THE DISCREPANT KINEMATICS OF RECOMBINATION AND COLLISIONALLY-EXCITED IN NGC 7009 AS A FUNCTION OF IONIZATION STRUCTURE

Anabel Arrieta[1], Michael G. Richer[2], Leonid Georgiev[2] & Silvia Torres-Peimbert[2]

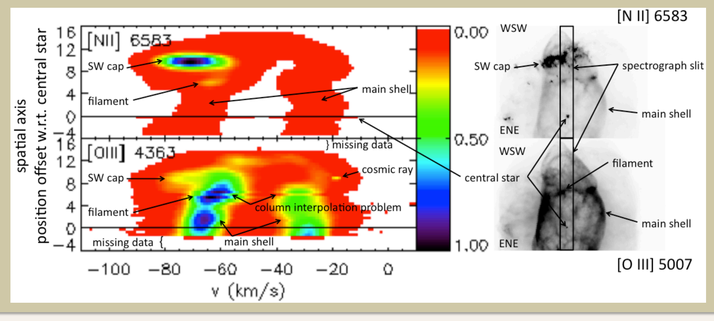
[1]Departamento de Física y Matemáticas, Universidad Iberoamericana, [2]Instituto de Astronomía, Universidad Nacional Autónoma de México

The abundance discrepancy in ionized plasmas

- Emission lines are used to infer the abundances of C, N, O, Ne, Cl, S, and Ar in ionized plasmas throughout the universe.
- Normally, collisionally-excited (probihited) emission lines are used, though the much fainter recombination lines may also be used for at least C, N, O, and Ne for nearby objects.
- There is a long-known result that the recombination lines of C, N, O, and Ne indicate higher abundances than the collisionally-excited lines (e.g., Wyse 1942, Liu 2010).
- This result gives rise to what is known as the "abundance discrepancy" between the chemical abundances inferred from these two types of lines.

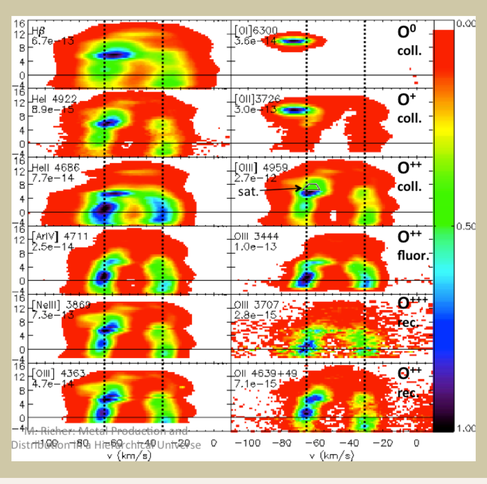
UVES observations of NGC 7009

- NGC 7009 was chosen because of its ADF ~ 5.
- The data were acquired with the UVES spectrograph at the VLT.
- A "long slit" was oriented along the major axis.
- Position-velocity (PV) diagrams were constructed, revealing the kinematics of the nebular plasma.

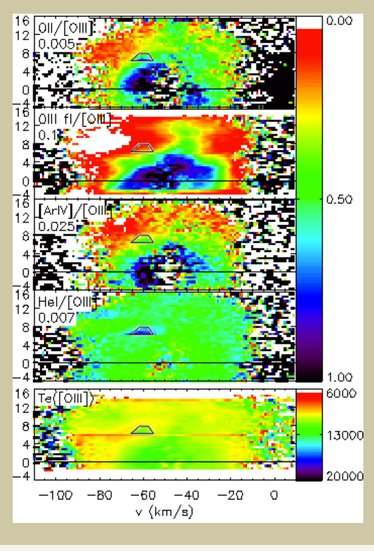


Kinematics throughout NGC 7009

- **upper left:** emission line and peak intensity
- **horizontal line:** slit position of the central star
- **dashed lines**: mean velocity of approaching and receding walls in O II ll4639+4649
- There are subtle changes as a function of ionization state.



- Ratios of PV diagrams He I λ4922/[O III] λ4959: sanity check, the lines coincide (constant ratio), as expected.
- OII λλ4639+4649/[O III] λ4959: some emission throughout the O^{++} zone, as expected.
- **A strong emission from the innermost part of the O^{++} zone.**



Two plasma components

In NGC 7009, there are two emission components for the O^{++} recombination emission.

One arises, as expected, throughout the O^{++} zone.

The other arises in the innermost part of the O^{++} zone.

