

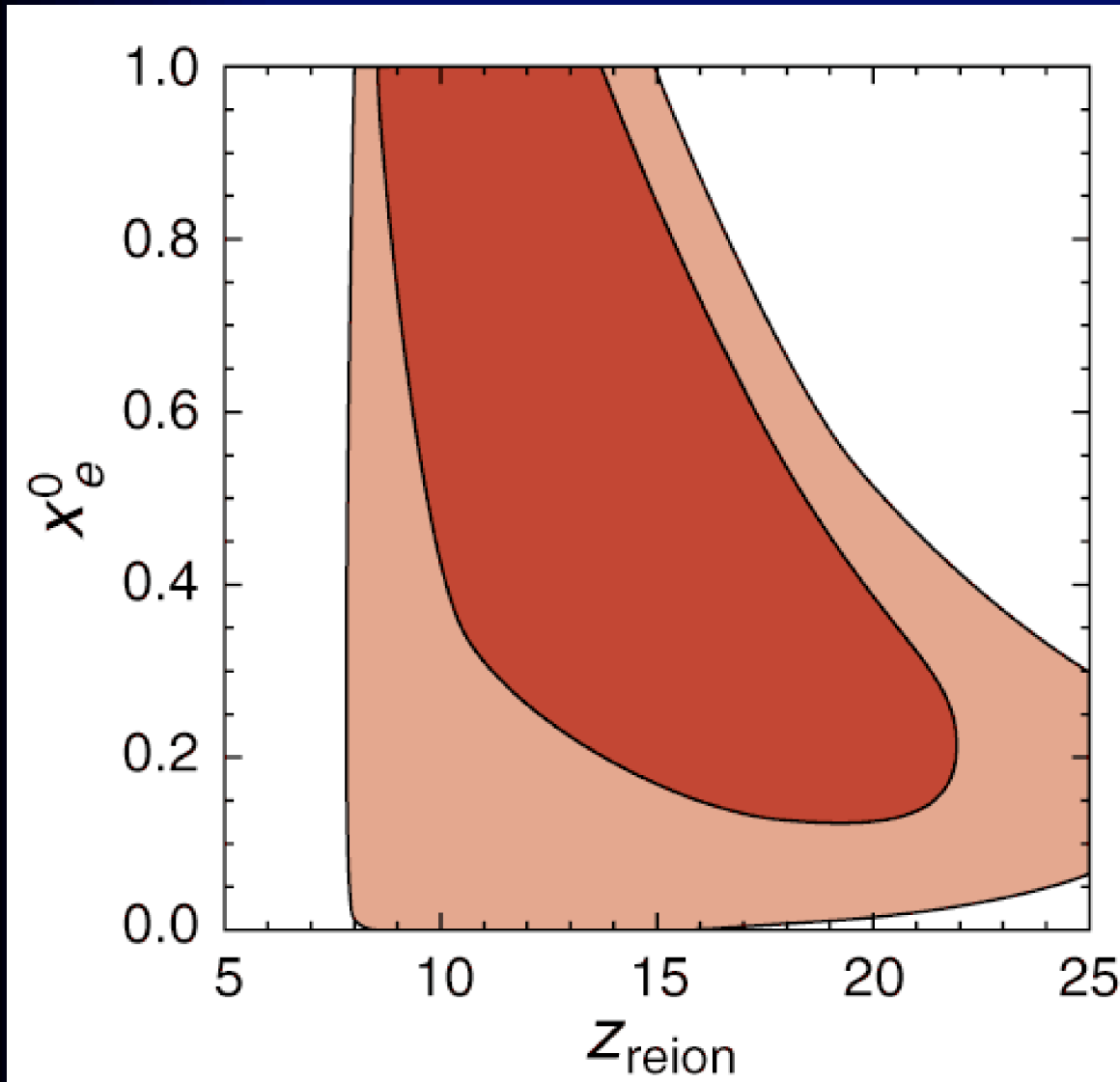
# <sup>no</sup> Galaxies at $z = 7.7$ : results from the DAzLE lensing cluster survey

Bram Venemans (ESO)

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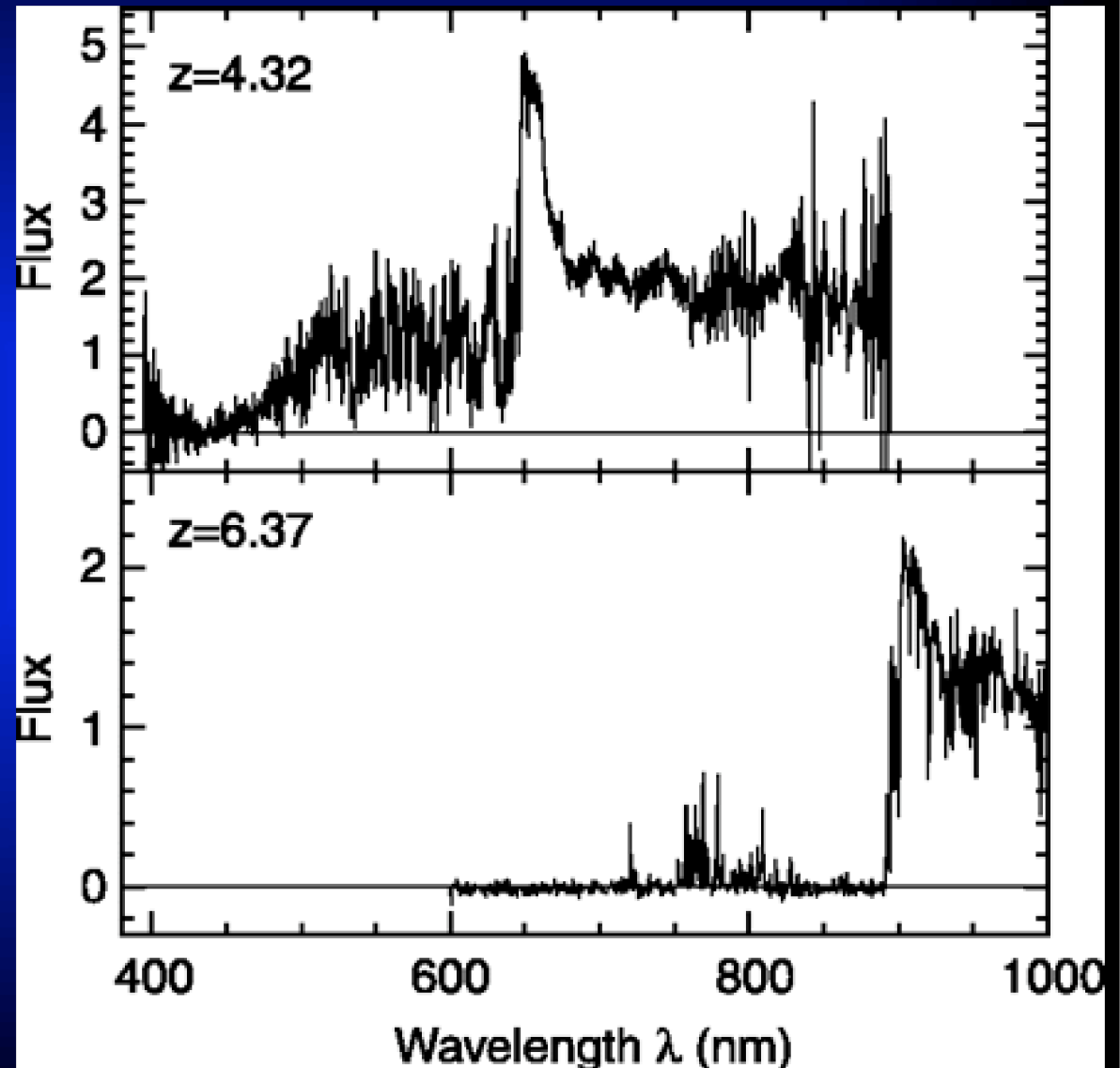
# Context: Epoch of Reionisation



WMAP: Universe  
becomes ionised  
at  $z=8-14$   
(Spergel+ 2007)

# Context: Epoch of Reionisation

SDSS quasars:  
spectra show that  
reionisation was  
complete around  
 $z \sim 6$  (Fan+ 2006)



# Context: Epoch of Reionisation

- WMAP: Universe becomes ionised at  $z=8-14$
- Quasars: reionisation completed around  $z\sim 6$
- Old stars in  $z\sim 6$  galaxies, metals in quasar hosts

→ Significant population of star forming galaxies at redshifts  $z \gg 6$ : where? how many? luminosity?

