P. G. Pérez-González

Understanding the mass assembly of galaxies at 0<z<4: Spitzer's contribution and open questions

We will present the main results of our research about the assembly of galaxies at z<4 based on the data obtained by the deepest Spitzer surveys carried out with IRAC and MIPS during the cryogenic mission. These data in the near-, mid- and far-IR have allowed us to obtain unprecedentedly robust estimations of the obscured SFRs and stellar masses of distant galaxies. Analyzing SFR and stellar mass functions in several redshift bins at 0<z<4, we have found and quantified that galaxies formed following a downsizing scenario, with the most massive systems assembling early in the lifetime of the Universe and very quick (i.e., with very high star formation efficiencies, and a significant amount of obscured starbursts), while less massive systems assembled later and/or more slowly. However, Spitzer has left several open questions that still hamper our current understanding about the formation and evolution of galaxies. I will discuss three of these results and how future facilities such as Herschel, ALMA, E-ELT or JWST can lead to a more robust and detailed (with higher spatial resolution and depth) characterization of how galaxies formed in the early Universe: (1) the mid-to-far IR colors of galaxies evolve with redshift, departing considerably from the typical values observed in the local Universe, specially at z>1.5-2.0; (2) the IMF might not be universal, evolving to a top-heavy IMF at z>1.5; (3) obscured AGN may be ubiquitous in high-z galaxies, playing a significant role in the downsizing scenario.

Understanding the mass assembly of galaxies at 0<z<4: *Spitzer's* results and open questions

Pablo G. Pérez-González

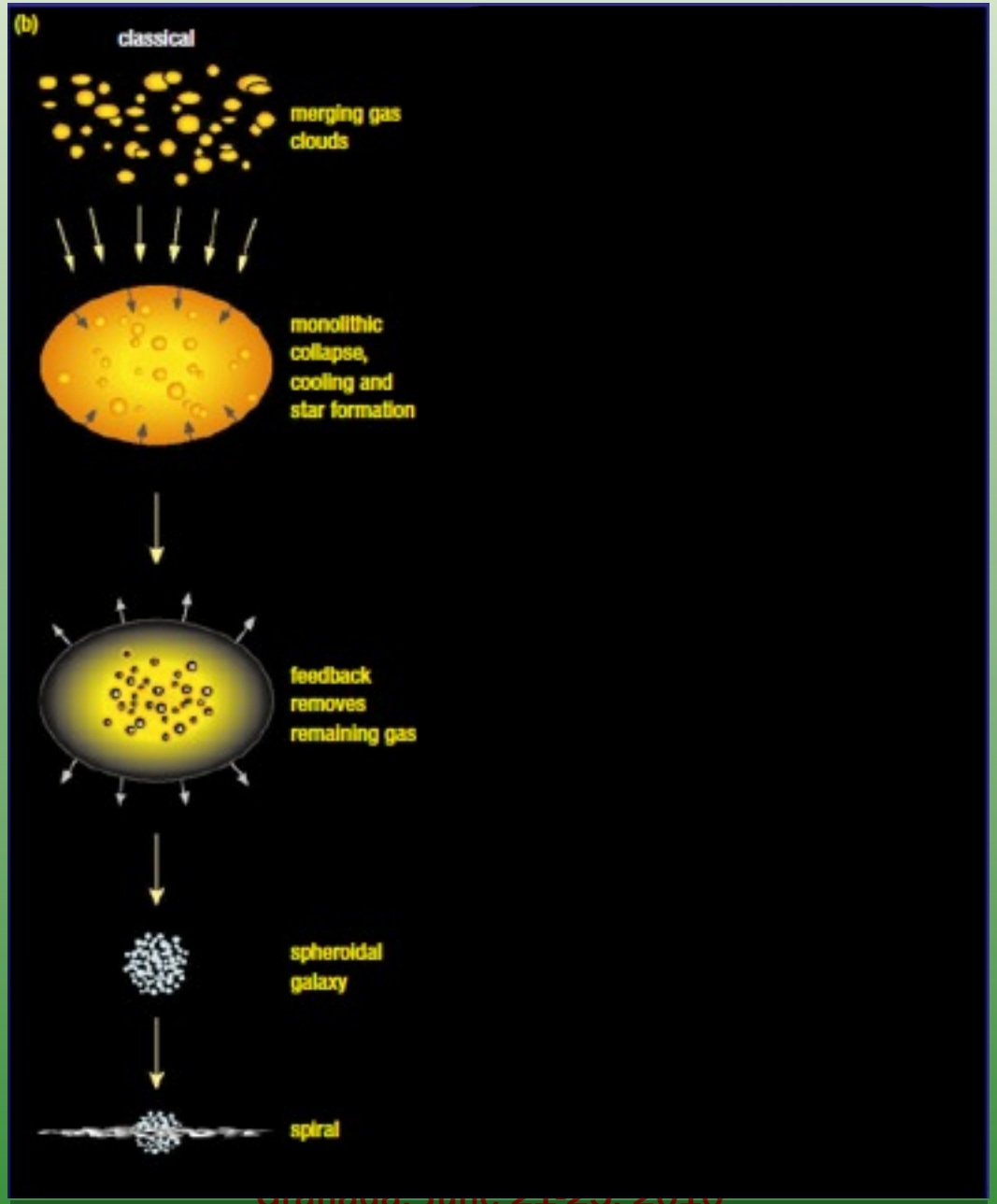
Ramón y Cajal Associate Professor at UCM
Associate Astronomer at Steward Observatory

Collaborators: a lot!!! (SHARDS and HLS Teams).
Special mention to Guillermo Barro, Eiichi Egami, Marie Rex, Tim Rawle, Nacho Trujillo.

Universidad Complutense de Madrid (UCM)

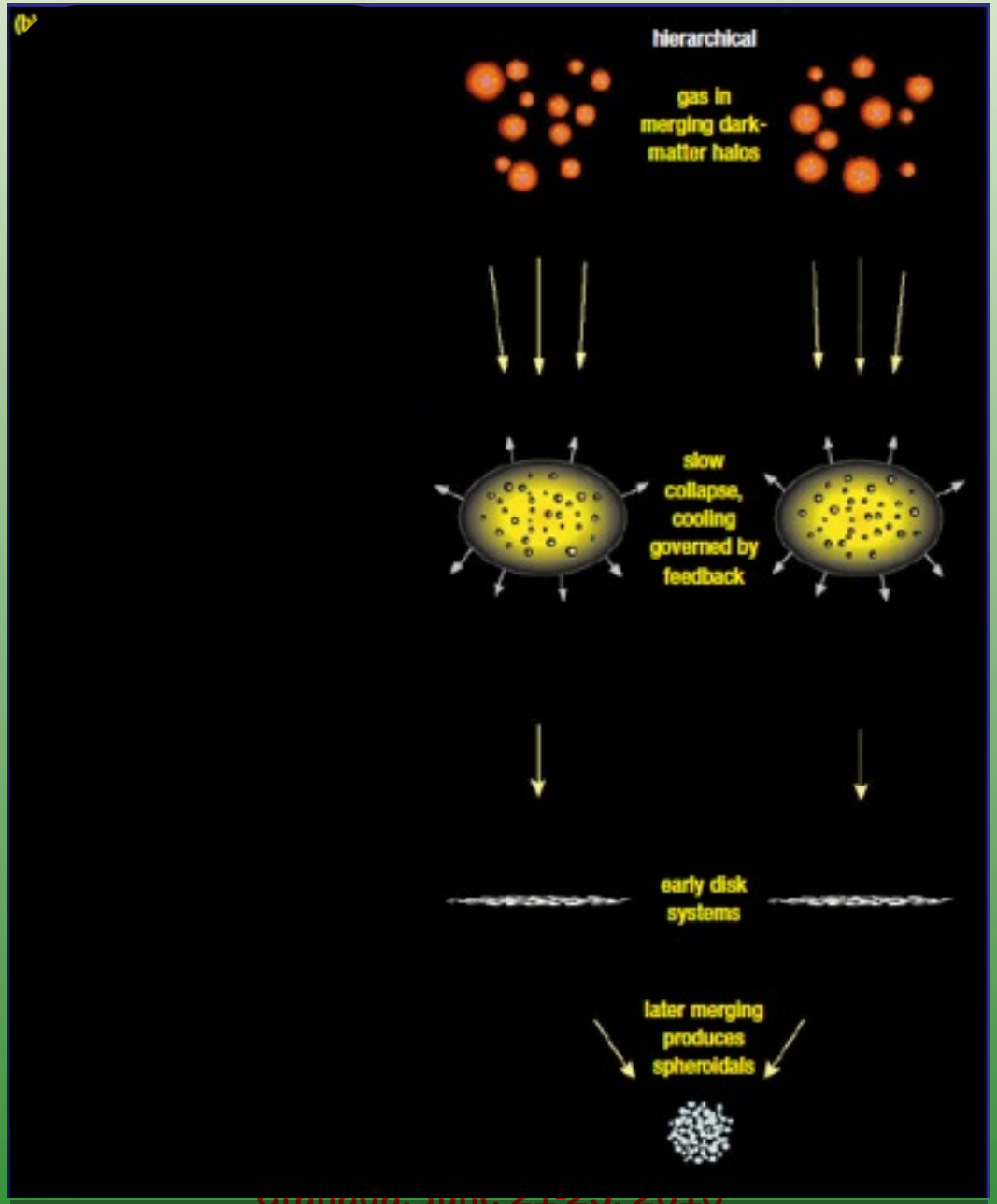
University of Arizona (UofA)

The classical view on galaxy formation



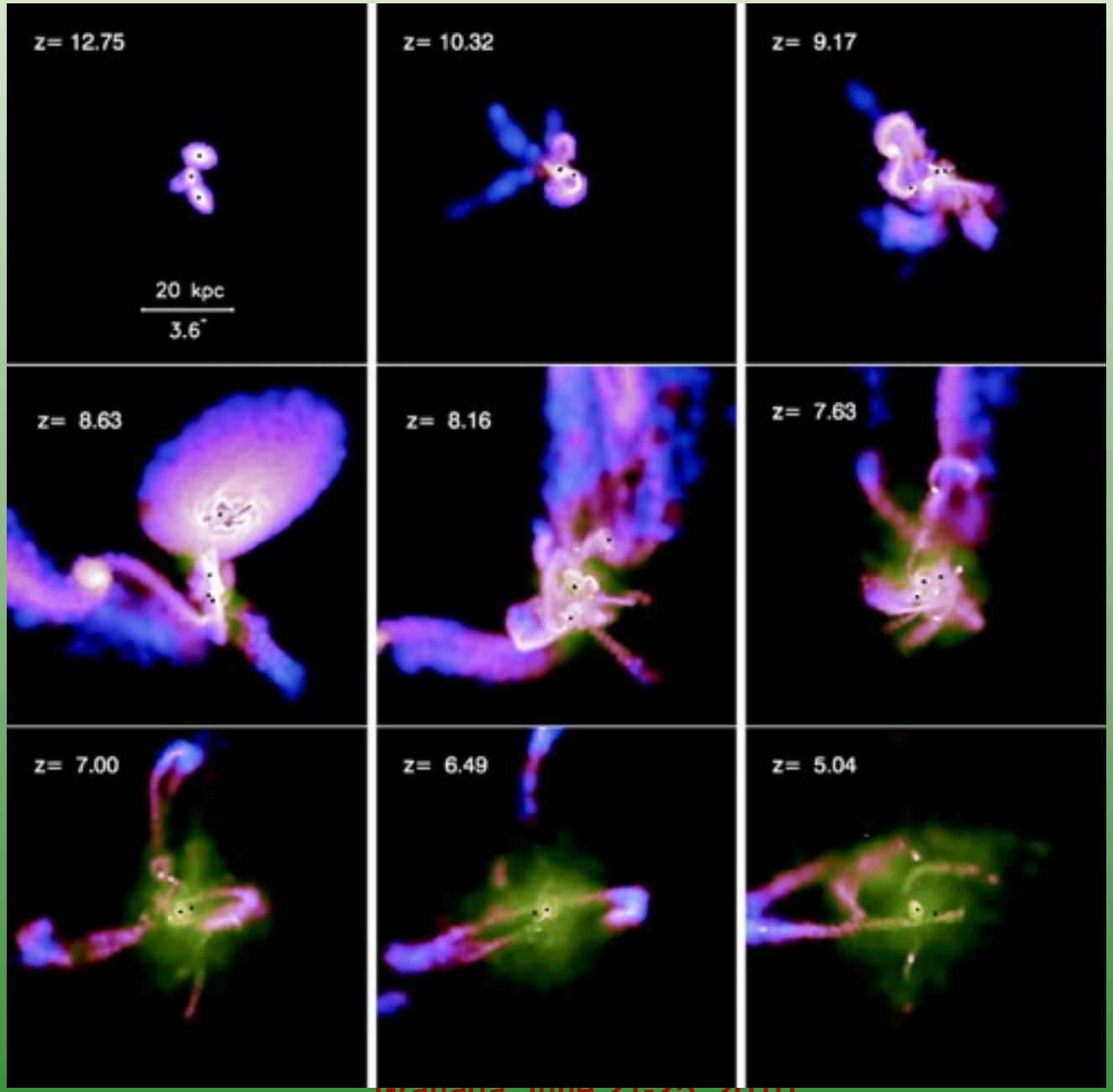
Ellis et al. (2000)

The current paradigm for galaxy formation



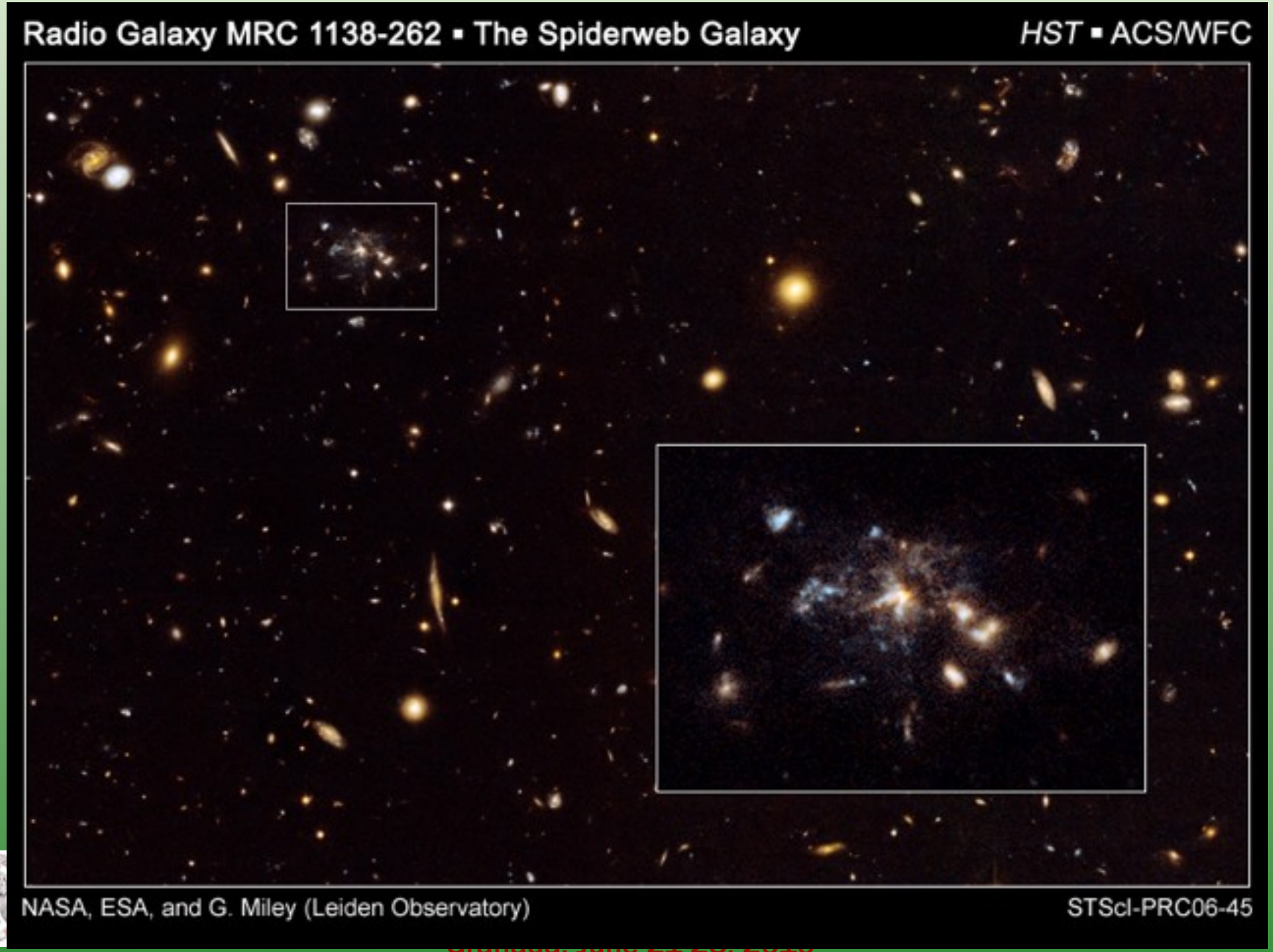
Ellis et al. (2000)

The paradigm for galaxy formation: models



Li et al. (2008)

The paradigm for galaxy formation: data



Miley et al. (2006)

Is all the fish sold?
Do we really understand galaxy evolution?

My job: trying to understand galaxy formation

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- **Reasons for *Spitzer's* breakthrough on how galaxies assembled their mass?**
  - **IRAC observing window and sensitivity allows to probe the rest-frame NIR (best proxy for $\mathcal{M}_\star$) up to z~4.**

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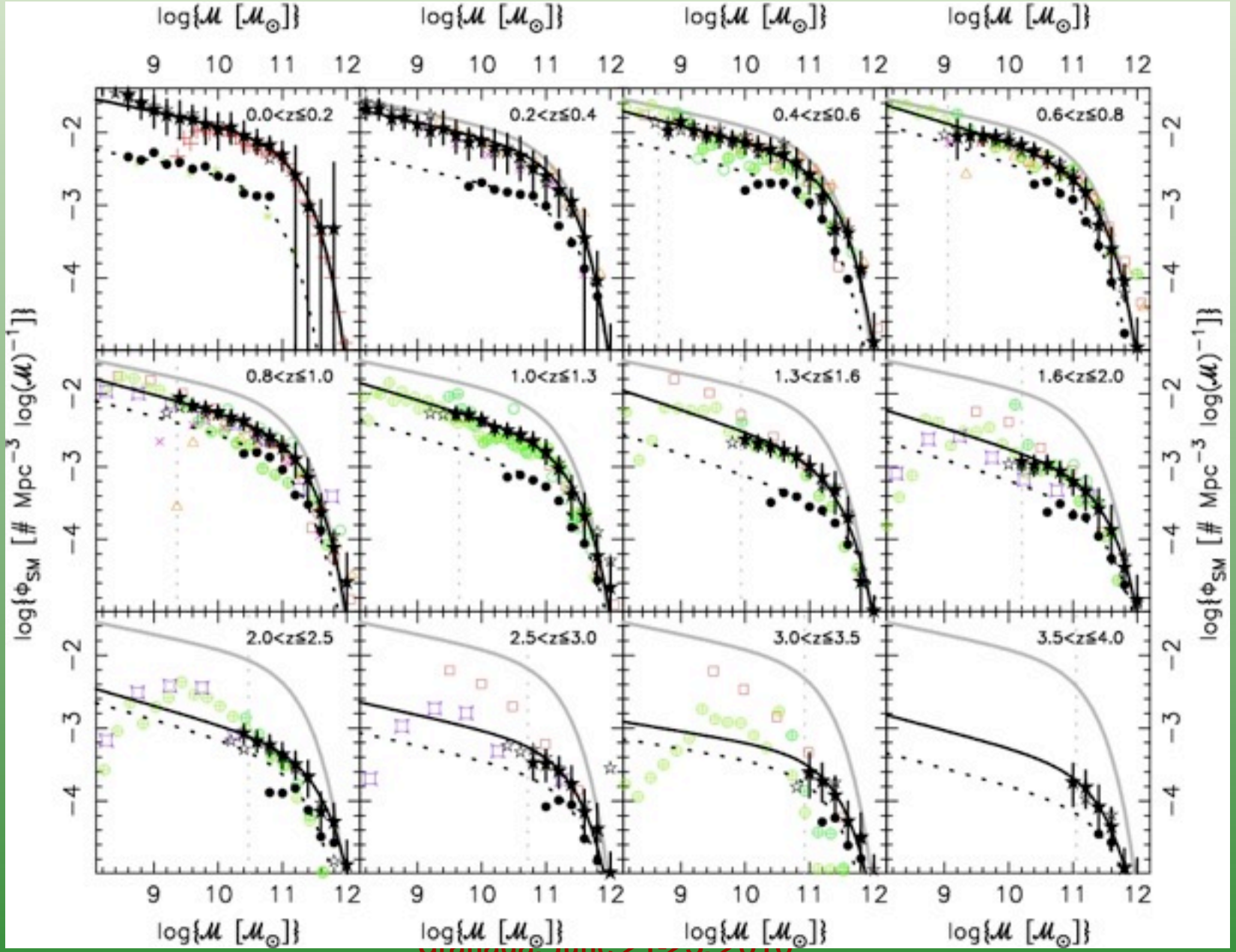
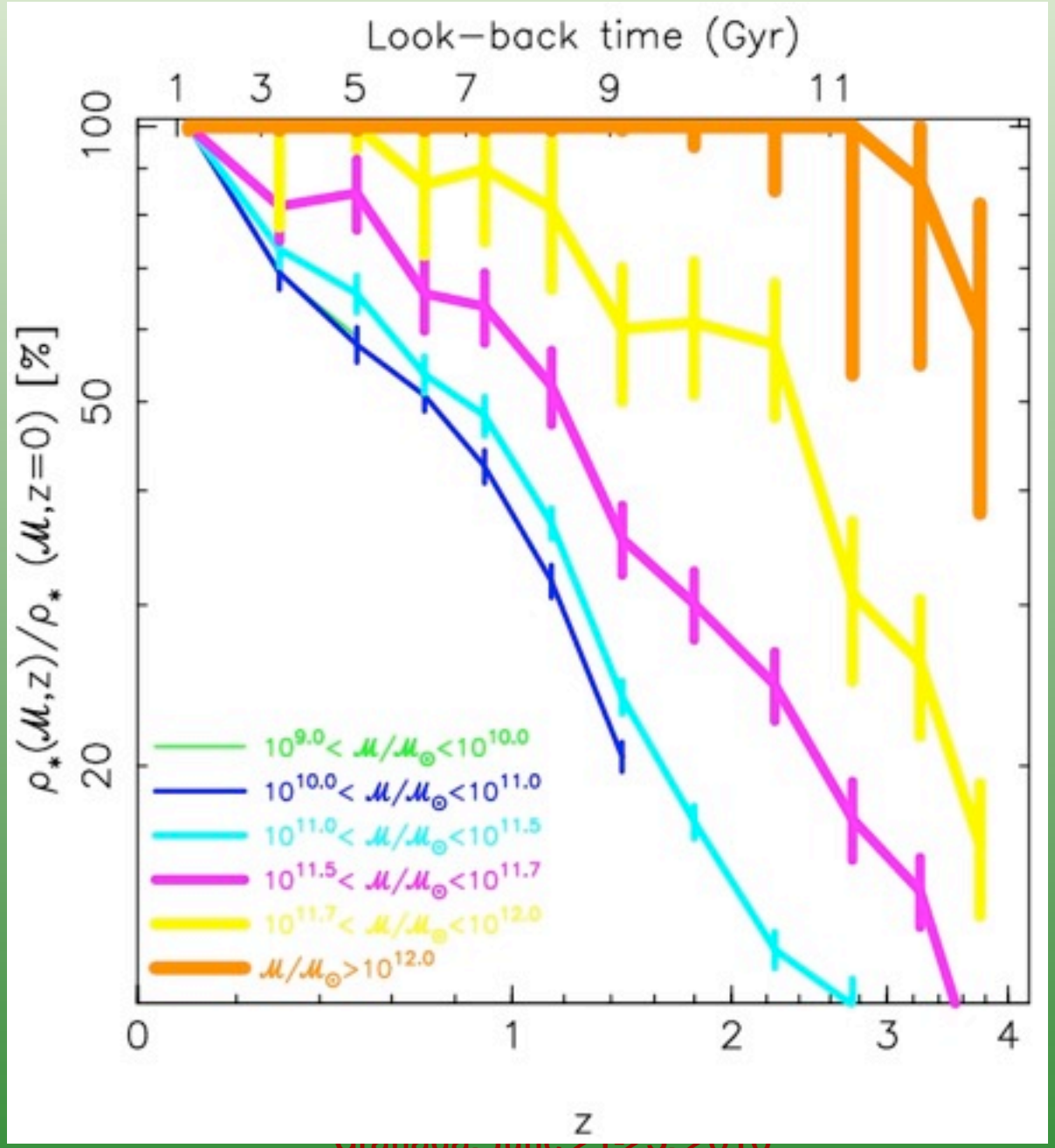
- **Some results and open questions.**
- **Answers to some of the open questions (i.e., more data): HLS (PI Egami) and SHARDS (PI me).**

