Pre-Main Sequence Binaries

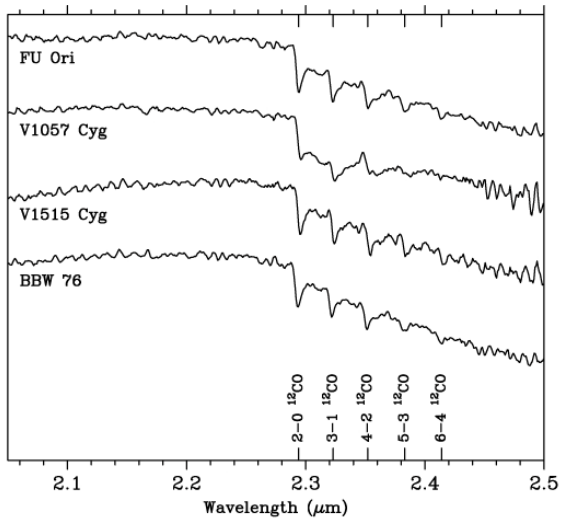
Statistics and Dynamical Evolution II

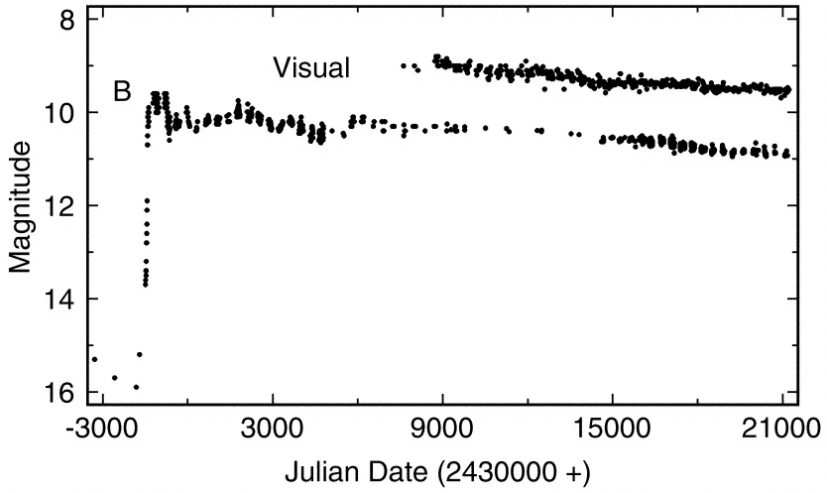
Bo Reipurth
University of Hawaii

The Youngest Binaries

- In his presentation, Mike Connelley has derived the first accurate determinations of binarity among Class I sources

- I will here try to connect the binarity of the youngest stars to other youthful phenomena such as HH jets and FU Orionis eruptions





FUor Eruptions

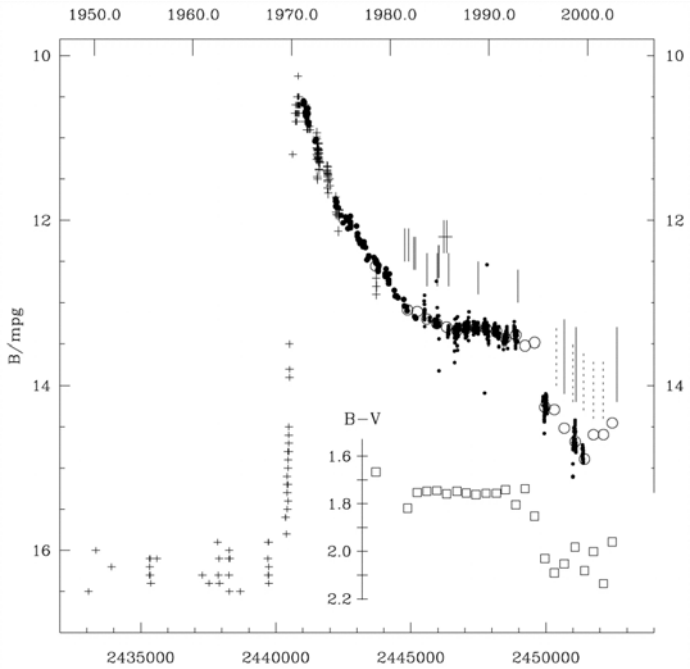
- FUors are eruptive variables in star forming regions, brightening by 5-6 mag
- They have F- or G-type supergiant spectra without emission lines (Herbig 1977).
- In the near-IR they have strong broad CO bandheads in absorption (Reipurth & Aspin 1997).
- Only about a dozen FUors or FUor-like objects are known.
- FUor events are likely to be repetitive, but too few are known for good statistics

