Understanding the Formation of NGC 4550, a lenticular galaxy with counter-rotating stellar discs

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What is a Lenticular Galaxy?

A lenticular galaxy is a featureless disc galaxy with a central bulge, that generally appears red due to the old, faint stars it contains (see main image). Spiral galaxies have the same structure, but also contain hot, bright young stars that light up their spiral arms, which can be seen in Fig. 1. Theories for the evolution of spiral galaxies suggest that once the star formation activity stops in these galaxies, the brightest stars will quickly die off, causing the spiral arms to fade. Eventually a featureless disc containing old stars is left behind, transforming the galaxy into a lenticular.

Theories for this transformation focus on the disappearance of the gas within the galaxy, which is vital for star formation. It was first noticed by Dressler et al, (1980) that lenticular galaxies tend to favour denser environments, such as the centres of galaxy groups and clusters, while spirals were more frequently found in open space. As a result, many theories for the transformation of spirals to lenticulars focus on interactions with neighbouring galaxies or the cluster itself, in which the gas is either used up in a rapid starburst event or is completely stripped from the galaxy.

Figure 1. The spiral galaxy M51. Image courtesy of the Isaac Newton Group of Telescopes, La Palma

Why is NGC 4550 so Important?

In order to truly understand the evolution of lenticular galaxies from spirals, we need to be able to explain the formation of the more unusual lenticular galaxies we find. One such example is NGC 4550, which appears as a normal edge-on lenticular galaxy in the Virgo Cluster but contains two counter-rotating stellar discs and a gaseous disc that co-rotates with the secondary stellar disc. Around 10% of lenticular galaxies contain a counter-rotating stellar disc, but these are usually significantly smaller than the main disc (Kuijken, Fisher & Merrifield, 1996). In NGC 4550 however, both stellar discs contain similar stellar masses and extend out to the full diameter of the galaxy, which can be seen in the plot in Fig. 2 of the line-of-sight velocity of each disc along the length of the galaxy.

