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The magnetic obliquities of accreting T Tauri stars

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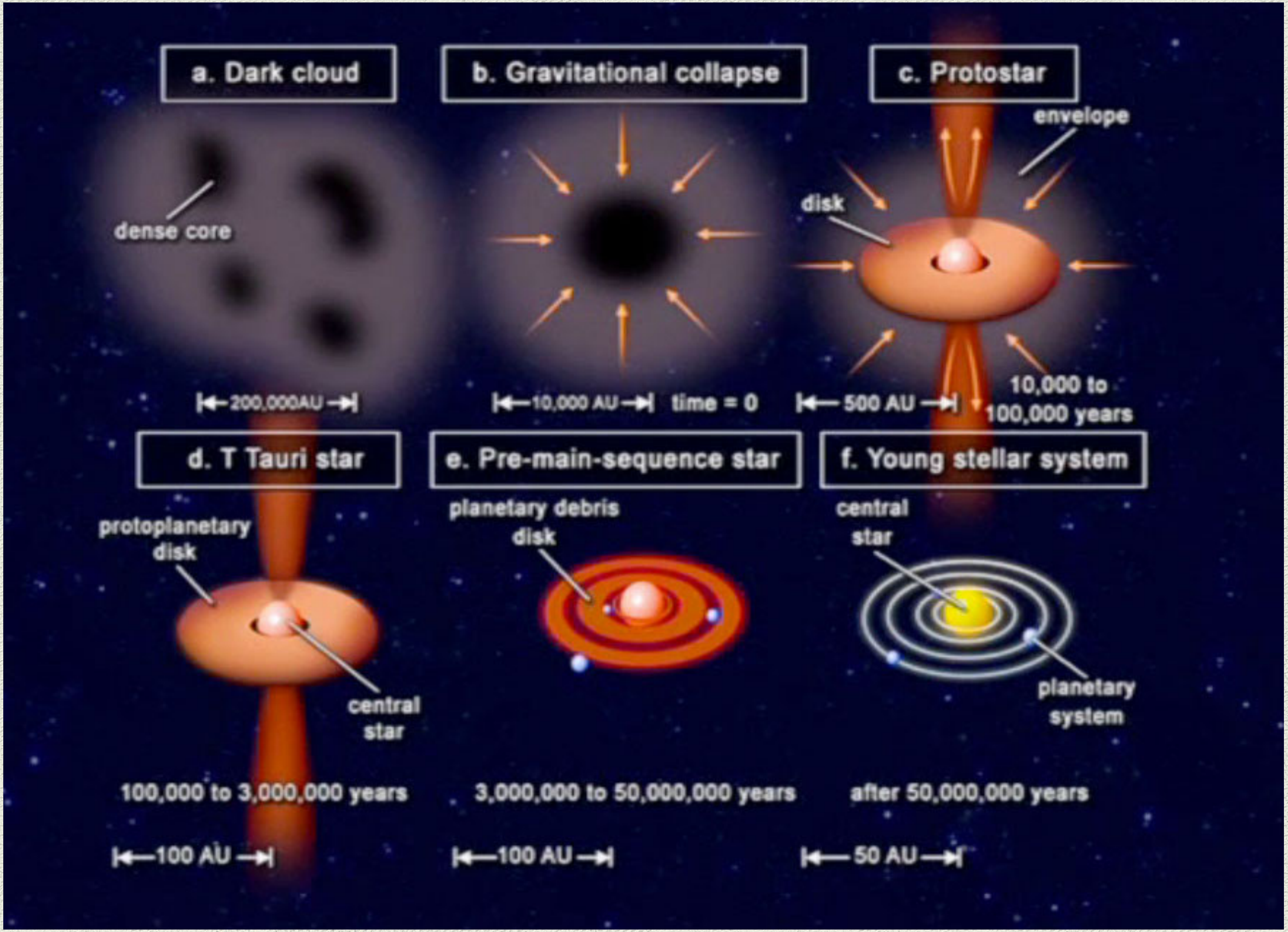
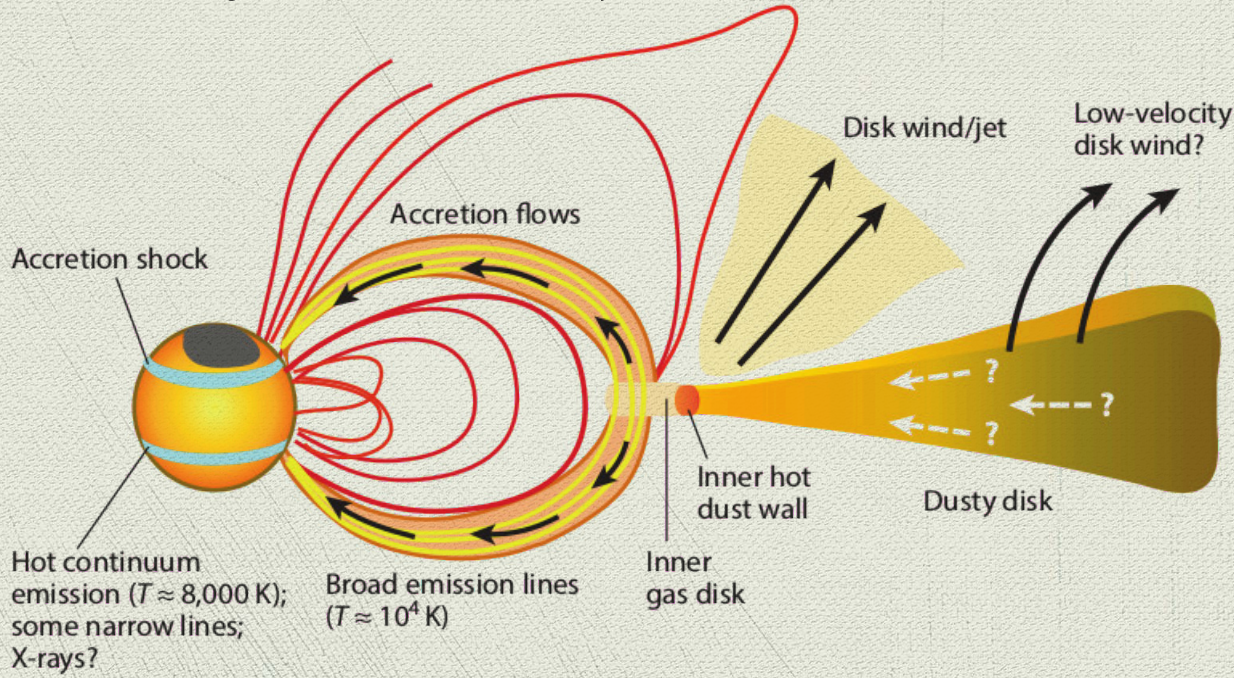
Introduction:



The formation of a low mass star begins with the gravitational collapse of a dense core within a Giant Molecular Cloud.
(1AU = distance between Sun and Earth)

After ~1Myr it is called a **T Tauri star**, characterized by a forming star undergoing gravitational contraction, surrounded by a disk of gas and dust from which matter accretes onto the star. The inner part of the accretion disk interacts with the strong stellar magnetic fields (~1kG) and the process of accretion of matter from the disk to the star is then guided by the magnetic field (see below). This interaction can also lead to the launching of winds and jets.



(Figure from Hartmann et al. 2016)

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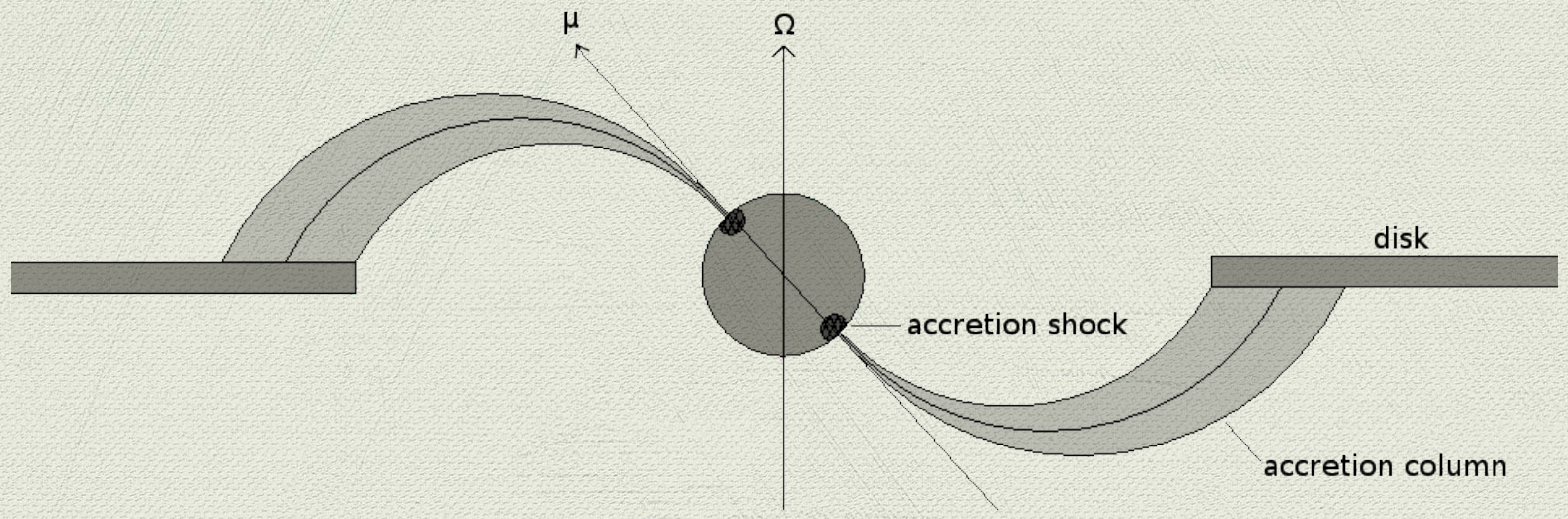


The **magnetic obliquity** is the angle of misalignment between the axis of the stellar magnetic field (μ) and the stellar rotation axis (Ω). This misalignment strongly affects the geometry of the accretion flow and can lead to the formation of warps in the inner accretion disk.

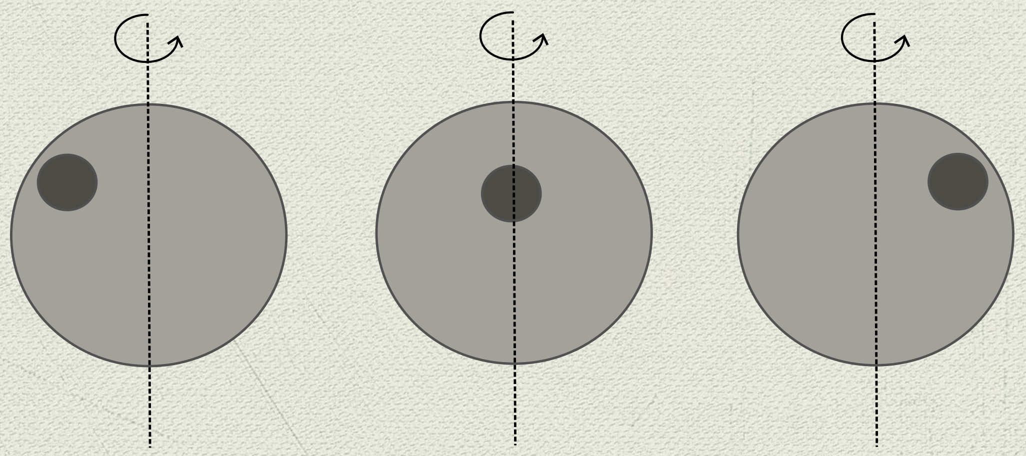
To better understand the role of the magnetic obliquity in star formation, we need to measure it for a large number of T Tauri stars, then perform a statistical study in search of correlations between it and different parameters of the star/disk/accretion.

