Status and perspectives of EBL limits from Fermi/LAT and IACTs

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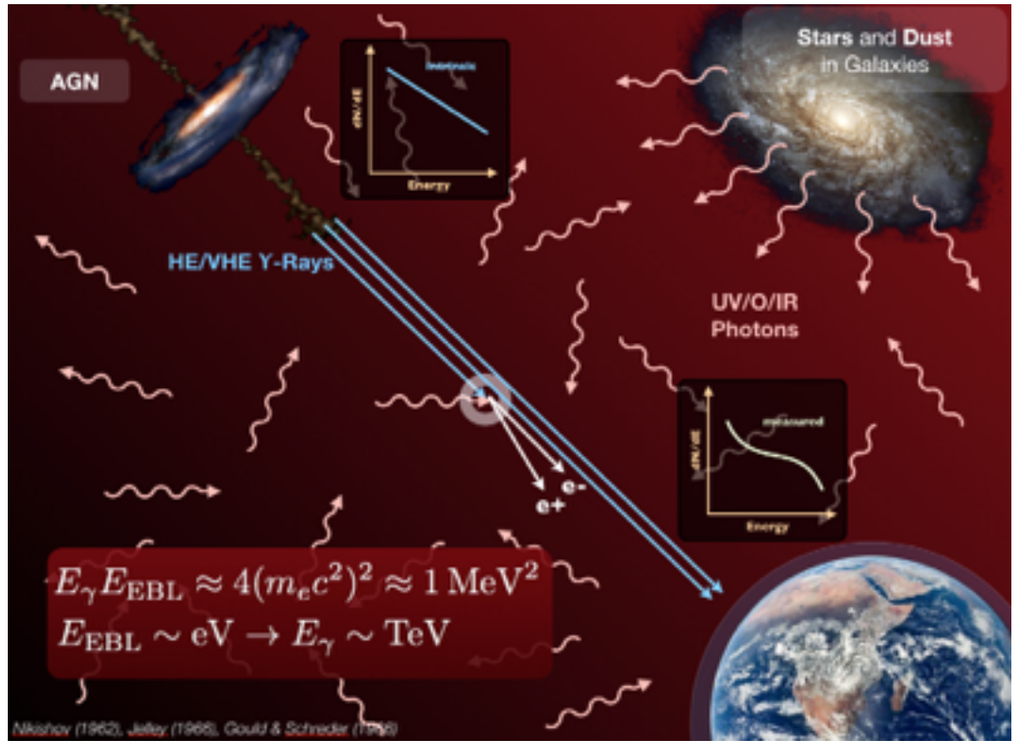
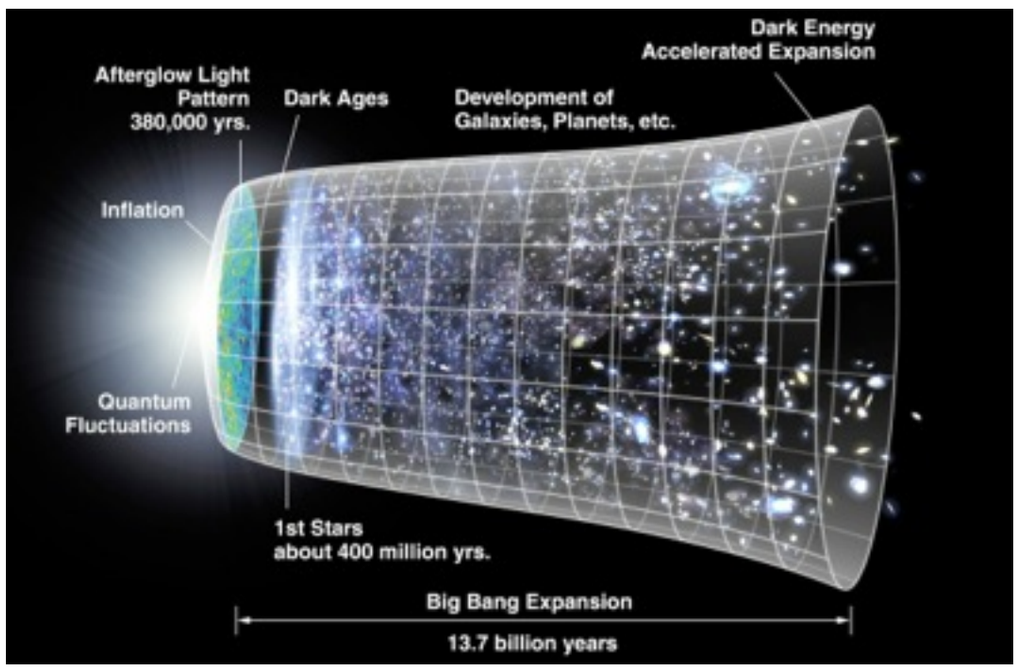
CTA Meeting
The extreme universe viewed in very-high-energy gamma rays 2015

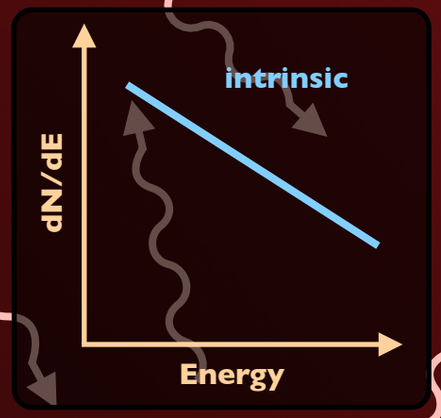
Outline

- Extragalactic Background Light (EBL)
- Indirect methods to measure EBL
- Instruments to measure HE/VHE gamma rays
- Limits by Fermi-LAT
- Limits by Imaging Cherenkov Telescopes
- Future perspective: CTA





AGN

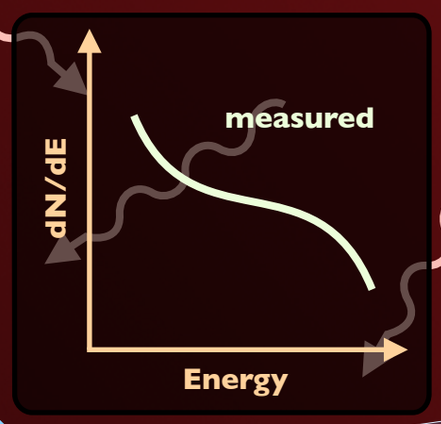


HE/VHE γ-Rays

Stars and **Dust**
in Galaxies

UV/O/IR
Photons

e+ e-



Pair production:

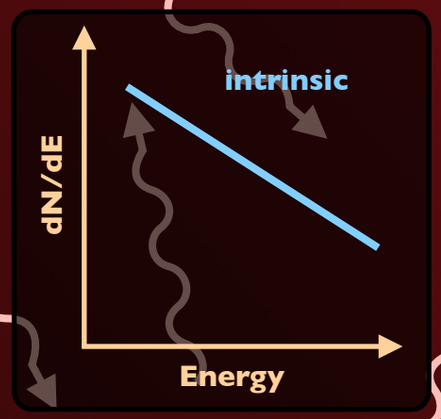
$\gamma_{\mathrm{TeV}}\,\gamma_{\mathrm{EBL}} \rightarrow e^+ e^-$

$$E_\gamma E_{\mathrm{EBL}} \approx 4(m_e c^2)^2 \approx 1\,\mathrm{MeV}^2$$

$$E_{\mathrm{EBL}} \sim \mathrm{eV} \rightarrow E_\gamma \sim \mathrm{TeV}$$

Nikishov (1962), Jelley (1966), Gould & Schreder (1966)

AGN



Stars and **Dust**
in Galaxies

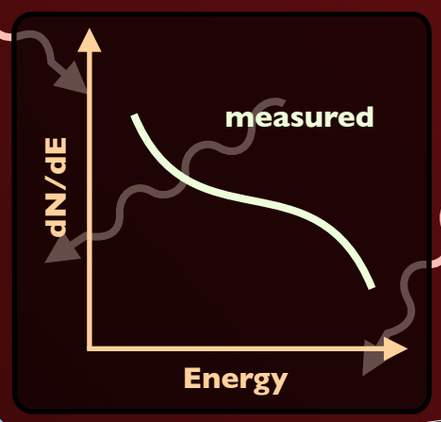
HE/VHE γ-Rays

UV/O/IR
Photons

Constrain the EBL density

- Measured spectrum + assumptions about the intrinsic spectrum
- Many sources at different redshifts to disentangle EBL and intr. spectrum

e-
e+



Unique information

- Strong foregrounds hamper direct measurements
- Redshift resolved
- True integrated measurement

Stecker, de Jager 1992, Aharonian et al 2006, Mazin & Raue 2007 ...

AGN

HE/VHE γ-Rays

Stars and **Dust**
in Galaxies

UV/O/IR Photons

e-
e+

Investigate EBL sources

- Star & dust in galaxies
- Population III stars
- Exotic contributions

Study star formation rate density

- Structure formation history

Santos et al. 2002, Fernadez & Komatsu 2006, Raue, Kneiske, Mazin 2009, Gilmore 2011, Raue & Meyer 2012, ...

The EBL energy density: data

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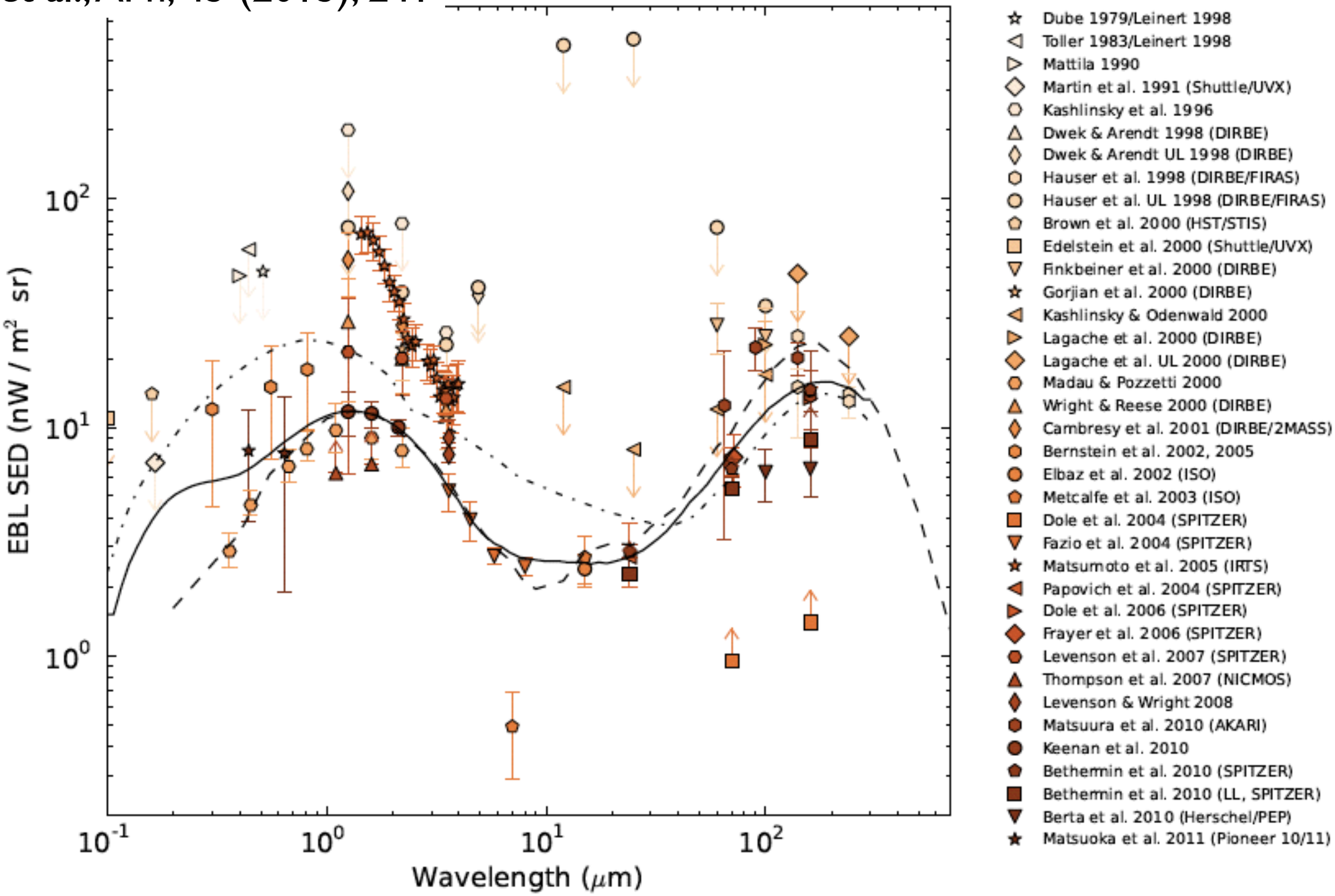
(Werner-Heisenberg-Institut)

