HI and AGN Morphology in NGC 3998

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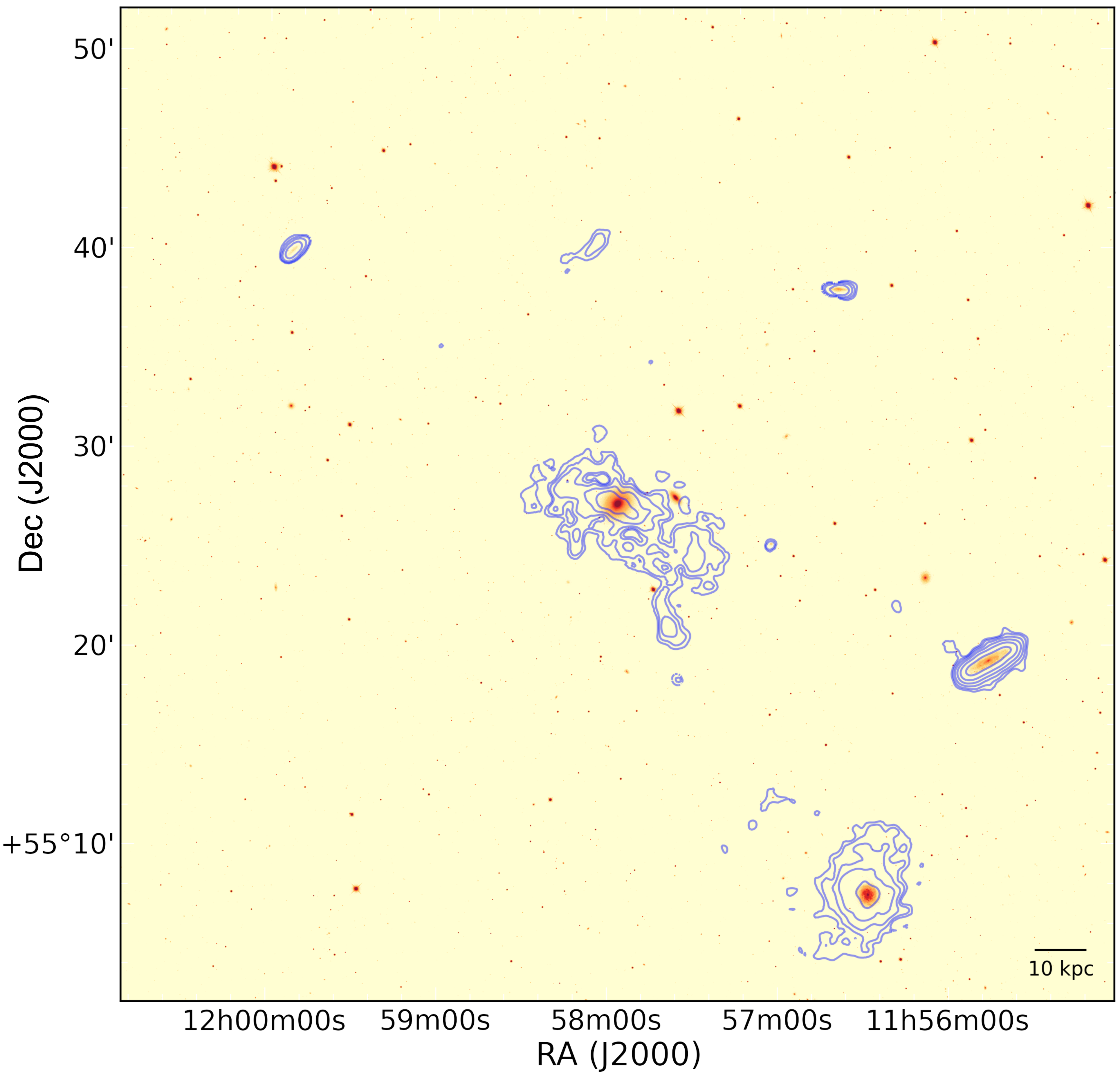
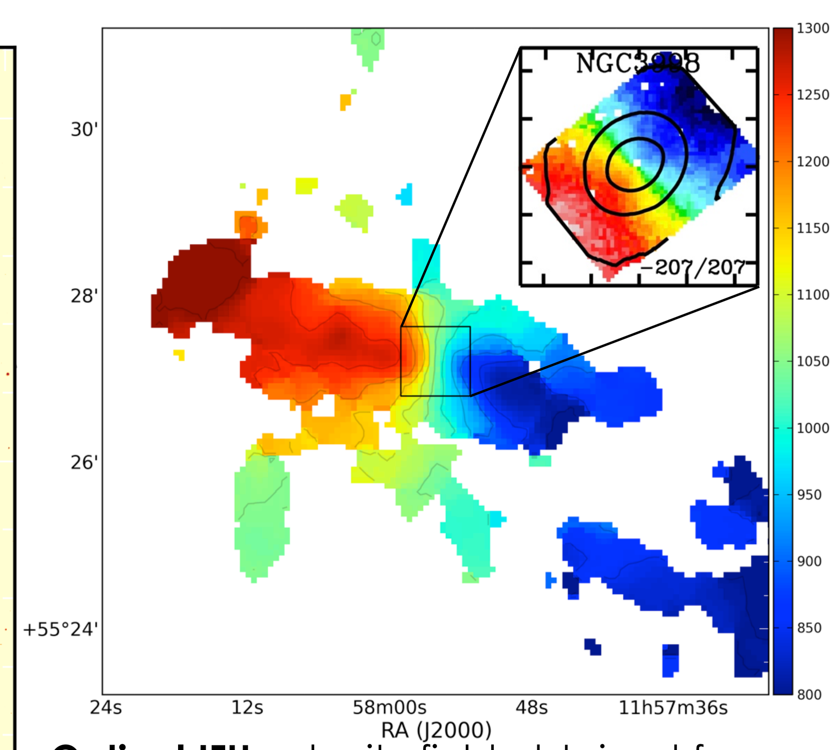
NGC 3998 is an early-type galaxy and is a distant cousin of Cen A (Morganti et al. 2010). The deep radio continuum image unveiled by WSRT shows a complex S-shaped or bubble-type morphology. This diffuse morphology could be driven by either starbursts or the AGN (e.g. the case of Mrk 6, Kharb et al. 2006). Here we utilize multi-wavelength data to determine a few simple timescales, which we can use to compare the likelihood of either driver of the diffuse emission.

