FIR/Submm/MMm telescopes To the JCMT and beyond ALMA; In historic perspective

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ESO emeritus

Introduction

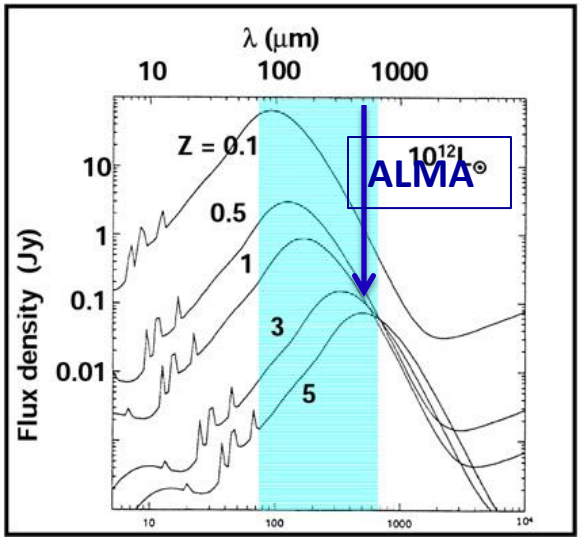
- ***(F)IR/Submm/Mm science objectives strongly connected***
- **Development of FIR/submm/mm observatory capabilities has extra dimension: altitude.**
- **Evolution of *Space missions* and *Ground-based Observatories* are entangled; also development of *detection* and *receiver* systems and other technologies.**

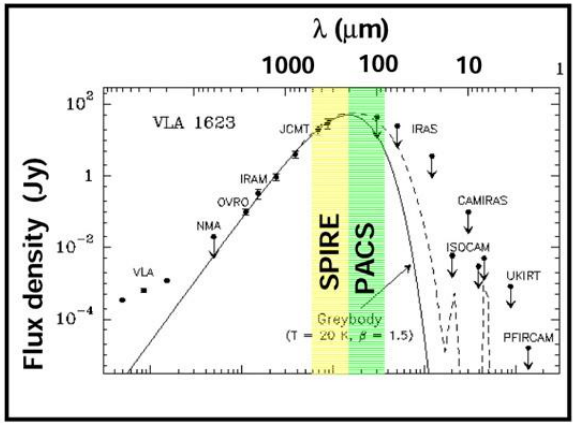
Topics addressed:

- ***Introduction***
- ***(F)IR/Submm/mm Space Missions***
- ***Single Dish observatories***
- ***Submm/mm Interferometers >>>>Submm/mm Hubble"***

Science in the Mm/Submm Range addresses **the Cool Universe**

- Spectral coverage for:
  - Black-bodies 5-100 K
    - continuum radiation
    - dust grains (re-)radiating
  - Gasses excitation 10-few100 K
    - Atomic/ionic lines
    - Molecular Universe
      a.o. water lines, CII, etc.
  - IR gal & ISM SED peaks, out to high Z and Cosmic Background!
- Emphasis:
  - Formation and evolution of galaxies
  - Formation of stars and planets
  - ISM physics & chemistry
  - Solar system bodies





