From 1D-FTS to BEAR:

The Imaging FTSs in astronomy

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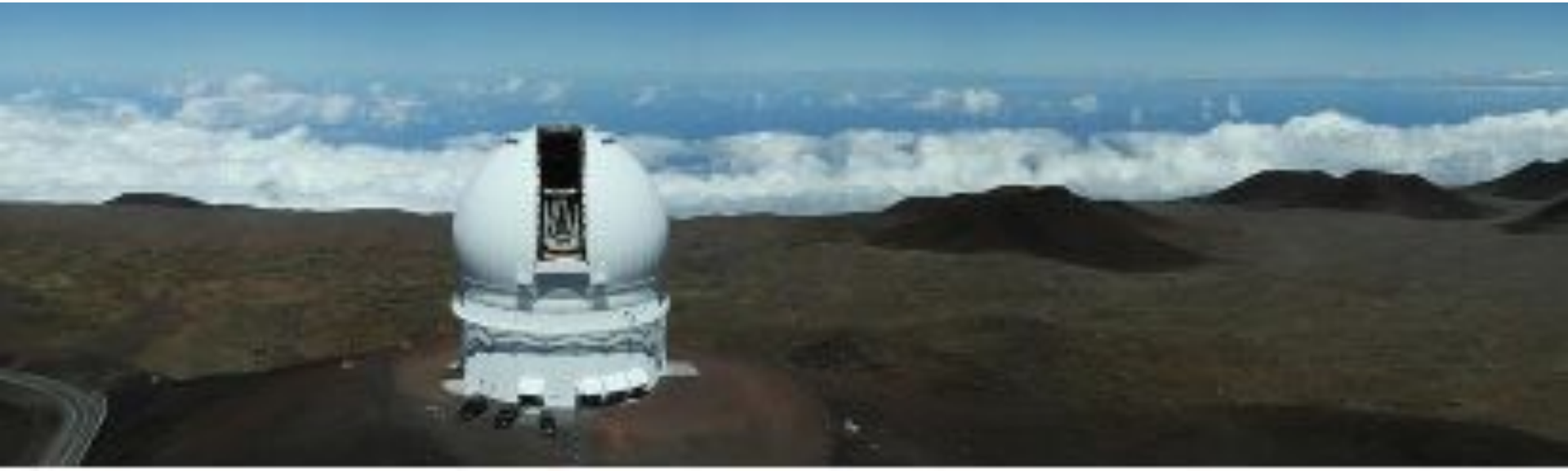


CONTENTS

INTRODUCTION

FTS in astronomy has a long history: in the 70's more than 20 groups worldwide engaged in a program of FT-IR

Milestones

- "Atlas des spectres dans le proche infrarouge de Vénus, Mars, Jupiter et Saturne" *J. Connes, P. Connes, J.P. Maillard,* ***1969***
- Aspen International Conference on Fourier Spectroscopy ***1970***
- FTS at the 193-cm OHP telescope: Ph.D thesis *J-P Maillard* ***1973***
- Kitt Peak FTSs
  - McMath solar FTS ("Babar") *J. Brault* ***1975***
  - 4-m Mayall Telescope FTS *D. Hall, S. Ridgway* ***1979***
- Voyager I and II IRIS FTS *R. Hanel* ***1979***
- Kuiper Airborne Observatory FTS *H. Larson, G. Michel* ***1980***
- CFHT-FTS *J-P Maillard, G. Michel* ***1982***

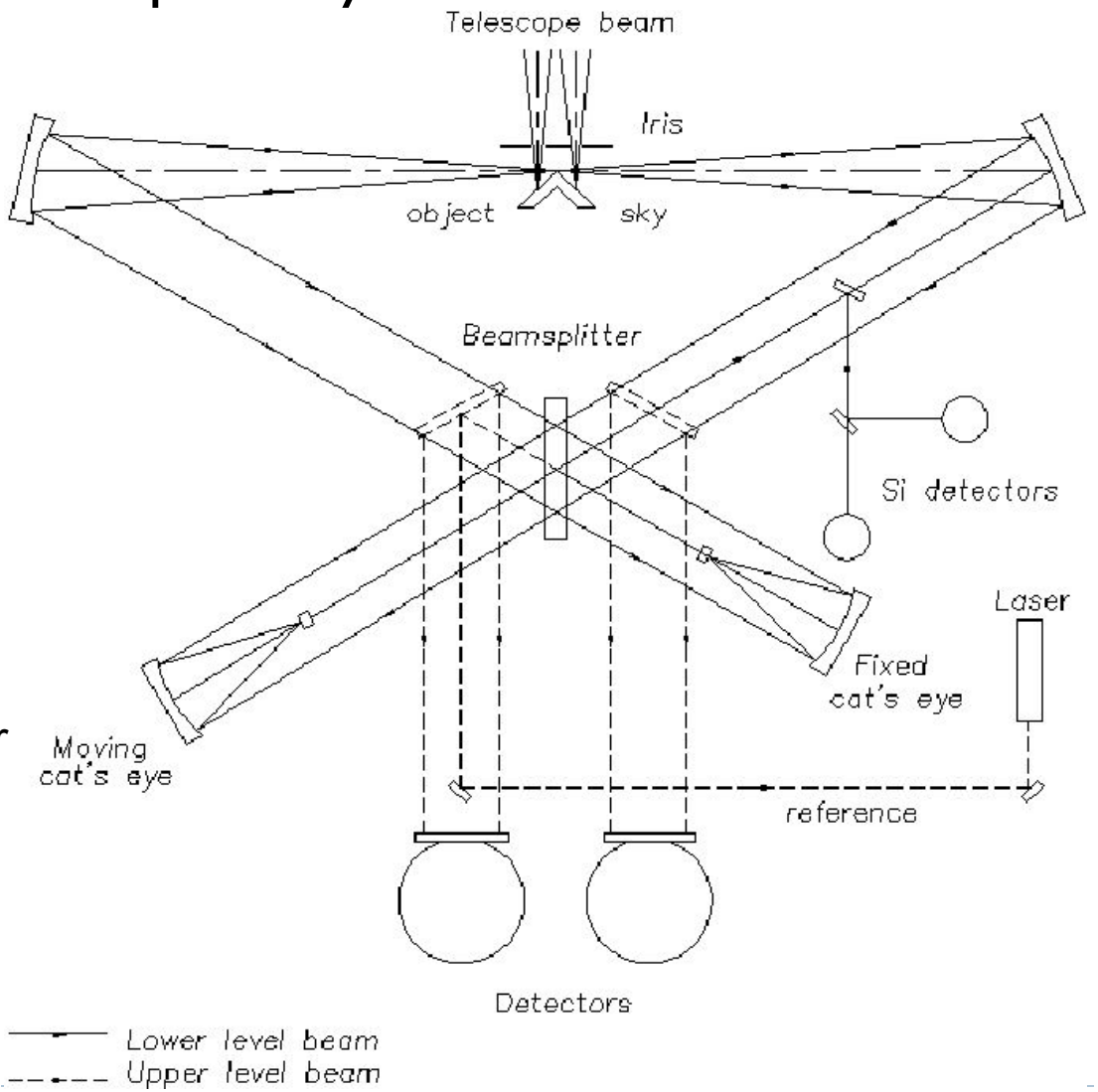
The French Fourier's commando from Aimé Cotton Lab at the Aspen Conference on FT Spectroscopy, March 16 – 20, 1970

I:1D-FTS at the CFH Telescope

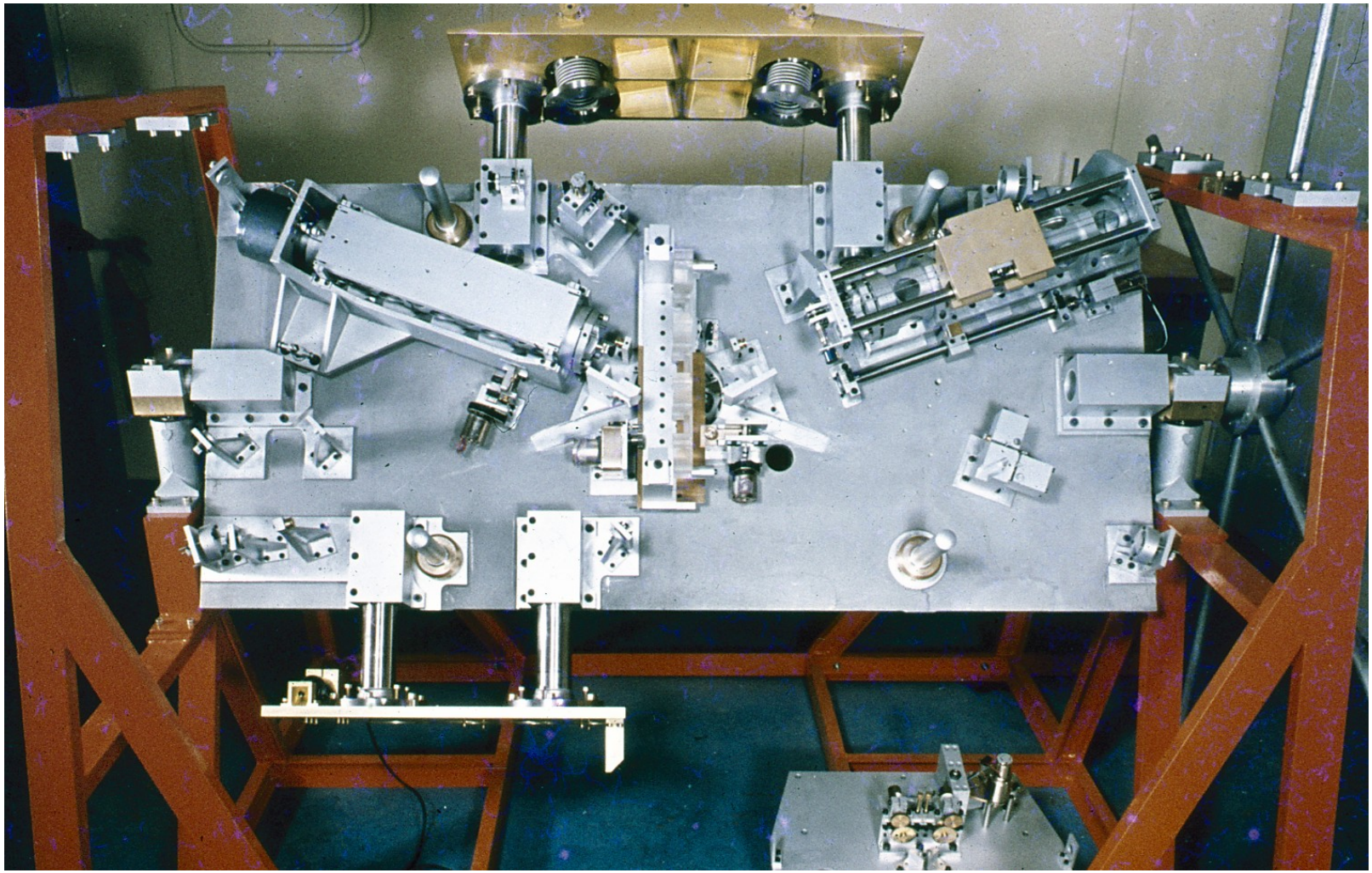
Designed and assembled at Meudon Obs. (1978 – 1980)

- Dual input/dual output interferometer based on cat's eye retroreflectors
- Both input ports placed on the sky
- Telescope entrance pupil imaged on the beamsplitter
- One IR InSb dewar on each output port.

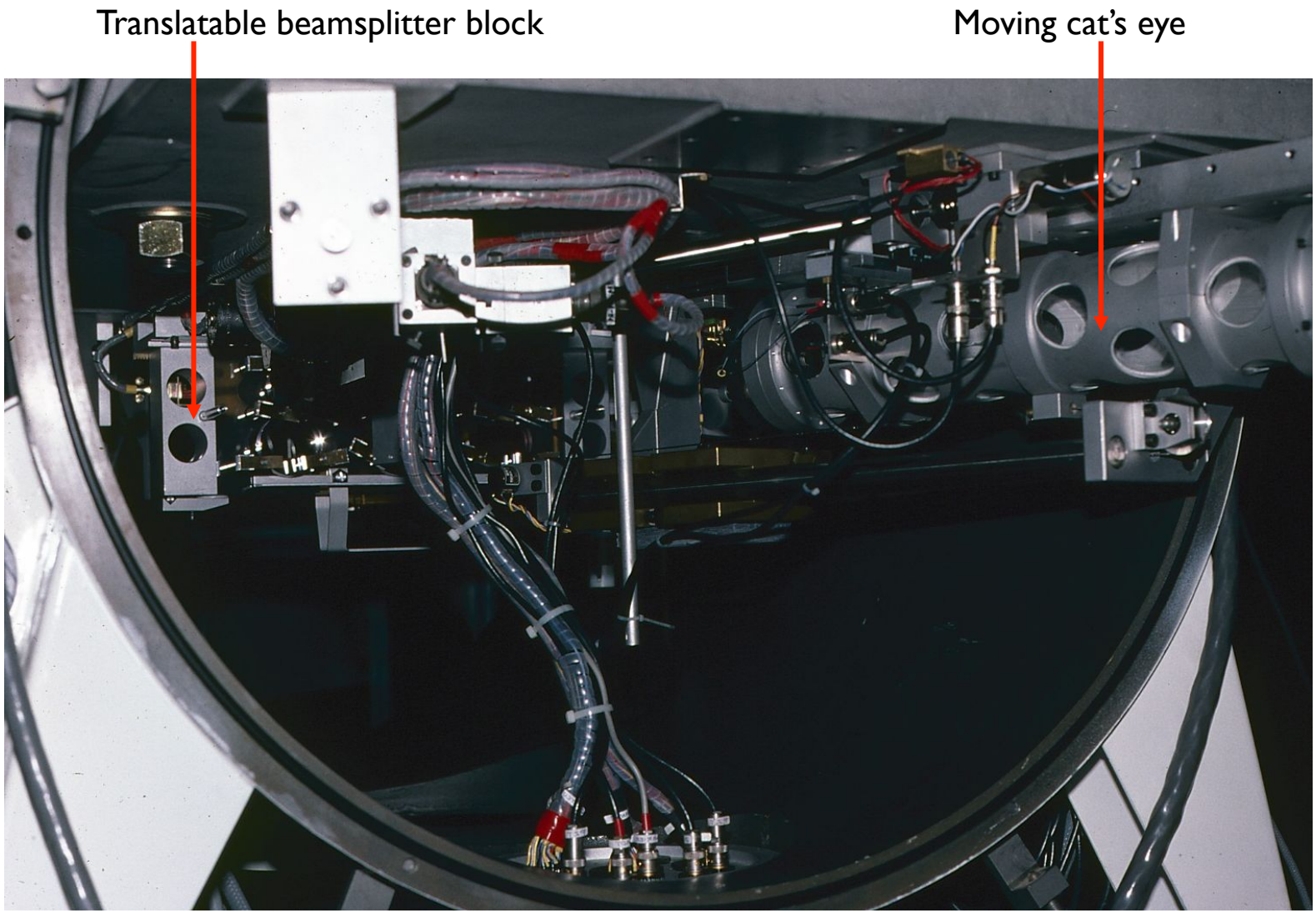
Optical layout of the CFHT-FTS



The FTS optical bench at Meudon Obs.



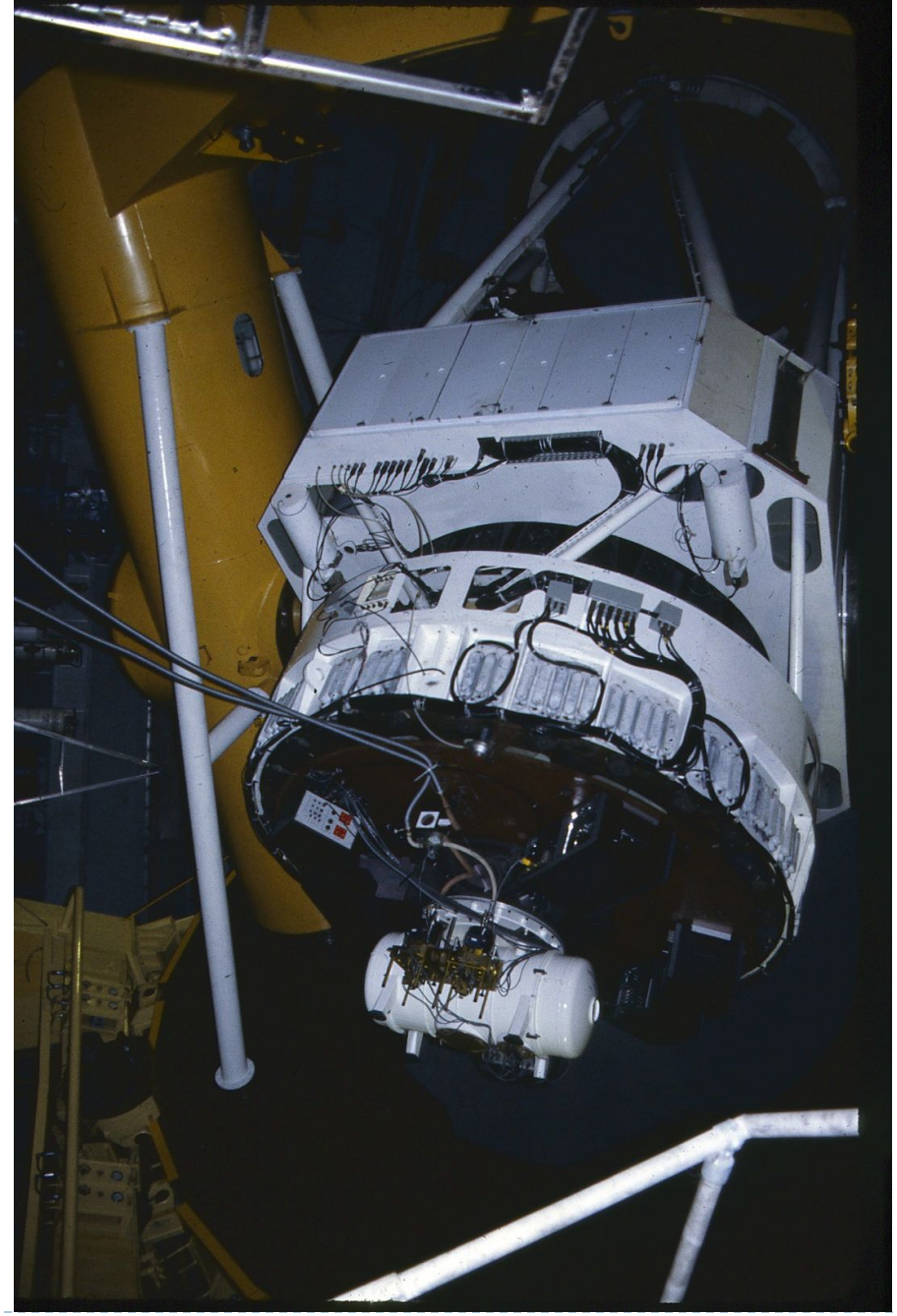
The FTS on a Cass focus simulator and its electronics in test at OHP (Apr. 1980)



The vacuum tank open: view of the FTS

CFH-FTS main parameters

- Focus *f/35 IR Cass. focus*
- Design *Dual input, dual output with cat's eye mirrors*
- Max. FOV *24"*
- Max. OPD *60 cm*
- Max. resolution *0.01 cm^{-1} (R_{max} = 5x10^5 à 2 μm)*
- Spectral coverage *0.9 – 5.4 μm*
- Detectors *2 InSb* + (later) *2 InGaAs*
- Beam splitters *3 permutable, compensated pairs*
- <u>OPD control</u> *step-by-step scanning*
- Source of metrology *stabilized monomode He-Ne laser*
- Operation *at dome temp. – possible under vacuum*



The FTS at the CFH Telescope Cass focus

during an observing run, showing the vacuum tank protecting the interferometer and the two InSb dewars

