NeV emission in LRGs

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Why LRGs?

Luminous Red Galaxies (LRGs) are intrinsically red elliptical galaxies. They are the most massive galaxies in the universe, and are more likely to be found towards the centre of galaxy clusters. LRGs contain the majority of the stellar matter of the local universe, most of which is in the form of an old passively evolving population. As they are luminous they can be observed over great distances, and they are easy to identify photometrically as a result of their relatively uniform stellar population.

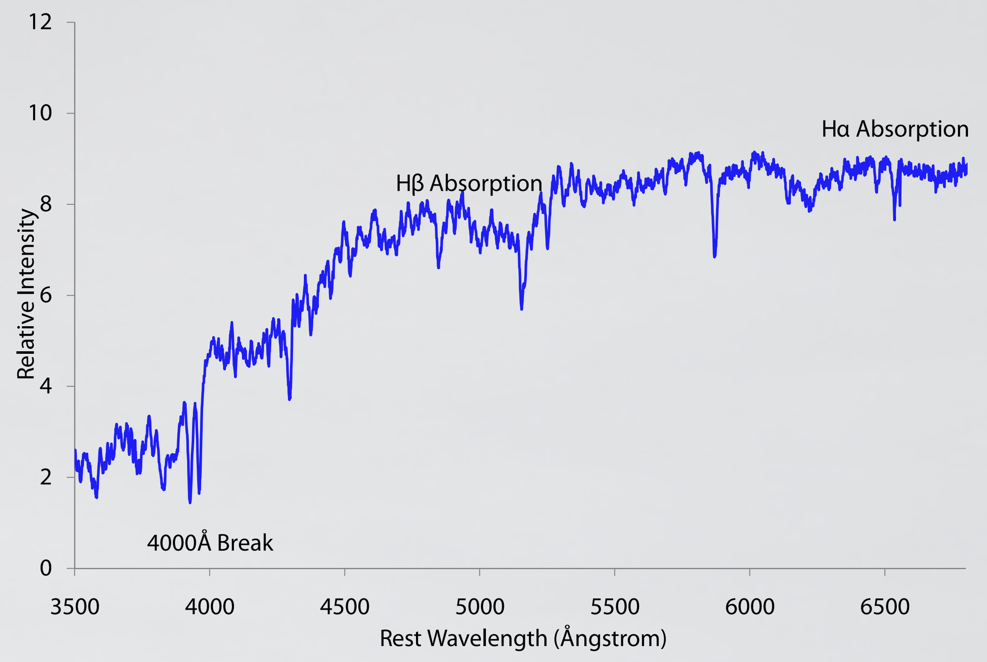
LRGs and galaxy evolution

It is now widely accepted that galaxies evolve from successive mergers of smaller gravitationally-bound structures. This hierarchical model of galaxy evolution is a natural consequence of the widely accepted ΛCDM cosmology. In accordance with this principle the most massive galaxies are believed to be the newest, however the vast majority of these galaxies appear passive with old stellar populations. Detailed theories of galaxy formation must therefore allow for successive mergers whilst quenching significant star formation. Semi-analytic models predict the observed characteristics of galaxies today through a balance of merging rates, star formation, cooling flows, supernovae and AGN feedback parameters, all of which need to be thoroughly tested through observations. It is therefore extremely important to understand more about the relationship between AGN and star formation in galaxies. We have chosen to concentrate on LRGs as it is relatively easy to detect small but significant variations from the typical passive SEDs.

