

# Light element abundances in NGC 5128 from planetary nebulae

Jeremy R. Walsh, ESO

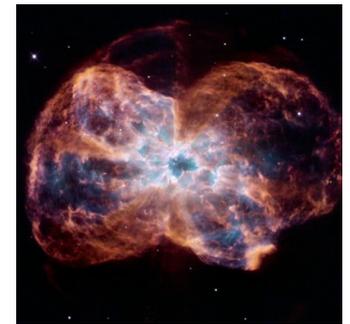
George H. Jacoby, WIYN

Reynier Pelletier, Kapteyn Lab., Groningen

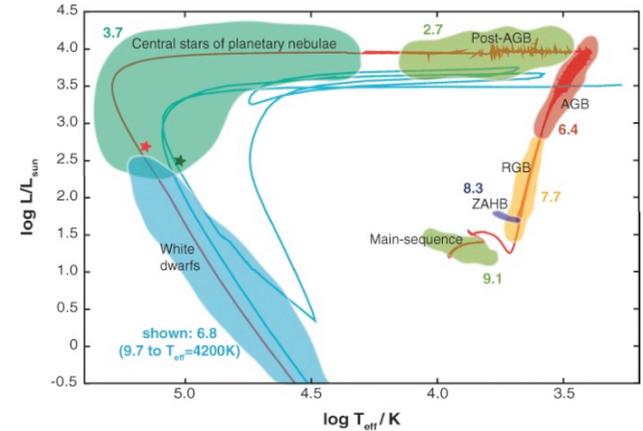
Nic A. Walton, IoA, Cambridge



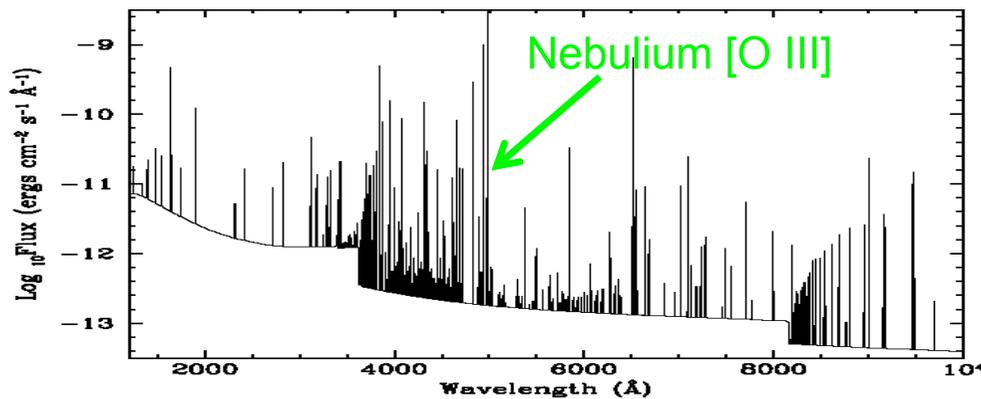
# Planetary nebulae



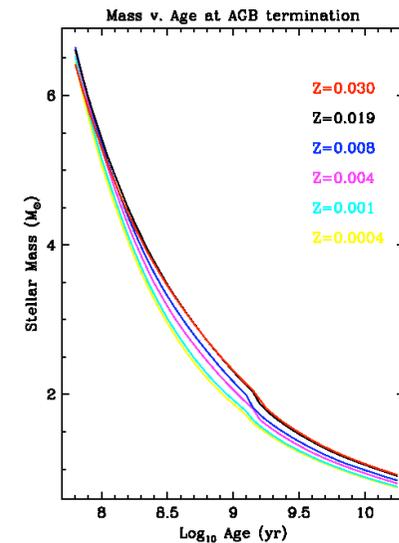
- Low mass ( $\sim 0.7-7M_{\odot}$ ) main sequence stars undergo a planetary nebula (PN) phase at ages 0.1-10Gyr depending on initial mass, following the red-giant branch (RGB) and asymptotic giant branch (AGB) to the white dwarf cooling track
- Length of PN phase  $\sim 10^4$  yr (depending on core mass)
- Emission from the expanding shell ionized by the hot (50-150,000 K) central star

