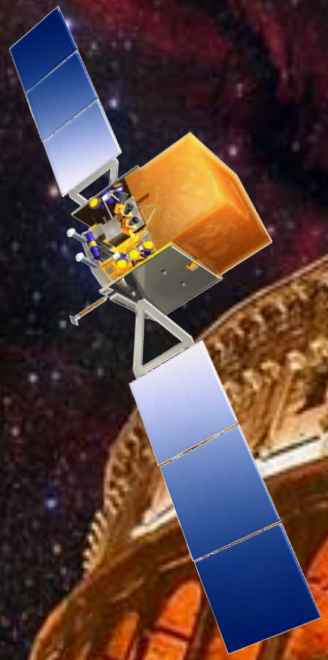
Highlights from the Fermi Symposium



ROMA

9-12 May, 2011

Aldo Morselli
INFN Roma Tor Vergata


The LAT at 2 Years
Happy 2nd Birthday, Fermi!
and 17 days from the 3 rd !!!
11 June 2008

Fermi is Making a Major Impact

Science, December 2009

THE RUNNERS-UP >>

Opening Up the Gamma Ray Sky

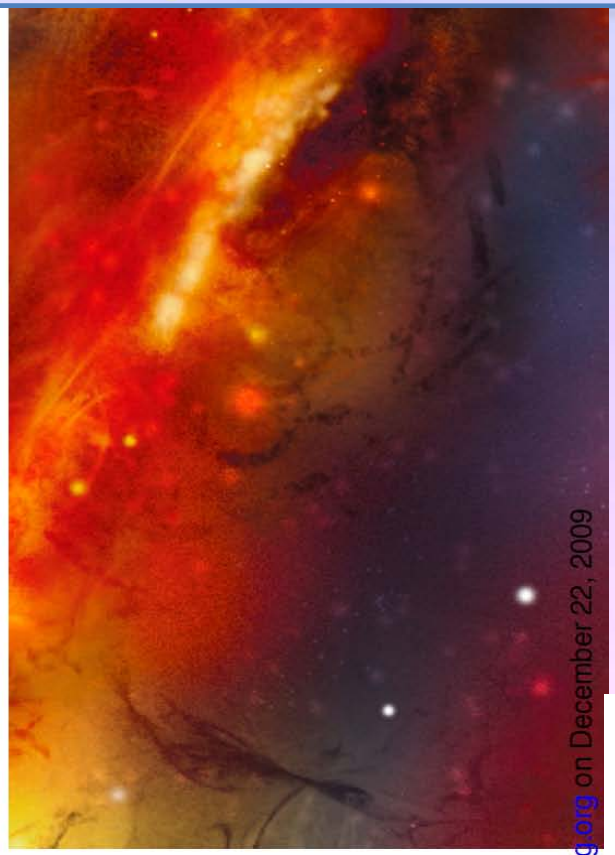
LIKE A LIGHTHOUSE BLINKING IN THE NIGHT, A pulsar appears to flash periodically as it spins in space, sweeping a double cone of electromagnetic radiation across the sky. Since the discovery of the first pulsar 4 decades ago, astronomers have detected hundreds more of these enigmatic objects from the pulsing radio waves they emit. Now, astronomers have opened a new channel of discovery—the highly energetic gamma ray spectrum—to find pulsars that radio observations could not detect. The advance, part of a torrent of recent gamma ray observations, is giving researchers an improved understanding of how pulsars work, along with a rich haul of new pulsars that could help in the quest to detect gravitational waves.

The findings come from the Fermi Gamma-ray Space Telescope, which has been mapping the gamma ray universe since it was launched by NASA in June 2008. Combing through data the telescope collected in its first few months, an international team discovered 16 new pulsars; strong gamma ray pulsations from eight previously known pulsars with spin times of milliseconds, proving that these objects pulse brightly at gamma wavelengths as well as in the radio range; and high-energy gamma rays from the globular cluster 47 Tucanae indicating that the cluster harbors up to 60 millisecond pulsars.

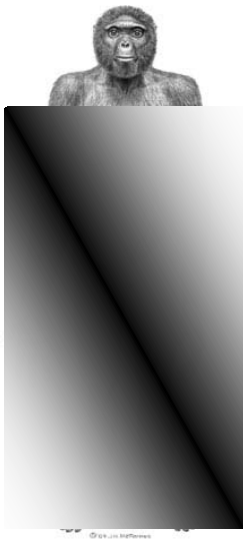
Those Fermi results might be just the beginning. Armed with their new knowledge of pulsar behavior, researchers are checking whether some of the unidentified gamma ray sources Fermi has detected might be pulsars. In November alone, teams of astronomers in the United States and France discovered five new millisecond pulsars by training ground-based radio telescopes on candidate objects Fermi had pointed out—a much more targeted search technique than scanning the sky blindly with ground-based radio telescopes.

Gamma ray beams of pulsars are believed to be wider than their radio beams, so in principle a space-based gamma ray telescope should be more likely to encounter and discern a pulsar's sweep than a radio telescope on Earth is. However, Fermi's forerunner—the Compton Gamma Ray Observatory, which flew from 1991 to 2000—did not have much luck finding these objects. What has made the difference is Fermi's high sensitivity, which enables it to detect pulsations that would have been too faint for Compton.

Already, the discoveries are shedding new light on the physics of pulsars. Researchers



from www.sciencemag.org on December 22, 2009



Breakthrough of the Year was the reconstruction of the 4.4-million-year-old ***Ardipithecus ramidus*** skeleton

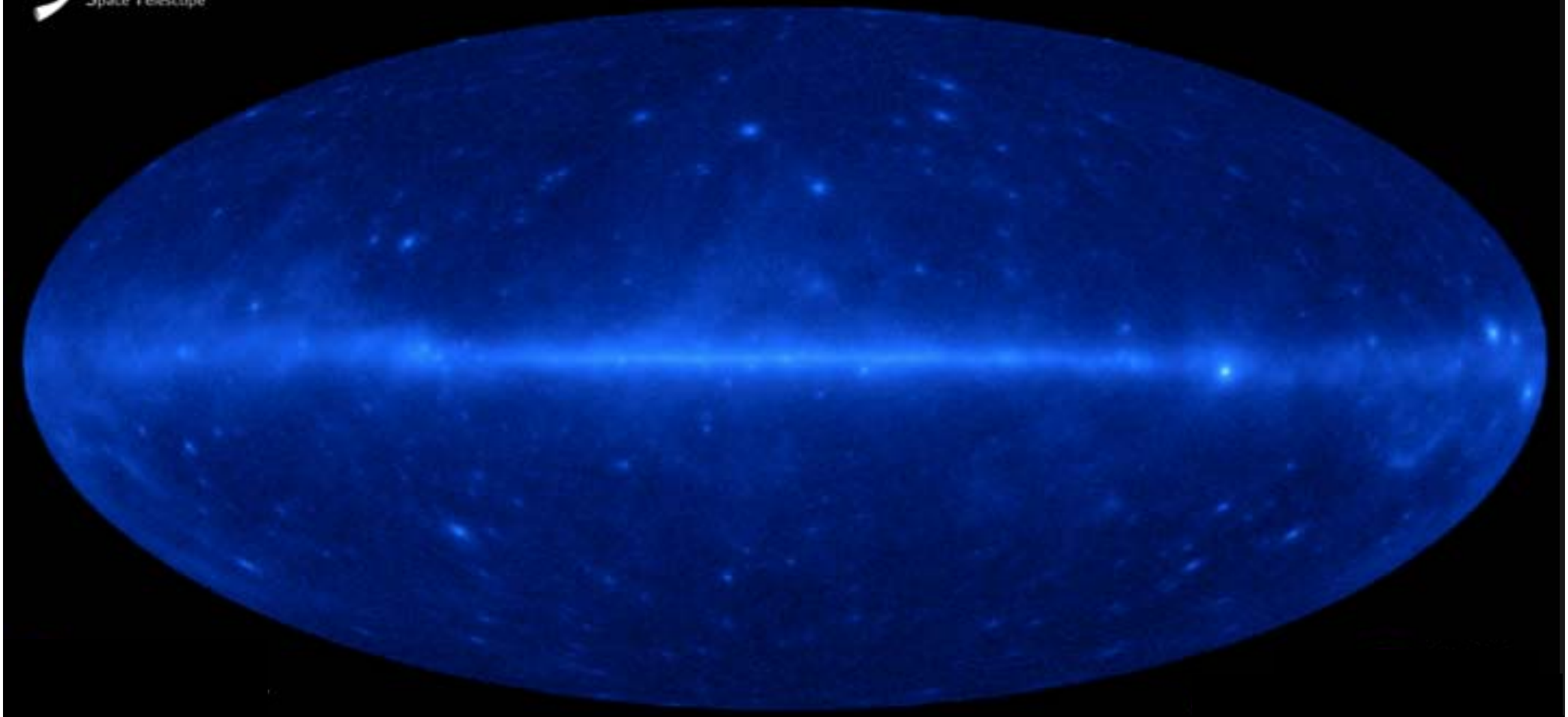
2011 Rossi Prize

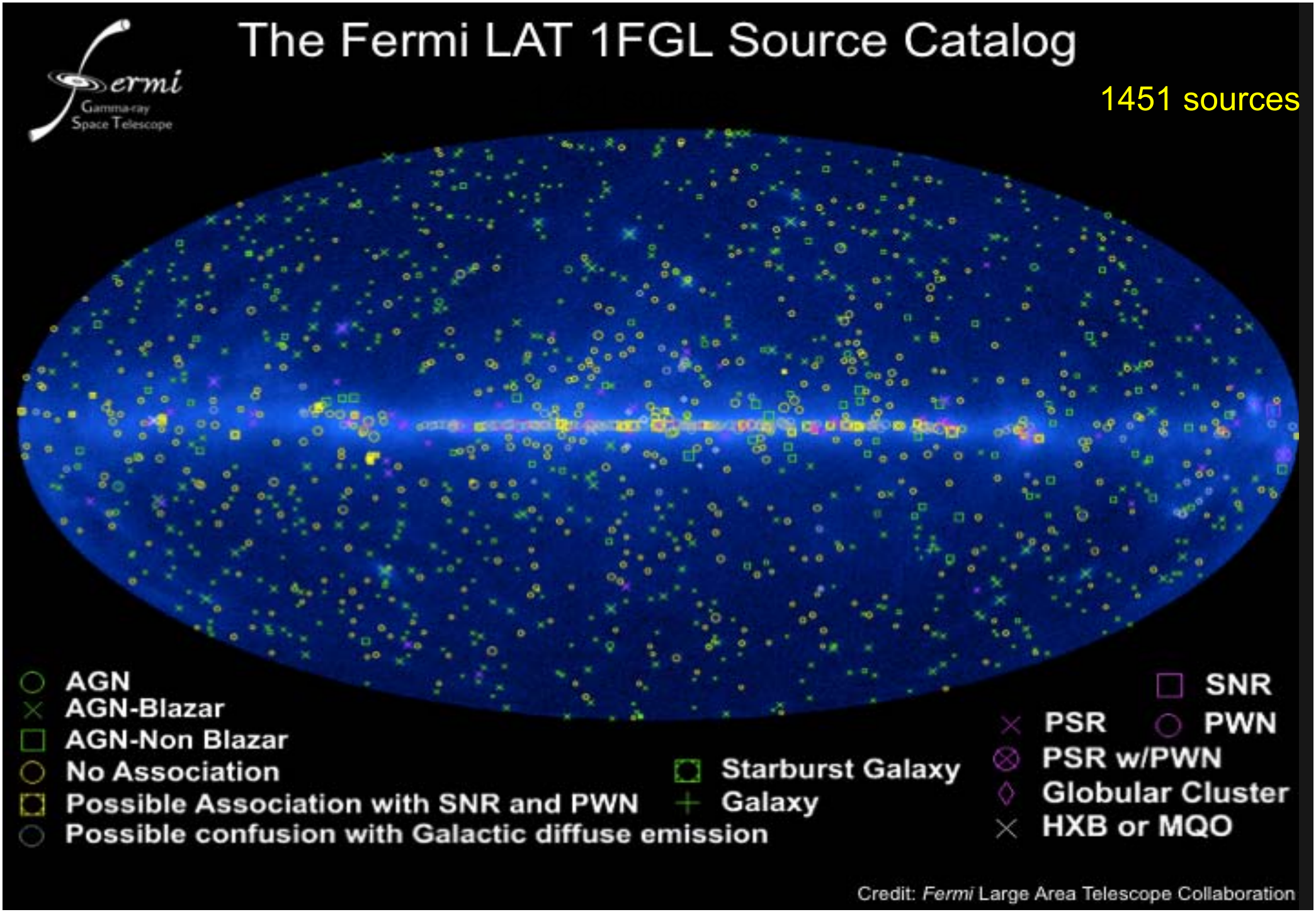
- The 2011 Rossi Prize is awarded to the Fermi Gamma Ray Space Telescope Large Area Telescope team for enabling, through the development of the Large Area Telescope, new insights into neutron stars, supernova remnants, cosmic rays, binary systems, active galactic nuclei, and gamma-ray bursts.

