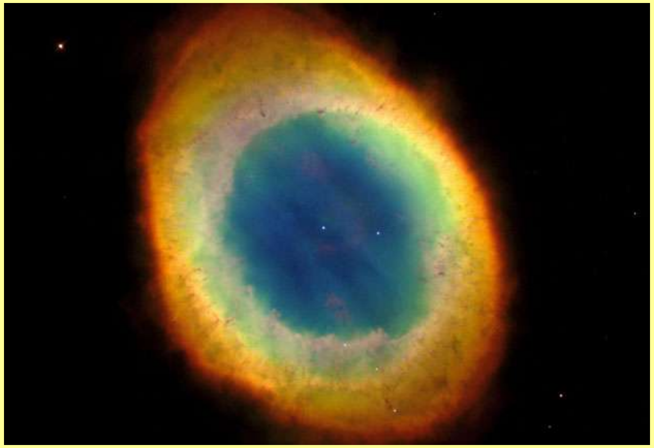
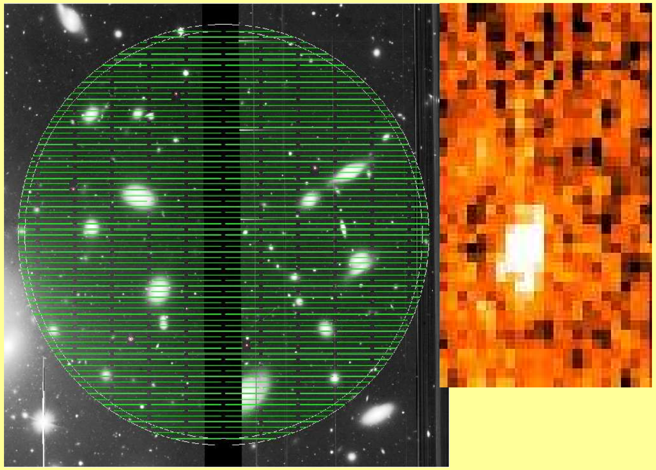
Intracluster Planetary Nebulae in the Coma cluster: first detections and future prospects





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Based on observations with FOCAS @ Subaru

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ICPNe in the Coma cluster:

Coma is one of the best studied nearby clusters; of these, it is the richest and the most compact one. It provides a laboratory for studying the effect of a dense environment on galaxy evolution.

Presence of Intracluster light is established from SB measurements (Bernstein et al. 1995). The brightest PNe in the Coma cluster at ~100 Mpc distance have fluxes of 2.2×10^{-18} ***erg/s/cm***^{2} **.**

To detect even the brightest Coma PNe we must find a way to decrease substantially the noise from the night sky!

Multi Slit Imaging Technique (MSIS)

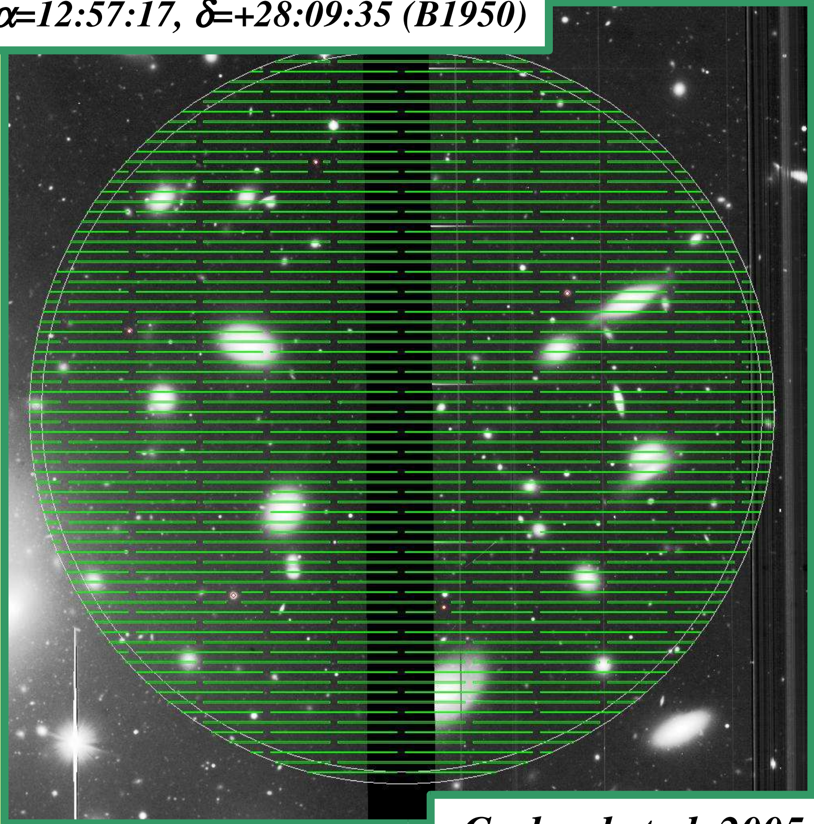
It combines a mask of parallel multiple slits with a narrow band filter, centred on redshifted [OIII] 5007 Å line at Coma redshift, to obtain spectra of all PNe that lie behind the slits. Dispersing the sky noise allows measurement of very faint fluxes.

