A Guide to Emission and Absorption Lines and "What they mean".

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Abstract

This is a simple document which will hopefully/eventually be a pretty complete list of various emission lines and 'what they mean'. That is to say, when a paper reports a flux of a certain line, why is that line special? Is it because that line indicates current star formation, past star formation or maybe AGN activity. We shall hopefully discuss a few line ratios and spectral diagnostic plots.

1 The Lines

Croom et al. (2004) N.B. 13.6 eV $\equiv$

2 Forbidden vs. Permitted

Forbidden lines are spectral lines which are very improbable (not really forbidden). Their emission indicates very low densities in order for the electrons to survive in higher orbits without collisions long enough to emit rare wavelengths.

Great resource: Interpreting Emission-Line Spectra and Star Formation in Galaxies.

Straight from Wikipedia: Forbidden mechanism. In physics, a forbidden mechanism or forbidden line is a spectral line emitted by atoms undergoing nominally "forbidden" energy transitions not normally allowed by the selection rules of quantum mechanics. In formal physics, this means that the process cannot proceed via the most efficient (electric dipole) route. Although the transitions are nominally "forbidden", there is a small probability of their spontaneous occurrence, should an atom or molecule be raised to an excited state.

Forbidden emission lines have only been observed in extremely low-density gases and plasmas, e orbidden lines of nitrogen ([N II] at 654.8 and 658.4 nm), sulfur ([S II] at 671.6 and 673.1 nm), and oxygen ([O II] at 372.7 nm, and [O III] at 495.9 and 500.7 nm) are commonly observed in astrophysical plasmas. These lines are important to the energy balance of such things as planetary nebulae and H II regions. The forbidden 21-cm hydrogen line is particularly important for radio astronomy as it allows very cold neutral hydrogen gas to be seen.

3 Narrow vs. Broad

Broad-Line Region. The lines arising here include hydrogen and helium recombination lines, permitted and semi-forbidden lines such as C IV and [C III (most of these in the emitted UV), and complex multiplets of Fe II. The lack of other lines suggests densities in excess of 107 cm^{-3}, and some considerations suggest values as high as 10^{11}. At these densities, recombination is a very efficient radiator; a typical BLR requires only 10^6 solar masses.

And Seyfert Galaxies. The spectra of Seyfert galaxies typically contain:

- Non-thermal continuum emission;
- Narrow ($\rightarrow$ low velocity), forbidden ($\rightarrow$ low density material) lines which do not vary detectably ($\rightarrow$ large emitting region)
- Broad ($\rightarrow$ high velocity), permitted lines which vary on fairly short timescales ($\rightarrow$ small emitting region)
- Also, strong emission in the radio, infrared, ultraviolet, and X-ray parts of the spectrum.

Table 1: Ionization Energies of some (mainly UV) emisson lines

Ion name	Wavelenght / Angstroms	Ground Level	Ionized Level	Ionization Energy / eV
H I	912	$^2\mathrm{S}\frac{1}{2}$	n/a	13.598
[O I]	1304	$^3\mathrm{P}_2$	$2p^3\ ^4\mathrm{S}^\circ_{\frac{3}{2}}$	13.618
Mg II	2800	$^2\mathrm{S}_{\frac{1}{2}}$	$2p^6\ ^1\mathrm{S}_0$	15.035
Fe II	1787	$^6\mathrm{D}\frac{9}{2}$	$3d^6\ ^5\mathrm{D}_4$	16.199
Si II	1260	$^2\mathrm{P}^\circ_{\frac{1}{2}}$	$3s^2\ ^1\mathrm{S}_0$	16.345
Al II	1671?	$^1\mathrm{S}_0$	$3s\ ^2\mathrm{S}_{\frac{1}{2}}$	18.829
Al III	1857	$^2\mathrm{S}_{\frac{1}{2}}$	$2p^6\ ^1\mathrm{S}_0$	28.448
[O II]	3727	$^4\mathrm{S}^\circ_{\frac{3}{2}}$	$2p^2\ ^3\mathrm{P}_0$	35.121
C III]	1909	$^1\mathrm{S}_0$	$2s\ ^2\mathrm{S}_{\frac{1}{2}}$	47.889
He II	1640	$^2\mathrm{S}_{\frac{1}{2}}$	n/a	54.417
[O III]	5007	3P0	$2p\ 2P1/2$	54.93554
C IV	1548	$^2\mathrm{S}_{\frac{1}{2}}$	$1s^2\ ^1\mathrm{S}_0$	64.494
N V	1240	$^2\mathrm{S}_{\frac{1}{2}}$	$1s^2\ ^1\mathrm{S}_0$	97.890