The Fermi LAT 1FGL Source Catalog

Fermi Gamma-ray Space Telescope

1451 sources




The Fermi LAT 1FGL Source Catalog
Fermi
Gamma-ray
Space Telescope
1451 sources
AGN
AGN-Blazar
AGN-Non Blazar
No Association
Possible Association with SNR and PWN
Possible confusion with Galactic diffuse emission
Starburst Galaxy
Galaxy
SNR
PSR
PWN
PSR w/PWN
Globular Cluster
HXB or MQO
Credit: Fermi Large Area Telescope Collaboration

- **Some highlights from the first ~3 years in orbit:**
  - **γ-ray only pulsars**
  - **population of γ-ray millisecond pulsars; implications for gravitational wave searches**
  - **high-energy GRBs; new window to look for violations of Lorentz invariance**
  - **Large population of active galaxies detected: emission by supermassive black holes**
  - **new source populations: novae, globular clusters, starburst galaxies**
  - **γ-ray flares from Crab nebula**
  - **limits on dark matter and interesting data from the galactic center**
  - **Precision measurement of electron-positron spectrum of cosmic rays**

- **Some highlights from the first ~3 years in orbit:**

~170 billion LAT event triggers

- GBM Triggers: 1194 (654 GRB, 141 TGF, 174 SGR, 56 solar flare)
- # Autonomous Repoint Requests (ARR):58
- Highest-z LAT GRB: 4.35
- Highest-energy photon from a GRB: 33 GeV (at 82s, z=1.82)
- Highest-z LAT AGN:3.1
- # Gamma-ray pulsars: 88
- # Millisecond Pulsars (MSPs): 27
- # Gamma-ray-only (blind) pulsars: 26
- # new radio MSPs due to LAT data: 31
- Public data access: >8TB

- **Towards the Second Fermi LAT Catalog 2FGL:**

2FGL almost ready to go, with following features

- Much improved diffuse representation, new limb component
- ~1888 sources, vs. 1451 (1134 for (revised))1FGL
- 12 extended sources
- Pulsars fit with exponential cutoff, others log parabola if appropriate
  - better characterization of sources, improved fits to nearby weaker sources
- Better source finding efficiency: both detecting faint sources and resolving nearby sources

• 277 1FGL sources are not represented

Some reasons:

New requirements for localization

Extended sources were represented by more than one point source

Improved galactic diffuse model

There, but not significant enough (flared during first 11 months)

Toby Burnett

- **Towards the Second Fermi LAT Catalog 2FGL:**

Type	Number	Percentage of total
Active Galactic Nuclei	832	44%
Candidate Active Galactic Nuclei	268	14%
Unassociated	594	32%
Pulsars (pulsed emission)	86	5%
Pulsars (no pulsations yet)	26	1%
Supernova Remnants/ Pulsar Wind Nebulae	60	3%
Globular Clusters	11	< 1%
Other Galaxies	7	< 1%
Binary systems	4	< 1%
TOTAL	1888	100%

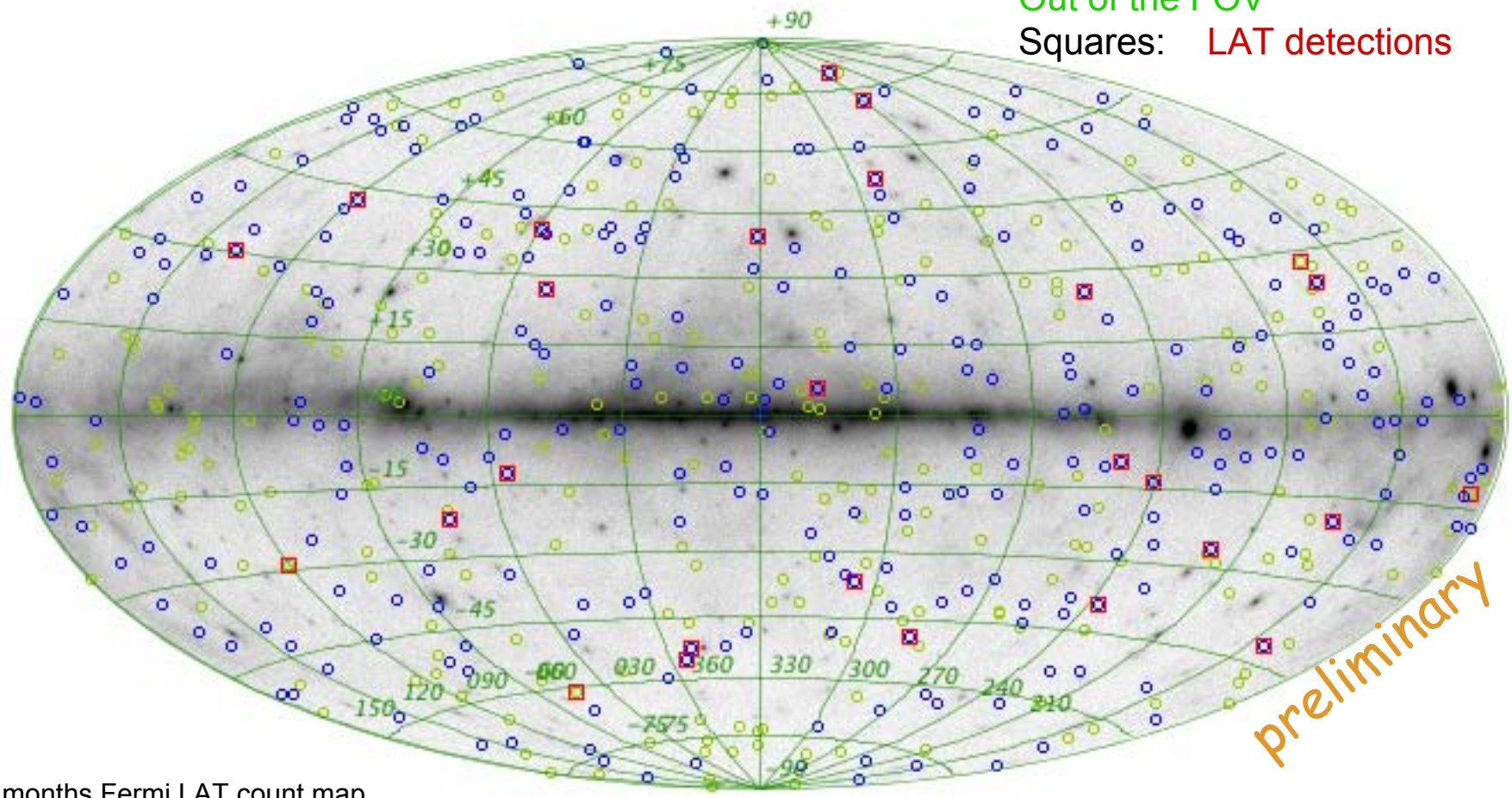
Dave Thompson

Very Preliminary - Work Still In Progress

GRB's Fermi detections as of 2011-01-20

~550 GBM GRB (since Aug 2008)
27 LAT GRB (7 LAT LLE-only GRB)

Circles: In Field-of-view of LAT (<70˚): 275
Out of the FOV
Squares: LAT detections



11 months Fermi LAT count map

Omodei

GRB's Fermi detections

Bottom line

- The broad band spectra seen by Fermi does not fit into any of the frameworks of existing models.
- Fermi results forces us to re-think of questions that were thought to be solved.

Pe'er

High Energy Activity from the Crab

AGILE detection of enhanced gamma-ray emission from the Crab Nebula region

ATel #2855; *M. Tavani (INAF/IASF Roma), E. Striani (Univ. Tor Vergata), A. Bulgarelli (INAF/IASF Bologna), F. Gianotti, M. Trifoglio (INAF/IASF Bologna), C. Pittori, F. Verrecchia (ASDC), A. Argan, A. Trois, G. De Paris, V. Vittorini, F. D'Ammando, S. Sabatini, G. Piano, E. Costa, I. Donnarumma, M. Feroci, L. Pacciani, E. Del Monte, F. Lazzarotto, P. Soffitta, Y. Evangelista, I. Lapshov (INAF-IASF-Rm), A. Chen, A. Giuliani(INAF-IASF-Milano), M. Marisaldi, G. Di Cocco, C. Labanti, F. Fuschino,M. Galli (INAF/IASF Bologna), P. Caraveo, S. Mereghetti, F. Perotti (INAF/IASF Milano), G. Pucella, M. Rapisarda (ENEA-Roma), S. Vercellone (IASF-Pa), A. Pellizzoni, M. Pilia (INAF/OA-Cagliari), G. Barbiellini, F. Longo (INFN Trieste), P. Picozza, A. Morselli (INFN and Univ. Tor Vergata), M. Prest (Universita` dell'Insubria), P. Lipari, D. Zanello (INFN Roma-1), P.W. Cattaneo, A. Rappoldi (INFN Pavia), P. Giommi, P. Santolamazza, F. Lucarelli, S. Colafrancesco (ASDC), L. Salotti (ASI)*

*on **22 Sep 2010; 14:45 UT***

Distributed as an Instant Email Notice (Transients)

Password Certification: Marco Tavani (tavani@iasf-roma.inaf.it)

Subjects: Pulsars

Referred to by ATel #: 2856, 2858, 2861, 2866, 2867, 2868, 2872

AGILE is detecting an increased gamma-ray flux from a source positionally consistent with the Crab Nebula.

Integrating during the period 2010-09-19 00:10 UT to 2010-09-21 00:10 UT the AGILE-GRID detected enhanced gamma-ray emission above 100 MeV from a source at Galactic coordinates (l,b) = (184.6, -6.0) +/- 0.4 (stat.) +/- 0.1 (syst.) deg, and flux F > 500 e-8 ph/cm2/sec above 100 MeV, corresponding to an excess with significance above 4.4 sigma with respect to the average flux from the Crab nebula (F = (220 +/- 15)e-8 ph/cm^2/sec, Pittori et al., 2009, A&A, 506, 1563).

We strongly encourage multifrequency observations of the Crab Nebula region.

No corresponding flare in X-rays with INTEGRAL (Atel # 2856), Swift (Atel # 2858, 2866), or RXTE (Atel # 2872) or NIR (Atel #2867). No evidence for active AGN near Crab (Swift, Atel # 2868).

Fermi LAT confirmation of enhanced gamma-ray emission from the Crab Nebula region

ATel #2861; *R. Buehler (SLAC/KIPAC), F. D'Ammando (INAF-IASF Palermo), E. Hays (NASA/GSFC) on behalf of the Fermi Large Area Telescope Collaboration*

*on **23 Sep 2010; 17:34 UT***

Distributed as an Instant Email Notice (Transients)

Password Certification: Rolf Buehler (buehler@slac.stanford.edu)

Subjects: >GeV, Pulsars

Referred to by ATel #: 2866, 2867, 2868, 2872

Following the detection by AGILE of increasing gamma-ray activity from a source positionally consistent with the Crab Nebula occurred from September 19 to 21 (ATel #2855), we report on the analysis of the >100 MeV emission from this region with the Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope.

Preliminary LAT analysis indicates that the gamma-ray emission (E >100 MeV) observed during this time period at the location of the Crab Nebula is (606 +/- 43) x10^-8 ph/cm2/sec, corresponding to an excess with significance >9 sigma with respect to the average flux from the Crab nebula of (286 +/- 2) x10^-8 ph/cm2/sec, estimated over all the Fermi operation period (only statistical errors are given). Ongoing Fermi observations indicate that the flare is continuing.

The flaring component has a spectral index of 2.49 +/- 0.14. Its position, Ra: 83.59 Dec: 22.05 with a 68% error radius of 0.06 deg, is coincident with the Crab Nebula.

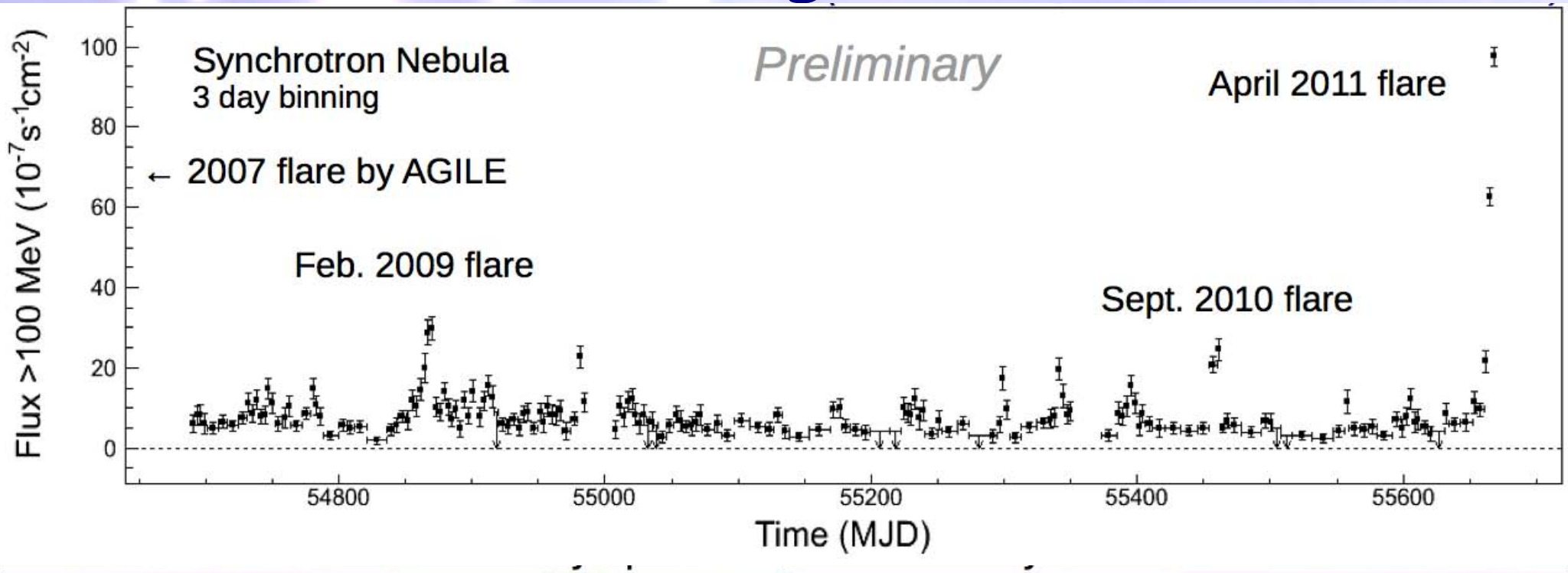
Fermi will interrupt its all-sky scanning mode between 2010-09-23 15:49:00 UT and 2010-09-30 15:49:00 UT to observe the Crab Nebula. Afterwards regular gamma-ray monitoring of this source will continue. We strongly encourage further multifrequency observations of that region.

