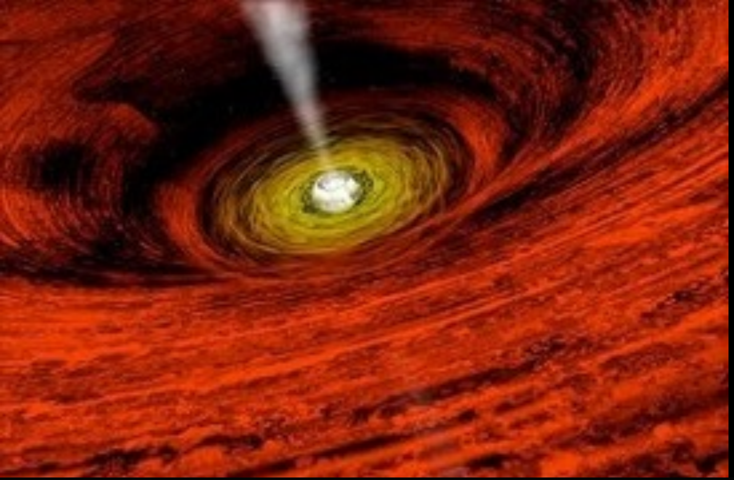
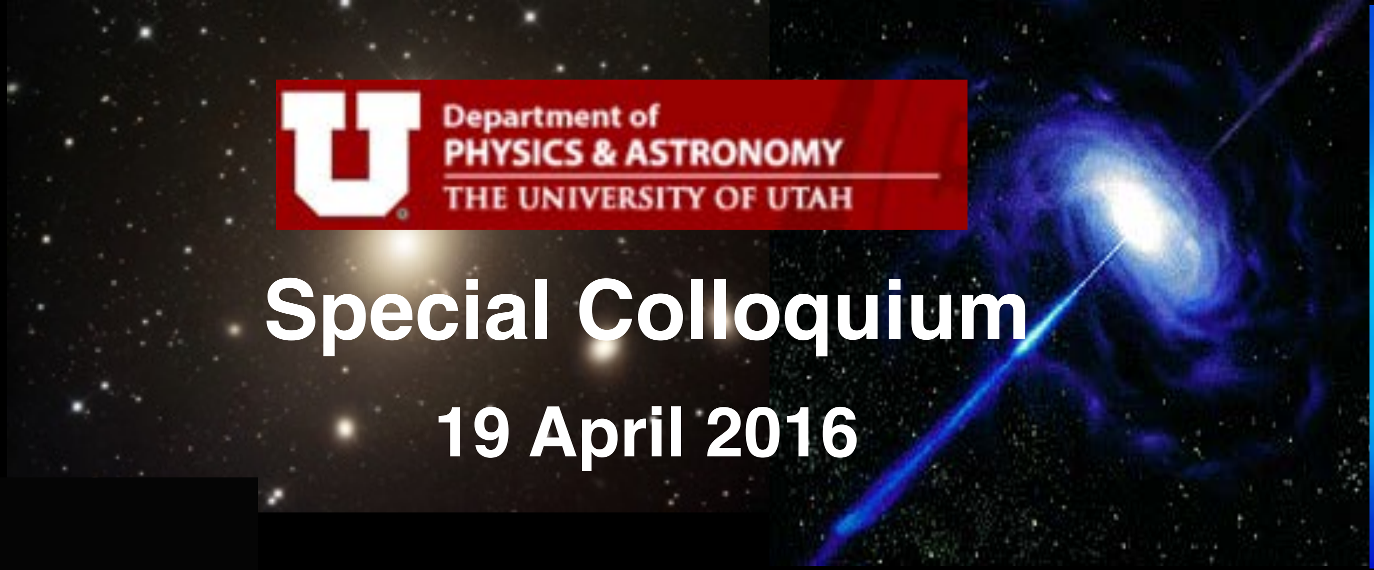
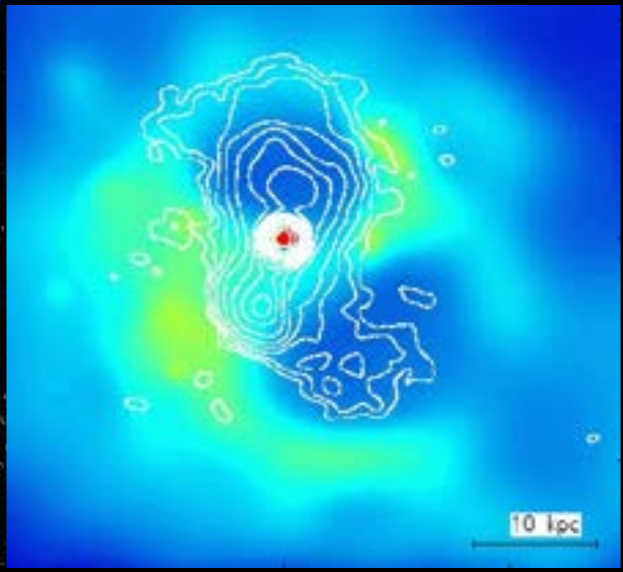




Department of PHYSICS & ASTRONOMY THE UNIVERSITY OF UTAH

Special Colloquium

19 April 2016

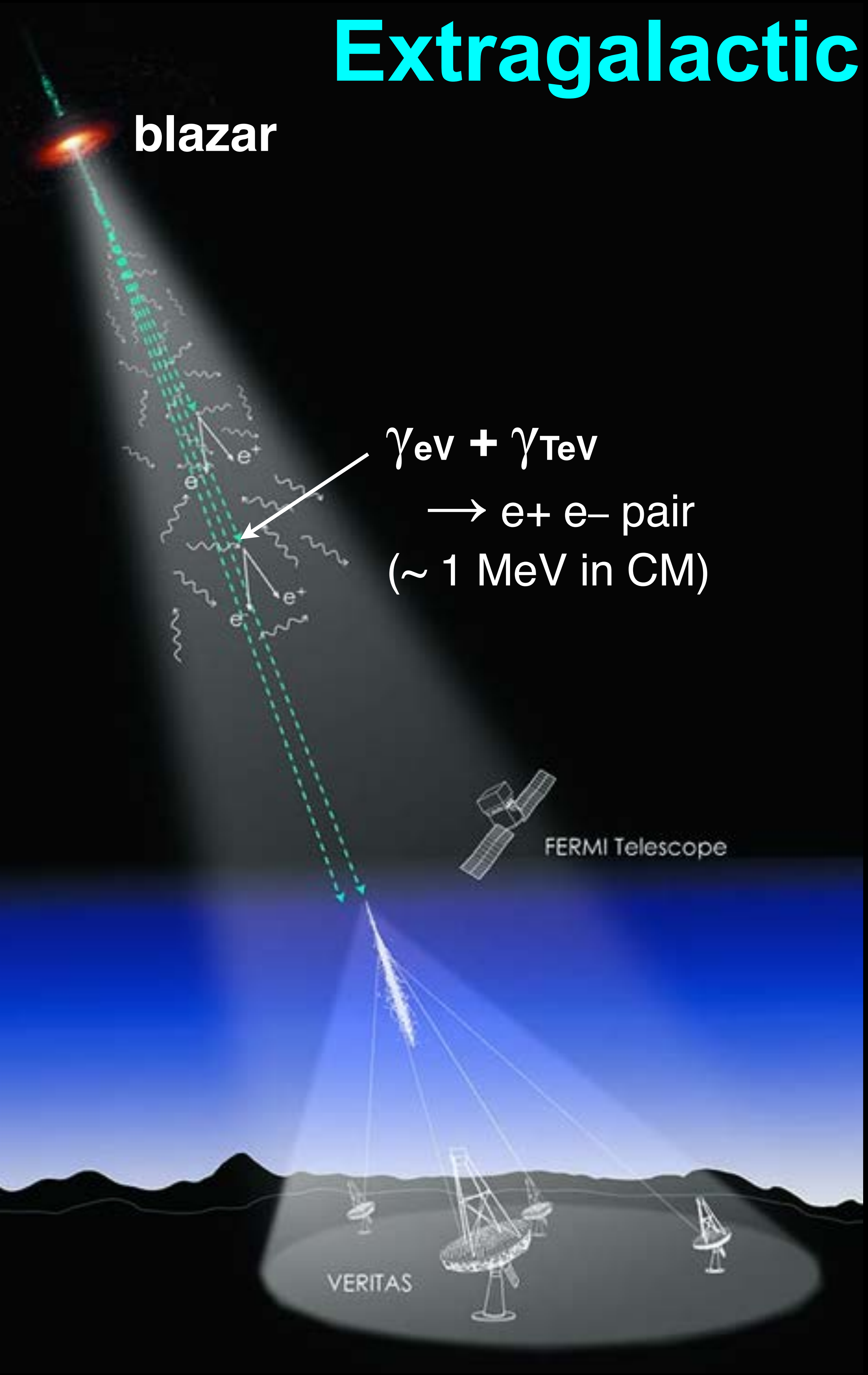


Measuring the Extragalactic Background Light with Gamma Rays

Joel Primack

Fermi Gamma-ray Space Telescope

Extragalactic Background Light (EBL)



$\gamma_{eV} + \gamma_{TeV}$

$\longrightarrow$ e+ e– pair

(~ 1 MeV in CM)

Data from (non-) attenuation of gamma rays from blazars and gamma ray bursts (GRBs) give upper limits on the EBL from the UV to the mid-IR that are only a little above the lower limits from observed galaxies. New data on attenuation of gamma rays from blazers now lead to statistically significant measurements of the cosmic gamma ray horizon as a function of source redshift and gamma ray energy that are independent of EBL models. These new measurements are consistent with recent EBL calculations based both on multiwavelength observations of thousands of galaxies and also on semi-analytic models of the evolving galaxy population. Such comparisons account for (almost) all the light, including that from galaxies too faint to see.

Scientific American June 2015

All the Light There Ever Was

Galaxies in every corner of the universe have been sending out photons, or light particles, since nearly the beginning of time. Astronomers are now beginning to read this extragalactic background light

By Alberto Domínguez, Joel R. Primack and Trudy E. Bell

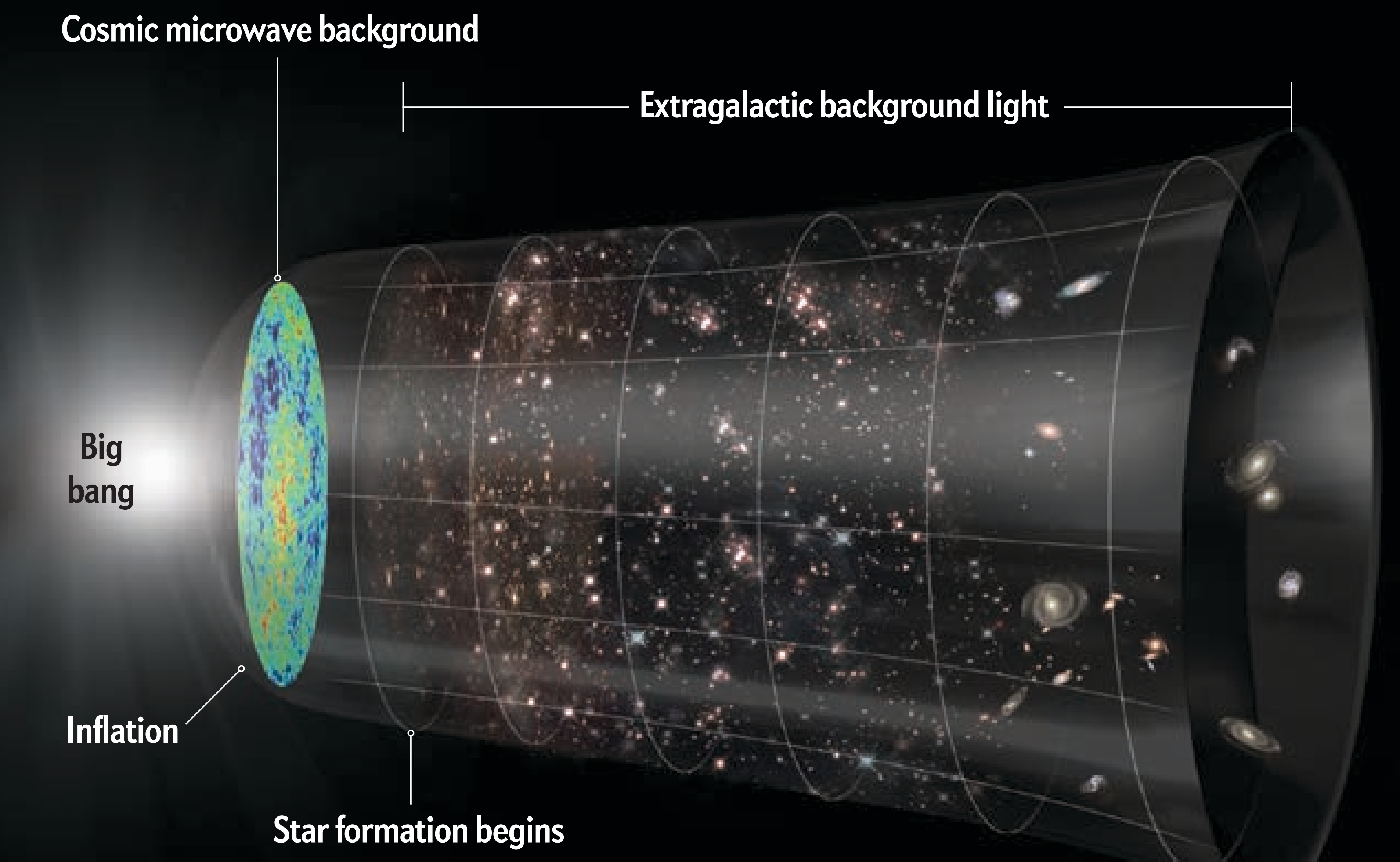
Alberto Domínguez is a postdoctoral fellow in the department of physics and astronomy at Clemson University, where he studies galaxy evolution and cosmology.

Joel R. Primack is Distinguished Professor Emeritus of Physics at the University of California, Santa Cruz. He is one of the main developers of the modern theory of cosmology, dark matter and galaxies.

Trudy E. Bell is a former editor of *Scientific American* and *IEEE Spectrum* and author of a dozen books.

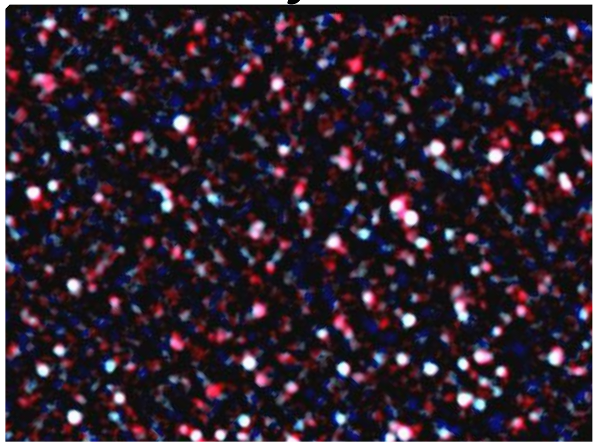
Extragalactic Background Light

The extragalactic background light (EBL) includes all the light from all the galaxies that have ever shined. It began to accumulate when the first stars and galaxies formed, roughly 200 million years after the big bang, and new galaxies add their light all the time. Still, because space is so vast (and expanding), this light is dim and diffuse. The cosmic microwave background (CMB) is another radiation field that also pervades the universe. The CMB, however, does not grow with time; rather it was formed all at once, about 400,000 years after the big bang.

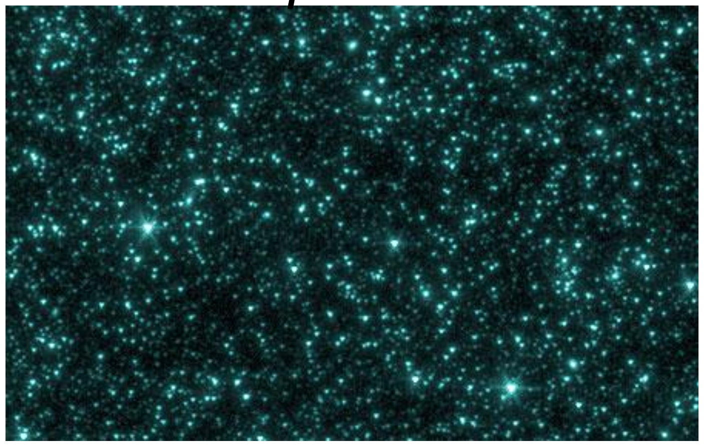


Cosmic Extragalactic Backgrounds

Herschel far-IR

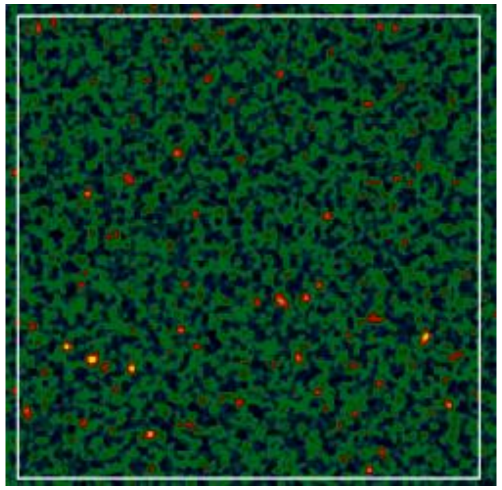


Spitzer mid-IR

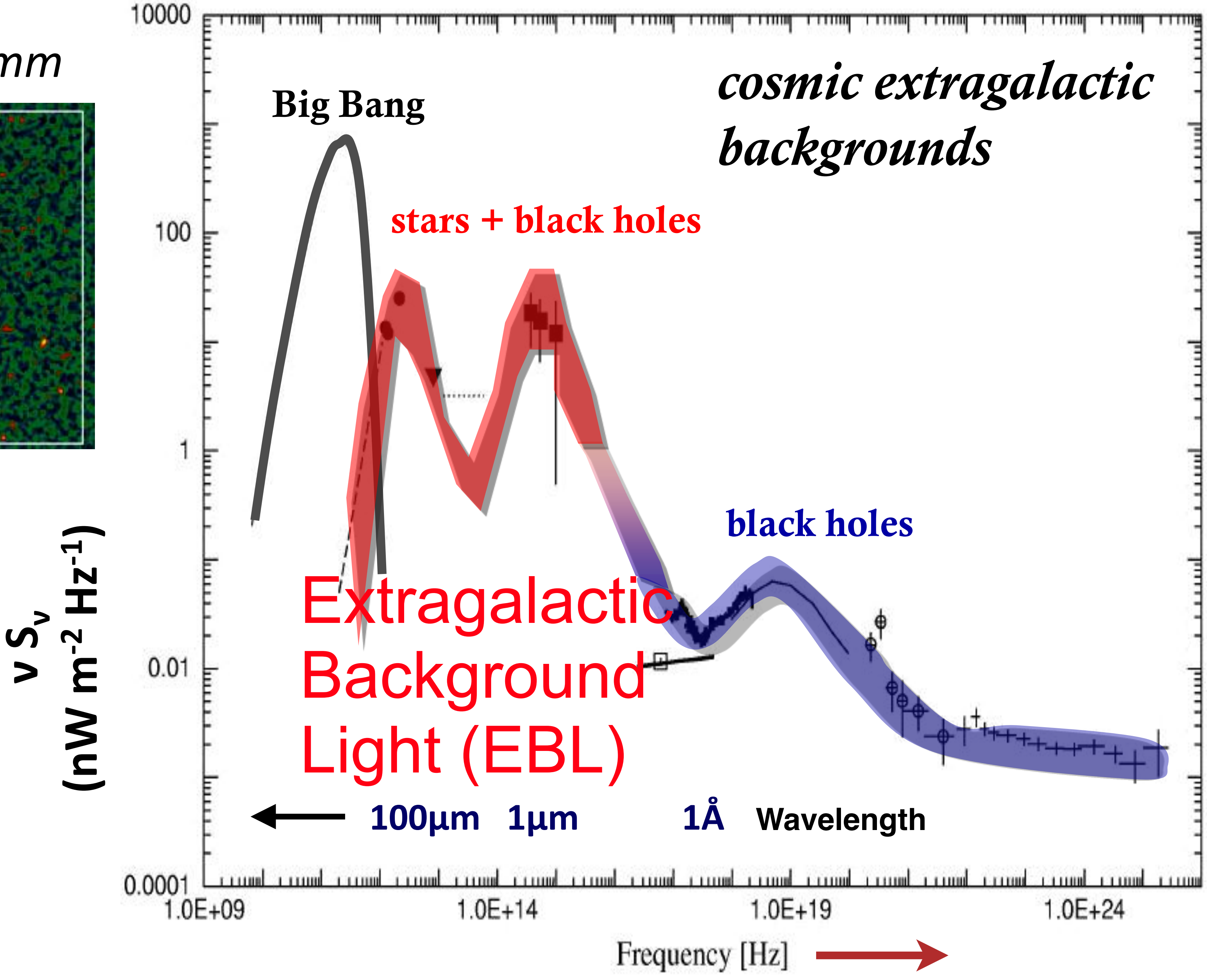


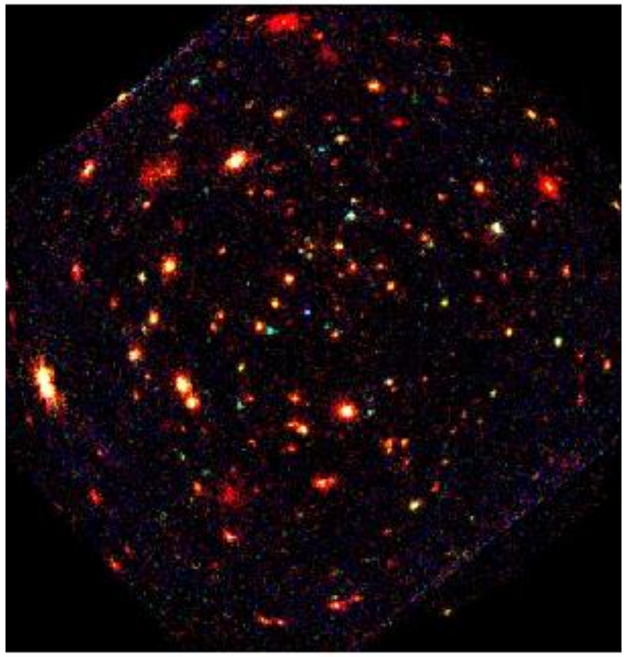
HST-optical/UV

0.850-1.2mm



in the future:
ALMA, CCAT..





