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KNOW (BETTER) YOUR NEIGHBOUR: NEW HI STRUCTURES IN MESSIER 33 UNVEILED BY A MULTIPLE PEAK ANALYSIS OF HIGH-RESOLUTION 21-CM DATA

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Abstract. In our quest to constrain the dynamical and structural properties of Local Group spirals from high-quality interferometric data, we have performed a neutral hydrogen survey in the direction of Messier 33. Here we present a few preliminary results from the survey and show the benefits of fitting the HI spectra by multiple peaks on constraining the structure of the Messier 33 disk. In particular we report on the discovery of new inner spiral-like and outer annular structures overlaying with the well-known main HI disk of Messier 33. Possible origins of the additional outer annular structure are presented.

Keywords: Galaxies: individual: M33, NGC 598, Galaxies: ISM, Galaxies: kinematics and dynamics, Galaxies: structure, Local Group, Techniques: imaging spectroscopy

1 Context

The dynamical and structural properties of HI disks of nearby spirals mainly result from the analysis of the 0th and 1st moments of HI spectra obtained from single-dish and interferometric observations. Curiously more thorough analyses of HI spectra making profit from current high spectroscopic precision and sensitive cm-data remain rare.

In 2006 we have started a HI survey of the most massive spiral disks from the Local Group (except the Milky Way) to revisit their structure, kinematics and dynamics. Aperture synthesis at DRAO combined with short spacing data have been used to perform 21-cm observations of the Andromeda galaxy (Messier 31) at spectral resolution $\lesssim 5$ km s^{-1}, angular resolution ~ 300 pc ($D \sim 800$ kpc) and sensitivity down to $\sim 2 \times 10^{19}$ cm^{-2} (Chemin et al. 2009).

Since many spectra are far from being dominated by one single HI component we have shown that the moment analysis of datacubes was not appropriate (see Fig. 1 and §3.2 of Chemin et al. 2009, and left panel of Fig. 1 below). This is the reason why we developed a 'search and fit' algorithm of multiple (gaussian) components. Applied to new Messier 31 data this algorithm has allowed the detection of sometimes up to five HI significant components per profile, which had never been reported beforehand for nearby HI spirals. So many multiple peaks likely result from the combination of extreme projection effects of the warped Messier 31 disk with internal and external dynamical perturbations (spiral density wave, lagging halo, expanding gas shells, accretion of gas from the intergalactic medium or from nearby minor companions, etc). The discovery of outer HI spurs and spiral arm was also reported, as well as the characterization of the disk warp in terms of twist and tilt angles and the measurement of the most extended rotation curve for Messier 31.

We note that this kind of hyperspectral decomposition within multiple gaussian peaks is not new and has been used several times (e.g. Sicotte & Carignan 1997; Oh et al. 2008). It is nonetheless not generalized in HI studies. From a dynamical point-of-view, the multiple peak analysis has led to (marginally) different rotation velocities and inclinations than those derived with another recent and high-quality HI datacube of Messier 31 from the 0th- and 1st-moment analysis (Braun et al. 2009; Corbelli et al. 2010). Again, such differences have already been reported (see e.g. Figs. 11 and 13 of Oh et al. 2008).

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2 Yet another new HI survey of Messier 33

In pursuit of our project we present here very preliminary results for Messier 33, a late-type spiral whose HI disk is known to be warped (Corbelli & Schneider 1997). The 21-cm interferometric data were still obtained at DRAO (combined with the Arecibo data of Putman et al. 2009) but at a larger spectral resolution (3.3 km s^{-1}) than for Messier 31 observations. Of course it is very likely to detect multiple components with highly resolved spectra. However this does not guarantee the success of detecting *realistic* ones because noise becomes important at high resolution. Furthermore the number of components that can be fitted per spectra depends on the resolution. With more and more peaks found in an individual spectrum (as for Messier 31), it becomes less and less straightforward to interpret the data and identify for instance the component that is the most representative of the disk circular rotation to those that are caused by all abovementioned perturbing effects. The HI datacube of Messier 33 has thus been filtered to lower resolution to simplify the hyperspectral decomposition.

3 Preliminary results: evidence for new HI structures in Messier 33

Other recent HI surveys of Messier 33 have been performed at VLA and Arecibo (Thilker et al. 2002; Putman et al. 2009). The VLA data of Thilker et al. (2002) have allowed to determine for the first time the inner structure of the HI disk with unprecedented details (resolution of 20 pc). The Arecibo data of Putman et al. (2009) were more appropriate to study the nearby environment of Messier 33 at a resolution of about 1 kpc. In particular they have shown the HI disk of Messier 33 is surrounded by arc-like structures and clumps. A hint of such perturbations had been presented in another (earlier) Arecibo view of Messier 33 (Corbelli, Schneider, & Salpeter 1989). Our DRAO survey has thus an intermediate angular resolution to them.

