Imaging and Spectroscopy of Large-Scale Hα Filaments in M86

George Jacoby (WIYN), Jeff Kenney, Tomer Tal, Hugh Crowl (Yale), John Feldmeier (NOAO/YSU)

Using the KPNO 4-meter and the WIYN telescopes, we present evidence for large-scale, spatially complex, Hα + [N II] emission surrounding the infalling Virgo elliptical galaxy M86. A comparison of the Hα emission with other ISM tracers shows evidence for at least two major interactions: a high-velocity (1500 km/s) ICM-ISM interaction, and a higher velocity (3000 km/s) ISM-ISM collision with the spiral galaxy NGC 4388. These data show how galaxy and cluster gas is distributed, heated, and ejected during cluster mergers.

Introduction

The elliptical galaxy M86 is the most massive member of a galaxy group now merging with the rest of the Virgo cluster (Schindler et al. 1999). M86 is blueshifted by 1300 km/s with respect to the mean redshift of Virgo, and is thought to be falling into the cluster from behind. M86 is the nearest example of a sub-cluster merger, providing the best opportunity to understand what happens to the galaxy ISM and cluster ICM during such a dramatic interaction.

M86 has an unusually complex ISM, with a strong plume of X-ray emission extending to the NW, a compact HI distribution offset to the S/SE and extended far infrared emission (Rangarajan et al. 1995; Li & van Gorkom 2001; Stickel et al. 2003). The favored picture of M86 is of supersonic ram-pressure stripping, but many uncertainties persist.

Here we add new pieces to the puzzle: a wide-field Hα + [N II] image around M86 that shows an intricate set of filamentary features. We supplement this imaging with follow-up spectroscopic observations.

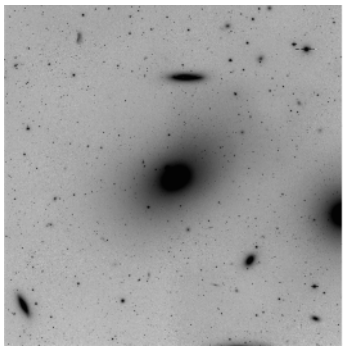

Fig 1. – Our R-band image of M86, and the galaxies surrounding it. This image is 36' x 36', corresponding to 164 x 164 kpc at our adopted distance to M86. The other luminous galaxies in this frame, starting at North, and proceeding clockwise around M86, are NGC 4402, M 84, NGC 4387, NGC 4388 (just off the bottom edge), NGC 4425, and in the upper left, IC 3355. The disturbed spiral, NGC 4438, is just off the image to the left.

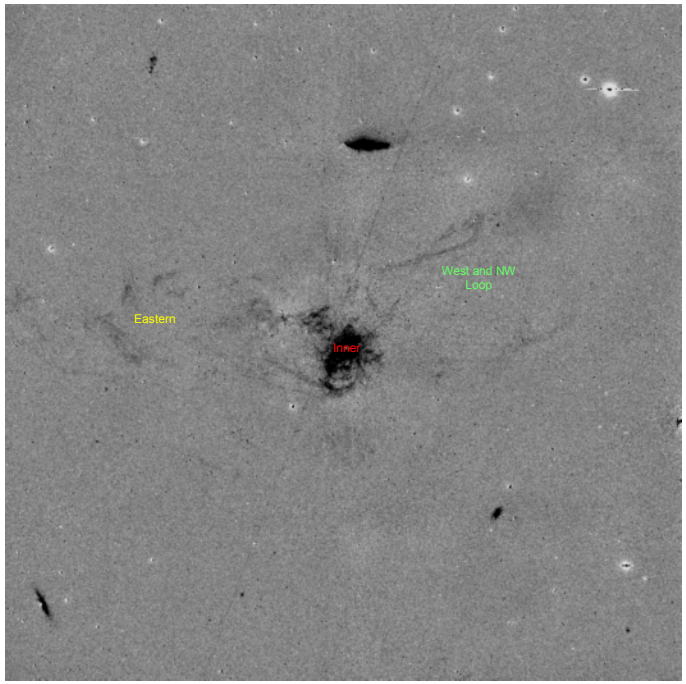

Fig 2. – Our continuum-subtracted Hα + [N II] image of M86, with an identical scale as Figure 1. Large filaments of Hα emission range over the entire image. We identify three distinct morphological regions, labeled above.

Spectroscopic Results

We obtained spectroscopy at 7 positions near M86 with the Sparsepak integral field unit on the WIYN telescope in March 2004. Sparsepak (Bershady et al. 2004) is a 90-fiber array which loosely covers an 80" x 80" field of view. The fibers feed the WIYN Bench Spectrograph with a 860 line/mm grating providing a dispersion of 0.46 A/per pixel, and spectral resolution of 1.6A = 80 km/s.