Chandra/XMM –X-ray

Extragalactic Background Light (EBL)

- The usual plot of $\lambda I_\lambda = dI/d \log \lambda$ vs. $\log \lambda$ shows directly the ENERGY DENSITY $\rho_\lambda = (4\pi/c)\, \lambda I_\lambda$ in the EBL:

  $$1\ \mathrm{nW/m^2/sr} = 10^{-6}\ \mathrm{erg/s/cm^2/sr} = 2.6\times10^{-4}\ \mathrm{eV/cm^3}$$

  Total EBL $\Omega_{EBL}^{obs} = (4\pi/c)\, I_{EBL}/(\rho_{crit}\, c^2) = 2.0\times10^{-4}\, I_{EBL}\, h_{70}^{-2}$

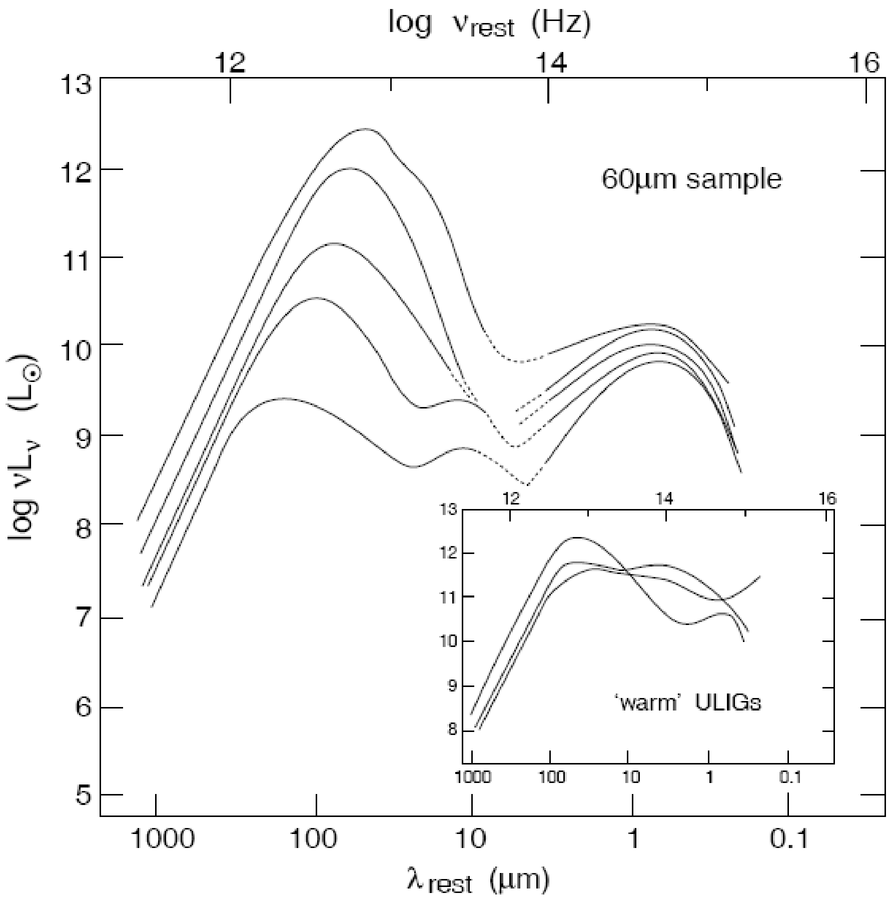
  The estimated I_{EBL}^{obs}= 60-100 nW/m^2/sr translates to

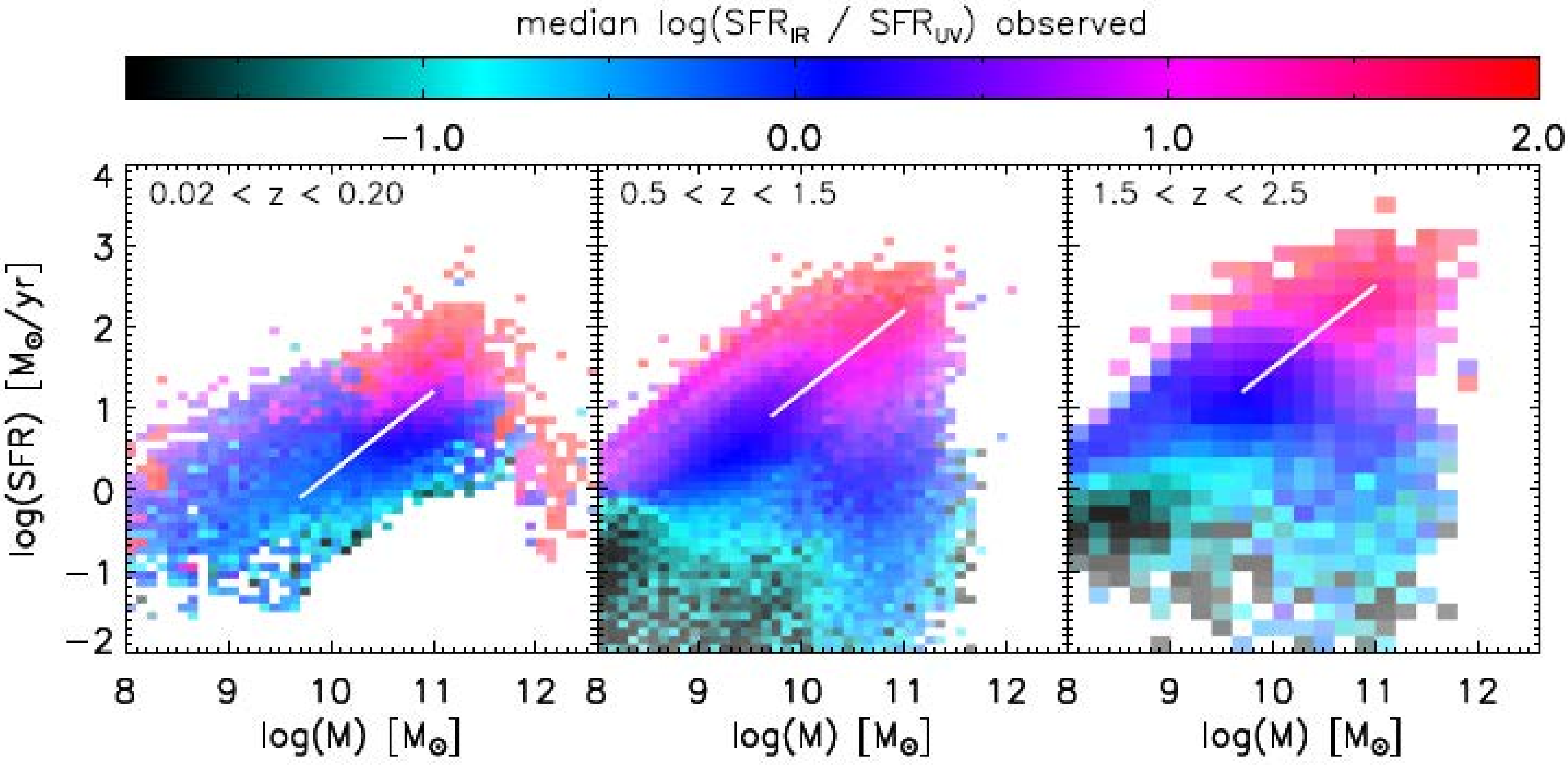
  $$\Omega_{EBL}^{obs} = (3\text{-}5)\times10^{-6} \quad (\text{about } 5\% \text{ of } \Omega_{CMB})$$

- Local galaxies typically have $E_{FIR}/E_{opt} \approx 0.3$, while the EBL has E_{FIR}/E_{opt} = 1-2. **Hence most high-redshift radiation was emitted in the far IR.**

Luminosity-Dustiness Correlation

LIRG: $L_{FIR} \geq 10^{11} L_\odot$ ULIRG: $L_{FIR} \geq 10^{12} L_\odot$ HLIRG: $L_{FIR} \geq 10^{13} L_\odot$





more luminous and massive galaxies are (much) more obscured: for starbursts and (U)LIRGs a de-reddening of the UV-emission does not succeed: the central starburst is behind a 'black screen' and the UV emission comes from a lower obscuration component; even de-reddened Hα fails by about a factor of 10; ULIRGs/starbursts often have 'post-starburst' UV/optical SEDs while the real starburst is completely hidden

Sanders & Mirabel 1996, Meurer et al. 1999,Wuyts et al. 2011

EBL Evolution Calculated from Observations Using AEGIS Multiwavelength Data

Alberto DomÍnguez, Joel Primack, et al. (MNRAS, 2011)

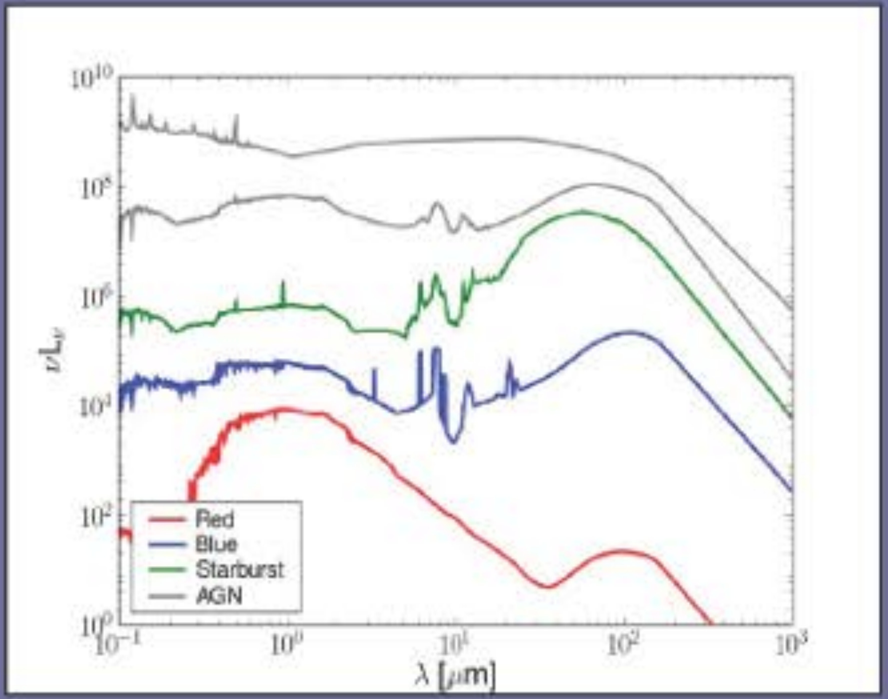
$$j_i(\lambda,z) = j_i^{faint} + j_i^{mid} + j_i^{bright} =$$

$$= \int_{M_1}^{M_2} \underline{\Phi(M_K,z)}\,\underline{f_i}\,\underline{T_i(M_K,\lambda)}\,dM_K +$$

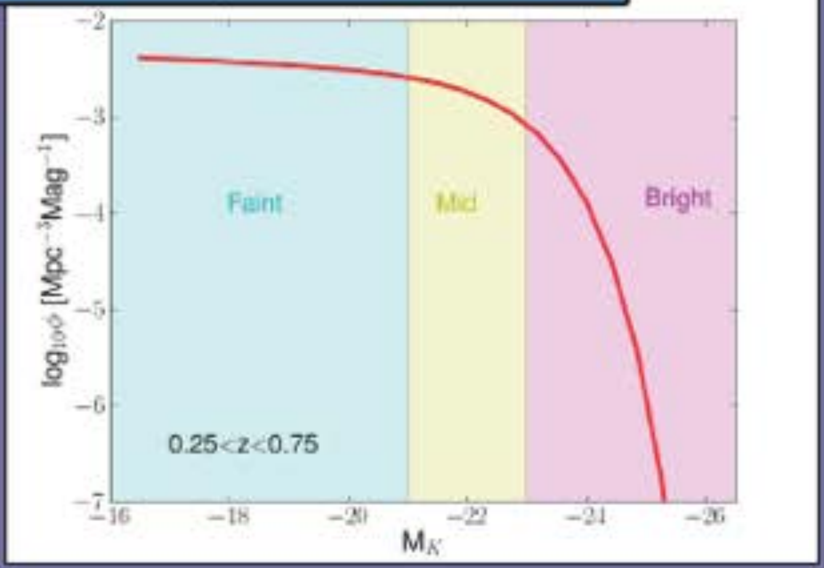
$$+ \int_{M_2}^{M_3} \underline{\Phi(M_K,z)}\,\underline{m_i}\,\underline{T_i(M_K,\lambda)}\,dM_K +$$

$$+ \int_{M_3}^{M_4} \underline{\Phi(M_K,z)}\,\underline{b_i}\,\underline{T_i(M_K,\lambda)}\,dM_K$$

Spectral energy distributions
SWIRE template library, Polletta+ 07



Luminosity function
observed K-band, Cirasuolo+ 09



Spectral-type fractions

$$\lambda I_\lambda(z) = \frac{c}{4\pi}\int_z^{z_{max}} j_{total}[\lambda(1+z)/(1+z'),z']\left|\frac{dt}{dz'}\right|dz'$$

0.7 □°

The AEGIS Survey...

...is unlocking the secrets of galaxy and large-scale structure formation over the last 9 billion years.

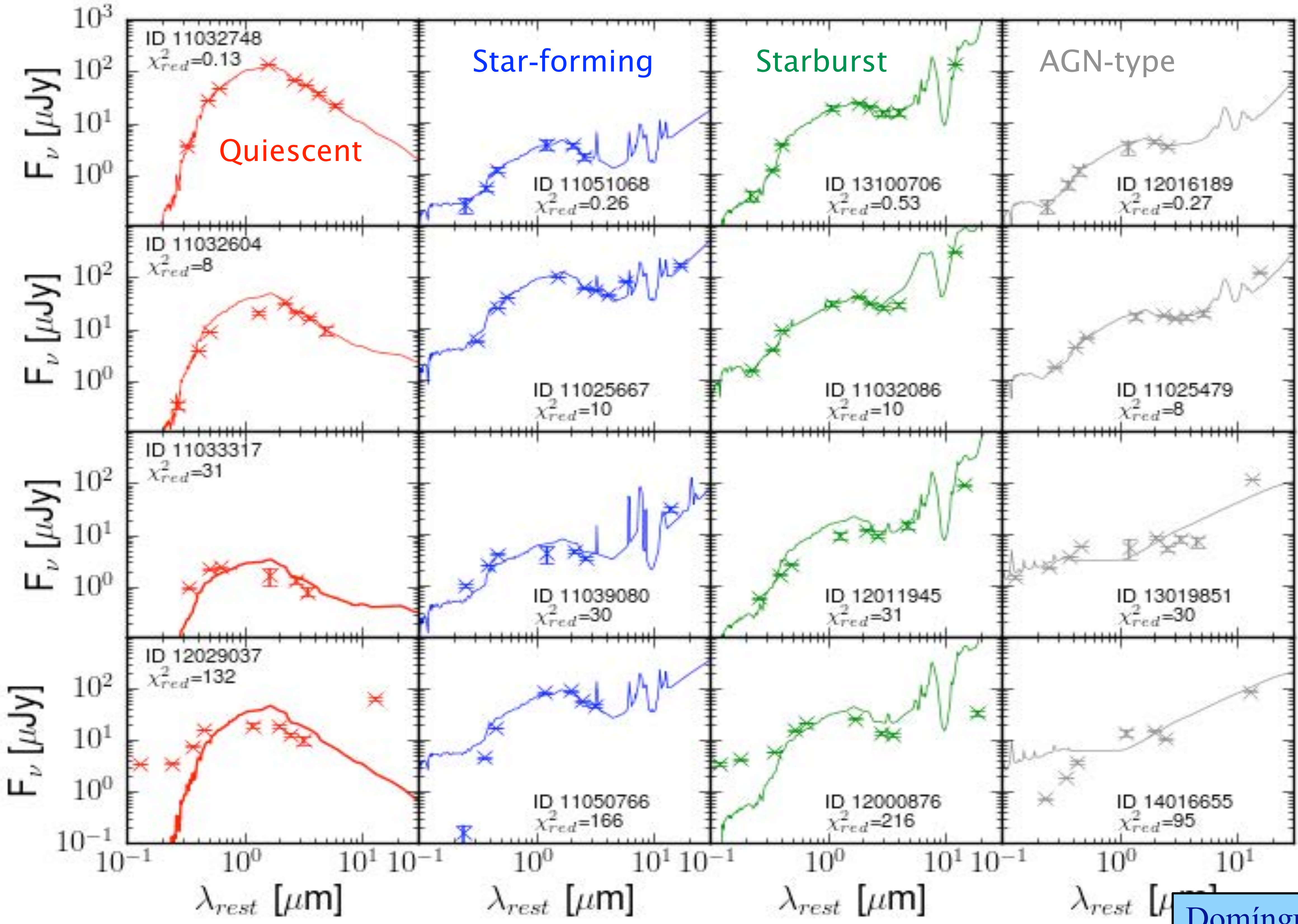
AEGIS is targeted on a special area of the sky, called the Extended Groth Strip (EGS), that has been observed with the world's most powerful telescopes on the ground and in space, from X-rays to radio waves.

Each telescope contributes its own key information to create a complete portrait of every galaxy. By looking out far into space and back in time, AEGIS literally shows us galaxies in all their glory that are emerging from infancy into adulthood. More...

http://aegis.ucolick.org/

χ^2 SED Fitting

Le PHARE code for fitting the SWIRE templates in FUV, NUV, B, R, I, Ks, IRAC1, 2, 3, 4 and MIPS24



Best SED Fits

Worst SED Fits

Domínguez+ 11

SED-Type Evolution

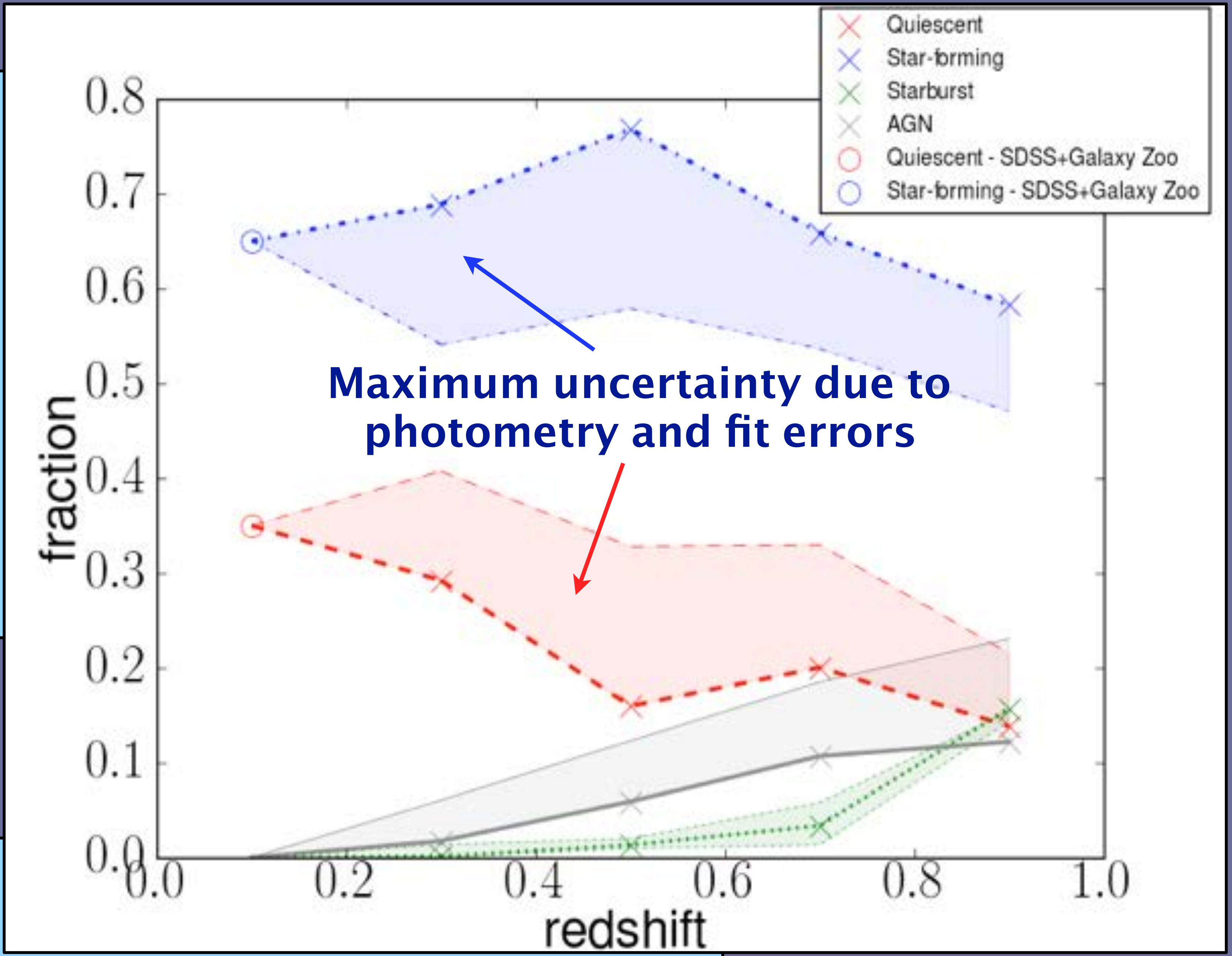
Local fractions, z<0.2:

Goto+ 03, morphologically classified from Sloan converted to spectral classification using results from Galaxy Zoo

Skibba+ 09 ~6% blue ellipticals
Schawinski+ 09 ~25% red spirals

Results:

35% red-type galaxies
65% blue-type galaxies



Maximum uncertainty due to photometry and fit errors

High-redshift universe, z>1:

Two approaches:
1. Keep constant the fractions of our last redshift bin (Fiducial Model), or
2. Quickly increase starburst population from 16% at z = 0.9 to 60% at z ≥ 2

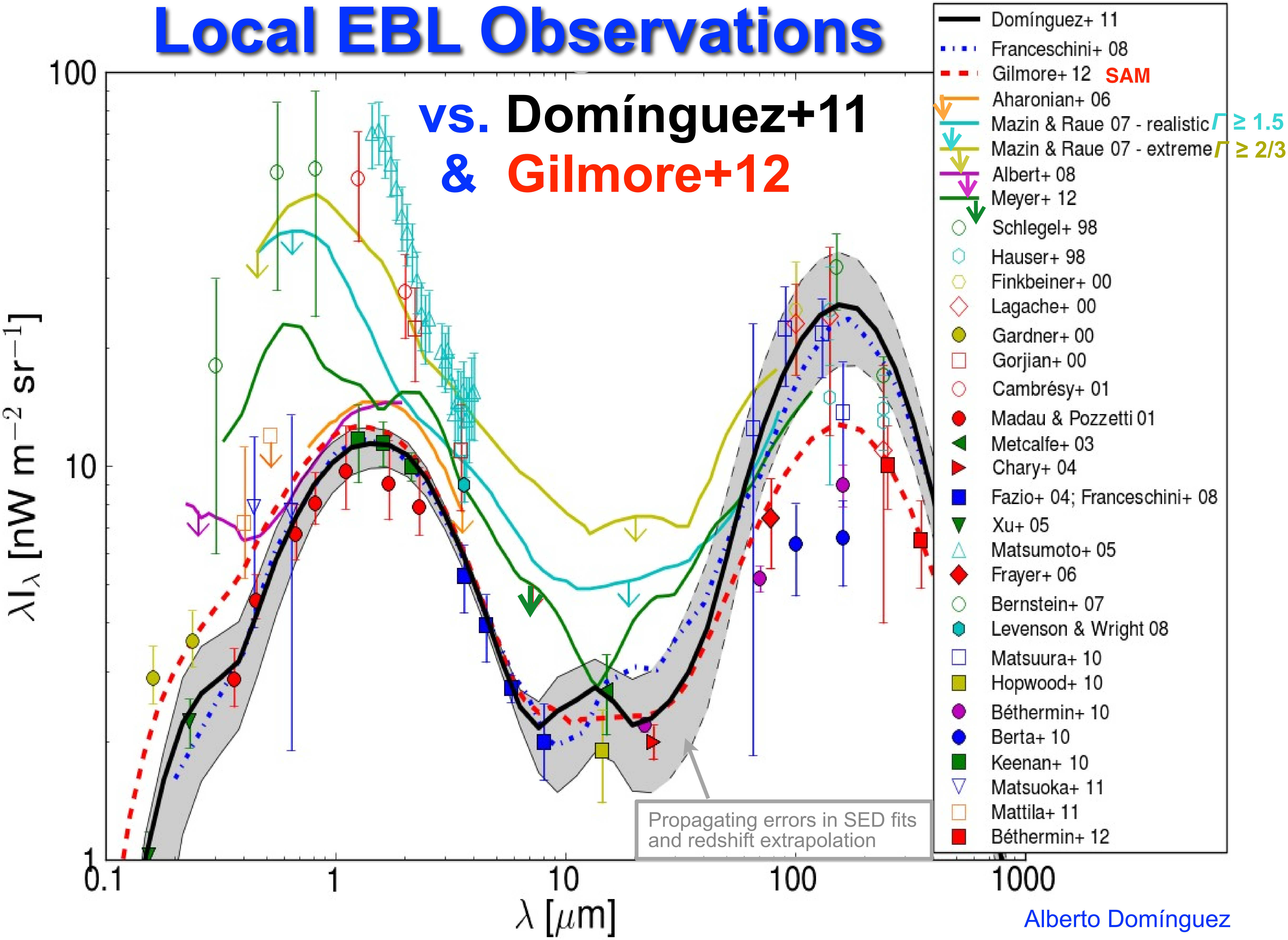
We find that the differences in the predicted EBL are small except at long wavelengths, affecting attenuation only for E ≥ 5 TeV.

