The number density of Hα emitters

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INAF - OSSERVATORIO ASTRONOMICO DI BOLOGNA

In collaboration with Euclid Consortium team and WFIRST team:
Empirical models: C. M. Hirata, J. E. Geach, A. Cimatti, O. Cucciati
SAMs: C. Baugh, A. Merson, P. Norberg, and D. Shi
FMOS data: Valentino, F.; Daddi, E.; Silverman, J. D. et al.
HOD: F. Castander, P. Fosalba, L. Blot, and validation team
WISP-extended: C. Scarlata, M. Bagley, D. Eisenstein, A.Cimatti, et al.

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Hα Empirical models

HαLF is a key input for forecasts for future near-IR spectroscopic missions (Euclid, WFIRST) , but also Galaxy evolution (SFRD)

LFs from Hα surveys:

Euclid Wide (Hα @ 0.9<z<1.8, 15,000 deg^2, F<2e-16 cgs)
Euclid Deep (Hα @0.4<z<1.8, 40 deg^2, F<0.5e-16)
WFIRST (Hα @ 1<z<2, 2200 deg^2, F<1e-16)

Low-z : - **Optical spectroscopy**

High-z : - **NIR single slit spectroscopy: but small area, single objects**

- **NIR Narrow-band: large area but small z range**
- NIR slitless spectroscopy (NICMOS & WF3): large z range but small area

WARNING: ALL LOW STATISTIC SURVEYS

⇒ We have updated old empirical model by Geach et al. 2010 using a complete set of observed LFs, including also the most recent ones from grism and slitless HST spectroscopy;

Observed Hα Luminosity Function

Table 1. The empirical Schechter parameters for the various surveys considered, ordered by redshift. Units are Mpc^{-3} ($\phi_\star$) and erg s^{-1} ($L_\star$).

Redshift	α	$\log_{10} L_\star$	$\log_{10} \phi_\star$	delta-z	Area	Instr.	Reference(s)	Models
0.0225	−1.3	41.47	−2.78	0-0.045	471	prism	Gallego et al. (1995)	1,2
0.07, 0.09	−1.59	41.65	−3.14	0.02	0.24	Narrow-band	Ly et al. (2007)	1,2
0.2	−1.35	41.52	−2.56	0-0.3	0.03	CFHT	Tresse & Maddox (1998)	1,2
0.24	−1.35	41.54	−2.65	0.02	1.54	Narrow-band	Shioya et al. (2008)	1,2
0.24	−1.70	41.25	−2.98	0.02	0.24	Narrow-band	Ly et al. (2007)	1,2
0.4	−1.28	41.29	−2.4	0.02	0.24	Narrow-band	Ly et al. (2007)	1,2
0.4	−1.75	41.57	−3.12	0.02	2	Narrow-band	HiZELS (Sobral et al. 2013)	1,2,3
0.6	−1.27	41.72	−2.51	0.3-0.9	0.037	HST+WF3	WISP (Colbert et al. 2013)	1,2,3
0.73	−1.31	41.97	−2.319	0.5-1.1	CFRS	ISAAC	Tresse et al. (2002)	1,2
0.84	−1.56	41.92	−2.47	0.04	2	Narrow-band	HiZELS (Sobral et al. 2013)	1,2,3
1.05	−1.39	42.49	−2.948	0.7-1.4	0.029	HST+NICMOS	Shim et al. (2009)	1,2,3
1.2	−1.43	42.18	−2.7	0.9-1.5	0.037	HST+WF3	WISP (Colbert et al. 2013)	1,2,3
1.25	−1.6	42.87	−3.11	0.7-1.8	0.0012	HST+NICMOS	Hopkins et al. (2000)	1,2
1.3	−1.35	42.81	−2.801	0.7-1.9	0.018	HST+NICMOS	Yan et al. (1999)	1,2,3
1.47	−1.62	42.23	−2.61	0.04	2	Narrow-band	HiZELS (Sobral et al. 2013)	1,2,3
1.65	−1.39	42.55	−2.768	0.7-1.9	0.029	HST+NICMOS	Shim et al. (2009)	1,2,3
2.23	−1.59	42.53	−2.78	0.04	2	Narrow-band	HiZELS (Sobral et al. 2013)[a]	1,2,3
2.23	−1.72	43.22	−3.96	0.04	Goods-S	Narrow-band	Hayes et al. (2010)[b]	1,2
2.23	−1.6	43.07	−3.45				HiZELS (Geach et al. 2008) and Hayes et al. (2010)[a,b]	1,2
2.23	−1.35	42.83	−3.2	0.04	0.6	Narrow-band	HiZELS (Geach et al. 2008)[a]	1,2

[a]The Sobral et al. (2013) analysis includes a superset of the fields used for the earlier HIZELS paper (Geach et al. 2008).
[b]Hayes et al. (2010) present results both internal to their HAWK-I data, and a joint fit including the Geach et al. (2008) results.

1- We assume Hα only (at high-z only statistically corrected for blended [NII]: Hα=(Hα+[NII])*0.7)

