Detection of VHE Gamma-Rays from AGN close to z~1

by Andrew Taylor

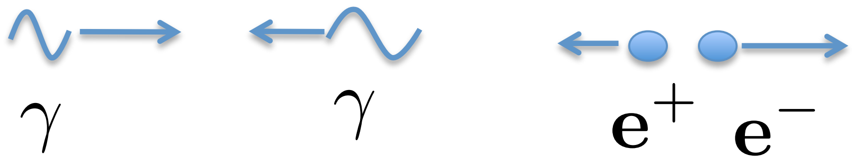
Based on: **Astron.Astrophys. 575 (2015) A21**

H.E.S.S.

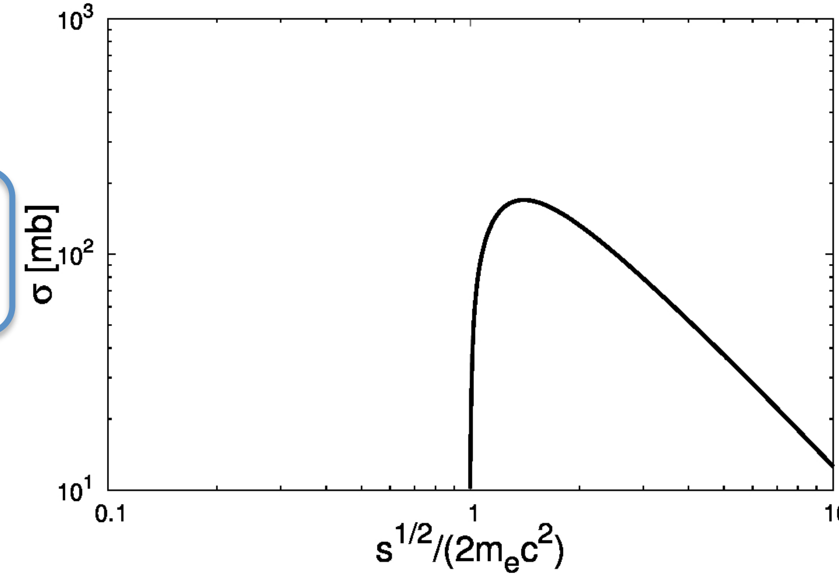
Talk Outline

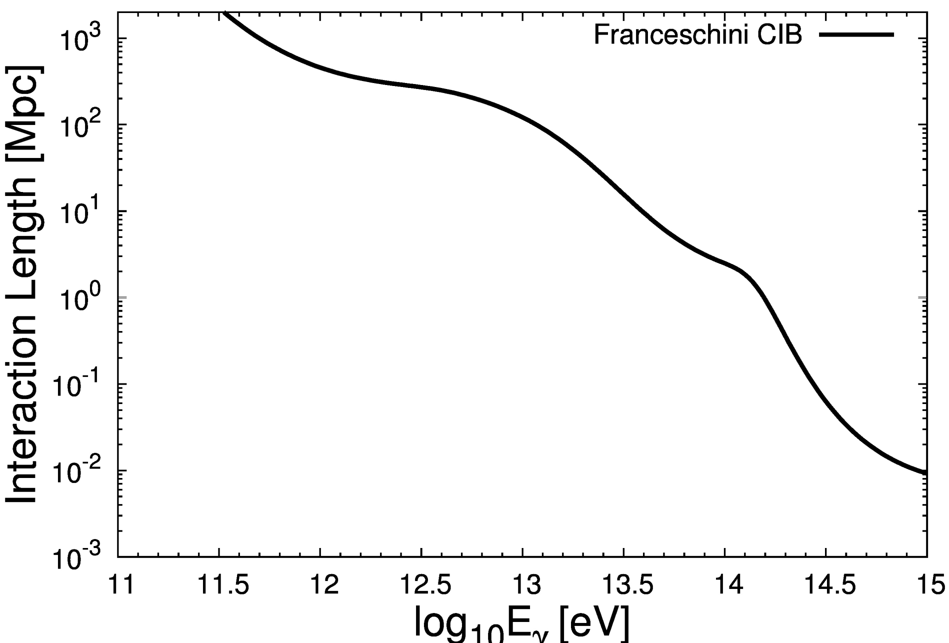
- EBL attenuation effects for high redshift sources
- Present observational situation for z~1 AGN
- Future observations- where to look and with what?
- The possibility of seeing “over the horizon”
- Conclusion

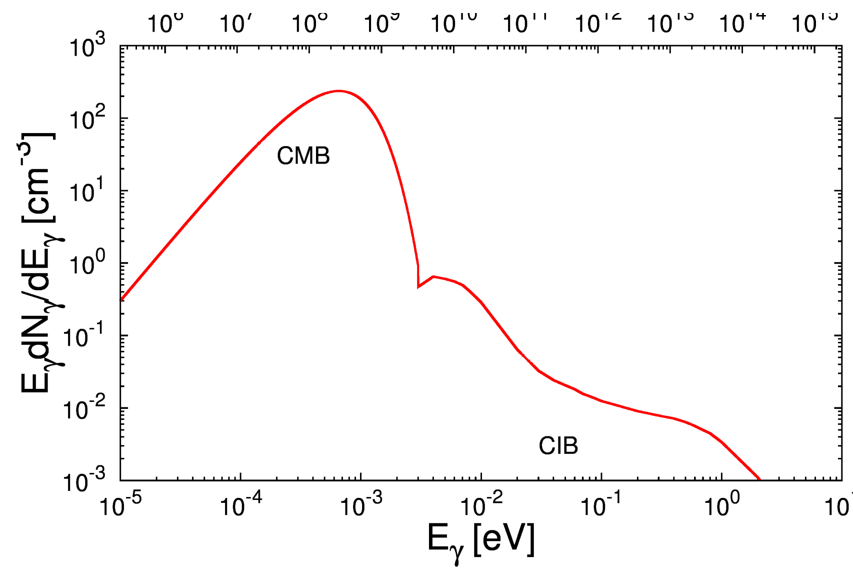
Extragalactic Background Light (EBL) Attenuation of Gamma-Rays



$$R = \frac{2m_e^2}{E_\gamma}\int \frac{1}{\epsilon^2}\frac{dn}{d\epsilon}d\epsilon \int_0^{E_\gamma \epsilon/m_e} \epsilon' \sigma_{\gamma\gamma}(E_\gamma, \epsilon')d\epsilon'$$







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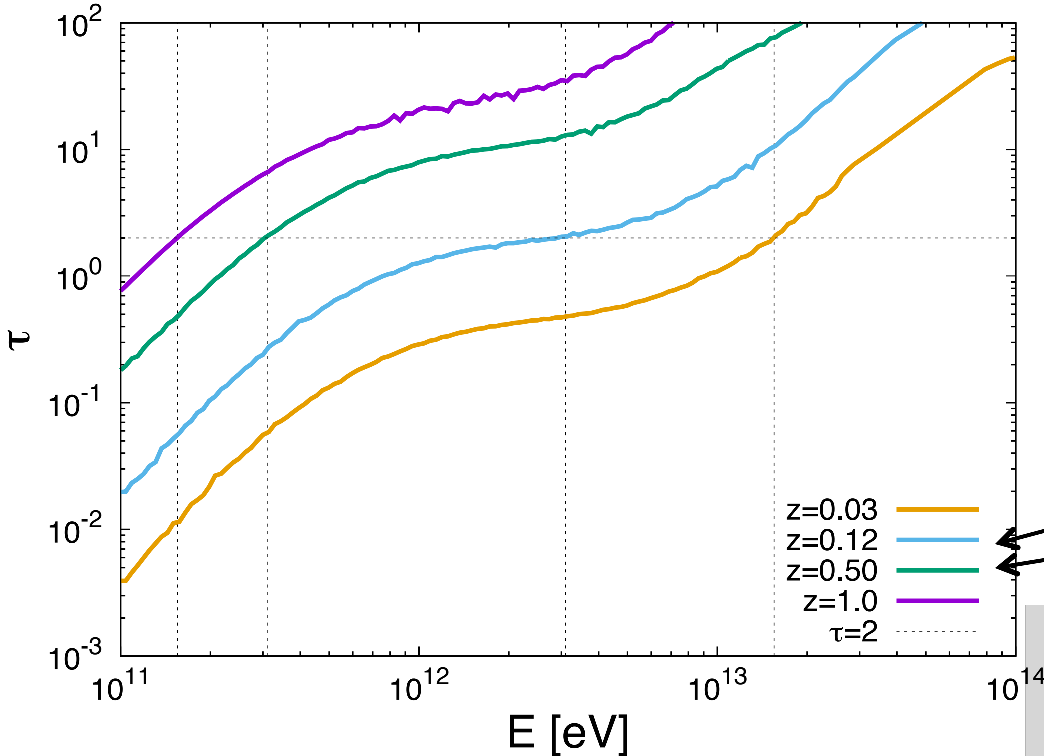
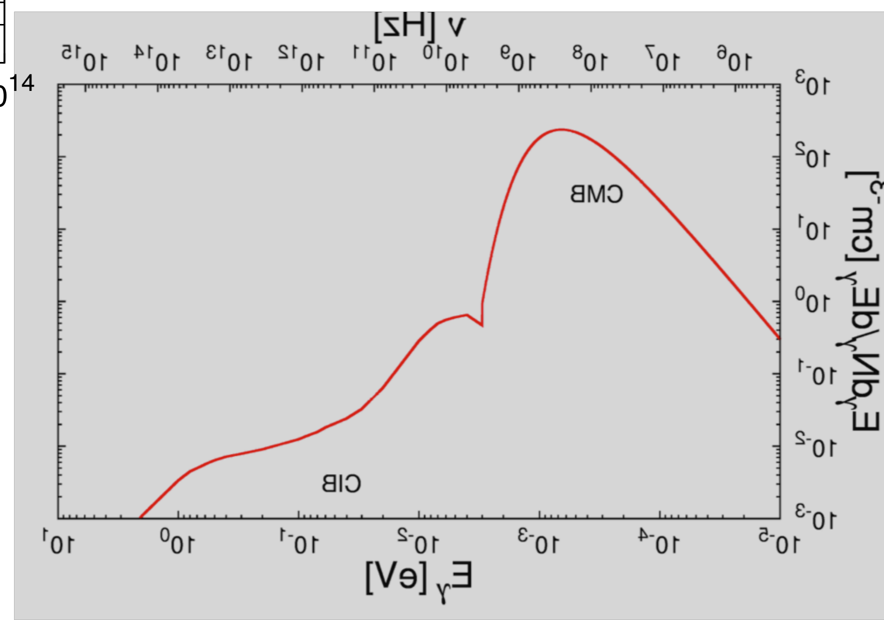
$$E_\gamma^{TeV} E_\gamma^{eV} \approx 1$$

