Recent studies of planetary nebulae and BCDs with VLT FLAMES and VIMOS

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Integral field spectroscopy of planetary nebulae: mapping the line diagnostics and hydrogen-poor zones with VLT FLAMES*

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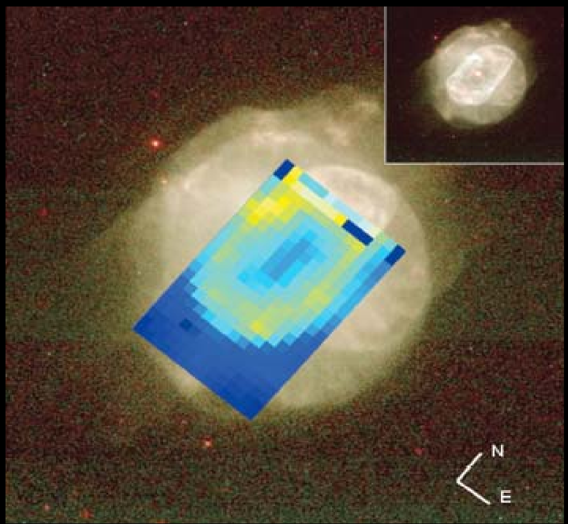
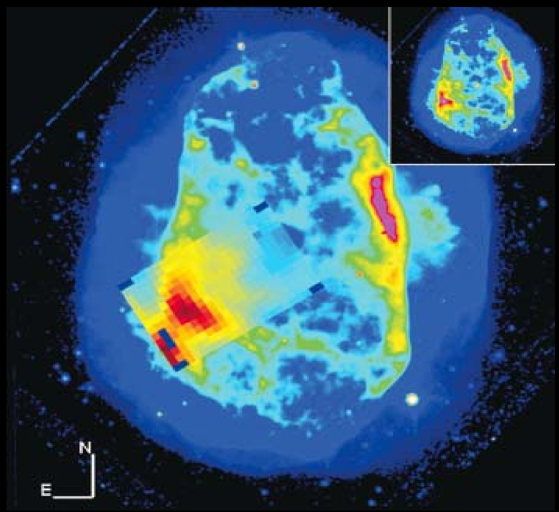
Mon. Not. R. Astron. Soc. 386, 22–46 (2008)



NGC 5882



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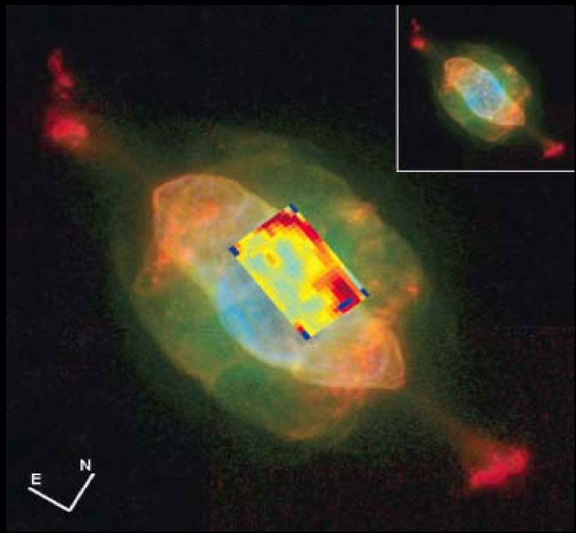


NGC 7009

Traditional Long Slit Spectroscopy

Long, narrow (~1 – 2 arcsec) slit:

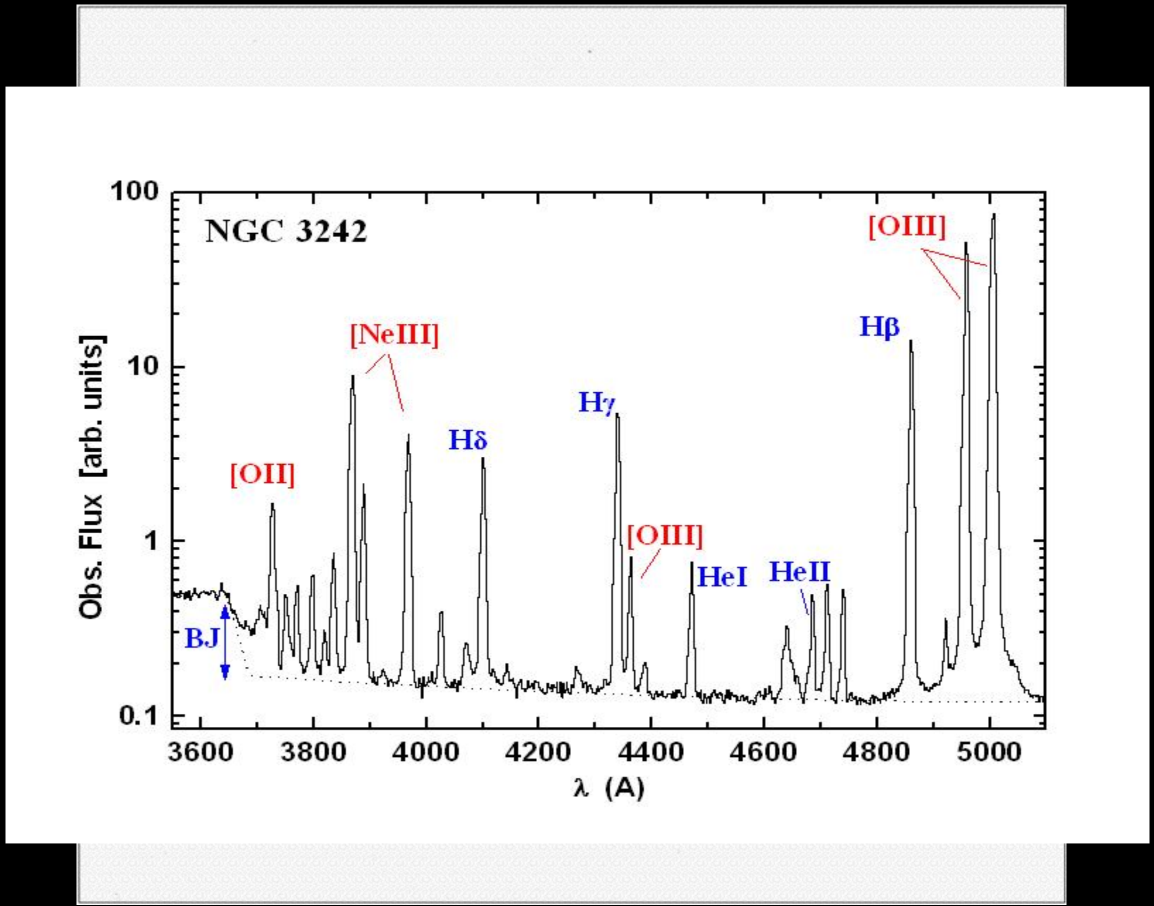
- Spectral resolution $\lambda/\Delta\lambda$ ~ 3000 (FWHM ~ 2 Å/pix)
- Spatial resolution > 1 arcsec/pixel
- Slit can be “fixed”, or “scanning”

× Seeing is not sampled

× Loss of flux either side of the slit

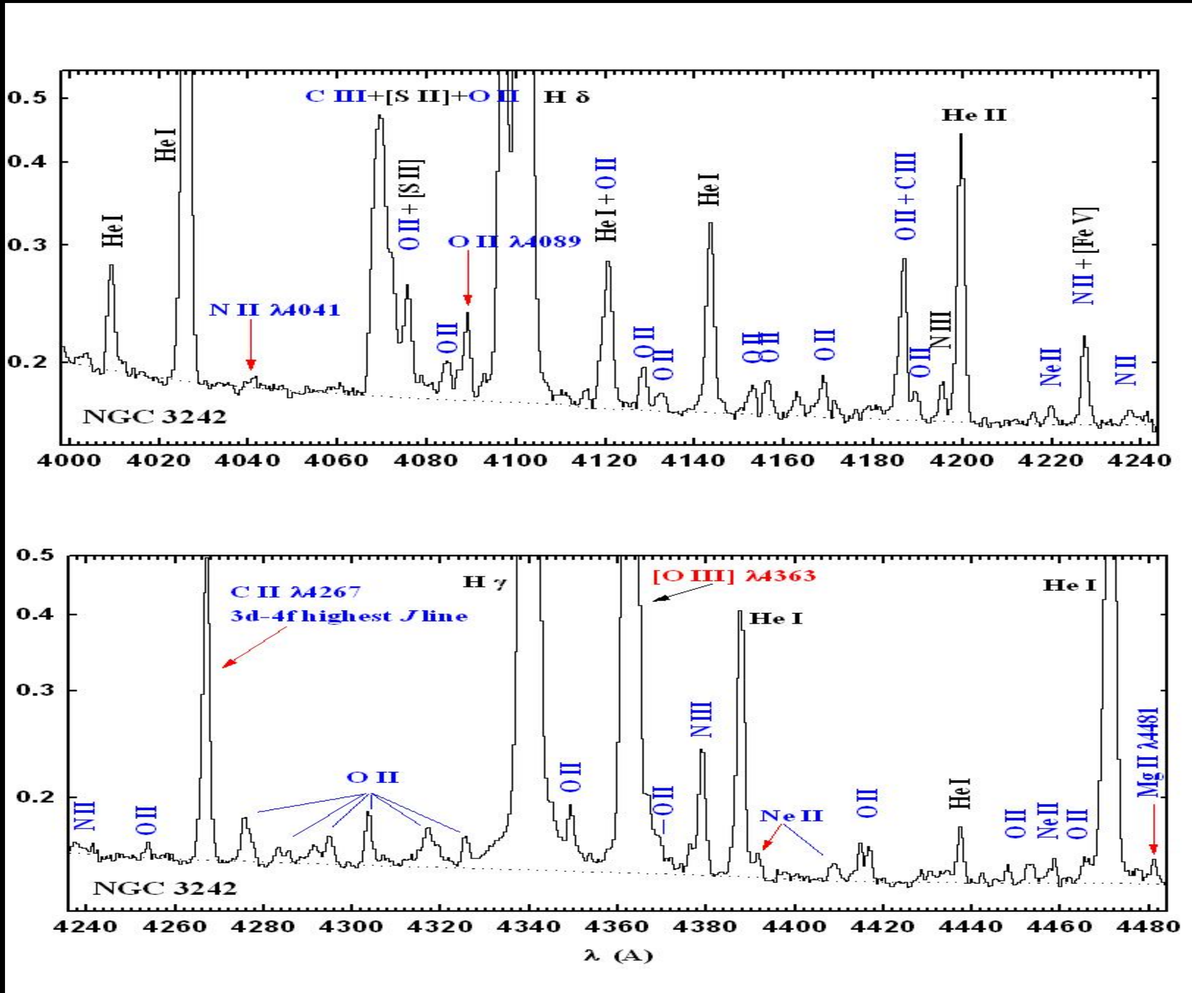
× Loss of spatial info in 2nd dimension

Échelle spectrographs yield higher spectral resolution, but are difficult to flux-calibrate



NGC 6720 (Ring Nebula, HST)
Garnett & Dinerstein 2001

‘Weak line’ Nebular Spectroscopy



Optical recombination lines (ORLs) of heavy ions:

Can be ~1000 times fainter than Hβ, or the strong CELs

C II λ4267 (the strongest)

O II, N II , Ne II

ESO 1.52m, long-slit spectrum (~ 30min)

Tsamis et al. 2003b

ORLs are useful diagnostics of abundances for C, N, O, Ne

The *nasty* Abundance Anomaly problem

- In PNe abundances of C, N, O, Ne measured from recombination lines (ORLs) are ~2 – 80 times *higher* than abundances measured from CELs (e.g. Tsamis et al 2003b, 2004; Liu et al 1995, 2000; Wesson et al 2005)

- In HII regions the discrepancy is ~2 – 5

  (e.g. Peimbert et al 1993; Tsamis et al 2003a, 2005; Peimbert 2003; Esteban et al 2005)

Likely solution? A "dual abundance" nebula

Nebulae may contain two distinct gas phases:

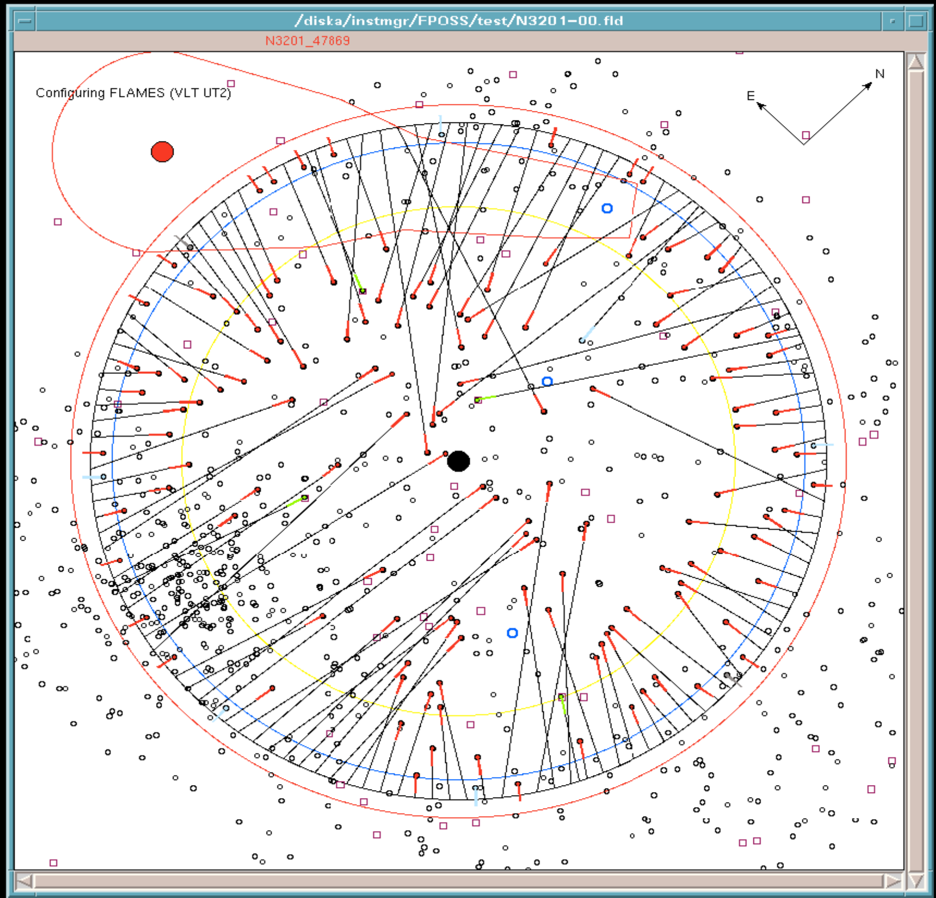
(1) A component at normal temperature ($T_e \sim 10^4$ K) and normal metallicity emitting the strong CEL flux

(2) A hydrogen-deficient, high-metallicity component of low temperature ($T_e \sim 10^3$ K), with super-solar C,N,O,Ne abundances, emitting most of the metallic ORL flux, but essentially no CELs.

