Annotated Bibliography Template – ASTR 341

Goals

- What is your purpose in reading this paper? Based on the title, what might you be able to learn from it and how might that knowledge help you with your project?
Answer: This gives a good overview of the stuff we are going to be looking at this semester in Astro 341. It is a review paper so it will be dense and *thorough.* I anticipate to be learning about the rotation of YSOs and the kind of data we can take, the science we can do and why it is valuable.

- Do you have any specific questions you want to answer?
For example: "I want to know if M-dwarfs and brown dwarfs form in different ways", or "I want to understand whether the observations in this paper are similar to what I'm doing".
Answer: I'd like to understand why the rotation rates of brown dwarfs contain valuable information. And why their rotational periods are so short.

Abstract/Summary

The abstract will usually provide complete clarification of the title and describe the essence of this study.

- What new questions does the abstract pose to you, if any?
Answer: What does specific angular momentum mean? Is it per unit mass like specific star formation? Why is it the radii for YSOs are "poorly known?" Is it an issue of resolution? Does the mass/rotation relation only have to do with classical angular momentum conservation or are there other things at play here? What is ZAMS?

Introduction

Read through the introduction, then answer the following. It should outline what work has been done prior to this paper to set the stage/answer big outstanding questions in the field.

- What is the overall importance of this research?
Answer: This research is important in order to fill in a gap of our knowledge when it comes to stellar evolution. What is happening at these YSO phases of stars? How does a star like the sun evolve onto the main sequence? How is it that planets form around stellar systems? In the discussion and contemplation of the history of the universe the early stages of stellar evolution are critical information if we want to continue to move up the hierarchy of structure in the universe.

- What are the authors doing in this paper?
Answer: The authors are reviewing the "current understanding" of a variety of relations between rotation and YSOs. It is a review paper, so it is trying to convey

the information that we have from this field and consolidate it into one document for the community working on this kind of science to refer to and digest.

Use textbook or internet to get more information about **three** unfamiliar terms/concepts from the introduction:

- Topic 1: The angular momentum problem of star formation
    - http://www.mpia.de/homes/mordasini/slidesws1123/L2starformation.pdf
    - "Angular momentum is an enemy of star formation. To form a star, a gas cloud must get rid of a large amount of angular momentum…If angular momentum is conserved, the cloud must rotate 10-8 times slower than young stars. The latter typically rotate with 50-200 km/s which implies a cloud rotation speed of 0.05 to 0.1 cm/s i.e. mm/s!"
    - Also refer to Bodenheimer 1995
- Topic 2: T-Tauri Stars
    - http://astronomy.swin.edu.au/cosmos/T/T+Tauri+Stars
    - There is a star called T-Tauri itself
        - The rest are named for this star
    - Variable stars. T-Tauri is a binary system with a much fainter companion
    - NO FUSION. Radiation coming from gravitational compression (?)
- Topic 3: Jets
    - http://astronomy.swin.edu.au/cosmos/S/Stellar+Jets
    - Reasonable mechanism for angular momentum loss.
    - Due to the accretion of material onto the object
    - Rate of expulsion can increase or decrease depending on the accretion material. If there are 'bullets' of accreting material, then we see a sudden increase in the outflow.
    - These Jets appear to be coming out of the magnetic poles of the object

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Figures, Graphs and Tables

Read through all of the figures/graphs/tables and their captions before reading the rest of the paper. Try to get as much information out of them as possible. Then return to them again once you start reading through the paper.

After reading abstract, intro and methods, but *before* reading results and discussion:

Identify and include the **three** most important/useful figures or tables from the paper below (i.e. your highlight reel). For each figure, answer the following:

- Figure or Table: Figure 1
    - Light curves from an object in the I Band over seven years of photometric monitoring at Wesleyan. The period of rotation are the same, but the magnitudes vary from year to year.
    - How are these measurements made? (it may be helpful to paste in the description from the methods)
        - "Typically, one searches for periodicity using the Lomb-Scargle periodogram technique which is effective for unevenly spaced data sets. Evaluation of the false alarm probability (FAP) associated with a peak of

any given power can be tricky and is best done with a Monte Carlo simulation of the data." (Pg. 3)
    - What conclusions can you draw from this data?
        - The periods are staying the same over the course of seven years so the rotation rate is the same within error. What is interesting is the variability in the magnitude over the years.
    - How does this data contribute to the argument the authors are making?
        - This information is a good display of the variability in T-Tauri stars
    - What questions does this data raise for you?
        - What is the difference between weak and classical systems

- Figure or Table: Figure 4.
    - Describe: The evolution of rotation period with the age of these objects
    - How are these measurements made?
        - *"Fig. 4 shows the results from Scholz and Eisl'offel (2004b). Plotted are the VLM periods for σ Ori and the Pleiades plus evolutionary tracks. The dotted lines show the evolution assuming angular momentum conservation, i.e. the tracks are completely determined by the contraction process. It is clear that this is not a reasonable description of the available period data, because the models predict an upper period limit < 20 h in the Pleiades, whereas the observed periods range up to ~ 40 h."*
    - What conclusions can you draw from this data?
        - As the stars get older, they rotate slower. However, these lines appear to just be models computed with assumptions of rotation speed loss according to classical mass-angular momentum relation
    - How does this data contribute to the argument the authors are making?
        - Assuming certain parameters our models of the rotation speed of these VLM stars, these data correspond to our predictions well
            - "Thus, some kind of rotational braking must play a role for VLM objects on these timescales"
                - I.e. there must be some sort of braking mechanism
    - What questions does this data raise for you?
        - If the success of this data is conditional ("*It is clear that this is not a reasonable description of the available period data, because the models predict an upper period limit < 20 h in the Pleiades, whereas the observed periods range up to ~ 40 h"),* then why is it included in this paper for reference?

