Universidad Complutense de Madrid,
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Madrid 20-21/06/2013

Properties of SFGs at intermediate redshift selected from SHARDS

Antonio Cava
Universidad Complutense de Madrid, Spain
(soon @ Geneva Observatory, Switzerland)

PI: Pablo G. Pérez-González

SHARDS team: G. Barro, A. Cava, M. Balcells, N. Cardiel, J. Cenarro, J. Cepa, S. Charlot, A. Cimatti, C. Conselice, E. Daddi, J. Donley, D. Elbaz, I. Ferreras, J. Gallego, R. Gobat, R. Guzmán, A. Renzini, G. Rieke, J.M. Rodríguez-Espinosa, L. Tresse, I. Trujillo, V. Villar, J. Zamorano

TALK OUTLINE

- Introduction
- Survey and data characteristics (see Pablo's talk)
- Origin and relevance of Els as SF indicator
- ELGs selection from SHARDS data
- ELGs properties from [OII]
- Conclusions

SHARDS: current status

Filter #	Filter name	Central wavelength at AOI=10.5° (nm)	Width at AOI=10.5° (nm)	Exposure time (s)	Depth (AB mag)	Seeing (arcsec)	Transmission file
01	F500W17	500	15	3780	27.0	N/A	AOI=0°
02	F517W17	520	16	4445	27.0	N/A	AOI=0°
03	F534W17	536	17	4800	27.0	N/A	AOI=0°
04	F551W17	552	14	5190	27.0	N/A	AOI=0°
05	F568W17	569	14	5810	27.0	N/A	AOI=0°
06	F585W17	586	15	6125	27.0	N/A	AOI=0°
07	F602W17	603	16	7440	27.0	N/A	AOI=0°
08	F619W17	619	16	7920	27.0	N/A	AOI=0°
09	F636W17	636	16	9180	27.0	N/A	AOI=0°
10	F653W17	653	16	10440	27.0	N/A	AOI=0°
11	F670W17	668	16	4550	26.5	N/A	AOI=0°
12	F687W17	688	17	9270	26.5	N/A	AOI=0°
13	F704W17	704	18	6120	26.5	N/A	AOI=0°
14	F721W17	720	19	6600	26.5	N/A	AOI=0°
15	F738W17	738	15	7965	26.5	N/A	AOI=0°
16	F755W17	754	15	9000	26.5	N/A	AOI=0°
17	F772W17	771	16	9900	26.5	N/A	AOI=0°
18	F789W17	789	16	12250	26.5	N/A	AOI=0°
19	F806W17	806	16	14300	26.5	N/A	AOI=0°
20	F823W17	825	15	18540	26.5	N/A	AOI=0°
21	F840W17	840	16	21120	26.5	N/A	AOI=0°
22	F857W17	856	16	24240	26.5	N/A	AOI=0°
23	F883W35	880	34	16480	26.5	N/A	AOI=0°
24	F913W25	910	28	0 (OTELO)	26.5	N/A	AOI=0°
25	F941W33	941	34	32000	26.5	N/A	AOI=0°

Cat. V. 1.14.2

Cat. V. 1.13.2

Used for the analysis

WEB VERSION

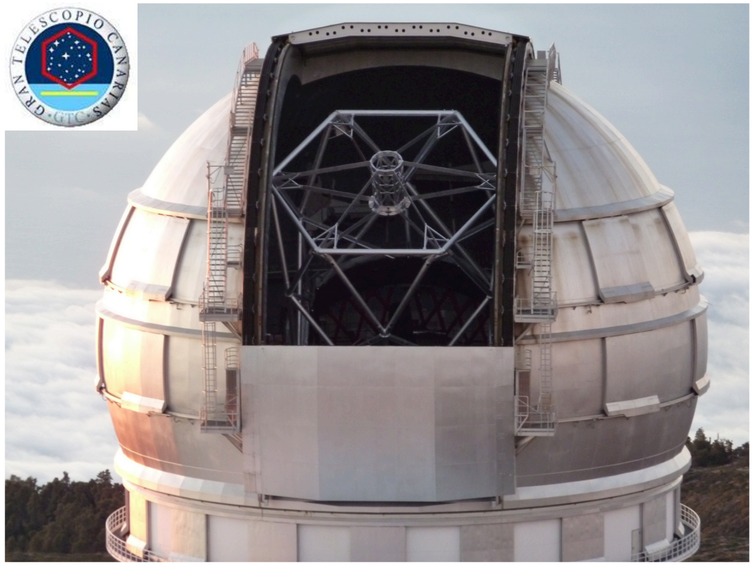
SHARDS: observations

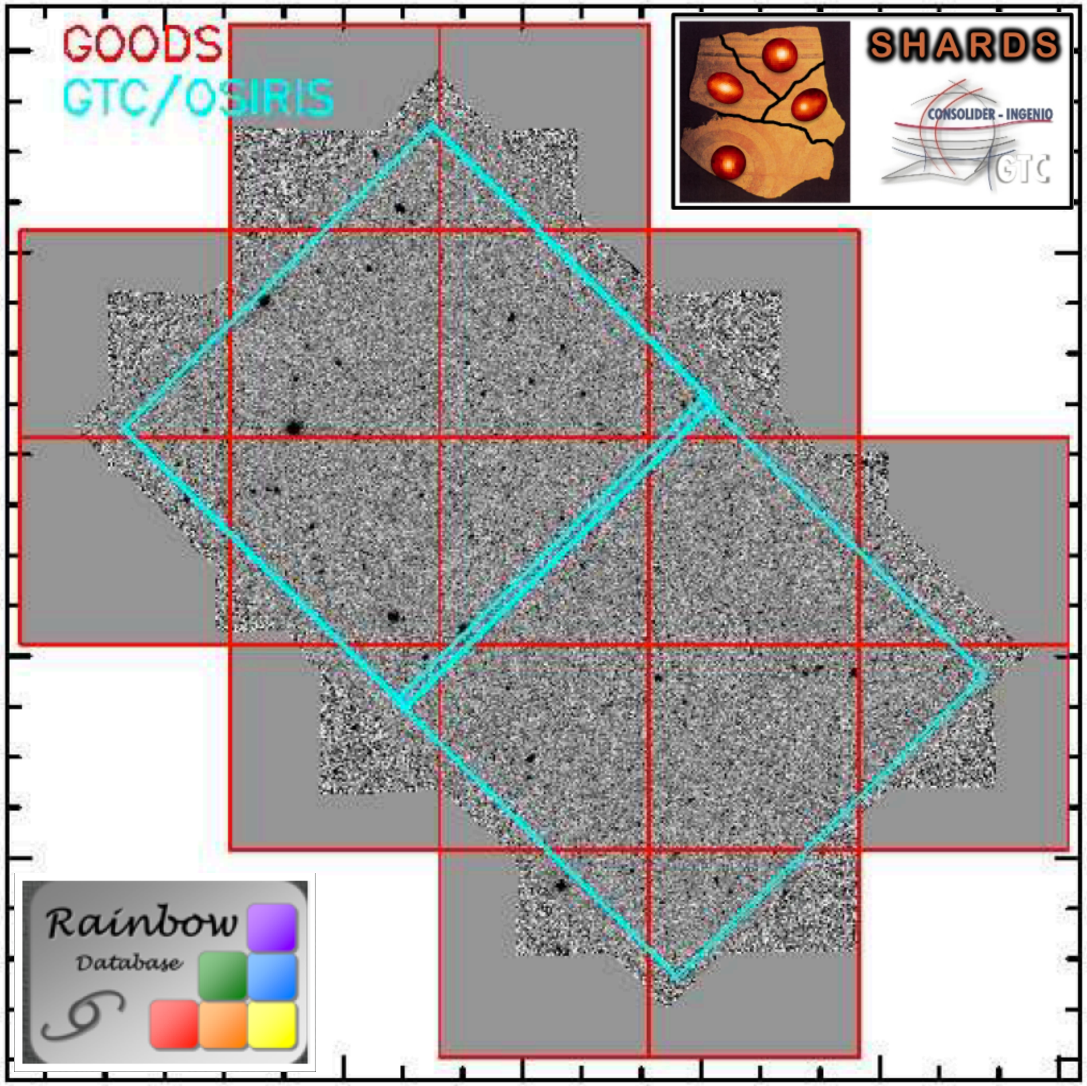
Some GOODS reasons to target the GOODS-N field:

- Extremely extended multi-wavelenght coverage: from X-rays to radio → *well sampled SEDs*

- very good spectroscopic coverage (necessary for photo-z calibration and specific flux calibration issues)

- observable from 10m class telescope, GTC, with OSIRIS instrument

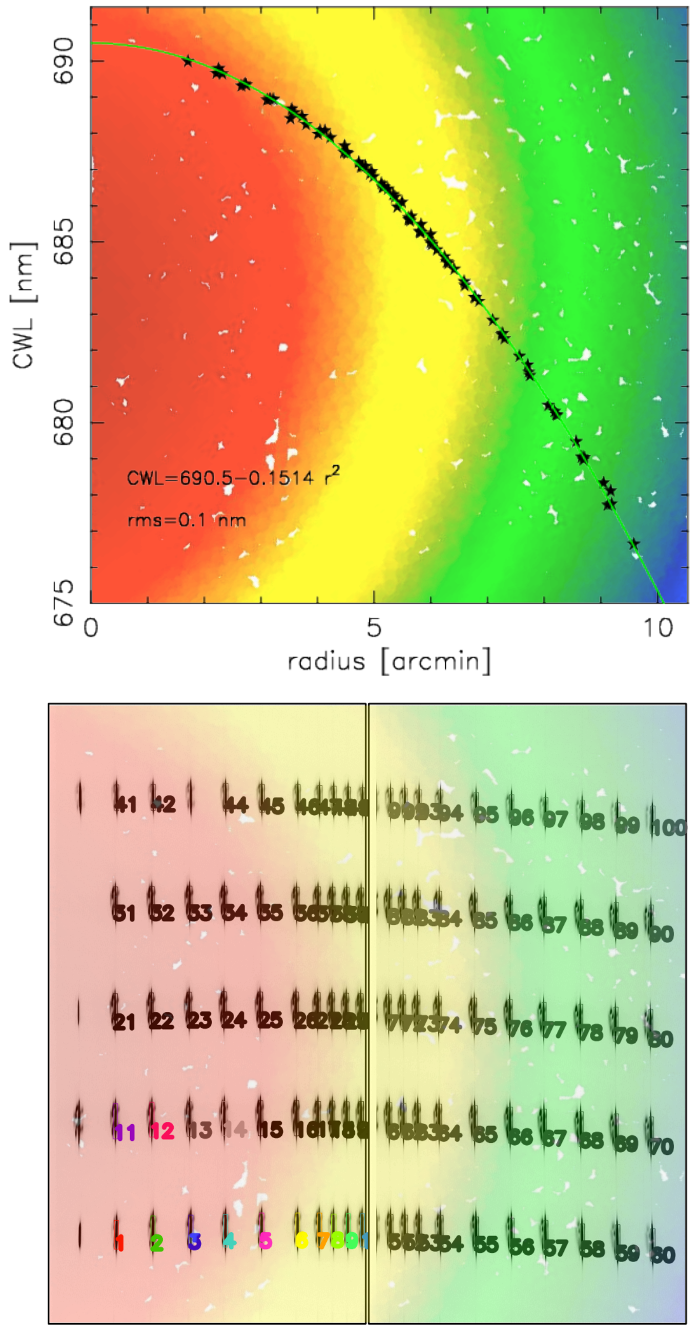




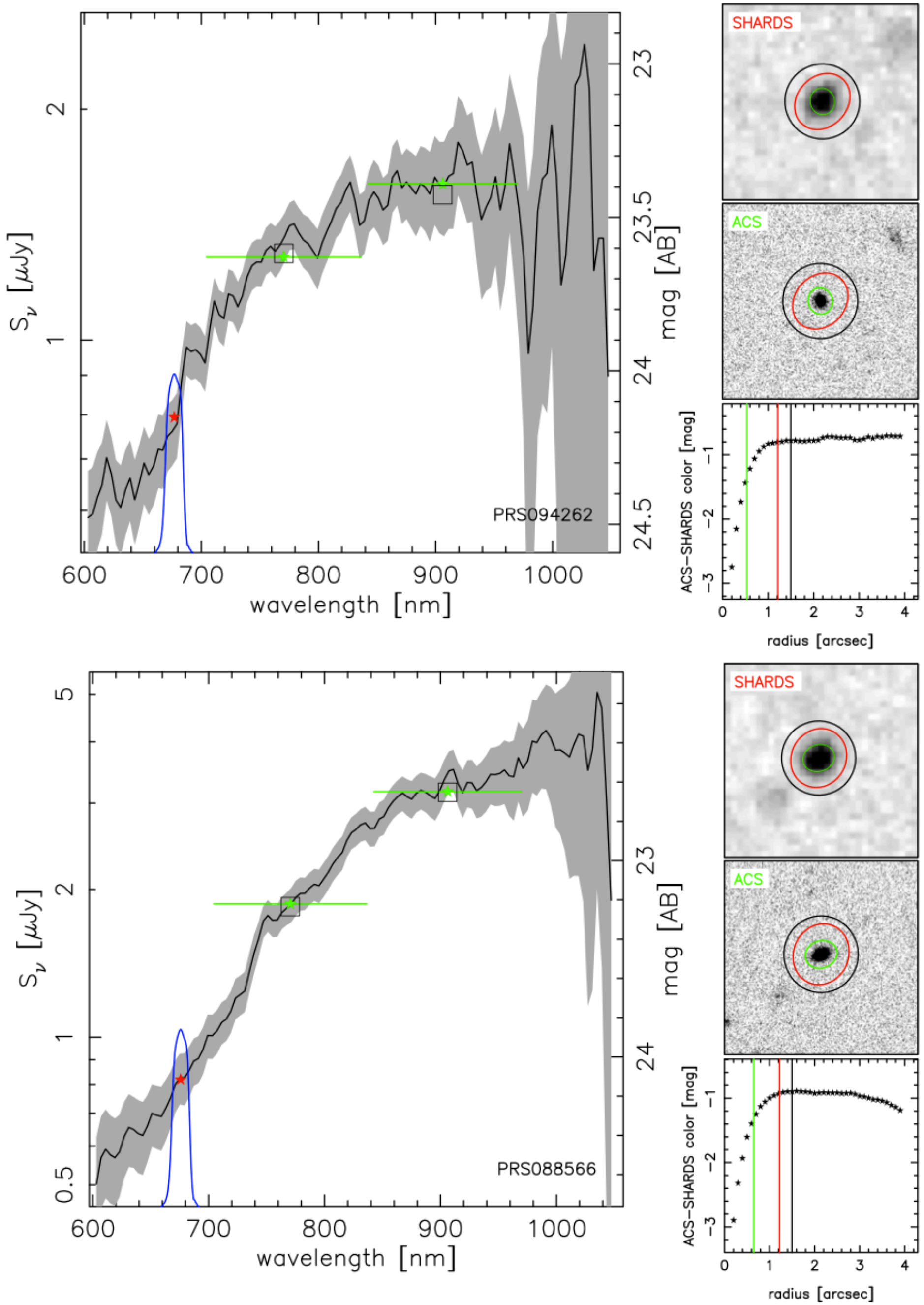
Spectral range	3650-10000 A
F.O.V.	7.8' x 8.5' (imaging; 7.8' x 7.8' unvignetted)
Plate Scale	0.125" (imaging and Spectroscopy)
Detector	2 x 2048 x 4096 Marconi CCD42-82 (with a 9.2" gap between them)
Pixel Size	15 µm/pix
Detector Quantum Efficiency (QE)	50% (400 nm), 90% (600 nm), 80% (800 nm), 40% (900 nm)
Image quality	EER80 < 0.15" (Imaging mode). Distortion < 2% in all the detector

SHARDS: calibrations

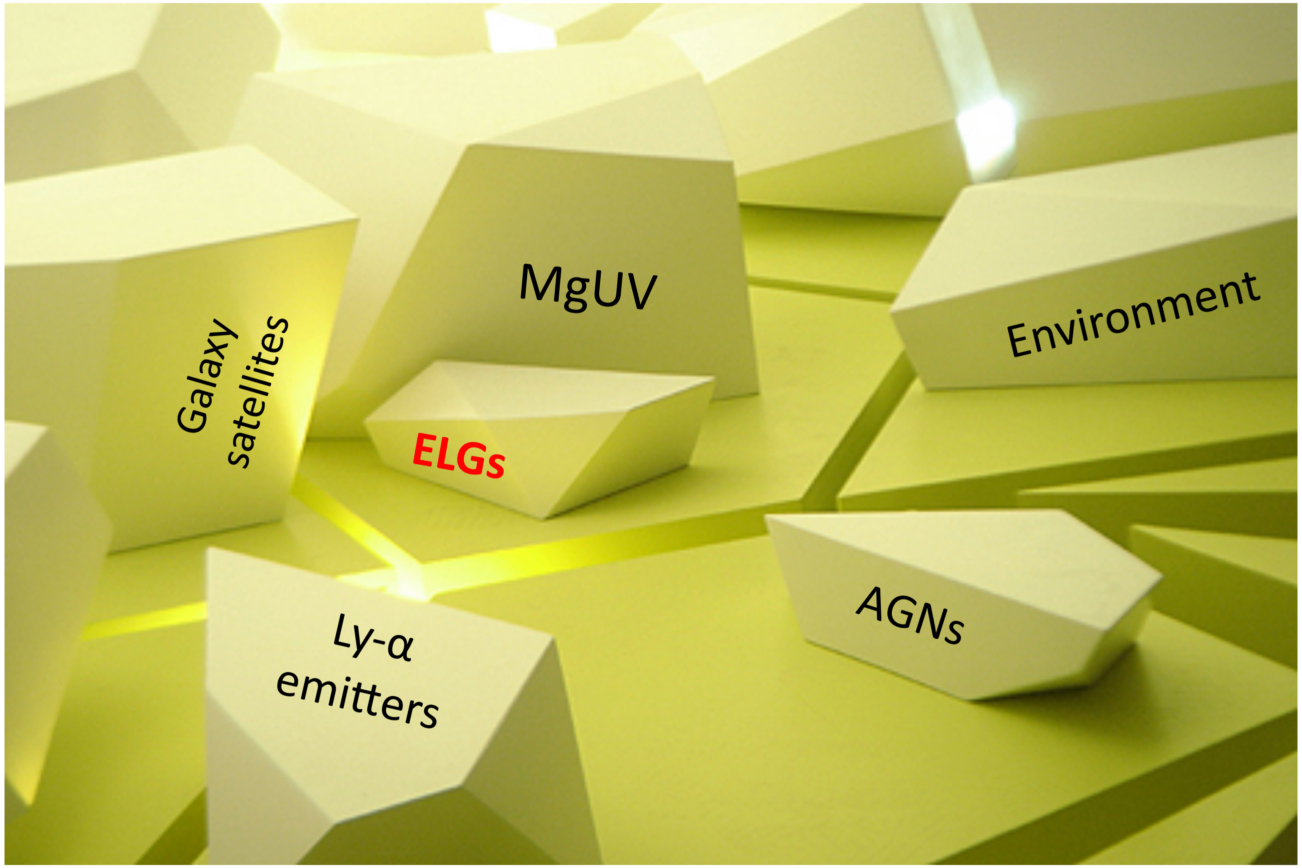
CWL vs FOV position



Flux calibration (HST grism spectra + TKRS/DEEP3 + models)



Shards of SHARDS



Shards of SHARDS: SFGs/ELGs

What and why is it important?

