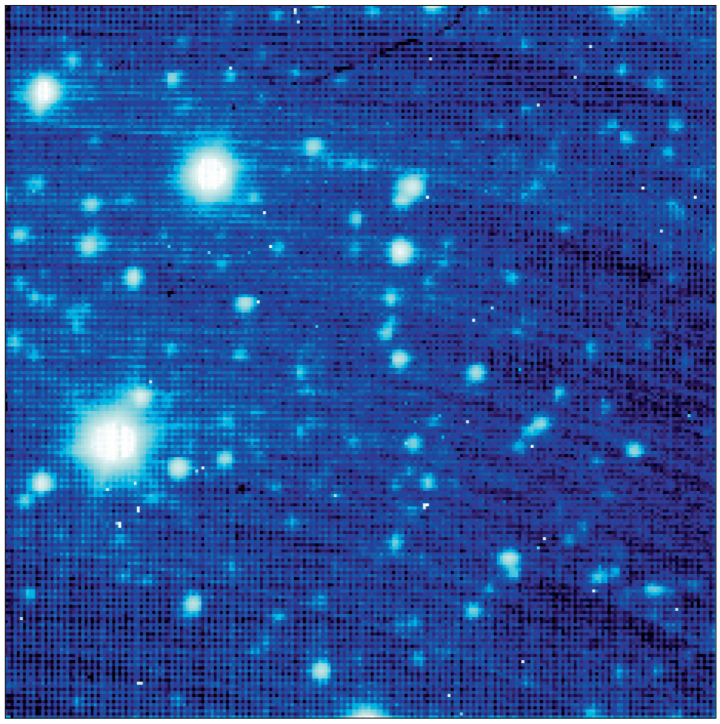


6

Doppler Tomography of Accretion Disks: Ultrahigh-Resolution Astronomy

Paul Callanan

One of the many achievements of astronomy over the last few decades has been to greatly improve the detail in astronomical images. This has occurred right across the electromagnetic spectrum — in radio, optical and even X-ray wavelengths.

High resolution radio images are accomplished by the techniques of interferometry. The best optical images are obtained using similar techniques from the ground, or by direct imaging from space. Even in the X-ray, the finely polished mirrors of the Chandra X-ray observatory (with surfaces fashioned to an accuracy of a few atomic diameters) generate images of comparable detail to those obtained optically from the ground.

Despite these advances, it remains very difficult to resolve the disk of a star, or of a planet orbiting another star. If astronomical image-making were possible with even higher resolution, then the door would be open to the study of many new phenomena.

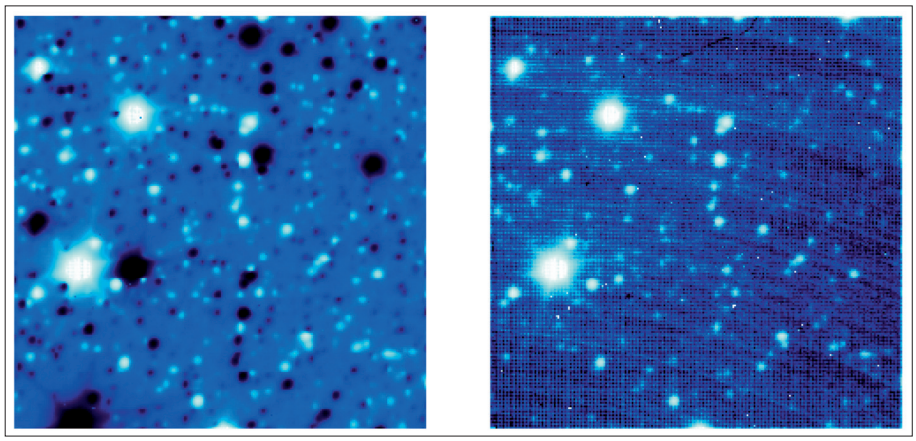
Two-dimensional stars

A relatively new technique has been developed to study a particular type of astronomical object, found in many parts of our Galaxy (and others).

Disks of gas are known to orbit many different types of stars. For example, a residue of material orbited the "proto-sun," before it settled down to life as a normal star. This material was initially in the form of a disk, from which the planets eventually formed. Such disks are observed around other young stars today.

Many binary star systems in our Galaxy also harbor such disks. In these systems, a neutron star, white dwarf or black hole orbits a companion star. The binary is so "tight" that material is accreted from the companion star to the

compact object, forming a disk as it does so. This "accretion disk" is heated by the viscous interaction of the gas and any irradiation from the compact object (often a highly luminous emitter of X-rays). It appears almost like a two-dimensional star, with a temperature that increases dramatically towards it center.



