ASTROPHYSICS FROM THE RADIO TO THE SUB-MILLIMETRE

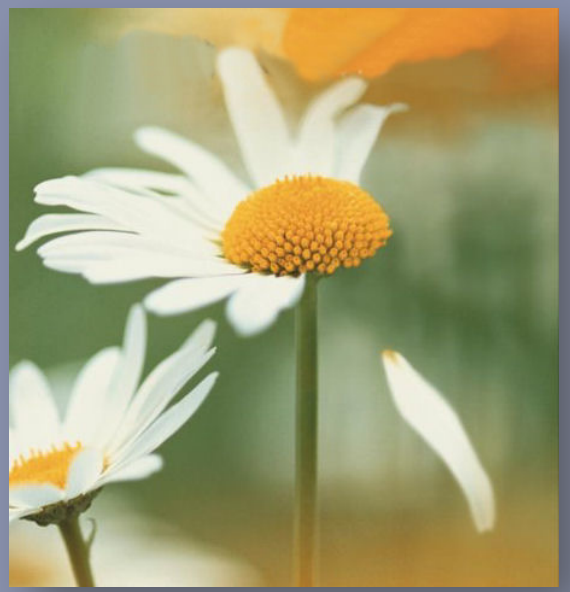
BOLOGNA, 16 FEBRUARY 2012

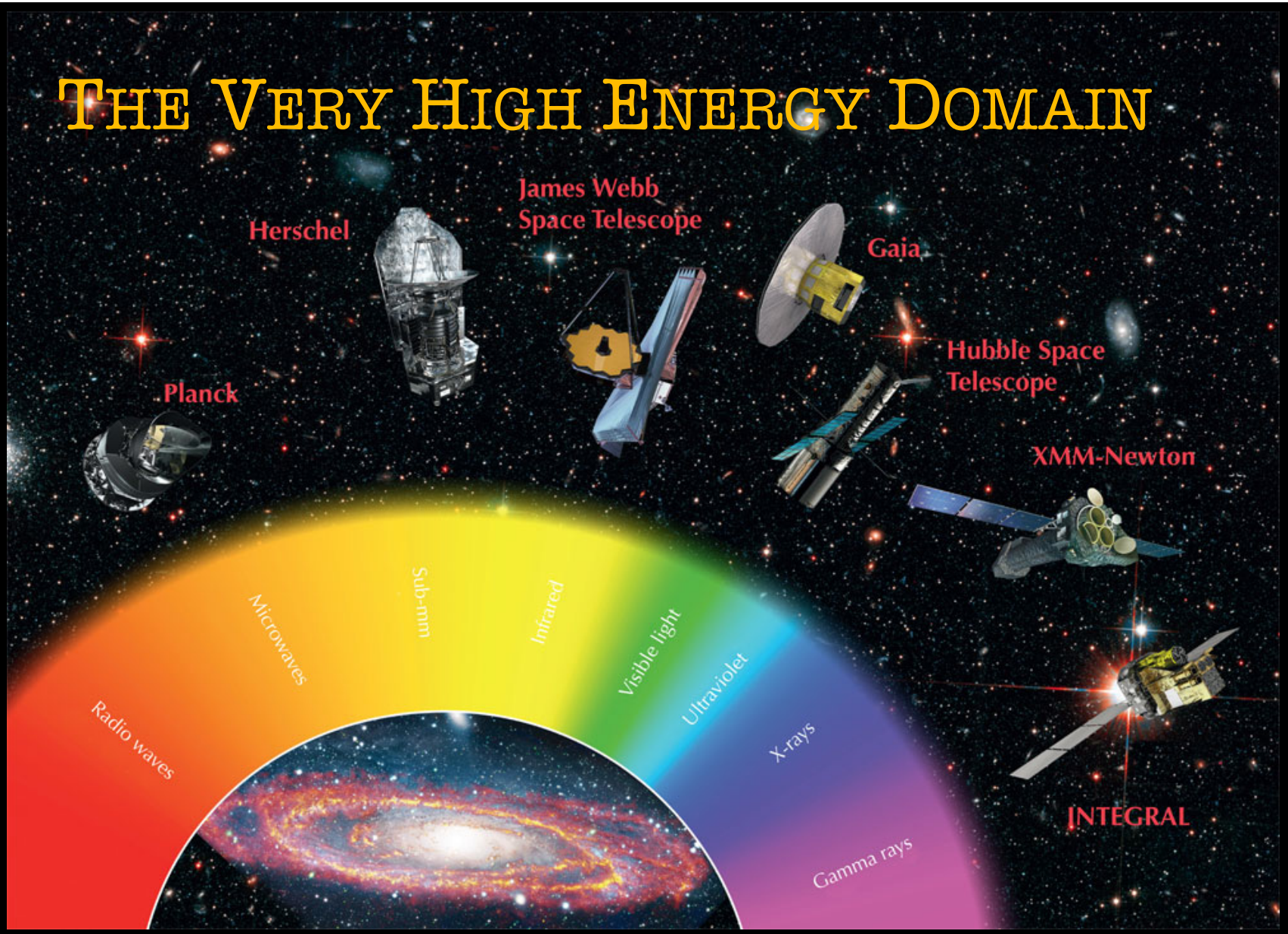
ELISA PRANDINI
PADOVA UNIVERSITY & I.N.F.N.

THE OTHER SIDE OF THE COIN:
THE CIB AS SEEN BY VHE GAMMA-RAY BLAZARS

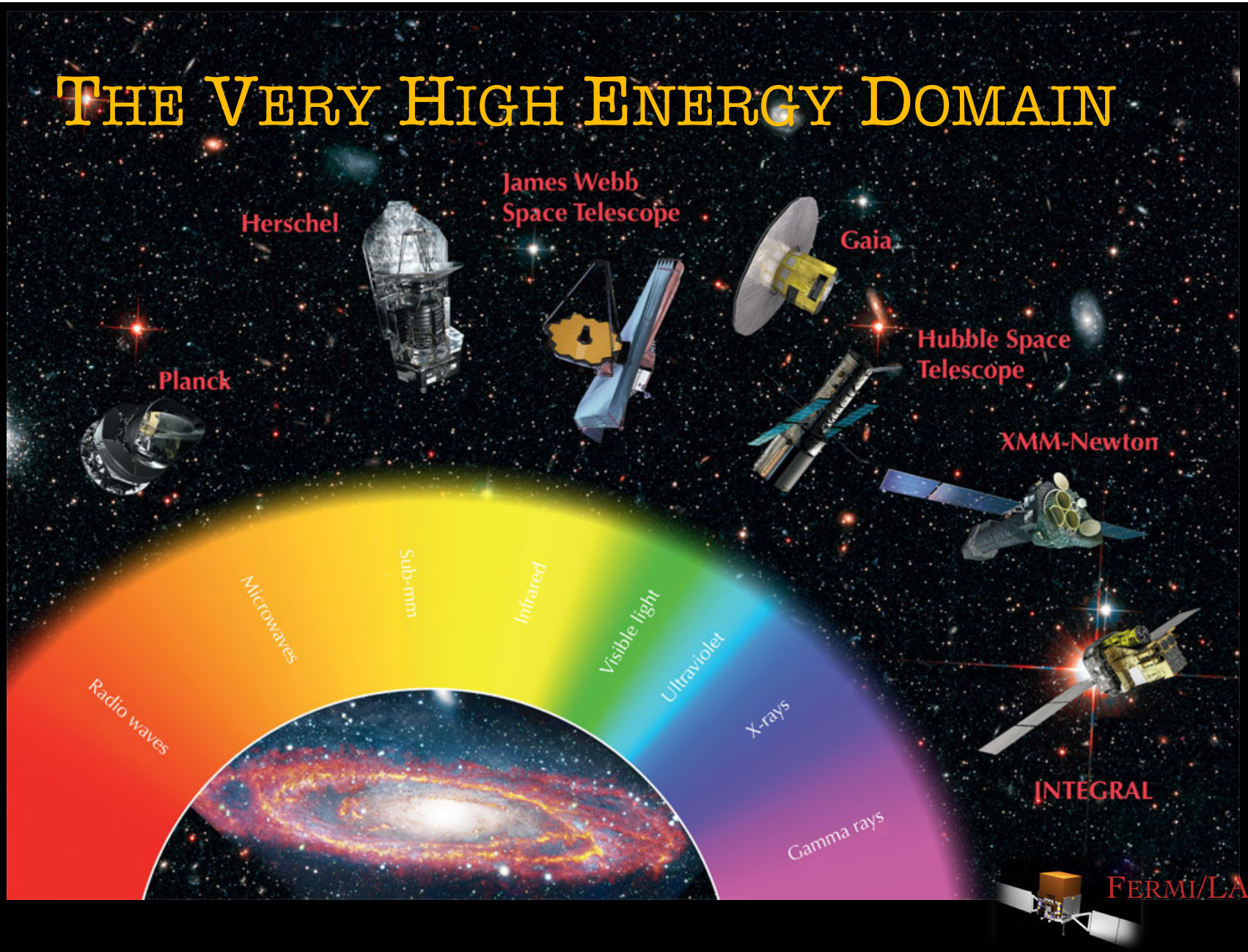
Outlook

- The very high energy gamma-ray sky
- Energetic emission from Blazars
- Interaction with the extragalactic background light
- Models
- Some Results
- Conclusions

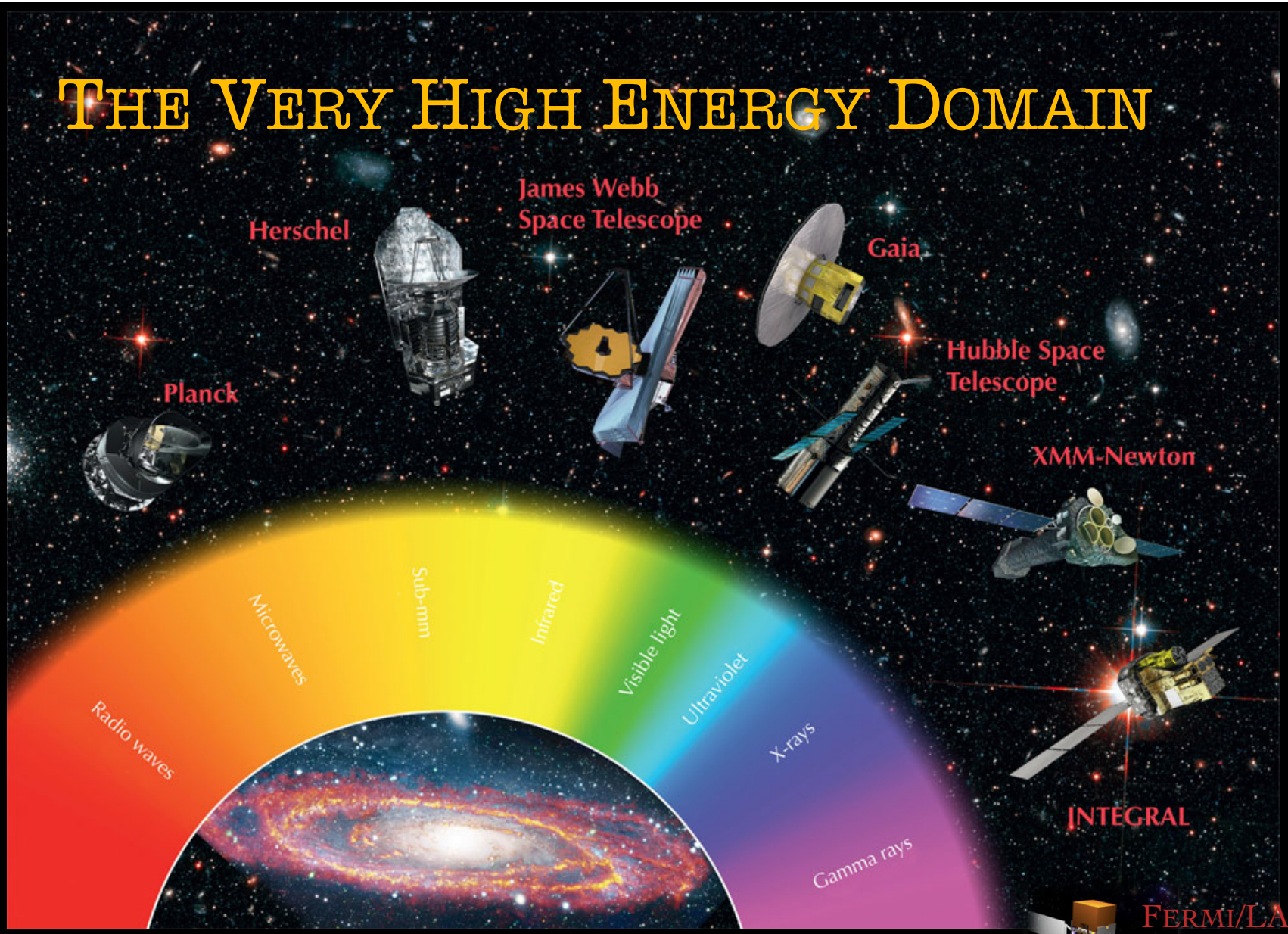



THE VERY HIGH ENERGY DOMAIN
James Webb
Space Telescope
Herschel
Gaia
Hubble Space
Telescope
Planck
XMM-Newton
Radio waves
Microwaves
Sub-mm
Infrared
Visible light
Ultraviolet
X-rays
Gamma rays
INTEGRAL

The Very High Energy Domain



The Very High Energy Domain



The Very High Energy Domain

- VHE: stands for 100 GeV < E < 30 TeV
  - This is the typical energy range of a IACT Telescope (MAGIC, HESS, VERITAS)
  - This energetic window was opened in 1989 by Whipple

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1989ApJ...342..379W

THE ASTROPHYSICAL JOURNAL, 342:379–395, 1989 July 1

OBSERVATION OF TeV GAMMA RAYS FROM THE CRAB NEBULA USING THE ATMOSPHERIC CERENKOV IMAGING TECHNIQUE

T. C. WEEKES,[1] M. F. CAWLEY,[2] D. J. FEGAN,[3] K. G. GIBBS,[1] A. M. HILLAS,[4] P. W. KWOK,[1] R. C. LAMB,[5] D. A. LEWIS,[5] D. MACOMB,[5] N. A. PORTER,[3] P. T. REYNOLDS,[1,3] AND G. VACANTI[5]

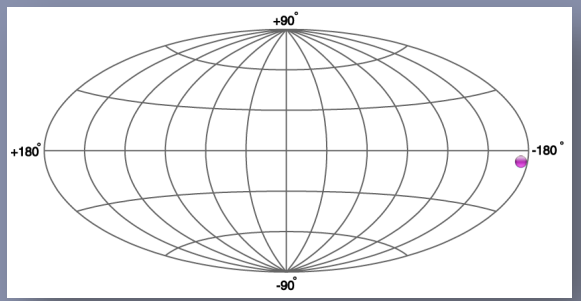
Received 1988 August 1; accepted 1988 December 9

