The extragalactic planetary nebulae as tracers of evolved stellar population

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RASPUTIN workshop

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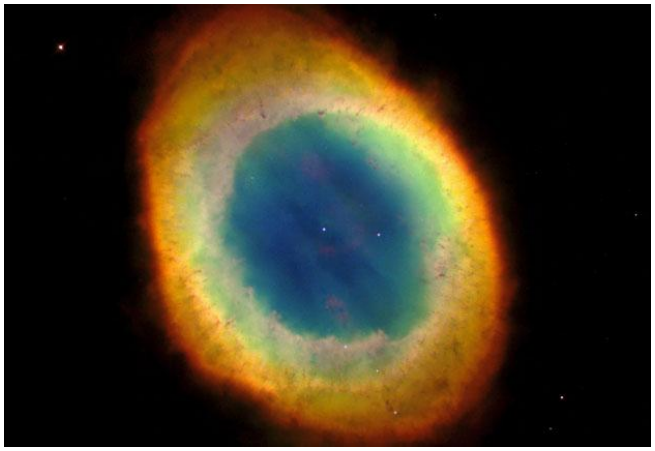
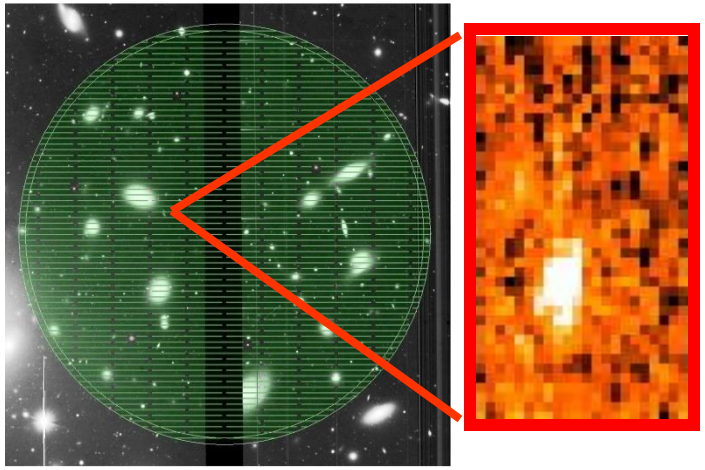
Planetary Nebulae

Ring nebula M57





- A typical Galactic PN is roughly 0.3 pc in diameter; when observed in external galaxies, PNs are unresolved emission of green light at 5007 Å ([OIII]).
- About 2000 PN are known in the MW out of 200 billion stars, mostly in the MW plane and about 800 in the bulge.
- In MW 95% of the stars end their lives as PNs, the remaining 5% as SN.
- Up to 15% of the core star's UV energy is re-emitted in the [OIII] 5007 Å line

Outline

1. **Motivation: PNs as distance indicators & tracers of stellar populations**
2. The PN populations in the Virgo cluster core
3. Conclusions

Motivation I. PNLF in [OIII]@5007Å

[OIII] fluxes of a PN population:

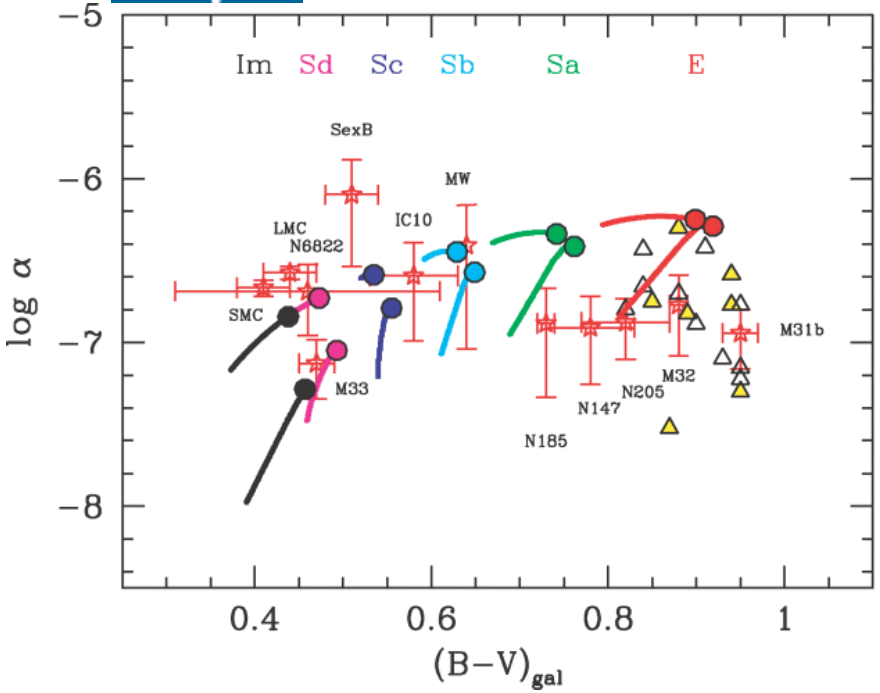
$$m_{5007} = -2.5 \log F([OIII]_{5007}) - 13.74 \quad \text{(Jacoby 1989)}$$

$$N(M) \propto e^{0.307M} x (1 - e^{3(M^*-M)}); \; M^* = -4.51 \; \text{(Ciardullo+1989)}$$

- $F^*([OIII]_{5007}) = 3.2 \times 10^{-10}$ erg/s/cm^2 @MW Bulge
- $F^*([OIII]_{5007}) = 2.4 \times 10^{-14}$ erg/s/cm^2 @M31
- $F^*([OIII]_{5007}) = 9.6 \times 10^{-17}$ erg/s/cm^2 @Virgo
- $F(*[OIII]_{5007}) = 2.2 \times 10^{-18}$ erg/s/cm^2 @Coma => it corresponds to ~2 photons/min on 8m tel.

