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S. Collin, F. Combes, and I. Shlosman

Hydrodynamic Simulations of Light Bipolar Large Scale Jets

Martin Krause, Max Camenzind

Landessternwarte Heidelberg-Königstuhl, 69117 Heidelberg, Germany

Abstract. We have carried out simulations involving both jets, removing the artificial boundary condition at the symmetry plane. We use a low density contrast (IGM/jet approximately 10000) and take into account a decreasing density profile. We find that the jet bow shock undergoes two phases: first a nearly spherical one and second the well-known cigar-shaped one. We propose Cygnus A to be in a transition phase, showing currently clear signs from both phases. In a further simulation with thermal cooling, three typical phases of such jets are found. This may be relevant to high redshift radio galaxies.

1. Introduction

Recently, X-ray observations of nearby active cluster centers as well as emission line studies of high redshift radio galaxies (HZRG) have been carried out with the new generation of instruments (Chandra/XMM, VLT/FORS). These kinds of objects are considered to belong to the same class at different evolutionary stages [Carilli et al., 2001]. At least one low redshift object (Cygnus A, compare Fig. 1) shares some of the properties of the high redshift relatives, namely low jet density ($\approx 10^{-4}\times$ environment) and high power ($> 10^{46}$ erg/s) [e.g. Krause, 2002a].

2. Setups & Results

We present two simulations with the code NIRVANA [Ziegler &Yorke 1997]. The first one (RUN1) is a 3D hydrodynamic calculation adapted to literature parameters of Cygnus A. The second simulation (RUN2) is a 2.5D simulation of a very light jet with cooling.

Simulation results for RUN1 are displayed in Fig. 1. The bow shock is initially spherical (not shown here). Reaching the critical radius [Krause, 2002b], which is in this case only $\approx 2r_{\mathrm{j}}$, the hot bubble defined by the bow shock slowly starts to elongate in jet direction. At 0.3 million years (Ma), cigar shaped extensions to the bow shock form, and the axis ratio now grows rapidly. Cygnus A shows such a hot bubble and just seems to enter the cigar phase [Smith et al., 2002].

The evolution of a jet with cooling of the shocked IGM can be described by **three phases**. Before significant cooling (phase 1, t=1.39 Ma), the situation

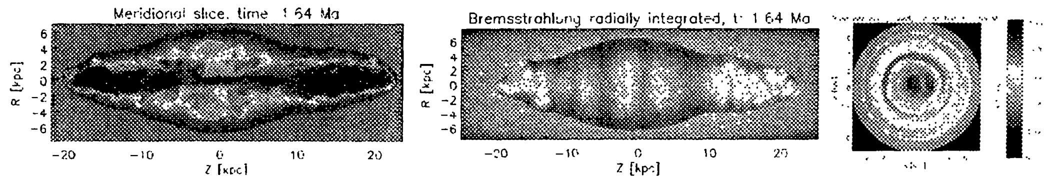

Figure 1. Density (left) and integrated X-ray emission (middle: "edge on", right: pole on).

Figure 2. Three phases (density is shown) of cooling of the shocked IGM: Adiabatic (left), dense shell (middle), disrupted shell (right).

is very similar to the previous simulation. Then, the shocked gas cools all at the same time, thereby loosing its pressure. It gets compressed into a smooth neutral shell (phase 2, t=3 Ma). This shell is instable and forms condensations of down to 10^6 solar masses in the simulation (phase 3, t=6.8 Ma). They are likely to form stars. Since the typical Jeans mass is also about one million solar masses, the prefered mode should be globular cluster formation [Krause 2002a]. The excess of globular cluster systems around the brightest cluster galaxies can be explained by the globular clusters formed in the shocked shell.

3. Conclusions

Very light jets first blow up a spherical bubble. Then the aspect ratio increases and sometimes cigar shaped extensions develop. With cooling of the thermal gas, the appearance is unchanged before the cooling time is reached. Then the shocked IGM collapses to a thin mainly neutral shell, and finally this shell disrupts by thermal instabilities and globular cluster formation.

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