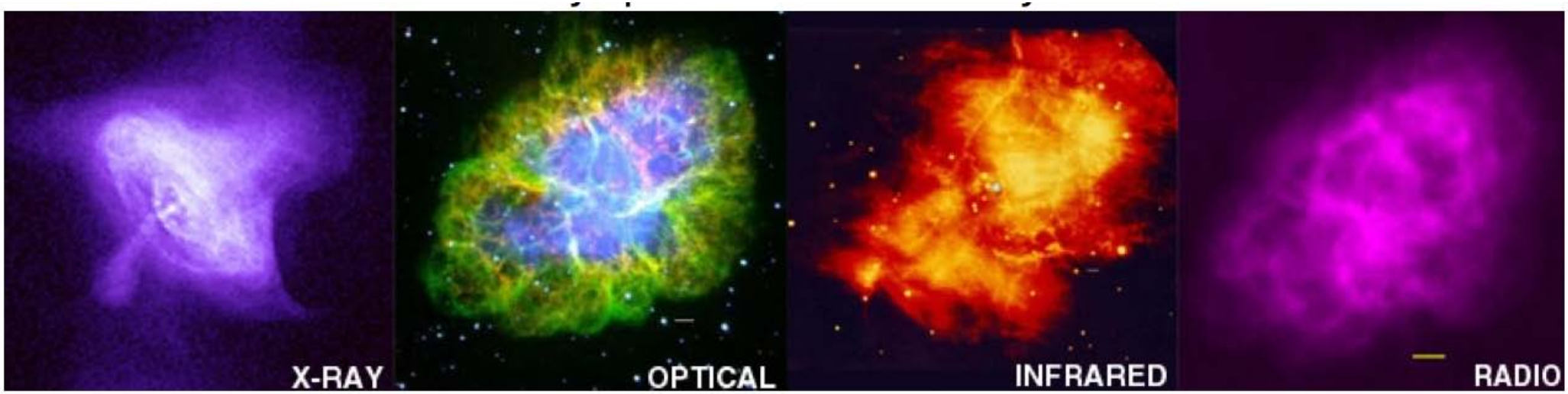
For this source the Fermi LAT contact person is Rolf Buehler (buehler@stanford.edu).

The Fermi LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

Flaring CRAB

Buehler

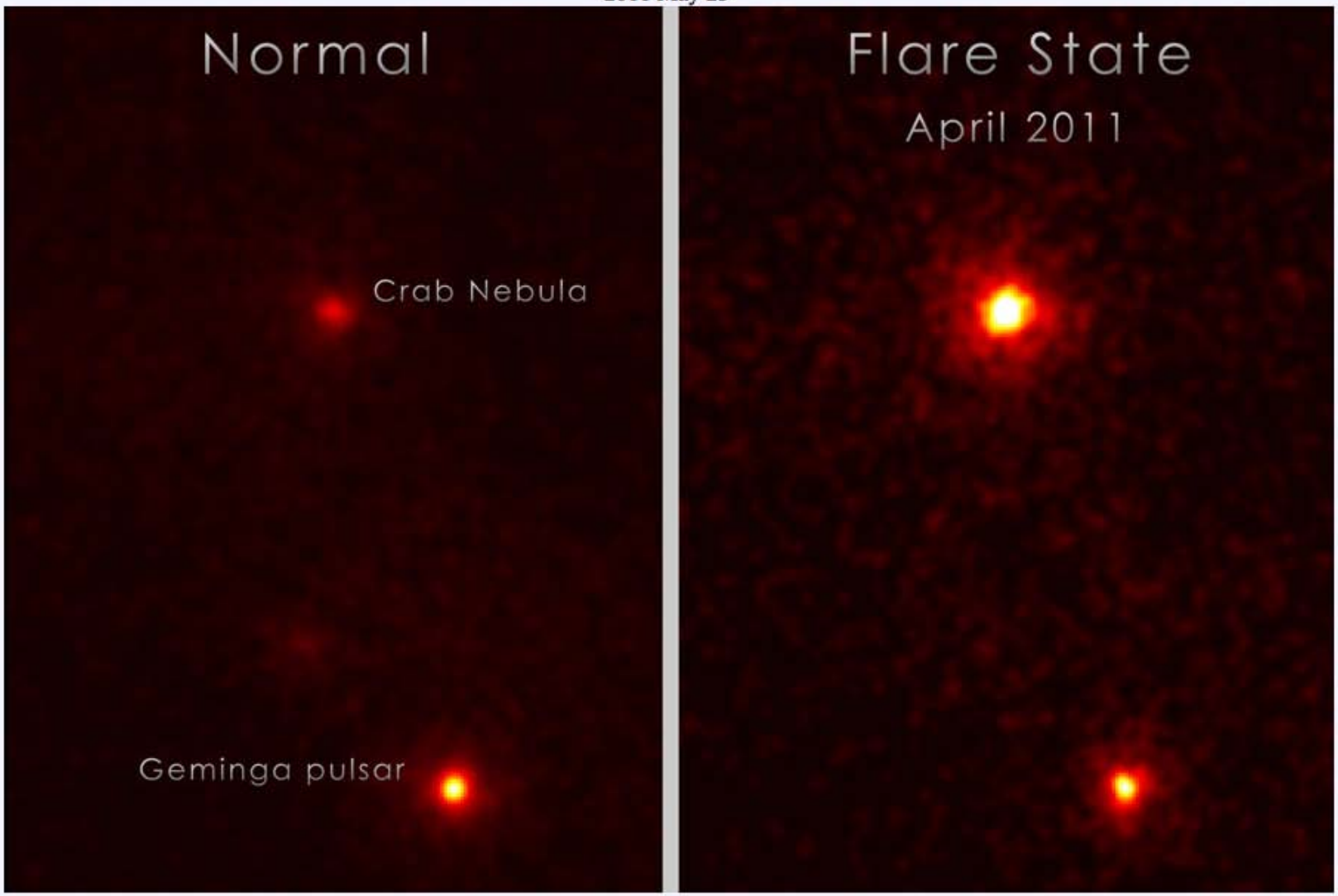




Astronomy Picture of the Day

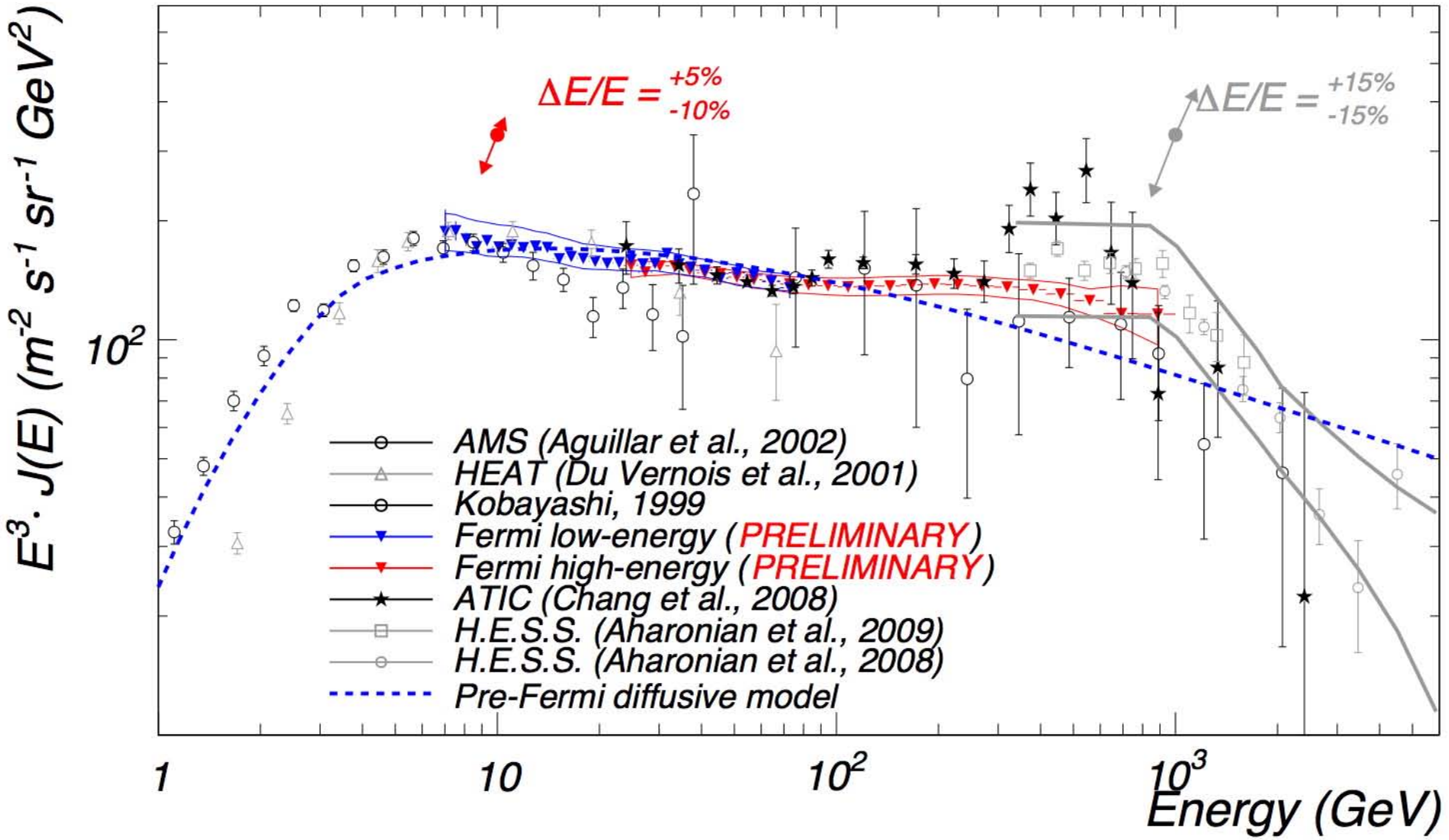
Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

2011 May 23



An Unexpected Flare from the Crab Nebula
Credit: NASA, DOE, Fermi LAT, R. Buehler (SLAC, KIPAC)

Fermi Electron + Positron spectrum

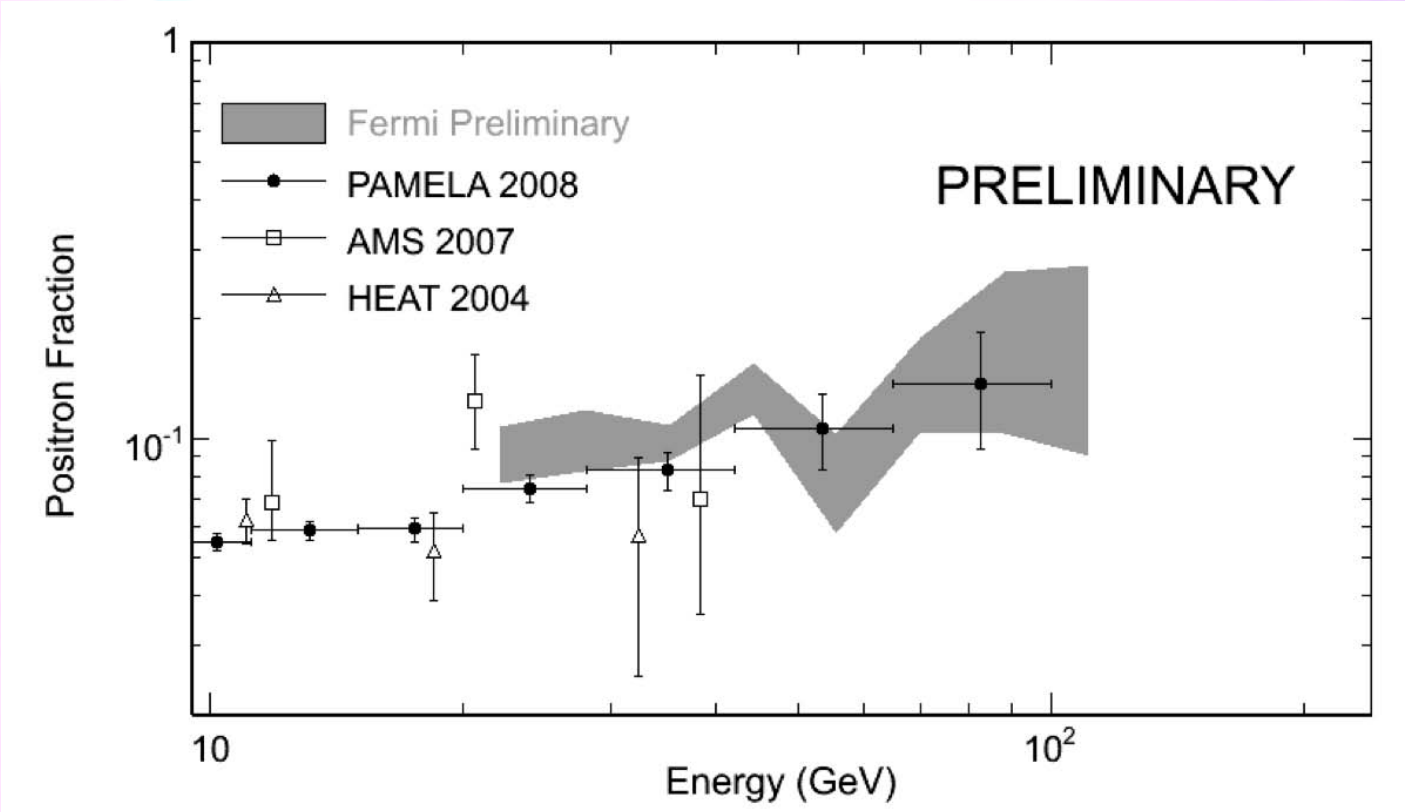


Extended Energy Range (7 GeV – 1 TeV) One year statistics (8M evts)