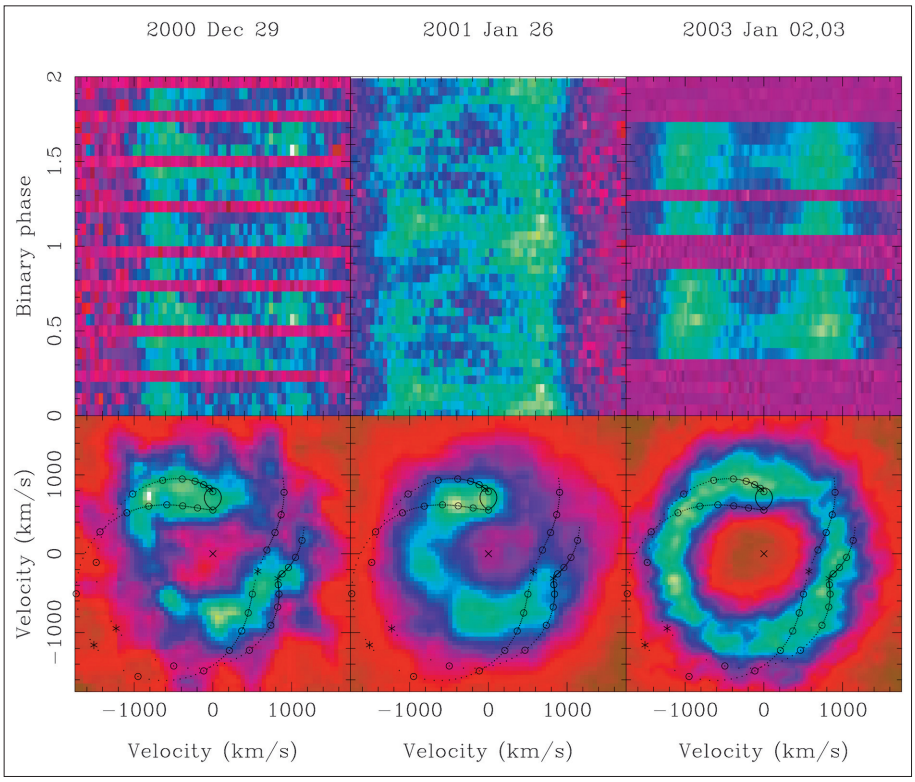
Indirect imaging of accretion disks

At first sight, the idea of studying the structure of such disks seems technically impossible. A disk comparable in size to the sun even at a moderate distace would require an angular resolution of a few millionths of a second of arc: that is 100 to 1,000 times smaller than the best resolution radio or optical observations can offer. Here, a candidate system is shown, but the phenomena that require study are nearly beyond the limit of the telescope.

However, many of these accretion disks are in binaries with relatively short orbital periods (several hours to days). Hence, we get to see various aspects of the accretion disk projected along our line of sight, and this allows us to construct maps of the accretion disk, in a way similar to that used in X-ray Computer Aided Tomography (CAT) scans. Indeed, the technique is called Doppler tomography of accretion disks.

In a CAT scan, X-rays are passed through a plane of the body from many different angles, and an image is obtained for each. These images can be combined using the "maximum entropy method" (MEM) to produce a reliable 2-D image of the X-ray absorption within the body.

In the case of a binary star, the system itself rotates for us. Hence we can observe the spectrum of the accretion disk from many lines of sight. This spectrum contains many emission lines; the structure and location of such lines provides us with information about the speed of the material from which they came. A



line with a laboratory wavelength of λ_0, say, is shifted to either longer wavelengths (to the red) or shorter wavelengths (to the blue) depending on whether the gas emitting the line is travelling towards or away from us. This is called the Doppler effect. (See Chapter 12 for another example.)