[OIII] fluxes from PNs in Virgo and beyond are of the same order of the Lyα@z=3.14, [OII]3727Å@0.34 emissions. Small HII regions in ETGs halo may also mimic bright PNs (Gerhard et al. 2002, ApJL, 589, 121; Ryan Weber et al. 2004, AJ, 127, 1431)

Motivation II. PN visibility lifetime & α values



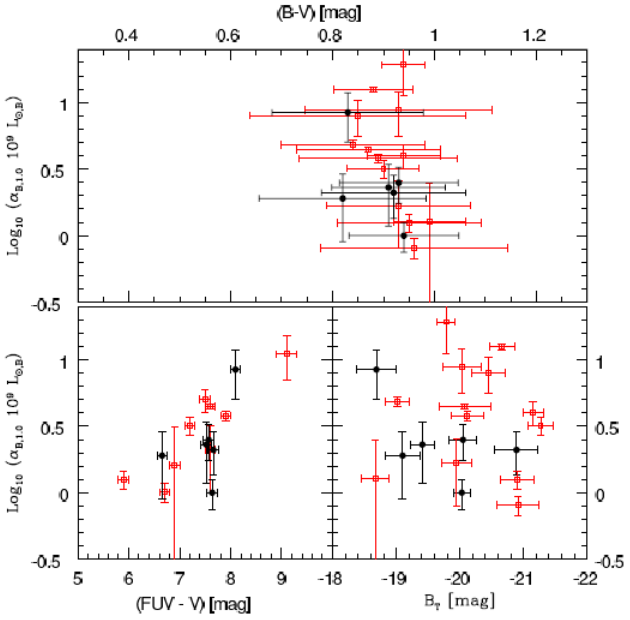
Buzzoni+2006, MNRAS, 368, 877

The luminosity specific PN number

$$\alpha = N_{PN}/L_{bol,gal} = B\tau_{PN}$$

It is function of metallicity and age of the parent stellar populations.

The observed values of α show a strong scatter in red and old stellar populations (Hui+93, Ciardullo+05, Coccato+09. Cortesi+13)



$\alpha_{B,1.0}$ for ETGs: Ellipticals and S0s

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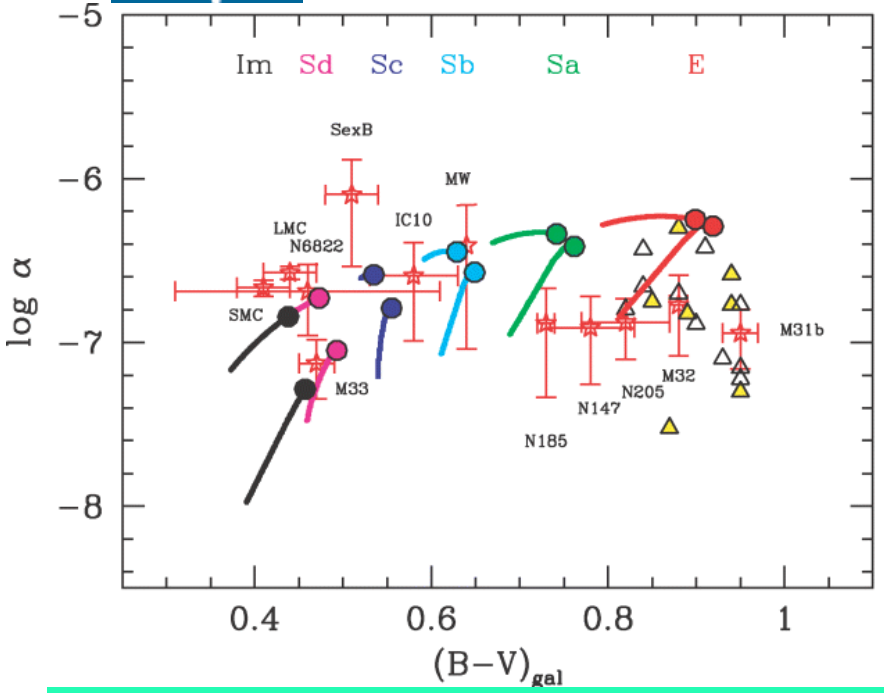

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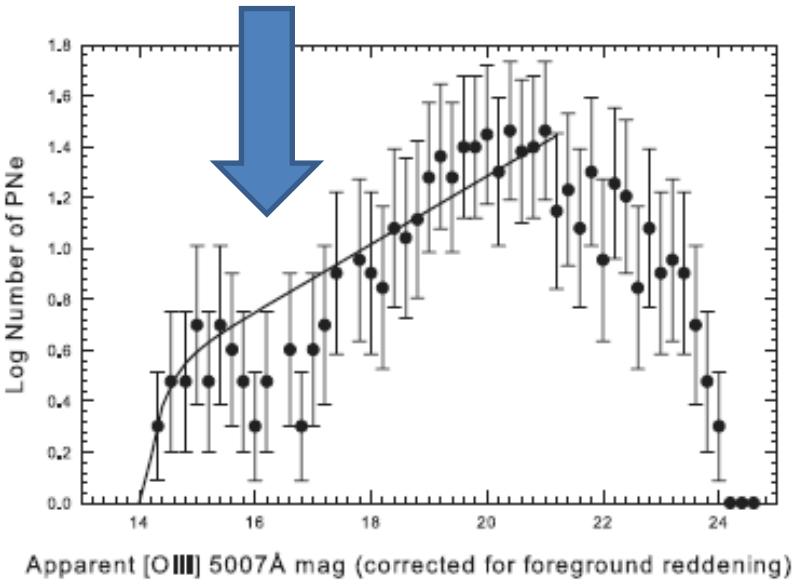
τ_{PN} can be estimated using v_{exp} and D_{PN} , as

