Remote Sensing of a Comet at Millimeter and Submillimeter Wavelengths from a Comet-Orbiting Spacecraft

Hunt for Molecules Symposium

Observatory of Paris

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Samuel Gulkis

Jet Propulsion Laboratory

California Institute of Technology

COMET MISSIONS (to date)

Comet	Mission	Date	Distance(km)/ Velocity(km/sec)
1P/Halley	Giotto	Mar 1986	596 km
21P/Giacobini-Zinner	ICE (comet tail)	Sept 1985	7682 km
1P/Halley	Vega 1+2 Sakigake/Suisei	Mar 1986 Mar 1986	10000 /77.7 3000
26P/Grigg-Skjellerup	Giotto	1992	596 km
19P/Borrelly	Deep Space 1	2001	2000 km
81P Wild-2	STARDUST	2004	236 km
9P/Tempel-1	Deep Impact	July 2005	0 (500)/10.2

*Rosetta 67P/Churyumov-Gerasimenko / 2014

encounter at ~ 3.5 AU

MIRO Investigation Team

**Jet Propulsion Laboratory,
California Institute of Technology**
- S. Gulkis (PI)
- M. Allen
- M. Frerking
- M. Hofstadter
- M. Janssen
- T. Spilker

California Institute of Technology
- D. Muhleman

Univ. of Massachusetts
- F. P. Schloerb

Observatoire de Bordeaux
- D. Despois

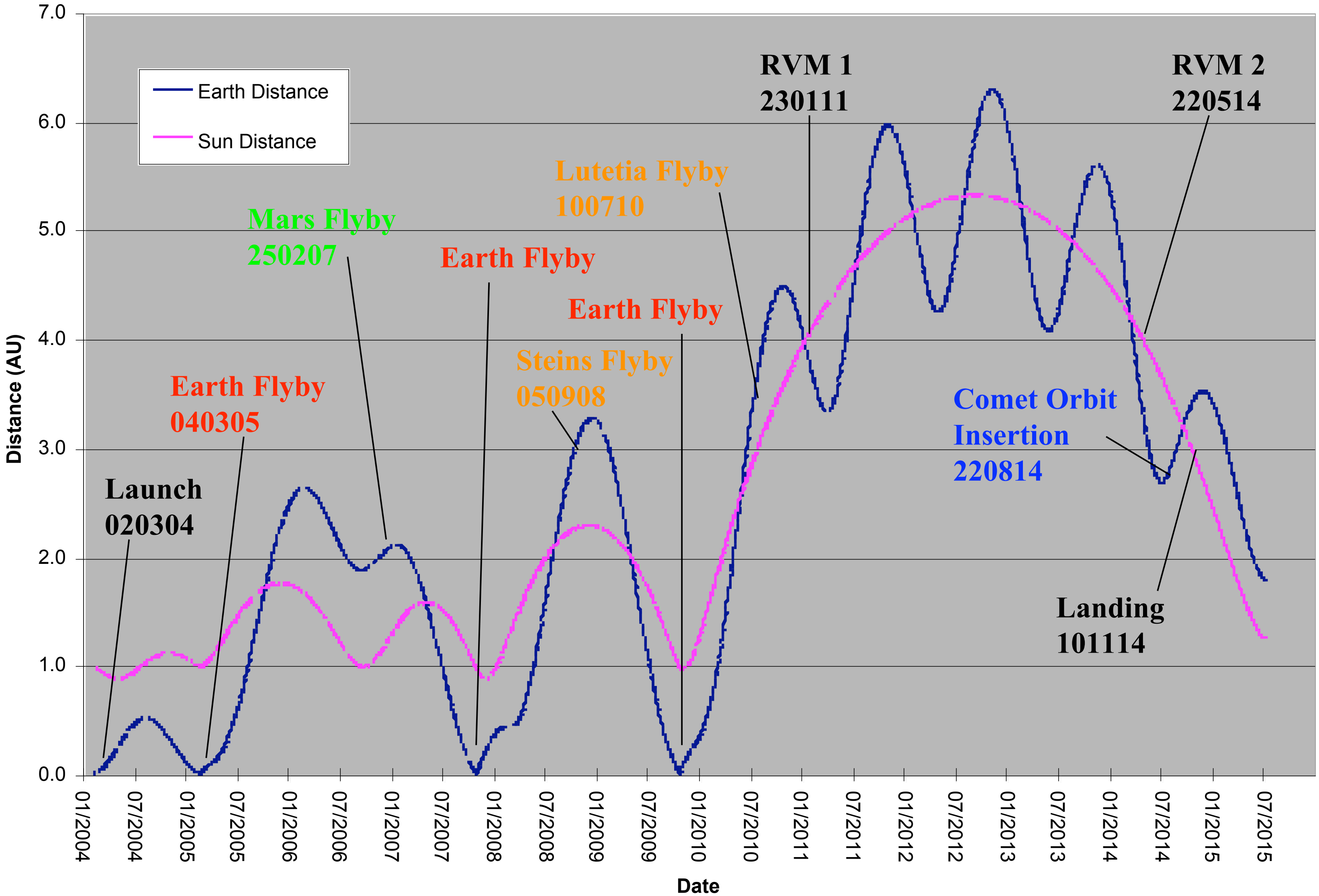
Observatoire de Paris - Meudon
- G. Beaudin
- N. Biver
- D. Bockelee-Morvan
- J. Crovisier
- P. Encrenaz
- T. Encrenaz
- E. Lellouch