ELGs are good tracers of SF

How has the Universe built up its stellar and metal content?

High-z formation efficiency?

Loz-z formation efficiency?

Z=0 → use the Hα luminosity density of the local Universe:

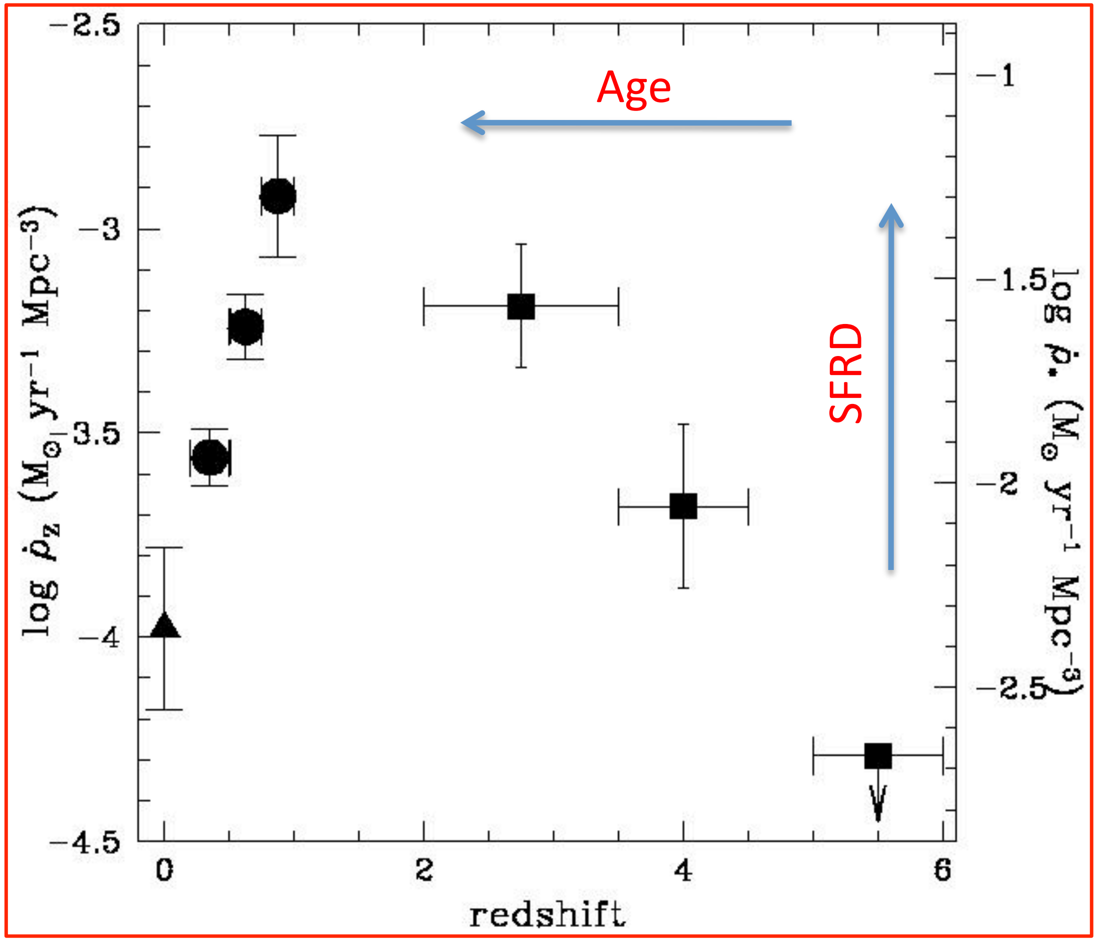
$L_D(H\alpha)$ → SFRD(z=0) (e.g. Gallego et al. 1995)

Z>0 → use other optical/UV SF indicators from deep/large spectro-photometric surveys of Distant Galaxies to compute the Luminosity Density:

$L_D(\Gamma,z)$ → SFRD(z) (e.g. Madau et al. 1996)

Shards of SHARDS: SFGs/ELGs

What and why is it important?

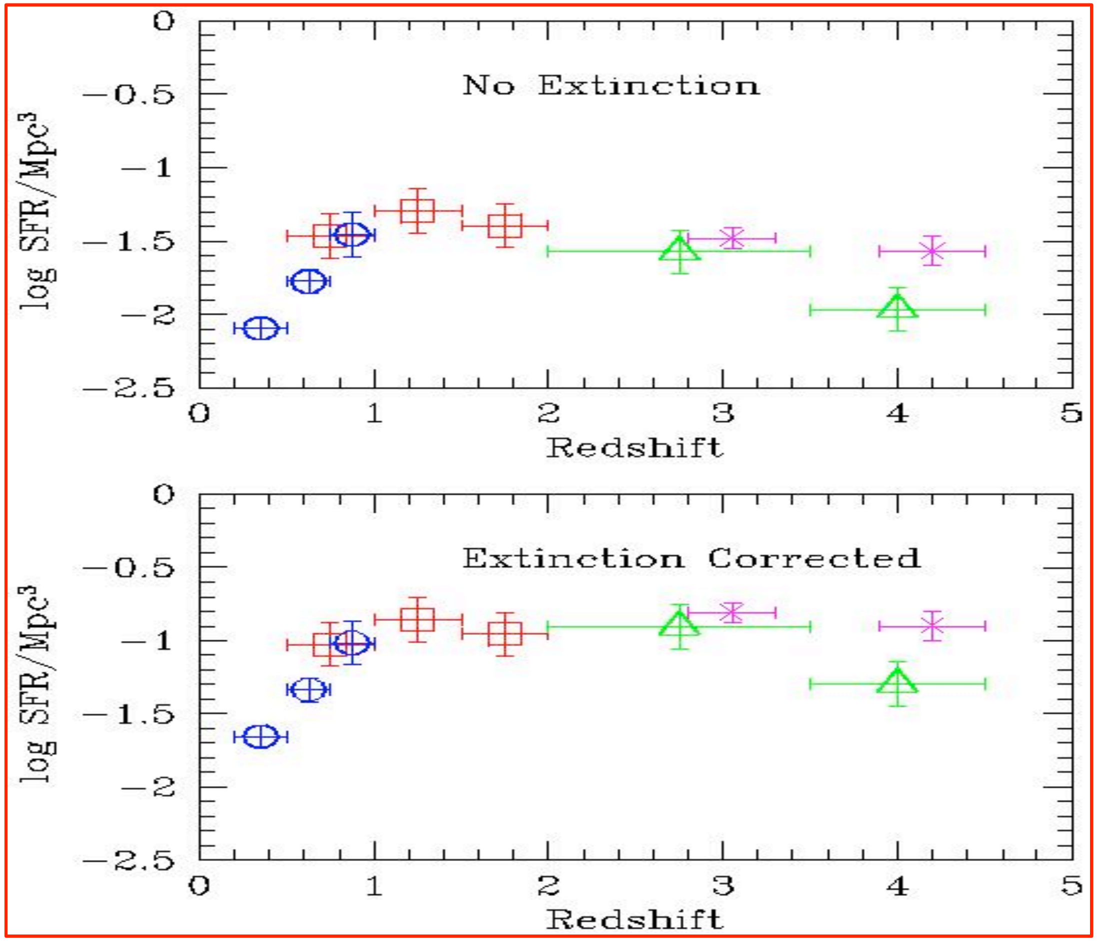


Madau+98

The star (and element) formation history of the universe, from the HDF (Madau 1998).
The early data used for this figure indicated a strong peak in the SFR at about z ~ 1-2.

Shards of SHARDS: SFGs/ELGs

What and why is it important?

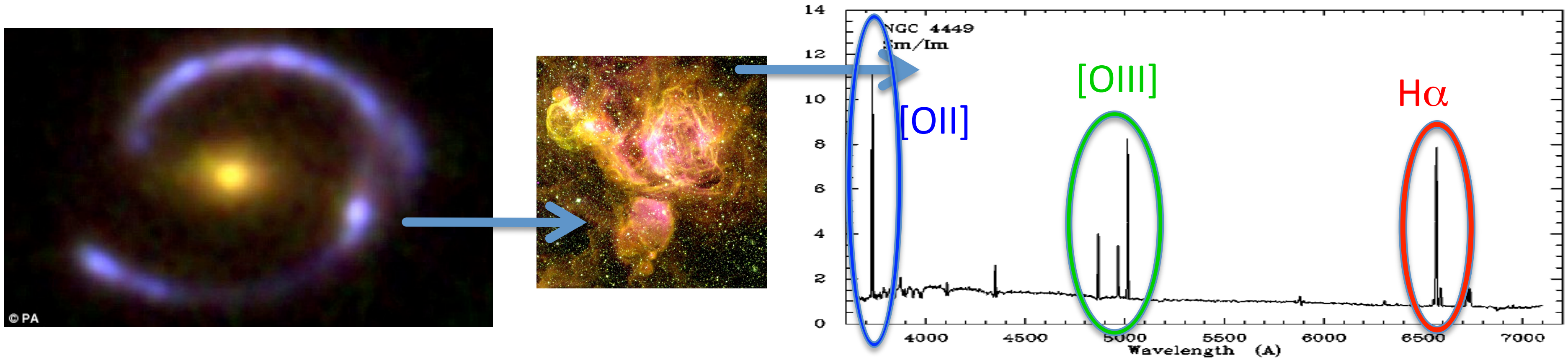


The star (and element) formation history of the universe, from the HDF (Steidel 1999). The data used for this figure indicated a weak peak in the SFR at about z ~ 1-2 followed by a flat behavior.

Shards of SHARDS - Science: ELGs

Why to study ELGs?

Young, bright stars are usually embedded in clouds of gas which are photoionized by energetic photons from these stars.



The nebular lines effectively re-emit the integrated stellar luminosity of galaxies shortward of the Lyman limit, so they provide a direct, sensitive probe of the young massive stellar population.

Only stars with masses of >10 $M_\odot$ and lifetimes of t<20 Myr contribute significantly to the integrated ionizing flux, so the emission lines provide a nearly *instantaneous measure* of the SFR, independent of the previous star formation history.

Most applications of this method have been based on measurements of the **Hα** line but **other lines/methods can be used** as well.

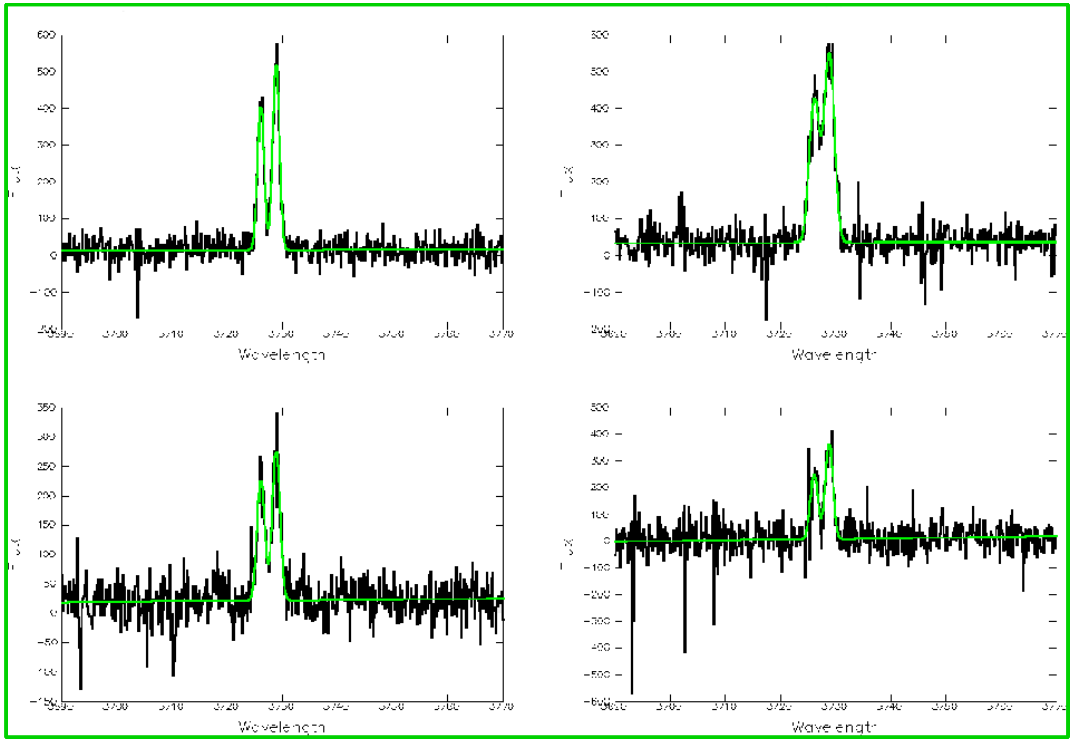
Shards of SHARDS – Science: [OII] and SF

Why to use [OII]?

The Hα emission line is redshifted out of the visible window beyond z≈0.5, so bluer SFR tracers can provide a very useful estimate of the systematics of SFRs in samples of distant galaxies.

The strongest emission feature in the blue is the [OII]λ3727 *forbidden-line* doublet.

(The ${}_2D^{3/2} \rightarrow {}_4S^{3/2}$ and ${}_2D^{3/2} \rightarrow {}_4S^{5/2}$ transitions give rise to the 3726.1 Å and 3728.8 Å emission lines respectively.)



Shards of SHARDS – Science: [OII] and SF

Why to use [OII]?

The lumnosity of the [OII] forbidden line is not directly coupled to the ionizing luminosity and is sensitive to abundance and the ionization state of the gas, but can be empirically calibrated (through Hα) as a quantitative SFR tracer.

$$\mathrm{SFR}(M_{\odot}\,\mathrm{year}^{-1}) = (1.4 \pm 0.4) \times 10^{-41} L[\mathrm{OII}]\ (\mathrm{erg\ s}^{-1}) \qquad \text{(Kennicutt 1998)}$$

<u>Other important SFR tracers include:</u>

- UV radiation (dominated by young star radiation field, SFR scales linearly with luminosity; 1500-2500Å from ground only at z>1; extinction is an issue, $t \sim 10^8 yr$)

- MIR/FIR re-radiation (fraction of UV radiation absorbed by dust and re-emitted in the mid-/far-IR, $t \sim 10^9 yr$)

- integrated colors (e.g. U-V; imprecise and model dependent but provide average SFR properties for large galaxy samples, $t > 10^9 y$)

Shards of SHARDS – Science: [OII] and SF

The Conditions of Emission of Forbidden Lines.
By A. S. Eddington, F.R.S.

In announcing the discovery of forbidden lines in nebulæ, Dr. Bowen pointed out that their occurrence depends on the free path being so great that the atom is unlikely to have a collision during the full duration of the metastable state. Nevertheless, it is generally felt that some further explanation is needed. All with whom I have discussed the subject have been impressed by the apparent difficulty of accounting for the great brightness of the forbidden lines in comparison with ordinary lines. A recent paper by J. Woltjer * is written from this standpoint. Although I at first shared this opinion, I have now come to the conclusion that we have been approaching the problem too elaborately, and that all that is needed is a rather obvious addendum to Bowen's original condition :

The stimulating radiation must be so weak that the atom is unlikely to absorb a quantum during the full duration of the metastable state.

Let (2) be a metastable state, the forbidden transition being 2 → 1. Let (3) be the state next above (2), from which there is an ordinary transition to (2). For a definite example, suppose that the full duration of (2) is 1 sec. and of (3) is 10^{-8} sec.

3 - Stable state

2 - Metastable state

1 - Stable state

First, let the radiation † be moderately strong so that each atom (whether in the normal or excited state) absorbs about once in 10^{-3} sec. Then practically all the atoms arriving by any route at state (3) will forthwith emit, only 1 in 10^5 being arrested and jerked to some higher state by absorption. A fixed proportion will emit the line 3 → 2 and reach state (2). Of these, only 1 in 1000 will go on to state (1); the others are forestalled by absorption which diverts them to higher states. Accordingly the forbidden emission in 2 → 1 is very much less than ordinary emission.

