A new model for the Antennae System

Simon Karl, Thorsten Naab - University Observatory Munich

Abstract

In the framework of hierarchical structure formation ellipticals can form from merging smaller disk galaxies. The nearby interacting *"Antennae" galaxy pair* (NGC 4038/39) is one of the best-studied local systems of merging spirals, thus, offering an ideal laboratory for galaxy evolution models. The Antennae are believed to be in a state prior to their final encounter with rapid subsequent merging, which locates them at the first position in the Toomre (1977) merger sequence. Here we present high-resolution, self-consistent numerical simulations of the Antennae system and compare it to observations by Hibbard et al. (2001). We are able to obtain a close match to the observed morphology and kinematics of the system. This is the first step in a row of detailed theoretical studies of the physical properties in this merging system.

Numerical Setup

For our model of the Antennae galaxies we set up equilibrium galaxy models, each consisting of a Hernquist (1990) DM halo and stellar bulge component, and additional exponential stellar and gaseous disks. Details are given in Table 1. The ratio of luminous to dark matter is M_{bary}:M_{DM}= 1:4, where NGC 4038 is modeled as a 'Sc galaxy' with bulge-to-disk ratio B/D = 0.2, NGC 4039 as a 'Sb galaxy' with B/D = 0.4. Each galaxy has a total mass M_{tot} = $8.3\ 10^{10}\ M_{\odot}$ and a disk gas fraction of 20%. All simulations are run using the fully parallel SPH code Gadget2 (Springel 2005).

Initially the galaxies move on elliptical orbits ($e \approx 0.8$) with pericentric separation r_p = *11.5 kpc* and initial separation of one virial radius $r_{init} \approx$ *62 kpc.*

Tab. 1

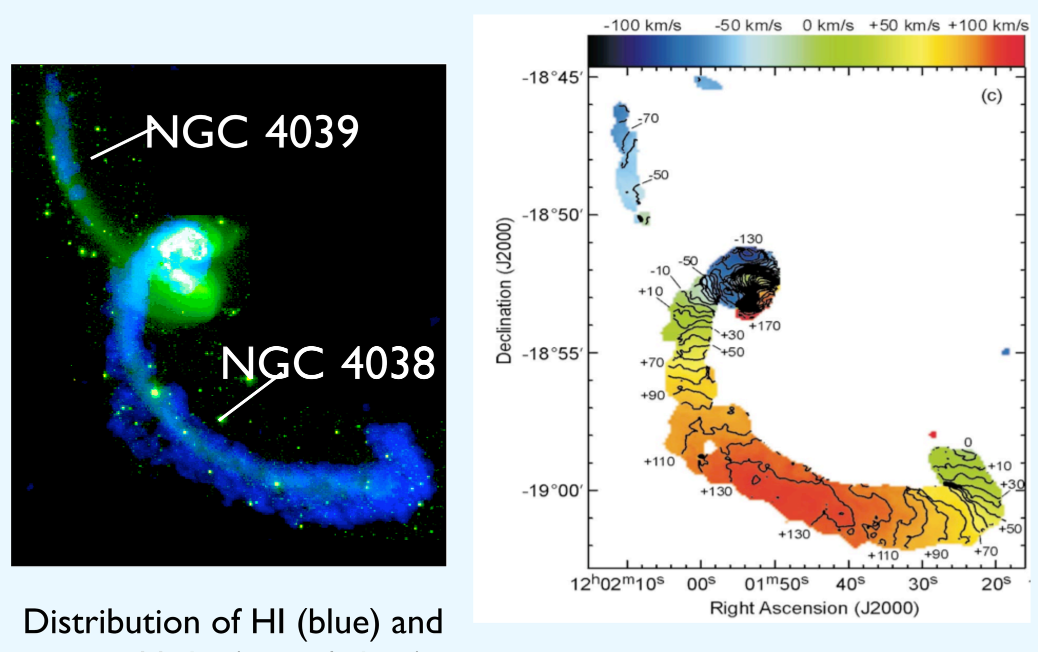
Radial disk scale h_{Disk}	Vertical disk scale z_0	Bulge scale length h_{Bulge}	Rotational velocity @ 6 kpc
2.0 kpc	0.42 kpc	0.42 kpc	187 km/s

References:
- Baldi et al., *2006, ApJ, 336, 158*
- Brandl et al., *2005, ApJ, 635, 280*
- Hernquist, *1990, ApJ, 356, 359*
- Hibbard et al., *2001, AJ, 122, 2969*
- Springel, *2005, MNRAS, 364, 1105*
- Springel&Hernquist, *2003, MNRAS, 339, 289*
- Toomre, A.,, *1977, in "Evolution of Galaxies and Stellar Populations", ed. B.M. Tinsley*
- Wang et al., *2004, ApJS, 154, 193*
- Whitmore et al., *AJ, 1999, 118, 1551*