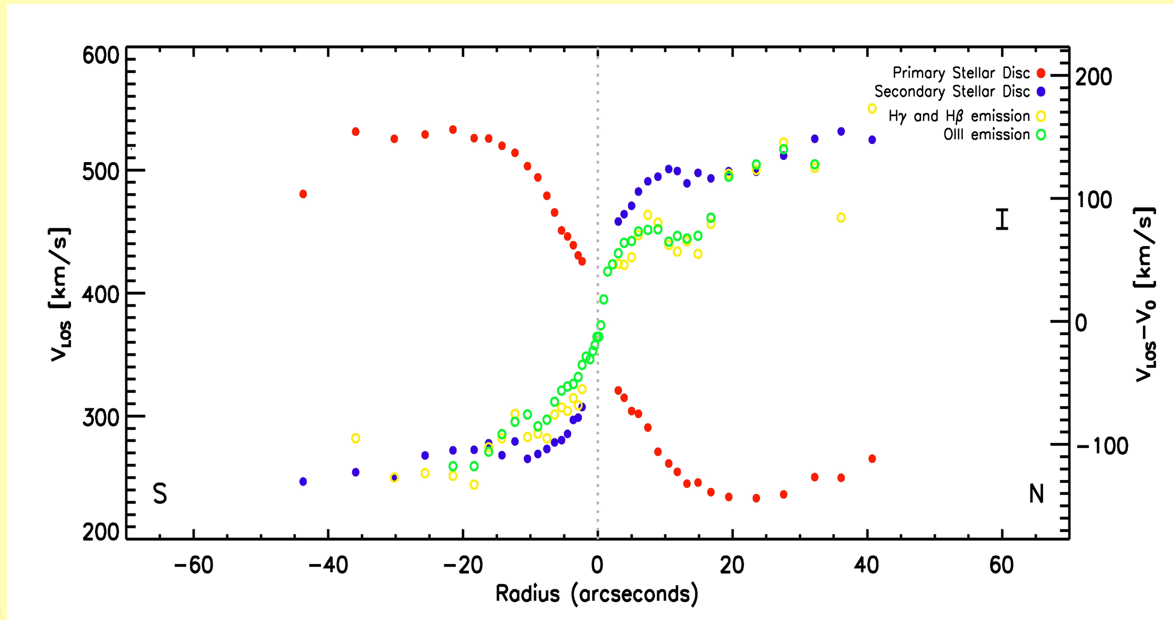
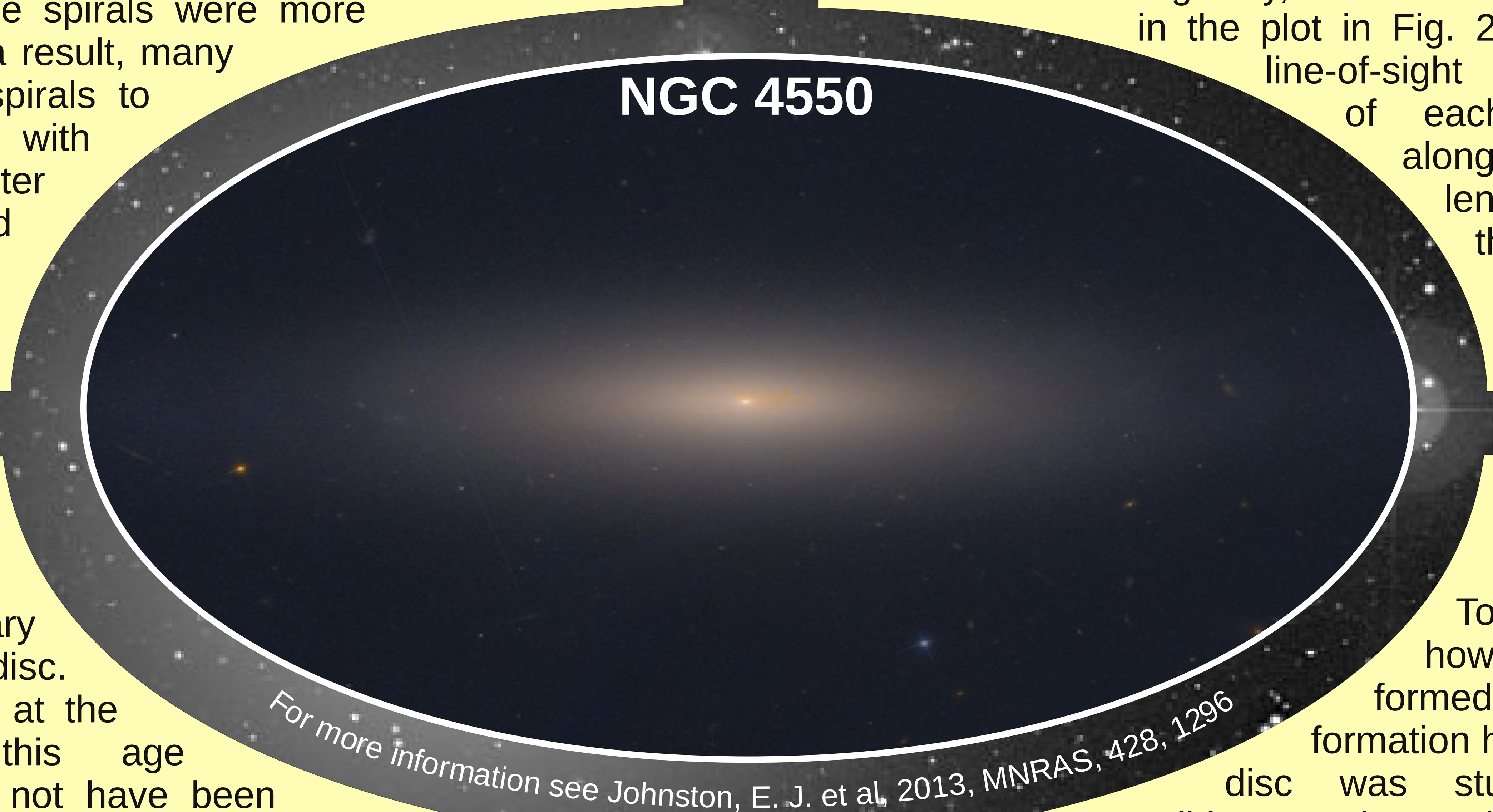


Figure 2. The line-of-sight velocity (V_{LOS}) of the two stellar discs in red and blue, and the gaseous disc (as measured from the Hβ, Hγ and $[OIII]_{\lambda5007}$ emission lines, shown in yellow and green) along the major-axis of the galaxy.