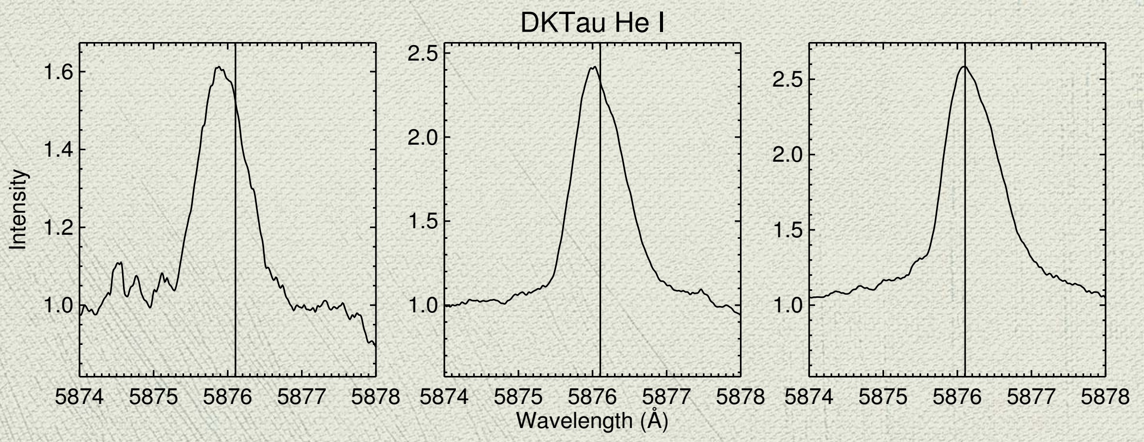
One way to measure the magnetic obliquity is from the He I emission line, which is formed in the accretion shock — the region where the accreting material impacts the stellar surface. These shocks are formed very close to the star's magnetic poles, so by measuring their location on the star we can infer the magnetic obliquities.

As the star rotates, the accretion shock at times moves towards our line-of-sight and at times moves away from our line-of-sight, leading to Doppler shifts in the radial velocity of the He I line. The amplitude of this shift ($\Delta V_{rad}(HeI)$) is related to the latitude (l) of the hot spot via the relation:

$$\Delta V_{rad}(HeI) = 2\ v \sin i \cos l$$

where $v \sin i$ is the star's rotational velocity projected in our line-of-sight (this can be measured directly in the spectrum).





