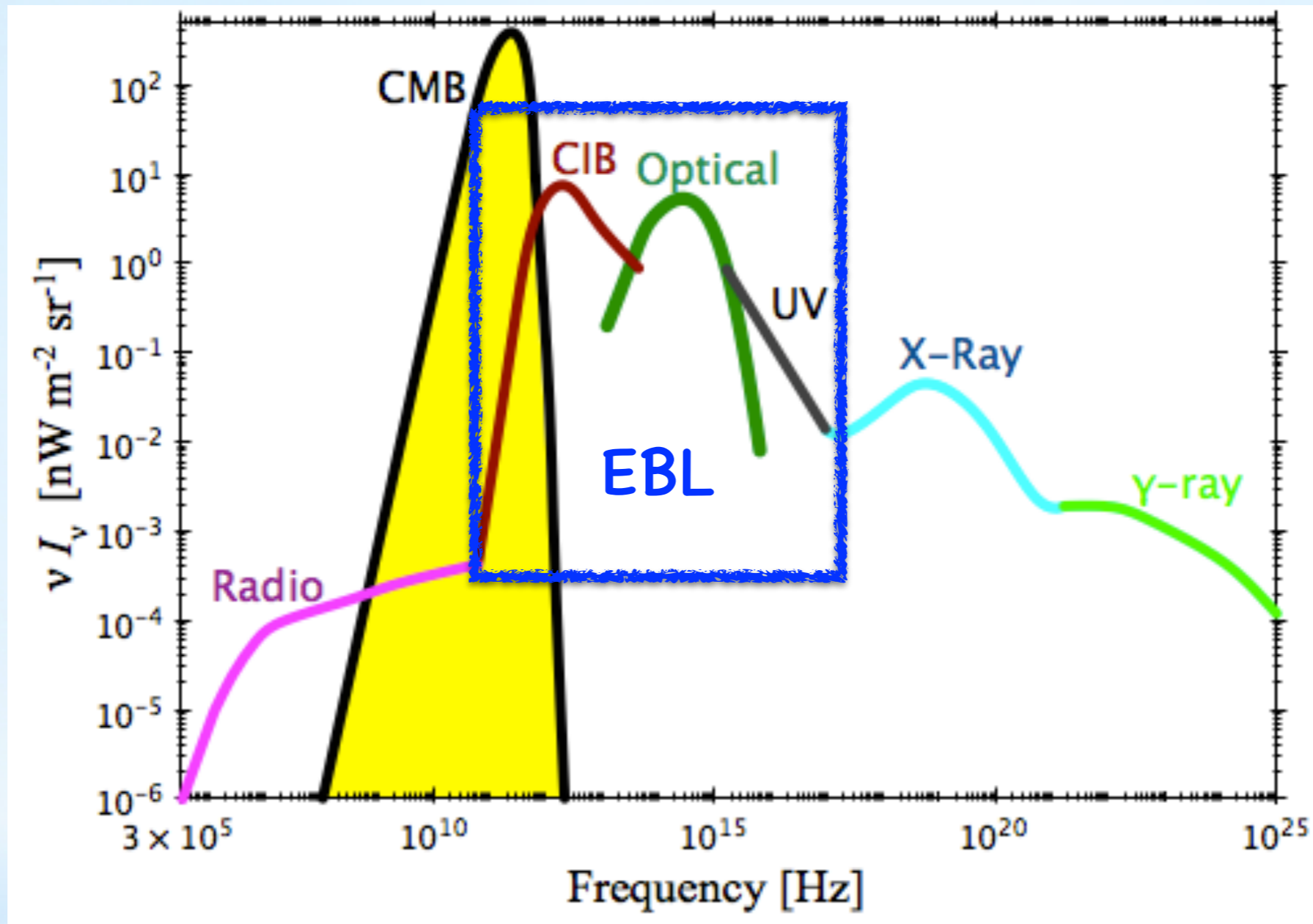


## The Measurements of the Extragalactic Background Light (EBL)

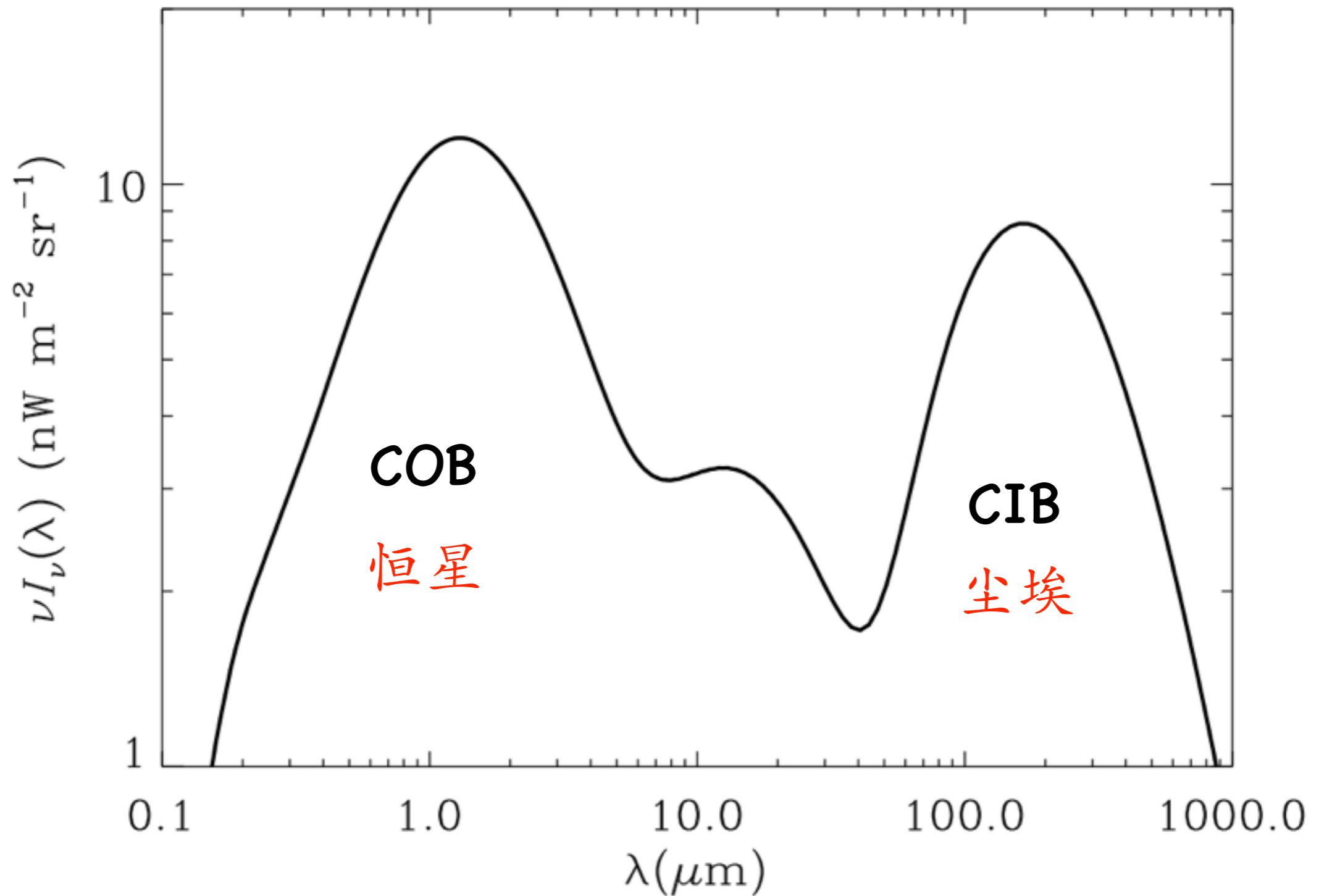
岳斌（报告人）， 巩岩， 袁强

# What is the EBL?

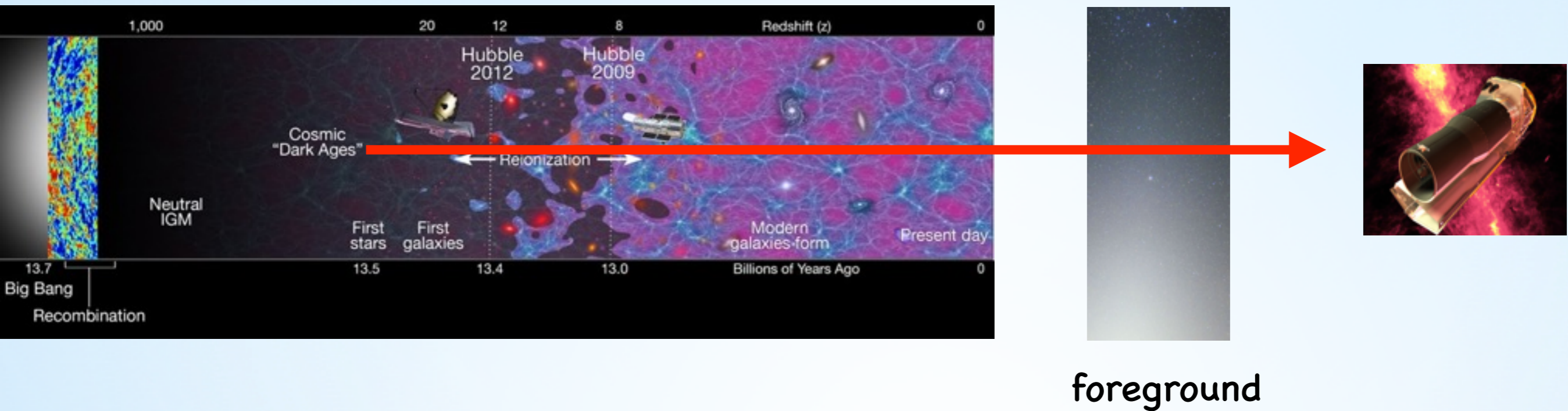


自UV至IR (0.1–1000 μm) 波段的宇宙背景光，总能量约为CMB的5%，仅次于CMB。

# 双峰特征:



EBL is the integrated star formation history