Domínguez+11

Local EBL Observations

vs. Domínguez+11

& Gilmore+12



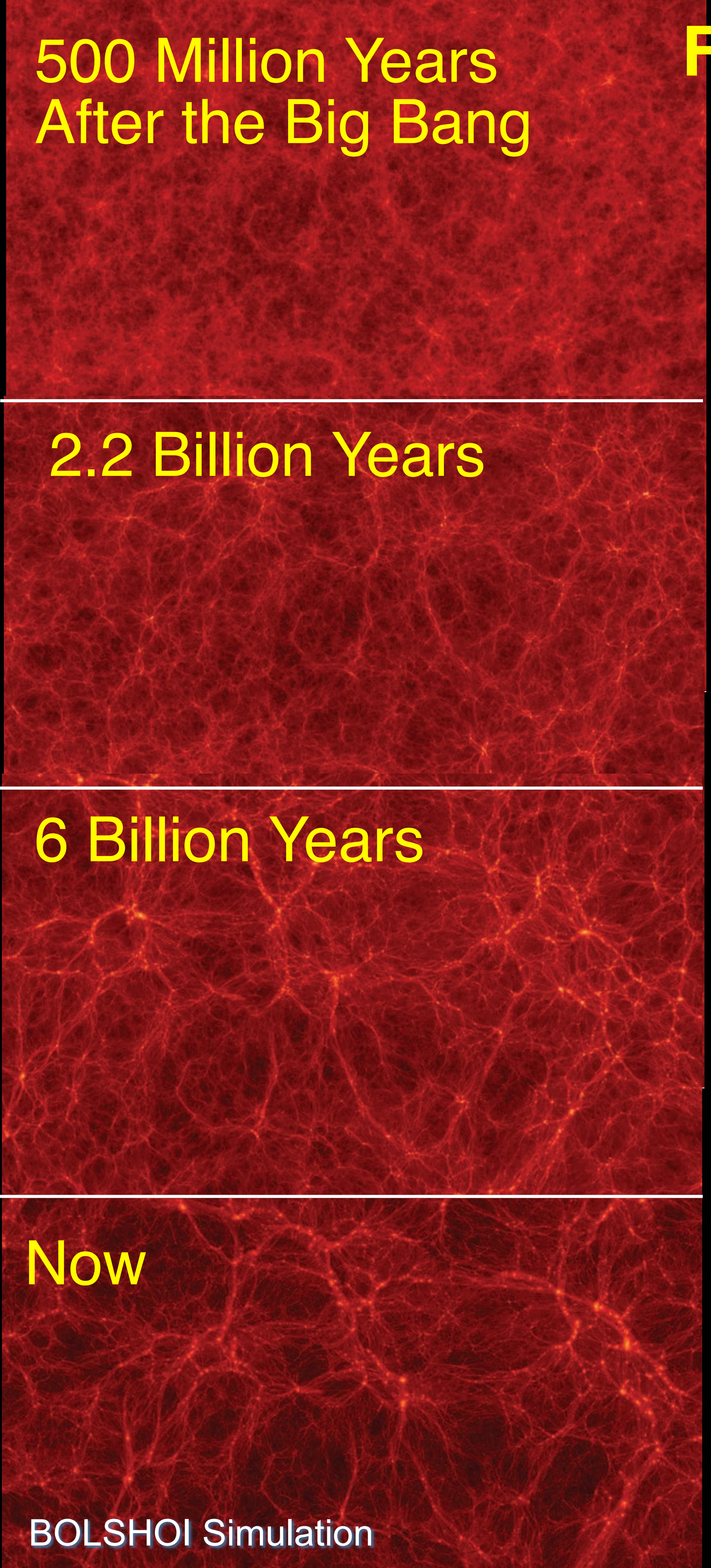
Propagating errors in SED fits and redshift extrapolation

Alberto Domínguez

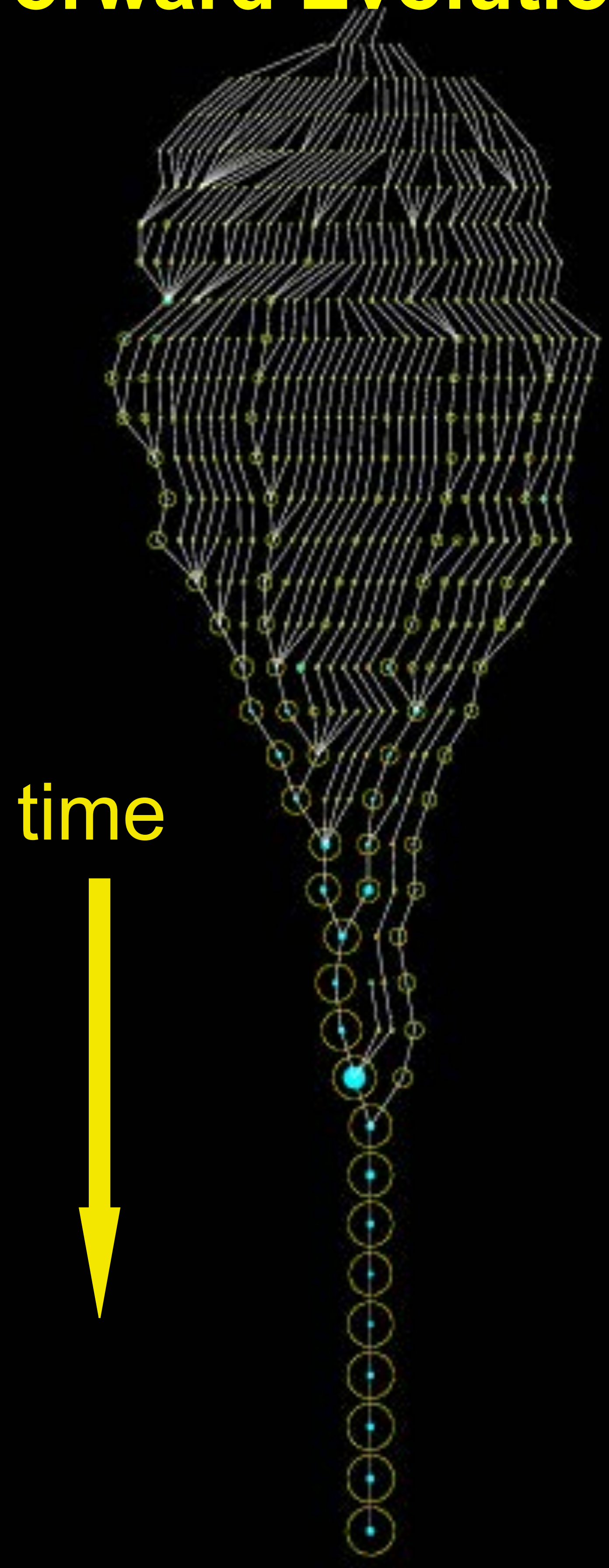
EBL Calculated by Forward Evolution using SAMs

When we first tried doing this (Primack & MacMinn 1996, presented at Felix Aharonian's first Heidelberg conference), both the stellar initial mass function (IMF) and the values of the cosmological parameters were quite uncertain. After 1998, the cosmological model was known to be ΛCDM although it was still necessary to consider various cosmological parameters in models. Now the parameters are known rather precisely, and our latest semi-analytic model (SAM) used the current (WMAP5/7/9) cosmological parameters. With improved simulations and better galaxy data, we can now normalize SAMs better and determine the key astrophysical processes to include in them.

Remaining uncertainties include whether the IMF is different in different galaxies (possibly "bottom-heavy" in massive galaxies), feedback from AGN, the nature of sub-mm galaxies, and the star formation rate at high redshifts.



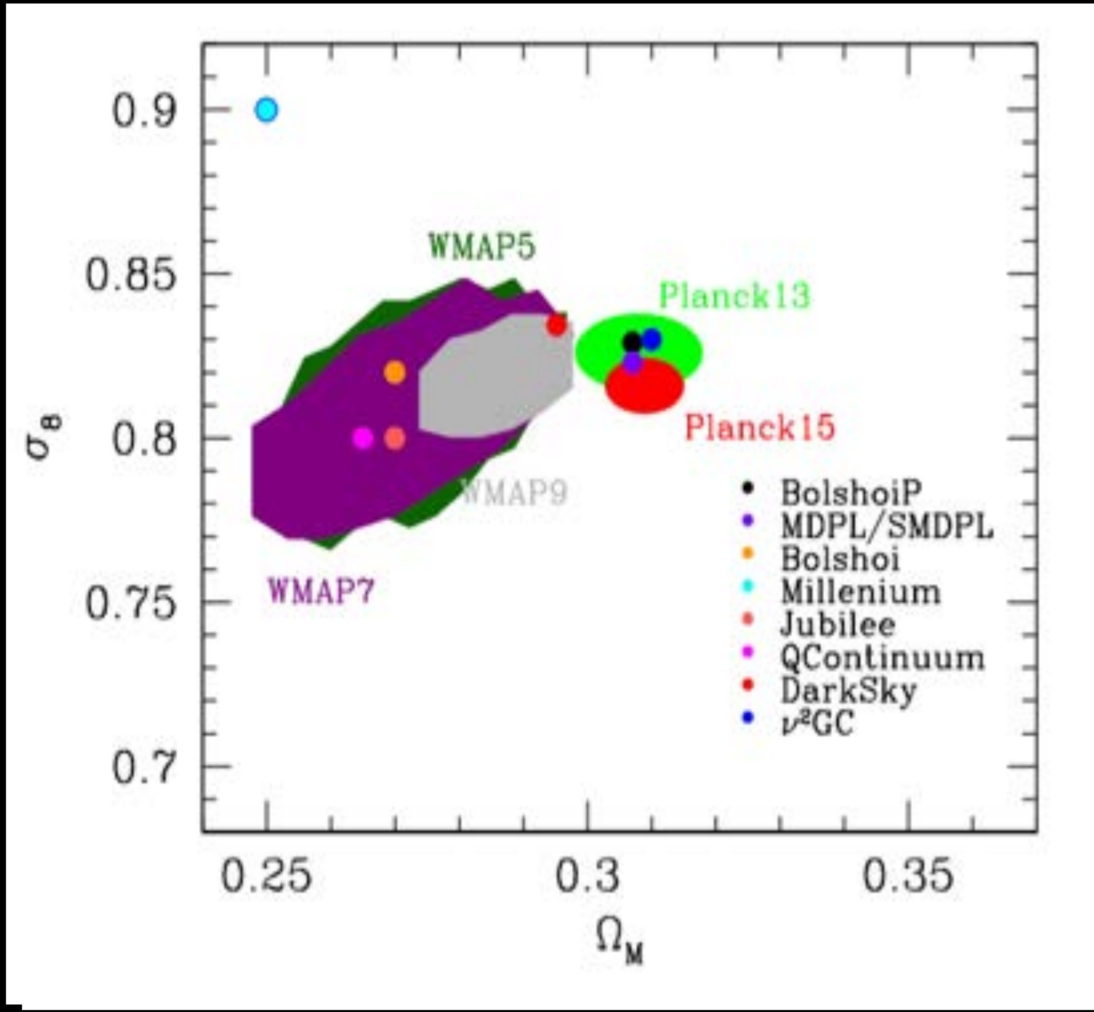
Forward Evolution



Wechsler et al. 2002

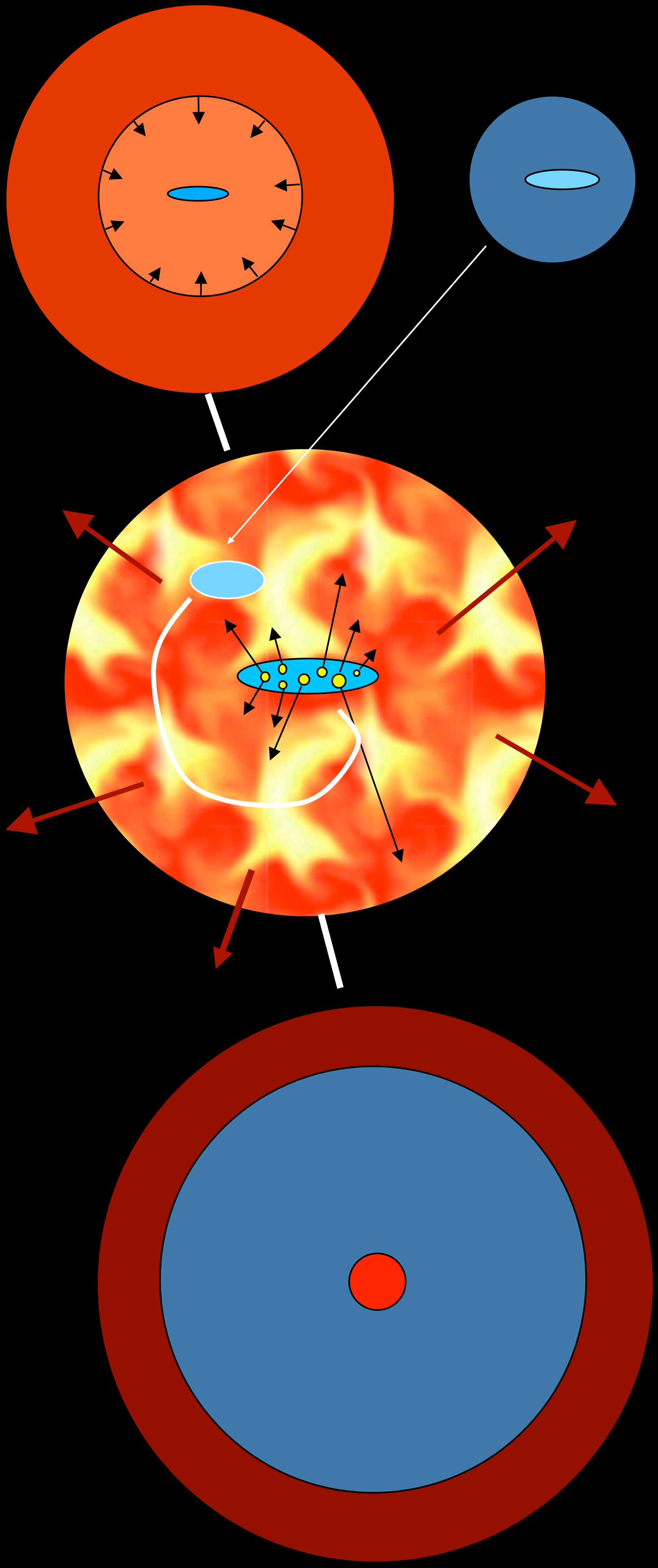
Present status of ΛCDM “Double Dark” theory:

- cosmological parameters are now well constrained by observations



- mass accretion history of dark matter halos is represented by ‘merger trees’ like the one at left

SAM Galaxy Formation

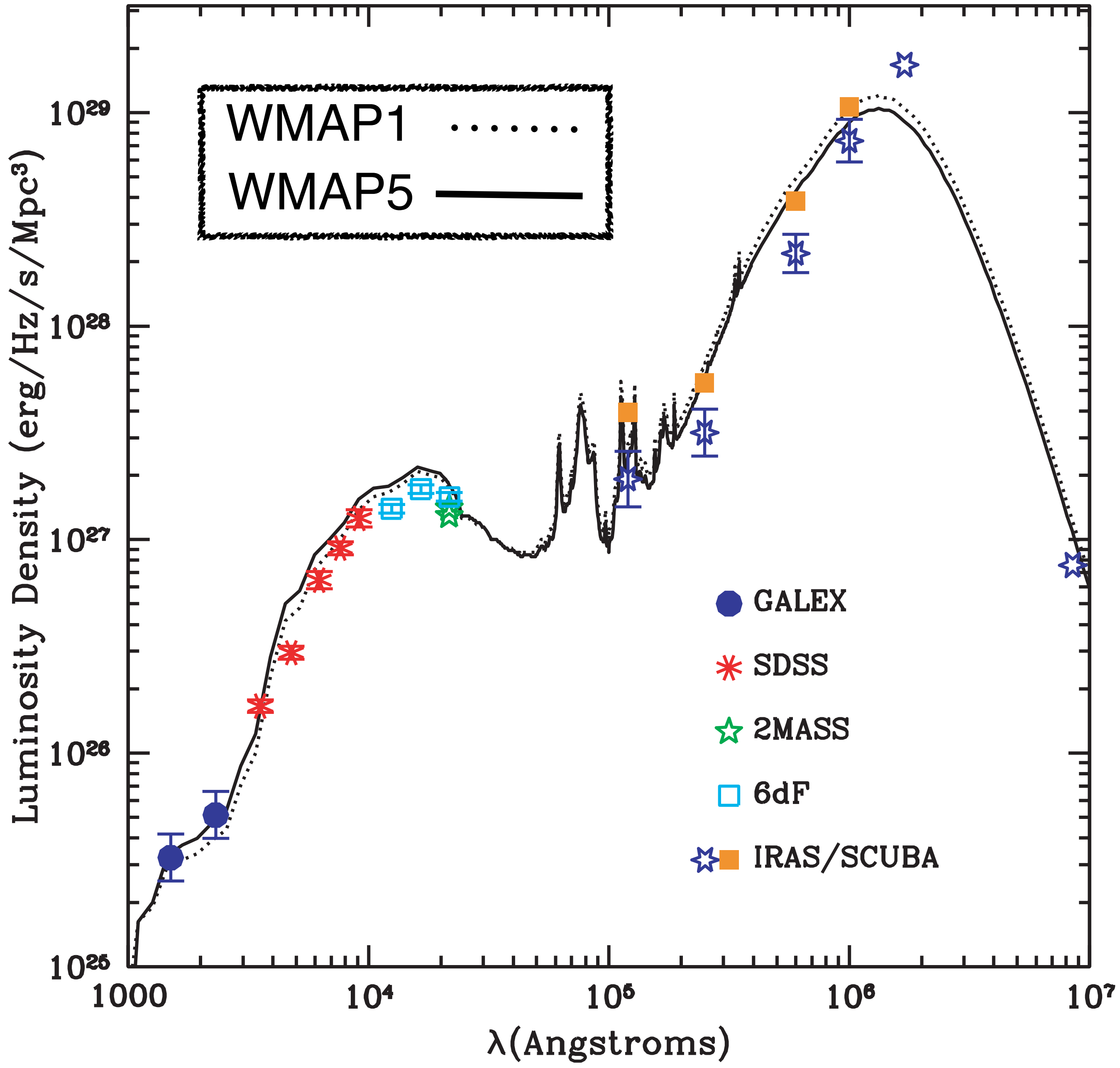


- gas is collisionally heated when perturbations ‘turn around’ and collapse to form gravitationally bound structures
- gas in halos cools via atomic line transitions (depends on density, temperature, and metallicity)
- cooled gas collapses to form a rotationally supported disk
- cold gas forms stars, with efficiency a function of gas density (e.g. Schmidt-Kennicutt Law)
- massive stars and SNae reheat (and in small halos expel) cold gas and some metals
- galaxy mergers trigger bursts of star formation; ‘major’ mergers transform disks into spheroids and fuel AGN
- AGN feedback cuts off star formation

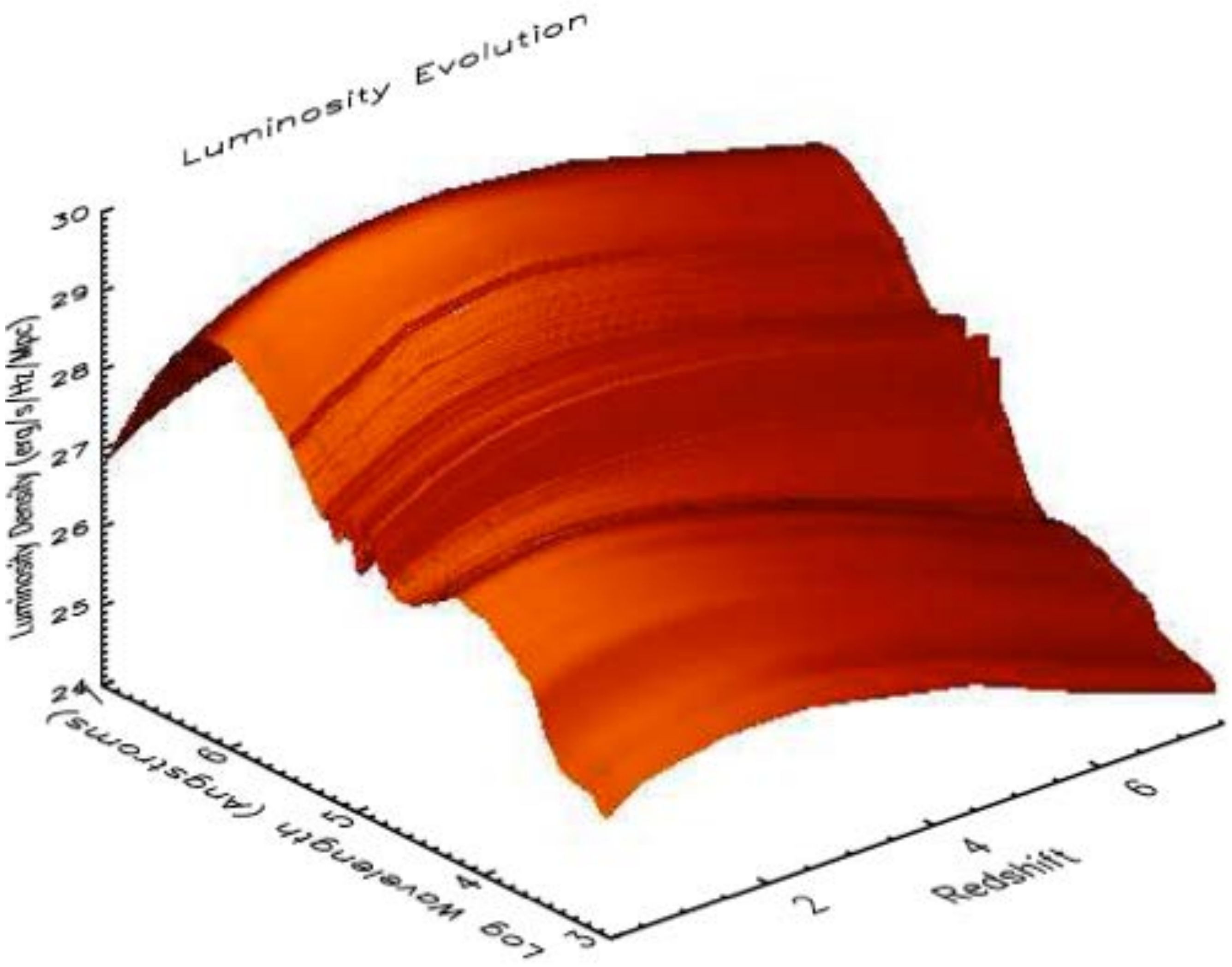
White & Frenk 1991; Kauffmann+1993; Cole+94; Somerville & Primack 99; Cole+00; Somerville, Primack, & Faber 01; Croton et al. 2006; Somerville +08; Fanidakis+09; Guo+2011; Somerville, Gilmore, Primack, & Domínguez 2012 & Gilmore +2012 (discussed here); Porter, Somerville, Primack 2014ab

Some Results from our Semi-Analytic Models

z=0 Luminosity Density



Evolving Luminosity Density

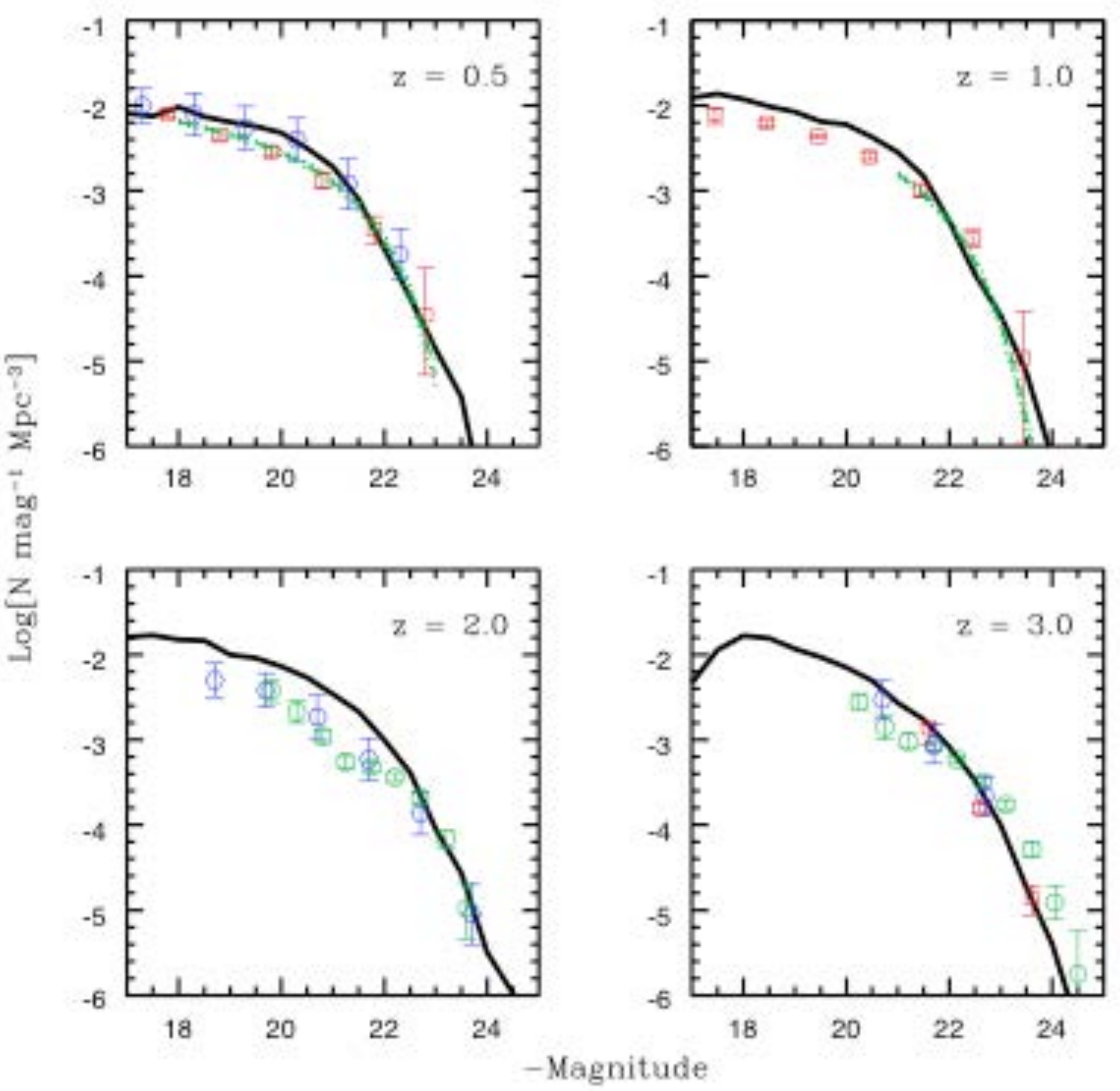


Gilmore, Somerville, Primack, & Domínguez (2012)

