Star formation and early evolution in the ISO data-base

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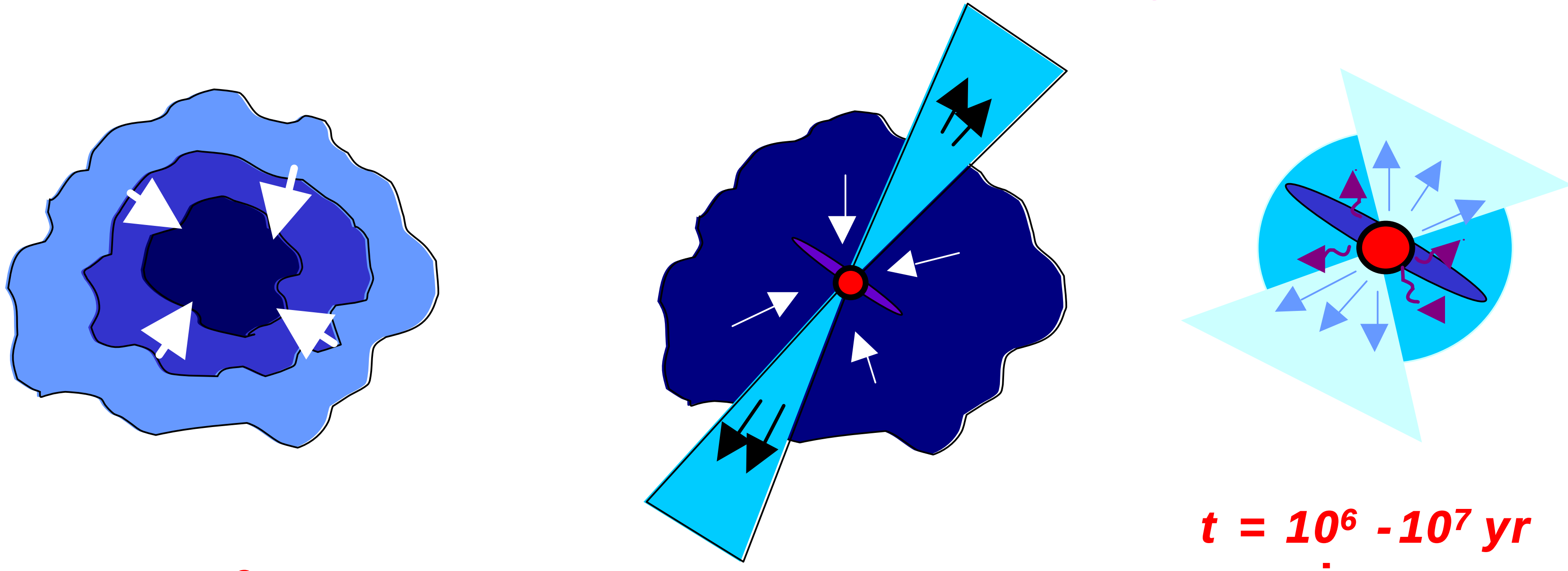
Outline:

- Importance of MIR and FIR for star formation studies
- Overview of observations performed by ISO
- Availability of archive data for star formation studies
- Example of a survey programme exploiting the ISO archive
- Comments and conclusions

The Infrared view of Star forming systems



t* = 0 *yr
collapsing dense core

external heating from ISM

t* = $\boldsymbol{10^4}$ - $\boldsymbol{10^5}$ *yr
protostellar phase (Class 0/I)

heating due to shocks (accretion and outflows)

t* = $\boldsymbol{10^6}$ - $\boldsymbol{10^7}$ *yr
pre-main sequence phase (Class II/III)

heating due to stellar photons

Þ **Isolated star formation:** Interaction (proto-)star with its envelope

Þ **Collective star formation:** Census of embedded objects, IMF

Fields covered by ISO Observations

- Pre-stellar cores
- Characterization of young stellar objects
- Census of protostars, IFM
- Outflows
- Pre-main sequence stars and circumstellar disks

Þ for a total of 830 hrs (2530 observations)

Þ only ~20% of observations published
(in ~137 refereed articles)

Pre-and proto-stellar cores

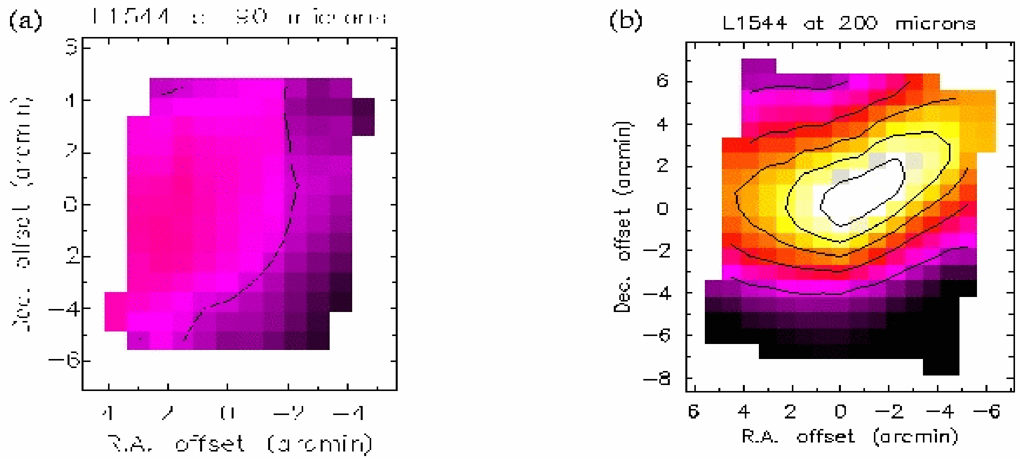
- 15 OT proposals using PHT and CAM
  - *83 hrs ISO time, 188 observations*
  - *~22% of observations published*

