Ay126 Interstellar Medium: Homework 1

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Spirit: An ideal homework has three goals: (1) Pedagogy (application of the concepts taught in the class to data with the expectation that by completing the problem set the student gains confidence in her/his understanding). (2) Whet the the student's curiosity in matters beyond that discussed in the class. (3) In the process of devising the homework the instructor acquires deeper understanding of the subject.[1] *A student can make a homework educational and interesting or tedious. Your choice.*

[1] **Fraunhofer lines.**[2] Please browse around for a pictorial spectrum obtained by Joseph von Fraunhofer. Research and link each line to a specific transition(s) .e.g. D_1, D_2 would be due to resonance line of neutral sodium, $1s^2 2s^2 2p^6 (3s\ ^2S_{1/2} \rightarrow 3p\ ^2P_{1/2,3/2})$. [5 pts]

[2] **Wavelengths, measured and stated.** Consider an HII region which is conveniently located, at a particular epoch, such that it has zero radial velocity with respect to both Palomar as well as the Hubble Space Telescope. Compute the observed wavelengths (in Angstroms) of the first three Balmer & Lyman lines. [trigger warning: tricky] [10 pts]

[3] **Deuterium.**[3] We have good evidence that following the Big Bang the Universe had, by mass fraction, 75% (H), 25% (He), $^2D_1$ (approximately 3×10^{-5}), $^3He_2$ (about 10^{-5}) and trace amounts of Lithium. Over time the periodic table is built up and Li and D gradually destroyed.

Forward to the present time. Consider an HII region (temperature, 8000 K). Hα is produced when a free electron combines with a proton and cascades down to ground level of H. Assume that the recombination consideration is the same for H and D. Set the peak of the Hα emission line to unity. Plot (with some regard to precision, including line width) the line profile of the resulting Hα and Dα lines. *Only after finishing this exercise read Hébrard et al. (2000).* [5 pts]

[4] **Positronium.**[4] Say a source has spewed out lots of positrons which permeate the

[1] which is why better research is done at teaching+research institutions as opposed to purely research enterprises.

[2] If you wish to be a dedicated researcher then you may wish to identify lines, in addition to the capital letter designations, lines with lower case designations as in a, b, ...

[3] For the interested student: look into possible new targets like HII regions in the outer Galaxy. Why am I suggesting this specific locale?

[4] The curious student may wish to note that diffuse emission in the 511 keV line is seen towards the inner Galaxy (Prantzos et al. 2011) An intellectually adventurous students may wish to investigate the detectability of the corresponding positronium recombination.

ISM. The positrons eventually recombine with electrons and emit "Balmer lines". Once the positron reaches the ground state ($^1S_0$) the s-orbital has sufficient probability at the location of the electron that the mean lifetime is 0.13 ns. What is the wavelength of the Lyβ and Hα line? [5 pts].

[5] **Wolf Rayet Stars.** In 1867 Charles Wolf and Georges Rayet discovered eponymous "Wolf-Rayet" (WR) stars (in the Cygnus constellation) using a 40-cm telescope at the Paris Observatory. The continuum clearly showed that the stars were very hot. The novelty was that these stars, unlike other stars, showed strong and broad *emission* features. We now know that WR stars have lost their envelope i.e. these are the cores of stars with the surface devoid of hydrogen and almost certainly are the progenitors of Type Ib/Ic supernovae.

Conti et al. (1983), using image-tube spectrographs at the Kitt Peak and Cerro Tololo Observatories, reported the following features in a number of WR stars: 4200 Å, 4340 Å, 4541 Å, 4686 Å, 4860 Å, 5411 Å and 6560 Å. Edward Pickering[5] noting that some of these lines coincided with Balmer lines (e.g. Hα, Hβ etc.) attributed the lines to "an unusual state of hydrogen."[6]

Back to the problem set: follow Rydberg's steps (order the features in wave numbers, not wavelengths, and look for a pattern involving ratios of integers)[7] and figure out the element which can account for these features. *Please first solve the problem using basic knowledge of the Bohr model. Only then you should troll the web or better still read Plaskett (1922).* [15 pts]

[6] **Radio Recombination Lines (RRL).**[8] LOFAR is a new facility in radio astronomy operating in the 10–240 MHz. RRL arise when a free electron combines with an ion. The RRL designation is as follows: H109α is the line that results when an electron combines with a proton and cascades from Rydberg energy level $n = 110$ to $n = 109$ whereas H137β is 139→137 (and so on).

Asgekar et al. (2013), using LOFAR, report the following lines Carbon RRL towards Cas A: C548α and C518α (amongst other lines). Compute the rest frequencies of these lines (as accurately as makes sense). Next, why is that only Carbon RRL lines are detected from the cold/warm netural medium (CNM/WNM) but not that from H, He, O and N? [10 pts]

References

A. Asgekar et al., A&A 551, L11 (2013)
P. S. Conti et al., ApJ 268, 228 (1983)
G. Hébrard et al., A&A 364, L31 (2000)
H. H. Plaskett, JRASC 16, 137 (1922)
N. Prantzos et al., RvMP 83, 1001 (2011)

[5] I am taking some liberty here. Pickering discovered the lines discussed above in 1896 in the spectra of ζ Puppis. Pickering was a pioneering astronomical spectroscopist. He discovered the first spectroscopic binary. Pickering started the tradition at Harvard College Observatory of hiring women to process astronomical data. It is worth reading `https://en.wikipedia.org/wiki/Harvard_Computers`. Pickering's leadership led to the Henry Draper catalog.

[6] Despite his erroneous conclusions Pickering's astronomical observations played a major rule in the physical understanding of astronomical spectroscopy (Plaskett 1922).

[7] Note that the reported above are actual measurements and are affected by measurement approach, measurement errors and the radial velocity of the star.

[8] IMNHO the field of RRL is enjoying a renaissance. Lots of old issues can be revisited with LOFAR and MWA. Delectable summer project.