Next, let the radiation be so weak that each atom absorbs about once in 10 seconds. As before, the atoms arriving at state (3) will forthwith emit, a fixed proportion of them travelling to state (2). But

Nebulium (1927)
[OII] λ3729

Coronium (1930)
[Fe13+] λ5303

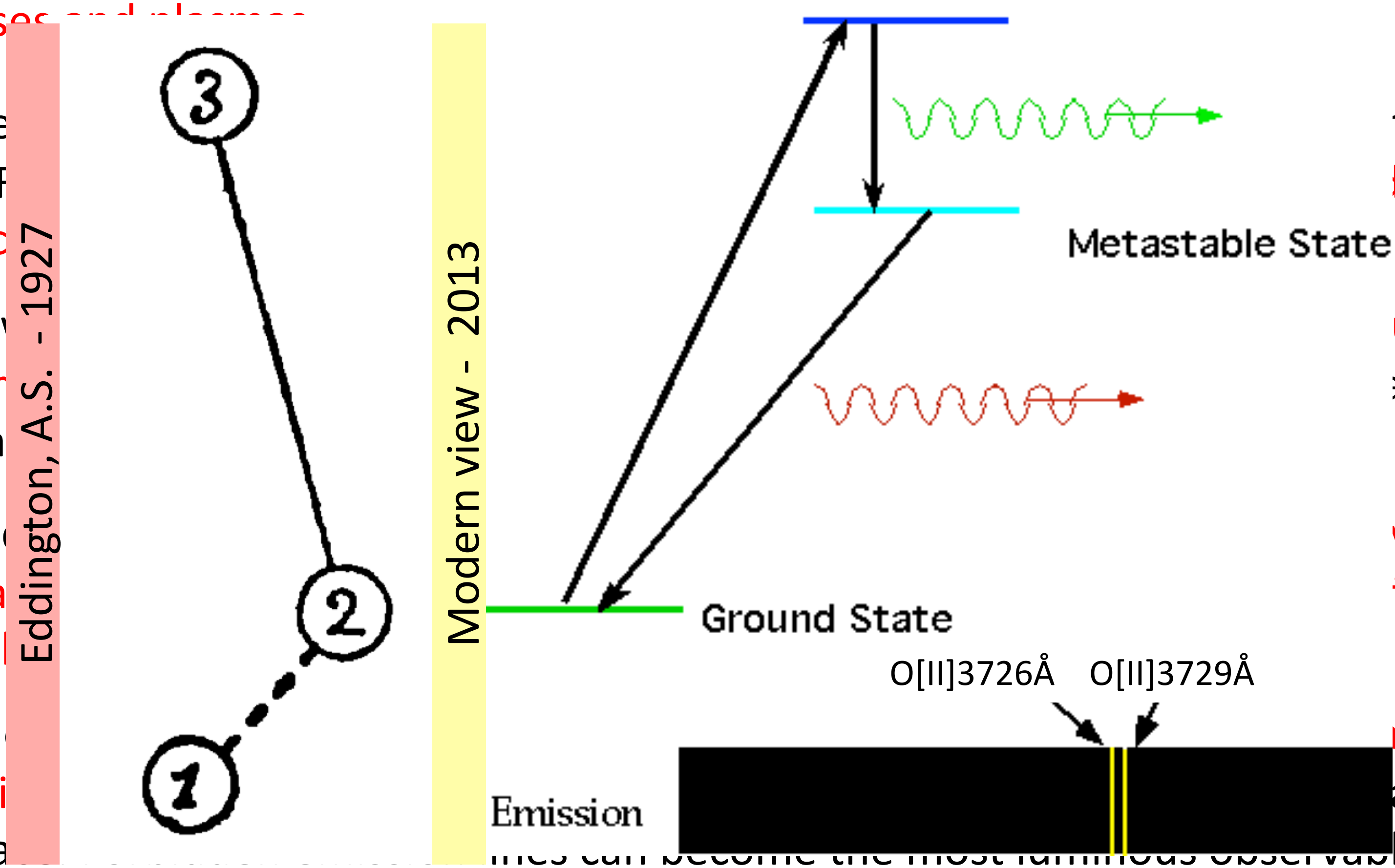
Eddington, A.S., MNRAS, 88, 134-138, **1927**

Shards of SHARDS – Science: [OII] and SF

Basic principles of observed emission lines

(modern view, 2013)

Forbidden emission lines have only been observed in extremely low-density gases ...



Eve ... n^{-3} at
CEF ... le-
exc

Ho ... ubic
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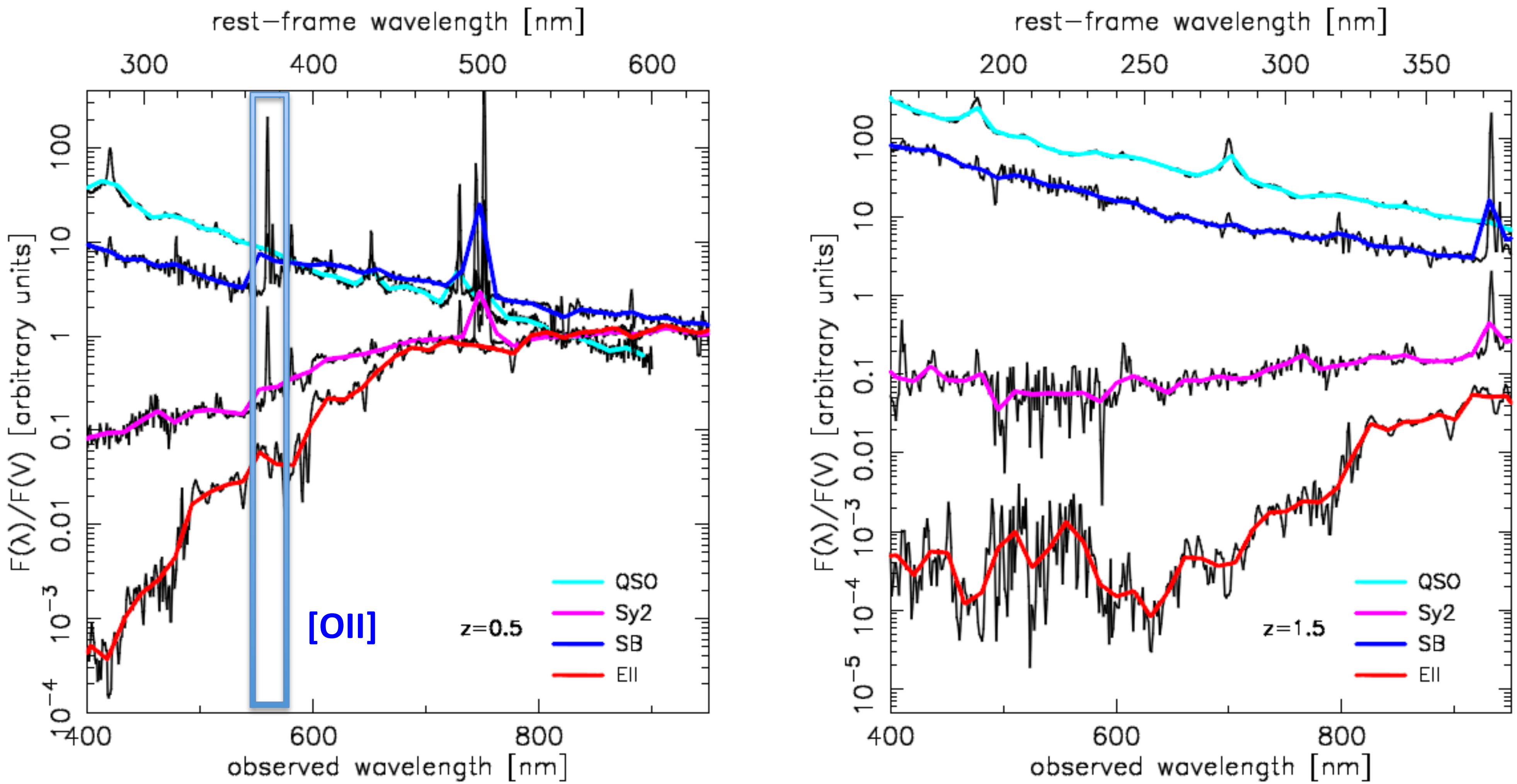
ma

Un ... y
rea ... ing a
for

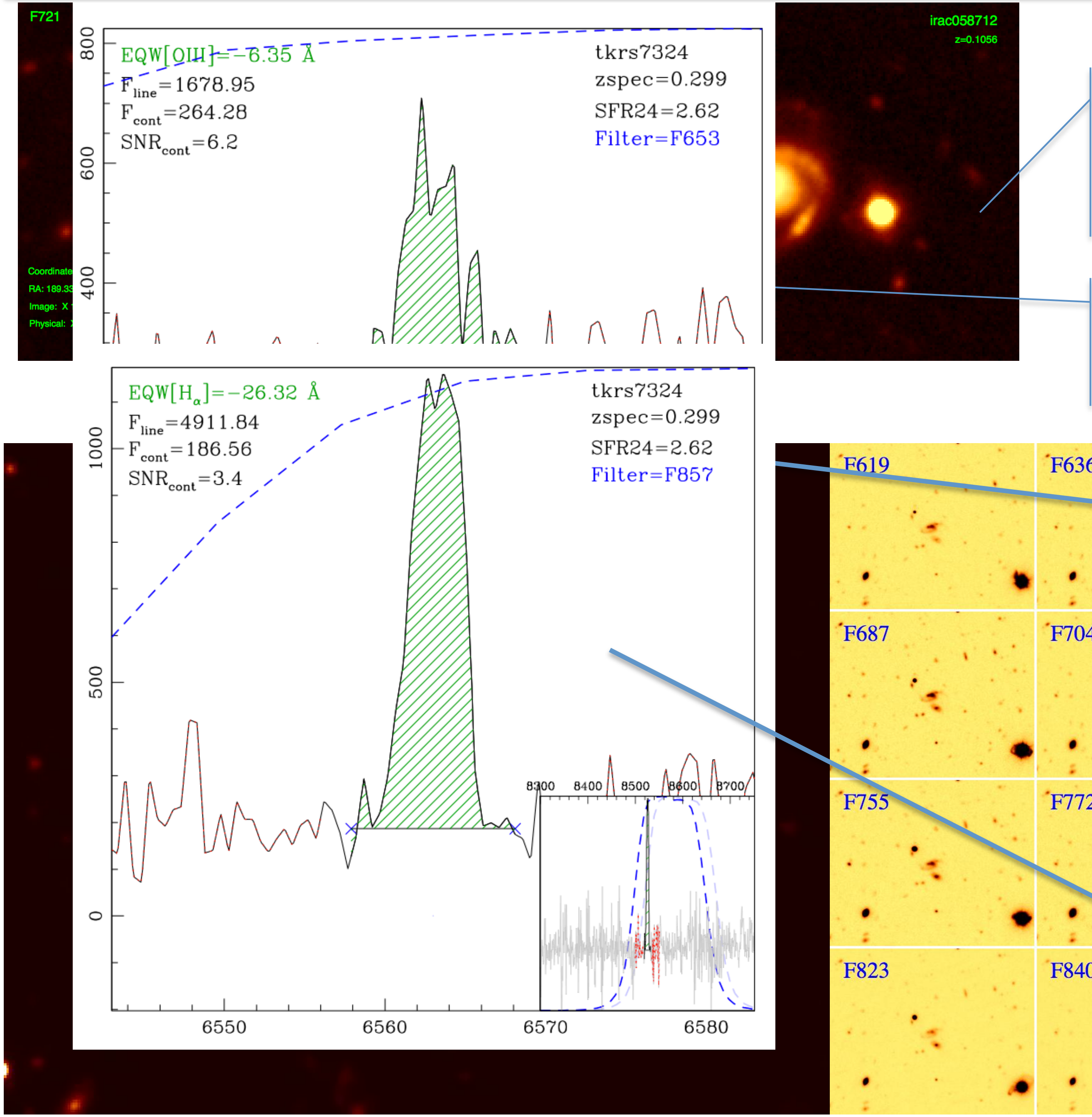
Sin ... t for
a si ... as in
spa ... le
lines.

Shards of SHARDS - Science: ELGs

SHARDS was optimized for the study of R&D galaxies but ELGs were also within the goals of the survey