- Dust emission, temperature profiles
- Cores internal structure through absorption measurements

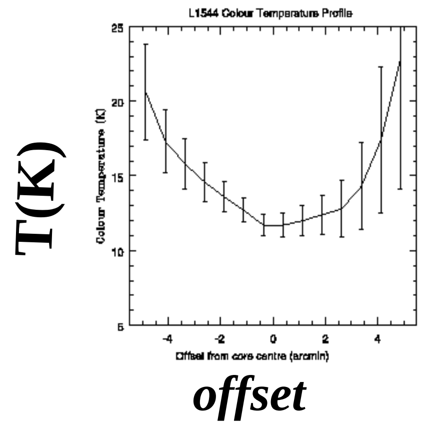
Still to be done:

- Comparison between starless and protostellar cores

Pre-stellar Cores imaging with PHT-C



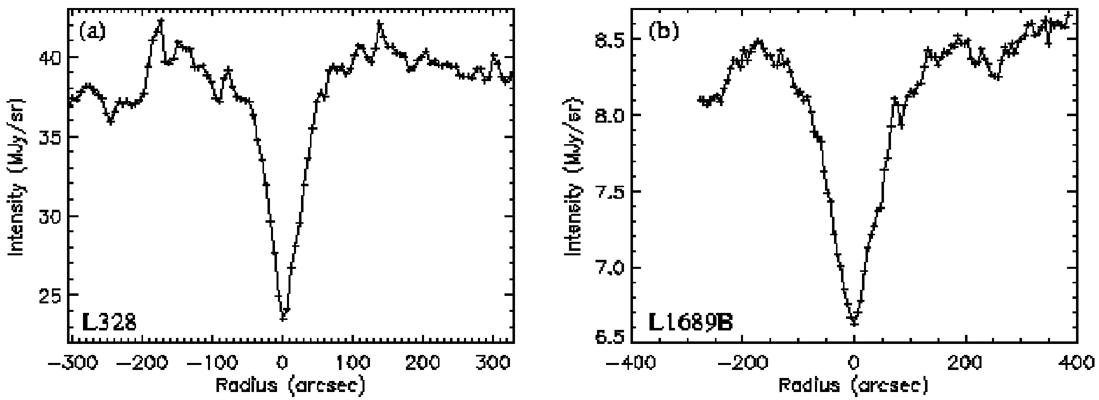
L1544



(Ward-Thompson et al. 2002)

Pre-stellar Cores structure with CAM

absorption against the mid-IR background



(Bacmann et al. 2000)

Study of young stellar objects

- 29 GT+ OT proposals using the four instruments
    - *257 hrs of ISO time, 766 observations*
    - *~20% of observations published*

BUT

- *only 5% of PHT observations published*

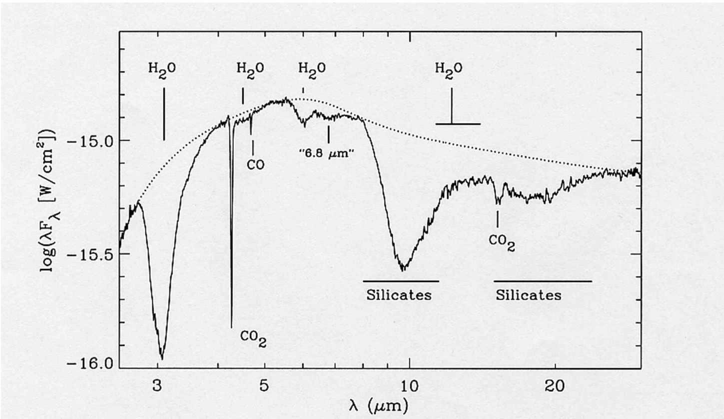
- Gas and dust features from protostellar environments
- Spectral Energy Distributions (SEDs)

Still to be done:

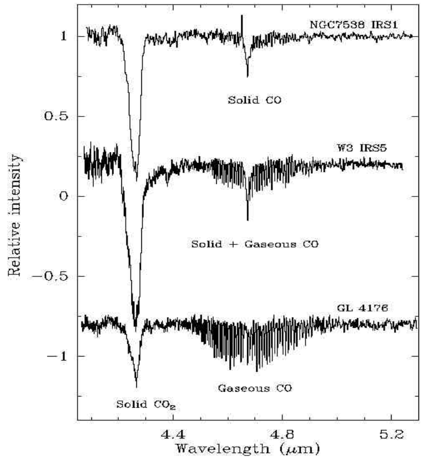
g Systematic studies on the SEDs

Spectra of young stellar objects (YSOs)

SWS spectra of dust/gas absorption features

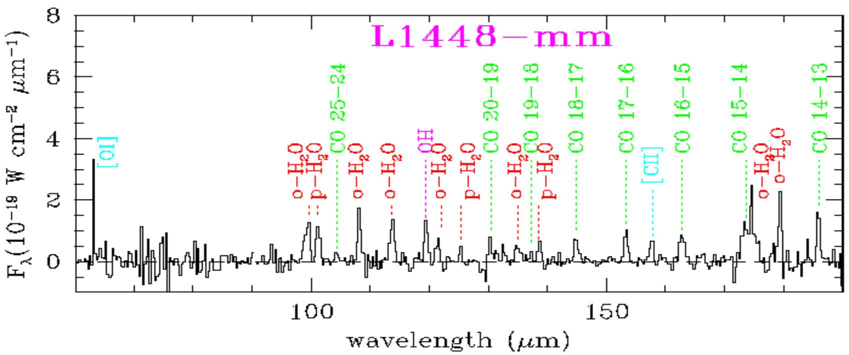


(Boogert et al. 2000)



(van Dishoeck et al. 1998)

LWS line emission spectra



(Nisini et al. 1999)

- First detection of water vapour lines
- Gas/dust abundance ratios
- Physical conditions of the warm circumstellar gas

Outflows and HH objects

- **15 GT+ OT proposals using SWS, LWS and CAM**
  - ***127 hrs of ISO time, 259 observations***
  - ***~12% of observations published***

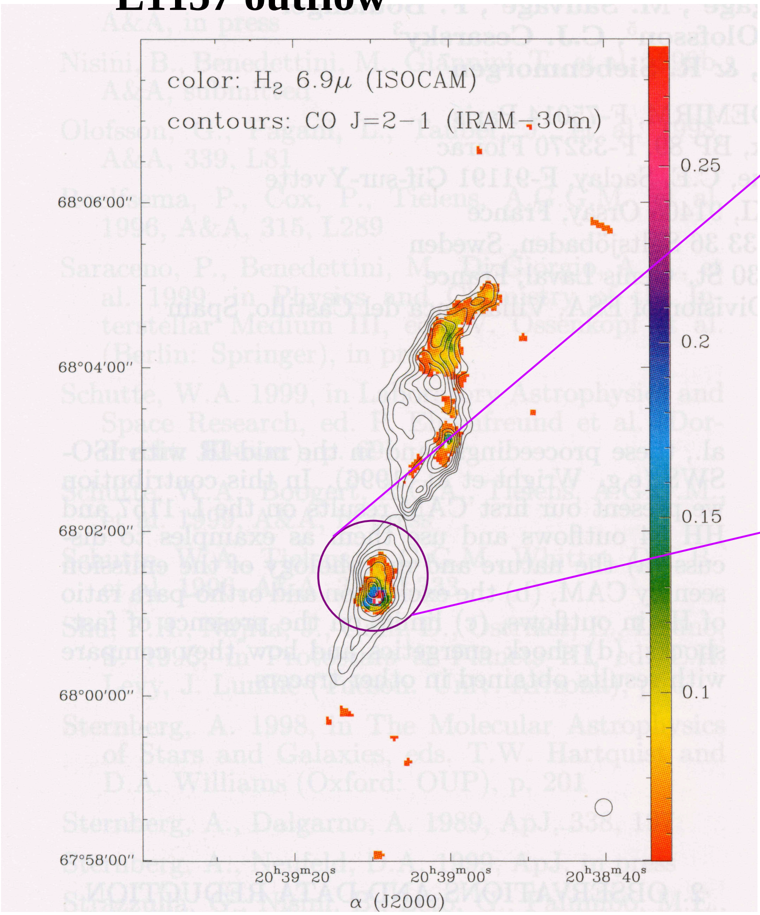
- Study of the shock interaction between jets and ambient medium
- Trace the gas+dust cooling in the post shocked gas

Still to be done:

γ CAM H_2 0-0 lines imaging
γ Emission from shock heated dust (CAM, LWS)

