A Simultaneous Optical and X-ray Variability Study in the Orion Nebula Cluster

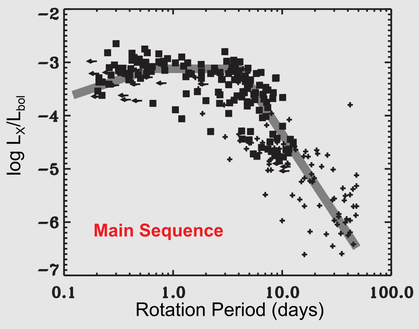
K.G. Stassun (Vanderbilt), M. van den Berg (CfA), E. Feigelson (Penn State), E. Flaccomio (INAF), D. Ardila (JPL), M. Barsony (SFSU), G. Basri (Berkeley), R. Mathieu (Wisconsin)

Motivation

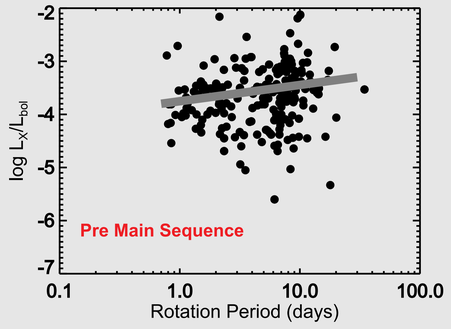
Fact: *On the main sequence, stellar X-ray luminosity is highly correlated with stellar rotation, consistent with a picture in which X-rays are produced by rotationally driven dynamos powering magnetically active coronae.*

Fact: *No such X-ray/rotation connection has been found in pre-main-sequence stars.*

Question: *Is a different mechanism--perhaps accretion--responsible for the production of X-rays in pre-main-sequence stars?*



Main sequence stars *exhibit a clear correlation between X-ray luminosity and stellar rotation period. The solid line indicates the three regimes with increasing rotation speed (from right to left): linear, saturated, super-saturated.*



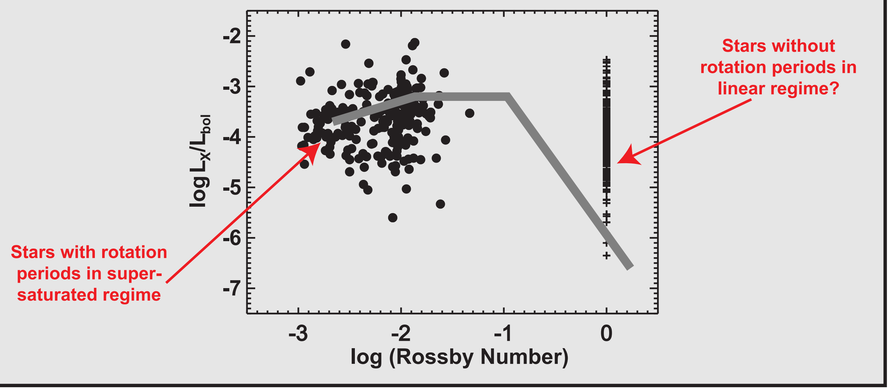
Pre main sequence stars *exhibit a very different pattern of X-ray luminosity vs. rotation period. The solid line indicates a statistically significant correlation similar to that in the super-saturated regime found in main sequence stars.*

Interpretations

Rotation: *X-ray emission from pre-main-sequence stars does know about stellar rotation. Stars with known rotation periods are biased to higher X-ray luminosities than stars for which rotation periods are not known. Evidently, only stars with large X-ray luminosities possess sufficiently large star spots to make rotation period measurements possible. The implication is that X-ray production is related to surface magnetic activity.*

Accretion: *We find no compelling evidence for time-correlated optical and X-ray variability in a sample of 800 pre-main-sequence stars. The implication is that accretion hot spots are not strong sources of X-ray emission.*

A rotation-activity relationship after all? *The Rossby numbers associated with pre-main-sequence stars, and the positive correlation observed between rotation period and X-ray luminosity, imply that stars with known rotation periods may be in the super-saturated regime of an underlying rotation-activity relationship. Might stars lacking rotation periods be very slow rotators, forming the linear regime?*