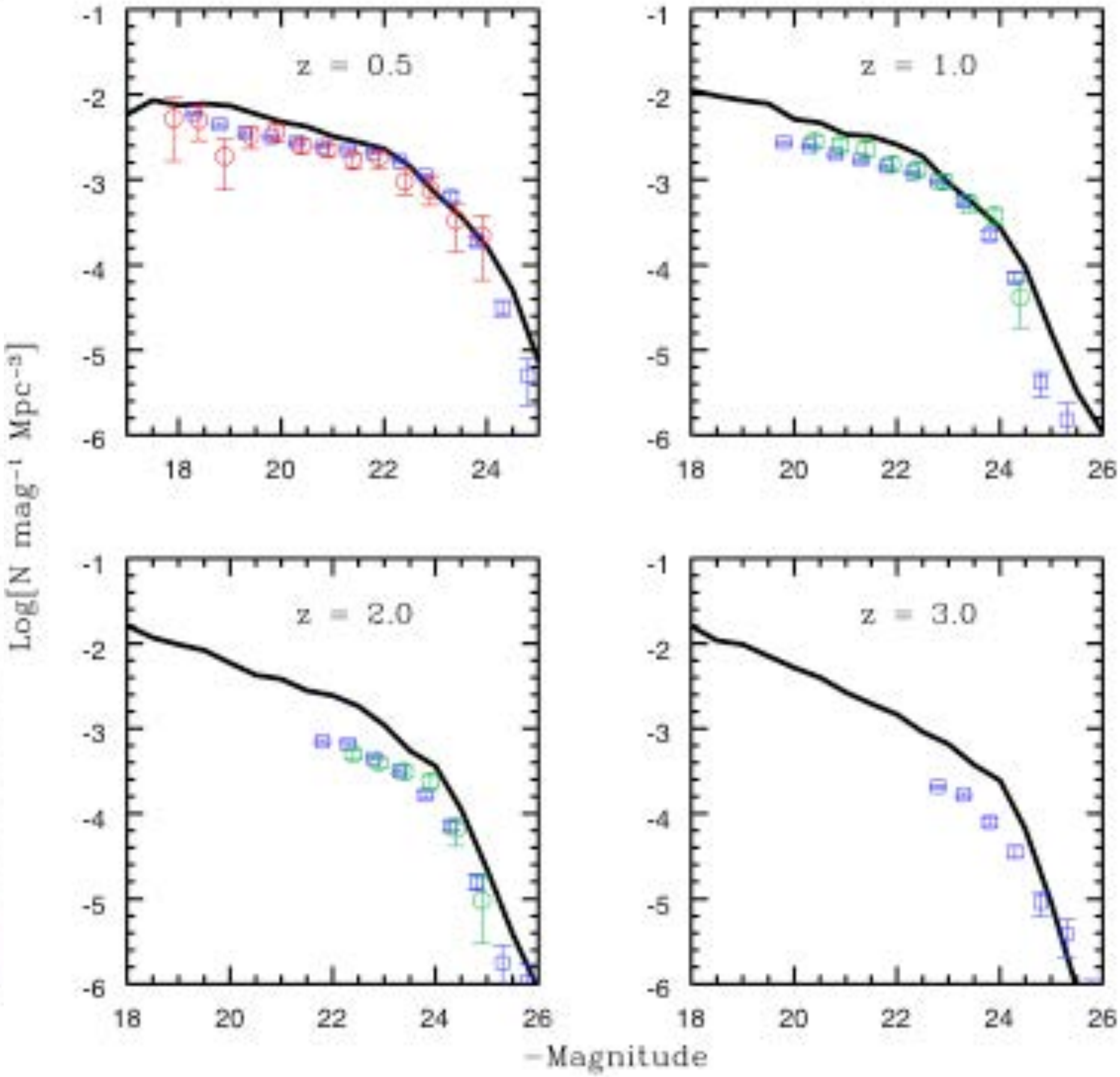
Some Results from our Semi-Analytic Models

Evolving Luminosity Functions

B-band



K-band



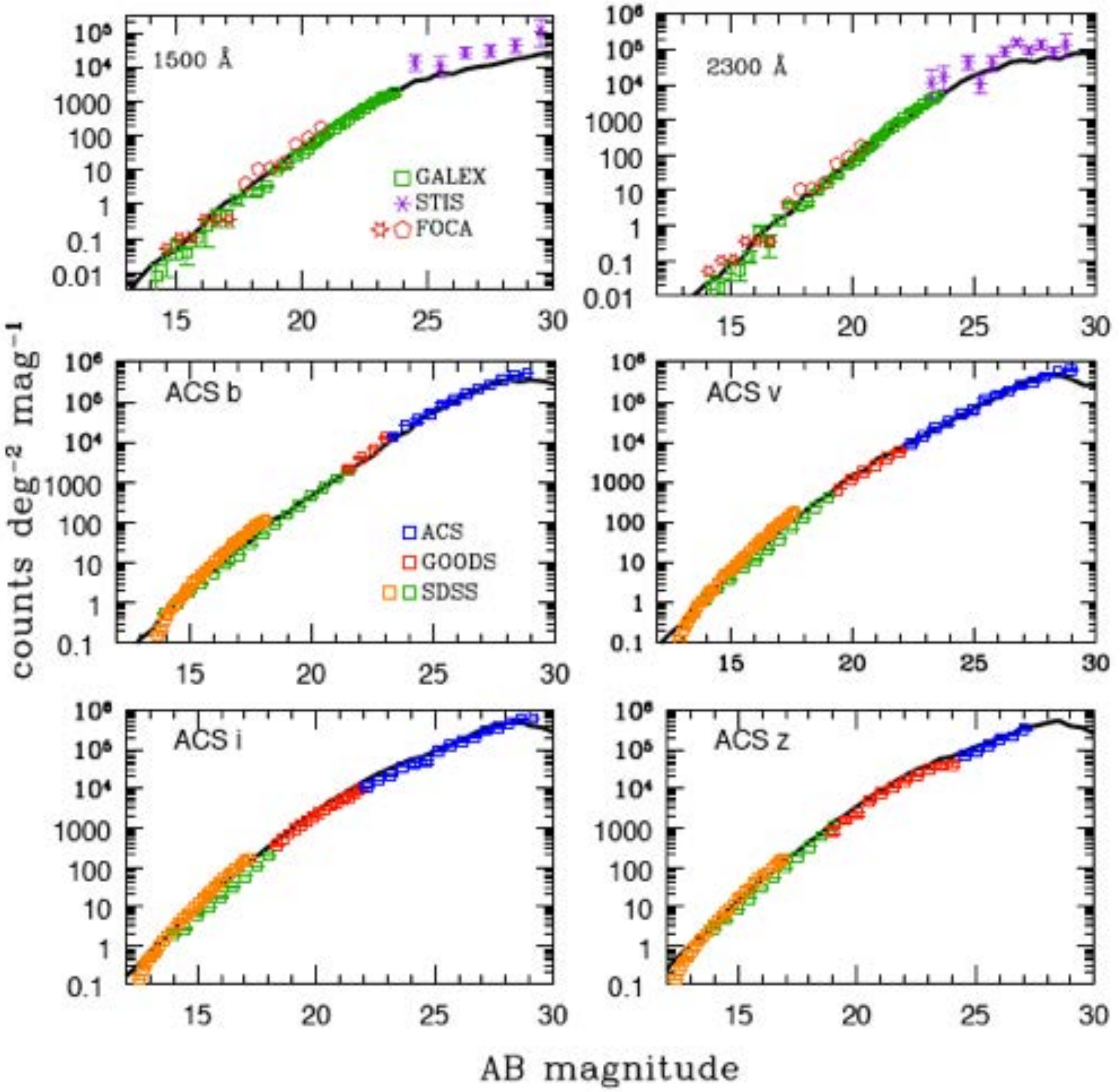
An advantage of the SAM approach is that it is possible to compare predictions and observations at all redshifts and in all spectral bands.

Gilmore, Somerville, Primack, & Domínguez (2012)

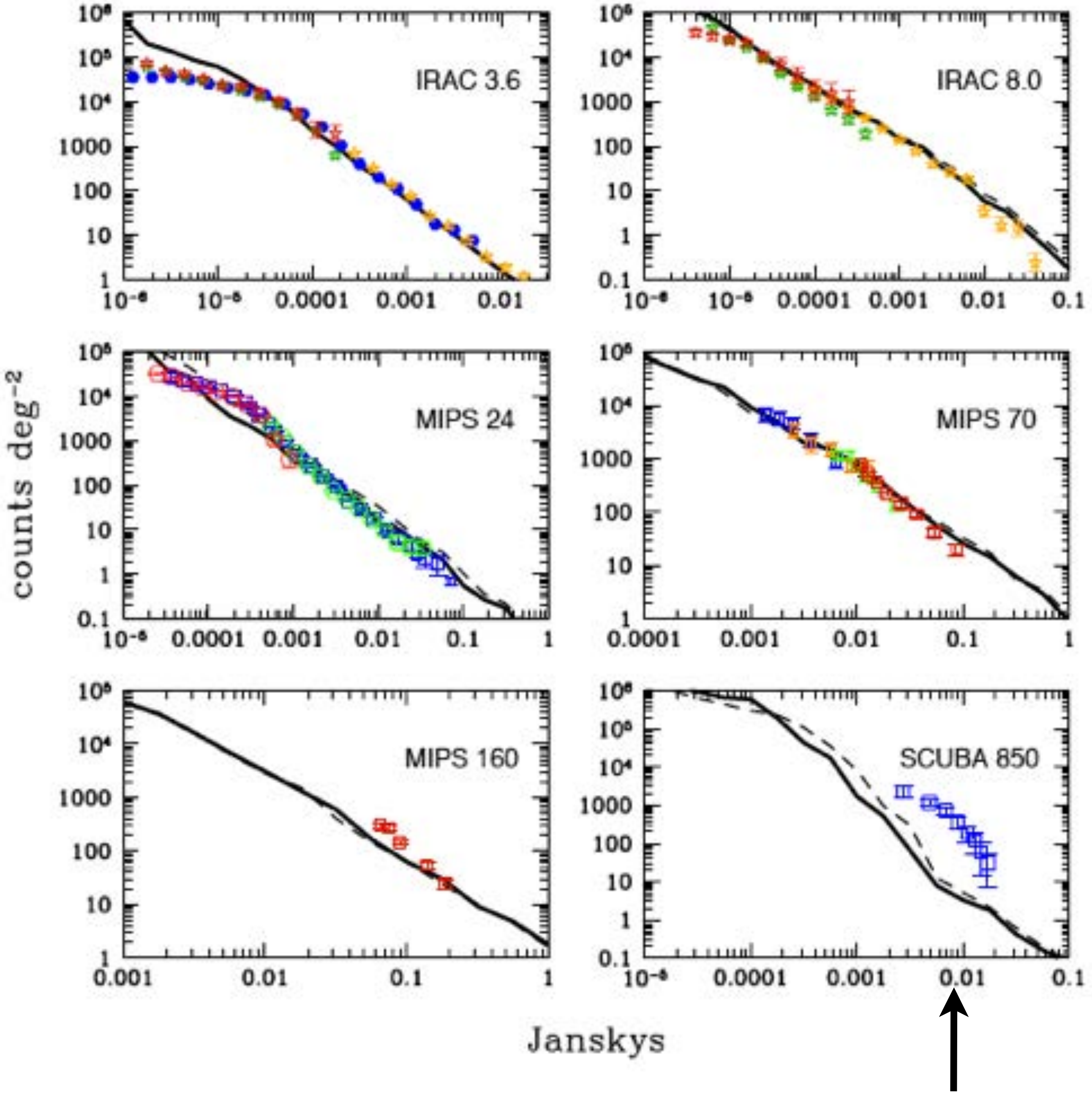
Some Results from our Semi-Analytic Models

Number Counts in UV, b, v, i, and z Bands

3.6, 8, 24 and 24, 70, 160, & 850 μm Bands

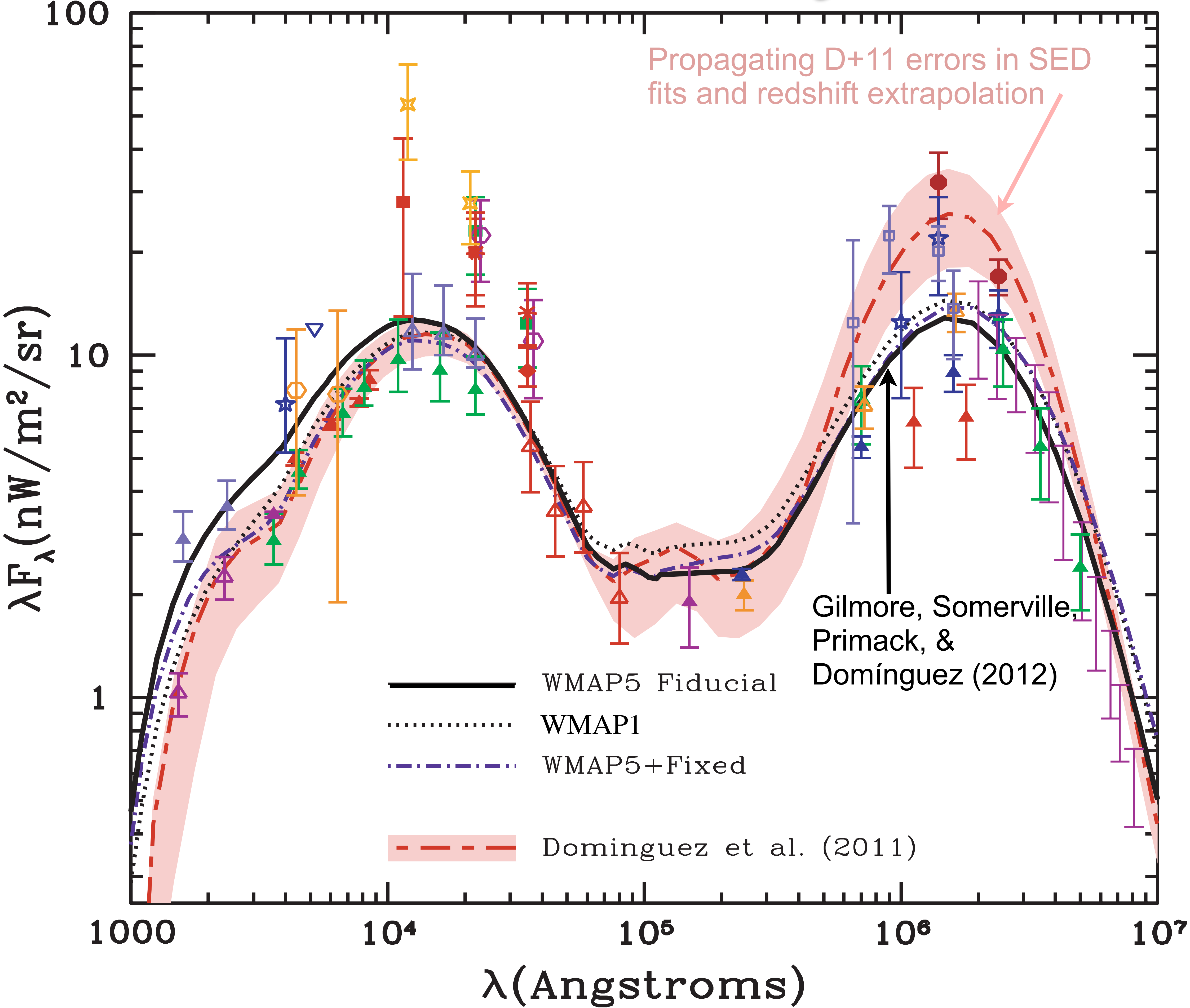


Somerville, Gilmore, Primack, & Domínguez (2012)



Worst failure is at 850 μm

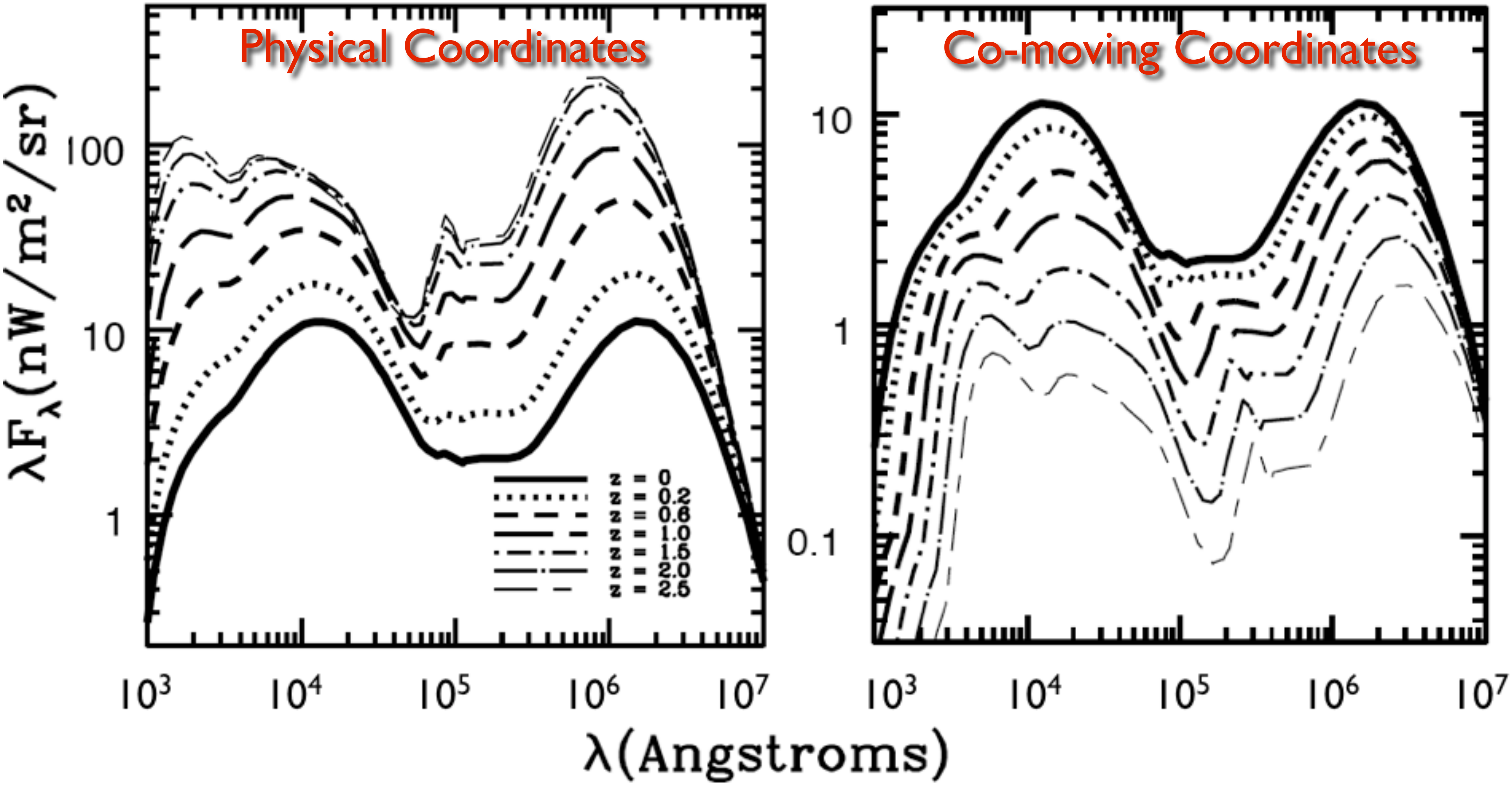
EBL from our Semi-Analytic Models



Propagating D+11 errors in SED fits and redshift extrapolation

Gilmore, Somerville, Primack, & Domínguez (2012)

Evolution of the EBL



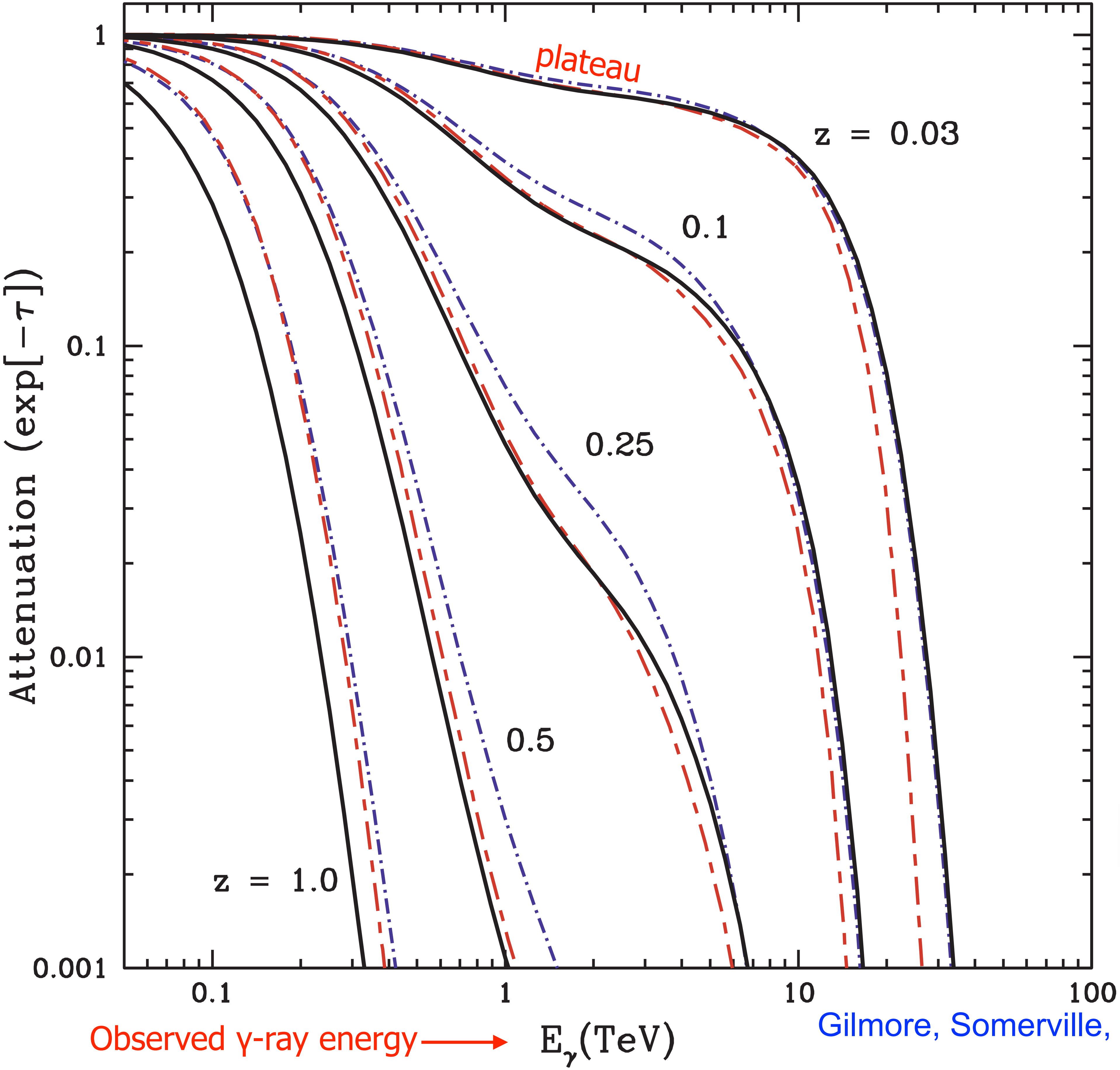
Physical Coordinates

Co-moving Coordinates

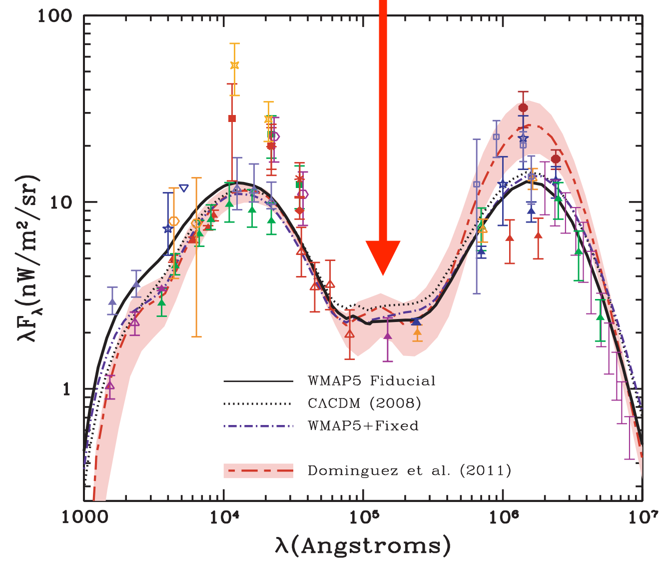
The evolution of the EBL in our WMAP5 Fiducial model. This is plotted on the left panel in standard units. The right panel shows the build-up of the present-day EBL by plotting the same quantities in comoving units. The redshifts from 0 to 2.5 are shown by the different line types in the key in the left panel.

Gilmore, Somerville, Primack, & Domínguez (2012)

Predicted Gamma Ray Attenuation



Increasing redshift causes absorption features to increase in magnitude and appear at lower energies. The plateau seen between 1 and 10 TeV at low z is a product of the mid-IR valley in the EBL spectrum.



