The MIRO EXPERIMENT ON THE ROSETTA ORBITER

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ESAC – December 3, 2013

Outline

- The MIRO Science Team
- Overview of comets
- MIRO Instrument and Science Objectives

MIRO Co-Investigator Science Team

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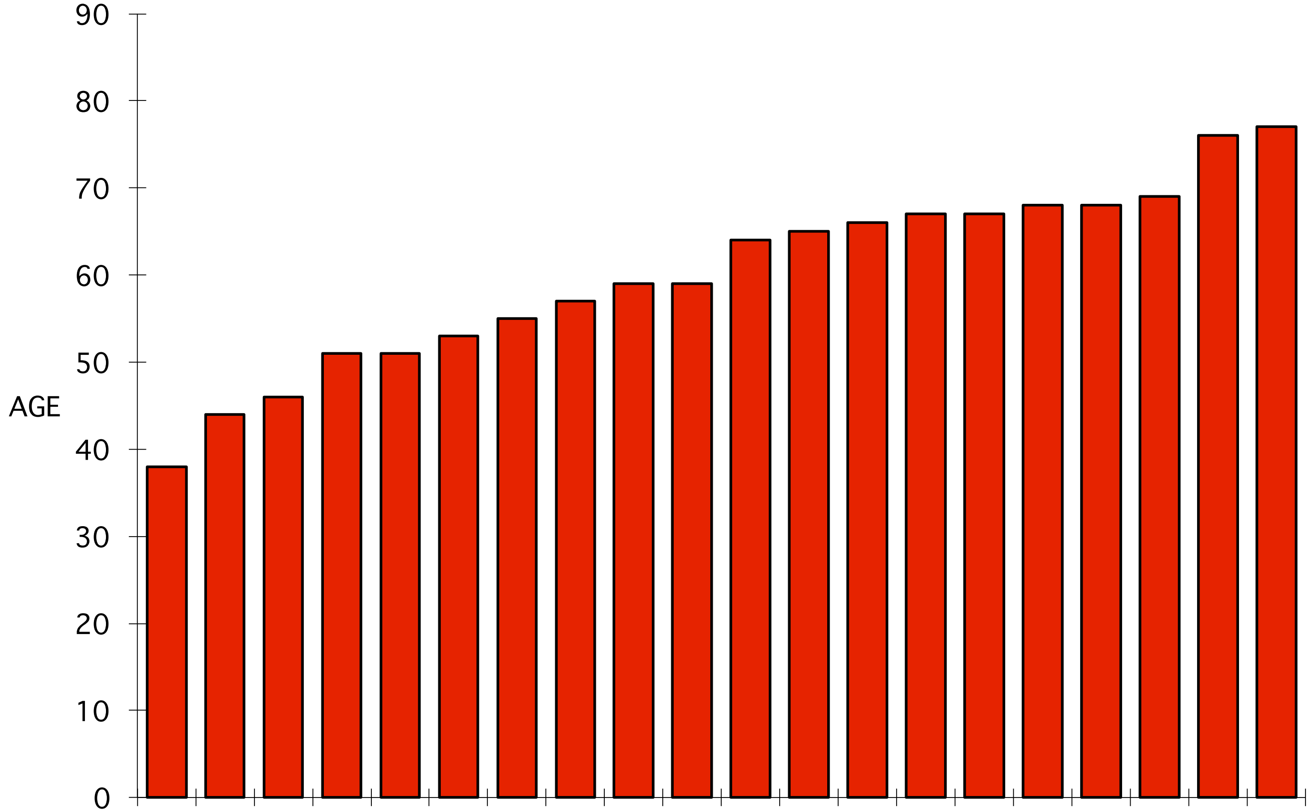
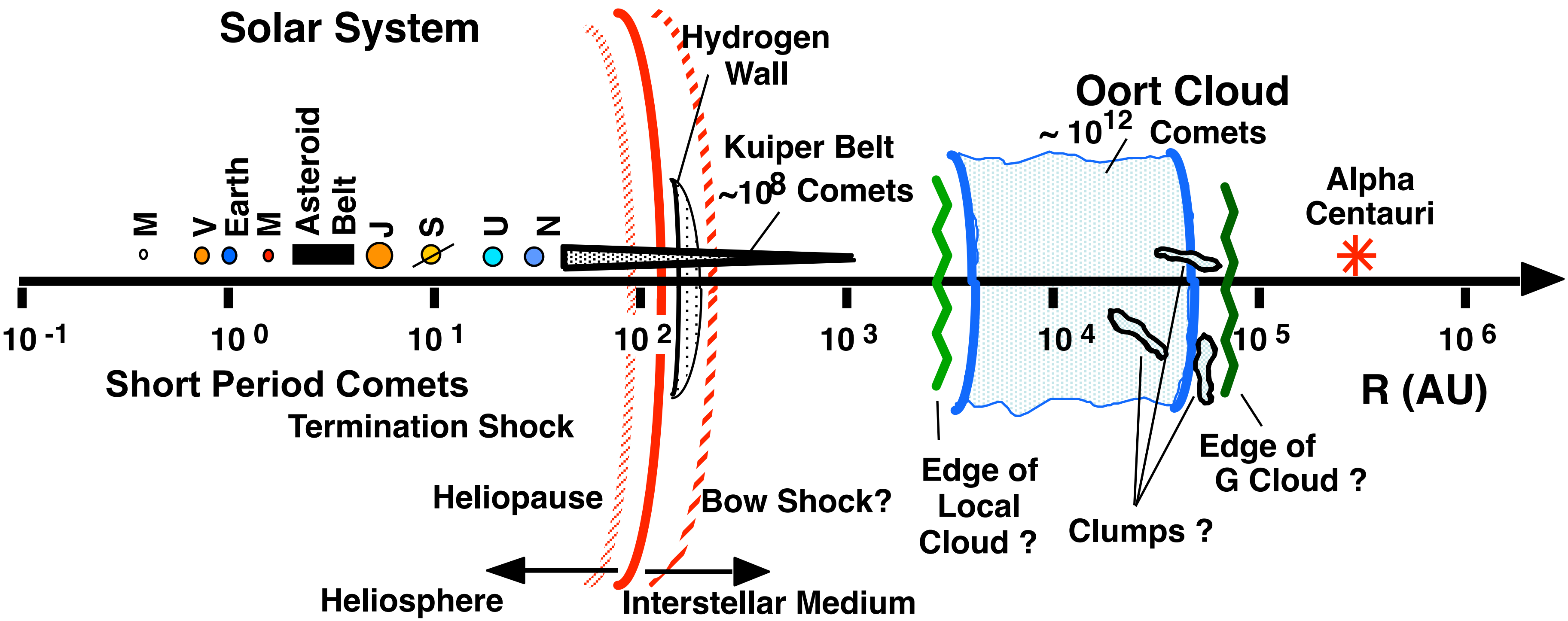
AGES OF MIRO TEAM MEMBERS IN 2014

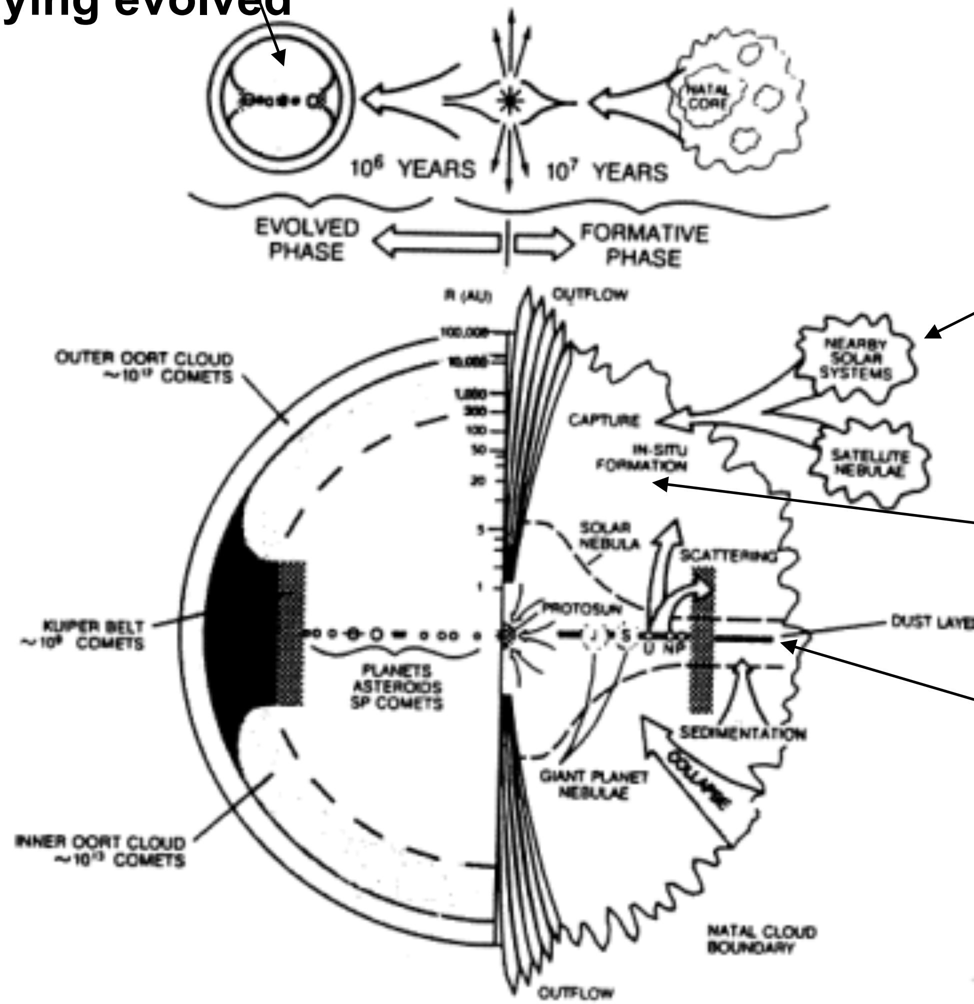


SCALE OF THE HELIOSPHERE AND LOCAL INTERSTELLAR MEDIUM



(Mewaldt,1998)

With MIRO we are trying to learn about formative phase by studying evolved phase



Captured

In-situ formation

Scattered from plane of formation

Mumma, Weissman, and Stern, 1993

Why the interest in comets?

- Comets offer clues to composition and processes at work during or following the accretion of the cores of the outer planets
  - Abundances of volatile materials provide information on composition and temperature of formation
  - Structure of nucleus shows how comets were assembled
- Origin of life on Earth
  - Presence of organic materials in the dust
  - Possibility that prebiotic chemistry may have taken place on dust particles
- Long history of observations and study of physical processes in comets

Science Questions/Motivation

- **How did the nucleus form in the first place?**
- **What can we infer about the conditions present at the time of formation?**
- **How are volatiles stored in the nucleus? As ices, clathrates, organic materials?**
- **What is the relationship between gas and dust?**
- **Are parent molecules distributed homogenously or heterogenously in the nucleus?**
- **What is the porosity of the nucleus?**
- **Why do jets form in certain places and not others?**
- **How does the comet evolve with distance from the sun?**
- **What can comets tell us about the formation of the solar system?**

Remnants of the Solar Nebula ?