✓ The Abundance problem is due to compositional inhomogeneities within the PN

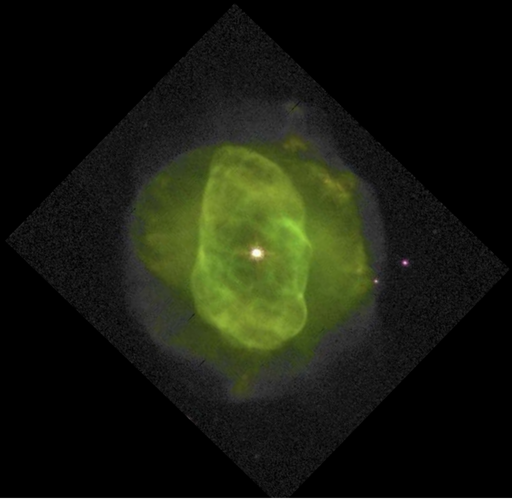
The VLT FLAMES Argus IFU

The positioning plate holding the fibres

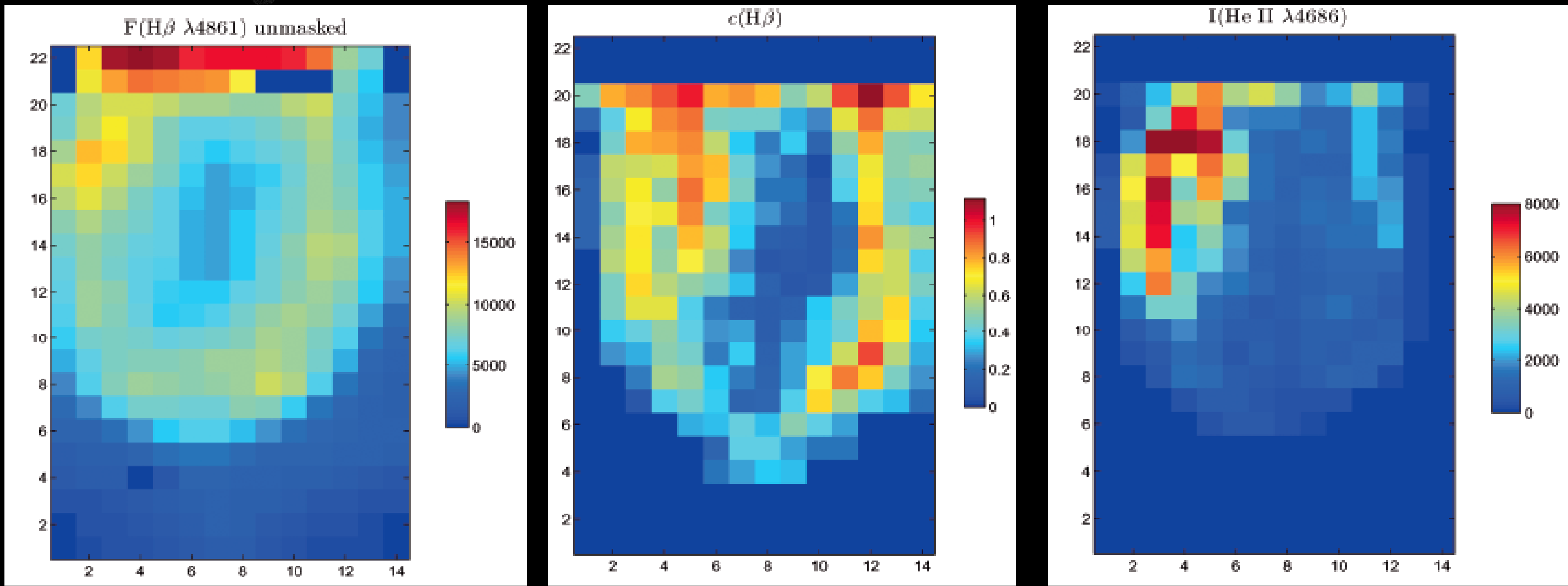


The dedicated software allocating fibres to the user-selected guide star and sky positions during phase II preparation

http://www.eso.org/instruments/flames/inst/Giraffe.html



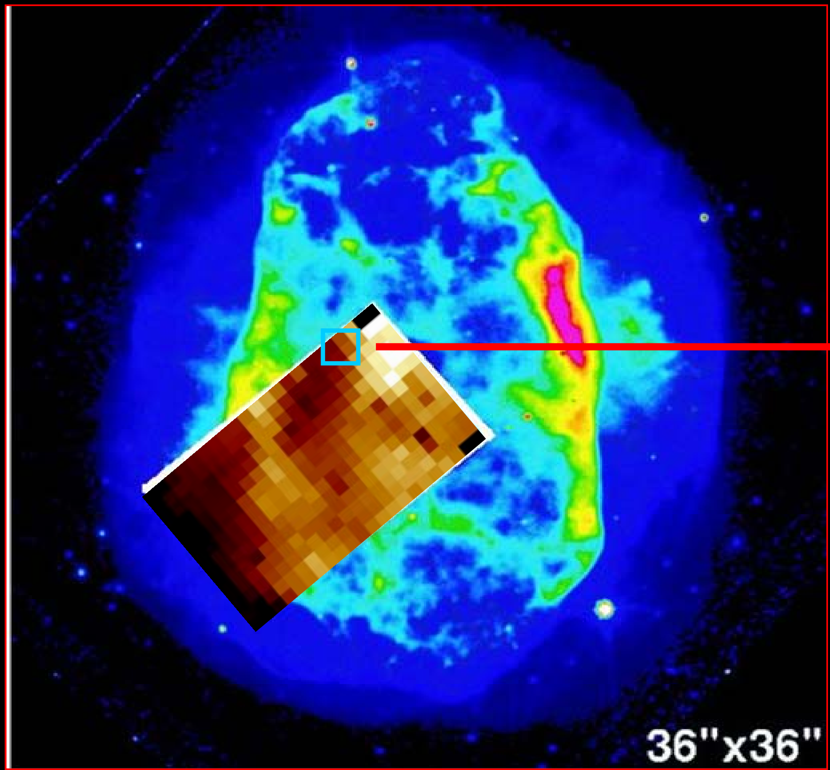
Spectral mapping of NGC 5882

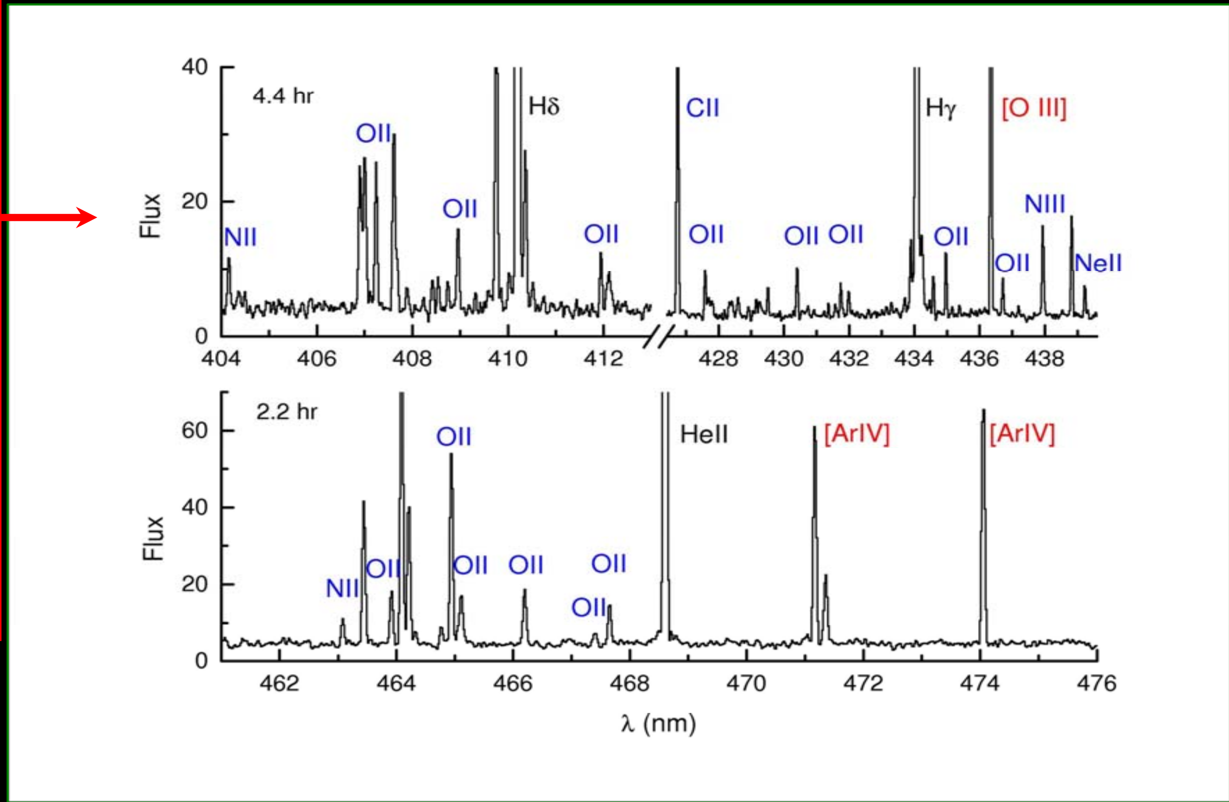


0.52”x0.52” spaxels: physical size ~ 4 milli-pc

2nd row from top has three dead fibres; blank corner pixels correspond to sky fibres; DAR affecting top two rows

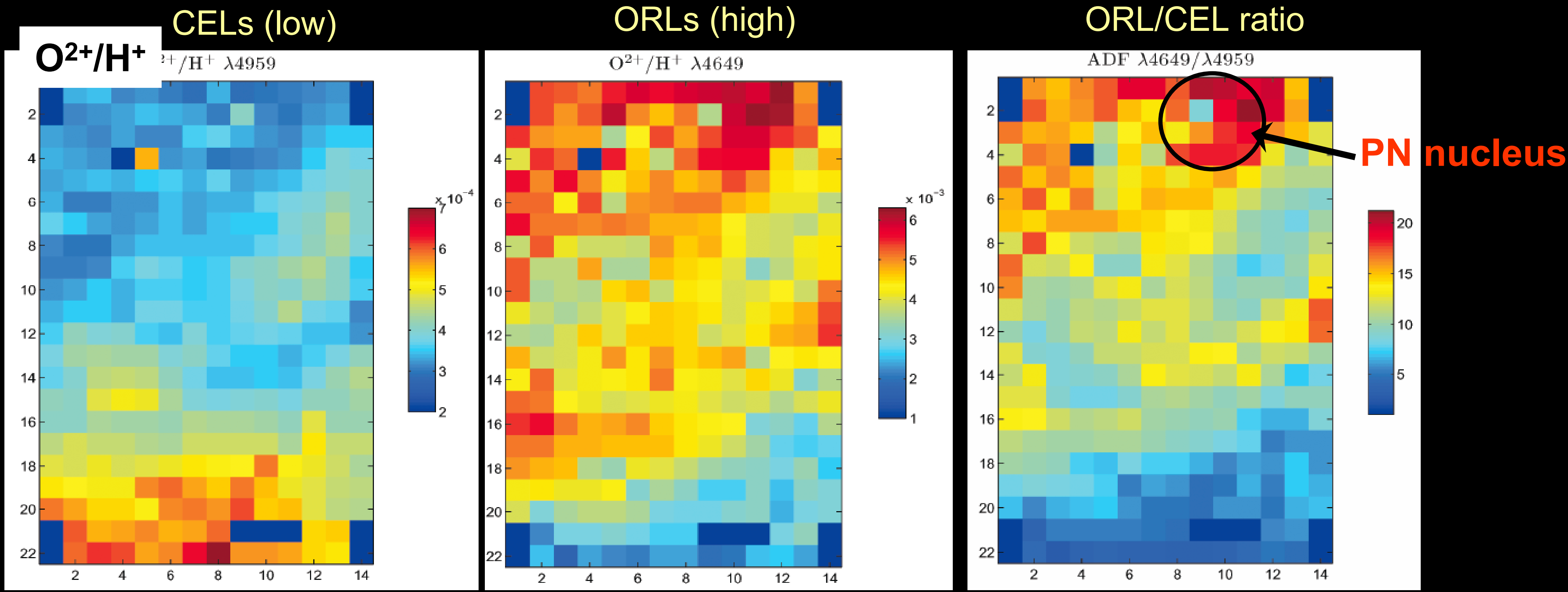
Integral Field Spectroscopy (FLAMES @ the VLT)