Problem: very faint, invisible in the optical

→ Discovery method: Ly $\alpha$  emission line surveys

# Optical surveys for LAEs

- Successful method: narrow band imaging of the Ly $\alpha$  line in dark gaps in the airglow: many galaxies confirmed! (e.g. this conference et al. 2009)
    - 6700 Å;  $z=4.5$ ; e.g. Rhoads+ 2000; Ouchi+ 2003
    - 8120 Å;  $z=5.7$ ; e.g. Hu+ 2004; Ouchi+ 2005
    - 9200 Å;  $z=6.6$ ; e.g. Hu+ 2002; Kodaira+ 2003; Kurk+ 2004; Rhoads+ 2004
    - 9600 Å;  $z=6.9$ ; e.g. Iye+ 2006; Ota+ 2008
- at these red wavelengths CCDs have poor QE and sky relatively bright, success due to very large FOV.

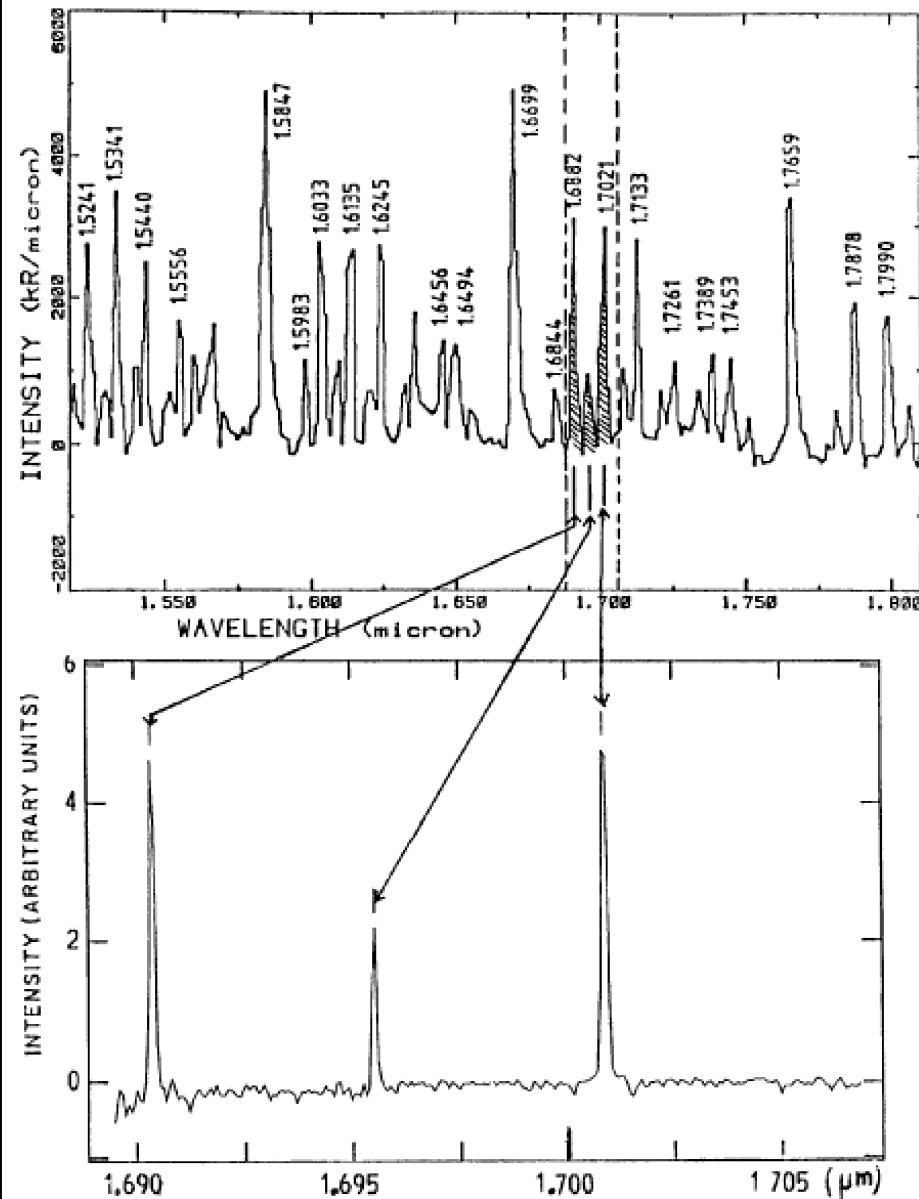
**To go to higher redshifts, need to go into infrared**

# Surveys for LAEs in the near infrared

The sky background increases rapidly towards the infrared, going from 18.6 AB mag arcsec<sup>-2</sup> in the z-band to 16.9 AB mag arcsec<sup>-2</sup> in J

However, the infrared sky background is dominated by OH emission lines

# The infrared OH sky (Maihara+ 1993)



## GOOD NEWS

The 1.0 to 1.8  $\mu\text{m}$  IR sky is very dark between the OH lines which contain 95% of broad band background

## NOT SO GOOD NEWS

The gaps are narrower than in the optical; filter widths of 0.1% ( $\sim 10\text{\AA}$ ) are needed compared with 1% filters in optical ( $\sim 100\text{\AA}$ )

# Difficulties for narrow band Lyman $\alpha$ searches in the near infrared

Filters need to have widths of  $10\text{\AA}$  or  $0.1\%$  to avoid OH lines (c.f.  $100\text{\AA}$  in the optical)

- Narrower band means a smaller redshift range so wide angular field is needed to increase the volume searched.

Some of the technical issues

- Filter manufacture; filter width of  $0.1\%$  ( $10\text{\AA}$ ) BUT you also want the central wavelength to  $0.01\%$  ( $1\text{\AA}$ )
- Field angle causes an off-axis shift of central  $\lambda$
- Out of band blocking



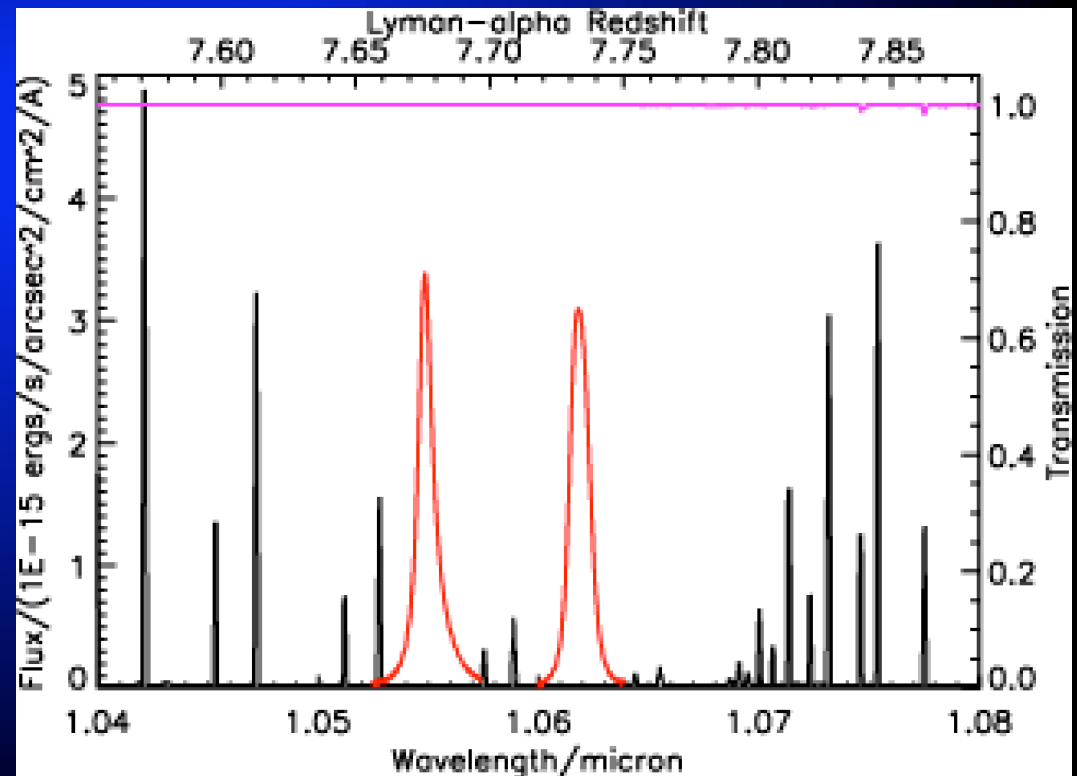
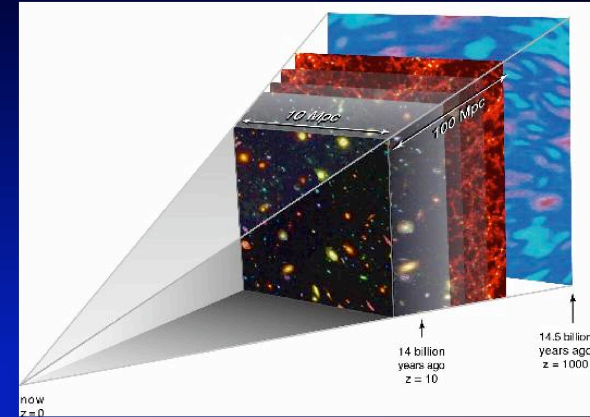
# DAzLE – Dark Ages z Ly $\alpha$ Explorer