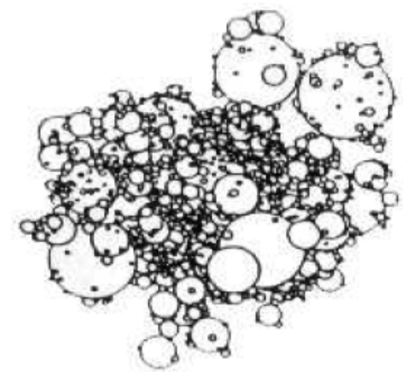
- Orbits
  - Appear to have formed between 20-100 AU
  - Some ejected out to Oort cloud
  - Evolved in extremely cold environment
- Composition
  - Rich in volatiles suggests low temperature formation- but not too low
  - Similarity to icy interstellar grains
  - Isotopic ratios
  - Abundances(depletion of noble gases, H)
- Absence of differentiation (small size)
  - Gravitational did not appear to play a role in formation
  - Accumulation depended on condensed matter on grains

Understanding the evolution of comets

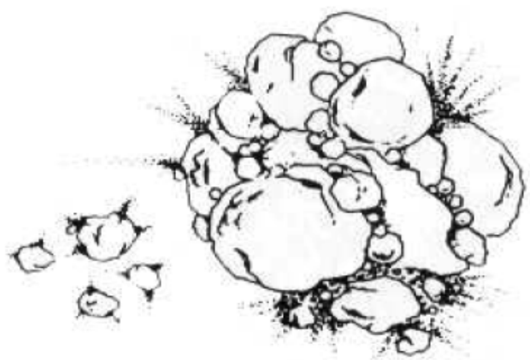
- What are the physical properties of cometary nuclei?
- Which of the nucleus properties are primordial?
- Do comets have mantles? What factors control the rates of growth of mantles? Can the mantle properties be used to determine age?
- What fraction of the nucleus surface is covered with gas vents and mantle? What is the relationship between mantle and vent coverage?
- What are the grain coma expansion velocities?
- What conditions cause comets to outgas at large heliocentric distances? At night?
- How does outgassing vary with temperature?
- What are the subsurface temperature profiles of the nucleus?
- How does the coma form?
- What percentage of the coma gas originates from the surface? Subsurface? Grains?
- What role does nucleus shape, albedo, rotation rate, etc. have on the coma?

Models of Cometary Nucleus(image Donn(1991))

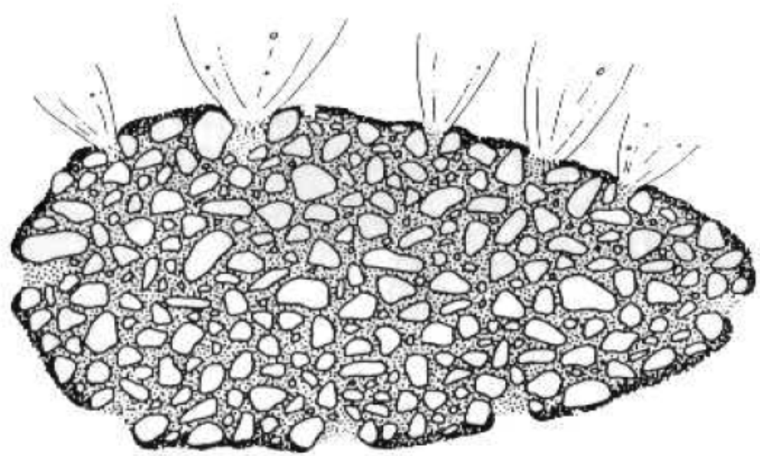
Dirty Snowball - Whipple(1950)



Fluffy Agregate - Donn(1986)

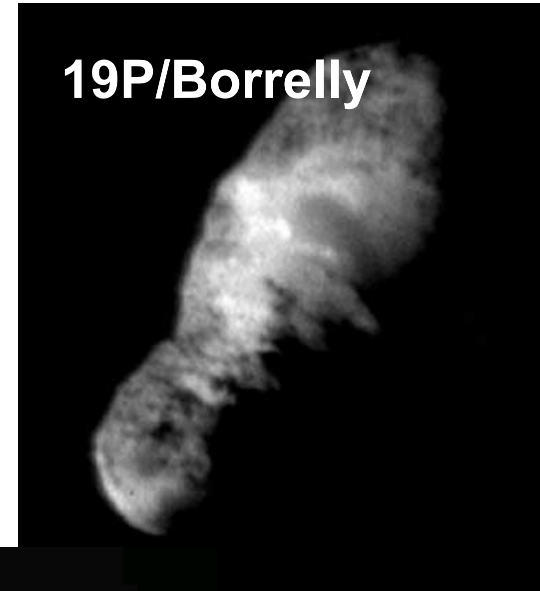


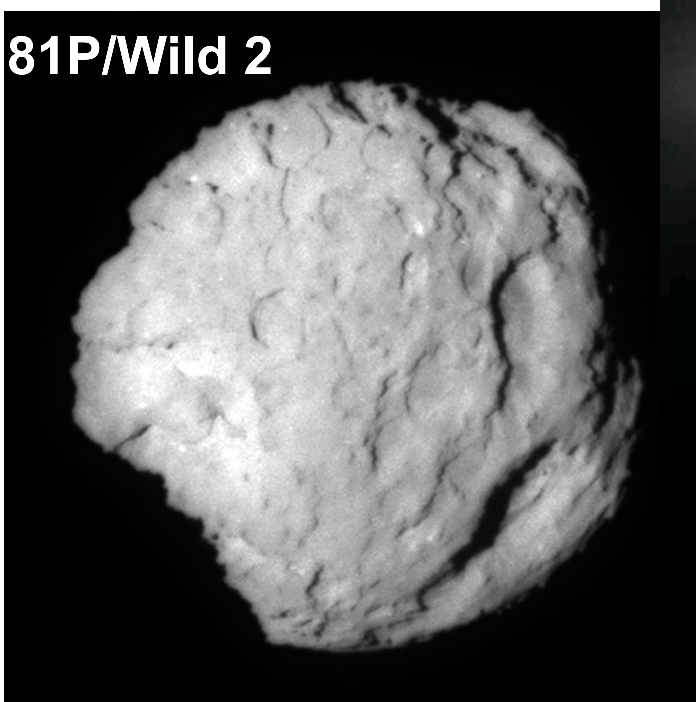
Rubble Pile - Weissman(1991)

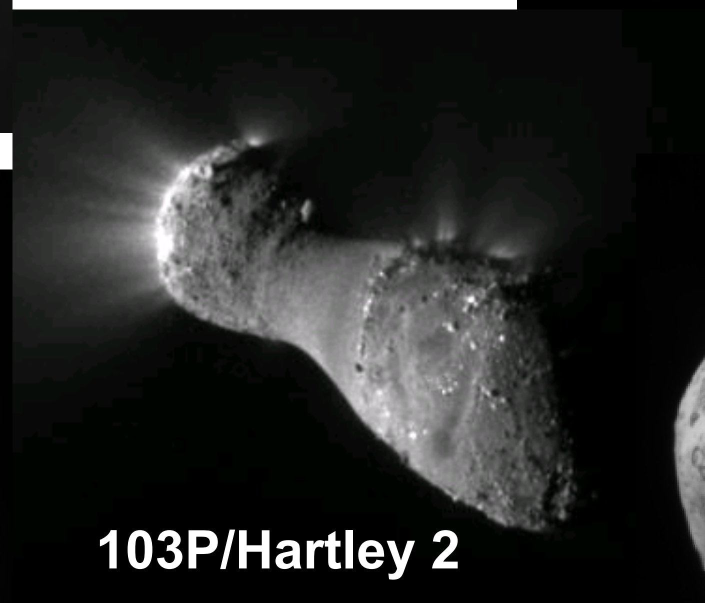


Icy-Glue -Gambosi and Houpis (1986)

Any Two Alike?

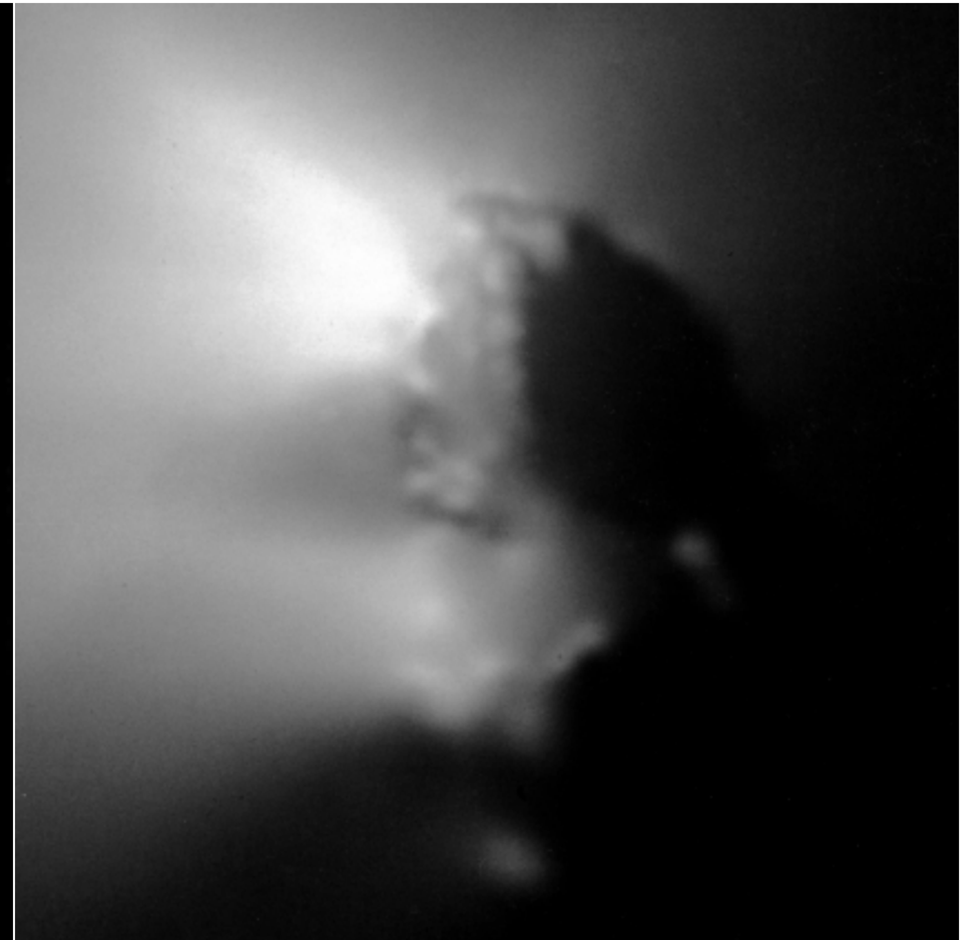






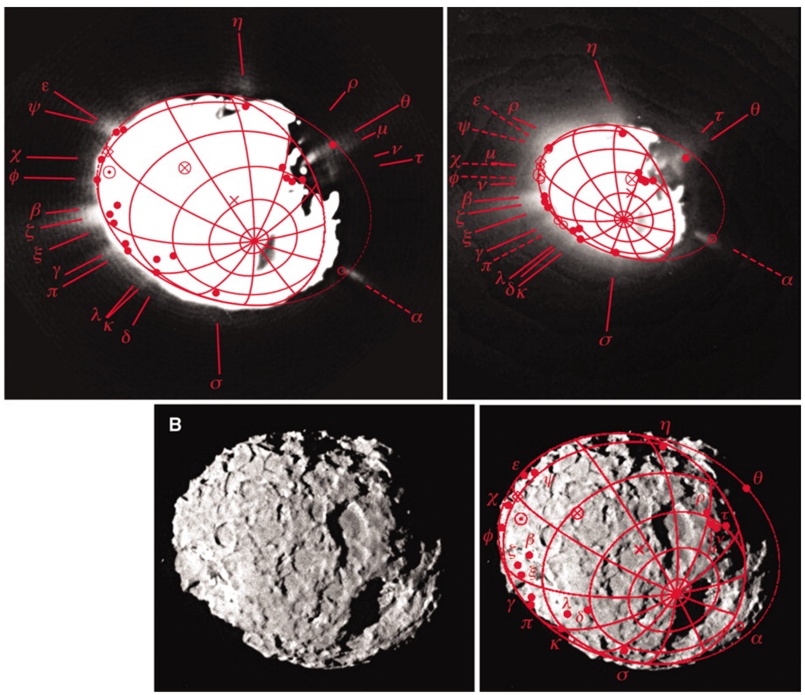
Wild 2 from Stardust 2004

Halley from GIOTTO 1986



Results from Stardust at Comet Wild 2

From Sekanina et al. 2004, Science 304



- Numerous discrete jets
- Dust lies on conical sheets emanating from point like regions
- Jet originate from both illuminated and dark side of nucleus

