Spatially resolved emission line mapping of extra-galactic HII regions using OSIRIS-TF @ GTC

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Local Universe Survey (LUS)

- Get spectral information using imaging techniques
  - high spatial resolution (~1 arcsec)
  - low spectral resolution (~15 Å)

- Narrow-band imaging observations of
  - nearby (D<11 Mpc)
  - large (size≥4 arcmin)

  galaxies using OSIRIS/TF at the 10.4-m GTC

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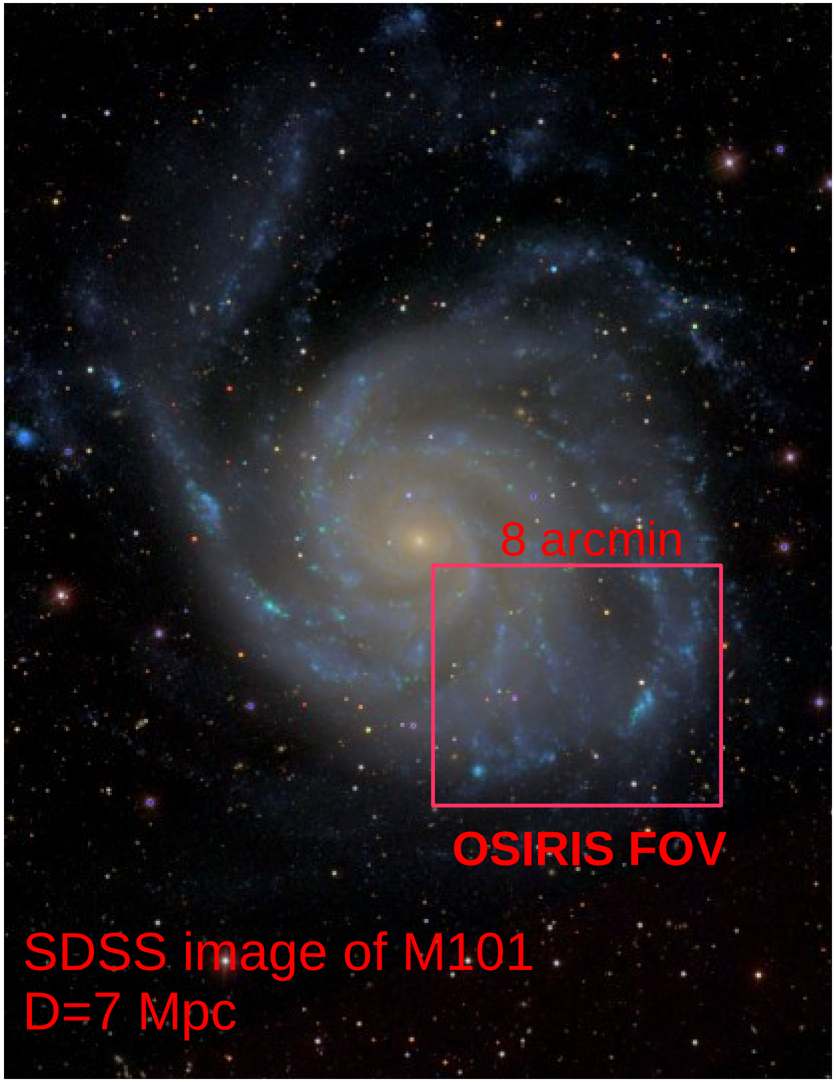
Pilot Study: Flux Calibrated Emission-Line Imaging of HII regions in M101-SW

(Mayya et al. 2012)



- **Spanish-Mex. Observing Time in June 2009** was allocated to observe M101 – SW
  ~2 hours on target + overheads

- Tunable Filters (FWHM= 18 Å)
  Hα+ [NII] (2 exp. of 180 seconds per scan)
  Scanned wavelengths (20 Å spacing):
  6528,6548,6568,6588,6608,6628,6648,6668 Å

  [SII] (3 exp. of 180 seconds per scan)
  (6696,6716,6736,6756,6776,6796,6816)

- Seeing ~ 0.9 arcsec ~ 35 pc
  Image scale= 0.125 arcsec/pix

Basic Tunable Filter Formulae and imaging characteristics (problems)

Problem 1:

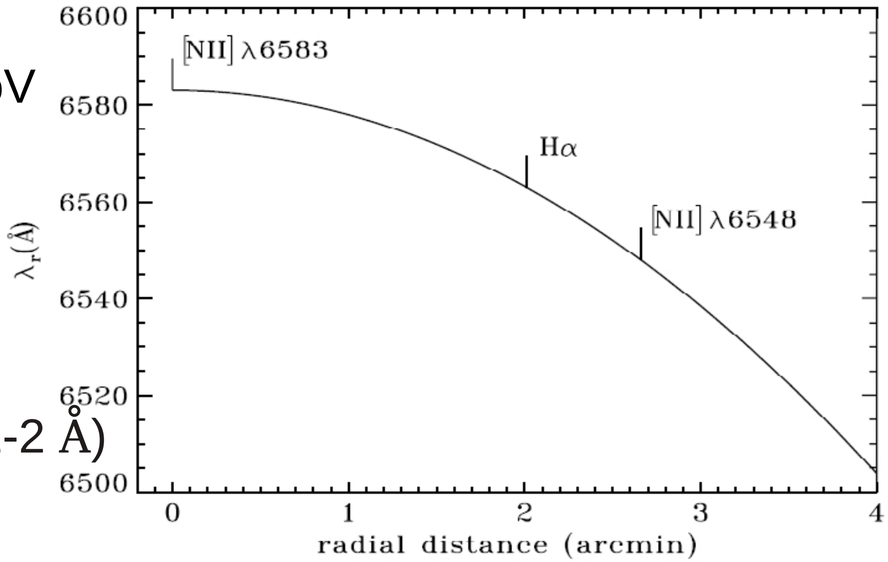
Imaged wavelength changes acros the FoV

$$\lambda_r = \frac{\lambda_c}{\sqrt{1 + 6.5247 \times 10^{-9} r^2}},$$

Méndez-Abreu et al. 2011

λc – λ at the optical center (tuning uncertainty 1-2 Å)

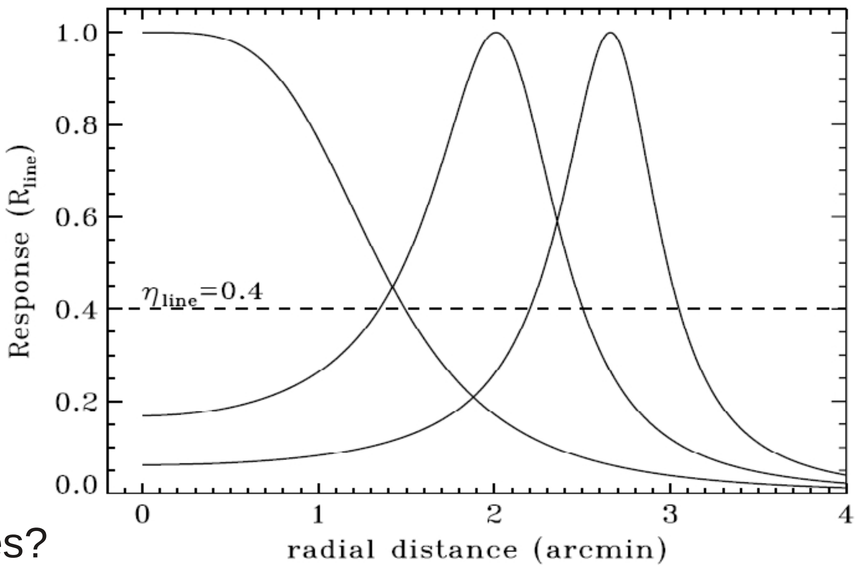
r – distance (in pixels) from the optical center



Problem 2:

Filter Response function is not flat-top

$$R_\lambda(r) = \left(1 + \left[\frac{2(\lambda - \lambda_r)}{\text{FWHM}}\right]^2\right)^{-1}.$$



Problem 3: Dithered images have different effective wavelength for the same object.

Problem 4:

How to flux calibrate narrow-band TF images?

We have solved all these problems to successfully generate emission-line maps

Reduction Procedure

implemented in home-made IRAF pipeline

1. **Basic reduction:** bias, and flat corrections.

Images of different dithered positions were not coadded until they are wavelength-corrected.

