Mercedes Richards, Professor

Computational Astrophysics

1. Questions and Objectives

The primary focus of the research performed by Dr. Mercedes Richards is to develop a better understanding of the process of mass transfer in interacting binaries and the influence of magnetic activity on the accretion process. She has employed a multifaceted approach to model and create images of the accretion flows in interacting binaries. Such accretion flows occur in a wide variety of systems, including compact binaries (novae, dwarf novae, polars, X-ray binaries), non-compact systems (e.g., Algols), and accreting brown dwarfs. Her work has focused on binaries which contain a hot blue main sequence star with a cool magnetically-active companion that fills its Roche lobe (Algols), and also the detached magnetically-active RS CVn binaries in which no Roche lobe overflow is expected. The non-compact Algol binaries are in the slow phase of mass transfer and are not usually associated with violent phenomena, hence they provide a unique environment in which we can observe mass transfer by Roche lobe overflow. Moreover, since the mass-losing star is magnetically-active, the influence of magnetic fields on the mass transfer process can also be examined. Dr. Richards has studied cycles of magnetic activity on cool stars in binaries and also long term magnetic cycles on the Sun.

Dr. Richards has used tomography, hydrodynamic simulations, as well as observed and synthetic spectra to study the accretion structures in non-compact binaries, to understand the physical processes that influence the flow of gas between the stars, and to produce 3D velocity images of these gas flows. Her research encompasses the disciplines of Stellar Astrophysics, Computational Astrophysics, Exoplanets and Brown Dwarfs, and Astrostatistics.

2. Discoveries and Milestones

In the specific area of Computational Astrophysics, Dr. Richards is known for her historic work on the hydrodynamic simulations of gas flows in the non-compact direct-impact binaries where the gas flow from the mass-losing star makes direct contact with the surface of the mass gaining star. She was also influential in the creation of a new computer code (called SHELLSPEC) to synthesize the spectra of accretion structures in interacting binaries. She has also used tomography and other visualization techniques to make images of the gas flows in interacting binaries.

Richards and her collaborators

(1) created the first hydrodynamic simulations to illustrate the dynamics of mass transfer in Algol-type interacting binaries.

(2) created the first synthetic velocity maps (tomograms) using hydrodynamic simulations.

(3) produced the first 3D Doppler tomograms of gas flows beyond the orbital plane in the entire class of interacting binary stars by using a technique called the Radioastronomical Approach.

(4) used 3D Doppler tomography to identify loop prominences on the cool mass-losing star that can alter the flow of gas between stars.

(5) used Doppler tomography to produce the very first 2D images of gas flowing along the predicted gravitational trajectory in interacting binaries.

(6) used tomography to create 2D images of gas flows in interacting binaries, including accretion disks, gas streams, and magnetic structures.

(7) developed the first code (called SHELLSPEC) to synthesize the spectra of interacting binaries by modeling the accretion disk, gas stream, and other structures in a moving medium.

(8) used synthetic and observed spectra to extract, for the first time, the separate sources (e.g., accretion disk, gas stream), that contribute to the spectra of interacting binaries.

(9) found the first observational evidence that eccentric accretion disks can exist as stable structures in binary star systems (e.g., in TT Hya).

(10) coordinated a 23-year spectroscopic study of the non-eclipsing system of CX Dra involving six observatories in five countries, and identified the location of the accretion structures in the binary.

(11) derived the properties of the shock region in direct impact binaries.

(12) discovered that cool stars in Algol-type and RS CVn binaries have radio flares with predictable periodicities of 49 days to 140 days binaries based on a 5.6 year continuous radio survey.

(13) analyzed circularly polarized radio flares to demonstrate that the magnetic field on the cool star in the Algols and RS CVns is strongest before the flare and weakens during the flare.

(14) discovered the first evidence of a precessing accretion disk in the Algols using radio data.

(15) studied nova light curves to find evidence of precessing accretion disks and membership in the intermediate polar group.

(16) performed a statistical analysis of sunspot number data to explain why the length of the sunspot cycle varies between 10 and 12 years by examining the long-term 188-year periodic cycle of variability in terms of historic sunspot minima like the Maunder Minimum.

3. Current Computational Astrophysics Projects

Active research projects of interest to graduate students:

(1) Use the SHELLSPEC spectrum synthesis code to isolate the spectroscopic contributions of the accretion disk, gas stream, hot spot, and other emission structures for 12 Algol binaries. This has only been done for one binary so far. These synthetic spectra will be compared with the observations to derive the physical properties of the separate components of the accretion flows.

(2) Use Doppler tomography to produce 2D images of wide binaries based on the observed spectra and difference spectra. Such images would otherwise be impossible to obtain since these binaries are unresolved even with the largest telescopes.

(3) Generate hydrodynamic simulations for comparison with the tomograms using the properties of accretion structures derived from tomography.

(4) Use the Radioastronomical Approach on a large sample of binaries to create multiwavelength 3D images of the gas flows in these systems.

(5) Develop an independent 3D Back-projection Doppler tomography technique to check the results from the Radioastronomical Approach.

(6) Convert the 2D and 3D Doppler images into normal Cartesian pictures.

4. Participants/Personnel (last 5 years)

Senior Researchers: Jan Budaj, Alon Retter, Elena Slobounov (Research Computing & Cyber-infrastructure)

Graduate Students: Megan Comins, Brendan Miller, Manodeep Sinha

Undergraduate Students: Michael Rogers, Tae, Kang, Derek Einsig, Michael Peth, John Fisher

5. Student Highlights:

Mike Rogers (undergraduate) led the project in which sunspot data were analyzed to examine why the length of the sunspot cycle varies typically between 10 and 12 years.

6. Links:

Home page: http://www.astro.psu.edu/users/mrichards/
Research page: http://www.astro.psu.edu/users/mrichards/webpage/research.html
Publications: http://www.astro.psu.edu/users/mrichards/webpage/papers.html
Shellspec code: http://www.ta3.sk/~budaj/shellspec.html

International Conference: 2011 July 18 – 22, IAU Symposium 282, "From Interacting Binaries to Exoplanets: Essential Modeling Tools," Tatranská Lomnica, Slovakia (www.ta3.sk/IB2E/)

Press Release: 2003 Aug. 22 on "Major Flares are Predictable on Far-Away Stars, Analysis of Radio Observations Reveals," Office of Public Relations, Eberly College of Science, Penn State University. (http://www.science.psu.edu/alert/Richards8-2003.htm)

2009 July 30: "Stellar Detective: A Profile of Professor Mercedes Richards," Penn State Live, Penn State University. (http://live.psu.edu/story/40752/nw63)

Other links:
http://www.rps.psu.edu/unplugged/spring09/March25.html
http://www.rps.psu.edu/unplugged/spring09/richards.html
http://www.rps.psu.edu/0405/flares.html
http://www.rps.psu.edu/probing/pluto.html