We observed 4 positions near the center of M86, and 3 selected positions further out, which we focus on here. The results are plotted in Figure 5, below. All three positions have velocities within 200 km/s of the systematic velocity of M86, indicating that the Hα clouds are associated with M86, not the Virgo ICM (+1050 km/s), or NGC 4388 (+2500 km/s). We have not detected any emission with velocities near 2000 km/s, like those in the HI tail of NGC 4388. Such emission may well exist at other positions: we have only sampled a small fraction of the area spectroscopically.

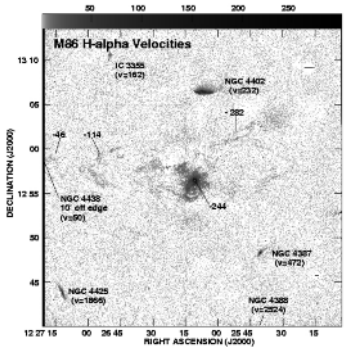

Fig 5. – The mean radial velocities of our Sparsepak observation fields, compared to the radial velocities of M86, and other nearby galaxies. NGC 4438 is just off the image to the left, with a radial velocity of 50 km/s.

Imaging Observations and Hα Morphology – 1

We used the KPNO 4-m telescope and the MOSAIC camera on February 11, 2002 to image M86. Five exposures were taken through a Hα narrow-band filter and five were taken through the R band for continuum subtraction. The total exposure time was 4800s in Hα and 600 in R. Our image is sensitive to Hα emission from radial velocities approximately between -2500 and +1100 km/s (M86's radial velocity is -244 km/s).

The Hα + [N II] emission, seen in Figure 2, is extremely complex. We identify three separate distinct regions:

1. The inner 1-2', which we will not discuss here
2. The eastern features, which we identify with an ISM disturbed and shocked by a high-velocity collision with the spiral galaxy NGC 4388
3. The NW features, which we identify with a tail of gas stripped by an ICM-ISM interaction

Hα Morphology - 2

The Hα + [N II] emission compared to the X-ray emission from M86 is shown in Figure 3. There is a close spatial coincidence between the two maps, in particular the NW loop feature are coincident with the southern edge of the bright X-ray plume. Analysis of X-ray maps from Finoguenov et al. (2004) suggest a temperature gradient and shockfront at about the location of the NW Hα loop. It is also likely that the true length of the Hα tail is much longer than it appears on the sky, due to projection effects.

There is also a clear connection between the eastern Hα features, and a tail of HI gas stripped from the spiral galaxy NGC 4388, which lies 20' south of M86 (Oosterloo & van Gorkom 2005; see Figure 4). The end of the HI tail is bracketed by the semi-circular arc and triangular Hα features. This strongly suggests an interaction between the ISM of M86 and NGC 4388, during a close, high-velocity encounter.

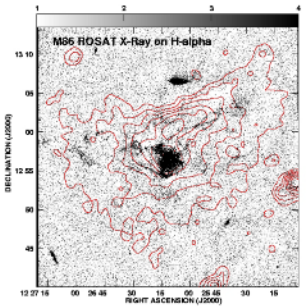

Fig 3. – The Hα image overlaid with the 0.1-2.4 keV emission from the ROSAT satellite. Virtually all of the Hα + [N II] features are located within the bright X-ray halo of M86. The bright X-ray plume/ridge is just north of the NW Hα loop. The X-ray contours are logarithmic, with intervals of $\sqrt{2}$

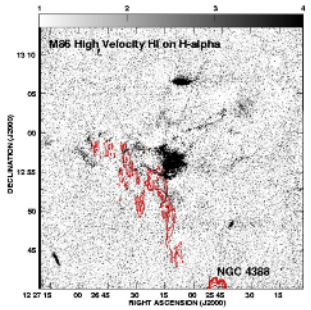

Fig 4. – The Hα image overlaid with the HI map of Oosterloo and van Gorkom. There is a clear correspondence from the tidal tail originating from NGC 4388, and the Hα emission on the eastern side.

Discussion and Future Work

Although the structure of M86's Hα emission is complex, portions of it can be easily attributed to specific interactions between M86's interstellar medium, the Virgo cluster's intracluster medium, and the stripped interstellar medium of NGC 4388. These interactions cause a large loss of the galaxies' gas, and the excitation and disturbance of the gas remaining. Some of the gas should eventually feed a central AGN. However, most of the gas has become much less tightly bound, and will probably be stripped off in future cluster encounters.

We plan additional Sparsepak spectroscopy and imaging in Hα and in [S II] to better understand the physical conditions of the different emission regions. Closer comparison of our data to the higher resolution *Chandra* data of M86 may also be revealing, especially in the center regions.