



Fermi

Gamma-ray Space Telescope



## The 5<sup>th</sup> Fermi Symposium: Summary and Outlook

**Eric Charles**  
**SLAC / KIPAC**  
**Nagoya, 2014-10-24**

# Outline

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- **Fermi Instrument, Data & Data Products**
  - **Status & Acknowledgements**
  - **New developments (Pass 8 & 3FGL Catalog)**
- **Fermi Science**
  - **Themes: new data / new models / new questions**
  - **A (brief) tour of science topics**
    - **Heavy personal bias toward observations over modeling**
- **Outlook**
- **Thank You**



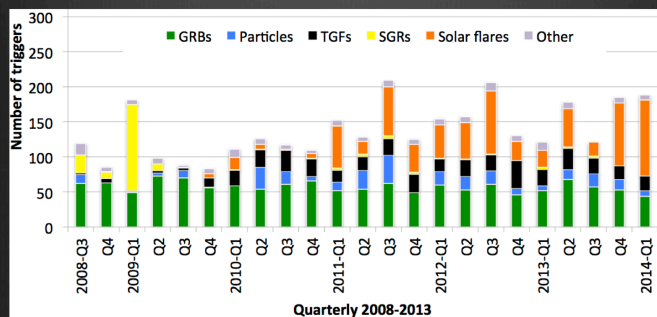
# **FERMI INSTRUMENT, DATA AND DATA PRODUCTS**

# Fermi Spacecraft & Instruments are Working Well

## McEnergy

### GBM

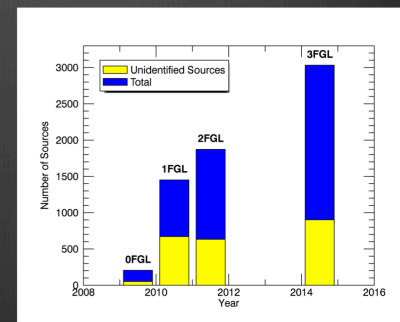
- $2 \times 10^{12}$  detector counts resulted in **3469 transient triggers**
- 1491 GRB, 510 TGF, 178 SGR bursts, 829 solar flares
- >4500 GBM BA shifts by ~40 member team
- 539 GCN circulars



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### Large Area Telescope

- Triggered on >380 billion (380,000,000,000) events
- Processed 73,859,565,213 events in ISOC pipeline, > 1.0 PB
  - Hundreds of data quality monitor shifts
- 3033 sources in 3<sup>rd</sup> Fermi LAT source catalog
- 160 Pulsars
- >1500 AGN



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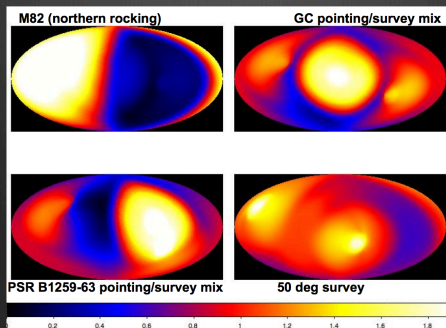
- **LAT:  $3.8 \times 10^{14}$  Triggers, 73,859,565,213 events processed on ground**
- **GBM:  $2 \times 10^{12}$  detector counts resulted in 3469 transient triggers**
- ***Fermi* responded to 28 ToO requests: Sun, AGN, Crab, Novae, binary systems**
- **In Dec 2013, *Fermi* transitioned to a new observing strategy designed to enhance coverage at the Galactic Center while retaining all-sky coverage**

# Lots of Dedicated People to Make it Work

## Fermi SSC

### Science Support Center

- Planned >330 observatory timelines
- Responded to 28 ToO requests: Sun, AGN, Crab, Novae, binary systems



McEnergy

## Operations

### Flight Operations Team

- Scheduled 18358 contacts with TDRSS
- Executed 10218 procedures on the observatory
- Respond to an average of ~10 observatory alerts per day
- Perform daily, weekly and quarterly review of spacecraft and instrument health and safety



## Instrument Teams

# What does Pass mean?

- Each pass corresponds to a version of the Fermi LAT data
- It implies a whole package:
  - Instrument simulation
  - Reconstruction code
  - Event selection
  - Instrument Response Functions (IRFs)
  - Systematic uncertainties
  - Isotropic template (which includes the cosmic-ray residual background)
  - And sometimes more (Galactic diffuse model, Earth limb template, Sun+Moon template)
- It's only when we have validated the whole package that we can release it to the public.

Bruel

& many others

# Predictions Two Years Ago at Monterrey

Digel 2012

## Highlights from the 5<sup>th</sup> Fermi Symposium

- Pass 8 in wide use
- 3FGL



# LAT Pass 8 Era is Starting

## De-ghosting

Bruel

### ACD

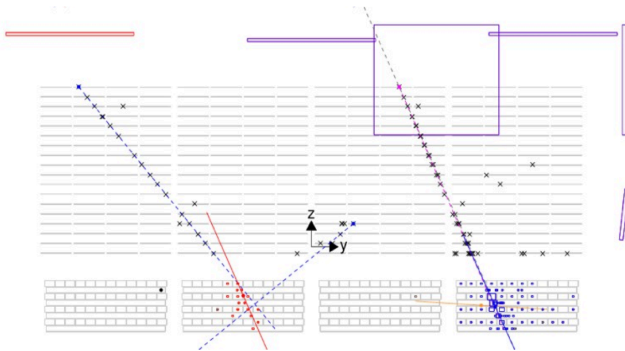
Remove tiles with no trigger veto but with a signal that should have fired the veto

### Tracker

Remove hits from time-over-threshold and tower trigger information

### Calorimeter

Perform clustering and cluster classification and keep the most gamma-like

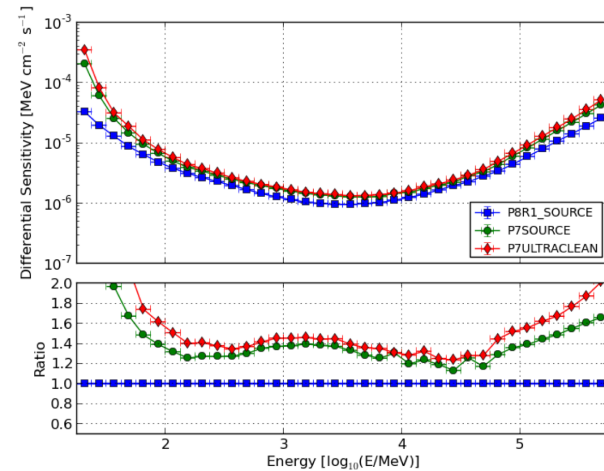


Fermi LAT collaboration

5th Fermi Symposium Nagoya Oct 22 2014

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## Source sensitivity



Fermi LAT collaboration

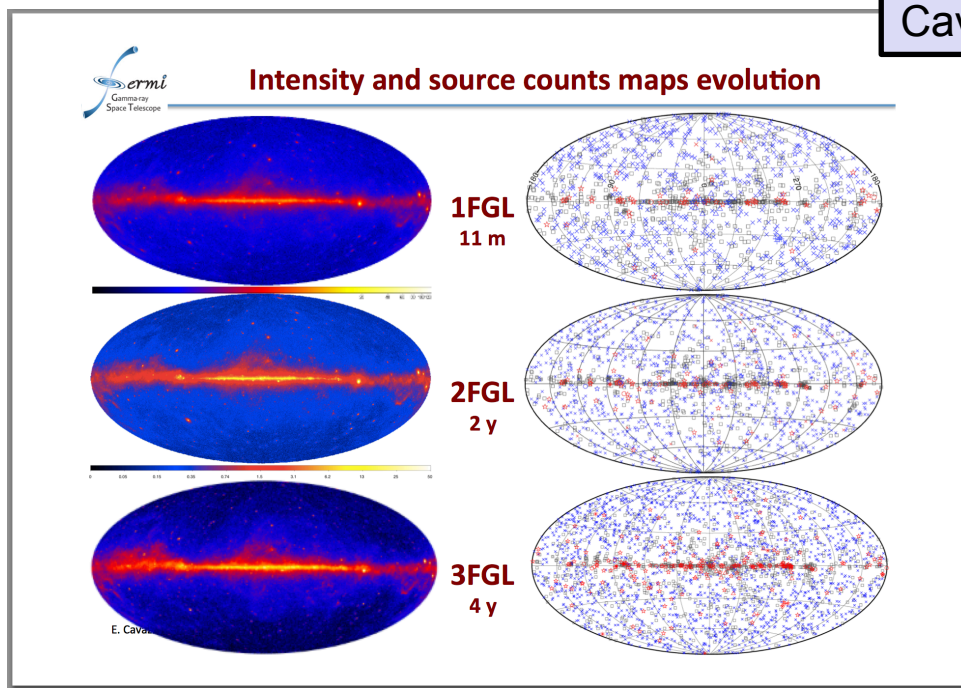
5th Fermi Symposium Nagoya Oct 22 2014

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- Many results using Pass 8 data, including:
  - 2FHL Catalog (Ajello),
  - PG1553 variability (Ciprini),
  - Impulsive phase of solar flares (Desainte)
  - Pulsar discoveries (Laffon)
  - Dwarf Spheroidal DM search (Anderson)
  - DM annihilation line search (Albert)
  - GRB Searches (“Vianello”)

# The Third Fermi-LAT Source Catalog (3FGL)

Cavazzuti



- The 3FGL catalog uses the Pass 7 reprocessed data set
  - Improved PSF w.r.t. Pass 7
- Deepest catalog from 100MeV to 300GeV
- Significant analysis refinements w.r.t. 2FGL catalog
  - 3033 sources (1873 in 2FGL)

	<b>3FGL</b>
<b>Total</b>	<b>3033</b>
<b>Unassociated</b>	992 (33%)
<b>AGNs</b>	1691 + 66 (ID) (58%)
<b>PSRs</b>	29 + 137 (ID)
<b>PWN</b>	2+9 (ID)
<b>SNR</b>	11+12 (ID)
<b>GLC</b>	15
<b>SBG</b>	4
<b>HMB</b>	3 (ID)
<b>spp</b>	51
<b>Others</b>	11 (gal+Nova+BIN...)
<b>Extended</b>	25
<b>High/Low  b </b>	2193/841

*preliminary*

# Catalogs are Drivers for Other Studies

Cavazzuti

- Population studies: LogN – LogS, Luminosity Function
- Long term studies
- Reference for [works on individual sources](#) (included provides starting source model for any ROI)
- Dichotomy between [gamma-ray detected](#) and [gamma-ray non-detected blazars](#) at other wavelengths
- [Timing correlations](#) between the activity in the gamma-ray bands and other bands
- Correlation between [gamma-ray AGNs](#) and the sources of [ultra high-energy cosmic rays / high-energy neutrinos](#)
- Sample to probe the [Extragalactic Background Light / InterGalactic Magnetic Field](#)
- [Contribution of AGNs to the extragalactic diffuse gamma-ray background](#)
- Finding [new MSPs](#)
- Triggering [dedicated studies of SNRs](#)
- Constrain the [population of unresolved Galactic sources](#)
- Build the [next generation model for diffuse Galactic emission](#)

## Other New / Upcoming “Catalogs”

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- **GBM Soft-Gamma Repeater (SGR) Catalog** Kouveliotou
- **LAT Supernova Remnant Catalog(SNRCat)** Brandt
- **3<sup>rd</sup> LAT Active Galactic Nuclei (3LAC)** Lott
- **2<sup>nd</sup> LAT Hard Source List (2FHL)** Ajello
- **LAT-detected Solar Flare List** Omodei
- **GBM X-ray Burst (XRB) Catalog** Jenke
- **GBM GRB Catalog Updates** Briggs



## Fermi Mission Prospects

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- **Orbit re-entry in the range 2026 - 2044 (depending on solar activity)**
- **No consumables**

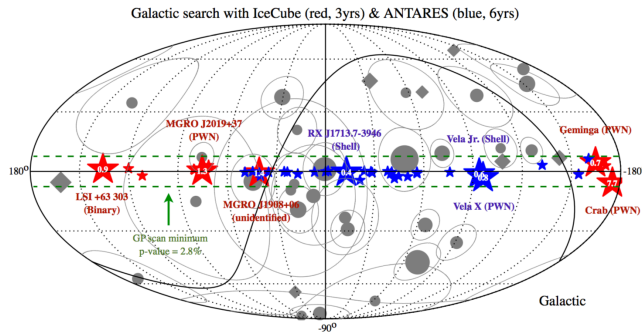
*“Precedence suggests that NASA does not turn off fully operational missions.”*

*-Julie McEnery*

# New Synergies other Instruments

Ahlers

## Neutrino Point-Source Limits



- relative strength of neutrino limits assuming hadronic TeV  $\gamma$ -ray emission (only shown for selected strong sources):

$$F_{\gamma}(E_{\gamma} > E_{th}) / F_{\nu}^{90CL}(E_{\nu} > E_{th}/2)$$

✗ caveats: soft spectra, low energy cutoffs and extended emission

## Proposed Source Candidates

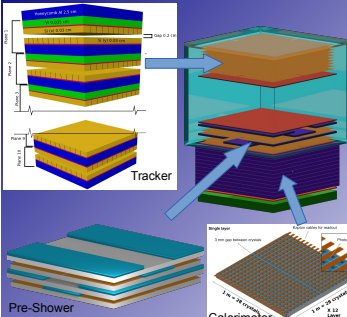
- **Galactic:** (full or partial contribution)
  - heavy dark matter decay [Feldstein *et al.* 1303.7320; Esmaili & Serpico 1308.1105]
  - peculiar hypernovae [Fox, Kashiyama & Meszaros 1305.6606; MA & Murase 1309.4077]
  - diffuse Galactic  $\gamma$ -ray emission [e.g. Ingelman & Thunman'96; MA & Murase 1309.4077]
  - unidentified Galactic TeV  $\gamma$ -ray sources [Fox, Kashiyama & Meszaros 1306.6606]
  - sub-TeV diffuse Galactic  $\gamma$ -ray emission [Neronov, Semikoz & Tchernin 1307.2158]
  - "Fermi bubbles" [Su, Stajter & Finkbeiner'11; Crocker & Aharonian'11; Lunardini & Razzaque'12 [MA & Murase'13; Razzaque'13; Lunardini *et al.*'13 ]
- **Extragalactic:**
  - association with sources of UHE CRs [Kistler, Stanev & Yuksel 1301.1703 [Katz, Waxman, Thompson & Loeb 1311.0287; Fang, Fujii, Linden & Olinto 1404.6237]
  - GZK from low  $E_{max}$  blazars [Kalashev, Kusenko & Essey 1303.0300]
  - cores of active galactic nuclei (AGN) [e.g. Stecker *et al.*'91; Stecker 1305.7404]
  - AGN jets [e.g. Murase, Inoue & Dermer 1403.4089; 1406.2633]
  - low-power  $\gamma$ -ray bursts (GRB) [Murase & Ioka 1306.2274]
  - starburst galaxies [e.g. Loeb & Waxman'06; He *et al.* 1303.1253 [ Murase, MA & Lacki 1306.3417; Anchordoqui *et al.* 1405.7648; Chang & Wang 1406.1099]
  - hypernovae in star-forming galaxies [Liu, Wang, Inoue, Crocker & Aharonian 1310.1263]
  - galaxy clusters/groups [Berezinsky, Blasi & Ptuskin'97; Murase, MA & Lacki 1306.3417]