ABSTRACT

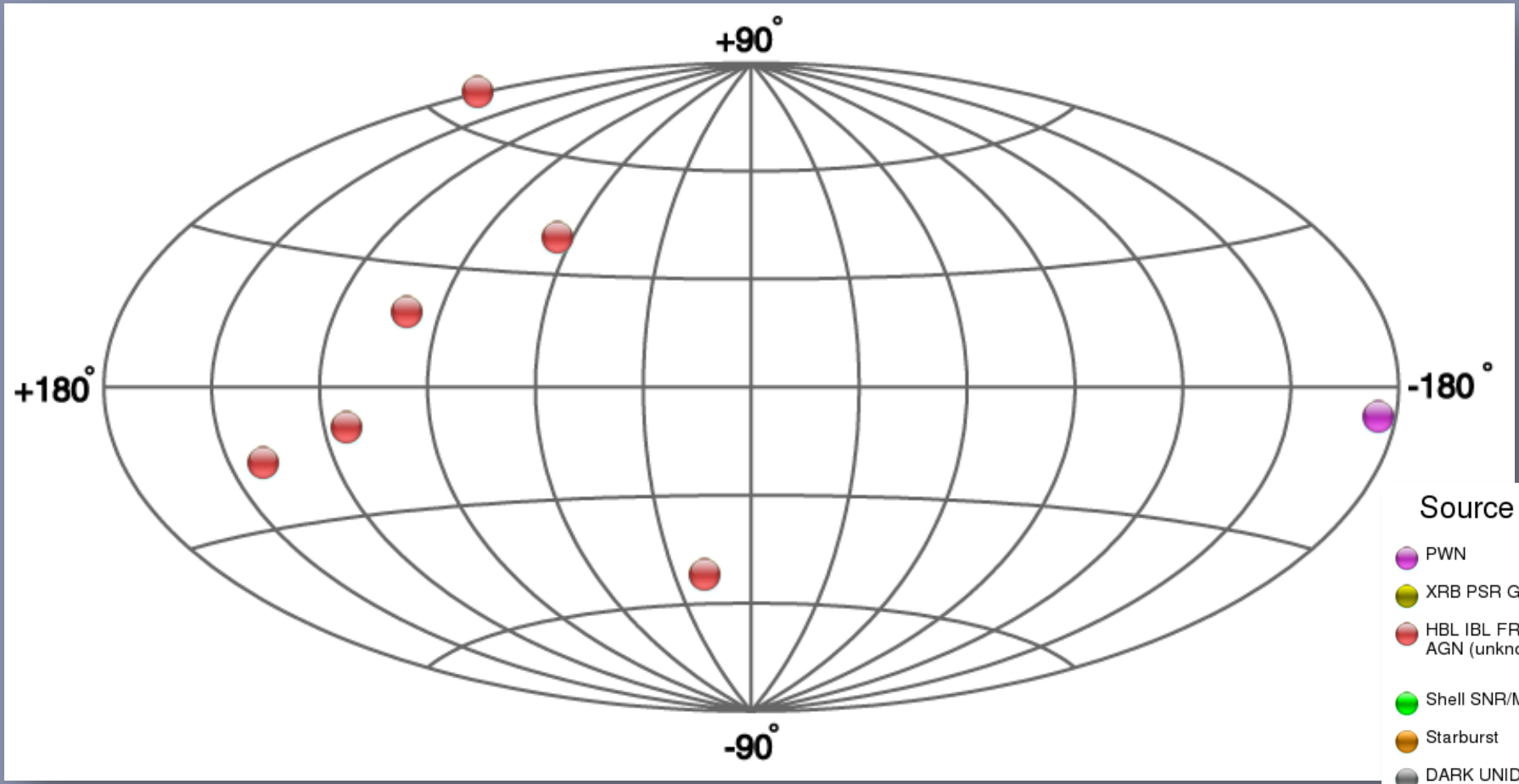
The Whipple Observatory 10 m reflector, operating as a 37 pixel camera, has been used to observe the Crab Nebula in TeV gamma rays. By selecting gamma-ray images based on their predicted properties, more than 98% of the background is rejected; a detection is reported at the 9.0 σ level, corresponding to a flux of 1.8×10^{-11} photons cm^2 s^{-1} above 0.7 TeV (with a factor of 1.5 uncertainty in both flux and energy). Less than 25% of the observed flux is pulsed at the period of PSR 0531. There is no evidence for variability on time scales from months to years. Although continuum emission from the pulsar cannot be ruled out, it seems more likely that the observed flux comes from the hard Compton synchrotron spectrum of the nebula.

Subject headings: gamma rays: general — nebulae: Crab Nebula — pulsars — radiation mechanisms

Discovery of a significant flux of TeV gamma-rays from the **Crab Nebula**

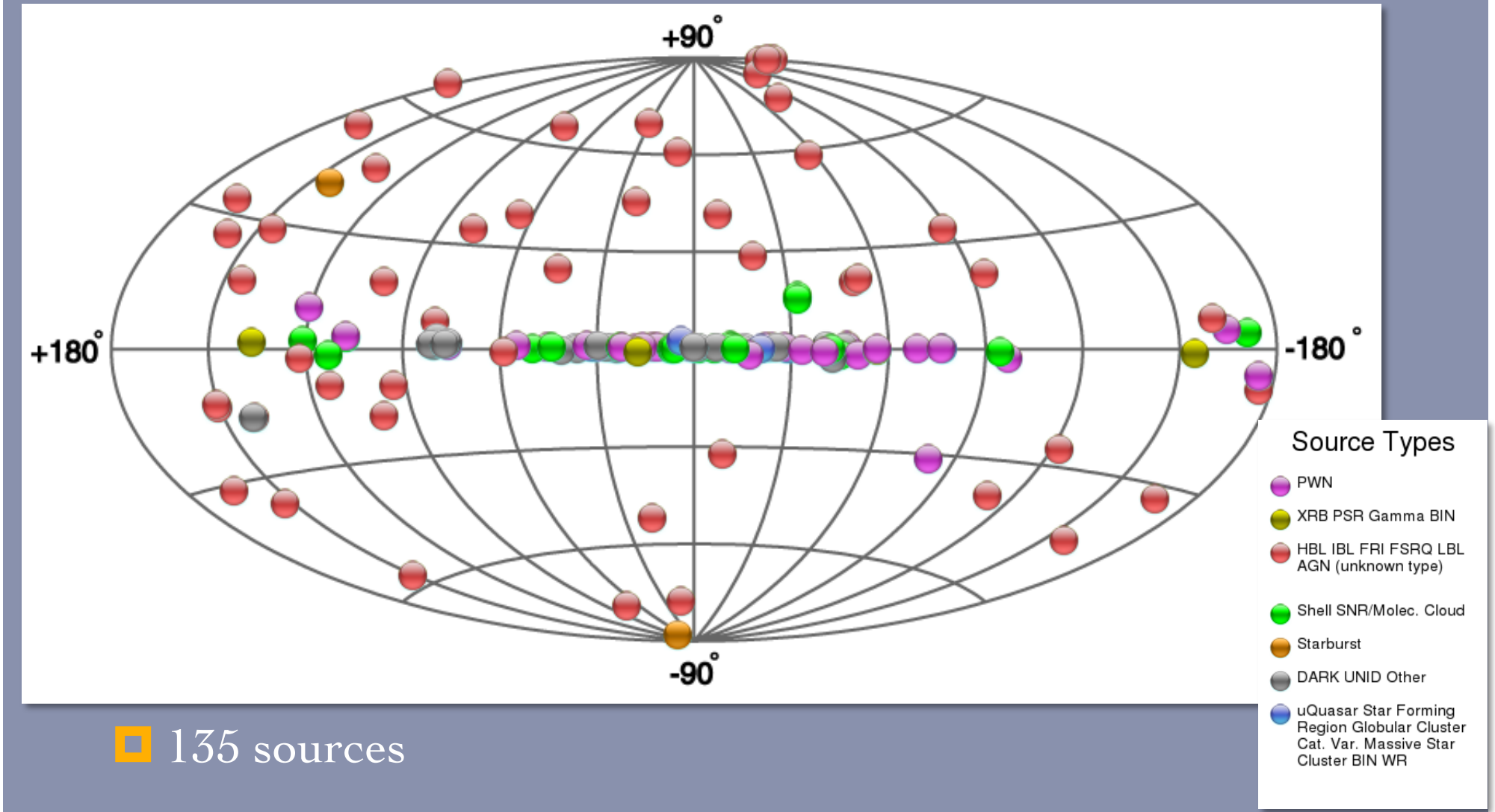


10 years later: 1999



- 6 new sources detected (extragalactic)

Now: the VHE sky in February 2012

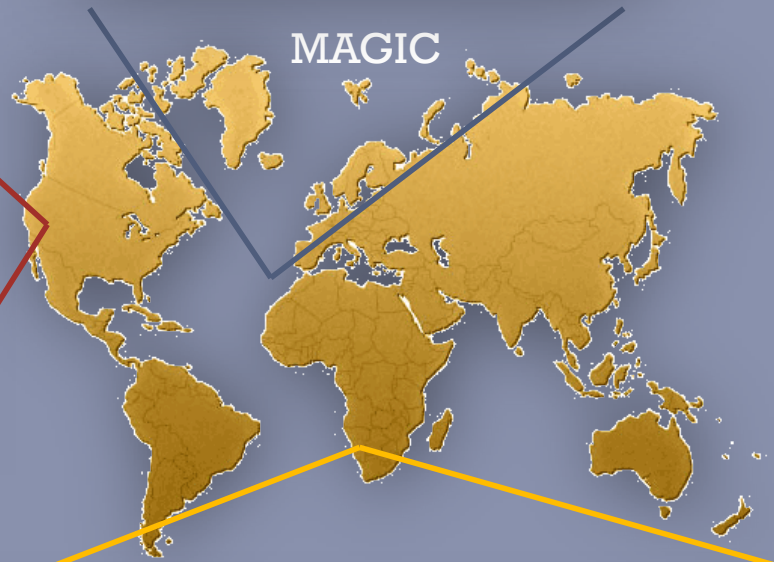


- 135 sources

Main IACT Observatories in the world

MAGIC

VERITAS



H.E.S.S.

