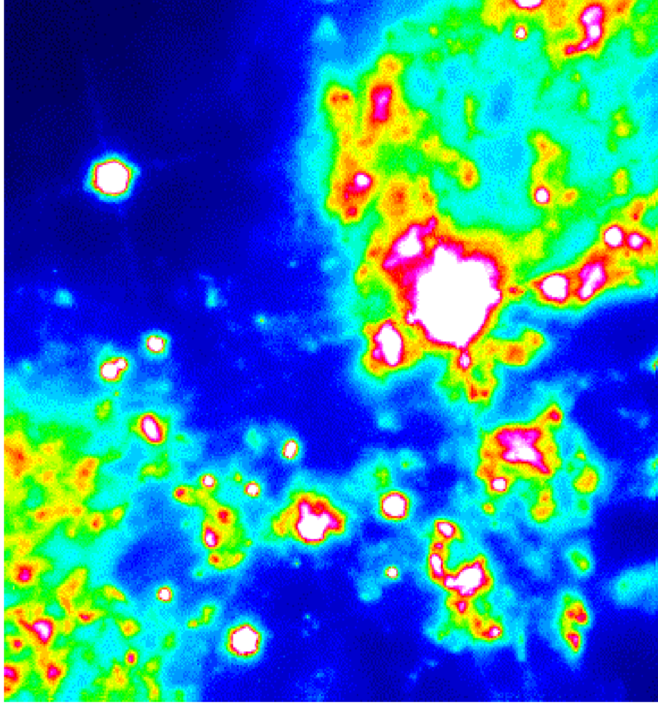
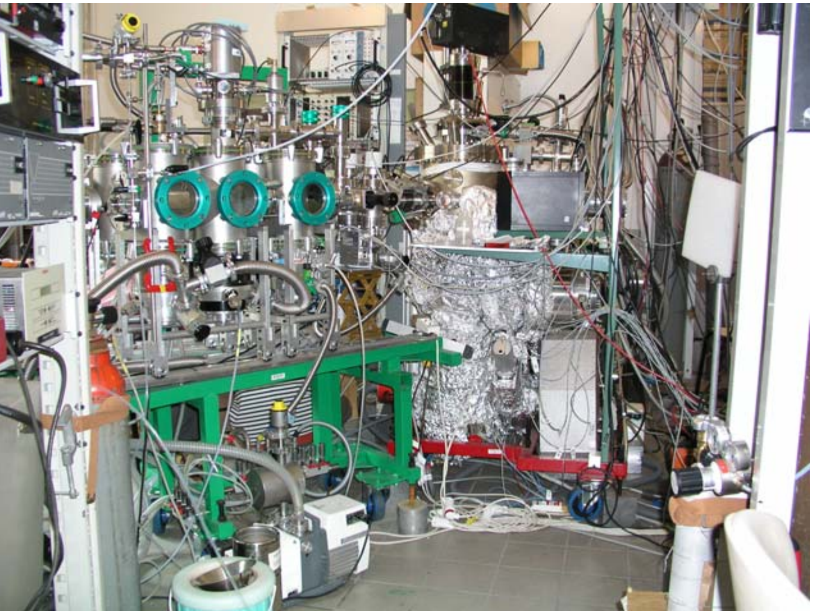
H_2

des régions de formation stellaire



à l'astrophysique de laboratoire



l'Observatoire de Paris

Université de Cergy-Pontoise

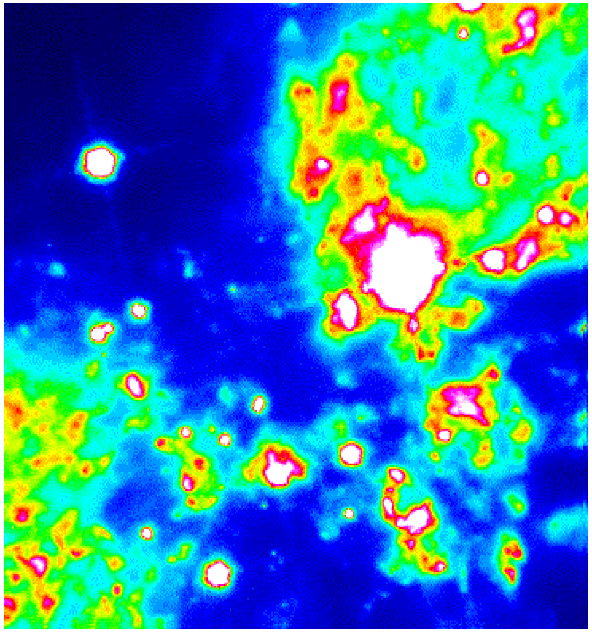
LERMA

Laboratoire d'Étude du Rayonnement et de la Matière en Astrophysique

Star Forming Regions

Reflexion Nebulae	(NGC 2023, NGC 7023)
Star Forming Regions	(OMC1, M17)
Dark Clouds	(Barnard 68, BHR 71)
Extragalactic regions	(N88 in the SMC)

Emission de H_2 dans l'IR,
bandes J, H, K, L et M



La tétralogie de l'Astrophysique

Buts: Interpréter les observations pour élucider les mécanismes en œuvre dans les "objets" étudiés.

Comparer leurs résultats à ceux des observations et déterminer ainsi de façon indirecte les caractéristiques des "objets"

Observational results

X, UV, Visible, IR,
Radio (submm, mm, cm)
Complex conditions

Theoretical modelling

Large chemical networks
Physical processes
Rate equations, numerical methods

Laboratory simulations

Simplified (?) conditions

Atomic and molecular data

Basic physics and chemistry
Laboratory spectroscopy

Expériences au laboratoire simulant dans des conditions simplifiées certains milieux étudiés

- mesurer les paramètres physiques et chimiques manquants pour une modélisation correcte

Importance in astronomy of the H_2 formation process on the star formation process

- stars form from the gravitational collapse of ISM clouds
- H_2 is the main constituent of the ISM
- the rate of gravitation collapse depends on a balance between:

gravitational forces compressing the material	internal pressure of the clouds resisting to compression

- requires knowledge of the exothermicity disposal in the cloud to model realistically the gravitational collapse

(1 or 2 orders of magnitude depending on the mechanism)

Nascent H_2 with internal energy (rovibrational) -> H_2 will cool through radiation of IR photons

Grain heating (no IR emission) -> cool H_2

The molecular cloud collapse more readily

Nascent H_2 with large translational and small internal energies -> Heating of the cloud

Slow collapse

How to extract informations from the observations ?

Numerical models

The main goal is to

-Deduce from the *H_2 line ratios, width, shift …*
measured at different locations

- the *physical conditions* of the medium

- the likely associated *excitation processes*.

Numerical shocks models

(Ref. Le Bourlot, Pineau des Forêts, Flower, Cabrit, 2002)

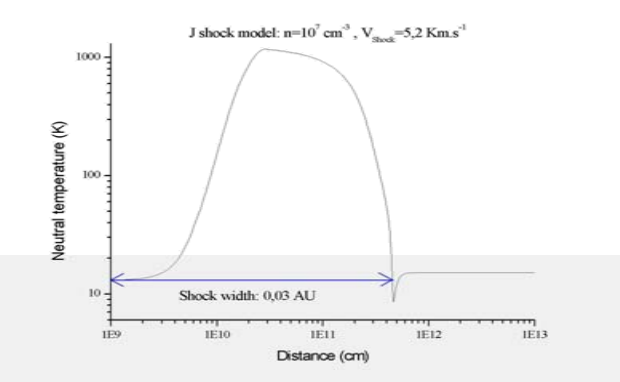
We use for this purpose ***interstellar medium evolution models with different shock types***.

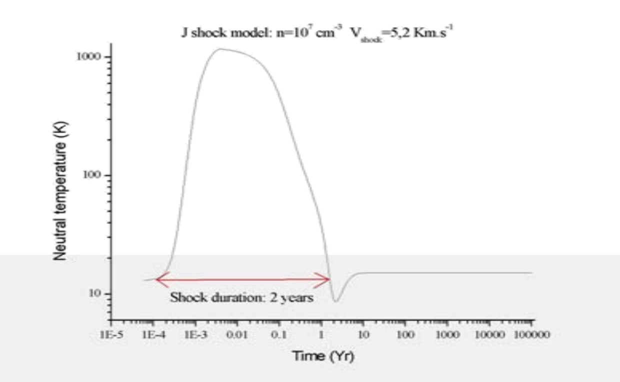
The planar, time-independent MHD equations (the magnetic field value is important to distinguish between J and C shocks) are solved in parallel with the chemical equations (self-consistent manner).

Complete set are also included of: chemical species, reactions,
momentum and energy transfer processes,
and **grain properties**

Shock models give (among many other results):

- The **absolute intensities** of many H_2 emission lines over a wide wavelength range.
- The evolution of the **main physical parameters** in the shock-dominated region (temperatures, densities…)





Numerical PDR models

(Ref. Le Petit, Roueff, Le Bourlot, 2002)

In PDRs (***Photon Dominated Regions***) H_2 excitation arises from *UV pumping*.

The stationary, 1-dimension model computes the cloud structure at each point solving (in parallel):

- The radiative transfer equations
- The chemical equilibrium equations
- The collisional excitation and de-excitation equations for all the species
- The thermal equilibrium equations

Essential parameters are the cloud density and the incident radiation flux falling onto the medium (depending on the background sources).

Recent modifications now allow:

- to treat the problem of clouds illuminated onto their **two faces**
- to use a **deuterium-based chemistry** in the calculations.

The set of species, ***grains properties*** *and other various parameters are basically the same than in the shock models.*

Photoionization code CLOUDY

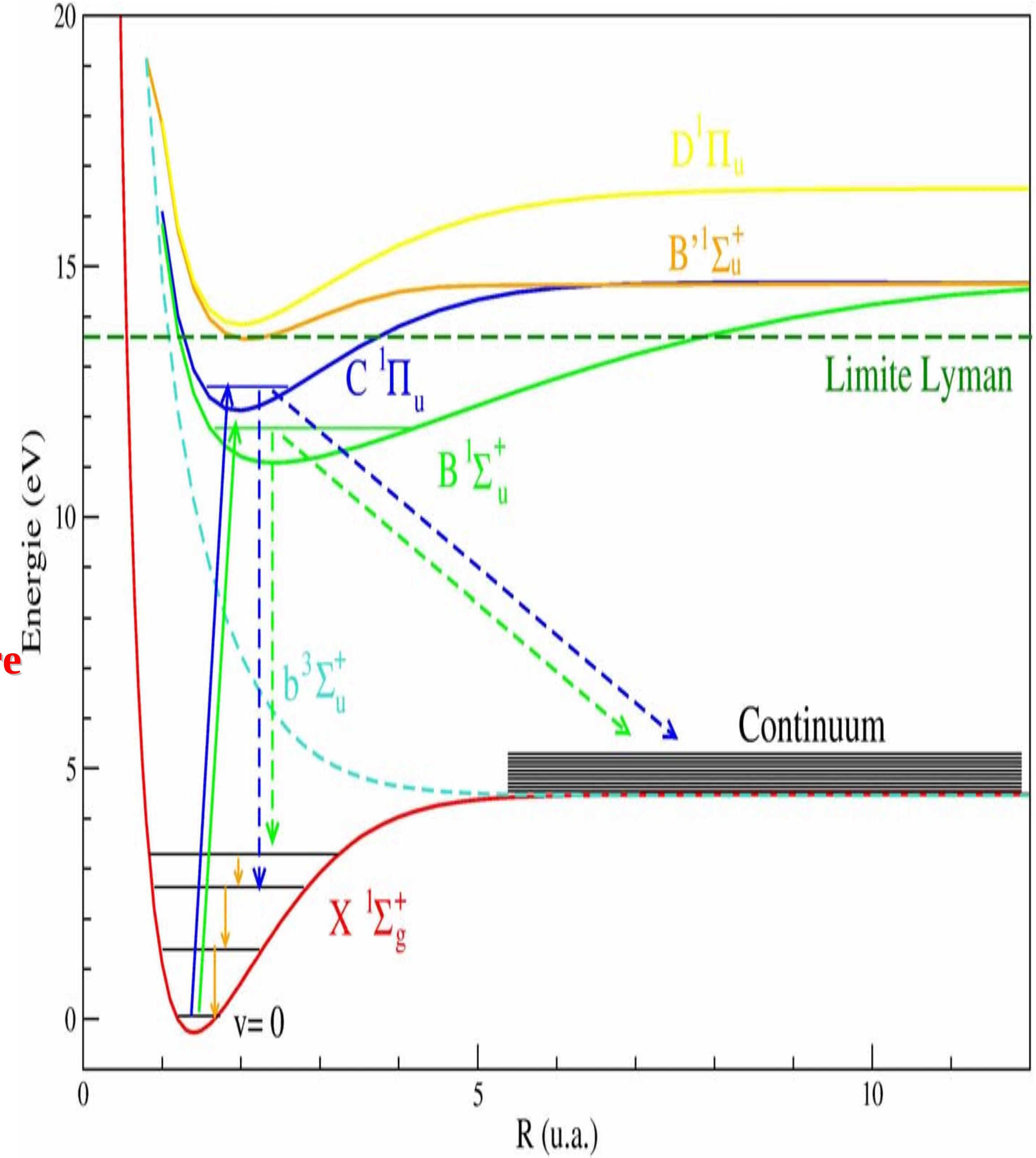
(Ref. Ferland, 2003)

To simulate non-equilibrium plasmas and predict their spectra.

