Astrofisica Nucleare e Subnucleare

Dark Matter Searches - II

Dark Matter
Status and Perspectives

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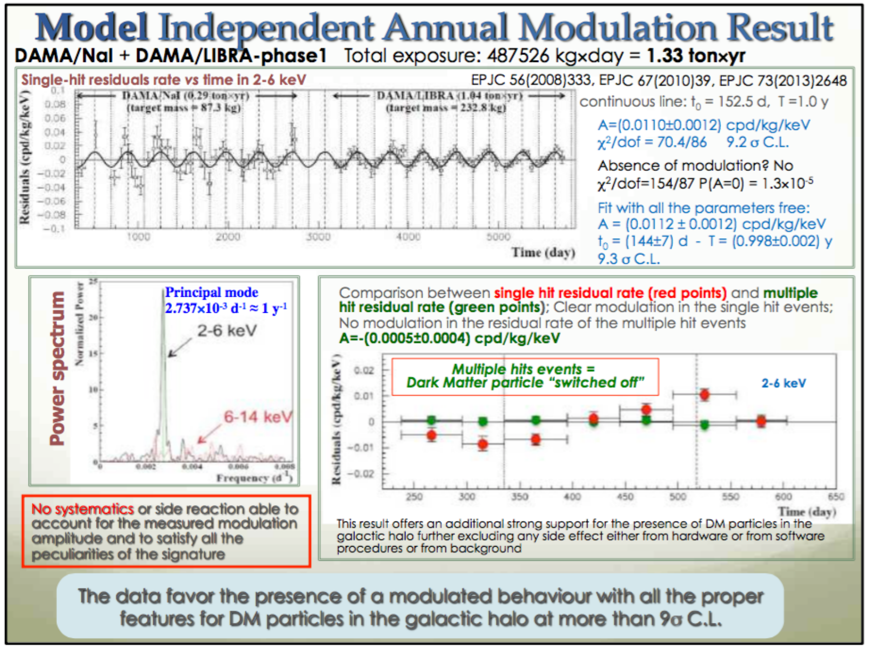
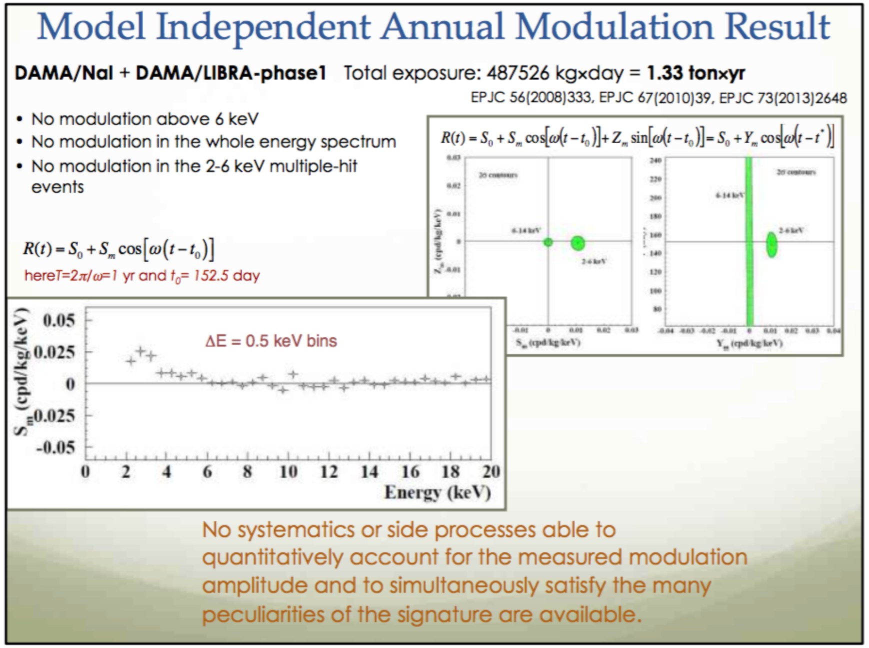
Giornate di studio sul Piano Triennale INFN
Centro "Le Ciminiere", Catania − 3.12.2015

Annual modulation: DAMA, 9.2σ with 1.33 ton x yr, 15 cycles





From Belli's talk at TAUP 2015, http://taup2015.to.infn.it

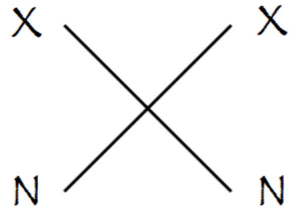
Compatible with: DM scattering on nuclei (5-100) GeV WIMPs
DM scattering on electrons (0.3-6) KeV ALPs

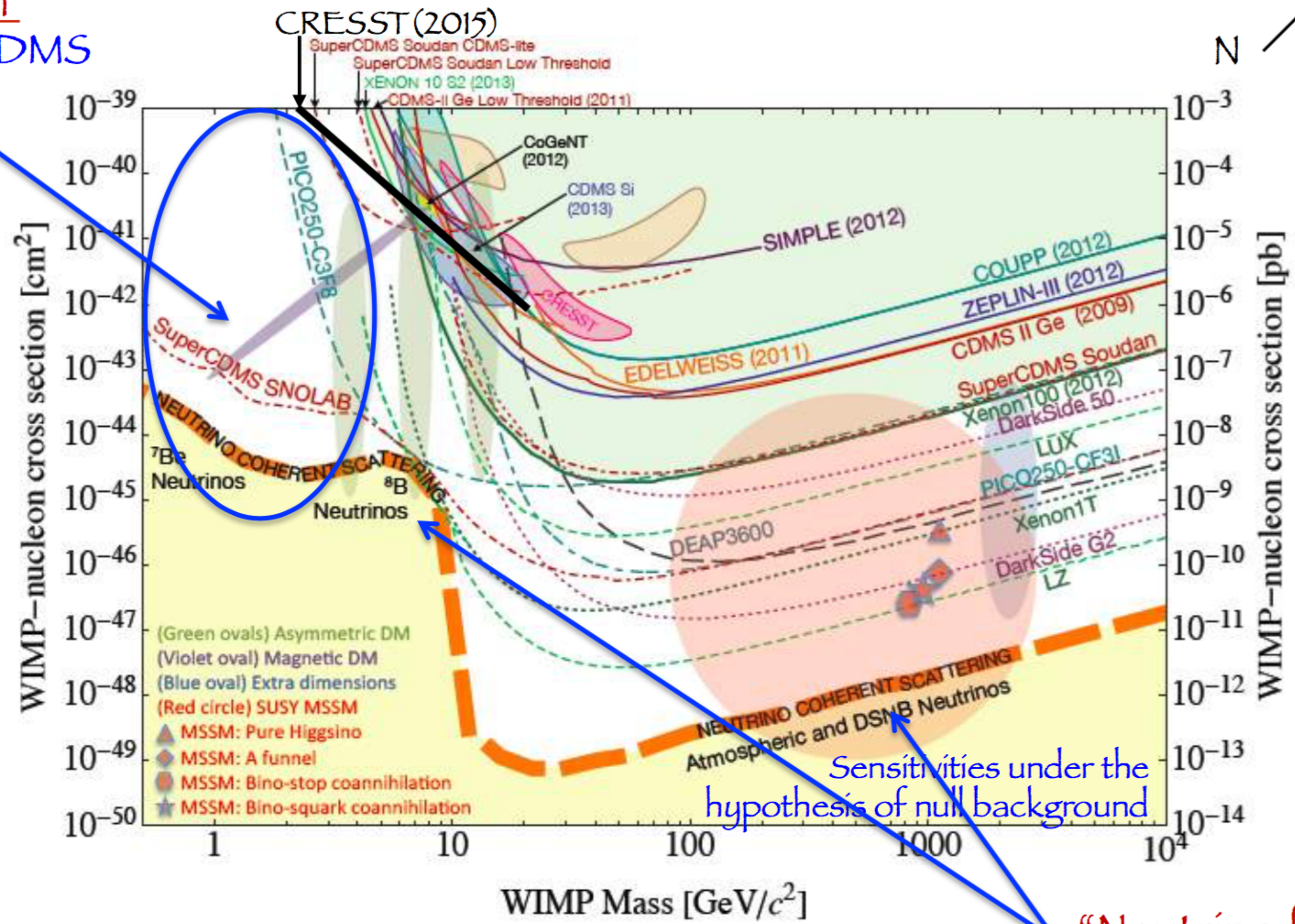
Light WIMPs window

CRESST

SuperCDMS

...





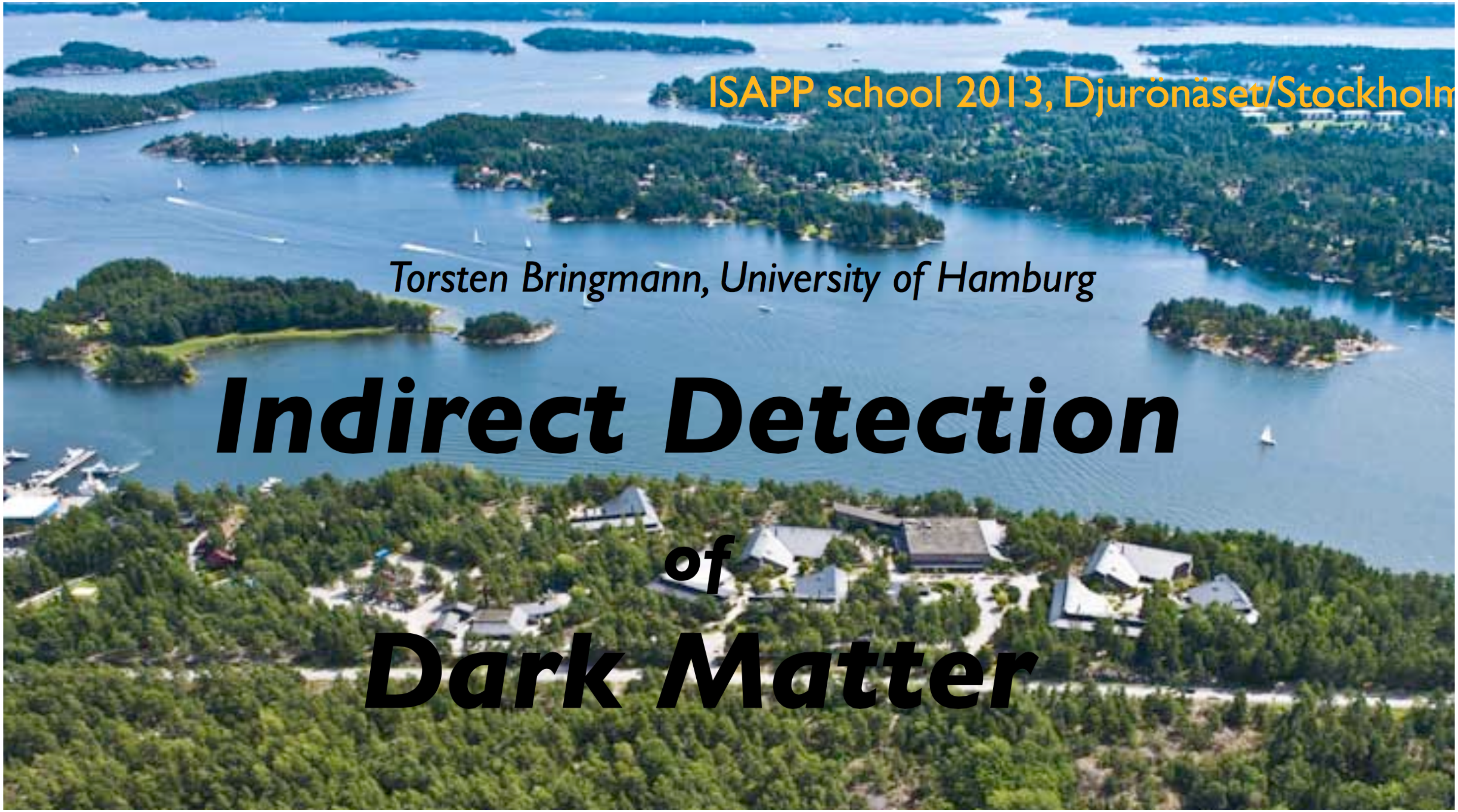
"Neutrino floor"

XENON1T (LXe)

DarkSide (LAr)

Lux, LZ, ...

Bounds and expected sensitivities for DM-nucleus scattering
Under the hypothesis of contact-type interactions

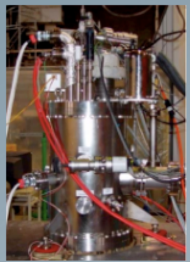


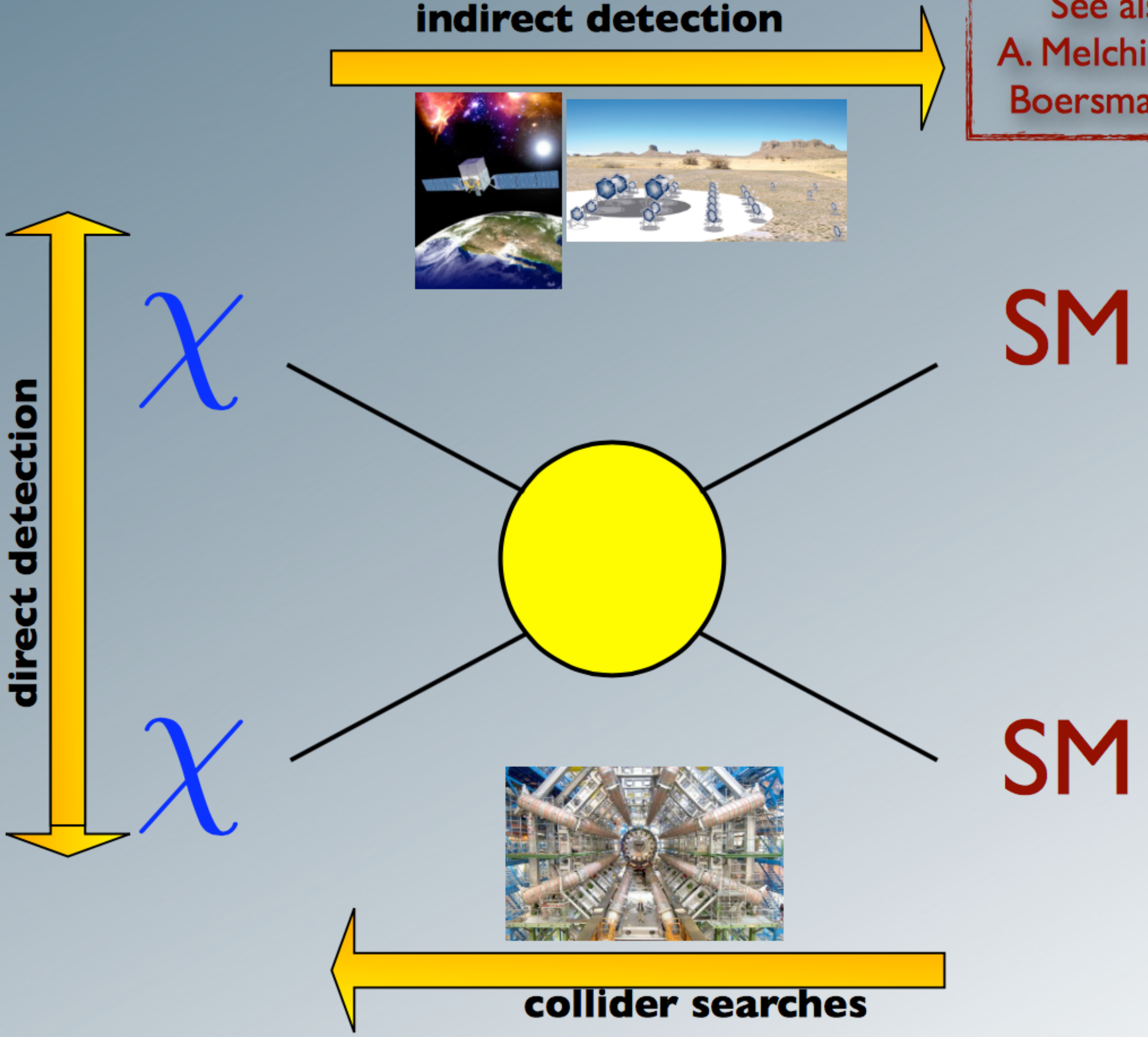
ISAPP school 2013, Djurönäset/Stockholm
Torsten Bringmann, University of Hamburg
Indirect Detection
of
Dark Matter

WIMPs do interact with the SM!

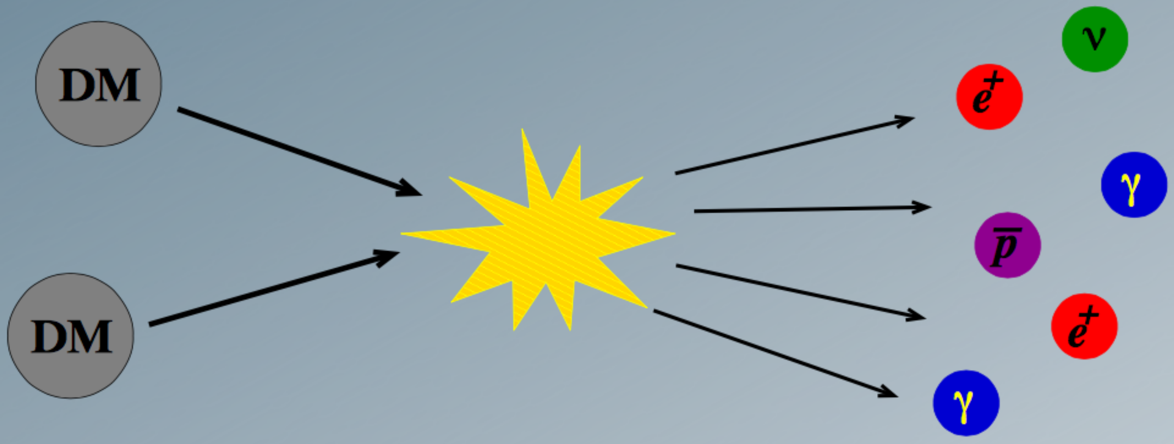
See also lectures by A. Melchiorri, J. Conrad, D. Boersma and F. Donato...

See lectures by J. Gascon





Indirect detection in one slide

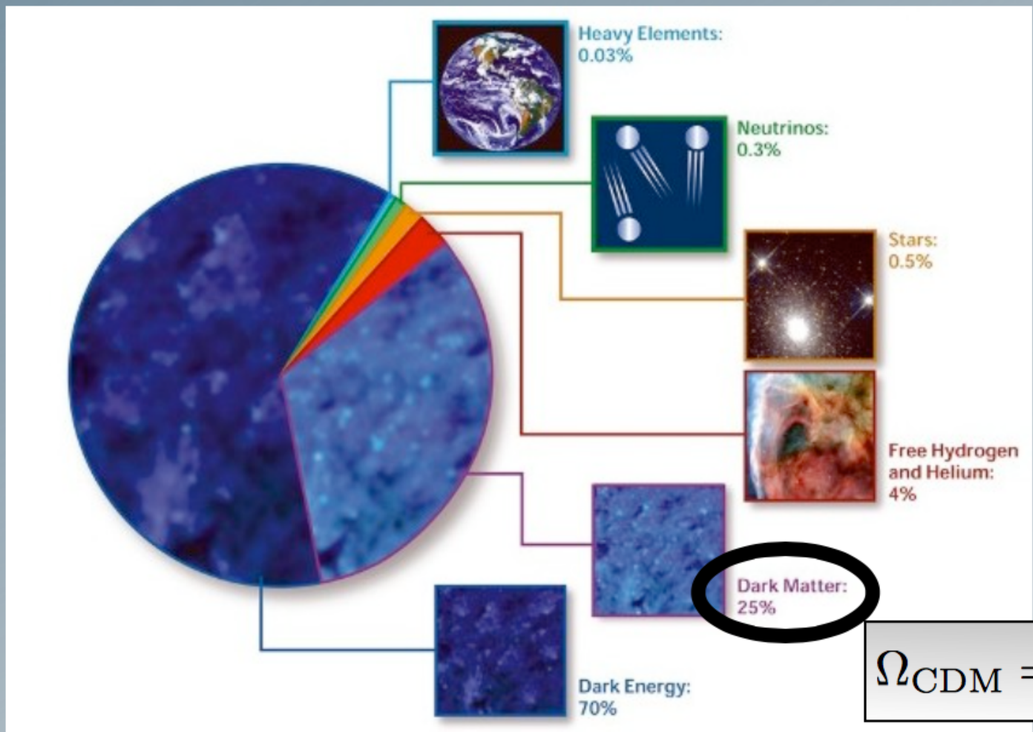


- DM has to be (quasi-)stable against decay...
- … but can usually pair-annihilate into SM particles
- Try to spot those in cosmic rays of various kinds
- The challenge: i) absolute rates
  ⇝ regions of high DM density
  ii) discrimination against other sources
  ⇝ low background; clear signatures

Distribution of dark matter

- Annihilation sensitive to DM density *squared*

  → need to know this quantity very well!



NB: in general

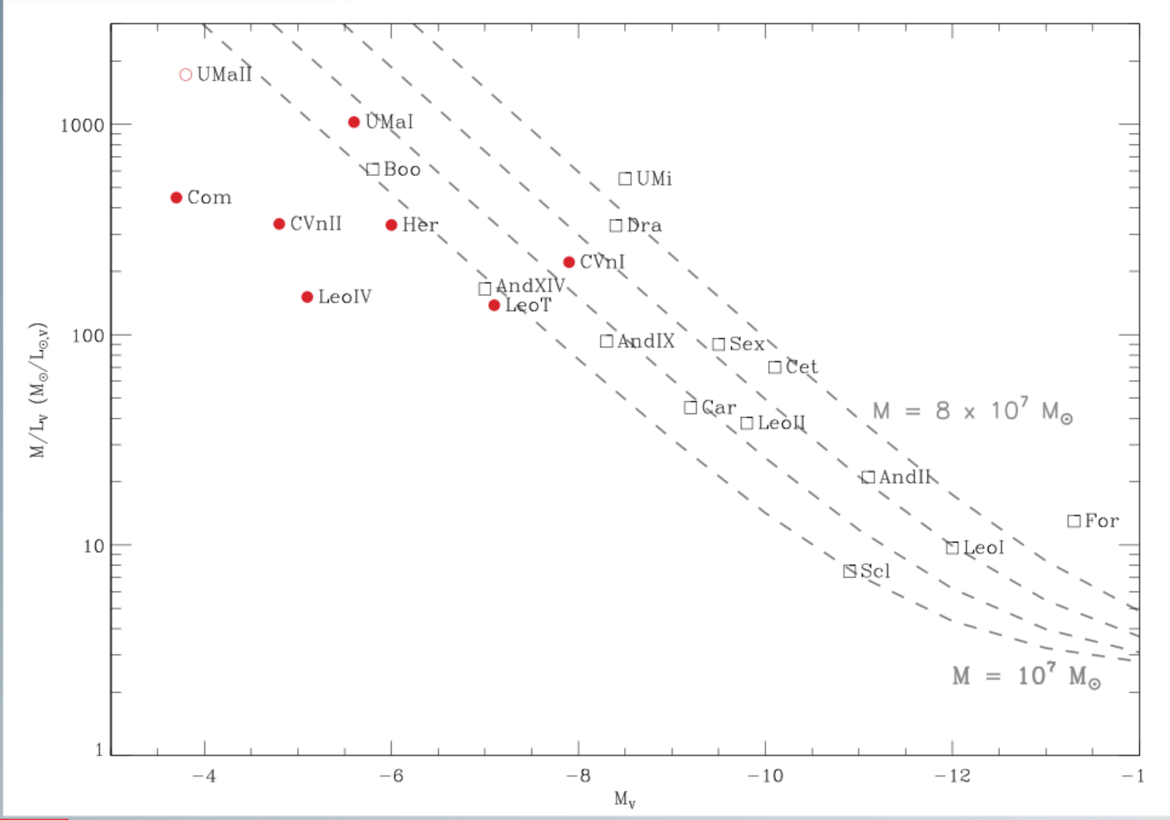
$\Omega_\chi^{\rm local} \neq \Omega_{\rm CDM}$!!!

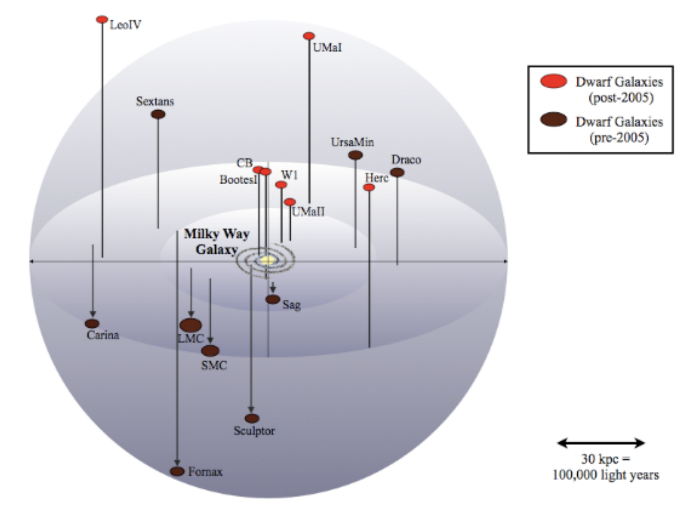
$\Omega_{\rm CDM} = 0.233 \pm 0.013$ on **large** scales

- [For comparison: *decaying* DM directly proportional to density]

Dwarf galaxies

- Use Jeans equation to relate observed velocity dispersion of stars to total mass distribution
  ➡ highest known mass-to-light ratios!





J.~D.~Simon, M.~Geha, ApJ 670, 313 (2007)

Substructure

- *N*-body simulations: The DM halo contains not only a smooth component, but a lot of substructure!
- Indirect detection effectively involves an averaging:

$$\Phi_{\rm SM} \propto \langle \rho_\chi^2 \rangle = (1 + {\rm BF}) \langle \rho_\chi \rangle^2$$

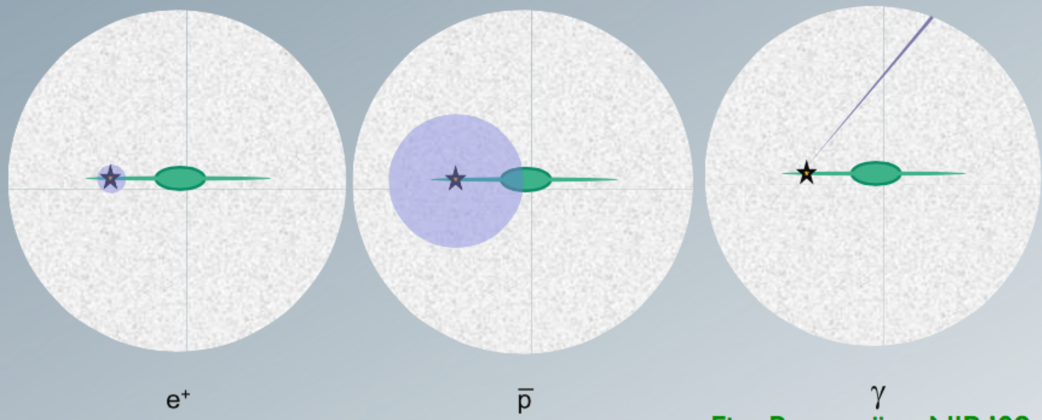
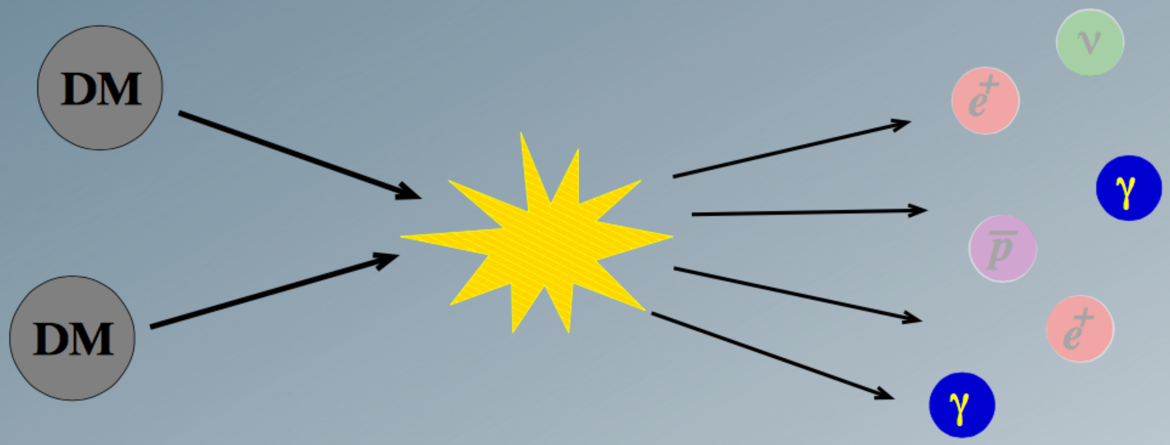


Fig.: Bergström, NJP '09

- "Boost factor"
  - each decade in $M_{\rm subhalo}$ contributes very roughly the same
    e.g. Diemand, Kuhlen & Madau, ApJ '07

    ⇒ *important to include realistic value for* $M_{\rm cut}$ *!*
  - depends on uncertain form of microhalo profile ($c_{\rm V}$ ...) and dN/dM (large extrapolations necessary!)

