ANALYSIS OF A BLOWOUT IN GALAXY NGC 3628 USING INFRARED POLARIZATION

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Summary
Infrared images of galaxy NGC 3628 were analyzed to determine if a blowout exists in this spiral galaxy. IRAF astronomy software was used to prepare images for analysis in Axum. By imaging polarized infrared radiation from the dust in the interstellar medium, the blowout was detected by finding an anomaly in the magnetic field geometry. Infrared images are used in astronomy to see deep within dusty galaxies that cannot otherwise be visually analyzed.

Introduction

The question addressed in this project was whether a blowout exists in galaxy NGC 3628, a spiral galaxy in the Leo Triplet. It is seen edge-on from Earth. Radio and x-ray emissions indicate that starbursts are occurring in the nucleus of this galaxy. NGC 3628 is being disturbed and warped by its two neighboring galaxies M65 and M66. As a result, there are significant amounts of radio waves and x-rays being emitted, which prompted this study to look for a blowout caused by massive star formation (1).

Magnetic fields play an important role in the star-formation process, especially in the central regions of starburst galaxies where star formation is powerful (1). Galaxy NGC 3628 rotates in a plane with its magnetic field torroidal with the plane of the galaxy. The magnetic field is aligned with the disk of the galaxy because of the gravitational effects of the galaxy (2). The magnetic field is normally stable in all directions, but when a blowout occurs from star formation, the magnetic field is shifted, changing the magnetic field as the blowout expands (1).

Blowouts in galaxies are attributed to massive star formation. As star-forming clouds collapse, density and temperature increase. The temperature and density are highest at the center of the cloud, where new stars are forming. Any visible light from the formation process is absorbed by the gas and dust surrounding it. During the later stages of the process, the region becomes hot enough for its radiation to blow away most of the material. Only then can it be seen in the visible spectrum. Until then, the process must be analyzed in the infrared (3).

Infrared is not polarized at its source. However, infrared from the galaxy is polarized by dust in the interstellar medium. This dust polarizes approximately one percent of the infrared. The dust grains are like little Frisbees with a diameter of nearly 0.1 μm, spinning with the magnetic field aligned with the spin axis of the dust grains (1).

A dust belt and dust clouds surround NGC 3628. This dust obscures visible observation of features in the galaxy behind the dust belt (1). Dust grains in interstellar clouds tend to be aligned to the magnetic field of the galaxy. By using infrared, the configuration of the magnetic field can be mapped based on the polarization of the infrared due to the alignment of the dust grains. A polarizer, which is a material that absorbs infrared oscillations with a specific angle of vibration but not the component oriented at right angles, can show the angle of polarized infrared (5).

The purpose of this project was to ratify the existence of a blowout by mapping the magnetic field in NGC 3628 using images taken in polarized infrared. It is possible to map the magnetic field geometry of this galaxy using polarization, because the net polarization of infrared from the galaxy points along the magnetic field of galaxy NGC 3628 (1).

The telescope used in this project imaged in the near-infrared (1.65 μm = 1,650 nm). Near-infrared was used, because the dust in front of the galaxy blocks light at visible wavelengths. Far-infrared is not absorbed by the dust in the galaxy. The telescope also used a rotating half-wave plate in front of the polarizer. The wave plate rotated the plane of polarization of the infrared from the galaxy, producing a clearer signal than the polarizer (1).

Only one other spiral galaxy, M82, has a confirmed blowout (6). The practical applications of this project not only expanded knowledge of blowouts and galaxies, but illustrated the effectiveness of using polarized infrared astronomy for such analyses.

Methods

Raw images of galaxy NGC 3628, along with the surrounding sky and the observatory dome, were used in this project. These images were taken in IR by Terry Jay Jones, PhD on 14-16 February 2002 at the NASA Infrared Telescope Facility (IRTF) in Mauna Kea, Hawaii. The images were analyzed using IRAF, a common astronomical image processing software program. A list of operations and commands for all of the following methods can be seen in Table 1 (Appendix A). A glossary of terms can be found in Appendix B.