Shock model program (Pineau des Forêts, Flower, Roueff, Le Bourlot)

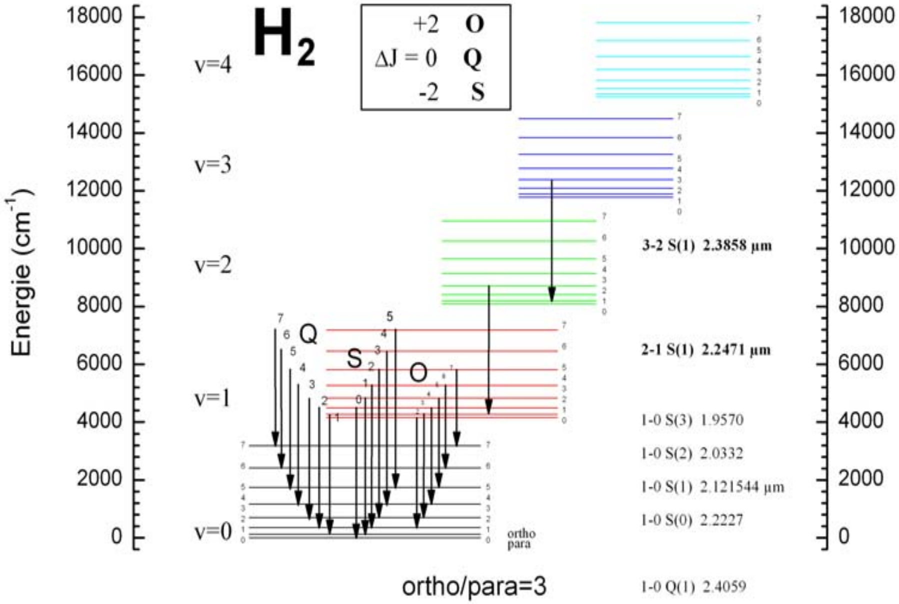
```
!---- shock parameters -------------------------------------------------------
C                        ! shock type : 'C' or 'J', Steady state : 'S'
3                        ! Nfluids : 1, 2 ou 3
1.0D0                    ! Bbeta -> Bfield = Bbeta * sqrt(nH)
30                       ! Vs -> shock speed (km/s)
1.0e3                    ! Vn - Vi initial (cm s-1)
0.01                     ! op_H2 -> initial H2 ortho/para ratio (999.9 -> ETL)
4.650                    ! T(n,i,e) -> initial gas temperature (K)
1.0D6                    ! nH_init -> initial value for n(H) + 2.0 n(H2) + n(H+) (cm-3)
15                       ! Tgrains -> initial grain temperature (K)
0                        ! Cool_KN -> 1: Kaufman & Neufeld cooling
!---- environment ------------------------------------------------------------
5.0D-17                  ! Zeta -> cosmic ray ionization rate (s-1)
0.D0                     ! RAD  -> flux radiation (multiplicative factor)
0.D0                     ! Av   -> initial extinction (magnitudes)
!---- numerical parameters ---------------------------------------------------
10000                    ! Nstep_max   -> max number of integration steps
5                        ! Nstep_w -> number of steps between 2 outputs
49                       ! NH2_lev -> Number of H2 levels included
150                      ! NH2_lines_out -> Max number of H2 lines in output file
BOTH                     ! H_H2_flag -> H-H2 collisions : DRF, MM or BOTH
1                        ! iforH2 -> Formation on grain model (1, 2, 3, 4)
2                        ! ikinH2 -> Kinetic energy of H2 newly formed (1, 2)
1.00D09                  ! XLL -> caracteristic viscous length (cm)
1.00D-7                  ! Eps_V -> precision of computation
3.00D8                   ! timeJ -> shock age (years)
2.00D8                   ! duration_max -> max. shock duration (years)
1                        ! Force_I_C -> 1: Force Ion Conservation
!---- output specifications --------------------------------------------------
FD                       ! species: 'AD' (cm-3), 'CD' (cm-2) or 'FD' (n(x)/nH)
AD                       ! H2 levels: 'AD' (cm-3), 'CD' (cm-2) or 'ln(N/g)'
local                    ! H2 lines: 'local' (erg/s/cm3) or 'integrated' (erg/s/cm2/sr)
!-----------------------------------------------------------------------------
  INTEGER:: iforH2 = 1   ! Flag : H2 formation on grains
                         !   0: 1/3 of 4.4781 eV in internal energy (=> 17249 K) (Allen, 1999)
                         !   1: Proportional to Boltzman Distrib at 17249 K
                         !   2: Dissociation limit : v = 14, J = 0,1 (4.4781 eV)
                         !   3: v = 6, J = 0,1
                         !   4: fraction = relative populations at t, initialised as H2_lev%density
                         !                and changed during integration

  INTEGER:: ikinH2 = 1   ! Flag : H2 formation energy released as kinetic energy
                         !   1: 0.5 * (4.4781 - internal)
                         !   2: Inf(1.4927 eV, 4.4781 - internal)
```

H_2 Spectroscopy



Principaux mécanismes à l'œuvre dans le MIS:

PDRs
Chocs
Formation de H_2 sur les grains



Transitions de H_2 dans la bande K

bandes

K J H

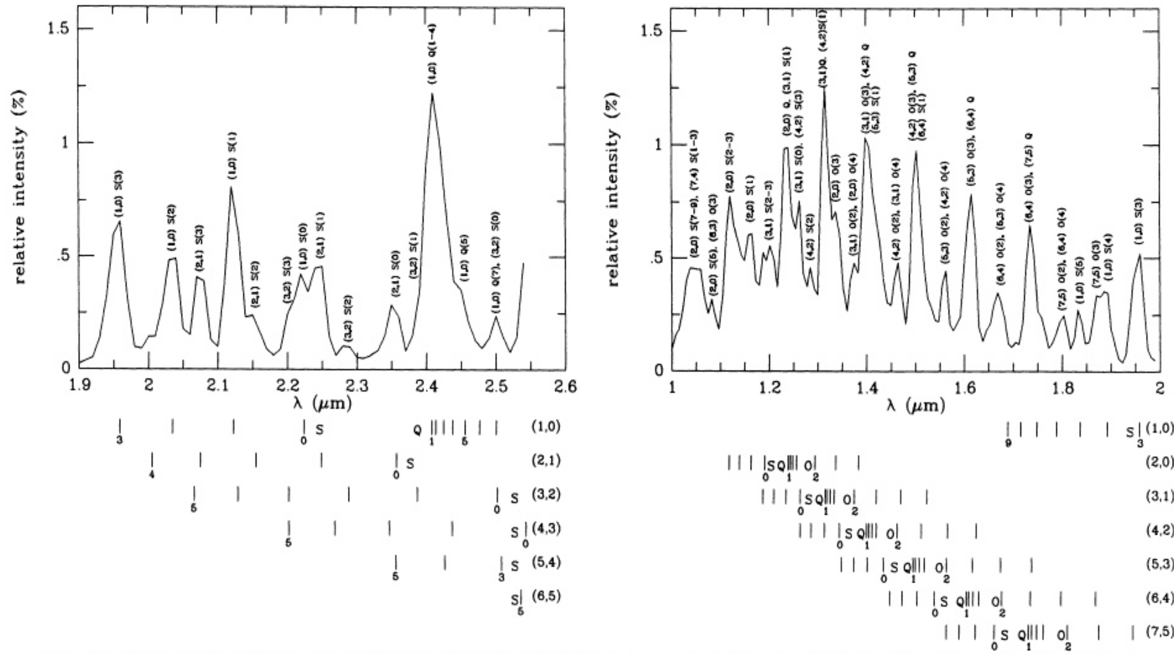


FIG. 2.—Simulated low-resolution spectra of H_2 emission in reference model 14. The model spectra have been convolved with Gaussians of width $\Delta\lambda = 0.02$ μm (*left*) and $\Delta\lambda = 0.015$ μm (*right*). Line positions in various vibration-rotation bands are indicated below each spectrum, and the major contributors to each strong feature are identified. The intensity is shown as a percentage of the total fluorescent intensity per resolution element; i.e., the intensity scale is in units $0.01 I_{total}/\Delta\lambda$, or 3.835×10^{-4} ergs s^{-1} cm^{-2} μm^{-1} sr^{-1} for the left panel and 5.113×10^{-4} ergs s^{-1} cm^{-2} μm^{-1} sr^{-1} for the right panel.

BHR71

3 colors composite image in the visible showing:

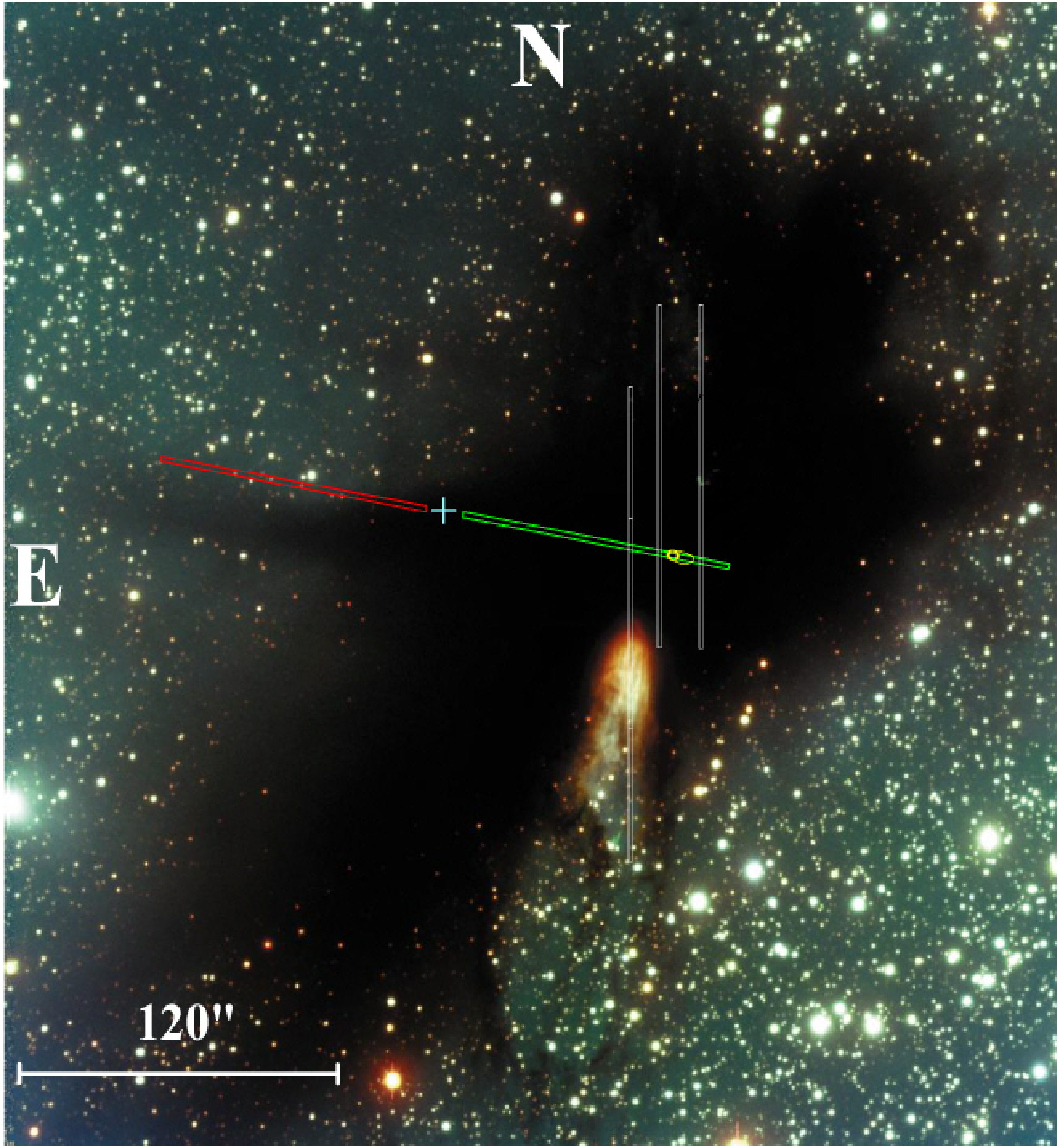
-The dark cloud which absorbs the light from the background stars

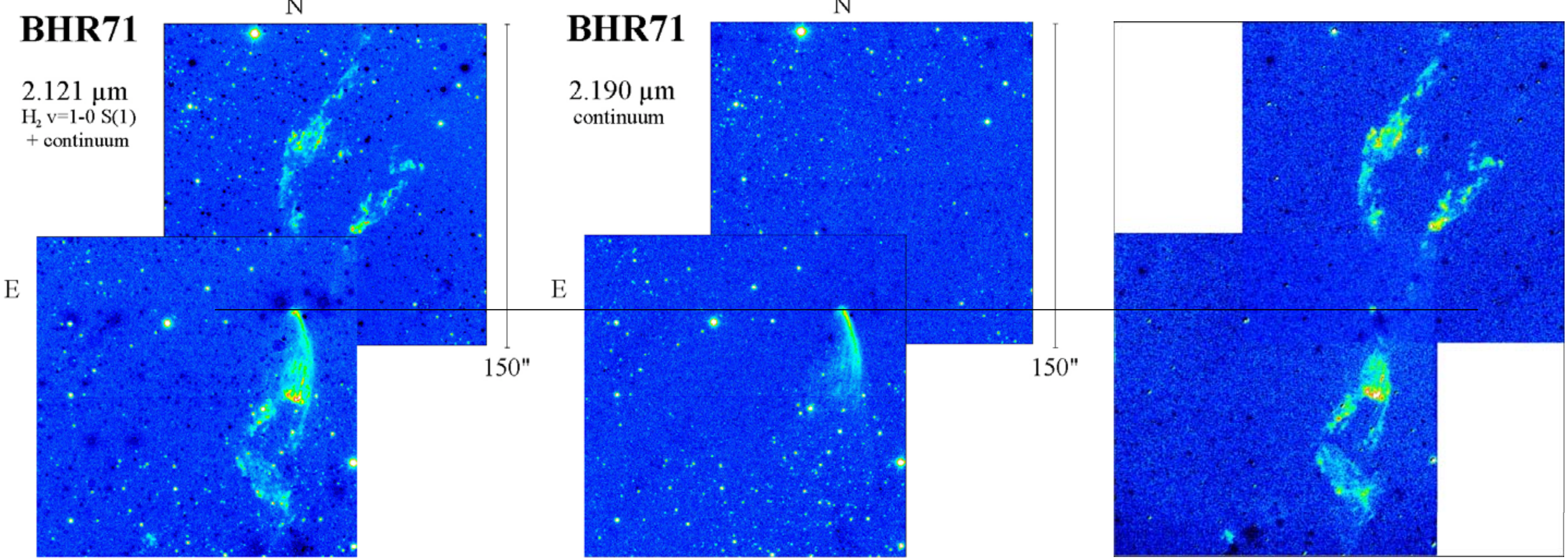
- A proto-star (IRS1) in formation inside the dark cloud and the associated ejecta to the South

- spectrograph slit positions used for this study are indicated

- Alves and Lada
The ESO Messenger n°103 March 2001

- Lemaire, Field, Pineau des Forêts, Callejo
Near infrared emission from a protostar in BHR71, ApJ in preparation





ESO - VLT (ISAAC) July 2002

ESO - VLT (ISAAC) July 2002

H_2 emission in the K band

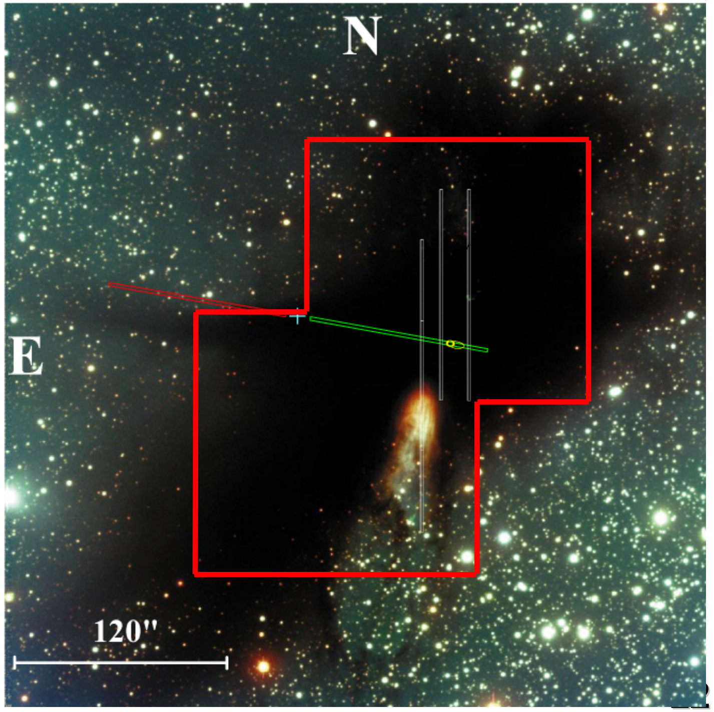
BHR71

3 colors composite image in the visible showing:

-The dark cloud which absorbs the light from the background stars

- A proto-star (IRS1) in formation inside the dark cloud and the associated ejecta to the South

- spectrograph slit positions used for this study are indicated

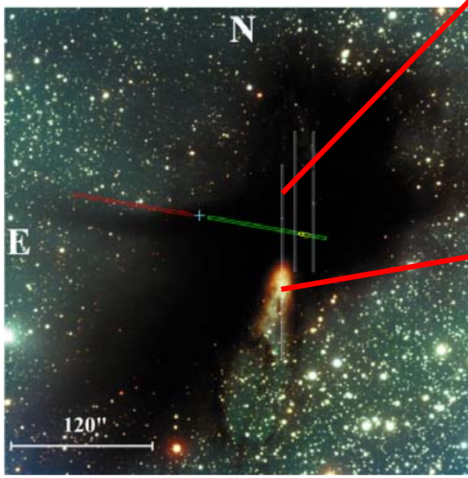


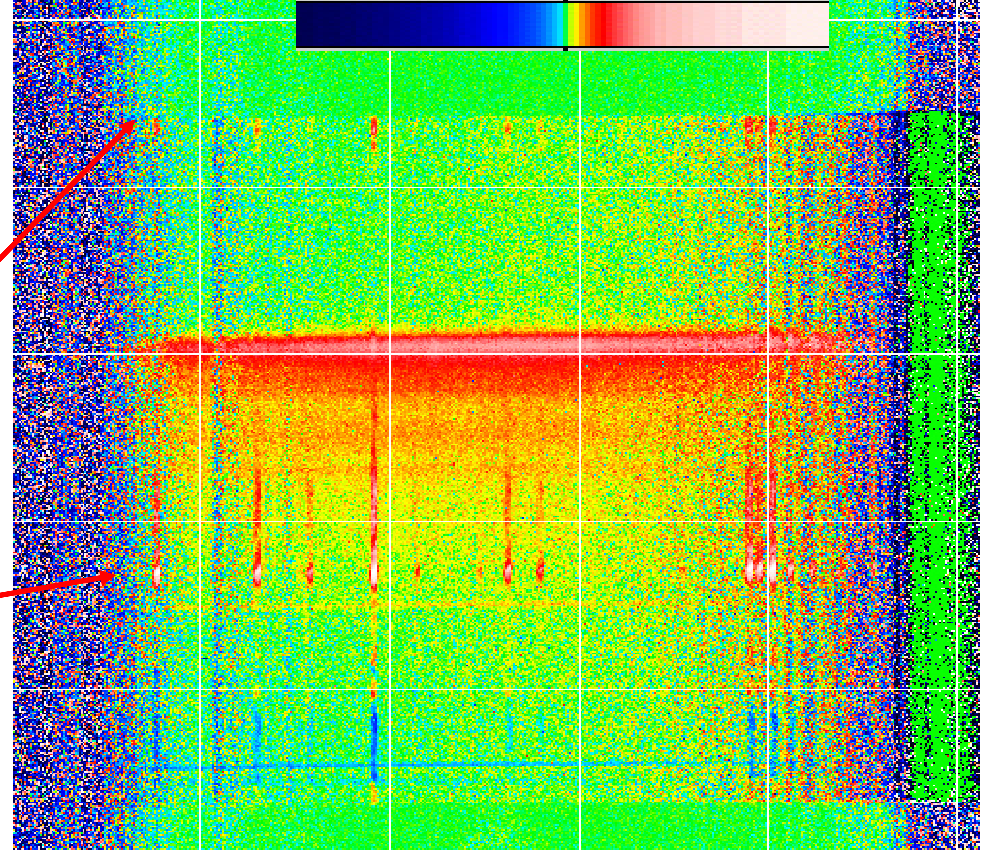
- Alves and Lada; The ESO Messenger n°103 March 2001

BHR 71 Spectroscopy

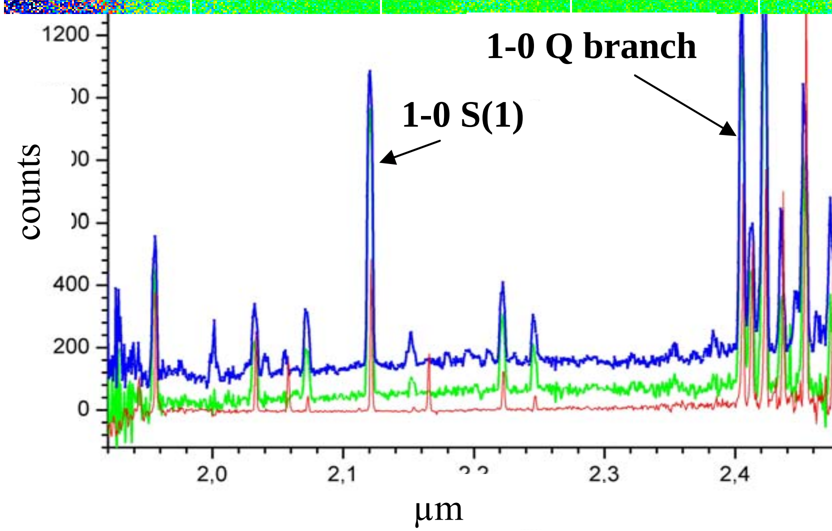
K Band spectrum (1.8 à 2.5 µm) obtained at VLT (ESO) with the ISAAC instrument

The spectral image to the right corresponds to the slit position on the picture





Integrated spectrum on the brightest spot.



