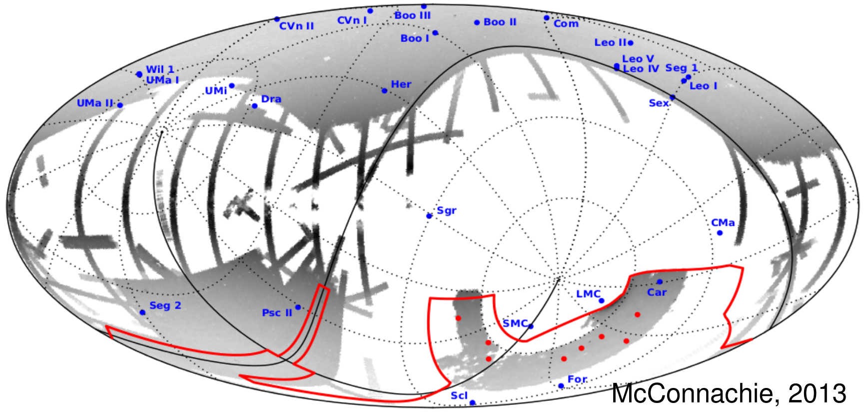


$$E_{IC} = 5.3 \times 10^{-3} \left(\frac{E_e}{\mathrm{GeV}}\right)^2 \frac{\epsilon_0}{\mathrm{eV}} \mathrm{GeV}$$

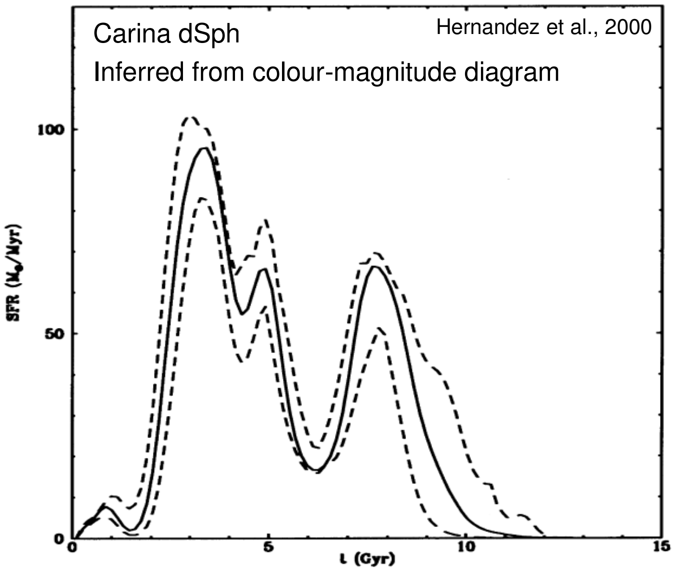
Dwarf spheroidal galaxies



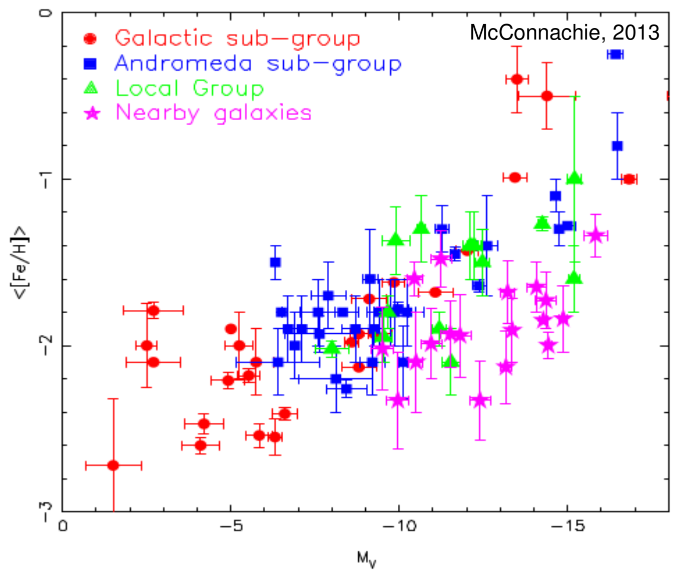
Many dSph discovered with SDSS and DES, and likely many more to come from near-future surveys.



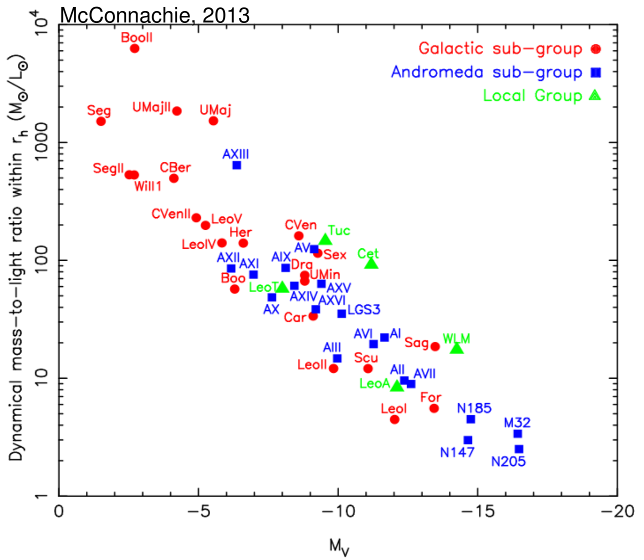
Low level of star formation



Metal-poor stellar systems



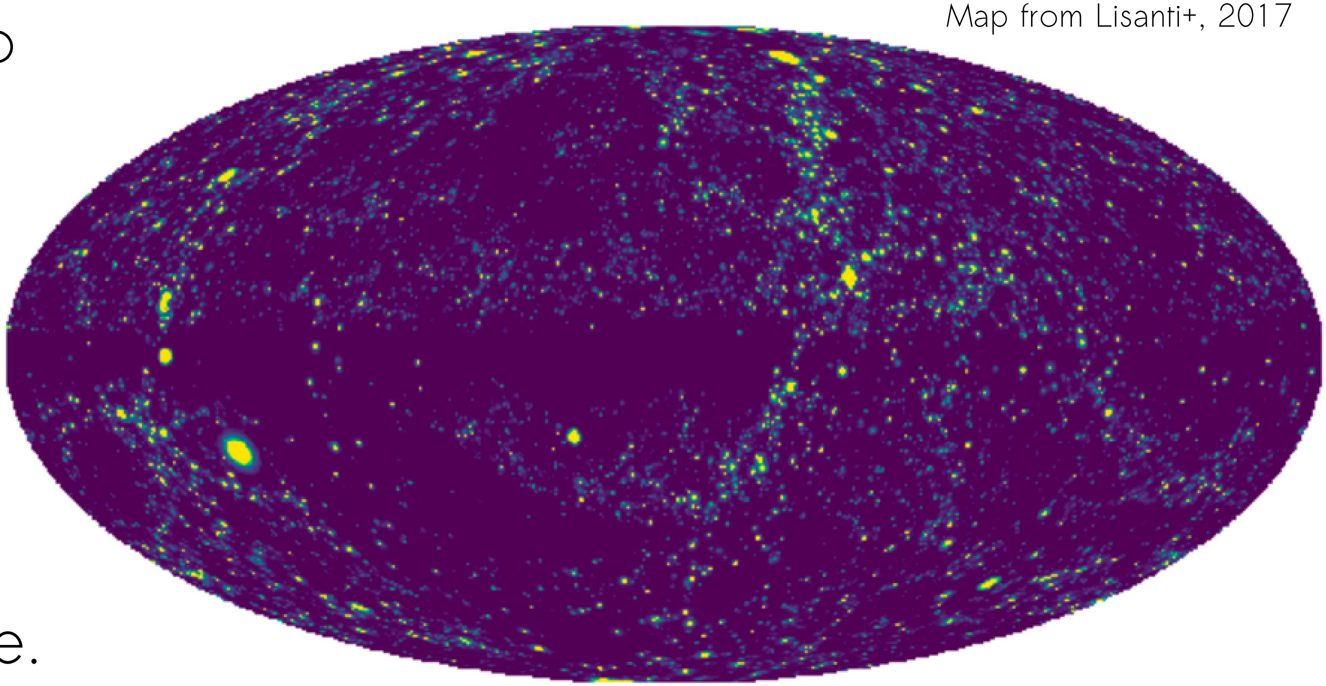
High mass-to-light ratio

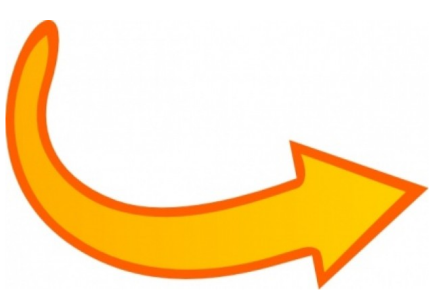


DM in the unresolved background

Even if DM halos are too **faint** to be individually detected in gamma-rays, they form the most **numerous** population in the Universe.

Map from Lisanti+, 2017



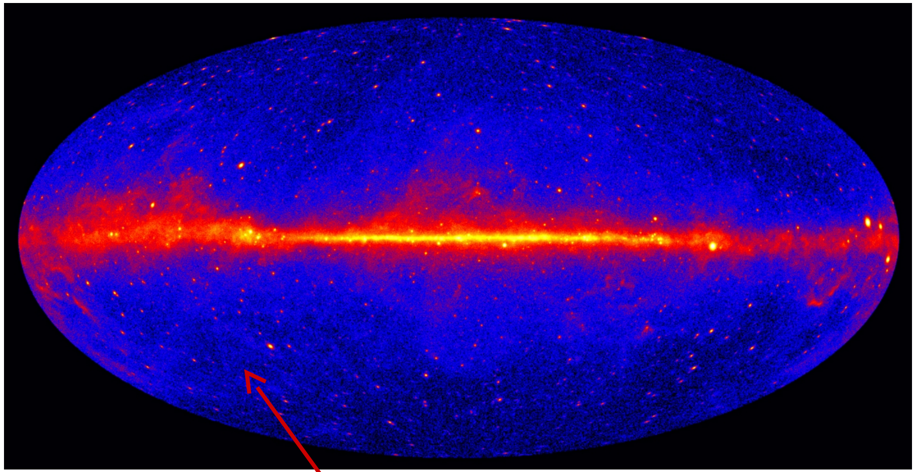


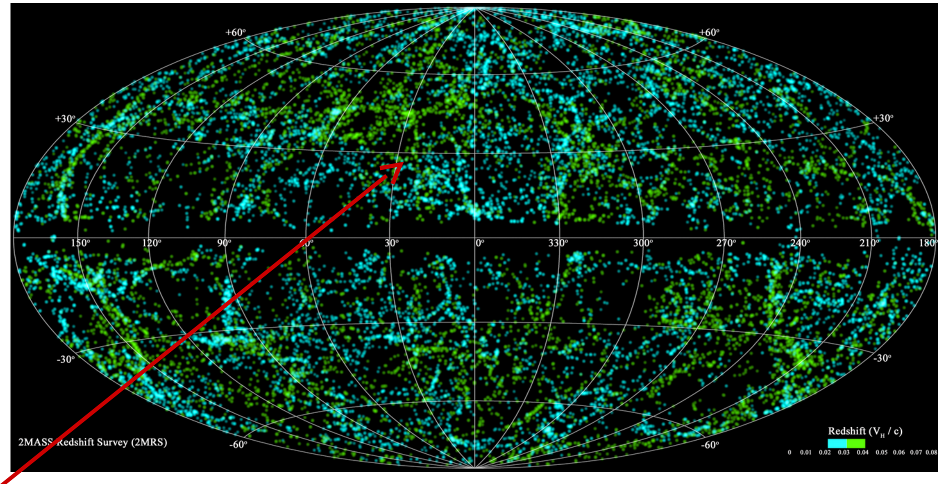
The **DM "cumulative" signal** and its spatial coherence (**angular correlations**) might be observable in the **unresolved** extragalactic sky

2-point angular cross-correlation

Map where we believe **DM-induced photons** are present (e.g. from WIMP DM in the Fermi-LAT map)

Gravitational tracer of the DM distribution in the Universe (e.g. lensing or galaxy/cluster catalog)





$$< \delta_a(\theta_1)\ \delta_b(\theta_2) > \rightarrow \mathrm{CCF}^{ab}(|\theta_1-\theta_2|) \rightarrow C_l^{ab}$$

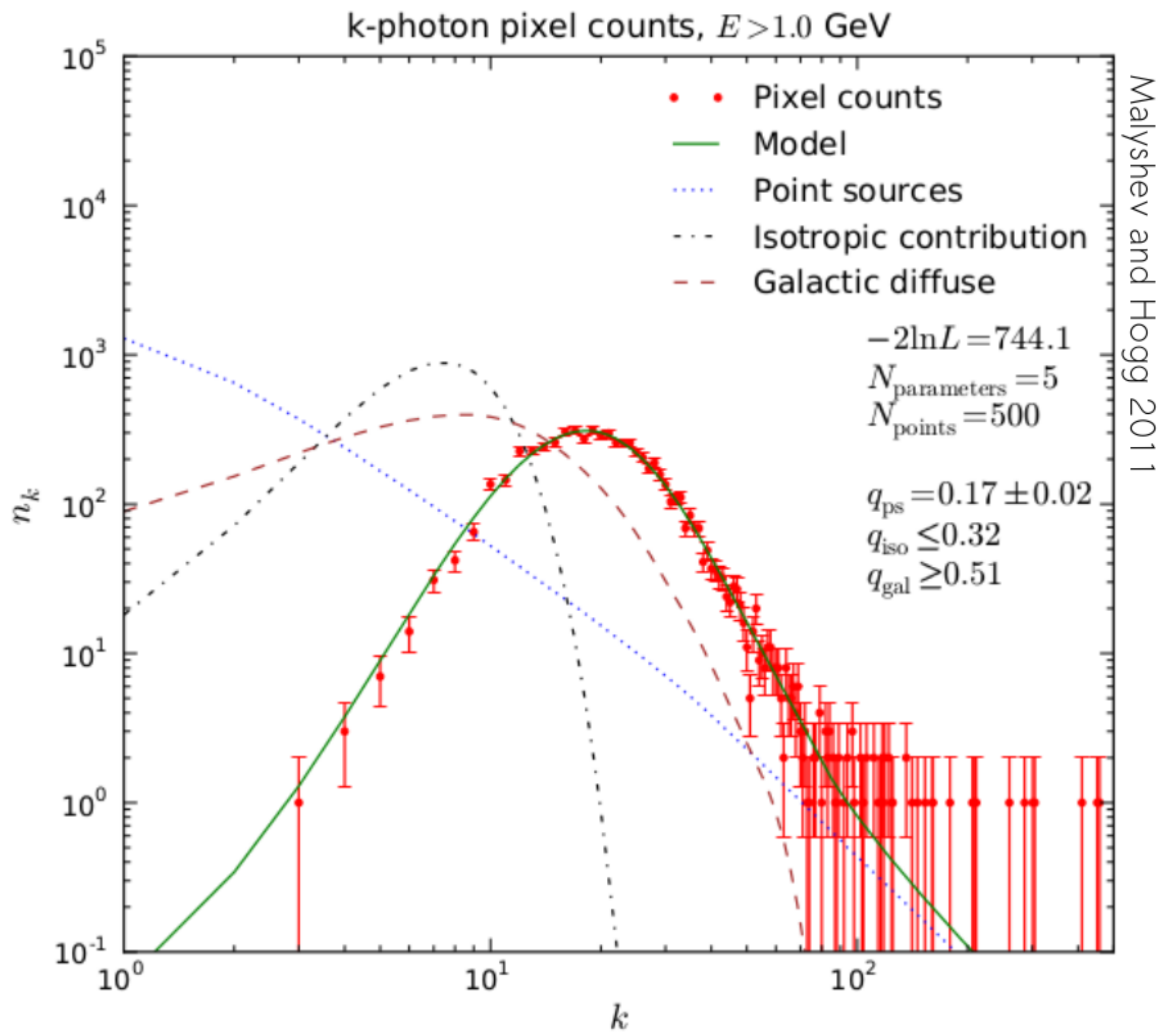
correlation in physical space

correlation in harmonic space

1-point probability distribution function

→ number of pixels versus flux (or number of photons) in the pixel

(different components have different pdf)