EBL Attenuation



PKS 2155-304

PG 1553+133



$$\frac{\mathbf{E}_{\gamma}^{\mathbf{TeV}}\mathbf{E}_{\gamma}^{\mathbf{eV}}}{(\mathbf{1}+\mathbf{z})^{\mathbf{2}}} \approx \mathbf{1}$$

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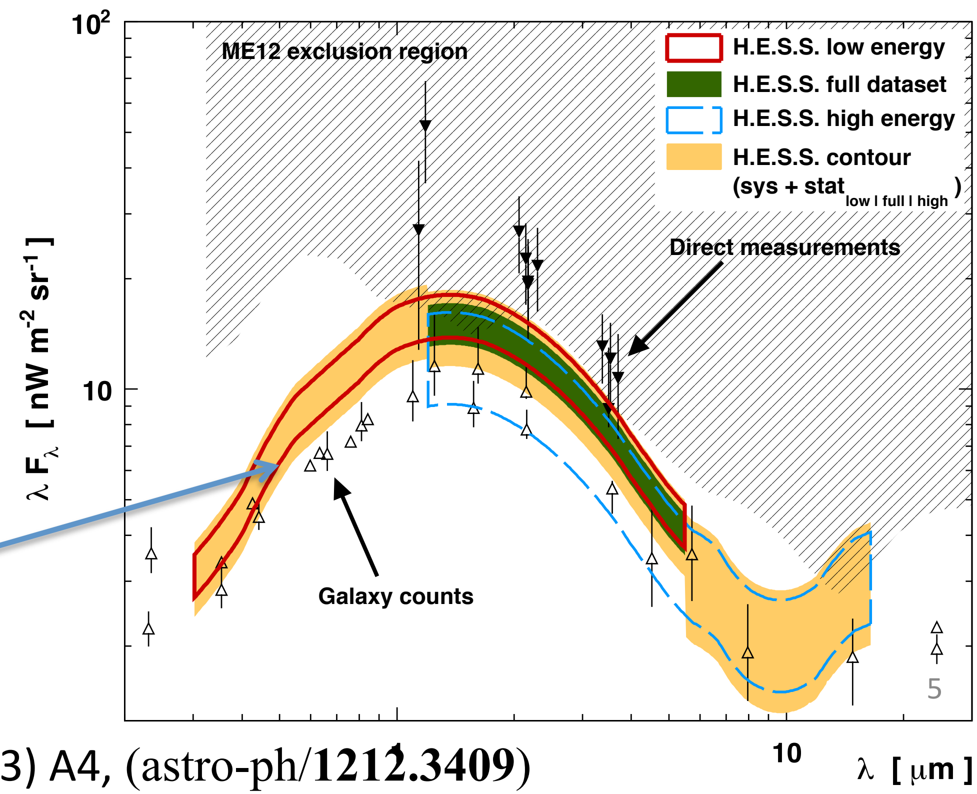
Our Understanding of the Part of the EBL Relevant for z~1 AGN

$$\frac{\mathbf{dN_{obs}}}{\mathbf{dE}} = \frac{\mathbf{dN_{intr.}}}{\mathbf{dE}} \times \exp(-\mathbf{a} * \tau)$$

$$\mathbf{a = 1.27^{+0.18}_{-0.15} \pm 0.25_{sys}}$$

Data set	z	$E_{\min} - E_{\max}$ [TeV]	$\lambda_{\min} - \lambda_{\max}$ [μm]
Mrk 421 (*1*)	0.031	0.95 – 41	1.2 – 49
Mrk 421 (2)	0.031	0.95 – 37	1.2 – 44
Mrk 421 (*3*)	0.031	0.95 – 45	1.2 – 53
PKS 2005-489 (*1*)	0.071	0.16 – 37	0.22 – 44
PKS 2005-489 (2)	0.071	0.18 – 25	0.25 – 30
PKS 2155-304 (*2008*)	0.116	0.13 – 19	0.30 – 23
PKS 2155-304 (*1*)	0.116	0.13 – 5.7	0.19 – 6.8
PKS 2155-304 (2)	0.116	0.13 – 9.3	0.19 – 11
PKS 2155-304 (*3*)	0.116	0.13 – 14	0.19 – 17
PKS 2155-304 (*4*)	0.116	0.18 – 4.6	0.19 – 5.5
PKS 2155-304 (*5*)	0.116	0.13 – 5.7	0.27 – 6.8
PKS 2155-304 (*6*)	0.116	0.15 – 5.7	0.19 – 6.8
PKS 2155-304 (*7*)	0.116	0.20 – 7.6	0.22 – 9.0
1ES 0229+200	0.14	0.29 – 25	0.45 – 30
H 2356-309	0.165	0.11 – 34	0.18 – 40
1ES 1101-232	0.186	0.12 – 23	0.20 – 27
1ES 0347-121	0.188	0.13 – 11	0.22 – 13

$$\mathbf{z > 0.5}$$



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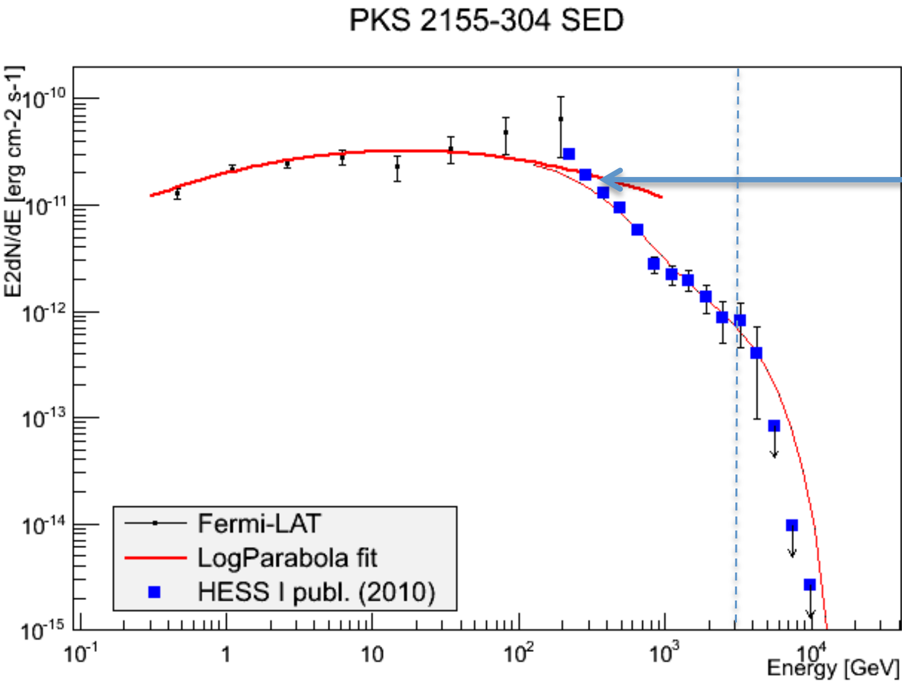
Astron. Astrophys. 550 (2013) A4, (astro-ph/**1212.3409**)

Probing the EBL Attenuation with Different Sources



Note EBL induced break features for "high" redshift AGN occur at Fermi/HESS transition energy range