2. Astrometry and Joining CCD1 and CCD2:

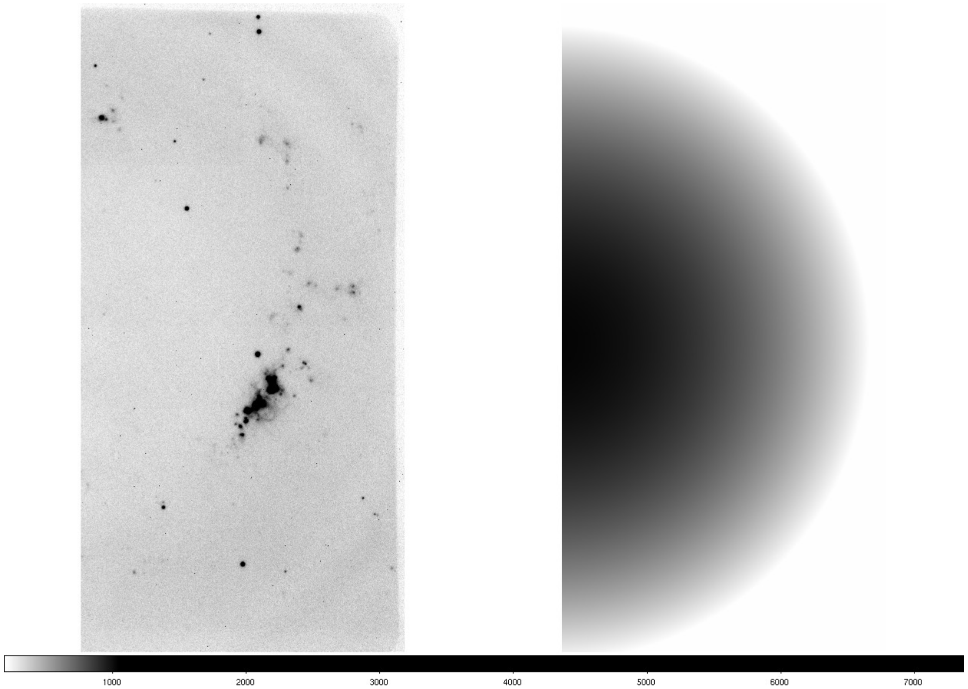
`ccxymatch`, `ccmap`, `mkpattern`, `ccsetwcs`, `wregister` (applied to the images and the *λ-images*)

3. Wavelength-dependent response correction (image re-construction)

For every scan position we have:

CCD2 TF Image
λc=6608 Å

CCD2 λ "*Image*"
λc=6608 Å



Variation of Lambda across the FOV

First, some equations for image reconstruction

Observed Count Rate — Filter Response

$$F(x,y) = \frac{I_{\rm line}(x,y) R_{\rm line}(r)}{\kappa} + {\rm Cont}(x,y) + {\rm Sky}(r). \quad (4)$$

A trivial manipulation of the above equation gives:

Conversion Factor

$$I_{\rm line}(x,y) = \frac{\kappa (F(x,y) - {\rm Cont}(x,y) - {\rm Sky}(r))}{R_{\rm line}(r)}. \quad (5)$$

By making a simple substitution

$$C(x,y) = F(x,y) - {\rm Cont}(x,y) - {\rm Sky}(r), \quad (6)$$

where $C(x,y)$ is the sky and continuum subtracted count rate at a position x, y of the image, the above equation can be re-written as:

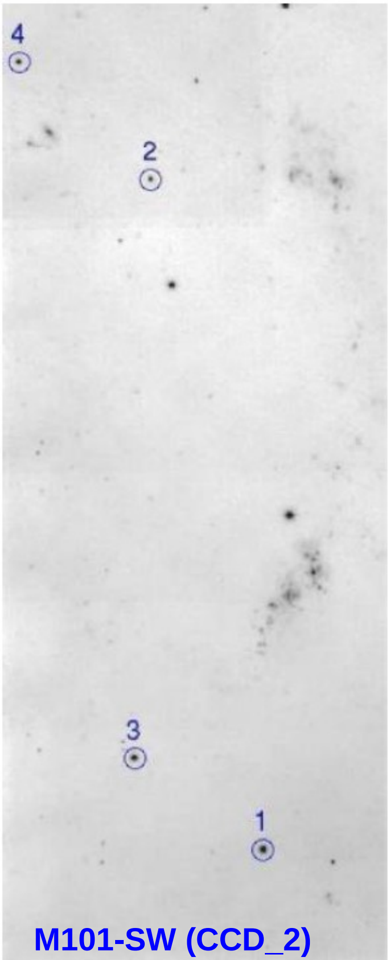
$$I_{\rm line}(x,y) = \frac{\kappa C(x,y)}{R_{\rm line}(r)}. \quad (7)$$

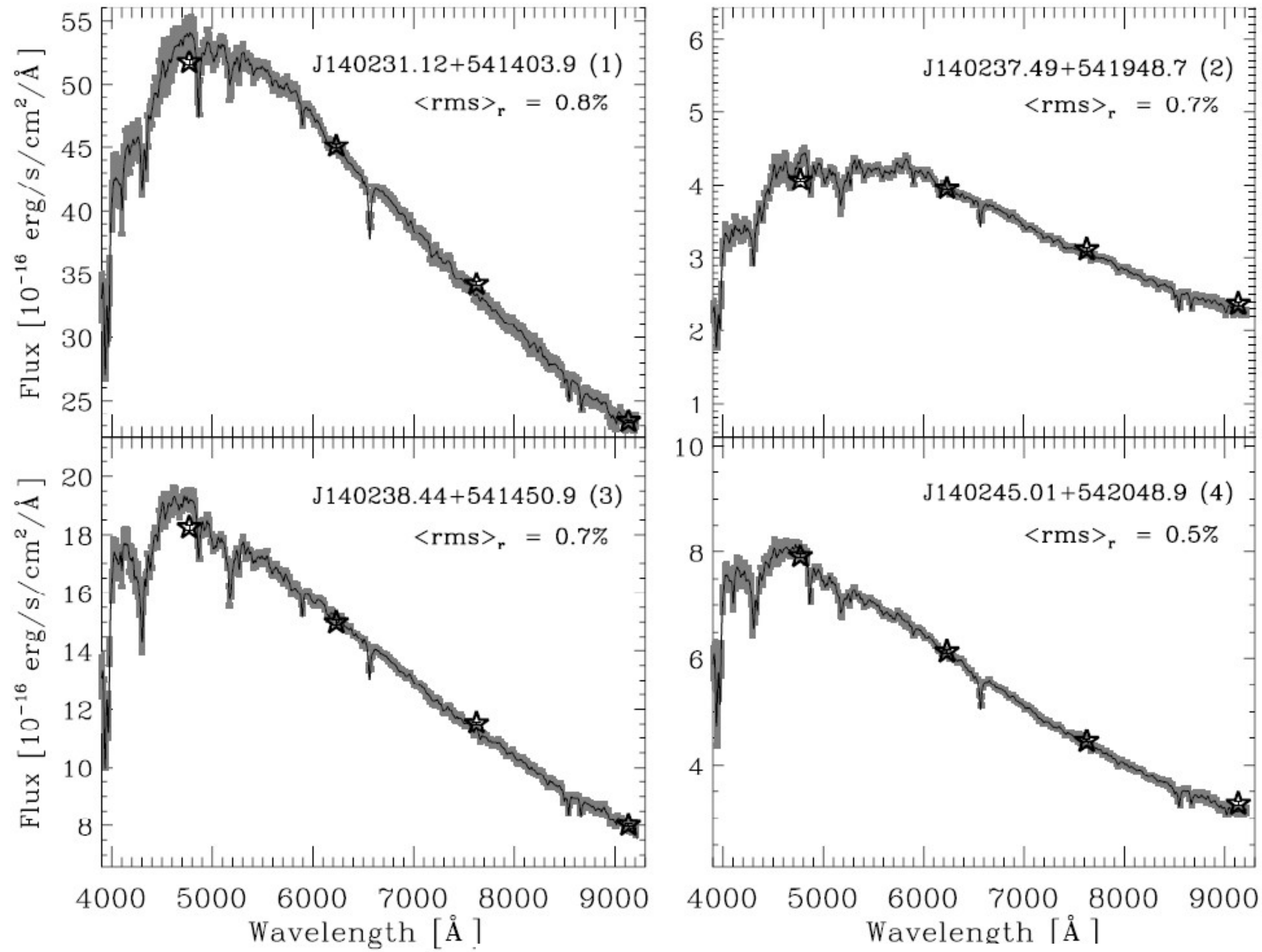
Sky(r): Sky image, obtained by averaging in annular zones of width=FWHM/2=9 Ang .

Cont(x,y): Continuum image, created from the bluest wavelength of the scan. It can also be created by combining images where the contamination due to the lines is less than a few per cent.

κ is the conversion factor between count rates and intensity (see next).

Flux Calibration Coefficient (κ)





- Select several isolated SLOAN stars (1,2,3,4 ...)
- Use the SEGUE (http://segue.uchicago.edu/) spectroscopic data base to fit the observed SEDs
- The *best-spectrum* is used then to find the conversion between count rates and flux in the narrow band images (integrating the TF response with the best-fit SEGUE spectrum)

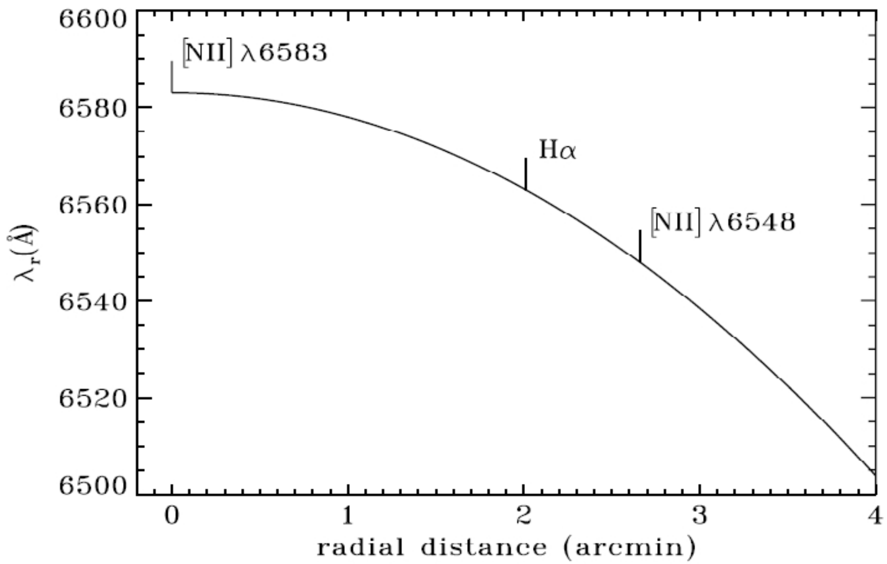
Derived Values of Calibration Coefficients