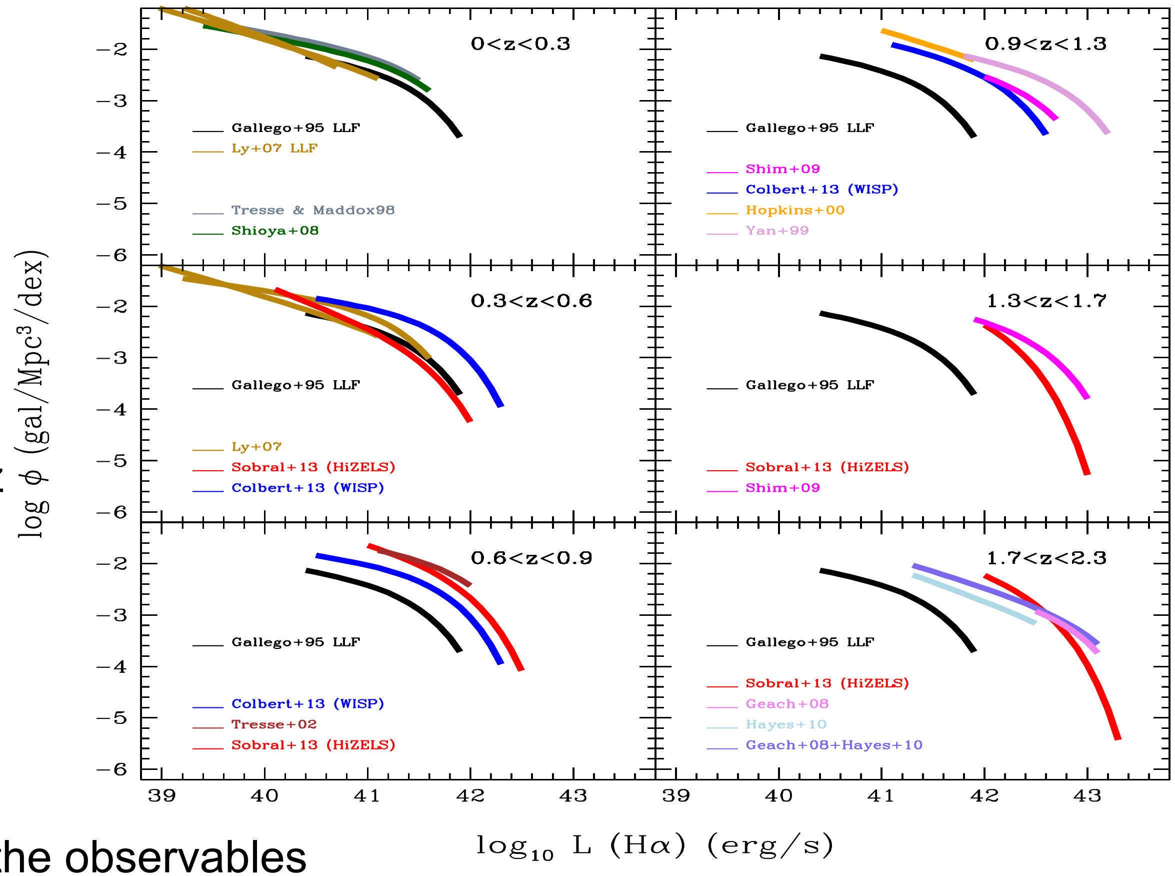
2-Hα observed, i.e. not corrected for extinction (1 mag or 0.4 dex in log(L*) if not specified)

Observed Hα Luminosity Function

1- Clear Luminosity evolution

2- No clear density evolution

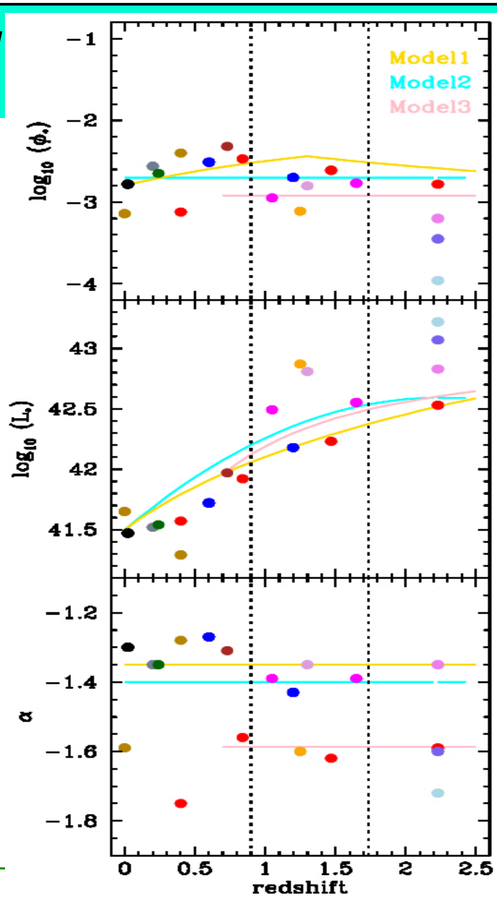
3- No well defined faint slope at high-z



➔ To take into account the scatter in the observables we have used 3 different approaches (both in LF shape and its evolution):

Empirical Hα evolution model

- we have used 3 different approaches both in the **LF shape** and **its evolution**:



1. Model 1

$$\phi(L,z)\,\mathrm{d}L = \phi_\star\left(\frac{L}{L_\star}\right)^{\alpha} \mathrm{e}^{-L/L_\star}\,\frac{\mathrm{d}L}{L_\star},$$

$$L_\star(z) = L_{\star 0}(1+z)^{\delta}$$

and

$$\phi_\star(z) = \begin{cases} \phi_{\star 0}(1+z)^{\epsilon} & z < z_{\mathrm{break}} \\ \phi_{\star 0}(1+z_{\mathrm{break}})^{\epsilon}\left(\frac{1+z}{1+z_{\mathrm{break}}}\right)^{-\epsilon} & z > z_{\mathrm{break}} \end{cases}$$

2. Model 2

$$\phi(L,z)\,\mathrm{d}L = \phi_\star\left(\frac{L}{L_\star}\right)^{\alpha} \mathrm{e}^{-L/L_\star}\,\frac{\mathrm{d}L}{L_\star},$$

$$\log_{10} L_\star(z) = -c(z - z_{\mathrm{break}})^2 + \log_{10} L_\star(z_{\mathrm{break}}).$$