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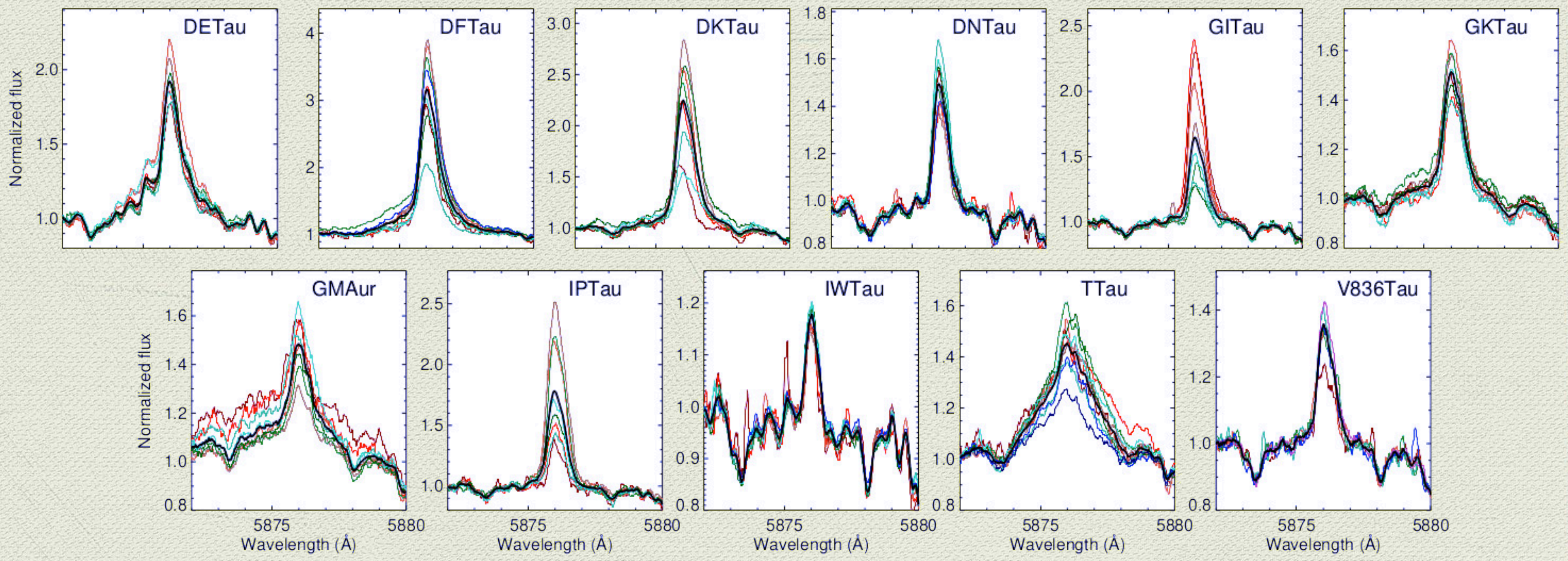
