Mapping the oxygen abundance in an elliptical galaxy (NGC 5128)

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Metallicity and abundance determination methods in early-type galaxies

- Photometrically derived metallicities from integrated colours
- Photometric metallicities for individual stars through colour-magnitude diagrams
- Spectroscopic methods for integrated light:
  - Lick indices (e.g. Mg b, Fe 5270Å), but some ratios e.g. Mg/Fe
  - Full spectrum synthesis
- Globular clusters, photometric and spectroscopic methods
- HII regions
- ISM or extra-galaxy X-ray spectroscopy, e.g. Mg/Fe (Matsushita)
- Molecular spectroscopy, e.g. C/O
- Planetary nebulae

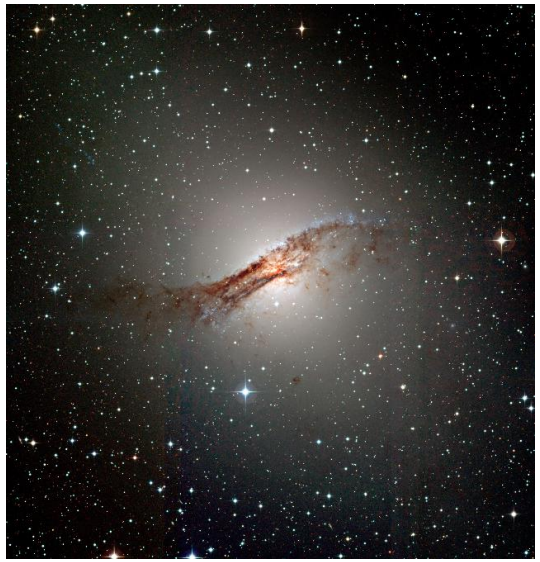
KEY

Metallicity Z

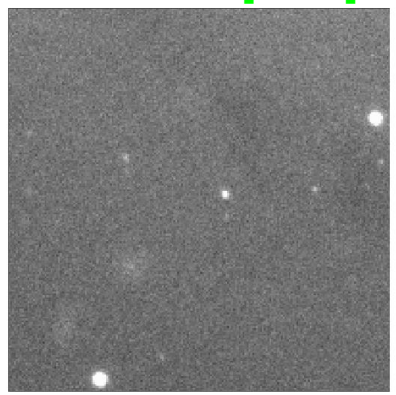
Light element abundances

Heavier element ratios

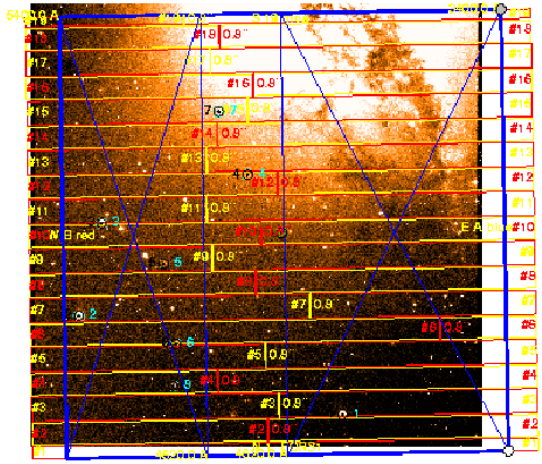
Why NGC 5128?



