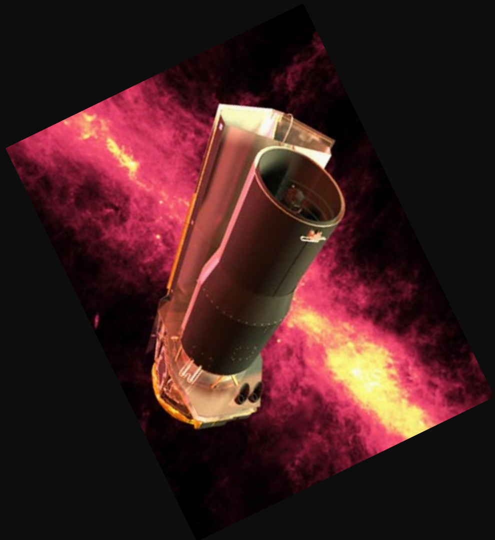
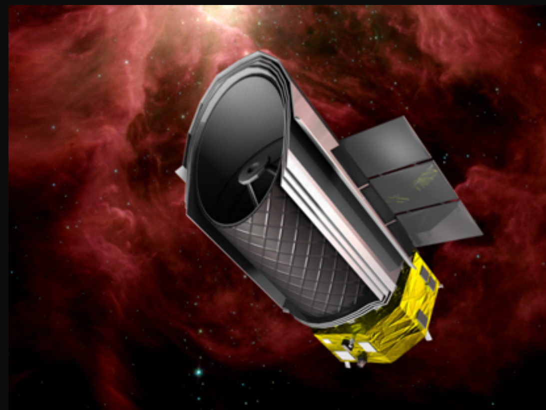
Star formation: from Herschel to SPICA

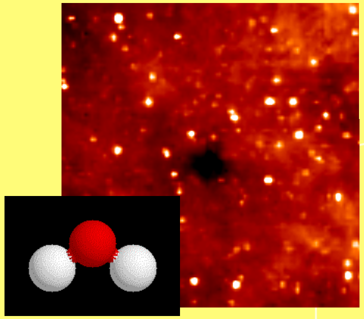




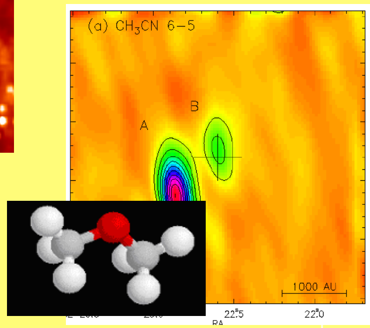
Cecilia Ceccarelli
Institut de Planétologie et d'Astrophysique de Grenoble

Some related reviews:
Van Dishoeck 2004, ARAA; Nisini et al. 2005, SSR; Ceccarelli et al. 2007, PPV; Melnick 2009, ASP; Evans 2011, IAU; Caselli & Ceccarelli 2012 AAR

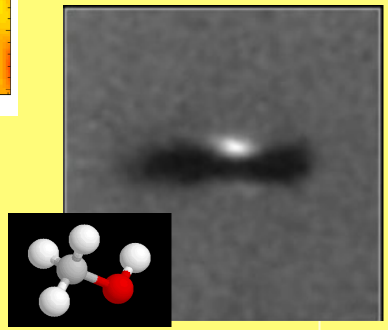
FROM A DIFFUSE CLOUD TO A SUN + PLANETARY SYSTEM
FROM ATOMS & SIMPLE MOLECULES TO LIFE



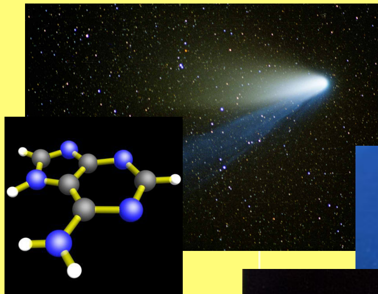
1- PRE-STELLAR PHASE: cold and dense gas
FORMATION OF SIMPLE MOLECULES

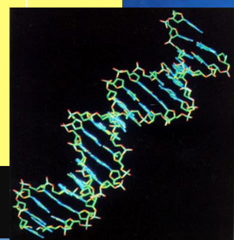


2- PROTOSTELLAR PHASE: collapsing, warm dense gas
FORMATION OF COMPLEX MOLECULES



3- PROTOPLANETARY DISK PHASE:
cold and warm dense gas
SIMPLE & COMPLEX MOLECULES





4- PLANETESIMALS FORMATION : grains agglomeration

5- PLANETS FORMATION AND THE "COMETS/ASTEROIDES RAIN"
CONSERVATION AND DELIVERY OF OLD MOLECULES + LIFE

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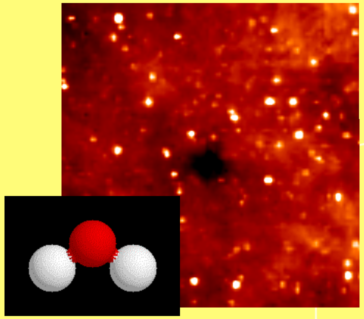

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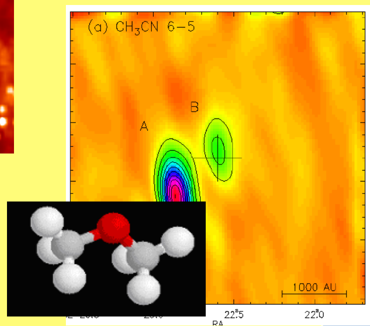

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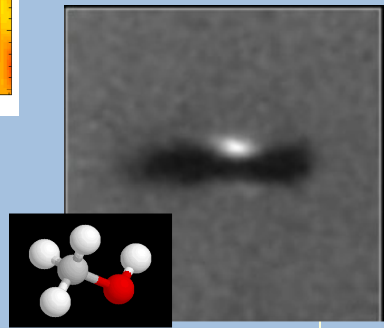

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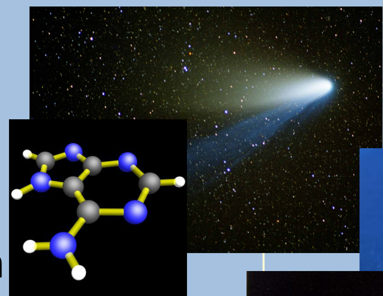

