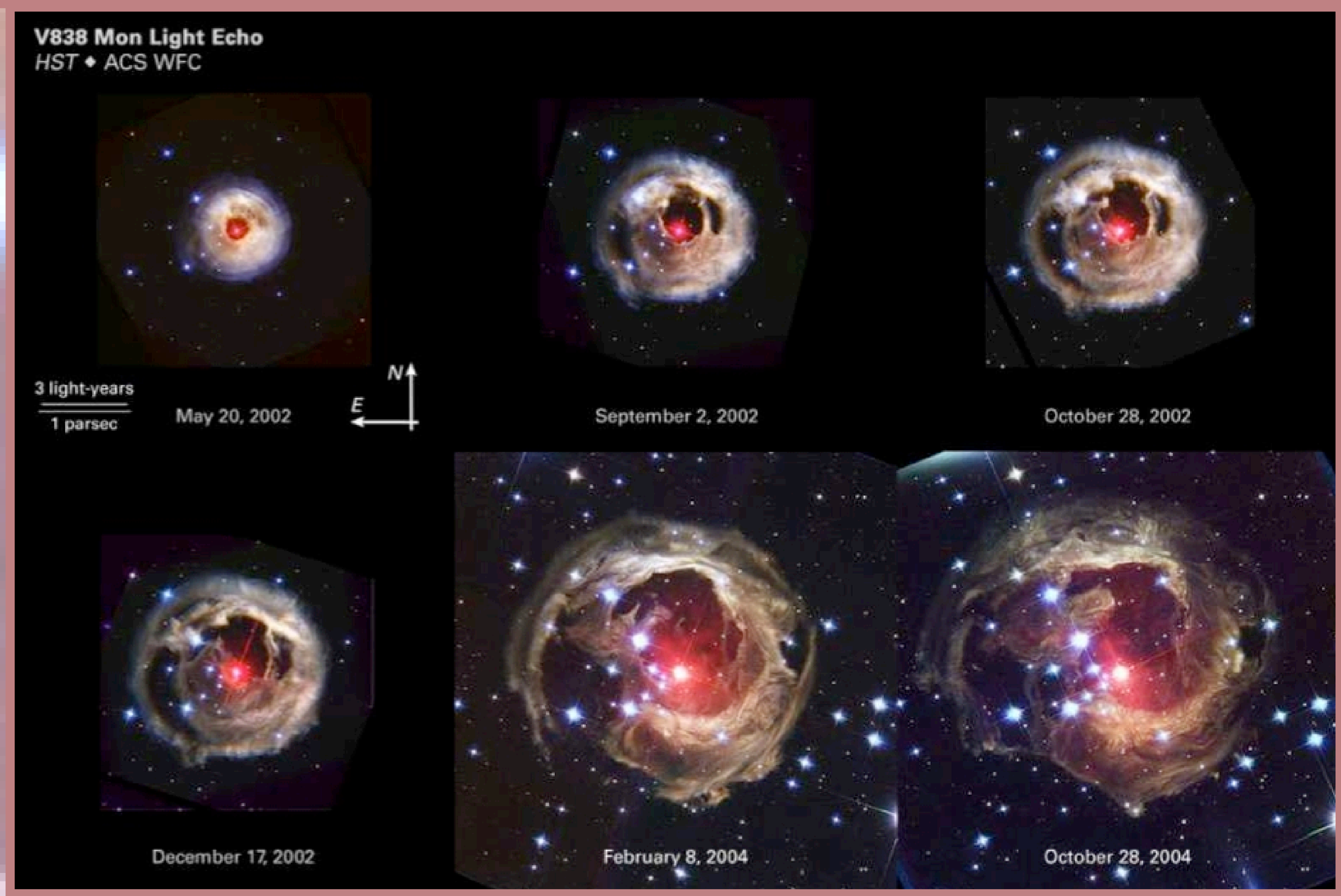
A 3-D view of V838 Monocerotis

K. Exter, H. Bond (STScI)

with Corradi, Crause, Dopita, Henden, Levay, Munari, Panagia, Sparks, Starrfield, Sugarman, Wagner, White

V838 Mon is a highly unique star. It first came to attention in 2002 with three outbursts, and has remained in the public eye since due to its spectacular light echo and the fact that we are still not sure what really happened. During the outbursts the star remained an extremely cool, luminous supergiant, and photometrically and spectrally unlike any other observed stellar event. Most ideas now centre on a stellar merger or planetary infall. Since its discovery, a few possibly similar objects have been found: very recently one in M85, one in M31, and V4332 Sag. V838 Mon is fainter than the most recent counterpart, but it has one thing the others do not: its spectacular and evolving light echo.

