



Results on high redshift star-forming galaxies with the X-shooter

Sandro D'Odorico, ESO



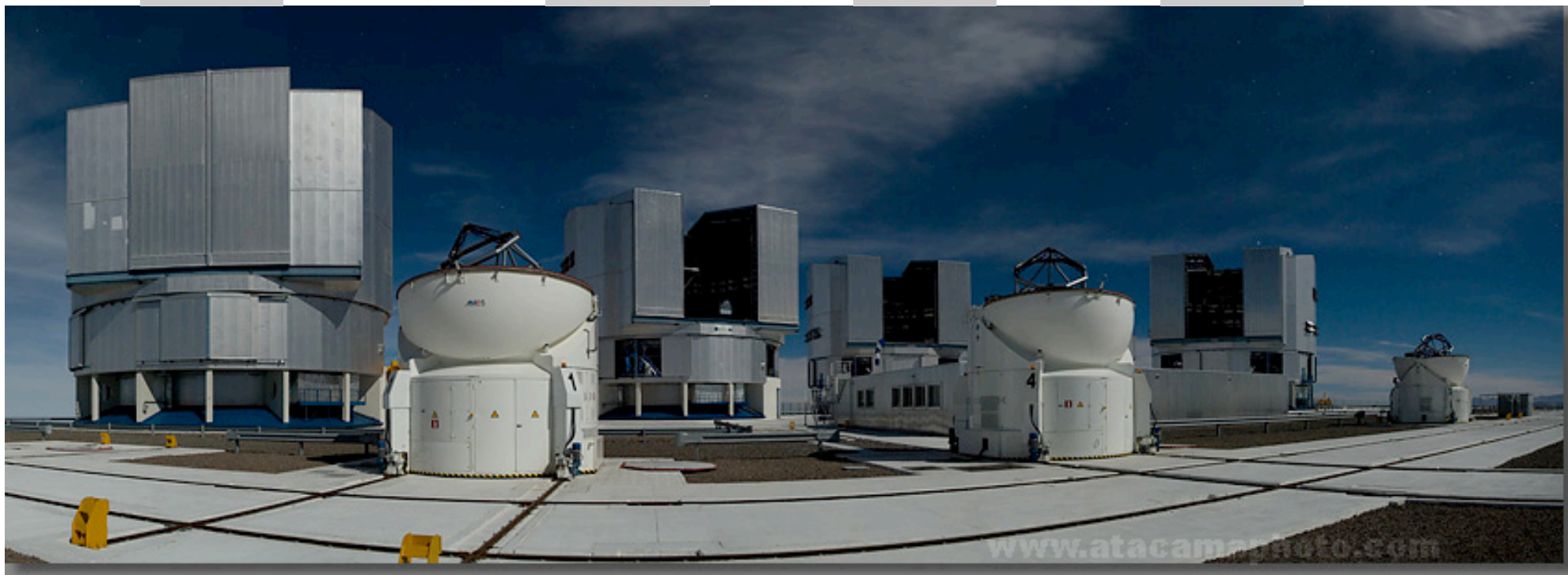
VLT UT Instruments on October 2010

CRIRES
FORS
VISITOR FOCUS

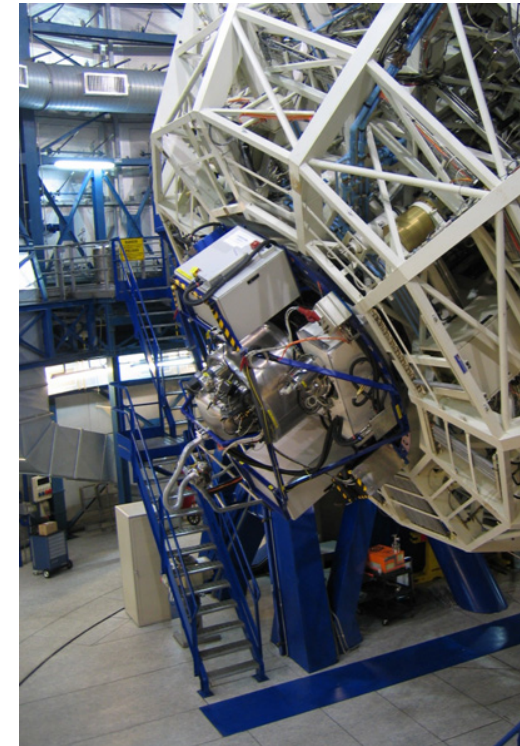
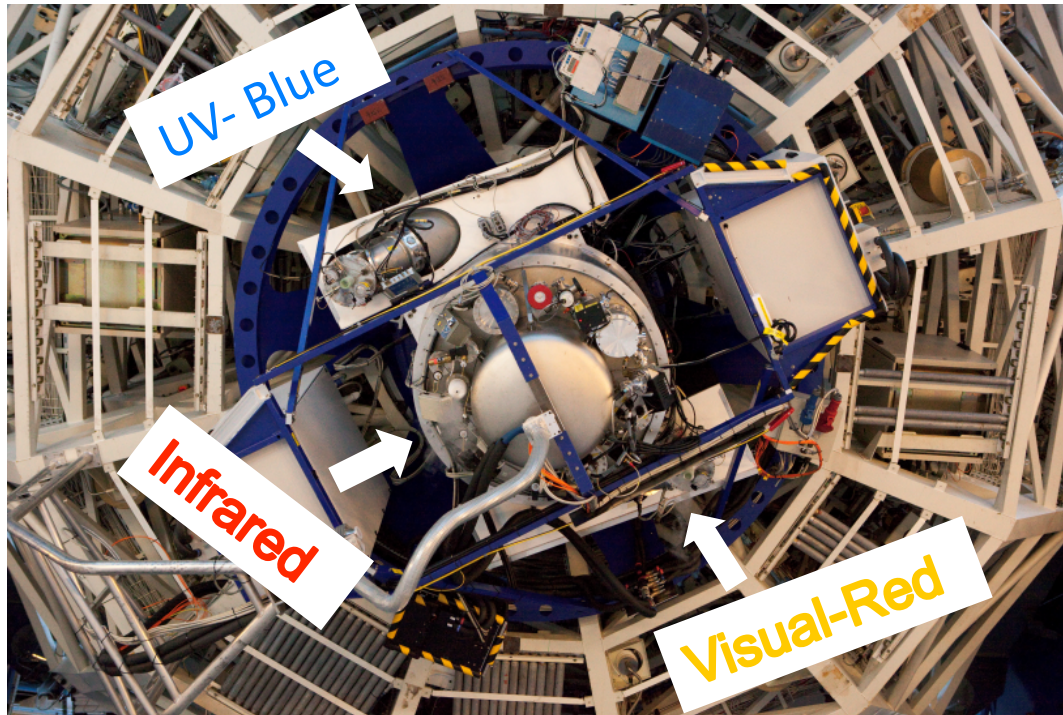
UVES
FLAMES
X-shooter

VIMOS
VISIR
ISAAC

NACO
SINFONI
HAWK-I



X-shooter at the Cass focus of the 8m UT2



- X-shooter is the first of the 2nd generation of VLT instruments, in regular operation since 3Q 2009
- It was built in 5 years from formal approval by a Consortium of ESO and institutes from Denmark, France, Italy and the Netherlands
- It consists of three fixed format echelle spectrographs which operate in parallel and deliver an intermediate resolution spectrum of faint targets from 310 to 2400 nm



Why this talk at this meeting ?