of our Universe, including the radiation from: e.g., first stars, reionization galaxies...



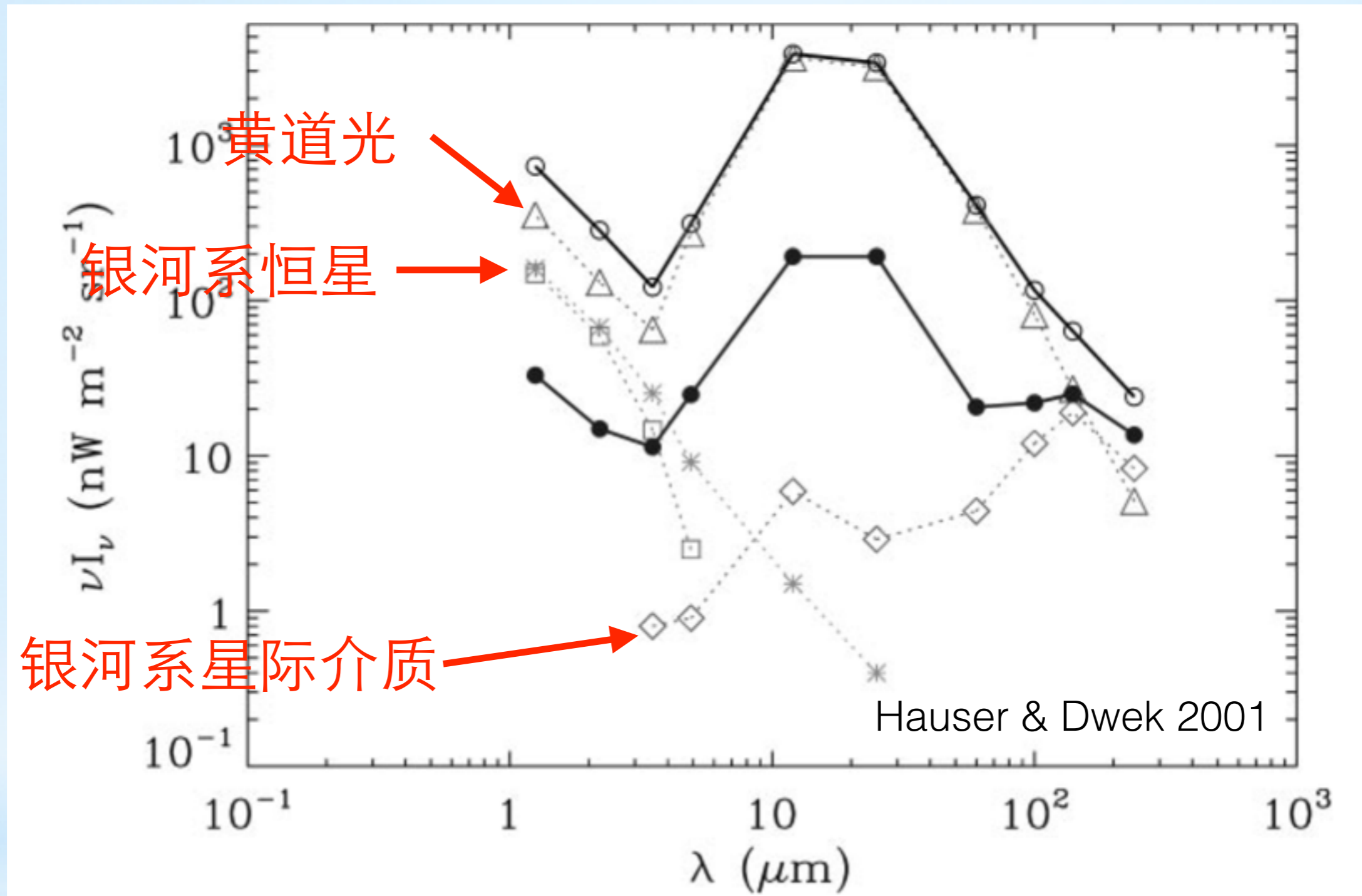
$$F = F_{\text{EBL}} + F_{\text{FG}}$$

$$\approx \frac{c}{4\pi} \int dz \frac{\nu l_{\nu} \dot{\rho}_{\star}(z)}{H(z)(1+z)^2} + F_{\text{FG}}$$

e.g. Flux@NIR [ $\text{nWm}^{-2}\text{sr}^{-1}$ ]:

高红移星系:	$\sim 0.1 - 1$
低红移星系:	$\sim 10$
黄道光:	$\sim 100 - 1000$

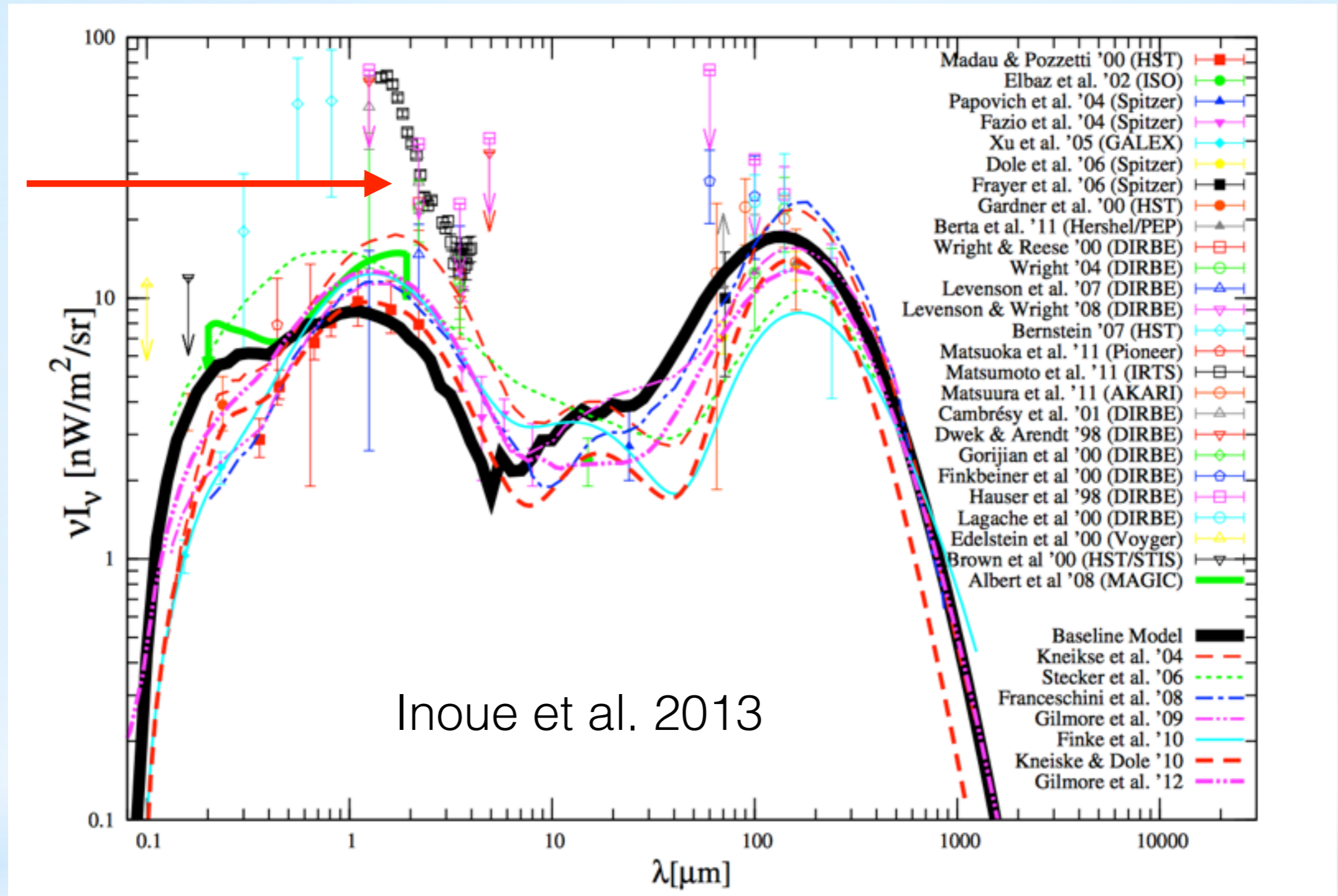
# 直接观测的困难：EBL $\ll$ 前景



In direct measurements, the **modeled** foreground is subtracted, the residual is considered as the EBL

# Summary of some direct measurements:

excess?



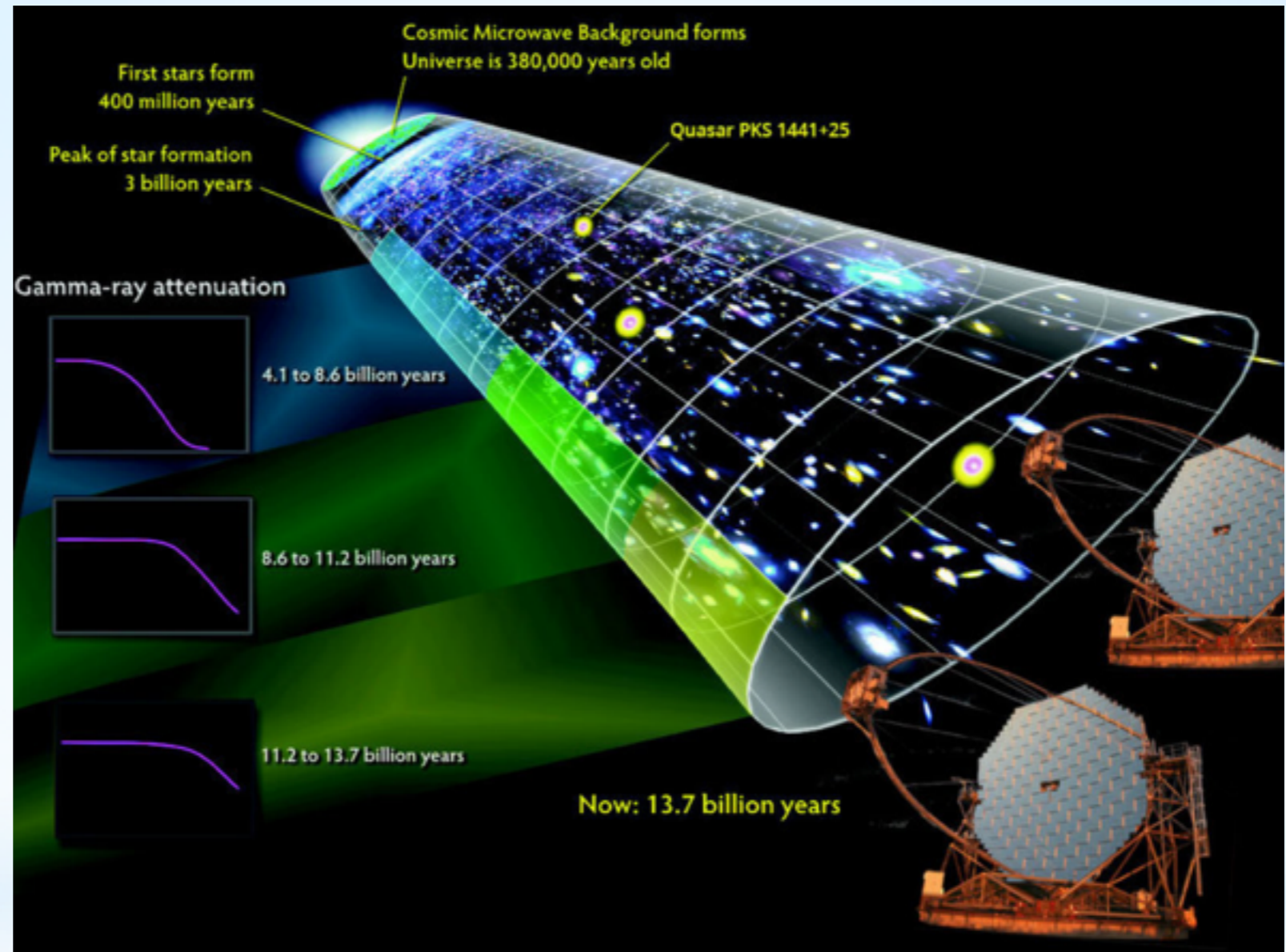
问题：直接测量值超出的部分是来自未知的天体？还是误差？

# 间接测量



pair production:

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



$$F_{\text{obs}}(E) = F_{\text{int}}(E) e^{-\tau_{\gamma\gamma}(E)}$$

$$\tau_{\gamma}(E_{\gamma}, z) = \int_0^z \left(\frac{dl}{dz'}\right) dz' \int_{-1}^{+1} d\mu \frac{1-\mu}{2} \int_{\epsilon'_{\text{th}}}^{\infty} d\epsilon' n_{\epsilon}(\epsilon', z') \sigma_{\gamma\gamma}(E_{\gamma}, \epsilon', \mu)$$

