Progress Report on the Second Year of ATP02 Grant NAG5-13306
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Strong-field Gravitational Effects in the Timing and Spectroscopy of X-Ray Binaries
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During the past year, this grant mainly supported the work of graduate student (now postdoc) Jeremy Schnittman and the PI Edmund Bertschinger. Schnittmen received his PhD for this work in February, 2005. He is continuing to work with me under this grant as a postdoc for six months before starting a postdoctoral fellowship at the University of Maryland under the supervision of Alessandra Buonnano, Coleman Miller, and Chris Reynolds.

Progress Report on Black Hole Accretion Dynamics

Using the ray-tracing code described in Refs. 1 and 4 below, we developed additional features to the hot spot model to explain the broadening of the quasi-periodic oscillation (QPO) peaks as well as the damping of higher frequency harmonics in the power spectrum. We derived a number of analytic results that agree closely with more detailed numerical calculations. Three primary pieces are developed: the superposition of multiple hot spots with finite lifetimes and random phases, a width in the radial distribution of geodesic orbits, and the scattering of photons from the hot spot through a corona around the black hole. The complete model is used to fit the observed power spectra of both type A and type B QPOs seen in XTE J1550--564, giving confidence limits on each of the model parameters. These results were presented in a conference paper (Ref. 5 below) and in a refereed publication (Ref. 2).

We also explored the possibility of using higher-order statistics, particularly the bispectrum and bicoherence, to distinguish between competing QPO models. These methods were applied to the hot spot model and a method was proposed to map out the spacetime metric around Kerr black holes in Ref. 3 below.

As an extension of the simple scattering model presented in Ref. 7, we also developed a Monte Carlo code to calculate the detailed propagation of photons from a hot spot emitter scattering through a high-temperature, low-density corona surrounding the black hole. Each photon is followed until it is either captured by the black hole or is ``detected" by a distant observer. The coronal scattering has two major observable effects: the inverse-Compton process alters the photon spectrum by adding a high energy power-law tail, and the random scattering of each photon effectively damps out the highest frequency modulations in the X-ray light curve. We simulated photon spectra and light curves for comparison with RXTE data, resulting in important theoretical implications for the hot spot model of High Frequency QPOs. This work was presented at the 22nd Texas Symposium on Relativistic Astrophysics at Stanford in December, 2004 (Ref. 6 below), and is currently being prepared for publication in ApJ.

To gain more insight into the continuum photon energy spectrum, we followed the formulation of Novikov & Thorne (1973) for describing the structure of a relativistic

"alpha-disk" around a Kerr black hole. The resulting equations of vertical structure can be integrated at each radius to give the complete density and temperature profile of the steady-state disk. Inside of the inner-most stable circular orbit (ISCO), the gas is propagated along a plunging geodesic trajectory, evolving according to one-dimensional classical hydrodynamics in the local inertial frame of
the fluid. Given the surface temperature of the disk everywhere outside of the horizon, the observed spectrum is calculated using the transfer function mentioned above. The features of this modified thermal spectrum may be used to infer the physical properties of the accretion disk and the central black hole. Coupled with the Monte Carlo electron scattering code, the thermal spectrum from the steady-state disk is modified by the inverse-Compton effects to give a total integrated spectrum for the disk. This work is also currently being prepared for publication.

Refereed publications:

1. J.D. Schnittman and E. Bertschinger 2004, "The Harmonic Structure of High-Frequency Quasi-Periodic Oscillations in Accreting Black Holes", ApJ 606, 1098

2. J.D. Schnittman 2005, "Interpreting the High Frequency QPO Power Spectra of Accreting Black Holes," ApJ 621, 940

3. T.J. Maccarone and J.D. Schnittman 2005, "The bicoherence as a diagnostic for models of high-frequency quasi-periodic oscillations," MNRAS 357, 12

Unrefereed publications:

4. J.D. Schnittman and E. Bertschinger 2004, "A Hot Spot Model for Black Hole QPOs," in "X-ray Timing 2003: Rossi and Beyond," AIP Conference Proceedings, Vol. 714, ed. P. Kaaret, F.K. Lamb, and J.H. Swank (Melville, NY: American Institute of Physics), 40

5. J.D. Schnittman 2004, "Features of the High Frequency QPO Power Spectrum in Accreting Black Holes," 2004 AAS HEAD meeting

6. J.D. Schnittman 2005, "Coronal Electron Scattering of Hot Spot Emission Around Black Holes," to appear in Proceedings of the 22nd Texas Symposium on Relativistic Astrophysics, Stanford University, December 13-17, 2004 (preprint astro-ph/0502048)

7. J.D. Schnittman 2005, "Radiation Transport Around Kerr Black Holes," MIT PhD thesis