- In his scientific career **Bob** has always stressed the importance of spectroscopy as diagnostic tool of the physical properties of galaxies (and successfully used it)
- He wrote the chapter on high z emission line galaxies for the X-shooter proposal science case (2003)
- He chaired the Science Team of the X-shooter during its development phase (2004-2008)



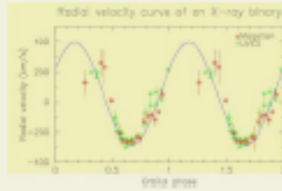
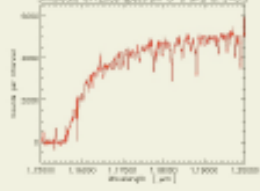
X-shooter Science Case (2003 Instrument Proposal)

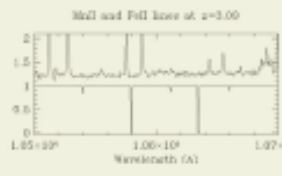

The Lynx arc (a lensed emission line galaxy at $z=3.4$, Fosbury et al 2003): an example of an ideal target for X-shooter observations



ESO/STC-324a
20.03.2003

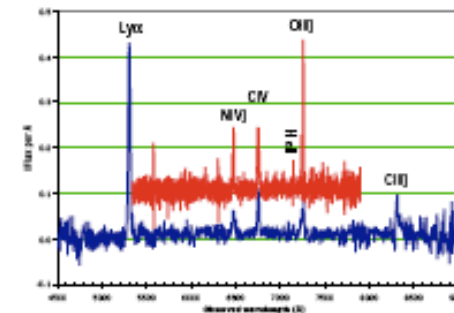
UV – VIS – J+H band, Intermediate Resolution, High Efficiency Spectrograph for the VLT

