



Fermi · Gamma-ray Space Telescope



Constraining dark matter signal from a combined analysis of Milky Way satellites using the Fermi-LAT

Maja Llena Garde
on behalf of the Fermi-LAT collaboration
IDM 2010 Montpellier

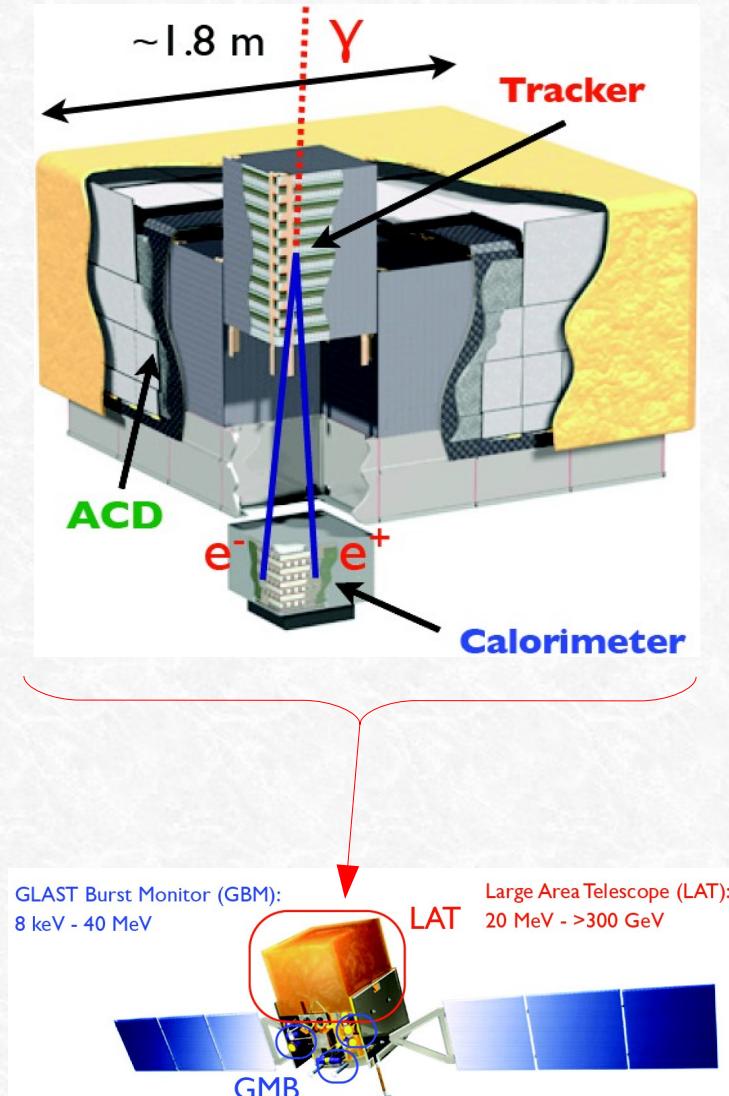


Outline

- Overview
 - Fermi-LAT
 - dSphs
- Analysis
 - Combined Likelihood
 - Systematic Uncertainties
 - Analysis details
- Results
- Conclusions

Fermi-LAT

- Launched on June 11, 2008
 - 16 identical modules in a 4x4 array, where each module is made up by a tracker for direction determination and a calorimeter for energy measurements
 - Field of view is ~2.4 sr
 - Energy range 20MeV to >300GeV
 - LAT observes the entire sky every ~3 h (2 orbits)
- ⇒ LAT is a great instrument for DM searches!



DM signal in High Energy γ -rays

The γ -ray flux from self-annihilating dark matter can be expressed as:

$$\Phi_{WIMP}(E, \Psi) = J(\Psi) \times \Phi^{PP}(E)$$



 Astrophysical factor Particle physics factor

$$J(\Psi) = \int_{l.o.s} dl(\Psi) \rho^2(l)$$

$$\Phi^{PP}(E) = \frac{1}{2} \frac{\langle \sigma v \rangle}{m_{WIMP}^2} \sum_f \frac{dN_f}{dE} B_f$$

The particle physics factor has two spectral features:

- Continuum
- Line - “smoking gun”