Max Planck Institute for Solar System Research(Lindau)
- P. Hartogh
- W. H. Ip(NCU,Taiwan)
- I. Mann(Wilhelm)
- H. Rauer (DLR)

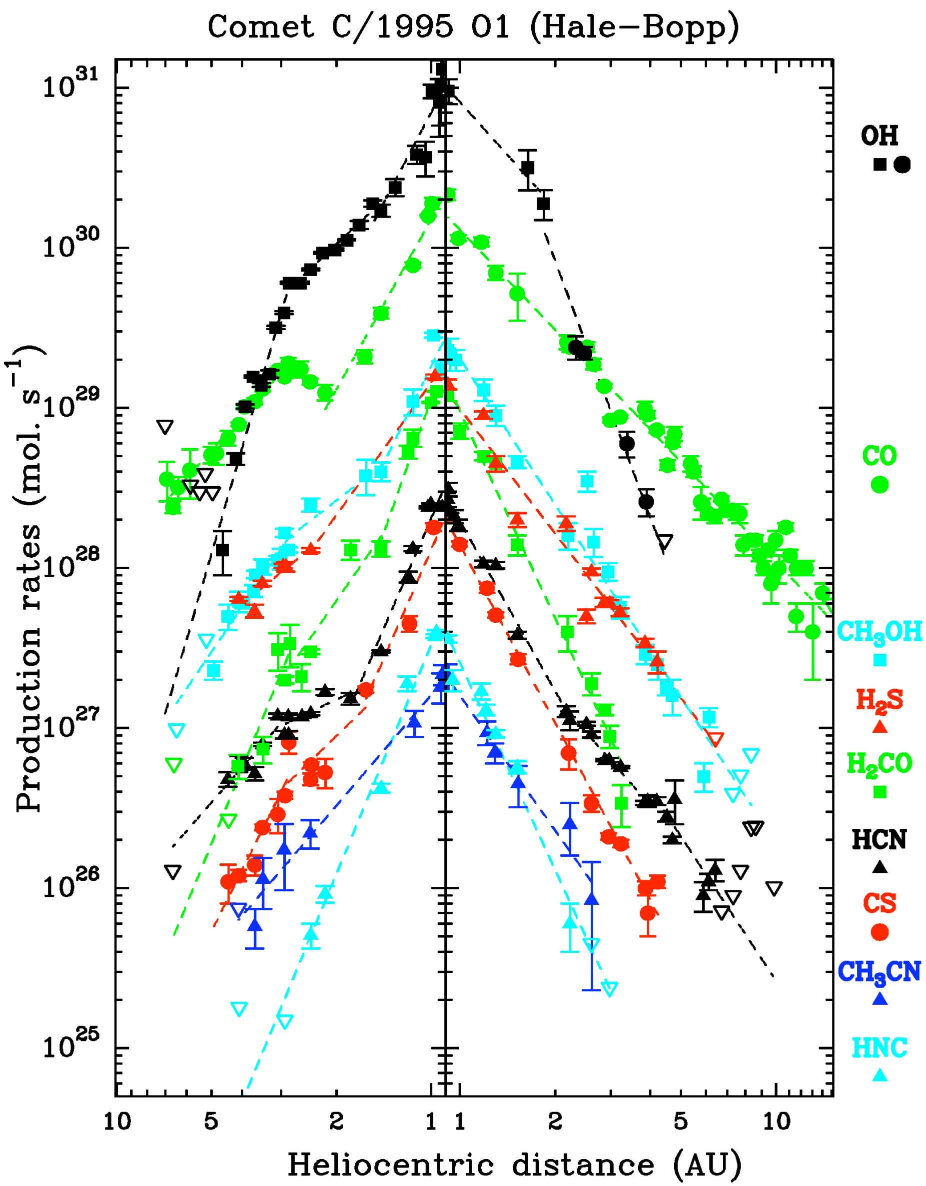
ROSETTA MISSION OVERVIEW

- THIRD CORNERSTONE MISSION OF ESA-LAUNCH MARCH 2, 2004
- MISSION TO COMET 67P/CHURYUMOV-GERASIMENKO
  - LANDER WITH EIGHT INVESTIGATIONS
  - ORBITER WITH ELEVEN SCIENTIFIC INSTRUMENTS (17 MONTHS)
- OBJECTIVES
  - Origin of comets/relationships interstellar materials/implications for origin of solar system
