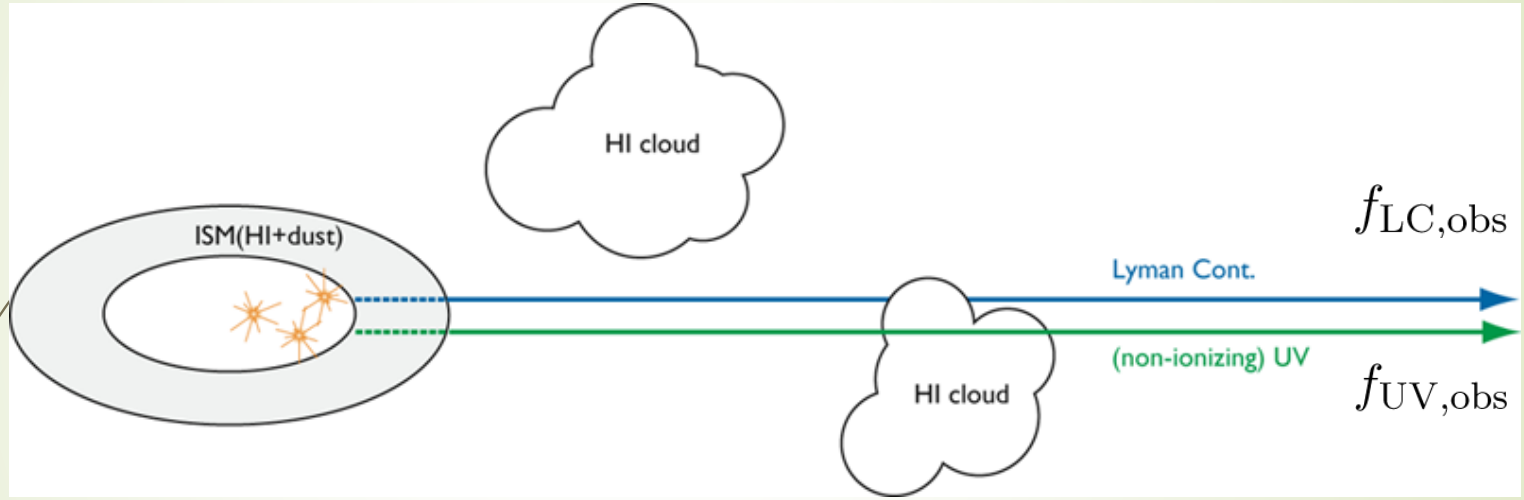
Lyman Continuum Galaxies

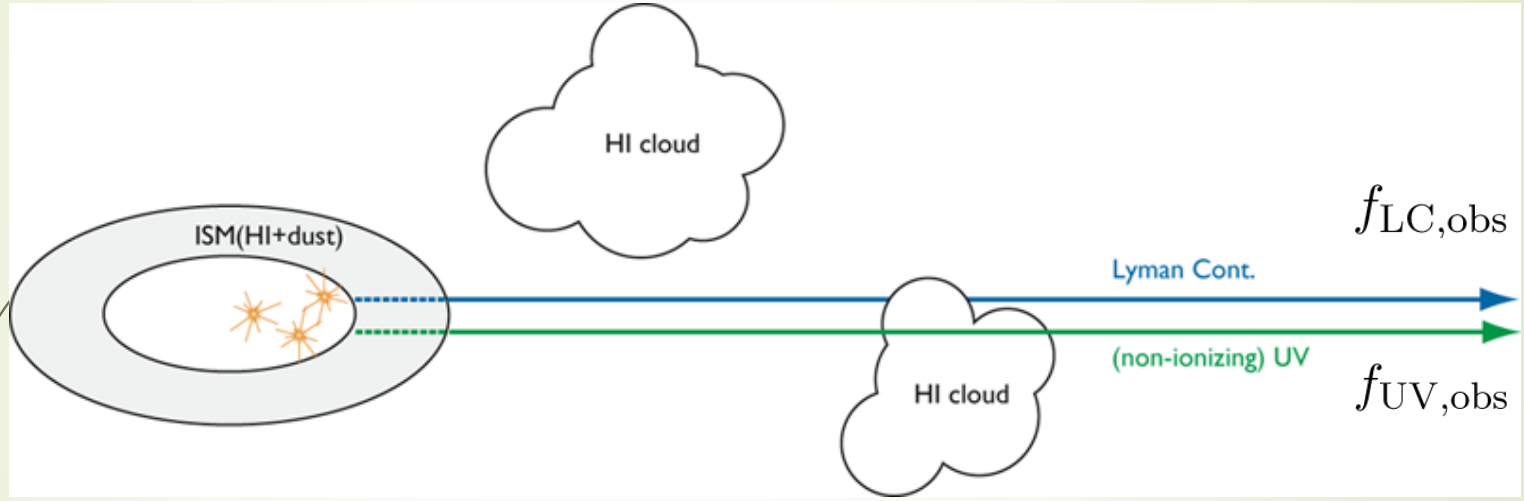
Ikuru Iwata (Subaru Telescope, NAOJ)

LyC escape fraction



$$f_{\rm esc} = L_{\rm LC,out}/L_{\rm LC,int}$$

LyC escape fraction



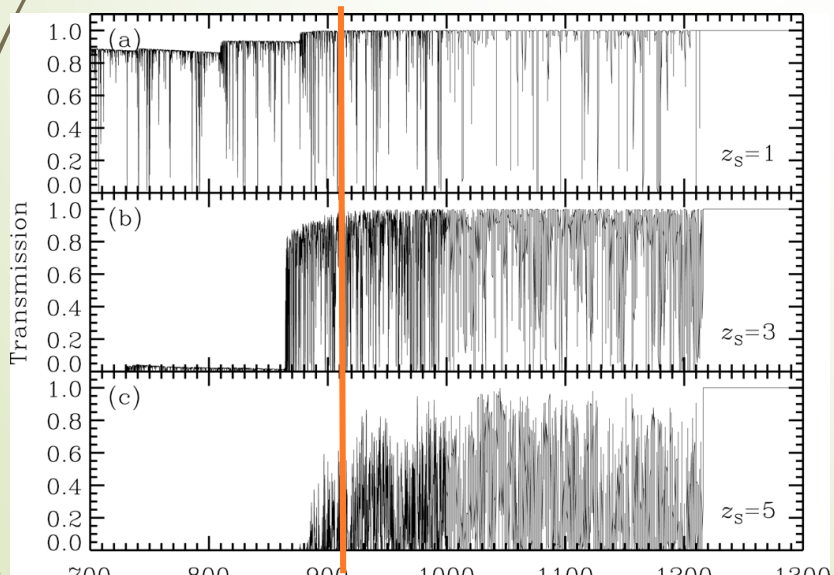
$$f_{\rm esc} = L_{\rm LC,out}/L_{\rm LC,int}$$

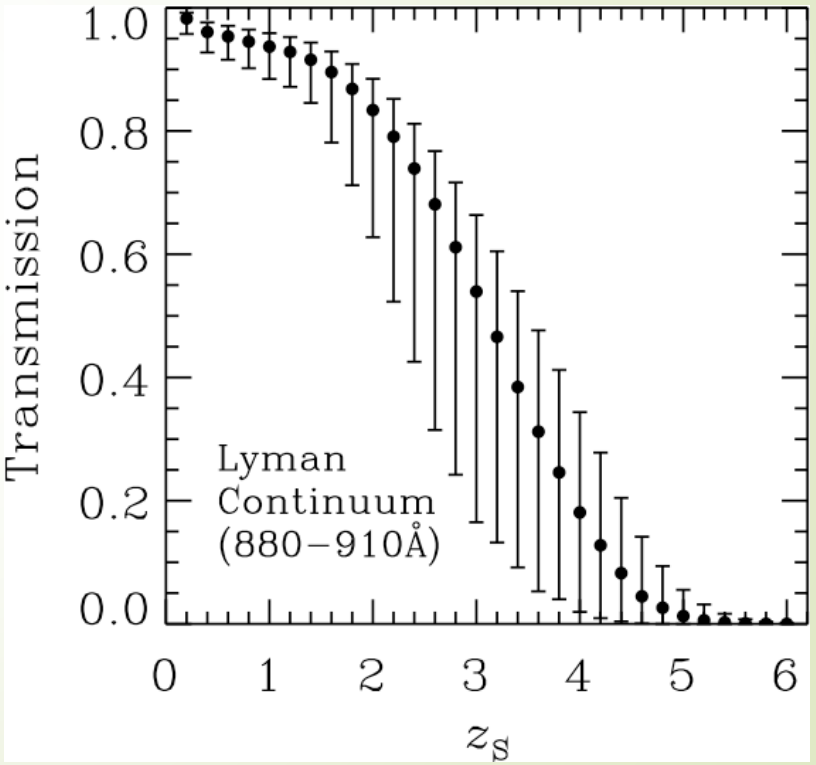
$$f_{\rm esc} = 10^{-0.4A_{\rm UV}} f_{\rm esc,rel}$$

$$f_{\rm esc,rel} = \frac{(L_{\rm LC,out}/L_{\rm LC,int})}{(L_{\rm UV,out}/L_{\rm UV,int})} = \frac{(L_{\rm UV}/L_{\rm LC})_{\rm int}}{(f_{\rm UV}/f_{\rm LC})_{\rm obs}} \exp(\tau_{\rm IGM,LC})$$