4 Type 1.5, 1.8 and 1.9s

In 1981, Donald Osterbrok introduced the notations Seyfert 1.5, 1.8 and 1.9, where the subclasses are based on the optical appearance of the spectrum, with the numerically larger subclasses having weaker broad-line components relative to the narrow lines. For example, Type 1.9 only shows a broad component in the H line, and not in higher order Balmer lines. In Type 1.8, very weak broad lines can be detected in the Hβ lines as well as H, even if they are very weak compared to the Hα. In Type 1.5, the strength of the Hα and Hβ lines are comparable.

Variations in the relative strength and visibility of the Balmer lines have led some investigators to define more detailed subdivisions of Seyferts. Seyfert 1.5 galaxies have moderate- strength broad Hα and Hβ; Seyfert 1.8 have weak broad Hα and Hβ; and Seyfert 1.9 have weak broad Hα and only narrow Hβ (see Osterbrock & Ferland 2006; Ho 2008).

5 Ionization Line

NIST is your friend!!!
http://physics.nist.gov/PhysRefData/ASD/ionEnergy.html

THIS LINK!!!:
https://dept.astro.lsa.umich.edu/ cowley/ionen.htm

And also,
http://www.pa.uky.edu/∼verner/atom.html

5.1 High-Ionization Line

From Wu et al. (2012) "...are clearly AGNs as evidenced by strong, high-ionization emission lines such as O vi, C iv, and/or C iii]."

"High-ionization BALQSOs (HiBALs) contain strong, broad absorption troughs shortward of high-ionization emission lines and are typically identified through the presence of C IV absorption troughs (Trump et al., 2006)."

5.2 Low-Ionization Line

"LoBALs are QSOs that have BALs from ions at lower ionization states such as Al III or Mg II " (Gibson et al., 2009)

5.3 SDSS-IV Project 0169: Outflows of Highly-Ionized Gas and Their Role in Galaxy Evolution

Added by: Francisco Muller-Sanchez
Collaborators: Julie Comerford, Becky Nevin, Jenny Greene, Nadia Zakamska

We propose a MaNGA program to perform what will be the largest-ever study of the kinematics of the optical high-ionization (or coronal) lines in nearby Active Galactic Nuclei (AGN). The data give us high signal-to-noise observations of several coronal lines (such as [Ne V], [Fe VII] and [Fe X]) in several hundreds of nearby active galaxies ($z \sim 0.03$). The coronal lines are of interest for a variety of reasons. First, they are unique tracers of accretion-powered nuclear activity. In contrast to [O III] or Halpha, which are commonly used to study the narrow-line region (NLR), the coronal lines are free of contributions from star formation. Furthermore, the coronal line [Ne V] 3426 is often the only forbidden line identified in high-z spectra of AGN and is therefore used to identify AGN unambiguously in deep and wide multiwavelength surveys. Finally, the coronal lines can be employed as diagnostics of AGN-driven outflows, and are thus a useful ingredient of feedback models. Our Keck/OSIRIS and VLT/SINFONI integral-field work has shown that bipolar outflows are observed in all coronal-line regions (CLRs), but not in all NLRs, emphasizing the importance of high-ionization lines to study AGN outflows (Mller-Snchez et al. 2011). We will use the extraordinary MaNGA datasets to: *(i)* measure the size and power of the CLR, and trends with the AGN properties, *(ii)* determine the physical conditions (temperature and density) of the coronal gas from ratios of two coronal lines or a coronal line and a lower ionization line present in the spectrum (e.g., [Ne V]/[O III], [Fe X]/[O II], [Fe VII] 3760/ [Fe VII] 6087), *(iii)* analyze the velocity and dispersion maps of [Fe VII], [Fe X] and [Ne V] to detect signatures of outflows in the high-ionization gas, and *(iv)* measure the mass and energy imparted by the AGN outflow into the interstellar medium. Specifically, we will compare the 2D kinematic data with models comprising biconical outflows superimposed on disk ro tation. Finally, we also plan to compare the kinematics of the CLR with that of the NLR to determine the mass outflow rate and kinetic luminosity of the outflowing gas over a wide range of ionization.