ICRR
Institute for Cosmic Ray Research
University of Tokyo

DM et al., APh, 43 (2013), 241



The EBL energy density: models

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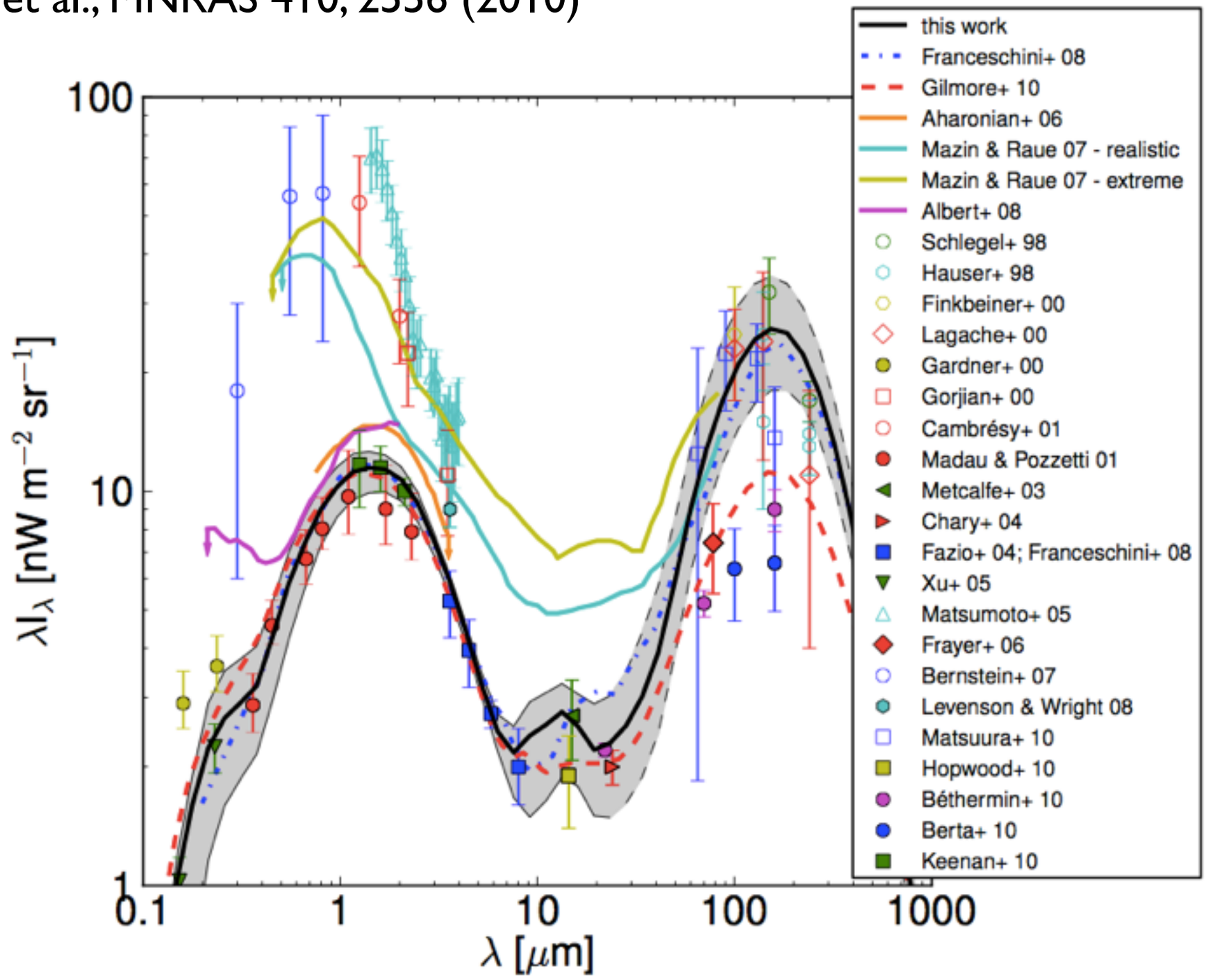
Dominguez et al., MNRAS 410, 2556 (2010)



Imprint of the EBL on spectra of HE/VHE gamma ray spectra of distant sources

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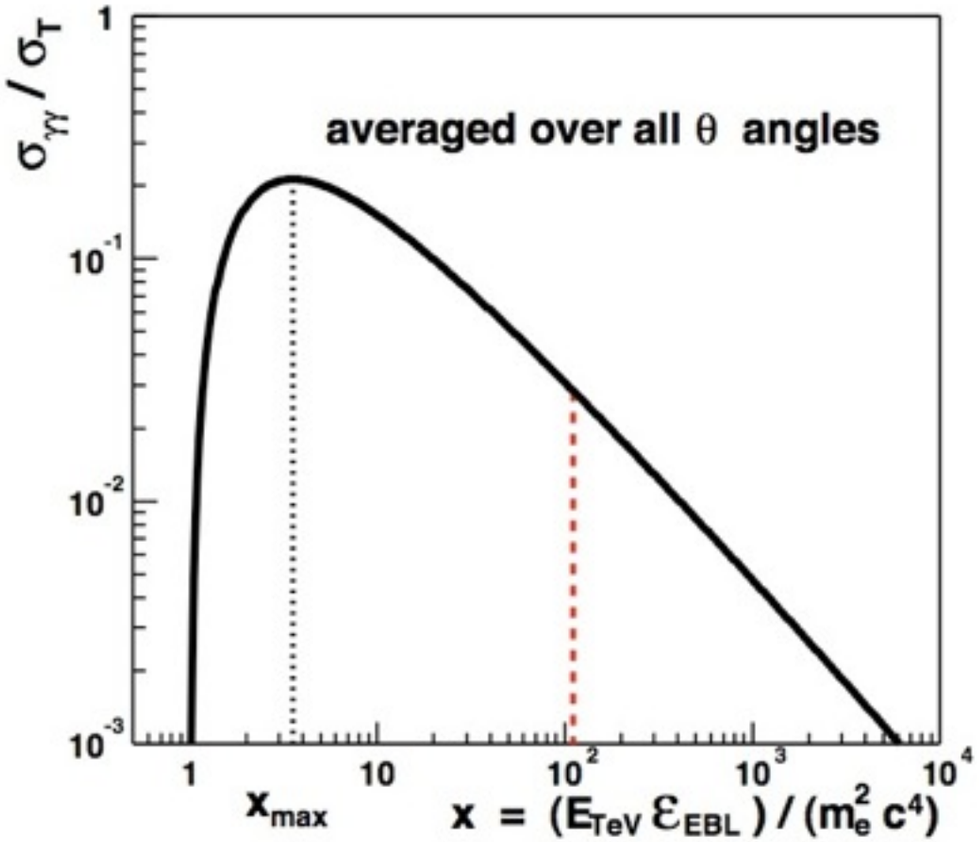
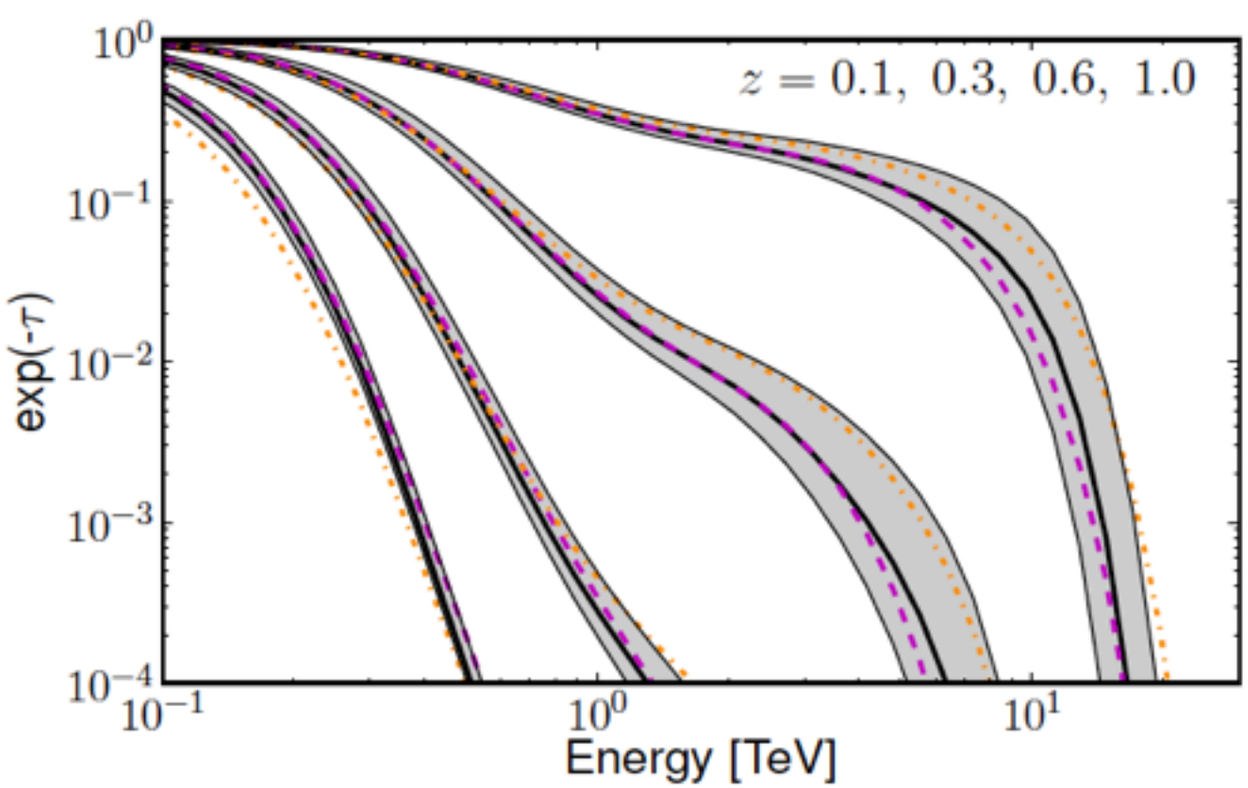
- Cross section of pair production:
  - peaks at ~4*$E_{threshold}$
  - Delta function approximation is not precise



- Attenuation of Gamma-ray flux is calculated by integrating over number density of EBL, angles between photons, and distance to the source.
- The attenuation factor is sensitive to the EBL density



Dominguez et al., MNRAS 410, 2556 (2010)

Indirect methods to measure the EBL: Sources

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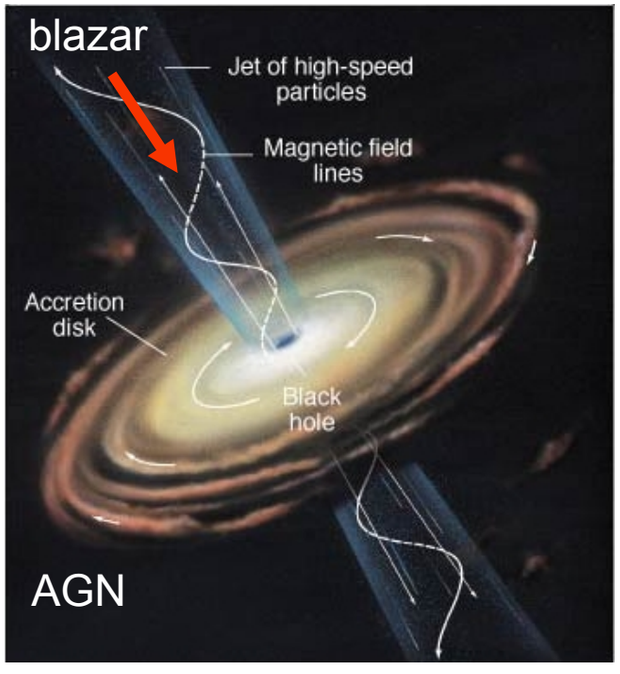
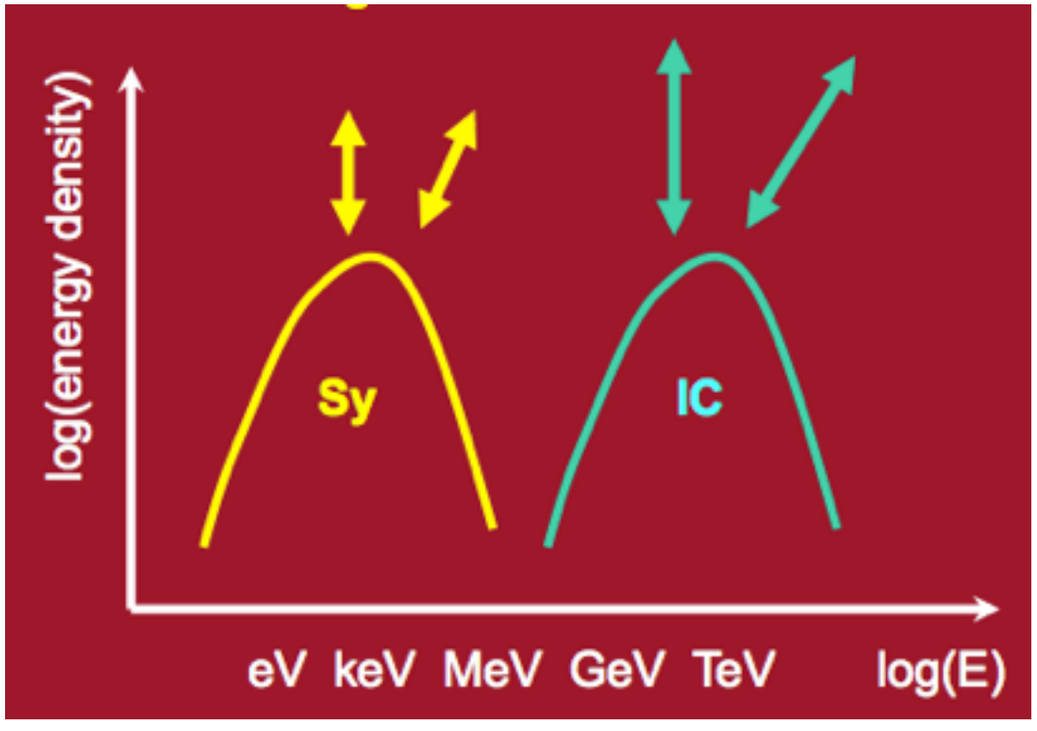
- Typical extragalactic source at HE/VHE gamma rays is a **blazar**





- Factories of violent, broad band (up to high energy) non-thermal radiation
- Blazars: relativistic plasma jet, highly variable
- TeV blazars (above 100 GeV): ~50 out of 61 are HBL (High-peaked BL Lacertae)

- Typical energy spectrum has a 2-bump structure
- First bump is synchrotron emission from electrons
- Second bump probably Inverse Compton (IC) from the same population of photons (SSC) or IC from external photon fields (EC)