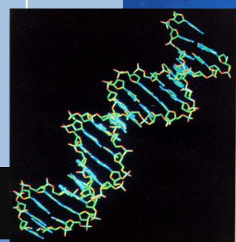

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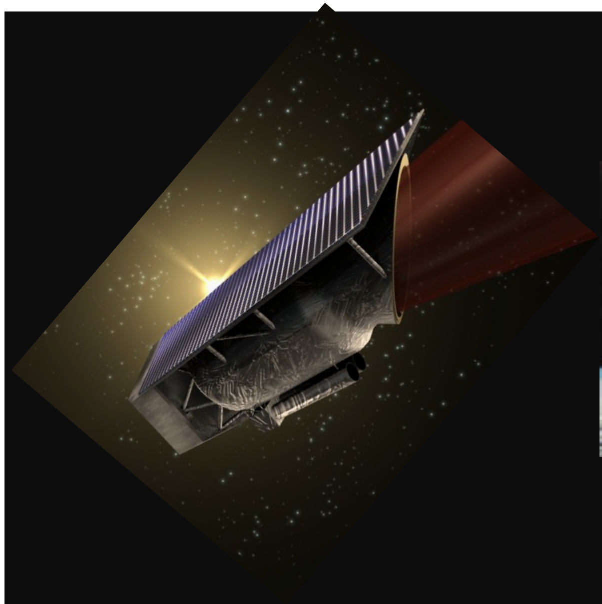
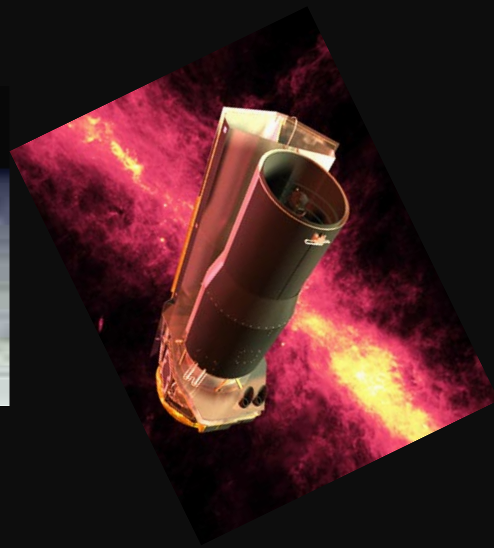
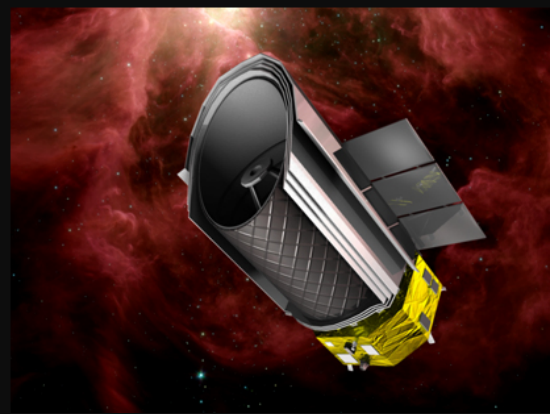


OUTLINE

1. The census
2. The structure
3. The chemistry
4. The outflow



From ISO, SPITZER, AKARI… HERSCHEL to SPICA:
the heritage and open questions

OUTLINE

1. The census
2. The structure
3. The chemistry
4. The outflow

THE CENSUS

IN ORDER TO STUDY THE STRUCTURE AND EVOLUTION OF PROTOSTARS WE NEED TO HAVE THE OBJECTS TO STUDY: THE LARGEST POSSIBLE SAMPLE COVERING THE LARGEST POSSIBLE ENVIRONMENT CONDITIONS, POSITIONS IN THE GALAXY, AND EVOLUTIONARY STATUS.

WE NEED A CENSUS OF THE PROTOSTARS IN OUR GALAXY

THE CENSUS

IRAS: THE START OF THE STORY WITH THE FIRST CATALOGUE

LIMITED SENSITIVITY, SPATIAL RESOLUTION AND FREQUENCY COVERAGE

➔ DEFINITION OF CLASS I, II, III

GROUND BASED SURVEYS IN THE IR AND mm

➔ INTRODUCTION OF CLASS 0 (and CLASS –I /prestellar cores)

ISO: ISOCAM MAPPED IN THE MIR (7 and 14 μm) A FEW deg^2 OF NEARBY STAR-FORMING REGIONS

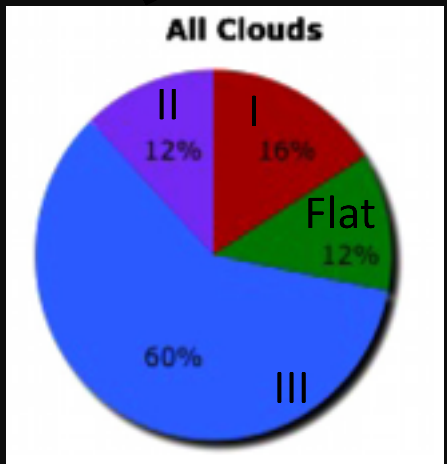
SPITZER: MAPPED 15.5 deg^2 OF FIVE LARGE NEARBY MOLECULAR CLOUDS

➔ DISCOVERY OF THE VELLOS

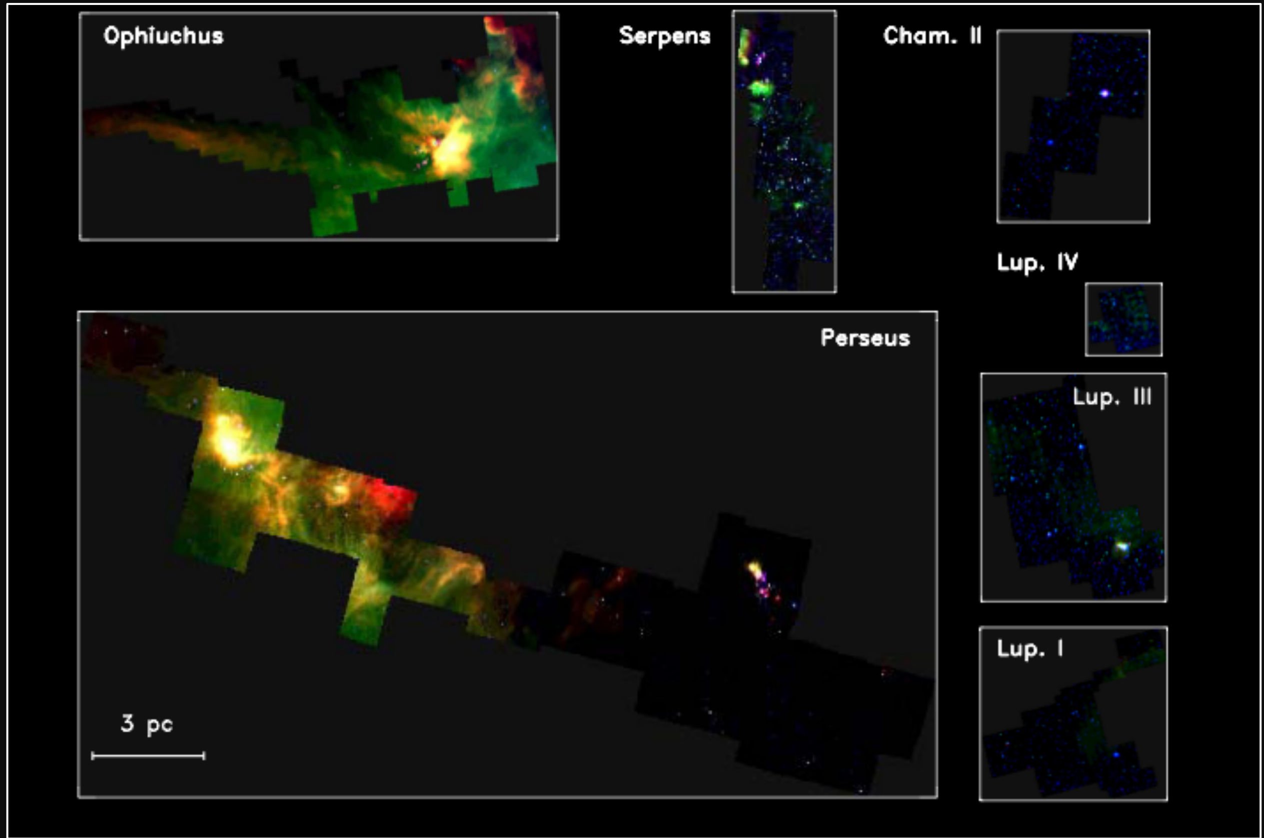
HERSCHEL: FULL MAP OF THE GALACTIC PLANE AND OF THE GOULD BELT STAR FORMATION REGIONS