Positron Fraction

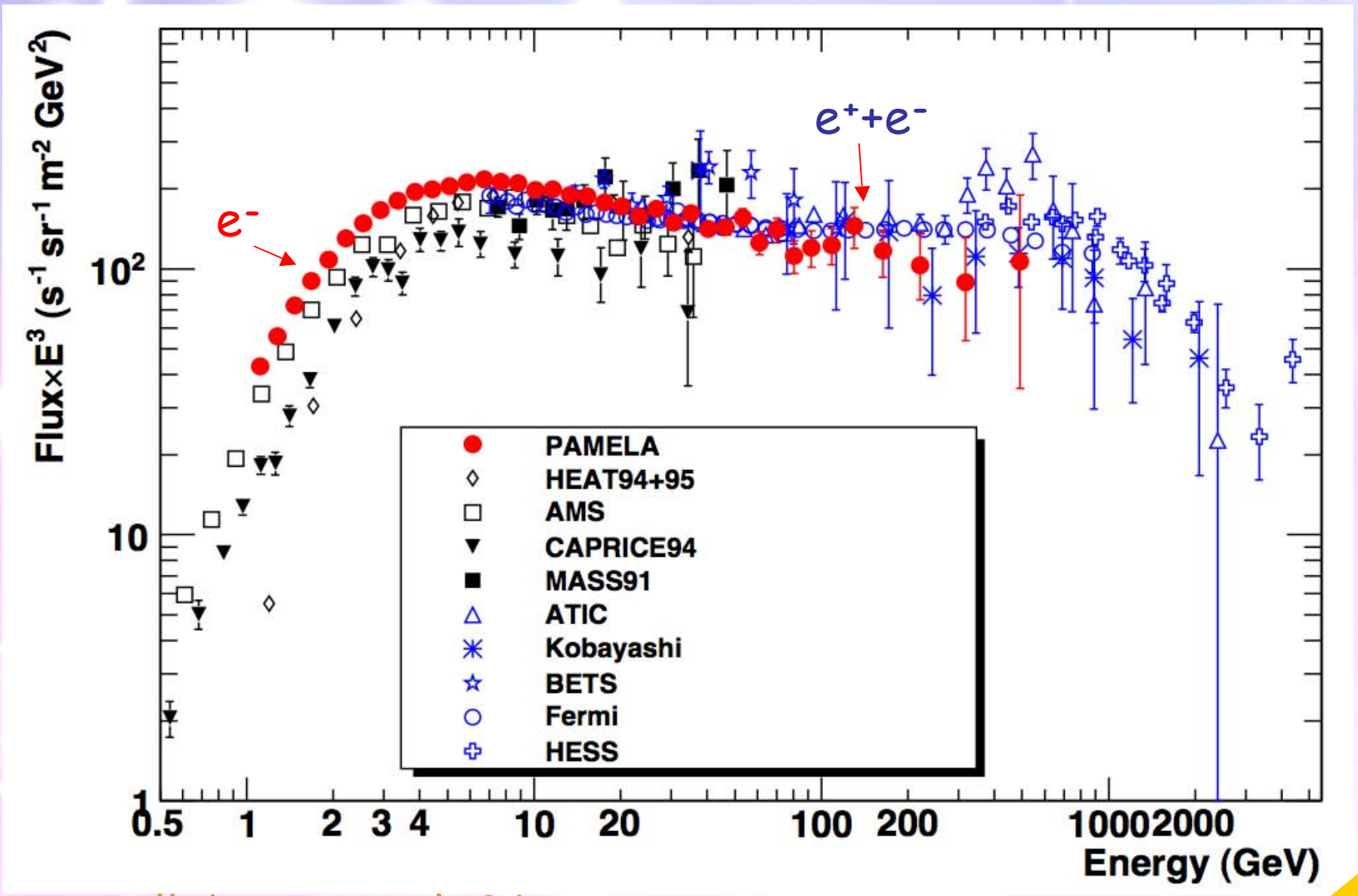
The Fermi-LAT has measured the cosmic-ray positron and electron spectra separately, between 20 and 130 GeV, using the Earth's magnetic field as a charge discriminator

- **The two independent methods of background subtraction, Fit-Based and MC-Based, produce consistent results**
- **The observed positron fraction is consistent with the one measured by PAMELA**



Mittshumsiri

e^- from PAMELA



see talk by Sparvoli 26 morning

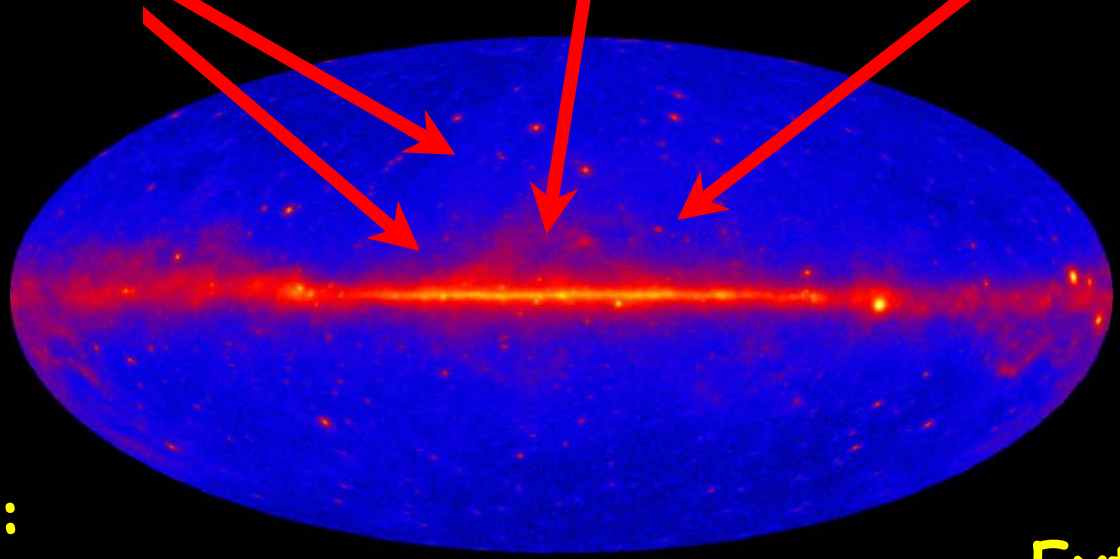
Vannuccini

Search Strategies

Satellites:
Low background and good source id, but low statistics

Galactic center:
Good statistics but source confusion/diffuse background

Milky Way halo:
Large statistics but diffuse background



And electrons!

and Anisotropies

Spectral lines:
No astrophysical uncertainties, good source id, but low statistics

Galaxy clusters:
Low background but low statistics

Extra-galactic:
Large statistics, but astrophysics,galactic diffuse background

Pre-launch sensitivities published in Baltz et al., 2008, JCAP 0807:013 [astro-ph/0806.2911]

They Play Together!

Direct Detection

Relic scattering RIGHT HERE at low energy. Push to larger target mass, lower backgrounds, directional sensitivity?

Accelerators

Direct production. Push to higher energy

Observations

Push toward finding and studying galactic halo objects and large scale structure.

Indirect Detection

Relic interactions (annihilations, decays) Understand the astrophysical backgrounds in signal-rich regions. Reveal the detailed astrophysical distribution of dark matter.

Simulations

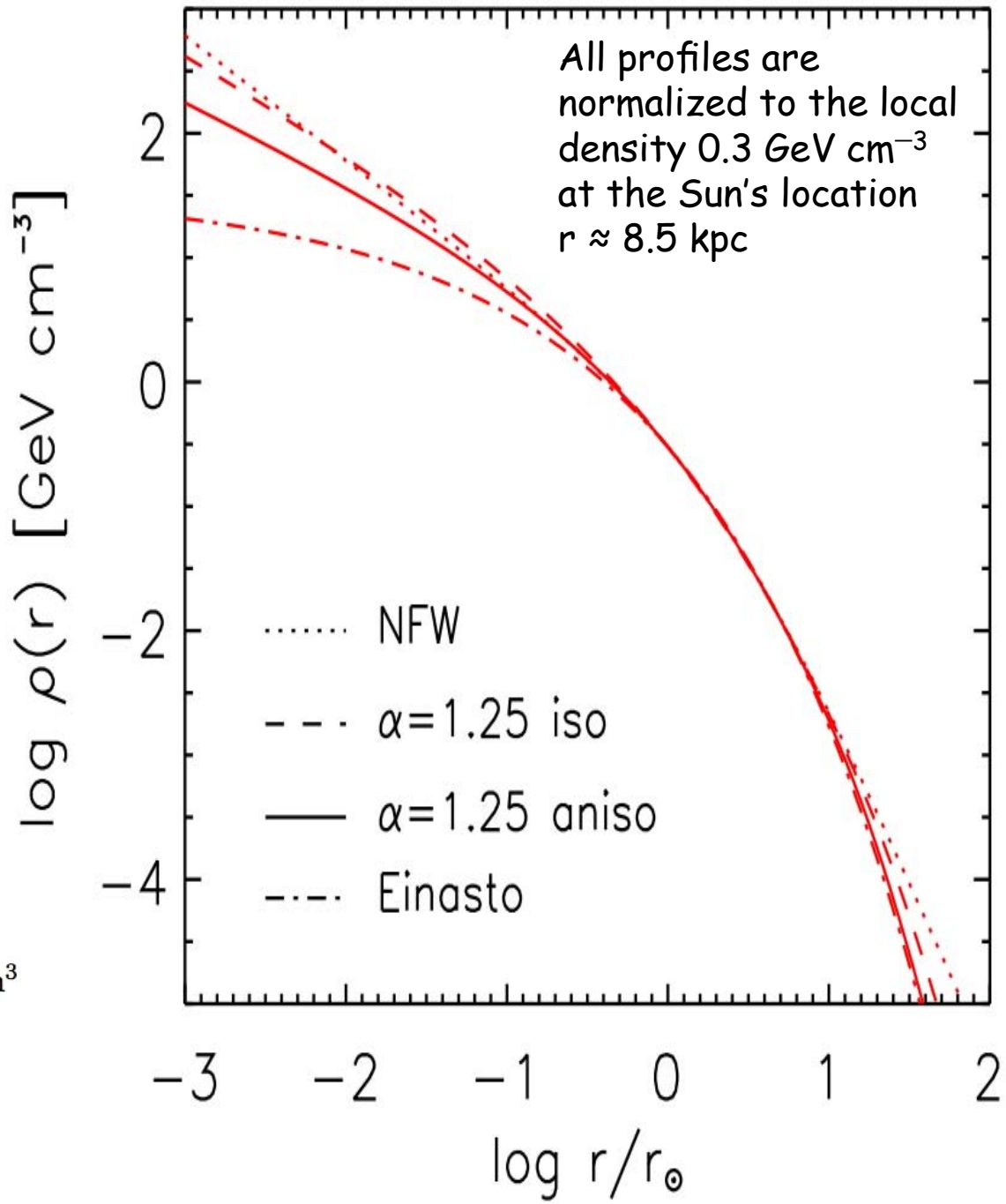
Large scale structure formation. Push toward larger simulations, finer details.