Indirect methods to measure the EBL: Assumptions

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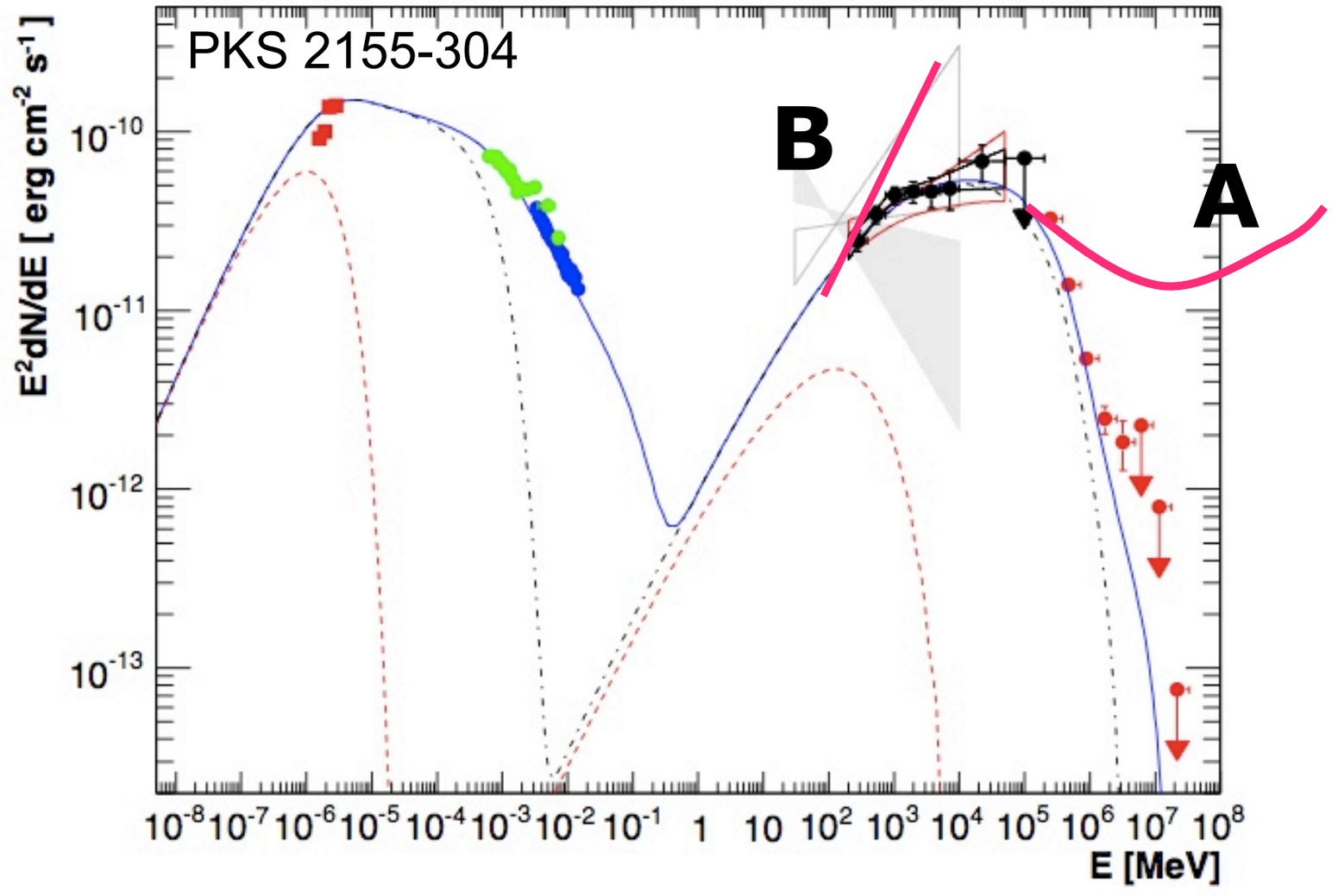
- **<u>There is no pile-up</u>** at highest gamma rays energies measured



Indirect methods to measure the EBL: Assumptions

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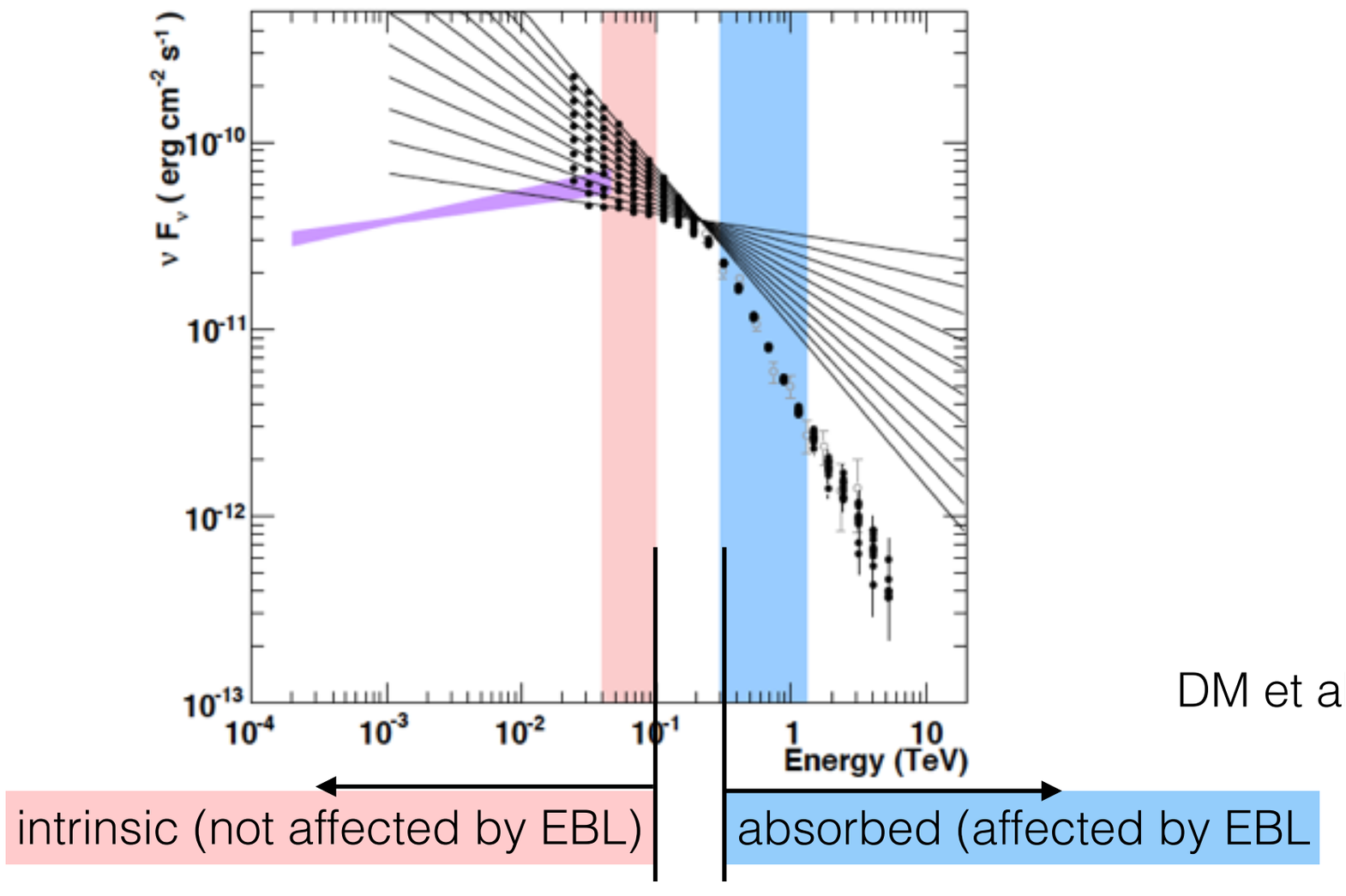
- **There is no hardening of the energy spectrum** between HE regime (typically measured by Fermi-LAT)
  and VHE regime measured by the imaging Cherenkov telescopes



DM et al, Aph 43, 241-251 (2013)

Indirect methods to measure the EBL: Assumptions

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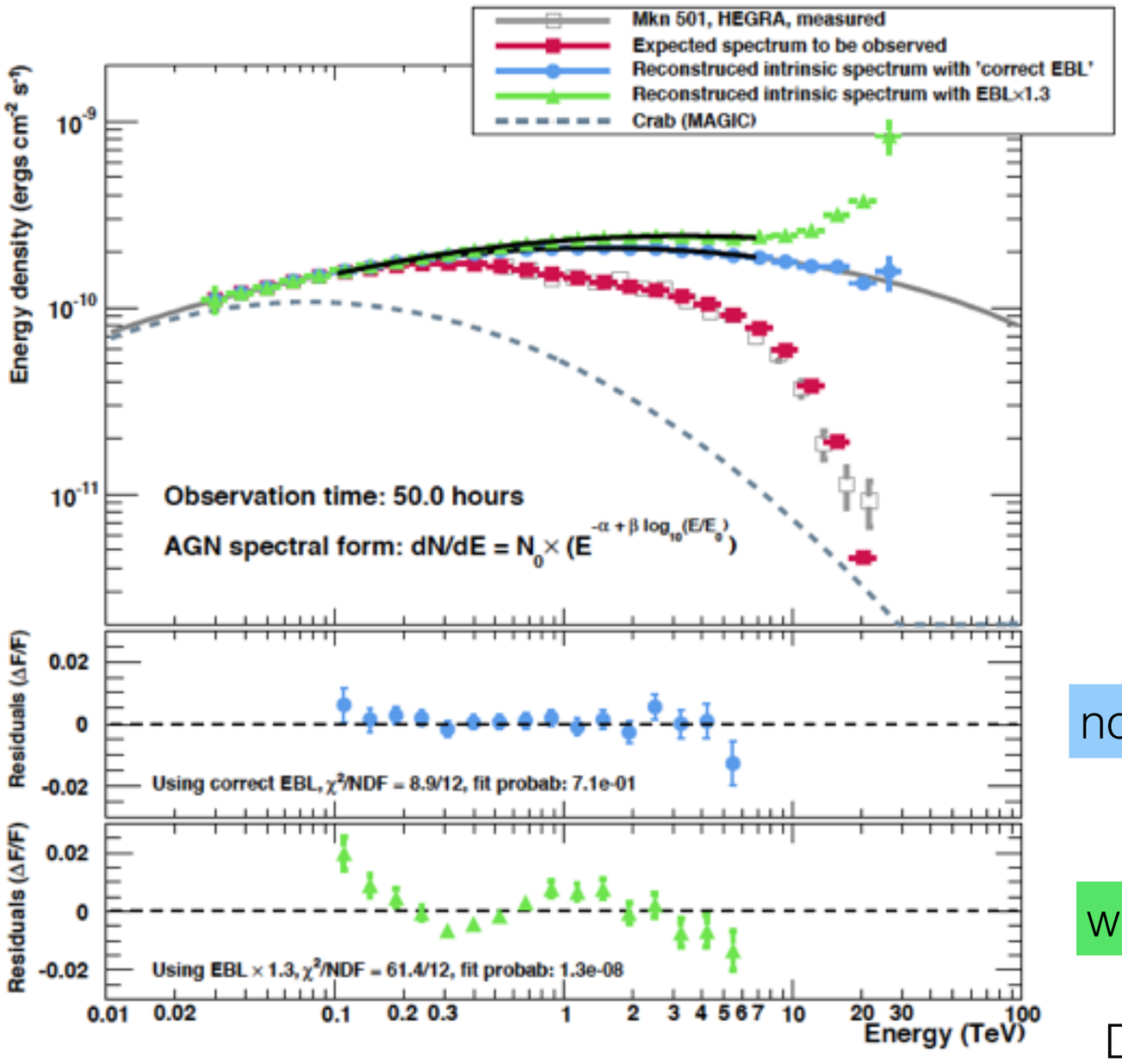
- **The intrinsic energy spectrum is smooth**



no wiggles with correct EBL density

wiggles with in-correct EBL density

DM et al, Aph 43, 241-251 (2013)

Indirect methods to measure the EBL: Instruments

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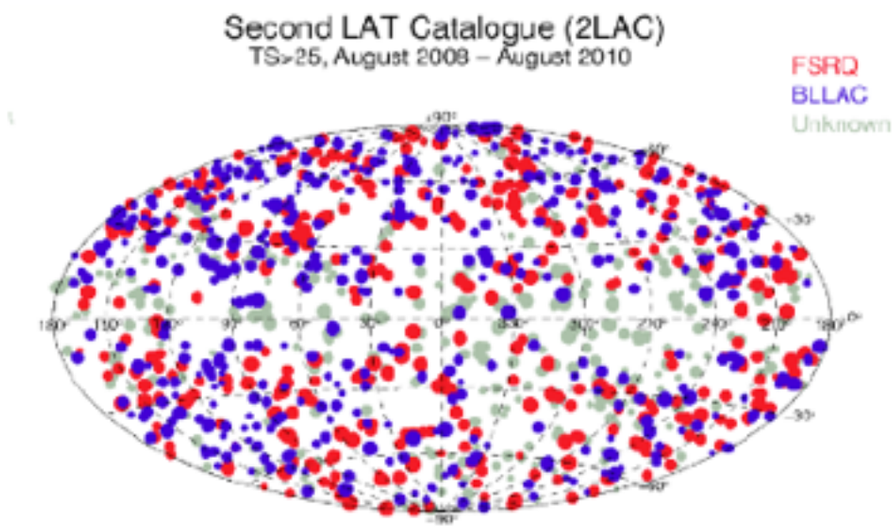
- High energy gamma rays are measured by Fermi-LAT (also Agile)

Large Area Telescope (LAT):
- >20 MeV - > 500 GeV
- 2.4 sr FoV (scans entire sky every ~3hrs)

100 MeV < E < 300 GeV

- *Fermi* detected >1000 AGN with redshift up to 3.1
- Perfect set to probe the EBL



2LAC-clean sample:
310 FSRQs
395 BL Lacs
156 Blazars with unknown type
24 AGNs Ackermann+11, ApJ 743, 171

Indirect methods to measure the EBL: Instruments

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Very High energy gamma rays are measured by **Imaging Atmospheric Cherenkov Telescopes (IACTs): H.E.S.S., MAGIC and VERITAS** (as well as Water Cherenkov Detectors (HAWC) which, however, have a much worse energy resolution)