LyC escape fraction: a key parameter to understand cosmic reionization

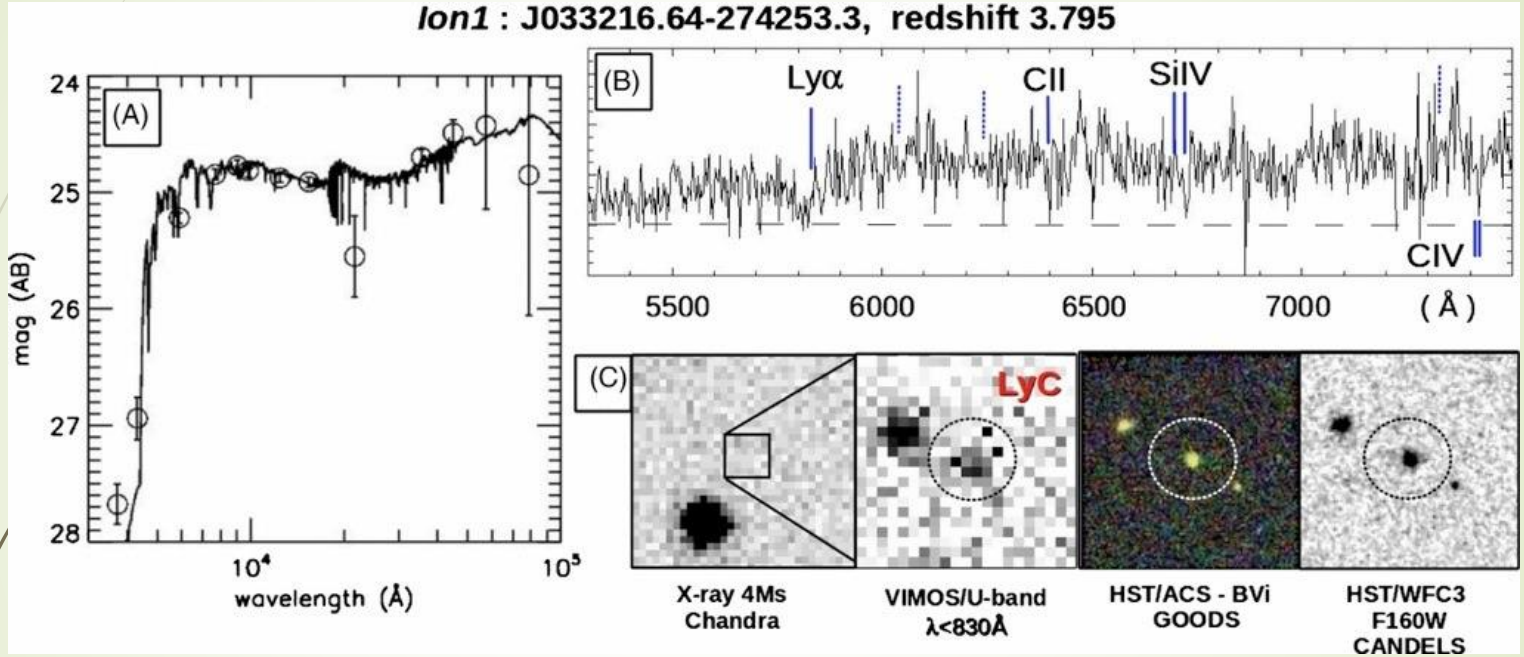
- Direct measurement at z>5 is impossible due to IGM opacity
- Constraints at lower redshifts are still poor
- IGM opacity is stochastic, different with sightlines





Inoue and Iwata 2008 MN 387, 1681
Inoue+ 2009 MN 442, 1805

‘Robust’ LyC galaxies

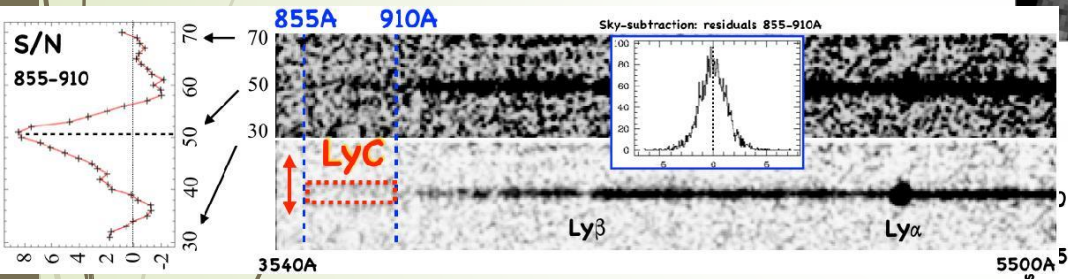


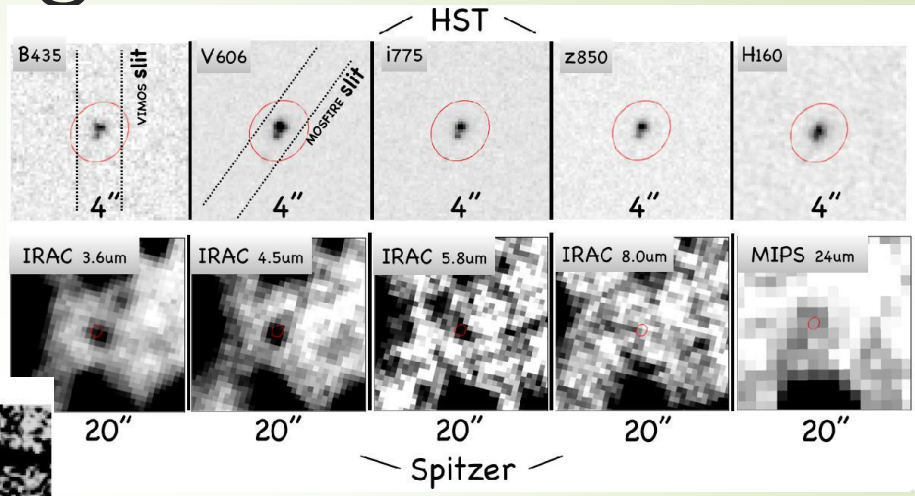
- Blue UV slope, No Lya emission, weak UV abs. lines
- Compact morphology
- fesc,rel > 82%, fesc>56%