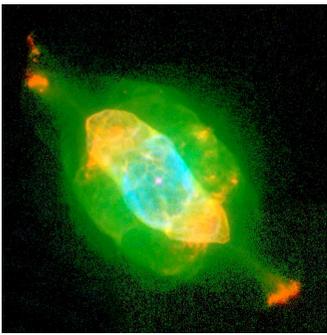


Herwig, F. 2005  
Annu. Rev. Astron. Astrophys. 43: 435-79



giving  
 $He^{4+}$

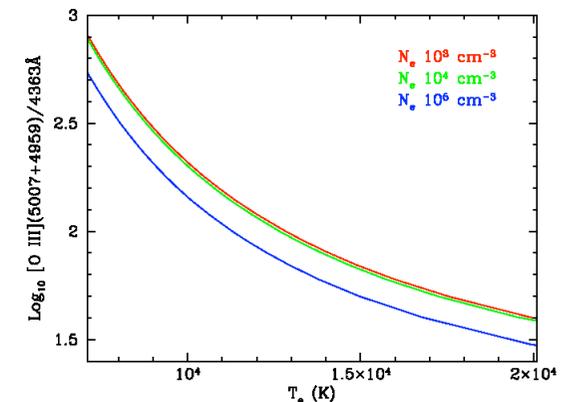
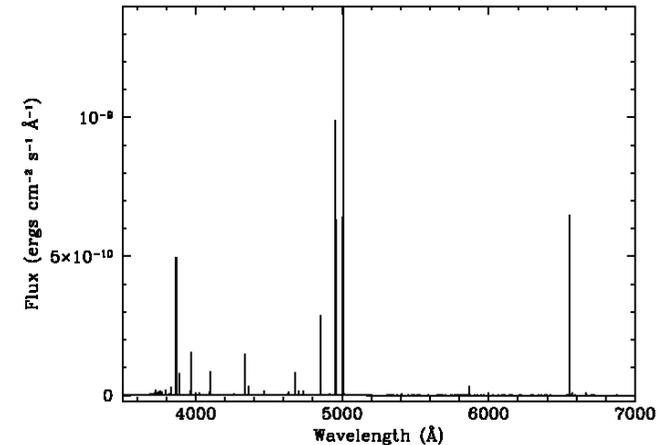




# Planetary nebula spectra

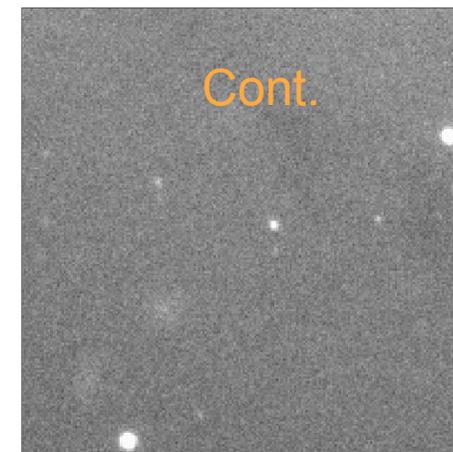
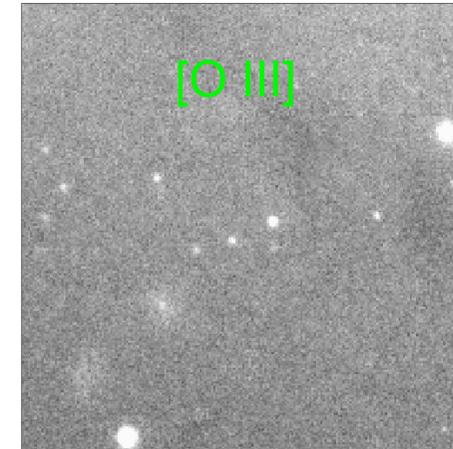


- O is the most efficient coolant for the nebula
- $< 15\%$  of the stellar luminosity ( $1-2 \times 10^4 L_{\odot}$ ) is emitted in a single collisionally excited line  $O^{++} \ ^1D_2 - \ ^3P_2$  [O III]5007Å
- This strong line allows detection of PN; high [O III]/H $\alpha$  ratio discriminates against HII regions
- Other lines of H, He, N, Ne, Ar, S prominent in optical spectra of PN
- Line ratios dependent on  $T_e$ ,  $N_e$  and abundance
- Some line ratios of same species depend on  $T_e$  and/or  $N_e$ . Example: [O III]5007/4363  $\Rightarrow T_e$
- Determine O abundance:
  - [O II]3727Å / H $\beta$   $\Rightarrow O^+/H^+$
  - [O III]5007Å / H $\beta$   $\Rightarrow O^{++}/H^+$
  - O IV 1401Å / H $\beta$   $\Rightarrow O^{3+}/H^+$
  - $O/H = O^+/H^+ + O^{++}/H^+ + O^{3+}/H^+ + \dots$