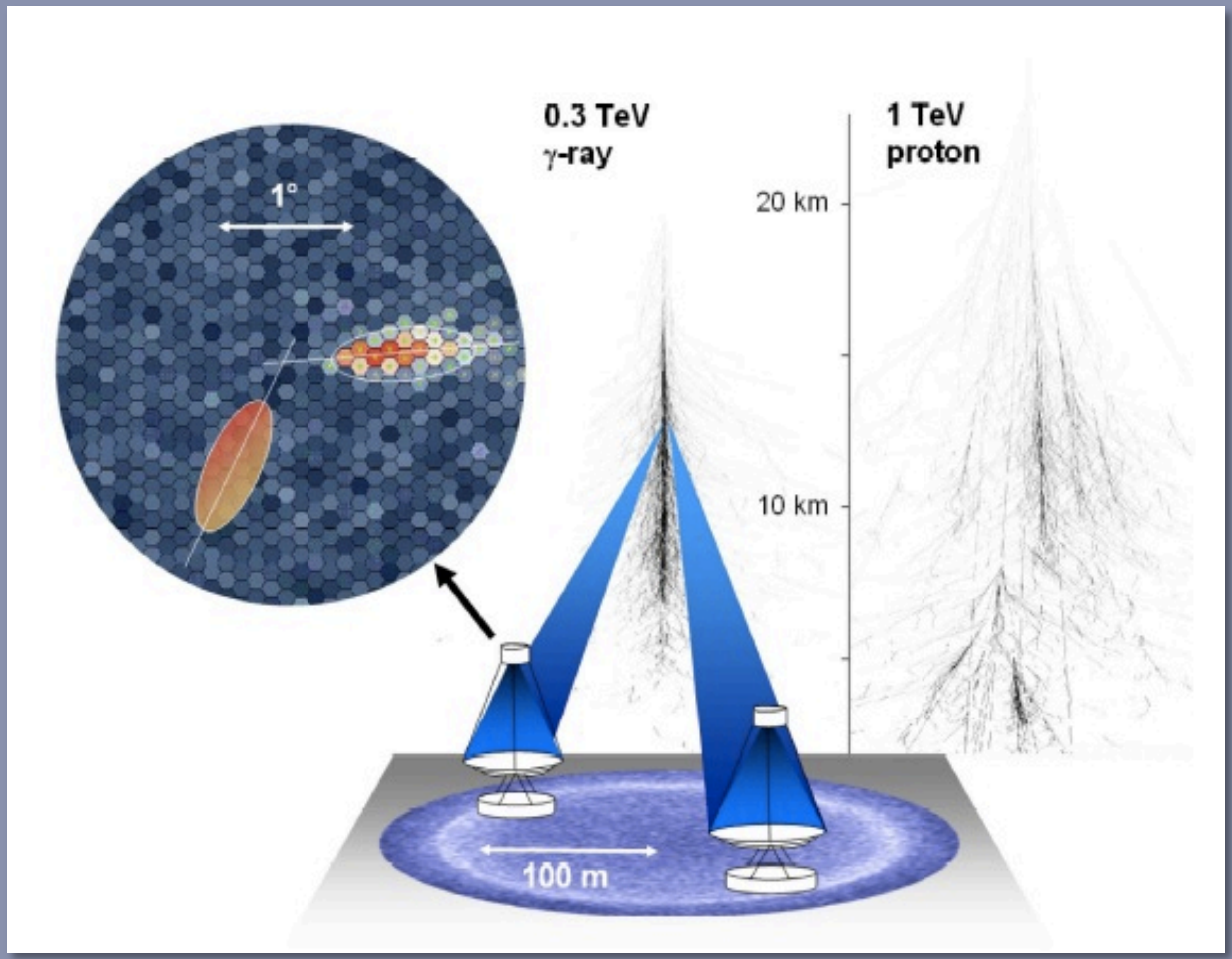
Detection Technique: IACT

Imaging

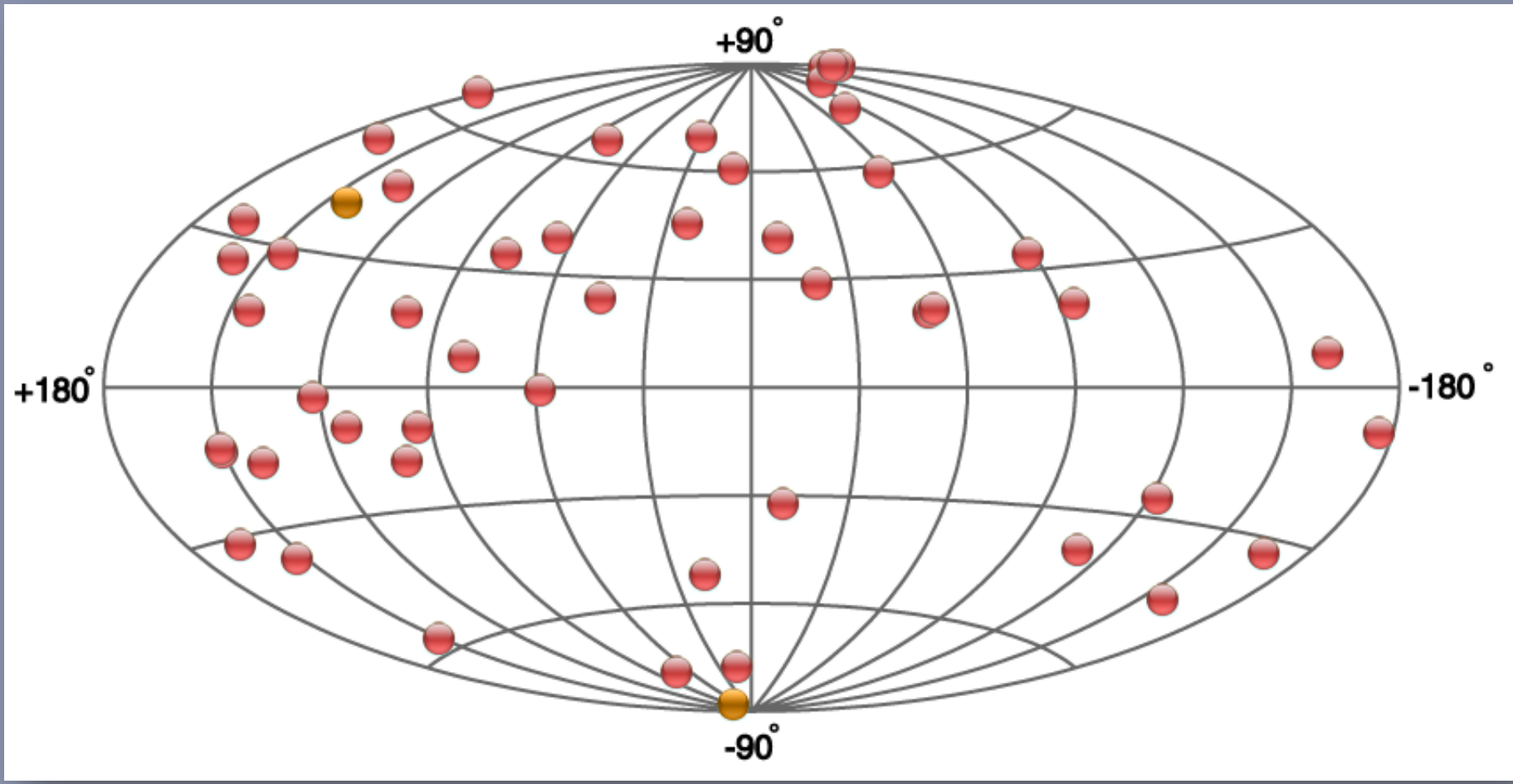
Atmospheric

Cherenkov

Technique



Extragalactic Sources



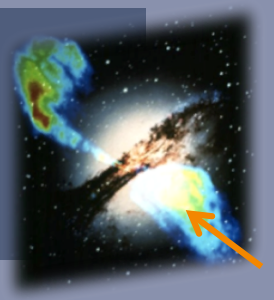
51 OBJECTS: 2 starbursts, 3 radio-galaxies, 46 blazars

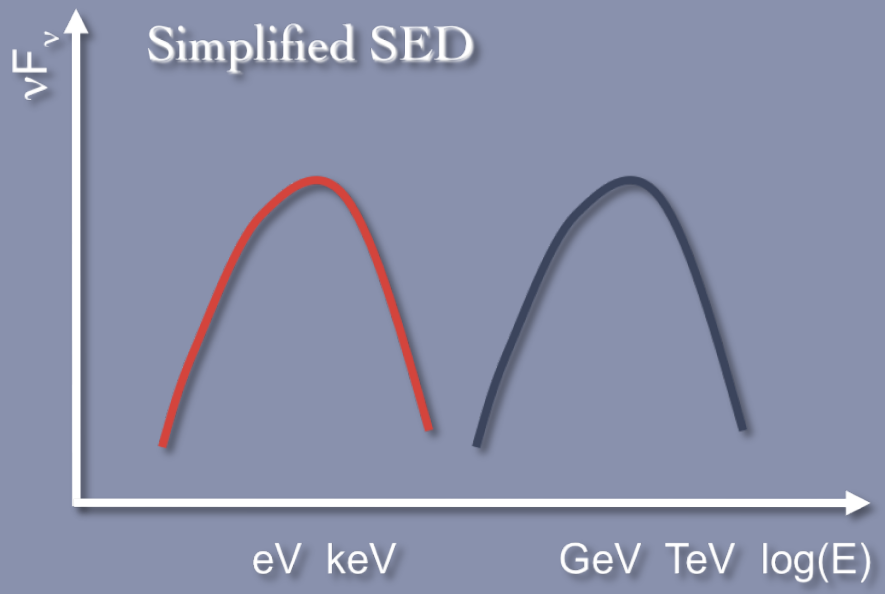
NAMES & NUMBERS

NAME	TYPE	DISTANCE	NAME	TYPE	DISTANCE
MAGIC J2001+435	HBL	unknown	1ES 1312-423	HBL	0.105
PKS1424+240	IBL	unknown	PKS 2155-304	HBL	0.116
VER J0521+211	AGN	unknown	B3 2247+381	HBL	0.119
HESS J1943+213	HBL	unknown	RGB J0710+591	HBL	0.125
1ES 0033+595	HBL	unknown	H 1426+428	HBL	0.129
1ES 1440+122	IBL	unknown	1ES 1215+303	LBL	0.130
NGC 253	**Starburst**	2500 kpc	1ES 0806+524	HBL	0.138
M82	**Starburst**	3900 kpc	1ES 0229+200	HBL	0.140
Centaurus A	**FRI**	0.002	1RXS J101015.9-311909	HBL	0.143
M87	**FRI**	0.004	H 2356-309	HBL	0.165
NGC 1275	**FRI**	0.018	RX J0648.7+1516	HBL	0.179
IC 310	AGN	0.019	1ES 1218+304	HBL	0.182
Markarian 421	HBL	0.031	1ES 1101-232	HBL	0.186
Markarian 501	HBL	0.034	1ES 0347-121	HBL	0.188
1ES 2344+514	HBL	0.044	RBS 413	HBL	0.190
Markarian 180	HBL	0.045	PKS 0447-439	HBL	0.200
1ES 1959+650	HBL	0.048	1ES 1011+496	HBL	0.212
AP Lib	LBL	0.049	1ES 0414+009	HBL	0.287
1ES 1727+502	HBL	0.055	S5 0716+714	LBL	0.310
PKS 0548-322	HBL	0.069	1ES 0502+675	HBL	0.341
BL Lacertae	LBL	0.069	PKS 1510-089	FSRQ	0.360
PKS 2005-489	HBL	0.071	4C 21.35	FSRQ	0.432
RGB J0152+017	HBL	0.080	3C66A	IBL	0.444
1ES 1741+196	HBL	0.083	PG 1553+113	HBL	0.500
SHBL J001355.9-185406	HBL	0.095	3C279	FSRQ	0.536
W Comae	IBL	0.102			

from TeVCat:
http://tevcat.uchicago.edu/

Blazars SED



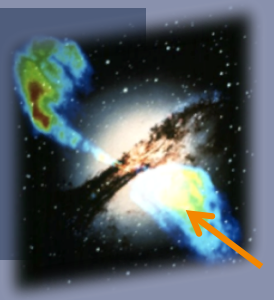


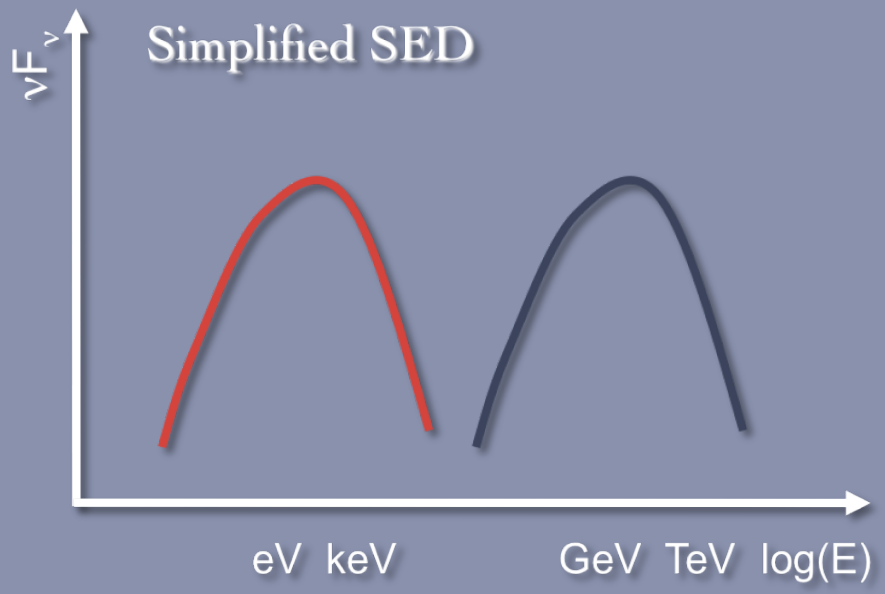
SYNCHROTRON EMISSION

HIGH ENERGY EMISSION

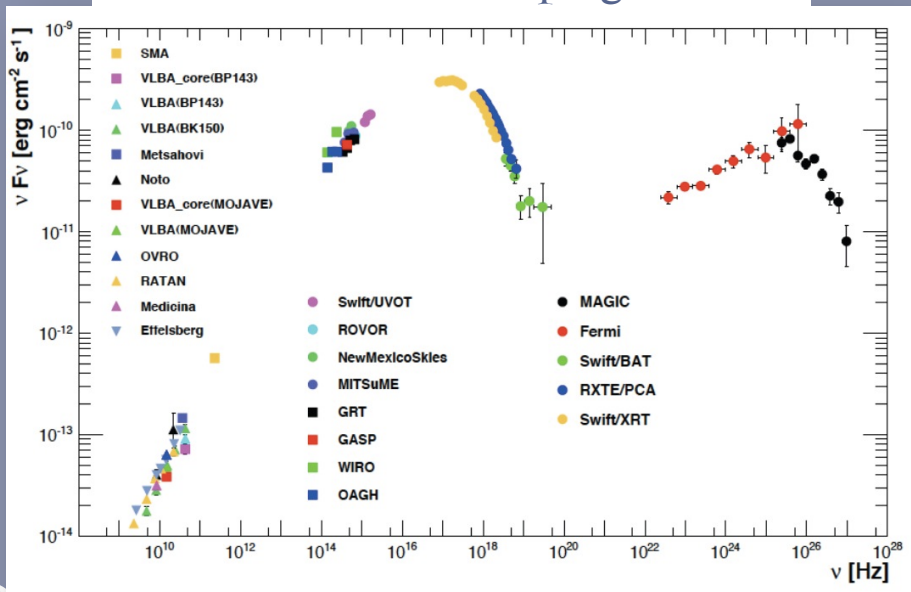
- Leptonic models (Inverse Compton)
- Hadronic models (π^0 decay)

Blazars SED





Mkn 421 MWL campaign 2009



[Fermi/LAT + MAGIC + mwl partners, 2011]

SYNCHROTRON EMISSION

HIGH ENERGY EMISSION

Leptonic models (Inverse Compton)

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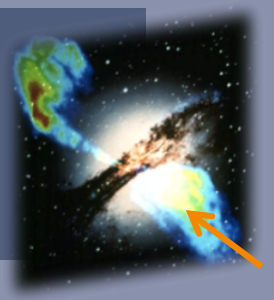
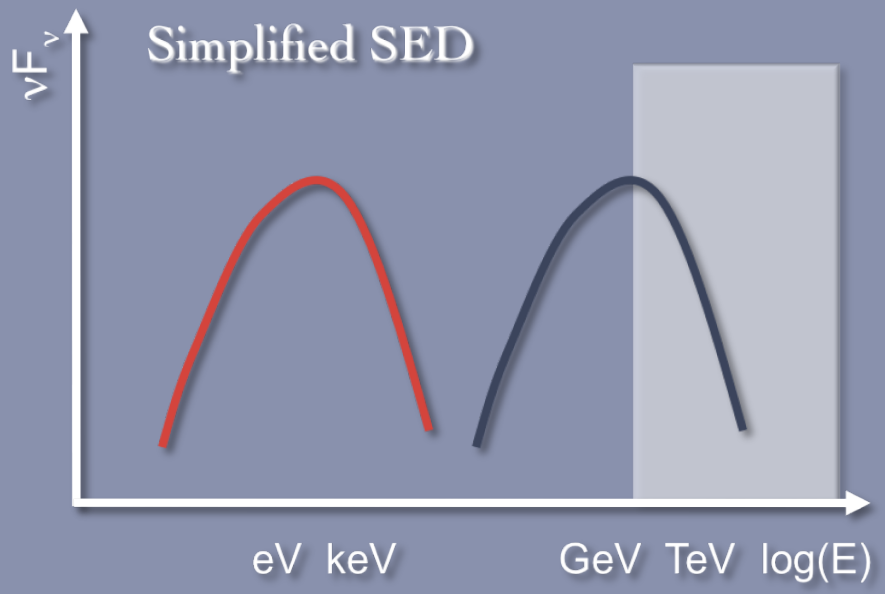
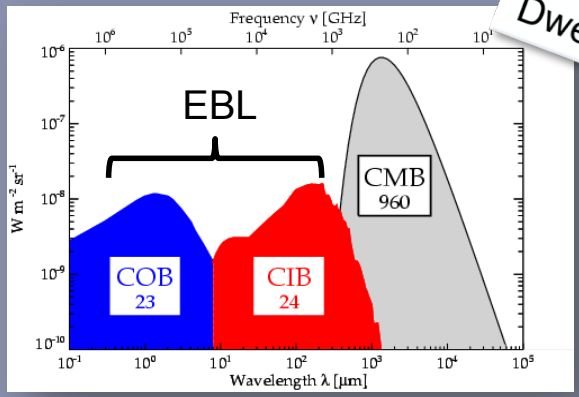
Blazars SED





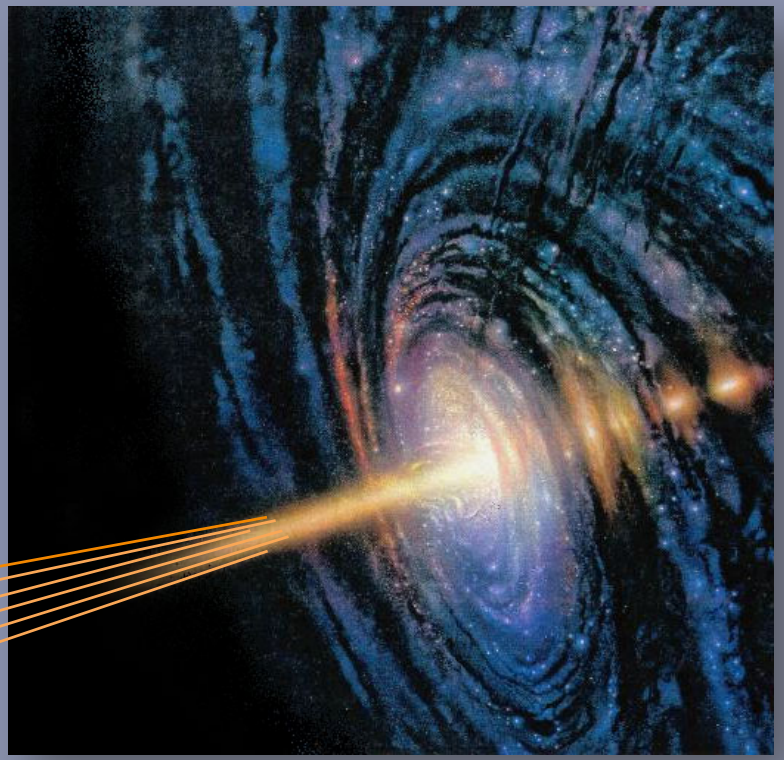
VHE gamma rays from blazars are related to CIB... why?

