A NEW PATH FOR PARTICLE DARK MATTER SEARCHES

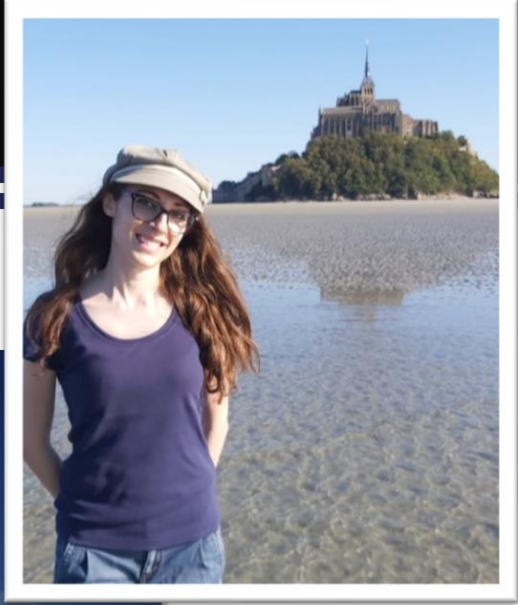
CROSS-CORRELATION BETWEEN 21CM INTENSITY MAPPING AND GAMMA RAYS

Speaker: Elena Pinetti

Cosmology from Home 2020

University of Turin & Sorbonne University

TWO LABS FOR A JOINT-PHD



Sorbonne University (France)

University of Turin (Italy)

arxiv:1911.04989

Synergies across the spectrum for particle dark matter indirect detection: how H I intensity mapping meets gamma rays

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Our goal

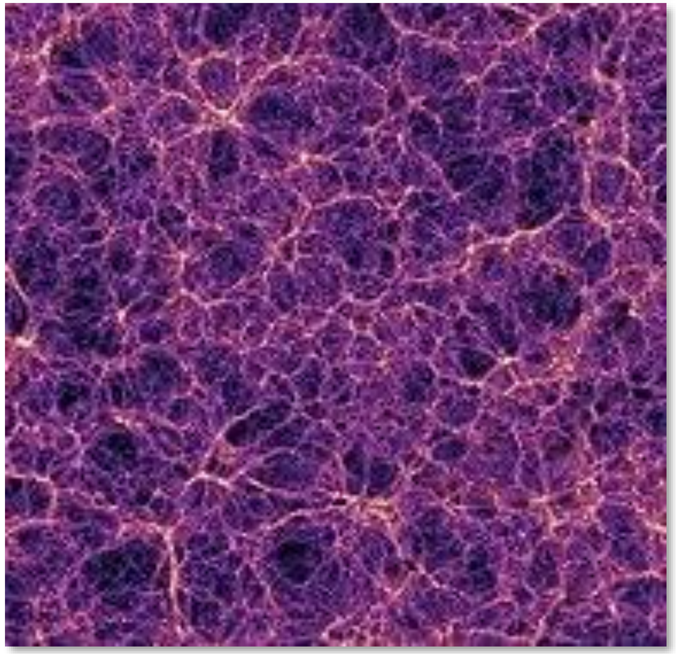

DARK MATTER
GRAVITINO
PROTON
PHOTON
e
e
e-
NEUTRINO
NEUTRALINO
AXION
AXION
MUON
NEUTRON
QUARK
DARK ELECTRONS
VISIBLE MATTER
Wimp
DARK NEUTRON

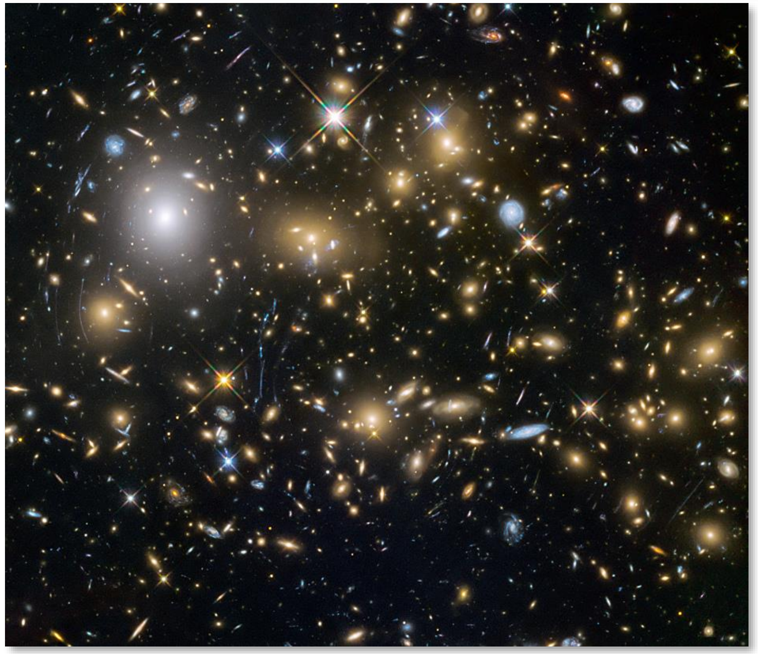
Outline

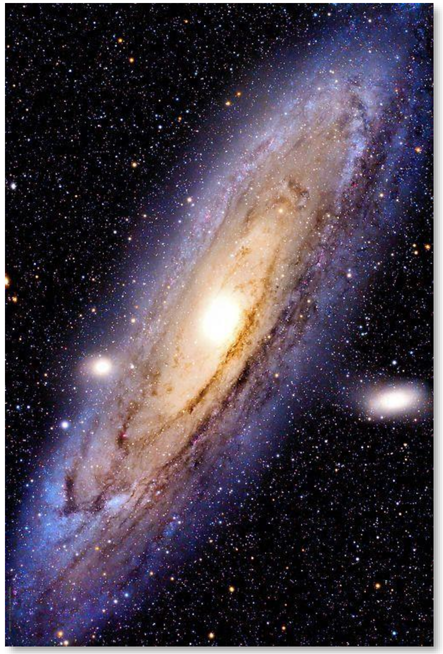
- Why cross-correlations are a powerful approach for indirect detection of Dark Matter particles?
- Observables
- Angular power spectrum
- Detectability of astrophysical sources
- Bounds in Dark Matter parameter space