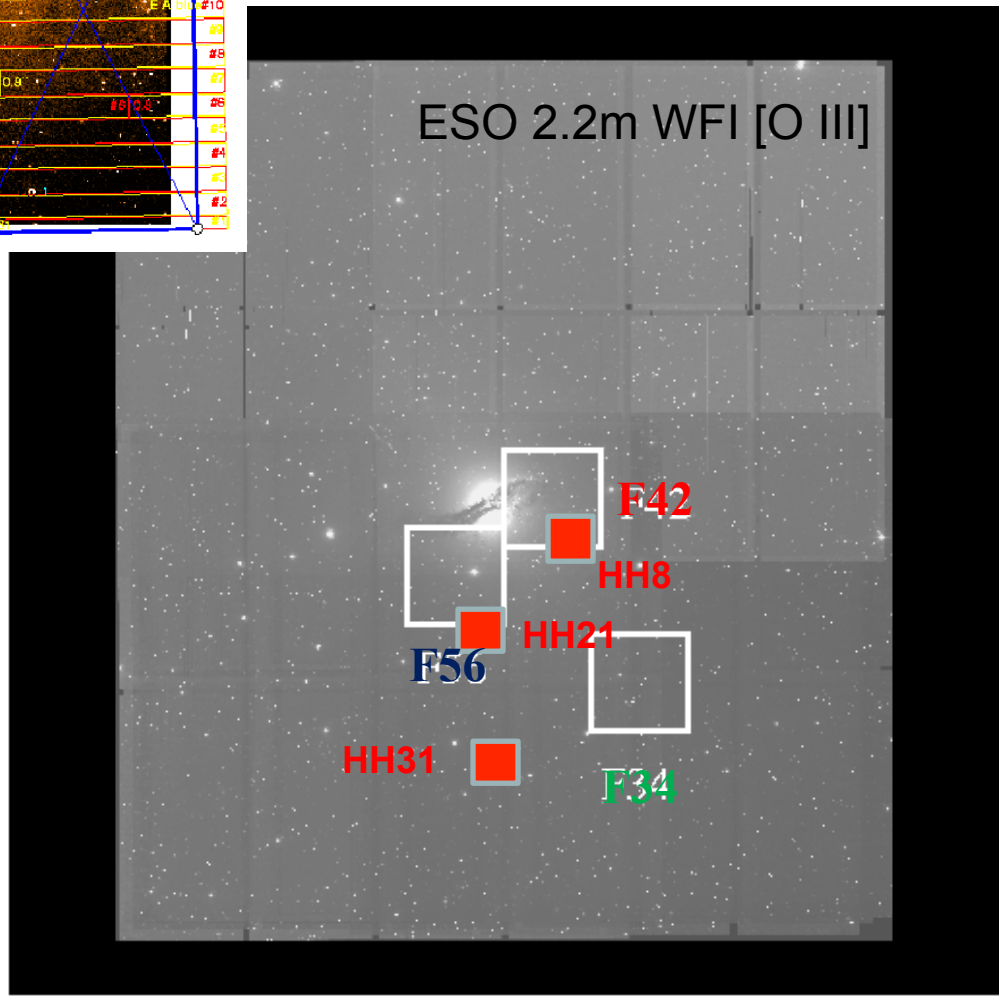
- At 3.8Mpc (distance modulus 27.91: Harris[2] & Rejkuba, 2010) the nearest large/giant elliptical galaxy (Hubble type S0; L_V = -21.5 mag.)
- Rather a typical early-type galaxy! Up to 75% have emission lines or other indicators of dust and molecular gas (Sauron and ATLAS[3D] surveys, e.g. Sarzi et al., 2006)
- Many PNe in NGC 5128 easily detectable from on/off [O III] imaging. Currently >1200 known (Hui et al. 1995; Peng et al. 2004; Walsh et al 2012)
- Brightest PN has $m_{5007Å}$ = 23.5 mag. PNe detectable to ≥27.5 mag. except in high surface brightness nuclear region
- Optical spectra of brighter PN provide line fluxes of diagnostic O, Ne, He, S, Ar emission lines