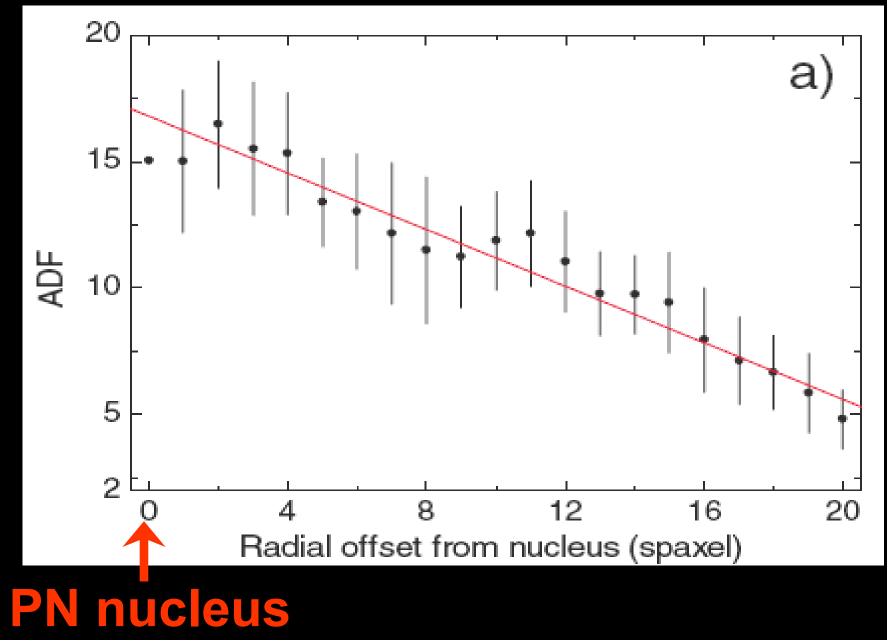




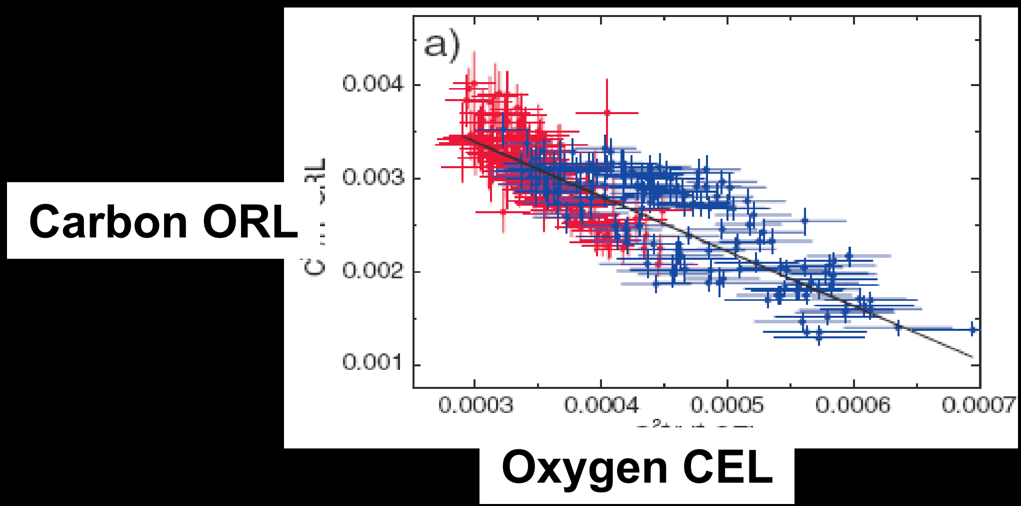
Spectrum from a single 0.52”x0.52” spaxel recording ORLs of strength < 1% that of Hβ
Typical S/N > 10 for weak OII 4089, 4649-Å lines

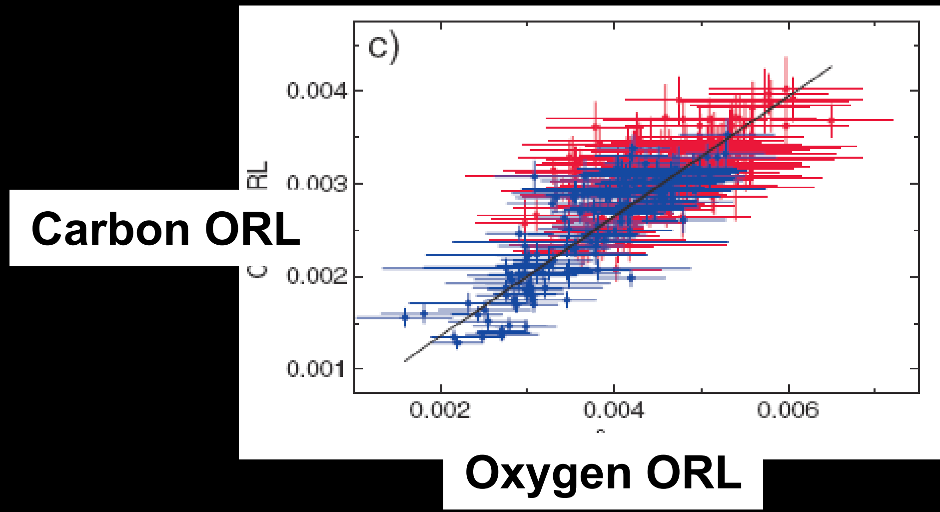
FLAMES yields ~300 spectra per field





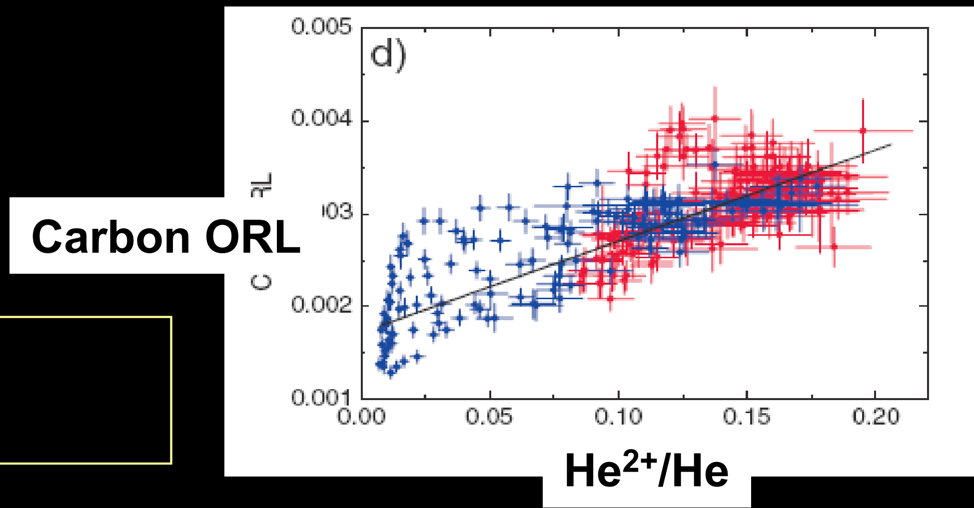
✓Similar trend in other PNe





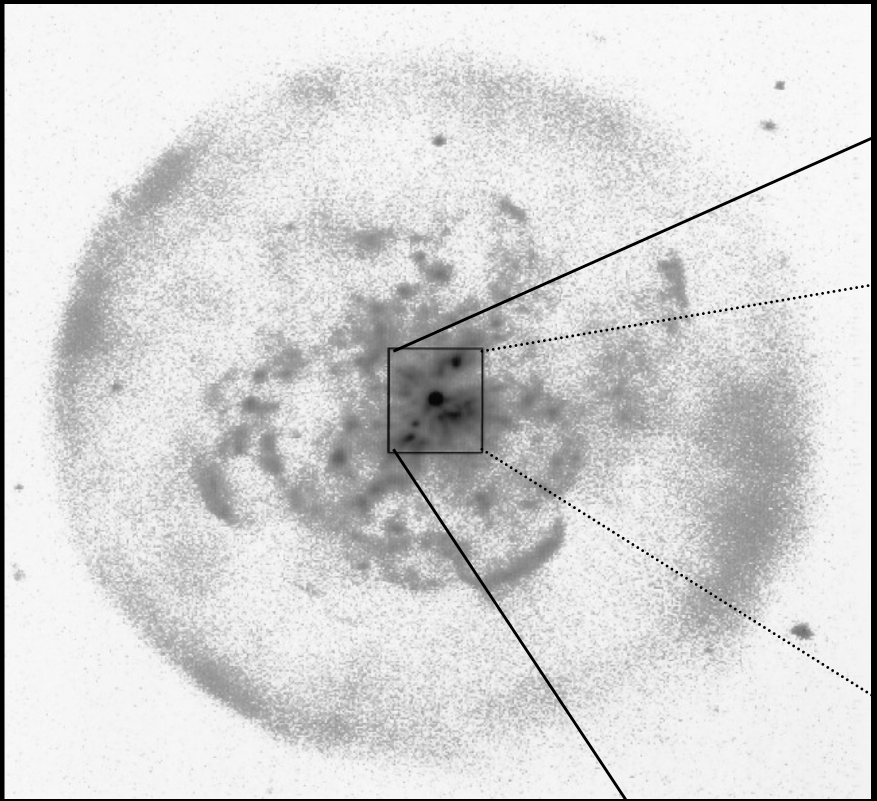
The trends between the ORL-CEL & ORL-ORL abundance diagnostics lie in completely opposite directions:

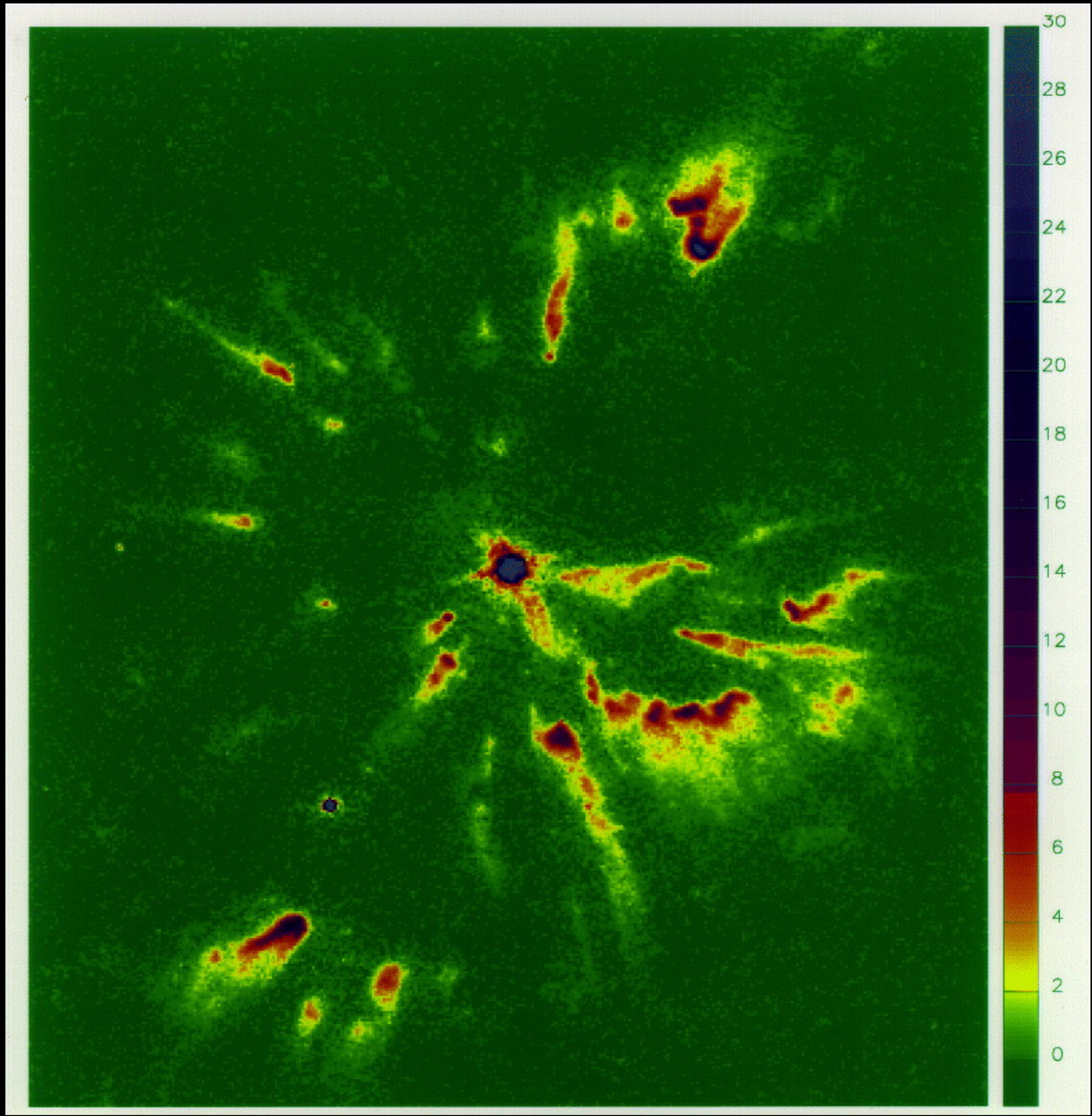
Chemically inhomogeneous nebula?