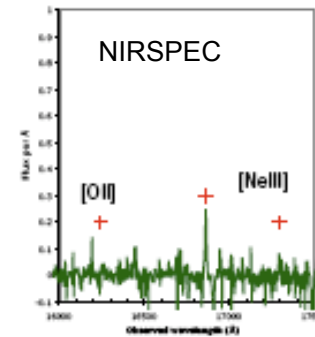



Part 1 – Science Case

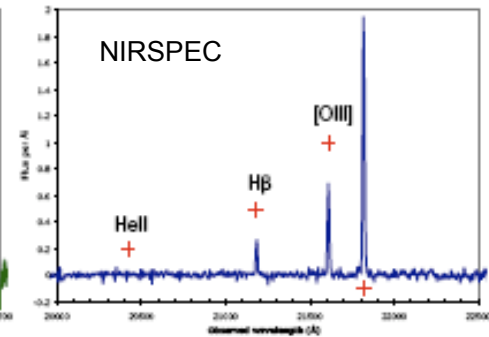
LRIS



NIRSPEC



NIRSPEC



ESI

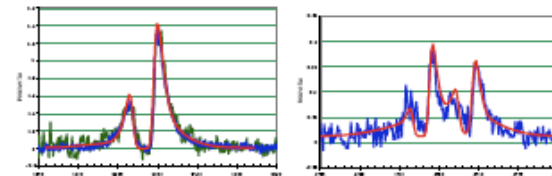


Figure 7.5 Multipiegussian fits to the Ly α and C III lines in the Keck ESI spectrum of the Lynx arc. The absorption components in these resonance lines indicate the presence of a highly ionized wind with a column density of about 10^{13} cm^{-2} in each ion



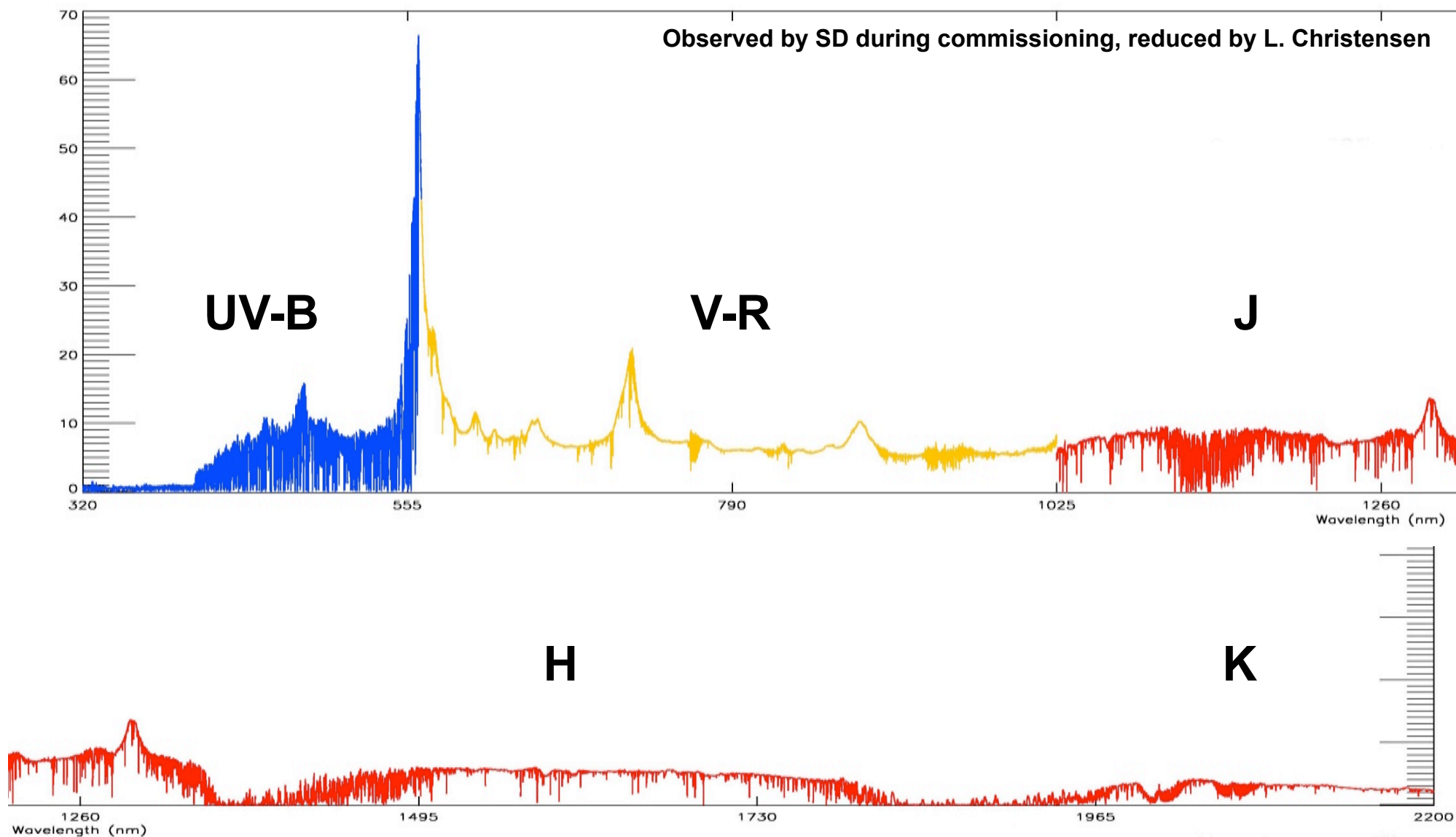
X-shooter : **unique instrument advantages in the study of high redshift , star forming galaxies:**

