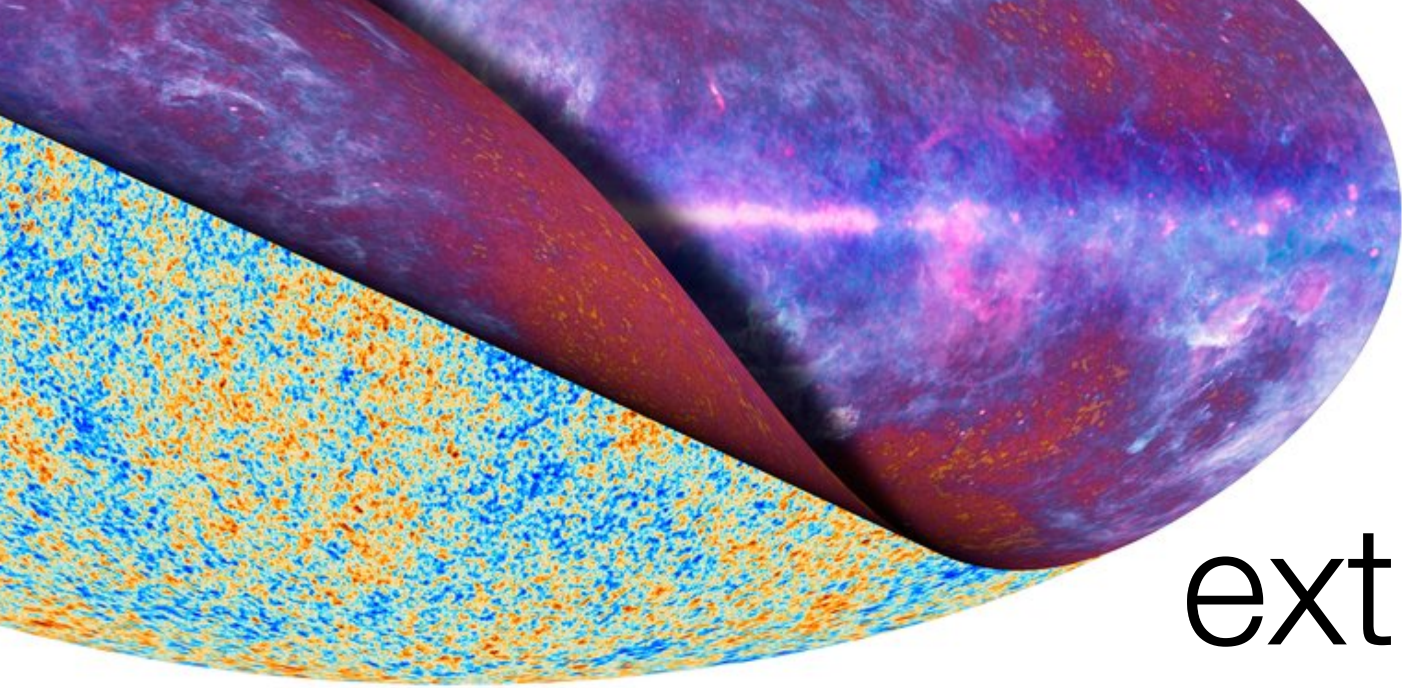


extragalactic background light: a review

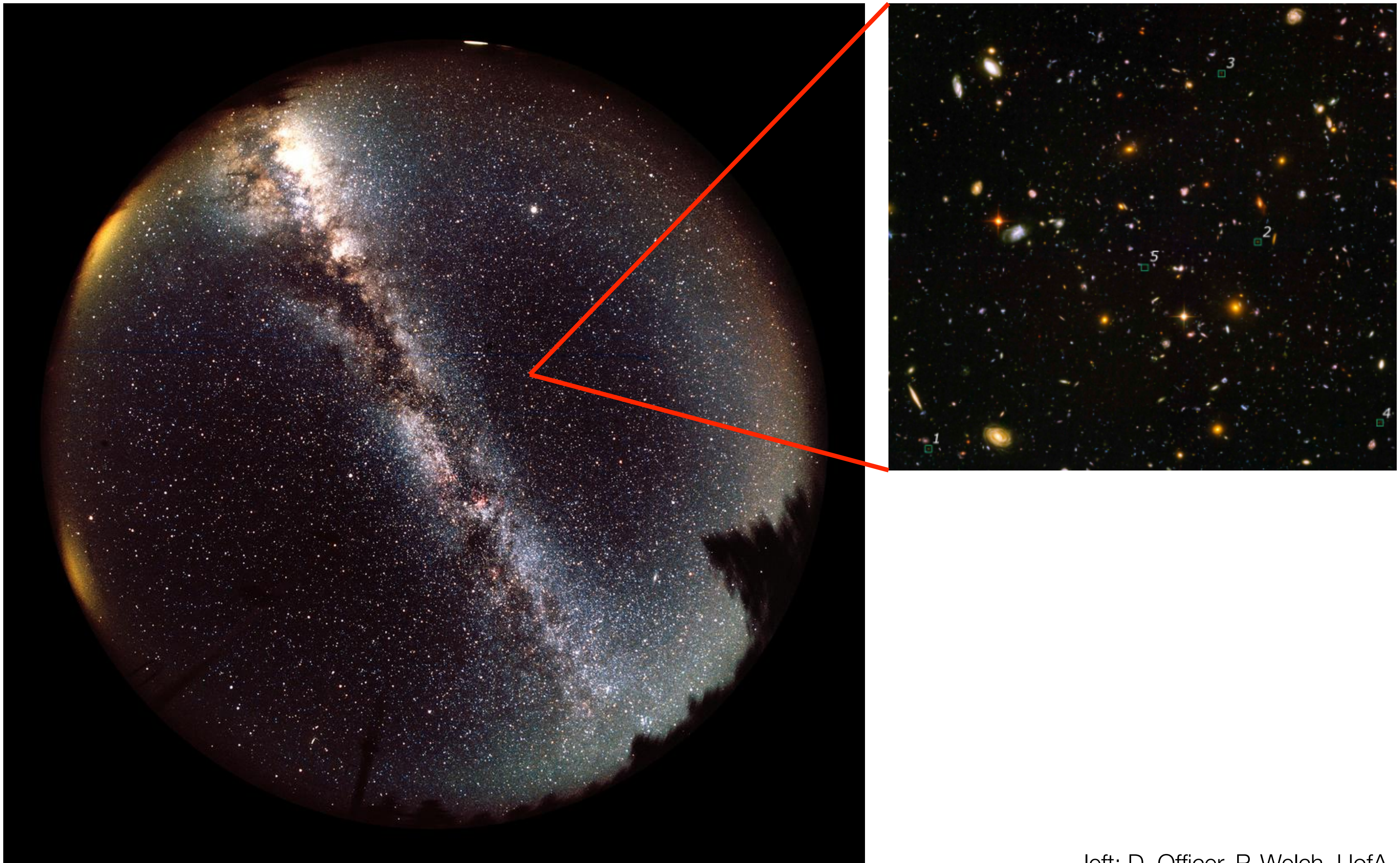
Hervé Dole

Institut d'Astrophysique Spatiale, Orsay, France
Université Paris Sud & CNRS
Institut Universitaire de France
http://www.ias.u-psud.fr/dole/

The scientific results that we present today are the product of the Planck Collaboration, including individuals from more than 50 scientific institutes in Europe, the USA and Canada

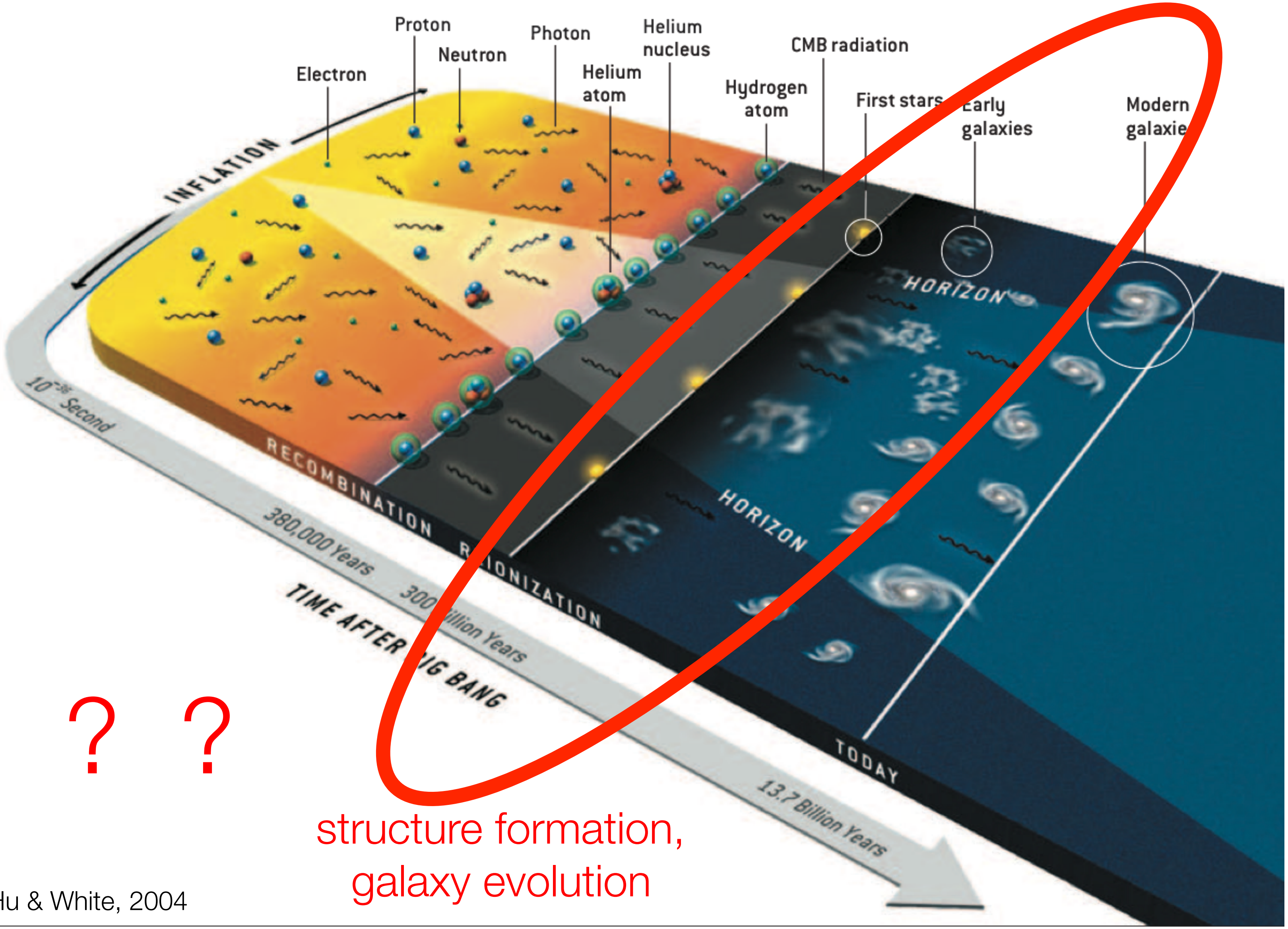
Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA) and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

why is the night sky dark ?



left: D. Officer, P. Welch, UofA
right: NASA, HST

history of the universe



Hu & White, 2004

extragalactic background light

EBL (Extragalactic Background Light) tells us about the processes involved in galaxy formation & evolution (budget for radiation emission by nucleosynthesis & gravitation, presence of dust, …)

CIB (Cosmic Infrared Background) level and structure depend on history of energy production in the post-recombination Universe [Kashlinsky, 2005]

outline

1. 4 motivations for the big picture

2. the extragalactic background light measurements
    1. COB CIB: various intensity measurements
    2. fluctuations
    3. at other frequencies
    4. « local » EBL

3. encoded informations in the extragalactic background
    1. galaxies contributing to the EBL: CIB
    2. transparency
    3. models
    4. CIB/EBL as a new probe for large scale structure

4. conclusions

1. 4 motivations

- galaxy populations, transparency
- structure formation
- energy budget
- cosmology

from EBL to galaxy populations

- galaxies
  - physical processes driving the evolution?
  - gravitation: black hole and AGN
  - strong, weak, electromagnetic: nucleosynthesis: star formation
  - relative importance ? redshift evolution ?

- TeV gamma emission of AGN
  - peak of photon-photon interaction
    - λIR(μm) ~ Eγ(TeV)
  - constraints on the intrinsinc spectrum of blazars ?

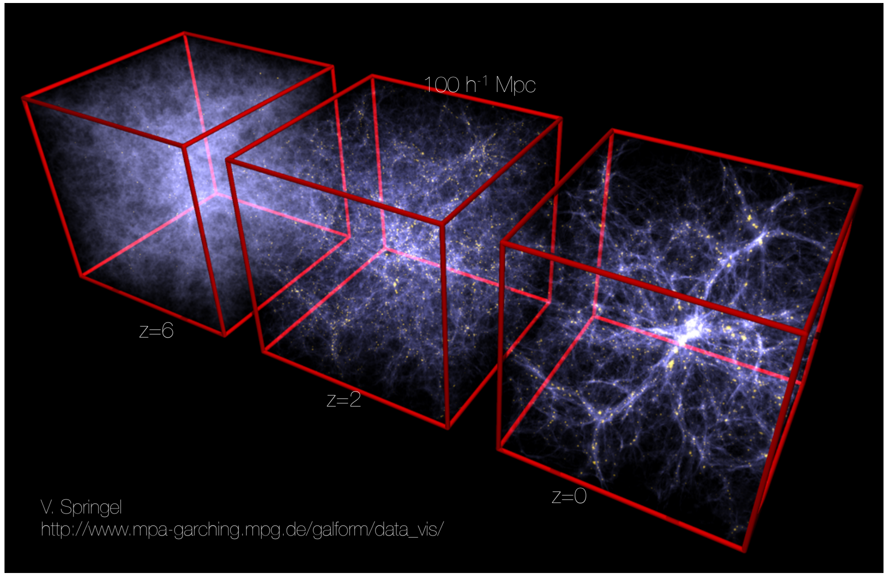
structure formation

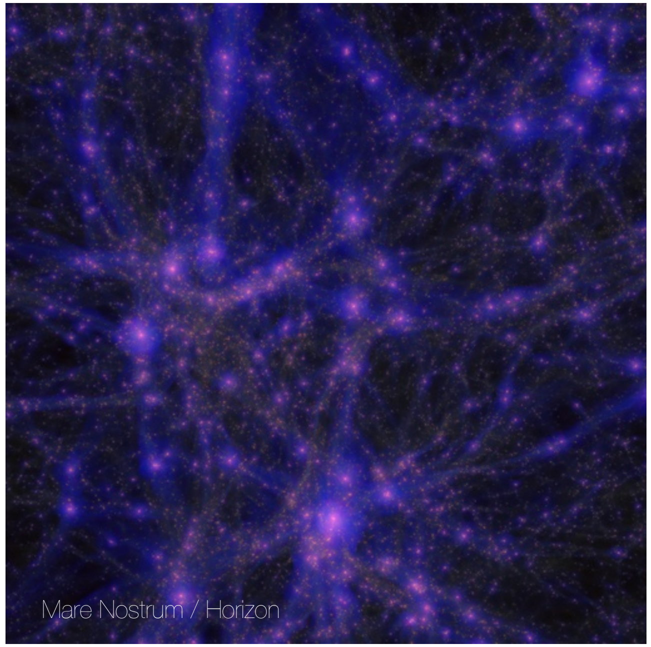
- Hierarchical structure formation ?
  - dark matter « well » described
  - what about « visible matter »?

  - in general, simulations reproduce well data in the visible (number counts, luminosity functions, redshift distributions, angular correlation functions)

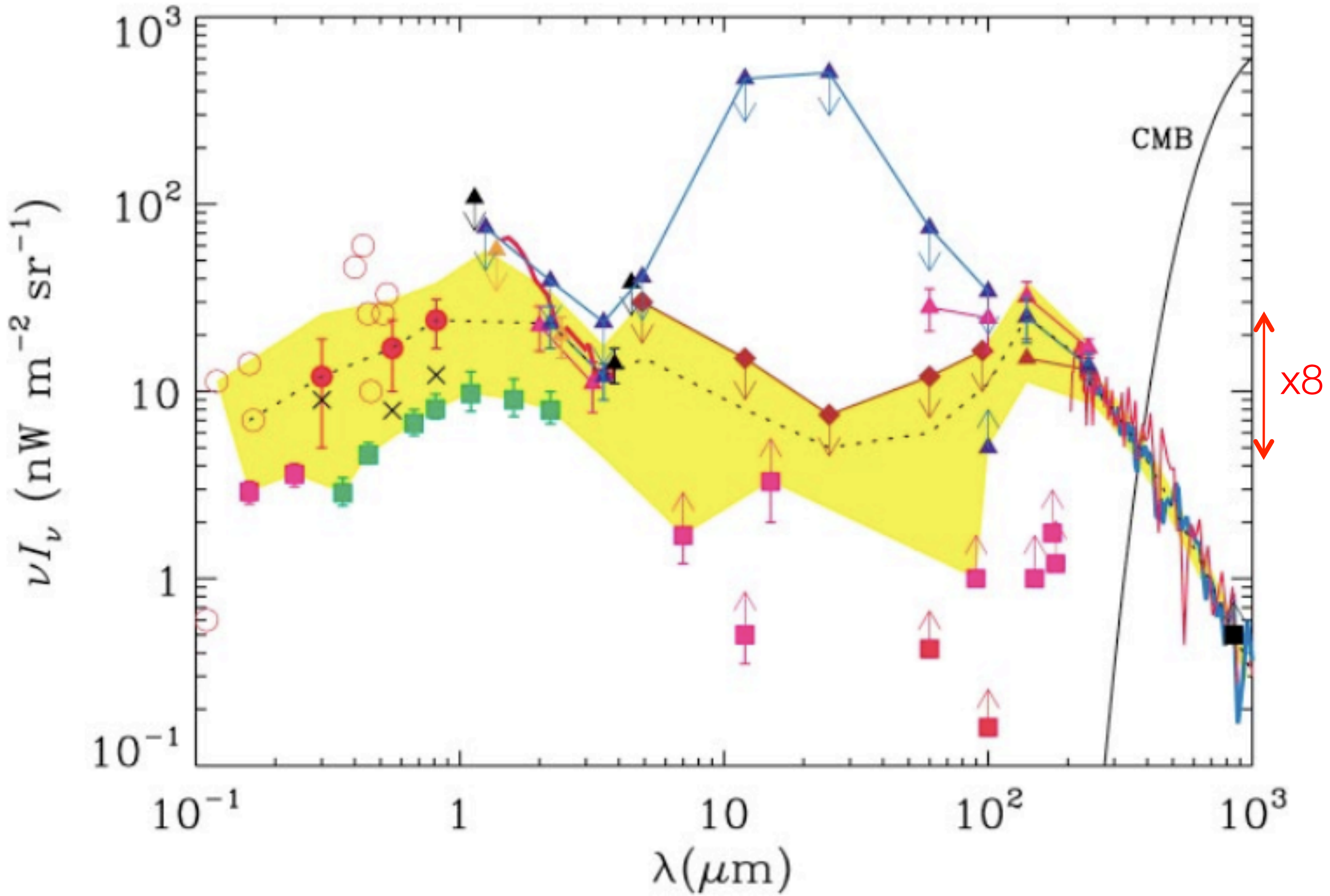
  - in general, they **do not** reproduce well infrared data
    - After all, is it that important ?

  - poor understanding of the gas (baryons) physics cooling





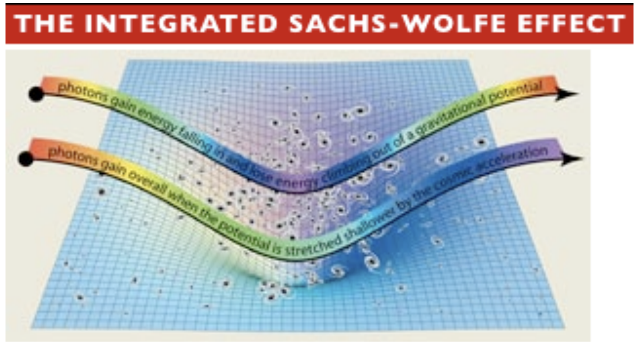
energy budget for galaxy formation



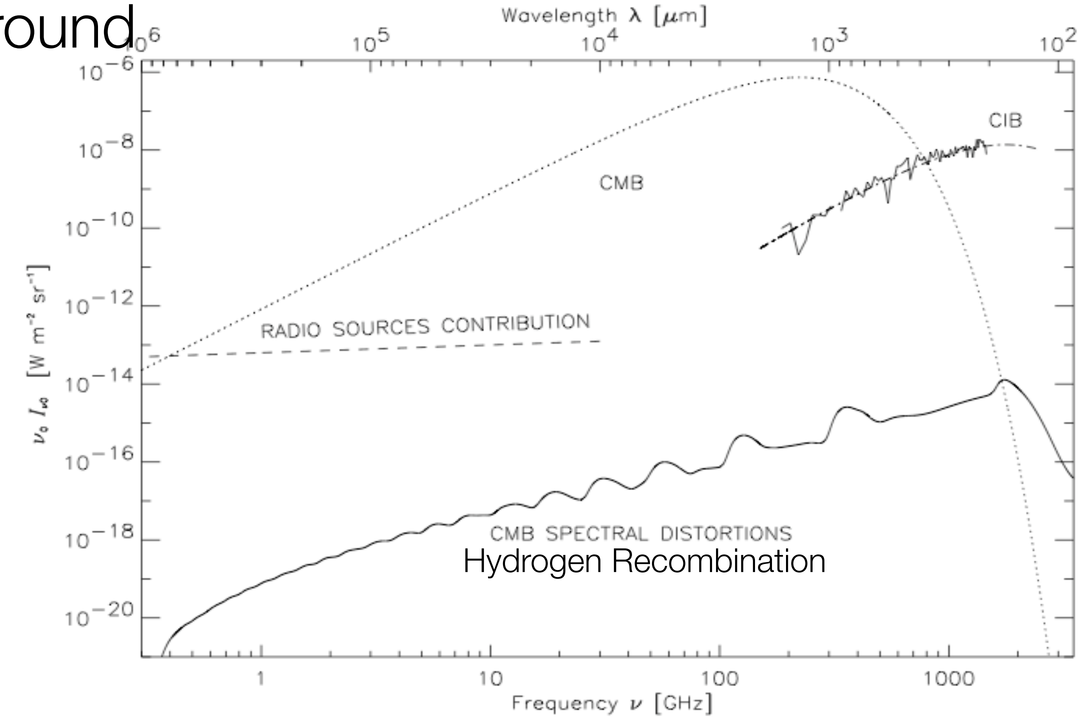
Hauser & Dwek, 2001, ARAA

cosmology and early structures

- dark energy equation of state
  - ISW: correlations EBL - CMB ?
- reionization at z>6 ?
  - structure of the background
- recombinations: H, He
  - CIB contaminates



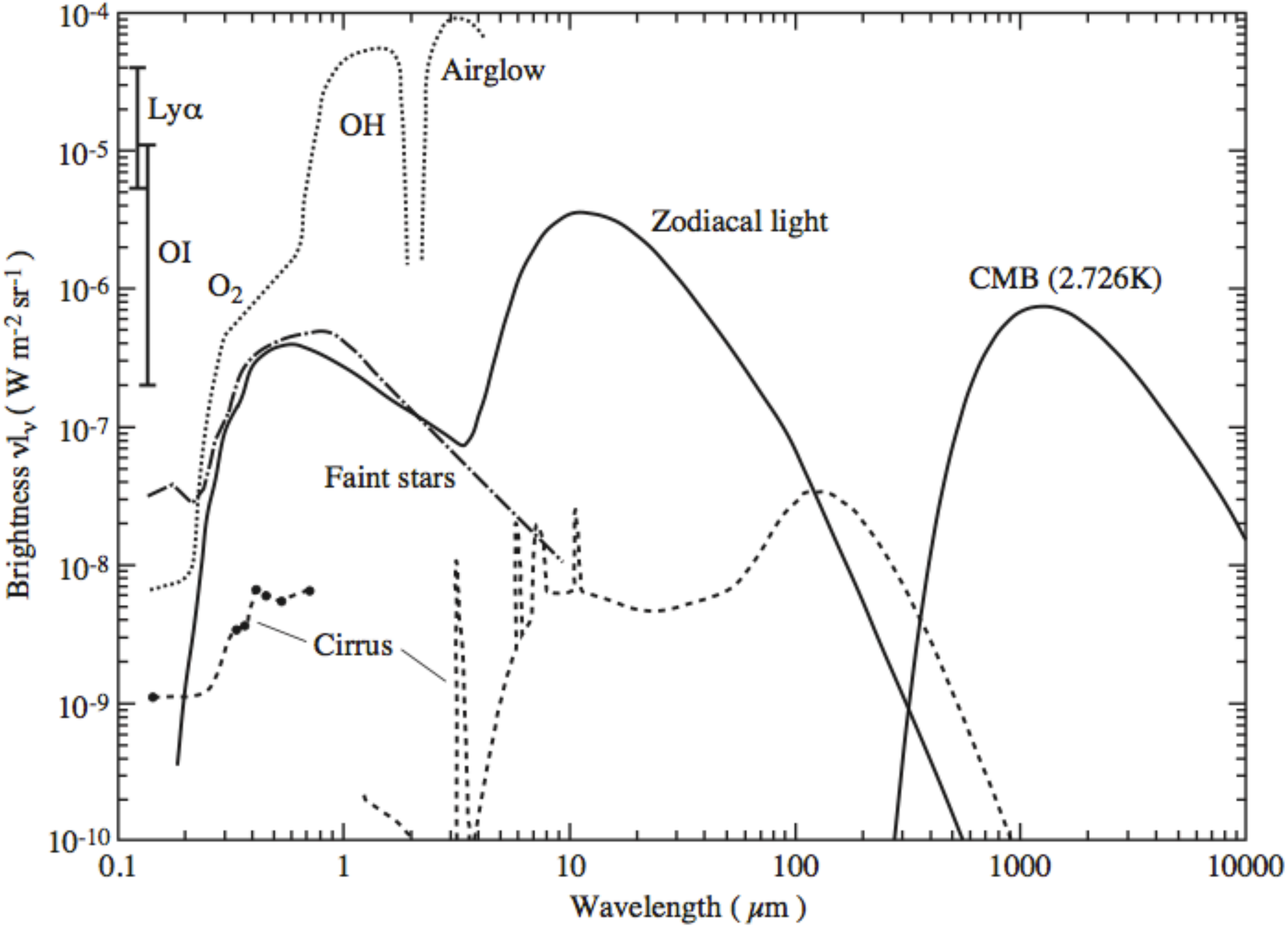
Physicsworld.com – May 2004



Rubino-Martin et al., 2006
see also e.g. Chluba & Sunyaev, 2007

2. a long quest for EBL measurements

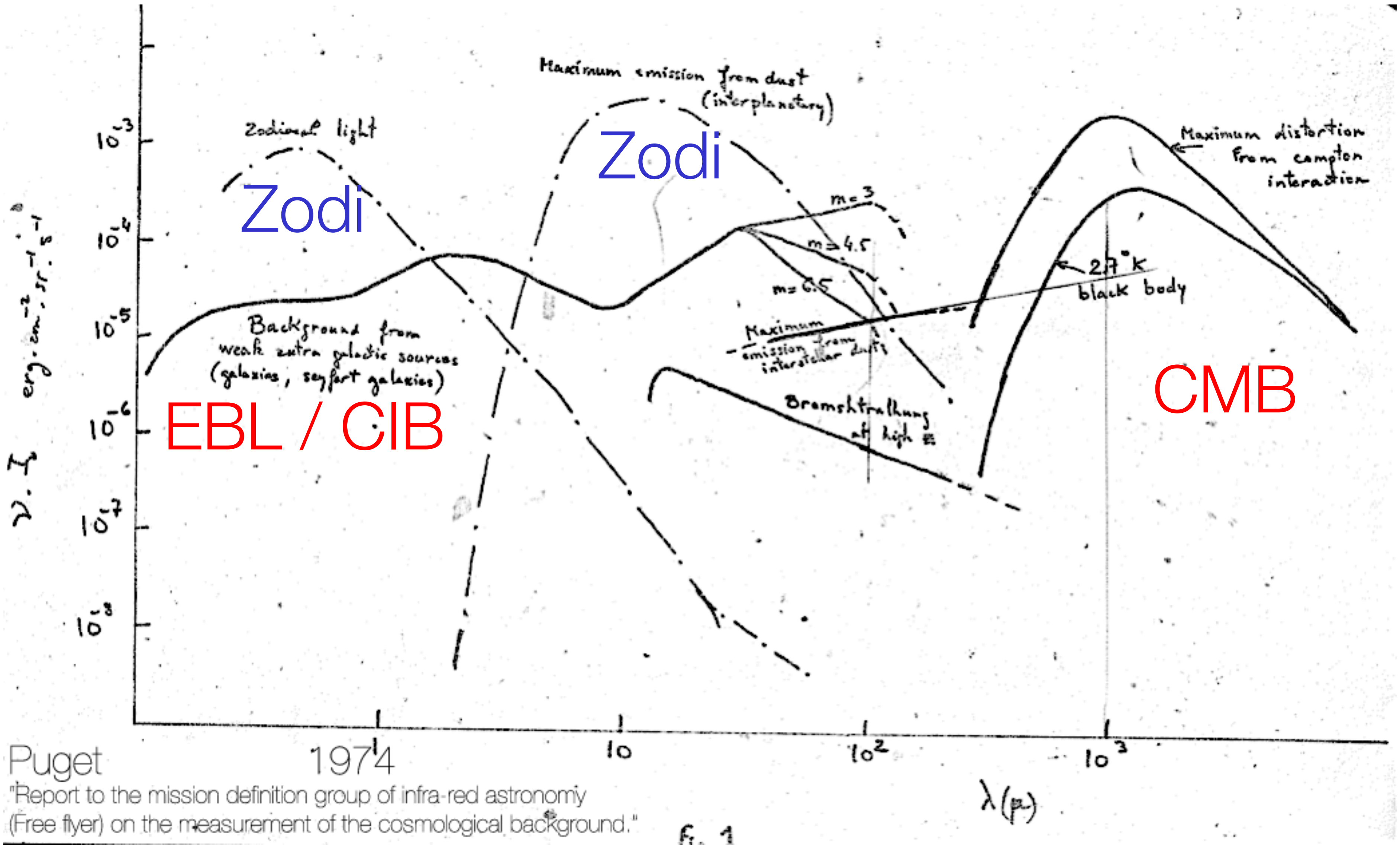
in 1997...



