International X-ray Observatory (IXO)

Fundamental Accretion Physics with IXO

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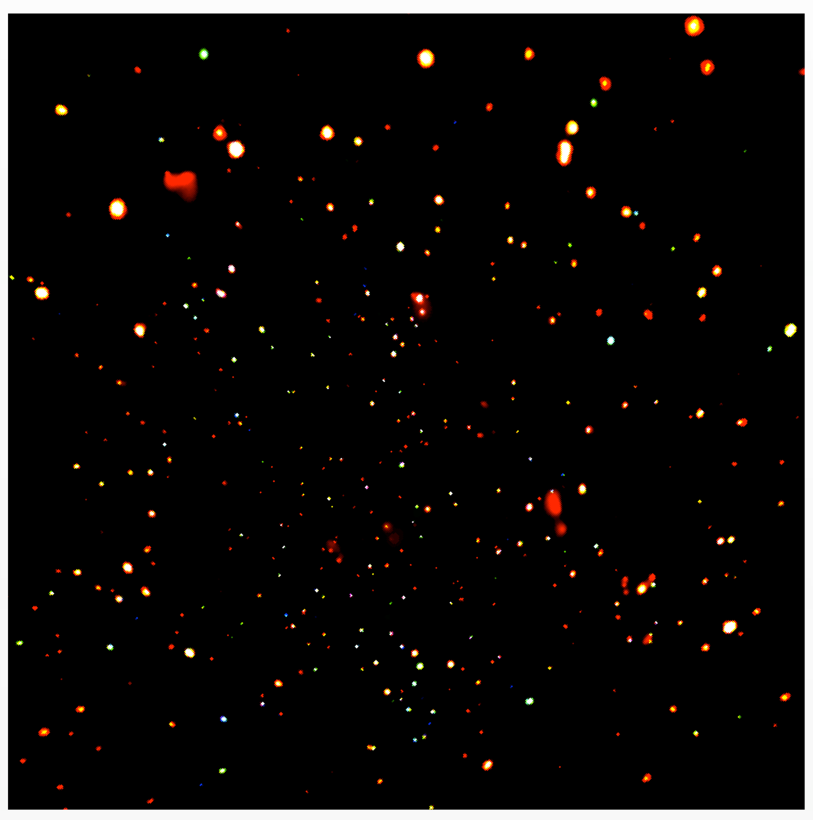
Summary: The physical processes that drive accretion onto black holes and other compact objects remain observationally elusive, owing to the limited mirror area and spectral resolution of present X-ray missions. Revealing the physics behind active disk accretion requires spectroscopy on important dynamical times and the ability to detect orbital motion. Understanding the nature of quiescent accretion requires extraordinary sensitivity. *IXO is the first and only planned X-ray mission that can finally unravel the complex and important physical processes that mediate accretion onto black holes and other compact objects.*

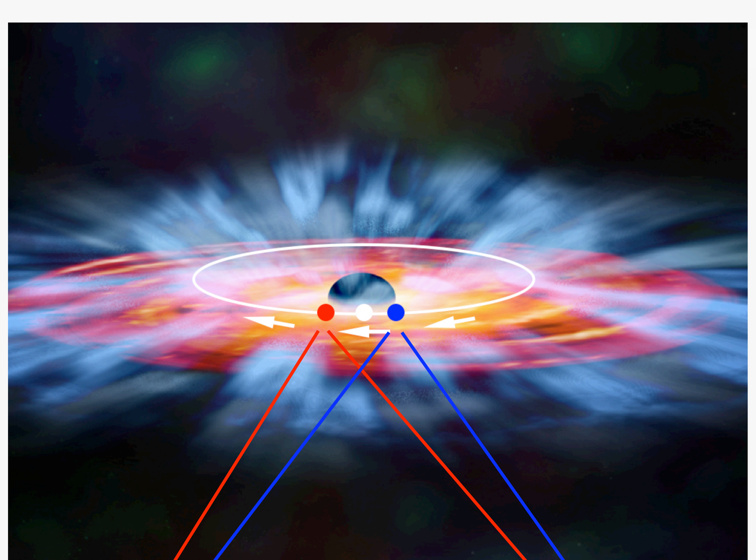
How do accretion disks fuel black holes?