3. Model 3

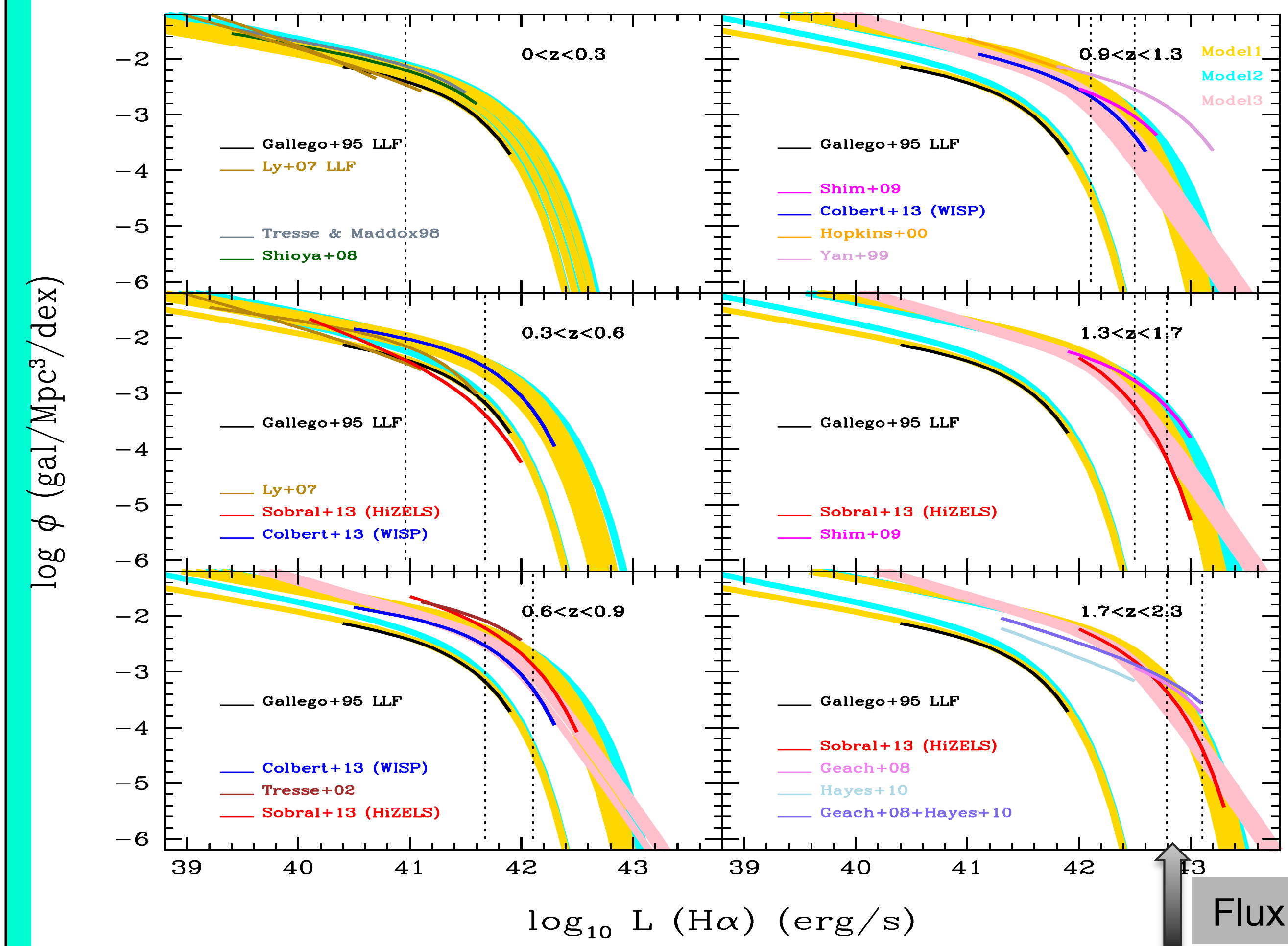
$$\phi(L,z) = \frac{\phi_\star}{L_\star}\left(\frac{L}{L_\star}\right)^{\alpha}\left[1 + (\mathrm{e}-1)\left(\frac{L}{L_\star}\right)^{\Delta}\right]^{-1} \quad \text{(broken power law)}$$

$$\phi(L,z) = \frac{\phi_\star}{L_\star}\left(\frac{L}{L_\star}\right)^{\alpha} e^{-(1-\gamma)L/L_\star}\left[1 + (\mathrm{e}-1)\left(\frac{L}{L_\star}\right)^{2}\right]^{-\gamma} \quad \text{(hybrid)}$$

$$\log_{10} L_\star = \log_{10} L_{\star,\infty} + \left(\frac{1.5}{1+z}\right)^{\beta} \log_{10}\frac{L_{\star,0.5}}{L_{\star,\infty}}.$$

$$\log_{10}\phi_\star = \log_{10}\phi_{\star,1} + \frac{d\log_{10}\phi_\star}{da}\left(a - \frac{1}{2}\right)$$

Reproducing the Hα Luminosity Functions



Flux (Hα)>3e-16 @ z

➔ The 3 Models well reproduce the scatter in the observed LFs.

Model 1- Higher normalization

Model 2 - Higher bright-end LF

Model 3 - Extended tail at high Luminosity, but lower normalization.

Predicted Hα Galaxy counts

OBSERVED DATA:

+ from WISP (points)

+ LFs integrated over 0.7<z<1.5 (dotted)

MODELS 1, 2, 3 :

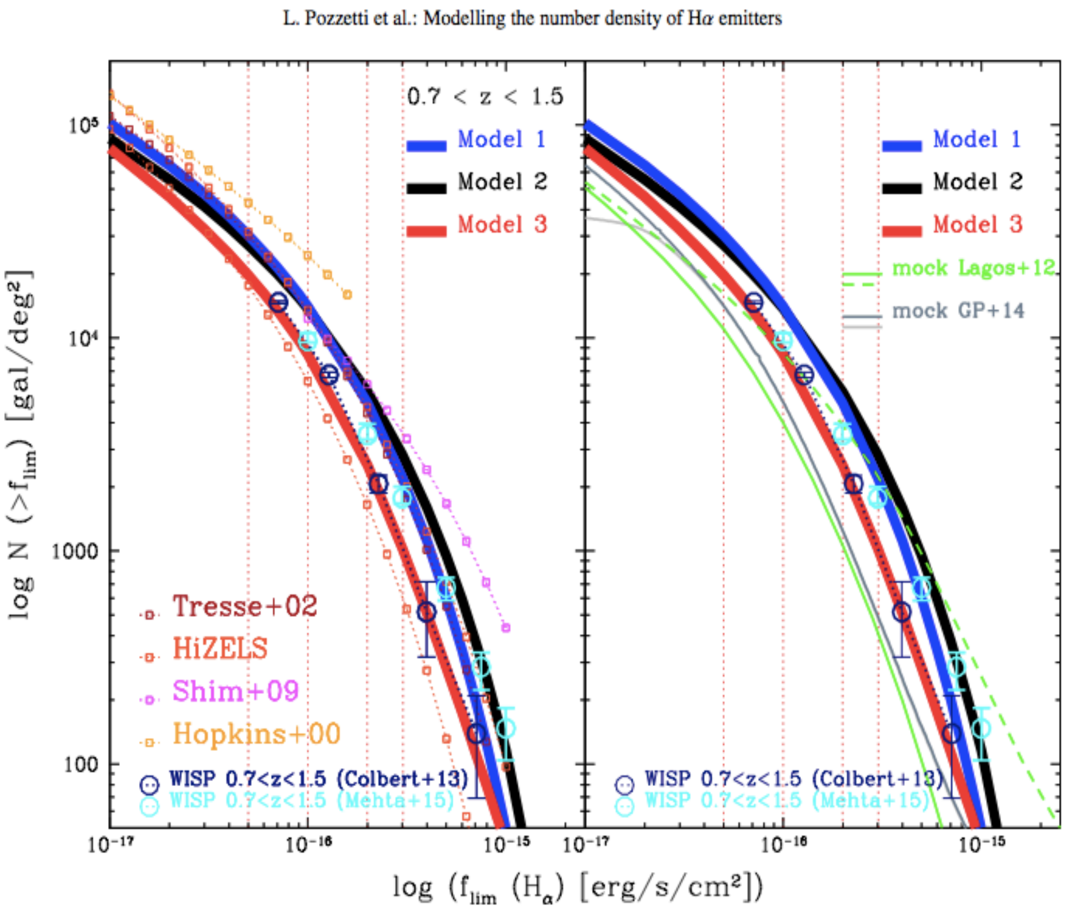
+ Modesl 1, 2 reproduce the range of data, but slightly higher than WISP;

+ Model 3 reproduce better WISP but lower than most of LFs.