Milky Way Dark Matter Profiles

$$\rho(r) = \rho_\odot \left[\frac{r_\odot}{r}\right]^\gamma \left[\frac{1 + (r_\odot/r_s)^\alpha}{1 + (r/r_s)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$

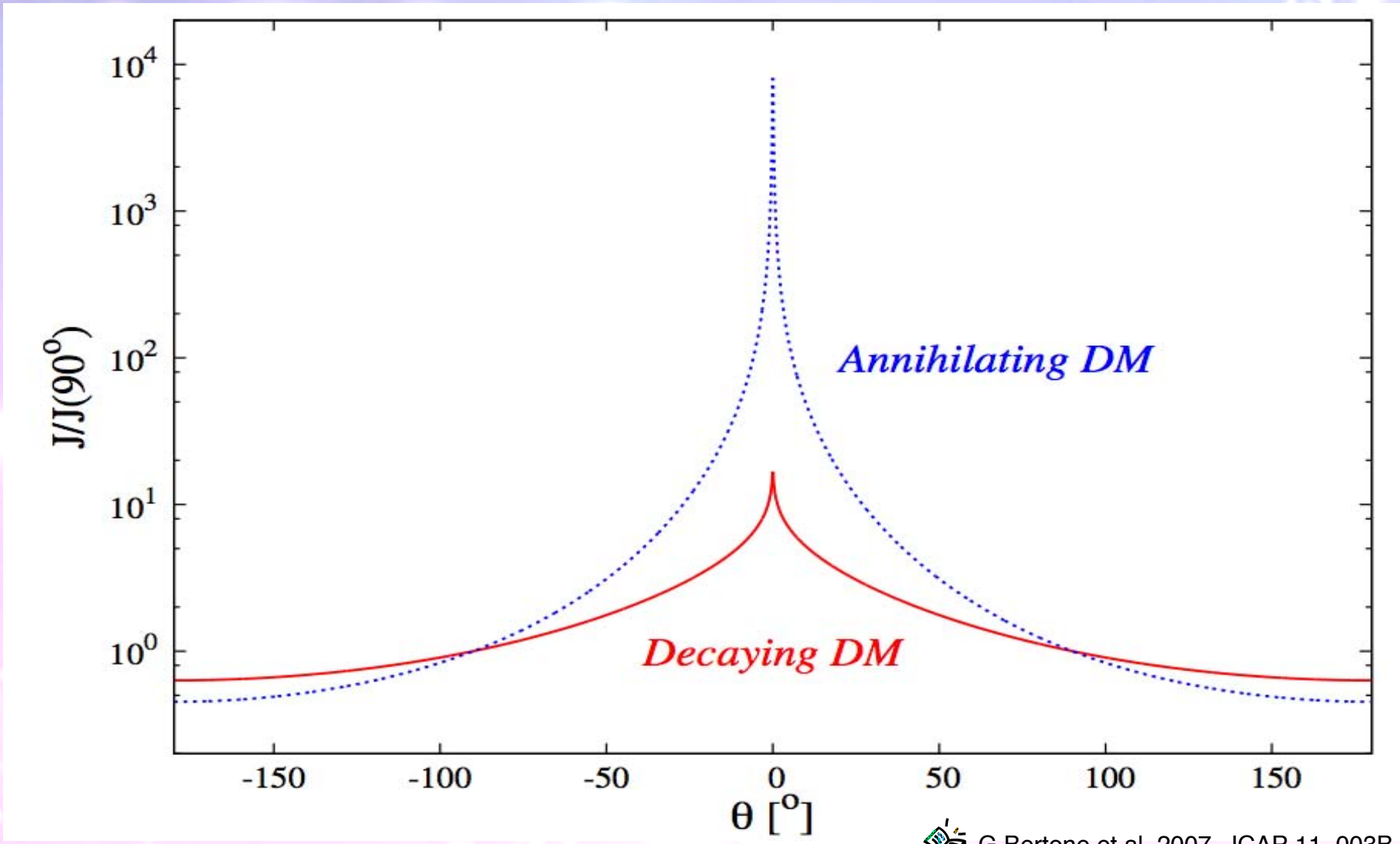
Halo model	α	β	γ	r_s in kpc
Cored isothermal	2	2	0	5
Navarro, Frenk, White	1	3	1	20
Moore	1	3	1.16	30

Einasto | $\alpha = 0.17$ $r_s = 20\,\mathrm{kpc}$ $\rho_s = 0.06\,\mathrm{GeV/cm^3}$



A.Lapi et al. arXiv:0912.1766

Different spatial behaviour for decaying or annihilating dark matter



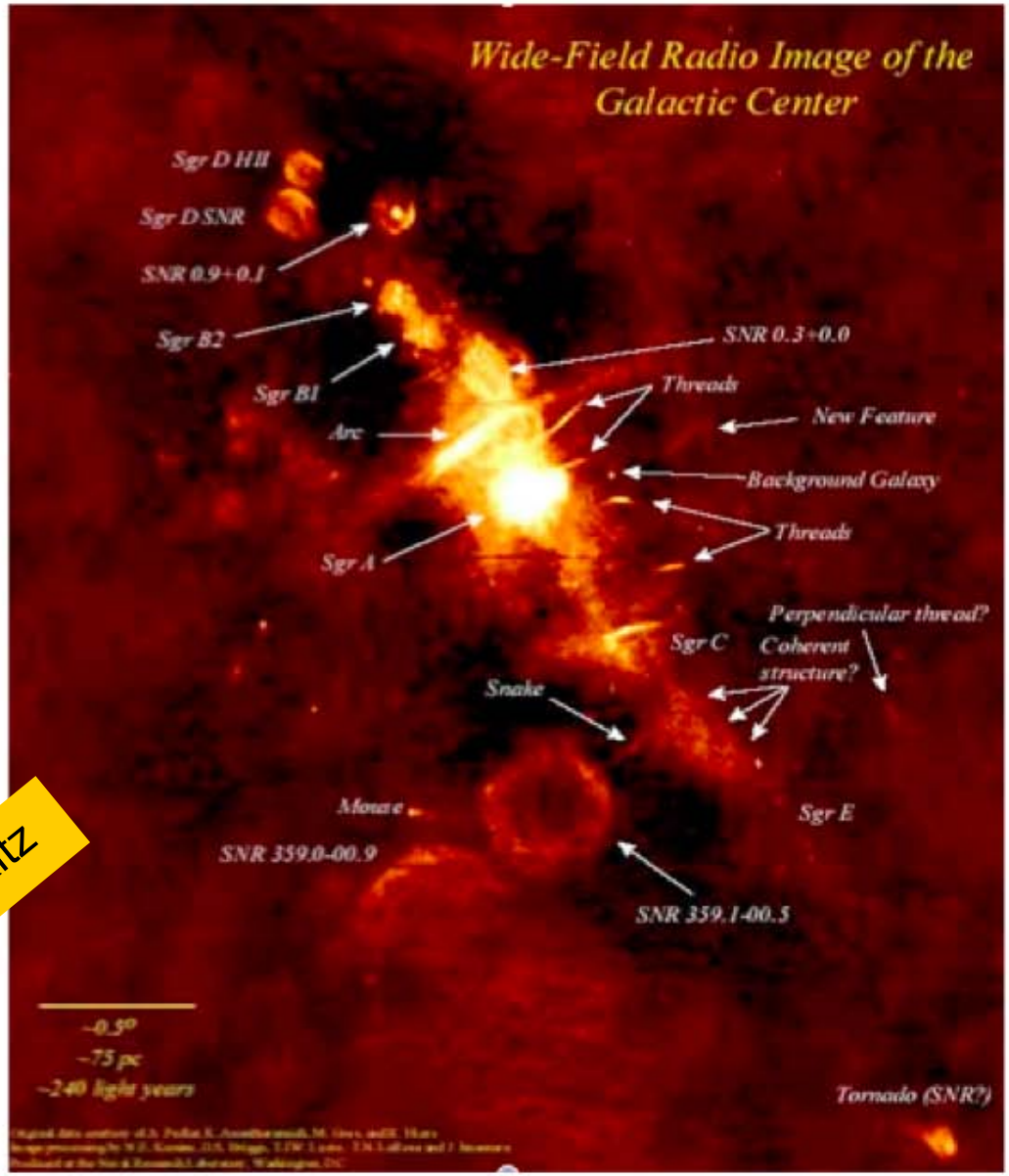
G.Bertone et al. 2007, JCAP 11, 003B

The angular profile of the gamma-ray signal is shown, as function of the angle θ to the centre of the galaxy for a Navarro-Frenk-White (NFW) halo distribution for decaying DM, solid (red) line, compared to the case of self-annihilating DM, dashed (blue) line

Inner Galaxy

- "*Lasciate ogne speranza, voi ch'intrate*" – Dante Alighieri

- *"If you're going through hell, KEEP GOING!" - Winston Churchill* (emphasis added)

