High Energy Processes in Young Stellar Objects

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ABSTRACT

In this paper, I present background knowledge for high energy processes in Young Stellar Objects (YSO), including observation results, theoretical model. In addition, I also summarize the recent development in the field of high energy processes in YSO, especially the relationship between X-ray luminosity and rotational period.

1. Young Stellar Objects (YSO)

Pierre-Simon Laplace in his *Exposition du Systeme du Monde* (1796) for the first time gave us an idea of star forming as a gravitationally collapsing cloud. In 1945, Alfred Joy found a class of unusual emission line from variable stars near dark clouds, which later were confirmed as classical T Tauri stars. T Tauri stars have convective stellar interiors with monotonically decreasing luminosity but nearly constant surface temperatures, powered principally by gravitational contraction rather than nuclear reactions.

There were some observation breakthroughs made in the past century. Outflows from YSOs were observed with P Cygni-type profiles (Herbig 1962) and they are common in YSOs. It believed that they are powered by magnetic field induced by intervention between young star and circumstellar disk (Uchida & Shibata 1984). Circumstellar disks were also directly imaged by millimeter interferometer (Dutrey et al 1994) and Hubble Space Telescope (McCaughrean & O’dell 1996).

There are several evolutionary phases as YSOs evolves. Figure 1 illustrates the phases in subsequence: protostars, CTT stars, and weak-lined T Tauri (WTT) stars. The evolutionary phase is generally determined by SED in infrared and millimeter band.
<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>Infalling Protostar</th>
<th>Evolved Protostar</th>
<th>Classical T Tauri Star</th>
<th>Weak-lined T Tauri Star</th>
<th>Main Sequence Star</th>
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</thead>
<tbody>
<tr>
<td>Sketch</td>
<td><img src="Image" alt="Sketch" /></td>
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<td>Age (Years)</td>
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<td>$10^5$</td>
<td>$10^6 - 10^7$</td>
<td>$10^6 - 10^7$</td>
<td>$&gt; 10^7$</td>
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<tr>
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<td>Class I</td>
<td>Class II</td>
<td>Class III</td>
<td>(Class III)</td>
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<td>Thick</td>
<td>Thick</td>
<td>Thin or Non-existent</td>
<td>Possible Planetary System</td>
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<td>Strong</td>
<td>Strong</td>
<td>Weak</td>
</tr>
<tr>
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<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
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<tr>
<td>Non-Thermal Radio</td>
<td>No</td>
<td>Yes</td>
<td>No ?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Fig. 1.— Evolutionary Phase for YSOs
2. Origin of X-ray Emission in YSOs

X-ray activity in YSOs behaves in a resemblant way as those X-ray active star. It is generated by powerful magnetic field line reconnection event. However, due to the much more complicated structure and poor understanding of YSOs, it is very hard for us to make a precise prediction.

Generally, there are four possible origins for X-ray activity in YSOs (Fig 2):

1. Solar-type multiple fields with both footprints rooted in the stellar photosphere. X-ray activity is created by differential rotation and convection under the photosphere.

2. Field lines connecting the star to circumstellar disk at its corotation radius. This model is supported by rotational spindown (Edwards et al 1993), magnetically funneled accretion and collimated outflows.

3. Field lines above corotation radius. It was predicted by some models that X-ray-emitting plasmoids will be ejected from the disk by reconnection event caused by star-disk differential rotation.

4. Magnetic loops with both feet in the disk. The combination of differential rotation and convection in the disk may produce a self-amplifying magnetic dynamo in the disk.(Feigelson et al 1999)

3. Tracers of Magnetic Field

Since X-ray activity is caused by magnetic lines reconnection event, It is very important for us to understand the magnetic activity going on in the YSOs.