How&when galaxies formed: SMF @ z<4



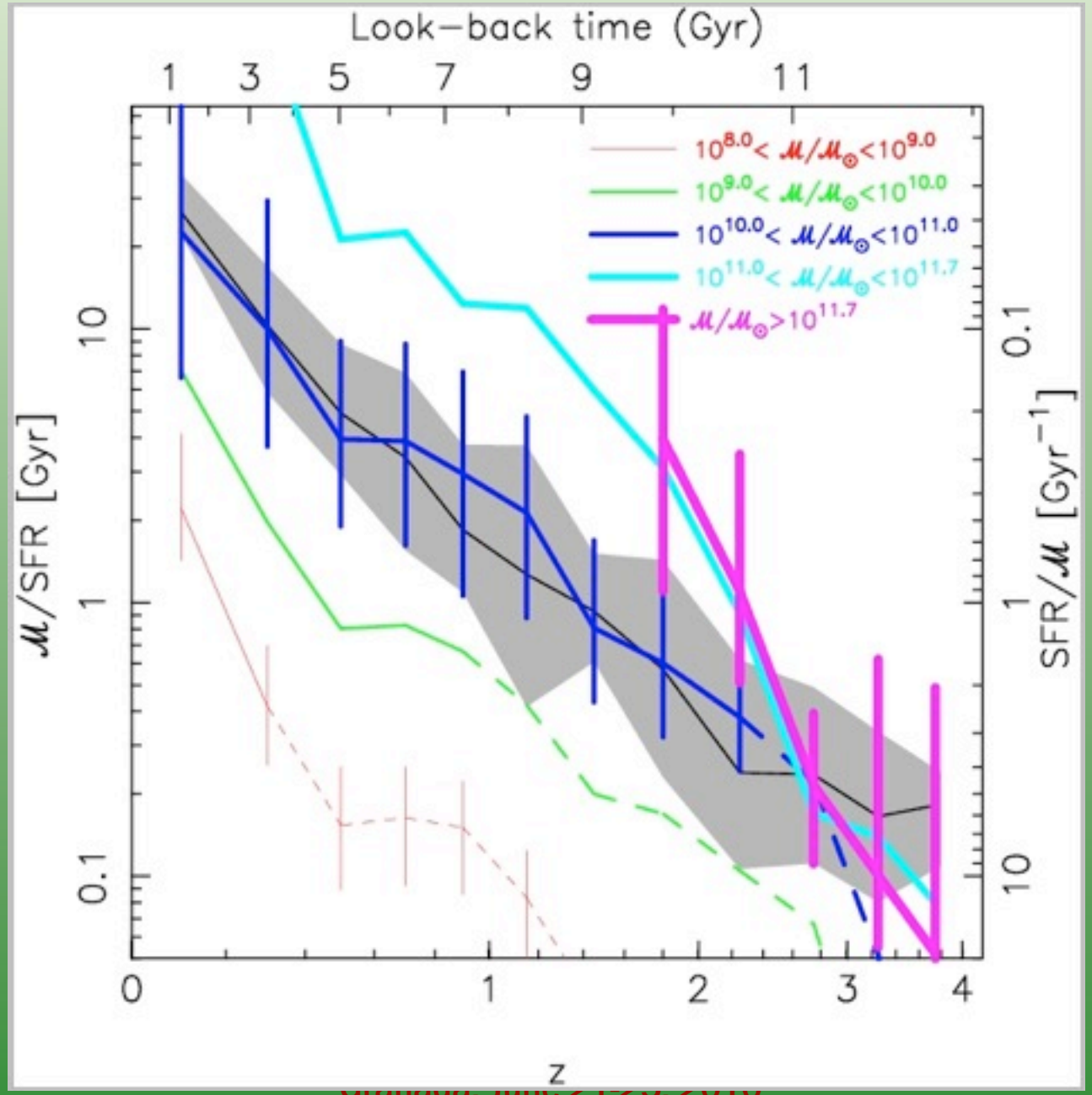
Pérez-González et al. (2008a)

The current paradigm vs. downsizing



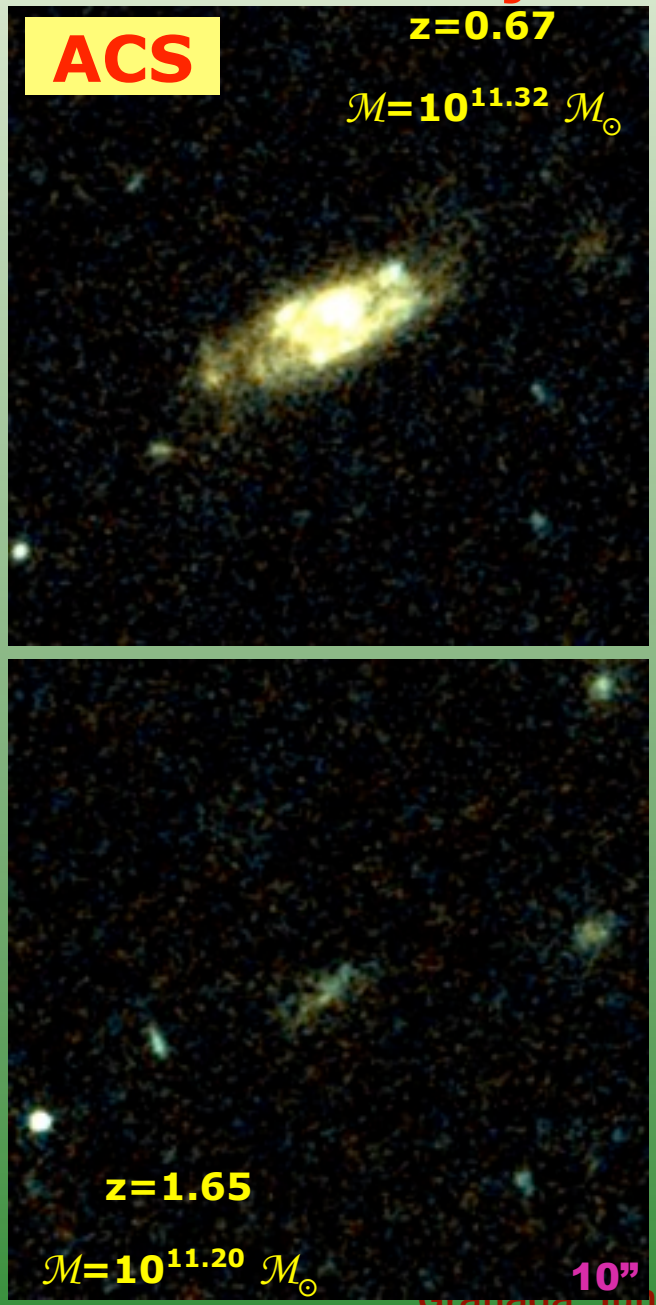
Pérez-González et al. (2008a)

Quantifying downsizing



Pérez-González et al. (2008a)

Mass assembly vs. size/morphology



Pérez-González et al. (2008b)

disks

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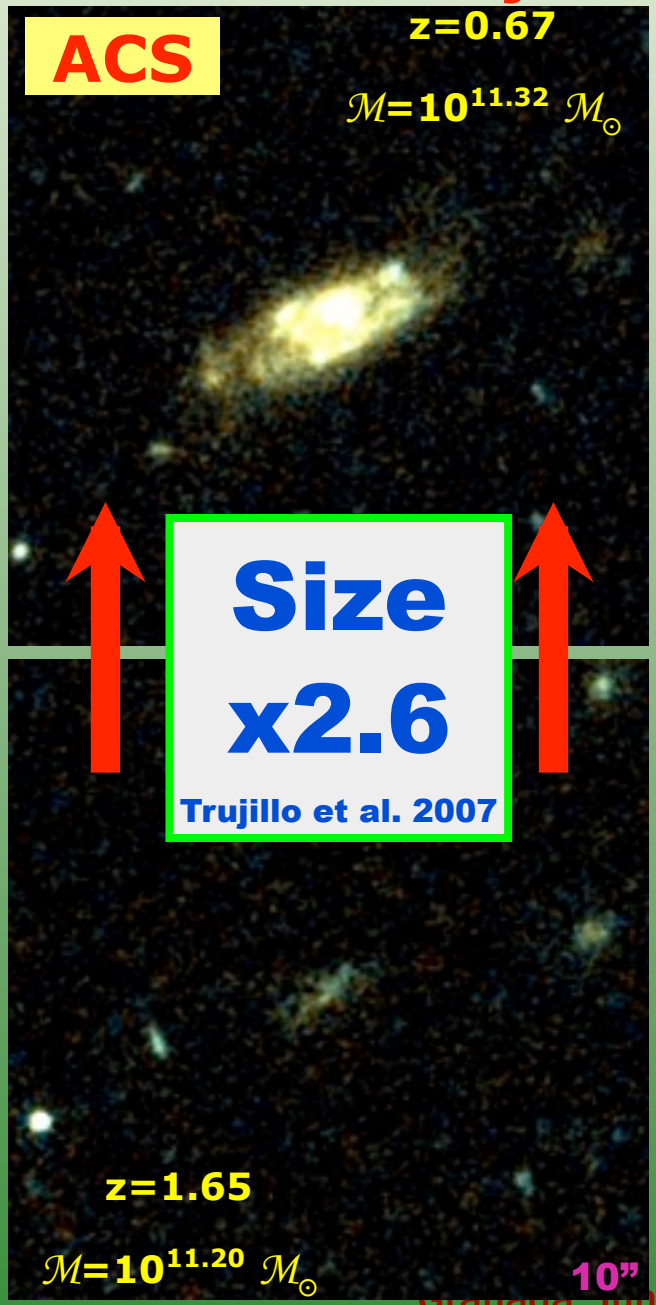

Pérez-González et al. (2008b)

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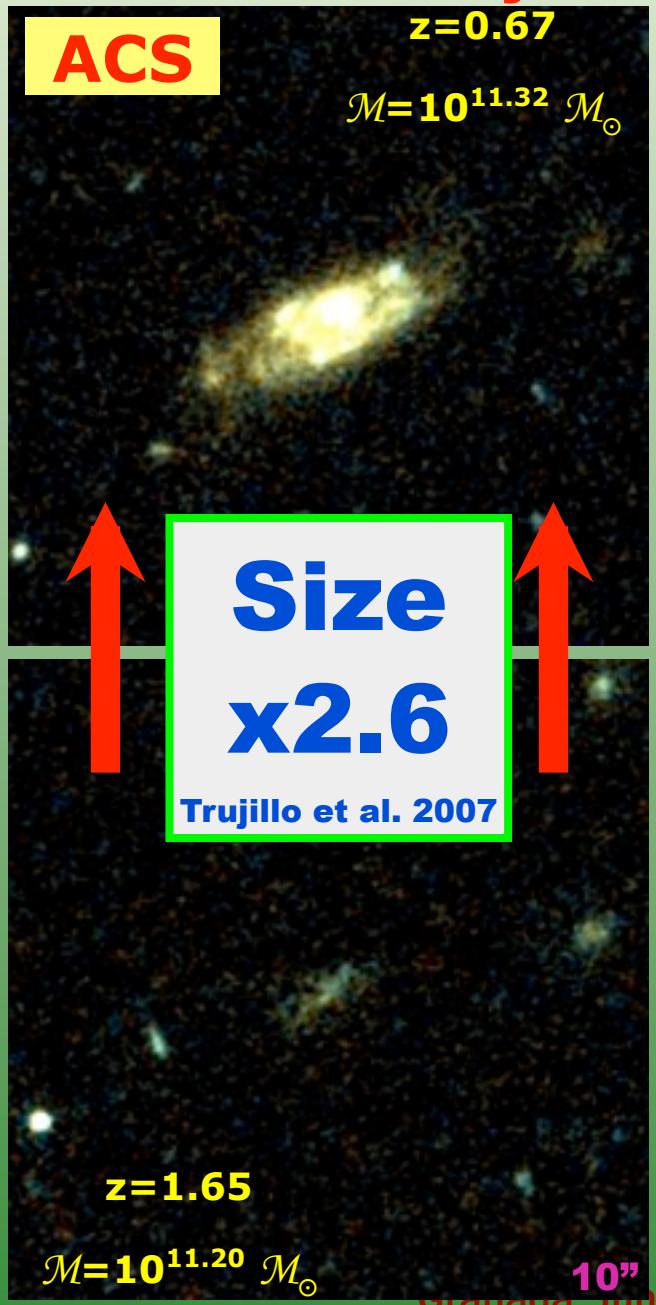

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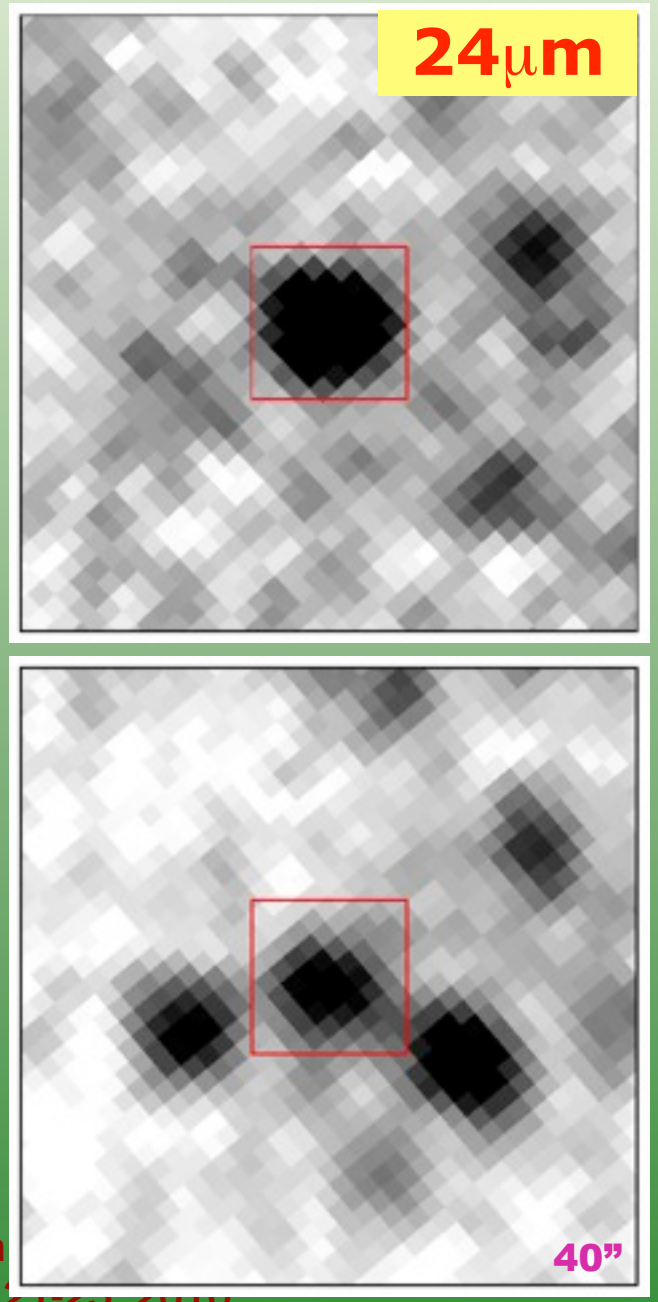

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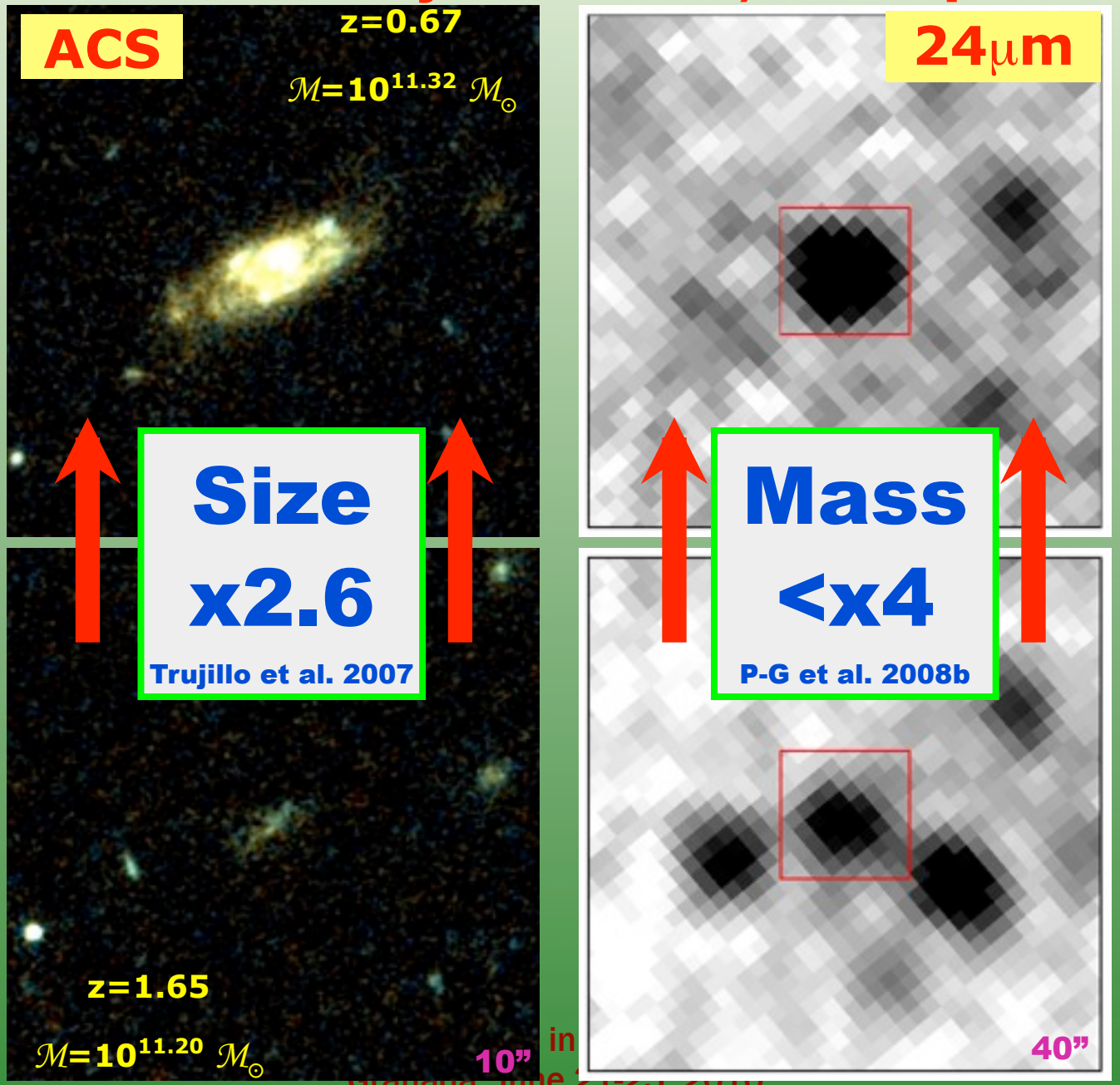

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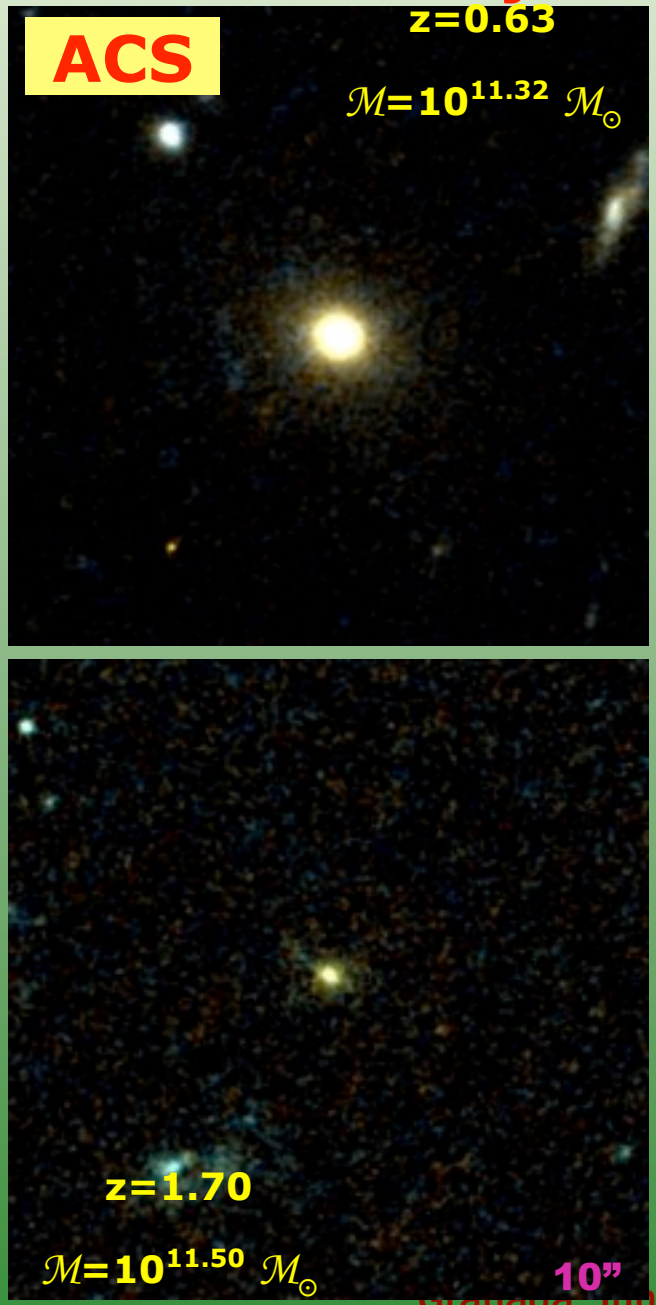