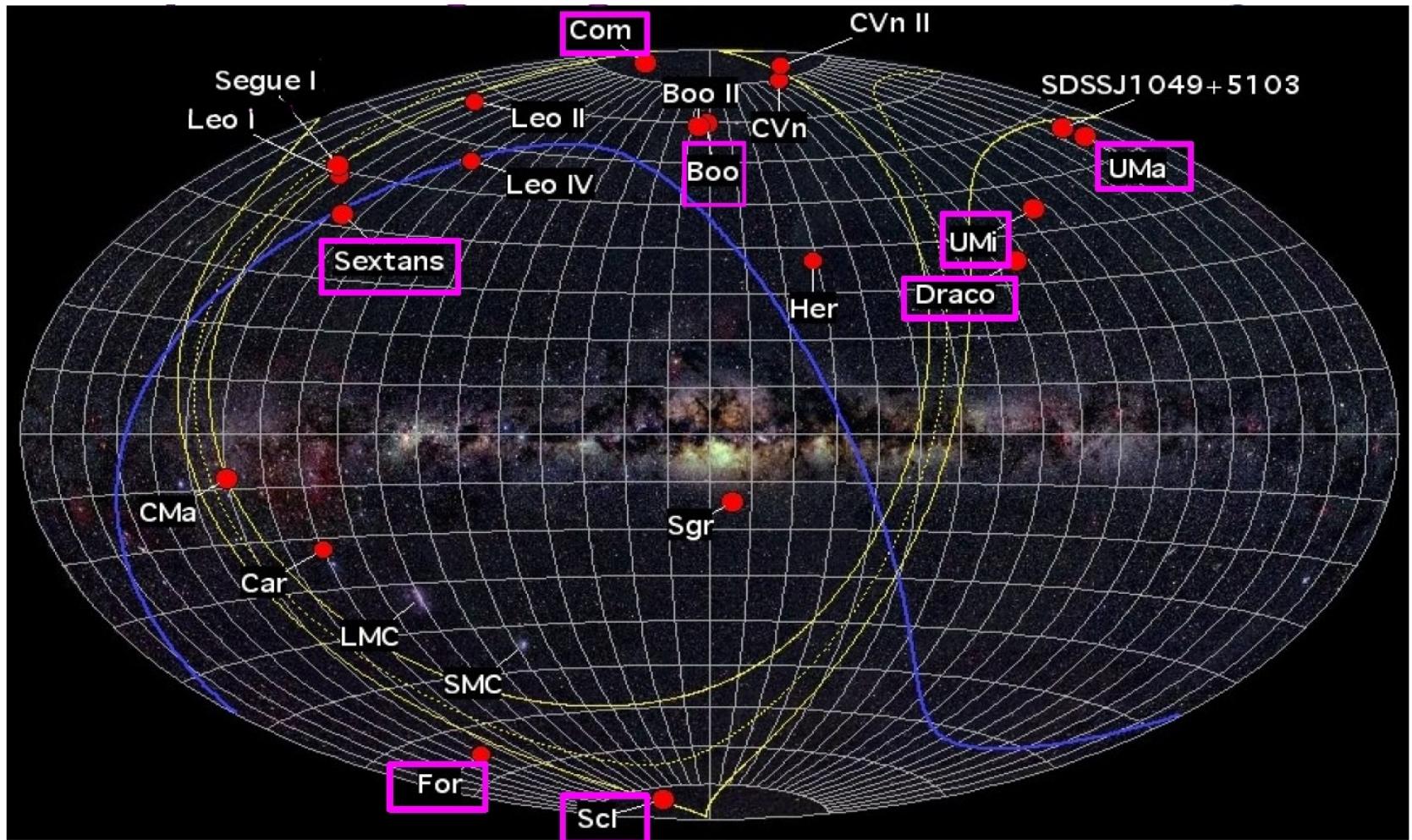
(*Fermi Line paper: A. A. Abdo et al Phys. Rev. Lett. 104, 091302 (2010)*)

Why dSphs?

- dSphs are DM dominated systems (they have very high M/L ratios).
- Many dSphs are closer than 100 kpc to the Galactic Centre.
- Low background
 - Most dSphs are expected to be free from other astrophysical γ -ray sources.
 - Small content of gas and dust.
- Low statistics.

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Position of the dSphs



dSphs in this analysis

Dwarf	J $10^{19} \text{ GeV} + 2 \text{ cm}^{-5}$	Galactic Coordinates	
		$ l $	b
Bootes I	$0.16^{+0.35}_{-0.13}$	358.08	69.62
Coma Berenices	$0.16^{+0.22}_{-0.08}$	241.9	83.6
Draco	$1.20^{+0.31}_{-0.25}$	86.37	34.72
Fornax	$0.06^{+0.03}_{-0.03}$	237.1	-65.7
Sculptor	$0.24^{+0.06}_{-0.06}$	287.15	-83.16
Sextans	$0.06^{+0.03}_{-0.02}$	243.4	42.2
Ursa Major II	$0.58^{+0.91}_{-0.35}$	152.46	37.44
Ursa Minor	$0.64^{+0.25}_{-0.18}$	104.95	44.80

Values from A. A. Abdo et al 2010 ApJ 712 147

Combined Likelihood

- Statement: DM spectrum is the same in all dSphs
- Stacking analysis feasible
- Combined likelihood stacking:

$$L(\sigma v, m_\chi; obs) = \prod_{i=1}^N L_i(\sigma v, m_\chi, C, b_i; obs_i)$$

DM properties
Same for all dSphs

Constants (e.g.
branching fraction
in our case)

Individual parameters
(e.g. galactic diffuse
normalization...)