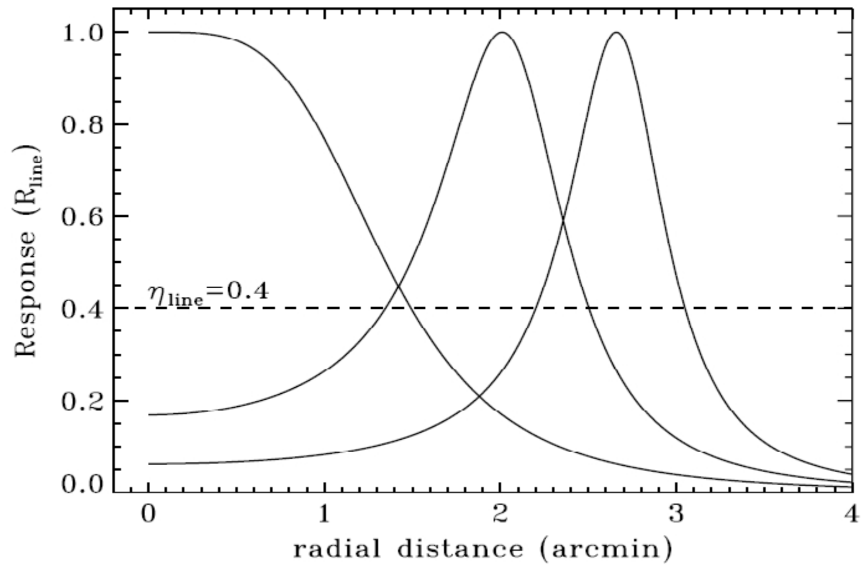
TF scan	κ (10^{-18} ergs^{-1} cm^{-2}/(ADU/s))
Hα+[N II]-P1	6.54 ± 0.27
Hα+[N II]-P2	6.63 ± 0.28
S II-P1	7.06 ± 0.14
S II-P2	7.06 ± 0.21
S II-P3	7.27 ± 0.23

~3% error

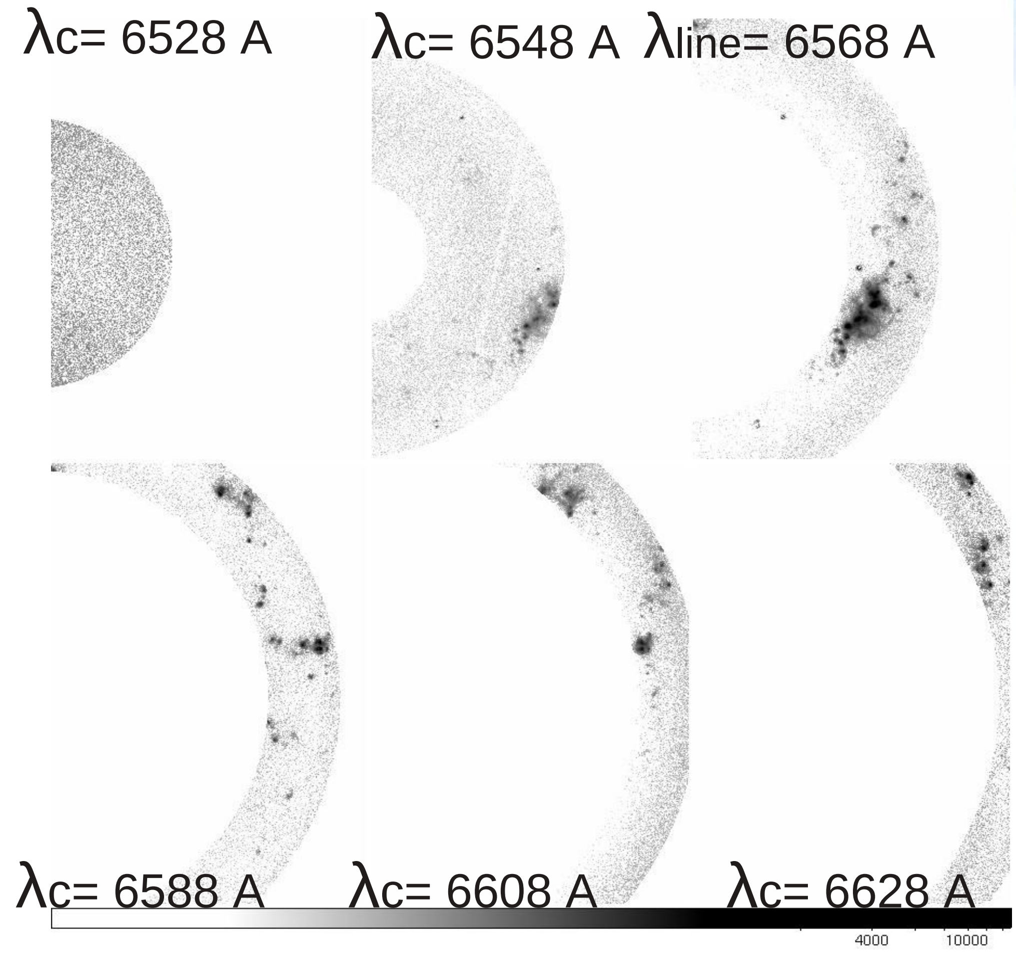
Making the Collage:
Coadding Monochromatic Image Sections

For a single scan:

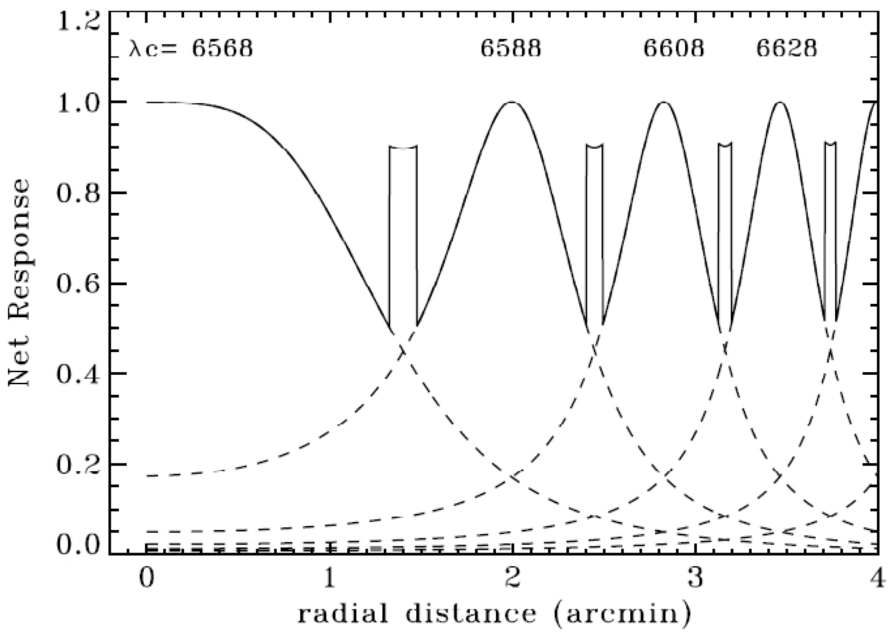




At the reconstruction wavelength, retain only that section of an image where response η_{line}> 40%.