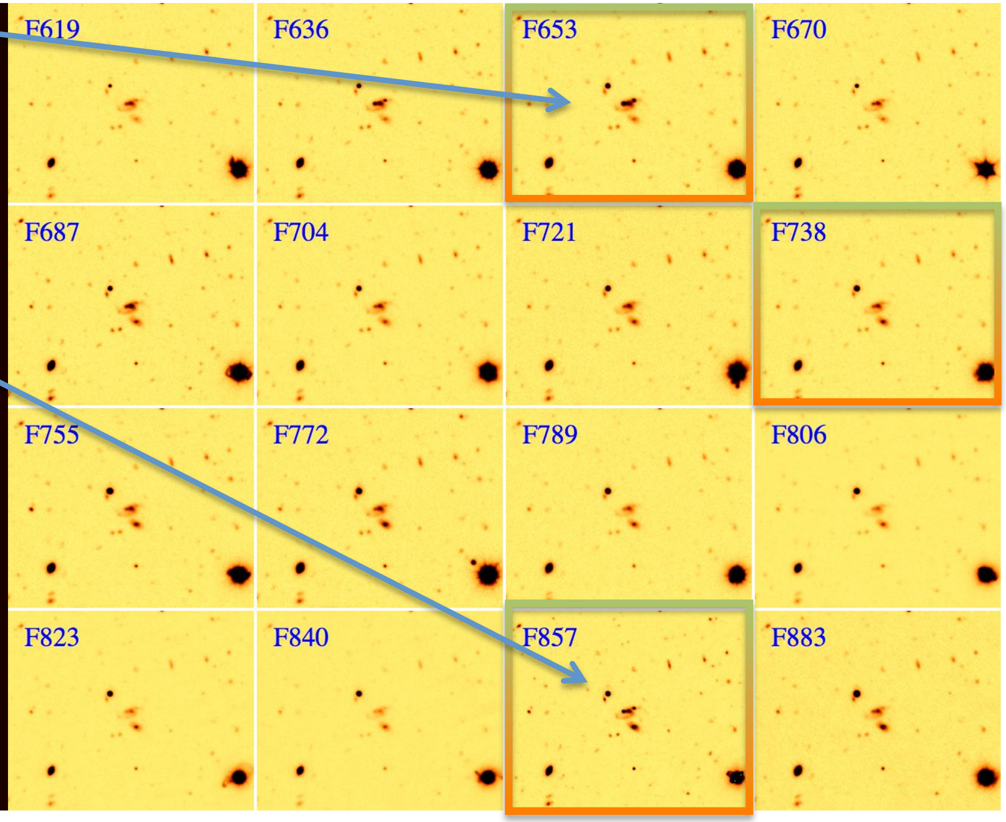


Shards of SHARDS - Science: ELGs

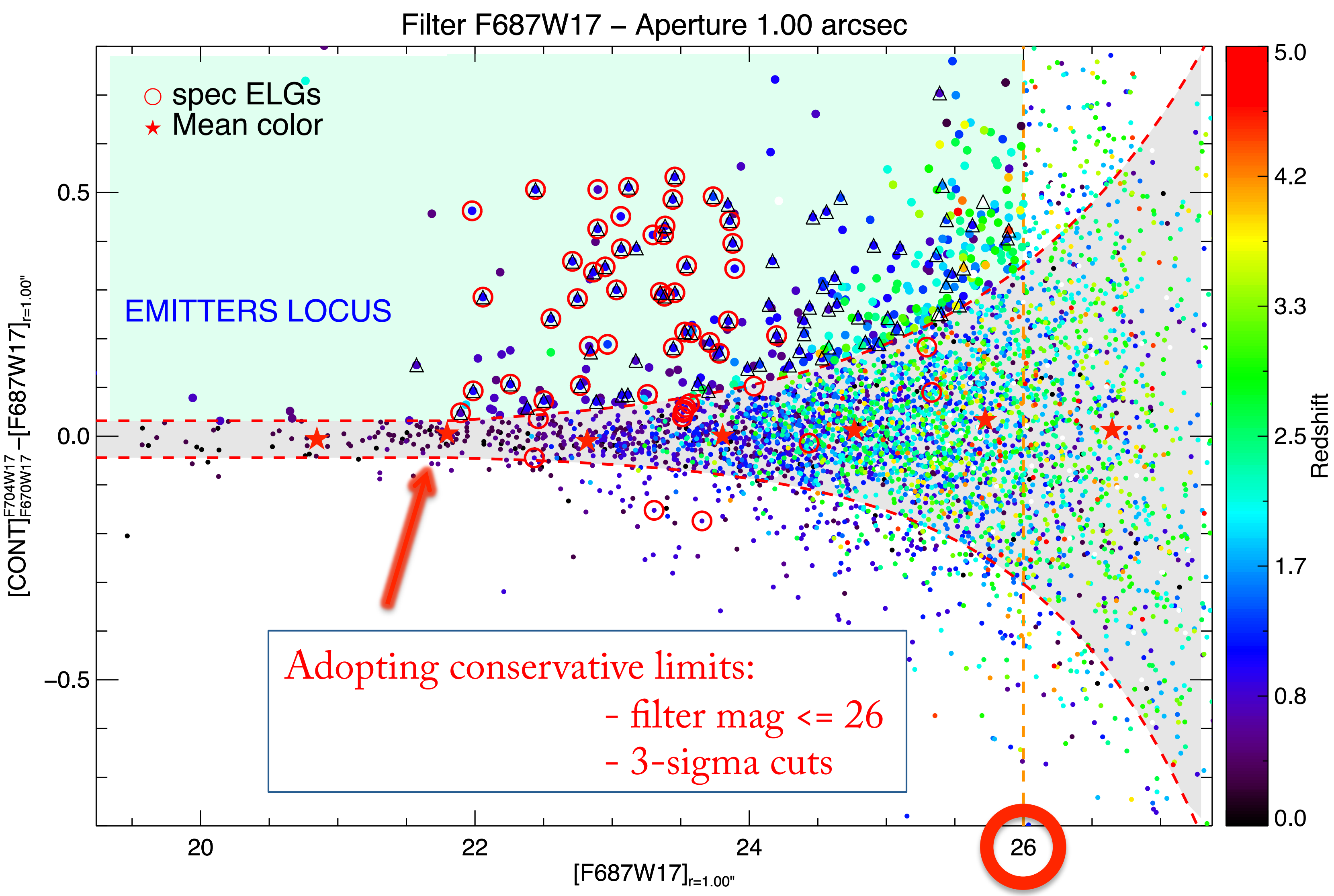


RAINBOWFICATION directly in the images Hα expected at F721

Ghost effects removal and characterization



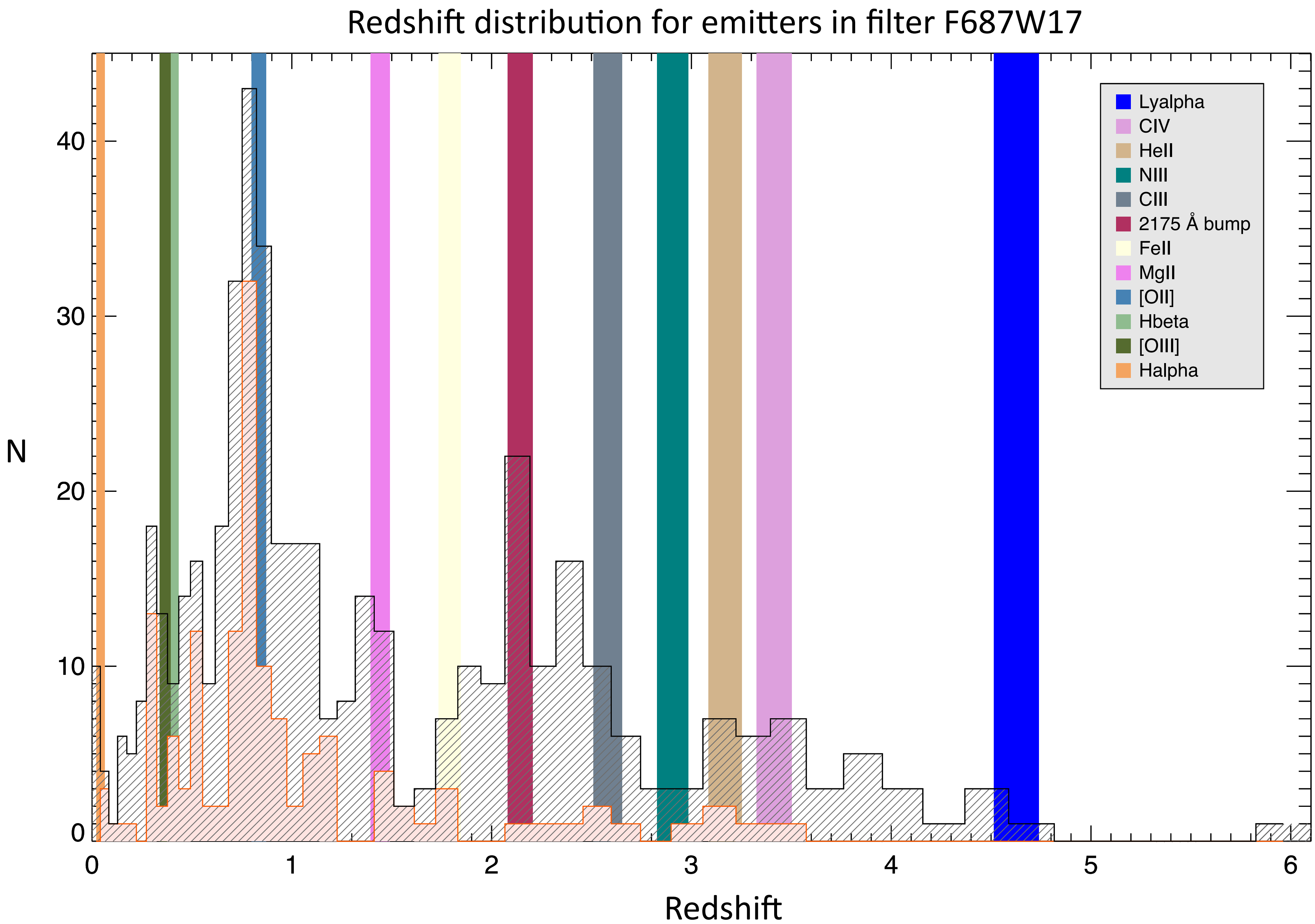
SHARDS: ELGs selection



Adopting conservative limits:

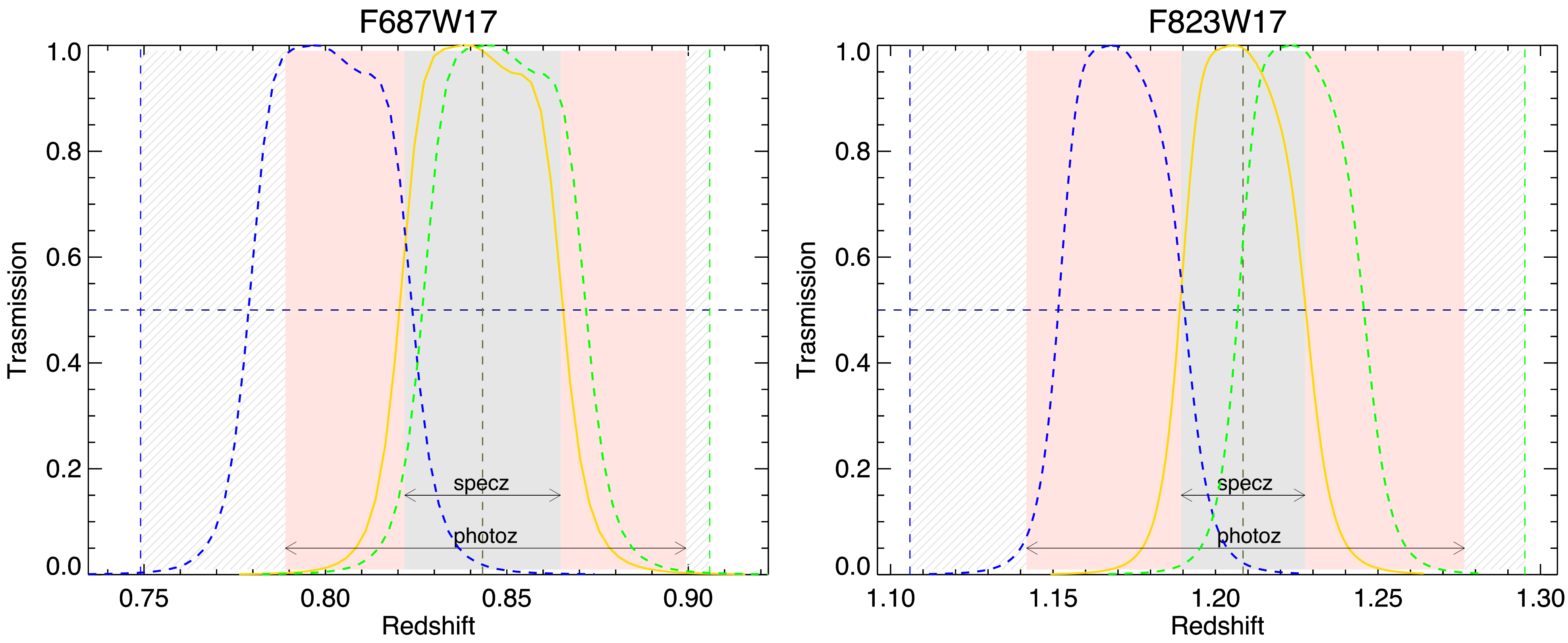
- filter mag <= 26
- 3-sigma cuts

SHARDS: ELGs distribution



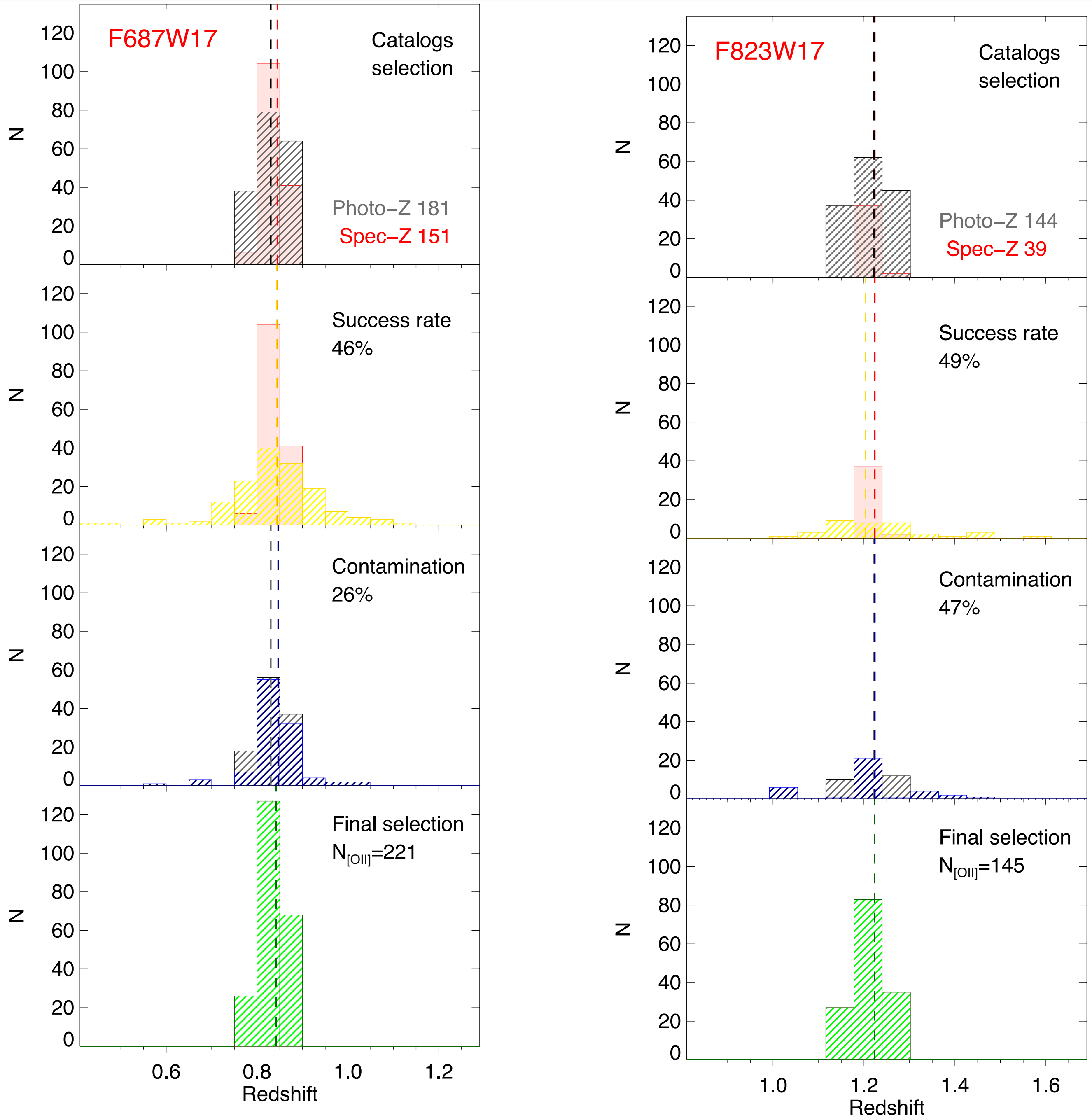
SHARDS: ELGs selection

SELECTION FUNCTION

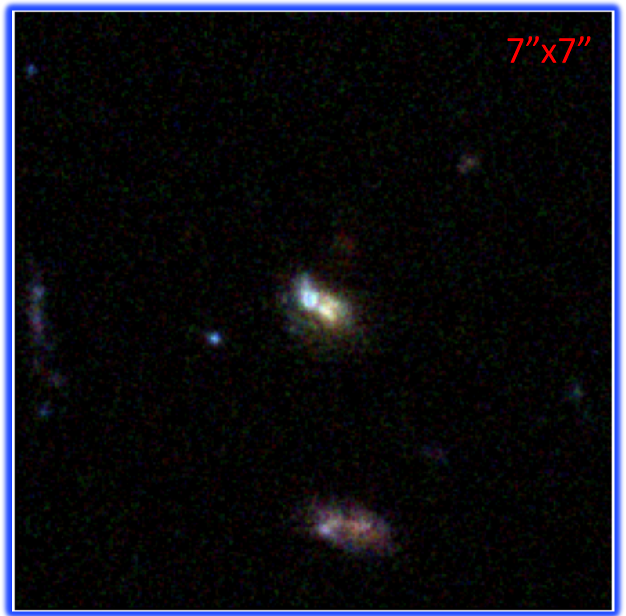


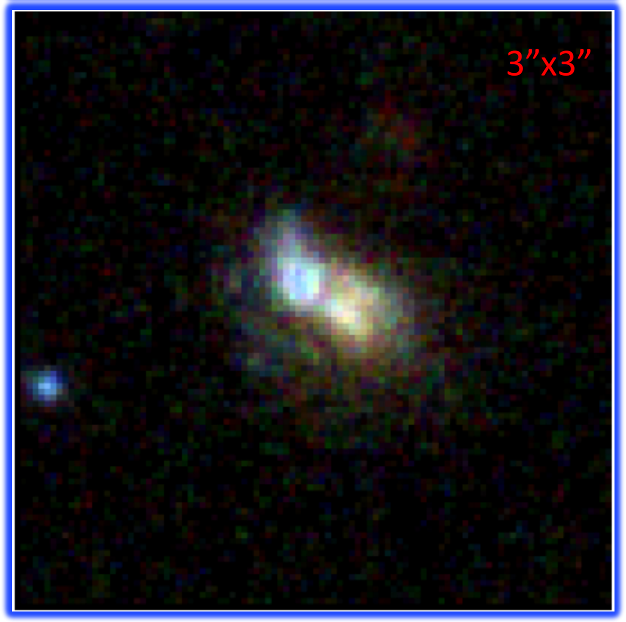
Not a simple redshift interval but depending on the CWL calibration curve.