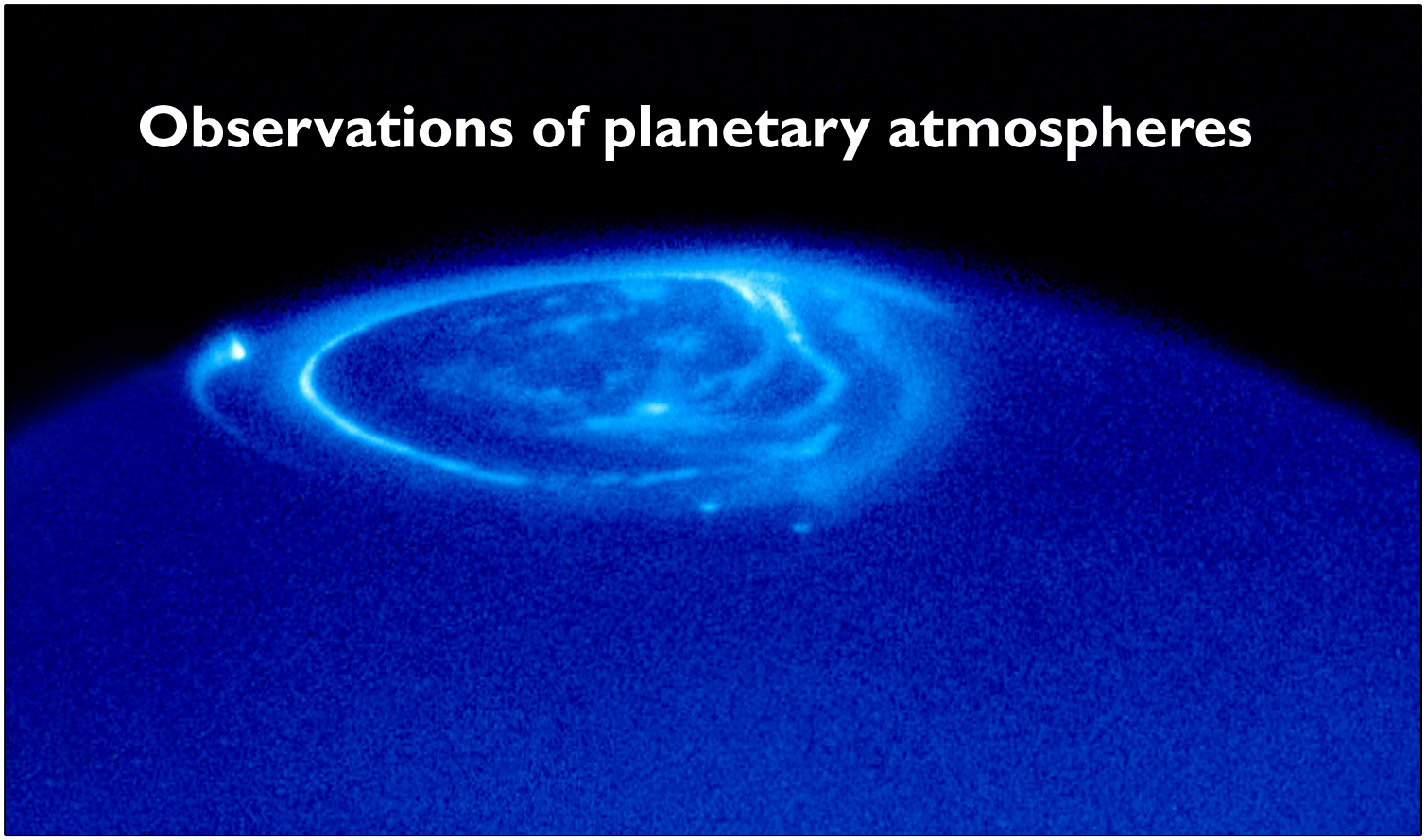
Delivered at Mauna Kea: **Aug. 1980**
(no IR focus)

<u>In operation</u>:
1983 - 2001

High resolution spectroscopy with the FTS

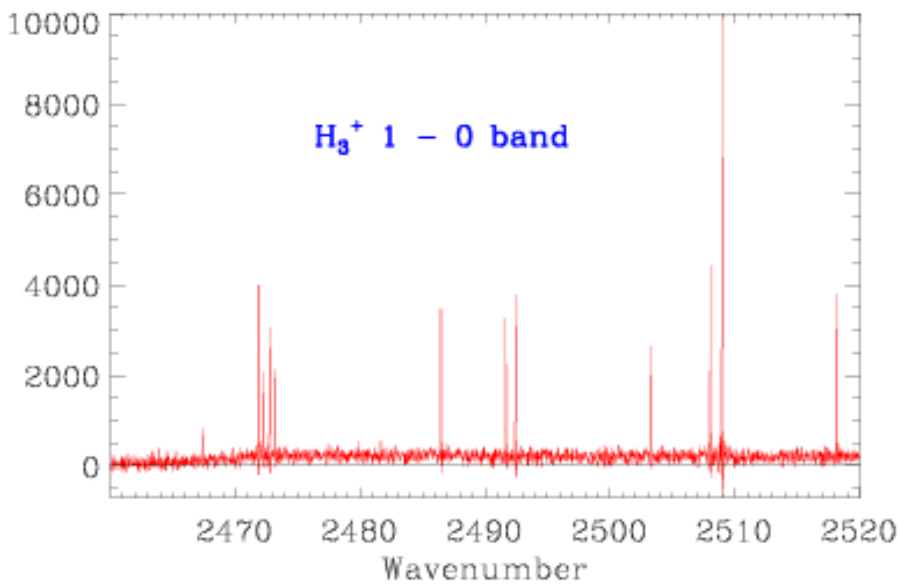
Review in: *Recent results in astronomical Fourier transform spectroscopy*

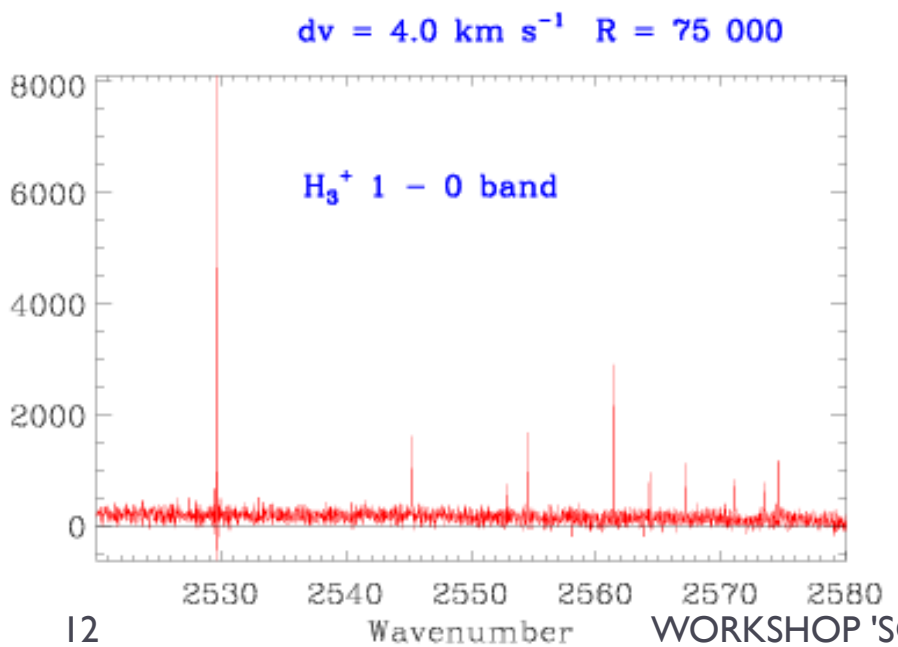
J.P. Maillard, Spect. Chim. Acta, 51A, 1105 (1995)



HST Image (WFPC2 camera) of the north auroral zone in H_2 (UV band) of Jupiter

Spectrum of the auroral zones of Jupiter in infrared





H_3^+ ion detected *for the first time* on Jupiter in the auroral zones from the 2 – 0 band at 2 μ m with the FTS

$$H_2^+ + H_2 \longrightarrow H_3^+ + H$$

Detection of H_3^+ on Jupiter,

Drossart, P., Maillard, J.P. et al, Nature, 340, 539 (1989)

High resolution spectrum of the H_3^+ emission in the 1 – 0 band at 4 μ m in the south auroral zone of Jupiter

H_3^+ fundamental band in Jupiter's auroral zones at high resolution from 2400 to 2900 inverse centimeters,

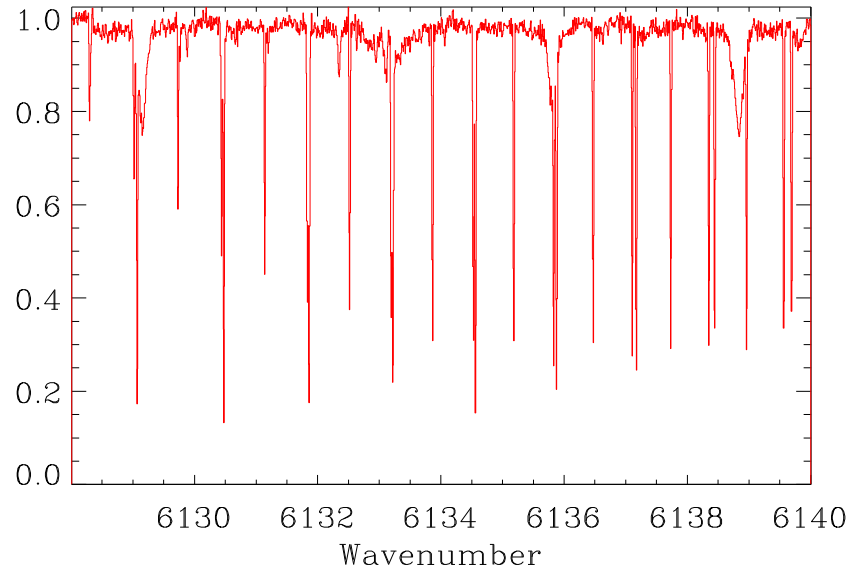
Maillard, J.P., Drossart, P., et al, ApJ, 363, 37 (1990)

High resolution spectra of Mars atmosphere

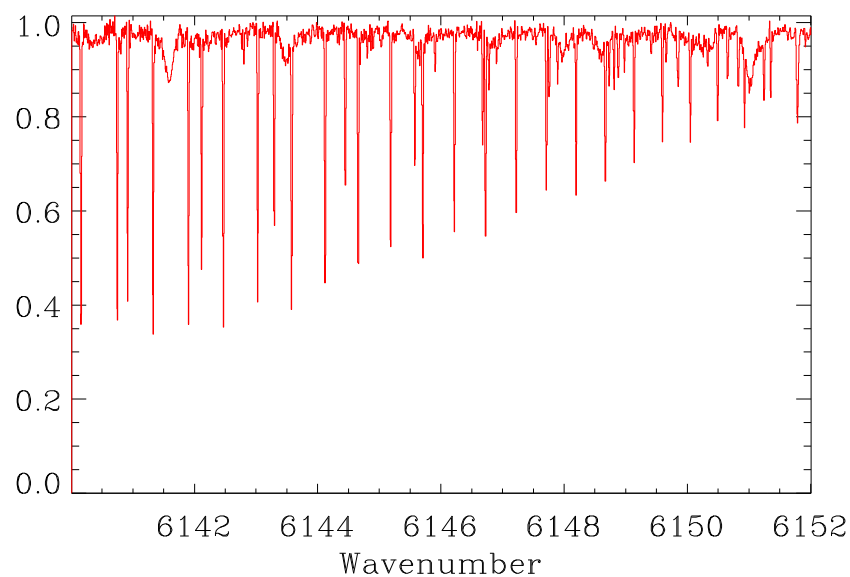
Measurement of the O^{16}/O^{18} ratio from the CO_2 isotopes from spectra at **R ≈ 420,000** in the H band (1.6 μ m) observed in Sept. 1999.

Oxygen and carbon isotope ratio in the Martian atmosphere

Krasnopolsky, V.A., Maillard, J.P., Owen, T.C. et al., Icarus 192, 396, 2007



$d\sigma$ = 0.0147 cm^{-1} R = 418,500



Mars observed at 3.4 μ m for the search of methane at **R = 220,000** (Jan. 1999)

Detection of Methane in the Martian atmosphere: Evidence for life ? Icarus 172, 537, 2004

THE ENVIRONMENT OF HIGH-MASS YSOs BY FTS HIGH-RESOLUTION ABSORPTION SPECTROSCOPY

J.P. Maillard (1) & G.F. Mitchell (2)

(1) Institut d'Astrophysique de Paris (CNRS), France

(2) Saint Mary's University, Halifax, N.S., Canada

Observing program of the **CO Δv = 1 bands at 4.7 μm** carried out toward massive young stellar objects still embedded in their parent molecular cloud → **probing gas and dust all along the line of sight**.

TABLE 1

LOG OF THE OBSERVATIONS

Source	Date	Integration Time (minutes)
GL 2136	1987 Jul 11	128
W3 IRS 5	1988 Sep 30	96
S140 IRS 1	1987 Jul 12	160
	1988 Sep 30	224
NGC 7538 IRS 1	1988 Oct 2	144
NGC 7538 IRS 9	1988 Oct 1	160
LkHα 101	1988 Oct 2	40
MWC 349A	1987 Jul 10	80

Thanks to the high resolution of the FTS and the spectral coverage, observation at **R = 40,000** (≈ 8 km/s) of a large set of ^{12}CO and ^{13}CO lines:

- excitation conditions of the molecular gas and its kinematics
- detection of episodic outflows from the massive stars

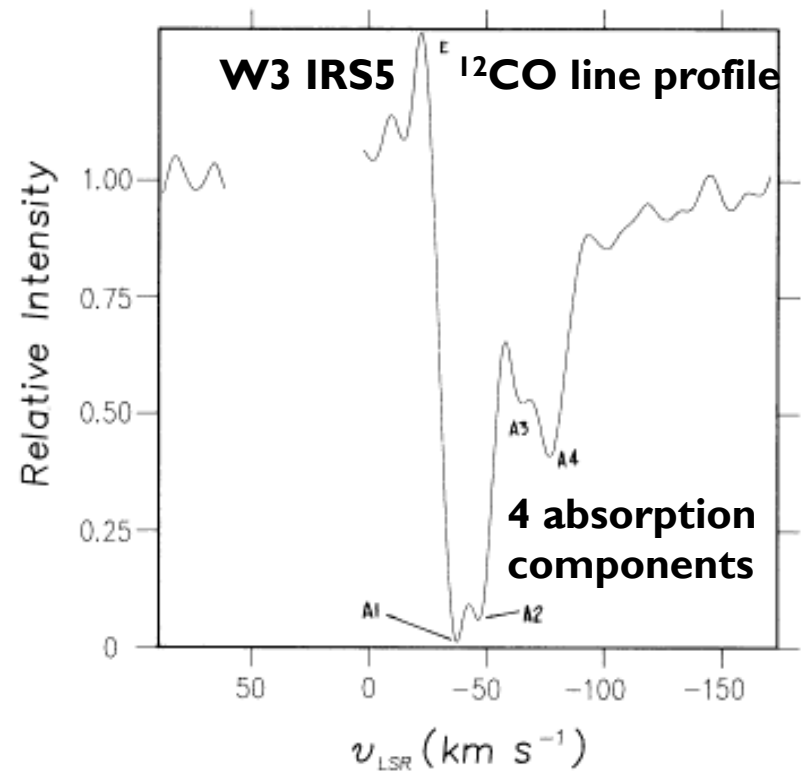


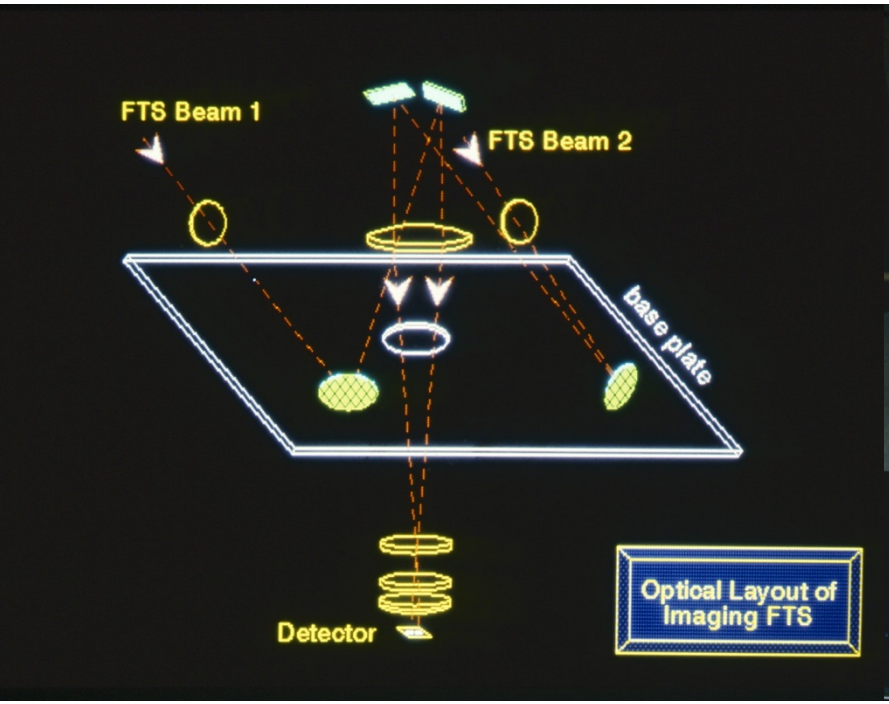
FIG. 1.—An average kinematic profile of nine ^{12}CO $v = 0 - 1$ lines in W3 IRS 5. The profile is an average of the P3, P6, P7, P8, P9, P12, R1, R3, and R7 lines. Telluric lines have been removed by ratioing the spectrum with a spectrum of α Lyr. The gap in the spectrum corresponds to the position of saturated telluric CO lines. The four absorption components labeled A1, A2, A3, and A4 have velocities $v_{LSR} = -42$ km s^{-1}, -53 km s^{-1}, -73 km s^{-1}, and -84 km s^{-1}. The total velocity range of the absorption is ≈66 km s^{-1}. A probable emission component is labeled by E.

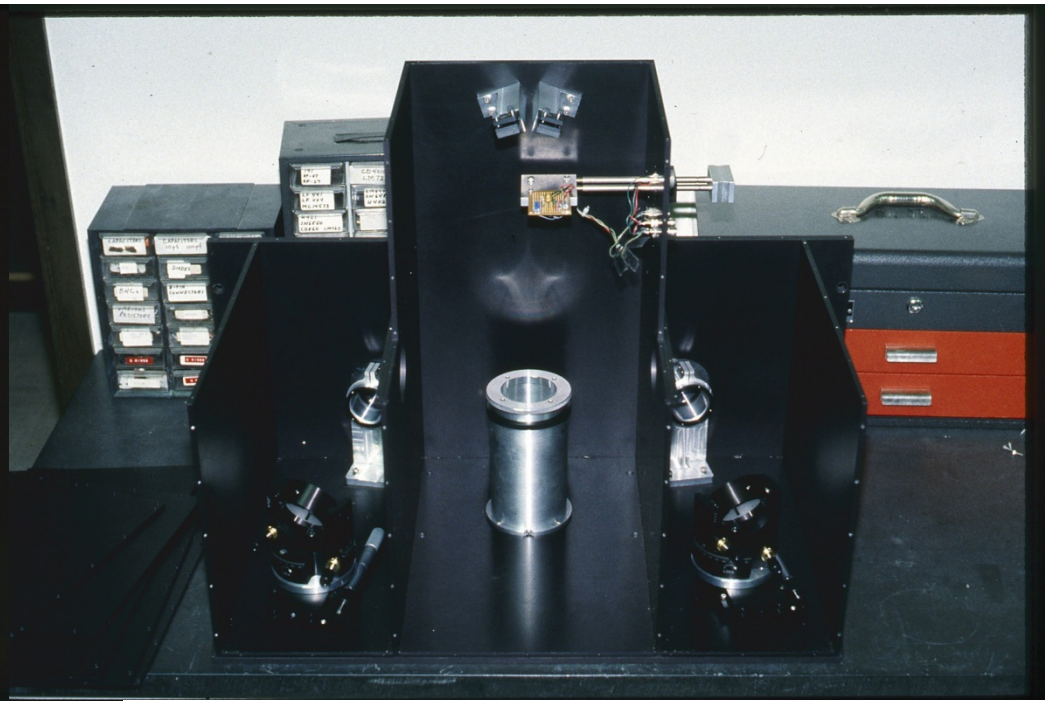
Source of many papers:

- The detection of high-velocity outflows from M8E-IR *ApJ 327, L17 (1988)*
- The detection of a discrete outflow from the young stellar object GL490 *A&A 201, L16 (1988)*
- The ratio of solid to gas phase CO in the line of sight to W33A *ApJ 333, L55 (1988)*
- The gas environment of the young stellar object GL 2591 studied by infrared spectroscopy *ApJ 341, 1020 (1989)*
- Hot and cold gas toward young stellar objects *ApJ 363, 554 (1990)*
- Episodic outflows from high-mass protostars *ApJ 371, 342 (1991)*
- The $^{12}C/^{13}C$ abundance ratio in NGC 2264 *ApJ 404, L79 (1993)*
- A multi-transition CO study of GL 490 *ApJ 438, 794 (1995)*
- The Star-forming core of Monoceros R2 *ApJ 487, 346 (1997)*

II. 2D-FTS at the CFH Telescope

Operation started in 1989: the CFH-FTS could be easily fitted to an imaging mode since it has been originally built with a step-by-step OPD scanning mode → just needs a mechanical interface to couple a camera to the FTS and a FTS-CCD synchro .