MIRO Instrument

Submillimeter instruments in general

- Submillimeter, Millimeter, and Radio spectroscopy provides a powerful technique for studying rotational transitions of molecules in a cold environment
  - Very high spectral resolution provided with heterodyne receivers
  - Gas velocities and column abundances can be measured for many molecules known to be important constituents in comets and exospheres
- Simultaneous continuum and spectroscope measurements provide near surface and sub-surface temperature measurements and gas outflow rates - important for the modeling of asteroid and comet nucleus regoliths and comae
- Signal levels proportional to temperature. Very cold object objects (primitive bodies) can be detected without cooling detectors

Primary Measurement Objectives

- **Absolute abundances of major volatile species**
- **Fundamental isotope ratios for water**
- **Surface outgassing rates**
- **Surface morphology**
- **Nucleus Subsurface temperatures and gradients**
- **Kinetic velocities of gas jets close to nucleus surface**
- **Subsurface temperatures and gradients in two asteroids**
- **Absence or presence of low levels of water vapor in asteroid environment**

MIRO Science Objectives

- Characterize the abundances of major volatile species and key isotope ratios in the nucleus ices
- To understand the processes controlling outgassing in the surface layer of the nucleus
- Study the processes controlling the development of the inner coma
- Globally characterize the nucleus subsurface to depths of a few centimeters or more
- To set limits on the amount of gas in the asteroid environment (any evidence of subsurface water ice)

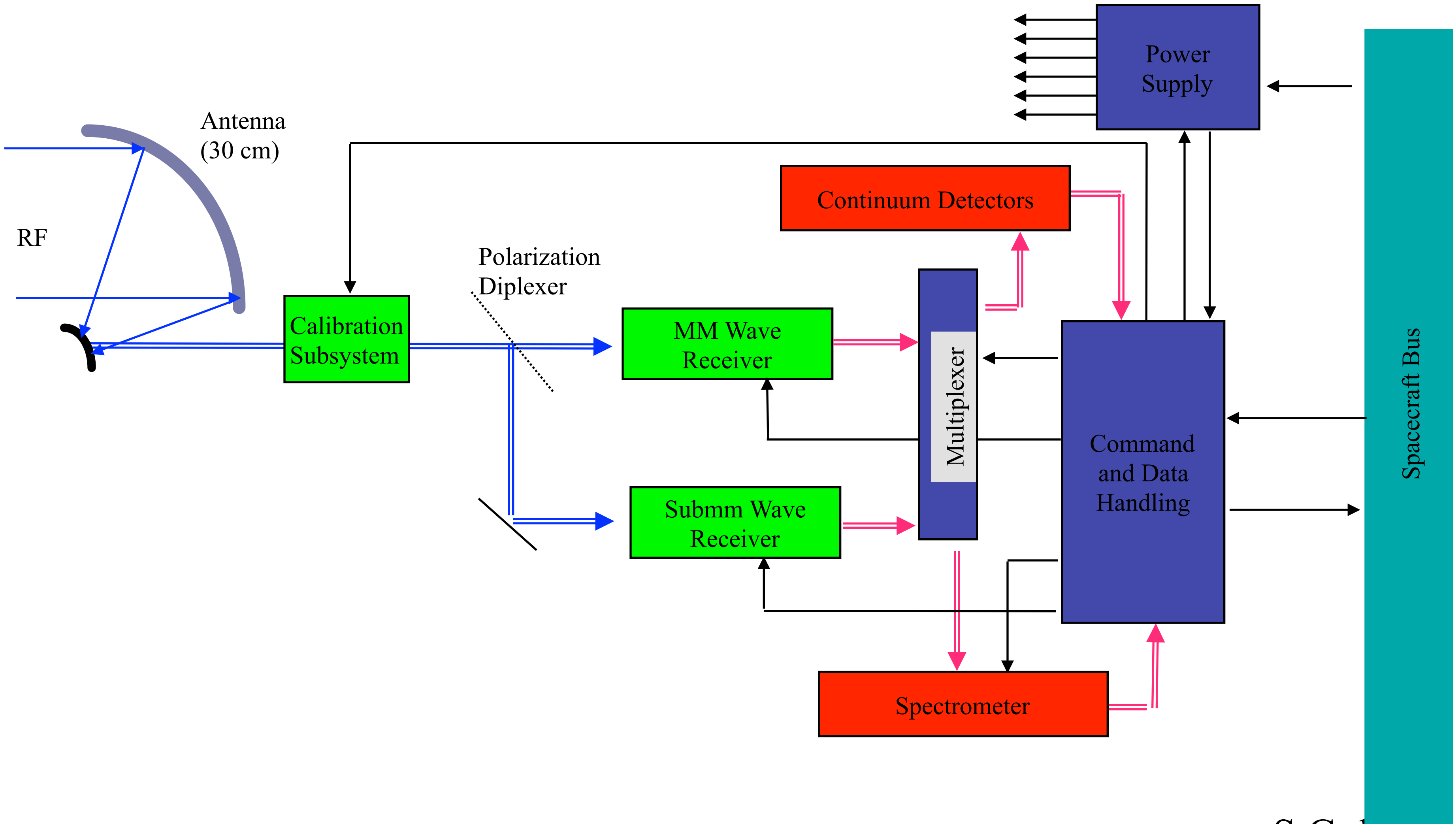
Measurements

- Measure abundances of H2O, CO, CH3OH, NH3, 17O/16O, and 18O/16O
- Measure surface temperature and outgassing rates for water, carbon monoxide and other volatiles
- Measure density, temperature, and kinematic velocity
- Identify morphological features on the basis of outgassing rates and surface & sub-surface temperatures
- Measure outgassing flux of water and carbon monoxide

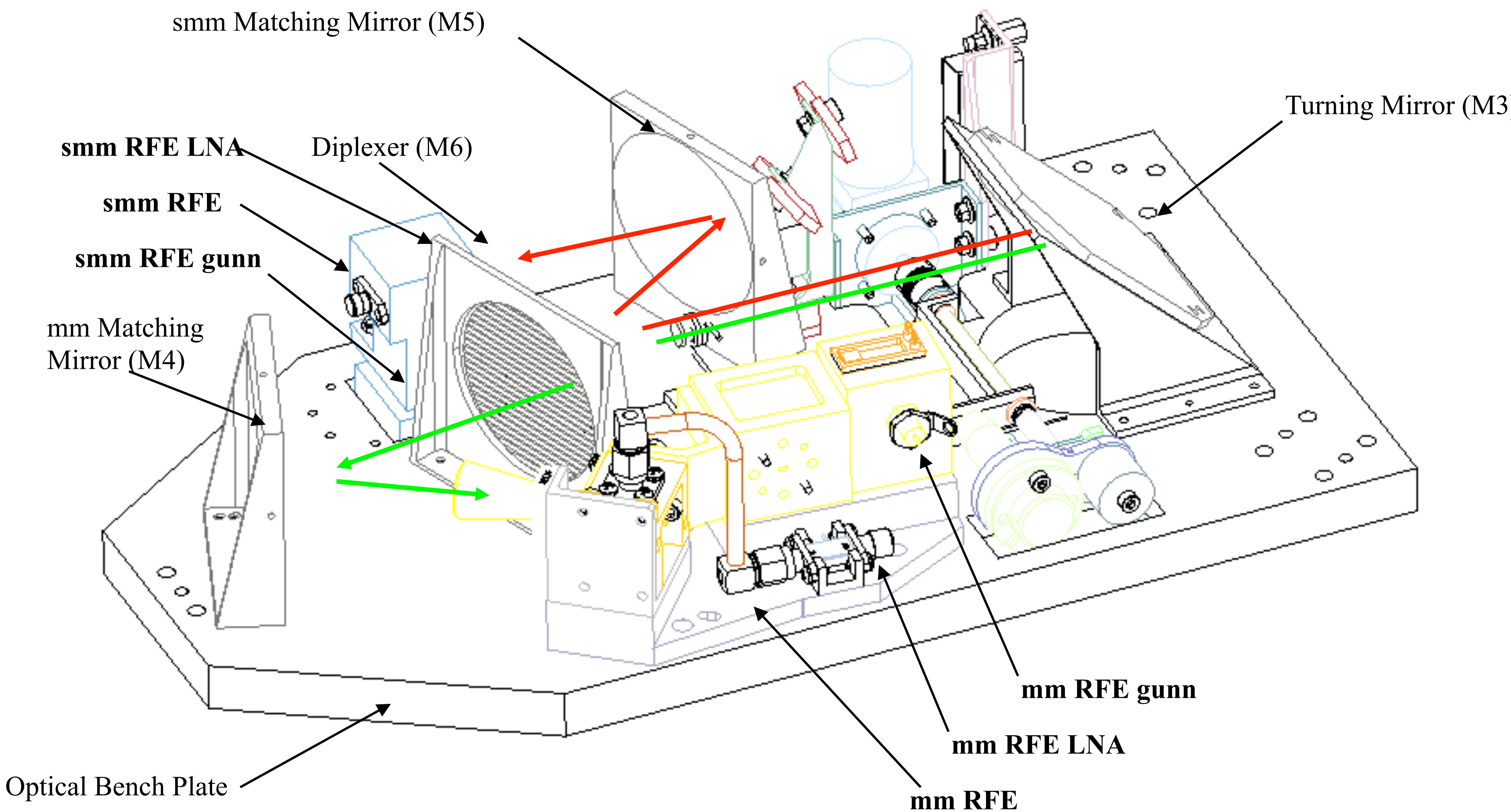
Performance Parameters

	Millimeter	Submillimeter
Telescope		
Diameter	30 cm	30 cm
Beam-Size (FWHM)	23.7x24.7 arc min	7.6 arc min
Foot-Print (10 km nadir distance)	75 m	25 m
Spectral Characteristics		
Frequency	188.5-191.5 GHz	547.5-580.5 GHz
IF Bandwidth	550 MHz	1100 MHz
Spectral Resolution		44 kHz (.023 km/s)
Individual spectral bandwidth		20 MHz (11 km/s)
Spectral Bandwidth/# Channels		180 MHz/4096
Radiometric Characteristics		
DSB Noise Temp.	800K	3800K
RMS Spectroscopic Senstivity (300 kHz, 2 min.)		2K
RMS Continuum Sensitivity(1 sec)	< 1 K	< 1 K
Data Collection Rate	2.1 kbps	