FORS1 MOS observations



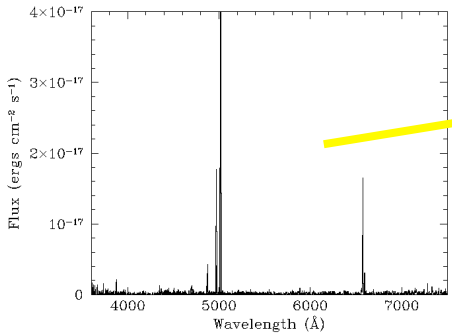
FORS1 MOS and
WF/PC2 fields

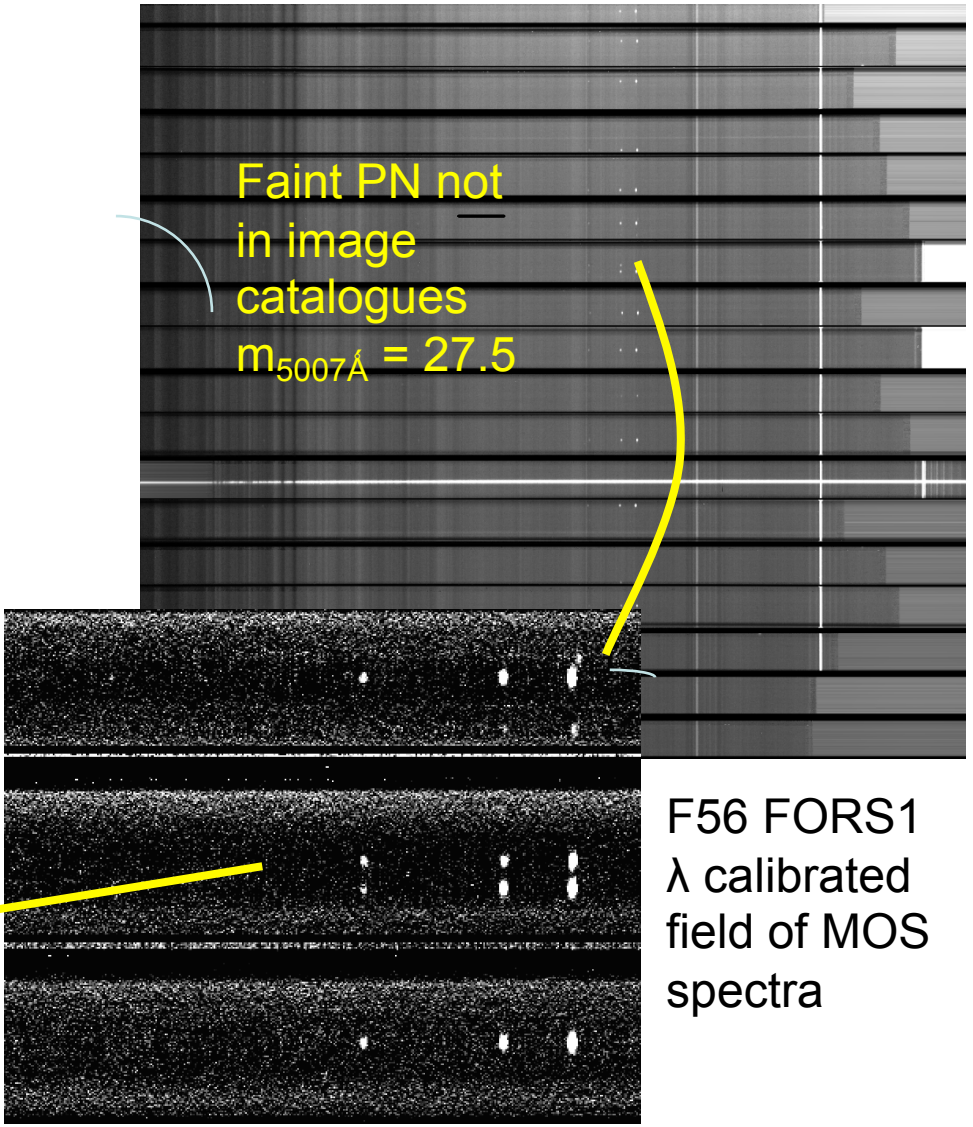


- Three fields at a range of radial offsets of 4’ (F42), 7.5’ (F56) and 14.5’ (F34)
- Catalogued PN from Hui et al. (1993), maximizing number of PNe observed per field with18 slitlets of FORS1
- Blue spectra – (600B) 3500-5500Å, R~2.3Å for [O II] 3727 to [O III] 5007Å
- Red spectra - (300V) 4500-8500Å R~5Å for Hα/Hβ, He I, [N II], etc.
- Exposures to 3hrs per field per spectral range