EUCLID MOCKS (using Durham SAMs)

- counts lower (by a factor >2) than Mod. 1,2,3:

- Higher counts at bright fluxes (>1e-15) for unextincted fluxes



Predicted Hα redshift distribution

★ **Halpha dN/dz:**

OBSERVED DATA:

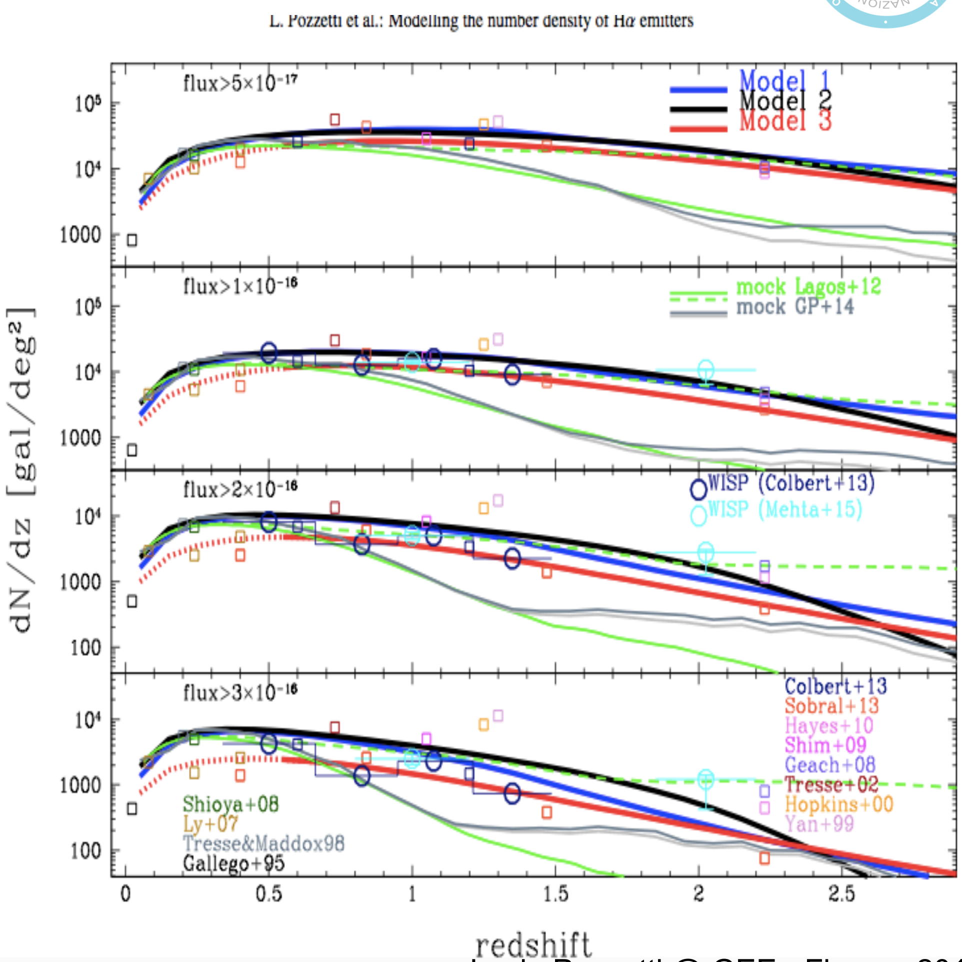
+ from Halpha surveys (points)
+ WISP

MODELS 1, 2, 3 :

+ Modesl 1, 2 reproduce the range of counts,
  but slightly higher than WISP;
+ Model 3 reproduce better WISP
  but lower than most of LFs.

EUCLID MOCKS (using Durham SAMs)

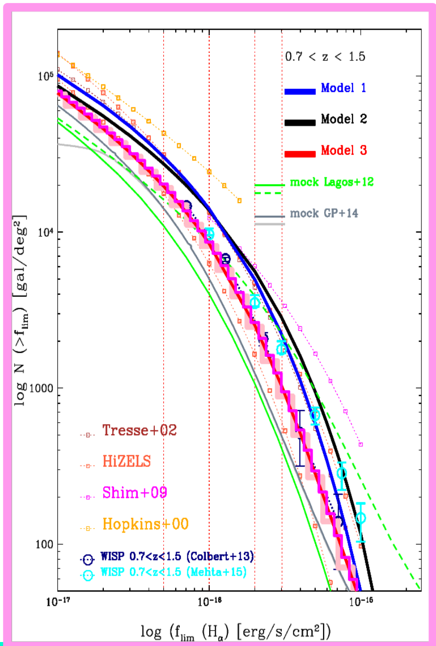
- Mocks predicted counts lower than Models 1,2,3:
  Consistent up to z~2 only if consider unextincted
  Halpha fluxes.