Similar approach as in searches for high z(>5) Lyα *(Tran et al. 2004).*

MSIS observations were carried out with the FOCAS spectrograph at the 8.2m Subaru telescope on April 21-23, 2004. Spatial resolution was 0".1 pix^{-1}; we used grating 300B, giving a measured dispersion 1.4 Å pix^{-1}. Effective spectral resolution is 4.4 Å, or 440 km/s.

We used the N512 filter, centred at λ= 5121 Å & FWHM = 60Å $\Leftrightarrow \pm 1.6 \times \sigma_{Coma}$.

α=12:57:17, δ=+28:09:35 (B1950)



Gerhard et al. 2005, ApJ, 621, L93

- ***60 Å projects down to a 43 pix spectrum***
- ***The area surveyed by this mask conf. is 12% of the whole FOCAS FOV***
- ***Measured Seeing during obs. 0".6 – 0".8***
- ***Monochromatic, point-like emitters appear as elongated ellipses on the CCD, with width ≈ 4 pix and height of 5 pix.***

How many PNe do we expect per slit configuration?

SB in the Coma field is B=25.7 mag /□” , then B_{tot} = 13.28 & L_B = 7.6 $\times 10^{10}$ L

Evolved stellar population with $\alpha_{1.0,B}$ = 5.6 $\times 10^{-9}$ PN $L_{B,}$

- *We expect 425 PNe associated with Coma ICL in this field.*
- *Because only a fraction (12%) is surveyed by mask, and sources may not be centred on slit, so about half may be dimmed:*

  ⇒ We expect to detect approx. 20-30 PNe per mask.

What signal-to-noise can be achieved?

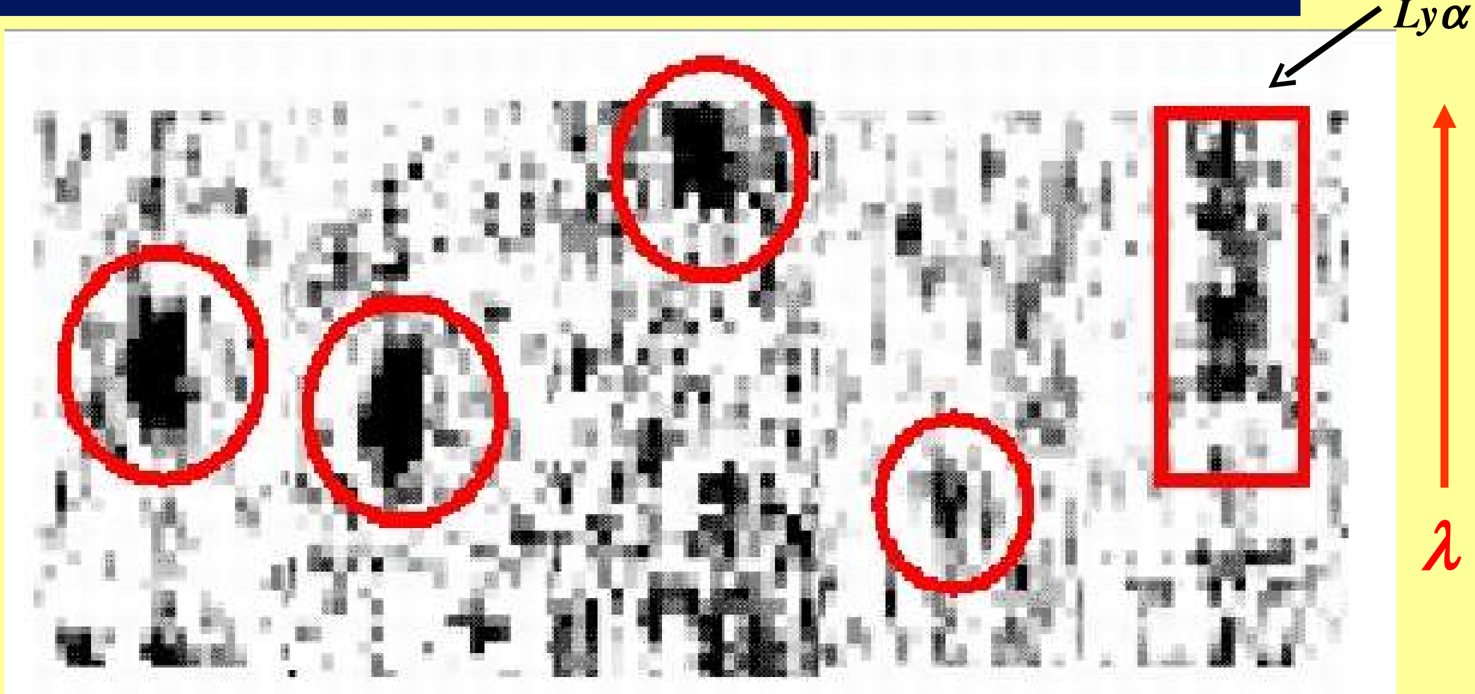
A PN as a point-like monochr. source falls onto $n=k'\pi\phi^2/(4\sigma_x\sigma_y)$ pixels; for our observations ϕ=FWHM=0”.6; k’=1.4, $\sigma_x = \sigma_y$ =0”.1