Dark Matter in the Universe

- Milky Way
- External galaxies
- Clusters of galaxies
- Cosmic web







Searches for DM as a new particle

- **Production at collider**

- **Direct detection**

  (In)elastic scattering of DM off nuclei of electrons

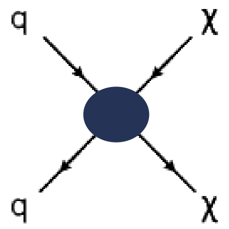
  Searches in underground laboratories

- **Indirect detection**

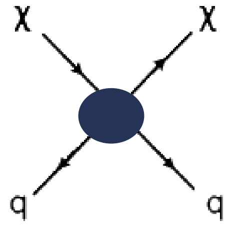
  Messengers produced by annihilation or decay of DM particles in the galaxy and beyond:

  - γ
  - ν
  - Cosmic rays ($e^{\pm}$, $\bar{p}$, $\bar{D}$, antinuclei)

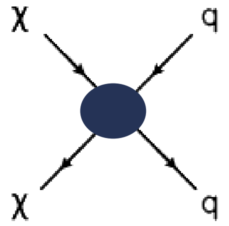
  Searches with detector in space, on the ground, underwater/ice/ground



Production at Collider



Direct Detection

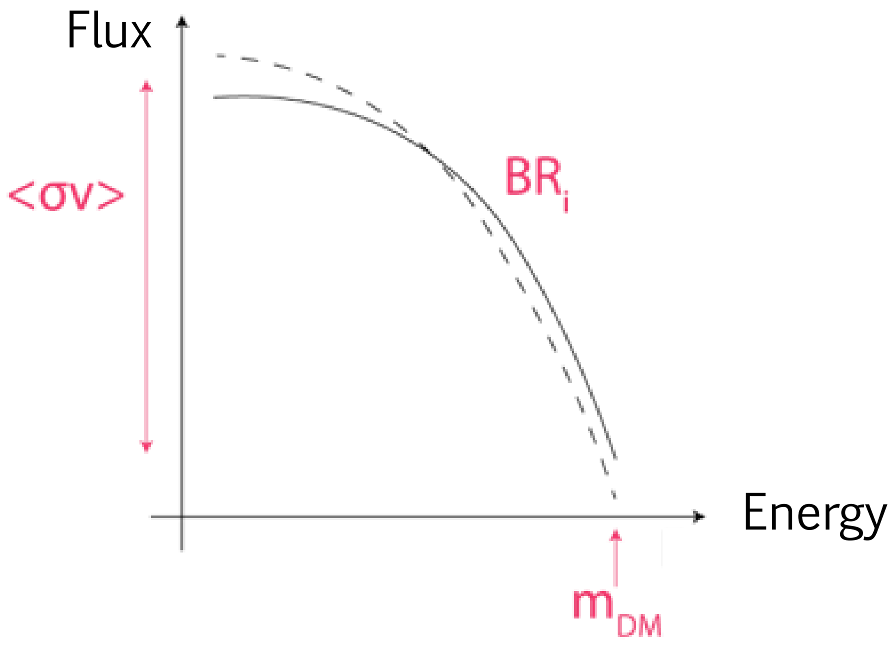


Indirect Detection

Anatomy of an indirect detection signal

The relevant properties of a DM particle that we can derive from indirect detection are:

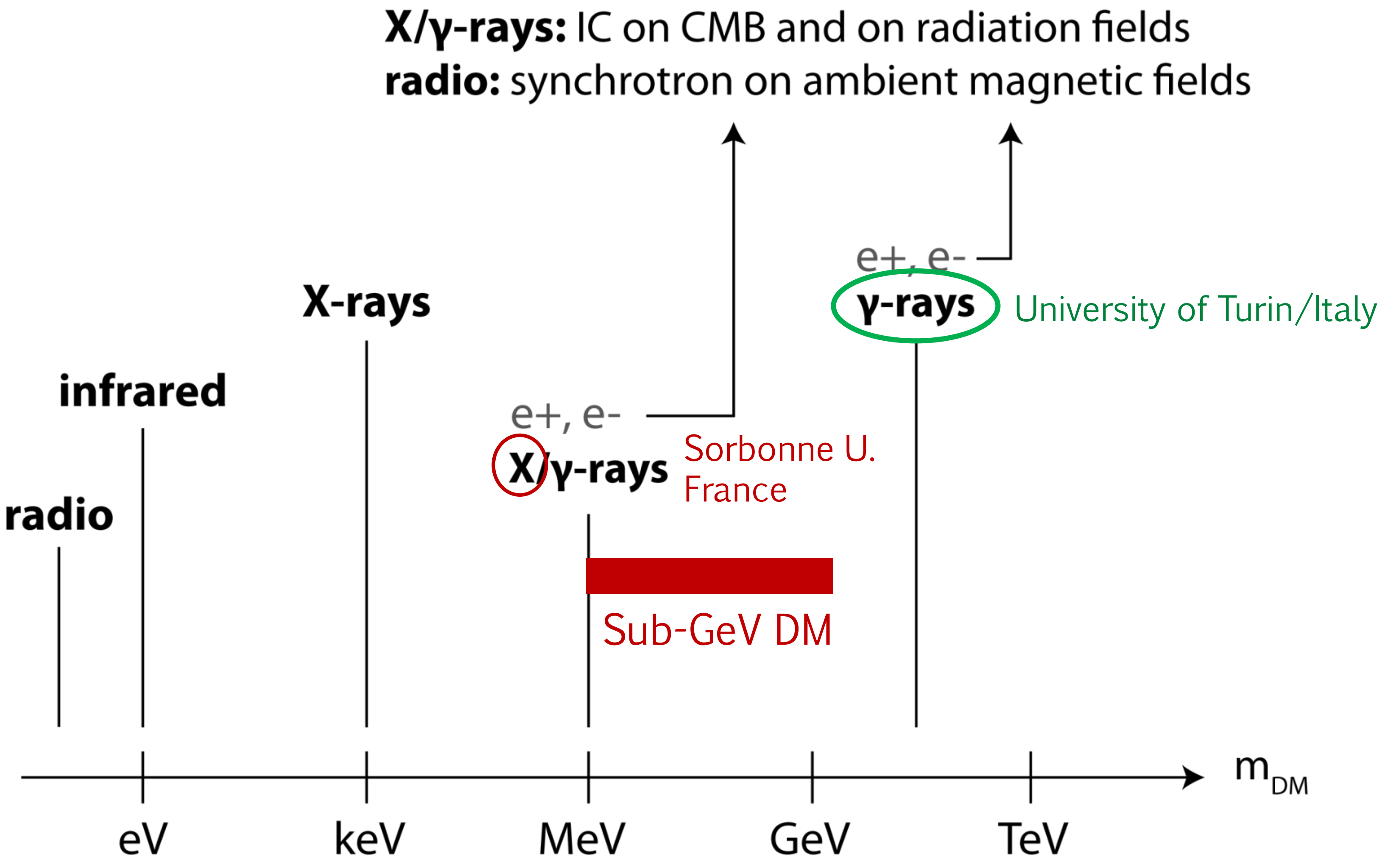
- Annihilation cross-section or decay rate
- Mass
- Branching ratio in the different final states