HI Environment

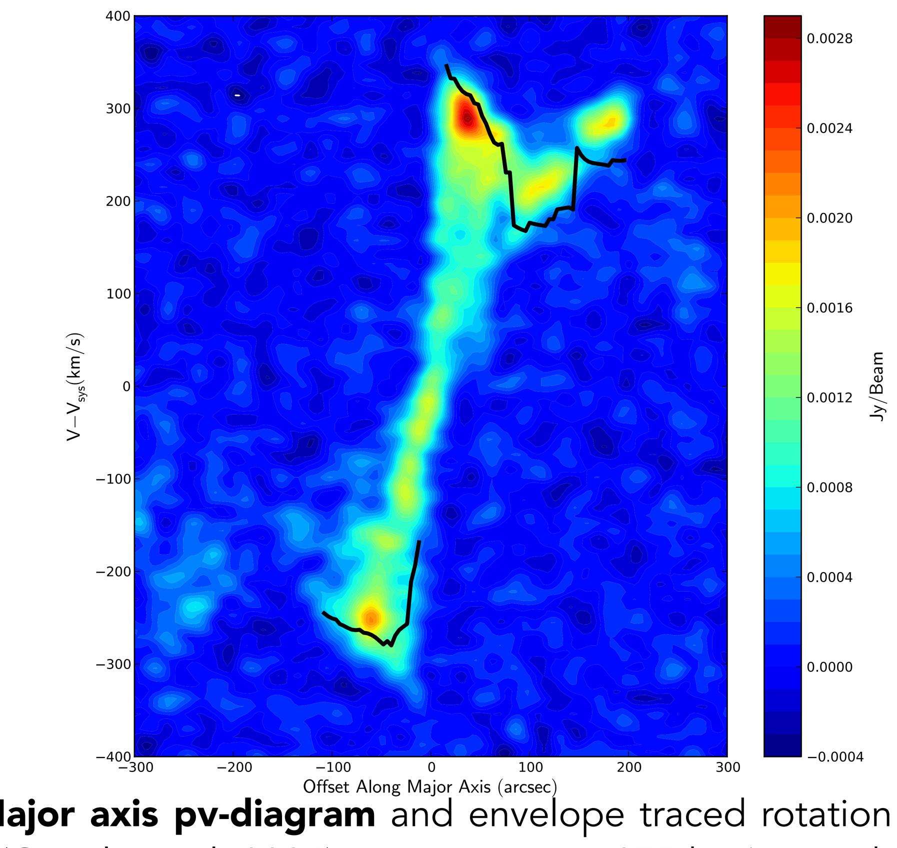


SDSS *R* image of NGC 3998 and its companions, with HI moment-0 contours overlaid. The HI contours are $S_{HI} = N_0 \times 2^n$ ($N_0 = 2 \times 10^{19}$ cm^{-2}, n=0,1,2,...). This shows the ongoing interaction between these galaxies, and suggests that NGC 3998 may have accreted much of its gas from its neighbors. Despite the complex HI morphology, the HI seems to be regularly rotating (see the pv-diagram in the next inset). Assuming a close encounter with a neighbour & v_{pec} ~ 500 km/s: $\tau_{encounter}$ ~ 10^8 y.