The ORL-emitting plasma is somehow associated with high ionization regions

PN: Abell 30





HST-WFPC2 [O III] λ5007

Ejection of O-rich clumps from star which has H-deficient atmosphere. The clumps have cold cores and they emit strong heavy element ORLs

× Only a few such PNe known since the 80's: our VLT PN belong to a normal population and do not have H-deficient central stars.

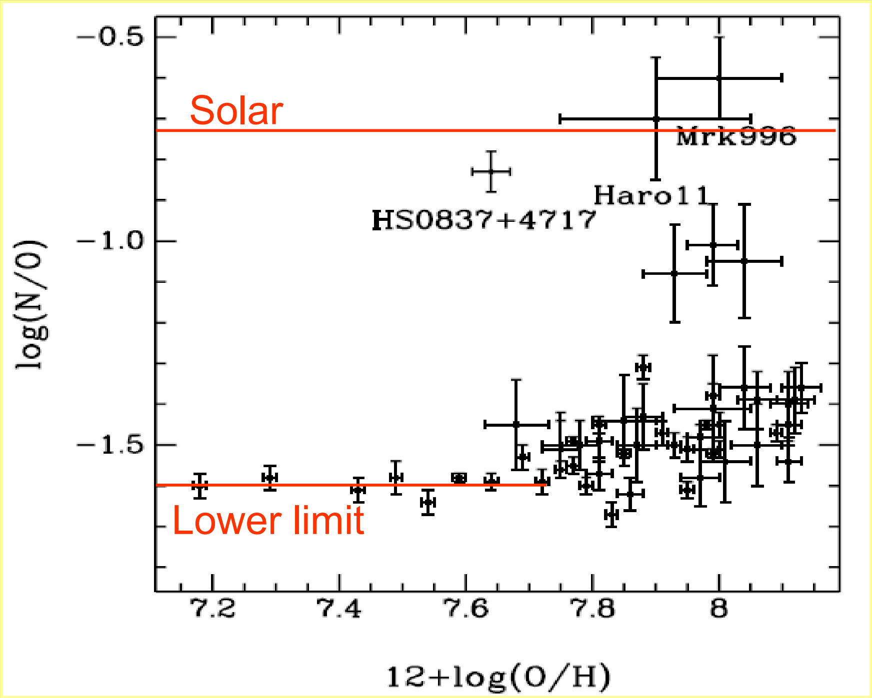
A VLT VIMOS study of the anomalous BCD Mrk 996: mapping the ionised gas kinematics and abundances†

B. L. James[1⋆], Y. G. Tsamis[1,2⋆], M. J. Barlow[1], M. S. Westmoquette[1], J. R. Walsh[3], F. Cuisinier[4], and K. M. Exter[5]

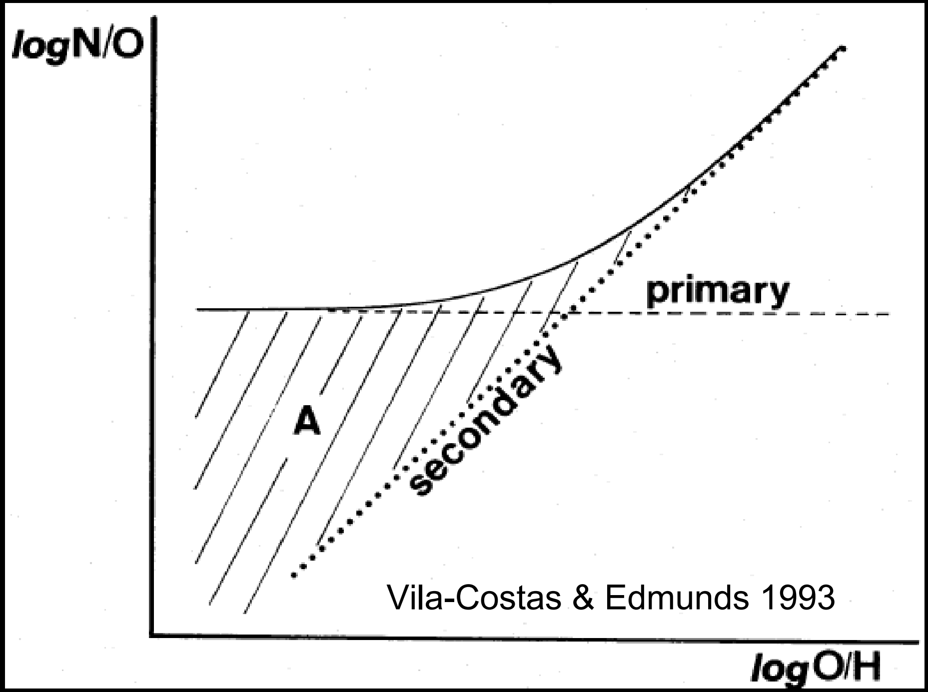
MNRAS *in press* (arXiv:0903.2280)

Part of PhD project of Bethan James *at UCL (from October in STScI)*

The evolution of Nitrogen abundances in BCDs



Pustilnik et al. 2004

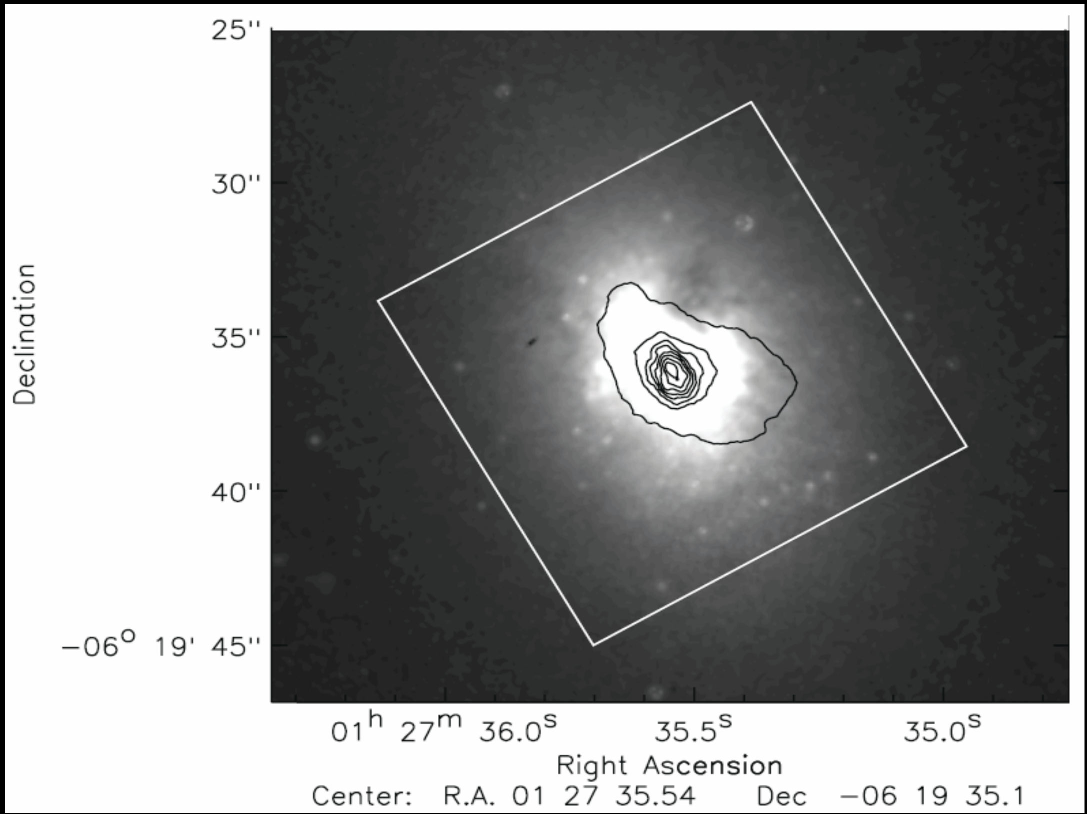


At low *Z* primary Nitrogen is produced with Oxygen from massive stars (M > 9 Msol)

As the starburst ages, secondary N from stars of all masses and primary N from AGBs is produced: resulting scatter. Outlying galaxies with ~solar N/O are rare and require an explanation.

They contain Wolf-Rayet stars and/or show evidence of mergers. Nitrogen enrichment from WR-winds? Inaccurate long slit analyses?

Markarian 996



Thuan, Izotov & Lipovetsky (1996)

D = 22 Mpc

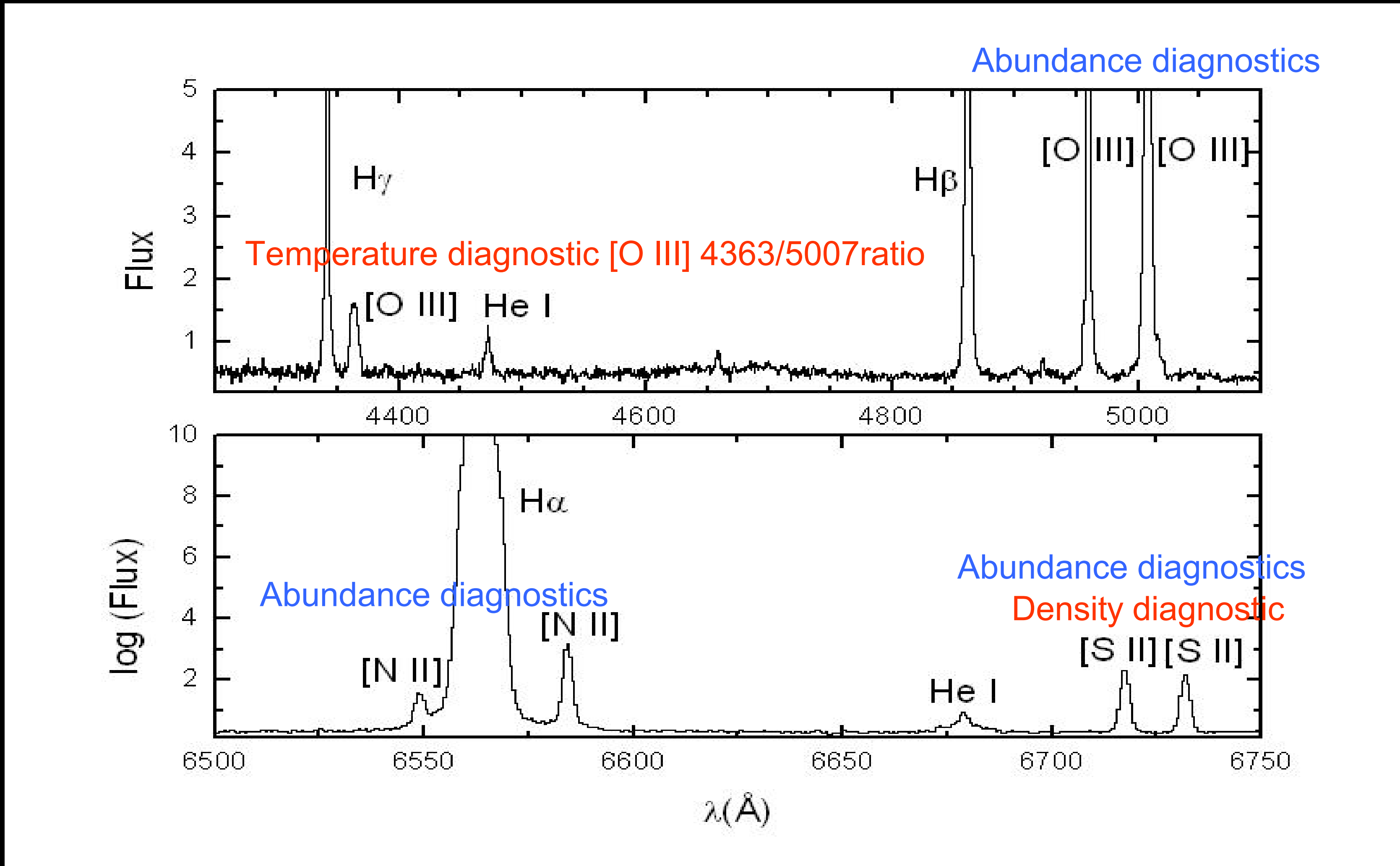
Size: a few times 30 Doradus

O/H ~ 0.10 x Solar (previously published!)