Range of redshifts due to present uncertainty in source's value

$$\frac{\mathbf{E}_\gamma^{\mathbf{TeV}}\mathbf{E}_\gamma^{\mathbf{eV}}}{(\mathbf{1}+\mathbf{z})^{\mathbf{2}}} \approx 1$$

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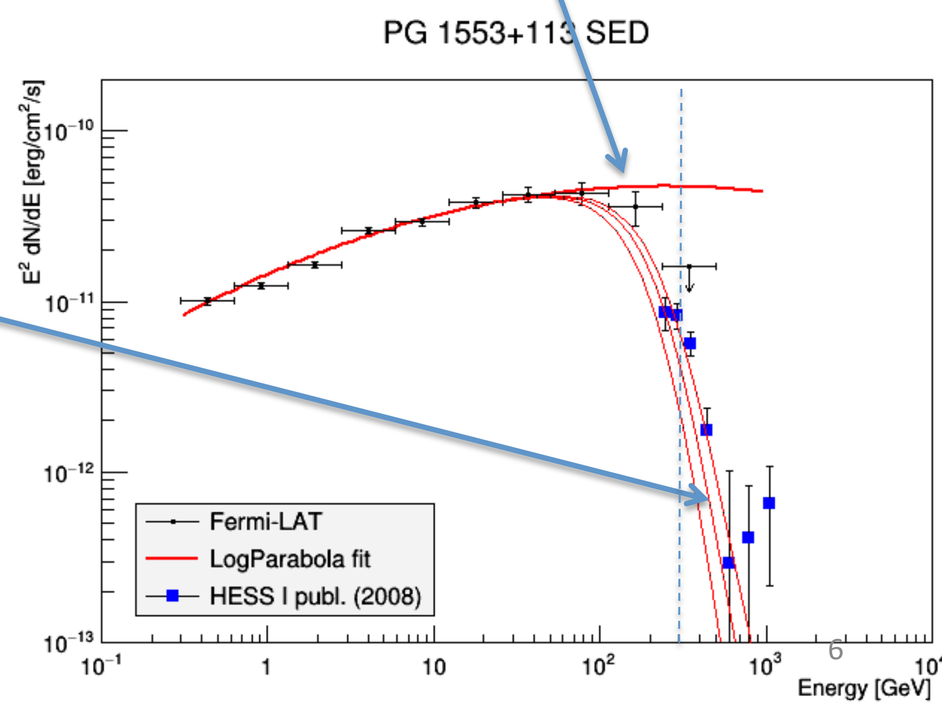
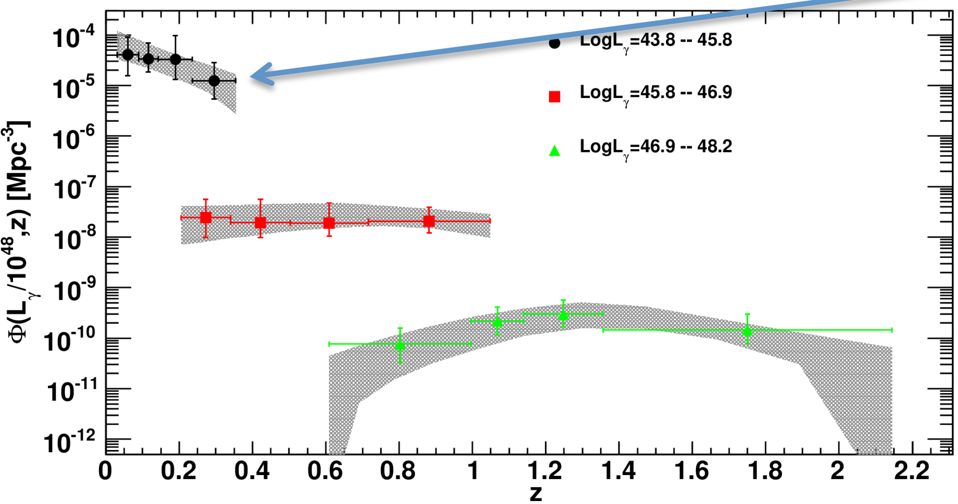


Future ACT Tests of Blazar Evolution/Location

- Reminder:
  Blazar -> BL Lac (FR1) -> HSP

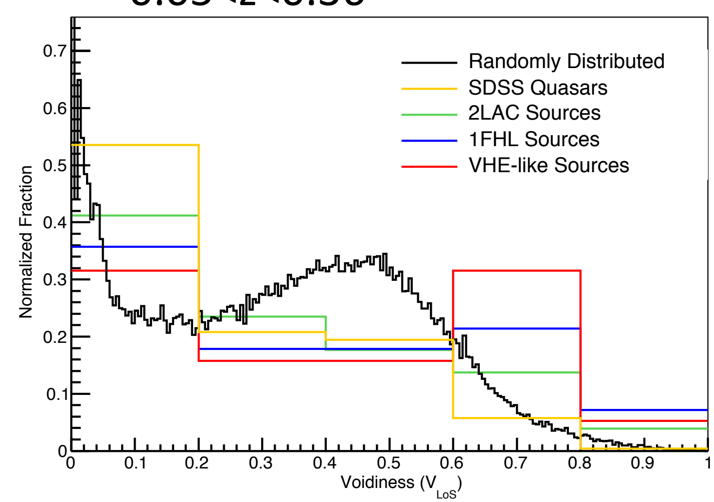
- Negative evolution supports idea that FSRQ (gas accreting) AGN evolve into BL Lac (gas starved) AGN

HSP AGN



From astro-ph/1310.0006 (Ajello et al. 2014)

0.05<z<0.36



From astro-ph/1407.6370 (Furniss et al. 2015)

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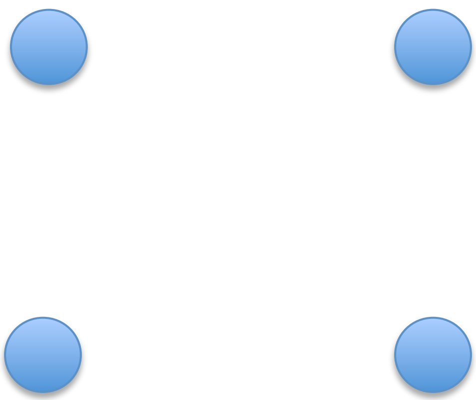
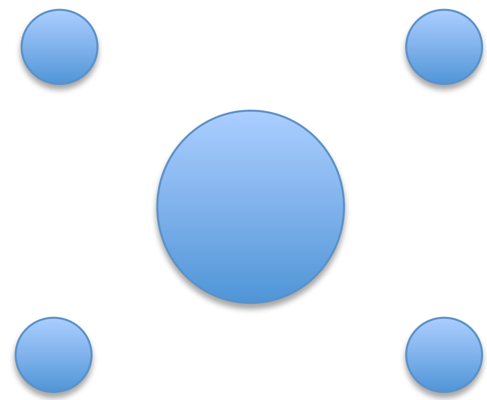
Future Observations- The "PhaseII" Era

H.E.S.S. Phase I: 2002-2012
- 4 telescopes of 12m
- 100 GeV - 100 TeV

H.E.S.S. Phase II: 2012-++
- Addition of CT5 to the array: 28m
- ~30 GeV - 100 TeV





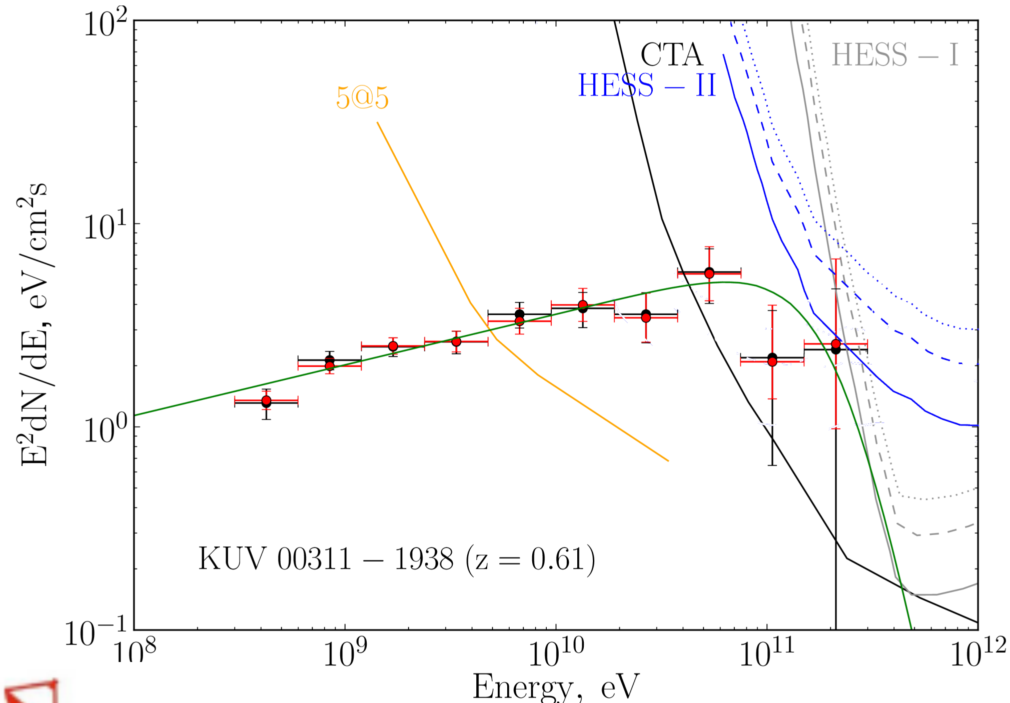
CT5 allows E < 100 GeV measurements — best for:
- High redshift AGN + GRBs
- EBL studies at large z