- IR narrow band imager with OH discrimination at R=1000 filters
- 2048x2048 pix Rockwell Hawaii-II
- scale 0.2"/pixel
- FOV 6.8x6.8 arcmin<sup>2</sup>
- Minimum shift of filter curve over FOV

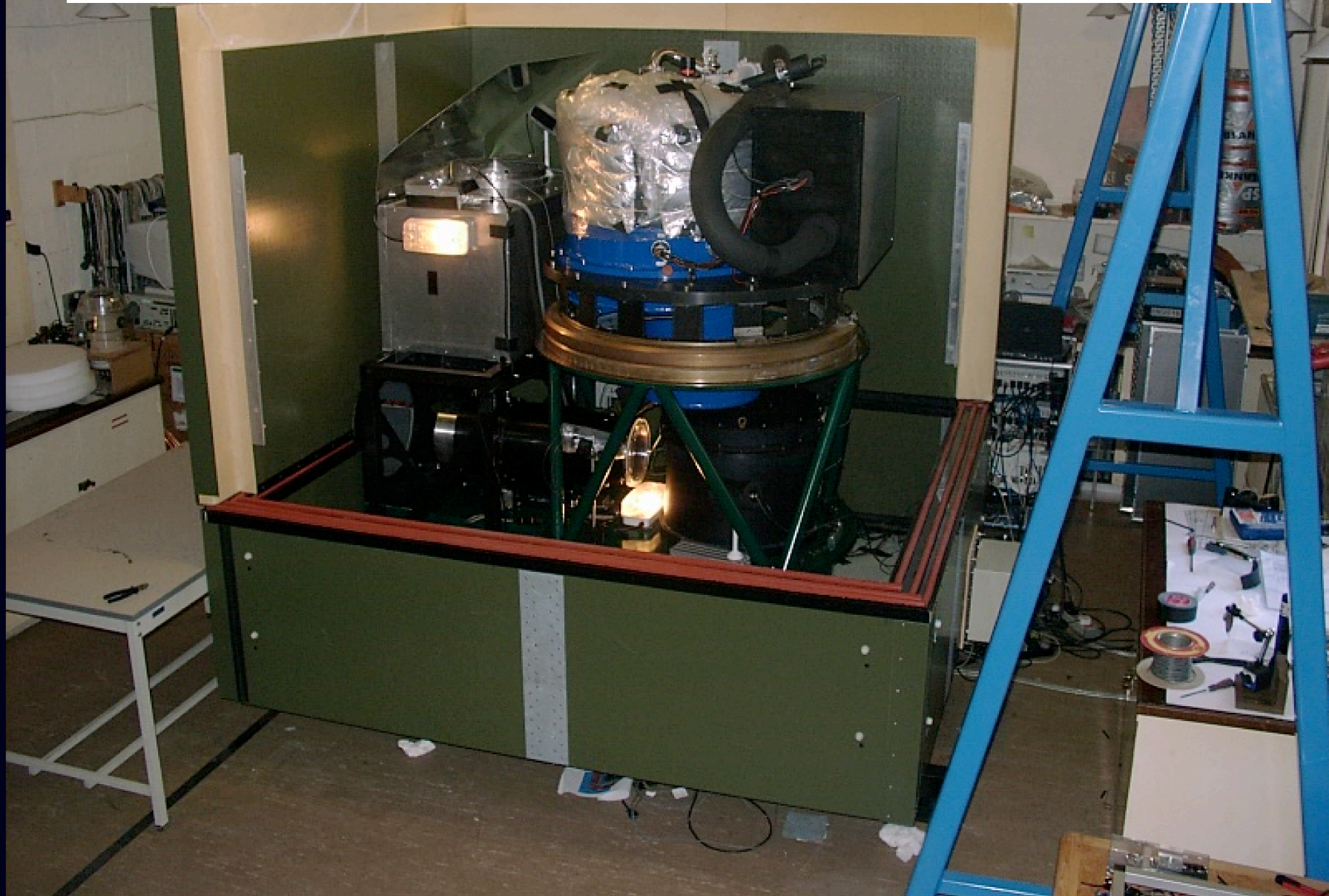
Idea is to look  
between OH lines



See Horton+ 2004



# DAzLE in the lab in Cambridge

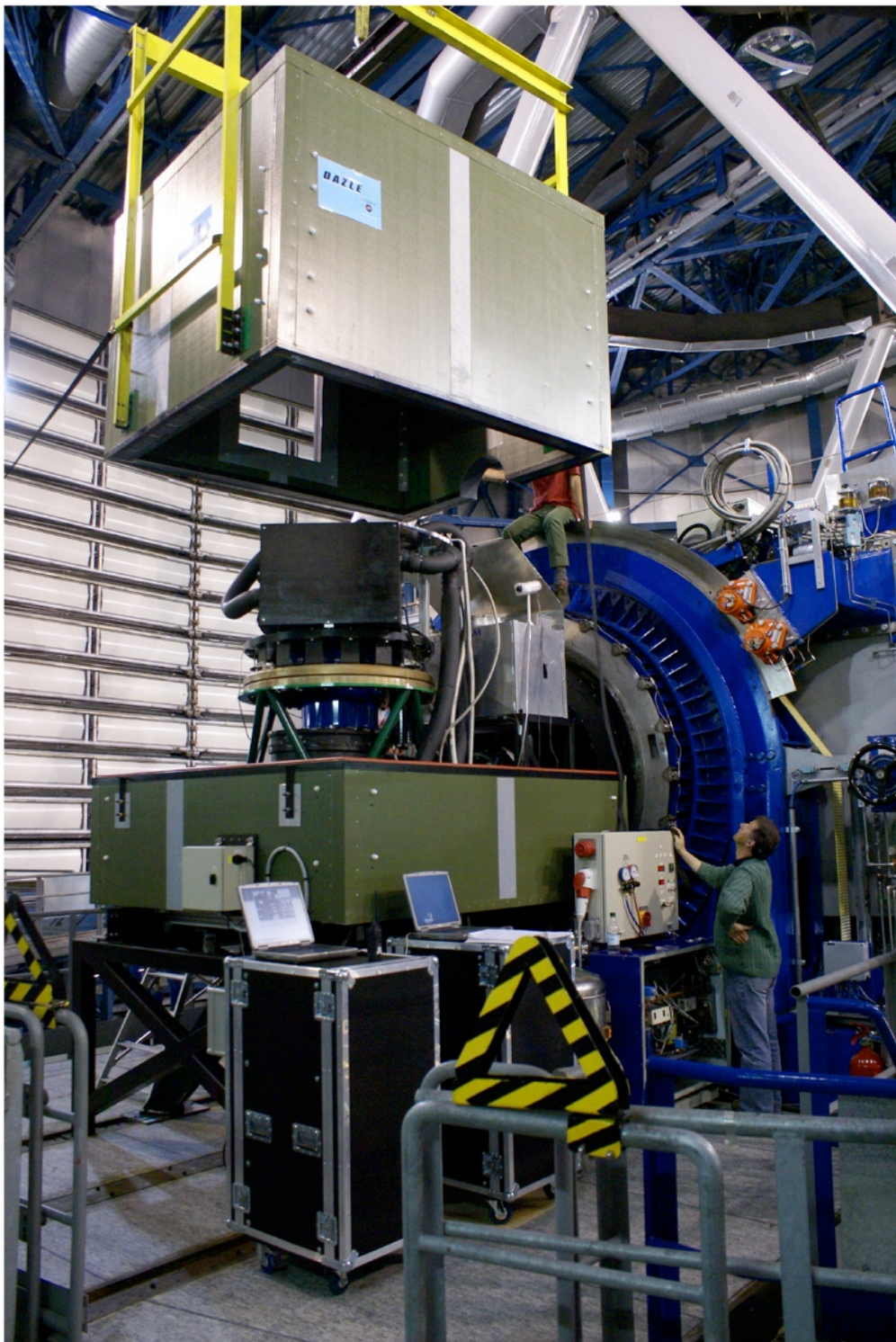


October 2006

**DAZLE**  
arrives at  
Paranal



Final assembly  
of DAzLE at the  
visitor focus on  
VLT UT3  
(October 2006)