N/O ~ 1 – 5 x Solar

Our VIMOS study: 13” X 13” IFU
1600 spectra, HRblue, HRorange gratings

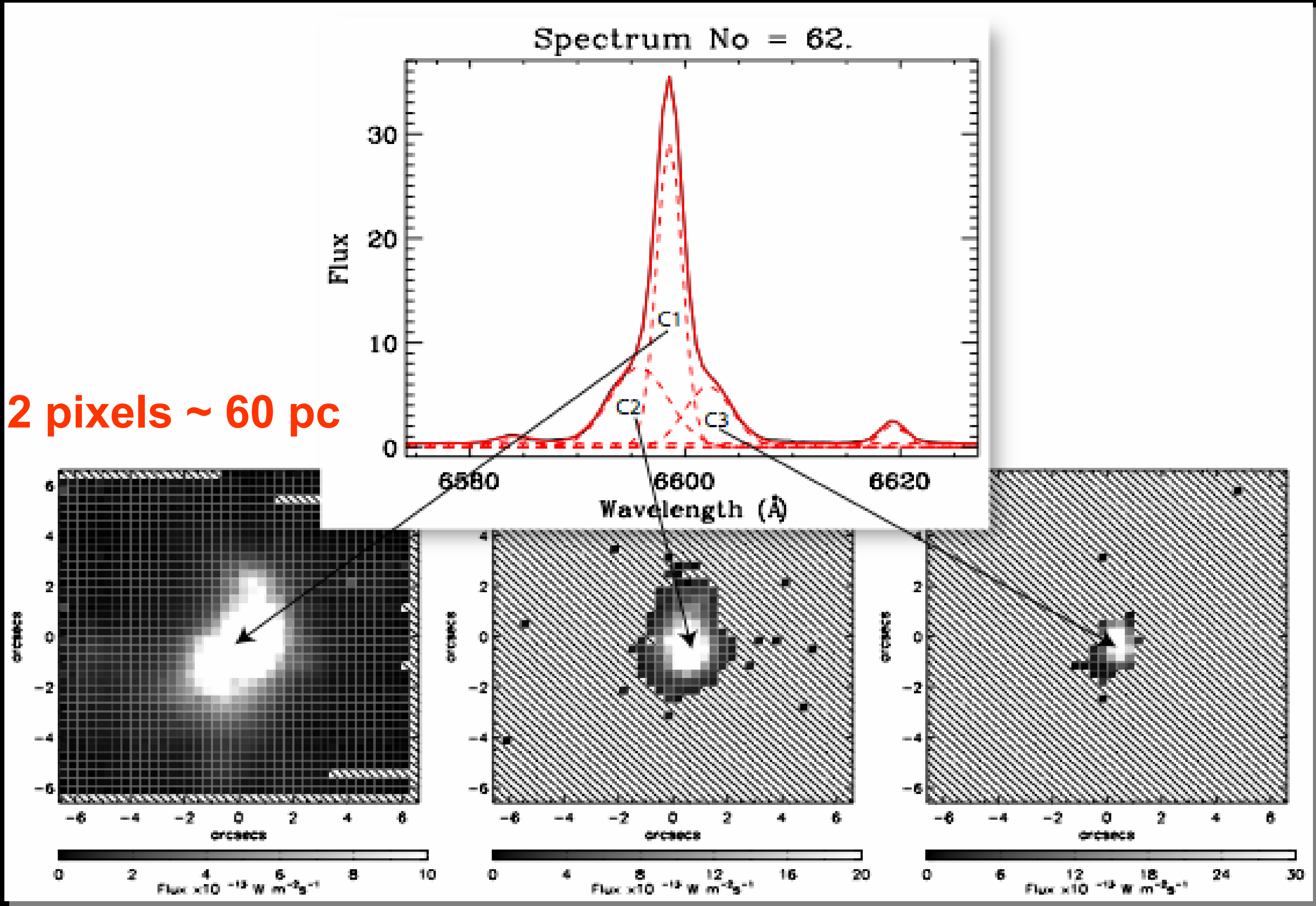
Spectrum extracted from a single 0.33” x 0.33” VIMOS pixel



Velocity resolution ~ 120 km/s FWHM

~ 30 min exp.

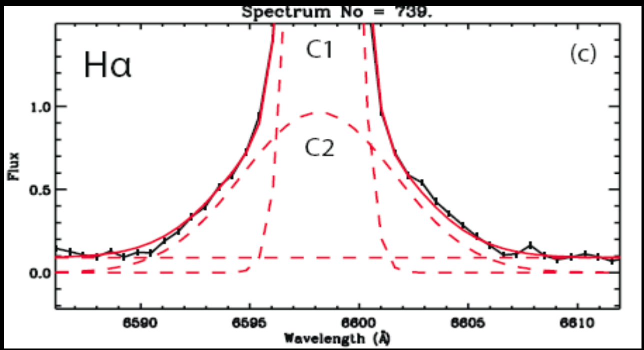
Spectral maps of MRK 996 in the light of Hα 6563 Å: multi-component line fitting (x 1600)



2 pixels ~ 60 pc

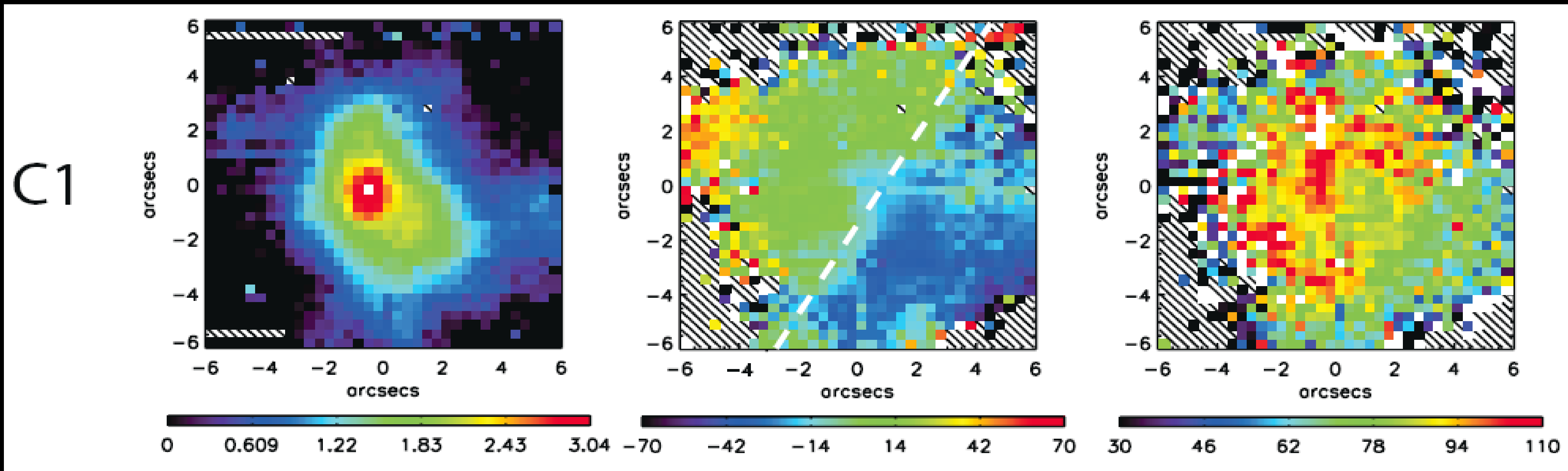
James, Tsamis, Barlow et al. 2009, MNRAS (arXiv:0903.2280)

Flux, radial velocity, and FWHM maps of the various components of Hα



FWHM (km/s)

6563 Hα	C1	116.5± 0.9

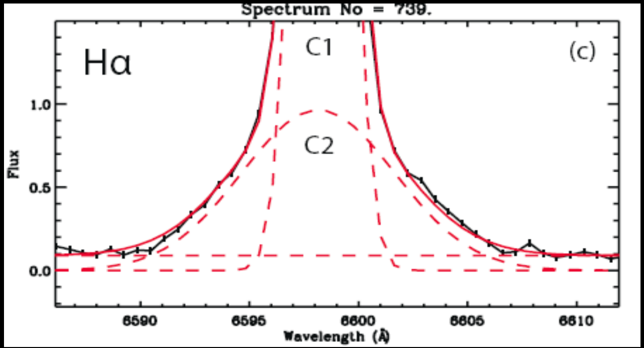


Flux

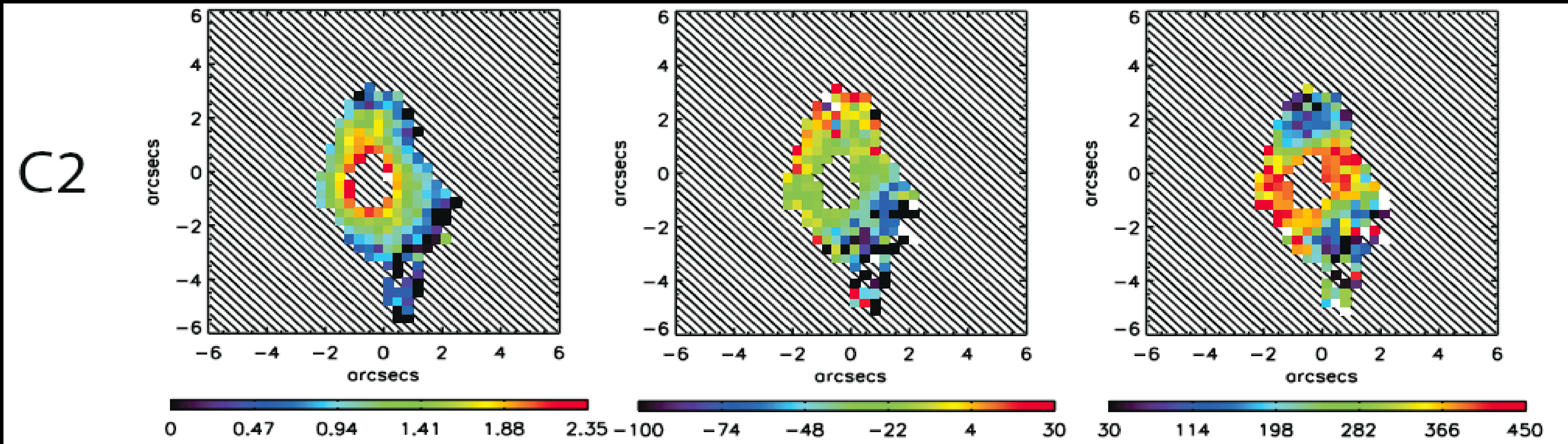
Radial velocity (km/s)

FWHM (km/s)

