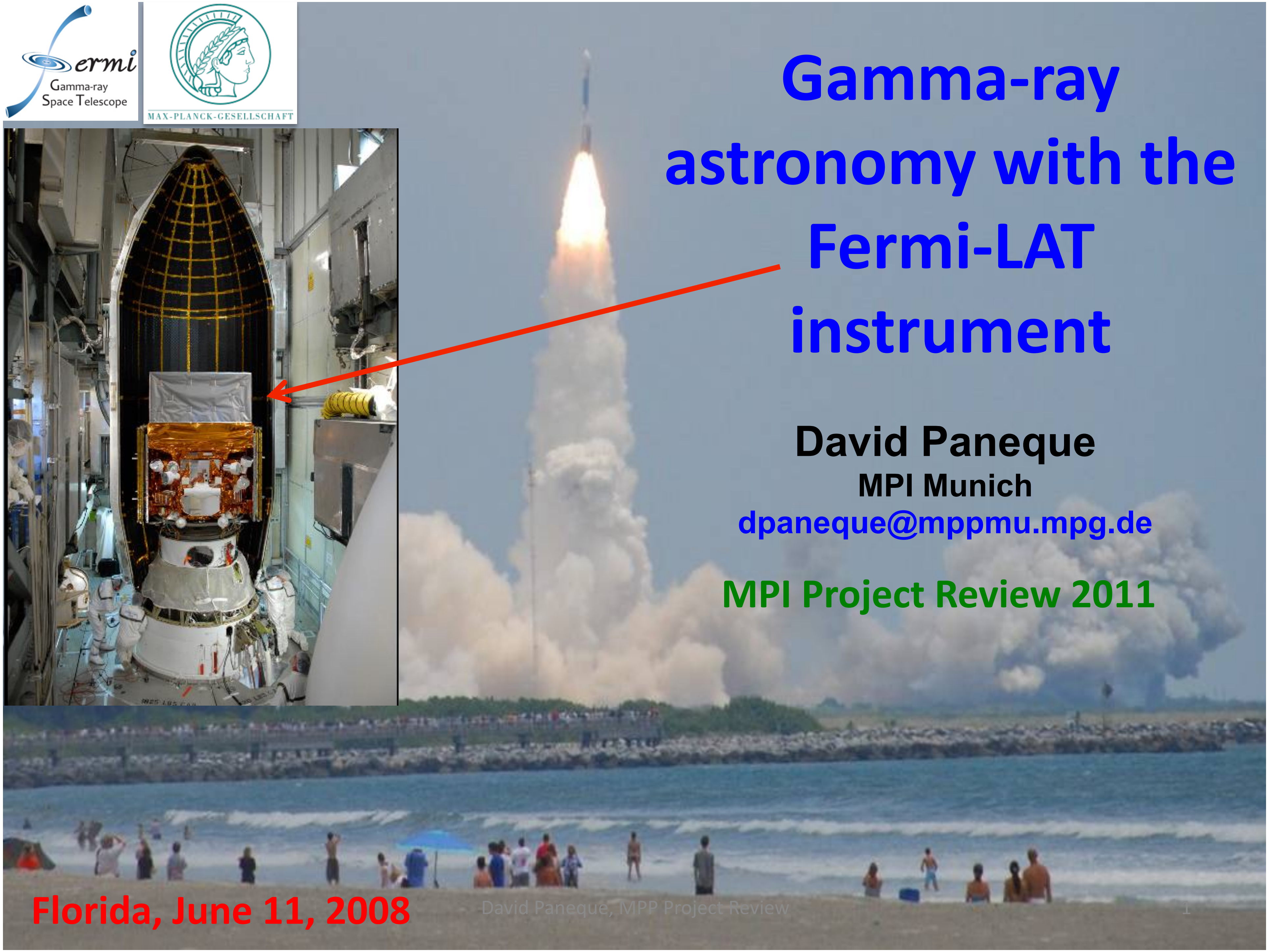

Gamma-ray astronomy with the Fermi-LAT instrument

David Paneque
MPI Munich
dpaneque@mppmu.mpg.de

MPI Project Review 2011

Florida, June 11, 2008

Gamma-ray astronomy with the Fermi-LAT instrument

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Project Review 2011

Outline

1 – Brief overview of the Fermi mission (→ the Large Area Telescope)

2 – Some (few) selected results

3 – Work done/led by MPI Munich

4 – Conclusions and outlook

Instrumentation for gamma-ray astronomy (the big picture)

	Exploration phase	**Established field**	**“Ultimate” (?) generation** **(*population + precision studies*)**
	~ 10 sources	**~ 100 sources**	**~ 1000-10000 sources**
Pair conversion experiments (MeV-GeV) **Space**	*70s (SAS-2, COS-B)*	*90s (EGRET)*	Now **Fermi**
Ground ***Cherenkov Telescopes (GeV-TeV)***	*80-90s (WHIPPLE, HEGRA,CAT)*	*00s* ***(Cangaroo, HESS, MAGIC, VERITAS)***	future **CTA**

Now **MAGIC II HESS II VERITAS upgraded**

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Novel discipline

lots of room for improvement and potential discovery

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Novel discipline

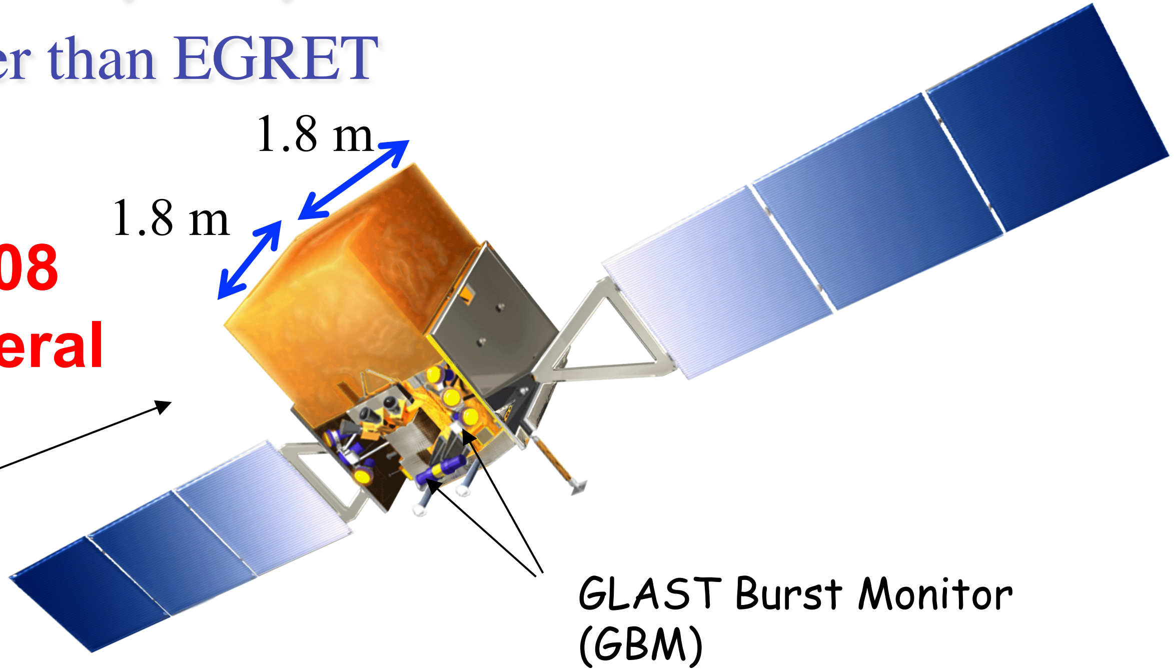
The Max-Planck-Institute in Munich (Prof. Teshima)
Is very actively involved in MAGIC, Fermi and CTA,
→ Forefront of experimental gamma-ray astronomy

lots of room for improvement and potential discovery

1 - Fermi mission (brief overview)

- **Fermi: An International Science Mission to perform gamma-ray astronomy, with an additional X-ray detector for GRBs**
  - Large Area Telescope (LAT); 20 MeV – >300 GeV
  - GLAST Burst Monitor (GBM); 10 keV – 30 MeV
- **The strategy** *(5 years operation, 10+ years goal)*
  - Survey mode ⇒ entire sky every three hours
  - Sensitivity ~ 30 better than EGRET

Launch: June 11th 2008
Cape Canaveral



1 - Fermi mission (brief overview): The LAT instrument

modular design

4x4 array of identical towers: Tracker + Calorimeter + Electronics Module.

1 - Fermi mission (brief overview): The LAT instrument

modular design

4x4 array of identical towers:

Tracker/Converter (TKR):

- **Silicon strip detectors .**
- **W conversion foils.**
- **~73 m^2 of silicon (total).**
- **~9x10^5 electronic chans.**
- High precision tracking, small dead time.

Calorimeter (CAL):

- **1536 CsI crystals.**
- 8.5 radiation lengths.
- Hodoscopic.
- Shower profile reconstruction (leakage correction)

1 - Fermi mission (brief overview): The LAT instrument

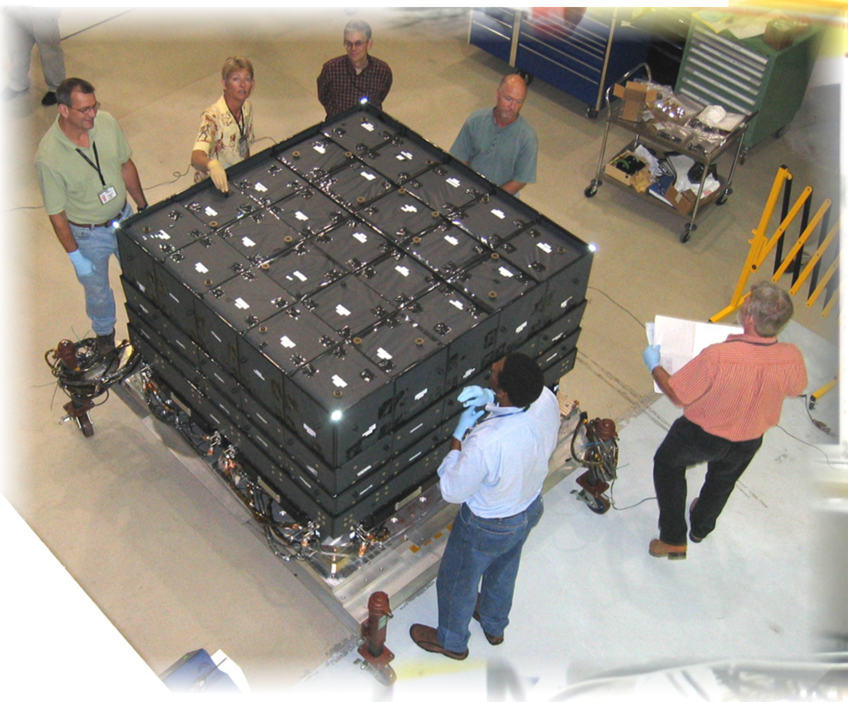
Challenging design: 1.8m x 1.8m x 1.2m ; 2800 kg, 1M channels; but only 650 W

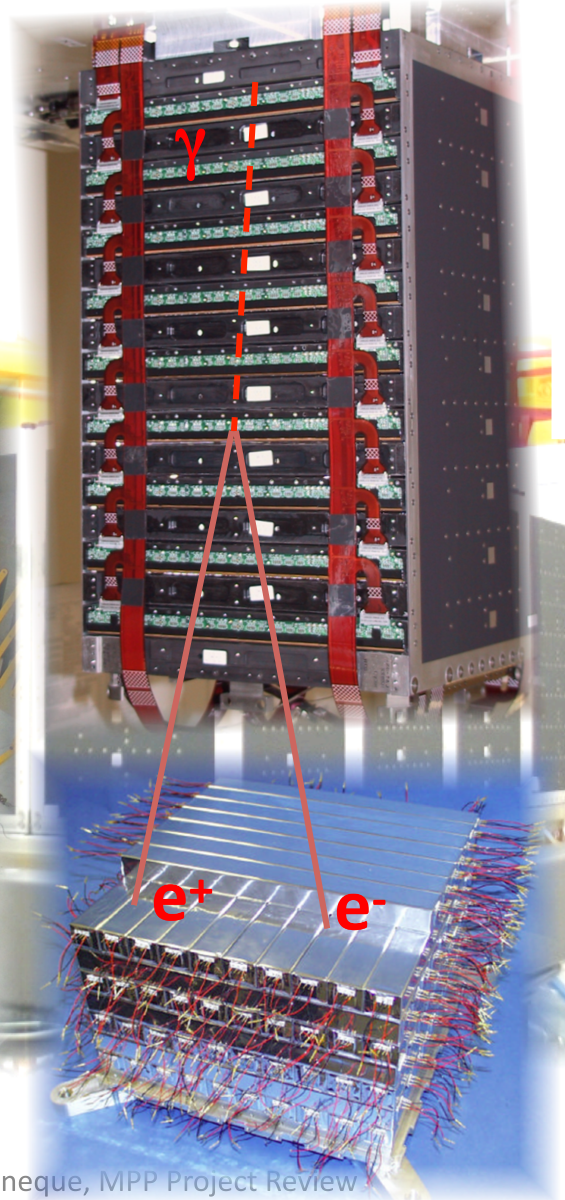
modular design

4x4 array of identical towers:

Anti-Coincidence (ACD):

- Segmented (89 tiles).
- Self-veto @ high energy limited.
- 0.9997 detection efficiency (overall).





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- Shower profile reconstruction (leakage correction)

LAT performance: improvement at GeV energies

LAT is the next great step beyond EGRET in the GeV band, providing a huge leap in capabilities:

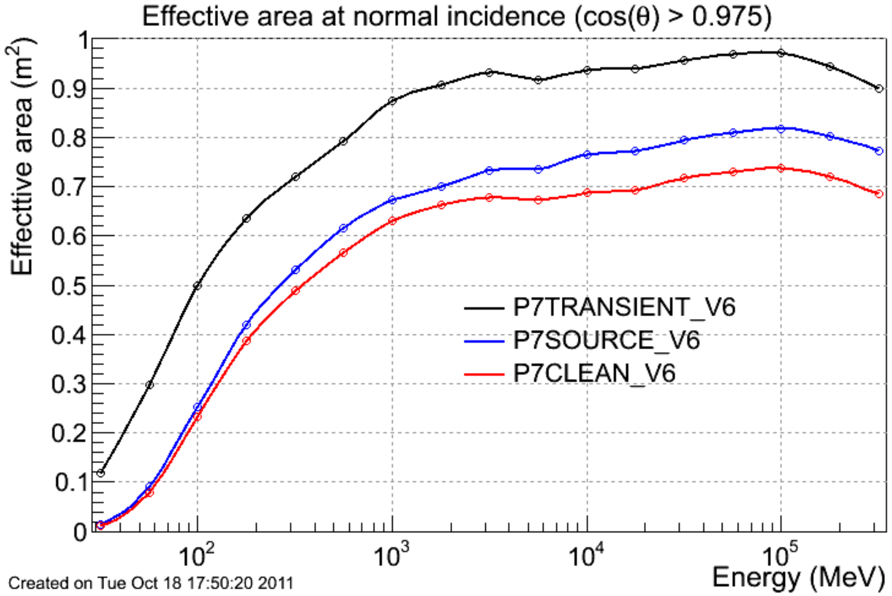
- *Large FOV (~20% of sky), factor 4 greater than EGRET*
- *Complete Sky coverage (~3 hours)*
- *Angular resol. for gamma rays (PSF)> 3x better than EGRET*
- *Large effective area > 5x larger than EGRET*
- *4 decades in energy, including Unexplored E > 10 GeV*

→ ***Results in factor > 30 improvement in sensitivity***
> 100 above 10 GeV

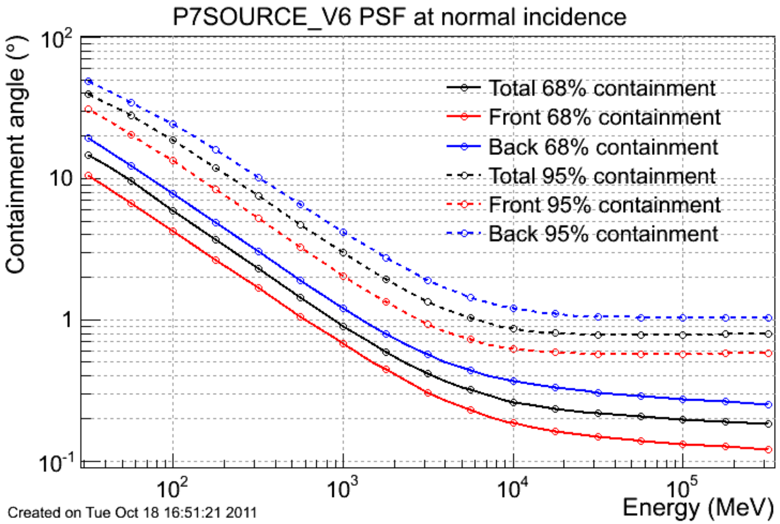
- ***Smaller dead time (27 microsec; 4000x better than EGRET)***

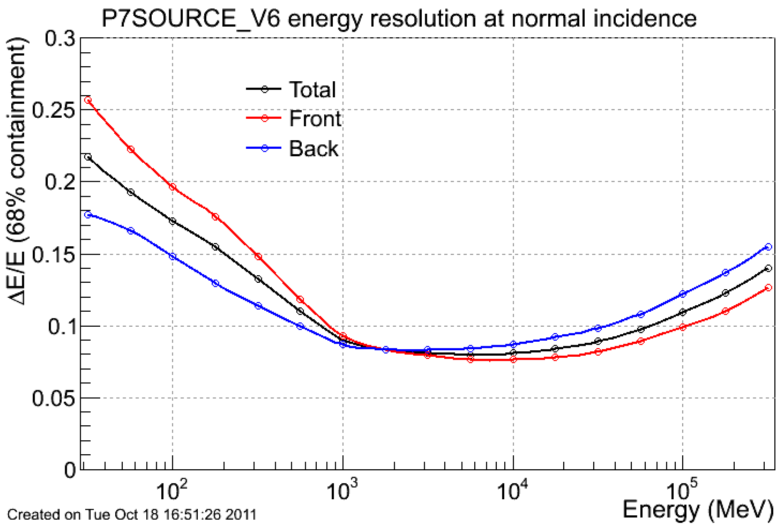
→ ***Excellent for fast&bright transient events***

LAT performance: summary



Effective Area: ~ 0.8 m² (on axis)
Energy Resolution: ~8%
PSF (68%) at 100 MeV ~ 5°
PSF (68%) at 10 GeV ~ 0.2°
Field Of View: 2.4 sr

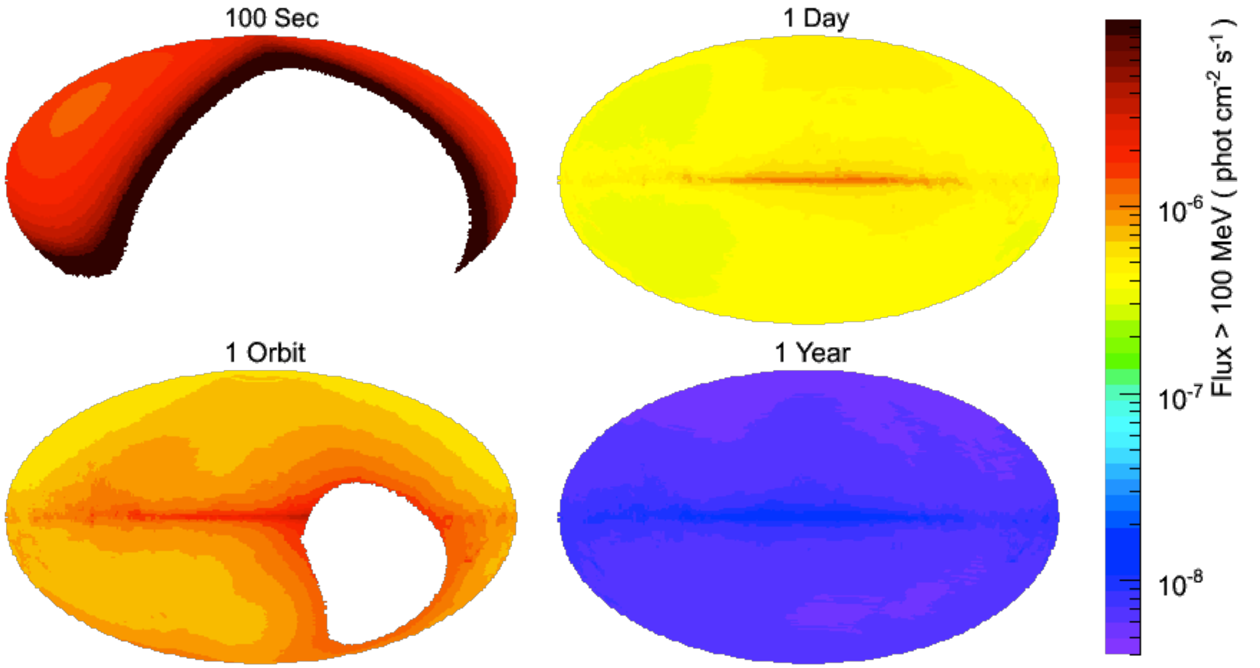




LAT performance: sensitivity

LAT sensitivity on 4 different timescales:

100 s, 1 orbit (96 mins), 1 day and 1 year



- **In survey mode, the LAT observes the entire sky every two orbits (~3 hours), each point on the sky receives ~30 mins exposure during this time.**
- **After 1 day, exposure is rather uniform (factor 2)**

2 - Some selected results

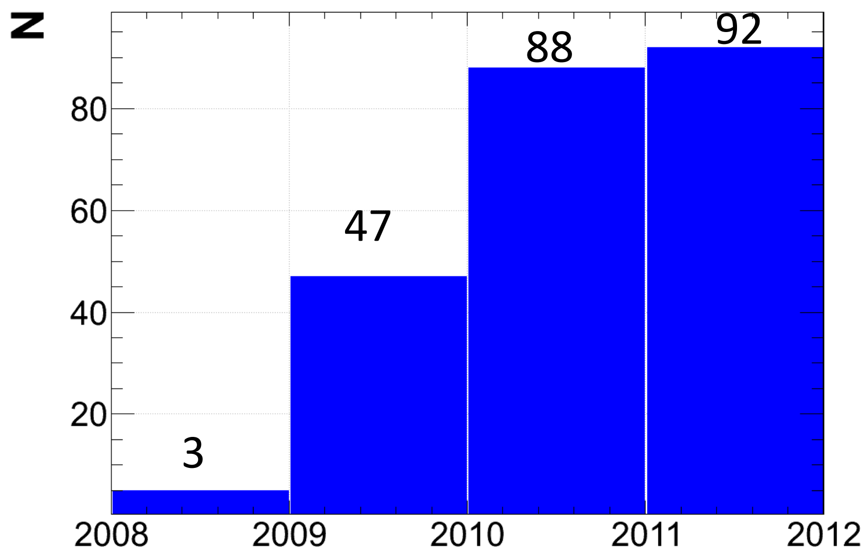
Scientific publications from Fermi collaboration (Cat1+Cat2+Cat3) until Dec18th, 2012