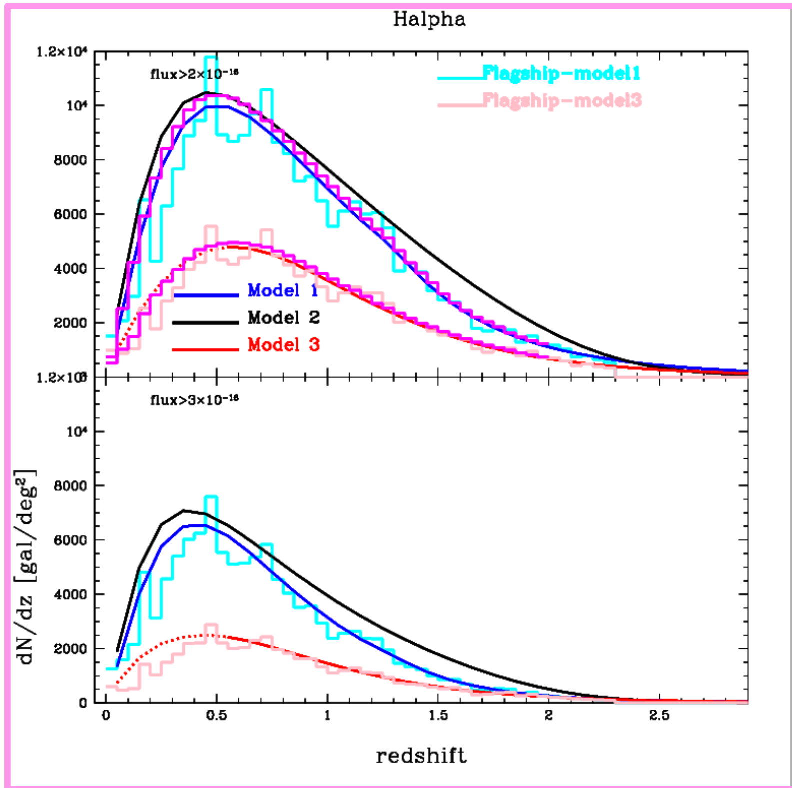


FLAGSHIP GALAXY MOCK

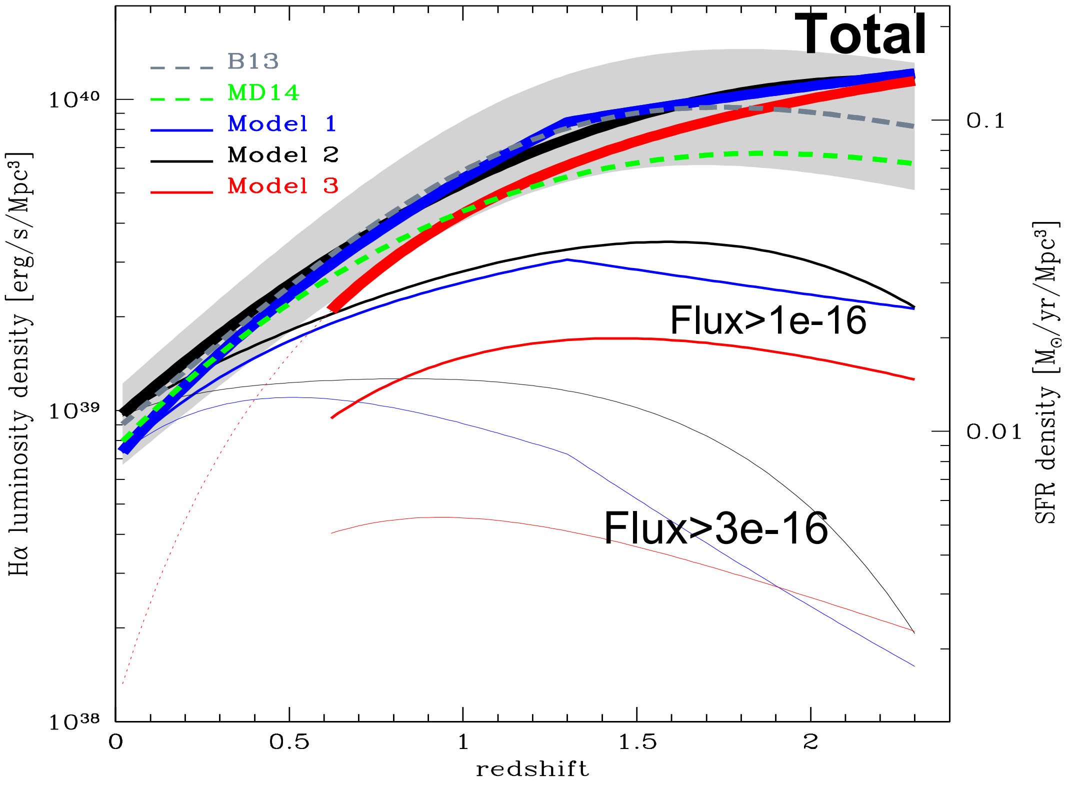
Flagship galaxy mock (HOD tecnique) by the ICE group (Castander, Fosalba, Blot et al.) based on the **Flagship N-body simulation** halo catalog generated at the University of Zürich.
[Area= 1 octant of the sky → up to 15,000 deg^2]
→ **FLAGSHIP 1.3.3 CALIBRATED ON MODEL 1 AND 3**

[Validated for the Science Performance Verification (SPV) of Euclid and will be used in E2E simulations]





Hα Luminosity Density or SFRD



We have derived SFHs from Halpha luminosity density (LD):

- The Total LD of Models 1,2,3 are consistent with SFH from Behroozi et al. 2013 and Madau&Dickinson 2014

- LD (>1e-16 @ z=1.5) see ~30% of the Total LD,. F>0.5e-16 ~50%

New Hα data: FMOS

★ ***Incoming Halpha data at high-z:***

(Valentino, …, LP, et al. 2017)

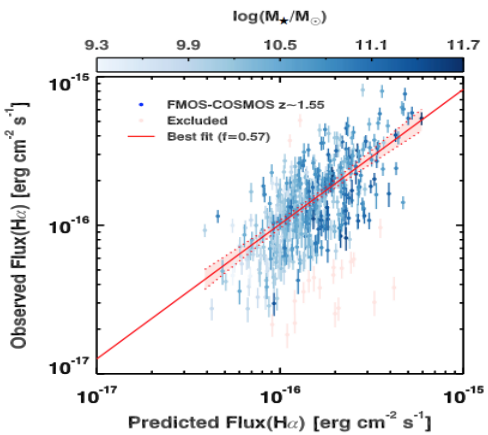
1. **COSMOS+ FMOS**

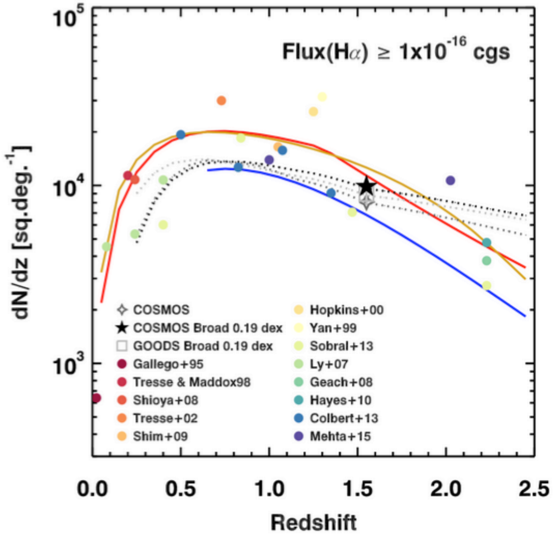
FMOS: slit near-IR spectroscopy (flim~2e-17)