Absolute and relative observed intensities of the molecular hydrogen (H_2) lines are compared to the values calculated by sophisticated theoretical models, adjusting their parameters.
This leads to the determination of the physical and chemical (density, temperature, velocity, turbulence, nature of the exciting sources (shocks, UV radiation…) reigning in the object(s) under study.

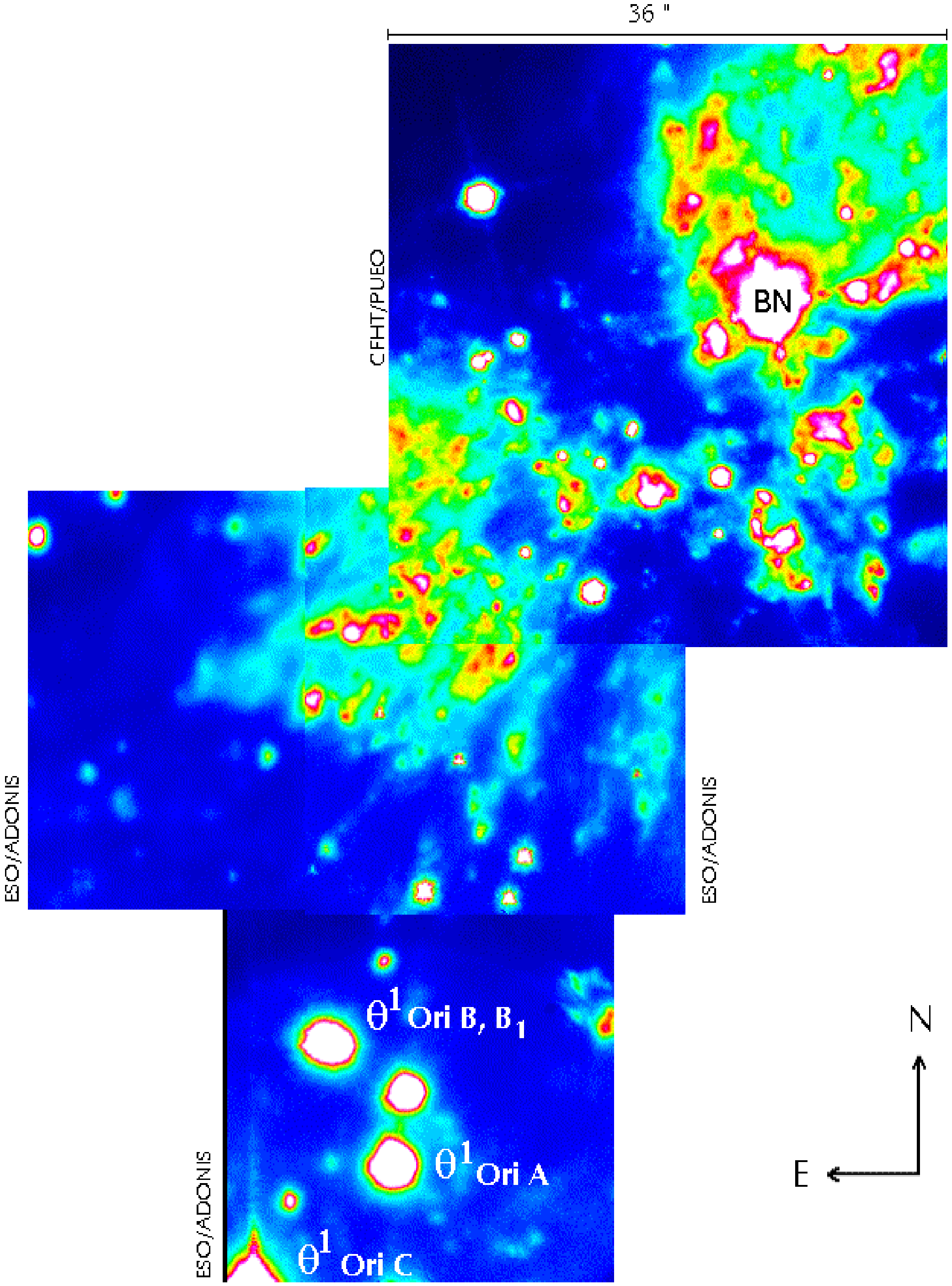
OMC1

ORION Molecular Cloud 1

- Giant molecular clouds
  where high mass stars form
  trigger the formation of low mass stars
- Located at 450 pc
- Lying between
  - BN-KL (fast outflows, shocks)
  - Trapezium stars (intense UV field)

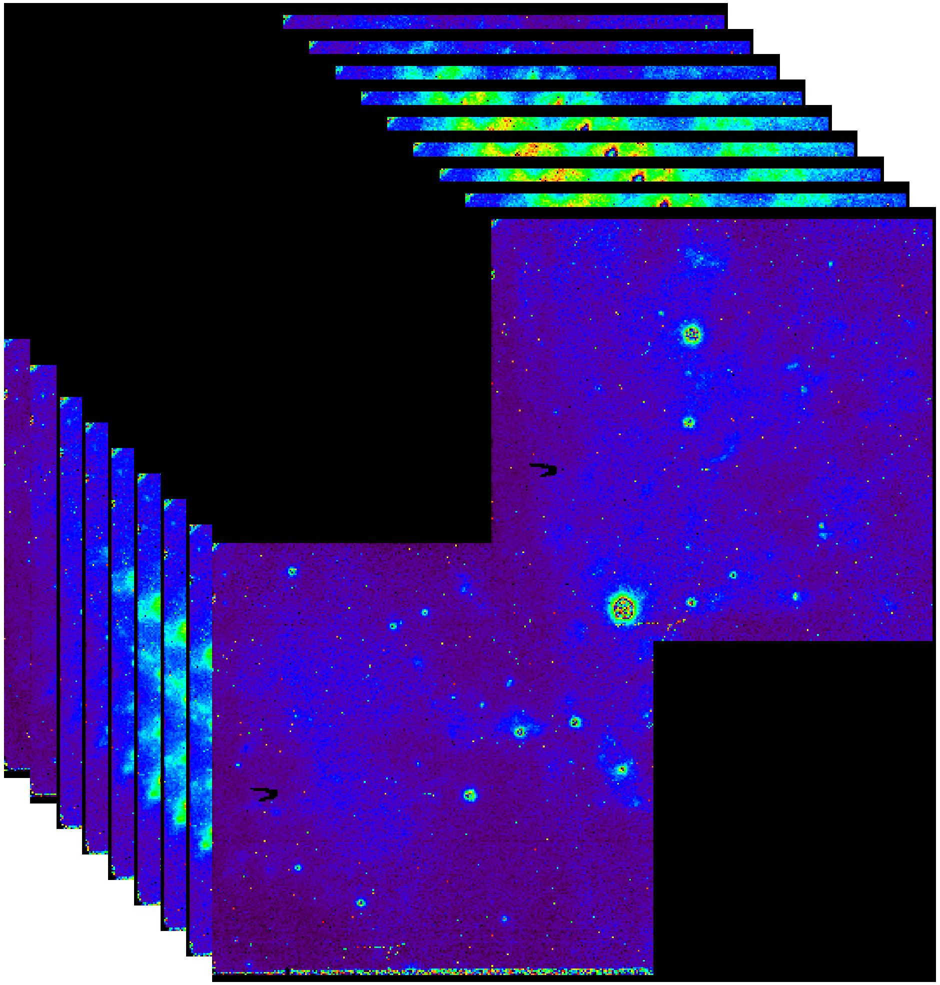
Composite image obtained by using Adaptative Optics (AO) at ESO & CFHT 3.6m telescopes

Spatial resolution:
0.15 "
Wavelength:
2.121 μm
Spectral resolution
$\lambda/\Delta\lambda$=100
Infrared H_2 emission
v=1-0 S(1) line + continuum



