Image Digitising and Analysis of Outflows from Young Stars

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Abstract

We present IIIaJ, IIIaF and IVN band images of HH objects digitised from the ESO/SERC Southern Sky Survey plates. These form part of a digital image data base of southern HH objects, which allows the identification of emission and reflection nebulosity and the location of the obscured sources of outflows.

Keywords: Image Processing, ISM: jets and outflows, ISM: individual objects: (HH 34, HH 46/47), stars: formation

1 Introduction

The availability of the ESO/SERC Sky Survey has made scanning of the southern skies for planetary nebulae, supernova remnants and diffuse nebulae possible. Several catalogues of sources on these plates have been published, sometimes accompanied by photographs of the more important objects.

With the advent of low cost PC computers, frame grabbers and video cameras it has become possible to digitise and enhance areas of interest on these survey plates. Applying digital techniques to the images from the IIIaJ, IIIaF and IVN surveys allows the separation of line and continuum sources in the galactic plane (Zealey et al., 1994).

In this paper we outline an application of digital methods to the study of outflows driven by mass loss from Young Stellar Objects (YSOs). Evidence that a YSO is undergoing mass loss is provided through the effect the stellar wind has on the surrounding medium. Phenomena such as bipolar molecular outflows, masers and the Herbig-Haro (HH) objects and jets are all indicators of a YSO undergoing mass loss.

Observations at optical and infrared wavelengths have shown that HH objects and jets are regions of shock-excited gas emitting in Hα and forbidden excitation lines of [O I]$\lambda\lambda$6300,6363 and [SII]$\lambda\lambda$6716,6731 in the visible and H_2 (2.12 μm) in the infrared. The different shock structures and excitation conditions of a HH complex can be distinguished by comparing images obtained in optical and infrared emission lines with differing excitation parameters i.e.: [S II] emission is indicative of $v_{shock} \approx 100$ km s^{-1}, while the presence of H_2 emission indicates slower shocks ($v_{shock} \approx 40$ km s^{-1}).

HH objects and jets are associated with both low-luminosity ($L_{bol} \approx$ 1-100 $L_\odot$) T Tauri stars and high-luminosity YSOs ($L_{bol} \approx 10^3$ $L_\odot$) such as IRAS sources (Mundt 1988, Reipurth 1994). The visibility of the source depends on the amount of obscuration, the orientation of the flow and circumstellar disk. Due to heavy extinction from the surrounding star forming clouds, many YSOs are obscured at optical wavelengths. Near Infrared images often provide the first identification of the driving source of the outflow as the optical extinction becomes less important at longer wavelengths.

Morphological features present in most outflows include:

- An embedded YSO which drives the outflow;
- A collimated jet and counter jet;
- A section where the jet disappears, but isolated emission knots remain;
- A working surface (bow shock) with associated HH complex.

2 Optical Surveys and Morphological Studies

The abundance of nearby stellar outflow complexes accessible to observation from the southern hemisphere provides us with the opportunity to study highly supersonic outflows for comparison with theoretical models. Since the publication of the original catalogue of 43 HH objects (Herbig 1972), there has been a substantial increase in the number of known sources due to advances in imaging technology, especially in CCD imagery through narrow-band filters. Catalogues have been compiled by Schwartz (1977; deep red objective-prism survey of southern HH objects), Hartigan and Lada (1985; V, R, I, and Hα CCD images of suspected HH objects), Strom et al. (1986; broadband V, I, Hα and [S II] CCD images), Von Hippel et al. (1988; literature survey up to 1988) an Reipurth (1994; extensive notes on individual HH objects with detailed references to the literature). Plans are underway to incorporate [S II], Hα and broadband images into Reipurth's catalogue (Reipurth 1995).

The ESO/SERC surveys provide matching deep IIIaJ, IIIaF and IVN images of the Southern Sky. Although Reipurth and others have searched the survey material for HH objects, little systematic use has been made of them to identify the driving sources of these flows. HH objects lying close to bright reflection nebula are often swamped by reflected light on IIIaJ and IIIaF plates. Digital Imagery allows sophisticated enhancement techniques to be applied to areas of interest. Use of photographic and more recently digital unsharp masking techniques allows the detection of new emission sources e.g. HH 247 (Malin et al. 1987). It is also possible to overlay IIIaJ, IIIaF and IVN images with infrared and radio maps of sources.