The first step of re-imaging involved uniformly cropping and sorting the images by type. Images of the galaxy were first labeled "a" then images of the surrounding sky were labeled "b." Using the IRAF software package, the "b" images were subtracted from the "a" images to filter out IR not emitted by the galaxy itself, resulting in sky-subtracted images of the galaxy.

A similar operation was used to filter out unwanted IR from images of the observatory dome with the lights on and the lights off. This resulted in images called flats. These flats were subtracted—"lights off" from "lights on." The flats were then sorted by observation angles—0°, 22.5°, 45°, and 67.5°— and averaged at each angle, resulting in four flat fields. Then, all erroneous values due to imperfections in the telescope lens, called hot pixels, were manually located on the display program and averaged with neighboring pixels in both the object images and the flat fields. After hot pixels were averaged, irregularities in pixel response in flat fields were normalized by dividing the image by the average value of the pixels. Each normalized flat was then divided by the sky-subtracted images according to angle of observation in order to correct irregularities of the mirror and to remove all observatory-based IR.

In order to combine the resulting images of the galaxy correctly, the center of the galaxy in every image was estimated using the brightest pixel, and then the center of the galaxy was calculated to 0.001 pixels. Using the calculated coordinates, each image of the galaxy was shifted from the central coordinates by aligning the centers of the first images in the series. After the galaxy images were aligned, they were combined. Then the processes of smoothing the images with a 9 x 9 pixel box and masking out noise were done before the images were translated.

After translation, the data were transferred to a spreadsheet in the astronomy software program Axum. The values imported from Axum were the x, y-coordinates and the pixel value at each coordinate for the four images taken at the four angles. A magnetic field overlay was created by a vector plot using X, Y,θ, and P outlined in the following equations:

$$Q = I_0 - I_{45}$$
$$U = I_{22.5} - I_{67.5}$$
$$I = 0.5 \times \left(I_0 + I_{22.5} + I_{45} + I_{67.5}\right)$$

$$P = \frac{\sqrt{Q^2 + U^2}}{I}$$
$$\theta = \frac{0.5 \times 180}{\pi} \text{Atan}\left(\frac{U}{Q}\right)$$

Results

Figure 1 shows the image of galaxy NGC 362 that is the result of sky-subtraction, flat fielding, shifting, and combining all images at the same angle. Figure 2 shows the resultant image after smoothing and translating by a 9 x 9 pixel box.

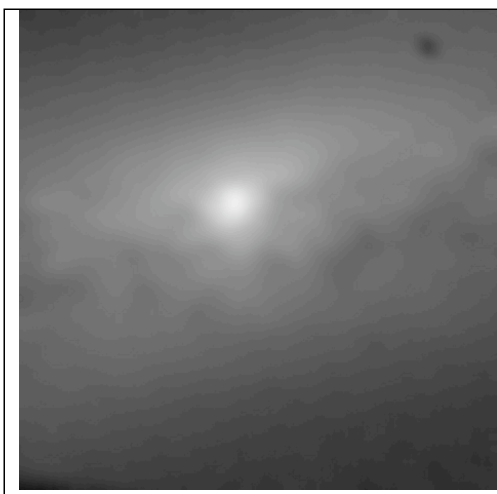

Figure 1: Resultant Image of NGC 3628

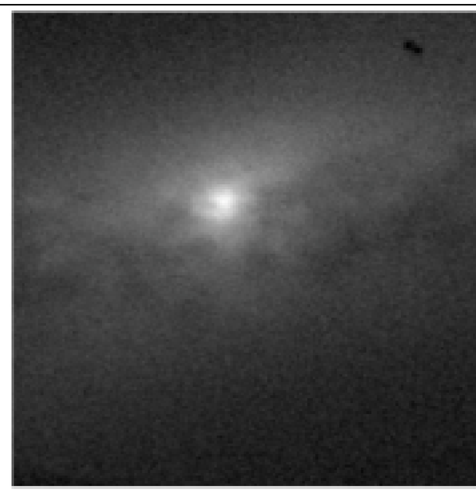

Figure 2: 9 x 9 image of NGC 3628

Figure 3 shows the geometry of the magnetic field, while Figure 4 shows the magnetic field overlaid on the image shown in Figure 2. Most of the polarization vectors are aligned with the plane of the galaxy, as would be expected for a normal galaxy. In the regions highlighted by the red circle, the polarization vectors point outward, indicating that some phenomenon is pulling the magnetic field with it as it moves outward.