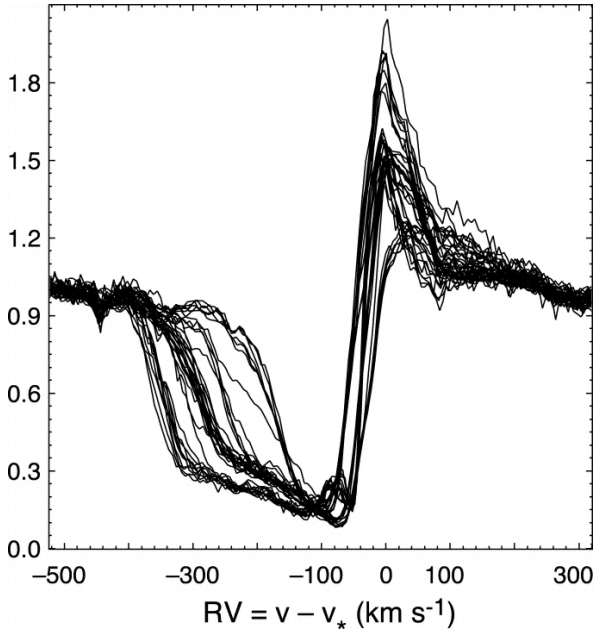
Decay Times and Activity

- The two best studied FUors are FU Orionis itself, which erupted in 1936, and V1057 Cyg, which exploded in 1970.

- The two objects have similar amplitudes, but whereas FU Ori is still near maximum light, V1057 Cyg has decayed dramatically, as seen in the lightcurve here.

- Even near minimum, V1057 Cyg has extreme mass loss, with dramatic P Cygni profiles that is highly variable. The figure shows spectra between 1996 and 2001, from Herbig et al. (2001).





Herbig et al. 2001

Triggering Mechanisms

- Several triggering mechanisms have been proposed:

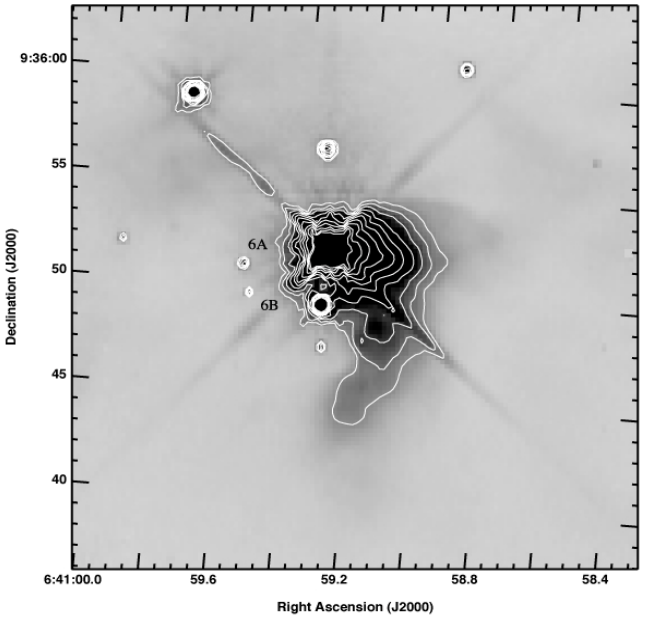
[1] A throttle mechanism in which the accretion rate through a disk varies around the more stable infall rate from an envelope (Hartmann & Kenyon 1996)