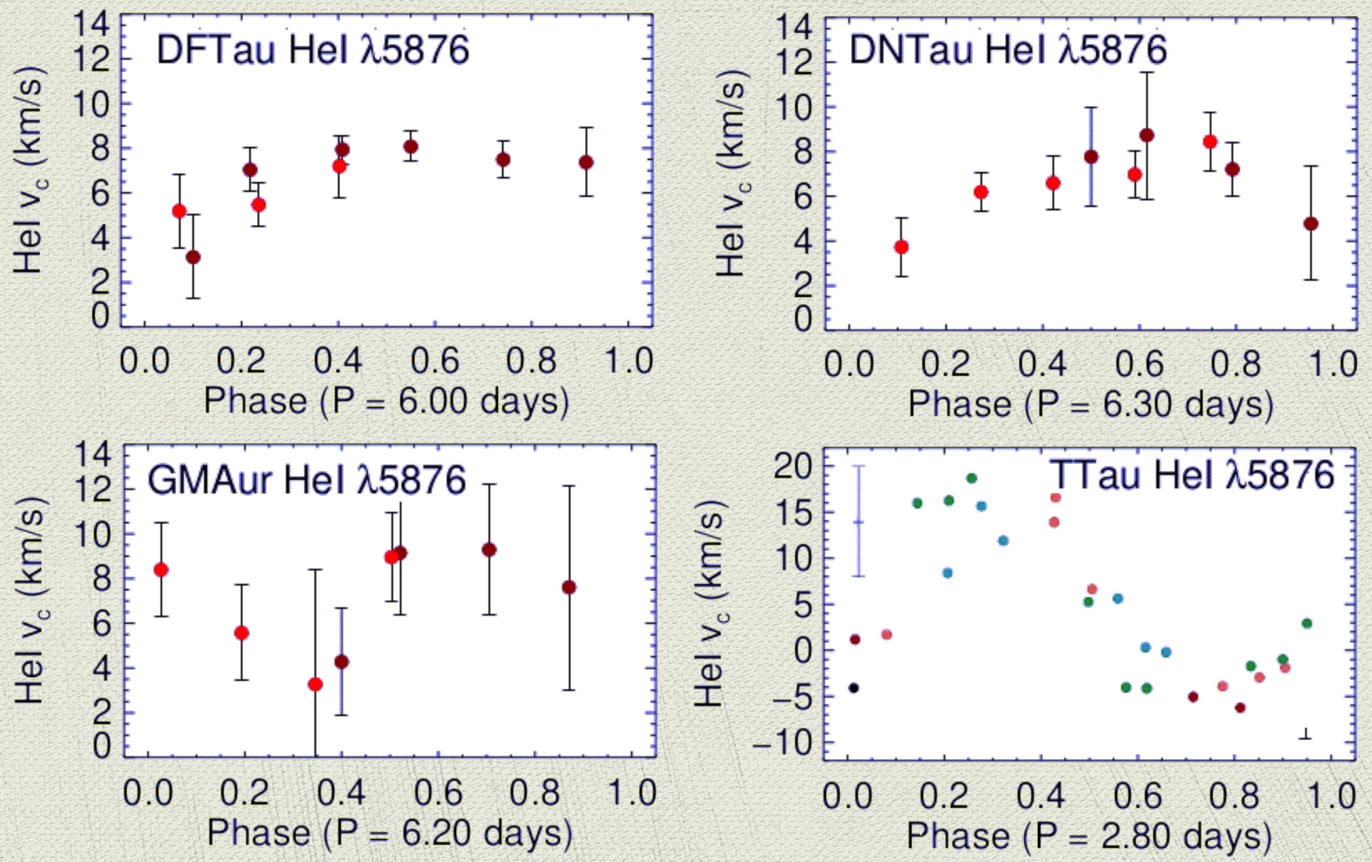
Observations:

11 T Tauri stars were observed over ~8 nights with the SOPHIE high-resolution spectrograph (in France)

Their He I line profiles (shown on the right) show strong variability in intensity, as well as in radial velocity.



Results:



The plots to the left show 4 examples of how the radial velocity of the He I line varies over the stellar rotation cycle. We use the amplitudes of this variation to infer the magnetic obliquities (table on the right).

This sample of 11 T Tauri stars presents relatively small magnetic obliquities (at most 23 degrees), meaning that their magnetic fields are not strongly misaligned with the stellar rotation axis.

Star	Θ (°)
DETau	6^{+11}_{-6}
DFTau	15 ± 10
DKTau	18^{+8}_{-7}
DNTau	13^{+11}_{-10}
GITau	12 ± 9
GKTau	5^{+7}_{-5}
GMAur	13^{+16}_{-13}
IPTau	7^{+12}_{-7}
IWTau	6^{+14}_{-6}
TTau	23^{+11}_{-10}
V836Tau	10^{+12}_{-10}

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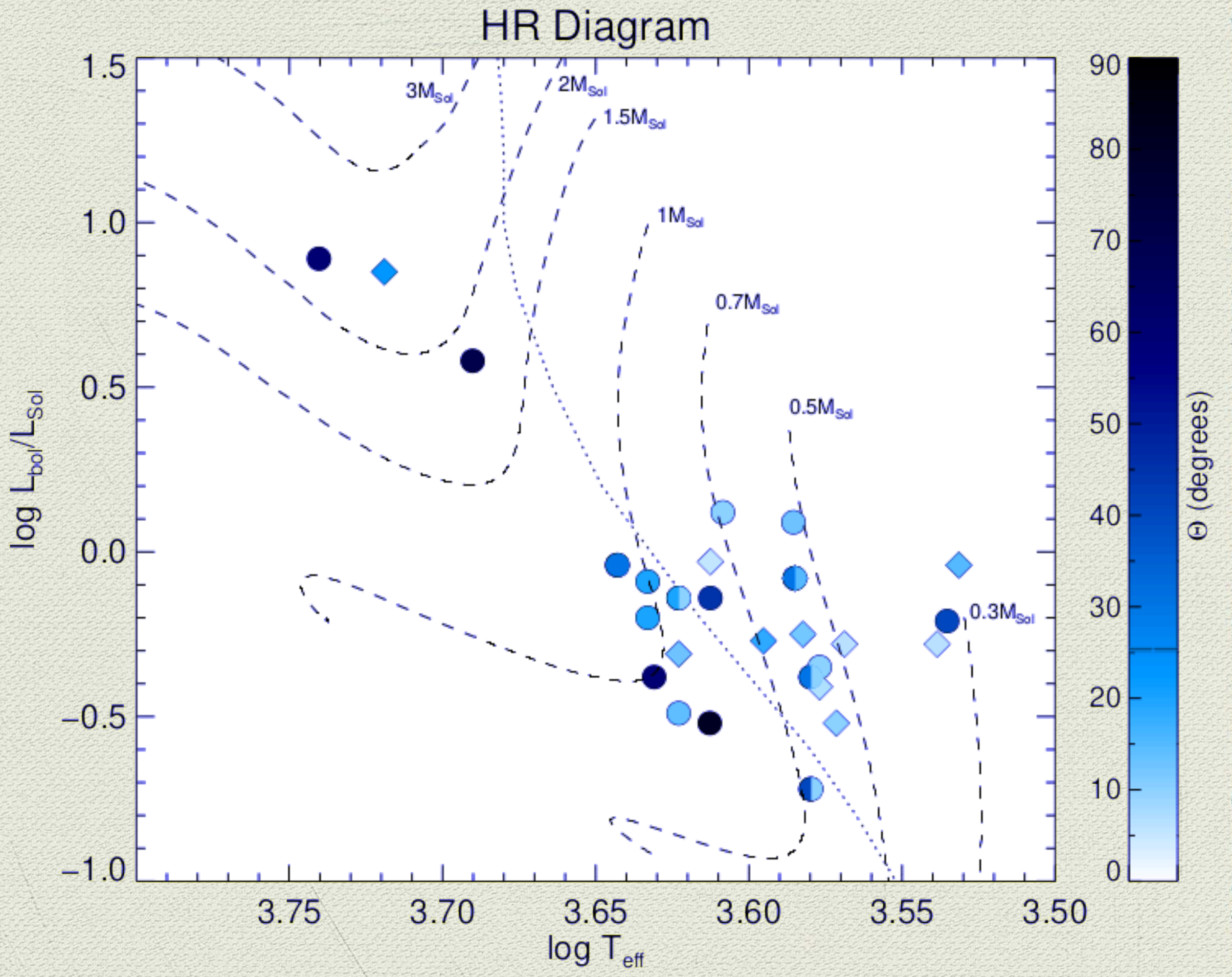
Discussion:

Other studies in the literature show that large magnetic obliquities ($\geq 40°$) are not uncommon among accreting T Tauri stars. Joining our sample with these data, we plot an HR diagram (a plot of luminosity versus temperature), with our sample in diamonds and the sample from the literature in circles, and with a color gradient representing the magnetic obliquity measured for that star. Stellar evolutionary models from Tognelli et al. (2011) are plotted as dashed lines, showing the theoretical temporal evolution for stars of different masses. The dotted line represents the point at which a star will begin to develop a radiative core and no longer be fully convective.

We can see a tentative trend between the magnetic obliquity and the position of a star on the HR diagram, indicating that there may be a significant difference between the magnetic obliquities of stars that are fully convective and those that have developed a radiative core.



Conclusion:

The sample studied here shows small magnetic obliquities, in slight disagreement with other studies from the literature. This may reflect a possible trend between the magnetic obliquity and the interior structure of a star, in which stars that are fully convective seem to have smaller magnetic obliquities than those with a radiative core.

Results published in: McGinnis, P., Bouvier, J. & Gallet, F. 2020 MNRAS, 497, 2142