Leinert et al., 1997, A&ASS

2. a long quest for EBL measurements

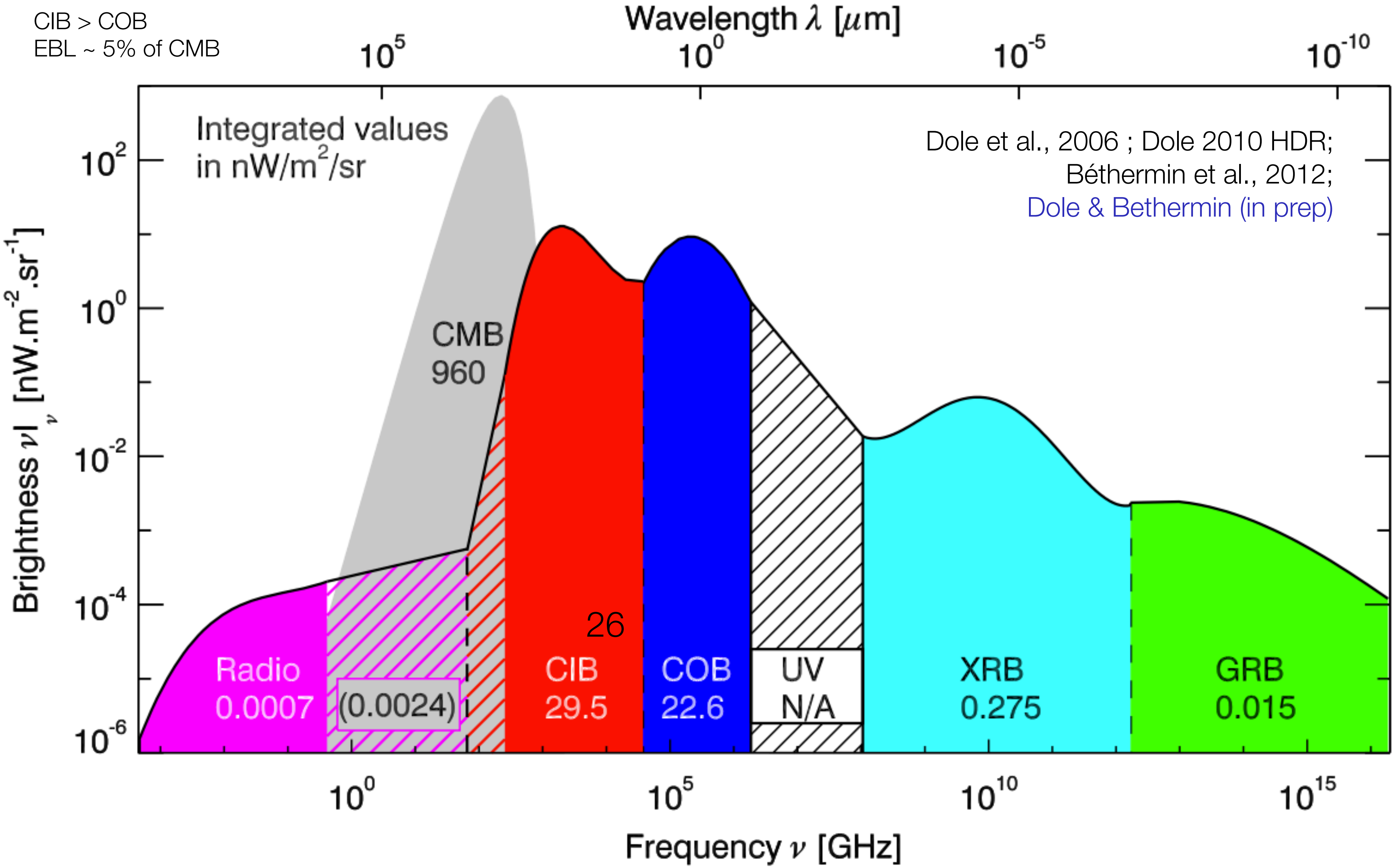
and earlier in the mid 70s



Puget, 1974

Extragalactic Backgound Light SED

CIB > COB
EBL ~ 5% of CMB



extragalactic background light

- Gamma-rays
- X-rays
- UV
- optical
- infrared – submillimeter
- radio

- total EBL ~50 nW/m^2/sr (Dole+06, Béthermin+13, D&B in prep)

extragalactic background light

- Gamma-rays
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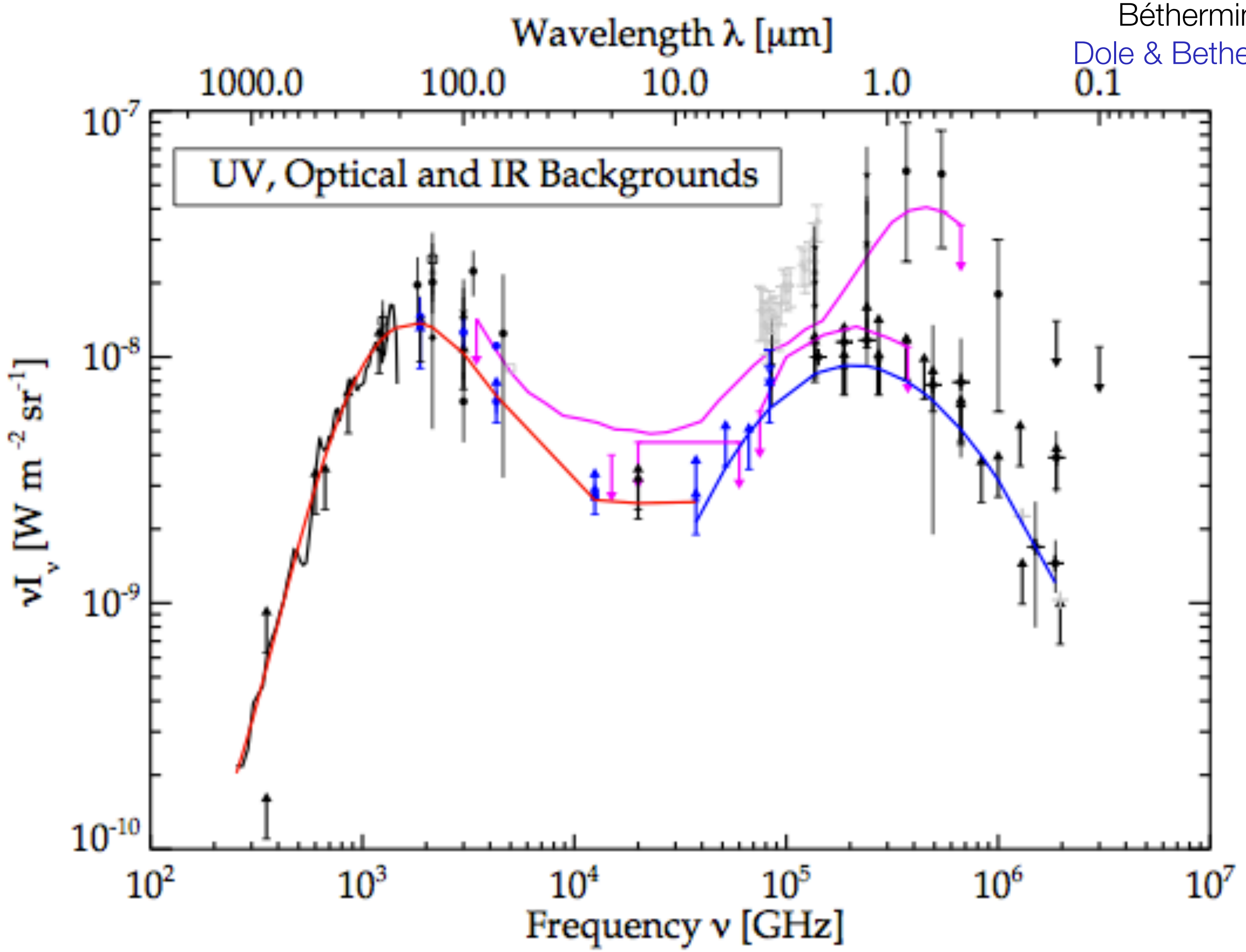
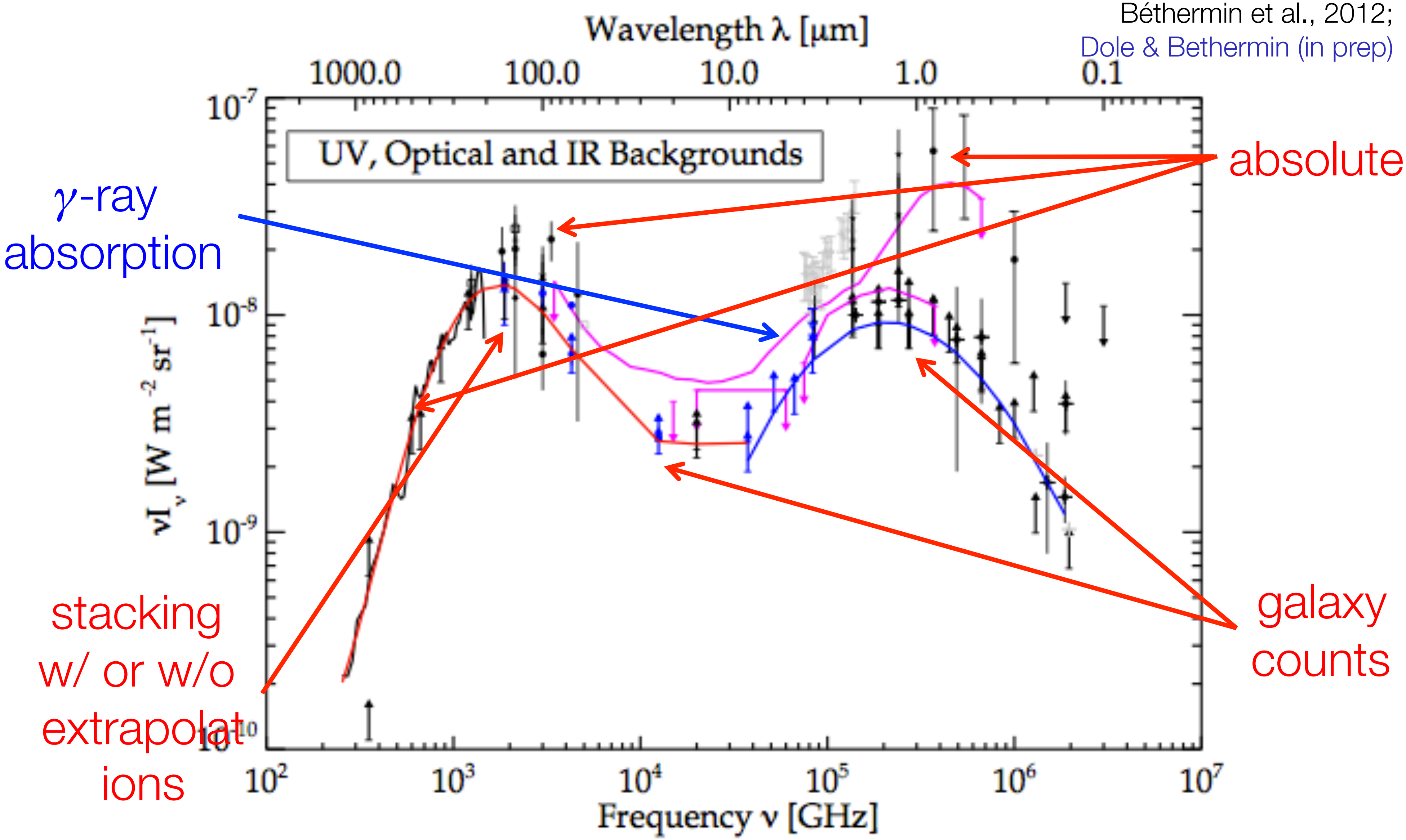
2.1 COB CIB

Dole et al., 2006 ; Dole 2010 HDR;
Béthermin et al., 2012;
Dole & Bethermin (in prep)



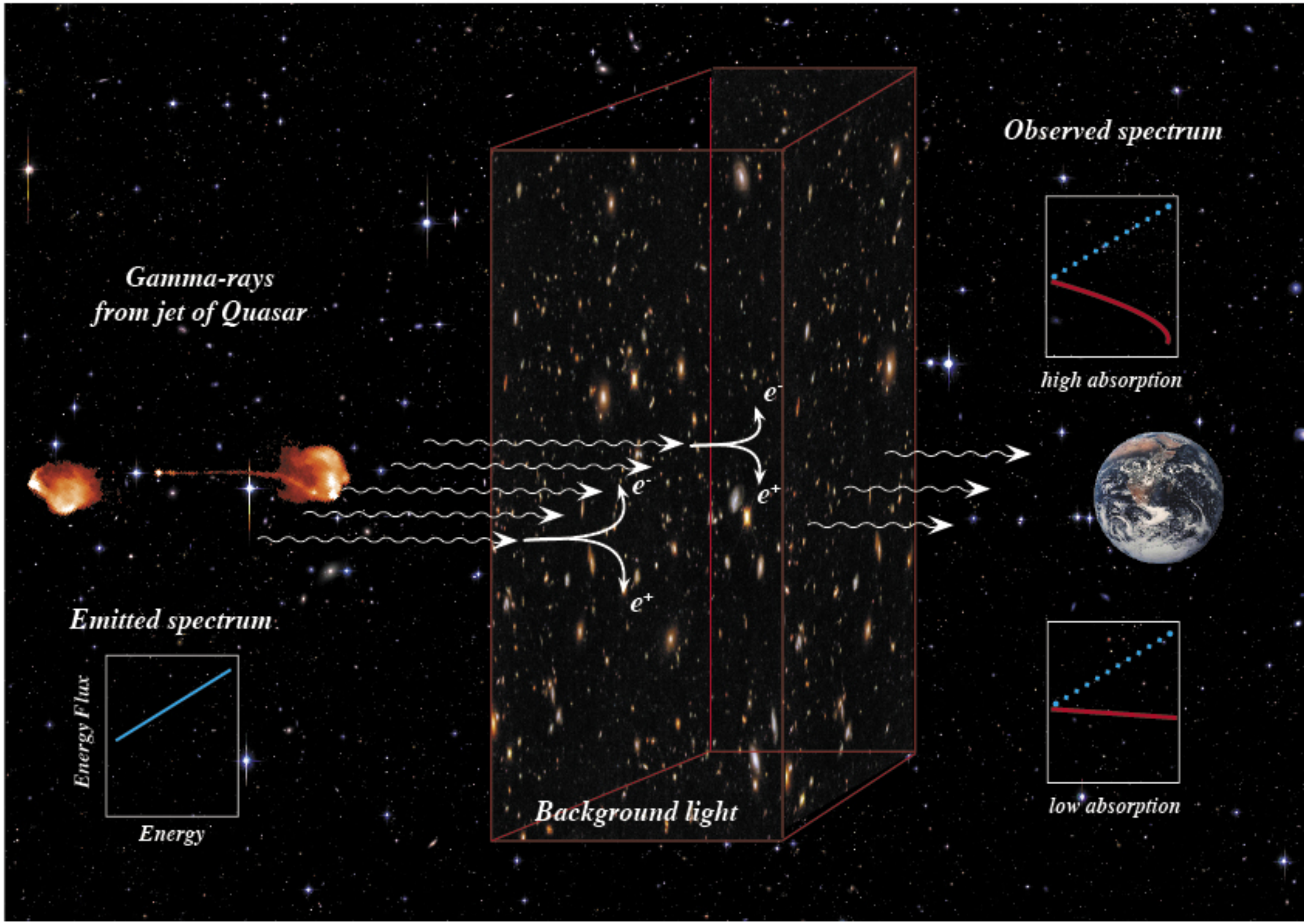
different kind of estimates

Dole et al., 2006 ; Dole 2010 HDR;
Béthermin et al., 2012;
Dole & Bethermin (in prep)



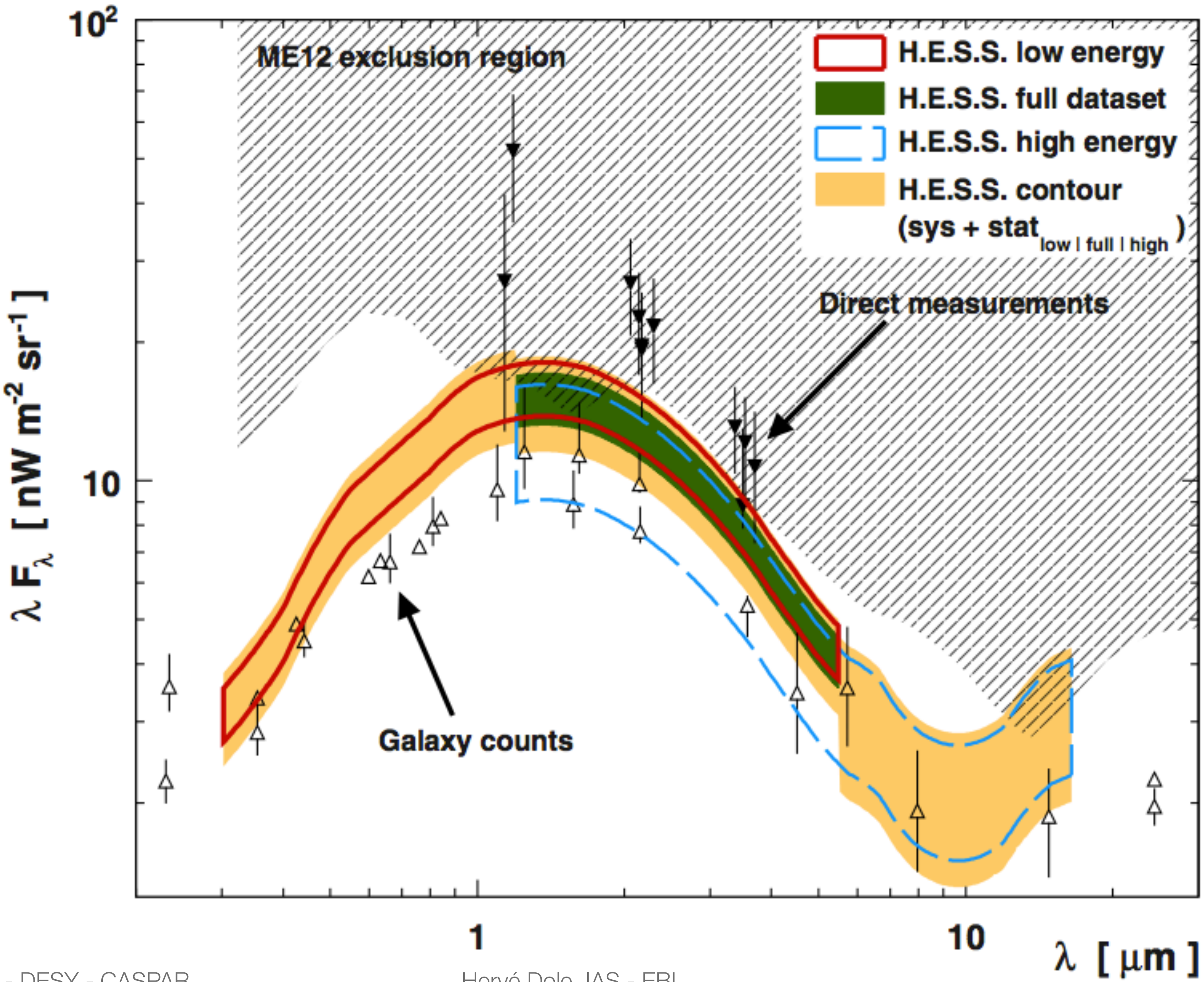
γ-rays absorption

gives upper limits



H.E.S.S, Nature, 2006
Aharonian et al., 2006, Nature
Aharonian et al., 2007, A&A

latest HESS results

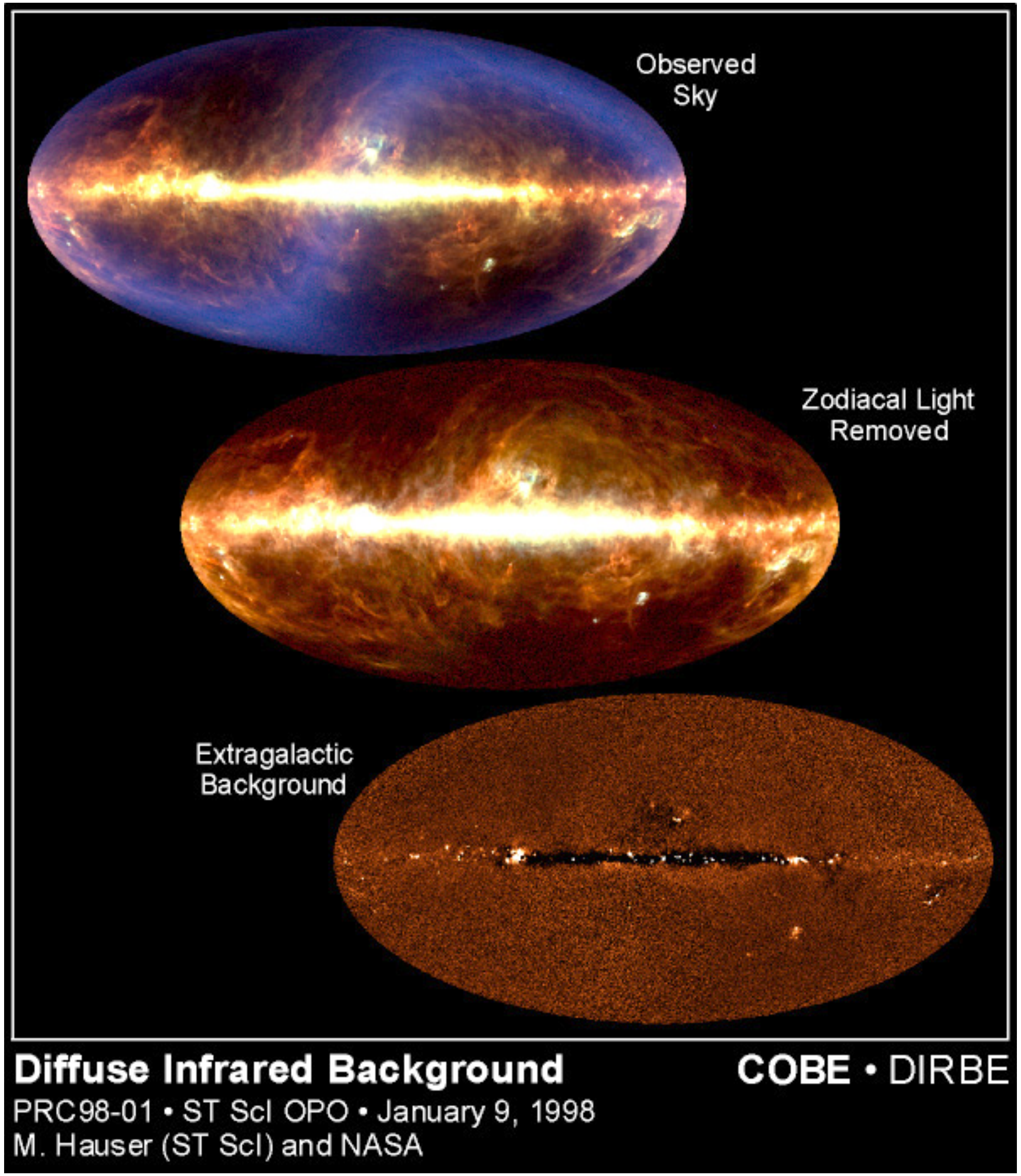


HESS Collab., 2013, A&A

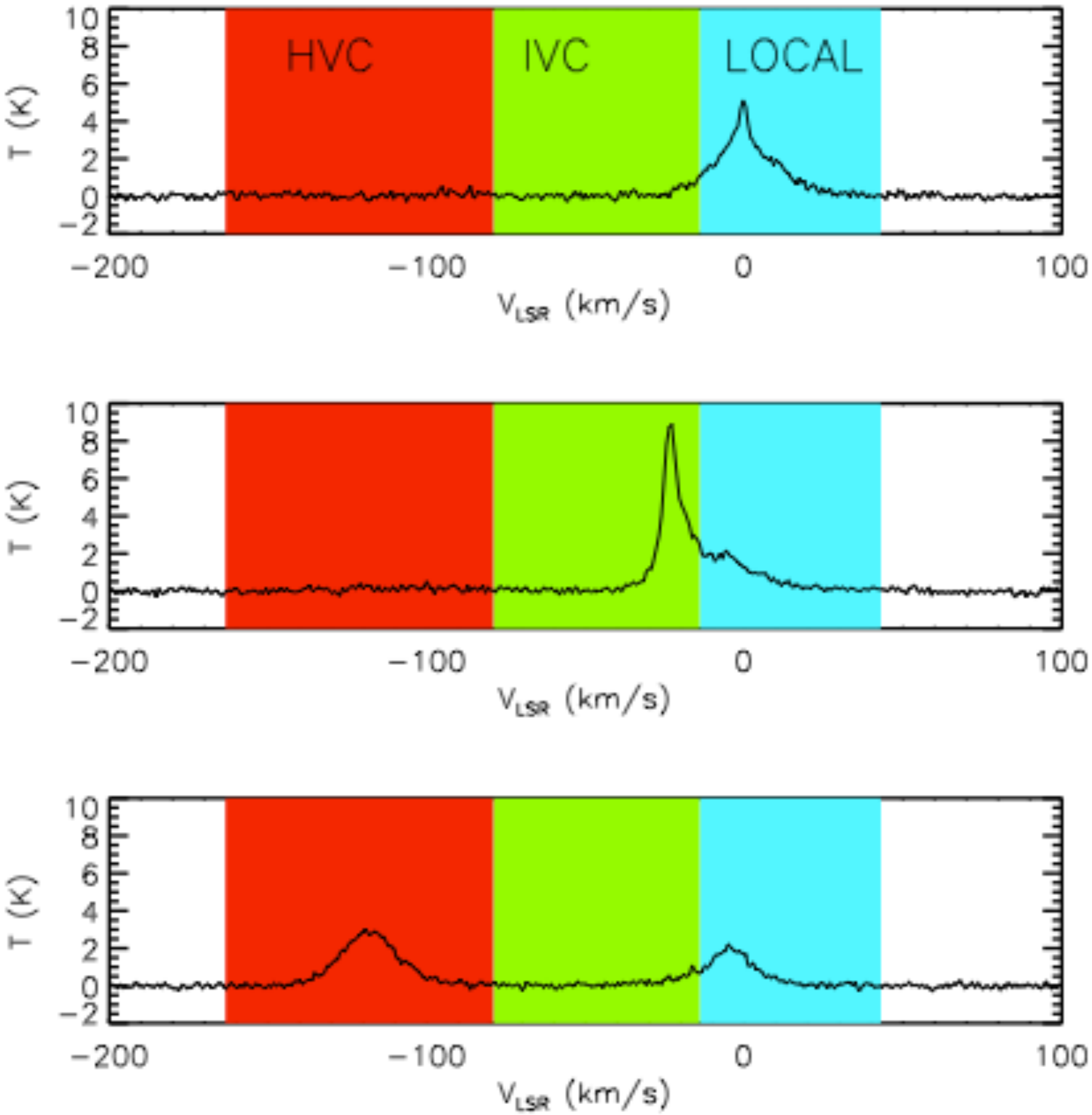
absolute measurements

- incredibly difficult
- but very useful !

- systematic effects
- quality of foreground model + removal
- 1% of zodi error -> factor of 2 CIB in NIR



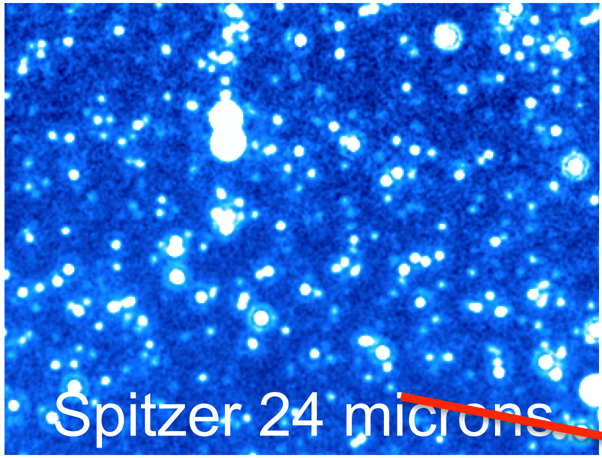
absolute measurements – cirrus removal



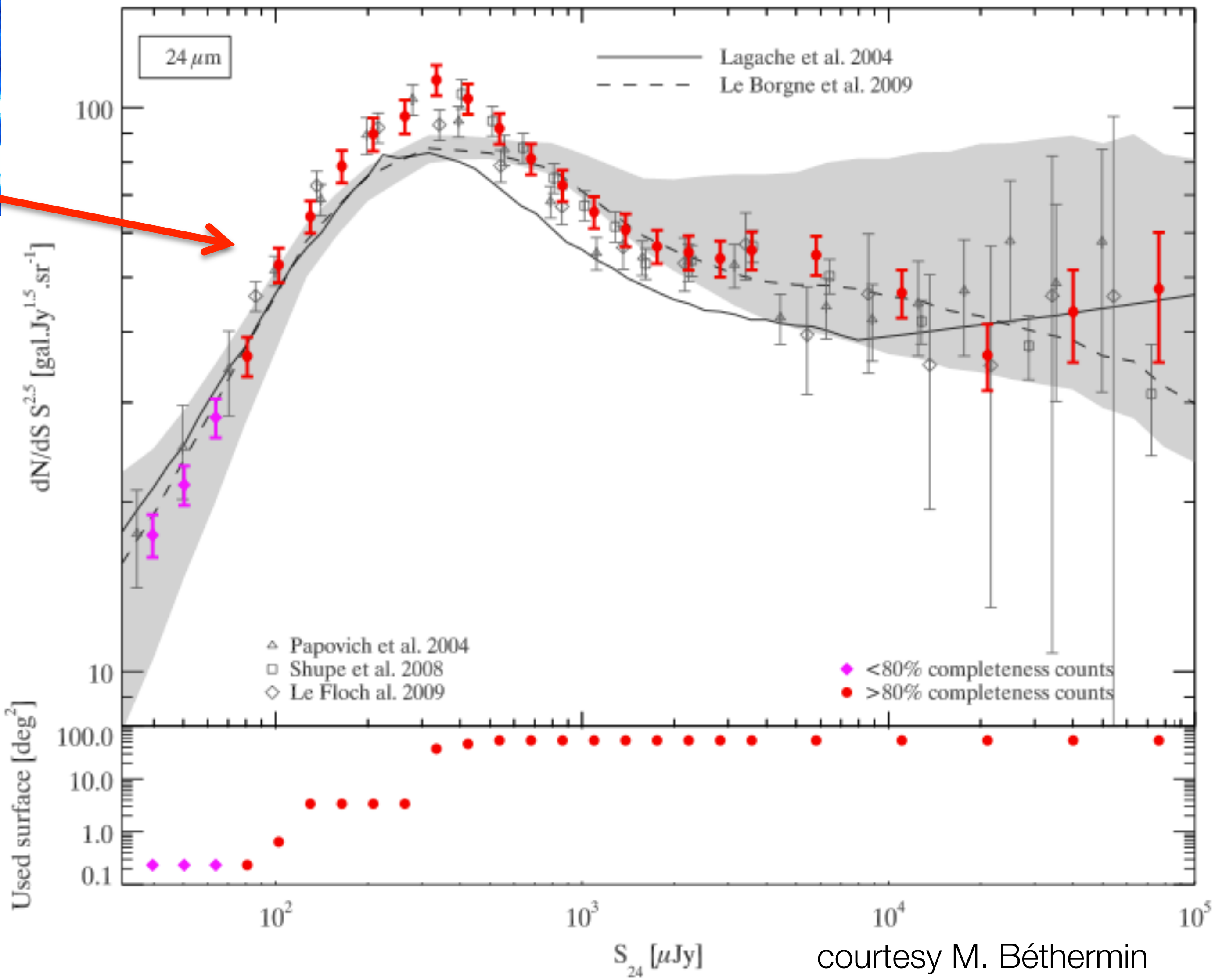
Decomposition of the HI emissivity into 3 components (Penin+12b, see also Miville-Deschênes+05)

courtesy M. Béthermin

number counts – lower limits

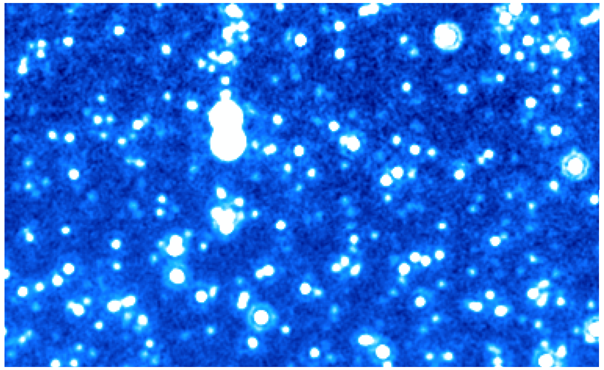


Galaxy number counts at 24 microns (Béthermin+10a)