Gilmore, Somerville, Primack, & Domínguez (2012)

Gamma Ray Attenuation due to $\gamma\gamma \rightarrow e^+e^-$

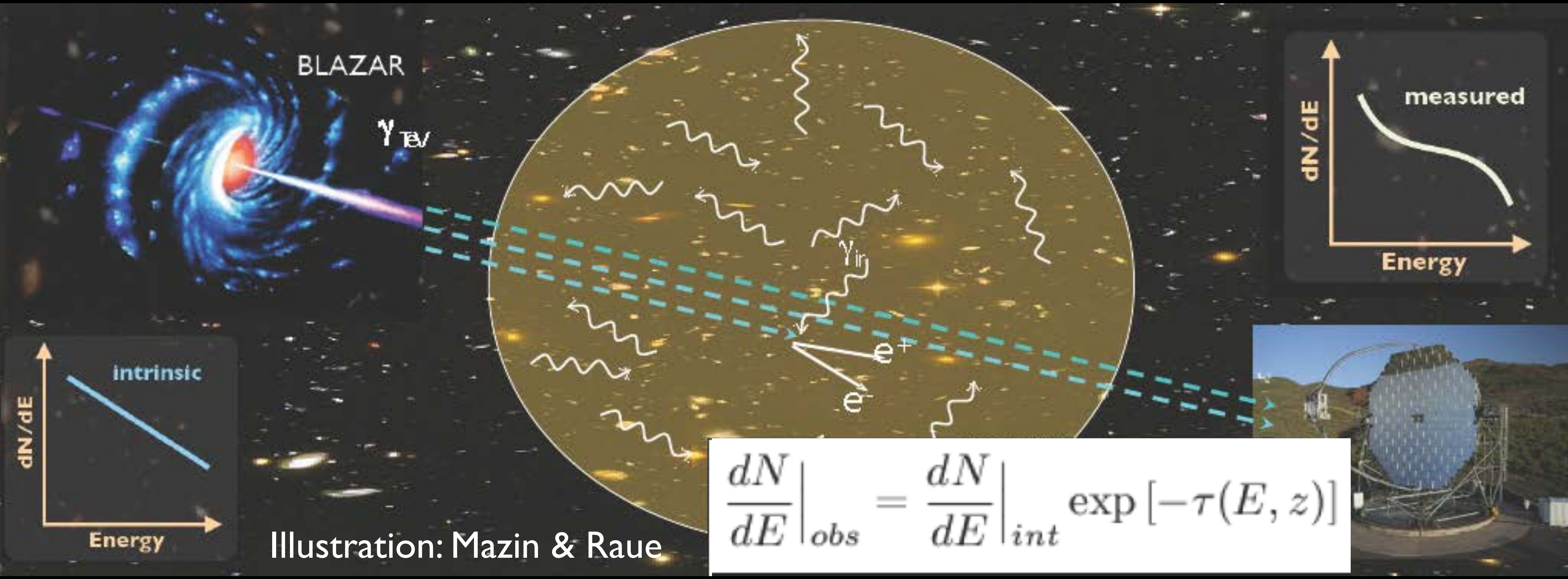
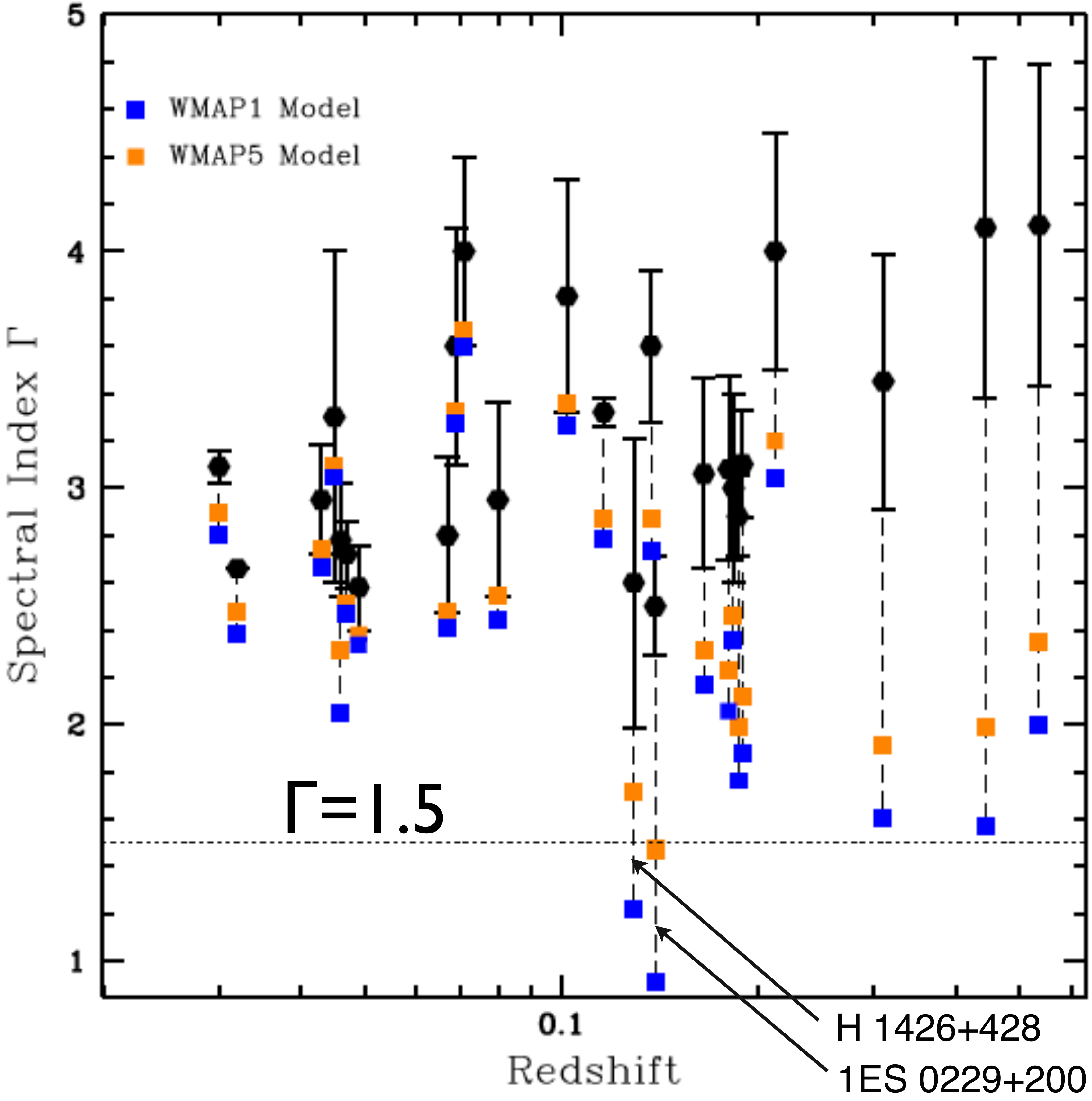


Illustration: Mazin & Raue

$$\left.\frac{dN}{dE}\right|_{obs} = \left.\frac{dN}{dE}\right|_{int} \exp\left[-\tau(E,z)\right]$$

If we know the intrinsic spectrum, we can infer the optical depth $\tau(E,z)$ from the observed spectrum. In practice, we typically *assume* that $dN/dE|_{int}$ is not harder than $E^{-\Gamma}$ with $\Gamma = 1.5$, since local sources have $\Gamma \geq 2$. More conservatively, we can assume that $\Gamma \geq 2/3$.

Reconstructed Blazar Spectral Indexes



Γ=1.5

H 1426+428

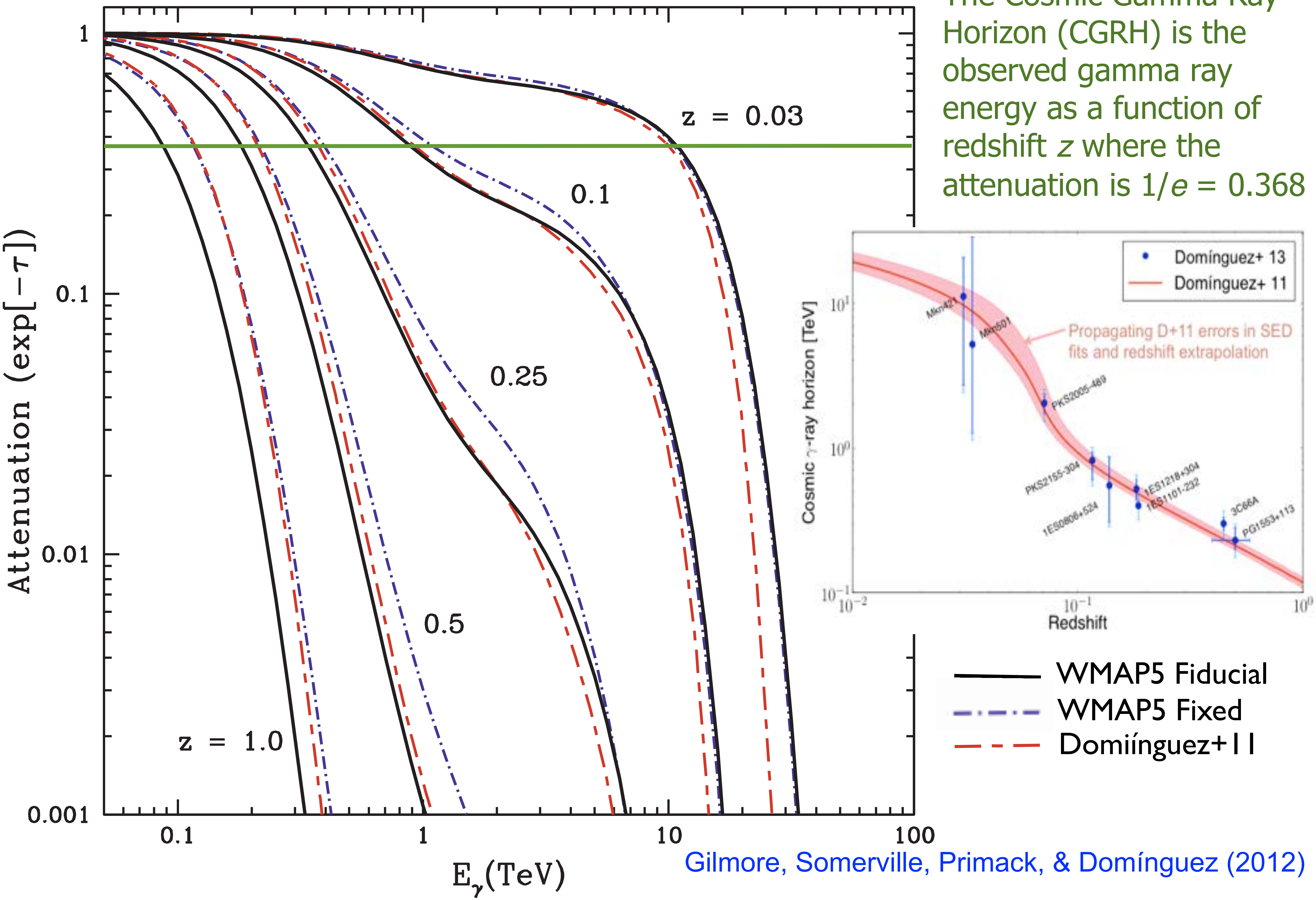
1ES 0229+200

With our SAM based on WMAP5 cosmological parameters and Spitzer (Rieke+09) dust emission templates, all high redshift blazars have intrinsic spectral indexes Γ≥1.5, as expected from nearby sources.

(Of course, the spectrum could be harder than Γ≥1.5.)

Predicted Gamma Ray Attenuation

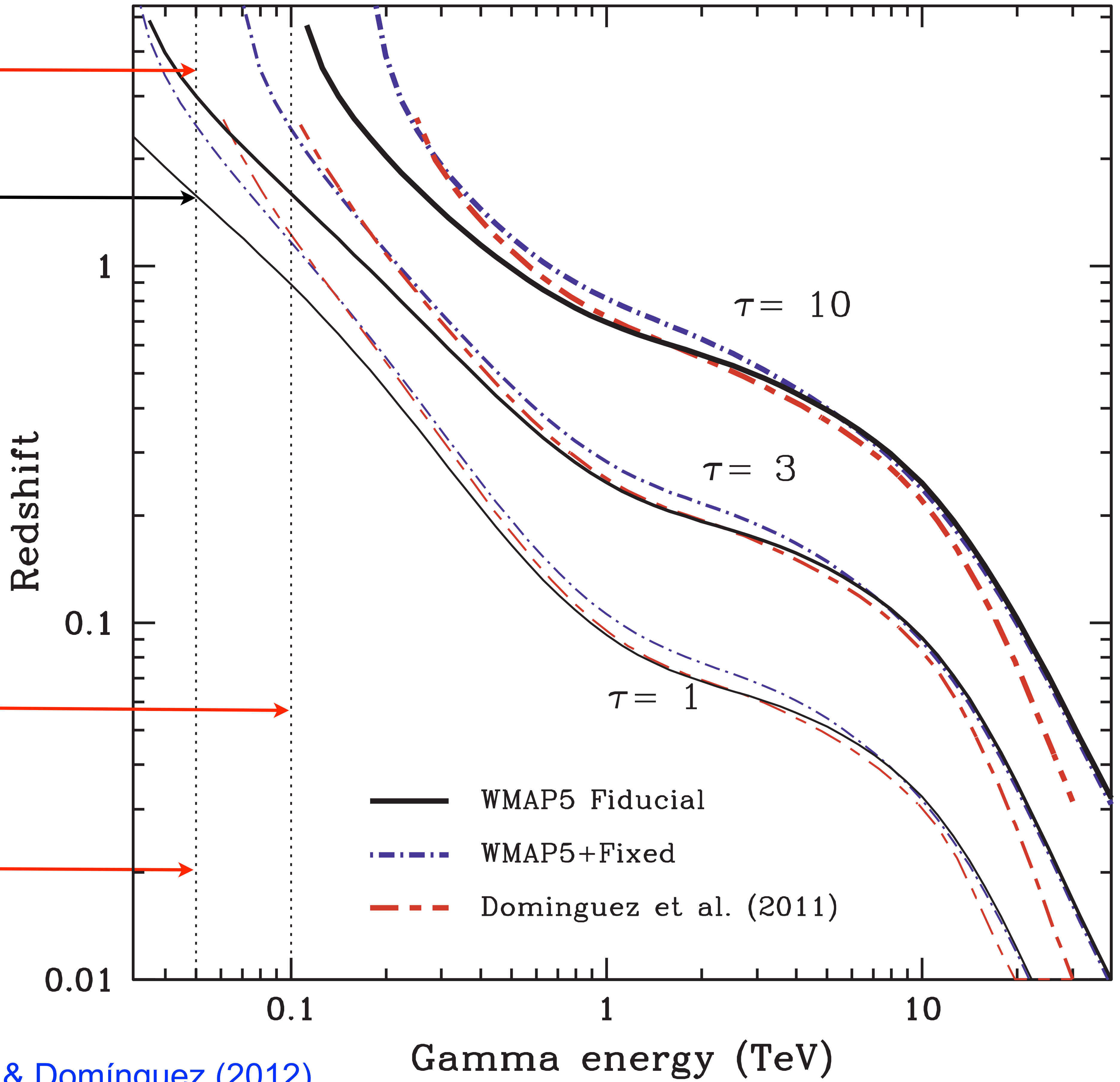
The Cosmic Gamma Ray Horizon (CGRH) is the observed gamma ray energy as a function of redshift *z* where the attenuation is 1/*e* = 0.368



Gilmore, Somerville, Primack, & Domínguez (2012)

Cosmic Gamma-Ray Horizon

With a 50 GeV threshold, we see to z≈1.5-3 with less than 1/e attenuation!



100 GeV Threshold

50 GeV Threshold

Gilmore, Somerville, Primack, & Domínguez (2012)

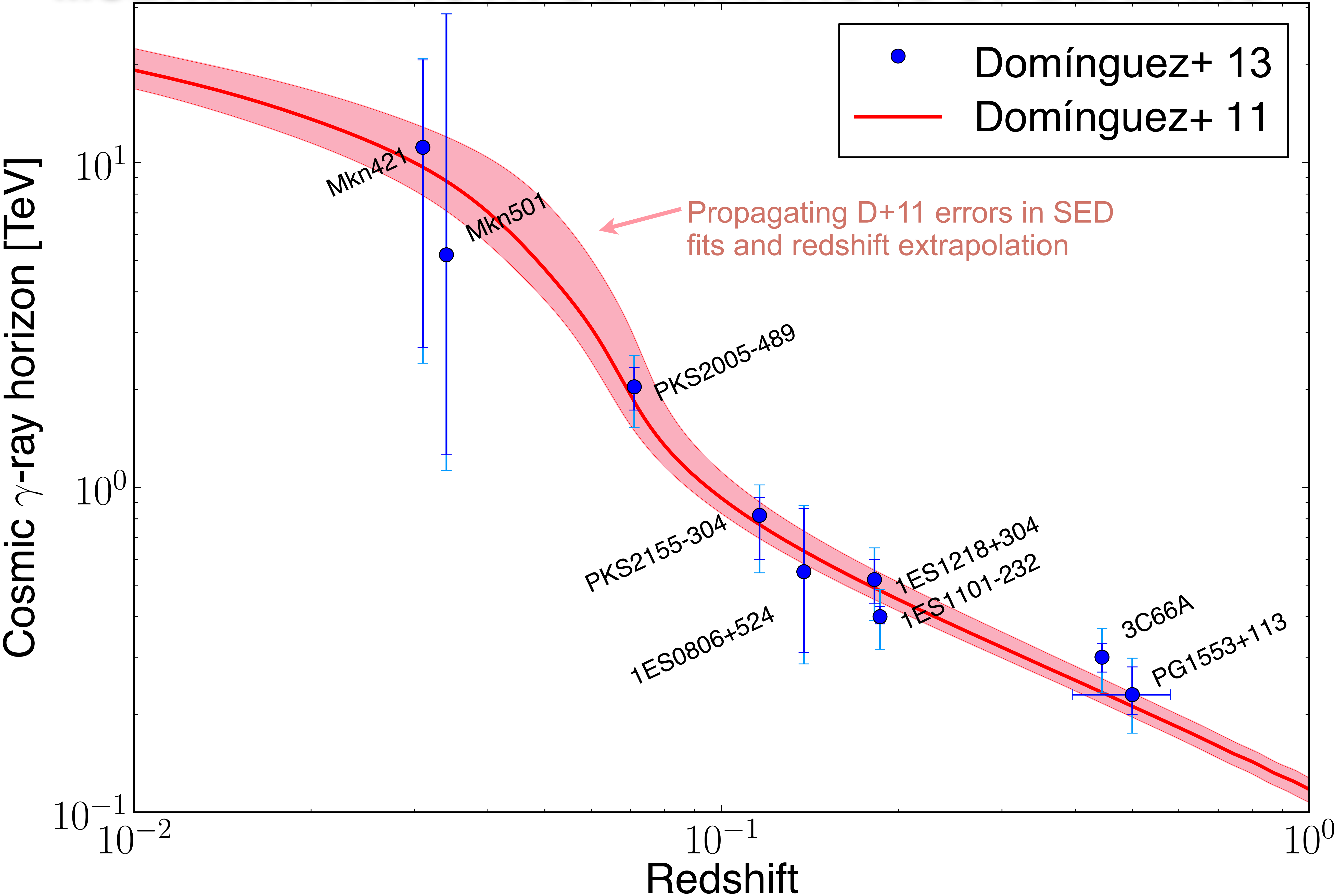
DETECTION OF THE COSMIC γ-RAY HORIZON FROM MULTIWAVELENGTH OBSERVATIONS OF BLAZARS

ApJ 770, 77 (2013)

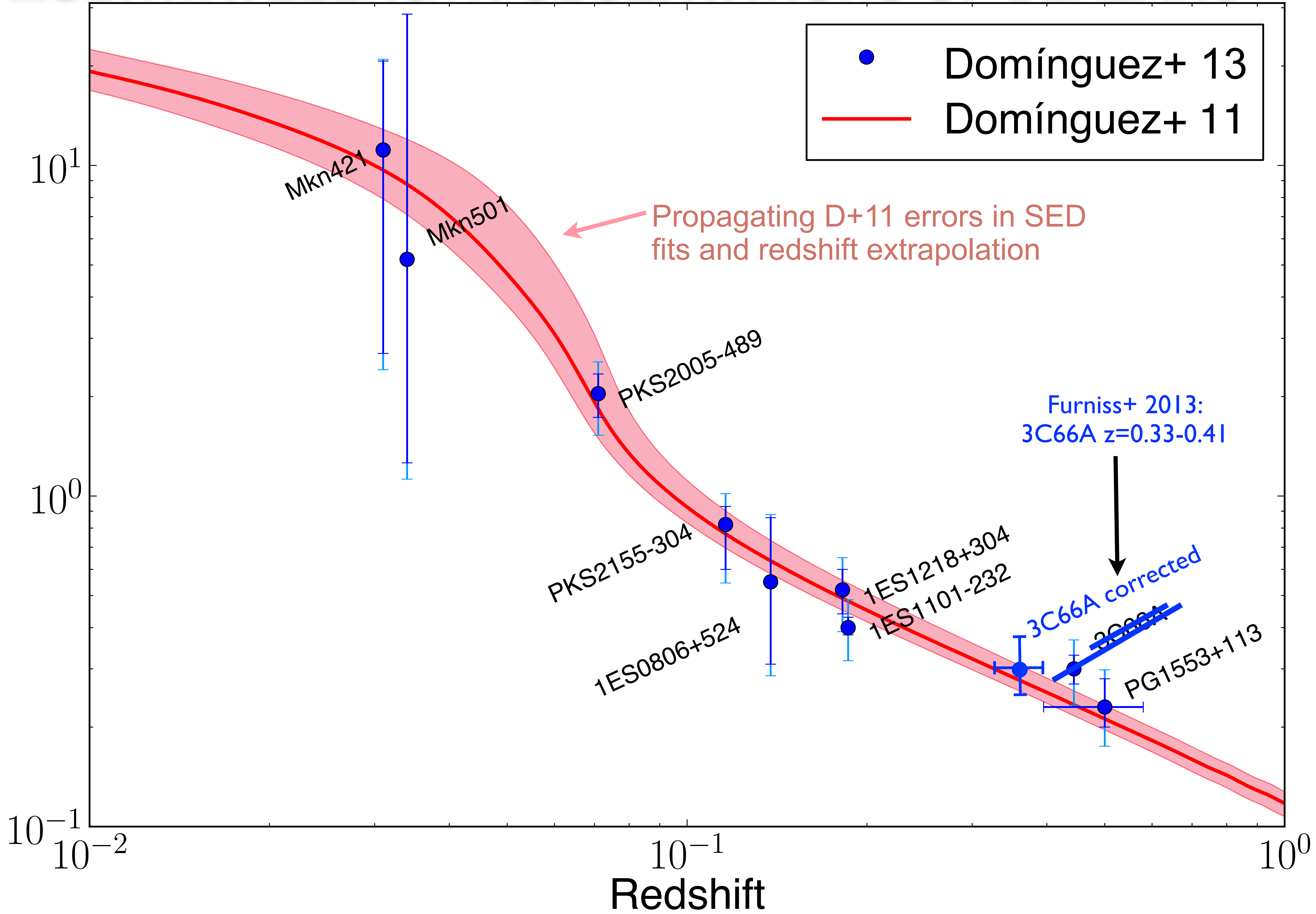
A. Domínguez, J. D. Finke, F. Prada, J. R. Primack, F. S. Kitaura, B. Siana, D. Paneque

The first statistically significant detection of the cosmic γ-ray horizon (CGRH) that is independent of any extragalactic background light (EBL) model is presented. The CGRH is a fundamental quantity in cosmology. It gives an estimate of the opacity of the Universe to very-high energy (VHE) γ-ray photons due to photon-photon pair production with the EBL. The only estimations of the CGRH to date are predictions from EBL models and lower limits from γ-ray observations of cosmological blazars and γ-ray bursts. Here, we present synchrotron self-Compton models (SSC) of the spectral energy distributions of 9/15 blazars based on (almost) simultaneous observations from radio up to the highest energy γ-rays taken with the Fermi satellite. These SSC models predict the unattenuated VHE fluxes, which are compared with the observations by imaging atmospheric Cherenkov telescopes. This comparison provides an estimate of the optical depth of the EBL, which allows a derivation of the CGRH through a maximum likelihood analysis that is EBL-model independent. We find that the observed CGRH is compatible with the current knowledge of the EBL.

DETECTION OF THE COSMIC γ-RAY HORIZON FROM MULTIWAVELENGTH OBSERVATIONS OF BLAZARS



DETECTION OF THE COSMIC γ-RAY HORIZON FROM MULTIWAVELENGTH OBSERVATIONS OF BLAZARS



Propagating D+11 errors in SED fits and redshift extrapolation

Furniss+ 2013:
3C66A z=0.33-0.41

The Imprint of the Extragalactic Background Light in the Gamma-Ray Spectra of Blazars

M. Ackermann, M. Ajello, et al. (Fermi),

(Fermi), *Science* 338, 1190 (2012)

ABSTRACT The light emitted by stars and accreting compact objects through the history of the universe is encoded in the intensity of the extragalactic background light (EBL). Knowledge of the EBL is important to understand the nature of star formation and galaxy evolution, but direct measurements of the EBL are limited by galactic and other foreground emissions. Here, we report an absorption feature seen in the combined spectra of a sample of gamma-ray blazars out to a redshift of *z* ~ 1.6. This feature is caused by attenuation of gamma rays by the EBL at optical to ultraviolet frequencies and allowed us to measure the EBL flux density in this frequency band.