50 GeV < E < 100 TeV

Limits from Fermi-LAT

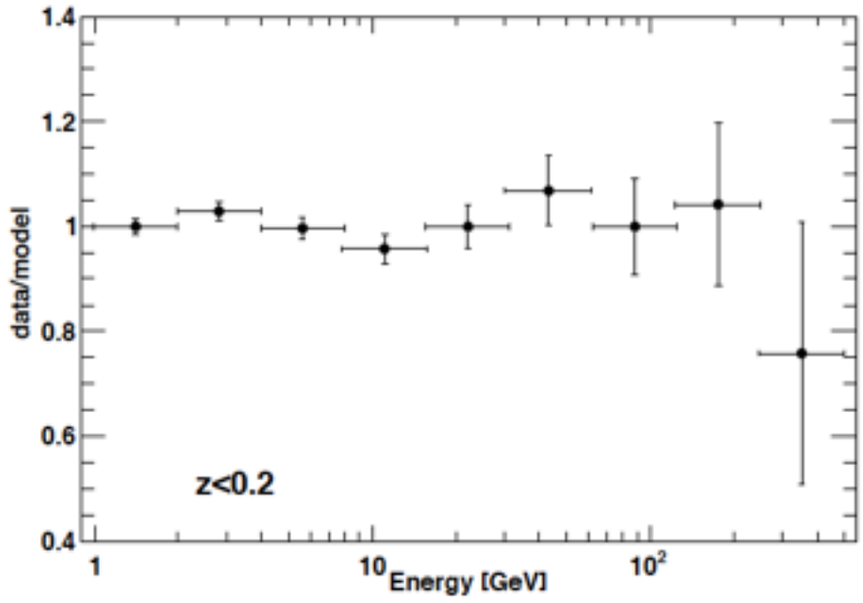
- Idea: $F(E)_{observed} = F(E)_{intrinsic} \cdot \exp(-b \cdot \tau_{model})$ with b as a free parameter
- $F(E)_{intrinsic}$ is **extrapolated** from measured spectrum in unabsorbed energies to higher energies **from the same data.**
- $F(E)_{observed}$ is measured spectrum.
- τ_{model} is gamma-ray optical depth calculated from a given theoretical EBL model
- Expected result:
  - b=0: there is no EBL
  - b=1: the EBL model is correct

Fermi-LAT, Science, 338, 1190 (2012)

Limits from Fermi-LAT

- Assumption: BL Lac spectra follow a parabolic shape
- Residuals for best fit b are flat

Average of the residuals with respect to the best fit models for all z<0.2 bin.



Results (wrt to Franceschini+08 model):

- z<0.2 : TS_{det}~4 and b=1.18(+/0.94)
- 0.2<z<0.5: TS_{det}~7 and b=0.82(+/-0.41)
- 0.5<z<1.6: TS_{det}~25 and b=1.29(+/-0.42)
- Weighted average: b=1.02(+/-0.23)

1. *~6σ detection of the EBL absorption feature*
2. *Data compatible with low-opacity models*

11

- Results: EBL is detected and consistent with state-of-the-art EBL models

Fermi-LAT, Science, 338, 1190 (2012)

Limits from Fermi-LAT

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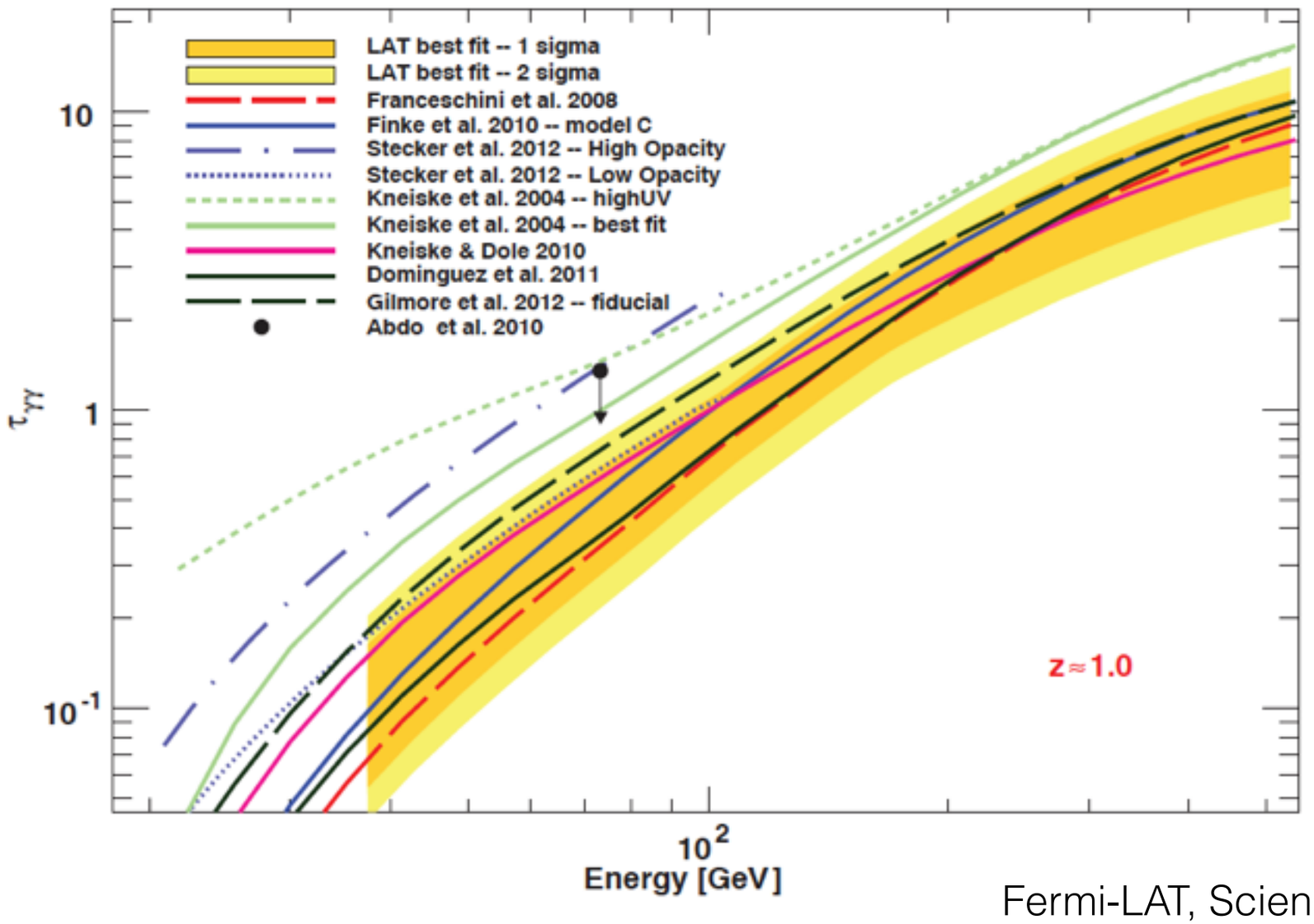
- EBL is detected and consistent with state-of-the-art EBL models



Fermi-LAT, Science, 338, 1190 (2012)

Limits from Fermi-LAT

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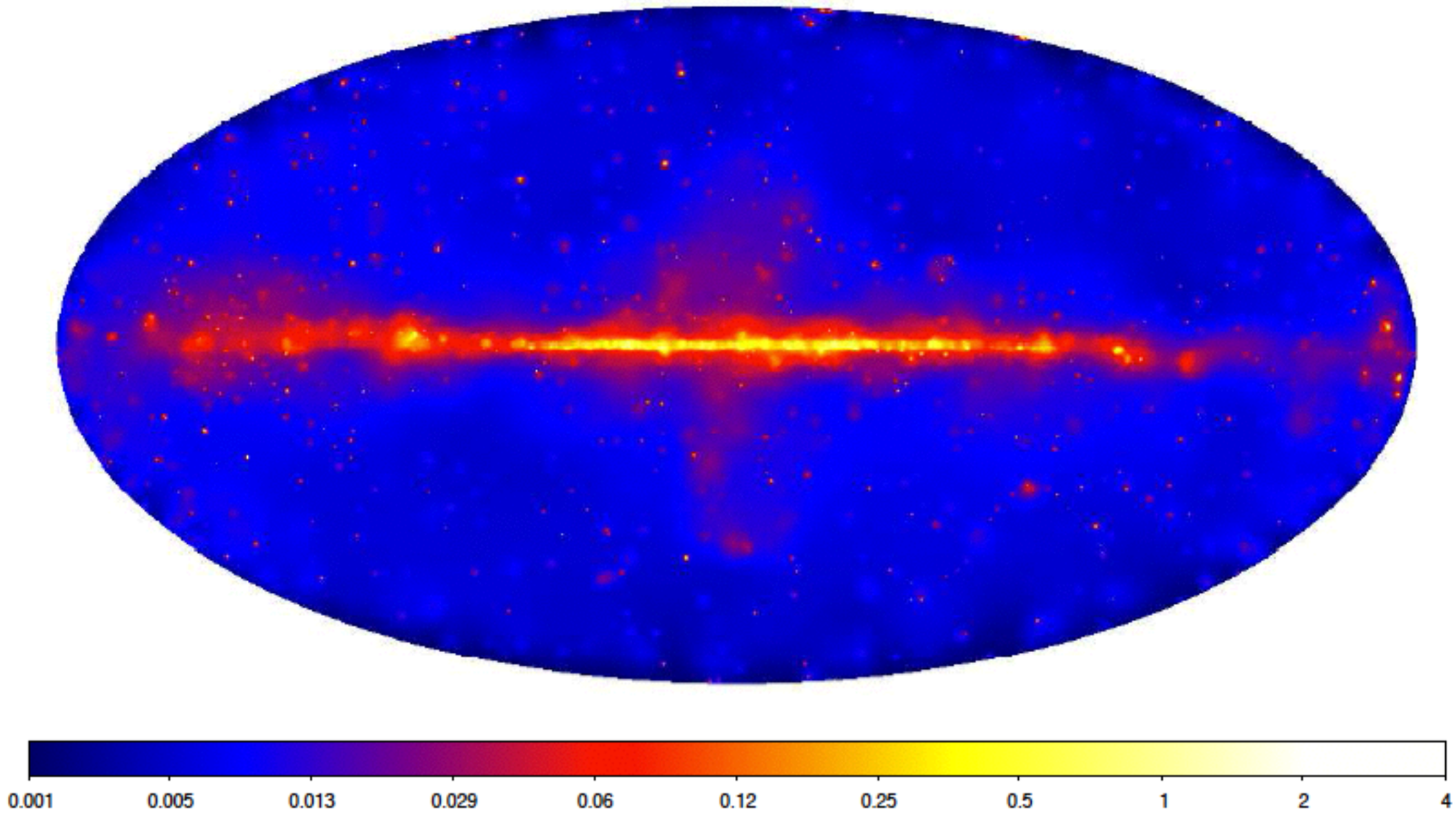
- 2FHL: Second Fermi Hard Source Catalog, 50GeV < E < 2 TeV



Fermi-LAT, ApJ submitted, arXiv:1508.04449

Limits from Fermi-LAT

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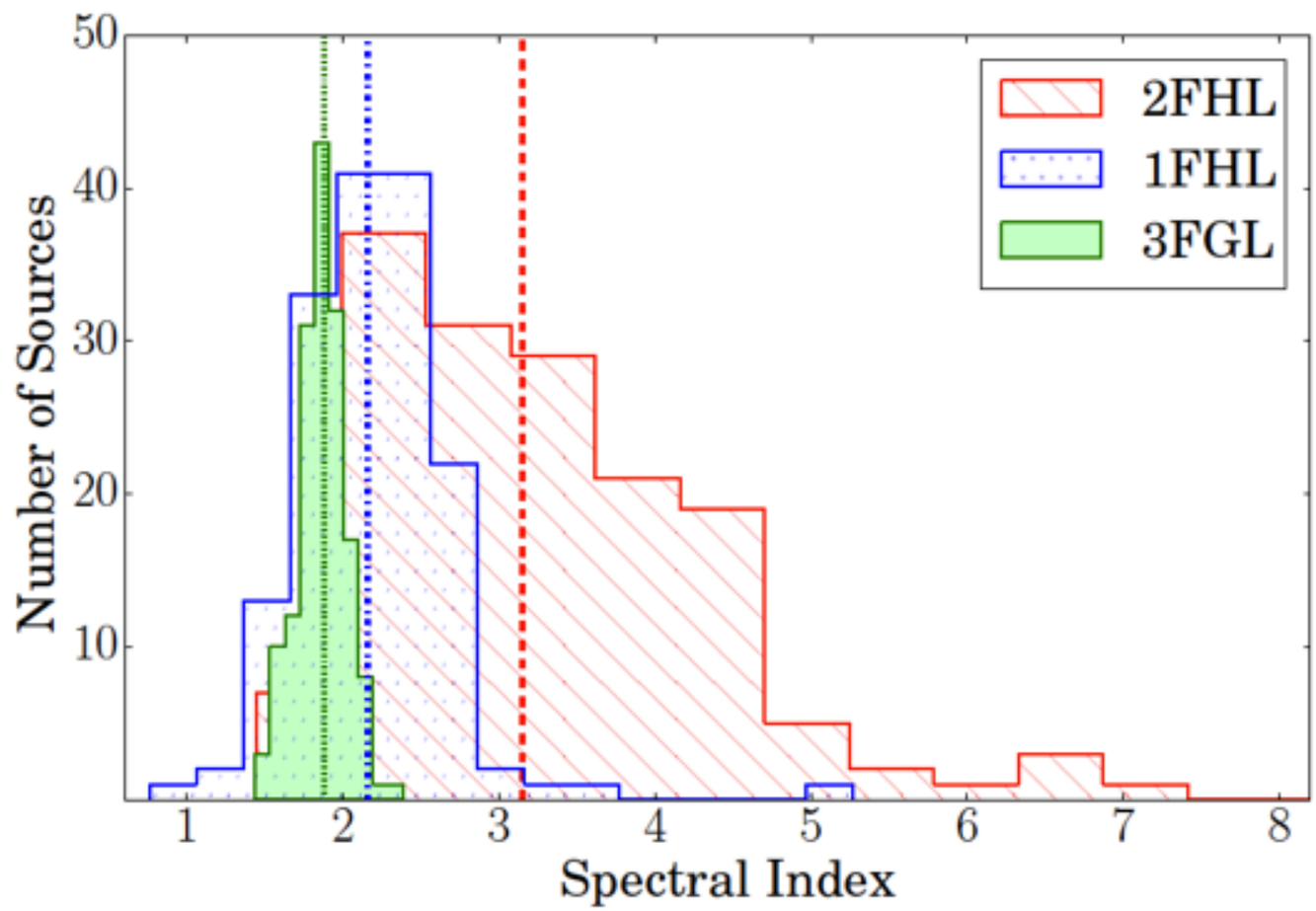
- 2FHL: Second Fermi Hard Source Catalog, 50GeV < E < 2 TeV