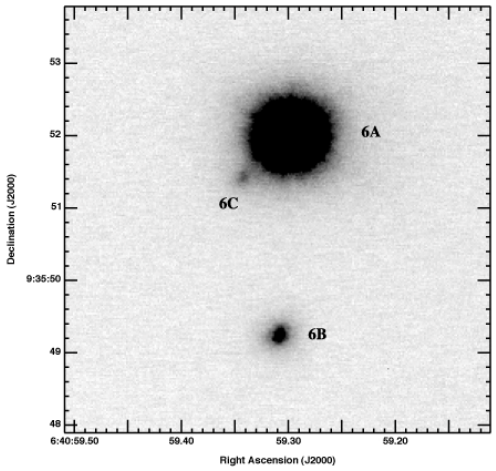
[2] A large-scale thermal ionization instability may affect the disk and lead to occasional emptying-out of the inner disk regions (Bell & Lin 1994)

[3] A companion star on an elliptical orbit may perturb the inner disk regions during periastron passage (Bonnell & Bastien 1992)

Binary FUors

- Several FUors have companions, including the famous Z CMa and L1551 IRS5.
- In two cases, both components in a binary are known to be FUors: RNO 1B/C (Kenyon et al. 1993) and AR6A/B (Aspin & Reipurth 2003).
- Given the rarity of FUors, this would be extremely unlikely if the events were not related, i.e., whatever triggered the eruption in one should be connected to what triggered the eruption in the other.
- The separations of the above FUor pairs are so large that it would take several thousand years from a periastron passage to reach their present locations. FUor eruptions probably do not last that long.

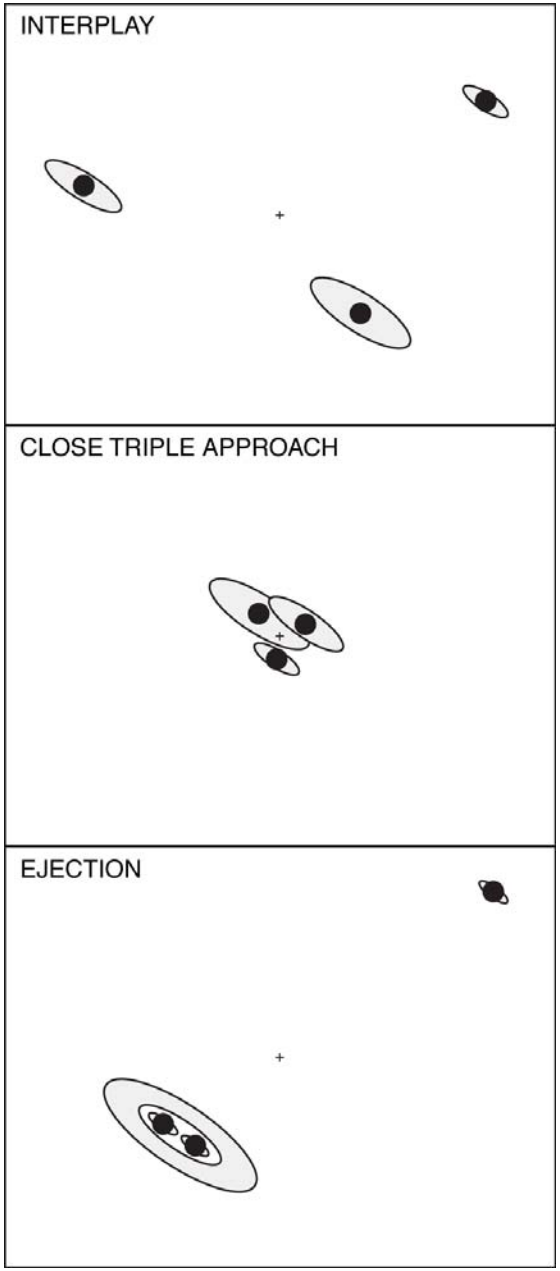




The Disintegration of Multiple Systems

- Newborn multiple systems decay on time scales of tens of thousands of years from a non-hierarchical to a hierarchical configuration.