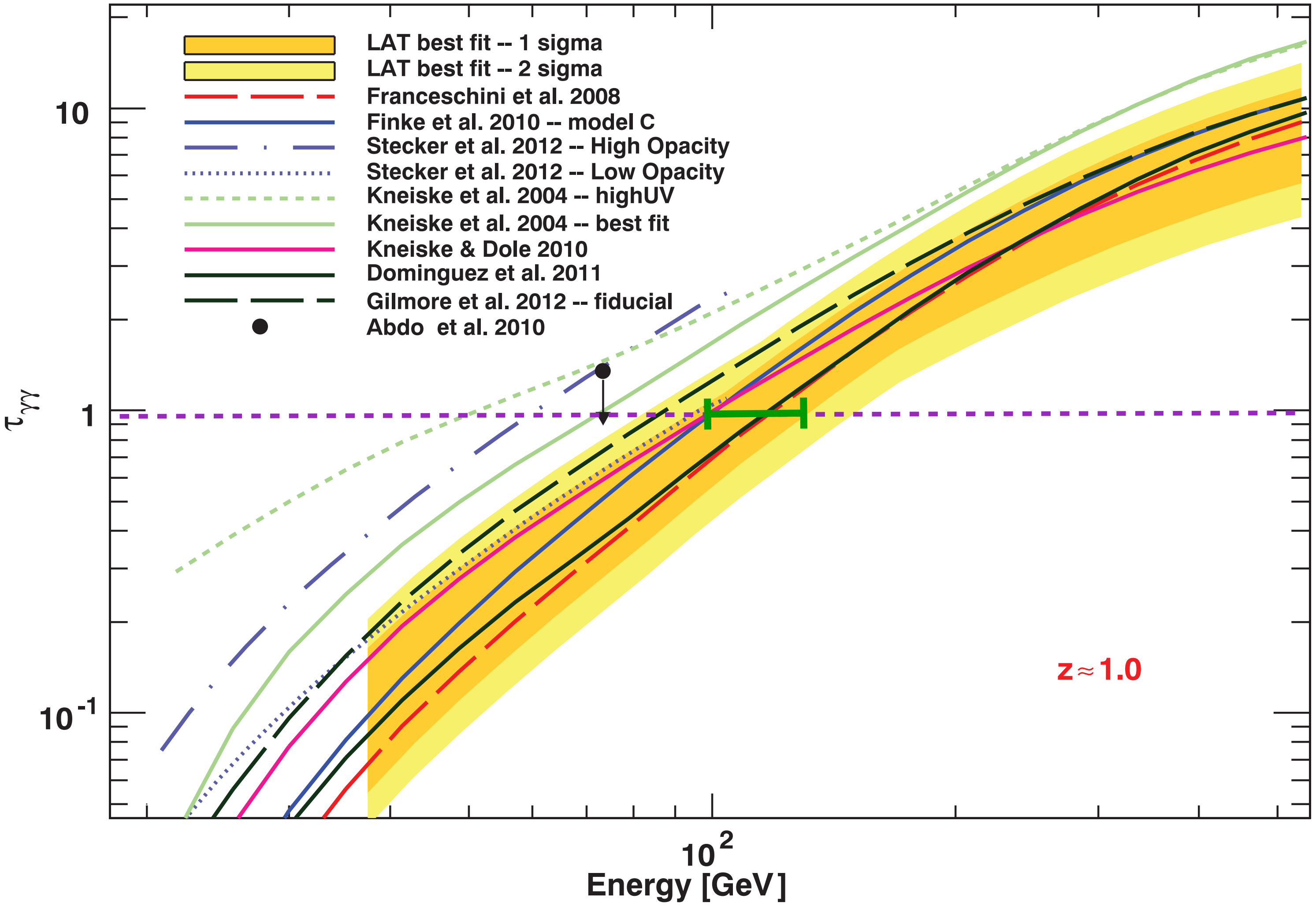


Fig. 1. Measurement, at the 68 and 95% confidence levels (including systematic uncertainties added in quadrature), of the opacity $\tau_{\gamma\gamma}$ from the best fits to the Fermi data compared with predic- tions of EBL models. The plot shows the measurement at z≈1, which is the average redshift of the most constraining redshift interval (i.e., $0.5 \lesssim z < 1.6$). The Fermi-LAT measurement was derived com- bining the limits on the best-fit EBL models. The downward arrow represents the 95% upper limit on the opacity at z = 1.05 derived in A. A. Abdo et al., Astrophys. J. 723, 1082 (2010).

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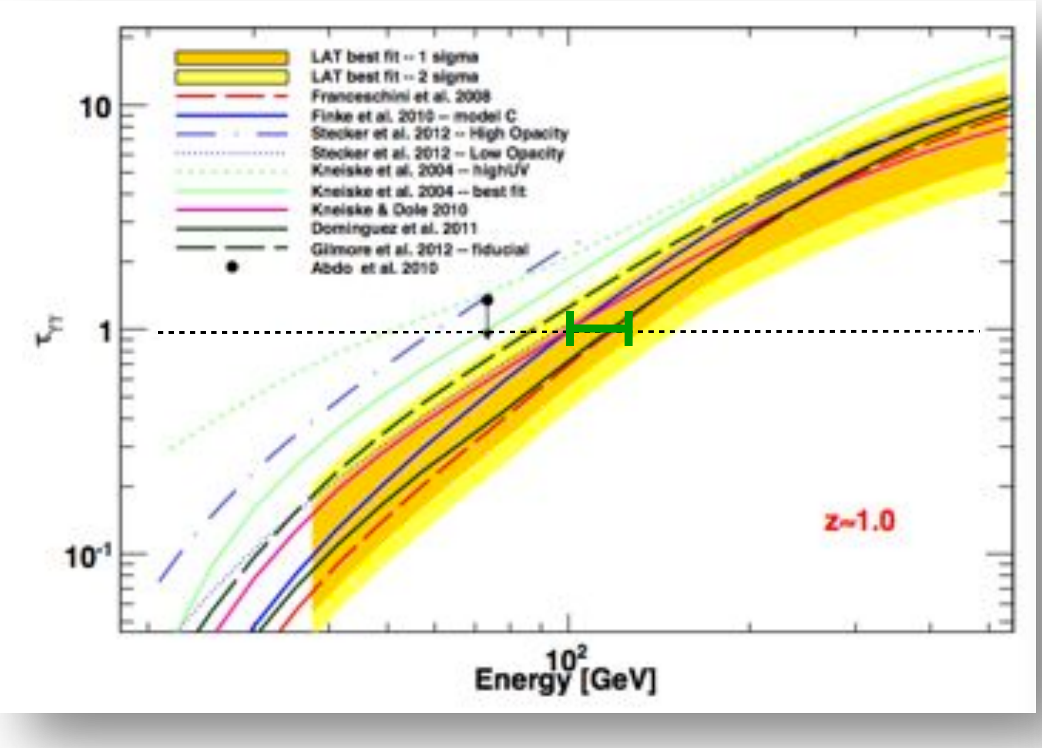
M. Ackermann, M. Ajello, et al. (Fermi), Science 338, 1190 (2012)

Composite Likelihood Results

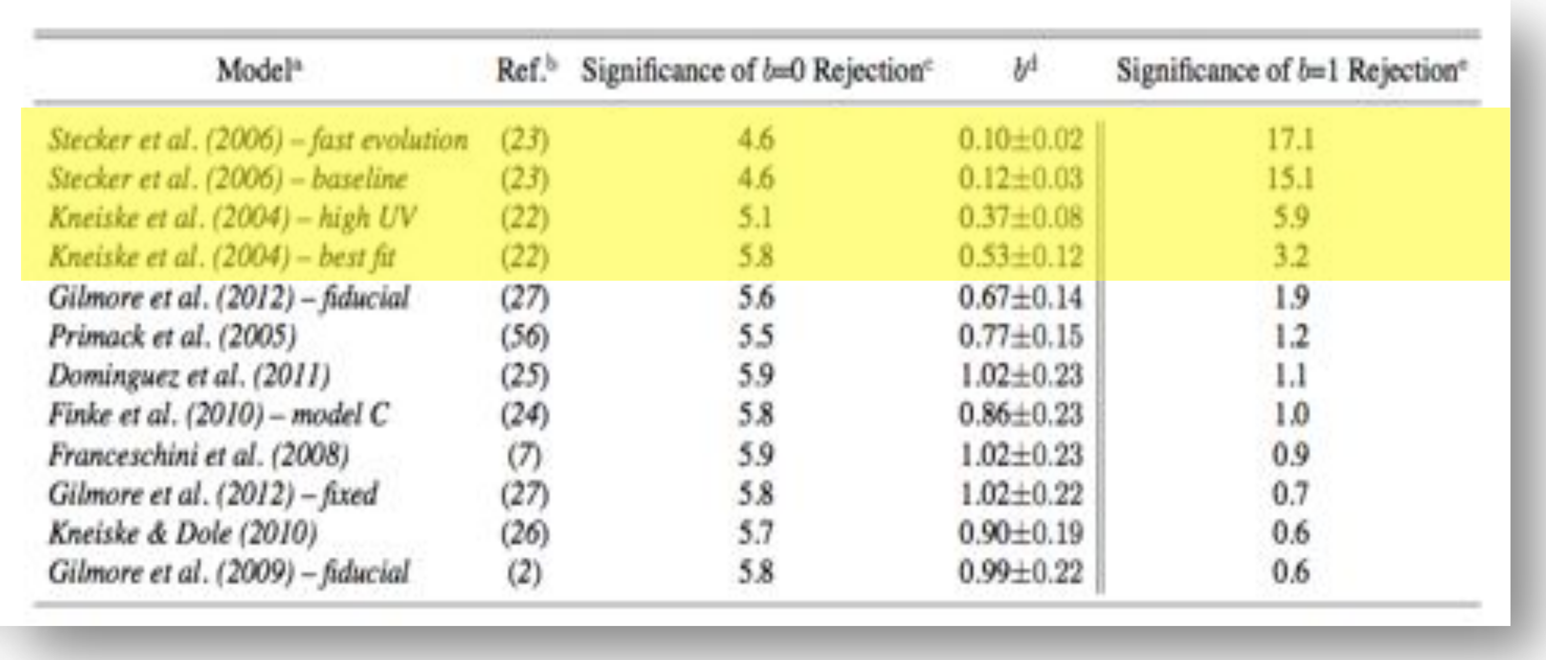
- A significant steepening in the blazars' spectra is detected
- This is consistent with that expected by a 'minimal' EBL:
  - i.e. EBL at the level of galaxy counts
  - 4 models rejected above 3sigma
- All the non-rejected models yield a significance of detection of 5.6-5.9 σ
- The level of EBL is 3-4 times lower than our previous UL (Abdo+10, ApJ 723, 1082)



EBL Detection Significance

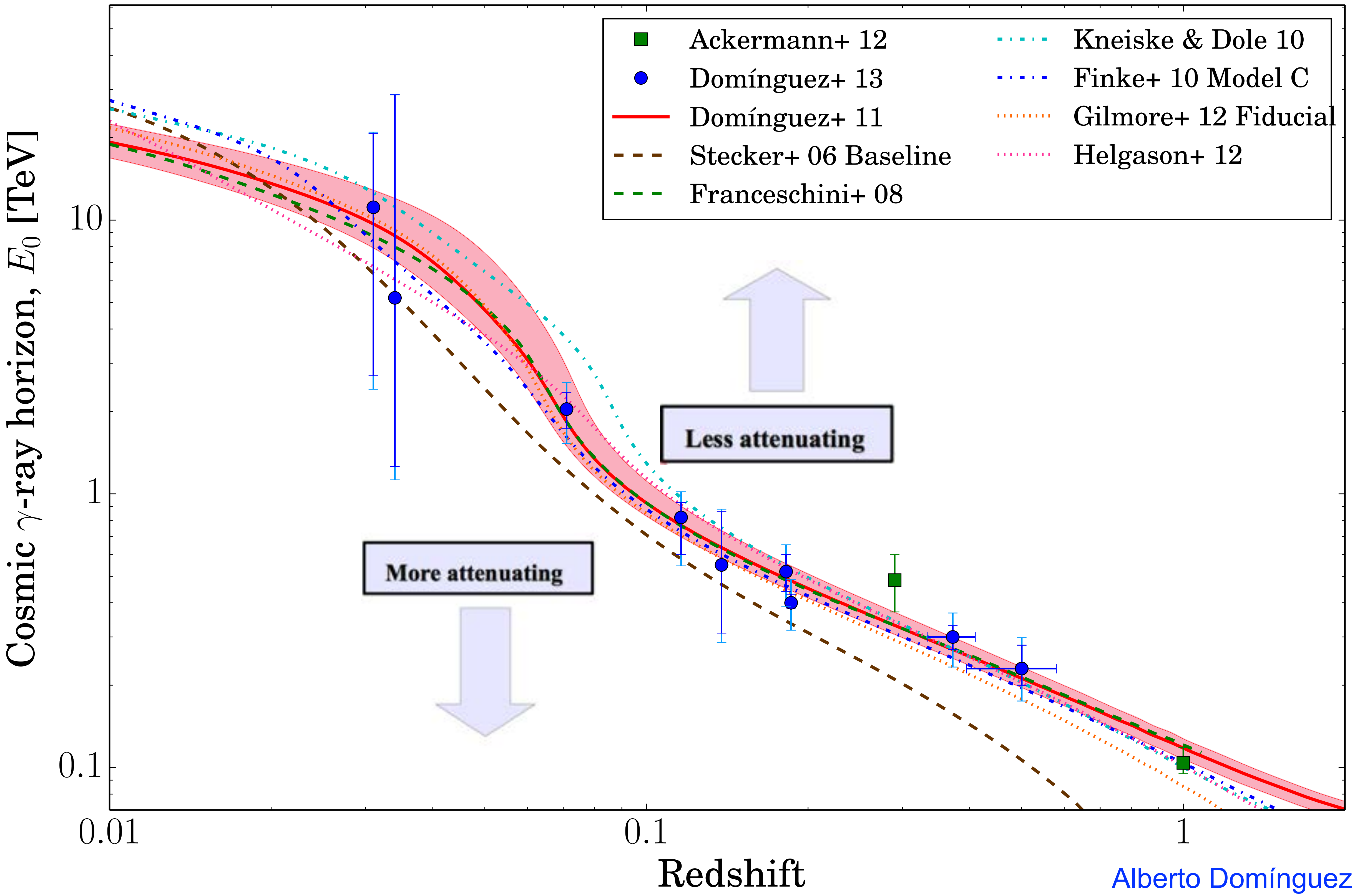
Model Rejection Significance

Ackermann+12



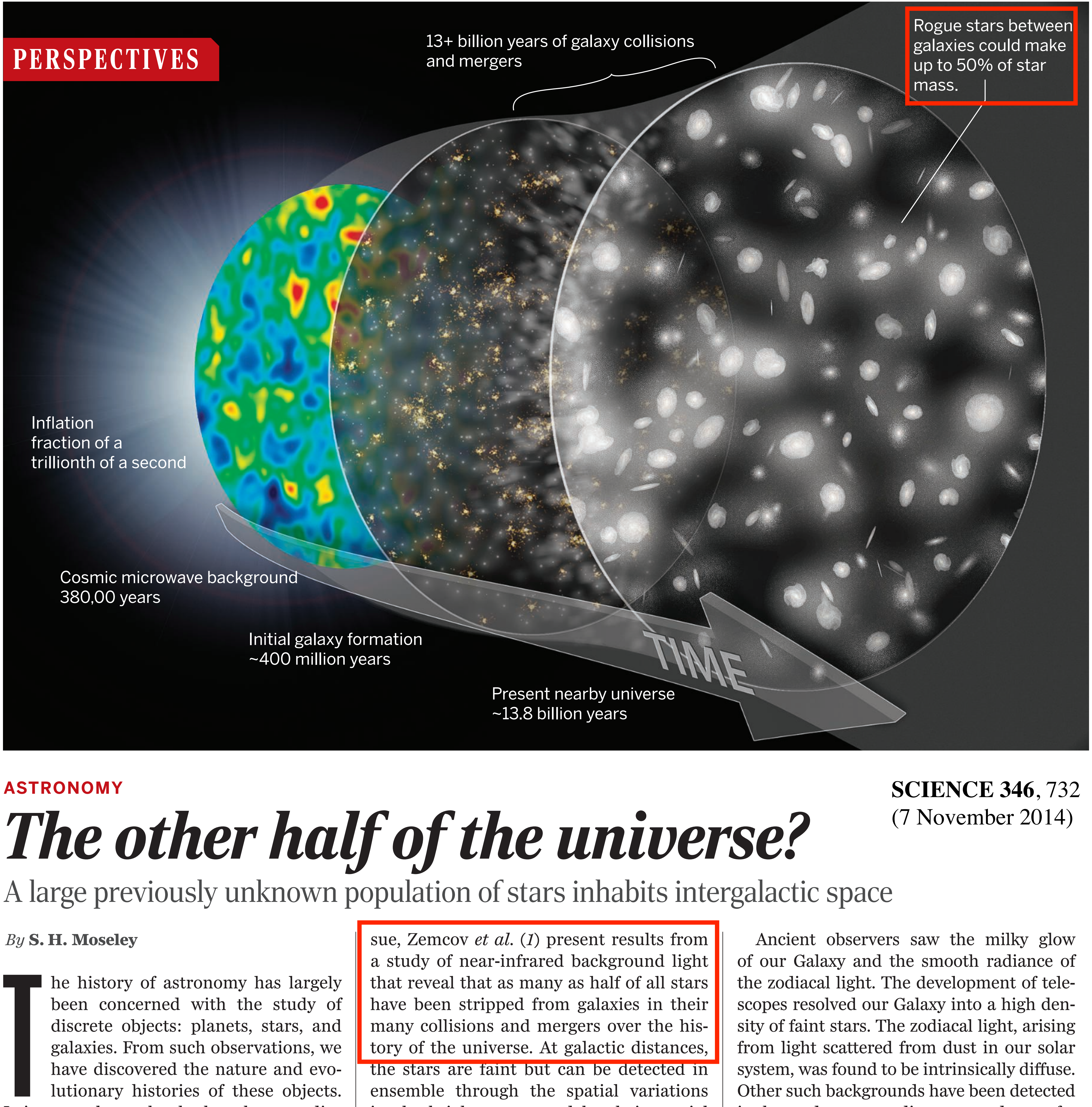
Model[a]	Ref.[b]	Significance of b=0 Rejection[c]	b[d]	Significance of b=1 Rejection[e]
Stecker et al. (2006) – fast evolution	(23)	4.6	0.10±0.02	17.1
Stecker et al. (2006) – baseline	(23)	4.6	0.12±0.03	15.1
Kneiske et al. (2004) – high UV	(22)	5.1	0.37±0.08	5.9
Kneiske et al. (2004) – best fit	(22)	5.8	0.53±0.12	3.2
Gilmore et al. (2012) – fiducial	(27)	5.6	0.67±0.14	1.9
Primack et al. (2005)	(56)	5.5	0.77±0.15	1.2
Dominguez et al. (2011)	(25)	5.9	1.02±0.23	1.1
Finke et al. (2010) – model C	(24)	5.8	0.86±0.23	1.0
Franceschini et al. (2008)	(7)	5.9	1.02±0.23	0.9
Gilmore et al. (2012) – fixed	(27)	5.8	1.02±0.22	0.7
Kneiske & Dole (2010)	(26)	5.7	0.90±0.19	0.6
Gilmore et al. (2009) – fiducial	(2)	5.8	0.99±0.22	0.6

Cosmic Gamma-Ray Horizon Compared with EBL Models



Alberto Domínguez

Really??



ASTRONOMY

SCIENCE 346, 732
(7 November 2014)

The other half of the universe?

A large previously unknown population of stars inhabits intergalactic space

By **S. H. Moseley**

The history of astronomy has largely been concerned with the study of discrete objects: planets, stars, and galaxies. From such observations, we have discovered the nature and evolutionary histories of these objects.

sue, Zemcov *et al.* (*1*) present results from a study of near-infrared background light that reveal that as many as half of all stars have been stripped from galaxies in their many collisions and mergers over the history of the universe. At galactic distances, the stars are faint but can be detected in ensemble through the spatial variations

Ancient observers saw the milky glow of our Galaxy and the smooth radiance of the zodiacal light. The development of telescopes resolved our Galaxy into a high density of faint stars. The zodiacal light, arising from light scattered from dust in our solar system, was found to be intrinsically diffuse. Other such backgrounds have been detected

On the origin of near-infrared extragalactic background light anisotropy

Michael Zemcov,[1,2] Joseph Smidt,[3,4] Toshiaki Arai,[5,6] James Bock,[1,2]* Asantha Cooray,[4] Yan Gong,[4] Min Gyu Kim,[7] Phillip Korngut,[2,1] Anson Lam,[8,1] Dae Hee Lee,[9] Toshio Matsumoto,[5,10] Shuji Matsuura,[5] Uk Won Nam,[9] Gael Roudier,[2] Kohji Tsumura,[11] Takehiko Wada[5]

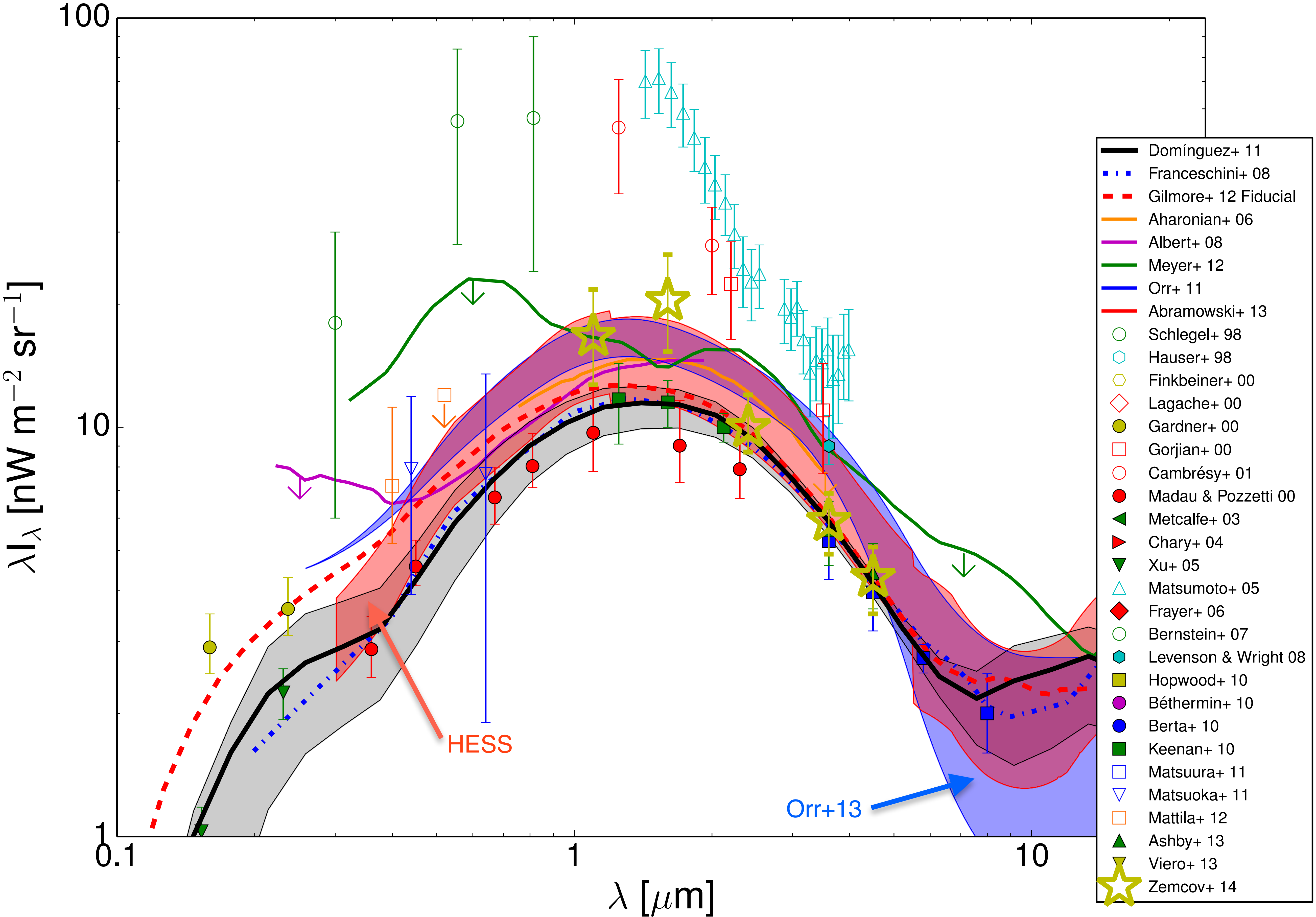
SCIENCE 346, 732 (7 November 2014)

Extragalactic background light (EBL) anisotropy traces variations in the total production of photons over cosmic history and may contain faint, extended components missed in galaxy point-source surveys. Infrared EBL fluctuations have been attributed to primordial galaxies and black holes at the epoch of reionization (EOR) or, alternately, intrahalo light (IHL) from stars tidally stripped from their parent galaxies at low redshift. We report new EBL anisotropy measurements from a specialized sounding rocket experiment at 1.1 and 1.6 micrometers. The observed fluctuations exceed the amplitude from known galaxy populations, are inconsistent with EOR galaxies and black holes, and are largely explained by IHL emission. The measured fluctuations are associated with an EBL intensity that is comparable to the background from known galaxies measured through number counts and therefore a substantial contribution to the energy contained in photons in the cosmos.