Layout of the interface attached to the FTS to image the field of the two output beams on a single 2D-detector

The mechanical interface built at UH-Manoa thanks to close Doug Simons' collaboration

From the CFH Bulletin of 1990, 1st sem.

First 2D Spectroscopy Tests in the IR with a CCD and the FTS

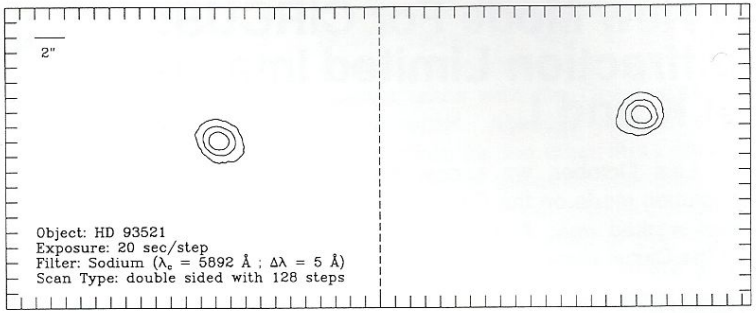
Introduction

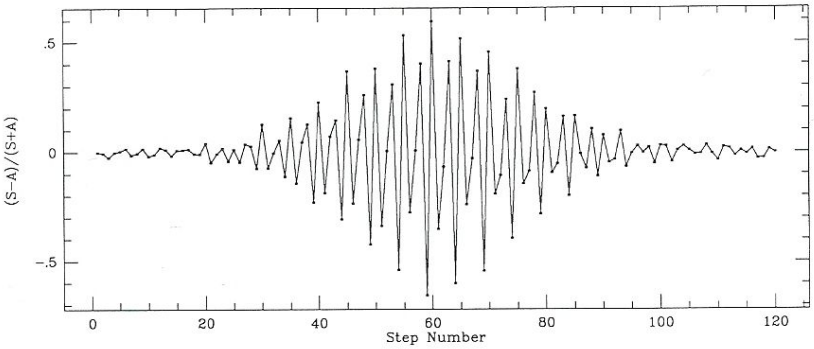
The FTS has been successfully coupled to the Institute for Astronomy's 800x800 optical CCD, in an effort to make a Fourier imaging spectrometer. The primary goal of the FTS-CCD interface project has been to create an instrument that is capable of making both high spatial and spectral resolution observations of a variety of objects. Possible applications include *very* efficient velocity dispersion mapping of galaxies and star clusters, as well as high resolution imaging/spectroscopy of complex line emission fields.

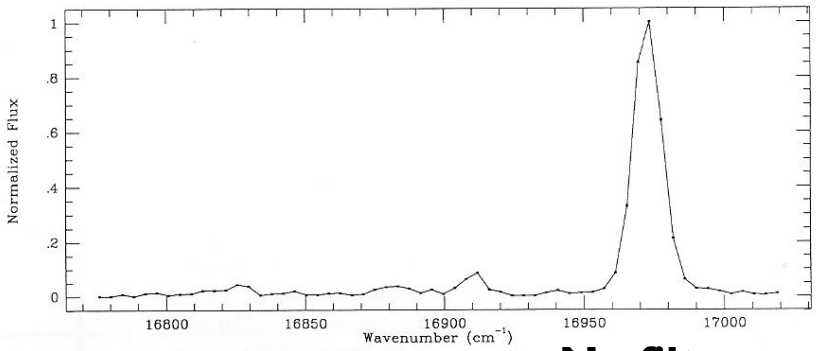
Not in the IR but **in the visible**, with a UH CCD camera coupled to the FTS:

Observation of a star (HD93521) through a Na filter at R ≈ 1000, during a **test run of July 1989** (*with D. Simons & L. Cowie*)

The 2 images of a star on the CCD







Na filter

First operation of an astronomical Imaging FTS

From the CFH Bulletin of 1991, 1st sem.

Update on the 2D FTS Project

Considerable progress has been made over the past year in the development of the optical 2D FTS. This unique instrument is designed to sequentially record CCD images through the complementary outputs of the FTS while the FTS steps through a scan. In this way spatial and spectral information about targets is acquired simultaneously in an efficient manner.

Results from a run of June 1990. The UH CCD camera replaced by a CFHT CCD camera: Observation of a star and planetary nebula

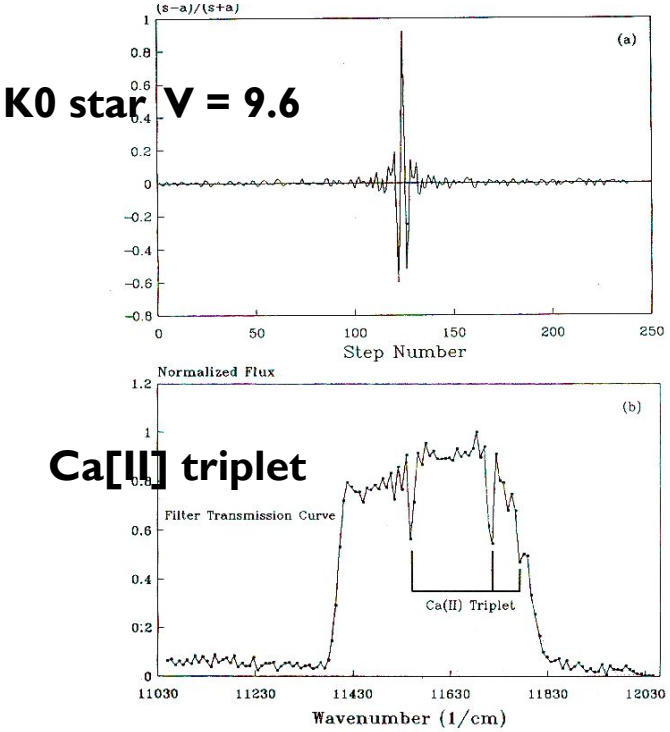
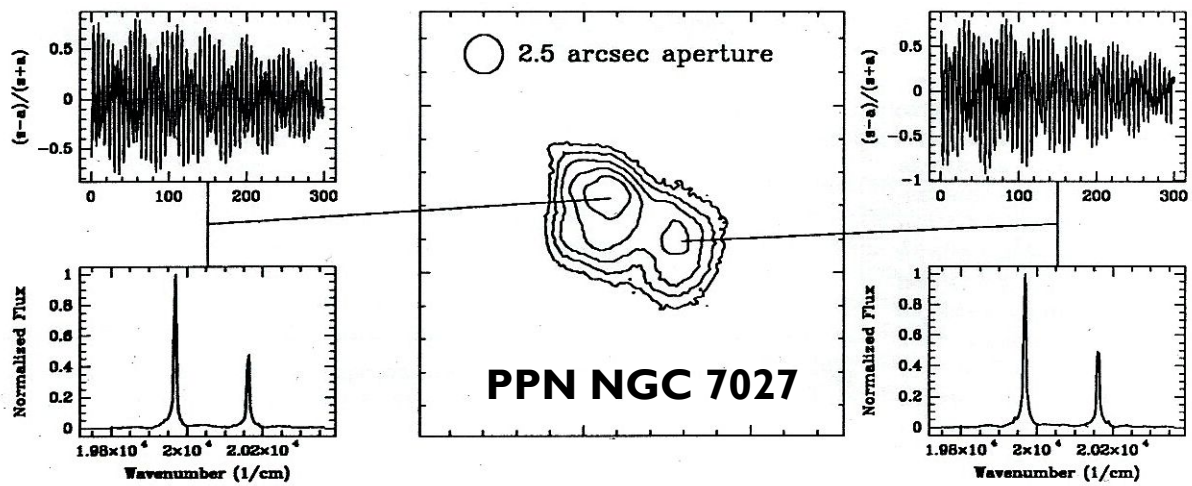


Fig. 7(a,b). A 250 steps double sided interferogram (a) and corresponding spectrum (b) of the star HD 114682 are shown. Prominent in the spectrum is the Ca(II) triplet and the filter's transmission curve.

Fig. 8. Spectra and interferograms from the planetary nebula NGC 7027 are presented. The scan was made through an O[III] (80 Å bandpass) filter with 300 singlesided steps. The entire nebula fits in the instrument's 20" field of view.



D.A. Simons, J.P. Maillard and L. Cowie

LATEST NEWS ON INSTRUMENTATION

From the CFH Bulletin of 1993 2nd sem.

Progress with 'Bear:' The Imaging Fourier Transform Spectrometer

Two science programs were incorporated into our March 1993 run, which was the first time one of the Redeye cameras was coupled to the FTS, forming Bear.* One program included scans of the dark side of Venus in an attempt to map out the Venusian disk through several of its atmospheric infrared windows. The other program was designed to image H_2 and H_3^+ emission from the polar regions of Jupiter (north and south). The

This run posed unique challenges for the Bear team, since we were not only using a new camera system but were attempting to couple that system to the FTS to effectively create a new instrument. The fact that Bear was used successfully for the March 1993 run is a testament to the skill of the CFHT technical staff.

D. Simons, J-P. Maillard, J. Kerr, C. Clark, S. Smith, S. Massey

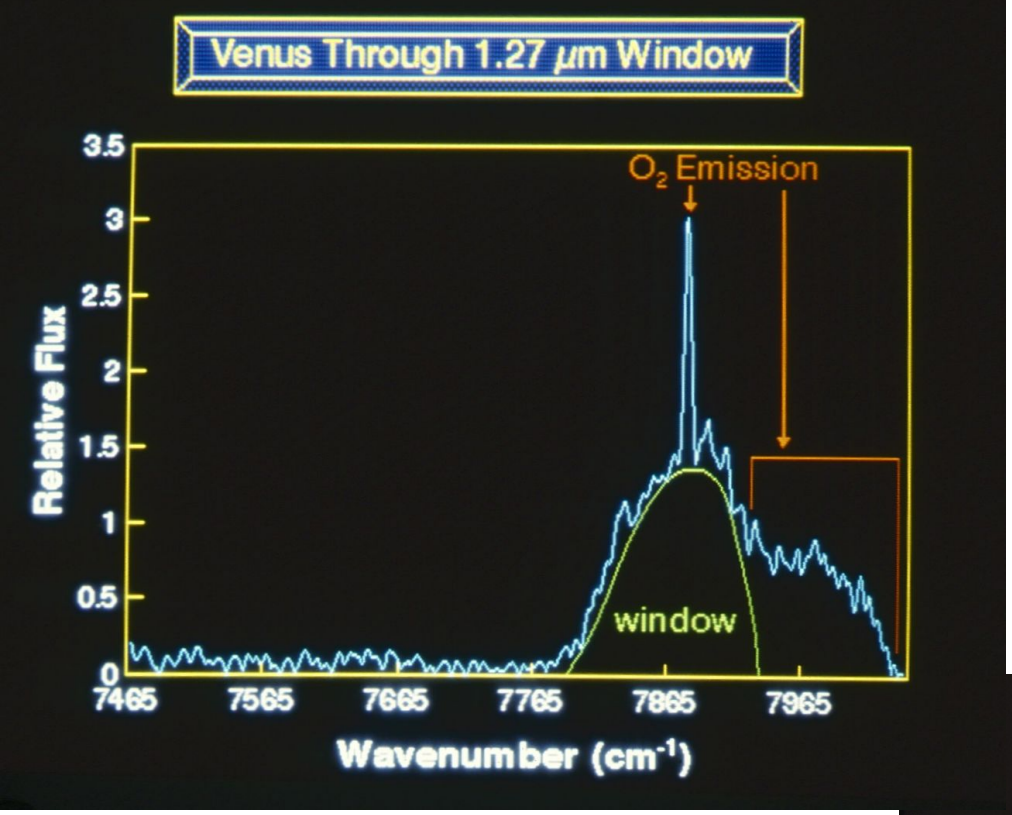
Imaging Fourier Transform Spectrometer

B E A R

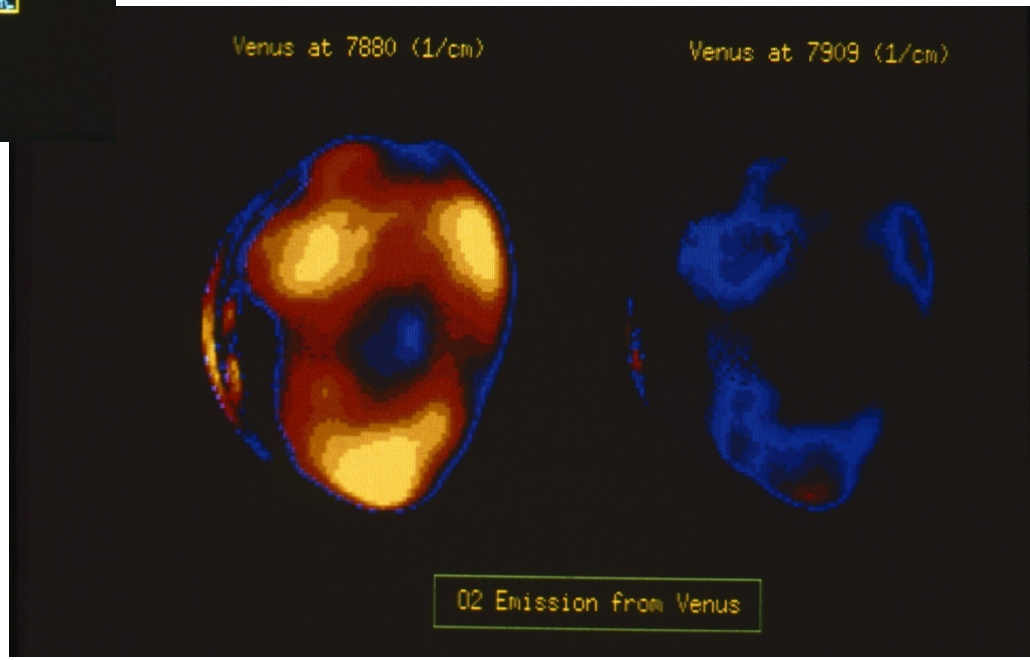
Bidimensional Experience with Array Receiver

Best Experimental Astronomical Research

** In case you were wondering, the name "Bear" stems from the collective imagination of the CFHT software group and dates back to the days when "Lions (a.k.a. Pumas), and Tigers" were abundant on the summit. They felt a Bear was needed at the zoo. We are still trying to retrofit an acronym onto Bear. Some possibilities include "Bidimensional Experience Adapting Redeye" or "Best Experimental Astronomical Research"!*



First scientific result with BEAR:
Spectro-imaging of the dark side of Venus in the 1.27 μm O_2 emission with an imaging FTS
presented at the Division for Planetary Science (DPS) 1993 meeting



Spectrum at R ≈ 1800.
1.27 μm O_2 emission + thermal continuum in the dark side of Venus.
The high-resolution spectrum of the 1.27 μm O_2 band at **R≈25,000** had been previously obtained with the FTS in standard mode.

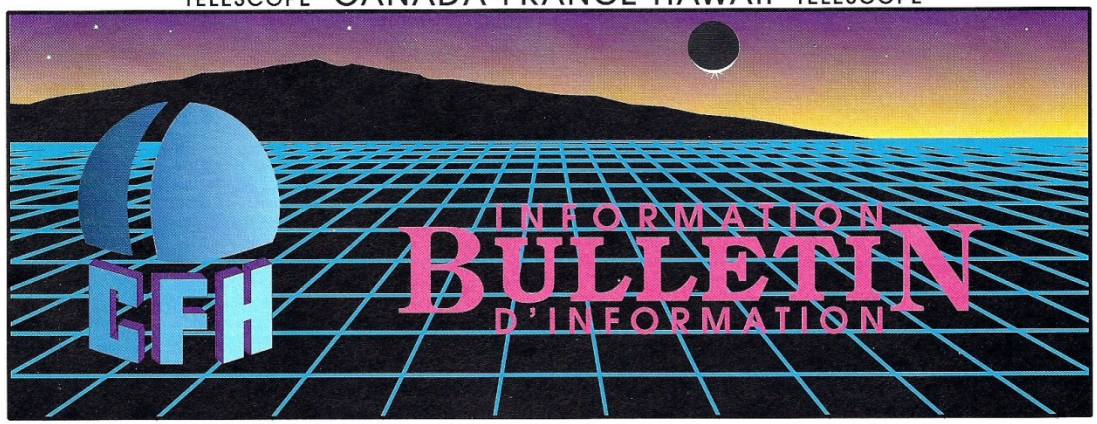
From the CFH Bulletin of 1995 1st sem.

BEAR makes the front cover with the image of the H_2 shell (line 1-0 S[1] at 2.12 μm) of a young planetary nebulae BD + 303639 compared to the distribution of the ionized hydrogen (Brγ line) .

P. Cox, J.P. Maillard and F. Rigaut

BEAR became officially a CFH instrument for semester 1995 A

TELESCOPE CANADA-FRANCE-HAWAII TELESCOPE



BULLETIN NO. 32 1995 FIRST SEMESTER

Bear Observations of BD+30°3639

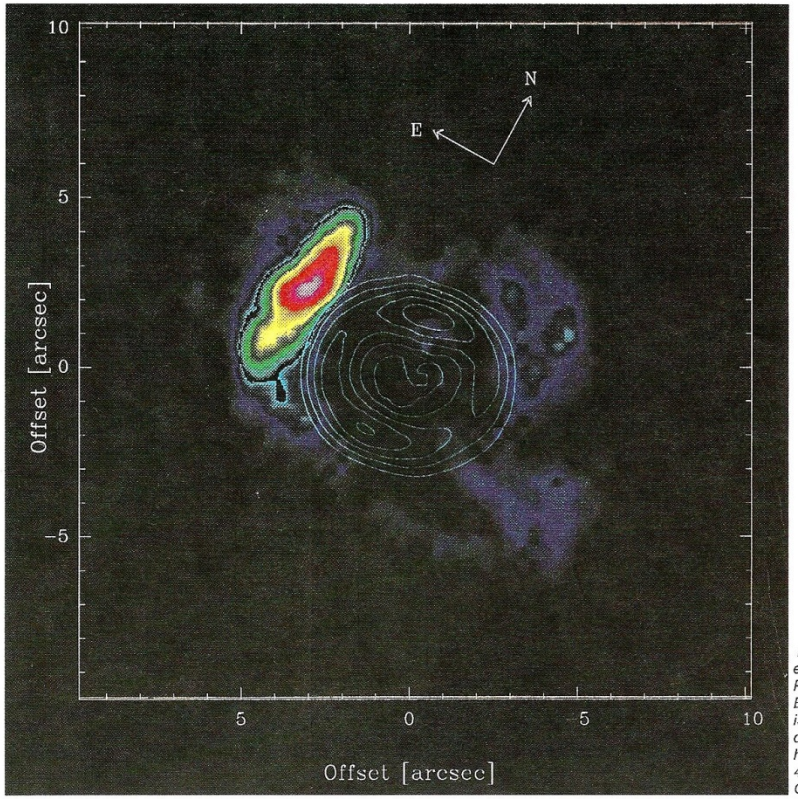
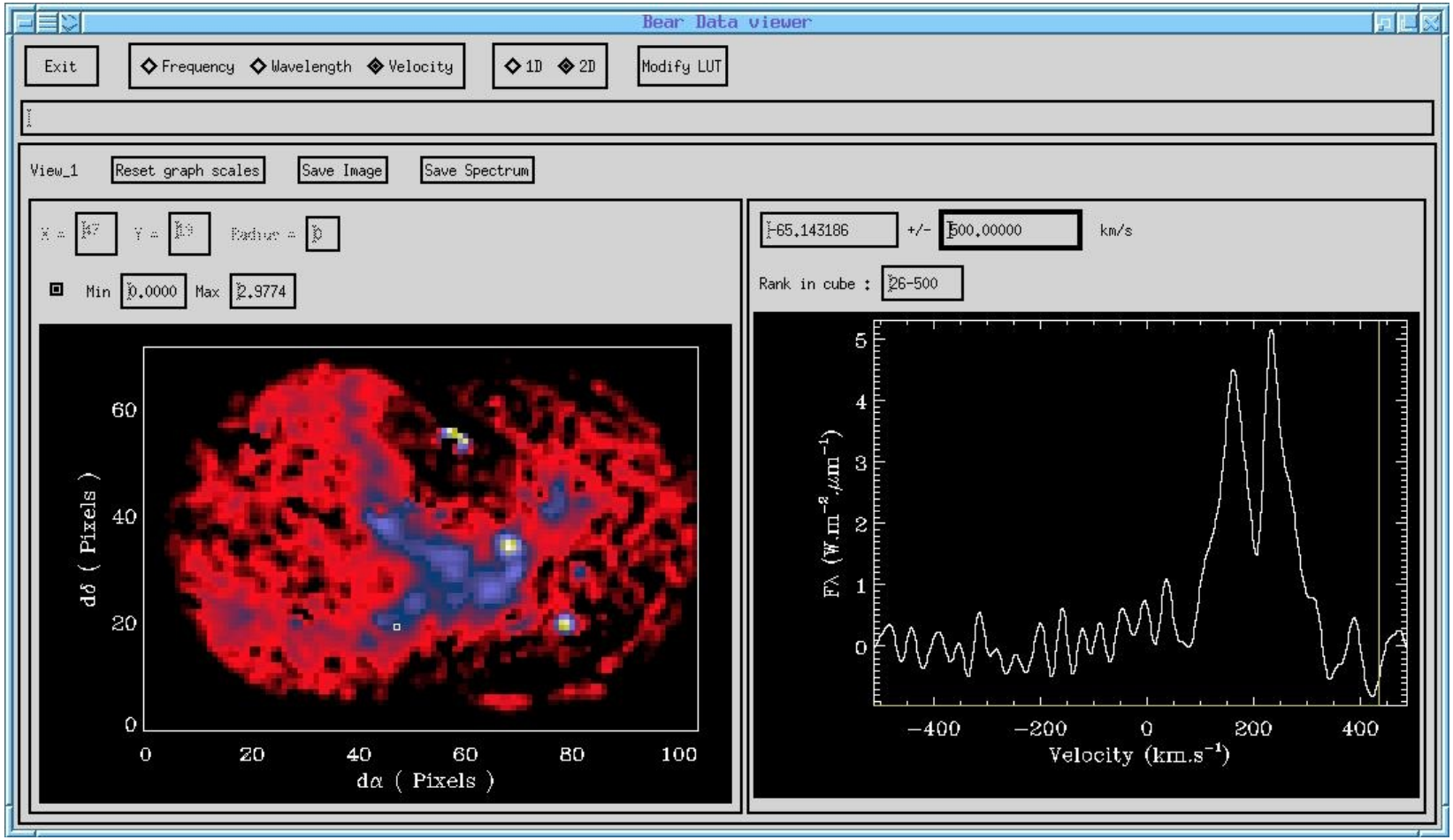


Figure 1: Molecular H2 emission of the young Planetary nebula BD+303639. The blue isocontours show the distribution of ionized hydrogen in the Brγ line at 4616 cm⁻¹. (see article by Cox & Maillard on p. 18).