Indirect DM searches



Gamma rays:

- Rather high rates
- No attenuation when propagating through halo
- No assumptions about diffuse halo necessary
- Point directly to the sources: clear spatial signatures
- Clear spectral signatures to look for

Gamma-ray flux

The expected gamma-ray flux [$\mathrm{GeV^{-1}cm^{-2}s^{-1}sr^{-1}}$] from a source with DM density ρ is given by

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\Delta\psi) = \int_{\Delta\psi}\frac{d\Omega}{\Delta\psi}\int_{\mathrm{l.o.s}} d\ell(\psi)\rho^2(\mathbf{r}) \; \frac{\langle\sigma v\rangle_{\mathrm{ann}}}{8\pi m_\chi^2}\sum_f B_f \frac{dN_\gamma^f}{dE_\gamma}$$

astrophysics — particle physics

for point-like sources: $\simeq (D^2\Delta\psi)^{-1}\int d^3r\,\rho^2(\mathbf{r})$

$\Delta\psi$: angular res. of detector

D : distance to source

$\langle\sigma v\rangle_{\mathrm{ann}}$: total annihilation cross section

m_χ : WIMP mass $(50\,\mathrm{GeV} \lesssim m_\chi \lesssim 5\,\mathrm{TeV})$

B_f : branching ratio into channel f

N_γ^f : number of photons per ann.

angular information
+ rather uncertain normalization

high accuracy
spectral information

Local DM density

- standard value:

$$\rho_\odot^{\rm DM} \sim 0.3 \to 0.4 \, \frac{\rm GeV}{\rm cm^3}$$

...

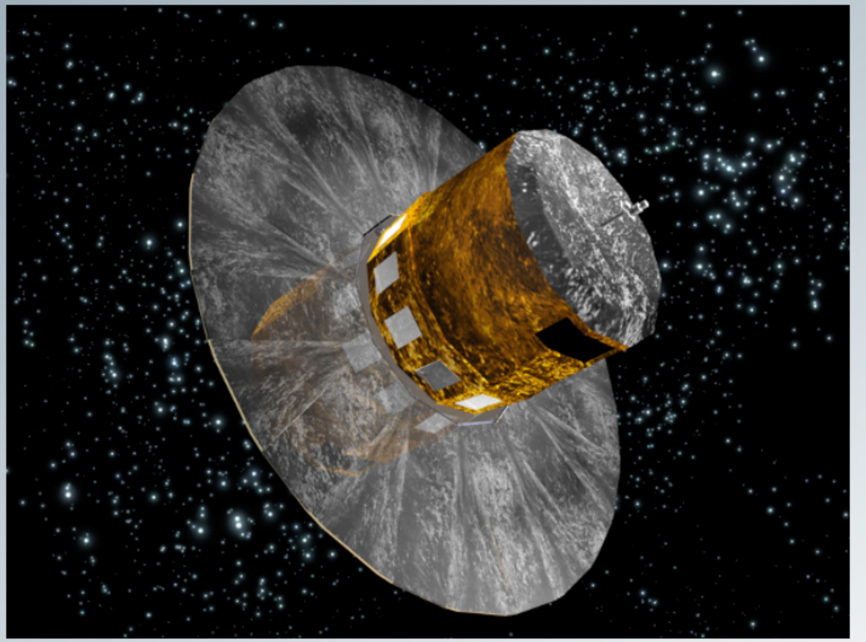
0.30 ± 0.05
Wydrow, Pim & Dubinski, ApJ '08

0.39 ± 0.03
Catena & Ullio, JCAP '10

0.43 ± 0.11 ± 0.10
Salucci et al, A&A '10

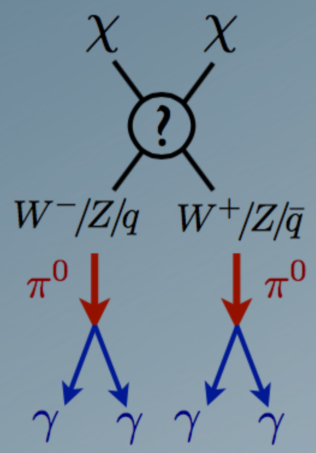
...

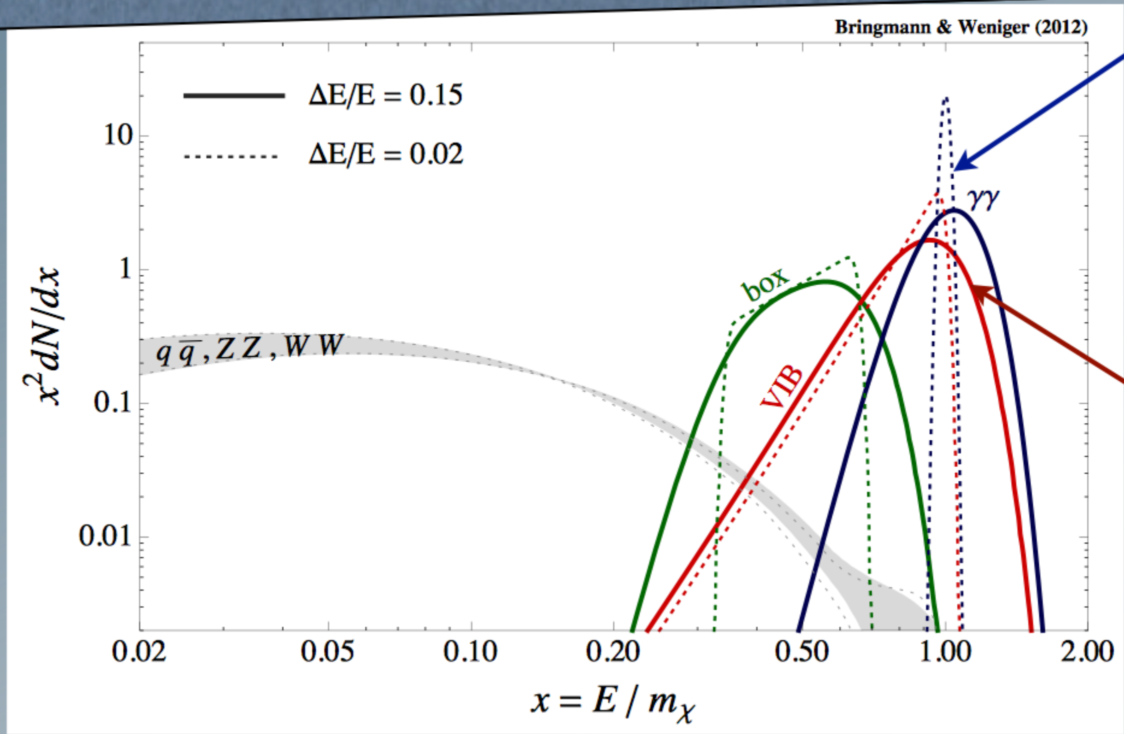
- Gaia (ESA mission, launch 11/13) will collect position and radial velocities of $\sim 10^8$ stars



➡ *will settle the issue…!*

Annihilation spectra





Monochromatic lines

$\chi\chi \to \gamma\gamma, \gamma Z, \gamma H$

$\mathcal{O}(\alpha_{\rm em}^2)$

(Virtual) Internal Bremsstrahlung

$\chi\chi \to \bar{f} f\gamma, W^+W^-\gamma$

$\mathcal{O}(\alpha_{\rm em})$

- ## Secondary photons
  - *many* photons but
  - featureless & model-independent
  - difficult to distinguish from astro BG

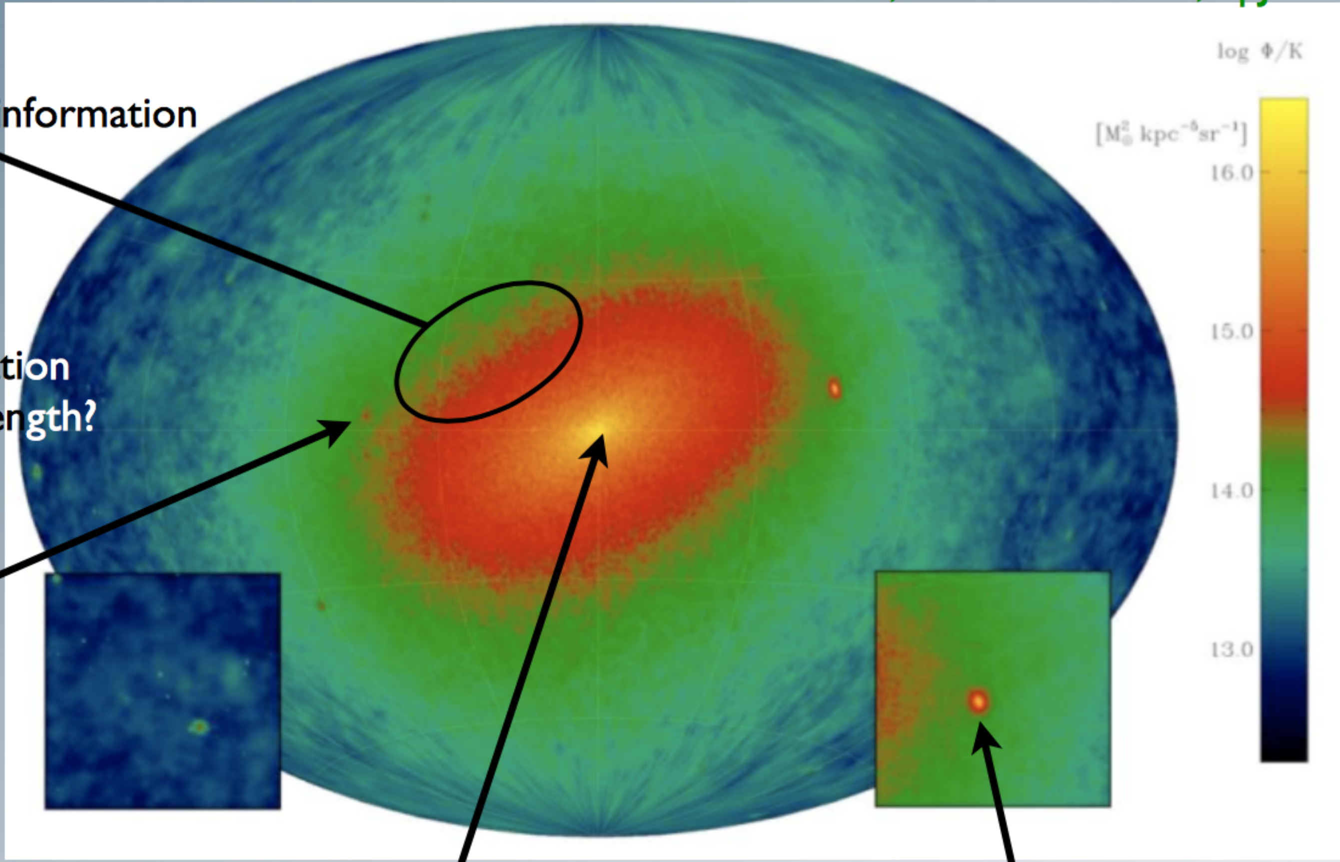
  ➡ *good constraining potential*

- ## Primary photons
  - direct annihilation to photons
  - model-dependent 'smoking gun' spectral features near $E_\gamma = m_\chi$

  ➡ *discovery potential*

Possible targets

Diemand, Kuhlen & Madau, ApJ '07



Galactic halo

- good statistics, angular information
- galactic backgrounds?

Galaxy clusters

- cosmic ray contamination
- better in multi-wavelength?
- substructure boost?

Dwarf Galaxies

- DM dominated, M/L~1000
- fluxes soon in reach!

Extragalactic background

- DM contribution from all z
- background difficult to model
- substructure evolution?

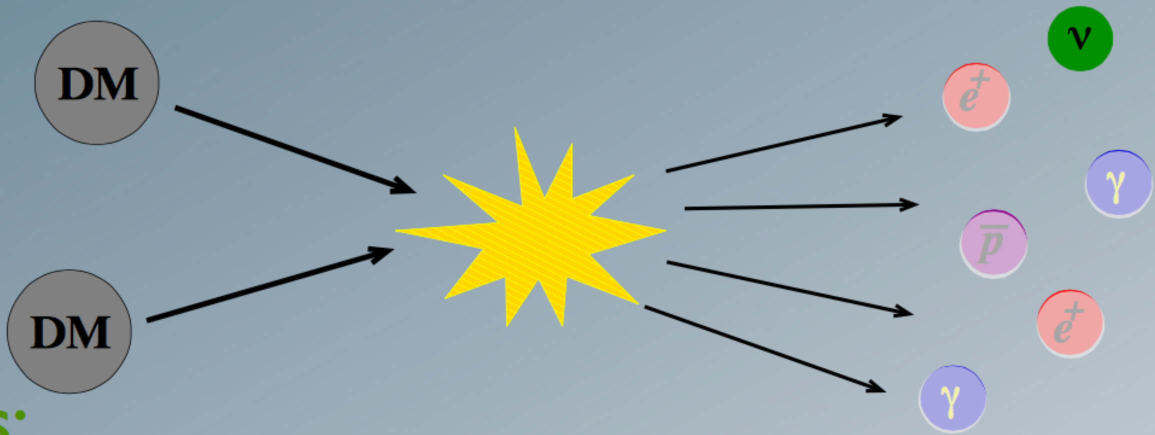
Galactic center

- brightest DM source in sky
- large background contributions

DM clumps

- easy discrimination (once found)
- bright enough?

Indirect DM searches



Neutrinos:

- Unperturbed propagation like for photons
- But signal significance (for the same target) usually considerably worse
- New feature: signals from the center of sun or earth!

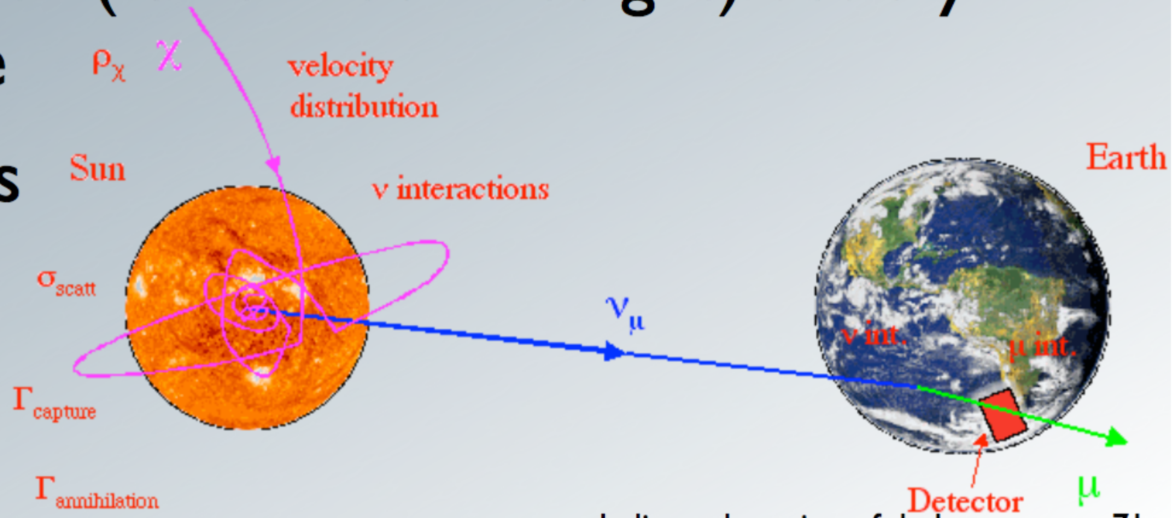
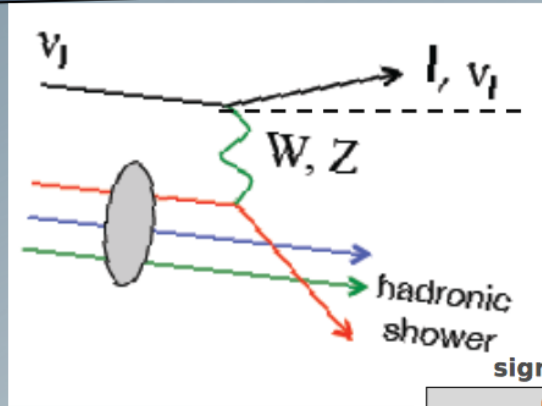


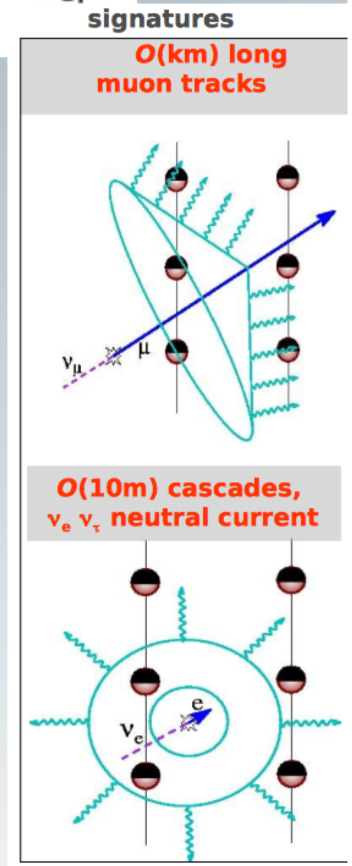
Fig. from J.Edsjö

Detection principle

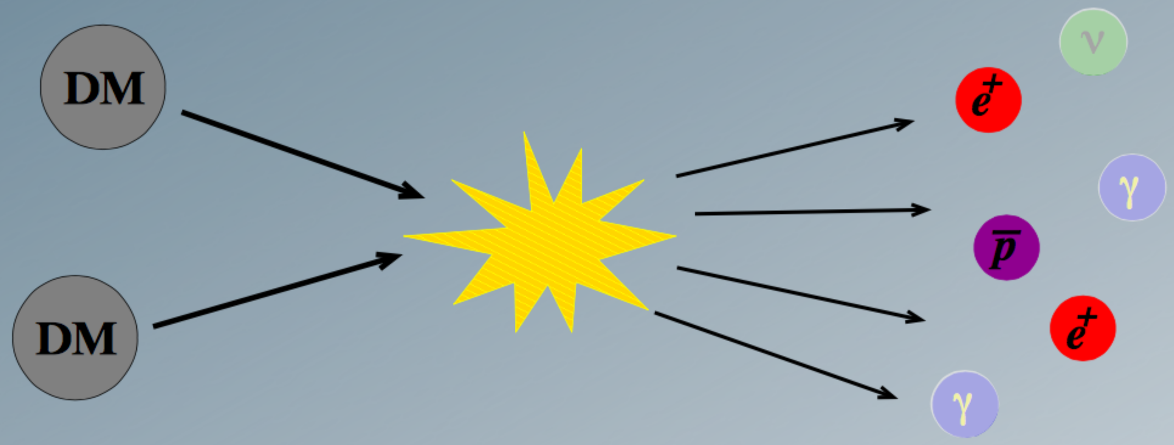


- Array of optical modules in transparent medium (ice/water) to detect Cherenkov light from relativistic secondaries
  (mostly sensitive to muons because they have the longest tracks)
- opening angle: $\Theta_{\mu\nu} \approx 0.7^\circ \cdot (E_\nu / \mathrm{TeV})^{-0.7}$
  ⇨ possible to do neutrino astronomy!
- tiny *x*-sections & fluxes: *need HUGE volumes!*
- background muons:
  - down-going: atmospheric neutrinos
  - up-going: also induced by cosmic rays
    (hitting the atmosphere the far side of the earth)

  ⇝ look for excesses in any given direction



Charged cosmic rays



- GCRs are confined by galactic magnetic fields
- After propagation, no directional information is left
- Also the spectral information tends to get washed out
- Equal amounts of matter and antimatter
  ⇨ focus on antimatter (low backgrounds!)

Cosmic ray propagation

- Little known about Galactic magnetic field distribution
- Magnetic fields confine CRs in galaxy for $E \lesssim 10^3\,\mathrm{TeV}$
- Random distribution of field inhomogeneities
  $\rightsquigarrow$ propagation well described by diffusion equation

$$\frac{\partial \psi}{\partial t} - \nabla \cdot (D\nabla - v_c)\psi + \frac{\partial}{\partial p} b_{\mathrm{loss}} \psi - \frac{\partial}{\partial p} K \frac{\partial}{\partial p} \psi = q_{\mathrm{source}}$$

often set to 0 (stationary config.)

Diffusion coefficient, often $D \propto \beta (E/q)^\delta$

convection

energy losses

diffusive reacceleration $K \propto v_a^2 p^2 / D$

Sources (primary & secondary)

Analytical vs. numerical

How to solve the diffusion equation?

- **Numerically**
  - ⊕ 3D possible
  - ⊕ any magnetic field model
  - ⊕ realistic gas distribution, full energy losses
  - ⊖ computations time-consuming
  - ⊖ for most users a "black box"

e.g. GALPROP

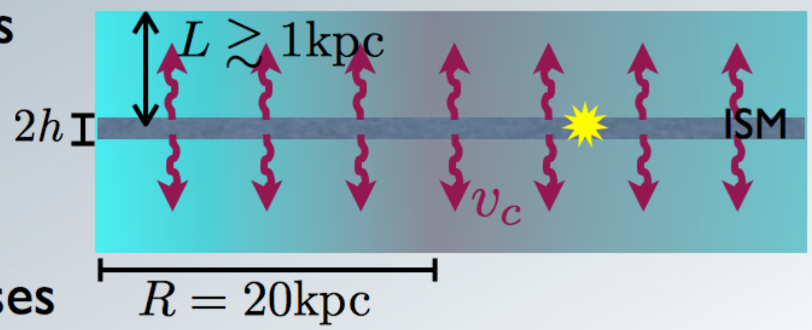
Strong, Moskalenko, …

DRAGON

Evoli, Gaggero, Grasso & Maccione

- **(Semi-)analytically**
  - ⊕ Physical insight from analytic solutions
  - ⊕ fast computations allow to sample full parameter space
  - ⊖ only 2D possible
  - ⊖ simplified gas distribution, energy losses

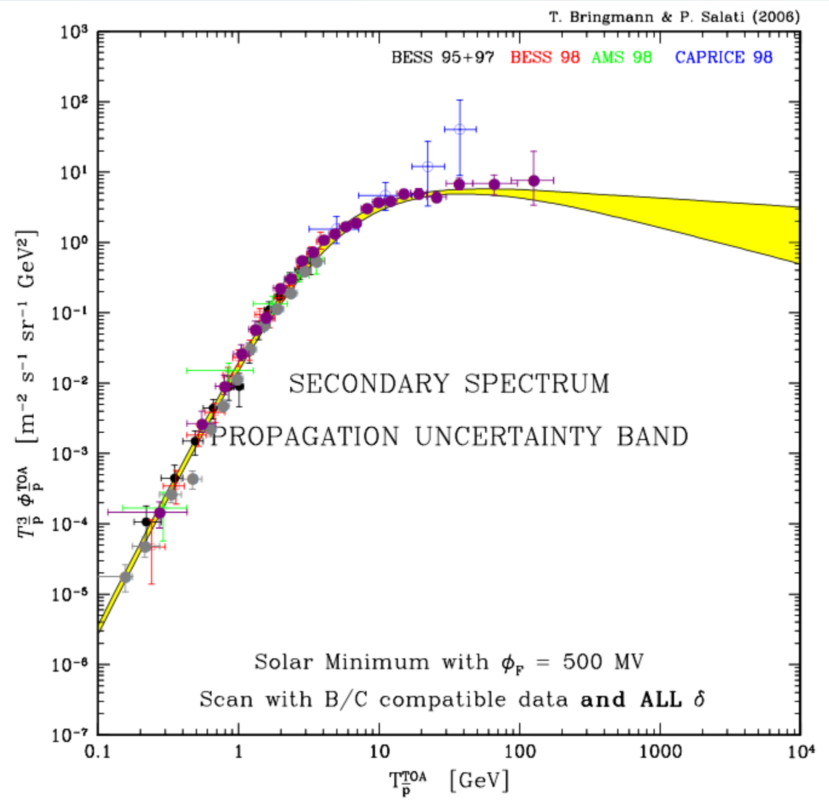
e.g. Donato, Fornengo, Maurin, Salati, Taillet, …



E.g. secondary antiprotons

- Propagation parameters $(K_0, \delta, L, v_a, v_c)$ of two-zone diffusion model strongly constrained by B/C

  Maurin, Donato, Taillet & Salati, ApJ '01
- This can be used to predict fluxes for other species:



TB & Salati, PRD '07

excellent agreement with new data:

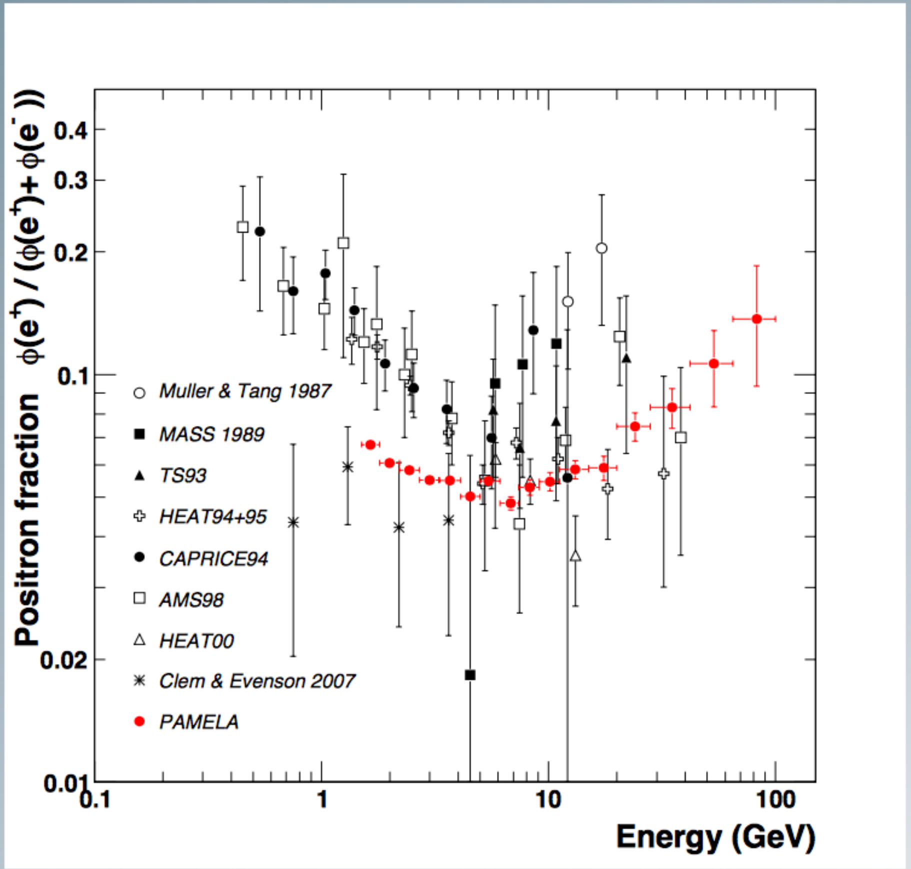
BESSpolar 2004
Abe *et al.*, PRL '08

PAMELA 2008
Adriani *et al.*, PRL '10

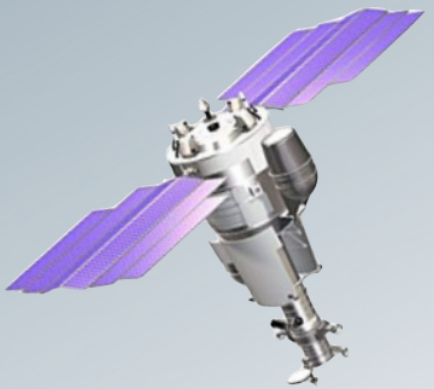
➡ very nice test for underlying diffusion model!

Positrons

Excess in cosmic ray positron data has triggered great excitement:



PAMELA

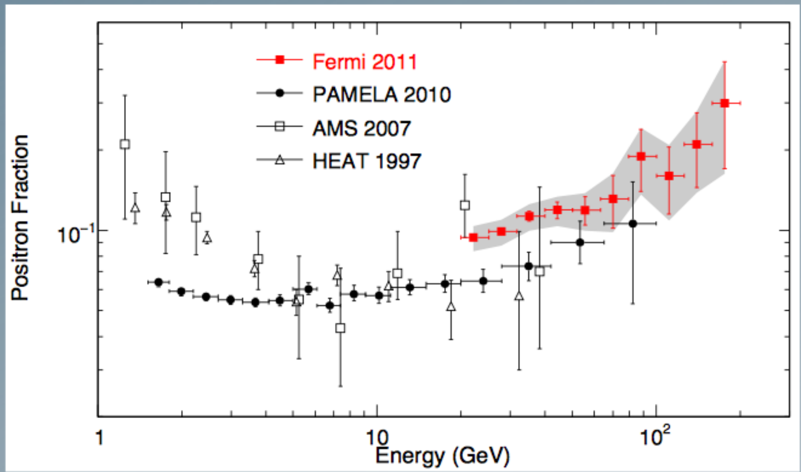


Adriani *et al.*, Nature '09

➪ Are we seeing a DM signal ???