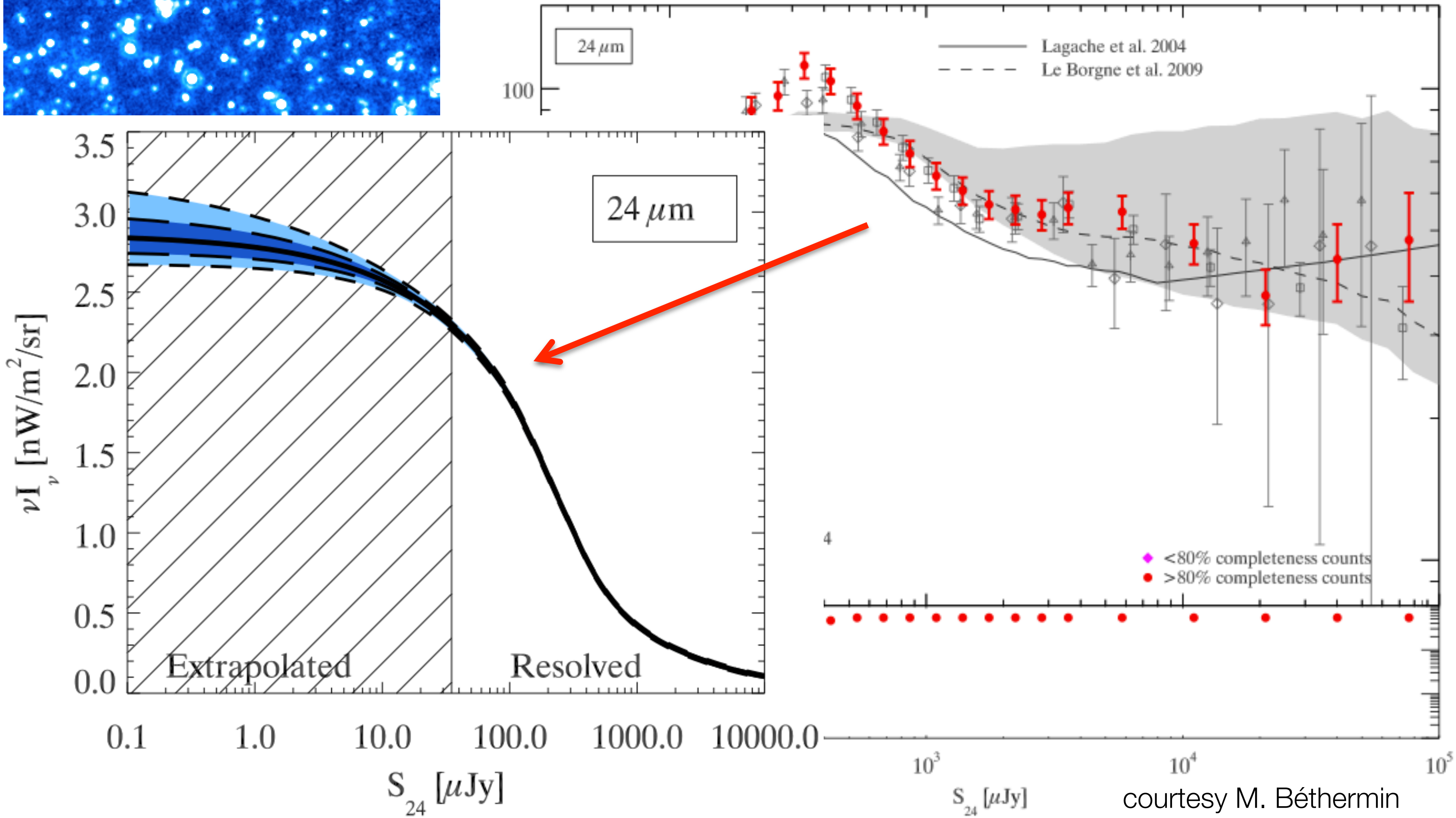


courtesy M. Béthermin

number counts – lower limits

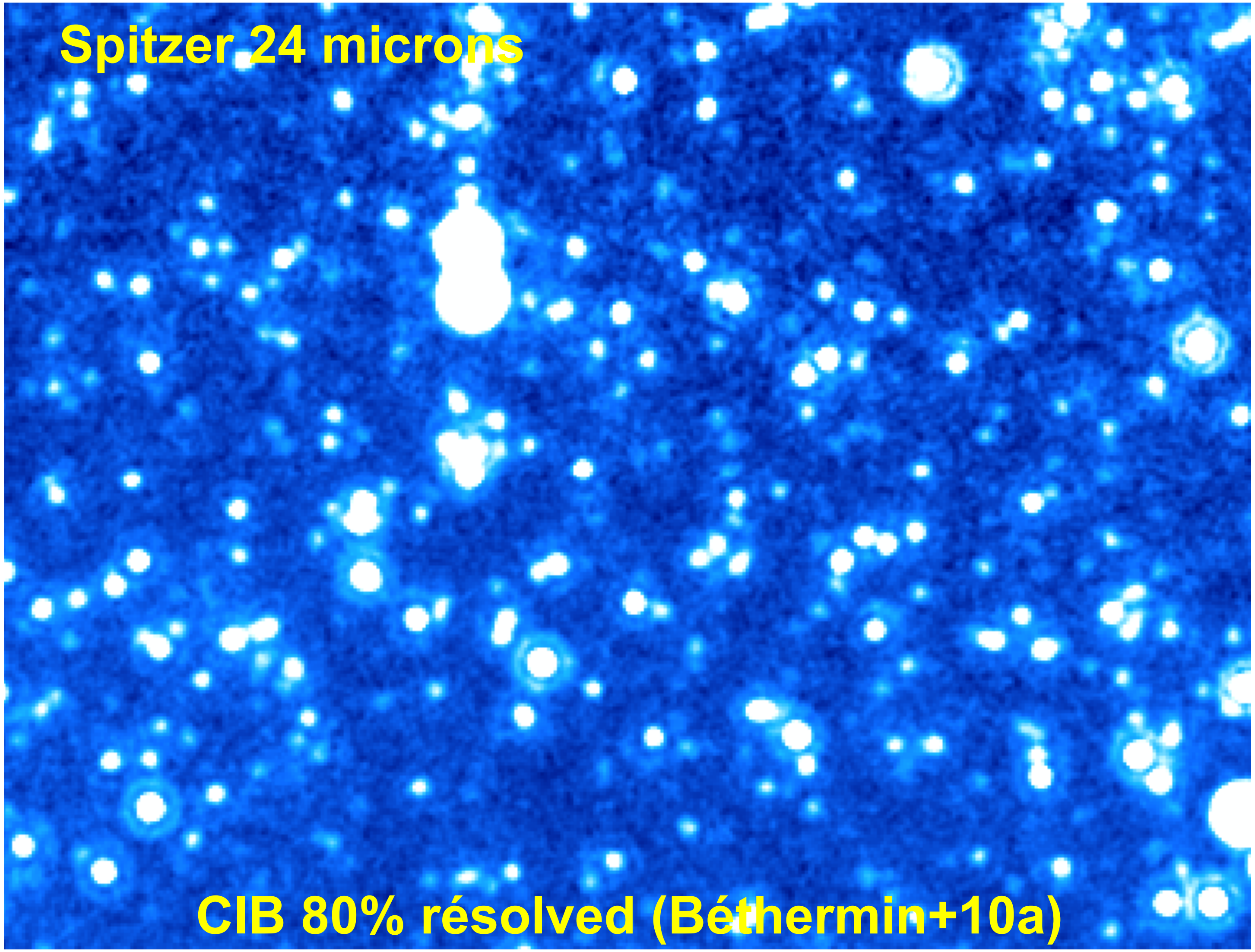


Galaxy number counts at 24 microns (Béthermin+10a)



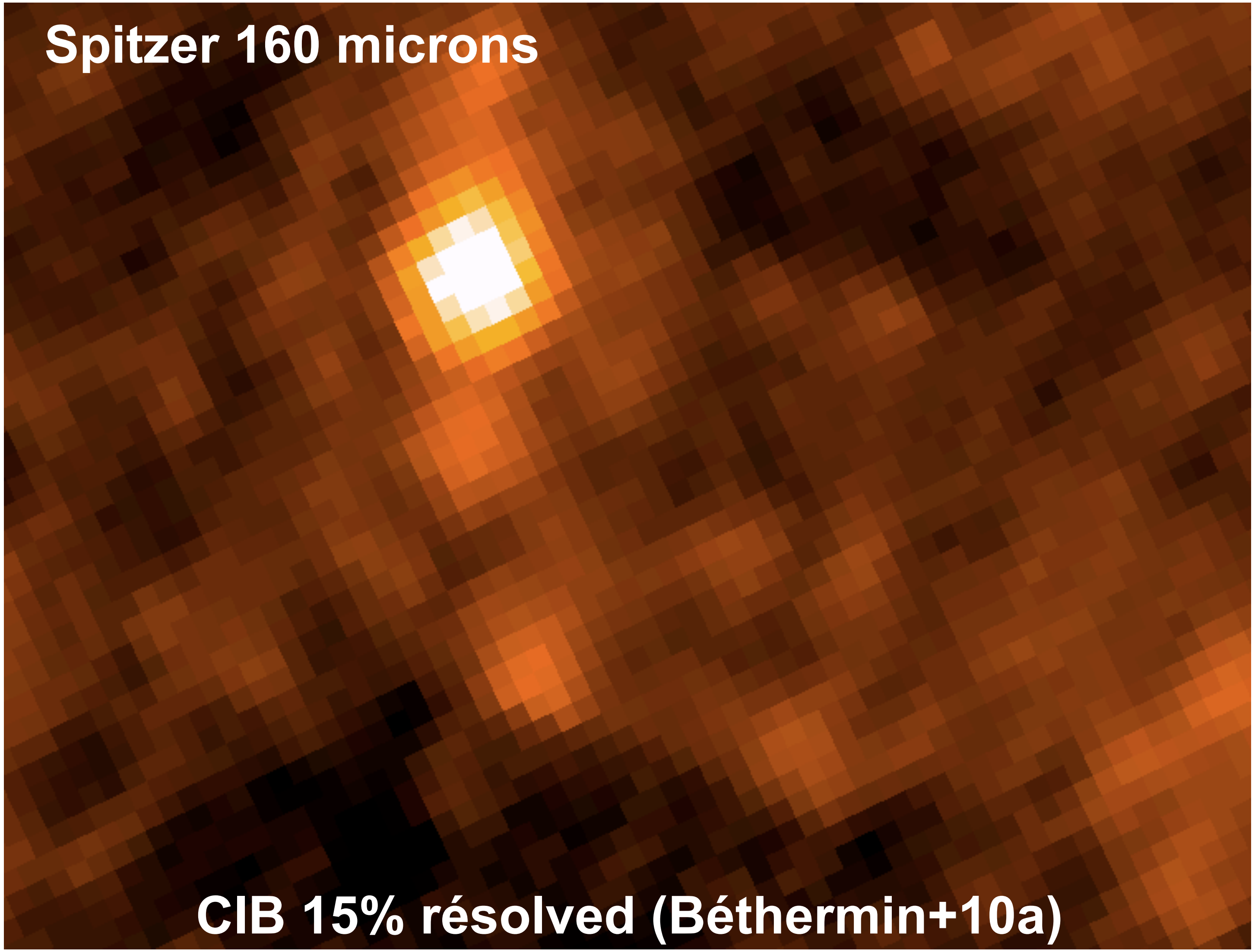
courtesy M. Béthermin

resolving the CIB: confusion



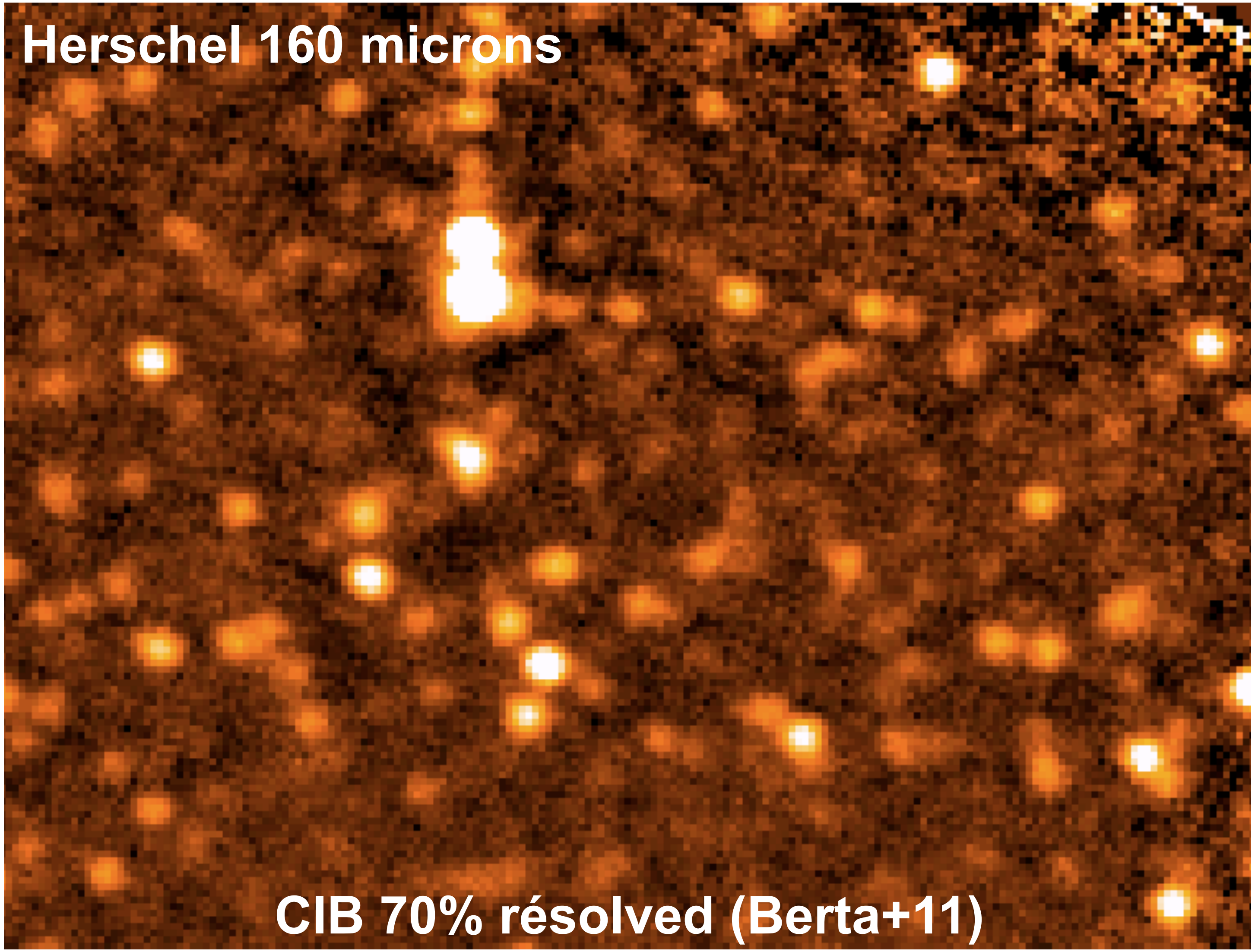
courtesy M. Béthermin

resolving the CIB: confusion



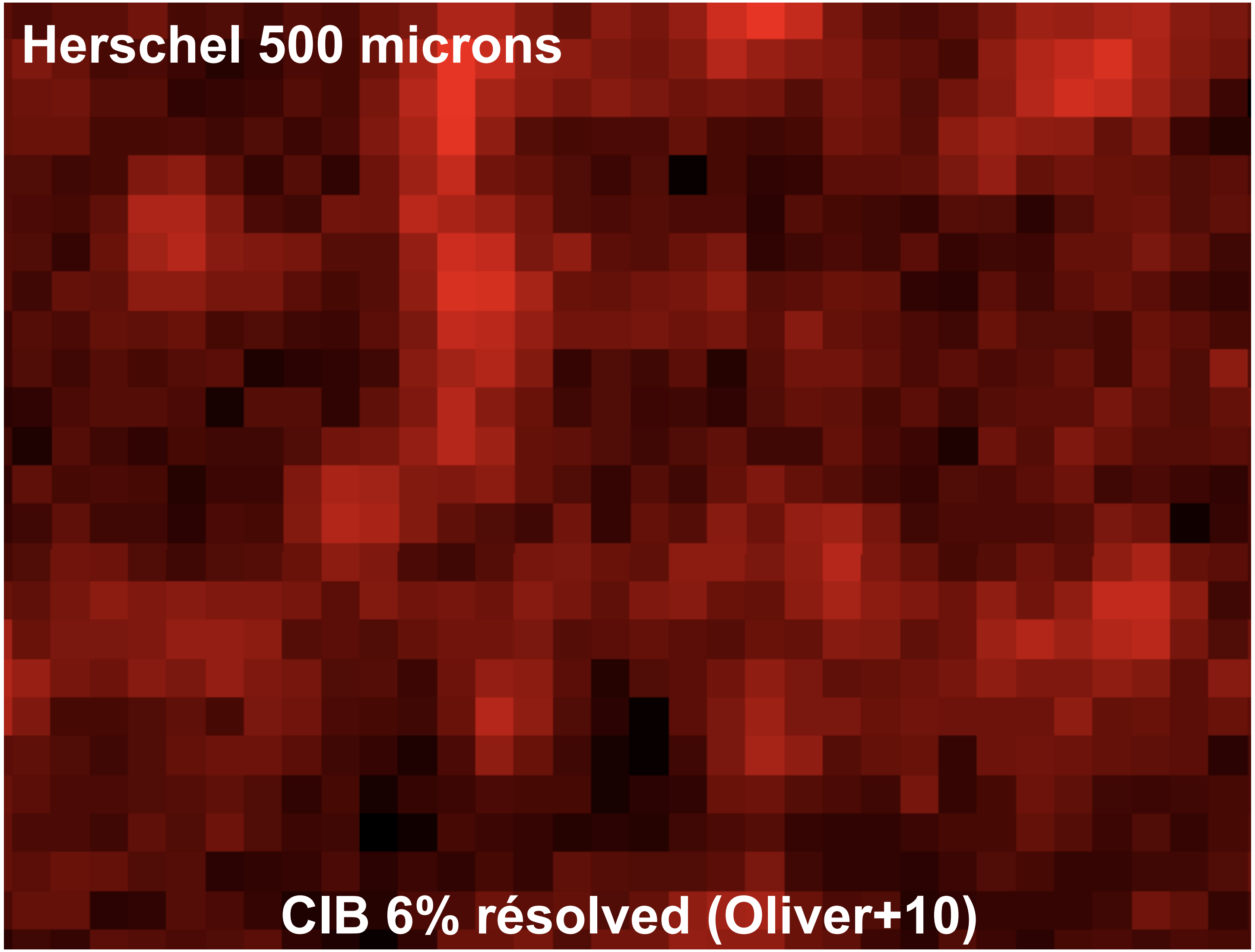
courtesy M. Béthermin

resolving the CIB: confusion



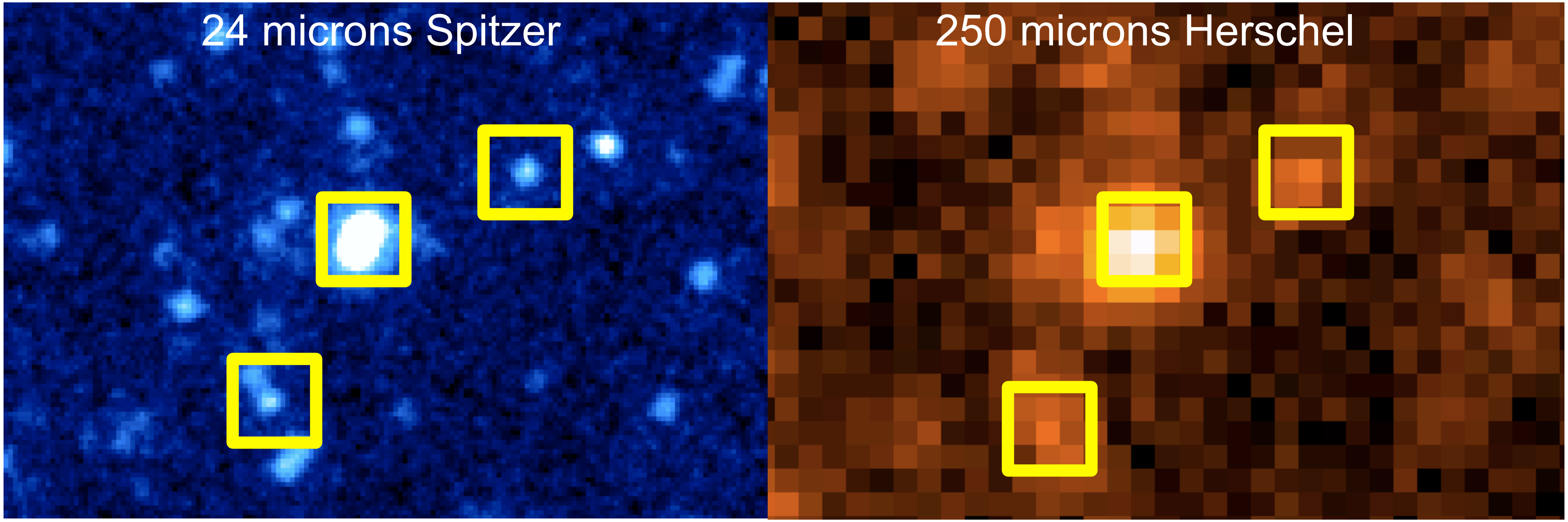
courtesy M. Béthermin

resolving the CIB: confusion

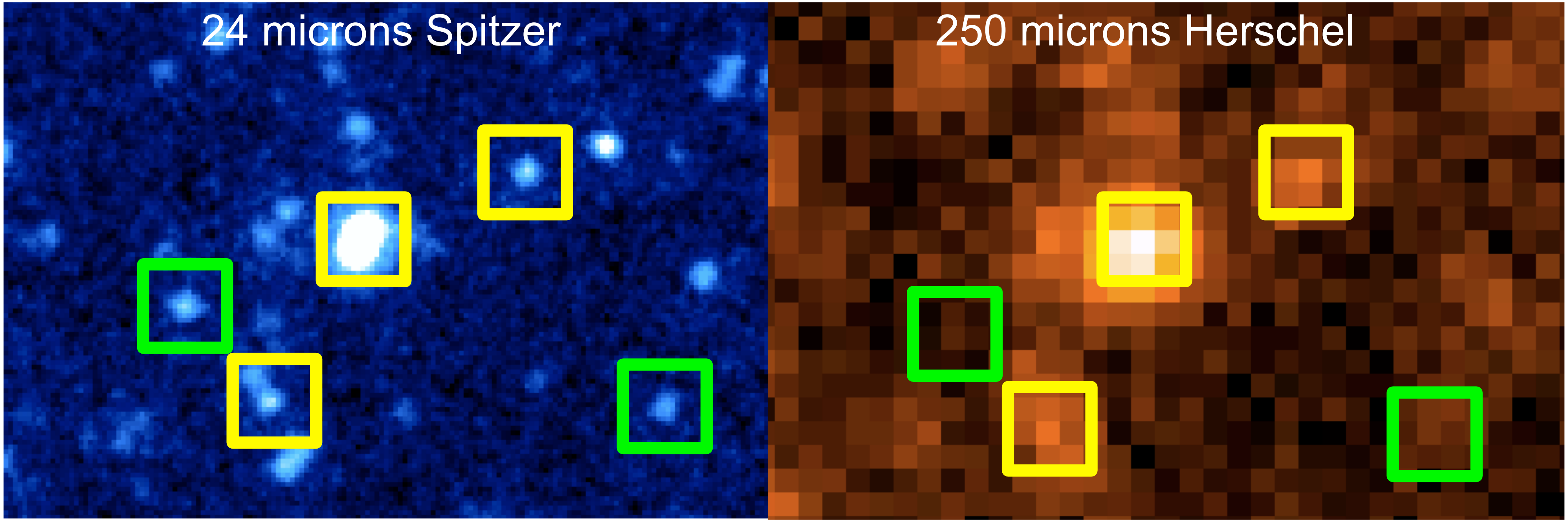


courtesy M. Béthermin

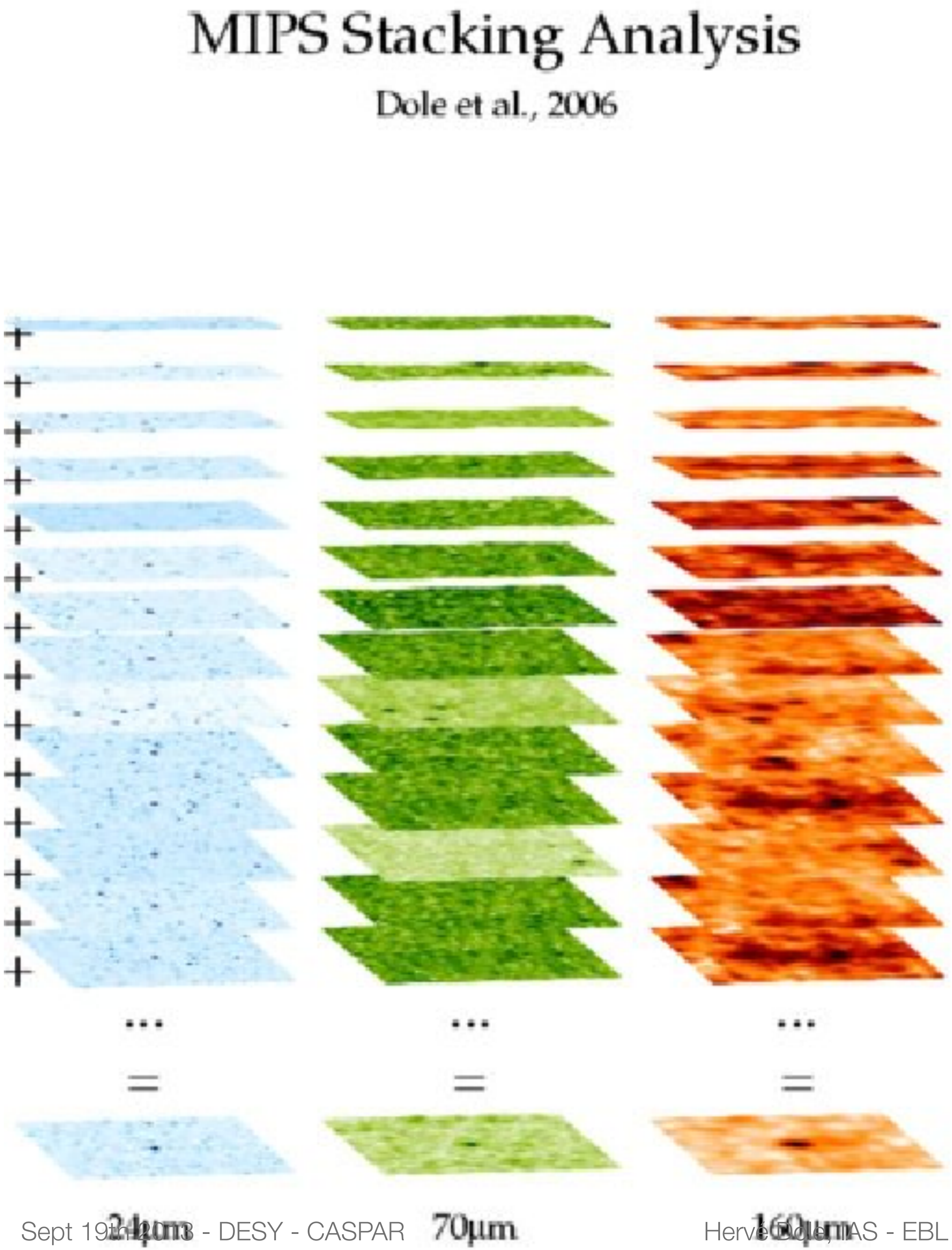
using the 24 micron observations as a prior