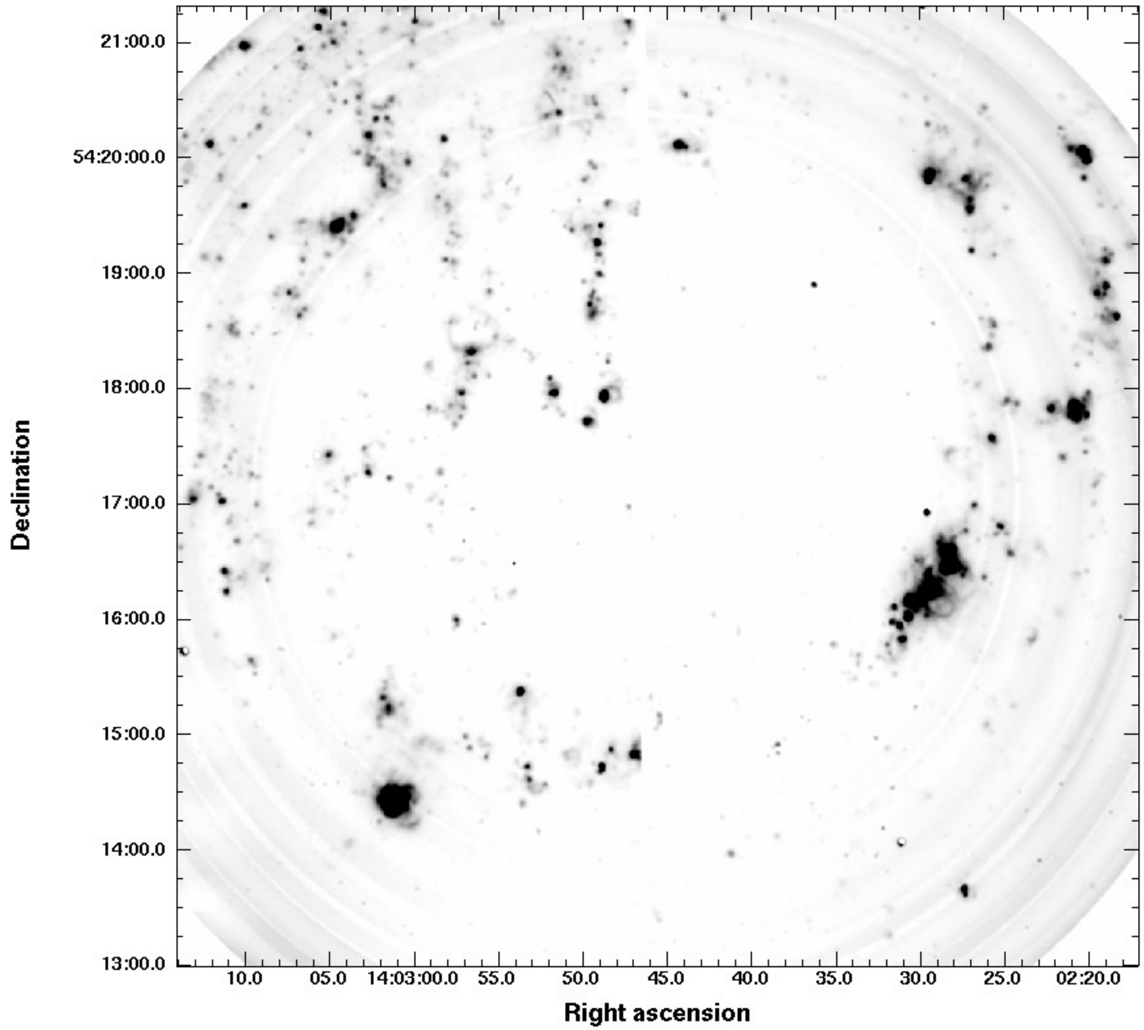


Monochromatic Image in Hα



The net response curve for the reconstruction of the Hα image. After adding the different image sections, divide the resulting image by the net response.

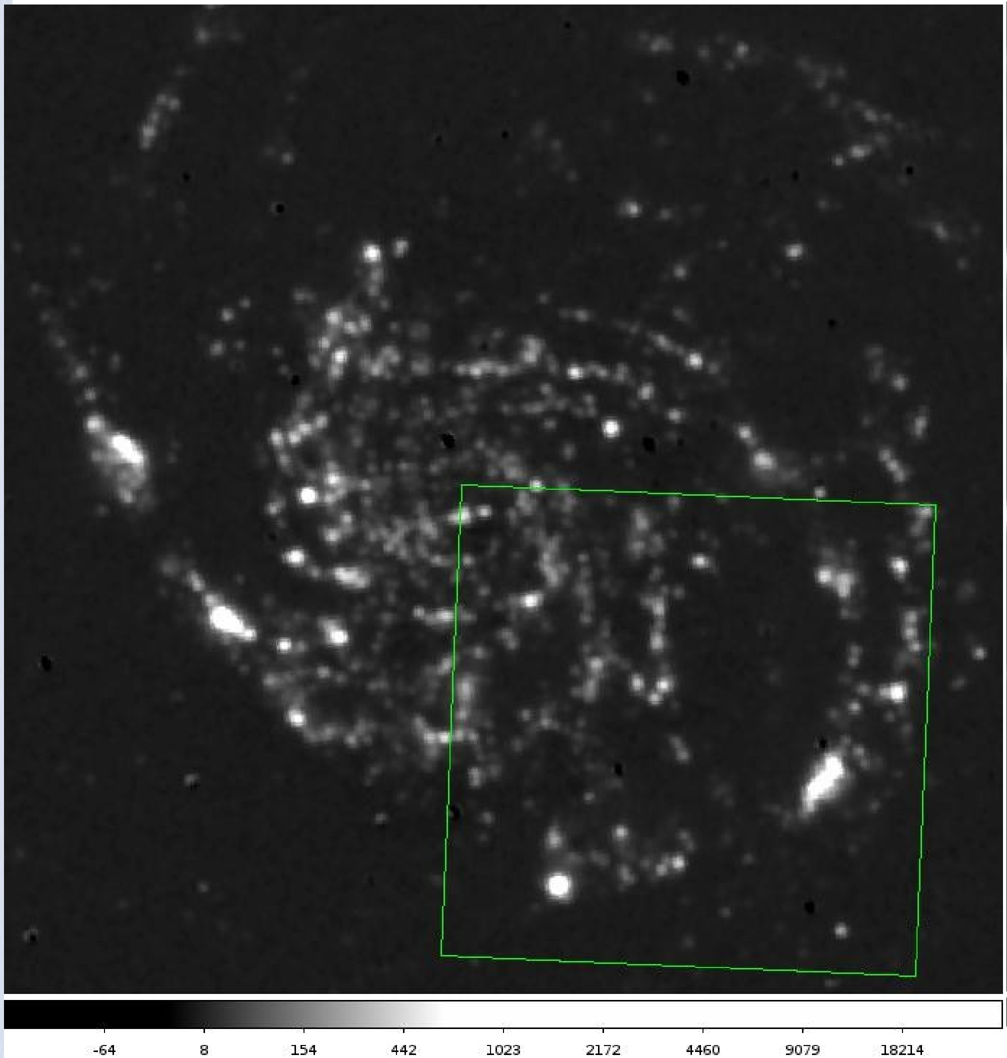
Final Hα image. 5σ = 8×10^{-17} erg s^{-1} cm^{-2} $arcsec^{-2}$

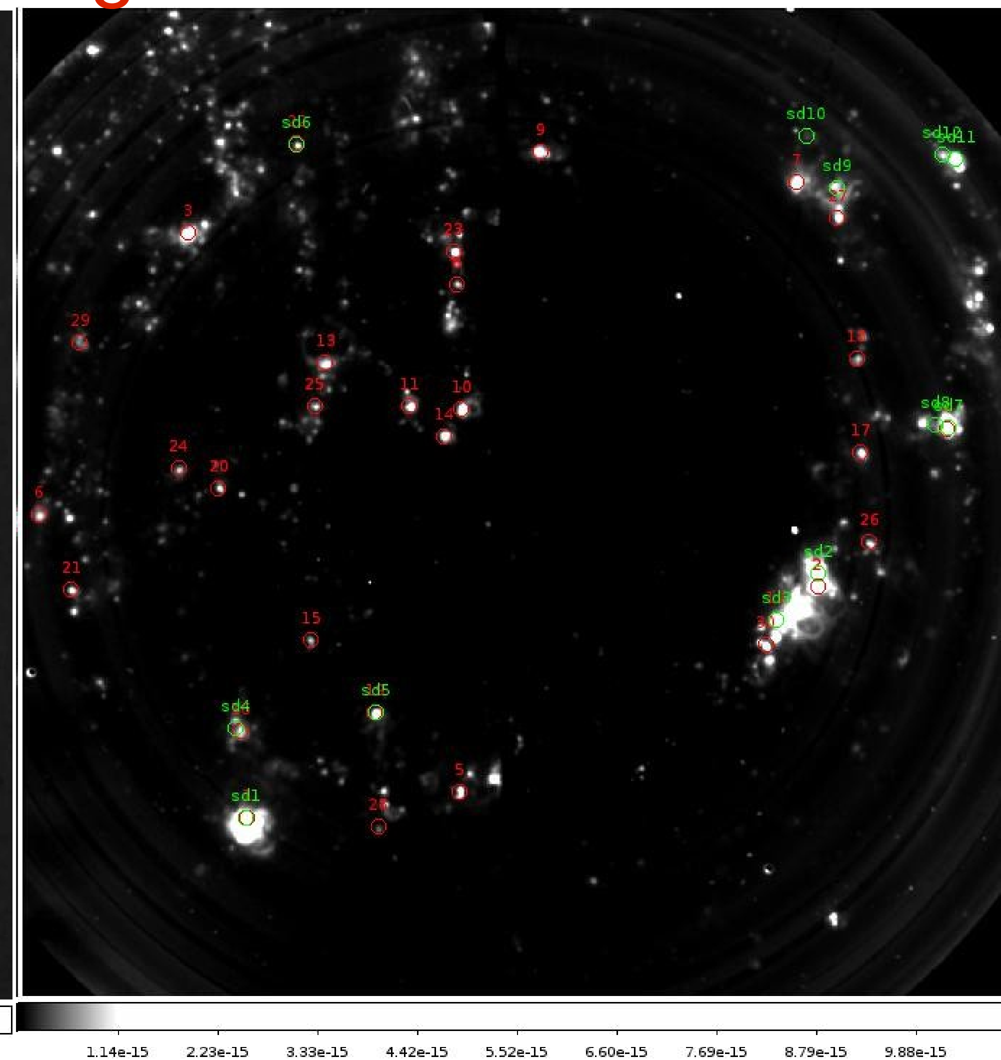


Comparison with published Hα Images, SDSS Spectroscopy and Theoretical Line Ratios

Hα Images

Hα Image (NED; Hope et al. 2001)