HI and Stellar Kinematics

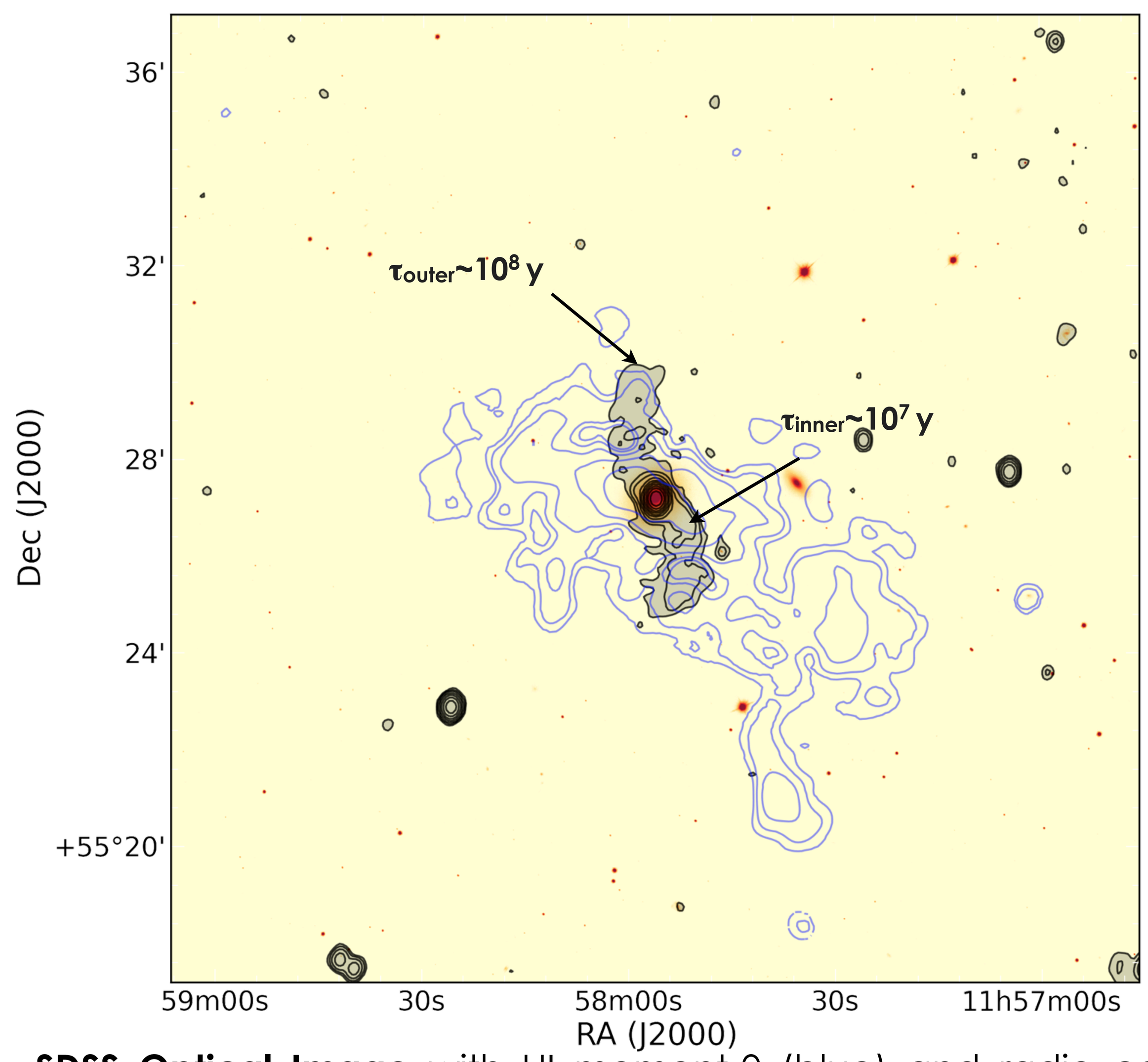


Optical IFU velocity field obtained from SAURON observations (Krajnovic et al. (2011), Emsellem et al. (2004)), with HI Mom-1 Velocity Field, ϕ_{HI}= 70°, ϕ_{IFU}=134.5°



Major axis pv-diagram and envelope traced rotation curve (Gentile et al. 2004). Assuming v_c = 275 km/s at a distance of 4 kpc (~1′), we calculate an orbital period of ~10^8 yr, less than the average age of the stellar content (>10^9 yr).

HI and Radio Continuum Morphology



SDSS Optical Image with HI moment-0 (blue) and radio continuum (black) filled contours. The HI contours are as above, and the radio continuum contours are S_{con} = 0.15 x 2^n mJy beam^{-1} (n=0,1,2,...). Using the method outlined in Churazov et al. 2001, we derive the timescales for the jet driven bubbles to reach their inner (τ_{inner} ~ 10^7 y) and outer (τ_{outer} ~ 10^8 y) positions.

NGC 3998 is an early-type galaxy observed as part of the ATLAS3D (Cappellari et al (2011)) survey. In the optical NGC 3998 is an unremarkable red and dead galaxy, showing no sign of ongoing star-formation. The average age of the stellar population > 10 Gyr (McDermid et al. (in prep)).

Deep radio observations of NGC 3998 with WSRT (10 x 12 hrs) reveals a drastically different picture to what is observed in the optical. NGC 3998 is involved in interactions with its neighbors. It has a large HI content, in comparison with other ATLAS3D galaxies of similar morphology (M_{HI} ~ 3 x 108 $M_\odot$, D = 13.7 Mpc, (Serra et al. (2012)) and harbours a young, possibly restarted, flat-spectrum AGN (Healey et al. (2007)). In addition, the radio continuum reveals diffuse emission with a complex morphology, which is likely a relic of past activity.

The HI is distributed along a polar structure, and has a component which is regularly rotating (~1′ - see the velocity field below). The offset between the HI and stellar position angle is quite large (65°). In addition, the principle axis of the radio continuum lobe emission is offset from the HI.

What is the driver of the diffuse continuum morphology? Is it starburst driven, or AGN driven? Using the case of Mrk 6 as a template, we use the multi-wavelength data to compute various important timescales (illustrated above) - the average age of the stars τ_{stars} ~ 10^9 y, the time since the latest encounter $\tau_{encounter}$ ~ 10^8 y, the timescale for the HI disk to form τ_{HI} ~ 10^8 y and the time taken for the radio continuum bubbles to rise to the inner and outer distances: τ_{inner}~10^7 y and τ_{outer}~10^8 y (using the method from Churazov et al. 2001). Since τ_{stars} >> τ_{outer}, we can rule out a starburst driven origin of the bubbles; and τ_{outer} ~ τ_{HI} ~ $\tau_{encounter}$ suggests that a previous encounter between NGC3998 and its neighbours could've played a part in initiating the AGN activity.

References

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