- Use profile likelihood as implemented in MINUIT/MINOS

Main advantage of Combined Likelihood:

- analysis can be individually optimized
- combined limits are more robust (under individual background fluctuations and under individual astrophysical modelling uncertainties).

Systematic Uncertainties

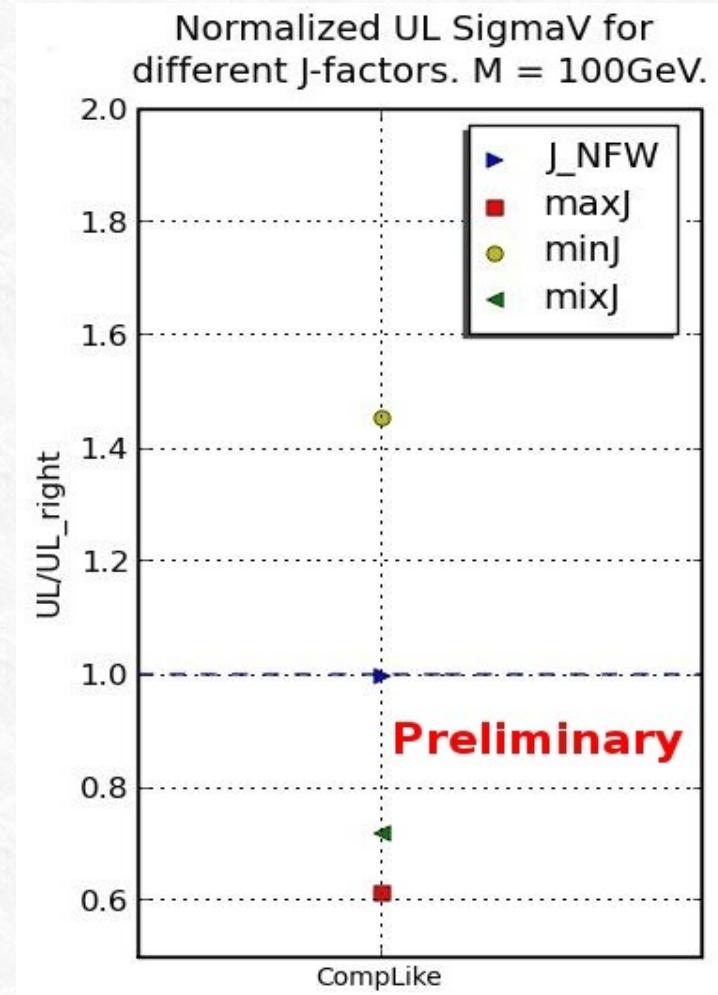
Uncertainties mainly arise from

- **J-factors, 20 - 200%**
(Fermi dSph paper: A. A. Abdo et al 2010 ApJ 712 147)
- **Effective area of the LAT, 5 - 20%, energy dependent**
(http://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_caveats.html)

This has not been implemented here yet.

J-factor Uncertainties

- $M = 100\text{GeV}$
- The plot shows normalized upper limits on DM cross-section for different J-factors.
 - J_NFW case: J used in the analysis
 - maxJ case: all $J_{\text{NFW}} + 1\sigma$ positive error
 - minJ case: all $J_{\text{NFW}} - 1\sigma$ negative error
 - mixJ case: 50% J + 1sigma positive error,
50% J - 1sigma negative error
- *Combined results are less sensitive to J-factor changes. (Up to a factor ~5 for individual limits)*