Disk accretion onto supermassive black holes supplies approximately 20% of the ionizing radiation in the universe. In the Chandra Deep Field North, for instance, every point source is an accreting black hole.

Despite considerable theoretical work, observational evidence of how accretion disks transfer matter onto black holes - essentially a problem of removing angular momentum from accreting gas - remains observationally elusive.

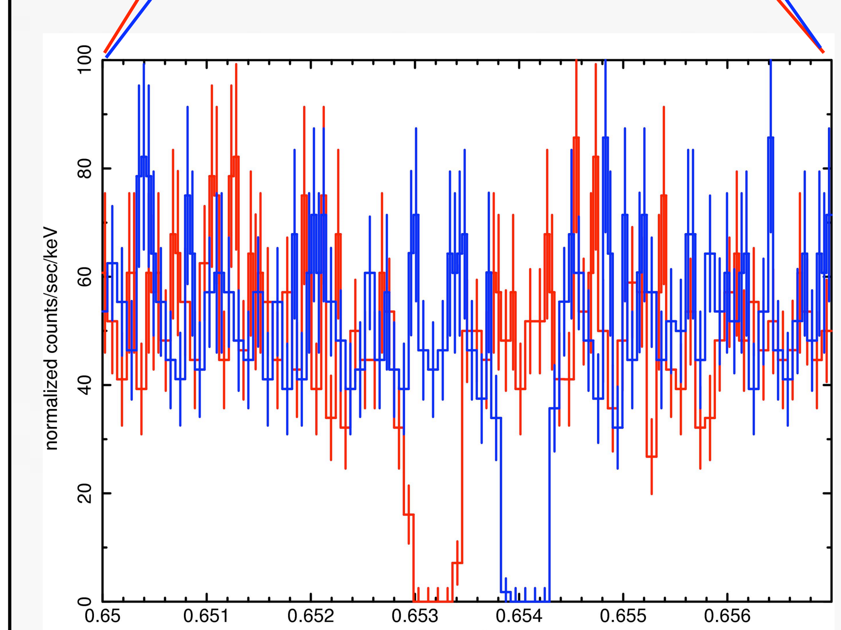
One means by which a disk can transfer angular momentum is to drive a magneto-centrifugal wind, which may later collimate into a jet. Such winds were described by Blandford & Payne (1982) and facilitate disk accretion in young stellar systems (Calvet, Hartmann, & Kenyon 1993). These winds may work in concert with MRI within the disk (Balbus & Hawley 1991).



With IXO, spectroscopy of accretion onto black holes will finally rival optical and IR spectroscopy of accreting young stars.

The spectral resolution and collecting area of IXO make it possible to reveal orbital motion - and therefore disk winds that transfer angular momentum - in more than 20 AGN.

Through IXO spectroscopy, distant orbiting material can be seen to transit the face of the central engine via Doppler shifts in absorption lines.