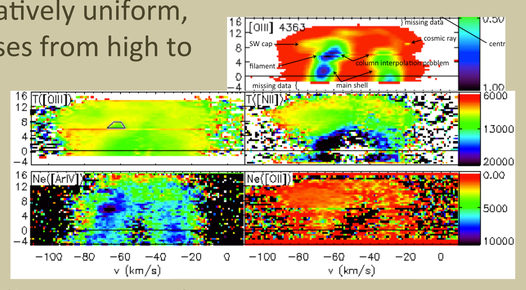
Based upon our data, all of the foregoing holds for Ne

Given the similar velocity structure for C II and N II lines, the foregoing presumably holds for these lines as well.

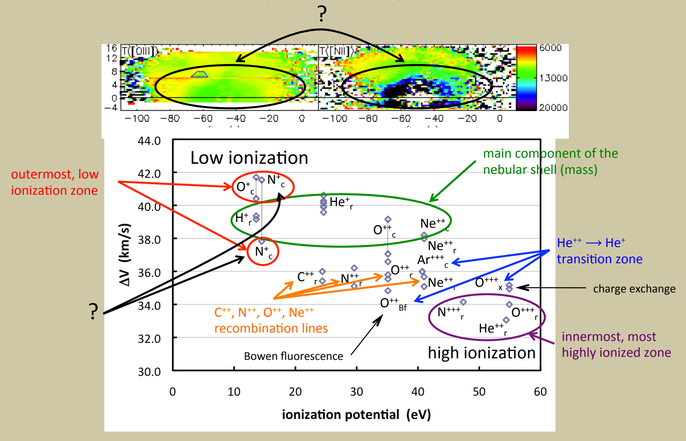
In NGC 7009, there is an emission component in recombination lines of O^{++} and Ne^{++} that arises from a different volume from that emitting collisionally-excited lines of the same parent ions (and probably for C^{++} and N^{++} too).

Temperature and density throughout NGC 7009

- Constructing PV diagrams of the physical conditions requires using ratios of observed PV diagrams.
- The density within NGC 7009 is relatively uniform, except in the filament, and decreases from high to low ionization zones.
- The temperature within NGC 7009 is uniform in the upper (western) part of the PV diagram.
- The temperature increases near the central star.
- The [O III] and [N II] temperatures disagree near the central star.

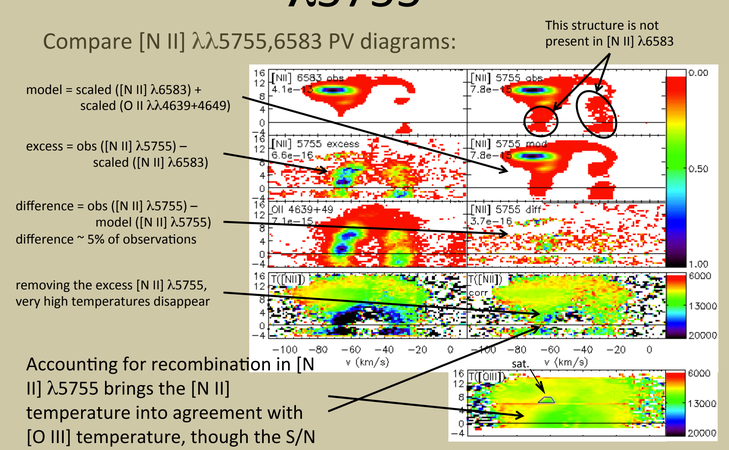


Is [N II] λ5755 a common cause for these two oddities?



Recombination in [N II] λ5755

Compare [N II] λλ5755,6583 PV diagrams:



model = scaled ([N II] λ.6583) + scaled (O II λλ.4639+4649)

excess = obs ([N II] λ.5755) – scaled ([N II] λ.6583)

difference = obs ([N II] λ.5755) – model ([N II] λ.5755)
difference ~ 5% of observations

removing the excess [N II] λ.5755, very high temperatures disappear

Accounting for recombination in [N II] λ.5755 brings the [N II] temperature into agreement with [O III] temperature, though the S/N is lower.

The abundance discrepancy

In NGC 7009:

- **We find an emission component in recombination lines of O^{++} and Ne^{++} that arises from a different volume from that emitting collisionally-excited lines of the same parent ions.**
- **For multiple plasma components, the ADF may simply reflect different chemical compositions for each component. Until now, the debate has been on which abundance is correct? Possibly, both are, but pertain to different plasma components.**