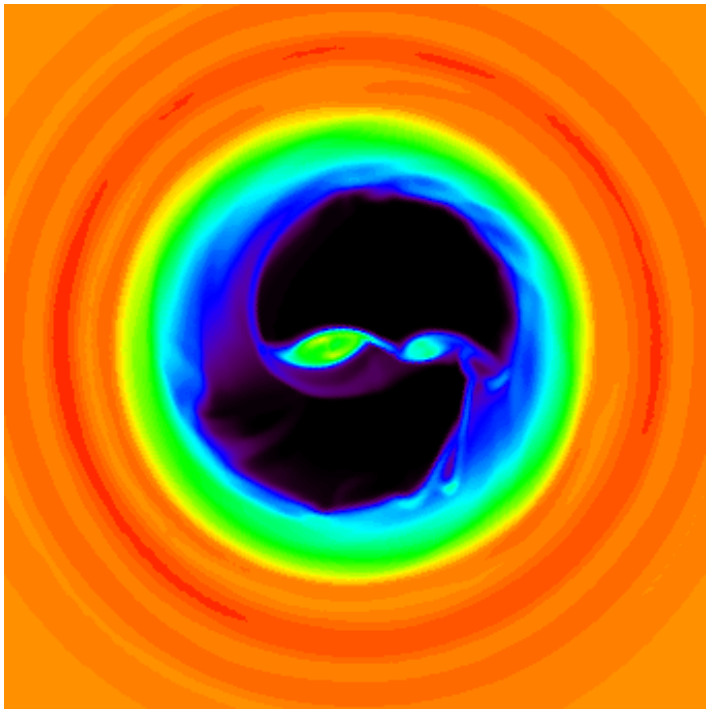
QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.



Courtesy of Michael Sterzik

Orbital Evolution of Newly Bound Binaries

- An ejection will in some cases lead to a bound system and sometimes to an escape.
- A quadruple non-hierarchical system will often break up into two binary systems, which sometimes detach from each other, and sometimes form a bound hierarchical quadruple system.
- The dynamic evolution is a stochastic process that cannot be predicted, only studied statistically.
- In the process of being bound, such newly formed binaries will have highly eccentric orbits (e~0.9).
- These newborn binaries will evolve with significant viscous interactions, and as a result start to spiral together.



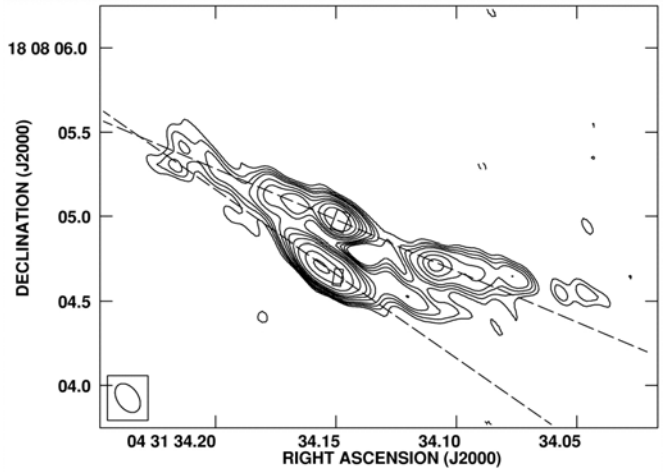
Courtesy P. Artymowicz

Herbig-Haro Jets and FUors

- As the components spiral towards each other on highly eccentric orbits, they trigger disturbances at periastron leading to increased accretion and outflow, eventually forming the highly collimated Herbig-Haro jets.