Modified: 2015-12-03 02:55 by Francisco Muller-Sanchez

6 Warm-Hot Intergalactic Medium (WHIM)

https://astro.uni-bonn.de/~porciani/igm/whim.pdf

7 Star-forming

"Still actively star-forming, as indicated by a significant amount of [OII]λ3727 in emission."
e.g. Mostek et al. 2012 and 2013 (and refs there in).

Table 2: The Lines

Name	Wavelength / Å	Transition	Rest Passband	Interpreation	Reference
Lyman-α	1215.67	2 to 1	~FUV	Major QSO line	1
Lyman-β	1025.18	3 to 1	~FUV		1
Lyman-γ	972.02	4 to 1	~FUV		1
Lyman Limit	911.27	∞ to 1	~FUV		1
H-α	6563.	3 to 2	R,r	Recent major SF or AGN activity	2
H-β	4861.	4 to 2	B,V,g		2
H-γ	4341.	5 to 2	U,B,u		2
H-δ	4102.	6 to 2	~FUV	Previous SF history	3
Balmer Limit	3646.	∞ to 2	~FUV		2
HI	3646.	∞ to 2	~FUV		2
HII	3646.	∞ to 2	~FUV		2
HeI	3646.	∞ to 2	~FUV		2
HeII	3646.	∞ to 2	~FUV		2
HeIII	3646.	∞ to 2	~FUV		2
CIV	3646.	∞ to 2	~FUV	Major QSO line	2
OII	3646.	∞ to 2	~FUV	Major QSO line	2
OIII	3646.	∞ to 2	~FUV	Recent major SF line	2
OIII	5007.	∞ to 2	~FUV	Recent major SF line	2
Ca II H	3999.	∞ to 2	~FUV	Old stellar pop	3
Ca II K	4001.	∞ to 2	~FUV	Old stellar pop	3
NII	5007.	∞ to 2	~FUV		2
NeV	3646.	∞ to 2	~FUV	Major QSO line	2
[OIII λ 5007/ Hβ]				"BPT" diagram reliable tool for determining source	2, 4, 5
[NII λ 6583/ Hα]				of line emission from a galaxy visually differentiate	2,4,5
				between Seyferts, LINERs and SF gals. However, only at	
				"low" redshifts since need Hα, (not at $z \sim 1$).	
				Modified BPT with $(U - B)$ colour replacing	
				[NII λ 6583/ Hα] e.g. Montero-Dorta, 0801.2769.	
[SII λ 6583/ Hα]		∞ to 2	~FUV	Major QSO line	2,4. 5
[α/Fe]	3646.	∞ to 2	~FUV	Major QSO line	2
NV	1???.67	2 to 1	~FUV	Major QSO line	1
SiIV	1???.67	2 to 1	~FUV	Major QSO line	1
CIV	1???.67	2 to 1	~FUV	Major QSO line	1
CIII]	1???.67	2 to 1	~FUV	Major QSO line	1
MgII	1???.67	2 to 1	~FUV	Major QSO line	1

