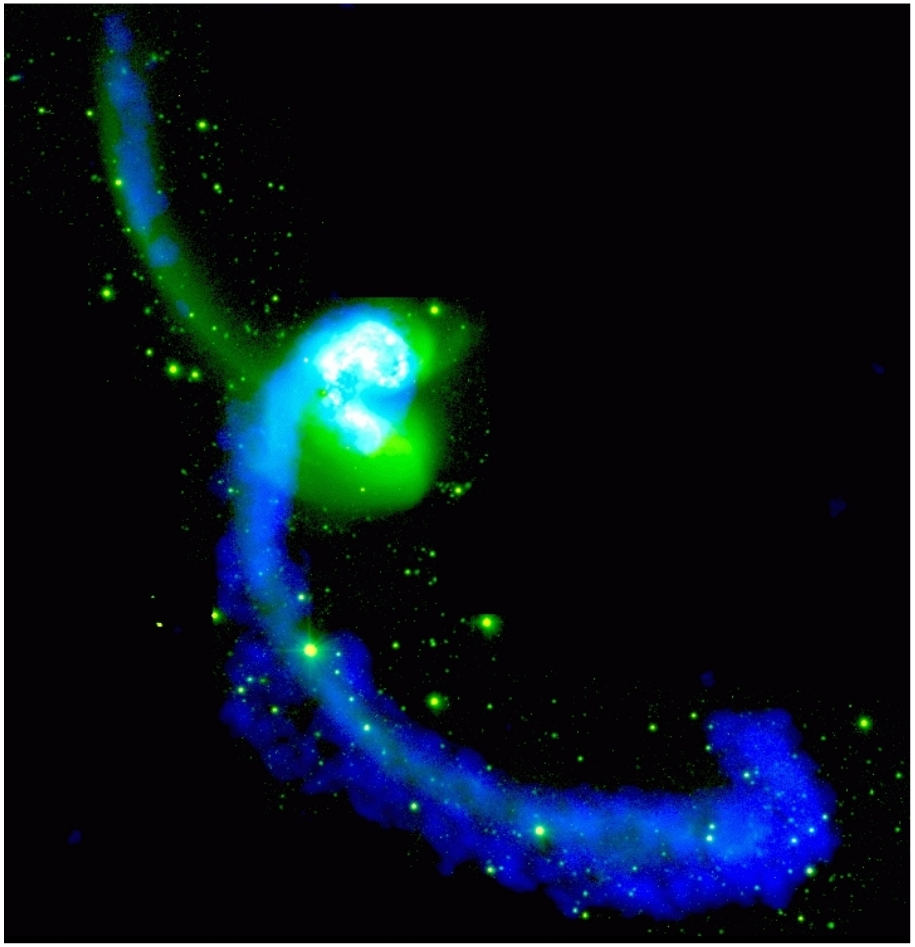

Simulations of the Antennae galaxies - galaxy evolution in our backyard

in collaboration with:

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Interacting Galaxies and Binary Quasars
Trieste
4/5/12

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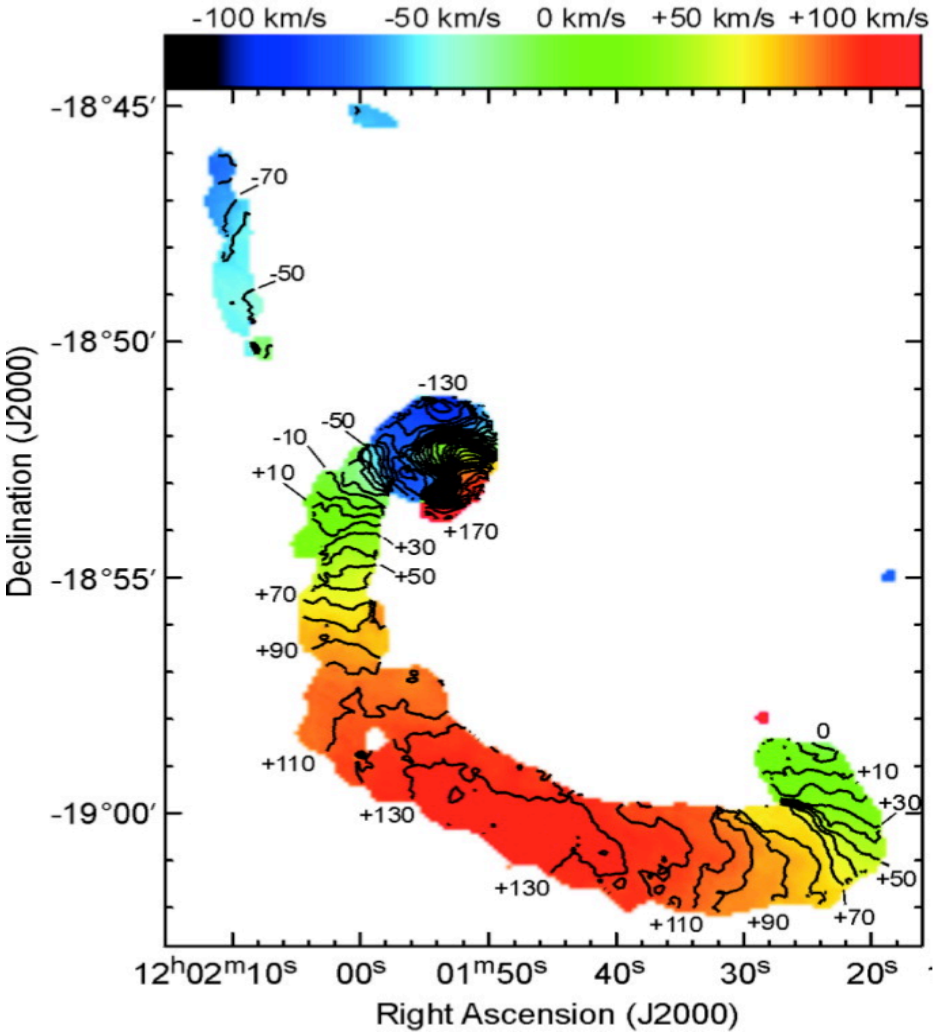
The Antennae galaxies – a key to galactic evolution

