A MUSE view of high-ADF planetary nebulae

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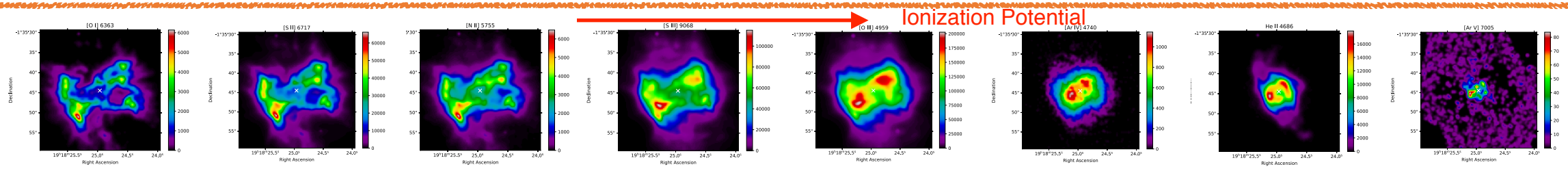
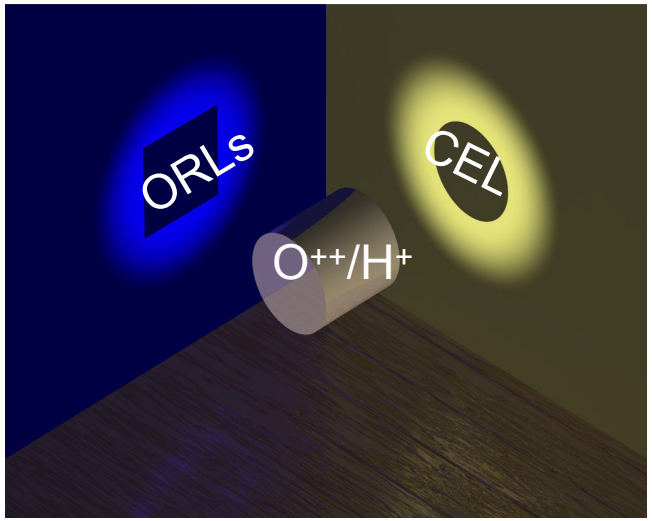
We present results from deep MUSE data in extended mode obtained for three planetary nebulae (PNe) with previously reported high abundance discrepancy factors (ADF). The spatially resolved emission maps of recombination lines (ORLs) and collisionally excited lines (CELs) of oxygen ions point to two different plasma components: one hot component with standard metallicity, and a much cooler plasma with a highly enhanced content of heavy elements relative to hydrogen. We have automatically measured the spatial flux distribution for dozens of emission lines on each object. With the resulting cubes, we construct spatially-resolved maps of the electron density and temperature (from several diagnostics) for each PN, the ionic abundances, and the O^{++} abundance discrepancy. In all objects, the abundance discrepancy clearly peaks in the central part of the nebula, in agreement with previous findings from long-slit spectra. Two of the analyzed PNe (NGC 6778 and Hf 2-2) have confirmed post-common-envelope binary central stars, the evolution of which has increasingly been linked to the high-ADF phenomenon in PNe. We also find evidence of strong contribution of recombination emission to the auroral [N II] and [O II] lines, emphasizing the importance of taking this effect into account when analyzing data from this type of PN.