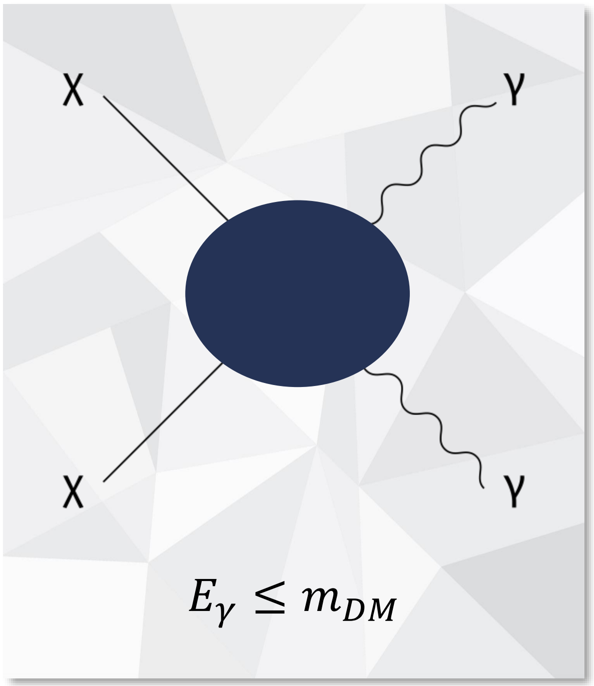


Signal amplitude → m_{DM} , $\langle \sigma v \rangle$

Spectral features → m_{DM} , BR

Multiwavelength research of Dark Matter





Total gamma-ray flux from Dark Matter particles

$$\Phi_\gamma^{DM}(E_\gamma,\psi) = \frac{1}{4\pi}\frac{\langle\sigma_{ann}v\rangle}{2m_{DM}^2} g_\gamma(E_\gamma)\, J(\psi)$$

Particle Properties

Energy spectrum per annihilation event

Angle in the sky

DM density

$$J(\psi) = \int_{l.o.s} \rho^2(r(\lambda,\psi))\,d\lambda$$

Line of sight

Anisotropies

The Unresolved Gamma-Ray Background is given by the sum of contributions from independent astrophysical sources/DM

- At first approximation: isotropic
- At deeper level: there are anisotropies

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Cross-correlation of an EM signal with a gravitational tracer


Particle Dark Matter
Modified Gravity

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- ❑ Observables
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Observables