→ see talk by Silvia Manconi

Talk at a glance

<u>SIGNATURES</u> of

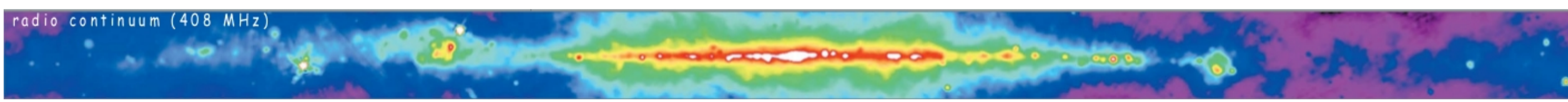
WIMP annihilations and ALP decays

in

dwarf spheroidal galaxies and unresolved backgrounds

@

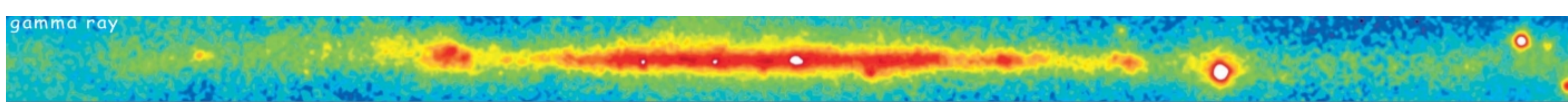
Radio



Near-InfraRed

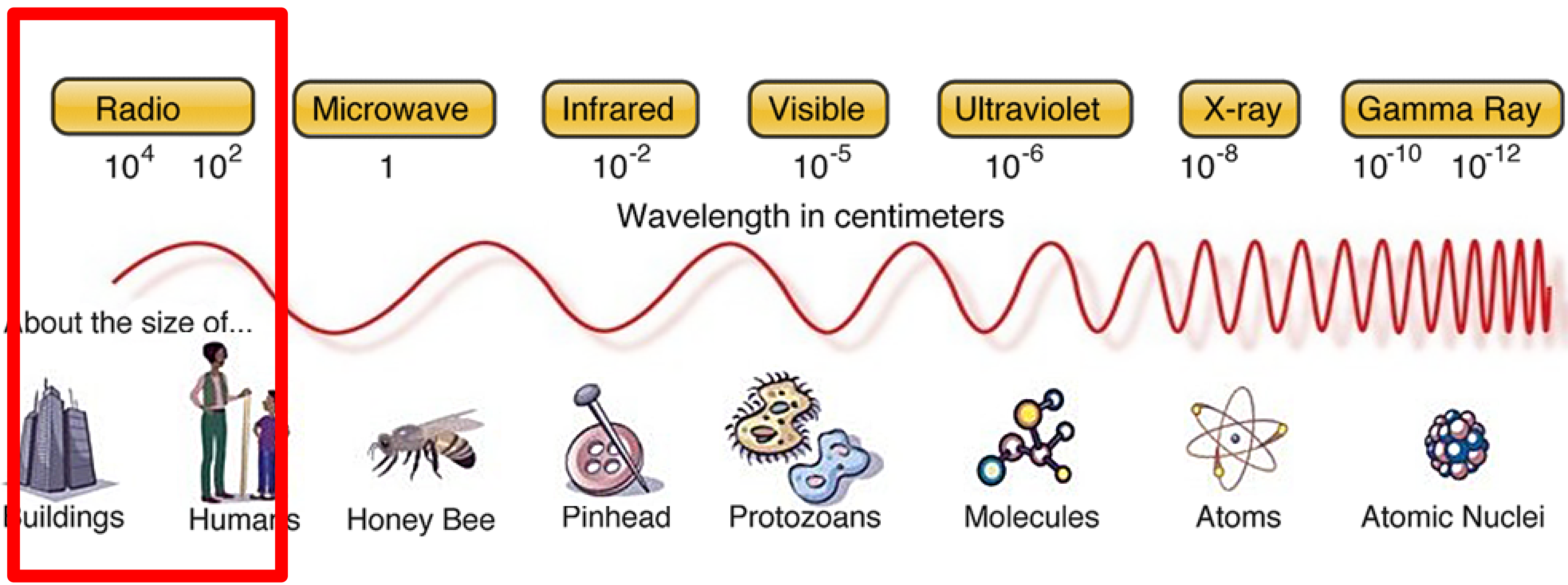
X-rays

Gamma-rays



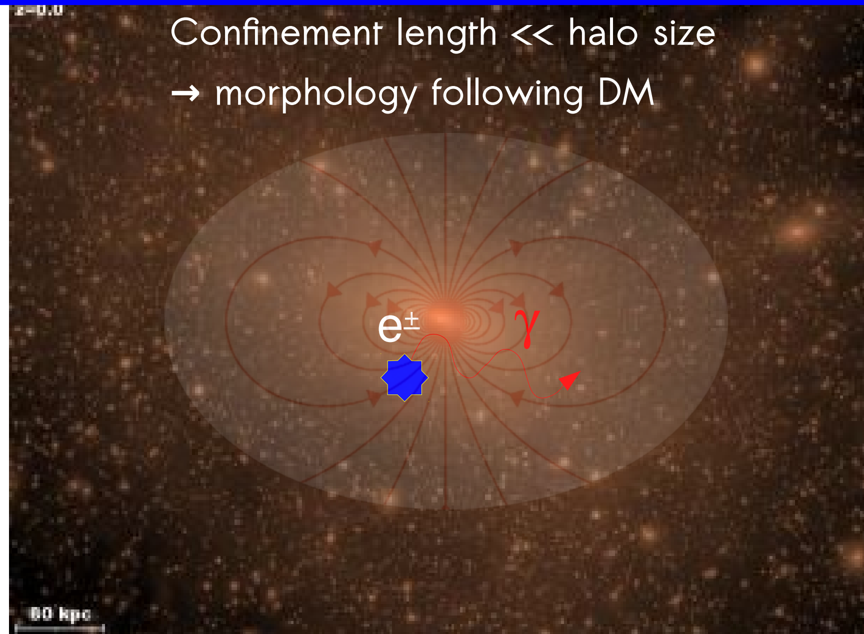
NASA images

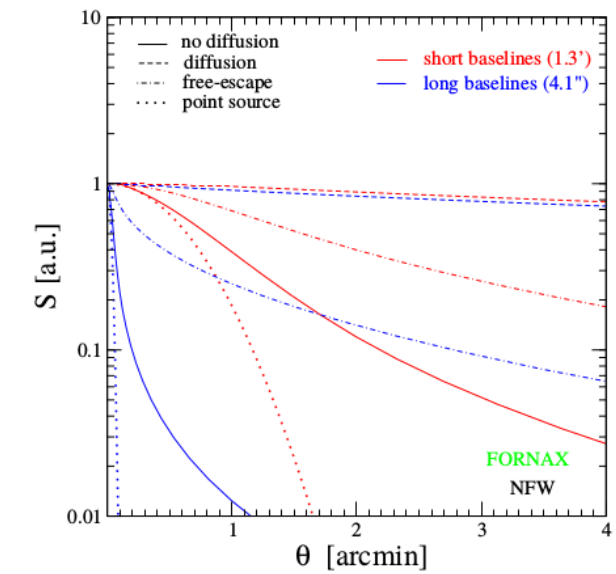
RADIO

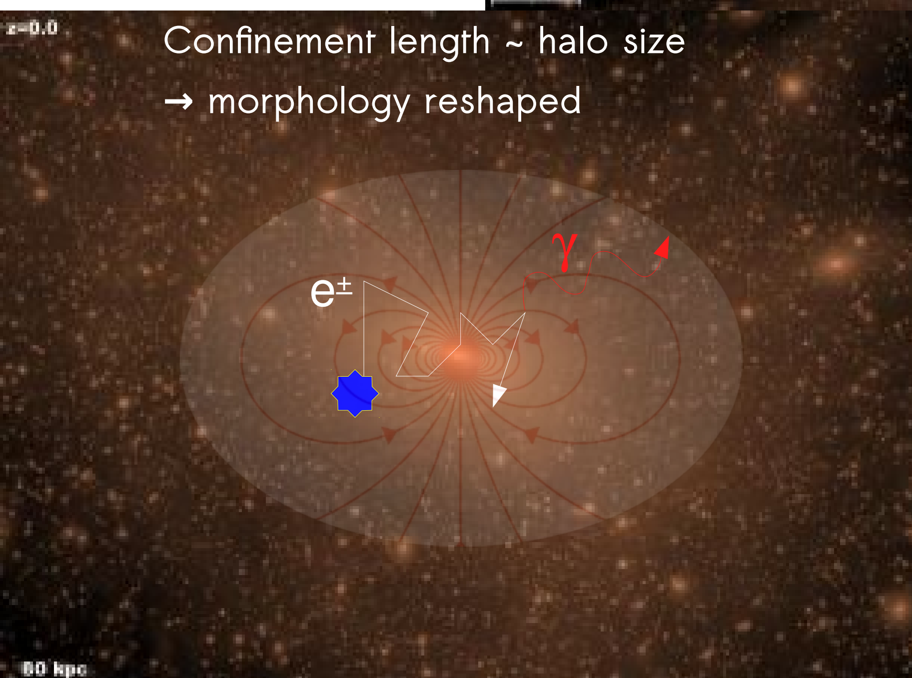

Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^4 10^2
1
10^-2
10^-5
10^-6
10^-8
10^-10 10^-12
Wavelength in centimeters
About the size of...
Buildings
Humans
Honey Bee
Pinhead
Protozoans
Molecules
Atoms
Atomic Nuclei

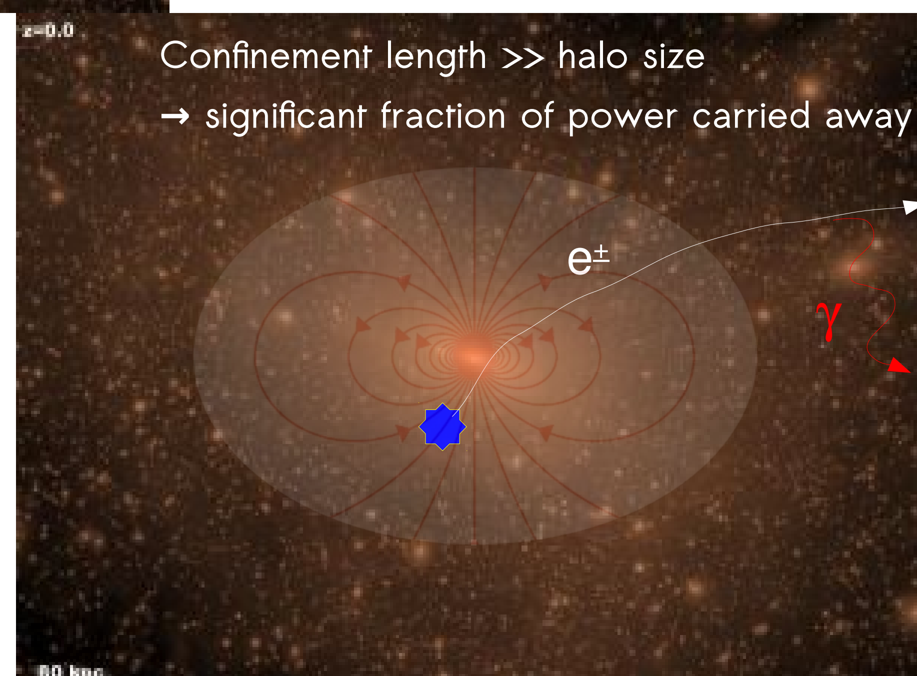
Transport of WIMP-induced e⁻/e⁺

= WIMP annihilation

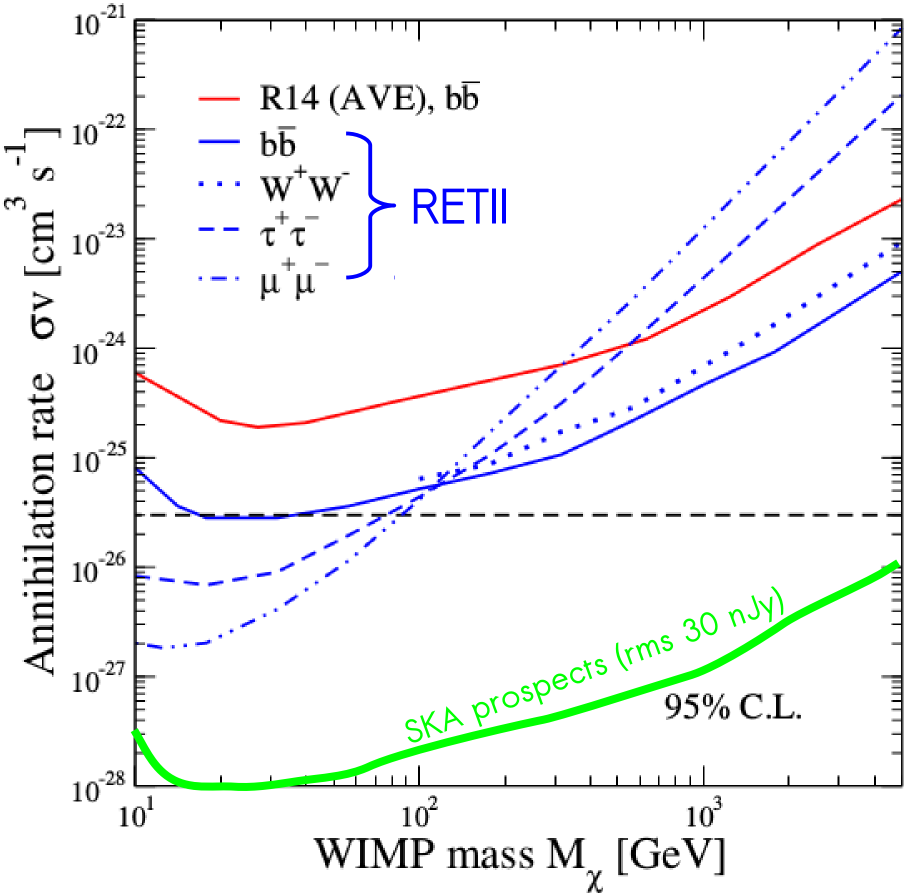


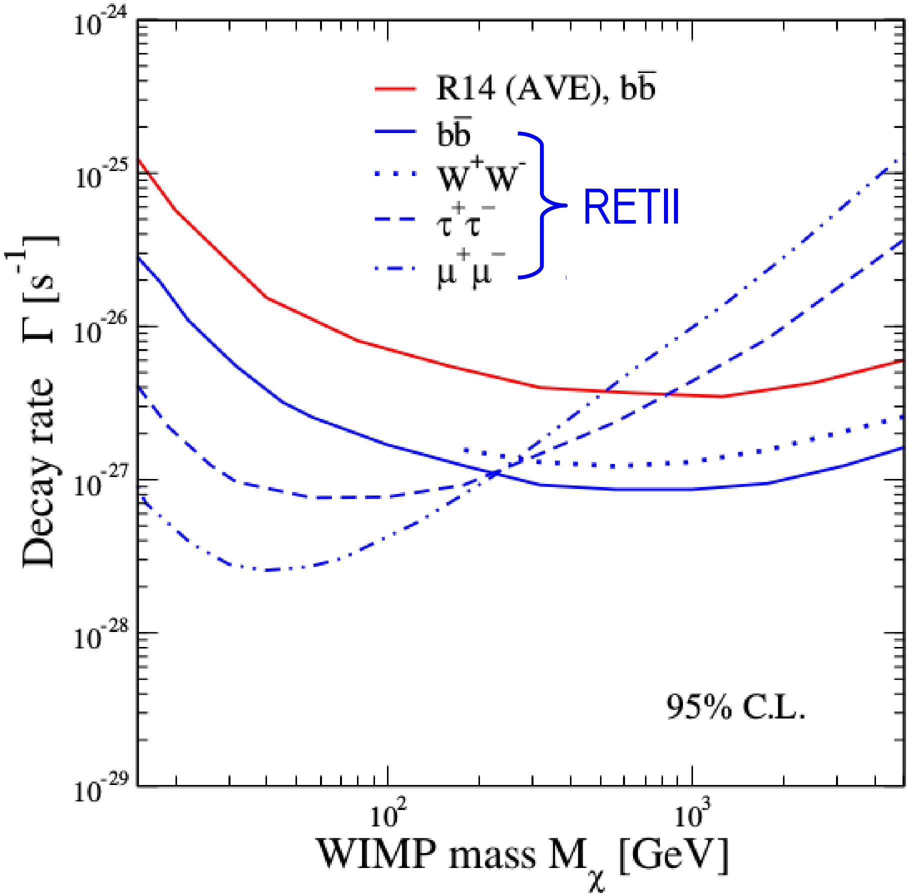






dSph bounds on WIMPs

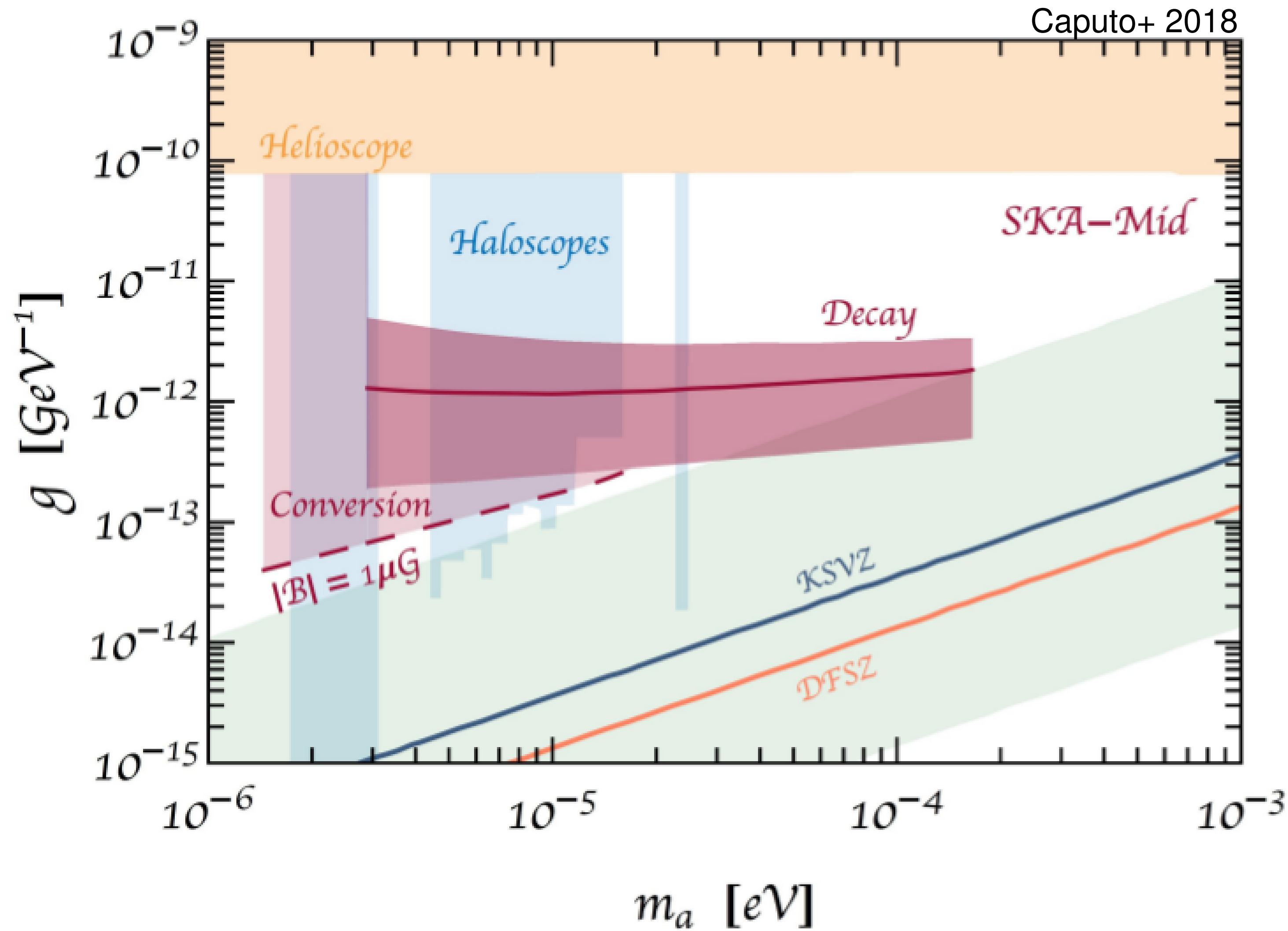




Within the next 10 years and regardless of the astrophysical assumptions,
it should be possible to **progressively close in on the full parameter space of WIMPs.**