- Multi-messenger (MM) astronomy
  - PeV neutrinos from Ice Cube Ahlers
  - Gravity-wave detectors Allen
- Multi-wavelength (MW) astronomy
  - eRosita (medium-energy X-ray)
  - CTA (High-energy gamma-ray)
  - SKA (radio)

# Proposed Missions

## The GAMMA-400 Space Mission

Author: Paolo Cumani on behalf of the GAMMA-400 Collaboration      Poster: 1.04



**Focus on:**

- Gamma-rays: 100 MeV – 3 TeV
- Electrons: 1 GeV – 20 TeV
- Protons/ nuclei: Up to  $10^{15}$ - $10^{16}$  eV

Pointing mode without Earth occultation

1300 orbit Turns: 30000 - 300000 km

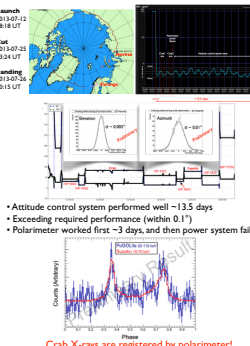
## Pathfinder flight of the Polarized Gamma-ray Observer (PoGOLite) in 2013

Takafumi Kawano (Ishikawa University) On behalf of the PoGOLite Collaboration

### Measuring of polarization

- Polarization: including information of magnetic fields and geometry of accretion disks
- Powerful way to identify acceleration mechanism in Crab nebula and other PWNs
- Past Observations of Crab nebula
  - PD ~ 20% at 2.6/5.2 keV (OSQAR)
  - PD ~ 50% at >100 keV (INTEGRAL)
- 10-100 keV band is not covered by previous observation
- Polarization angle aligns with pulsar rotation axis above 100 keV and the polarization degree is high (>~50%) with large error
- We aim to constrain the emission site of X-rays/gamma-rays by the detection of polarization

### Flight trajectory & Results



Launch: 2013-07-12 06:18 UT  
Cut: 2013-07-25 23:24 UT  
Landing: 2013-07-26 00:15 UT

- Attitude control system performed well ~13.5 days
- Exceeding required performance (within 0.1°)
- Polarimeter worked first ~3 days, and then power system failed

Crab X-rays are registered by polarimeter!

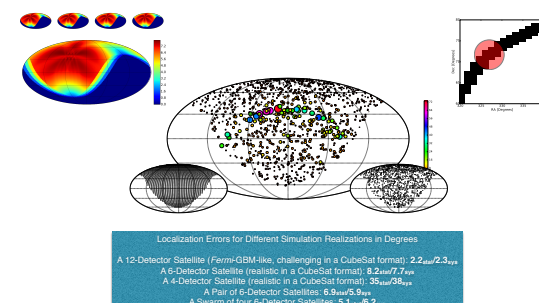
### PoGOLite balloon-borne instrument

- Collaboration campaign between Sweden, Japan and USA
- Observing polarized hard X-ray/soft gamma-ray (25-100 keV) from celestial objects
- Target objects: Crab, Cyg X-1 (hard state)
- Aiming for MDP ~10-20% for 200 mCrab source in single balloon flight for the full-size instrument (PoGO-217)
- First successful balloon flight of reduced area pathfinder polarimeter during July 12-26 of 2013

## BurstCube: A Gamma-ray Burst Detecting Swarm of CubeSats

NASA      Goddard SPACE FLIGHT CENTER

Jeremy S. Perkins<sup>1</sup>, Judith Racusin<sup>1</sup>, Julie McEnery<sup>1</sup> and John Krizmanic<sup>2</sup>  
<sup>1</sup>NASA/GSFC, <sup>2</sup>USRA/CRESST/GSFC



Localization Errors for Different Simulation Realizations in Degrees

- A 12-Detector Satellite (Fermi-GBM-like, challenging in a CubeSat format): 2.2<sub>min</sub> 2.3<sub>max</sub>
- A 6-Detector Satellite (realistic in a CubeSat format): 8.2<sub>min</sub> 7.7<sub>max</sub>
- A 4-Detector Satellite (realistic in a CubeSat format): 35<sub>min</sub> 28<sub>max</sub>
- A Pair of 6-Detector Satellites: 6.9<sub>min</sub> 5.5<sub>max</sub>
- A Swarm of four 6-Detector Satellites: 5.1<sub>min</sub> 6.2<sub>max</sub>

- Wide-Field MAXI (X-ray monitor)
- HARPO (MeV-GeV telescope & polarimeter)
- GAMMA-400 (GeV telescope & calorimeter)
- PoGOLite (Gamma-ray polarimeter)
- PANGU (MeV-GeV telescope & polarimeter)
- GRAINE (Ballon-based emulsion telescope)
- CALET GRB monitor
- TSUBAME (Micro-satellite X-ray polarimeter)
- BurstCube (GRB monitoring CubeSat “swarm”)

# FERMI SCIENCE: THEMES

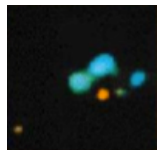


# $\gamma$ -rays Probe the Extreme, Non-Thermal, Universe

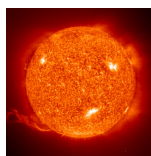
Dark Nebula



Dim, young star



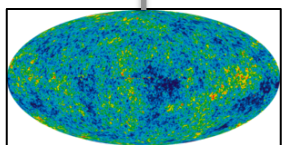
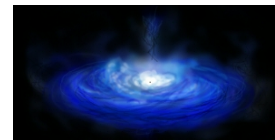
Our Sun



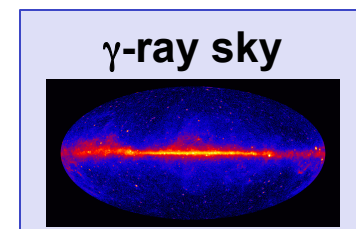
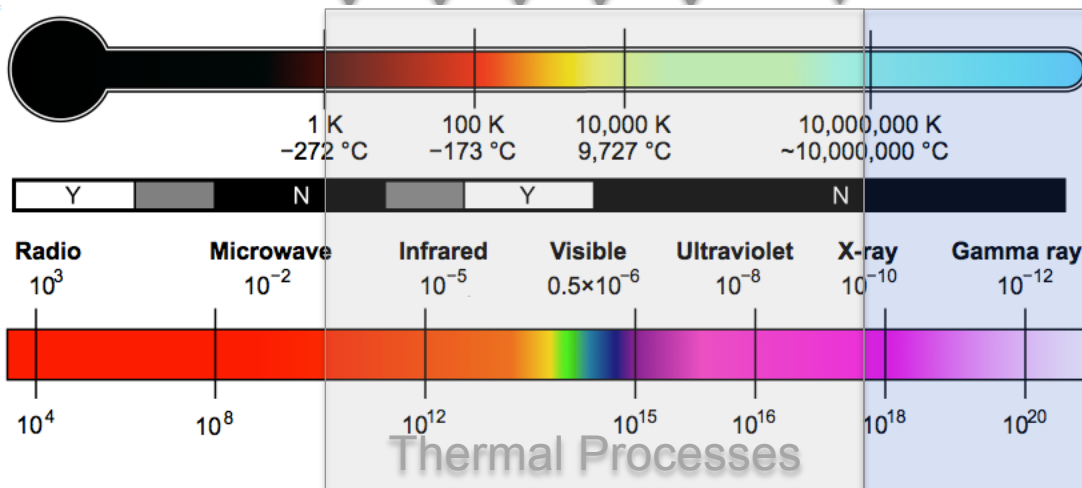
Globular Cluster



Accretion Disk



CMB



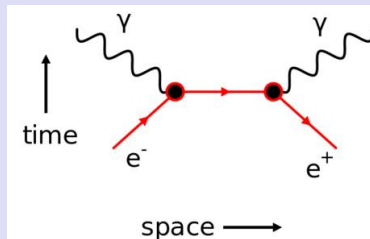
Energy & particle source



Acceleration mechanism



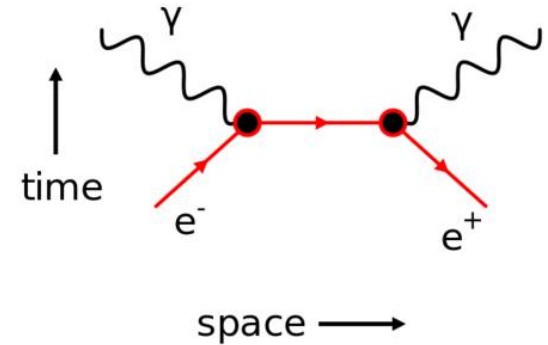
$\gamma$ -ray production mechanism



Foreground Effects



# Non-thermal $\gamma$ ray emission



**Energy source**

**Acceleration  
mechanism**

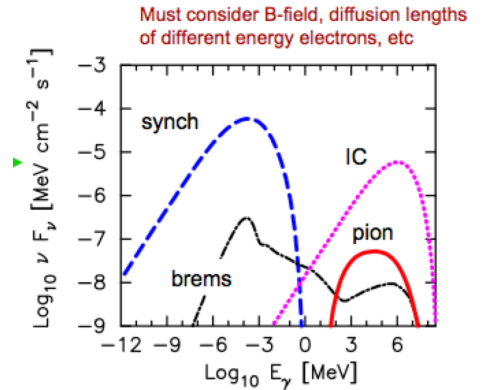
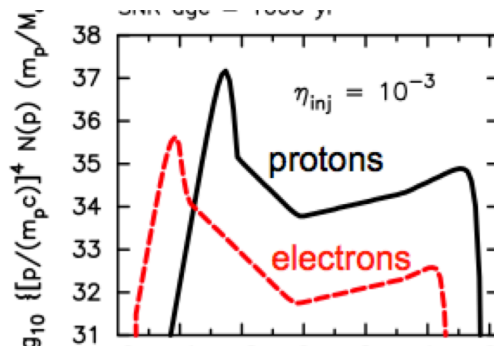
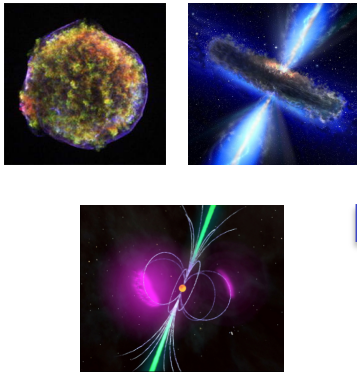
**$\gamma$ -ray production  
mechanism**



**Foreground absorption**

**$\gamma$  rays**

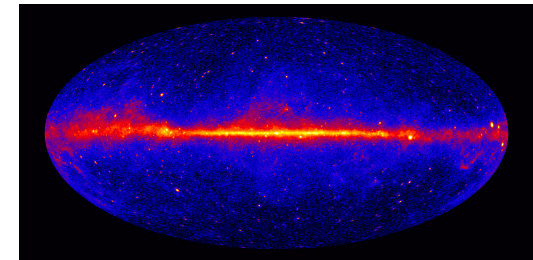
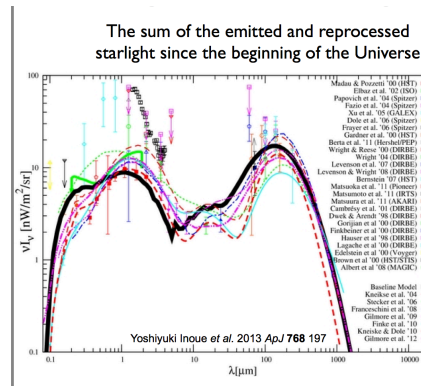
# Non-thermal $\gamma$ ray emission



Energy source

Acceleration mechanism

$\gamma$ -ray production mechanism



Foreground absorption

$\gamma$  rays

# Theme I: New Data Challenges Old Models

**If we could obtain the X-ray spectral variability...**

We infer the following X-ray spectral components for NGC 1275.

disc/corona emission    jet IC    reflection component

harder-when-brighter  
jet emission

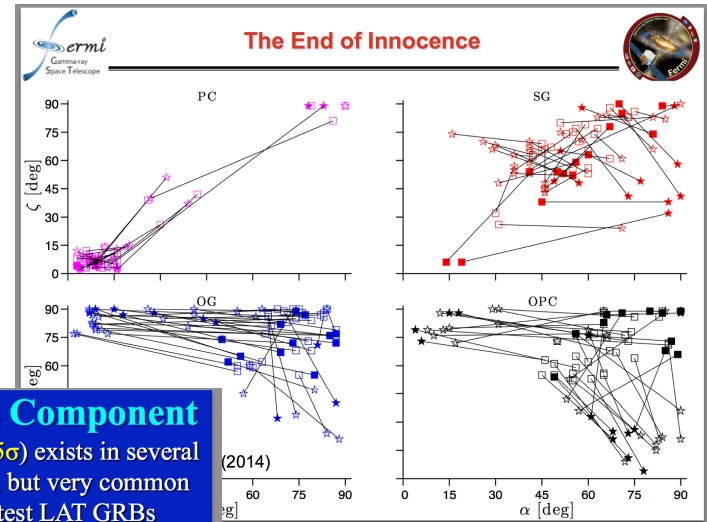
Variable component is jet emission

softer-when-brighter  
disc/corona emission

Variable component is disc/corona emission

However, Suzaku cannot distinguish these two scenarios.