- Mergers are drivers for galaxy evolution at all redshifts
- Antennae galaxies are the best-studied local major merger system

⇒ and ideal laboratory to study galaxy properties, ISM evolution, magnetic field evolution, star & cluster formation, etc., in galactic mergers.

HI kinematics & distribution

high–resolution VLA data: **~10”** spatial and **~5 km/s** kinematical resolution



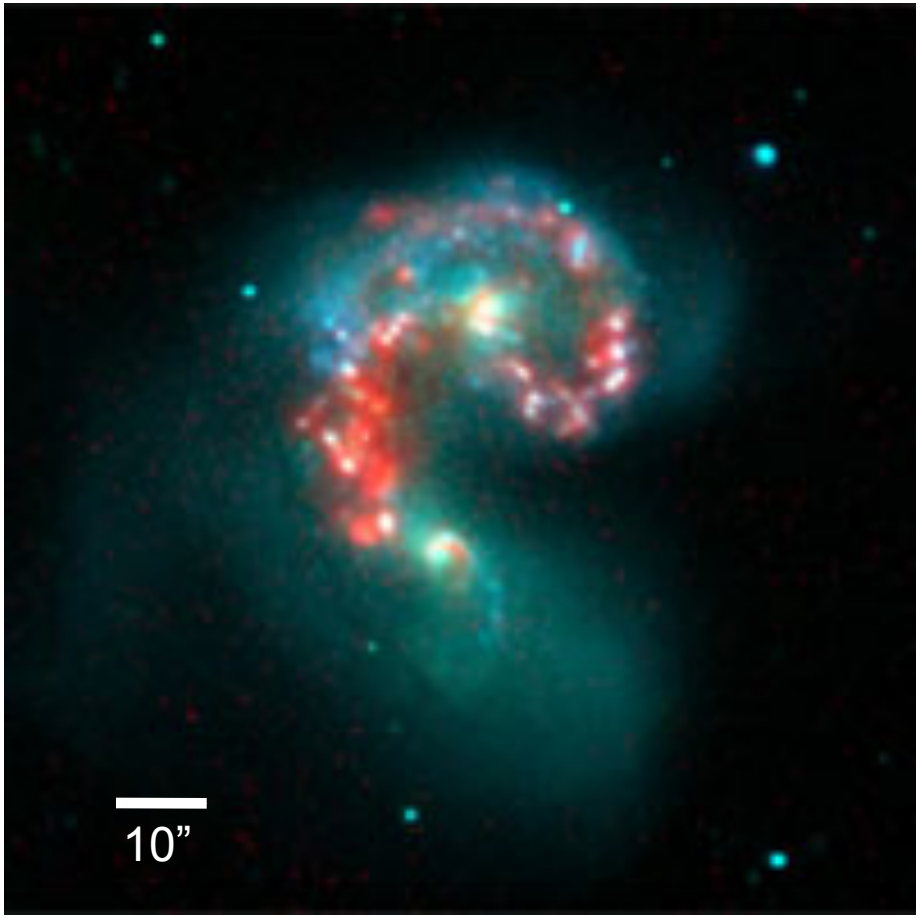
Hibbard et al., AJ 2001

The overlap starburst in the Antennae

- Detection of an off-nuclear star-burst in mid-IR (e.g. Wang et al. 2004, Brandl et al. 2005) and FIR (Klaas et al. 2010)

- Antennae are a special – and extremely difficult to model - system where the overlap starburst is outshining the nuclei

- **Other candidates:** Arp 140 (Cullen et al. 2007), II Zw 096 (Inami et al. 2010), NGC 6090 (Dinshaw et al. 1999, Wang et al. 2004), NGC 6240 (Tacconi et al. 1999, Engel et al. 2010)



(Wang et al. 2004)

Modelling the Antennae

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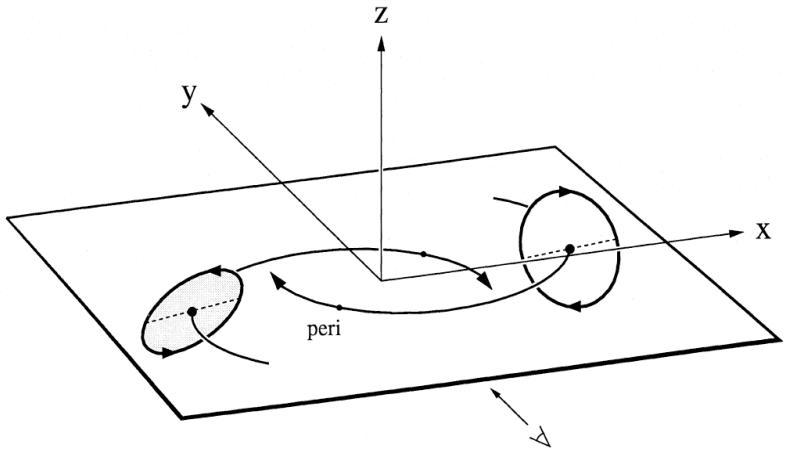
Gadget 2/3 including:

- radiative cooling / UV background
- SF incl. stellar feedback (Springel&Hernquist 2003)

Set up progenitor galaxies (stellar and gas disk, bulge, DM halo) in dynamical equilibrium and

- put on two-body orbit
- choose orientation of the disks
- 'observe' the system at a given time
- with the appropriate viewing angle
- at the appropriate distance, etc ...

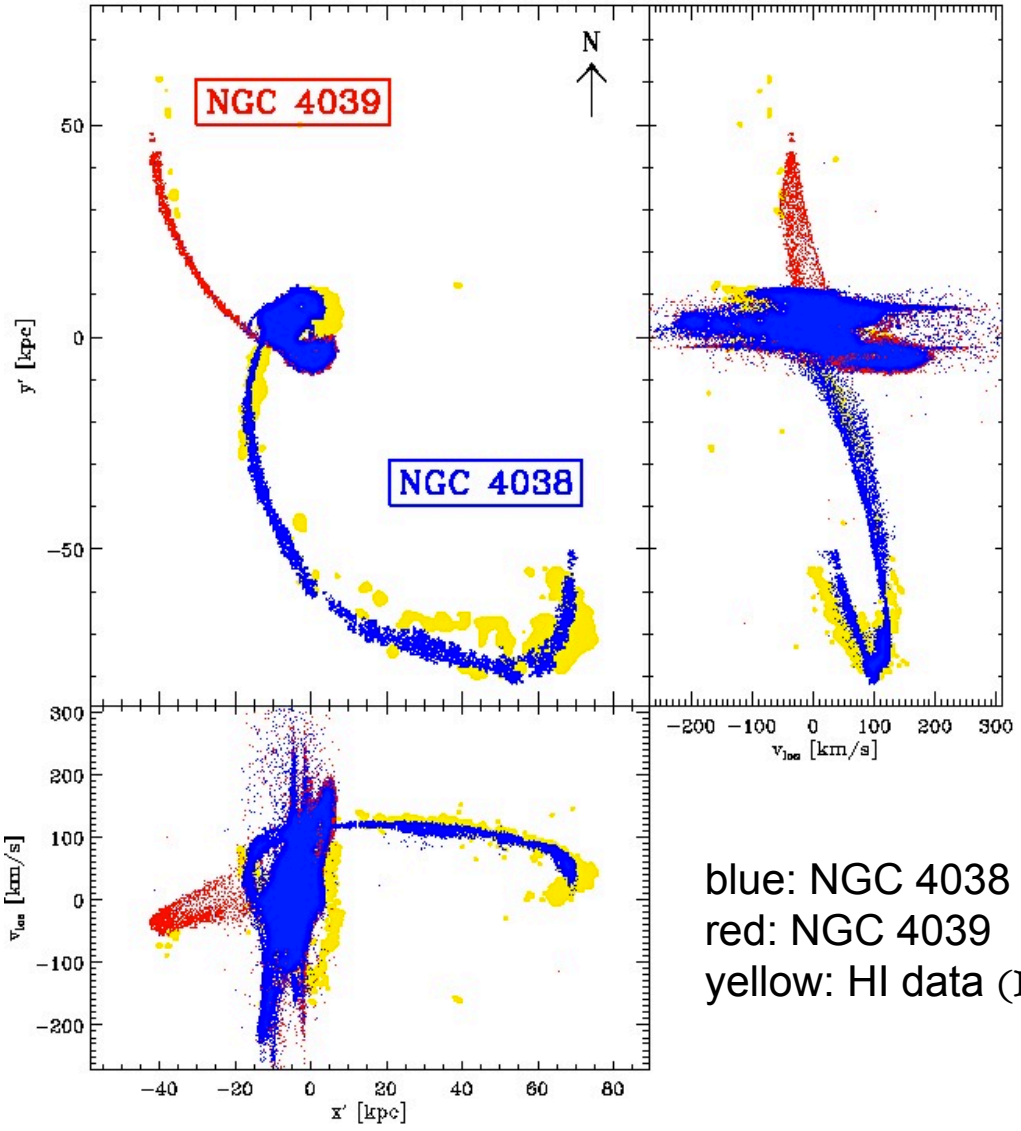


Our model: $M_{tot} = 5 \cdot 10^{11}\, M_\odot$, $M_{disk} = 3 \cdot 10^{10}\, M_\odot$, $M_{disk}:M_{bulge} = 3:1$, $f_{gas} = 20\%$

(Karl et al. 2010)

Resolution: $N = 1.2 \cdot 10^6$, $m_{bary} = 7 \cdot 10^4\, M_\odot$, $\varepsilon_{bary} = 35$ pc