In the same issue a paper from F. Rigaut on "**Display of the BEAR data cubes**" the sofware tool called **Cubeview** under IDL to vizualize the data cubes:

View of the graphic interface



- **1D mode at right** (spectrum or interferogram) at a position selected on the left window
- **2D mode at left** at a position (frequency or step) selected on the right window

BEAR data reduction software

A complete BEAR data reduction package under IDL called ***bearprocess*** has been developed, started at CFH, completed at IAP. **Two main steps:**

- ***prepcube*:** production of the final interferogram data cube (flat-fielding, sky subtraction, correction of cosmic rays, image registration).
- ***bear2d_cos*:** production of the spectral data cube by computing for each extracted interferogram its zero-OPD and then, its **FFT in cosine**.

Advantage: recording of only 50 steps before zero-OPD = division by a factor ≈ 2 of the total number of images to record. Important for a high-resolution instrument.

Additional packages:

- ***subcub_gen*:** generation of an oversampled data cube around one line (e.g. Brγ cube) from the original spectral cube, including the field phase correction.
- ***bear_calib*:** flux calibration of the spectral cubes from a reference star observed with BEAR through the same filter (filter transmission correction).
- ***merge_cube*:** merging of two spectral cubes to increase the observed field size.

2D-FTS at the CFH Telescope = **BEAR**

Entrance FOV : 24'' diameter

Detector : 256x256 NICMOS HgCdTe, used 2x180x180

Plate scale: 0.35''/pxl

Practical cube size: ≤ 1200 planes

Overhead time per step 2.2 s

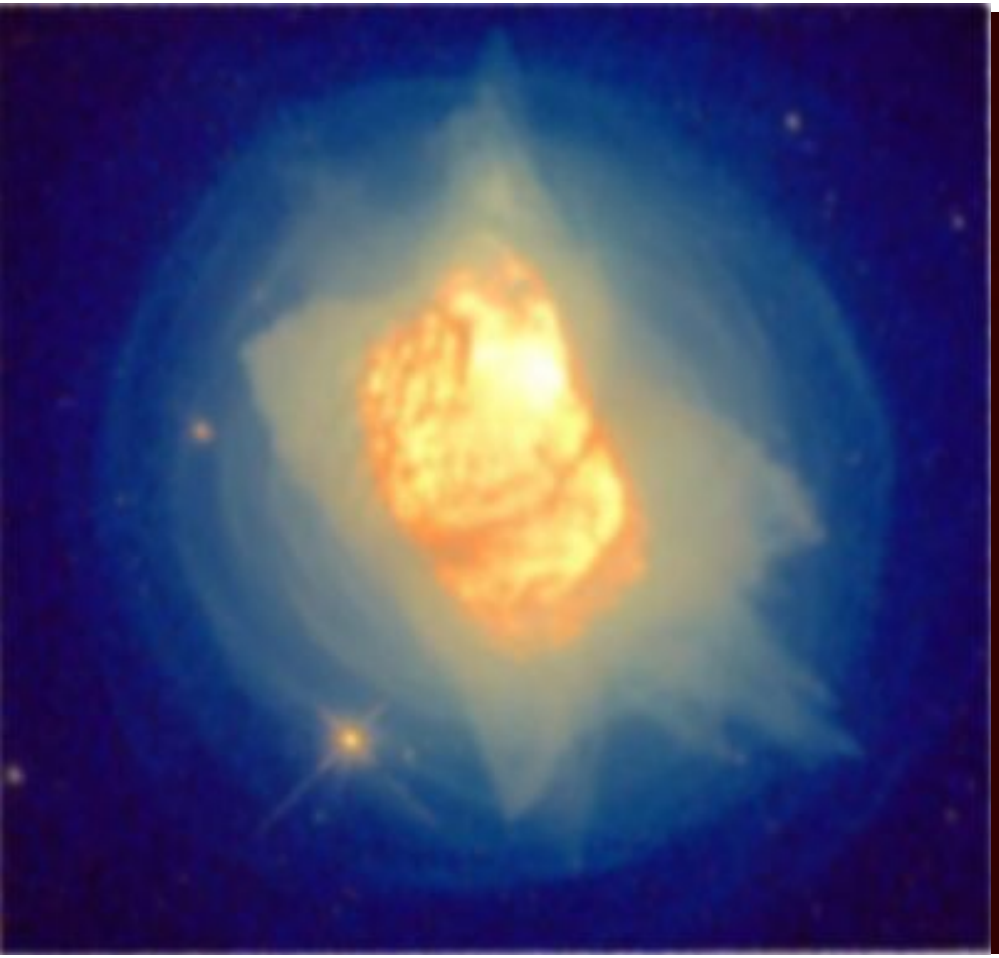
Practical max. resolution: ~ 30 000 (10 km/s)

Spectral domain: 1 – 2.5 µm, main programs in the K band

Scientific programs :

- planetary atmospheres (O_2 Venus, H_3^+, H_2 Jupiter)
- ➢ **planetary nebulae (H_2 envelope , ionized region, abundance measurements)**
- reflexion neb. (excitation conditions of H_2)
- ➢ **central parsecs of the Galaxy (population of massives stars, gas kinematics)**
- star forming regions (H, H_2 , flows, jets, shocks, gas kinematics) ….

Observation of the young planetary nebulae: **NGC 7027**



HST Image of the planetary nebulae in the visible (ionized region)

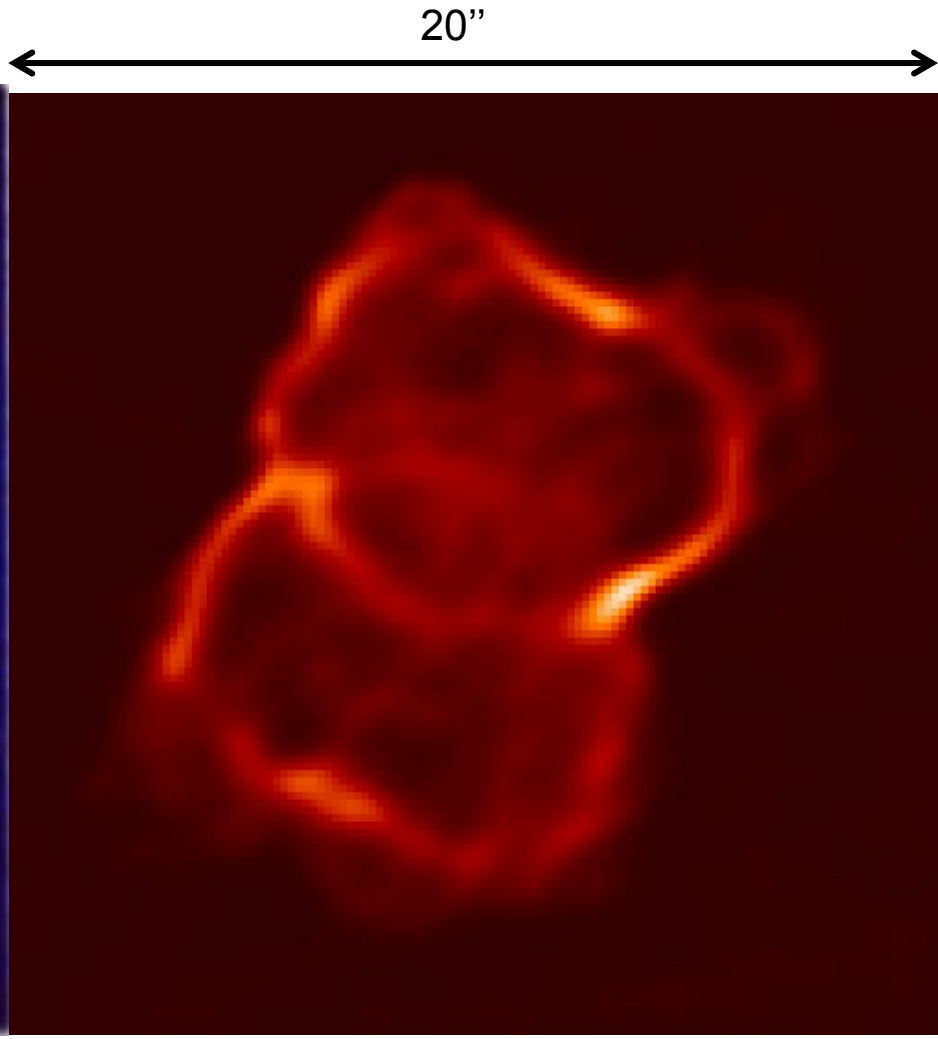
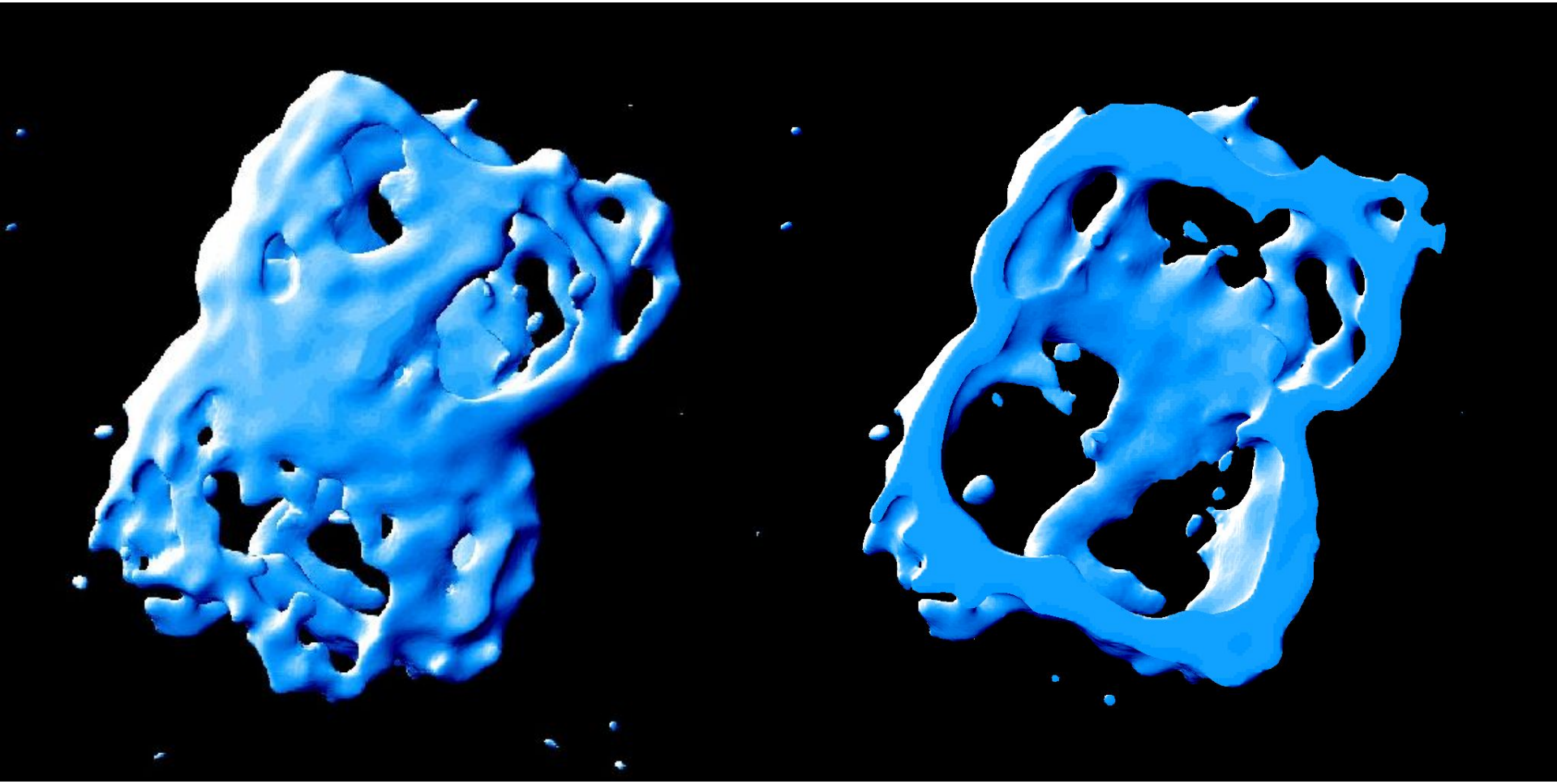


Image at 2.12 µm with BEAR of **only** the molecular envelope [line 1-0 S(1) H_2]

Observation of the young planetary nebulae: **NGC 7027**

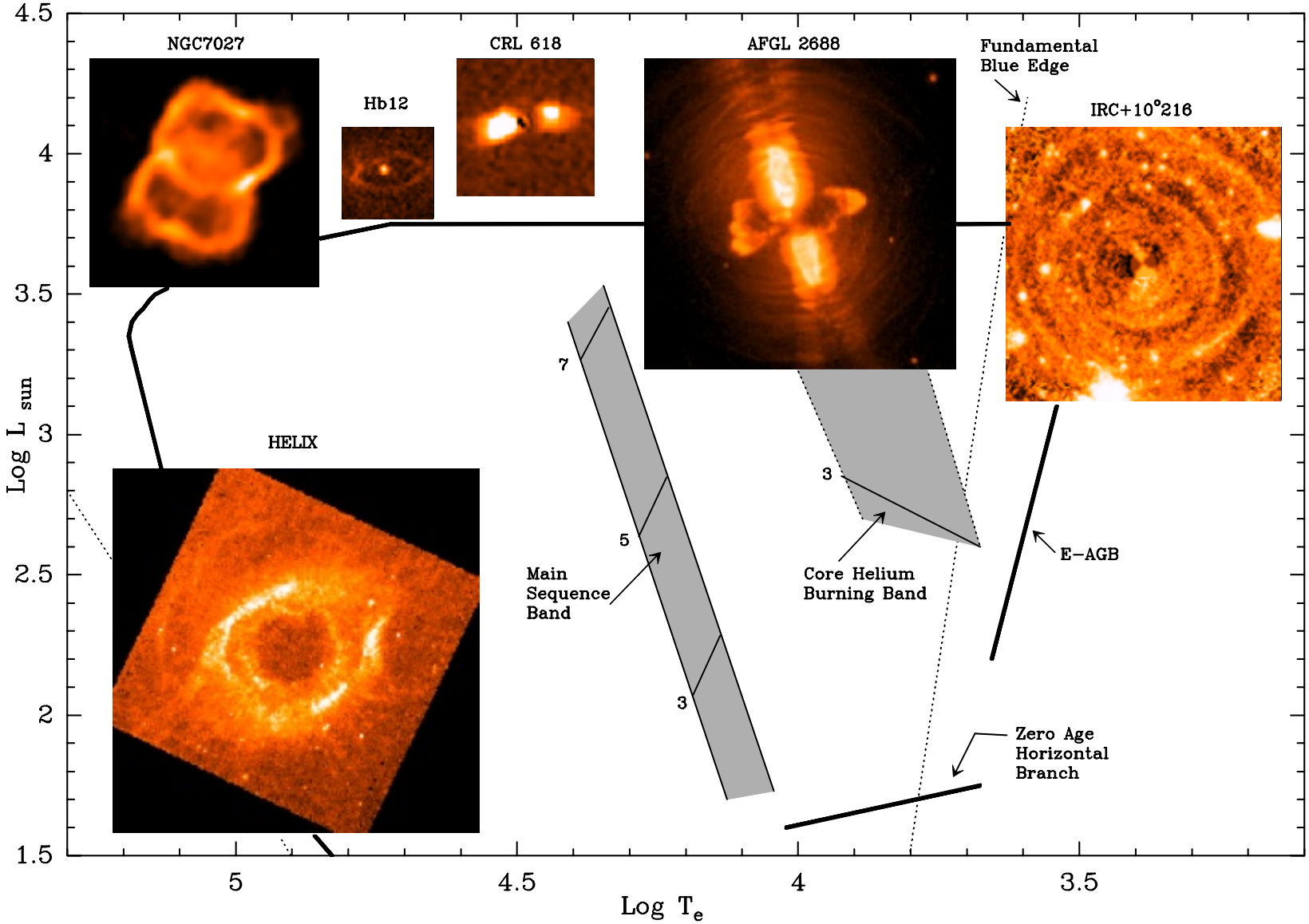


3D image of the H_2 envelope, showing the holes formed by bipolar collimated outflows from the central star

Cut through the molecular envelope

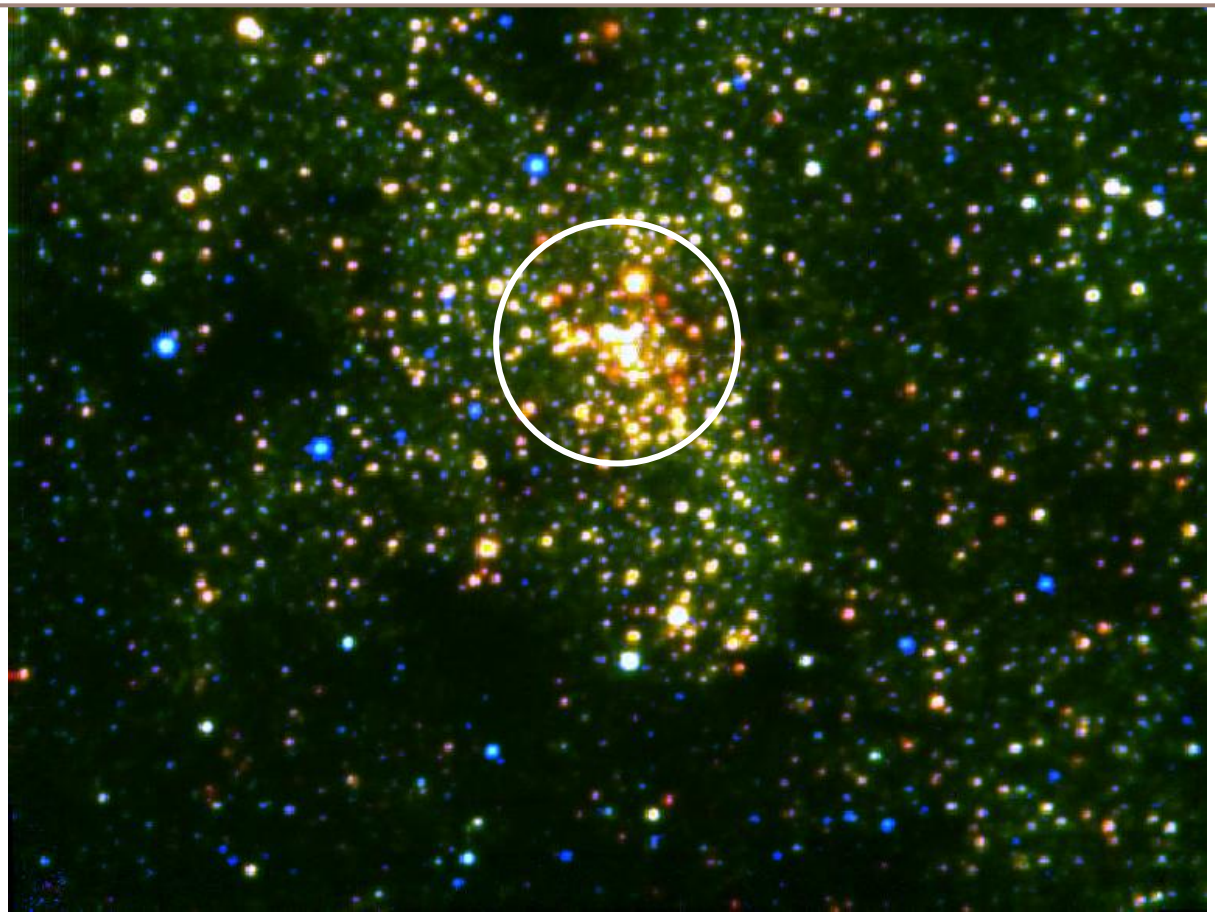
High resolution near-infrared spectro-imaging of NGC7027