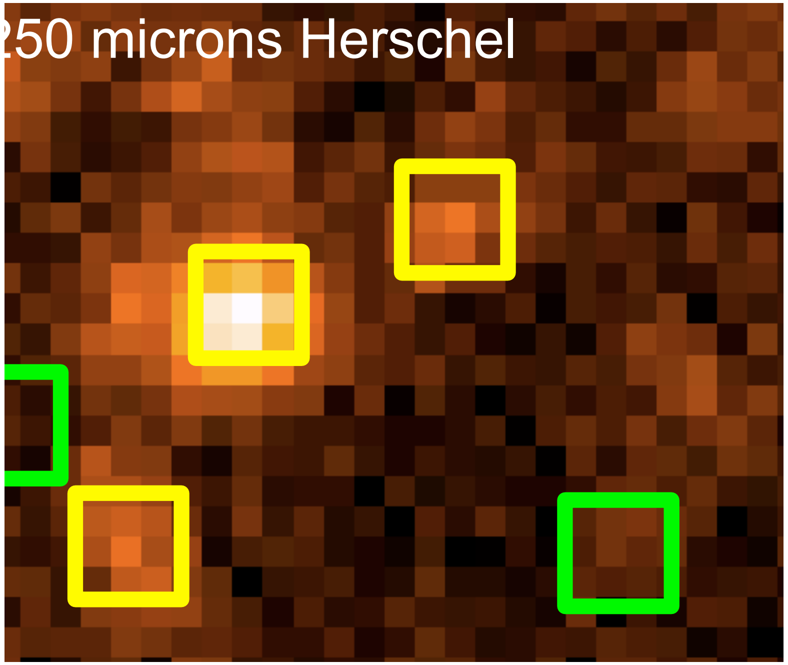


using the 24 micron observations as a prior

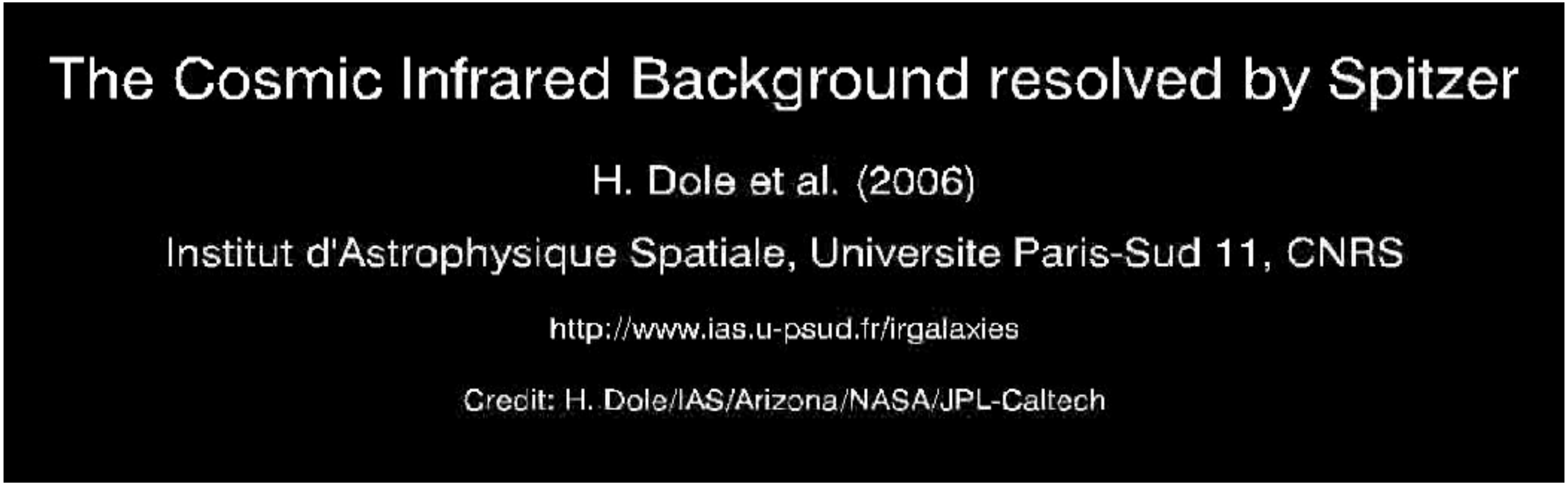


ations as a prior



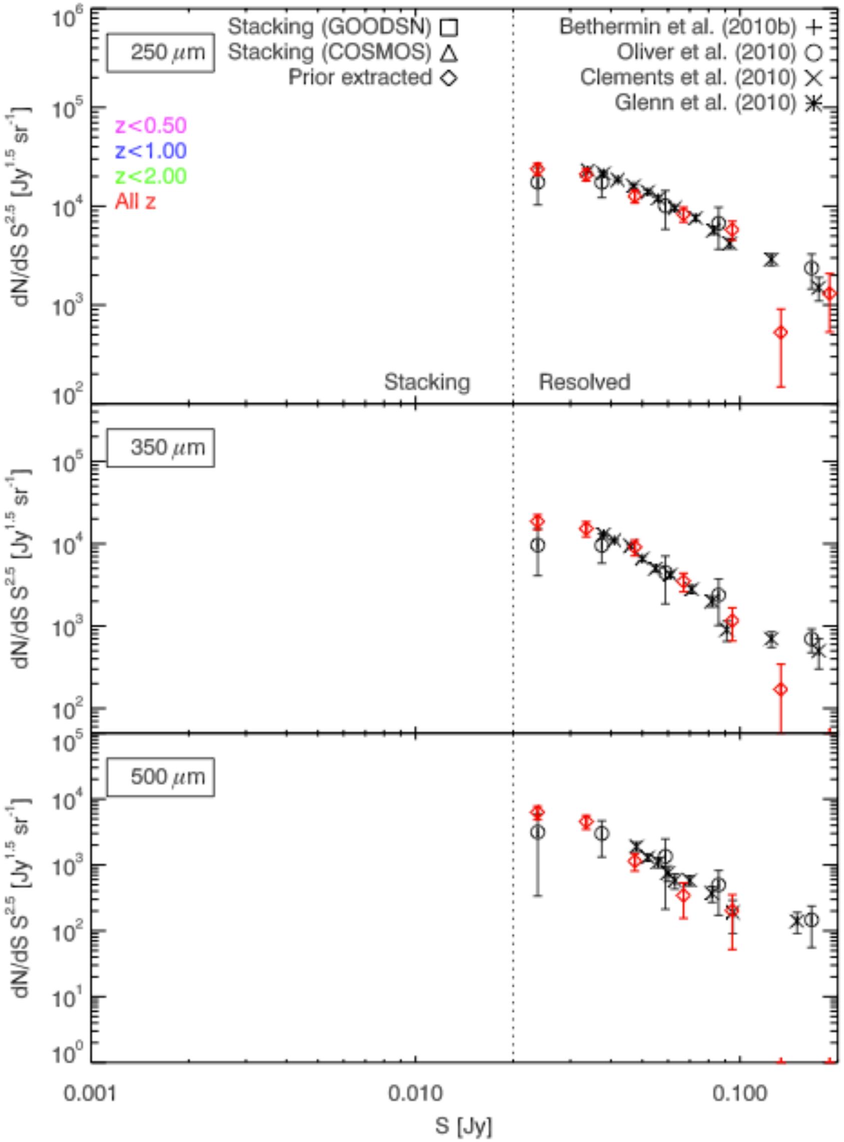


stacking: resolving the CIB at its peak

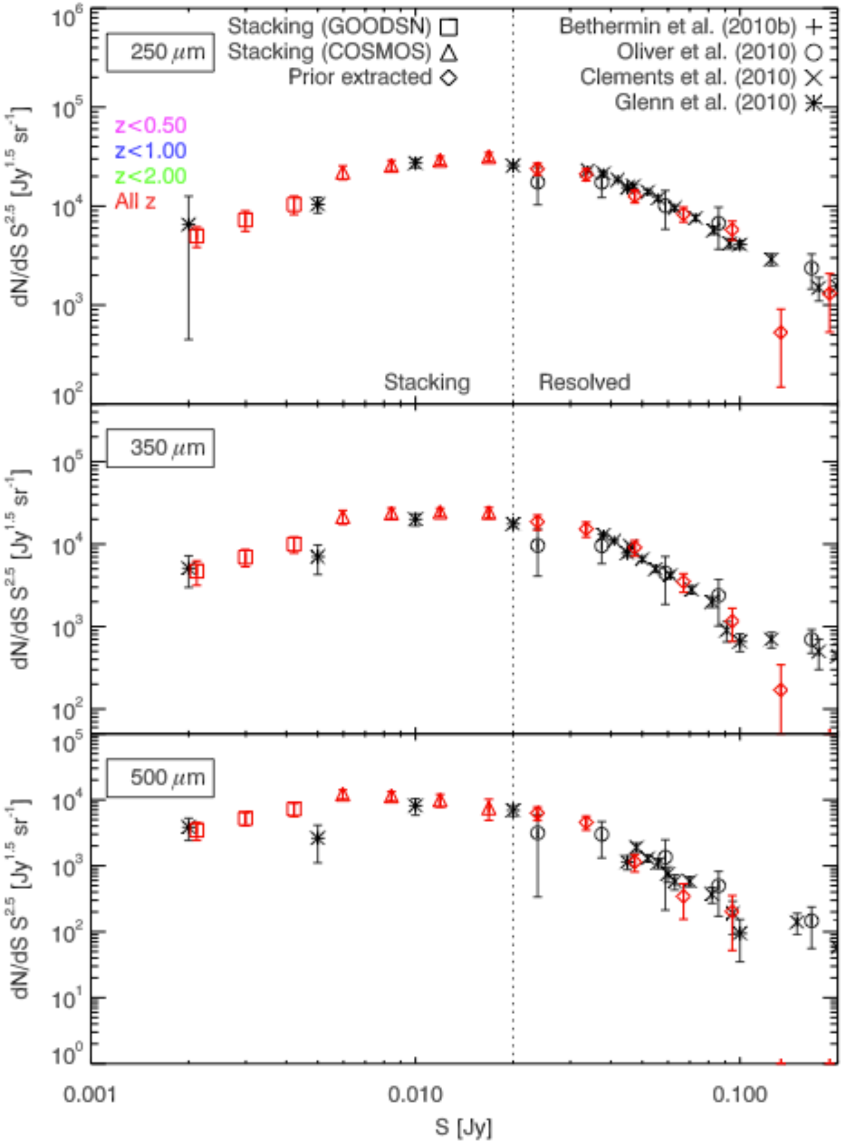


Dole et al., 2006

stacking – statistical studies

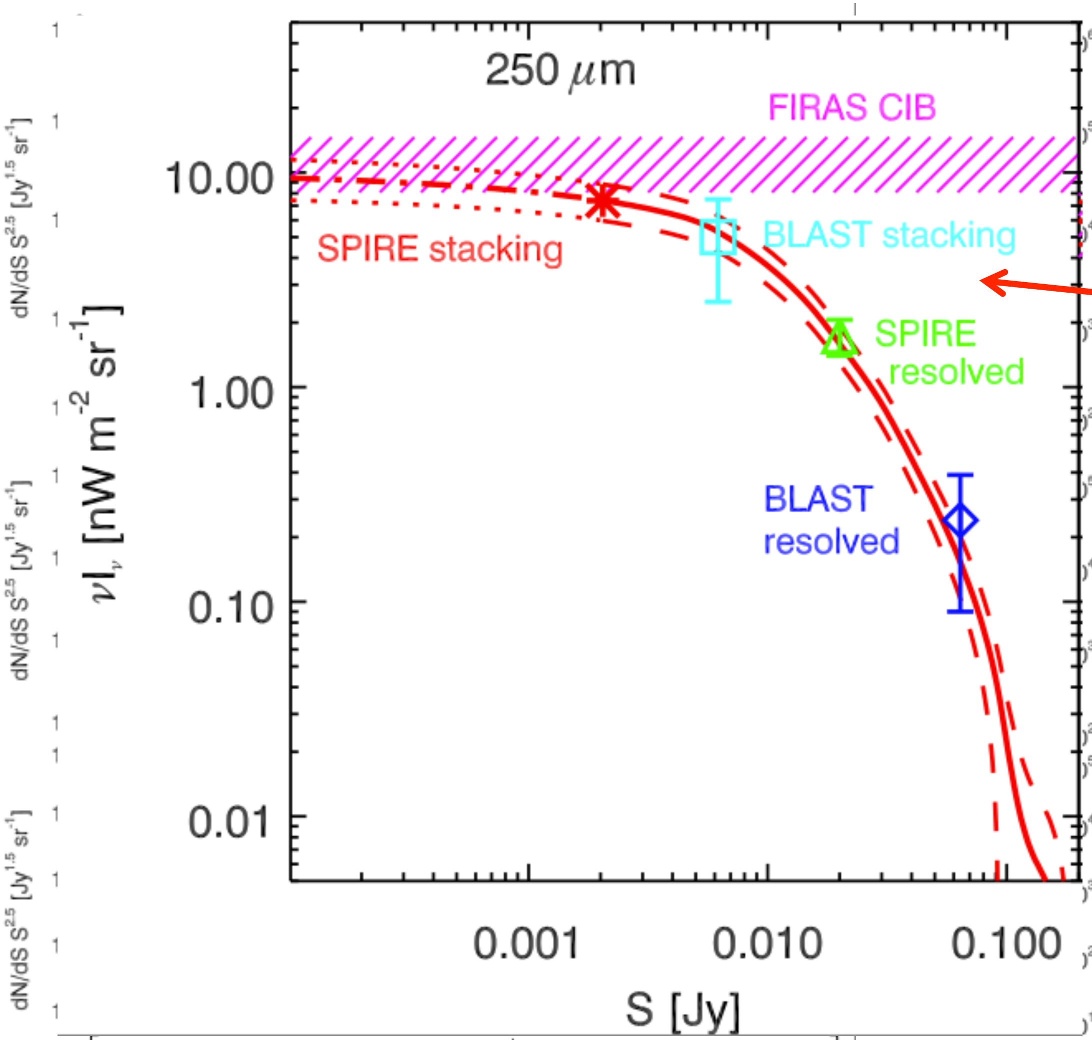


Resolved SPIRE number counts
(Béthermin+12b)



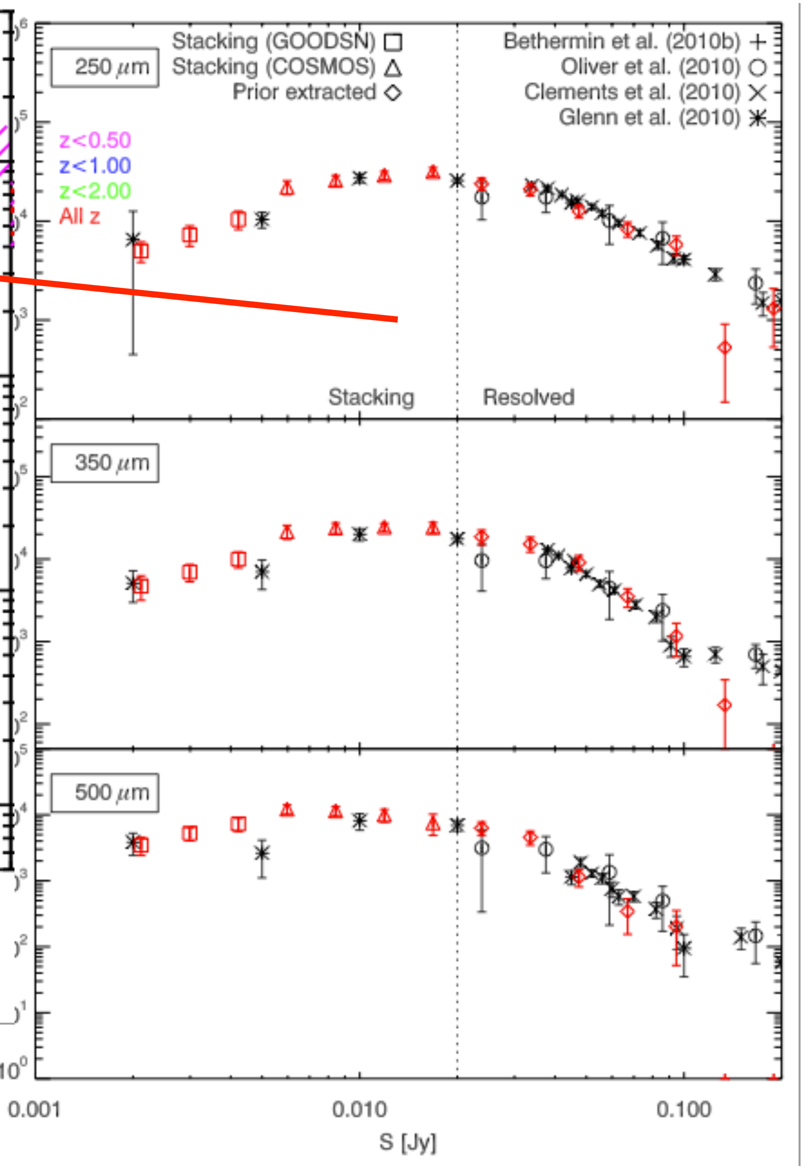
Number counts built by stacking
(Béthermin+12b)

stacking – statistical studies



Cumulative contribution to the CIB as a function of the flux cut (Béthermin+12b)

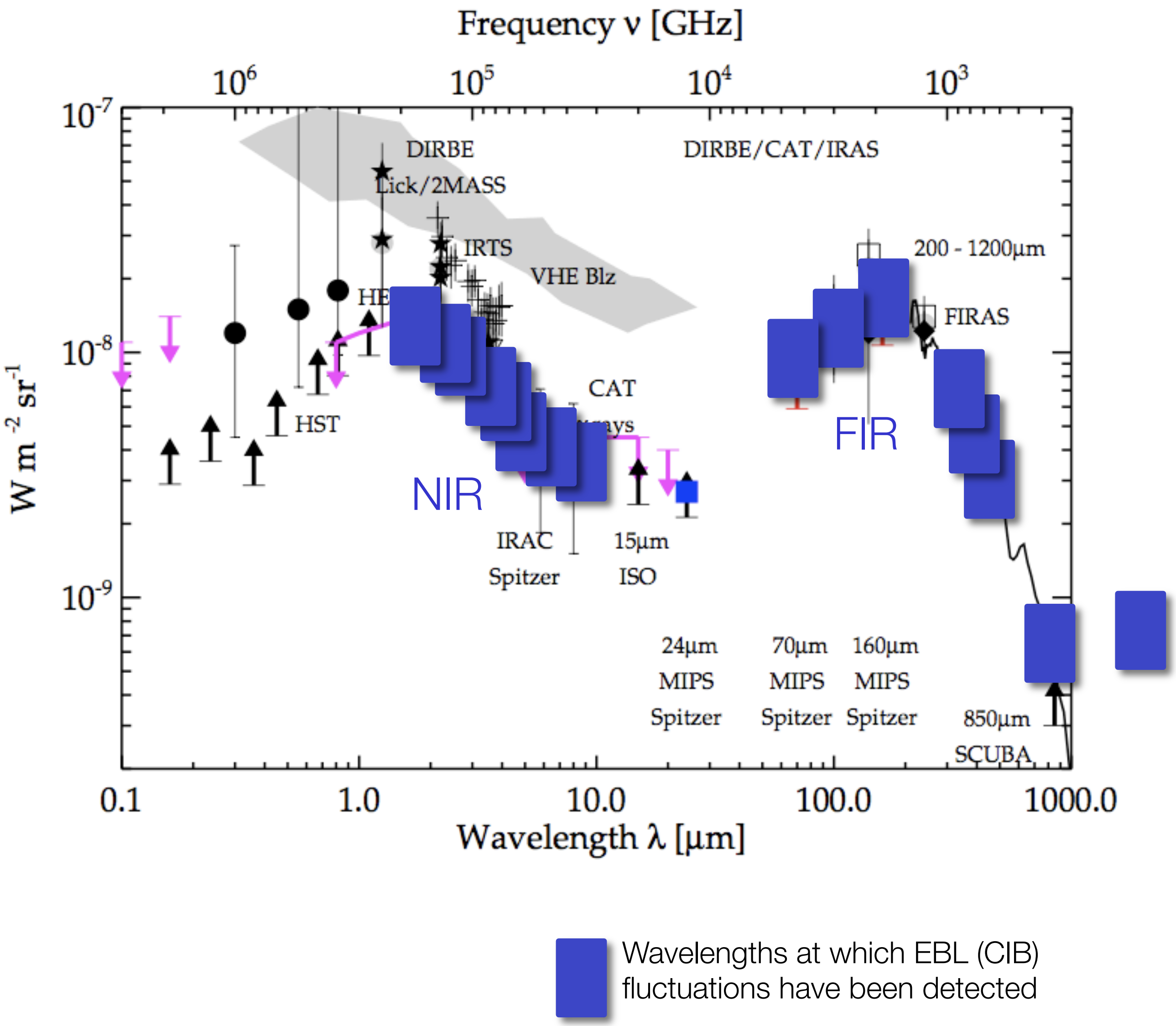
Resolved SPIRE number counts (Béthermin+12b)



Number counts built by stacking (Béthermin+12b)

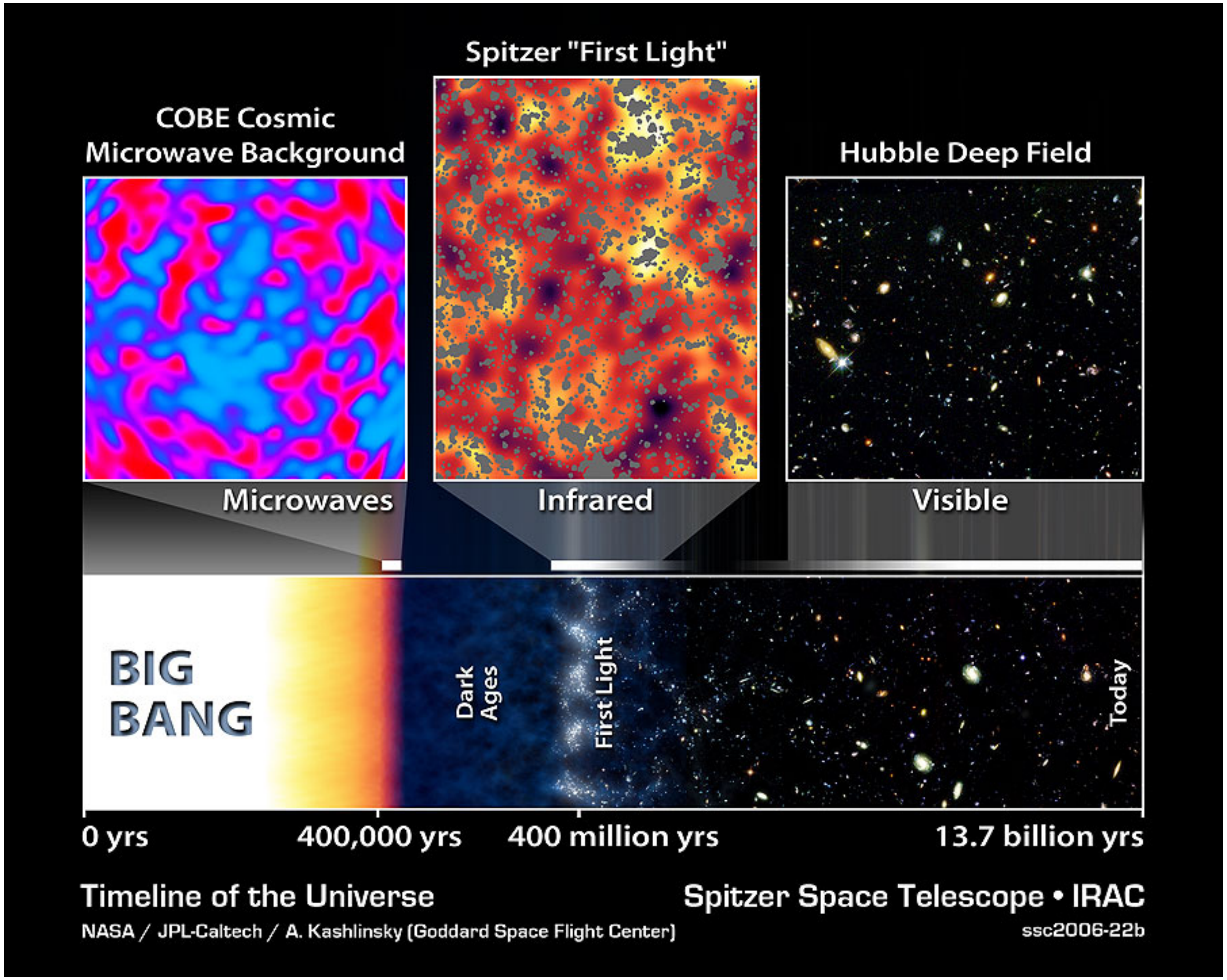
2.2 infrared background fluctuations

Detections:
- mm: Hall et al., 2010 SPT
- HFI: Planck collab, 2011,13
- 250, 350, 500um: Marsden; Viero; Amblard; BLAST; Herschel;
-170um: Lagache & Puget, 2000, ISOPHOT
- 160um: Lagache et al., 2007, Spitzer
-100um & 60um: Miville-Deschênes, Lagache, Puget, 2002, IRAS
-3.6, 4.5, 5.8, 8.0um: IRAC Kashlinsky et al
-1.25, 2.2, 3.5, 5um: Kashlinsky & Odenwald, 2000, DIRBE
-1.6um: Thompson et al. 2007, NICMOS
-1.4-2.4um: Matsumoto et al., 2004, IRTS
-J, H, K (1.25, 1.65, 2.17um): Kashlinsky et al. 2002 & Odenwald et al., 2003, 2MASS



NIRB fluctuations: z<2 or z>6 or popIII ?

Kashlinsky et al., 2007, ApJ

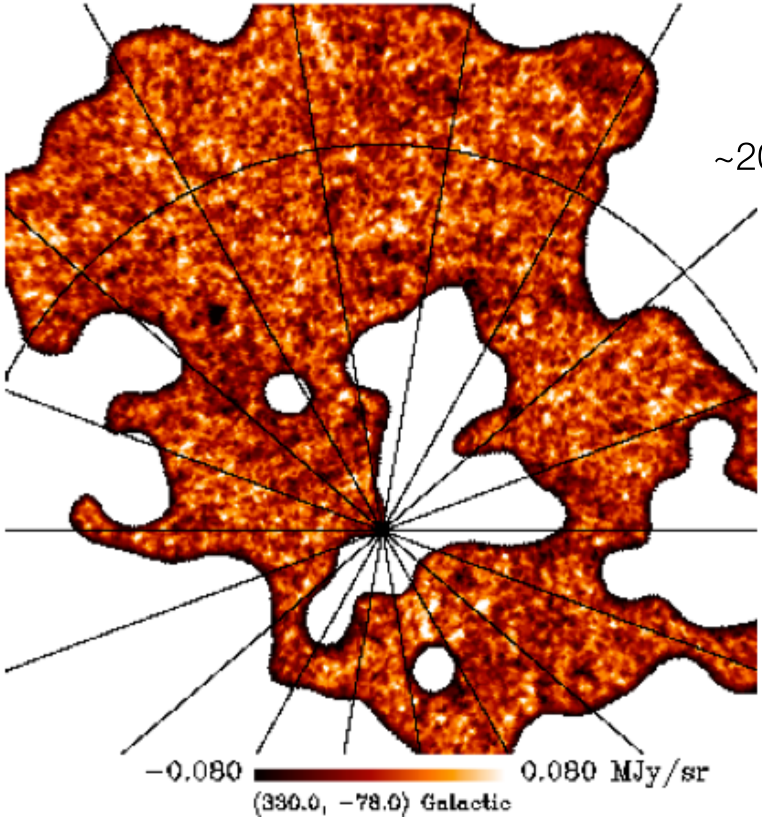


until recently there was controversy...

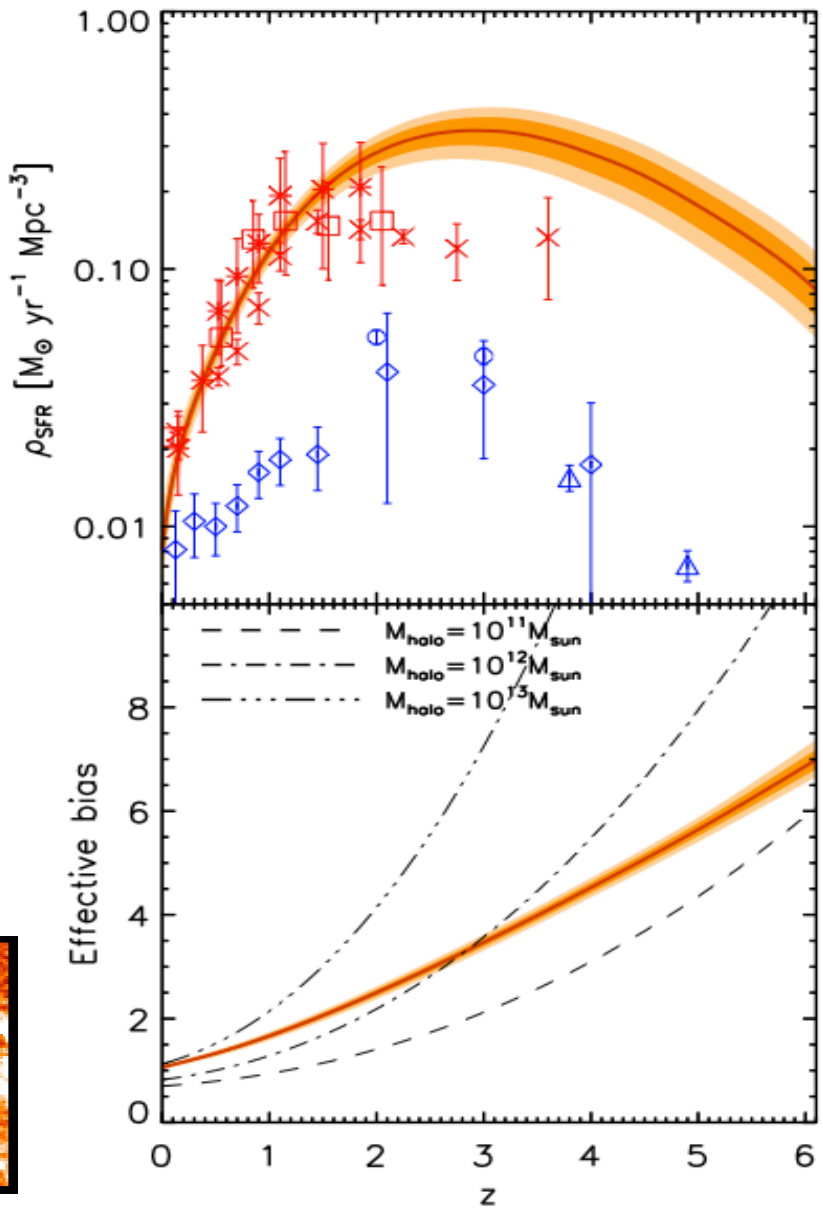
papers by Kashlinsky, or Thompson or Cooray etc

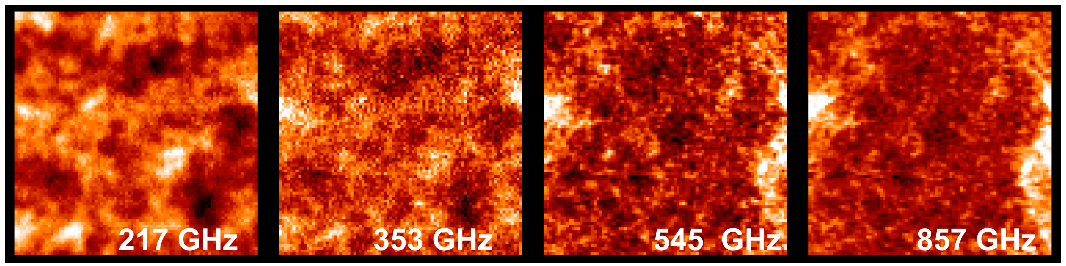
cf. A. Ferrara's talk

Planck submm CIB fluctuations



~2000 Sq. Deg



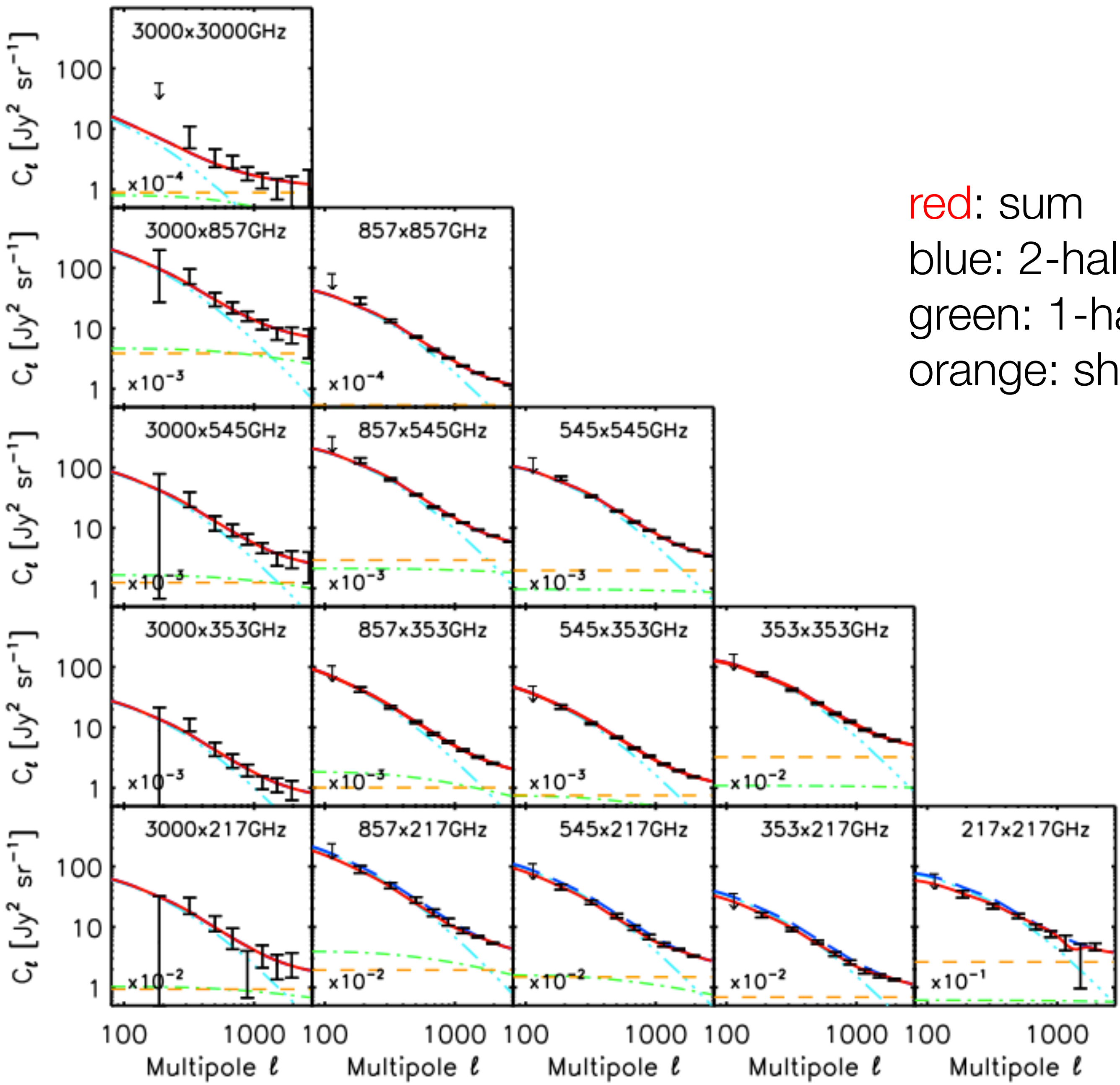


few 10 Sq Deg fields in 2011

Planck Collab., 2013, XXX, in press

Planck submm CIB fluctuations

Planck Collab., 2013, XXX, in press



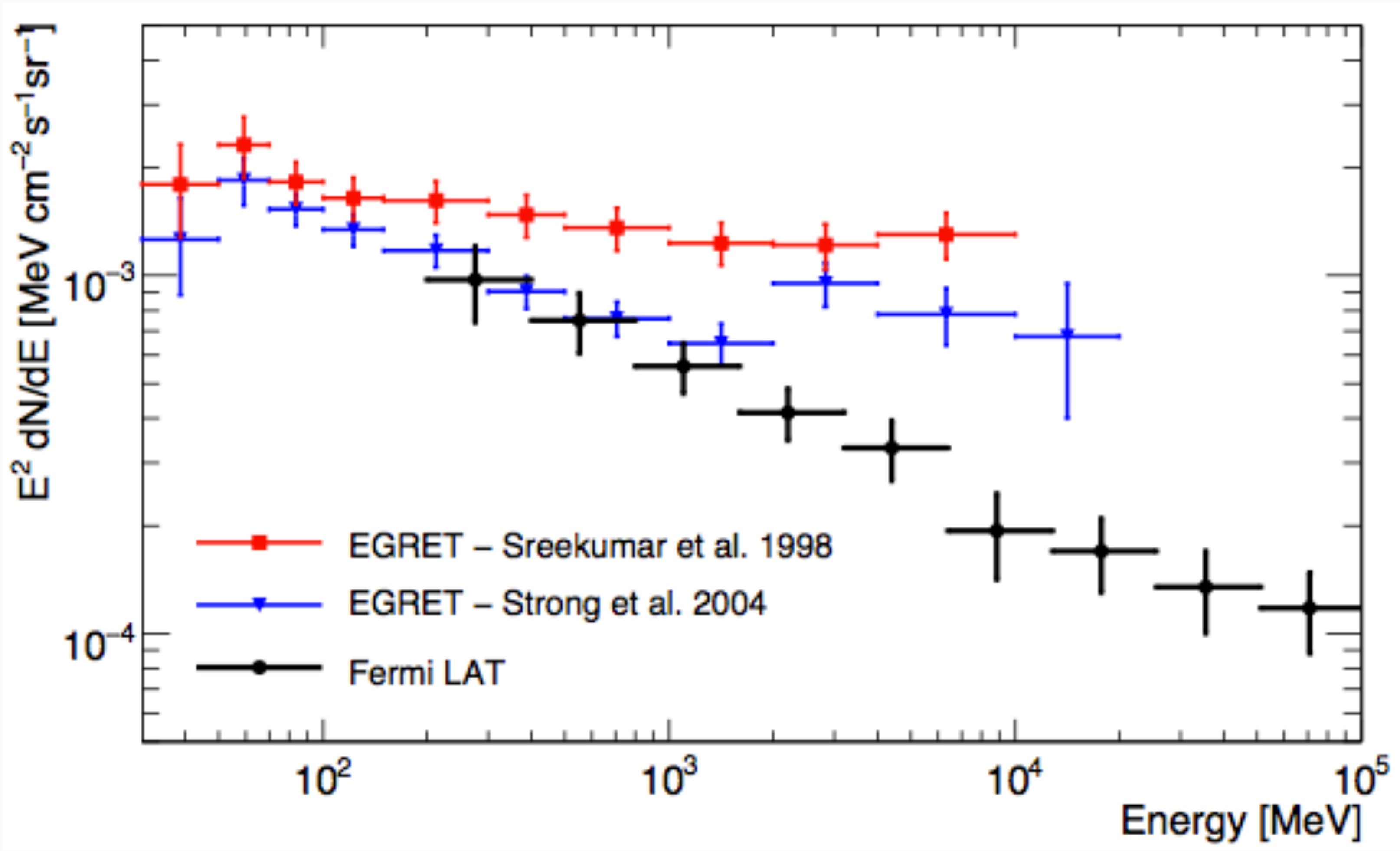
red: sum
blue: 2-halo term
green: 1-halo term
orange: shot noise

2.3 extragalactic background light

- Gamma-rays
- X-rays
- UV
- optical
- infrared – submillimeter
- radio

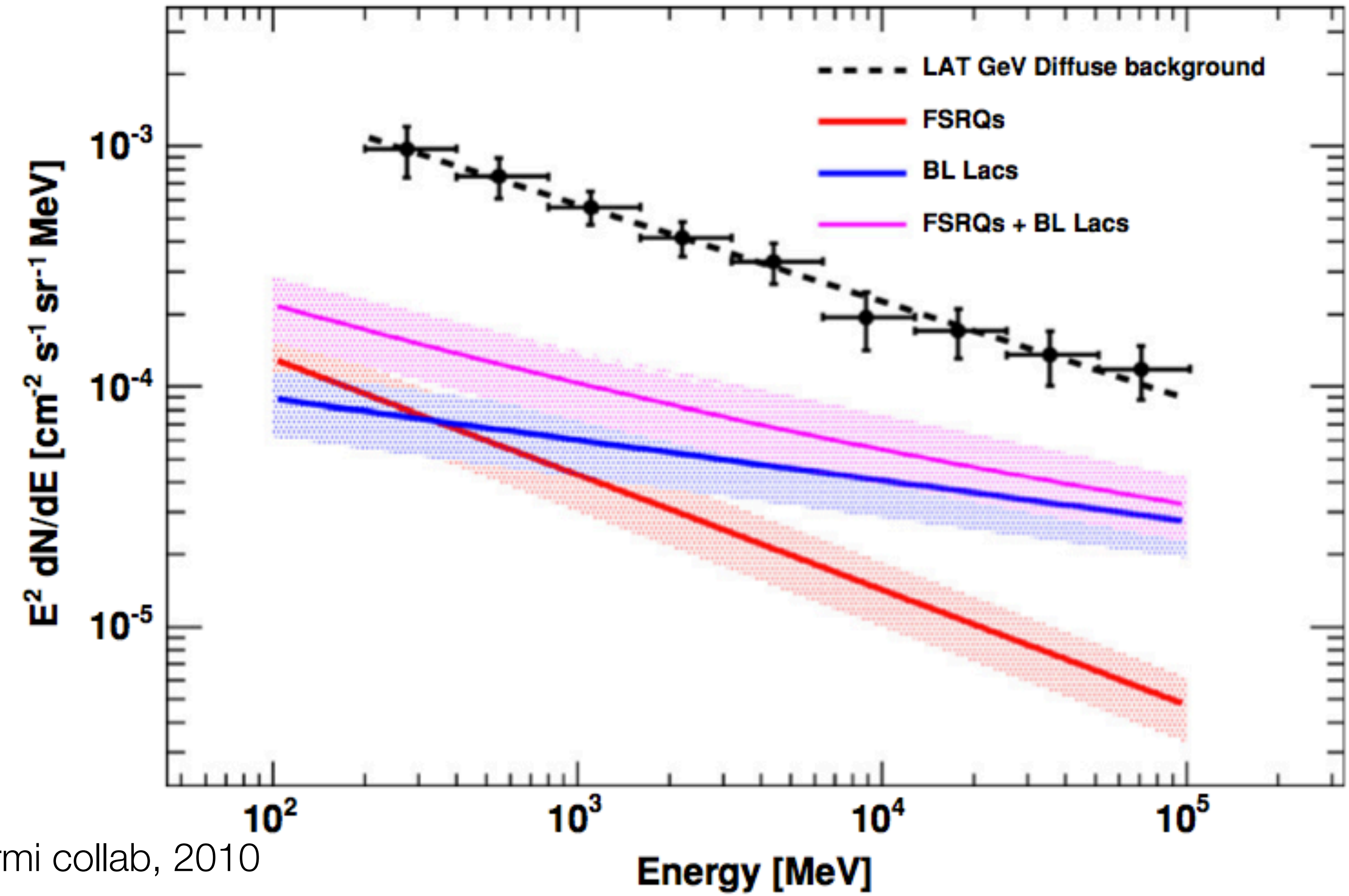
- total EBL ~50 nW/m^2/sr (Dole+06, Béthermin+13, D&B in prep)