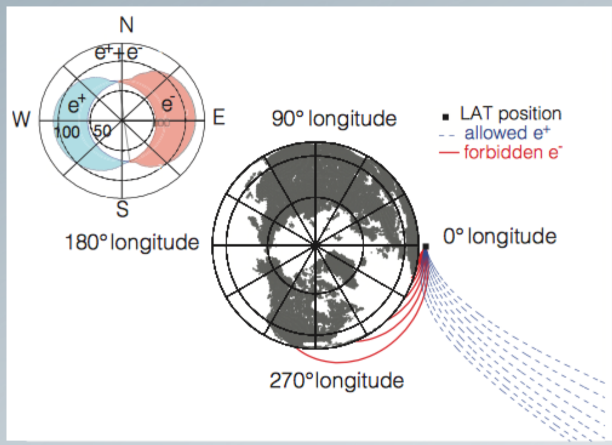
Independent confirmation

- By Fermi (!):

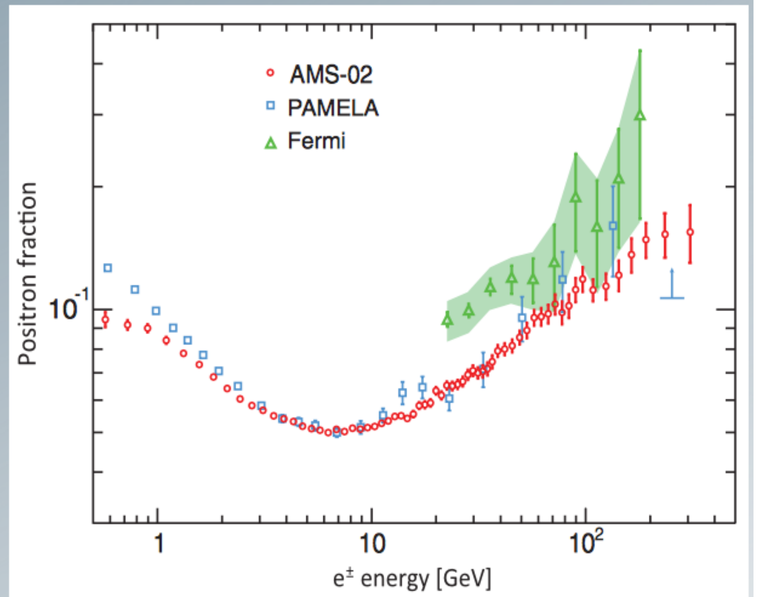


Ackermann *et al.*, PRL '12

NB: Fermi does not have a magnet on board, but uses the earth magnetic field!



- By AMS:



Aguilar *et al.*, PRL '13

S. Ting:

"Over the coming months, AMS will be able to tell us conclusively whether these positrons are a signal for dark matter, or whether they have some other origin"

Lepton propagation

- $e^{\pm}$ can also be described in same framework as $\bar{p}$!

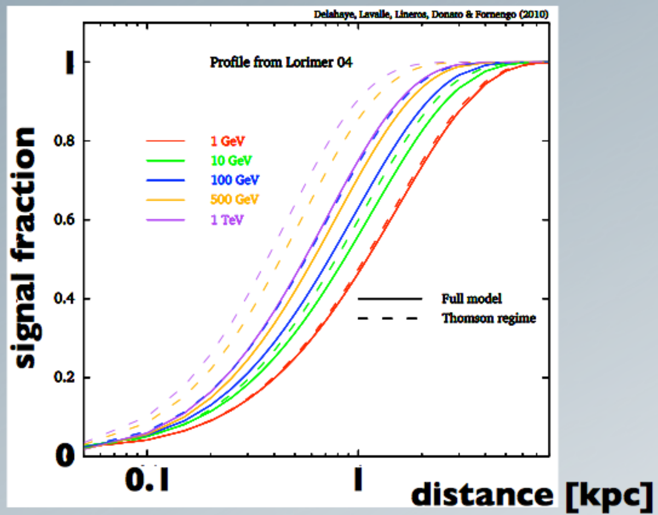
  Delahaye *et al.*, PRD '08, A&A '09, A&A '10

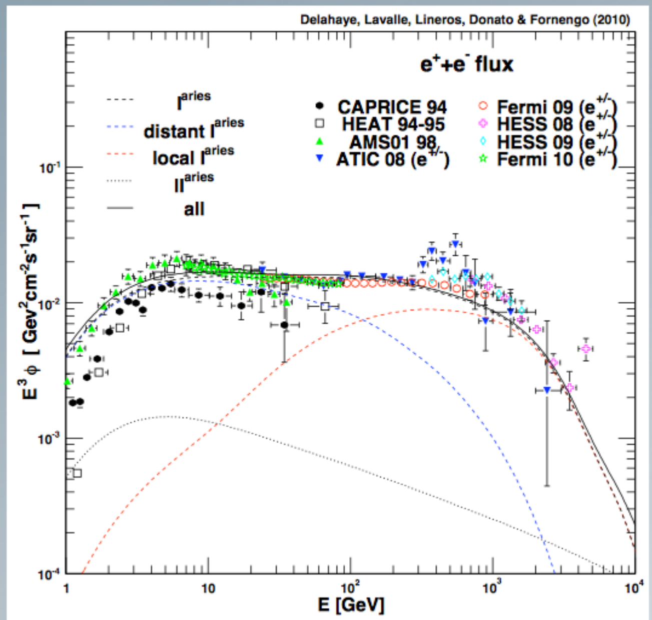
- Main difference to nuclei:

  energy losses are dominant

  [synchrotron + inverse Compton]

  ➡ mainly locally produced
  (~kpc for 100 GeV leptons)





- propagation uncertainties:
  - secondaries ~ 2-4
  - primaries ~5

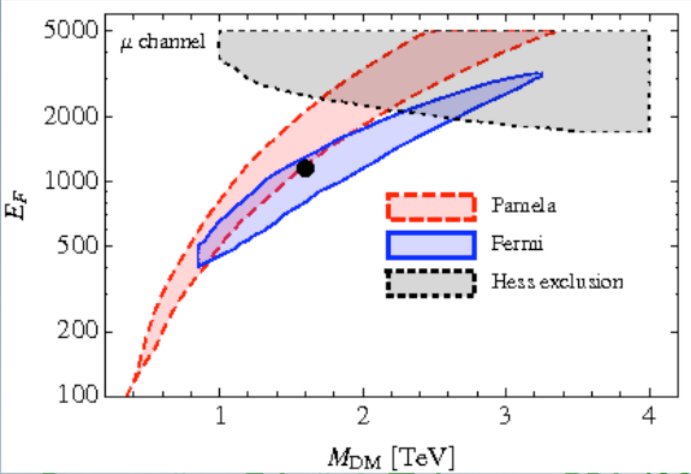
➡ need for local primary source(s) to describe data well above ~10 GeV

DM explanations

- Model-independent analysis:
  - strong constraints on hadronic modes from $\bar{p}$ data
  - $\chi\chi \to e^+e^-$ or $\mu^+\mu^-$ favoured
  - large boost factors *generic* – $\mathcal{O}(10^3)$

➔ highly non-conventional DM!

+ significant radio/IC constraints, see later!



Bergström, Edsjö & Zaharijas, PRL '09

- *and*: many good astrophysical candidates for primary sources in the cosmic neighbourhood:
  - pulsars Grasso *et al.*, ApP '09; Yüksel *et al.*, PRL '09; Profumo, 0812.4457
  - old SNRs Blasi, PRL '09; Blasi & Serpico, PRL '09
  - and further proposals...

take home message:

Positrons are certainly not the best messengers for DM searches!

DarkSUSY

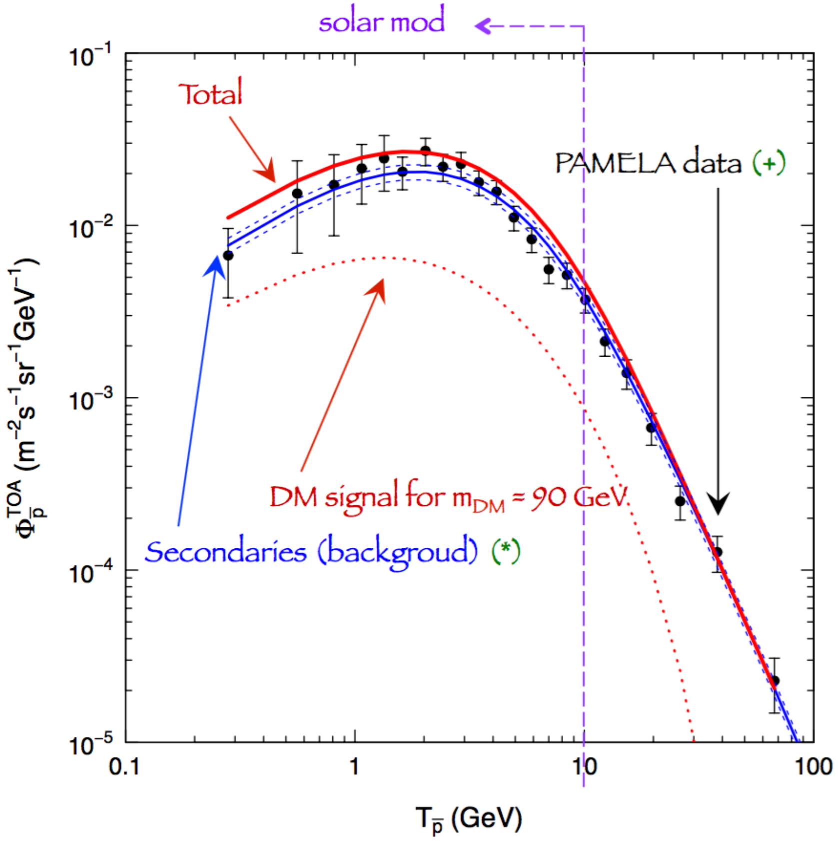
P. Gondolo, J. Edsjö, P. Ullio, L. Bergström, M. Schelke,
E.A. Baltz, T. Bringmann and G. Duda

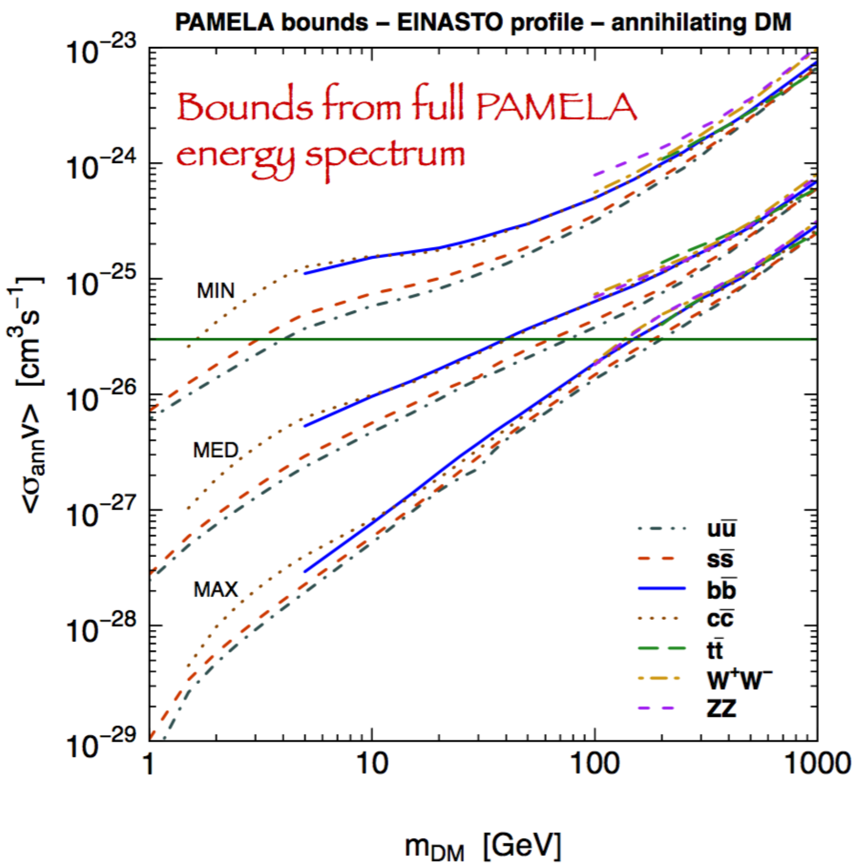
FREE DOWNLOAD ;)

http://darksusy.org

- Fortran package to calculate "all" DM related quantities:
  - *relic density + kinetic decoupling*
  - *generic SUSY models + laboratory constraints implemented*
  - *cosmic ray propagation*
  - *indirect detection rates: gammas, positrons, antiprotons, neutrinos*
  - direct detection rates
  - ...

Antiprotons



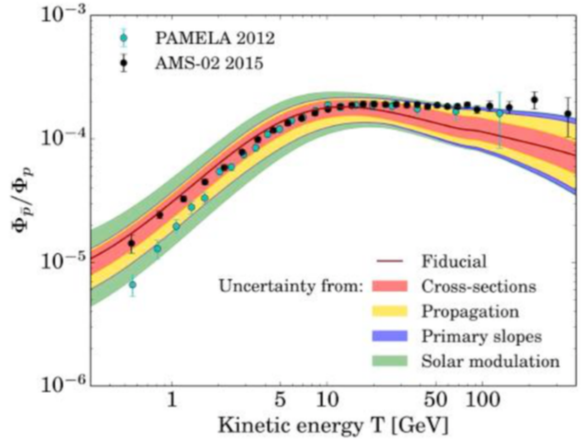


PAMELA

No evidence for deviation from astrophysical secondaries
Set stringent bounds on DM properties
Uncertainties from nuclear physics and galaxy transport

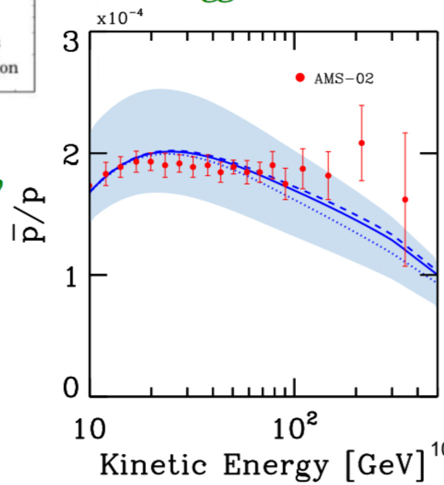
AMS-02 pbar/p

Kounine, 'AMS days at CERN, April 2015



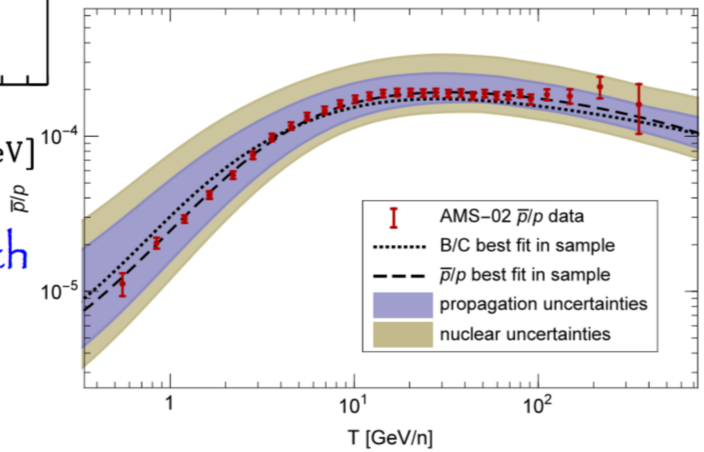
Giesen et al., JCAP 1509 (2015) 023

Evoli, Gaggero, Grasso, arXiv:1504.05175



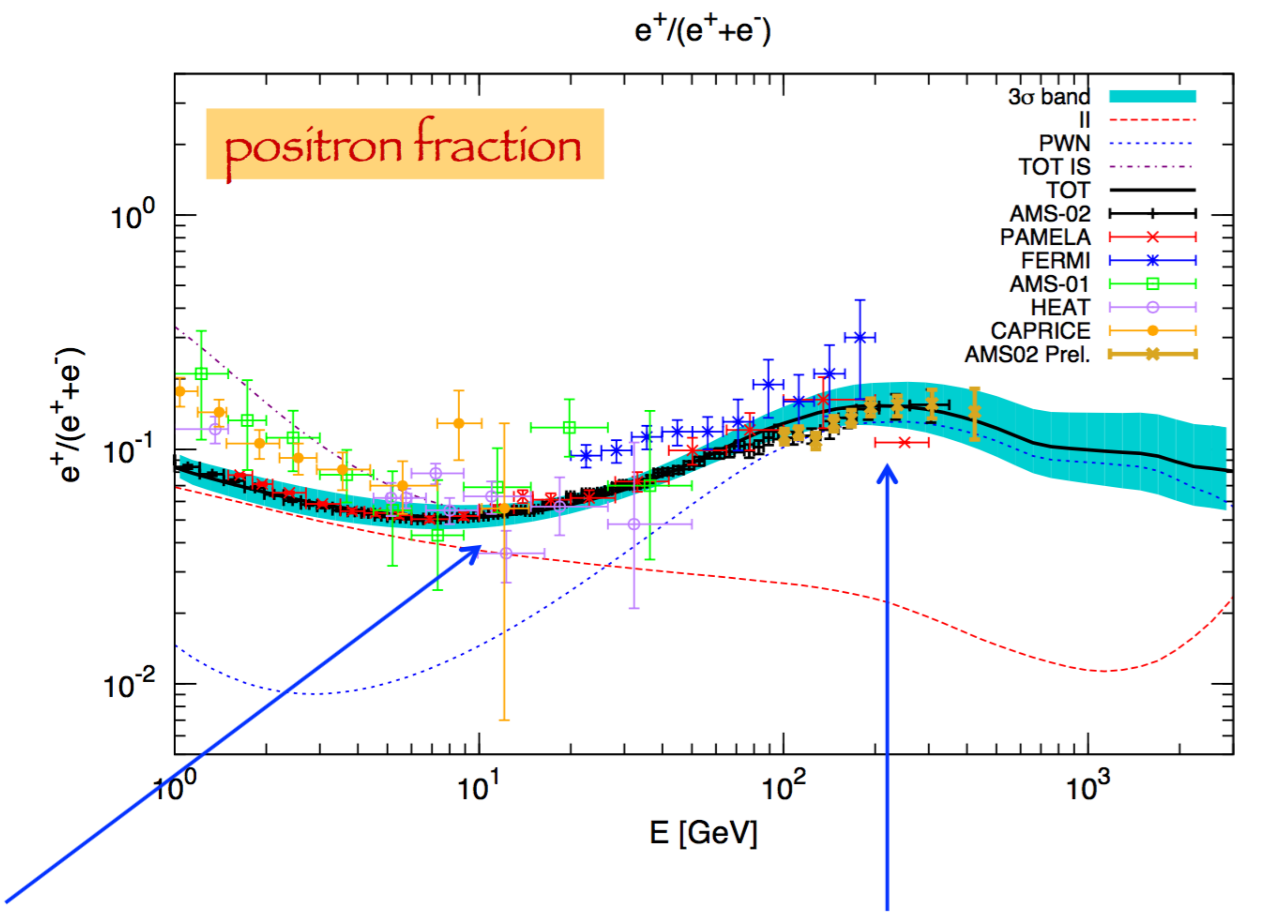
In addition AMS is bringing very detailed Information on cosmic rays nuclei (e.g. B/C) which will allow shaping the CR transport models (DRAGON, Galprop, Usine, non public codes)

This is relevant for both DM signals and its backgrounds



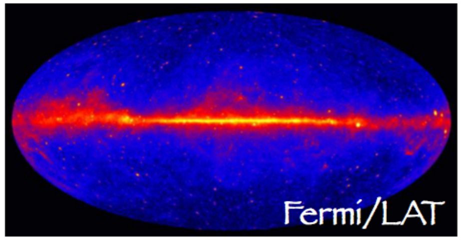
Kappl, Reinert, Winkler, JCAP 1510 (2015) 034

Positrons



Low energies: reproduced by secondary production

High-energy: (local) sources needed

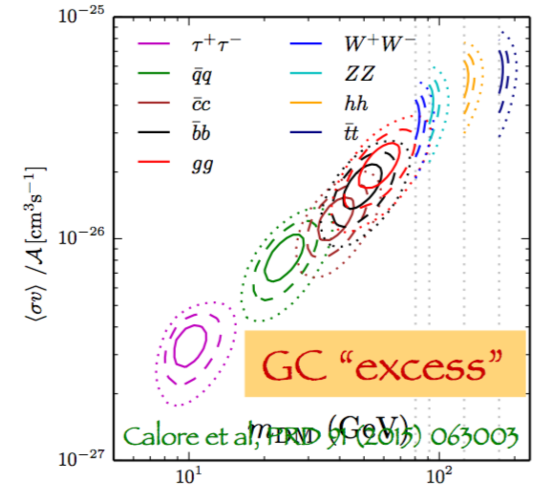


Gamma rays

Galactic center

Very interesting target, but difficult

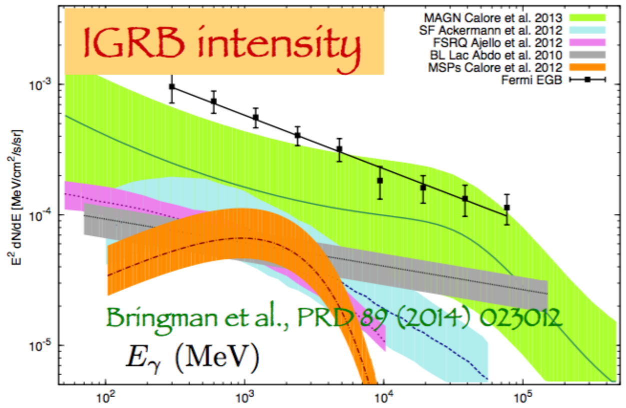
Potential hints, under hot discussion



Isotropic gamma ray background

Relevant for extragalactic DM

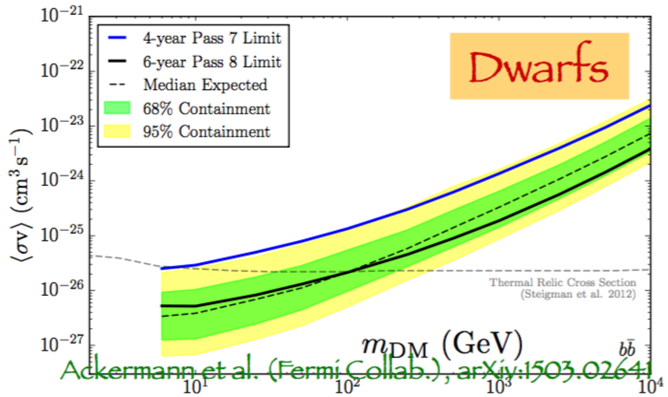
Complex to seperate a DM signal from astrophysical sources



Dwarf galaxies

One of the best targets (DM dominated)

Recently, new dwarfs have been discovered (DES): great potentiality



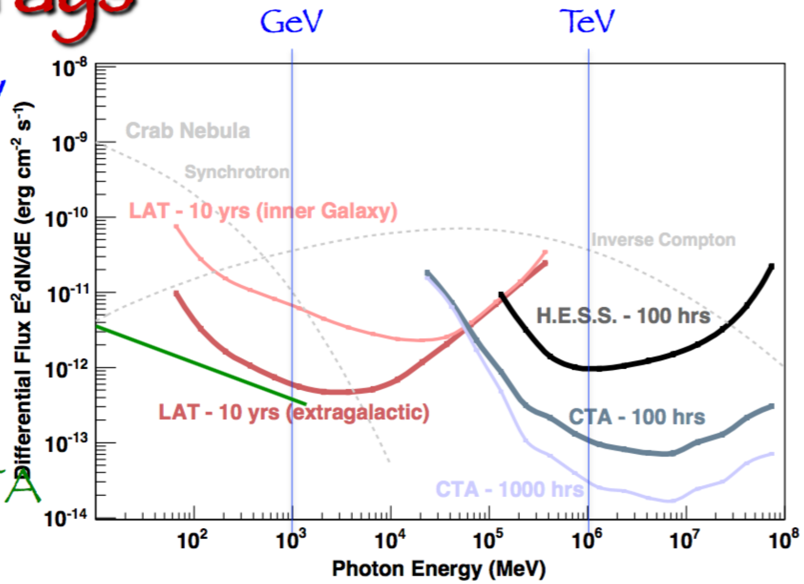
Gamma rays

- Higher energies (ground): >300 GeV

  Probe TeV+ DM

  Targets
    - Galactic center
    - DM clumps
    - dSphs galaxies
    - Galaxy clusters

  Magic, HESS, Hawc, LHAASO, CTA



- GeV – TeV energies (space) or even higher

  Probe GeV-TEV DM

  Improved energy and angular resolution

  DAMPE (2 GeV – 10 TeV), GAMMA400, HERD (up to PeV), ...

- Lower energies (space): MeV – GeV

  Probe subGeV DM or the low-energy tail of WIMP DM

  AstroGam, PANGU, ...