P. Cox, P. Huggins, J-P Maillard, et al, A&A 384, 603 (2002)

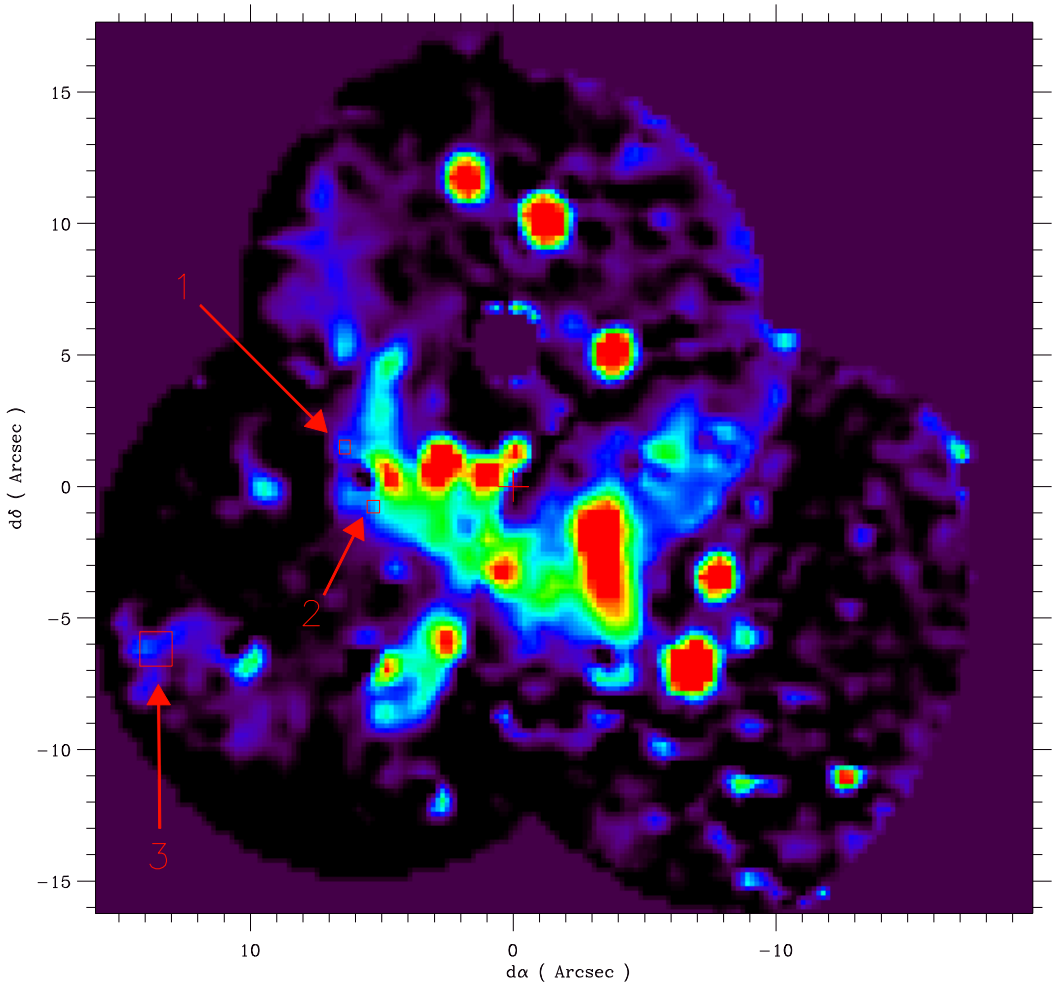


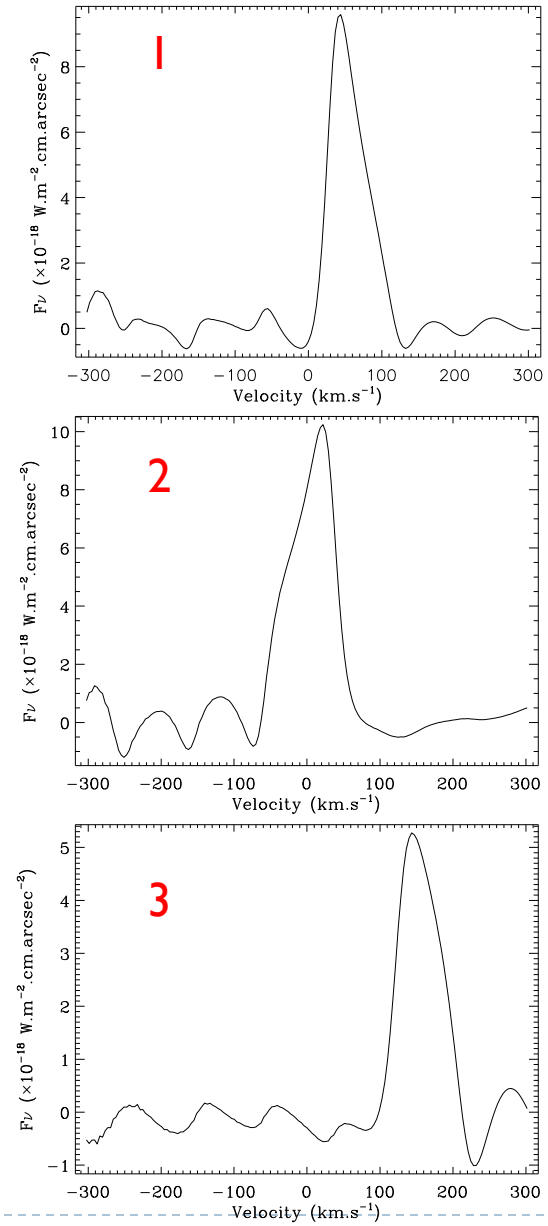
HR diagram from AGB to PN: sequence of evolution from the sources observed with BEAR

Stellar cluster at the Galactic Center (image NICMOS J, H et K)



Observation with BEAR of the ≈ 2 central parsecs (24" = 0.93 pc)



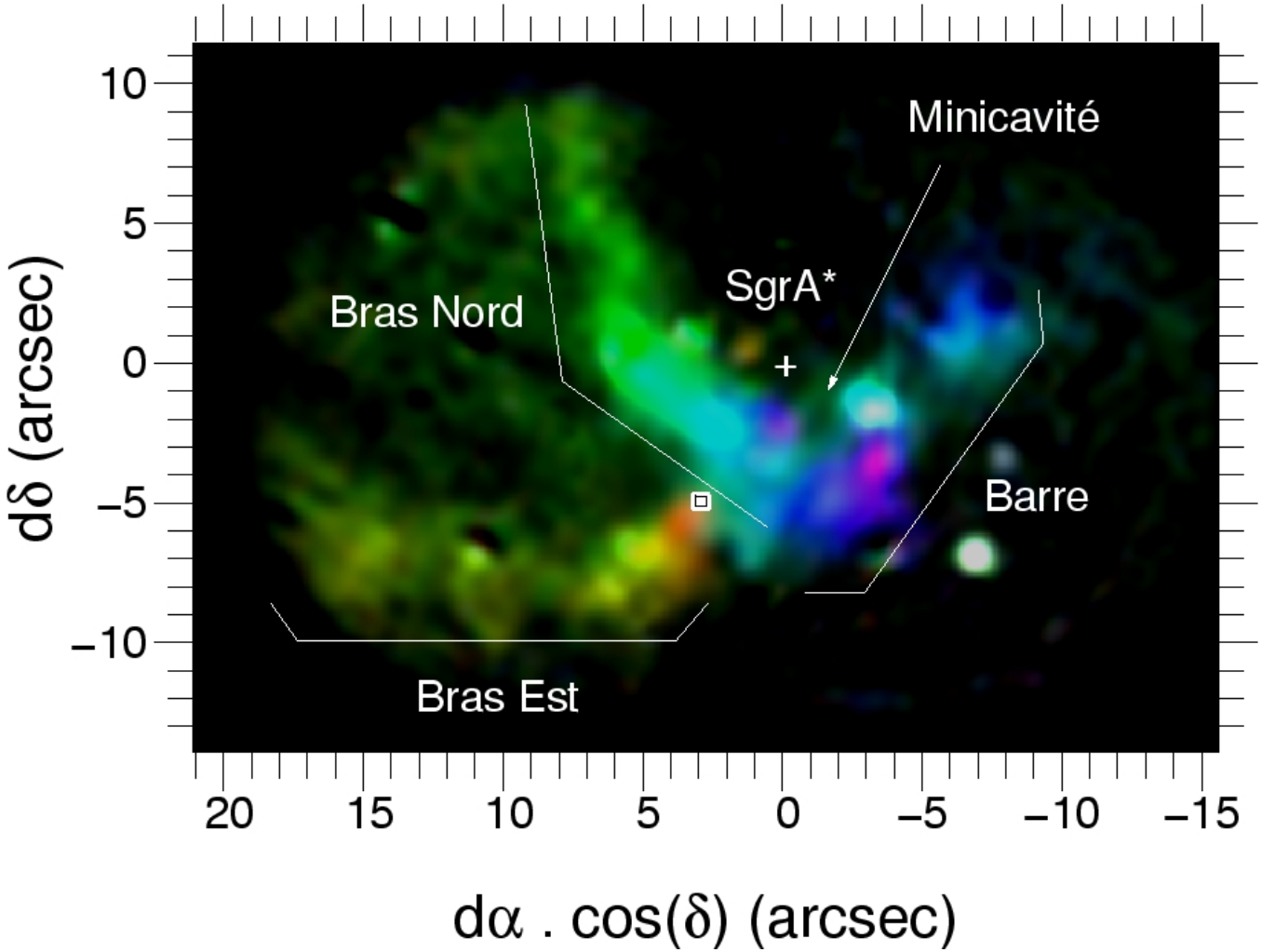


Three BEAR fields in the HeI line at 2.058 µm toward the Galactic Center (+ SgrA*):

- Central cluster of massives helium stars (red)
- Emission of the interstellar gas (blue)

3 examples of velocity profiles in the gas →

I. Dynamics of the gas in the central region of the Galaxy



Doppler Image of Sgr A West (**Minispiral** of hydrogen and helium) at the Center of the Galaxy, from the **Brγ** line **(2.16 µm).**

Identification of 9 gas flows forming the observed spiral structure with the Northern Arm, the Estearn Arm, the Barr…

Kinematic and structural analysis of the Minispiral in the Galactic Center from BEAR spectro-imagery, *Paumard, T., Maillard, J.P. & Morris, M.,* A&A, 426, 81 (2004)

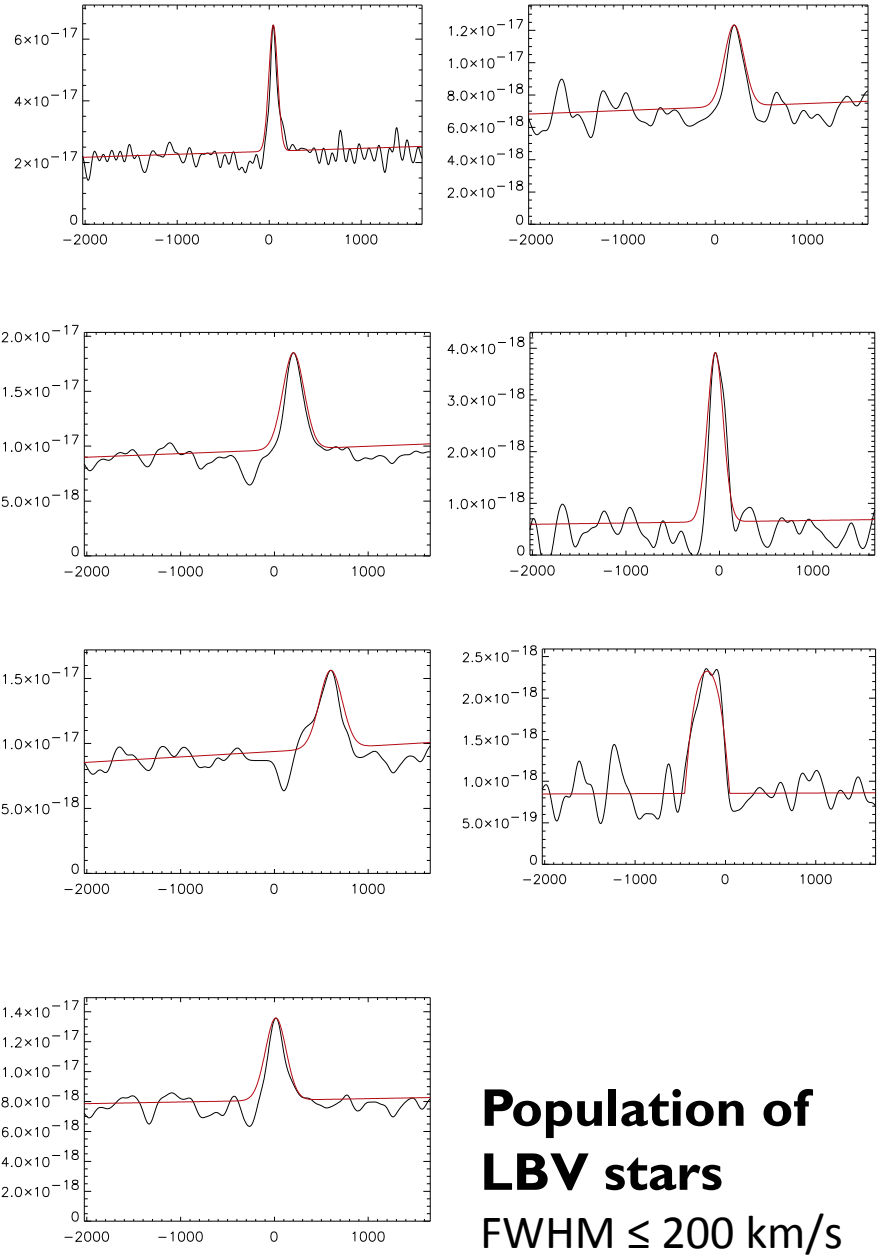
II. Study of the central cluster of massive stars at helium emission (He I 2.06 μm)

<u>Identification of **two populations** of helium stars</u>

- from their linewidth (*spectral resolution: 74 km/s*)
- from their magnitude
- from their spatial distribution around SgrA*

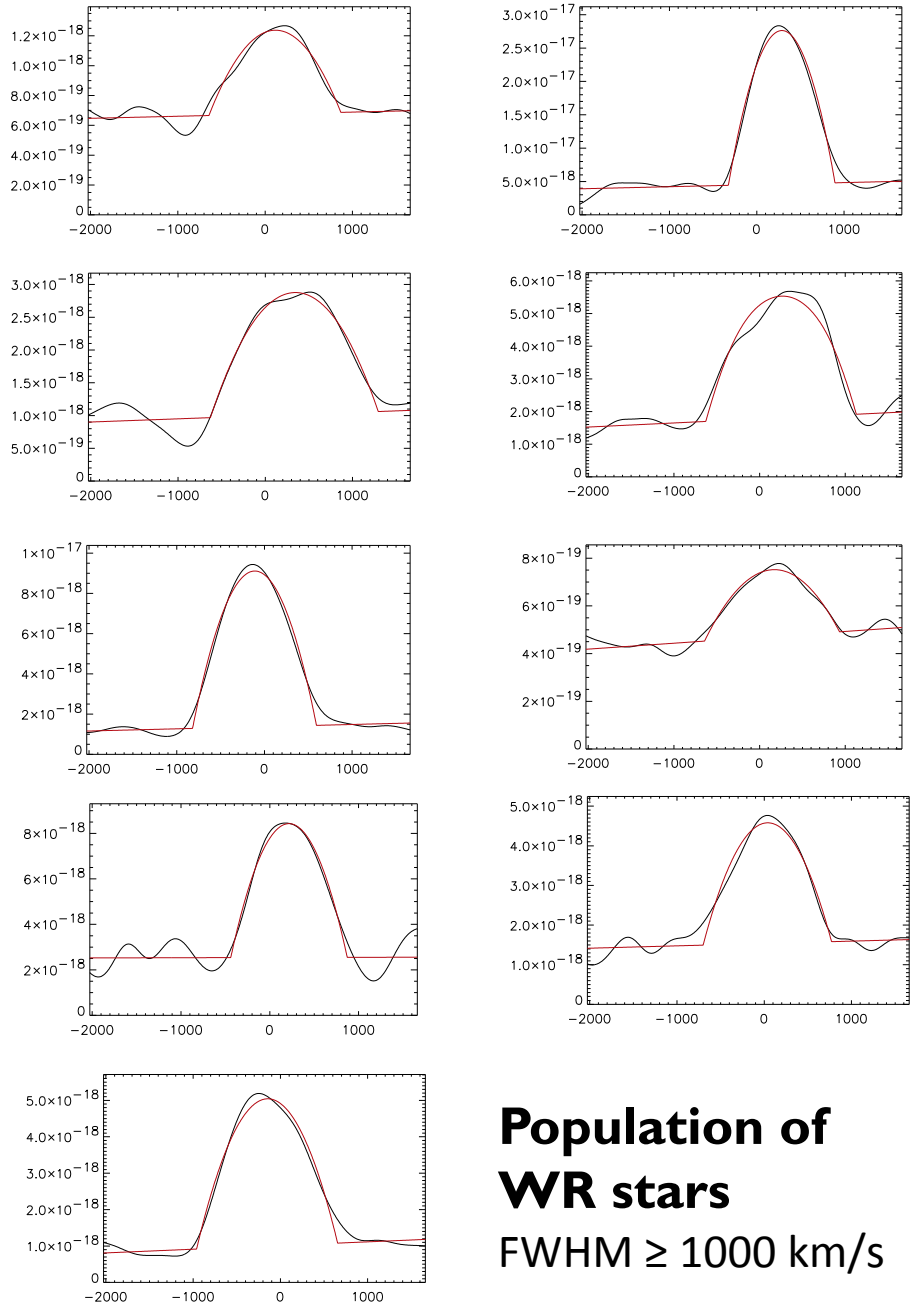
Origin of this cluster ? Possibility of the stellar formation in the environment of the SMBH SgrA*?

New results on the helium stars in the galactic center using BEAR spectro-imagery
Paumard, T.; Maillard, J. P.; Morris, M.; Rigaut, F., A&A 366, 466 (2001)



Population of LBV stars

FWHM ≤ 200 km/s



Population of WR stars

FWHM ≥ 1000 km/s

Last run of FTS-BEAR: Feb. 2001

Also the end of the IR focus

←The remnants of the IR upper end moved out of the dome!

To make sure the IR focus will never come back on the CFH telescope!

III: Imaging FTSs projects after BEAR

1. IFTS for NGST

1998: justified by the BEAR experience, paper of J. Graham et al. on "***The performance and scientific rationale of an infrared IFTS on a large space telescope***" (PASP, 110, 1205) stressing the interest of a wide-field, low resolution IFTS in space, in the 1 – 15 µm domain, for extragalactic astronomy.