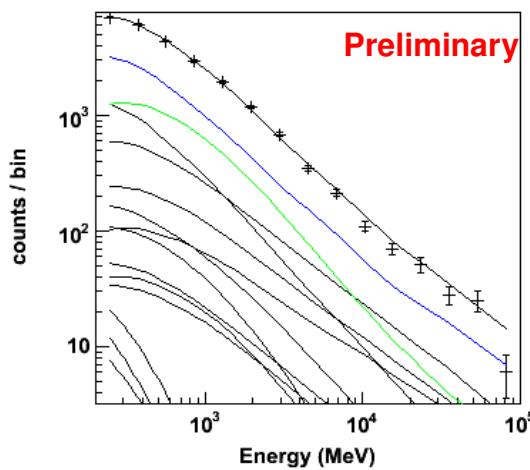


Analysis details

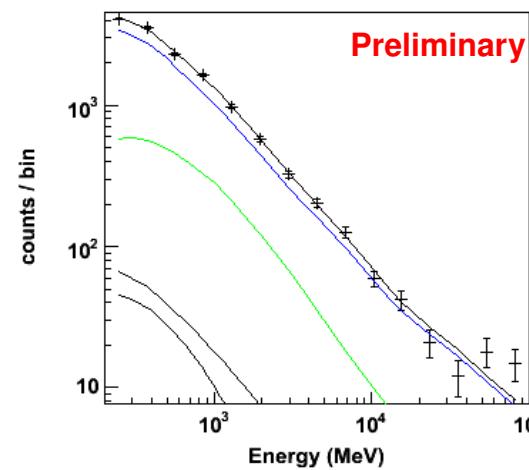
- **8 dSphs**
- **21 month data** from 2008-08-04 to 2010-05-12
- **Diffuse event class** (only events with the highest γ -like confidence)
- **Region of interest: 10° radius** centered on dSph location
- Energy range from **200MeV to 100GeV**
- Standard cuts removing Earth albedo (zenith angle $< 105^\circ$)
- Instrument response function: **P6_V3_DIFFUSE** (public)
- Models:
 - dSphs modelled as DM point sources (100% b-bbar, NFW profile)
 - Galactic and Isotropic diffuse models recommended by the Fermi-LAT collaboration
 - Point-like sources from the 11-months Fermi-LAT point source catalogue (*A. A. Abdo et al 2010 ApJS 188 405*)
- **Binned Likelihood** (using energy and spatial information)

Example spectra and residuals

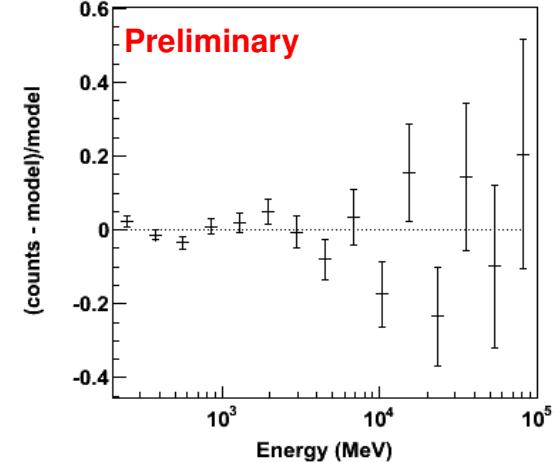
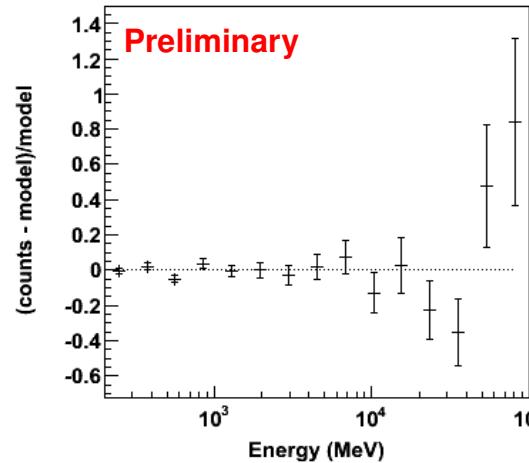
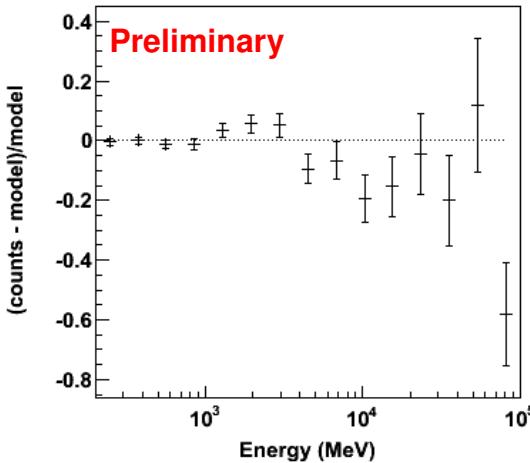
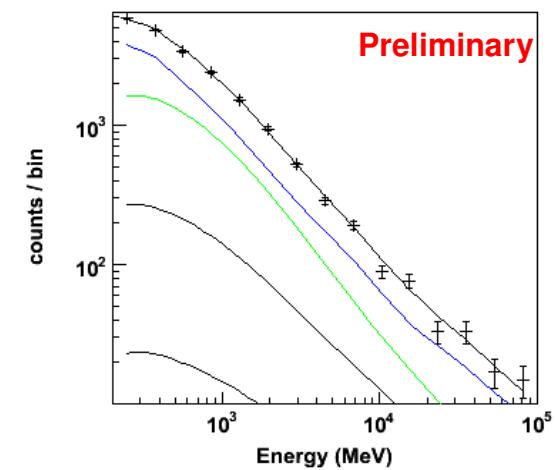
Coma Berenices