Stellar Populations Analysis

To determine how NGC 4550 formed, the star formation history of each disc was studied. It is possible to estimate the time since the last star formation event in each disc by calculating the age of the youngest, brightest stars present, which also dominate the light from that disc.

A series of stellar spectra were combined to give two spectra representing each stellar disc, which when added together would give the best fit to the galaxy spectrum. An example of this process can be seen in Fig. 3. To achieve the best fit, the gaseous disc was also modelled by gaussians representing the Hβ and Hγ emission features. The age of the youngest stellar population was then found by measuring the strength of the Hβ, Mgb and Fe absorption features and plotting these on the SSP model shown in Fig. 4.

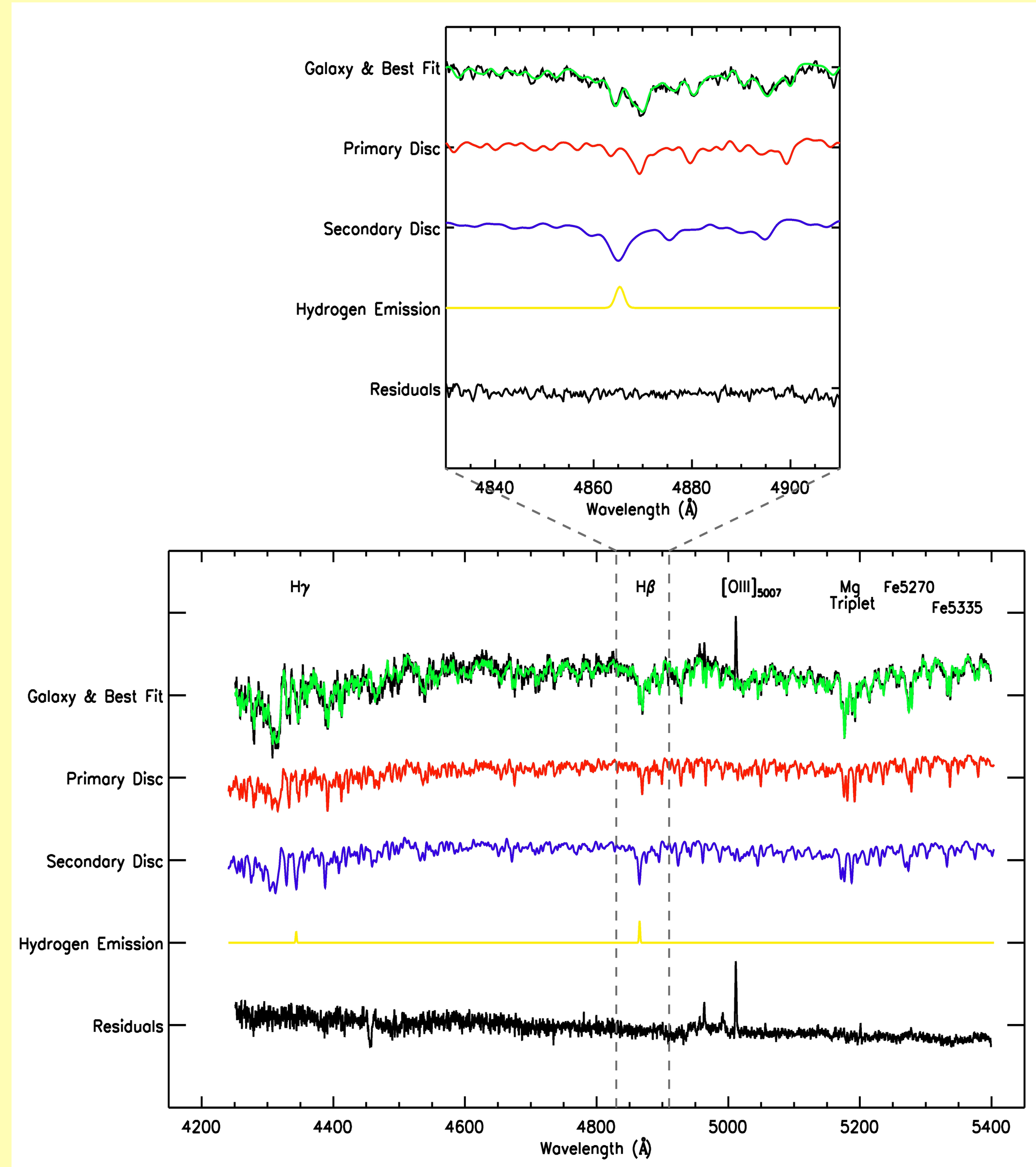


Figure 3. An example of how stellar spectra can be combined to give two new spectra, which can be co-added to fit the galaxy spectrum.