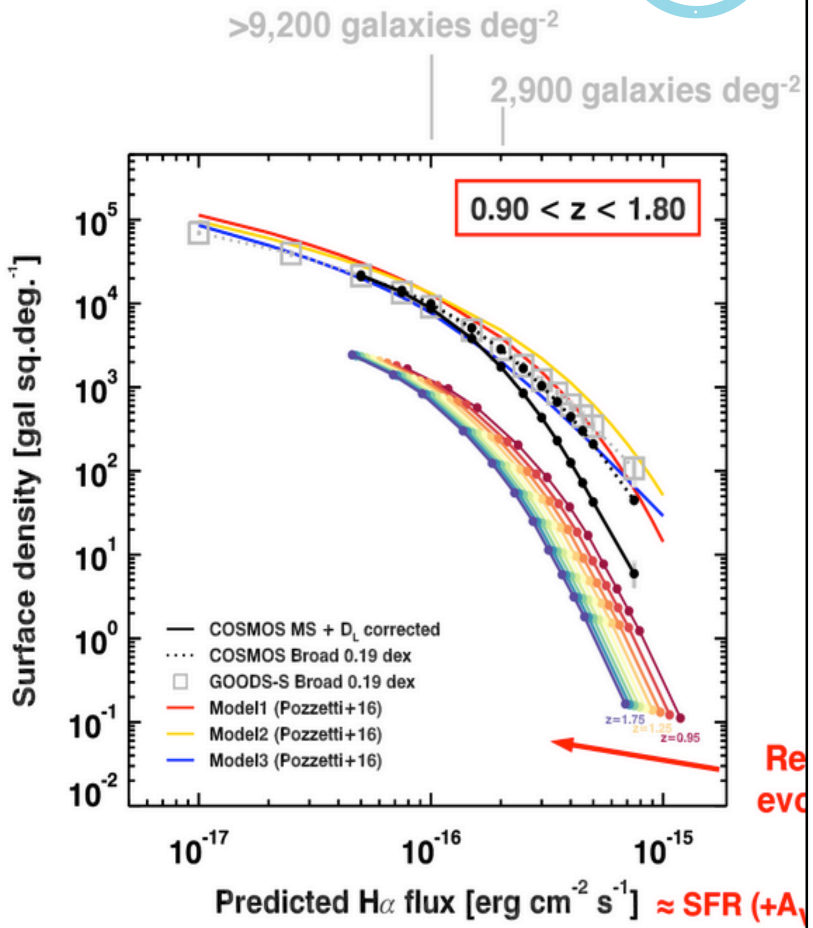
COSMOS sample of SFGs z~1.55 → 135 FMOS Halpha with flux>2e-16

⇒ calibration of Halpha prediction from SFR

⇒ number densities, EW, EL ratios







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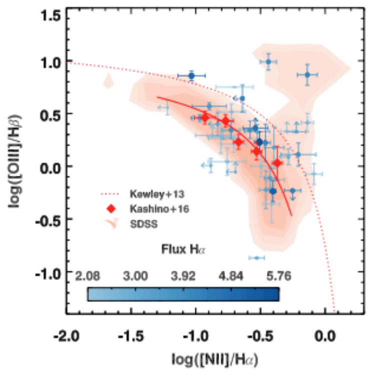
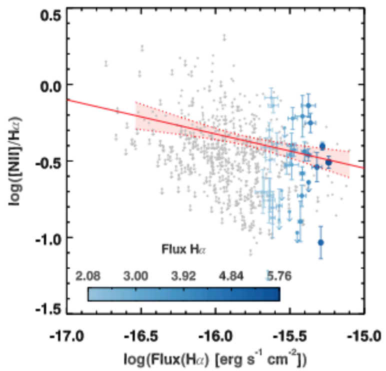
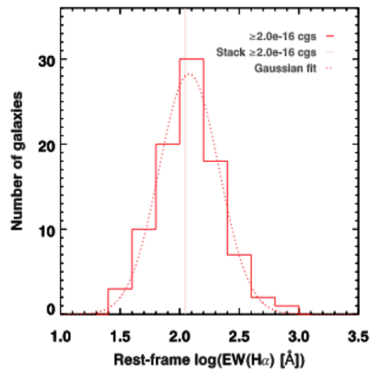
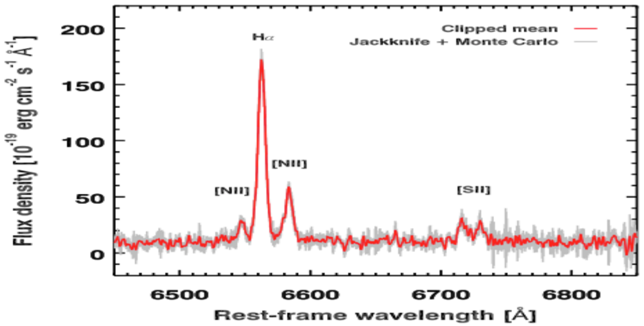
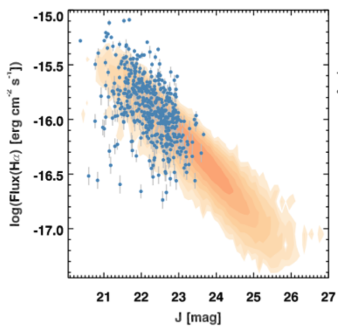
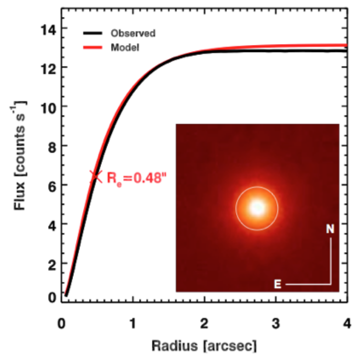