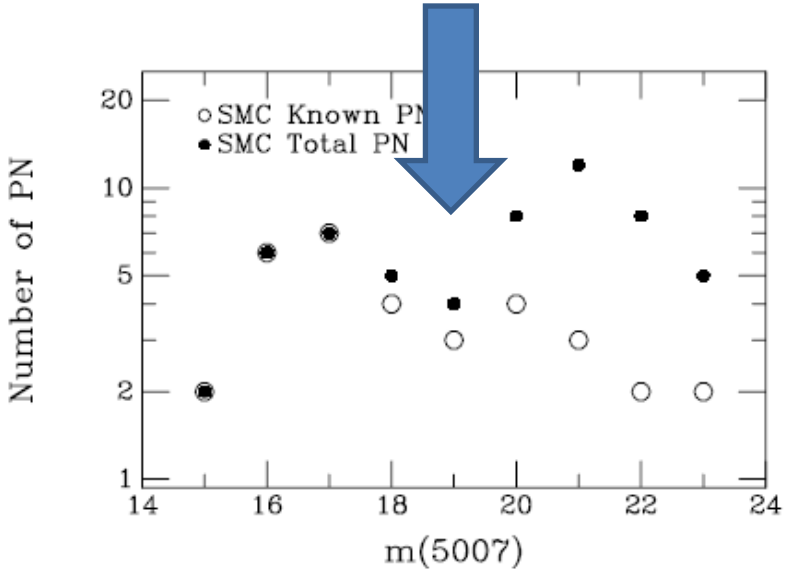
$\tau_{PN} = D_{PN} / v_{exp}$

In the Galactic bulge (560 PNs), D_{ave} = 0.3 pc & V_{exp} =30 kms^{-1}. Hence τ_{PN} is few 10^3 yrs => similar to values inferred for PN populations in ETGs

Motivation III. PNLF shapes

PNLFs show systematic variations: 1) the gradient at 1.5 mag below brightest is shallower depending on the star formation history (Ciardullo+2004,ApJ,614,167) and 2) presence of a dip in the magnitude range 1-4 below the brightest (Jacoby&DeMarco 2002, Reid & Parker 2010) in SF sps.





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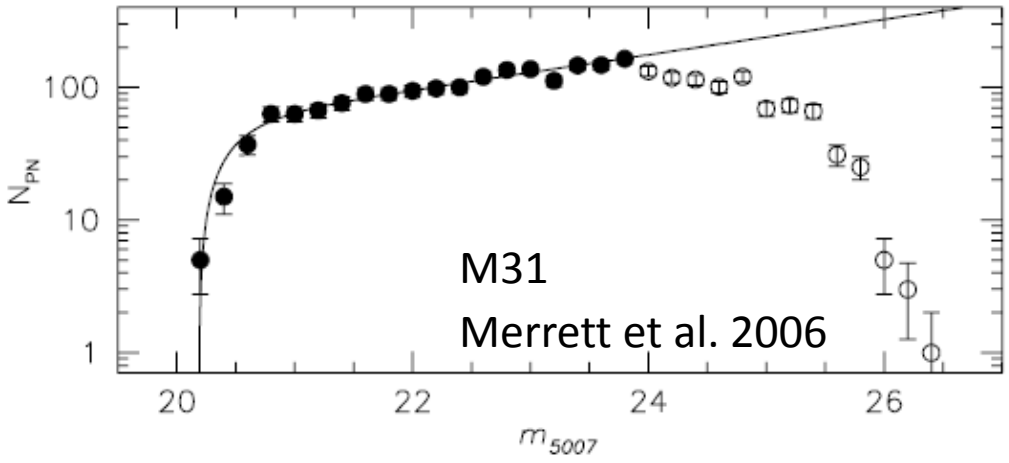

Motivation

- GOALS: PN samples can be used to map large scale variations of the parent stellar populations in external galaxies whenever these galaxies are either too far and individual stars cannot be resolved, or the surface brightness of the parent population is too faint, of the order of ~1% of the night sky!

1. Motivation: PNs as distance indicators & tracers of stellar populations
2. **The PN populations in the Virgo cluster core**
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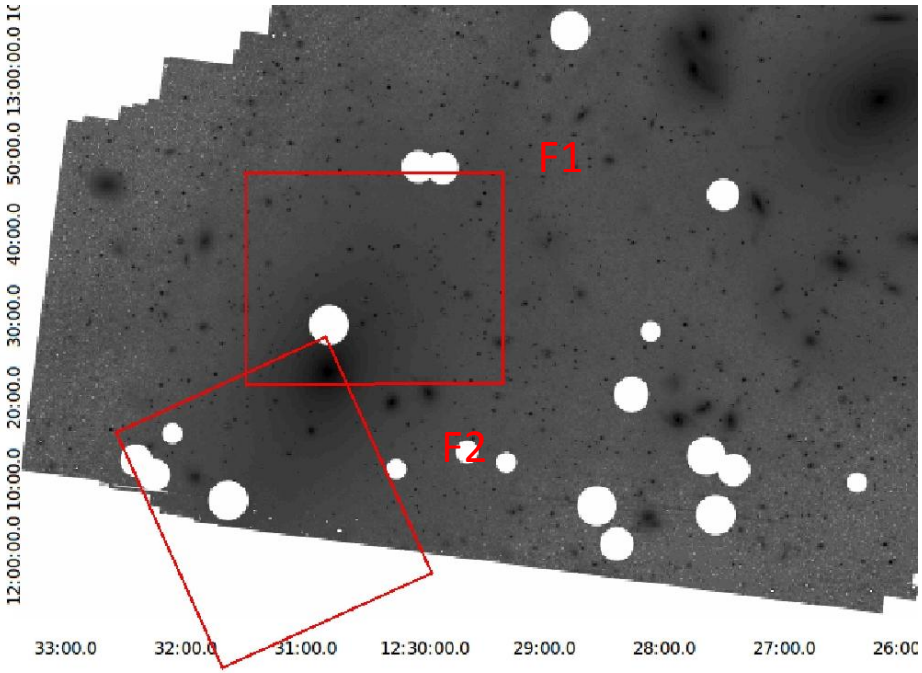
The PN populations in the Virgo cluster core