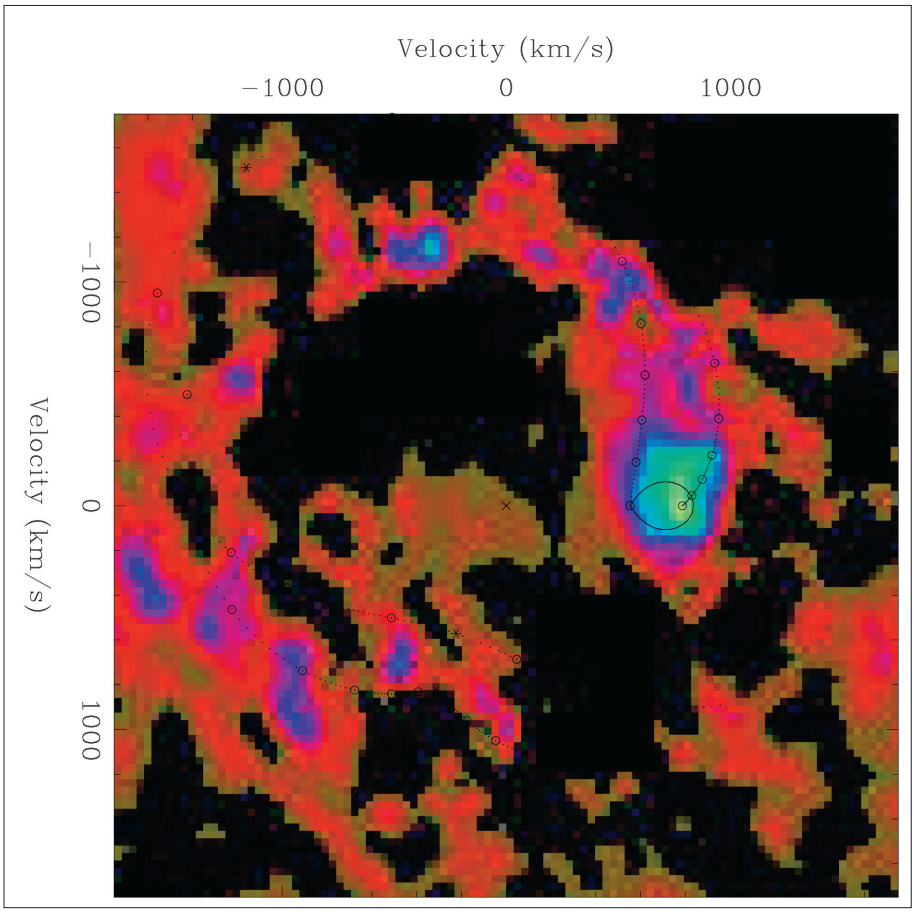
Spectrograms and Doppler images

Hence, these line profiles give information about the velocity of the gas in the disk, and from the variation of these profiles over the orbital phase we can create a map of the intensity distribution over the accretion disk — not in normal space but "velocity space".

The object here is the binary system with "black hole candidate" (a suspected black hole), numbered XTE J1118+480.

The top images here are "trailed" spectra of Hα emissions.

They are used to make "MEM Doppler maps," bottom, which record the position of the stars in the binary system in "velocity space": notice that both axes record velocity, and not position.



The result

By subtracting out symmetrical elements, it is possible to visualize emission concentrated toward the expected position of the secondary star of the pair.

The gas stream between the stars is the lower curve; the upper curve is the Keplerian disk along the stream; and the cross is the center of mass of the entire system.

If the material obeys Kepler's Laws as it orbits in the disk, then we can use the relationship between the gas velocity and its distance from the centre of the disk to generate, in theory, a map of the disk in real space.

As indirect as this technique is, it allows us to study phenomena that are otherwise completely inaccessible using other means.

For further reading

M.A.P. Torres, Paul Callanan et al., "MMT Observations Of The Black Hole Candidate XTE J1118+480 Near And In Quiescence," preprint at arXiv:astro-ph/0405509 (May 26, 2004).


M-0054-0021
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24
GLENFADA PARK NORTH
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7

The Bloody Sunday Tribunal Video Simulation

Darius Whelan

On Sunday, the 30th of January 1972, thirteen people were killed by British soldiers on the streets of Derry. The circumstances in which they died have been the subject of enormous on ongoing controversy. At the time, the British Army said that the soldiers had been firing at nail-bombers and gunmen. Many witnesses disagreed strongly, arguing that none of the shootings were justified because all of the victims had been unarmed civilians. A report was issued in the same year by the Widgery Tribunal; it found that there had been "no general breakdown in discipline" on the part of the soldiers, although some of the firing "bordered on the reckless." The coroner, reporting in 1973, concluded very differently that "it was sheer, unadulterated murder." In 1998, a new Tribunal was established to reassess the facts and provide a new report (photo at right). This Tribunal, chaired by Lord Saville, heard evidence for a number of years and is preparing its report as of this writing (winter 2006).

An interactive virtual reality system was developed specifically for use by the Bloody Sunday Tribunal in order to aid the orientation of witnesses when they gave their evidence. The system consisted of thousands of photographs and computer-generated images of Derry, both present-day and as it was in 1972.