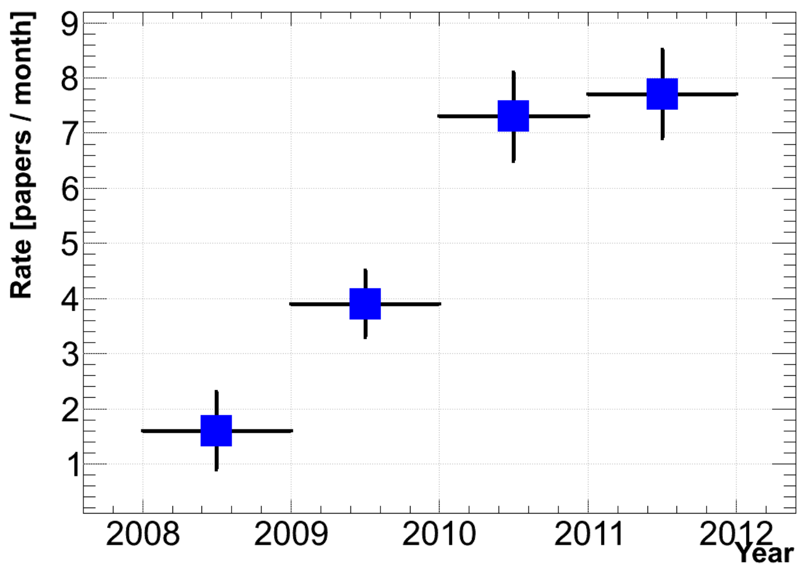
Information retrieved from http://www-glast.stanford.edu/cgi-bin/pubpub

Number of published papers = 230

Many more in the pipeline…

In the last 2 years, publication rate is about 7.5 papers per month





Fermi-LAT Awarded with the 2011 Rossi Prize (of the High Energy Astrophysics Division of the American Astronomical Society) *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.*

Difficult to choose what results to show …

2 – Some (few) selected results

2.1 – The gamma-ray sky (the big picture)

2.2 – Galactic sources → Pulsars

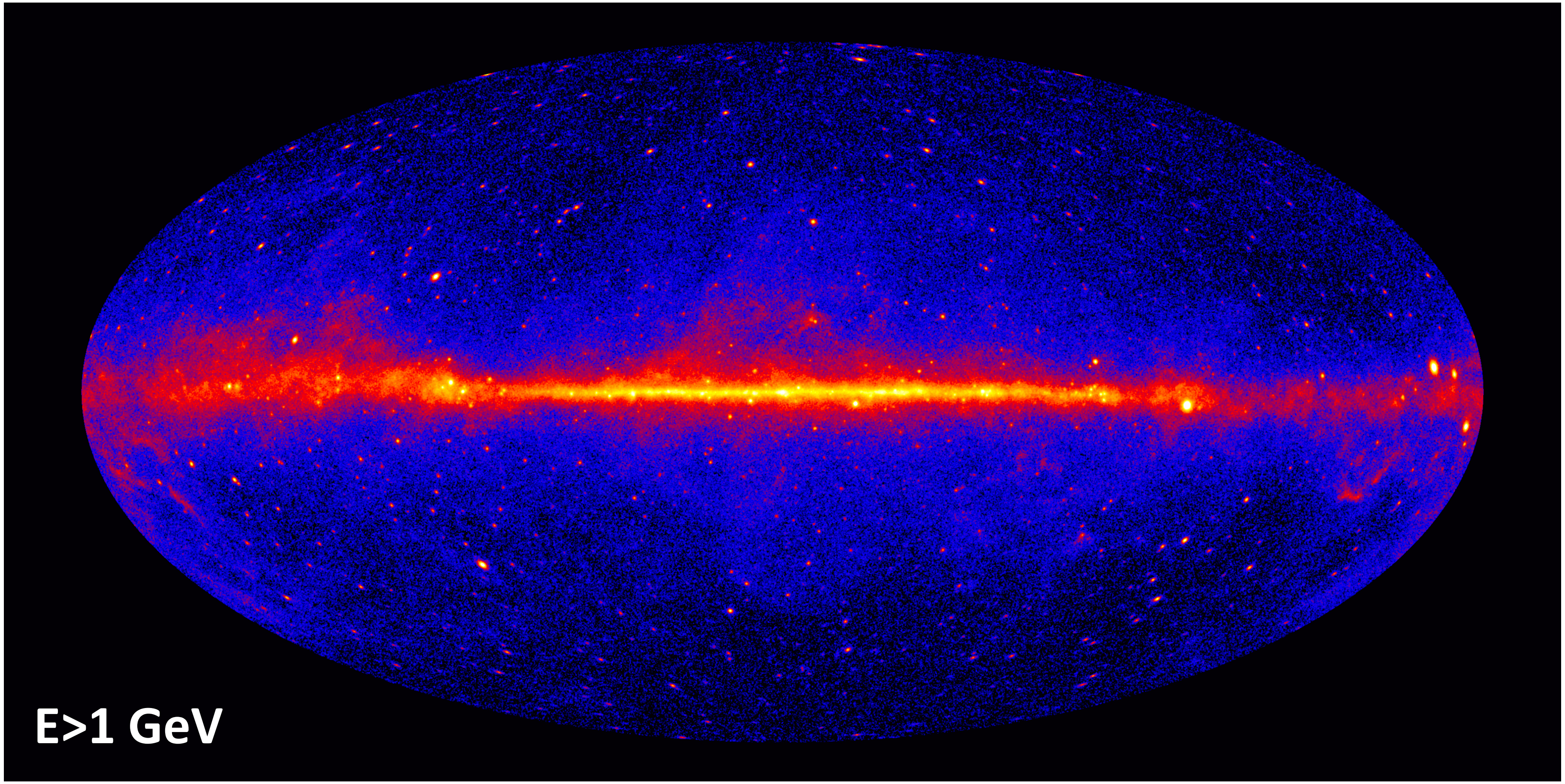
2.3 – Gamma-ray Bursts (GRB)

Very brief !!!

→ *Further results in MPP colloquium during the first quarter of 2012*

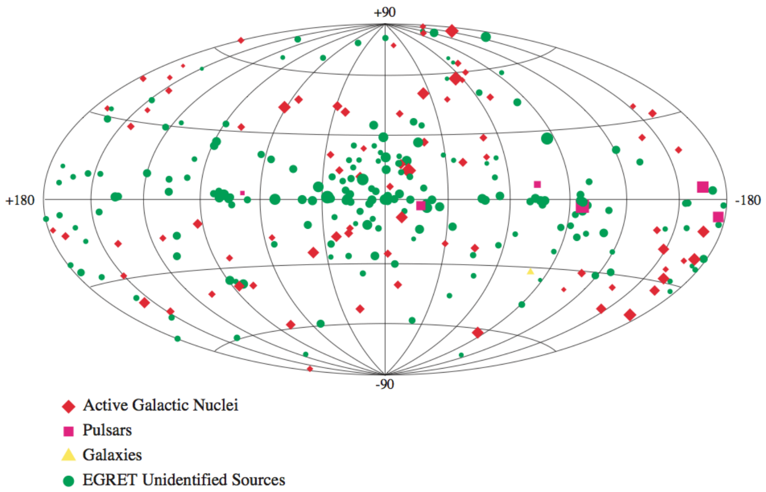
2.1 – The gamma-ray sky

This is how the sky looks when integrating over 3 years of Fermi-LAT data



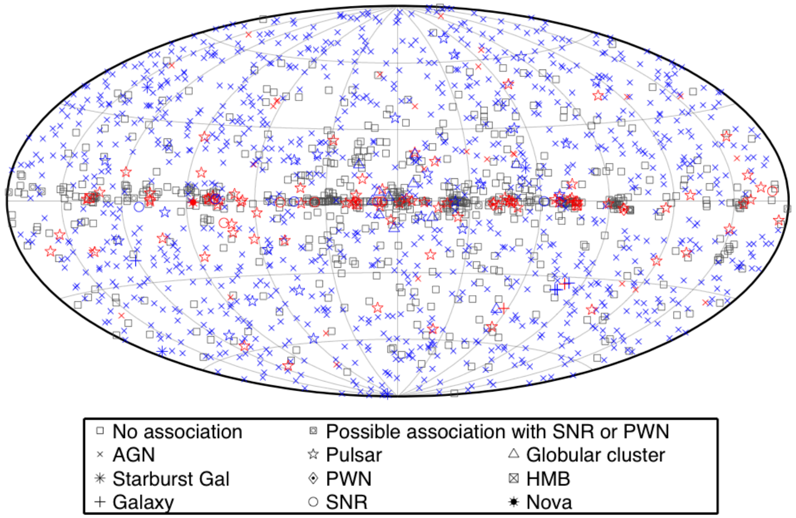
One can clearly identify diffuse structures, as well as point sources

2.1 – The gamma-ray sky : Gamma-rays above 100 MeV



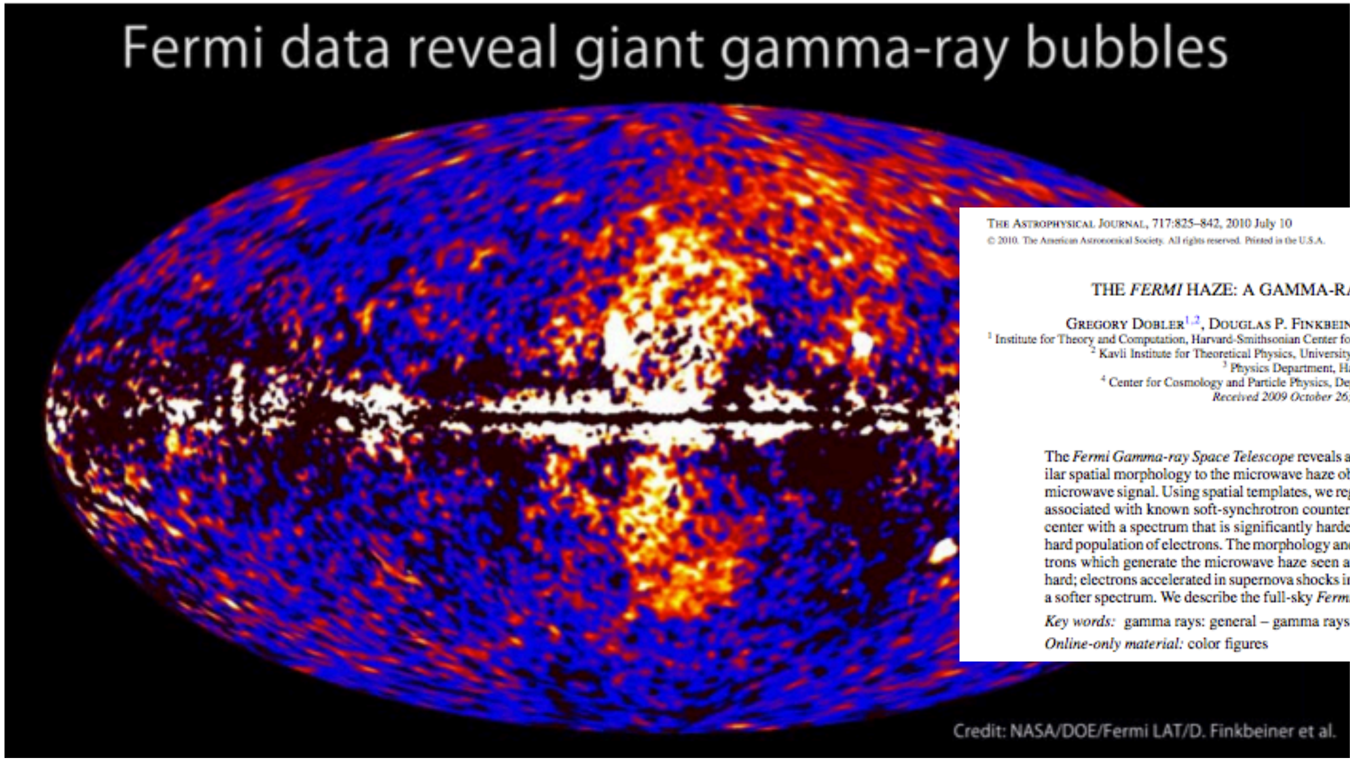
3rd EGRET Catalog
Hartman etal 1999
271 sources
170 unidentified
101 identified/associated

Large improvement in the knowledge of the gamma-ray sky in only ~10 years



2nd Fermi-LAT Catalog (2 years of operation)
Abdo etal 2011
1873 sources
576 unidentified
1297 identified/associated

2.1 – The gamma-ray sky : “the unexpected”



THE ASTROPHYSICAL JOURNAL, 717:825–842, 2010 July 10
doi:10.1088/0004-637X/717/2/825

THE *FERMI* HAZE: A GAMMA-RAY COUNTERPART TO THE MICROWAVE HAZE

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[2] Kavli Institute for Theoretical Physics, University of California, Santa Barbara Kohn Hall, Santa Barbara, CA 93106, USA
[3] Physics Department, Harvard University, Cambridge, MA 02138, USA
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Received 2009 October 26; accepted 2010 April 26; published 2010 June 18

ABSTRACT

The *Fermi Gamma-ray Space Telescope* reveals a diffuse inverse Compton (IC) signal in the inner Galaxy with a similar spatial morphology to the microwave haze observed by WMAP, supporting the synchrotron interpretation of the microwave signal. Using spatial templates, we regress out π^0 gammas, as well as IC and bremsstrahlung components associated with known soft-synchrotron counterparts. We find a significant gamma-ray excess toward the Galactic center with a spectrum that is significantly harder than other sky components and is most consistent with IC from a hard population of electrons. The morphology and spectrum are consistent with it being the IC counterpart to the electrons which generate the microwave haze seen at *WMAP* frequencies. In addition, the implied electron spectrum is hard; electrons accelerated in supernova shocks in the disk which then diffuse a few kpc to the haze region would have a softer spectrum. We describe the full-sky *Fermi* maps used in this analysis and make them available for download.

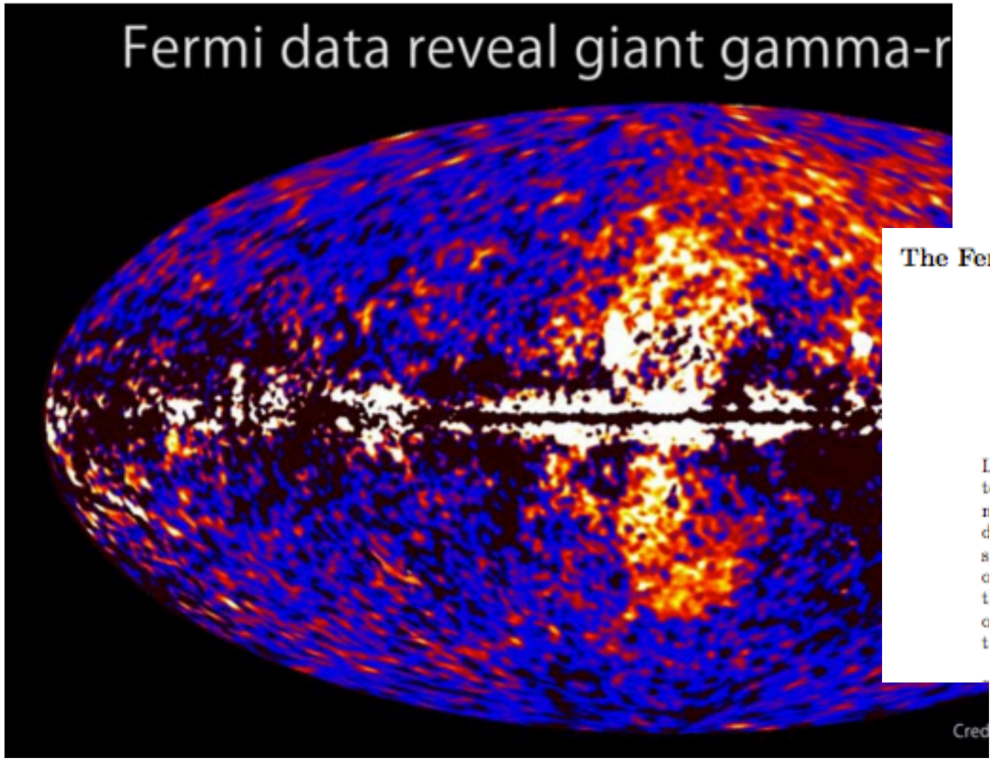
Key words: gamma rays: general – gamma rays: ISM

Online-only material: color figures

Almost symmetric structures (suggests relation to the Galactic Center)
Extended structures (~50 deg → ~10 kpc)
Hard energy spectrum (~E^{-2})
Possible sharp edges
Possible counterparts at microwave (WMAP) and X-ray (ROSAT)

Word of Caution: the shape of the features is sensitive to the diffuse model

2.1 – The gamma-ray sky : "the unexpected"



GIANT GAMMA-RAY BUBBLES FROM *Fermi*-LAT: AGN ACTIVITY OR BIPOLAR GALACTIC WIND?

MENG SU[1,3], TRACY R. SLATYER[1,2], DOUGLAS P. FINKBEINER[1,2]

Draft version October 19, 2010

ABSTRACT

Data from the *Fermi*-LAT reveal two large gamma-ray bubbles, extending 50 degrees above and below the Galactic center, with a width of about 40 degrees in longitude. The gamma-ray emission associated with these bubbles has a significantly harder spectrum ($dN/dE \sim E^{-2}$) than the IC emission from electrons in the Galactic disk, or the gamma-rays produced by decay of pions from proton-ISM collisions. There is no significant spatial variation in the spectrum or gamma-ray intensity within the bubbles, or between the north and south bubbles. The bubbles are spatially correlated with the hard-spectrum microwave excess known as the *WMAP* haze; the edges of the bubbles also line up with features in the *ROSAT* X-ray maps at 1.5 – 2 keV.

The Fermi Bubbles: Giant, Multi-Billion-Year-Old Reservoirs of Galactic Center Cosmic Rays

Roland M. Crocker[1*], Felix Aharonian[2,1†]
[1] *Max-Planck-Institut für Kernphysik, P.O. Box 103980 Heidelberg, Germany*
[2] *Dublin Institute for Advanced Studies, 31 Fitzwilliam Place, Dublin 2, Ireland*

(Dated: February 15, 2011)

Recently evidence has emerged for enormous features in the γ-ray sky observed by the Fermi-LAT instrument: bilateral 'bubbles' of emission centered on the core of the Galaxy and extending to around ±10 kpc above and below the Galactic plane. These structures are coincident with a

Origin of the Fermi Bubble

K.-S. Cheng[1], D. O. Chernyshov[1,2,3], V. A. Dogiel[1,2], C.-M. Ko[3], W.-H. Ip[3]

[1] Department of Physics, University of Hong Kong, Pokfulam Road, Hong Kong, China

[2] I.E.Tamm Theoretical Physics Division of P.N.Lebedev Institute of Physics, Leninskii pr. 53, 119991 Moscow, Russia

Fermi gamma-ray 'bubbles' from stochastic acceleration of electrons

Philipp Mertsch and Subir Sarkar
Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3NP, UK

(Dated: July 28, 2011)

Gamma-ray data from Fermi-LAT reveal a bi-lobular structure extending up to ∼ 50° above and below the galactic centre, which presumably originated in some form of energy release there less than a few million years ago. It has been argued that the γ-rays arise from hadronic interactions of high energy cosmic rays which are advected out by a strong wind, or from inverse-Compton scattering of relativistic electrons accelerated at plasma shocks present in the bubbles. We explore the alternative possibility that the relativistic electrons are undergoing stochastic 2^{nd}-order Fermi acceleration by plasma wave turbulence through the entire volume of the bubbles. The observed γ-ray spectral shape is then explained naturally by the resulting hard electron spectrum modulated by inverse-Compton energy losses. Rather than a constant volume emissivity as in other models, we predict a nearly constant surface brightness, and reproduce the observed sharp edges of the bubbles.

<u>Many efforts to try to explain this</u>

-Jets from the supermassive black hole ?

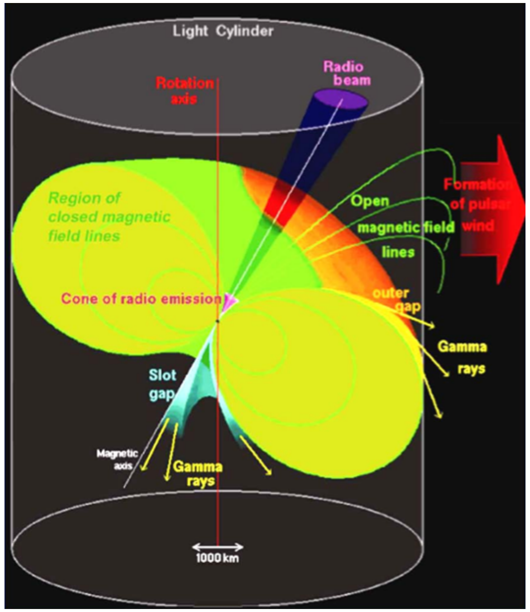
- What is being accelerated ? Electrons or protons (or both) ?