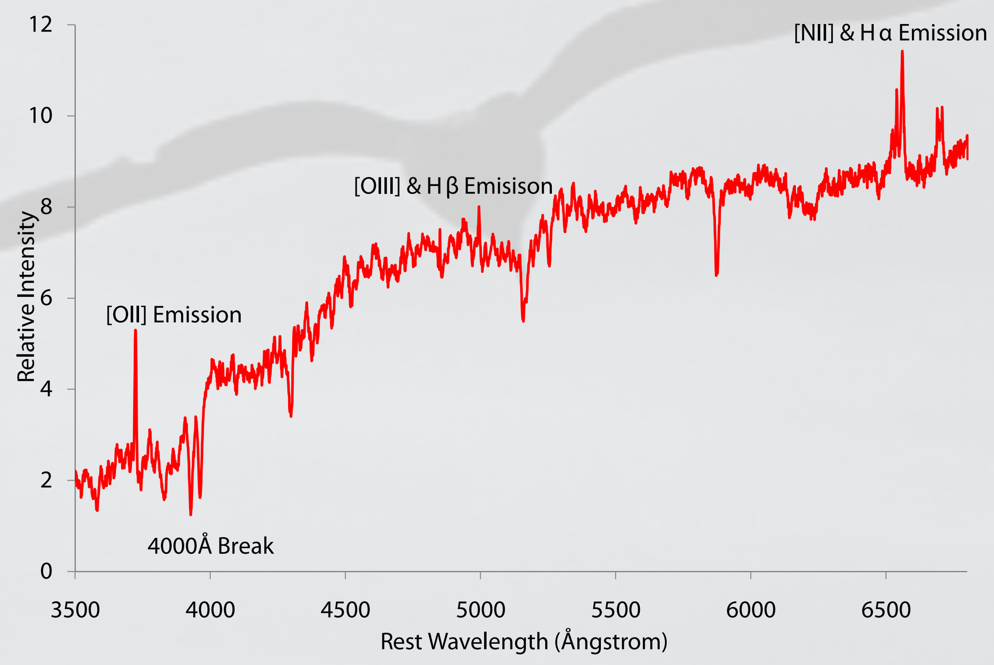
Average LRG spectra - the samples

We used well established colour cuts (Eisenstein et al., 2001) to select a sample of 73,000 LRGs from the SDSS DR6. Both samples comprise LRGs with a spectroscopically determined redshifts between 0.2 and 0.4, and an average S/N of at least 5. The average passive LRG spectrum was produced from a sample of 400 LRGs with no measured emission lines. The average 'active' LRG spectrum was selected from a sample of 400 LRGs classified as AGN using the BPT 'seagull wings' optical diagnostic (see below).

An average passive LRG spectrum



An average active LRG spectrum



Why NeV?

The vast majority of stars are not capable of producing enough energy to quadruply ionise Neon atoms. However, a hard non thermal radiation field produced by an AGN is an ideal environment for producing photons with significant energy to produce measurable quantities of NeV; this is further supported by the fact that NeV emission is always located toward the centres of galaxies (Abel & Satyapal, 2008).

IR NeV emission

IR NeV emission is firmly established as an indicator of AGN activity (e.g. Forjian et al., 2006). It is so successful at this task that the detection of IR NeV in previously optically identified pure star forming galaxies has resulted in reclassification, with an AGN contribution as high as 50% (Satyapal et al., 2008). However, data on these emission lines is restricted by the nature of IR surveys which often require extremely costly space telescopes.

Near UV NeV emission

There are three statistically significant transitions of NeV which arise in the near UV: 3300Å, 3347Å & 3427Å. These correspond to slightly less probable energy transitions in typical AGN environments, and therefore any emission lines here are expected to be weaker than the IR equivalents. Near UV emissions are also seriously affected by gas and dust extinction.

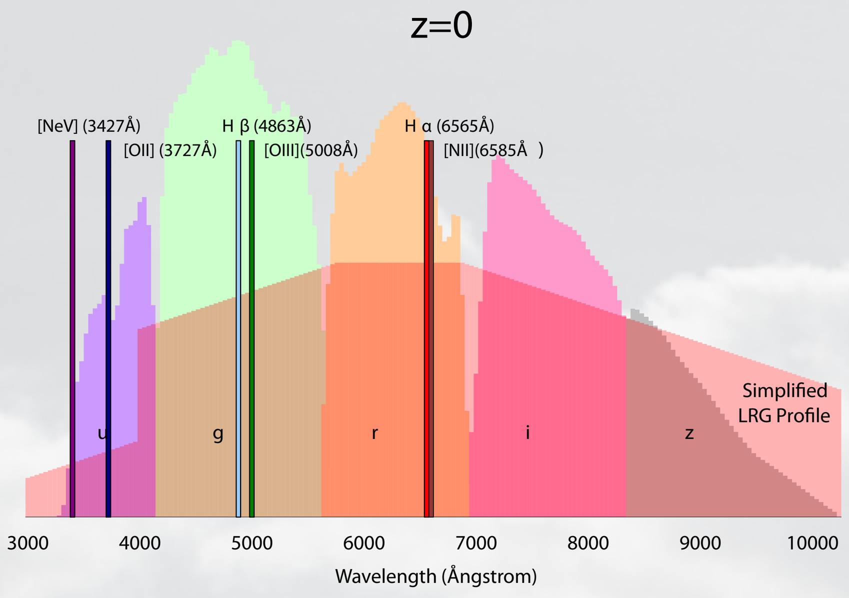
Rest-UV NeV emission has potential yet possibly limited use as an optical diagnostic for AGN at medium redshifts; any detection of this NeV emission should indicate a significant AGN contribution to the luminosity of a galaxy, but absence of this emission line does not necessarily mean the opposite.