Flux, radial velocity, and FWHM maps of the various components of Hα



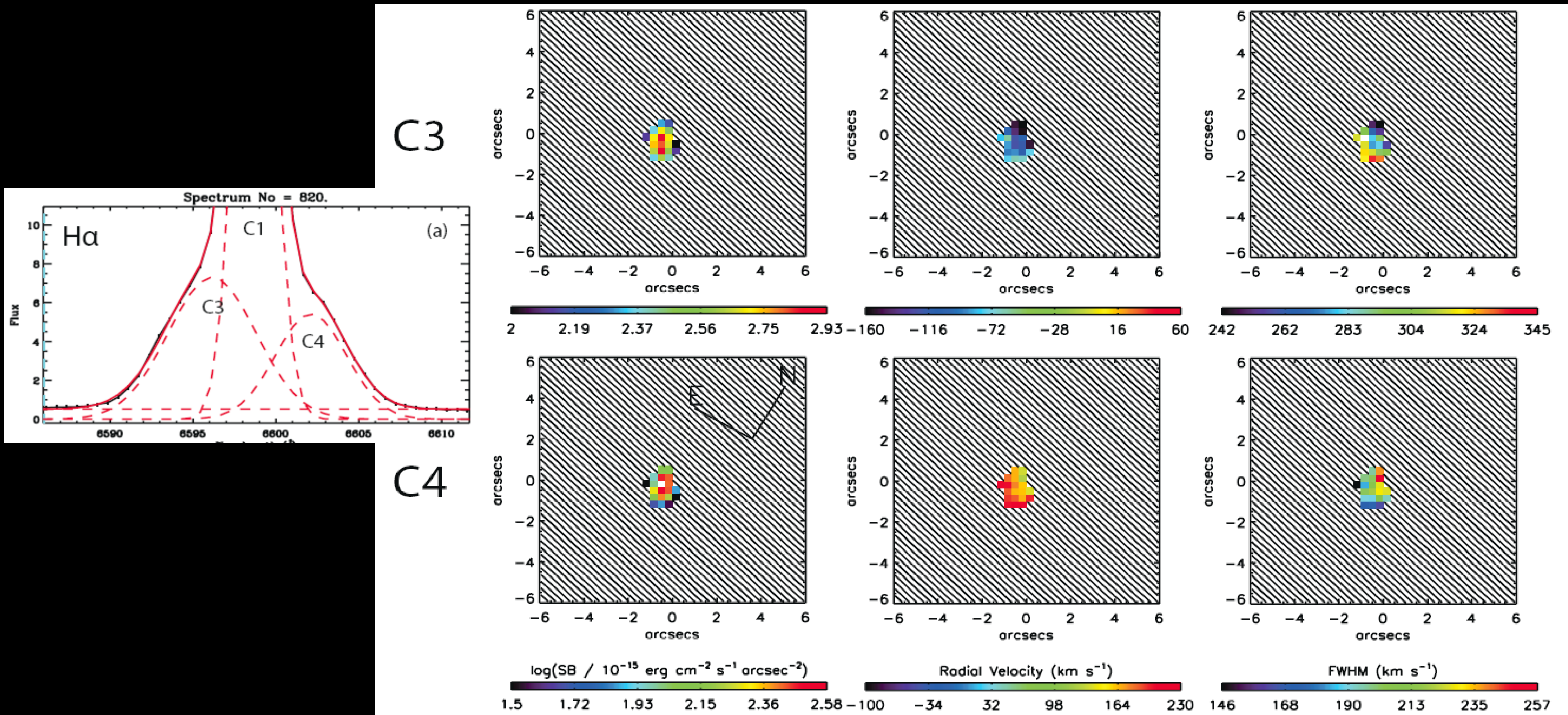
		FWHM (km/s)
6563 Hα	C2	420.5± 7.3



Flux **Radial velocity (km/s)** **FWHM (km/s)**

Flux, radial velocity, and FWHM maps of the various components of Hα

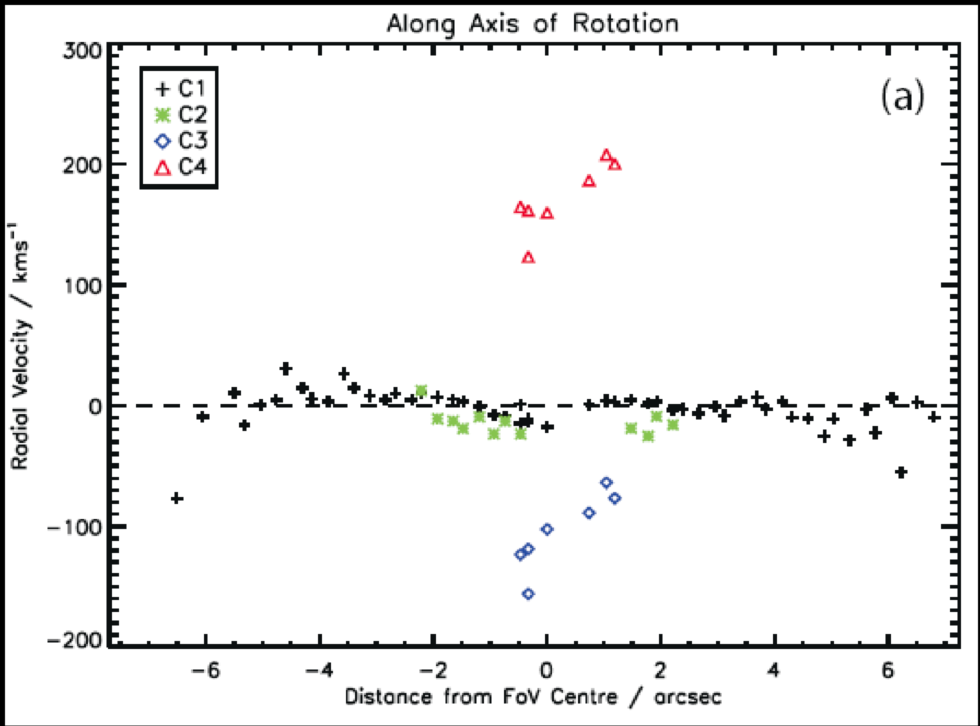
FWHM~200-300 km/s

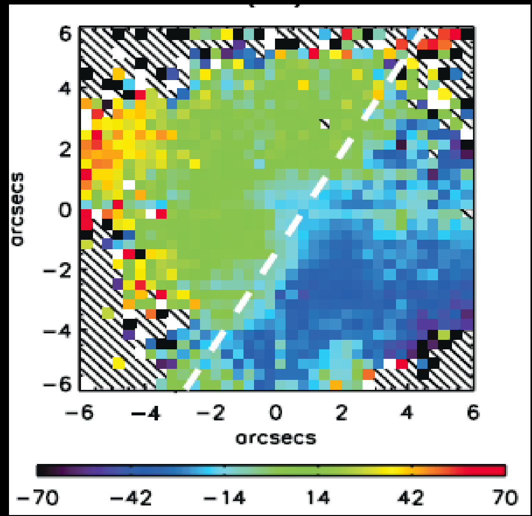


Flux **Radial velocity (km/s)** **FWHM (km/s)**

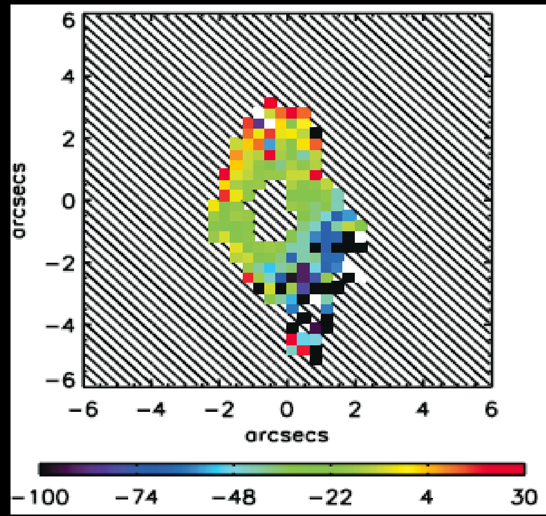
Kinematics: Identification of a mini-spiral (2 arcsec) in the nucleus

Position-Velocity diagram along the rotation axis

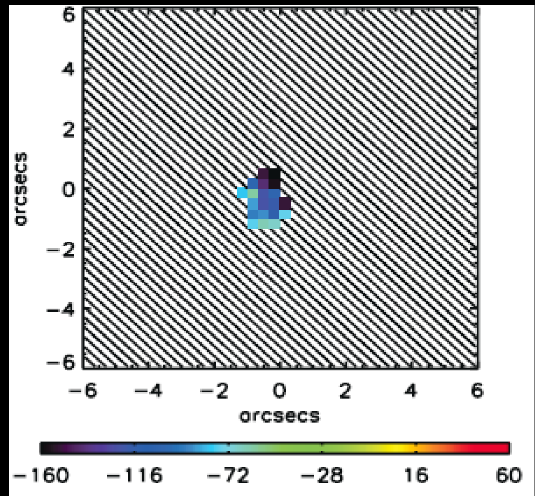




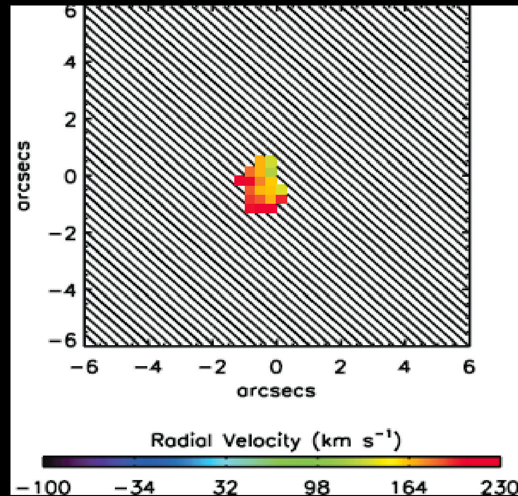
C1



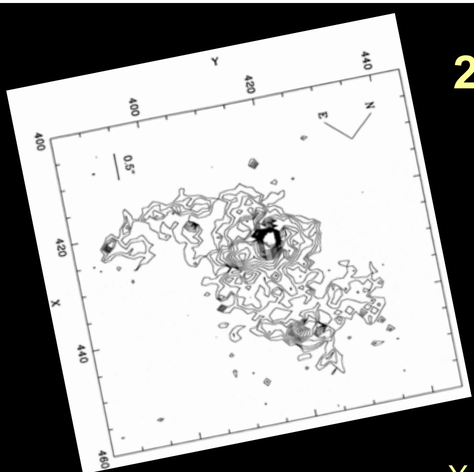
C2



C3



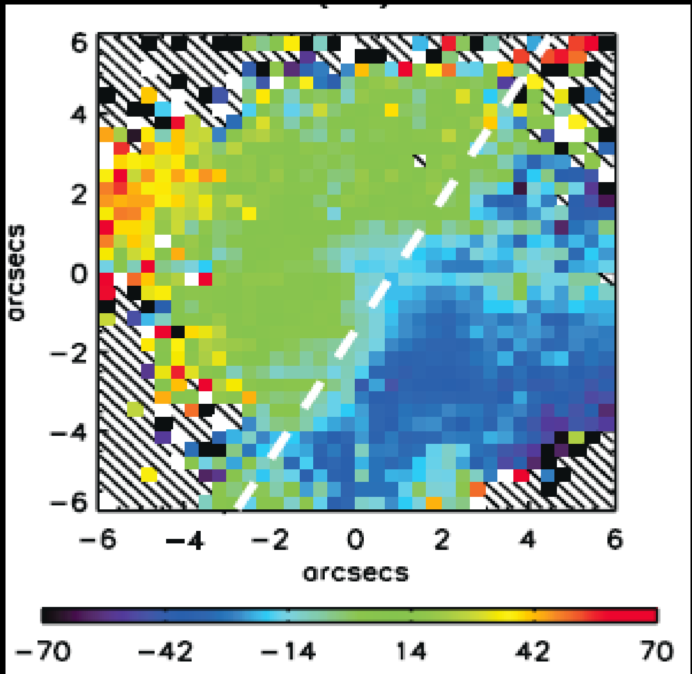
C4



200 pc

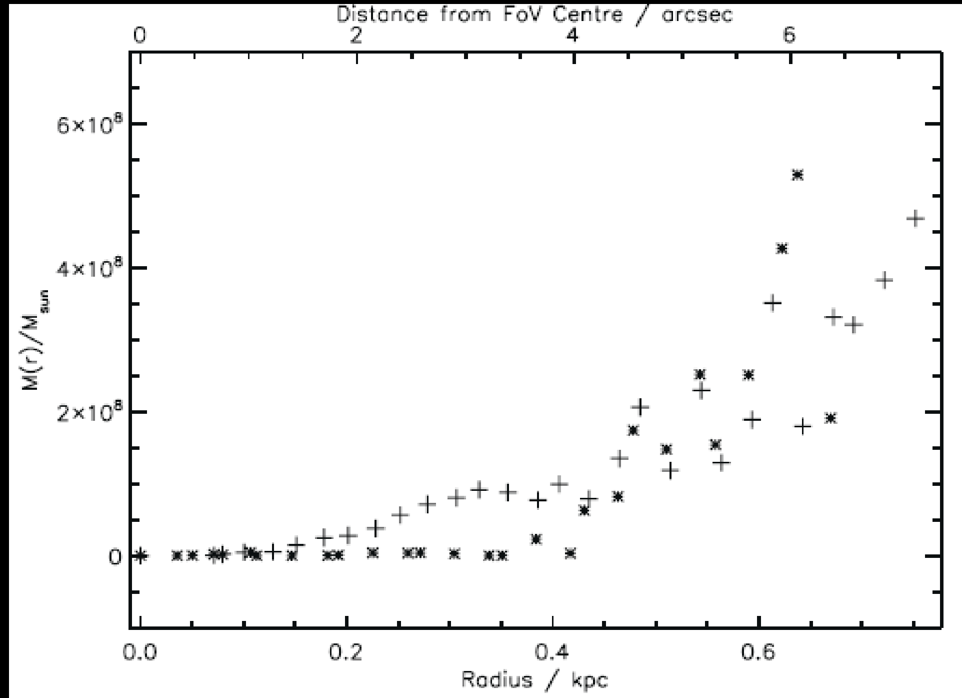
Thuan et al (1996)

Kinematics: Dynamical mass from the optical rotation curve



C1

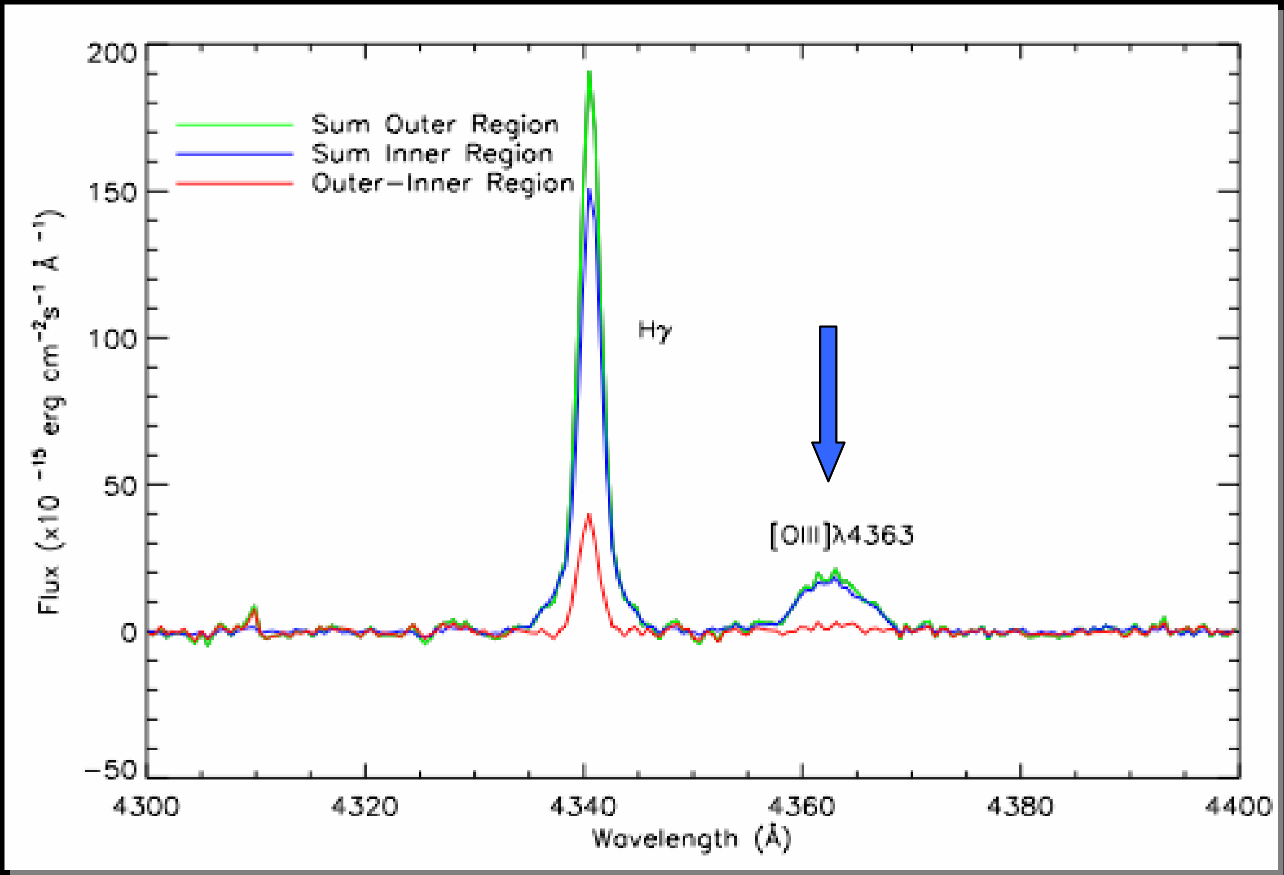
Rotation curve: mass as function of galactic radius