Very interesting puzzle: currently many open questions from the experimental and theoretical perspective

2.2 – Galactic sources: Pulsars

Fermi-LAT is playing a key role in the study of these extreme objects

Science cover page (Aug 2009)



6 gamma-ray pulsars in 9 years with EGRET → More than 100 in 3 years with LAT

Spectra of gamma-ray pulsars have a sub-exponential cutoff (not a super-exponential)

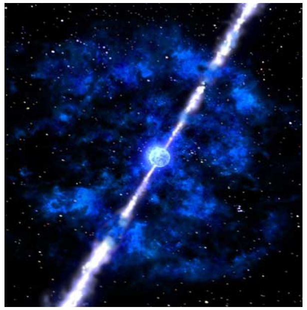
→ **Gamma-rays are NOT produced deep in the polar cap of the magnetosphere**

36 radio quiet pulsars have been found in blind searches of LAT data

→ Only 3 of them have (later on) been detected at radio

→ **Gamma-ray cone is wider than radio cone**

2.3 – Gamma-Ray Bursts (GRB)

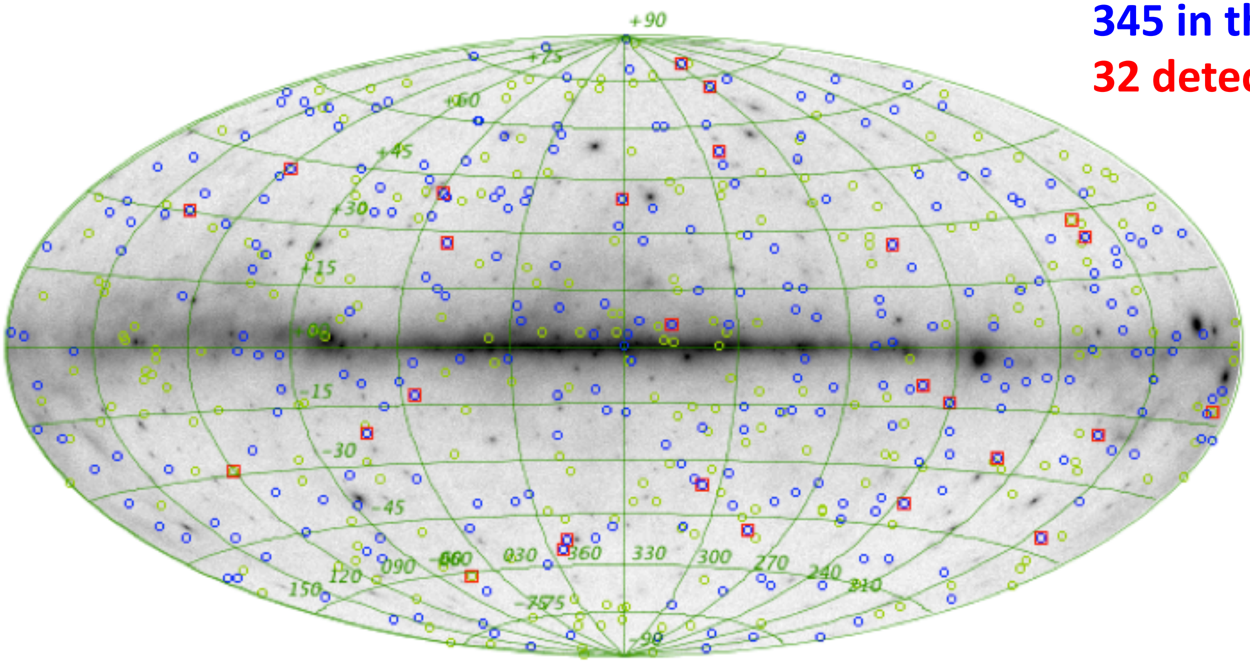


These are the brightest and most distant gamma-ray sources

They were very poorly studied before Fermi-LAT at energies above 100 MeV

Only 5 GRBs detected with EGRET in 9 years of operation

The quality of the detections was also hampered by the 0.1 second dead time in EGRET



682 GBM GRBs since Aug 2008

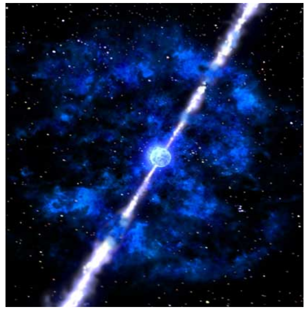
345 in the LAT field of View

32 detected by LAT

9 only visible with dedicated Low Energy analysis

2.3 – Gamma-Ray Bursts (GRB)

These are the brightest and most distant gamma-ray sources



Summary of properties of the LAT detected GRBs

GRB Name	GBM T90	N Pred. Events (>100MeV, Trans.)	HE Delayed Onset?	Long Lived HE Emission?	Maximum Energy (GeV)	Arrival time of the highest events (seconds since trigger)	Redshift
GRB080825C	Long	10	√	√	0.6	28.3	-
GRB080916C	Long	188	√	√	13.2	16.5	4.35
GRB081006	Long	13	√	√	0.8	1.8	-
GRB081024B	Short	11	√	√	3.1	0.6	-
GRB081207	Long	LLE	-	-	-	-	-
GRB090217	Long	17	√	√	1.2	179.1	-
GRB090227B	Short	3	-	-	0.0	0.0	-
GRB090323	Long	30	√	√	7.5	195.4	3.57
GRB090328	Long	50	√	√	24.5	261.7	0.736
GRB090510	Short	186	√	√	31.3	0.8	0.903
GRB090531B	Short	LLE	-	-	1.6	115.2	-
GRB090626	Long	LLE	√	√	2.1	111.6	-
GRB090902B	Long	314	√	√	33.4	81.8	1.822
GRB090926	Long	249	√	√	19.6	24.8	2.106
GRB091003	Long	3231	√	√	2.8	6.5	0.897
GRB091031	Long	15	√	√	1.2	79.8	-
GRB100116A	Long	14	-	√	13.1	296.4	-
GRB100225A	Long	LLE	-	-	-	-	-
GRB100325A	Long	6	-	√	1.9	71.4	-
GRB100414A	Long	27	√	√	4.7	288.3	1.368
GRB100724B	Long	22	-	-	0.2	61.8	-
GRB100728A	Long	4	-	-	0.1	81.2	-
GRB100728A	Long	LLE	-	-	0.1	81.2	-
GRB101014A	Long	LLE	-	-	-	-	-
GRB101123A	Long	LLE	-	-	-	-	-
GRB110120A	Long	5	-	-	1.8	72.5	-
GRB110328B	Long	LLE	-	-	1.6	514.7	-
GRB110428A	Long	17	√	√	2.6	14.8	-
GRB110529A	Short	LLE	-	-	-	-	-
GRB110625A	Long	12	-	√	2.4	272.4	-
GRB110721A	Long	29	-	√	1.7	0.7	0.38
GRB110731A	Long	65	√	√	3.4	436.0	2.83

(1) + (2) = Good news for ground based instruments

1) Most bursts show a delayed high energy emission (LAT vs GBM) and the high energy emission lasts longer than the low energy emission

2) Some bursts have an extra spectral component (a different mechanism at high energy?)

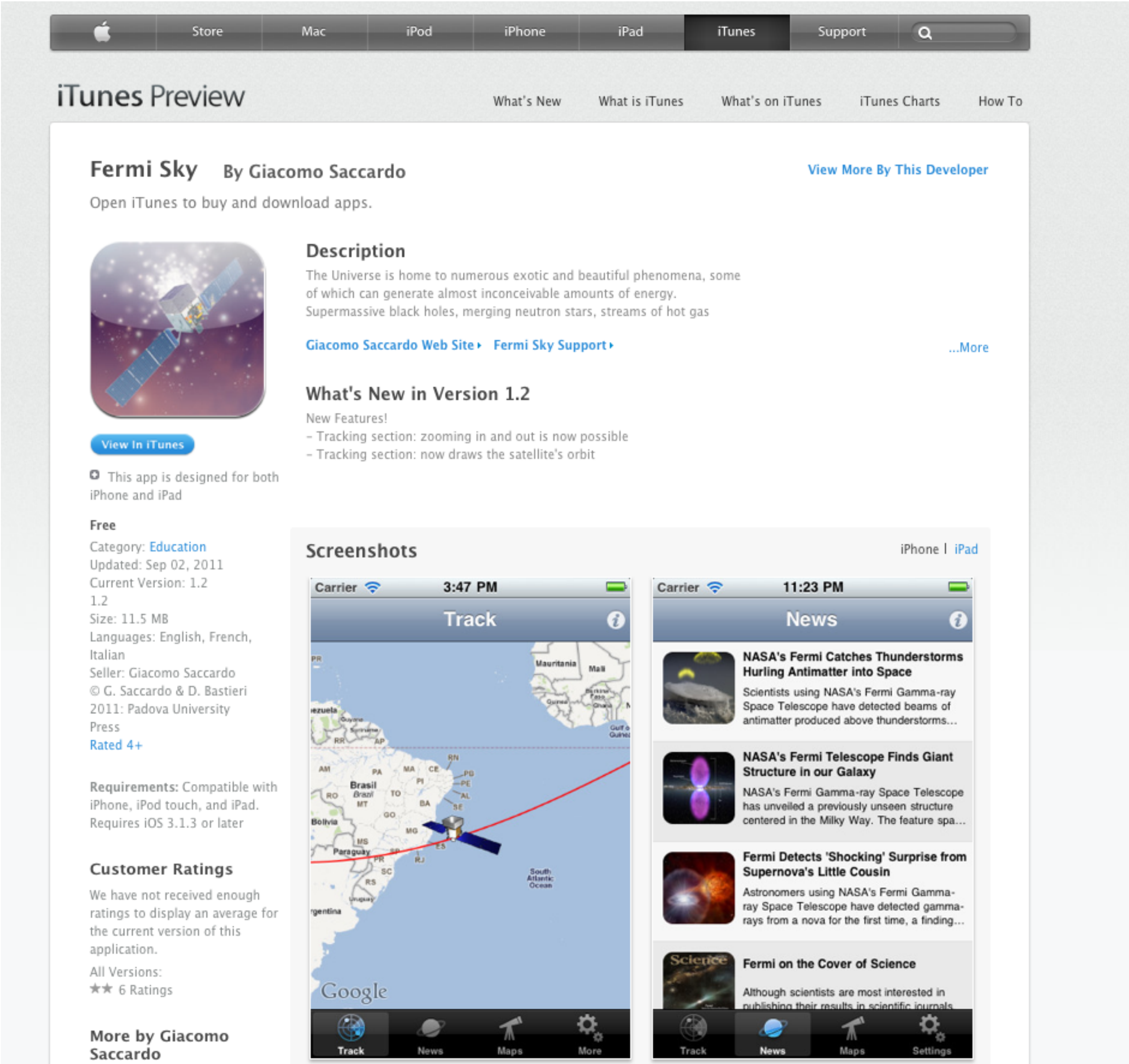
3) High energy photons and rapid variability sets lower limits to the Lorentz factor to ~1000 for some GRBs

4) GRBs can be used as tools to probe basic physics.

4.1 – Lorentz Invariance Violation

4.2 – EBL density

How to get the latest news on gamma-ray observations with Fermi



Fermi App For iPhone

Available on iTunes since May 2011

It is free !

3 – Work done/led by MPI Munich

3.1 – Contribution to ISOC

<u>We are part of the team of people that keeps the Fermi-LAT instrument in operation</u>

The Instrument Science Operation Center (ISOC) is "essentially" located at SLAC (~40 people)

But there is also a small group in INFN Pisa, Italy (3 people) and a small group here at <u>MPI (1 person)</u>

The ISOC is responsible for:

-LAT mission planning

-LAT flight software

-LAT science data processing and Instrument Data Monitoring

-Provide analysis products to end users

-→ Export products to the Fermi Science Support Center (FSSC) at the Goddard Space Flight Center (GSFC)

Automated science processing

→ Identification of flaring sources

→ Refinement of blind searches for GRBs

→ Light Curves for pre-selected

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Automated science processing
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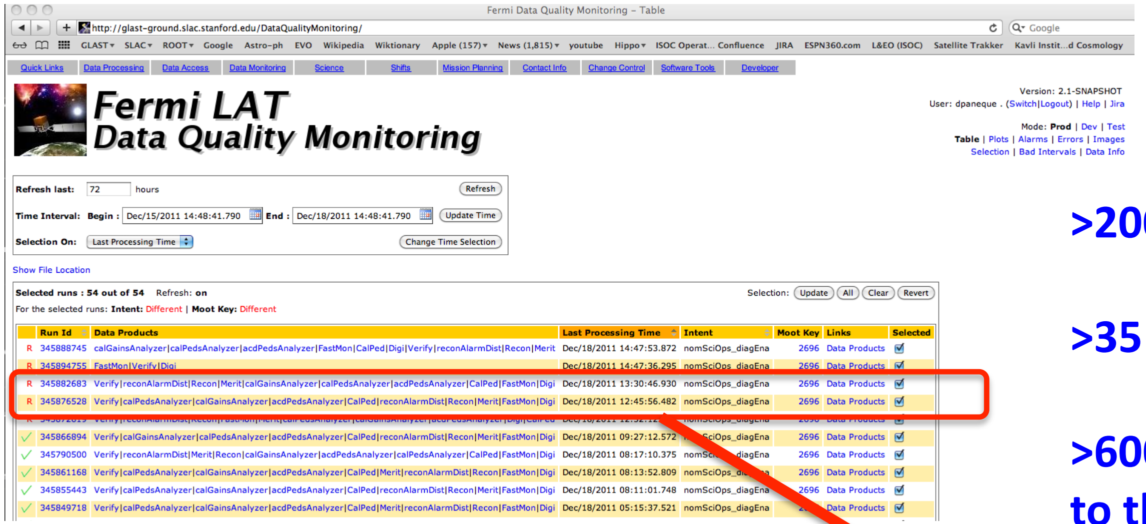


Since the start of scientific operation (Aug 2008)

>200 billion triggers

>35 billion events downlinked to ground

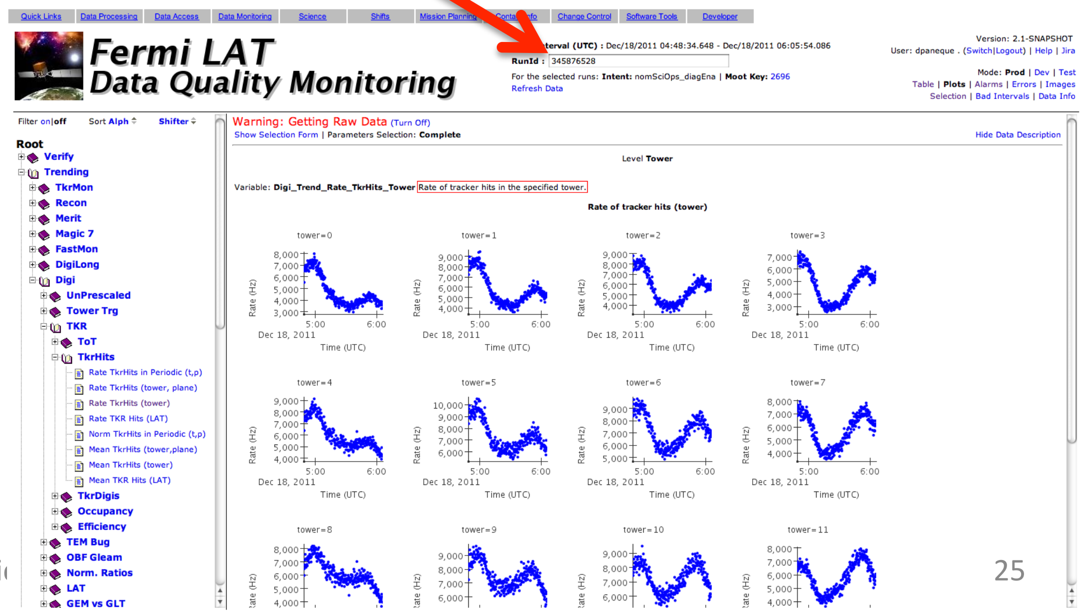
>600 million photon candidates released to the community (FT1 files)

>99% uptime

Almost all quantities (20000 variables per run !!) can be reviewed from web pages

A wealth of information that is used to monitor the LAT technical and scientific performance

Automatic procedures check these quantities and issue warnings/alarms whenever the variables are out of expectations



3 – Work done/led by MPI Munich

3.1 – Contribution to ISOC

Typically, these set of programs/procedures work well with minimal maintenance
→ Apart from taking monitoring shifts (one week every 1-2 months)

But this year we had an upgrade of the analysis tools, which required substantial modifications in the data monitoring pipeline

Pass 6

Pre-Launch algorithms,
With slight modifications
and Corrections (v3 → v11)

Pass 7

Completely new (re-optimization of the high-level analyses) algorithms to classify photons and charge particles.
Benefit from 2-year experience running the instrument
Available to the public from FSSC on August 1st, 2011

Next set of big modifications in the data monitoring pipeline are expected when moving from **Pass 7** to **Pass 8** (which might be happening in about 2 years)

3 – Work done/led by MPI Munich
3.2 – Study of Active Galactic Nuclei (AGNs)

Pictorial description of an AGN

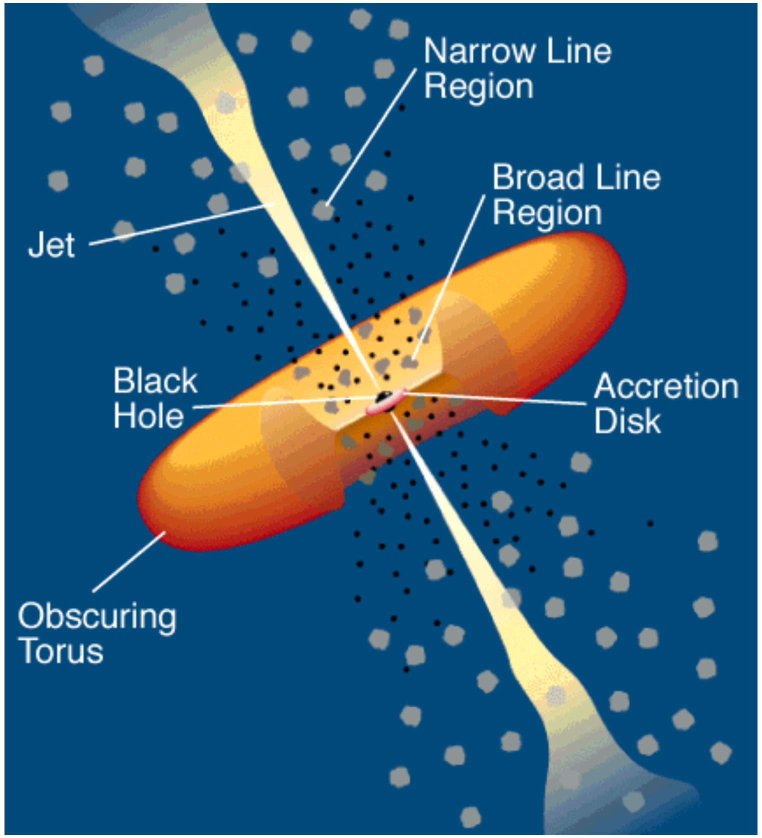


Image Credit: C.M.Urry & P. Padovani

Many Open questions:

- Location of the emission
    - Close or far away from Black Hole ?
- Leptonic vs hadronic emission models
- Acceleration/cooling in single or multi-zone
- Production of flares (which are the shortest timescales)
- Role of external photon fields
- Intrinsic spectra vs EBL-affected spectra
- Time-resolved emission models
- How jets are being formed
- How jets are kept collimated over kpc distances
- etc,etc, etc …

Roadmap → **We need population studies**
We need deep studies on individual sources

3.2 – Improve current understanding of AGNs : Population studies

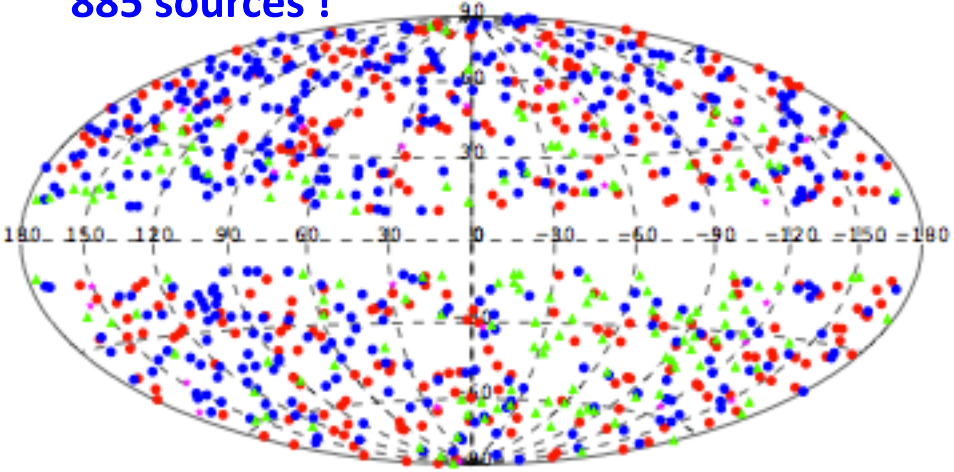
2nd LAT AGN Catalog (2LAC)

Ackerman et al (Fermi collab.), Accepted in ApJ

arXiv:1108.1420

E> 0.1 GeV

885 sources !



395 BL Lac

310 FSRQ

156 blazars of Unknown type

24 Non-blazar AGNs

MPI is leading a dedicated study at the highest Fermi energies (>10 GeV)

→500 sources !!!

- **→20% unknown**
- **→80% (of the remaining 80%) are AGNs**

A new catalog will be released to the community in about 3-4 months

We now start having sufficient statistics to perform population studies.

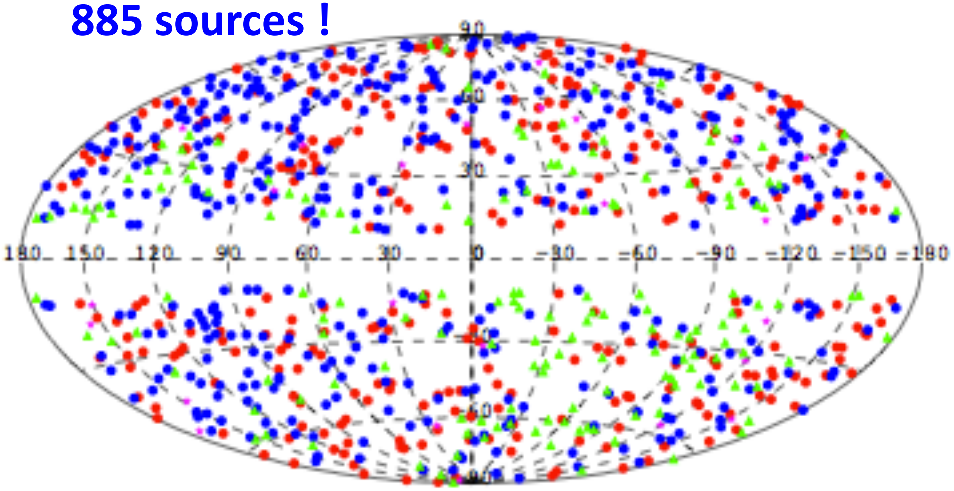
3.2 – Improve current understanding of AGNs : Population studies

2nd LAT AGN Catalog (2LAC)

Ackerman et al (Fermi collab.), Accepted in ApJ
arXiv:1108.1420

E> 0.1 GeV

885 sources !