➔THE UBIQUITY OF FILAMENTS AND THEIR IMPORTANCE (Sergio Molinari's talk)

THE SPITZER SURVEY of the Core to Disk (c2d) LP (Evans et al. 2003)



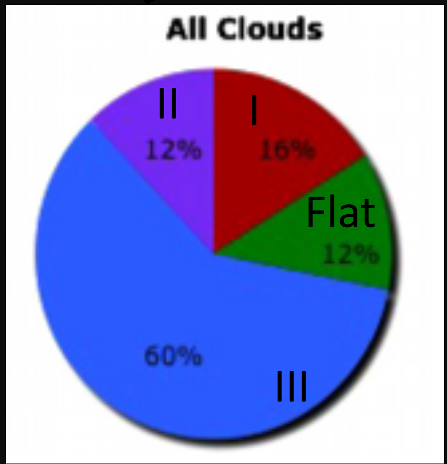
RESULTS



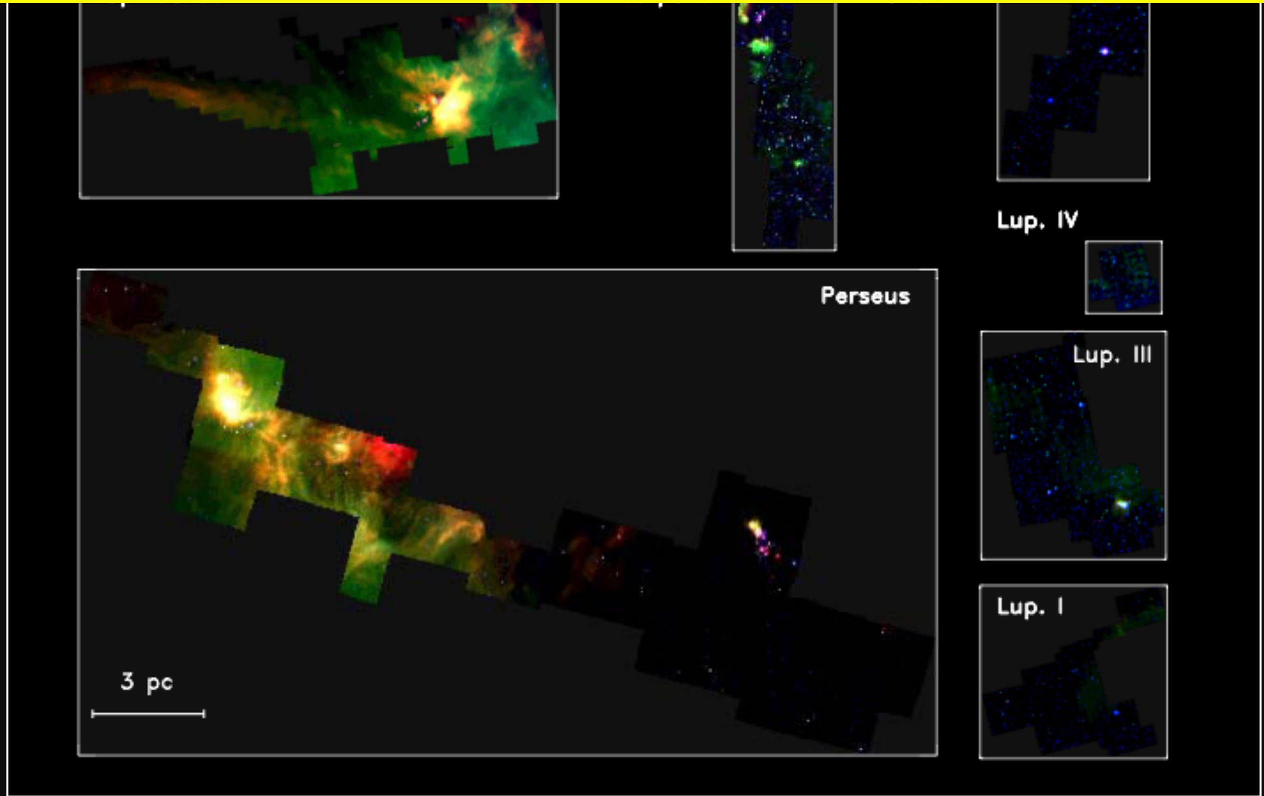
Evans et al. 2009

- RIVISITED LIFETIMES: ≈2Myr Class II, ≈0.5Myr Class I, ≈0.16-0.043 Class 0
- CONFIRMATION OF THE “LUMINOSITY PROBLEM”→NON-STEADY ACCRETION?

SPICA, A SUPER SPITZER/AKARI, WILL PROVIDE A HUGE DATASET AND LIKELY A NEW AND COMPLETE VIEW OF STAR FORMATION IN OUR GALAXY



RESULTS



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OUTLINE

1. The census
2. The structure
3. The chemistry
4. The outflow

THE STRUCTURE OF PROTOSTARS

WHY: WE WANT TO KNOW WHAT ARE THE DENSITY AND TEMPERATURE PROFILES TO UNDERSTAND WHAT ARE THE ACTORS/PROCESSES ENTERING THE STAR FORMATION PROCESS

OBSERVED PROFILES ⟷ **MODEL PREDICTIONS**

↓

How important are the magnetic fields, the turbulence? What did start the collapse?...

THE STRUCTURE OF THE PROTOSTAR

DERIVATION OF THE DENSITY AND TEMPERATURES PROFILES:

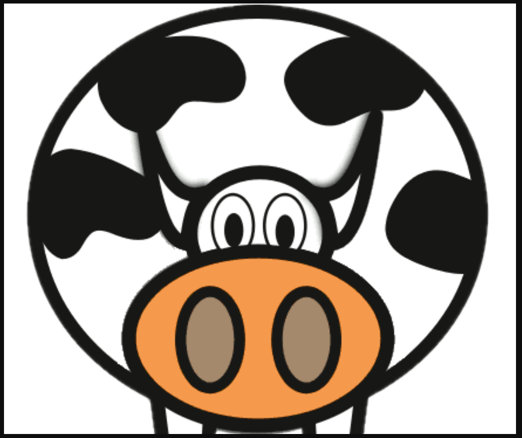
1) Dust density and temperature profiles