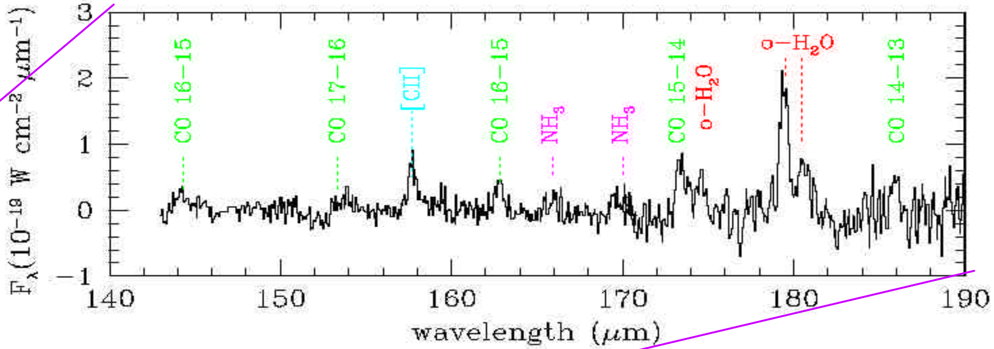
CAM H_2 0-0 lines imaging

L1157 outflow



(Cabrit et al. 1998)

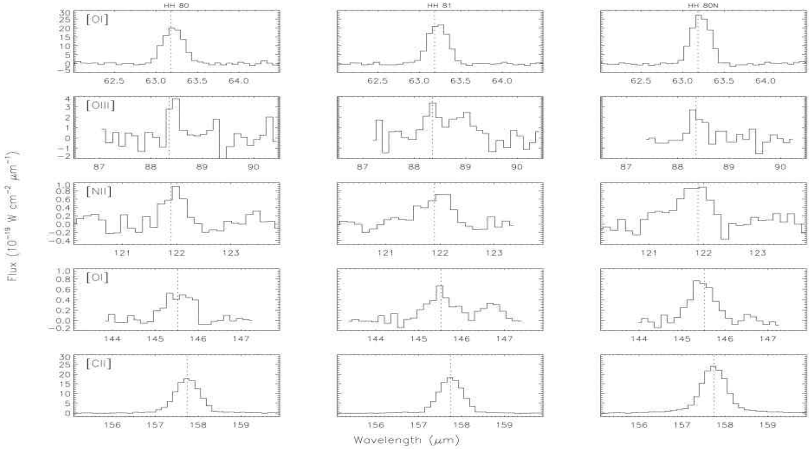
Warm gas cooling through LWS



(Giannini et al. 2001)

Ionic lines in HH objects

HH80 **HH81** **H80N**



[OI]

[OIII]

[NII]

[OI]

[CII]

(Molinari et al. 2001)

Census of YSOs

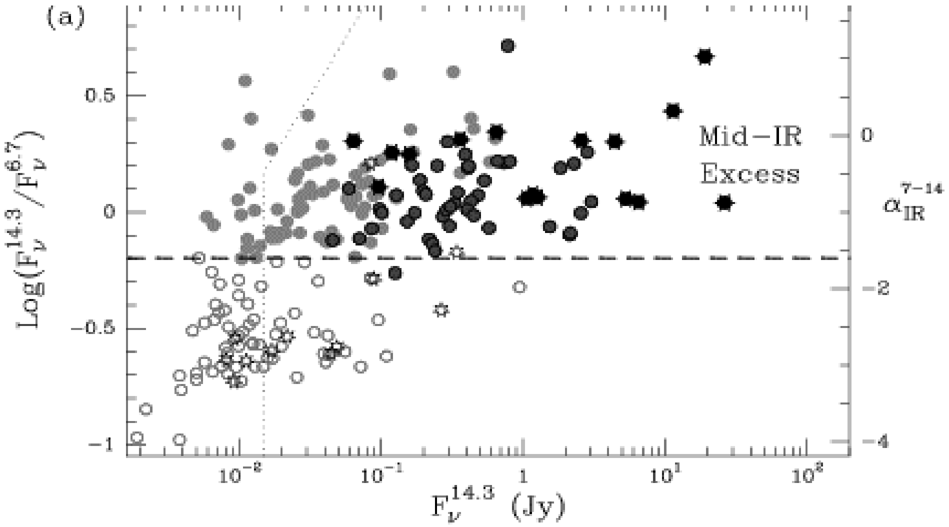
- 29 GT+ OT proposals using PHT, CAM and LWS
  - ***171 hrs of ISO time, 292 observations***
  - ***~22% of observations published***

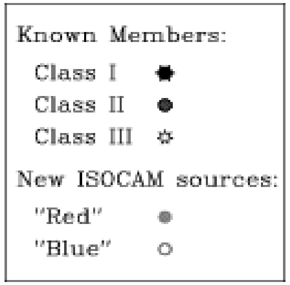
- Discover the embedded population of YSOs
- Luminosity functions of star forming regions

Still to be done:

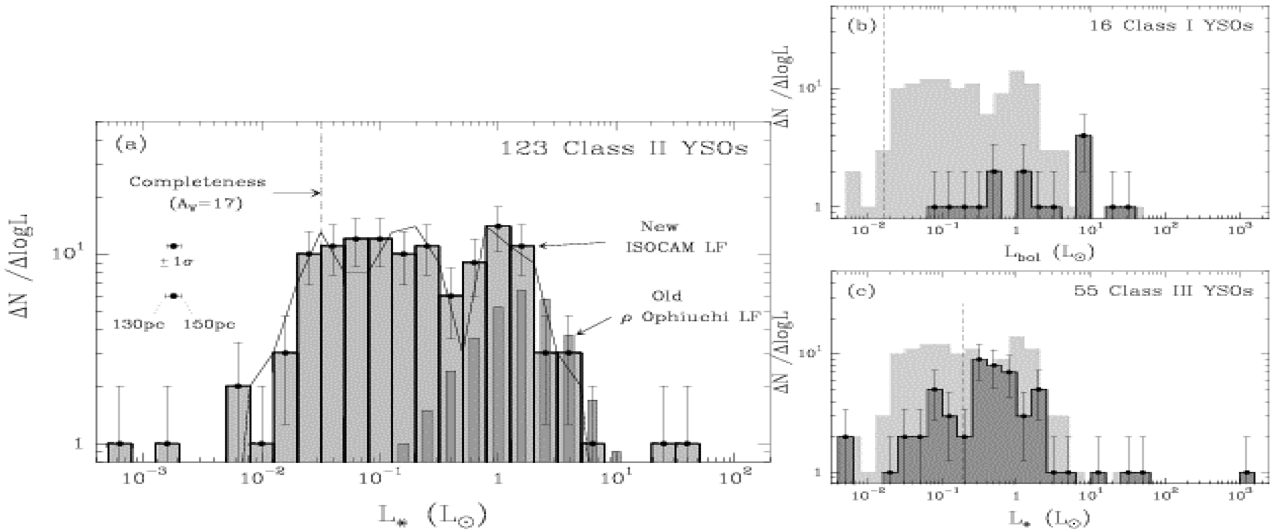
- Extend the study to other regions for comparison and catalogue the mid-IR source population

The r-Oph embedded cluster





(Bontemps et al. 2001)



Other investigated regions:

- Cha I (Persi et al. 2000)
- R CrA (Olofsson et al. 1999)
- Serpens (Kaas et al. 1999)

Pre-main sequence stars

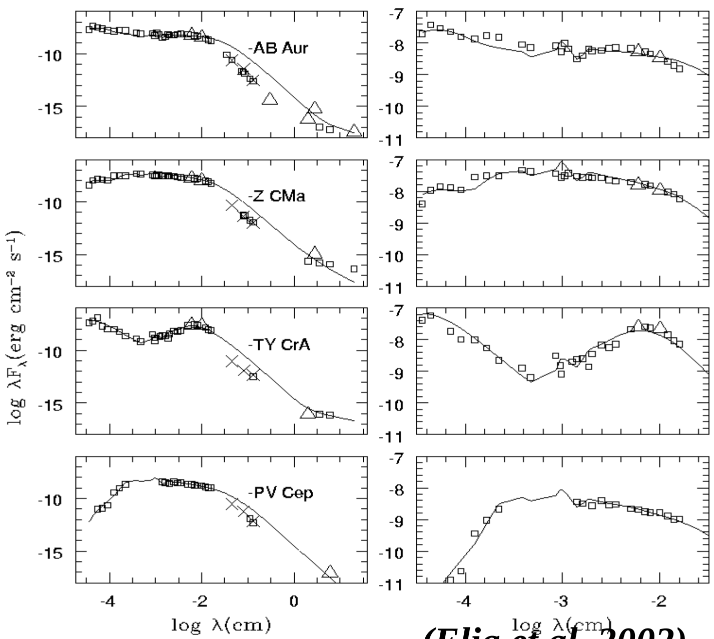
- 23 GT+ OT proposals using the four instruments
  - ***184 hrs of ISO time, 1009 observations***
  - ***~17% of observations published***

- **SEDs: Infrared excesses in the stars envelopes**
- **Circumstellar disks**
- **Circumstellar gas excitation**
- **Dust reprocessing by UV photons**

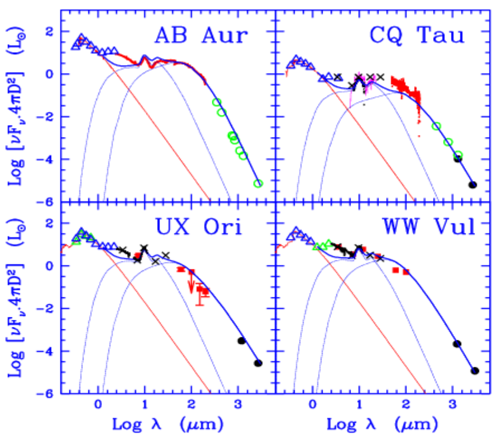
Still to be done:

- **Catalogue of observations (SEDs, Line list) for T Tauri stars**

Modelling the SEDs of HAeBe

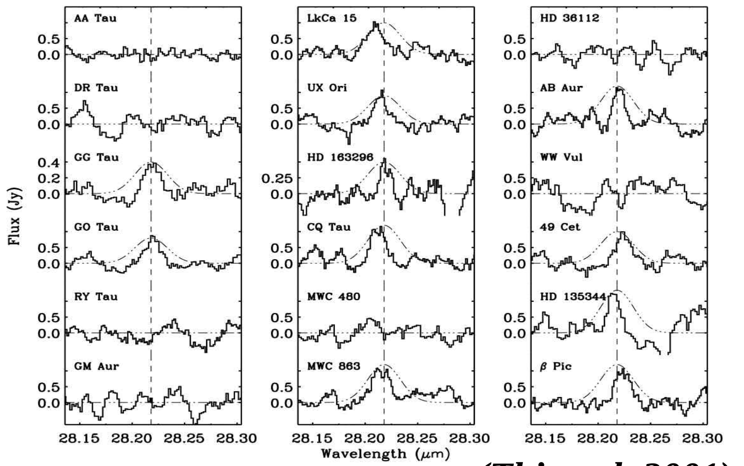


(Elia et al. 2002)



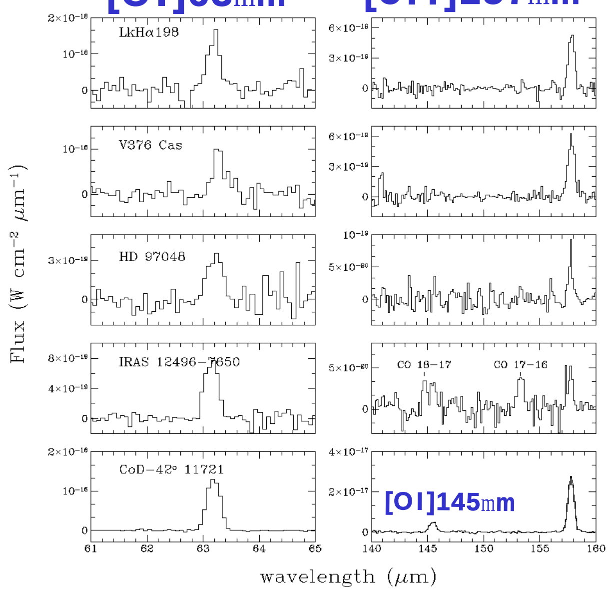
(Natta et al. 2001)

H_2 from T Tauri and HAeBe disks



(Thi et al. 2001)

PDR in the HAeBe envelopes



(Lorenzetti et al. 1999)

Survey of the Far Infrared Spectra of Young Stellar Objects

Objectives:

1 Study the gas excitation mechanisms in the circumstellar environments of different classes of sources _ statistical approach

1 Define how the different gas cooling channels evolve with the source age

1 Constrain the SEDs of YSOs

1 Provide a database for future space missions

Analyzed sample

_ 56 sources in different evolutionary phases

- **17 Class 0 sources**

  (out of the 45 listed by Andre` et al. 2000)
- **11 Class I sources**

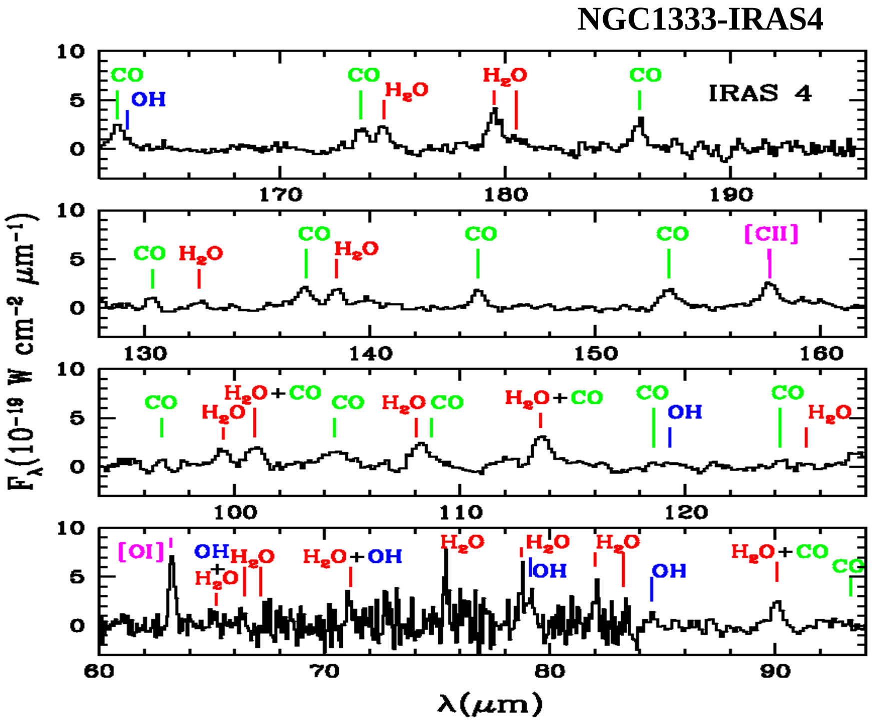
  (all the low luminosity (L< 50 Lo) from the LWS-GT observations)
- **26 Class II sources (Herbig Ae/Be)**

  (out of the 108 known (The` et al. 1994)