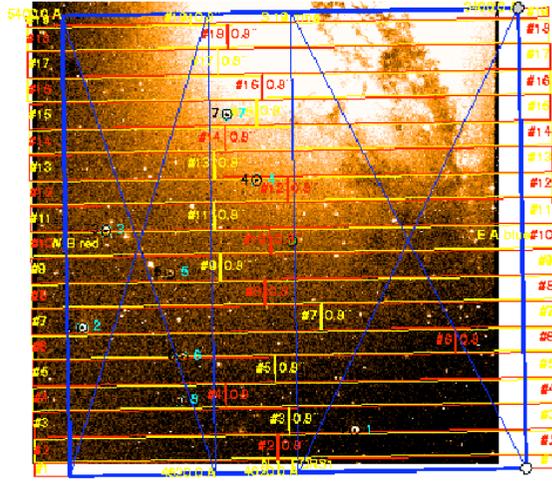
# Planetary nebulae in NGC 5128

- 785 PN catalogued in early 1990's (Hui et al, 1993); further 350 by Peng et al. 2004; another ~500 from NTT imaging survey => 1600 PN . All from on-band/off-band imaging
- The strong emission lines allow three probes:
  - Detection and photometry of PN from [O III] emission line objects. Luminosity function (PNLF) fitting => distance. E.g. Hui et al. (1993) measured 3.5Mpc to NGC 5128
  - Measurement of radial velocity of many PN from emission line(s) => rotation curve, mass estimate, dark matter
  - Measurement of many lines in a PN => abundances of light elements
- Three pronged programme:
  - Extensive imaging with NTT EMMI (imager / spectrometer) to obtain a very large sample over whole extent of galaxy (to <60kpc)
  - VLT FLAMES multi-fibre spectra of the strongest lines [O III]4959,5007Å for radial velocities (~1070 PN measured) → **Poster**
  - FORS multi-slit for detailed optical spectra (3500-7000Å) for abundance measurements (50 PN)





# FORS1 MOS observations



FORS1 MOS and  
WF/PC2 fields

ESO 2.2m WFI [O III]