Source classes:

Description	Associated Designator	Number
Pulsar	psr	1
Pulsar wind nebula	pwn	14
Supernova remnant	snr	16
Supernova remnant / Pulsar wind nebula	spp	4
High-mass binary	hmb	2
Binary	bin	1
Star-forming region	sfr	1
BL Lac type of blazar	bll	180
BL Lac type of blazar with prominent galaxy emission	bll-g	13
FSRQ type of blazar	fsrq	10
Non-blazar active galaxy	agn	2
Radio galaxy	rdg	4
Radio galaxy / BL Lac	rdg/bll	2
Blazar candidate of uncertain type I	bcu I	7
Blazar candidate of uncertain type II	bcu II	34
Blazar candidate of uncertain type III	bcu III	19
Normal galaxy (or part)	gal	1
Galaxy cluster	galclu	1
Total associated	...	312
Unassociated	...	48
Total in 2FHL	...	360

distribution for 158 BL Lacs that are common for 1FHL, 2FHL and 3FGL



Fermi-LAT, ApJ submitted, arXiv:1508.04449

Limits from Fermi-LAT

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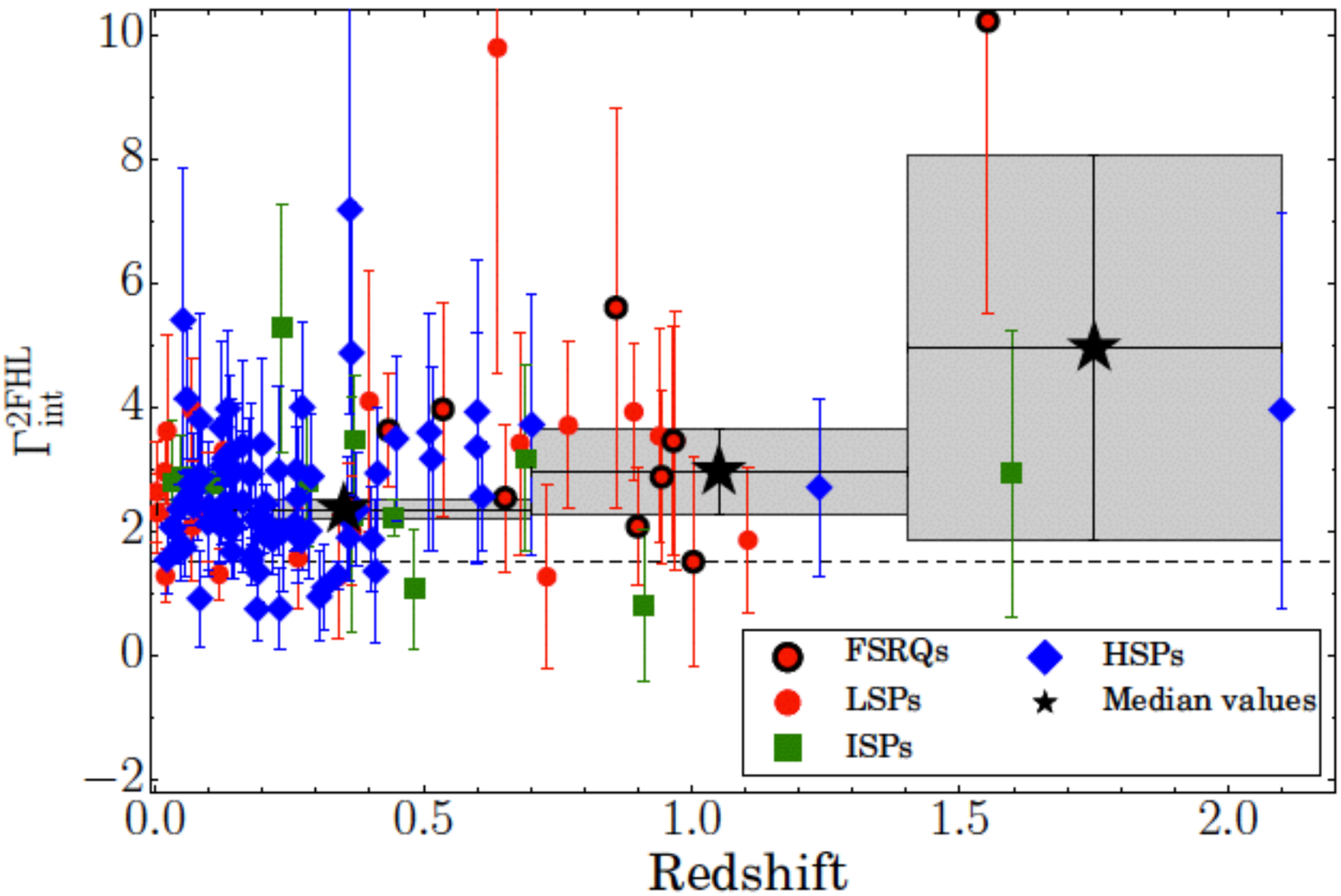
- Using 2FHL: No unexpected features found

Intrinsic spectral index: no evolution with redshift



Dominguez+Ajello, ApJ, 813 (2015) L34

Limits from IACTs

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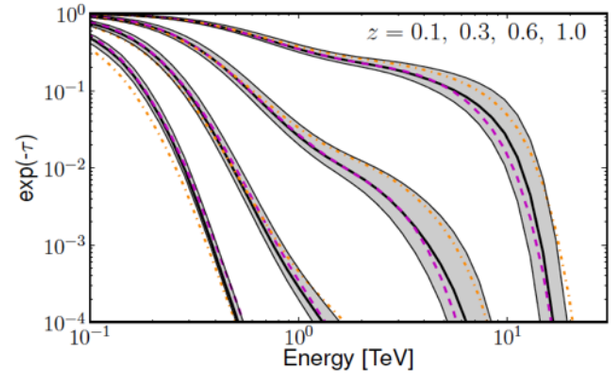
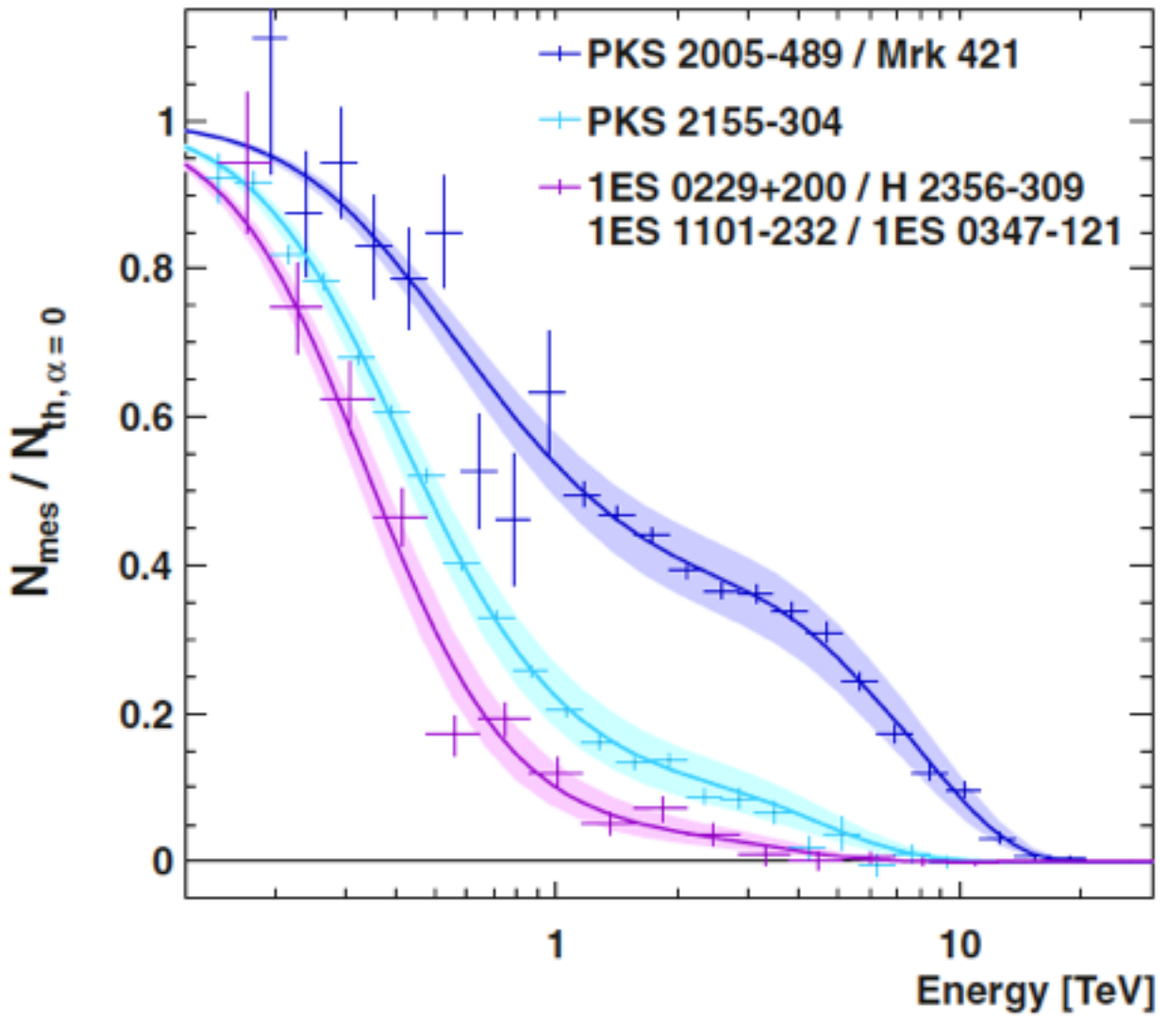
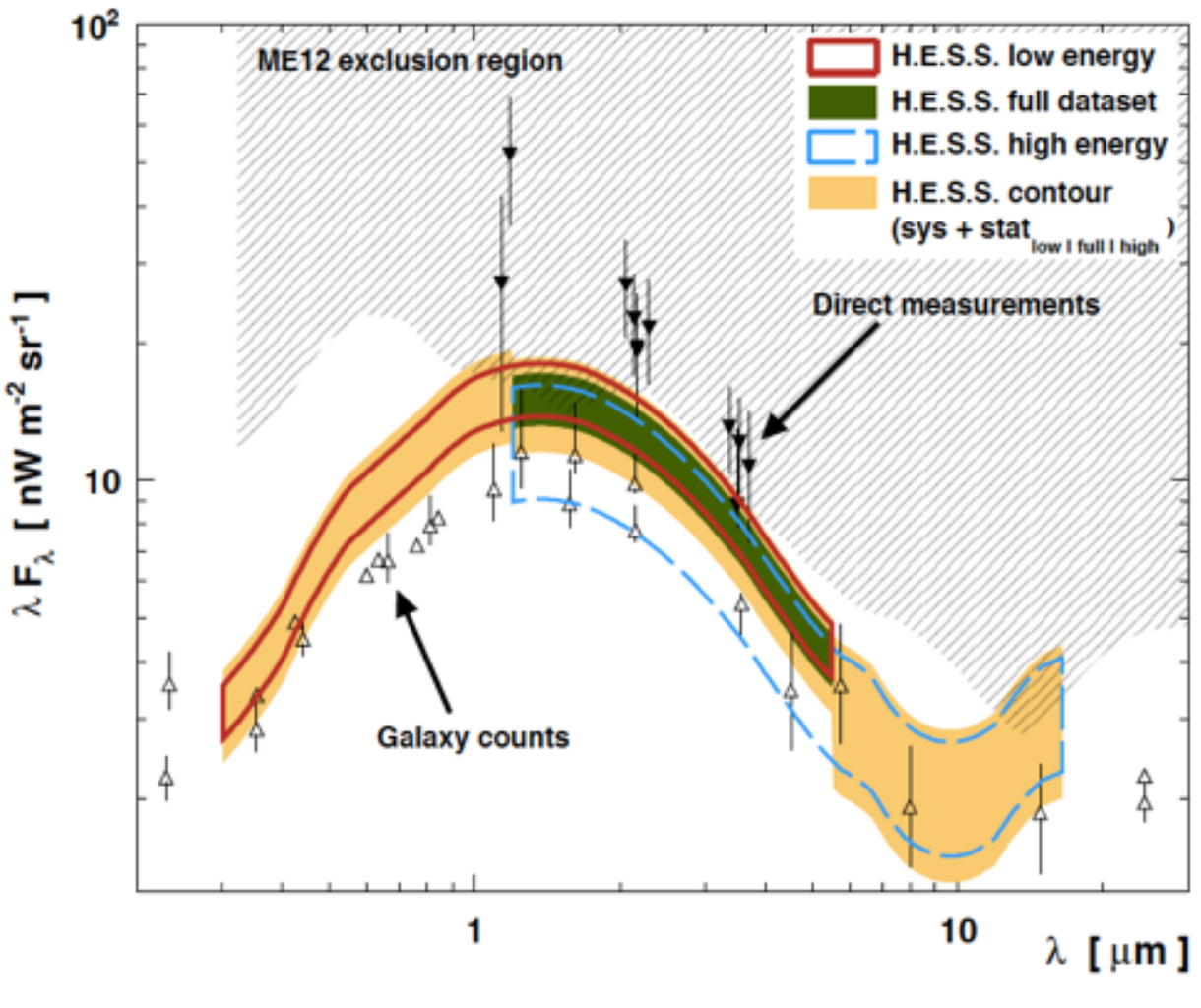
Reminder: effect of EBL:



- H.E.S.S. from several sources

H.E.S.S., A&A 550, 11 (2013)

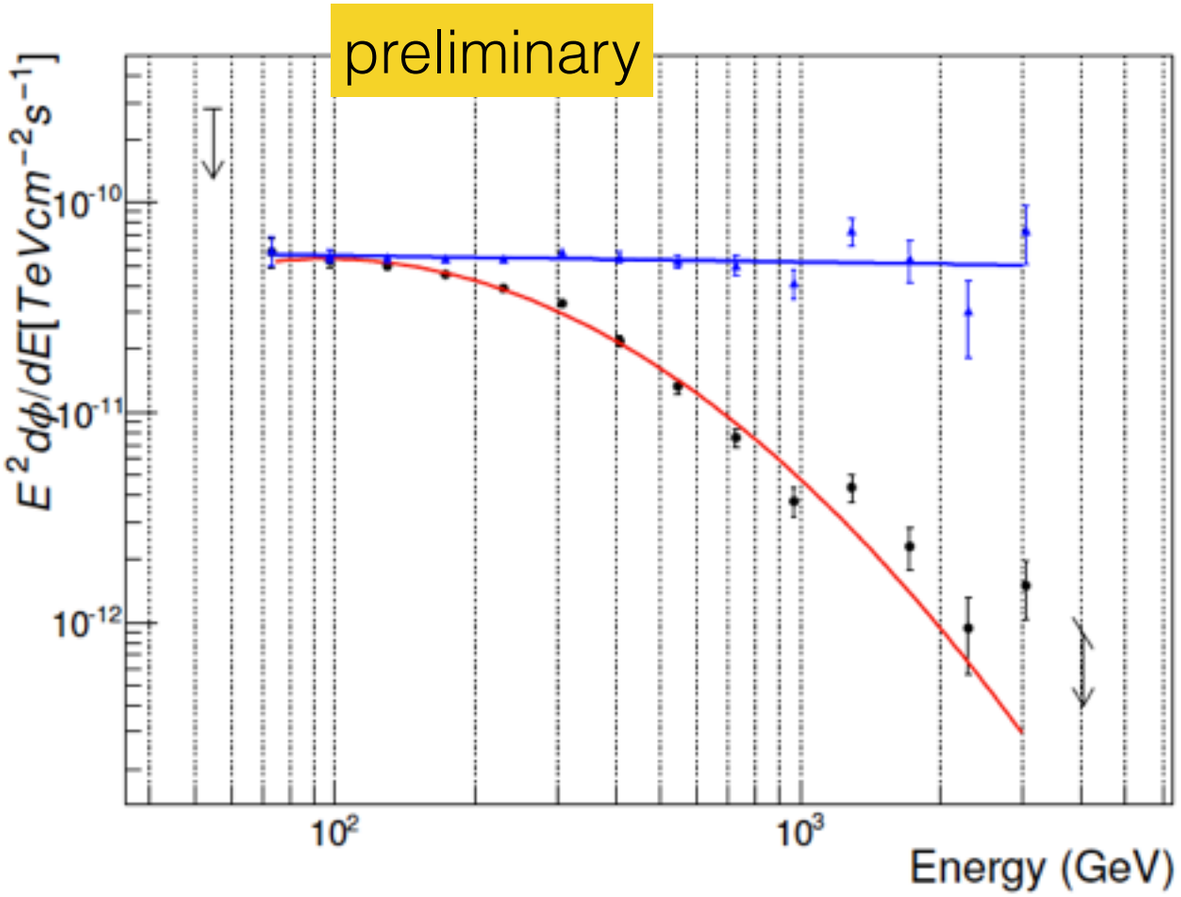




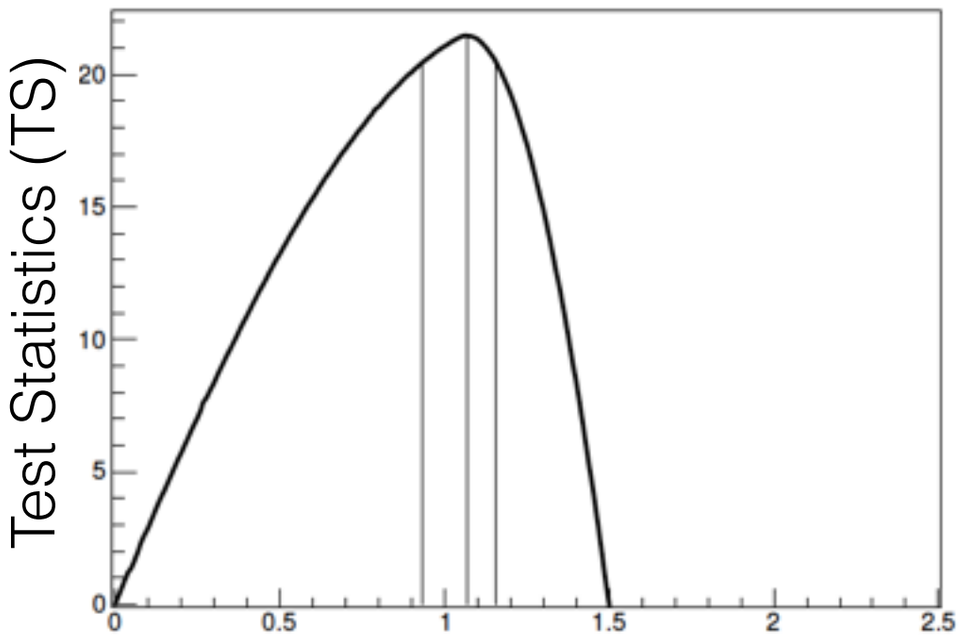
Limits from IACTs

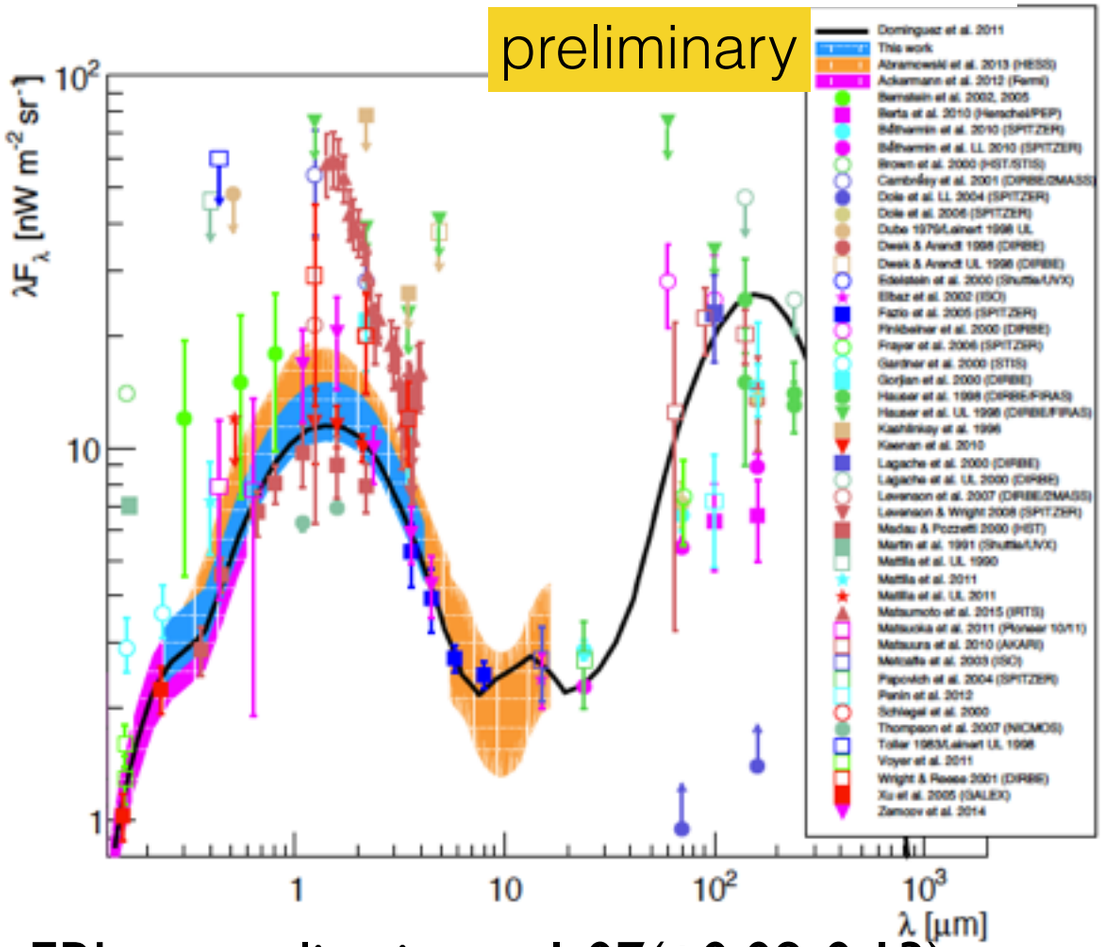
- MAGIC from single sources

MAGIC, submitted (2015)



Using data from 1ES1011+496 (z=0.211)



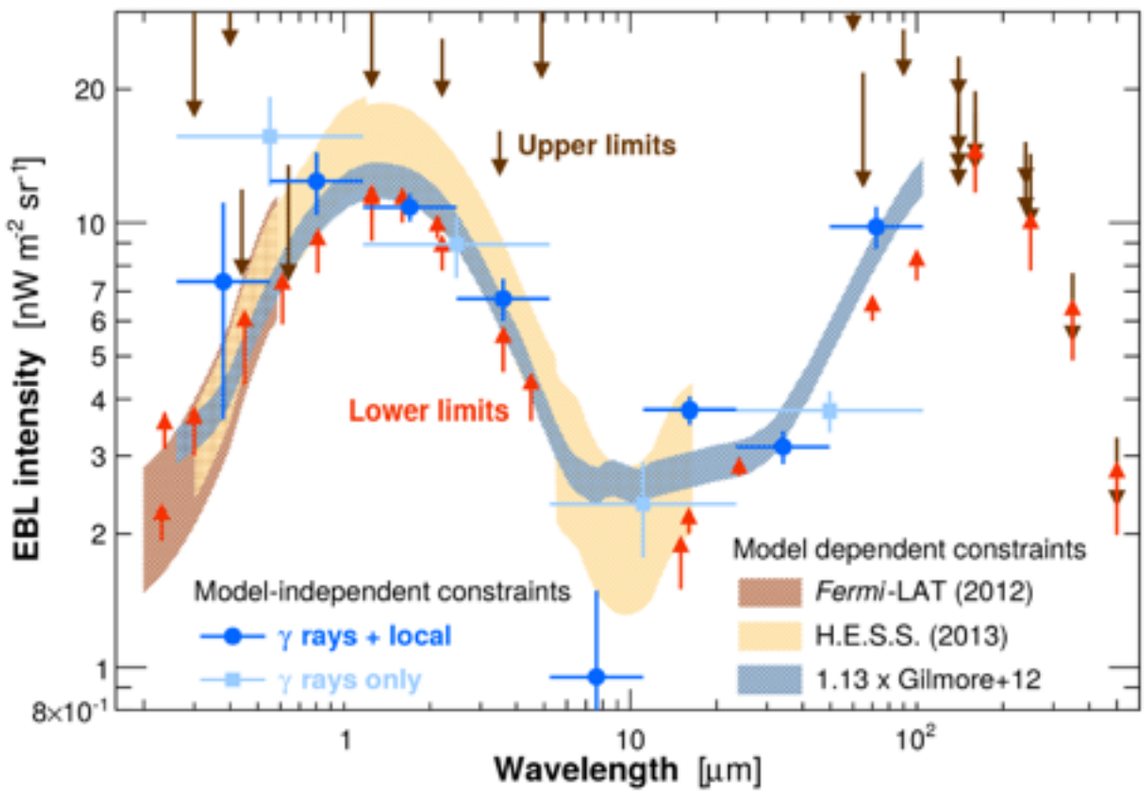


EBL normalization = 1.07(+0.09-0.13)stat (+0.11-0.07)syst

Limits from IACTs

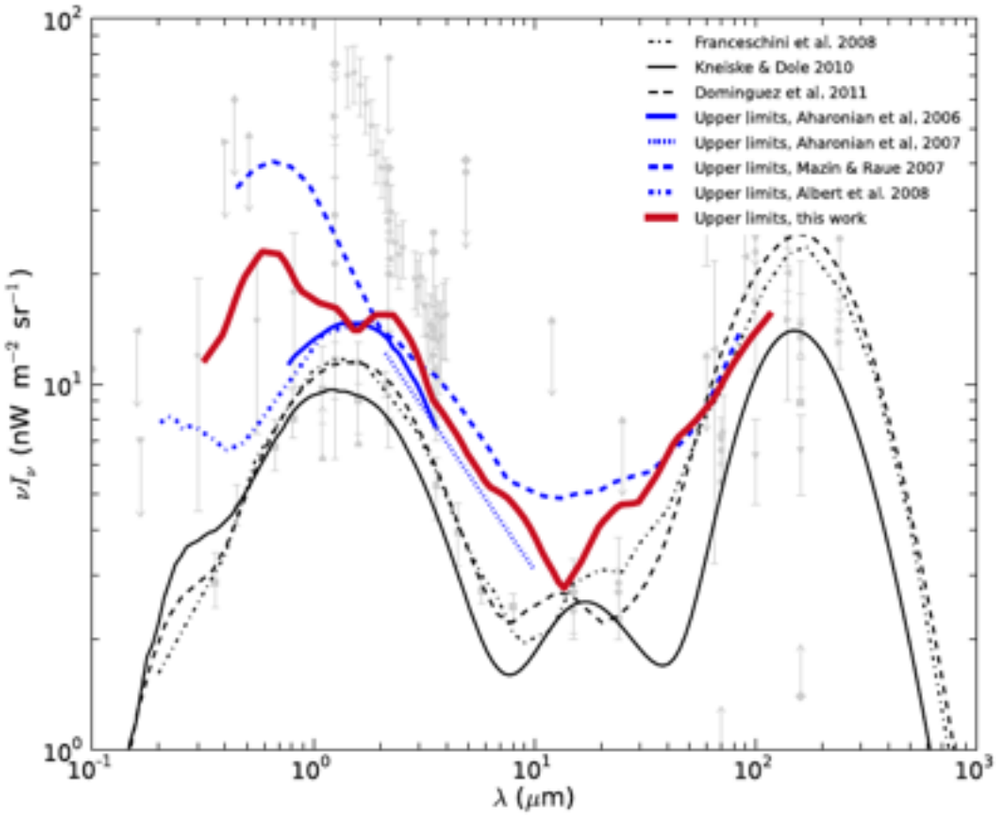
- Combined results from many sources and data from different experiments makes results more robust