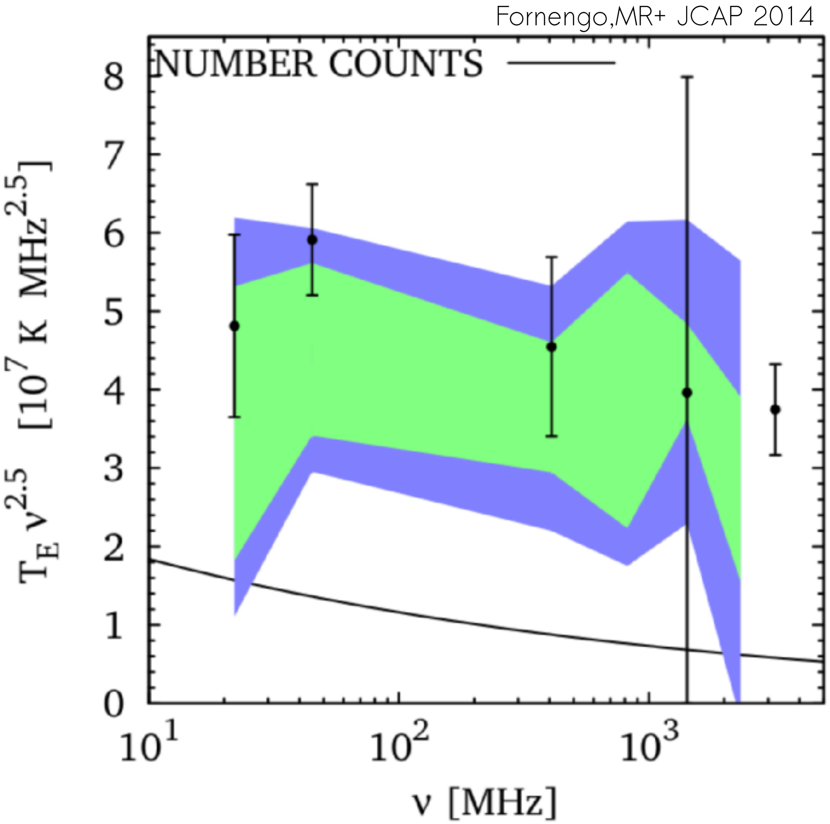
Forecasts for axion like particles

Sensitivity of the SKA to cold dark matter axions in dwarf spheroidal galaxies



The ARCADE excess

The extragalactic radio background appears to be **brighter** than extrapolation from number counts of AGN and SFG (**ARCADE-2** Collaboration 2009)



Possible explanations: (Singal, MR+ 2017)

I) Observations: issues on **calibration of zero level** for the low-frequency maps?

disfavoured?

II) **Galactic foreground**: rather peculiar underhanded aspects?

disfavoured?

III) Extragalactic sources

faint (<μJy), diffuse (Mpc scale) and/or exceptionally numerous population

(or truly diffuse/high-z cosmological sources)

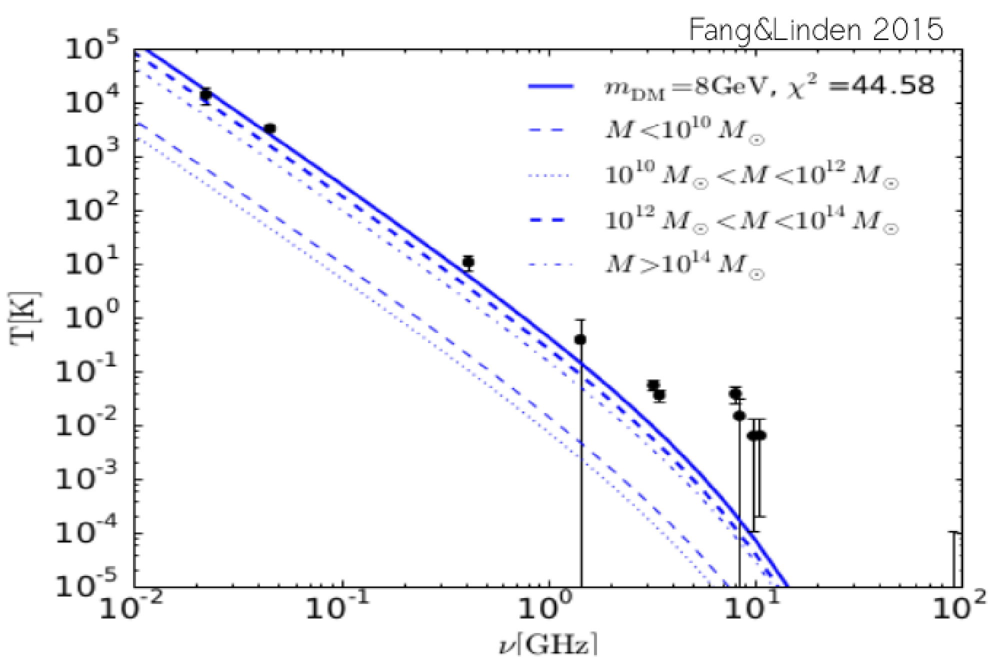
Proposed interpretations

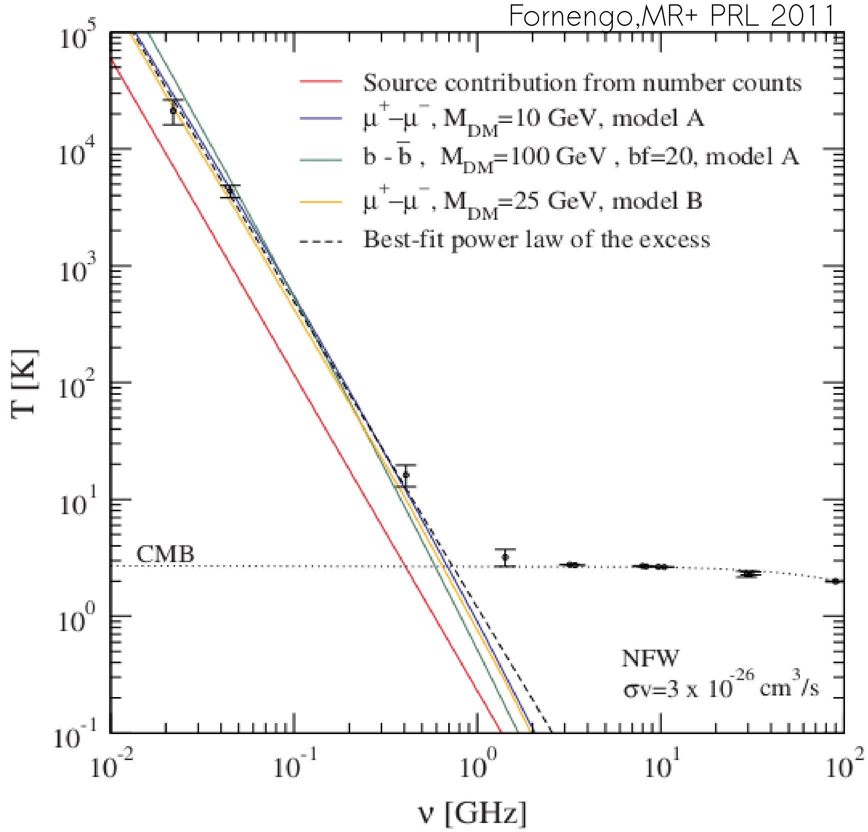
"New" radio source population taking over in the number counts at μJy level

(Singal+ 2010, Ysard&Lagache 2012, ...)

Galaxies would violate FIR-radio relation.

Fang&Linden 2015





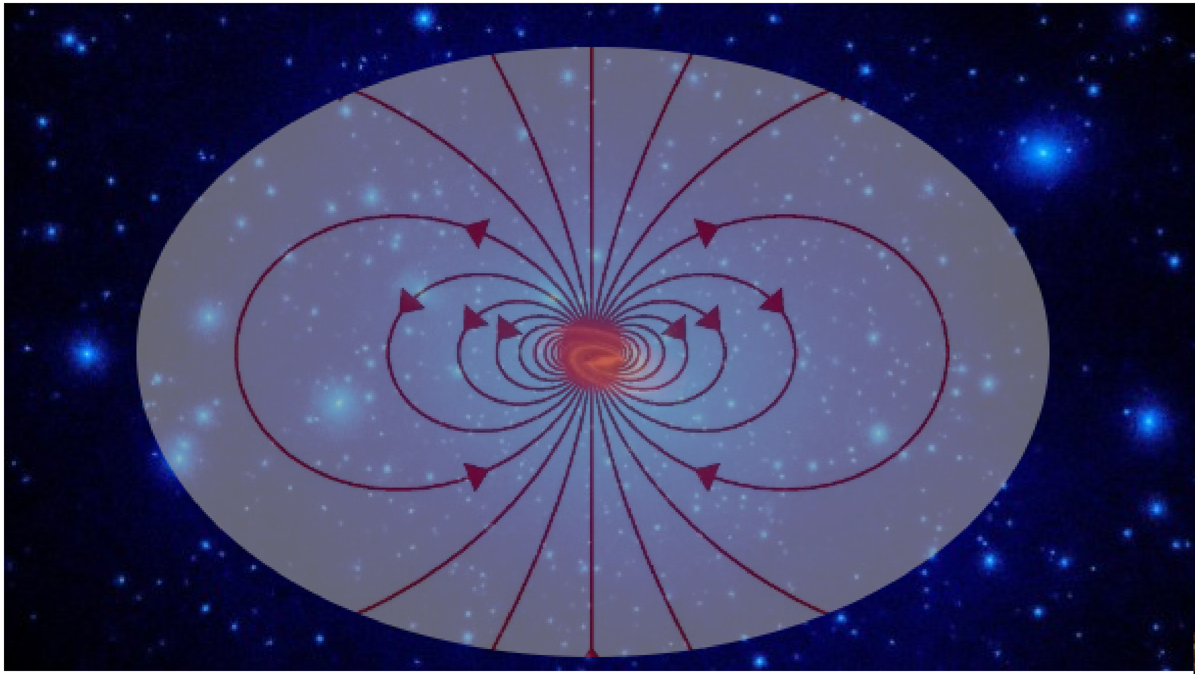
Requires **significant substructure contributions** and **large-scale magnetic fields**.

Where DM solution can work

"Traditional" structure
with non-quiescient baryonic distribution

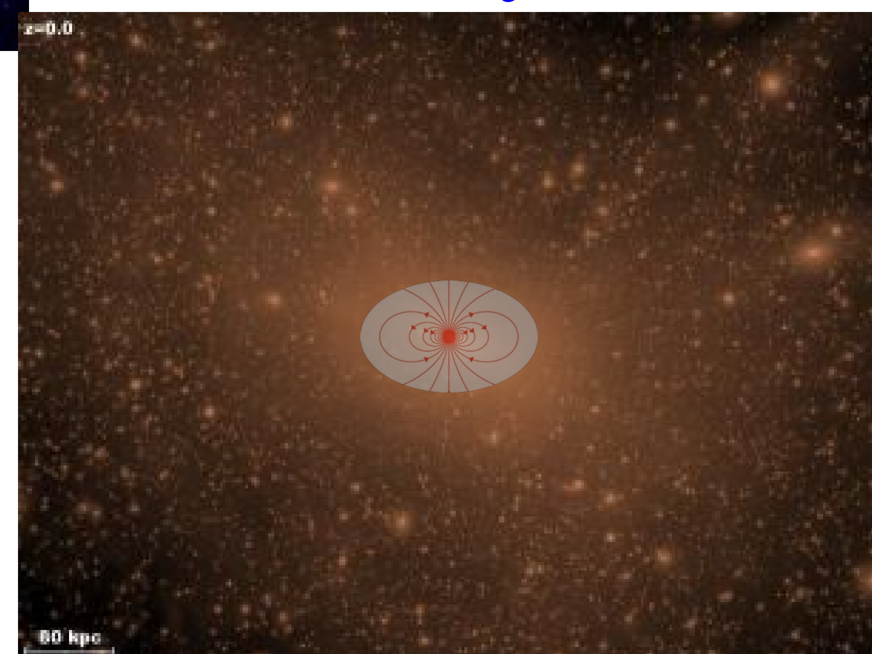
Dark structure

Where DM solution can work

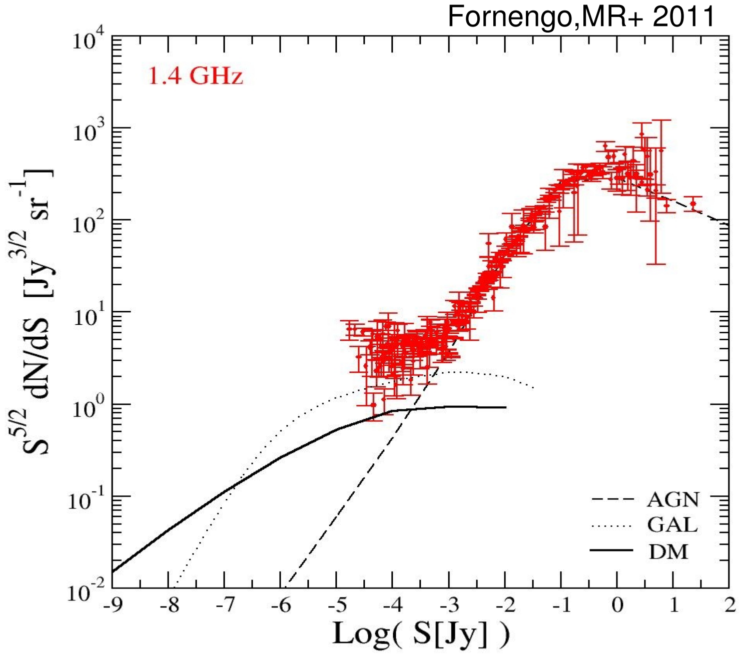


“Traditional” structure
with non-quiescient baryonic distribution
but large scale magnetic field