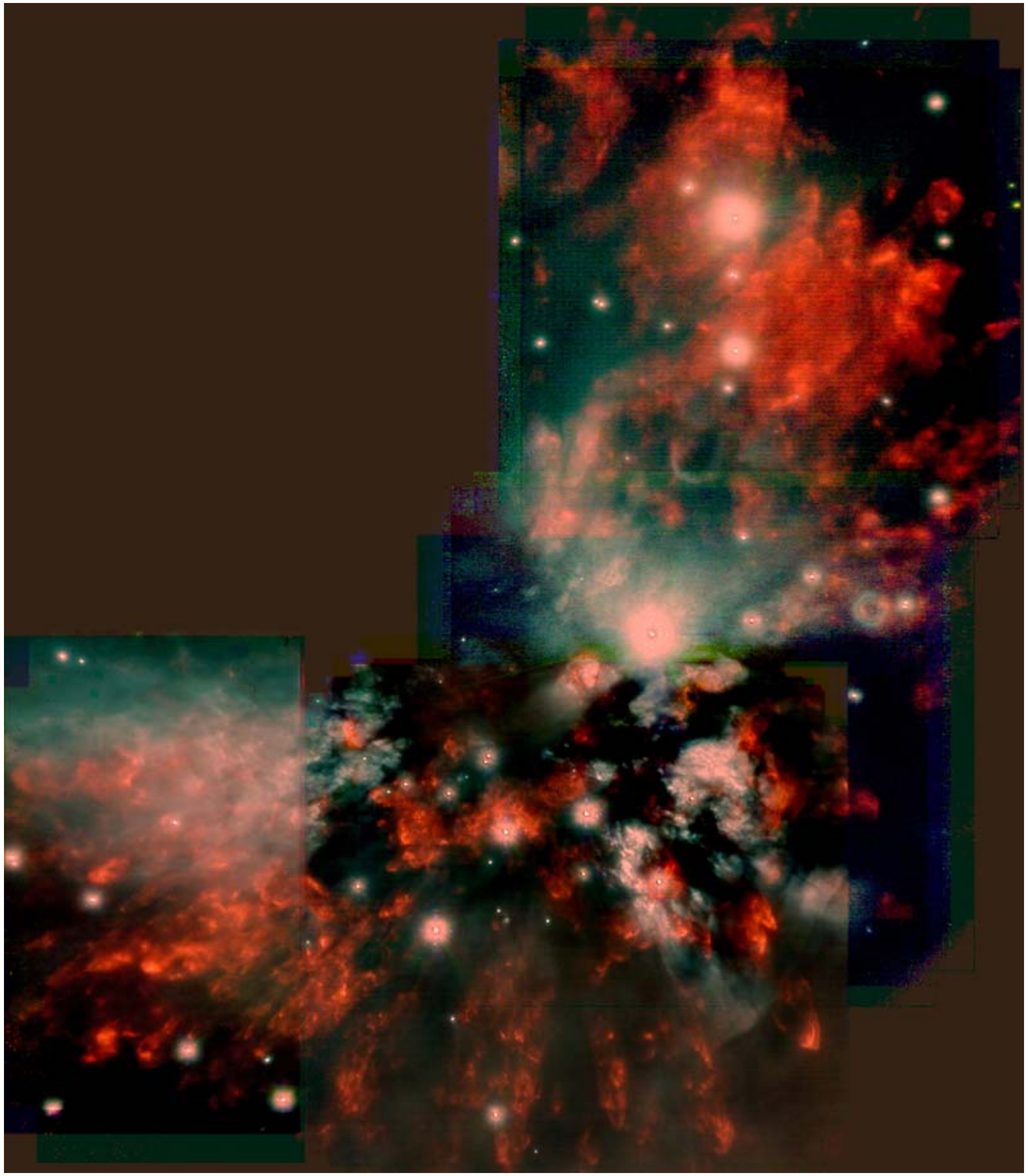
OMC1 Velocity field around BN-KL

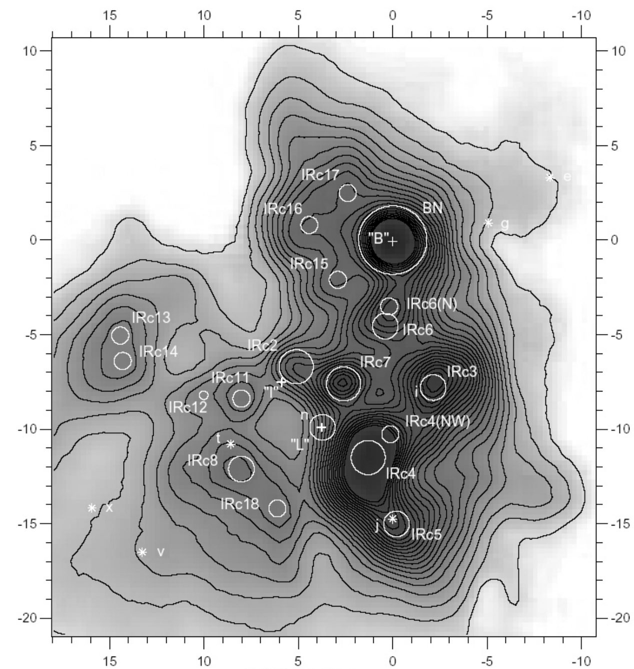
Integral field spectral movie obtained at CFHT using:
- **3.6 m mirror**
- **The adaptative optics (PUEO)**
- **A Fabry-Perot (GRIF)**



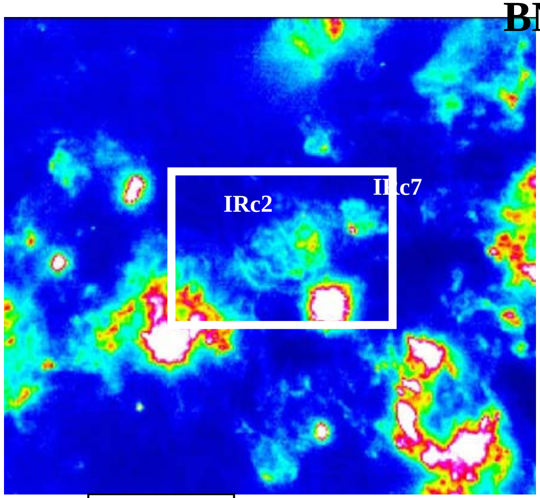
- **Gives access to the velocity field in this explosive region**
- **Reveals internal shocks associated with protostars within some clumps of gas**

Spatial resolution:
0.15 "
Infrared emission of H_2 around the v=1-0 S(1) transition
from 2.106 to 2.136 µm
Spectral resolution:
100 km.s^{-1} (R=3000)

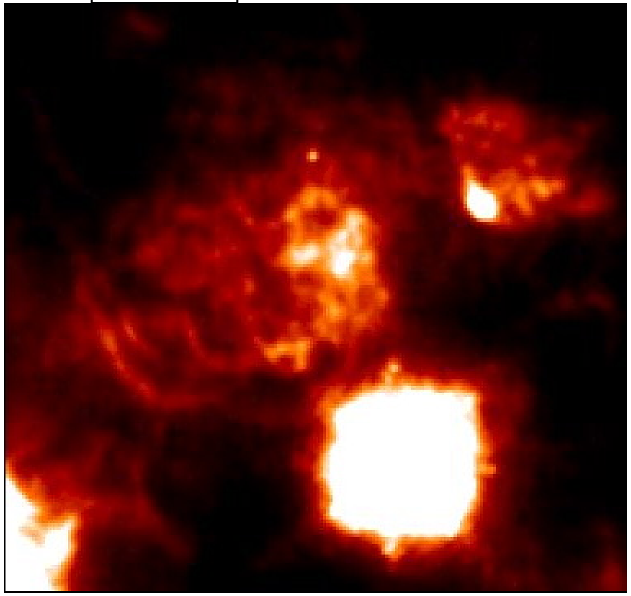




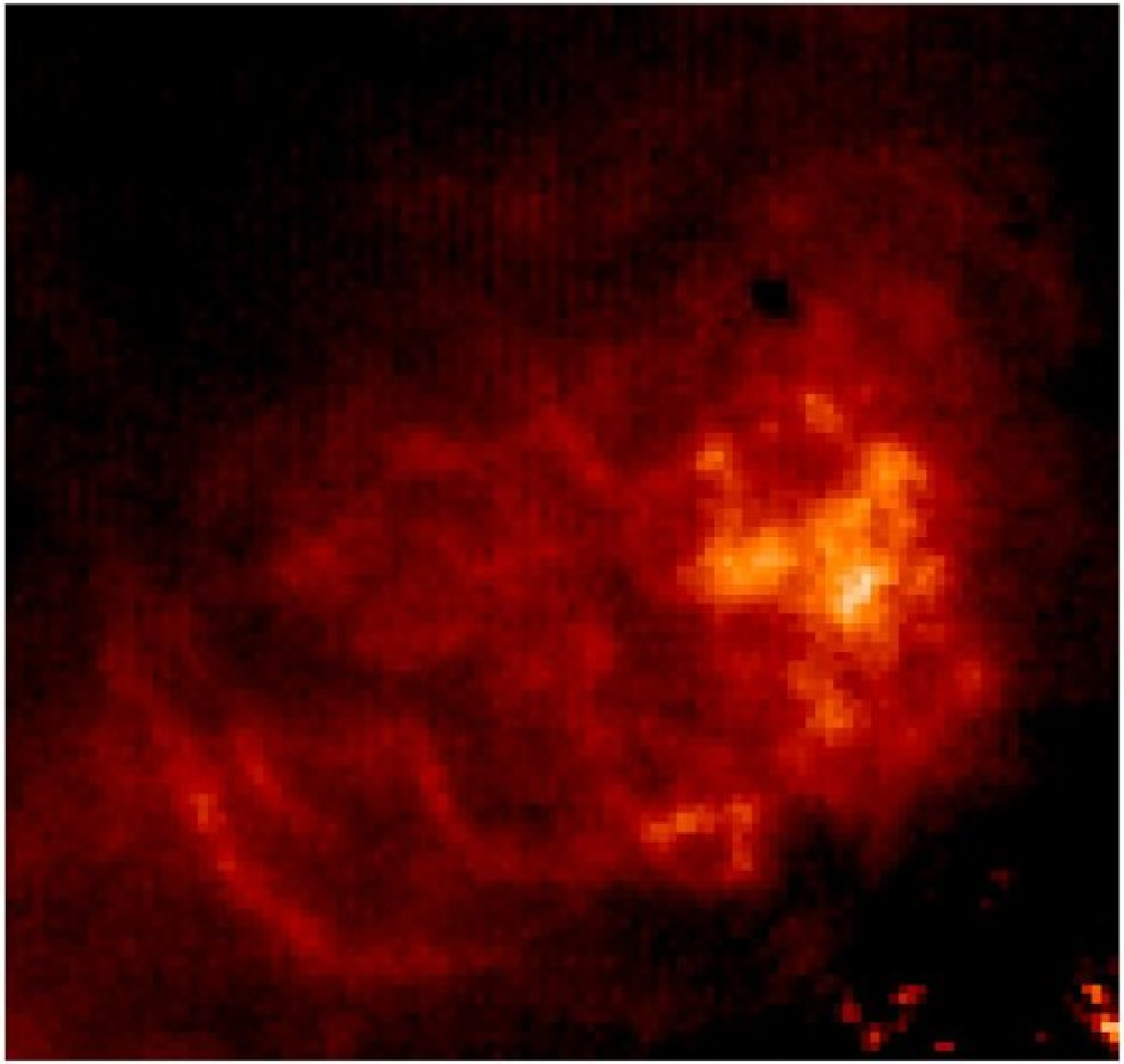
Trichromie (R,G,B)   2.12 µm, 2.24 et 2.27 µm (ESO-VLT NAOS-CONICA)
L'hydrogène moléculaire apparaît en rouge tandis que le continu est rose



2.12μm



Pure H2 emission: 2.12μm – 2.24μm



The width of the filaments (40-50 AU) appears to be actual shock width. This put important constraints on shock models in which
- density - magnetic field - shock velocity
determines the shock width.