Observations

There is a huge amount of data collected for the Antennae from ground and space missions, covering a wide range of wavelength regimes. Recent examples include: *optical HST WFPC data (Whitmore et al. 1999), near-IR WIRC (Brandl et al. 2005) and mid-IR IRAC (Wang et al. 2006) imaging, and, Chandra ACIS-S X-ray observations (Baldi et al. 2006).*

Here we use high-resolution VLA HI mappings of the Antennae (*~20", Δv=5.21 km/s*) by Hibbard et al. (2001) for comparison with our models, using the cold atomic gas as a sensitive tracer of the overall dynamics in the system (see Fig. 1).



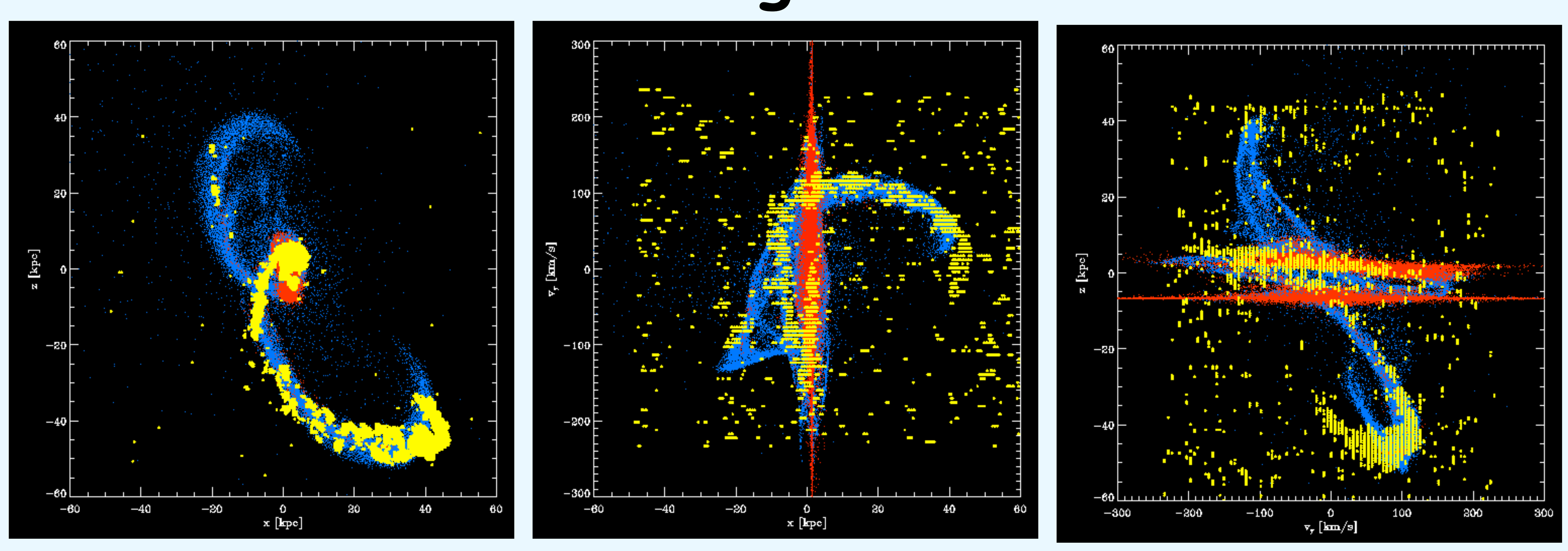
Distribution of HI (blue) and optical light (green/white) Intensity-weighted HI velocity map

Fig. 1

Results

We ran a set of low-resolution simulations (N_{tot} = *40,000*), varying the orientation of the disks and the viewing angle, until we obtained a good match with the observational data. This was followed by a high-resolution run (N_{tot} = *1,600,000*) including star formation, following the star formation model by Springel & Hernquist (2003). We obtain our 'best fit' at a time shortly before the second encounter, that is $t \approx$ *320 Myr* after pericenter and $t \approx$ *50 Myr* until final merging (see Fig. 2).

Fig. 2



Projection of our model at time of 'best fit' in a) X-Z (plane of the sky), b) X- V_Y and c) V_Y-Z. Only gas (blue) and newly formed star (red) particles are shown and compared to observational data (yellow)

The simulations do already include star formation and stellar feedback using subgrid physics as proposed by Springel & Hernquist (2003). We will investigate the detailed history and distribution of newly formed stars in comparison to observations, in particular in the *'overlap region'* of the two progenitor disks. This will enable us to adjust the star formation model and figure out the important physical properties controlling star formation in interacting galaxies.

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skarl@usm.uni-muenchen.de