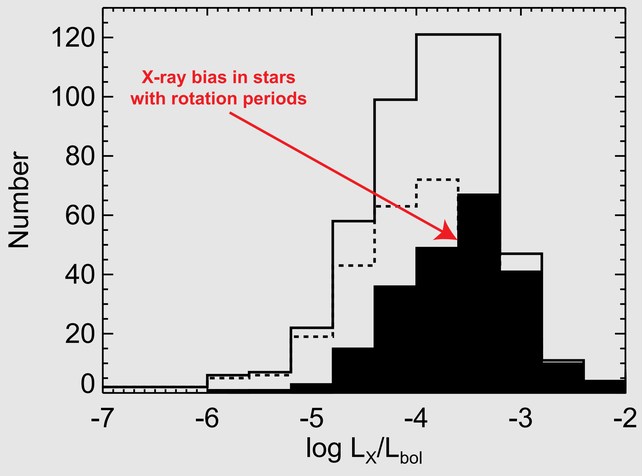


Observational Clues

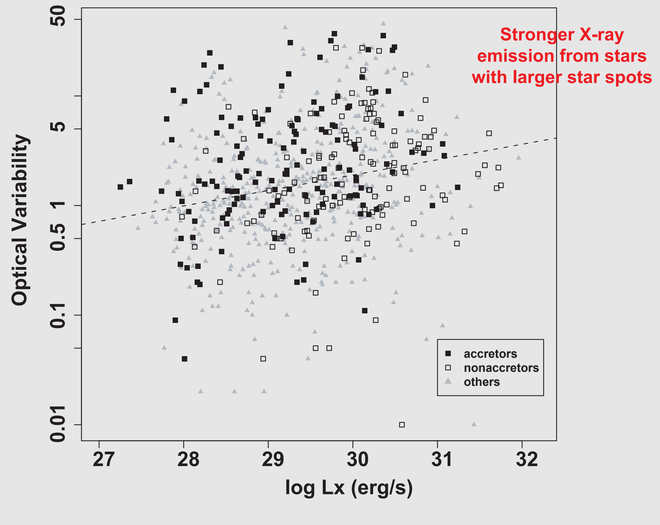
X-rays vs. Rotation Revisited:
A rotation-activity relationship after all?

We have analyzed all archival Chandra observations of pre-main-sequence stars in the Orion Nebula with rotation periods in the literature (rotation periods from optical surveys). Two key results are shown below. In both cases we can rule out selection effects/bias resulting from optical magnitude.

Finding: *Stars with rotation periods are significantly biased to high X-ray luminosities. Shown below: all stars detected in X-rays that have been searched for rotation periods (open histogram), stars yielding rotation periods (solid), stars without rotation periods (dashed).*



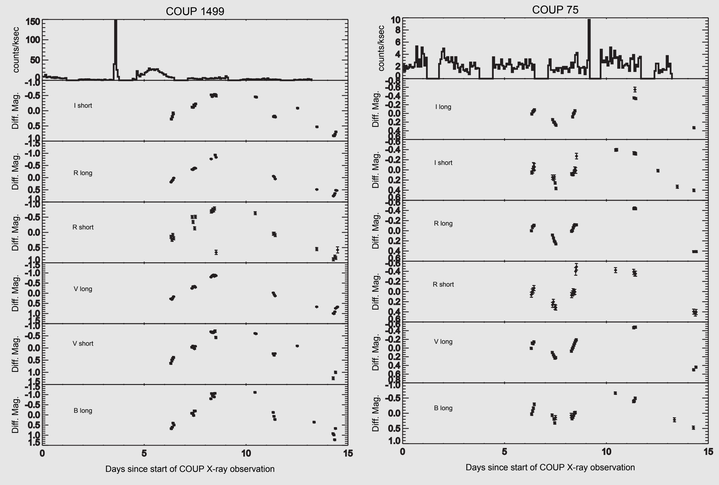
Finding: *The strongest correlation in our sample is between X-ray luminosity and optical variability (shown below). Stars with larger X-ray luminosities evidently have larger spots on their surfaces, which explains the rotation-period bias noted above. X-ray production in pre-main-sequence stars thus appears to be related to magnetic activity.*



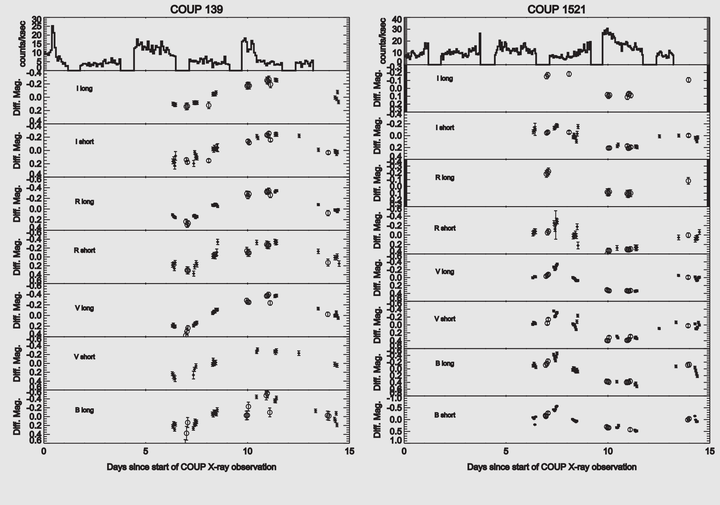
Optical vs. X-ray Variability:
X-ray production not driven by accretion?

We have obtained simultaneous X-ray and optical (BVRI) light curves of 800 pre-main-sequence stars in the Orion Nebula as part of the Chandra Orion Ultra-Deep Project, which provides an unprecedented, nearly continuous 850-ksec (10-day) X-ray exposure of the region. Optical variability is a tracer of magnetic activity and accretion activity in young stars. If a significant amount of X-rays are produced near the accretion hot spots that also give rise to optical variability, time-correlated X-ray and optical variability may be expected. Four example cases from this extensive dataset are shown below.

Finding: *The vast majority (~ 95%) of the 800 stars in our sample exhibit no time-correlated variability between their optical and X-ray light curves, whether or not they are accretors. Two typical examples are shown below.*



Finding: *A few stars do exhibit correlated or anti-correlated variability. One example of each is shown below. More detailed follow-up study of these rare cases may provide insight on coronal structures in young stars.*



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