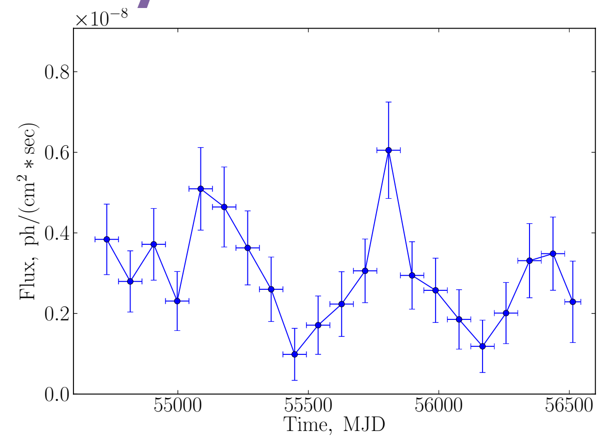
Future Observations- Where to Look?

Table of z>0.5, E > 100 GeV Fermi, high redshift, candidate sources

	Name	RA	Dec	Type	z	N_{30-100}	$N_{0.1}$	$N_{0.2}$	E_{max}	L/L_{Mrk421}	P
1	PKS 0139-09	25.358	–9.479	BLL	0.733	3	1	0	138	28	1.5E-03
2	PKS 0426-380	67.168	–37.939	BLL	1.111	19	2	0	134	595	1.7E-06
3	B2 0912+29	138.968	29.557	BLL	1.521(?)	9	1	0	126	680	1.9E-03
4	PMN J0953-0840	148.261	–8.672	BLL	0.590	5	1	0	120	107	1.4E-03
5	Ton 116	190.803	36.462	BLL	1.065(?)	15	1	0	114	468	2.1E-03
6	PG 1246+586	192.078	58.341	BLL	0.847(?)	20	1	0	104	289	1.6E-03
7	B3 1307+433	197.356	43.085	BLL	0.691	4	1	0	104	94	1.3E-03
8	BZB J1436+5639	219.240	56.657	BLL	0.680	5	1	0	106	48	2.5E-03
9	PKS 1424+240	216.75	23.800	BLL	0.6035	46	4	2	248	28	3.0E-13
10	4C +55.17	149.409	55.383	FSRQ	0.899	19	1	0	141	527	2.8E-03
11	PKS 1124-186	171.768	–18.955	FSRQ	1.048	6	1	0	108	336	1.5E-03
12	TXS 1720+102	260.685	10.227	FSRQ	0.732	0	1	0	187	19	2.8E-03
13	PKS 1958-179	300.238	–17.816	FSRQ	0.652	4	1	0+1	119	14	3.4E-03
14	PKS 2142-75	326.806	–75.603	FSRQ	1.138	1	1	0	135	62	2.5E-03
15	1RXS 005447.2-245532	13.695	–24.925	AGU	0.610	–	1	0	–	22	1.0E-03
16	KUV 00311-1938[1]	8.393	–19.359	BLL	0.610	14	0	2	152	121	1.7E-05
17	B3 0133+388[2]	24.135	39.100	BLL	0.750	29	0	1	108	453	1.2E-02
18	RGB J0250+172	42.658	17.203	BL	1.100(?)	4	0	1	358	179	1.1E-02
19	PKS B1130+008	173.190	0.574	BLL	0.678	1	0	1	140	24	6.4E-03
20	S4 1250+53	193.300	53.020	BLL	0.550	4	0	1	145	58	6.8E-03
21	S4 1749+70	267.137	70.098	BLL	0.770	10	0	1	110	69	1.0E-02

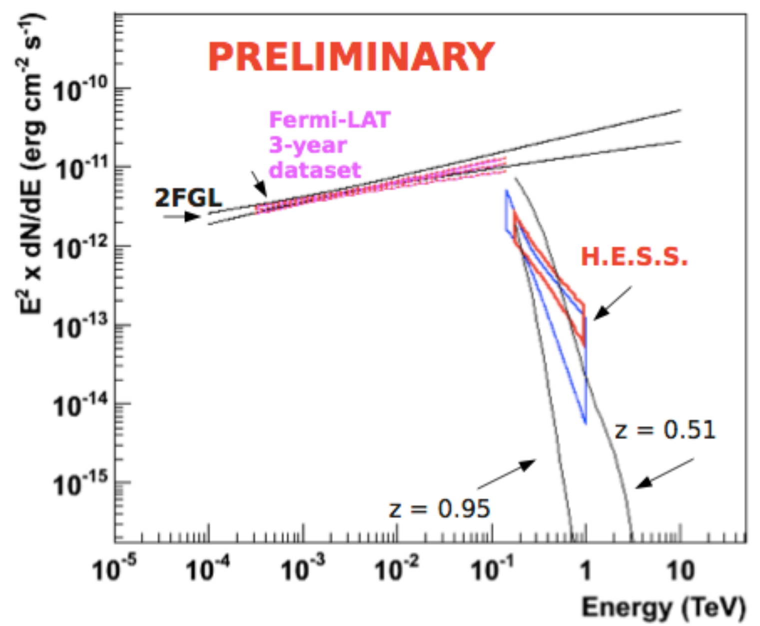
High Redshift AGN Recently Detected!





KUV 00311 (z=0.61)

AIP Conf.Proc. 1505 (2012) 490-493

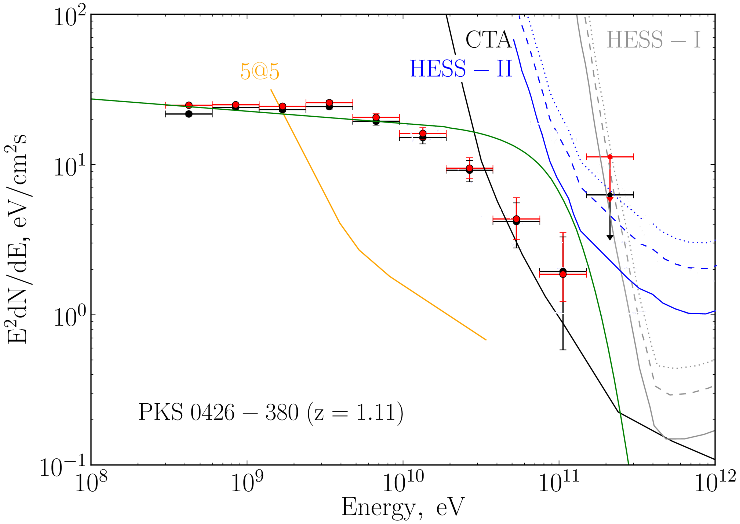


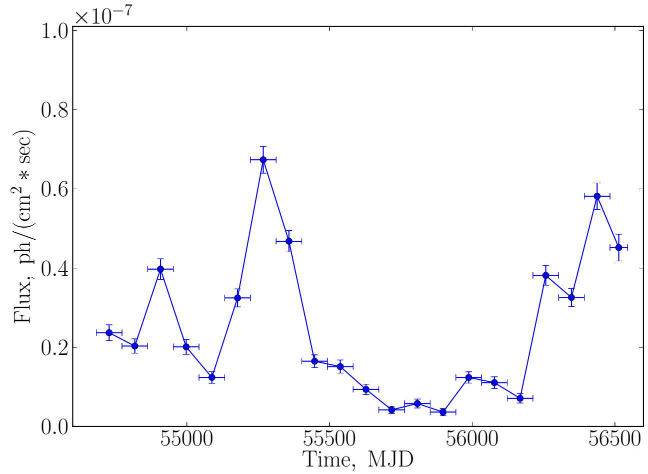
ApJ Letters, 785, L16, 2014

PKS 1424+240 which was also motivated from the list was also "recently" detected → sits along voidy line of sight!

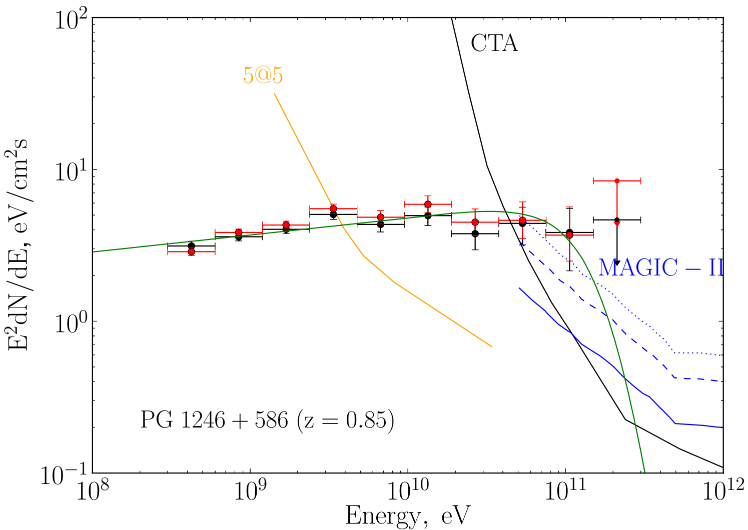
Future Observations- Where to Look?