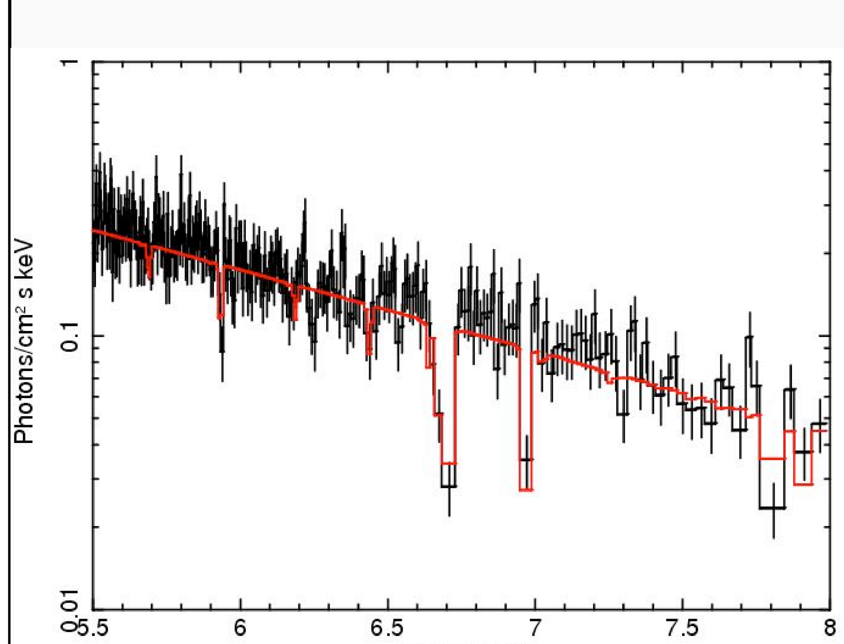


The spectra shown at left illustrate the ability of IXO spectroscopy to reveal rotating disk winds.

An orbiting absorber at 1000 GM/c^2 will take more than 30 ksec to transit the face of a central engine with a radius of 20 GM/c^2, for $M = 10^7$ Msun.

The red and blue IXO grating spectra represent the initial and final 5 ksec slices of a transit event. The shift of a narrow H-lke O VIII line is clear.

The radii and line parameters were drawn from time-averaged studies with the Chandra/HETGS.

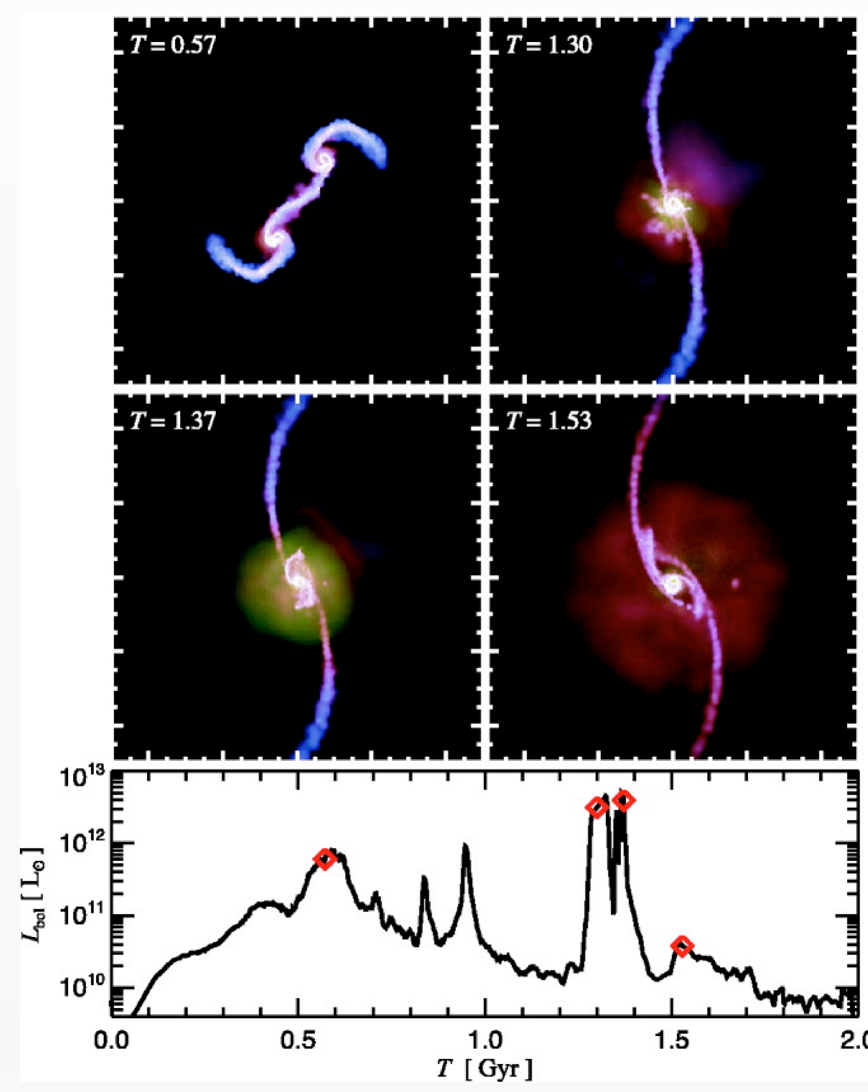


Stellar-mass black holes and neutron stars in binary systems represent another regime in which orbital timescales will become accessible.