- Parallel spectral coverage from the atmospheric cut-off at 310 nm to the K band (2300 nm): → ideal for targets of unknown redshift
→ guarantees accurate spectro-photometry
- At intermediate resolution, to derive from resolved emission and absorption lines physical properties and element abundances .
- Highly efficiency instrument, not detector noise limited, reaching the sky limit in ~10-40 min (NIR-UV respectively)



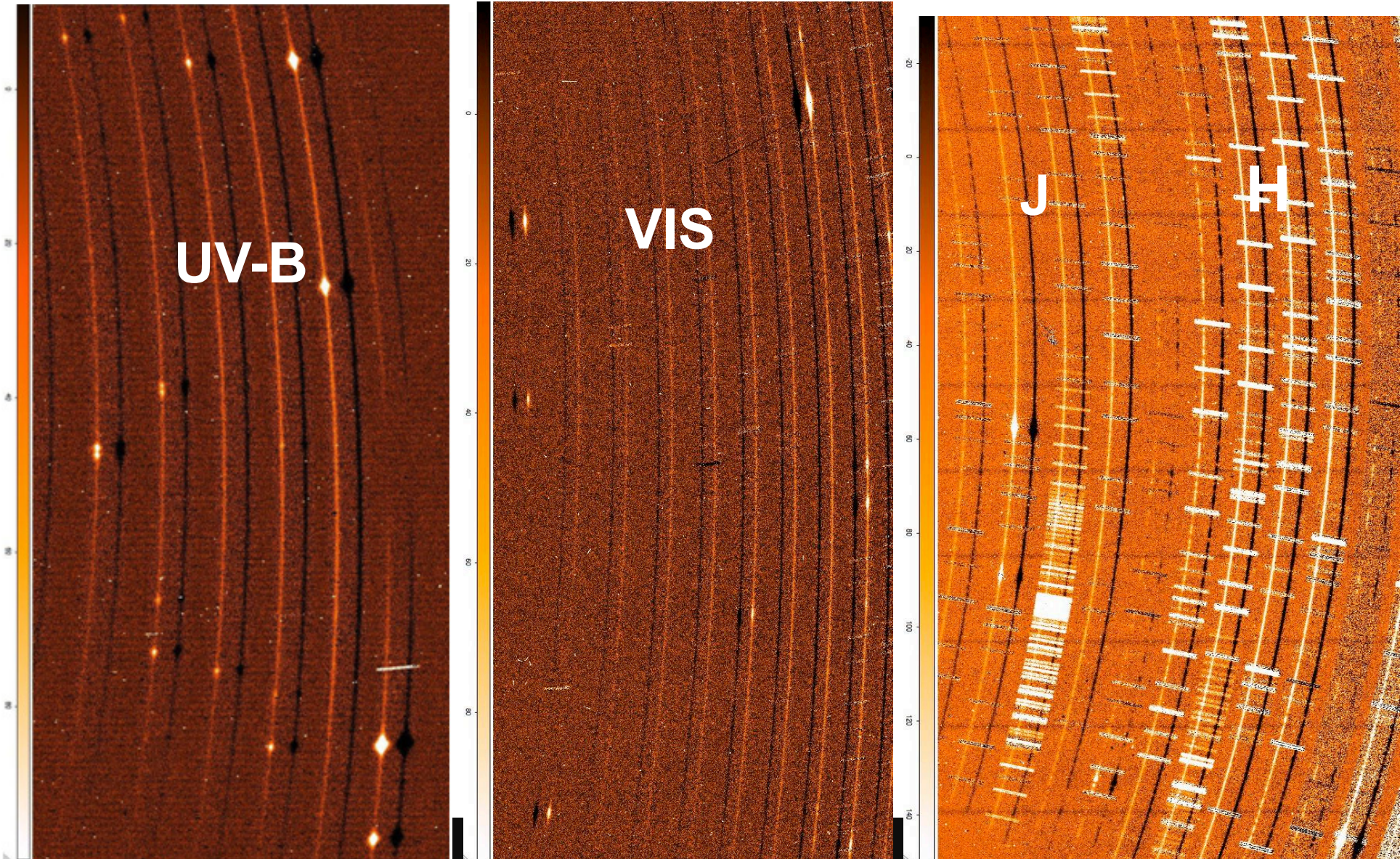
The advantage of the wide spectral coverage:

QSO B1422+231 ($V=16.5$; $z=3.62$; $4 \times 1200\text{s}$)





GRB host, starburst , emission line galaxy at $z=0.105$, $r=20.5$, $K=16.6$
(4x1200s exposures, combined for sky subtraction). UVB at $R=5100$, VIS at $R=8800$, NIR at $R=5600$