Sculptor



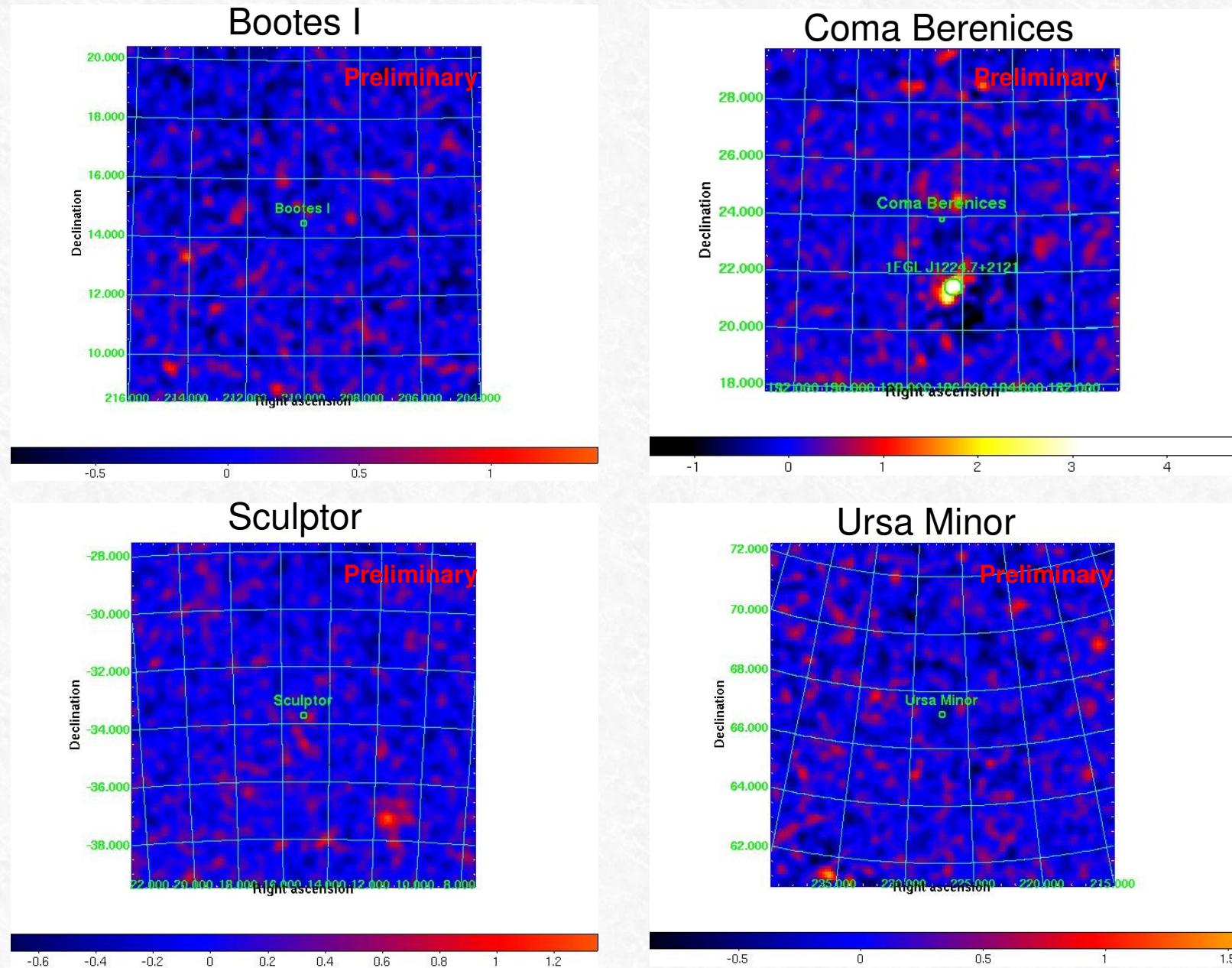
Ursa Minor



Isotropic Diffuse Galactic Diffuse DM Sources

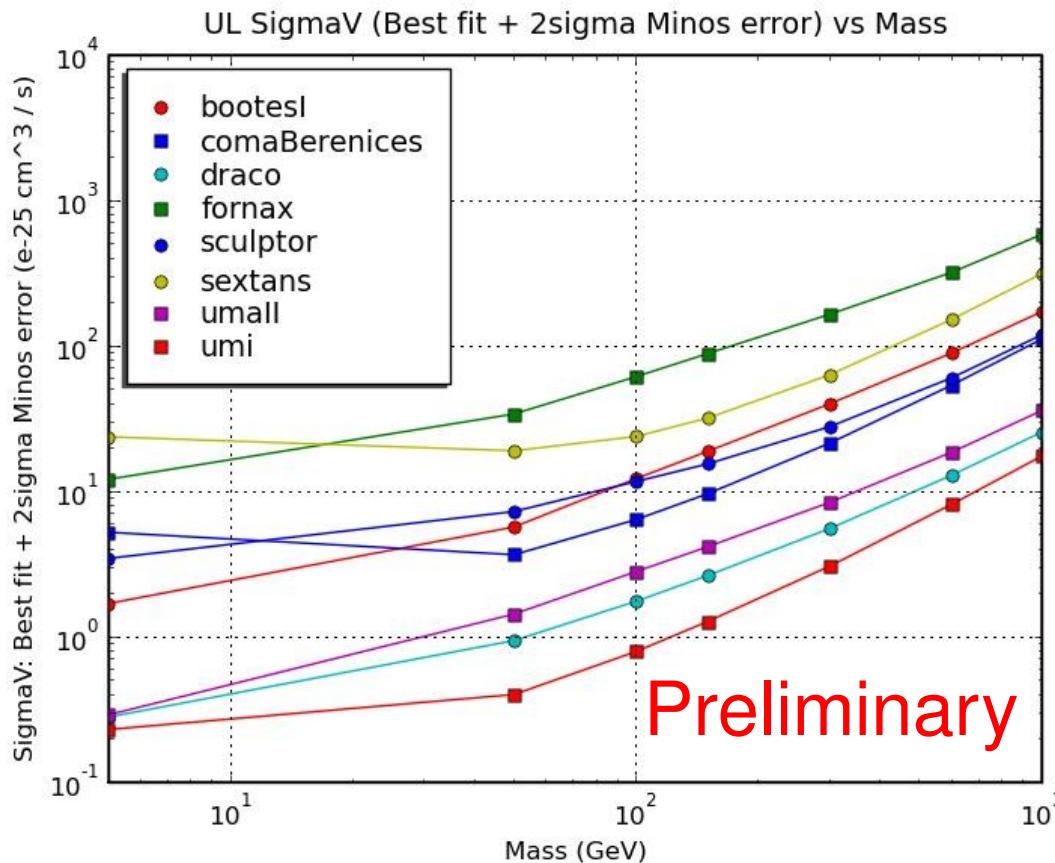