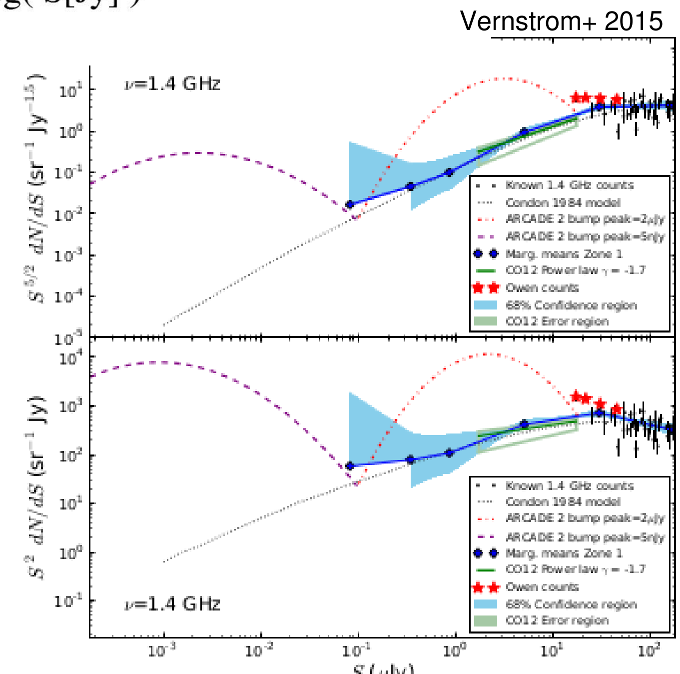
Dark structure
+ magnetic field

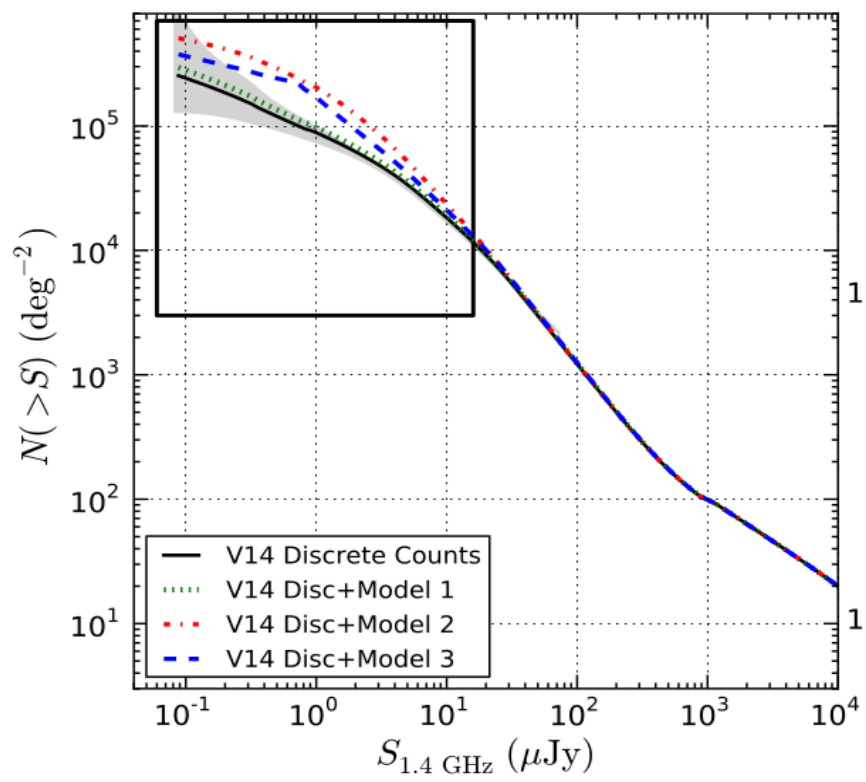


P(D)



Observations by **(Vernstrom+ 2015)** suggest a contribution due to diffuse emission <u>above the point-like contribution</u> (at the level of about 40% of the unresolved background)

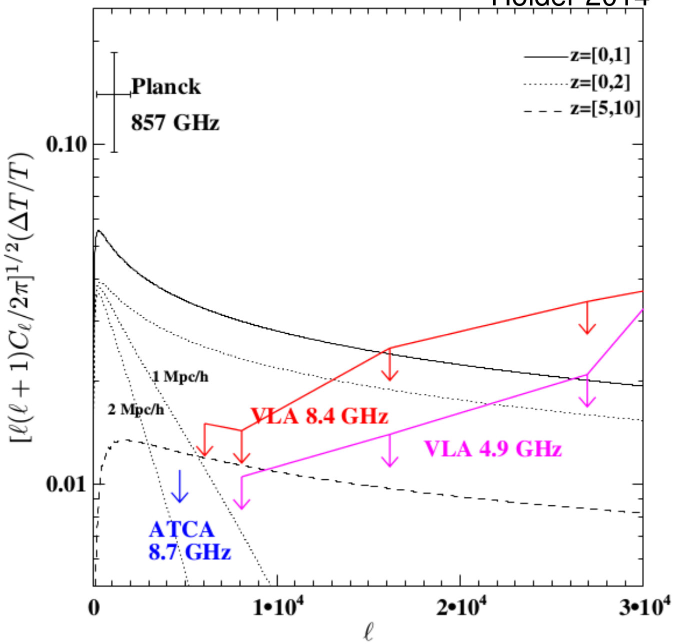




Auto and cross correlations

AUTO CORRELATION

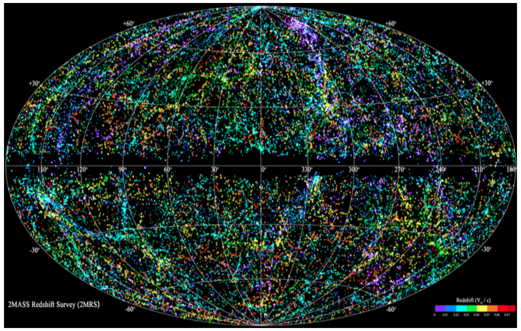
Holder 2014



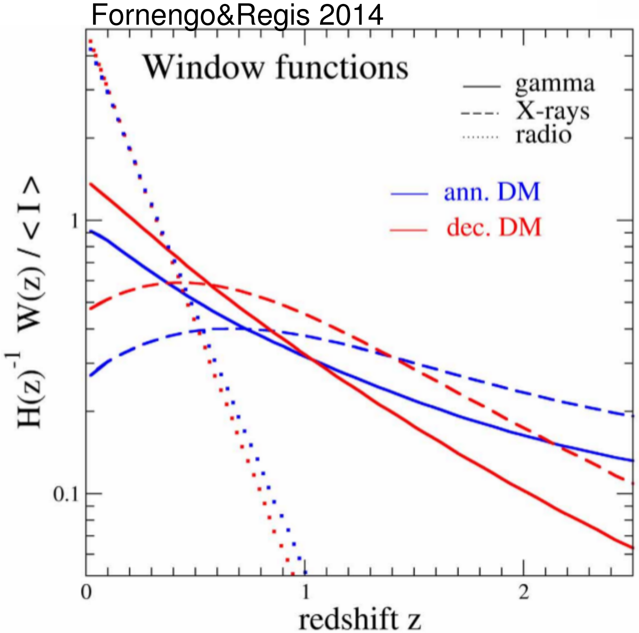
CROSS CORRELATION

with tracers of the

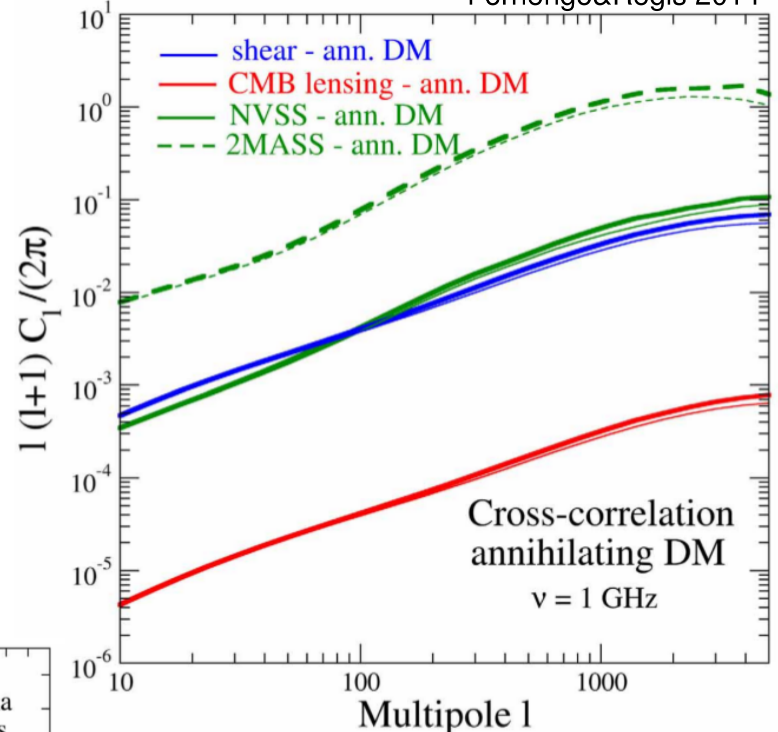
DM distribution



Fornengo&Regis 2014

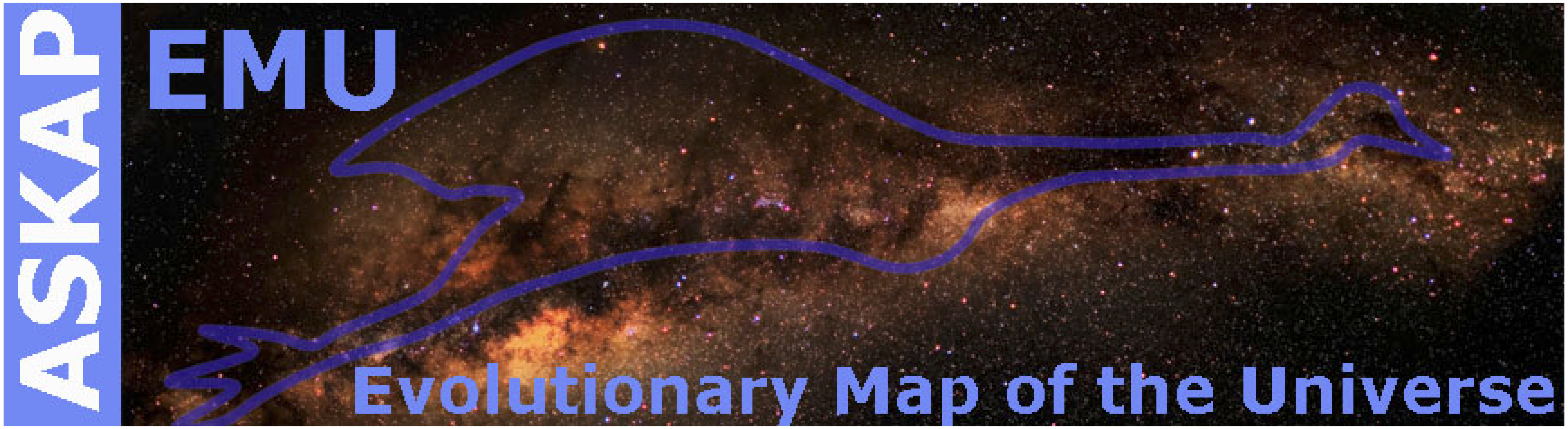


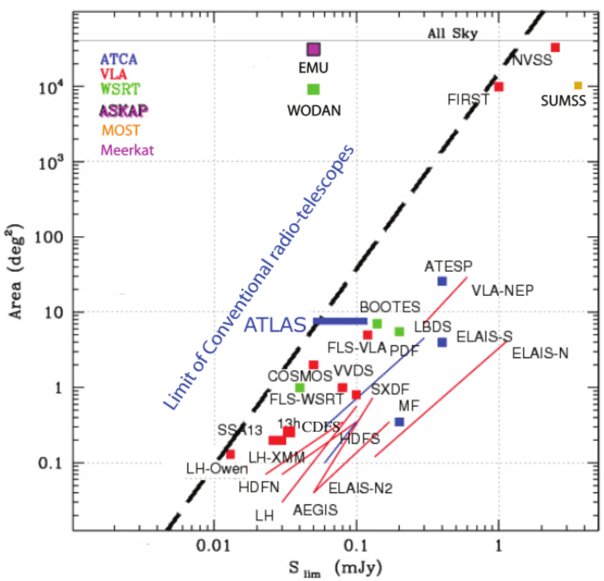
Fornengo&Regis 2014



Synchrotron signal from particle DM is concentrated at low z

Evolutionary Map of the Universe (EMU)

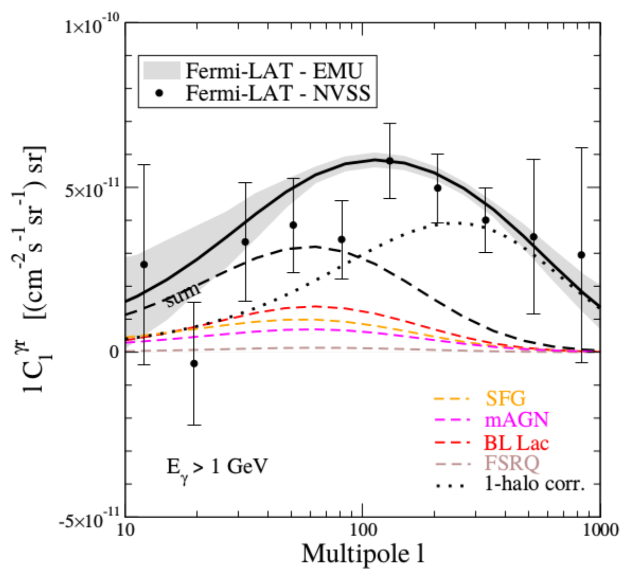




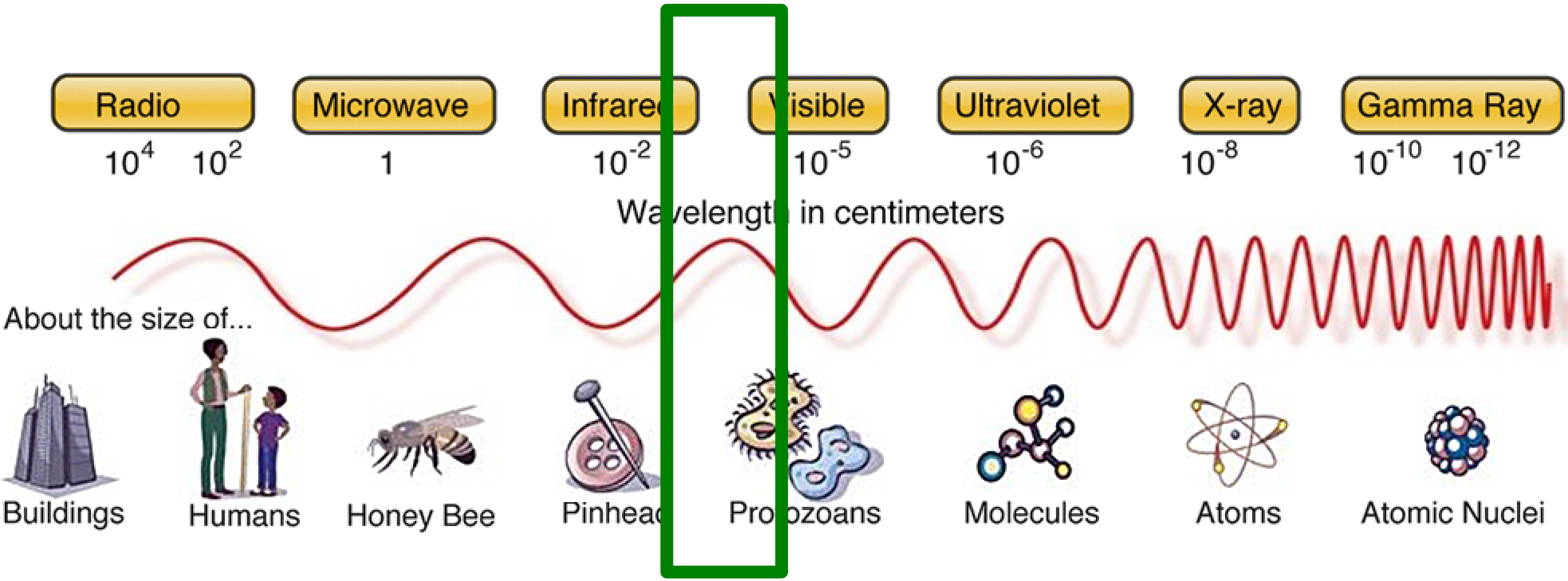
EMU is a deep (~10 μJy/beam rms) **radio continuum survey of the entire Southern Sky** (below +30 deg) at 1.4 GHz, with a 10 arcsec resolution and sensitive to scales up to ~15 arcmin.