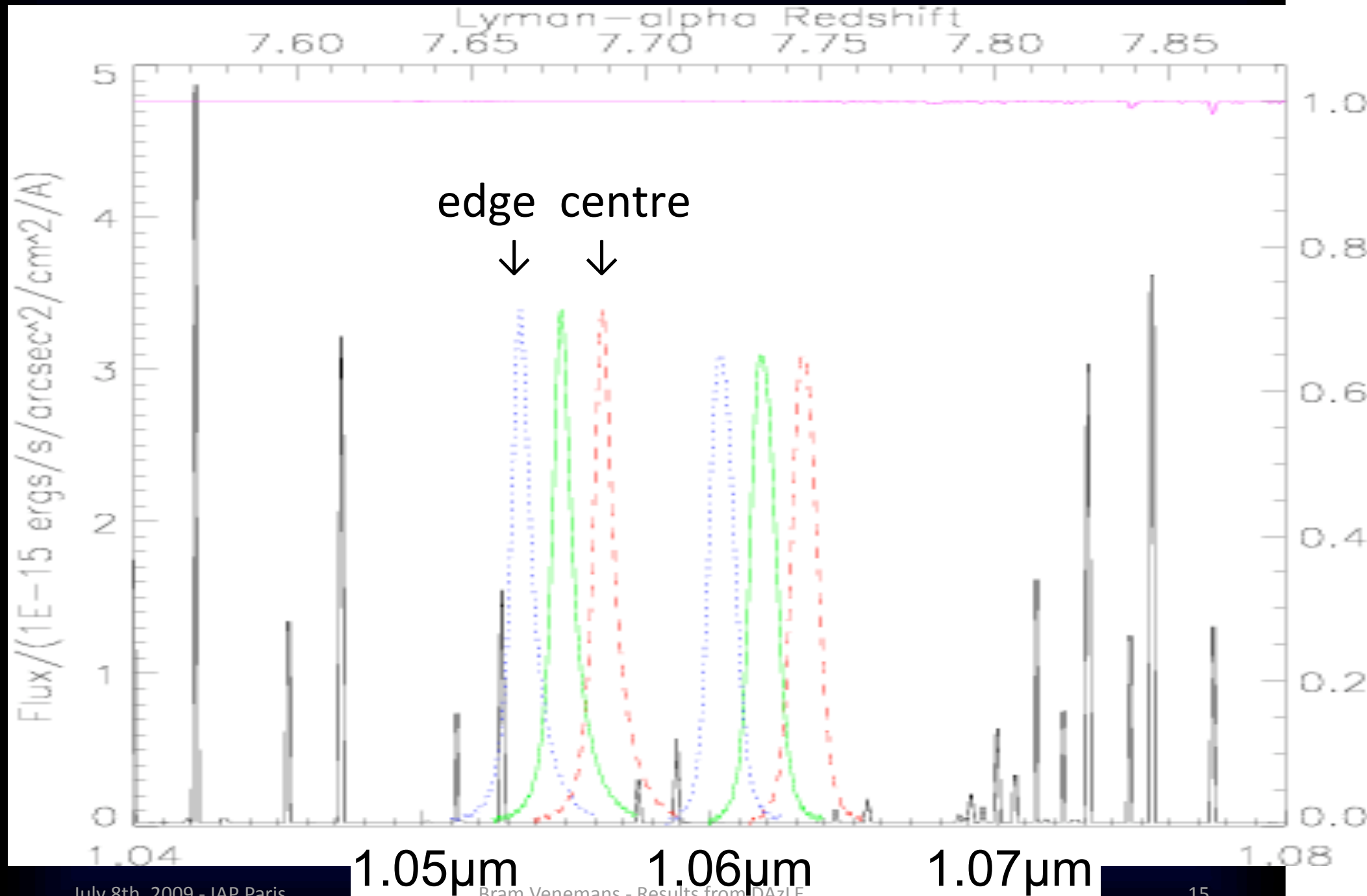
# DAzLE filters for Ly $\alpha$ at $z=7.7$

- Two filters centred at 1.056 $\mu\text{m}$  and 1.063 $\mu\text{m}$
  - FWHM  $\sim 9\text{\AA}$
- Volume imaged per filter per pointing: 700 Mpc<sup>3</sup>

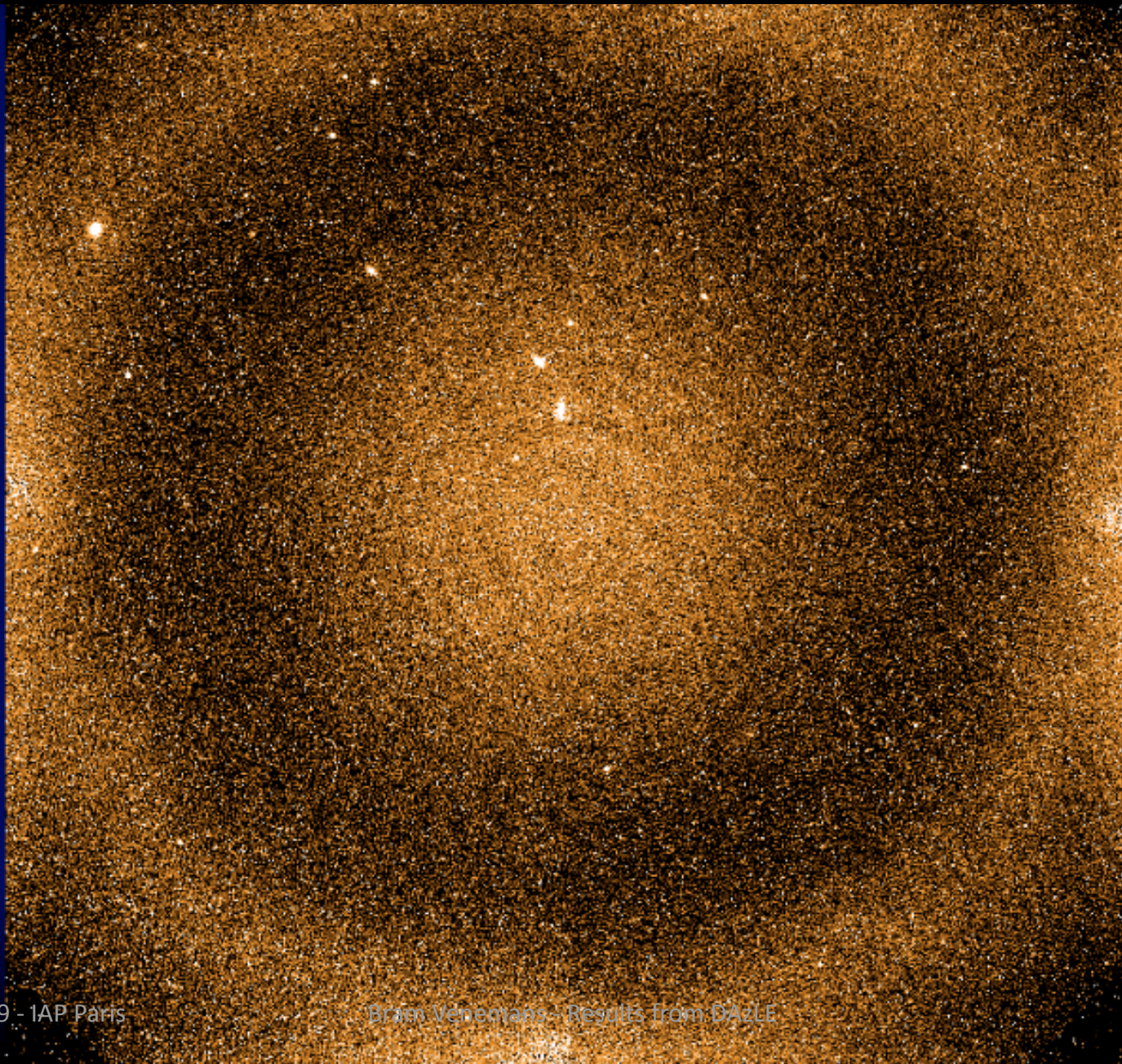
Technical challenge:

- Pushing technology to its limits
- More than €15k each
- It took 2 years to get acceptable filters from Barr!