Pérez-González et al. (2008b)

spheroids

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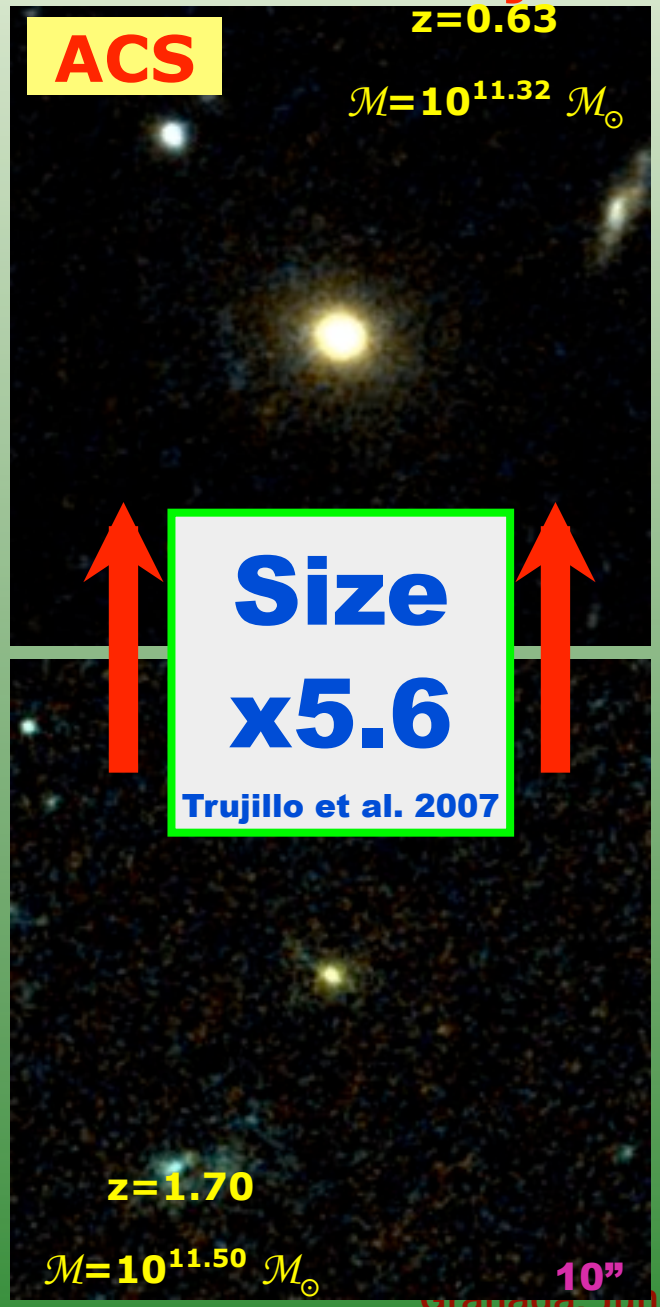

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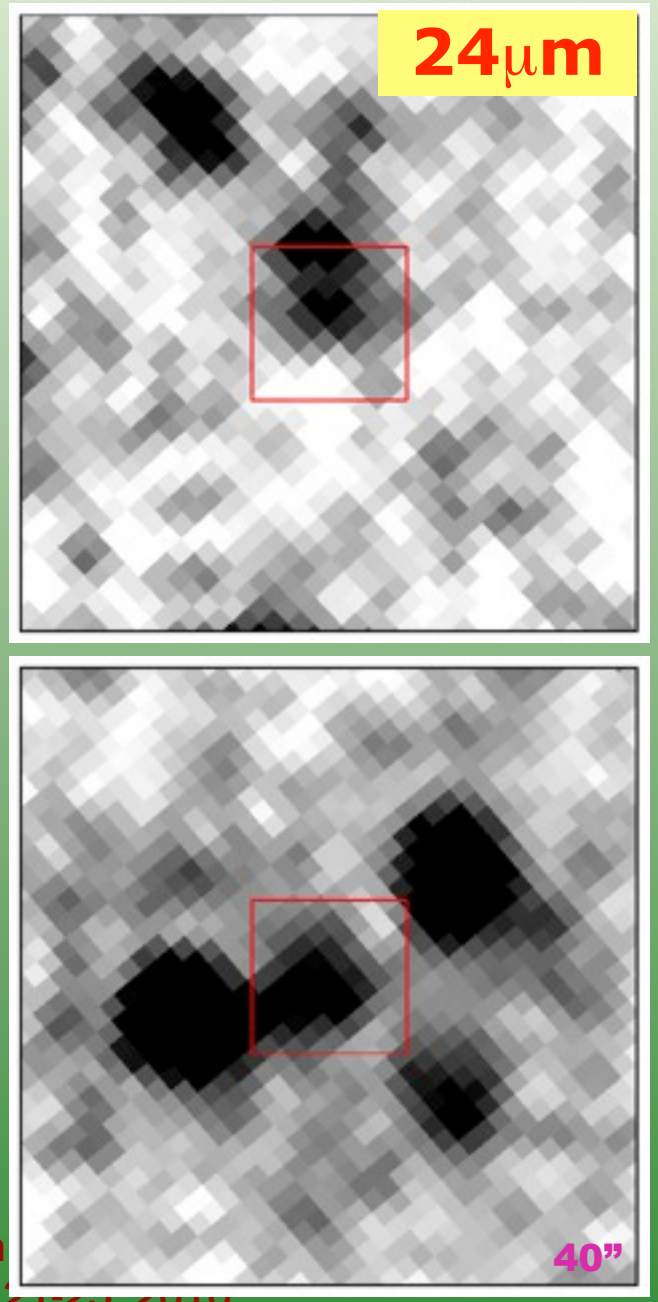

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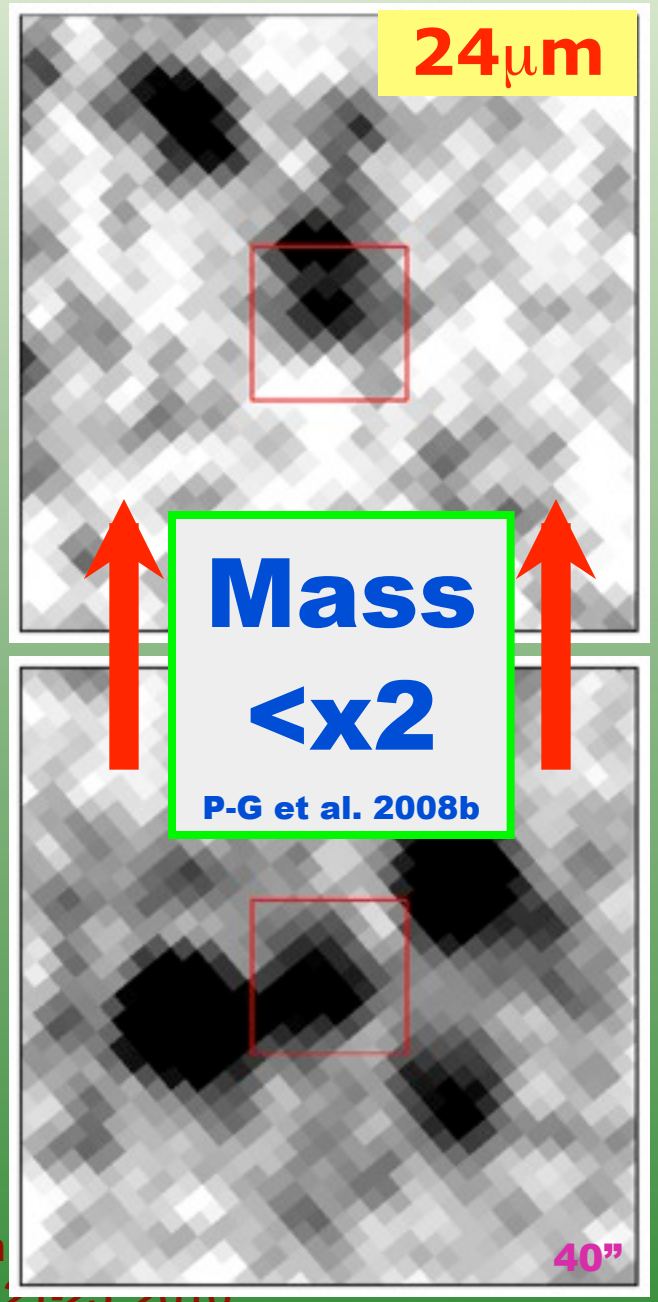


Size x5.6

Trujillo et al. 2007

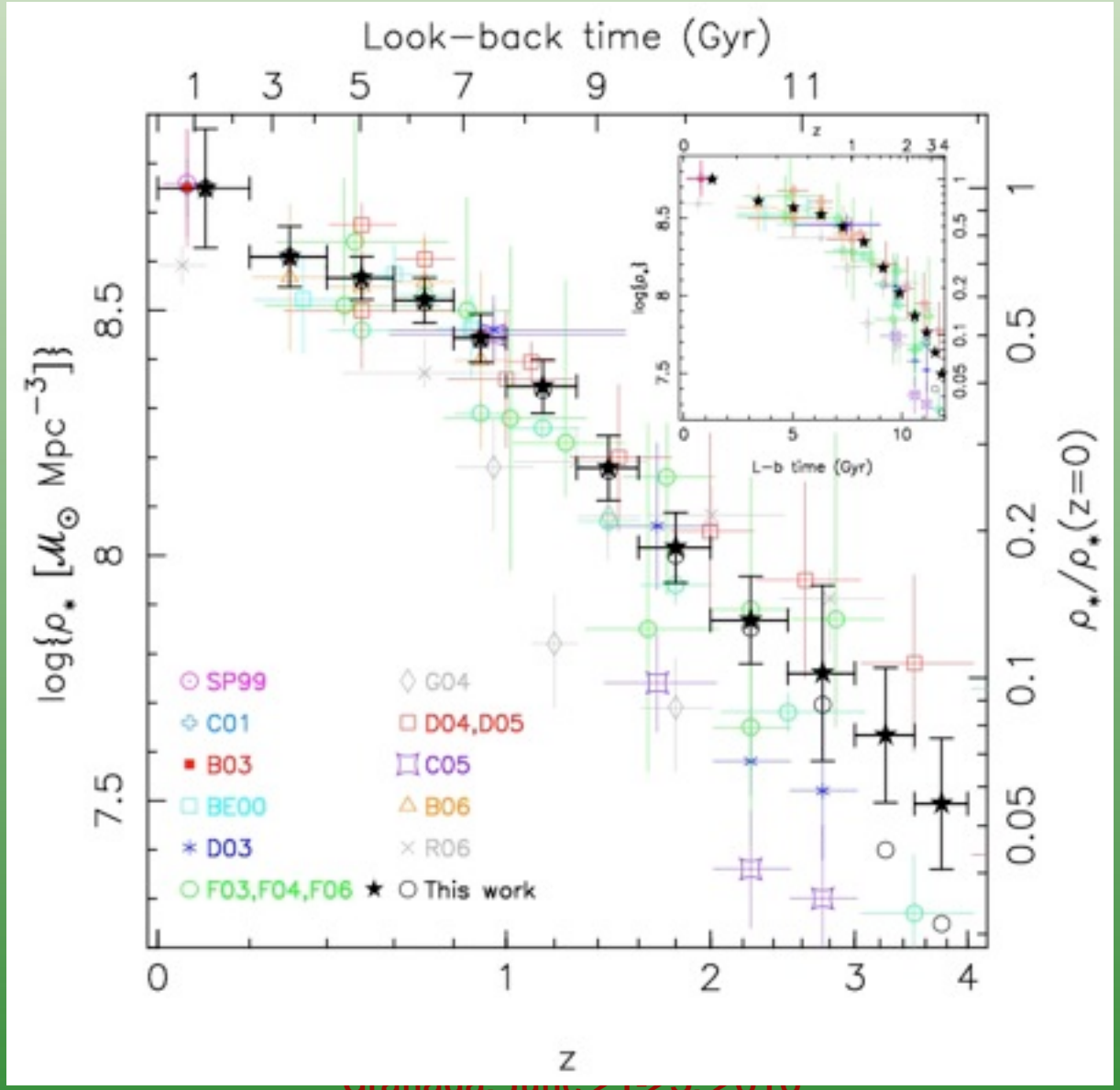
Mass <x2

P-G et al. 2008b

Pérez-González et al. (2008b)

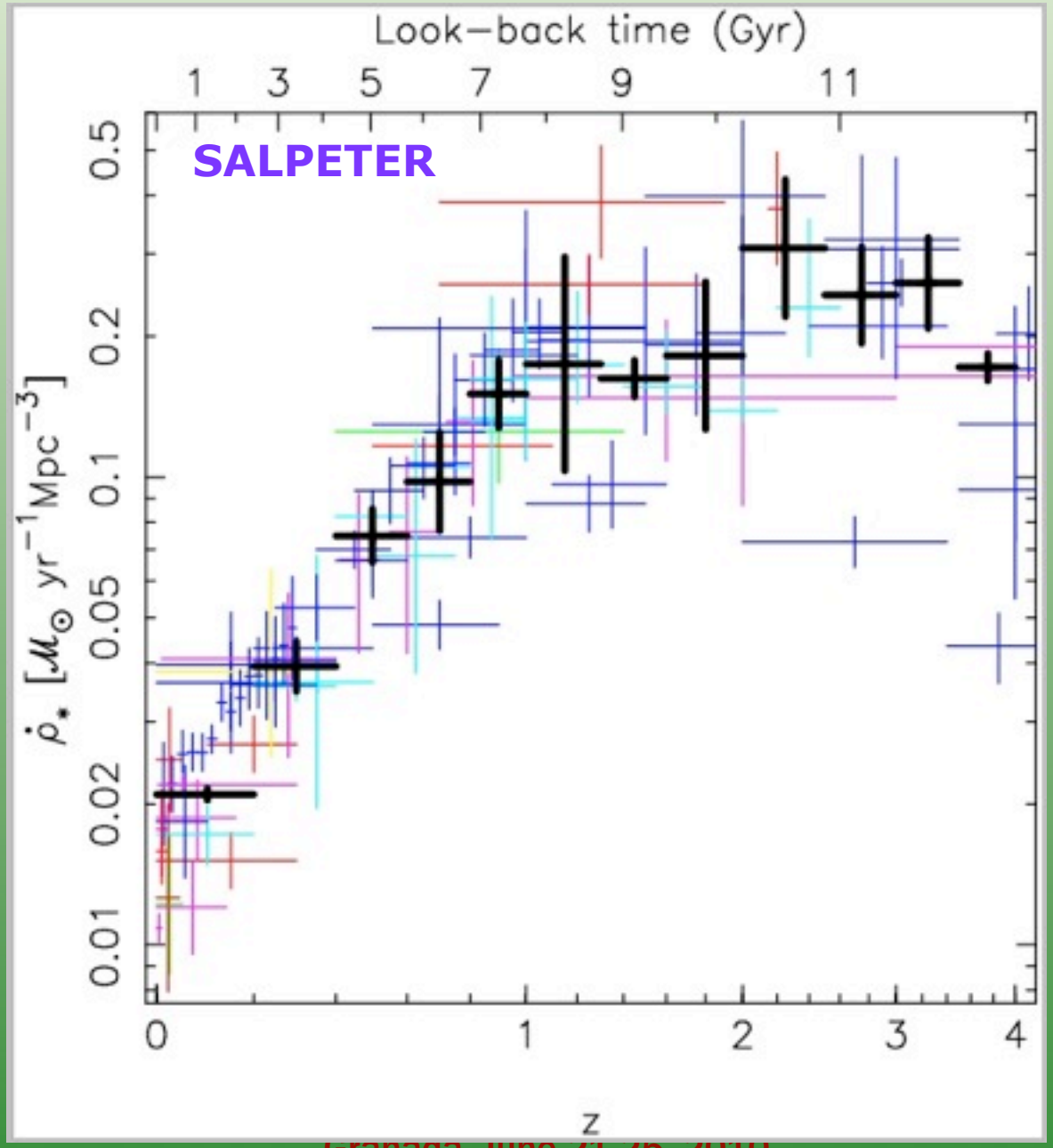
spheroids

More fun: evolution of the



Pérez-González et al. (2008a)

Do we really understand galaxy formation?



Pérez-González et al. (2005,2008a)

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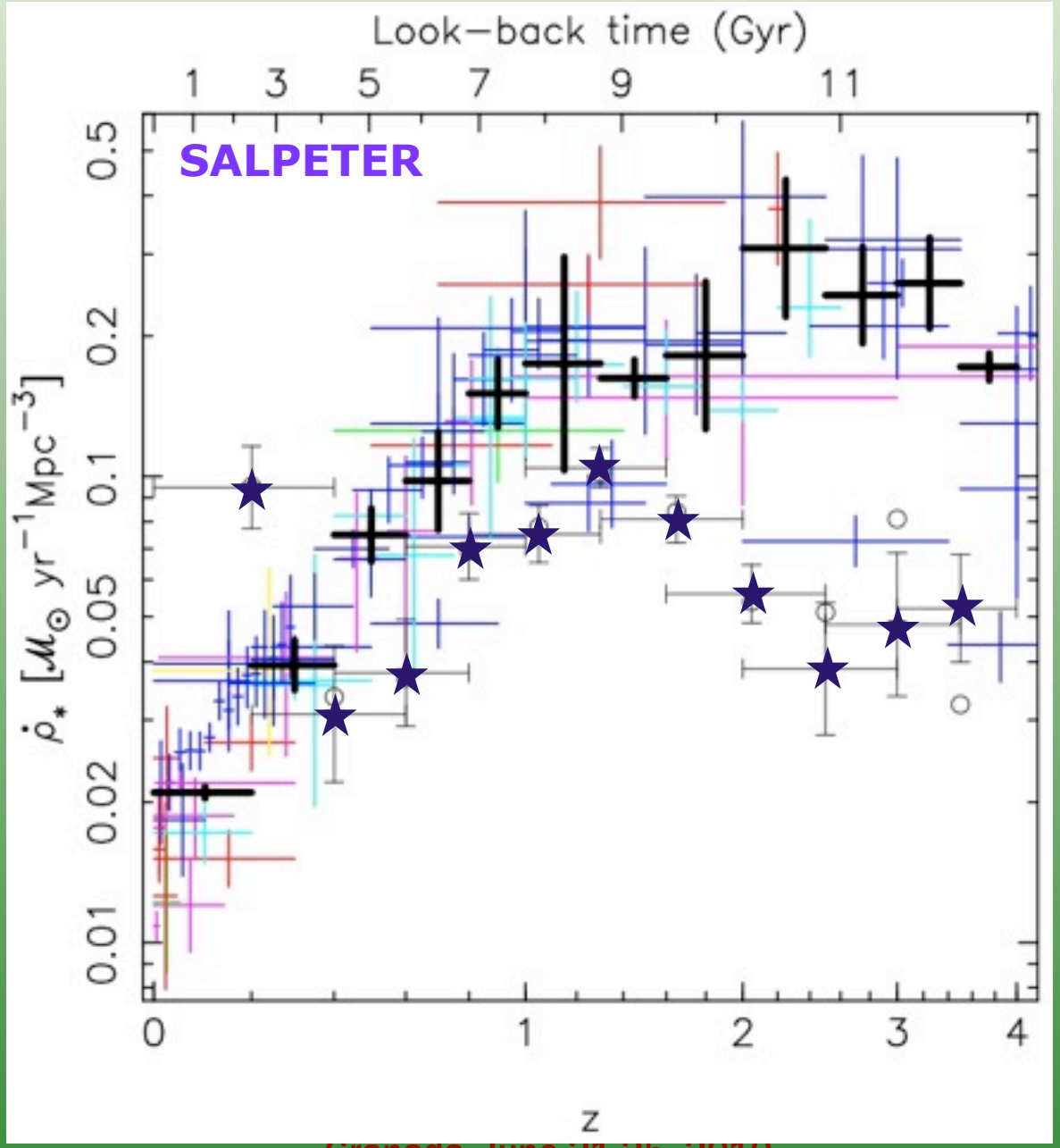

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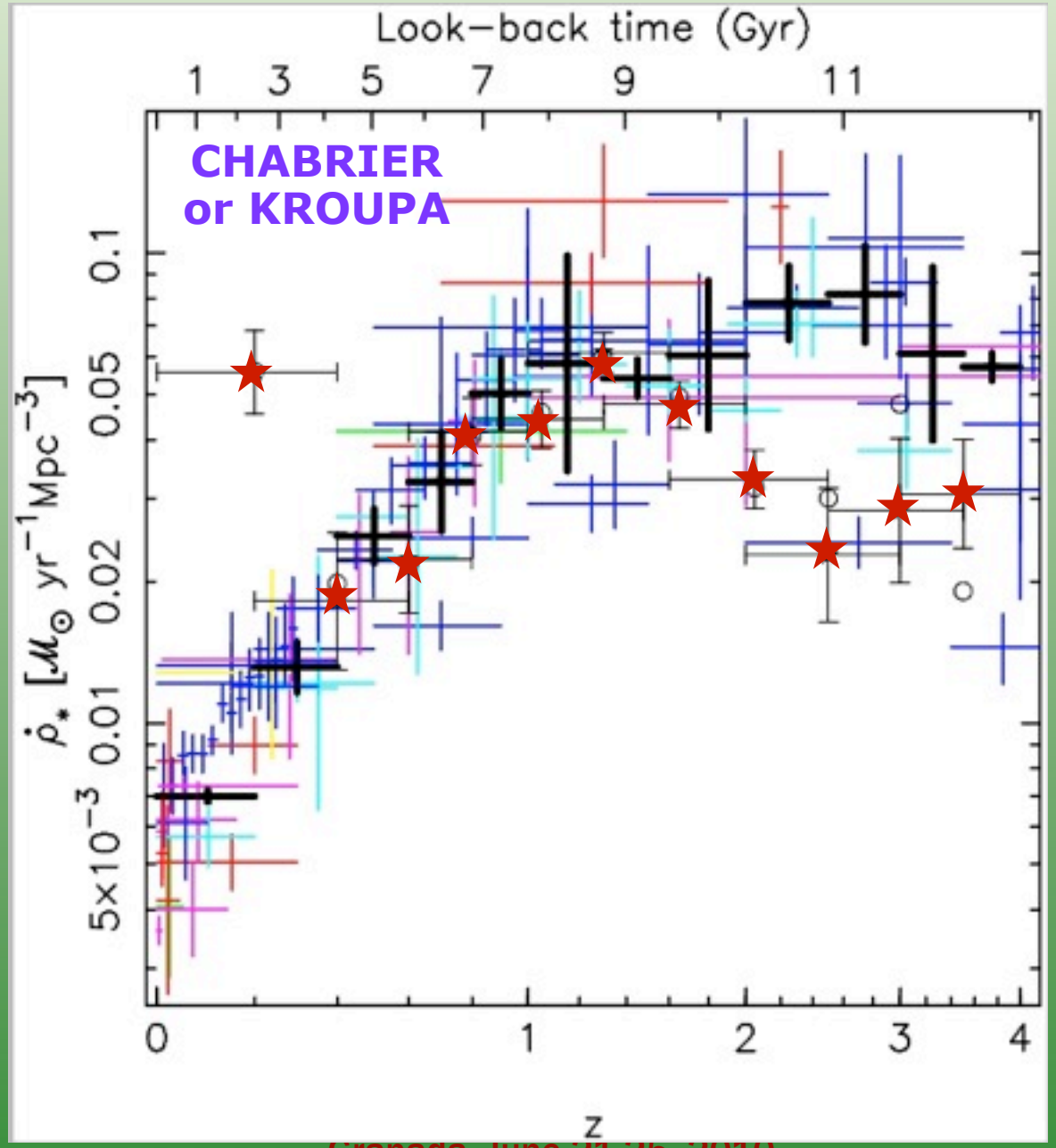