→ continuum spectral energy distribution + emission maps

2) Gas density and temperature profiles

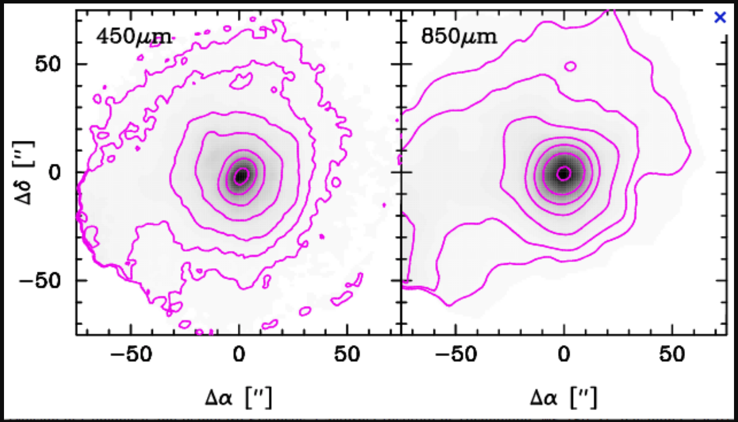
→ line spectra (emission + absorption)

OFTEN, SPHERICAL SYMMETRY ASSUMED, SOMETIMES 2-D, WITH THE ADDITION OF MORE PARAMETERS TO FIT

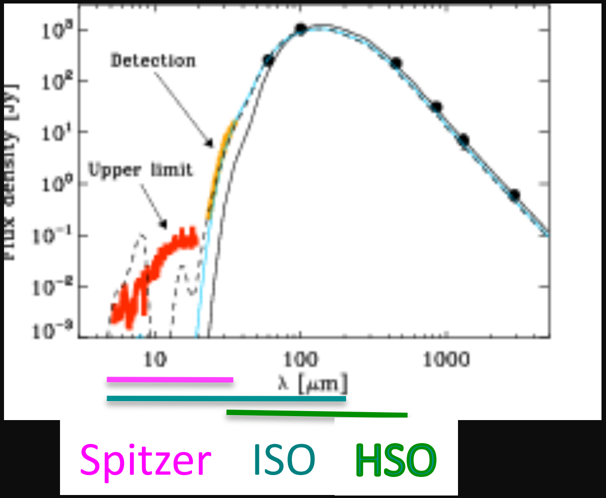


Dust temperature and density profiles

Shoier et al. 2002



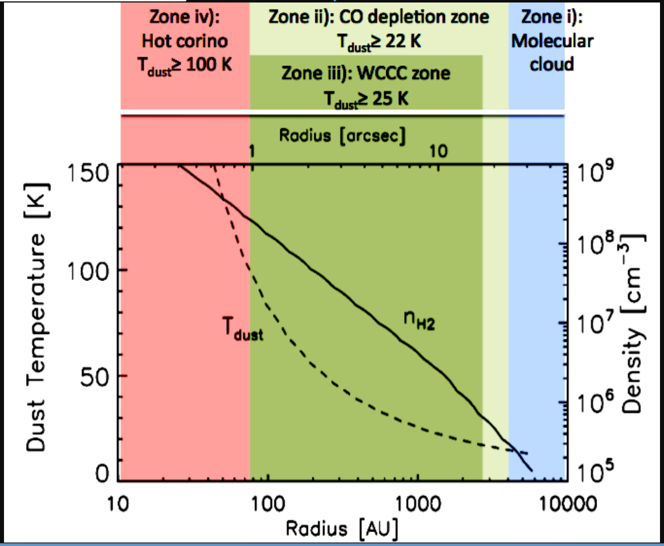
Schoier et al. 2007, Crimier et al. 2010



via dust radiative transfer modeling

e.g. DUSTY (Ivezik & Elitzur 1997, Withney et a. 2003; Robitaille et al. 2007, 2011)

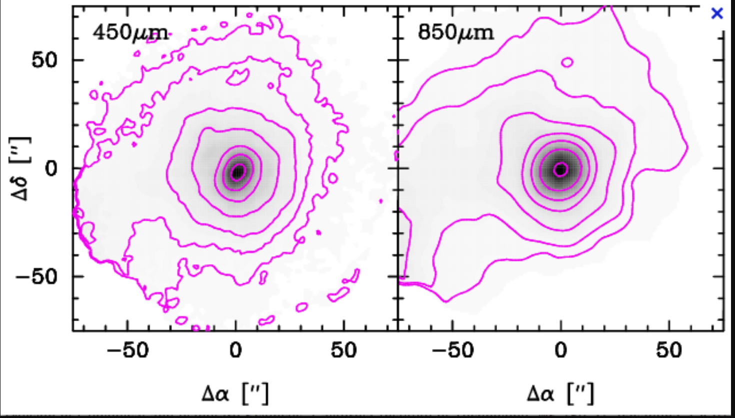
Crimier et al. 2010



Caselli & Ceccarelli 2012

Dust temperature and density profiles

Shoier et al. 2002



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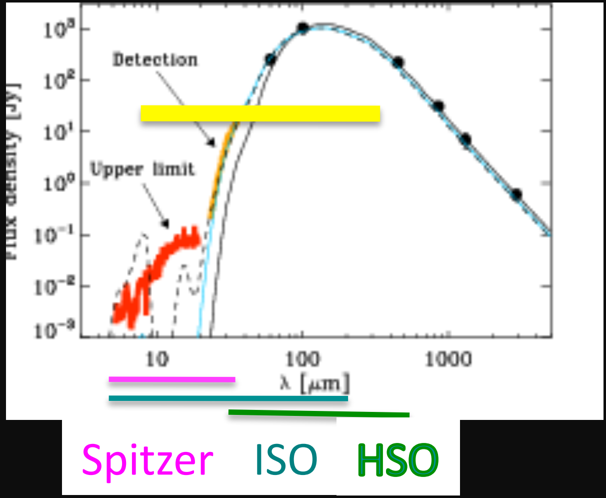

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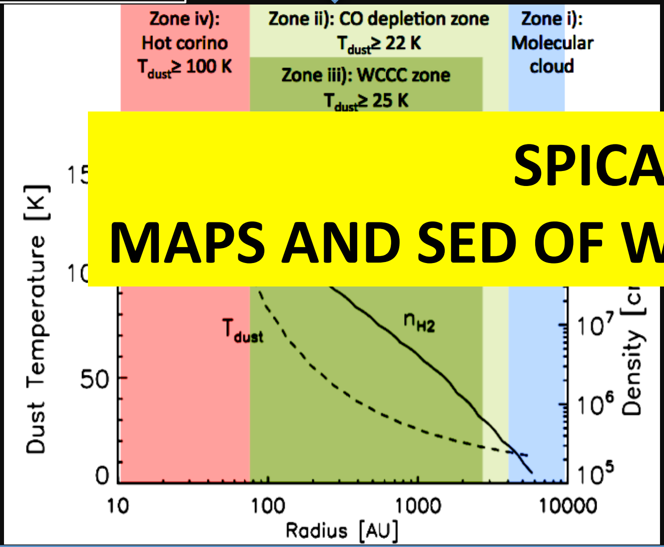


Ceccarelli 2012

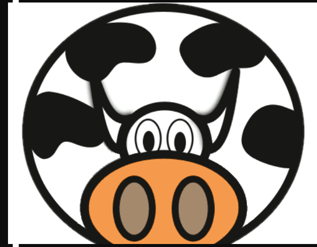
SPICA:

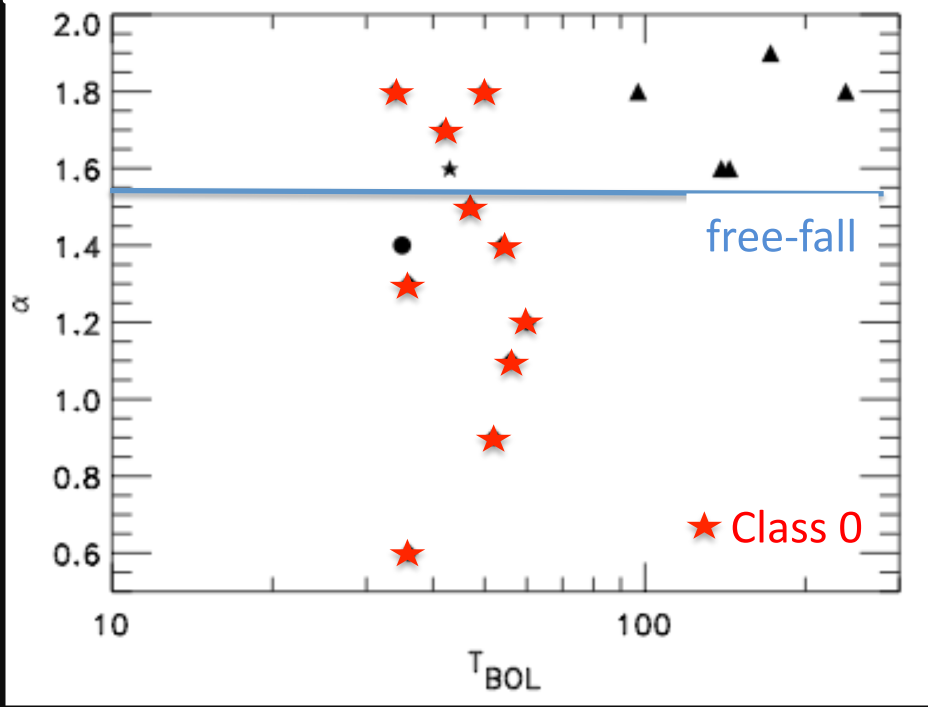
MAPS AND SED OF WEAK SOURCES

Dust temperature and density profiles

RESULTS

Most of the density profiles of Class 0 sources are consistent with the free-fall structure, within the error bars, with a few exceptions.





Jorgensen et al. 2002

QUESTIONS:

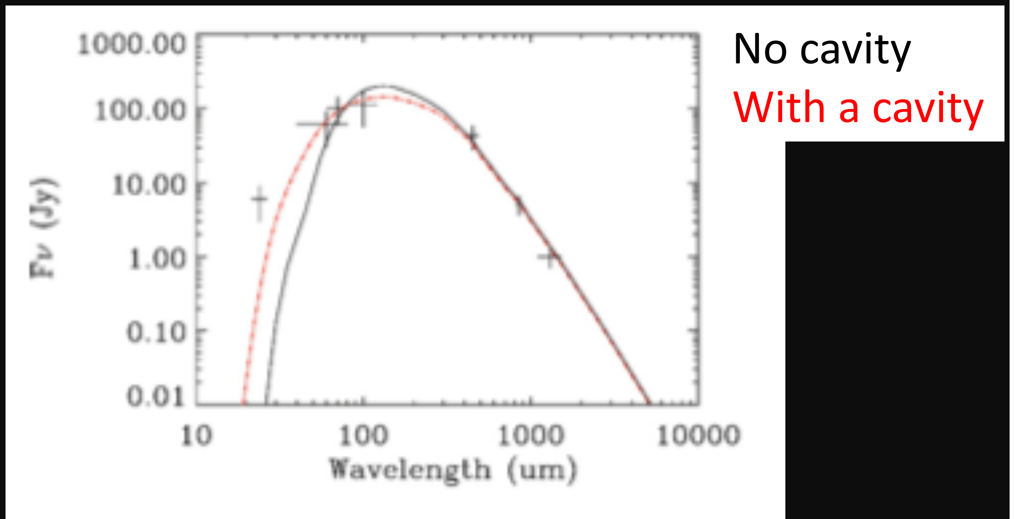
So far only the brightest objects have been modeled: what is the profile of low luminosity objects? Will they form ~1 M_o or << M_o stars ? Why, when and how?

=> Study of hydrostatic cores?

Dust temperature and density profiles

BUT IS THE COW REALLY SPHERICAL?

THE SPITZER AT 20-60mic OBSERVATIONS HAVE RAISED THE QUESTION WHETHER LARGE CAVITIES ARE PRESENT IN SOME PROTOSTELLAR ENVELOPES (e.g. Schoier et al. 2004, Jorgensen et al. 2005)



Crimier et al. 2010

THE CAVITY MODEL FITS THE SPITZER DATA BUT NOT THE LARGE SCALE MAPS (e.g Crimier et al. 2010)

..???....

IS THE NIR DUE TO A DISK?

Dust temperature and density profiles

SPICA WITH ITS 2-ORDERS OF MAG BETTER SENSITIVITY
WILL HAVE CERTAINLY A KEY ROLE TO PLAY HERE:

1. STUDY OF NEARBY LOW LUMINOSITY PROTOSTARS: HYDROSTATIC CORES?
2. STUDY OF DISTANT LOW-MASS PROTOSTARS: IS STAR FORMATION IN DIFFERENT ENVIRONMENT MUCH DIFFERENT TOO?
3. STUDY OF THE GEOMETRY (COMPLEMENTARY TO ALMA STUDIES): WHY NIR IS BRIGHT IN MANY EMBEDDED PROTOSTARS?

OUTLINE

1. The census
2. The structure
3. The chemistry
4. The outflow

THE CHEMICAL COMPOSITION

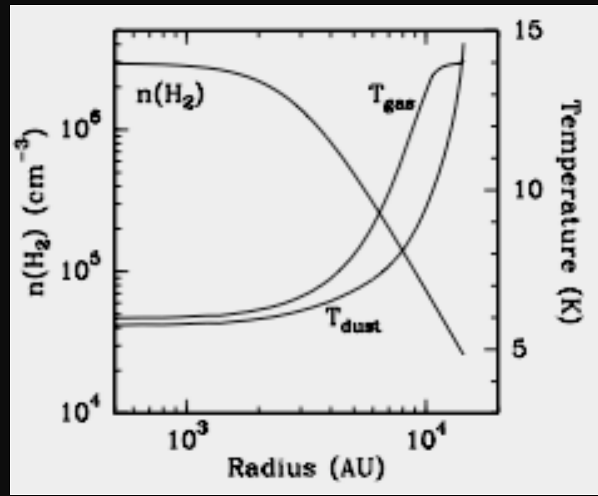
WHY: WE WANT TO KNOW WHAT IS THE CHEMICAL COMPOSITION ACROSS THE ENVELOPE TO UNDERSTAND THE PHYSICAL STATUS OF THE GAS AND THE HISTORY OF THE PROTOSTAR