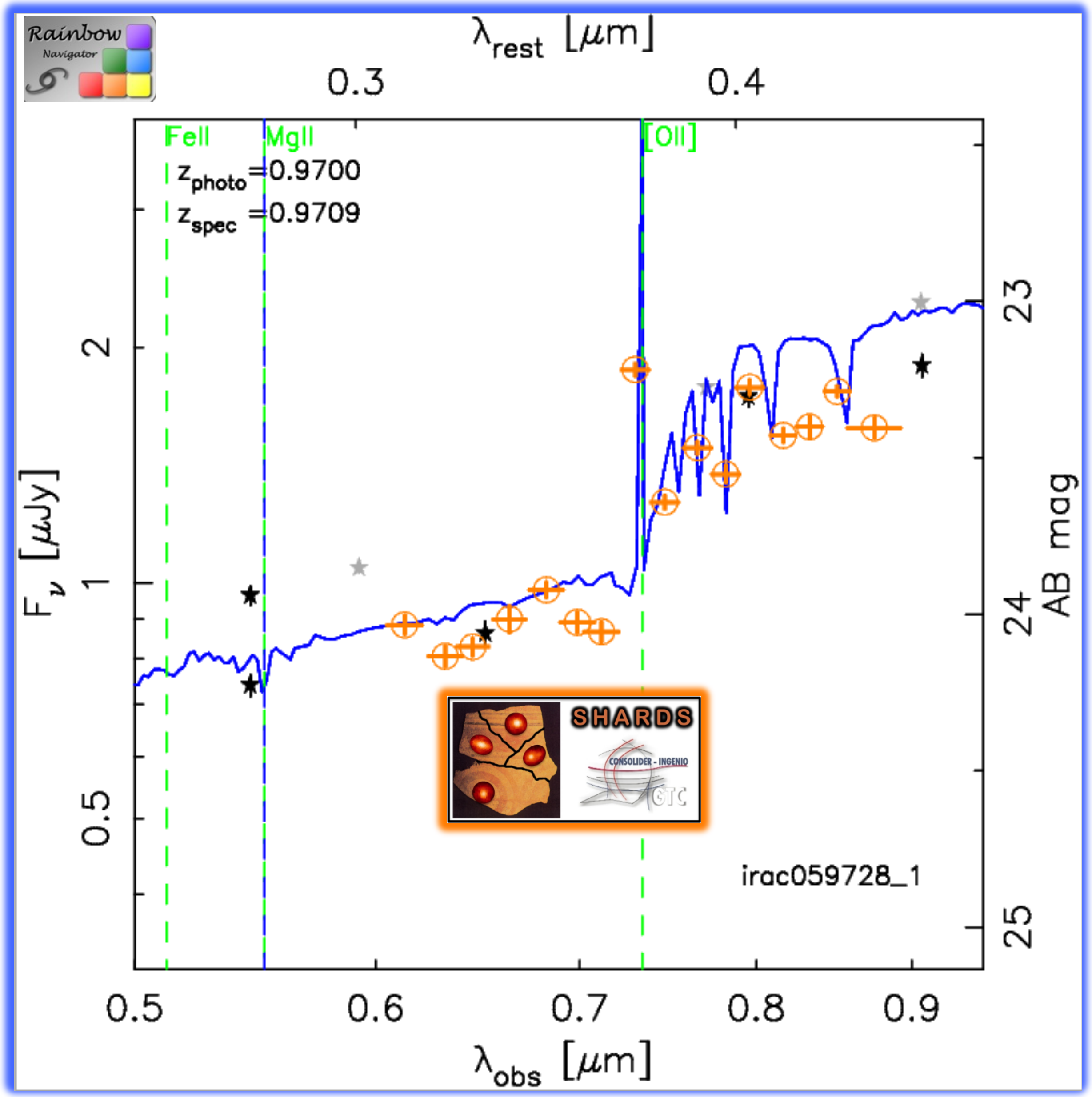
SHARDS: ELGs selection



SHARDS: Science - ELGs





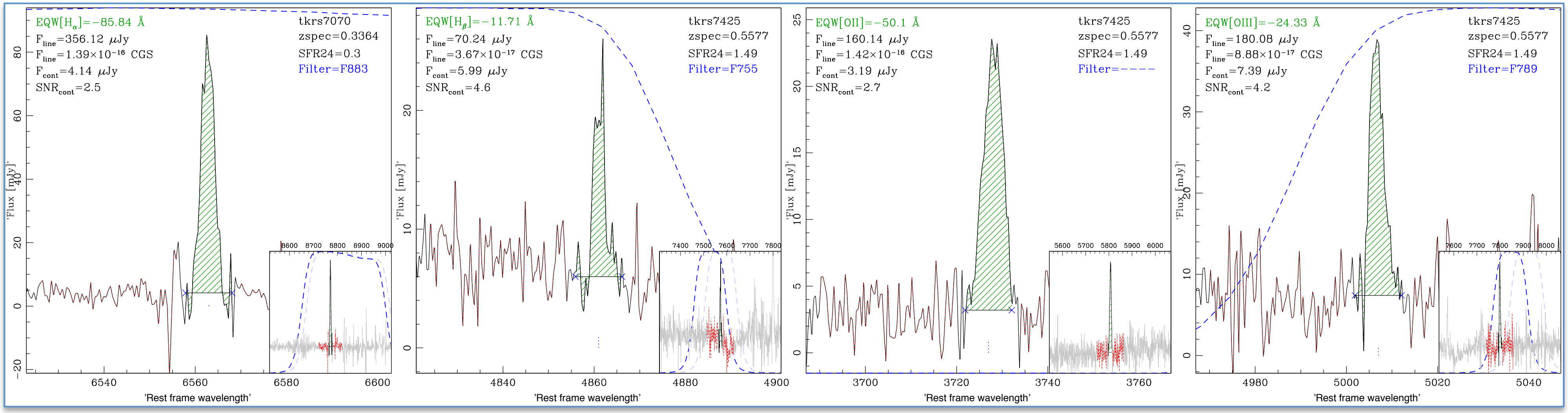


SHARDS: Science - ELGs

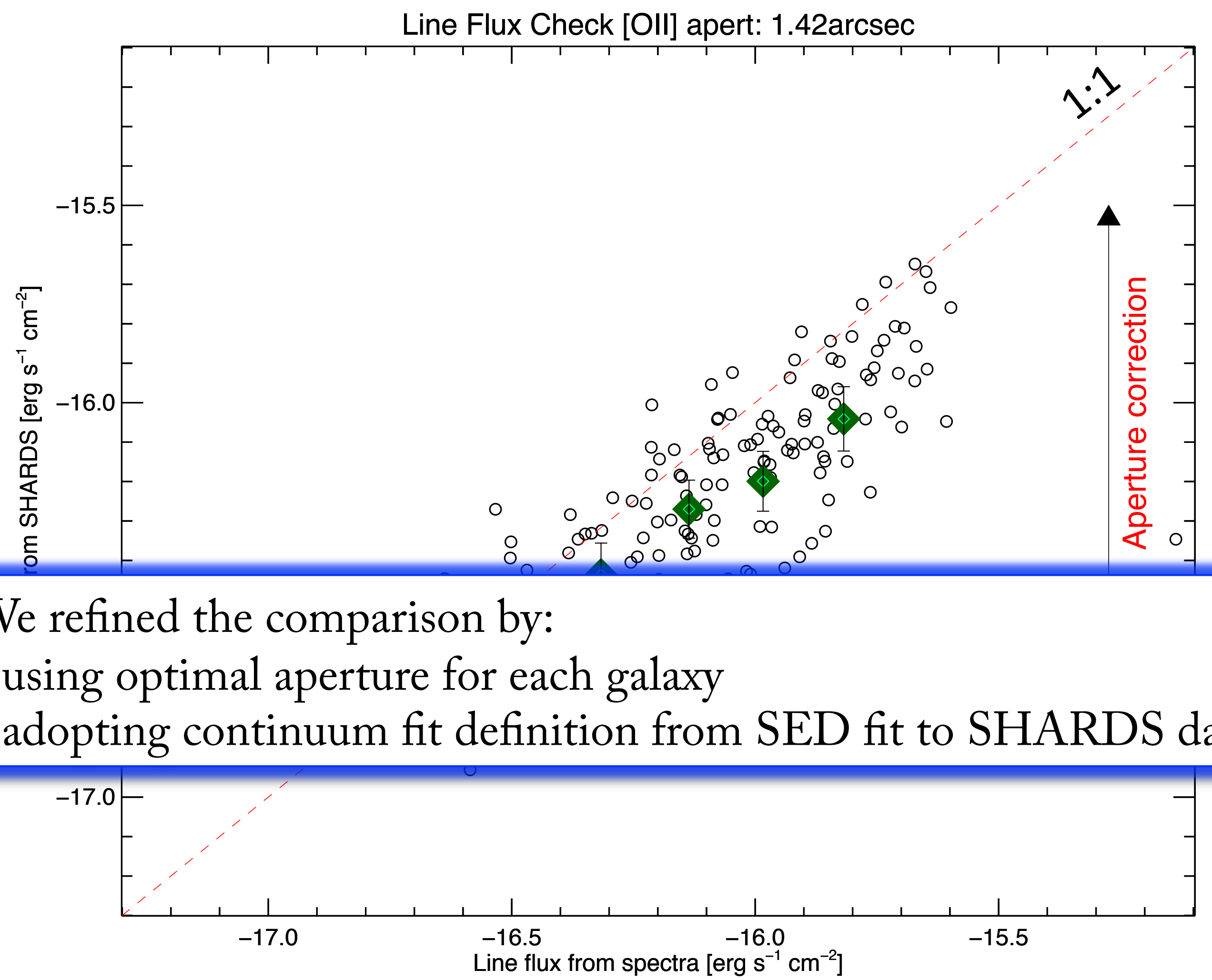
Using public spectra we check EWs and fluxes for SHARDS emitters:

- [OII]
- [OIII]
- H_α
- H_β

A deeper check including 13 emission and absorption features with a selfconsistent method (from Fritz et al. 2007) providing robust measurements and errors estimation is planned.



SHARDS: Science - ELGs



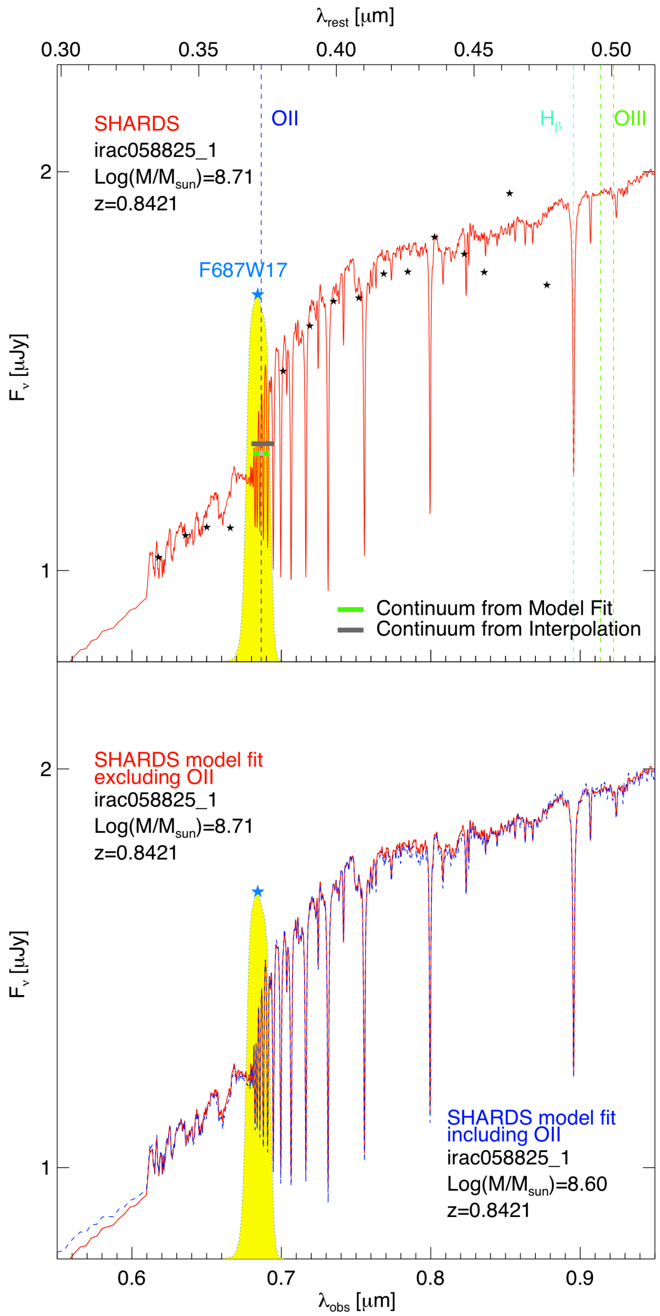
We refined the comparison by:
- using optimal aperture for each galaxy
- adopting continuum fit definition from SED fit to SHARDS data

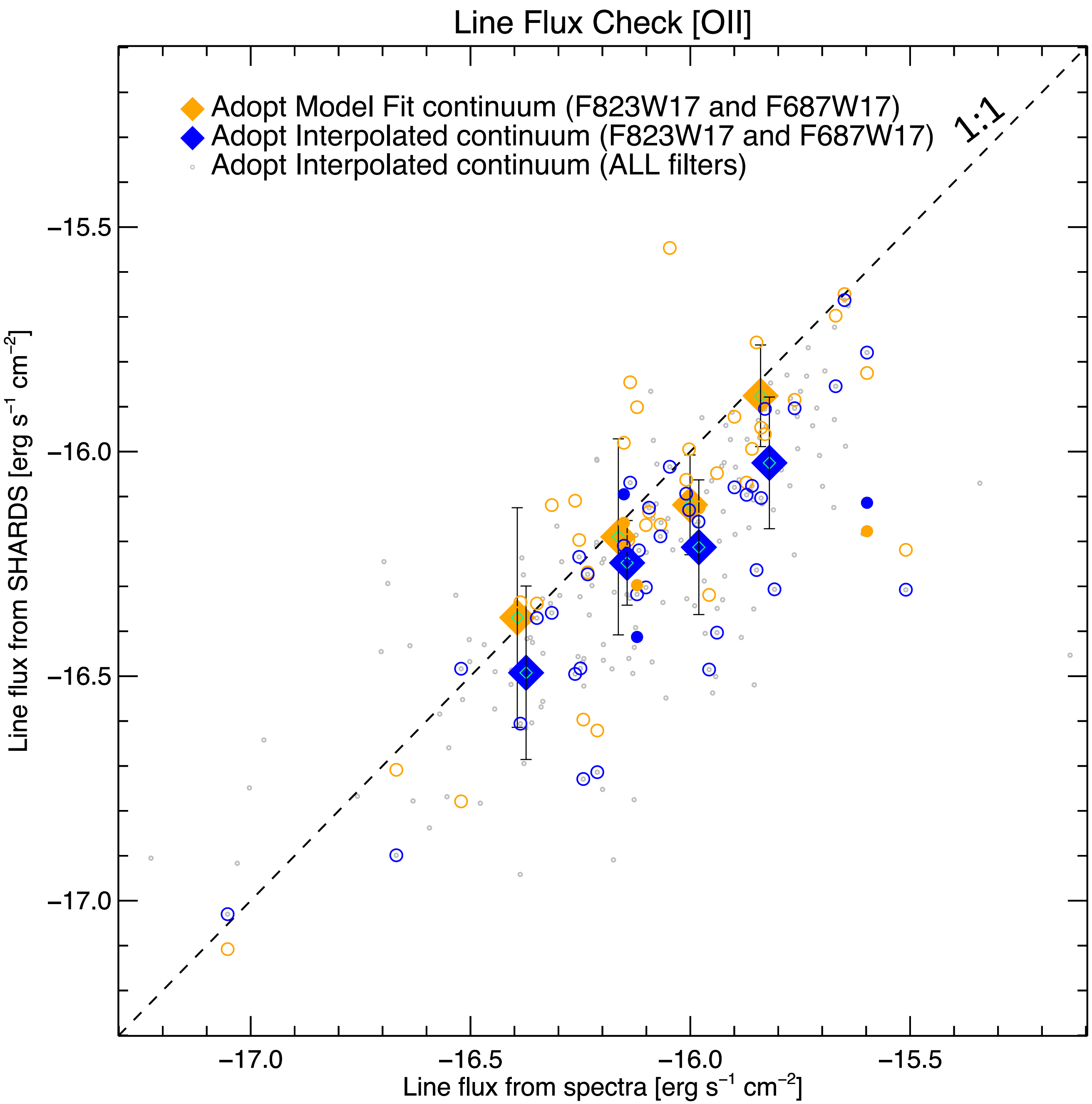
Factors affecting SHARDS to Spec line flux correlation:

- aperture effects

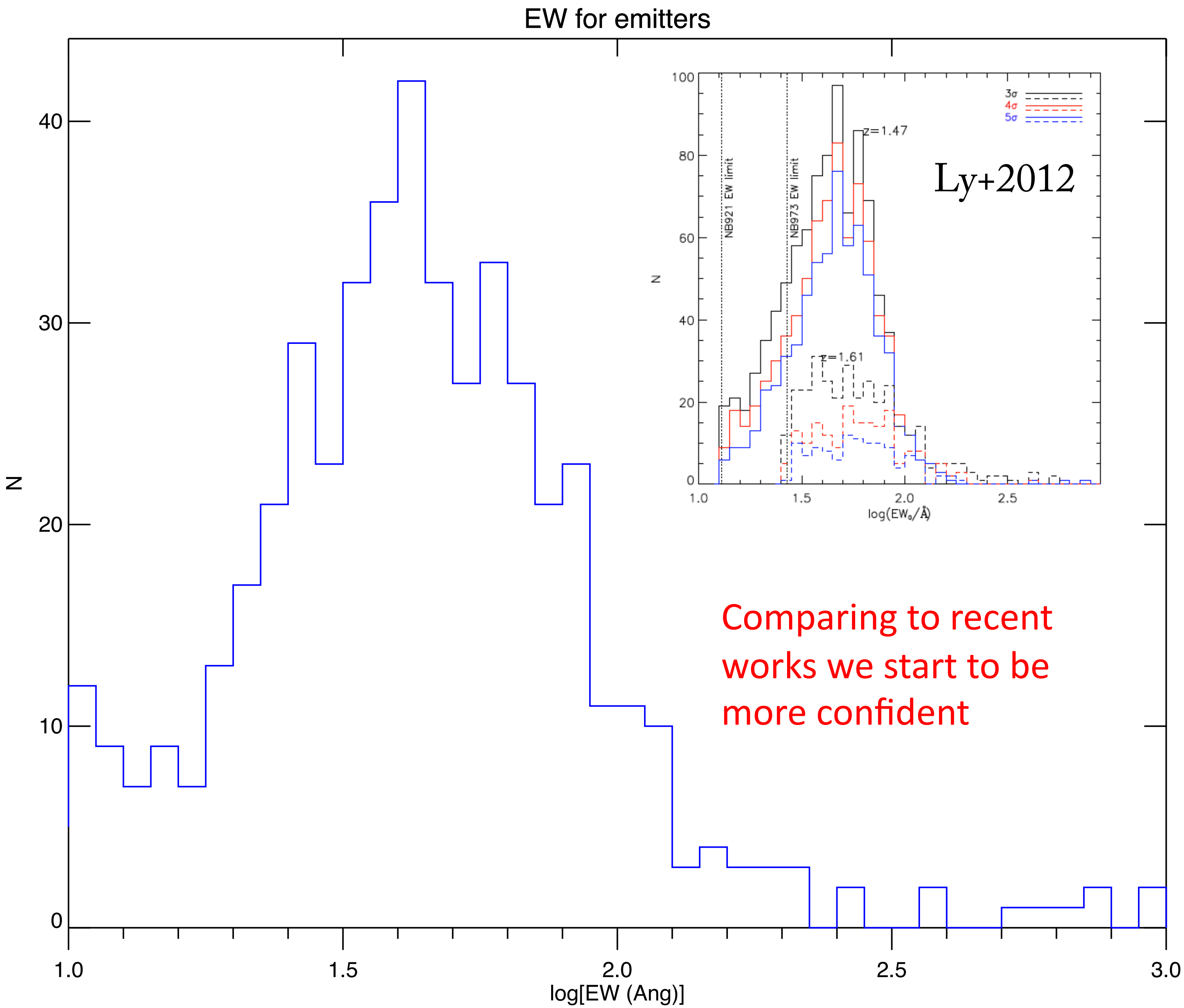
- spectral flux calibration

SHARDS: Science - ELGs





SHARDS: Science - ELGs



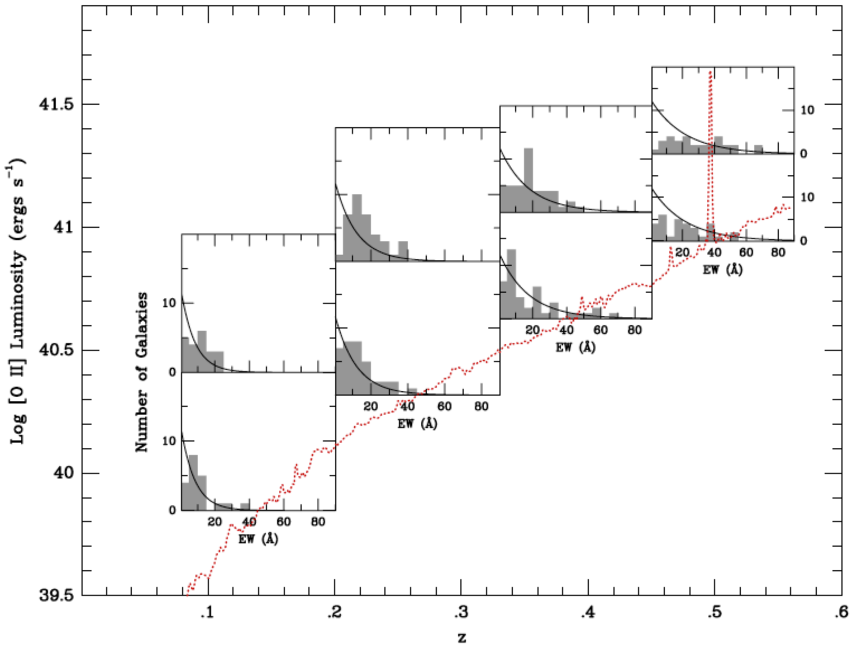
Comparing to recent works we start to be more confident