Context: High abundance discrepancy factors (ADF) in PNe

The ADF



$$ADF(X^{+i}) = \frac{X^{+i}/H^{+}(ORL)}{X^{+i}/H^{+}(CEL)} > 1$$

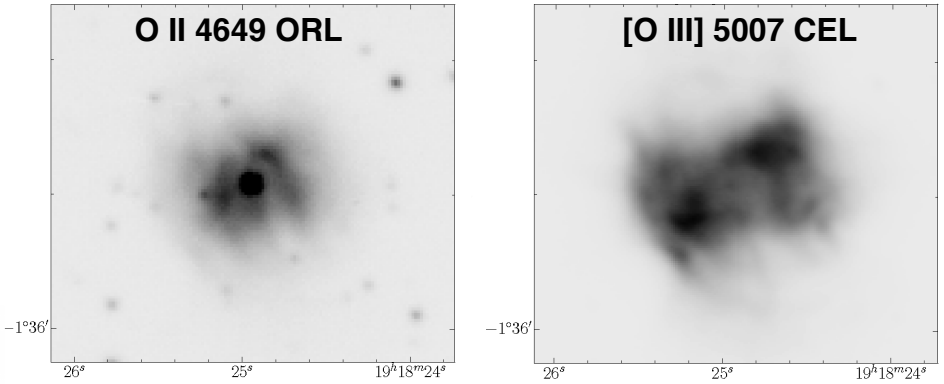
- Long-standing problem in photo ionized nebulae.
- For a given ion, abundances from faint optical recombination lines (ORLs) always higher than from collisional excited lines (CELs)
- The ADF in H II regions and the bulk of PNe is typically a factor of 2–3, but in ~10% of PNe, values greater than 10 are observed (Wesson+18)

See García-Rojas+19 for a review

Blue tunable filter OSIRIS@GTC

First direct image of the O II emission spatial distribution

NGC 6778. ADF~20

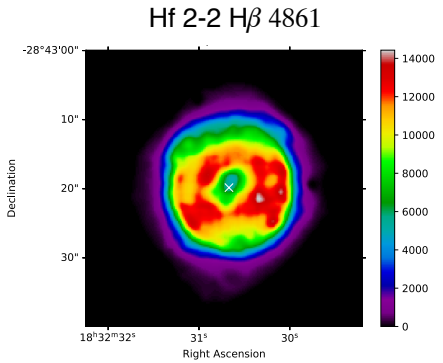


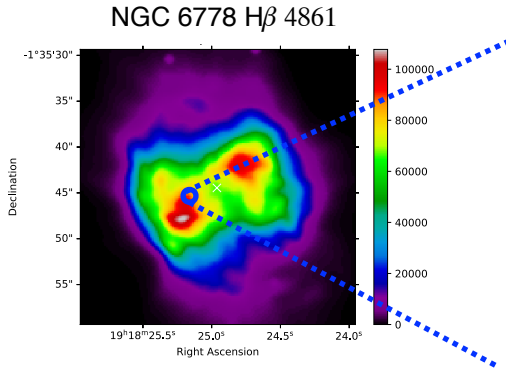
García-Rojas+16

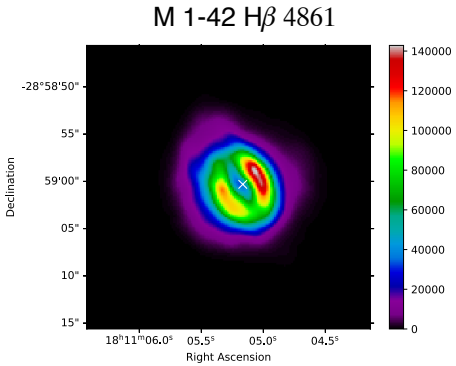
PNe with close binary central stars show very large ADFs that, generally, peak close to the central star system (see https://www.nebulousresearch.org/adfs/)