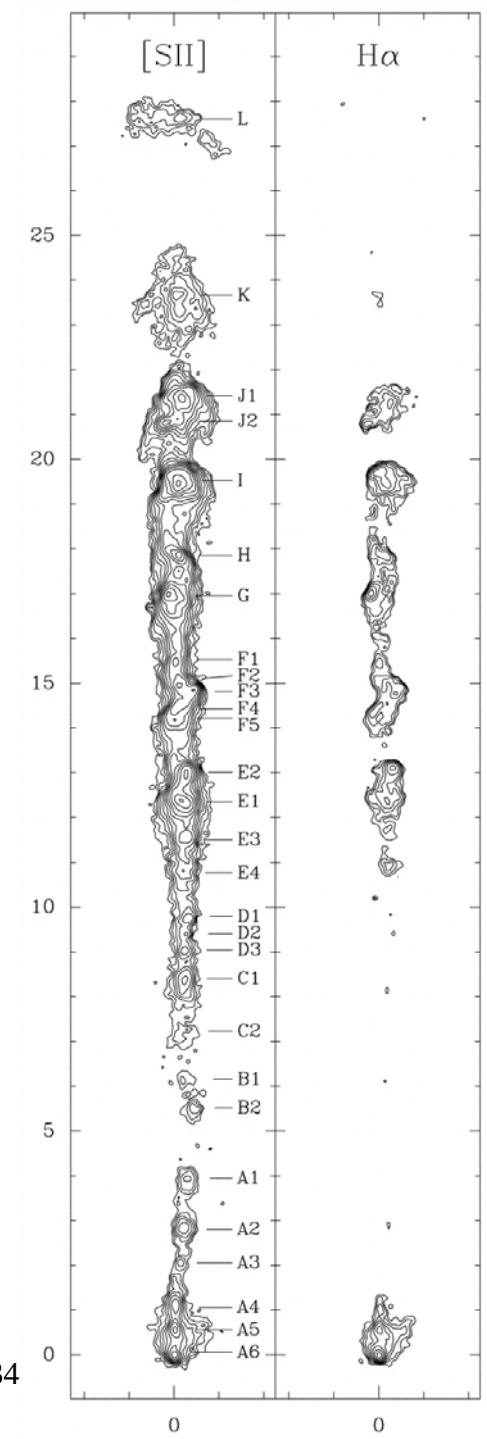
- Eventually they get so close (<10AU or so) that they disturb the inner regions where magnetic fields are anchored, and the stars lose the ability to produce jets, even though they still have major mass loss events.

- The final periastron passages before the individual stellar disks are converted to a circumbinary disk will appear as major accretion events, i.e. as FUors.



L1551 IRS5

In this picture, FUors occur right after the period of jet formation. Some FUors like L1551 IRS5 still drive small jets.



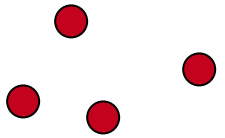
HH 34

Binary FUors and the Time Scale Problem

- The key to the disintegrating multiple star scenario is that it can solve the time scale problem: how does it happen that two stars next to each other can both turn into FUors but being too far apart to affect each other?

- The solution is that FUor pairs are really quadruple systems which transformed from an unstable non-hierarchical configuration to an orderly hierarchical configuration.

- The quadruple then evolves slowly through viscous interactions until the components are so close that they erupt in FUor outbursts at about the same time.



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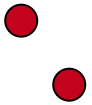

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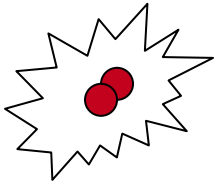