# intrinsic spectrum?

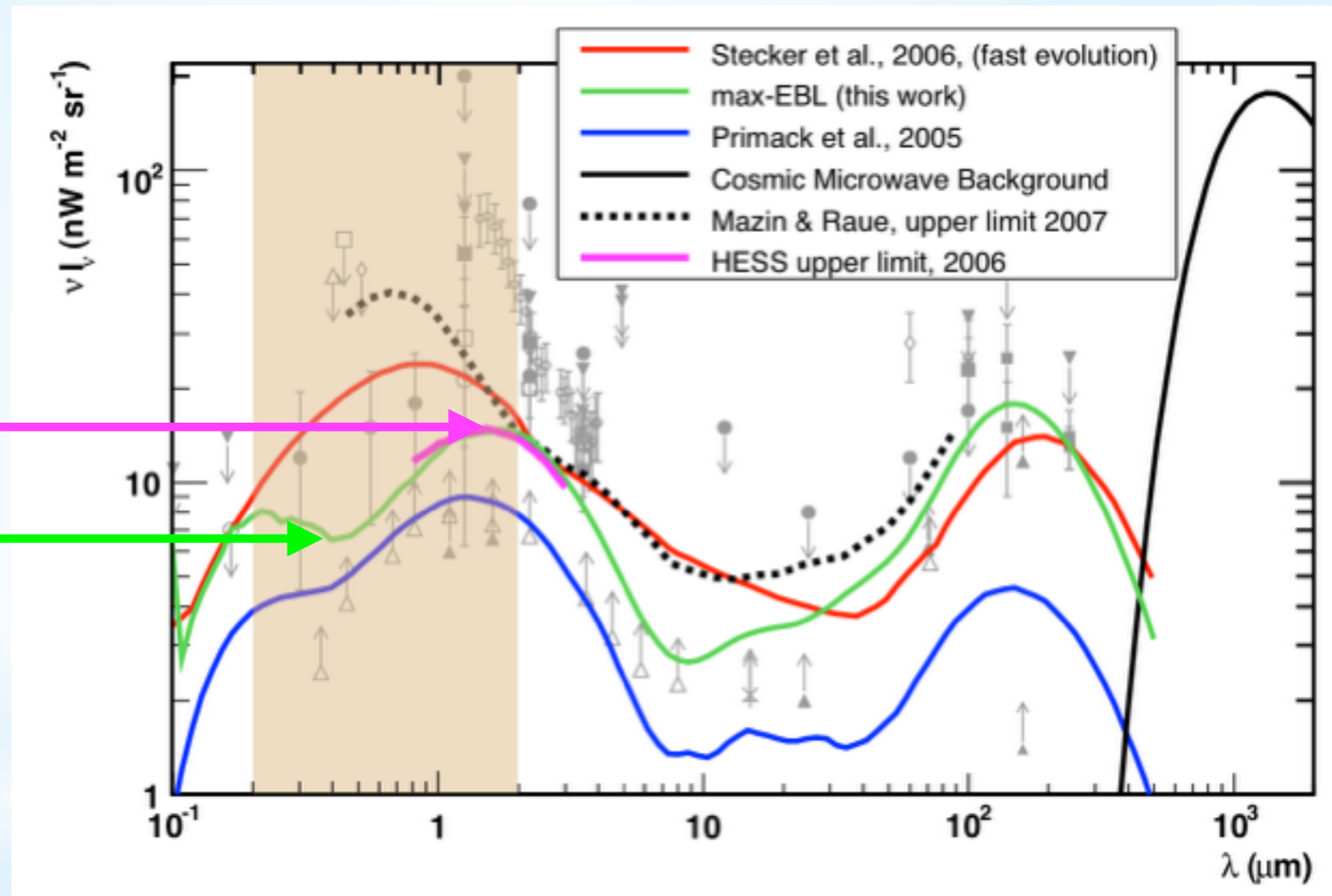
假定:  $F_{\text{int}}(E) \propto E^{-\Gamma}, \Gamma > 1.5$

或者:  $\Gamma > \Gamma_{\text{Fermi-LAT}}$

可给出**EBL**的上限:

HESS upper limit

MAGIC upper limit





# intrinsic spectrum?

Yuan et al. 2012

1. 假设源的内禀谱为幂律或者对数抛物线的形式;

$$F_{\text{int}}(E) = F_0 \times E^{-\Gamma}$$

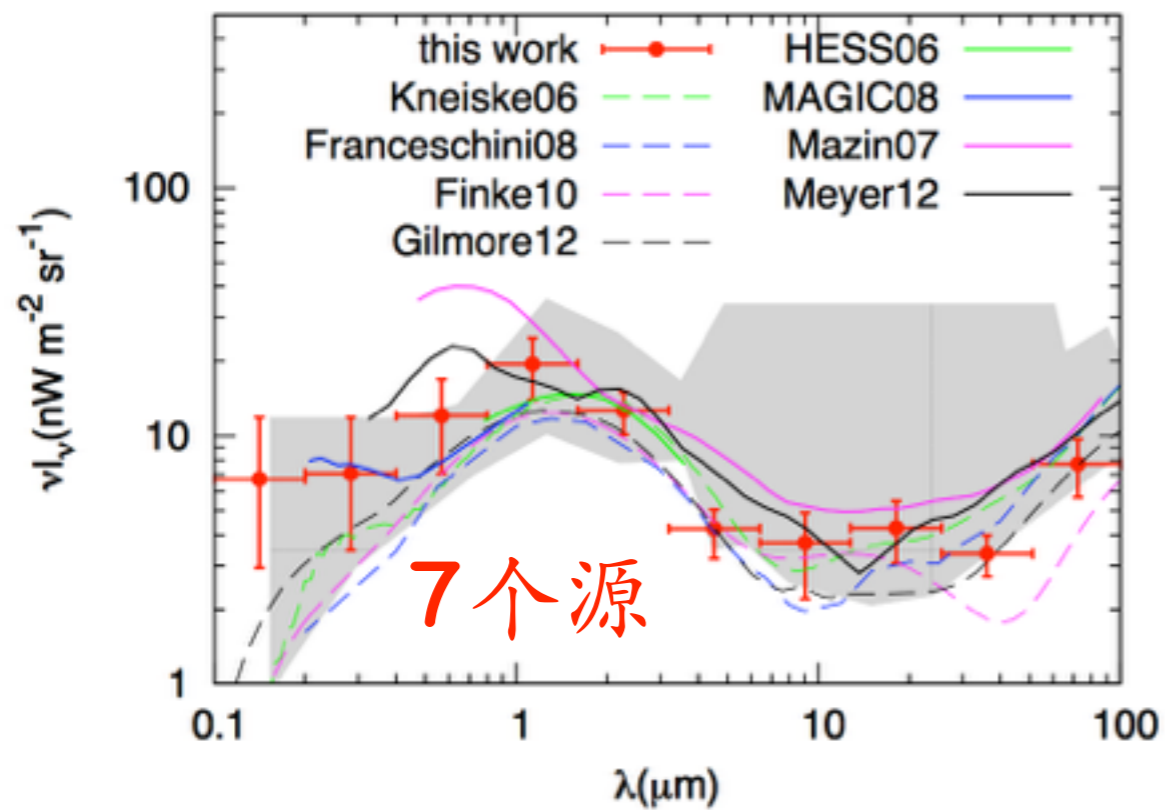
or  $F_{\text{int}}(E) = F_0 \times E^{-\Gamma - \beta \log(E)}$

2. 将每个内禀谱本身也做为自由度, 与**EBL**一同参与拟合;

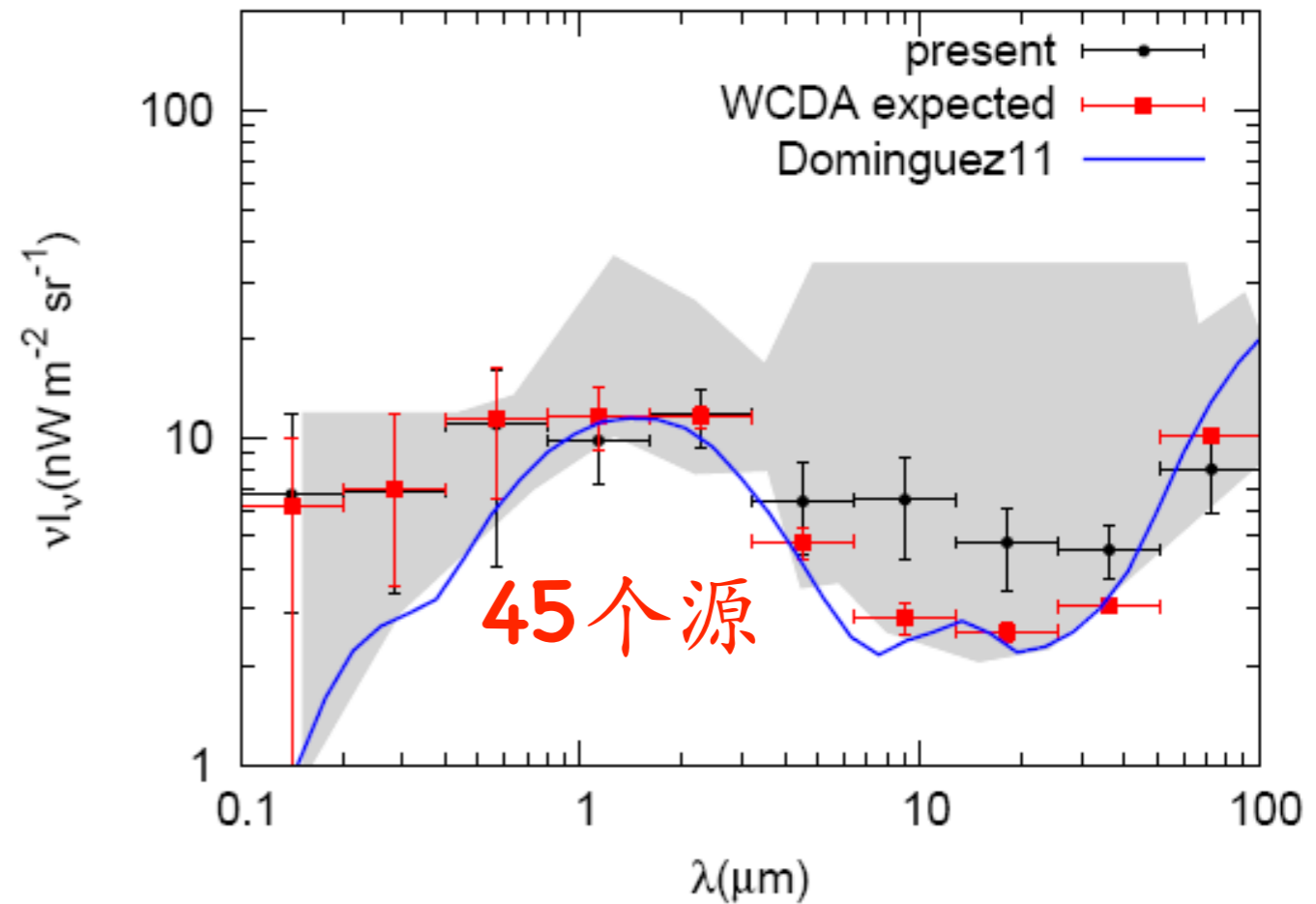
$$F_{\text{obs}}(E) = F_{\text{int}}(E) \times e^{-\tau(E, z)}$$