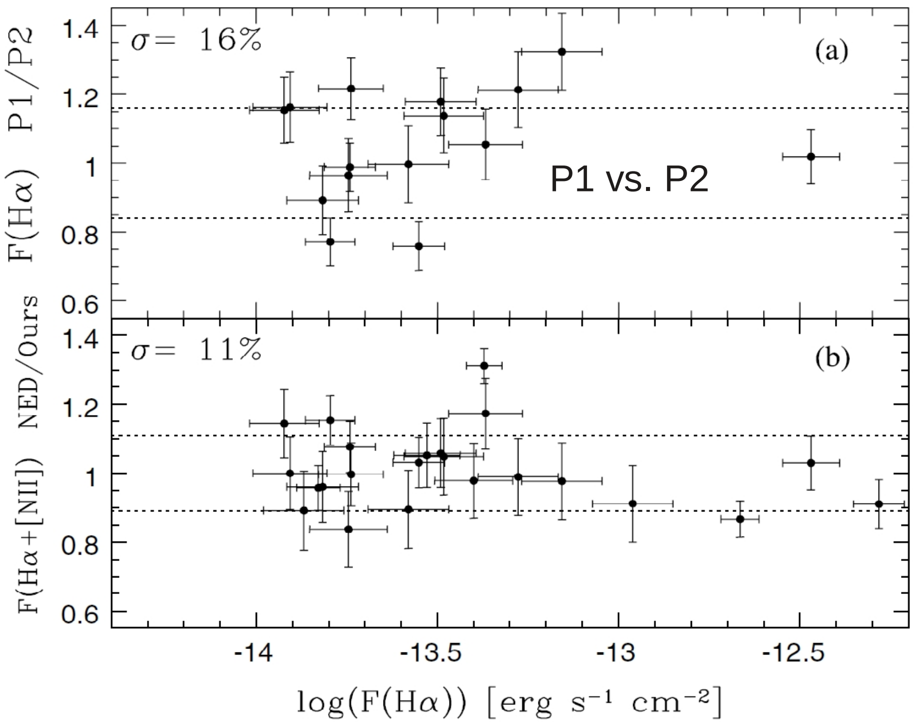


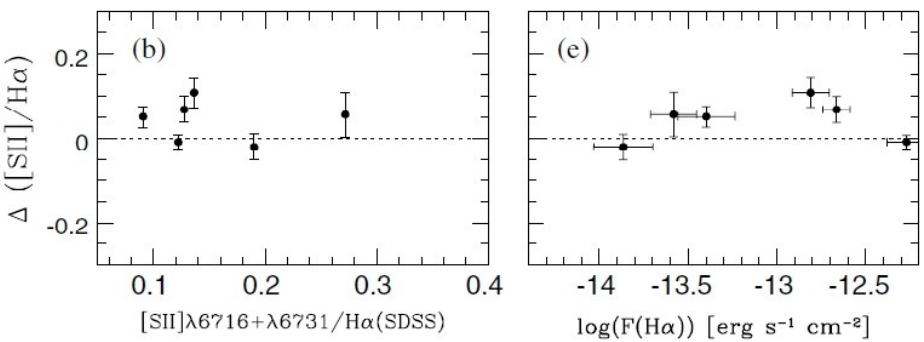
Comparison with published Hα Images, SDSS Spectroscopy and Theoretical Line Ratios

Hα fluxes of HII regions

SDSS Spectroscopic line ratios

Hα Image (NED; Hope et al. 2001)

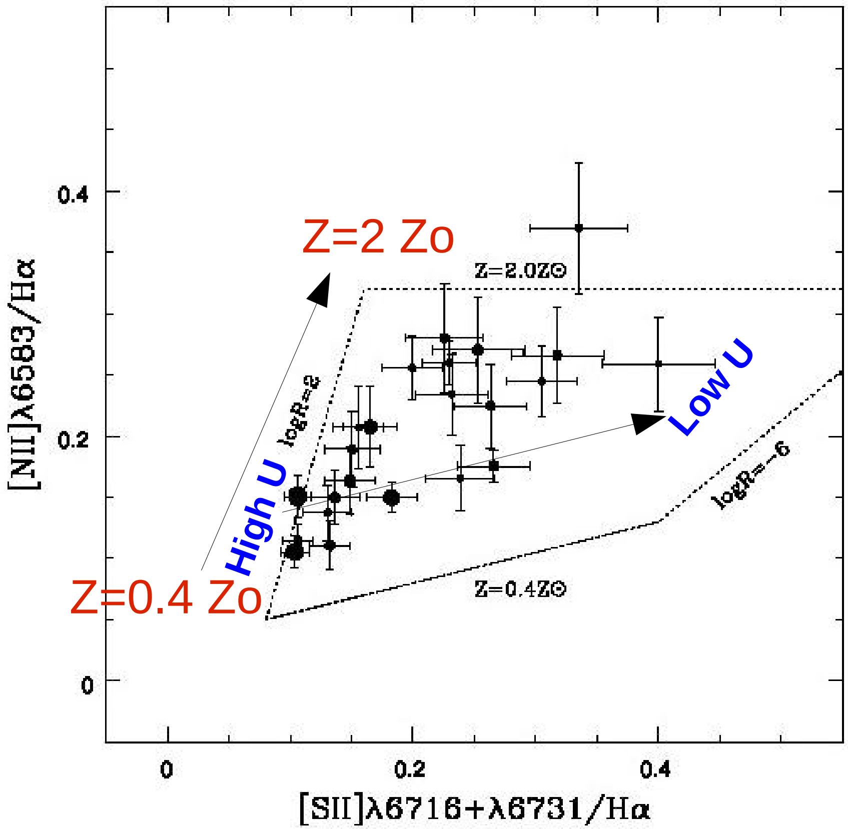




Hα flux error ~ 11% over a FoV of 7.5 arcmin

Comparison with published Hα Images, SDSS Spectroscopy and Theoretical Line Ratios

BPT diagram – observed vs theoretical limits (Dopita et al. 2006)



R = Cluster Mass/Pressure $\sim U^5$

Ionizing parameter $U = Q_{ph}/4\pi\ r^2\ c\ n_e$

Bright regions have low-metallicity and/or High Ionization parameter and vice versa.

What is the origin of this tendency?

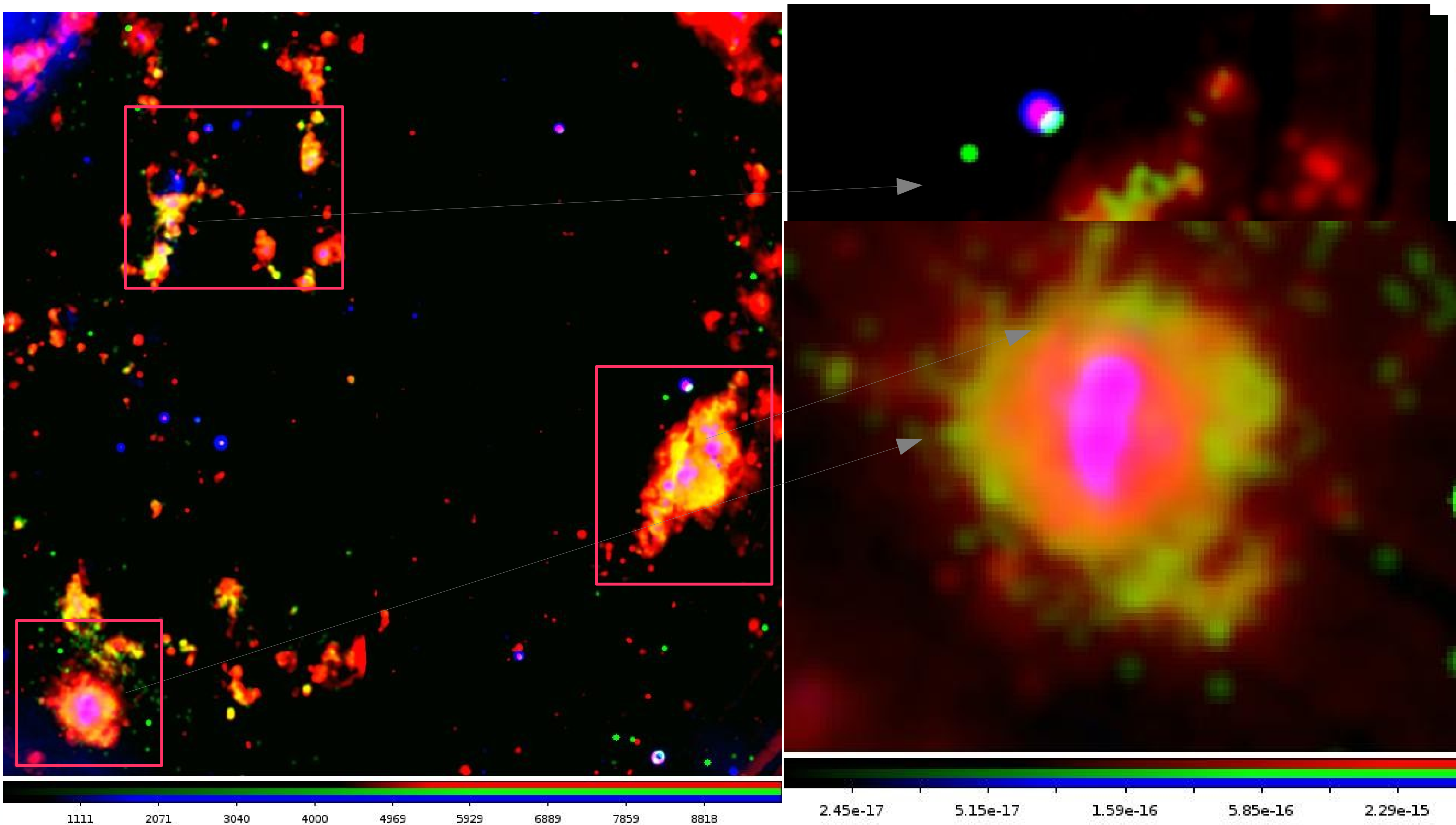
For r=r(Strömgren)

$$U \sim (Q_{ph}\ n_e)^{1/3}$$

===> **U** is expected to be higher for high mass clusters, provided n_e is independent of cluster mass.