OBSERVED SPECIES ⟷ **MODEL PREDICTIONS**

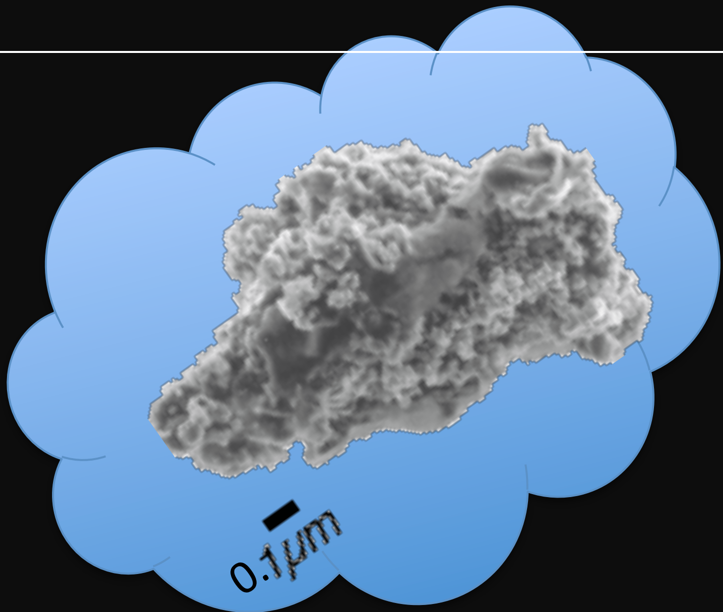
How is the gas cooled? What is the ionization? Why? Which species are in the gas phase, which are frozen? Why? What is the age of the protostar? What is the molecular complexity during the star formation process?...

PRE-COLLAPSE PHASE AND THE ICED DUST MANTLES FORMATION

BEFORE THE ONSET OF THE COLLAPSE, THE CONDITIONS (LOW TEMP AND HIGH DENS) ARE PROPITIUS TO THE FORMATION OF ICED DUST MANTLES



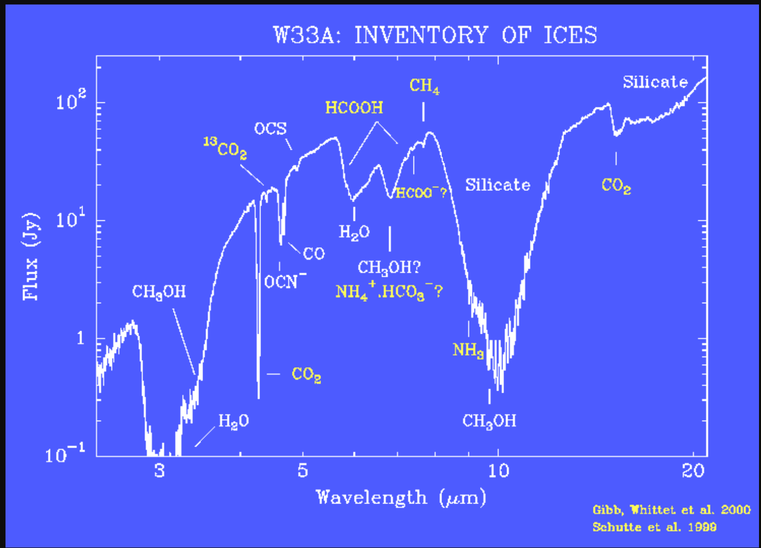
Caselli et al. 2012

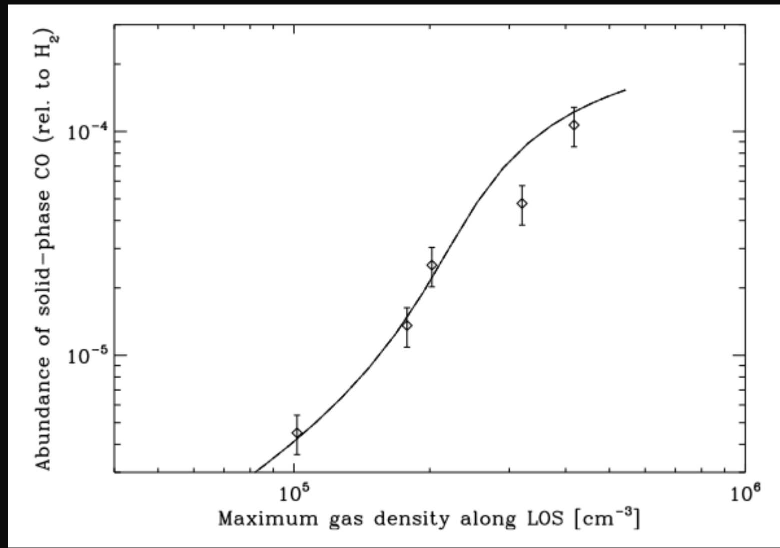


1) MOLECULES like CO FREEZE OUT ONTO THE DUST GRAINS
2) O, N, CO HYDROGENATION ON GRAINS FORM H_2O, NH_3, H_2CO, CH_3OH…

COMPOSITION OF THE GRAIN MANTLES

Whittet et al. 2010



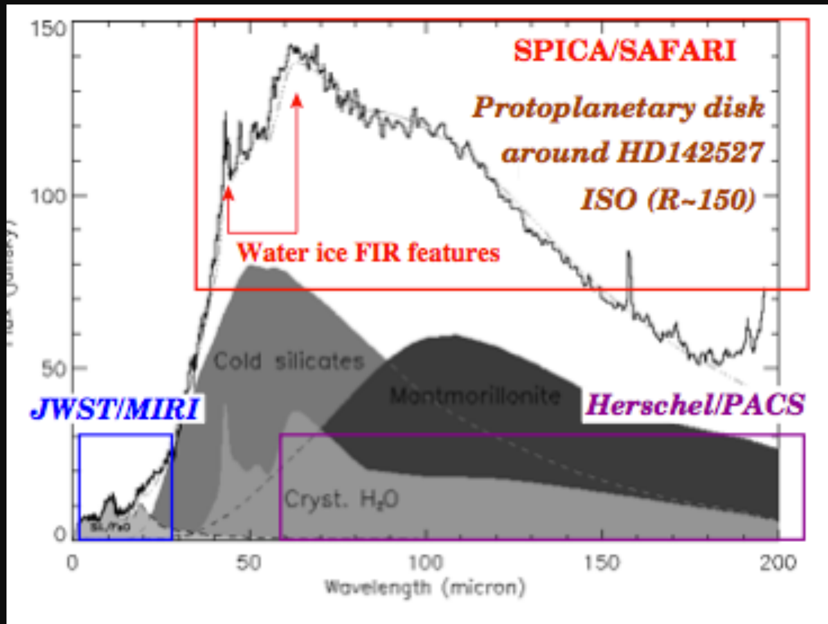


Pontoppidan 2006

ISO started the revolution, by providing the composition of the ices in massive protostars