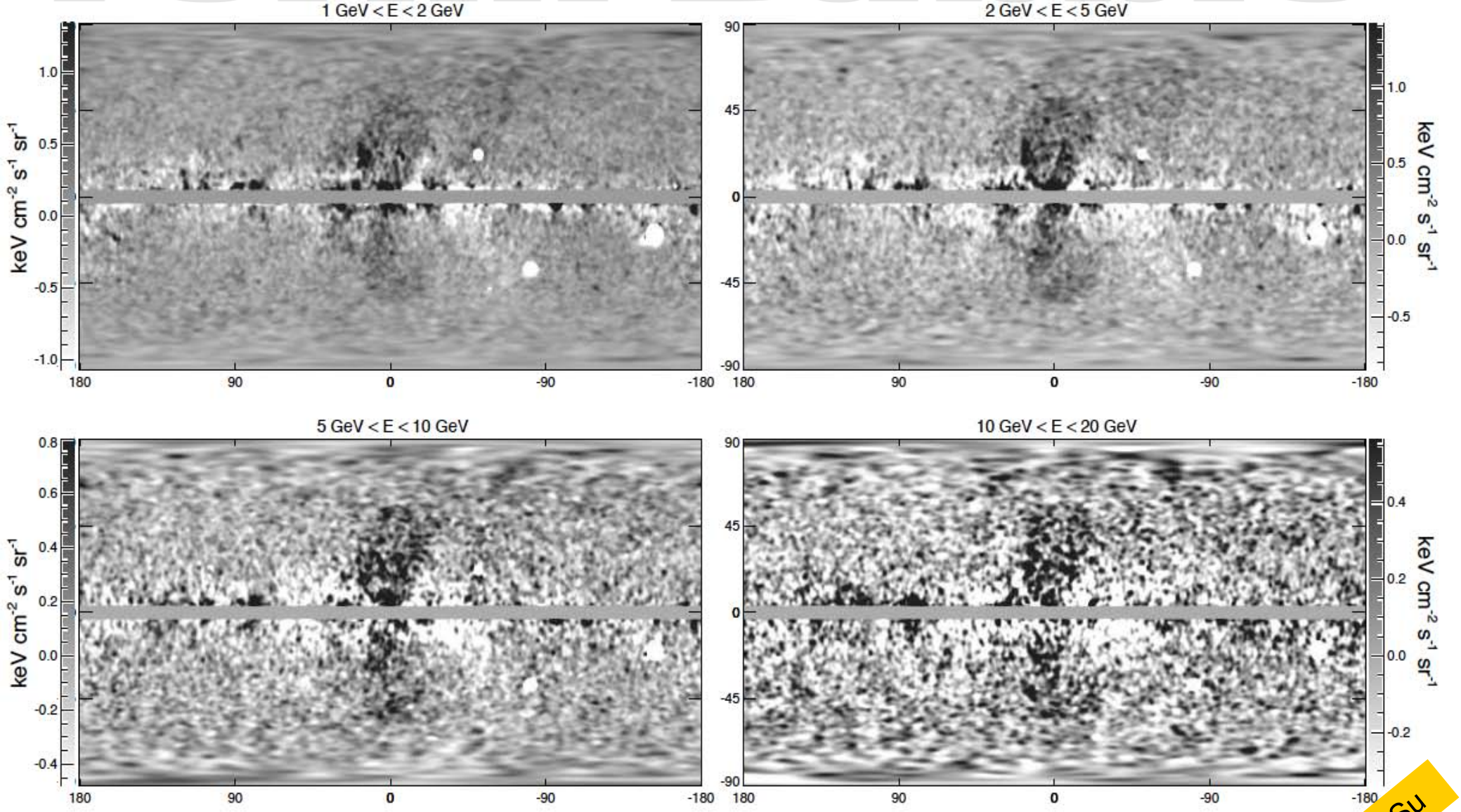


Steve Ritz

see talk by Beatriz Canadas afternoon 26

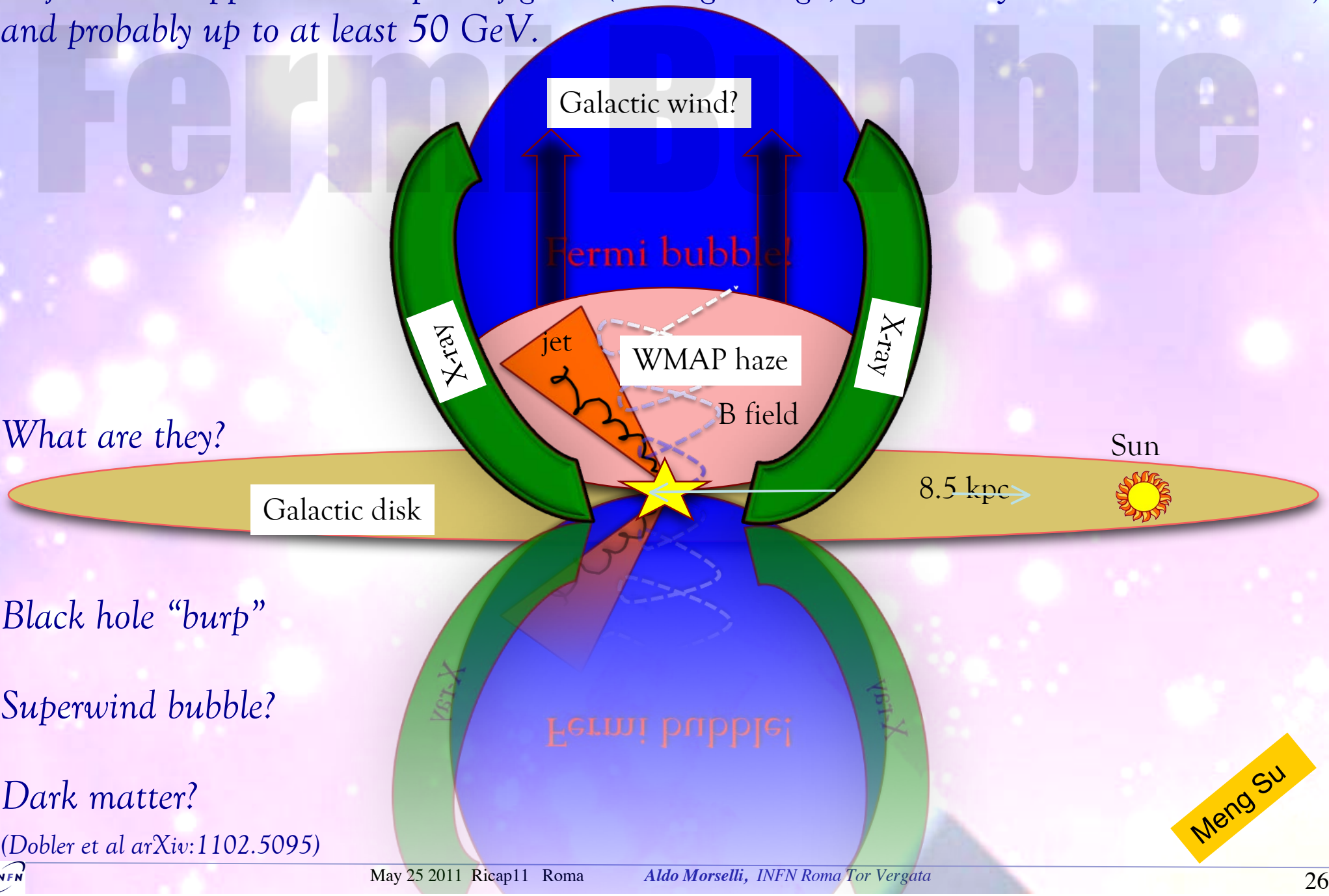
Fermi Bubble

Data minus Fermi diffuse emission model:



Meng Su

So far: there appear to be a pair of giant (50 degree high) gamma-ray bubbles at 1-5 GeV, and probably up to at least 50 GeV.



What are they?

Black hole "burp"

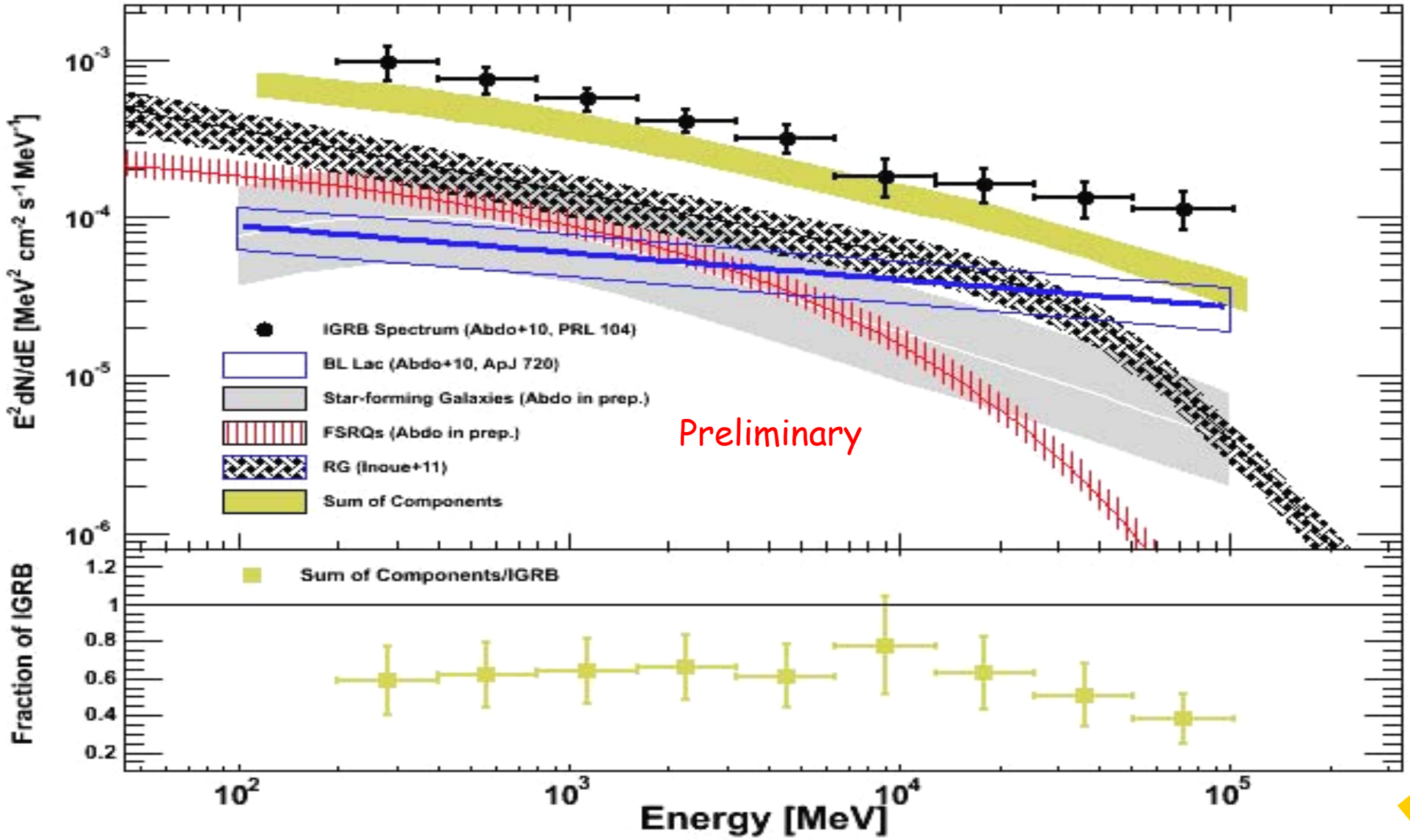
Superwind bubble?

Dark matter?

(Dobler et al arXiv:1102.5095)

Meng Su

Update on the Isotropic Gamma-ray Background (IGRB)