EGB – Fermi



E^2 dN/dE [MeV cm^{-2}s^{-1}sr^{-1}]
10^{-3}
10^{-4}
10^2
10^3
10^4
10^5
Energy [MeV]
EGRET – Sreekumar et al. 1998
EGRET – Strong et al. 2004
Fermi LAT

EGB – Fermi – by source type

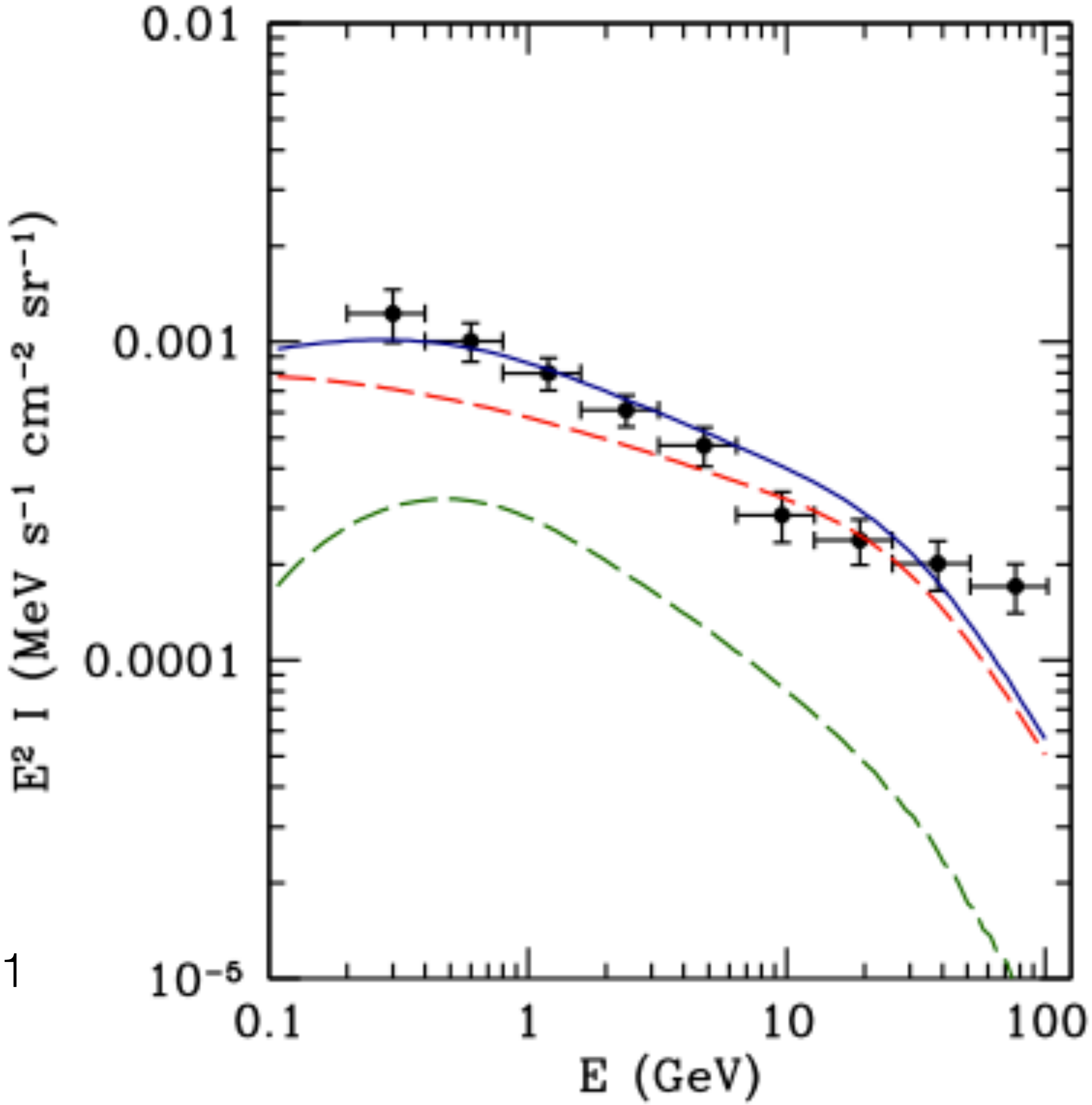


Fermi collab, 2010

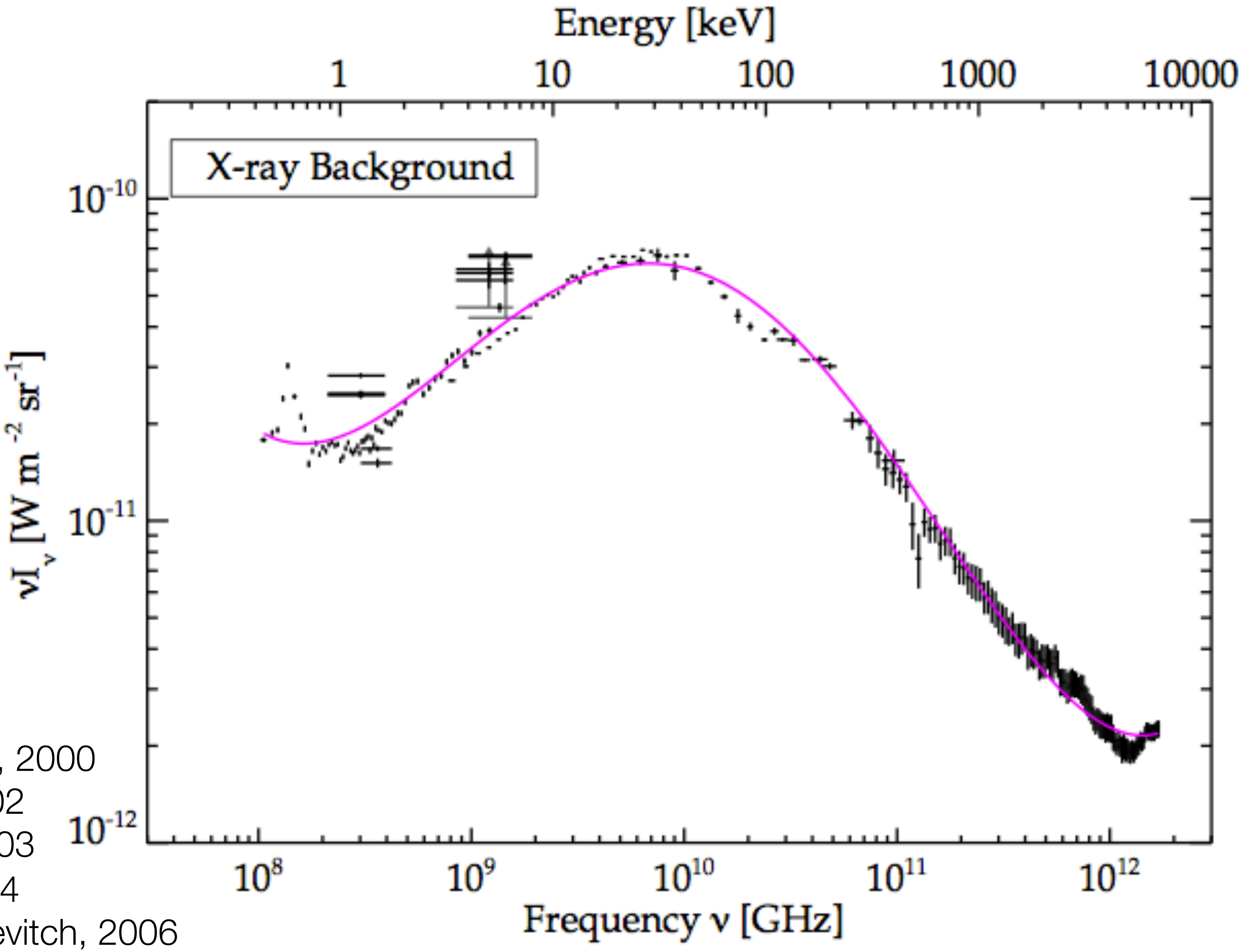
EGB – Fermi – model

star forming (green)
blazars (red)

e.g. Cavadini et al., 2011



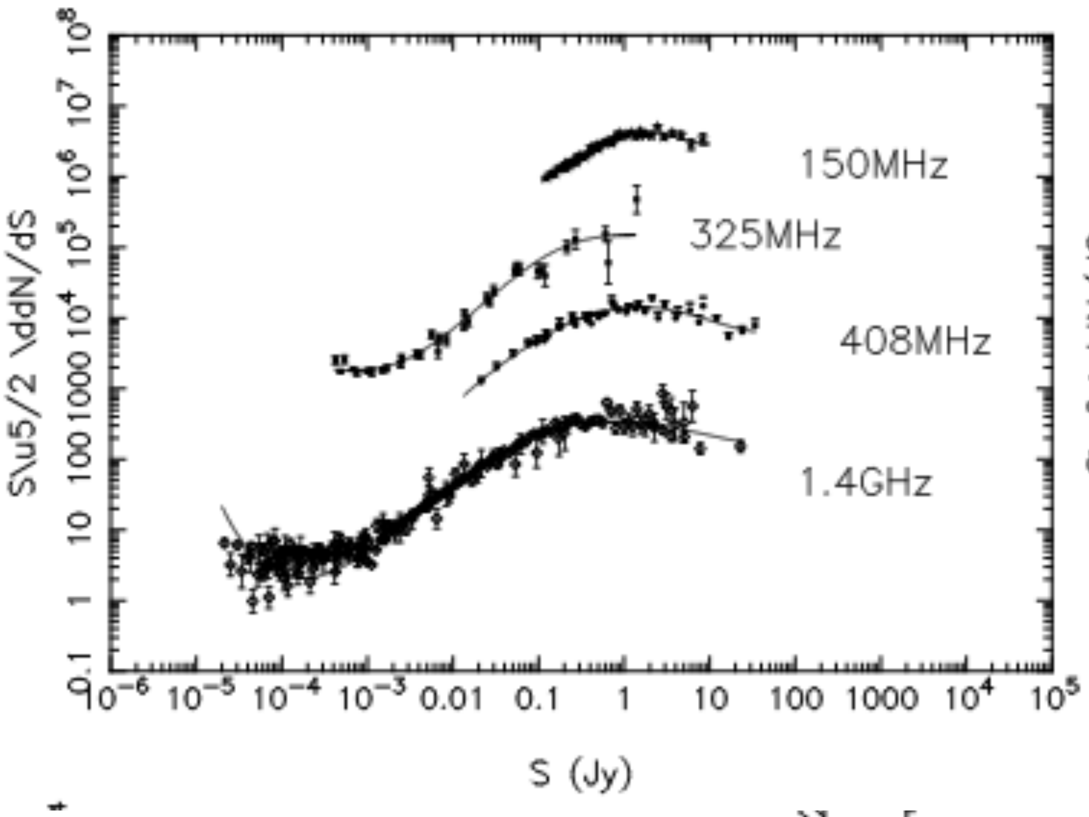
XRB

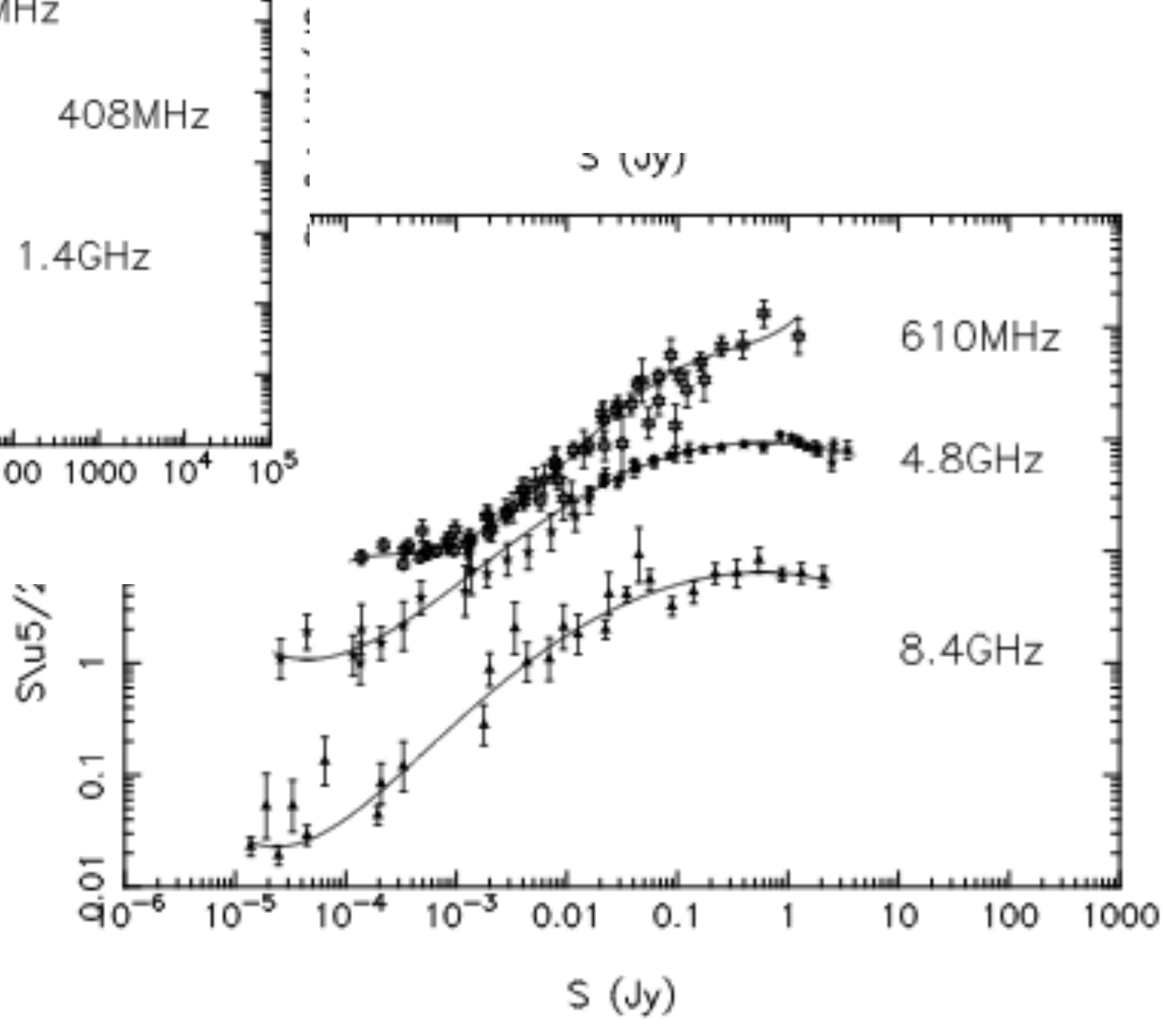


Dole 2010 HDR; Dole & Bethermin (in prep)

Mushotzky et al., 2000
Cowie et al., 2002
Moretti et al., 2003
Bauer et al., 2004
Hickox & Marckevitch, 2006
Kim et al., 2007

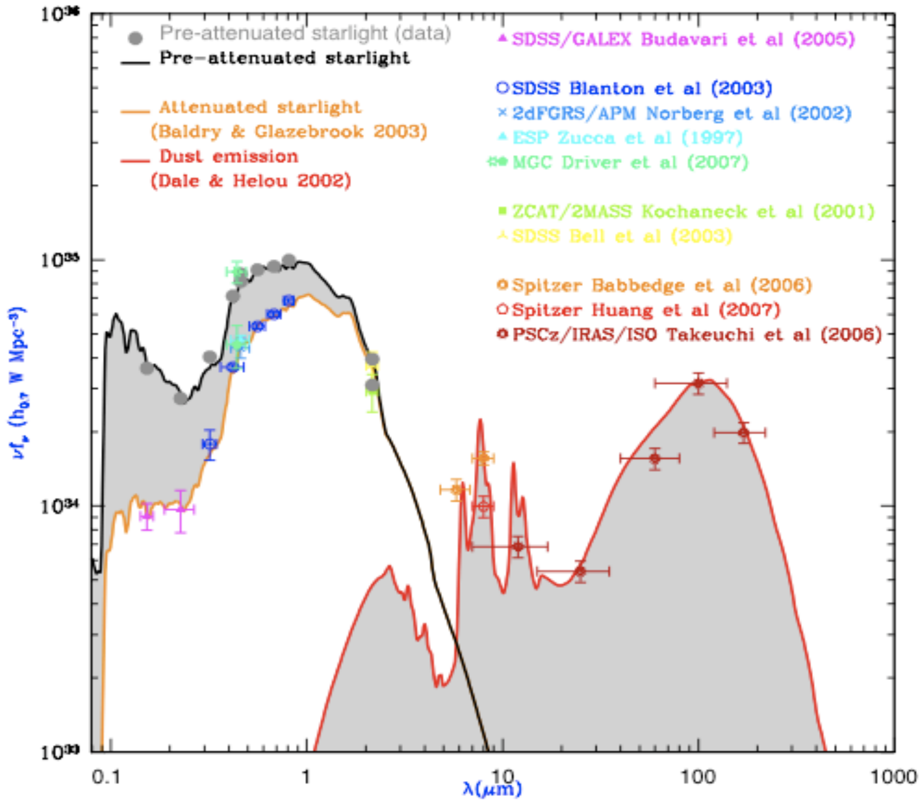
radio





e.g. Verstrom et al., 2011

2.4 also important: « local » EBL



IG. 4.— The cosmic energy output covering the region dominated by starlight (left peak) and by dust emission (right peak). The orange he shows the observed (uncorrected) cosmic energy output from the total nearby galaxy population, while the black line shows the same ter correction for the fraction of photons attenuated by dust. The discrepancy in the integrals over these two curves yields the total ergy of starlight lost to heating of the dust grains. If starlight is the only source of dust heating then this energy loss must equal the tal radiant energy of the dust emission (i.e., the two shaded regions must and do contain equal energy).

Driver + 2008

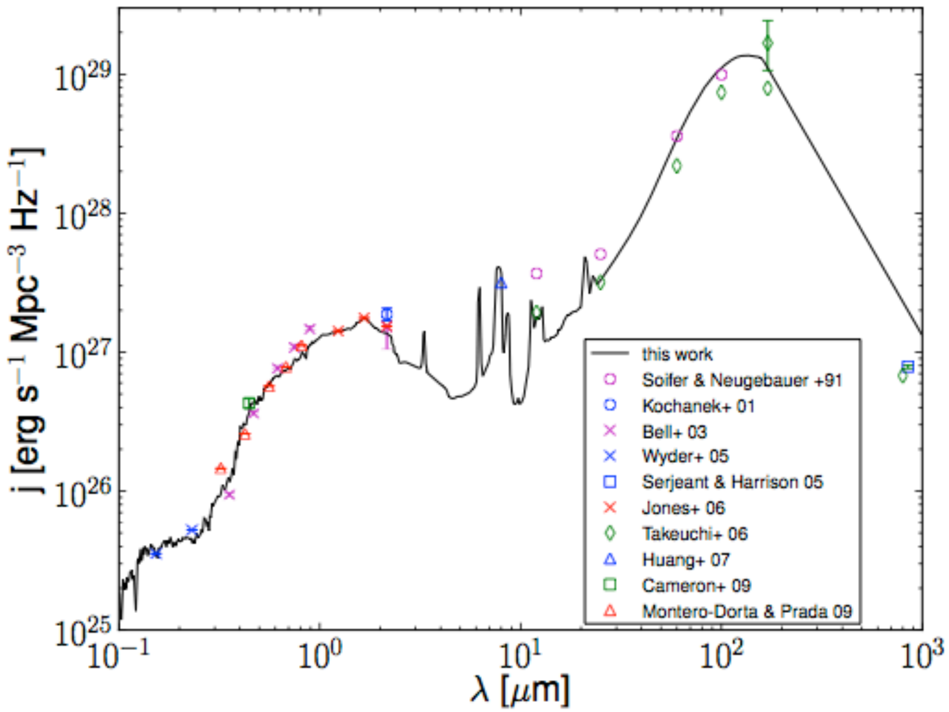
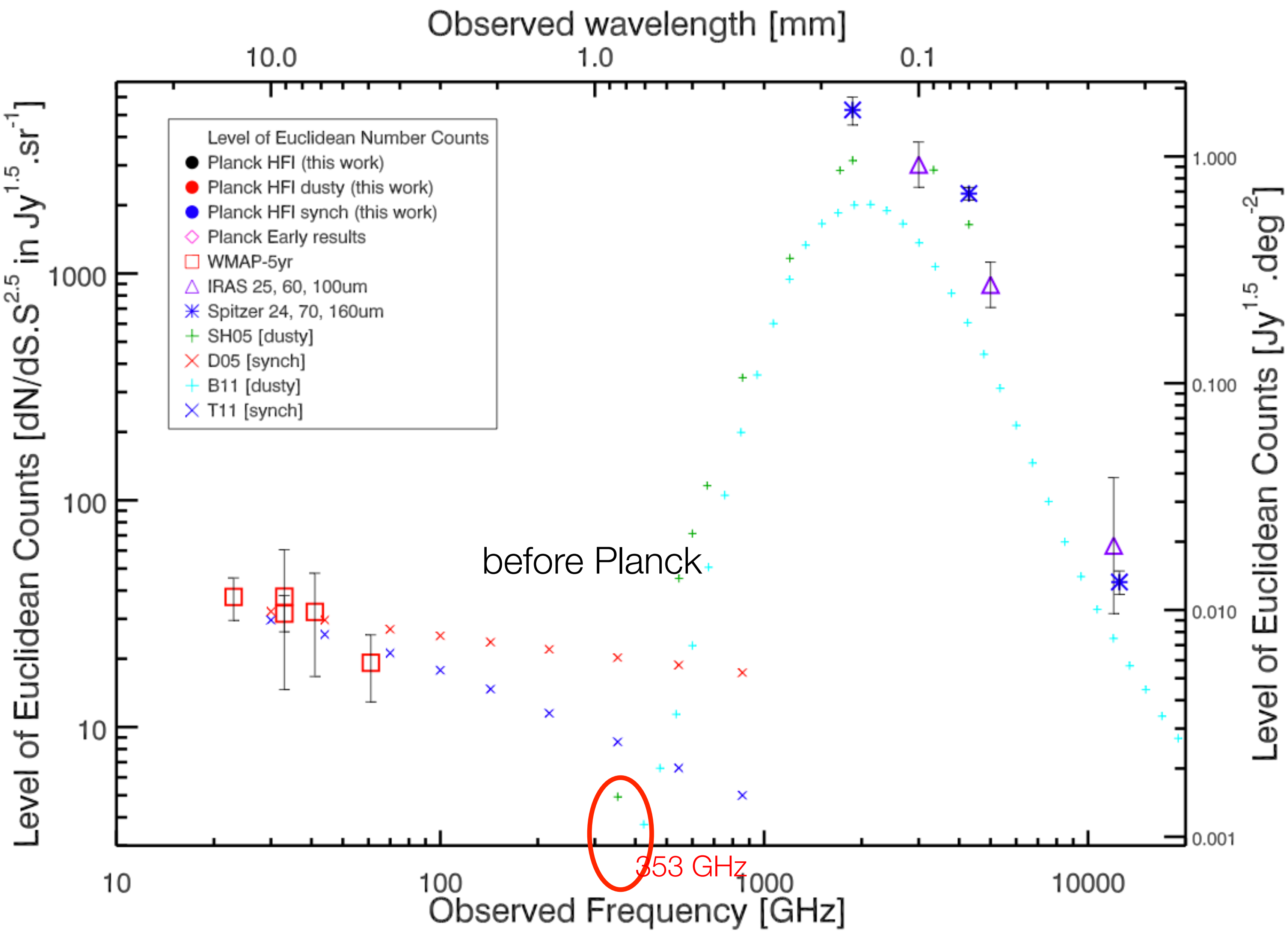


Figure 10. Comparison between our estimation of the local luminosity density (black line) and observational data from different sur 12, 25, 60, 100 μm from Soifer & Neugebauer (1991); K-band from Kochanek et al. (2001); u, g, r, i, z, K-band from Bell et al. (2 FUV, NUV from Wyder et al. (2005); 850 μm from Serjeant & Harrison (2005); bj, rf, J, H, K-band from Jones et al. (2006 25, 60, 100, two different analysis for 170, 800 μm from Takeuchi et al. (2006) (two different analysis); 8 μm from Huang et al. (2 B-band from Driver et al. (2008) and Cameron et al. (2009); and u, g, r, i, z from Montero-Dorta & Prada (2009).

Dominguez + 2010

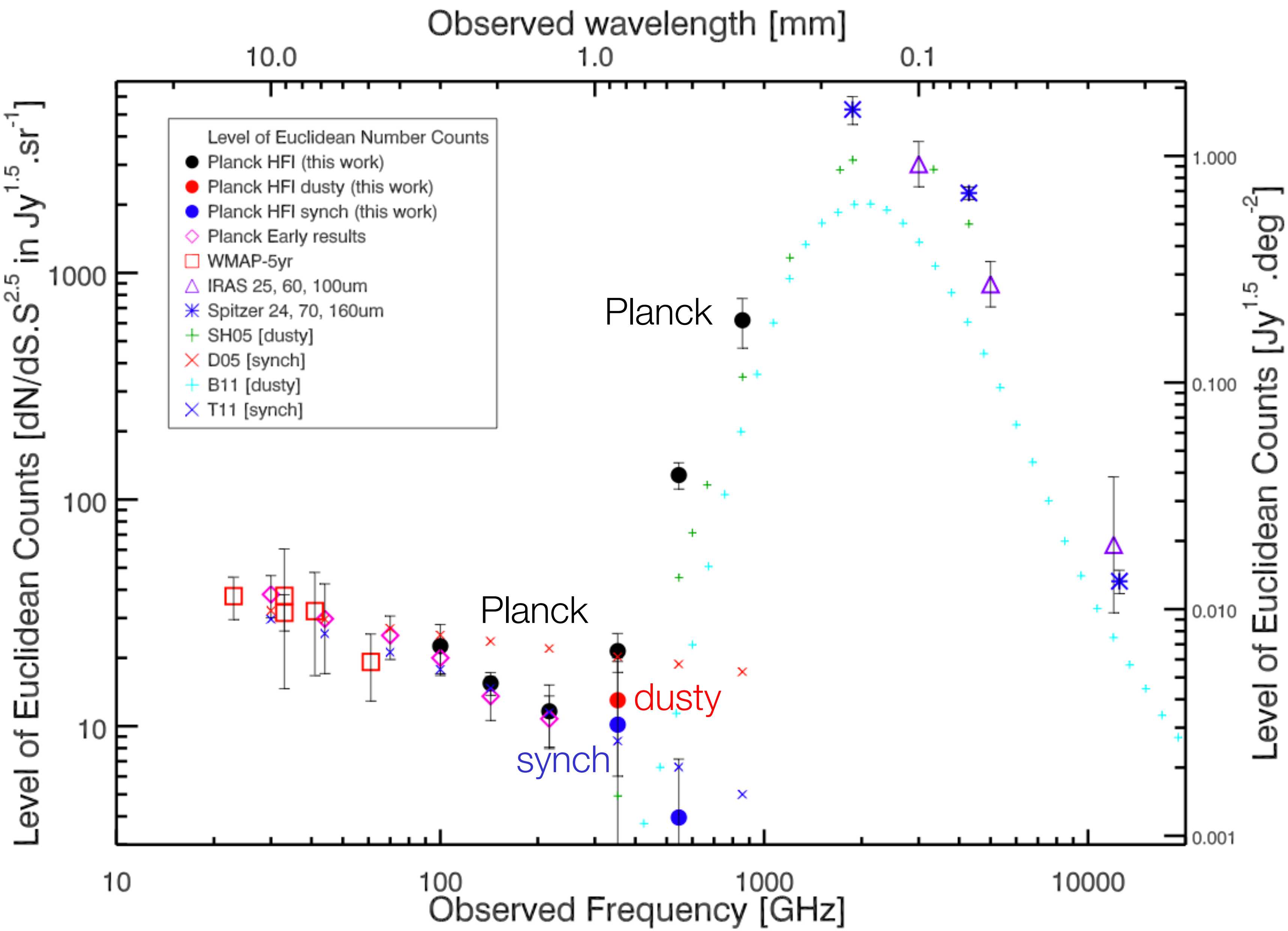
euclidean level of number counts



Planck Collaboration, Intermediate VII, 2013

euclidean level of number counts

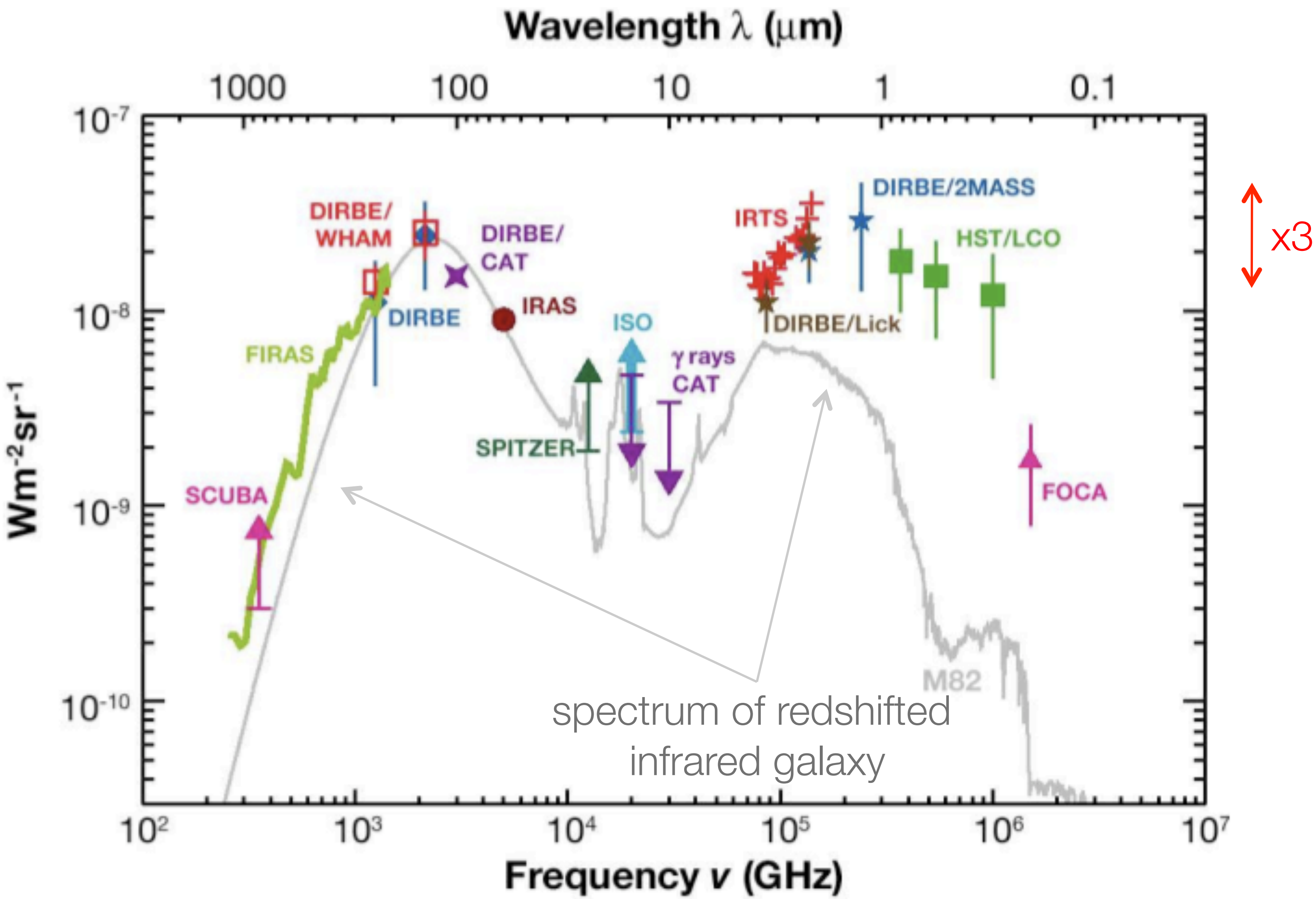
Planck Collaboration, Intermediate VII, 2013



3. encoded information in the EBL

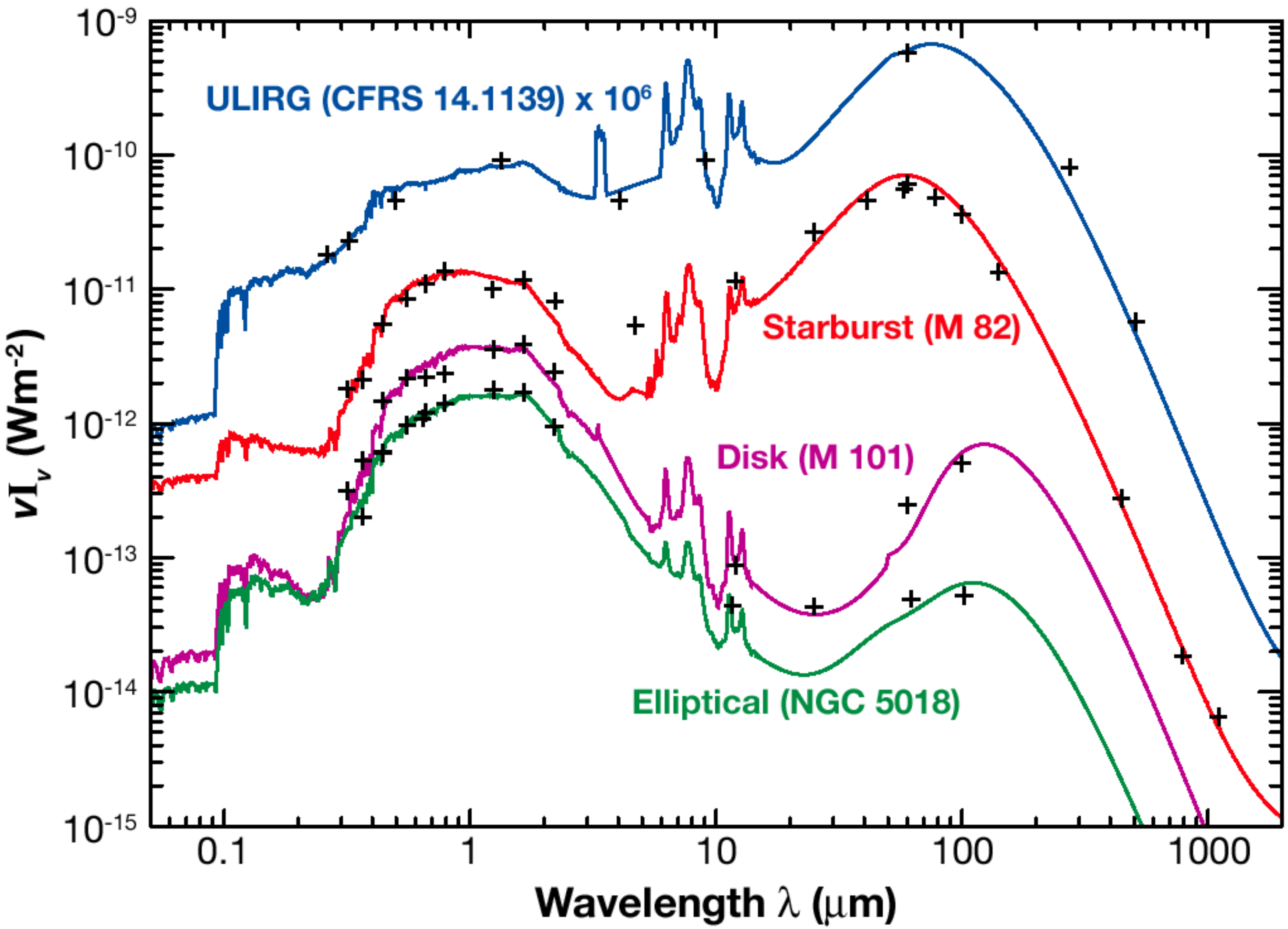
- 3.1 galaxy populations
- 3.2 implications for TeV opacity
- 3.3 EBL/CIB models
- 3.4 Planck & Herschel era: CIB as a new probe of LSS

3.1 galaxies contributing to the EBL ?