EM signals

γ rays
X rays
IR emission
Radio waves

✖

Gravitational tracers

Galaxy catalogues
Clusters catalogues
Weak lensing cosmic shear

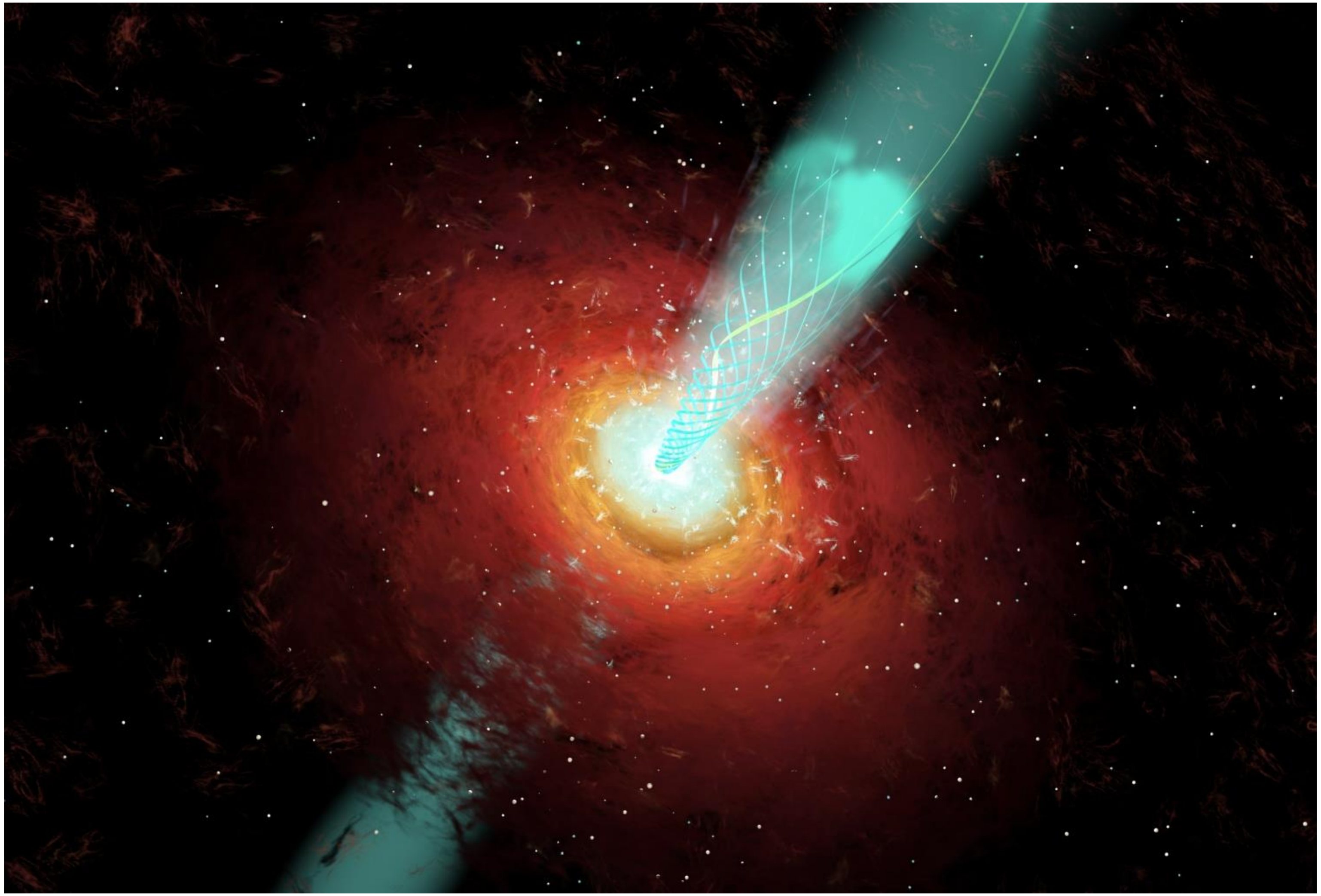
HI

NEW!

Cross-correlation γ rays x HI

Camera+, ApJLett 771 (2013) L5
Fornengo+, Frontiers in Physics, 2 (2014) 6
Camera+, JCAP 06 (2015) 029
Fornengo+, Ap. J. Lett. 802 (2015) 1 L1
Cuoco+, PRD 77 (2008)123518
Ando+, PRD 90 (2014) 023514
Ando, JCAP 1410 (2014) 061
Shirasaki+, PRD 90 (2014) 063502
Xia+, APJS 217 (2015) 15
Shirasaki+, PRD 92 (2015) 123540
Regis+, ApJS 221 (2015) 29
Shirasaki+, PRD 94 (2016) 063522
Troester+, MNRAS 467 (2017) 2706
Branchini+, ApJS 228 (2017) 1
Ammazzalorso+, PRD98 (2018) 103007
Colavincenzo+, MNRAS 491 (2020) 3225
Ammazzalorso+, arXiv:1907.13484

Gamma rays



- Dark Matter
- BL Lacs
- Flat-Spectrum Radio Quasar
- Misaligned Active Galactic Nuclei
- Star-Forming Galaxies

Intensity Mapping

Intensity Mapping

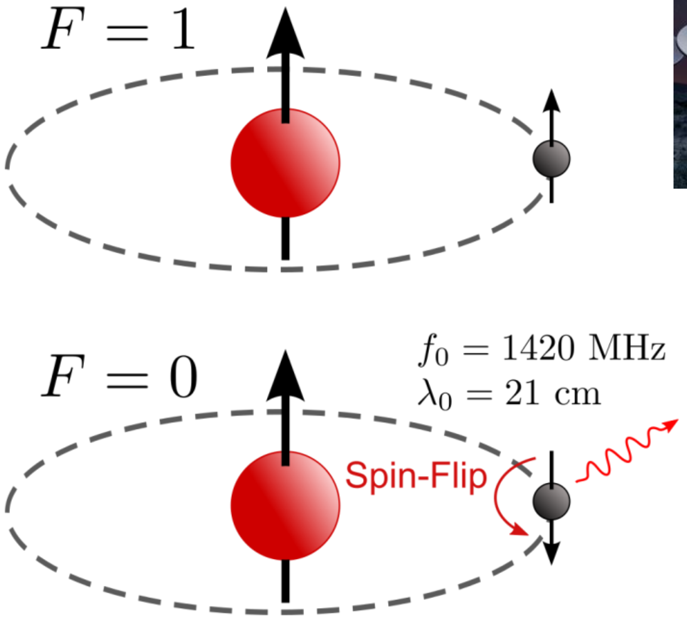
IM is a mapping of the intensity fluctuations of a tracer of the haloes mass

It allows to map the large-scale structure of the Universe with a measure of the intensity of the redshifted 21 cm line of HI.

Advantages:

$$\frac{\nu_o}{\nu_e} = (1+z)^{-1}$$

Not necessary to resolve galaxies individually



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Angular Power Spectrum

$$C_l^{(ij)} = \frac{1}{\langle I_i \rangle \langle I_j \rangle} \int \frac{d\chi}{\chi^2} W_i(\chi) W_j(\chi) P_{ij}\left(k = \frac{l}{\chi}, \chi\right)$$

Angular Power Spectrum

Window Functions

Non-Linear Power Spectrum

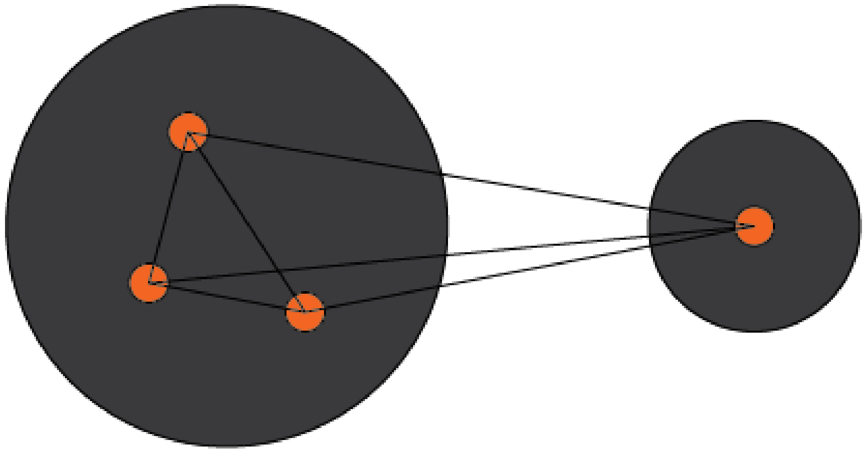
Non Linear Power Spectrum

In the Halo Model approach, the non linear power spectrum can be split into 2 terms which refer to 1 halo and 2 haloes, respectively:

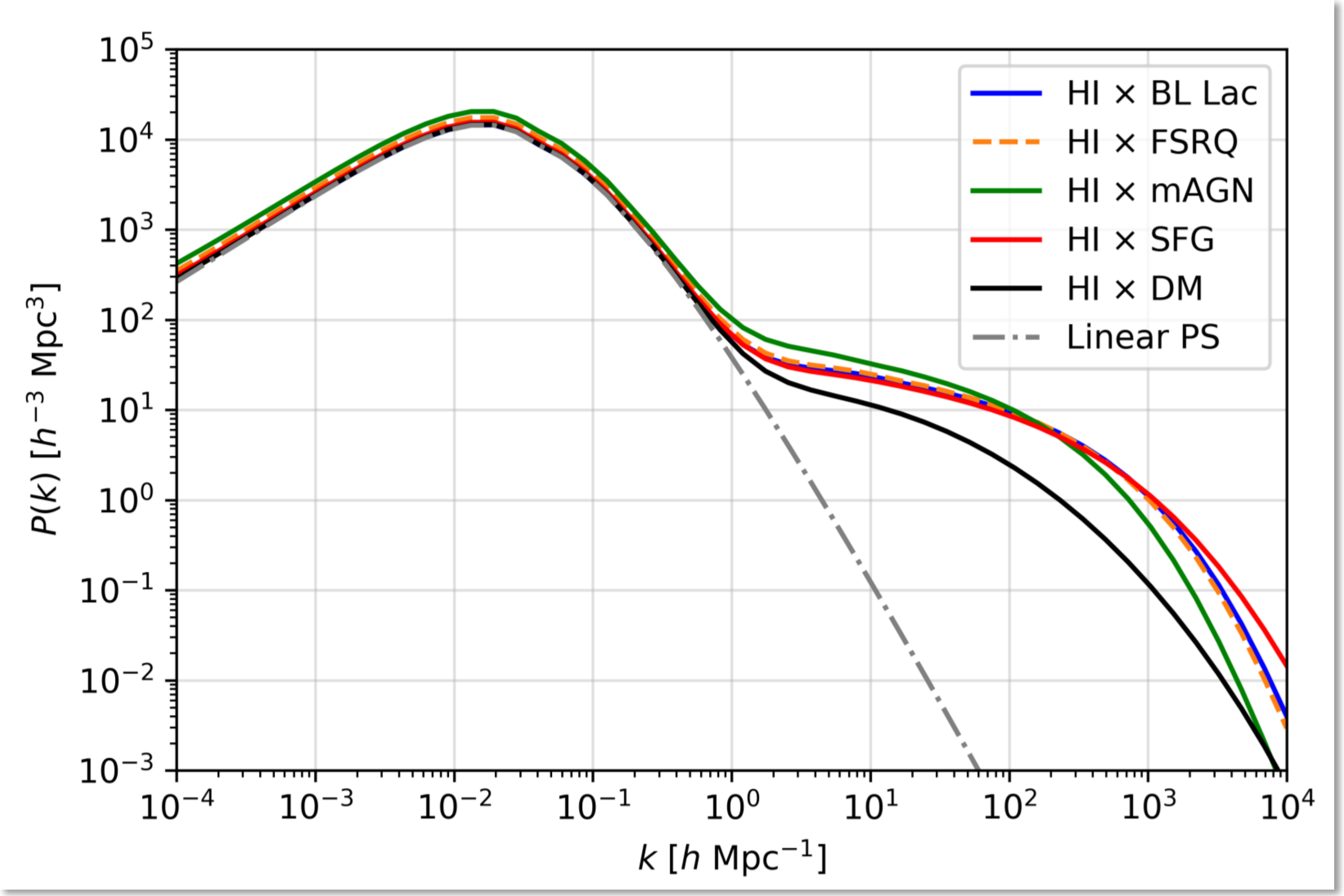
$$P_{ij} = P_{ij}^{1h} + P_{ij}^{2h}$$

$$P_{ij}^{1h} = \int_{M_{min}}^{M_{max}} dM \frac{dn}{dM} f_i^* f_j$$

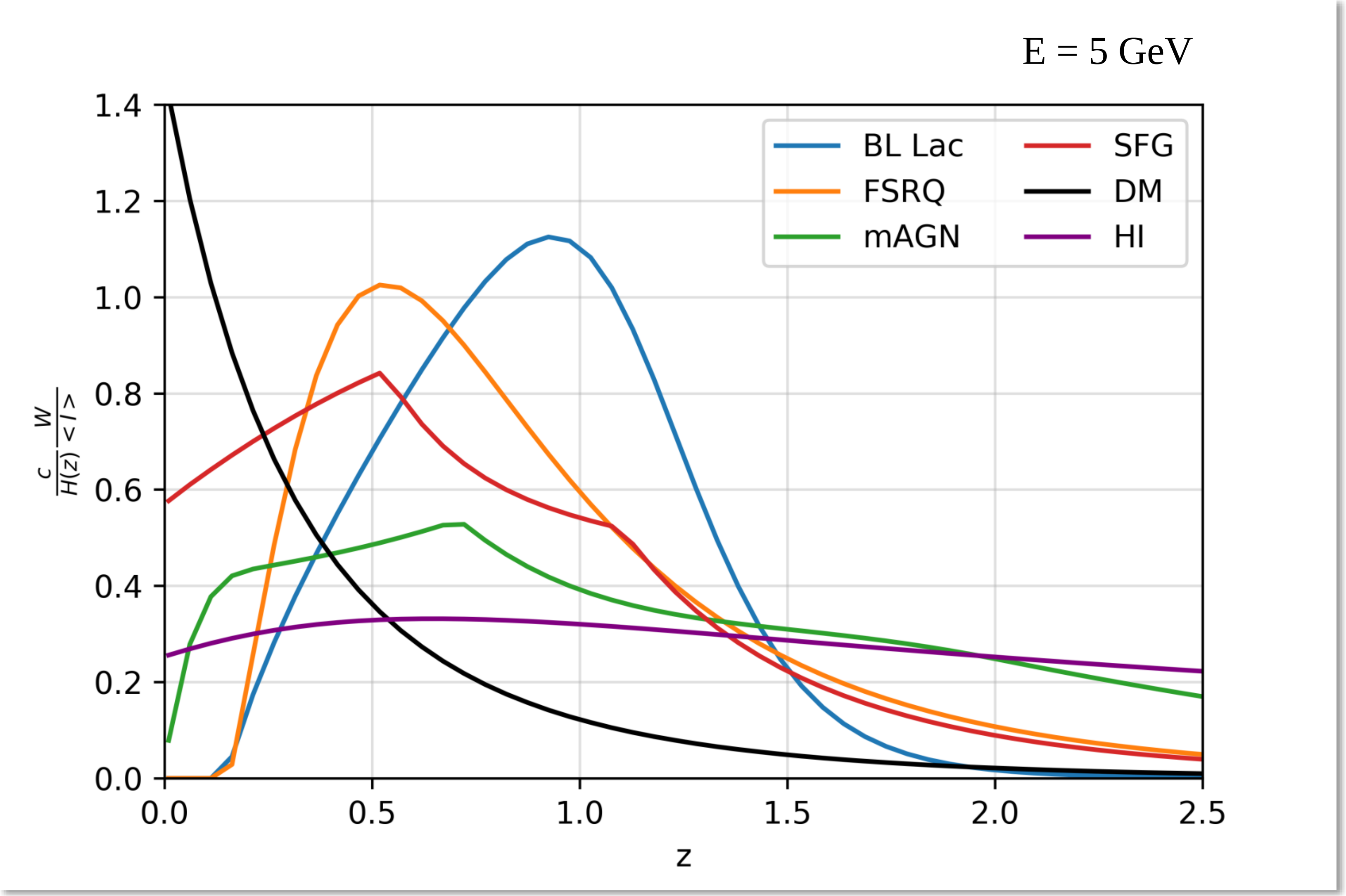
$$P_{ij}^{2h} = \left[\int_{M_{min}}^{M_{max}} dM_1 \frac{dn}{dM_1} b_i f_i^* \right] \left[\int_{M_{min}}^{M_{max}} dM_2 \frac{dn}{dM_2} b_j f_j \right] P_{lin}$$