  - Chemical, mineralogical and isotopic compositions of volatile and refractory elements in nucleus
  - Evolution of cometary activity with heliocentric distance
- FOUR PLANETARY (EMEE) GRAVITY ASSISTS
- TWO CLOSE ASTEROID FLYBYS (STEINS AND LUTETIA)
- EOM 8/31/15

ROSETTA DISTANCE FROM EARTH AND SUN



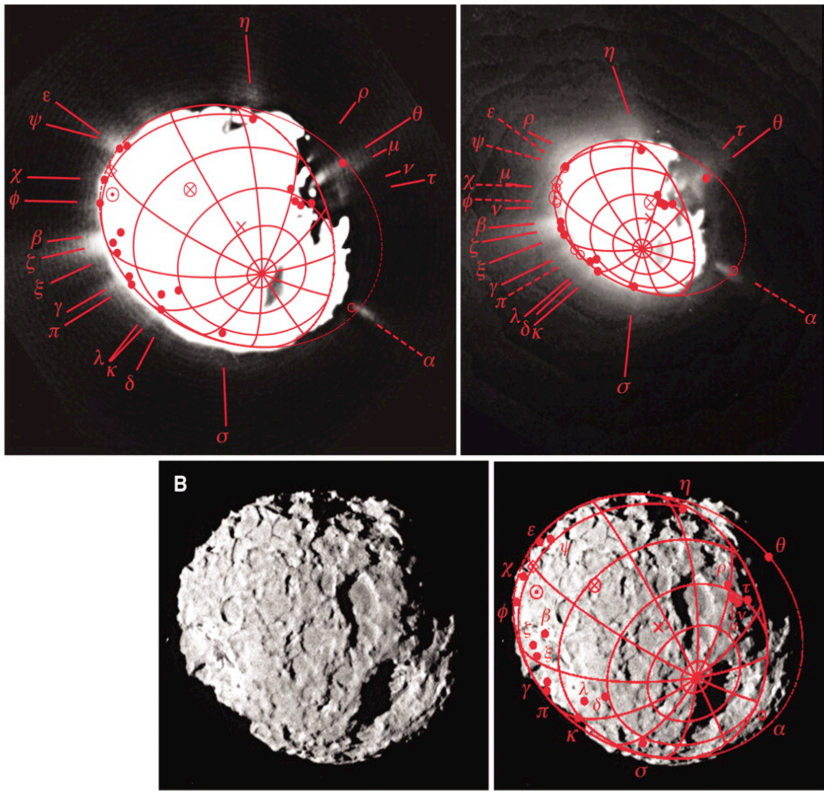
Progressive Release of 9 molecules by Comet C/1995 01 (Hale-Bopp)