For a total int. time of 3hrs, t_{exp}=1.08 $\times 10^4$ sec, tel. area of S = 5.281 $\times 10^5$ cm^2, overall eff. ε = 0.1, d= 1.45 Å/pix ($h\nu = 3.61 \times 10^{-12}$ erg = E_{5500}) we obtain:

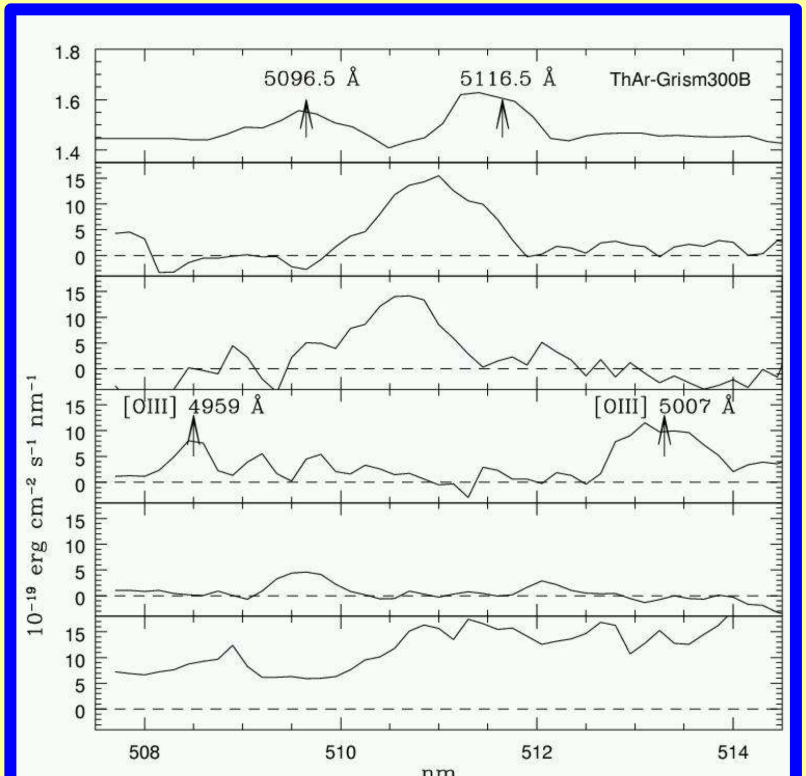
$$SNR_{PN} = 7.0 \times 10^{-0.4\Delta m} \times (d / 1.45\ \text{Å/pix})^{-1/2} (\phi/0''.6)^{-1} (\theta/6\sigma_y)^{-1/2} (t_{exp}/3\text{hrs})^{1/2}$$

Relative to the** **<u>sky noise in one pixel</u>**, **the S/N of a PN at the PNLF cutoff ($\Delta m=0$) would be 32. *Detection of a source is considered secure if S/N relative to sky noise in 1 pix is ≥ 9. In our data this correspond to $SNR_{PN} \geq 2$, i.e. 95% prob. of the source to be real.* ***Therefore** **<u>with the MSIS we can securely detect PNe about 1.4 mag down the PNLF .</u>***

