EX Lup Outburst in 2008

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- multiple spectral components in CO
- how they develop with time
- origin of disk instability
## EX Lup - prototype EXors


<table>
<thead>
<tr>
<th></th>
<th>FUors</th>
<th>EXors</th>
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</thead>
<tbody>
<tr>
<td>Outburst duration [yr]</td>
<td>&gt;10</td>
<td>~1</td>
</tr>
<tr>
<td>Outburst recurrence [yr]</td>
<td>&gt;200</td>
<td>5–10</td>
</tr>
<tr>
<td>Mass accreted during an outburst [$M_\odot$]</td>
<td>&gt;$10^{-3}$</td>
<td>$10^{-6}–10^{-5}$</td>
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<tr>
<td>Magnitude variation [optical mag]</td>
<td>4–6</td>
<td>2–5</td>
</tr>
<tr>
<td>Accretion luminosity [$L_\odot$]</td>
<td>few $10^{2}$</td>
<td>&gt;25</td>
</tr>
<tr>
<td>Outburst accretion rate [$M_\odot$ yr$^{-1}$]</td>
<td>$10^{-4}$</td>
<td>$10^{-6}–10^{-5}$</td>
</tr>
<tr>
<td>Envelope infall rate [$M_\odot$ yr$^{-1}$]</td>
<td>$5 \times 10^{-6}$</td>
<td>$10^{-7}–10^{-6}$</td>
</tr>
<tr>
<td>Wind velocity [km s$^{-1}$]</td>
<td>&gt;300</td>
<td>200–400</td>
</tr>
<tr>
<td>Mass loss rate [$M_\odot$ yr$^{-1}$]</td>
<td>$10^{-6}–10^{-5}$</td>
<td>$10^{-8}–10^{-6}$</td>
</tr>
<tr>
<td>Spectral features</td>
<td>absorption spectrum</td>
<td>emission line spectrum,</td>
</tr>
<tr>
<td></td>
<td>F/G-type supergiant like</td>
<td>T Tauri like, H$\alpha$ inverse P Cyg</td>
</tr>
<tr>
<td></td>
<td>deep CO absorption</td>
<td>CO abs./em., B$_r$ y emission</td>
</tr>
</tbody>
</table>

(observationally) small brother of FUor
(FU Ori variables)

Sipos et al. 2009, A&A
Where is outburst?

- Close to stellar surface - Herbig
  - Herbig 1989 ESO proceeding
  - expanding stellar shell?
  - cool spots on fast rotating star?

- Disk origin - Hartmann (FUors)
  - cool spots on fast rotating star?

- cool spots on fast rotating star?

- thermal instability *
Disk origin, for sure?

V1057 Cyg I 6173


double peak line interval - FUors
- cooler outer region rotates slower


Fair amount of chance it is “photospheric”
Outburst in 2008
largest in its record

- CRIRES, IRCS
- 6 epochs
- Apr-Aug 2008

R=100,000, R=20,000
dv=3 km/s, 15 km/s)
4.65-4.99 um  v=1-0 P(1)-P(32)

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Outburst in 2008
courtesy A. F. Jones

Goto et al. in prep.
Two gas components

**Outburst**
- decays fast
- broad (200 km/s)

**Quiescence**
- constant
- narrow (60 km/s)
Slab model

Outburst
- 0.03-0.2 AU
- $T_v=1500-3000K$

Quiescence
- 0.3 AU
- $T_v < 2000K$

transition zone
Outburst sets off at 0.2 AU

- evolves fast
- Inner disk cut off from outer disk there

- outer disk stays put
- outer disk only passively heated afterward

- wind seen in absorption
- inner disk drained to the star
what transition zone means?

- unseen companion
- protoplanetary cores

{ does not explain }
Thermal instability

- partially ionized disk

\[ T_{\text{disk}} \uparrow \quad T_V \downarrow \quad Q_{\text{viscous}} = Q_{\text{cooling}} \]

\[ T_{\text{disk}} \uparrow \quad T_V \uparrow \quad H^- \text{ opacity} \]

→ run-away local heating

- starts inner edge of the disk
- either internally or externally triggered
Thermal instability transition zone \(~0.1\) AU

- proceed inside out
- turned off at \(R_{\text{limit}}\)

Disk in motion picture

- Double peak
  - asymmetric
  - changes by epoch

- Hot spot
  - period is consistent

spiral onto the star

- Trigger?

**EX Lup outburst**
- CO vibrational band at 4.7 um
- 6 epochs from outburst to quiescent phase

**3 components**
- outburst (fast, hot, short-lived)
- quiescence (slow, cool, constant)
- wind

**Transition zone**
- at 0.2 AU
- massive accretion only within

**Hot spot**
- inhomogeneous accretion