3 Video Digitising Systems

We are digitally imaging all known southern stellar Herbig Haro complexes selected from Reipurth's Catalogue of Herbig Haro objects (Reipurth 1994) using a low cost PC/AT video digitising system. This system has been developed at the Department of Physics of the University of Wollongong from commercially available hardware and software.

The image digitising facility provides for the real time, 8-bit (256 grey scale), video digitising and analysis of photographic plate material (Zealey et al., 1994). The image digitiser system uses a PC/AT based video frame grabber.

The digitising board used is of PCVisionPlus type. Computer controlled Look Up Tables (LUT's) allow the stored 512×512 pixel image to be displayed in pseudo colour on a dedicated RGB image monitor. The video digitiser accepts video input from a Philips CCD video camera mounted on a Polaroid Laboratory Camera and a combination of lenses allows for both wide-field (300 mm square; 6 mm pixels) and microscopic (5 mm square; 10 μm pixels) imaging.

Plate illumination is provided either by a Chromega colour enlarger head for regions up to 5 cm square or a light box for larger areas.

Jandell's JAVA software allows real time enhancement and measurement of the digitised images. JAVA allows for spatial filtering, contrast enhancement, thresholding, simple backgrounding and source counting as well as photometric analysis. Images are stored as 8 bit TIFF (Tagged Image File Format) which are readable by a wide range of image software. Once images are captured from the screen, they are stored on a 600 Mb Ricoh Magneto Optical Drive and then copied onto floppy disks for transfer to other PCs with specialised imaging software. Image editing is done on JPL's Alchemy Mindworks GWS package which is useful for a first look at the images, cropping and scaling and conversion to GIF (Graphic Interchange Format) or other image formats. Further enhancement and addition of text is done in CORELDRAW or Adobe Photoshop.

4 Examples of Digital Images

At present, there are over 250 HH objects listed in Reipurth's Catalogue of Herbig Haro objects. The digital images obtained from the ESO/SERC IIIaJ, IIIaF and IVN survey material can be used to discriminate between emission and reflection nebulosity and to identify heavily reddened continuum sources.

The IIIaJ and IIIaF images provide a road map of shock-excited gas. The IIIaJ + GG395 plate/filter combination ($3950\text{Å} \leq \lambda \leq 5400\text{Å}$) is responsive to high excitation emission lines which include the [O III] $\lambda\lambda$4959,5007 line.

The IIIaF + RG630 plate/filter combination ($6300\text{Å} \leq \lambda \leq 6900\text{Å}$) is dominated by the low excitation Hα, [NII]$\lambda\lambda$6548,6583 and [S II]$\lambda\lambda$6717,6731 emission lines.

The IVN plates ($6950\text{Å} \leq \lambda \leq 9000\text{Å}$) do not contain any major emission lines that are known to be prominent in shock-excited regions of HH objects. The IVN band images therefore act as a probe for scattered continuum light from the embedded YSO.

The IIIaJ and IIIaF images can used together with published H_2 infrared images to clearly identify shock-excited emission regions over a range of excitation conditions (Zealey et al., 1992). In many cases, emission features in the IIIaJ, IIIaF and H_2 images do not coincide, which is indicative that either obscuration or excitation conditions vary across the objects.

The IVN images can be combined with published near infrared and continuum images to identify the driving sources of the outflows.

Examples of the digitised images are presented in Figures 1 and 2 for the HH 34 and HH 46/47 systems respectively. Both areas have also been studied in detail using CCD and IR cameras allowing a clear comparison to be made on the usefulness of the IIIaJ, IIIaF and IVN band digital imaging.

4.1 HH 34

HH 34 is an archetypal outflow which has been well studied at visible, infrared and millimetre wavelengths.