No DM signal was detected

Residual maps for $M_{DM}=150\text{GeV}$



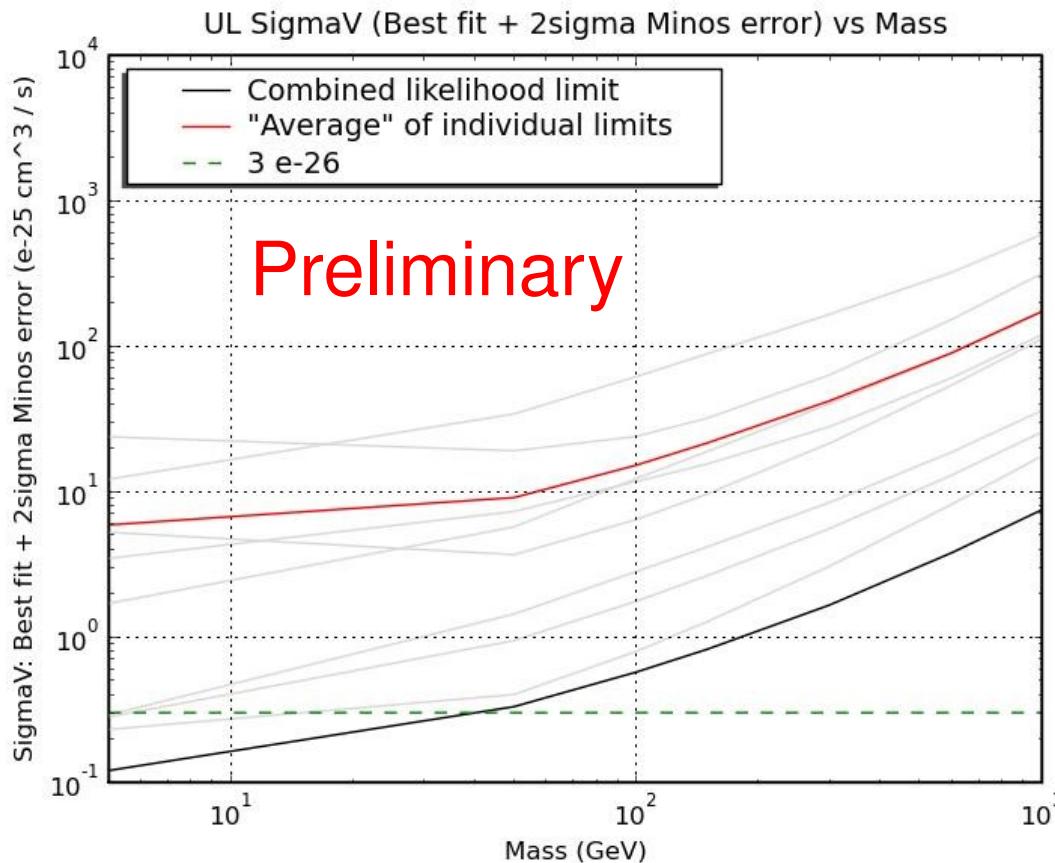
Individual Upper Limits on DM annihilation cross-section