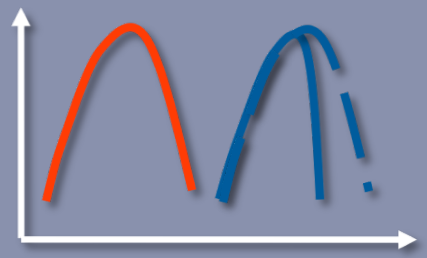
Above some tens of GeV, gamma rays interact with the optical and IR light (EBL) filling the Universe



Hauser & Dwek (2001)

VHE photons absorption by the Extragalactic Background Light





VHE photon + diffuse light

electron-positron pairs production

$\gamma_{VHE}\gamma_{EBL} \rightarrow e^{+}e^{-}$

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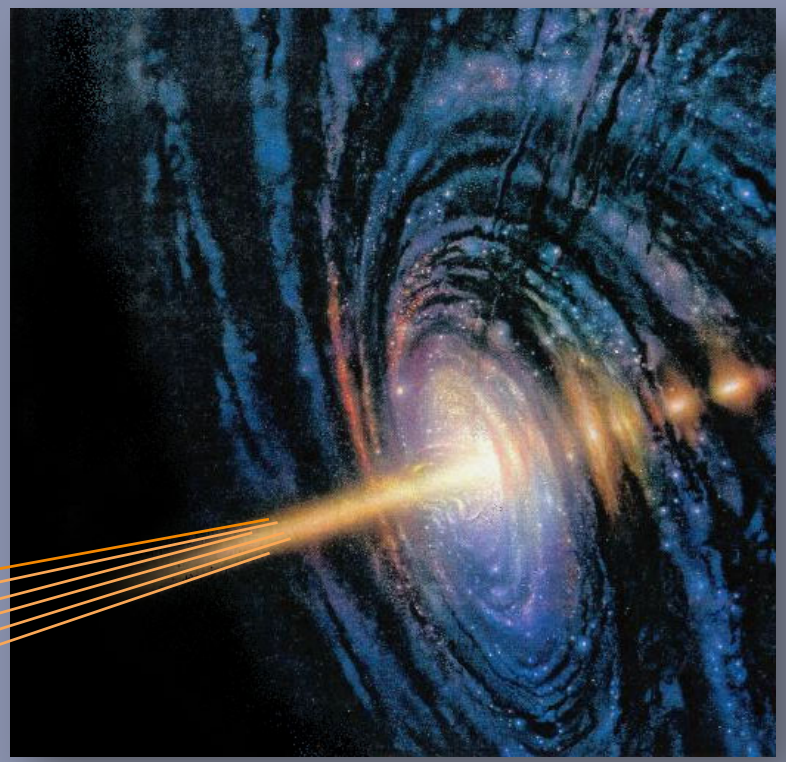
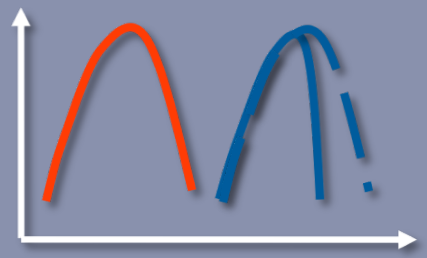




VHE photon + diffuse light

electron-positron pairs production

$\gamma_{VHE}\gamma_{EBL} \rightarrow e^+e^-$

Absorption:

$dF/dE_{OBS} = (dF/dE_{EM})\ e^{-\tau}$

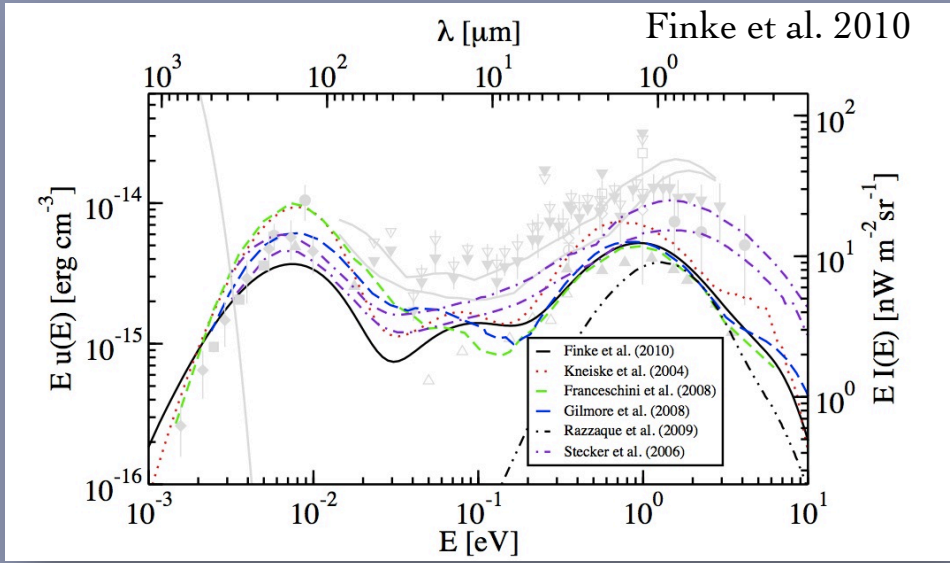
VHE GAMMA RAYS ARE PARTIALLY-TOTALLY ABSORBED, DEPENDING ON THEIR **ENERGY** AND **DISTANCE:**

$\tau(E, z)$

EBL Models

Absorption:
$dF/dE_{OBS} = (dF/dE_{EM})\ e^{-\tau}$

- We need an EBL model to estimate the INTRINSIC (de-absorbed) spectrum
- Include the IR AND OPTICAL BACKGROUNDS and their EVOLUTION
- Are quite close to galaxy counts
- Some models:
  - Franceschini et al. (2008)
  - Finke et al. (2010)
  - Kneiske & Dole (2010)



The absorption process

Absorption:
$dF/dE_{OBS} = (dF/dE_{EM})\ e^{-\tau}$

- Electron-positron pairs production:

$$\tau(E_\gamma, z_e) = c \int_0^{z_e} dz \frac{dt}{dz} \int_0^2 dx \frac{x}{2} \int_{\frac{2m_e^2c^4}{E_\gamma \epsilon x(1+z)}}^{\infty} d\epsilon \frac{dn_\gamma(\epsilon, z^*)}{d\epsilon} \sigma_{\gamma\gamma}(\beta)$$

Franceschini et al. 2008

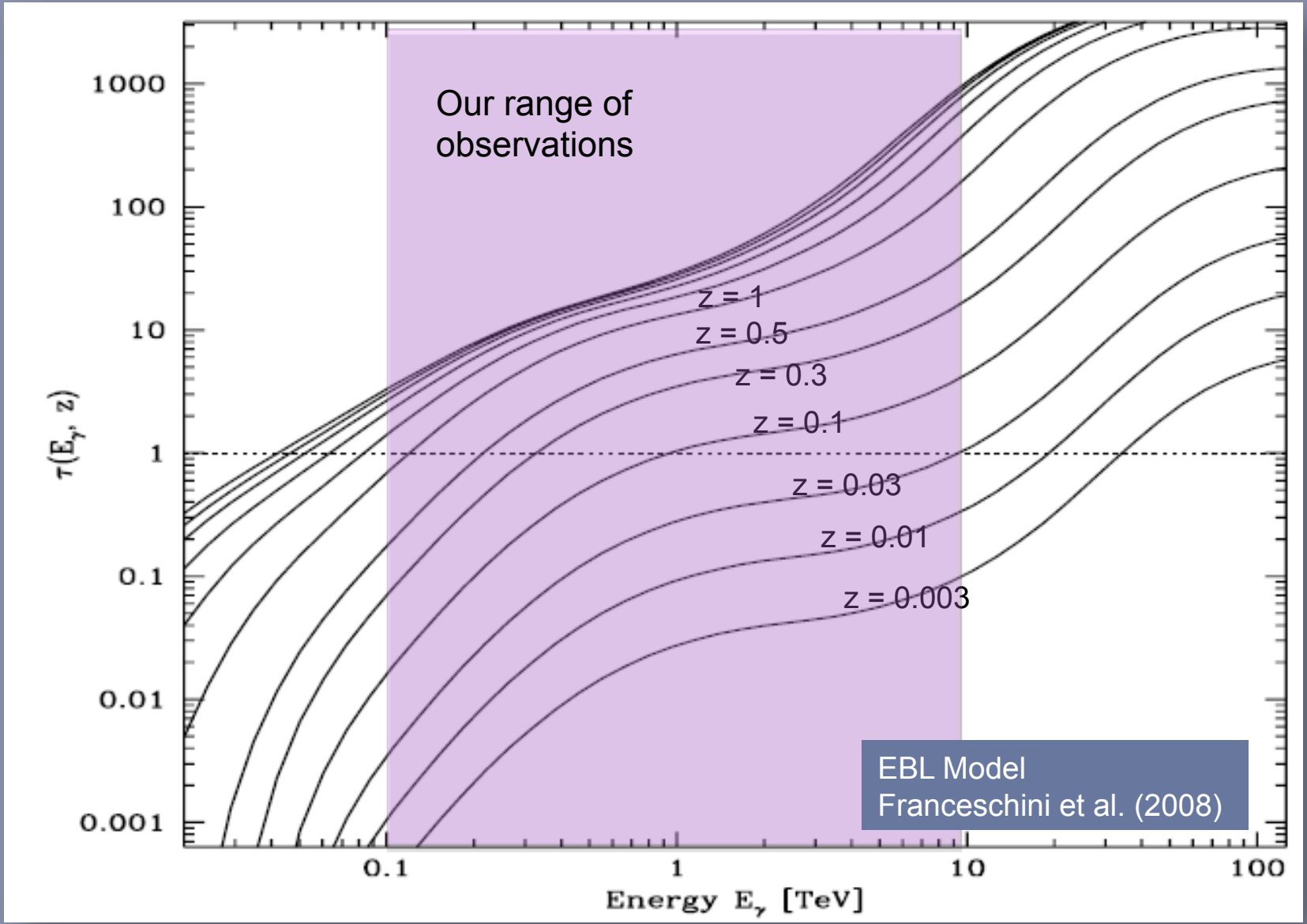
- Maximum absorption

$$\lambda_{max} \sim 1.24\ (E_\gamma\ [\mathrm{TeV}])\ \mu\mathrm{m}$$

E_γ	Energy Range
< 300 GeV	UV
300-600 GeV	Optical
0.6 – 2 TeV	Near-IR
~10 TeV	Far-IR
> 100 TeV	Microwaves