SPITZER and AKARI provided the composition of (bright) low mass protostars

COMPOSITION OF THE GRAIN MANTLES

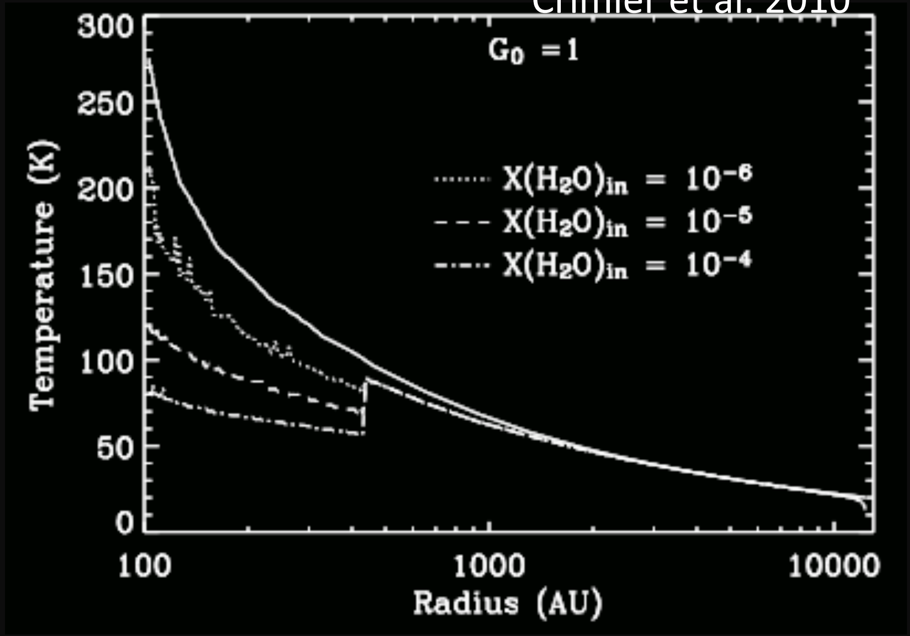


SPICA WILL PERMIT TO STUDY THE
ICE COMPOSITION AND GRAIN MINERALOGY
IN A HUGE SAMPLE OF PROTOSTARS (AND DISKS)

WATER: THE DOMINANT COOLANT IN THE INNERMOST WARM REGIONS (HOT CORES/CORINOS)

MODELS PREDICT THAT THE GAS MAY BE THERMALLY DECOUPLED BY THE DUST AT THE BORDER AND IN THE INNER REGION (WHERE $T_{DUST}>T_{ICE-SUBLIMATION}$) OF THE ENVELOPE, DEPENDING ON THE WATER ABUNDANCE IN THE INNER REGIONS.

Crimier et al. 2010



QUESTIONS:

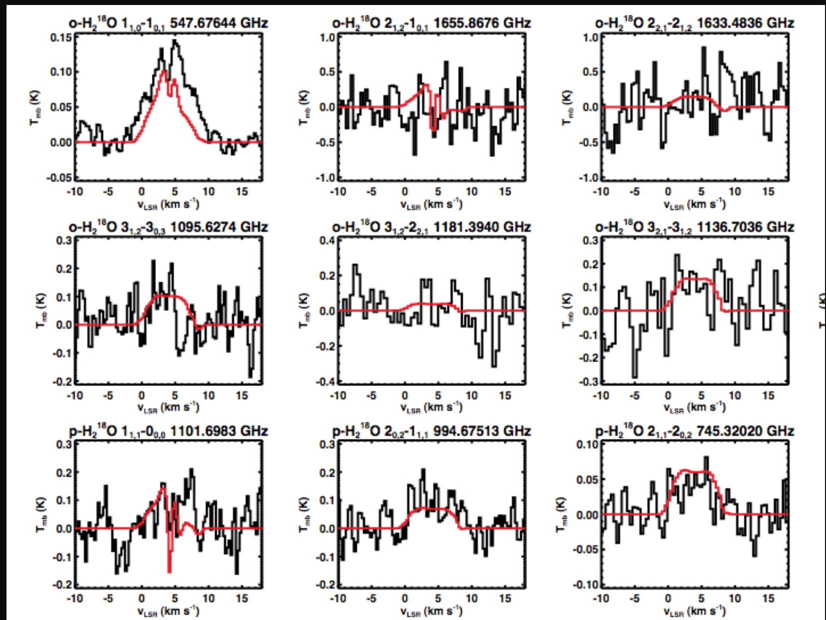
Does the thermal decoupling influences the dynamical collapse? How does it depend on the water abundance?

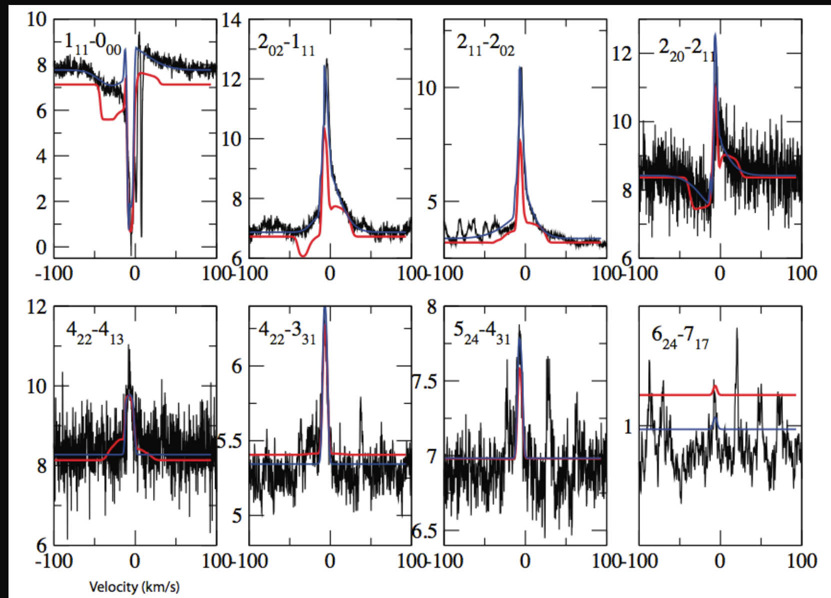
Gas temperature profile

HERSCHEL IS PROVIDING A MINE OF NEW DATA IN

LOW AND HIGH MASS PROTOSTARS

Coutens et al. 2012





Emprechtinger et al. 2013

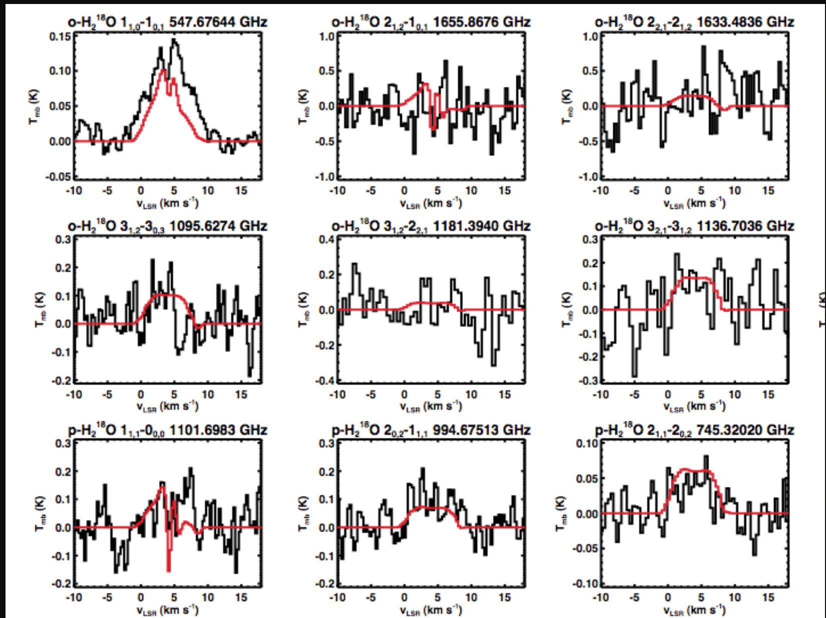
THE ABUNDANCE MEASURED IN THE HOT CORES/CORINOS SEEMS TO BE $<10^{-4}$ (=THE ABUNDANCE OF ICED WATER): WHY?