Lagache, Puget, Dole, 2005, ARAA

many types of galaxies in opt/IR



the ratio:

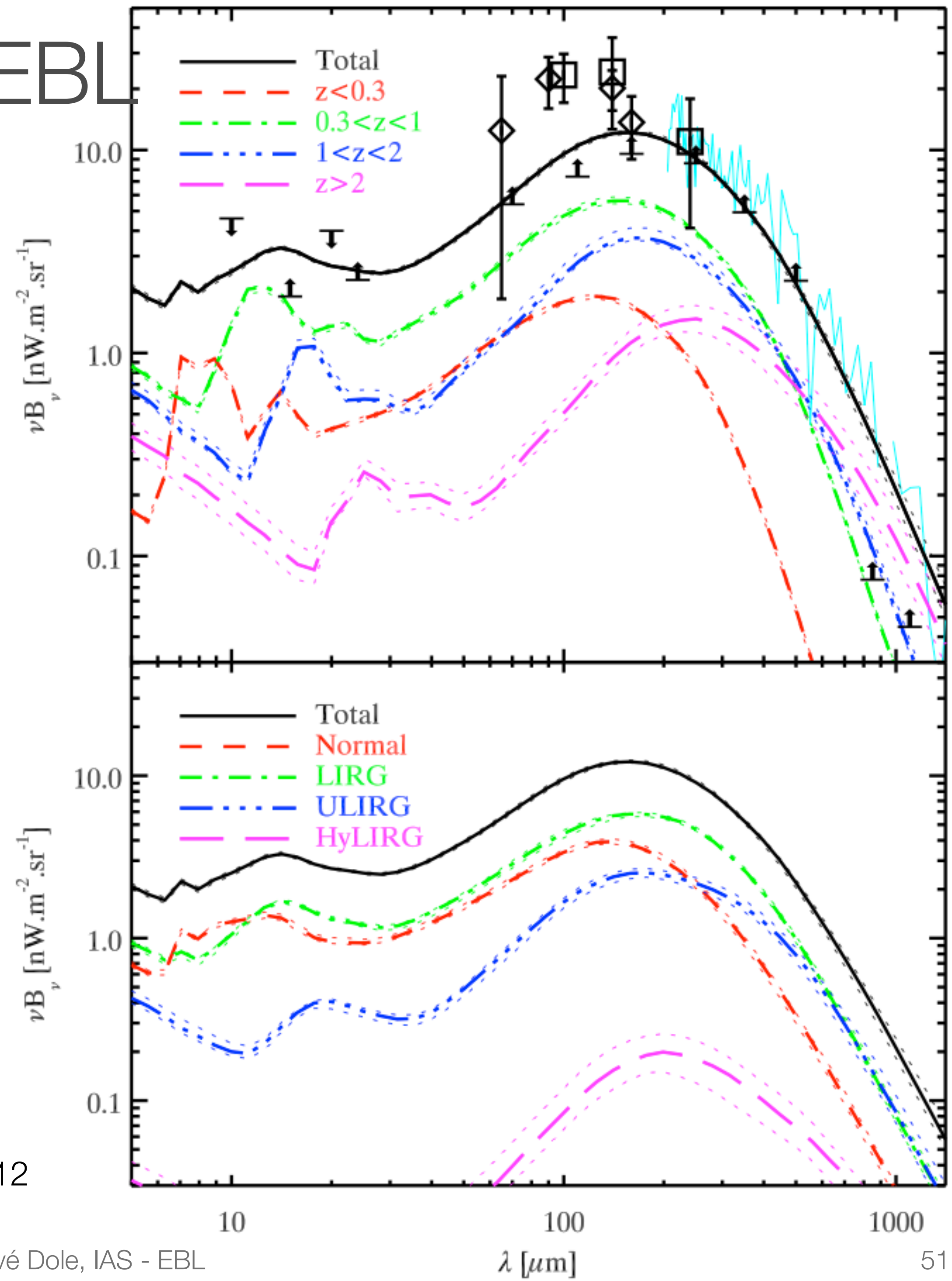
[UV+visible] / infrarouge

varies with the galaxy type

why such differences ?

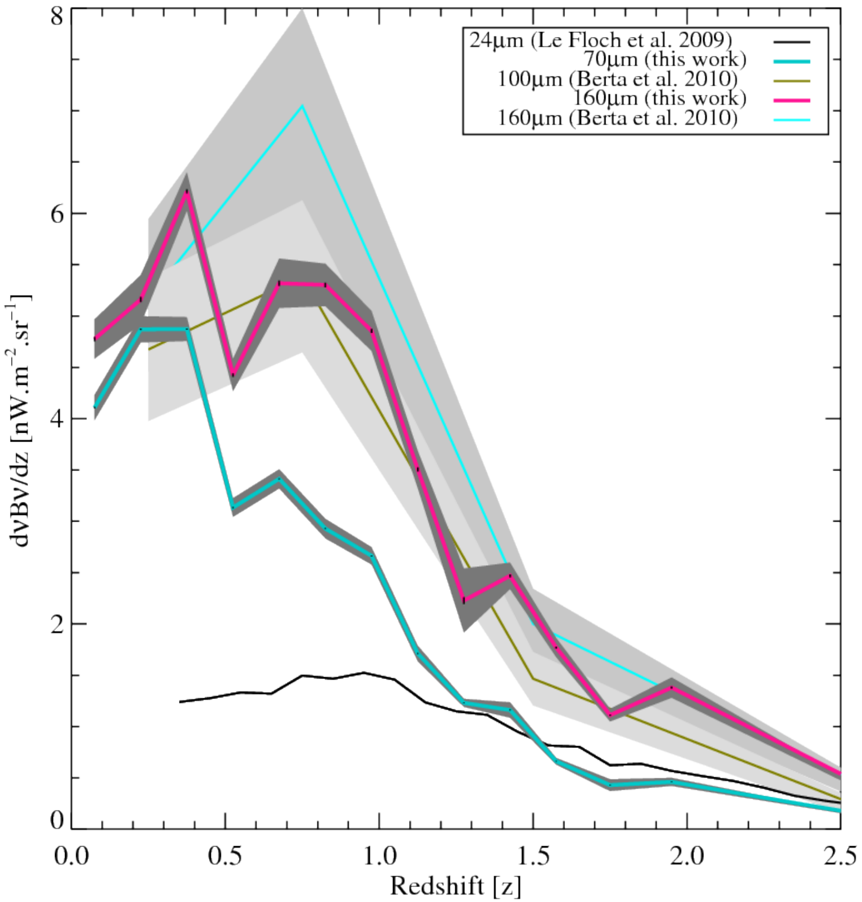
Galliano, dans Lagache, Puget, Dole, 2005, ARAA

contributions to the EBL



Bethermin et al.2012

CIB buildup vs z in the MIR and FIR



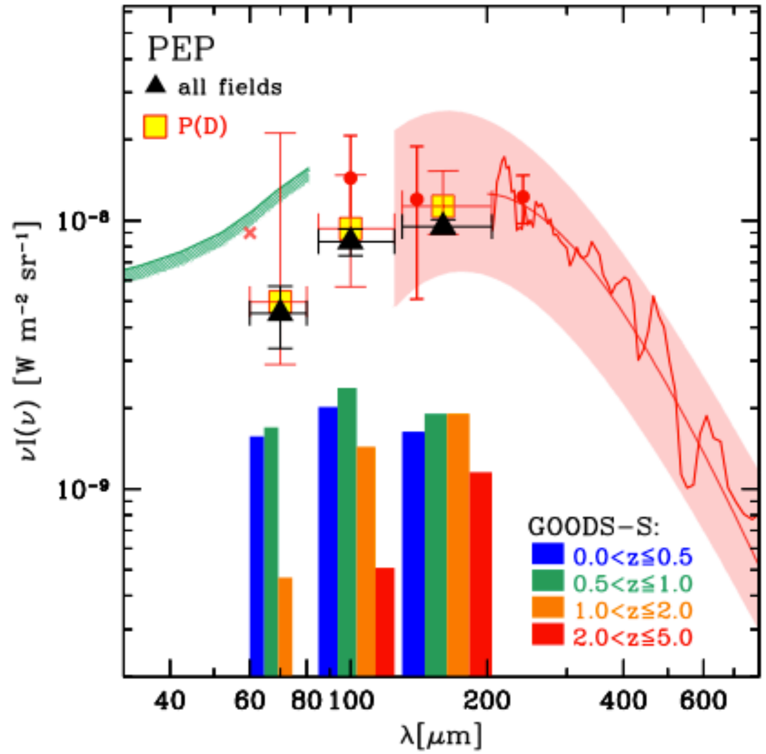
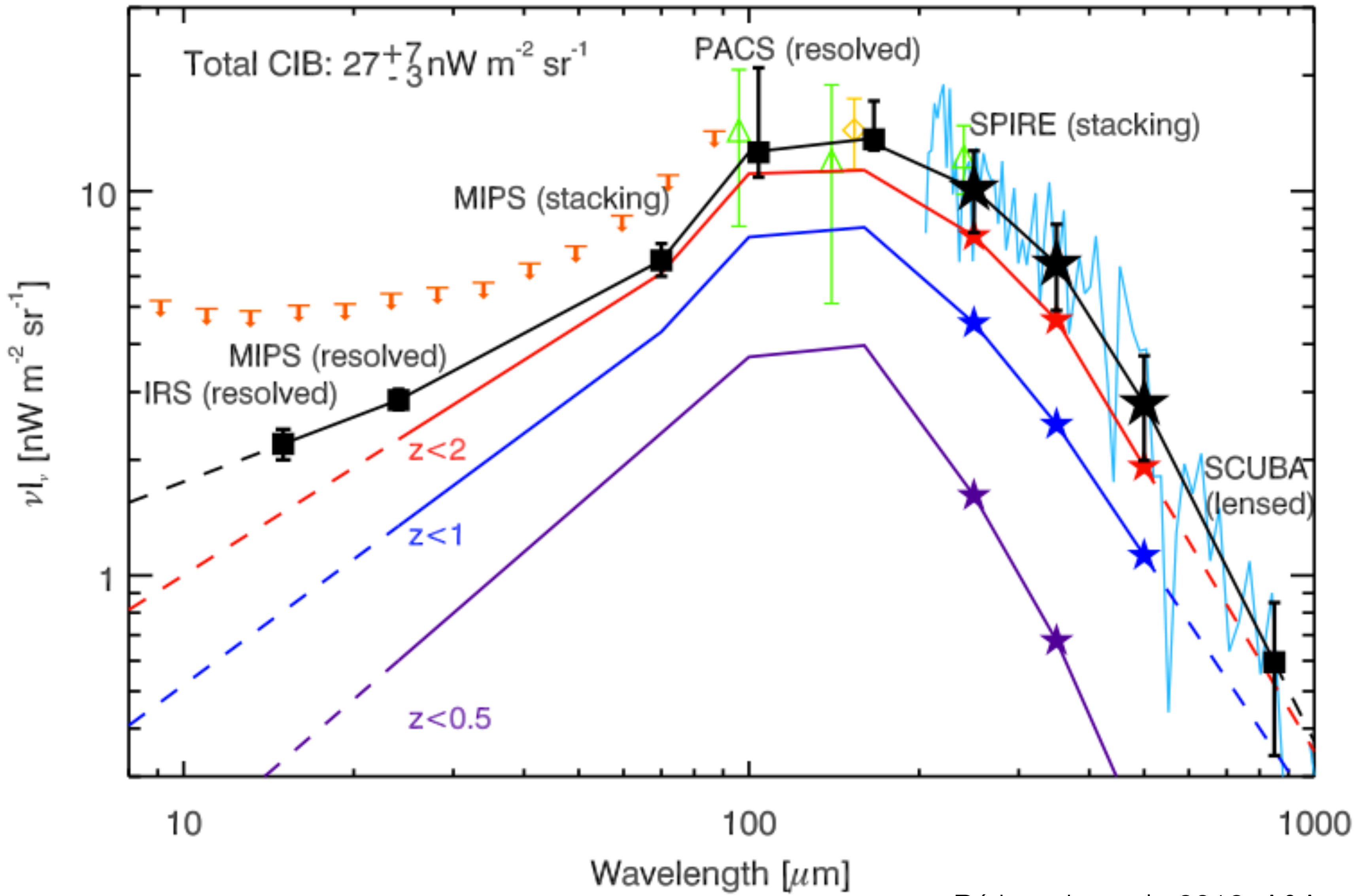


Fig. 13. The cosmic infrared background. Black filled triangles represent the total CIB emitted above the PEP flux limits, based on resolved number counts in GOODS-S, GOODS-N, Lockman Hole and COSMOS, evaluated as described in Sect. 6.2. Yellow squares belong to the *P*(*D*) analysis in GOODS-S. Histograms denote the contribution of different redshift bins to the CIB, over the flux range covered by GOODS-S. Literature data include: DIRBE measurements (filled circles, 1σ errors, Dole et al. 2006), FIRAS spectrum (solid lines above 200 μm, Lagache et al. 1999, 2000), Fixsen et al. (1998) modified Black Body (shaded area), 60 μm IRAS fluctuation analysis (cross, Miville-Deschênes et al. 2002), and γ-ray upper limits (green hatched line below 80 μm Mazin & Raue 2007).

Jauzac et al., 2011, A&A
Le Floc'h et al., 2009

Berta et al., 2011, A&A

CIB buildup vs z in the FIR – submm



Béthermin et al., 2012, A&A

observed n(z) of submm & mm sources

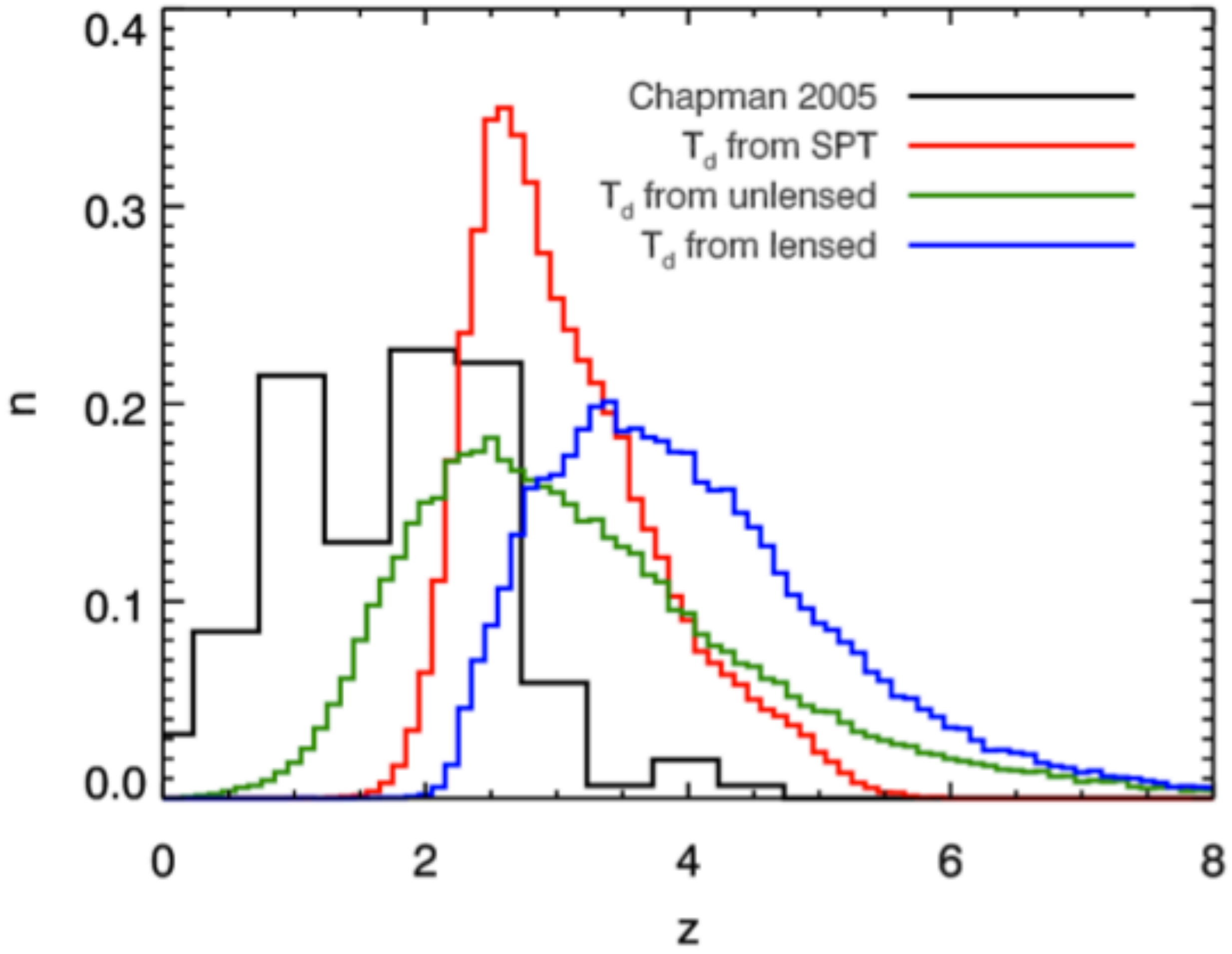
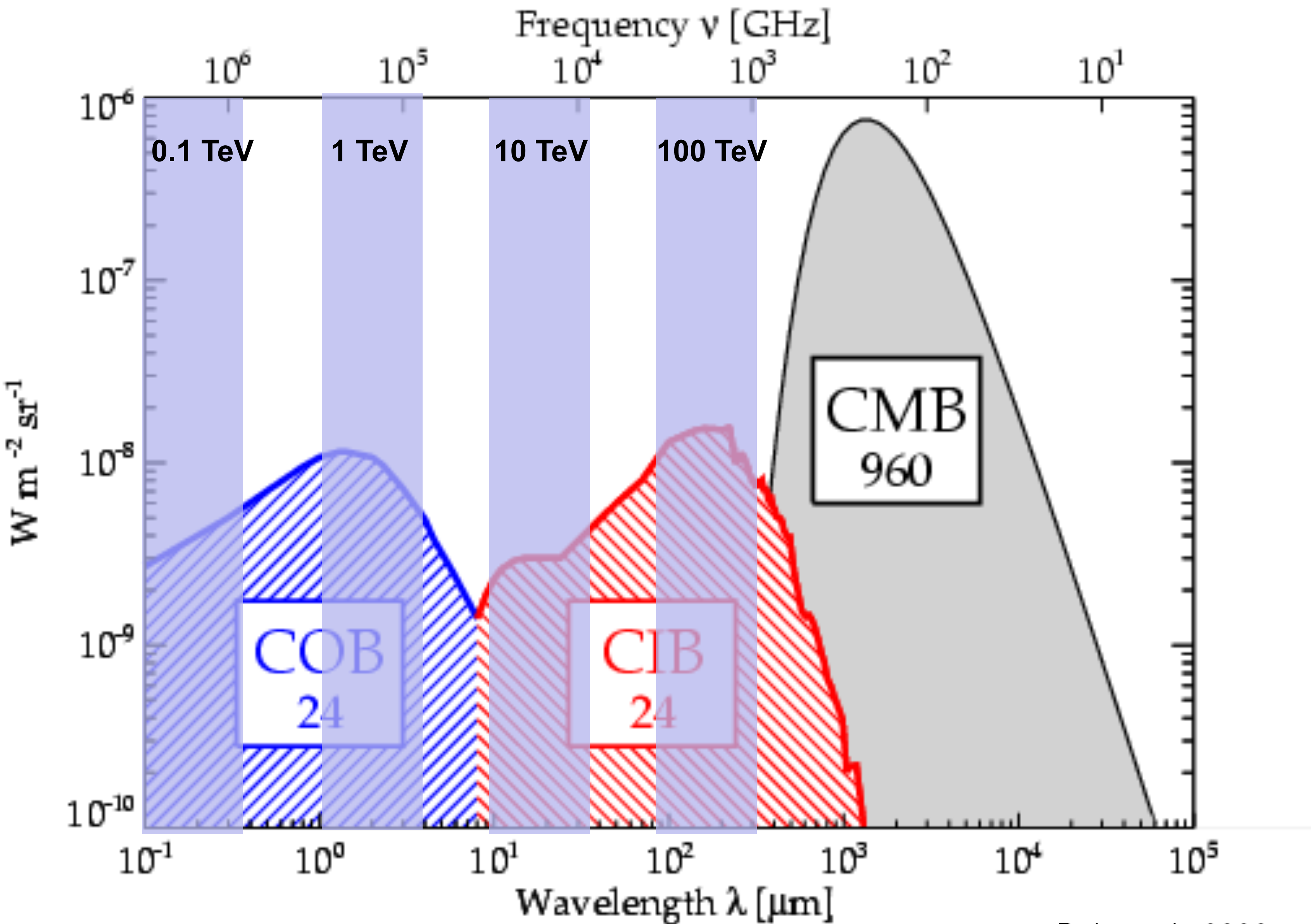


FIG. 6.— A comparison of our estimated redshift distributions of the SPT sources assuming a $T_{\rm d}$ distribution derived from: (red) the two spectroscopically confirmed SPT sources, (blue) all *lensed* high-z sources in the literature with 350 μm detections and spec-

Greve et al, 2012

3.2 implications for TeV opacity



Dole et al., 2006

implications for TeV opacity

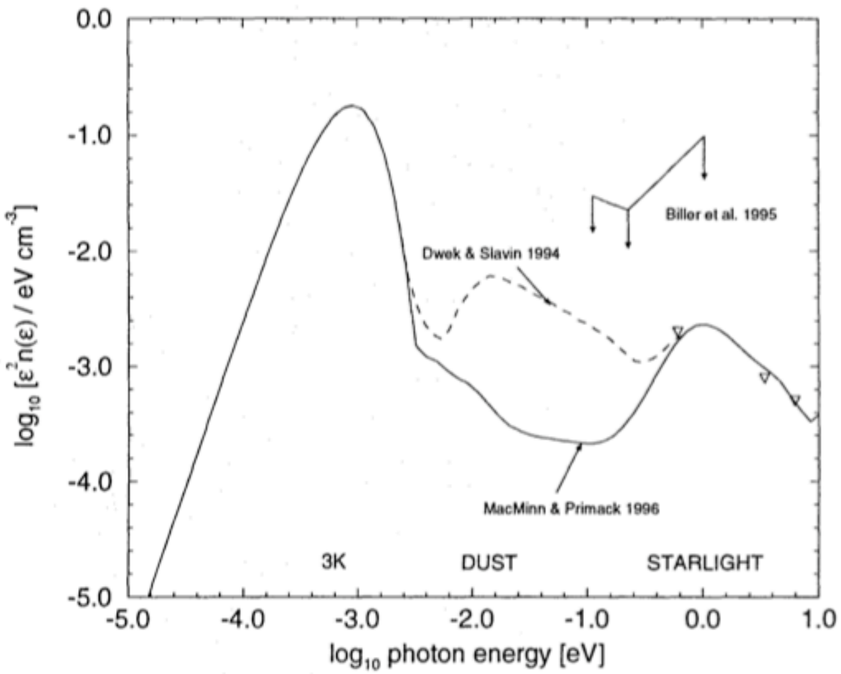


Fig. 2. Solid line: the infrared-to-ultraviolet diffuse background radiation field adopted in the present work. Dashed line: a diffuse background assuming that the γ-ray spectrum of Mrk421 cuts off at TeV due to cosmic absorption. Triangles denote estimates by Madau & Phinney (1996) of the optial-to-ultraviolet diffuse background based on deep galaxy surveys

Different EBL (level and history) create different gamma-ray horizon

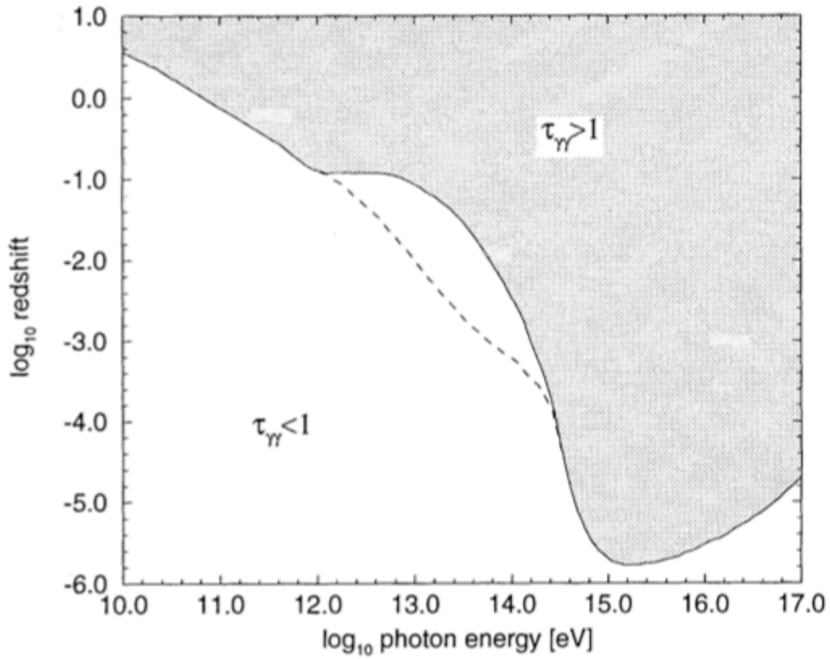
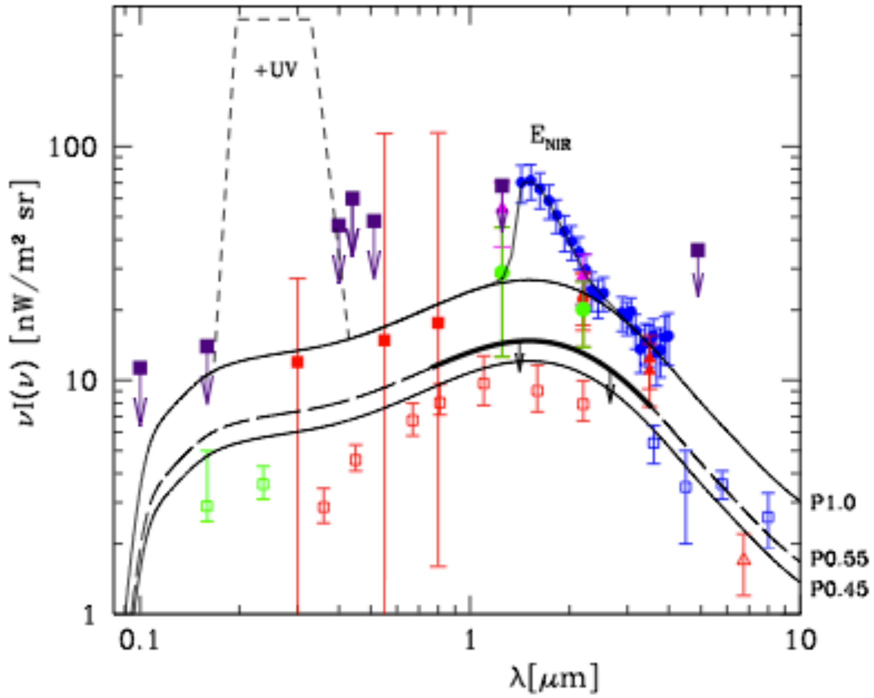
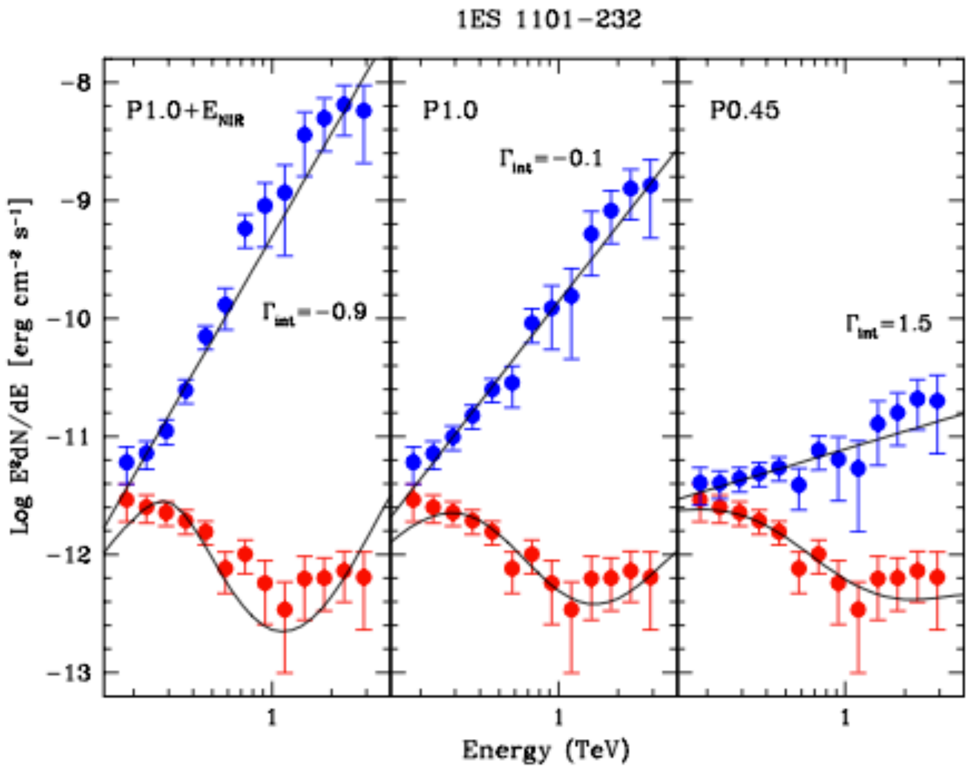


Fig. 1. The γ-ray horizons $\tau_{\gamma\gamma}(E, z) = 1$ corresponding to the two different diffuse background models shown in Fig. 2. The horizons were calculated assuming $\Omega = 1$, $q_o = 0.5$, $H_o = 75$ km s^{-1} Mpc^{-1} and a photon number density evolving with redshift as $n' d\epsilon' = (1 + z)^3 n d\epsilon$ (conserved number of photons)

Mannheim et al., 1996

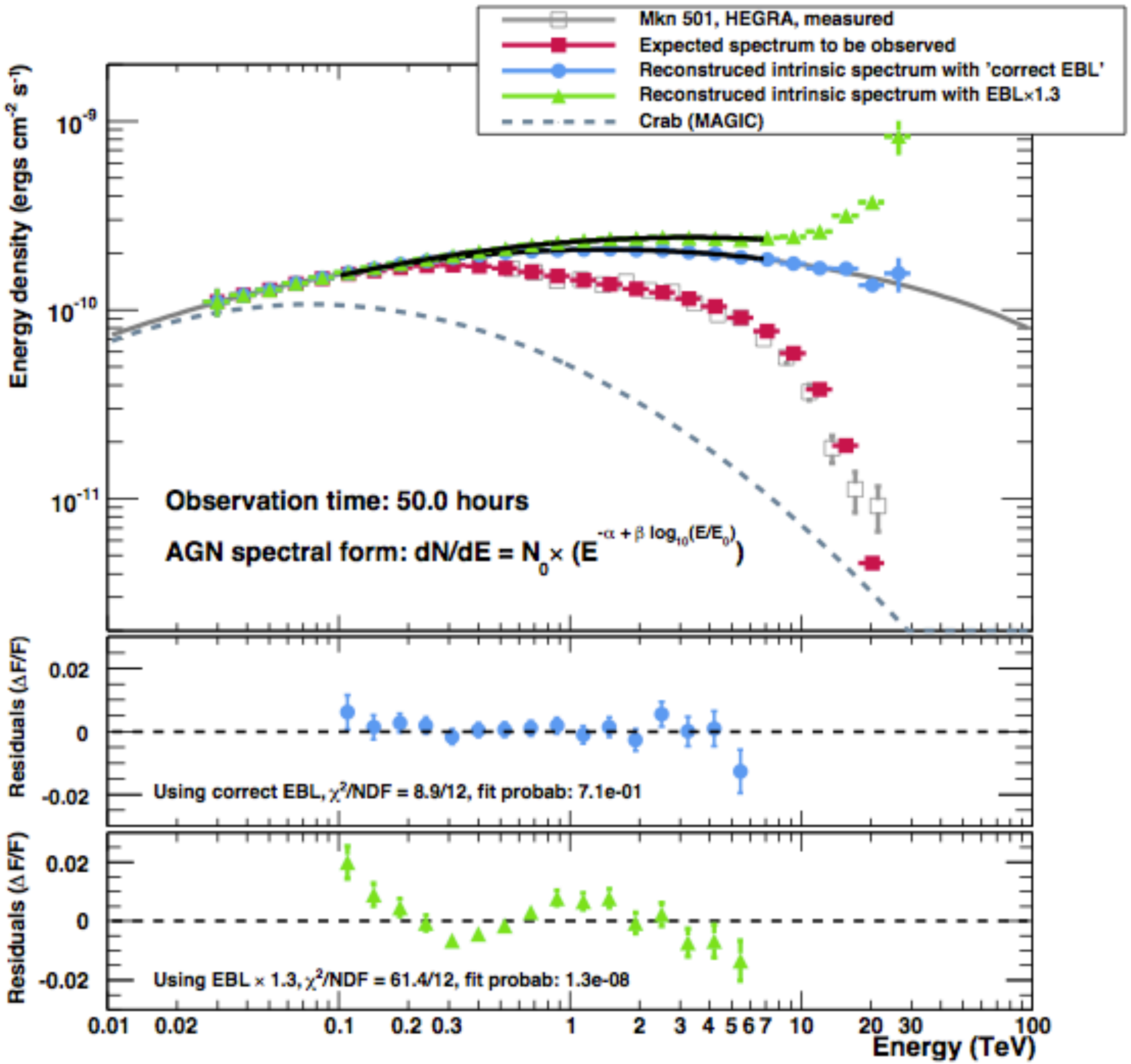
EBL or blazar spectra ?