γ-γ opacity

Absorption:
$dF/dE_{OBS} = (dF/dE_{EM})\ e^{-\tau}$



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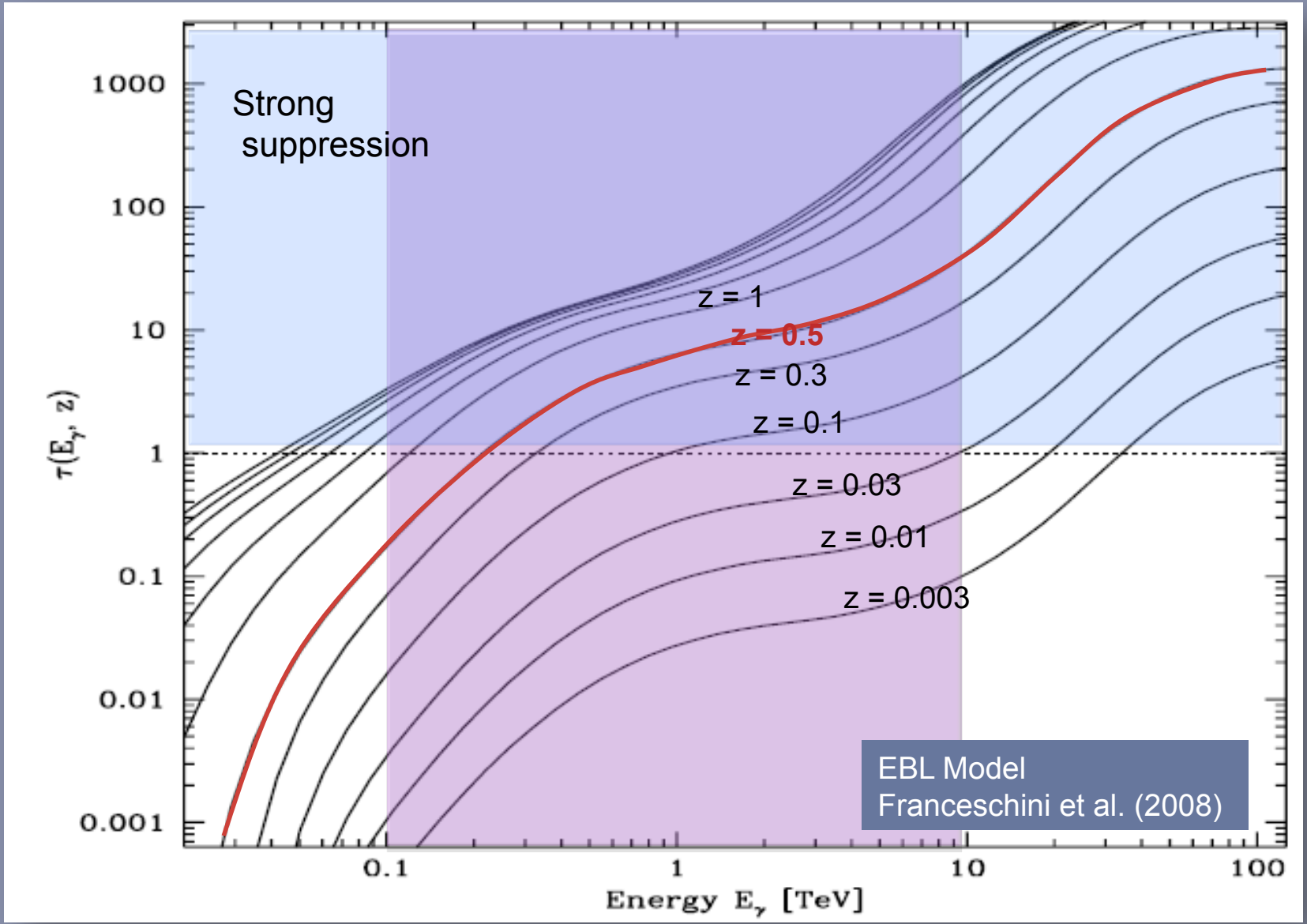
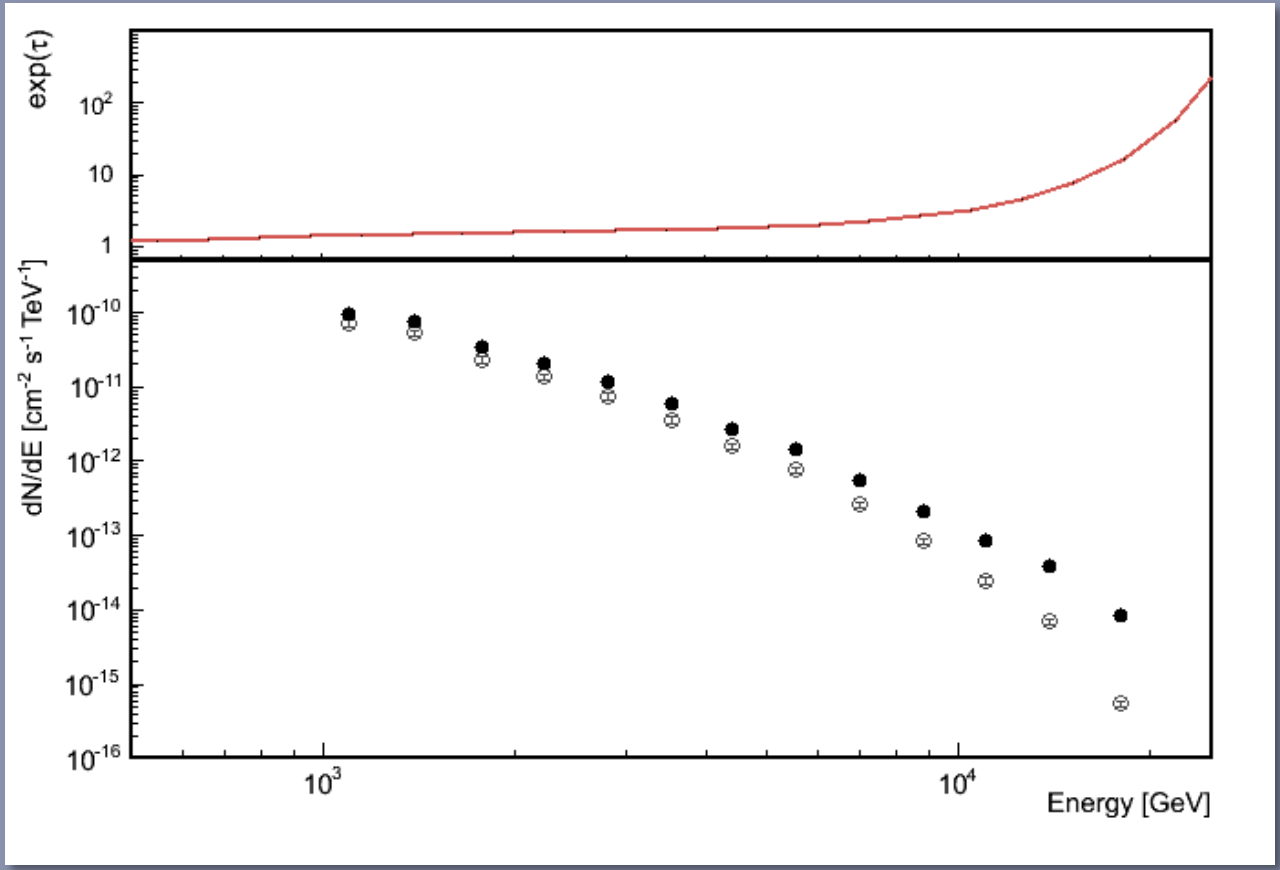


Example: absorption at low z

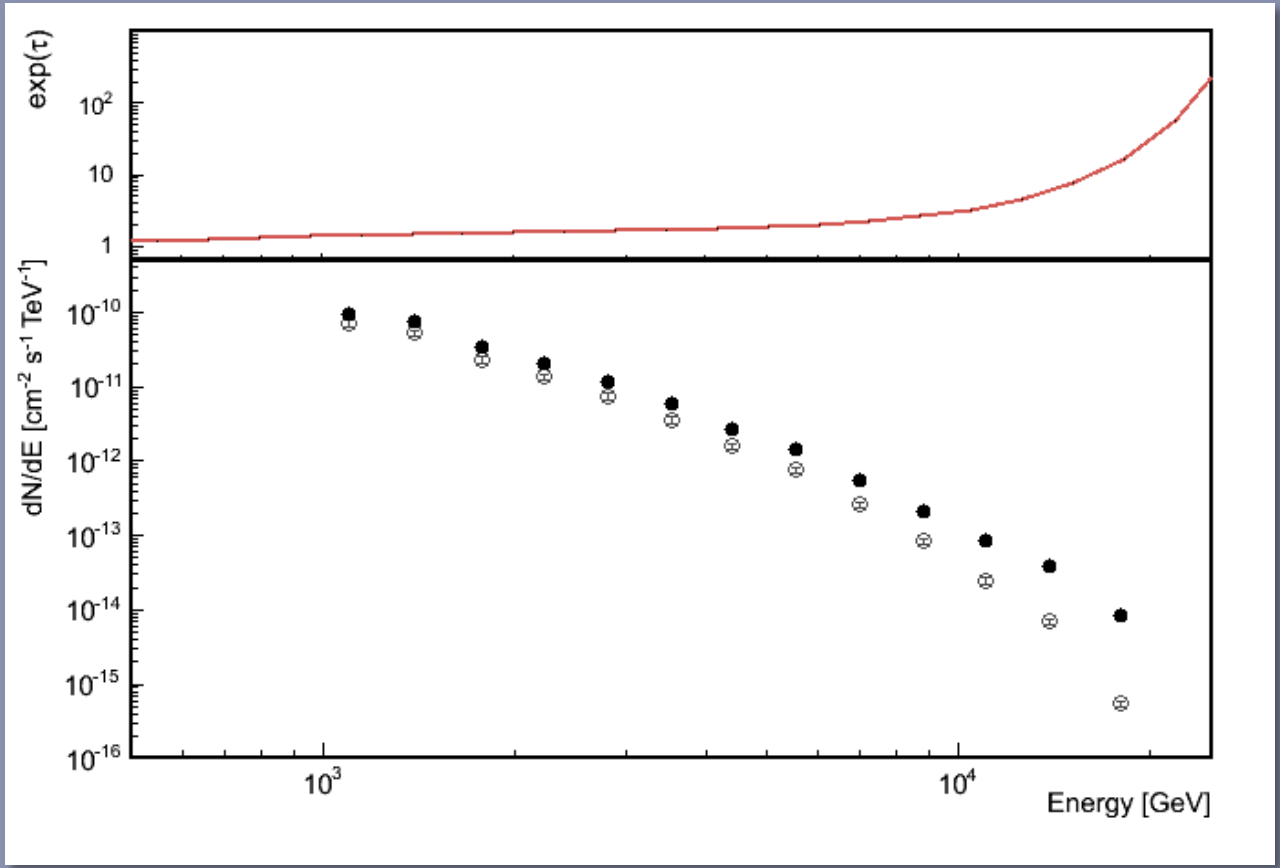


Mkn 421

HESS 2008

z = 0.03

Example: absorption at low z



Mkn 421

HESS 2008

z = 0.03

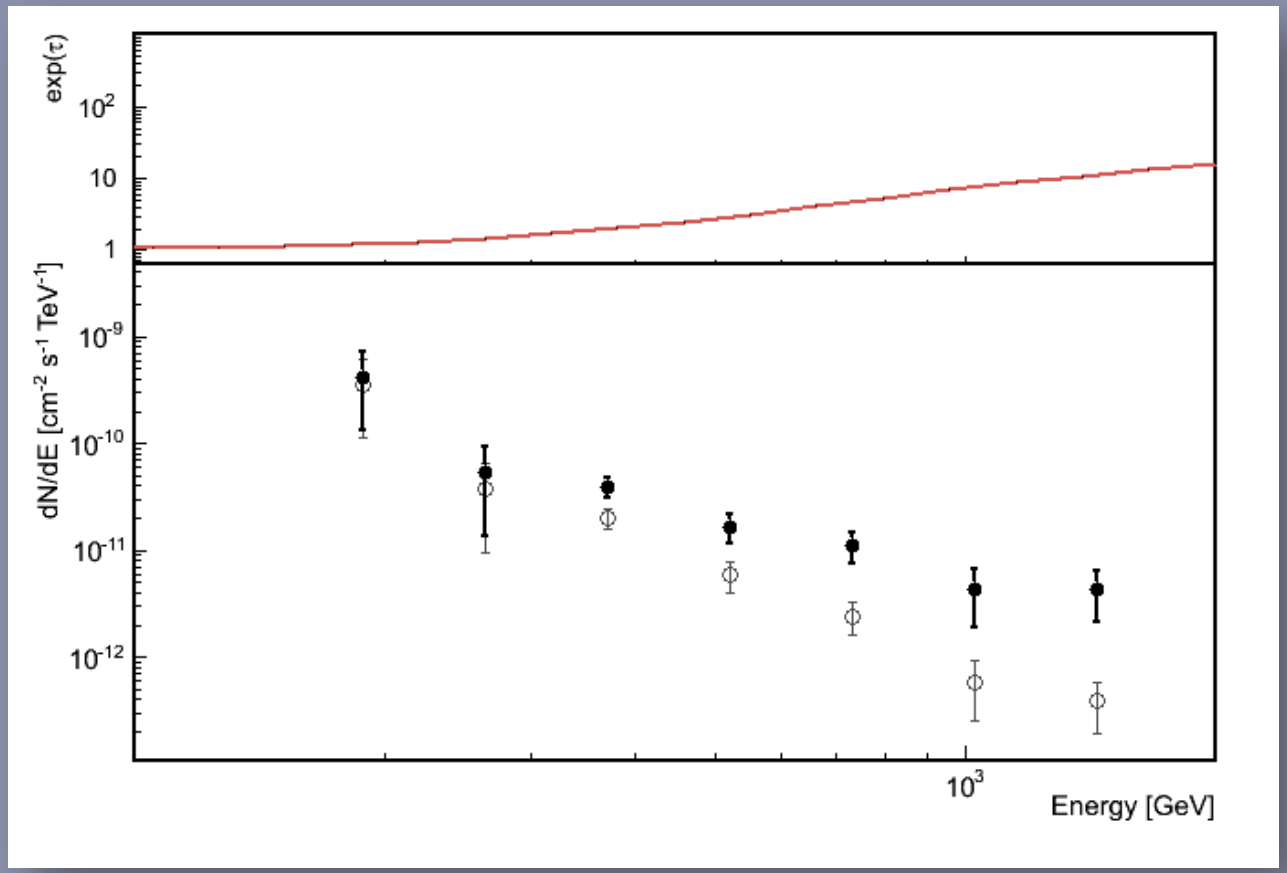
Absorption:

$dF/dE_{OBS} = (dF/dE_{EM})\ e^{-\tau}$

De-absorbed spectrum:

$dF/dE_{EM} = (dF/dE_{OBS})\ e^{\tau}$

Example: absorption at intermediate z

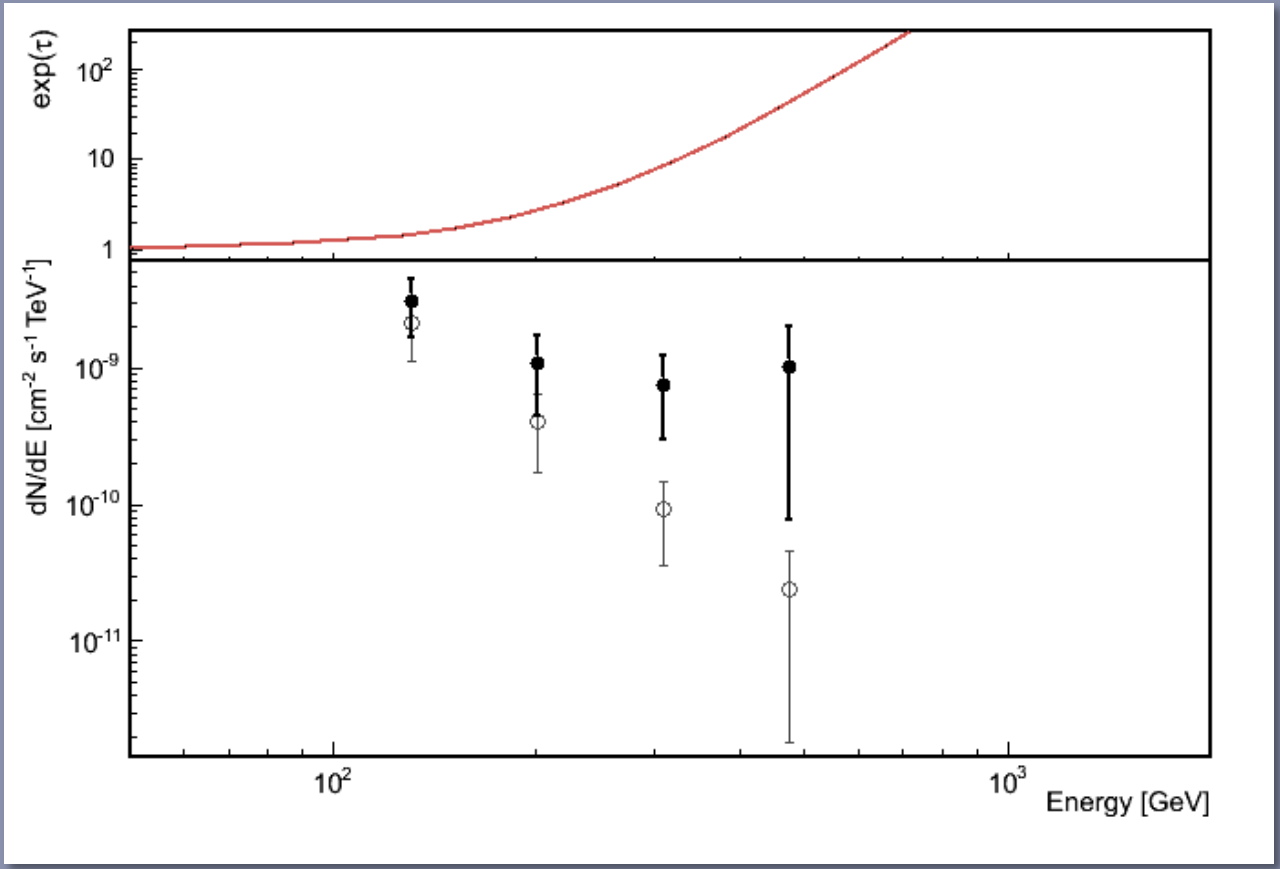


1ES 1218+304

z=0.182

VERITAS 2009

Example: absorption at "high" z

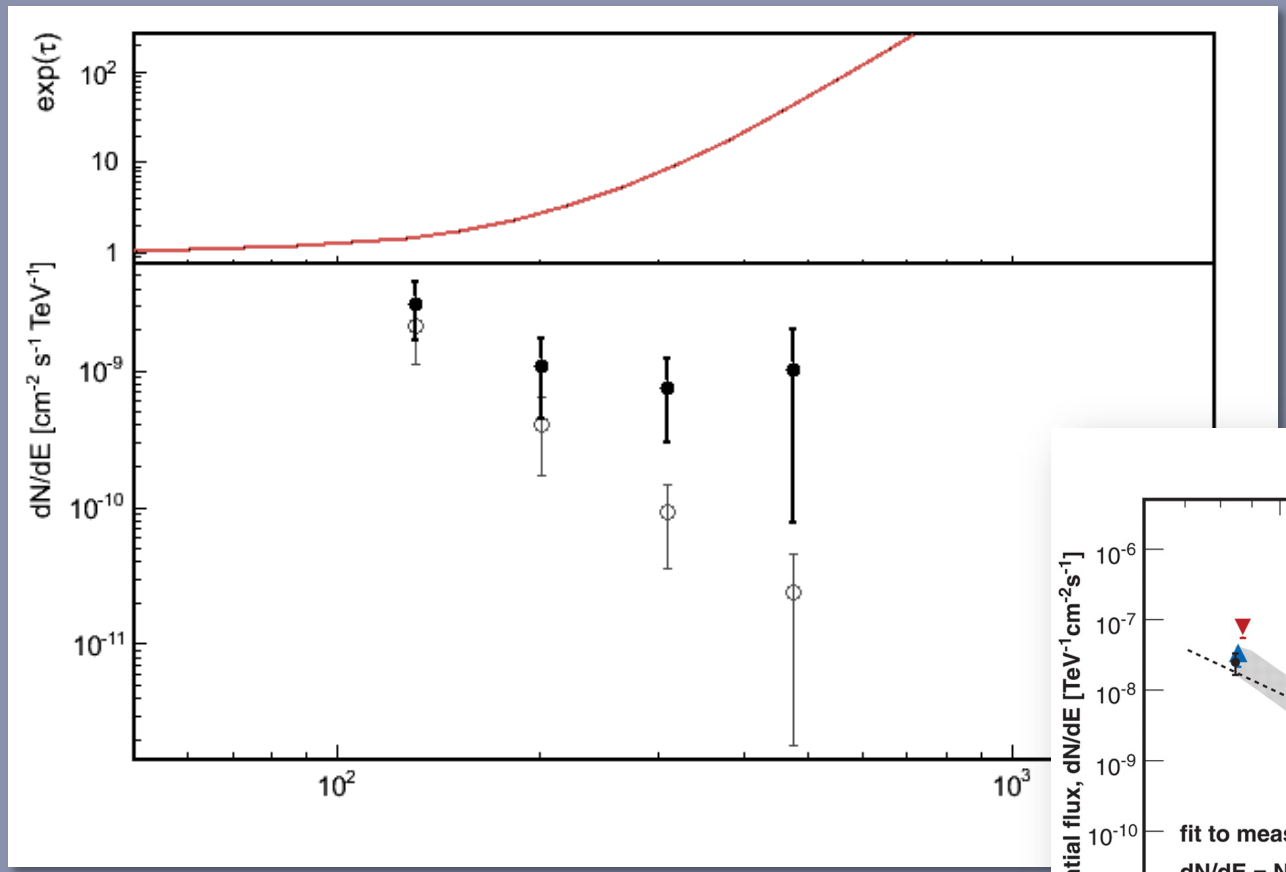


3C 279

z = 0.536

MAGIC 2008

Example: absorption at "high" z



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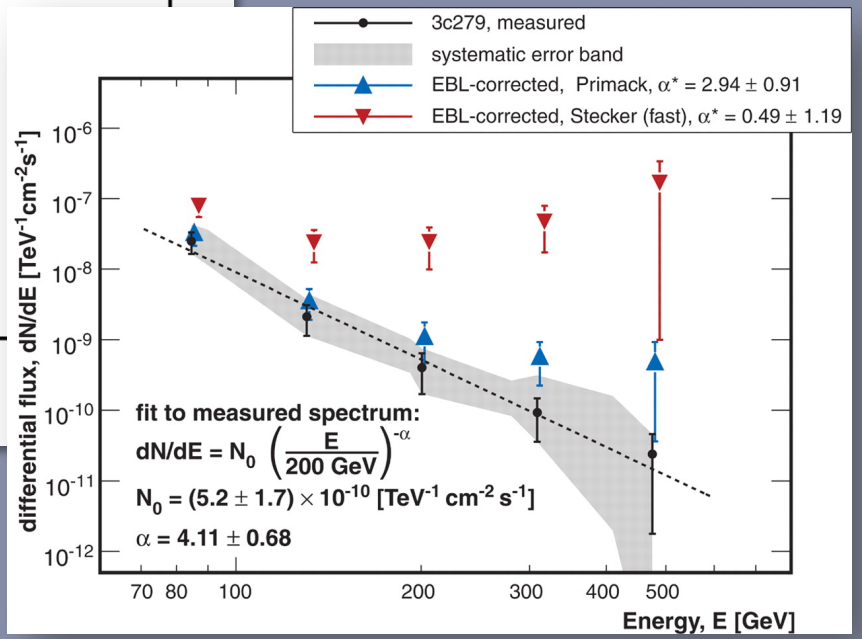
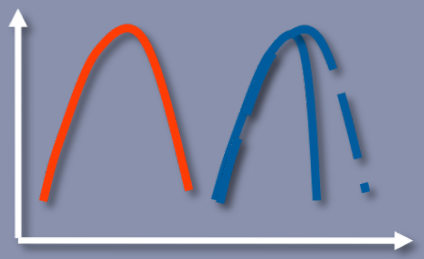
MAGIC 2008

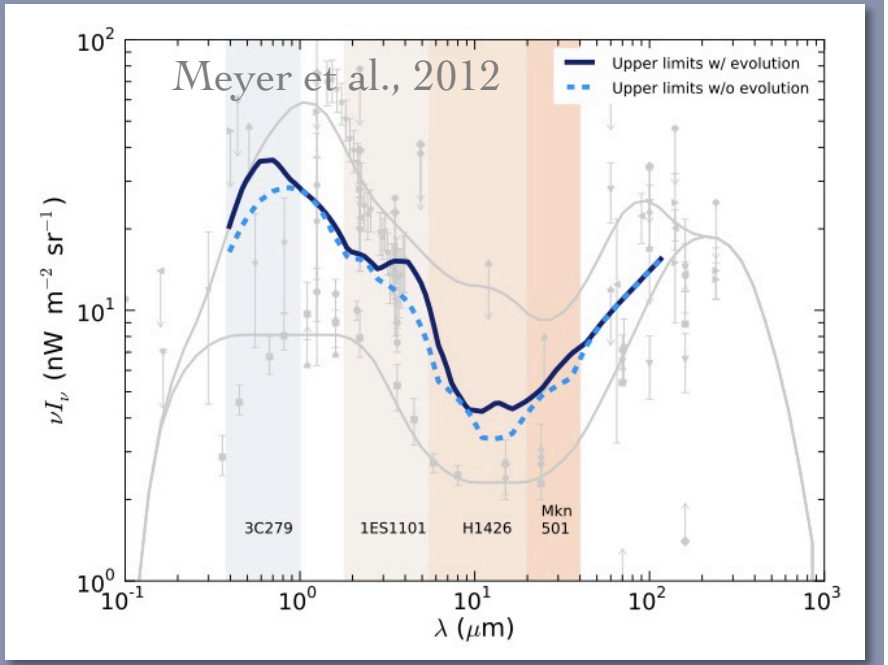


Potentiality

VHE GAMMA RAYS DATA +
HYPOTHESIS ON INTRINSIC SPECTRUM



- Set limits on EBL energy density (Aharonian et al. 2006; Mazin & Raue 2007, Meyer et al. 2012)



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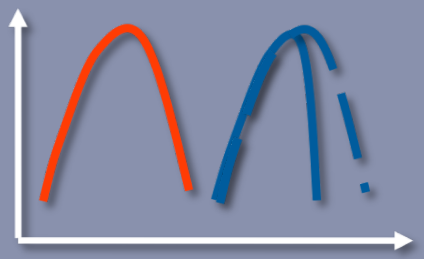
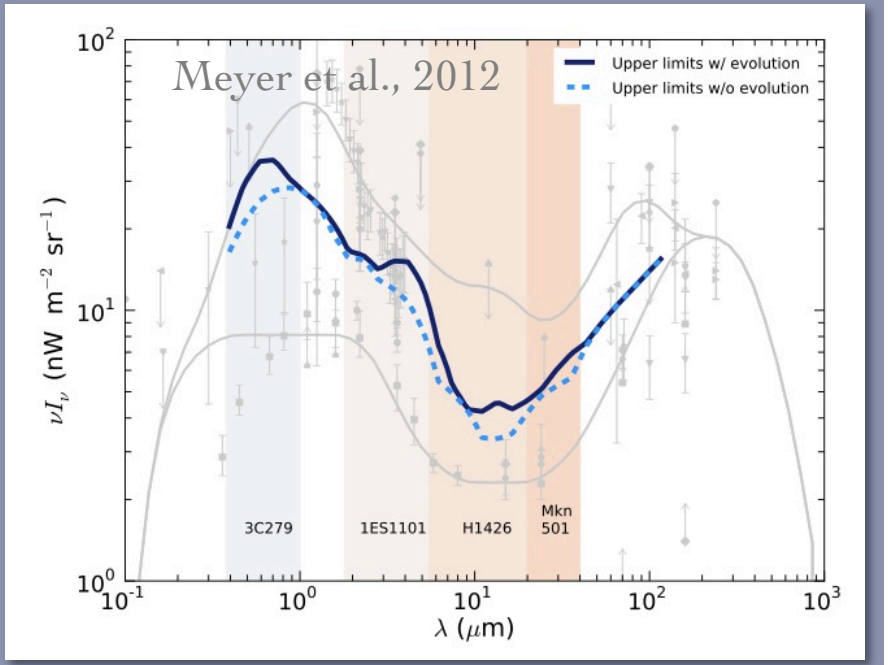


- Set limits on EBL energy density (Aharonian et al. 2006; Mazin & Raue 2007, Meyer et al. 2012)
- Can be used to estimate the blazar distance (Prandini et al. 2010, 2012)



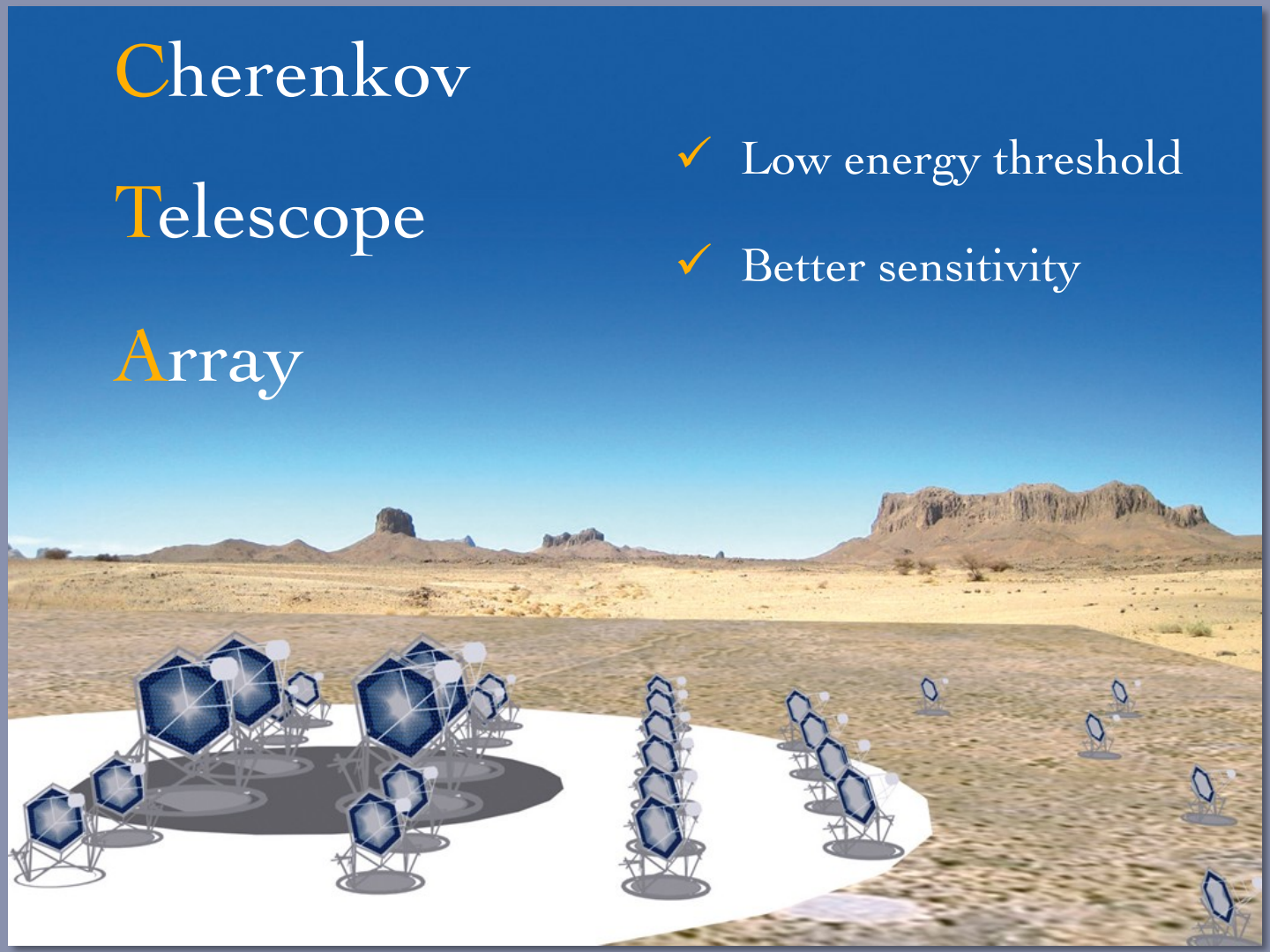
The future

Cherenkov

Telescope

Array

- ✓ Low energy threshold
- ✓ Better sensitivity



Conclusions

- Very high-energy gamma-ray emitters are observed with Cherenkov Telescopes
- The extragalactic sources seen at VHE (51) are in large majority NEARBY blazars
- There is a gamma-ray horizon, due to the interaction on VHE gamma-rays with IR and optical light
- Blazars can be used to test EBL models (while the absorption can be used to estimate their distance)
- This is only the beginning... CTA is coming!