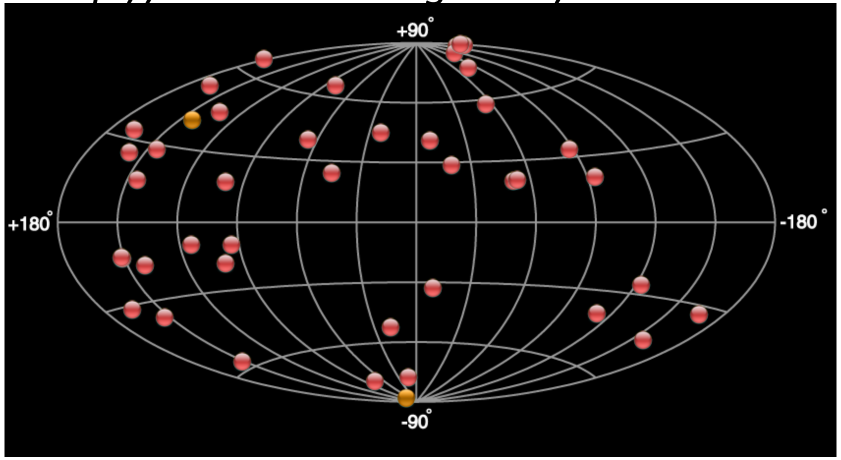


395 BL Lac
310 FSRQ
156 blazars of Unknown type
24 Non-blazar AGNs

Few TeV sources

VHE (>100 GeV) extragalactic sky (2011/12)
49 sources = 47 AGNs
+ 2 Starburst galaxies

http://tevcat.uchicago.edu/



38 BL Lac
3 FSRQ
3 Unknown type
5 Non-blazar AGNs

We now start having sufficient statistics to perform population studies.
But we need to increase the number of extragalactic TeV sources

3.2 – Improve current understanding of AGNs : Population studies

Since 2009 we have a program to characterize the Fermi sky at the highest energies and use this information to increase the number of TeV sources using information from Fermi-LAT

LAT overcomes some of the drawbacks of IACTs:
-Large duty cycle (85%) vs Small duty cycle (~10%)
-All sky coverage vs small Field of view (3-5 deg)

Fruitful cooperation between Fermi and IACTs since 2009

One can use Fermi information (specially at the highest energies) to increase the efficiency in the search for VHE sources with IACTs

→ Identification of good TeV source candidates to be observed with IACTs

3.2 – Improve current understanding of AGNs : Population studies

Since 2009 we have a program to characterize the Fermi sky at the highest energies and use this information to increase the number of TeV sources using information from Fermi-LAT

Name[1]	RA	DEC	Association	z	TeV Detection
C006	76.981	67.634	1ES0502+675	0.31	VERITAS, ATEL 2301
C004	39.368	-36.066	J02375-3603	?	
C017	219.272	56.689	RBS1409	0.15	
C023	300.306	43.884	?	?	MAGIC, ATEL 2753
B008	42.681	17.222	?	?	
C007	80.431	21.225	?	?	VERITAS, ATEL 2260
B021	84.162	-33.696	RXSJ05365-3343	?	
C010	102.679	25.044	1ES0647+250	0.2[2]	MAGIC, Taup2011
B011	49.896	18.813	MS03170+1834	0.19	VERITAS, ATEL 2486
C001	24.125	39.086	J0136+3905	?	
E069	354.758	21.397	J2338+212	0.29	
C009	102.212	15.274	?	?	VERITAS, ATEL 2486
B001	5.488	-18.935	?	?	
B064	294.216	-47.337	J1936-4719	0.26	
B027	124.069	-13.165	J08164-1311	?	
B061	275.947	-34.914	?	?	
B003	32.365	-52.477	J02093-5229	?	
B037	169.301	20.225	J11171+2014	0.14	
B034	163.420	49.477	J1053+4929	0.14	
C012	137.250	23.174	J09090+2311	0.22	
B042	190.804	36.437	J1243+3627	?	
B070	342.539	38.426	J2250+3824	0.12	MAGIC, ATEL 2910
C005	72.368	-43.826	J0449-4350	0.2	HESS, ATEL 2350
B010	49.924	41.528	NGC1275	0.02	MAGIC, ATEL 2916

[1] This column denotes the source name given by the dedicated source-search algorithm that I used.

[2] In 2009, the redshift of 1ES0647+250 was thought to be ~0.2. However, in 2010 and 2011 there were publications reporting a redshift of ~0.45.

List of promising TeV source candidates, according to a dedicated source search in low-cosmic-background 1-year accumulated Fermi-LAT data.

This list was sent to HESS, MAGIC and VERITAS on October 2009.

In only two years, 9 out of the 24 sources were detected at VHE (>100 GeV), which increased the known extragalactic VHE sky by ~25%. *The last column shows the announcement of these 9 VHE discoveries.*

Now we have 49 VHE AGN sources.

→ Every new VHE AGN discovery increases the VHE sky by 2%

view

3.2 – Improve current understanding of AGNs : Population studies

Since 2009 we have a program to characterize the Fermi sky at the highest energies and use this information to increase the number of TeV sources using information from Fermi-LAT

Name[1]	RA	DEC	Association	Name in 1-year list	z
FBT24_046	**102.688**	**25.064**	**1ES 0647+250**	**C010**	**0.45**
FBT24_015	45.869	-24.124	PKS 0301-243	—	0.26
FBT24_086	192.055	58.347	PG 1246+586	—	0.8
FBT24_058	137.328	23.182	RXS J09090+2311	C012	0.22
FBT24_106	267.115	70.099	S4 1749+70	—	0.77
FBT24_027	74.273	-23.404	PKS 0454-234	—	1.0
FBT24_004	20.130	-27.010	PKS 0118-272	—	0.56
FBT24_077	177.655	41.906	QSO CSO 1232	—	1.0
FBT24_062	149.425	55.386	QSO 4C 55.17	—	0.9
FBT24_023	67.169	-37.932	QSO PKS 0426-380	—	1.1
FBT24_038	84.687	-44.084	QSO PKS 0537-441	—	0.9

[1] This column denotes the source name given by the dedicated source-search algorithm that I used.

High-z blazars in the list with promising VHE candidates made with 2-year of accumulated Fermi-LAT data, and sent to the major IACTs in October 2010

Should detected at VHE (>100 GeV, these sources could be used as tools to study a large variety of things related to the environment traversed by the detected gammas-rays:

1 - Extragalactic Background Light (EBL)
2 - Intergalactic Magnetic Fields (IGMF)
3 – Tests of Lorentz Invariance Violation
4 - Search for Axion Like Particles (ALPs)

3.2 – Improve current understanding of AGNs :
→ Deep studies on single objects : classical TeV Mrk421 & Mrk501

Exquisite characterization of the high energy component, which can be detected with Fermi and Cherenkov Telescopes over 5 orders of magnitude (0.1GeV – 10 TeV)

Excellent laboratory for studying High Energy blazar emission

Strong gamma ray source &
Nearby object; z = 0.03; "low" EBL absorption, we see "almost" intrinsic features

Knowledge acquired with Mrk421 and Mrk501 might be applied to other objects (fainter and/or larger z). ***Or maybe not… some sources might be special. CAVEAT (!!)***

Things we know about those classical TeV sources (and HBLs in general)

Dominant gamma-ray emission mechanism is believed to have a leptonic origin (SSC) , at least in high (flaring) state

- **Fast variations (down to hours and sub-hours in VHE)**
- **X rays- Gamma-rays correlation (in general)**

Extensive Multi-Wavelength (MW) Campaigns

Broad-band and variable spectra of AGN sources require the coordination of instruments covering a large energy range

Radio: VLBA, OVRO, Effelsberg, Metsahovi…
mm: SMA, IRAM-PV
Infrared: WIRO, OAGH
Optical: GASP, GRT, MITSuMe, Kanata…
UV: Swift-UVOT
X-ray: Swift-XRT, RXTE-PCA, Swift/BAT
Gamma-ray: Fermi-LAT
VHE: MAGIC, VERITAS, Whipple

•More than 25 instruments participate covering frequencies from radio to TeV

Sources monitored regardless of activity

Extensive Multi-Wavelength (MW) Campaigns

Past MW campaigns

Mrk421 (Jan19th, 2009-Jun1st ,2009: 4.5 months)- Planned observations: every 2 days
http://www.slac.stanford.edu/~dpaneque/MW_Mrk421_2009/Obs.html

Mrk501 (Mar15th, 2009-Aug1st,2009: 4.5 months) -Planned observations: every 5 days
http://www.slac.stanford.edu/~dpaneque/MW_Mrk501_2009/Obs.html

Mrk421 (Dec8, 2009-Jun20 ,2010: 6 months)- Planned observations: every 1 days
http://www.slac.stanford.edu/~dpaneque/MW_Mrk421_2010/Obs.html

Mrk421 (Dec1, 2010-Jun15 ,2011: 6 months)- Planned observations: every 2 days
http://www.slac.stanford.edu/~dpaneque/MW_Mrk421_2011/Obs.html

Mrk501 (March1, 2011-Sep1,2011: 6 months) -Planned observations: every 3 days
http://www.slac.stanford.edu/~dpaneque/MW_Mrk501_2011/Obs.html

No TeV observations since mid June 2011

→ VERITAS is in the regular “summer shutdown”

→ MAGIC was shut down for hardware upgrade

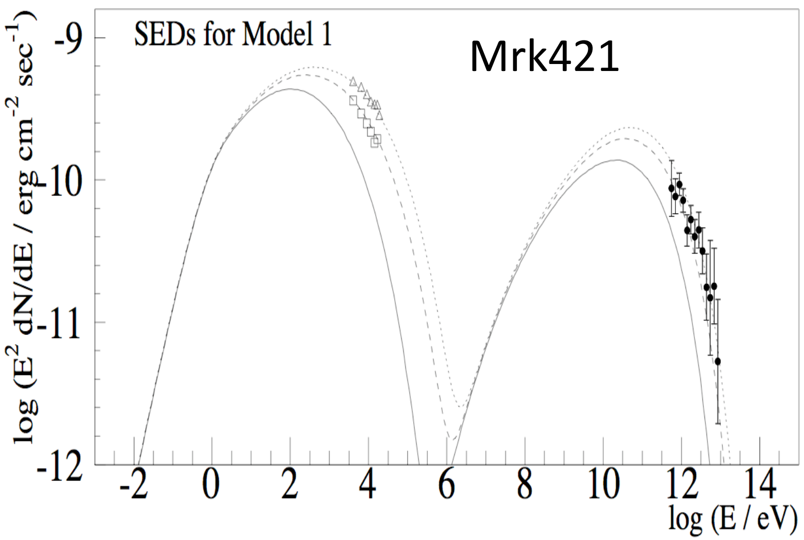
This is multi-year and multi-instrument program that will continue during the next years

Extensive Multi-Wavelength (MW) Campaigns

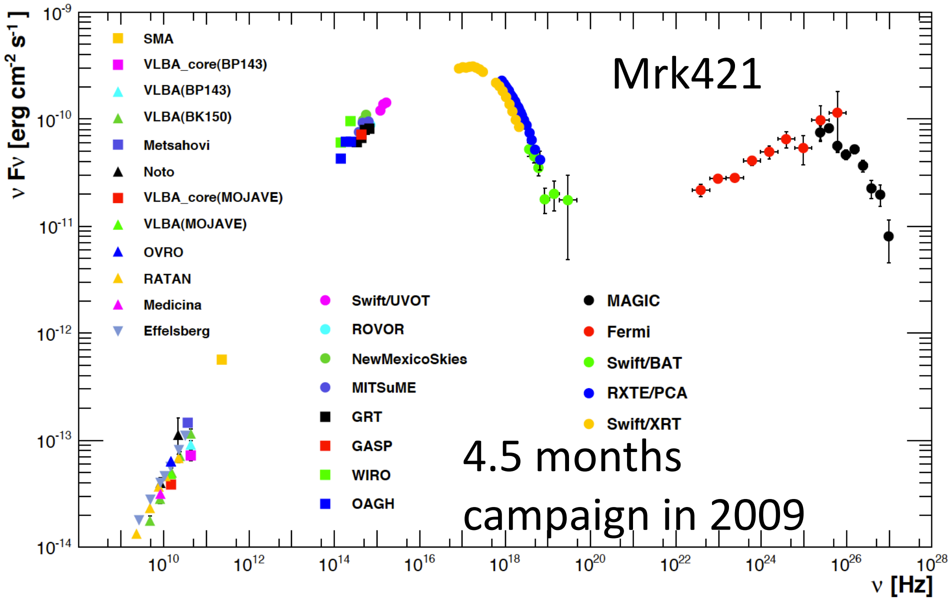
Many MW campaigns organized in the last 3 years.

→ much better energy and time coverage than in the past

Krawczynski 2001, Apj 559



Abdo et al 2011, ApJ 736, 131



→"less biased" study of the sources, as well as tighter constrains to the emission models

Involvement of VLBA (<u>sub-mas resolution</u>) and polarization is important because they bring spatial and structural information. *This is the only way of locating the region emitting the gamma-rays…*

Published papers with MW data on Mrk501/Mrk421

1 - Insights Into the High-energy gamma-ray Emission of Markarian 501 from Extensive Multifrequency Observations in the Fermi Era
Abdo, A. A. et al. 2011, ApJ, 727, 129
Fermi (Cat1)+MAGIC+VERITAS + External collaborators *(Paper led by **D.Paneque, MPI**)*

2 - Spectral Energy Distribution of Markarian 501: Quiescent State vs. Extreme Outburst
Acciari, V. A. et al. 2011, ApJ, 729, 2
Fermi (Cat2)+MAGIC+VERITAS. (*Paper led by Daniel Gall, Iowa University).*

3 - Fermi-LAT Observations of Markarian 421: the Missing Piece of its Spectral Energy Distribution
Abdo, A. A. et al. 2011, ApJ, 736, 131
Fermi (Cat1)+MAGIC + External collaborators *(Paper led by **D.Paneque, MPI**)*

Number of scientific publications will grow as we increase our pool of MW data for those objects (reduce the collected data and keep acquiring new MW data)

ongoing papers with MW data on Mrk501/Mrk421

Papers with the 2009 data

4 – Dedicated paper to the Mrk501 "VHE orphan" flare in May 2009
Fermi (Cat2)+VERITAS+External collaborators.
*Paper will be led by Ana Carolina Pichel (UBA, Argentina) and **D. Paneque (MPI)***

5 - Multifrequency variability and correlations for the 2009 campaign on Mrk421
Fermi (Cat2)+MAGIC+VERITAS+External collaborators.
*Paper will be led by **Nina Nowak and Ulisses Barres de Almeida (MPI)***

6 - Multifrequency variability and correlations for the 2009 campaign on Mrk501
Fermi (Cat2)+MAGIC+VERITAS+External collaborators.
Paper will be led by Nikola Strah (University of Dortmund, Germany) +
Nina Nowak and Ulisses Barres de Almeida (MPI, Germany)

Drafts of these papers should be ready by first quarter of 2012

ongoing papers with MW data on Mrk501/Mrk421

Papers with the 2010 data

7 – Dedicated paper on Mrk421 flare from January 2010
Fermi (Cat2)+MAGIC+(VERITAS)+External collaborators.
*Paper will be led by **Burkhard Steinke (MPI)***

8 – Dedicated paper on Mrk421 large flare from February 2010
Fermi (Cat2)+VERITAS+External collaborators
Paper will be led by Lucy Fortson (University of Minnesota, USA)

9 – Dedicated paper on Mrk421 flare from March 2010
Fermi (Cat2)+MAGIC+VERITAS+External collaborators
*Paper will be led by **Shangyu Sun (MPI, Munich)** and Nicola Galante (CfA Harvard)*

10 – Dedicated paper on high/low state in May 2010
Fermi (Cat2)+MAGIC+External collaborators
*Paper will be led by Andrea Boller (ETH, Zurich) and **David Paneque (MPI, Munich)***

11 – Overall MW variability/correlations for the 2010 campaign on Mrk421
Fermi +MAGIC+VERITAS+External collaborators.
*Paper will be led by **David Paneque (MPI, Munich)***

3.2 – Improve current understanding of AGNs: MW campaigns

We can learn many things from dedicated studies of the classical (bright) TeV sources Mrk421/Mrk501. Fermi+ IACTs can characterize the entire high energy bump

- Fermi data opens a "new window" to study those objects
  → Spectra reaching E>0.1 TeV; overlap with IACTs

- Collection of MW data is ESSENTIAL for understanding those complex objects.
  → We can only image these sources with VLBA (!!!)

Extensive MW data sets collected during 2009 and 2010 for Mrk421 and Mrk501

→3 scientific papers using the 2009 MW data are published
Very interesting results !!

→We are working on additional publications with the 2009 and 2010 data
8 additional (planned) papers in the pipeline.
3 of them expected by the first quarter of 2012

The 2011 extensive campaigns on Mrk421 and Mrk501 are finished. And we start planning the observations for the 2012 campaigns
These objects can be very different from season to season:

→ **We need well-sampled, coordinated monitoring of the broad-band SED lasting several years.**

4 – Conclusions and Outlook

4.1 – Fermi-LAT, in scientific operation since August 2008, provides a large leap in capabilities, which rapidly turned into precision measurements of previously known sources, as well as discovery of many more (including new classes) of sources, which allows for population studies.

→ Many "expected" results, but also many unexpected !!

→ **New data provides new challenges to the theoreticians**

This large amount of high quality and novel experimental observations translated into a very high publication rate: **~7.5 papers/month in the last 2 years**

4.2 – At MPI we are contributing to

Fermi-LAT operations (activated in the framework of ISOC)

→ **Systematic monitoring of the technical performance of LAT**

Science related to Active Galactic Nuclei (AGNs)

→ **Population studies of AGNs (mostly at the highest energies)**

→ Increase number of VHE AGNs

→ **Deep studies on sources through multi-year and multi-instrument obs. programs**

4.3 – In the next 1-2 years, we will try to expand our Fermi-related activities

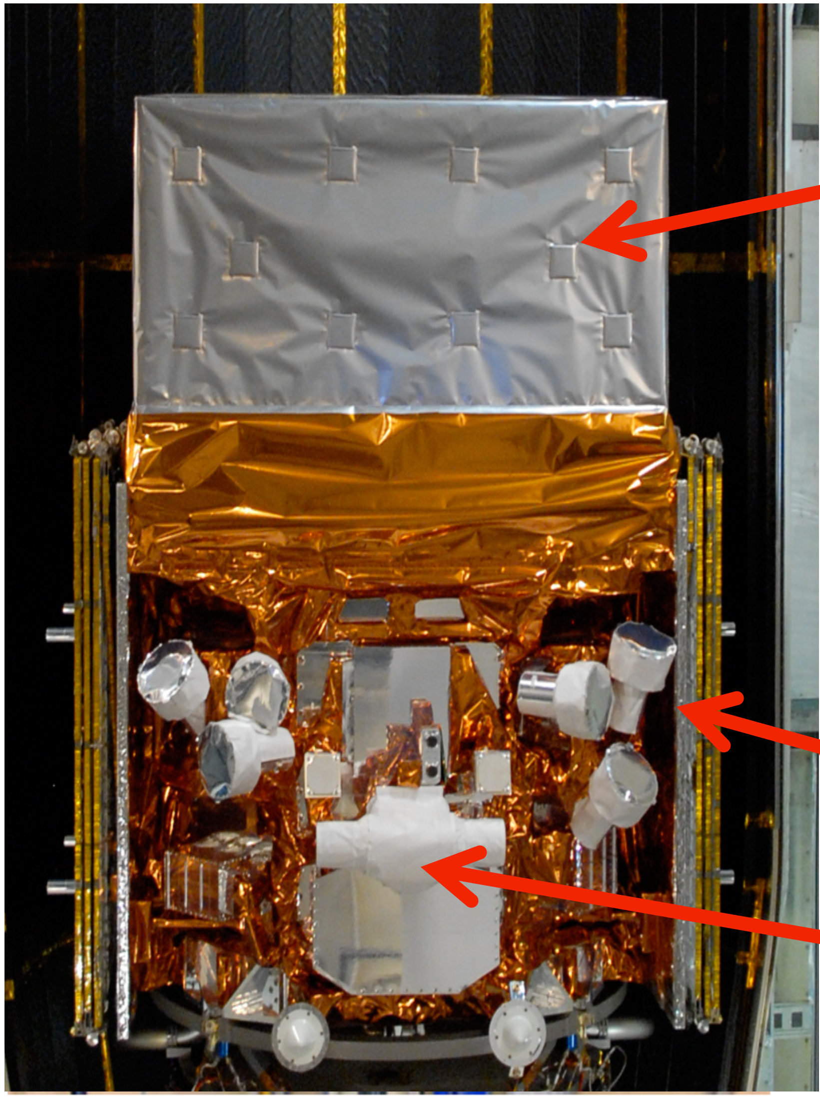
→ New analysis methods to improve sensitivity (Pass 8)

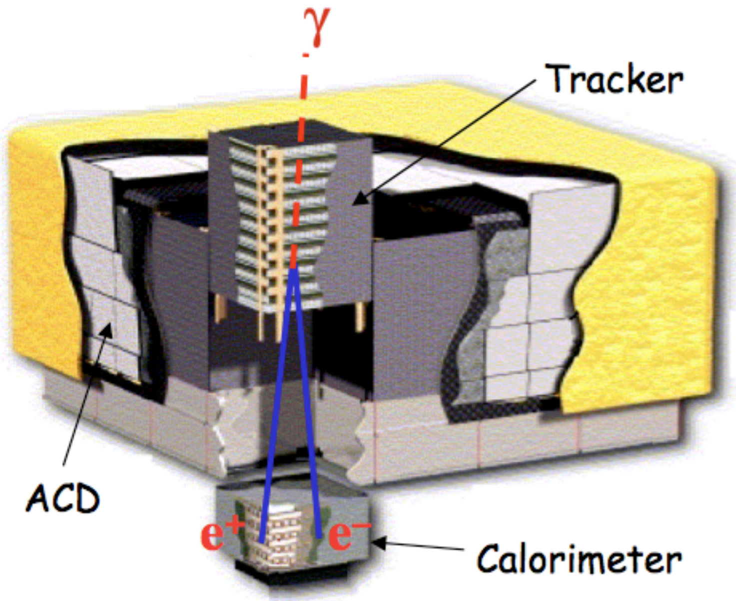
→ Address other scientific topics (EBL, Axion-Like-Particles, pulsars)

Backup

1 - Fermi mission (brief overview)

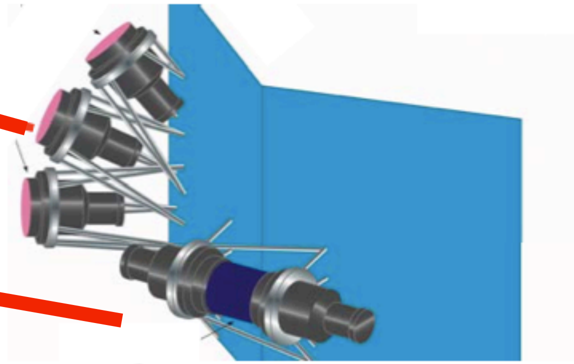
Spacecraft and the two instruments (LAT and GBM) integrated and working as a single observatory





Large Area Telescope

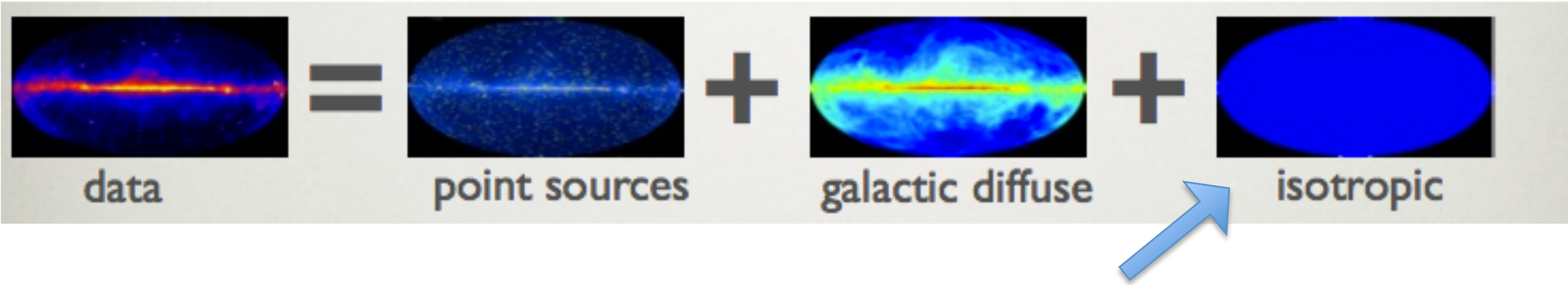
(20 MeV - > 300 GeV)



Glast Burst Monitor

(10 keV - 25 MeV)

2.1 – The gamma-ray sky: Extragalactic Gamma-ray Background (EGB)



EGB + Residual instrumental background

EGB
- **Unresolved point Src:** AGNs, GRBs, Galaxies
- **Diffuse processes:** Intergalactic shocks, UHE Cosmic ray interactions with EBL, CR interaction in small solar system bodies, Dark matter (?)