- In 2010 we started a new project to study dynamics and substructures in the M87 stellar halo using PNs as tracers out to 150 kpc
- Imaging project with SuprimeCAM@Subaru to cover 0.5 deg^2 in the M87 outer halo.
- Deep [OIII] and deep off-band V images.
- Identify PN candidates as [OIII] point-like emissions with no continuum.
- Spectroscopic follow-up with FLAMES@VLT; completed in March 2014
- **Ph.D Thesis of Alessia Longobardi (IMPRS@Garching) – More on A. Longobardi's poster N.27.**

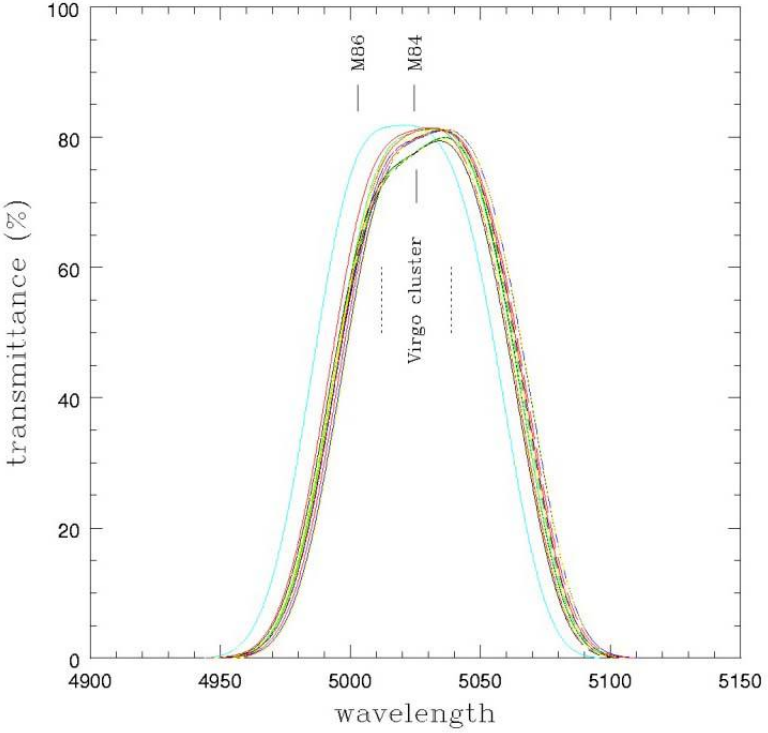
1. Motivation: PNs as distance indicators & tracers of stellar populations
2. The PN populations in the Virgo cluster core
   a. **SuprimeCAM@Subaru survey of M87**
   b. **FLAMES@VLT spectroscopic follow-up**
   c. **Properties of the PN populations in the Virgo core**
3. Conclusions

2a.SuprimeCAM@Subaru survey of M87

- SuprimeCAM observations of M87. For each field:
  - Total exposure [OIII] NB 6 hrs
  - Total exposure in V band 1.23 hrs
- Seeing in [OIII] & V images < 0’’.8