Studies of high redshift galaxies with X-shooter

Focussed on **Lensed galaxies** with magnifications 5-10 which can be studied in detail to high redshifts ($z \sim 5$). Most targets $1 < z < 4$

First results from public commissioning data and Danish GTO (2009-2010); proposals for new observations submitted

Fundamental complementary data : HST multi-color photometry (!), accurate lensing modeling

ASTROPHYSICAL MOTIVATION :

- ✓ *Confirm lensing nature of the systems*

- ✓ *Build up a sample of galaxies at high z with different selection criteria (unlike radio, x-rays emission, LBG ,Balmer jump selected)*

- ✓ *Deep study of the most interesting objects to understand the process of galaxy formation and interaction with the ISM*

- ✓ *Use redshifts to build up lensing model and to derive total mass of lensing galaxy/ clusters (\rightarrow explore luminous/dark matter ratios)*



Exploratory work on candidates from surveys of lensing systems (1)

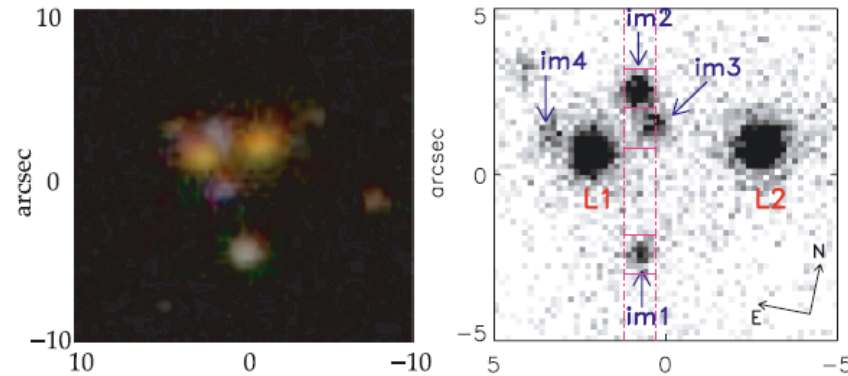
V. Belokurov, L. Christensen, M. Dessauges-Zavadsky, N.W.Evans, C. Grillo, J. Hjorth, M.Pettini, J. Richard, D. Schaerer, J. Vernet and S.D.

- Candidates from the CASSOWARY survey (Belokurov et al. 2009) selected from SDSS photometry. Relatively large separation (→mass of lensing galaxy). 2 candidates observed in commissioning and confirmed as star forming galaxies
- Candidates from deep observations of 25 clusters used as gravitational telescopes (P.I. M.Postman, HST Treasure Program with ACS and WFP3).
Hjorth et al, X-shooter GTO program, 11 targets observed

typical exposure times 60-90m

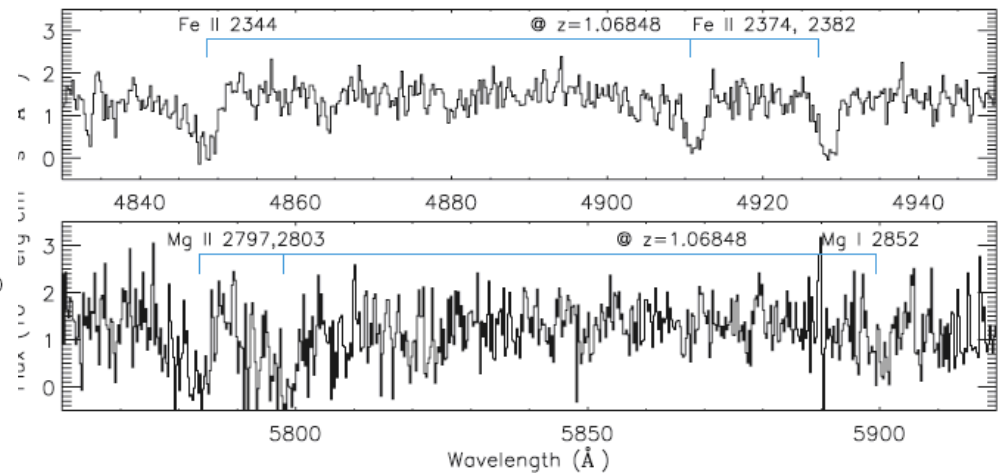
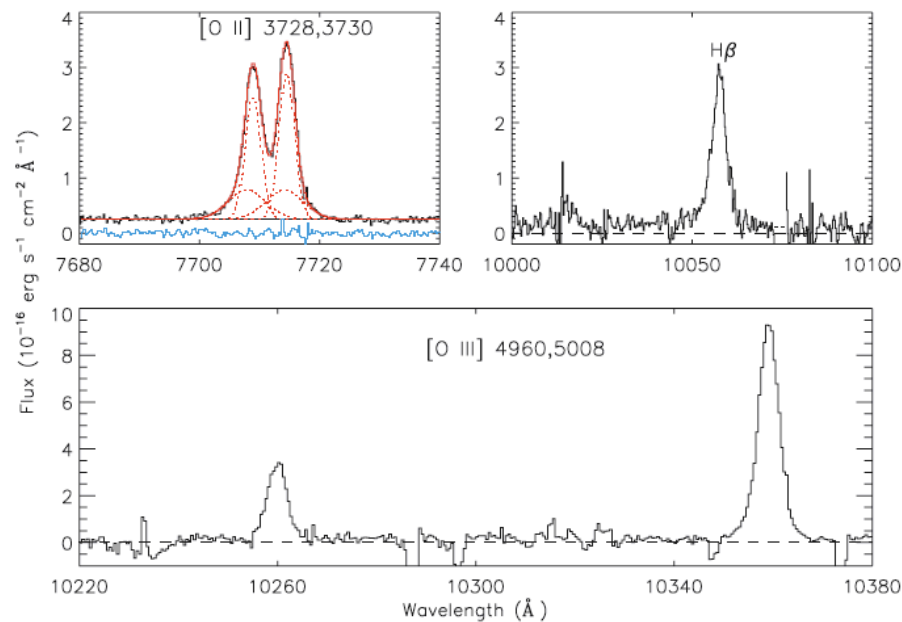