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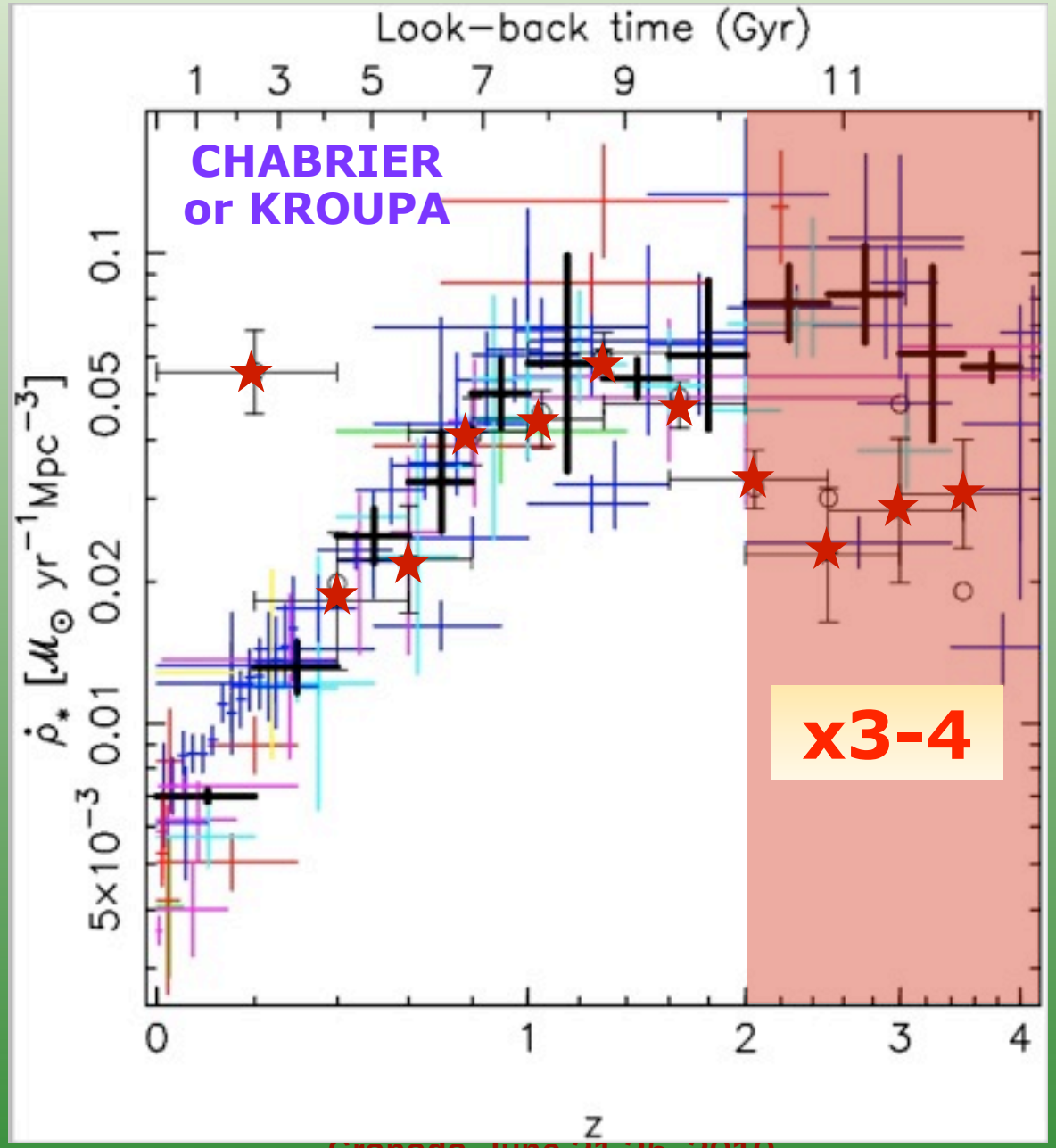

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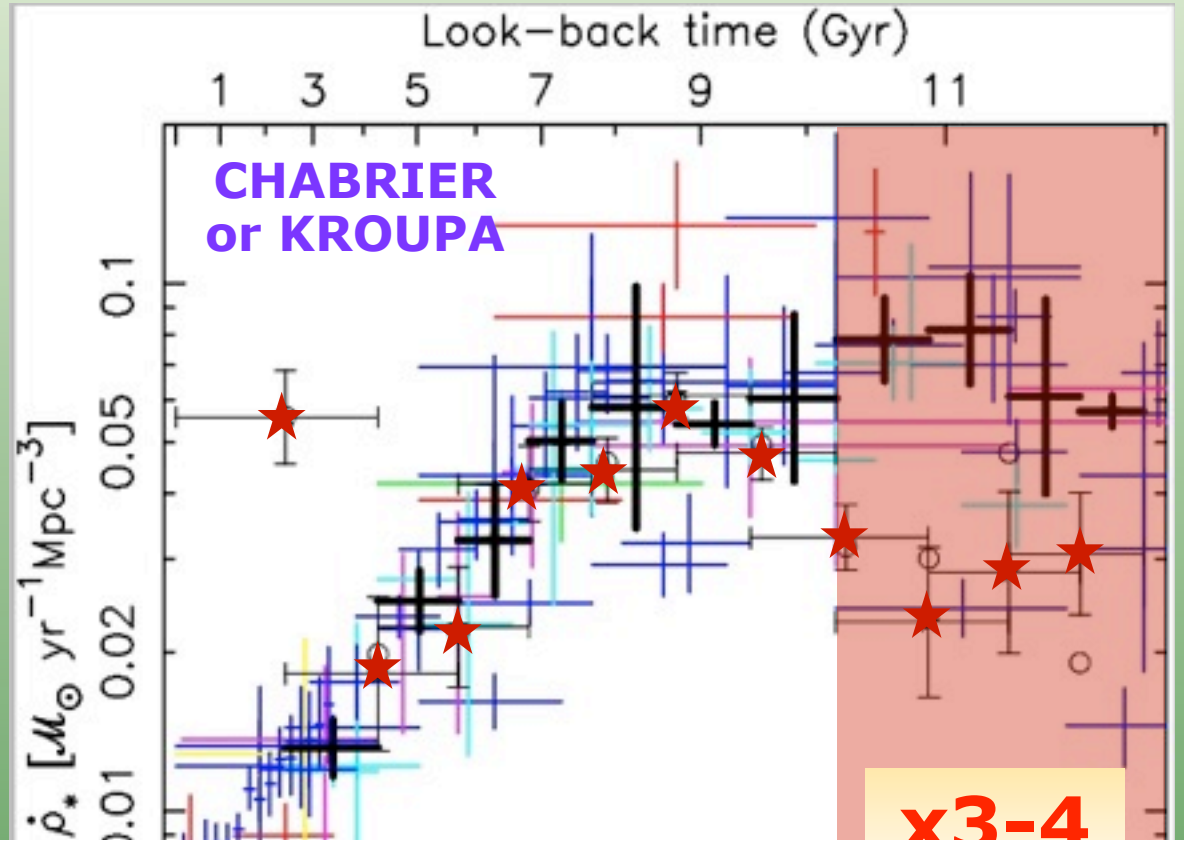

Pérez-González et al. (20

WEIRD EXPLANATIONS CHART (STARTING FROM WEIRDEST)

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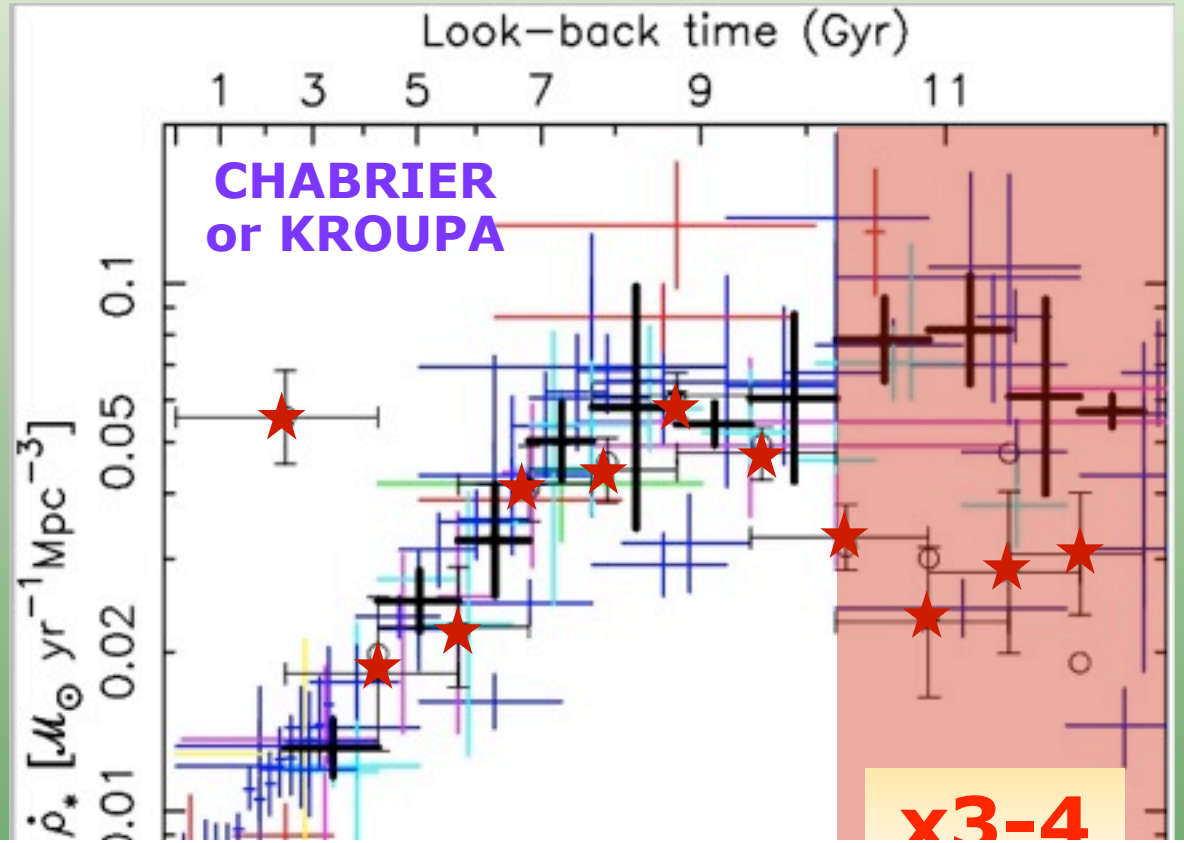

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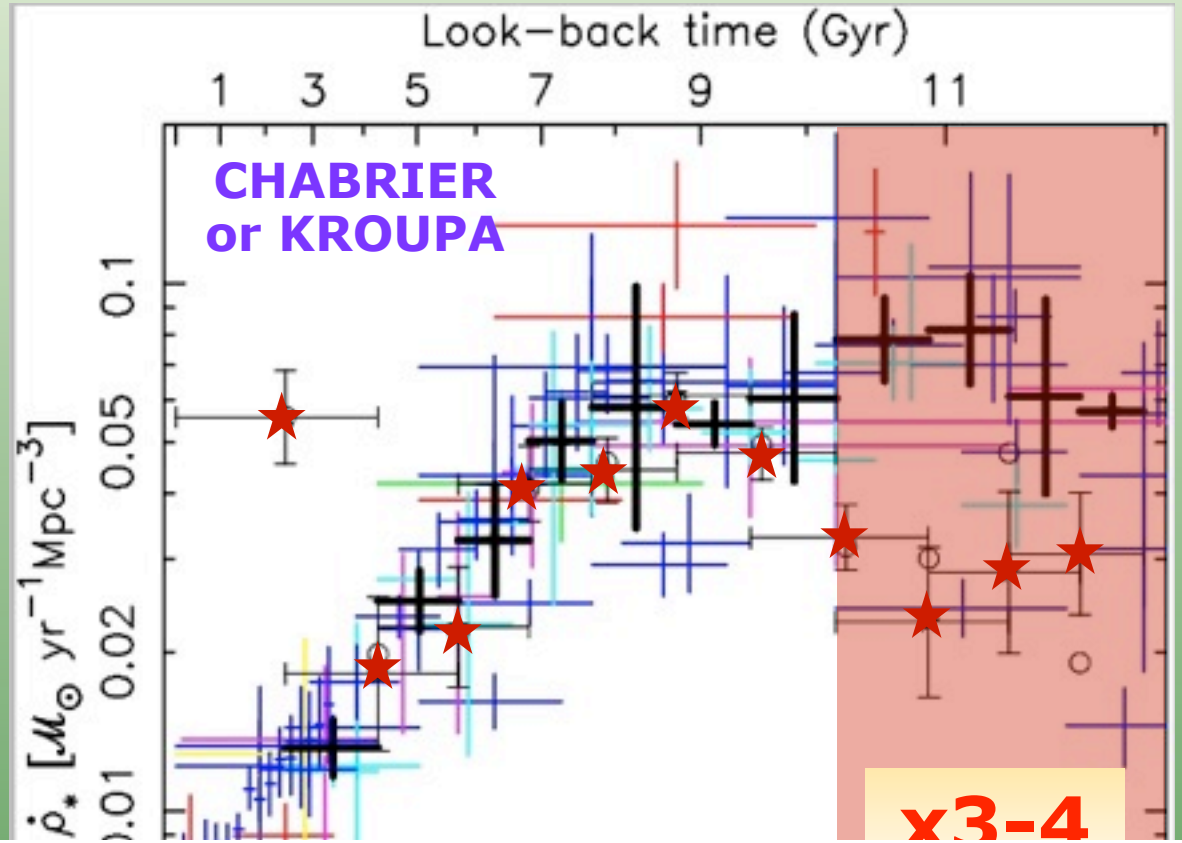

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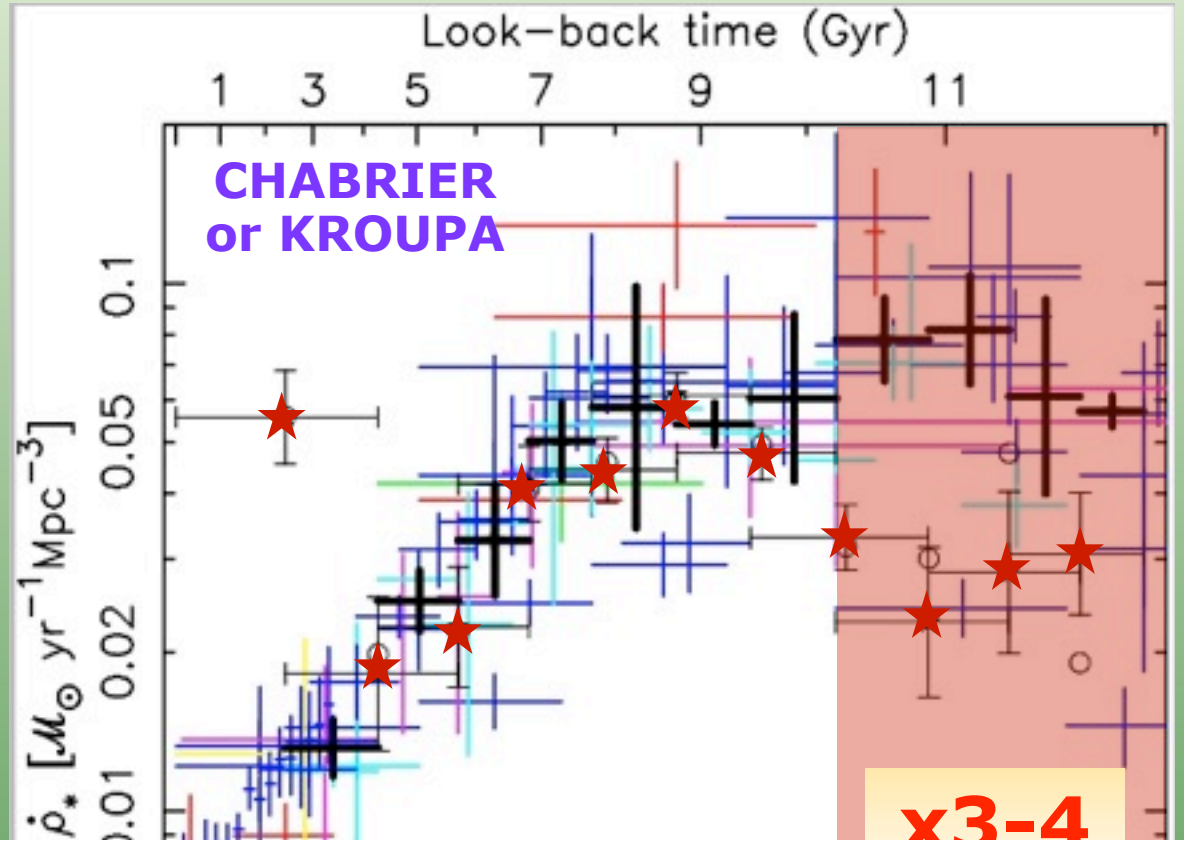

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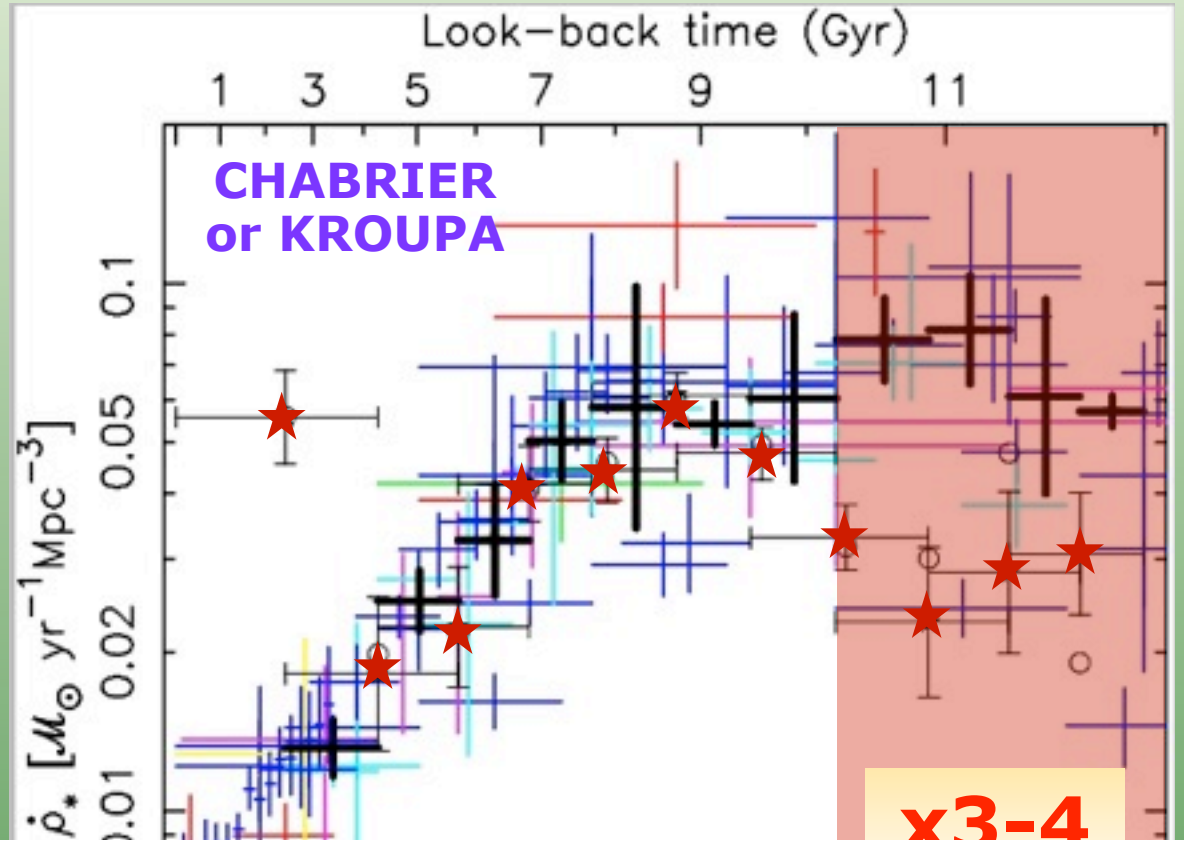

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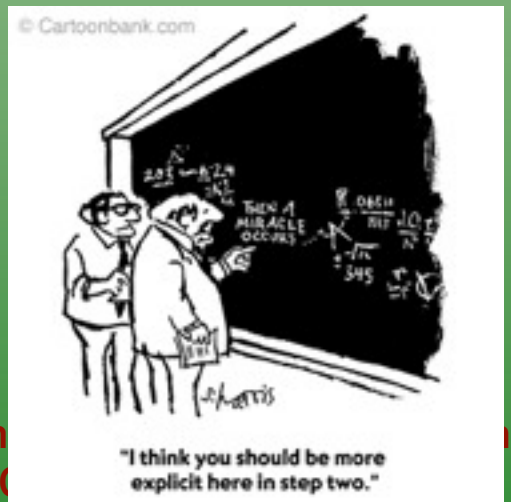
4. **IMF not universal** (also some Galactic evidence: Maness+ 07)
4. **Change in star formation mode** (burst mode vs. continuous)

And now what ? How can we advance



Extrem iverse

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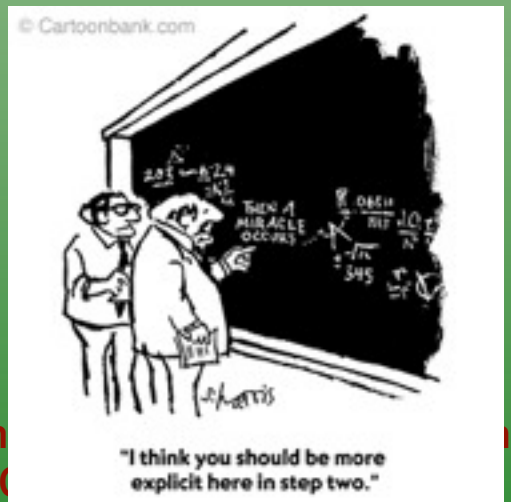

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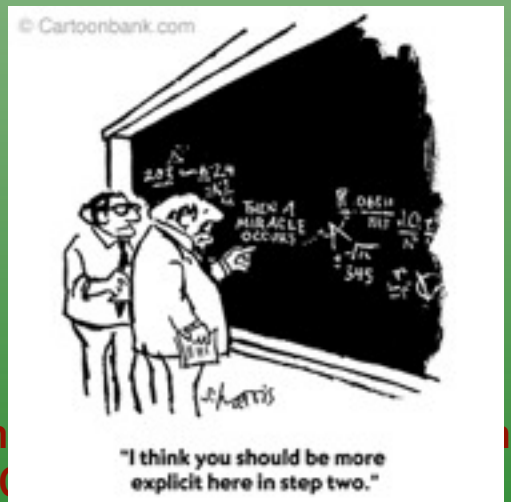

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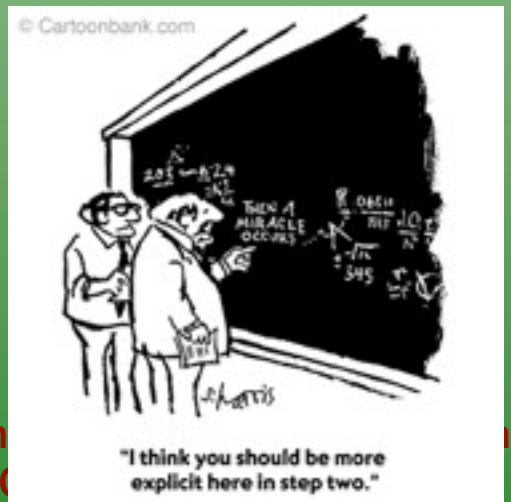

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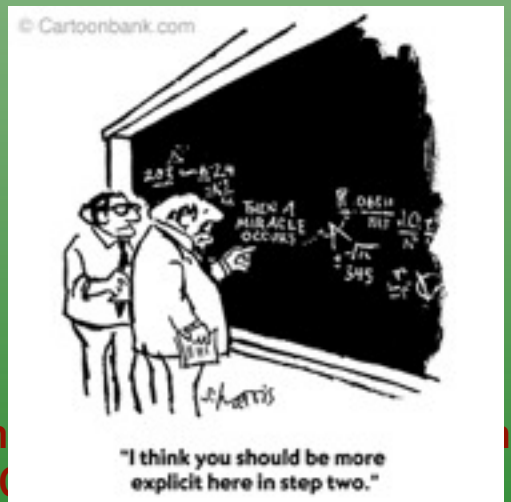