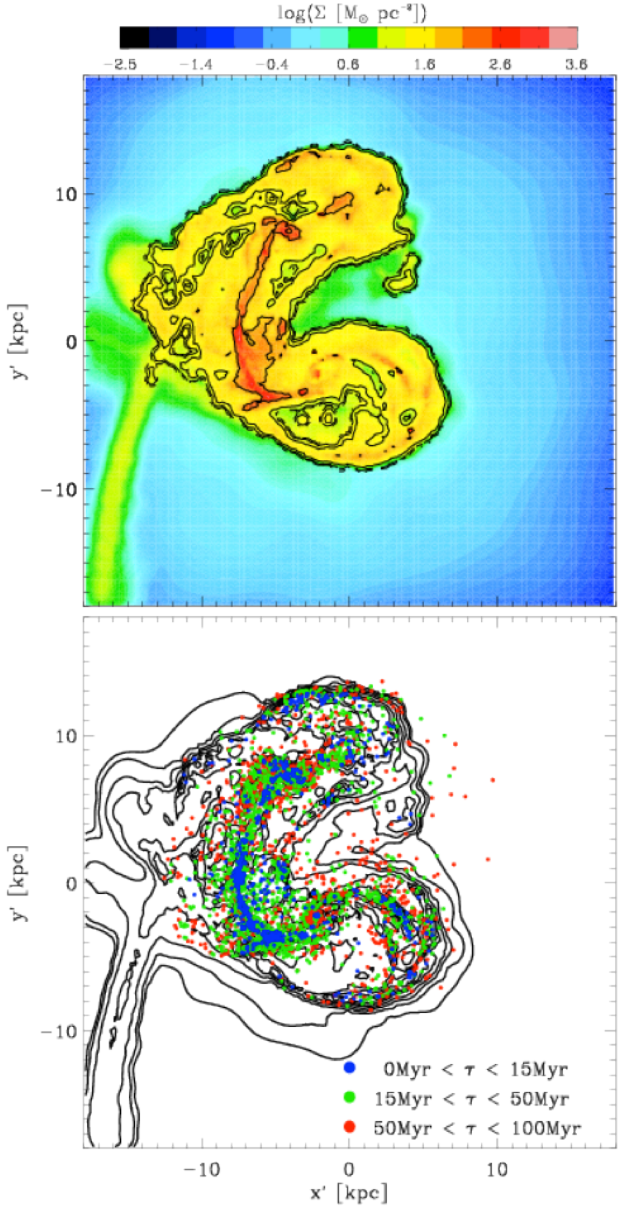
Matching the morphology & kinematics

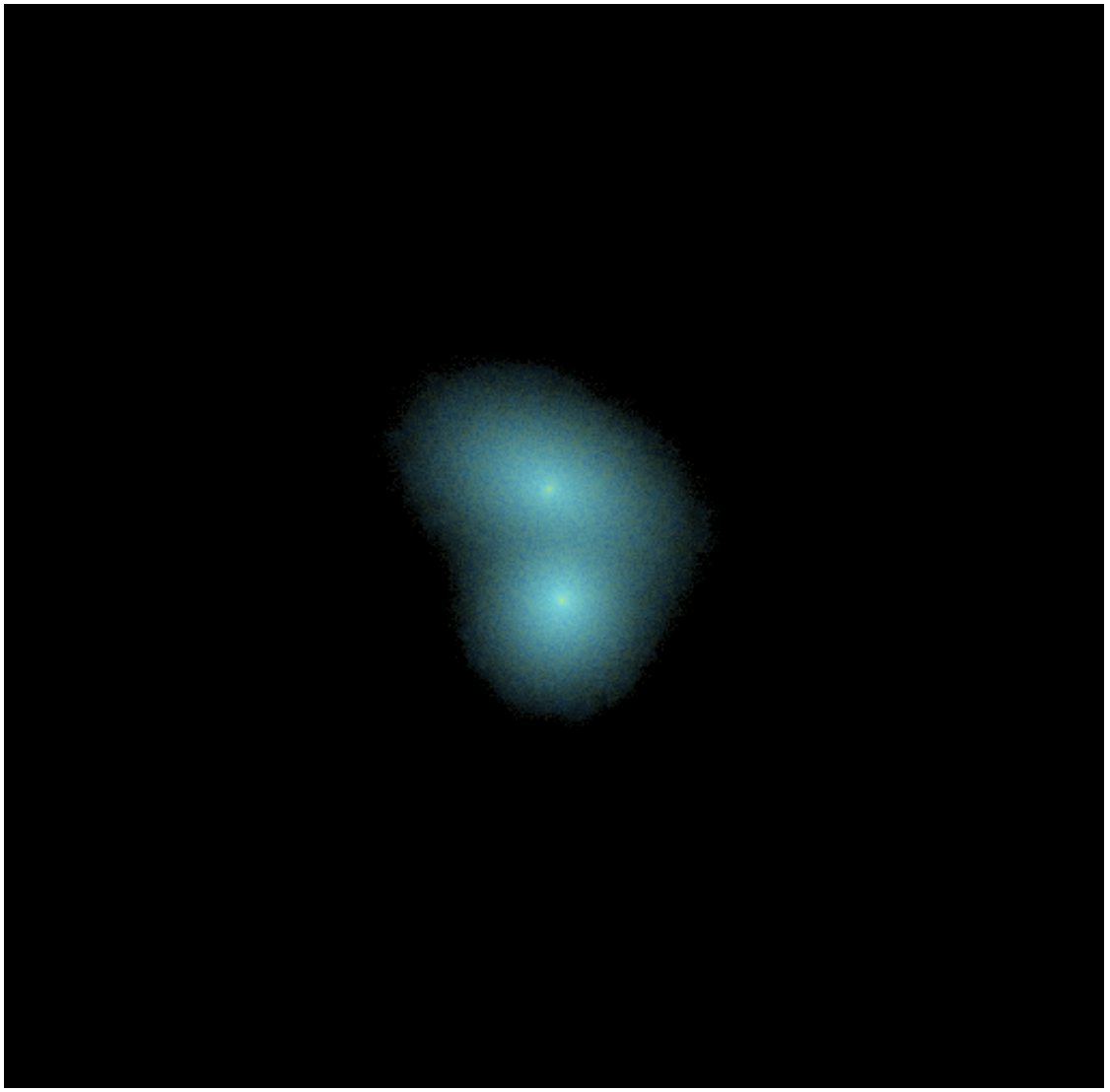


- Position-velocity diagram: good match to large-scale morphology and kinematics
- surface density threshold of 10^{20} cm^{-2} can explain the short northern arm

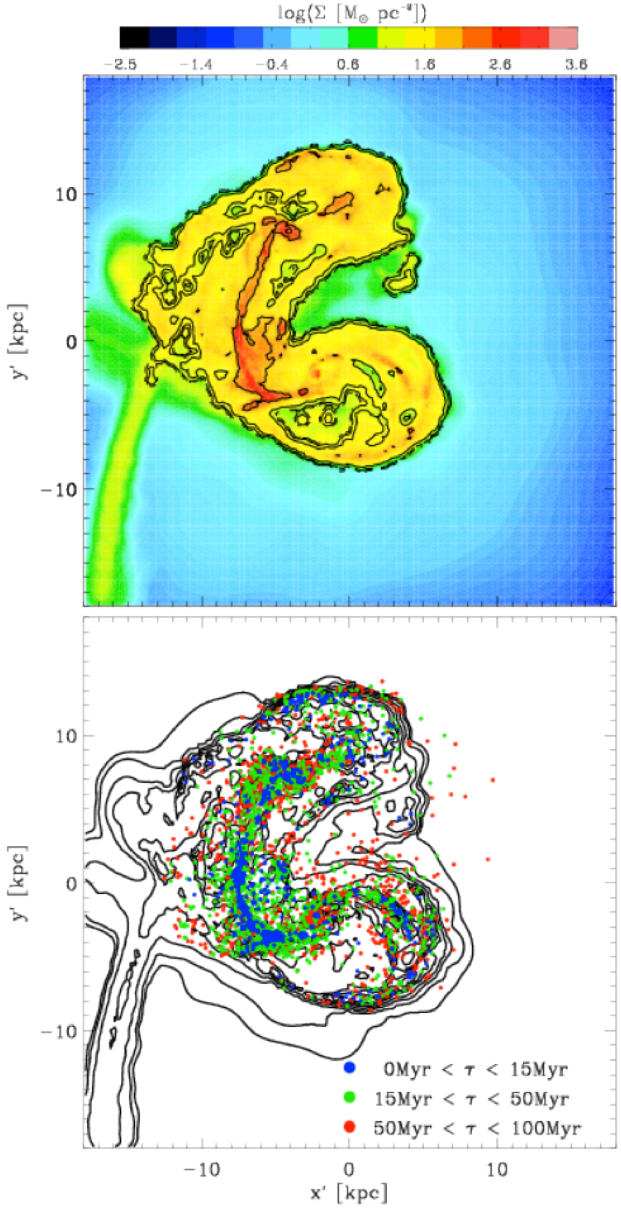
blue: NGC 4038
red: NGC 4039
yellow: HI data (Hibbard et al. 2001)

Central morphology after second encounter





Star formation rates and overlap starburst



	Simulation:	**Observation:**
Nucleus$_{4038}$:	SFR = 0.49 $M_\odot$ yr^{-1}	SFR = 1.17 $M_\odot yr^{-1}$
Nucleus$_{4039}$:	SFR = 0.44 $M_\odot yr^{-1}$	SFR = 0.50 $M_\odot yr^{-1}$
overlap region:	SFR = 10.88 $M_\odot yr^{-1}$	SFR > 4.84 $M_\odot yr^{-1}$

(Klaas et al. 2010)

total SFR ~ 14.32 $M_\odot yr^{-1}$

<->

observed SFR 5...20 $M_\odot yr^{-1}$

(Stanford et al. 1990, Zhang et al. 2001,
Brandl et al. 2009, Klaas et al. 2010)

This is a consequence of the revised orbit.
Test with RAMSES (Teyssier) & ENZO (Abel).