System Concept



Optical Bench Assembly



S.Gulkis
12/3/13 - 21

MIRO SPECTRAL BANDS

Millimeter Band Receiver

Submillimeter Band Receiver

CO 576.268 GHz

$H_2{}^{16}O$ 556.936 GHz
$H_2{}^{18}O$ 547.676 GHz
$H_2{}^{17}O$ 552.021 GHz

NH_3 572.498 GHz

CH_3OH 579.154 GHz
CH_3OH 568.566 GHz
CH_3OH 553.146 GHz

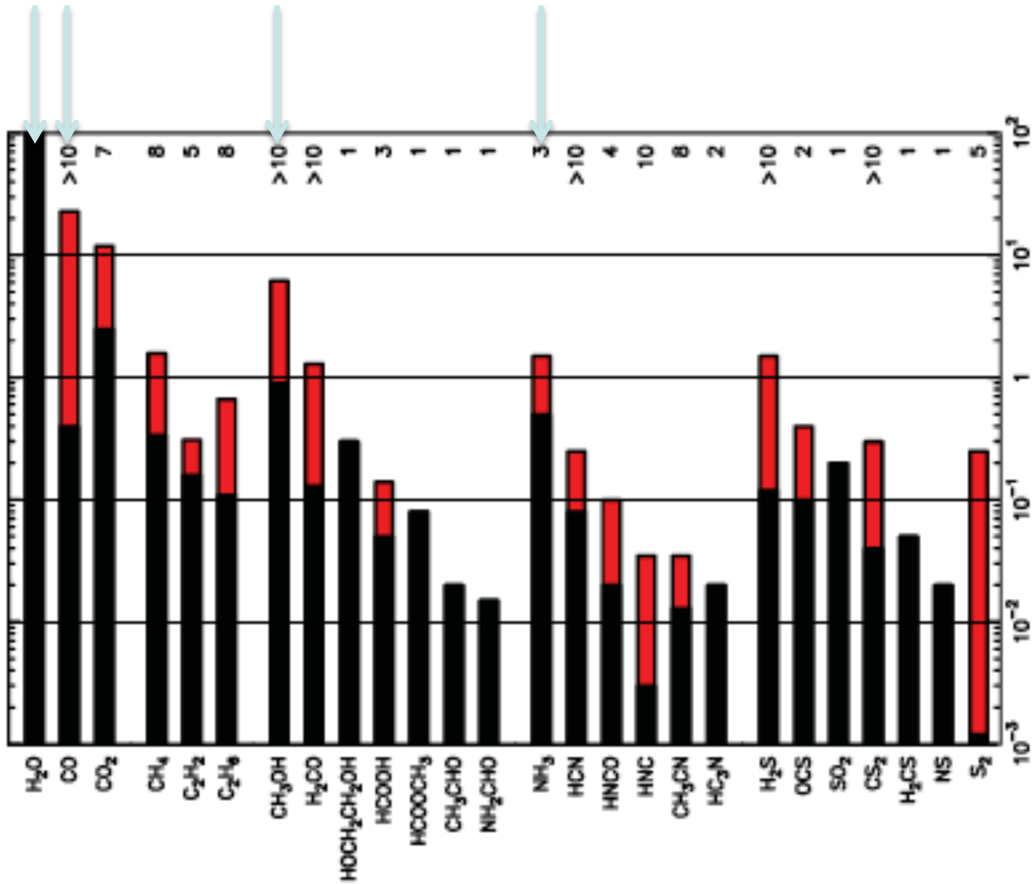
Continuum

Continuum

Comet Composition and MIRO Molecules

D. Bockelee-Morvan (2011)

The Molecular Universe
Proceedings IAU Symposium No. 280, 2011
José Cernicharo & Rafael Bachiller, eds.



H2O – most abundant molecule in coma, low temperature outgassing, 3 isotopologues

CH3OH – temperature probe

NH3 – main carrier of N

Measurement Capabilities and Characteristics

Measurement Capabilities

•Continuum temperatures in 2 bands

• High resolution spectroscopy

– H_2O, CO, NH_3, CH_3OH

Characteristics

• High spatial resolution(5 m@2km)

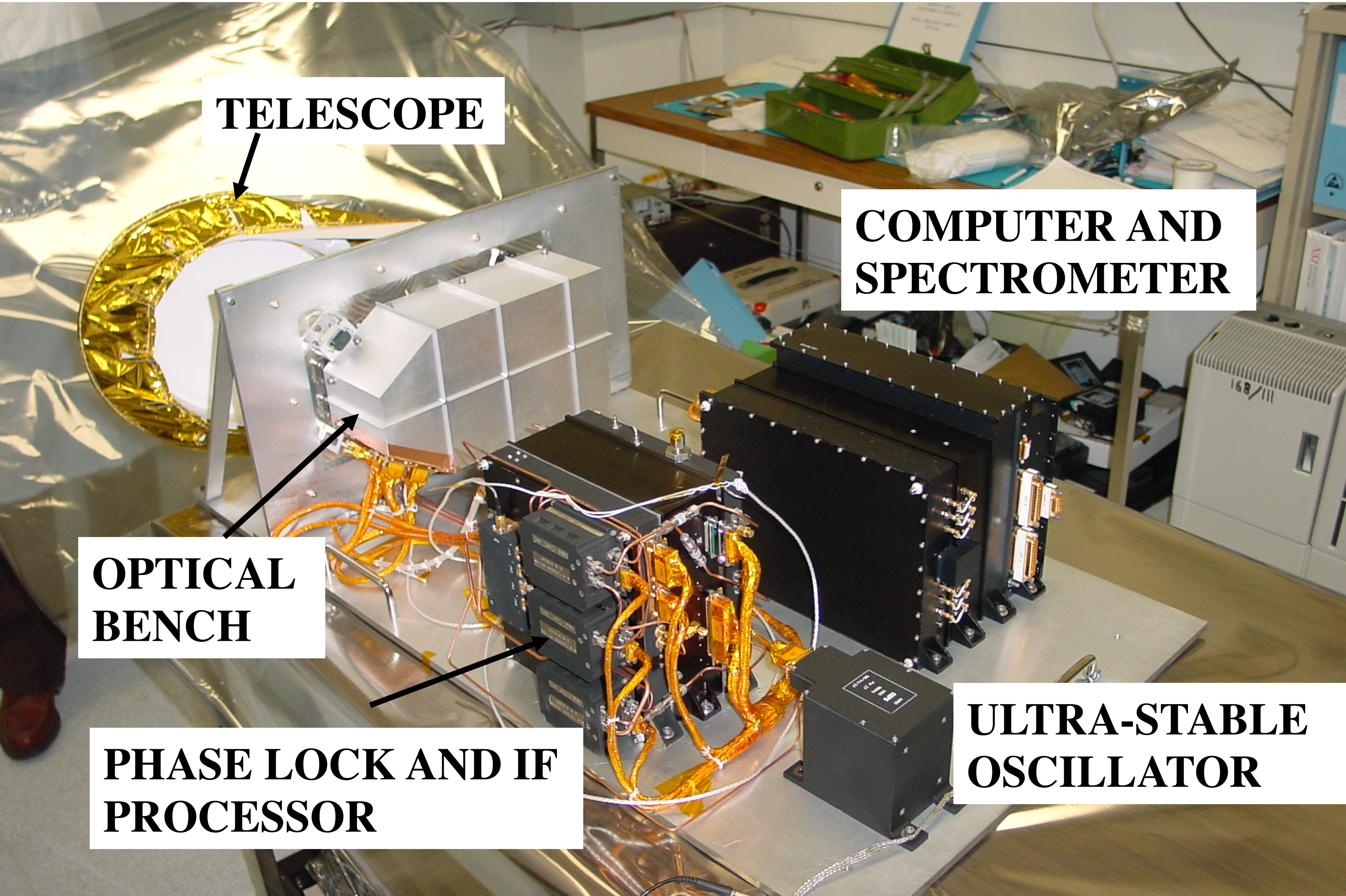
• High spectral resolution (44 kHz)