It is expected to detect about

70 million galaxies

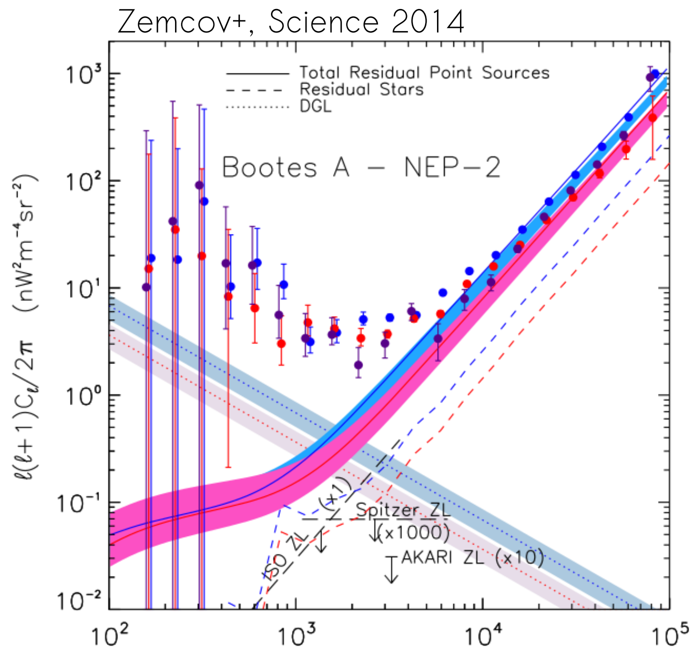


Near InfraRed



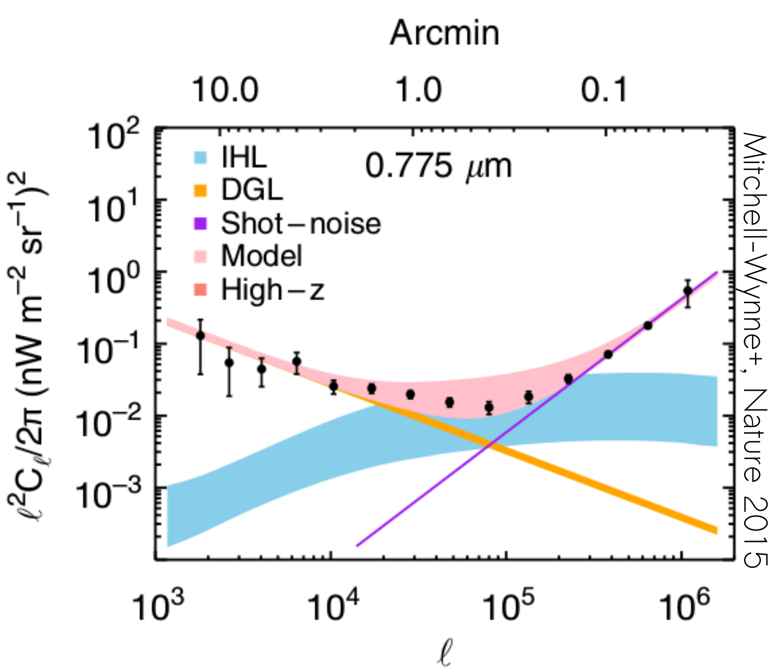
NIRB and Axion Like Particles

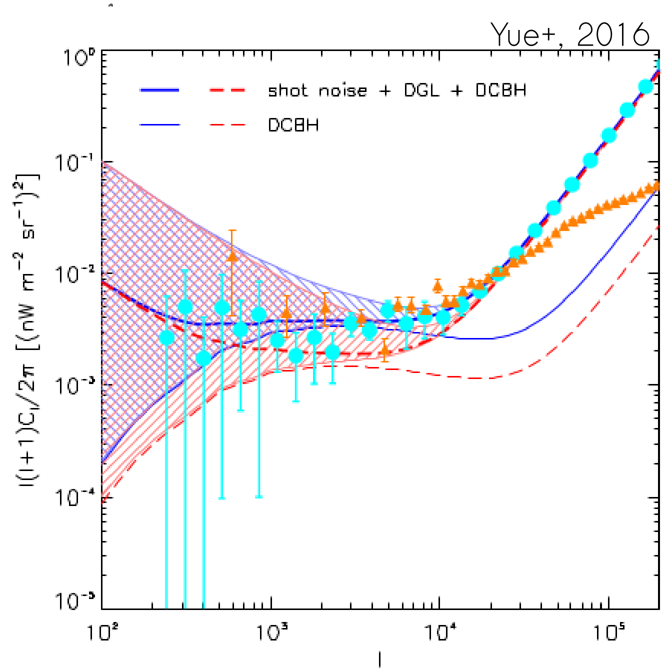
Excess in the NIRB autocorrelation angular power spectrum



Proposed explanations:

- Intra-halo light
- Early (z > 13) black holes
- Decay of ALPs of few eV



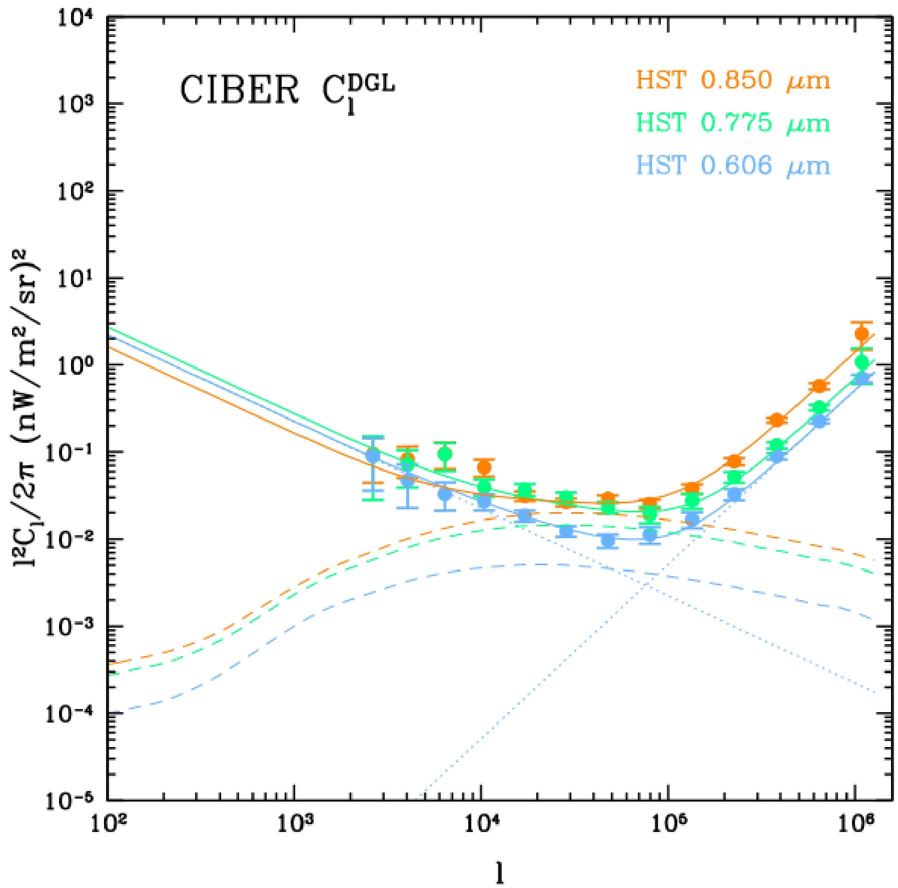


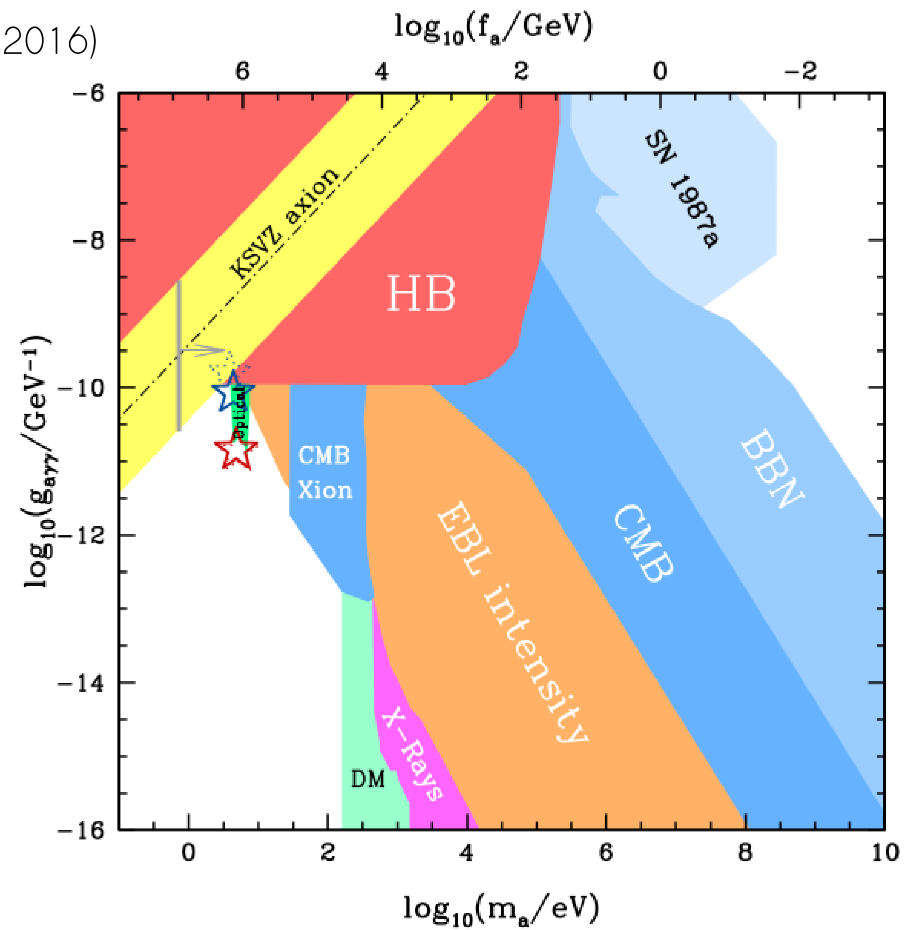
NIRB and Axion Like Particles

Excess in the NIRB autocorrelation angular power spectrum

→ decay of ALPs of few eV?

(Gong+ 2016)





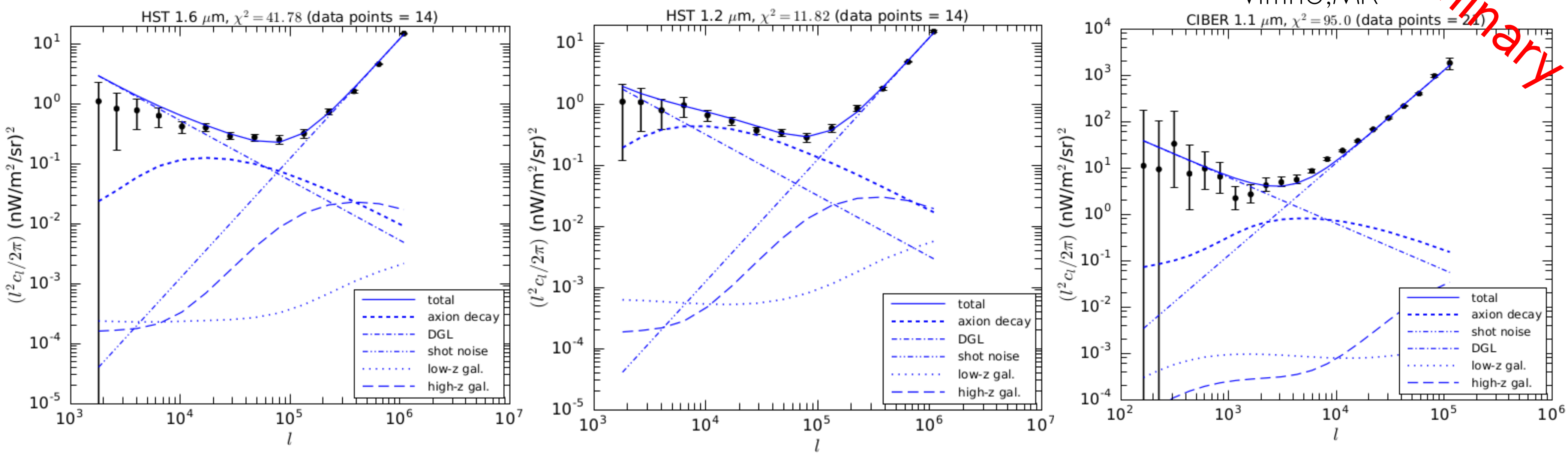
NIRB and Axion Like Particles

To be checked:

- Determination of the energy spectrum
- Cross correlation between different NIRB bands
- Cross correlation between NIRB and X-rays.

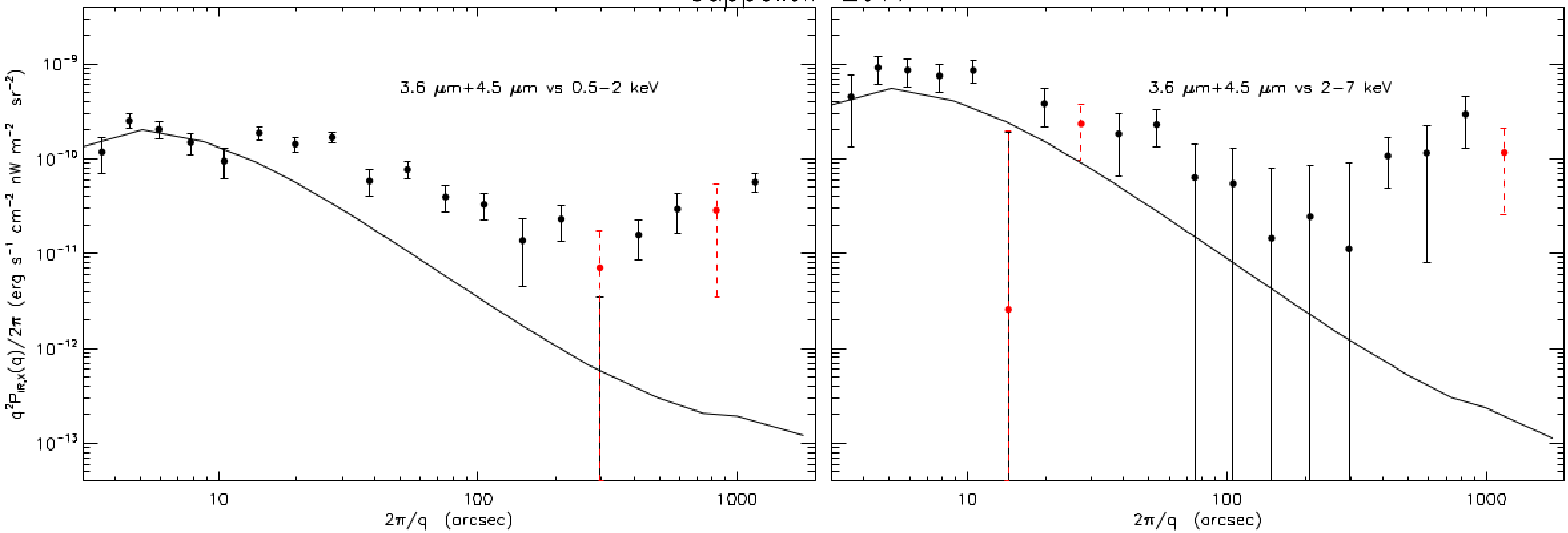
Preliminary

Vittino,MR+



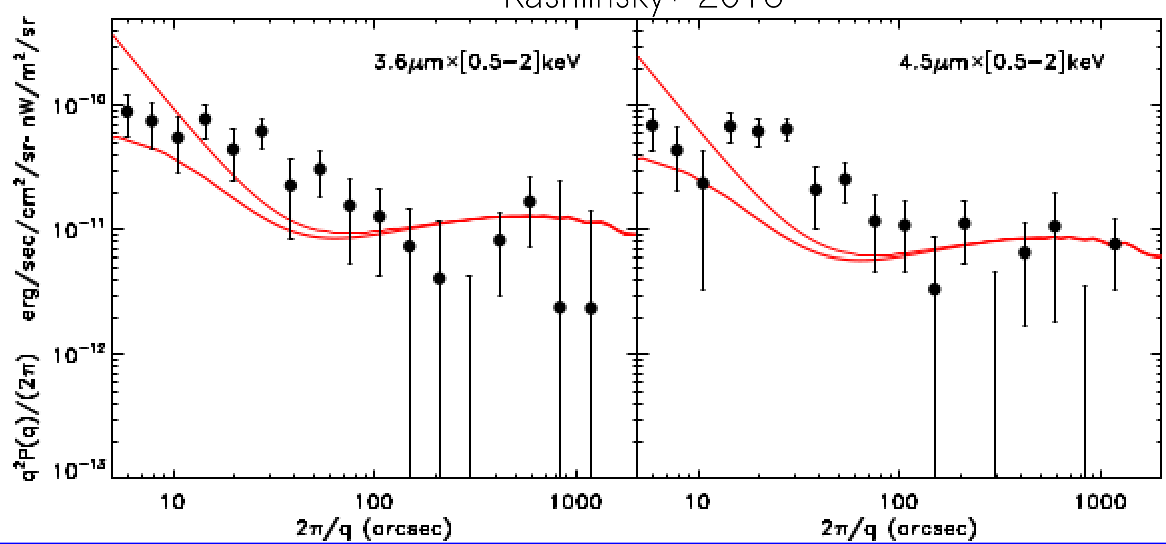
Cross correlation NIRB vs X-ray background

Cappelluti+ 2017

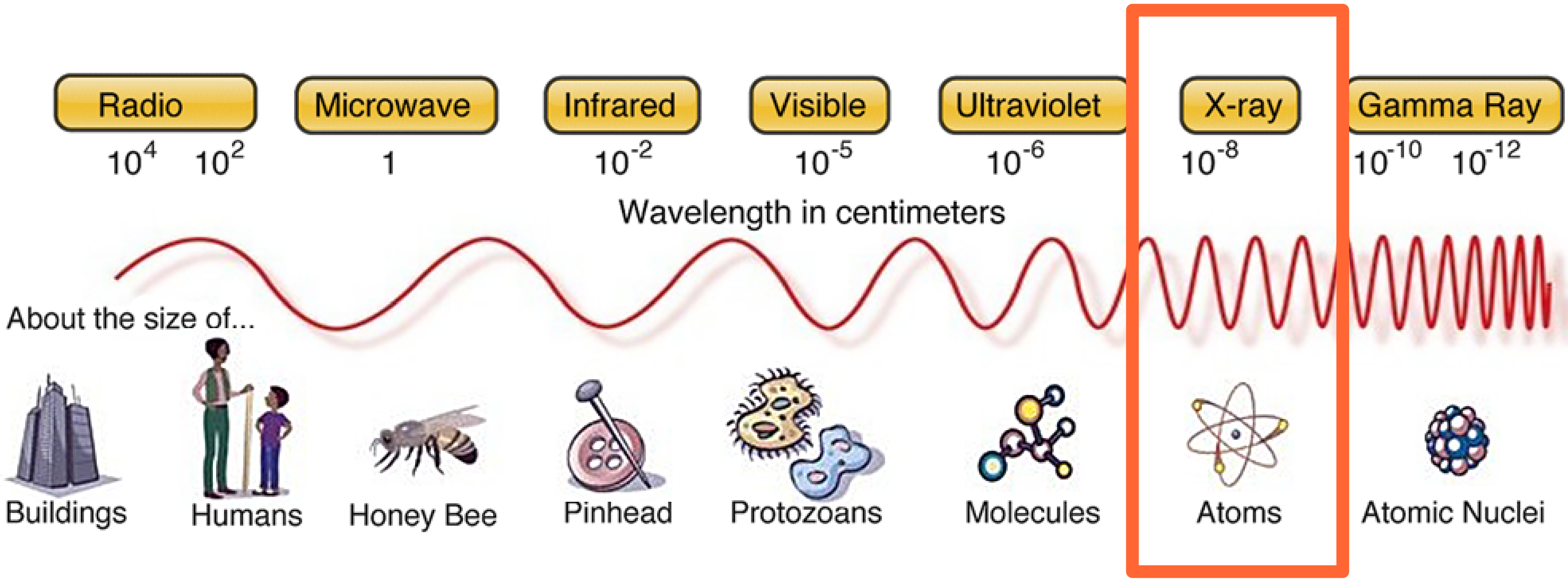


Kashlinsky+ 2018

Difficult to be explained by intra-halo light, possible for early black holes.