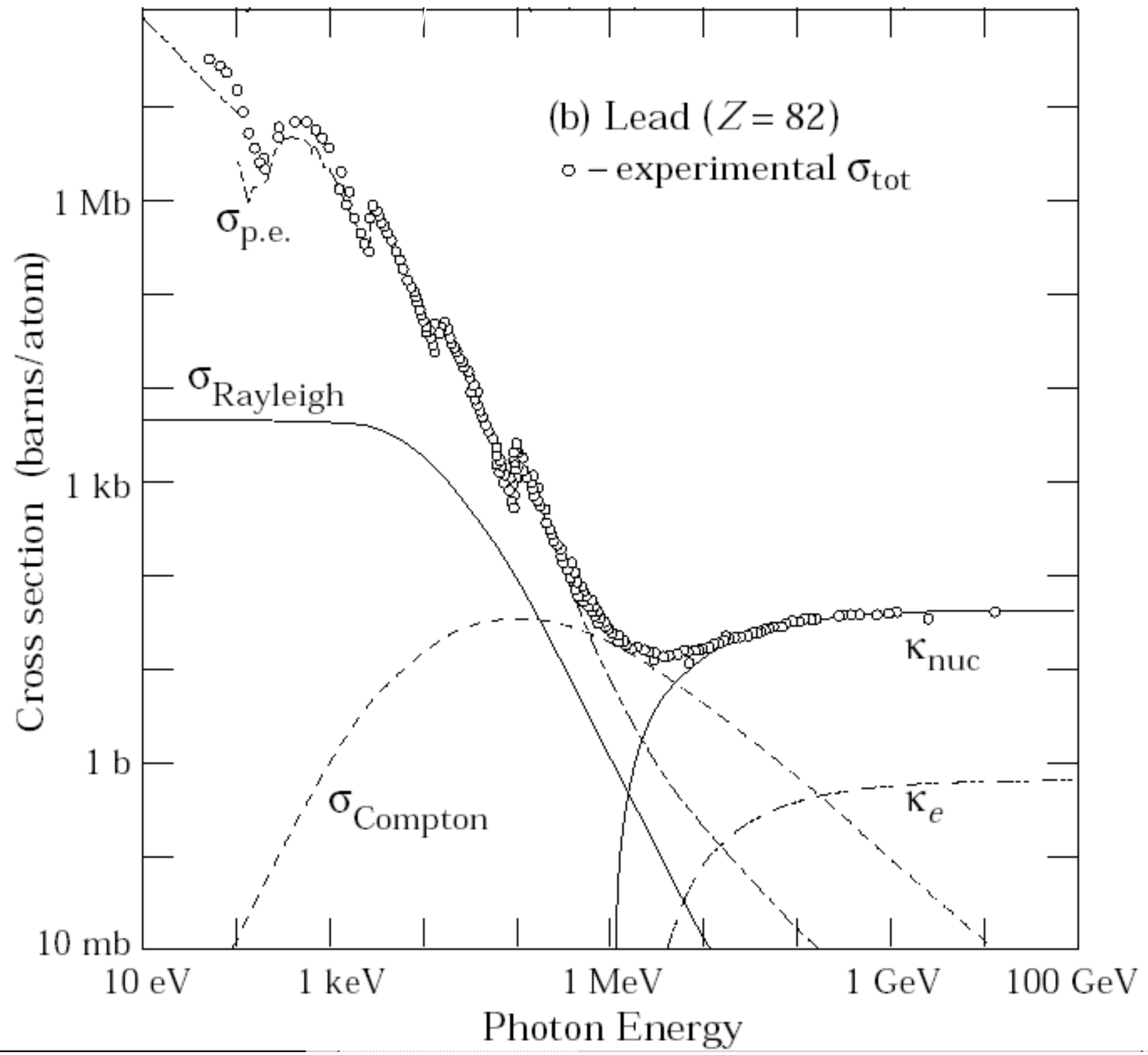
Astrofisica Nucleare e Subnucleare

GeV Astrophysics

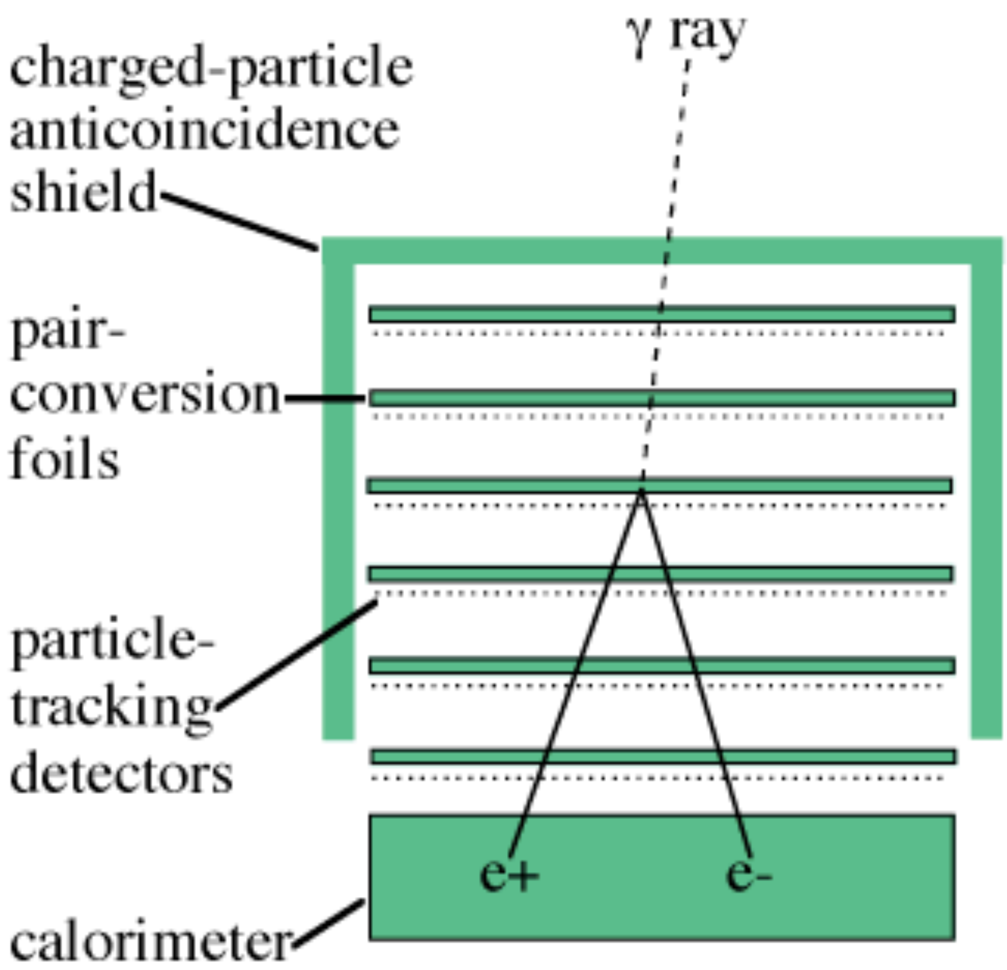
Exercise on GeV gamma-rays

- Find the web sites of AGILE and Fermi/LAT
- Check the status of “new” gamma-ray detectors (CALET, DAMPE, Gamma-400, HERD, other?)

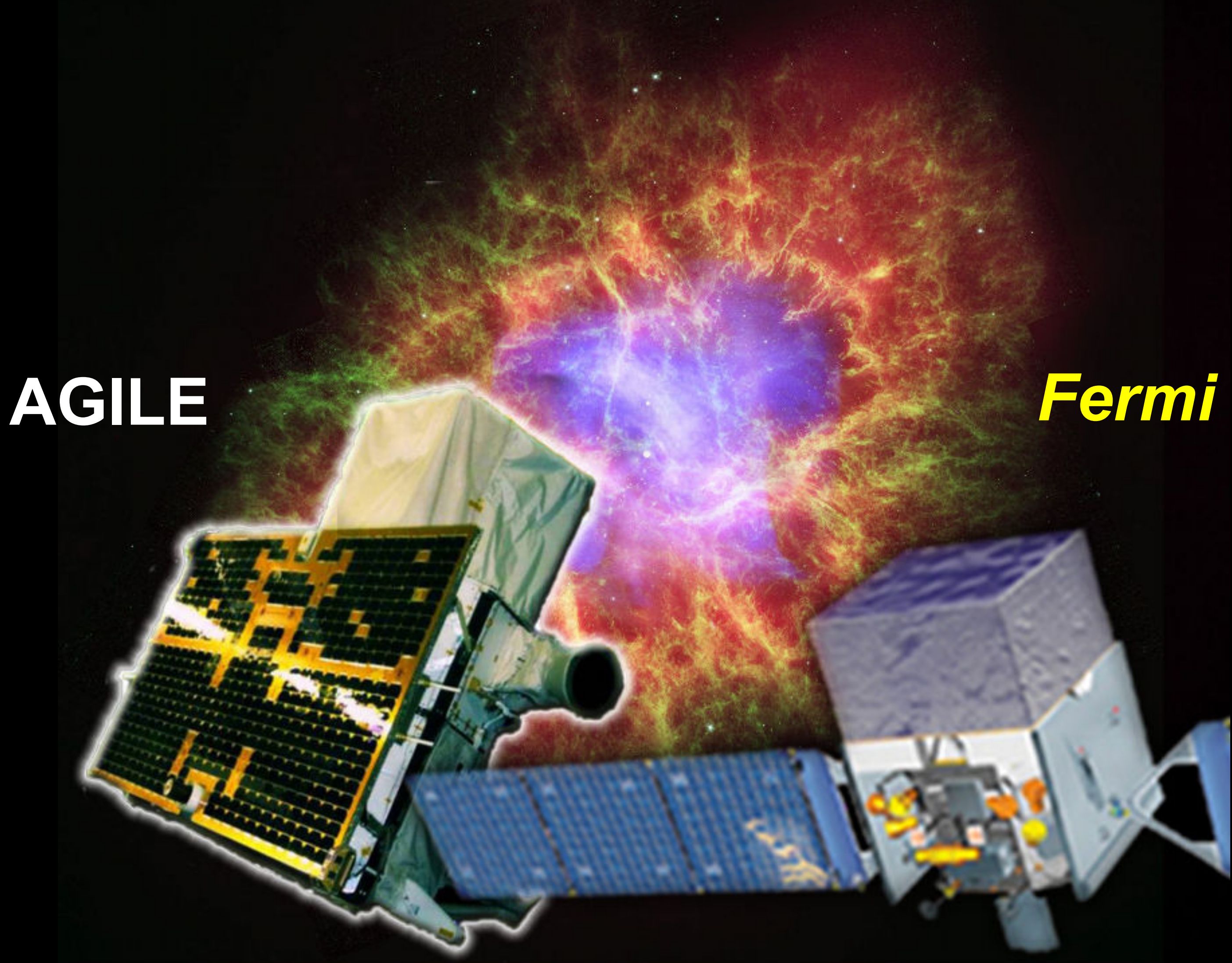
Photon Interactions



Detector Project



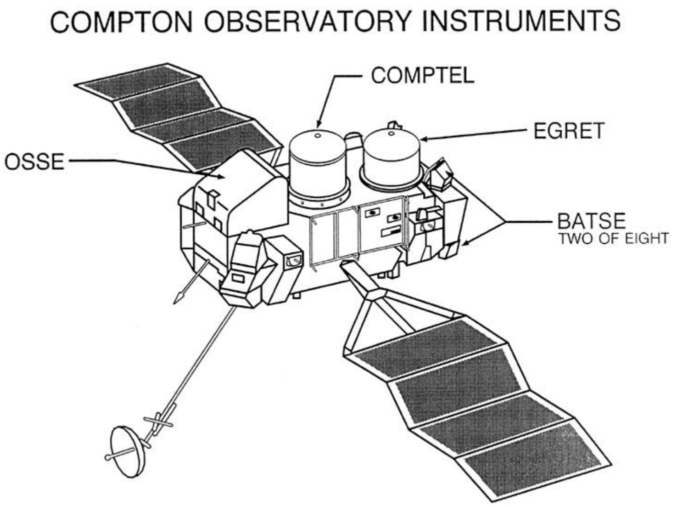
Gamma-ray astrophysics above 100 MeV

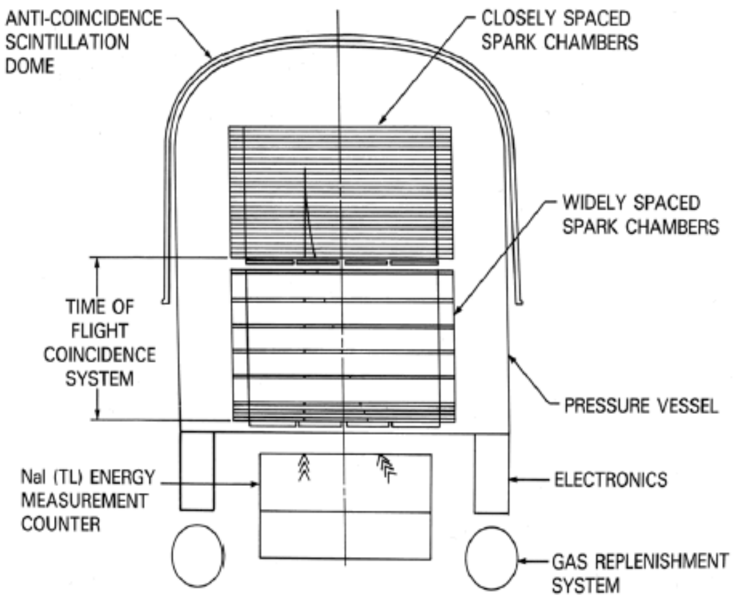


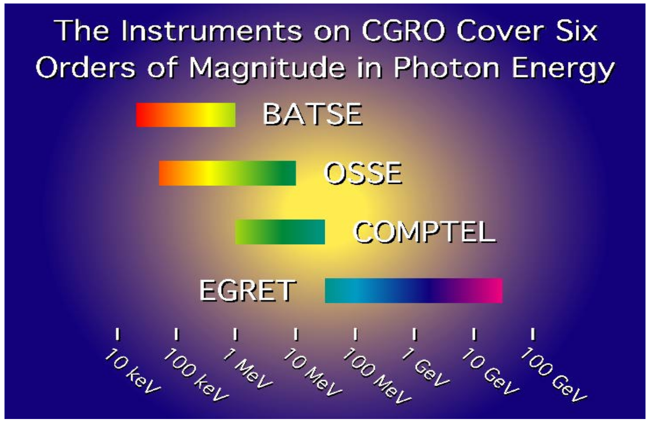
Picture of the day, Feb. 28, 2011, NASA-HEASARC

GeV Gamma-ray Astrophysics
The EGRET legacy

EGRET



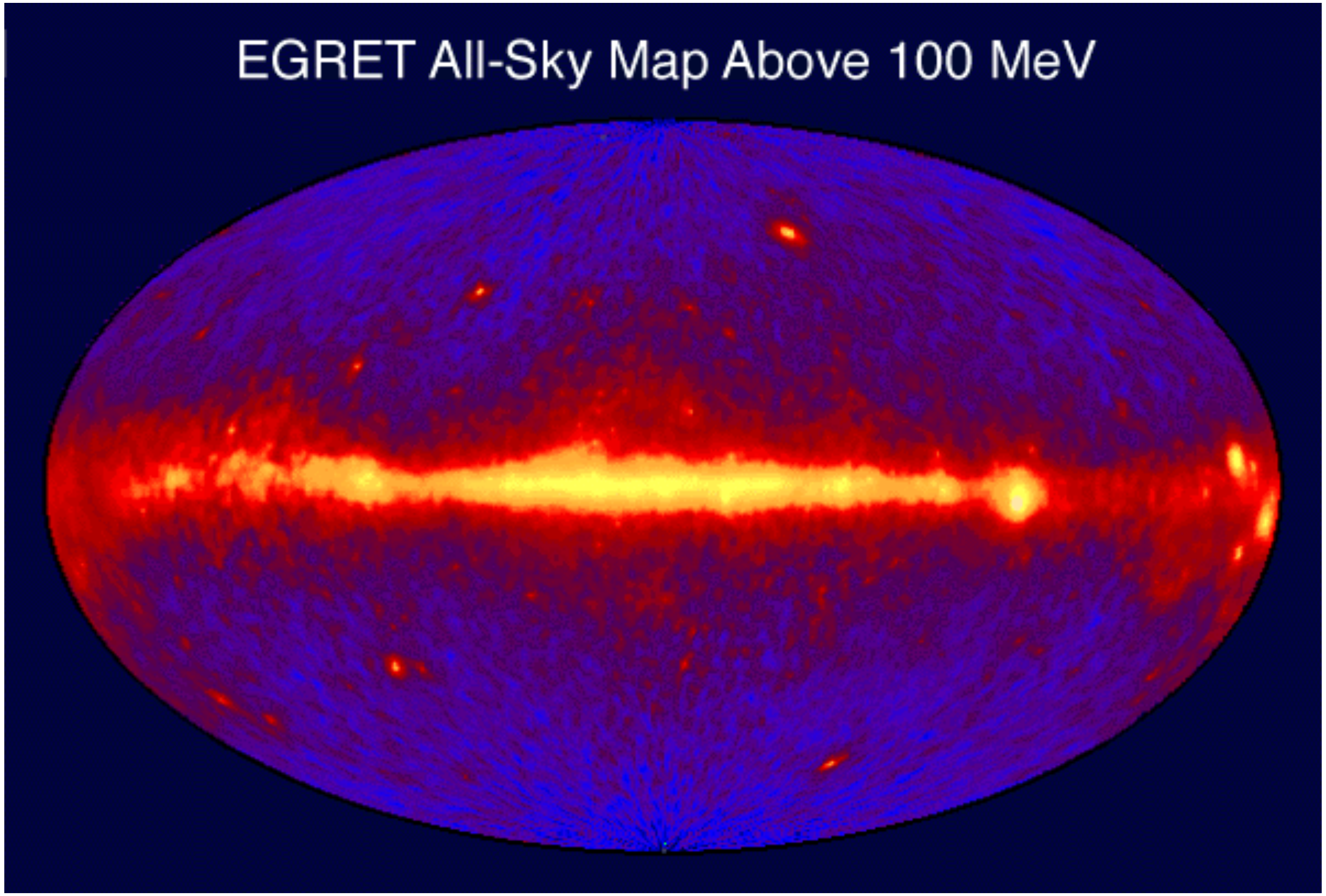




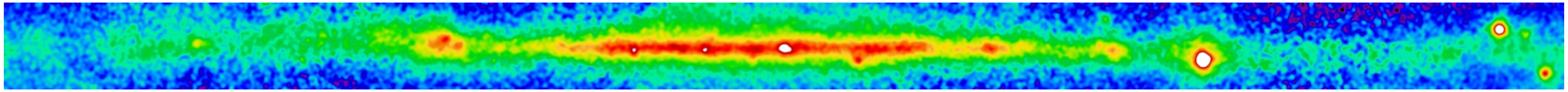
EGRET

- 1991-2000
- 30 MeV - 30 GeV
- AGN, GRB, Unidentified Sources, Diffuse Bkg

The HE sky from EGRET



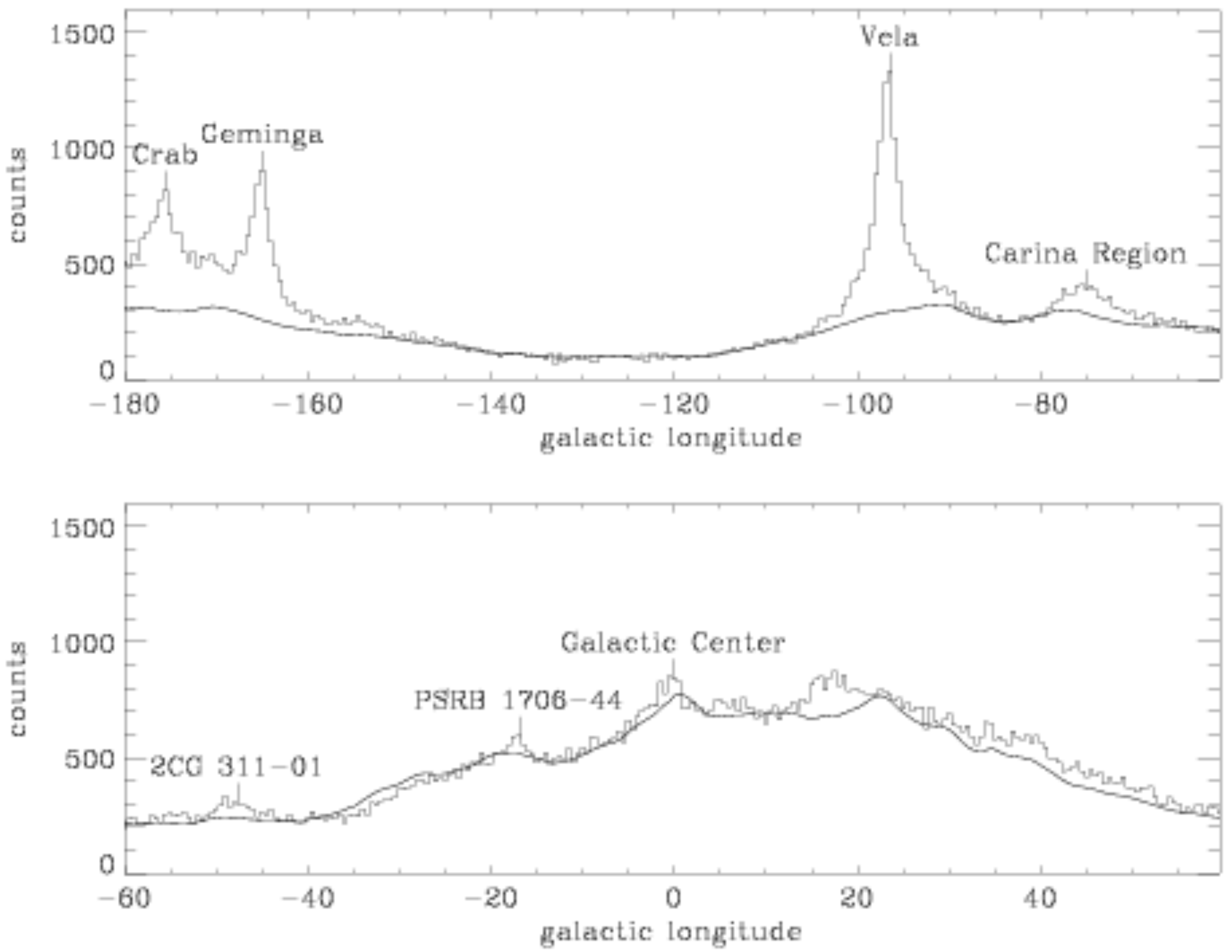
Analysis Topics



EGRET >300 MeV

- First a word about interstellar gamma-ray emission:
- Brightest at low latitudes, but detectable over the whole sky
- >60% of EGRET celestial gamma rays
- It fundamentally affects the approach to the analysis

Data Analysis



Analysis Topics: Source detection

- Source detection means at least 2 things:
  - Recognizing that you've detected a point source that you didn't know about (and defining its statistical significance and location on the sky)
  - Determining the significance of the detection of (or measuring an upper limit for) an already-known source

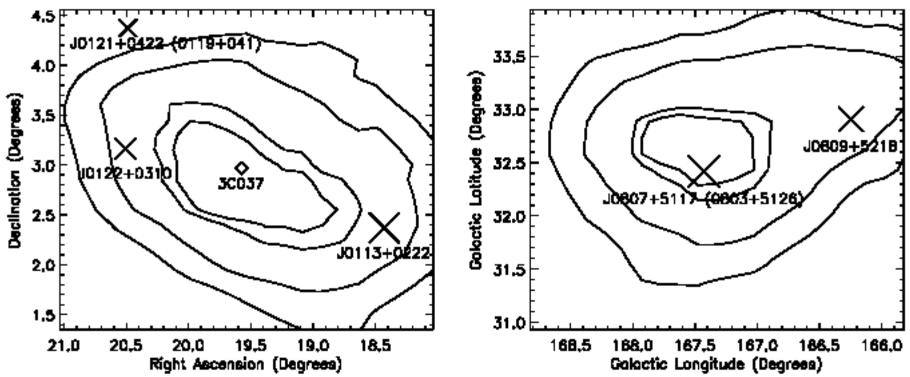


FIG. 3.—TS maps of possible composite 3EG sources. *Left*: 3EG J0118+0248. The 3EG identification 0119+041, the steep spectrum Mattox et al. (2001) counterpart 3C 037 (*diamond*), and our two new blazar counterparts (along the uncertainty region major axis) are shown. *Right*: 3EG J0808+5114. Again, two high-confidence identifications lie along the major axis.

Source location contours for two 3EG sources (Hartman et al. 1999). Potential (additional) counterparts, unresolved by EGRET, are indicated

Sowards-Emmerd, Romani, & Michelson (2003, ApJ, 590, 109)

Analysis Topics: Spectral analysis

- Well, this means measuring spectra
  - Mostly power laws resulting from shock acceleration, which is scale free
  - Spectral breaks occur for physics reasons and measuring them is diagnostic of the sources.
- For EGRET, the analysis of source spectra was a 2-step process
  - Fluxes were derived for fairly broad ranges of energy independently
  - Then a spectral model was fit
- The complication was that the exposure for a broad energy range depends on the source spectrum, so the fitting process was iterative.

$$F_\gamma = (2.01 \pm 0.12) \times 10^{-6}(E/0.214\ \mathrm{GeV})^{-2.18\pm0.08}\ \mathrm{photon\ (cm^2\ s\ GeV)^{-1}}\ .$$

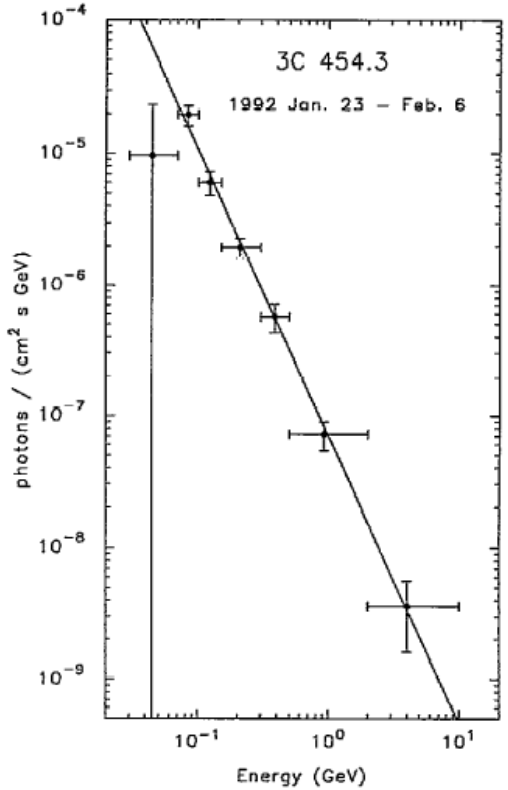
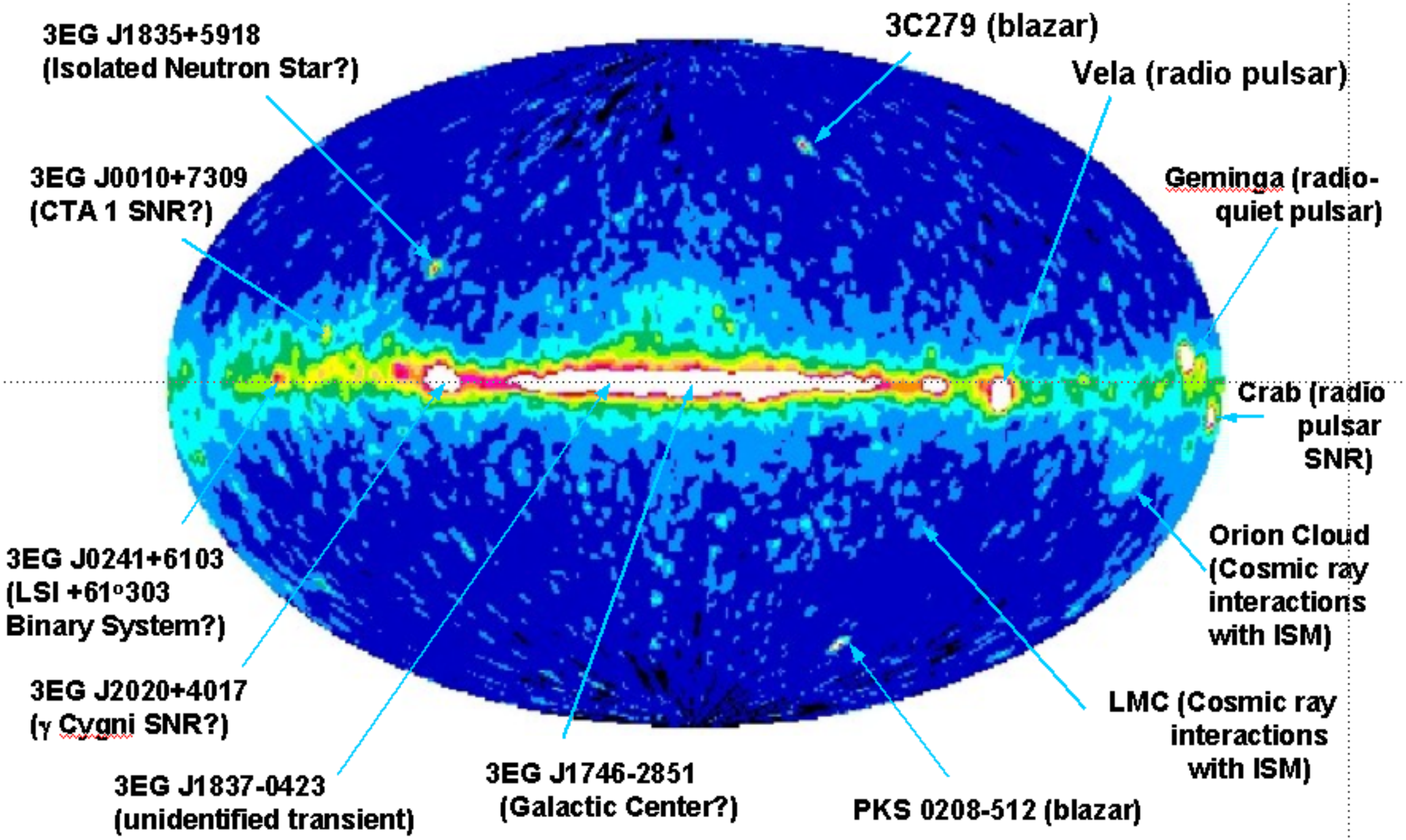


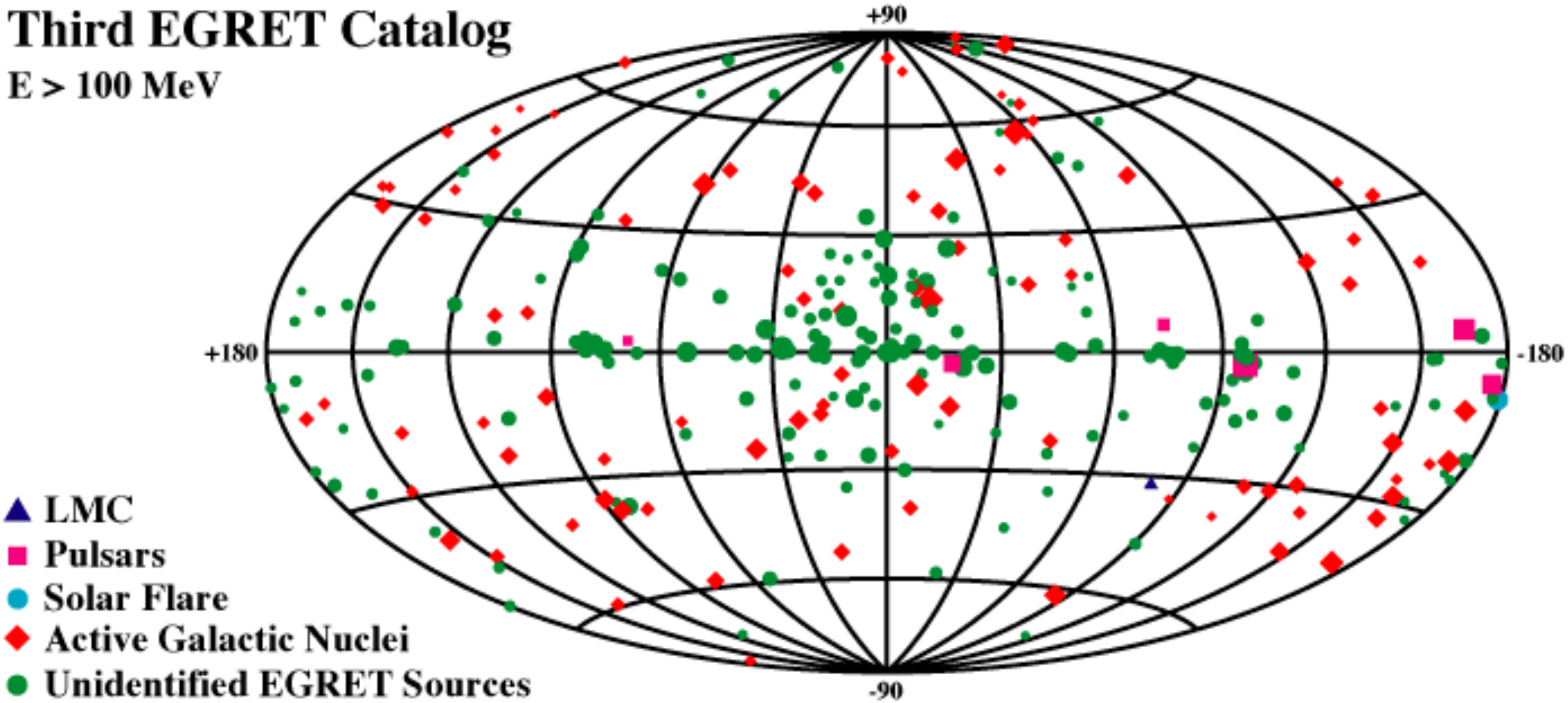
FIG. 3.—High-energy gamma ray spectrum of 3C 454.3 during the time interval 1992 January 23 to February 6. See text for comments on the 30–70 MeV point.