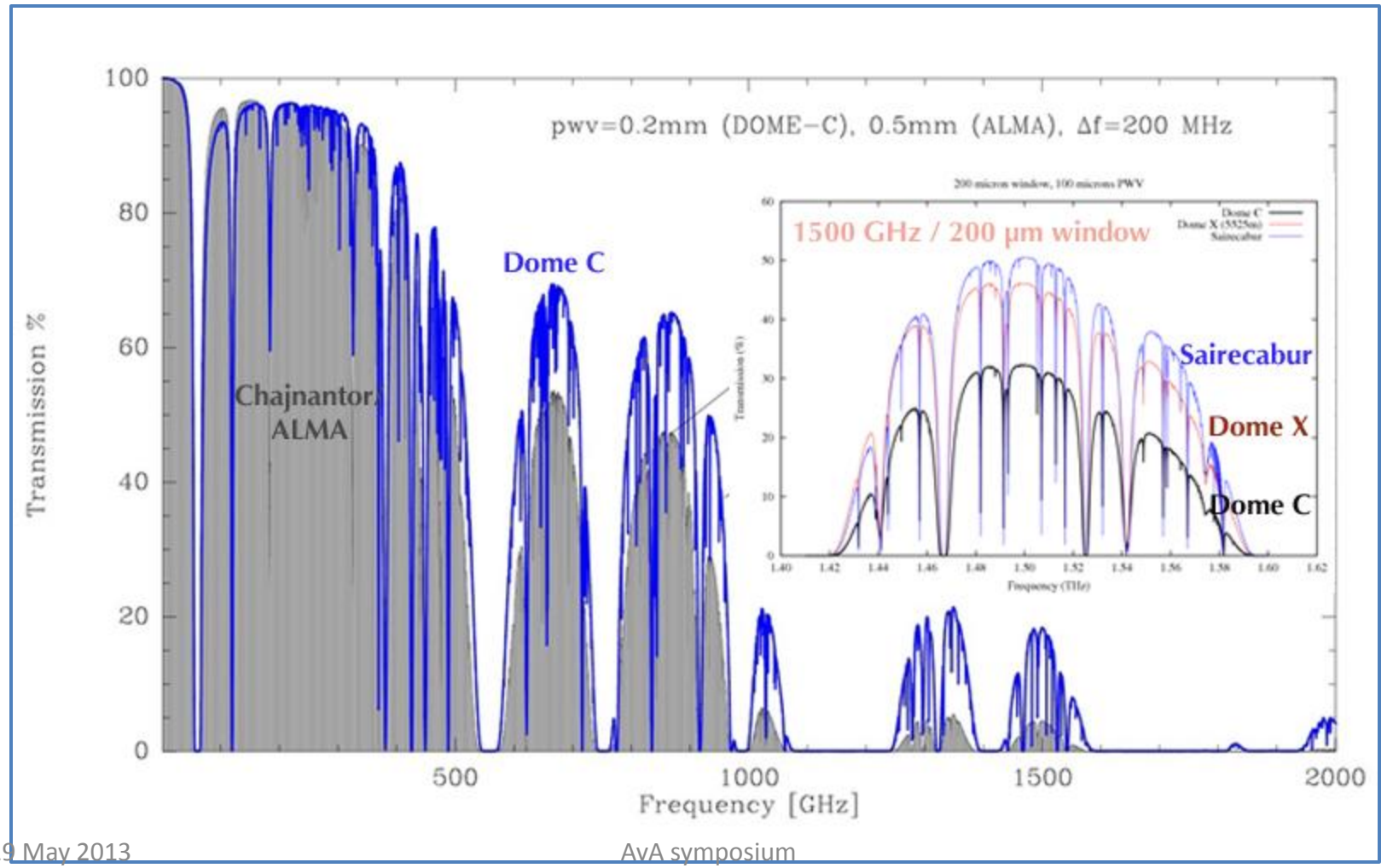
➢170 Molecules in Space

➢Table not complete

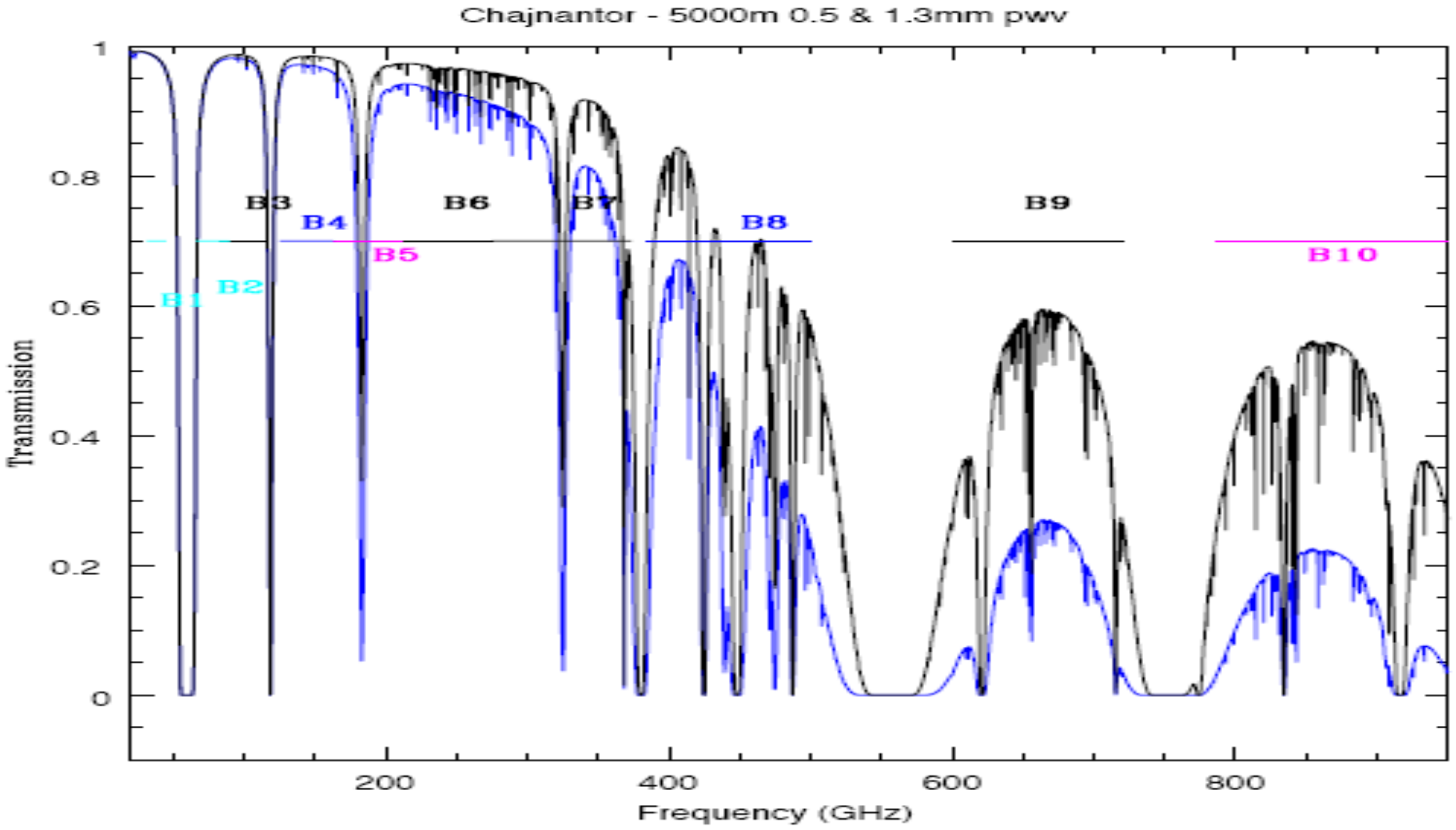
Molecules in the Interstellar Medium or Circumstellar Shells (160 as of 08/2011)

2 atoms 37	3 atoms 37	4 atoms 24	5 atoms 18	6 atoms 16	7 atoms 9	8 atoms 10	9 atoms 9	10 atoms 4	11 atoms 3	12 atoms 3	>12 atoms
H2	C3*	c-C3H	C5*	C5H	C6H	CH3C3N	CH3C4H	CH3C5N	HC9N	C6H6*	HC11N
AlF	C2H	l-C3H	C4H	l-H2C4	CH2CHCN	HC(O)OCH3	CH3CH2CN	(CH3)2CO	CH3C6H	C2H5OCH3	C60*
AlCl	C2O	C3N	C4Si	C2H4*	CH3C2H	CH3COOH	(CH3)2O	(CH2OH)2	C2H5OCHO	n-C3H7CN	C70*
C2**	C2S	C3O	l-C3H2	CH3CN	HC5N	C7H	CH3CH2OH	CH3CH2CHO			
CH	CH2	C3S	c-C3H2	CH3NC	CH3CHO	H2C6	HC7N				
CH+	HCN	C2H2*	H2CCN	CH3OH	CH3NH2	CH2OHCHO	C8H				
CN	HCO	NH3	CH4*	CH3SH	c-C2H4O	l-HC6H*	CH3C(O)NH2				
CO	HCO+	HCCN	HC3N	HC3NH+	H2CCHOH	CH2CHCHO	C8H–				
CO+	HCS+	HCNH+	HC2NC	HC2CHO	C6H–	CH2CCHCN	C3H6				
CP	HOC+	HNCO	HCOOH	NH2CHO		H2NCH2CN					
SiC	H2O	HNCS	H2CNH	C5N							
HCl	H2S	HOCO+	H2C2O	l-HC4H*							
KCl	HNC	H2CO	H2NCN	l-HC4N							
NH	HNO	H2CN	HNC3	c-H2C3O							
NO	MgCN	H2CS	SiH4*	H2CCNH (?)							
NS	MgNC	H3O+	H2COH+	C5N–							
NaCl	N2H+	c-SiC3	C4H–								
OH	N2O	CH3*	HC(O)CN								
PN	NaCN	C3N–									
SO	OCS	PH3 ?									
SO+	SO2	HCNO									
SiN	c-SiC2	HOCN									
SiO	CO2*	HSCN									
SiS	NH2	H2O2									
CS	H3+*										
HF	H2D+, HD2+										
HD	SiCN										
FeO	AlNC										
O2	SiNC										
CF+	HCP										
SiH	CCP										
PO	AlOH										
AlO	H2O+										
OH+	H2Cl+										
CN–	KCN										
SH+	FeCN										

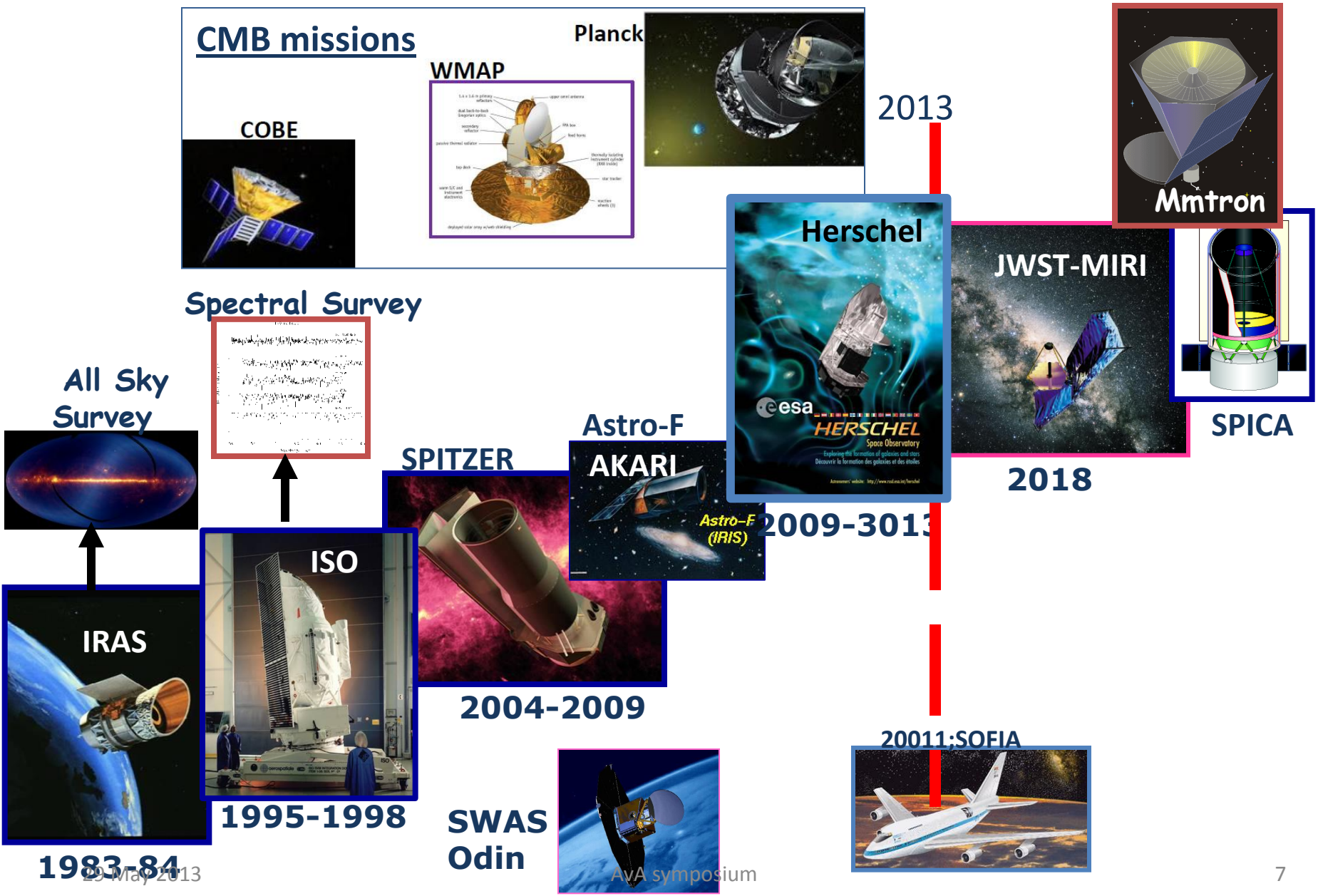
Altitude (Space) of the site is an important criterium