13-16 Sept

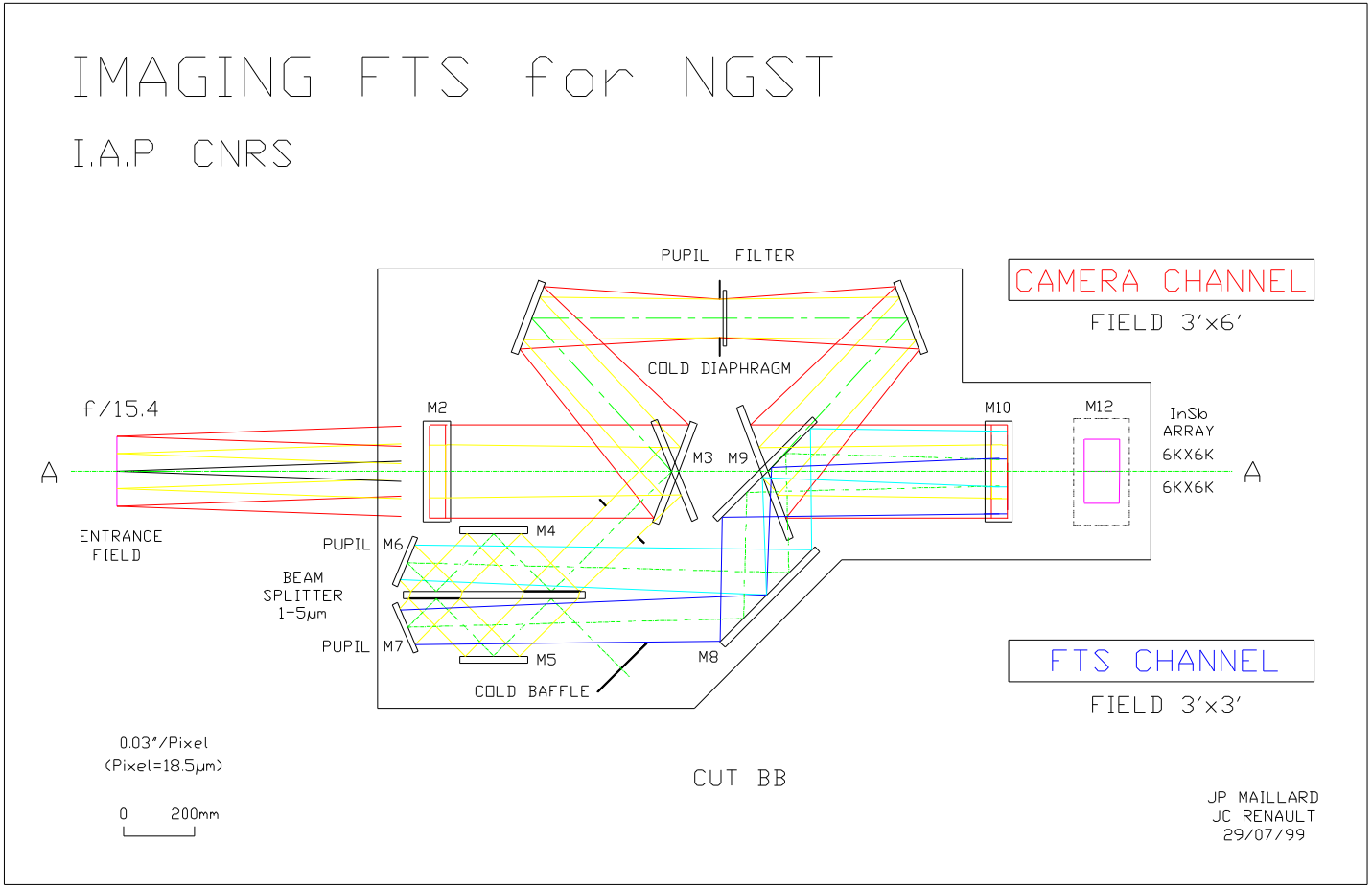
1999: Hyannis Conf. on ''*(Next Generation Space Telescope)* ***NGST Science and Technology Exposition***'' response to the Call for instrumentation from the « NASA Design Reference Mission » : cosmological objective

Result: 3 proposals of IR wide-field, diffraction-limited, low spectral resolution IFTS:

- *IFIRS: an IFTS for the NGST,* Graham, J.R. (UC Berkeley), 2000
- *A Canadian IFTS for the NGST,* Morris, S.L., Villemaire , A. et al (Herzberg Institute and ABB/Bomem), 2000 → **SpIOMM : first facility wide-field astronomical IFTS**

➢ *NIRCAM-IFTS: Imaging FTS for NGST*, Posselt, W., Maillard, J.P. & Wright, G. (Dornier, IAP, Edinburgh), 2000

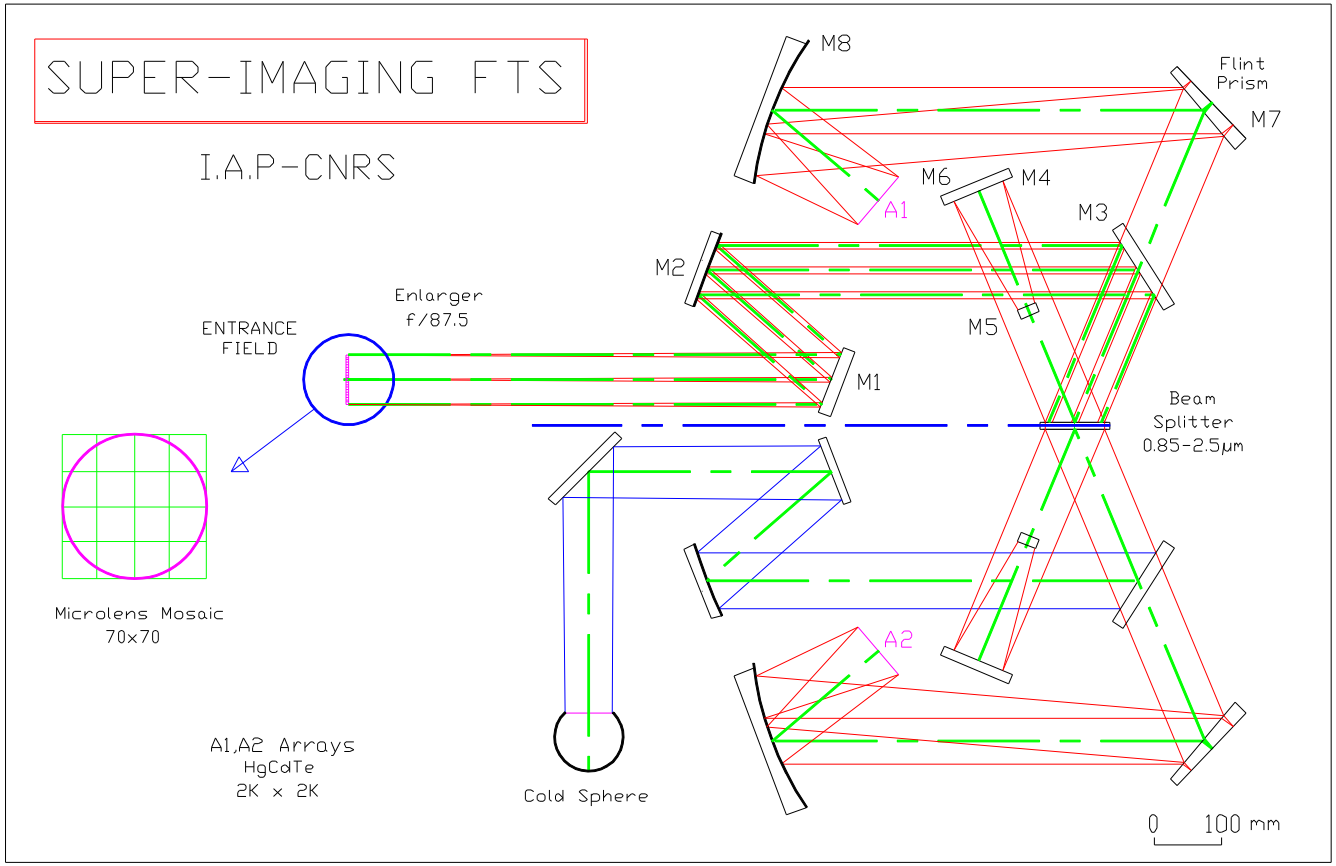
NIRCAM-IFTS for NGST



In parallel, proposal of a 2-channel 1 – 5 µm instrument <u>with the same camera</u>:

- low resolution Mach-Zehnder IFTS: 3'x3' FOV, dual output, full domain
- direct imager: 3'x6' FOV (*Comparison of two concepts of Imaging FTS,* Maillard, J.P., Proceedings of the Hyannis Conf., ASP Conf. 207, 479, 2000)

2. VLT/Super-IFTS (with post-dispersion)



- spectral domain: 0.85 – 2.5 µm
- FOV behind Adaptive Optics: 20" ; image sampling 0.05"
- R = 5×10^4 at 2 µm (*A Super-Imaging FTS for the VLT* Proceedings of the ESO Conf. **Scientific drivers for the ESO Future VLT/VLTI instrumentation,** Garching 11-15 June 2001 ESO symp. J. Bergeron, G. Monnet (Eds) p. 193, 2002

3. Molecular Hydrogen Explorer (H2EX)

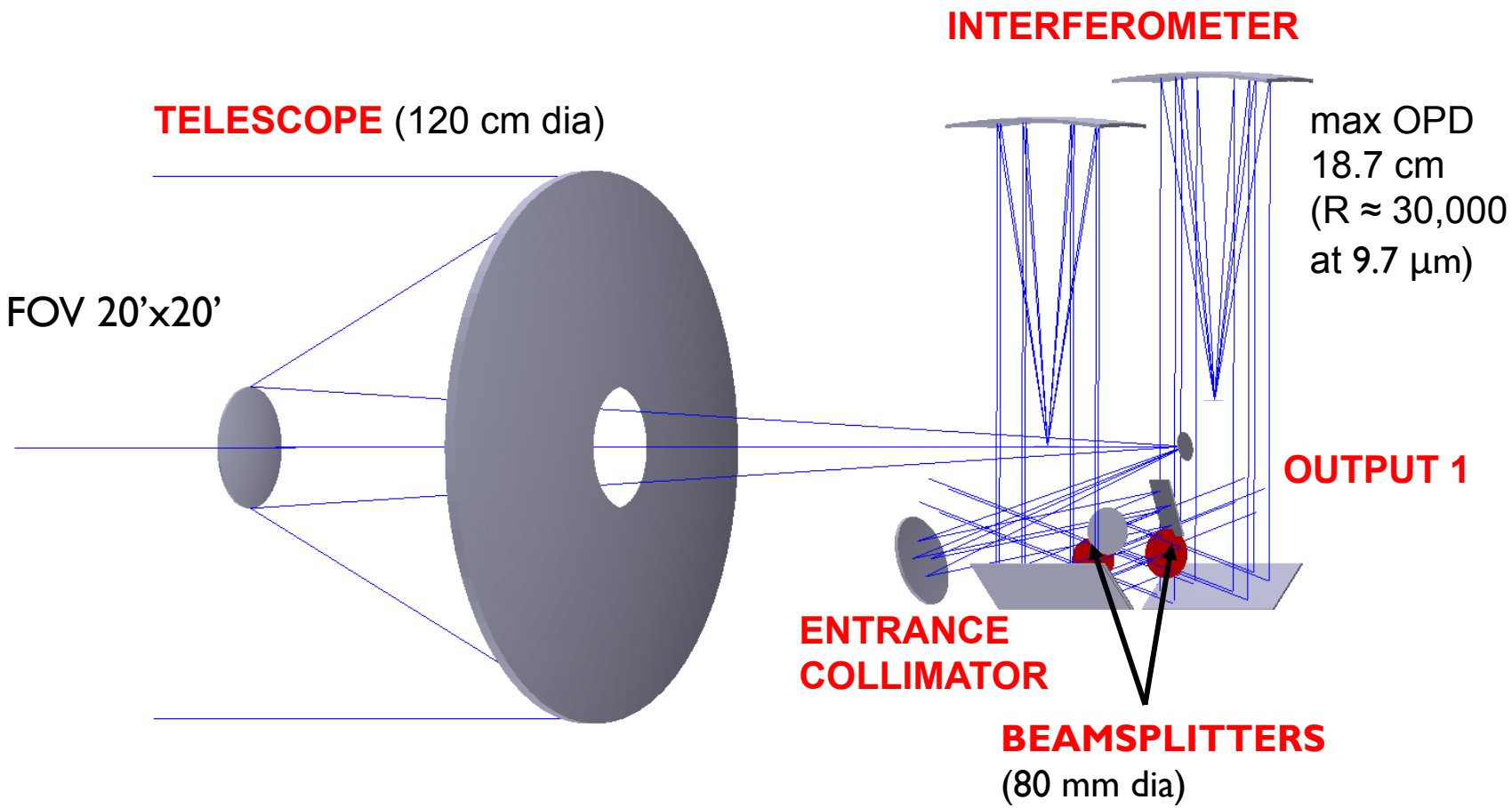
The H2EX-IFTS challenge

H2EX: a space mid-IR wide-field Imaging FTS for H_2

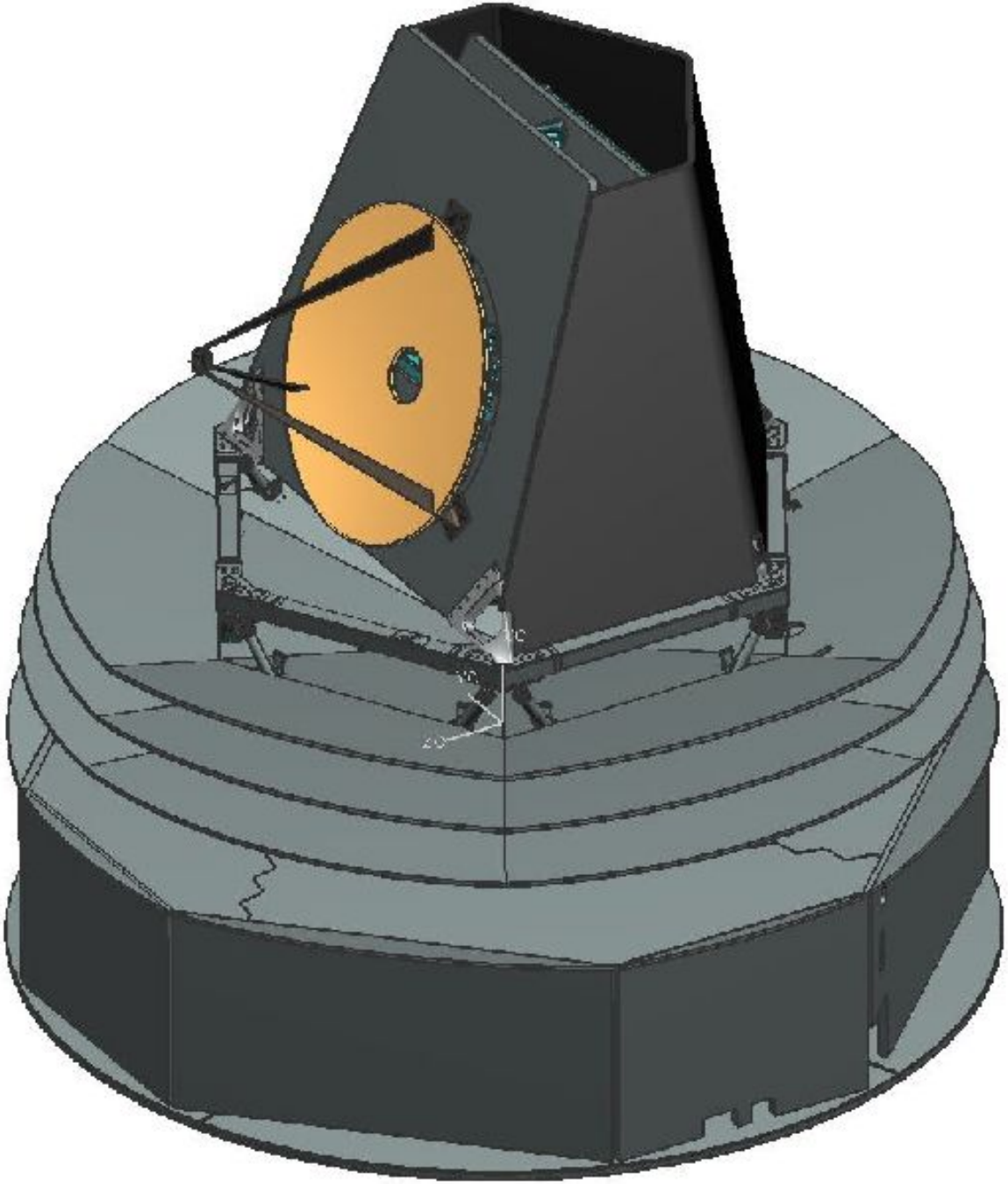
Boulanger, F., Maillard, J.P. et al. 2009, *The molecular hydrogen explorer H2EX*, Exp. Astron., 23, 277-302

- a wide imaging field $\geq 20' \times 20'$
- a spectral resolution $\geq 10^4$ at 28 μm OPD ≥ 20 cm
- a wide spectral coverage 9 - 30 μm
- a large enough telescope ≥ 1.2 m
- a diffraction-limited image quality at 10 μm
- a mid-IR high-efficiency optics all mirrors
- a space mission fitting in an existing platform (PLANCK)
- a cryogenic instrument < 40 K

Optical layout of the space "**Molecular Hydrogen Explorer**" submitted to ESA in June 2007 within the **2015 – 2025 Cosmic Vision** call, a wide-field Imaging FTS for large surveys of the rotational lines of H_2 at 28.2, 17.0, 12.3, 9.7 μm, in different extragalactic and galactic environments. Interferometer based on two parallel cat's eye mirror systems in push-pull motion.



H2EX payload supported by a Planck mission-type platform



4. Polar BEAR

Within the frame of an **European Program (ARENA 2006 – 2010)** for the development of astronomy in Antarctica, at Dome C, the French-Italian Concordia station, proposal of a "**Polar BEAR":** a wide-field imaging FTS behind a 2.5-m class IR-optimized telescope (PILOT, in collaboration with Australia)

The two buildings for winterover at Dome C (alt. 3300 m). Temperature ~ - 80°C in winter

An Imaging FTS in Antarctica

with wide-field and high-resolution capabilities
in the 1.8 to 5.5 μm range

- Access to the widest K, L and M windows from ground:
  $\Rightarrow$ *including K_{dark} 2.25 - 2.55 μm (free of OH emission)*
- Lowest thermal background in the K, L and M windows:
  $\Rightarrow$ *optimum S/N ratio*
- Less volume and mass constraints than in space:
  $\Rightarrow$ *possibility of high spectral resolution:*
- Long and continuous observing time in winter time:
  $\Rightarrow$ *deep spectroscopic surveys of extended regions*

Project: a 10' $\times$ 10' field IFTS with $R_{max} = 10^5$ at 2 μm behind a 2.5 m telescope *(Aus. PILOT project, J. Storey et al.)*

IV: Far-infrared Imaging FTSs

At these long wavelengths, interest of the multiplex properties of the FTS to obtain spectroscopic data on a source, at moderate resolution but on a broad spectral range. With the advent of 2D-detectors in the far-IR → possibility of IFTS

1. Akari/FIS-FTS

Akari (JAXA), a 68-cm space telescope cooled at 6K, launched in 2006, in operation for one year and half

Instruments: Far-Infrared Surveyor (FIS) for the far-IR domain (**70 – 170 μm**) with a camera used in all-sky survey mode and an IFTS used in pointed mode.

• interferometer	*Martin-Puplett type*
• max. OPD	*50 mm*
• mean resolution	*~500*
• detector	***70** – 115 μm Ge:Ga 3x20 array*
	*113 – **170** μ**m** Ge:Ga 3x15 array*
• pixel scale	*26.8" and 44.2"*
• FOV	*~1' 30" x 9' and 2'10" x 11'*

Observation of [OIII] 88 μm line in the 30 Doradus region, Kawada et al., 2011
Observation of the dust at the Galactic Center, Kaneda et al., 2012

2. Herschel/SPIRE an Imaging photometer and an IFTS

Herschel Space Observatory (ESA), a 3.5-m telescope, passively cooled, placed at L2, launched in May 2009. Ran out of helium: 29 April 2013!

The **Spectral and Photometric Imaging Receiver (SPIRE),** one of the three instruments onboard Herschel. Developed by a consortium of institutes (U. of Cardiff (PI) including CEA, LAM (France), U. of Lethbridge (Canada, D. Naylor) and institutes in UK, Spain, Italy, Sweden, USA (Caltech, JPL, U. of Colorado).