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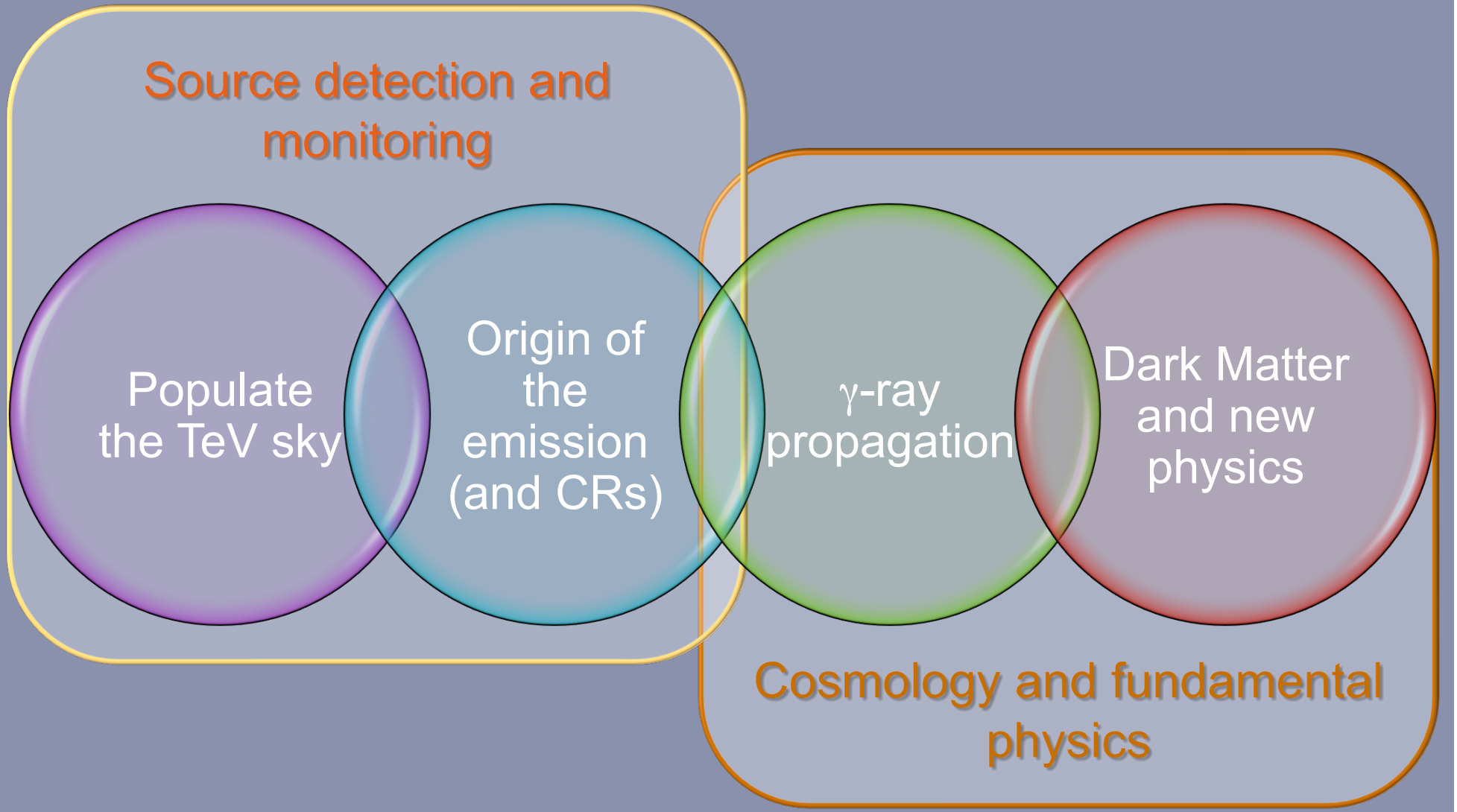
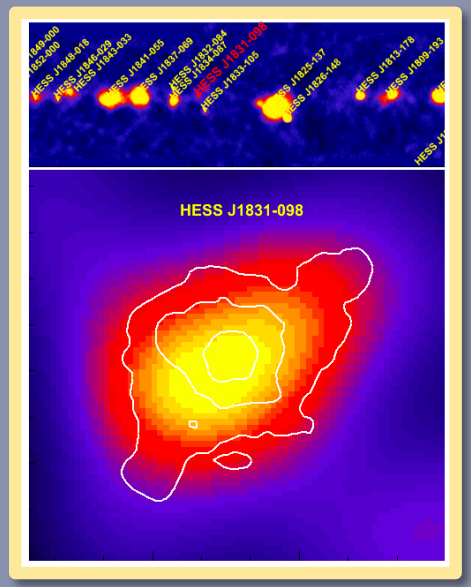
THANK YOU!