How Did NGC 4550 Form?

From the SSP model in Fig. 4 it can be seen that the primary stellar disc is significantly older than the secondary disc. Simulations have shown that if both discs were formed at the same time, this age difference could not have been achieved by more recent star formation activities occurring in only one disc. Instead, these results indicate that NGC 4550 either started off as a normal lenticular galaxy that formed around 11 Gyrs ago and later accreted gas into a gaseous disc from which the second stellar disc was produced, or is the result of a carefully controlled merger between two fully-formed galaxies. In the former scenario, the age of the stellar populations reflect when the second star formation activity occurred, while in the latter the ages simply reflect the ages of the progenitor galaxies.

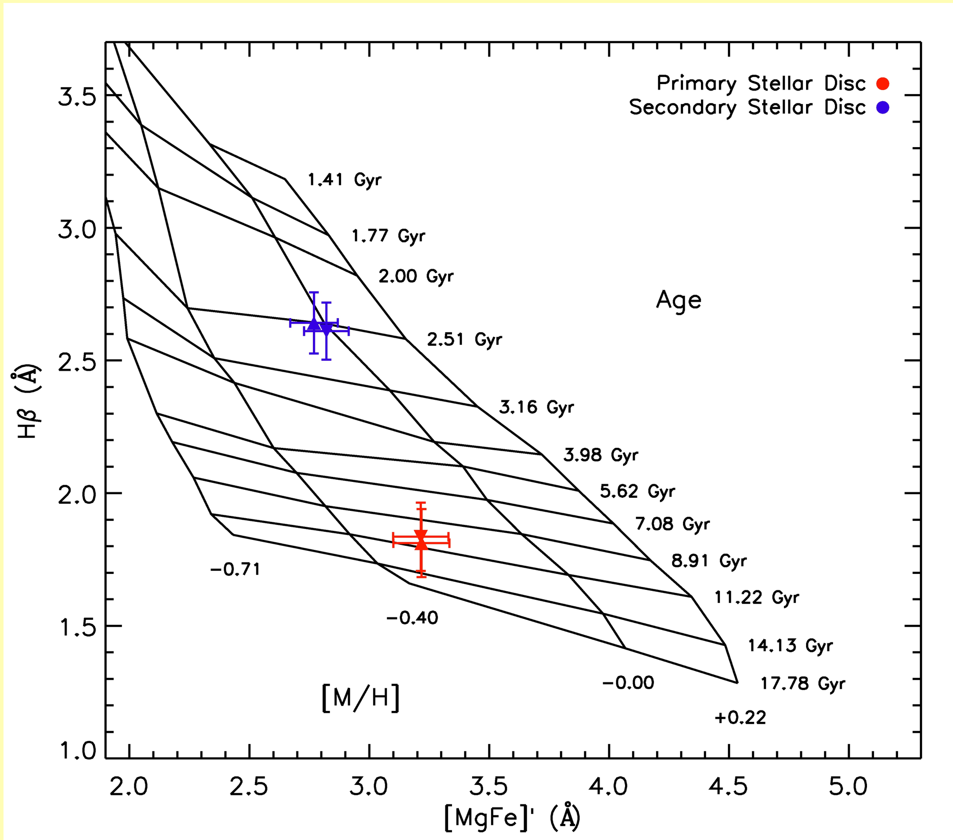


Figure 4. The Simple Stellar Population Model showing the light-weighted ages of the stars in each disc. The two data points for each disc show the consistency in the results from both semi-major axes of the galaxy.

References

Dressler A., 1980, ApJ, 236, 351
Kuijken K., Fisher D., Merrifield M. R., 1996, MNRAS, 283, 543