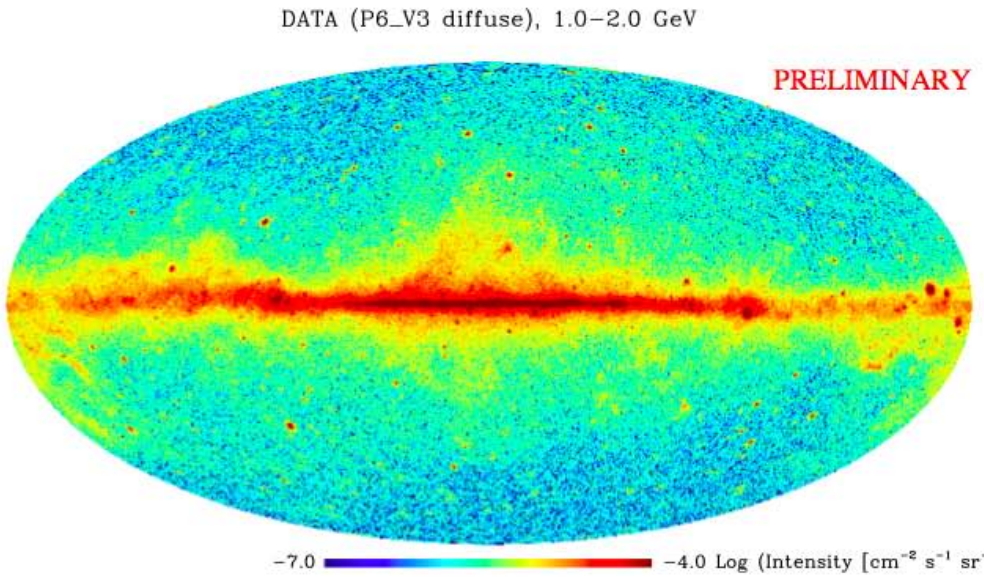


Ajello

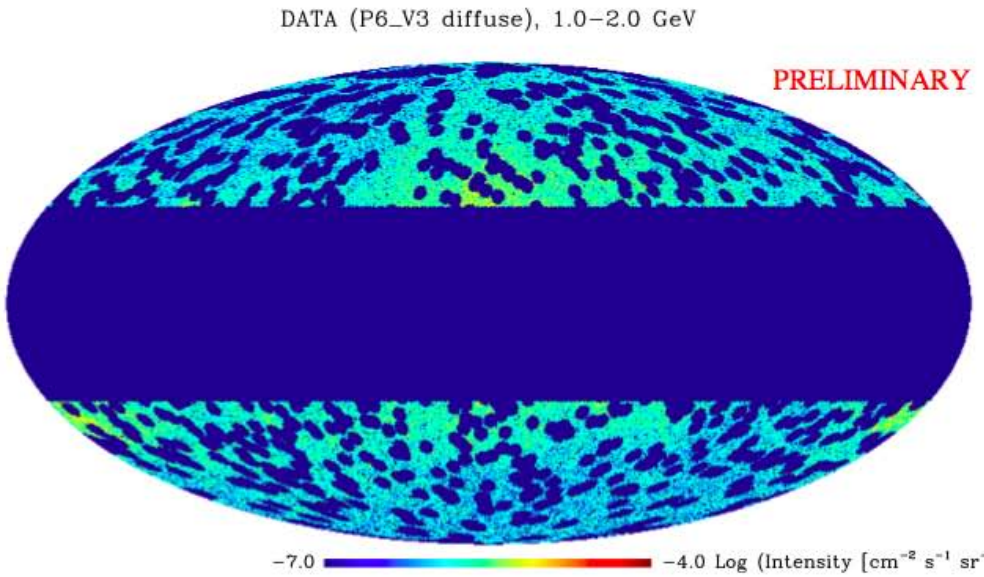
Anisotropies

1-2 GeV

All-sky map



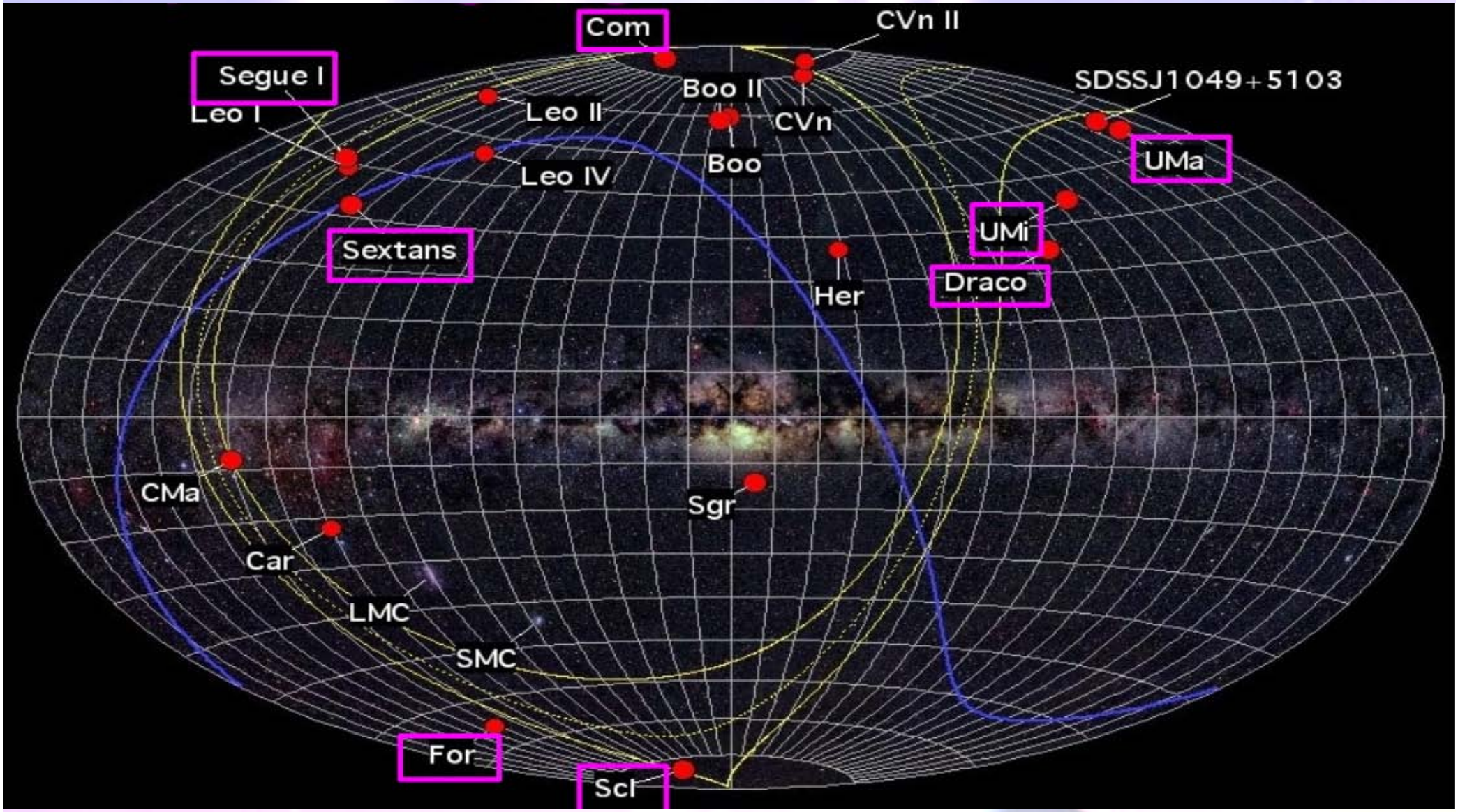
Map with default mask applied



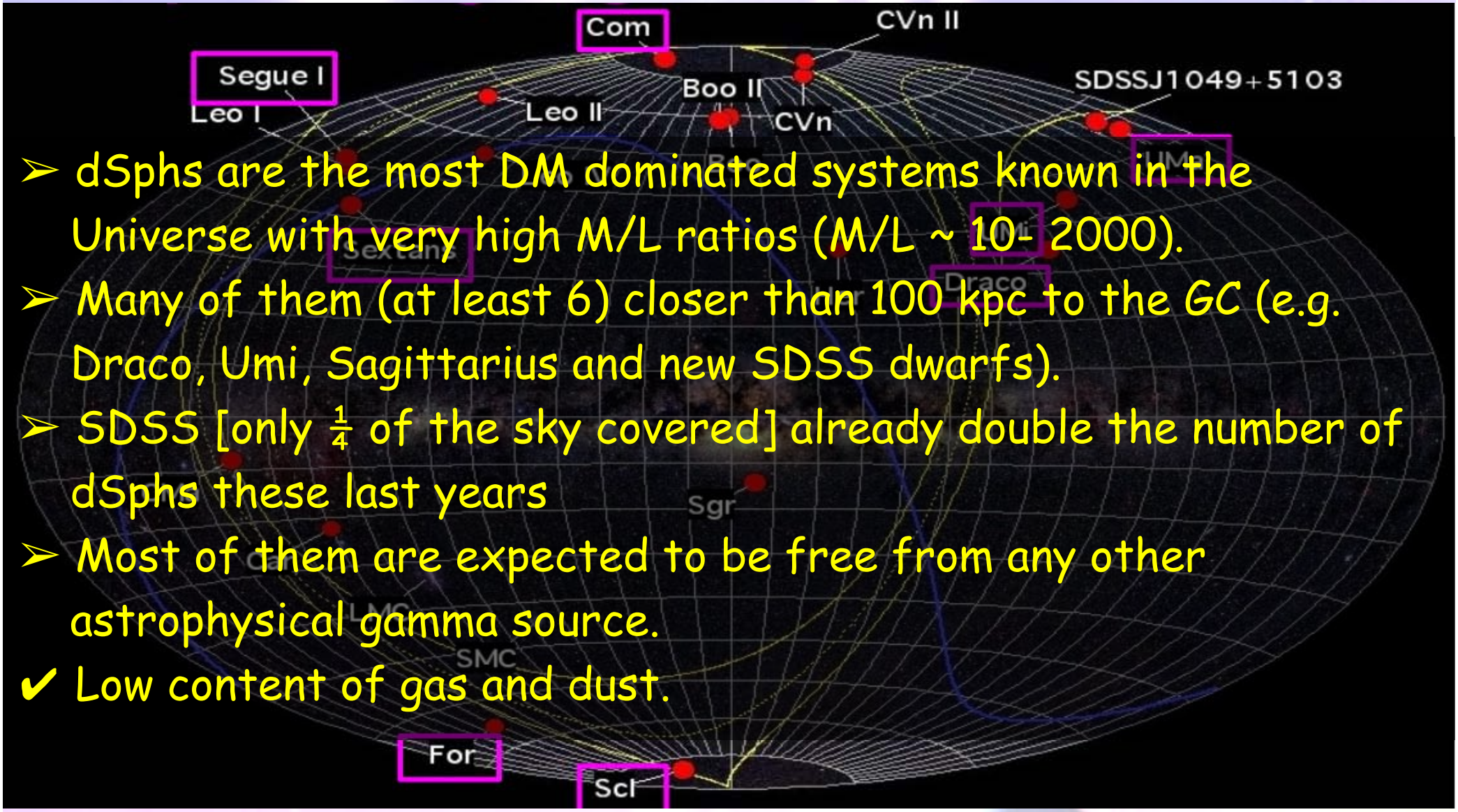
J. Siegal-Gaskins

see talk by Vincenzo Vitale and Mattia Fornasa this afternoon

Dwarf spheroidal galaxies (dSph) : promising targets for DM detection



Dwarf spheroidal galaxies (dSph) : promising targets for DM detection



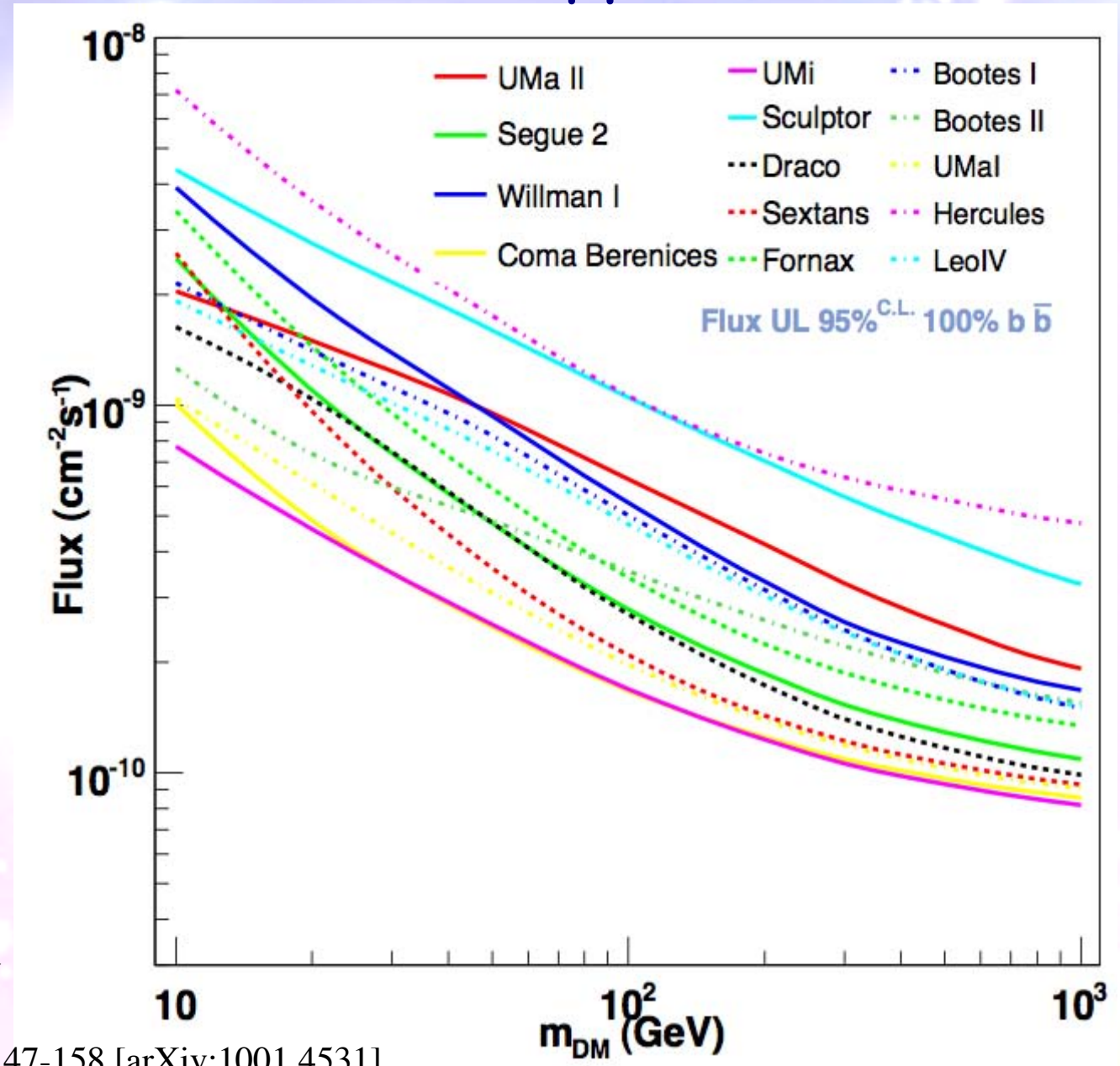
- dSphs are the most DM dominated systems known in the Universe with very high M/L ratios (M/L ~ 10- 2000).
- Many of them (at least 6) closer than 100 kpc to the GC (e.g. Draco, Umi, Sagittarius and new SDSS dwarfs).
- SDSS [only $\frac{1}{4}$ of the sky covered] already double the number of dSphs these last years
- Most of them are expected to be free from any other astrophysical gamma source.

✔ Low content of gas and dust.

Dwarf Spheroidal Galaxies upper-limits

No detection by Fermi with 11 months of data. 95% flux upper limits are placed for several possible annihilation final states.

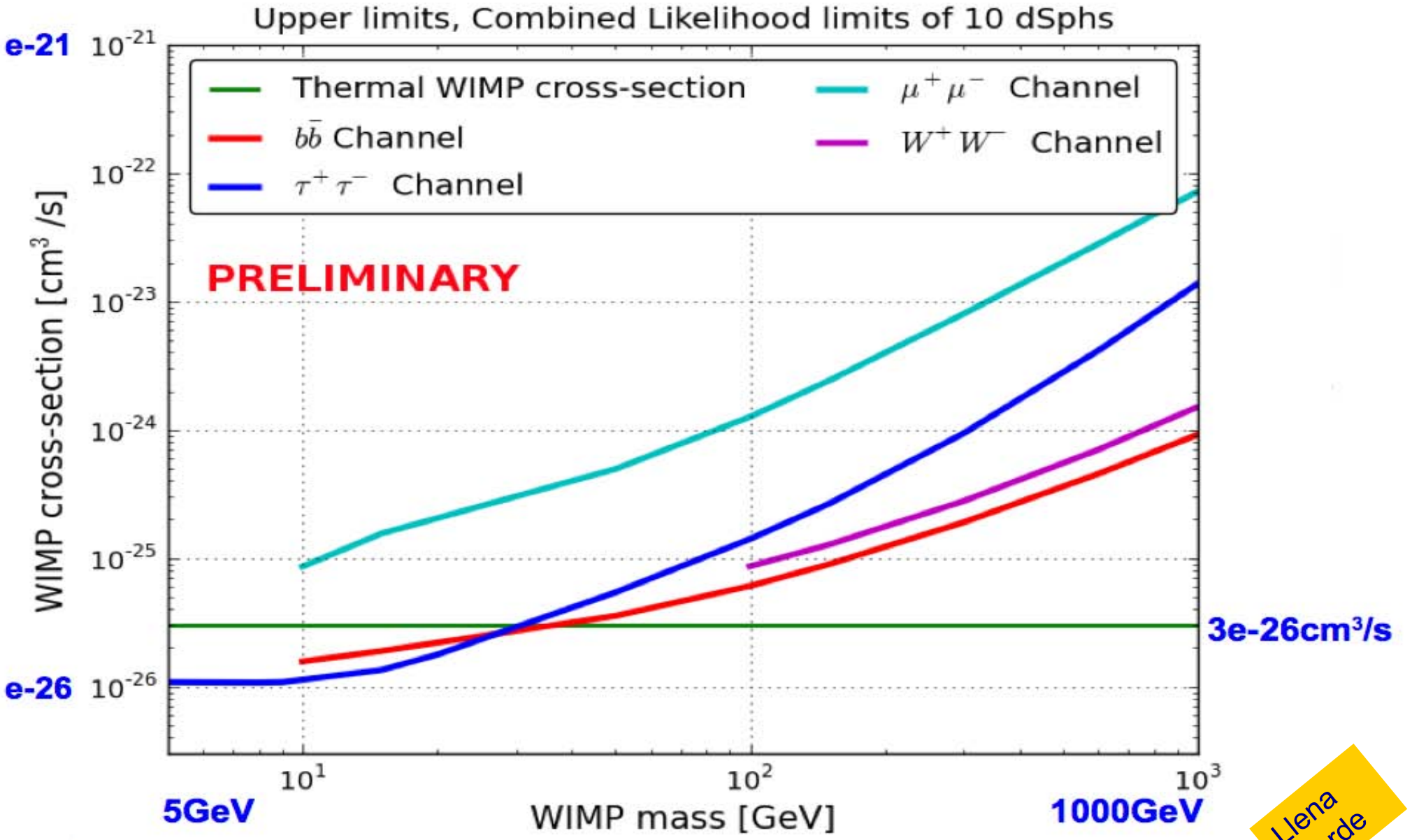
- Flux upper limits are combined with the DM density inferred by the stellar data(*) for a subset of 8 dSph (based on quality of stellar data) to extract constraints on $\langle \sigma v \rangle$ vs WIMP mass for specific DM models