First 2D spectra



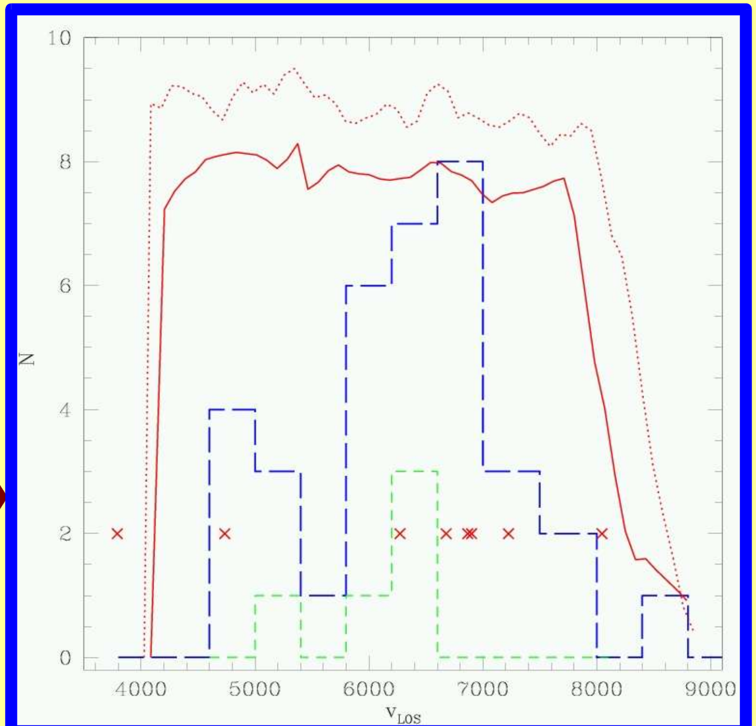
2D median averg. spectra of emission objects in Coma field. <u>Left 4 panels show PN candidates, from brightest to faintest</u>. Fluxes from 17,16,9,3 $\times 10^{-19}$ erg/s/cm², corresponding from 380 to 68 [OIII]5007 photons in 3 hrs!



1D spectra of PN candidates and Lyα. Comparison with arc lamp (top panel) indicate PN candidates are unresolved in λ.

The object in 3rd panel is sufficiently redshifted that <u>both lines [OIII] 4959, 5007 Å fall into filter bandpass.</u>

Velocity histogram for all 35 ICPNe in the 3 masks (Arnaboldi et al. in prep), and 5 PNe candidates detected in the halos of Coma galaxies (dashed green). V_{mean} = 6352 km/s and dispersion is σ=900 km/s. Overplotted is filter transmission curve (full & dotted red line).



Evidence that our unresolved emission sources are PNe in the Coma cluster:

3. ***They are unresolved both spatially and in wavelength.***
4. ***They have no detectable continuum, to a limit of 1.6 $\times 10^{-20}$ erg/s/cm^2/Å. Brightest object thus has EW > 110 Å.***
5. ***We have seen both lines of [OIII] doublet in the sources at sufficiently large recession velocity that also 4959Å is redshifted in the filter wavelength range.***
6. ***The emission fluxes of the brightest objects are consistent with those of the brightest PNe in a population at 100 Mpc distance.***
7. ***The number density of our candidates is consistent with that expected from the measured SB of the ICL in our Coma field.***
8. ***The distribution of recession velocities is centered around the Coma cluster and is inconsistent with a population of background objects uniformly distributed in velocity.***

The great majority of the detected PN candidates would be ICPNe in the Coma cluster!

Conclusions

• With the MSIS technique and 8m telescopes, can detect and measure velocities of PNe out to 100 Mpc distance. Can thus study the kinematics of the ICL in galaxy clusters up to Coma.

• In 3 nights with FOCAS @ Subaru, we found ≈35 ICPNe:
- unresolved in space and λ, without continuum
- the right fluxes for PNe at 100 Mpc, and number density
- second λ 4959Å line where bright and red enough
- not associated with galaxies in the field

• The ICPN velocity distribution in the Coma cluster core shows that even this dense cluster may not be dynamically mixed, but is in a state prior to complete merging of subclusters.

• The ICPNe in the Coma core show a possible population effect: faint and bright PNe have different velocity distributions