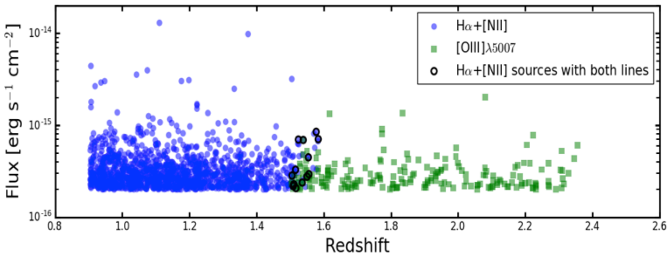


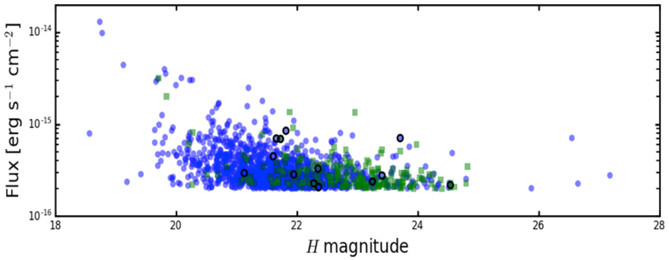
New Hα data: Extended WISP

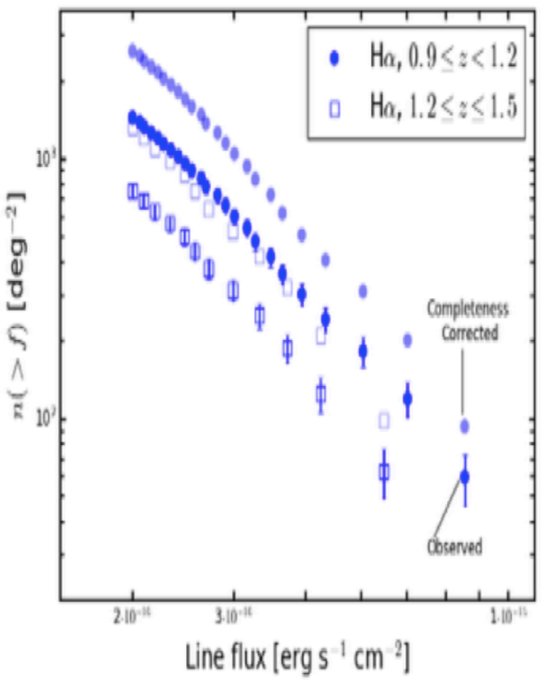
★ HST archival data (WISP extension)

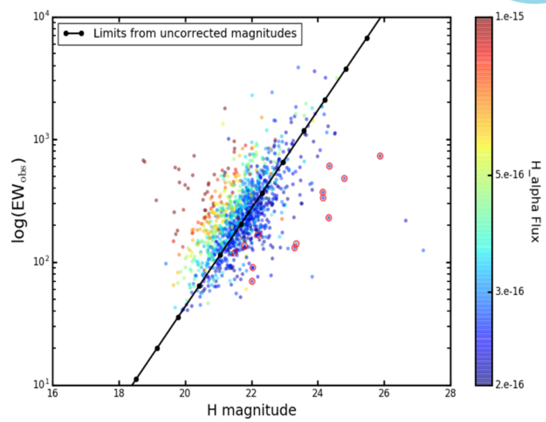
(PI. Scarlata, … + LP involved)

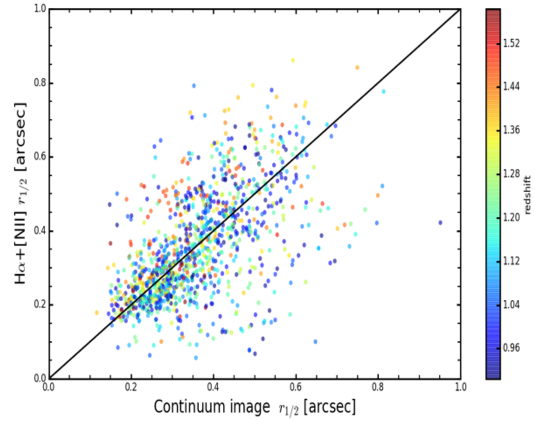
~450/480 HST field reduced [~0.335 sqdegs]
down to ~2e-16
~ 2200 Halpha emitters/deg^2 (0.9<z<1.5)
⇒ number densities, EW, sizes, EL ratios











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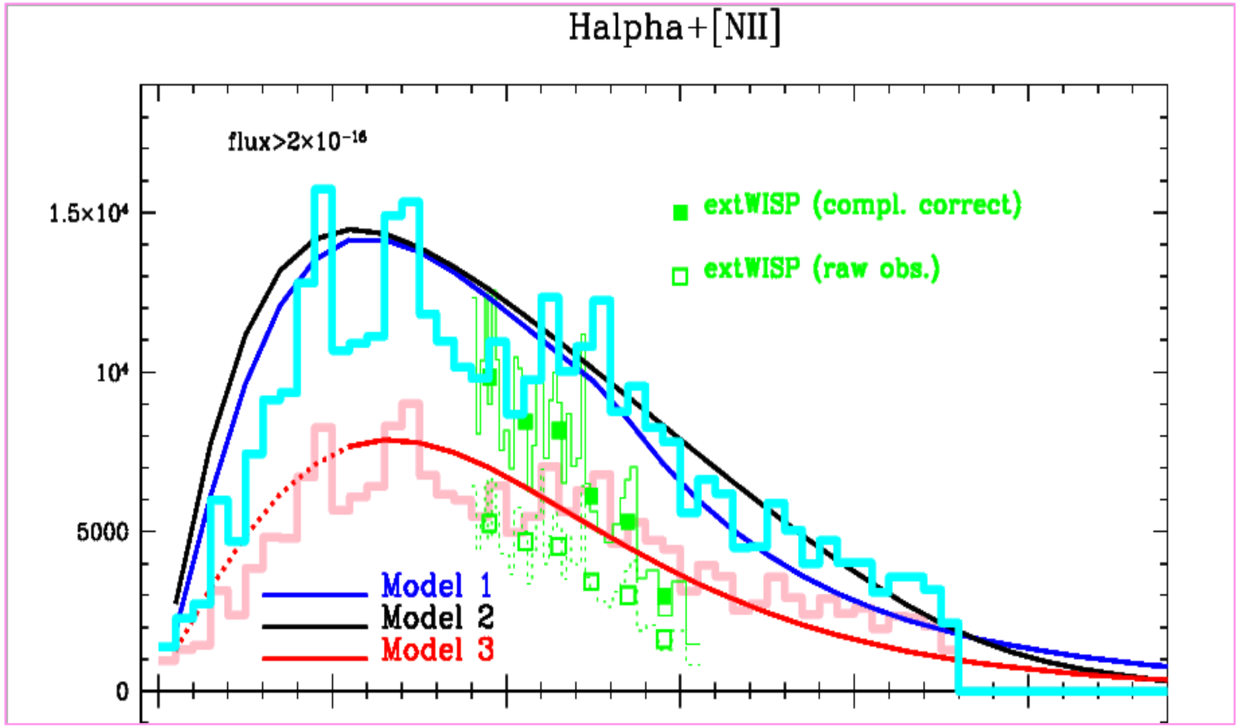