Working with a datacube of effective spectral resolution of 10 km s^{-1} our 'search and fit' algorithm of multiple peaks identifies sometimes up to 3 significant HI components in the datacube. An example of two distinct components is shown in Fig 1 (left-hand panel). Here the components are separated by $\sim$ 45 km s^{-1}. The total integrated HI emission of Messier 33 is shown Fig 1 (central panel). The external arc-lile structure and the SW clump are clearly detected, even within our $\sim$ 300pc-resolution data, as well as the 'main' inner disk. Multiple components are not observed over the whole field-of-view, as seen in Figure 1 (right panel), but are preferentially distributed along a 'secondary' spiral-like structure in the inner disk and an annular structure in the outer regions ($r \sim 80'$ or 19 kpc). It is obvious that none of these new structures would have been identified with a moment analysis of the datacube.

A preliminary tilted-ring model has been fitted to the velocity field of the 'main' HI component shown in the left-hand panel of Fig. 2. A significant twist of the orientation of the major kinematical axis is evidenced, as well as a tilt of the HI disk (Fig. 3). This result thus confirms the warped nature of the HI disk of Messier 33. The kinematics of the external arc-like structure does not differ so much from that of the inner disk, implying that this perturbation is bound to the disk. We have not yet fitted the warp parameters for it, as shown by constant inclination and position angles at those locations ($r > 100'$, Fig. 3).

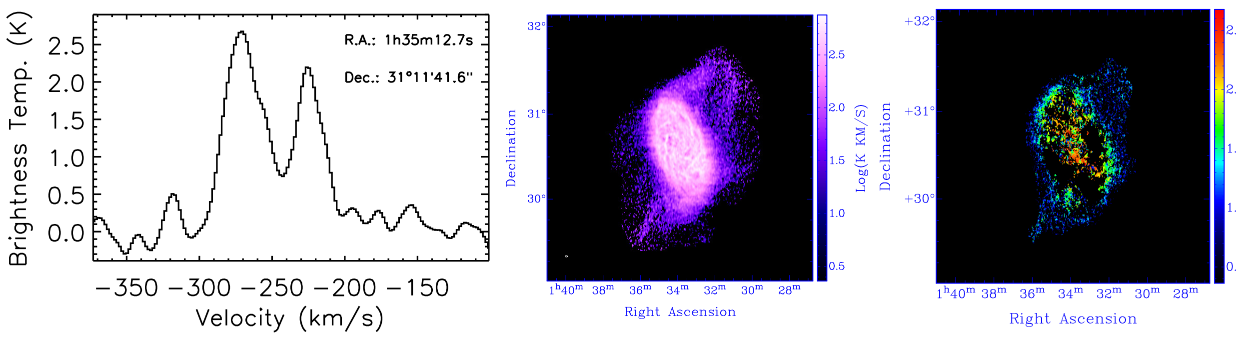

Fig. 1. Left: Illustration of a HI profile with two distinct components. **Middle**: Total integrated HI emission map of Messier 33. **Right:** HI integrated emission map of the 'secondary' fitted HI component in Messier 33. A logarithmic stretch is used for them.

The kinematics of the outer annular structure is shown in the middle panel of Fig. 2 and its residual field when subtracted from the velocity field of the 'main' HI component in the right-hand panel of Fig. 2. Differences

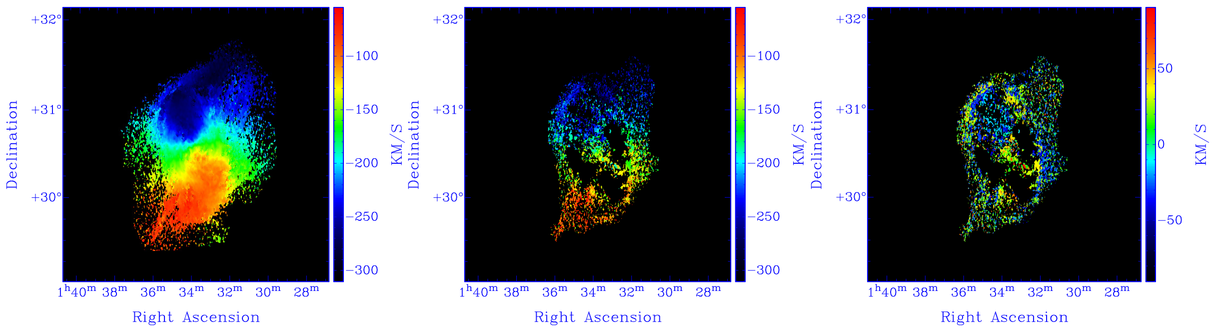

Fig. 2. Left: Velocity fields of the 'main' HI component of Messier 33. **Middle**: The secondary component. **Right:** The residual field from their mutual subtraction.