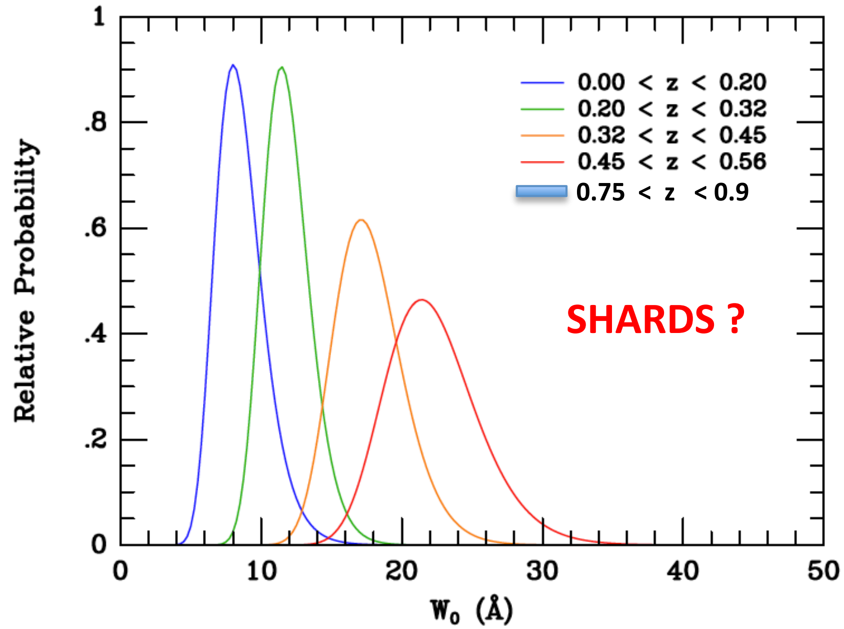
SHARDS ELGs: EWs and SFRs

EWs offer a quick way of examining the *relative importance of SF as a function of time*

[OII] flux measures the amount of SF in recent past (t<20Myr), while the continuum underlying the 3727Å reflects SF over a longer timestale (t~1Gyr) thus:

$$EW=F_{[OII]}/I_{cont}$$



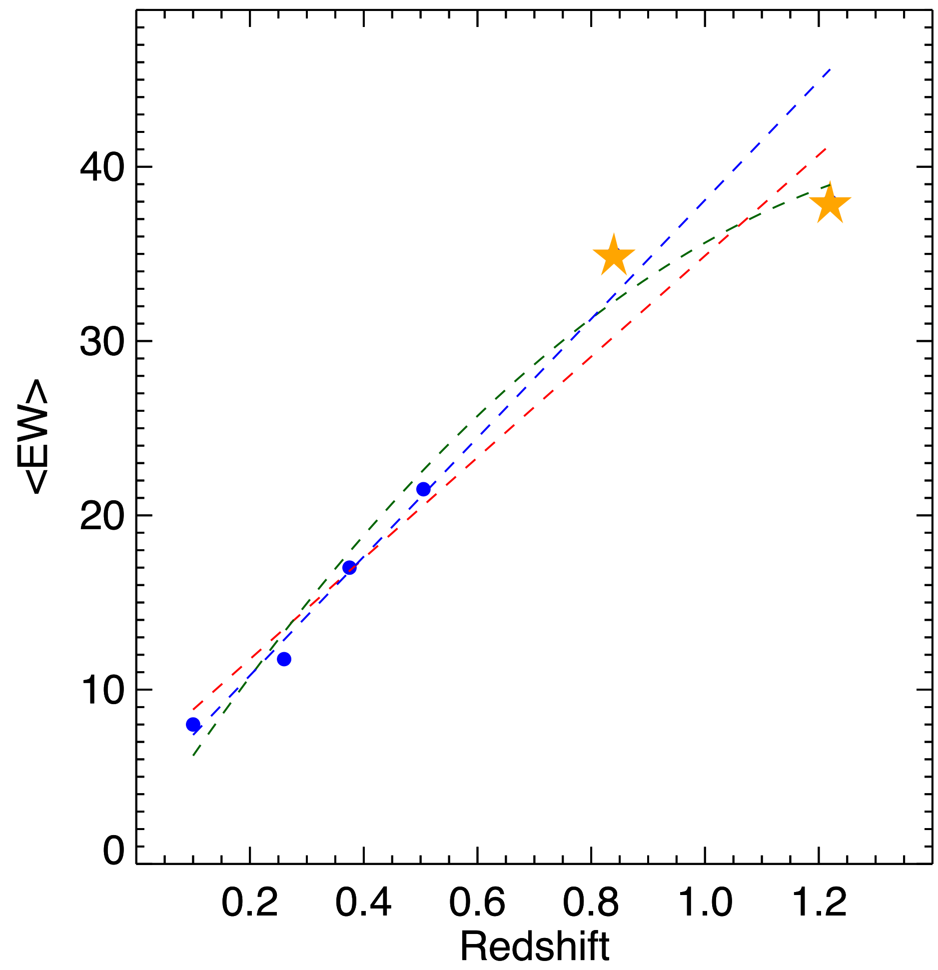


(from Ciardullo+2013)

Over the past ~5Gyr, the relative intensities of individual starbursts has decreased linearly with time.

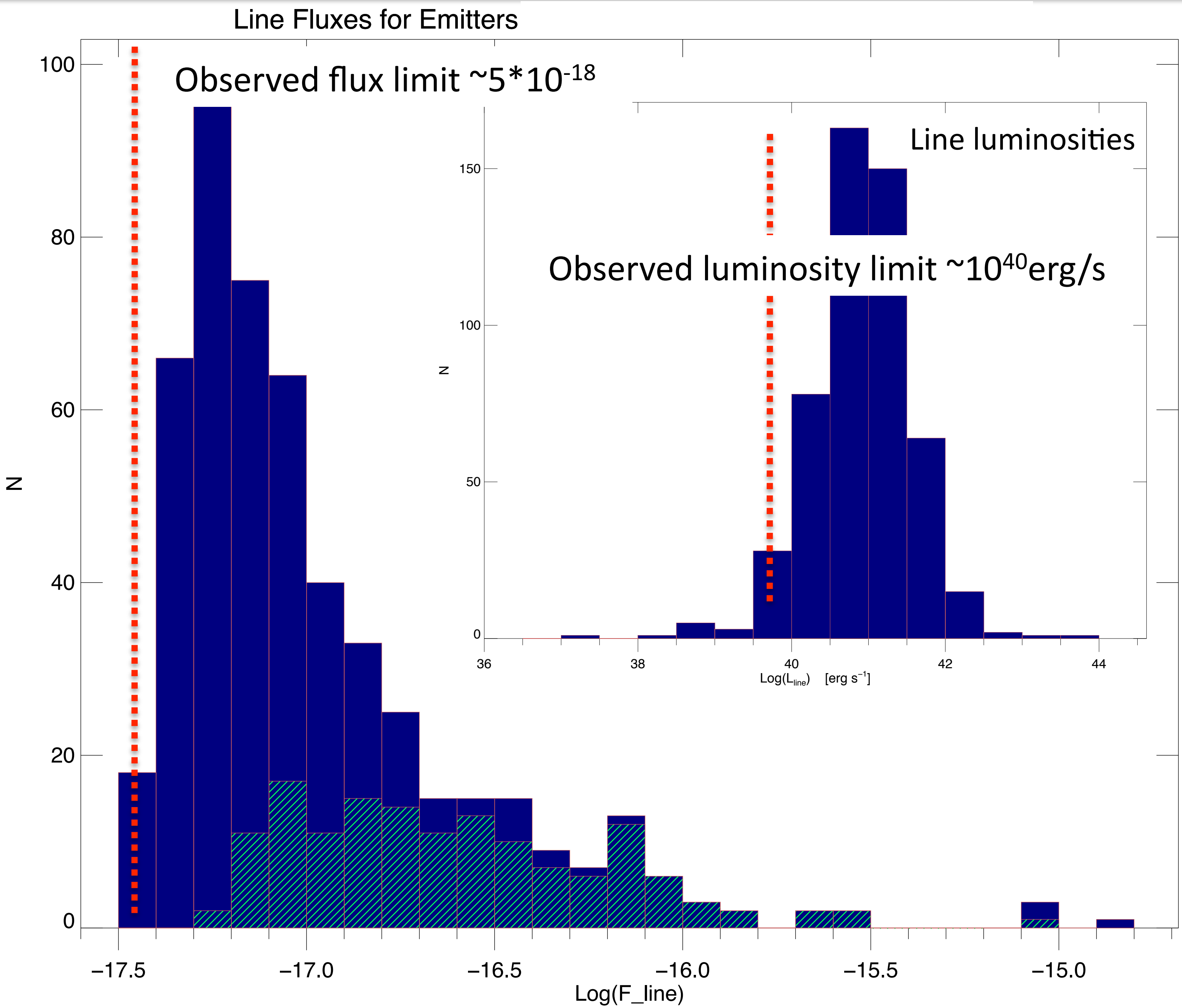
SHARDS ELGs: EWs and SFRs

EWs offer a quick way of examining the *relative importance of SF as a function of time*

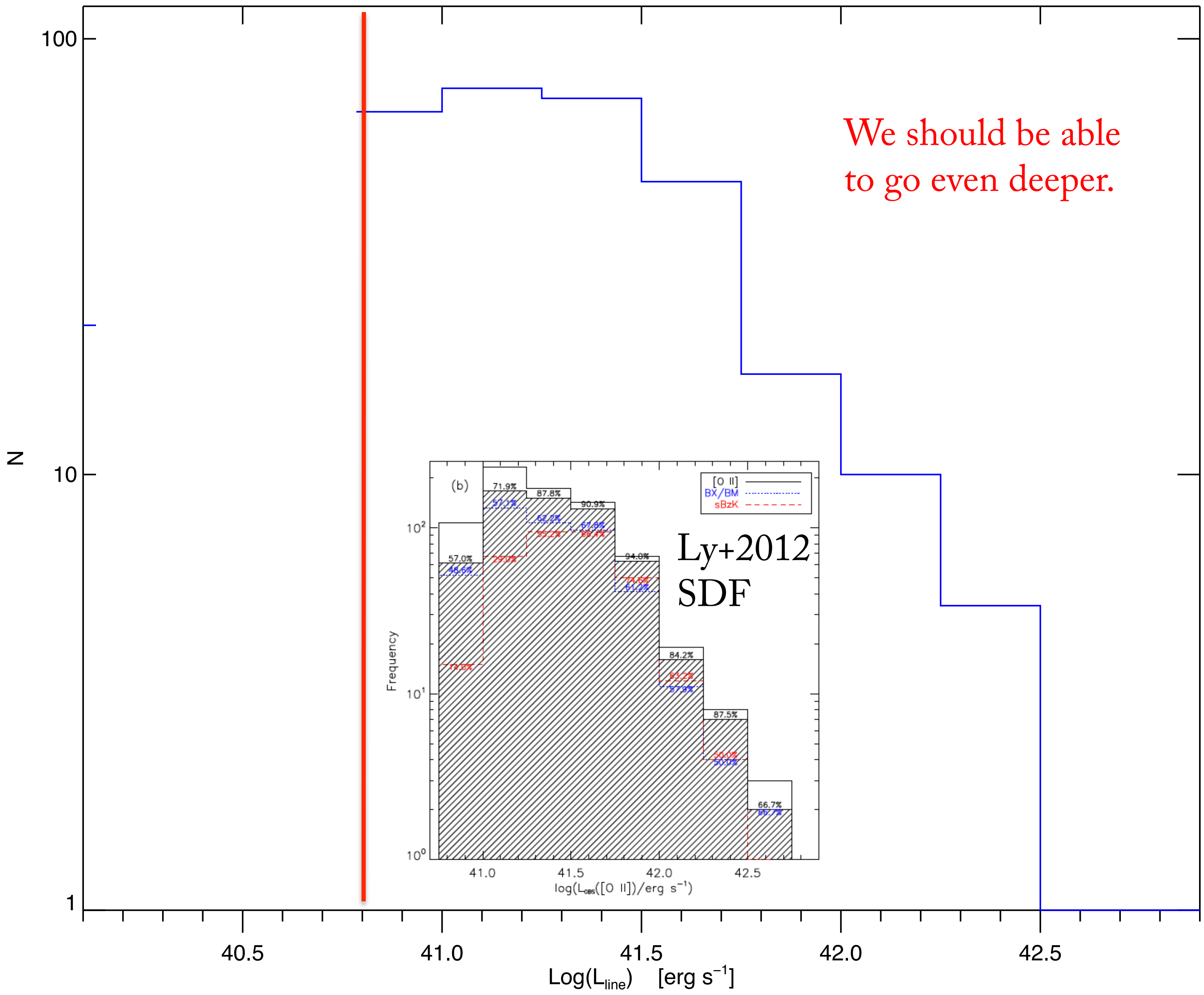


Over the past ~5Gyr, the relative intensities of individual starbursts has decreased linearly with time → but possible FLATTENING AT z~1 consistently with Madau plot : EW~(1+z)$^{\alpha}$

SHARDS: Science - ELGs



SHARDS: Science - ELGs



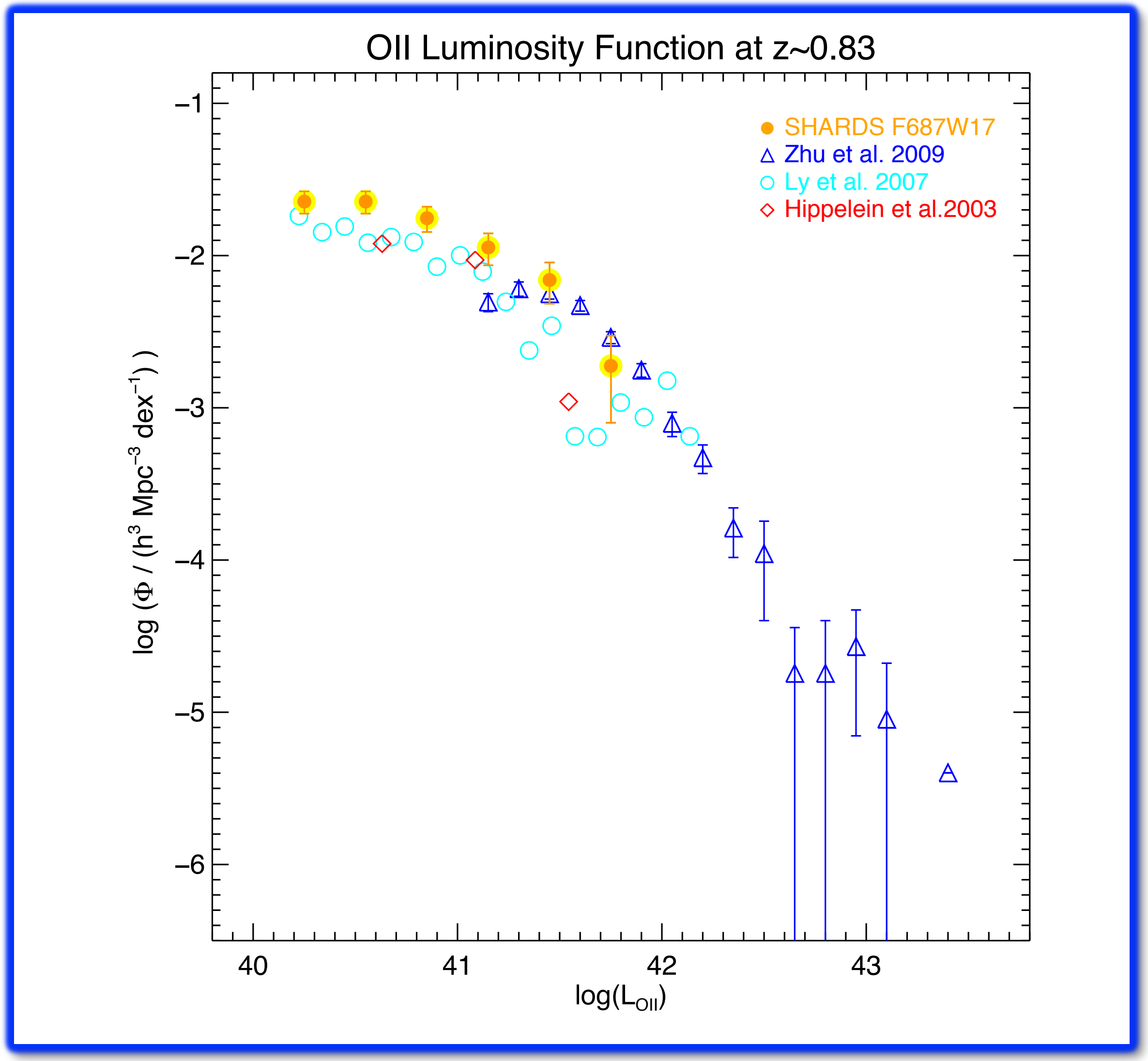
SHARDS: Science - ELGs

At this point we have all the necessary ingredients to build our observed luminosity function:

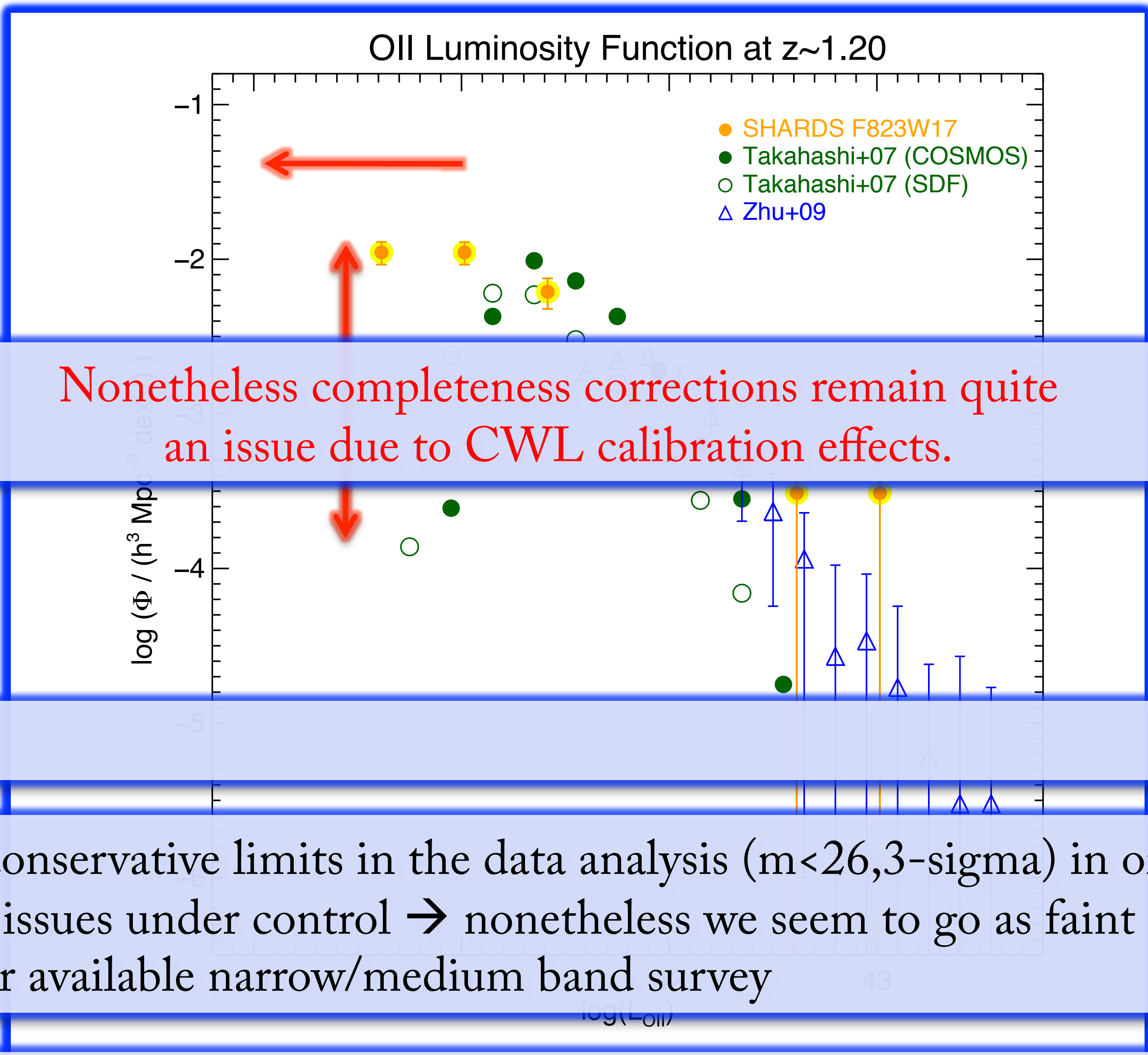
- EW
- number counts
- line fluxes
- line luminosities

We build the LFs for OII emission line galaxies selected as explained. The selected SHARDS filters are F687W17 and F823W17, whose observed CWLs correspond to redshift bin centered on z~0.84 and z~1.20, two well studied intervals with useful literature camparison data.

SHARDS ELGs: LF at 0.83



SHARDS ELGs: LF at z~1.2



Nonetheless completeness corrections remain quite an issue due to CWL calibration effects.

Note that:

✓ I adopted conservative limits in the data analysis (m<26,3-sigma) in order to keep completeness issues under control → nonetheless we seem to go as faint as (or more) than any other available narrow/medium band survey

✓ we can gain depth by exploting the full field of view and relaxing the adopted limits → (hopefully 1 mag fainter and 2.5-sigma) increasing statistics

SHARDS ELGs: LF and SFR

Next step is to derive SFRs and analyse SFR/sSFR-Mass reletion and Extinction properties in our sample.

SHARDS ELGs: EWs and SFRs

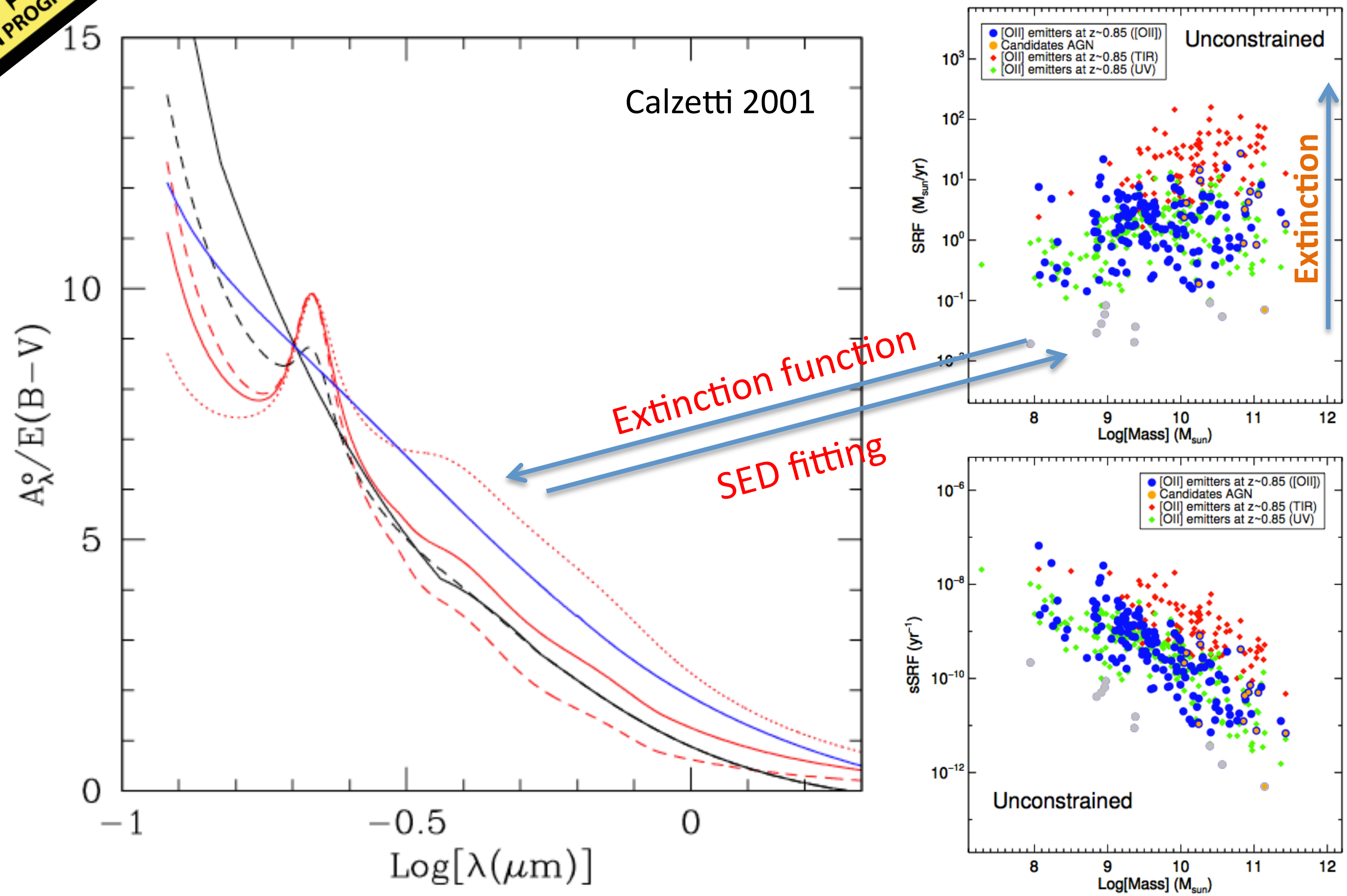
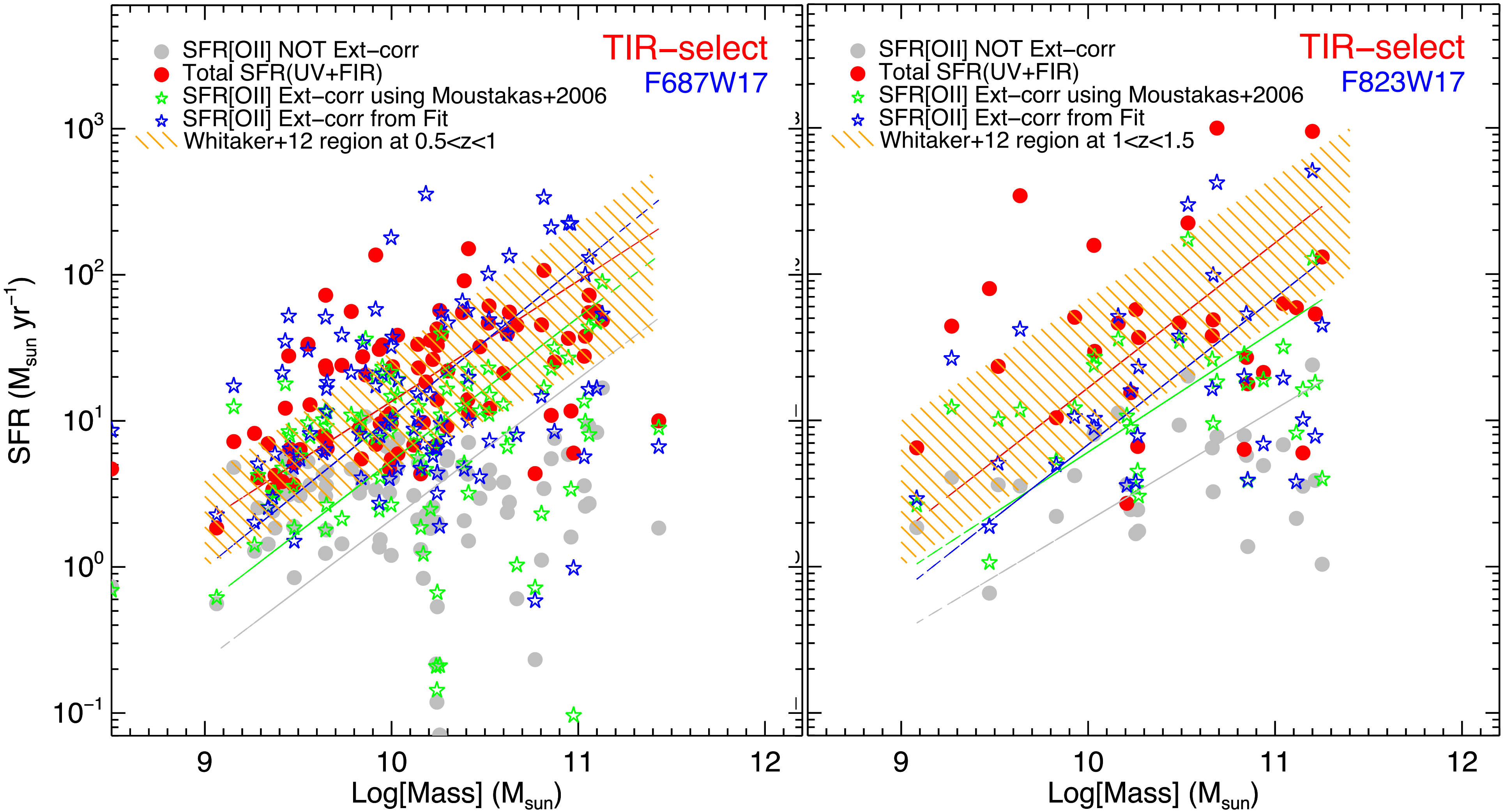


FIG. 8.— Star Formation Rate and Specific Star Formation Rate versus Mass relations. The three couples (SFR/sSFR) of panels show three different sample selections. On the left we plot only galaxies that have SFR determined from Total Infrared Luminosities. The central panels are for the galaxies having Ultraviolet SFR determinations. The right panels show the SFR-/sSFR-Mass plots where each sample include all the available SFR/sSFR galaxy determinations, independently by the adopted method. Blue points are $[OII]$-based SFR/sSFR determinations. Orange dots are AGN candidates.

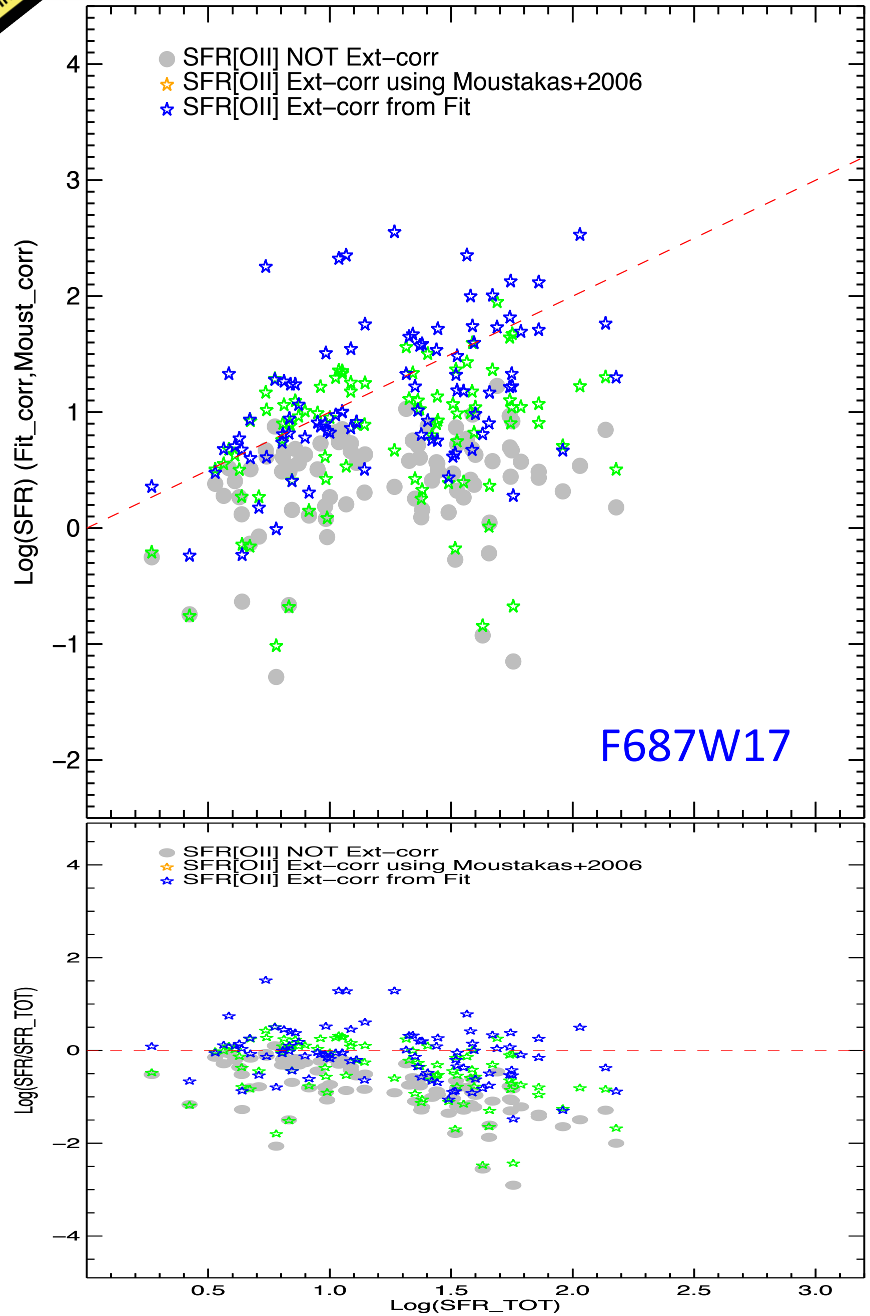
Cava et al., in prep.