Hartman et al. 1993 (ApJ, 407,L41),

EGRET All Sky Map

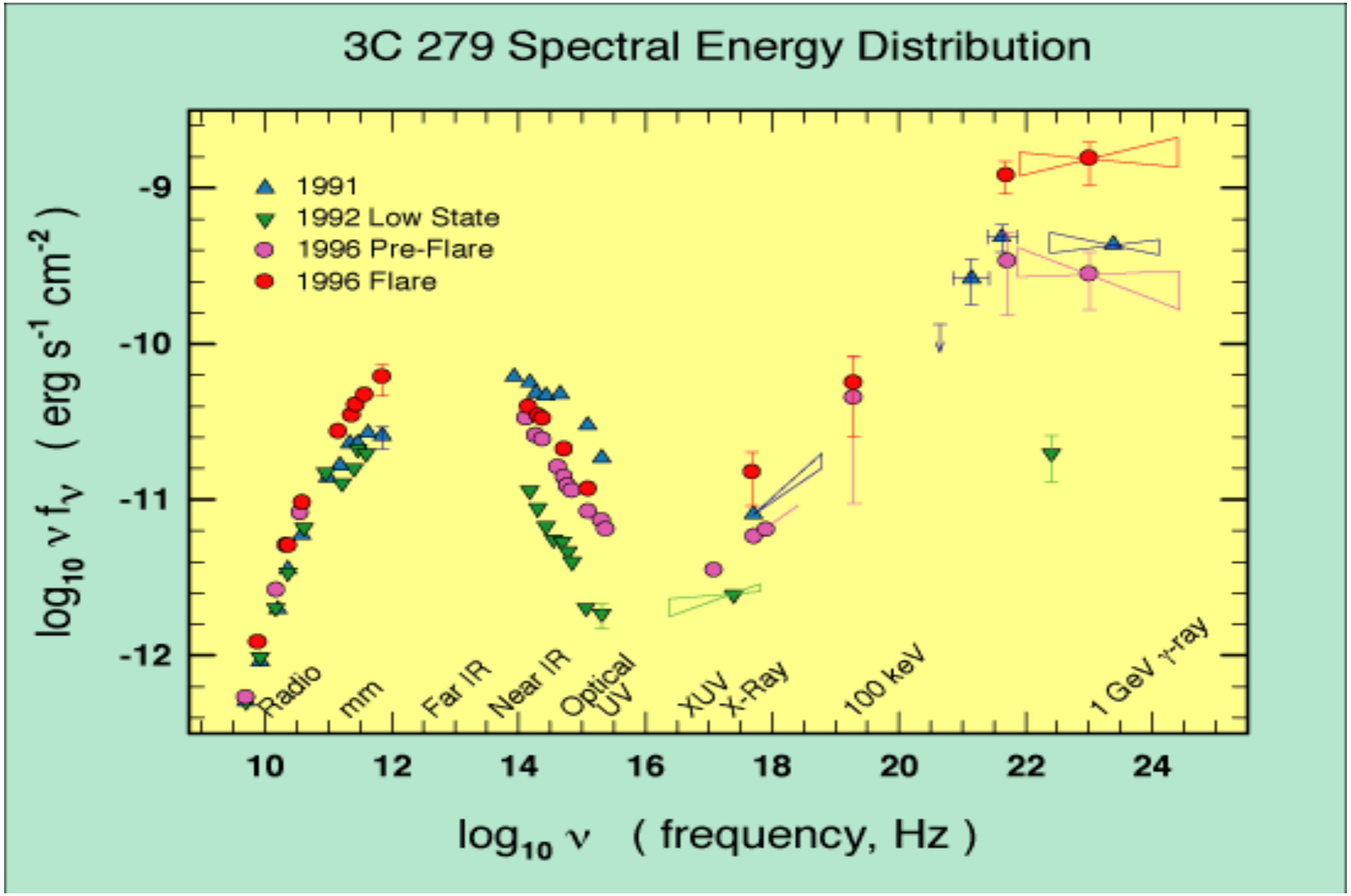


EGRET Gamma-ray Sources

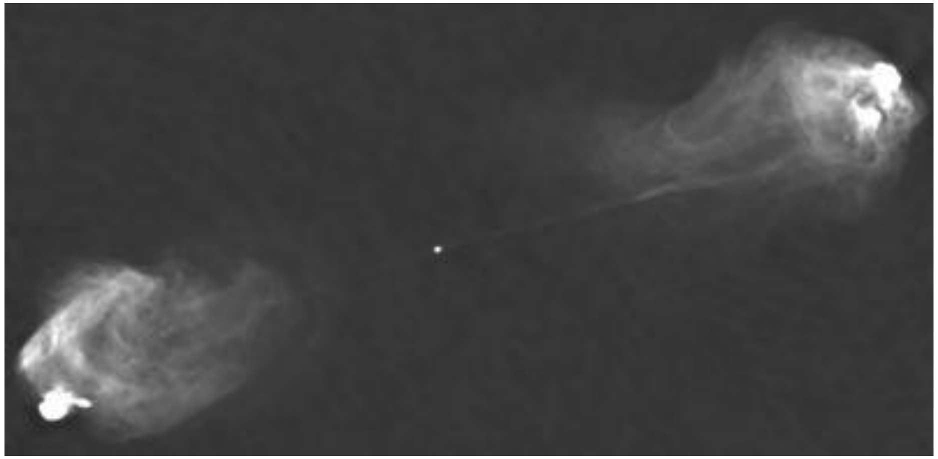


Challenge # 1

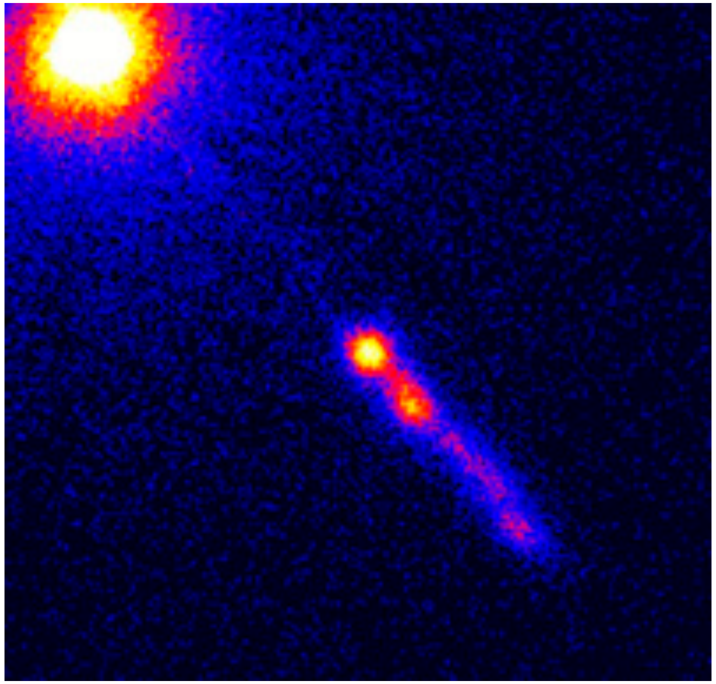
- Need simultaneous multiwavelength data to study variability and emission processes



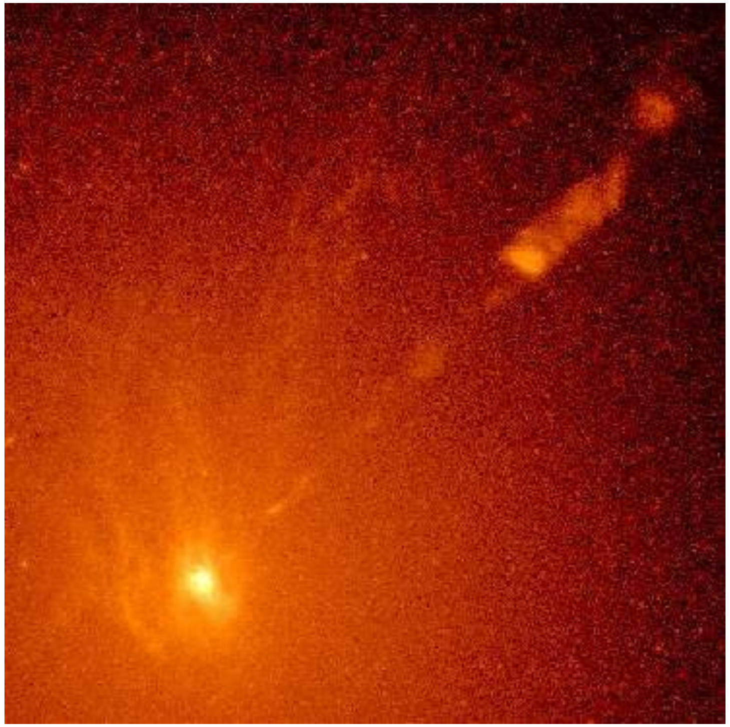
Active Galactic Nuclei



Radio

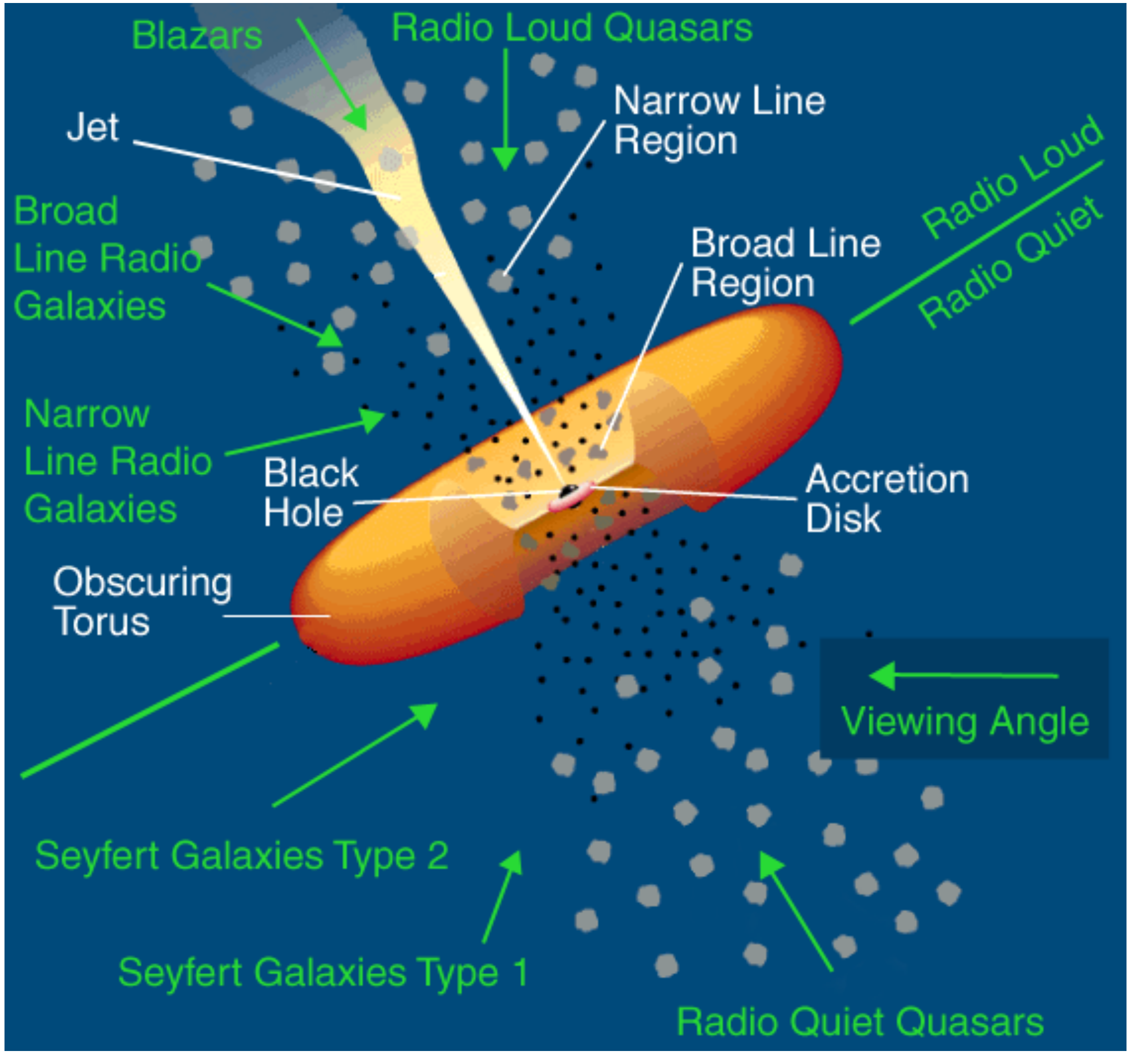


X-ray

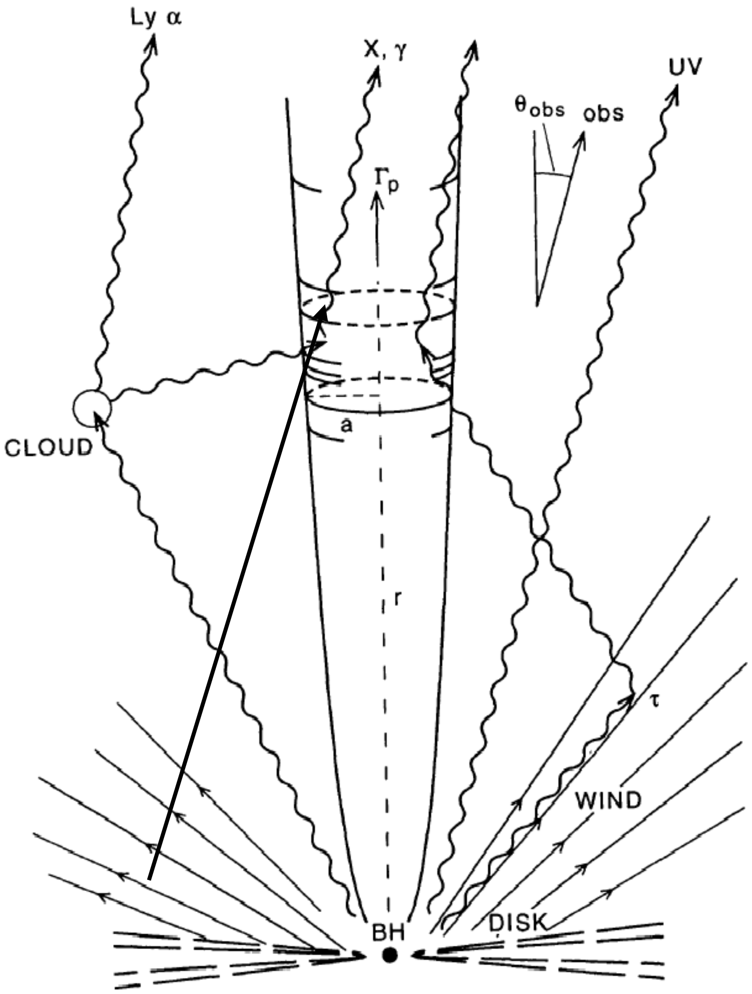


Optical

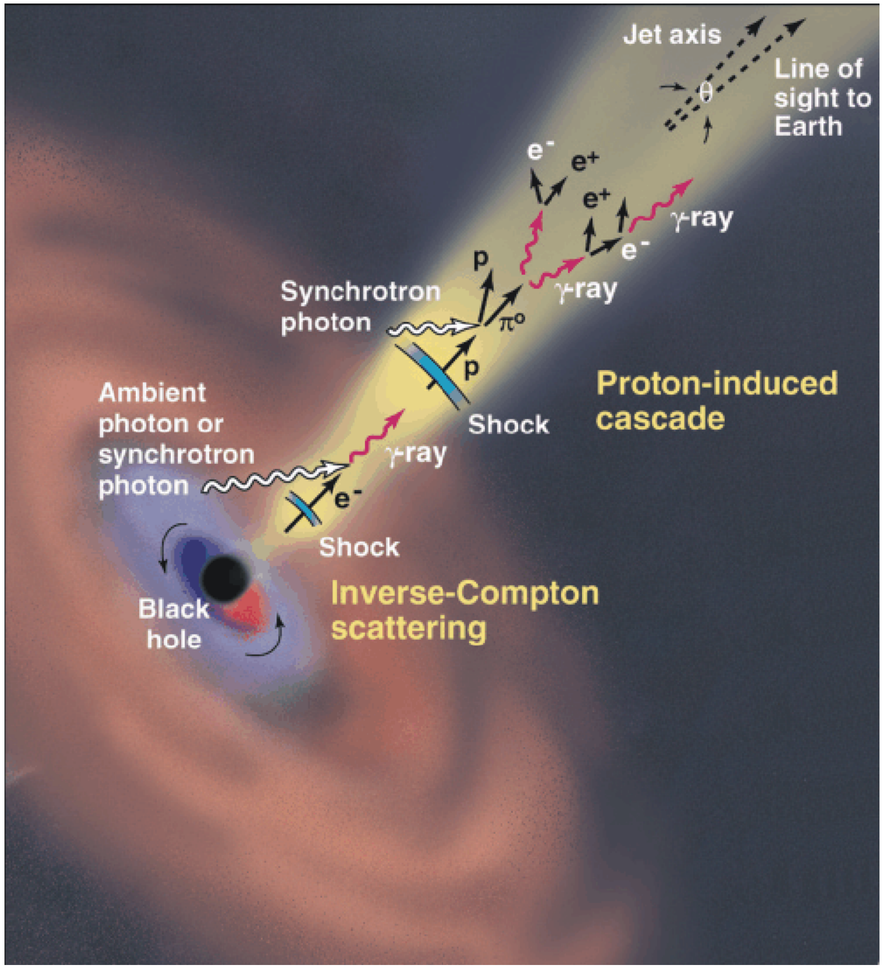
Active Galactic Nuclei



Models of AGN Gamma-ray Production

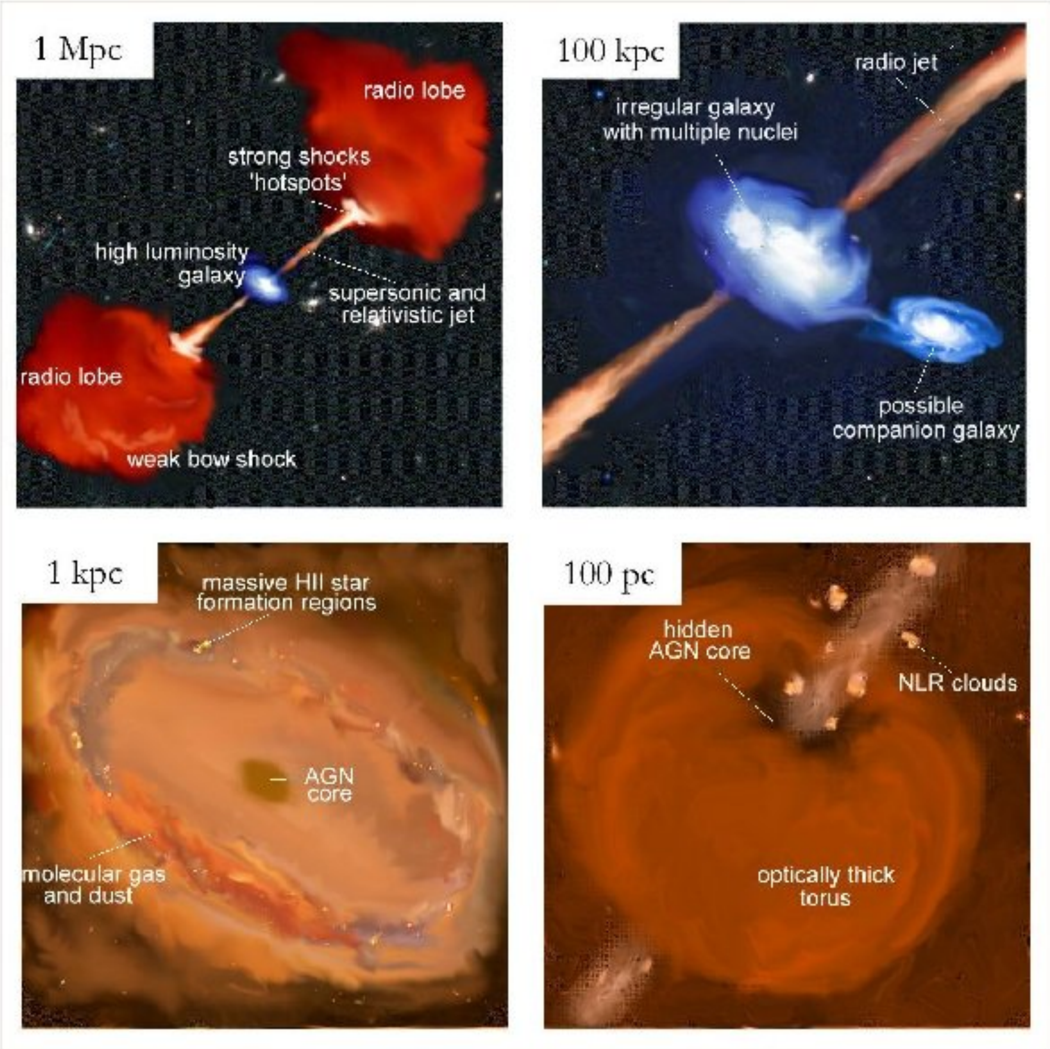


(from Sikora, Begelman, and Rees (1994))



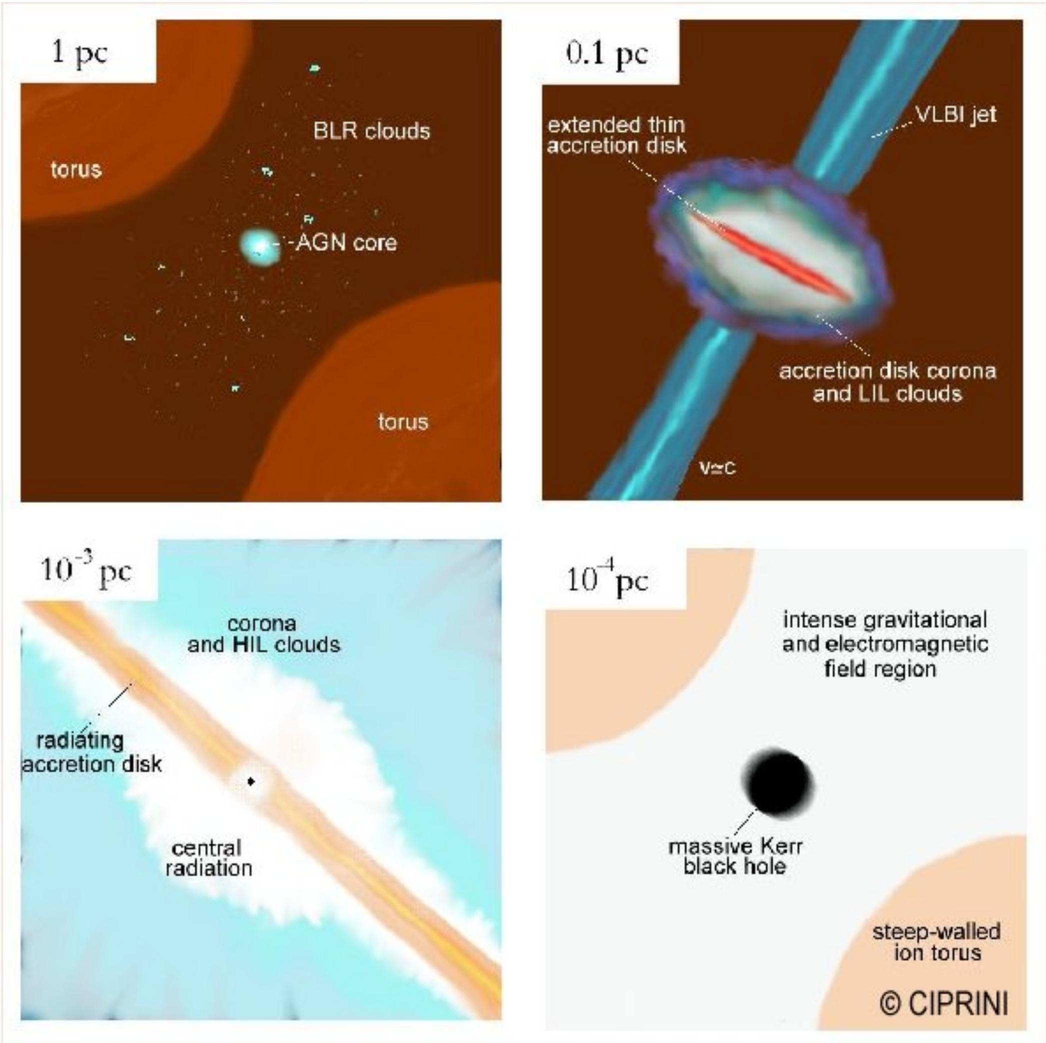
(credit:J. Buckley)