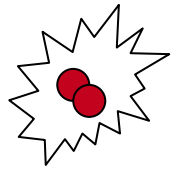

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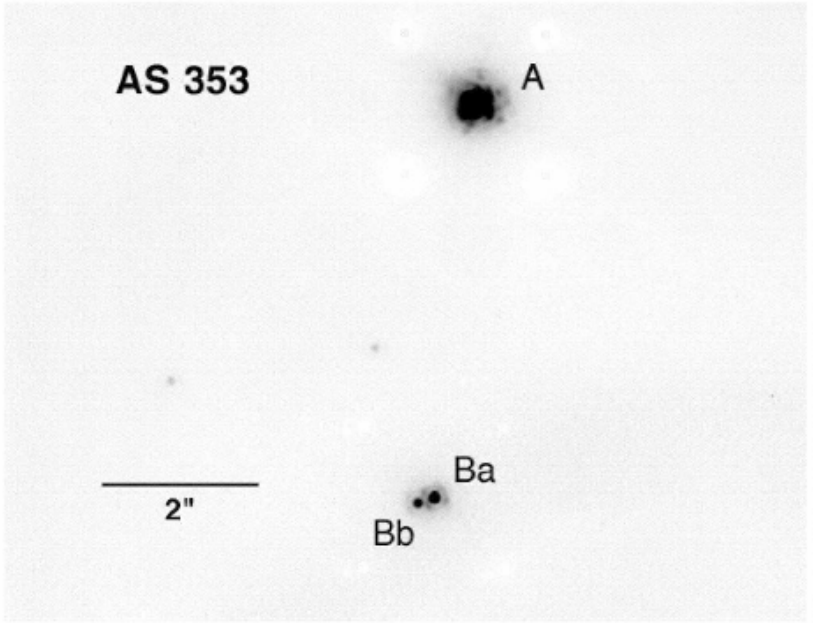
The Jet Source AS353A

- The HH 32 jet is driven by the young binary star AS353 A & B
- We observed this binary with Subaru and AO, and found that component B is an 0.3” binary (Tokunaga et al. 2004).
- Component A is unresolved, but should be a ~0.1” binary in order to produce the observed jet. It is a prime candidate to undergo a FUor eruption.



Dynamical Interactions in Pre-Main Sequence Evolution

Dynamical interactions between multiple components and their stochastic nature are essential for understanding a variety of phenomena in early stellar evolution:

1 - FUor outbursts

2 - The formation of brown dwarfs and the shape of the low-mass IMF

3 - The jet phenomenon

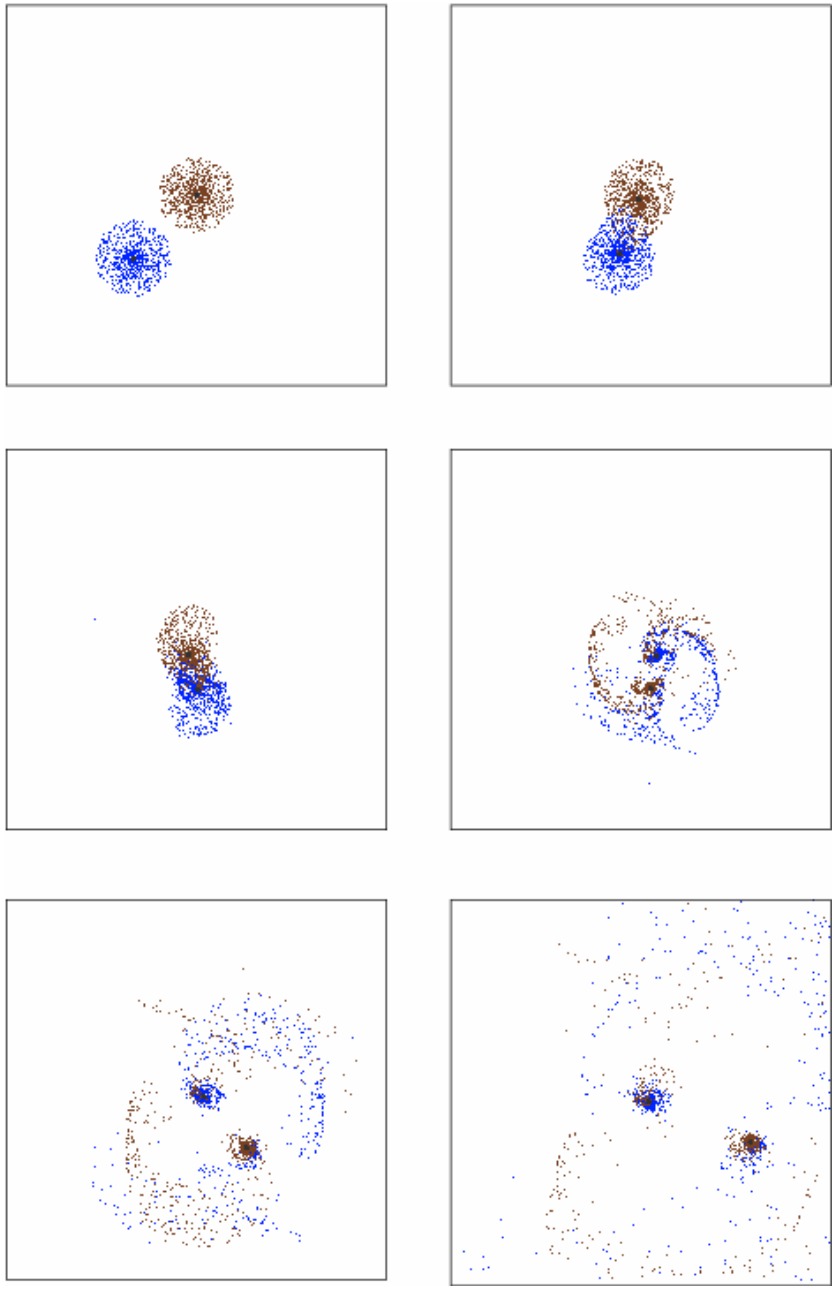
4 - The diversity of disk properties in CTTS and WTTS