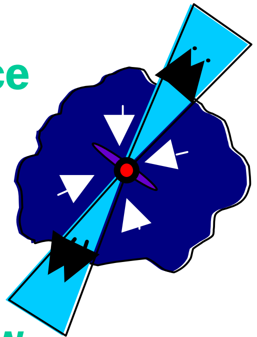
γFull LWS grating scans of star + outflow system

References: Lorenzetti et al. 1999, 2002; Giannini et al. 1999; Giannini, Nisini, Lorenzetti 2001; Nisini, Giannini, Lorenzetti 2002; Elia et al. 2002

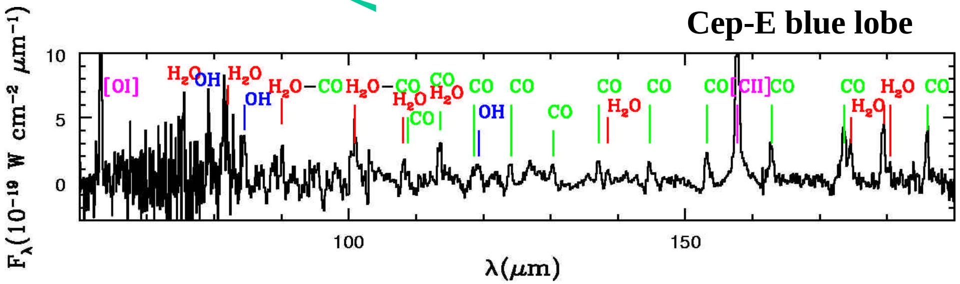
Low mass embedded young stellar objects (Class 0/Class I)



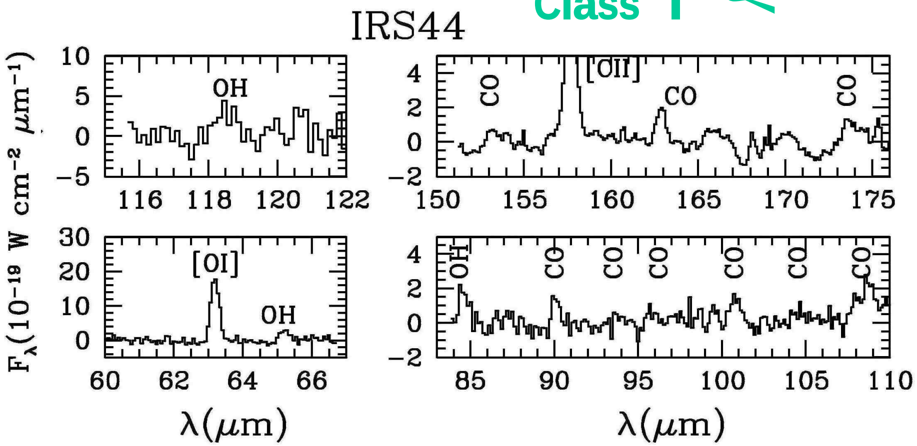
Class 0 on-source



Class 0 outflow

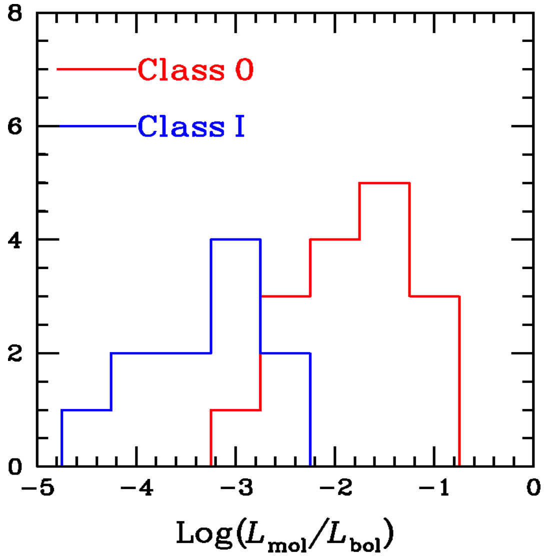


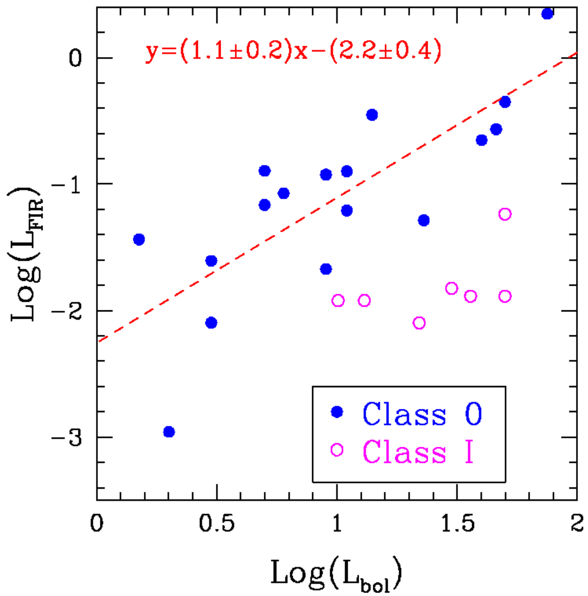
Class I



- Strong molecular emission from dense and warm gas (n=10^4-10^6 cm^{-3}, T=300-1500 K)
- Most of the emission likely coming from shocks
- Water observed only in Class 0 sources