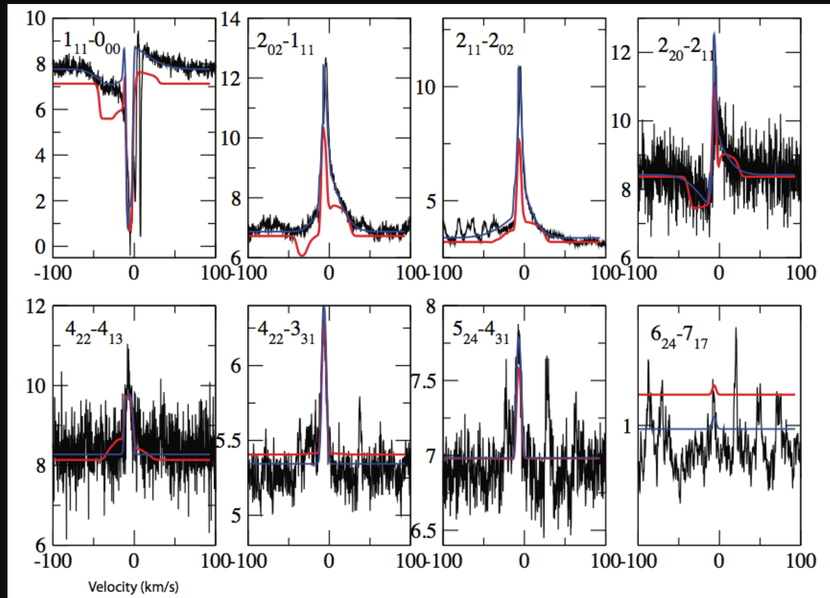
Gas temperature profile

HERSCHEL IS PROVIDING A MINE OF NEW DATA IN

LOW AND HIGH MASS PROTOSTARS

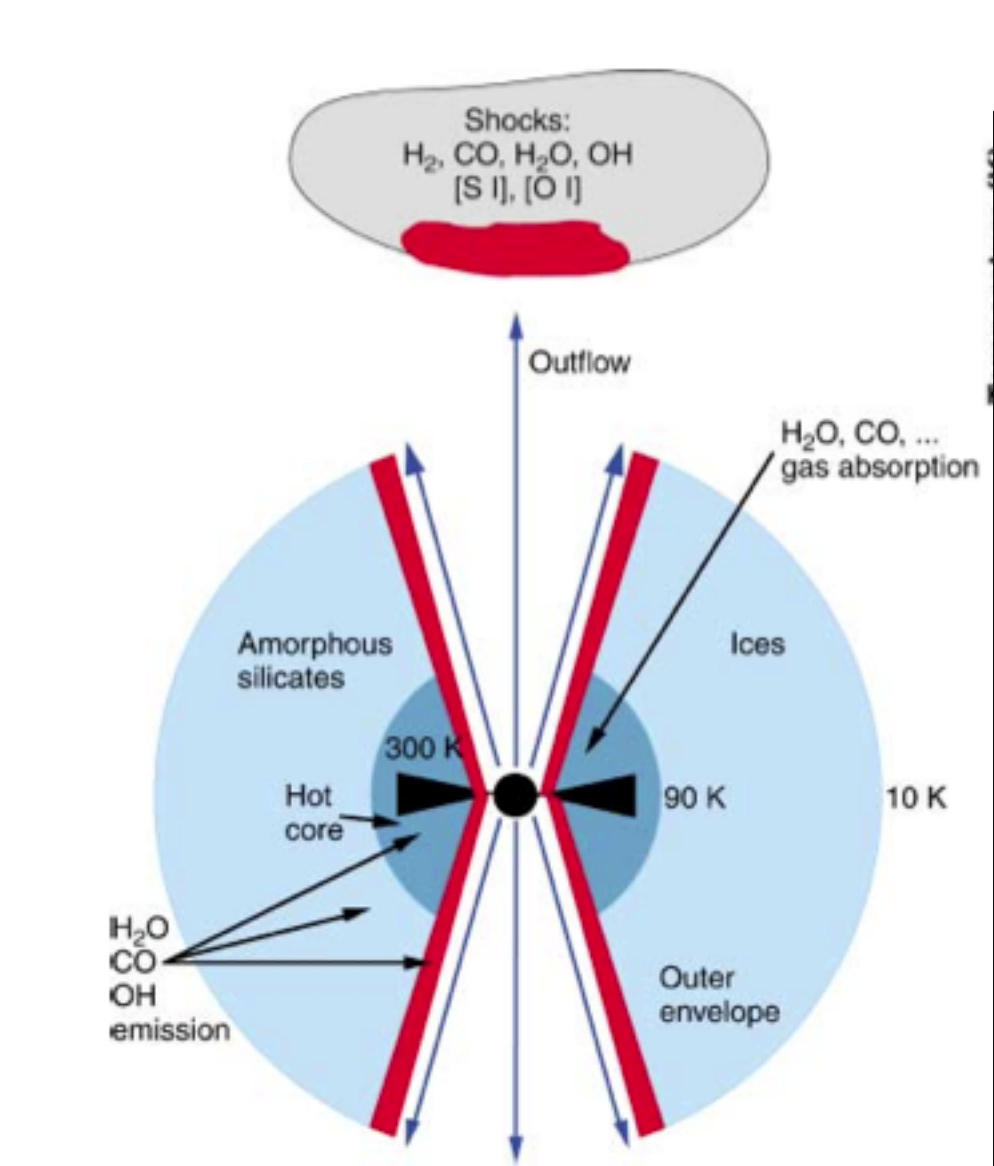
Coutens et al. 2012





Empreichtinger et al. 2013

SPICA WILL ALLOW TO STUDY A LARGE SAMPLE, EVEN THOUGH IT WILL NOT HAVE THE SPECTRAL RESOLUTION, PROVIDING A LARGE NUMBER OF H_2O LINES @38-210μm



ADAPTED FROM
van Dishoeck 2004, ARAA

ISO TO HERSCHEL STUDIES PROVIDE A COMPLEX PICTURE OF THE STRUCTURE OF LOW-MASS PROTOSTARS:

1. COLD ENVELOPE
2. HOT CORINO
3. INNER SHOCKS
4. UV ILLUMINATED GAS
5. INNER DISK