Further X-ray observations (XMM-Newton, NuStar, ASTRO-E)



### Distinct High-Energy Spectral Component

- Clearly ( $>5\sigma$ ) exists in several LAT GRBs, but very common in the brightest LAT GRBs
- Suggests that it is common but good photon statistics is needed for clear evidence

(GRB130427A; Ackermann+ 2014 Science, 343, 42)

(GRB090926A; Ackermann+ 2011)

(GRB090926B; Abdo+ 2009)

(GRB090510; Ackermann+ 2010)

(GRB080916C; Abdo et al. 2009, Science, 323, 1688)

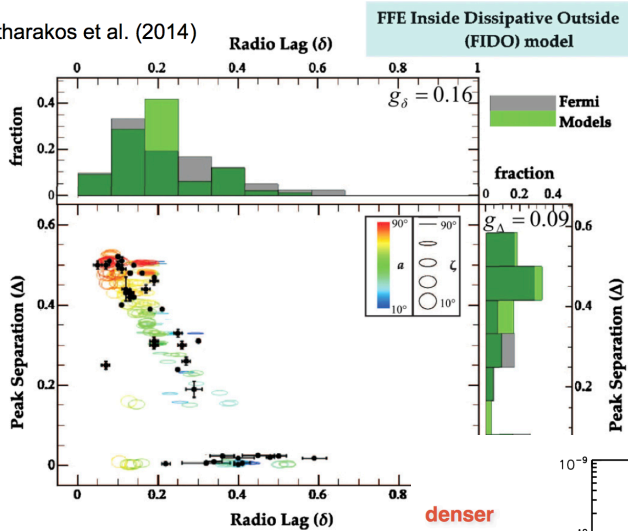
*“[The second pulsar catalog was the] end of being able to do science with cartoons.”*

-Matthew Kerr



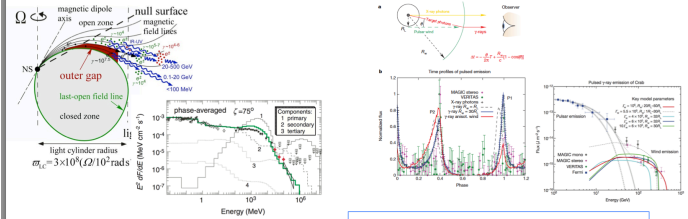
# Theme II: New Data Allow us to Make New Models

Kalopotharakos et al. (2014)



## New Models for Crab

- 1) Magnetospheric Cascade Model (K. Hirotani & MAGIC, Apj 742 43, 2011)
- 2) Pulsar Wind Scattering Model (F. Aharonian et al. Nature 482, 507, 2012)

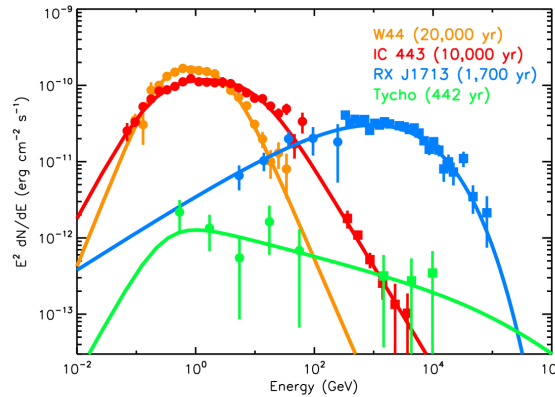


- 3) Light Cylinder Gap model (Bednarek MNRAS 424, 2012)

In order to test these models:

- Spectral Approach -> R. Zanin talk this morning
- **Pulse Shape Approach -> This talk**

T. Saito, 5th Fermi Symposium 2014/10/22



old ← → young

John W. Hewitt

5th Fermi Symposium - Nagoya, Japan



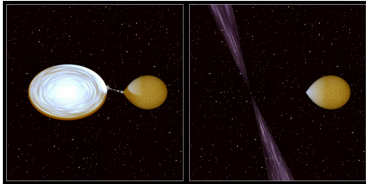
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*“When you are modeling you have to take into account all of these things. It can get very complicated”*

-Toni Venters

## Key puzzles

- Why have these systems stopped being full-fledged LMXBs?
- Do other LMXBs enter such low-luminosity accretion-disc states?
- What is going on in these peculiar accretion-disc states?
- How do these systems produce  $\gamma$ -rays?
- What is the ultimate fate of these systems?



Archibald (ASTRON) MSP  $\gamma$ -ray emission

## Proposed Source Candidates

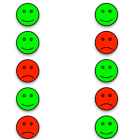
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  - galaxy clusters/groups [Berezinsky, Blasi & Ptuskin'97; Murase, MA & Lacki 1306.3417]

## Leptonic / Hadronic Summary



- **Gamma-ray spectrum**
- **Microwave haze**
- **No spectral changes**
- **Narrow boundary**
- **Absence of a visible shock front**

Leptonic / Hadronic



### Possible leptonic scenario: (Mertsch, Sarkar, Guo, Mathews etc.):

- Jets from the black hole create shock front
- Shock front dissipates, but leaves the plasma turbulences behind
- Electrons are accelerated on the turbulences with a characteristic time less than the cooling time

### Possible hadronic scenario: (Crocker, Aharonian):

- Wind from SNRs produces CR during several billions of years
- Magnetic fields confine the CR in the bubble volume
- WMAP haze produced by  $\sim 30$  GeV electrons in the SNR wind which have a characteristic cooling time  $\sim 10$  Myr

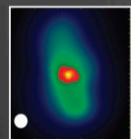
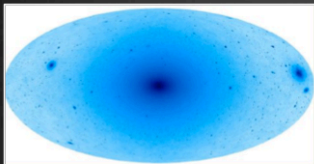
**"Lack of imagination is not proof of discovery"**  
-Dan Hooper

# FERMI SCIENCE: A (BRIEF) TOUR OF TOPICS

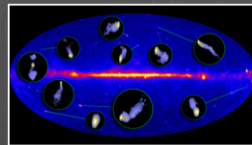
# From Local to Cosmological Sources

57 NASA press releases, over 15 million youtube/svs hits on Fermi animations

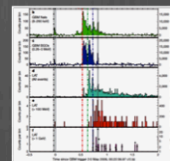
Dark Matter searches



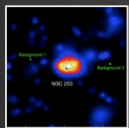
Radio Galaxies



Blazars

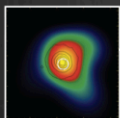
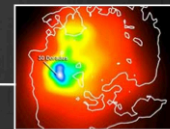


GRBs



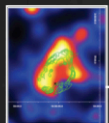
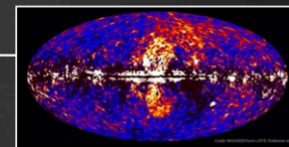
Starburst Galaxies

LMC & SMC

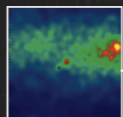


Globular Clusters

*Fermi* Bubbles

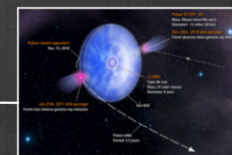


SNRs & PWN

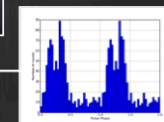


Novae

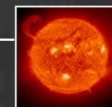
$\gamma$ -ray Binaries



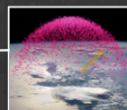
Pulsars: isolated, binaries, & MSPs



Sun: flares & CR interactions



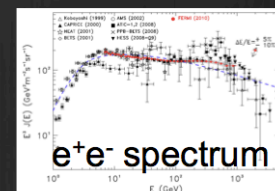
Terrestrial  $\gamma$ -ray Flashes



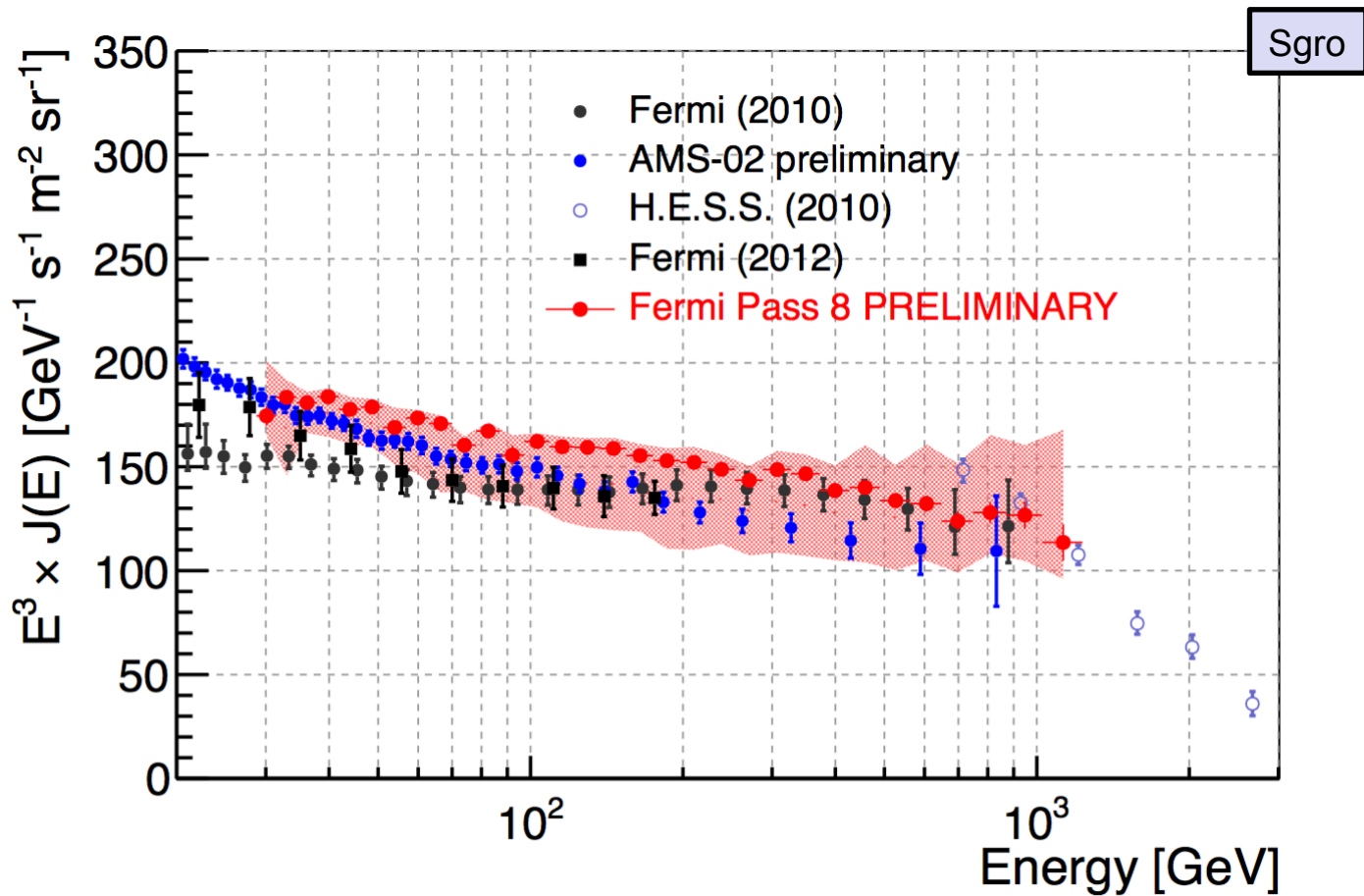
Unidentified Sources

Galactic

Extragalactic



# Updated Cosmic-Ray Electron Spectrum



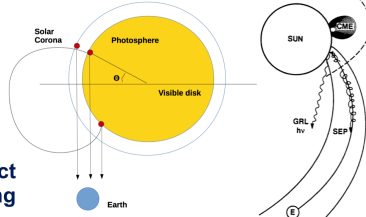
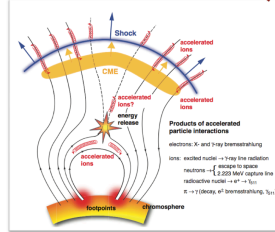
- Pass 8 update to Fermi-LAT Cosmic-ray electron spectrum
  - Up to > 1 TeV (Overlap w/ HESS)

# Gamma Rays from the Solar System

Omodei

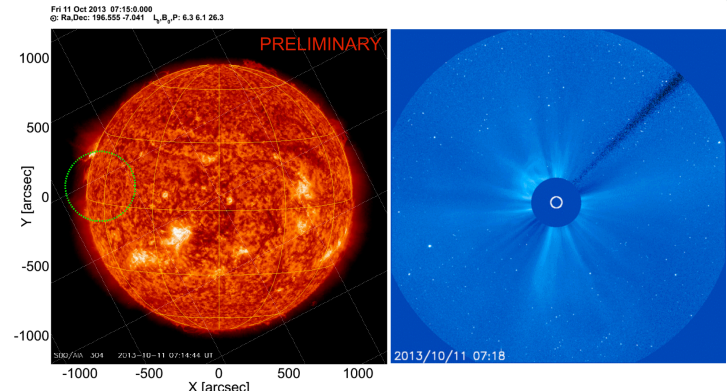
## Understanding particle acceleration and gamma-ray emission at the Sun

- Particles accelerated during the **impulsive phase** interact with the solar surface (right below the photosphere) producing gamma-rays (pion production most likely)
- Part of the accelerated particles can escape and eventually can be re-accelerated by the CME shock (This also explains the correlation with SEP)
- **Continuously accelerated** particles can travel along magnetic field lines, and interact with the dense solar surface in front of the solar limb.
- Alternatively, CME re-accelerated particles can travel back to the Sun along magnetic field lines and interact with dense region, explaining the long lasting emission.