How much of the diffuse extragalactic background is coming from unresolved point sources ?

→ *This is something we need to address if we want to use the EGB for studies of diffuse processes, like potential annihilation of Dark Matter particles*

By studying individual source populations (of resolved sources) one can derive the contribution to the EGB from the unresolved ones

2.1 – The gamma-ray sky: Extragalactic Gamma-ray Background (EGB)

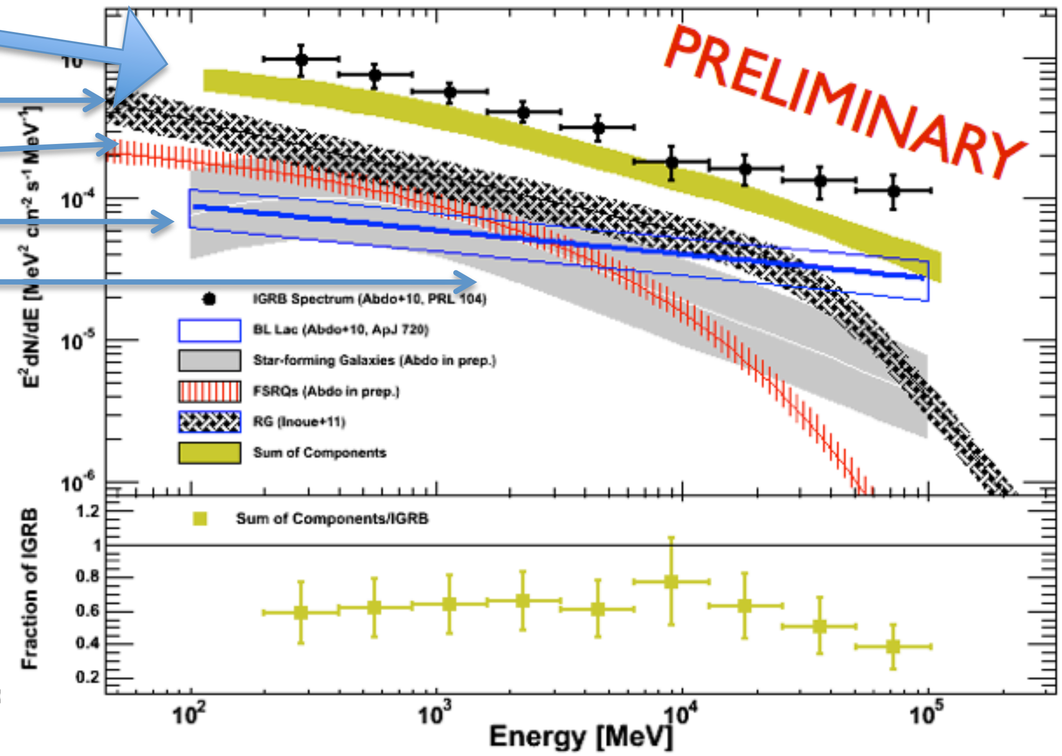
Sum of all components

Radio galaxies

FSRQs

BL Lacs

Star-forming galaxies



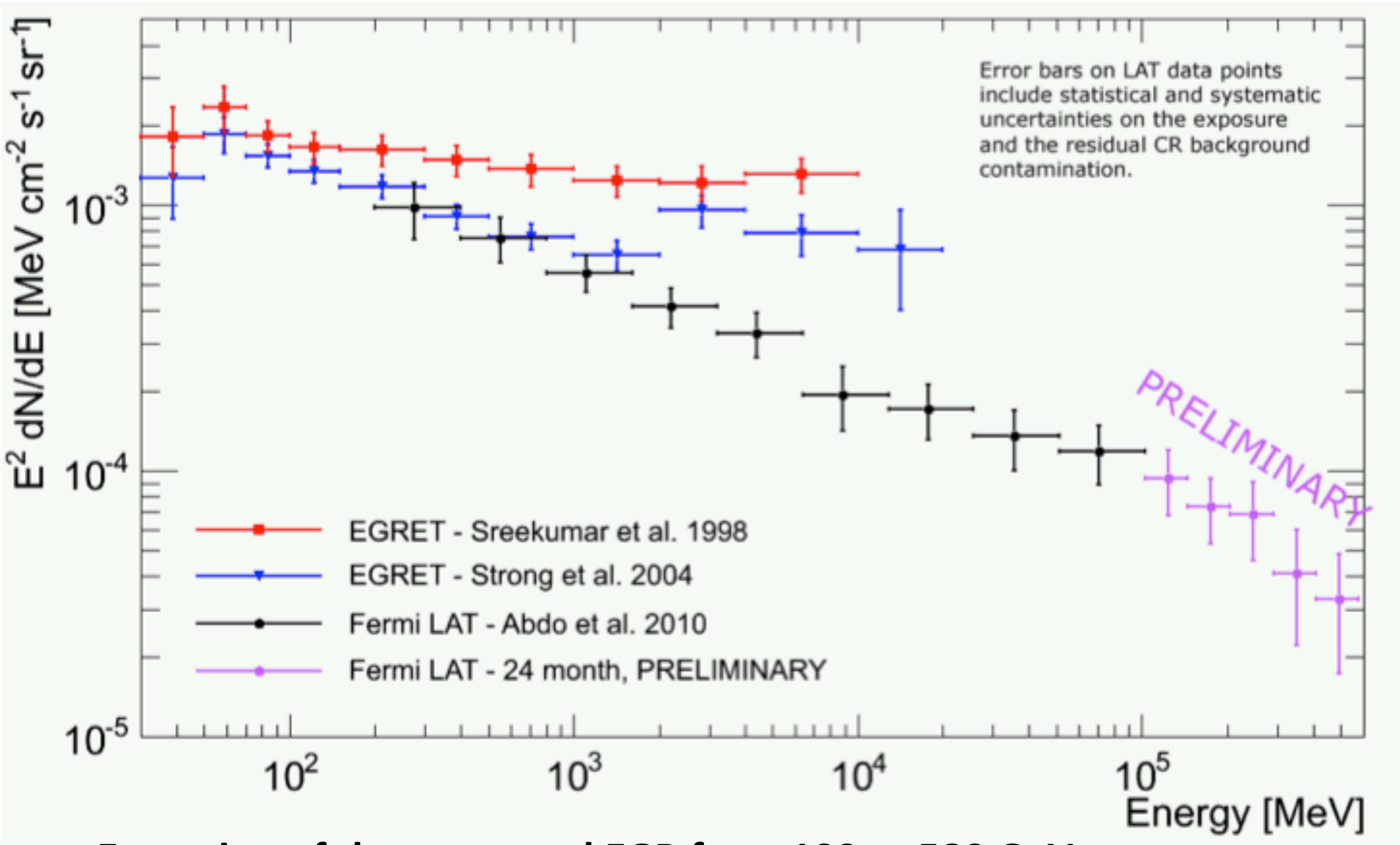
Non-resolved individual sources account for 50-80% of the EGB.

It seems there is room for something else…

Davi

25% uncertainty in foreground modeling is not taken into account

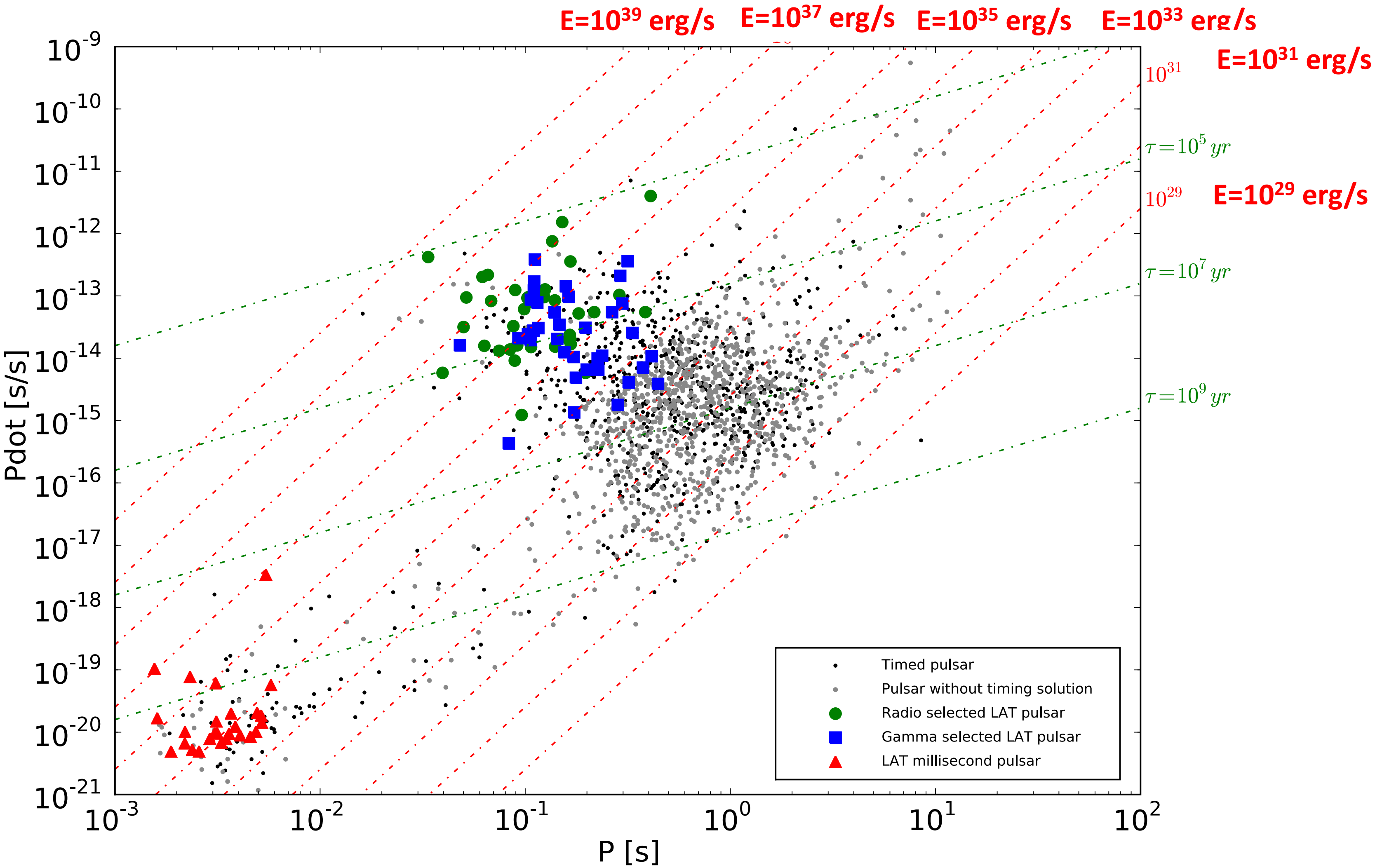
2.1 – The gamma-ray sky: Extragalactic Gamma-ray Background (EGB)



Extension of the measured EGB from 100 to 580 GeV

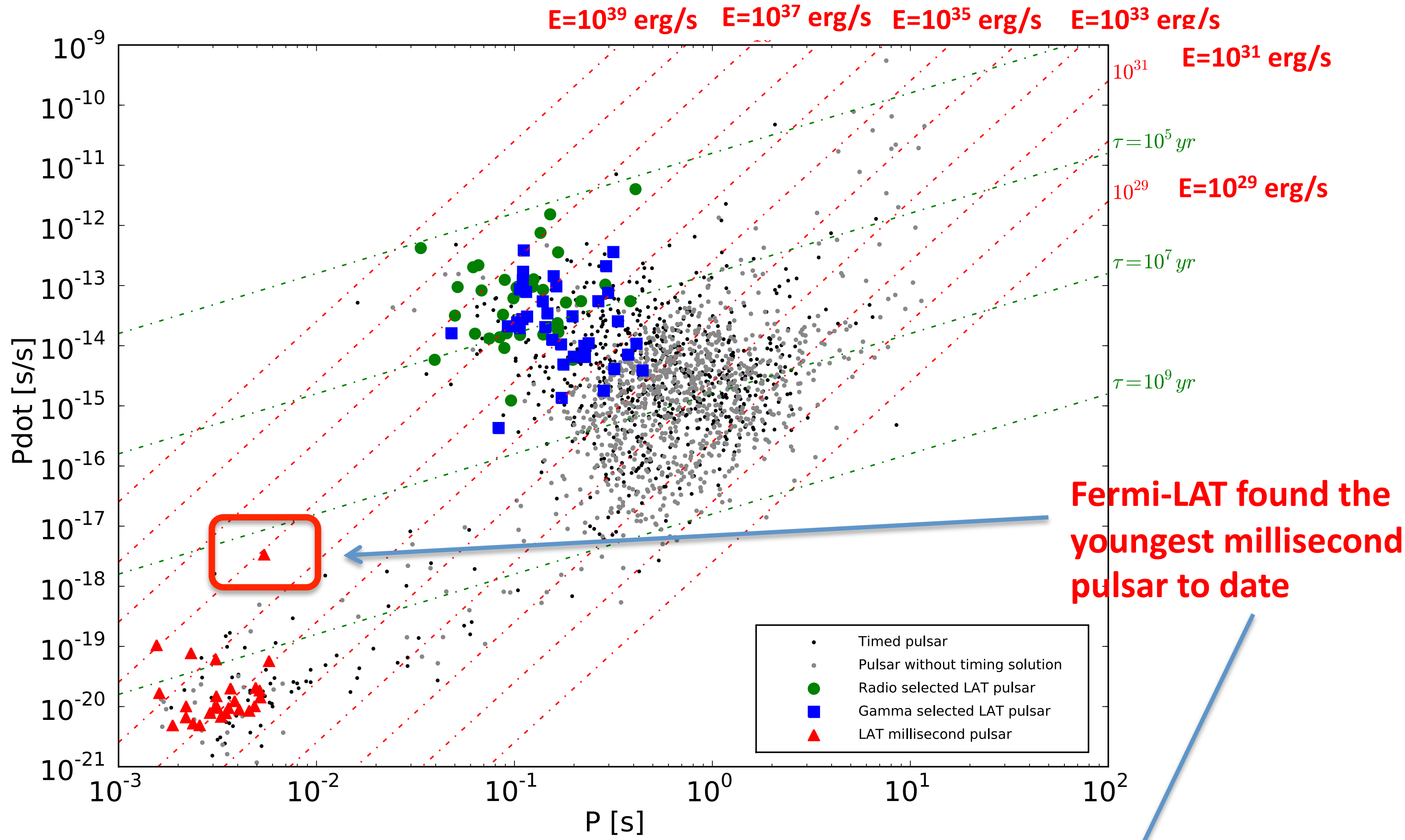
-> which could be extended beyond 1 TeV in the near future

The LAT is continuing to find pulsars, in coordination with the Pulsar Timing Consortium (Smith et al. 2008) and the Pulsar Search Consortium *Radio (primarily) and X-ray timing*



The gamma-ray pulsars are the ones with the highest spin-down power

The LAT is continuing to find pulsars, in coordination with the Pulsar Timing Consortium (Smith et al. 2008) and the Pulsar Search Consortium *Radio (primarily) and X-ray timing*



Application of novel techniques for pulsar blind searches from Gravitational Wave community accelerated further the discovery rate.

→ B. Allen et al (TAUP 2011) + NASA Press Conference 2011/11/02

http://www.nasa.gov/mission_pages/GLAST/news/young-pulsar.html

2.3 – Extragalactic sources: Deep studies of individual sources

Culprits for the relatively poor knowledge of AGN sources

1 - Time-evolving broad band spectra

Coordination of instruments covering different energies needed

2 - Poor sensitivity to study high-energy part (E>0.1 GeV)

Large observation times (with EGRET and "old" IACTs) were required for signal detection *Data often is NOT simultaneous*, and obtained only during high state

Recently, we had two "performance jumps" with respect to the past:

New Generation of IACTs online since ~6 years (low E_{th}, high sensitivity)

LAT in operation since 3 years (~30 times more sensitive than EGRET)

~100 times more sensitive at E>~10 GeV

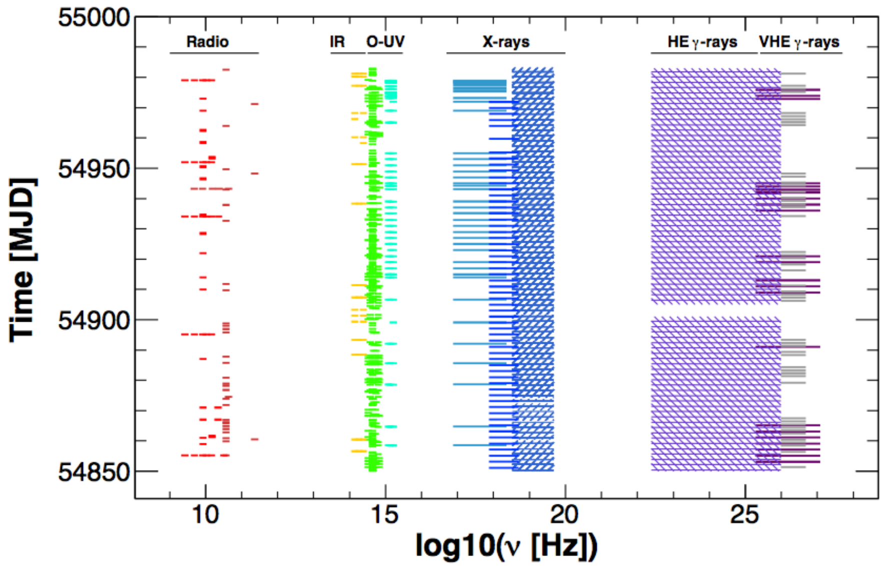
Enhanced observational capability can be used to improve our knowledge on AGNs

2 – Extensive MW Campaigns

The instruments participating in the campaigns provided a very good time and energy coverage for both sources

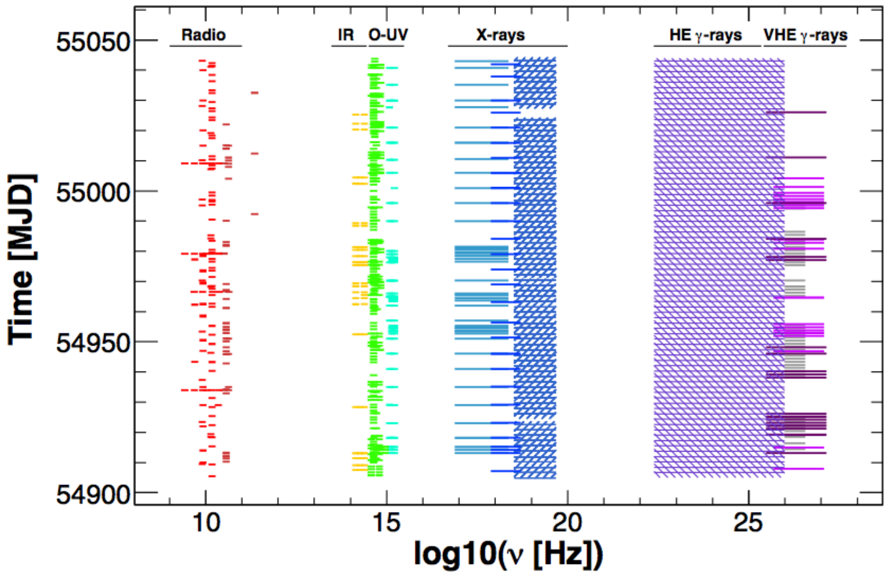
Abdo et al 2011, ApJ 736, 131

Mrk421 (campaign 2009)



Abdo et al 2011, ApJ 727, 129

Mrk501 (campaign 2009)



Most complete Time&Energy (published) coverage of Mrk421 to date

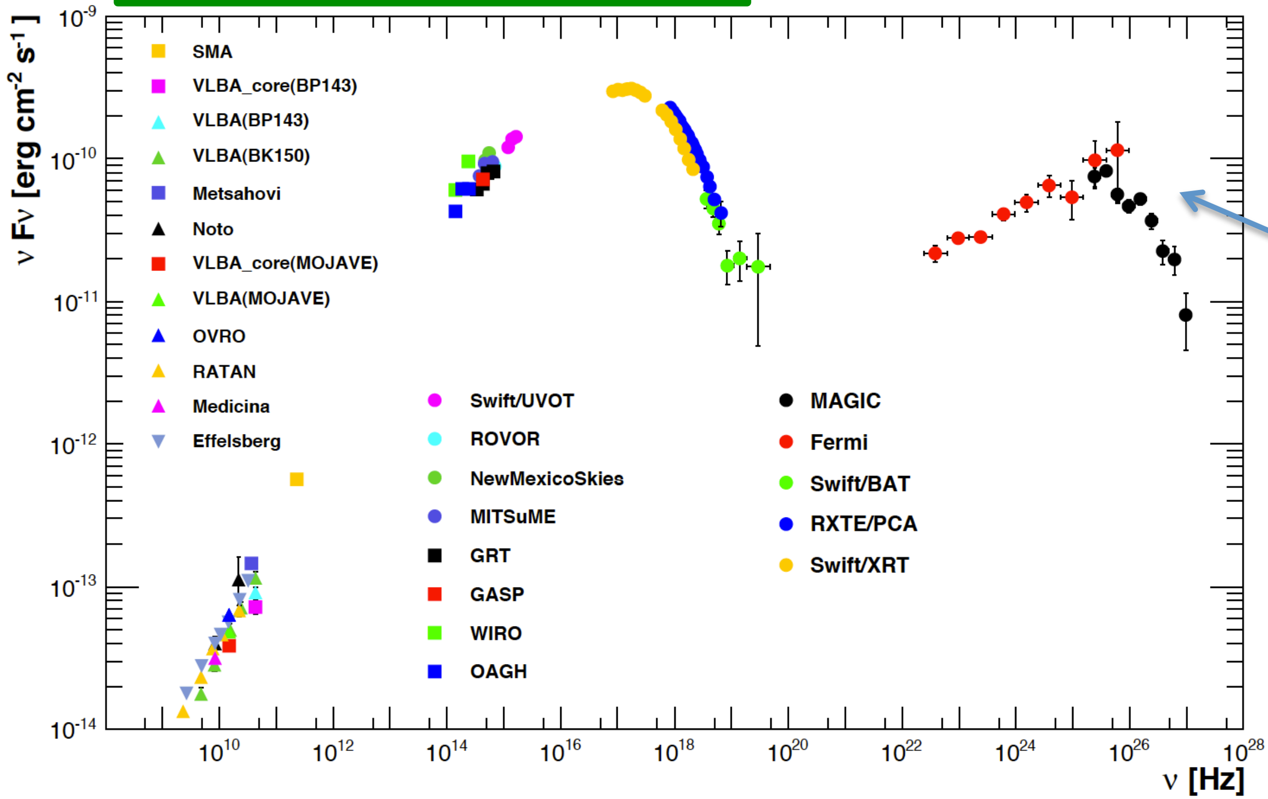
Collected data can be used to produce a good representation of the TRUE SED

Reliable interpretation of the SED (!!)