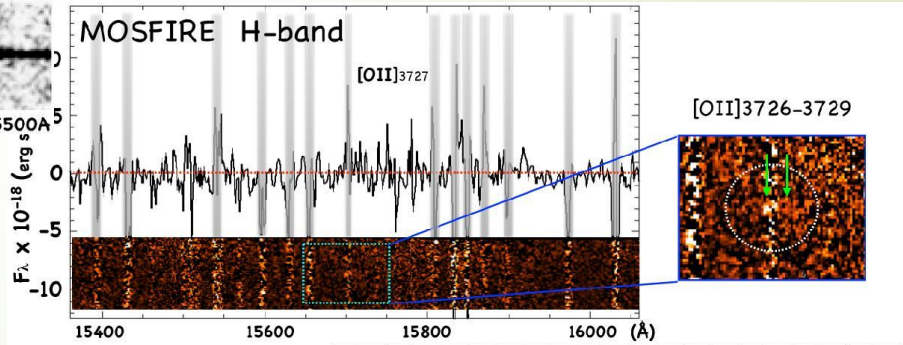
Vanzella+ 2012 ApJ 751, 70

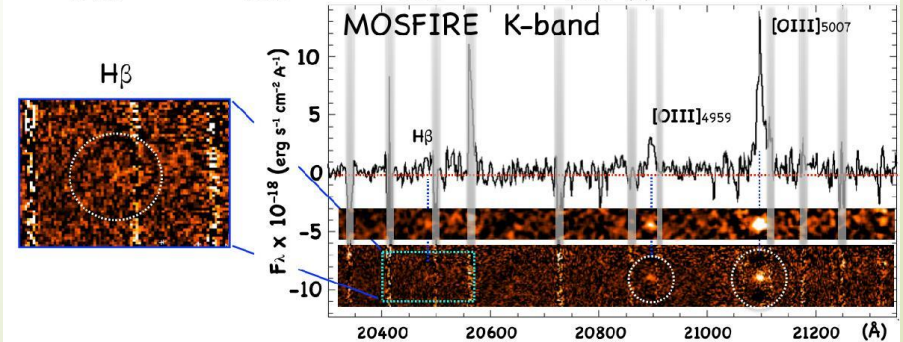
‘Robust’ LyC galaxies

- Ion2 at z=3.212



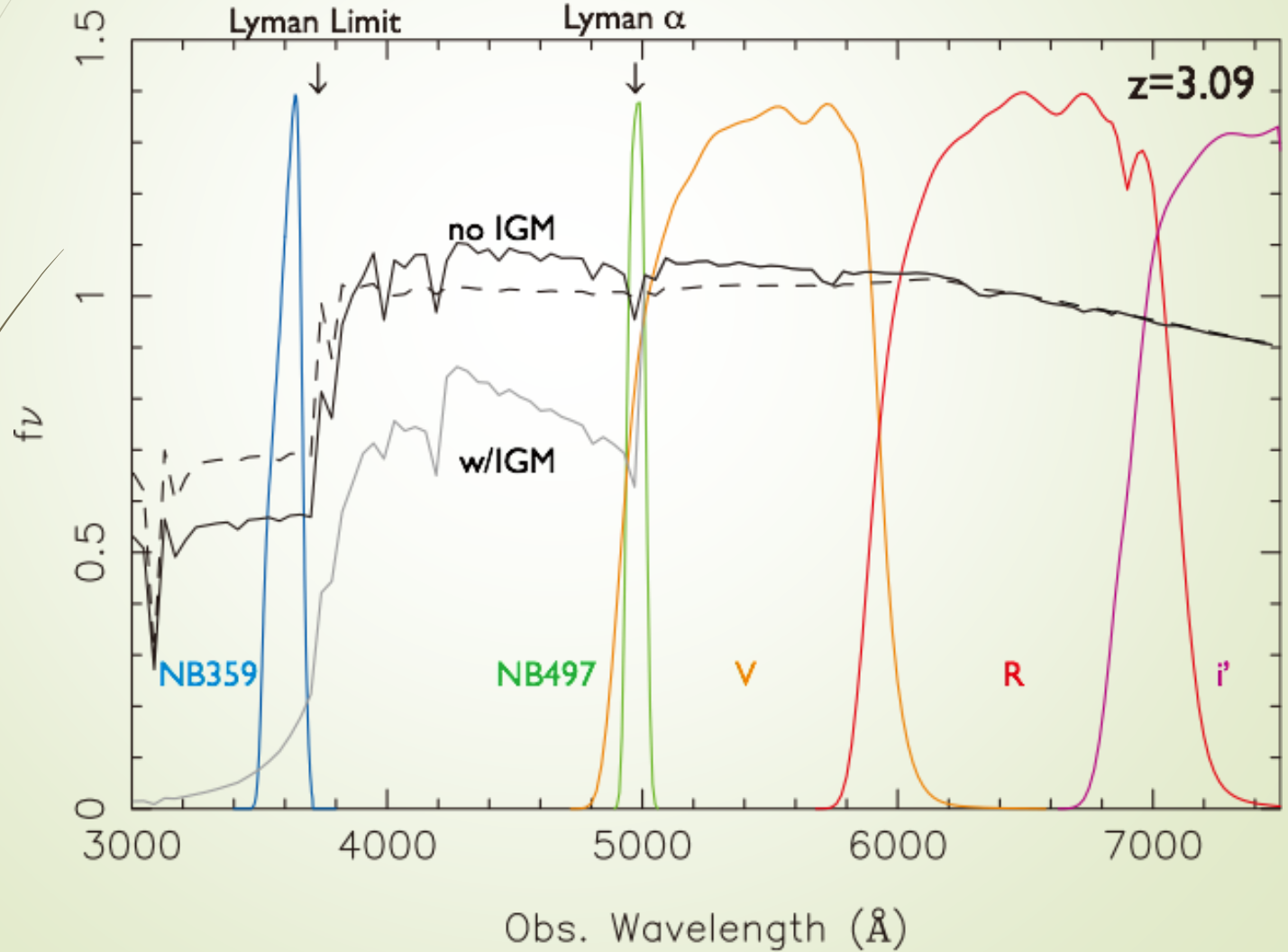






De Barros+ 2016 A&A 585, A51

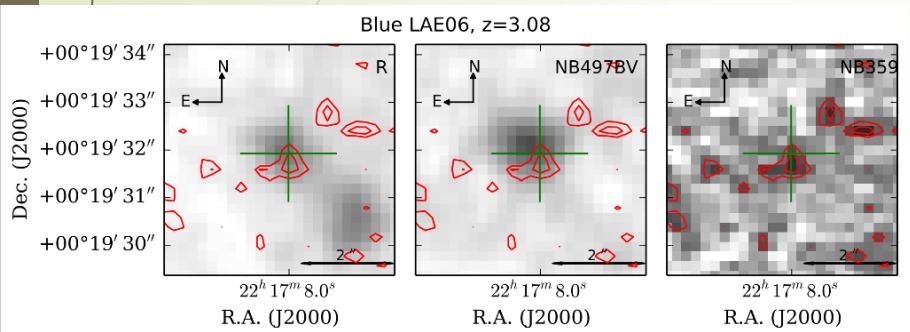
Suprime-Cam NB direct search for LyC at z=3.1

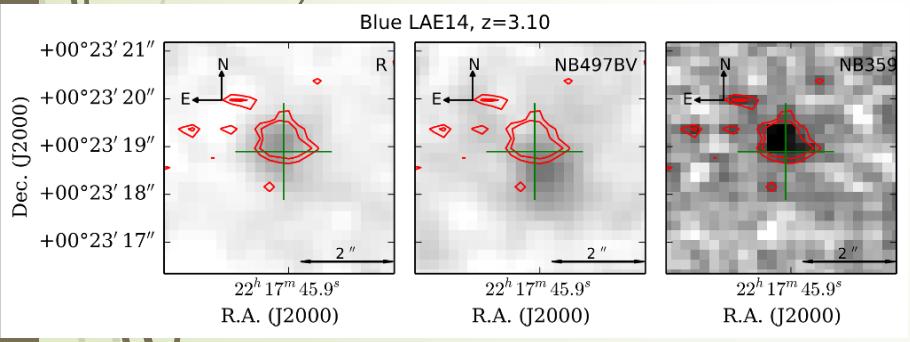


LyC search in SSA22 at z=3.1 with Suprime-Cam NB359

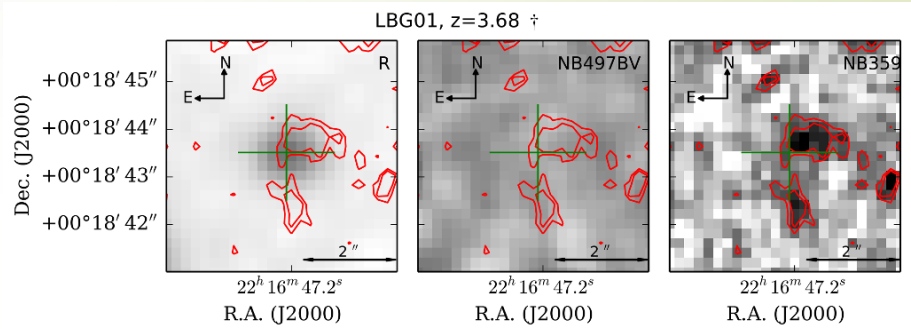
- Micheva et al. 2017a MN 465, 316
- Update of SSA22 S-Cam imaging with NB359 (Iwata+ 2009)
- Sample: 159 LAEs + 136 LBGs + with spec-z > 3.06
- NB359 detections: 18 LAEs, 7 LBGs
- Average LyC/UV flux ratios from stacking:
  - LAEs: <0.08, LBGs: <0.02
  - Escape fraction: LAEs: <0.15, LBGs: <0.01