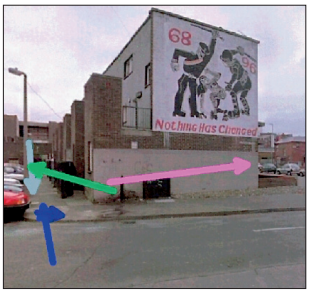
A combination of this application and touch-screen technology used in the hearing chamber allowed users to virtually walk the streets of Derry. Once a witness was viewing a particular "hotspot," he or she could view the scene from all angles. Witnesses could also draw arrows on the screen to record movements or events which they saw.

A sample piece of evidence using the virtual reality system

Ms. Nell McCafferty, a journalist, gave evidence that she witnessed certain events at a rubble barricade, including bodies being put into a jeep by soldiers (see the photo at the opening of this chapter). Mr. Christopher Clarke, QC, displayed a hotspot on screen and drew a blue arrow to indicate the line of sight she would have had from the window of a house in which she was located.

Following the line of sight indicated by the arrow, Mr. Clarke stated that Ms. McCafferty would have had a view of the rubble barricade. Earlier, another barrister, Lord Gifford, QC, had commented that as the house was slightly raised above the level of the ground, Ms. McCafferty would, when looking out of this window, have been able to see over the top of the fence.

A second piece of evidence

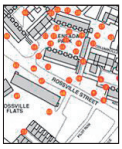


When Mr Denis Bradley (formerly Father Bradley) was called as a witness, he was shown certain hotspots on the screen and asked to point out exactly where he had observed a soldier standing when certain shots were fired. He marked the screen with various arrows. Then a barrister asked Mr Bradley the following question:

"The arrows show — the mauve arrow is where the people have been, the turquoise arrow is the route the soldiers came down, the green arrow is where the people were being taken by the soldiers back up into Glenfada Park North, the light blue arrow is approximately where the soldier was and the dark blue arrow is the direction into which he moved; is that right?"

Mr Bradley answered: "That is roughly correct."

The significance of the Virtual Reality system



In the earlier Widgery Tribunal hearings, extensive use had been made of maps, photographs and an architectural model of the area. The current Bloody Sunday Tribunal has vastly increased the amount of visual material available. The idea of bringing all of that information together into a virtual reality reconstruction (and including new images where necessary) proved to be of great assistance to the lawyers and witnesses trying to make sense of the complex events which occurred decades previously. Continuous reference was made to the photographs and maps, as well as the virtual reality recreation of 1972 Derry, especially as some buildings had been demolished since 1972.

Generally speaking, witnesses seemed to be quite comfortable with the virtual reality system, although it naturally took a few minutes for each witness to become familiar with this rather unusual means of representing the scenes. Witnesses quite often controlled the system, exploring the virtual space. Some witnesses corrected earlier statements based on what they saw on the virtual reality. For example, Mr Trevor McBride commented:

> Yes, if you can turn right, if I could put it like that again and maybe keep going right. I think just keep going right on. Now, if you could just stop there. I thought that I left the Shiels's home and came along this pathway, but I, I would not have been able to look to my right to have seen people lying at Abbey Park. So I think that the only route that makes any sense is coming down from Abbey Street down this little pathway where the tree is and then have glanced over to my right and have been aware of the people lying just where the car is, to the left of the car.

For the lawyers involved in the Tribunal, it was vital to be able to analyze the visual evidence in detail. It would not have been possible for a lawyer to participate in the Tribunal without studying maps, photographs, videotapes, and the virtual reality system in advance and being prepared to use those tools to clarify what witnesses were saying.

The Virtual Reality system made it possible to pose questions and to test witnesses' memories in a way that would not have been possible with photographs and maps. The Tribunal report is anticipated as this book goes to press; it will be interesting to see how the findings depend on the visual evidence and how it was deployed.

For further reading:

Bloody Sunday Tribunal website: www.bloody-sunday-inquiry.org.uk; British Irish Rights Watch Bloody Sunday Inquiry Reports: www.birw.org/bsireports/bsione.html; evidence of Nell McCafferty: Tribunal Transcript, Days 168 and 169; evidence of Denis Bradley: Day 140; evidence of Trevor McBride: Day 168. See further D. Mullan and J. Scally, *Eyewitness Bloody Sunday*, third edition (Dublin: Merlin, 2002); CAIN Web Service Bloody Sunday site: http://cain.ulst.ac.uk/events/bsunday/; UCR/California Museum of Photography Exhibition "Hidden Truths: Bloody Sunday 1972," January-March 2000: www.cmp.ucr.edu/photography/hidden/.