Resolving Power = 1.3e7

• Doppler gas flow velocity

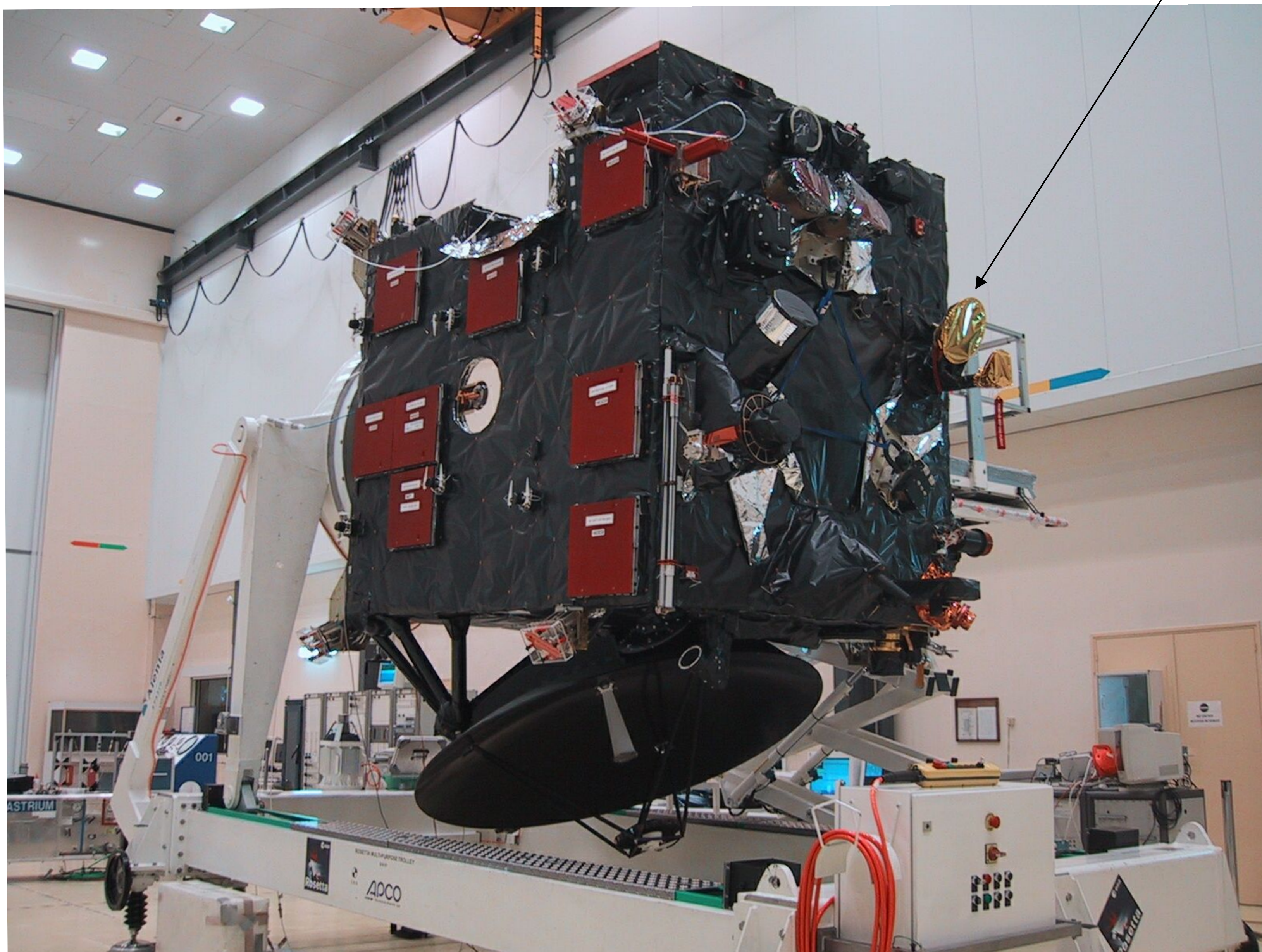
Accuracy ~10m/s

MIRO FLIGHT INSTRUMENT

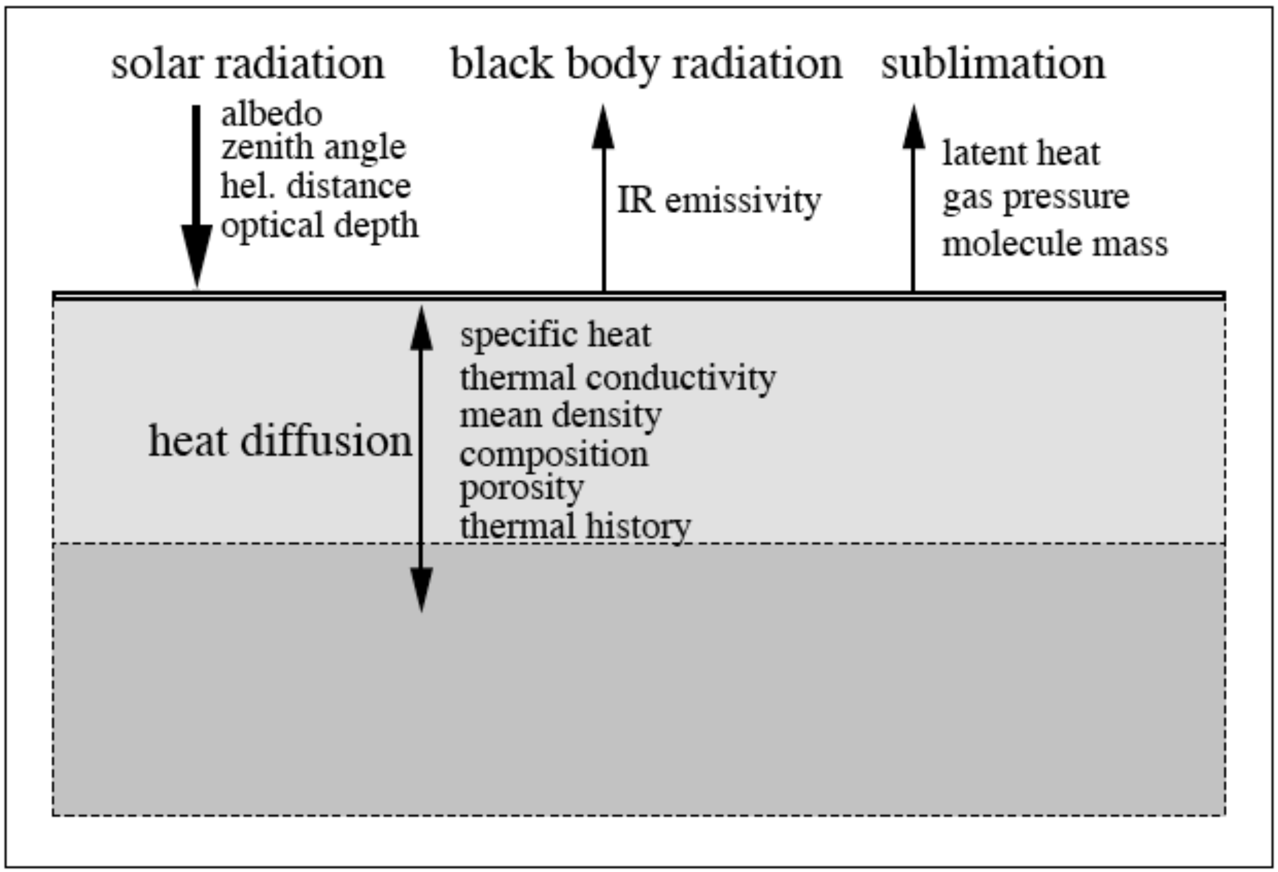


MIRO Structural Thermal Model - Sensor Unit

MIRO WITH DUST COVERS



Schematic of Energy Balance
after Voertzen(2003)



Energy Balance and Vaporization Rate

Vaporization of the nucleus

- temperature balance determined by absorbed solar flux, energy reradiated into space, latent heat of vaporized ices, and heat transported into interior

$$F_o(1-A_o)r^{-2}\cos(\theta)=\varepsilon\sigma T^4+\sum Z(T)L(T)+\kappa_d\nabla T_s$$

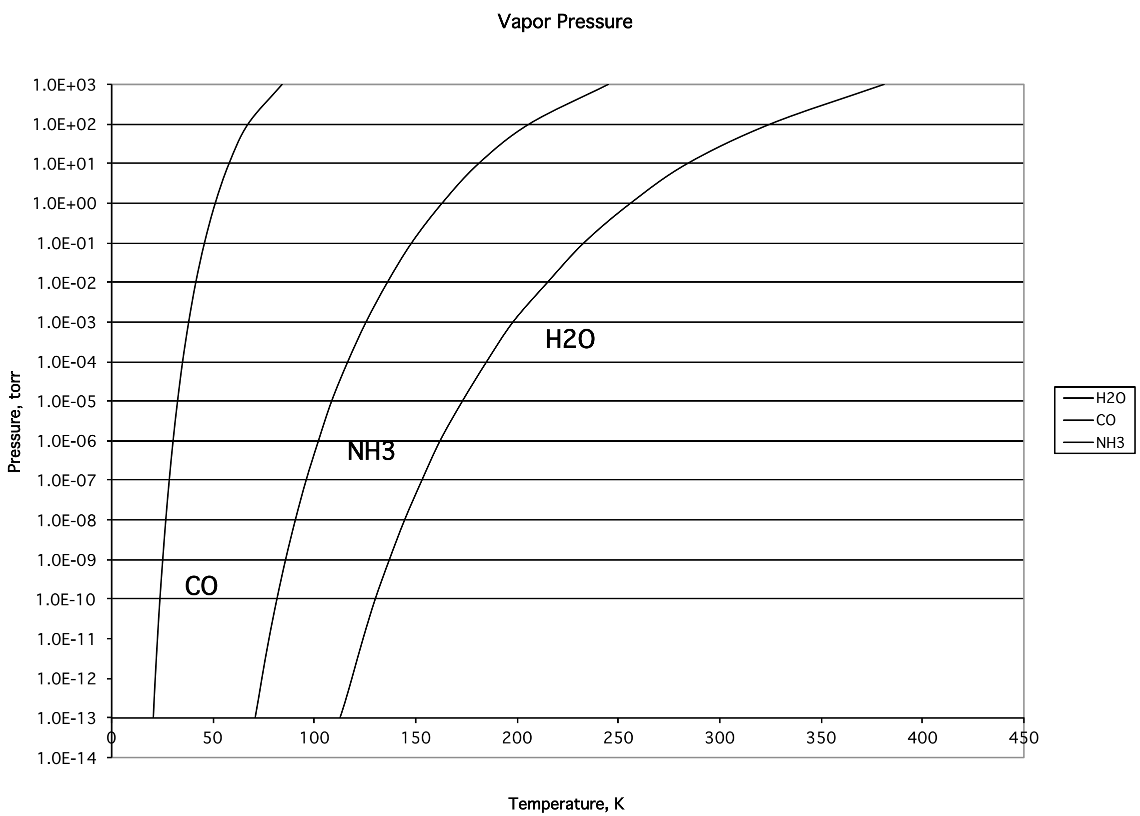
Vaporization Rate

$$Z = p_{sat}(2\pi mkT)^{-1/2}$$

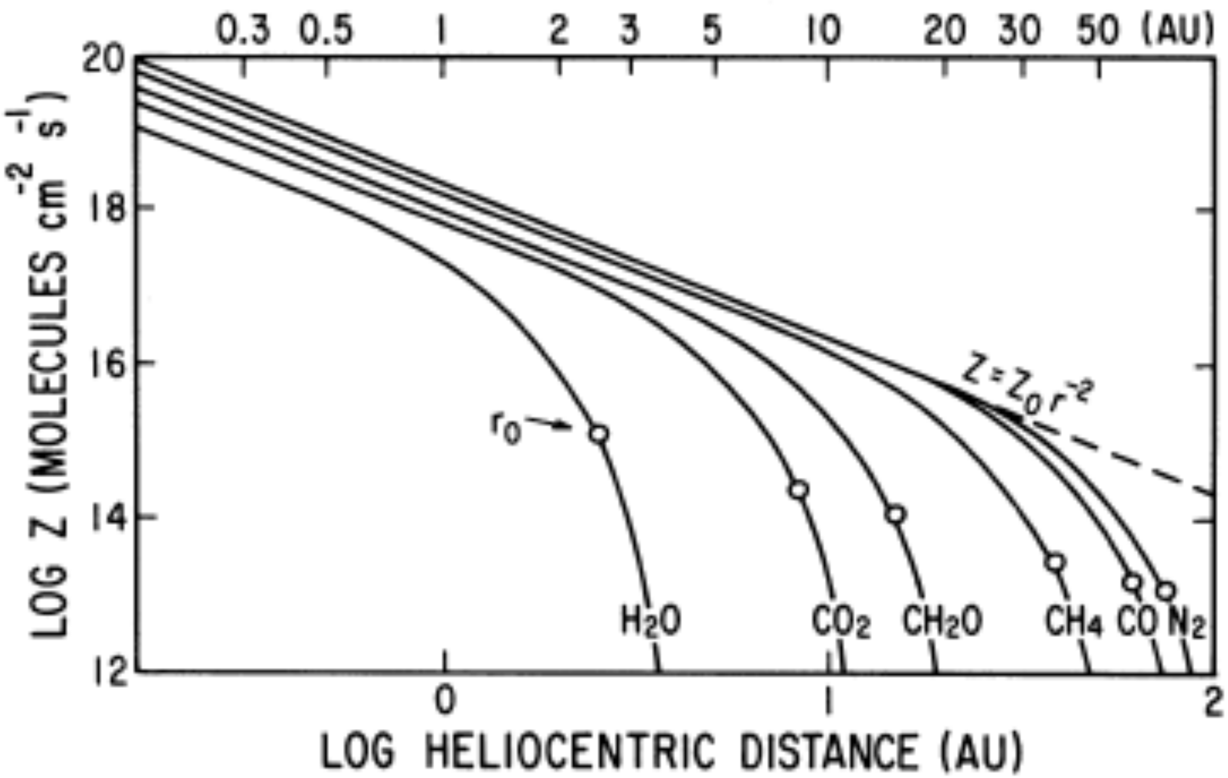
Expansion velocities of coma close to nucleus

- mean radial velocity at surface close to mean Maxwellian(0.5-0.66)
- molecules accelerate while expanding into vacuum
- sublimating gases drag away dust particles at the surface