3. 没有预先假定**EBL**的形式, 而是将其分为若干个**bin**, 每个**bin**都独立参与拟合。

# 结果:



Yuan et al. 2012



Bi et al.,  
LHAASO science document

对源的intrinsic spectrum不敏感，但是依赖大样本的精确能谱测量，这正是LHAASO的潜在优势！

# galaxy properties & star formation history from the EBL:

$$\epsilon_p I(\epsilon_p, z) = (1+z)^4 \frac{c}{4\pi} \int_z^{z_{\max}} dz' \left| \frac{dt}{dz'} \right| \frac{\epsilon' j_\epsilon(\epsilon', z')}{1+z'},$$

$$\begin{aligned} \epsilon j_\epsilon^{\text{star}}(\epsilon, z) &= m_e c^2 \epsilon^2 \int_{M_*^{\min}}^{M_*^{\max}} dM_* \xi(M_*) \\ &\times \int_z^{z_{\max}} dz' \left| \frac{dt}{dz'} \right| f_{\text{esc}}(\epsilon, z') \dot{\rho}_*(z') \dot{N}_*(\epsilon, M_*, t_*). \end{aligned} \quad (3)$$

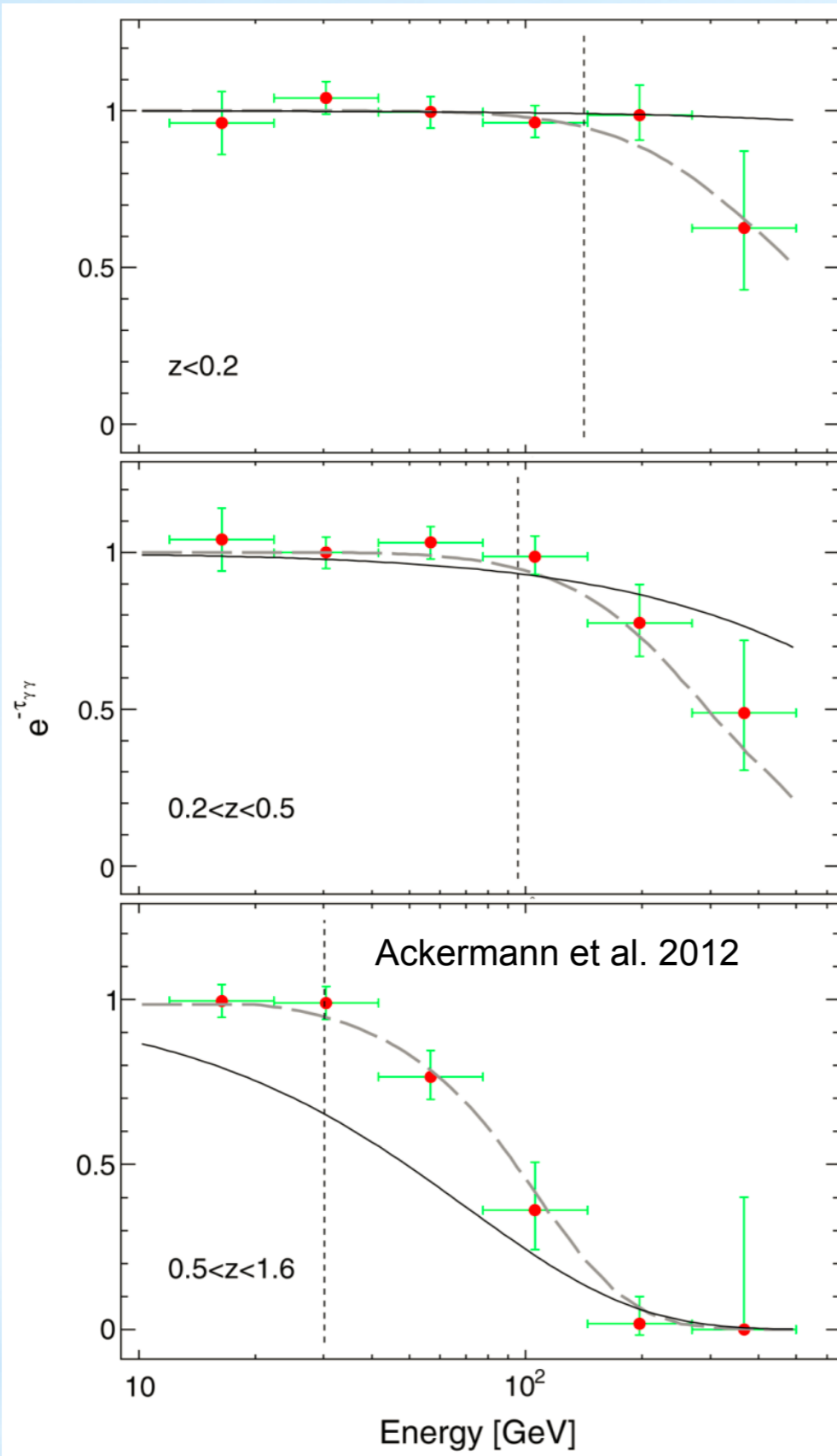
Here we take  $M_*^{\min} = 0.1 M_\odot$ ,  $M_*^{\max} = 100 M_\odot$ ,

观测：基于Fermi的150个Blazar的数据得出的3个红移bin内的吸收光深 (Ackermann et al. 2012)