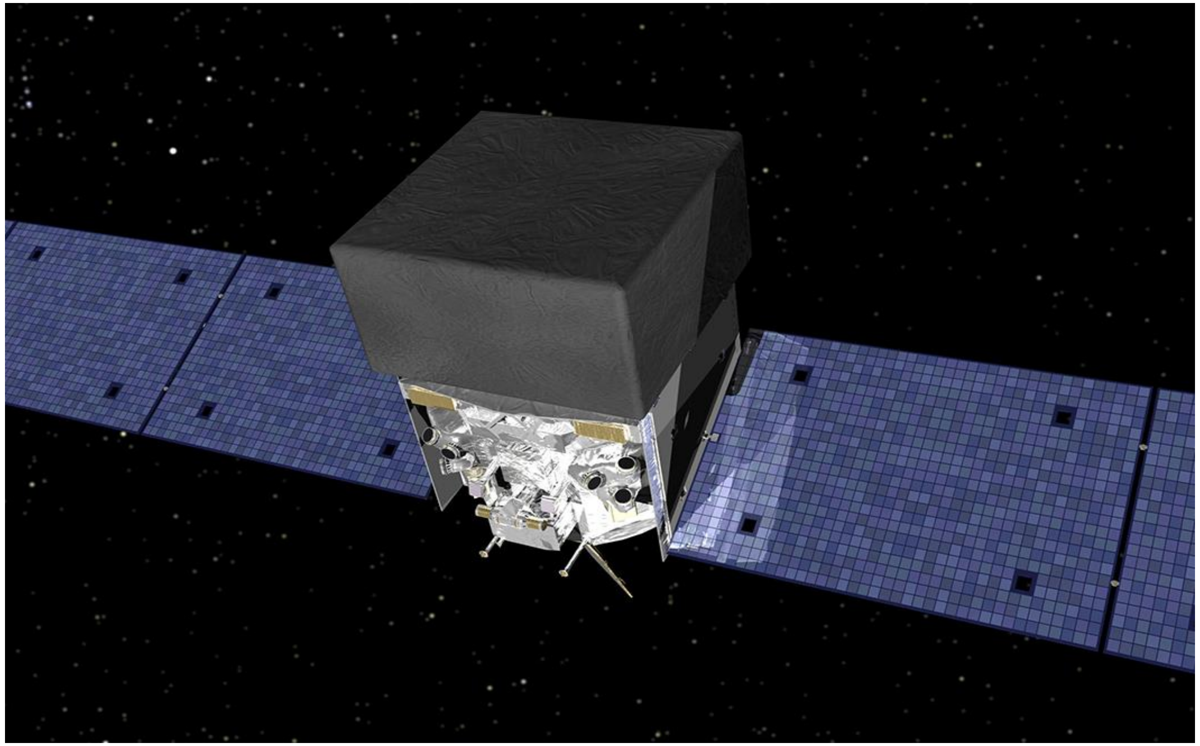
Cross-correlation HI x gamma rays



Window function



Experiments



Fermi Gamma-Ray Space Telescope

Square Kilometer Array, MeerKAT

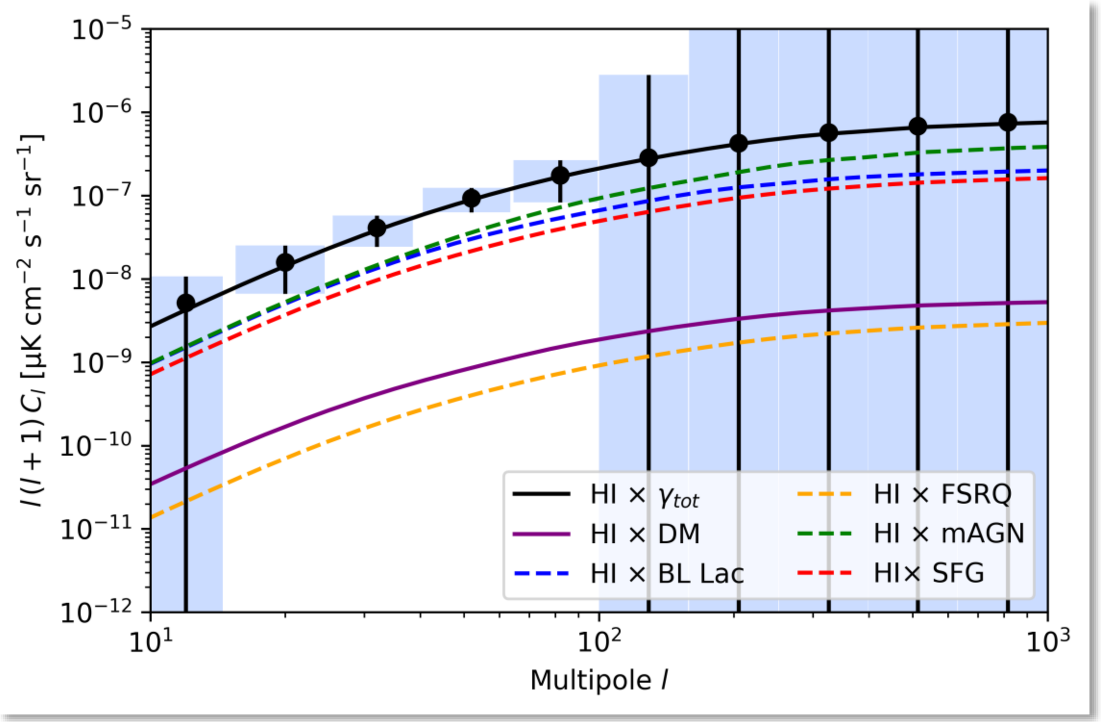
Experimental configurations

Bin	E_{min} [GeV]	E_{max} [GeV]	N_γ [$cm^{-4}s^{-2}sr^{-1}$]	f_{sky}	σ_0 [deg]
1	0.5	1.0	$1.056 \cdot 10^{-17}$	0.134	0.9
2	1.0	1.7	$3.548 \cdot 10^{-18}$	0.184	0.5
3	1.7	2.8	$1.375 \cdot 10^{-18}$	0.398	0.3
4	2.8	4.8	$8.324 \cdot 10^{-19}$	0.482	0.2
5	4.8	8.3	$3.904 \cdot 10^{-19}$	0.594	0.2
6	8.3	14.5	$1.768 \cdot 10^{-19}$	0.574	0.1