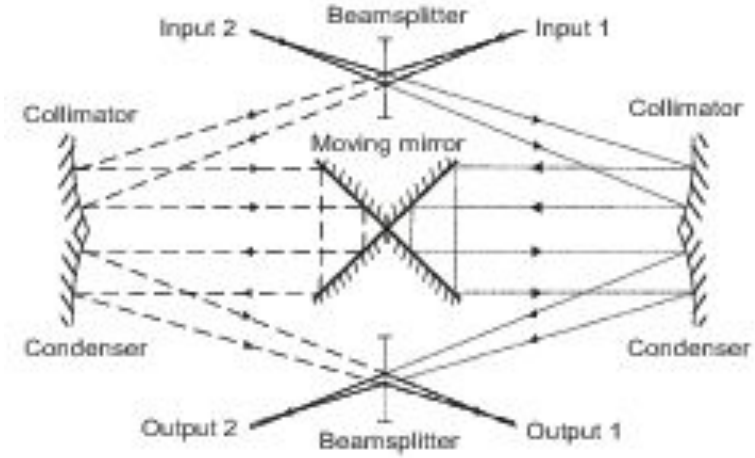
The SPIRE Imaging FTS

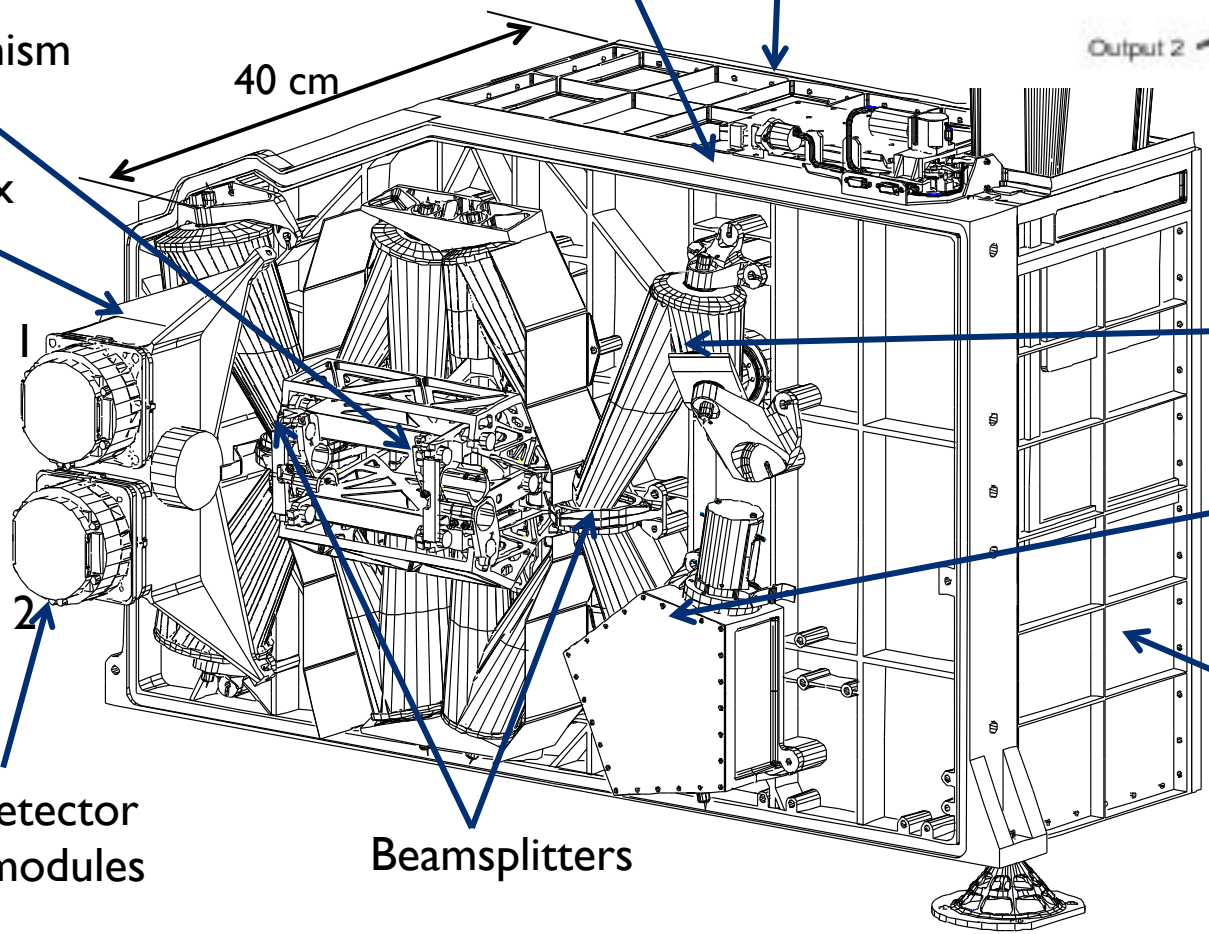
- Mach-Zehnder with back-to-back roof-top mirrors *dual input/dual output*
- Detector *37 pxl Ge bolometer array **194** - 312 μm (SSW)*
  *19 pxl Ge bolometer array 303 - **671** μm (SLW)*

one array detector on each output port to observe simultaneously the full domain

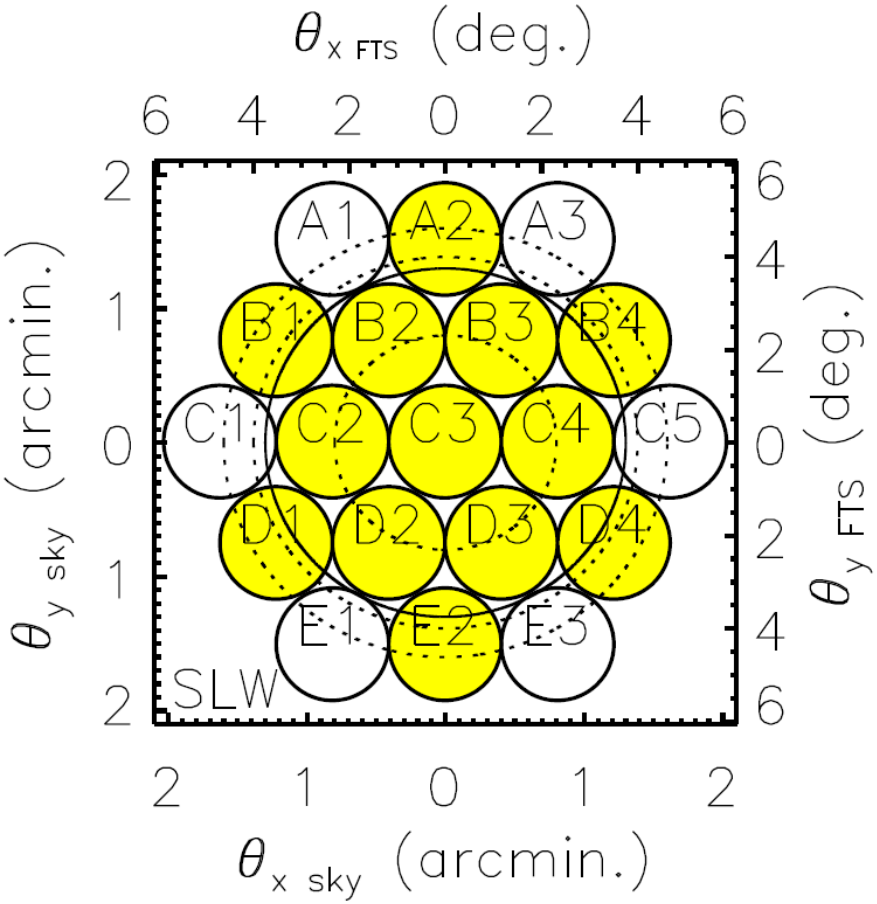
- FOV *2.6' dia*
- Beam FWHM *17" (250 μm), 35" (500 μm)*
- Max. spectral resolution *0.04 cm^{-1} (R ≈ 1000 at 250 μm, ≈ 500 at 500 μm)*
- Sensitivity limit *thermal emission from the telescope (80K, ε < 4%)*

SPIRE IFTS Layout and Optics

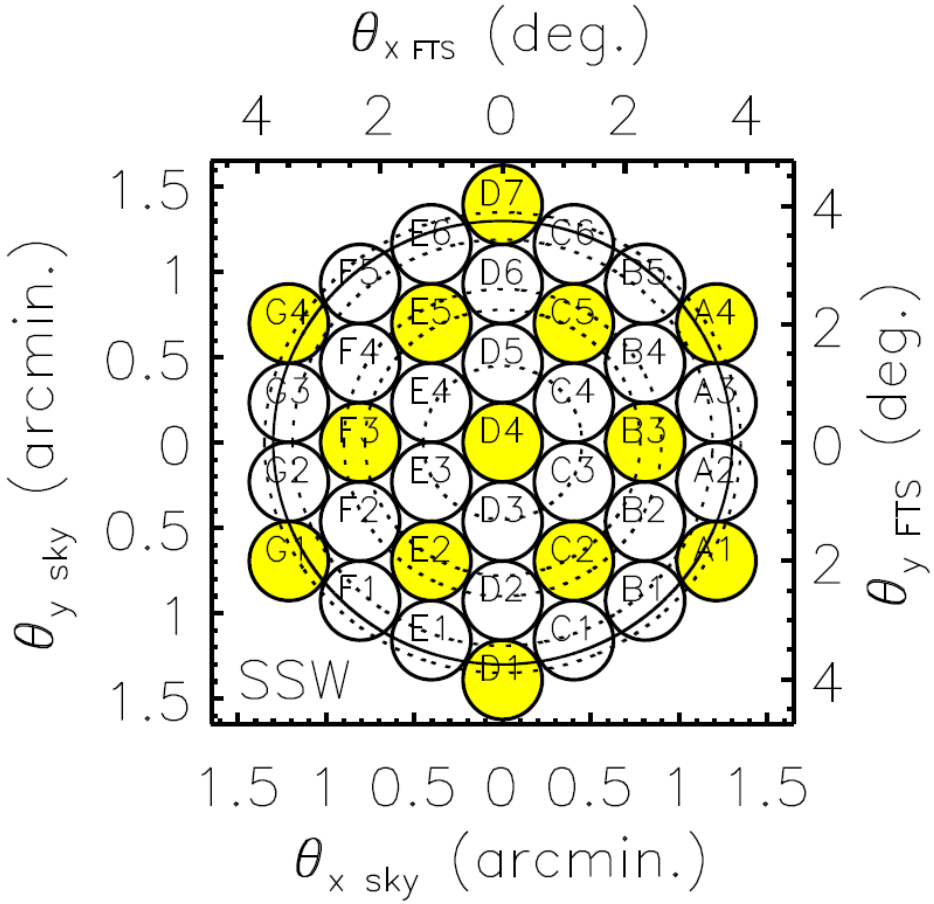




SLW



SSW

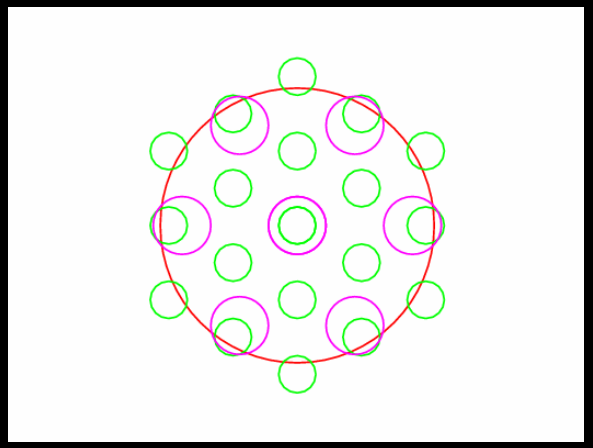


Angular position of the detector arrays on the sky and divergence angle within the IFTS. The solid circles represent the SPIRE IFTS 2.6' unvignetted FOV.

FTS Observing Modes

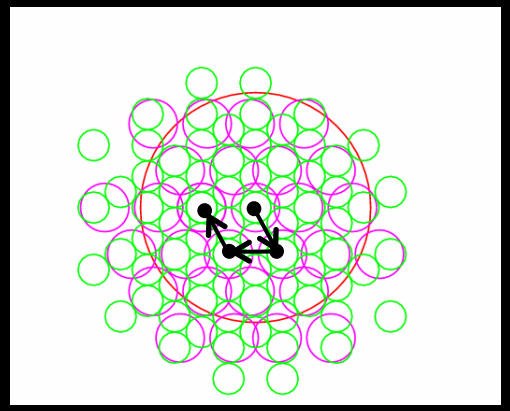
On behalf of D. Naylor

- Point source spectroscopy:



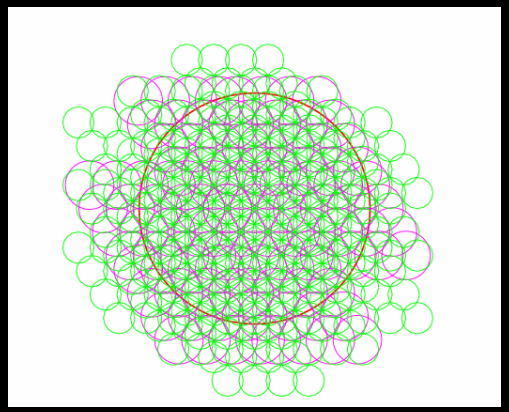
- Spectral mapping:

Intermediate image sampling



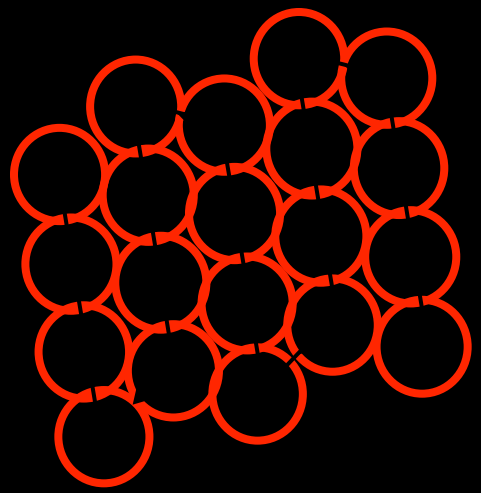
1 beam spacing
(4 jiggle positions)

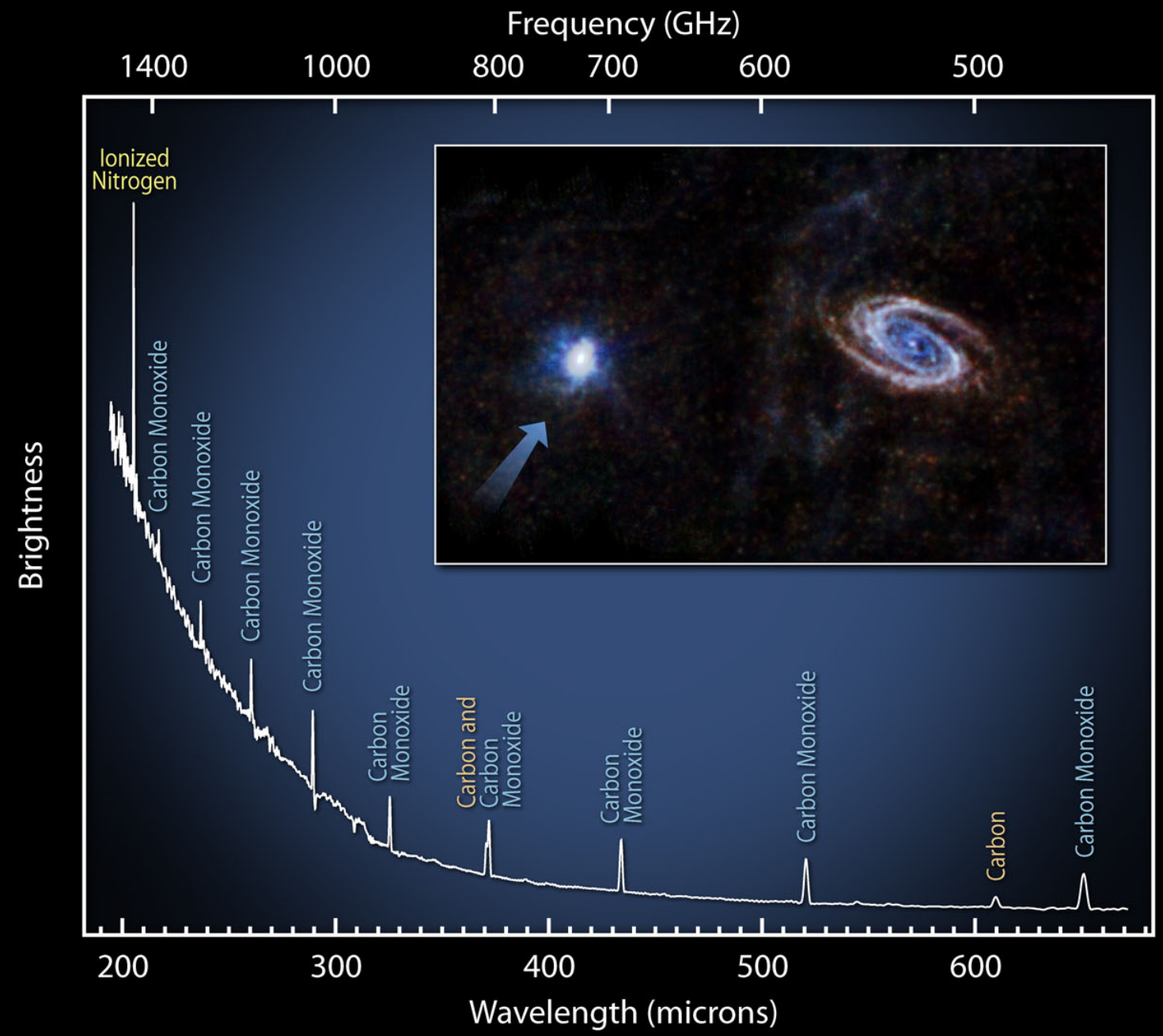
Full image sampling



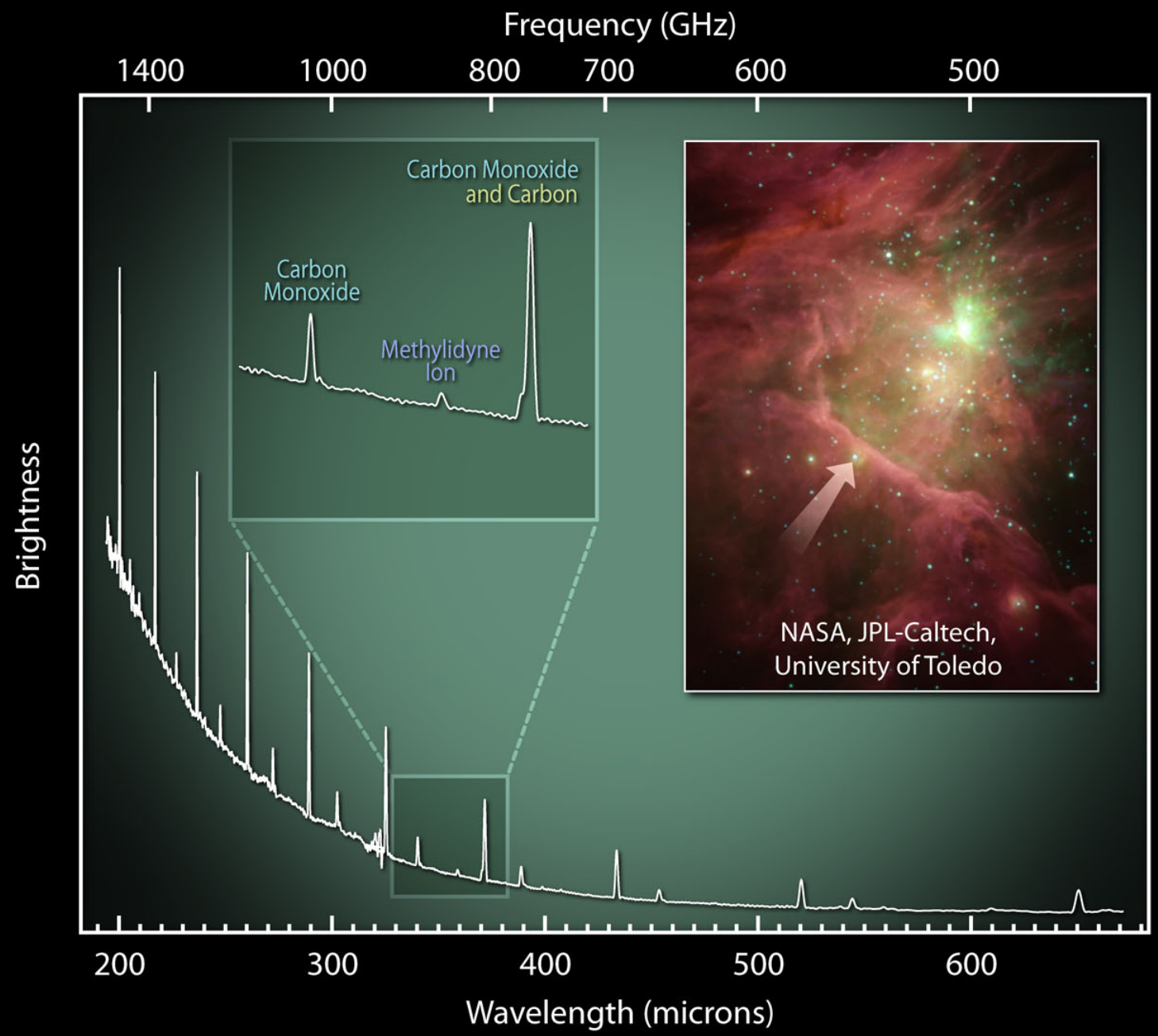
1/2 beam spacing
(16 jiggle positions)

Raster mapping for larger fields:





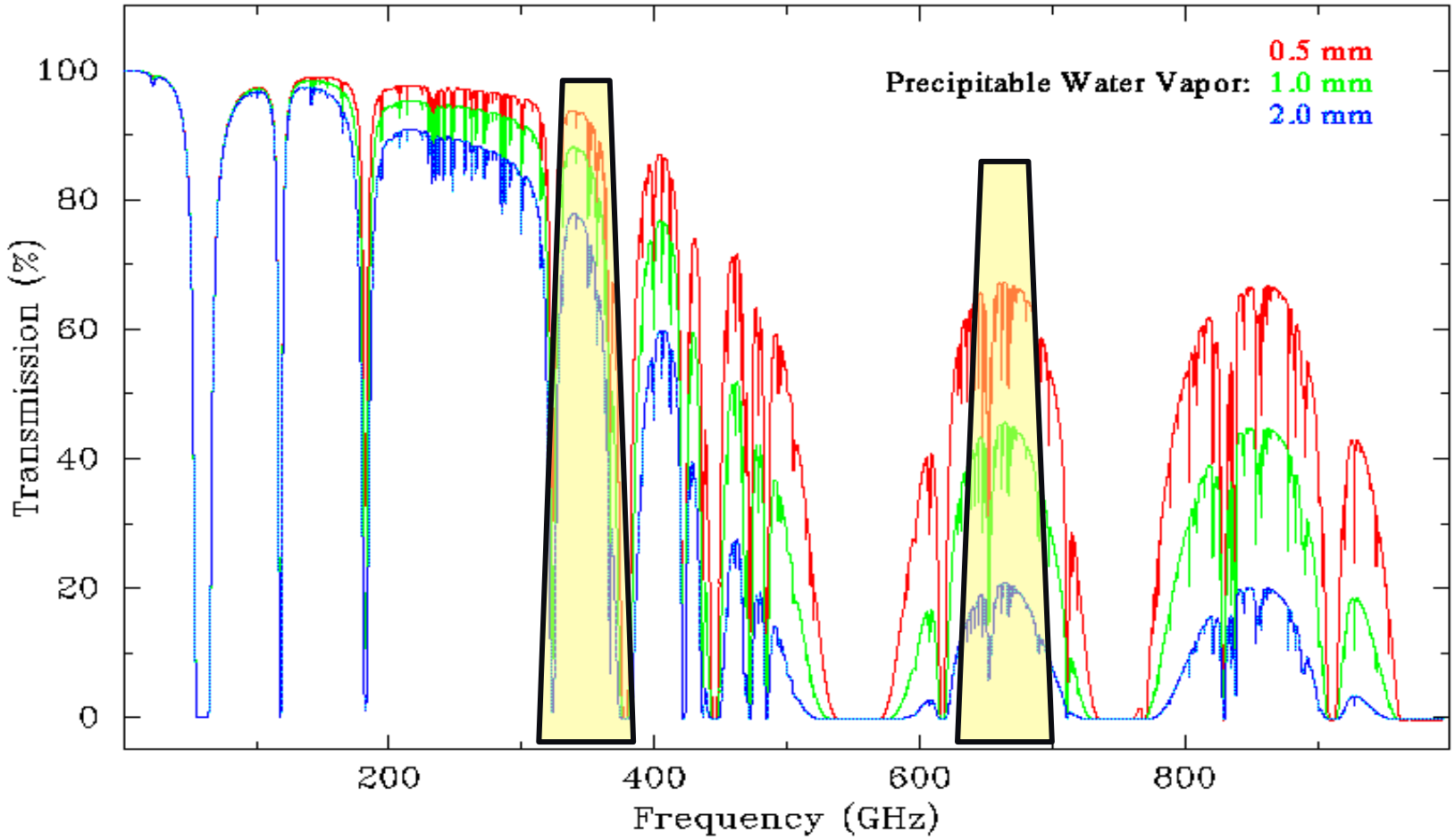
Messier 82



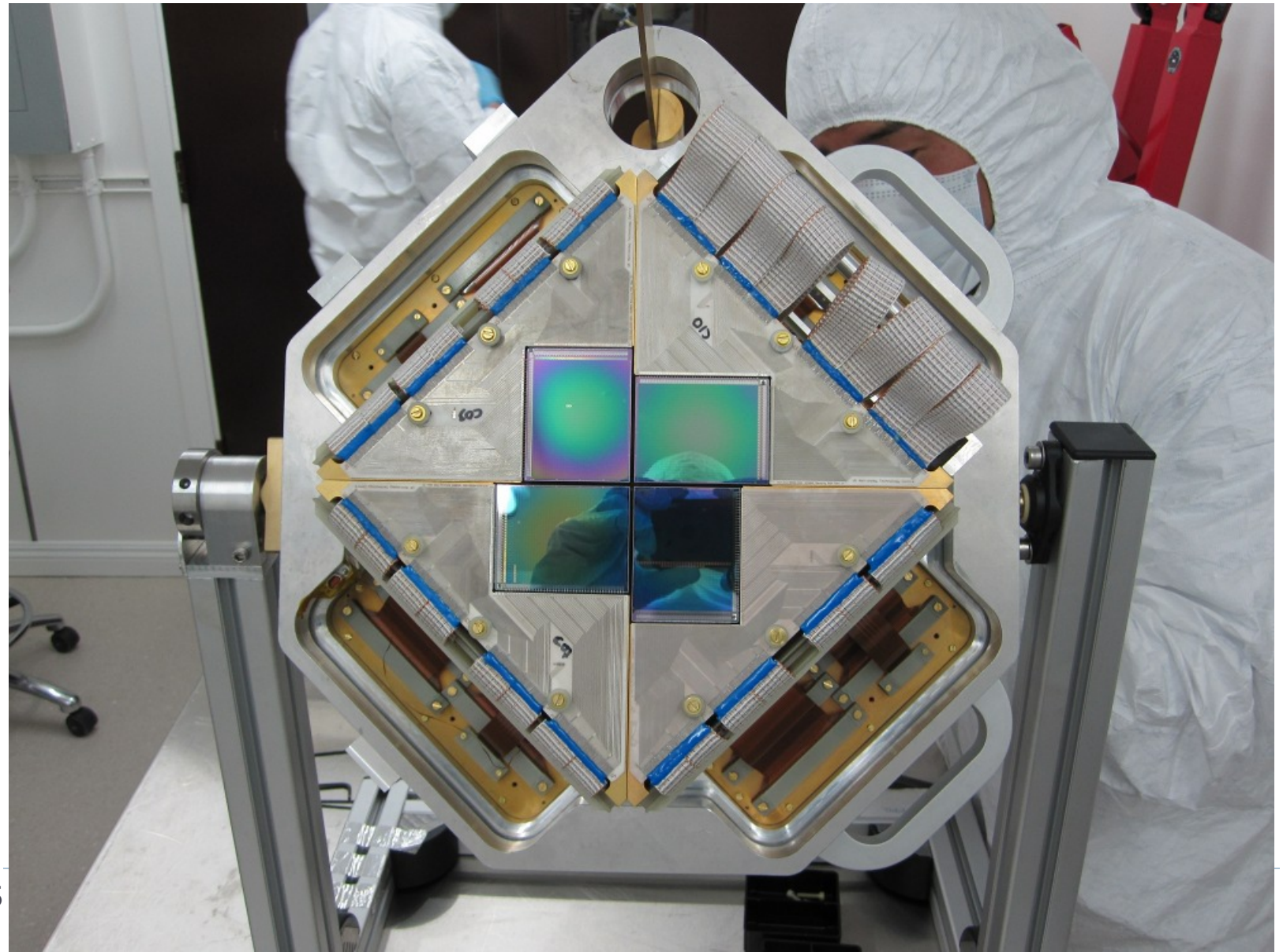
Orion Bar

3. Scuba-2/FTS-2

Scuba-2: Submillimetre Common-User Bolometer Array in its second version, a camera for submillimetric astronomy on JCMT. Four sub-arrays of 32x40 superconducting bolometers at 850 and 4 sub-arrays at 450 µm.



The 450 μm SCUBA-2 array



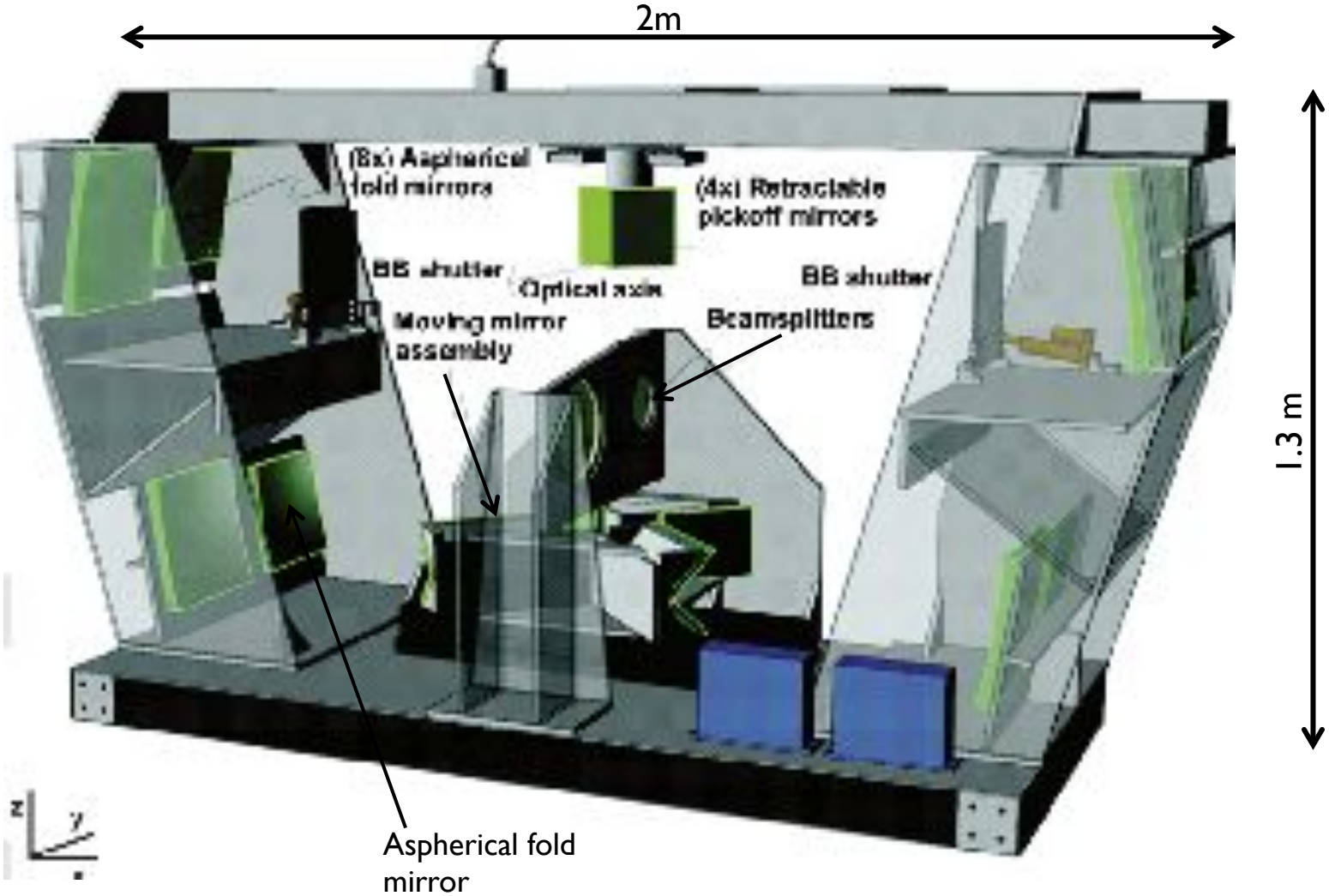
FTS-2

an Imaging FTS to use **Scuba-2**, developed at the Physics Dept, U. of Lethbridge. (Brad Gom, SCUBA-2 Spectrometer Project Manager).

- Telescope diameter — *15 m*
- Mach-Zehnder interferometer design — *dual input/dual output*
  same design as SPIRE
- Retro-reflecting systems — *corner cubes*
- Max. OPD — *100 cm*
- Max. limit of resolution — *0.006 cm^{-1}*
- Scuba-2 detectors *2 sub-arrays of 32x32 bolometers at 450 and 2 at 850 μm*

2 sub-arrays on each output port to observe simultaneously the two windows

- FOV — *3' dia*
- Observing modes — *due to vignetting of the beam at large OPD*
  SED mode on the full FOV at ~0.1 cm^{-1} resolution
  → R ≈ 120 at 850 μm, 230 at 450 μm
  Spectral line mode on ~1' FOV at max. resolution
  → R ≈ 2000 at 850 μm, 3700 at 450 μm
- Dominant noise source — *Atmospheric emission*



Scuba-2/FTS-2 instrument showing the 8 aspherical fold mirrors, the moving back-to-back corner-cube mirror assembly. Delivered Sept. 2010. Mounted at the JCMT Nasmyth focus (*from D.A. Naylor, B. Gom et al. Can. J. Phys. 91, 1, 2013)*

CONCLUSION: future of FTS in astronomy

1-D FT spectroscopy

has fallen in disuse in astronomical applications in the optical and IR domain due to the "**multiplex disadvantage".**

- Permanent interest in the **far-IR range**, as instrument for broad spectral surveys of a source (SPIRE, FTS-2, SAFARI project on SPICA). Complementary to heterodyne technics.

- Particular interest for planetary missions (e.g. onboard Voyager I, II, Cassini, Mars Express…). Spectral mapping on a broad spectral range with one or few detectors by combining low-resolution spectroscopy and spacecraft motion.

Could make possible extremely high resolution for stellar spectroscopy behind an ELT in the optical and near-IR domain: **R >> 10^5**

Proposal made for the E-ELT of an IFTS with 2 modes: VHR on point sources and HR spectro-imaging on a 2' FOV.

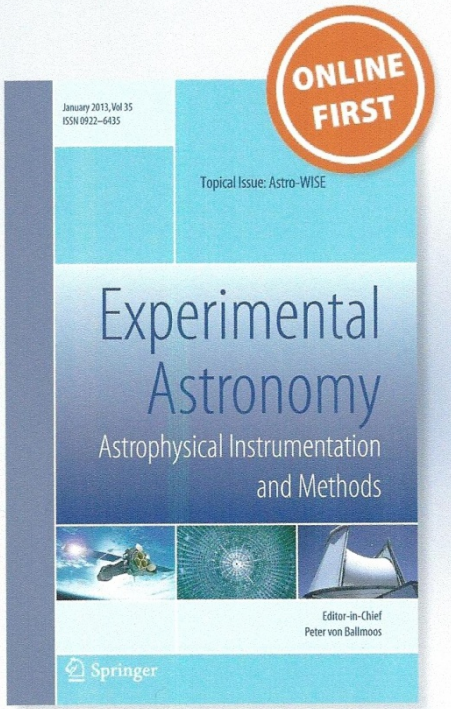
Integral wide-field spectroscopy in astronomy: the Imaging FTS solution

J. P. Maillard, L. Drissen, F. Grandmont & S. Thibault

Experimental Astronomy
Astrophysical Instrumentation and Methods

ISSN 0922-6435

Exp Astron
DOI 10.1007/s10686-013-9330-9

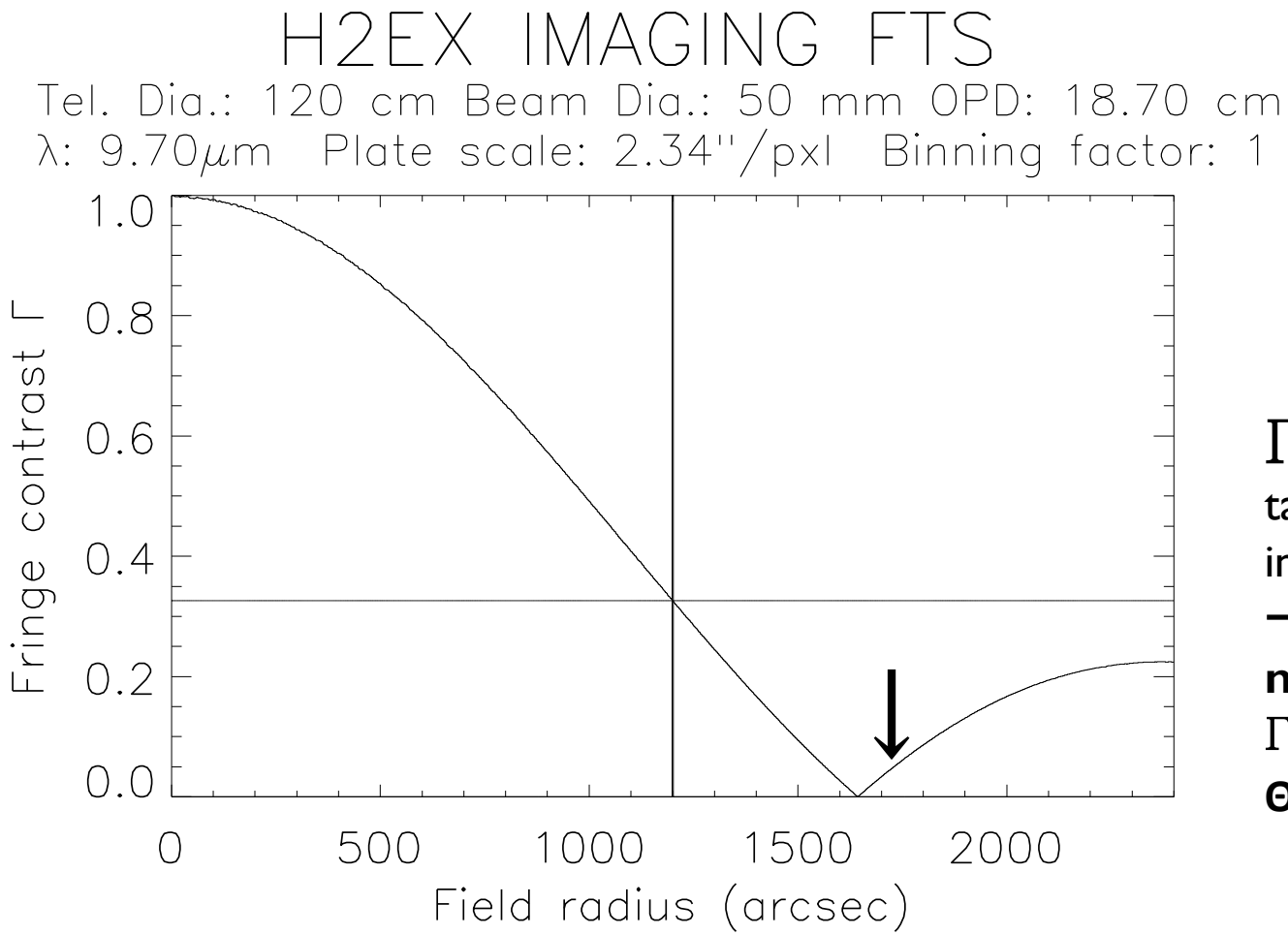


Springer

Good hope that the success of ***SITELLE*** will help the astronomical community to discover all the properties of the Imaging FTS.

To demonstrate the benefit of the Imaging FTS for astronomy, a review just published in the March issue of **Experimental ←Astronomy 2013**

THANK YOU !



$\Gamma = 0 \downarrow$

taille du pixel = inter-frange

→ champ **Θ maximum**

Γ **= 0** pour

Θ = 0.9°

Calcul de la fonction **Γ** ***au bord du champ*** *pour un projet de FTS Imageur spatial (H2EX)*

<u>Paramètres</u> : D_T diamètre du télescope, D_I diamètre du faisceau dans l'interféromètre, **δ** diff. de marche optique, **λ** longueur d'onde, échelle de foyer **Θ/*N*** (champ **Θ** détecteur ***NxN*** pixels) ***:*** D_T ***= 120 cm*** D_I ***= 50 mm*** δ_{max} ***= 18.7 cm (R = 32 000 à λ = 9.7 μm)***

2. Avantage multicanal du FTS Imageur

Comparaison entre spectromètre à réseau à fente longue et FTS imageur, pour même champ et même résolution spectrale

Largeur du spectre	$\Delta\sigma$
Résolution spectrale	$d\sigma$
Nombre d'éléments spectraux	$M = \Delta\sigma / d\sigma$
Taille du détecteur	$2\ N \times N$
Nombre d'éléments spatiaux	n

En une seule acquisition de données

Spect. fente longue (SpFL)	**FTSI**
$n = N^2 / M$	$n = N^2$

Pour un même temps total d'observation, couverture d'un grand champ :

- par M positions de la fente d'entrée pour SpFL,
- en une seule acquisition pour FTSI.

Dominé par le bruit de photon de la source :

- sur un fond continu $S/N_{FTSI} = S/N_{SpFL}$
- sur un **spectre en émission** $S/N_{FTSI} = \sqrt{Q}\ S/N_{SpFL}$

Raie d'intensité Q fois la brillance moyenne