FUELING NUCLEAR STARBURSTS

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Abstract. We present a numerical simulation of two merging equal-mass, gas-rich disk galaxies. Special emphasis is given to an accurate treatment of the interstellar medium physics and star formation with its feedback. We will explain how the negative feedback from young stars restricts the bulk of the star formation during the merger-induced starburst to the nucleus.

1. Star Formation in Numerical Simulations

The purpose of this study is to clarify the interaction between star formation and the interstellar medium (ISM) using numerical simulations. In particular we have adopted TREESPH, a hybrid N-body/Smoothed Particle Hydrodynamics code (Hernquist & Katz 1989) for our purposes. A full account of the modeling technique can be found in Gerritsen & Icke (1997, 1998).

The novelty of this work consists of the accurate treatment of the ISM physics. Briefly, the thermal balance in the ISM is regulated by a realistic treatment of stellar heating and radiative cooling, where the gas is allowed to cool down to $\sim 10\,\mathrm{K}$. While giant molecular clouds (GMCs) can be identified in the simulations, star formation proceeds in unresolved subclumps of GMCs. Hence star formation is treated in a semi-empirical fashion: star clusters are allowed to form (with a fixed assumed initial mass function) from those gas clouds that remain Jeans unstable for longer than the local cloud collapse time. This approach has the advantage of providing a link between the large-scale (resolved) properties of the galaxy being modeled and the (unresolved) sub-process of star formation, removing some of the

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arbitrariness in the necessarily crude treatment of star formation. The evolution of the young star clusters is followed in detail, and synthetic spectra of evolving star clusters (Bruzual & Charlot 1993) are used to trace the evolution of both the resulting radiation field and supernova (SN) energy. Particular successes of the model are:

- a realistic multi-phase ISM (cold, warm and hot gas) develops naturally;
- the star formation rate (SFR) obtained follows a Schmidt law (SFR $\propto \rho^n$), with exponent $n \approx 1.3$ (ρ is the local gas density), in agreement with observations;
- the SN energy is redistributed over the ISM in such a way that realistic ISM structures (e.g., holes with realistic sizes) are formed.

1.1. GALAXY MODEL

Our galaxy model consists of an isothermal (particle) dark halo, an exponential stellar disk and a gas disk, and is based on observations of the Sc galaxy NGC 6503. Adopting a stellar mass-to-light ratio of $(M/L_{\rm B})^* = 1.75$ (Bottema 1989) yields a total stellar disk mass of $3.49 \times 10^9\, M_\odot$ (much smaller than a typical L^* galaxy). Radial scale length of the disk is 1.16 kpc and scale height is 0.19 kpc. The gas distribution is modeled to decline linearly with radius out to 8 kpc with a total gas mass of $1.26 \times 10^9\, M_\odot$. The total mass of the dark halo inside 12 kpc is $25.0 \times 10^9\, M_\odot$.

2. Star Formation during Equal-Mass Merger

As a merger scenario, we put two model galaxies on parabolic orbits, with a pericenter of 2.5 disk scale lengths (2.9 kpc); one of the disks moves on an exactly prograde orbit, the other disk is highly inclined. The evolution of the merger is detailed in Gerritsen (1997). Evolutions of similar mergers can be found in Barnes & Hernquist (1996) and Mihos & Hernquist (1996), although the evolution of the gas differs in these simulations, since gas and star formation are treated differently in those simulations.

After the start of the simulation, the galaxies move in space largely unperturbed until the first passage. Then large spiral arms develop due to swing amplification, and the galaxies no longer follow the Keplerian orbit. The main bodies of both galaxies are transformed into a bar. At this time the galaxies no longer move away from each other but start to move back. They have a second passage, after which their centers begin to merge.

Figure 1 shows the evolution of the global SFR and phase diagrams of the ISM during the merger. The SFR is enhanced after the first encounter and reaches then a maximum of eight times the pre-encounter rate. This