Nicola Omodei - Stanford/KIPAC

## Where does the gamma-ray emission come from?



*Footpoints* not visible at the time of the gamma-ray detection  
High density region required for gamma-ray production

Nicola Omodei - Stanford/KIPAC

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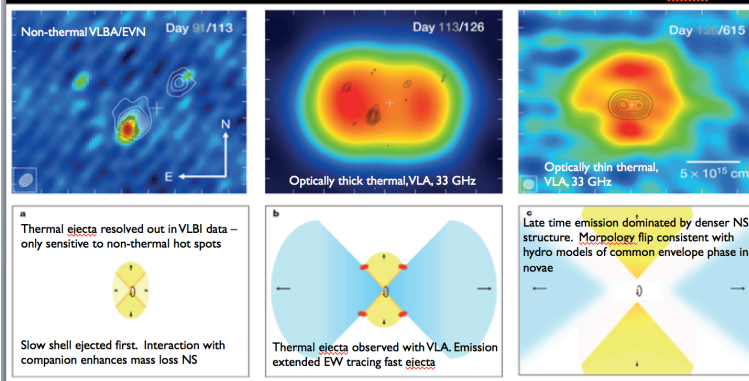
- **GBM + LAT Observation of Solar Flares** Omodei
- **Gamma rays correlated with coronal mass ejections**
- **Prompt gamma rays localized to active region**
- **Observation of gamma rays from flares beyond the Solar Limb**
- **Pass 8 reconstruction allows for study of impulsive emission** Desainte
- **Sun Monitoring / Quiet Sun observations** Omodei / Giglietto
- **Search for emission along the Ecliptic** Vandenbroucke
- **GBM observations of Terrestrial Gamma-ray Flashes** Briggs



# Galactic Transients (Novae / Binaries)

Nelson

Radio observations V959 Mon reveal sites of particle acceleration and a role for the binary in shaping the ejecta



Tam

Questions before 2014 May

- Will the gamma-ray flare repeat? **Yes.**
- If so, will it happen at a similar orbital phase? **Yes.**
- How many flares are there? **More than One.**
- Is there pre-periastron emission? **Probably.**  
How we characterize it? ...
- Is there contemporaneous X-ray flare? **Yes.**

- **MW observations of Galactic Novae demonstrate that binary dynamics affect the particle acceleration** Nelson
- **Superorbital variation in LSI +61° 303** Hadasch
- **Due to variations in circumstellar disc or mass decretion rate?**
- **Observation of Galactic Binary PSR B1259-63 periastron passage answers several open questions about that system** Tam

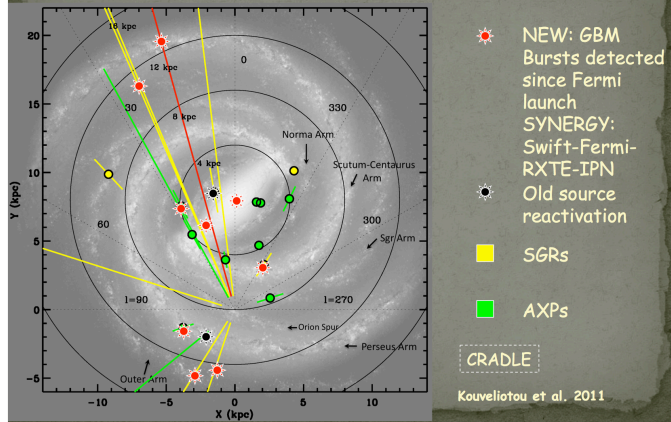


# Magnetars

Kouveliotou

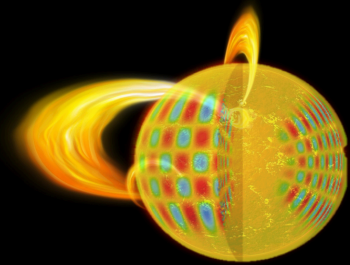
Watts

## Magnetar Distribution in our Galaxy



## SEISMIC VIBRATION MODELS

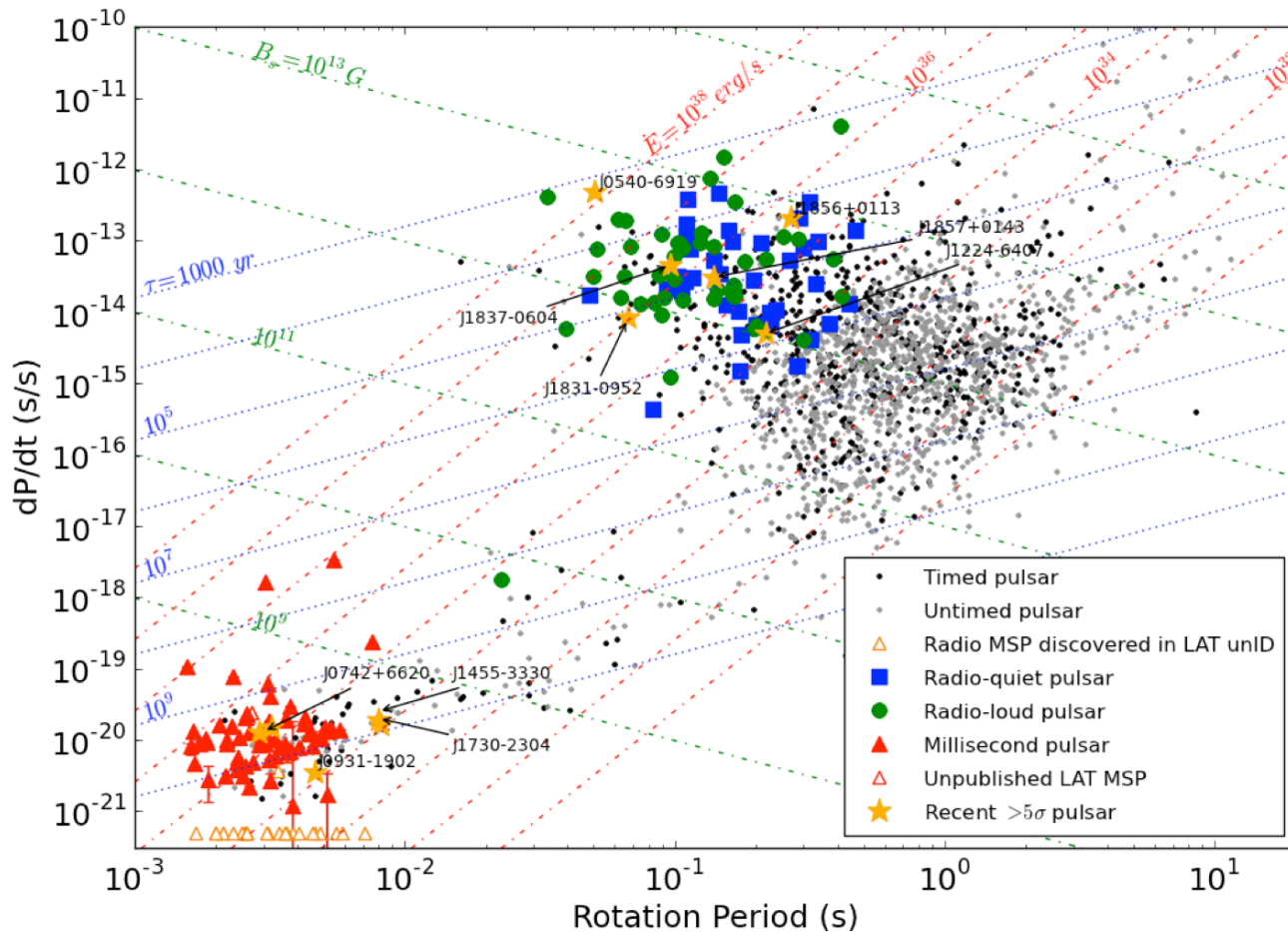
- Coupled magneto-torsional oscillations of crust/core.
- Alfvén modes are continua: frequency drifts intrinsic.
- Frequencies depend on mass, radius, superfluidity, crust composition, magnetic field strength and geometry.
- Decay times important.



See for example:  
 Gabler et al. 2013, 14;  
 Passamonti & Lander 2013,  
 Huppenkothen, Watts & Levin 2014

- **GBM observations of Magnetars**
  - **Soft-gamma repeater (SGR) Catalog**
  - **Correlation between outbursts & state changes**
- **Neutron star astro-siesmology**
  - **Detection of QPOs ~100 Hz by stacking moderate bursts from SGR J1550-5418 burst storm**

# Pulsar Hunting



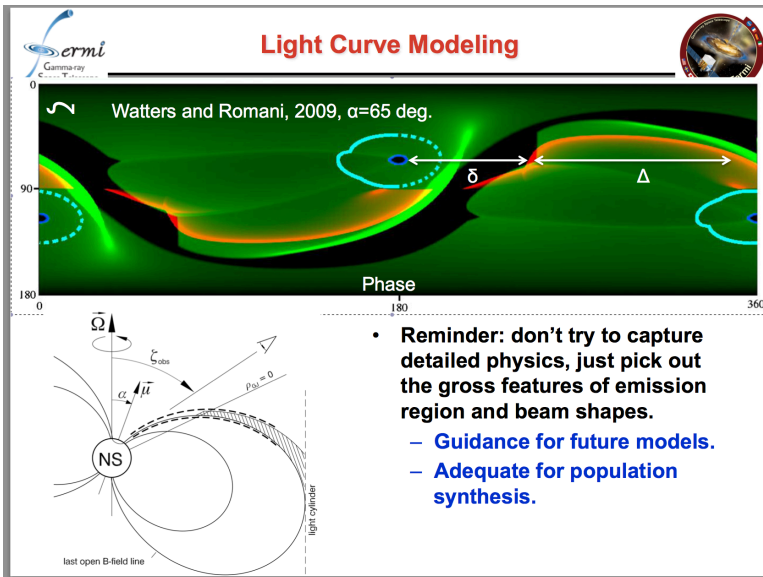
- 10 new pulsation detections w/ Pass 8 Laffon

- **MSP Fraction is Growing**

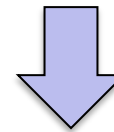
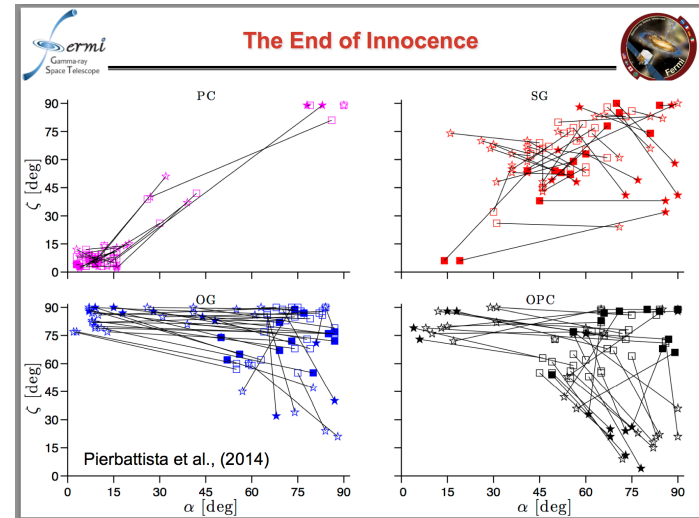
- **Observations of Candidate MSP Binaries Variability** Kong / Wang

# Pulsar Modeling

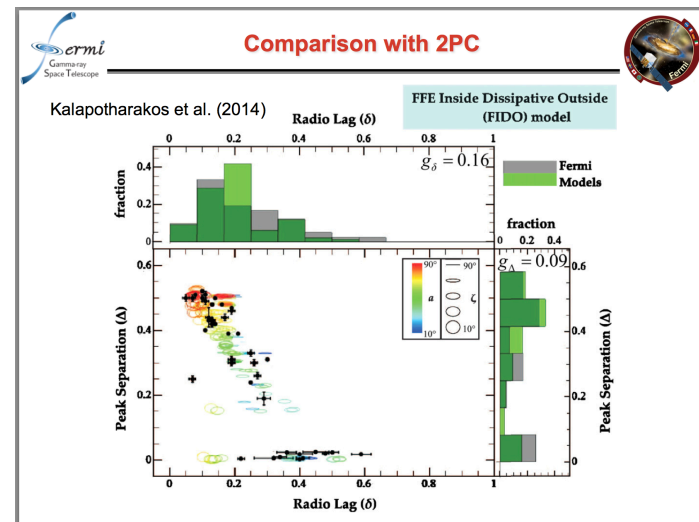
Kerr



- **Geometry plays key role** Johnston
- **LAT sample allow us to probe viewing / rotation phase space**
- **Initial radio + gamma combined models inconsistent**
- **Updated models fit gamma-ray data well** Timokhin



Include Microphysics,  
Reconsider Radio Model  
Buy Drill & Multimeter



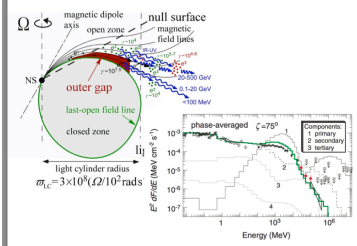
# Pulsars at Very High Energies

Saito

## New Models for Crab

1) Magnetospheric Cascade Model  
(K. Hirofani & MAGIC, ApJ 742 43, 2011)

2) Pulsar Wind Scattering Model  
(F. Aharonian et al. Nature 482, 507, 2012)



3) Light Cylinder Gap model  
(Bednarek MNRAS 424, 2012)

4) Current sheet model  
(Arka and Dubus, A&A 550, 2013)

5) Cyclotron instability model  
(Chkheide et al., ApJ 773, 2013)

In order to test these models:

- Spectral Approach  
-> R. Zanin talk this morning
- Pulse Shape Approach**  
-> **This talk**

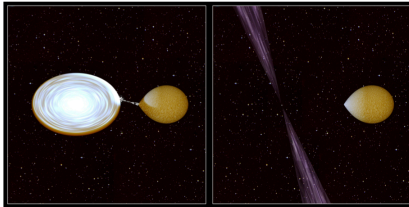
T. Saito, 5th Fermi Symposium 2014/10/22

- Pulsed emission from Crab detected by MAGIC up to ~2TeV
- Inverse Compton emission from electrons w/  $\Gamma > 5e6$
- Pulse width still very narrow at these energies
  - **Tightly constrains IC emission region**
- Interpulse “Bridge” emission also seen above 50GeV
- Pulsations from Vela observed above 50GeV Takata
- Phase-gated stacked analysis of *Fermi* pulsars sets upper limits McCann

# Pulsars Systems

## Key puzzles

- Why have these systems stopped being full-fledged LMXBs?
- Do other LMXBs enter such low-luminosity accretion-disc states?
- What is going on in these peculiar accretion-disc states?
- How do these systems produce  $\gamma$ -rays?
- What is the ultimate fate of these systems?