Extracting the PN spectra

- PNe at distance of NGC 5128 point sources (<0.05”)
- Galaxy continuum strong (e.g. Hβ absorption significant) near nucleus. Some slitlets have multiple PN
- No. of PN extracted:
  - Field F56: 21 PN
  - F42: 21 PN
  - F34: 9 PN
- 51 PN detected in total: $23.5 < m_{5007Å} < 28.1$
- 42 PNe with at least lines of Hβ, Hα, [O III], [N II] detected

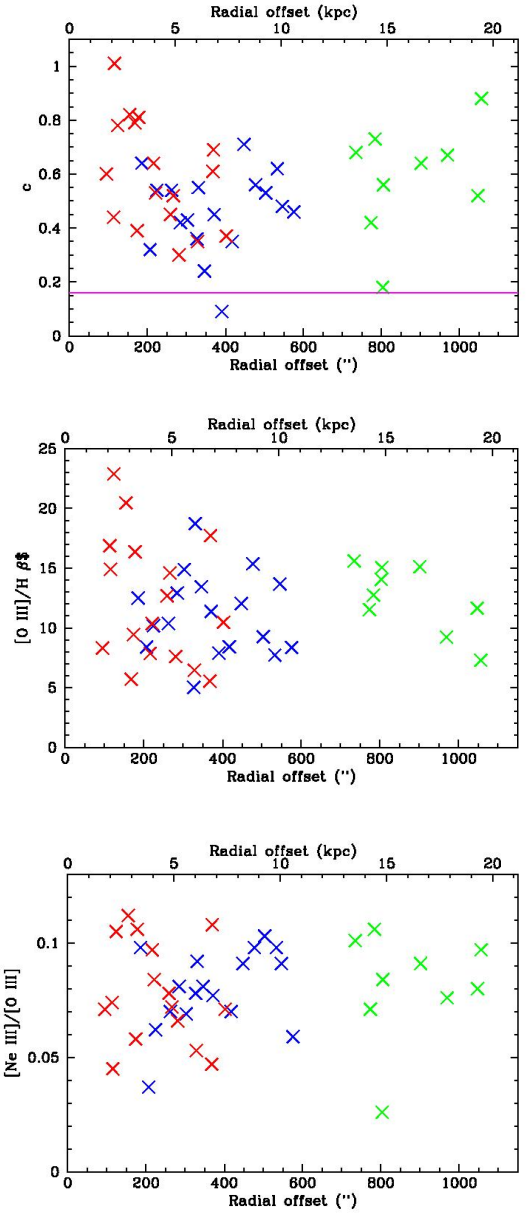




F56 FORS1 λ calibrated field of MOS spectra

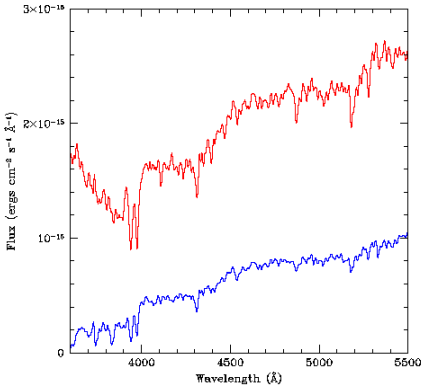
Observed PN emission properties

- Extinction correction (from Hα/Hβ and Case B). Limit is Schlegel et al. (1998) E_{B-V}=0.11. Either internal extinction in galaxy or PN intrinsically dusty
- [O III]/Hβ shows no trend with position in galaxy, except some higher values near centre (Field 42) – strong Hβ absorption
- [Ne III]/[O III] rather constant as found in other PN studies (MW, MC's). Ne/O ratio 'fixed' by high mass stellar enrichment (*SN II*). Implies at most marginal evidence for O enrichment by PN central stars **=>** use O as abundance tag for PN. O near Solar in NGC 5128 ([O/H] >-0.5) so O enrichment at low Z not important (talk by Karakas)