Active Galactic Nuclei



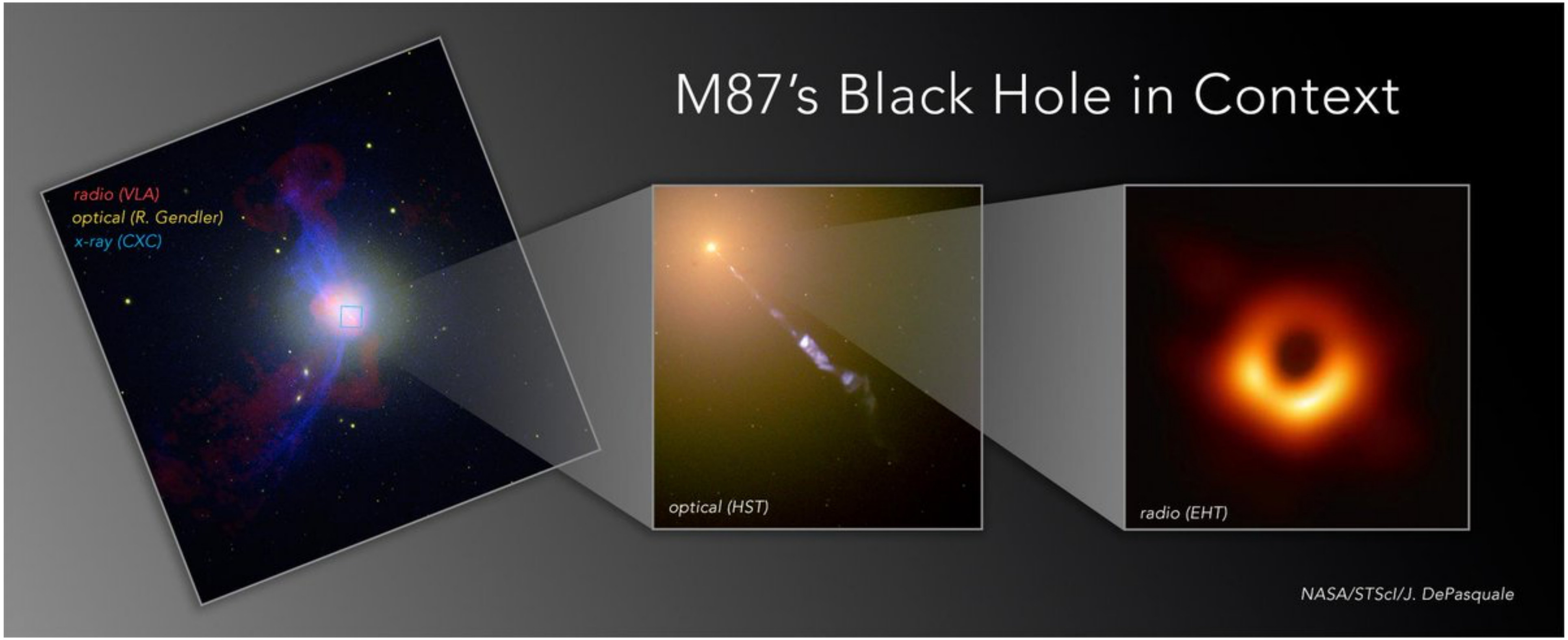
Artistic picture by S.Ciprini

Active Galactic Nuclei

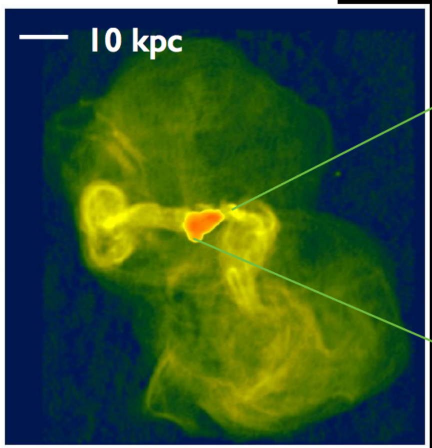


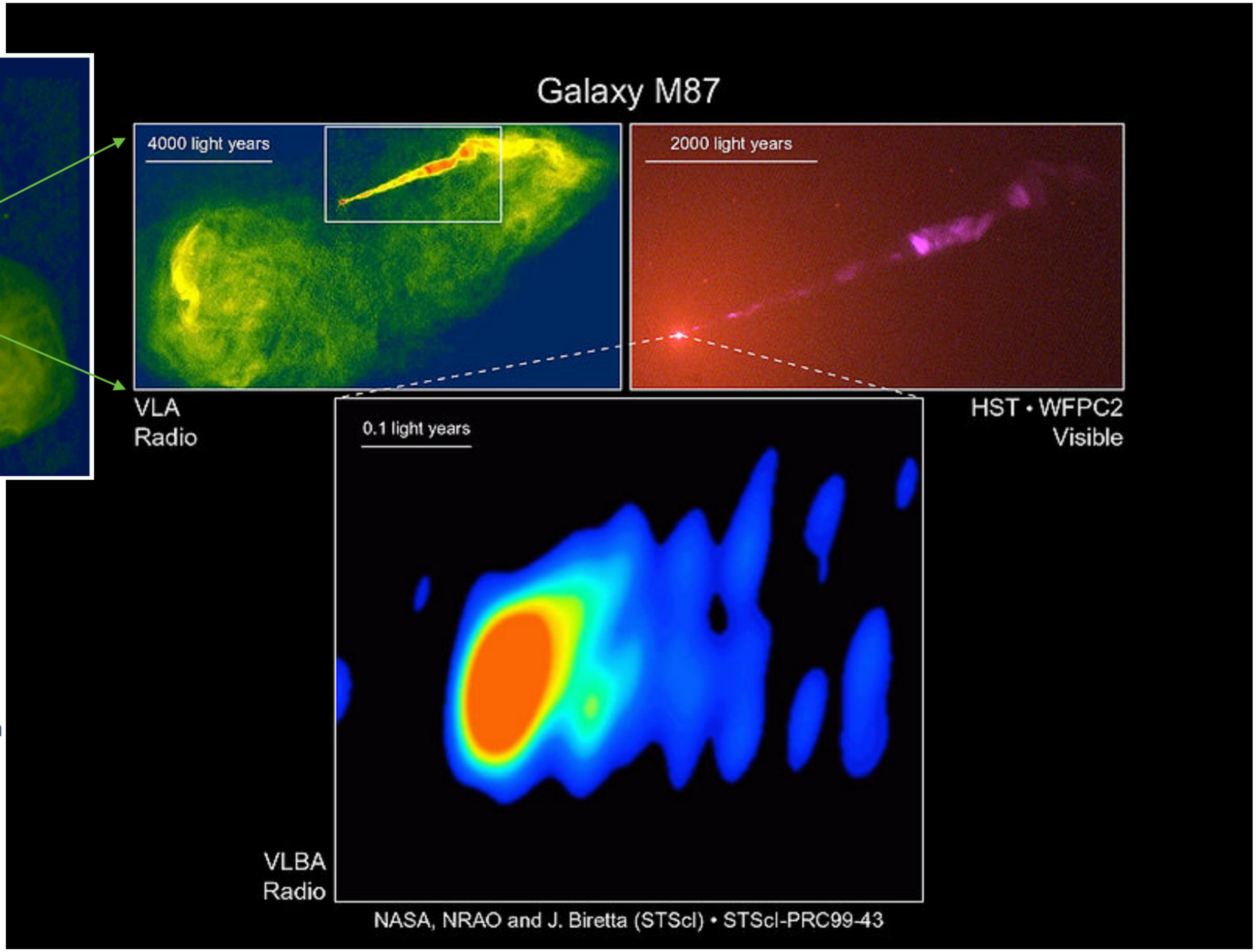
Artistic picture by S.Ciprini

M87 scales…


M87's Black Hole in Context
radio (VLA)
optical (R. Gendler)
x-ray (CXC)
optical (HST)
radio (EHT)
NASA/STScI/J. DePasquale

M87 scales…





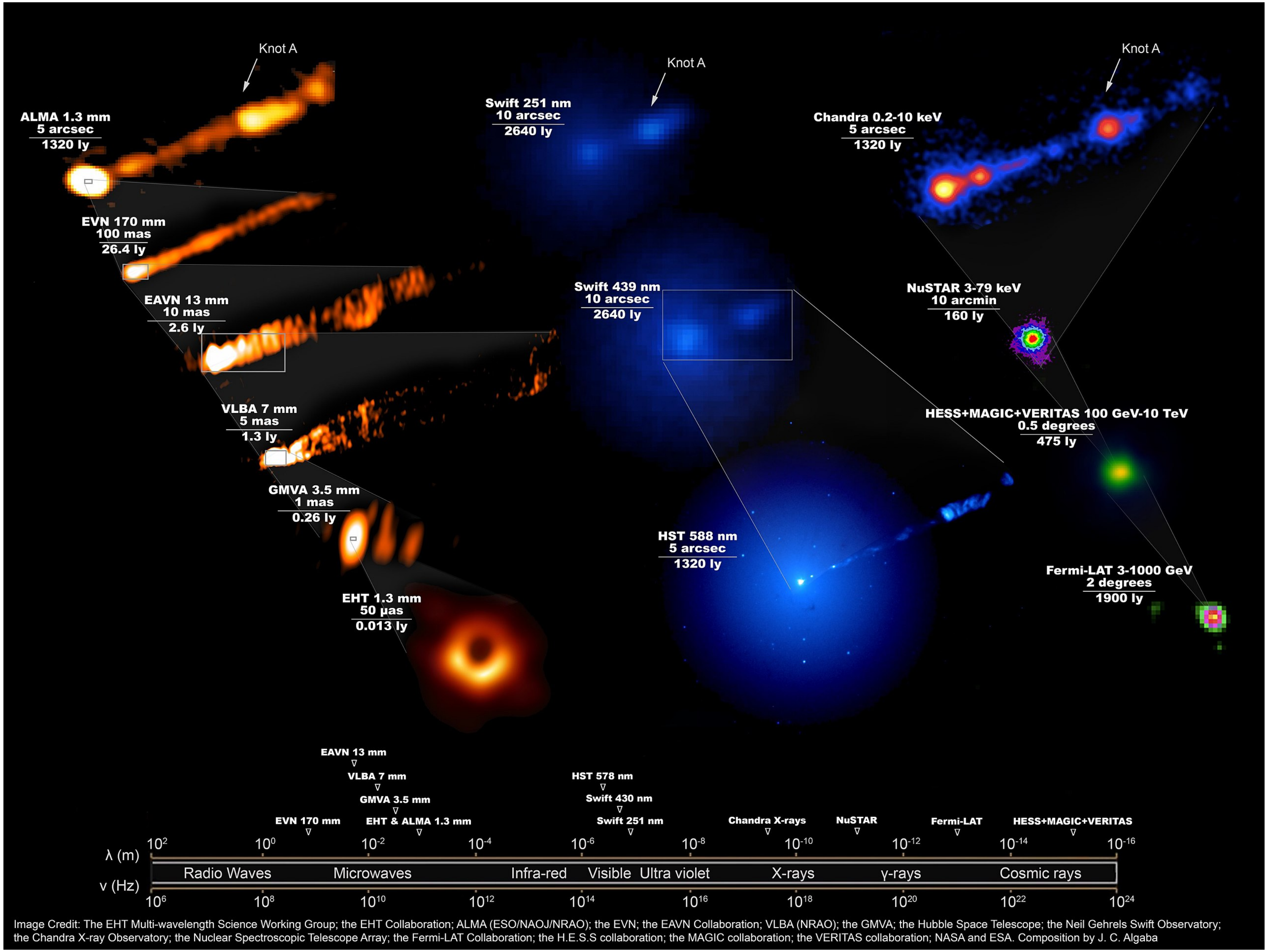
M87:

FR I radio galaxy

d~16 Mpc

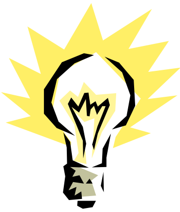
M_{BH}=(3-6)x10^9 M_{sun}

M87 scales…



Knot A
ALMA 1.3 mm
5 arcsec
1320 ly
EVN 170 mm
100 mas
26.4 ly
EAVN 13 mm
10 mas
2.6 ly
VLBA 7 mm
5 mas
1.3 ly
GMVA 3.5 mm
1 mas
0.26 ly
EHT 1.3 mm
50 µas
0.013 ly
Knot A
Swift 251 nm
10 arcsec
2640 ly
Swift 439 nm
10 arcsec
2640 ly
HST 588 nm
5 arcsec
1320 ly
Knot A
Chandra 0.2-10 keV
5 arcsec
1320 ly
NuSTAR 3-79 keV
10 arcmin
160 ly
HESS+MAGIC+VERITAS 100 GeV-10 TeV
0.5 degrees
475 ly
Fermi-LAT 3-1000 GeV
2 degrees
1900 ly
EAVN 13 mm
VLBA 7 mm
GMVA 3.5 mm
EVN 170 mm
EHT & ALMA 1.3 mm
HST 578 nm
Swift 430 nm
Swift 251 nm
Chandra X-rays
NuSTAR
Fermi-LAT
HESS+MAGIC+VERITAS
λ (m)
10^2 10^0 10^-2 10^-4 10^-6 10^-8 10^-10 10^-12 10^-14 10^-16
Radio Waves
Microwaves
Infra-red
Visible
Ultra violet
X-rays
γ-rays
Cosmic rays
ν (Hz)
10^6 10^8 10^10 10^12 10^14 10^16 10^18 10^20 10^22 10^24
Image Credit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope; the Neil Gehrels Swift Observatory; the Chandra X-ray Observatory; the Nuclear Spectroscopic Telescope Array; the Fermi-LAT Collaboration; the H.E.S.S collaboration; the MAGIC collaboration; the VERITAS collaboration; NASA and ESA. Composition by J. C. Algaba

AGN and the Extragalactic Background Light (EBL)



Look for roll-offs in blazar spectra due to attenuation:

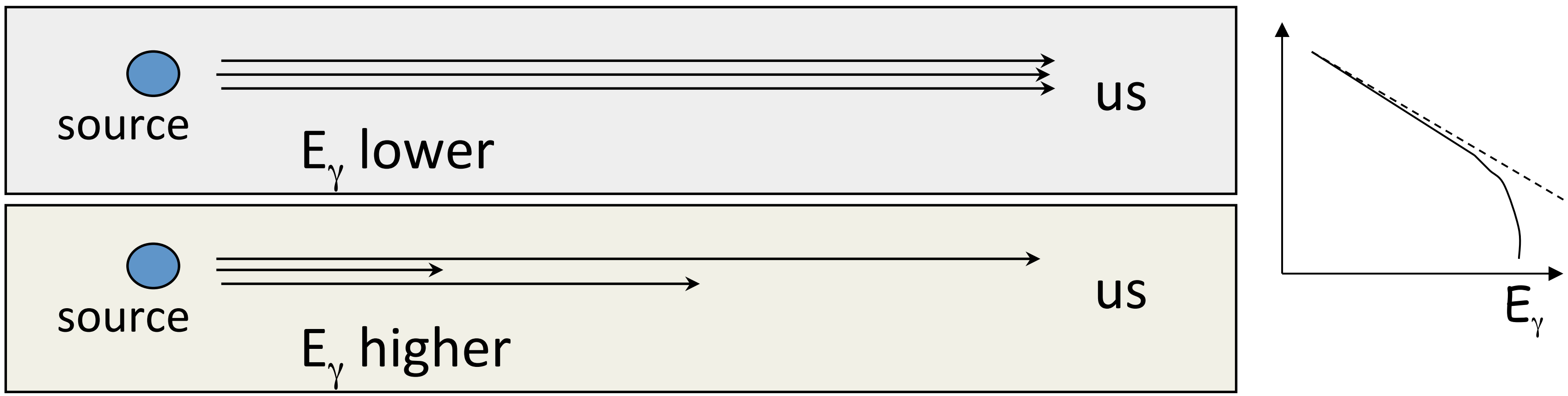
(Stecker, De Jager & Salamon; Madau & Phinney; Macminn & Primack)

the start: A.I. Nikishov, Sov. Phys. JETP 14 (1962) 393.

If $\gamma\gamma$ c.m. energy > $2m_e$, pair creation will attenuate flux. For a flux of γ -rays with energy, E, this cross-section is maximized when the partner, ε, is

$$\epsilon \sim \frac{1}{3}\left(\frac{1TeV}{E}\right)eV$$

For 10 GeV- 100 GeV γ - rays, this corresponds to a partner photon energy in the optical - UV range. Density is sensitive to time of galaxy formation.



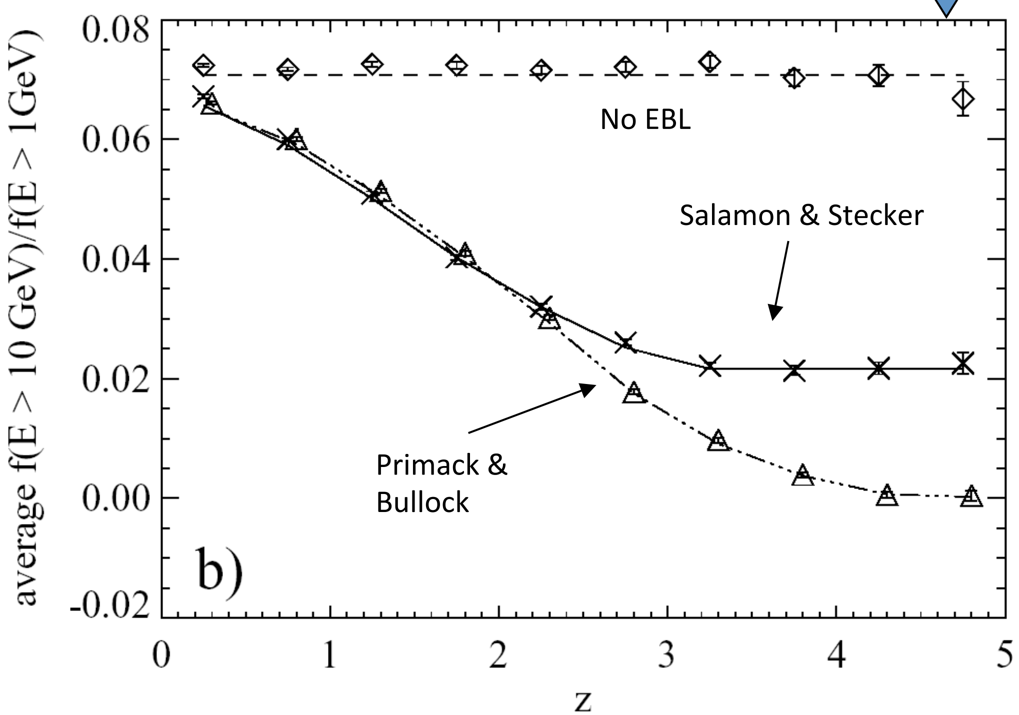
AGN and EBL

- **Important advances offered by Fermi:**

  (1) thousands of blazars - instead of peculiarities of individual sources, look for systematic effects vs redshift.

  (2) key energy range for cosmological distances (TeV-IR attenuation more local due to opacity).

- Effect is model-dependent (this is good):

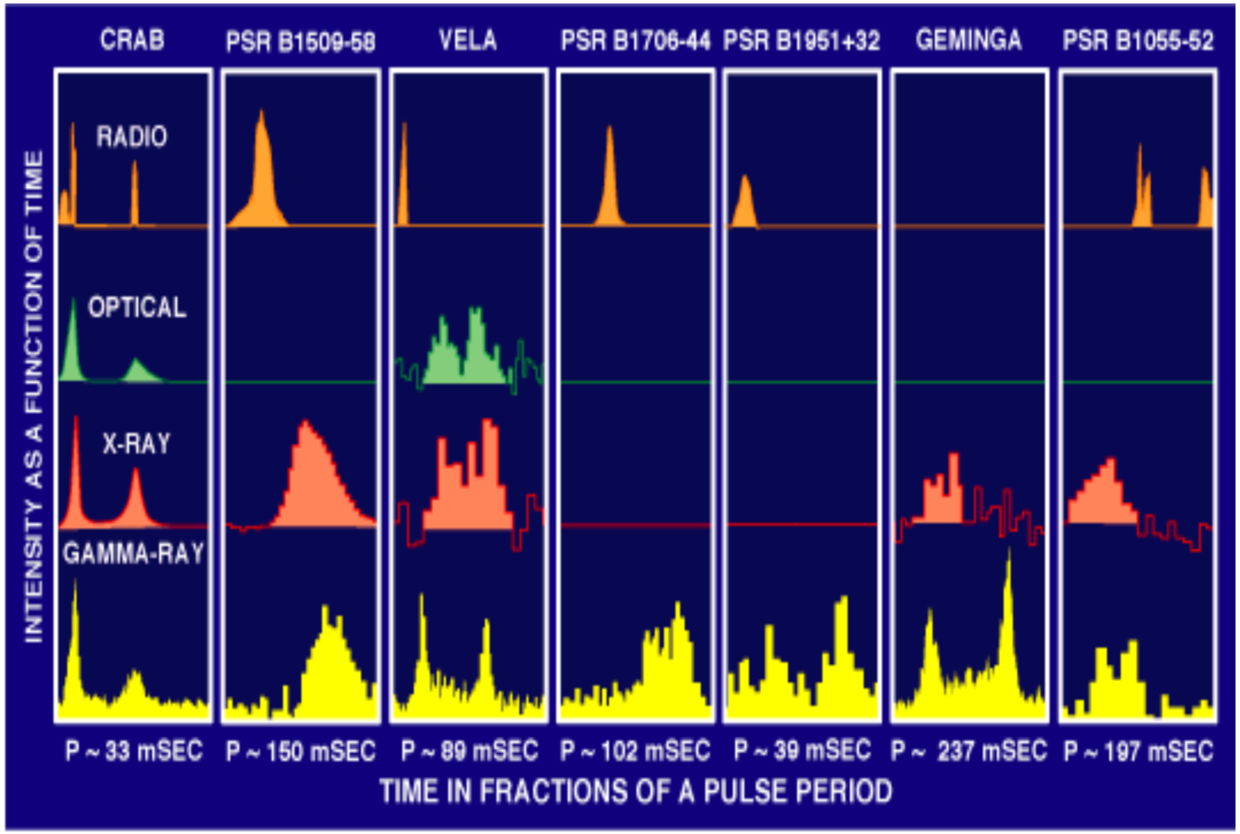


Caveats

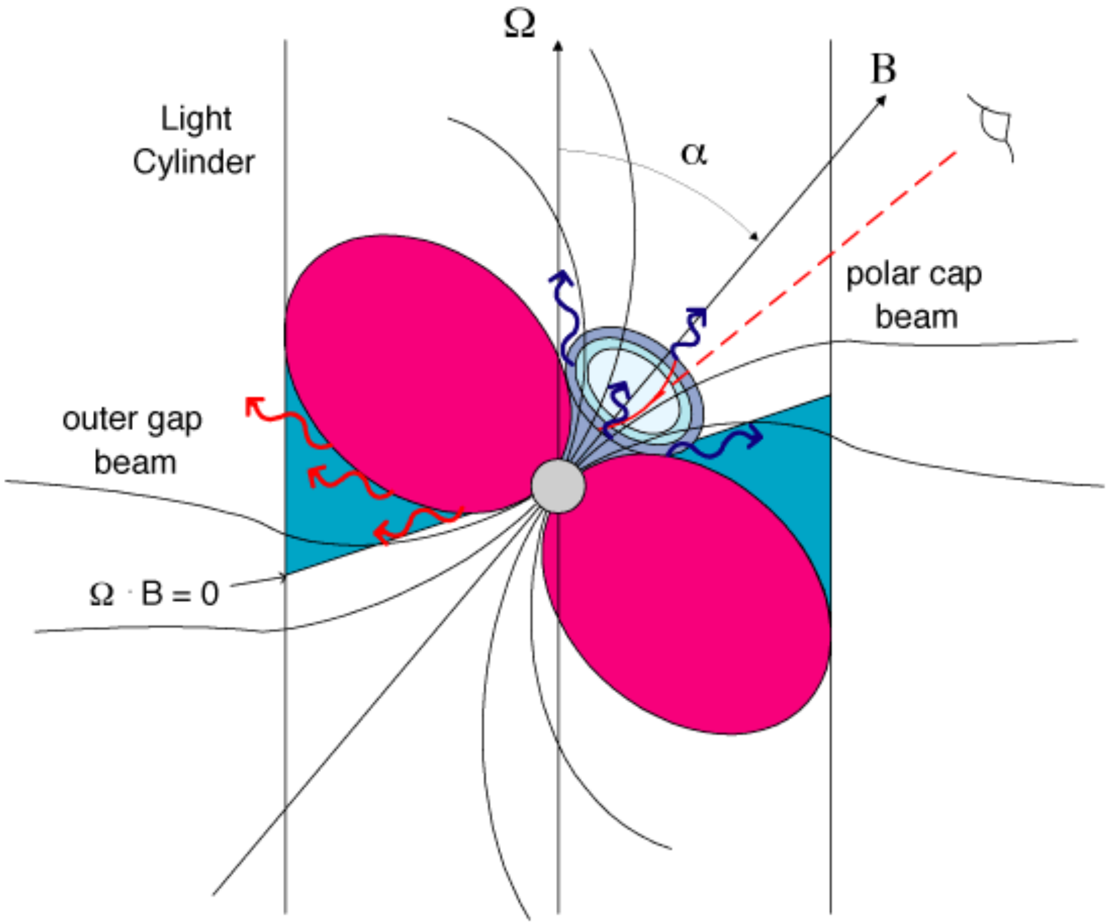
- How many blazars have intrinsic roll-offs in this energy range (10-100 GeV)? (An important question by itself for GLAST!)
- What if there is conspiratorial evolution in the intrinsic roll-of vs redshift? More difficult, however there may also be independent constraints (e.g., direct observation of integrated EBL).
- Must measure the redshifts for a large sample of these blazars!

Challenge # 2

- Need more exposure and optimal timing (and radio monitoring) to discover more gamma-ray PSRs.



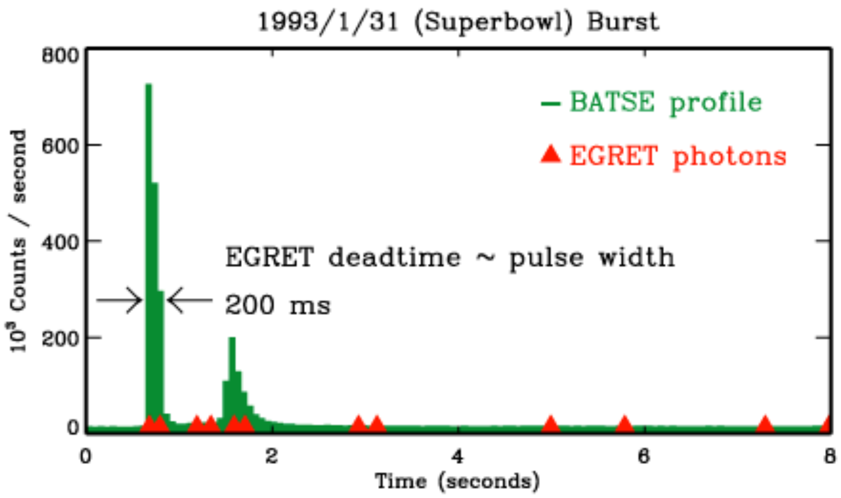
Pulsars



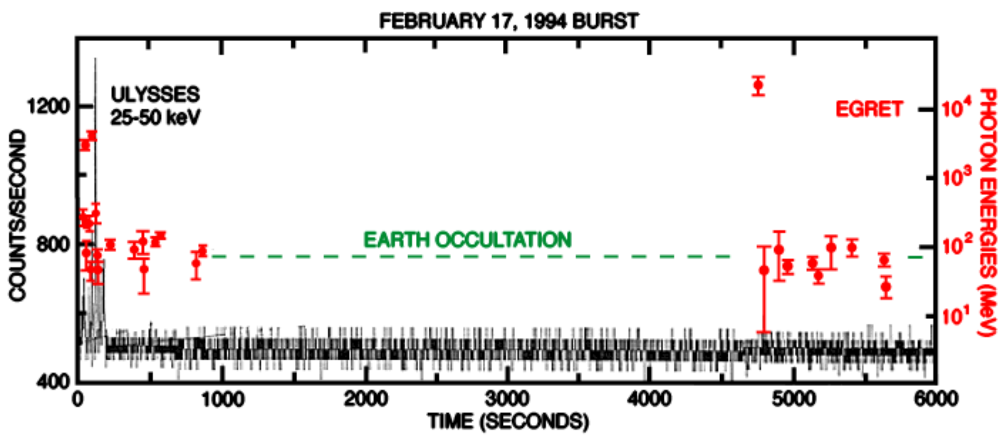
Challenge # 3

- Need fast timing for gamma-ray detection (improving EGRET deadtime, 100 msec → 100 microsec or less).