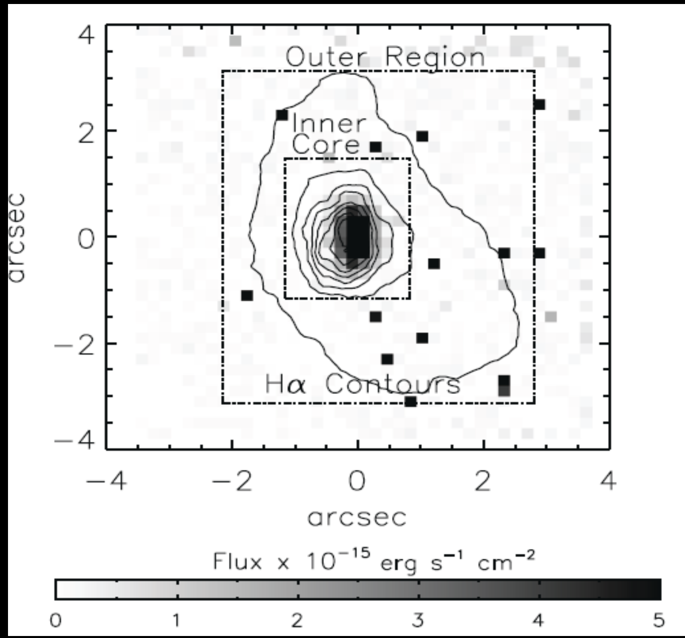


Mass of 5 x 10^8 Msol

One of very few <u>optical rotation curves</u> for BCDs

Physical conditions: the [O III] 4363 Å width in the inner/outer galaxy



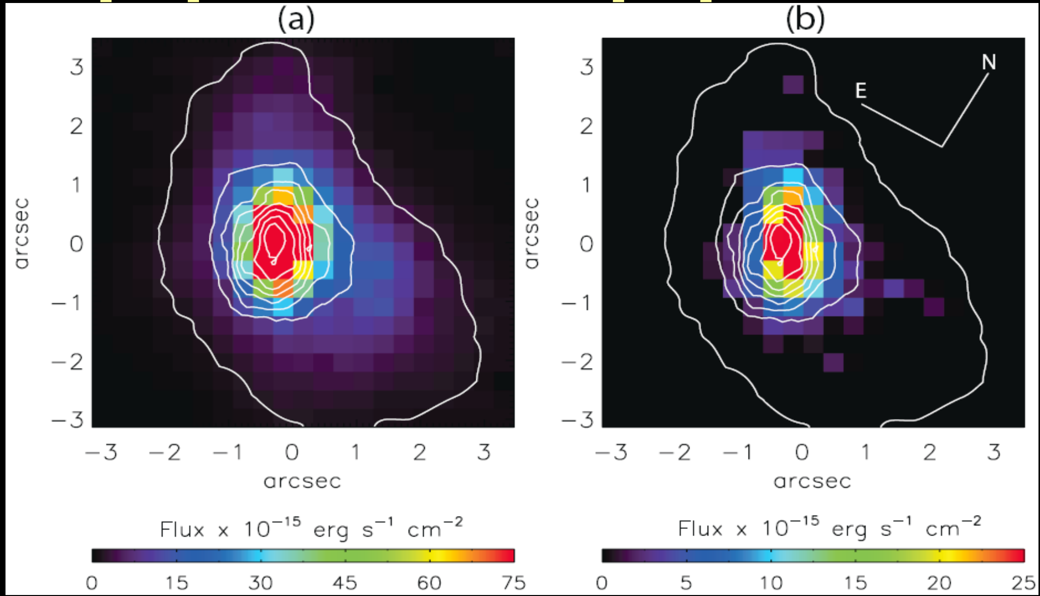


The narrow component of [O III] 4363 is not detected in the inner galaxy:

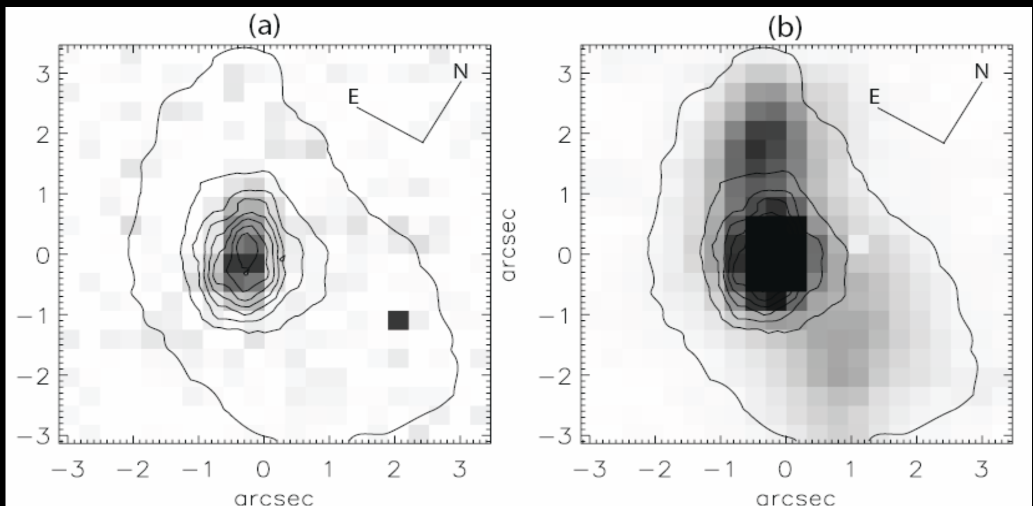
Temperatures based on the integrated [OIII] 4363/5007 ratio would be too high (18,000 K) and the resulting abundances too low

Tracking the width of broad/narrow diagnostic lines

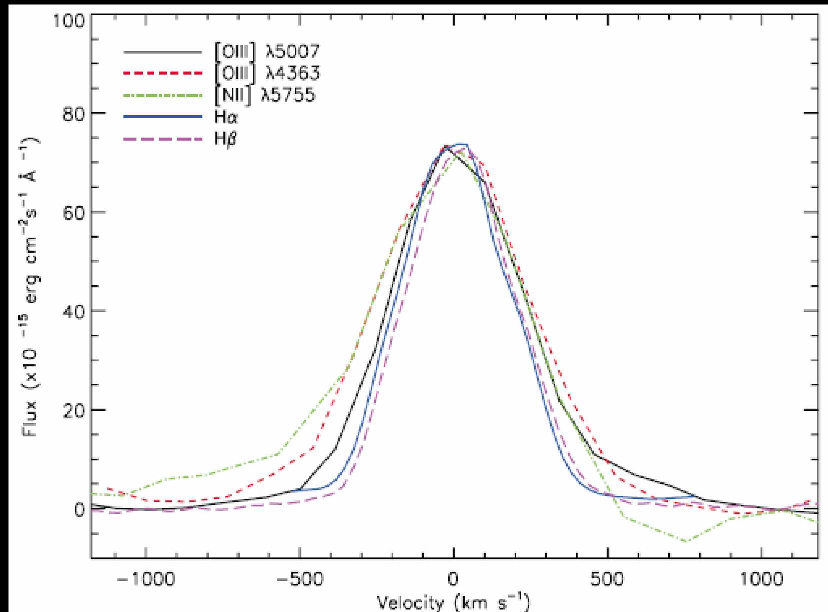
[OIII] 5007 narrow **[OIII] 5007 broad**



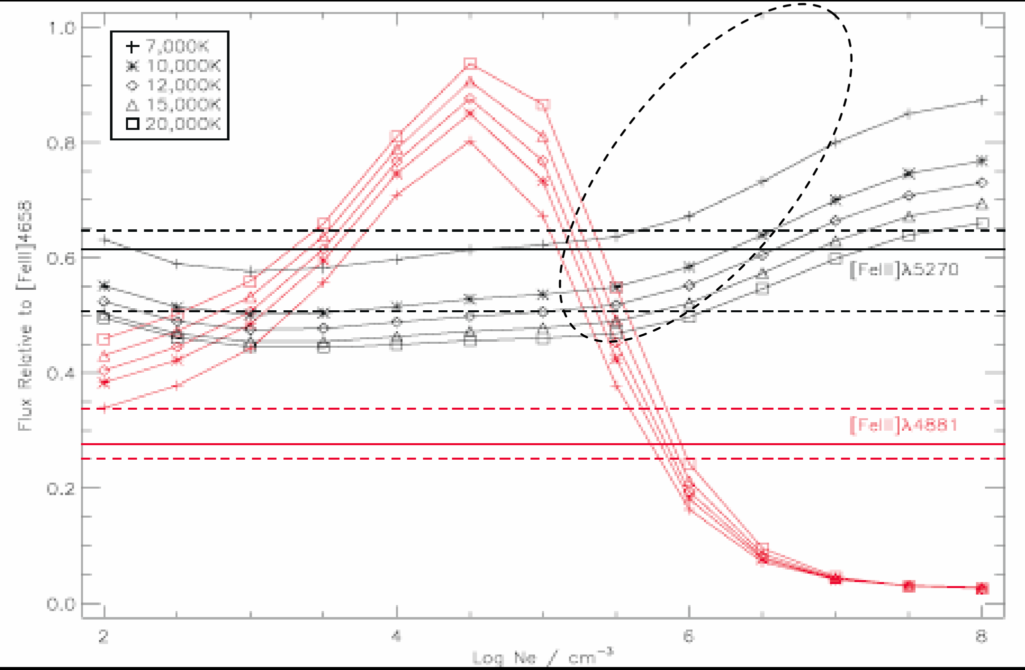
Crucially, the auroral lines [OIII] 4363 and [NII] 5754 Å are <u>only</u> found as broad components over the whole galaxy and <u>cannot</u> be used as straightforward temperature diagnostics



[N II] 5754 broad **[N II] 6584 narrow**



Physical conditions: Electron density

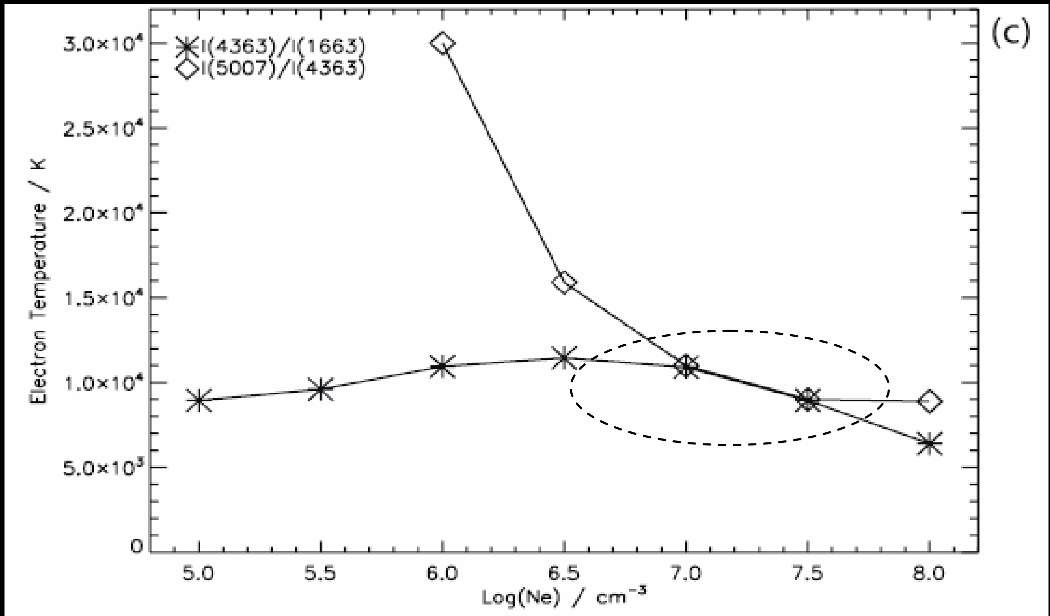


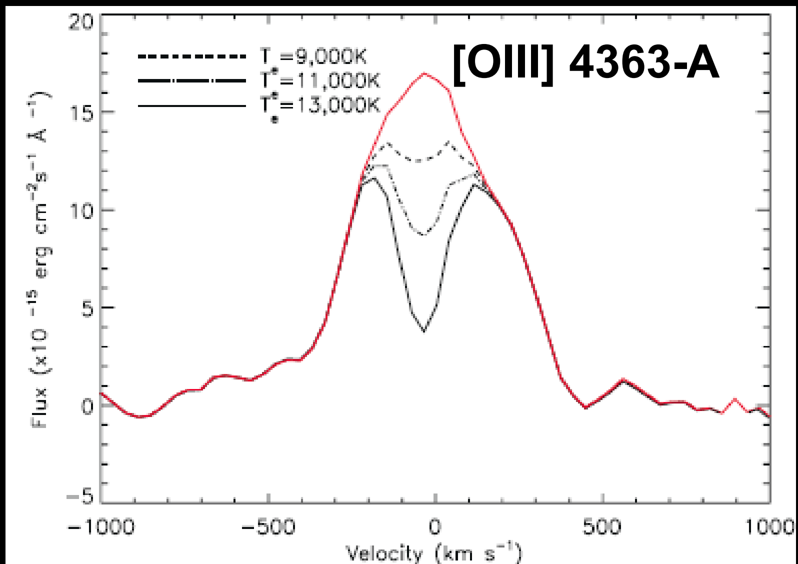
The [Fe III] line ratios 4881/4658 and 5270/4658 Å indicate electron densities of

~10^6 cm^{-3}

The line brightness peaks in the centre, so the central region of Mrk996 is very dense.