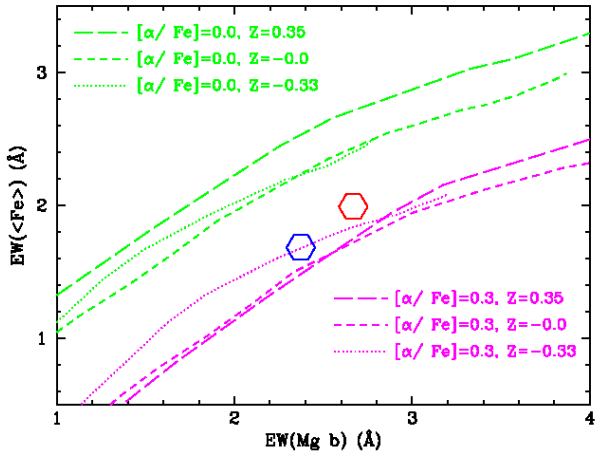


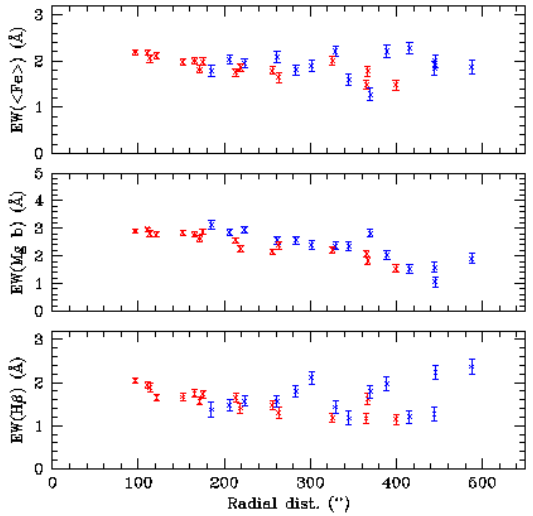
The stellar continuum

- Stellar continuum around PN measured in multislits
- Inner fields show absorption lines with metal rich signatures - Fe, Mg b, Hβ
- Range of Lick indices measured. Possible gradient with radius for Mg but not Fe (to 11 kpc)
- Comparison with stellar evolutionary tracks (Thomas et al. 2003) compatible with α-enhanced Z=-0.3 track



Extra-PN galaxy continuum
F42
F56

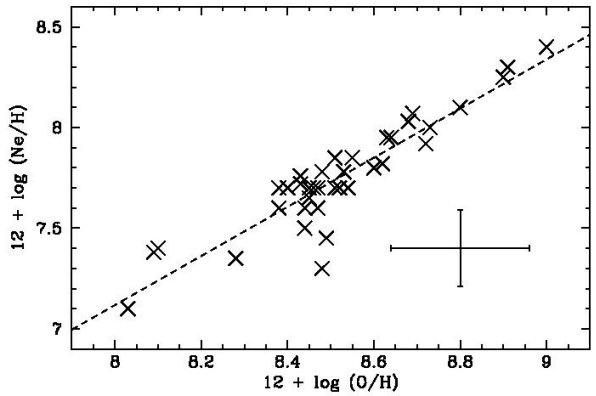


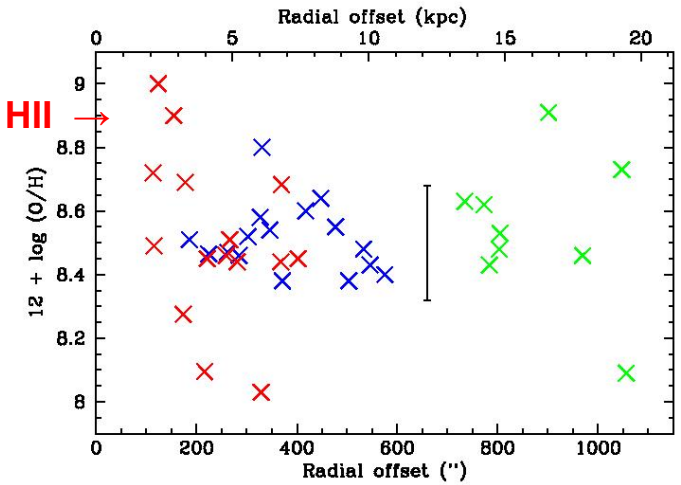


Lick indices v. radial offset (F42 and F56)