ALMA Bands at 5000m

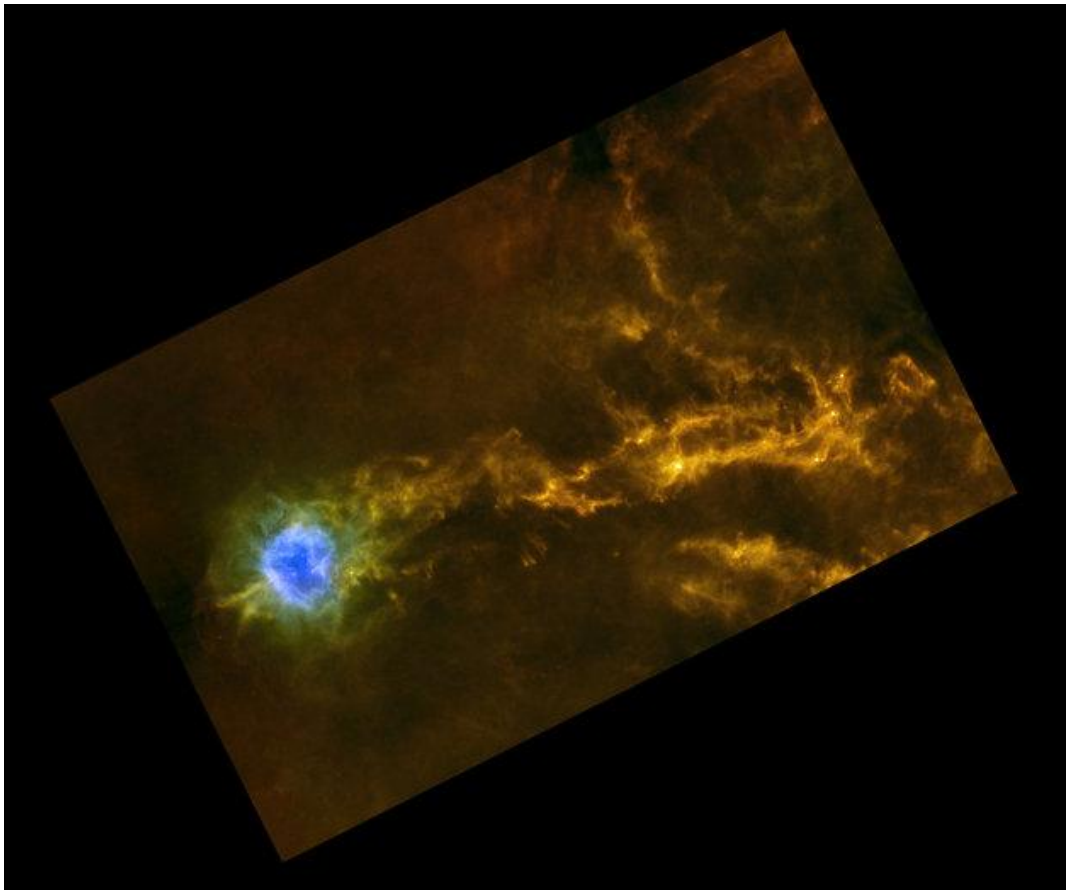


(F)IR/Submm/mm Space Missions



Start of the FIRST=Herschel project: Noordwijkerhout 1982

Herschel Results on Star Formation: Dense filaments of gas in IC5146



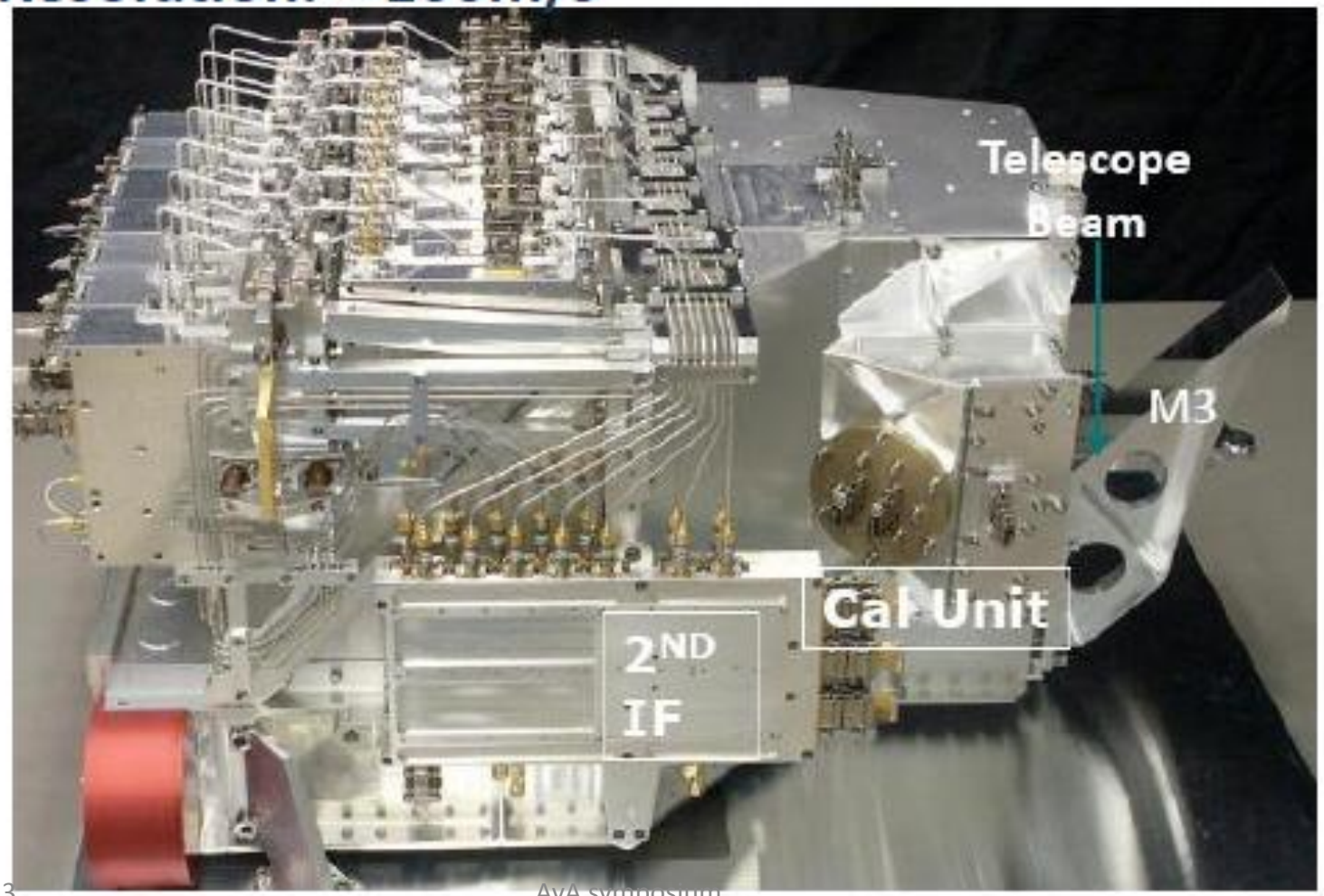
Dense filaments of gas in the IC5146 interstellar cloud.
This image was taken by ESA's Herschel space observatory at infrared wavelengths 70, 250 and 500 microns.
Stars are forming along these filaments.