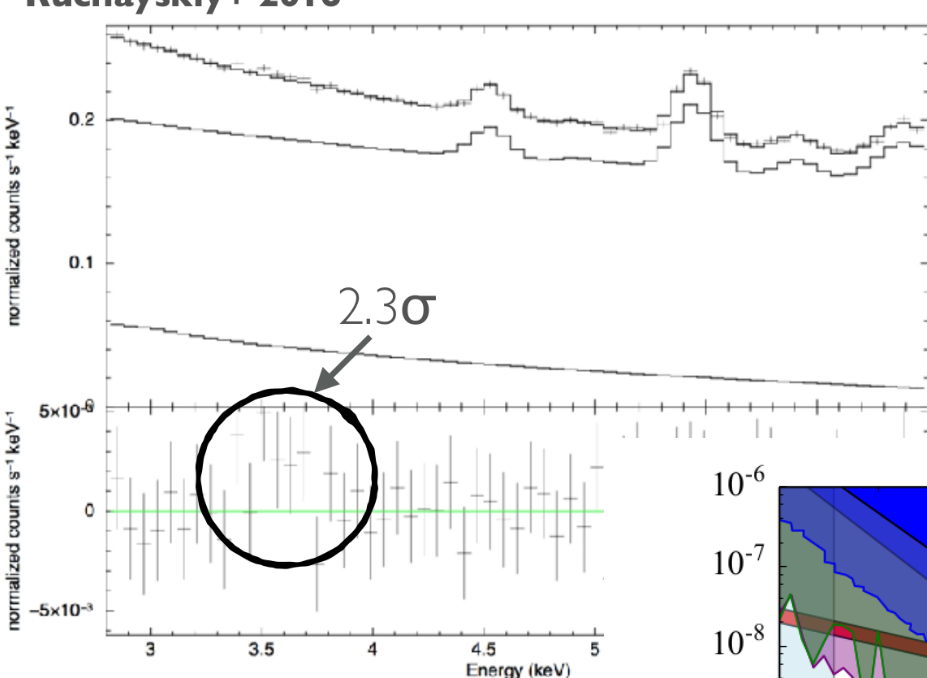
X-rays


Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^4
10^2
1
10^-2
10^-5
10^-6
10^-8
10^-10
10^-12
Wavelength in centimeters
About the size of...
Buildings
Humans
Honey Bee
Pinhead
Protozoans
Molecules
Atoms
Atomic Nuclei

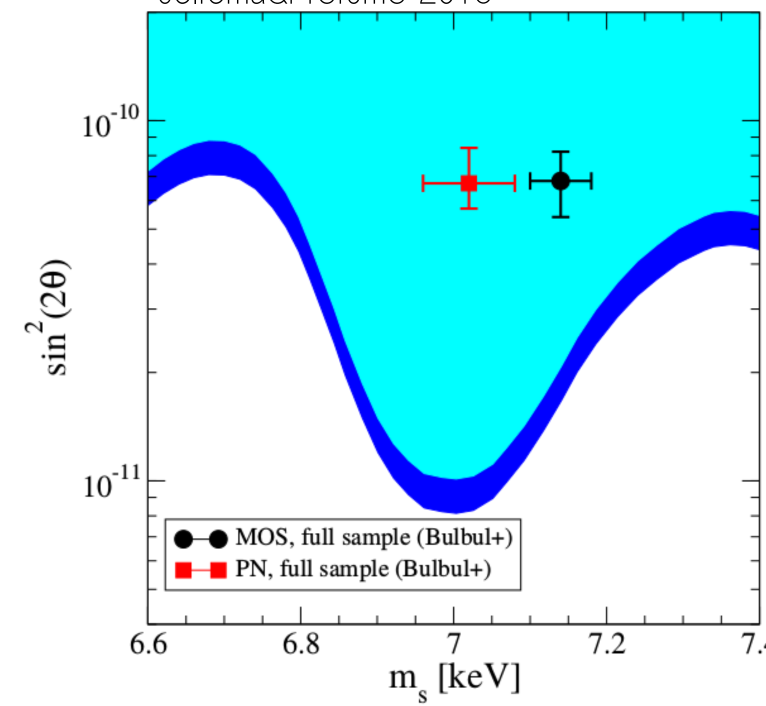
X-rays from sterile neutrinos in dSph

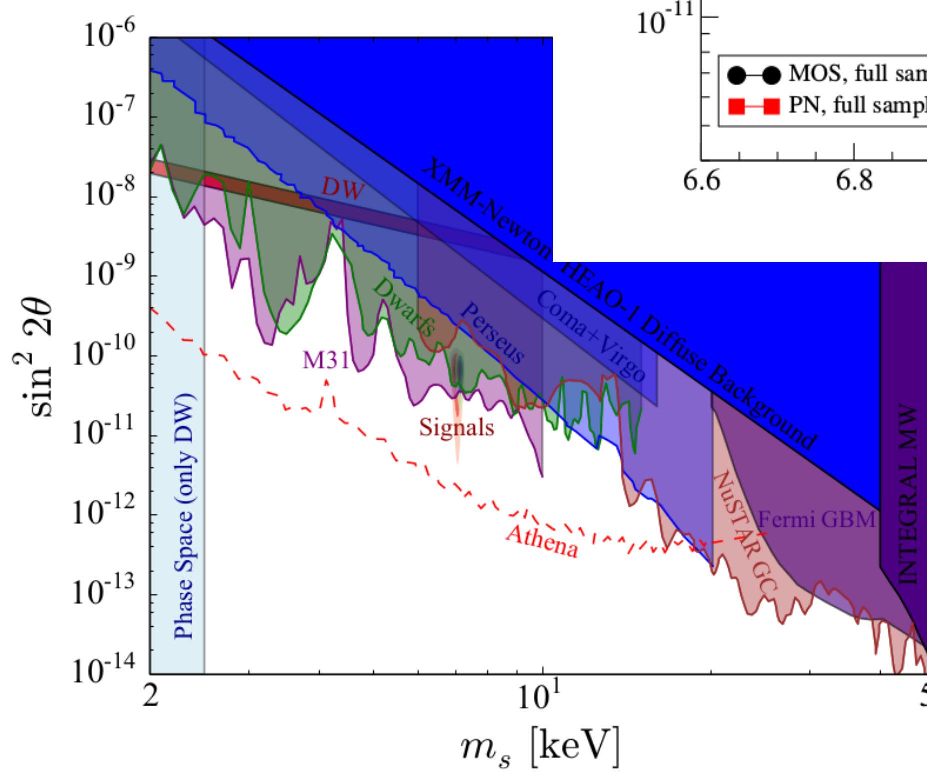
deep XMM-Newton of observations Draco dSph

Ruchayskiy+ 2016



Jeltema&Profumo 2016





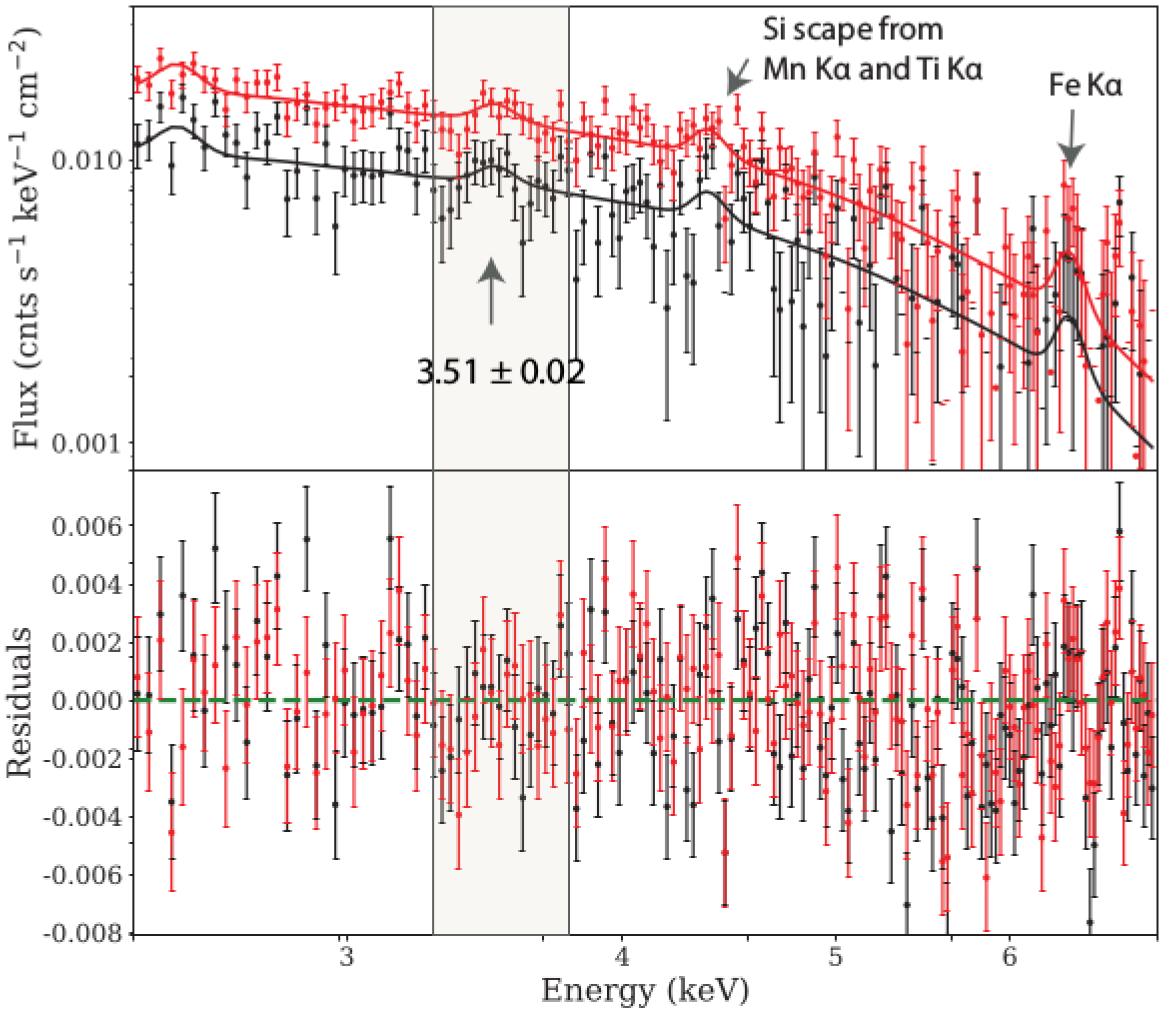
Abazajian 2017

X-rays from sterile neutrinos in the Galaxy

Cosmic X-ray Background observations using Chandra

→ 2.5-3σ evidence for a 3.5 keV emission line from DM in the Milky Way

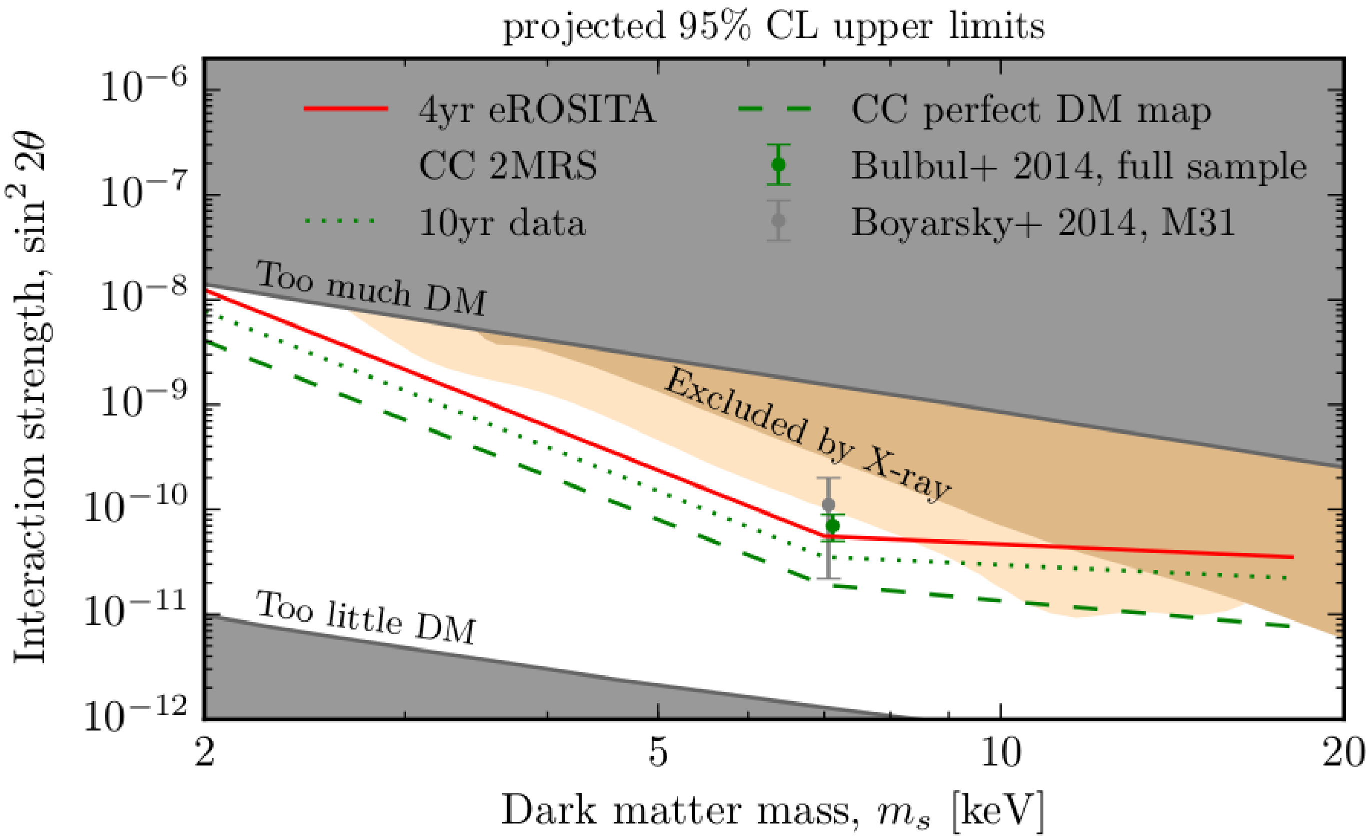
Cappelluti+ 2018



X-rays from extragalactic sterile neutrinos

Interesting projected sensitivity for the cross correlation between eROSITA and 2MASS

(Zandanel+ 2015)



