XMM-Newton deciphers the magnetic physics around forming stars

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In a special feature published this week, Astronomy & Astrophysics presents the first round of results from a large project conducted with XMM-Newton, the "XMM-Newton extended survey of the Taurus molecular cloud" (XEST). Starting in 2003, this program has been conducted by an international team of nearly 30 astronomers led by Manuel Güdel (Paul Scherrer Institute, Switzerland).

The large molecular gas cloud in the constellation of Taurus is the nearest star formation region and a star formation test environment for expert theorists and observers alike. The XMM-Newton project has provided by far the most sensitive and comprehensive X-ray survey of this region, for the first time systematically detecting almost all young stars embedded in the cloud as X-ray sources, including many objects with the lowest mass, the so-called brown dwarfs, and stars still in the process of growing, the so-called protostars. These X-rays are thought to be emitted by very hot gas held together by magnetic fields just above the surface of the star, much like the case of the solar corona although with much more intense X-rays.

Among the new results now issued, a complex of discoveries relates to the interface between the star and surrounding disks and jets in young stellar systems. The sensitive spectroscopy of the Taurus project has provided clear confirmation that those stars onto which gas streams are still falling from their gaseous surroundings emit less X-rays than stars in which these "accretion" processes have ceased. Analysing the high-resolution spectra from gas-accreting young stars, the team proved the presence of an unusual amount of cool gas (of 1-2 million degrees) in the stellar atmosphere in addition to the hotter coronal plasma (10 million degrees). The cool accretion streams originate in gas disks orbiting the star. As the gas falls toward the star, it seems to penetrate the hot regions of the corona and cools them as it mixes with the hot gas. Because the hot gas has cooled down, the remaining hot gas produces less X-rays. This so-called "soft excess" from cool gas is not seen in any non-accreting star; hence, non-accreting stars emit more X-rays than the still accreting stars.

After their observations of T Tauri stars that accrete very strongly, the team reports on an entirely new process, which they also confirm using Chandra observations of the same stars. In these stars, the X-rays are so strongly absorbed by the infalling gas that the team expected the stars to become nearly invisible in the optical range as well, because tiny dust particles are usually embedded in the gas streams, thus absorbing the visible light from the central star. Surprisingly, the star is still brightly visible, which means that the dust particles are not there. Manuel Güdel and his colleagues suggest that the starlight was strong enough to heat and destroy the dust at some distance from the star. As a result, the infalling gas streams close to the star no longer contain those grains. The gas alone does not absorb the optical stellar light, but only the X-rays.

At last, the team found that strongly accreting stars also emit an additional very soft, but unabsorbed, X-ray component. These are no X-rays formed in the corona by the infalling gas streams because they would also be absorbed. Instead, this new X-ray component must come from somewhere outside the star's corona where absorption is lower. The team suggests that these very soft X-rays come from the jets ejected by the central star in the polar direction. This hypothesis is confirmed by Chandra observations of one of the stars. This discovery was completely unexpected because there was no previous evidence of hot gas in this jet. The process that heats the jet gas to millions of degrees is unclear. Shock waves in the jets may be responsible, but the shock speeds are too low to release the needed energy. Alternatively, spiralling magnetic fields locked up in the outflowing jets could drive electric currents along the jet, which then heat the gas.

The X-ray jets may act like street lights to illuminate the disks directly from above. This leads to ionisation and heating of the disk surface, which in turn helps drive matter from the disk onto the star. XMM-Newton has thus for the first time given evidence of a closed loop of action and reaction in the environments of young stars, including cool gas streams falling from a disk down onto the star, thereby absorbing the underlying X-ray emission; the related magnetic fields drive jets out along the polar direction. These jets in turn generate X-rays that heat the disk and further enhance accretion.

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