Hands-On Session Introduction: Disk Models

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This hands-on session will introduce you to circumstellar disks:

- how they are studied,
- how they appear at different stages of their evolution,
- the different features they can exhibit.

Using:

Images

Spectral Energy Distributions (SEDs)

SEDs represents how bright a source is as a function of wavelength.
The "Fabulous Four" seen with IRAS (Backman & Paresce 1993)

\[ \beta \text{ Pictoris} & \epsilon \text{ Eridani} \]

\[ \text{Vega} & \text{ Fomalhaut} \]

Dust absorbs starlight and re-radiates that energy in the infrared
\[ \Rightarrow \] excess IR emission above the stellar photospheric emission.

A great number of disks were revealed with IRAS, and later ISO, Spitzer, Herschel..
Images in scattered-light (Optical Wavelengths)

Revealing micron-sized dust grains as they reflect starlight

With the Hubble Space Telescope (HST)

β Pictoris

Heap et al. (2000)

Fomalhaut

Kalas et al. (2005)

Golimowski et al. (2006)
Images in scattered-light (Optical Wavelengths)

Revealing micron-sized dust grains as they reflect starlight

With Gemini Planet Imager (GPI) and VLT/SPHERE

HR 4796 in the J-band (1.24 $\mu$m) with GPI

HD 106906 in the H-band (1.6 $\mu$m)

Arriaga et al. (2020)

Rule of thumb: a wavelength reveals dust grains of similar size.

Lagrange et al. (2016)
Images in thermal light (Far-IR up to mm wavelengths)

Revealing (sub)millimeter-sized dust grains as they re-emit starlight

With Herschel, James Clerk Maxwell Telescope (JCMT),
Atacama Large Millimeter Array (ALMA)

Vega – Herschel/PACS 70 µm

ε Eridani – JCMT 850 µm

Fomalhaut – ALMA 1.3 mm

Su et al. (2013)

Greaves et al. (1998)

MacGregor et al. (2017)

Images can provide a lot of information on the disks: their extent, their distance to the star, the presence of asymmetries, etc...

Detailed images are not always easy to obtain!
This Hands-On session will show you

- an overview of the type of characteristics you can learn about a disk from its SED,
- how sometimes different phenomena have the same effect, i.e., degeneracy,
- how images can help break the degeneracy.

We have chosen 4 objects that represent different evolution stages of disks; for each, we will have you explore the impact of significant parameters on images and SEDs.

HL Tau, the toddler
ALMA Partnership et al. (2015)

HH30, the teenager
Burrows et al. (1996)

PDS 70, the grown-up
Müller et al. (2018)

HR 4796, the elderly
Schneider et al. (2009)
Stars are born in molecular cloud cores, surrounded by large envelopes of dust and gas. The envelope falls onto a disk and is accreted from there onto the star.

HL Tau harbours a protoplanetary disk, and is also still surrounded by a large envelope.

Explore the effect of the envelope mass

ALMA Partnership et al. (2015)
HL Tau became famous when ALMA pierced through the envelope. It revealed that the largest grains in the disk:

- harbored a series of gaps.
- have settled in the midplane.

ALMA Partnership et al. (2015)

Explore the effect of the disk scale height and the presence of gaps
Over the course of a few hundred thousand years, the envelope is depleted.

The young star is left with its circumstellar accretion disk.

These stars are known as T Tauri stars.

The small grain distribution in the disks they harbour appear flared.
HH 30 hosts an edge-on protoplanetary disk.

The large dust grains have settled onto the disk midplane into a flat structure.

The small grains in their disks have a flared distribution.

Explore the effect of the disk flaring index, inclination, and dust mass.
A transition disk is characterized by the presence of a large central cavity. It may be carved out by some combination of:

- stellar wind
- radiation pressure
- grain growth
- accretion of primordial material onto the star
- perhaps even forming planets
PDS 70 is surrounded by a pre-transition disk.

There is a large gap extending from 1 AU to 60 AU.

Two planetary-mass companions were detected within the cavity.