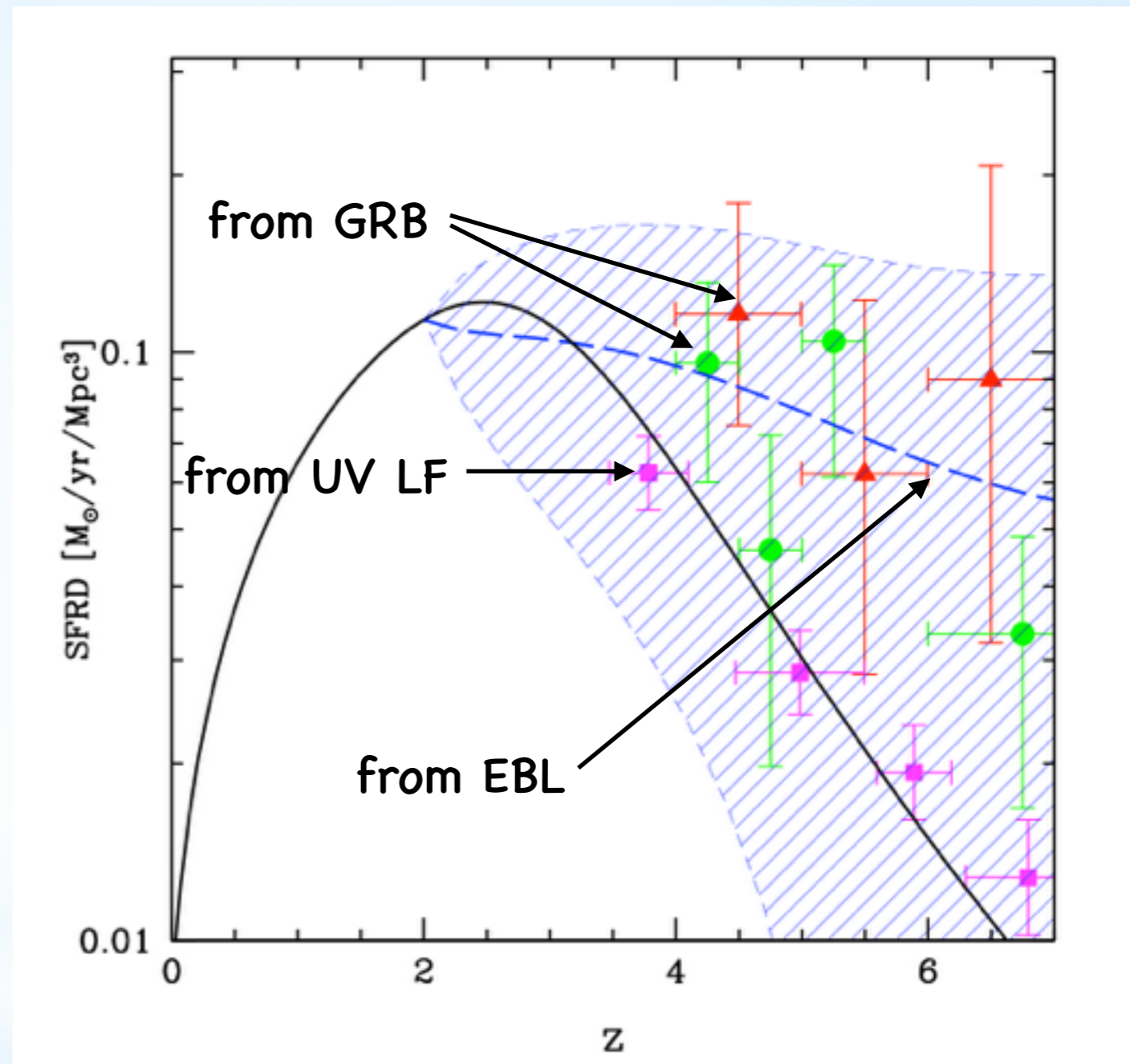
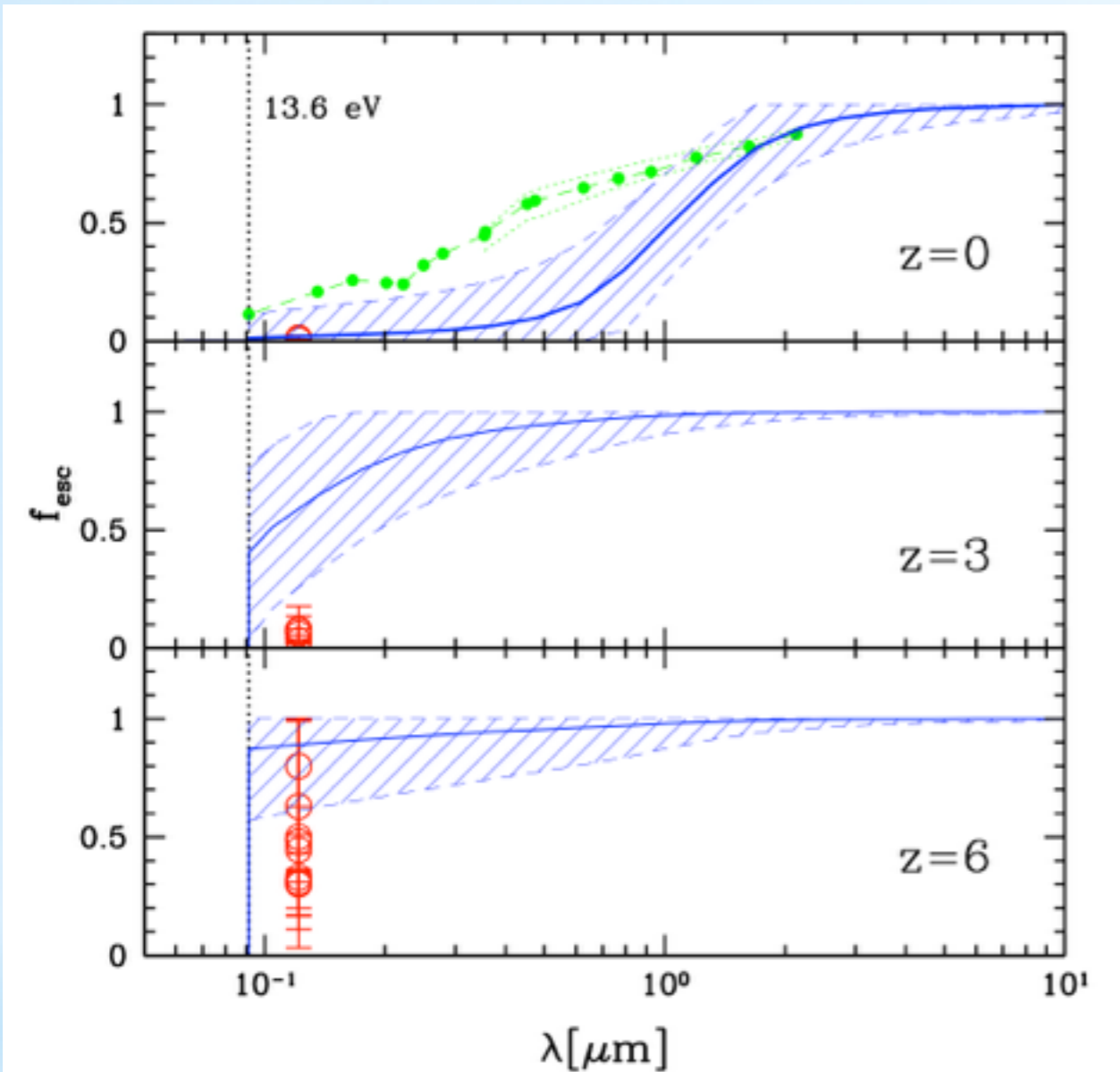
MCMC拟合

$$\chi^2 = \sum_{i=1}^N \frac{[\exp(-\tau_{\gamma\gamma}^{\text{obs}}) - \exp(-\tau_{\gamma\gamma}^{\text{th}})]^2}{\sigma_i^2},$$