Analysis of MUSE data

MUSE extended mode
460-920 nm. $\lambda/\Delta\lambda$~3500
0.2 arcsec pix^{-1}

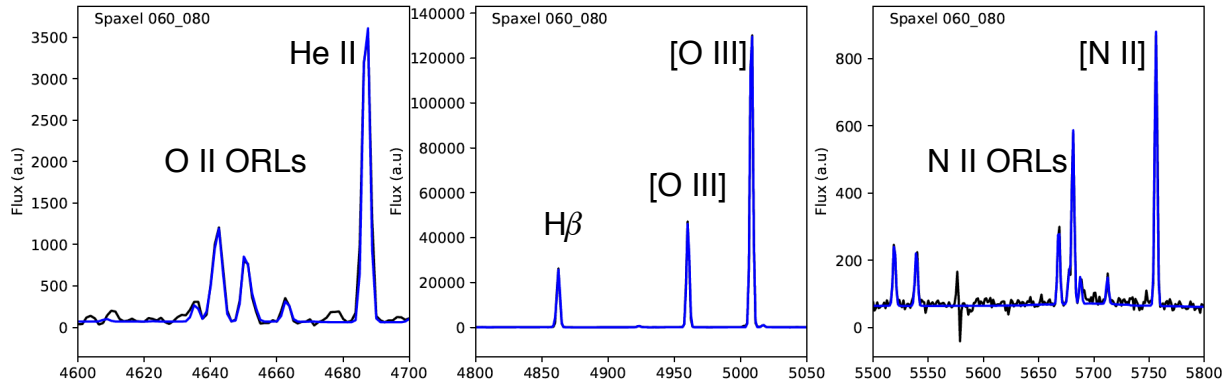


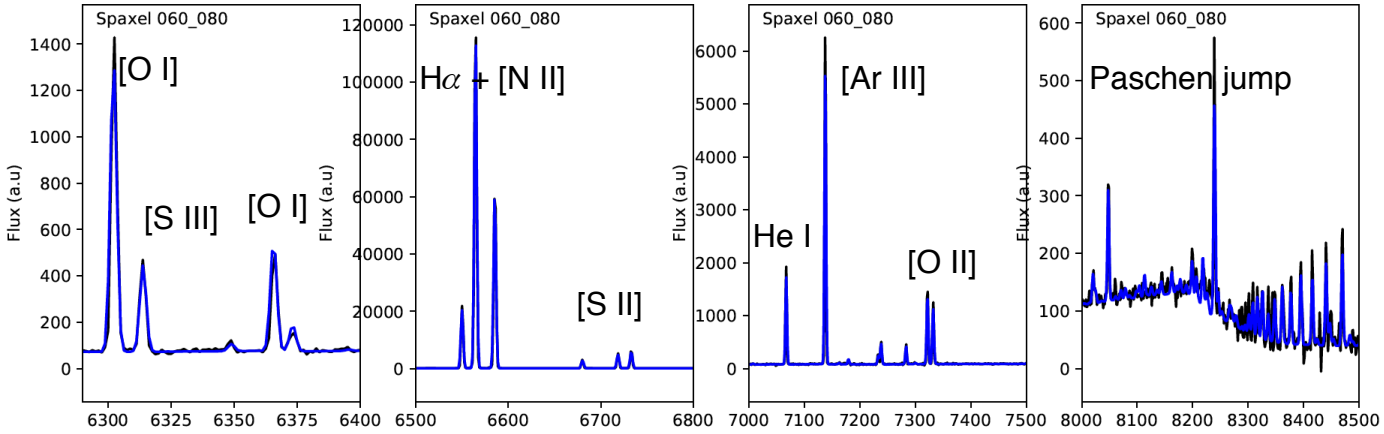




Three high-ADF PNe:

Hf 2-2 (ADF~70)
M 1-42 (ADF~20)
NGC 6778 (ADF~20)