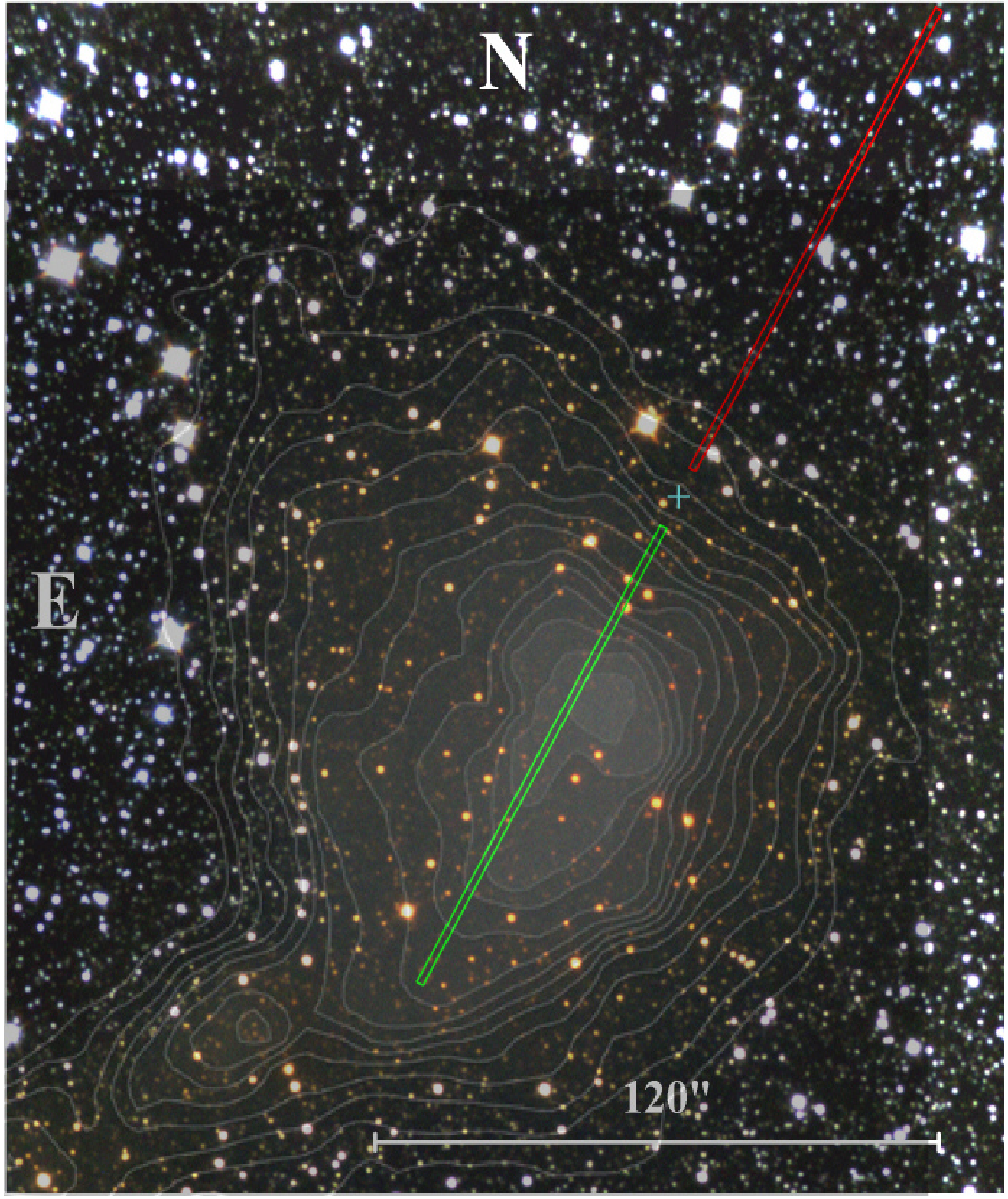
Barnard 68

Bok globule

composite image:
visible + infrared

Looking for H_2 formation
using VLT ISAAC
in spectroscopic mode

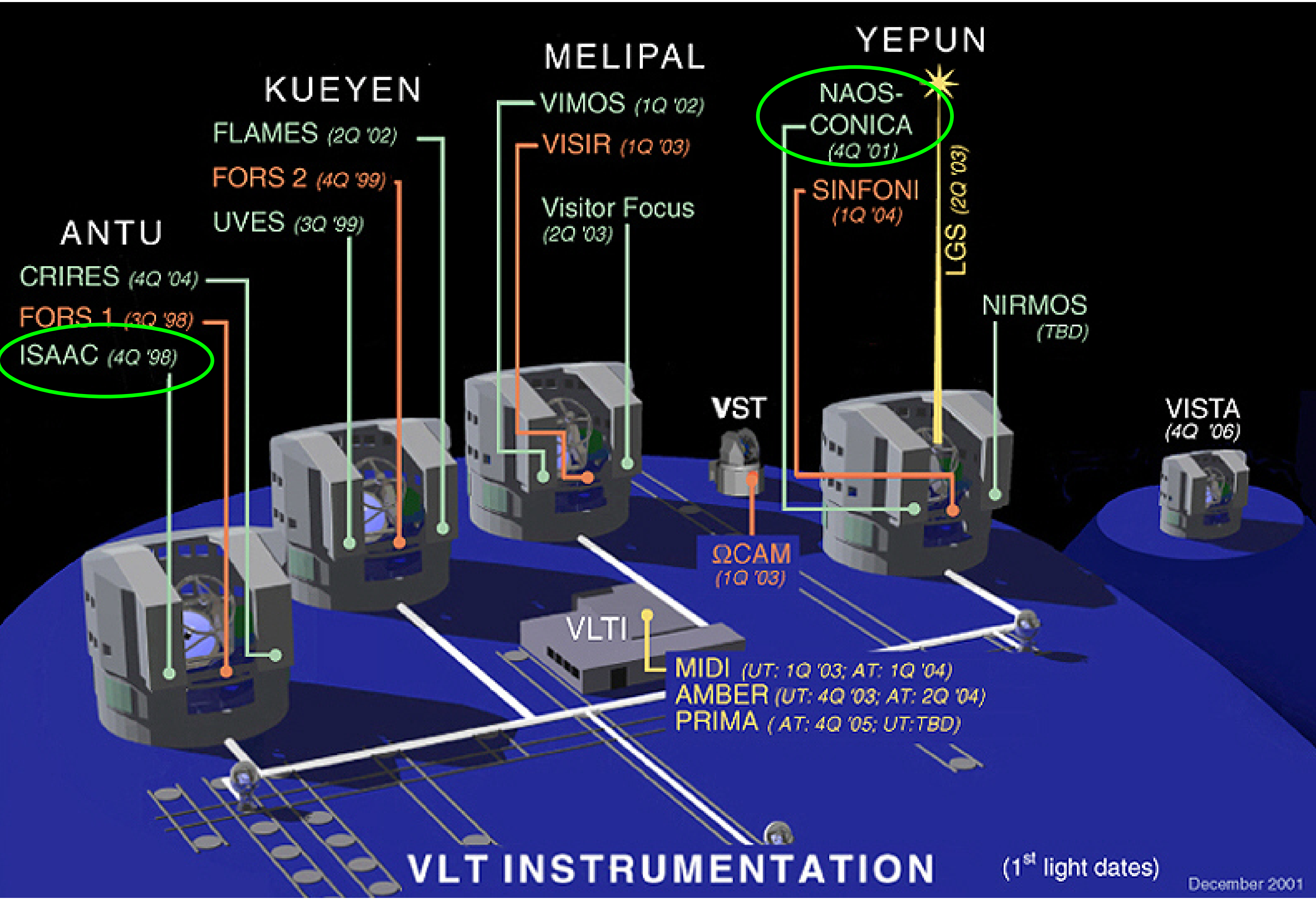
5 hours integration
no H_2 detection



Interstellar clouds,
from the diffuse nebula
to the sites of ongoing star formation

	K	cm^{-3}
Diffuse molecular clouds	50-100	$n \sim 10^2$
Cirrus clouds	10-100	$n \sim 10$ to 10^3
Dense molecular clouds	10-20	$n > 10^3$
Giant molecular clouds	15-40	$n > 10^3$

Mauna Kea volcano summit 4200 m (Hawaï) CFHT Observatory …and many others

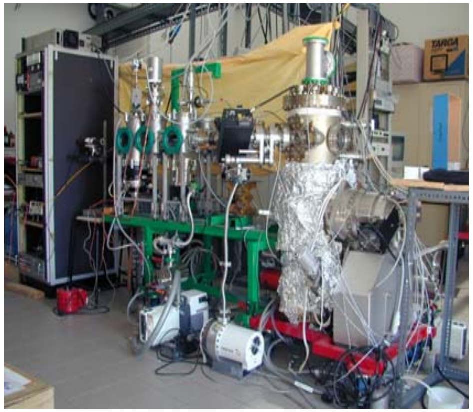


YEPUN
MELIPAL
KUEYEN
ANTU
NAOS-CONICA (4Q '01)
SINFONI (1Q '04)
LGS (2Q '03)
NIRMOS (TBD)
VIMOS (1Q '02)
VISIR (1Q '03)
Visitor Focus (2Q '03)
FLAMES (2Q '02)
FORS 2 (4Q '99)
UVES (3Q '99)
CRIRES (4Q '04)
FORS 1 (3Q '98)
ISAAC (4Q '98)
VST
ΩCAM (1Q '03)
VISTA (4Q '06)
VLTI
MIDI (UT: 1Q '03; AT: 1Q '04)
AMBER (UT: 4Q '03; AT: 2Q '04)
PRIMA (AT: 4Q '05; UT:TBD)
VLT INSTRUMENTATION
(1st light dates)
December 2001

Laboratory Astrophysics

Interstellar Grains
Spectroscopic Signatures

Laboratory experiment on H_2 formation on grains analogues



Formation of molecules on interstellar grains

H_2 does not form efficiently in the gas phase by radiative association of neutral H atoms

- 3 body reaction $H+H+H \rightarrow H_2$ — only with $n>10^{12}\ cm^{-3}$; 10^9 years in the ISM conditions
- 2 body reaction $H+H \rightarrow H_2$ — cannot get rid of the 4.5 eV bond energy via photon emission

-> Interstellar grains of dust act as catalysts

but very few known on the physics/chemistry of the processes

Surfaces, H_2 formation Retrospective

The gas-grain surface interaction is the main route for the molecule formation in the ISM - Gould and Salpeter (1963)

Interstellar grains acts as catalysts

- from the very simple H_2 formation
- to the more complex chemistry

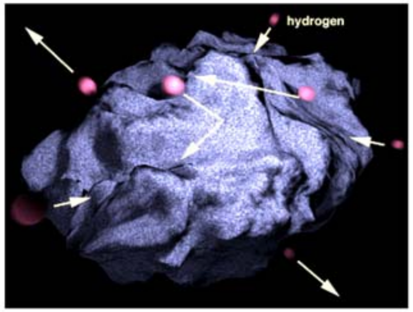


Figure 1.10–. H atoms interacting with an interstellar dust grain. The surface of the grain is uneven, and the atoms travel on it, can recombine or be released into the gas phase.

The kinetics of the reaction under interstellar conditions is still not well understood

- experimental aspects

  what is an interstellar grain ?

  how to work in the lab under interstellar conditions ?

  Low flux ($<10^{12}$ atoms/cm^2/sec) **and E_k** (10-300 K) **of H atoms**

  Low sample temperature (5-40 K), **Low background pressure** (10^{-10} torr)

- theoretical aspects

  what are the physical and chemical mechanisms involved ?

  what formalism to use to give account of them ?

Essential questions

At least 2 unanswered essential questions regarding H_2 formation in the ISM

$$H + (H - grain) \longrightarrow \underbrace{H_2(v,j) + K.E}_{\text{GAZ PHASE}} + grain$$

1 - On what surfaces and over what range of temperature can H atoms combine efficiently enough to form H_2 observed in the ISM

2 – What is the energy partitioning of the exothermicity of H_2 formation into the grain surface, into internal energy of H_2 and into kinetic energy of the product H_2

Composition and physical/chemical state of the interstellar grains

Class	Material	Signatures (abs., emi.)
bare material		
- Silicates	Olivine $Mg_{0.8}Fe_{1.2}SiO_4$	9.7 and 18 µm bands
- Graphite	the more active to form H_2	217.5 nm bump
- Amorphous carbon and HAC		7.6 µm bands
	active catalyst	
- PAHs		3.3, 6.2, 7.7 and 11.3 µm
- Sic		11.4 µm
- MgS		30 µm
core + ice mantle material (UV processed or not)		
- Ice covered grains		
	CO, H_2O, NH_3, CH_4, CO_2, N_2	
	Methanol	3.1, 4.6, 6.0, 6.85 µm
- Refractory organics covered grains		3.4, 6.0 µm

Grains origin: Novae, Supernovae, ejected stellar matter

Shock model program (Flower, Le Bourlot, Pineau des Forêts, Roueff)

```
!---- shock parameters -------------------------------------------------------
C                        ! shock type : 'C' or 'J', Steady state : 'S'
3                        ! Nfluids : 1, 2 ou 3
1.0D0                    ! Bbeta -> Bfield = Bbeta * sqrt(nH)
30                       ! Vs -> shock speed (km/s)
1.0e3                    ! Vn - Vi initial (cm s-1)
0.01                     ! op_H2 -> initial H2 ortho/para ratio (999.9 -> ETL)
4.650                    ! T(n,i,e) -> initial gas temperature (K)
1.0D6                    ! nH_init -> initial value for n(H) + 2.0 n(H2) + n(H+) (cm-3)
15                       ! Tgrains -> initial grain temperature (K)
0                        ! Cool_KN -> 1: Kaufman & Neufeld cooling
!---- environment ------------------------------------------------------------
5.0D-17                  ! Zeta -> cosmic ray ionization rate (s-1)
0.D0                     ! RAD  -> flux radiation (multiplicative factor)
0.D0                     ! Av   -> initial extinction (magnitudes)
!---- numerical parameters ---------------------------------------------------
10000                    ! Nstep_max   -> max number of integration steps
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1.00D-7                  ! Eps_V -> precision of computation
3.00D8                   ! timeJ -> shock age (years)
2.00D8                   ! duration_max -> max. shock duration (years)
1                        ! Force_I_C -> 1: Force Ion Conservation
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local                    ! H2 lines: 'local' (erg/s/cm3) or 'integrated' (erg/s/cm2/sr)
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                         !   1: Proportional to Boltzman Distrib at 17249 K
                         !   2: Dissociation limit : v = 14, J = 0,1 (4.4781 eV)
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                         !   4: fraction = relative populations at t, initialised as H2_lev%density
                         !                and changed during integration
  INTEGER:: ikinH2 = 1   ! Flag : H2 formation energy released as kinetic energy
                         !   1: 0.5 * (4.4781 - internal)
                         !   2: Inf(1.4927 eV, 4.4781 - internal)
```

Surfaces, H_2 formation Experimental aspects

Surface science:

*** Crystalline material**

*** Catalysis**

state specific detection of H_2 desorbing from surfaces

Zare	Kubiak et al (1985)	H_2 / Cu(110) and Cu(111)
Zacharias	Schröter et al (1991), Rutkowski et al (2001)	H_2, D_2, HD / Pd(100)
	Kolasinski et al (1992)	H_2 / Si(100) and Si(111)
Winkler	Pozgainer et al (1994)	H_2 / Ni polycrystalline
	….	