Exploratory work on candidates from surveys of lensing systems (2)



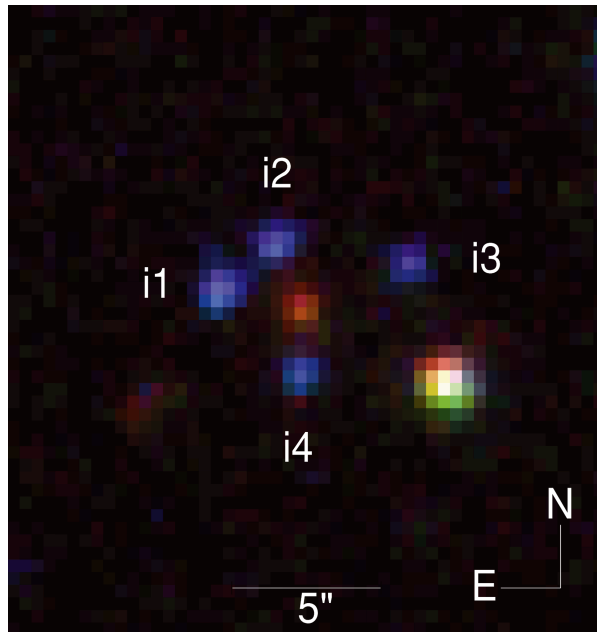
CSWA5, $z=1.07$,
Lensing elliptical L1 $z=0.37$
Im2 and im1, $r=20.9, 22.5$ respectively.

Christensen et al, MNRAS, 2010

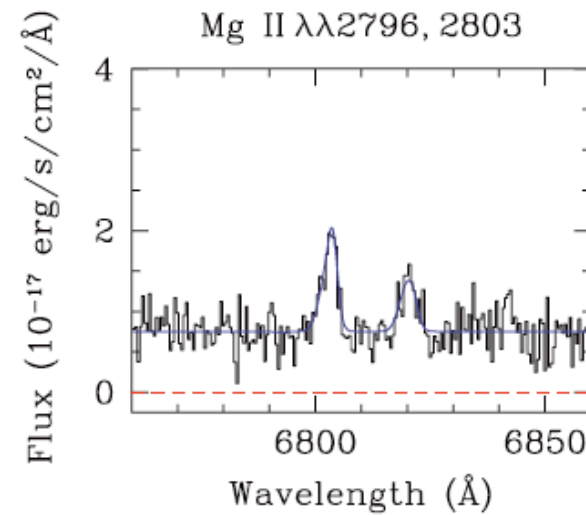
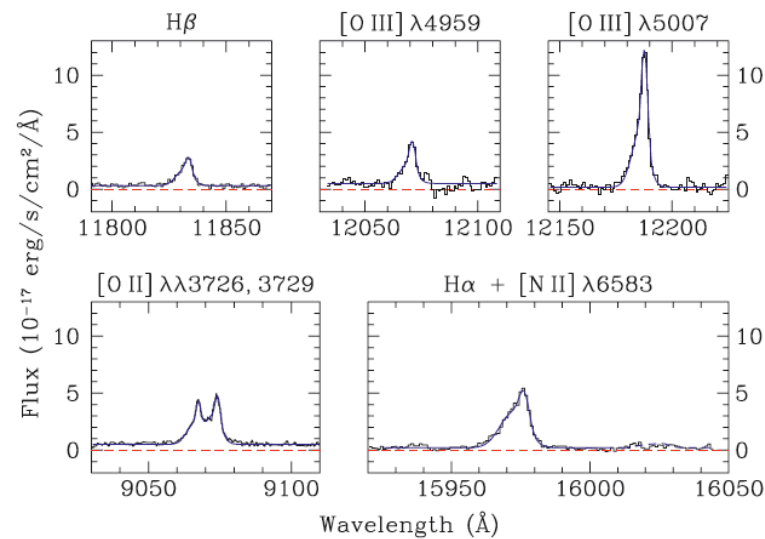