More recent quotation from Andover and Barr have delivery times of 3 months for €7500 per filter



# DAzLE image of GOODS South field





# DAzLE filters for Ly $\alpha$ at $z=7.7$

**NOTE:** observing in two adjacent filters allows rejection of various types of contaminants, including:

- transient objects (supernovae, moving bodies)
- objects with extreme colours, like EROs

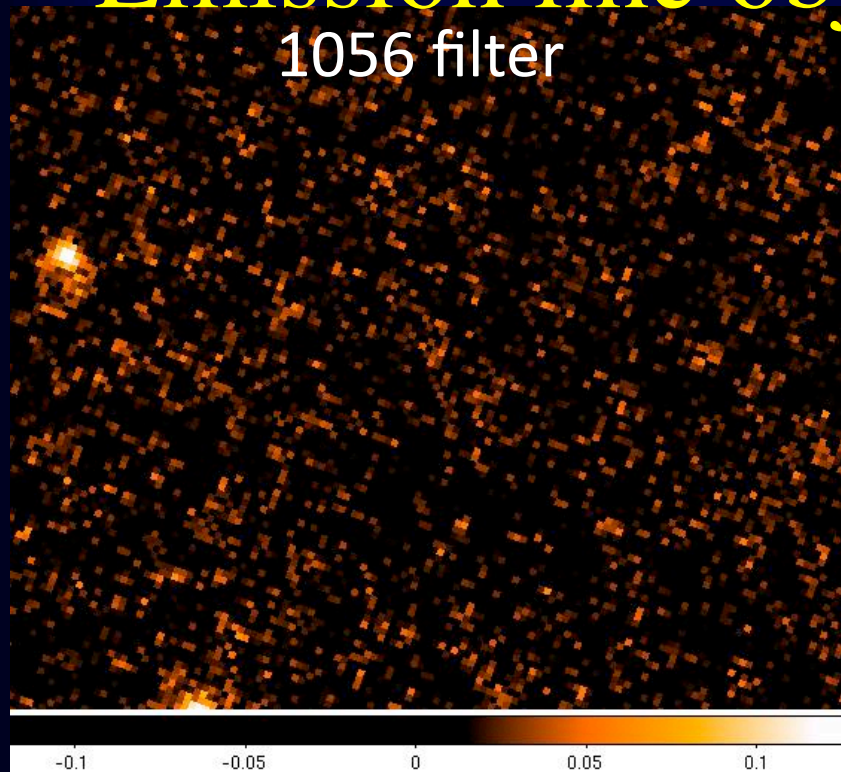
**Big advantage** over single narrow band observations (e.g. Cuby+ 2007)

# DAzLE observing runs at the VLT

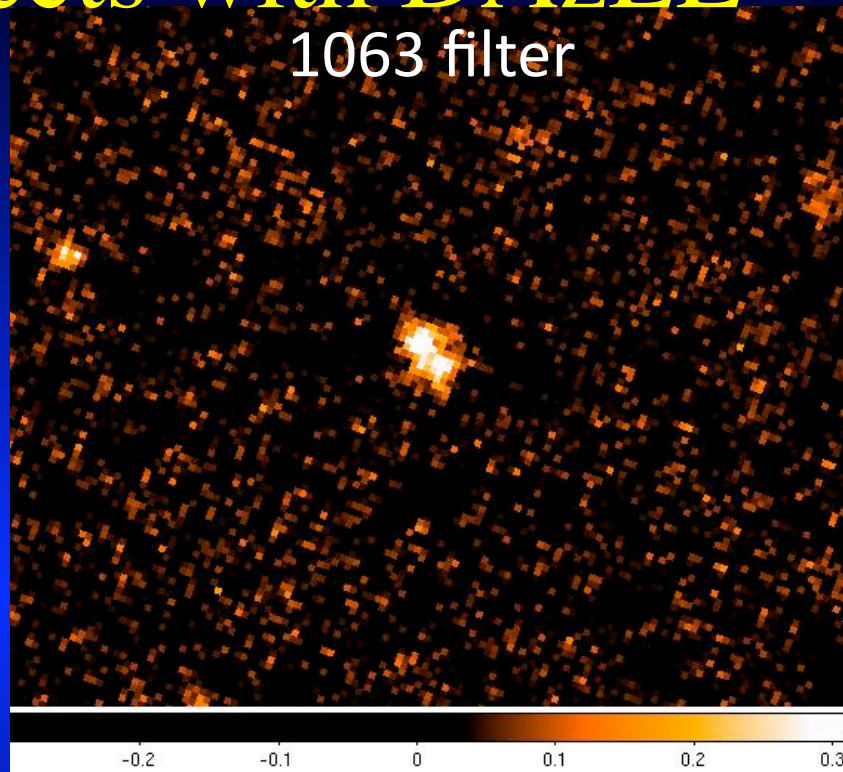
- Instrument assembly/removal went very smoothly
- 1-2 commissioning nights before science run
- **3 observing runs** between 11/2006 and 01/2008:
  - Two targeting blank fields (GOODS, COSMOS)
  - One targeting foreground clusters of galaxies
- Excellent image quality: images with half hour exposure time often had seeing  $< 0.5''$
- Data reduction underway (not straightforward),  
**Reduction of cluster data is finished, paper in prep.**