A light echo is formed by dust reflecting the radiation emitted during an outburst. That of V838 Mon has been imaged from the ground and HST in the optical, and is also seen (via re-radiation) in the IR (Spitzer images; Banjeree et al 2006, ApJ 644 57). As the outburst light travels away from the star, it illuminates the dust along a parabola (see below). Thus, an image of the light echo can give us the 3D position of all of the dust that is illuminated at that epoch (eg Sparks 1994, AJ 433 19).



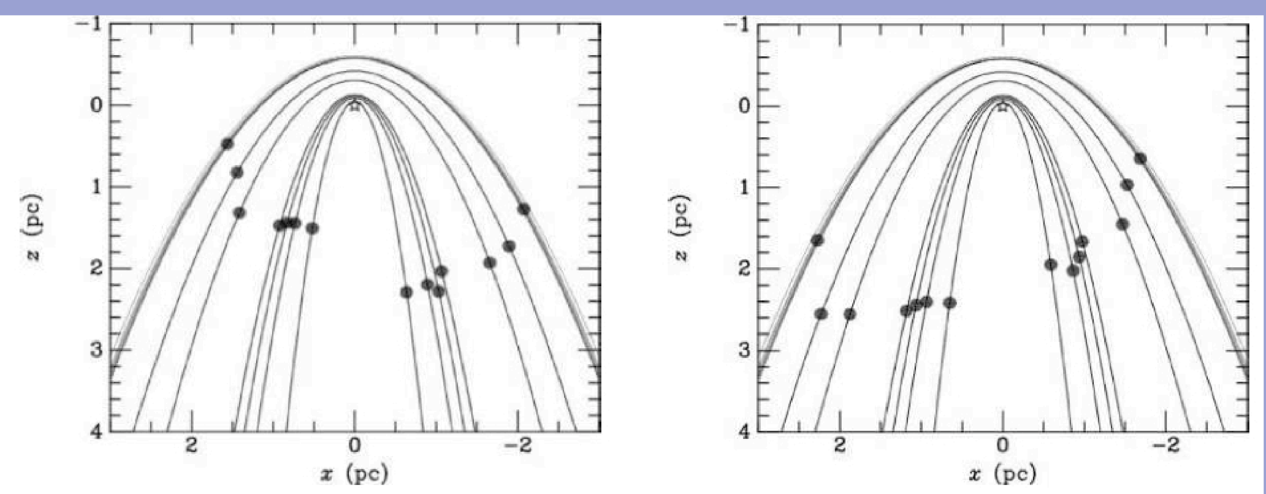
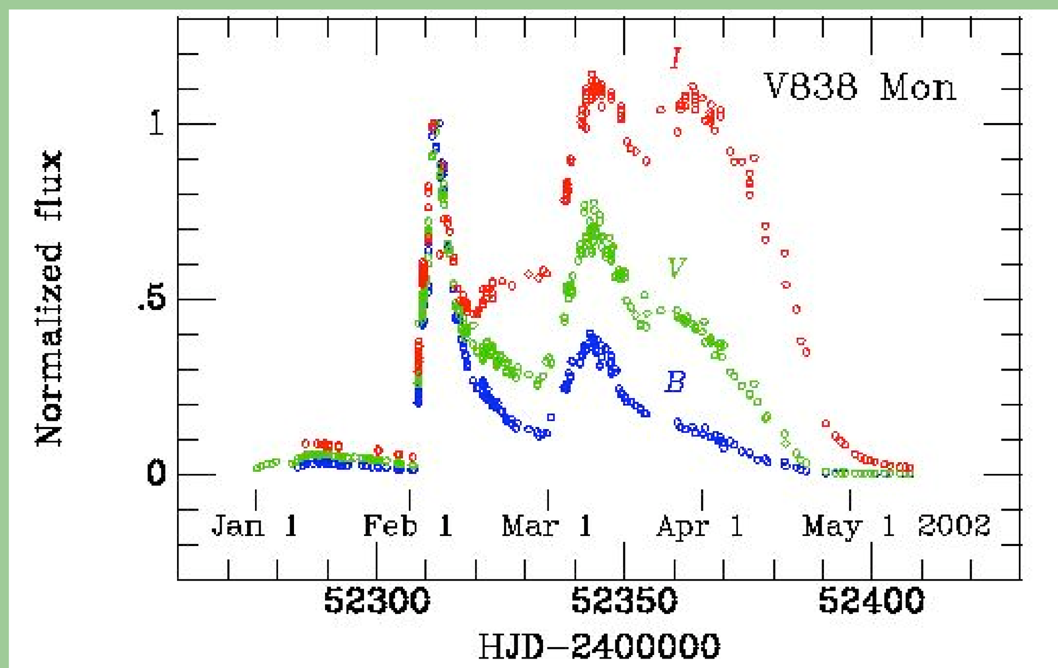