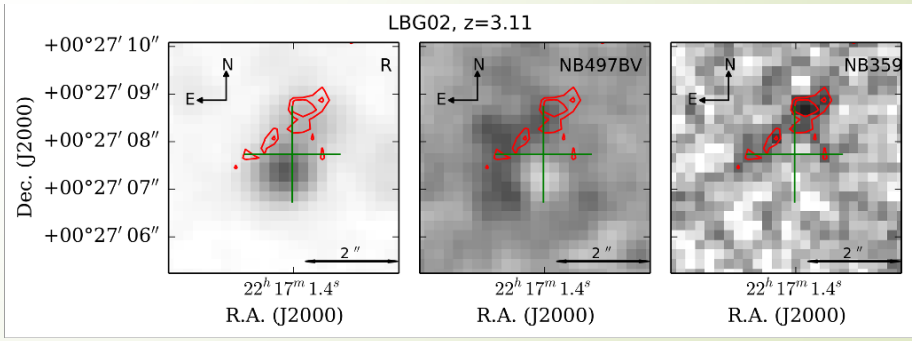
Montages of LyC candidates





Lyman a Emitters



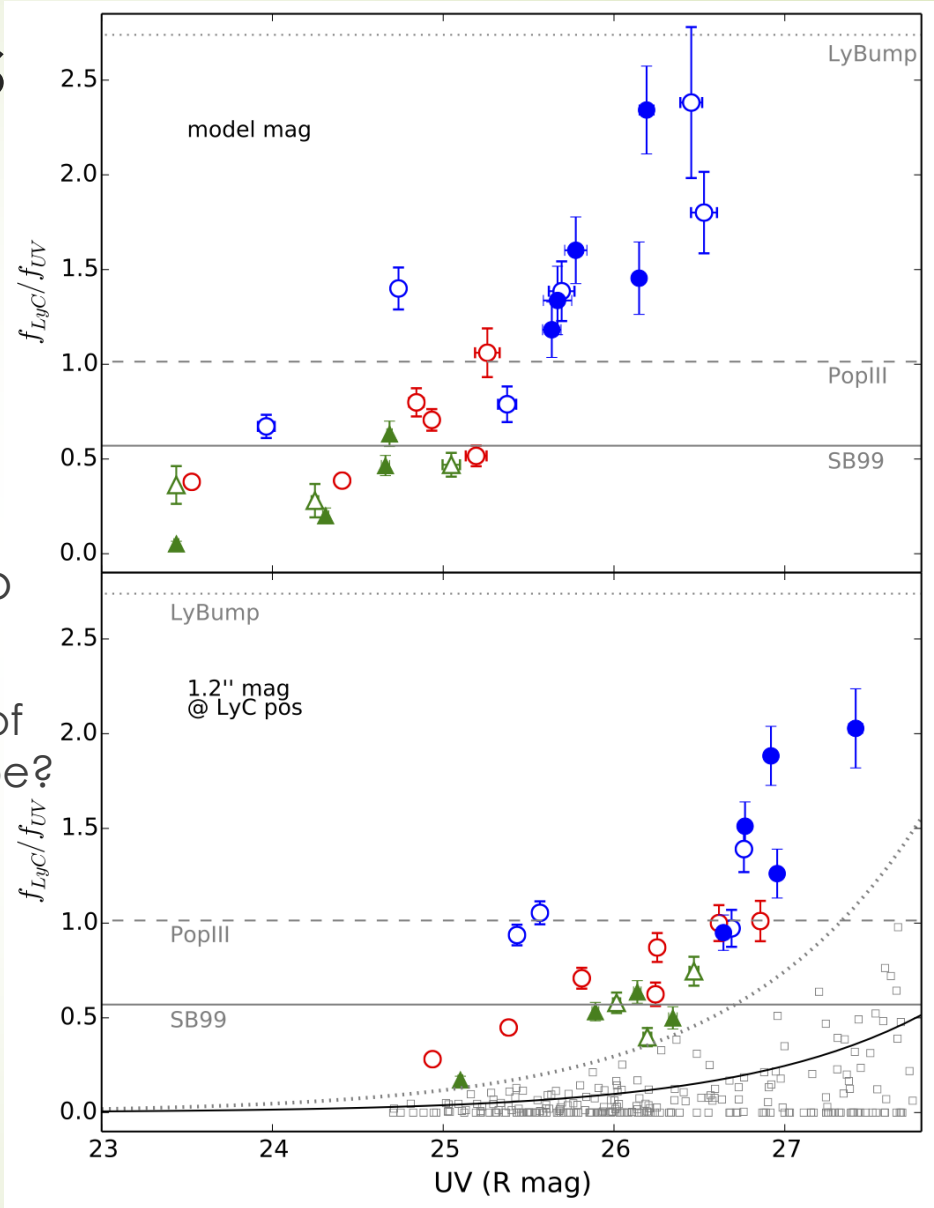


Lyman Break Galaxiesd

Micheva+ 2017 MN 465, 316

LyC/UV flux ratios

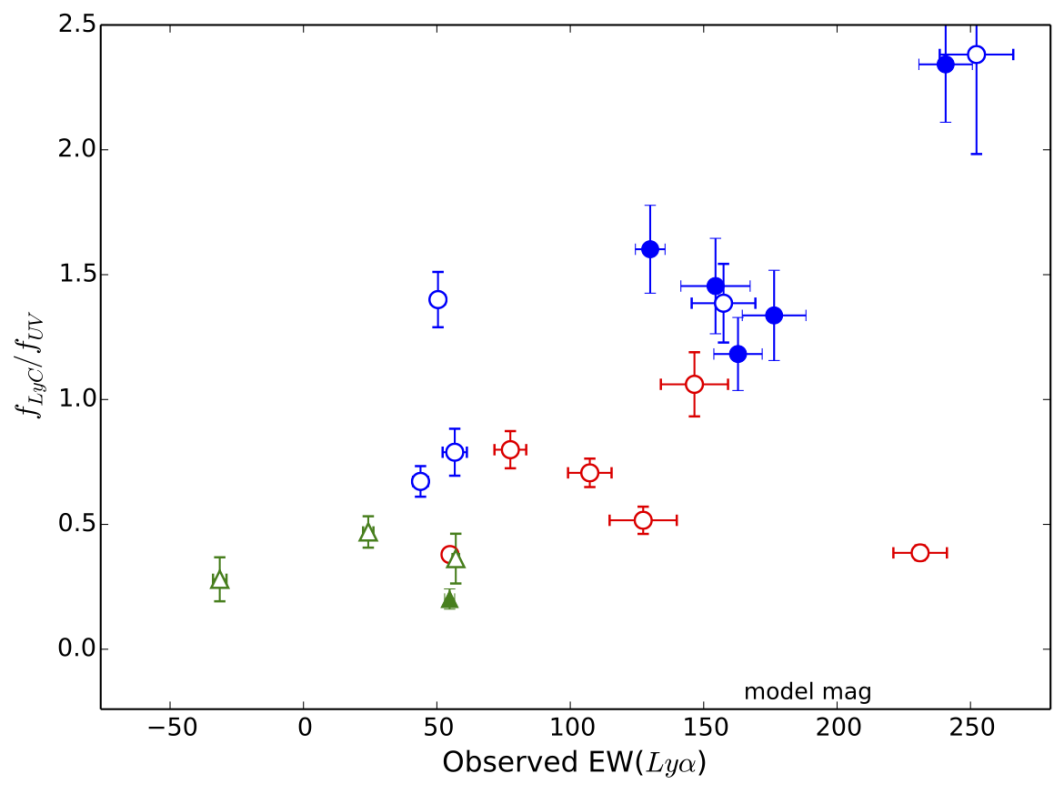
- Strong LyC leakers
  - Extremely metal poor stellar populations?
- LyC escape fraction seems to be bimodal
  - Some galaxies have 'holes' of ISM which enable LyC escape?
  - Fainter galaxies have higher LyC escape fraction?



Micheva+ 2017 MN 465, 316

Lya EW vs. LyC/UV flux ratio

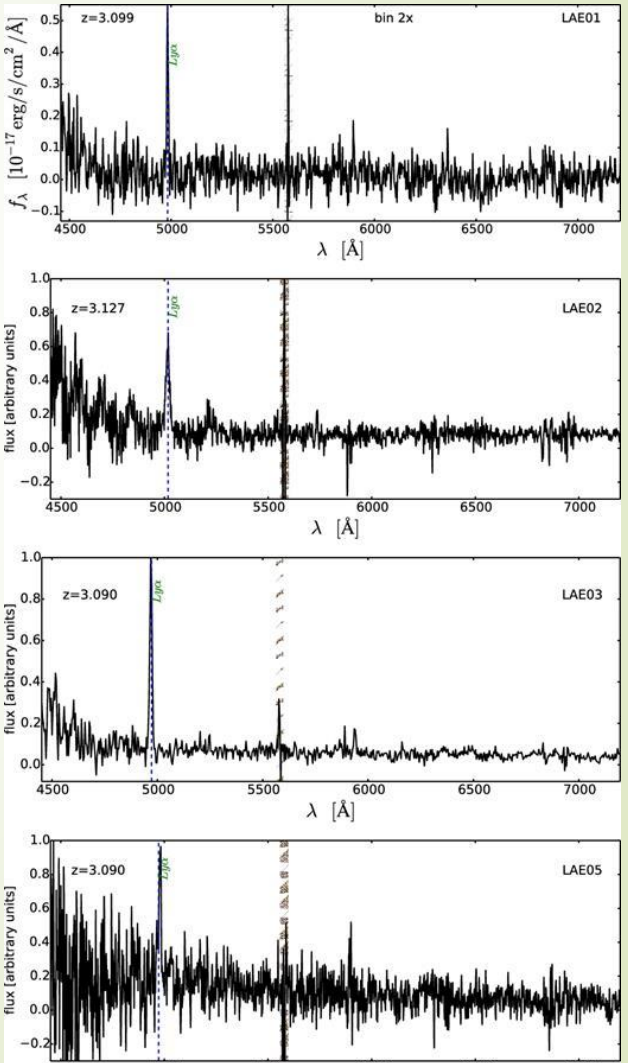
- Strong LAEs have higher LyC escape?