Astrophysical surface science:

*** polycrystalline**

*** amorphous**

desorption experiments

- doped Si bolometer surface Govers et al (1980)
- silicates and carbonaceous material

Vidali, Pirronello — Vidali, Pirronello et al (olivine: 1997, amorphous carbon: 1999)

- ice covered material (amorphous solid water)

Manico et al (2001), Roser et al (2002), E_k: Roser et al (2003)

Baurichter, Luntz — Hornekaer et al (2003, 2005)

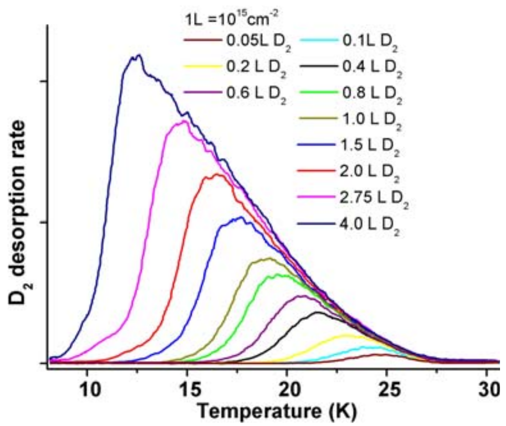
Dulieu et al (2005)

- HOPG Zecho et al (2002)

Surfaces, H_2 formation Experimental aspects

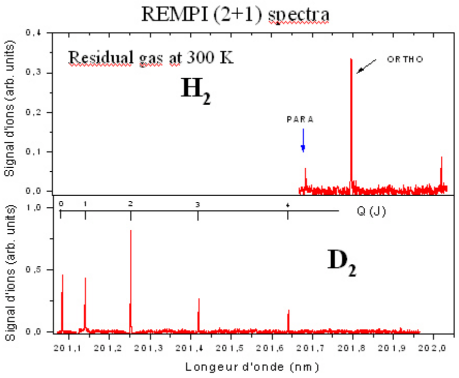
Diagnostics methods without state specific resolution:

* TPD-QMS
  (thermally programmed desorption)
* TOF-QMS

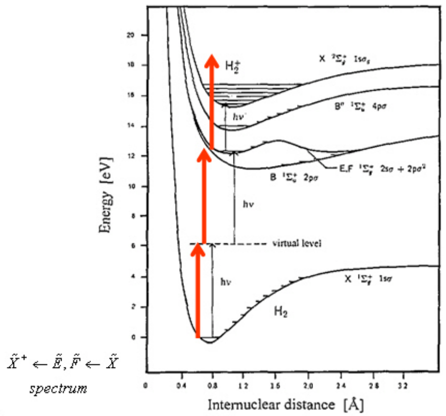


Diagnostics methods with state specific resolution:

* REMPI-TOF (λ scan)
* REMPI-TOF-TPD (λ fixed)



$n_{H2}(v,J)$ →
Population distribution of molecules desorbed from the surface



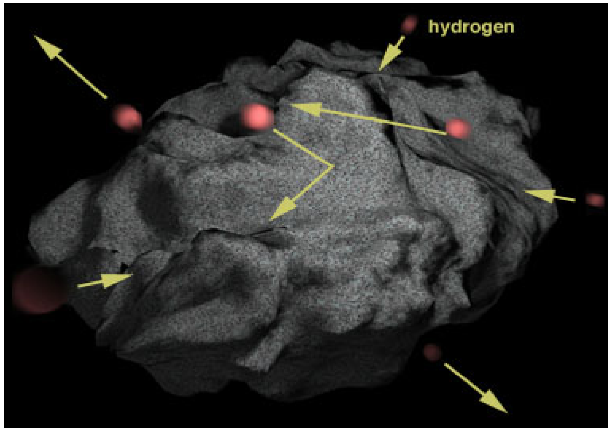
Pulsed tunable dye laser: 190-205 nm

Surfaces, H_2 formation

adsorption of gas on grains →	**collision H-grain** **thermal accommodation** **sticking in surface (or volume)**
diffusion →	**mobility on surface**
reaction →	**recombination and H_2 formation**
desorption →	**ejection of excited H_2**

slow process ~ 1 atom/day

$E_{v,J}$ E_k grain heating



Surfaces, H_2 formation Experimental aspects

Grain surface characteristics:

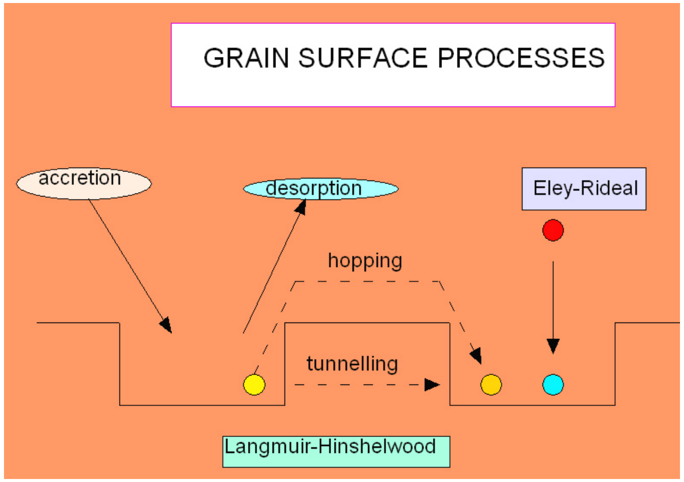
Atoms or molecules characteristics and interaction with the surface:

* morphology (crystalline, micro- or poly- crystalline, amorphous)
* role of the defects
* porosity (dense / fluffy), area/unit vol.
* bare grain size distribution (0.01 to 0.5 μm)
* surface temperature
* adsorption processes
* type of interaction with the surface (physi- vs. chemi-sorption)
* binding sites and energies
* ice morphologies and surface coverage (ice mantles, mixtures)

* flux of incoming atoms, kinetic temperature
* sticking coefficient
* mobility, time scales: residence time, migration time (10^{-12} to 10^{-3} s)
* formation processes
* recombination efficiency

* desorption kinetics (thermally activated mobility?)
* $E_{v,j}$ & E_k

Surfaces, H_2 formation   Theoretical aspects



Reaction mechanisms

-Eley-Rideal
prompt mechanism
occur at high H atom coverage rate
→create "hot" H_2

-Langmuir-Hinshelwood
migration mechanism by tunneling or thermal hooping
occur at low and high H atom coverage rate
→ create H_2 at surface temperature

- Interaction of atoms and molecules with surfaces:

* physisorption (vdW interaction)
* chemisorption (covalent bond)

- Desorption from grains results from:

pulsed heating (collisions, cosmic rays)
sputtering (CR, photo-induced desorption)
penetration length (CR vs. UV)
chemical reactions (exothermicity, stored energy)

Surfaces, H_2 formation Theoretical aspects

Data analysis
Modelling of surface chemistry on interstellar grains
Theoretical and computational methods:

$$n^{th}\ order: \quad \frac{dN(t)}{dt} = -k_n N^n e^{\left(-\frac{E_{des}}{k_B T_S}\right)}$$

n, k_n and E_{des} : empirically derived parameters

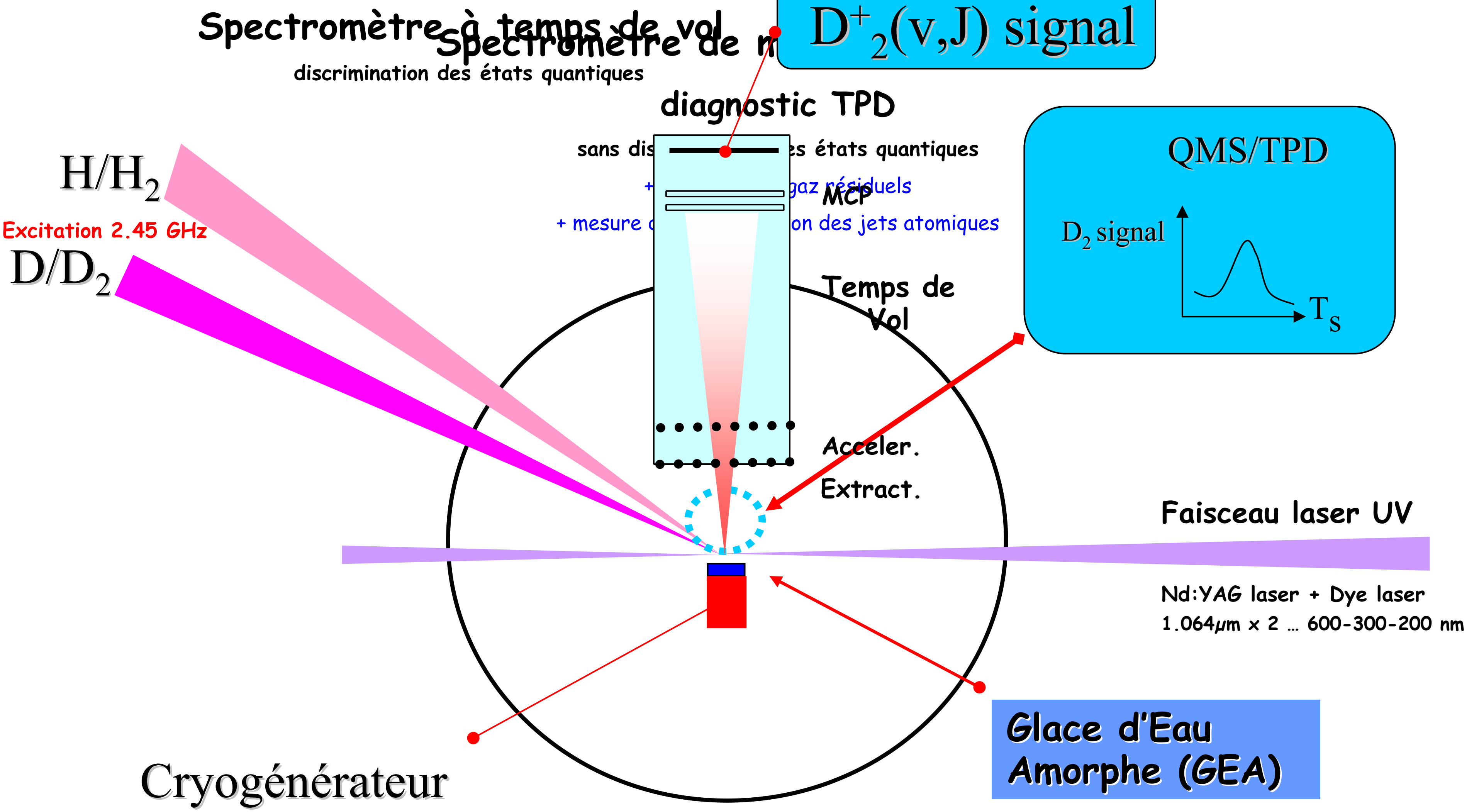
* Polanyi-Wigner equation
  analysis of TPD experiments
  → activation energy barriers for diffusion and desorption processes

* Rate equation model → production rate of H_2
* Modified rate equations

* Master equation → **O. Biham**

* Stochastic approaches of the surface chemistry → **S. Charnley**
Master equation, Monte-Carlo methods