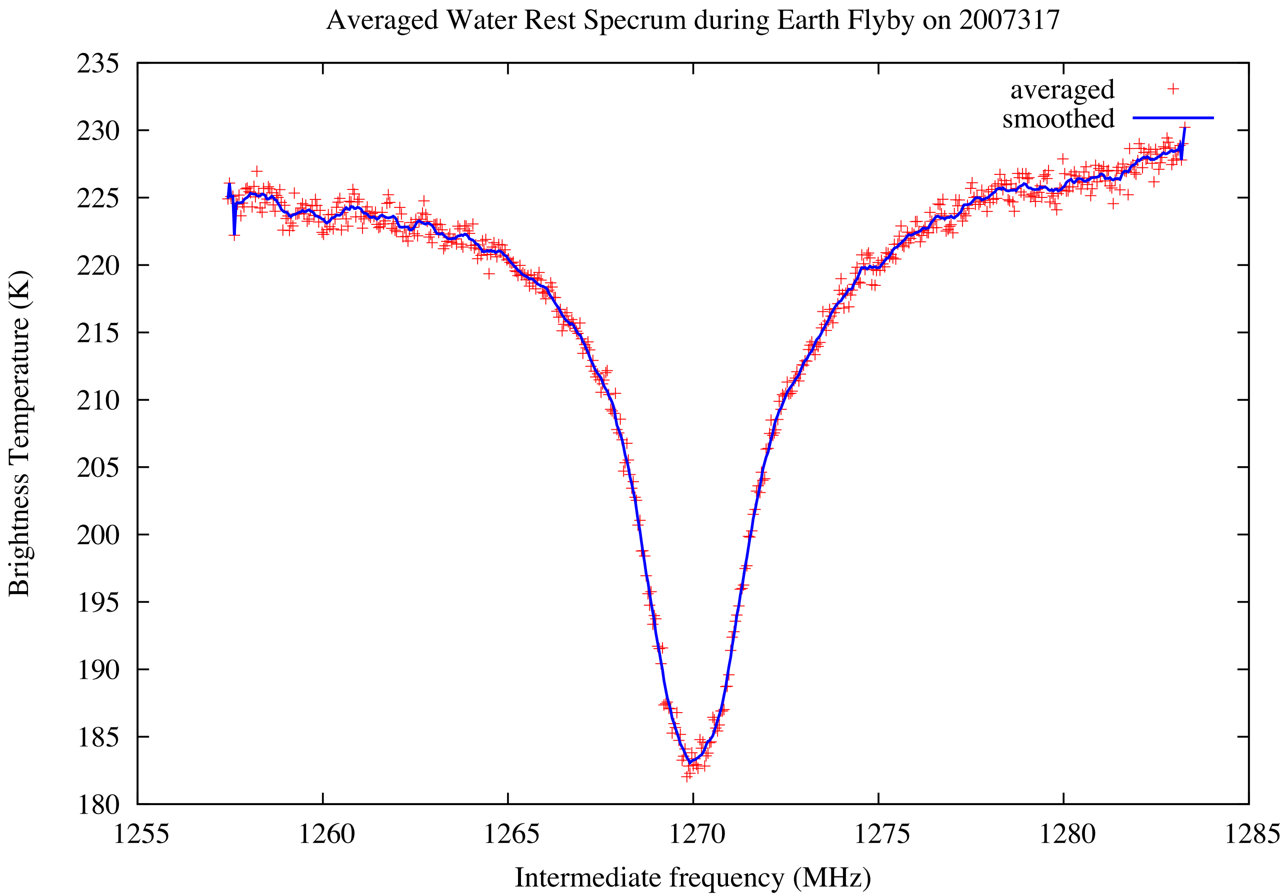
VAPOR PRESSURE OF WATER, AMMONIA, AND CARBON MONOXIDE AS A FUNCTION OF TEMPERATURE



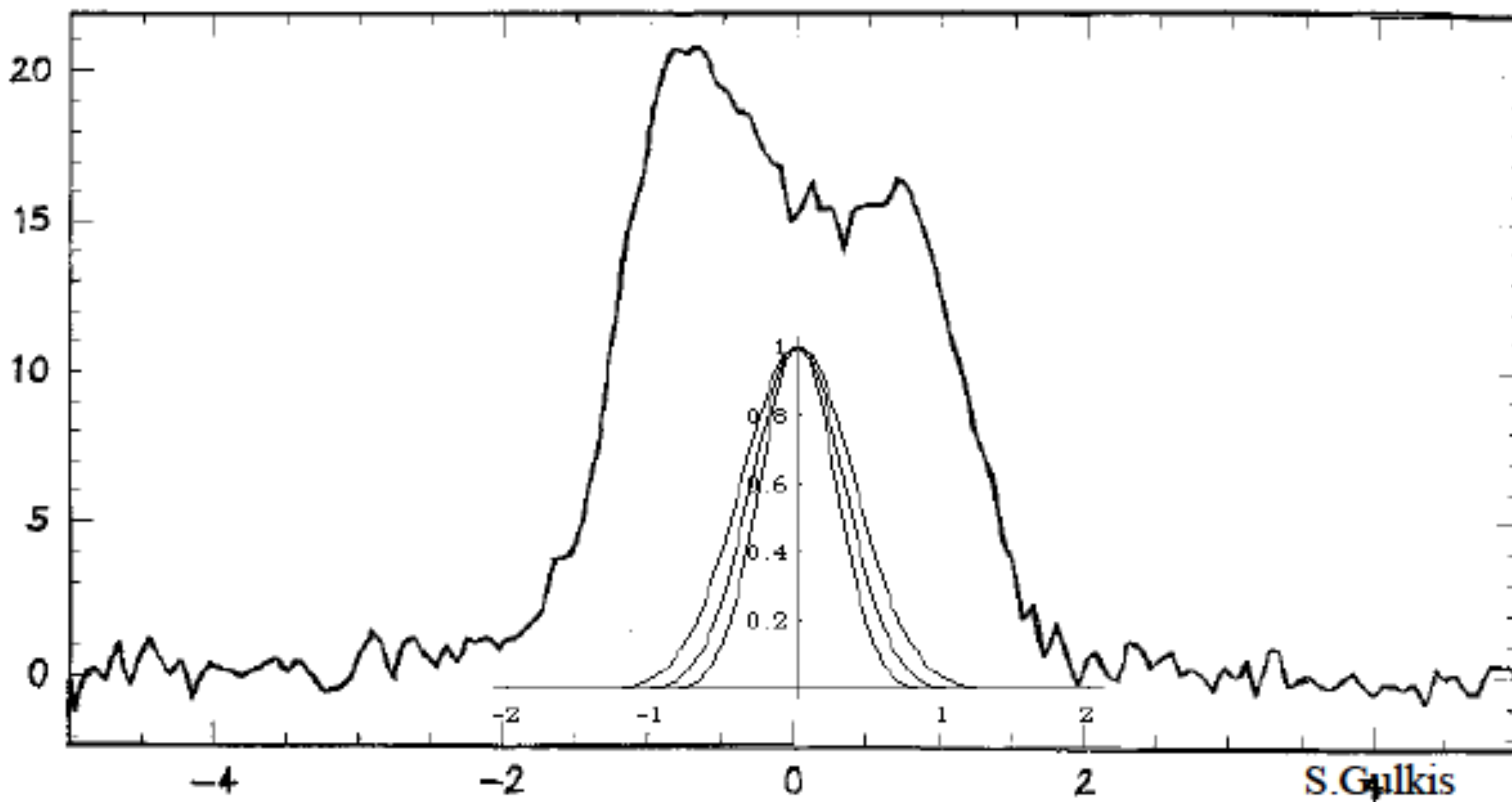
Dependence of Production Rates on Heliocentric Distance(Delsemme, 1982)



Pressure Broadened Spectral Line Observed with MIRO Instrument

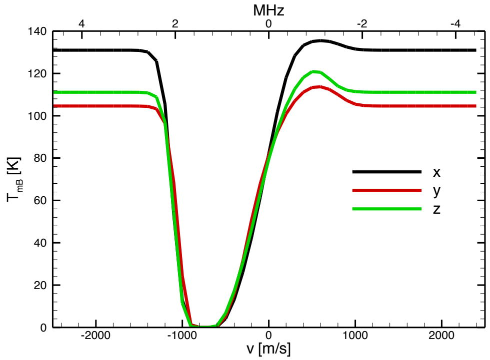


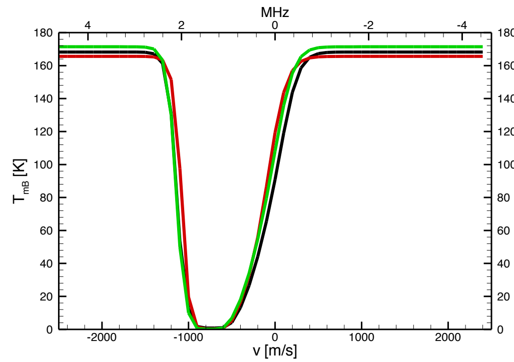
Comet HaleBopp   SMT Telescope - 28-MAR-1997
HCN(4-3): Freq = 354505.476 MHz : 100 kHz resolution: 2.6 min integration Tau: 0.3675   Tsys:874 EI: 49.11
Line Width ~ 3 km/s = 5 MHz
Dv: 7.3421E-02   Hel. Df: -8.6820E-02   Fi: 351805.431
Obs: Hartogh and Hofstadter

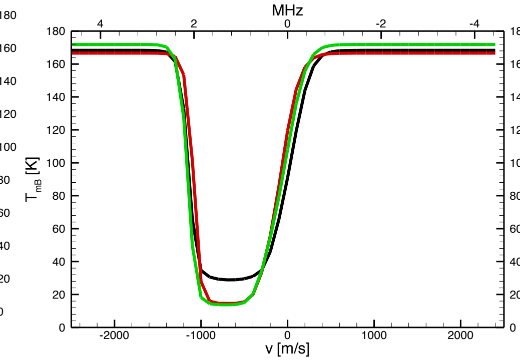


Simulated Observations of Water (557 GHz)

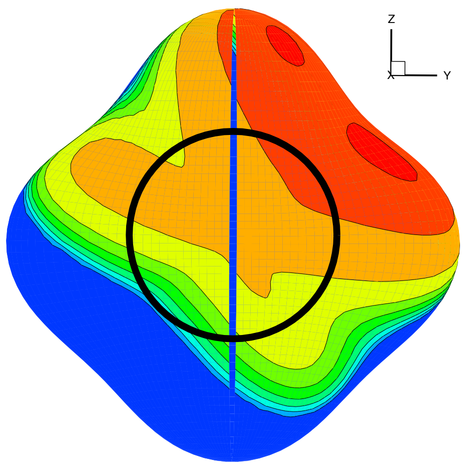
V.Zakharov, D.Bockelée-Morvan, N.Biver, J.Crovisier