Biver et al. 2002, E.M.P.90, 5

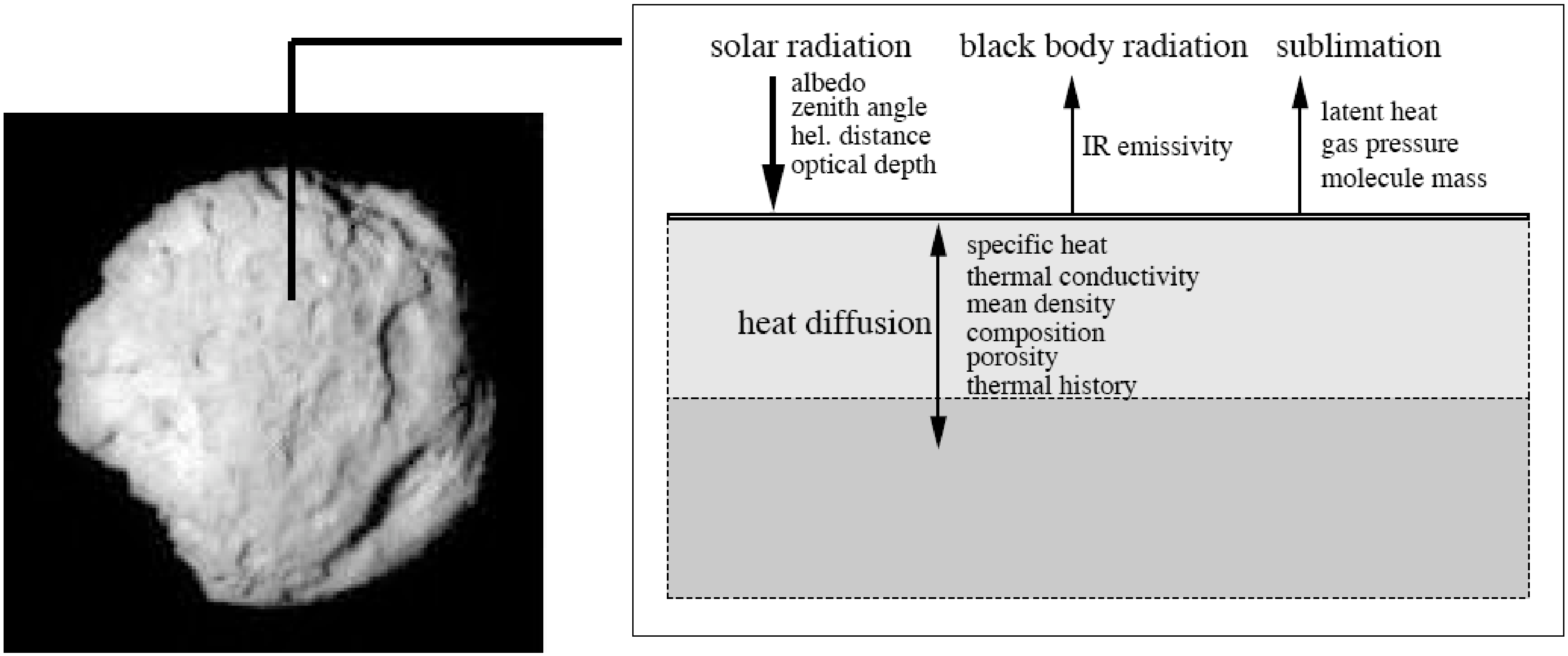
Results from Stardust at Comet Wild 2

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**

Energy Balance at Nucleus Surface



after Voertzen(2003)

Physics Related to Comet Evolution

Vaporization of the nucleus

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

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

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

Requirements for Understanding Sublimation from Cometary Nucleus

- **Gas and Dust Tracers**
- **Continuum temperature maps and temperature gradients**
- **Sufficient Angular Resolution to resolve nucleus**
  - **At 1 AU - 3 km diam comet subtends 2 x 10^{-8} radians (4 milli arc sec)**
  - **Two serious consequences of not resolving the nucleus are:**
    - **Surface features and including jets cannot be observed, and**
    - **The coma is observed in its entirety with gases streaming both towards and away from the the observer-for an isotropic outflow velocity of 1 km/sec, the effect of not resolving the coma is to broaden a spectral line at submillimeter wavelengths to several Mhz.**
  - **There is a need to get close to the nucleus**

