Particle dark matter signals in the anisotropic sky: a cross-correlation approach

Marco Regis (Torino)
Even if DM halos are too faint to be individually detected in gamma-rays, they form the most numerous population in the Universe. The DM “cumulative” signal or its spatial coherence might be observable.

Dig into the unresolved extragalactic sky
The idea is to have an **accurate tracer of the DM distribution** (gravitational potential) in the Universe, to be used as a **filter** in order to separate the **DM non-gravitational signal** from other astrophysical non-thermal emissions.

\[
\langle I_i(\vec{n}_1)I_j(\vec{n}_2) \rangle \rightarrow C^{ij}(\theta) \rightarrow C^{ij}_l
\]

- **correlation in physical space**
- **correlation in harmonic space**
Cross correlation with catalogs of galaxies

(see also talk by Alex Cuoco)
Observations of cross correlations between Fermi-LAT maps and galaxy catalogs


See also Shirasaki+ 2015
Cross correlation of Fermi-LAT with the 2MASS catalog

Two Micron All Sky Survey (2MASS)

770000 galaxies with mean redshift $z \sim 0.072$
DM interpretation/bounds

Plot from Sanchez-Conde talk, 2014

about subhalos model

TeV Particle Astrophysics 2016, CERN, 12/09/2016

Marco Regis
Cross correlation with catalogs of clusters

(in collaboration with E. Branchini, S. Camera, A. Cuoco, N. Fornengo, M. Viel, J. Xia)
Datasets

Rykoff+ 2014
26,350 clusters

Fermi-LAT PASS8 data between 0.5-100 GeV

Wen+ 2012,2015
158,103 clusters

Planck Coll. 2015
1,653 clusters
Measurements

Detection $>5\sigma$ for redMaPPer and WHL12
Evidence at $\sim 3\sigma$ for PlanckSZ
Cross correlation and stacking

Correlation function

\[ \omega(\theta) = \frac{1}{4\pi} \sum_{\ell=1}^{\infty} (2\ell + 1) C_\ell P_\ell(\cos \theta) \]

Stacking profile

\[ \langle \rho \rangle(\theta) = \int \frac{\ell \, d\ell}{2\pi} J_0(\ell \theta) C_\ell \]
Cross correlation with lensing surveys
Prospects for DM detection/bounds using cross correlation with shear

Cross-correlation with lensing surveys:
cleaner test and larger non-linear term

$\langle \sigma_a v \rangle$ [cm$^3$/s] vs $m_{DM}$ [GeV]

$\bar{b}\bar{b}$ channel
- Red: DMa Low
- Blue: DMa High
- Green: DMa NS

$\sigma_a$ bounds for $C_i^{\nu\nu}$

$\langle \sigma_a v \rangle$ [10$^{-26}$ cm$^3$/s] vs $m_{DM}$ [GeV]

DES+Fermi10yr
- Red: DES+Fermi10yr

Euclid++Fermissimo
- Green: DES+Fermi10yr

DMa Low
- Marg.
- Marg.+Priors
First attempt of measurement
(of the cross correlation between cosmic shear and the EGB)

Canada-France-Hawaii Lensing Survey (CFHTLenS) + 5yr Fermi LAT data
(Shirasaki, Horiuchi, Yoshida, PRD 2014)

CFHTLenS surveyed four separated fields for a total of \(~150\) sq. deg.
with \(11\) gal/arcmin\(^2\)

(DES \(\rightarrow\) 5000 sq.deg.)
Second attempt of measurement

(CFHTLenS and RCSLenS) + 7yr Pass8 Fermi LAT data

(RCSLenS surveyed ~785 sq. deg. with 5.5 gal/arcmin$^2$)
Third attempt of measurement

(CFHTLenS, RCSLenS and KIDS) x 7yr Pass8

Fermi LAT data between 0.5-500 GeV

(KIDS → 8.8 gal/arcmin²)

(Troester+ in preparation)
Cross correlation with CMB lensing

Fermi-LAT 6yr data

Planck 2015 data release
Cross correlation with CMB lensing

3σ evidence
Fornengo, Perotto, MR, Camera

Direct evidence of the extragalactic origin of the diffuse γ-ray background
Other wavelengths and particle DM candidates
Radio and X-ray anisotropies to probe synchrotron and IC emissions induced by WIMPs (Fornengo&MR, 2014)

Cross correlation between eROSITA with 2MASS to search for sterile neutrinos (Zandanel+ 2015)

NIRB anisotropies to test eV ALPs (Gong+ 2016, Vittino+ in preparation)
Established:
Excess in the NIRB autocorrelation angular power spectrum at multipoles ~ \(10^3\)
Possible explanation in terms of decay of ALPs of few eV
To be checked:
Energy spectrum, cross correlations between different NIRB bands and between NIRB and X-rays.
Angular cross correlations between extragalactic gravitational tracers and sky-maps containing possible non-gravitational DM signals are (and will more and more be) a powerful tool for constraining the particle DM hypothesis.

Thank you!
Angular power spectrum

\[ C_{\ell}^{XY} = \int d\chi \frac{W^X(\chi)W^Y(\chi)}{\chi^2} P_{XY}\left(k = \frac{\ell}{\chi}, \chi\right) \]

\[ \langle \mathcal{I}^X \rangle = \int d\chi W^X(\chi) \]

\[ \langle \tilde{f}_X(\chi, k)\tilde{f}_Y(\chi, k') \rangle = (2\pi)^3 \delta^3(k + k') P_{XY}(k, \chi) \]

\[
\text{FT of density field of the source}
\]

\[
\text{Window function}
\]

\[
\text{3D power spectrum}
\]
DM peaks at low $z$, whilst astrophysical sources peak at $z > 0.5$
Typically obtained from Simulations or Halo model

It is (roughly speaking) mapped in the multipole range $100 < l < 1000$
3D power spectrum

Typically obtained from Simulations or Halo model

Halo model

\[ P_{ij}(k) = P_{ij}^{1h}(k) + P_{ij}^{2h}(k) \]

\[ P_{ij}^{1h}(k) = \int dm \frac{dn}{dm} \hat{f}_{i}^{*}(k|m) \hat{f}_{j}(k|m) \]
\[ f = \text{FT of density field} \]

\[ P_{ij}^{2h}(k) = \left[ \int dm_{1} \frac{dn}{dm_{1}} b_{i}(m_{1}) \hat{f}_{i}^{*}(k|m_{1}) \right] \left[ \int dm_{2} \frac{dn}{dm_{2}} b_{j}(m_{2}) \hat{f}_{j}(k|m_{2}) \right] P^{\text{lin}}(k) \]

Required ingredients:
- Halo mass function \( dn/dm \)
- Concentration of halos \( c(m) \)
- DM distribution in halos (NFW, Einasto, Burkert, …)
  and the same for subhalos, or \( B(x,m,z) \)

Critical point: extrapolation from the resolution of numerical simulations down to \( m_{\text{min}} \)
The particle DM signal can fit the measured cross correlation between Fermi-LAT and 2MASS.
Degeneracy between DM interpretation and AGN hosted in big halos (groups or clusters)
Properties of the catalogs

Preliminary

- PlanckSZ
- redMaPPer
- WHL12