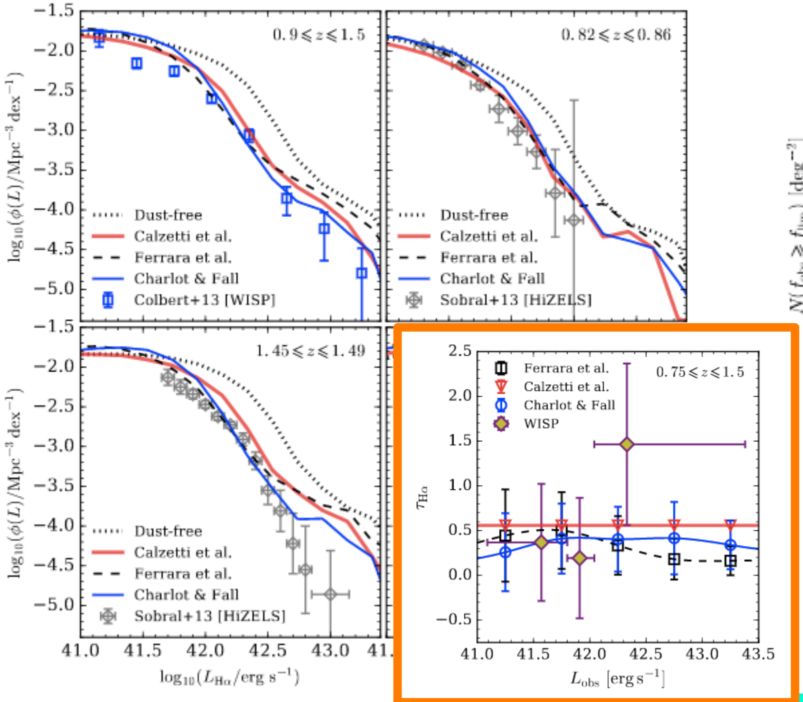
→ Halpha+ [NII] vs. WISP data between Model1 and Model 3

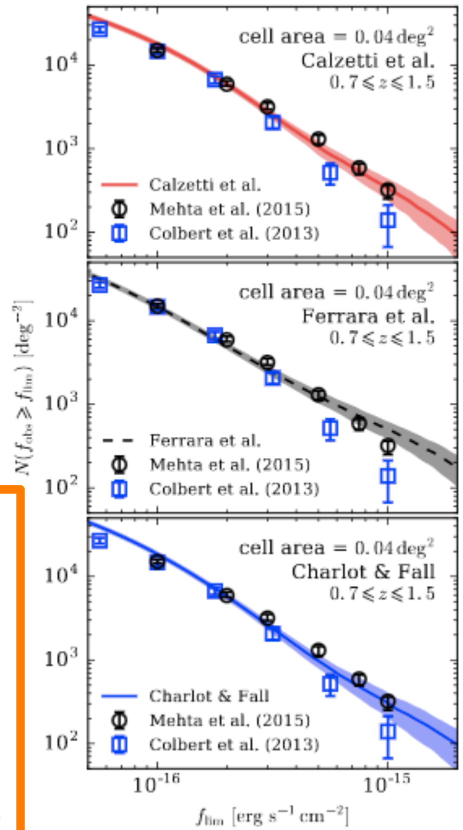
New Hα mock: SAMs (Galacticus)

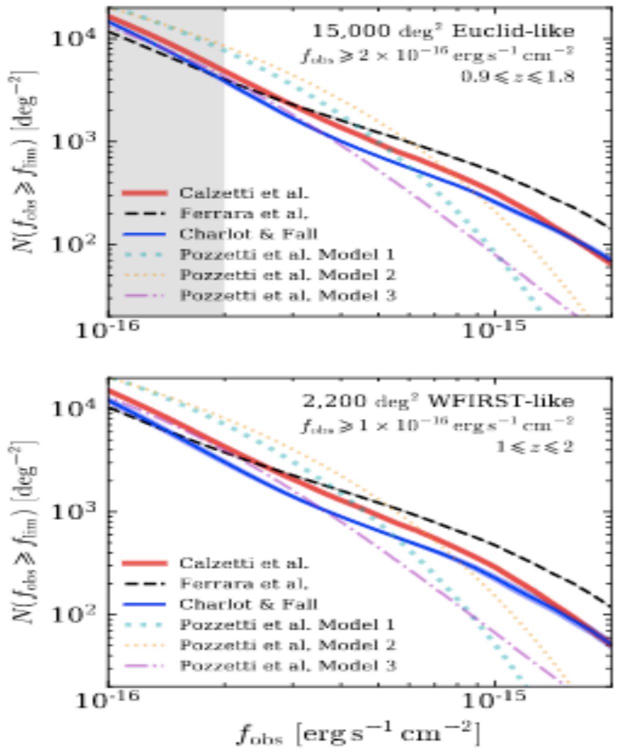
(Merson et al. 2017)

★ Semi Analitical model:

\+ SAM (GALACTICUS) with three different dust attenuation methods







→ weak dust attenuation is required to SAMs

Conclusions

Given the large scatter in the observed LFs covering similar redshift ranges, all the 3 models provide a good description of the data. In particular:

- Model 1, 2 reproduce a larger set of data, while Model 3 is extreme and reproduce only a subset of data, but more similar to Euclid/WFIRST slitless sp.
- New constrain from FMOS and extended-WISP survey.

→ Euclid Wide survey (0.9<z<1.8 on 15,000 deg^2) : ~72 million Hα emitters
→ Euclid Deep survey (0.4<z<1.8 40 deg^2) : ~ 1.3- 2 million Hα emitters
→ WFIRSTsurvey (1<z<2, 2200 deg^2) : ~ 16-26 million Hα emitters

→ LFs and SFHD

→ The 3 Models will be used by Euclid consortium for Science Performance Verification (SPV) for E2E simulations to derive completeness, purity vs. redshift and flux(Hα) and therefore the effective numbers of objects.