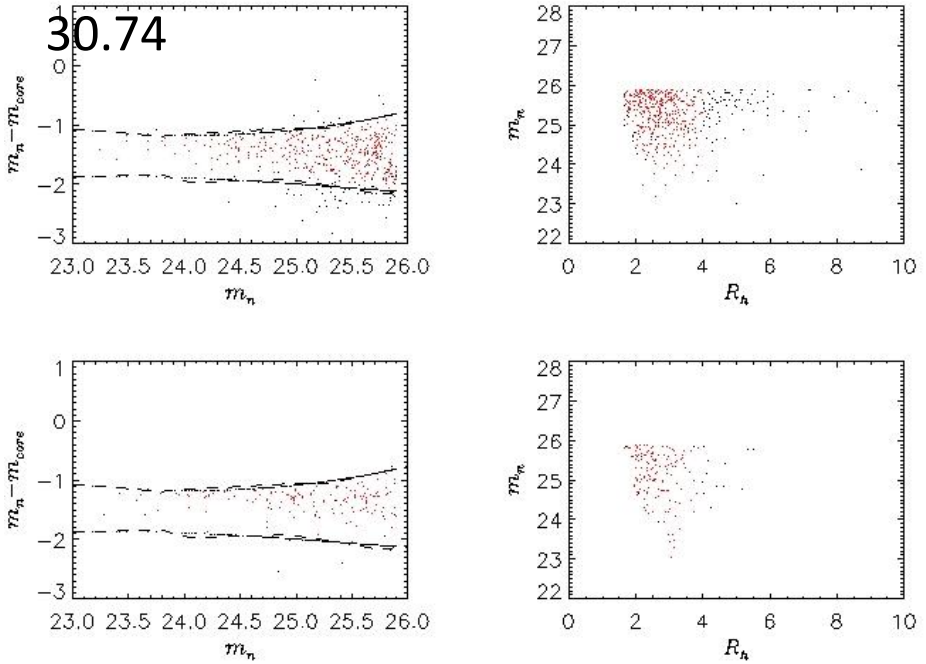


[OIII] filter transmission curve

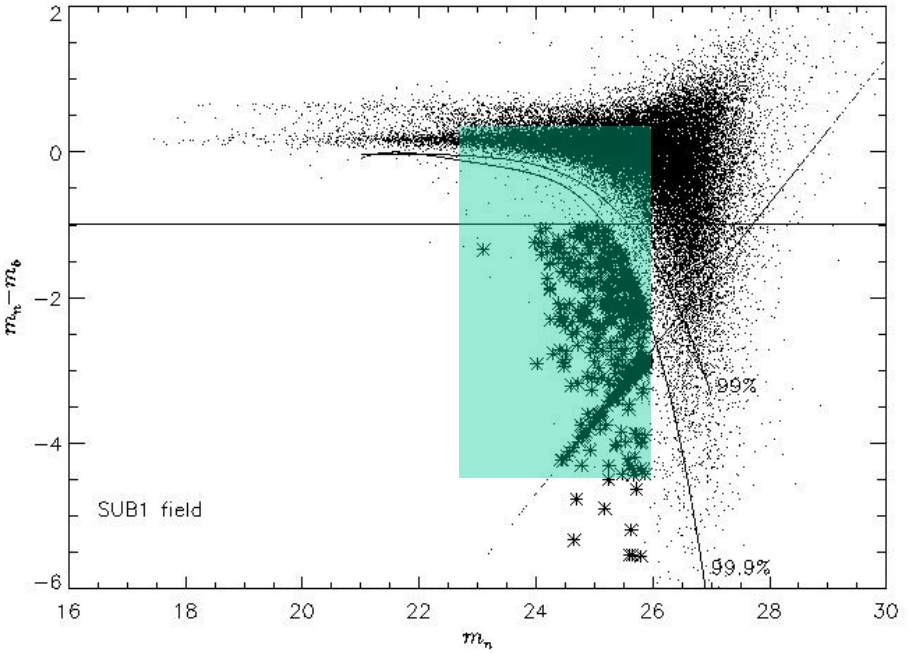


2a. SuprimeCAM@Subaru survey of M87

- Imaging data reduction: SuprimeCAM pipeline
- Catalogue extraction: SExtractor. Selection criteria for PN candidates from Arnaboldi+2002AJ123,760
- Final catalogue of 688 PN candidates in F1+F2, [OIII] limiting mags 28.5, i.e. 2.5 mags below the apparent magnitude of the PNLF cut-off for a distance modulus 30.74



Selection of point-like objects on the basis of the PSF shape



CMD for the selection of objects with a color excess in the [OIII] NB filter

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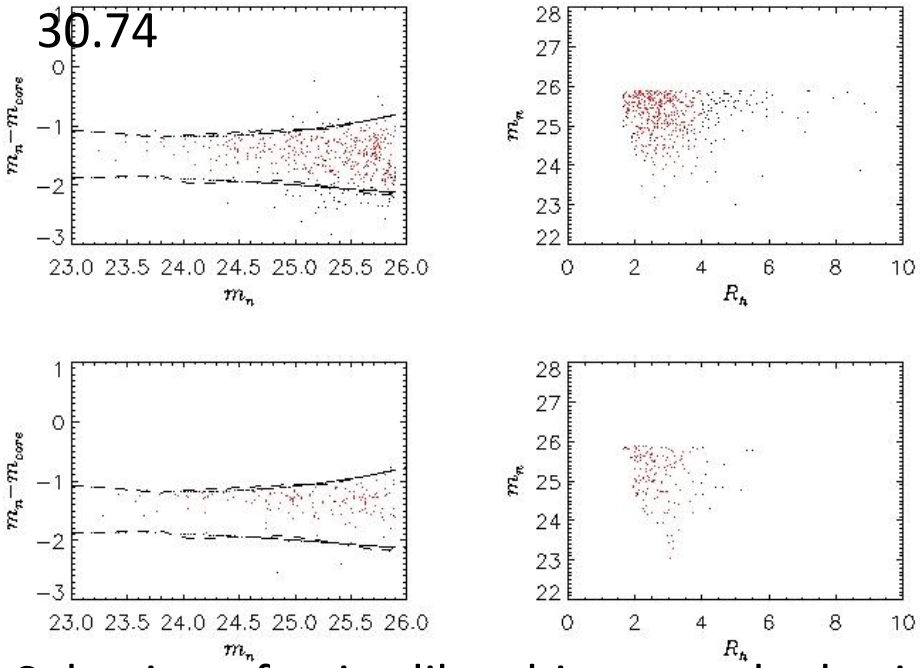

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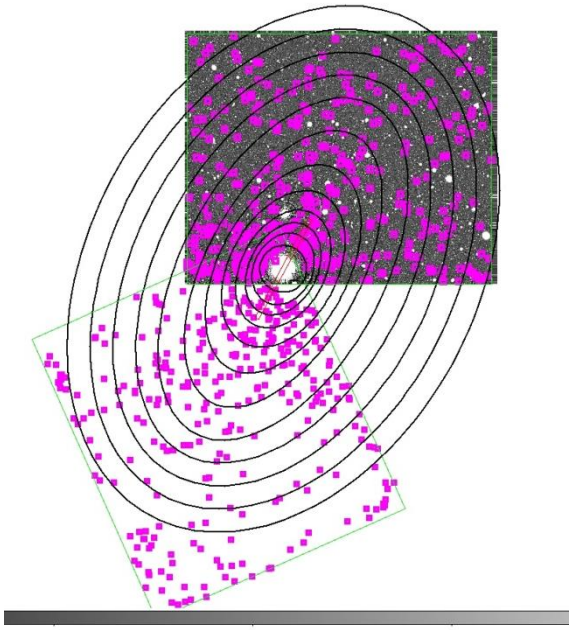