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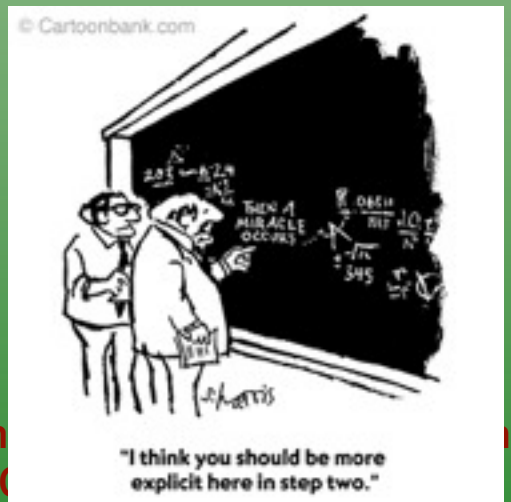
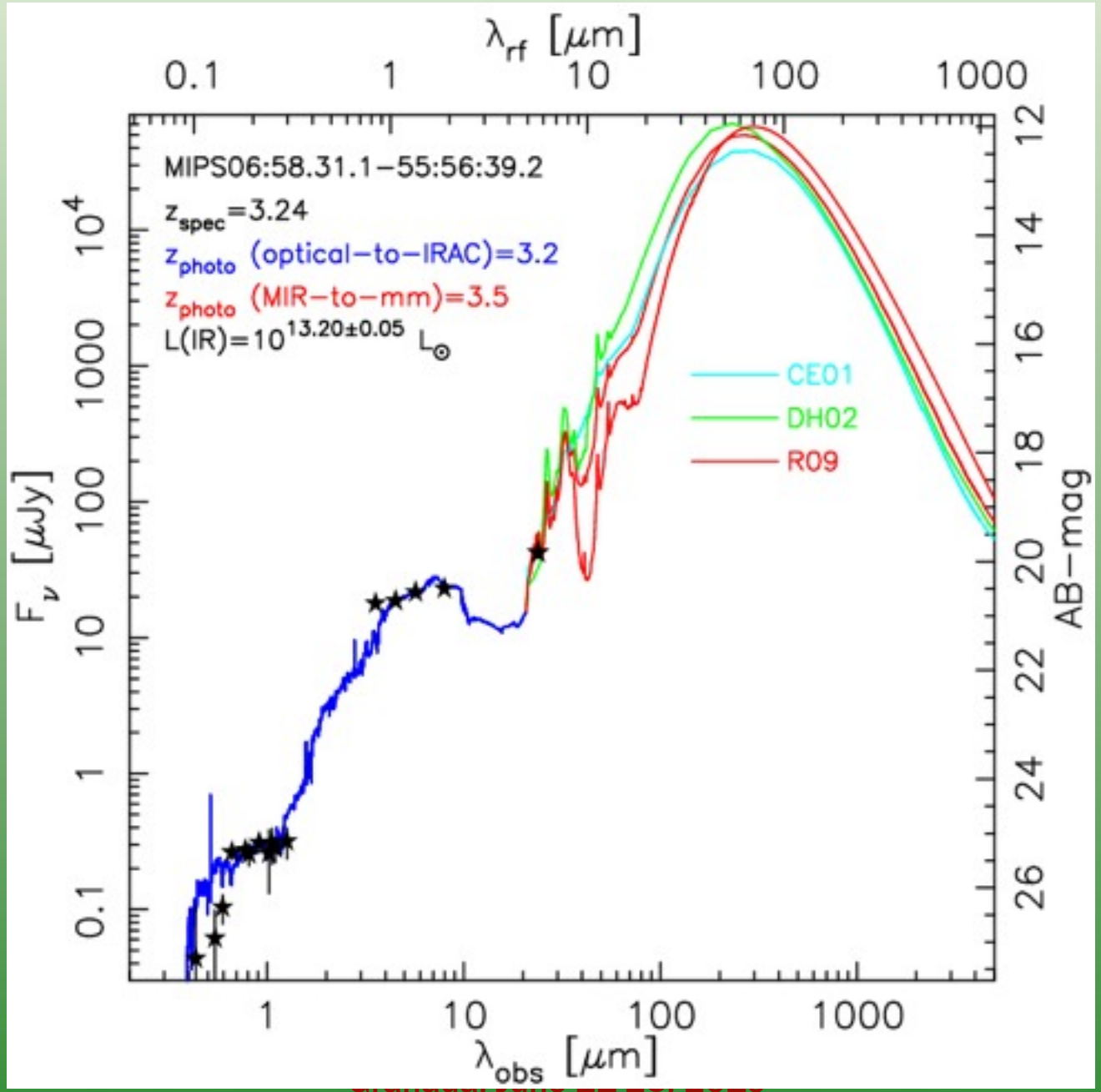
  - **Better physics in modeling of data: synthesis models in the NIR, dust emission models, IMF, AGN/SF interaction, star formation quenching, etc...**



Better IR-based SFRs: *Herschel* data



Adapted from Pérez-González et al. (2010)

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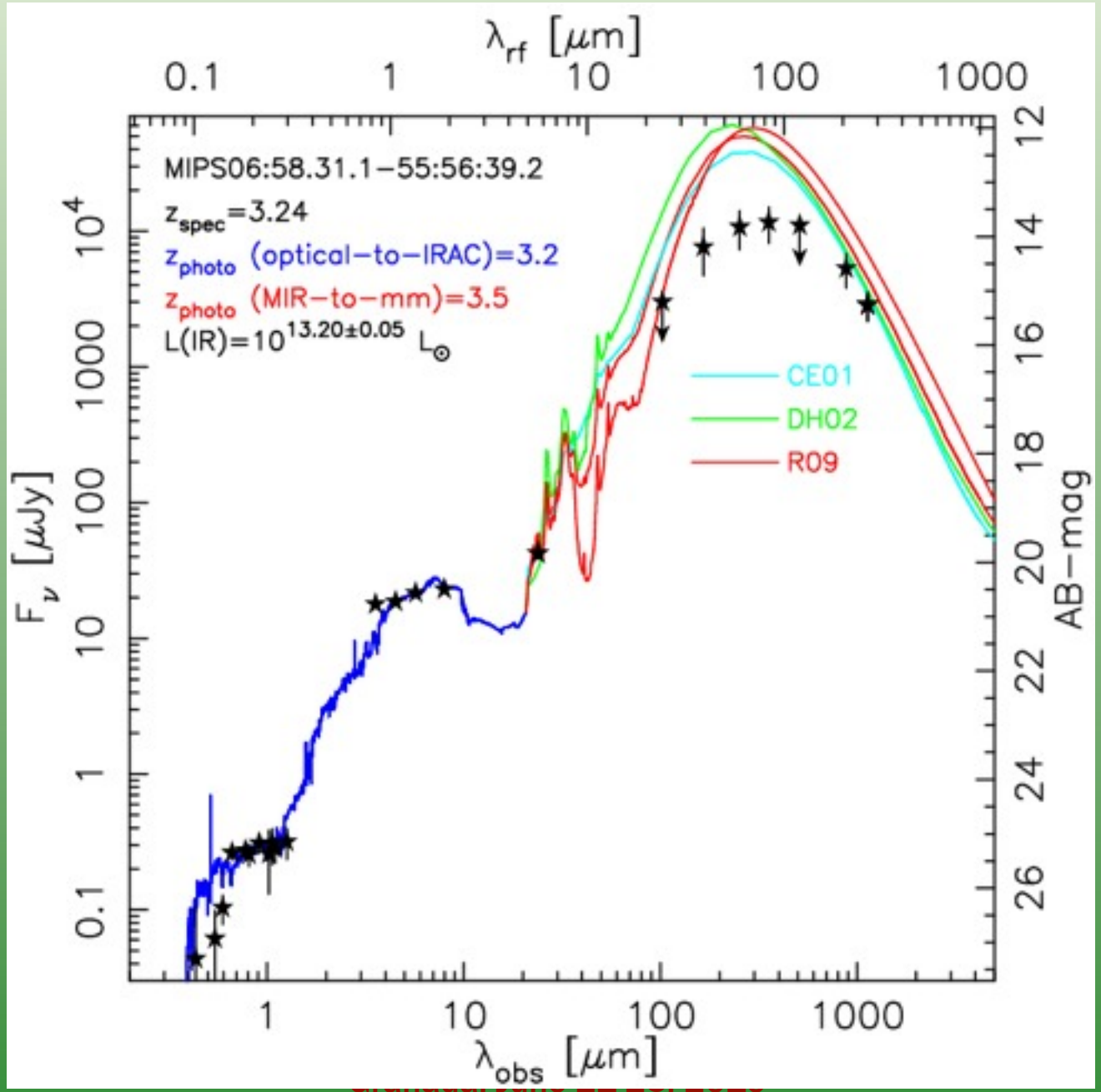

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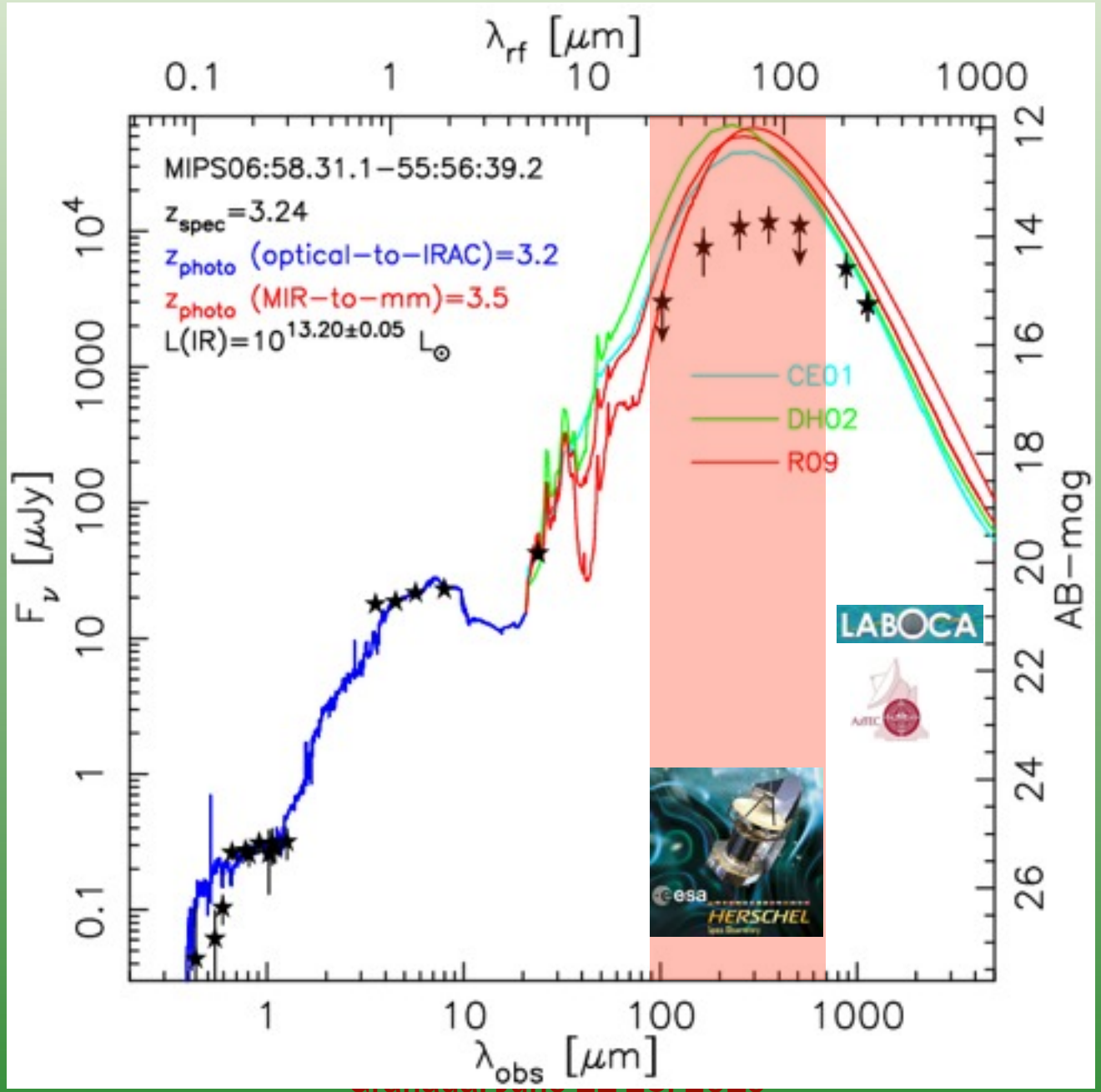

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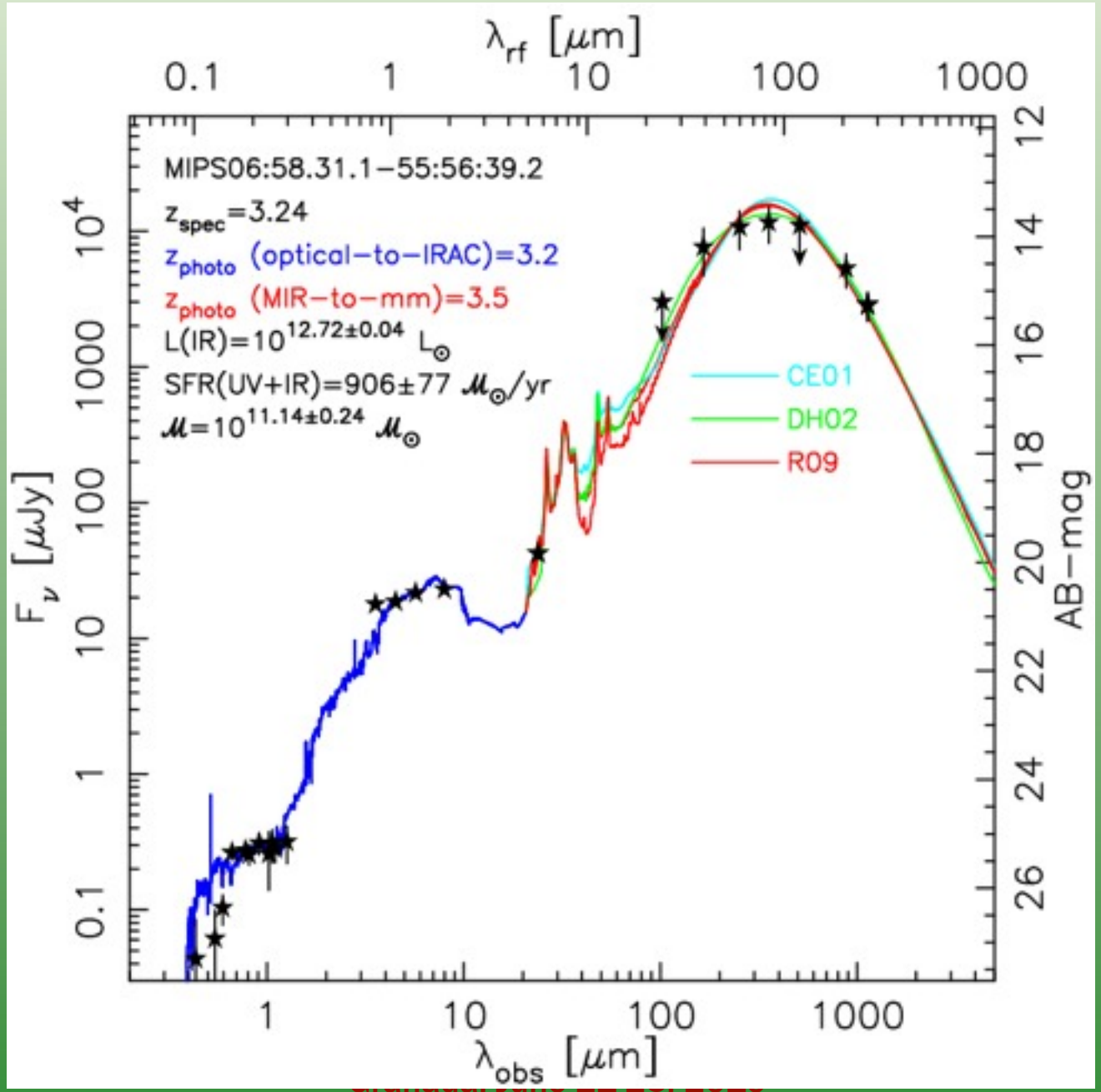
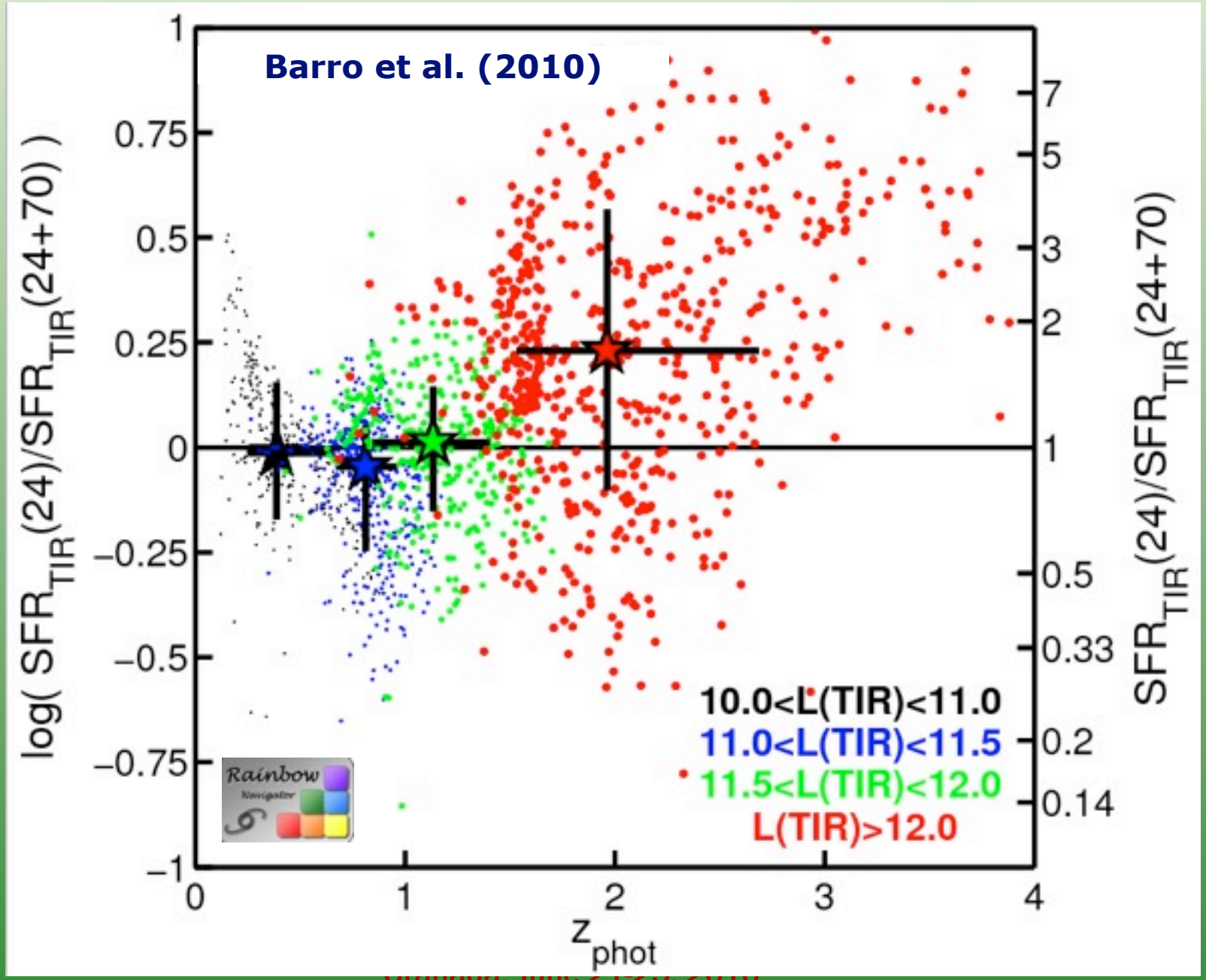


Adapted from Pérez-González et al. (2010)

Better IR-based SFRs: also with *Spitzer*!!



See also:
Papovich et al. (2007)
Rigby et al. (2008)

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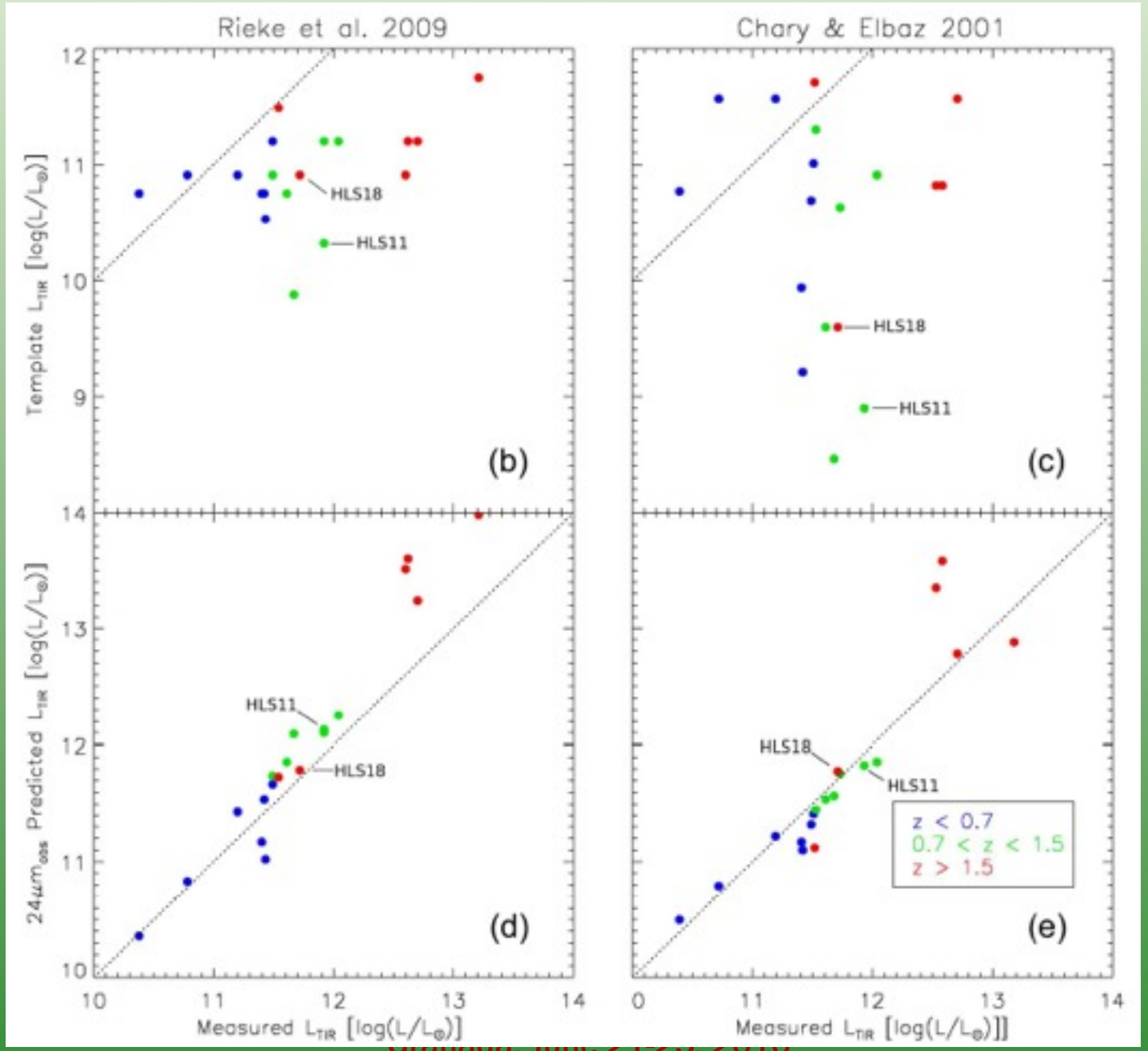
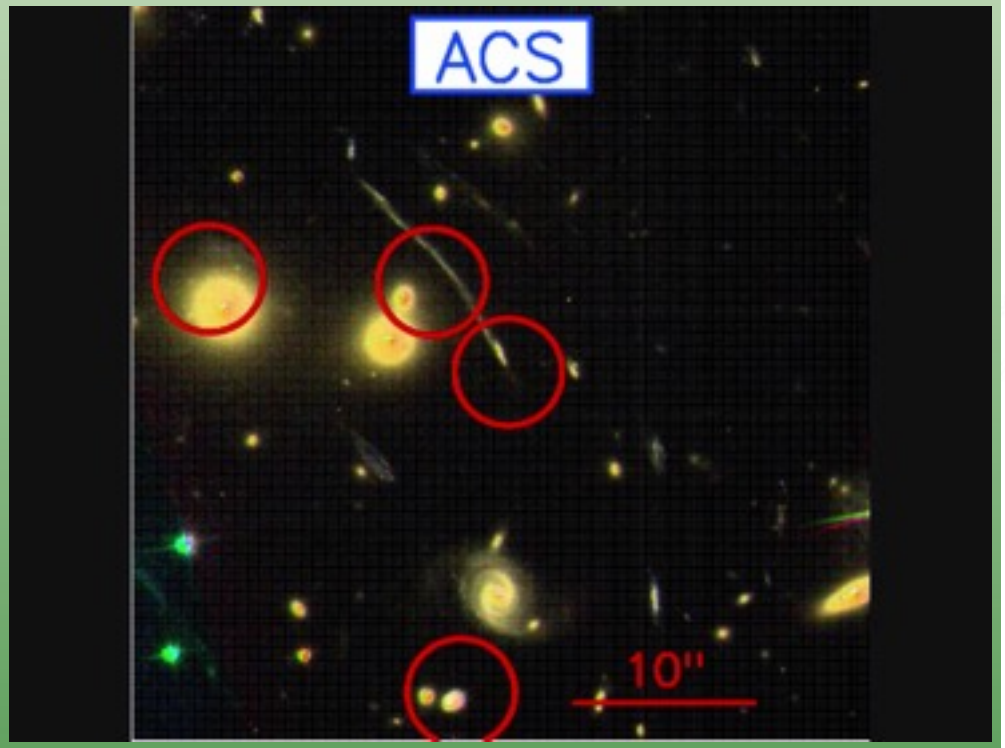
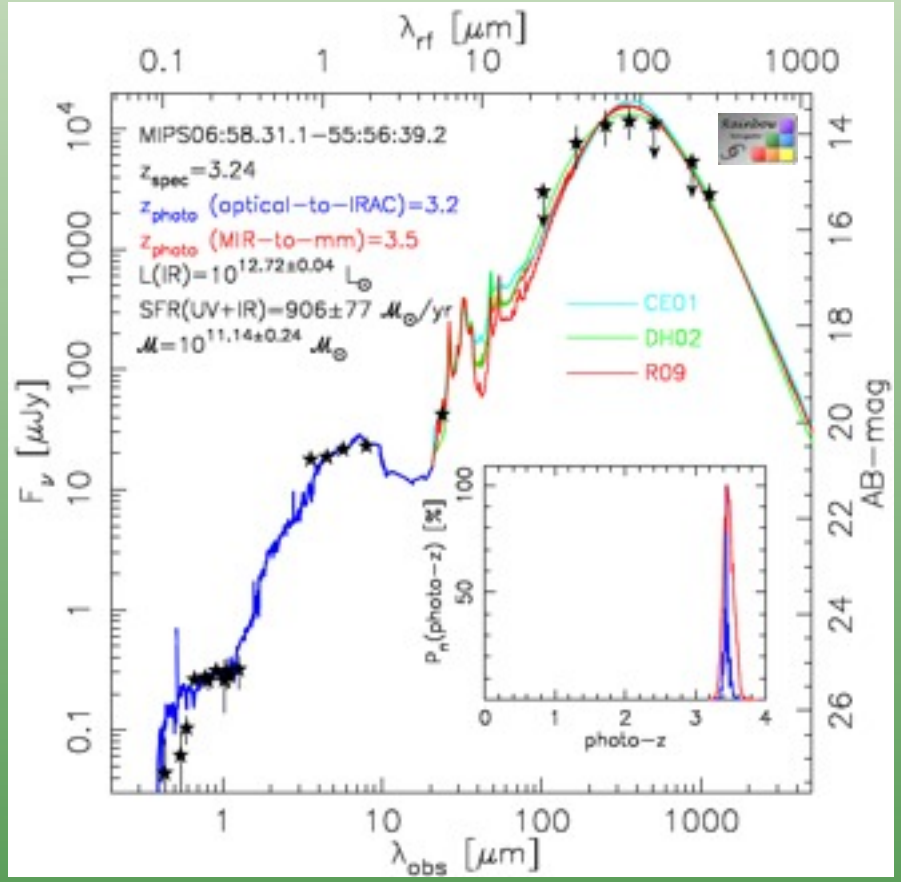