of radial velocities sometimes reach 40-50 km s^{-1} in absolute values. At this stage of our analysis it is too early to firmly identify which of the multiple components is the real tracer of the 'main' disk kinematics to that of the inner 'secondary' spiral-like structure on one hand, and to that of the outer HI annulus on another hand. Indeed the disk kinematics is strongly perturbed in those regions (warp, connection with the external arc-like structure, etc). It is also too early to constrain the exact origins of the inner 'secondary' spiral-like pattern and the outer annular structure. We retain the following hypotheses for this later:

- The annular structure has external origins to Messier 33. Gas accretion on the outer disk parts from e.g. the external arc-like strucure or the intergalactic medium could be ongoing. Messier 33 has an obvious perturbed environment, and past tidal interactions with other galaxies may not be excluded. Numerical simulations would be needed to test those assumptions.

- The annular structure is a genuine ring, with internal origins. For instance it could have been developed by gas accumulation at the outer Lindblad resonance. In this case an obvious perturbing density wave could be grand-design spiral structure of Messier 33. This hypothesis could be tested by measuring the pattern speed of the spiral density wave with a modified version of the Tremaine-Weinberg method, and by determining the locations of various Lindblad resonances.

- The annular structure is not a real ring but is only caused by a fortuitous projection effect of a peculiar warping of Messier 33 (and maybe also a disk flaring) at the periphery of the HI disk. One would need here gas orbits that have orientation angles significantly different from the constant one displayed in Fig. 3 from $r \sim 85'$ to generate a distinct structure in superimposition to the outer disk.

Noteworthy is the fact that insights for asymmetric HI profiles along a ring-like structure as caused by the warped gas orbits has been reported in Corbelli & Schneider (1997). The location of that ring-like structure found by Corbelli & Schneider (1997) corresponds with that of the external arc-like structure, but not to that of the outer HI annulus we evidence here. Furthermore the HI annulus does not share the same orientation parameters than the external arc-like structure (Fig. 1). Two different ring-like structures thus seem to coexist in the outer regions of Messier 33.

4 Conclusions

Provisional results from a new HI survey in the direction of Messier 33 performed with aperture synthesis observations at the Dominion Radio Astrophysical Observatory have been presented. Evidence for new HI structures in Messier 33 have been found from a multiple HI peak analysis of the datacube. Among them is the detection of an annular-like structure in the outer regions of the HI disk. That annulus does not correspond to the already known arc-like structure around Messier 33. Complete details of the observing campaign, the data reduction and the hyperspectral decomposition will be presented soonly (Chemin et al. 2013). Our main objectives are to revisit the structure and dynamics of Messier 33, derive an accurate and extended rotation curve for it, and model its mass distribution. With the results already obtained for the Andromeda galaxy, this new dataset should help to better constrain the evolution of massive spirals in the Local Group.

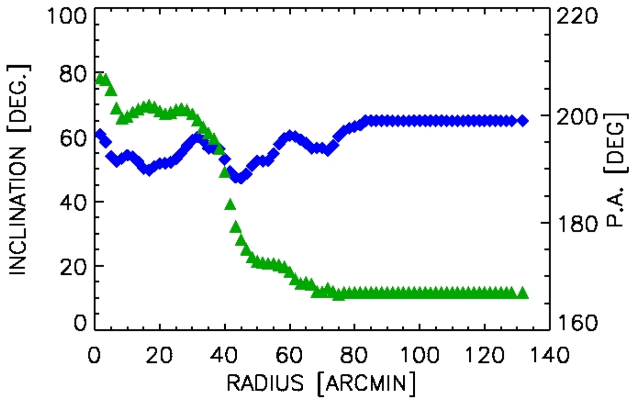

Fig. 3. Preliminary results of the tilted-ring model fitted to the 'main' HI velocity field of Messier 33 from central panel of Fig. 2. Blue squares are for the disk inclination and green triangles for the position angle of the major kinematial axis.

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