5 - The binary separation distribution function

Attempting to understand star formation through the birth of single stars is no longer a sufficient approach

Simulations of Disk-Disk Encounters

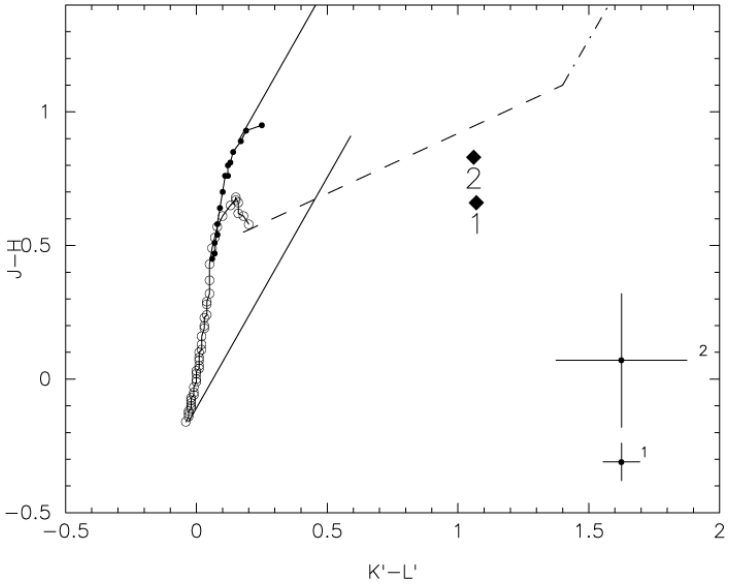
- Pfalzner and collaborators have explored the encounters of two stars with disks using SPH simulations.
- In the present simulation, a 1 Msun star with a disk with 50 AU radius moves past a similar object with a velocity of 10 km/sec in a grazing collision. The encounter generates strong spiral structures and leads to severe disk disturbance and truncation of the outer disk regions.