Rex et al. (2010)

See also Elbaz et al. (2010)

What can *Herschel* give us?





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Need for better dust emission templates

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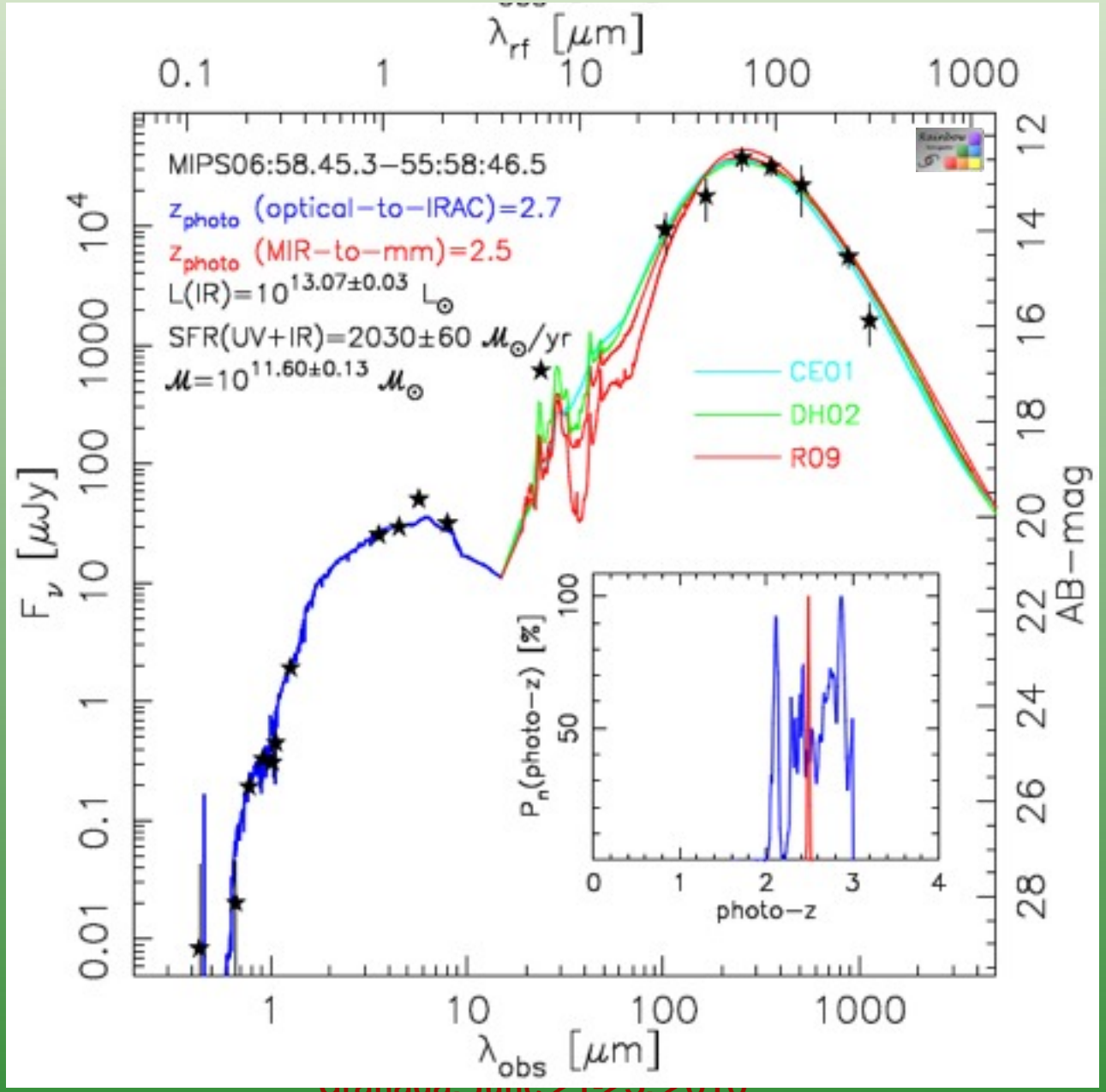

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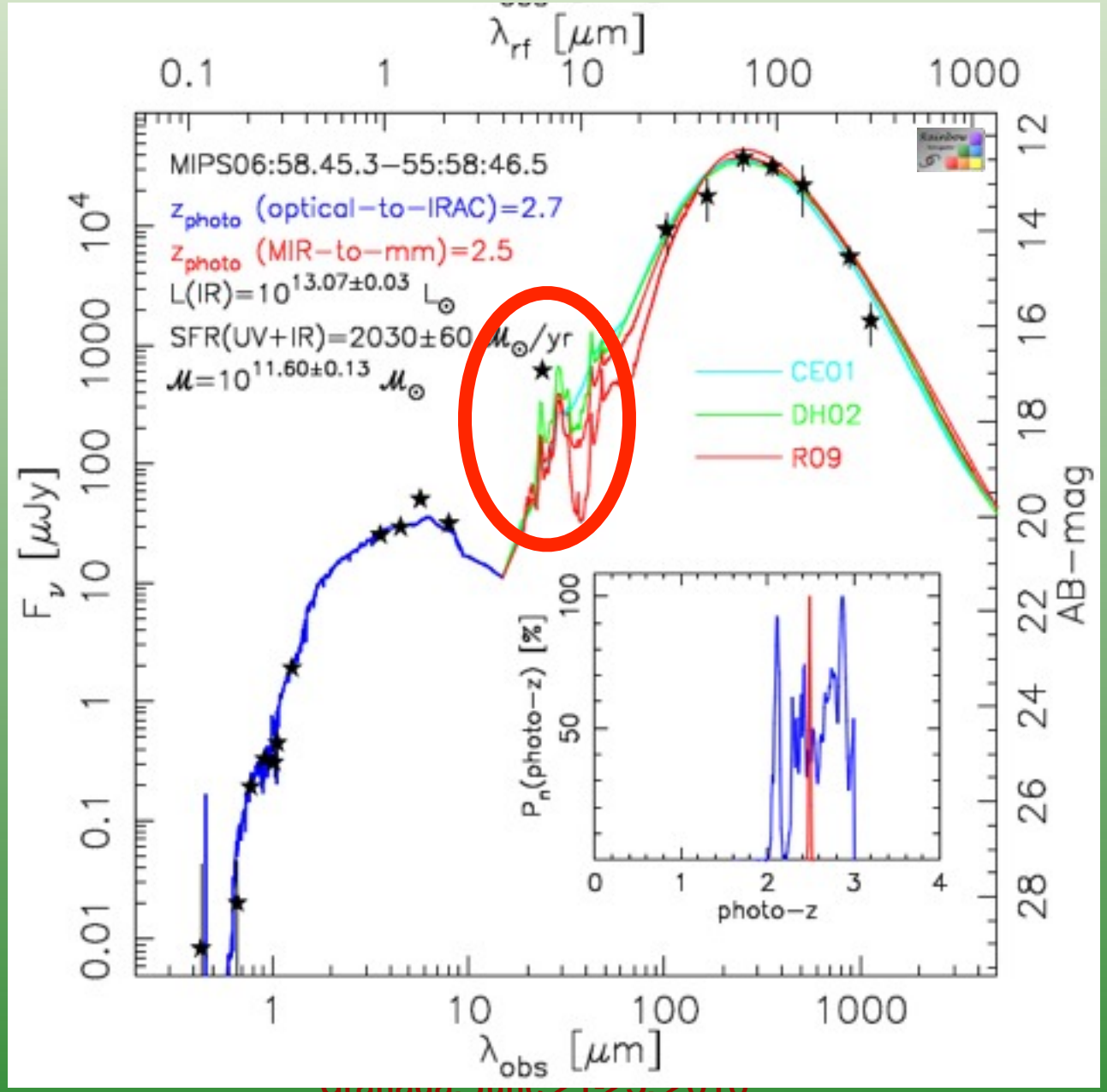

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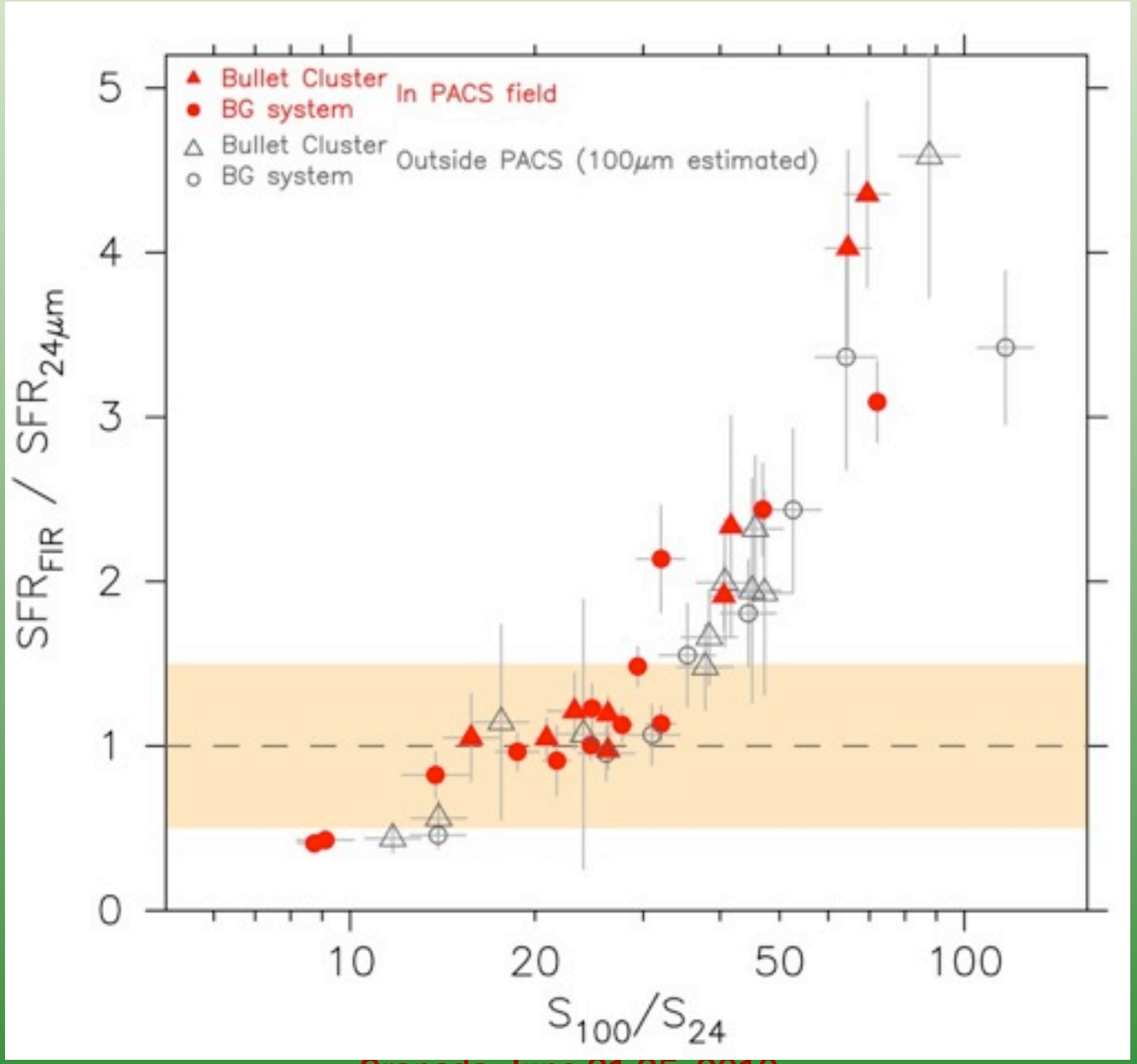
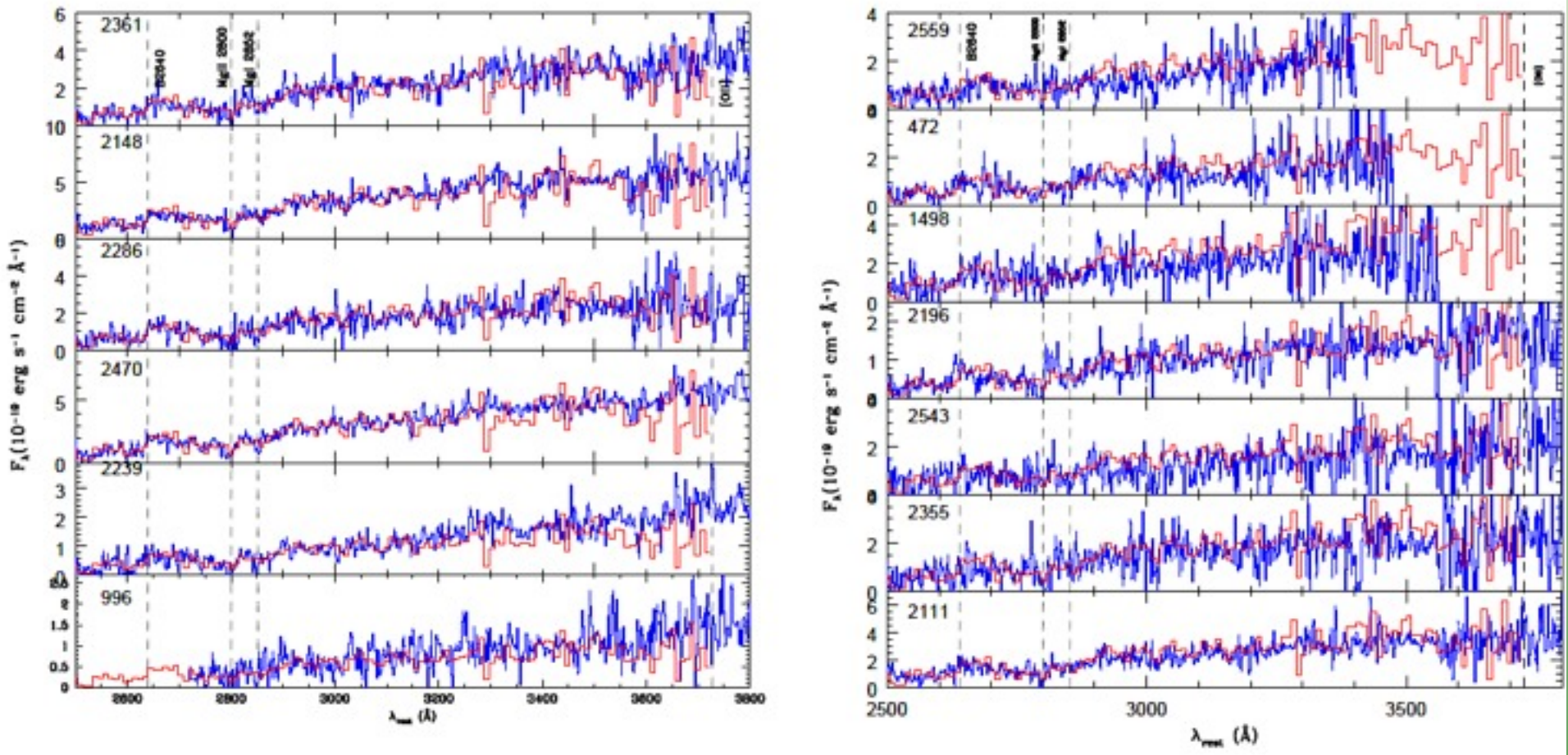


Rawle et al. (2010)

Characterizing in detail high-z galaxies



Cimatti et al. (2008)

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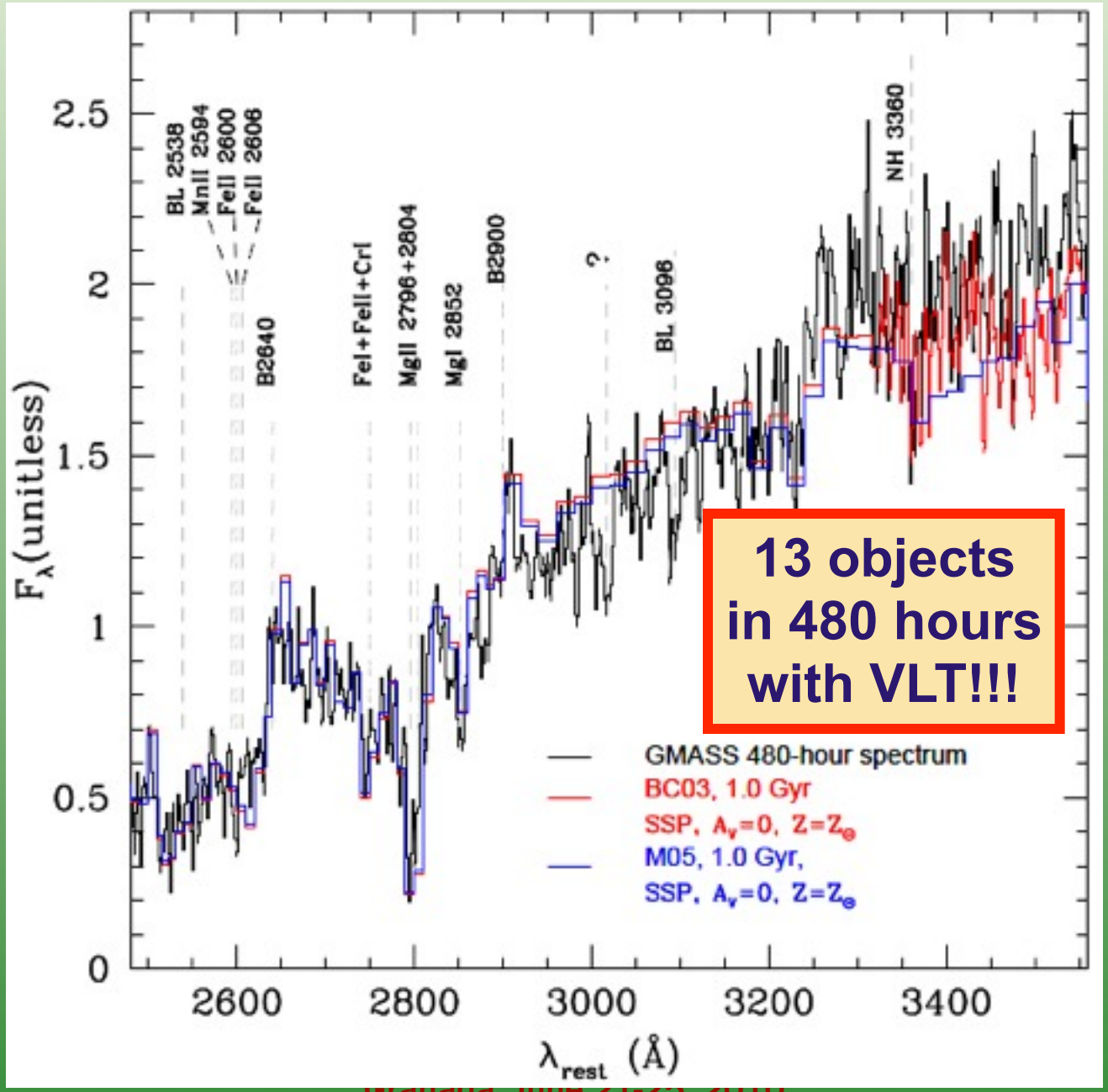