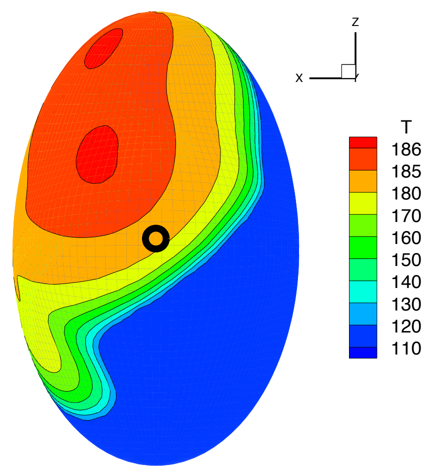




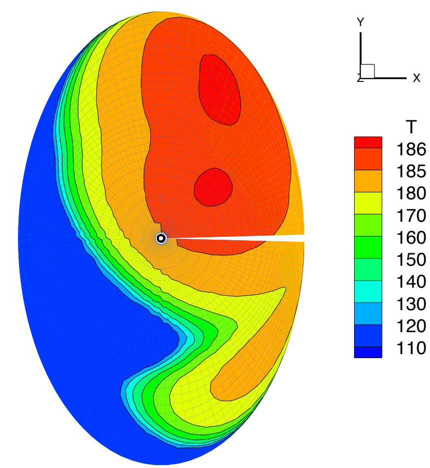
1000 km



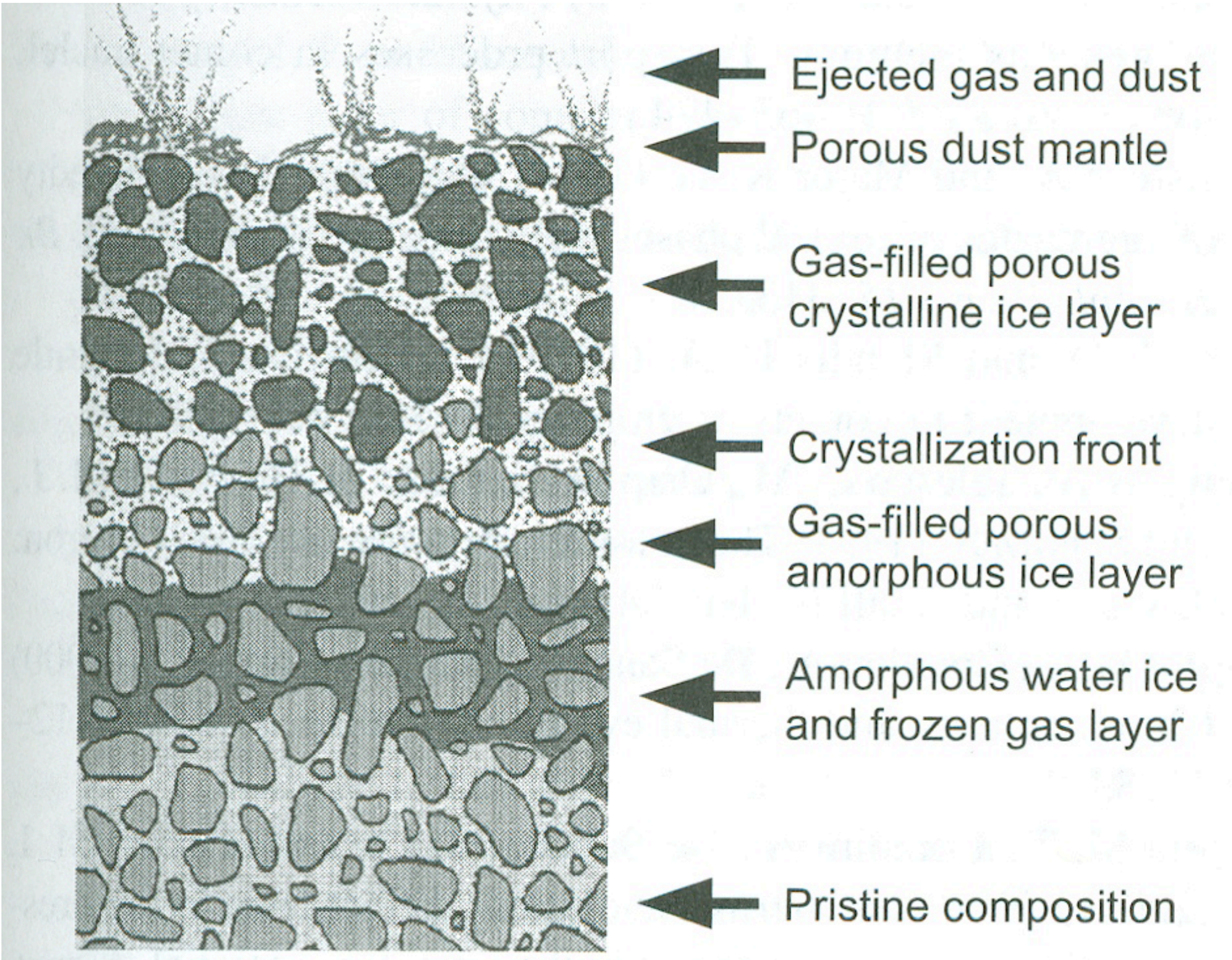
100 km



10 km

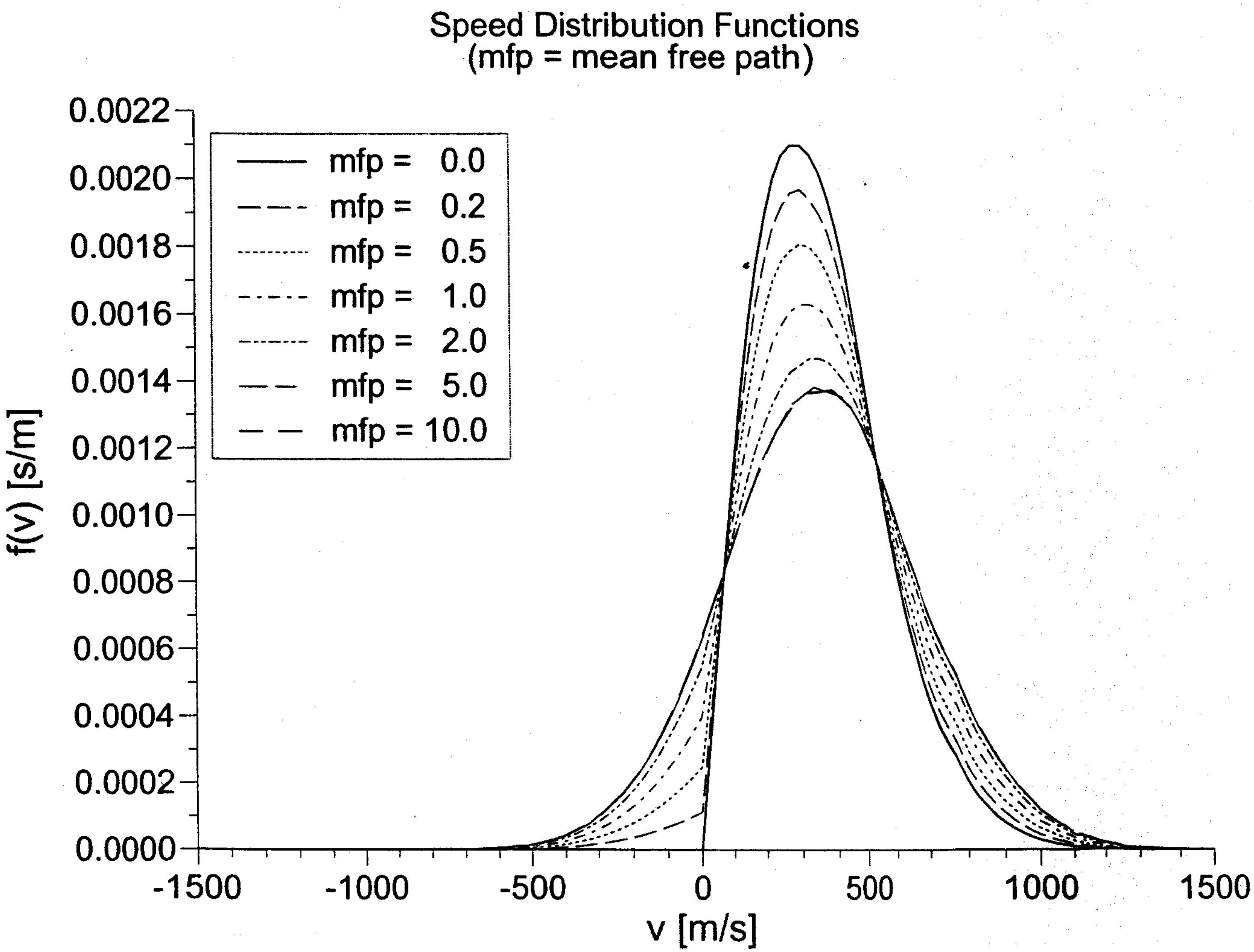


Cometary Nuclei Models Are Complex – surface and subsurface measurements are needed to refine the models



Prialnik, Benkoff, and Podolak (2004)

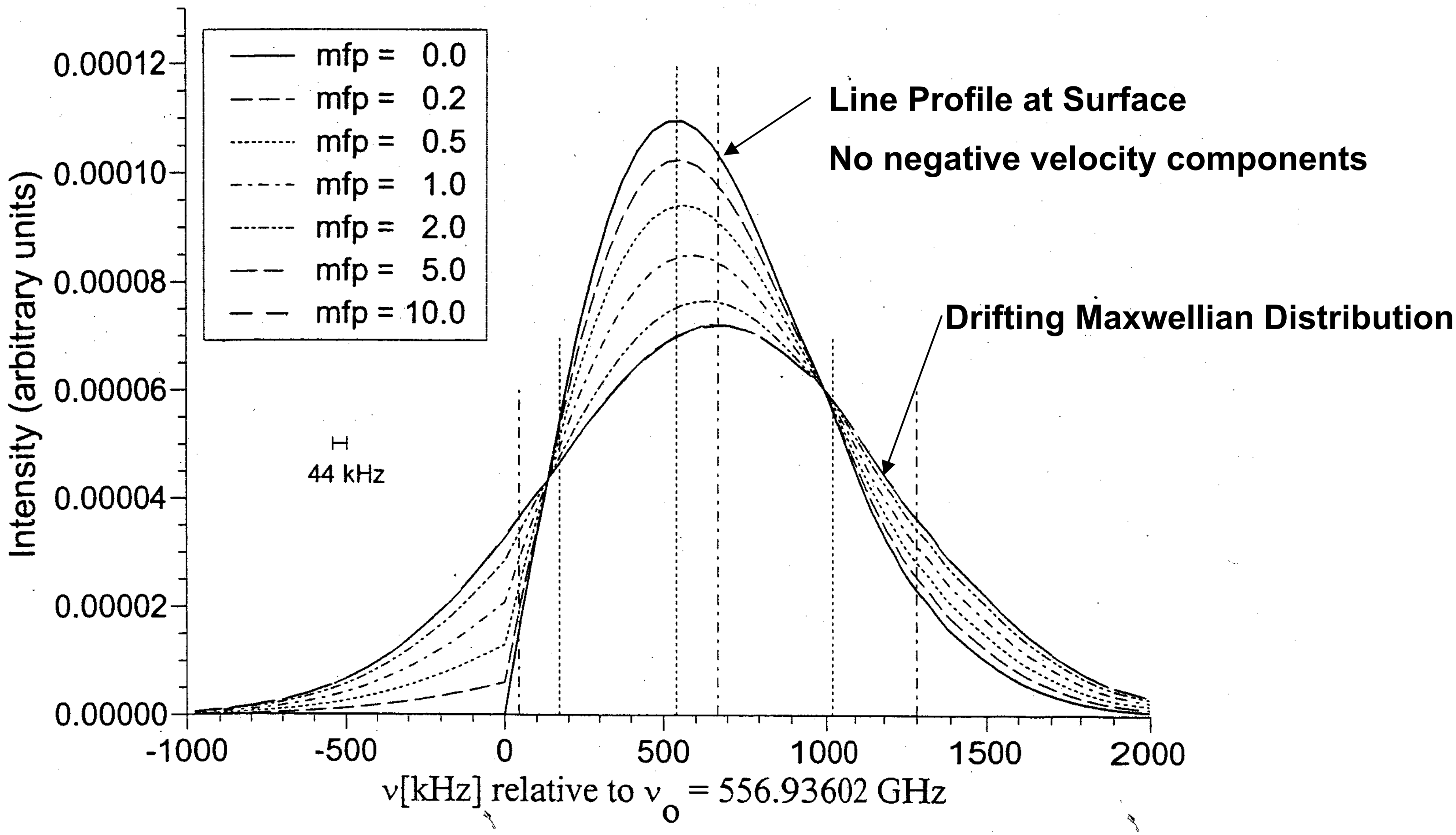
Subsurface T(K), composition, gas temperatures and velocities are all measureable with MIRO type instrument – Models of the nucleus determine expected parameters


Speed Distribution Functions
(mfp = mean free path)
mfp = 0.0
mfp = 0.2
mfp = 0.5
mfp = 1.0
mfp = 2.0
mfp = 5.0
mfp = 10.0
0.0022
0.0020
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
f(v) [s/m]
-1500
-1000
-500
0
500
1000
1500
v [m/s]