Line-ratio maps of individual HII regions

R cont (Blue) [SII]/Hα (green) Hα (Red)



Orion with PPAK (Sanchez et al. 2007)

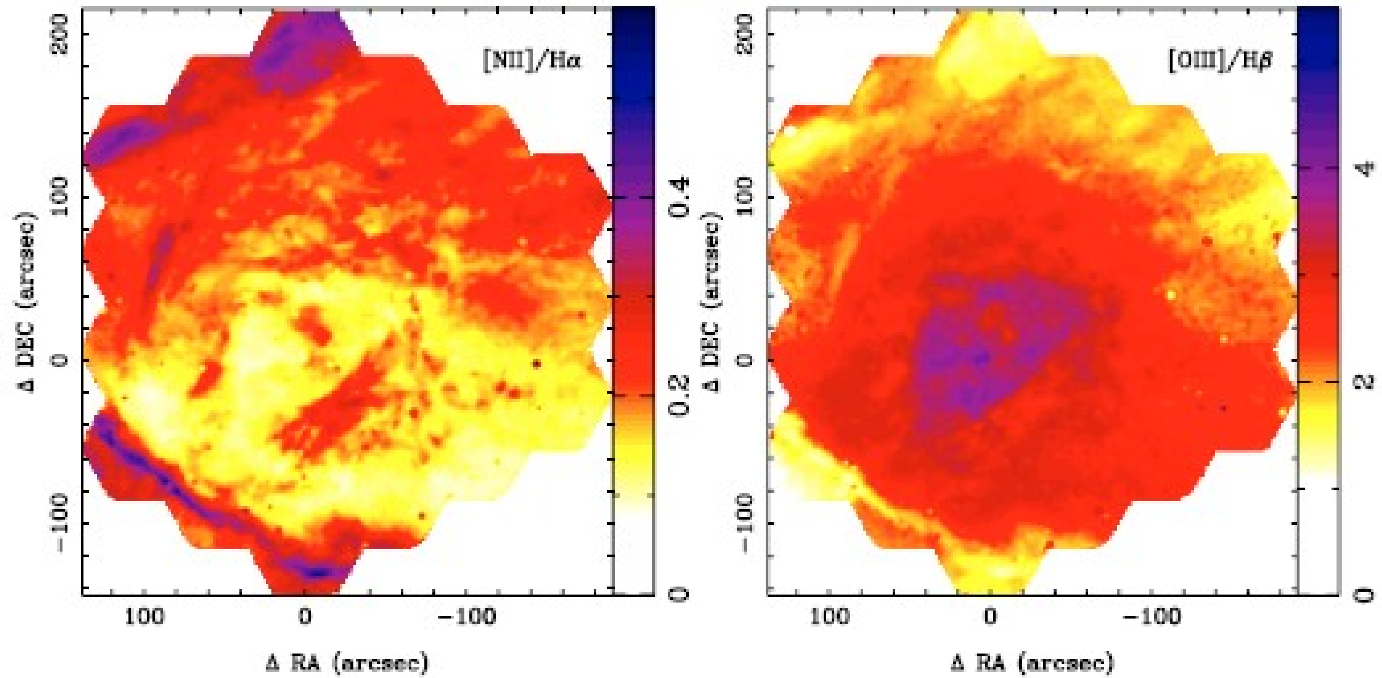
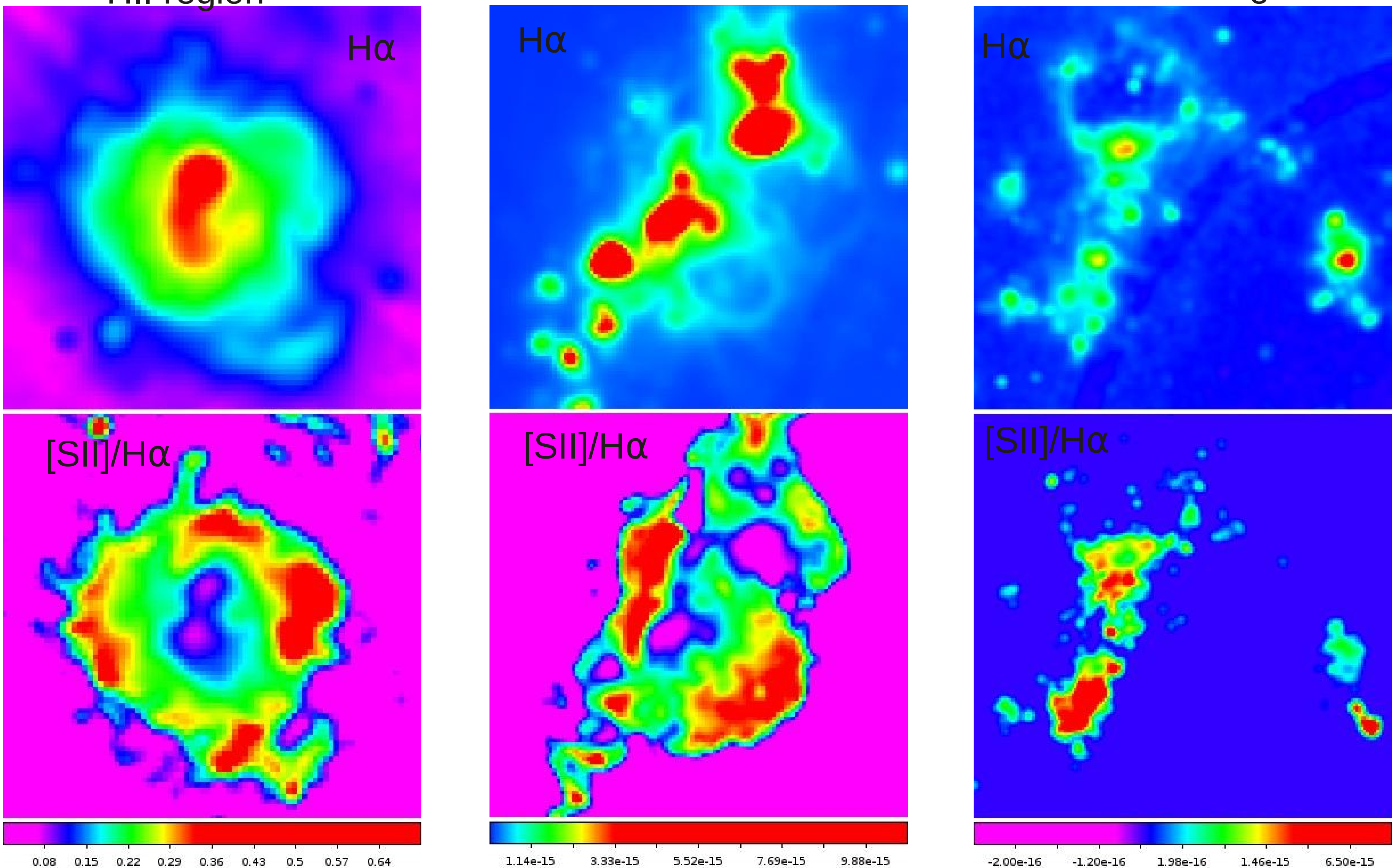


Fig. 6. Classical diagnostic line ratio maps. *Left*: [NII]λ6583/Hα line ratio map. *Right*: [OIII]λ5007/Hβ line ratio map.

With OSIRIS/TF, we can study the ionization structure of Giant extra-galactic HII regions in same detail as in Orion with PPAK