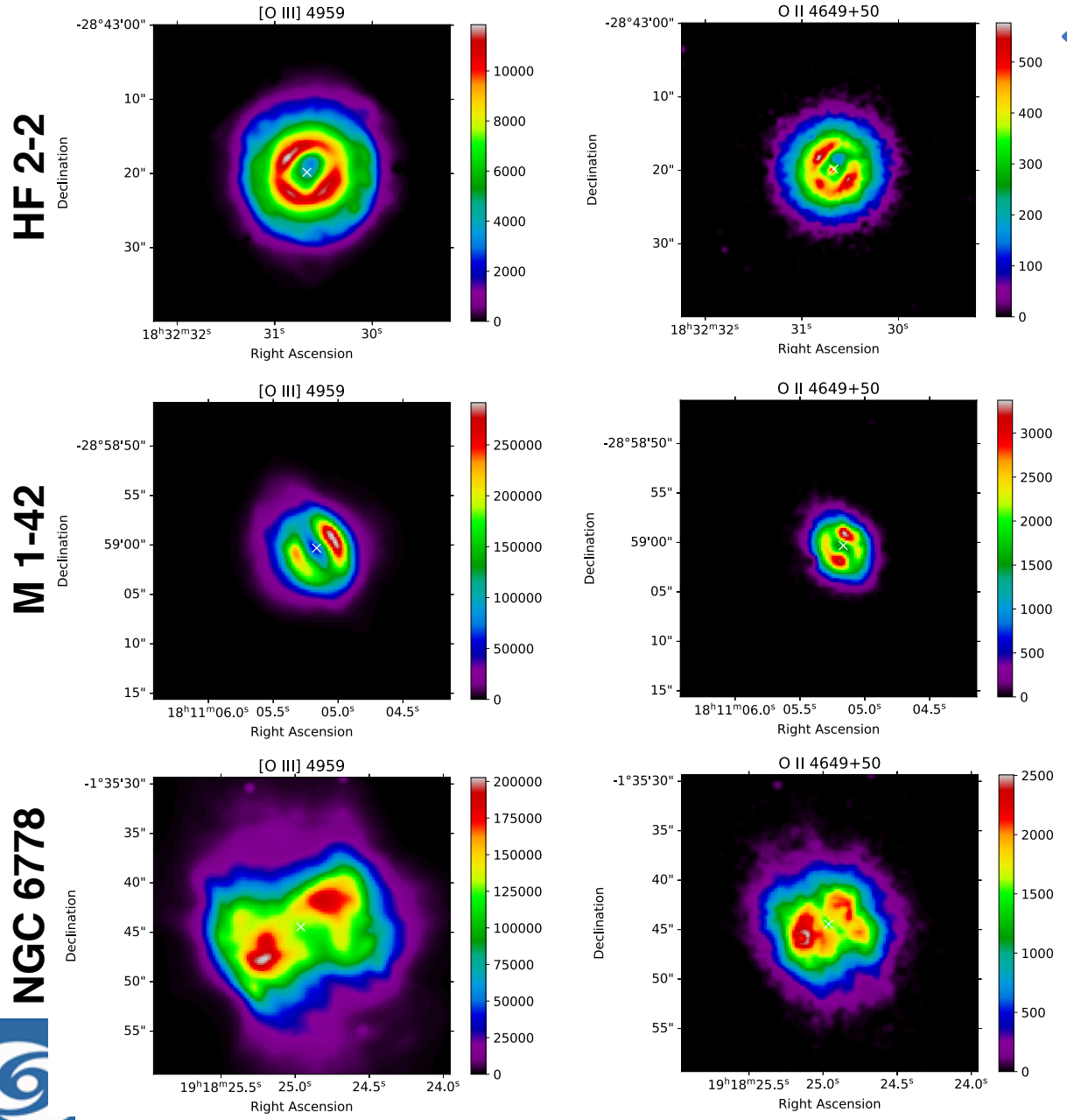




Automatic measurement of emission lines with ALFA (Wesson 2016)

Physical conditions and chemical abundances computed automatically with NEAT (Wesson+2012)