Herschel-HIFI design:

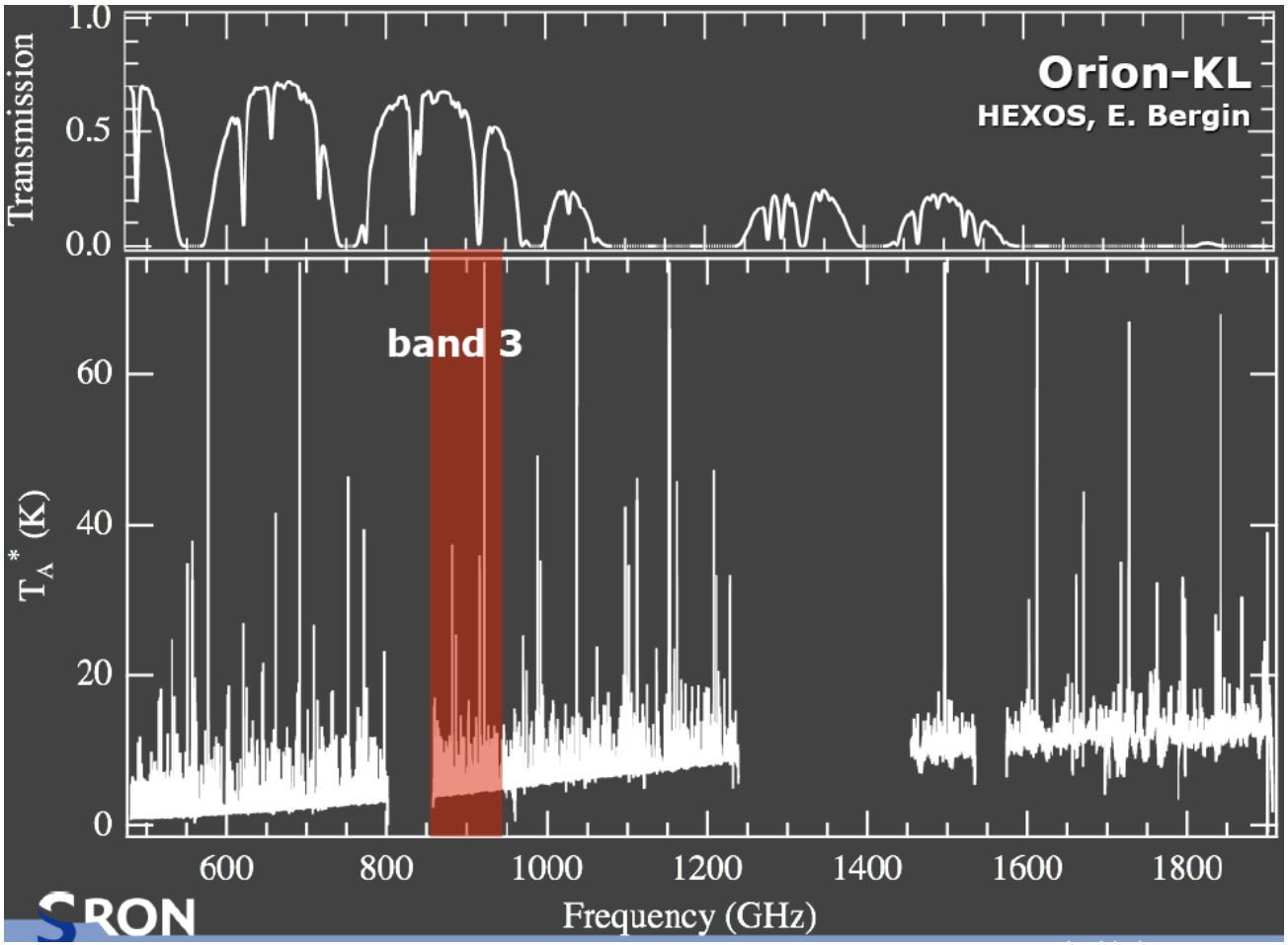
Wavelength Range: 480-1250, 1410-1910 GHz

Bandwidth: 4 Ghz wide;

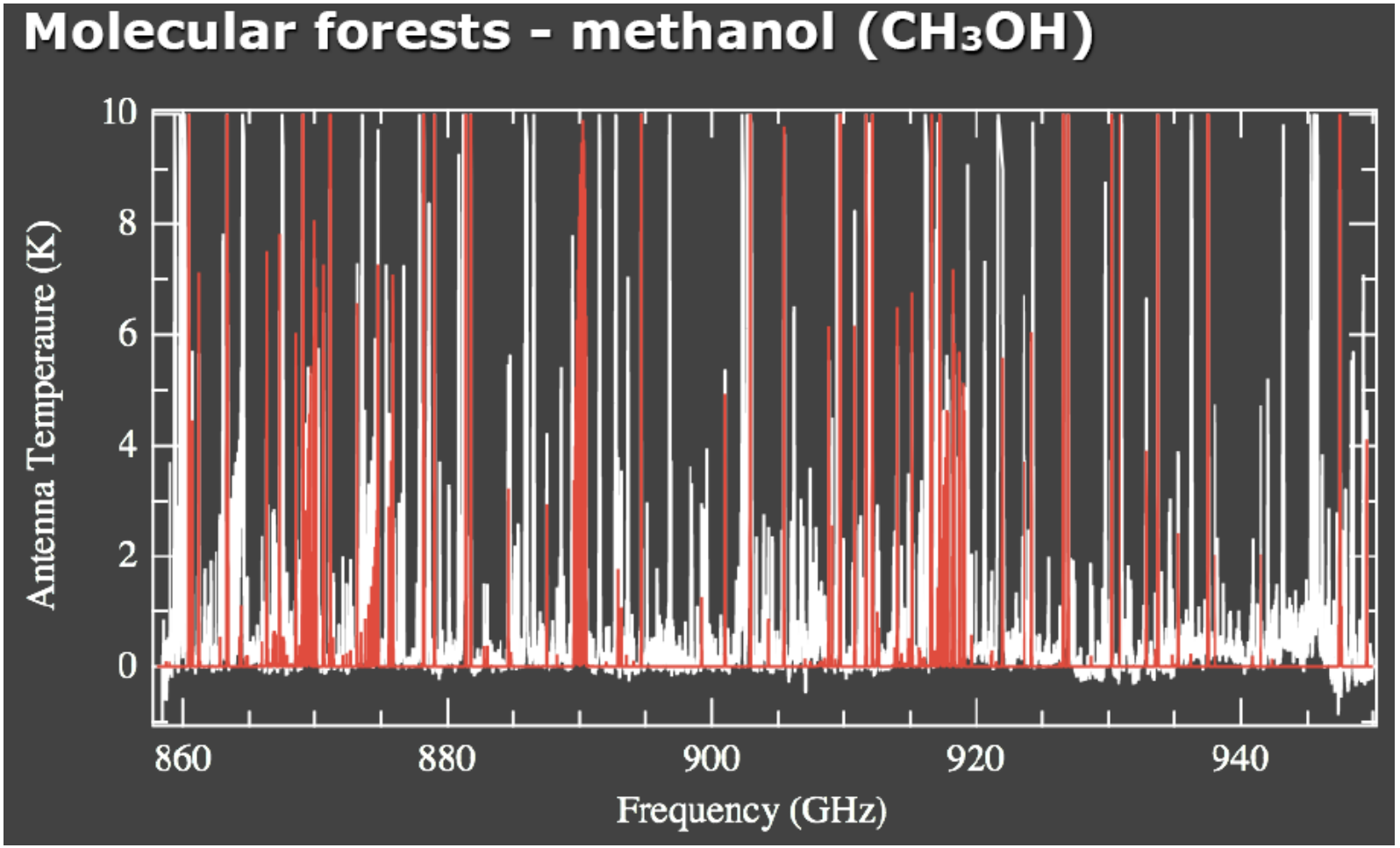
Resolution: < 100m/s



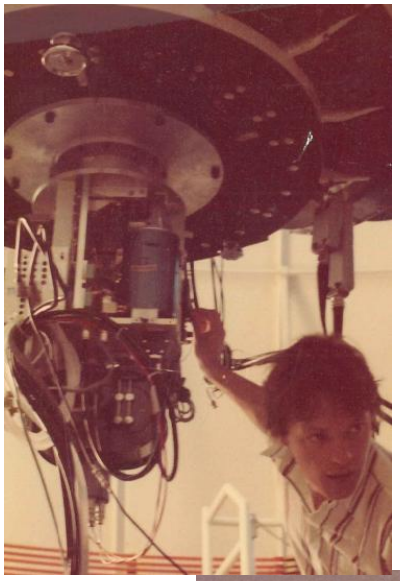
HIFI results-1:Orion scan

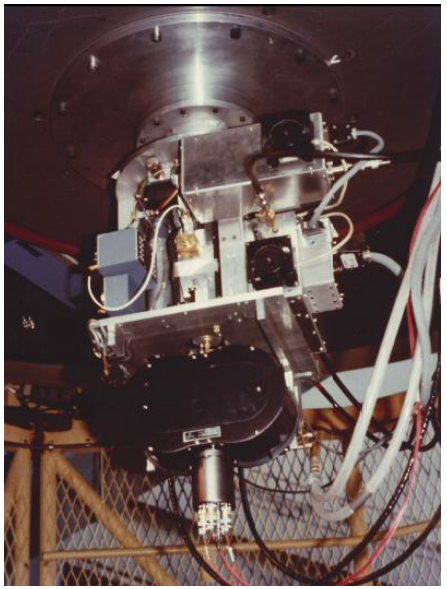


HIFI results-1:Orion scan



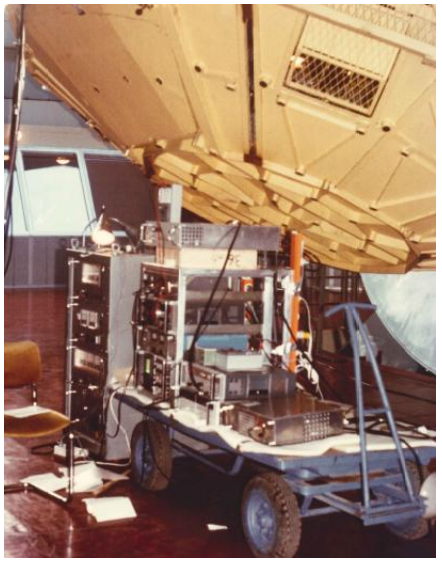
Before there was a JCMT: "Pearls for the Swines" period