7	14.5	22.9	$6.899 \cdot 10^{-20}$	0.574	0.09
8	22.9	39.8	$3.895 \cdot 10^{-20}$	0.574	0.07
9	39.8	69.2	$1.576 \cdot 10^{-20}$	0.574	0.07
10	69.2	120.2	$6.205 \cdot 10^{-21}$	0.574	0.06
11	120.2	331.1	$3.287 \cdot 10^{-21}$	0.597	0.06
12	331.1	1000	$5.094 \cdot 10^{-22}$	0.597	0.06

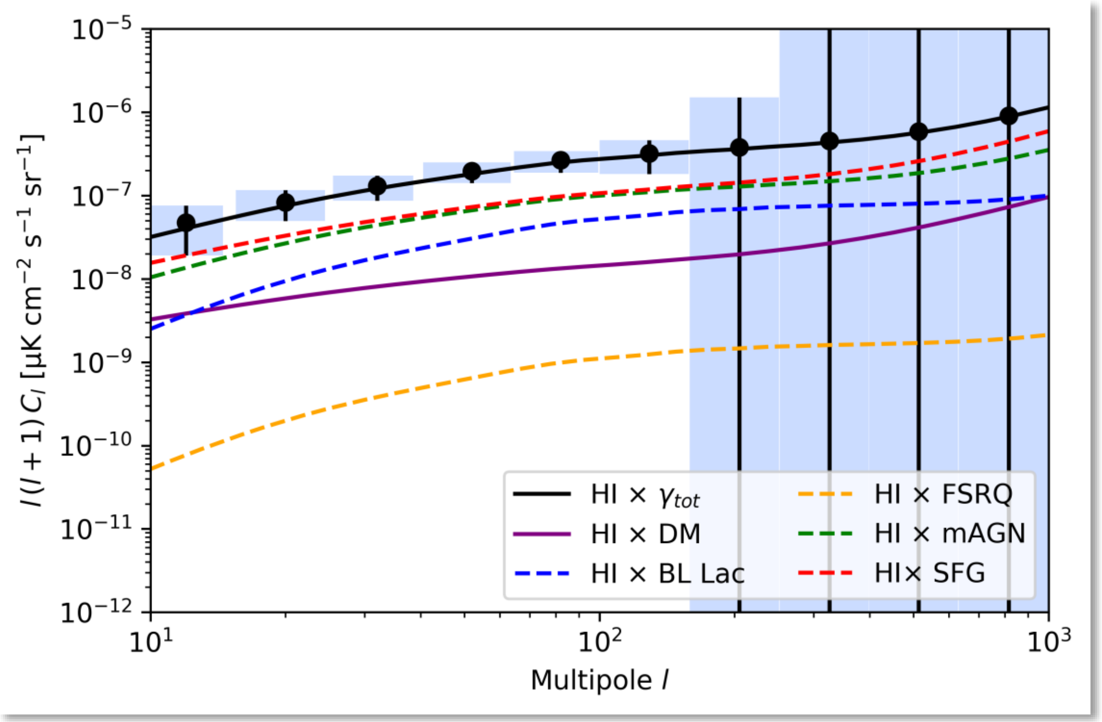
	MeerKAT	SKA1
S [deg^2]	4000	25000
f_{sky}	0.097	0.61
t [hr]	4000	10000
N_d	64	133 + 64
D_{dish} [m]	13.5	14.5
D_{interf} [km]	1	3
[z_{min}, z_{max}]	UHF-band: [0.4, 1.45] L-band: [0.0, 0.58]	Band 1: [0.35, 3.0] Band 2: [0.0, 0.5]
Configuration	Single-dish Interferometer	Single-dish Interferometer