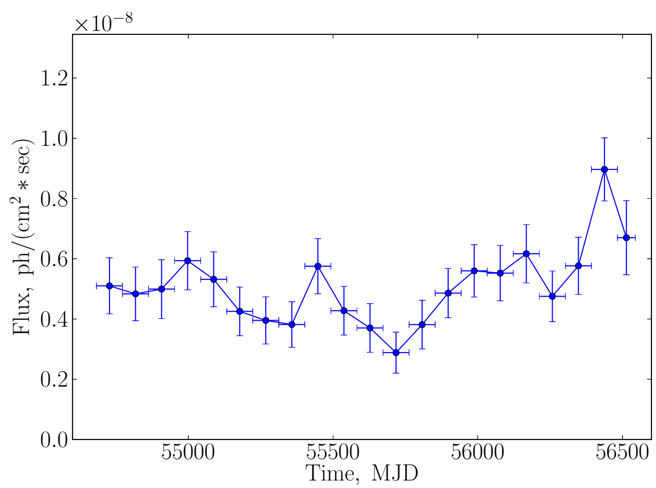
PKS 0426-380 (z=1.11)





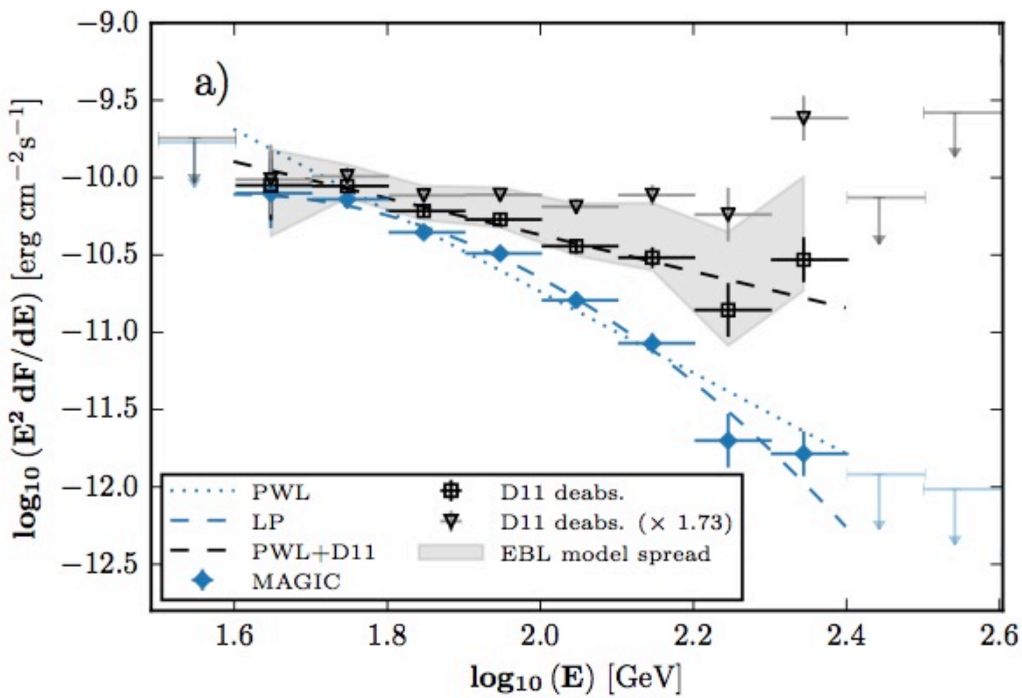
PG 1246+586 (z=0.85)





High Redshift Record- AGN Recently Detected by ACTs

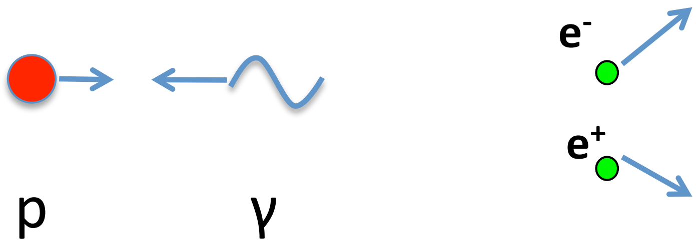
PKS 1441+25 (z=0.94)

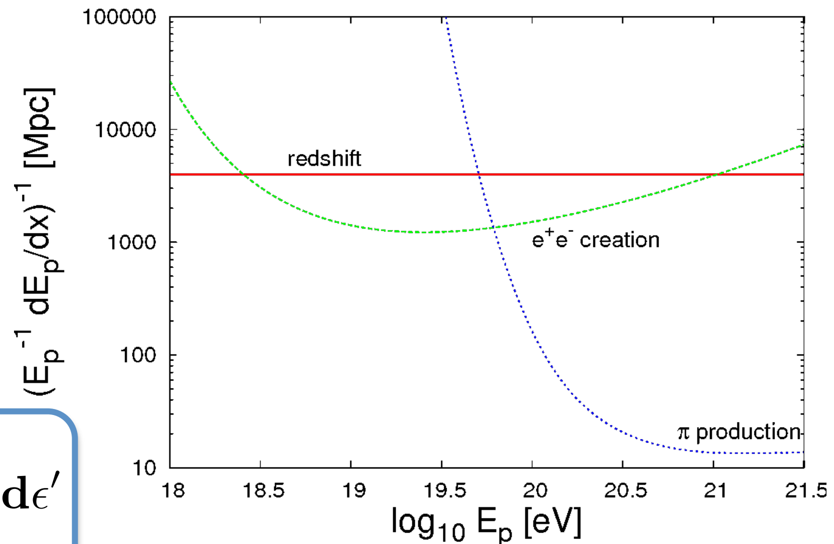


ApJ Letters, Volume 815, 22A_,(astro-ph/**1512.04434**)

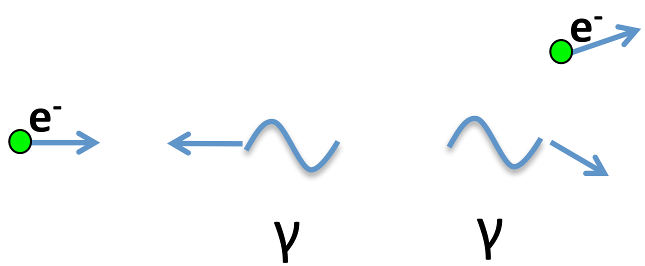
ApJ Letters, Volume 815, 23A_,(astro-ph/**1512.04435**)

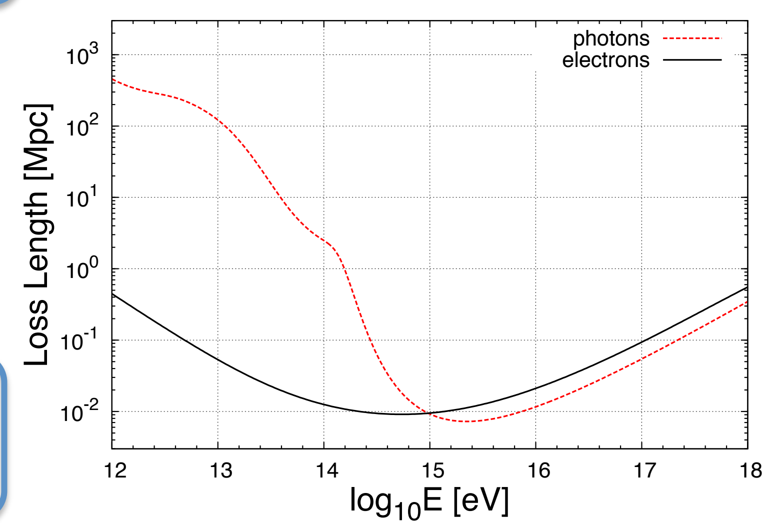
Seeing "Over the Horizon"





$$\mathbf{R} = \frac{2\mathbf{m_p^2}}{\mathbf{E_p^2}} \int \frac{1}{\epsilon^2} \frac{\mathbf{dN_\gamma}}{\mathbf{d}\epsilon} \mathbf{d}\epsilon \int_0^{4\mathbf{E_p}\epsilon/\mathbf{m_p}} \mathbf{k_{p\gamma}} \epsilon' \sigma_{\mathbf{p}\gamma}(\mathbf{E_p}, \epsilon') \mathbf{d}\epsilon'$$





$$\mathbf{R} = \frac{2\mathbf{m_e^2}}{\mathbf{E_e^2}} \int \frac{1}{\epsilon^2} \frac{\mathbf{dN_\gamma}}{\mathbf{d}\epsilon} \mathbf{d}\epsilon \int_0^{4\mathbf{E_e}\epsilon/\mathbf{m_e}} \mathbf{k_{e\gamma}} \epsilon' \sigma_{\mathbf{e}\gamma}(\mathbf{E_e}, \epsilon') \mathbf{d}\epsilon'$$