O abundance measurements

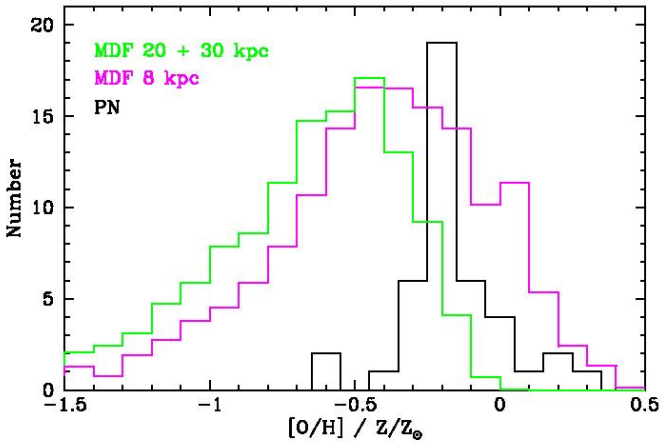
- T_e sensitive [O III]4363Å line detected in only 10 PN (S/N < 4); Ne sensitive [S II] doublet in 6 PN
- To determine reliable abundances from detected lines (He, N, O, Ne, Ar, S) *Cloudy* photoionization modelling performed (c.f. Jacoby & Ciardullo, 1999 for M31 PNe; Magrini et al. 2004 for M33 Pne; talk by Morisset)
- Simplest model: spherical shell, constant density, BB central star. Line fluxes of 40 PN spectra 'best' matched (considering line flux errors) by *Cloudy* models
- Comparative *Cloudy* runs and relaxing criteria (density law, model atmosphere, etc) showed [O/H] repeatable to ~ 0.1 – 0.15
- No obvious O radial gradient! Some higher values at low R. Abundances in HII regions in dust lane suggested to be high ([O/H] ~ +0.2)

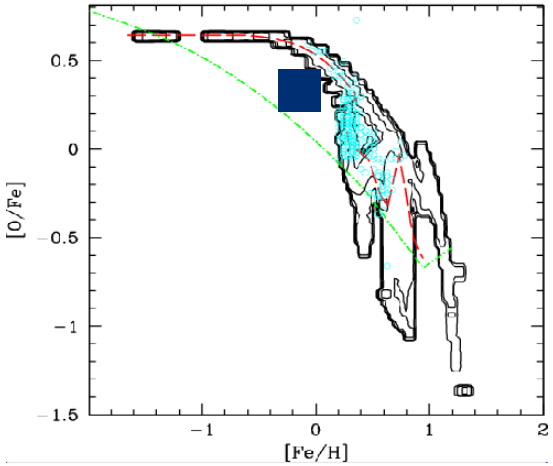




Oxygen Distribution Function (ODF)

- Metallicity Distribution Function (MDF) for the RGB, AGB and red clump stars in three fields from HST WF/PC2 photometry (Harris[2] 1999, 2000, 2002, Rejkuba et al. 2005) at radial offsets 8, 20 and 30 kpc
- PN give the Oxygen Distribution Function (ODF) for similar (2-20 kpc) range of radii
- Peak of ODF shifted by +0.35 wrt peak of MDF => [O/Fe] = +0.35 at Z = -0.5 [assuming PN progenitors and RGB coeval]
- Compare [O/Fe] with evolutionary models of early type galaxies to understand star formation history