# Constraints on escape fraction & star formation history

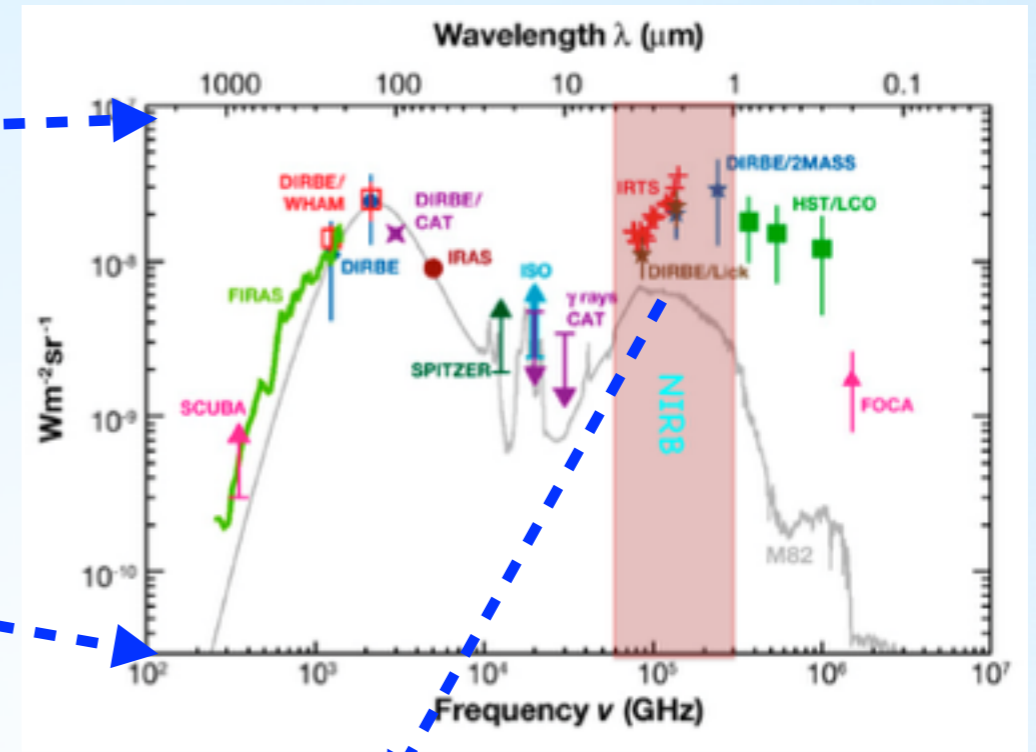
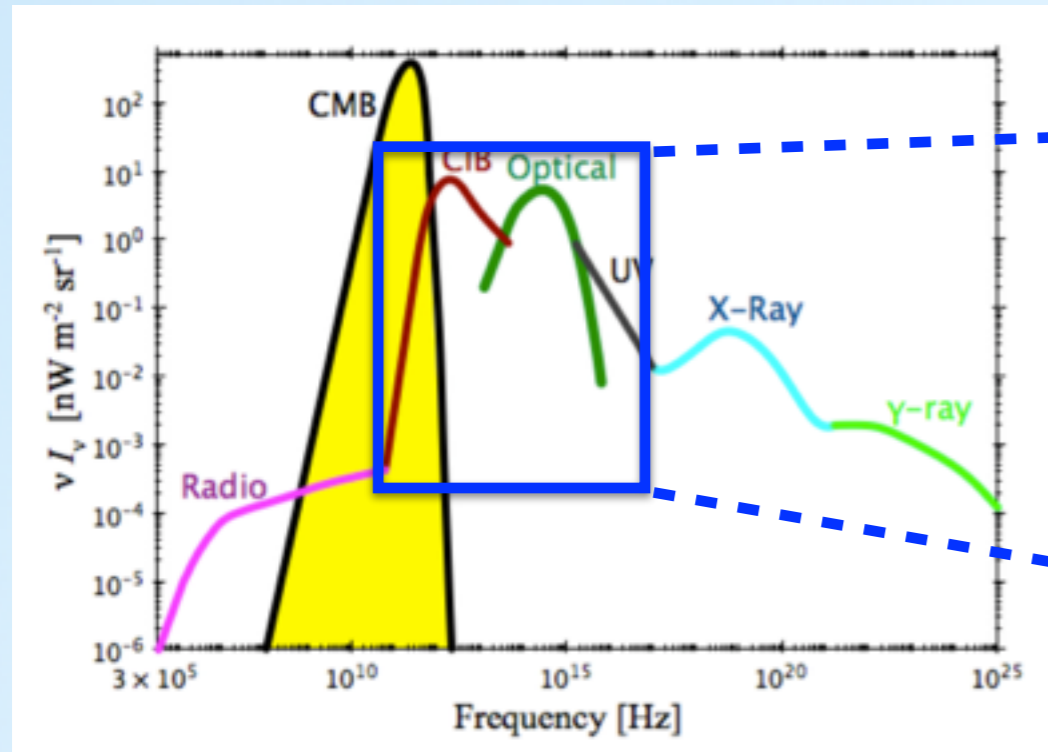
由于EBL的“积分”特征，即使低红移 $\gamma$ -ray源的观测，限制的也是包括高红移的整个恒星形成历史！



