# Blowing in the wind: An ALMA multiband study of dust in two protostellar winds

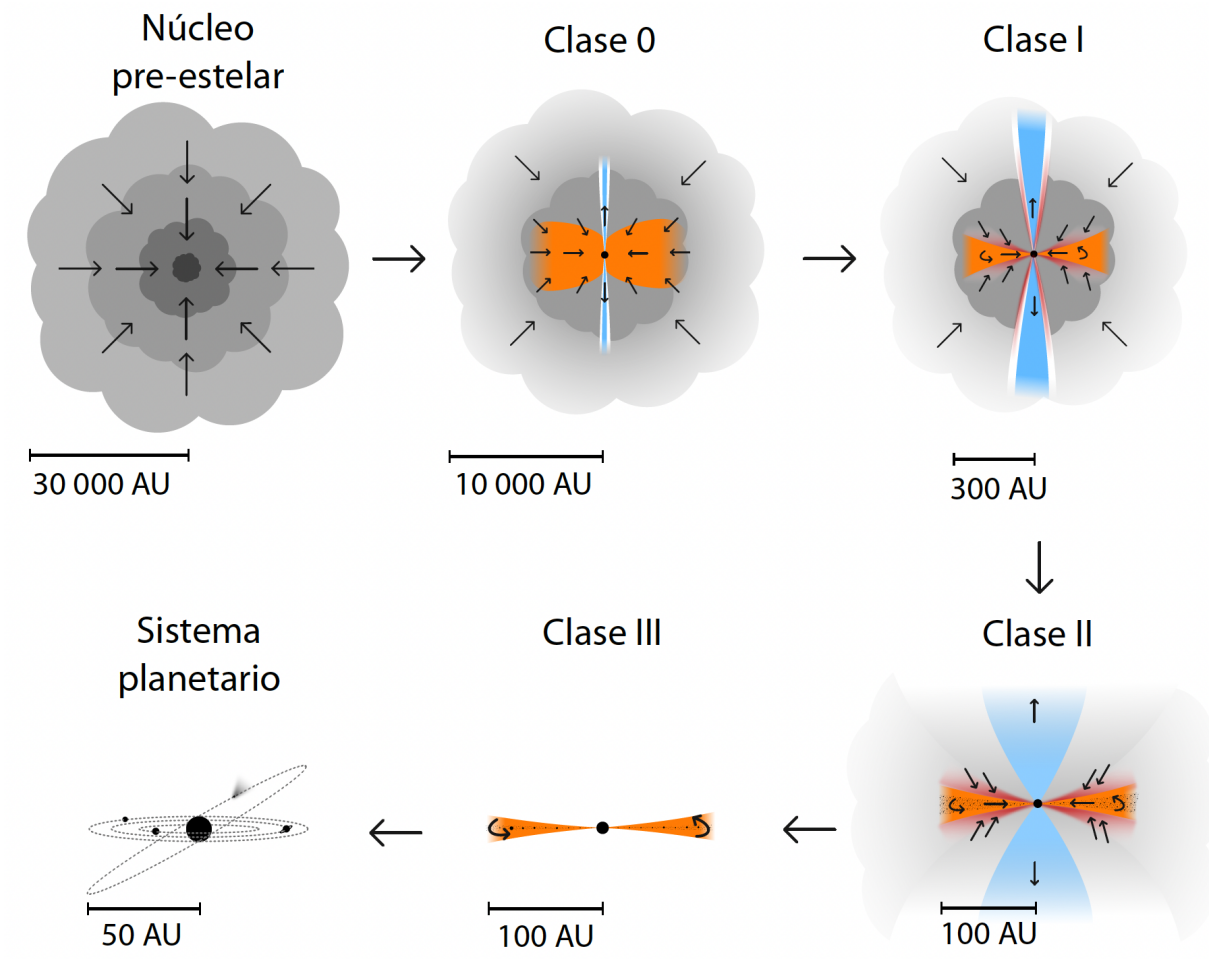
**Start:** August 2023

## Project Overview:

When stars form, material is flowing inward and outward simultaneously, through components known as infalling envelopes and outflowing winds, which eventually facilitates mass accretion onto a forming disk, and then the star itself. The aim of this project is to study the interface between protostellar disks and outflows, and test the hypothesis that dust can be carried away at this interface via a wind. Our group at NRAO, University of Virginia (USA), and Chalmers University of Technology (Sweden) has undertaken an extensive search of the ALMA Science Archive, and we found promising evidence for dust continuum morphology that match our hypothesis, that we now wish to expand by analyzing recent ALMA observations. Beyond the question of "is dust being launched into protostellar winds?" we seek to quantify at what level winds affect early disk formation and evolution. The scenario probed here has important impacts on the mass, composition, and evolution of the disk, which is ultimately the reservoir for planet formation. The selected student will organize several brand-new ALMA datasets, including unique high-frequency ALMA bands, for two protostellar sources, and make a comparison with a previous study (submitted for publication) of a third source. Experience with millimeter-wave observations, interferometry, and Python programming is welcomed, but not required, as this is a great opportunity for a student to learn imaging and analysis techniques for the first time.