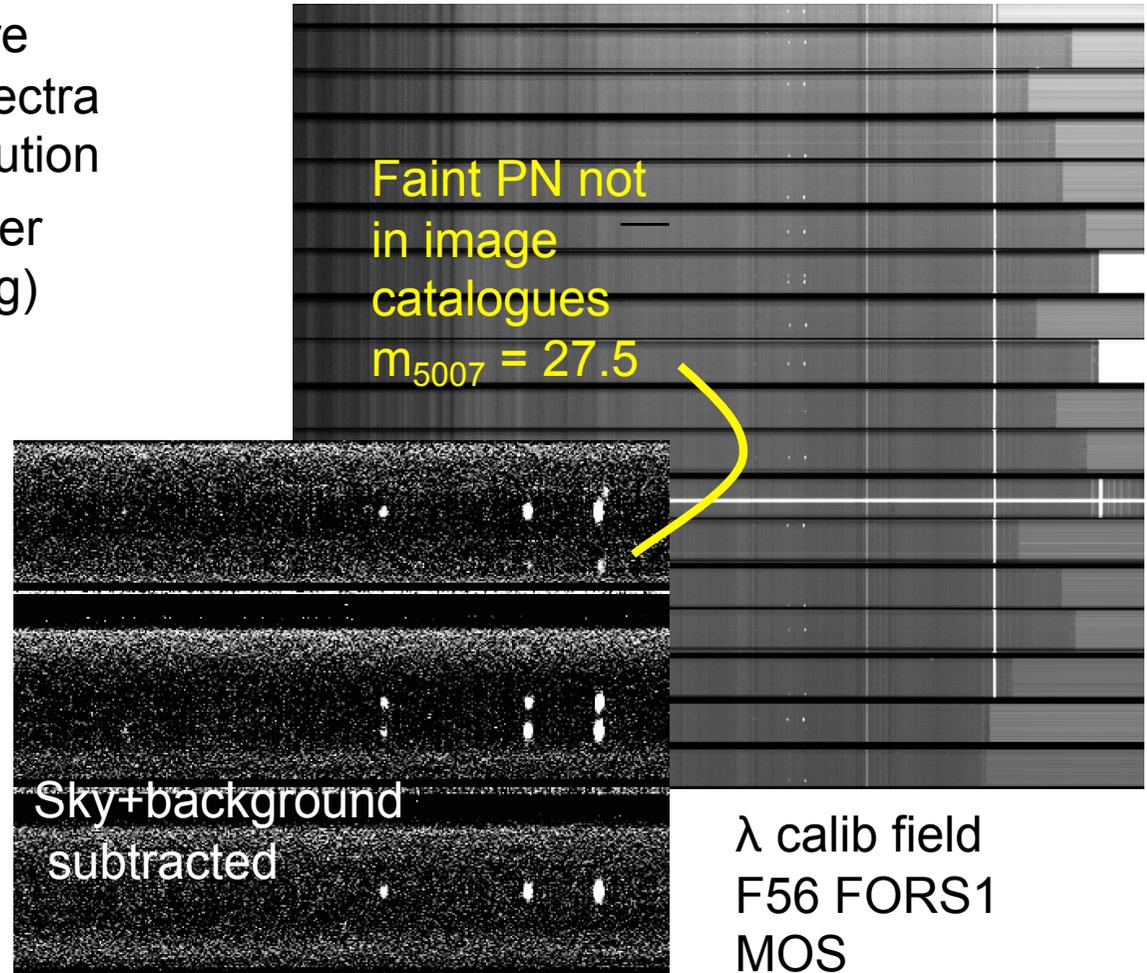
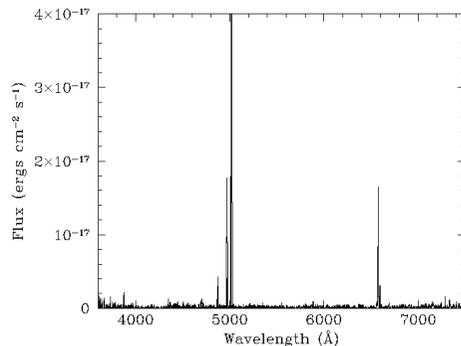
- Three fields at a range of radial offsets of 4' (F42), 7.5' (F56) and 14.5' (F34)
- Observing catalogued PN from Hui et al. (1993) maximizing number observed per field with 18 slitlets of FORS1
- Blue spectra – (600B) 3500-5500Å, R~2.3Å for [O II] 3727 to [O III] 5007Å
- Red spectra - (300V) 4500-8500Å R~5Å for H $\alpha$ /H $\beta$ , He I, [N II], etc.
- Exposures to 3hrs per field per spectral range



F42  
HH8  
F56  
HH21  
HH31  
F34

# Extracting PN spectra

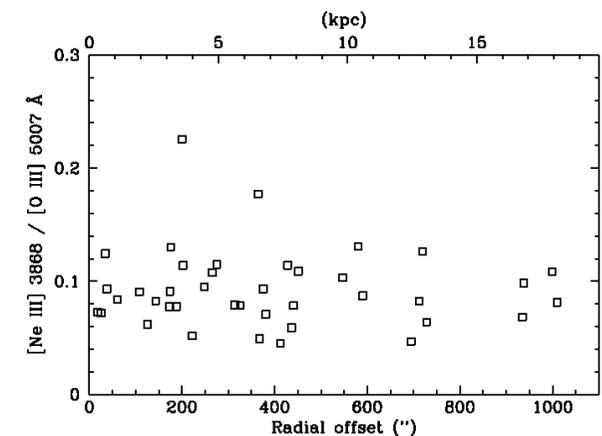
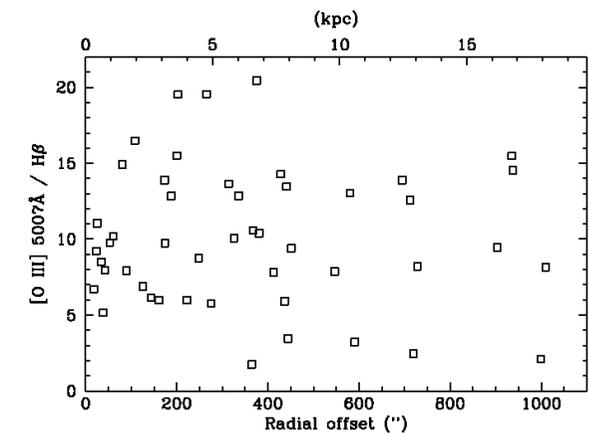
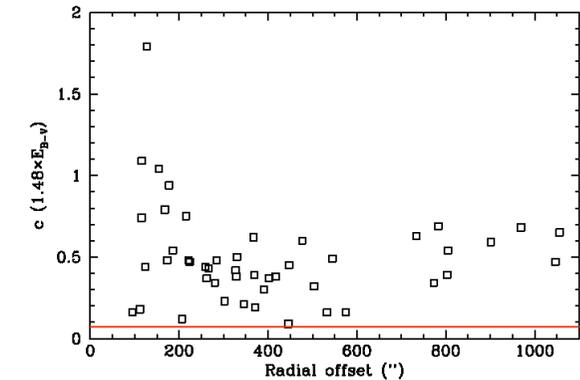
- PN at distance of NGC 5128 are point sources so extract PN spectra from background galaxy distribution
- Galaxy continuum strong in inner fields (e.g. H $\beta$  absorption strong)
- No. of PN extracted:
- Field F56: 20 PN
- F42: 21 PN
- F34: 9 PN
- 50 PN detected in total
- $23.5 < m_{5007} < 28.1$
- $[m_{5007} = -13.74 - 2.5 \log F_{5007}]$



