Infrared Survey of Pulsating Giant Stars in the Spiral Galaxy M 33: Dust Production, Star Formation History, and Galactic Structure

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Abstract. We introduce a near-IR monitoring campaign of the Local Group spiral galaxy M 33, carried out with the UK IR Telescope (UKIRT). The pulsating giant stars are identified and their distributions are used to derive the star formation rate as a function of age. We here present the star formation history for the central square kiloparsec. These stars are also important dust factories; we measure their dust production rates from a combination of our data with Spitzer Space Telescope mid-IR photometry.

1. Getting to Know the Milky Way from Studies of M 33

Given the difficulty of observing the central regions of our own Milky Way galaxy (van Loon et al. 2003) we might find out more about the structure and evolution of spiral galaxies by studying other nearby examples. Among the Local Group spiral galaxies, M 33 is smaller than the Milky Way and M 31 but it is viewed by us more favourably; the distance modulus to M 33 is $\mu = 24.9$ mag (955 kpc; Bonanos et al. 2006).

2. Pulsating Giant Stars as Tracers of Star Formation and Dust Production

Pulsating giant stars have reached the final stages of their evolution (their lives cut short by the severe mass loss initiated by these pulsations; van Loon et al. 2008). As their luminosity depends on their core mass, which depends on the birth mass, pulsating giant stars are good tracers of the population of stars formed when they themselves formed. Their cool, extended atmospheres are also fertile grounds for the formation of dust grains. As the grains intercept visual radiation from the star and emit it at infrared (IR) wavelengths we can measure the dust production rate by modelling the spectral energy distribution.

3. The United Kingdom Infrared Telescope Monitoring Survey of M 33

We used the United Kingdom Infrared Telescope (UKIRT) to monitor M 33 in the $K$ band (at a wavelength of 2.2 $\mu$m). This was done first for the central $4' \times 4'$ (a square kpc at the distance of M 33), mainly with the UIST instrument over the period from 2003 to 2007. Later in the campaign, images were taken with the WFCAM instrument,
covering essentially the entire extent of the visible disc of M 33 (Fig. 1). Occasionally, images were taken also in the J (1.2 µm) and H (1.6 µm) bands in order to obtain colour information. The survey and identification of variable stars are described in detail in Javadi, van Loon, & Mirtorabi (2011, Paper I); 812 variable stars were found and shown to be predominantly pulsating giant stars – the full photometric catalogue comprises 18 398 stars and is available from CDS.

4. The Star Formation in the Central Square Kiloparsec of M 33

The star formation history is described by the star formation rate, $\xi$, as a function of look-back time (“age”), $t$:

$$\xi(t) = \frac{f(K(M(t)))}{\Delta(M(t))f_{\text{IMF}}(M(t))},$$

where $f(K)$ is the observed $K$-band distribution of pulsating giant stars, $\Delta$ is the duration of the evolutionary phase during which these stars display strong radial pulsation, and $f_{\text{IMF}}$ is the Initial Mass Function describing the relative contribution to star formation.
Pulsating Giants in M 33

by stars of different mass. Each of these functions depends on the stellar mass, $M$, and
the mass of a pulsating star at the end of its evolution is directly related to its age ($t$).

![Graph showing star formation history](image)

Figure 2. The star formation history in the central square kiloparsec of M 33
derived from pulsating giant stars found in our infrared monitoring survey.

The resulting star formation history is shown in Fig. 2 and is described in detail
in Paper II (Javadi et al., submitted to MNRAS). The main features are that the large
majority of the stars were formed more than 4 Gyr ago, but that the subsequently quieter
star formation has been punctuated with epochs of enhanced rates of star formation of
which a recent one is detected to have occurred around 200–300 Myr ago, forming at
most 4% of all stars that have been formed over M 33’s lifetime (within the central
square kiloparsec).

The spatial distributions of the massive stars, intermediate-age Asymptotic Giant
Branch (AGB) stars and generally old Red Giant Branch (RGB) stars suggest that
young and intermediate-age stars were formed within the disc, while the oldest stars
may inhabit a more dynamically-relaxed configuration. Interestingly, the massive stars
concentrate in an area South of the nucleus, and the intermediate-age population shows
signs of a “pseudo-bulge” that however may well be a bar-like feature.

5. Dust Production in the Central Square Kiloparsec of M 33

Despite the complex diffuse emission and crowdedness in the central regions of M 33,
a significant fraction of the pulsating giant stars have been detected at mid-IR wave-
lengths (3–8 µm) with the Spitzer Space Telescope (Fig. 3 cf. McQuinn et al. 2007). It has been possible to estimate the mass-loss rates (and dust production rates) across a range of intensity (Fig. 4 Paper III in preparation).

6. On-going Work and Concluding Remarks

We are currently extending our study to the WFCAM data that cover the disc of M 33, to derive a global star formation history and dust production rate. We aim to establish a link between the dust return and the formation of stars within the prominent spiral arm pattern, and to map their subsequent dynamical relaxation into the inter-arm regions.

In conclusion, our method to derive the star formation history from pulsating giant stars has been validated for the central region of M 33. While model-dependent, our analysis is internally consistent and supports the Padova models we employed (Marigo et al. 2008) except that the super-AGB stars do seem to reach high luminosities and develop cool atmospheres and strong pulsation.
Figure 4. UKIRT + Spitzer (where available) photometry of four examples of red giant stars in the centre of M 33, that are affected by various levels of mass loss. The photometry is compared with dusty radiative transfer models (Nenkova et al. 1999) for oxygen-rich dust (yielding higher rates and higher luminosities beyond 10 µm) and carbon-rich dust. The light curves of these stars are presented in Paper I.

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