Ionization maps of selected HII complexes

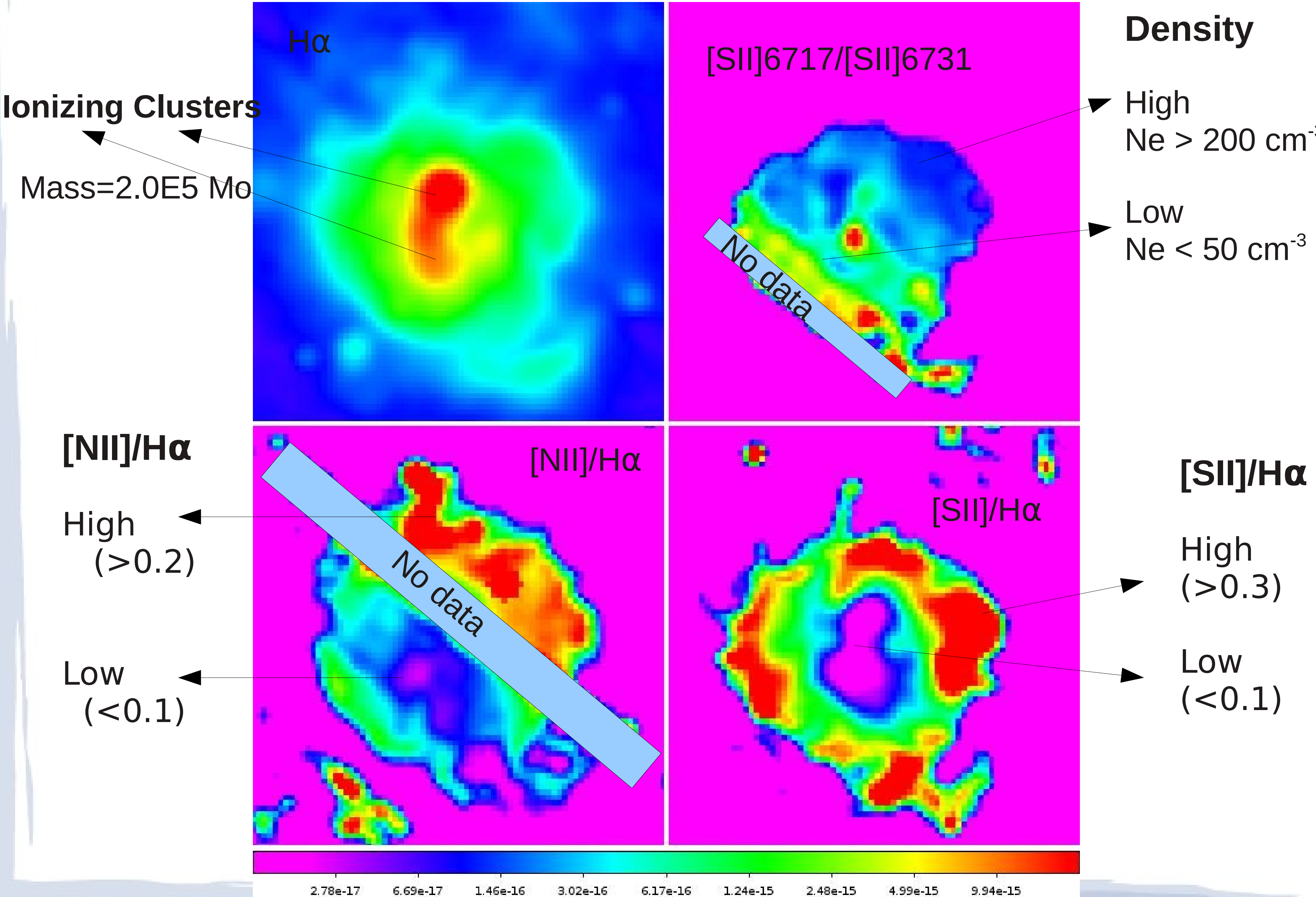
Massive (>10^5 Mo) “Isolated” HII region | Massive HII Complex | Low-mass (~10^4 Mo) inter-arm HII regions

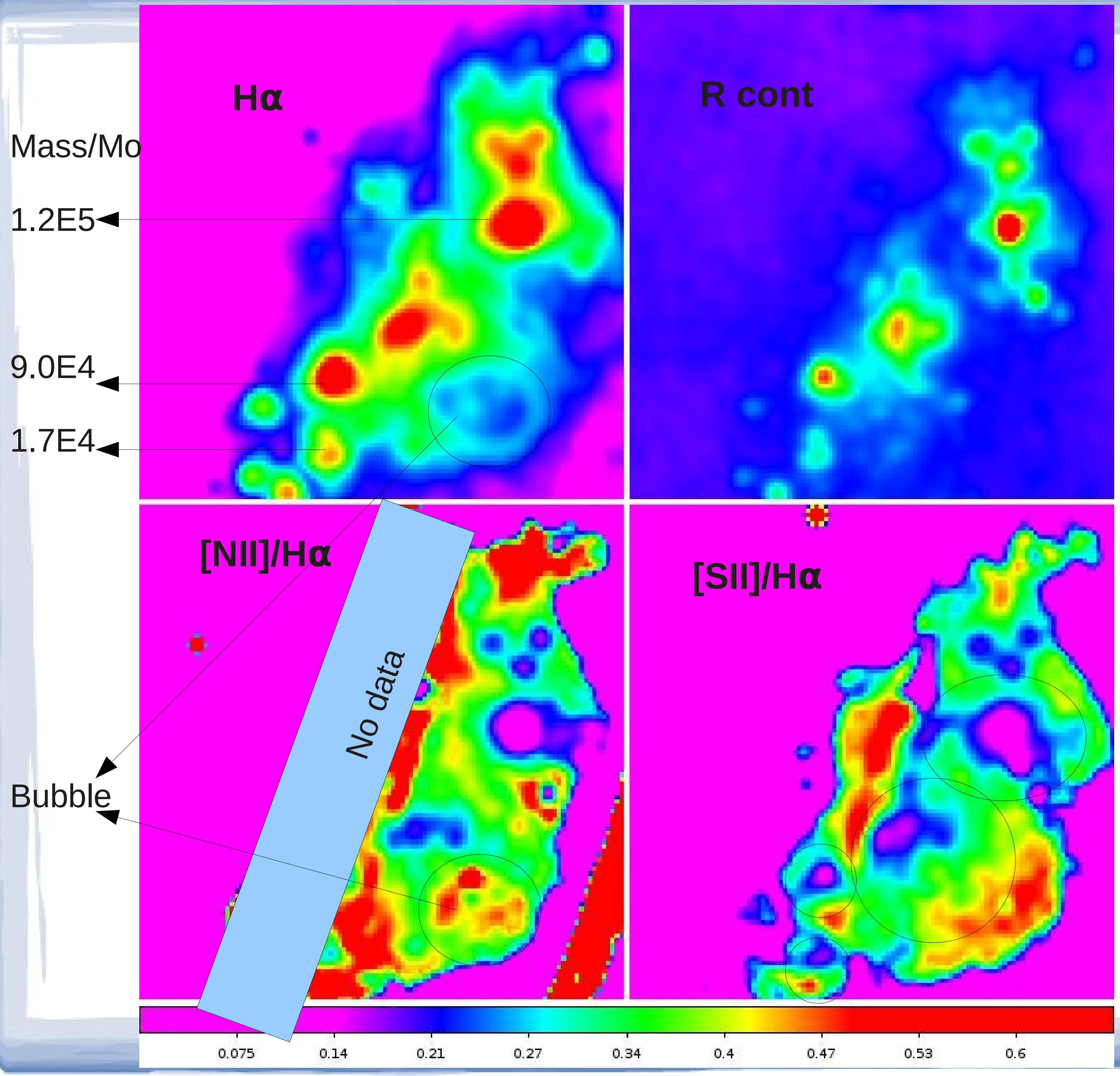


--- High U in the Inner zone around Massive clusters; Low-mass clusters lack the High U zone

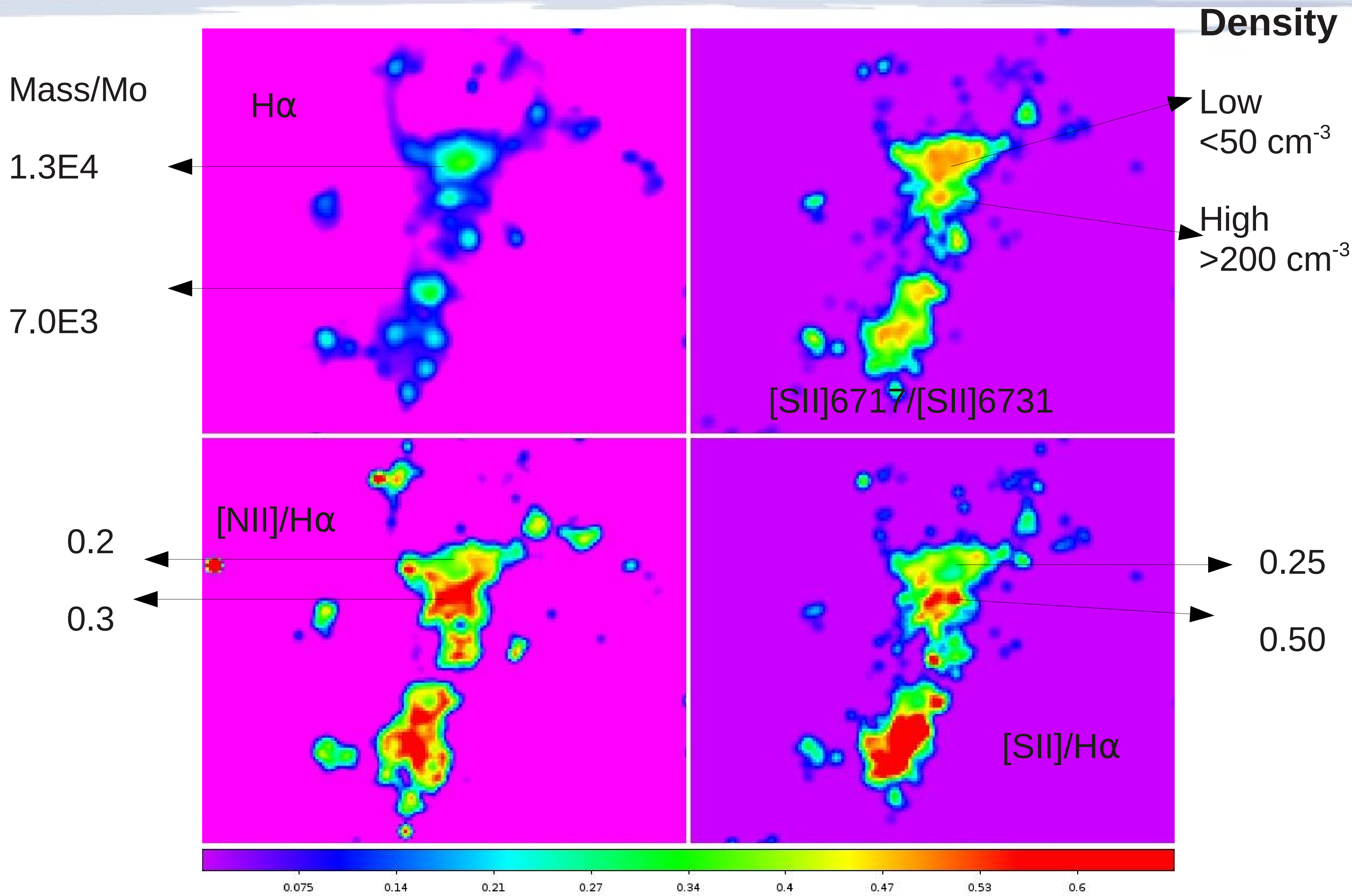
--- HII complexes with multiple ionizing clusters retain their ionization structure around each ionizing cluster