Inspection of the digitised IIIaJ and IIIaF images (Figure 1) show similar features to those visible in the deep [S II] image of Mundt (1988). Visible are the bow-shaped emission nebulosity, HH 34S, and the continuum reflection nebula, Re 24 (Reipurth 1985).

The IVN image (Figure 1) shows many of the strong infrared sources including HH 34 IRS, IRS5 and Re 22 (Reipurth 1985).

The reflection nebulosity, Re 23 (Reipurth 1985), may represent the brightest part the western wall of a cavity that contains the HH 34 jet. Re 23 shows a different morphology in the IIIaJ

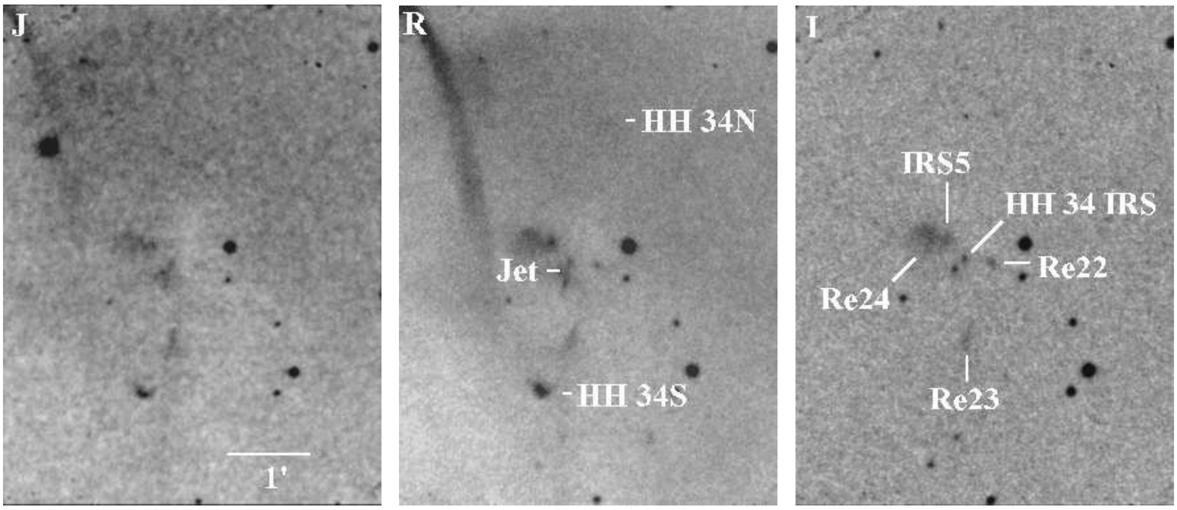

Figure 1: ESO/SERC IIIaJ (J), IIIaF (R) and IVN (I) images of the HH 34 system. The reflection nebulosity Re 23 may be tracing a cavity created by the HH 34 jet. The location of the energy source (HH 34 IRS) is clearly seen in the IVN band. North is up and East is left in all images.

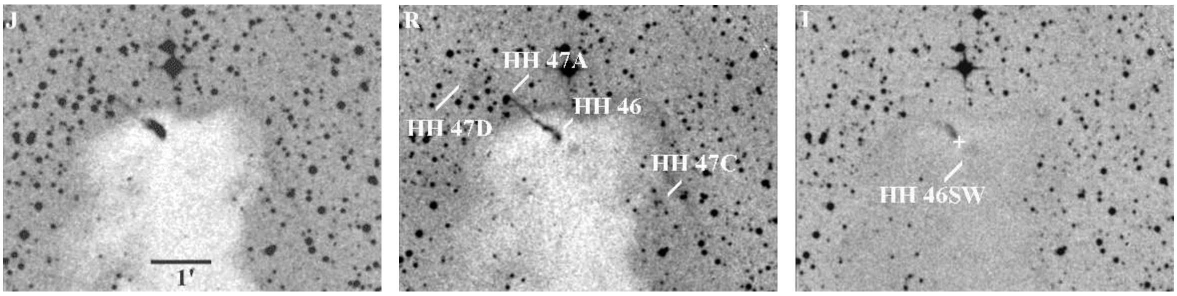

Figure 2: ESO/SERC IIIaJ (J), IIIaF (R) and IVN (I) images of the HH 46/47 system. The position of HH 46/47 IRS is indicated by the cross.

and IIIaF images and has been associated with a linear H_2 emission structure which is possibly a separate outflow (Zealey et al. 1993). HH 34N is just visible in the IIIaF band, no visible counterparts to an arc of infrared emission north of HH 34 IRS are seen.