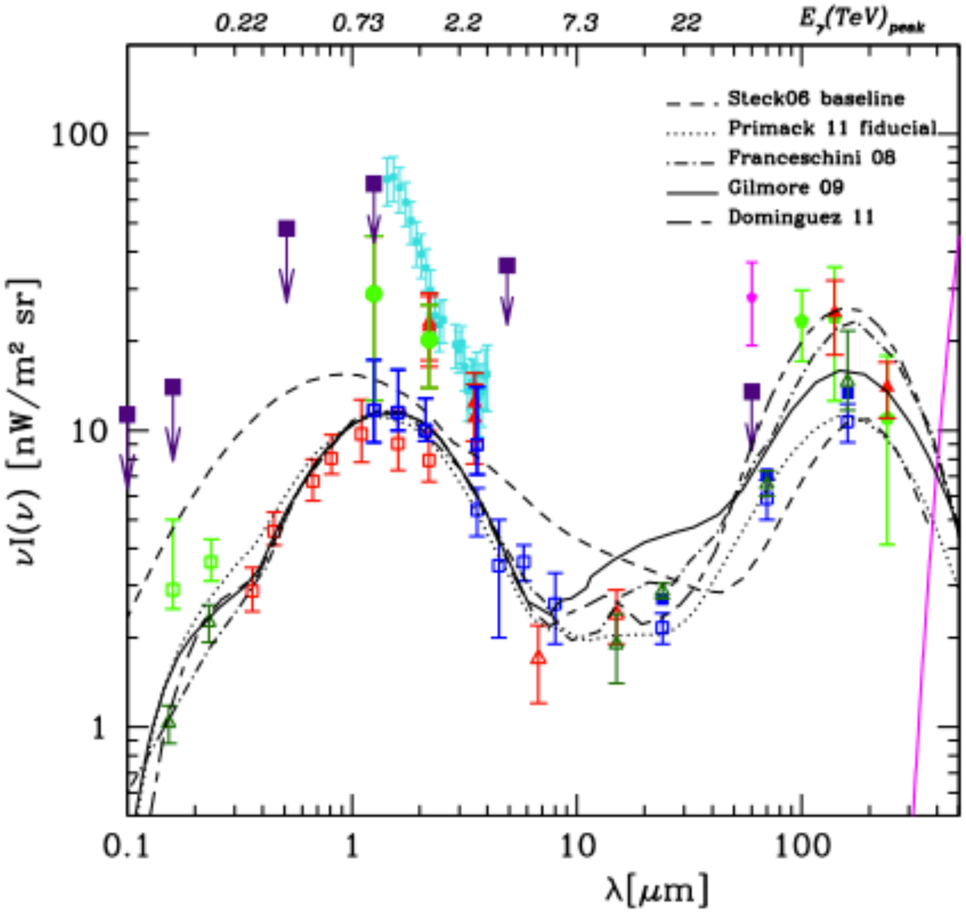
HESS collab, 2006
Costamante 2013

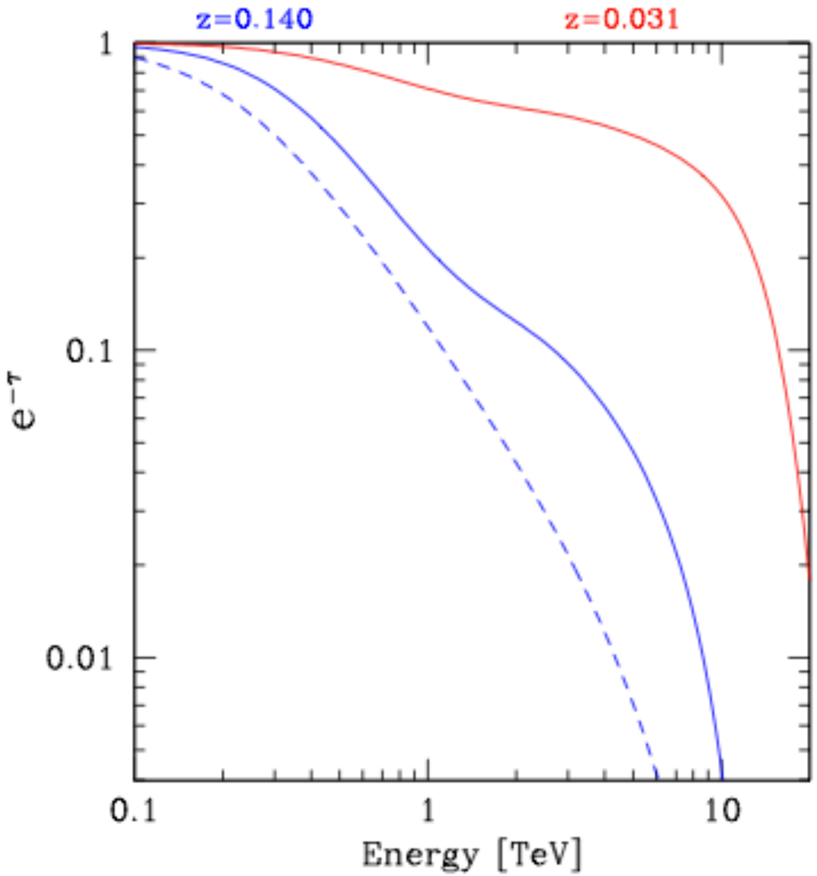
blazar spectra



Mazin 2013

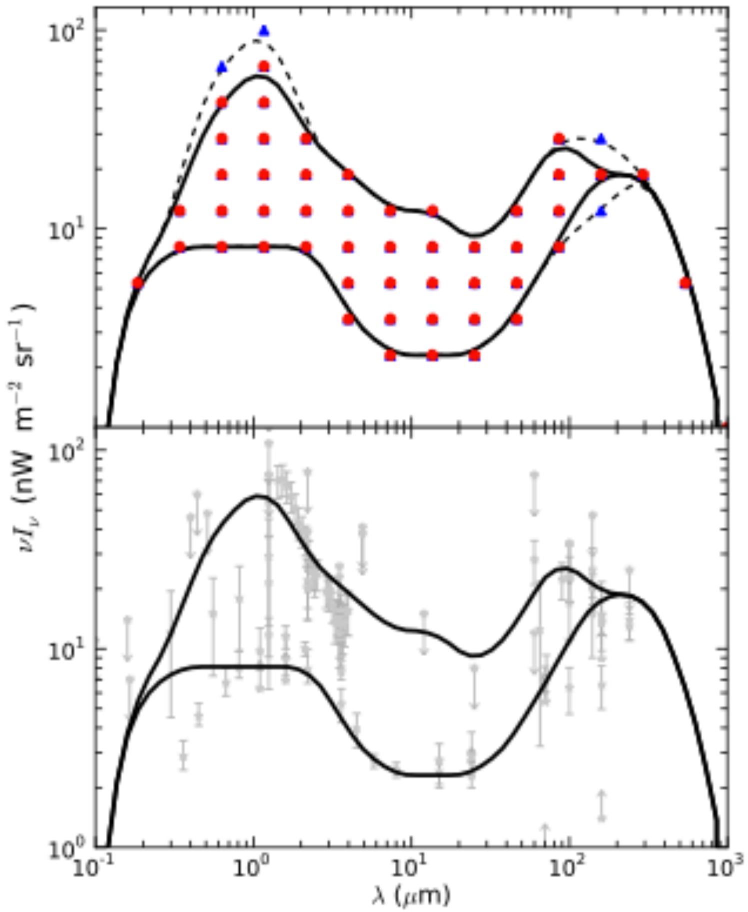
3.3 CIB/EBL models

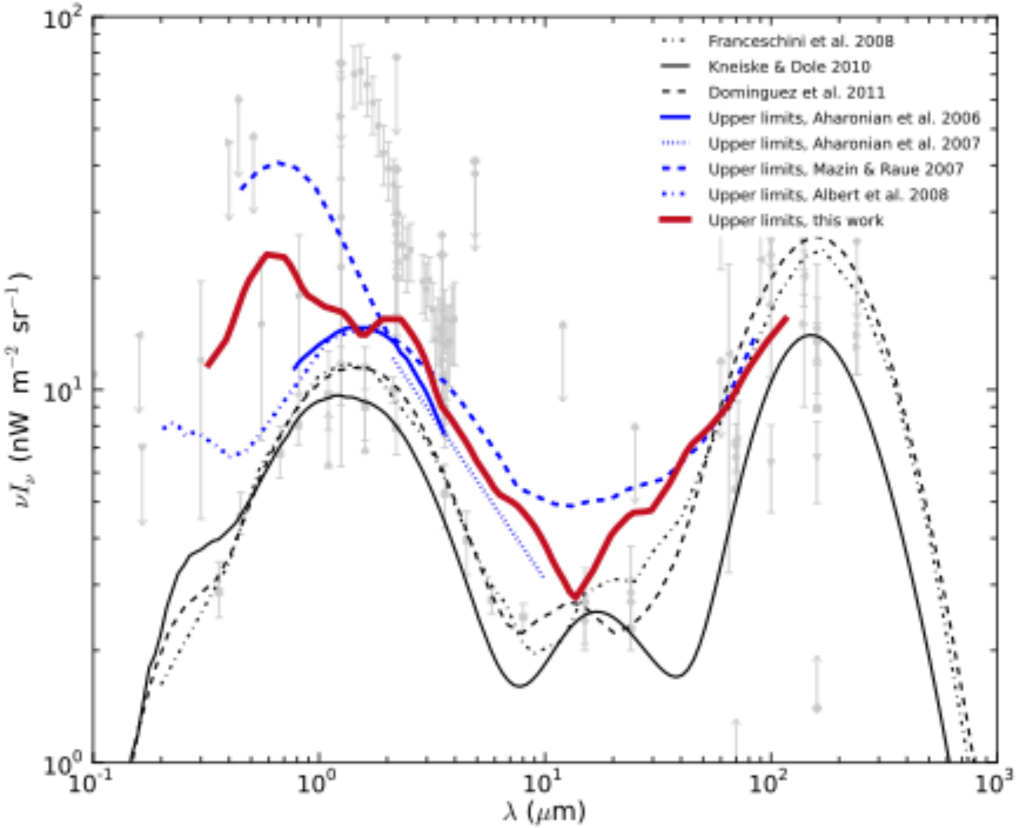




review by Costamante 2013

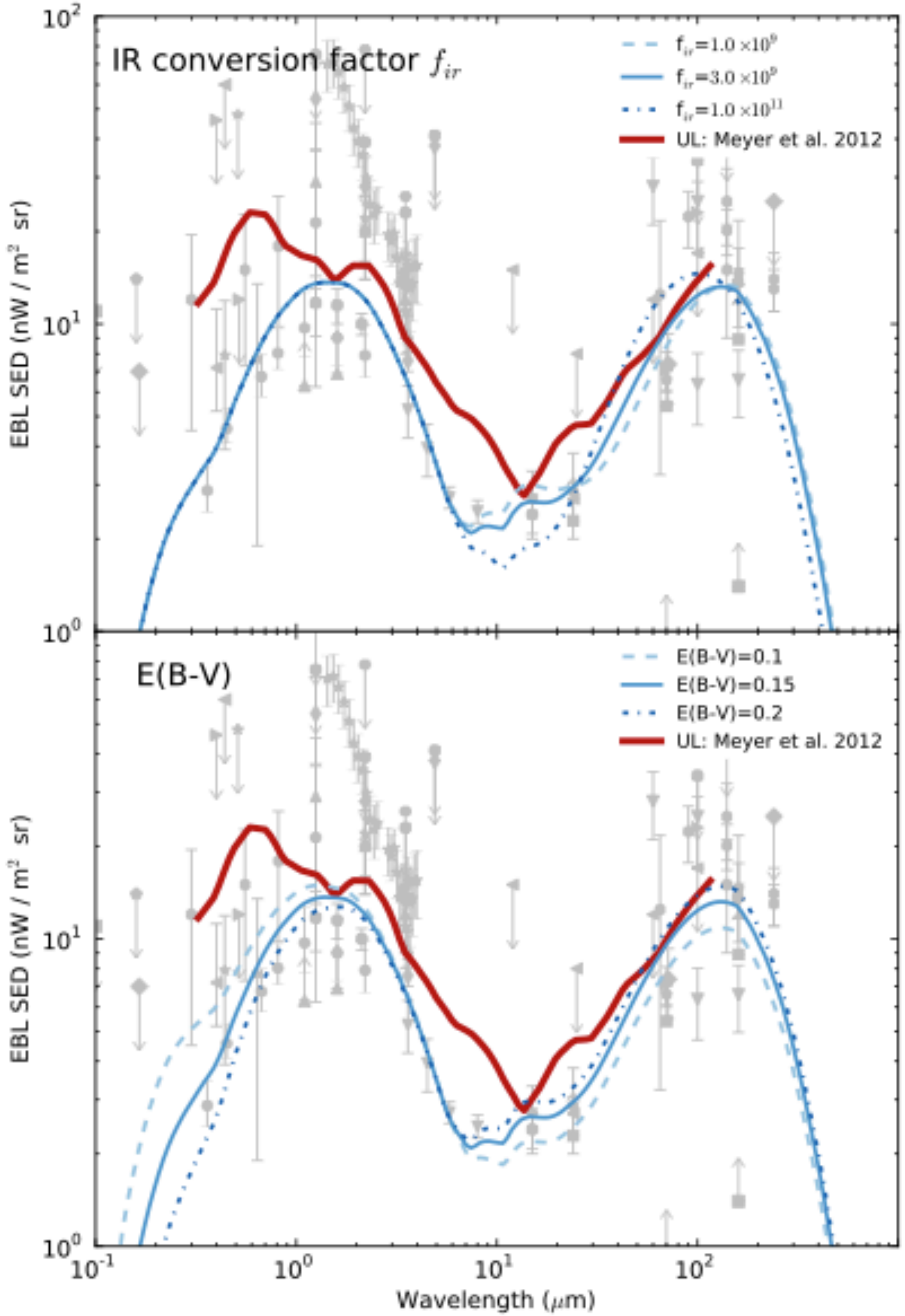
many models





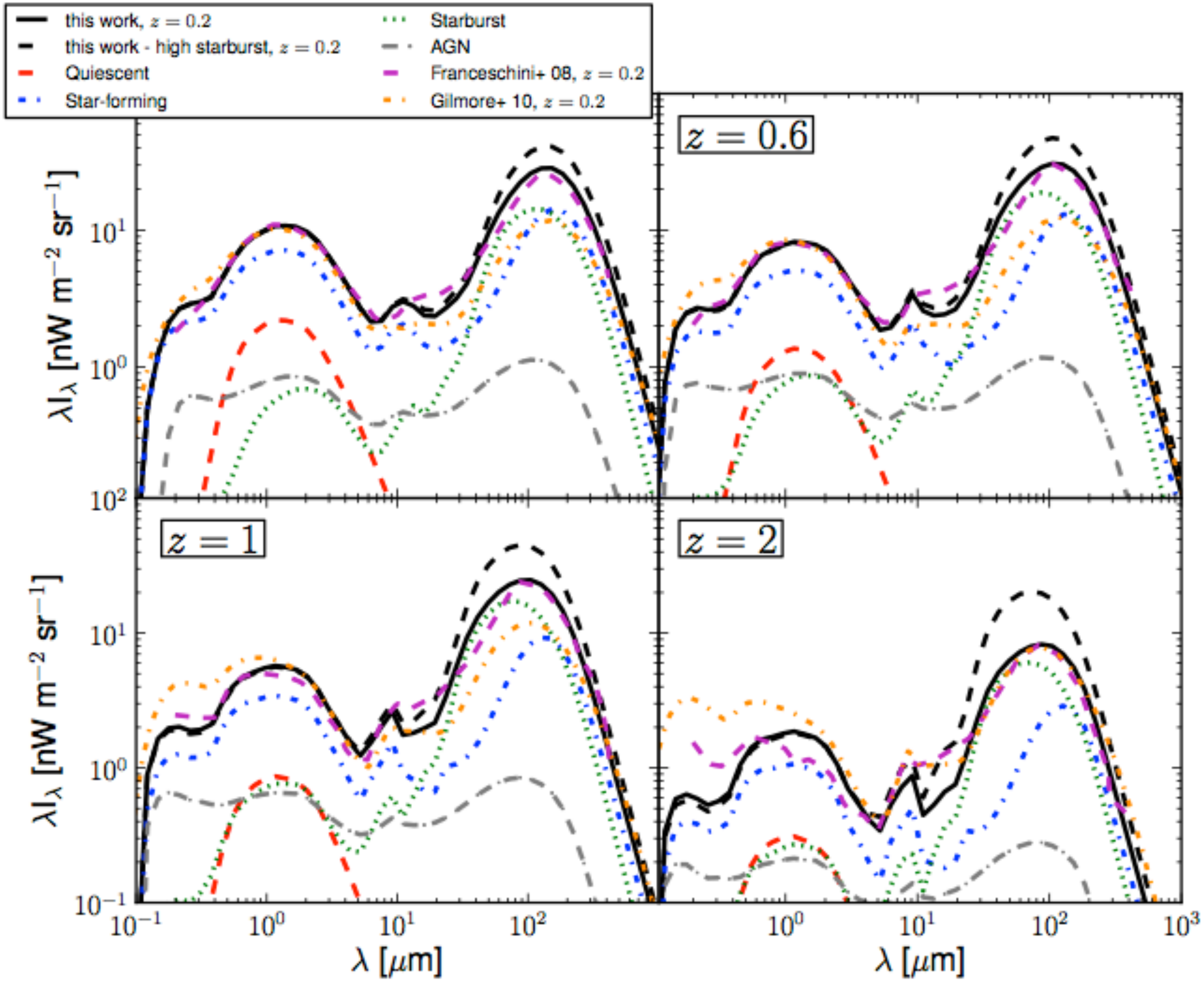
Stecker ; Franceschini; Kneiske & Dole; Raue ; Mazin; Mayer; etc..

various approaches



Raue & Meyer, 2012

EBL model and build-up



Dominguez + 2010

transparency at high energy

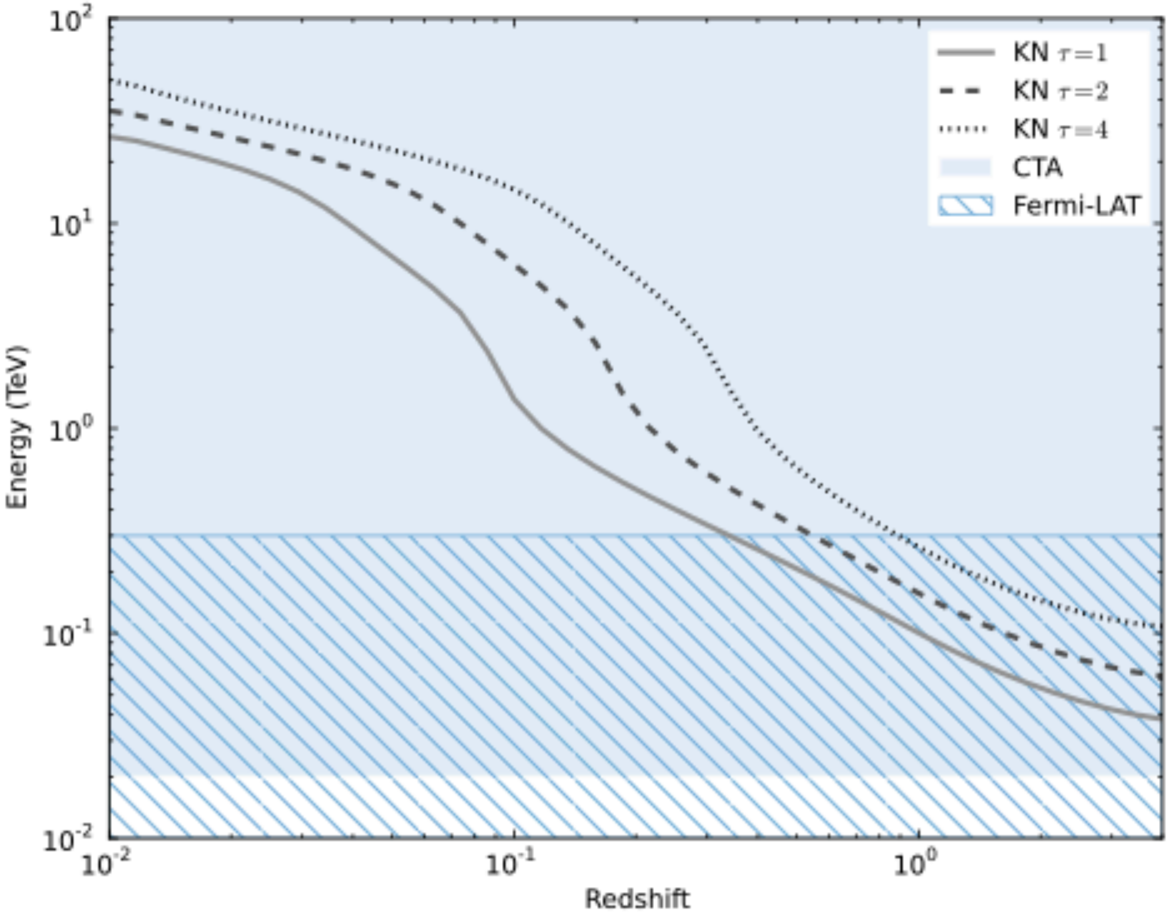
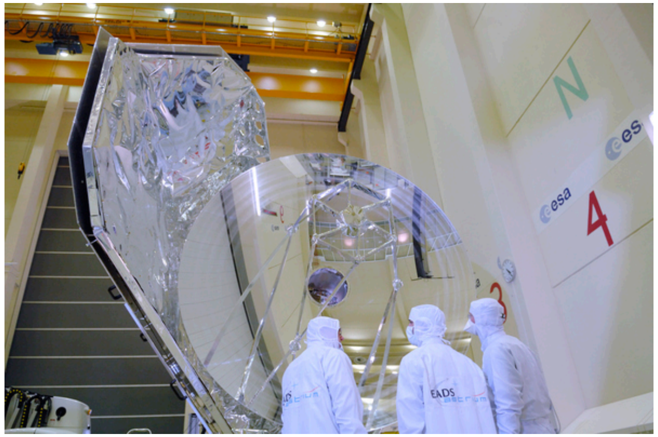
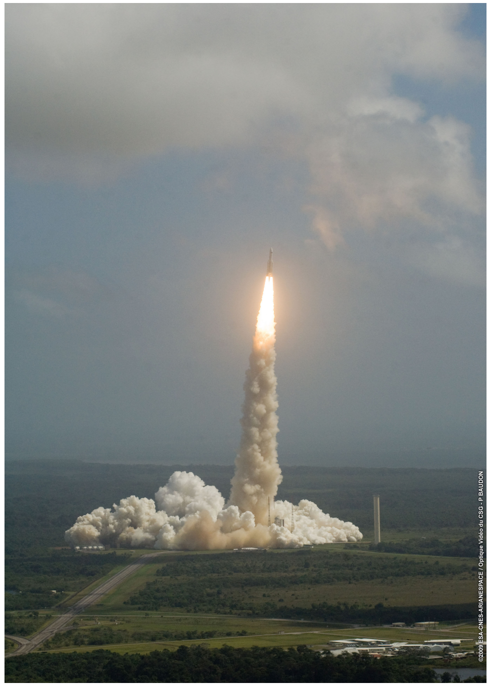


Figure 3: Energy at which an optical depth of τ =1, 2, and 4 is reached vs. redshift for the EBL model from [29] (KN, minimal EBL). Also shown are approximate energy ranges of CTA (20 GeV-100 TeV; shaded) and *Fermi*-LAT (100 MeV-300 GeV; hatched).