Results

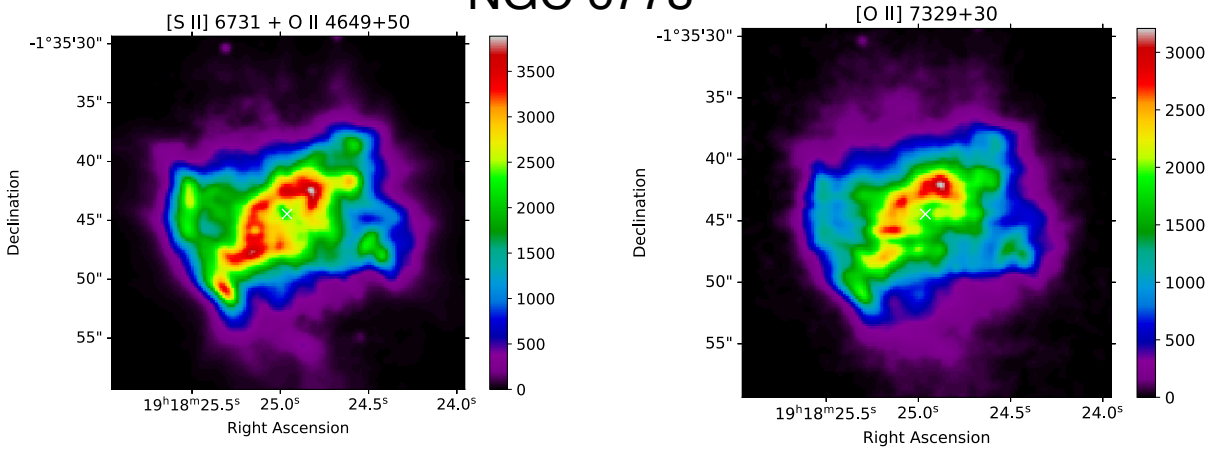


O++ spatial distribution

O II 4649+50 ORL emission more centrally distributed than [O III] 4958 CEL emission

Recombination contribution to [O II] 7320+30

NGC 6778



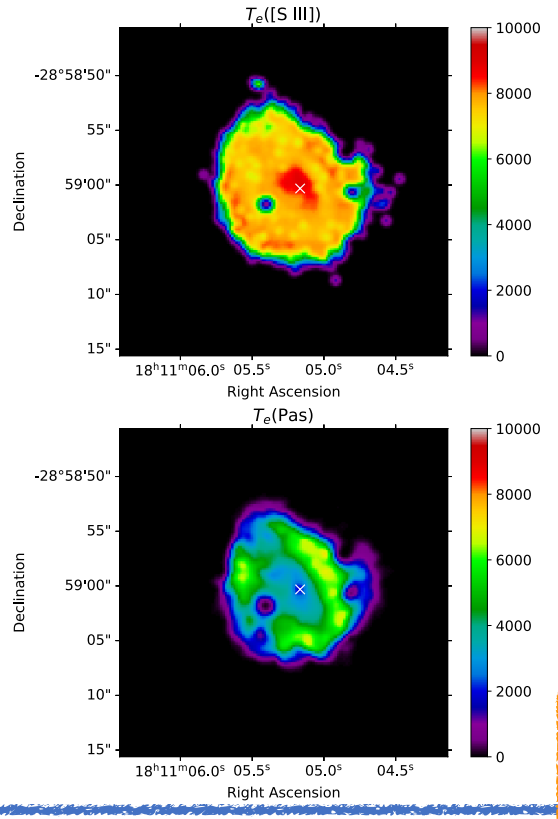
A map combining [S II] 6731 and O II 4640+50 emission maps (scaled) resembles the spatial distribution of [O II] 7329+30 emission (see also García-Rojas+19)

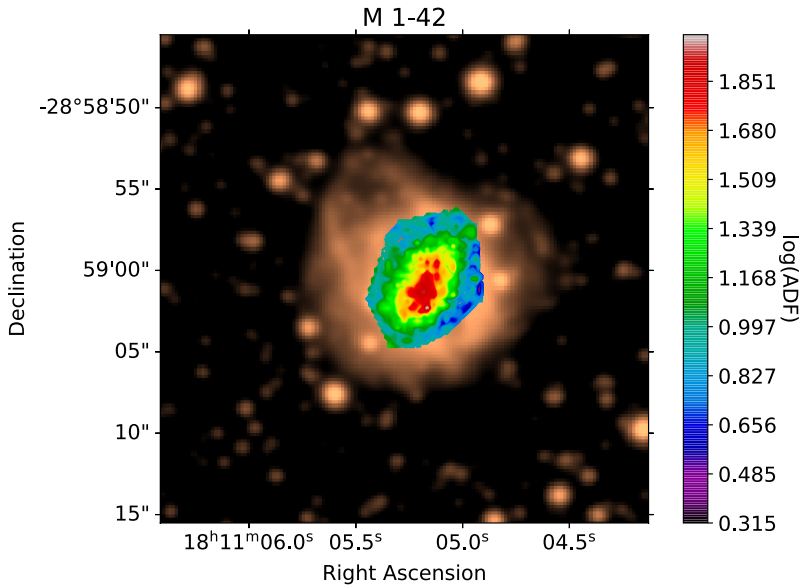
Results

O^{++}/H^{+} from ORLs and CELs computed using T_e([S III]) and n_e([S II])

