# CO in Young Stellar Objects: from low- to high-mass

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## INTRODUCTION

- Stars form in clouds of molecular gas and dust. During the earliest stages, important physical and chemical processes occur, constraining the composition and structure of the protostar.
- Most studies of star-forming regions focus exclusively on either low- or high-mass young stellar objects. A mass evolutionary trail is needed in order to achieve a uniform description of the star formation and the interaction of the protostar with its surroundings.

In this context, the *Herschel* key program **WISH**, *Water In Star-forming regions with Herschel*, traces water, CO and other important molecules through the different evolutionary stages of the formation process and across the entire mass spectrum (from $<10^{-1}$ to $>10^{3}$ $M_{sun}$).

### CO as a diagnostic:

- Easily excited and thermalized.
- Probes the components of the protostellar environment:
  - ✔ $^{12}$CO: traces the molecular outflows.
  - ✔ C$^{18}$O: traces the quiescent envelope gas.
  - ✔ $^{13}$CO: both.

## GOALS

➔ **Constrain the physical and chemical structure of protostellar environments as a function of mass.**

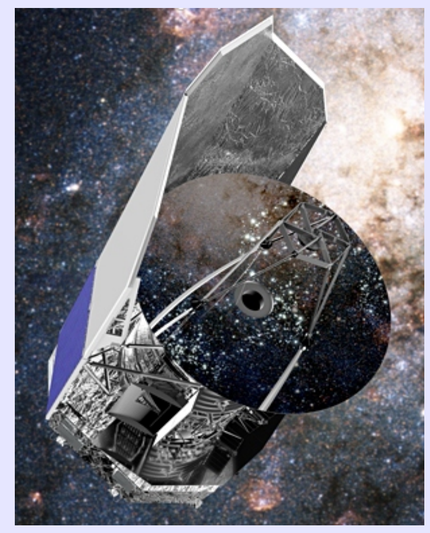
➔ **Compare properties of CO and its isotopologue emission lines for different transitions.**

➔ **Provide a reference for $H_2O$ and other molecules.**

## OBSERVATIONS

✗ ***Herschel*:**

- Sub-millimeter and far-infrared space telescope.
- Three instruments: *HIFI*, *PACS* and *SPIRE*.
- **HIFI:** Heterodyne Instrument for the Far Infrared.
  - Range: 157-625 micron
  - High spectral resolution: *Dv = 0.1 km/s* → tracing gas motion in protostars.

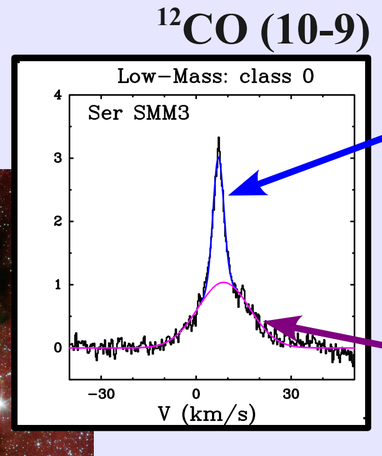


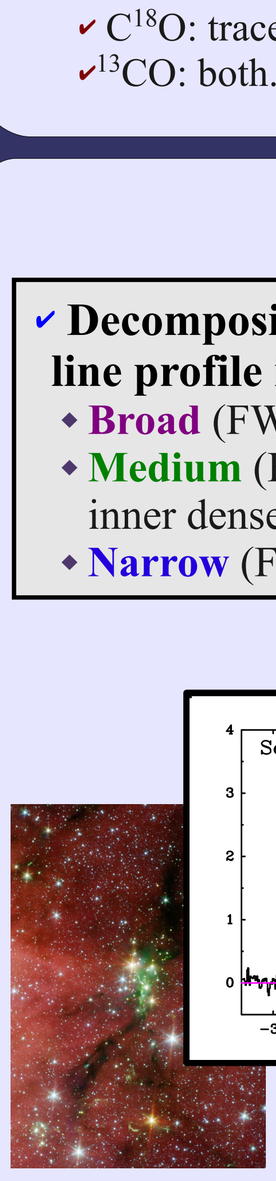
✗ **Sample:** **26** Low-mass; **6** Intermediate-mass and **19** high-mass YSOs.

## ANALYSIS

✔ **Decomposition of $^{12}$CO (10-9) and $^{13}$CO (10-9) line profile in different velocity components:**
- **Broad** (FWHM > 15 km/s): outflowing gas.
- **Medium** (FWHM ~5-15 km/s): shocked gas in the inner dense envelope.
- **Narrow** (FWHM < 5 km/s): quiescent envelope.