Bright Galactic sources will yield a spectrum like that shown at left every 3 seconds, corresponding to few*100 GM/c^2 for stellar-mass black holes and neutron stars.

The strength and shifts of He-like and H-like Fe lines, like those shown, can be traced orbit by orbit to reveal the nature of disk accretion.

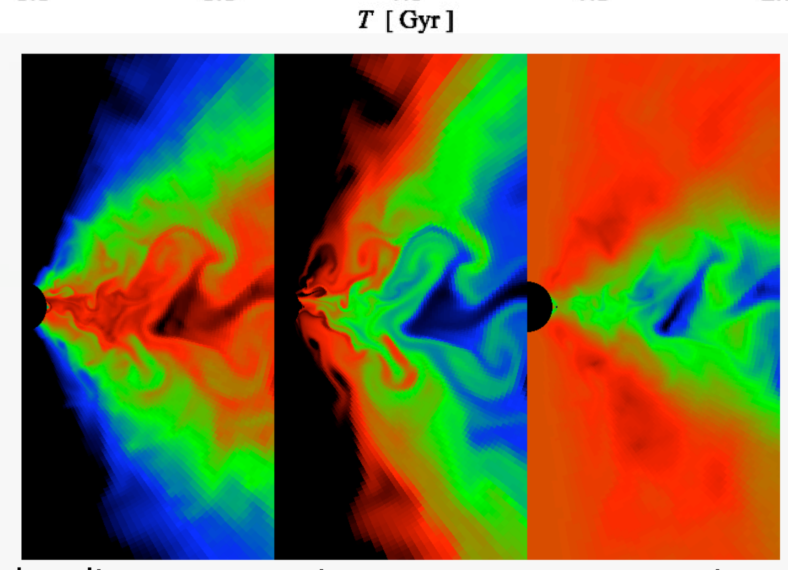
What is the fate of gas at low accretion rates?



Theoretical studies suggest that active accretion phases are but a flash in the much longer co-evolution of black holes and their host galaxies. The figure at left predicts active phases driven by a merger of two galaxies (Hopkins et al. 2005).

Observational studies reveal that most galaxies do not harbor AGN, and suggest AGN lifetimes of as little as 1 Million years.

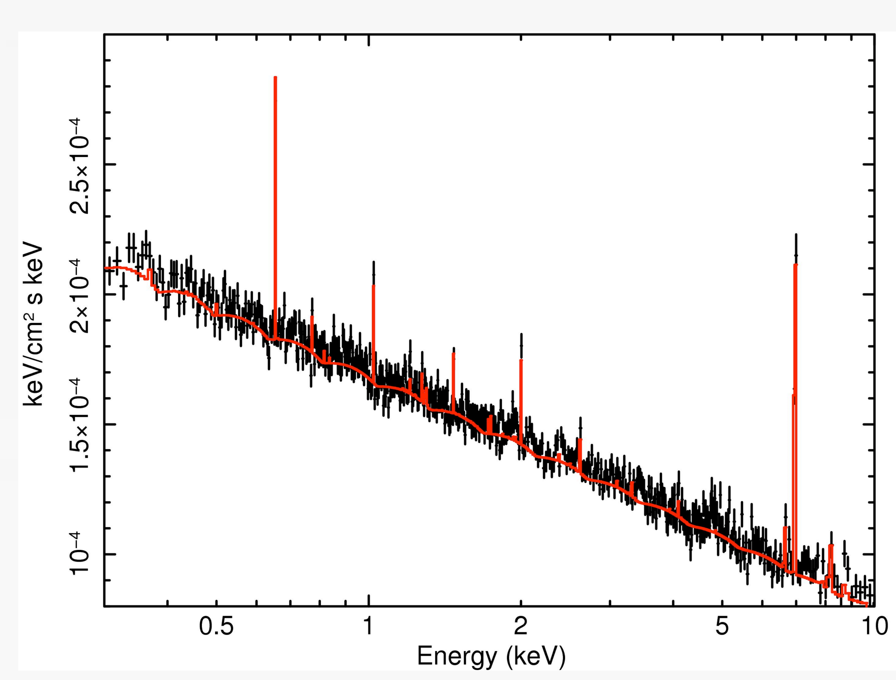
Thus, most black holes are not accreting at high fractions of their Eddington limit. If we are to understand accretion throughout the universe, and the full connection between black holes and their local environments, we must discover the nature of starved accretion onto black holes.