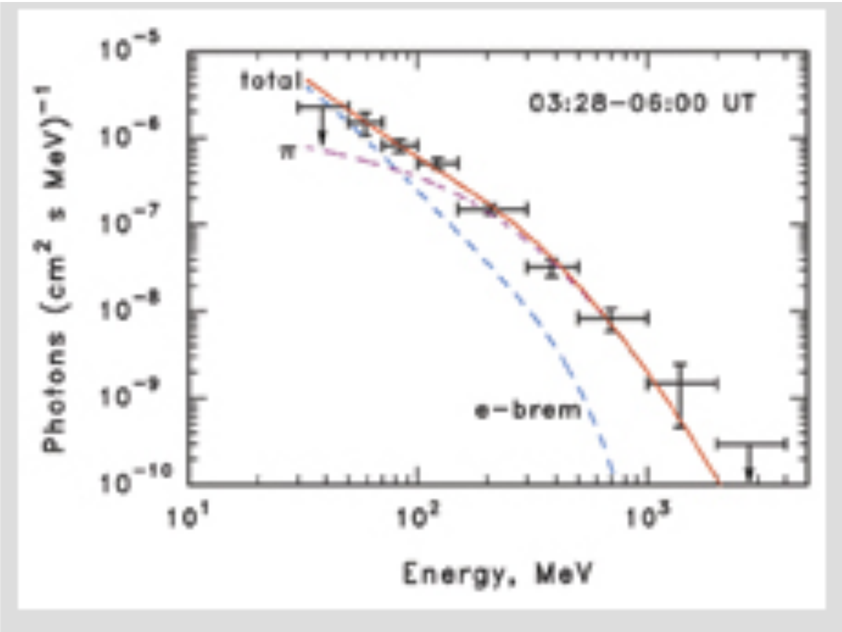
Prompt Emission (GRB 930131)

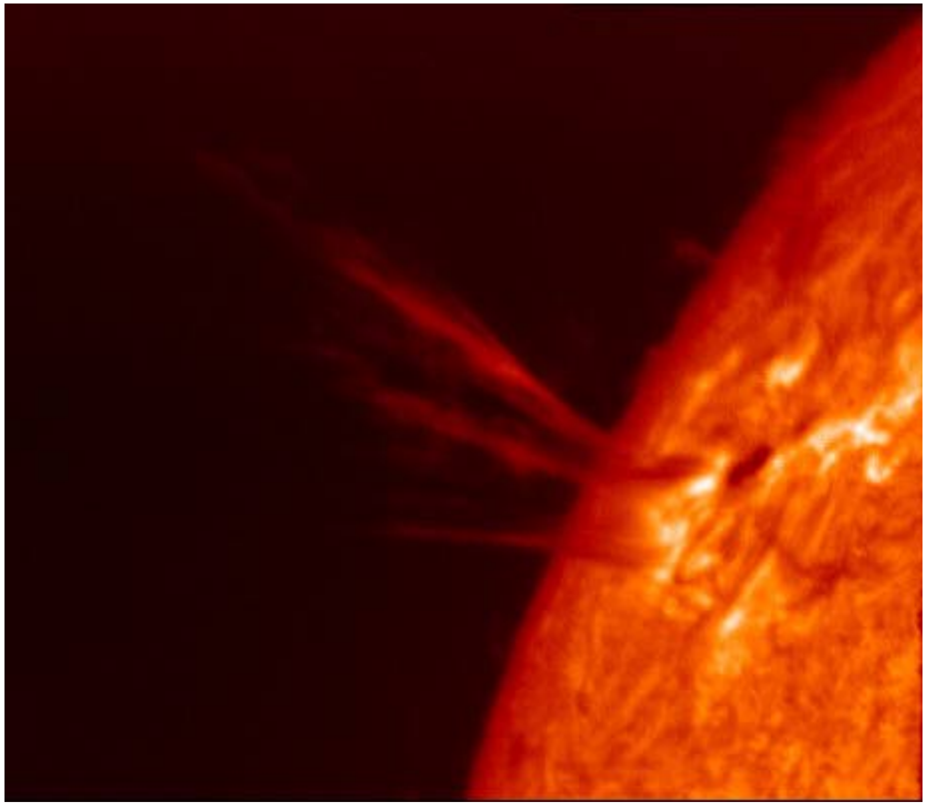


Delayed Emission (GRB 940217)

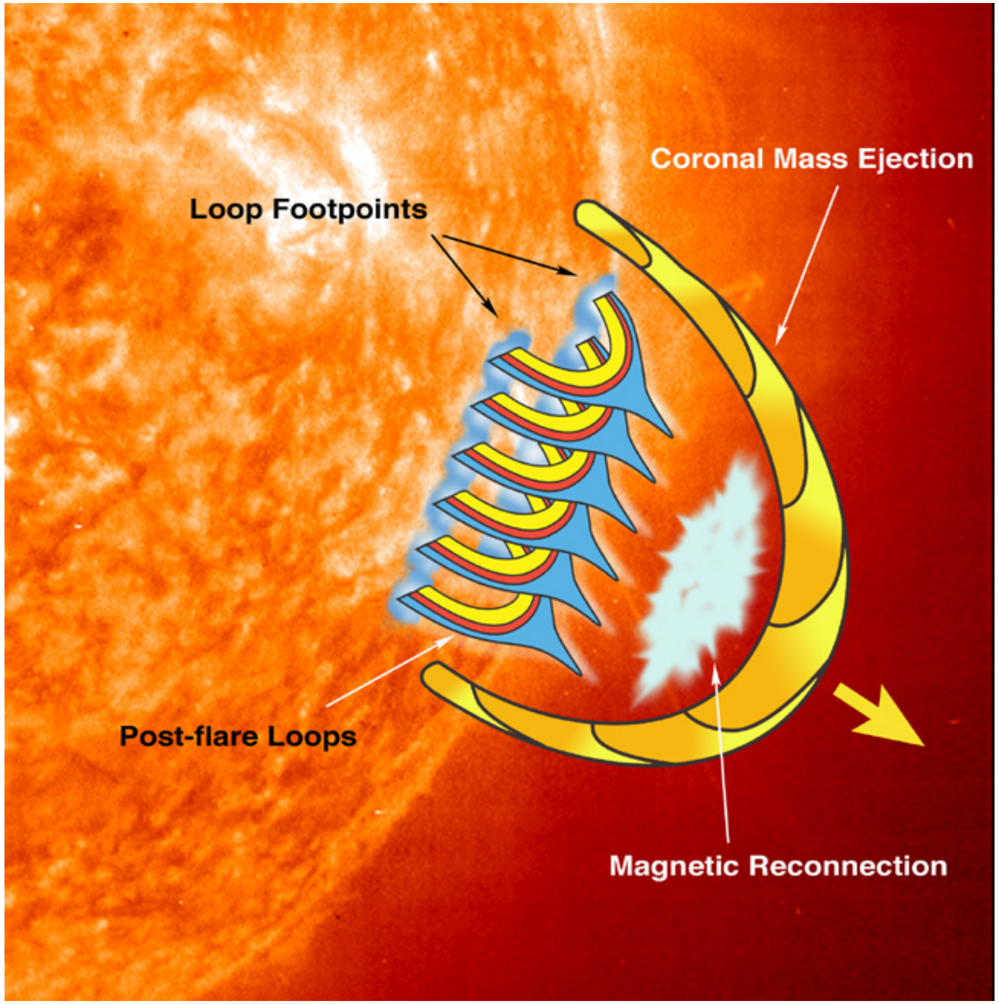


Solar flares



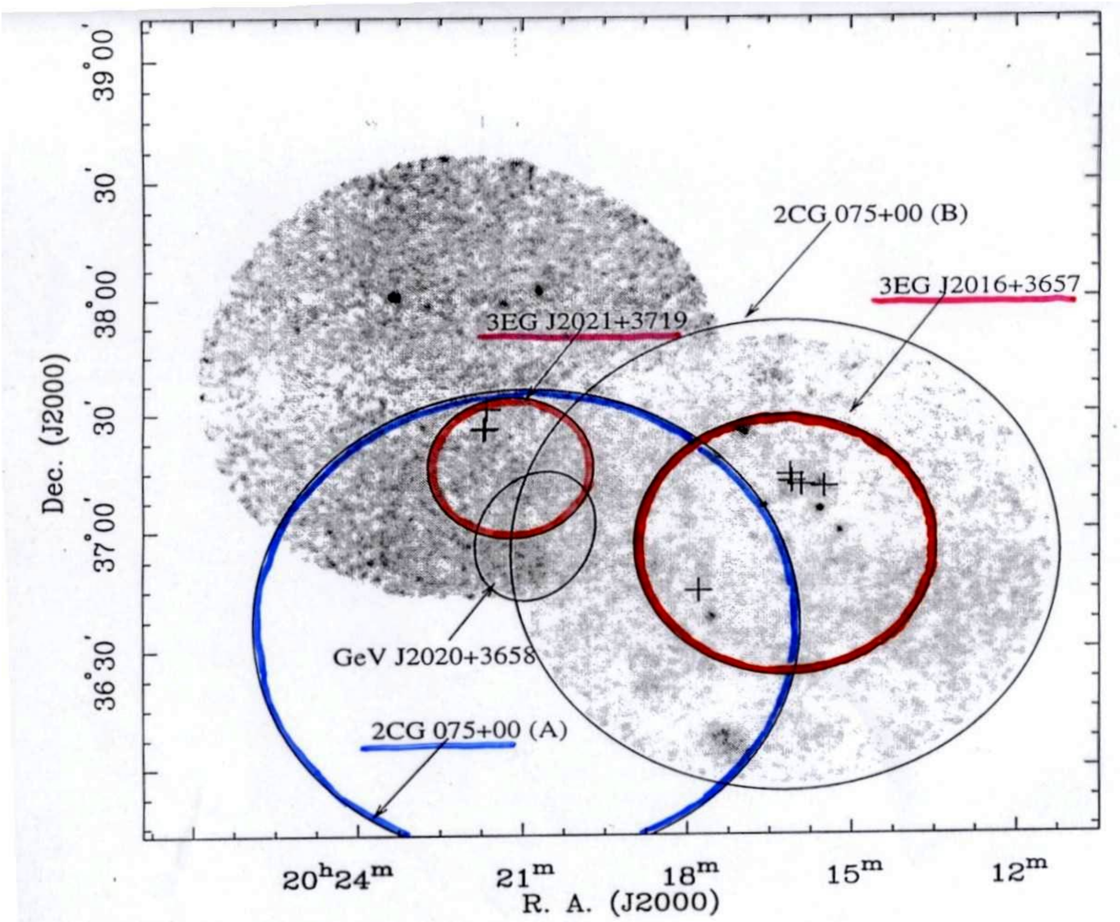


Solar Flares

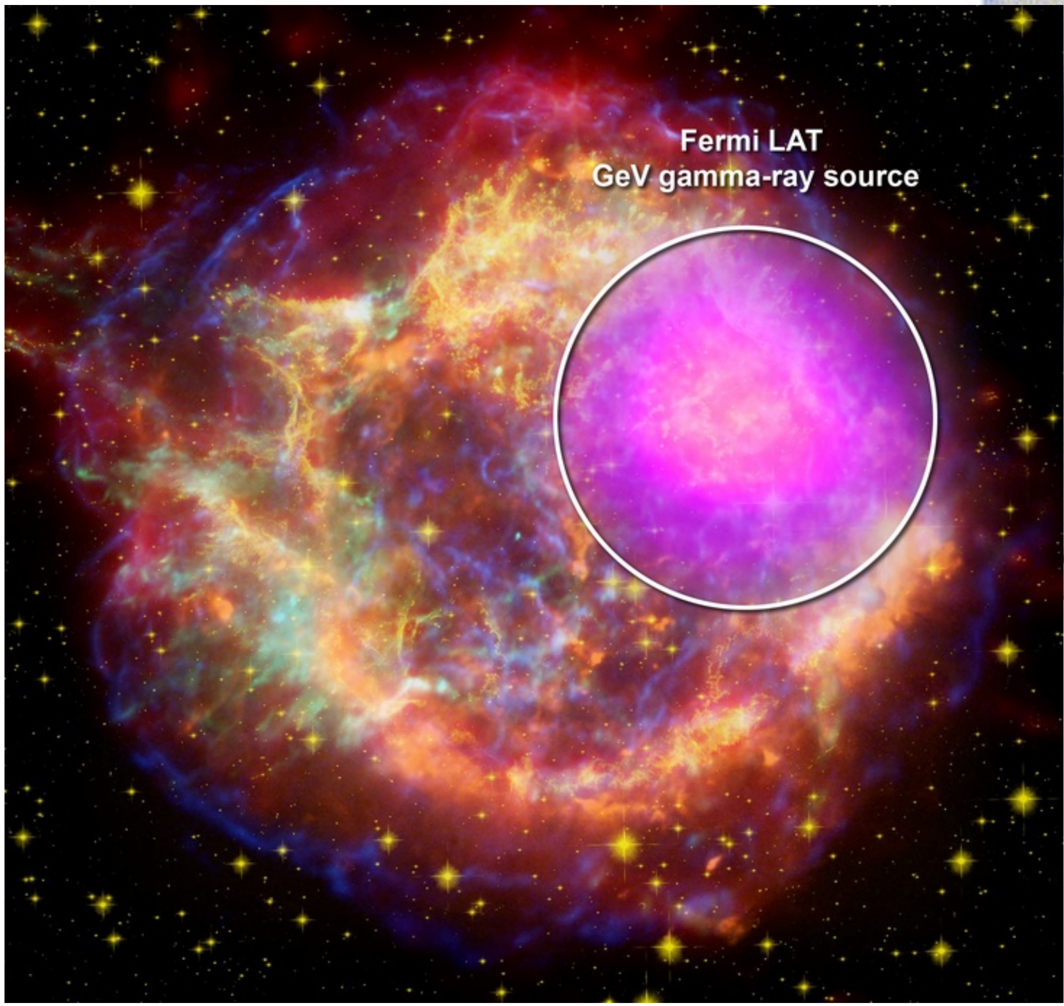


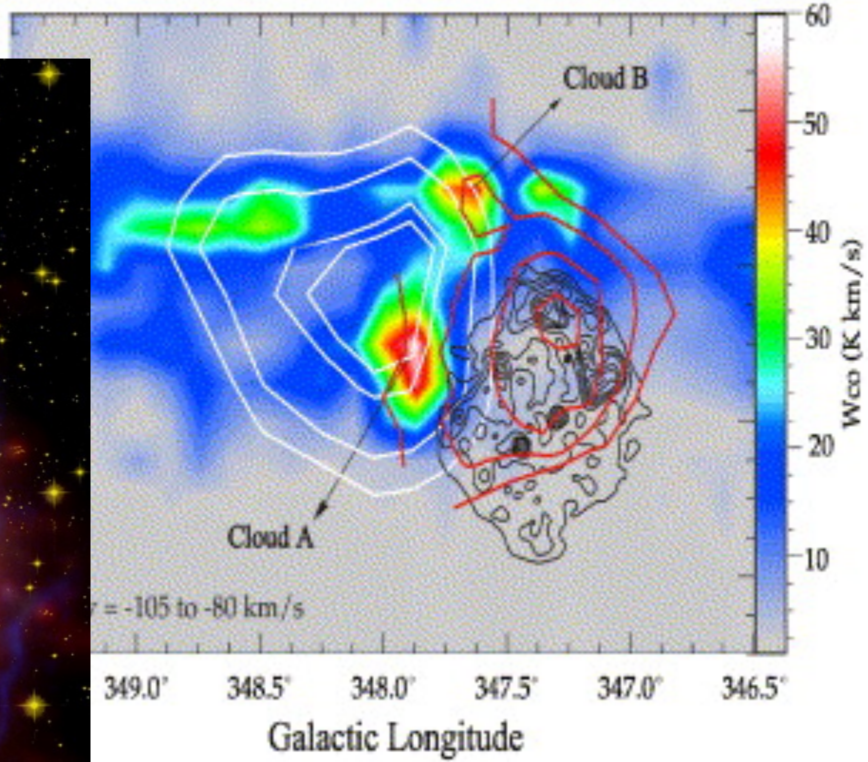
Challenge # 4

- Need arcminute positioning of gamma-ray sources (improving EGRET error box radii by a factor of 2-10).

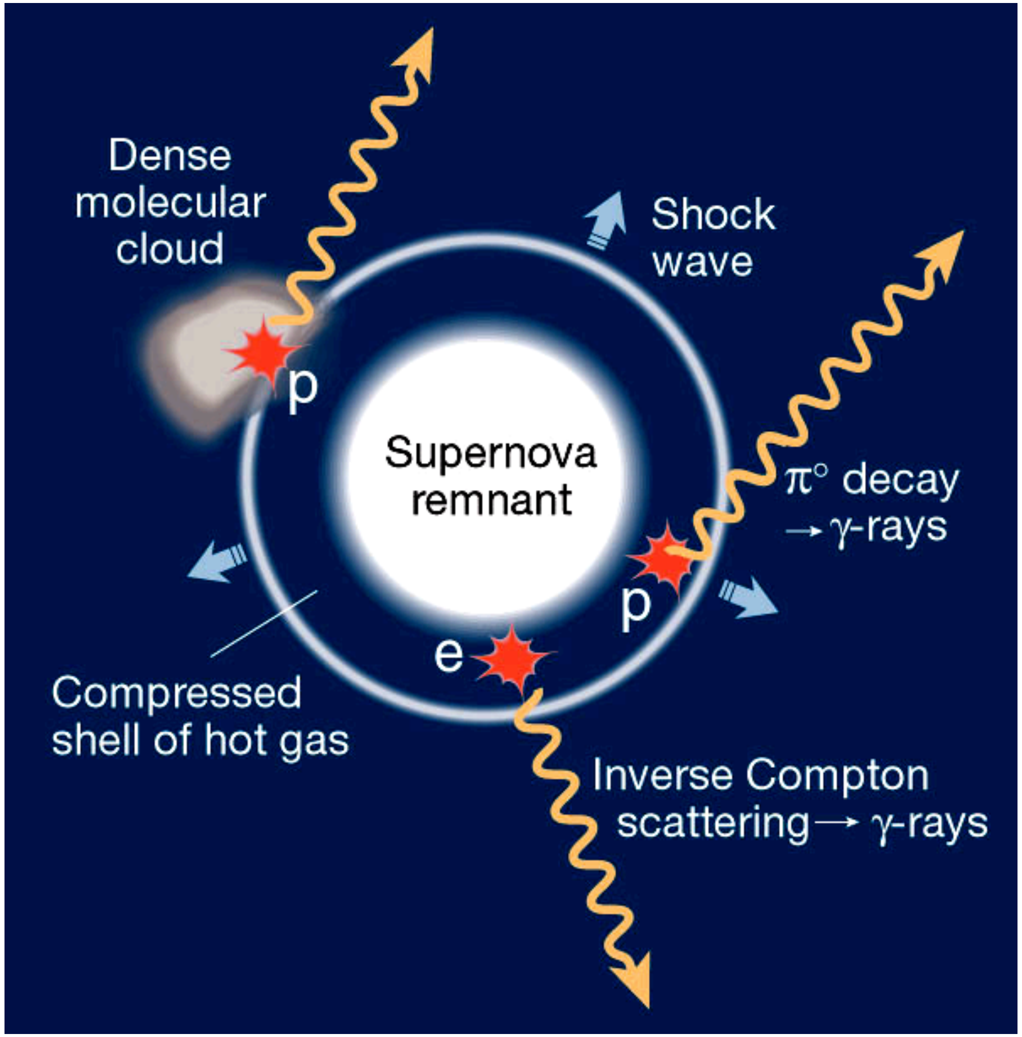


Supernova Remnants



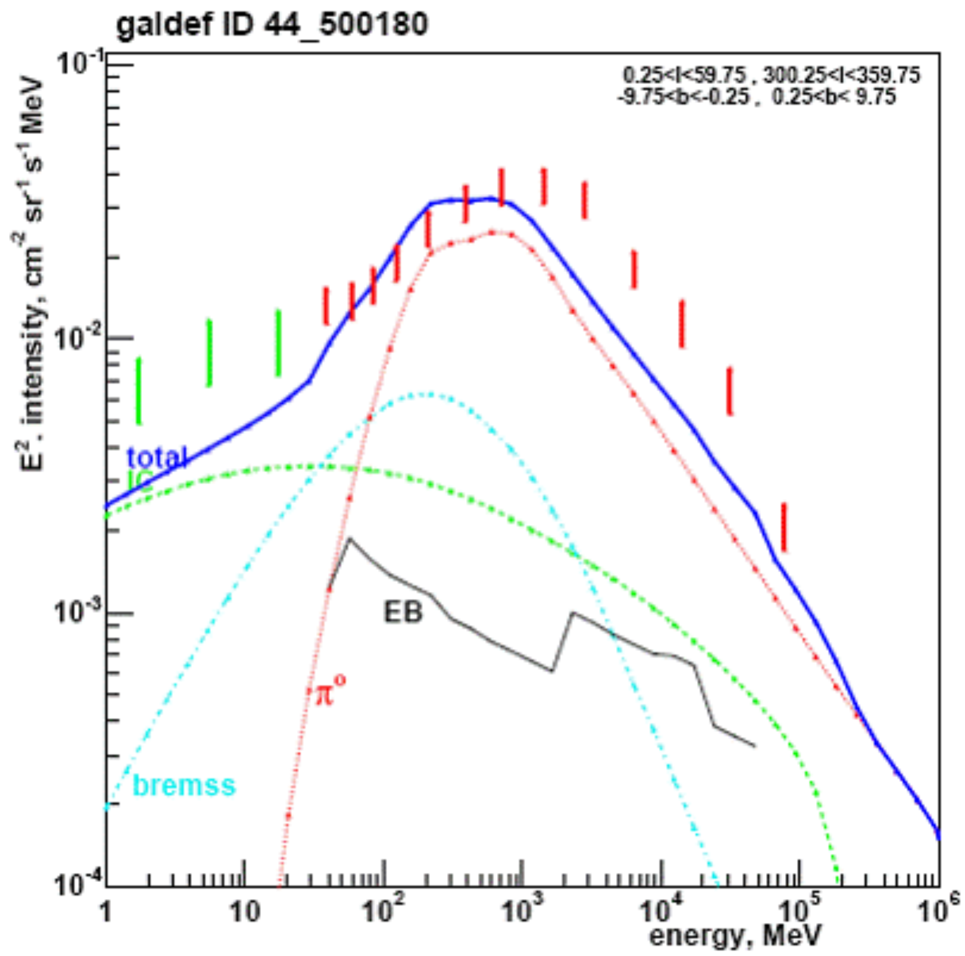


SNR

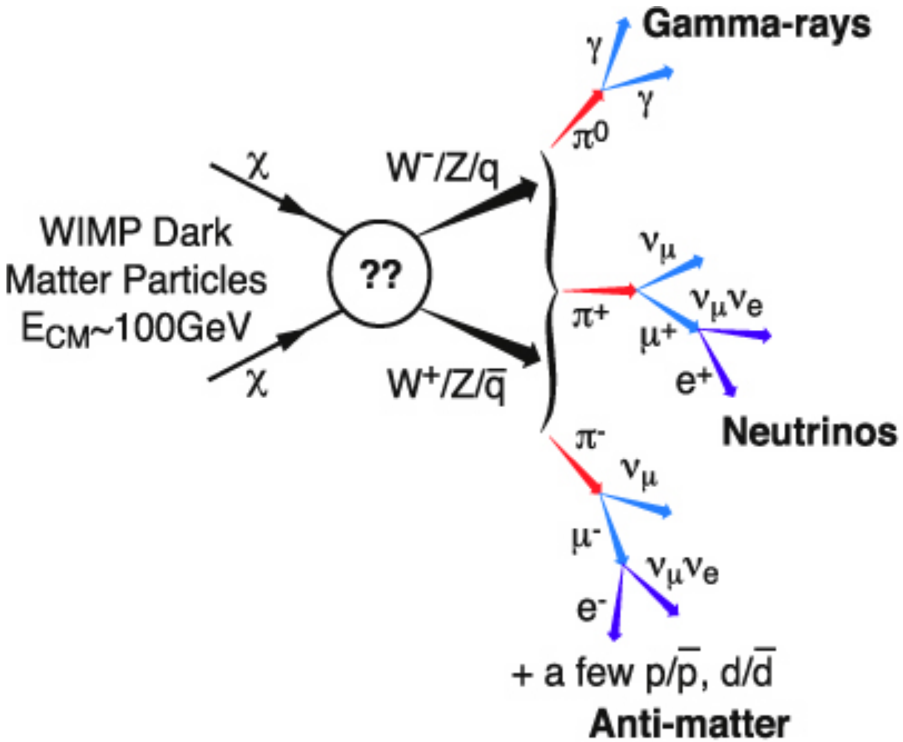

Dense
molecular
cloud
Shock
wave
p
Supernova
remnant
π° decay
→ γ-rays
p
e
Compressed
shell of hot gas
Inverse Compton
scattering → γ-rays

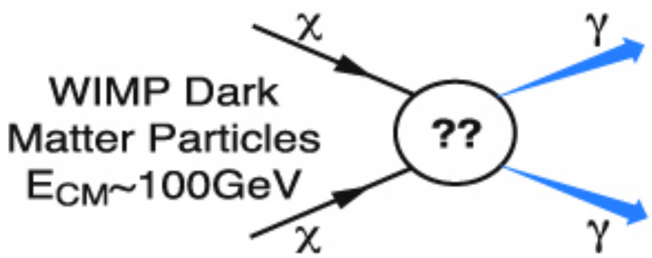
Challenge # 5

- Need improvements in Spectral Resolution fo check for DM signals



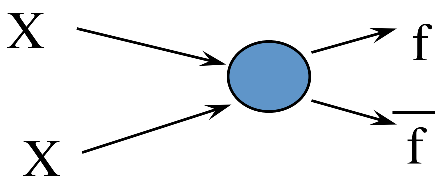
Dark Matter


Gamma-rays
γ
γ
π0
χ
W-/Z/q
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
W+/Z/q̄
νμ
νμνe
π+
μ+
e+
Neutrinos
π-
νμ
μ-
νμνe
e-
+ a few p/p̄, d/d̄
Anti-matter


χ
γ
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
γ

Particle Dark Matter

Some important models in particle physics could also solve the dark matter problem in astrophysics. If correct, these new particle interactions could produce an anomalous flux of gamma rays (“indirect detection”).

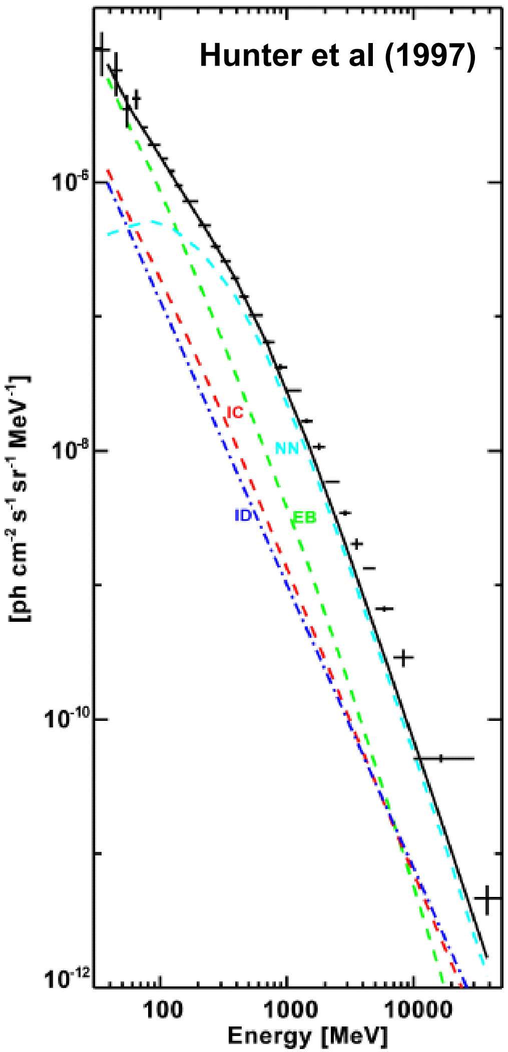


anomalous continuum
or $\gamma\gamma$ or $Z\gamma$ “lines”?

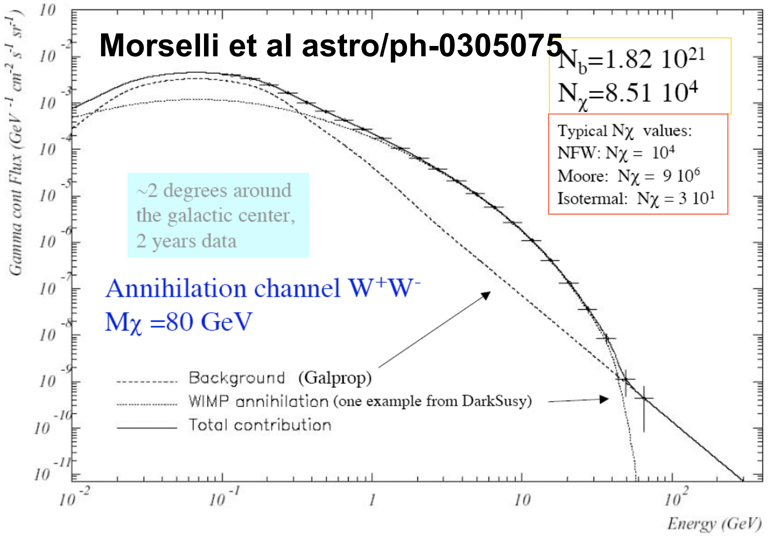
- Key interplay of techniques (see Baltz et al., astro/ph-0602187):
  - colliders (TeVatron, LHC, ILC)
  - direct detection experiments
  - indirect detection (best shot: gamma rays)
    - GLAST full sky coverage look for clumping throughout galactic halo, including off the galactic plane (if found, point the way for ground-based facilities)
    - Intensity highly model-dependent
    - Challenge is to separate signals from astrophysical backgrounds

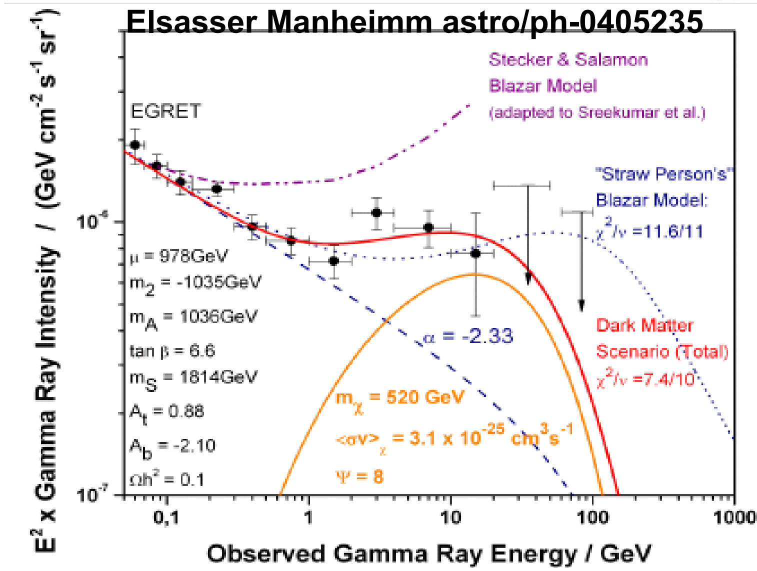
Just an example of what might be waiting for us to find!