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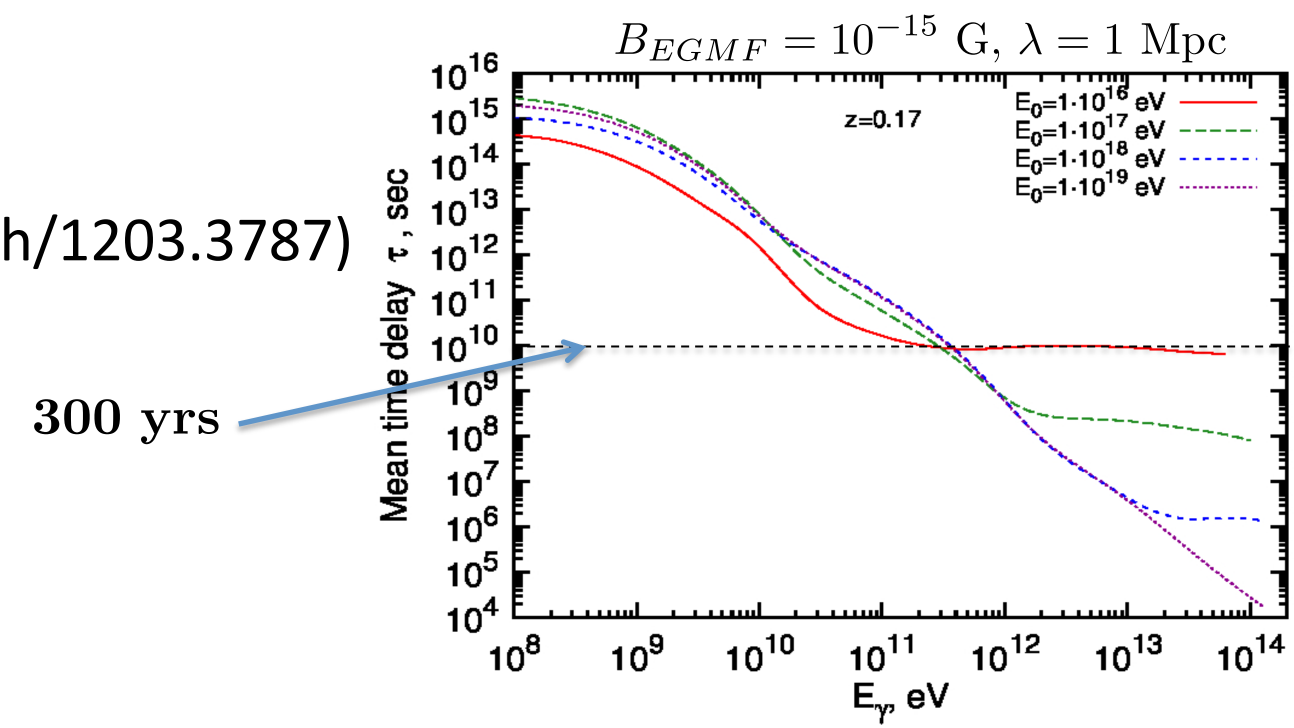
See astro-ph/1206.6715 (Aharonian et al. 2012)

Proton Fed Blazar Emission Model

- Kusenko & Essey have spearheaded the suggestion that some TeV blazars are powered through proton losses in the presence of weak (10^{-15} G) extragalactic magnetic fields
- If this is the case, these blazars would not be expected to show short time-scale variability structure

Prosekin et al. (astro-ph/1203.3787)



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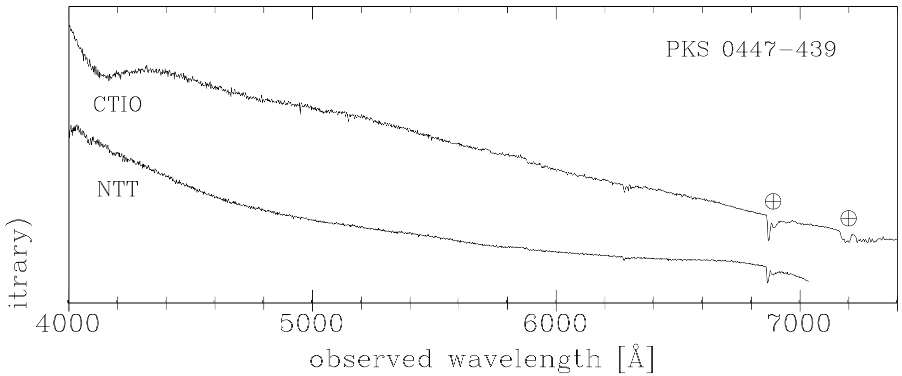
Importance of Accurate Redshift Determination

Potentially the case for B2 0912+29

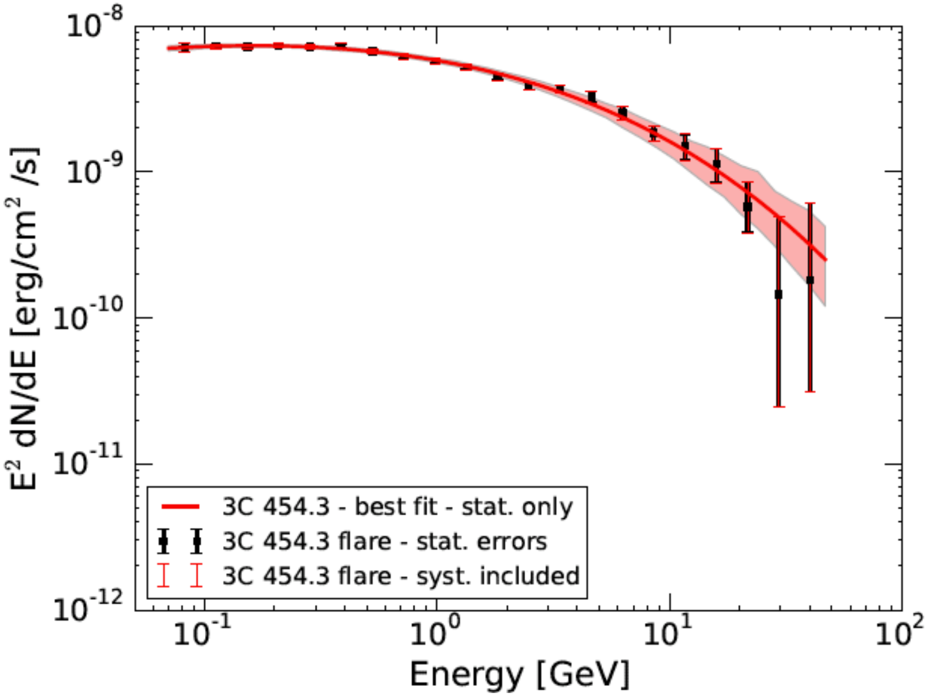
Example case- PKS 0447- 439; proposed to sit at z>1.25 (Landt et al. 2012)

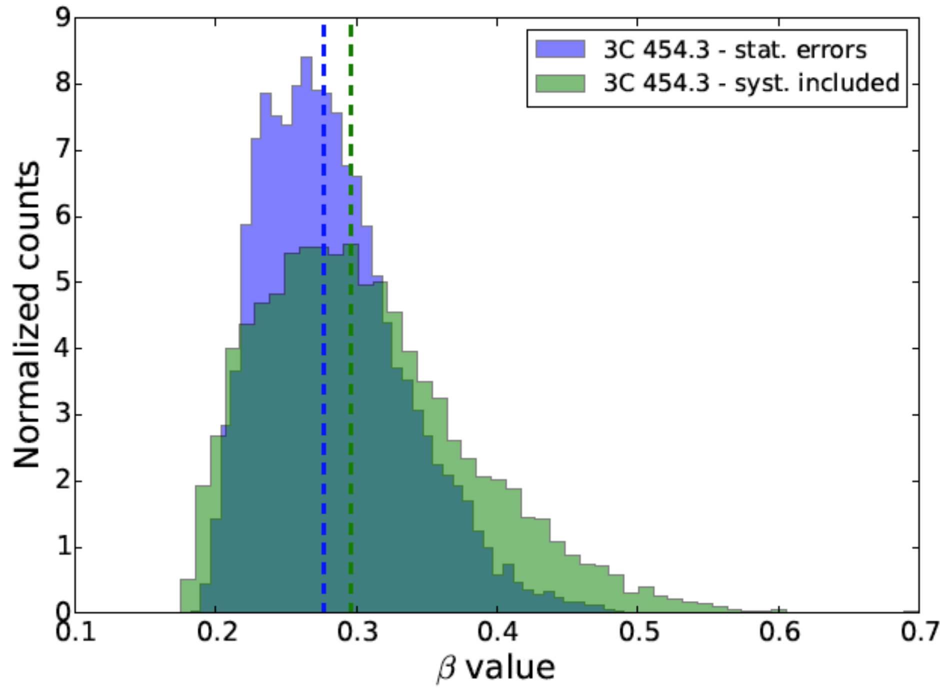


Claim on redshift has since been refuted by Fumagalli et al. (2012), Pita et al. (2012), and the HESS Collaboration (2013)