Criteria to distinguish Class 0 protostars:





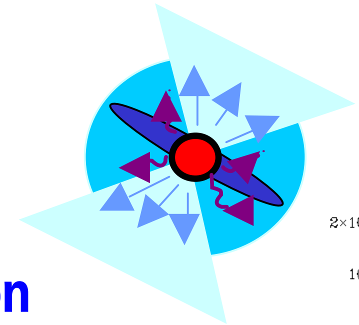
$L_{mol} = L_{H_2O} + L_{CO} + L_{OH} + L_{H_2}$ $L_{FIR} = L_{mol} + L_{OI}$

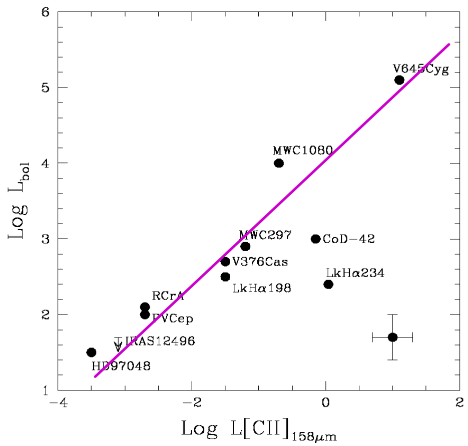
For Class 0 sources:

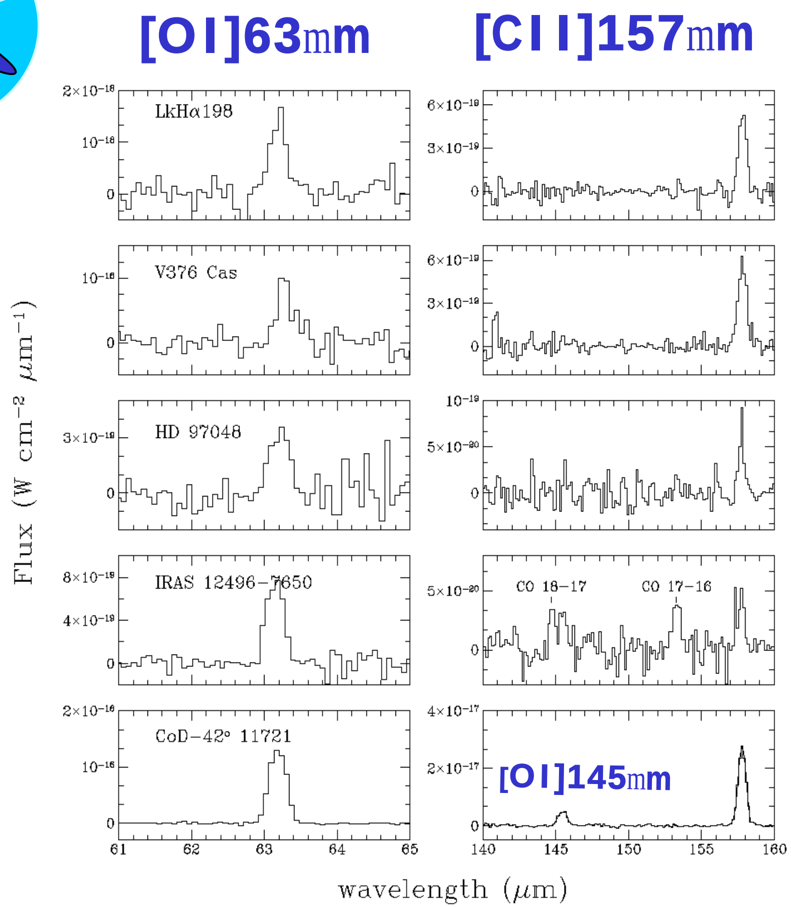
- $L_{FIR} \sim 10^{-2}\ L_{bol}$
- $L_{mol}/\ L_{bol} > 5\ 10^{-3}$
- X(H2O) > 10^{-5} Þ H_2O traces temporal scales of the order of 10^4-10^5 yrs

Class II sources of intermediate mass (Herbig Ae/Be)

- **densities < 10^4 cm^{-3}**
- **Mainly atomic emission**
- **Molecular emission only towards density peaks**
- **excitation mainly due to stellar photons**







Conclusions:

A lot of work still remain to be done with the ISO data

Most needed:

- γ COMPLETE SURVEYS OF CLASSES OF OBJECTS
- γ SEDs (four instruments)
- γ complete line lists from SWS+LWS spectra
- γ catalogues of embedded sources observed with CAM

BUT:

γ understand which fraction of the data are scientifically useful (e.g. PHT data or spectroscopic data with small integrations)

γ interaction with P.I. to become aware of possible problems (why these data have not been published?)