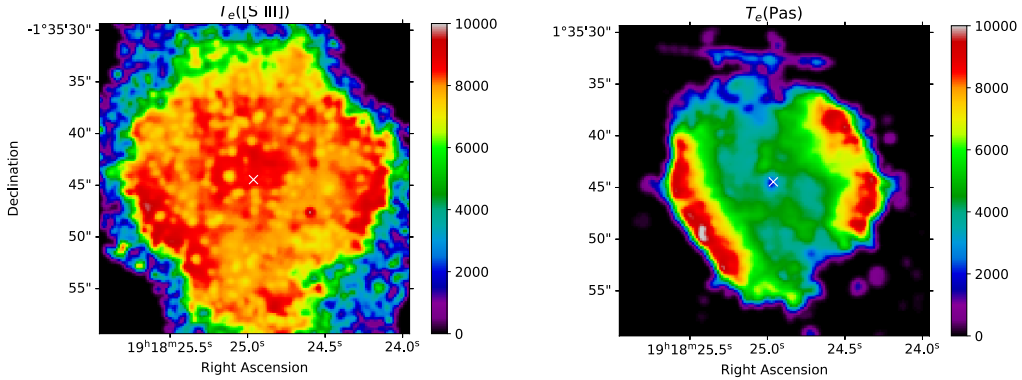
- T_e(Pas) drops in the inner zones of the nebula.
- ADF higher in the inner parts.
- No structure in the ADF owing to adopted T_e

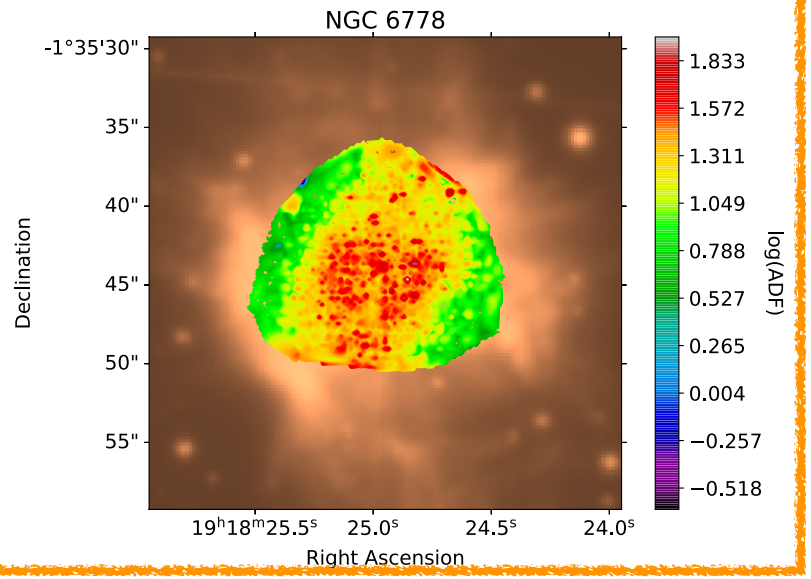
Two different plasma components





T_e([N II]) strongly affected by N^{++} recombination in M 1-42 and Hf 2-2





Impact and prospects for the future

★ Physical conditions and chemical abundances in high-ADF PNe should be taken with caution.

★ Recombination contribution in some CELs poses a challenge when using them as diagnostic tools.

What about the origin of metal-rich (H-poor) gas component?

★ Kinematics of ORLs. Analysis of FLAMES+ARGUS@VLT data of one high-ADF PNe.

★ Analysis of northern high-ADF PNe obtained with MEGARA (covering the missing blue range ($\lambda < 460$ nm) not observed with MUSE.