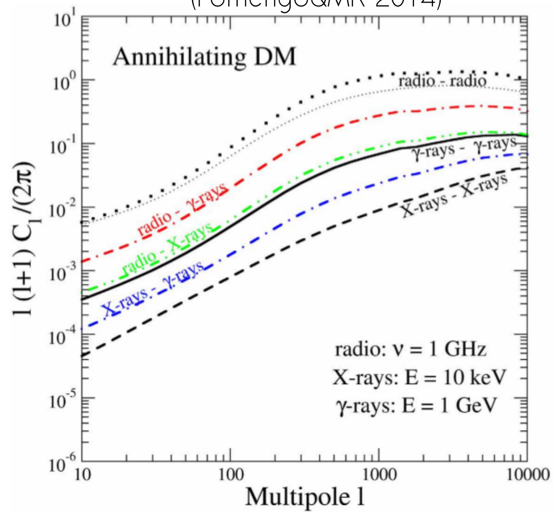
X-rays from WIMPs

Inverse Compton of DM-induced electrons and positrons on CMB

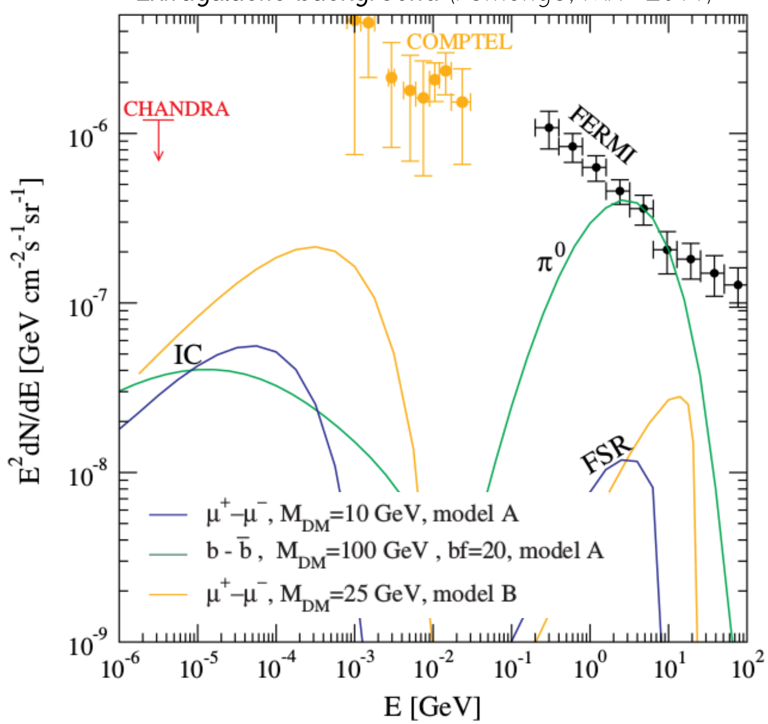
→ Typically not so constraining

Anisotropies

(Fornengo&MR 2014)

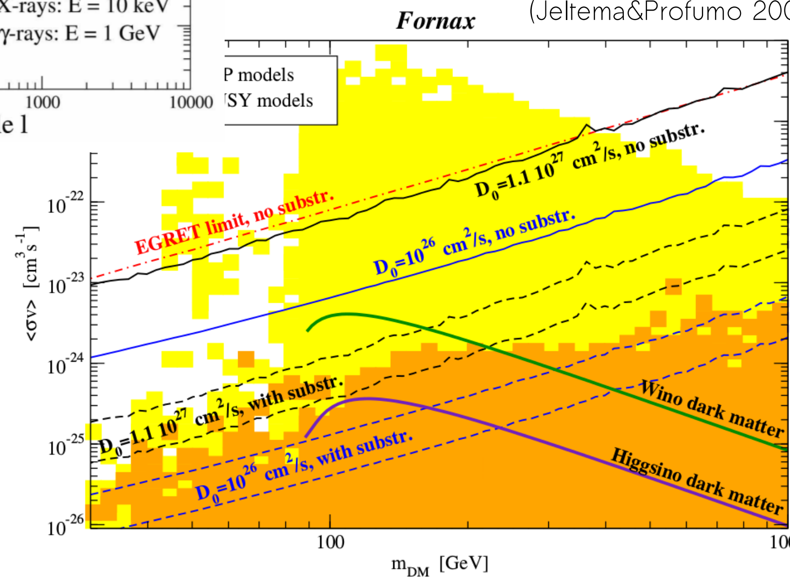


Extragalactic background (Fornengo, MR+ 2011)

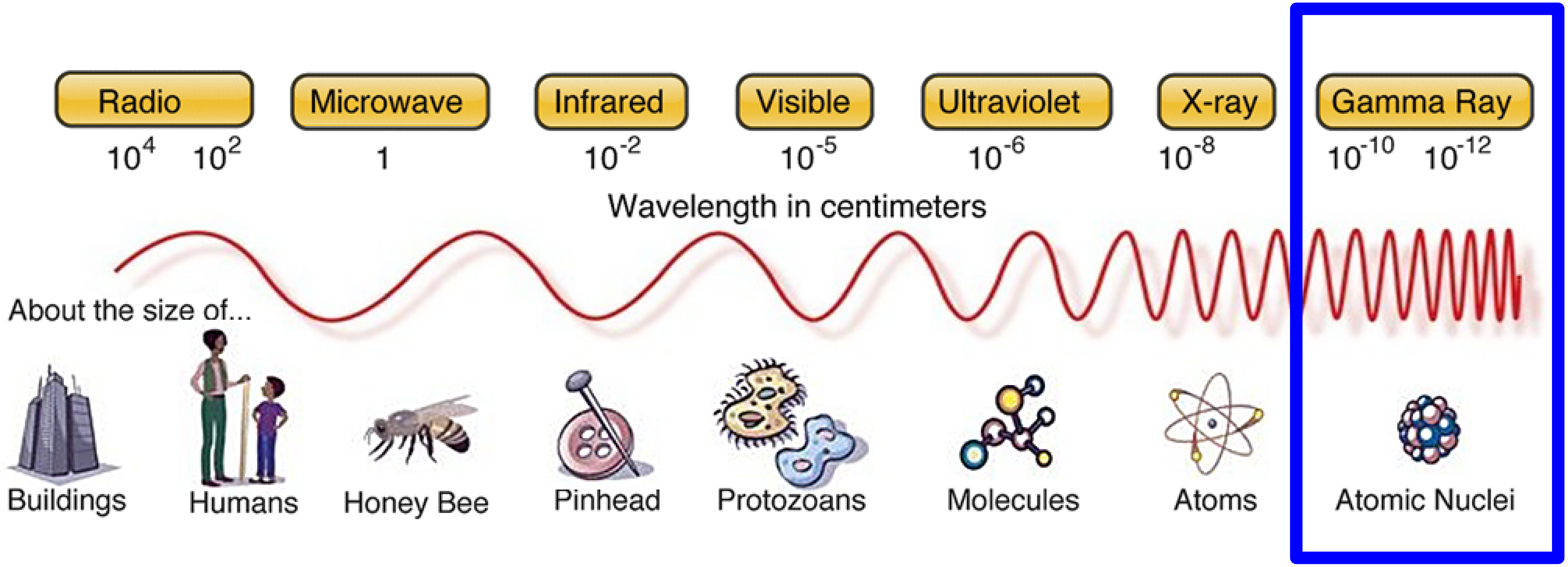


Dwarf satellites

(Jeltema&Profumo 2008)



Gamma-rays



Radio
Microwave
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Gamma Ray
10^4 10^2
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10^{-6}
10^{-8}
10^{-10} 10^{-12}
Wavelength in centimeters
About the size of...
Buildings
Humans
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Prediction for gamma-rays from dSph

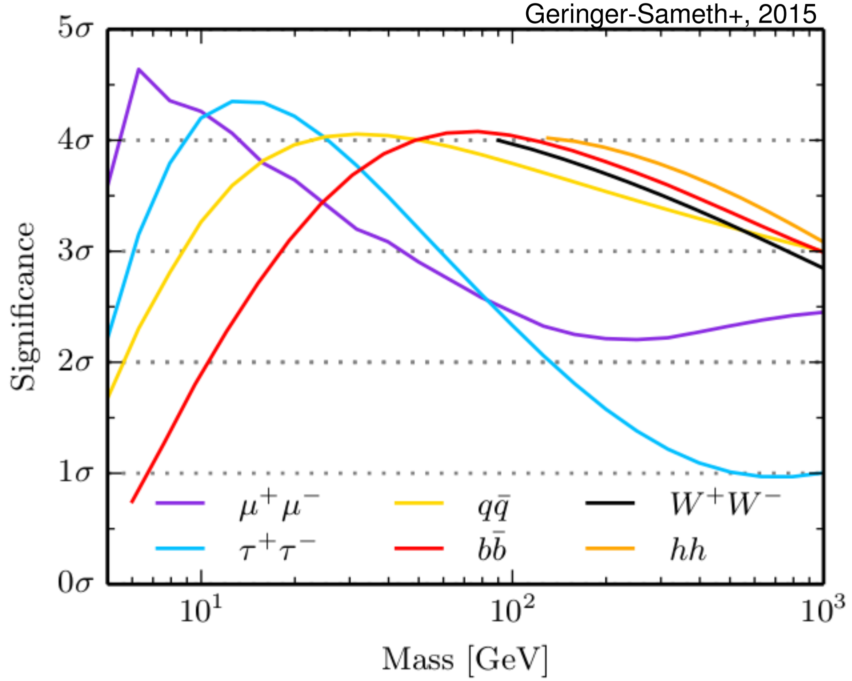
The detection of γ-ray emission from the direction of a dSph is guaranteed!

Prediction for dSph

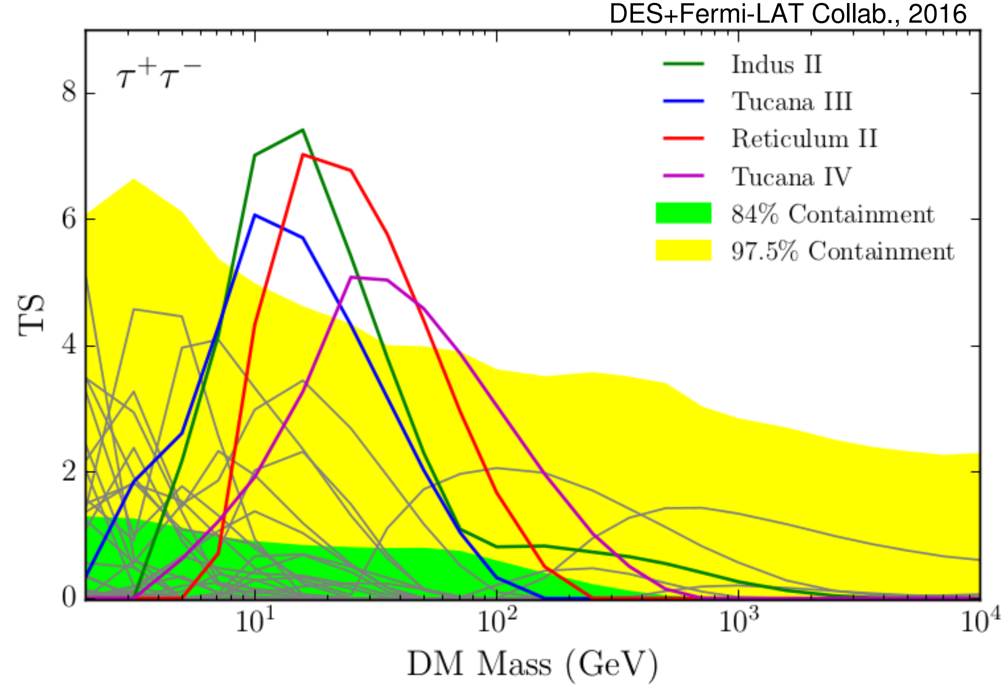
The detection of γ-ray emission from the direction of a dSph is guaranteed!

Are we already witnessing this situation?

Geringer-Sameth+, 2015

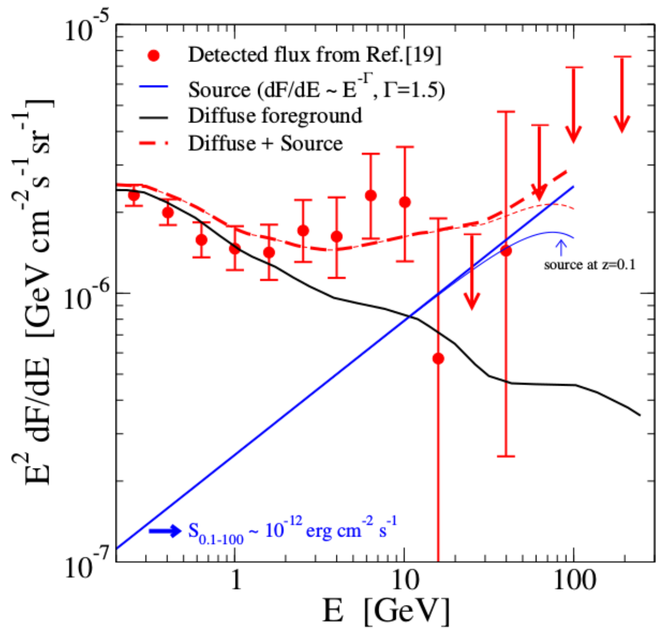


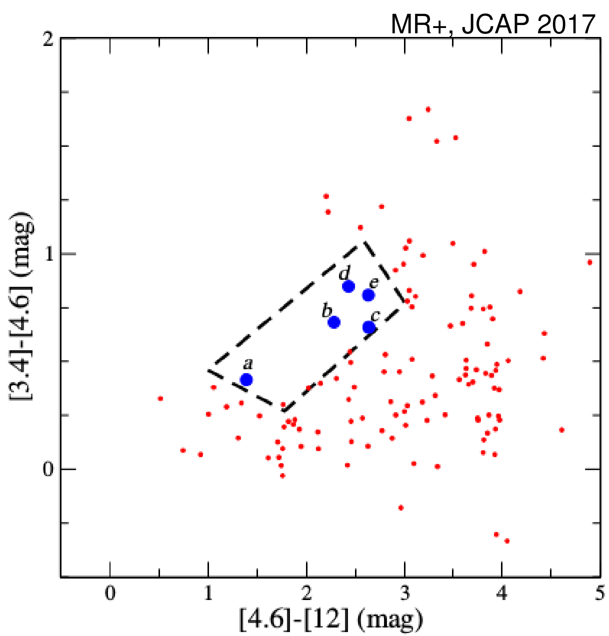
DES+Fermi-LAT Collab., 2016



Plenty of background sources in the Universe!

Already observed in ReticulumII ?





Radio counterpart for possible γ-ray excess

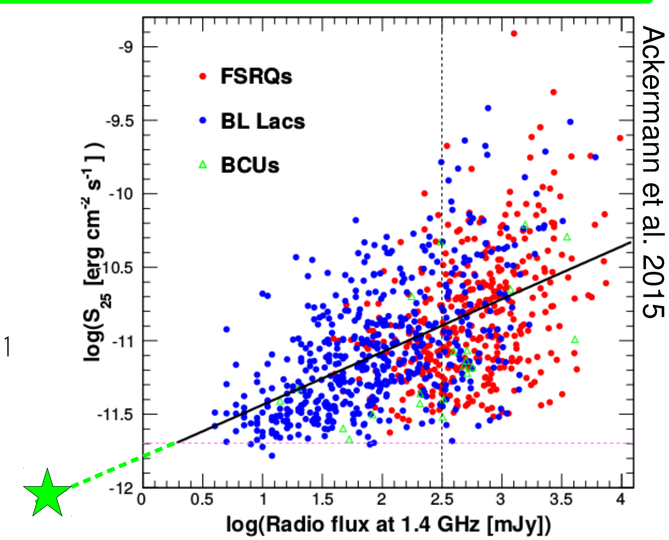
id	J2000 RA			J2000 DEC			Distance arcmin	Flux density mJy
a^*	03	34	46.0	−54	08	43.7	9.9	1.26 ± 0.07
b	03	34	29.6	−53	54	44.4	13.3	0.59 ± 0.04
c^*	03	35	49.4	−53	52	52.6	10.2	2.39 ± 0.15
d	03	34	52.5	−53	50	19.4	14.5	0.53 ± 0.04
e	03	35	32.4	−54	04	12.1	1.7	0.89 ± 0.05

$\beta > -1$

γ-rays:

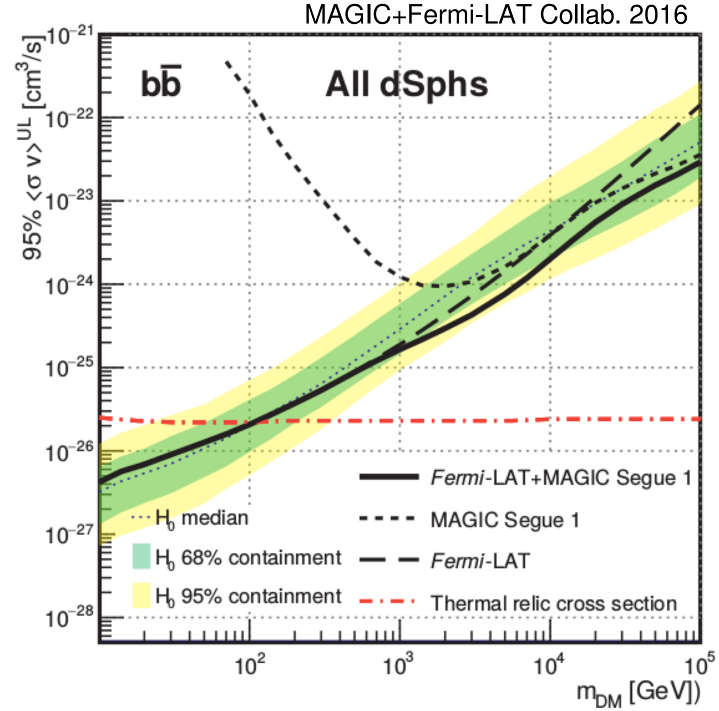
$\Gamma \sim 1.5$ → BL Lac?