Archibald (ASTRON)

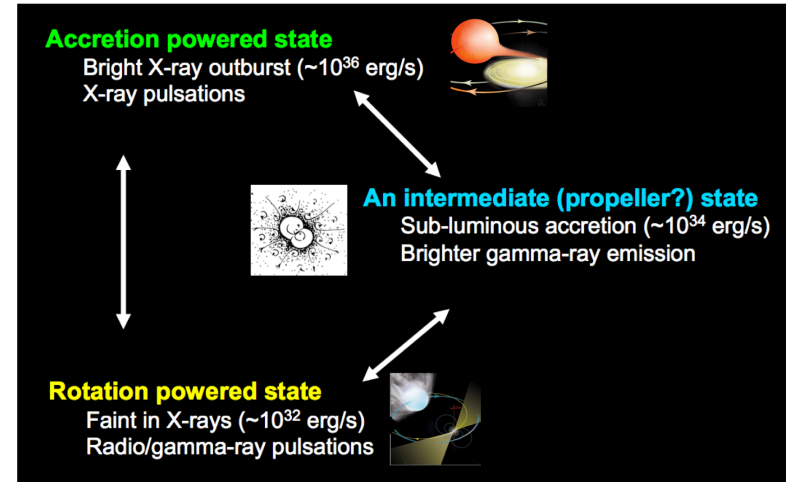
MSP  $\gamma$ -ray emission

2014 October 22

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Archibald

## The three stages of transitional pulsars

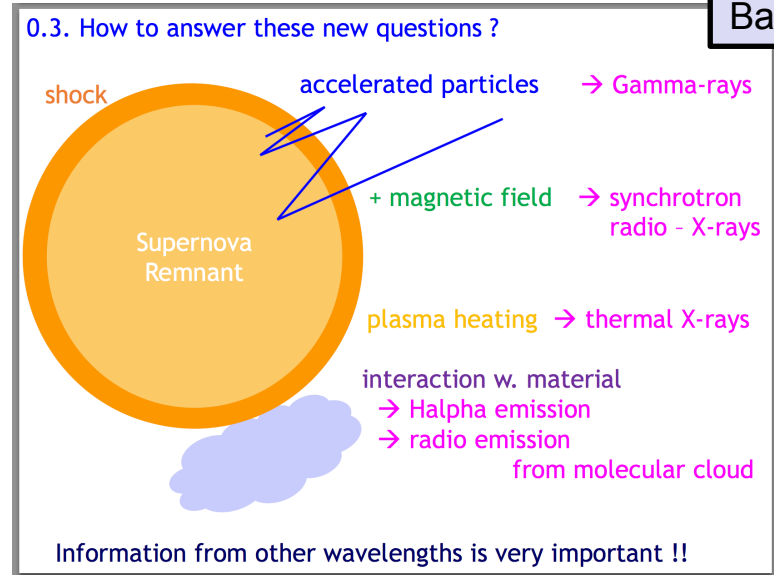
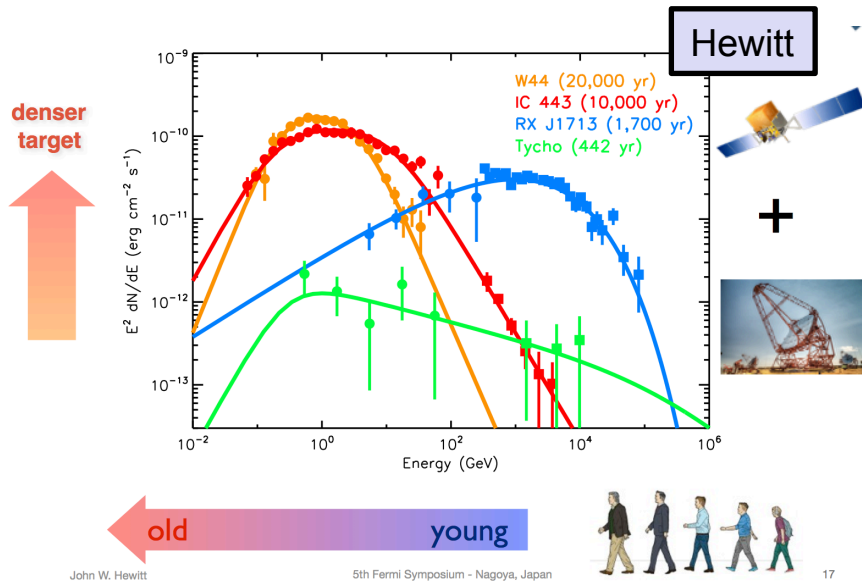


D. F. Torres

Torres

- Increase in number of eclipsing binary systems (spiders) with Fermi
- Surprising large fraction of new pulsars are spiders
  - Selection effects in searching for eclipsing binary systems with radio
- Transition objects switch to accreting state with high gamma-ray flux
  - Are seeing intra-binary shocks in gamma-rays? Roberts
  - Are pulses being shorted out, or simply obscured?

# Particle Acceleration in SNRs



- Excellent overview talks
- Dominant emission mechanism depends on SNR environment
  - Nearby target material
  - High-energy cutoff decreases with SNR age
    - Shock / confinement mechanism evolves
- First Pass 8 results
  - New SNR CTB 109 detected, RCW 86 is extended source
- SNR Catalog (32 classified GeV SNRs)

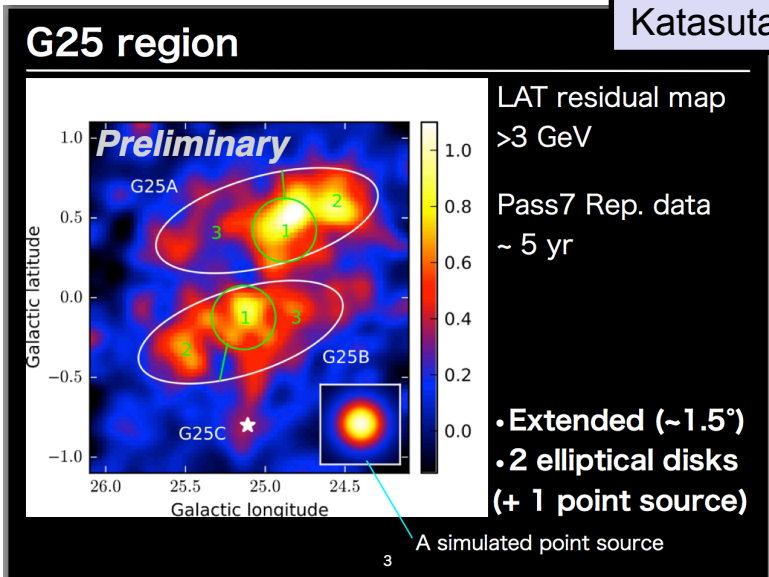
Caragiulo

Brandt / Di Palma

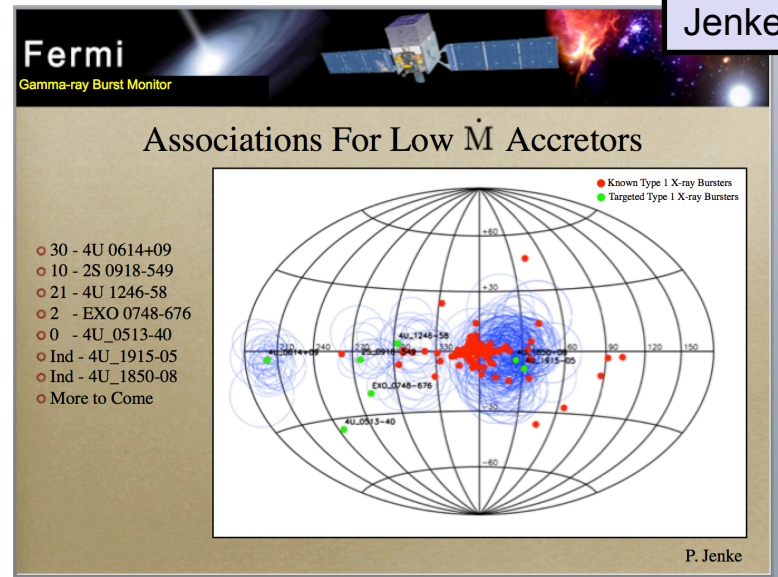


# Other Galactic Sources

Katasuta



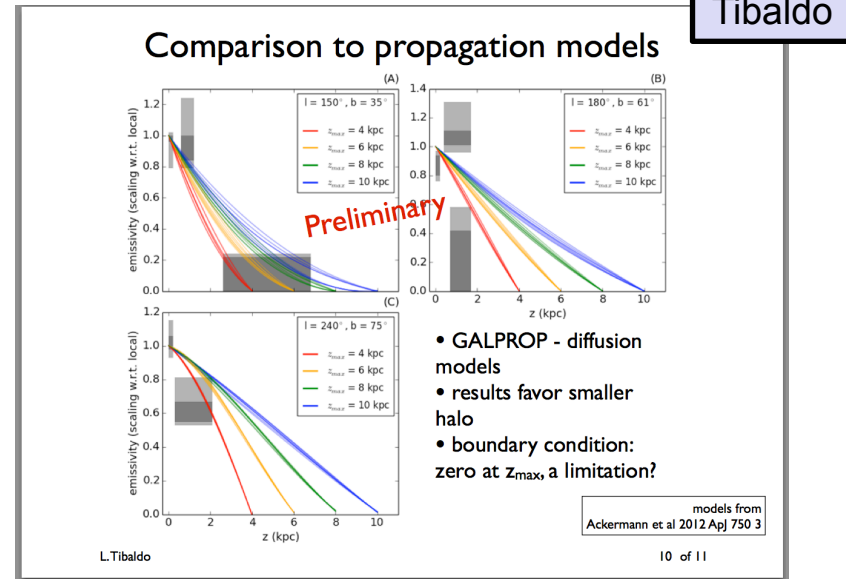
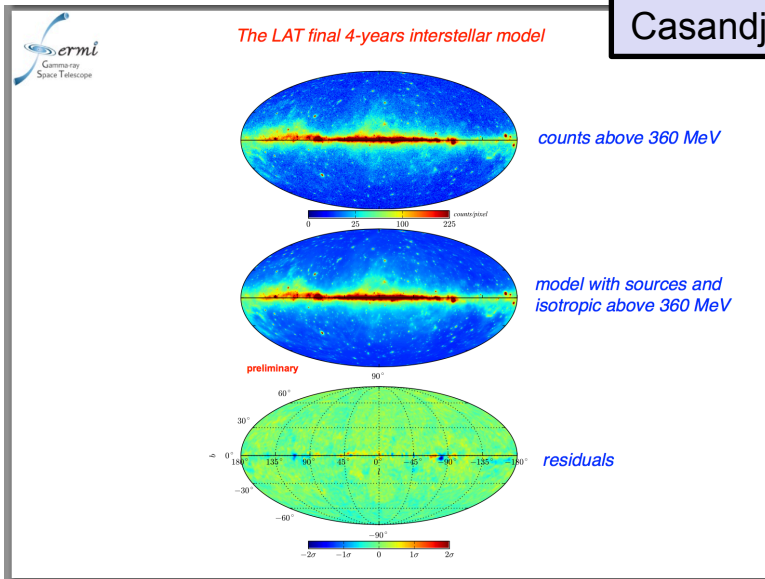
Jenke



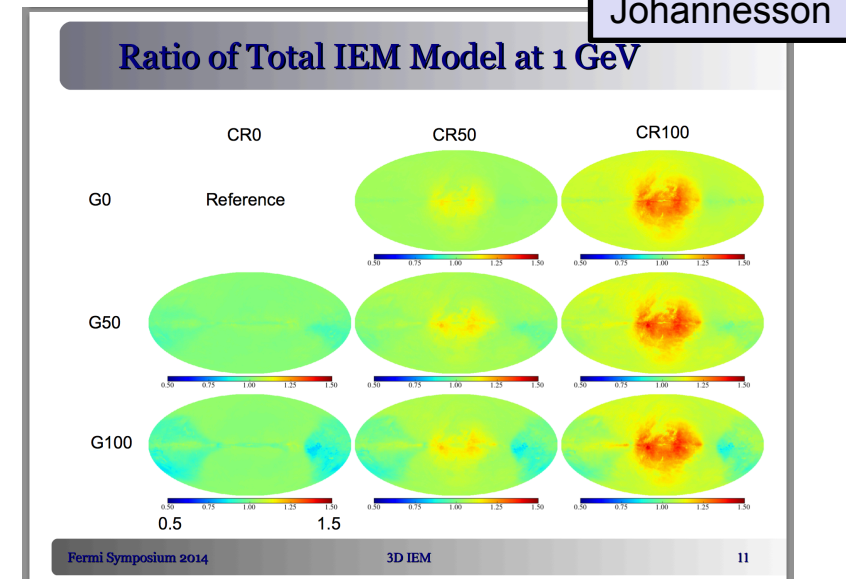
- Detection of gamma-rays from G25 star-forming region
- GBM Catalog of type 1 X-ray Bursts
- NS accreting matter from low-mass companion



# Galactic Diffuse Emission

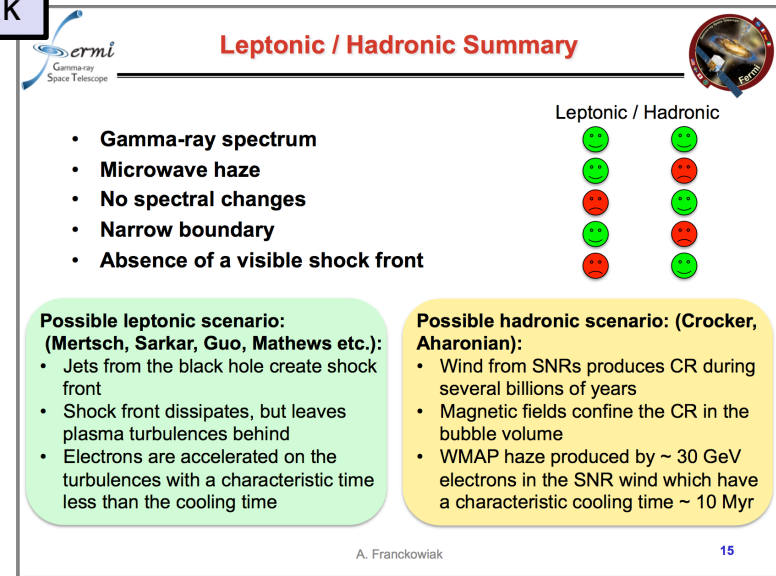
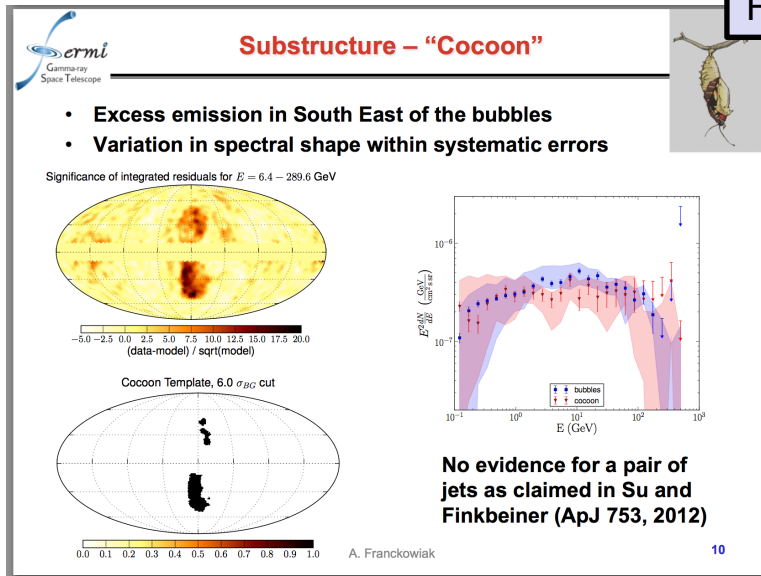


- LAT Diffuse emission model
- Extract emissivity variations w/ galactocentric radius
- High Velocity Cloud Study
- Extract emissivity variations away from galactic plane
- Effect of including 3D structure in GALProp modelling