Micheva+ 2017 MN 465, 316

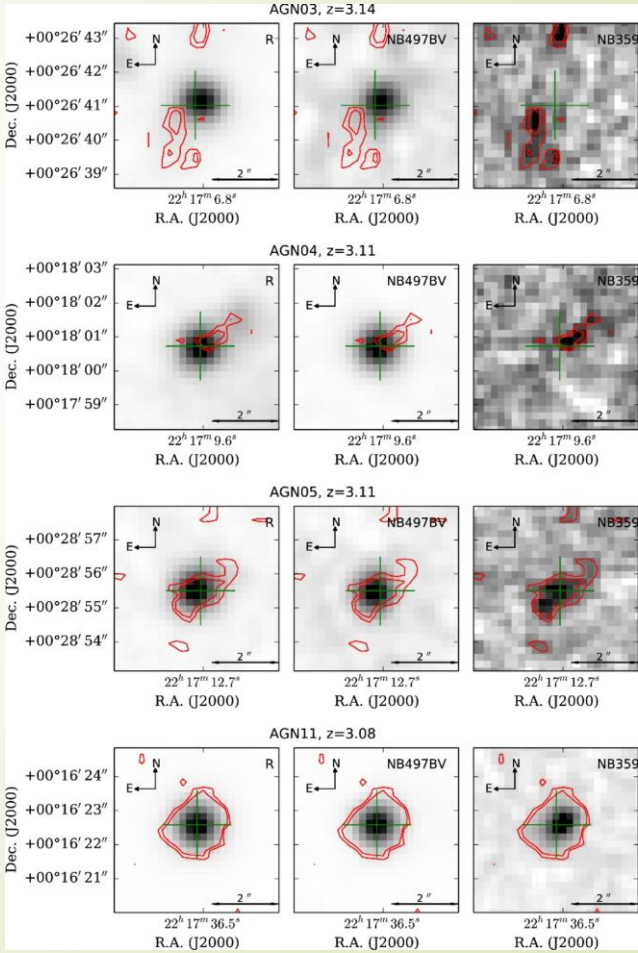
Optical spectra at the positions of NB359 detection

- Using FOCAS, VIMOS, LRIS
- Some objects are confirmed to be contaminated by foreground sources
- See also Nestor et al. 2013 ApJ 765, 47; Siana et al. 2015 ApJ 804, 17



LyC from AGNs

- Micheva et al. 2017b MN 465, 302
- 14 AGNs from the same SSA22 sample
- 4 AGNs with NB359 detections
  - 2 of them appear to be stellar LyC sources (or foreground)
- Contributions from AGNs for ionizing photon budget: 5-12%



Upcoming Observations

CHORUS: Cosmic HydrOgen Reionization Unveiled with Subaru

- PI: Akio Inoue (Osaka Sangyo Univ.)
- HSC intensive program with Narrow-band imaging:
  - NB387, 527, 718, (921), IB945, NB973

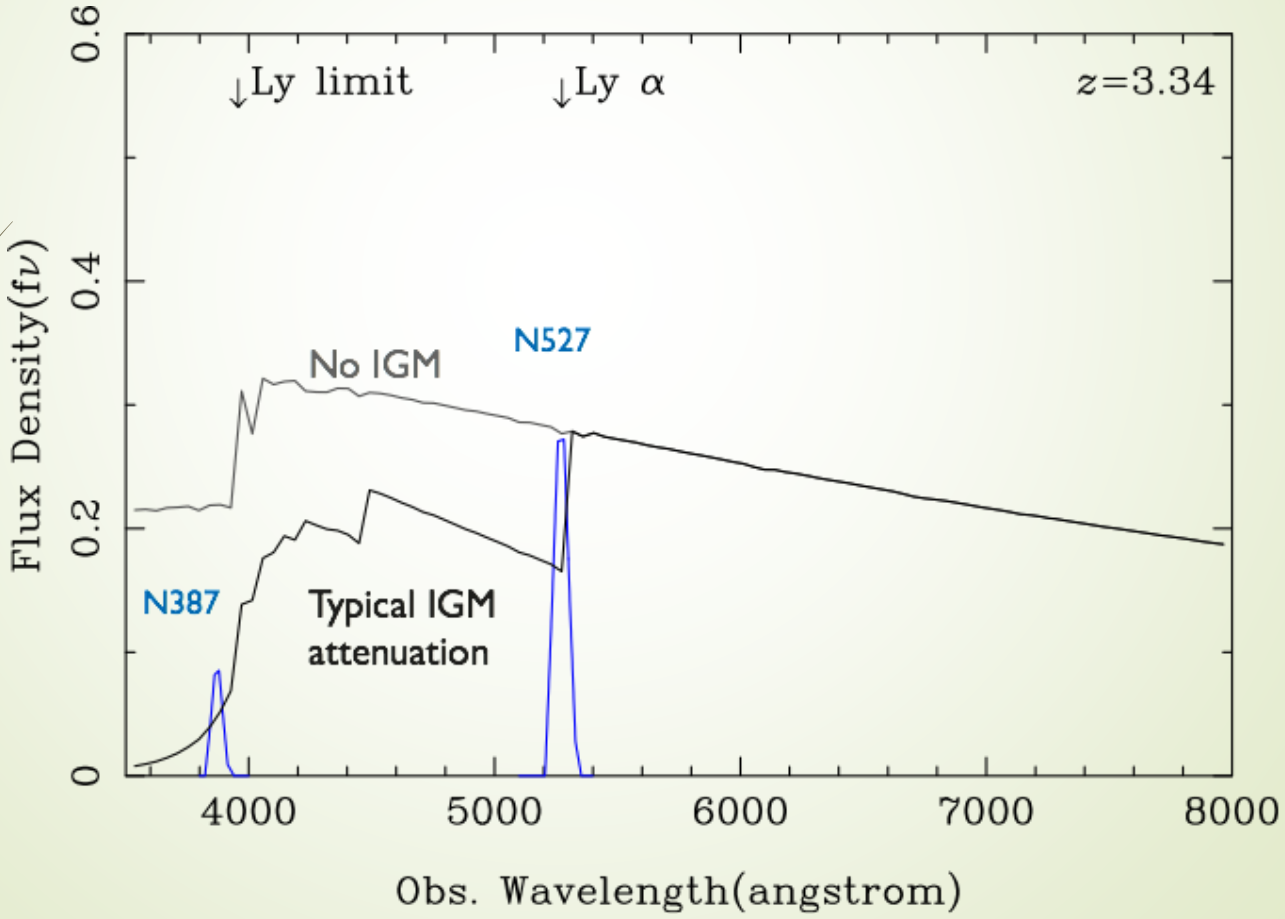
1. LyC emissivity of galaxies and AGNs at z~3 and 5
2. Faint AGN luminosity function at z~5
3. Abundance of Population III stars at z~2, 3, 5
4. Spatial variation of hydrogen neutral fraction at z~7

HSC project 194

- Starts in this January!