Exploratory work on candidates from surveys of lensing systems (3)



CSWA20, $z=1.43$,
 Lensing elliptical $z=0.741$
 $i1, i2, i3, i4 \rightarrow g=21.5$
 Pettini et al. MNRAS 2010

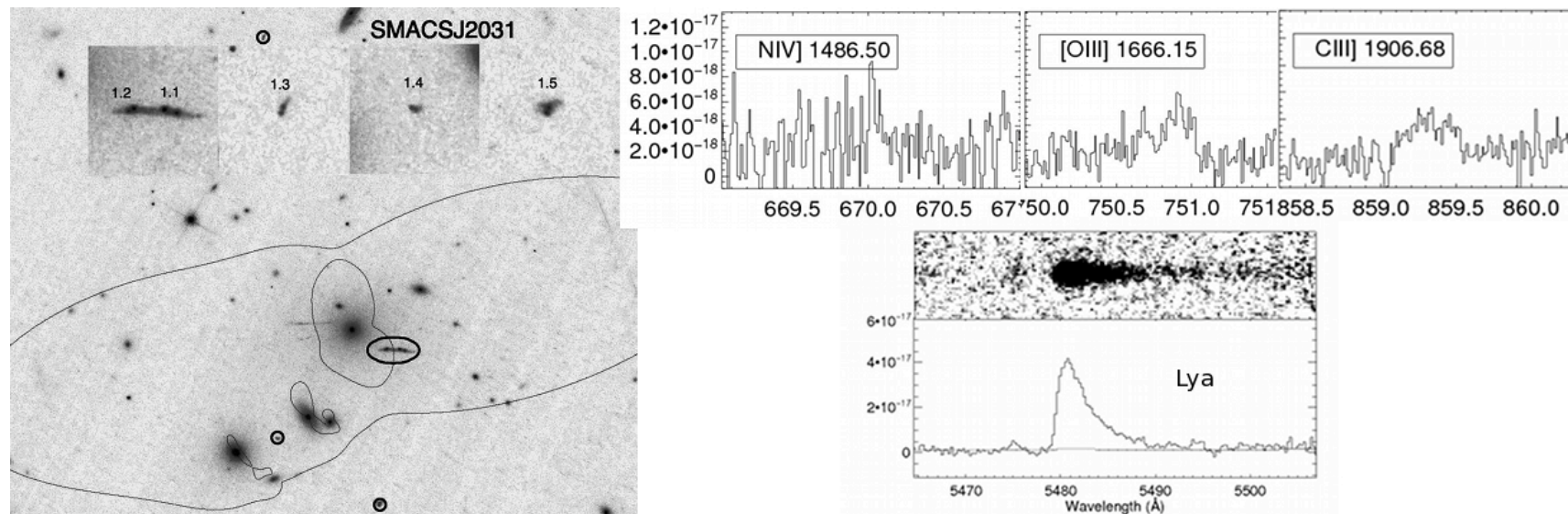




SUMMARY OF THE PHYSICAL PROPERTIES

Property	CSWA 5	CSWA 20
z	1.0686	1.4335
$\Delta V(\text{abs-em})$ (km s ⁻¹)	-9 ± 23	-49 ± 31
$12 + \log(\text{O}/\text{H})$	8.4 ± 0.1	8.1 ± 0.1
$\log(\text{N}/\text{O})$	-1.0 ± 0.1	—
$\text{O}/\text{O}_{\odot}$	0.4	0.25
M_* (10 ⁹ M _⊙)	0.8 ± 0.3	1.3 ± 0.2
Age (Myr)	25–50	55–80
$L_{1700 \text{ \AA}}/L^*$	3	6
SFR (UV) (M _⊙ yr ⁻¹)	4.2	26
SFR (H α) (M _⊙ yr ⁻¹)	6.6	21
SSFR (10 ⁻⁹ M _⊙ yr ⁻¹)	8 ± 2	6 ± 1

Arc in SMACS J2031-4036 – from the HST cluster survey,
Christensen et al. (2011, in preparation)



PROPERTIES (preliminary):

$z=3.5$, strong rest-frame UV lines, AB red magnitude 22.2, predicted magnification factor 11, double peak Ly alpha suggesting outflow, metallicity 0.1-0.3 depending on diagnostic ratio used



Detailed studies of selected high z objects to understand the process of galaxy formation and interaction with the ISM (1)

Lensed galaxies which show interesting properties (strong UV continuum, hints on very high T_e , very low metal abundances, peculiar velocity structure) and are sufficiently bright for good S/N observations. 6-10 hrs integration

➤ COMPLETED :

“8 o'clock arc” Allam et al.(2007); at $z=2.375$, $V \sim 21.4$

Dessauges et al (AA, 2010), Dessauges et al (AA, 2011, accepted)

➤ APPROVED PROGRAM UNDER WAY :

CSWA 20 Pettini et al.