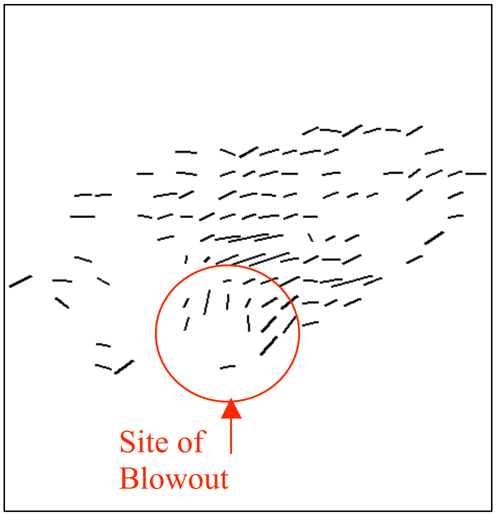

Figure 3: Magnetic field geometry

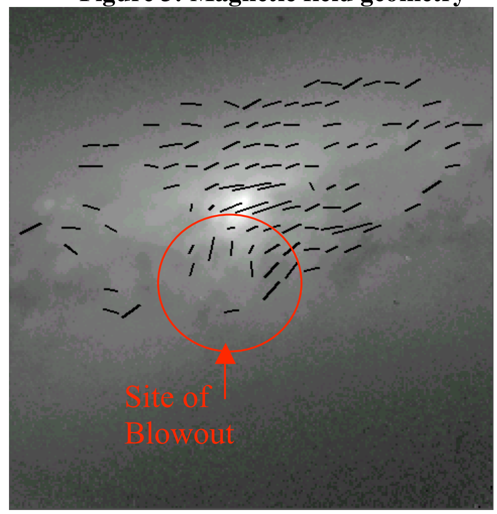

Figure 4: Magnetic field overlaid

Conclusion

While nothing in the visual image alone (Figure 2) indicates a blowout, the results of the magnetic field overlay strongly suggest that a blowout does exist in galaxy NGC 3628 in the area highlighted by the red circle in Figures 3 and 4. The magnetic field at the site of the blowout is clearly skewed perpendicularly to the magnetic field of the galaxy.

The next step of the project could be to analyze the same images using a 3 x 3 pixel box rather than a 9 x 9 pixel box. This smaller imaging area would allow for observation of the brighter regions in the galaxy versus the dimmer regions that are shown by a 9 x 9 pixel box.

Appendix A

Table 1: IRAF Commands and Descriptions

Method	Definitions	Package: Program	Command	Comments
Cropping	cutting an image to a uniform size	images.imutil: imcopy	cl>imcopy *.fit[12:245,12:245] *.fit	pixels excluded from the square from (12,12) to (245,245) were cut from the image
Sky-Subtracting	extracting light in the sky not emitted by the object in the image	images.imutil: imarith	cl>imarith @set1a.dt - @set1b.dt @set1.dt	set1a.dt is a list of "a" files; set1b.dt is a list of "b" files; set1.dt is a list of new image names
Creating Flat Fields	averaging individual images of a flat	images.immatch: imcom	cl>imcom @f0.dt flat-0.dt	f0.dt is a list of all flat images taken at 0°; flat-0.dt
Fixing Pixels	replacing hot pixels by averaging values of surrounding pixels	proto: fixpix	cl>fixpix *sc*.fit @badpixels.dt	badpixels.dt is a list of pixel coordinates that were fixed
Viewing Statistics	viewing numerical statistics of an	images.imutil: imstat	cl>imstat @f0.dt	f0.dt is a list of all flat images taken at 0°

