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

Yiannis Tsamis

(IAA/CSIC, Granada)
Integral field spectroscopy of planetary nebulae: mapping the line diagnostics and hydrogen-poor zones with VLT FLAMES

Y. G. Tsamis, 1,2 J. R. Walsh, 2 D. Péquignot, 3 M. J. Barlow, 1 I. J. Danziger 4 and X.-W. Liu 5

Traditional Long Slit Spectroscopy

Long, narrow (~1 – 2 arcsec) slit:

- Spectral resolution $\lambda/\Delta\lambda \sim 3000$
  (FWHM $\sim 2$ 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
Optical recombination lines (ORLs) of heavy ions:

- Can be \(\sim1000\) times fainter than \(\text{H}\beta\), or the strong CELs
- \(\text{C} \ II \ \lambda4267\) (the strongest)
- \(\text{O} \ II\), \(\text{N} \ II\), \(\text{Ne} \ II\)

ESO 1.52m, long-slit spectrum

\(\sim30\) min

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
CELs (low)

ORLs (high)

ORL/CEL ratio

O$^{2+}$/H$^+$

$\lambda$4959

Similar trend in other PNe

[$\lambda$4649/$\lambda$4959]

PN nucleus

[$\lambda$4649]

[$\lambda$4959]
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
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\textsuperscript{1*}, Y. G. Tsamis\textsuperscript{1,2*}, M. J. Barlow\textsuperscript{1}, M. S. Westmoquette\textsuperscript{1}, J. R. Walsh\textsuperscript{3}, F. Cuisinier\textsuperscript{4}, and K. M. Exter\textsuperscript{5}


\textit{Part of PhD project of Bethan James at UCL (from October in STScI)}
The evolution of Nitrogen abundances in BCDs

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

- **C1**
  - **Flux**: 6563 Hα
  - **FWHM (km/s)**: 116.5 ± 0.9
  - **Radial velocity (km/s)** map
  - **FWHM (km/s)** map
Flux, radial velocity, and FWHM maps of the various components of Hα

![Diagram showing Flux, Radial velocity (km/s), and FWHM (km/s) maps of Hα components C1 and C2.]

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

6563 Hα C2

420.5 ± 7.3
Flux, radial velocity, and FWHM maps of the various components of Hα

FWHM~200-300 km/s
Kinematics: Identification of a mini-spiral (2 arcsec) in the nucleus

Position-Velocity diagram along the rotation axis

Thuan et al (1996)
Kinematics: Dynamical mass from the optical rotation curve

Rotation curve: mass as function of galactic radius

Mass of $5 \times 10^8$ Msol
One of very few optical rotation curves 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

Crucially, the auroral lines [OIII] 4363 and [NII] 5754 Å are only found as broad components over the whole galaxy and cannot be used as straightforward temperature diagnostics.
Physical conditions: Electron density

The $[\text{Fe III}]$ line ratios $4881/4658$ and $5270/4658$ Å indicate electron densities of $\sim 10^6 \text{ cm}^{-3}$.

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

\[ N_e \sim 10^7 \text{ cm}^{-3} \]

The broad line region Te is normal \( \sim 11,000\text{K} \)

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

\[ \text{O/H} \sim 0.5 \text{ solar at least} \]

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)

$\log[OIII]5007/H\beta$

$\log[NII]6584/H\alpha$

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”).