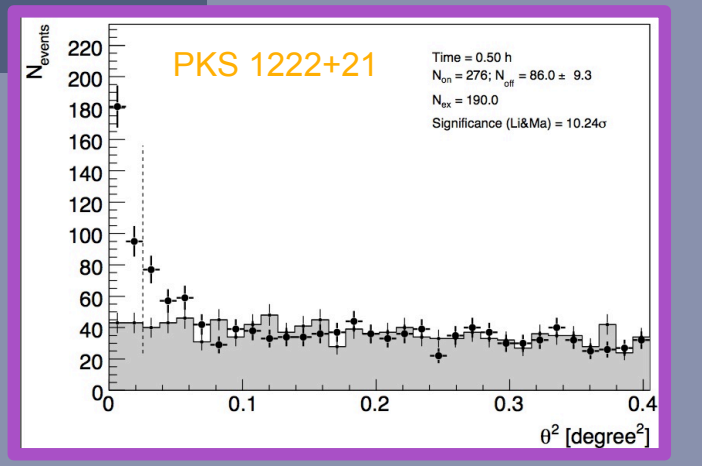
Backup Slides

IACT Astrophysics

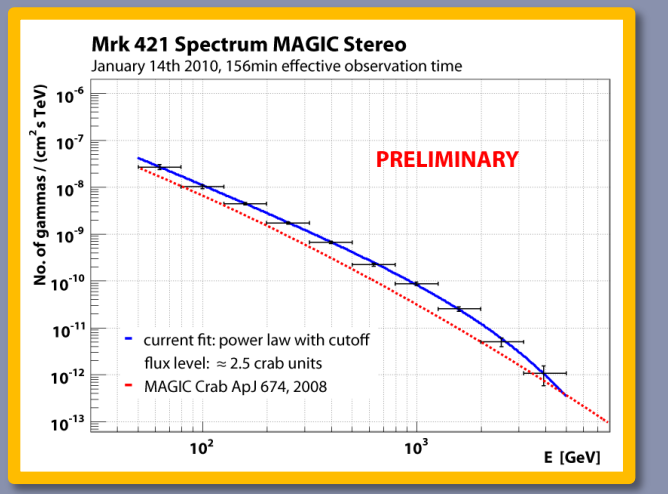


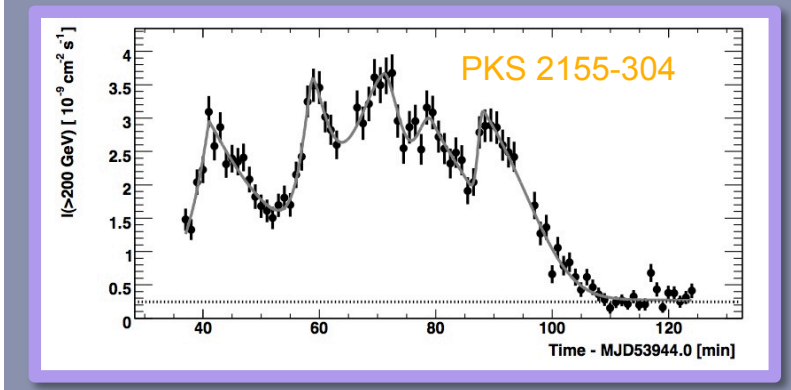
IACTs Observables



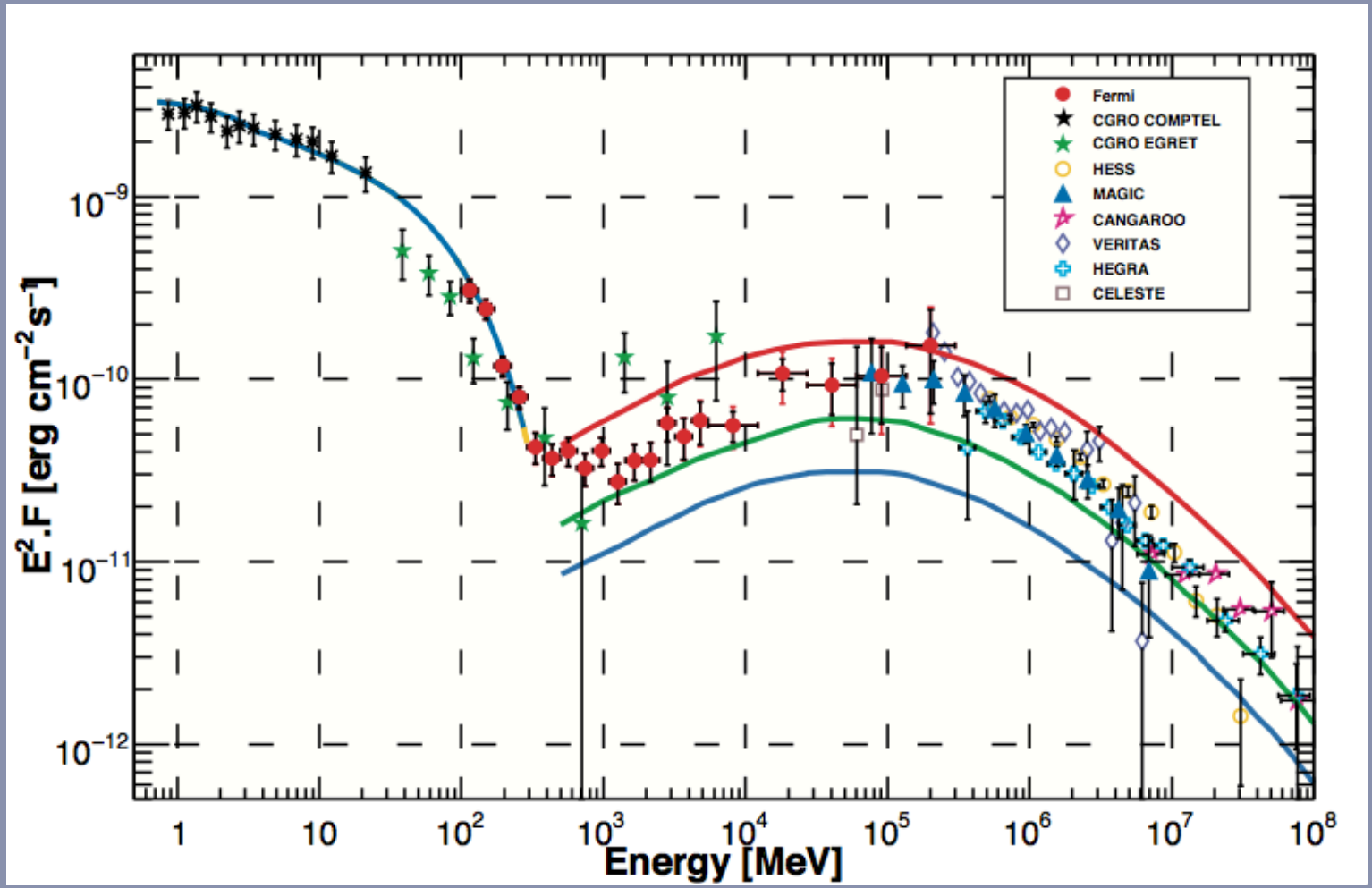


1. The signal (if any)
2. The significance-map
3. The differential energy flux
4. The timing evolution (LC)



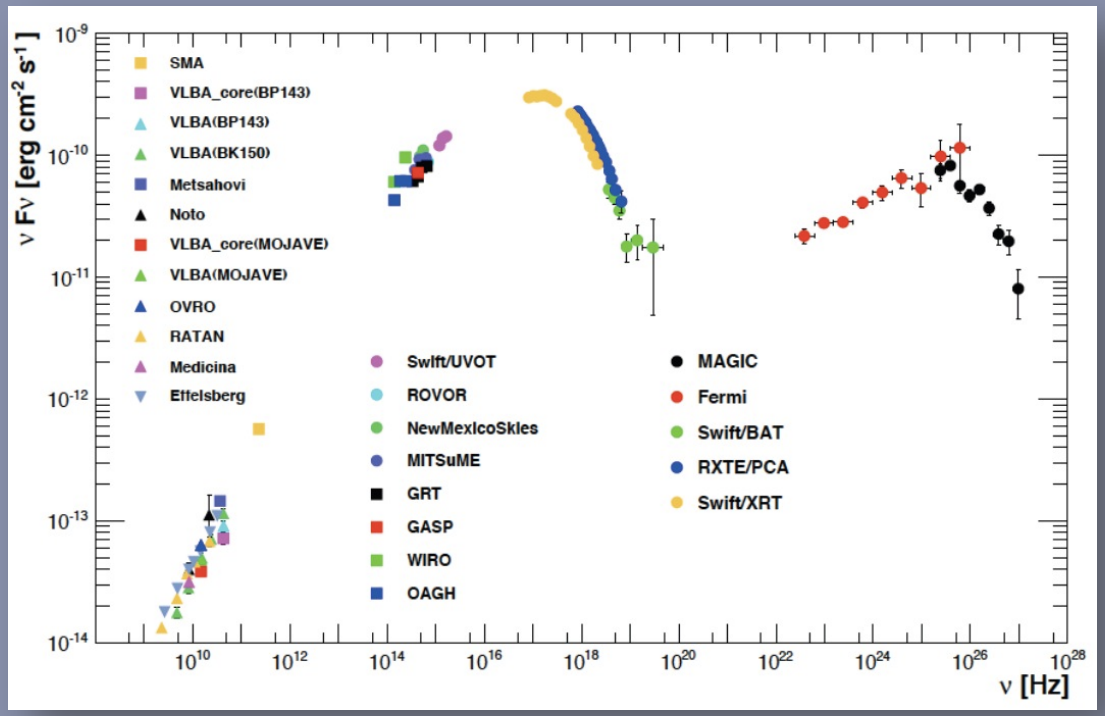


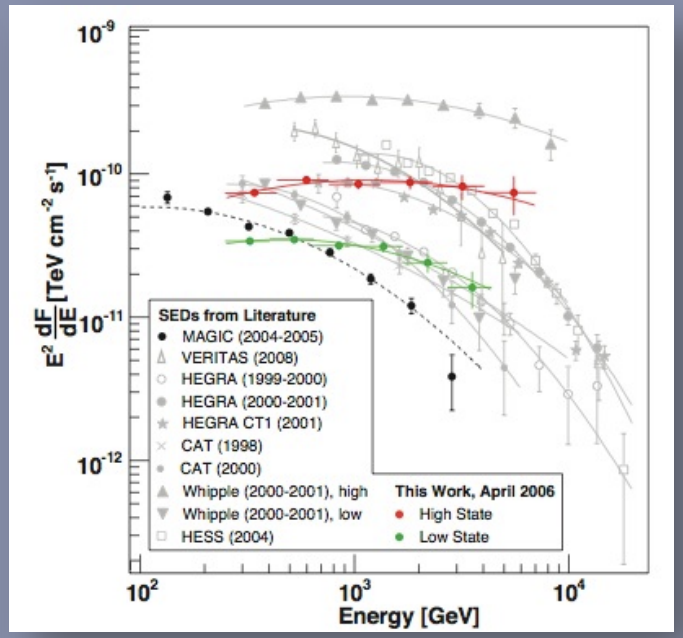
Our "standard" candle: the Crab Nebula



Good agreement between IACTs and overlap at lower energies (*Fermi*/LAT)

The blazars SED: Mkn 421 a real example



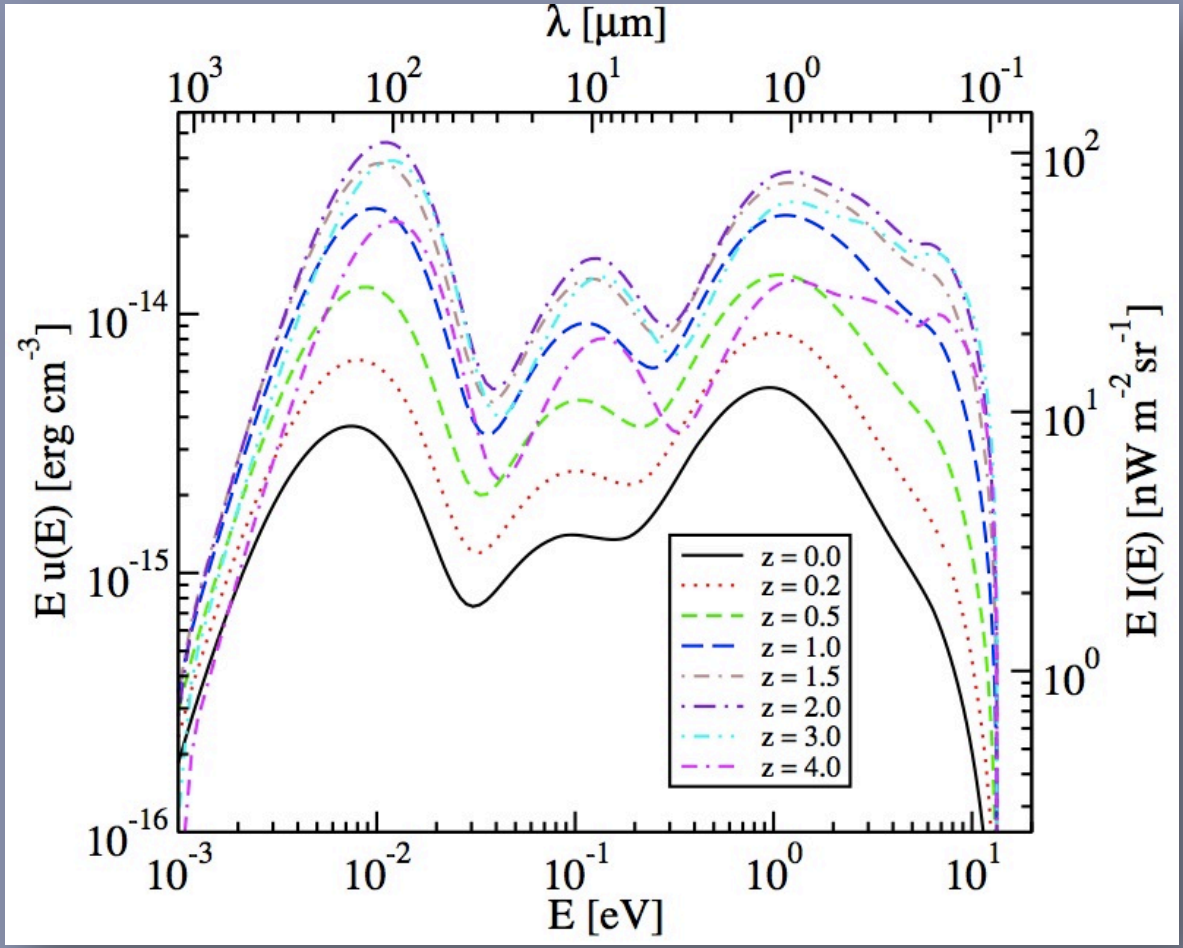


- Clear two bump structure
- High variability

EBL Models

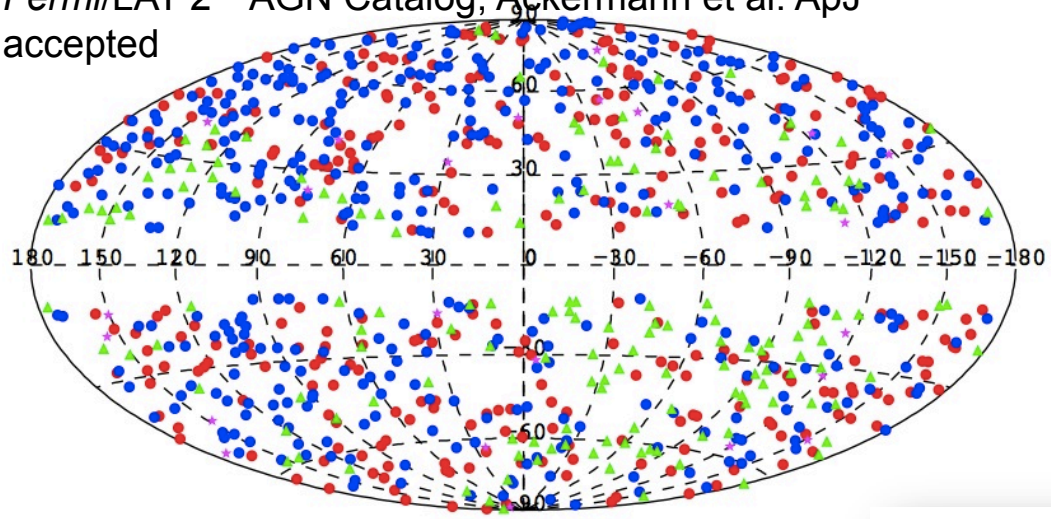
- **Empirical methods**: sum optical/IR emissions from sources at various redshifts using luminosity-dependent galaxy SEDs (Stecker et al., Franceschini et al.)
- **Model of galaxy formation** during mergers of dark matter halos, including supernova feedback, dust attenuation, metal production (Primack et al., Gilmore)
- **Inferring EBL spectrum from TeV** observations (Mazin & Raue)
- **Models based on integrating** stellar light with dust absorption (Kneiske & Dole, Finke et al.)

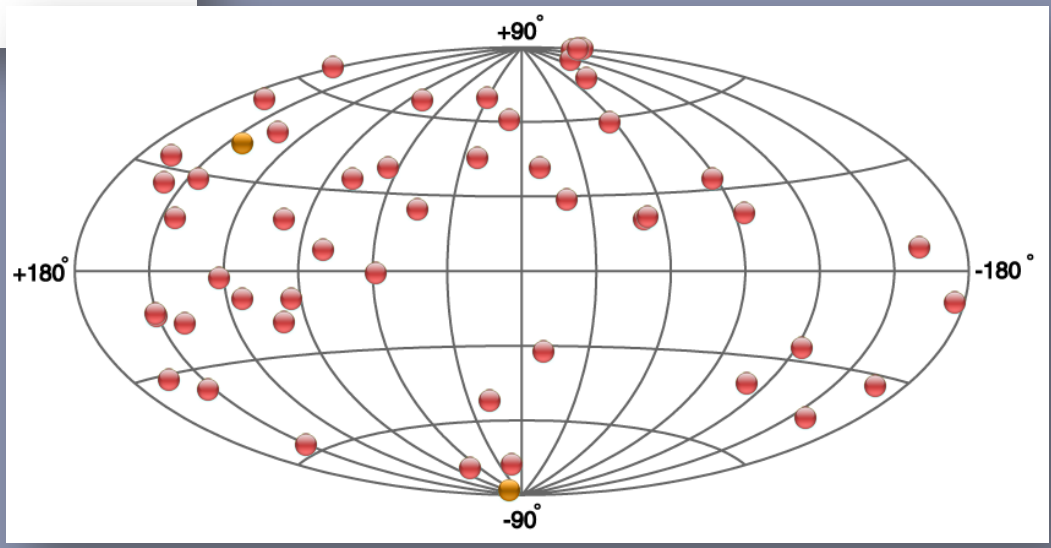
EBL evolution with z

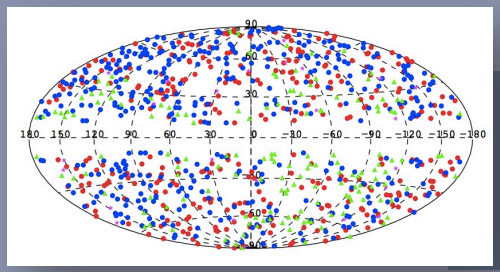


Fermi/LAT & VHE maps

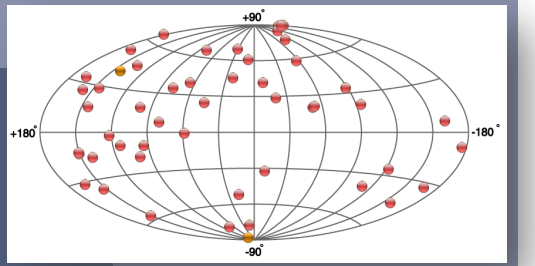
Fermi/LAT 2nd AGN Catalog, Ackermann et al. ApJ accepted



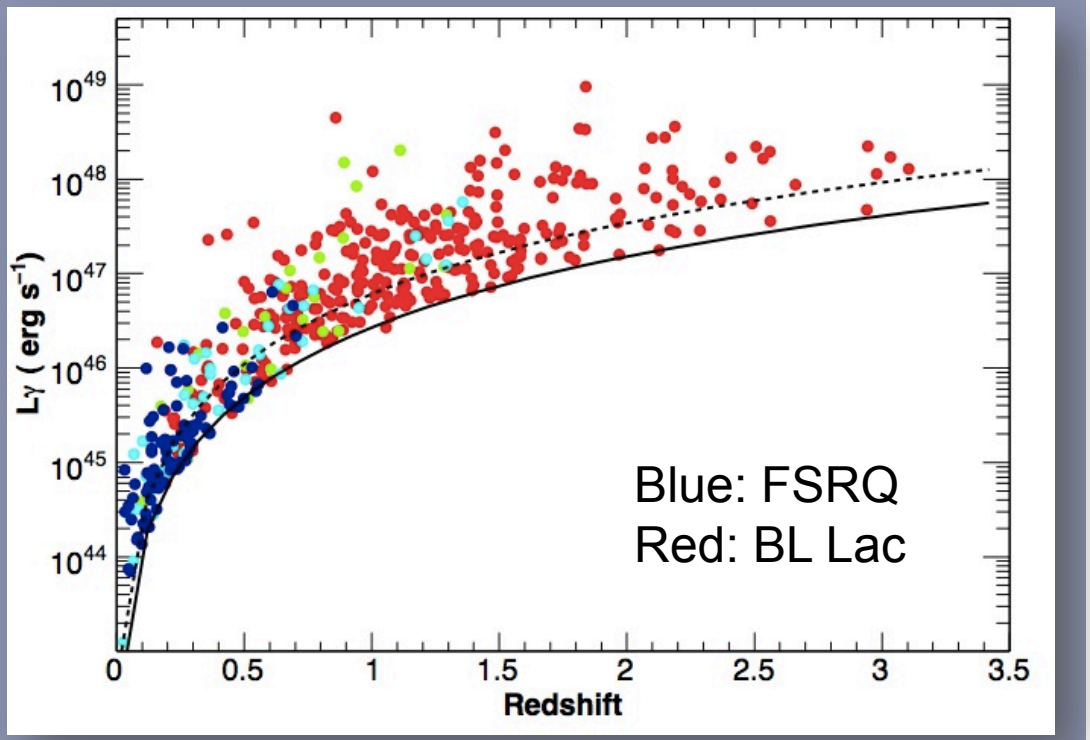




GeV vs TeV



- *Fermi*/LAT FSRQ
  - small redshift
  - peak at small frequencies
- *Fermi*/LAT BL Lac
  - large redshifts!
- We need better sensitivity & lower energy threshold



Fermi/LAT 2nd AGN Catalog, Ackermann et al. ApJ accepted