# Emission line objects with DAzLE

1056 filter



1063 filter

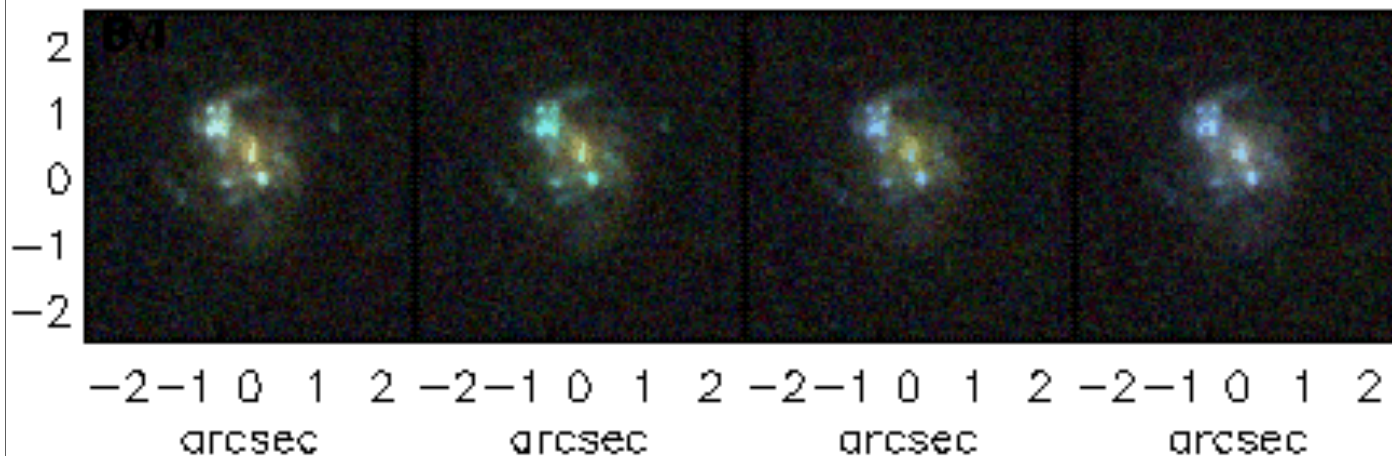


BVi

BVz

BiZ

ViZ



$z_{\text{phot}}=0.606$

$\Rightarrow$  H $\alpha$  emitter

$L \approx 4 \times 10^{43} \text{ erg s}^{-1}$

# The DAzLE lensing cluster survey

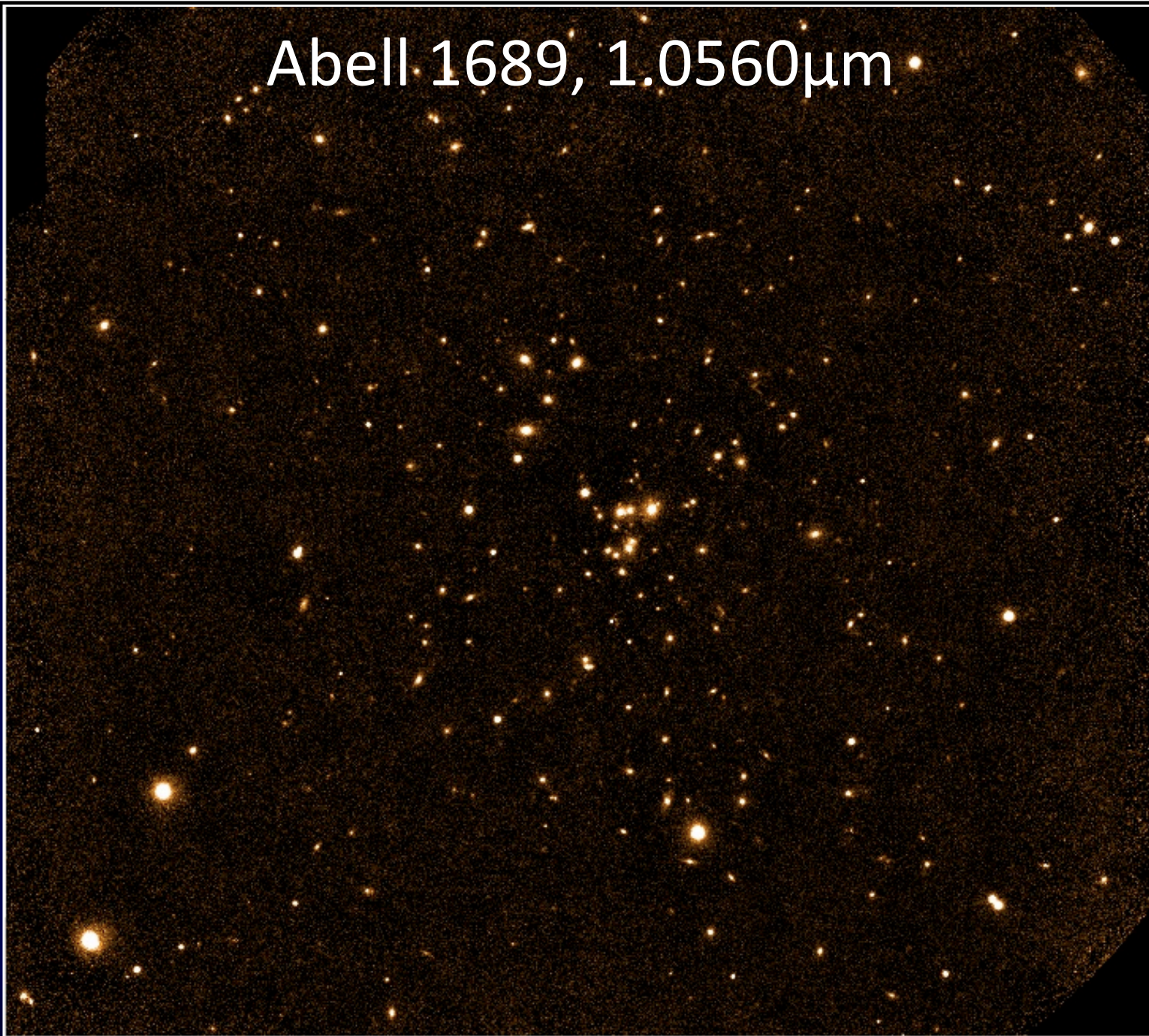
- 7 clusters observed with DAzLE at the VLT in two narrow filters in April 2007
- Limiting flux between  $1-3 \times 10^{-17}$  erg s<sup>-1</sup> cm<sup>-2</sup>

→ **No good candidate  $z=7.7$  galaxy found**

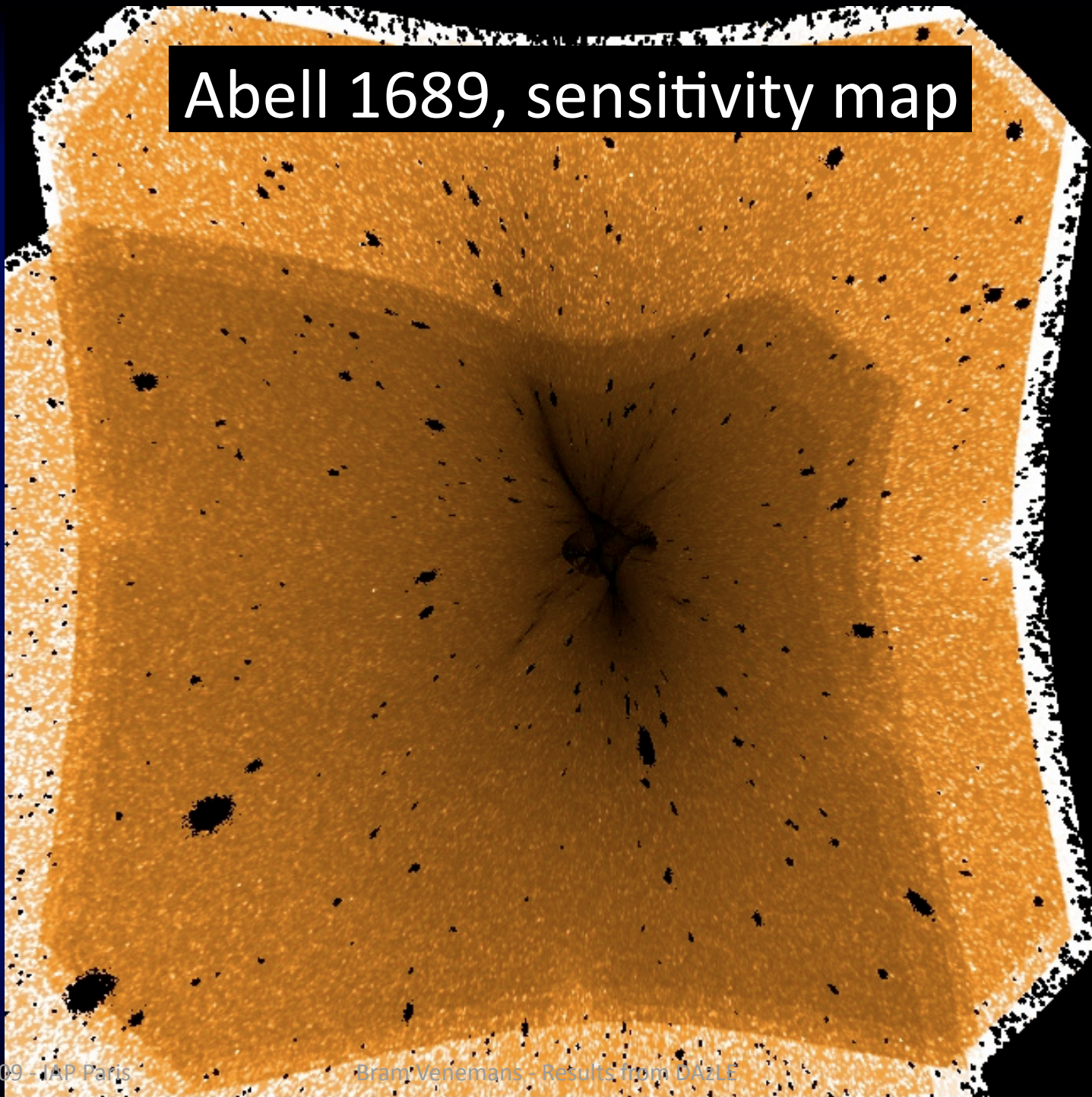
all emission line candidates are detected in deep optical images