The FIR starburst in the Antennae

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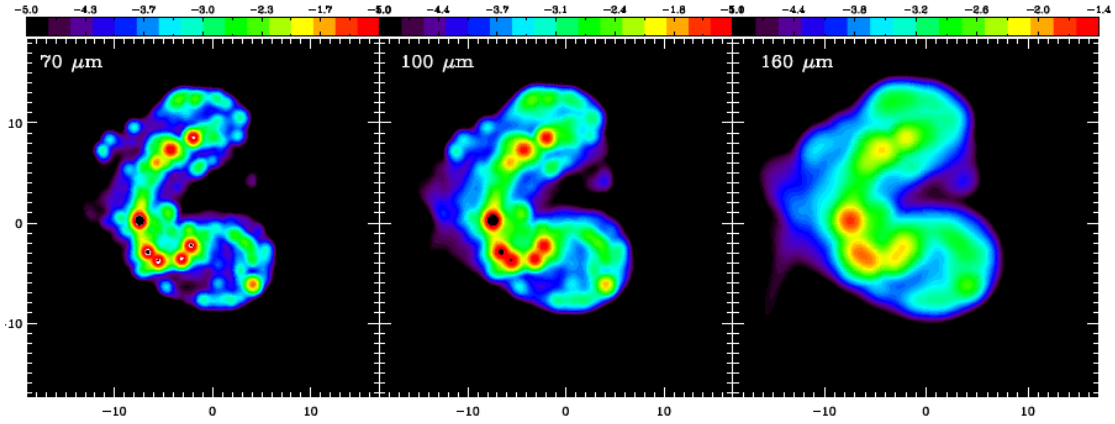
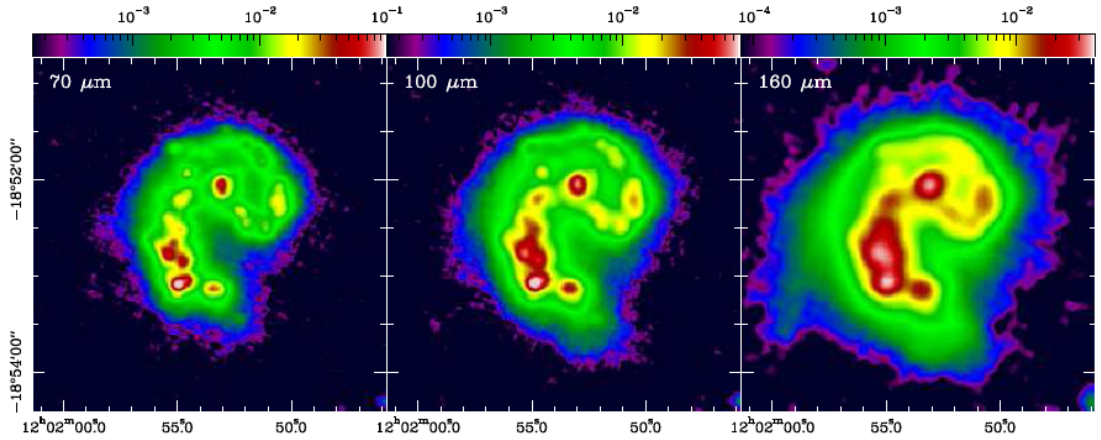
Sim:



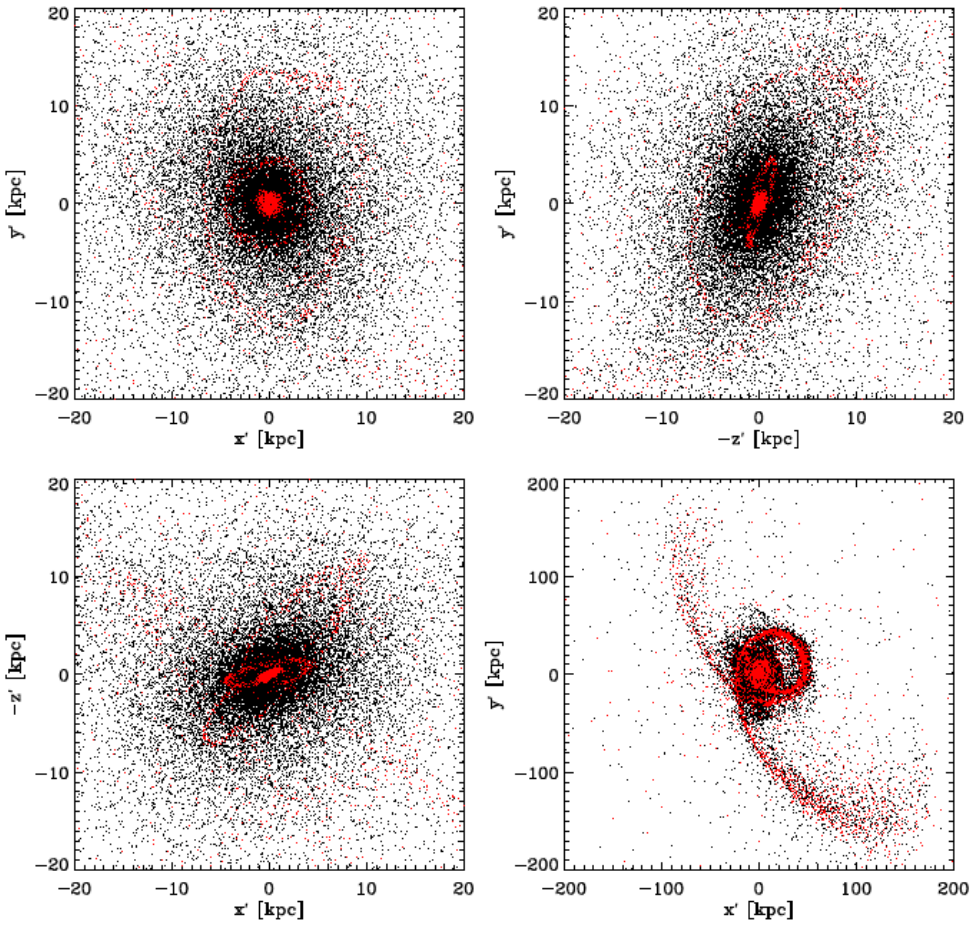
Obs:



(Klaas et al. 2010)

3D radiative transfer FIR maps of the system for direct comparison with observations (with T. Luntilla, P.H. Johansson & M. Juvela)

The fate of the Antennae galaxies



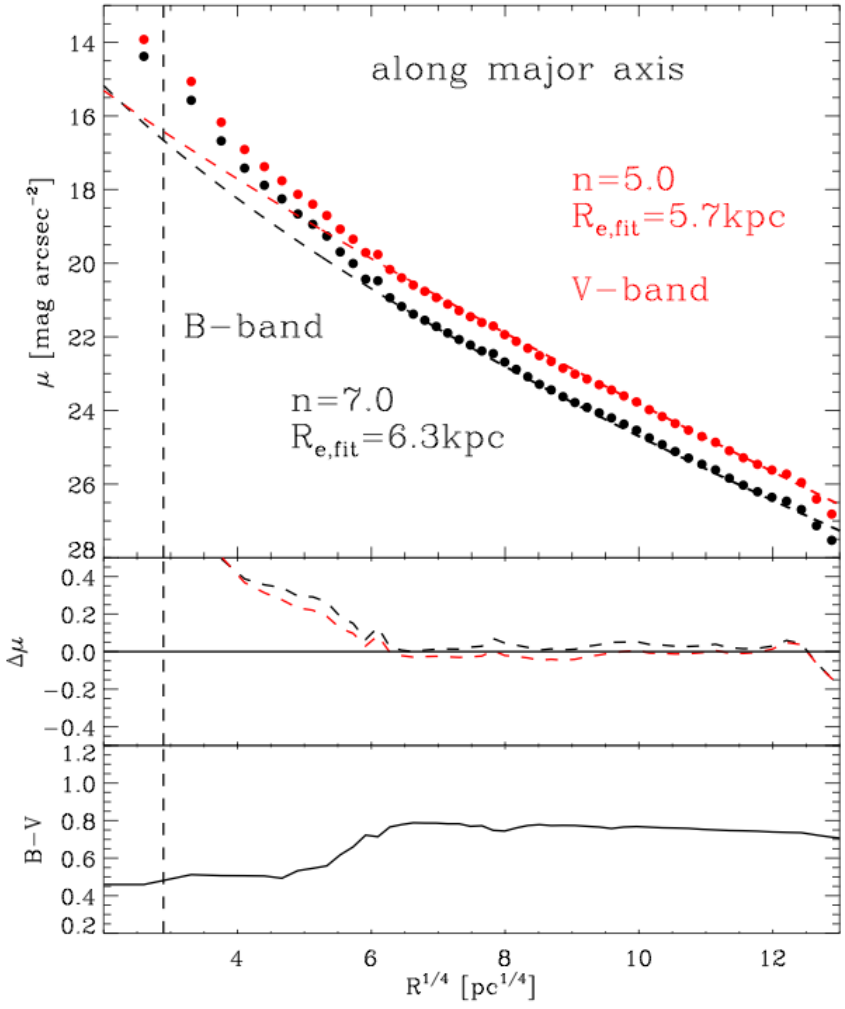
$\tau_{remnant}$ = 1 Gyr

Karl et al., in prep.

stars – black
gas – red

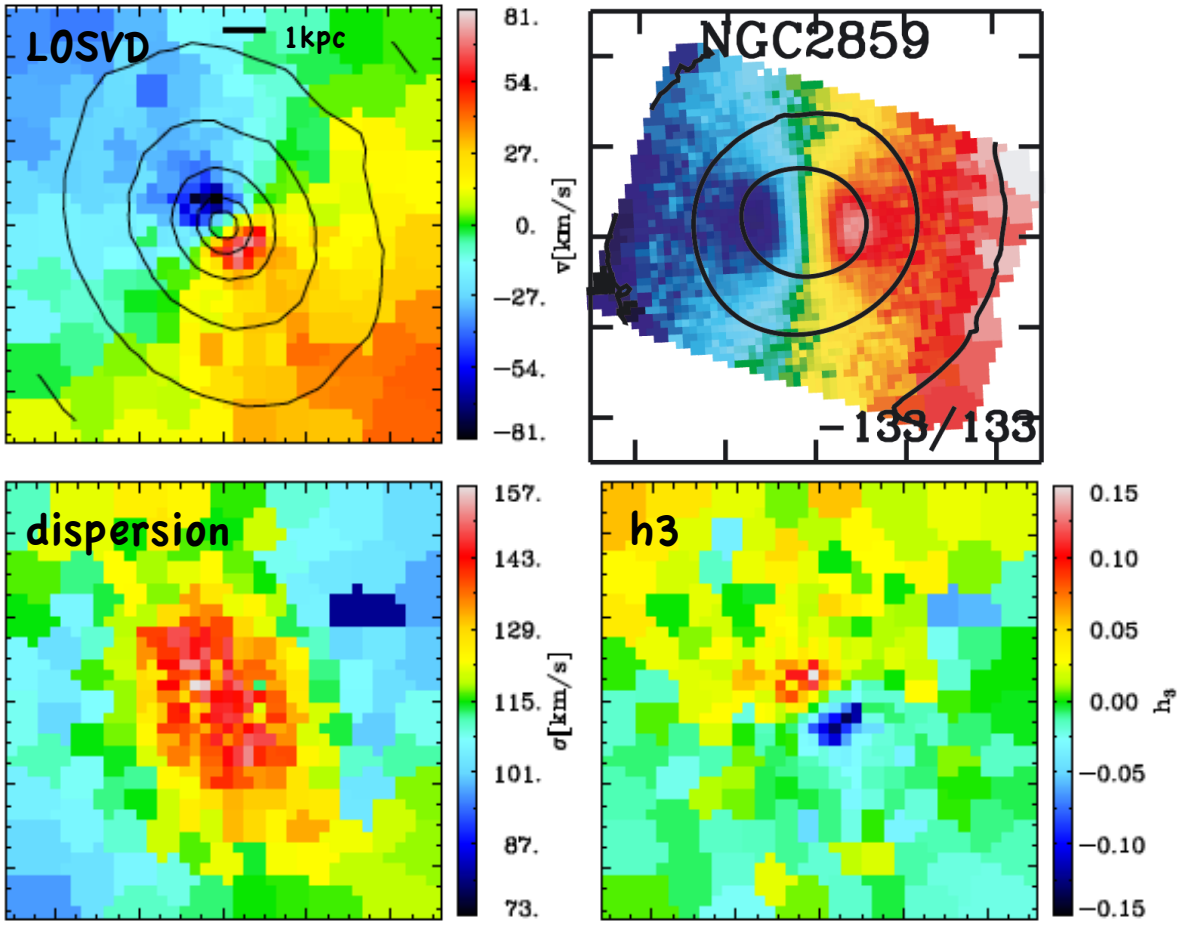
… oblate stellar system with tidal features and some gas at the center and in rings