Figure 3. Maps showing the locations of the outermost edges of the light echoes seen in the available *HST* images from 2002 (inner parabolas), 2004 (two intermediate parabolas), and 2005-6 (densely packed outer parabolas). The edges are shown in a north-south plane centered on V838 Mon (left), and in an east-west plane (right). Each parabola corresponds to the location of the illuminated dust at that epoch, and the large black dots show the (x, z) location of the outer edge along the corresponding parabola. Note that the x and z scales are in parsecs, and V838 Mon itself is located at the origin of coordinates. Both maps suggest that the dust lies in an ellipsoidal distribution, centered near the star.

Figure 2. Detail from *HST* image of the V838 Mon light echo on 2002 September 2. A dotted line drawn from V838 Mon through the "double-helix" feature at the upper right passes precisely through the axis of the helix.

One very big advantage of this light echo is that it allows us to study the dust surrounding V838 Mon, and this may help determine the cause of the outburst. The structure of the dust will provides a clue–does it look like material ejected from the star, or material that was already present–and the mass should also–a very massive nebula is unlikely to have come from the star itself, while a very low mass is unlikely to be pre-existing ISM. On the one hand, there are very high estimates of the total mass present. Banerjee et al. measured the mass of the circumstellar material by converting the IR luminosity into a dust mass; with an assumed dust-to-gas ratio they obtained a total mass of at least a few tens of solar masses, too much to have been ejected by the star (although they also see what could be newly formed dust close to the star). On the other hand, the appearance of the nebula does seem to suggest a stellar origin: the outer edge is quite well-defined and centred on the star; there are dust features that point straight back to the star; and there appears to be an equatorial plane, giving an appearance much like a PN, eg M 27 (Bond 2006, ASP conf on V838 Mon).

Figure 4. Left: *HST* image of V838 Mon on 2005 November 17. The surface brightness is highest along an "equatorial plane" passing through the star, marked with a dashed line to guide the eye. Right: amateur photograph of the planetary nebula M27. Note the striking resemblance of the light echo's structure to that of the planetary nebula.



We are therefore in the process of turning the HST images into a density map. Using a different method and with different data to Banjeree et al., we will have an independent measure to compare to. Each point on each of our images will be converted into a 3D element (voxel) of density at X, Y, X, using the Ra and Dec information from the images, and the position along the line of sight (Z-axis) deduced using the light echo equation: $Z = \surd 2ct - X^2/2ct$. We have BVI images at a number of epochs, and can interpolate between epochs to account for the missing dates. The colour of each point can be related to the colour of the light curve (which grew redder with time) to determine from what point in the outburst the illuminating light originated; as the outburst was not instantaneous, at any point in time one can consider we are looking at multiple overlapping light echos, one from each time in the outburst. The brightness of each point will then be converted into a density, with input from factors such as the dust composition, its scattering function, duration of the light pulse, input spectrum.... To calculate the total mass present we will also need to adopt a dust-to-gass mass ratio. At the end of this, we will have a high resolution 3D map of the density distribution around V838 Mon. The structure this map reveals, together with our mass estimate, will help us understand where the material came from.