$\lambda$  calib field  
F56 FORS1  
MOS  
spectrum

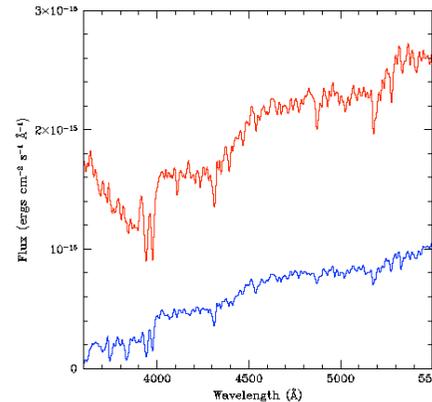
# Radial trends from PN emission

- Extinction correction (from  $H\alpha/H\beta$  and Case B). Limit is Schlegel et al. (1998)  $E_{B-V}=0.11$
- $[O III]/H\beta$  shows no trend, except some higher values near centre (Field 42). Assuming most PN have similar stellar temperature and most of O in  $O^{++} \Rightarrow O/H$  abundance
- $[Ne III]/[O III]$  rather constant as found in other PN studies (MW, MC's). Ne/O ratio 'fixed' by high mass star enrichment (SN II), thus marginal evidence for O enrichment by PN central stars

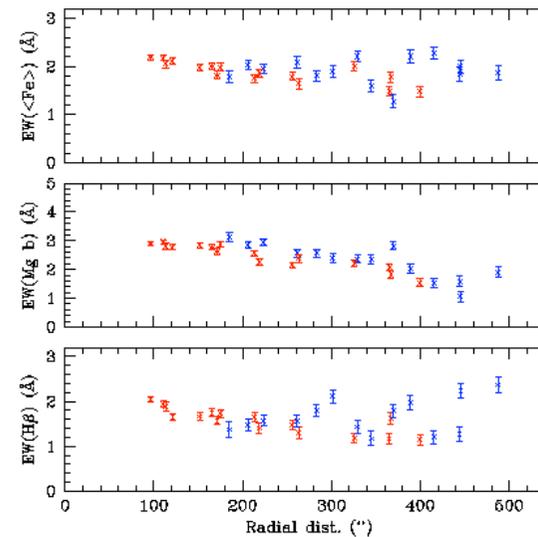
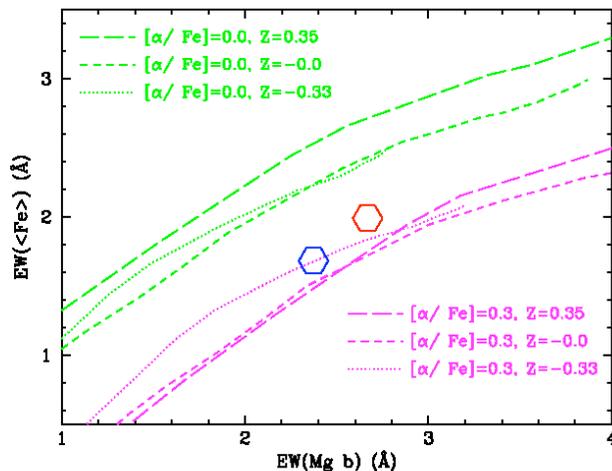