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- Individual limits improve by a factor ~ 1.7 (on average) w.r.t. the Fermi-LAT dSph paper
(A. A. Abdo et al 2010 ApJ 712 147)
- 100% b-bbar
- Evaluated at $M_{\text{DM}} = 5, 50, 100, 150, 300, 600$ and 1000 GeV
- Results checked against choice of ROI, fit range and binning.

Combined Upper Limits on DM annihilation cross-section



- Combined upper limit gives up to a factor 3 (45) better constraints compared to the best (average) dSph.
- The “average” limit of the individual cases is plotted here just to guide the eye. The grey lines are the individual limits and the dashed green line is the thermal WIMP cross-section.

Conclusions

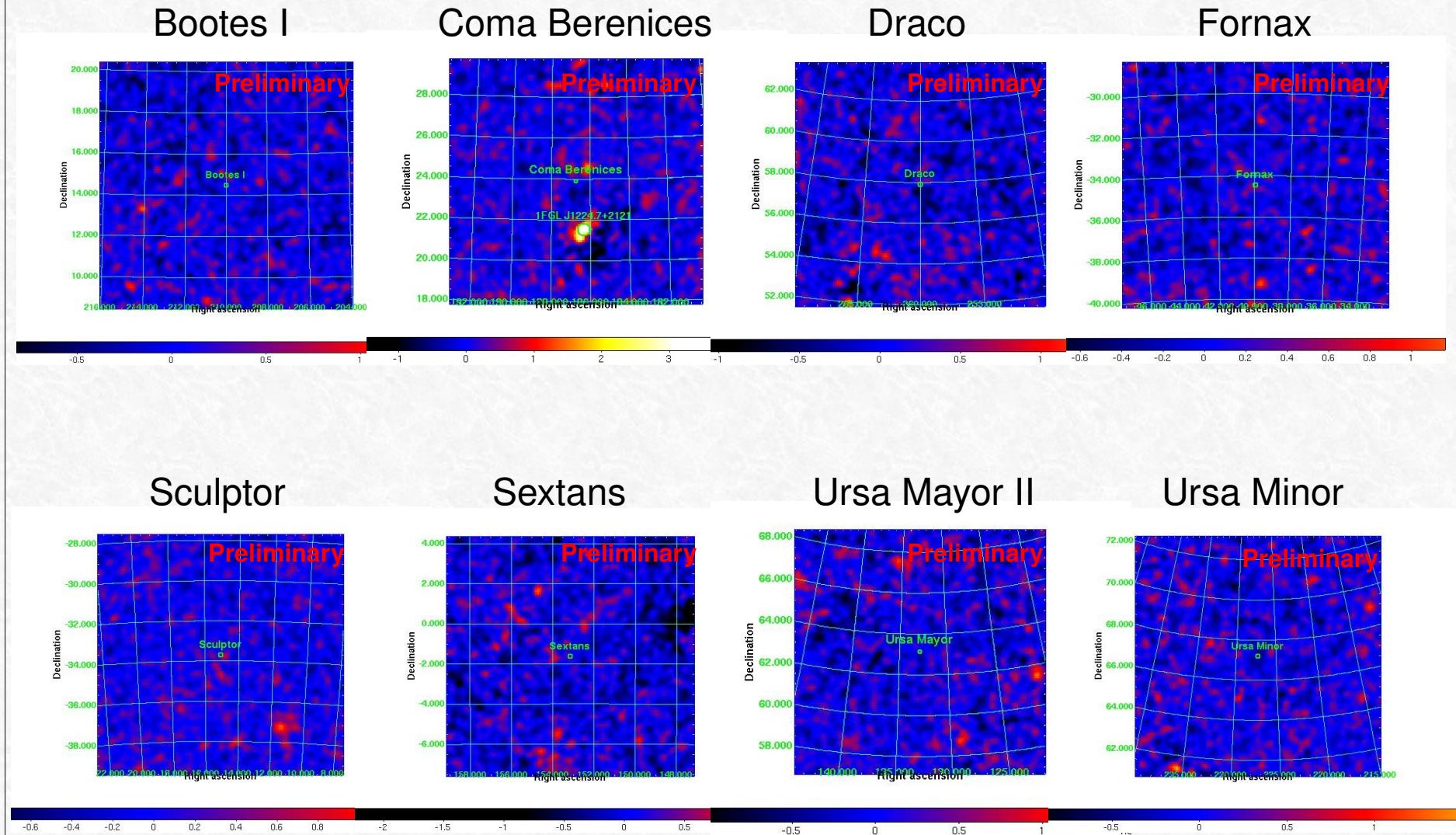
- A “stacking” analysis of 8 Fermi dSphs has been presented using a combined likelihood approach.
- Limits improve by a factor 3 (45) with respect to the most stringent (average) of the 8 individual limits, depending on mass.
- Results checked against choice of ROI, fit range and binning.
- Study of statistical properties and inclusion of systematic uncertainties in progress.
- Paper in preparation