(*) stellar data from the Keck observatory (by Martinez, Bullock, Kaplinghat)

Fermi Coll. ApJ 712 (2010) 147-158 [arXiv:1001.4531]

Dwarf Spheroidal Galaxies upper-limits Update



Llena Garde

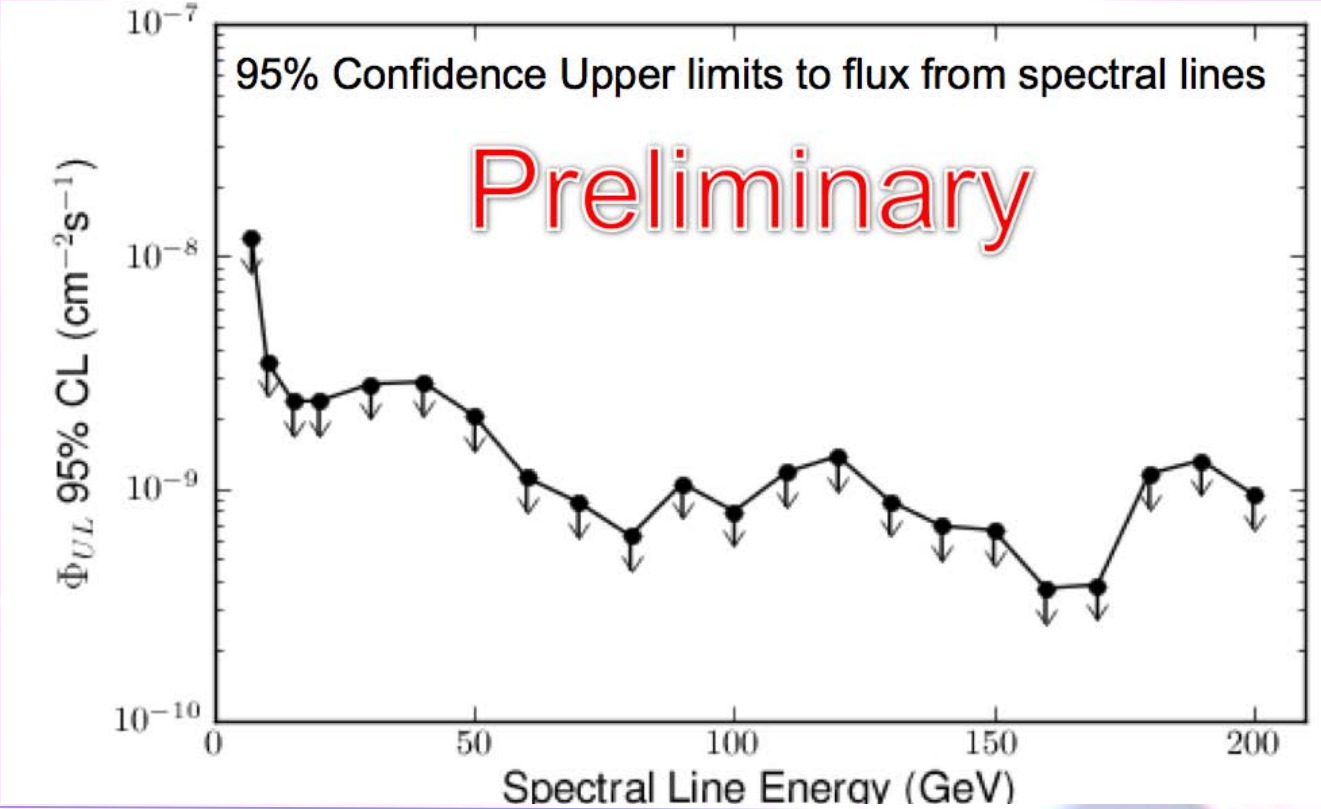
robust constraints including J-factor uncertainties

Fermi LAT 23 Month Line search results
Flux Upper Limits, 7 GeV – 200 GeV

- ± 20 % overall scale systematic error (+20 % systematic for UL).

Additional systematic on spectral structures with LAT resolution for E < 13.2 GeV of s/bg ~ 1%.

- **7 and 10 GeV bins use a modified event selection to reduce the systematic uncertainty associated with public IRFs**.
- For E > 12 GeV no indication of a spectral structure systematic effect is seen.

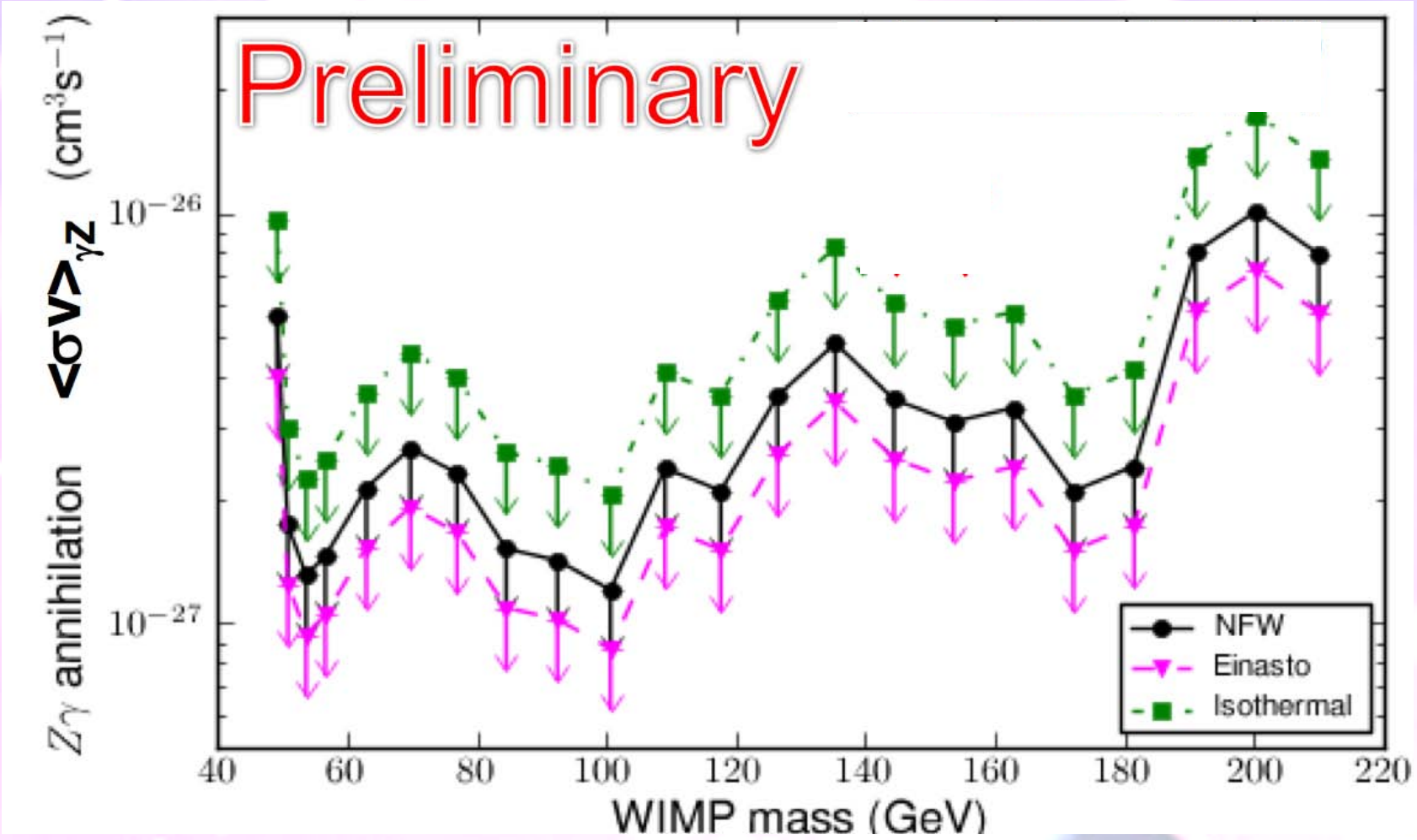


Bloom

Fermi LAT 23 Month γZ-Cross-section limits
7 GeV – 200 GeV

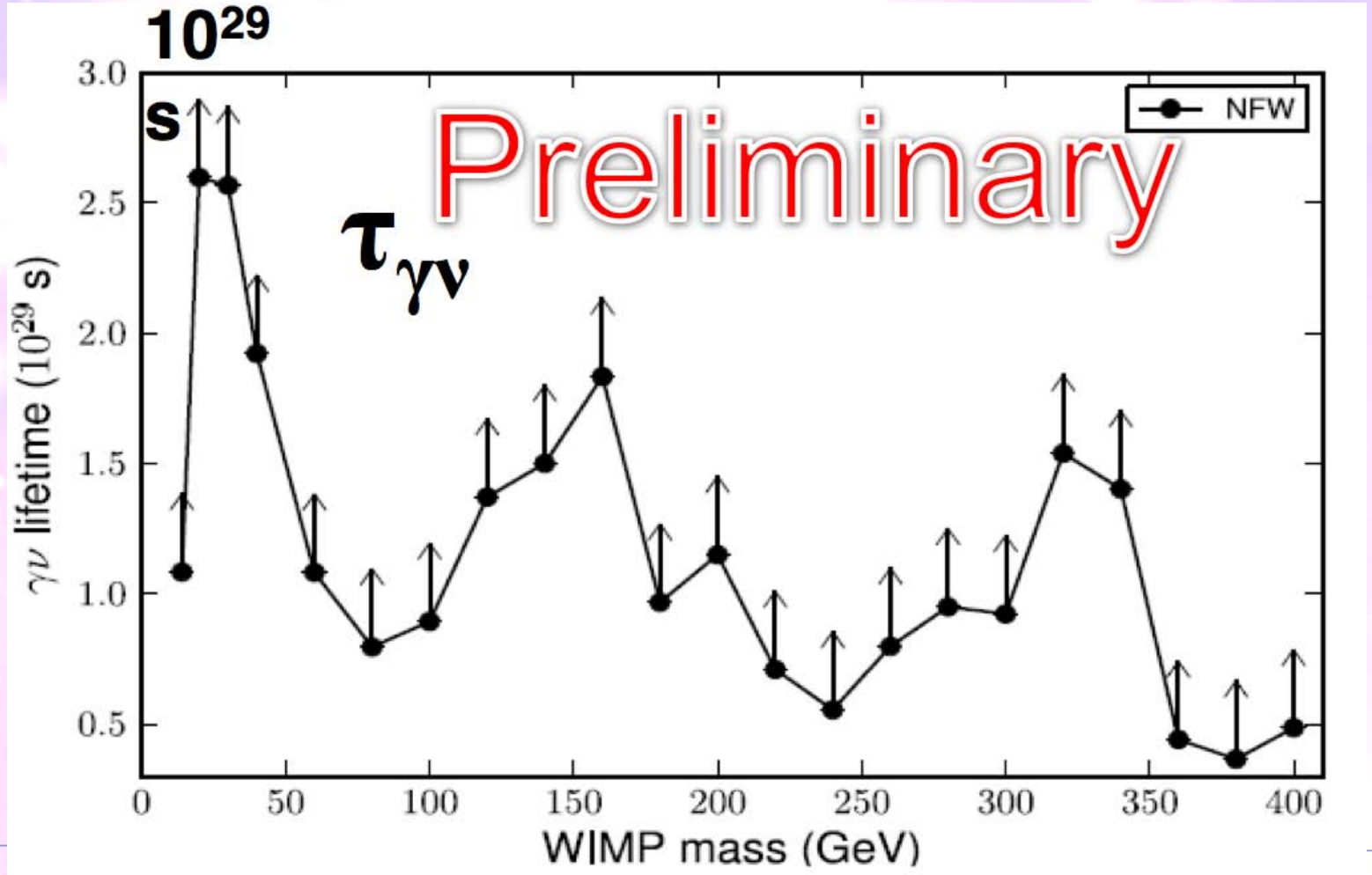
- ± 20 % overall scale systematic error (+20 % systematic for UL).

Additional systematic on spectral structures with LAT resolution for E<13.2 GeV of s/bg ~ 1%.



Decay lifetime lower limits

- Limits similar for all 3 DM density profiles due to linear dependence of flux on ρ
- Disfavors lifetimes smaller than 10^{29} s



Bloom

Looking Ahead

http://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_caveats.html

Many further improvements in instrument performance in progress

- Event reconstruction and choices of event selection "knobs" all determine instrument performance. For stability, standard event class definitions established with IRFs.
- Data were released with Pass6.
- Some known issues, described in Caveats on FSSC site and inLAT papers, addressed with patch to IRFs.
- Longer-term: Pass7 and Pass8 to address the remaining issues.
- Pass7 release imminent

Improved standard photon classes

Event analysis taking into account "ghost" events

- Working closely with FSSC on ease of use for user community.
- Exciting progress on Pass8, expected to be the ultimate version.

Future Surprises

We are just beginning...

- **Exposure continues to increase**
  - **Fainter sources become detectable**
  - **Increasingly detailed studies of bright sources**
  - **Catalogs become deeper and more detailed**
- **Time domain studies enter longer regimes**
- **Solar cycle beginning to warm up**
- **Plus, efforts continue to further improve performance and enhance analysis, particularly at low and high energies**

The longer we look, the more surprises we will see

Liz Hays

greetings from the Fermi Symposium