Biteau&Williams, arXiv:1502.04166



EBL detection

Meyer, DM,++ A&A 542 A59 (2012)



Stringent upper limits

Cosmology: Hubble parameter

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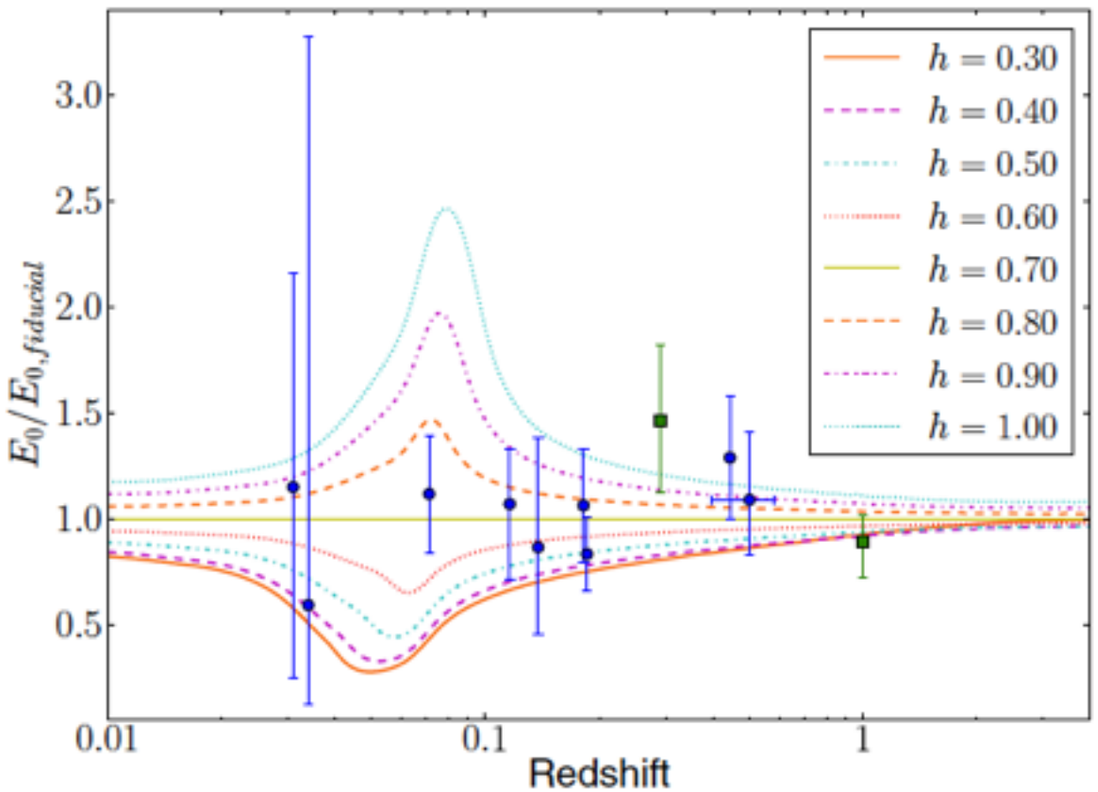
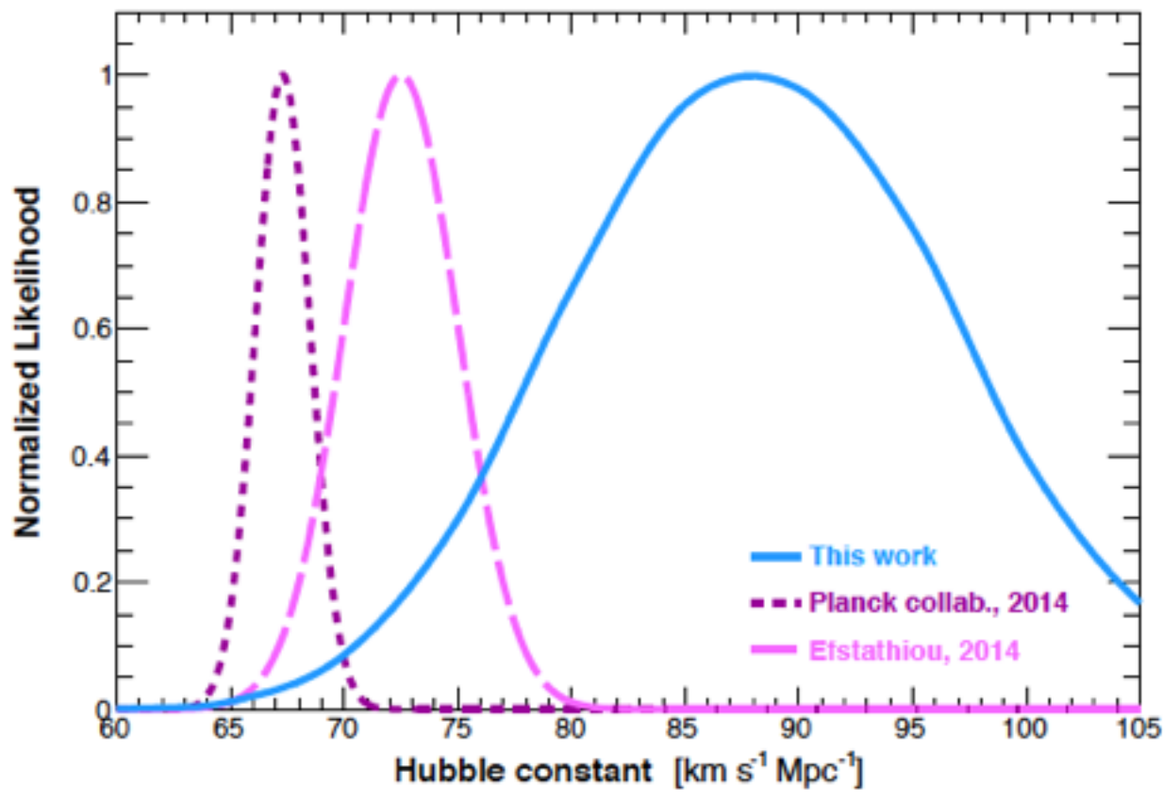
- Once EBL is known, the imprint of the EBL on VHE spectra of AGNs can be used to **independently** estimate their distance

Dominguez++, ApJ 770, 77 (2013)



H_0=($71.8^{+4.6}_{-5.6}$ (stat) $^{+7.2}_{-13.8}$ (syst)) km/s/Mpc

Biteau&Williams, arXiv:1502.04166



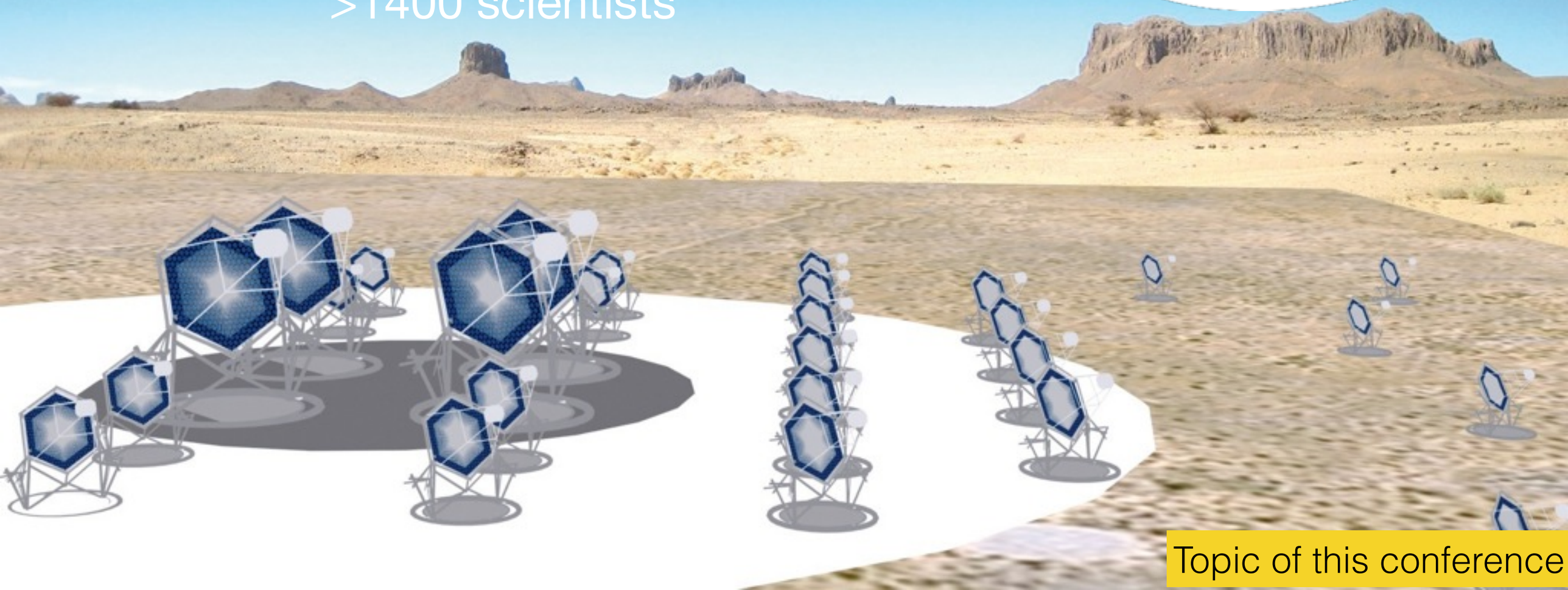
H_0= (88 +/-8 (stat) +/- 13 (syst)) km/s/Mpc

The future in VHE gamma ray astronomy:

10 fold sensitivity of current instruments
10 fold energy range
improved angular resolution
two sites (North / South)
operated as observatory