Broad Band (radio-TeV) SED of Mrk421

Average SED from the campaign observations

Abdo et al 2011, ApJ 736, 131



Mk421 was in relatively low state during the entire campaign

Fermi – MAGIC spectra cover, for the first time, the complete high energy component over 5 orders of magnitude without gaps

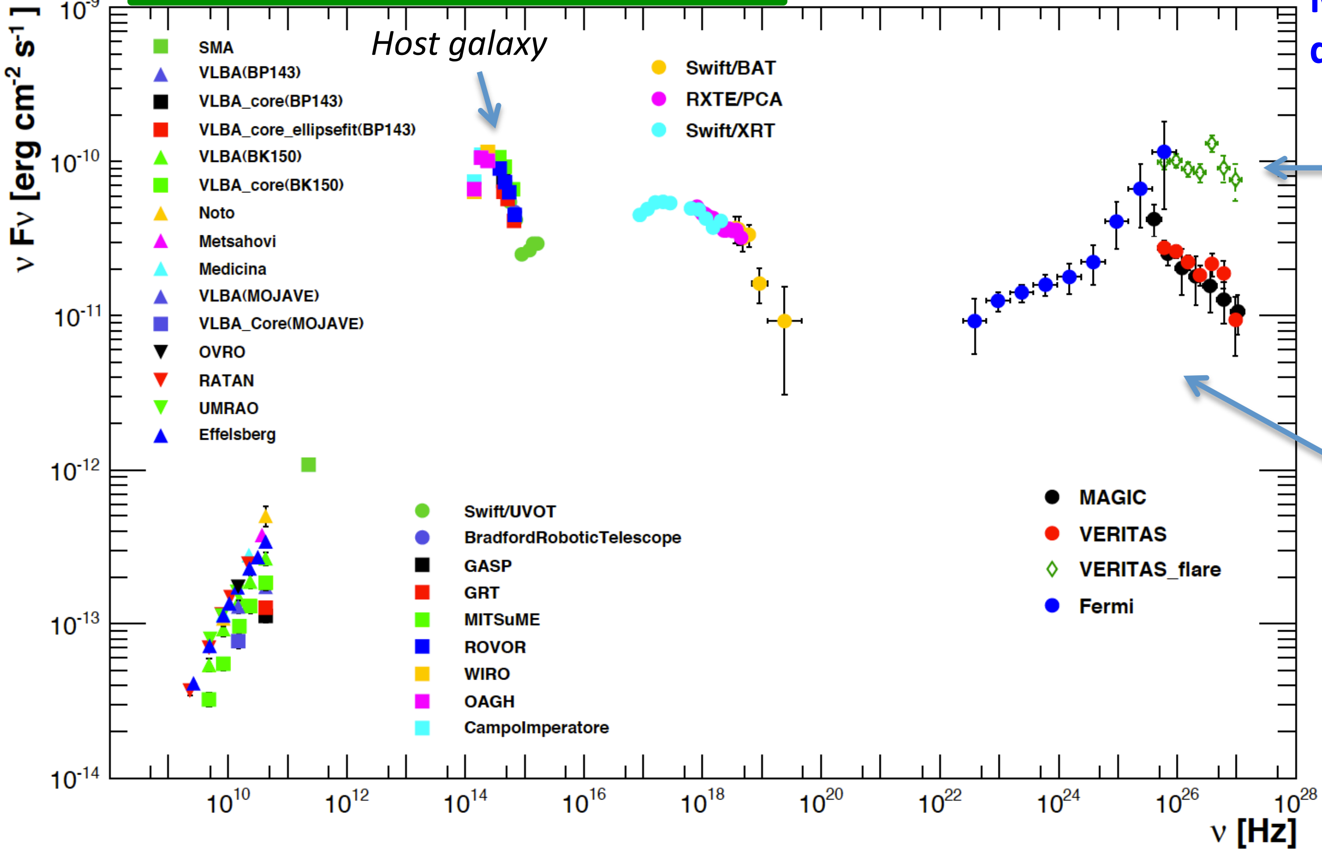
Agreement in overlapping energies among instruments (with different temporal coverage) indicates that we managed to get the true average SED of Mrk421 during the 4.5 months campaign.

Most complete SED ever collected for Mrk421

Broad Band (radio-TeV) SED of Mrk501

Average SED from the 2009 MW campaign on Mrk501

Abdo et al 2011, ApJ 727, 129



Mk501 was in relatively low state during most of the campaign

3-day spectrum from TeV flaring activity

For first time, Fermi–MAGIC/VERITAS spectra cover the complete high energy component over 5 orders of magnitude without gaps

Most complete SED ever collected for Mrk501

Modeling the Mrk501 and Mrk421 SED

Mrk501: Stawarz' code

Abdo et al 2011, ApJ 727, 129

R [cm]	1.3e17
B [G]	1.5e-2
delta	12.0
η_e	56
γ_{min}	600
s1	2.2
γ_{brk_1}	4.e4
s2	2.7
γ_{brk_2}	9.e5
s3	3.7
γ_{max}	1.5e7

Mrk421: Finke's code

Abdo et al 2011, ApJ 736, 131

R [cm]	5.2e16
B [G]	3.8e-2
delta	21.0
η_e	10
γ_{min}	800
s1	2.2
γ_{brk_1}	5.e4
s2	2.7
γ_{brk_2}	3.9e5
s3	4.7
γ_{max}	1.0e8

Similar model parameters for Mrk421 and Mrk501 (both during relatively low activity)
Is it by chance ?? Or are we dealing with some common properties for those 2 objects ??
Can we extrapolate this to other HSP - BL Lacs ??

How did the broad-band emission evolved during extensive campaigns ?

2 – Extensive MW Campaigns : Long term goals

The goal is build a very complete pool of MW data that allows us to make detailed studies on the observables we have:

- Quantify the overall (entire SED) flux variability and correlations during long baseline
- Correlate with VLBA images and polarization measurements
- Put strong constrains to the currently used emission models
  - → *Time dependent SED modeling !!*

These observations will allow us to address fundamental questions on how Mrk421 and Mrk501 (and perhaps HBLs in general) work:

- Nature of the radiating particles
- Location of the blazar emission
- Acceleration and radiation processes
- How flux variations are being produced; what changes in the source
- etc, etc…

Those multifrequency (multi-instrument) efforts will deliver several publications

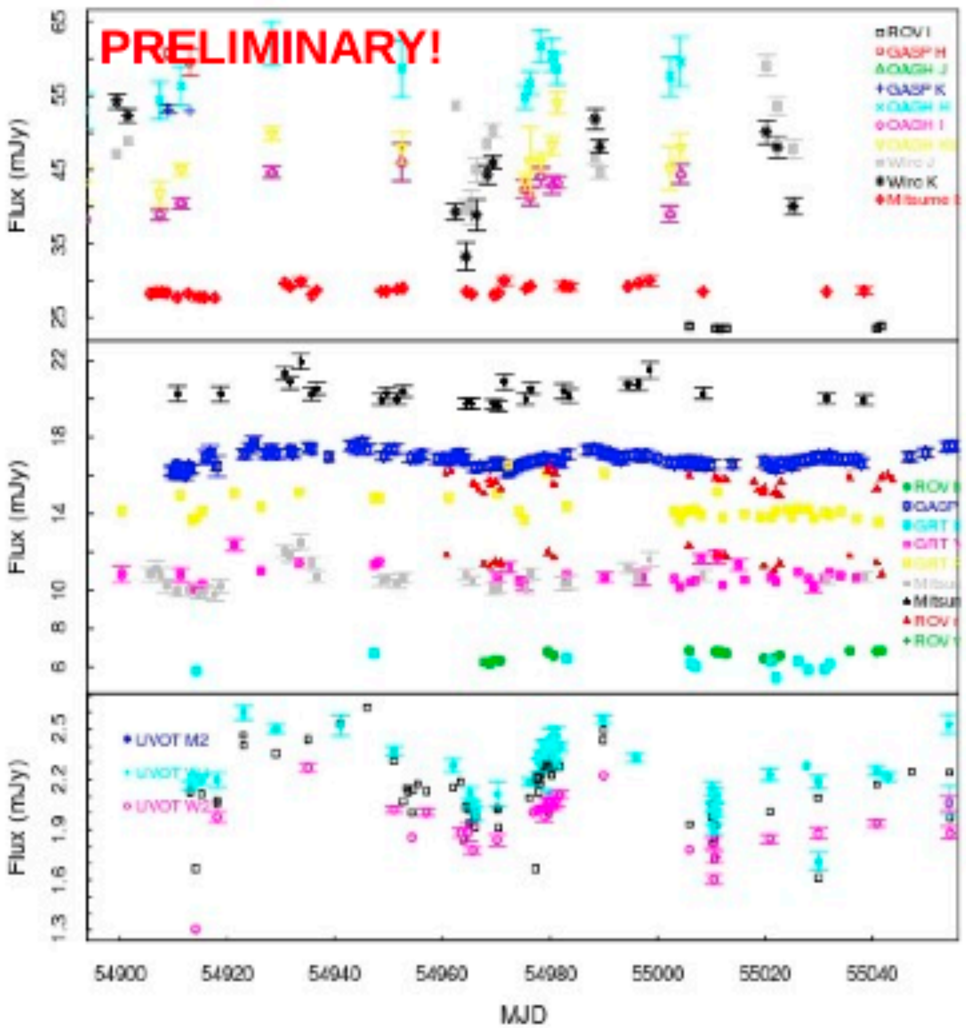
We plan to continue with these efforts during the coming years so that our pool of very complete MW data will grow and our knowledge on Mrk421 and Mrk501 (and perhaps blazars in general) will improve.

Multi-Instrument and Multi-year effort

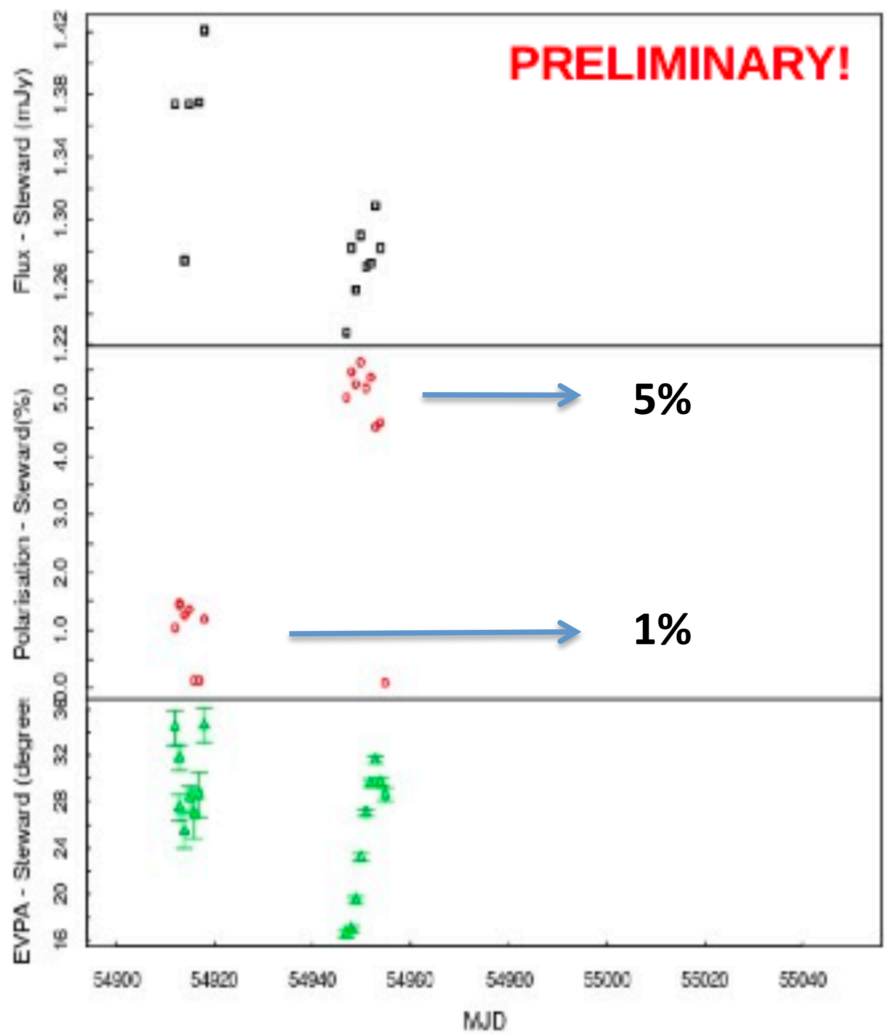
2.1 – Multi-band LC for Mrk501

Plots prepared by Ulisses Barres de Almeida (MPI)
Shown at ICRC2011

IR-Optical-UV



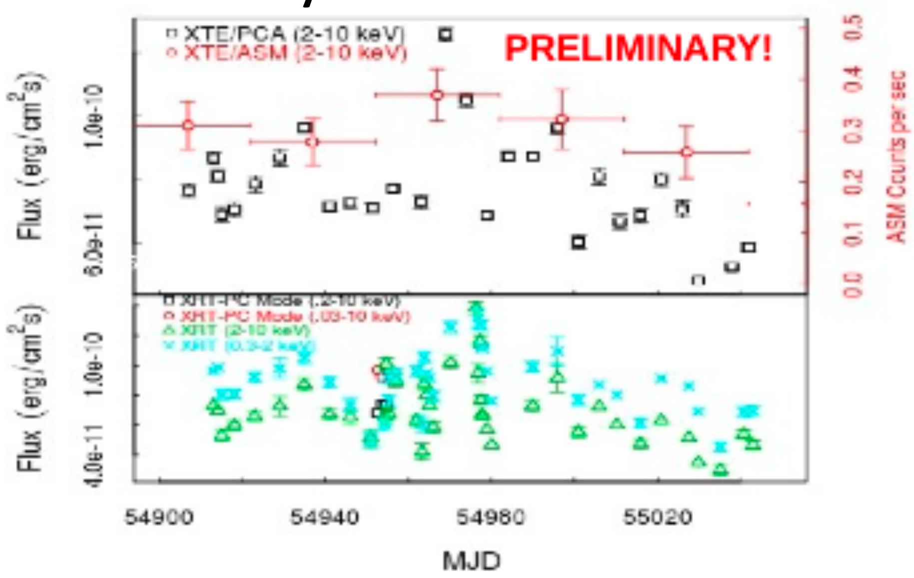
Polarization

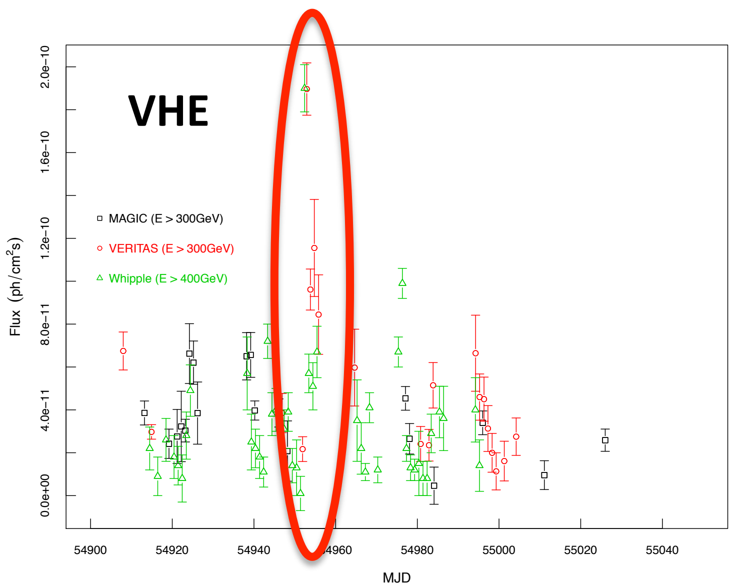


2.1 – Multi-band LC for Mrk501

Plots prepared by Ulisses Barres de Almeida (MPI)
Shown at ICRC2011

X-rays





Large flare in MJD 54952
(no obvious correlation with other wavelengths)

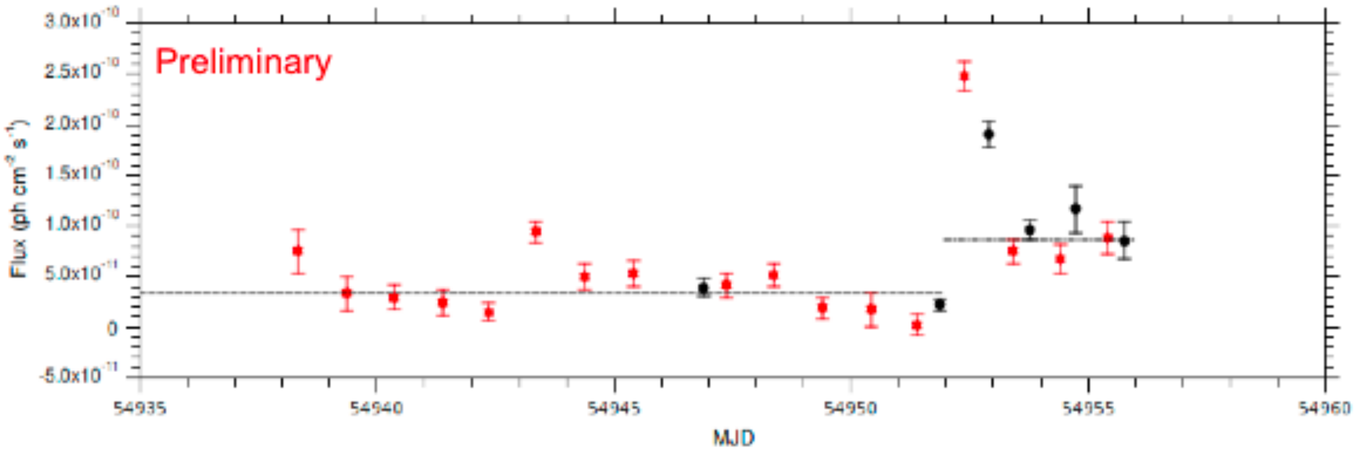
→ **probably an "ORPHAN" flare**

2.1 – Multi-band LC for Mrk501

Plots produced by Ana Carolina Pichel (UBA, Argentina)
Shown at ICRC2011

Dedicated publication with 3 weeks of data around the large VHE flare on Mrk501 (May, 2009)

VHE gamma-ray observations: VERITAS (E > 300 GeV) and Whipple (E > 400 GeV)



- 20h of live time for Whipple and 4h for VERITAS

High state: 54952-55
- The VHE flux increased by a factor of 5 during the VHE flare and then continued with high activity

MAGIC was scheduled for shutdown for drive system upgrade during end/ beginning of April/May 2009

2.1 – Multi-band LC for Mrk501

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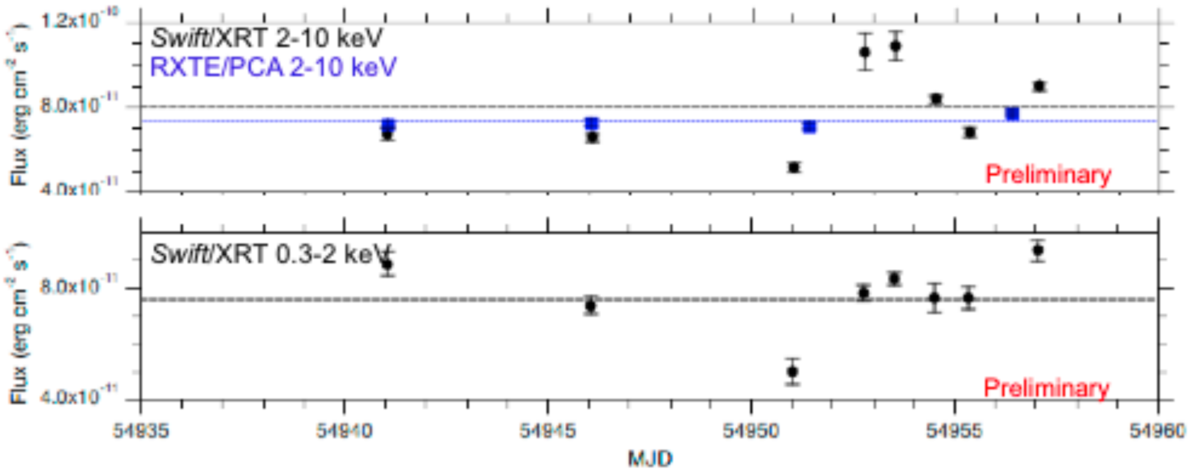
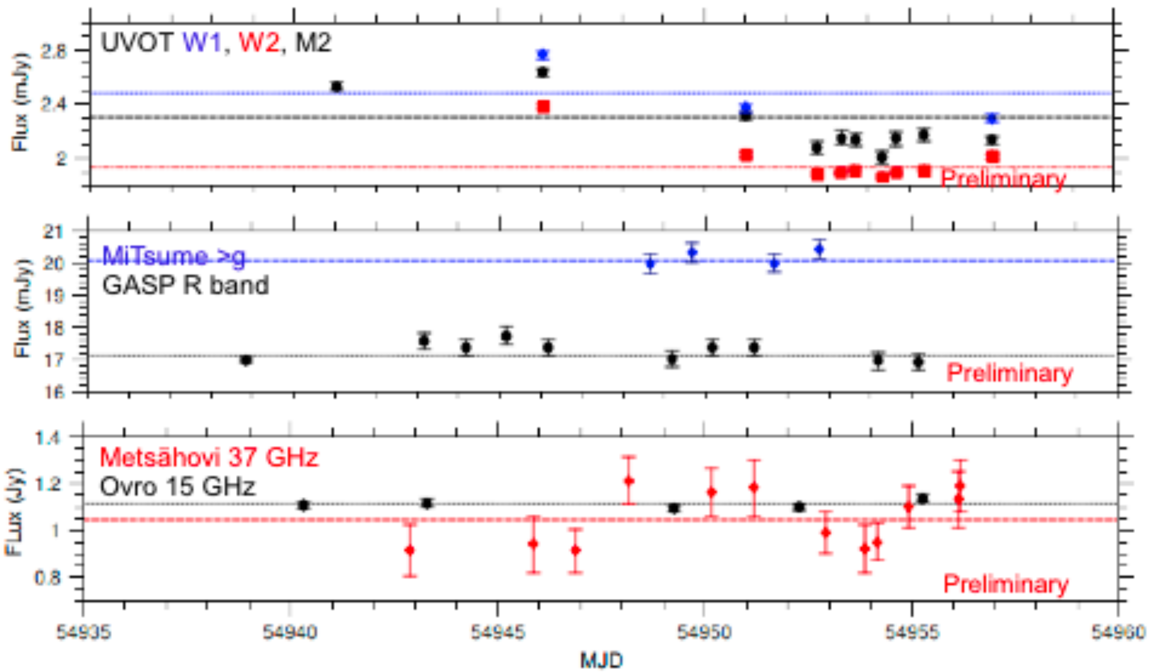