Schéma des expériences



Cryogénérateur

T_s=8-150K

nettoyage: 800 K

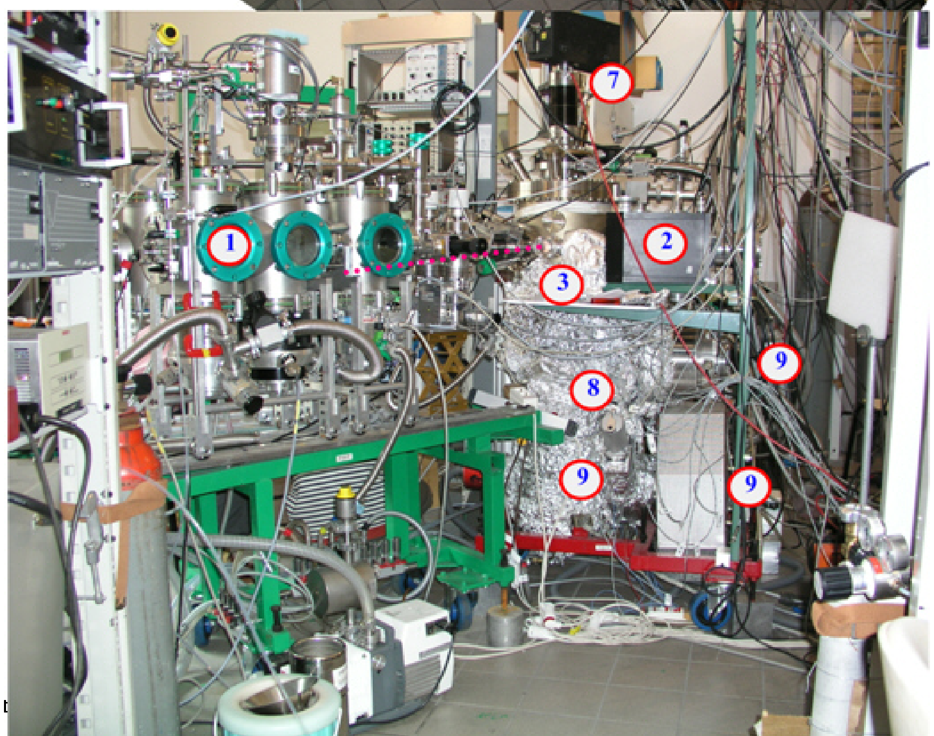
mesures de températures
et régulation

Enceinte ultra vide (<5 10^{-11} mbar, n~10^6cm^{-3})

pompages: primaire, turbomléculaire, ionique, sublimation de titane

+ étuvage à 120 C pendant une semaine après ouverture


Expérience "FORMOLISM"
LERMA/LAMAp
UMR 8112
Mai 2004
1
5
4
1
7
2


7
1
2
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9
8
9
9

RÉACTIVITÉ CHIMIQUE HÉTÉROGÈNE

Formation d'hydrogène moléculaire et de petites molécules sur des surfaces d'intérêt astrophysique à très basse température (FORMOLISM)

Etude de la formation de la molécule d'hydrogène sur une surface de glace d'eau amorphe (GEA)

- Compte tenu de la grande diversité des formes amorphes et cristallines de la glace d'eau et de leur intérêt actuel, il nous a semblé intéressant de commencer notre programme scientifique dans cette voie.

- De plus les mesures effectuées sur des surfaces couvertes d'un manteau de glaces (H_2O, CO…) sont en principe relativement plus simples à interpréter que celles menées sur des surfaces sèches.

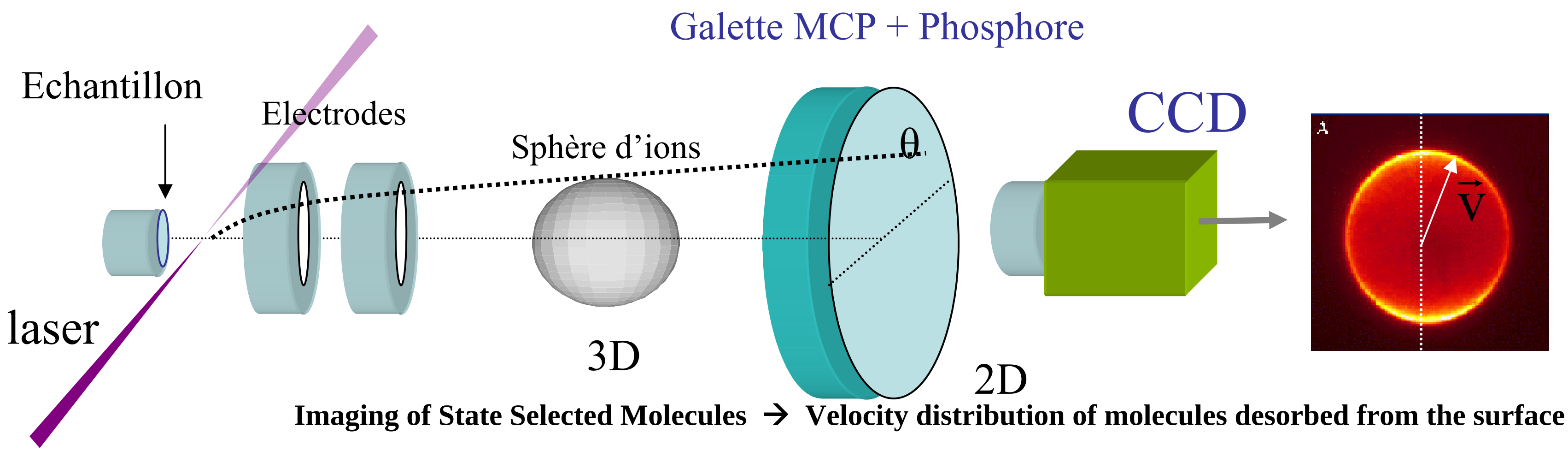
- En effet, la couverture d'un solide par une glace est homogène et dès que quelques monocouches ont été déposées, le substrat et ses défauts de surface ne jouent plus aucun rôle.

- Il s'agissait au départ de calibrer les résultats de notre expérience par rapport aux résultats obtenus récemment par Roser et al (ApJ 2002 et 2003) et Hornekaer et al (Nature 2003) en les complétant grâce à notre appareillage qui possède des diagnostics plus complets (TPD + REMPI/TOF).

- Si la majorité de nos premiers résultats concordent avec les leurs, quelques autres jettent des doutes sur certaines des mesures déjà publiées tandis que de nouveaux les complètent sur des aspects très importants négligés ou non observés auparavant.

PERSPECTIVES 2005-2009

1. Diagnostic supplémentaire sur l'énergie de translation des molécules formées,
projet d'imagerie ionique IONIM (ACI) en cours de test.



Imaging of State Selected Molecules → Velocity distribution of molecules desorbed from the surface

2. Diagnostic RAIRS sur les glaces: spectroscopie IR (10000-400 cm^{-1}) par TF
(spectroscope complet acquis, adaptation à l'enceinte ultra-vide courant 2005)
diagnostic des multiples états physiques des glaces d'eau dans les bandes à 3µm, diagnostic d'espèces nouvelles formées dans des réactions à basses températures

3. Préparation et caractérisation des échantillons solides in situ (C amorphe, graphite, silicates …)
(projet programmé pour le second semestre 2005)

4. Développements théoriques en relation avec l'équipe de Meudon (recrutement ?)

5. Nouvelle enceinte ultra-vide (projet 2006 …)

L'équipe d'astrophysique à l'Université de Cergy-Pontoise

Astrophysique de Laboratoire

Jean Hugues FILLION	MdC
François DULIEU	MdC
Hanouchah MOMENI	MdC
Saoud BAOUCHE	Doctorant → Postdoc
Lionel AMIAUD	Doctorant
Eric SOMSON	AI
Tahar AMORI	ITA

1 year postdoc ??

Astronomie et Astrophysique

Jean Louis LEMAIRE	Pr
Gonzague CALLEJO	Doctorant → ATER
Lars KRISTENSEN	Doctorant
Stephan DIANA	IE Informatique

L'équipe d'astrophysique LERMA-LAMAp
Collaborations nationales et internationales

Astrophysique de Laboratoire	A. Baurichter	Syddansk Univ. Odense	Dk
	A. Luntz, L. Hornaecker		
	V. Pirronello	Universita de Catania	It
	G. Vidali	Syracuse University	USA
	…		
Astronomie et Astrophysique	D. Field	Aarhus Universitet	Dk
	M. Gustafsson, F. Pijpers		
	D. Rouan	Observatoire de Paris	LESIA
	Y. Clénet	GriF (CFHT), NACO (VLT)	
	G. Testor	Observatoire de Paris	LUTH
	G. Pineau des Forêts	Université Paris-Sud, IAS, Orsay	
	M. Gérin, E. Falgarone	ENS Paris	
	…		

L'astrophysique à l'Université de Cergy-Pontoise

Laboratoire LERMA/LAMAp UMR 8112 CNRS & MEN

L'astrophysique observationnelle

Sujets d'étude:

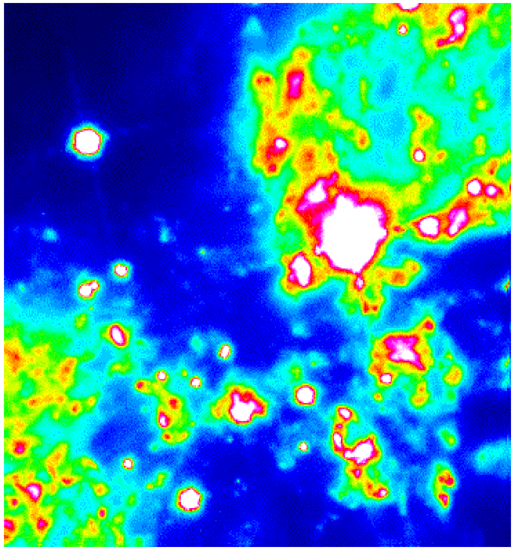
Le Milieu Interstellaire. Etoiles en formation

Observation – Interprétation

L'astrophysique de laboratoire

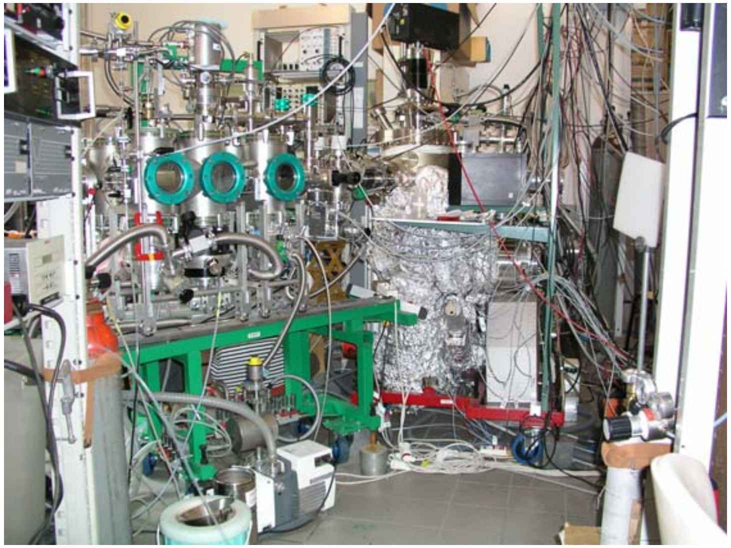
Sujets d'étude:

Formation de H_2 sur des surfaces simulant les grains interstellaires



Visite du laboratoire:
http://wwwusr.obspm.fr/~lamap/

Contributions:
CGVO
CRIdF
MEN
CNRS



Buts:

Comprendre l'Univers

Interpréter les observations pour élucider les mécanismes en œuvre dans les "objets" étudiés.

1) Modélisations théoriques basées sur les lois de la Physique et de la Chimie

- comparer leurs résultats à ceux des observations et déterminer ainsi de façon indirecte les caractéristiques des "objets".

Buts:

Comprendre l'Univers

Mesurer les caractéristiques physico-chimiques de réactions intervenant dans le milieu interstellaire.

2) Expériences au laboratoire simulant, dans des conditions simplifiées, certains milieux étudiés

- mesurer les paramètres manquants permettant une modélisation correcte des observations.