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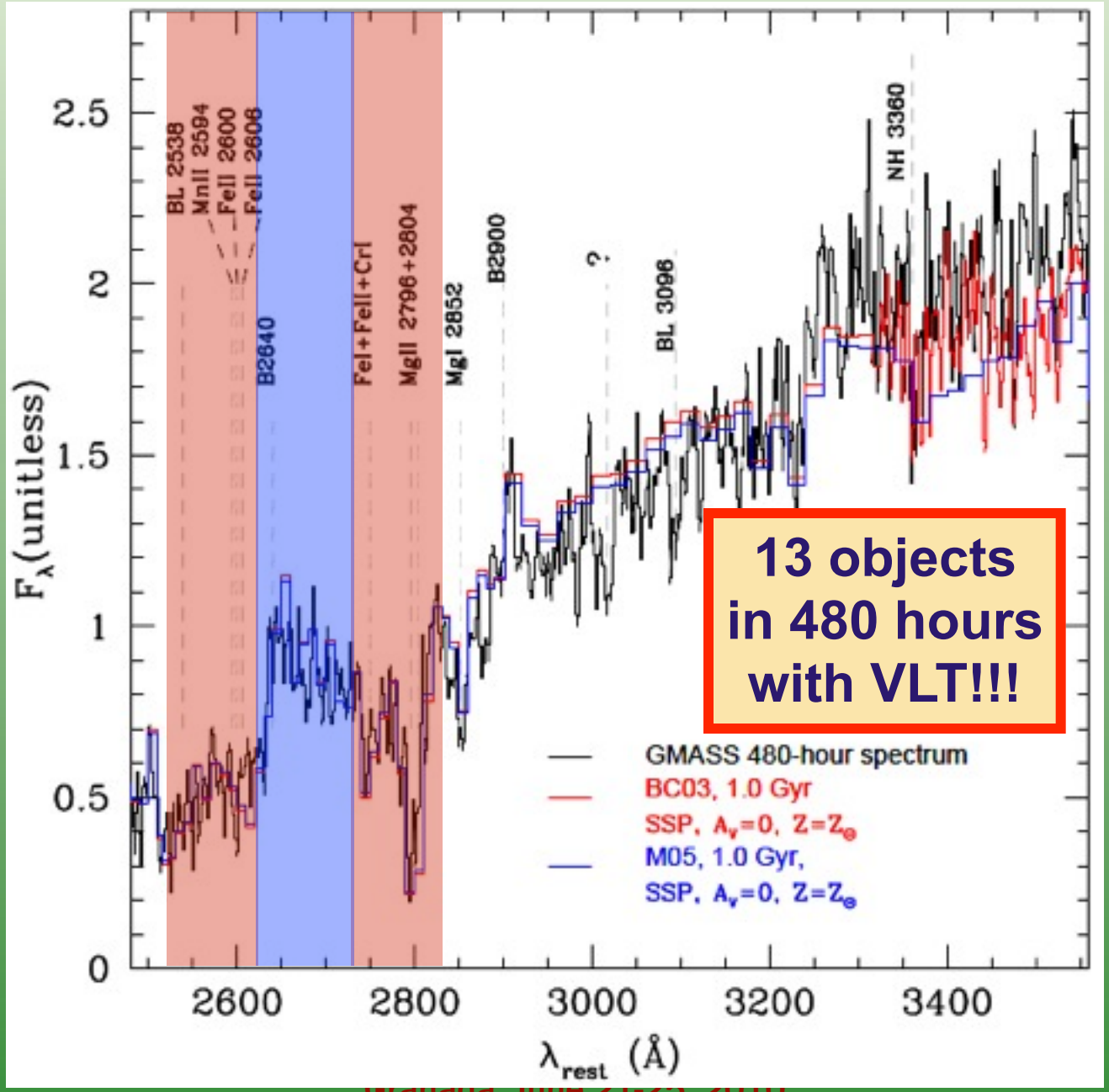

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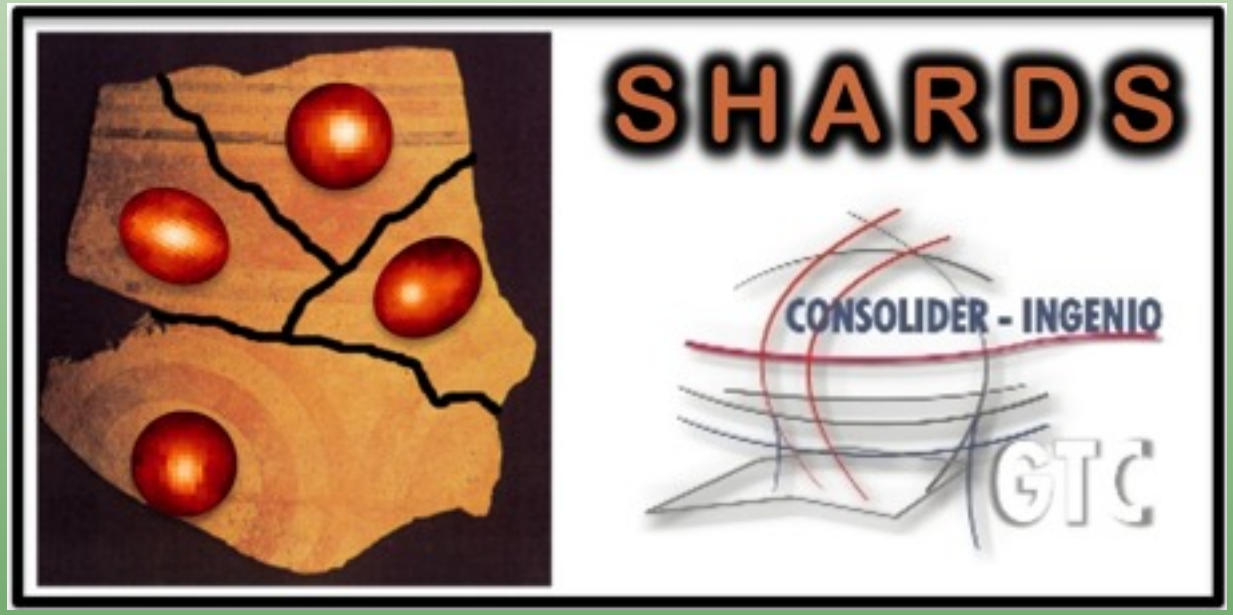
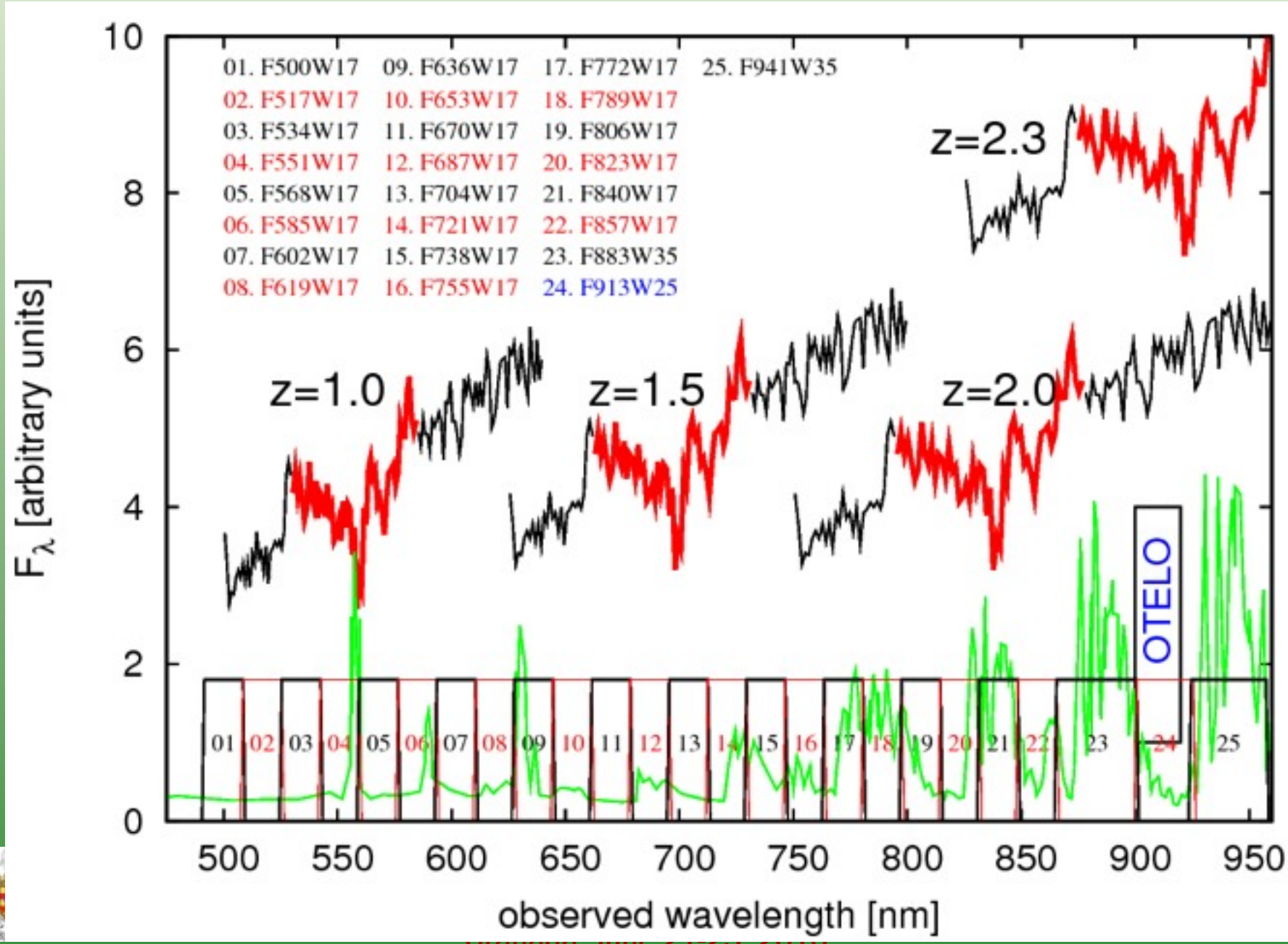
ESO/GTC Large Program: SHARDS, Survey for High-z Absorption Red and Dead Sources

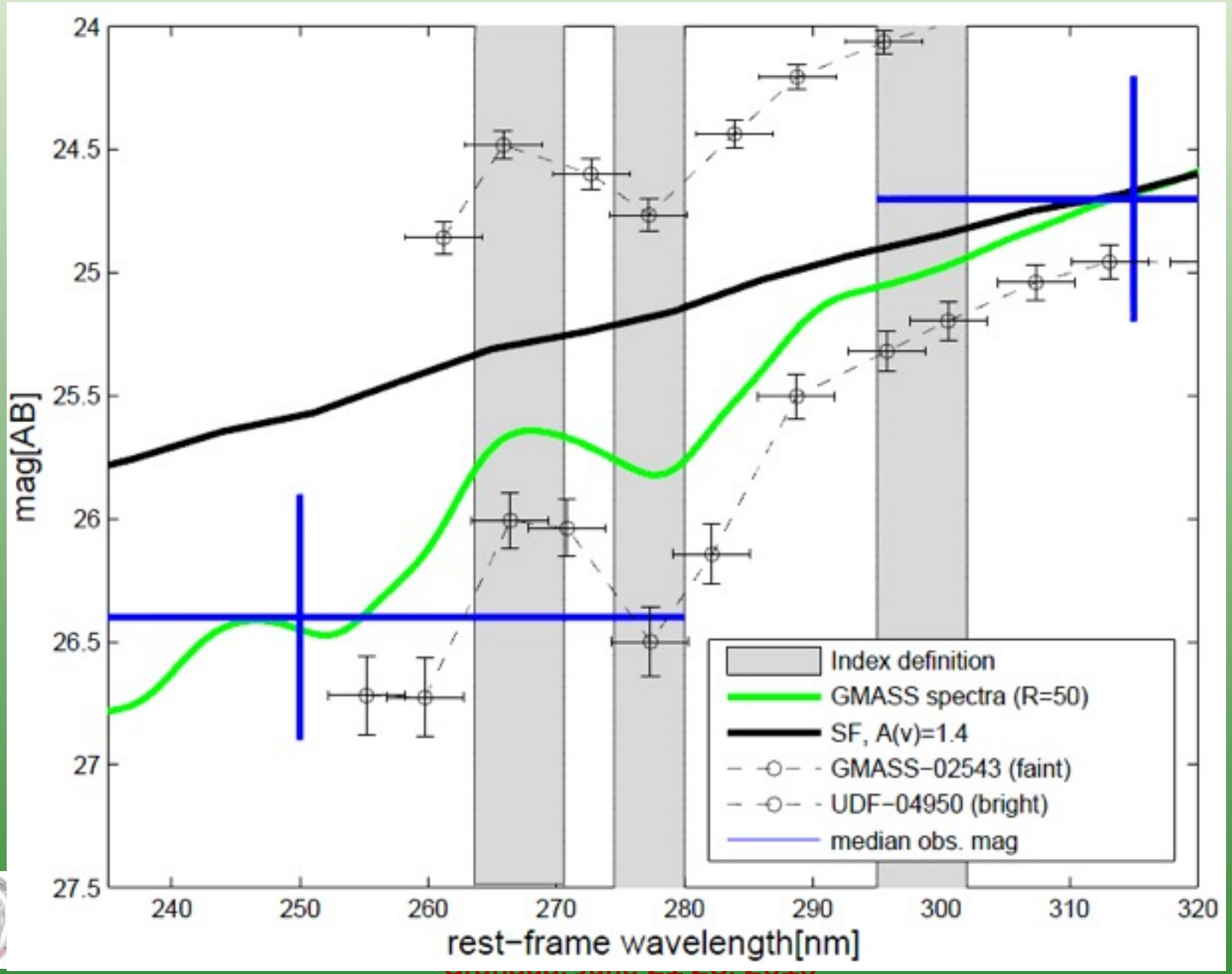


http://guaix.fis.ucm.es/~pgperez/SHARDS

SHARDS: spectro-photometry in GOODS-N



SHARDS: indices (e.g., Mg_{UV}) with photometry



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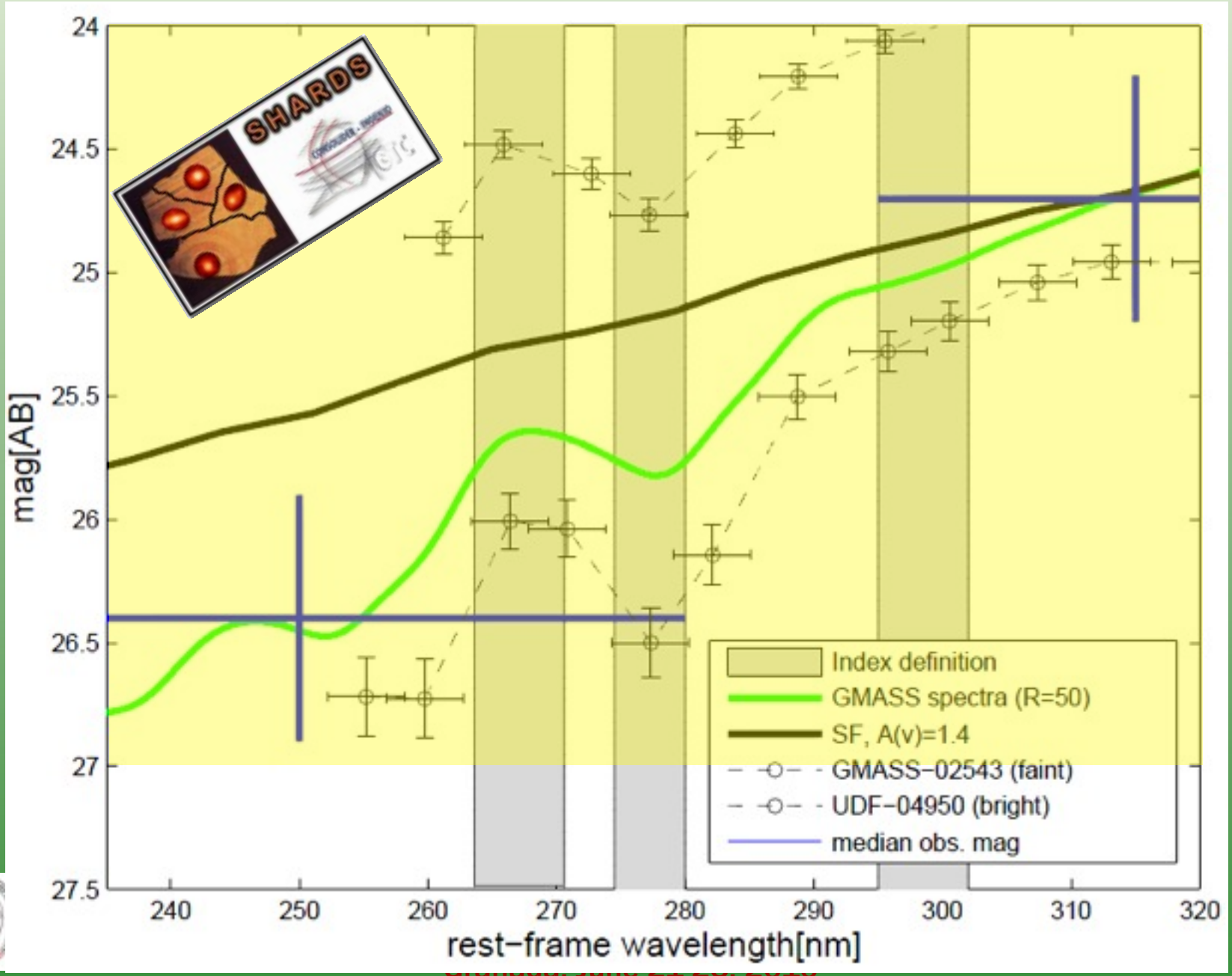

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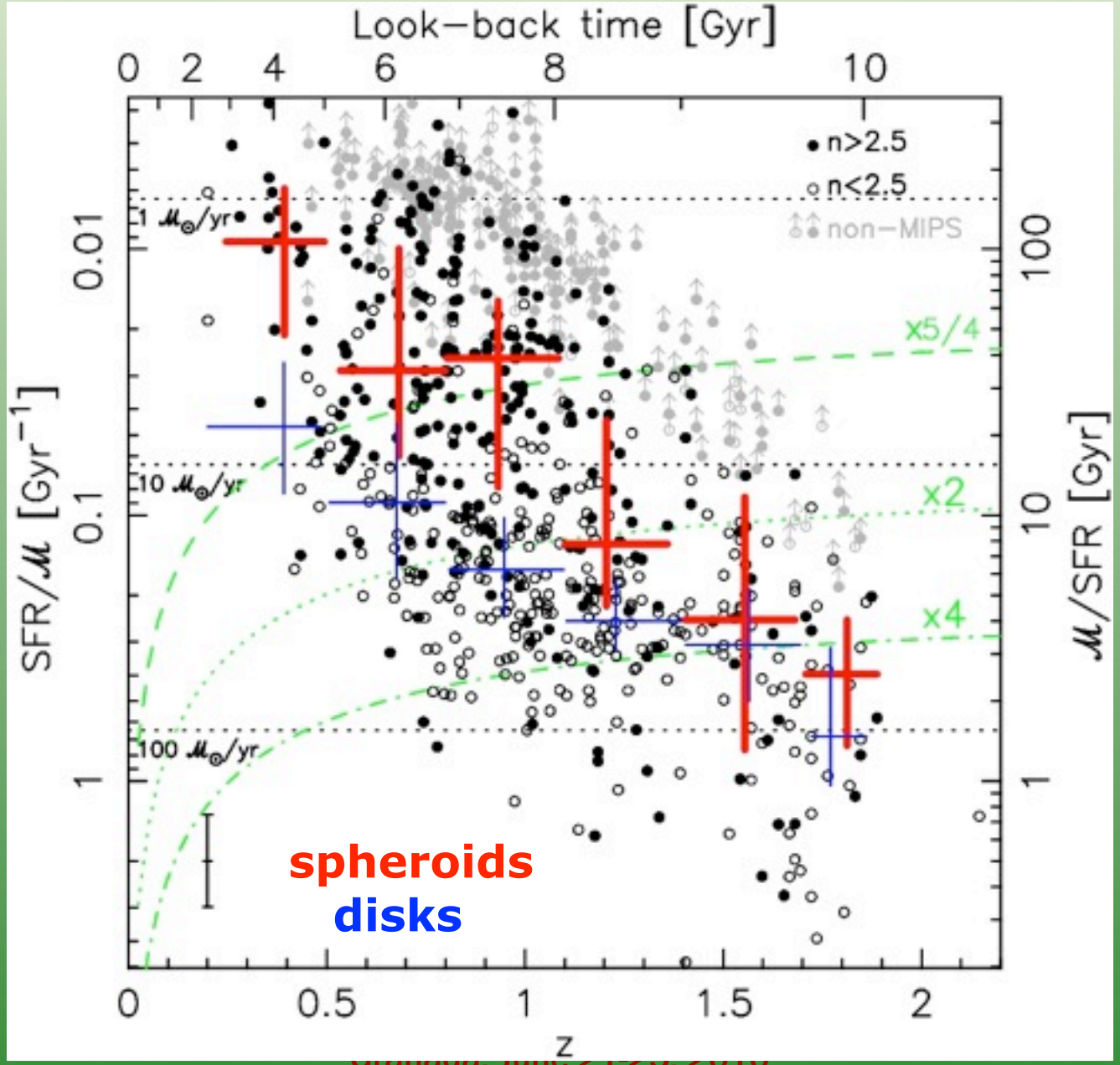
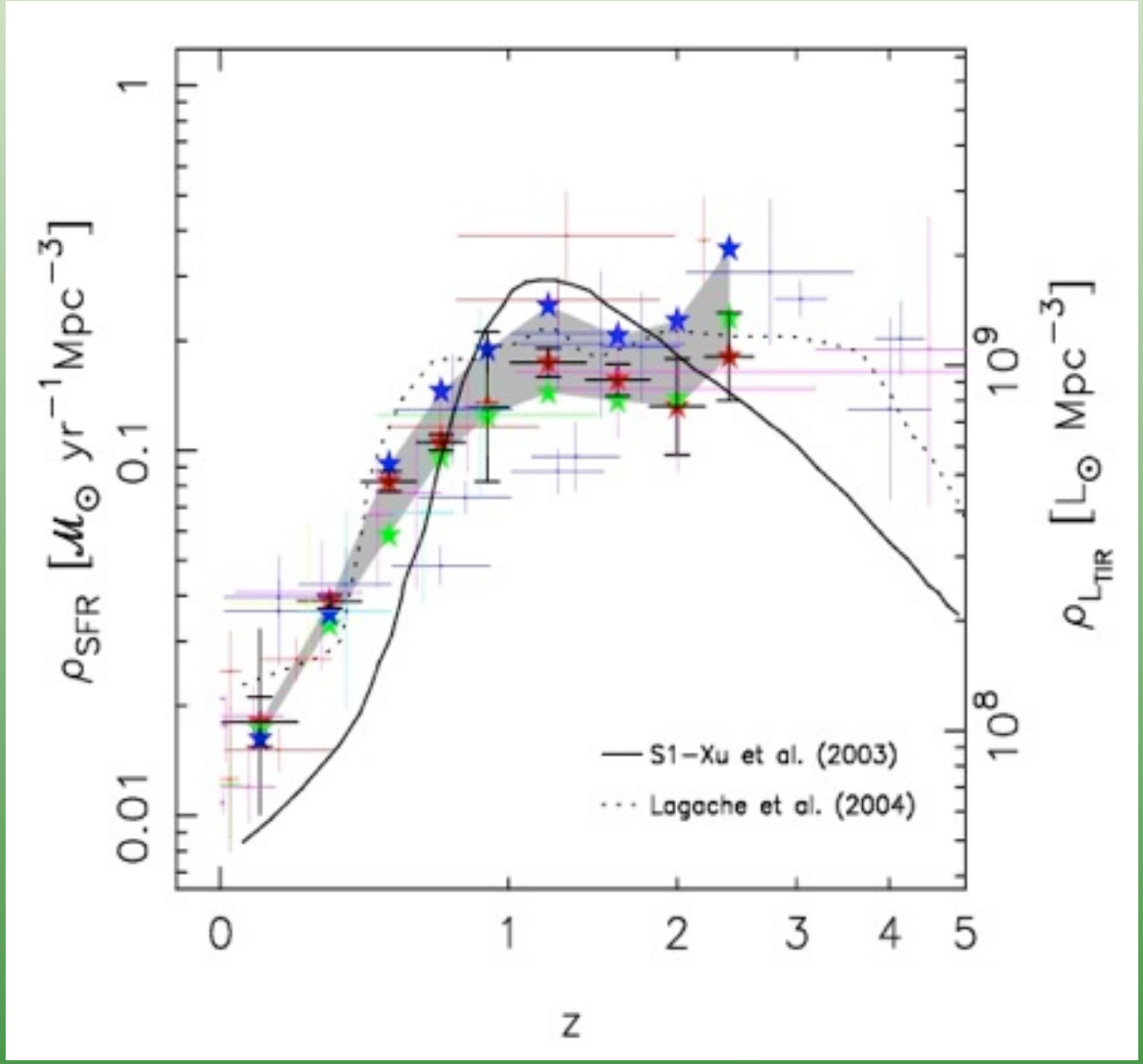
- **SFR/mass density mismatch: non-Salpeter IMF, IMF non-universal?, AGN contamination larger at high-z?, overpredicted SFRs at z>2?, change in SF mode (short and intense bursts at z>2)?, stellar masses are all wrong?, completeness issues?,...**