NeV emissions at both 3347Å & 3427Å are measured by the SDSS spectro1d pipeline. An initial analysis of DR6 data from SDSS has revealed that the 3427Å line is more prevalent. We have therefore chosen to focus on this single line.

Why SDSS?

The Sloan Digital Sky Survey (SDSS) (York et al., 2001) is the largest optical survey ever undertaken. The legacy survey is now complete, with images of almost 300 million objects and spectral data for over a million stars and galaxies. Photometric and spectroscopic data for DR6 is available freely over the internet at **http://casjobs.sdss.org/astro**.

z=0

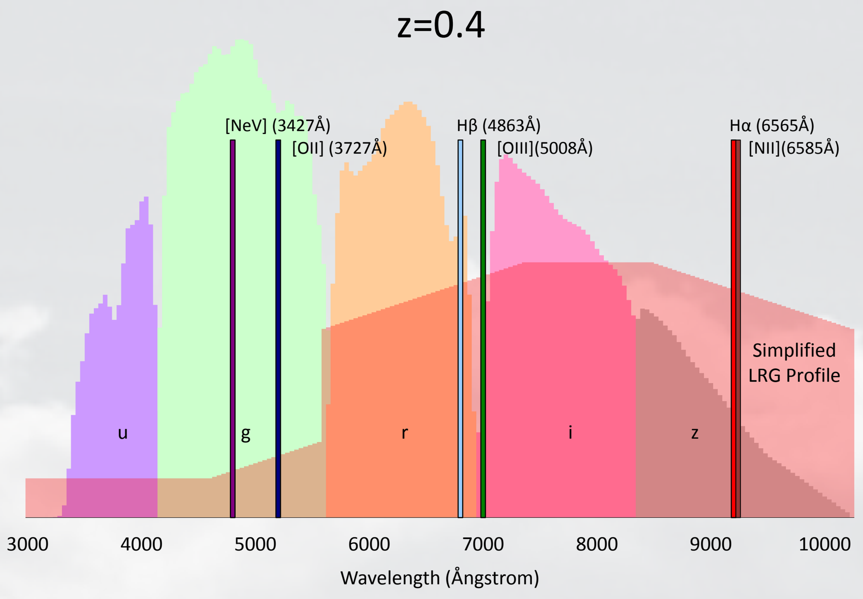


a) Schematic of SDSS photometric filters (u, g, r, i, z) and sensitivity together with the positions of key absorption and emission lines and LRG profile at z=0.

How to find LRGs in SDSS

LRGs are easy to target photometrically due to their prominent 4000Å break (see above). The position and strength of the break are established through a combination of colour (g-r) and (r-i) cuts. The LRG sample in SDSS is volume-limited up to the point where the 4000Å break moves into the r band (z ~ 0.4). SDSS has also been able to obtain spectra for LRGs up to a (magnitude limited) redshift of 0.5.

z=0.4

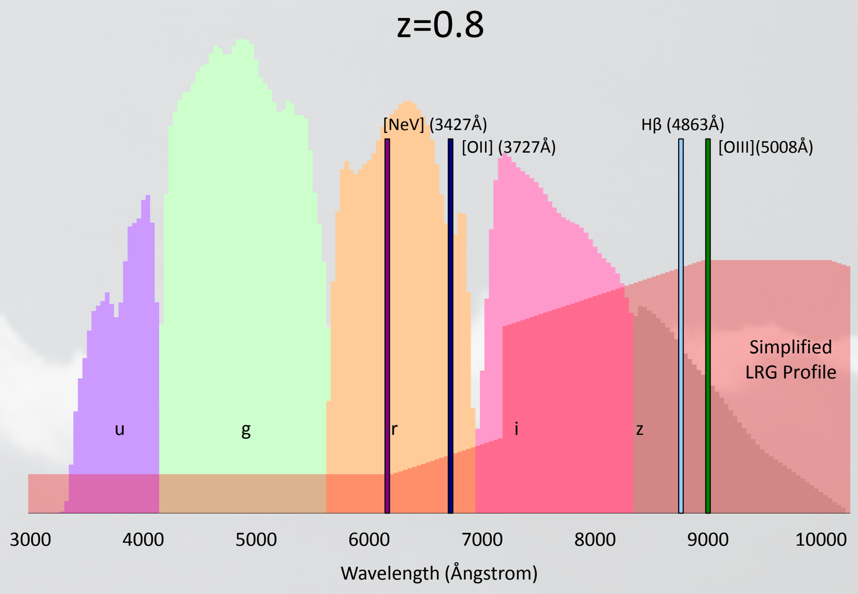


b) As before, but now for objects at z=0.4. The 4000Å break moves out of the photometric g band and the NII and Hα lines are now almost out of range.