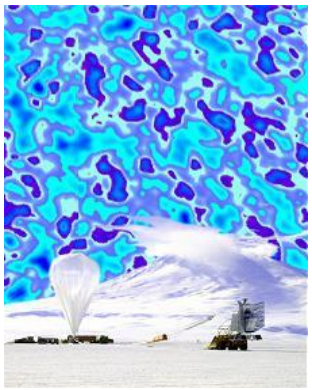


ESO
3.6m

Jung Frau Joch
0.6m



Single Dish Ground Based Submm/mm Observatories

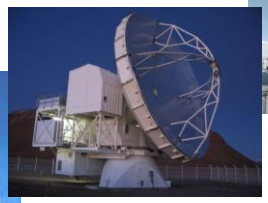


Submm/Mm
Balloon experiments

LMT

SPT

APEX

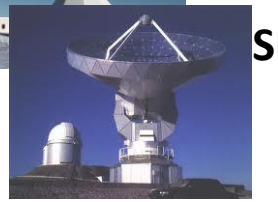


HH

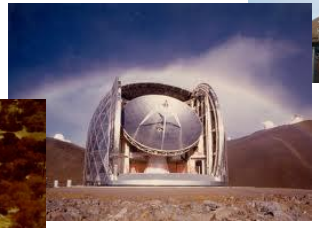
PdV

JCMT

SEST



CSO

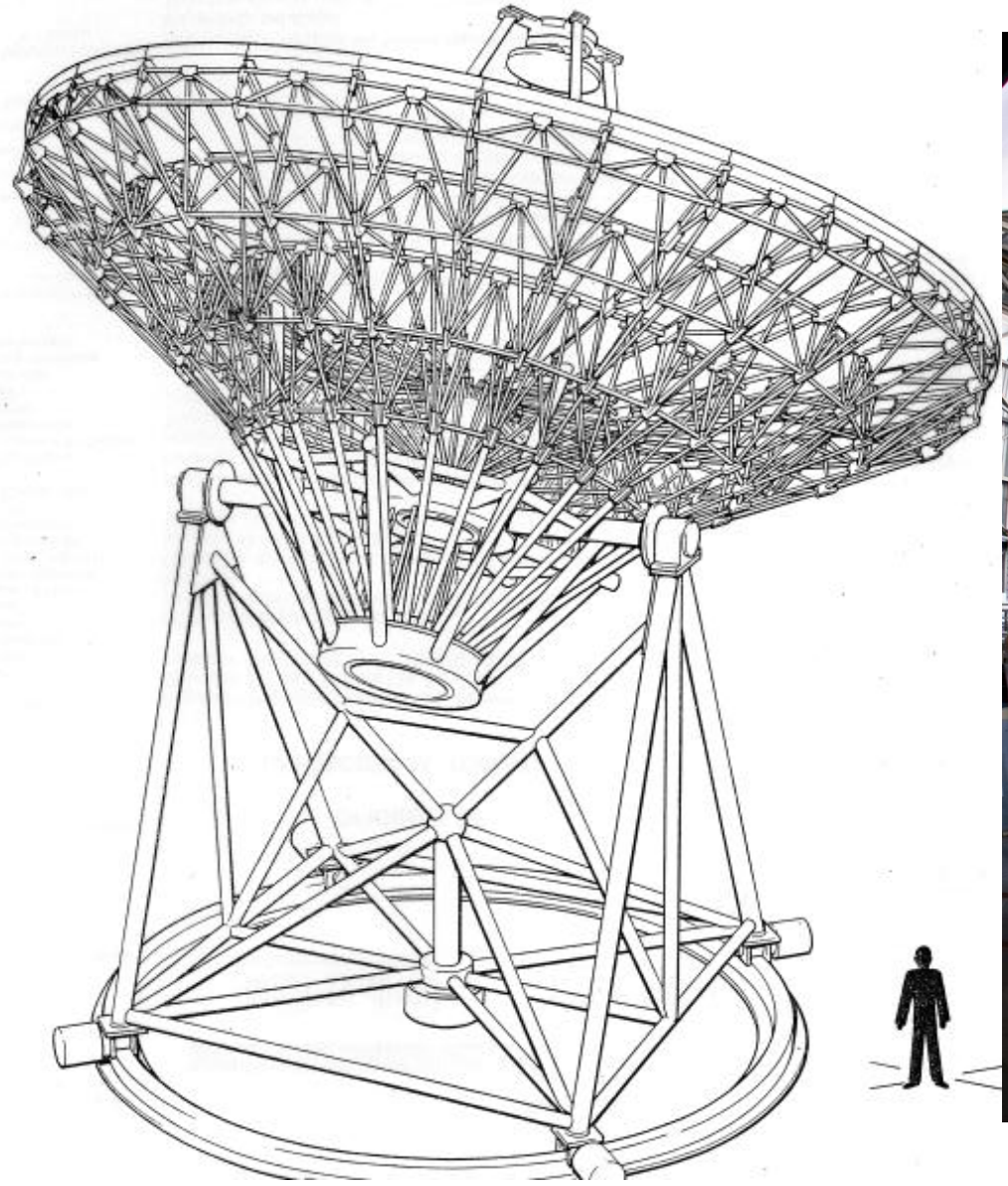


KP

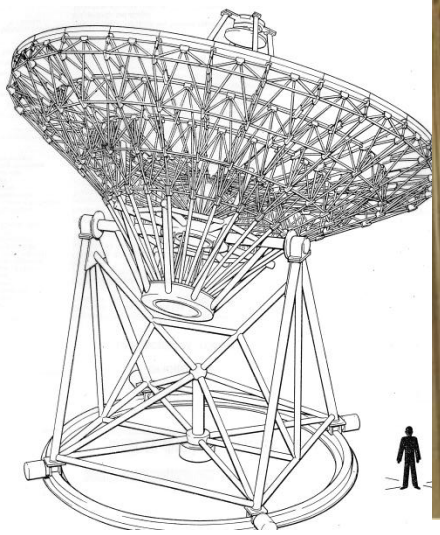
PM: NANTEN, ASTE, SUFFA, LLAMA, etc..

JCMT: UK/NL/(Ca)

JCMT with(out) receiver cabin



JCMT Receiver Working group visit to Genius (IJmuiden), Arnold as member.

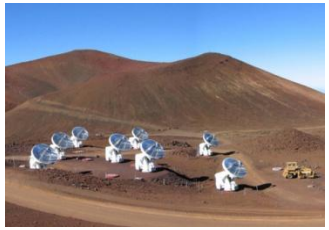


Submm/mm Interferometres

IRAM PdB (NOEMA)

6 (12) antennas, each
15 m in diameter

ATCA : 6 antennas each 22 m in diameter



SMA

8 antennas each 6 meters in diameter

CARMA

- 6 Antennas each 10.4 m. in diameter. (OVRO)
- 9 Antennas each 6.1 m. (Hat Creek)
- 8 Antennas each 3.5 m. in diameter. (SZA)

NRO: 6 antennas each 10 metres in diameter

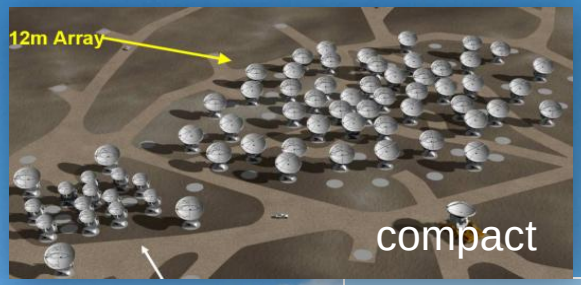
Interferometer Key Parameters

Table 1 Key parameter of existing and future millimeter/submillimeter interferometers.