X-ray bands:

- No significant flux variations

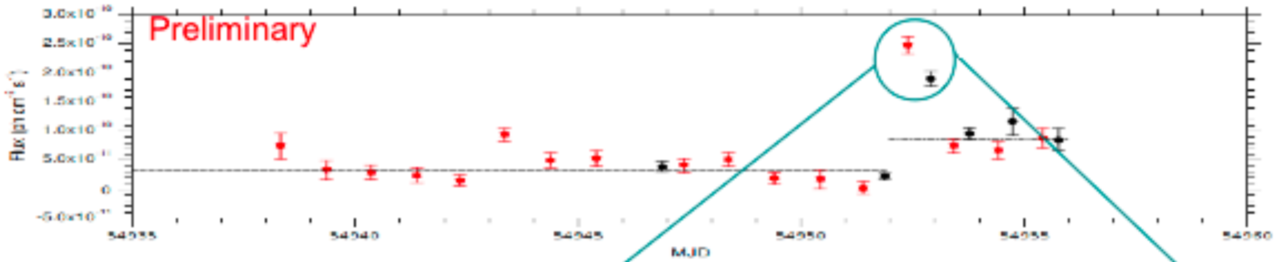


Optical and Radio:

- No significant flux variations

Plots produced by Ana Carolina Pichel (UBA, Argentina) Shown at ICRC2011

VHE flare



Fast variability: flux increase by factor 5 in 25 min

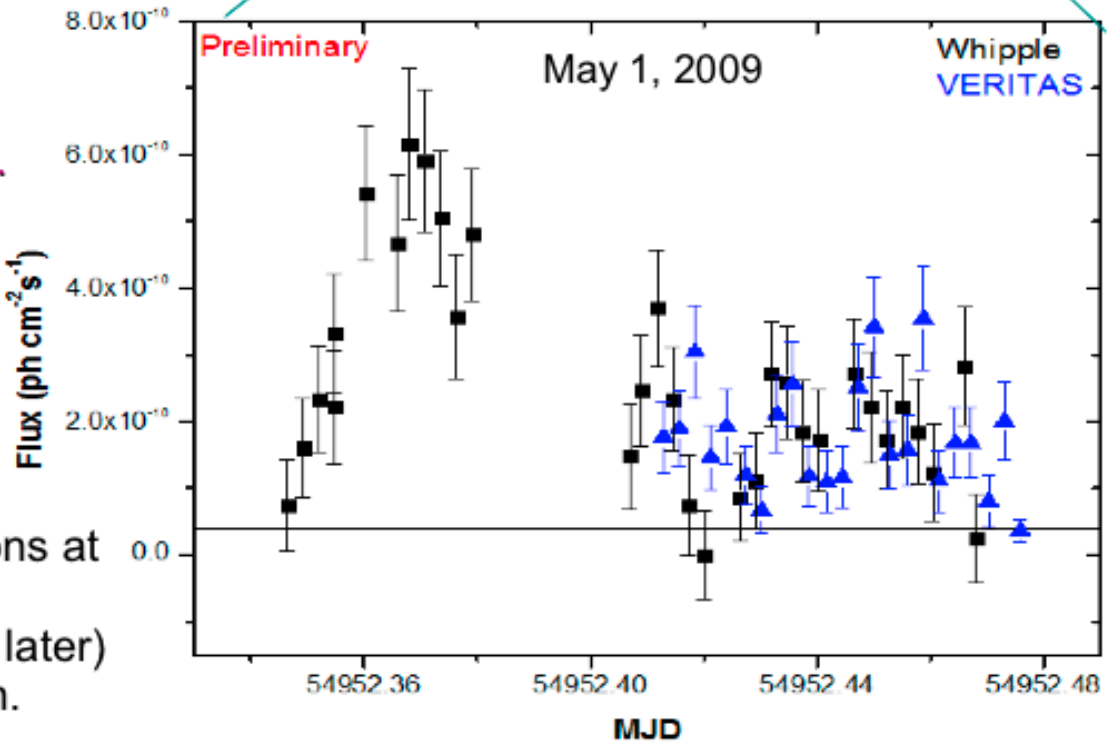
2.3 hours live time (Whipple)

20σ, Avg 2 Crab, 10 times the baseline flux.

1.4 hours live time (VERITAS).

23 σ, Avg 1.5 Crab, 6 times the baseline flux.

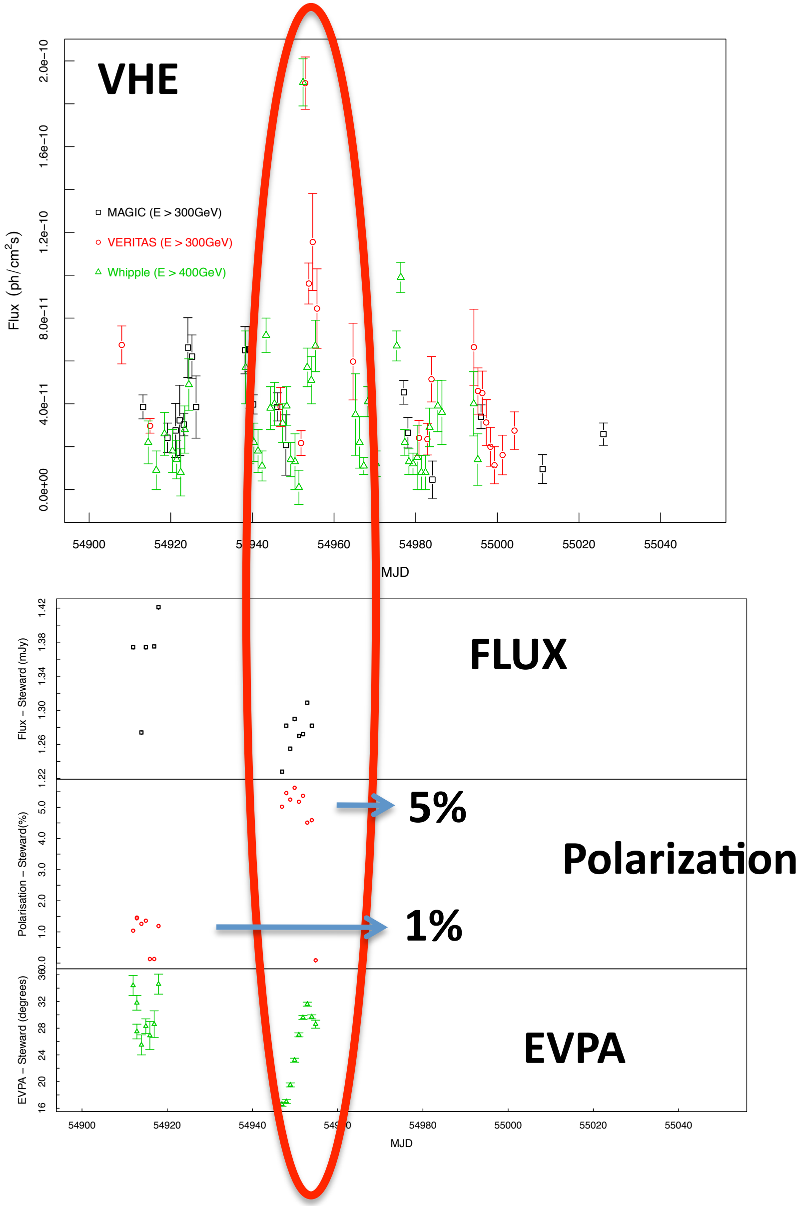
Whipple peak:
~4.5 Crab
with 6σ in 4 minutes.



No simultaneous observations at lower energies.
Contemporaneous obs. (7h later) in X-rays shows no variation.

2.1 – Multi-band LC for Mrk501

Plots prepared by Ulisses Barres de Almeida (MPI)
Shown at ICRC2011



Large flare in MJD 54952
(no obvious correlation with other wavelengths)
→ **probably an "ORPHAN" flare**

Around the VHE flare there was an increase in polarization by factor of 5, together with a rotation of EPVA by 15 deg (during about 3 days)

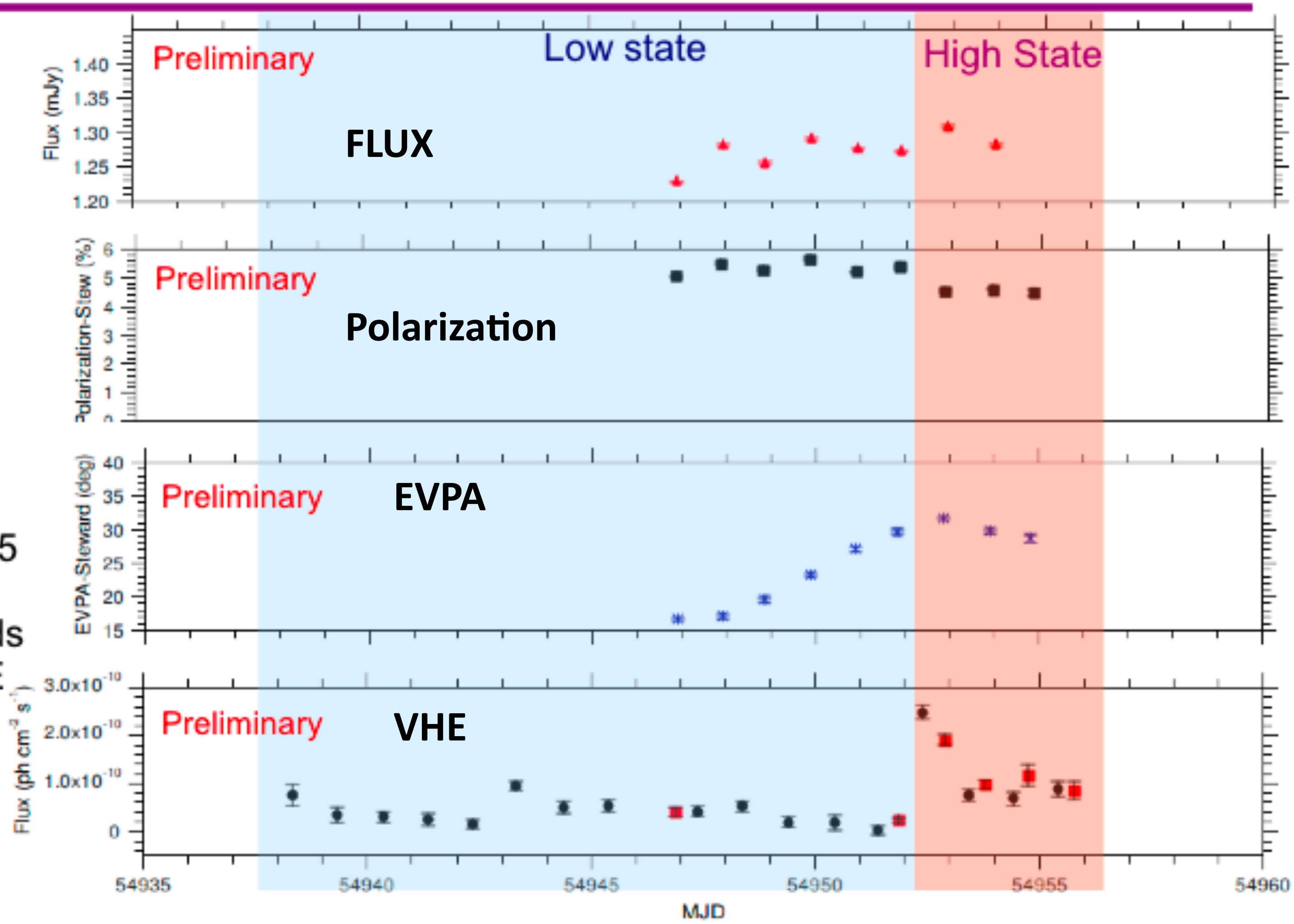
This event might have been produced by a single blob following a spiral path through coiled magnetic field in an accelerating flow, as suggested for the large flare in PKS1510 (Marscher et al. 2010)

Optical Polarization

Plots produced by Ana Carolina Pichel (UBA, Argentina) Shown at ICRC2011

The polarization dropped 15 % after the flare.

The polarization angle changes by 15 degrees in 3 days, and the rotation ends when the large VHE flare occurs.



Correlation of the change between polarization and gamma-ray flux could be related to a single event. It might be produced by a single blob following a spiral path through a coiled magnetic field in an accelerating flow.

Similar situation (*although with a much smaller rotation angle*) to the one observed on
BL Lac (*Marscher et al 2008, Nature, 452, 966*)
and
PKS1510-089 (*Marscher et al 2010 (ApJ 710 L126*)

The gamma-ray flare occurs at the end of the polarization rotation angle

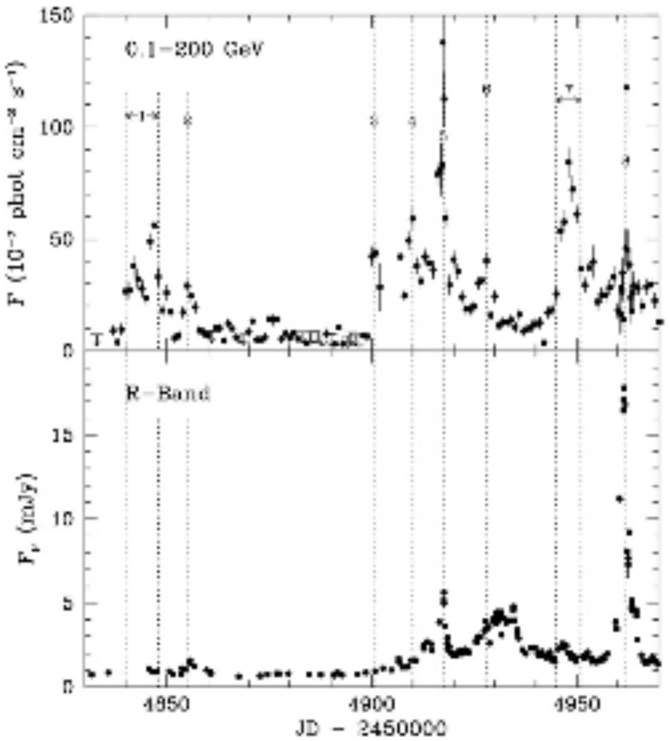


Fig2, Marscher et al 2010

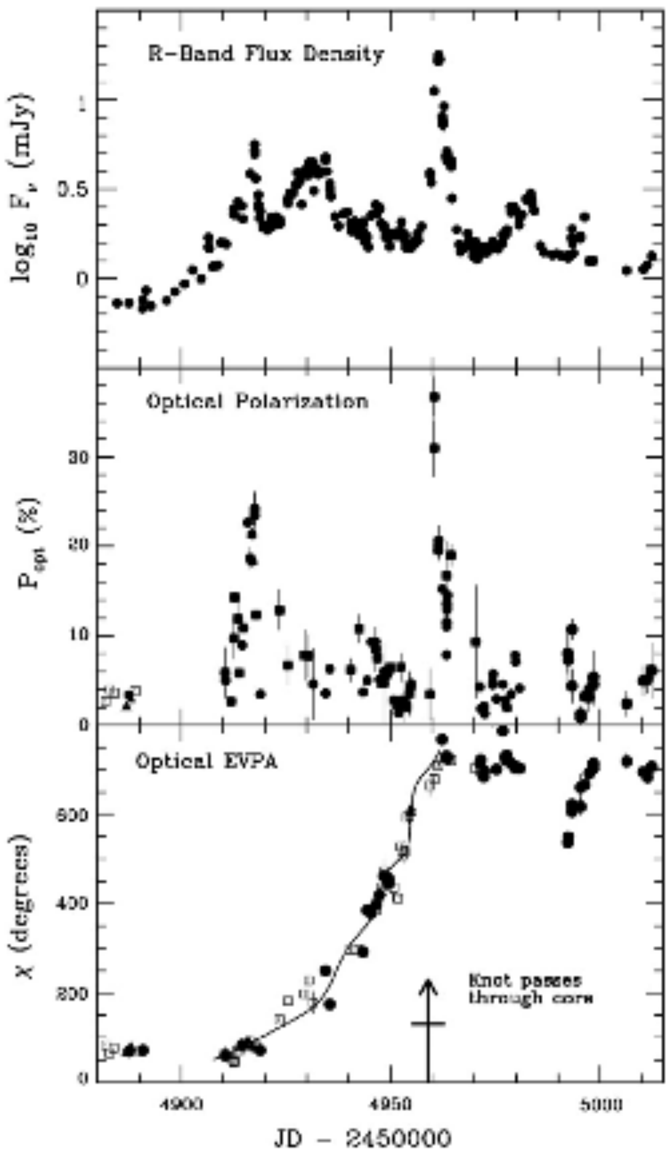


Fig4, Marscher et al 2010

But opposite situation to the one found in 3c279

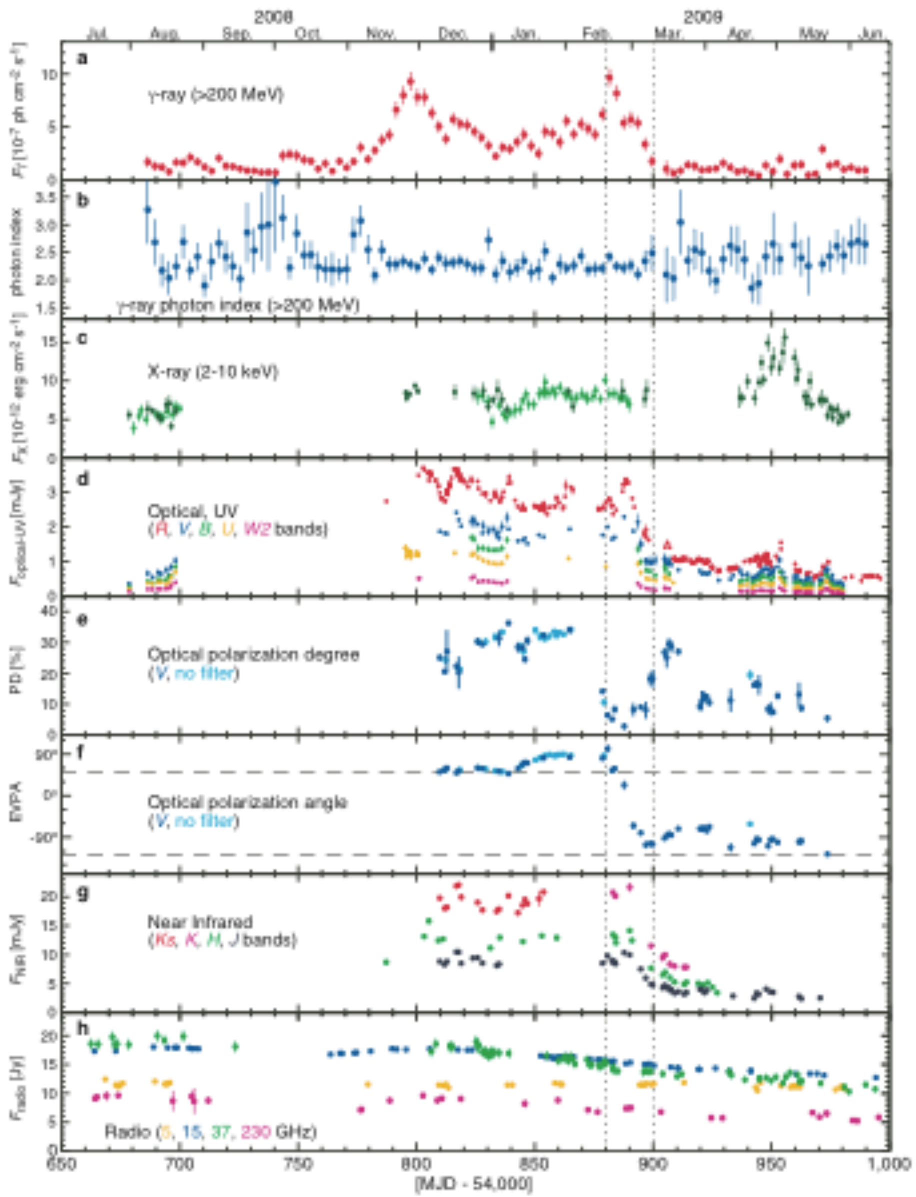
Abdo et al 2010, Nature 463, 919

The gamma-ray flare occurs at the beginning of the polarization angle rotation

Different mechanisms for different sources and/or flares

Anyhow, all these observations indicate very clearly that gamma-rays and a fraction of the optical emission are co-spatial, and that there is highly ordered magnetic field in the jet of blazars, **and that the HSP are not an exception**