Table 1. Contributions to near-infrared EBL anisotropy and intensity.

	fluctuation amplitude at large angular scales	IHL model-dependent intensity / anisotropy	deduced IHL intensity	IGL from previous measurements	ratio of the IHL and IGL intensities	inferred total background intensity
λ (μm)	**Measured $\delta\lambda I_\lambda$* (nW m^{-2} sr^{-1})**	$\frac{\lambda I_{\lambda,\mathrm{IHL}}}{\delta\lambda I_\lambda}$	**$\lambda I_{\lambda,\mathrm{IHL}}$‡ (nW m^{-2} sr^{-1})**	**$\lambda I_{\lambda,\mathrm{IGL}}$§ (nW m^{-2} sr^{-1})**	$\frac{\lambda I_{\lambda,\mathrm{IHL}}}{\lambda I_{\lambda,\mathrm{IGL}}}$	**$\lambda I_{\lambda,\mathrm{IHL}} + \lambda I_{\lambda,\mathrm{IGL}}$ (nW m^{-2} sr^{-1})**
1.1	$1.4^{+0.8}_{-0.7}$	5	$7.0^{+4.0}_{-3.5}$	$9.7^{+3.0}_{-1.9}$	0.7	$16.7^{+5.0}_{-4.0}$
1.6	$1.9^{+0.9}_{-0.8}$	6	$11.4^{+5.4}_{-4.8}$	$9.0^{+2.6}_{-1.7}$	1.3	$20.4^{+6.0}_{-5.1}$
2.4	0.32 ± 0.05†	7	2.2 ± 0.4	$7.8^{+2.0}_{-1.2}$¶	0.3	$10.0^{+2.0}_{-1.3}$
3.6	$0.072^{+0.019}_{-0.021}$	9	$0.65^{+0.17}_{-0.19}$	5.2 ± 1.0	0.1	5.9 ± 1.0
3.6#	$0.049^{+0.021}_{-0.007}$	9	$0.44^{+0.19}_{-0.06}$	5.2 ± 1.0	0.1	5.6 ± 1.0
4.5	0.053 ± 0.023†	7	0.37 ± 0.16	3.9 ± 0.8	0.1	4.3 ± 0.8

Local EBL Observations with Zemcov+14



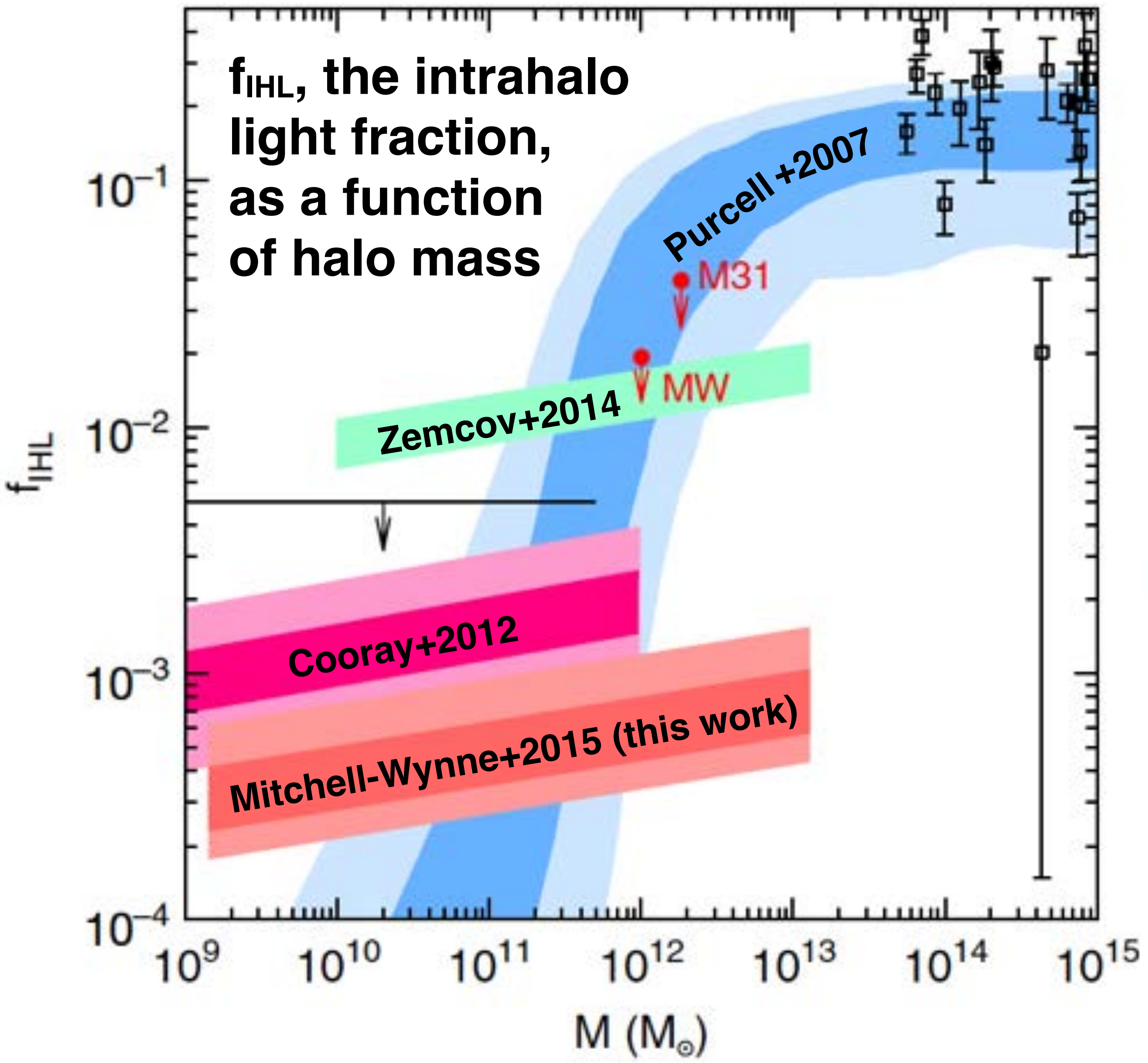
Alberto Domínguez

nature COMMUNICATIONS
2015

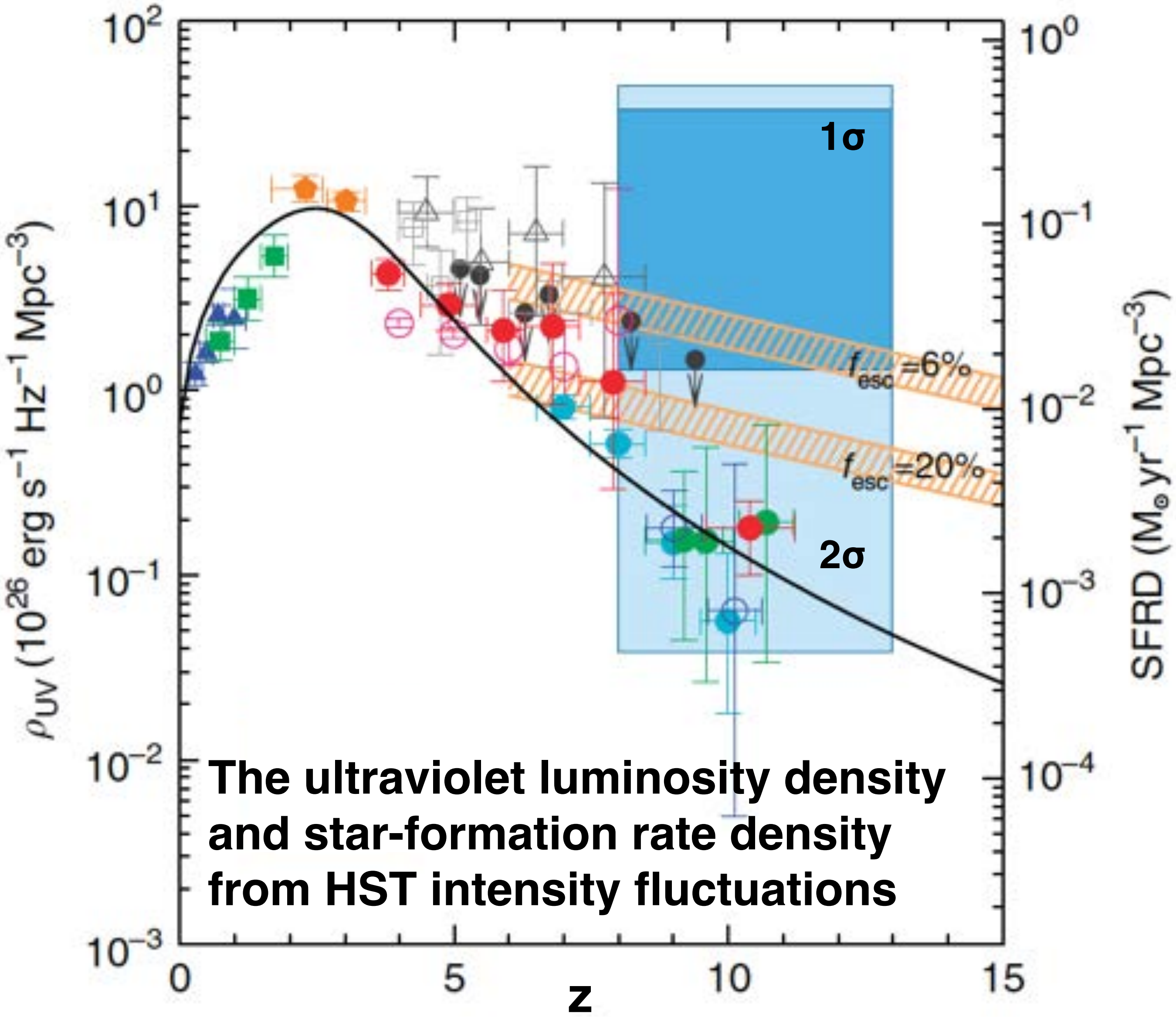
Ultraviolet luminosity density of the universe during the epoch of reionization

Ketron Mitchell-Wynne, Asantha Cooray, Yan Gong, Matthew Ashby, Timothy Dolch, Henry Ferguson, Steven Finkelstein, Norman Grogin, Dale Kocevski, Anton Koekemoer, Joel Primack & Joseph Smidt

The spatial fluctuations of the extragalactic background light trace the total emission from all stars and galaxies in the Universe. A multiwavelength study can be used to measure the integrated emission from first galaxies during reionization. Here we report arcmin-scale spatial fluctuations in GOODS-S with HST in five wavebands between 0.6 and 1.6 mm. This level of integrated light emission allows for a significant surface density of fainter primeval galaxies that are below the point-source detection level in current surveys.



The dark and light shaded regions show the 95 and 68% ranges of fIHL from anisotropy measurements, and from an analytical prediction (Purcell+2007, blue). Intracluster measurements are shown as boxes (Gonzalez+2005), with 1s errors. The red downward arrows denote the 95% confidence upper limit on fIHL estimated for Andromeda (M31) and our Milky Way (MW).

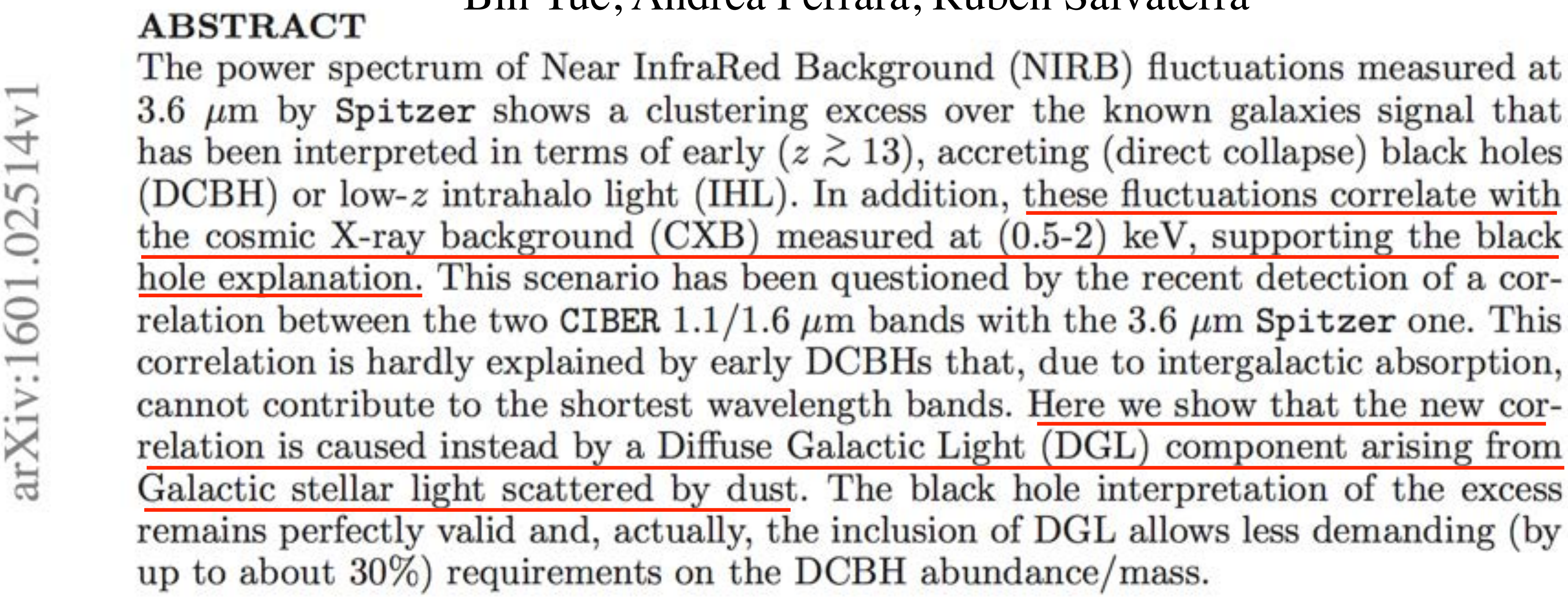


Shown are luminosity function extrapolations and integrations down to MUV = −13. Our measured star formation rate densities (blue rectangle) are consistent with previous works at z = 8 to 10, however only extremely bright galaxies are directly detected. For reference we plot the theoretically expected relation between ultraviolet luminosity density and redshift to reionize the universe and/or to maintain reionization using an optical depth to reionization of τ = 0.066 ± 0.012 (Planck 2015). We take a gas clumping factor of C = 3 and show two cases where the escape fraction of galaxies is 6 and 20%.

See also: Seo et al. 2015, AKARI CIB Fluctuations, ApJ, 807, 140

Updated analysis of near-infrared background fluctuations

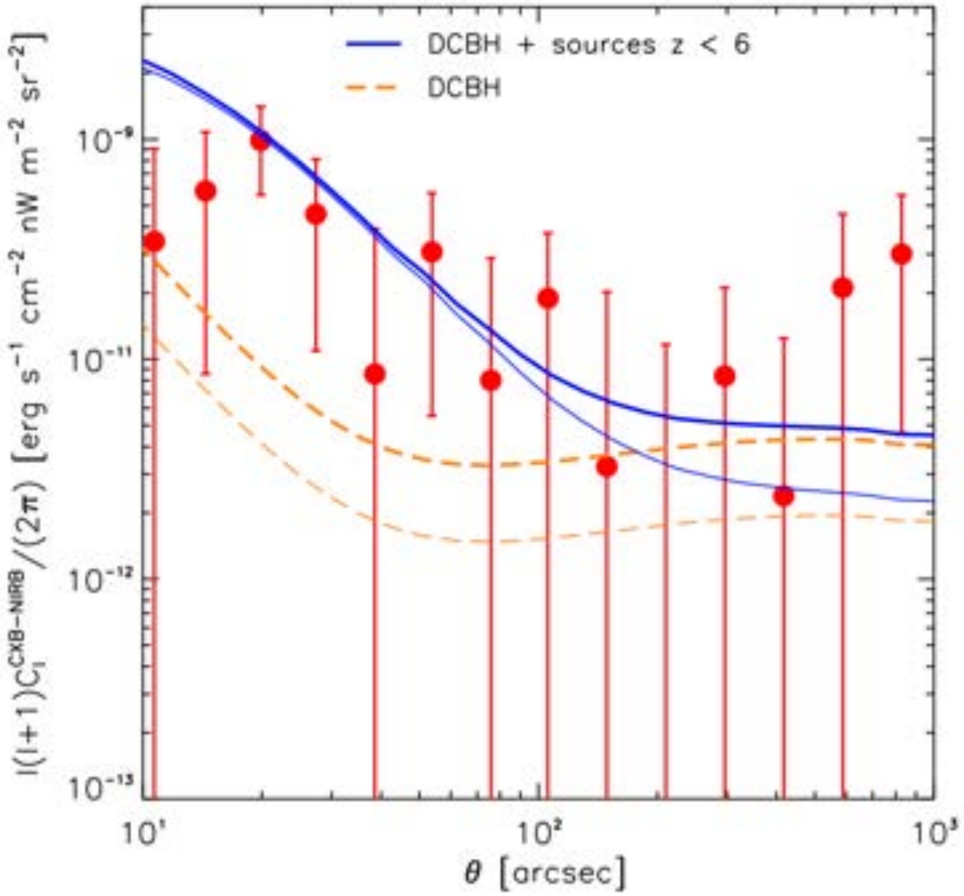
Bin Yue, Andrea Ferrara, Ruben Salvaterra



arXiv:1601.02514v1

ABSTRACT

The power spectrum of Near InfraRed Background (NIRB) fluctuations measured at 3.6 μm by `Spitzer` shows a clustering excess over the known galaxies signal that has been interpreted in terms of early ($z \gtrsim 13$), accreting (direct collapse) black holes (DCBH) or low-z intrahalo light (IHL). In addition, these fluctuations correlate with the cosmic X-ray background (CXB) measured at (0.5-2) keV, supporting the black hole explanation. This scenario has been questioned by the recent detection of a correlation between the two `CIBER` 1.1/1.6 μm bands with the 3.6 μm `Spitzer` one. This correlation is hardly explained by early DCBHs that, due to intergalactic absorption, cannot contribute to the shortest wavelength bands. Here we show that the new correlation is caused instead by a Diffuse Galactic Light (DGL) component arising from Galactic stellar light scattered by dust. The black hole interpretation of the excess remains perfectly valid and, actually, the inclusion of DGL allows less demanding (by up to about 30%) requirements on the DCBH abundance/mass.



The Direct Collapse Black Hole (DCBH) scenario in Yue et al. 2014 MNRAS describes ~$10^{5\text{-}6}$ $M_\odot$ SMBH formation at redshifts z = 20 to 13.

Figure 3. (0.5 – 2.0) keV CXB – 3.6 μm IR cross-correlation power spectrum. Points are observations from Cappelluti et al. (2013); dashed curves show the contribution from DCBHs; solid curves are the sum of DCBH and remaining $z < 6$ sources (AGNs, galaxies and hot gas, from Helgason et al. 2014). Thick (thin) lines are for the fiducial (reduced) model with $\rho_\bullet = 4 \times 10^5\ M_\odot \mathrm{Mpc}^{-3}$ ($\rho_\bullet = 2.7 \times 10^5\ M_\odot \mathrm{Mpc}^{-3}$) at peaks.

THE EXTRAGALACTIC BACKGROUND LIGHT, THE HUBBLE CONSTANT, AND ANOMALIES: CONCLUSIONS FROM 20 YEARS OF TEV GAMMA-RAY OBSERVATIONS

J. Biteau[1] & D. A. Williams[2]
Santa Cruz Institute for Particle Physics and Department of Physics,
University of California at Santa Cruz, Santa Cruz, CA 95064, USA

ApJ 2015

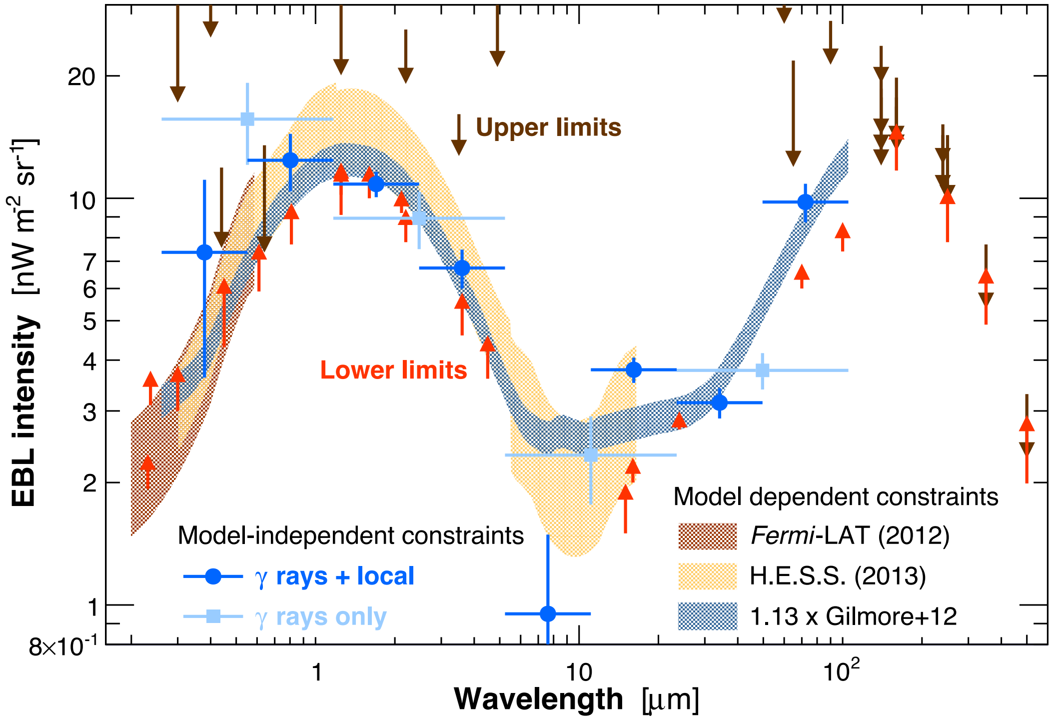
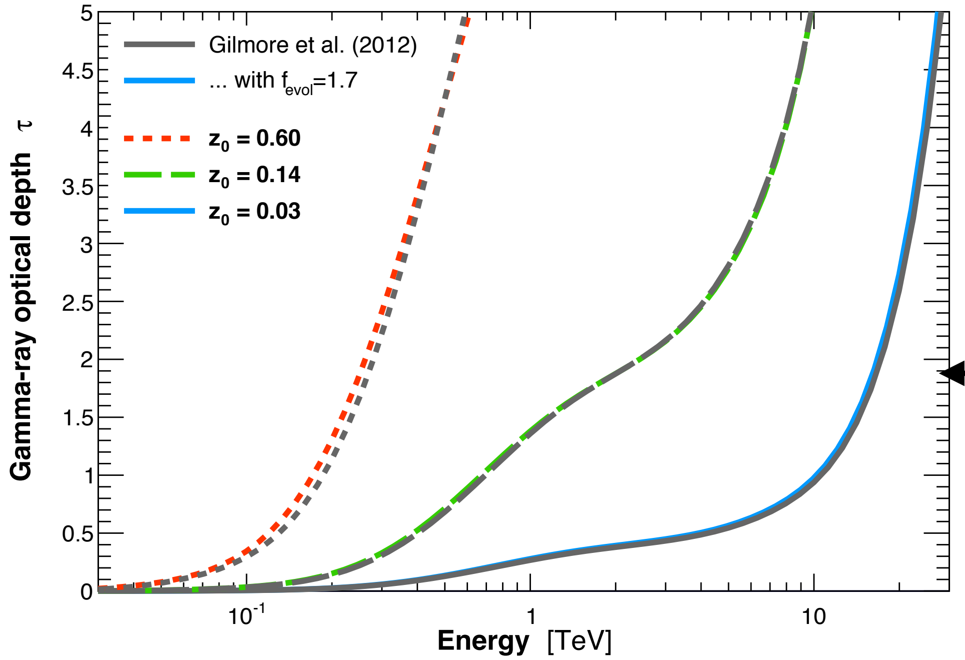


FIG. 3.— EBL intensity at $z = 0$ as a function of wavelength. The best-fit spectra derived in this work are shown with light blue (gamma rays only, four-point spectrum) and blue points (gamma rays + direct constraints, eight-point spectrum). Lower and upper limits are shown with orange upward-going and dark-brown downward-going arrows, respectively. For comparison with the work of Ackermann et al. (2012) and H.E.S.S. Collaboration (2013f), the $1\,\sigma$ (stat. + sys.) contour of the best-fit scaled-up model (Gilmore et al. 2012) is shown as filled blue region, using a scaling factor of 1.13 as shown in Table 4.