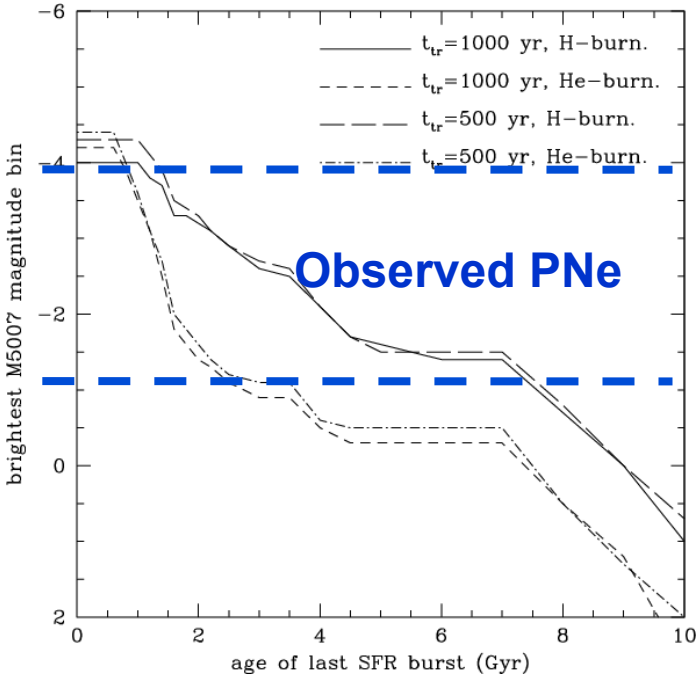


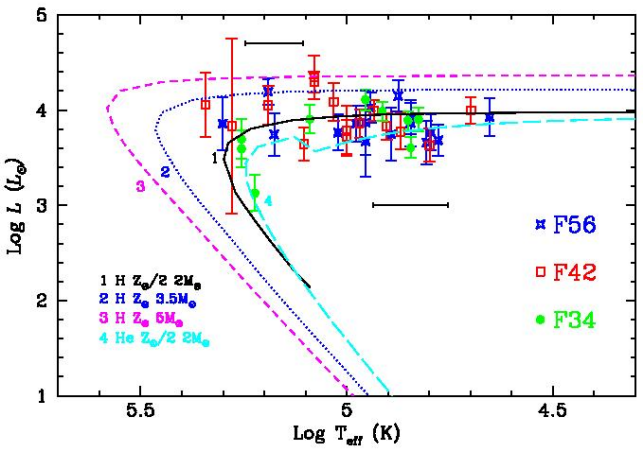


Distribution of stellar [O/Fe] in elliptical galaxy at 1Re from chemical evolution models (Pipino et al. 2008)

PN and star formation history

- Photometric studies indicate bulk of stars (~75%) in NGC 5128 formed ~12 Gyr ago
- Minor component (~25%) may be as young as 2-4 Gyr (e.g. Rejkuba et al. 2011) and Z>0.3 solar
- Brightest PNe should correspond to stars 2-5 Gyr old, at least ~2$M_{\odot}$ PN progenitor stars (from comparison to Marigo et al. 2004 population models and HR diagram)
- PNe for old component corresponds to entry to AGB for a ~1$M_{\odot}$ star from evolutionary tracks; ~2$M_{\odot}$ for younger component
- Do all observed PNe arise from last merger episode or are some/many older, arising from binary star progenitor route(s)?
- No evidence for PN from high mass progenitors (enhanced He and N abundance –Type I: ~3-8$M_{\odot}$) in sample





PNe in elliptical galaxies – the future

- Larger spectroscopic sample in NGC 5128 amenable to 8m telescope projects, to extend results to larger R_e, fainter PNe and fainter abundance and diagnostic indicators – e.g. [S II] and [S III] for abundances, N_e and T_e; [Ar IV] for N_e and abundance; carbon abundance from C II 4267Å?
- Spectra of PNe obtained in area of putative subgroup (based on velocities): using O to decide merger origin by a dwarf / giant galaxy
- Determine reliable abundances for *HII* regions in the dust lane and in entrained jet material. VLT FORS spectra in hand
- Extend resolved star photometry of red-giants with HST and for AGB stars in IR with ground-based AO (C-type/O-type)
- Next step to push to early type galaxies at ~10 Mpc (e.g. NGC 4697) – requires long exposures to >10 hrs for all but the brightest few PNe
- Spectroscopy of resolved stars and recombination line abundances of PNe in early-type galaxies really have to await ELTs

Thanks!