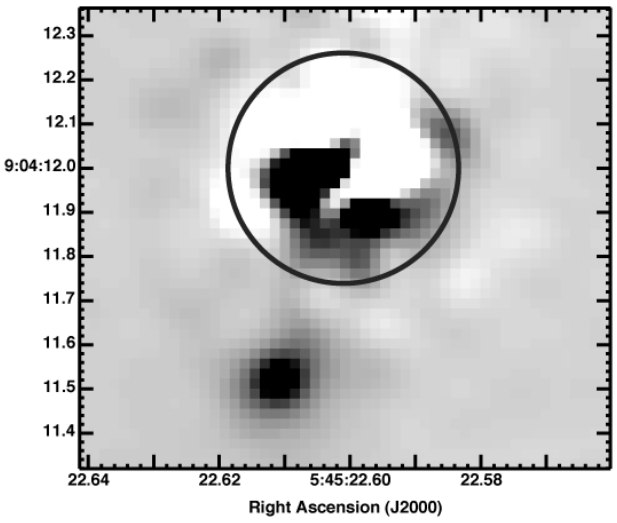


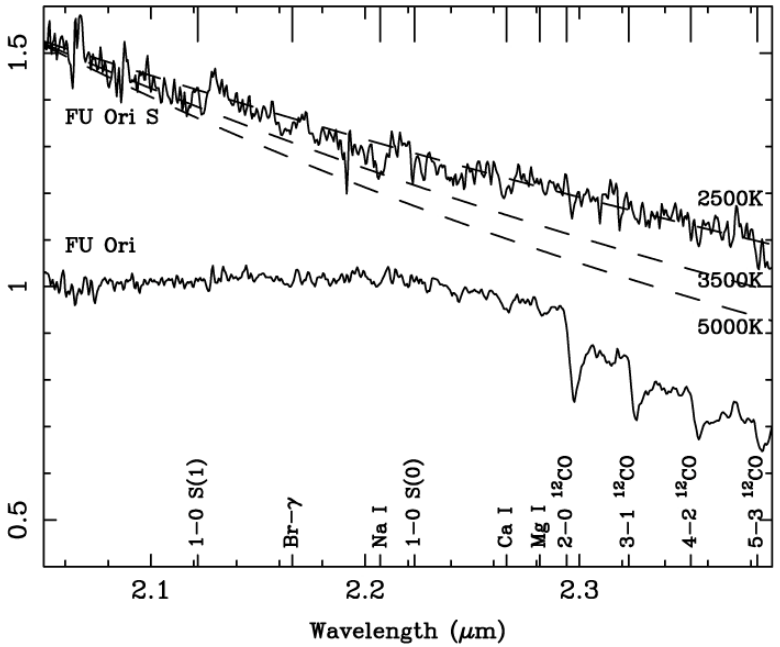
Pfalzner, Henning, Kley 2000

The Companion to FU Orionis

- Wang et al. (2004) discovered a star 0.5” (230AU) from FU Ori and suggested it could be a companion.
- We used Subaru to do photometry and spectroscopy and indeed found the new companion to be a pre-main sequence star, most likely a K-type star with IR excess (Reipurth & Aspin 2004)







Is the FU Ori Companion related to the Eruption?

- If the companion was ejected in 1936 when FU Ori erupted, then it must have a tangential velocity of 15 km/sec. This is highly unlikely, since we do not see T Tauri stars zooming around in star forming regions.

- But the companion could have been ejected a few thousand years ago. FU Ori must in this picture be a close binary with a separation of roughly 10 AU, i.e. the system should be a triple. In the intervening years the newborn binary has had time to spiral together, reaching now the period of FUor outbursts.

- We should be able to detect this close binary spectroscopically, since the mean velocity would be around 5 km/sec. However, in a highly eccentric orbit almost all the velocity change occurs near periastron, which took place in 1936. Currently little velocity variability is expected.

Do All Stars go through a FUor Phase?

- Herbig, Petrov, & Duemmler (2003) have suggested that FUor events may take place only in a subset of all T Tauri stars.
- This would naturally be the case if only those stars that eventually become spectroscopic binaries have outbursts.
- Studies of metal-poor field stars, for which statistics are particularly good, indicate that 18+-4% are spectroscopic binaries (Carney et al. 2003)
- Although fewer stars may undergo FUor eruptions in this picture, each of them may undergo several or many eruptions.
- FUors are signposts of the formation of spectroscopic binaries.

What Next?

- We are now planning a major study of all FUor and FUor-like objects, to look for companions.
- The first object studied, a new FUor candidate known as HBC 515, turned out to be a 0.5” binary based on Subaru AO observations.
- A detailed spectroscopic analysis of multi-epoch high resolution spectra is underway (Reipurth, Herbig, & Aspin 2006).
- If the binary triggering mechanism is correct, then we should expect to find numerous binaries or triples among the FUors.