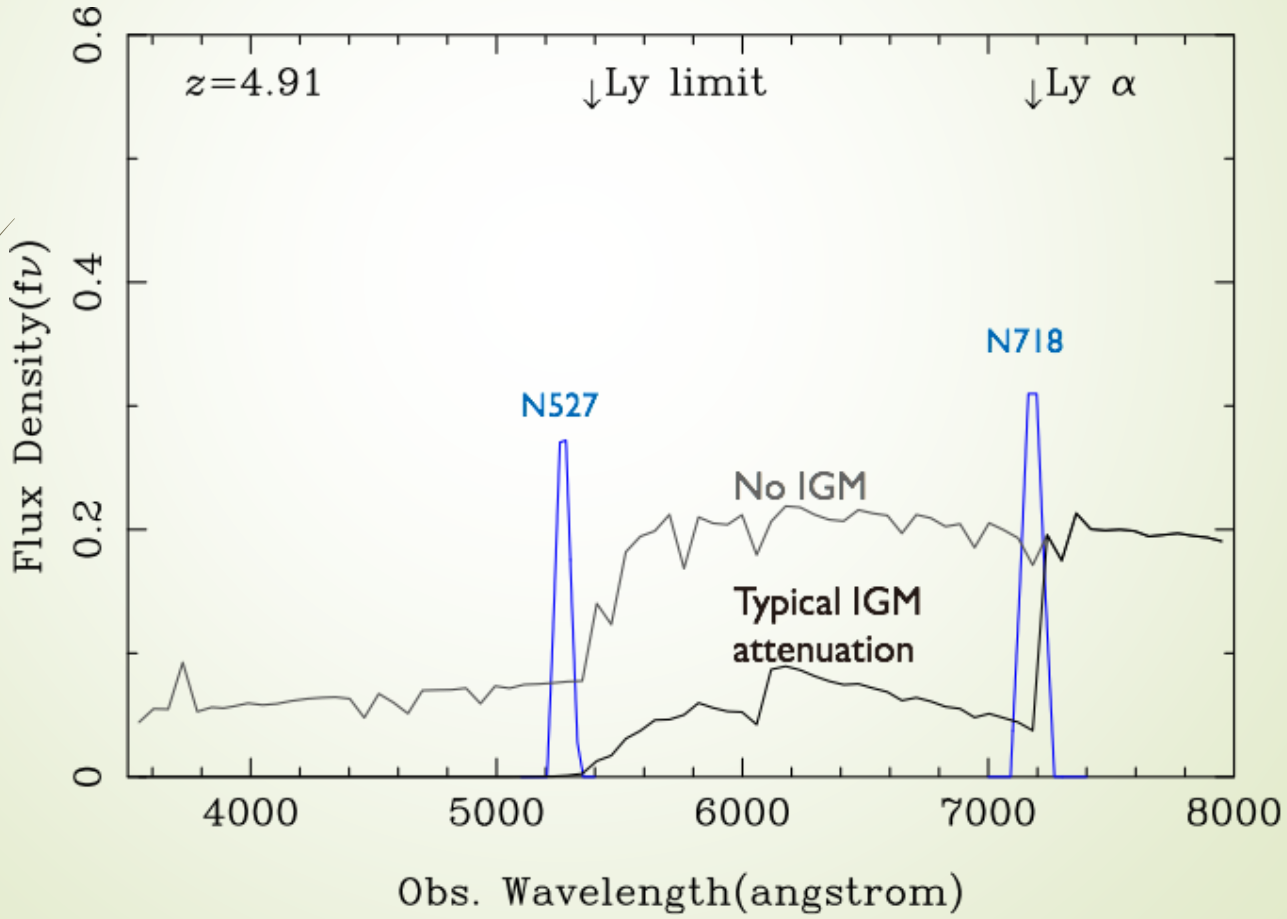
CHORUS: LyC at z=3.3

- NB387 + NB527

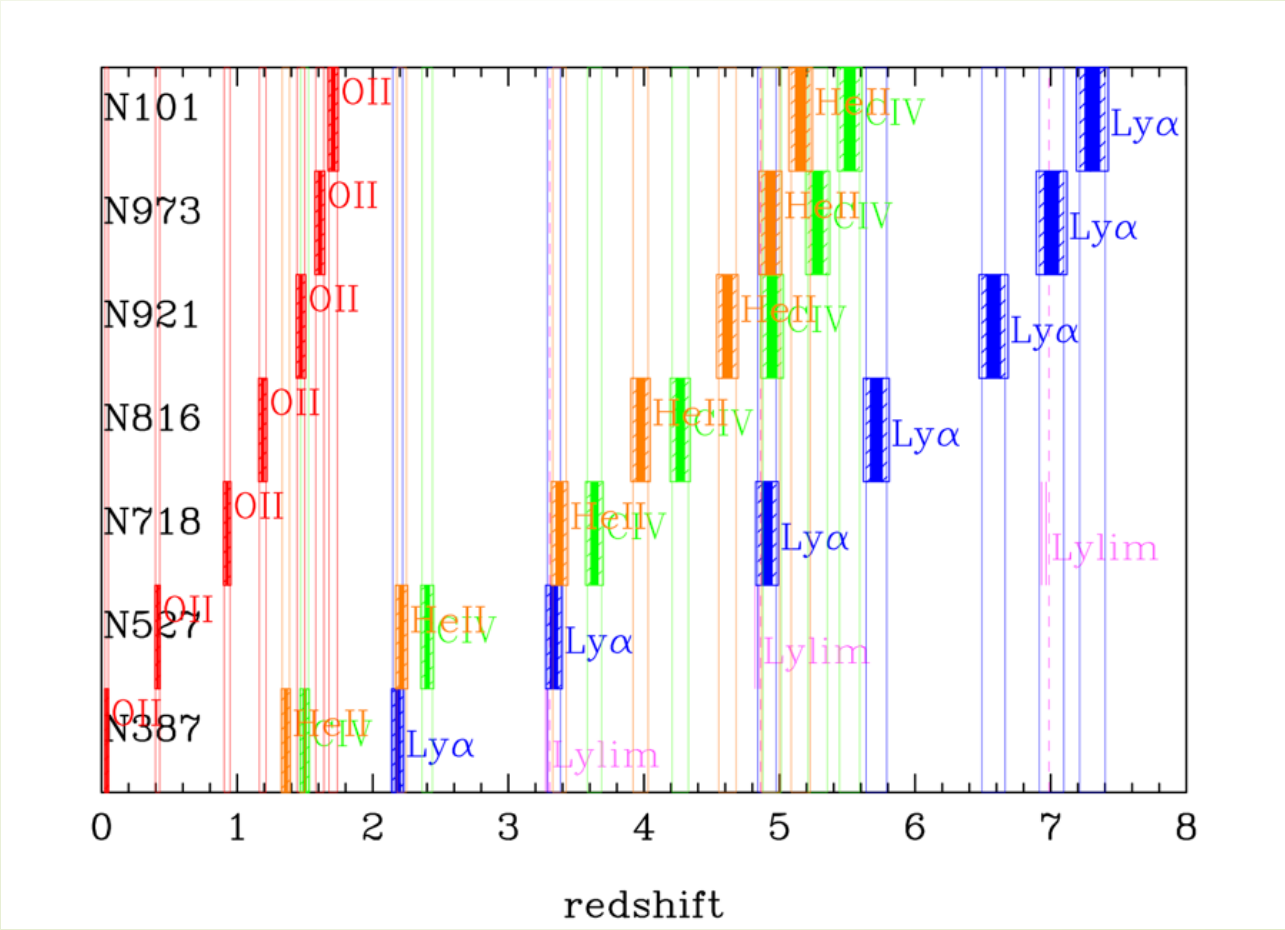


CHORUS: LyC at z=4.9

- NB527 + NB718



CHORUS:
Power of Multi-NBF Survey



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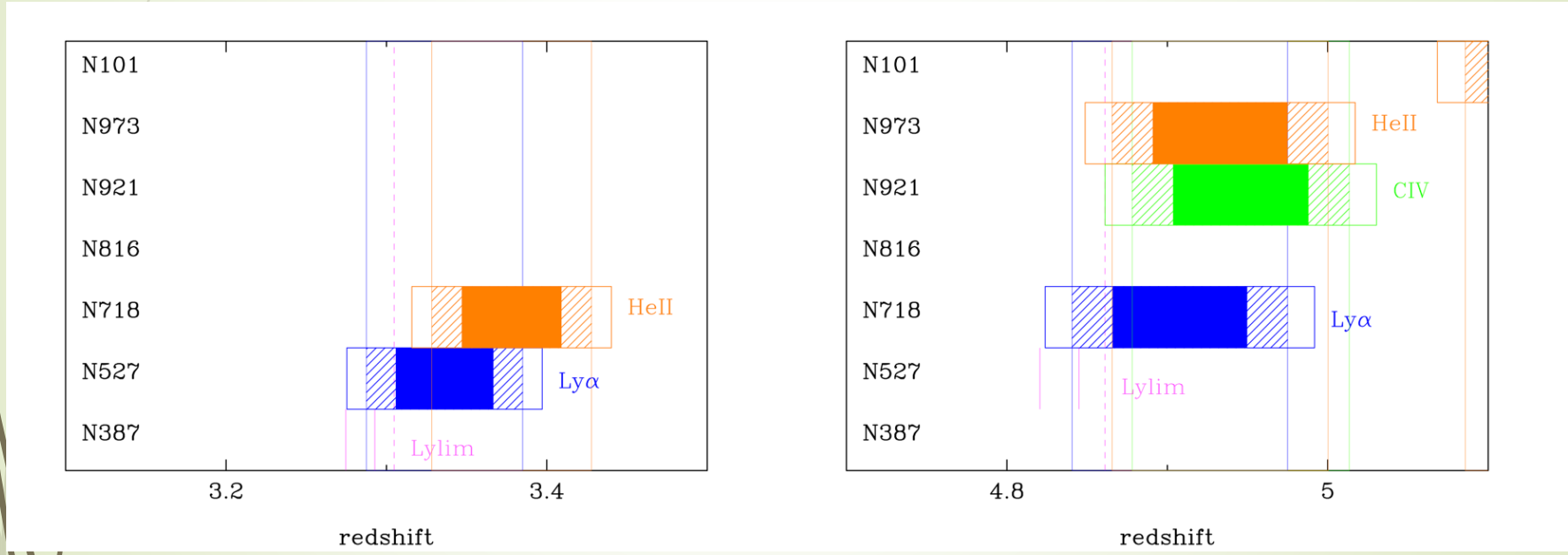
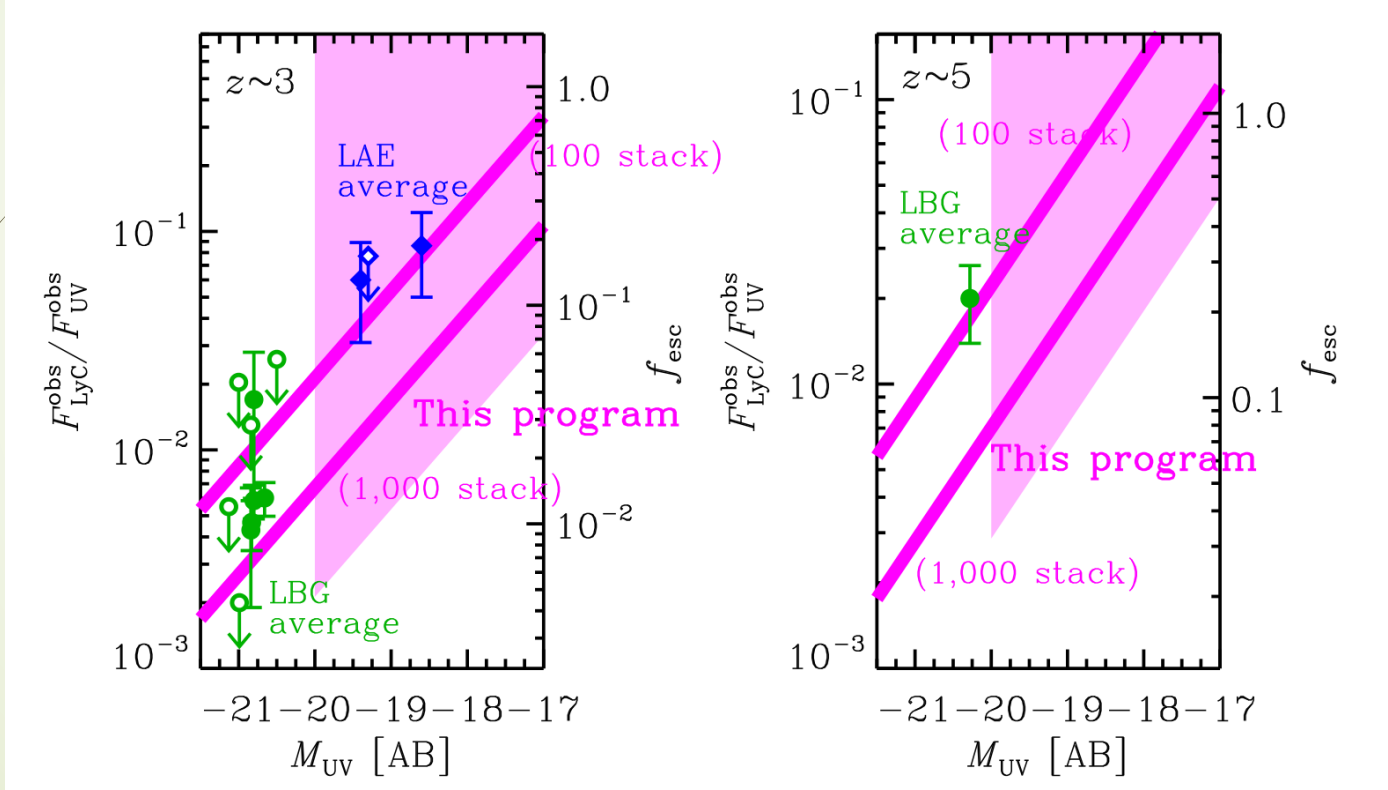