	image			
Normalizing Flats	dividing the flat by its value to set the average to one	images.imutil: imarith	cl>imarith fc0731-67.fit / 5805 fc0731-67.fit	fc0731-67.fit is a galaxy image taken at 67°; 5805 is the value given by imstat
Flat Fielding	dividing by a flat field to extract all observatory light from object images	images.imutil: imarith	cl>imarith @all0.dt / flat-0.fit @ff-all0.dt	all0.dt is a list of all galaxy images taken at 0°; flat-0.fit is the flat field; ff-all-0.dt is a list of the new image names
Centering	finding the center of an object by the brightest pixel	xtools: center	cl>epar center ff-NGC*.fit NGCcoor.dt NGCcenter.dt	epar is shorthand for "edit parameters"; ff-NGC*.fit is all images beginning with ff-NGC; NGCcoor.dt is a list of manually-found centers; NGCcenter.dt is a list of computer-calculated coordinates
Shifting	aligning images to the central coordinate	images.imgeom: imshift	cl>imshift @NGC0.dt @sNGC.dt shifts_file=NGCshift0.dt	NGC0.dt is the file names that were shifted; sNGC0.dt is a mirror file of the NGC0.dt with an “s” in front of the file names because they are the names of the shifted files; NGCshift0.dt is a list of the shifts of the images
Combining	adding images	images.immatch: imcombine	cl>imcom @sNGC0.dt NGC0com.fit	sNGC0.dt is an input file containing the names of all shifted and combined image files; NGC0com.fit is the name of the combined image
Smoothing	using a square box 9 pixels by 9 pixels to make noise less	images.imfilter	cl>boxcar NGC0.fit 9smNGC0.fit 9 9	NGC0.fit is the image; 9smNGC0.fit is the new image name; 9 9 are the box dimensions
Masking	covering noise in an image	images.imutil: imreplace; images.imultil: imarith	cl>imreplace mask.fit 0 upper=0.916954 cl>imreplace mask.fit 1 lower=0.9 cl>imarith 9smNGC0.fit * mask.fit NGC0masked.fit	mask.fit is the image that was used to cover the other images; 0.916954 is the upper limit for all pixels that were 0; 0.9 is the lower limit for all pixels that were 1; 9smNGC0.fit is the image that was multiplied (*), resulting in NGC0masked.fit
Translating	picking every ninth pixel to create a new image	images.imgeom: imlintran	cl>imlintran @9sm.dt @3trans.dt 0 0 9 9	9sm.dt is a data file that contained the names of the images that were translated; 9trans.dt contained the new images names; 0 0 are the rotation angles; 9 9 are the number of output pixels per input pixel, that must be greater than 1 to reduce the image

Appendix B

Glossary

- Angle of Observation: The angle of the polarization measured by the camera.
- Bad Pixels: The irregular values due to defects in the camera, referred to as "hot pixels."
- Center: The center of the galaxy as determined by the brightest pixel.
- Central Coordinates: The first set of coordinates for the universal center to which all other images were aligned.
- Flats: The IR pictures of the closed observatory dome with the telescope pointed at the dome with the polarizer set at the same four angles as images were taken.
- Flat Field: A composite image of all flats taken at a certain angle creating an image of uniform light.
- Flat Fielding: The process of dividing by the flat field to remove pixel to pixel variations in response a flat field so IR was spread more uniformly.
- Masking: The process of covering unneeded pixels by a "mask" with a value of zero.
- Pixel: The smallest discrete element of an image or picture (usually a single-colored dot).
- Pixel Response: The process of reading IR using a CCD camera attached to the telescope.
- Masking: The process of hiding unimportant pixels on the periphery by laying a black cover over the image to show only the galaxy.
- Shifting: The process of aligning a set of pictures to a single point
- Sky-subtraction: The process of subtracting images of the sky that surround the galaxy from the ones taken directly of the galaxy in order to eliminate excess IR.
- Smoothing: The process of using a square box 9 pixels by 9 pixels to smooth noisy data.
- Sub Sampling or Translating: The process of taking every third or ninth pixel, depending on the smoothing box, and creating a new image consisting of only those pixels.

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