Showing that the assumed redshift evolution of the EBL spectrum $\propto(1+z)^{1.3}$ is consistent with Gilmore et al. (2012).

The Astrophysical Journal, 779:32 (23pp), 2013 December 10

HerMES: THE CONTRIBUTION TO THE COSMIC INFRARED BACKGROUND FROM GALAXIES SELECTED BY MASS AND REDSHIFT*

Marco P. Viero et al.

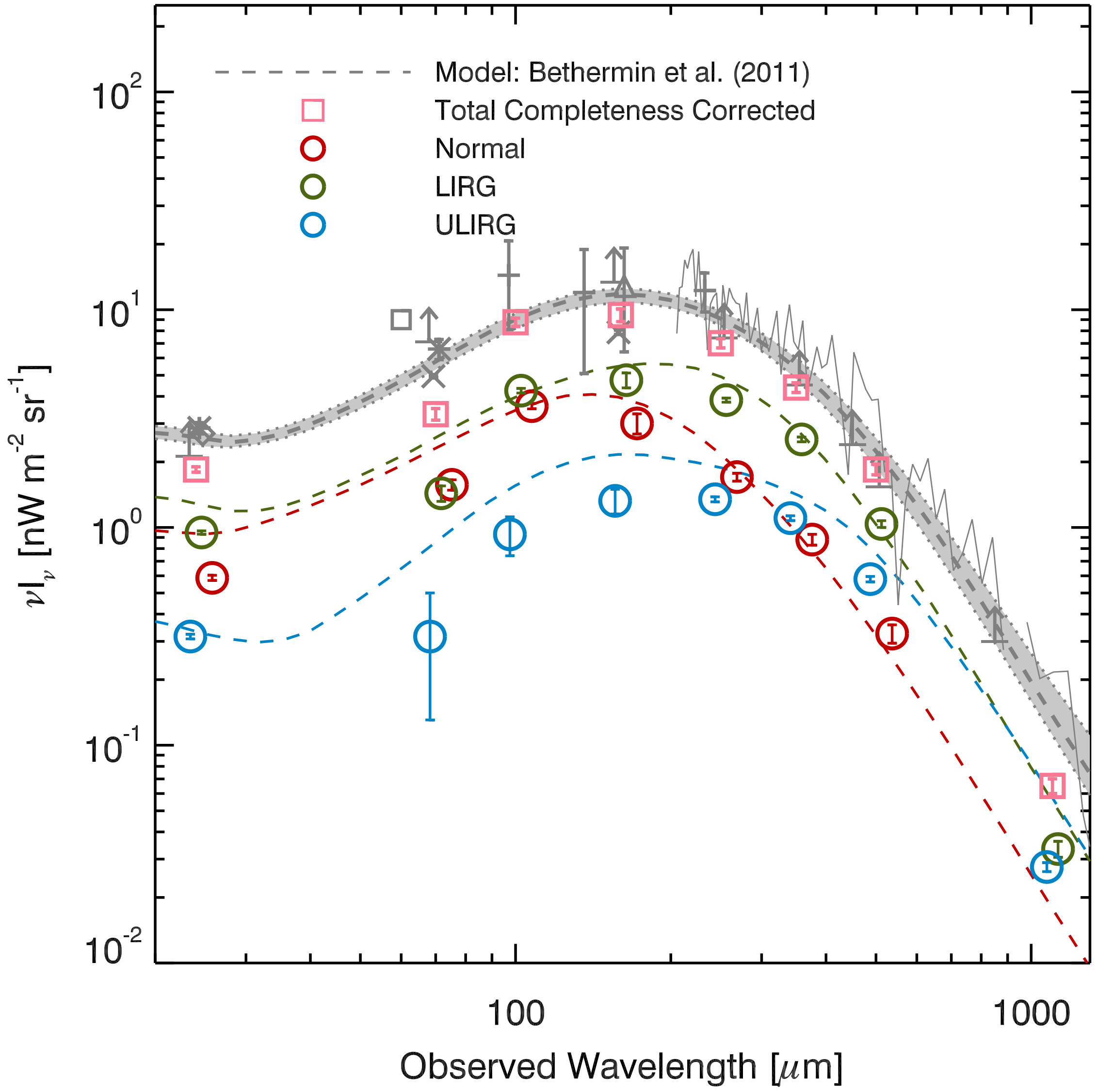
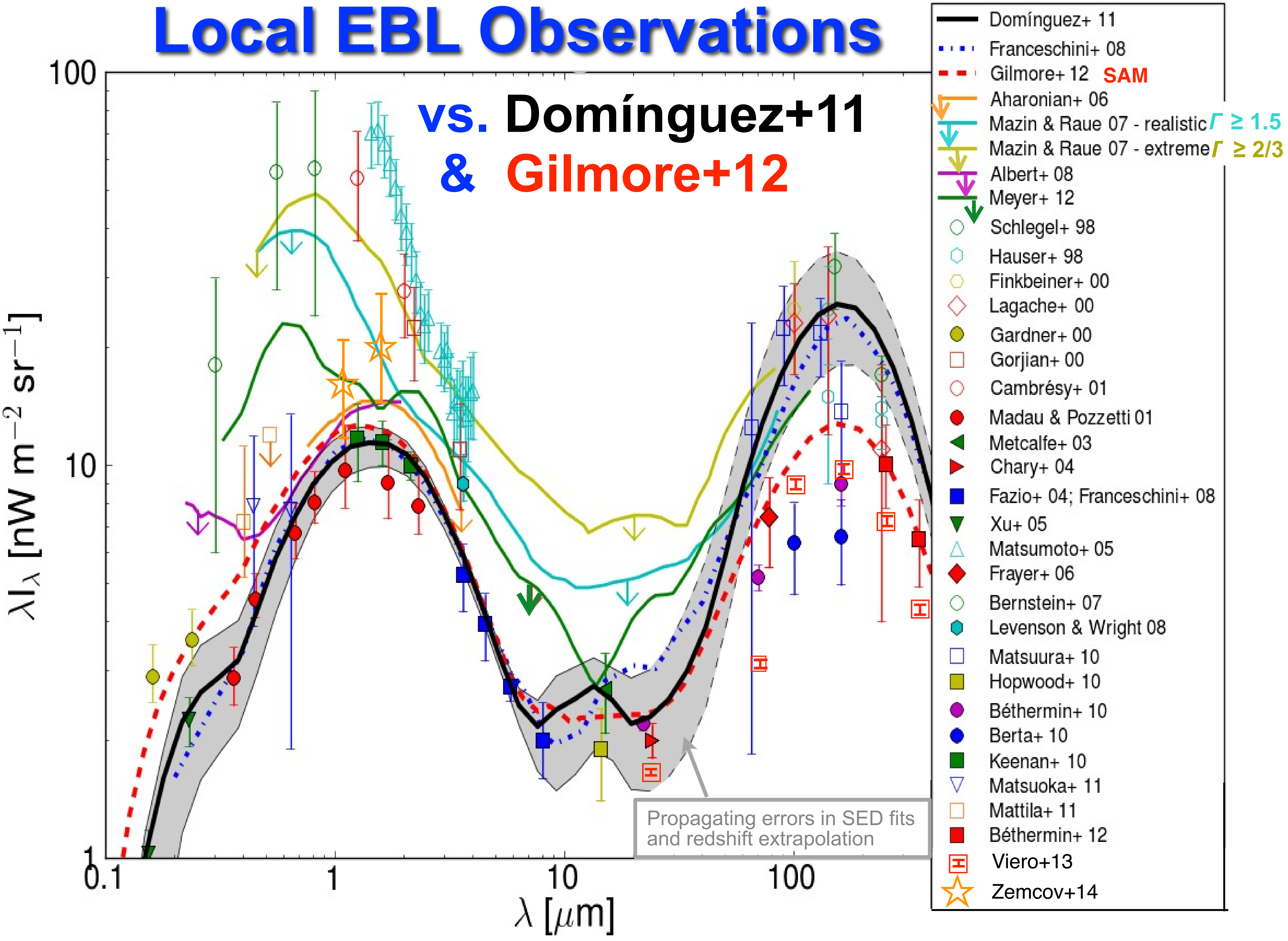


Figure 10. Contribution to CIB from “normal” galaxies ($L < 10^{11}\ L_\odot$), LIRGs ($L < 10^{11-12}\ L_\odot$), and ULIRGs ($L < 10^{12-13}\ L_\odot$). Normal galaxies and LIRGs contribute equally to make up most of the intensity at $\lambda \lesssim 70\ \mu$m, which is more sensitive to lower redshifts, while at longer wavelengths LIRGs and eventually ULIRGs contribute most to the signal. Also plotted are model predictions from Béthermin et al. (2010, Figure 13, bottom panel), with the LIRG and ULIRG predictions somewhat high. Although the model is a simple parametric fit to counts at multiple wavelengths, the high estimates for the LIRGs and ULIRGs lends weight to the suggestion that we are missing luminous, dust-obscured sources in our sample (Section 5.4.2).

See also: Leiton, Elbaz, et al. 2015, A&A 579, A93; Viero et al. 2015, arXiv:1505.06242v2

Local EBL Observations

vs. Domínguez+11 & Gilmore+12



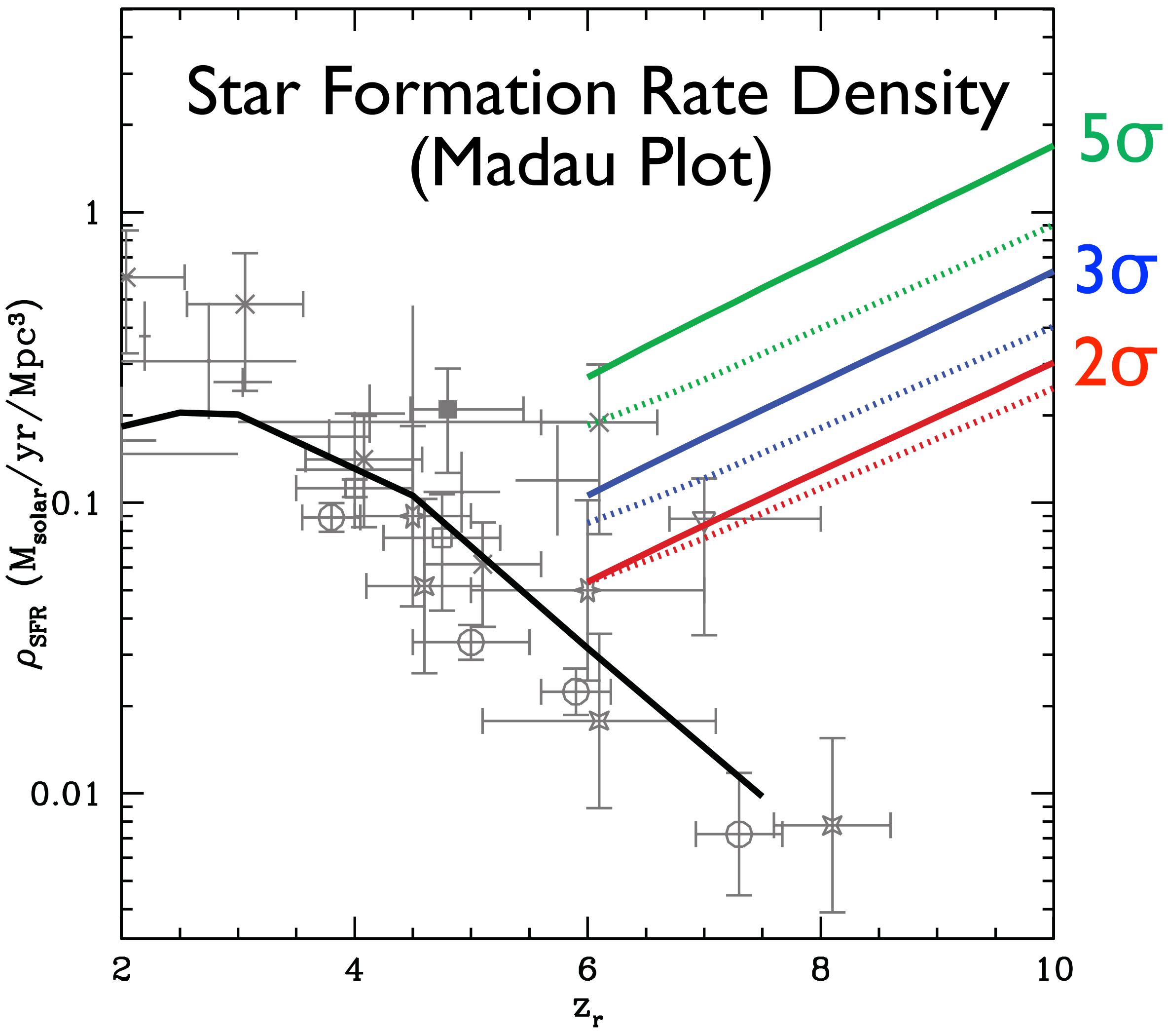
Propagating errors in SED fits and redshift extrapolation

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY **420,** 800–809 (2012)

Constraining the near-infrared background light from Population III stars using high-redshift gamma-ray sources

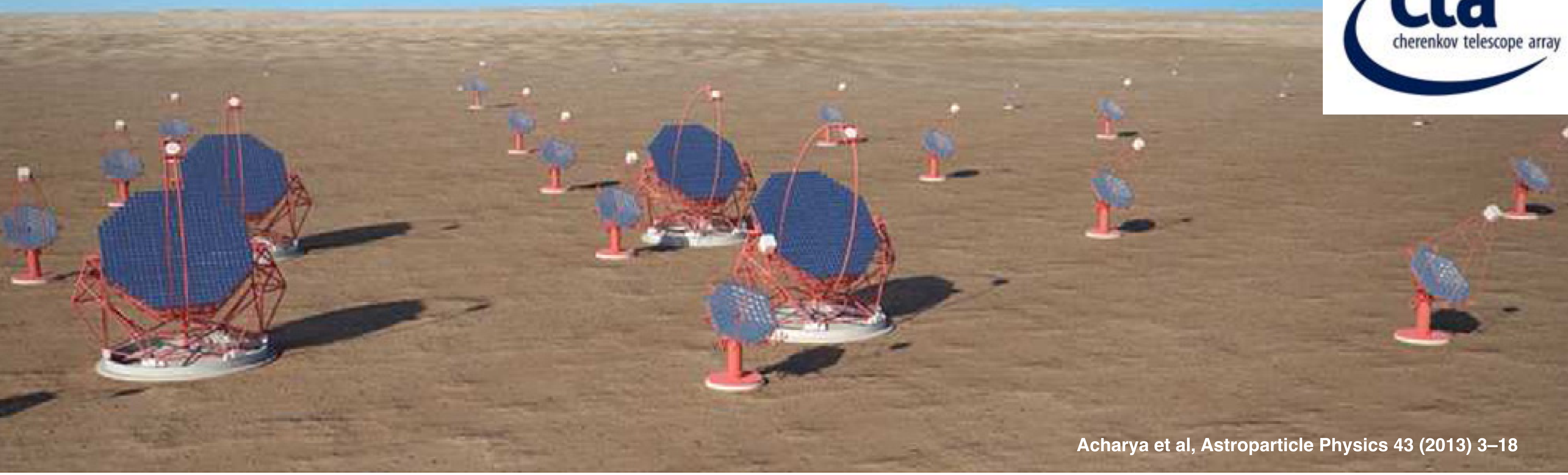
Rudy C. Gilmore

ABSTRACT The *Fermi* satellite has detected GeV emission from a number of gamma-ray bursts and active galactic nuclei at high redshift, $z \gtrsim 1.5$. We examine the constraints that the detections of gamma-rays from several of these sources place on the contribution of Population III stars to the extragalactic background light. Emission from these primordial stars, particularly redshifted Lyman α emission, can interact with gamma-rays to produce electron–positron pairs and create an optical depth to the propagation of gamma-ray emission, and the detection of emission at >10 GeV can therefore constrain the production of this background. We consider two initial mass functions for the early stars and use derived spectral energy distributions for each to put upper limits on the star formation rate density of massive early stars from redshifts 6 to 10. Our limits are complementary to those set on a high near-infrared background flux by ground-based TeV-scale observations and show that current data can limit star formation in the late stages of re-ionization to less than 0.5 $M_\odot$ yr^{-1} Mpc^{-3} . Our results also show that the total background flux from Population III stars must be considerably less than that from resolved galaxies at wavelengths below 1.5 μm.

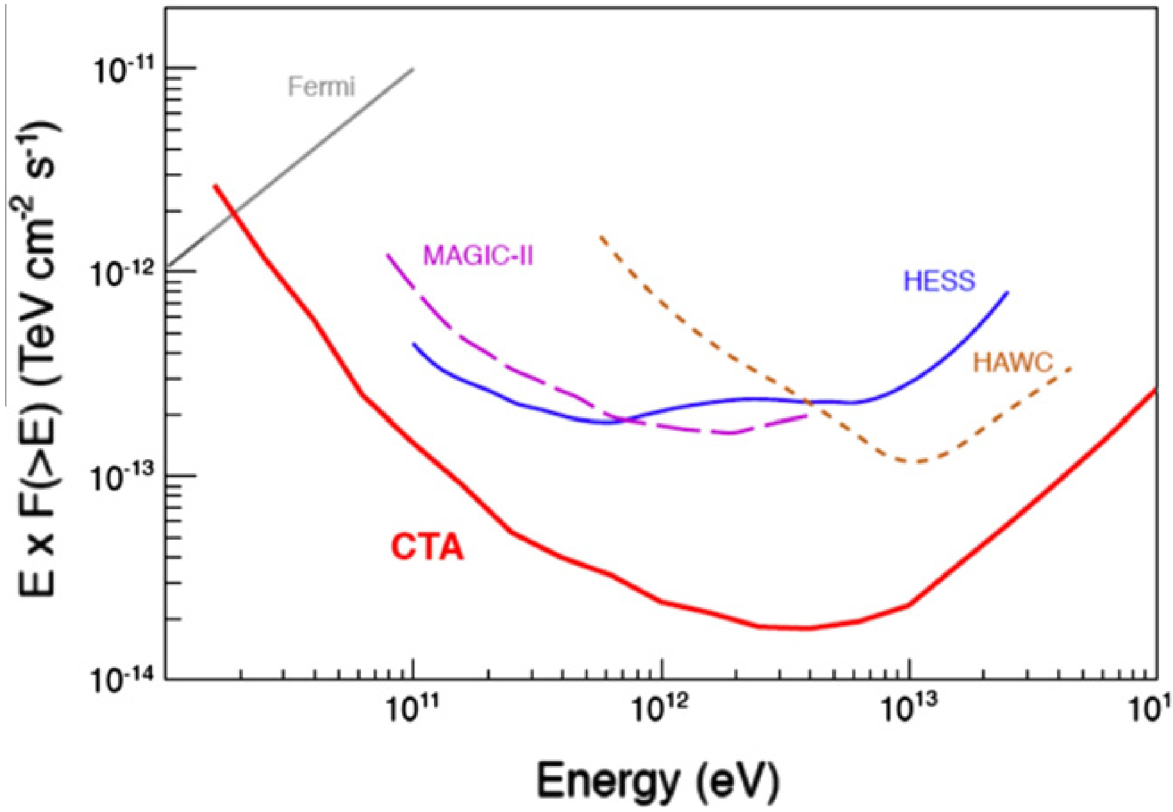


Upper bounds on the redshift *z* = 6 - 10 Pop-III SFRD in two possible scenarios with future *Fermi* GRBs, in the Larson IMF case. The solid lines show the limits from a GRB with the same redshift and spectral characteristics of GRB 080916C (*z* = 4.35), but with a highest energy observed photon of 30 GeV (160 GeV as emitted) instead of 13.2 GeV, in combination with the 5 most constraining $z \gtrsim 2$ sources (Abdo+2010). The dotted lines show a case with a GRB at *z* = 7 and a highest energy observed photon at 15 GeV (120 GeV emitted).

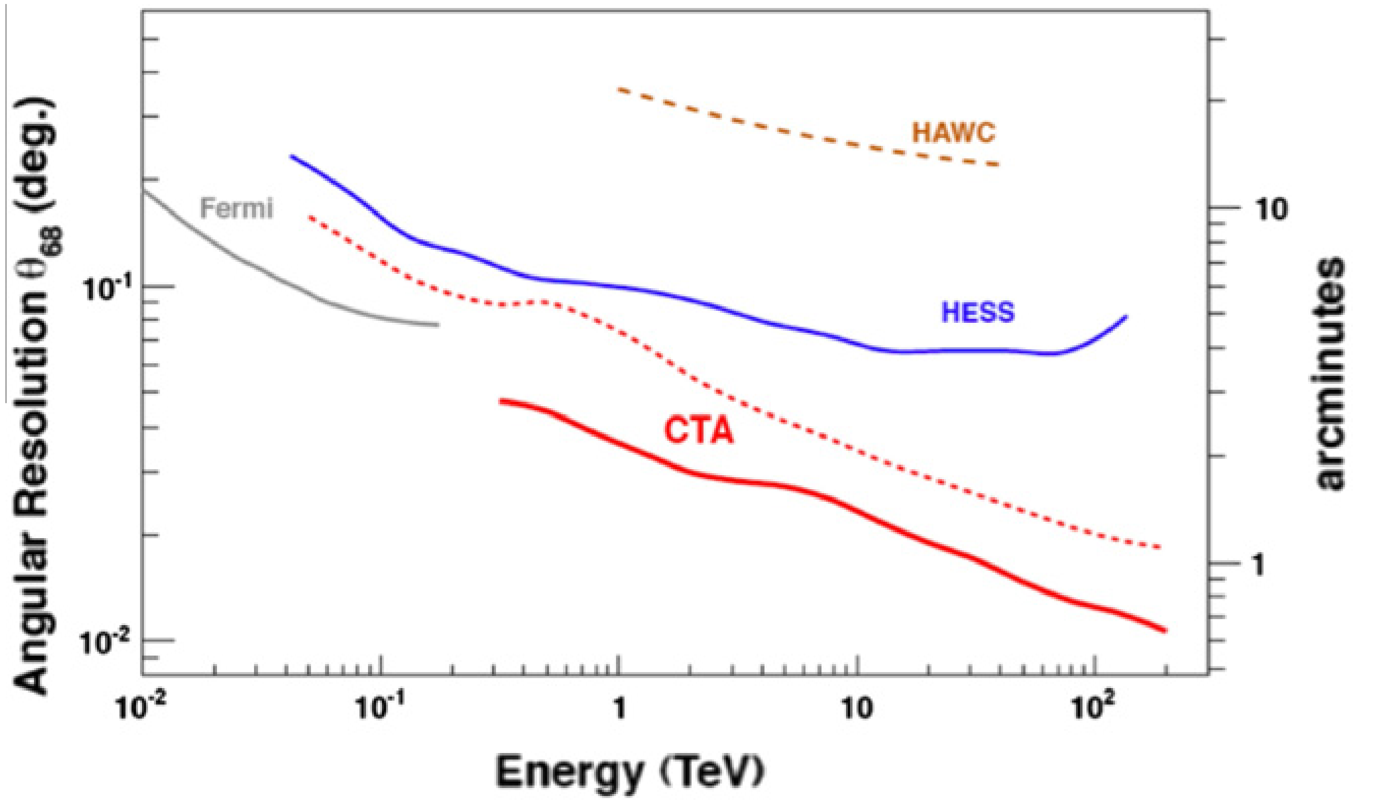
CHERENKOV TELESCOPE ARRAY


Acharya et al, Astroparticle Physics 43 (2013) 3–18

The Cherenkov Telescope Array (CTA), a collaboration between more than 1,000 scientists from 31 countries, will consist of around 100 dishes in Paranal, Chile, on the grounds of the European Southern Observatory, and around 20 more in La Palma, Spain at the Roque de los Muchachos Observatory. — *Nature* 16 July 2015



Integral sensitivity for CTA from MC simulations, together with the sensitivities in comparable conditions (50 h for IACTs, 1 year for Fermi-LAT and HAWC) for some gamma-ray observatories.



Angular resolution for CTA, compared with some existing and future VHE gamma-ray observatories. The solid line provides the angular resolution of CTA obtained from events with ten or more images, the dashed line shows the angular resolution for events with only two images.

Conclusions

New data on attenuation of gamma rays from blazers

- Fermi data on 150 blazars at $z = 0$ - 1.6 (Ackermann+12)
- X-ray + Fermi + ACT SSC fits to 9 blazars (Dominguez+13)
- ACT blazars & EBL evolution model (Biteau&Williams15)

now lead to statistically significant measurements of the cosmic gamma ray horizon and EBL as functions of source redshift and gamma ray energy. These new measurements are consistent with recent EBL calculations based both on multiwavelength observations of thousands of galaxies and also on semi-analytic models of the evolving galaxy population. Such comparisons account for (almost) all the light at UV to mid IR wavelengths, including that from galaxies too faint to see.

Measurements of near-IR EBL fluctuations could indicate light from high-redshift galaxies and/or direct-collapse SMBHs.

Catching a few high-redshift GRBs with Fermi or low-threshold atmospheric Cherenkov telescope array (CTA) could provide important new constraints on the epoch of reionization $z > 6$.