Very Bright Fermi Flaring AGN- Crazy Diamond (3C 454.3), z~0.86

$$\mathbf{\Phi} = \mathbf{\Phi_0} \left(\frac{\mathbf{E}_\gamma}{\mathbf{E_0}}\right)^{-\mathbf{\Gamma}} \exp\left(-\left(\frac{\mathbf{E}_\gamma}{\mathbf{E_c}}\right)^{\beta_\gamma}\right)$$





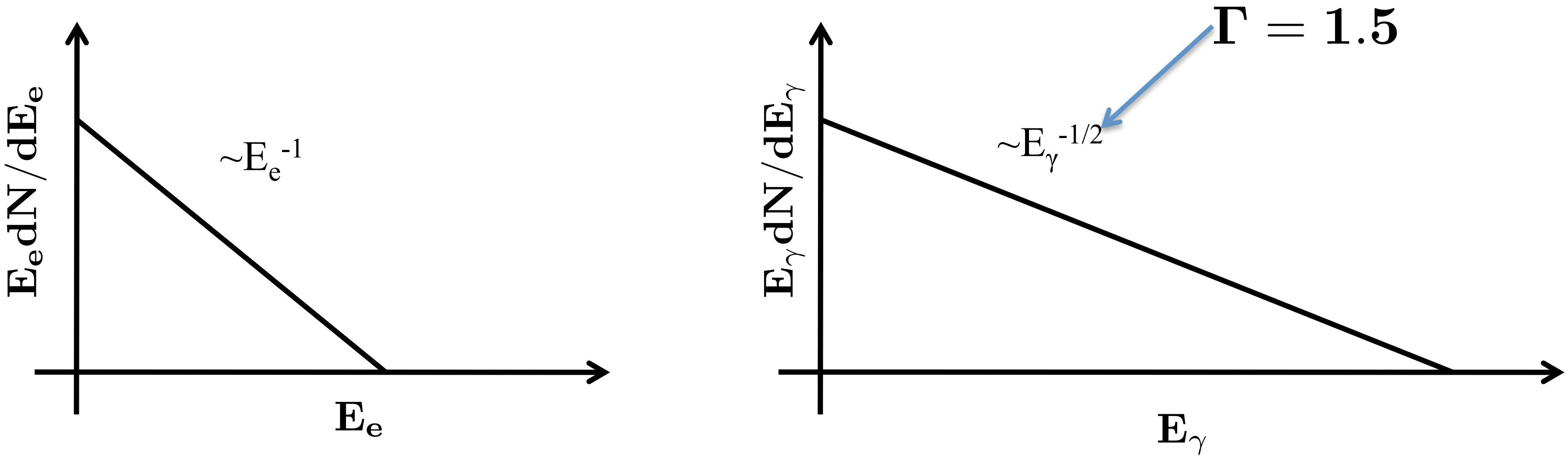
(see poster by Carlo Romoli)

Conclusion

- VHE gamma-rays from high redshift AGN (z~1) are sensitive to a component of the EBL not yet thoroughly probed
- We are now in a new era of ACTs in which these AGN may now be probed….particularly promising for bright variable sources
- Candidate high redshift (z~1) AGN have been suggested from Fermi observations
- Seeing photons from sufficiently beyond the horizon would be very exciting, pointing to different propagation channels
- Future CTA observations of the BRIGHTEST AGN flares (eg. Crazy Diamond) would access to the acceleration mechanism

HESS Upper Limits on the EBL

$$J(E_\gamma) = J_0(E_\gamma) \times e^{-\tau(E_\gamma, z)}$$



$$\frac{\mathbf{dN}}{\mathbf{dE_\gamma}} \propto \mathbf{E_\gamma^{-\Gamma}}$$

Assume intrinsic gamma-ray spectra have Γ > 1.5

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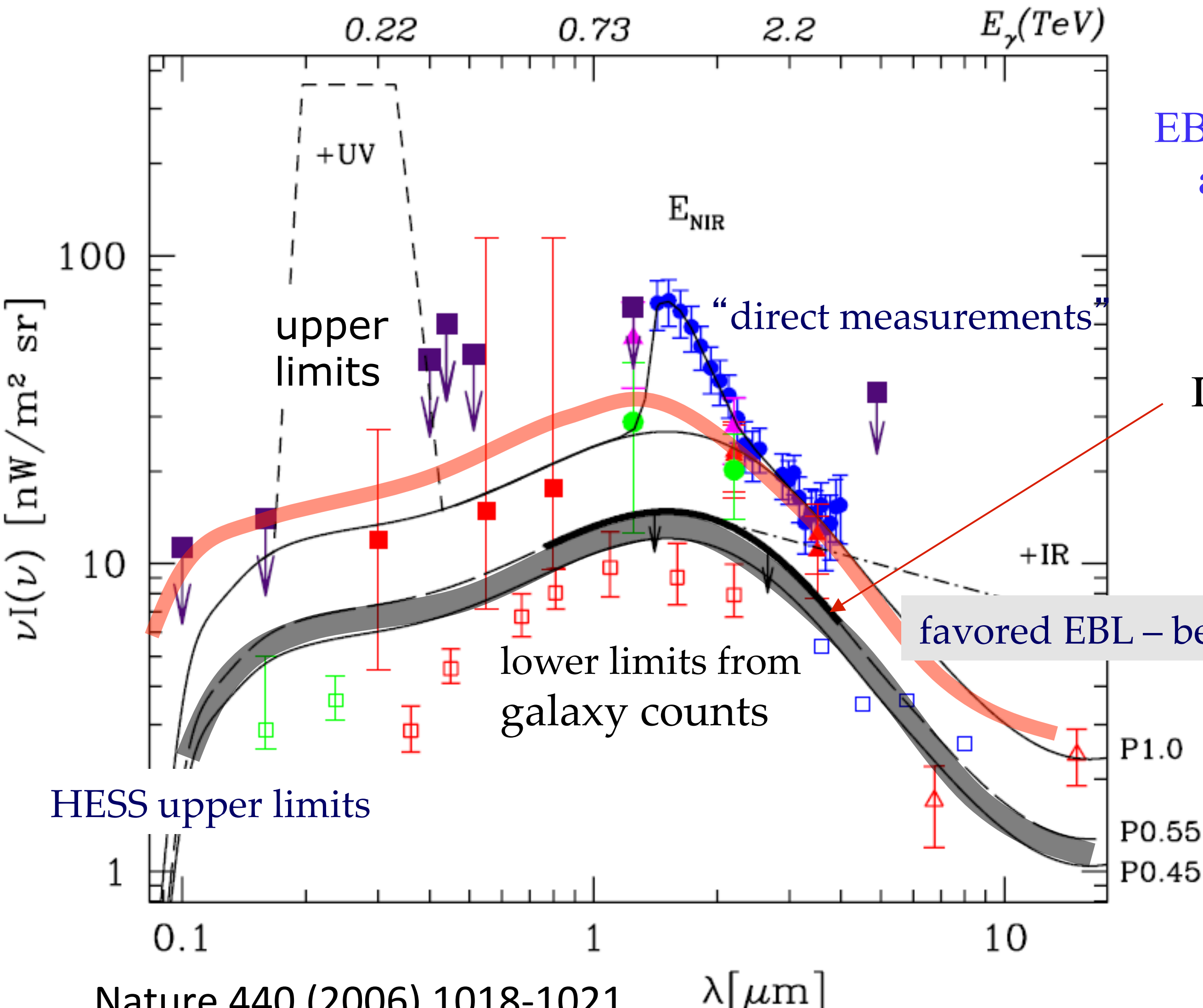
HESS Upper Limits on EBL- Good Agreement with Recent EBL studies



EBL (almost) resolved at NIR ?

