Dark Matter Searches via cross-correlations with Large Scale Structures

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Indirect Detection of Dark Matter: the General Framework

1) WIMP Annihilation  Typical final states include heavy fermions, gauge or Higgs bosons

2) Fragmentation/Decay  Annihilation products decay and/or fragment into some combination of electrons, protons, deuterium, neutrinos and gamma rays
Fermi Gamma-Sky, P8, PSF3-only, >1 GeV
(72 months (6 yrs), ~3.4M events)
The Extra-Galactic Gamma-ray Background (EGB)

- Power Law for $E < 100$ GeV
- Spectral softening at high energies
The origin of the EGB

- many astrophysical sources are guaranteed to contribute, e.g.:
  - blazars
  - star-forming galaxies
  - millisecond pulsars
  - AGNs
  - clusters of Galaxies
  - clusters Shocks
  - cascades from UHECRs
  and...
  - Dark matter(?)

- relatively featureless total EGB intensity spectrum $\rightarrow$ lack of spectral handles to ID individual components
Resolved Sources - 3FGL catalogue

~3000 sources

- AGN
- AGN-Blazar
- AGN-Non Blazar
- Galaxy
- Starburst Galaxy
- Radio Galaxy
- Seyfert Galaxy
- Unassociated
- Possible Association with SNR and PWN
- Nova
- PSR
- PWN
- PSR w/PWN
- SNR
- Globular Cluster
- HMB

Credit: Fermi Large Area Telescope Collaboration
Anisotropy Features of the EGB-IGRB

• Besides the energy spectrum there is much more information to explore!

• In the last years a lot of work on this:

• Anisotropy energy spectrum (IGRB auto-correlation) (Fornasa, Cuoco+ 2016)

• Pixel count fluctuations (1pPDF) (see Lisanti+ 2016, Zechlin+ ApJS 2015, Feyereisen+ JCAP 2015)

• Cross-correlations (next slides)
Besides the energy spectrum, the various components differ also by their distribution in $z$. In particular DM is expected to peak at low redshift.

Need to isolate the IGRB emission coming from different redshifts!
Tomography of the IGRB via x-correlation with LSS

The different z-coverage of each catalogue allows to isolate the IGRB at different z effectively performing a Tomography of the IGRB.

- This provides a strong handle to better separate components and eventually DM.

See also:
Xia et al. MNRAS 2011,
Ando, JCAP 2014,
Ando, Benoit-Levy,
Komatsu PRD 2014
Advantage: traces directly the total matter. No bias modeling required.
Disadvantage: not ready yet. Best result at the moment a small patch of the sky from DES. But interesting results to come with full DES maps and in the future Euclid.
A further possibility is to cross-correlate with the LSS gravitational potential estimated through its lensing effect on the CMB. Indeed, a ~3 sigma correlation is present (Fornengo+ ApJ, 2015). Interesting for the future if lensing maps will improve.
DM emission in the IGRB should trace the Large Scale Structures of the Universe.

Galaxy Catalogues can be used as LSS template to cross-correlate with

Regis, Xia, Cuoco+, PRL 2015
Fermi Maps

- 60 months P7REP_clean_v15 data
- galactic diffuse model subtracted: ring_2year_P76_v0.fits
- Galactic latitude mask (>30 deg), point sources mask (2FGL and 3FGL catalog) and Lobes-LoopI mask
- Mostly flat residuals apart a small deficit in Taurus region. Region is masked anyway by the catalogues mask
- CCF calculated with Polspice.
- PSF correction taken into account in the models, rather than the data.
- Errors calculated from Polspice. Checked that they agree with Jack-Knife estimate.
- In the plot each model is normalized as predicting 100% of the IGRB.
- Models are simple implementation of the assumption that IGRB sources follow LSS with some bias.
Exploiting the correlations with other catalogues, degeneracies can be removed.
Fermi-2 SDSS-QSO X-Correlation

CCF above 500 MeV
Global multi-component fit

- DM can be included in the fit as a further component. There is some weak hint for DM (< 2 sigma), but not very significant.
- SFGs seem to give the main contribution to the IGRB, while blazars are subdominant.
Global multi-component fit (II)

- mAGN can be further added to the fit. In this case several degeneracies appear. mAGN and SFGs give the main contribution, while DM cannot be distinguished anymore from the other components.
• Limits on the DM contribution can be placed, although they depend on the DM Halo substructure modeling.
• They are, however, competitive even in the most conservative substructure boost scenario (i.e. no boost)
• CCF calculated with Polspice.
• PSF correction taken into account in the models, rather than the data.
• Errors calculated from Polspice. Checked that they agree with Jack-Knife estimate.
• In the plot each model is normalized as predicting 100% of the IGRB
• Models are simple implementation of the assumption that IGRB sources follow LSS with some bias
• A fit with DM only is equally good as the multi-component fit. Degeneracy prevents from distinguishing the two scenario. The DM only scenario (cor the 2MASS correlation) is thus viable in principle.

• In this scenario, also, DM gives a subdominant contribution to the IGRB (inset plot), as generically expected.
• A large DM contribution to the 2MASS correlation cannot be excluded, since, due to the peaking at low z, an high 2MASS correlation does not affect the correlations at higher z.
• Further analyses with more statistics will help to clarify this picture.
• New Pass 8 data from Fermi-LAT provide more statistics and less cosmic-ray contamination
• More statistics --- > more bins, better spectrum
• New, almost all-sky, catalogue to use besides 2MASS: WixSC

Wise x SuperCosmos photoz catalog, Bilicki et al. 2016
Summary and Conclusions

- Cross correlation of the IGRB with LSSs provides a way to isolate the IGRB contribution in different redshift, i.e. to perform Tomography

- The methods provides strong constraints on the DM contribution to the IGRB

- In principle 2MASS correlation can be explained and fitted with DM without violating other constraints

- The picture is evolving rapidly and soon more gamma-ray data, better LSS catalogues and precise lensing shear maps will provide further insights and stronger sensitivities