	Altitude (m)	N_{ANT}	Diameter (m)	Coll.Area (m^2)
IRAM PDBI	2550	6	15	1060
CARMA	2200	15	6/10	772
SMA+CSO+JCMT	4080	10	6/10/15	481
NMA	1340	6	10	471
IRAM NOEMA	2550	12	15	2120
ALMA	5060	50	12	5652

The ultimate Submm/mm interferometer: ALMA?

An array of **66 antennasusing *aperture s***, *as a* “zoom telescope” over the *entire accessible mm/submm* wavelength

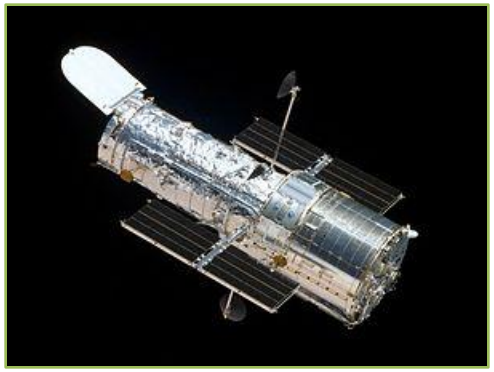


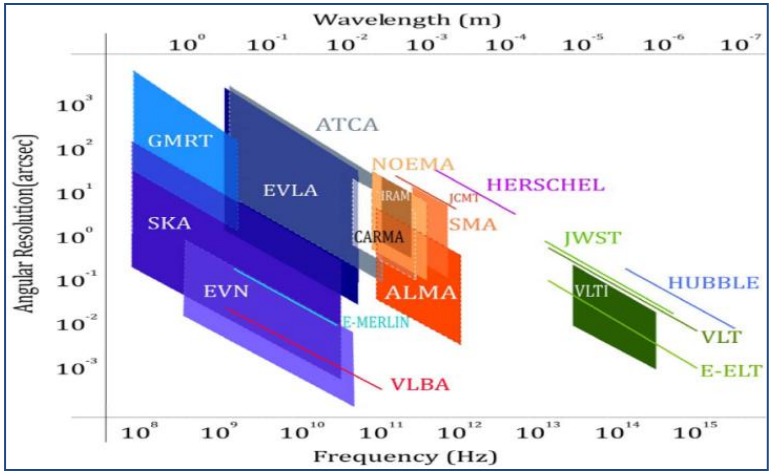
Built to operate

>30 yrs

Remotely operated from OSF Control room

ALMA Science Capabilities:





Angular Resolution

- ~8 times better that Hubble ST
- ~10-100 times better than current mm interferometers

Spectral resolution sub-km/s

(>10 times better than Hubble GHRS)

Sensitivity:

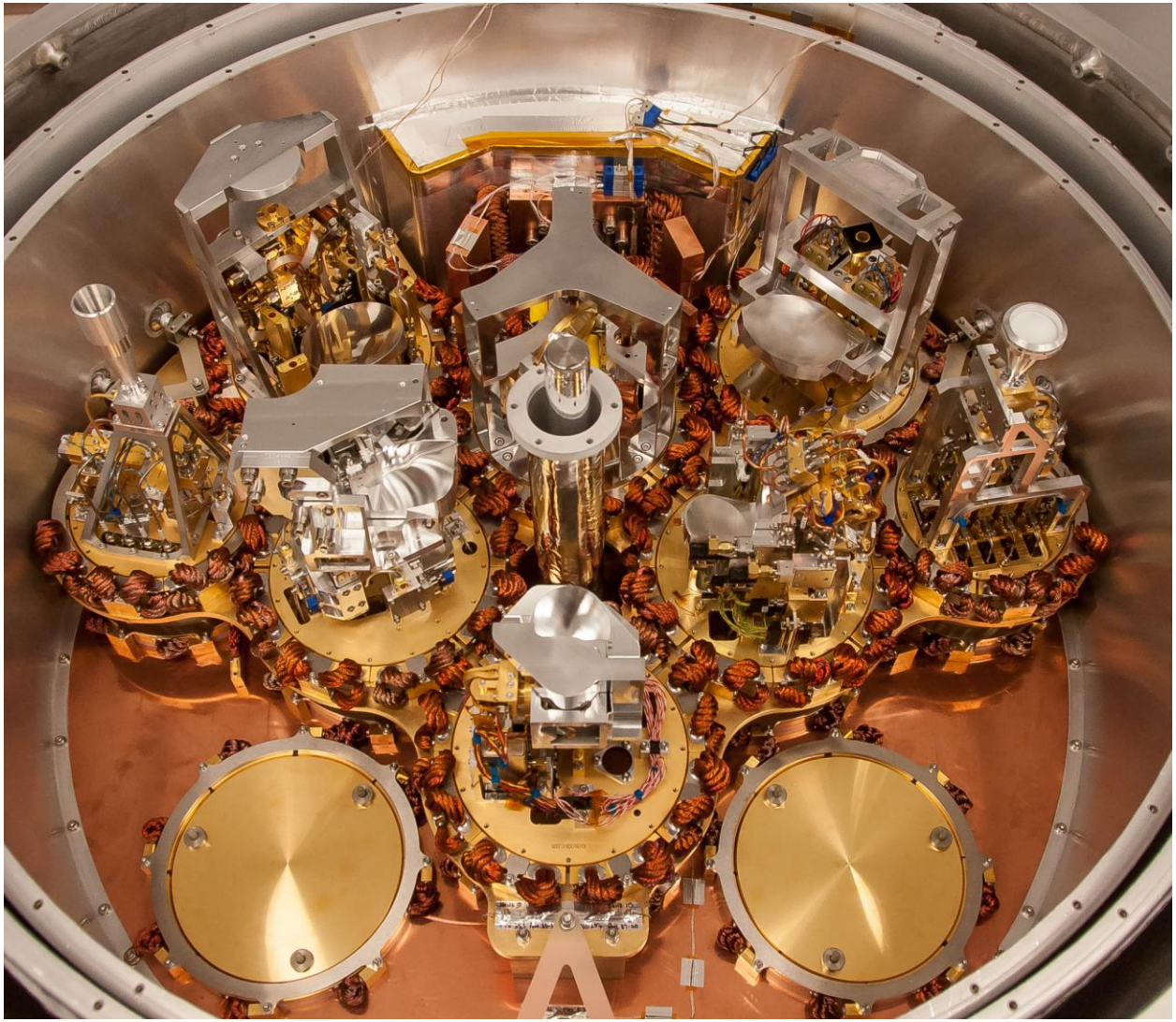
- large increase:

  10—100 times from:

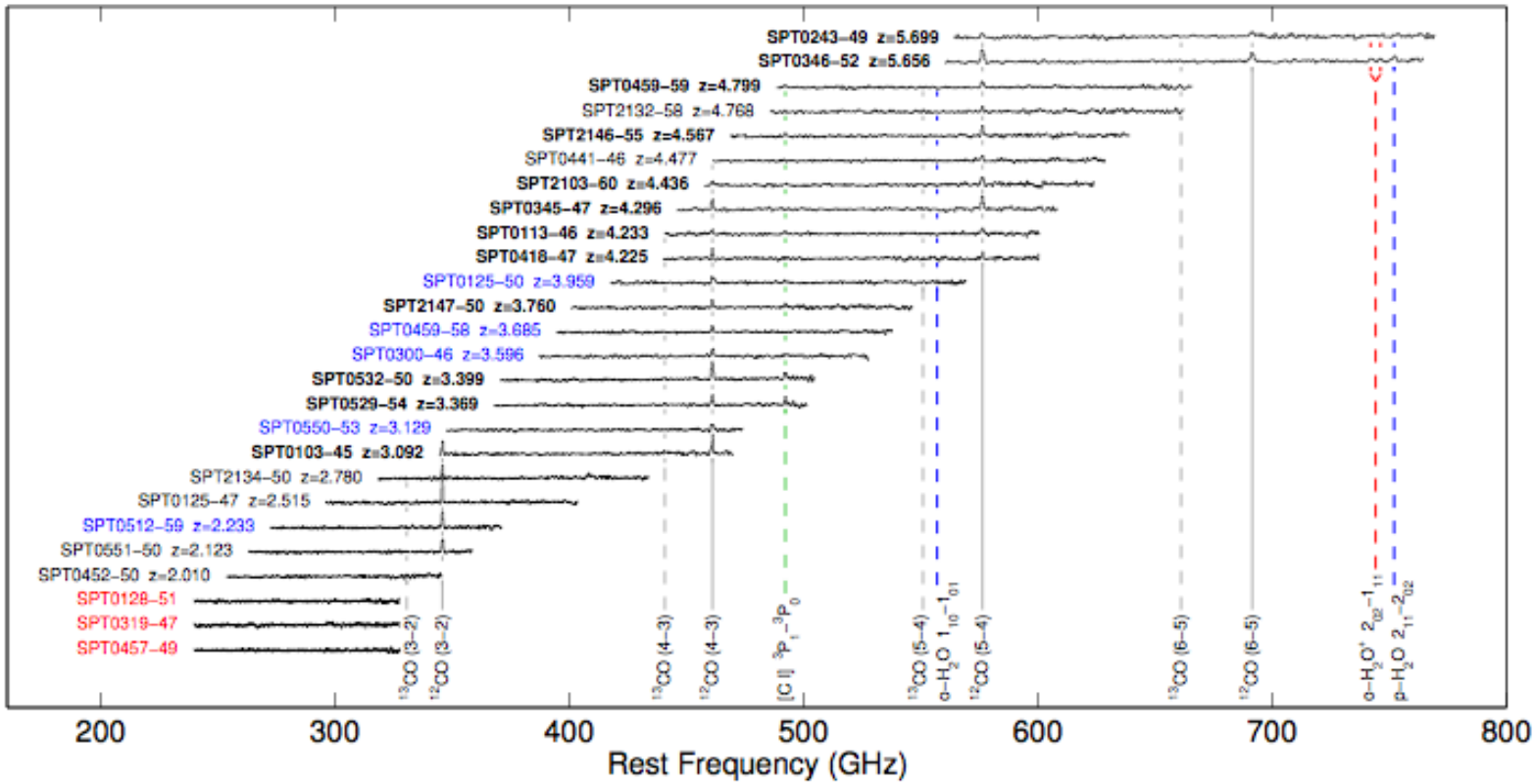
  - 7000m^2 collecting area
  - State of the art receivers