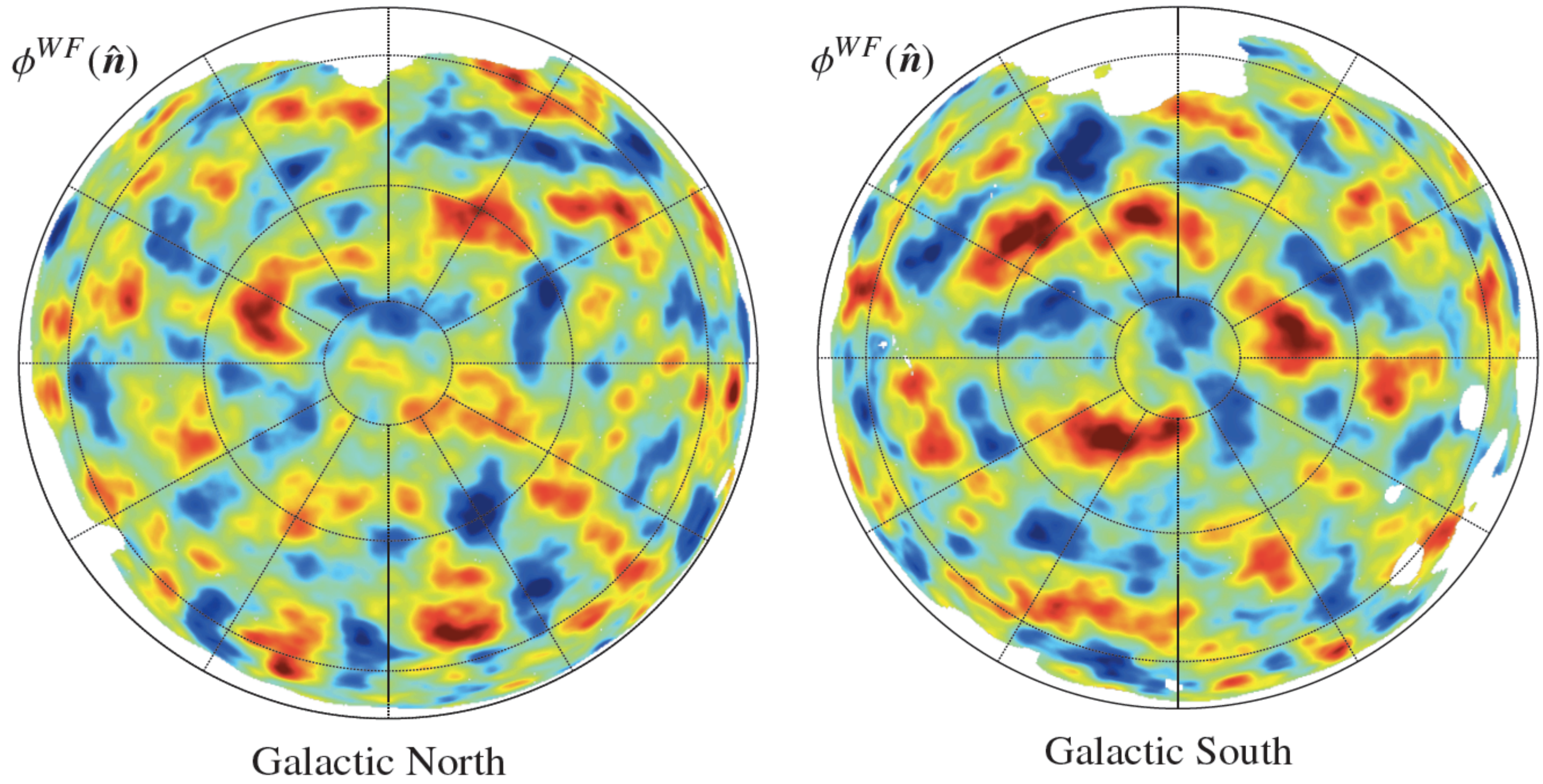
Kneiske & Dole, 2010
Mazin 2013

3.4 the Planck et Herschel era:
CIB as a new probe for large scale structure





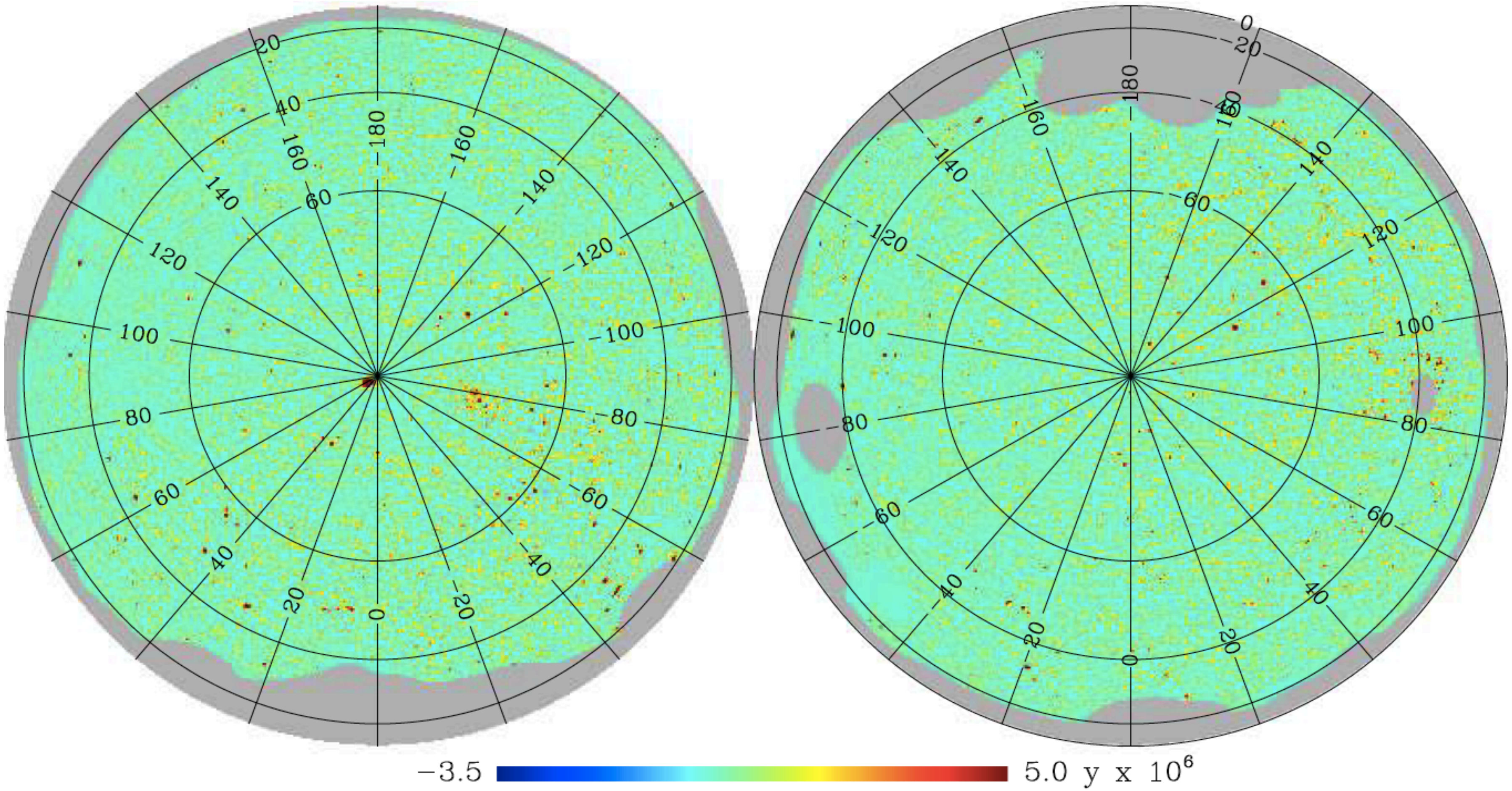
Planck all-sky map of the dark matter



Planck 15 months
Planck Collaboration, 2013, 17

Planck map of the baryon distribution

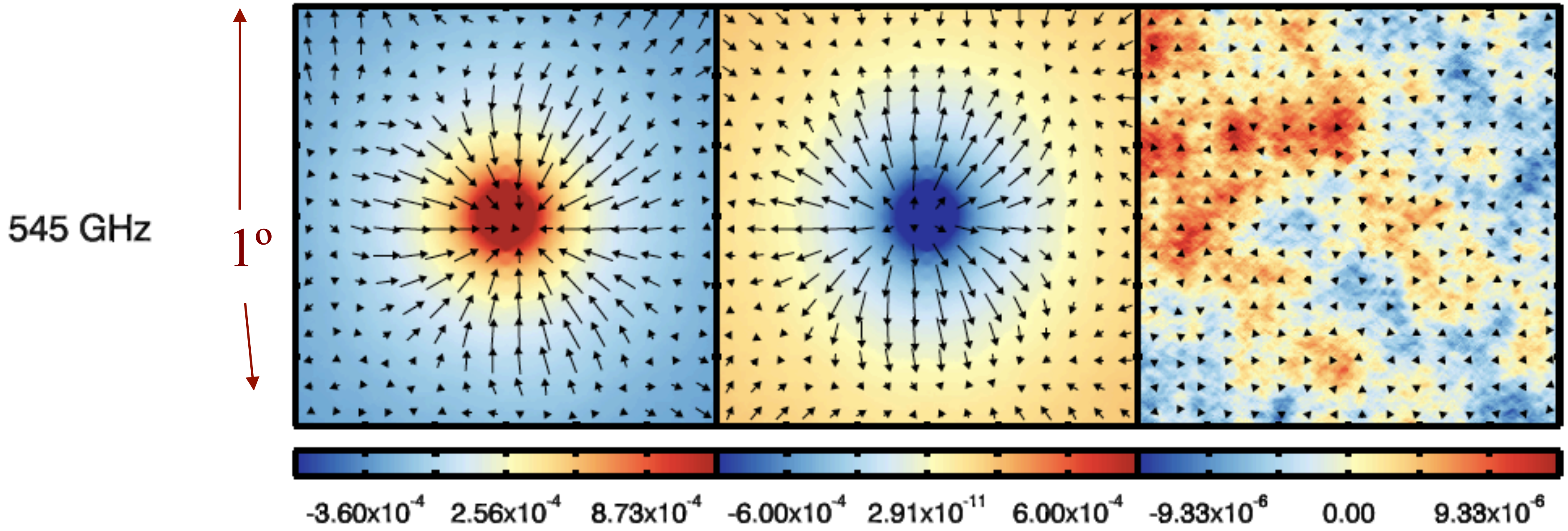
Planck can also image the gas (baryon) distribution in the low-redshift Universe using scattering of CMB photons off the electrons. This SZ (Sunyaev-Zeldovich) effect causes a change in the shape of the CMB spectrum



Planck 15 months
Planck Collaboration, 2013, 21

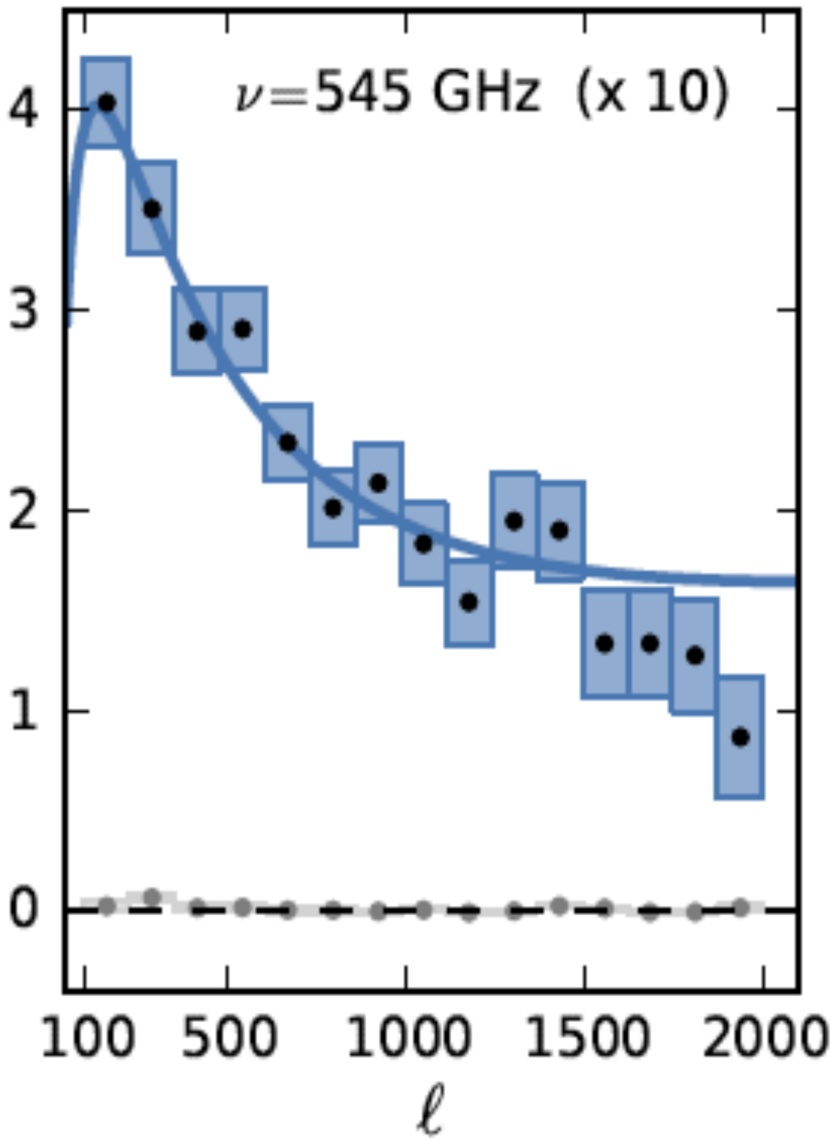
CIB peaks correspond to mass peaks

Stacking the Planck mass maps at the positions of peaks and troughs of Cosmic Infrared Background leads to a strong detection of the mass associated with these distant star forming galaxies. This is mostly Dark Matter.



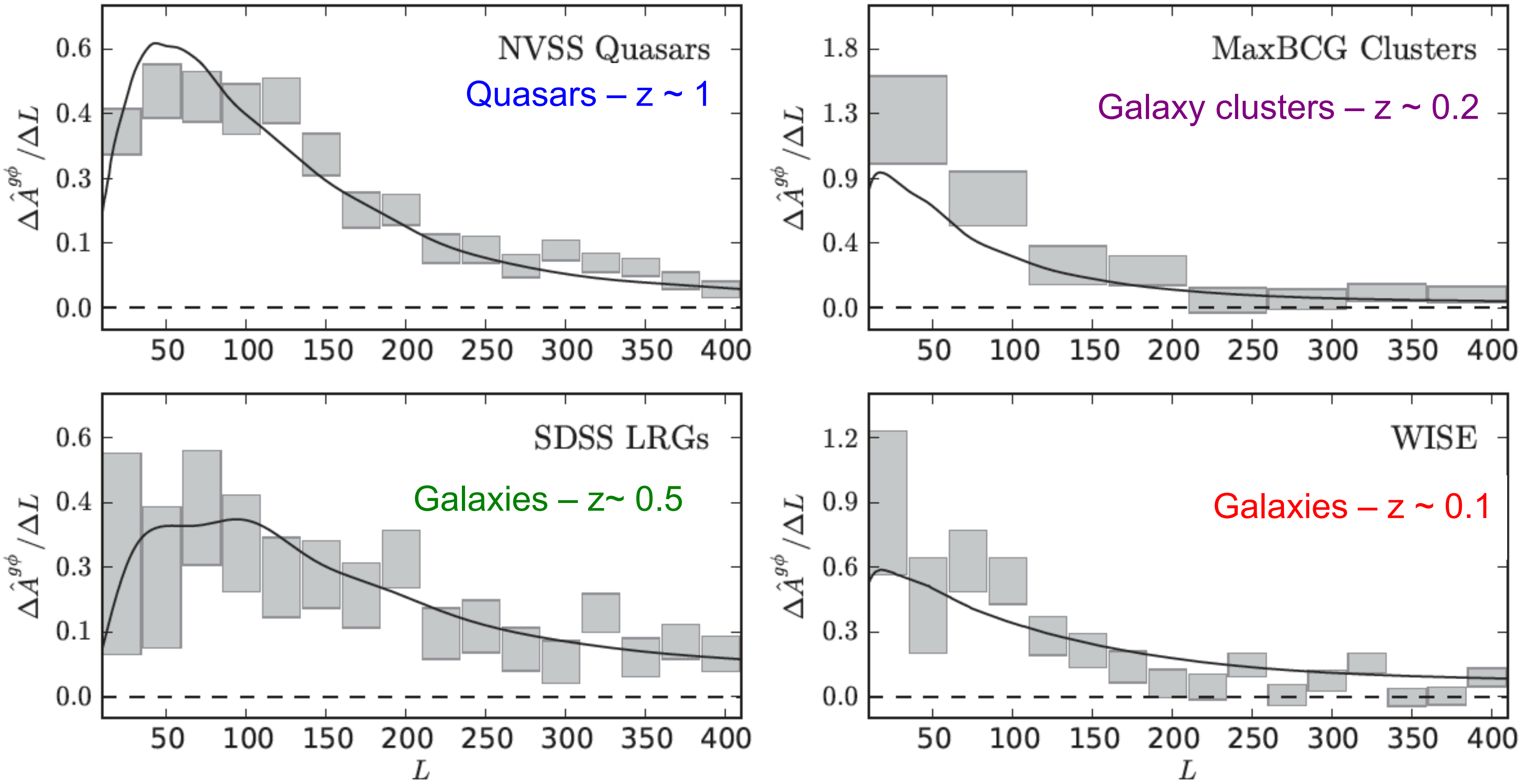
Planck 15 months
Planck Collaboration, 2013, 18

mass and CIB maps correspond closely



Planck 15 months
Planck Collaboration, 2013, 18

galaxies mirror the Planck mass map



Planck 15 months
Planck Collaboration, 2013, 17, 19

SPT & Herschel do the same

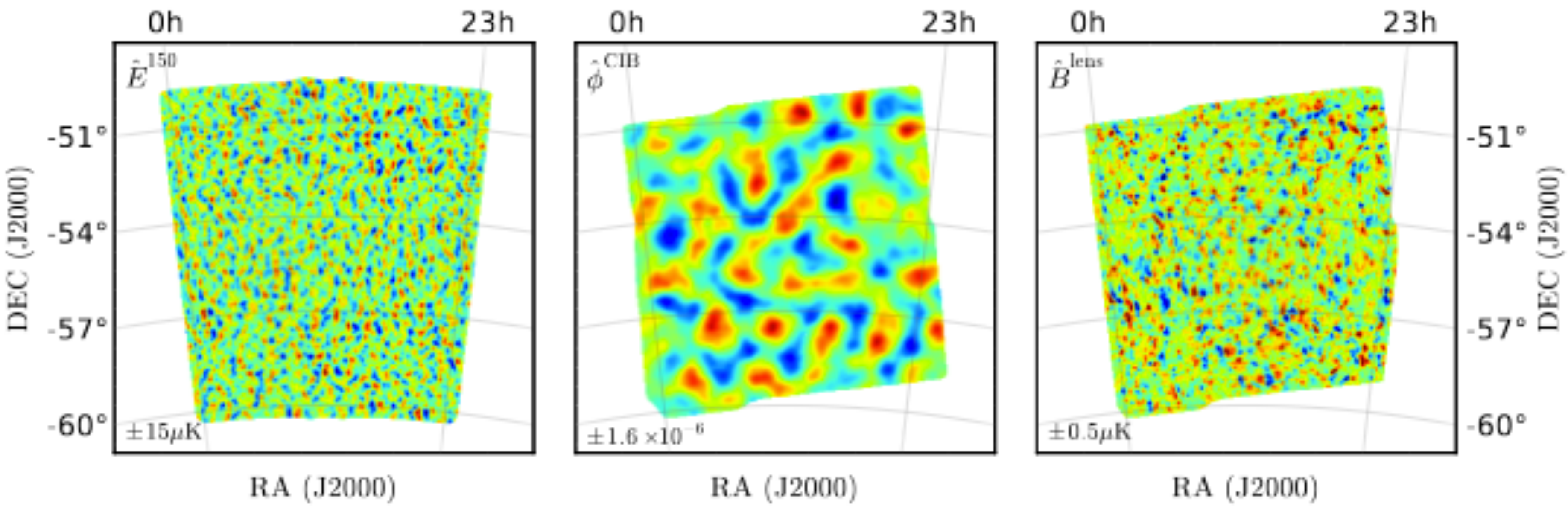


FIG. 1: (Left panel): Wiener-filtered E-mode polarization measured by SPTpol at 150 GHz. (Center panel): Wiener-filtered CMB lensing potential inferred from CIB fluctuations measured by *Herschel* at 500 μm. (Right panel): Gravitational lensing B-mode estimate synthesized using Eq. (1). The lower left corner of each panel indicates the blue(-)/red(+) color scale.

Hanson et al., 2013 arXiv

EBL as a nasty foreground for cosmology

is the Poisson term well contrained ?

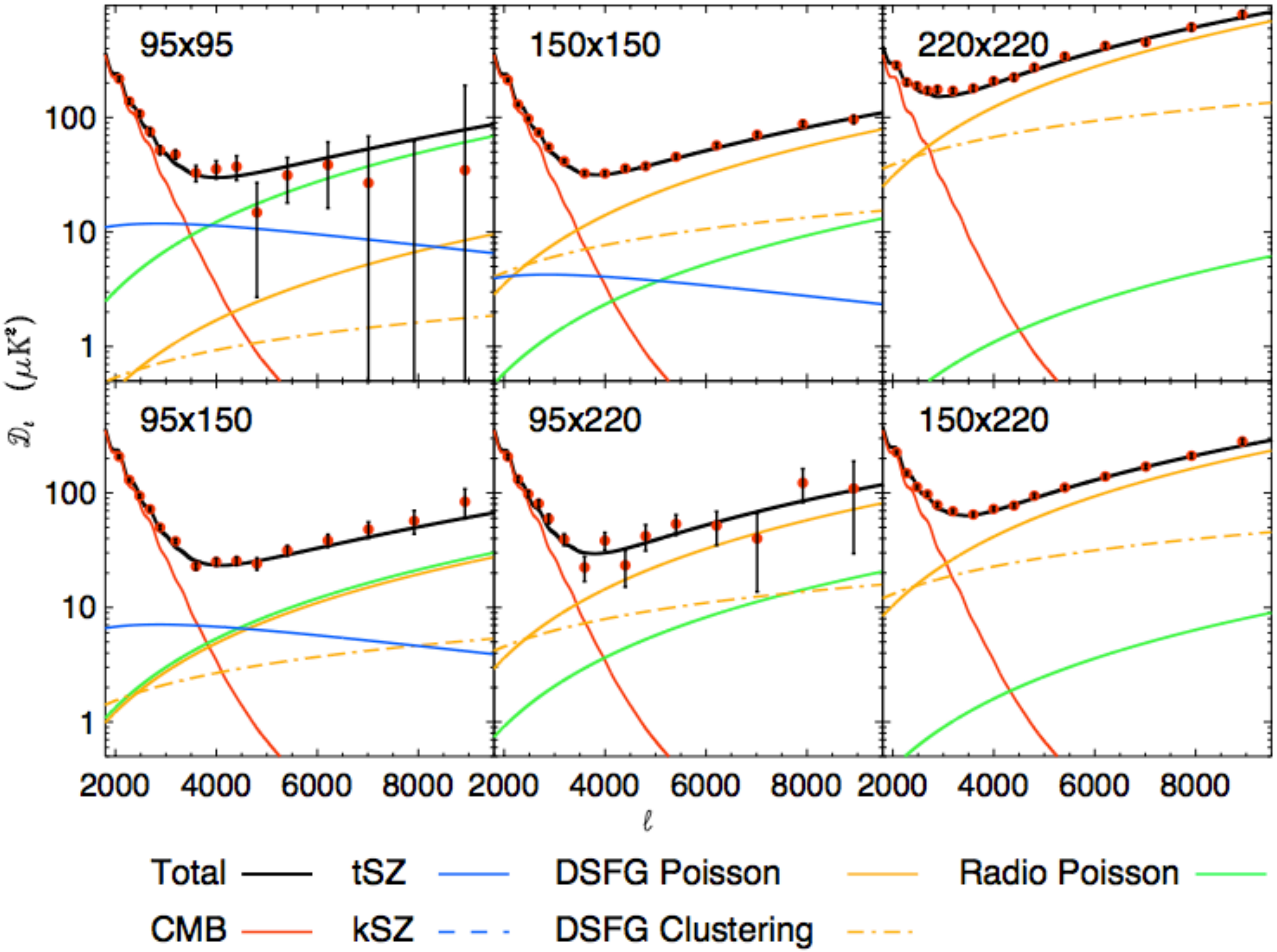
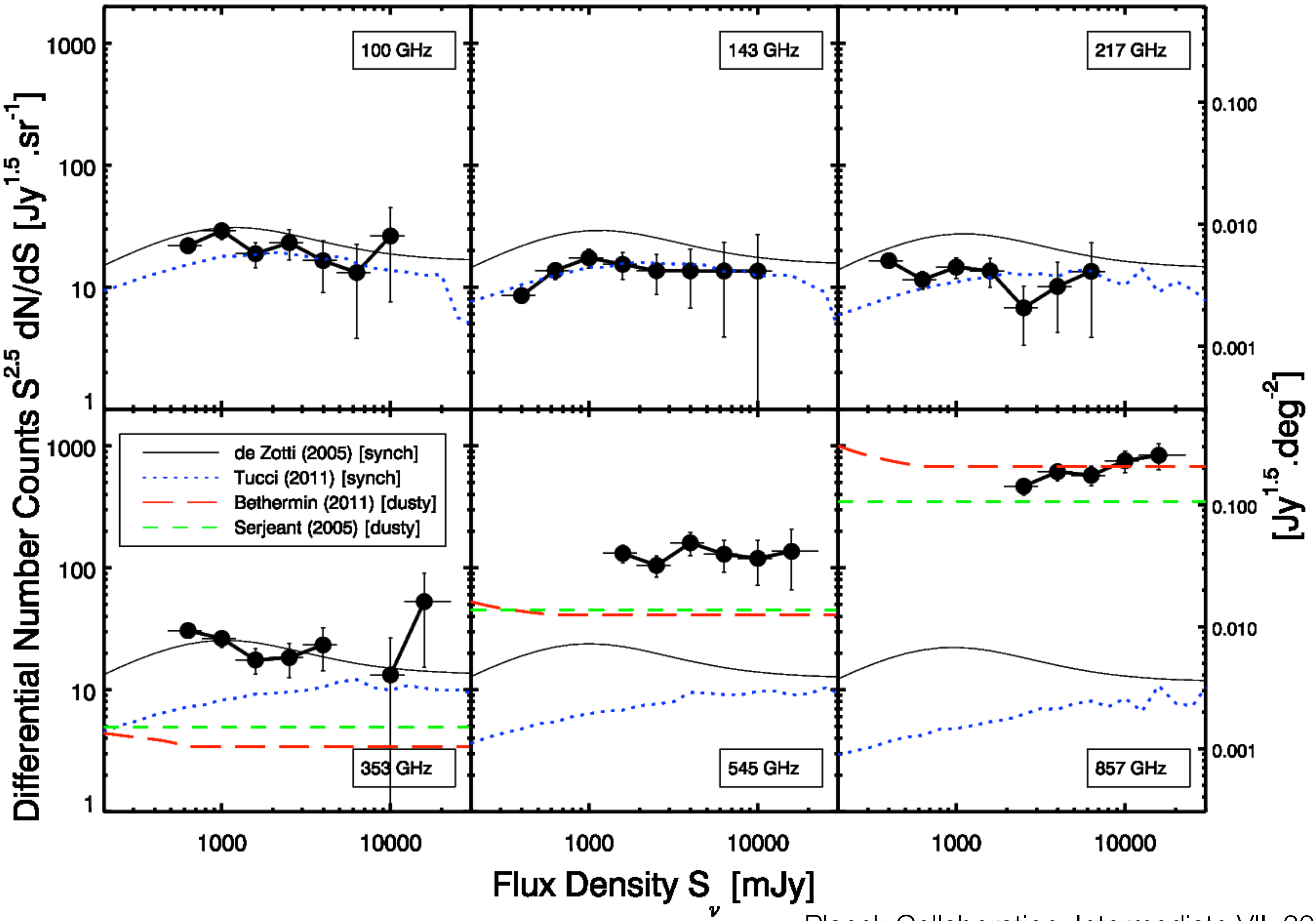


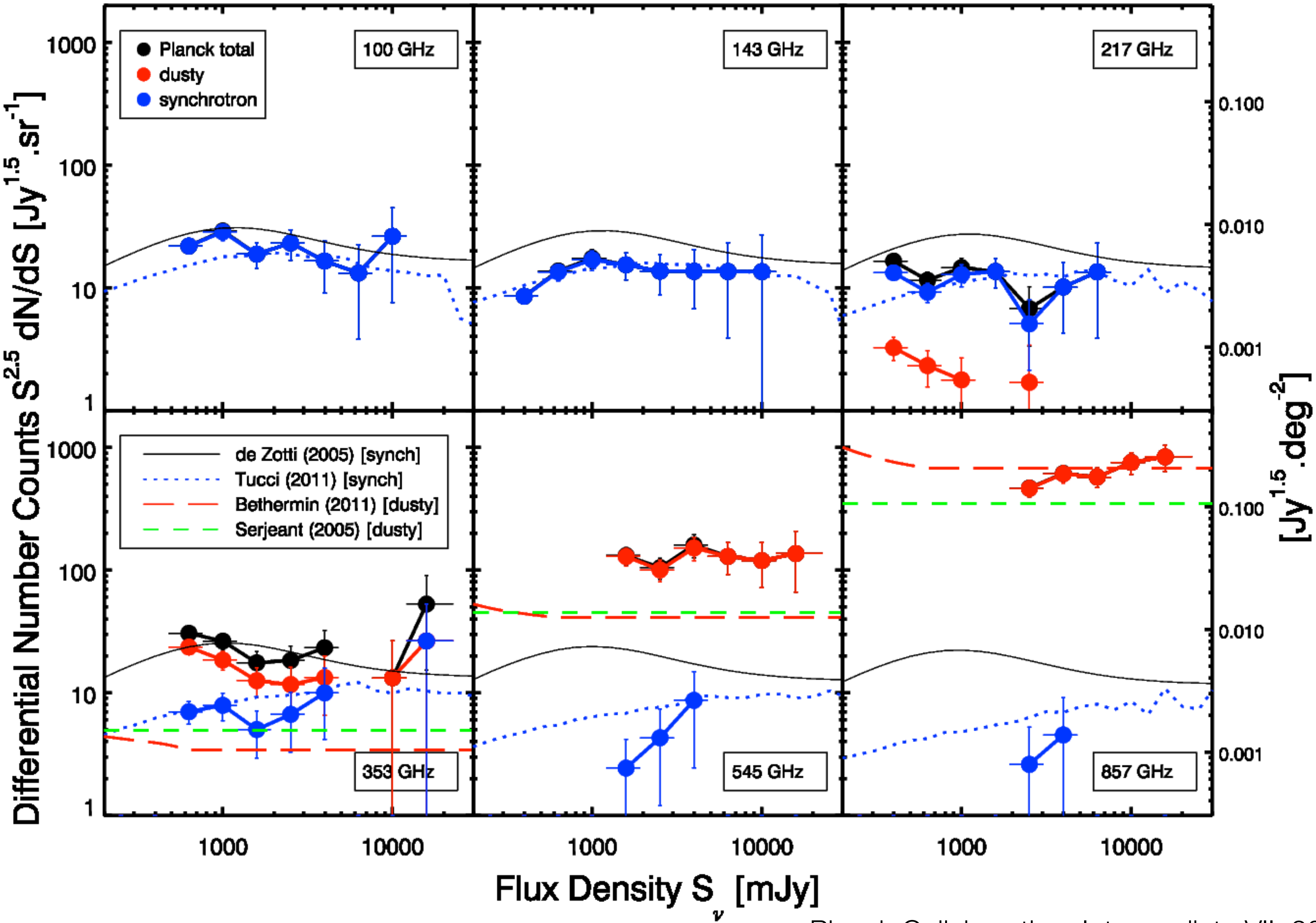
FIG. 3.— The six auto- and cross-spectra measured with the 3-frequency SPT data. Overplotted on the bandpowers is the best-fit model for the fiducial set of model parameters. Note that the bandpowers have not been corrected by the best-fit calibration or beam uncertainties in the MCMC chains. In addition to the complete model (**black lines**), each individual model component is shown. The tSZ effect is marked with the **blue solid line**. The best-fit kSZ power is near-zero and off-scale. The Poisson power from DSFGs and radio galaxies are shown by **solid orange and green lines** respectively. The clustered component to the DSFGs is shown with a **orange dot-dash line**.

number counts 100 – 857 GHz



Planck Collaboration, Intermediate VII, 2013

number counts 100 – 857 GHz



Planck Collaboration, Intermediate VII, 2013

other topics linking EBL and LSS

- clusters and CIB, via e.g. SZ and CIB Xcorrelation
- ISW using CIB

- more on the galaxy population side
  - Xcorrelation of CIB and XRB or γRB ?
  - contribution of e.g. star-forming galaxies to the XRB et γRB

conclusion: what tells us the EBL [1]

- encodes the output of galaxy formation evolution
- is now well measured over >20 orders of magnitude
  - FIR/submm now well measured – Spitzer & Herschel
- gives the energy budget (photons) for galaxy formation and evolution; useful to:
  - constrain the models
  - quantify the relative contributions of nucleosynthesis vs accretion
- gives a degenerate information

- need for more output energy in the infrared at higher z
  - testimony of the central role of LIRG (Luminous IR galaxies)
- tells us about the opacity to TeV photons

conclusion: what tells us the EBL [2]

- beyond the EBL intensity: its angular structure: extragalactic background fluctuations
  - tell us about the emitting sources

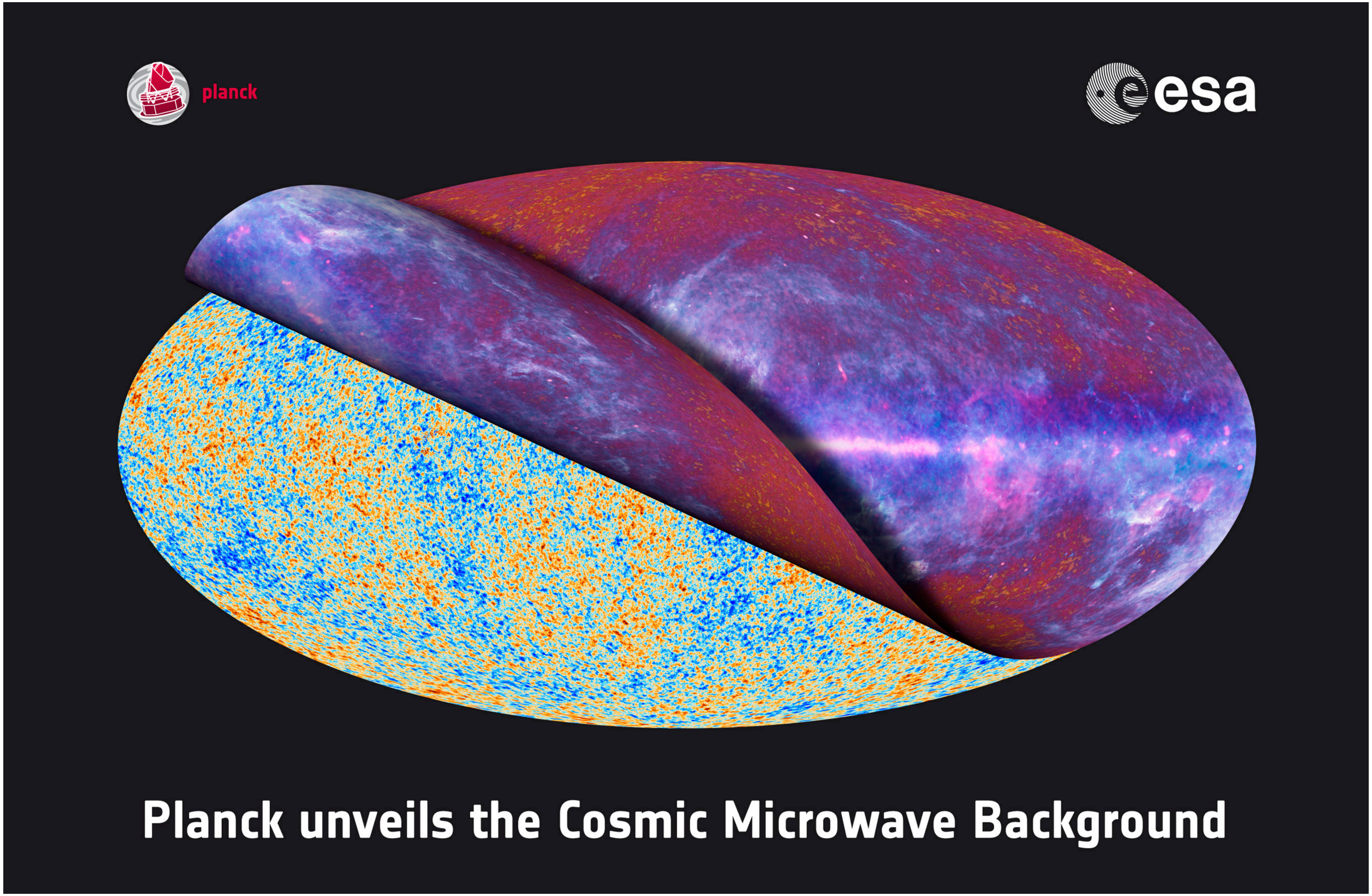
- in the far-infrared (> 70um)
  - CIB not completely resolved in galaxies
  - fluctuations probe the galaxies populations making-up the bulk of the background
  - breaktrough w/ Planck & Herschel

- in the near- and mid-infrared (<30um)
  - CIB almost resolved into galaxies
  - fluctuations also probe the faintest populations:
    - popIII ? zodi ou cirrus ? very high-z galaxies ? faint low-z galaxies ? sources at EoR ? early black holes ?

many prospects

- EBL as a tracor of large scale structure
- physics of galaxies & blazars
- link between frequencies using cross-correlations
  - e.g. IR vs X or IR vx gamma
  - for galaxy population studies (e.g. SF vs AGN)

end


planck
esa
Planck unveils the Cosmic Microwave Background