Ackermann et al. (2018)

Forecast for 21 cm line x γ rays



Band 1: 0.35 < z < 3.0



Band 2: 0 < z < 0.5

$$\Delta C_l^{HI\times\gamma} = \sqrt{\frac{1}{(2l+1)\,f_{sky}}\left[\left(C_l^{HI\times\gamma}\right)^2 + \left(C_l^{\gamma\gamma} + \frac{N_\gamma}{B_{l,\gamma}^2}\right)\left(C_l^{HI\times HI} + \frac{N_{HI}}{B_{l,HI}^2}\right)\right]}$$

$$\langle\sigma v\rangle = 3\cdot 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}$$

$$m_\chi = 100\ \mathrm{GeV}$$

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SNR for astrophysical sources

$$SNR^2 = \sum_{i=l,E} \left(\frac{C_i^{HI \times S}}{\Delta C_i^{HI \times S}} \right)^2$$

$$SNR = n\,\sigma$$

MeerKAT

UHF-band	3.7σ
L-band	3.6σ

L-band: $0 < z < 0.58$

UHF-band: $0.4 < z < 1.45$

Square Kilometer Array

Band 1	4.6σ
Band 2	5.7σ

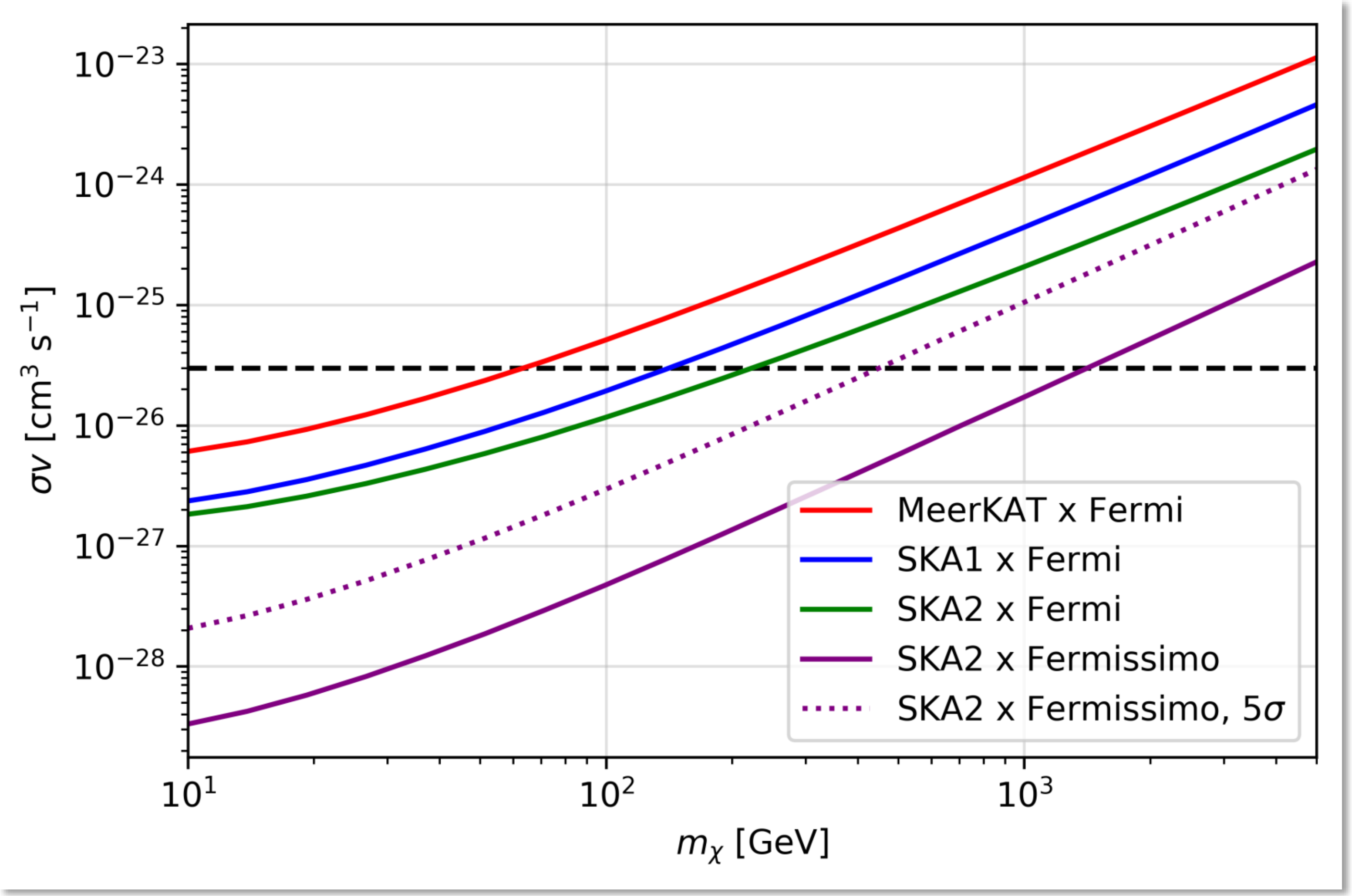
Band 1: $0.35 < z < 3$

Band 2: $0 < z < 0.5$

Forecast for Dark Matter bounds

$$\Delta\chi^2 = \chi^2_{DM+S} - \chi^2_S$$

$$\boxed{\Delta\chi^2(\sigma v) = 4}$$ 95% CL



Take Home message

1. The cross-correlation HI $\times\ \gamma$ rays is a very promising channel

2. MeerKAT: SNR = 3.7σ
   SKA1: SNR > **5σ**

3. Competitive bounds for DM with SKA1 and SKA2+Fermissimo:

SKA1+Fermi	2σ bound	$0.65 \times \langle\sigma v\rangle_{th}$
SKA2+Fermissimo	2σ bound	$0.02 \times \langle\sigma v\rangle_{th}$
	5σ detection	$0.10 \times \langle\sigma v\rangle_{th}$

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Thank you for your attention!