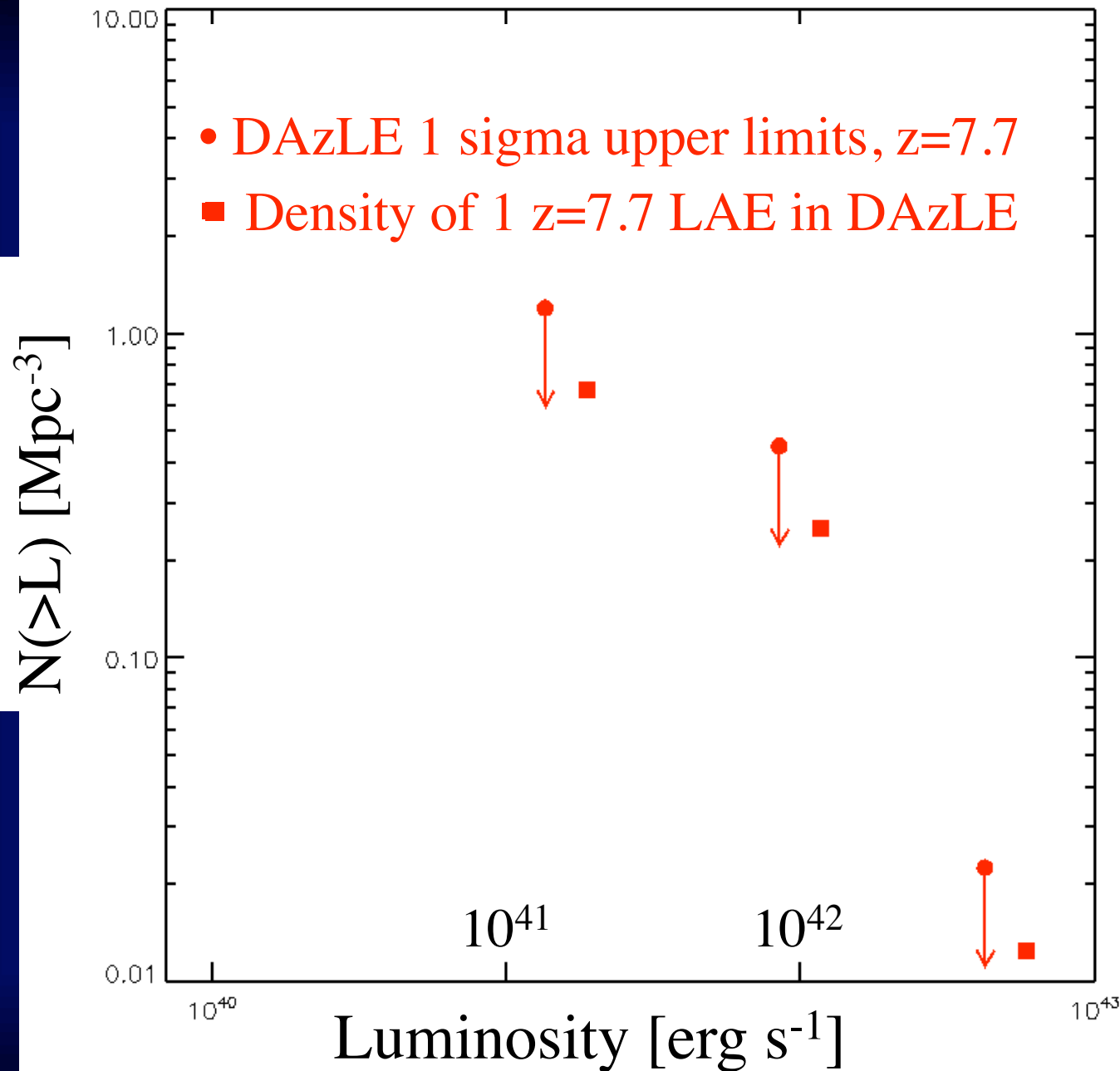
- Using cluster mass profiles to compute the magnification over the field → limits on density