# Stellar continuum

- Stellar continuum around PN measured in multislits
- Inner fields show absorption lines with metal rich signatures - Fe, Mg b, H $\beta$
- Lick indices measured (but without templates!). Possible gradient with radius for Mg but not Fe (to 11 kpc)
- Comparison to stellar evolutionary tracks (Thomas et al. 2003) compatible with  $\alpha$ -enhanced  $Z=-0.3$  track

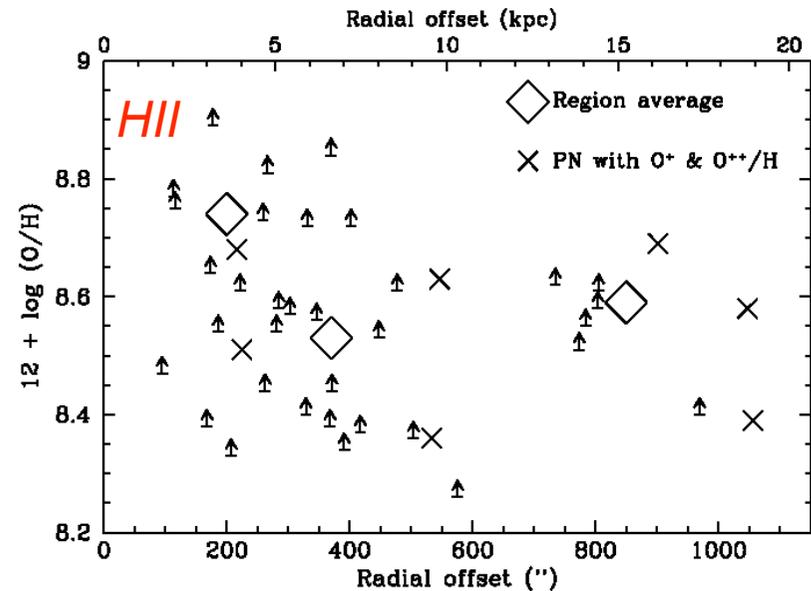


Extra-PN galaxy continuum  
**F42**  
**F56**



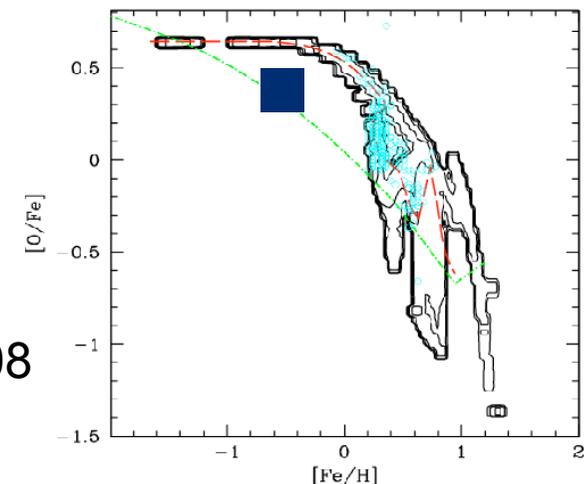
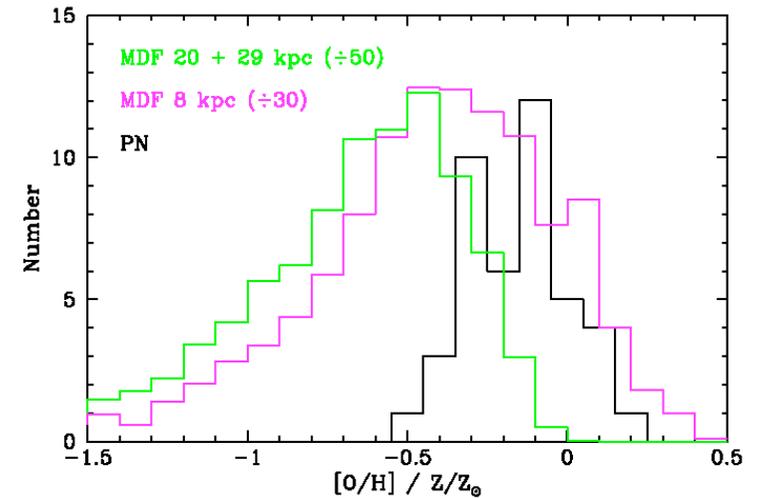
# Abundance measurements