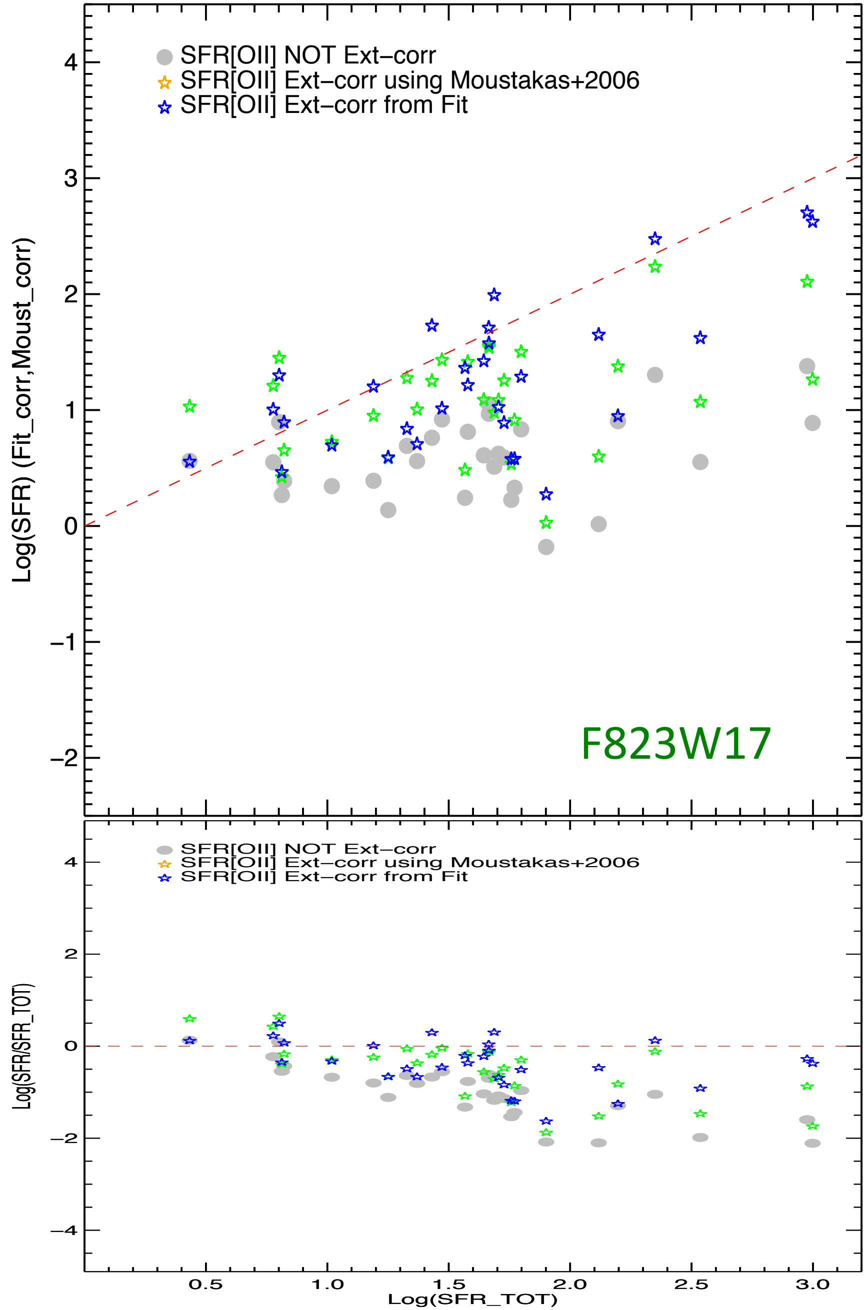
SHARDS ELGs: LF and SFR

Extinction corrected SFR

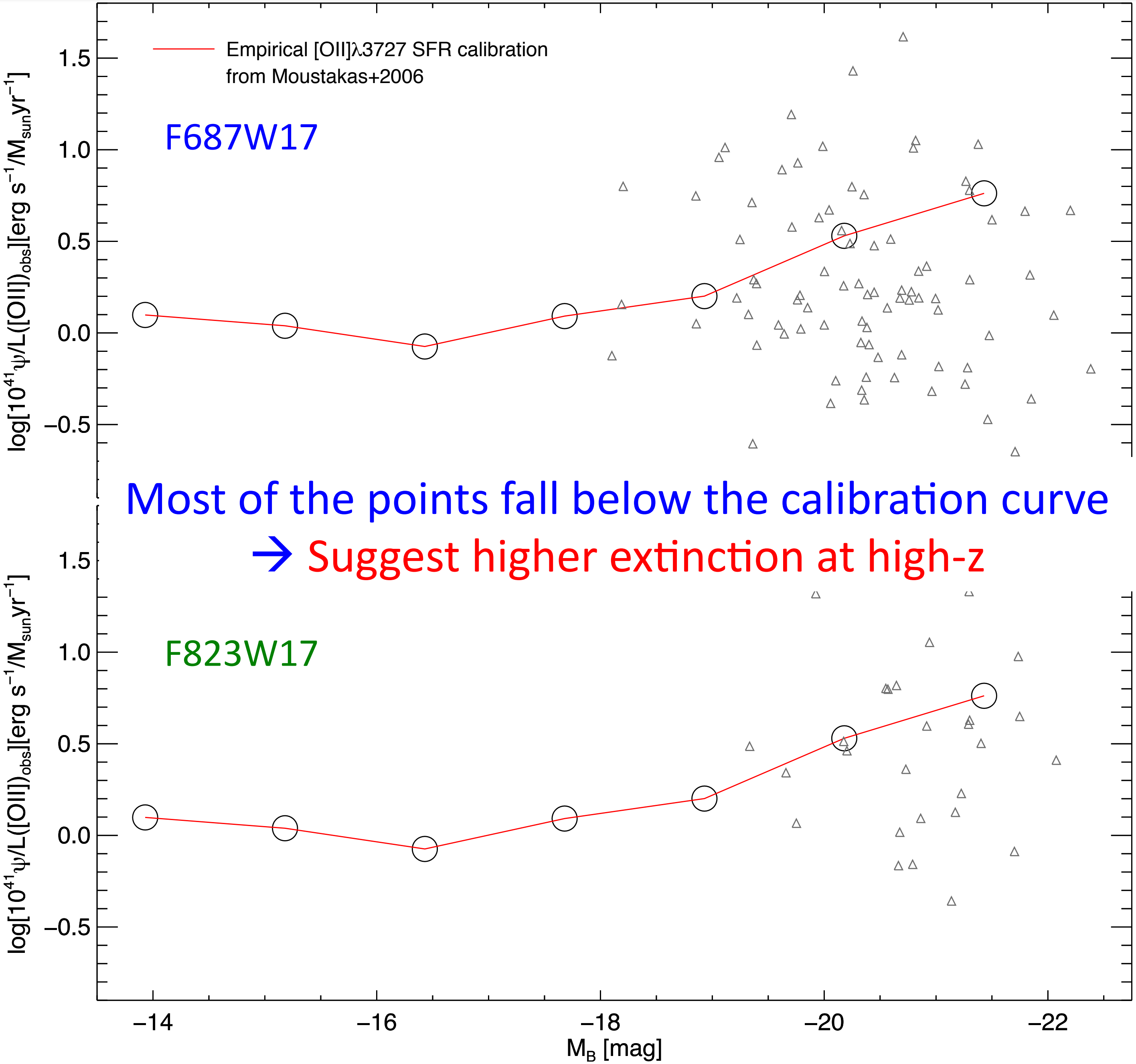


SHARDS ELGs: LF and SFR





SHARDS ELGs: LF and SFR



Most of the points fall below the calibration curve

→ Suggest higher extinction at high-z

SHARDS ELGs: LF and SFR

More coming soon…

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Preprint typeset using LaTeX style emulateapj v. 11/10/09

SHARDS VIEW OF STAR FORMING GALAXIES AT REDSHIFT $Z \sim 0.84$ AND $Z \sim 1.23$

ANTONIO CAVA[1] AND SHARDS TEAM

(Dated: Submitted: June 20, 2013)
Last edited: June 20, 2013

ABSTRACT

We use data from the Survey for High-z Absorption Red and Dead Sources (SHARDS), an ESO/GTC Large Program carried out with the OSIRIS instrument on the 10.4m Gran Telescopio Canarias (GTC) to perform a detailed study of star-forming galaxies at intermediate redshift. SHARDS is an ultra-deep optical spectro-photometric survey of the GOODS-N field covering 130 arcmin^2 at wavelengths between 500 and 950 nm with 24 contiguous medium-band filters (providing a spectral resolution R$\sim$50). The data reach an AB magnitude of 26.5 (at least at a 3σ level) with sub-arcsec seeing in all bands. We exploit the data selected in two SHARDS filters, F687W17 and F823W17, to select Emission Line Galaxies (ELGs) and investigate the properties of $[OII]$ emitters at redshift ~ 0.84 and ~ 1.20 respectively. Emission line fluxes, line luminosities, derived Star Formation Rates (SFRs) and extinction properties of this galaxy population are derived and analysed.

Subject headings: galaxies: starburst — galaxies: photometry — galaxies: high-redshift — infrared: galaxies.

1. INTRODUCTION

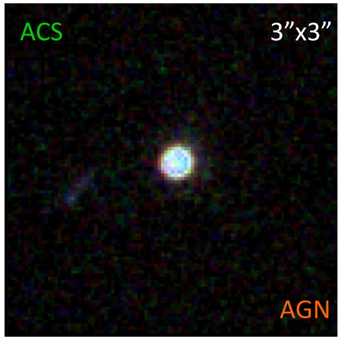
In this paper, we exploit data from the *Survey for High-z Absorption Red and Dead Sources* (SHARDS), an ESO/GTC Large Program awarded 180 hours of GTC/OSIRIS time during 2010-2013, to perform a de-

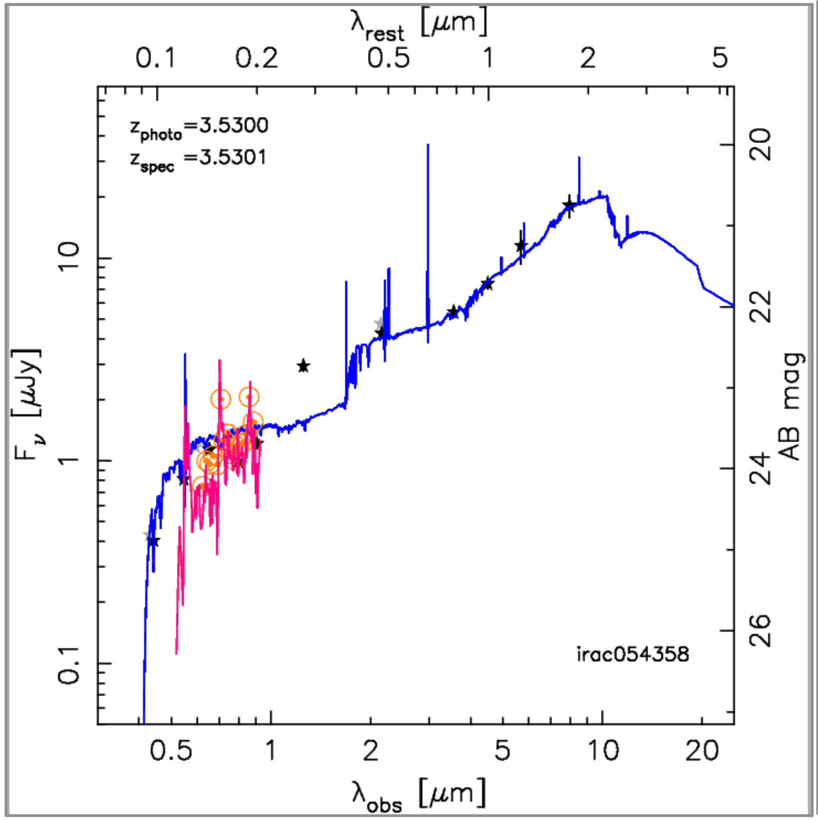
data quality. Our survey prioritizes the detailed study of the faintest galaxies at the highest redshifts over the analysis of closer galaxy populations and the Large Scale Structure at intermediate redshift, and thus focuses on a smaller area than the surveys mentioned above. Indeed, SHARDS was planned to reach up to 3 mag fainter than

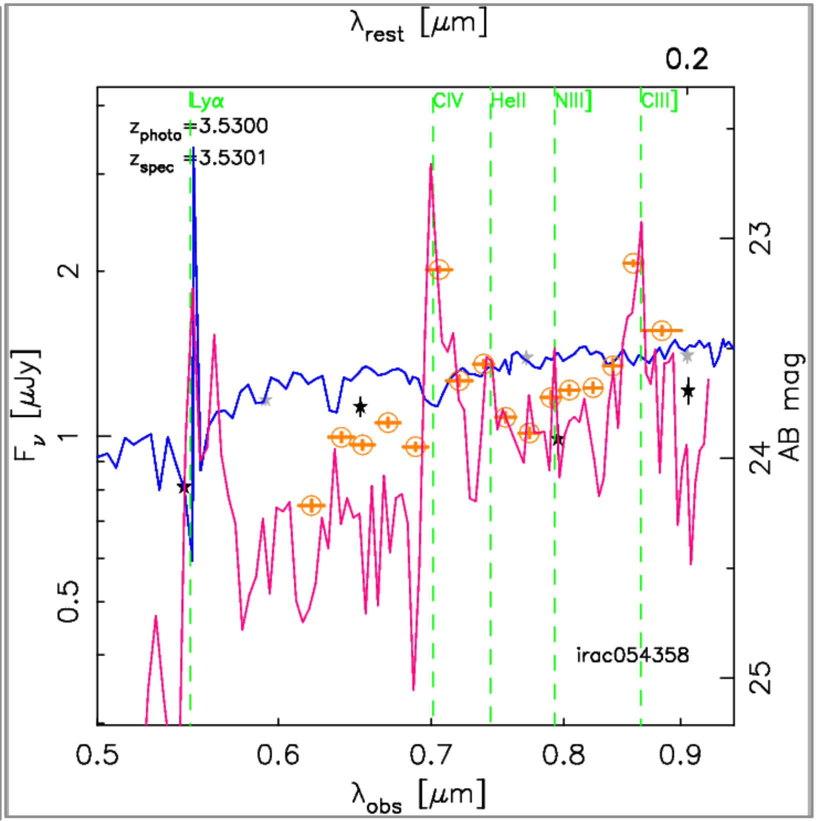
Shards of SHARDS – Science: AGNs

Strong emission lines from AGNs allow us to go at higher redshifts…

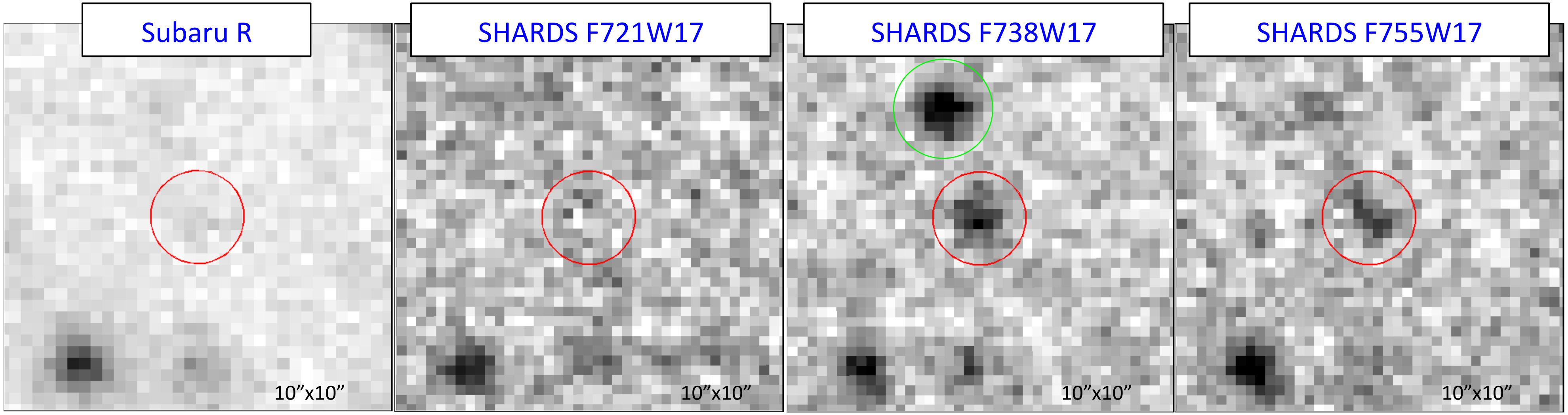
SEE Almudena's talk in the afternoon



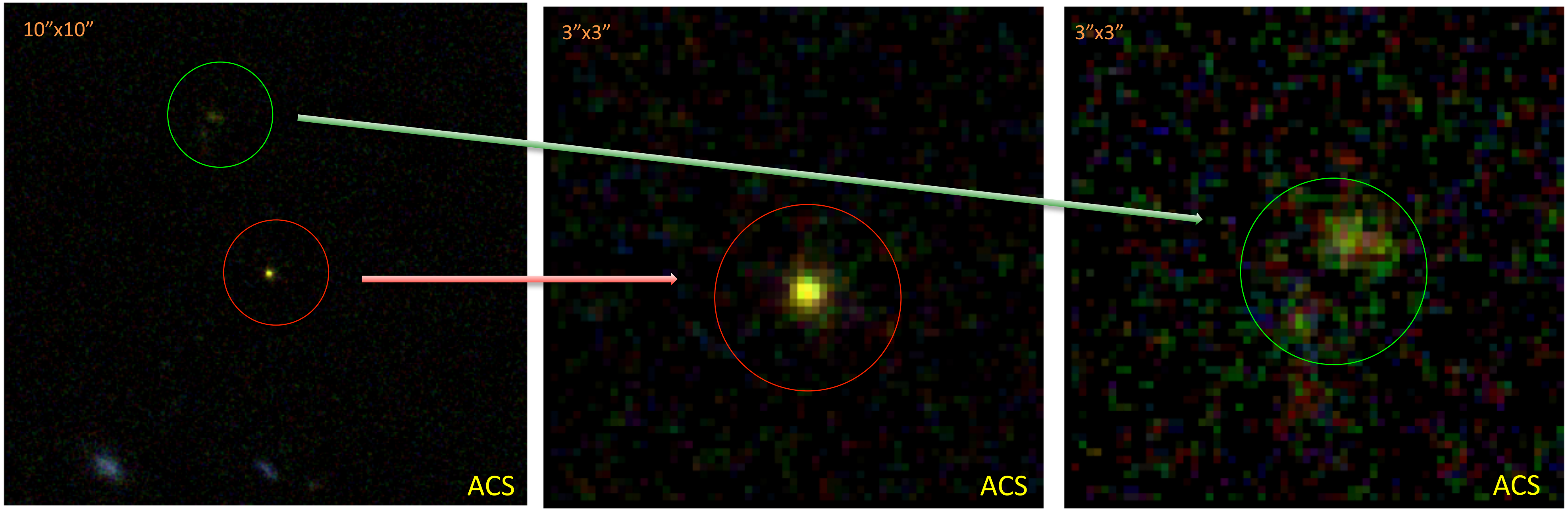




Shards of SHARDS - Science: LAEs at z~5



SEE JoseMiguel’s TALK in the afternoon



SHARDS ELGs: conclusions

- You should be convinced now that a lot of interesting science can be done with SHARDS data and ELGs: SF in intermediate-z galaxies, AGNs, Lyman-a emitters are just few examples

- The project on intermediate-z SF galaxies is in an advanced stage providing very robust resuts about SFRs, sSFRs, Exctintion and their relation with Mass and Redshift

- A first draft will be circulated very soon within the interested group and then to the whole Team, hopefully by (beginning of) July.

- Natural extensions of this projects are needed planned (LFs, complete filter set analysis, …) → see discussion session tomorrow

THANK YOU FOR YOUR ATTENTION!!!