- Coverage entire submm/mm spectral range

ALMA Cryostat with 8 bands



First spectroscopic redshift survey with ALMA



Bold = unambiguous redshift from ALMA

black = single lines with ALMA, confirmed with C+ or CO(1-0) with APEX or ATCA

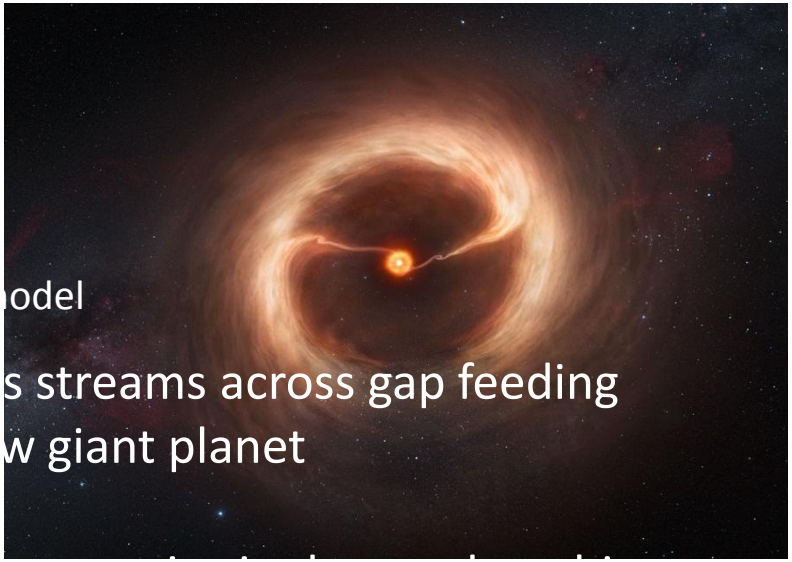
blue = single line detected with redshift, most likely redshift from photo-z

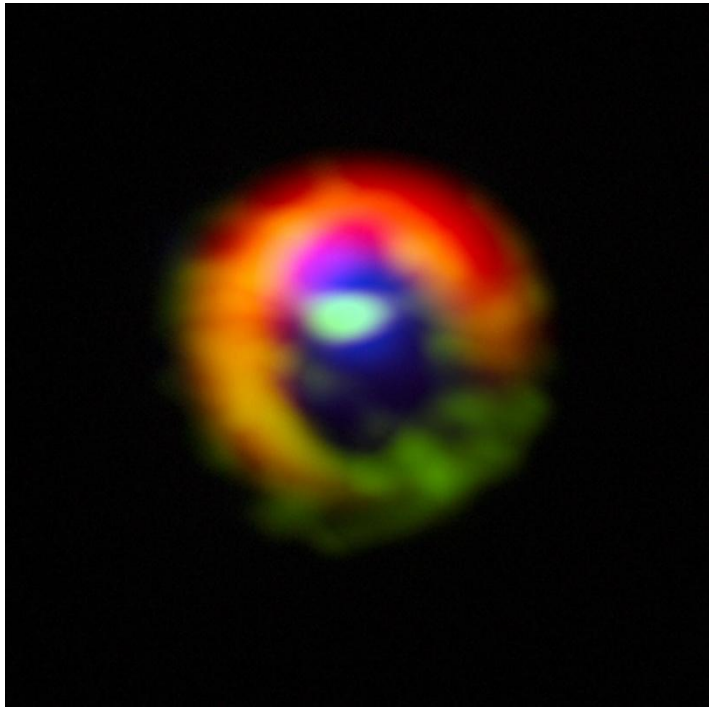
red = no line detected

ALMA Cycle 0 Band 3
100 GHz compact configuration
26 sources
5 tunings in the 3 mm band
10 minutes per source

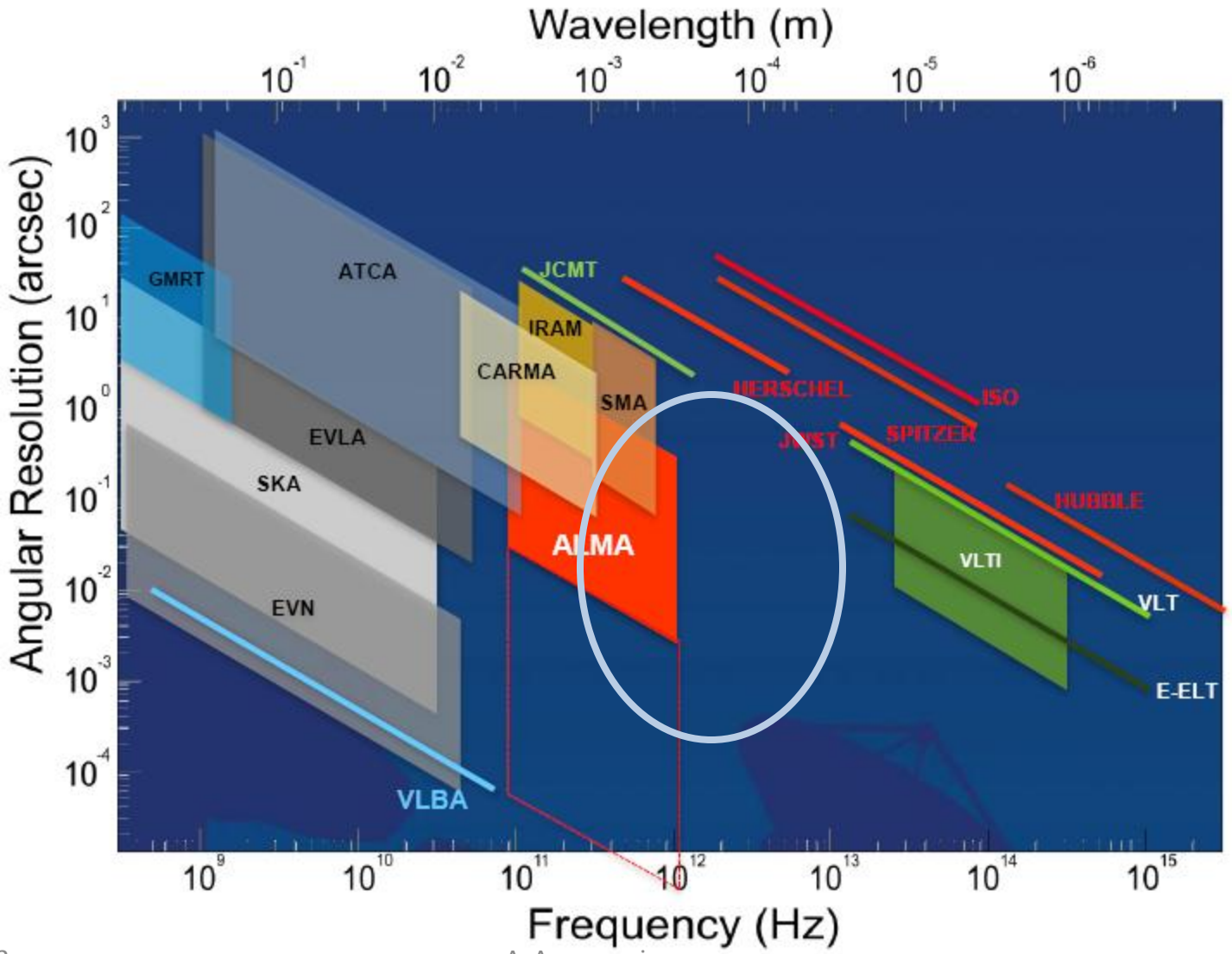
Vieira, Marrone, Chapman, DeBreuck, Hezaveh, Weiss, *et al.* Nature in press