Mass assembly vs. size/morphology



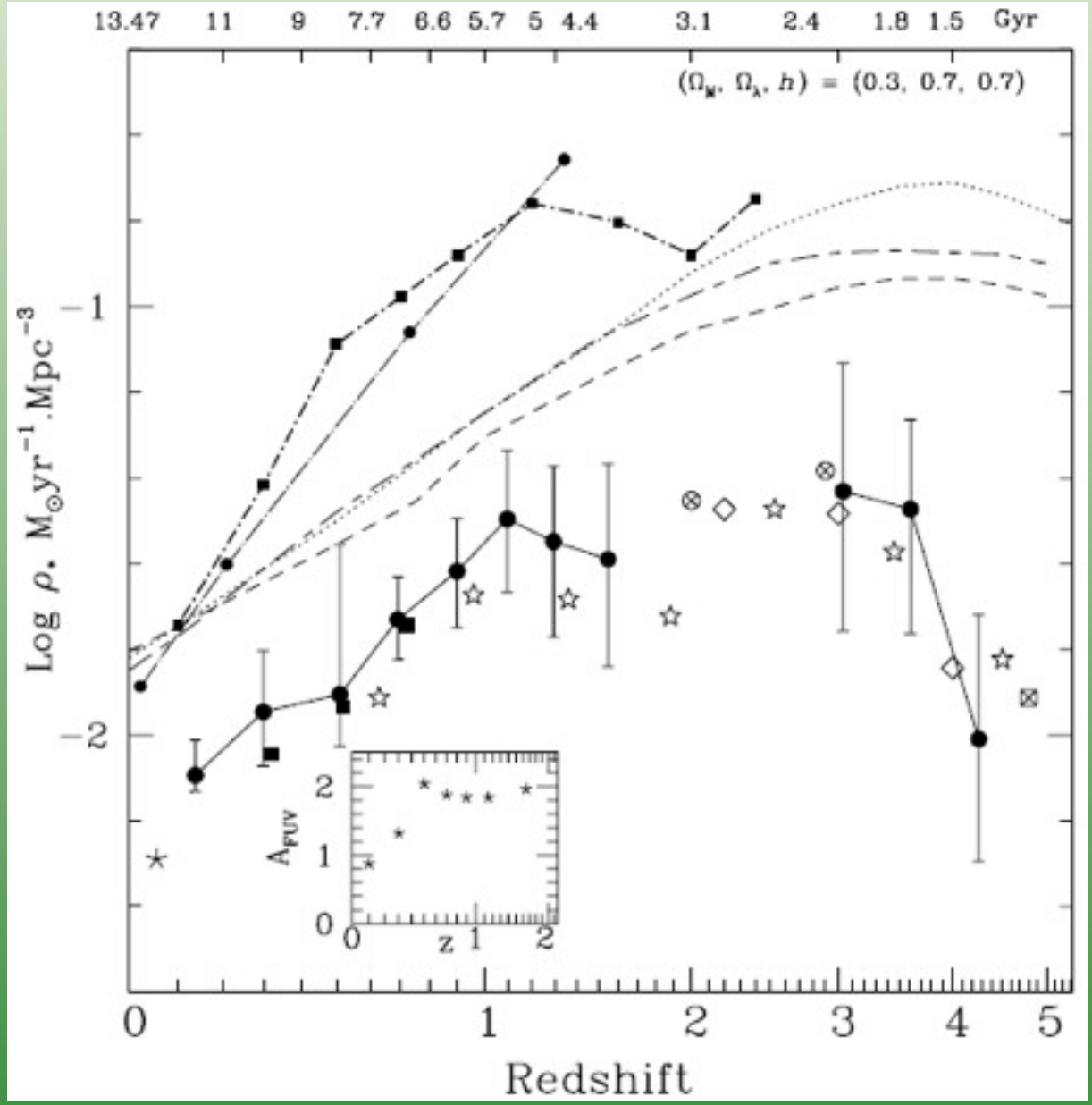
Pérez-González et al. (2008b)

Importance of obscured SF: ρ_{SFR} @ z<3



Pérez-González et al. (2005)

Importance of obscured SF: *UV vs IR @z<1*



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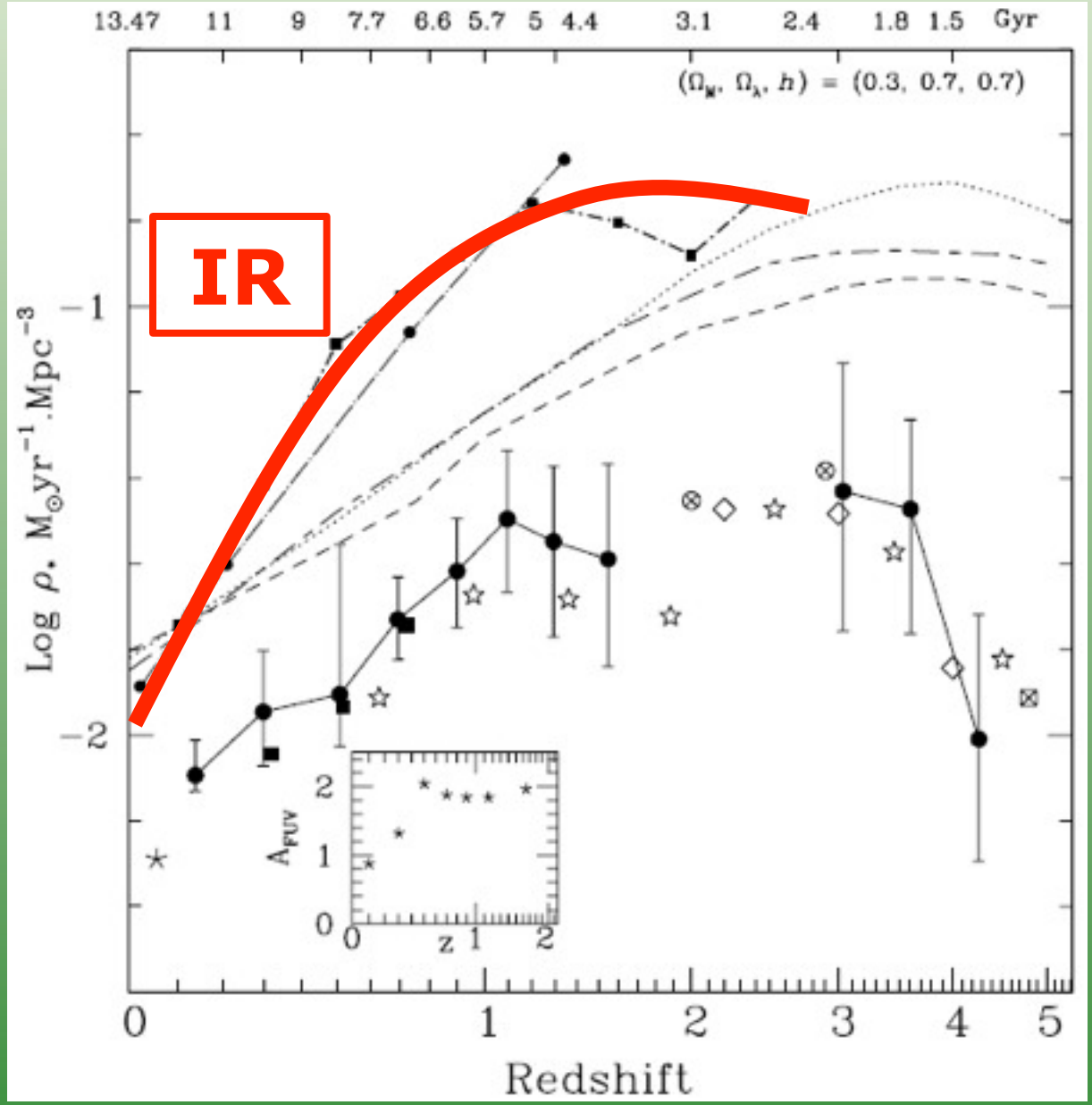

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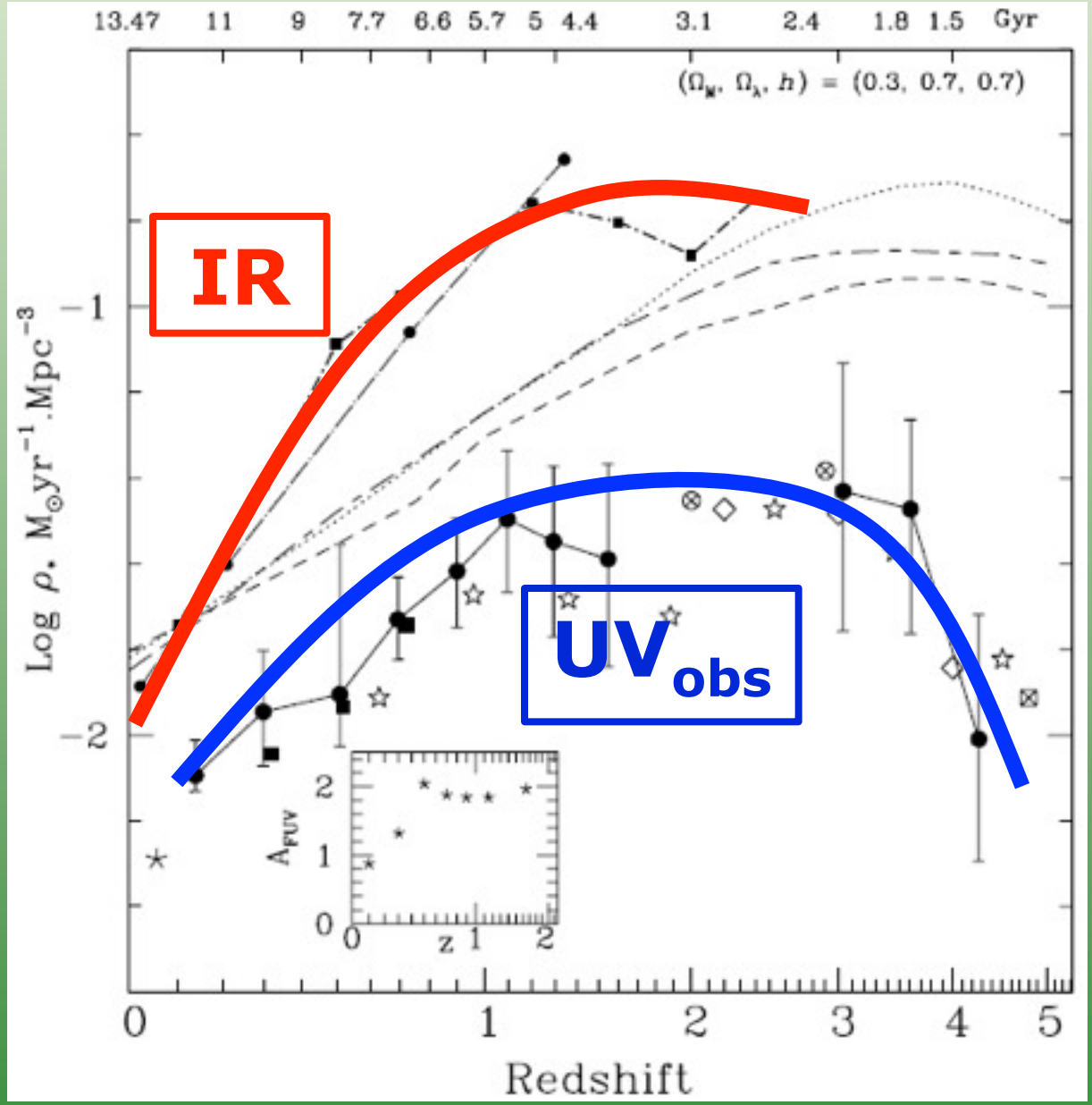

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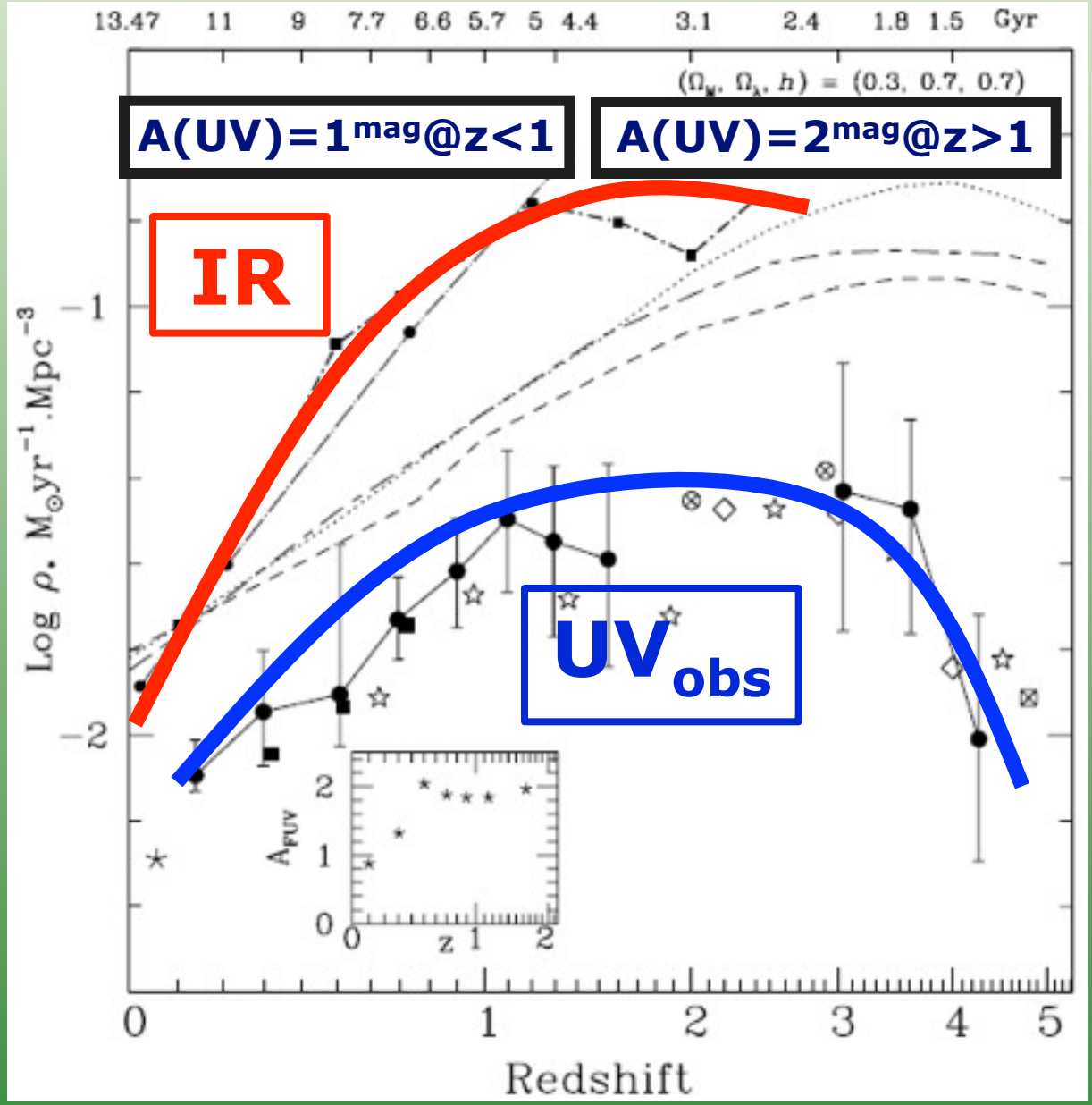

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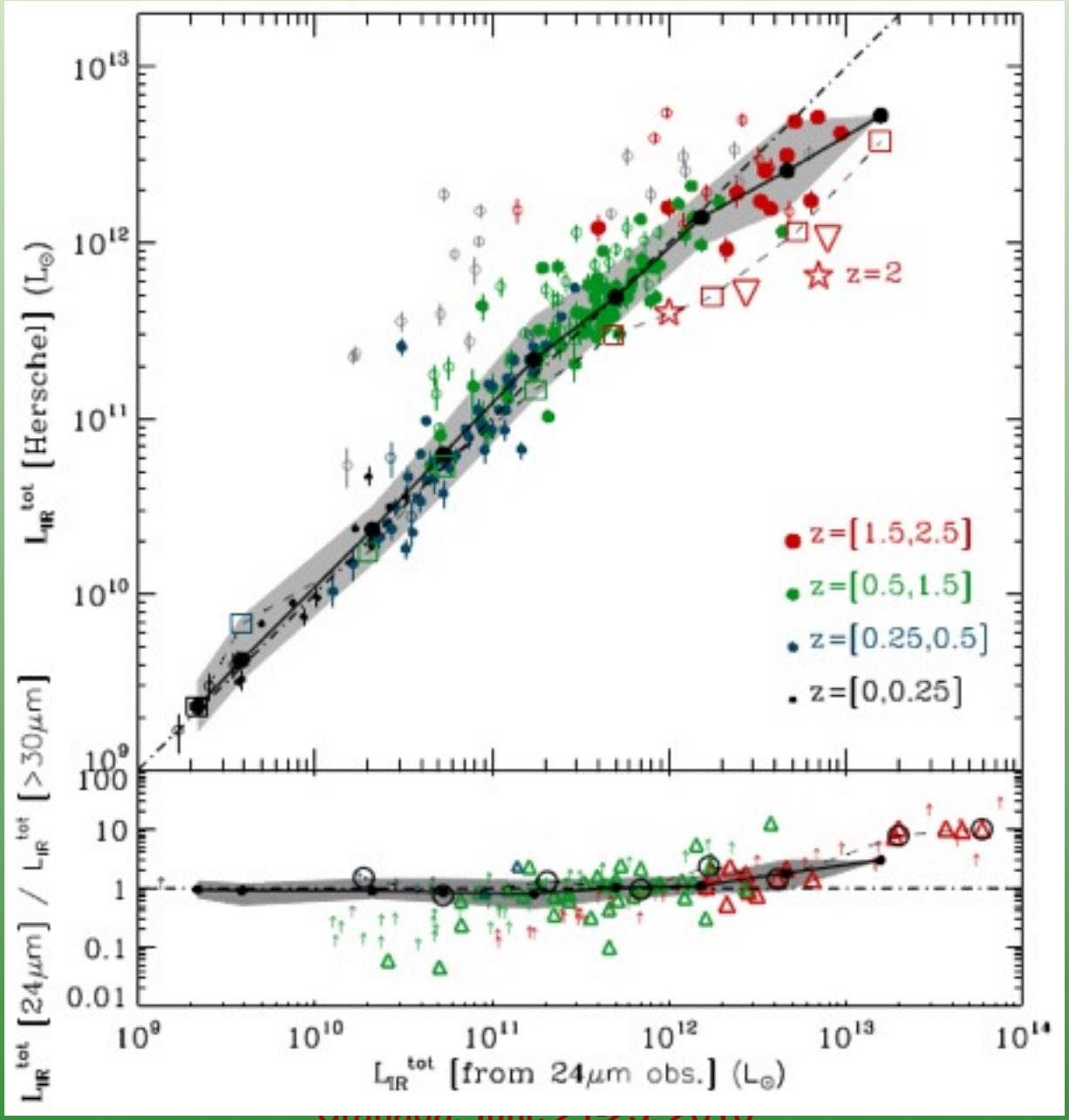

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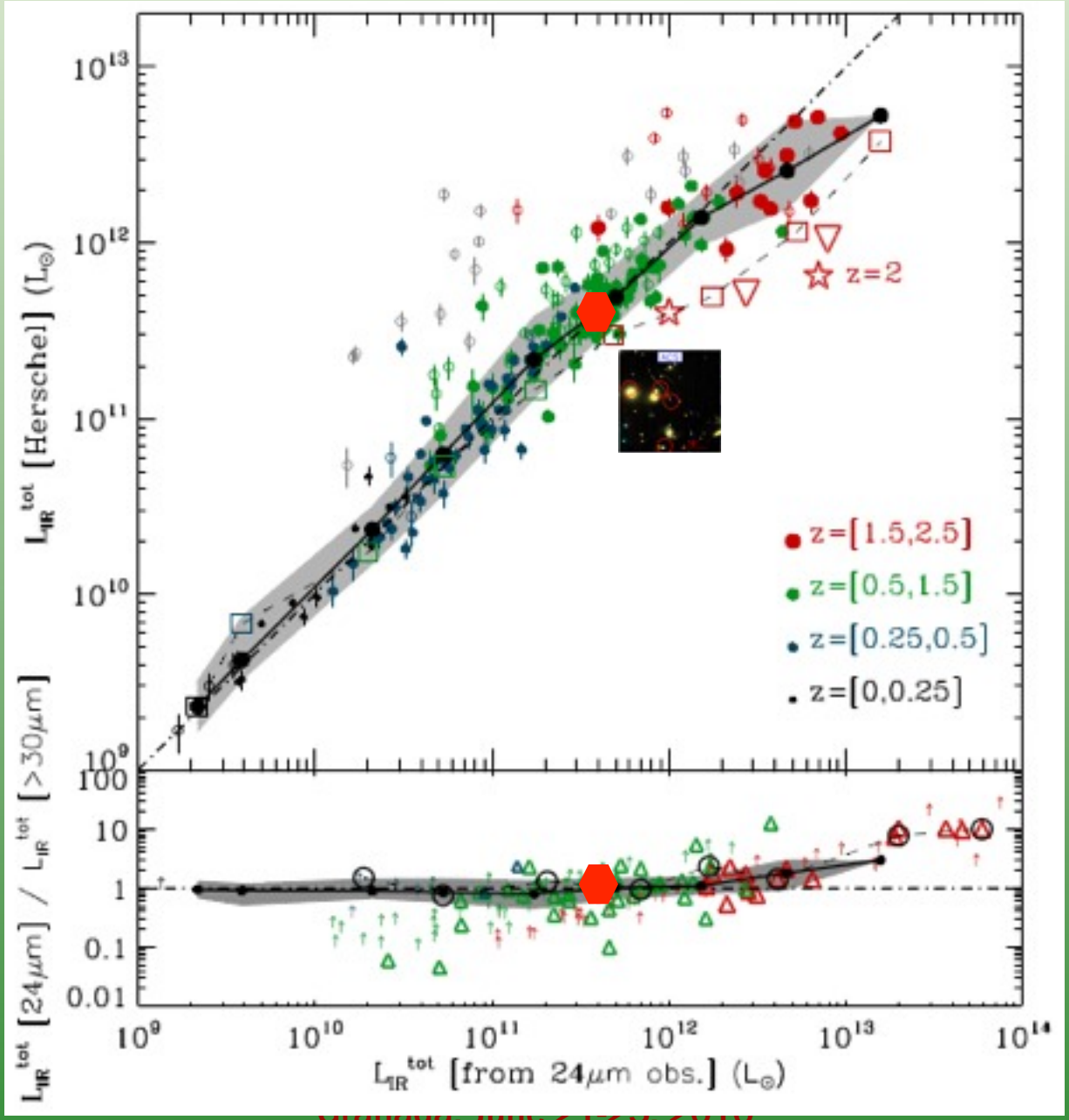

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- **Proposed as an ESO/GTC Large Program in March 2009 (PI: Pérez-González, 20 co-I's).**
  - **20 nights (180 hours) awarded in 2010.**
  - **2 GTC/OSIRIS pointings in GOODS-N with 25 filters.**
  - **GTC/Consolider Project approved 150,000€ grant to buy set of 25 medium-band (FWHM=17 nm) filters.**