Key absorption and emission lines

The prominent 4000Å break is due to a combination of CaII and high Balmer absorption lines. Hα and Hβ absorption are also features of passive LRGs. Star formation is usually indicated by OII emission and a reduction in Hα and Hβ absorption. It is more difficult to identify AGN activity in the optical, but it is possible by comparing combinations of emission lines, including Hα, Hβ NII and OII.

z=0.8



c) At z=0.8 LRGs become considerably fainter. The 4000Å break now enters the photometric i band. NeV is now the best placed optical diagnostic.

Traditional AGN diagnostics

Baldwin, Phillips & Terlevich (1981) first established empirical optical diagnostics to distinguish between emissions resulting from thermal emission (starlight) and power-law emission (AGN). These are based on relative intensities of pairs of emission lines; the most common diagnostic compares the emission line ratios of OIII/Hβ against NII/Hα, and is known as the BPT diagram. Kewley & Dopita (2002) calculated the maximum possible emission line contributions from starlight, and therefore established a theoretical dividing line representing an upper limit for star forming galaxies. Kauffmann et al. (2003) proposed a different dividing line by assuming strong correlations between ionisation parameters and metallicity in star forming galaxies. More recently, Stasinska et al. (2006) performed a detailed analysis using SDSS data. This analysis estimated the contribution from AGN in the 'transition' between the two dividing lines as up to 20% of the total luminosity of the galaxy.

Although the BPT diagram is now a well-established method to distinguish between normal star forming galaxies and AGN hosts, it is limited for galaxy surveys at medium redshifts as the traditional emission lines are shifted out of optical range. Rest-UV NeV emission therefore has the potential to indicate AGN activity in such surveys as it is shifted into optical range.

Testing NeV with BPT 'seagull wings'

How good is rest-UV NeV emission as an indicator of AGN activity? We tested it by recreating a simple BPT plot of galaxies within the redshift range 0.2 to 0.4, which is the best window for the required combination of emission lines. Only data with a high signal to noise ratio was included in the sample, and objects classified as QSOs were excluded. This is a simplified plot as the emission line values were estimated by

a) the SDSS 1dspec pipeline and

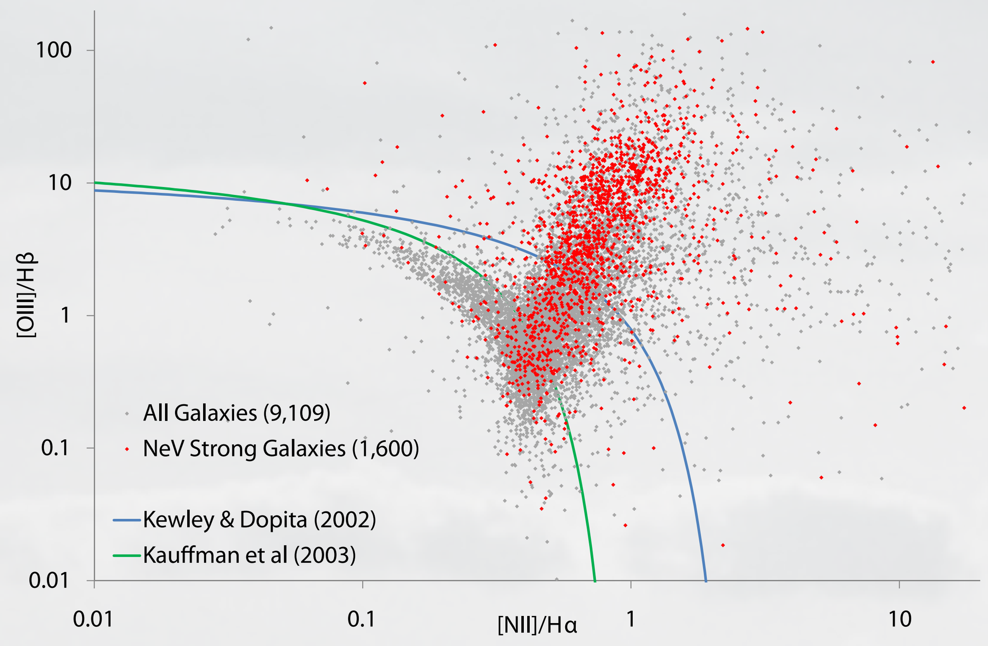
b) the subtraction of a simple model of stellar continuum

The results are displayed in the next panel.