density entropy ang. momentum

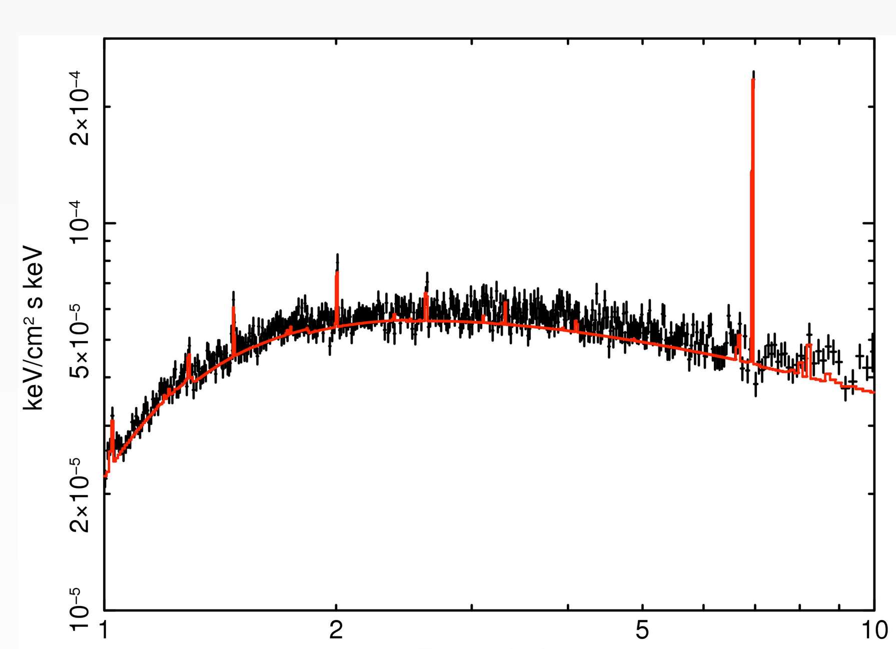
At low fractions of the Eddington limit (10^{-4} and below), it is all but impossible for a standard thin accretion disk to operate. Rather, disks may become very thick and inefficient in generating radiation. The picture at left is taken from a simulation of such an accretion flow (Stone et al. 1999).

In basic terms, we do not know if gas is bound to black holes at low accretion rates. Although gas and radiation may could be advected across the event horizon (e.g. Narayan & Yi 1994), viscous heating may be sufficient for most gas to become unbound and driven away in a wind (Blandford & Begelman 1999).



At left, a simulated IXO calorimeter spectrum of a line-poor 50 keV thermal plasma is shown. Such a spectrum would be observed in a 100 ksec observation of M87 or NGC 4143. Or indeed. from any of 40 low-luminosity black holes within 30 Mpc with a known mass, enabling correlations with feedback parameters such as star formation rate.

Revealing whether or not gas is bound to black holes at low accretion rates, or driven away in a wind, requires the line spectroscopy that only IXO can provide. Line ratios reveal plasma temperatures, line strengths reveal the size of the accretion region (Narayan & Raymond 1999), and line shifts reveal whether the gas is an outflowing wind or a bound, hot, advective flow.



Stellar-mass black holes and neutron stars in the Milky Way will provide an equally good set of sources to study accretion at low rates. The spectrum shown at left is again a 50 keV thermal plasma observed for 100 ksec, assuming a source at 10^{-6} Eddington, a distance of 8.5 kpc, and modest foreground absorption. A sample of 10-20 such spectra can easily be obtained with IXO over a nominal mission lifetime.