Some good illustrations of the star formation process:

- http://coolwiki.ipac.caltech.edu/index.php/File:Starformationcartoon.png
- https://figshare.com/articles/figure/Current_view_of_protostellar_evolution/654555
- The following figure is from Magnus Persson (link here)




# Project Details:

The aim of this project is to see if there is evidence for dust being launched from two sources that we observed with ALMA, B228 and B335.

We already did a case study of one source, HH212. That study is submitted for publication, and you can read the recent draft here. Now, we would like to extend the search to other sources, to investigate whether the phenomenon is more common.

The observations were made with the Atacama Large Millimeter/Sub-millimeter Array (ALMA) telescope, located in the Atacama Desert of Chile. You can find some information about the telescope at this webpage.

# Resources on star formation (in increasing order of complexity):

*José: color code – orange is for read, green is for currently reading

(1) https://www.scientificamerican.com/article/how-is-a-star-born/
(2) https://www.americanscientist.org/sites/americanscientist.org/files/2005223144527_306.pdf
(3) http://coolwiki.ipac.caltech.edu/index.php/Studying_Young_Stars
(4) More details: http://coolcosmos.ipac.caltech.edu/resources/star_formation/
*J.: this page is no longer available.

# Papers to read:

*Observational papers on B228 or B335, protostars, dust, winds etc:*

1. Bjerkeli et al. (2019) on Kinematics around the B335 protostar down to au scales
2. Bjerkeli et al. (2023) on Episodic infall towards B335 https://ui.adsabs.harvard.edu/abs/2023arXiv230614531B/abstract
3. Shoemaker et al. (2023), our recent paper about dust in the wind of HH212
   Dust_In_Wind_draft.pdf
4. Lee et al. (2018) about the disk wind of HH212 https://iopscience.iop.org/article/10.3847/1538-4357/aaae6d/pdf
5. Tabone et al. (2020) about studying the disk wind of HH212 with ALMA https://www.aanda.org/articles/aa/full_html/2020/08/aa34377-18/aa34377-18.html
6. Vazanno et al. (2021) includes the source B228, although they use the name IRAS15398 https://ui.adsabs.harvard.edu/abs/2021A%26A...648A..41V/abstract

*Theoretical/computational papers on protostars:*

1. coming…

*Overview/Review type papers (these are typically longer…):*

1. Pascucci et al. (2022) on "The Role of Disk Winds in the Evolution and Dispersal of Protoplanetary Disks" https://arxiv.org/pdf/2203.10068.pdf
2. Frank et al. (2014) on observations and theory of outflows or winds https://ui.adsabs.harvard.edu/abs/2014prpl.conf..451F/abstract
3. Arce et al. (2007), great overview of outflows: https://arxiv.org/pdf/astro-ph/0603071.pdf
4.

# Next steps:

**(with "skillset" you are developing written in orange highlighted text)**
**José: color code – orange is for done, green is for currently working on it.*

## Next steps after August 10, 2023 :

- Download the data available here: https://virginia.box.com/s/biwc8hduwq34b7joo6pwiyl7loir9pkh
- Get access to Linux on your computer, or ask Adele for access to NRAO remote computers.
- Download CARTA, a visualization tool available here: https://cartavis.org/
- Open the datasets in CARTA. Save an image of each dataset, and label it with the source, frequency band (Band 5 or Band 9), central frequency, and angular resolution. Central frequency and angular resolution are available in the header.

## Next steps after previous is completed (but not necessarily in the next week):

- Explore plotting contours using CARTA. See the help documentation here.
- Compare images you made with other images of the same source in the literature, for example Figure 1 of Bjerkeli et al. (2023) or Figure A1 of Bjerkeli et al. (2019) for the source B335.
- Read one (or more) of the papers linked above. We can talk about some advice for reading scientific papers. You can also review this article about "How to read a scientific paper".
- Learn about using Python to make images of astronomy observations. This webpage looks like a good tutorial.

## Next steps after September 28, 2023:

- Do a brief literature review of the recent papers on B335 and B228. (FYI, I included a new paper in the list above, Vazzano et al. 2021)
    - What class is each source (Class 0 or I)?
    - What are the masses of each source?
    - What are the distances to each source?
    - What star forming regions are these sources found in?
    - What are the alternate names for each source? Hint, you can use: http://simbad.u-strasbg.fr/simbad/ , using either the "basic search" for the source names (Barnard 335 and Barnard 228), or use the coordinates of each source.
    - Save any interesting references that seem relevant to our research on the dust continuum for these sources. We would like to know if any other papers:

    - show a figure of these sources that reveals the extended continuum morphology (even if they didn't discuss it extensively)
    - Show outflow emission to indicate the direction and shape of the gas material going away from the star (some likely molecules are CO, SiO, CS, and maybe SO)
    - Show "extended" shapes of emission that is due to accretion (material flowing onto the star)
- **Note**: The most common place to look for astronomy papers is this webpage: https://ui.adsabs.harvard.edu/ I use this browser extension to see if there are "free" versions of articles available online: https://unpaywall.org/
- **Hint:** If you find a good, recent paper about one particular source, read the introduction section and you'll usually find references to other papers about the source.