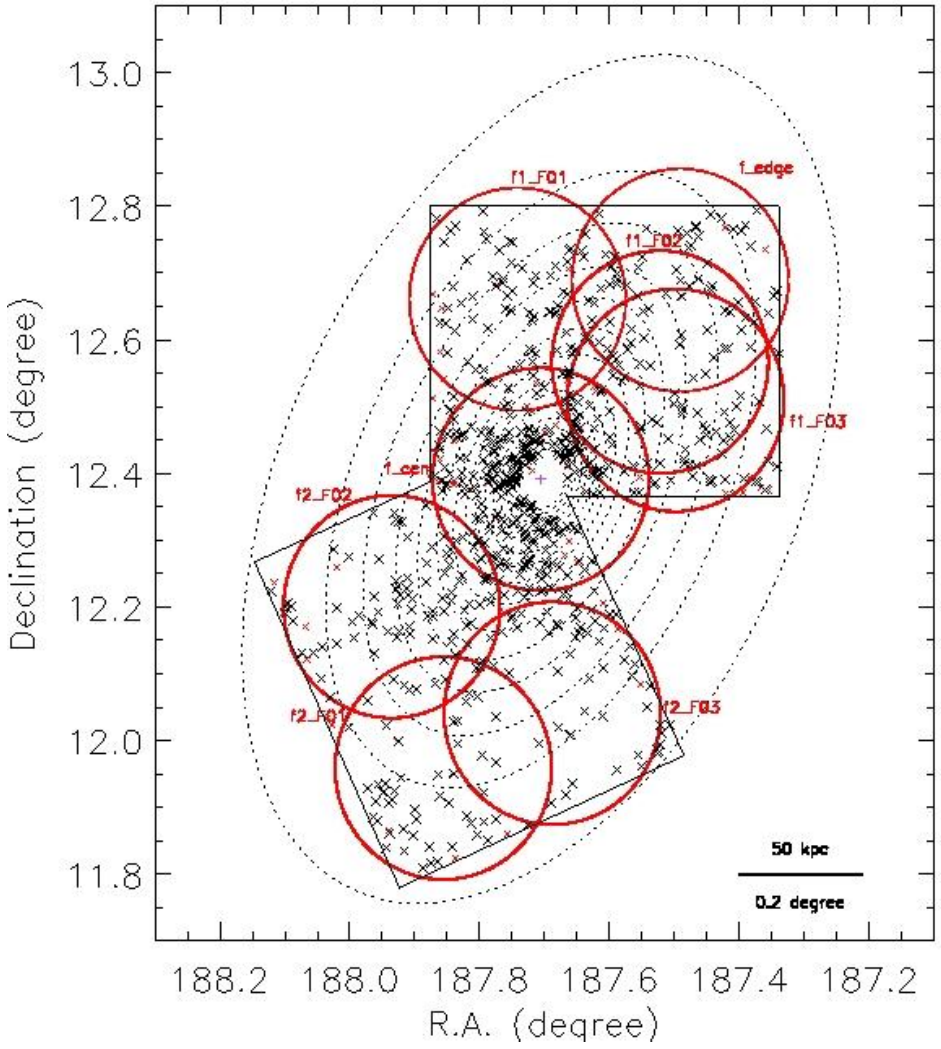
Distribution of PN candidates in the M87. Ellipses show isophote' contours

2b. FLAMES@VLT spectroscopic follow-up

Spectroscopic follow-up with FLAMES@UT2 on VLT; 14 fiber configurations; Spectral resolution R=22500.

289 spectr. confirmed PNs (Longobardi et al. 2014, A&A, sub., and Longobardi et al. poster N. 27)

Additional 12 PNs from Doherty et al. 2009 (D09)