NeV in LRGs

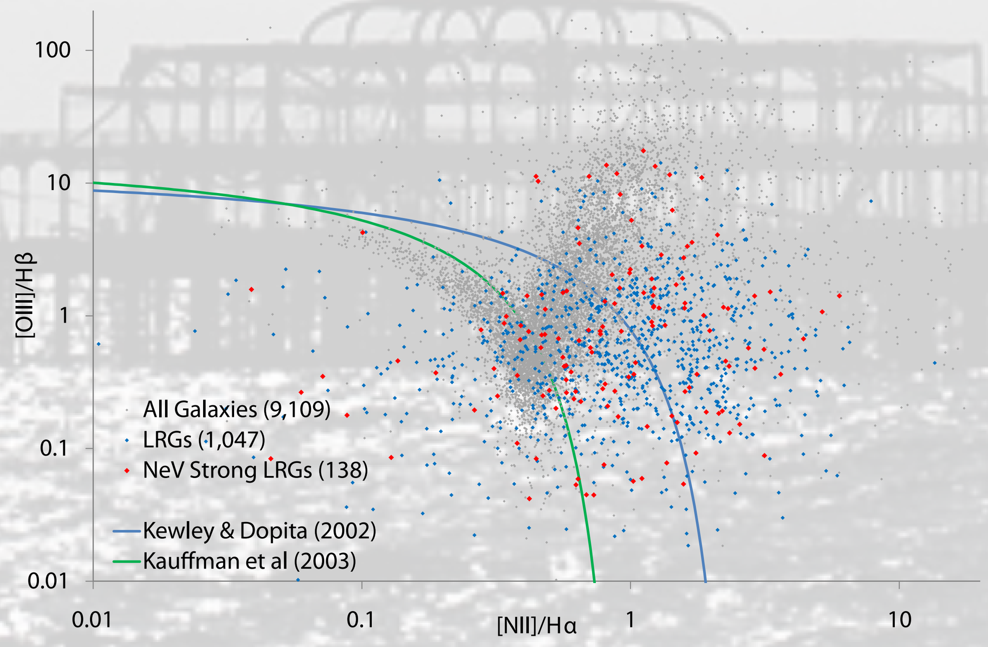
We identified 1,047 LRGs with all four emission lines as measured by the SDSS 1dspec pipeline; this represented less than 2% of the total LRG sample. The LRG plot in the next panel shows the LRG population (blue) against the total galaxy population (grey), with NeV strong LRGs indicated in red.

NeV in galaxies



Almost a quarter of galaxies classified as AGN (Kauffmann et al., 2003) show strong NeV emission. 90% of NeV emitting galaxies are classified as AGN.

NeV in LRGs



Only 15% of LRGs classified as AGN show strong NeV emission, although the proportion of NeV strong AGNs remains close to 90% of the total NeV sample.

Results so far

	Galaxies		LRGs	
Total Sample	9,053	100%	1,047	100%
AGN (Including transitional objects)	6,197	68%	905	86%
Star Forming Galaxies	2,856	32%	142	14%
With NeV Emission	1,600	18%	138	13%
AGN	1,446	16%	122	12%
Star Forming Galaxies	154	2%	16	2%

In contrast to the total galaxy sample, the active population of LRGs is not neatly classified. This is to some extent expected due to our selection process; we are actively seeking passively evolving galaxies, which would automatically exclude starburst galaxies (the left seagull wing) or Seyfert galaxies (the top right of the seagull wing). It is therefore not surprising that the majority of active LRGs are loosely classified as LINERs in the BPT diagram.

Further work

Future work includes:

a) Establishing the stellar populations of NeV strong galaxies and LRGs with emphasis on 'transitional' objects lying between the two classification systems

b) Investigating galaxies at higher redshifts; e.g. the 2SLAQ survey (Cannon et al., 2006) has obtained spectra for over 10,000 LRGs with a redshift range of 0.4<z<0.8.

References

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