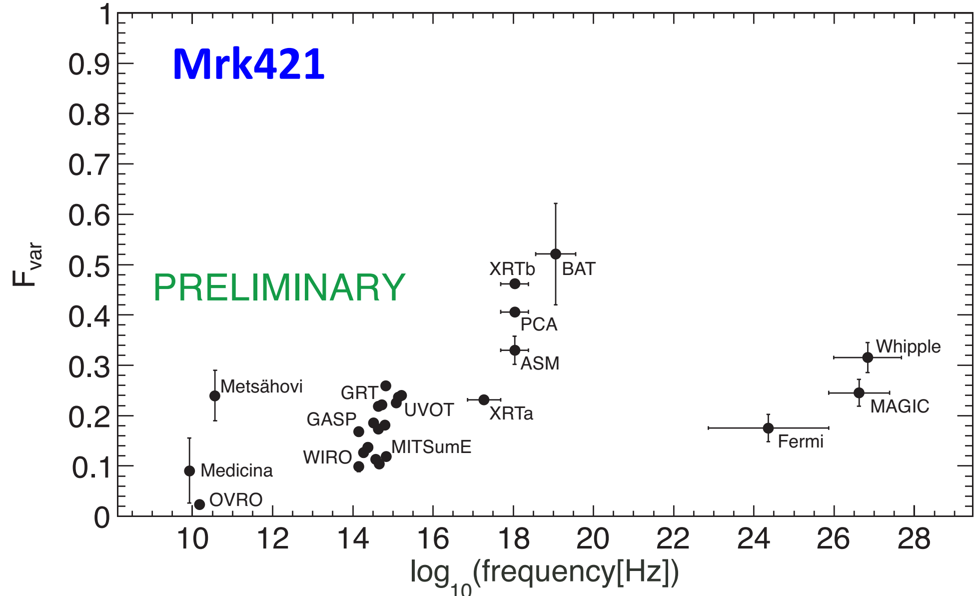
Fig 1, Abdo etal 2010

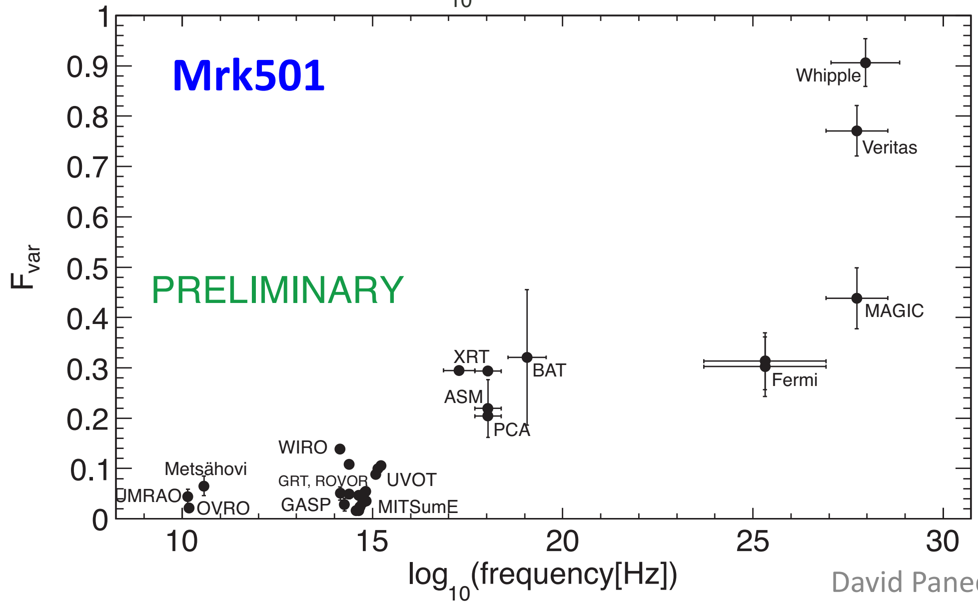


3.2 – Variability vs Energy

Plots produced by Nina Nowak (MPI, Munich)

Fractional Variability is quantified according to prescription in Vaughan etal 2003





Slightly different variability patterns for Mrk421 and Mrk501

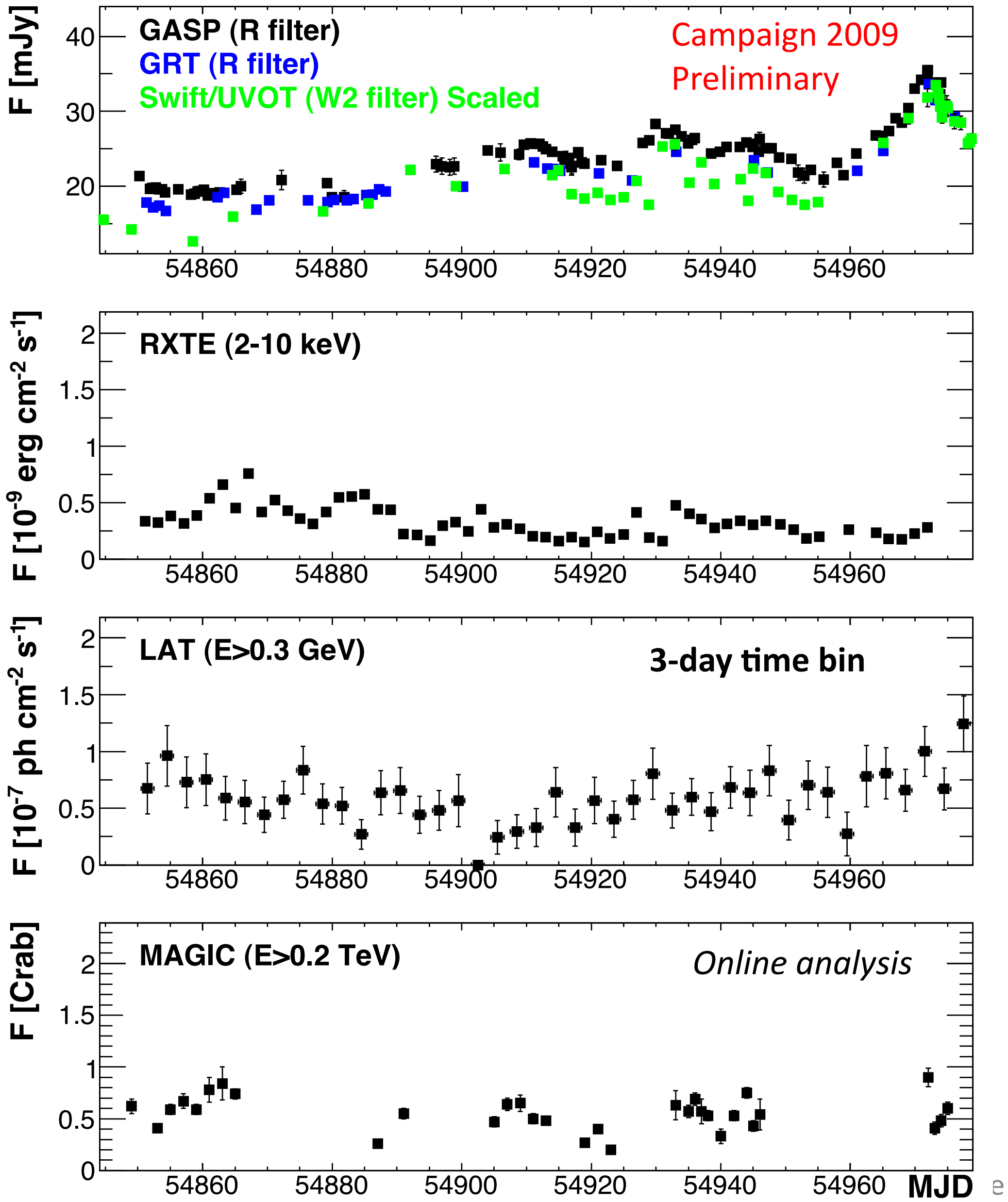
Both sources were in relative low activity, apart from flaring activity in May 2009 for Mrk501, which dominates the Fvar at VHE

Mrk421 shows slightly larger Fvar at X-ray frequencies

At optical frequencies, the values are not compatible because they are not "host galaxy corrected". The relative contribution of the host galaxy in Mrk501 is higher than in Mrk421

At radio, both sources are essentially not variable, with the exception of Metsahovi (37 GHz) for Mrk421

Mrk421: PRELIMINARY Multi-frequency activity (2009 Campaign)

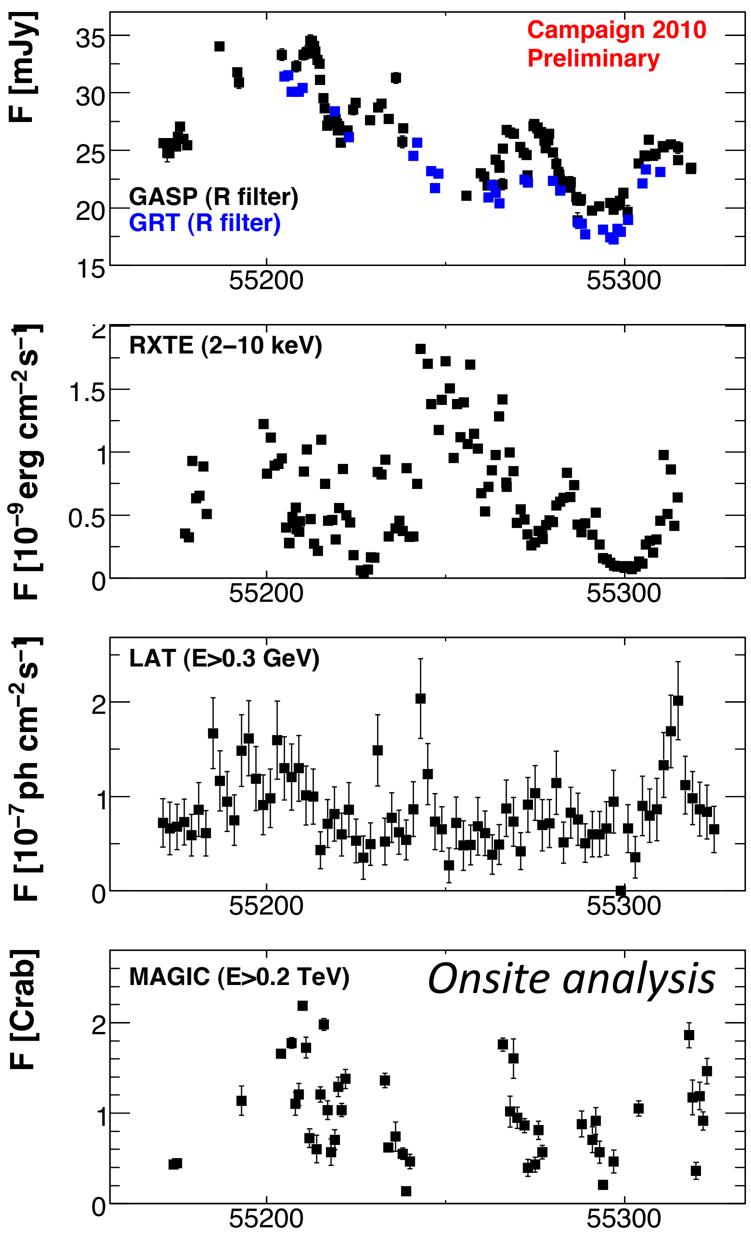


Only some instruments are shown !!!!

During the 2009 campaign the variations were relatively mild

Mrk421: PRELIMINARY Multi-frequency activity (2010 Campaign)

Only some instruments are shown !!!!



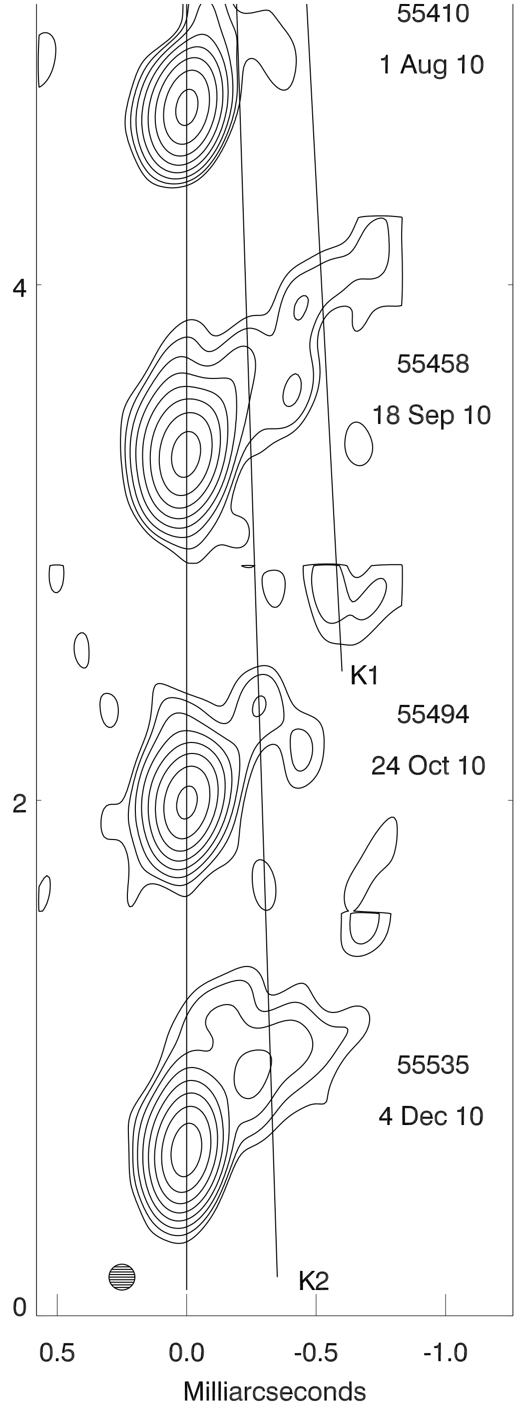
MW Data shown in these plots spans from Dec2009 to May2010

Mrk421 showed large variability at all energies!!

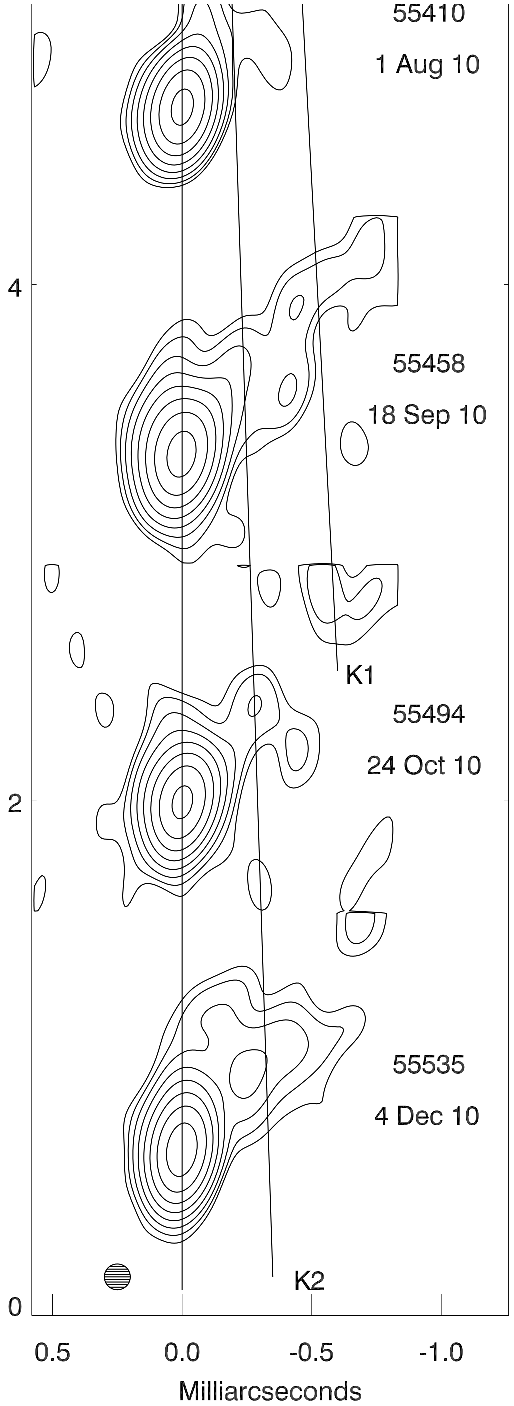
Great opportunity to study blazar variability

Large complexity in the multi-frequency variability. *Different flavors of flaring activity*

The only chance we have to move forward in the understanding of Mrk421 is to deal with all energy bands simultaneously during a long baseline



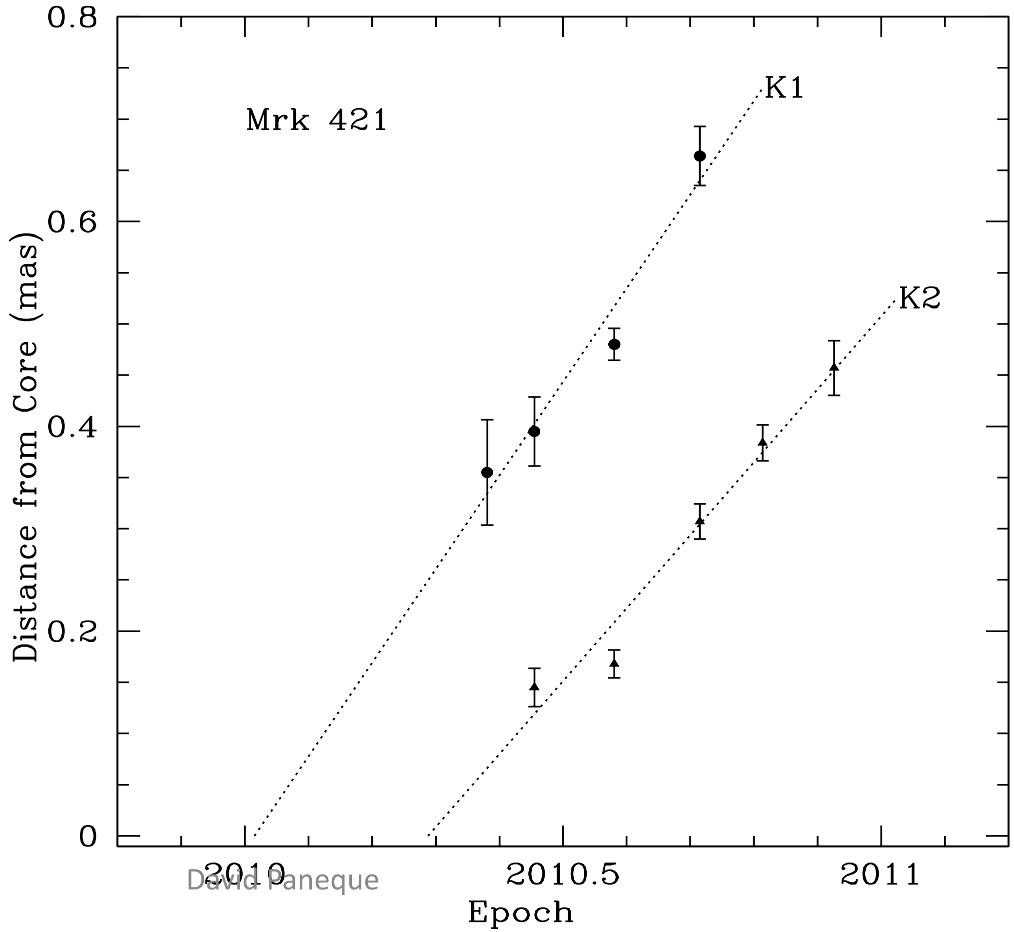
VLBA from the Boston Univ. Blazar group (Marscher & Jorstad). They joined the MW campaign on 2010 and Mrk421 is now one of their high priority sources.



VLBA from the Boston Univ. Blazar group (Marscher & Jorstad). They joined the MW campaign on 2010 and Mrk421 is now one of their high priority sources.

PRELIMINARY: VLBA components K1 and K2 seem to have been "emitted" from the core in Jan and mid March 2010

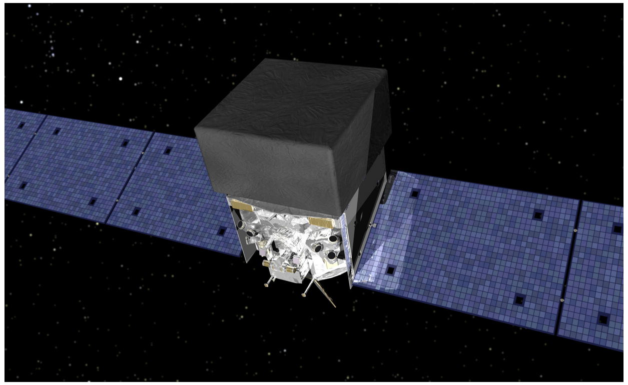
These blobs crossing the VLBA core could be related to the January and March flares (<u>but not with the big Flare in Feb.</u>)



Instrumentation for gamma-ray astronomy (the big picture)

Pair production telescopes
e.g. EGRET, AGILE, Fermi

Direct detection of gamma

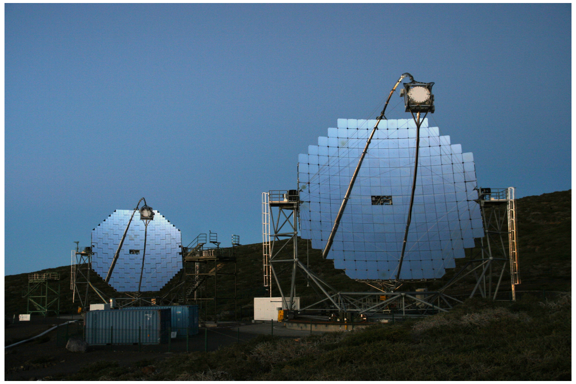


Space-based
Large duty cycle (~85%)
Large field of view (20-60 deg)
Excellent background rejection
Small effective areas (~m^2)
Energy range ~0.2 – 300 GeV

Good sensitivity

Imaging Atmospheric Cherenkov Telescopes (IACTs)
e.g. HESS, MAGIC, VERITAS

Indirect detection of gamma through Cherenkov Light

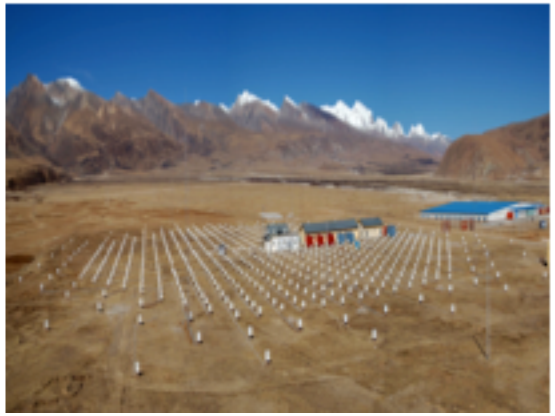


Ground-based
Low duty cycle (~10%)
Small FoV (2-4 deg)
Very Good background rejection
Large effective area (~10^5 m^2)
Energy range ~50 GeV– 100 TeV

Excellent sensitivity

Extensive Air Shower (EAS) arrays
e.g. Milagro, Tibet, ARGO

Indirect detection of gamma through secondaries



Ground-based
Large duty cycle (~90%)
Big FoV (30-40 deg)
Moderate background rejection
Good effective area (~10^2 m^2)
Energy range ~100 GeV– 100 TeV

Moderate sensitivity