- $T_e$  sensitive [O III]4363Å line detected in 4 PN; 3 in outer field (low background)
- Summed all spectra in each field for higher S/N line detections. Apply mean  $T_e$ ,  $N_e$  diagnostics to all PN in each field
- Determined He/H, O/H, N/H and Ne/H for each PN where lines detected
- PN without detected [O II] => lower limit to O/H.  $\text{He}^{++}/\text{H}$  to correct for unseen ionization stages (e.g.  $\text{O}^{3+}$ )
- Abundances in HII regions in dust lane suggested to be high ([O/H] ~ +0.2)



# Oxygen Distribution Function (ODF)

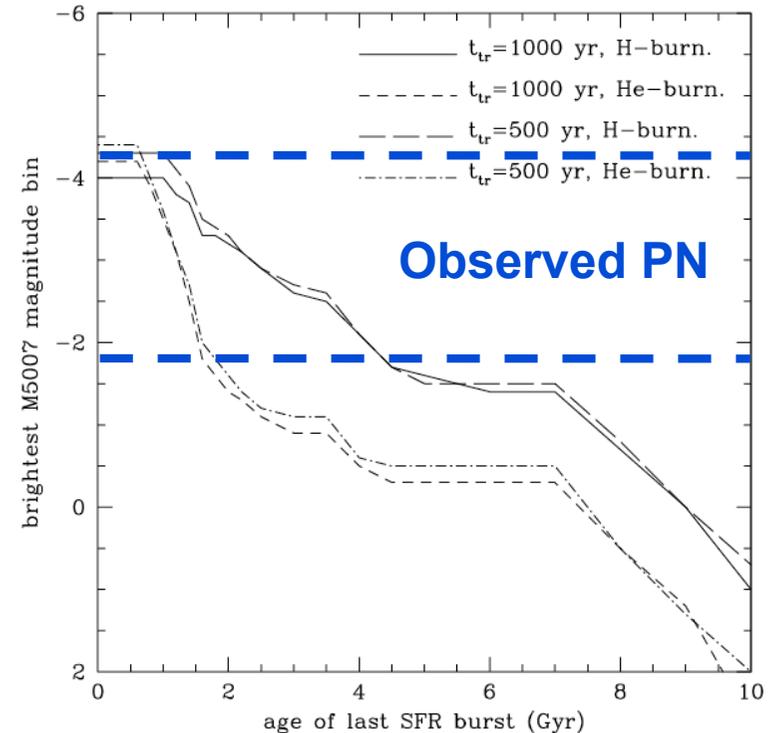
- Metallicity Distribution Function (MDF) for the RGB, AGB and red clump stars in three fields from HST WFPC2 (Harris<sup>2</sup> 1999, 2000, 2002) and Rejkuba et al. (2005) for outer field
- PN give the Oxygen Distribution Function (ODF) for similar range of radii
- Peak of ODF shifted by +0.35 wrt peak of MDF =>  $[O/Fe] = +0.35$  at  $Z = -0.5$
- Can compare  $[O/Fe]$  with models



From Pipino et al 2008  
at  $1R_e$

# PN and star formation history

- Photometric studies indicate the youngest stars in NGC 5128 5-8 Gyr old
- Corresponding to entry to AGB for a  $\sim 2M_{\odot}$  star from evolutionary tracks
- Models not in agreement with data – difficulties of modelling the PN evolution and associating a given [O III] flux with an initial MS stellar mass
- No evidence for PN from high mass progenitors (enhanced He and N abundance – *Type I*)



From Marigo et al. 2004

# PN in NGC 5128 - Conclusions

- Emission lines measured in 50 PN in NGC 5128 over offset range 2-20 kpc
- O/H measured in 6 PN, lower limits in further 35 PN
- $-0.35 < [\text{O}/\text{H}] < +0.20$
- ODF displaced by +0.3 dex with respect to MDF
- No evidence of a radial gradient in [O/H] from the PN, but some higher values at low galactocentric offset
- PN *probably* from the last major star formation episode