$^{12}$CO (10-9)



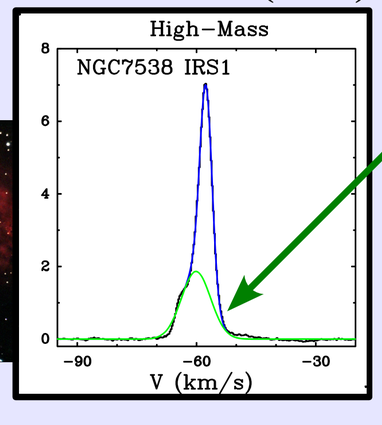



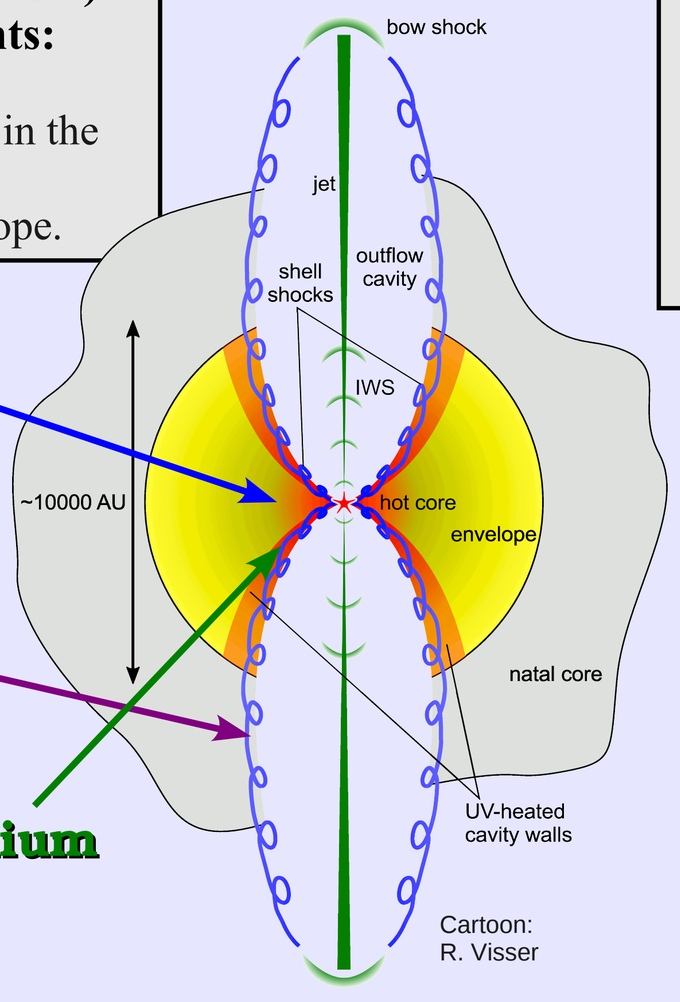
**Narrow**

**Broad**

**Medium**

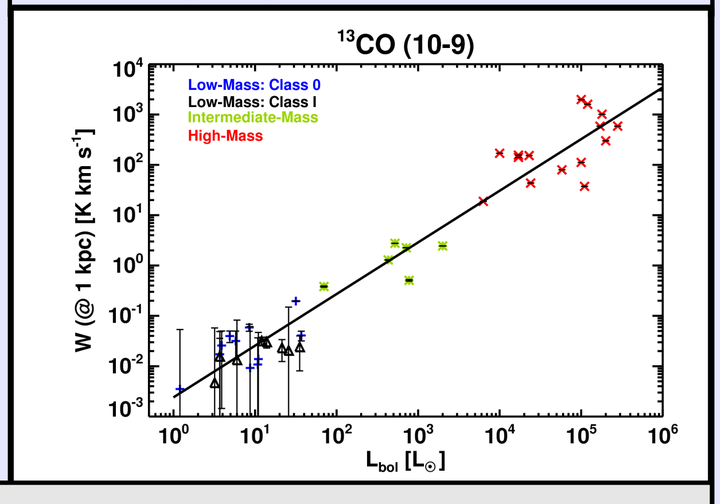
$^{13}$CO (10-9)




✔ **Study the CO ladder in each velocity component:**
- Constrain the $T_{kin}$ and *N(CO)*.
- Quantify the relative heating mechanisms (passive heating by the envelope, UV heating, shocks) across the mass spectrum.
- Reference frame for $H_2O$.

Correlation between the integrated intensity, ***W***, and $L_{bol}$, observed in **all CO and isotopologue lines.**




✔ **Interaction of protostars with the surrounding seems to have similar characteristics across the studied luminosity range.**

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