4.2 HH 46/47

HH 46/47 is also a well studied flow at visible, infrared and millimetre wavelengths. Many of the optical features discovered using CCD techniques are clearly visible on the ESO/SERC survey films, without enhancement.

The IIIaJ and IIIaF images (Figure 2) of HH 46/47 show the faint emission features associated with the blue shifted, bow shaped nebulosity HH 47D and red shifted bow shock working surface HH 47C as observed in the [S II] CCD images of Eislöffel and Mundt (1994).

The strong reflection nebulosity around the source and in the region of HH 46 dominates the IIIaJ image. Both the IVN (Figure 2) image and the infrared image (Figure 3; Zealey et al., 1993) fail to show a central point source, due to the presence of a dense obscuring disk surrounding the source.

The IVN band image displays emission, which may be due to reflection nebulosity associated with HH 46, HH 46SW and the region of the counterjet.

None of the IVN, IIIaF or IIIaJ images shows emission from the red shifted flow which is

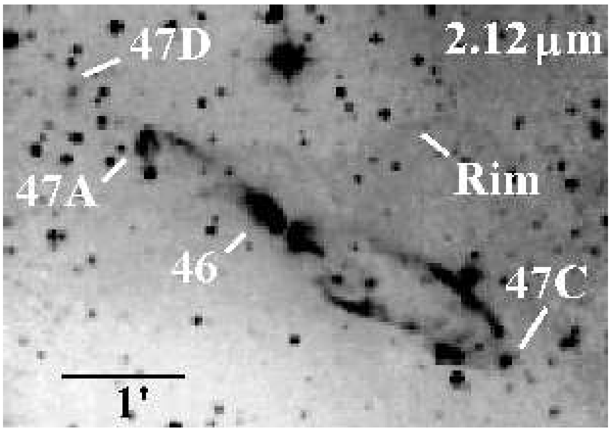

Figure 3: H_2 image of the HH 46/47 system from Zealey et al. (1993). The blue shifted flow terminates in HH 47D. The red shifted lobe occupying the lower right of the image can be traced back to HH 46/47 IRS, at field centre.

clearly seen in the 2.12 μm image (Zealey et al., 1993). This again indicates the high obscuration in this direction due to the dark cloud in which HH 46/47 is embedded.

5 Future Developments

This project has shown the effectiveness of low cost video digitising in analysing and searching ESO/SERC Sky Surveys for emission line sources. Future surveys, including the proposed Hα emission line survey of the southern sky to be carried out by the UKST, will provide deep, high resolution images of galactic plane sources.

The application of digital techniques to archival photographic material, while not providing the depth of CCD imaging, does allow the identification of the main features associated with outflows. It is particularly applicable to the discovery of new structures associated with flows more extensive than can be covered by existing CCD formats ($< 10'$).

Ongoing work on the detection of filamentary sources associated with supernova remnants, wind shells and star formation regions is difficult near strong reflection or emission nebulosity. The use of background subtraction techniques using low cost digital imaging systems will increase our success in detecting such features.

We intend making the final image database available on the World Wide Web (WWW) with the hope that future work at near-infrared wavelengths will determine if reddened sources visible on the IVN images are driving the optical HH flows seen in the IIIaJ and IIIa-F images. Access to on-line catalogues has grown substantially over the last few years. An advantage of putting imaging or large data catalogues on the network is that the data is easily accessible and available to the public domain as soon as refereeing is completed.

Examples of catalogues relevant to star formation include Bo Reipurth's A General Catalogue of Herbig-Haro objects (Reipurth 1994) and the Catalogue of Emission Line Stars (Herbig and Bell 1988).

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