8 o'clock arc: one of the better studied high redshift normal galaxies

Database: X-shooter medium resolution spectra from 330 to 2400 nm, HST WFPC2 and NICMOS observations (5 bands), Spitzer (4 bands)

Measurements:

Emission and absorption lines in the X-shooter range, SED from UV to 8 μm , 2D geometry from HST

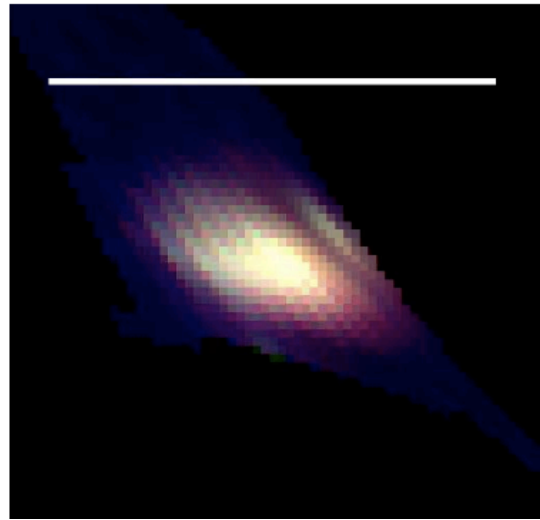
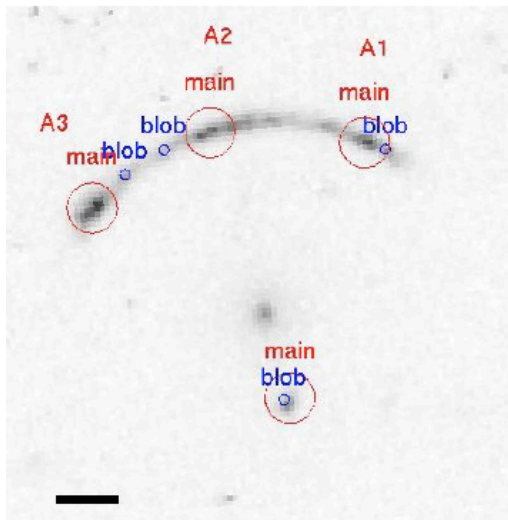
Results:

Accurate redshifts from emission and absorption lines, ISM abundances, gas and stellar extinctions, ionized gas abundances, SFR, dynamical mass, mass and age from fitting spectrum and SED with stellar population models

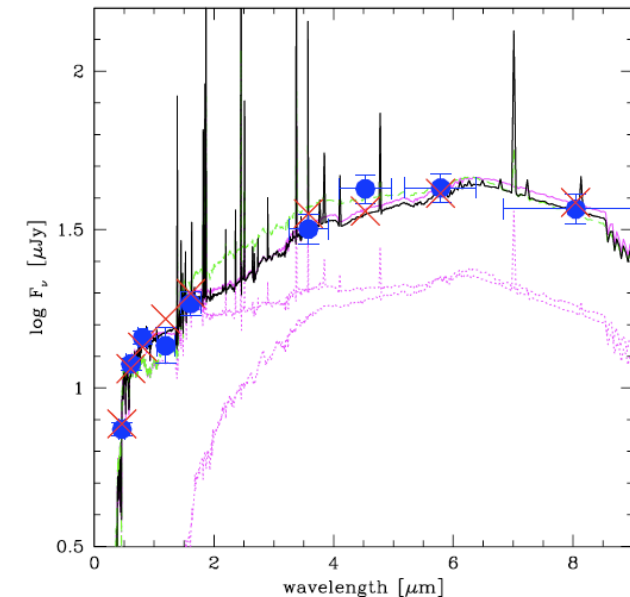


8 o'clock arc: one of the better studied high redshift normal galaxies

Results:



From the velocity structure, the imaging and the lensing model it has been possible to reconstruct a 2D image of the lensed galaxy



SED of the galaxy (X-shooter spectra +HST +Spitzer photometry)



A tool to measure the mass of the lensing galaxies/ clusters

Grillo & Christensen (2011)

Lensing galaxy in the CSWA 5 system:

Fitting spectrum+SDSS photometry with population synthesis models
leads to a stellar mass estimate of $3 \times 10^{11} M_{\odot}$

Total (dark+luminous) projected mass of $1.3 \times 10^{12} M_{\odot}$ within the
Einstein radius from lensing model

HENCE $f_{\text{DM}} = 0.8$