- Figure or Table: Figure 6
    - Describe: Observationally obtained rotation periods of brown dwarfs and similar objects within the substellar limit
    - How are these measurements made?
        - It seems that this data was taken much similar to how we did in Arizona, however there may be some bias due to this: "*Please note that the upper period limit in the youngest clusters may be set, in part, by the upper period detection limit*." They also come from the Sholtz 2004 paper (it is reference as 2004a, what does this mean in terms of the publication?).
    - What conclusions can you draw from this data?
        - As the brown dwarfs evolve their periods get faster. They are considered to be "field" brown dwarfs after 1 Gyr.
    - How does this data contribute to the argument the authors are making?

        - In terms of the context of the rest of the paper this figure affirms that brown dwarfs fall into the same sort of behavior as the other YSOs described thus far. They discuss this figure in terms of the trends of the upper and lower limits of the period. This puzzles the authors as we expect to see some contraction along the timescales exhibited on the x-axis which would lead to much faster rotations than observed.
    - What questions does this data raise for you?
        - This must mean there is some sort of mechanism for the expulsion of mass or area. But there are no more proto-planetary disks or jets observed around brown dwarfs, so this puzzles me.

After reading results and discussion:

- Describe any additions/corrections/new insights/questions based on reading the author's interpretations of the figures.
  For example: "The color-magnitude diagram in Figure 2 actually showed two populations of stars, not just one, and was meant to show trends in evolution. I want to know why the populations look different even though they're the same age."
  Answer: From the figures the author appears to show a variety of confidence and lack thereof in the work done. The moral I've gotten from the data is that it coincides with our expectations, but in a peculiar way. Why that is, we don't know yet. This brown dwarf rotation section will be important. Overall the figures that I have shown are displaying period evolution with time. The significance of this I am still trying to wrap my head around. I know rotation is an important quantity, but I want to know about how that data is unpacked and turned into other useful information. Our theory and observation DO NOT coincide.

Body of the paper: Results & Discussion

Now it is time to read through the entire paper.

From your reading of the Results & Discussion sections, try to answer **at least three** of the questions that you came up with from reading the title, abstract and figures. Do not get bogged down in the details of the procedure or analysis sections. Read for broad concepts that will allow you to understand the figures.

- Question 1: ZAMS?
  Answer: ZAMS are zero age main sequence stars. They are interesting as these are the very first stars that evolve onto the main sequence (e.g. "zero age" they have just arrived there). These objects are the bridge between YSOs and field stars.

- Question 2: Angular momentum loss
  Answer: It appears that the loss of angular momentum is due to many mechanisms but must obey our classical understanding of the relation between mass/size and angular momentum. What these mechanisms *are* appear to be poorly understood thus far. Jets and contraction seem to be popular and well mentioned in the paper, but the behavior of the angular momentum never seems

to really be “behaved”. It doesn’t go how we expect.

- Question 3: Why do we look at angular momentum/rotation periods
  Answer: Rotation period gives us information about the angular momentum which in turn can provide information about the sizes and masses of the objects we are observing. For brown dwarfs from figure 6 it seems that the evolution of rotation period with time does not go as was modelled. Rotation periods of other things like VLM stars do evolve on a trajectory that is somewhat expected.

Take-home for you

- Briefly summarize what from this paper is relevant to your project.
  For example: "Good introduction that explains...", "Table 2 has the collection of data for related types of stars", "Interesting examples of young stellar object lightcurves", etc.
  Summary: Subsection of section 4 titled Brown Dwarfs about BD rotation will *definitely* be useful to me as this is what my project is looking at/dealing with. The rest of it provides good context for the work I will be doing for my project and the projects of my collogues.

- List questions to follow up that are relevant to your project.
  Answer: How is it that these upper and lower limits on rotation applied to data taking techniques? Is it that they won’t consider objects BDs outside of those bounds? If so, then how do people come to a consensus about this. Herbst mentions that if we extend the lower limits then we can assume that there must be a decent mass loss over 1Gyr in order to explain the period change. The mechanism for this is still unknown. Can we do any modelling to test this? Since this paper has been published have there been developments?

- List methods/techniques that may be of use to you.
  Answer: Modelling methods outlined in figure 4. Selection criteria used for BDs outlined in section 4.3, Monte Carlo simulations described on page 3 (?). Will/can we do any modelling like shown in fig 4 for BDs instead of VLM stars.

- List any references that you want to follow up.
  Answer:
    - Scholz and Eislöffel 2004, 2004a/b, 2005
    - Nakajima 1995
    - Rebolo 1995
    - Martin and Zapatero-Osorio, 1997

*Adapted from templates used in the Jaswal and Follette Labs, Amherst College.