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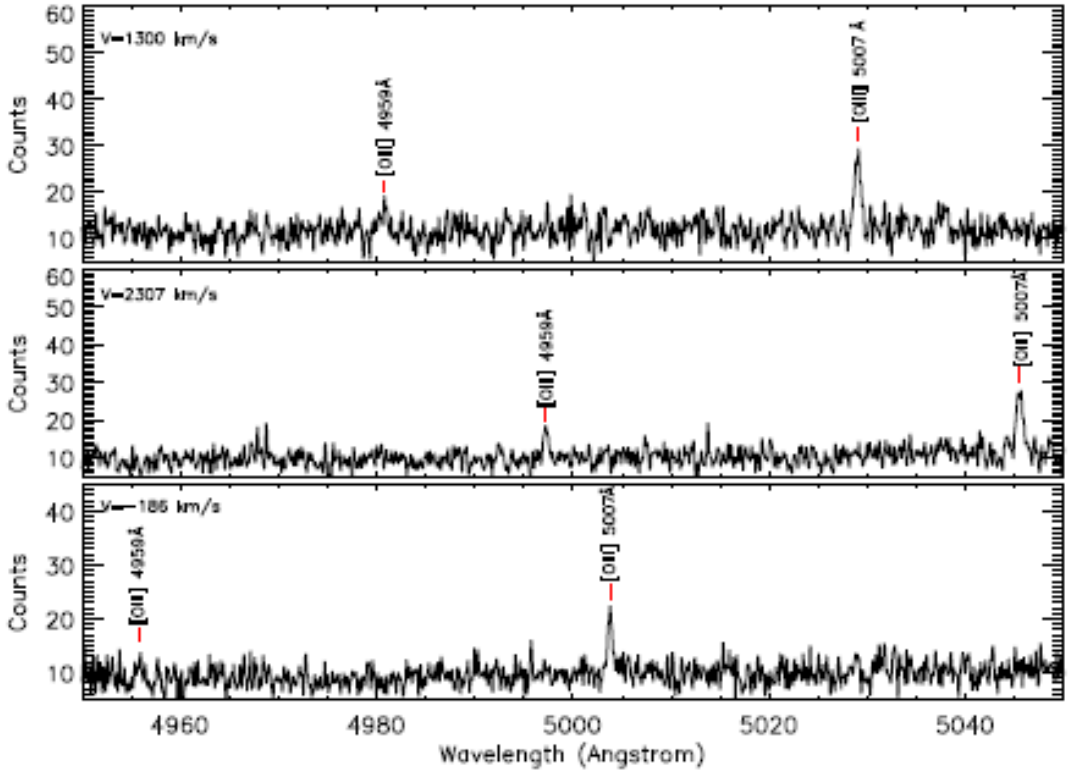
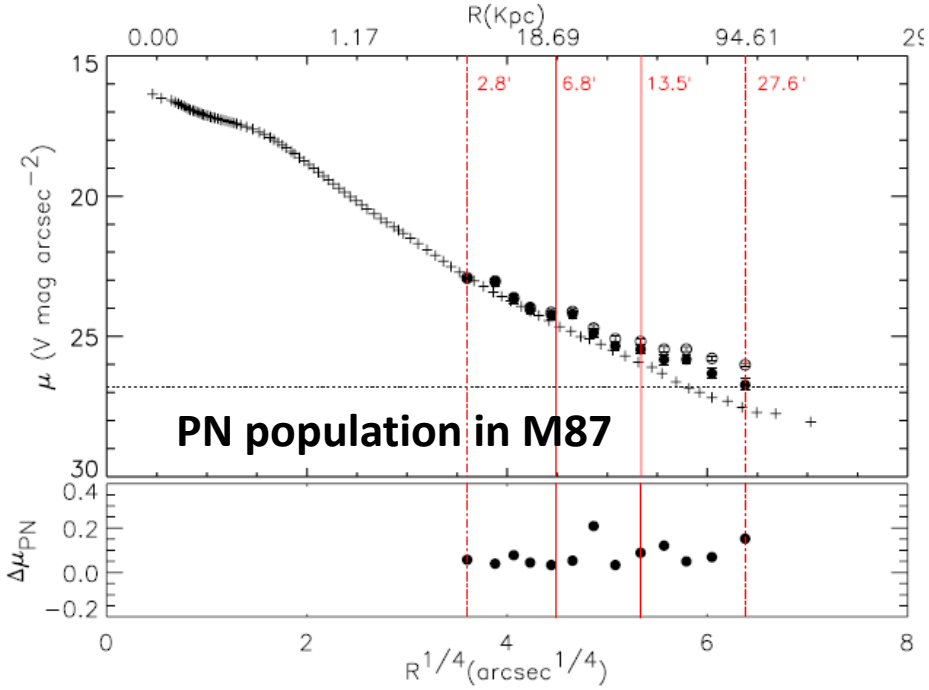


Single PN spectra – From Longobardi+2014

2c.Properties of the PN populations in the Virgo core: α values



PN number density profile matched to μ_V

$$\tilde{\Sigma}(R) = [\alpha_{2.5,\mathrm{halo}} I(R)_{\mathrm{halo,bol}} + \alpha_{2.5,\mathrm{ICL}} I_{\mathrm{ICL,bol}}]$$

$$= \alpha_{2.5,\mathrm{halo}} \left[I(R)_{\mathrm{K09,bol}} + \left(\frac{\alpha_{2.5,\mathrm{ICL}}}{\alpha_{2.5,\mathrm{halo}}} - 1 \right) I_{\mathrm{ICL,bol}} \right]$$

Two component photometric model

$\alpha_{2.5,ICL}=2.5x\alpha_{2.5,M87}$

The α values translate into different PN visibility lifetimes:

$\tau_{PN}=1.1\ 10^4$ yr in ICL and $4.5\ 10^3$ yr in M87 halo

Longobardi et al. 2013, A&A, 558, 42
Longobardi et al. 2014, A&A, sub.

2c. Properties of the PN populations in the Virgo core: PNLF in M87

We generalize Ciardullo's 1989 formula and account for stellar populations effects:

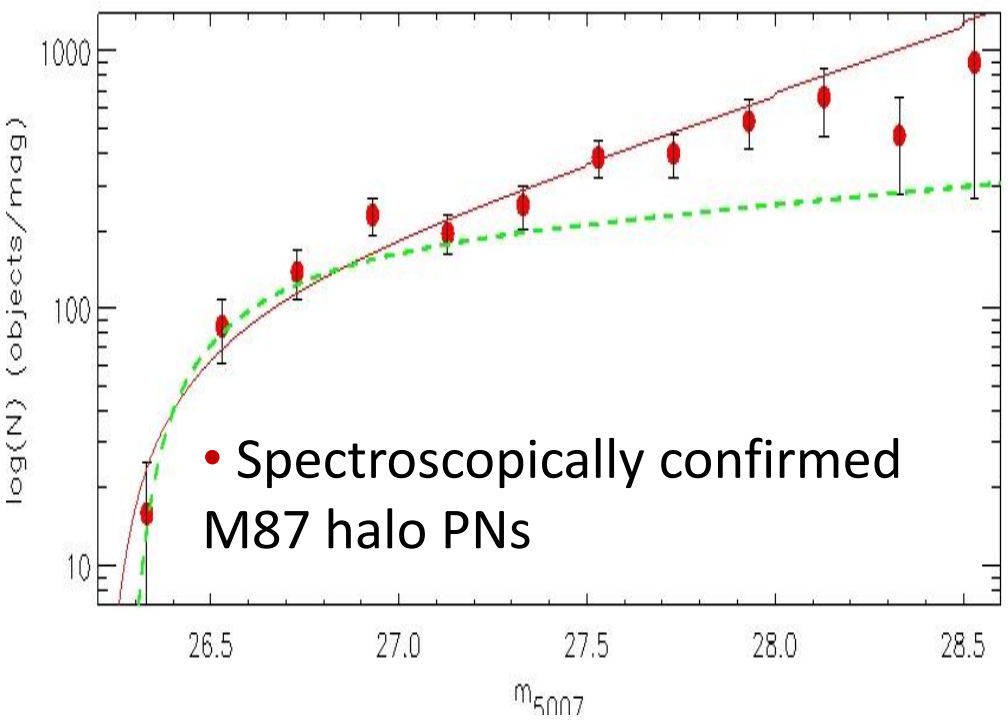
$N(M) = \mathbf{c_1} e^{\mathbf{c2}M}(1-e^{3(M^*-M)})$;

$M^*=-4.51$ (Ciardullo+1989)

C_1 is related to α at first order

C_2 is related to the gradient at fainter m_{5007} than the cutoff

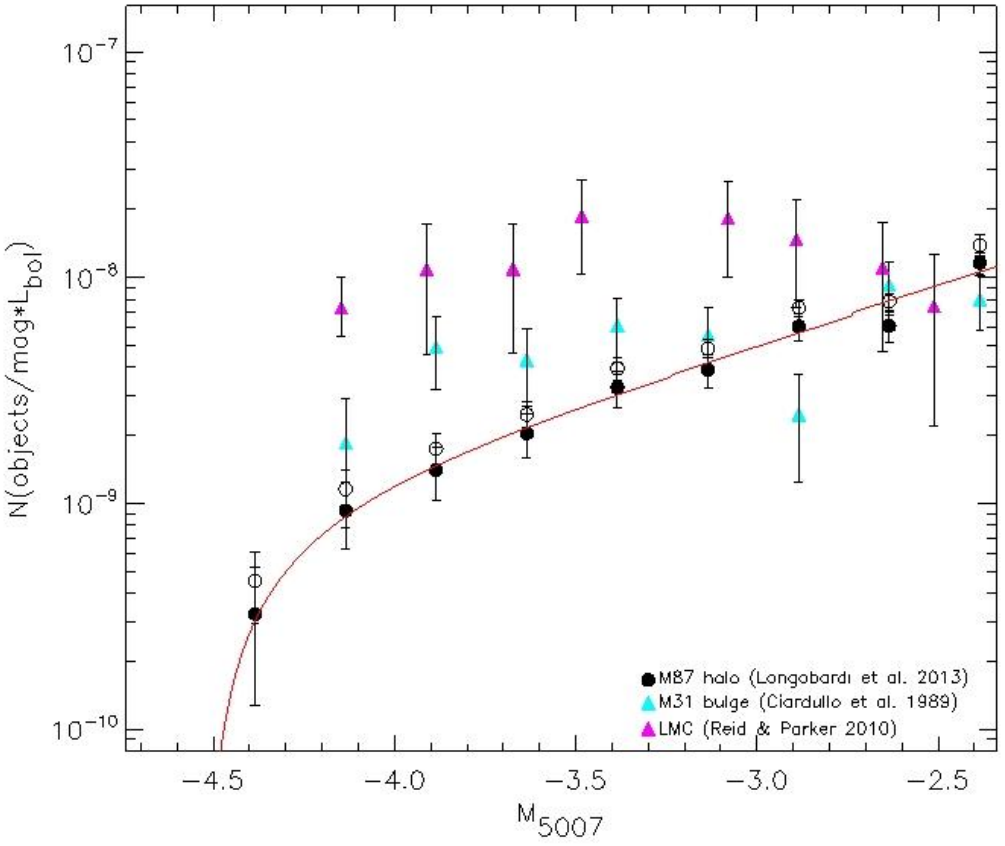
Longobardi et al. 2013, A&A, 558, 42



For M87: c_2=1.17 and m-M= 30.74

2c. Properties of the PN populations in the Virgo core: PNLF in M87

- PNLFs from different PN & stellar populations.
- Complete to 2.5 mag down the PNLF cut-off & spec. confirmed.
- Normalize them by $L_{bol,\odot}$ of the light, in the same region where PNs are detected.
- PNLF for **LMC**, **M31** and **M87** (Arnaboldi, Longobardi, Gerhard in prep.)



M* is invariant, but the gradient changes! It is steeper than for Galactic & M31 bulge PNs

Conclusions

- Luminosity specific PN number (α) values, PN visibility lifetime and the PNLF shape are functions of the star formation history and metallicity of the parent stellar population.
- The M* at the PNLF bright cut-off is invariant!
- There are two distinct PN populations in the Virgo core: the M87 halo PNs and ICPNs.
- <u>The PN population in the M87 halo stars is different from M31/Galactic bulge PNs.</u>