8 Metallicity

e.g. http://arxiv.org/abs/1509.01279 [N II]/Hα and [O III]/Hα

Given the capability of the current integral field instruments, the only practical method to measure metallicity in high-redshift galaxies is to use strong-line metallicity calibrators. The direct measurement of metallicity (T_e method) is not feasible for individual galaxies at this redshift since it relies on the measurement of emission lines that are too faint to detect. In this work, we use the [N II] λ6584/Hα ratio (N2) and the ([O III] λ5008/Hβ)/([N II] λ6584/Hα) ratio (O3N2) with the calibrations from **?** - PP04, **?** - S14, and Maiolino et al. (2008) - M08:

$$12 + \log\left(\mathrm{O/H}\right) = 8.90 + 0.57 \times \mathrm{N2} \tag{N2, PP04}$$

$$12 + \log\left(\mathrm{O/H}\right) = 8.62 + 0.36 \times \mathrm{N2} \tag{N2, S14}$$

$$12 + \log\left(\mathrm{O/H}\right) = 8.73 - 0.32 \times \mathrm{O3N2} \tag{O3N2, PP04}$$

$$12 + \log\left(\mathrm{O/H}\right) = 8.66 - 0.28 \times \mathrm{O3N2} \tag{O3N2, S14}$$

where N2$\equiv$ log([N II]λ6584/Hα) and O3N2$\equiv$ log (([O III] λ5008/Hβ)/([N II]λ6584/Hα)).
E+A (e+a) galaxies have... (Roseboom et al. 2006 and refs therein).
k+a galaxies have... (Roseboom et al. 2006 and refs therein).

9 References

References

Croom S. M., Smith R. J., Boyle B. J., Shanks T., Miller L., Outram P. J., Loaring N. S., 2004, MNRAS, 349, 1397

Gibson R. R., et al., 2009, ApJ, 692, 758

Maiolino R., et al., 2008, Astron. & Astrophys., 488, 463

Trump J. R., et al., 2006, ApJS, 165, 1

Table 3: The Lines, in increasing Wavelength (Basis for this table from SDSS SkyServer Schema Browser, SpecLineNames view `http://casjobs.sdss.org/dr6/en/help/browser/browser.asp`)

name	value	description
UNKNOWN	0	0.00
OVI_1033	1033	1033.82
Lya_1215	1215	1215.67
NV_1241	1241	1240.81
OI_1306	1306	1305.53
CII_1335	1335	1335.31
SiIV_1398	1398	1397.61
SiIV_OIV_1400	1400	1399.80
CIV_1549	1549	1549.48
HeII_1640	1640	1640.40
OIII_1666	1666	1665.85
AlIII_1857	1857	1857.40
CIII_1909	1909	1908.73
CII_2326	2326	2326.00
NeIV_2439	2439	2439.50
MgII_2799	2799	2799.12
NeV_3347	3347	3346.79
NeV_3427	3427	3426.85
OII_3727	3727	3727.09
OII_3730	3730	3729.88
Hh_3799	3799	3798.98
Oy_3836	3836	3836.47
HeI_3889	3889	3889.00
CaII K_3935	3935	3934.78
CAII H_3970	3970	3969.59
He_3971	3971	3971.19
SII_4072	4072	4072.30
Hd_4103	4103	4102.89
G_4306	4306	4305.61
Hg_4342	4342	4341.68
OIII_4364	4364	4364.44
Hb_4863	4863	4862.68
OIII_4933	4933	4932.60
OIII_4960	4960	4960.30
OIII_5008	5008	5008.24
Mg_5177	5177	5176.70
Na_5896	5896	5895.60
OI_6302	6302	6302.05
OI_6366	6366	6365.54
NI_6529	6529	6529.03
NII_6550	6550	6549.86
Ha_6565	6565	6564.61
NII_6585	6585	6585.27
Li_6708	6708	6707.89
SII_6718	6718	6718.29
SII_6733	6733	6732.67
CaII_8500	8500	8500.36
CaII_8544	8544	8544.44
CaII_8665	8665	8664.52

Table 4: The Refs

Name	Year	Journal	Volume	Page	Section(s)
Croom et al.	2004	MNRAS	375	600	????
Kriek et al.	2007	astro-ph	0611724	v4	3
Roseboom et al.	2006	MNRAS			
Baldwin, Phillips & Terlevich	1981	MNRAS			
Yan et al.	2006				