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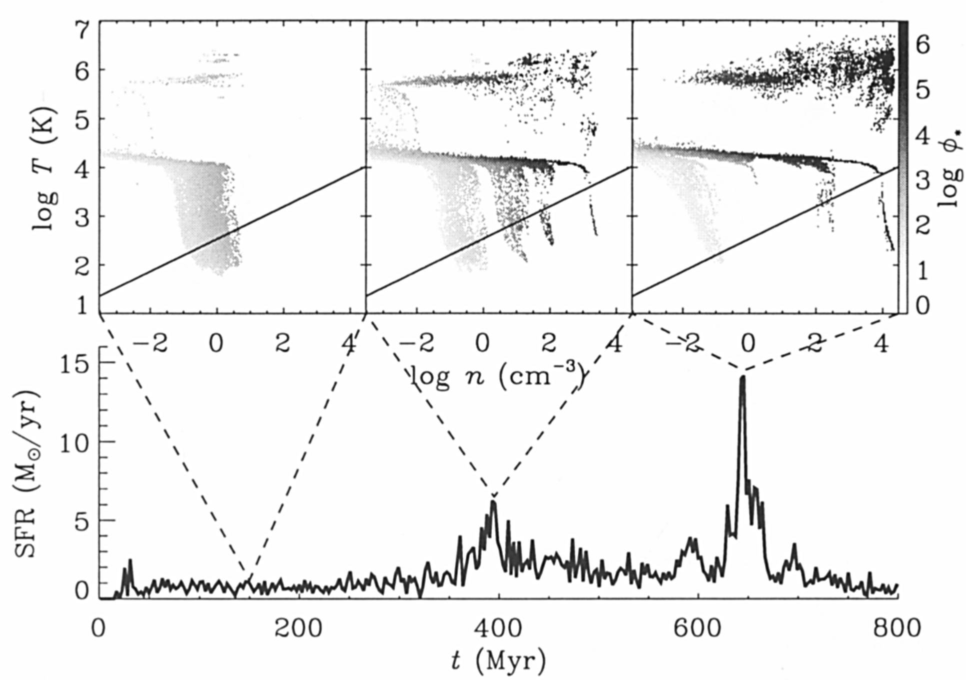

Figure 1. Evolution of the ISM and SFR during the merger. Each dot in the upper panels corresponds to a gas particle. Shown are the gas number density vs temperature, where the greyscale corresponds to the intensity of the stellar radiation field. Gas particles which fall below the solid line (Jeans criterion) may form stars on a dynamical timescale. The lower plot shows the evolution of the global SFR.

occurs when a bar causes the gas to flow into the nuclei of the separate galaxies as can be seen in the left panel of Fig. 2.

The SFR reaches a second peak just before the final merging of the nuclei of the individual galaxies (right panel of Fig. 2). During this burst the SFR is enhanced by a factor 20: most nuclear gas is converted into stars. Afterwards the SFR drops to very low levels.

3. Interstellar Medium

The top panels of Fig. 1 show the evolution of the ISM during the merger. In the left diagram the unperturbed ISM is visible. The cold gas is confined to a rather limited range in density. Gas below a critical density cannot cool and remains warm, which implies a thermal threshold to star formation.

The middle panel shows the ISM at first star forming burst. The density of the densest gas has increased by three orders of magnitude. Likewise the intensity of the stellar radiation field increased. Cold gas condensations appear at various distinct densities. In between gas occupies densities where

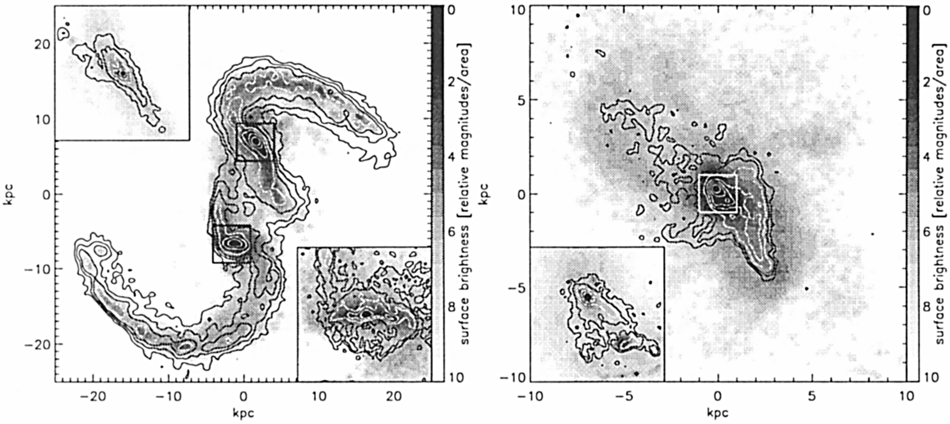

Figure 2. Distribution of gas and stars at first (left) and second (right) peak of the SFR. Greyscale represent the (absorption free) K-band stellar distribution with the intensity scale in magnitudes. The contours represent the gas surface density, with separations of one magnitude. Insets show close-ups as indicated by the boxes.

the stellar heating prevents its cooling and hence star formation.

This effect is at its extreme in the right panel, which shows the ISM at the peak SFR. The influence of the thermal threshold is especially strong now and limits ongoing star formation to either the merging nuclei or the tails. All gas not in those locations is kept warm and does not participate in star formation.

4. Conclusion

Dynamical and thermal processes in merging galaxies cooperate to produce nuclear starbursts. The dynamics drive gas into the nuclei. The energy produced when this high-density gas is converted into stars prohibits star formation outside the nuclear region. The stronger the starburst, the stronger this thermal threshold acts. Thus the strongest starbursts are nuclear.

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