The fate of the Antennae galaxies



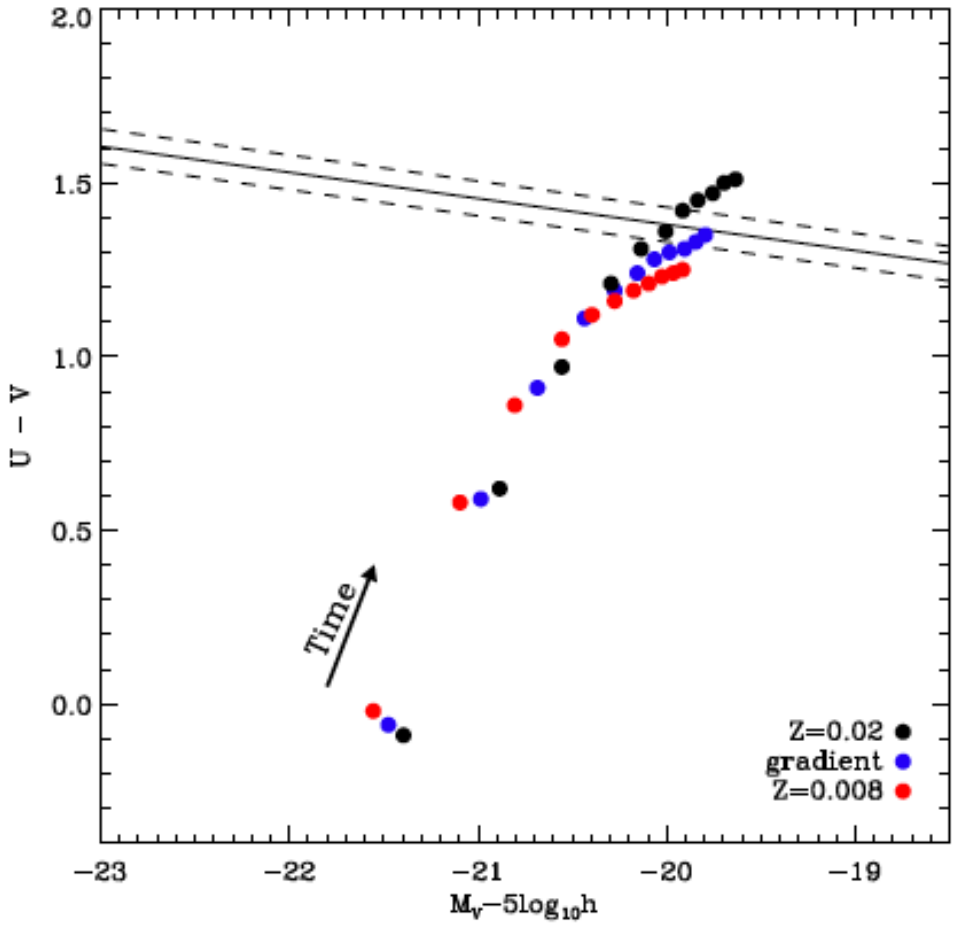
… 'typical' extra-light low-mass elliptical (see Kormendy et al. 2009)

The fate of the Antennae galaxies



… with a central rotating component (see ATLAS^{3D} papers)

The fate of the Antennae galaxies



colour-magnitude relation by McIntosh et al. 2005

… but you will have to wait a while, 3-4 Gyrs (see Naab & Ostriker 2009)

Summary

- First Antennae simulation to match in detail the observed morphology & kinematics and the overlap starburst.
- Strength and spatial distribution of the star-burst is due to the short epoch after the second encounter when a gas-rich overlap region is forming.
- The phase of the merger is more advanced than previously assumed (-> revision of the Toomre sequence?)
- For this model the remnant will evolve into a low mass elliptical galaxy for high metallicity of progenitors.
- More details on ISM physics, outflows, etc., to come …

FIN