Constraints on LyC/UV ratios with CHORUS



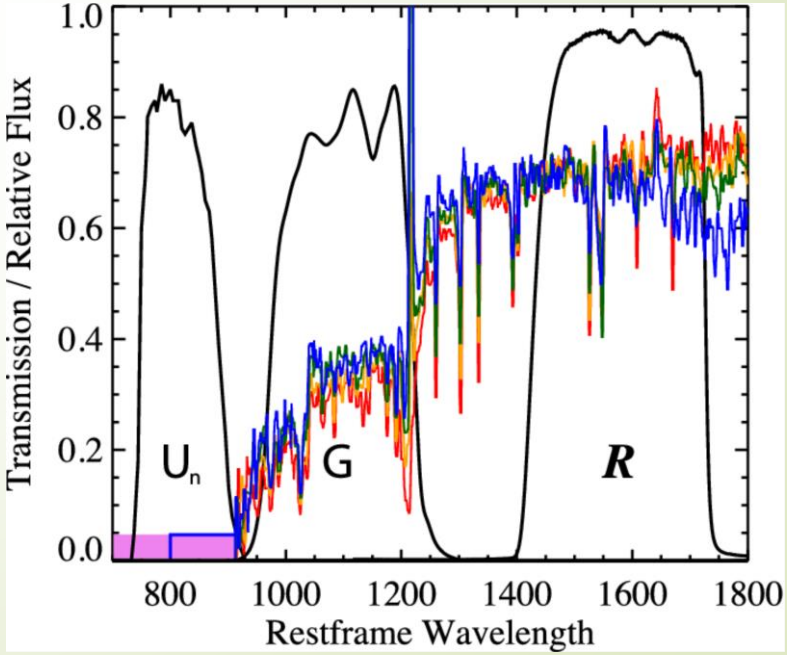
Unique search in depth, area, and redshifts

Search for ‘missing’ Lyman Continuum Galaxies

HSC project 212

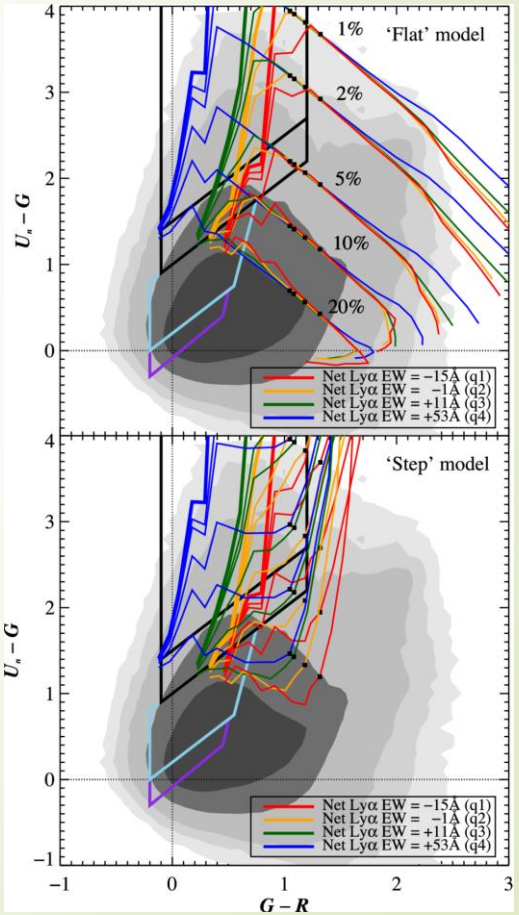
Lyman break method misses LyC leakers

- Cooke et al. 2014 MN 441, 837
- Lyman break method assumes average IGM attenuation. However, IGM opacity has large fluctuation between sightlines.
- LyC leak can change amount of Lyman break and colour



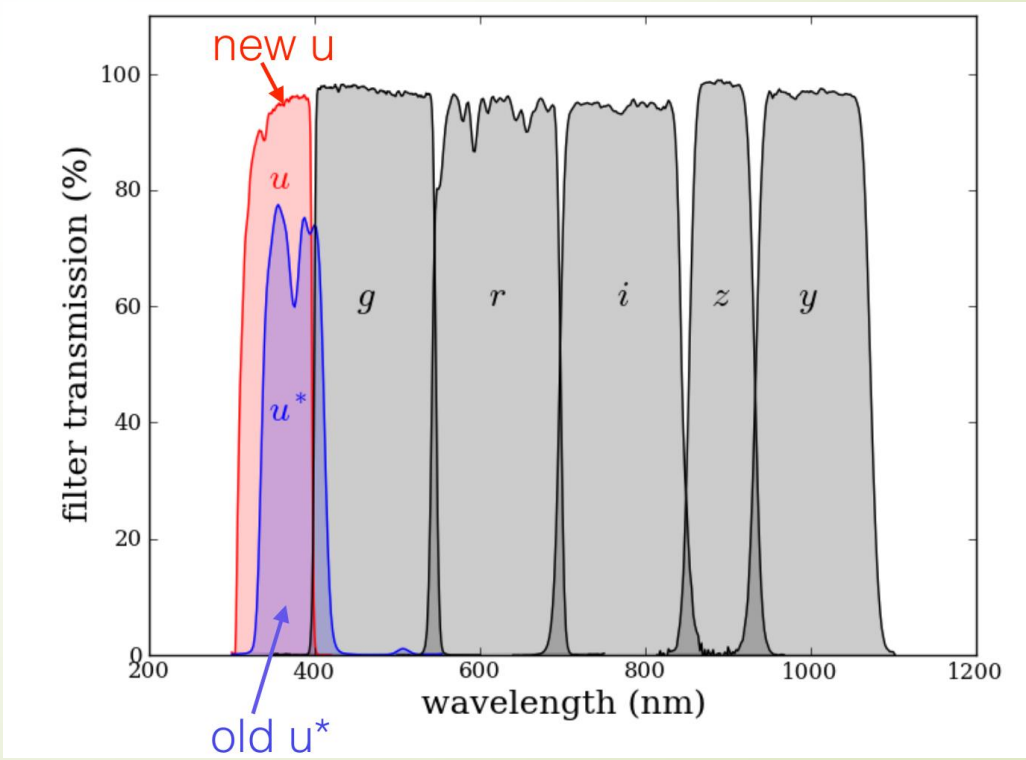
Lyman break method misses LyC leakers

- Cooke et al. 2014 MN 441, 837
- Significant portion of galaxies (Lyman Continuum Galaxies; LCGs) could be missed in standard colour selection criteria
- CFHTLS sample – follow-up spectroscopy is on-going