All diagonostic maps:



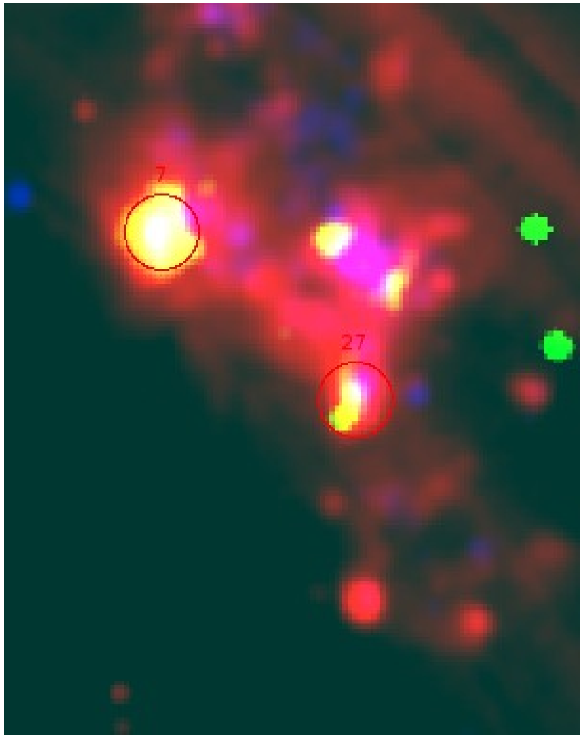
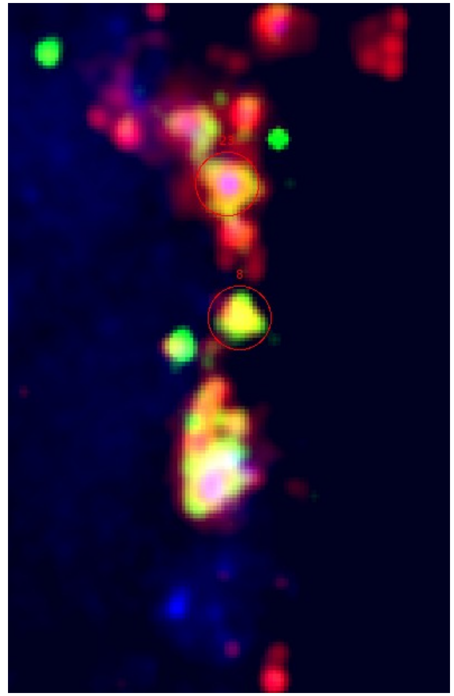
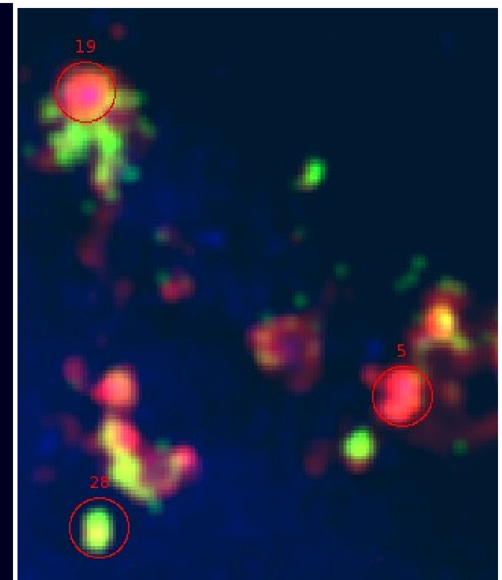
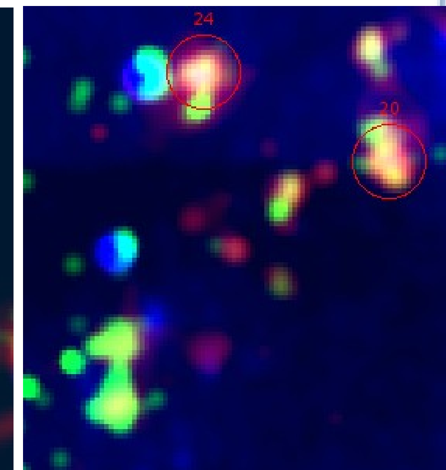
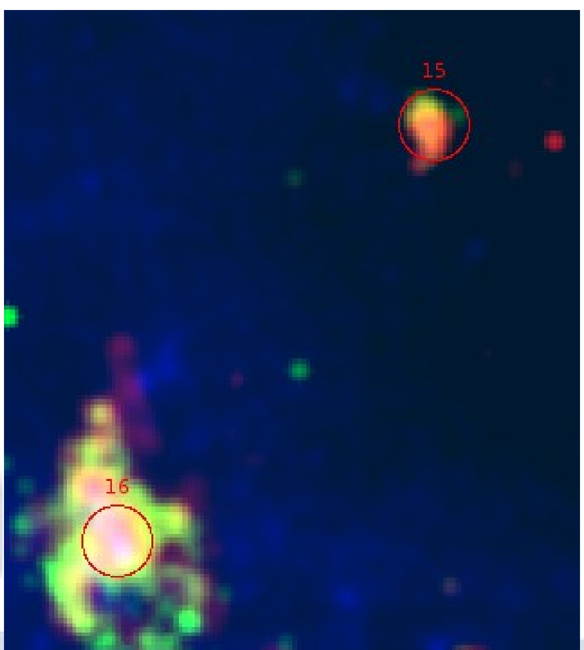
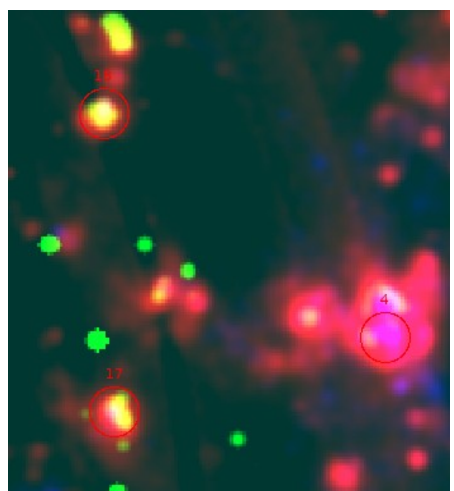
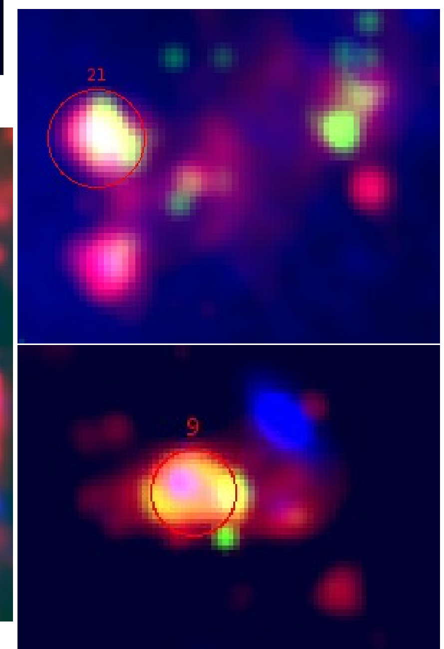
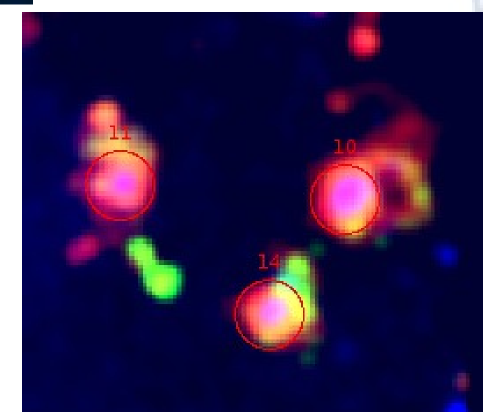


Hα
R cont
Mass/Mo
1.2E5
9.0E4
1.7E4
[NII]/Hα
No data
[SII]/Hα
Bubble
0.075
0.14
0.21
0.27
0.34
0.4
0.47
0.53
0.6



- Photo-ionization models will be required

Other HII regions (Low-mass 0.6-3x10^4 Mo)

- Will be analyzed using Photo-ionization models

Summary and Open questions

- Emission-line images obtained through narrow-band TF imaging technique are accurate enough to prepare seeing-limited maps of Ionization structures of giant HII regions in nearby galaxies.

- The integrated ionization parameter **U** of HII complexes is dictated by the zone closest to the ionizing cluster.

- Low-mass (inter-arm) HII regions lack High **U** zones

- Hα filaments and bubbles are seem around several HII regions

- The ionization structure of giant HII regions seem to be unaffected by the cluster winds
  - Are they too young?
  - Only gravity matters? (R. Terlevich's talk)

Thanks