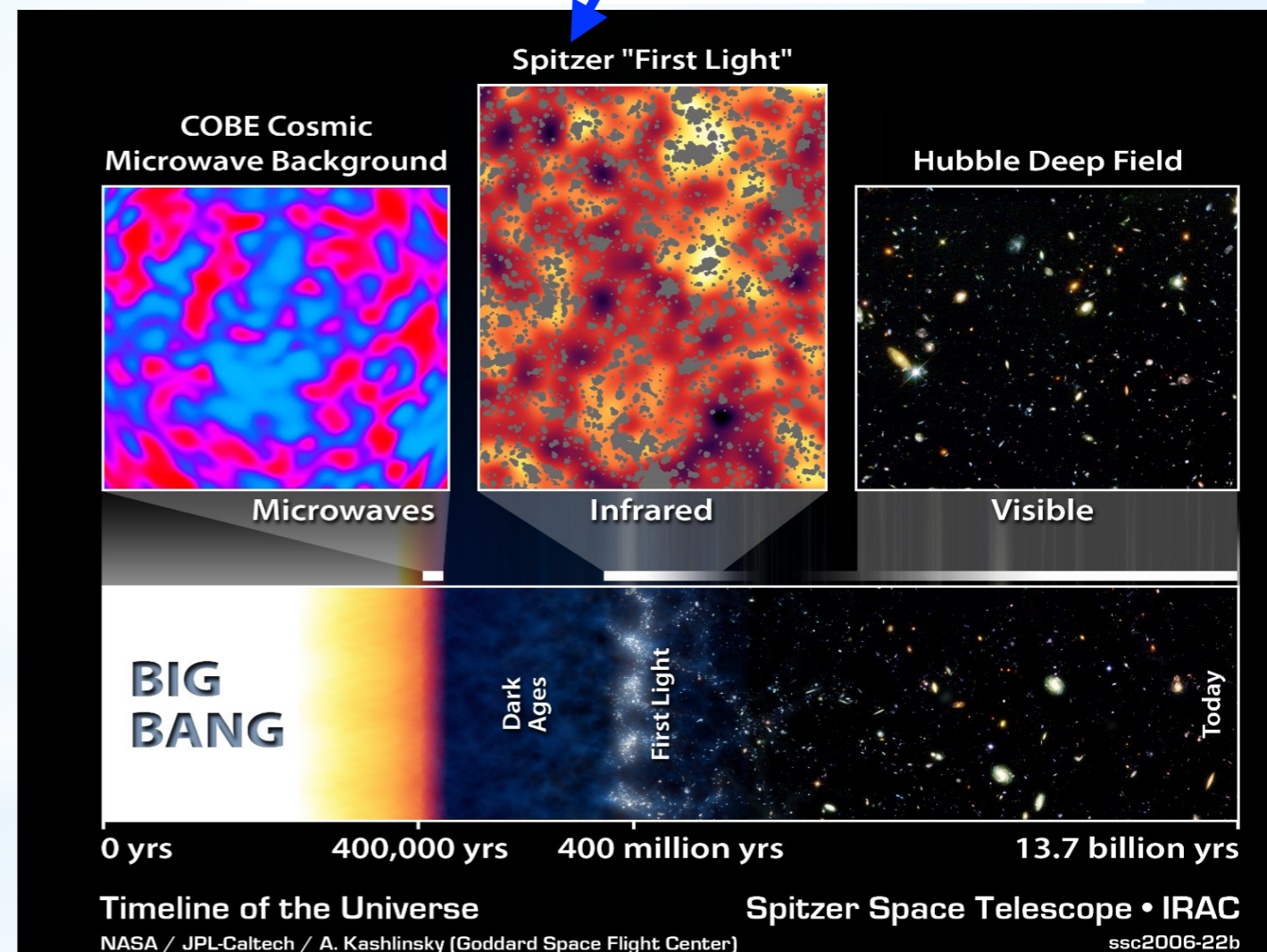
Gong et al. 2013

EBL的结果表明， $z > 6$ 时有足够的星系完成再电离。

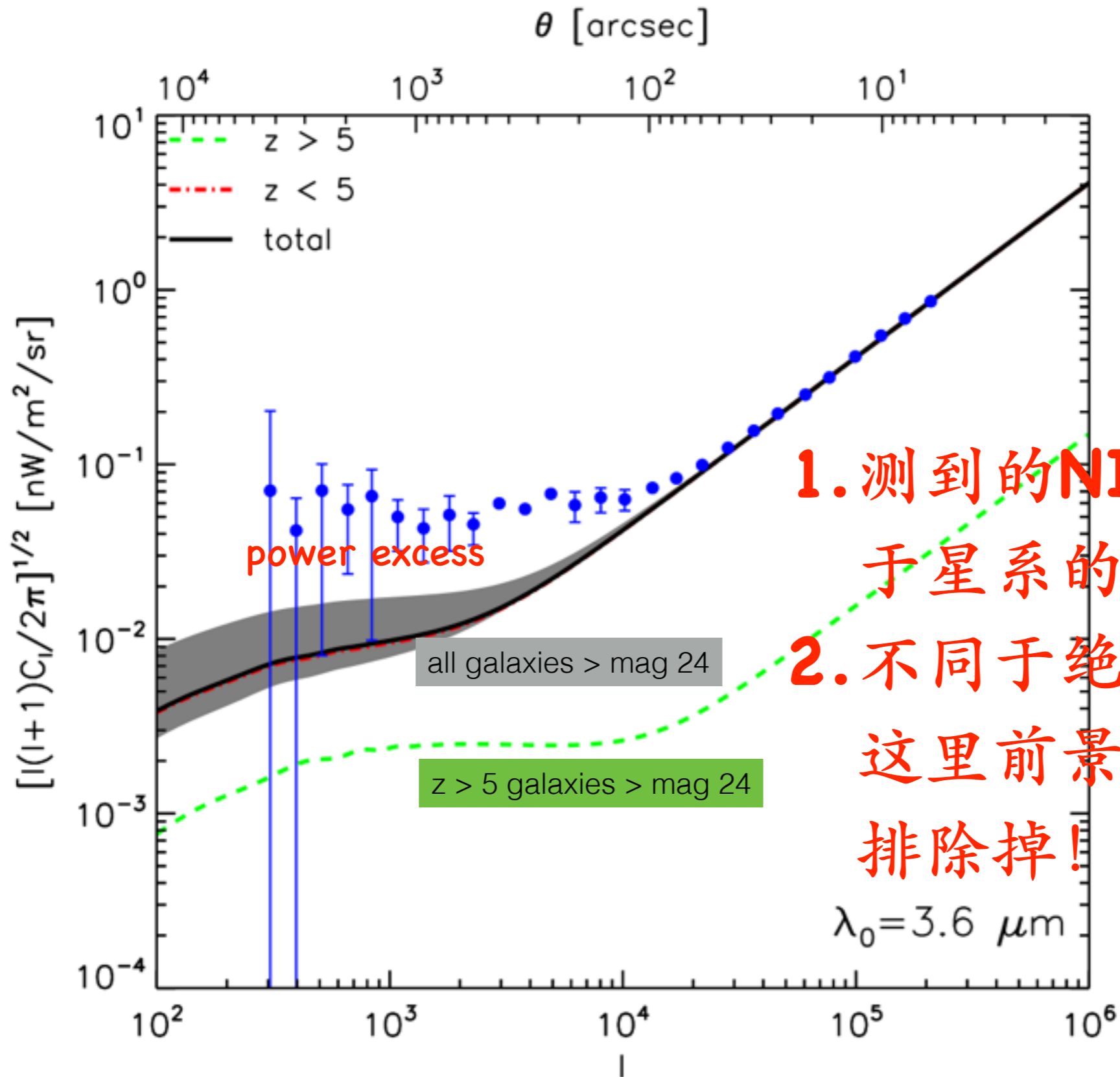
# The Near InfraRed Background (NIRB) fluctuations



1. 第一代恒星/第一代星系的辐射主要在UV波段，红移到今天恰好到NIR波段 (~1 - 5  $\mu\text{m}$ );
2. 测量绝对强度受前景的干扰很大，而分析fluctuations可以排除前景的影响。



# NIRB map的角功率谱 $\rightarrow \delta F$ vs. $\theta$



1. 测到的NIRB功率谱远高于星系的贡献!
2. 不同于绝对强度的测量, 这里前景的影响已经被排除掉!

不能通过“放大”高红移星系的数量或发光能力来解释上述超出，因为有如下的限制：

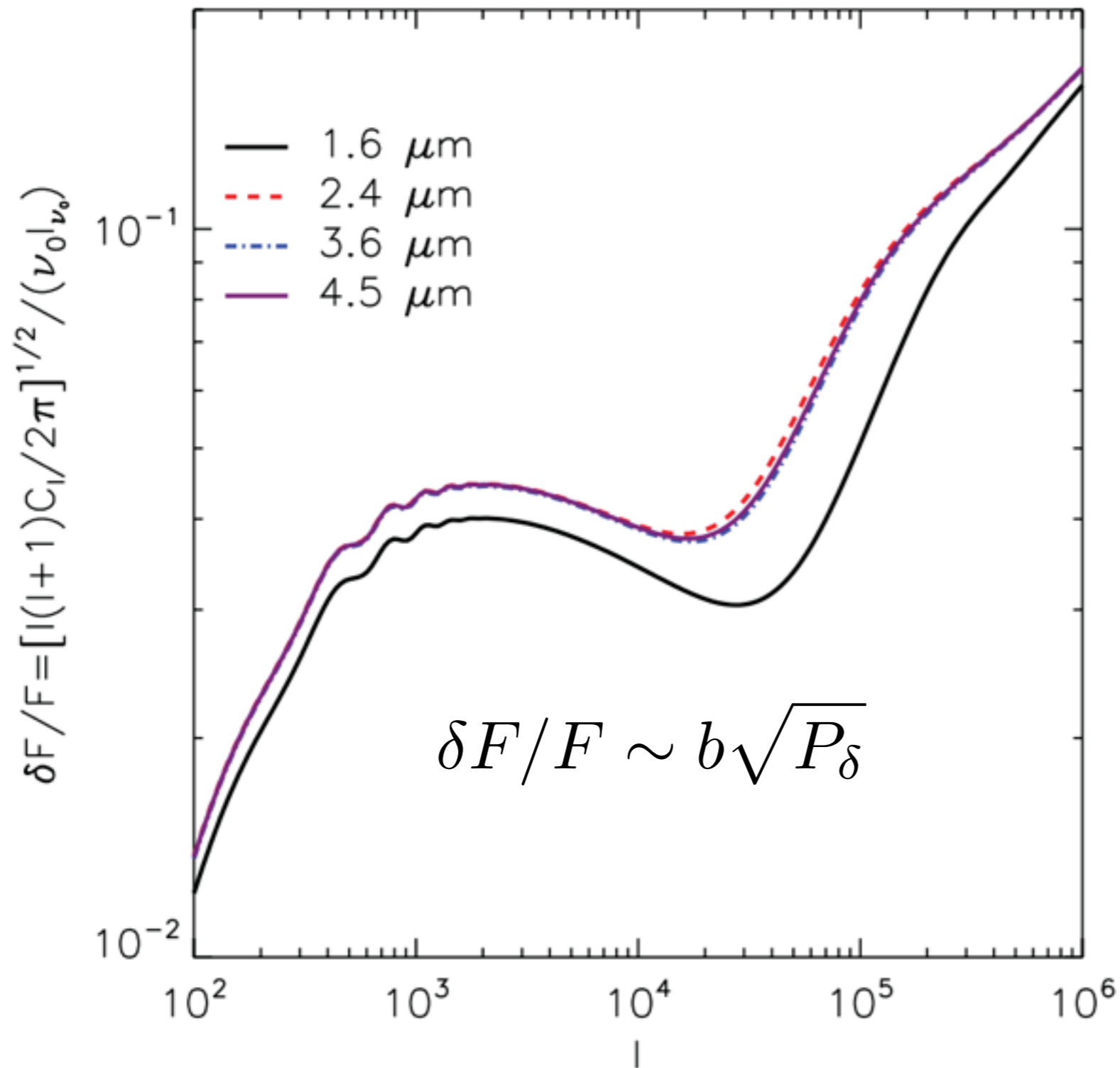
1. 高红移星系的光度函数；
2. 再电离的历史；
3. 恒星形成本身的物理机制(e.g. star formation efficiency)。



# 新的源?

1. 第一代恒星 (早期的motivation)
2. Intrahalo light (星系之间的游离恒星所发出的光, Cooray et al. 2012, Zemcov et al. 2014)
3. 直接坍缩形成的中等质量黑洞 (Yue et al. 2013, 2014)
4. Axion decay (Gong et al. 2016)
5. Primordial black holes (Kashlinsky et al. 2016)
6. ....

NIRB fluctuations的测量可给出 $\delta F$ , 结合其它方法测到的 $F$ , 可得知源的**bias**等性质。



对于高红移( $z > 5$ )的星系来说,  $\delta F / F \sim 5\%$

# 结论：

- EBL是研究宇宙恒星形成历史的极佳手段；
- LHAASO为更精确测量EBL的绝对强度带来了契机；
- 人们试图在NIRB的fluctuations中寻找第一代恒星、第一代星系、或者其它新的奇异天体存在的迹象；
- 能否加强二者之间的关联？

谢谢大家！