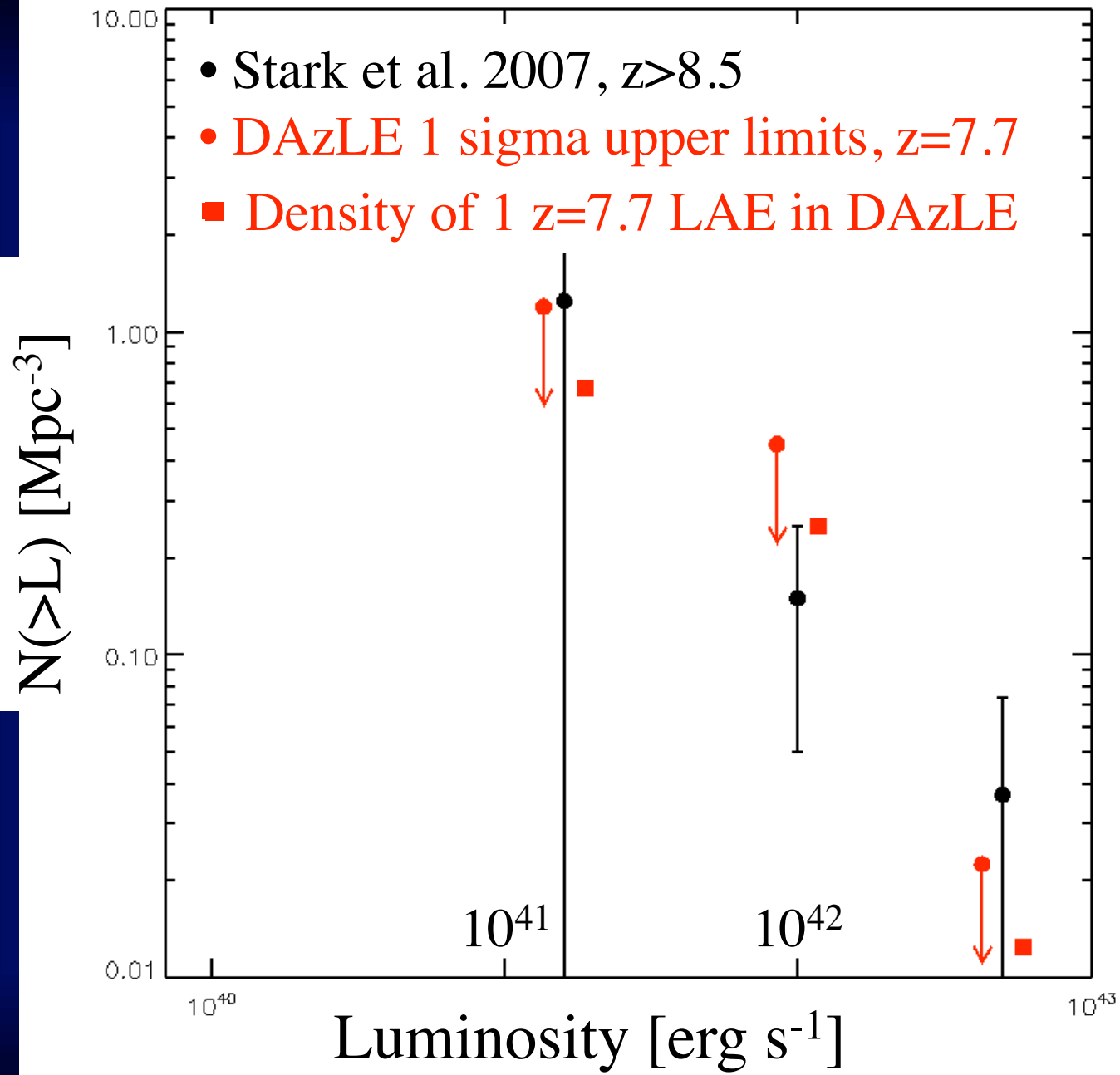
# Abell 1689, 1.0560 $\mu\text{m}$



# Abell 1689, sensitivity map



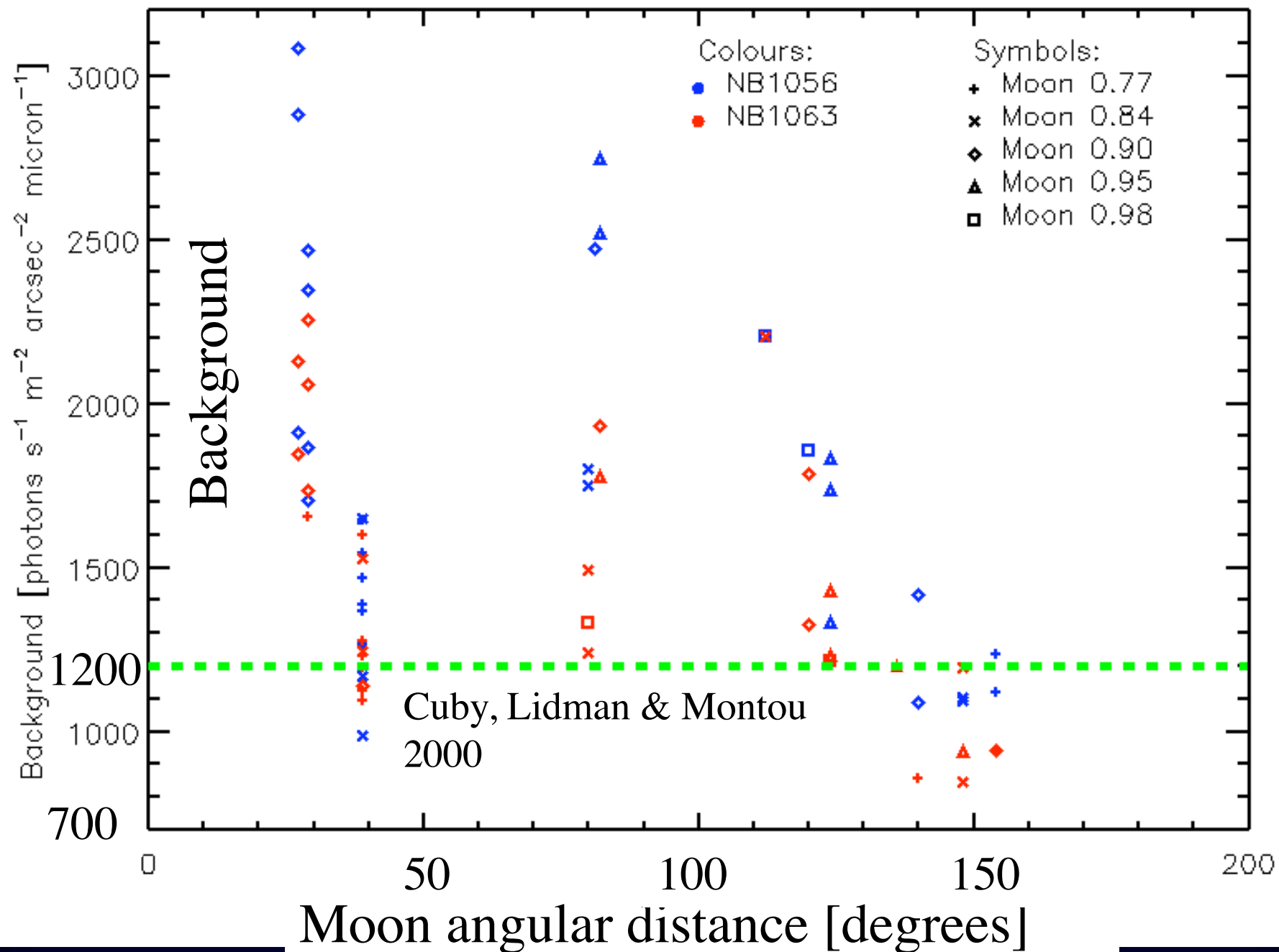


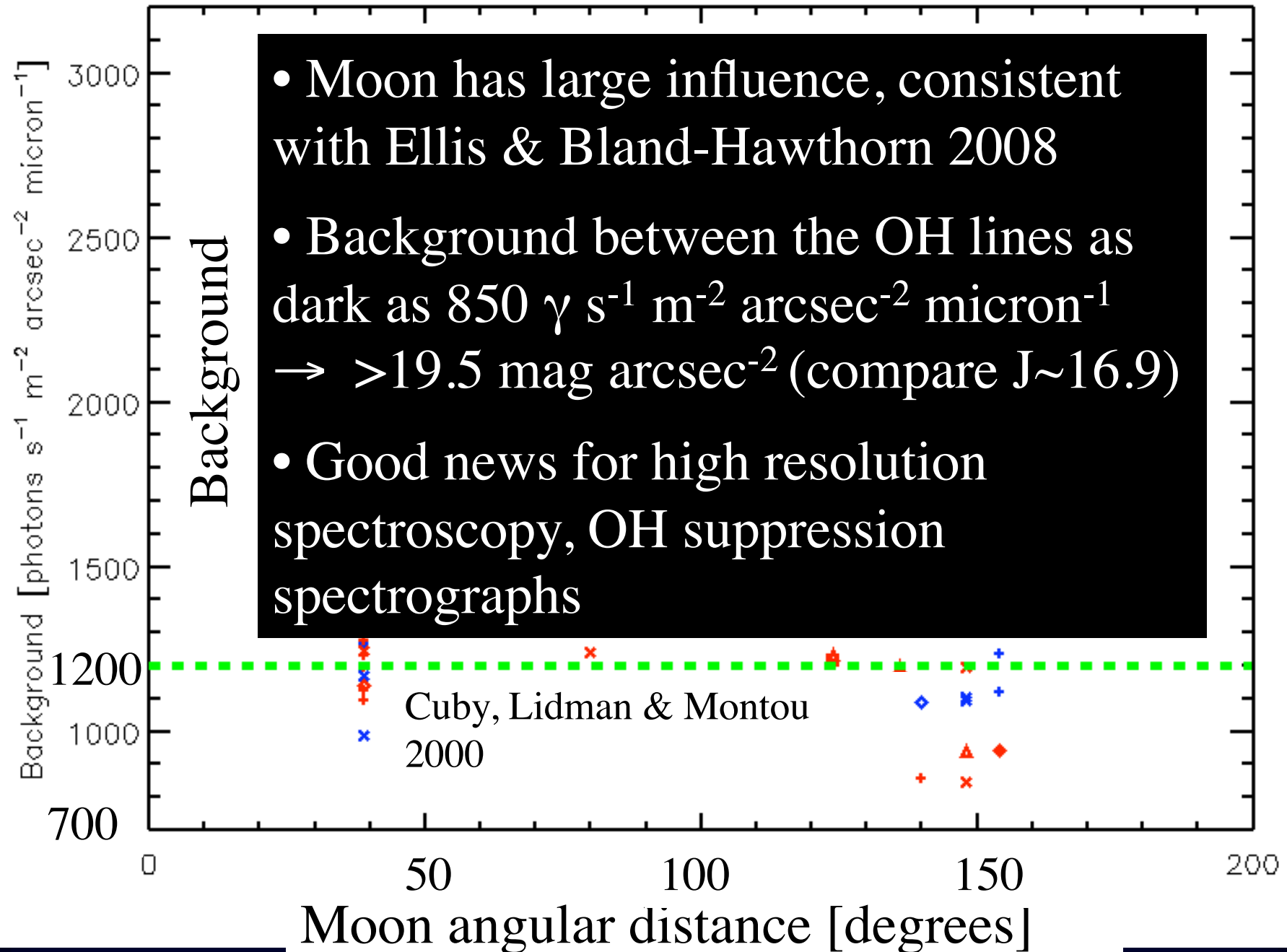




# (Preliminary) results from DAzLE

- In 7 cluster field no  $z=7.7$  LAE found
- The density of low luminosity  $z=7.7$  LAEs consistent with  $z<7$  LFs and with models, maybe lower than numbers at  $z>8.5$
- Reduction of more DAzLE data in progress
- Will constrain the luminosity function at the brighter end ( $L > 5 \times 10^{42}$  erg s<sup>-1</sup> cm<sup>-2</sup>)
- The DAzLE images provide new estimates of the inter-OH sky background





# Summary

- Sky in the infrared is very dark between the OH lines, but the gaps are small ( $\sim 10\text{\AA}$ )
- DAzLE is a specialised IR imager capable of handling narrow filters to observe between the OH
- Three observing runs with DAzLE on the VLT visitor focus to search for  $z\sim 7.7$  galaxies
- Data reduction in progress, no high- $z$  galaxy found so far... but data will put constraints on the luminosity function of  $z=7.7$  galaxies
- More results at  $z=7.7$  from the VLT will come from NB search with HAWK-I, see B. Clément's poster