Physical conditions of broad and narrow line regions





Density of nuclear broad line region from [O III] 1663/4363, 4363/5007 line ratios again consistent as being very high

$N_e \sim 10^7$ cm^{-3}

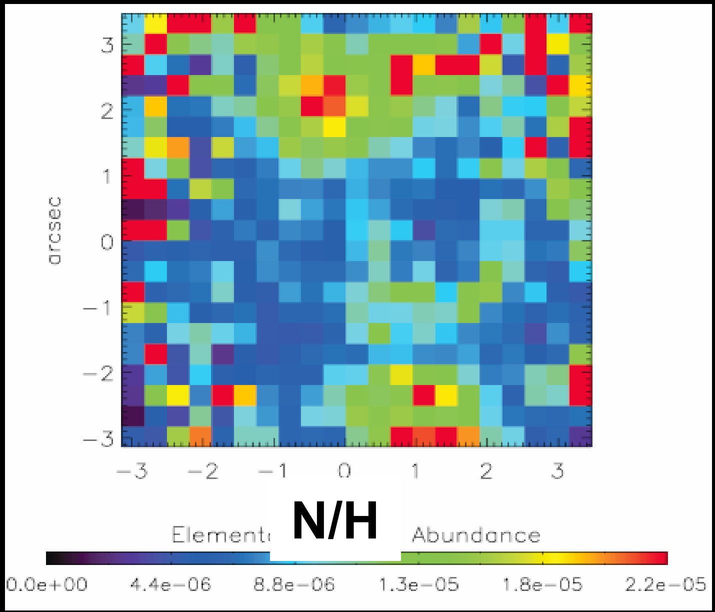
The broad line region Te is normal ~ 11,000K

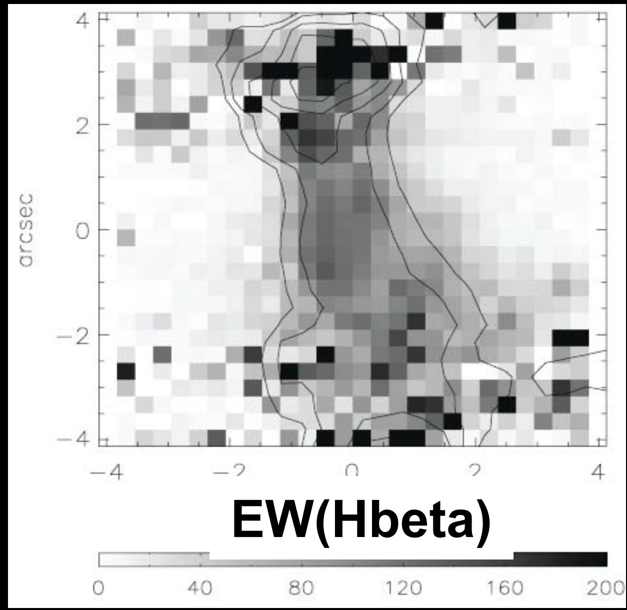
For the narrow line region an upper limit Te = 10,000K was found. Adopting the above values resulted in

O/H ~ 0.5 solar at least

3 x higher than published

Abundances and N enrichment





The N/H in the narrow line gas peaks outside the nucleus.

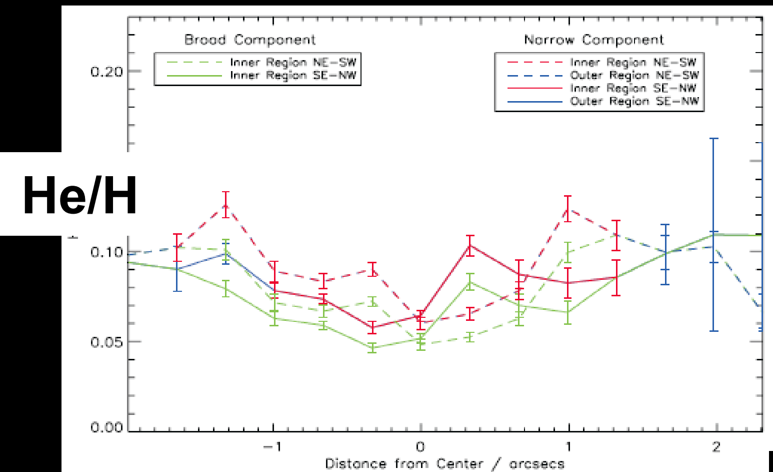
N/O (narrow) ~ 0.20 x solar
N/O (broad) ~ 4 x solar

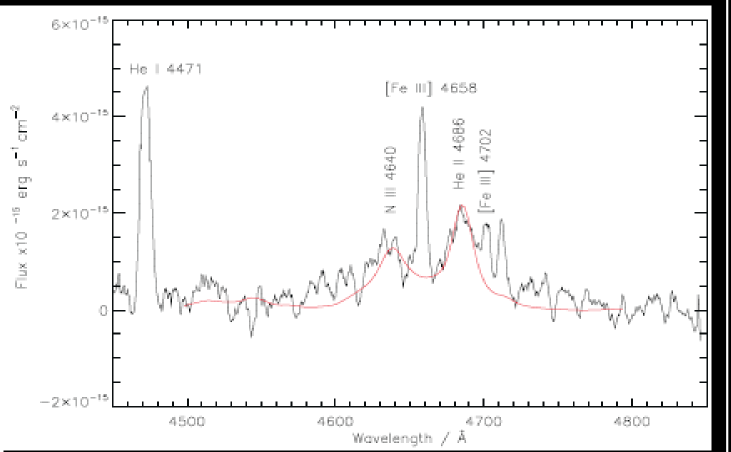
✓ N/H in dense broad line nuclear gas is 20x that in extended narrow line region!

✓S/O and Ar/O ~ solar (in both broad/narrow region).

✓No He/H differential between narrow/broad regions.

✓3000 WR (WNL+WC stars in nucleus) and 150,000 OB-type stars

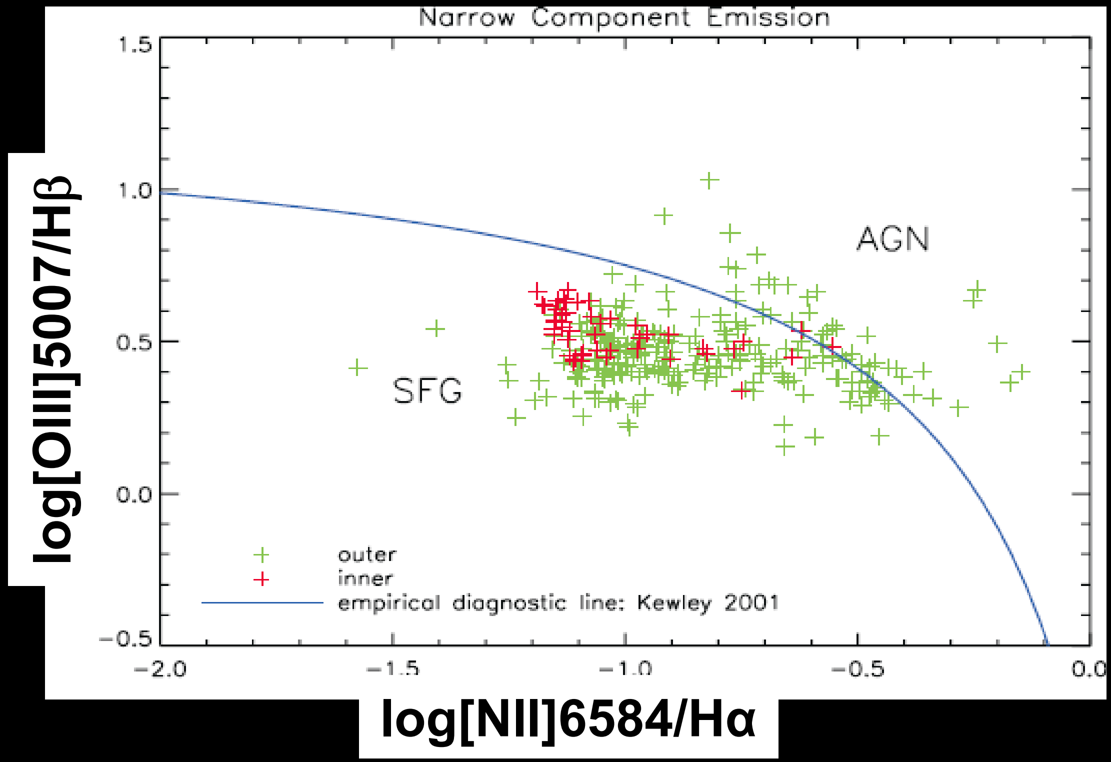




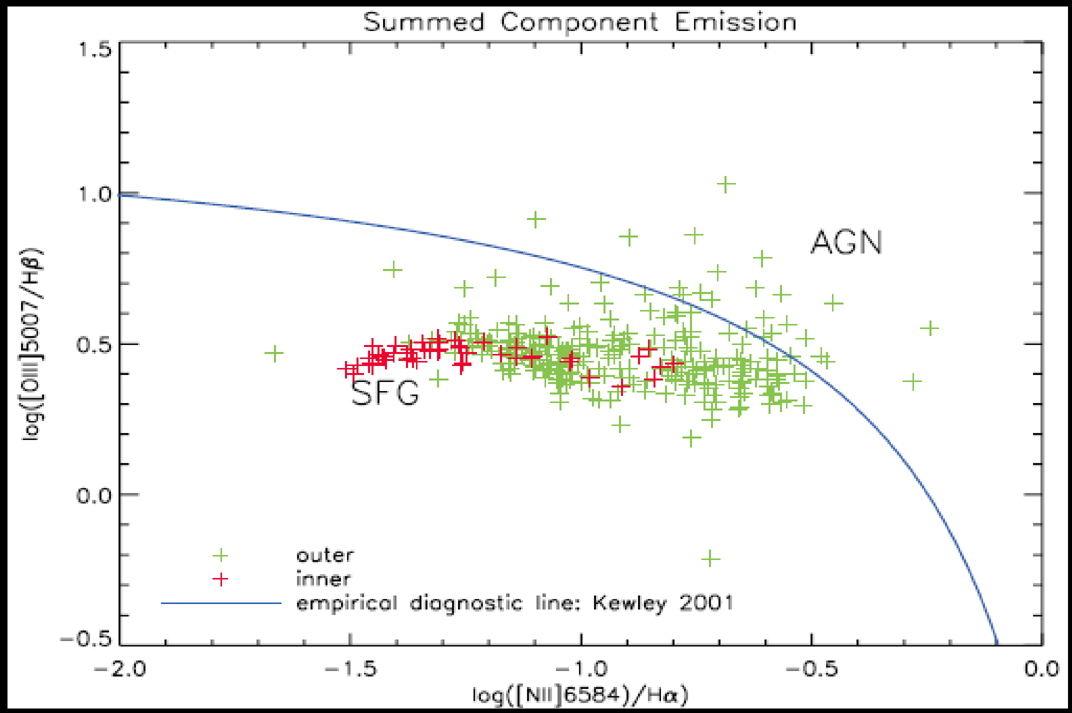
Age ~ 3 – 5 Myr

Diagnostic excitation diagrams

Narrow component gas only



Full line profile (narrow+broad)



Diagrams in the literature make use of integrated line ratios (right-hand side), but note the introduced bias when the diagnostic lines are not resolved!

Conclusions

- FLAMES and VIMOS are unique machines for the study of nebulae and galaxies.
- FLAMES Argus yields higher velocity resolutions (~9 km/s) with many spectral settings (~3500 – 8000 A), but has fewer fibres ~300. Can allocate “sky fibres” for sky subtraction.
- VIMOS IFU provides a large FoV with 1600 fibres, but at lower velocity resolution and does not cover the [OII] 3727-A doublet. With 4 individual spectrograph/CCD components it can be tricky to handle during the reduction. No “sky fibres”.
- The ESO pipeline (via the “GASGANO” tool) can handle the data reduction. FLAMES Argus also has its own pipeline from the Geneva Obs (“girBLDRS”).