CLAUDS: CFHT Large-Area U-band Deep Survey

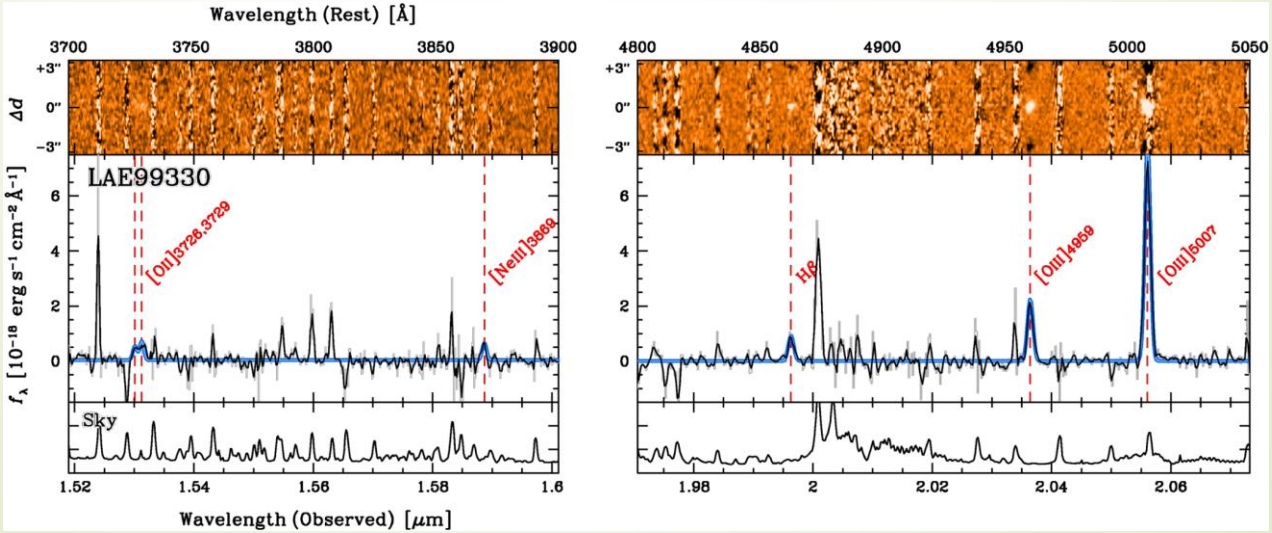
- PI: M. Sawicki
- HSC SSP Deep layer, U=27AB
- 0.5 mag. deeper, 5x wider search of LCGs

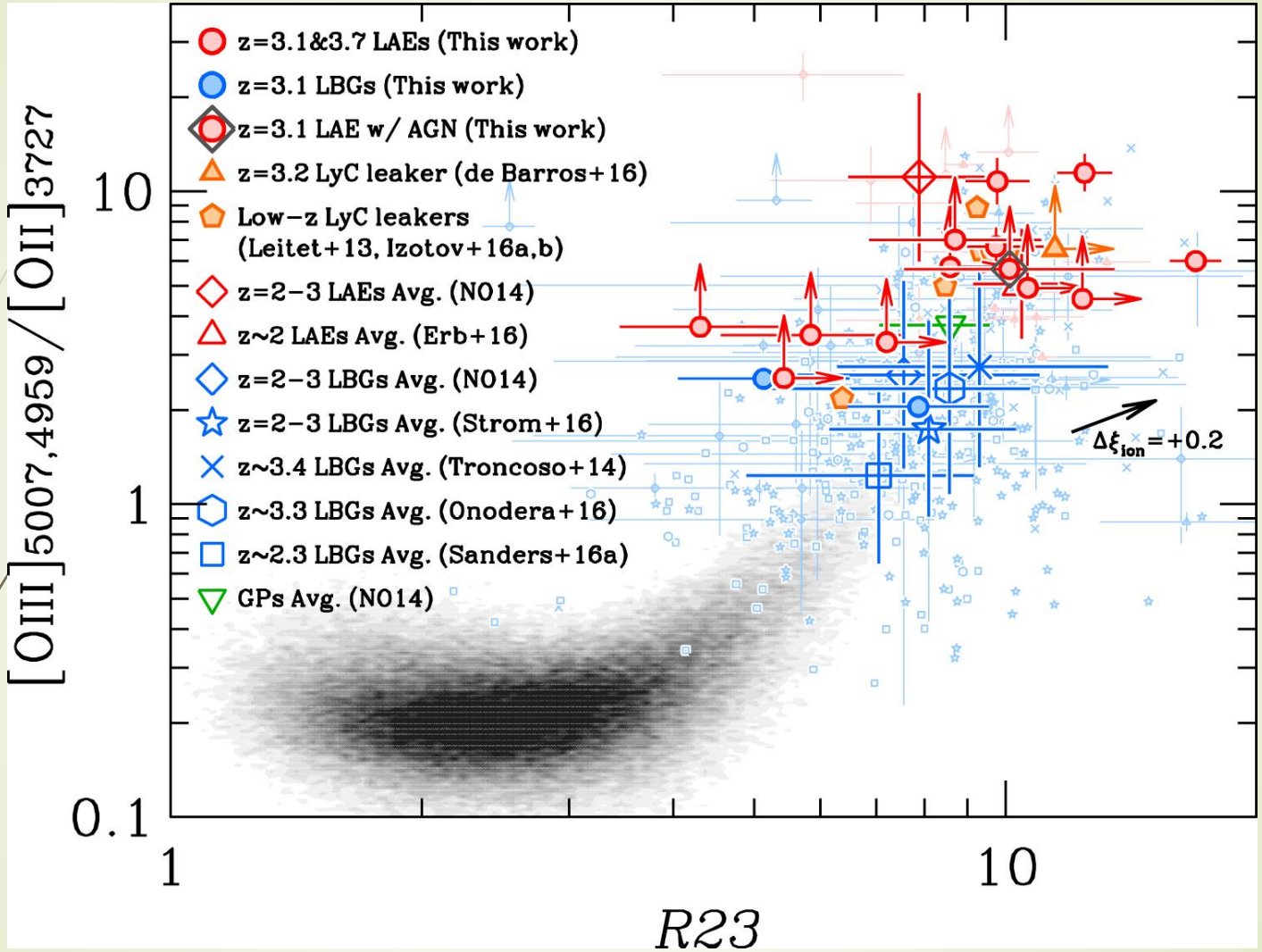


Follow-up Spectroscopy with Keck

MOSFIRE spectroscopy of strong emitters

- Nakajima, Ellis, Iwata+ 2016 ApJ 831, L9
- Higher [OIII]/[OII] than those for LBGs
  - Higher LyC photon production
  - Analogues of ionizing sources at z>7?





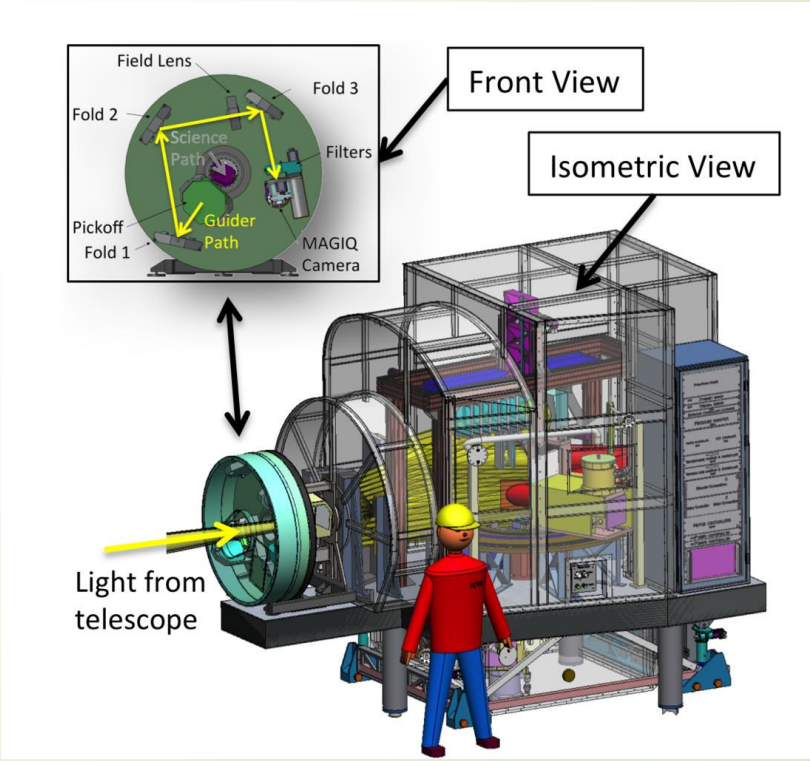
Nakajima+ 2016 ApJ 831, L9

Prospects of Keck collaboration

- Deeper HSC NB observations
- Follow-up spectroscopy
  - Optical: LRIS, DEIMOS, and KCWI
    - Confirm redshifts, discriminate foregrounds
    - Confirm LyC (LRIS, KCWI)
  - Near-IR: MOSFIRE, OSIRIS
    - Line diagnostics to understand ISM status
- Requires extremely sensitive observations
  - Keck is the best facility
  - High spatial resolution desired

KCWI

- Blue channel expected in operation from 2017
- 350-560 nm (to 1050nm, R channel)
- 20" x (8.3, 16.5, or 33)"
- 0.5" x (0.35 – 1.4)"
- R: 1,200 – 6,200



Subaru-Keck collaboration: Sample

- NB selected sample from S-Cam and CHORUS+
  - SSA22, GOODS-N, COSMOS, SXDS
  - Characterize strong LyC leakers
- U-band selected Lyman Continuum Galaxies
  - Unbiased view of LyC leakage from z~3 galaxies
- Number of nights: 10 - ∞