Γ=1.5

favored EBL – before HESS

Nature 440 (2006) 1018-1021
astro-ph/**0508073**

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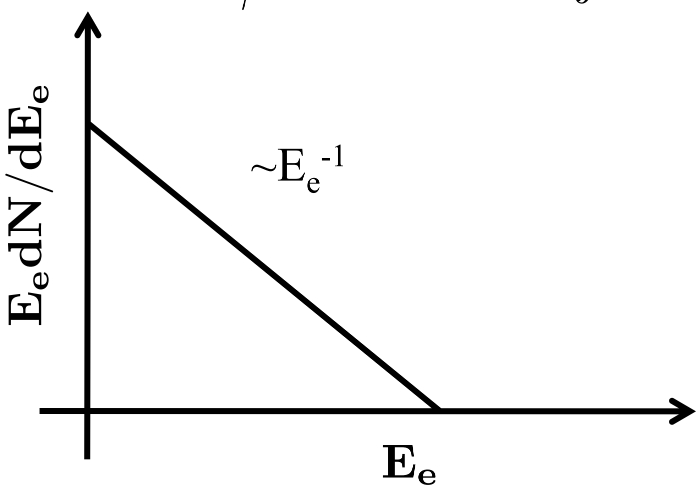
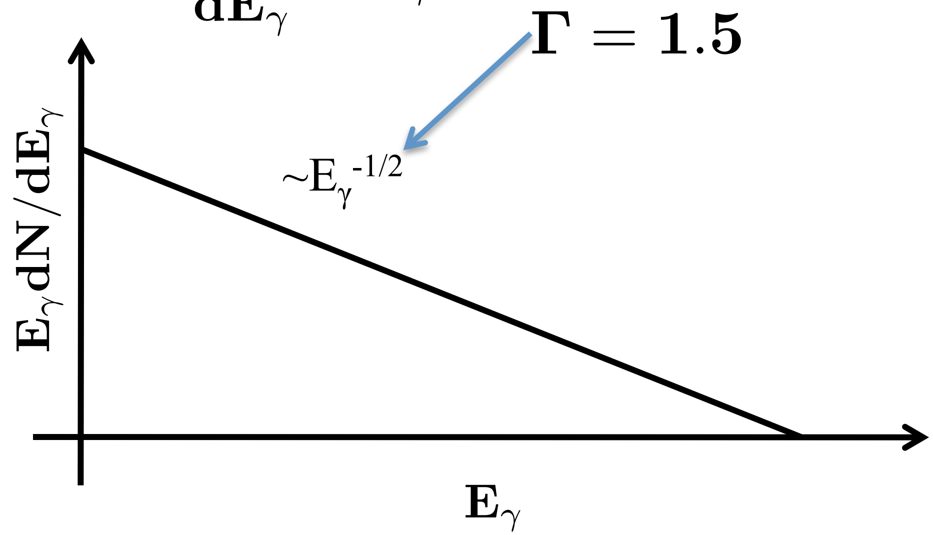
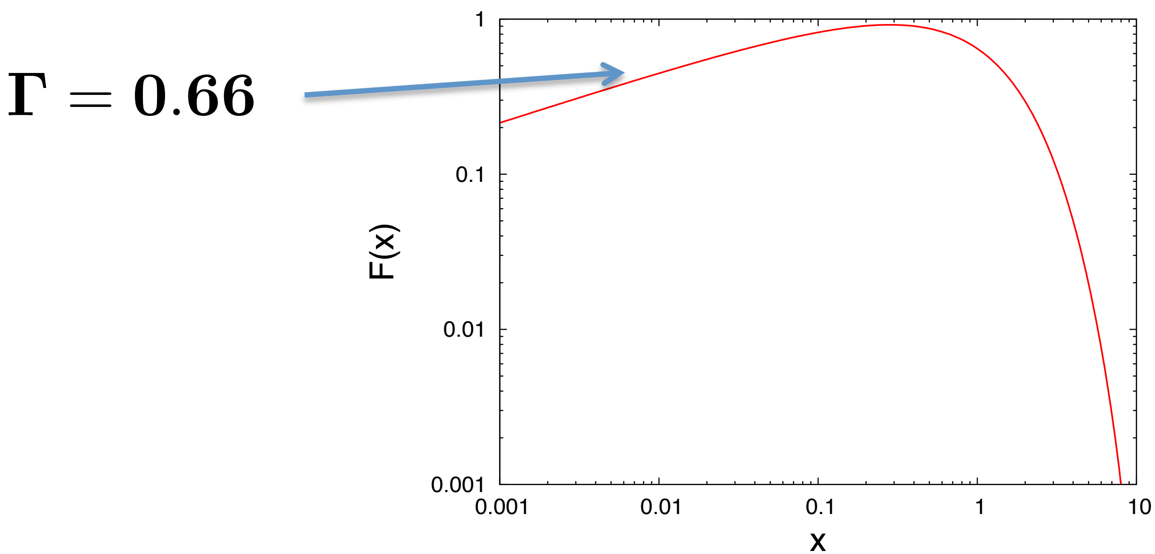
Hard Spectra can be Problematic

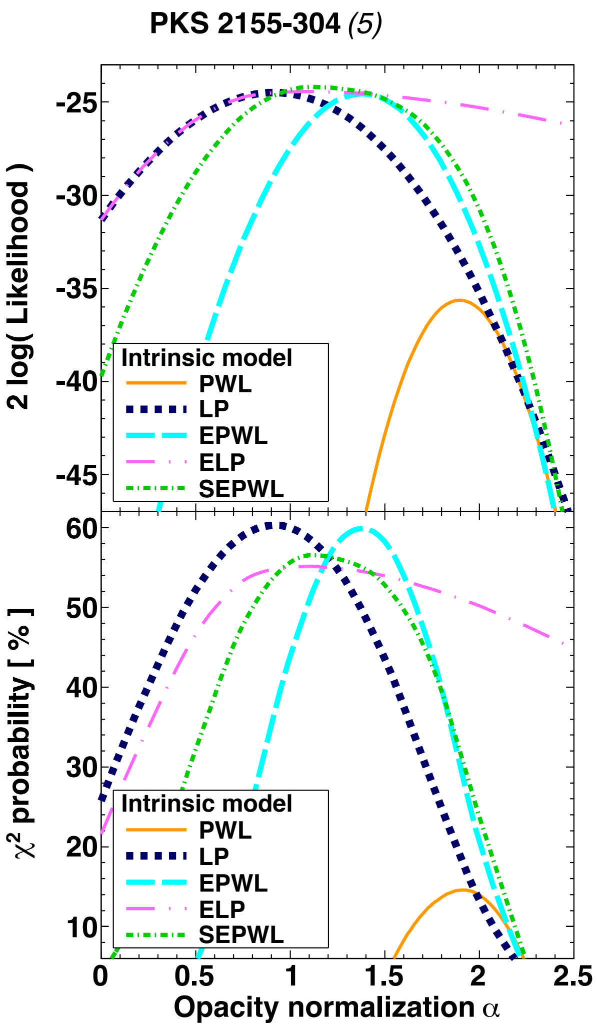
$$\mathbf{E_\gamma \frac{dN}{dE_\gamma} \propto E_\gamma^{-(\alpha-1)/2} \int F(x) x^{(\alpha-3)/2} dx}\,,\quad \mathbf{\frac{dN}{dE_\gamma} \propto E_\gamma^{-\Gamma}}$$







HESS Upper Limits on EBL- Good Agreement with Recent EBL studies



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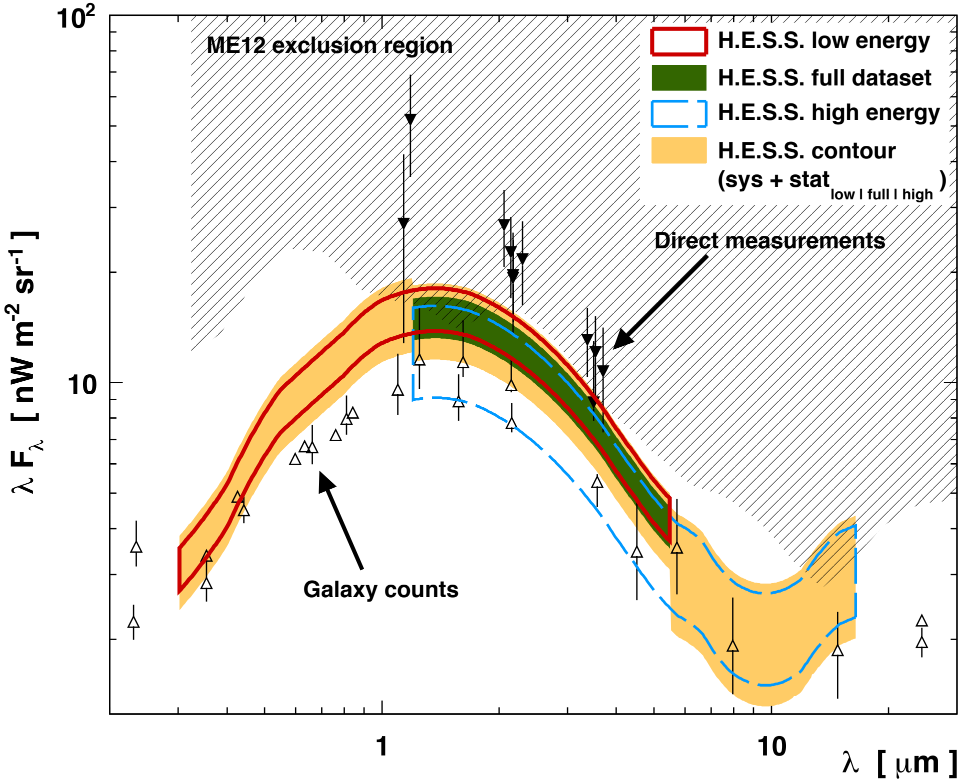

Astron. Astrophys. 550 (2013) A4, (astro-ph/**1212.3409**)