# Fermi Bubbles Update

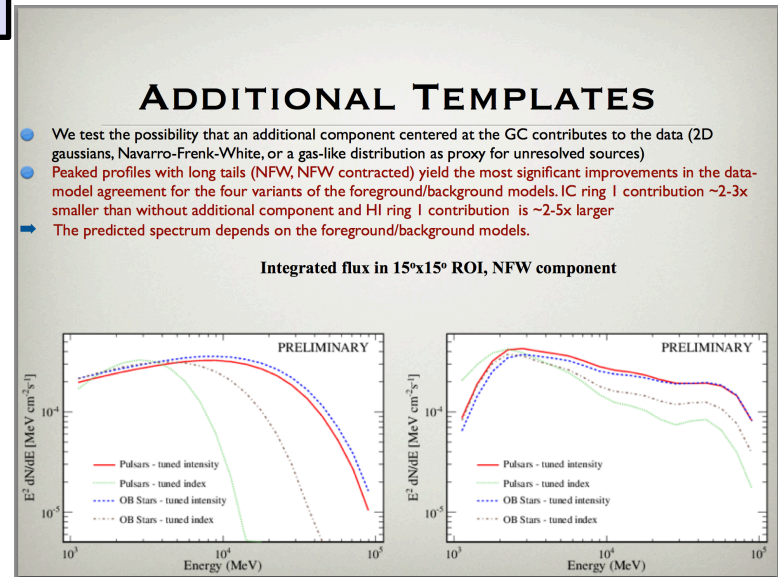
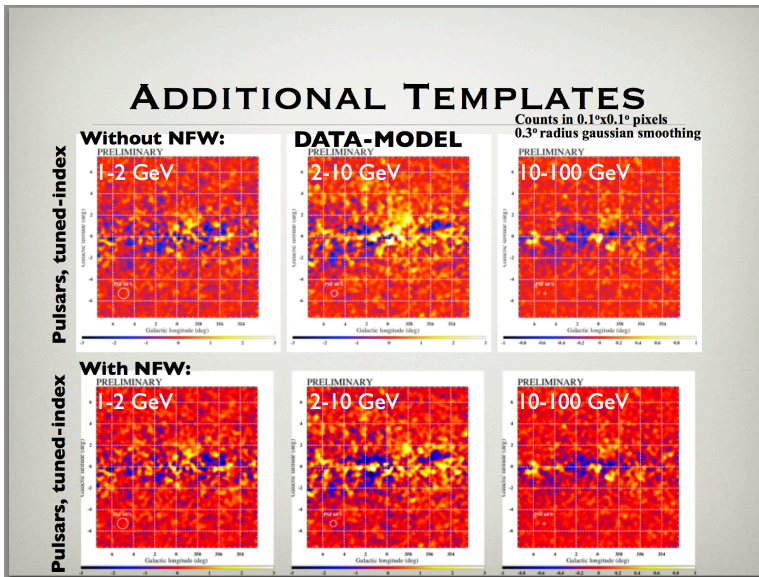
Frackowiak



- **Updated study of Fermi Bubbles**
- **Iterative procedure to extract bubble morphology then fit for bubble spectrum**
- **High-energy cutoff**
- **North / south bubbles have similar spectrum**
- **Evidence for cocoon, but not for jet**
- **Leptonic / Hadronic models both have strong / weak features**

# Diffuse Emission from the Galactic Center

Murgia



- **Template-based and GALProp-template hybrid analyses both find excess in the 2-10GeV range** Murgia / Casandjian / Linden / Calore
- **The best-fit spectrum and morphology depends somewhat on the modeling of the background / foreground**
- **One plenary & most of 1 parallel session on interpretations**
- **More on this topic later**

# “Galactic” Sources: Magellanic Clouds

Martin

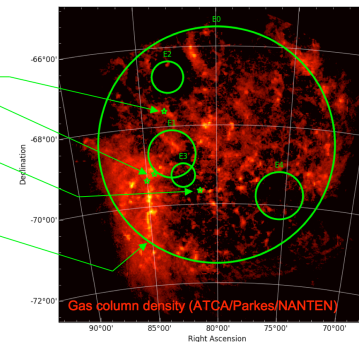
## LMC: model

### What are the emission components ?

- Model-fitting over 200MeV-100GeV
- Iteratively add point sources and gaussians until fit stops improving

### The global LMC picture

- 4 point sources
  - 1 unid
  - 2 pulsars (J0540 and J0537)
  - 1 SNR (N132D)
- 4/5 extended sources
  - Disk (E0)
  - North (E2)
  - West (E4)
  - Near 30Dor (E1/E3)



5th Fermi Symposium - 21 Oct 2014

Pierrick MARTIN for the Fermi/LAT collaboration

5

- **Impressive Results from:**
  - **HESS -- TeV discovery of 3 sources in the LMC**
    - **Including 30 Doradus C superbubble**
  - **Fermi-LAT– Two pulsars and 1 SNR detected in LMC**
    - **Higher emissivity regions correlate with supergiant cavities / shells**

# Active Galactic Nuclei

Reimer

## Three corner marks

### A. AGN AS A POPULATION AND THE BLAZAR PHENOMENON

Won't address here; see talks by Yoshiyuki Inoue, Markus Ackermann, Marco Ajello, Elisabetta Cavazzuti, Benoit Lott,...

### B. THE PHYSICS OF GAMMA-RAY EMITTING AGN

Won't address misaligned AGN (see talks by Y. Fukuzawa, I. Edahiro, E. Meyer, K. Hada, J. Sitarek) or NLSy1 (see posters by F. D'Ammando, H. Shirakawa)

### C. AGN AS A TOOL

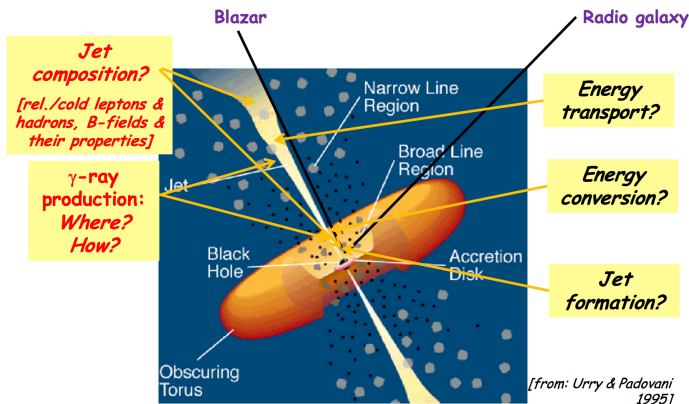
Won't address here; see poster by Alberto Dominguez on EBL

- AGN are by far the largest source class in LAT catalogs
- Many different ways to pursue science with AGN

# Gamma-Ray Emission from AGN

Reimer

## Jets of Active Galactic Nuclei: open questions



Anita Reimer, Innsbruck University

5th Fermi Symposium, Nagoya, Oct. 2014

## Conclusions

- Where are the  $\gamma$ -rays produced? -
  - The 'crisis' on the location of the  $\gamma$ -ray emitting region as a sign of sub-structure in the emission region?
- Diagnosing particle injection -
  - Understanding interplay between acceleration & radiation key to understand broad variety of curvature in photon spectra.
    - > couple acceleration models with emission models
    - > phenomenological prescription to bridge AGN jet emission models with particle injection/acceleration models
- On the jet composition -
  - Soft TeV-PeV  $\nu$ -spectra unlikely produced photohadronically by luminous  $>6\text{eV}$  photon emitters if  $\gamma$ -ray &  $\nu$ -emission co-spatial.

Anita Reimer, Innsbruck University

5th Fermi Symposium, Nagoya, Oct. 2014

- Many important questions are still open
- Where are the gamma-rays coming from?
  - Doesn't always come from near SMBH
- Is there a single "Blazar sequence"?
- Maybe, moving towards the "Blazar envelope"



# Tracking down AGN Emission Region w/ MW Data

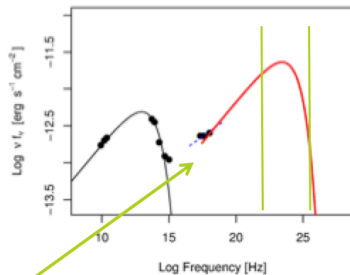
Meyer

## The Test: How to Rule out IC/CMB

[Georganopoulos+ 2006]

The IC Component is a copy of the synchrotron, shifted in frequency and luminosity.

**That shift is parameterized ONLY by  $B/\delta$ , no other free parameters.**



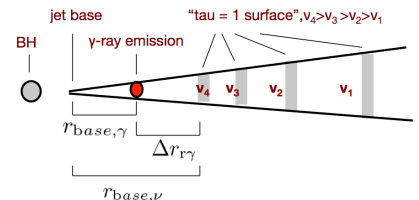
Getting the X-rays just right means fixing  $B/\delta$  and consequently implies a high level of **gamma-ray emission** which should be **detectable with Fermi**

Larsson

## Locating the $\gamma$ -ray emission

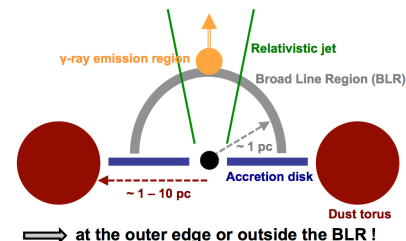
Fuhrmann et al. 2013, MNRAS, 44

- radio/radio lags: "time delay core shifts" and VLBI proper motion
- "Königl type", continuous jet
- absolute distance of gamma-ray emission region to the jet base:



$$r_{base,\gamma} = r_{base,\nu} - \Delta r_{\gamma}$$

⇒ **3C 454.3 @ 3 mm:**  
 $\Delta r_{\gamma} = 1.0 \pm 0.5$  pc  
 $r_{base,\nu} \sim 1.8$  to  $2.6$  pc  
 ⇒  $r_{base,\gamma} \sim 0.8 - 1.6$  pc



⇒ **at the outer edge or outside the BLR !**

5<sup>th</sup> Fermi Symposium—Nagoya, Japan—20–24 October 2014

- **AGN jets resolved in Radio & X-ray data (for nearby sources)**
- **Correlated variability with gamma rays can help to establish emission region**
- **Several cases where gamma rays appear to come from well downstream (~1-10 pc) in the jet**

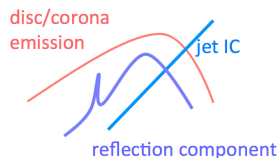


# Understanding AGN Variability

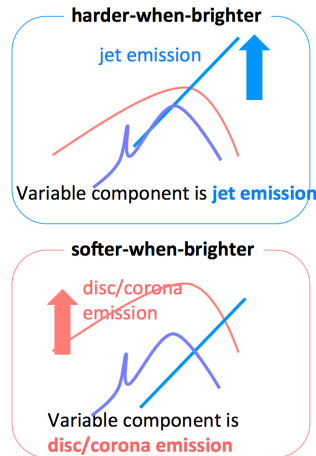
Edahiro

If we could obtain the X-ray spectral variability...

We infer the following X-ray spectral components for NGC 1275.



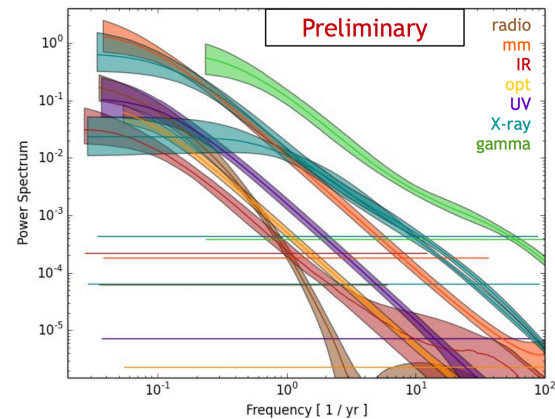
However, Suzaku cannot distinguish these two scenarios.



Further X-ray observations (XMM-Newton, NuStar, ASTRO-H) are important.

Sobolewska

Variability of 3C 273 from radio to  $\gamma$ -ray



Sobolewska+2015 (in prep.)

Malgosia Sobolewska - CAMK/Warsaw 5. International Fermi Symposium 20-25 October 2014 Nagoya, Japan slide 20/20

- MW data help disentangle which spectral components are varying
- Stochastic processes at play, broadband study of variability power helps to test models
- Surprising observation of  $\sim 720$  day periodic feature in gamma-ray, optical and radio bands in BL Lac object PG1553+133
- Dynamics near the SMBH

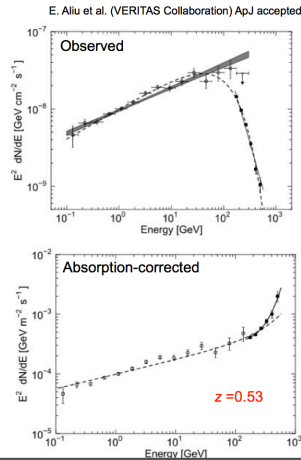
Ciprini

# AGN as a tool

Furniss

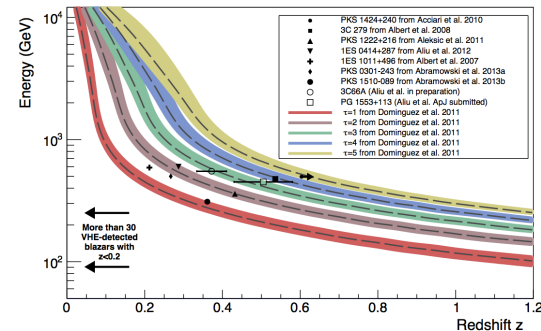
## PG 1553+113

- Blazar detected between 160 and 560 GeV
- $0.395 \leq z < \sim 0.58$  from far UV observations
- 80 Hours of data from May 2010 to June 2012 show steady emission
- 7% Crab
- Place limits on the EBL or  $z$  assuming intrinsic emission does not show spectral hardening



## The Gamma-ray Horizon

- EBL opacity curves (Dominguez et al. 2011)
- PKS 1424+240 probes an opacity of  $\tau > 5$
- 3C 66A and PG 1553+113 also pushing up in opacity
- S3 0218+35 @  $z=0.944$  detected by MAGIC between 100-200 GeV probes  $\tau \sim 2.5$



- **AGN population at cosmological distances**
  - **Blazar are the brightest persistent objects in the universe**
  - **Gamma-rays from AGN probe much of the history of the Universe**
  - **At high-energy pair-production off of optical or infrared light will attenuate gamma-ray flux**

# GRBs

Granot

## Synergies with other instruments & Conclusions

- **Current:** Swift, optical/radio telescopes, NuSTAR, Suzaku, TeV (HAWC, IACTs), ...
- **Multi-messenger:** neutrinos (Ice Cube), UHECRs, gravitational waves
- **Future:** CTA, SVOM, LSST, ZTF, SKA, aLIGO/VIRGO, Astro-H, X/γ-ray polarimetry, ISS-lobster, ...
- *Fermi* has greatly contributed to GRB science
- We got some answers, but more new questions
- *Fermi* GRBs also contributed to non-GRB science
- There is still a lot to look forward to...