Dark Matter Searches



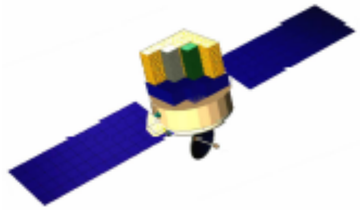
- WIMP annihilation in galactic centre or galactic halos
- Extragalactic WIMP annihilation relic
- SUSY dark matter
- Kaluza Klein dark matter





➢ this science require large sensitivity on a broad energy range, localization power, energy resolution, time resolution for variability search … key elements for the whole GLAST physics program

Detector Project



Sources Classes Predicted for GLAST

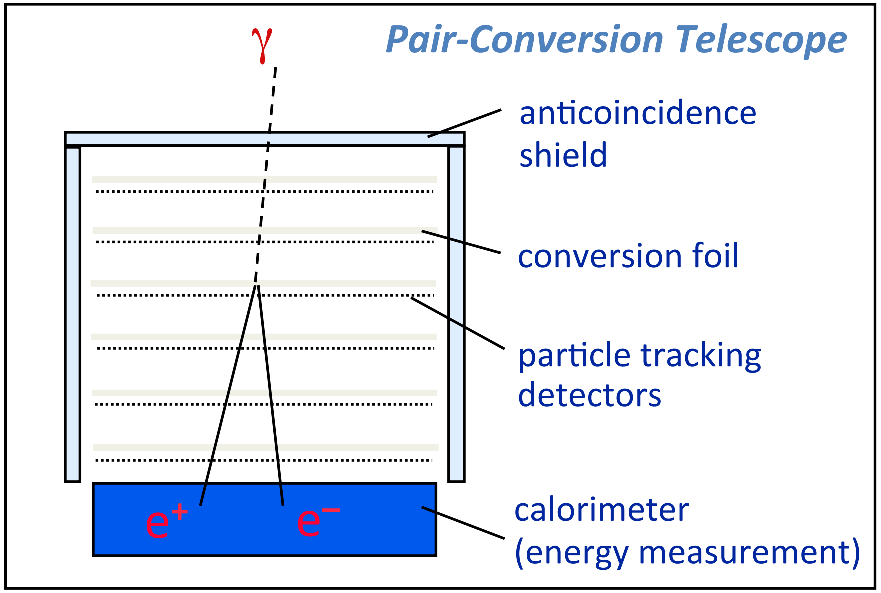
Source Class	Basis for Prediction
Active Galactic Nuclei (AGN)	EGRET quasars
Diffuse Cosmic Background	EGRET, Theory
Gamma Ray Bursts (GRBs)	EGRET, BATSE, Milagrito
Molecular Clouds, Supernova Remnants Normal Galaxies	COS-B, EGRET, Theory
Galactic Neutrons Stars (NS) & Black Holes (BHs)	COS-B, EGRET
Unidentified Gamma-ray Sources	COS-B, EGRET
Dark Matter	Theory

Detector Project

- Instrument must measure the direction, energy, and arrival time of high energy photons (from approximately 20 MeV to greater than 300 GeV):

- photon interactions with matter in GLAST energy range dominated by pair conversion:
  determine photon direction
  clear signature for background rejection

- limitations on angular resolution (PSF)
  low E: multiple scattering => many thin layers
  high E: hit precision & lever arm



Energy loss mechanisms:

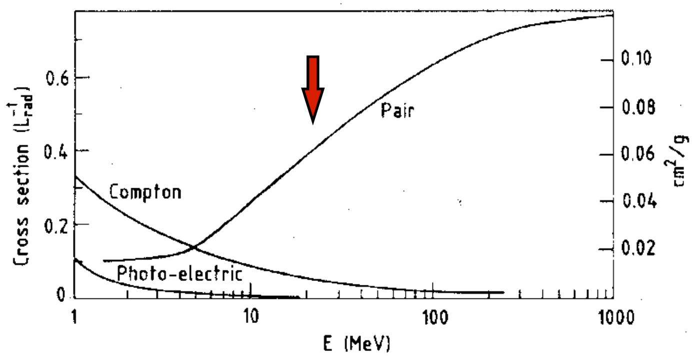


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

- must detect γ-rays with high efficiency and reject the much larger (~10^4:1) flux of background cosmic-rays, etc.;
- energy resolution requires calorimeter of sufficient depth to measure buildup of the EM shower. Segmentation useful for resolution and background rejection.

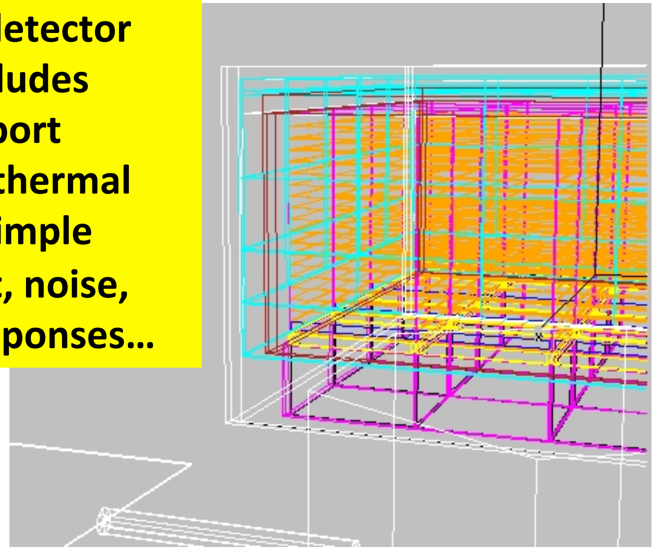
Detector Project

The LAT design is based on detailed Monte Carlo simulations.
Integral part of the project from the start.

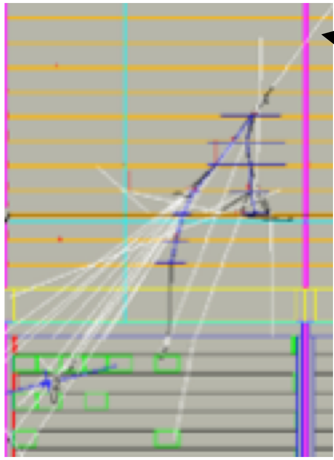
- **Background rejection**
- **Calculate effective area and resolutions (computer models now verified by beam tests). Current reconstruction algorithms are existence proofs -- many further improvements under development.**
- **Trigger design.**
- **Overall design optimization.**

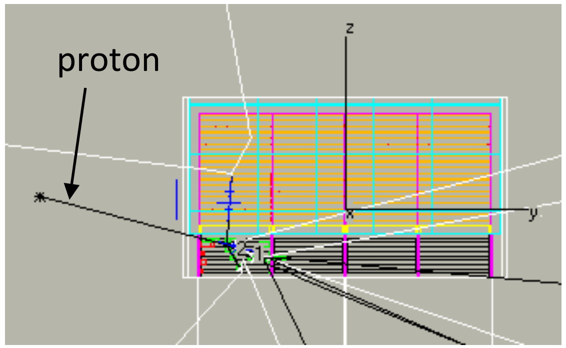
Simulations and analyses are all C++, based on standard HEP packages.

Detailed detector model includes gaps, support material, thermal blanket, simple spacecraft, noise, sensor responses...

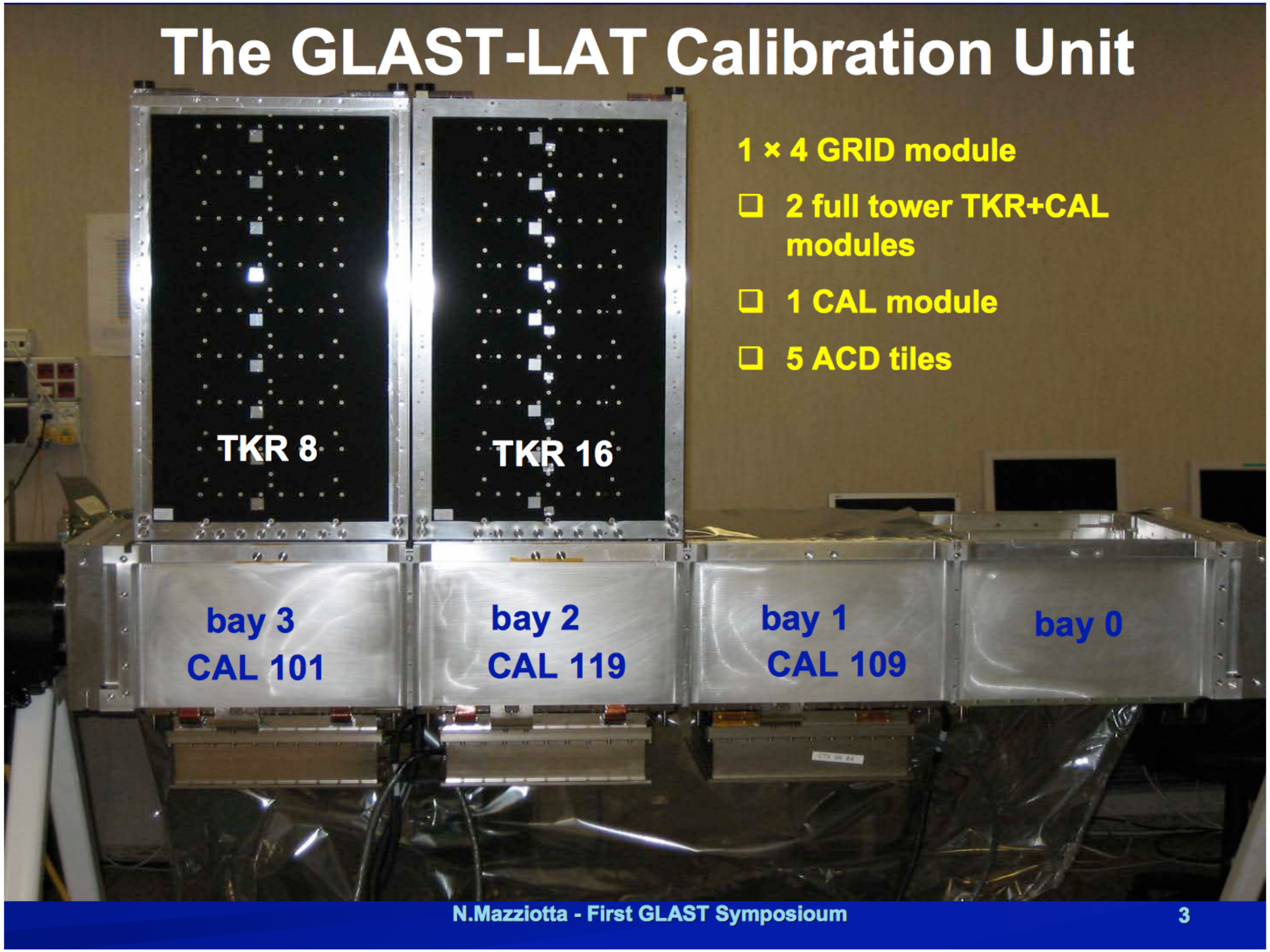


Instrument naturally distinguishes gammas from backgrounds, but details matter.



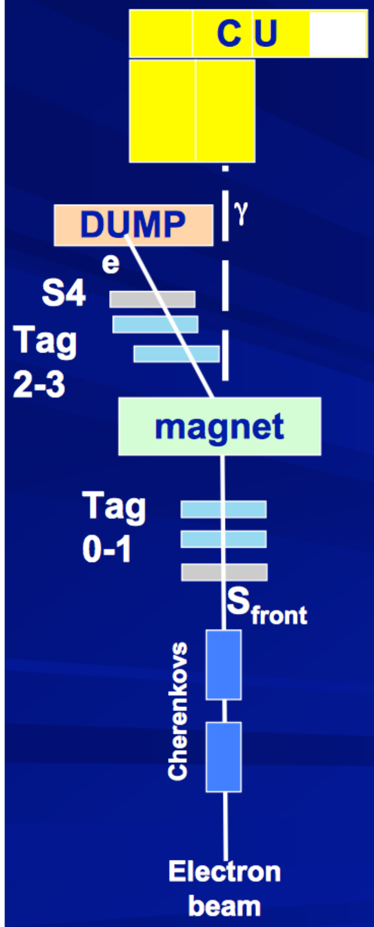


Beam test


The GLAST-LAT Calibration Unit
1 × 4 GRID module
2 full tower TKR+CAL modules
1 CAL module
5 ACD tiles
TKR 8
TKR 16
bay 3
CAL 101
bay 2
CAL 119
bay 1
CAL 109
bay 0
N.Mazziotta - First GLAST Symposioum
3

Beam test

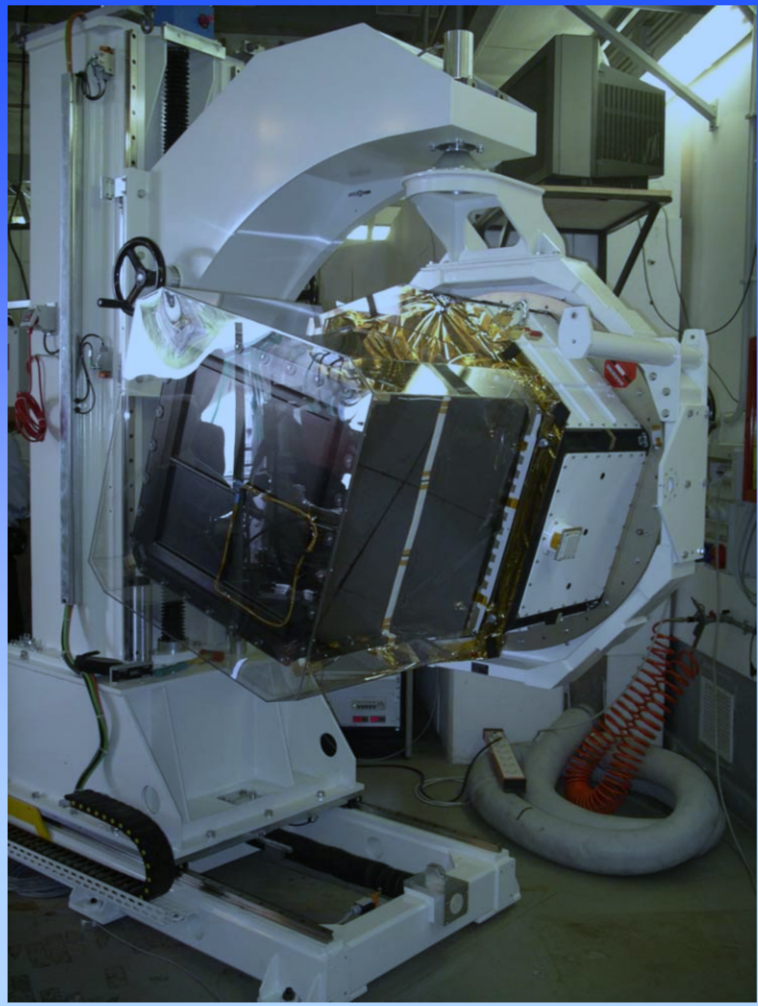
Photon configuration set-up



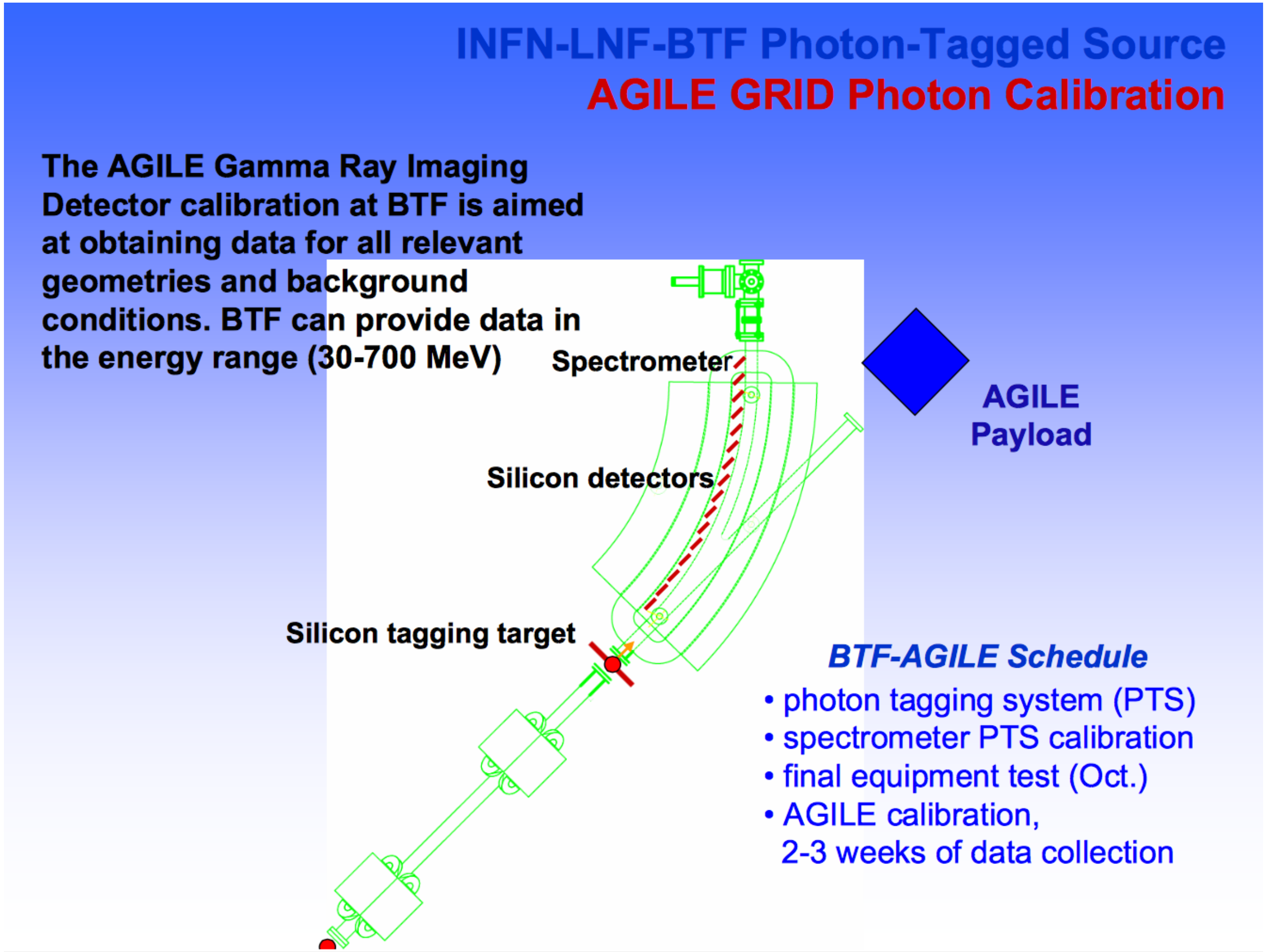
The gamma ray beam at the CERN PS T9 line was produced by bremsstrahlung between electrons and the upstream materials. A magnet has been used to well separate electrons from photons. Finally a beam dump has been used to stop electrons.

- Tagged photon beam
  - An external tracker (4 x-y view silicon strip detector) was used to track electrons upstream and downstream the magnet, read-out by means of an external DAQ
  - Trigger on S4&S_{front} & Cherenkovs
  - External DAQ was synchronized with the CU one, then the data have been merged with the CU one
  - Different electron beam energy in the range 0.5-2.5 GeV and magnetic field intensity have been used to provide a gamma spectrum to the CU below 2 GeV
- Not tagged photon beam
  - Trigger on S_{front} & Cherenkov
  - Full bremsstrahlung spectrum from 2.5GeV/c electron beam

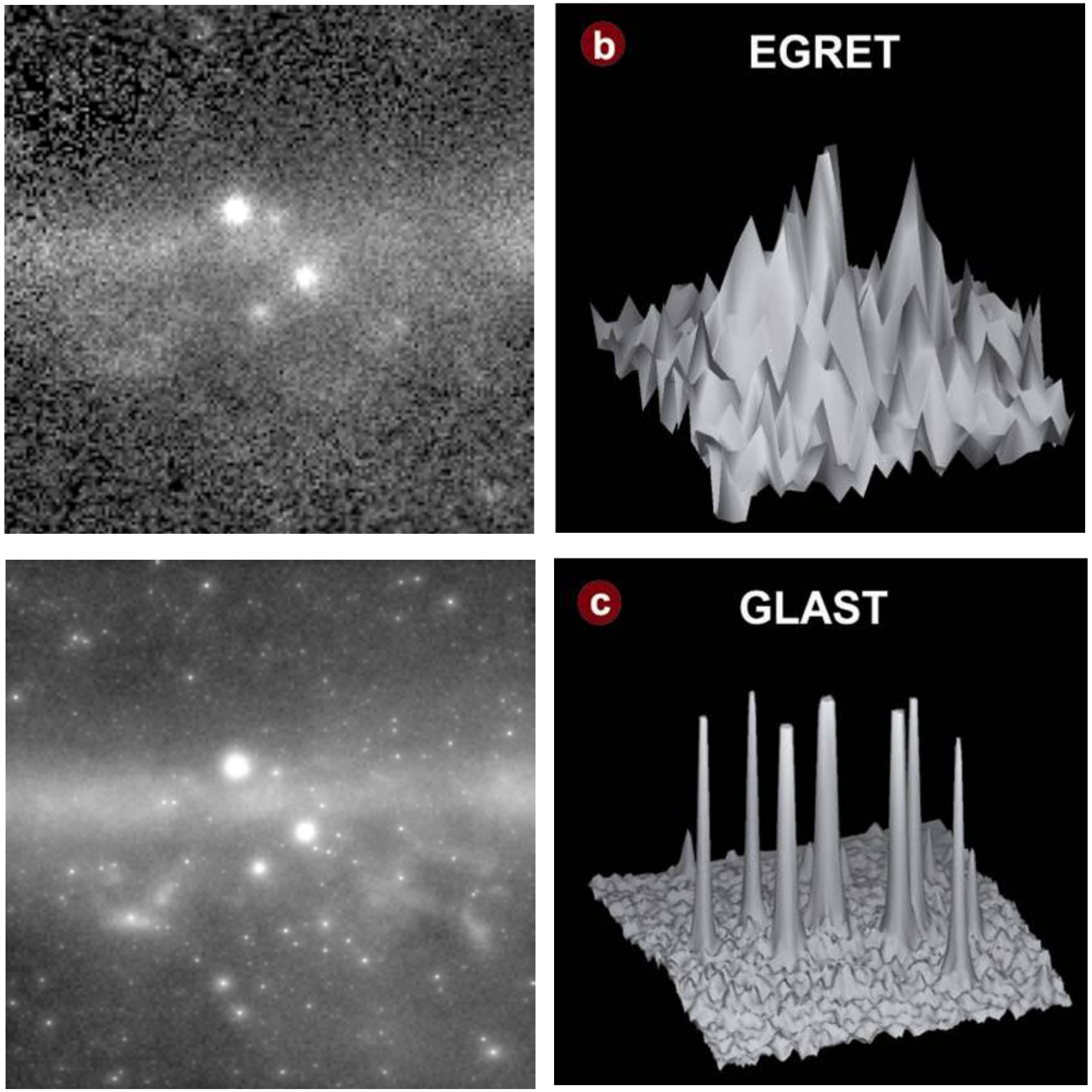
AGILE calibration



AGILE calibration



Technology impact -- PSF



Cygnus region (15^0 x 15^0), $E\gamma > 1$ GeV

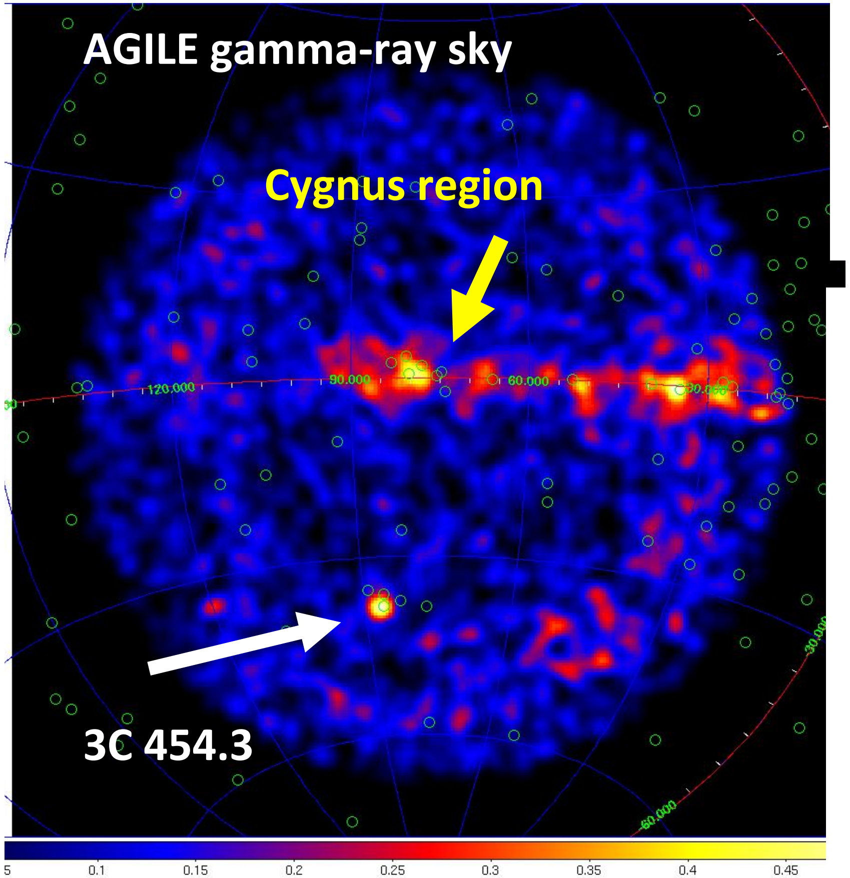
EGRET
(1991-2000)
Phases 1-5

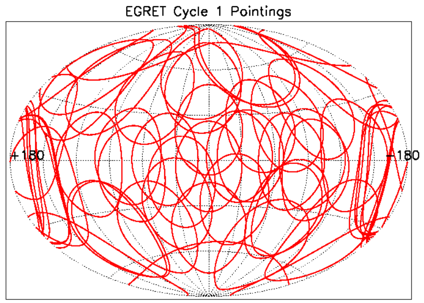
Spark chamber
- **sense electrode spacing ~mm**
- **sensitive layer depth ~cm**
    - ***up to 28 hit over >1m***

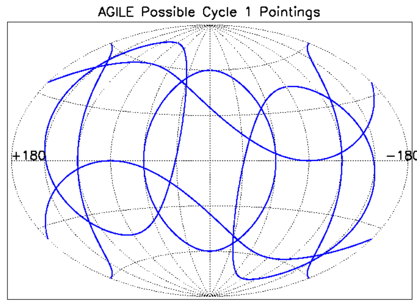
LAT
(2008- >2013)
1-yr simulation

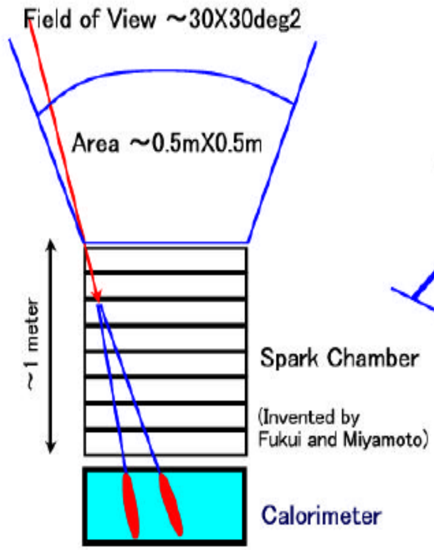
Si-strip detectors
- **sense electrode spacing ~0.2mm**
    - ***better single hit resolution***
- **sensitive layer depth ~0.4mm**
    - ***up to 36 hit over 0.8m***
    - ***converter proximity to minimize MCS***

Technology impact - FoV

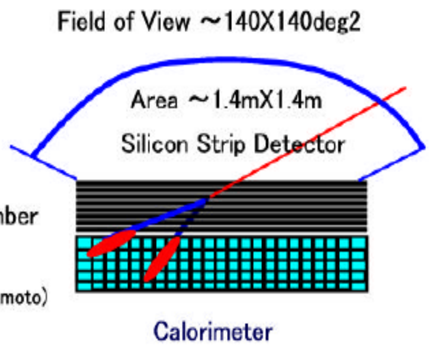








EGRET on Compton GRO



GLAST Large Area Telescope

After a long story ...