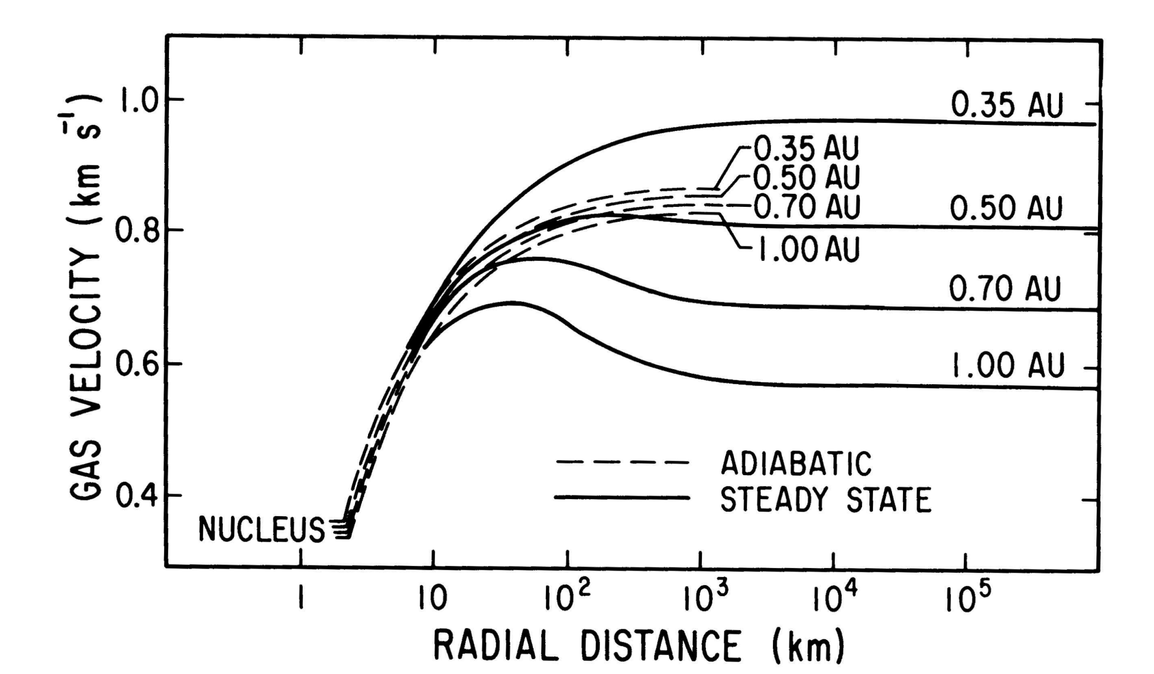
$H_2{}^{16}O$ 556.936 GHz Line Profiles at various mean free paths(mfp)

Figure shows evolution of line shape as a function of mfp

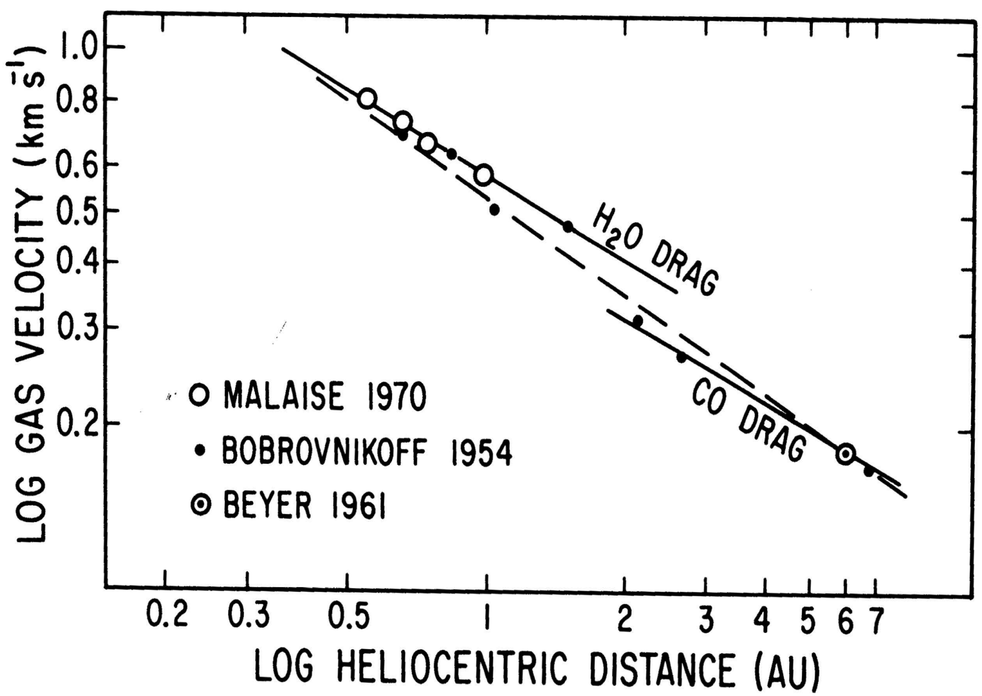
[mfp = 0.1 - 10 meter] (after Huebner, 2004)



Expansion Velocities of Water coma at four heliocentric distances(Delsemme, 1982)

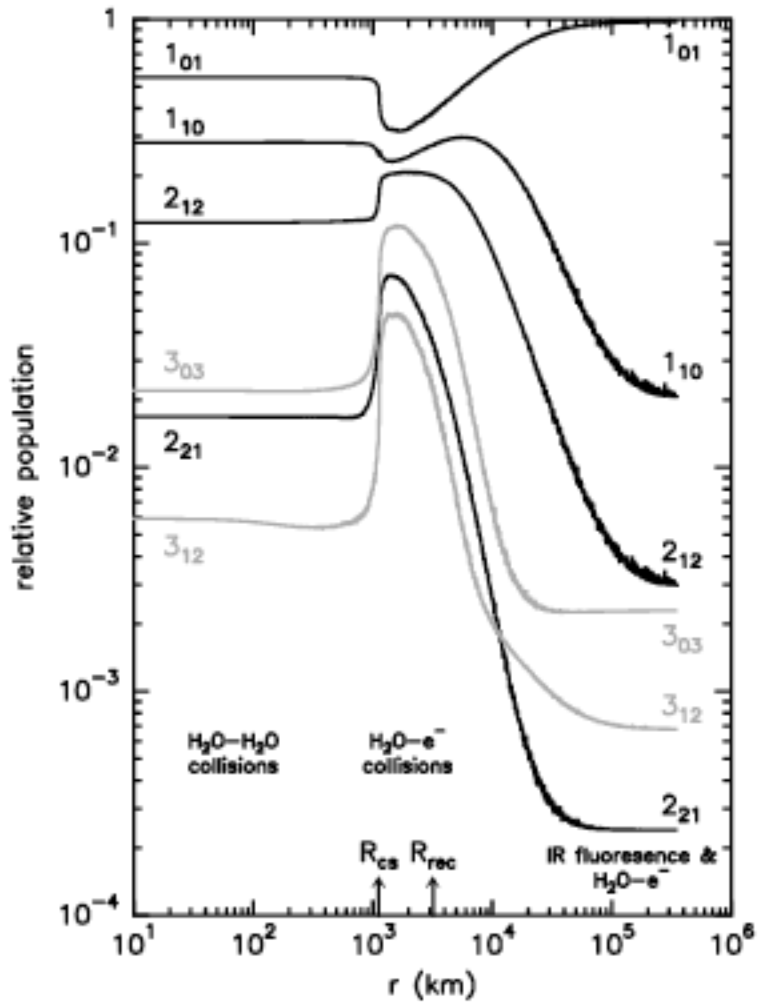


Observed Expansion Velocites in Cometary Comae (Delsemme, 1982)



Relative Energy Level Populations of Water Molecule as function of distance from nucleus –

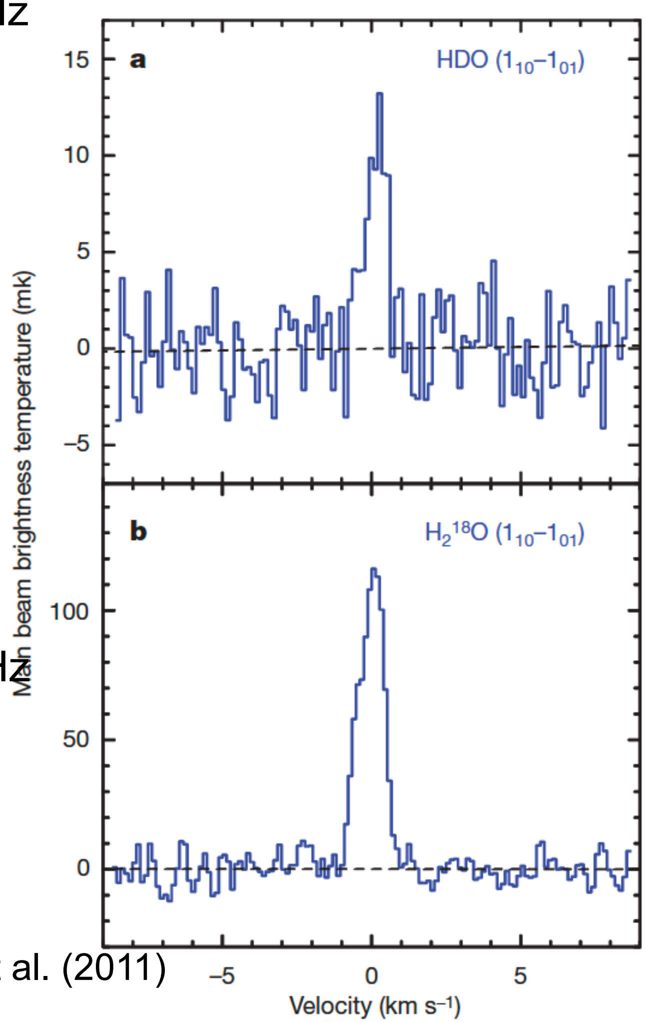
Bensch and Bergen, 2004



Ocean Like Water -Comet 103P/Hartley 2

509.292 GHz

547.676 GHz

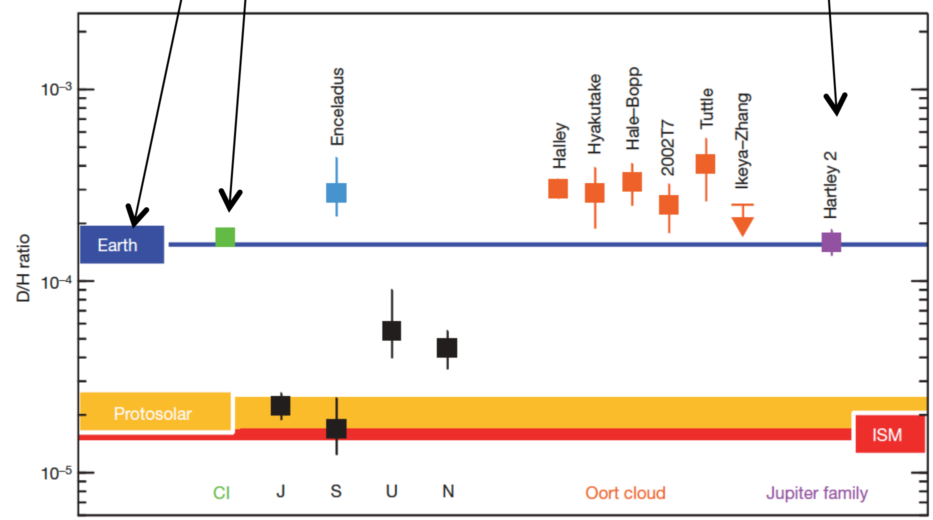


Hartogh et al. (2011)

Herschel measurements

CI carbonaceous chondrites

Earth



47 Days Till Wakeup

~~The End~~

THE BEGINNING

ISOTOPIC RATIOS IN COMETS, SOLAR SYSTEM, AND INTERSTELLAR

Boice and Huebner(Weissman et al. 1999)

SPECIES	SOLAR SYSTEM	INTERSTELLAR	COMETS
D/H	1-2 X 10^{-5}	1.5 X 10^{-5}	3.2 X 10^{-4}
D/H		10-4 TO 10^{-5}	1.9-3.5 X10^{-4}
12C/13C	89	43 +- 4	95 +- 12
12C/13/C		65 +- 20	70 TO 130
12C/13C		12 TO 110	10 T0 1000
14N/15/N	272	400	>200
16O/18/O	498	400	493
24Mg/25Mg	7.8		VARIABLE
25Mg/26Mg	0.9		<2
32S/34S	22.6		22
56Fe/54Fe	15.8		15