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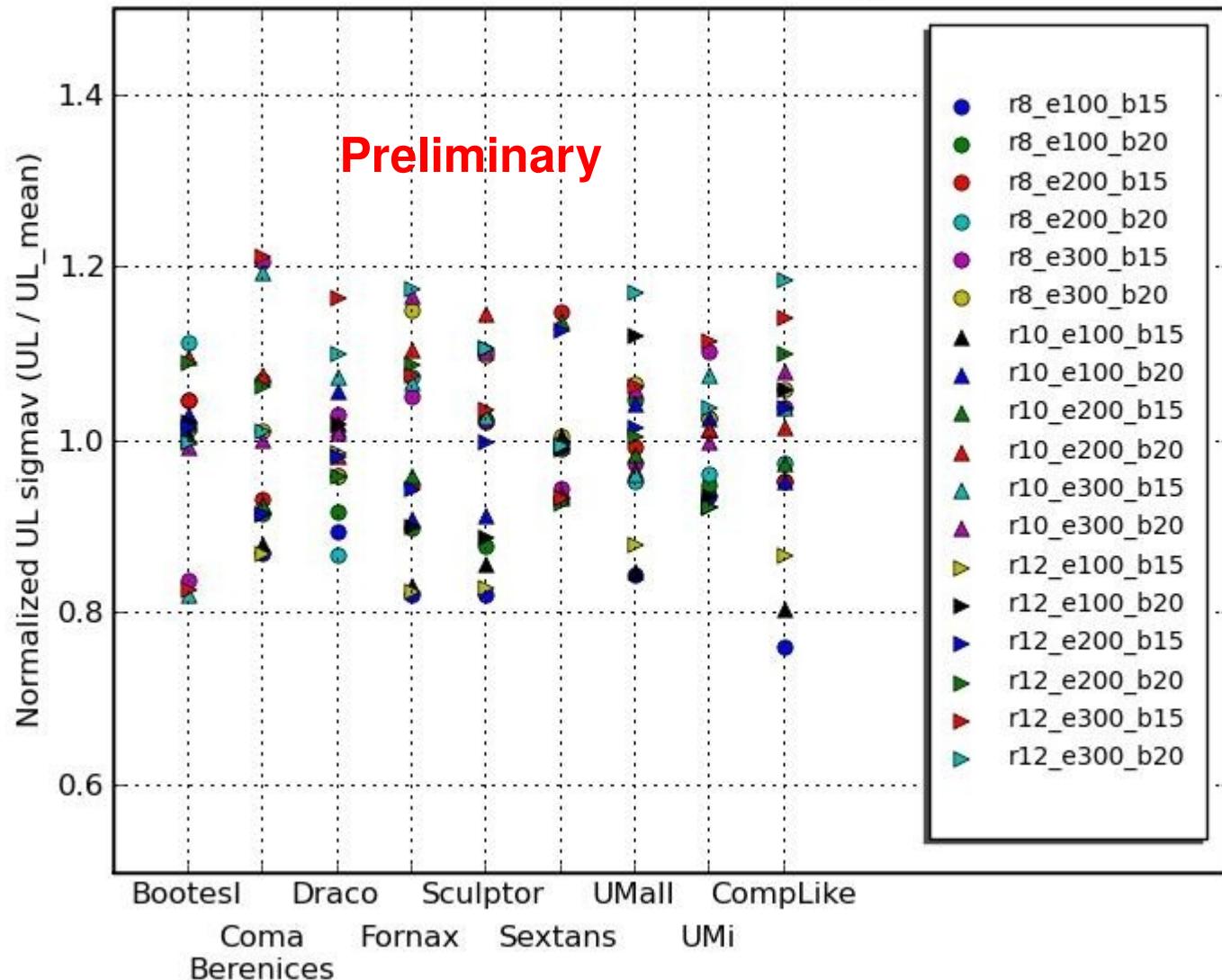
Back up slides

All residual maps for $M_{\text{DM}} = 150 \text{ GeV}$



Consistency test

UL SigmaV (Best fit + 2sigma Minos error)
 for different ROIs, Emins and binning. $M = 100\text{GeV}$.



J-factor Uncertainties

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