Veres

## RADIATION SOURCES- TWO ZONE MODEL

- ▶ Synchrotron peak from photosphere, BB (Mészáros & Rees 2011)
- ▶ FS/RS synchrotron
- ▶ FS/RS SSC (Sari & Esin 2001)
- ▶ Prompt up-scatters on FS/RS electrons (Beloborodov 2005, Murase et al., 2011)
- ▶ BB+FS, BB+RS (Ryde 2005; Ando & Mészáros 2008)
- ▶  $p^+$  sync., FS+RS, RS+FS (Razzaque et al., 2009, He et al. 2011)
- ▶ Max synch./KN cutoffs (Guetta & Granot 2003)



Péter Veres (GWU)

名古屋市 (Nagoya) October 24, 2014

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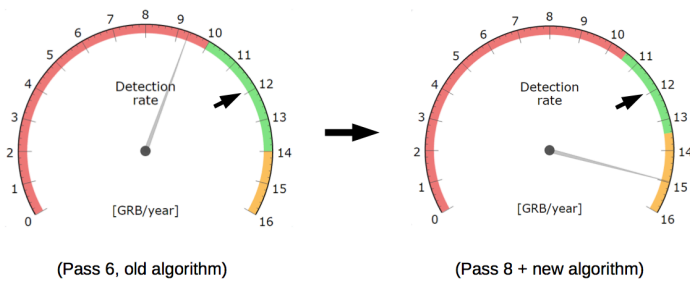
- Understanding of GRBs has changed with *Fermi* data
- Distinct High-energy components to emission
- Temporal lags between MeV and GeV emission
- This has prompted development of new models
- Pass 8 model great promise below 100 MeV
- Also much large effective LAT field-of-view

# Many More GRBs, and one very Special GRB

Vianello

## Now exceeding expectations

(Standard likelihood detections, no LLE)



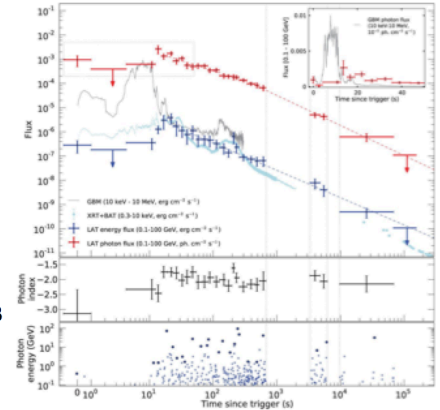
Racusin



## Remarkable Features of GRB 130427A



- **Bright! - Highest GRB fluence ever recorded**
- **LAT (>100 MeV) emission was extremely bright and long-lasting**
- **Relatively low redshift, but not subluminal**
- **Bright prompt optical flash and afterglow**
- **Long lived broadband radio – X-ray afterglow**
- **Most Luminous SN-GRB association – SN2013cq**



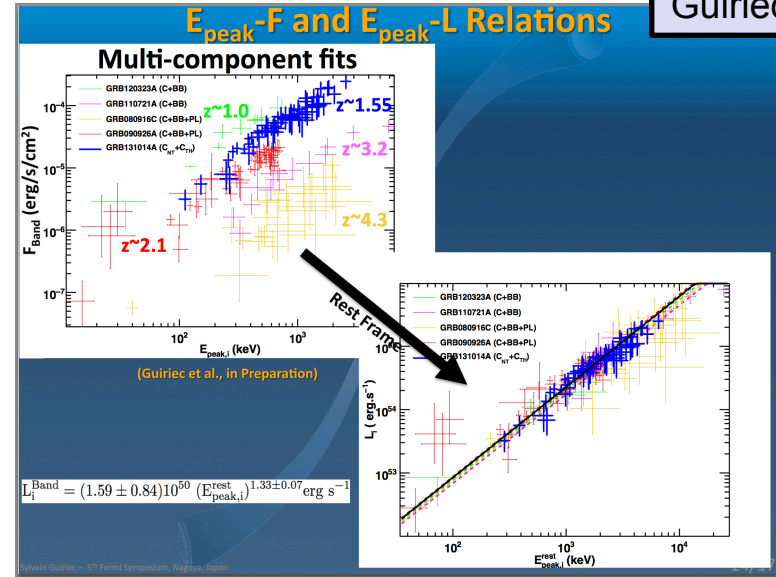
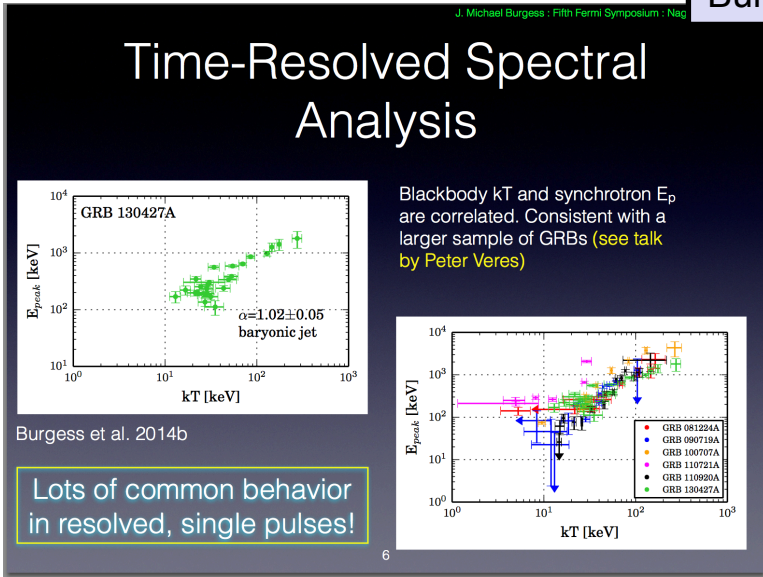
Ackermann et al. 2013, Science

- **Unrelated improvements have significantly increase the number of LAT-detected GRBs (now up to 100)**
  - **Pass 8 reconstruction**
  - **GRB search algorithm**
- **Unprecedented quality data from GRB 130427A give us a new view of GRB physics**

# Moving Beyond the “Crisis of the Band Model”

Burgess

Guiriec

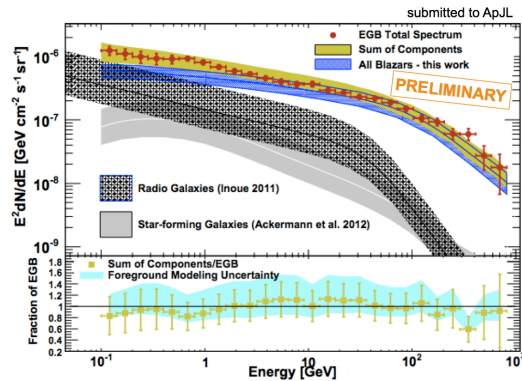


- “Crisis of the Band Model” was a bit topic at 4<sup>th</sup> Fermi symposium
- Phenomenological Band model no longer adequate to explain GRB spectra
- New efforts to move beyond the Band Model
  - Physically motivated modeling (e.g. Burgess)
  - Testing consistency of extra components beyond Band model (e.g., Guiriec)
- Much more detailed modeling Veres

# Isotropic Diffuse Emission

Ackermann

## Source populations contributing to the EGB



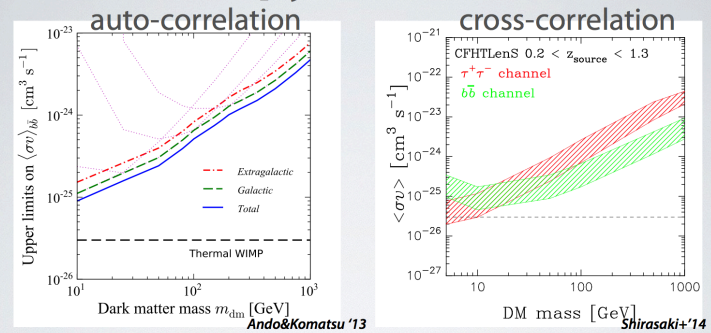
- ... but reality might be more complex.
- Multiple populations might contribute to explain the observed spectrum.
- Blazars seem to dominate above few GeV.

Markus Ackermann | 5th Fermi Symposium, Nagoya | 23/10/2014 | Page 14



Inoue / Shirasaki

## Anisotropy & Dark Matter



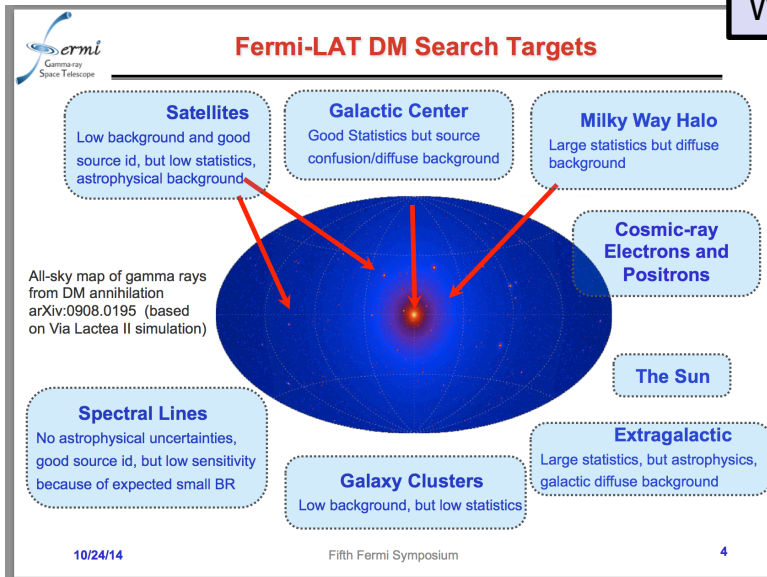
- Angular power spectra of CGB is a powerful tool to constrain the DM properties (e.g. Ando & Komatsu '06, '13).
- Cross-correlation between cosmic shear and CGB will be a new powerful tool (e.g. Shirasaki+'14) -> **See Shirasaki's talk.**

- Isotropic gamma-ray background (IGRB) from 100MeV to  $> 500$  GeV
- **Spectral rollover above 100 GeV**
- Unresolved blazars, other AGN & starburst galaxies appear to account for most of the IGRB
- More information can be obtained from anisotropy or cross-correlation analyses

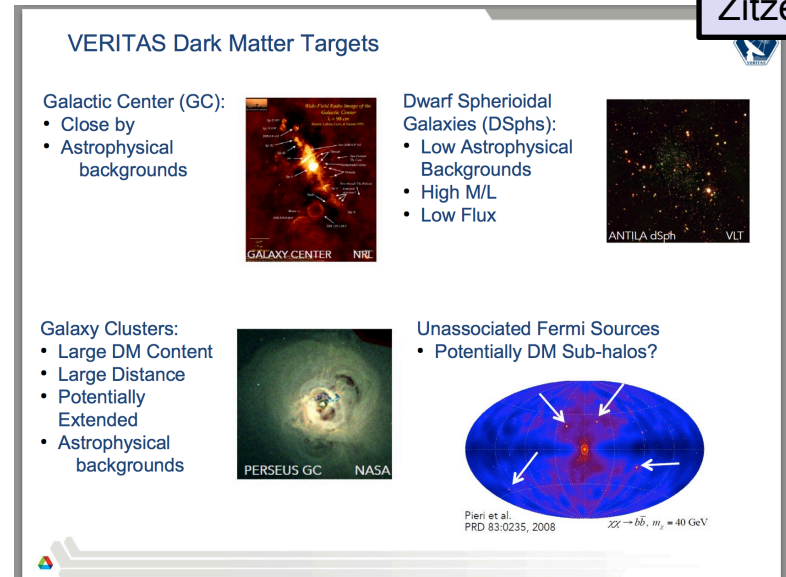


# Dark Matter Searches

Wood



Zitzer



- **Very nice summaries of DM searches from Wood (mainly LAT) and Zitzer (Veritas)**
  - **Wide variety of search targets, most have no observed signal**
  - **GeV Galactic center excess (more later) and positron fraction are main potential signals**
    - **Possible alternative astrophysical interpretations**
- **Also, a comprehensive talk about primordial black holes**
- **GBM search for spectral lines from sterile neutrinos**

MacGibbon

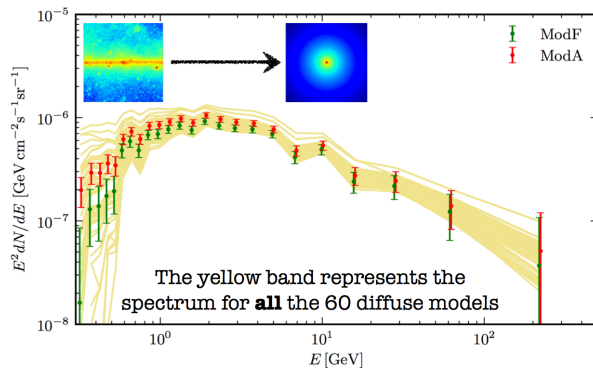
Horiuchi



# Galactic Center Excess Uncertainties

Calore

## Results: excess emission spectrum



- ✓ Existence of an extended excess emission associated with the GCE template.
- ✓ Energy spectrum peaked at 1-3 GeV and rising at low energies.
- ✓ Excess still significant at high energies, for the **whole** set of diffuse models.