Müller et al. (2018)

Haffert et al. (2019)

Explore the effect of the gap width, the gap depth, and the presence and temperature of a planet.
After a few million years, the gas in the disk is dispersed and the star becomes a main-sequence star. What is left is a debris disk:

- analogous to the objects first discovered by IRAS;
- much less massive than a protoplanetary disk (little or no gas);
- dominated by a second generation of dust formed from collisions of large remnant bodies.

This debris disk is a narrow ring, perhaps shepherded by the presence of one or more planets.

Chen et al. (2020)

Explore the effect of the radial location of the ring and the dust grain size.
You will investigate science questions of the following type:

- What can an SED tell me about X for this specific system?
- And what do images tell me about X?
- Do I need an image to complement the SED or is the SED sufficient to retrieve the information I need?
- Is there an underlying physical phenomenon at play?

You will find all the questions gathered in a Multiple Choice Questions Google Form.

Find these questions, as well as all the background on each disk in the Disk Models documentation (linked from the hands-on session page).
**Using Python and RADMC3D**

You will be provided with the outputs, i.e., SEDs and images, of a radiative transfer code called RADMC-3D, developed by Cornelis P. Dullemond.

This code computes how a disk dust grains interact with the light from the star, either reflecting it (scattered emission) or absorbing and re-emitting it (thermal emission).

You will use RADMC3DPy, a Python library developed to process the outputs of RADMC-3D runs.

Note that what we call best fit is actually more like the nominal model that fits certain aspects of the SEDs and images, and we use that "best fit" to show the effect of varying model parameters.
You will either use Jupyter or Google Colab Notebooks

Please refer to the Hands-on Session website

**Before the Workshop**

For each set of hands-on session, you can choose to either install Python and associated software packages on your computer, or download and use Google Colaboratory (Colab) notebooks, which run in your Google Drive using a virtual machine and do not require a Python installation. Either choice will allow you to go through the same hands-on activities; if you install Python, you will work with Jupyter notebooks, and if you use Google, you will work with Google Colab notebooks. No prior Python experience is required to participate in the hands-on sessions.

[CLICK HERE FOR THE PYTHON INSTRUCTIONS]
[CLICK HERE FOR THE GOOGLE COLAB INSTRUCTIONS]

- Jupyter notebooks require Python installation
- Google Colab does not require Python installation, but you need to set-up the notebook.

Please do this BEFORE the session (takes about 1/2 hour)

Do not hesitate to take a look at/use the #python-help Slack channel.
There will be one Jupyter/Google Colab notebook per disk. You will work through it, cell by cell:

- use the pre-filled code and modify it, changing the file name for the model SED or image
- or copy/paste the code into new cells.

Link to the Google form at the very bottom of each Notebook. Fill it out several times (e.g., each time you are done with a disk) & skip questions you cannot answer.

After submitting you will see the answer key for the questions you submitted.
Live Hands-On Session - Tuesday 12:45pm (PT)

Leads: Virginie Faramaz & Elise Furlan

Our wonderful team of volunteers!

- Isabel Rebollido – HLTau
- Marion Villenave – HLTau
- Lina Kimmig – HH30
- Karl Stapelfeldt – HH30
- DJ Dong – PDS70
- Kellen Lawson – PDS70
- Shih-Yun Tang – PDS70
- Geoff Bryden – HR4796
- Daniel Carrera – HR4796

You will be assigned randomly to one of our nine zoom breakout rooms.

Each room will have a primary object assigned, as well as helper.

Please use the Zoom chat function to ask questions to your helper.

If you’ve finished working on the object assigned to the room, don’t change room, change object!
After the Live Session

We’ll be here throughout the week to help you!

You can use

- The documentation and references therein.
- Slack to ask your questions.
- The Hands-On Lab in Gather to work in groups.
- The Multiple-choice questions Google Form.

After the workshop, we will hand you a complete documentation that will include detailed answers to the questions, as well as input commands from RADMC3D (in case you ever want to run the code yourself).

We hope you will enjoy what we have prepared for you and will have pleasant learning experience!
Smith, B. A. & Terrile, R. J. 1984, Science, 226, 1421