ALMA first results: images of disks with cavities



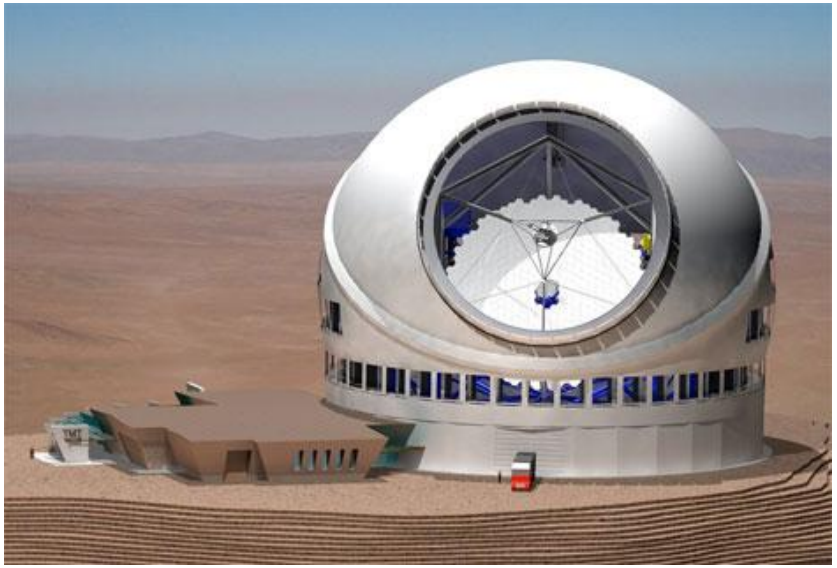


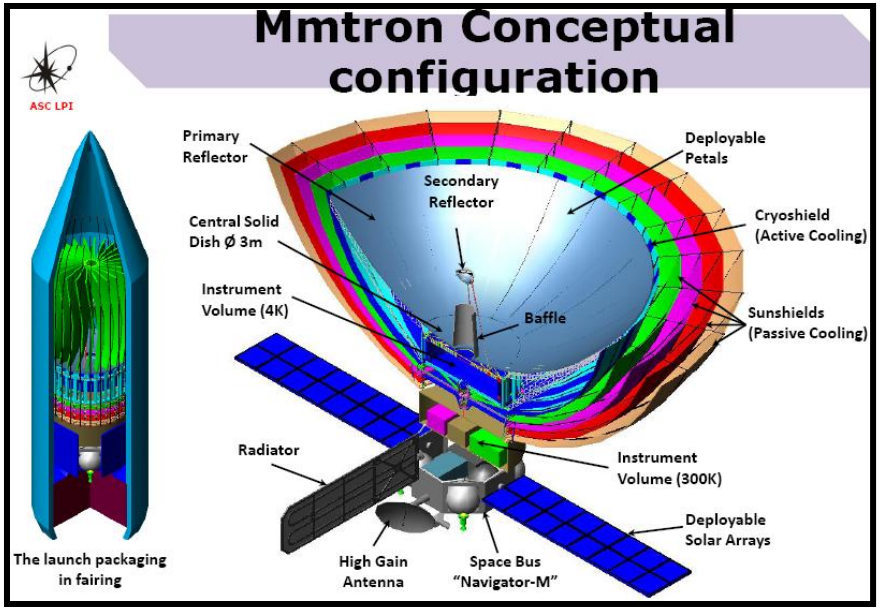
The FIR Angular Resolution Capability Gap



The Future Single Dishes

CCAT: 25 m in diametre



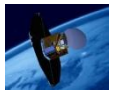


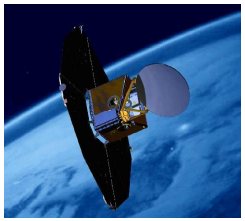
Scientific requirements for Instrumentation

Required detectors *NEP*:	**≤ 10^{-19} W/√Hz**
Sensitive to polarization	
Requirements for the Imaging Specifications:	
Wavelength coverage:	**20 – 3000 μm (goal)**
Spatial resolution:	**≈ 5''@200 μm**
Field of view:	**≈ 6'@300 μm**
Requirements for the Spectroscopic Specifications:	
Low resolution:	**λ/Δλ ≈ 3**
Wavelength coverage:	**20 – 3000 μm (goal)**
Medium resolution:	**λ/Δλ ≈ 1000**
Wavelength coverage:	**20 – 3000 μm (goal)**
High resolution:	**λ/Δλ ≥ 100000**
Wavelength coverage:	**50 – 500 μm (goal)**
Requirements for the Interferometric Specifications :	
Wavelength coverage:	**300 μm – 17 mm (goal)**
Resolution :	**λ/Δλ ≥ 100000**
Noise temperature:	**lowest available**

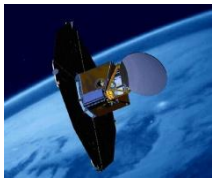
ESPRIT: Exploratory SPace submm Radio Interferometric Telescope

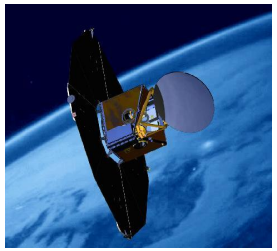
Hubble resolution in the FIR

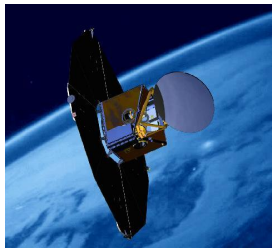


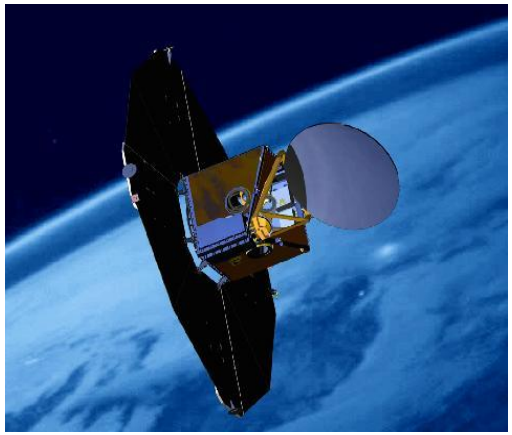


Th. de Graauw, J. Cernicharo, A. Bos, J. Bregman, L.Darcio, J-W den Herder, A. Gunst, F. Helmich, P. Maat, J, Noordam, A. Quirrenbach, P. Roelfsema, L. Venema, P. Wesselius, W. Wild, J. Martin-Pintado, P. Yagoubov, et al.





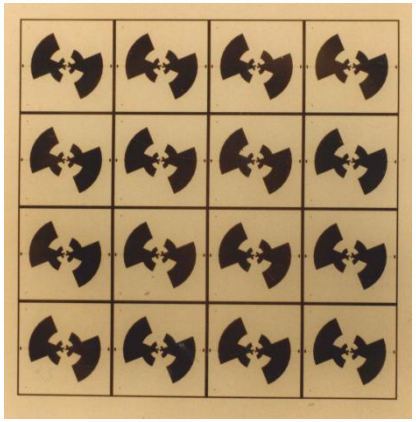




Arnold and SRON: personal liaison for ASTRON

Arnold's Submm Mixer array dream:

- Cross-guide couplers (fast and practical)
- One eye on QO designs: LogPer
- Effort was aborted



Present status on receiver arrays:

- 8 pixels 460-498GHz; 8 for 800-920; KOSMA
- 7 pixels 660-690GHz; 7 for 800-880; MPIfRA/Champ+

In development:

128 pixel for 460-500 GHz; KOSMA/Caltech/JPL; CCAT

Balanced mixers!!

PM: ALMA-MADE discussion on ASTRON role in ALMA front-end fabrication (Astro-Tech)

Concluding

- **ASTRON (Dwingeloo) always extremely hospital for Submm development teams in the Netherlands: Utrecht and Groningen.**
- **In exchange of ideas, equipment and sharing workloads**
- **Team of Jean with Arnold and Bert**

Arnold,
Many Thanks
and
Best Wishes for the Future