$S_{25} \sim 10^{-12}$ erg cm^{-2}s^{-1}

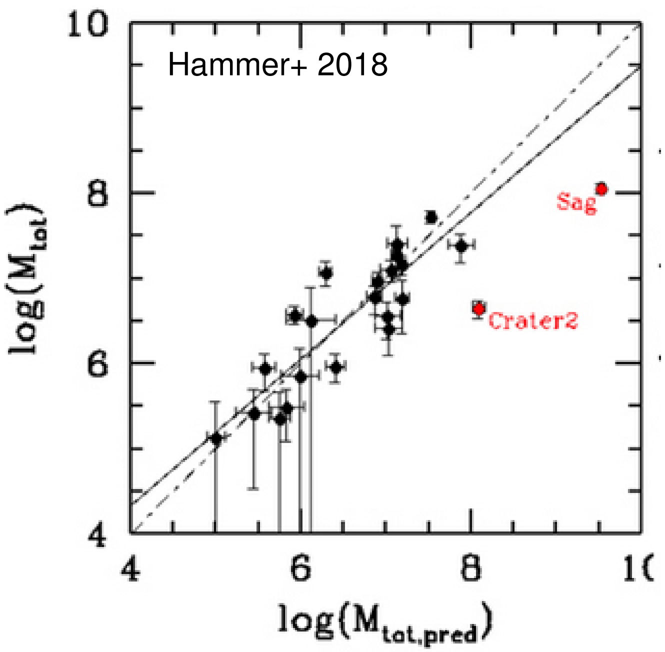


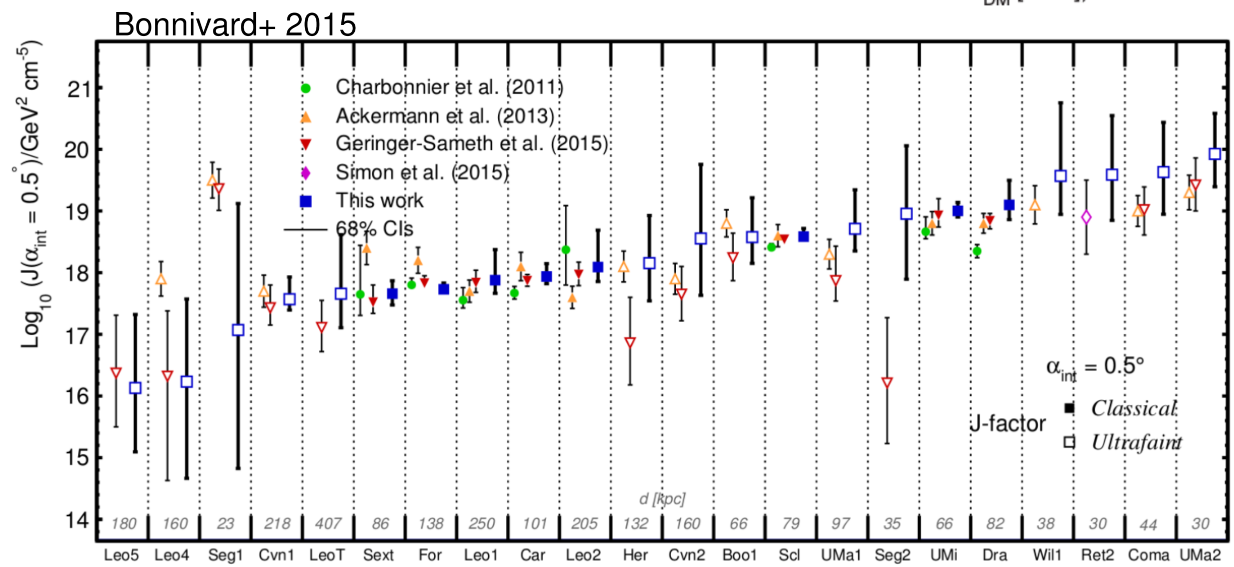
Bounds from dSphs

Typically considered as the most robust bound on WIMPs



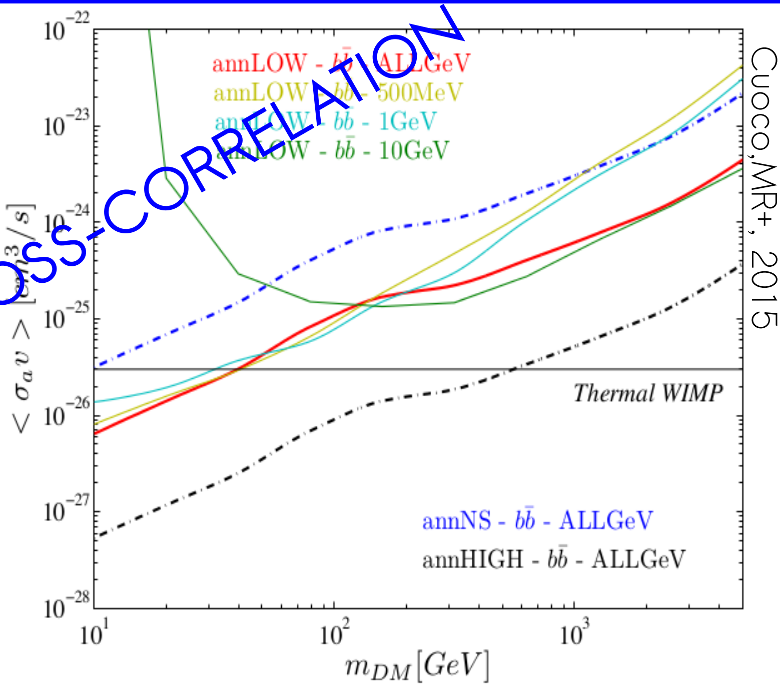
… but some doubts regarding the DM distribution in dSphs



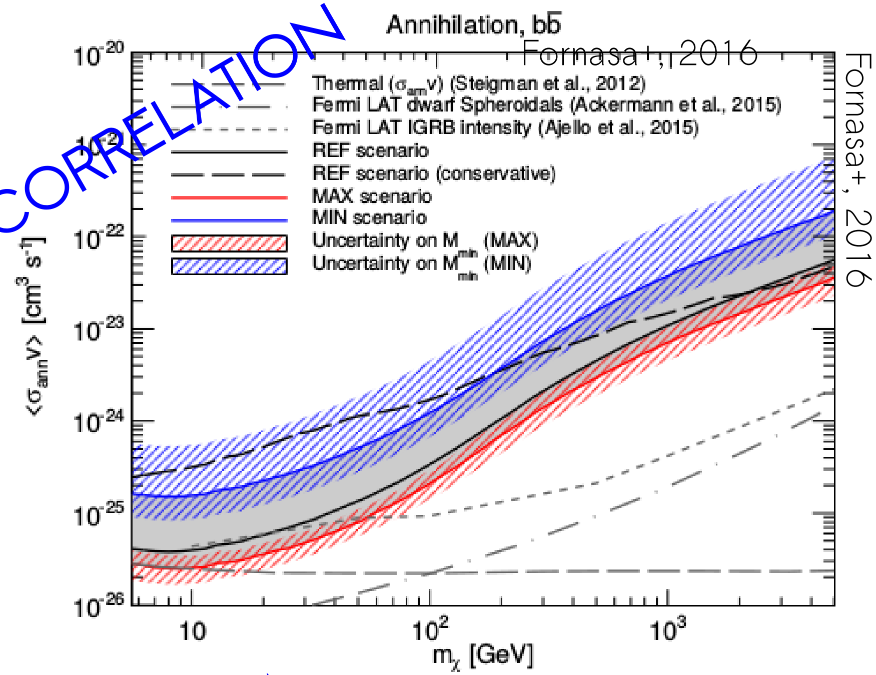


Bounds from UGRB observables

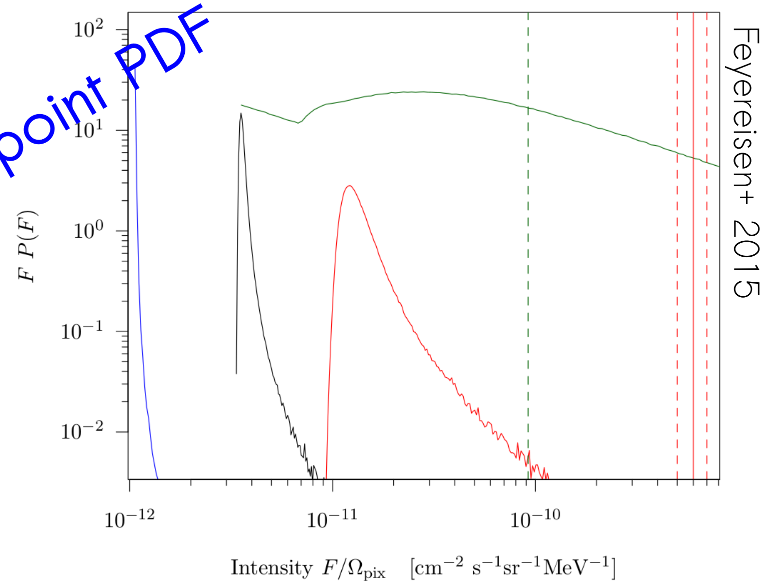
CROSS-CORRELATION



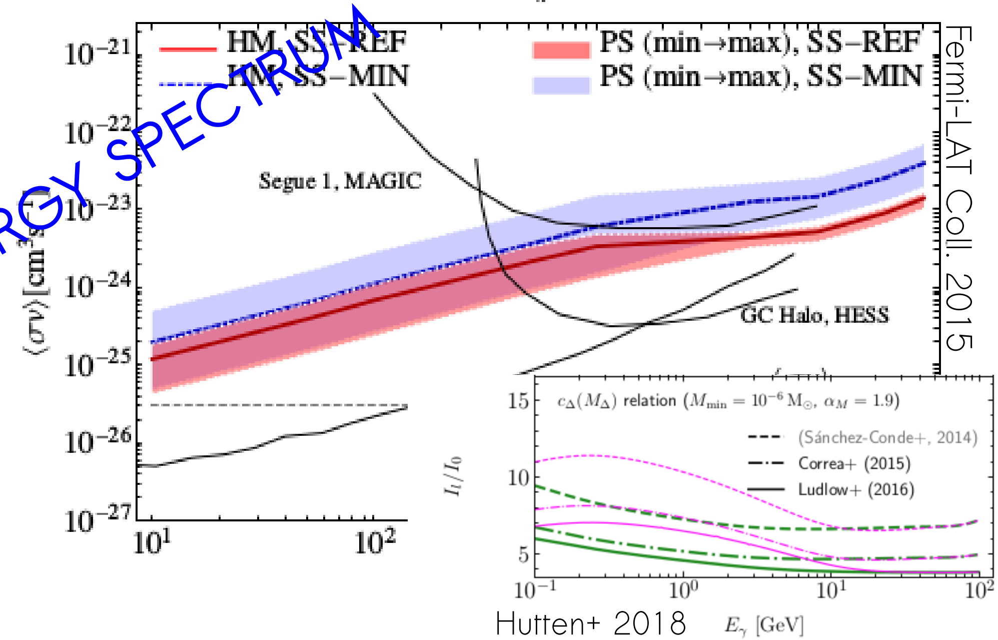
AUTO-CORRELATION



1-point PDF

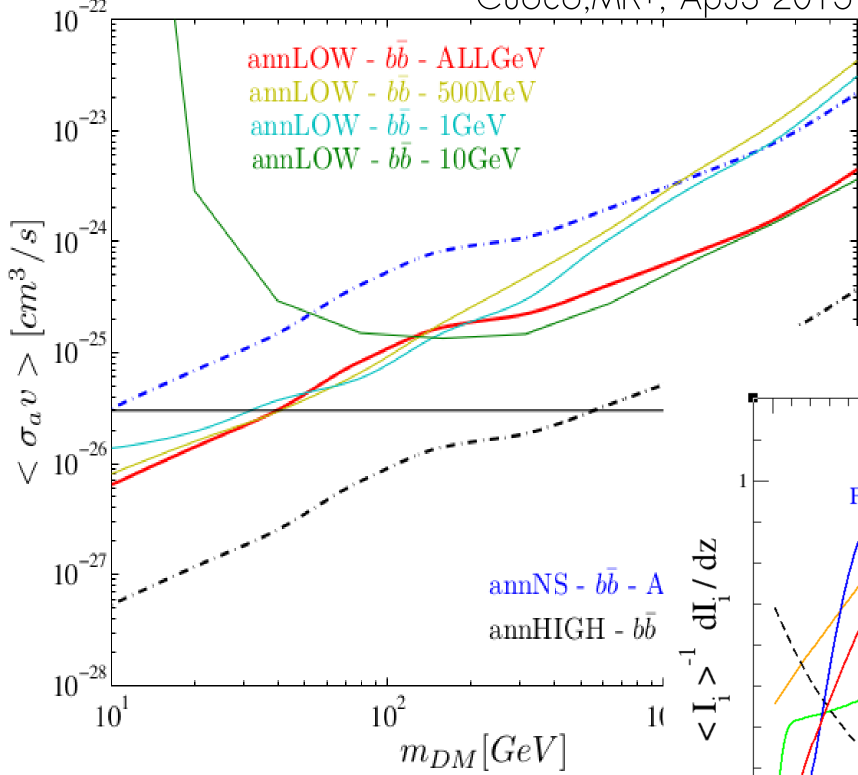


ENERGY SPECTRUM

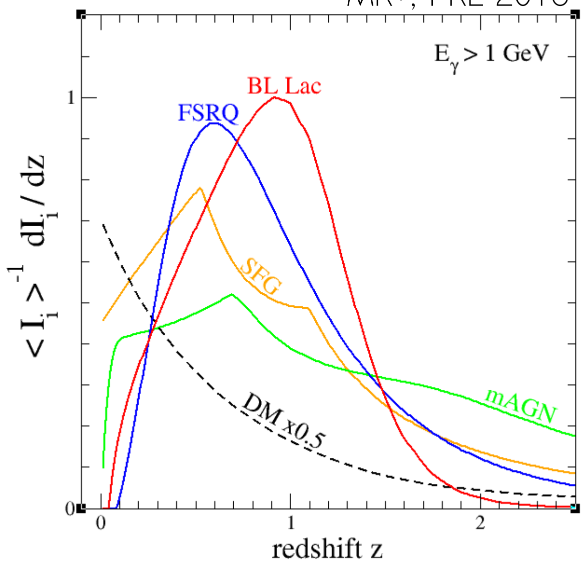


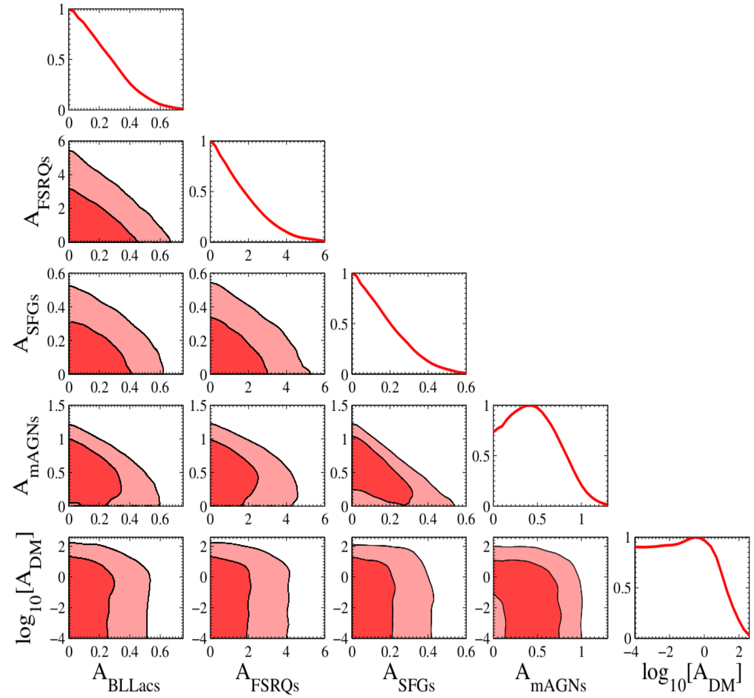
Angular cross-correlation

Cuoco,MR+, ApJS 2015



MR+, PRL 2015





→ Promising technique

→ Significant degeneracies are still present in current analyses

Conclusions

(let's hope dark matter has non-gravitational interactions..)

Different particle DM candidates can show up with indirect signatures in different frequency bands.

Even though it sounds like an oxymoron, particle DM is a multi-wavelength business!