There are several traditional ways of measuring magnetic field. Detecting Zeeman splitting in absorption lines is one of them, but sometimes the absorption lines is faint and
confusing, which makes this method very difficult. However, success has been made and it is indicated that the fields covering a large fraction of photosphere is around 1-3 kG(Feigelson et al 1999). Monitoring photosphere spots is the other method.

In X-ray range, it is shown that YSOs X rays are optically thin thermal bremsstrahlung with associated ionized metal emission lines from multitemperature plasmas with $1 < T_x < 100MK$ (Montmerle et al 1991). Equipartition magnetic field strength is approximately $10^2$ G.

We can also trace the magnetic activity in radio-continuum. The emission mechanism is quite clearly gyrosynchrotron radiation, produced by mildly relativistic electrons with energies around 1 MeV spiraling in 1 G fields(Dulk 1985).

4. X-ray Property and Effects on Circumstellar and Interstellar Environment

Repeating imaging shows that most X-ray T Tauri stars vary on time scales of days or longer and any given moment, five to ten percent of the stars are caught in a high amplitude flare with time scales of hours(Feigelson et al 1999). The X-ray spectra show multitemperature plasma and are often modeled as a soft component with $T_x \simeq 2−5MK$ and a hard component with $T_x \simeq 15−30MK$, although weak emission at higher temperature may be present(Preibisch 1997).

There are a number of correlations between X-ray and other stellar properties. For example, X-ray luminosity is proportional to bolometric luminosity. What’s more, $L_x$ is also correlated with stellar mass, photospheric temperature, stellar radius and rotation(Feigelson 1993).

X-ray activity affects its ambient environment in many ways such as changing ionization rate, heating, modification of gas chemistry and dust grain composition. X-ray ionization of
a fraction of the primarily molecular gas within and around YSOs is particularly important because of its role in coupling gas and magnetic fields. YSO X-rays penetrate to some distance towards the midplane in the inner disk, whereas they reach all disk material in the outer disk. The inner disk thus has a midplane neutral dead zone surrounded by an ionized zone (Gammie 1996).

5. $L_x - P_{rot}$ Relationship

For those X-ray active main sequence star, there is a general trend of increasing X-ray activity with decreasing rotational period. However, in Chandra Orion Ultra-deep Project (COUP), the YSOs revealed in the survey don’t quite follow $L_x - P_{rot}$ relationship. Instead of an anti-correlation between X-ray activity and $P_{rot}$, those YSOs shows positive slope in data fitting, $\log(\frac{L_x}{L_{bol}}) = -4.21(\pm0.07) + 1.27(\pm0.09)\log(P_{rot}[days])$ (Feigelson & Babu 1992).

Despite of a correlation between X-ray activity and $P_{rot}$, there is a very large scatter in the relationship, which has a standard deviation of 0.7 dex (Preibisch et al 2005) compared with 0.5 dex (Pizzolato et al 2003).

Short term and long term variability can only account for $0.4 \sim 0.5$ dex scatter, the remaining scatter can be explained by the large scatter in the relationship between $L_x$ and $L_{bol}$ for those accreting YSOs.

6. Conclusions

High energy processes are prevalent in low mass YSOs. If X-ray emission begins in the earliest Class 0 phase, then YSO ionization may crucially affect the gravitational collapse
of star formation.

X-ray emission is prevalent in the Class I-II phases, X-ray ionization is quite likely to play a central role in the astrophysics and evolution of the circumstellar disk.

$L_x$ and $F_x$ are anti-correlated with $P_{rot}$, but $L_x/L_*$ is correlated or has no dependence on $P_{rot}$. The scattering in $L_x - P_{rot}$ relationship for young stars is an combining force of X-ray variability and accreting TTSs. Relative lower $L_x/L_*$ for accreting TTSs is due to the fact that magnetic reconnection cannot heat up dense plasma in mass-loaded accretion region.
Fig. 2.— Four different mechanism inducing X-ray activity in YSOs
Fig. 3.— Spectral energy distribution of Bremsstrahlung Radiation
REFERENCES


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