Talk by S.Murgia

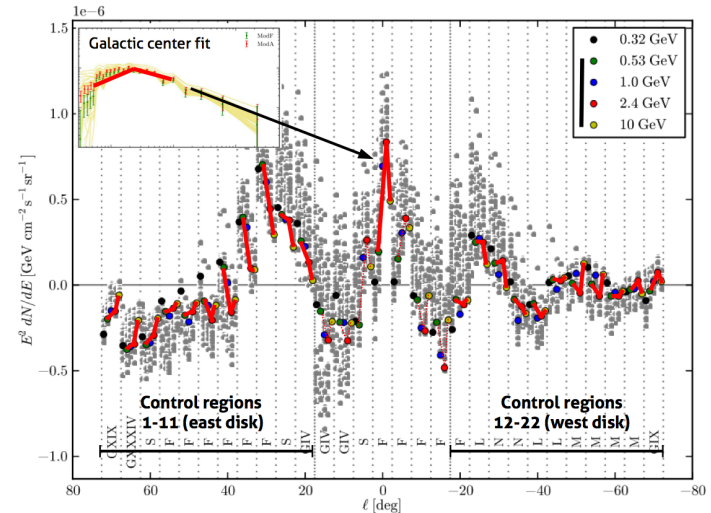
Francesca Calore - University of Amsterdam

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V Fermi Symposium

Weniger

## Flux in excess template shifted along the Galactic plane

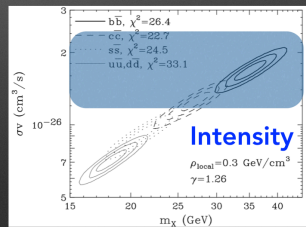
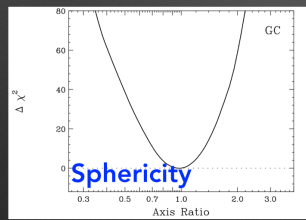
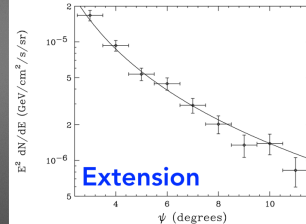
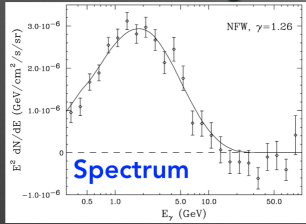


- **Very impressive talks by Calore & Weniger characterizing systematic uncertainties in studying Galactic center excess**
- **Probing of family of GALProp-based foreground models**
- **Empirically quantify goodness-of-fit of foreground/background models using control regions along the Galactic plane**
- **GC-excess is robust against systematic uncertainties**
- **Morphology is also robust. Spectrum less so, broken power law is equally good fit as DM bb spectrum**

# Galactic Center Excess Interpretation

Linden / Hooper

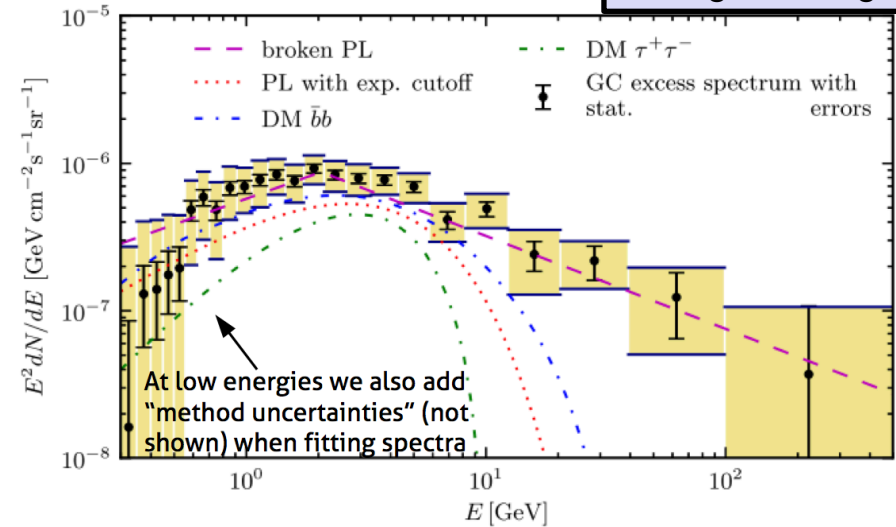
## Why: Dark Matter



Daylan et al. (2014, 1402.6703)

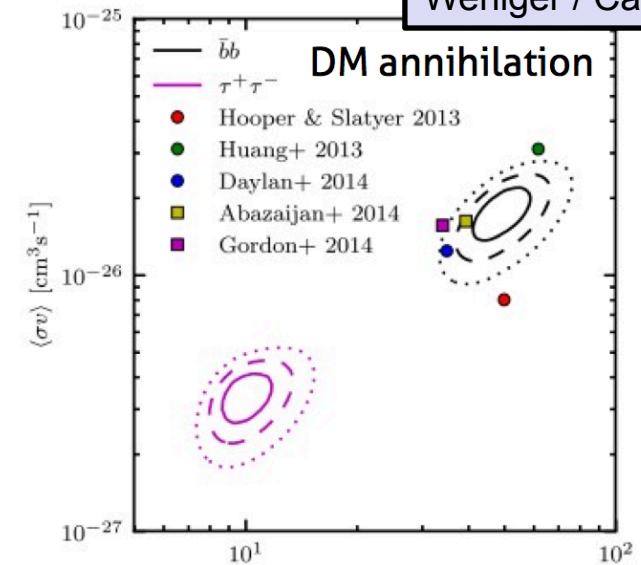
see talk by Dan Hooper

Weniger / Murgia



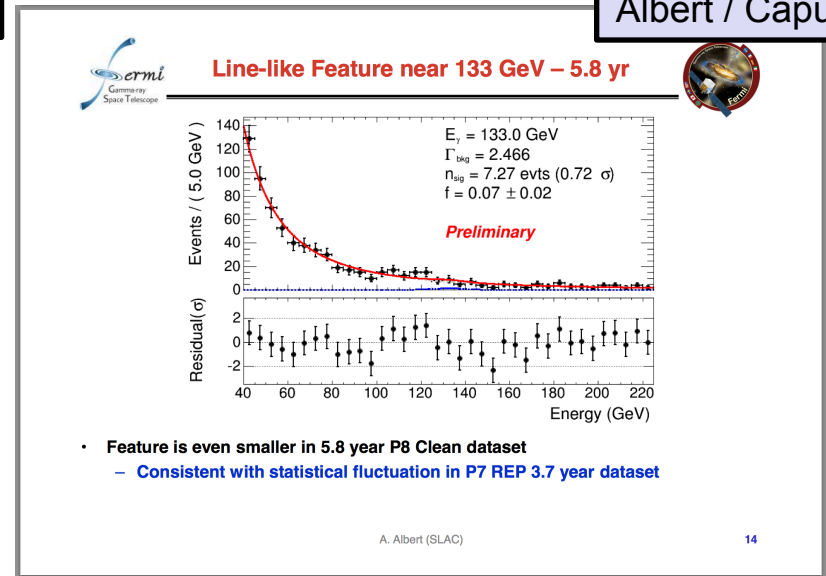
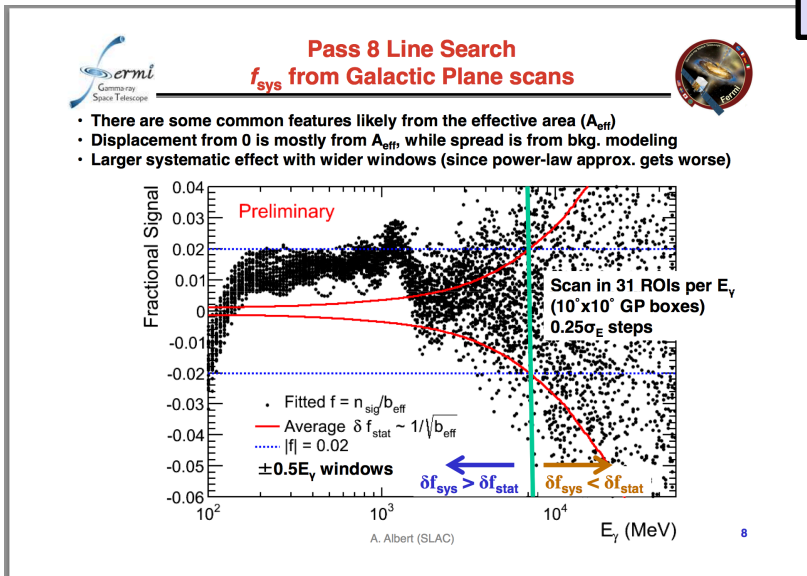
Weniger / Calore

- GC excess is consistent with DM interpretation in several ways
- Sphericity, extension and intensity disfavor some other proposed interpretations
- Most favored DM fits cluster near  $3\sigma$  contours of Calore et al. DM  $b\bar{b}$
- $\langle\sigma v\rangle \sim 2e-26$   $M_\chi \sim 50$  GeV



Albert

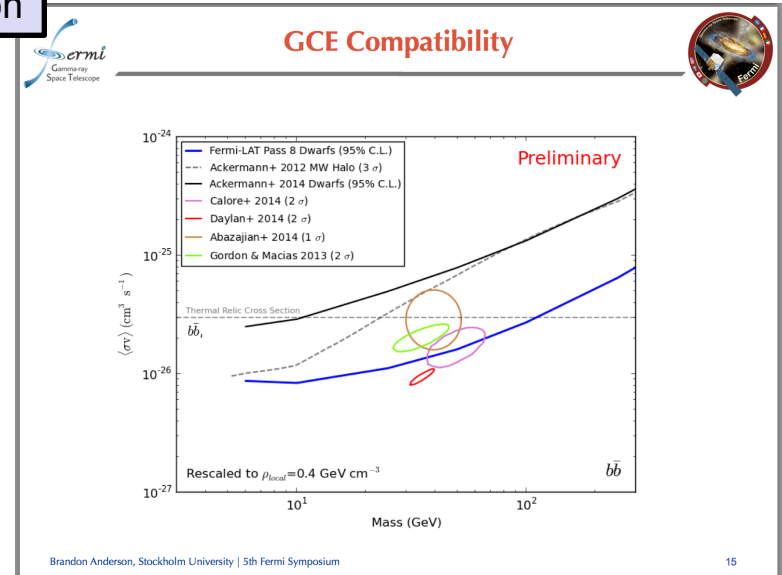
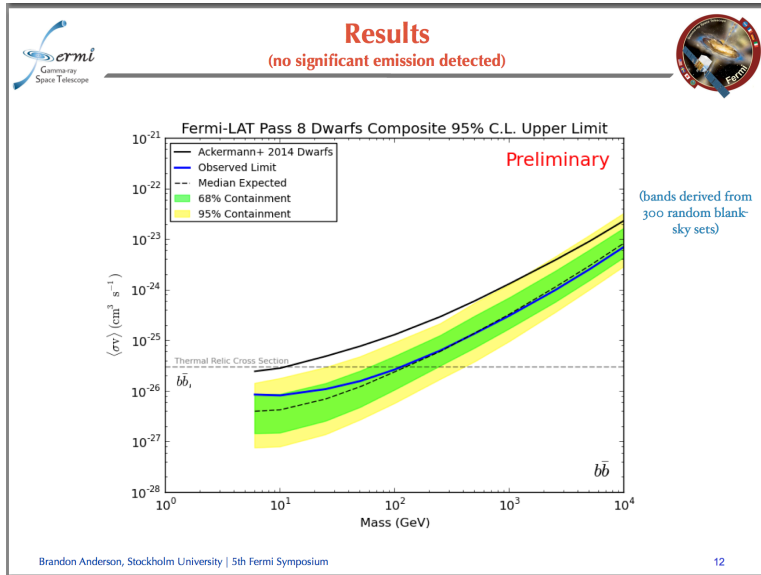
Albert / Caputo



- “Low energy” (< 10 GeV) line search was systematically dominated
- Empirically quantified systematic uncertainties with scan of control region
- 135 GeV Feature has faded into obscurity (0.7 $\sigma$  pre-trial)

# Dwarf Spheroidal DM Search

Anderson



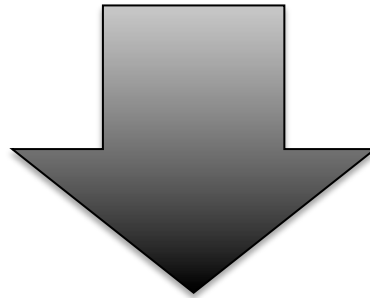
- Updated stacked Dwarf Spheroidal search to Pass 8
- No signal observed, new upper limits fall very close to expected values
- Limits are “in tension” with favored regions from GC analysis
  - Note however that GC analysis error ellipses don’t include scaling uncertainties from DM density

# OUTLOOK

## New Data Feeds Discoveries

---

- **Pass 8 data opens LAT low-energy range**
- **3FGL catalog and various source class specific catalogs will be a key element of many upcoming multi-wavelength studies**



## Highlights from the 6<sup>th</sup> Fermi Symposium

- **New discoveries and models facilitated by 3FGL catalog**
- **4FGL catalog (Pass 8 based)**



# Many New Questions Posed at This Meeting

### Key puzzles

- Why have these systems stopped being full-fledged
- Do other LMXBs enter such low-luminosity accretion
- What is going on in these peculiar accretion-disc states
- How do these systems produce  $\gamma$ -rays?
- What is the ultimate fate of these systems?

### Leptonic / Hadronic Summary

	Leptonic	Hadronic
• Gamma-ray spectrum	●	●
• Microwave haze	●	●
• No spectral changes	●	●
• Narrow boundary	●	●
• Absence of a visible shock front	●	●

**Possible leptonic scenario: (Mertsch, Sarkar, Guo, Mathews etc.):**

- Jets from the black hole create shock front
- Shock front dissipates, but leaves plasma turbulences behind
- Electrons are accelerated on the turbulences with a characteristic time less than the cooling time

**Possible hadronic scenario: (Crocker, Aharonian):**

- Wind from SNRs produces CR during several billions of years
- Magnetic fields confine the CR in the bubble volume
- WMAP haze produced by ~ 30 GeV electrons in the SNR wind which have a characteristic cooling time ~ 10 Myr

### The three stages of transitional pulsars

**Accretion powered state**  
Bright X-ray outburst (~10<sup>36</sup> erg/s)  
X-ray pulsations

**An intermediate (propeller?) state**  
Sub-luminous accretion (~10<sup>34</sup> erg/s)  
Brighter gamma-ray emission

**Rotation powered state**  
Faint in X-rays (~10<sup>32</sup> erg/s)  
Radio/gamma-ray pulsations

### Understanding particle acceleration and gamma-ray emission at the Sun

- Particles accelerated during the impulsive phase interact with the solar surface (right below the photosphere) producing gamma-rays (pion production most likely)
- Part of the accelerated particles can escape and eventually can be re-accelerated by the CME shock (This also explains the correlation with SEP)
- Continuously accelerated particles can travel along magnetic field lines, and interact with the dense solar surface in front of the solar limb.
- Alternatively, CME re-accelerated particles can travel back to the Sun along magnetic field lines and interact with dense region, explaining the long lasting emission.

### Alternative possibilities

- A cloud/star falling in the jet?
- The short time scale and flickering can be explained by the size of the shock irregularities.
- But the luminosity of IC 310 flare would require an extreme beaming of the emission.
- Jets-in-jet models:
- The short time scale can be explained by a jet composed of smaller sub-jets pointing in the direction of the observer

### Jets of Active Galactic Nuclei: open questions

**Jet composition?** (rel./cold leptons & hadrons, B-fields & their properties)

**γ-ray production: Where? How?**

**Energy transport?**

**Energy conversion?**

**Jet formation?**

### Comparison to propagation models

- GALPROP - diffusion models
- results favor smaller halo
- boundary condition: zero at  $Z_{max}$ , a limitation?

models from Ackermann et al 2012 AgJ 750 3

**Otsukaresama deshiita!**  
**“I see you have been working very hard!” or maybe “Good job!”**

有難う 御座います

# Thanks!!!

## Local Organizing Committee

Lynn Cominsky  
Yasushi Fukazawa  
J.D. Myers  
Tsunefumi Mizuno  
Judy Racusin  
Hiromitsu Takahashi  
Hiro Tajima  
Yasuyuki Tanaka  
Toni Venters

NASA, DOE & international  
agencies supporting the mission



Contributors & Session Chairs

## Science Organizing Committee

Julie McEnery  
and the Flight Operations Team

### Flight Operations Team

- Scheduled 18358 contacts with TDRSS
- Executed 10218 procedures on the observatory
- Respond to an average of ~10 observatory alerts per day
- Perform daily, weekly and quarterly review of spacecraft and instrument health and safety



Markus Ackermann  
Bill Atwood  
Ronaldo Bellazzini  
Roger Blandford  
Elliott Bloom  
Philippe Bruel  
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# 有難う 御座います

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Tajima-san

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