World-wide cooperation
32 countries
150 institutes
>1400 scientists

cta
cherenkov telescope array

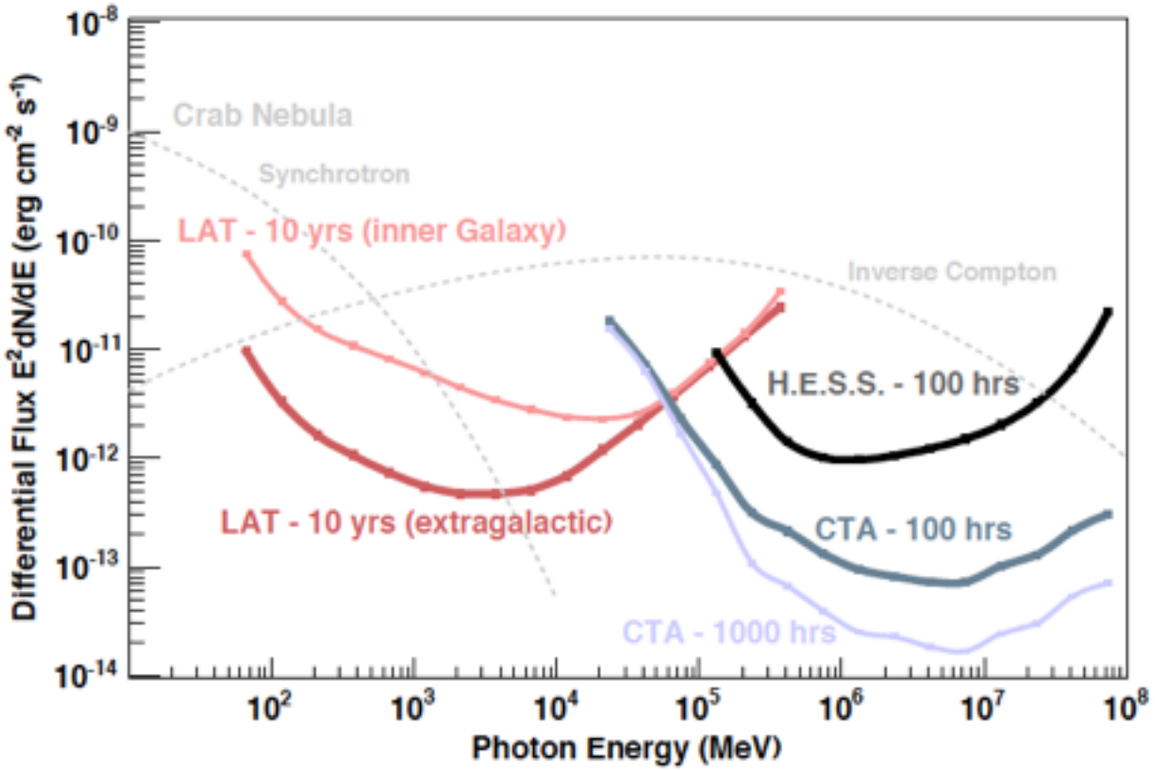


Topic of this conference

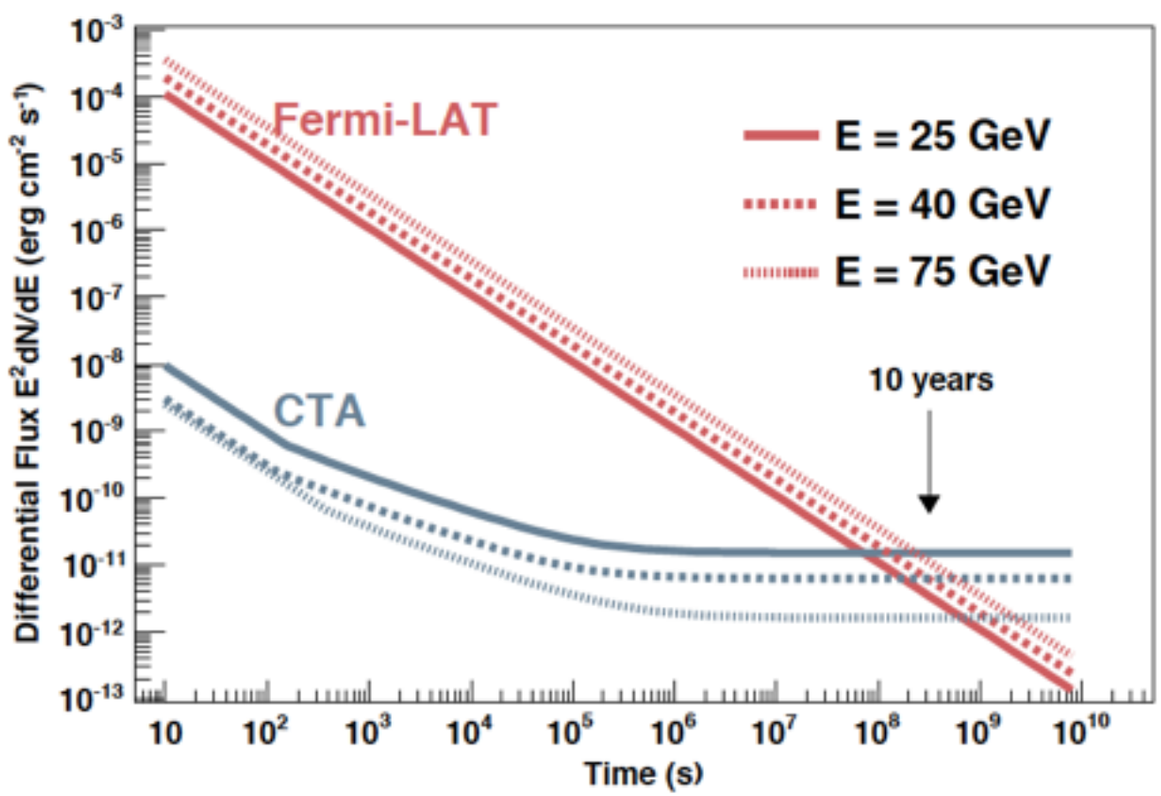
Future prospects: CTA

- CTA will have two observatories, North and South, cover 20 GeV to >300 TeV, survey capabilities

sensitivity vs energy



sensitivity vs time at low energies



Plots from Funk&Hinton, AP 43, 348-355 (2013)

CTA: Key Science Projects

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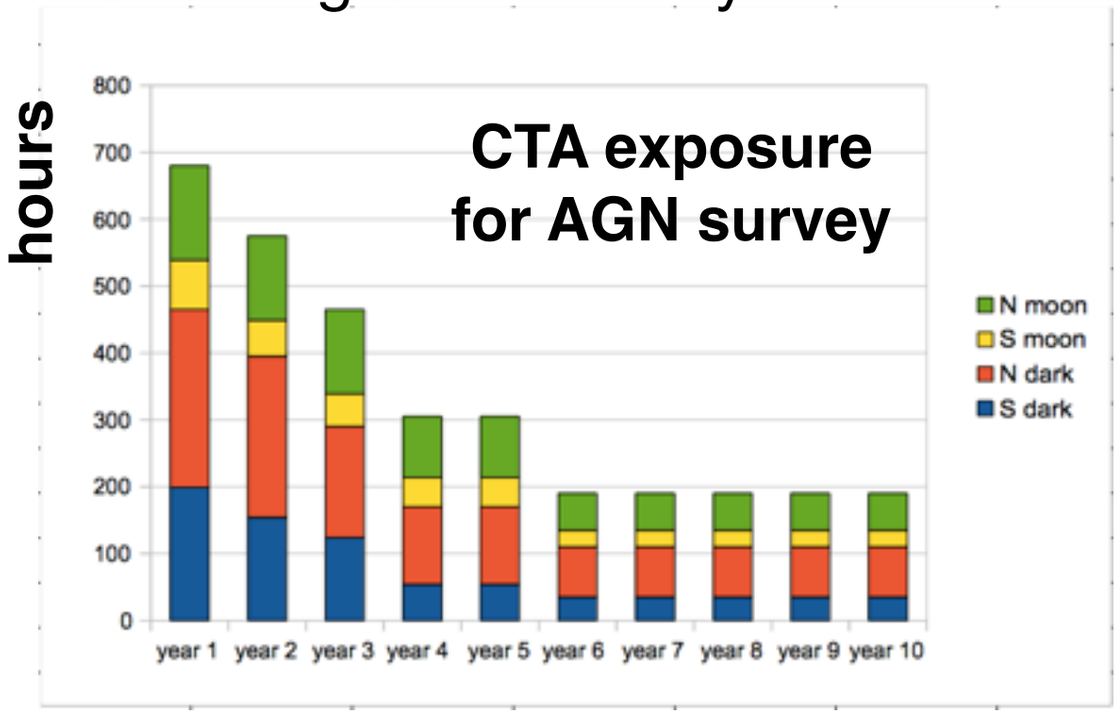
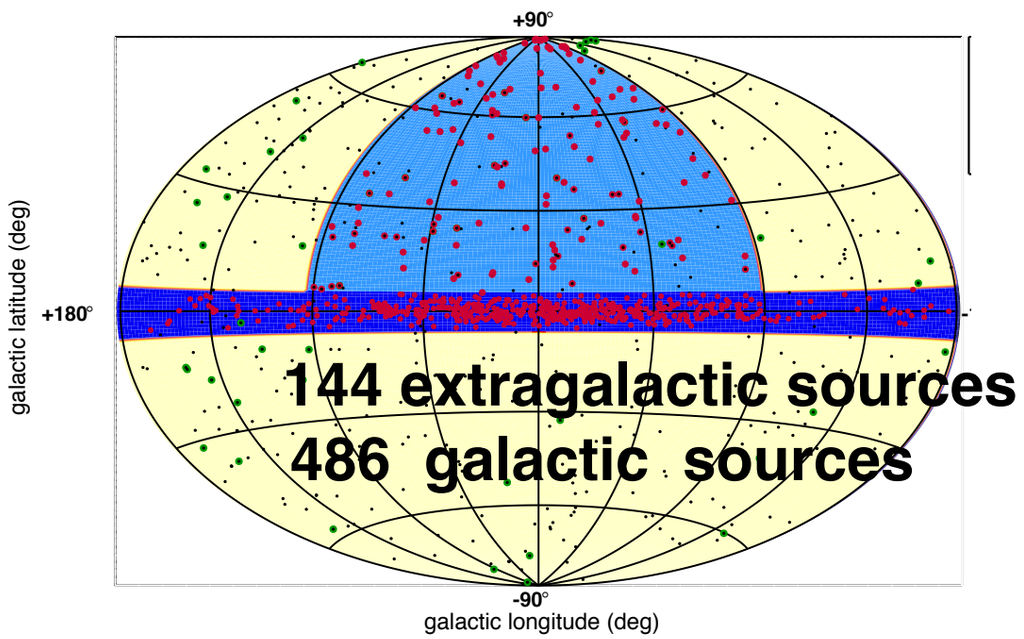
- Three of 10 KSPs will deal (at least partially) with EBL and IGMF:
  - AGN survey:
    - obtain high quality spectra of ~50 bright blazars at different z
    - extensive Target of Opportunity program
  - GRBs: chance to obtain high quality signal from z>1 (actually there is no upper limit on z)
  - Extragalactic survey: find new hard spectra GeV-TeV sources



Time distribution for extragalactic KSPs

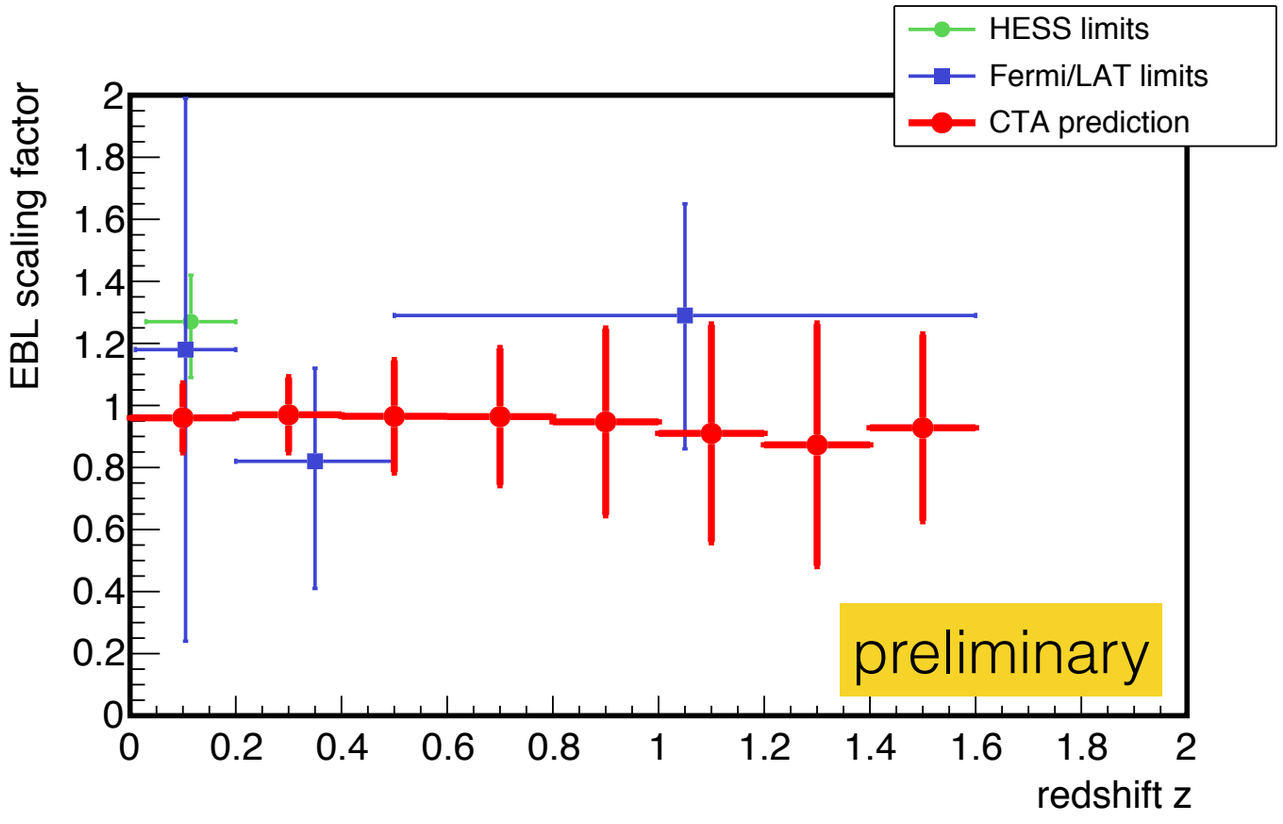


CTA Galactic and extragalactic surveys

Future prospects: CTA

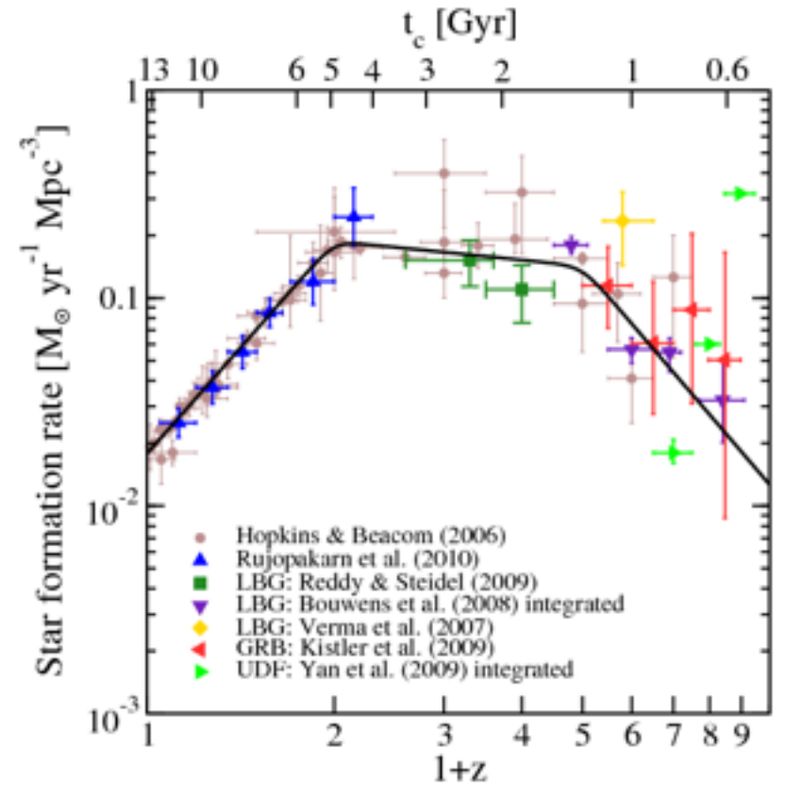
- **<u>CTA can measure the evolution of the EBL</u>**, which can help constraining the star and galaxy evolution scenarios

sensitivity of CTA to resolve EBL evolution



DM, in preparation

Star formation rate is not well determined at z>1



Horiuchi & Beacom, ApJ 723, 329-341 (2010)

Conclusion

- EBL can be constrained and detected indirectly with Fermi/LAT and Imaging Cherenkov Telescopes
- Derived limits are **consistent with the EBL from resolved sources**
- which means that the current limits and measurements suggest that at z=0 **there is no significant contribution to the EBL by unresolved sources**
- Some pile-ups at high energies in the spectra of blazars are intriguing but not significant yet (could be a sign of axion-like particles)
- CTA will be an effective machine to resolve EBL evolution to z=2

BACKUP

Limits from IACTs: axions

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- Contradicting results:
  J. Biteau & D. Williams (2015) vs. D. Horns & M. Meyer (2012)