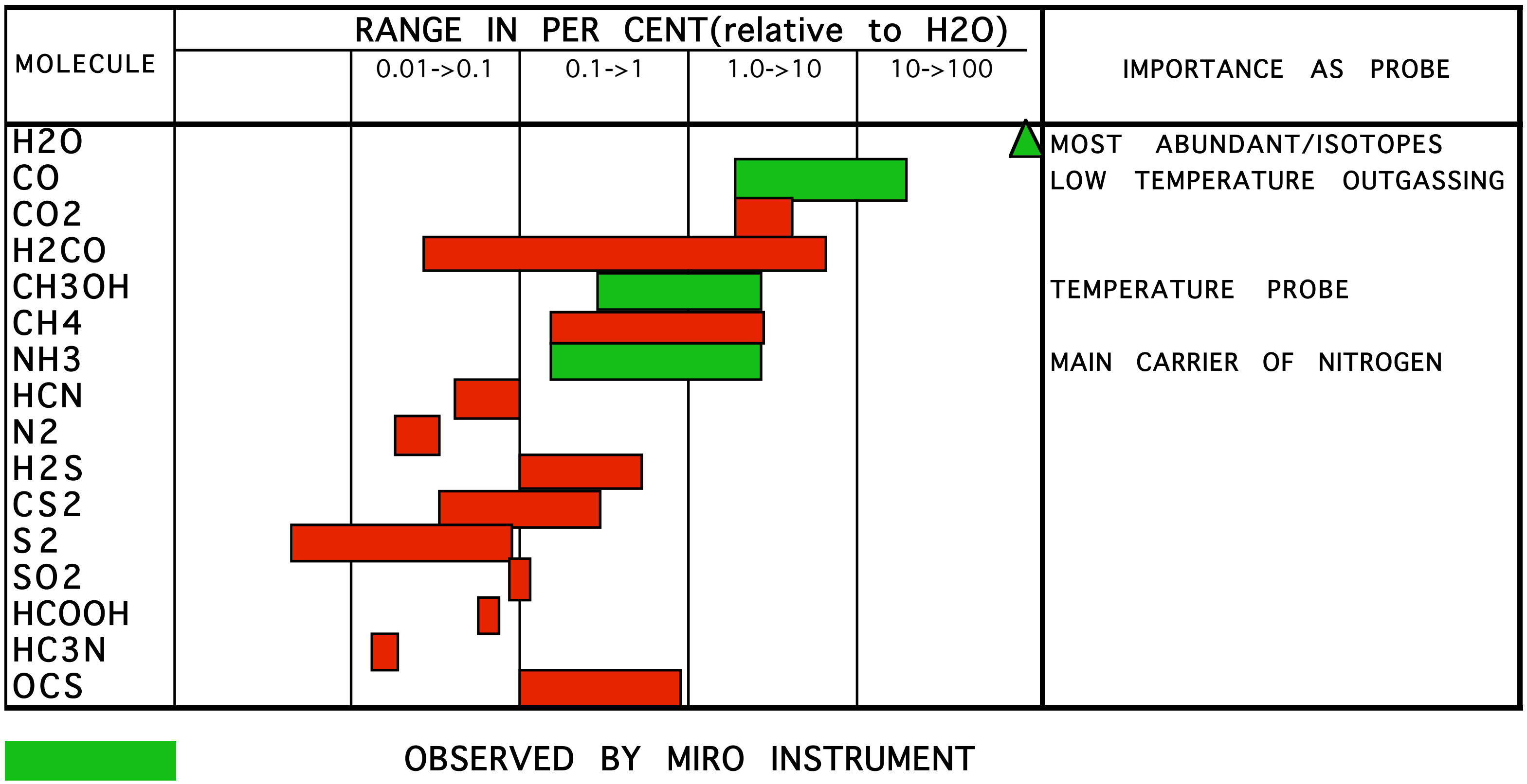
MIRO SPECTRAL LINES

FREQUENCIES AND TRANSITIONS

SPECIES		FREQUENCY(Mhz)	TRANSITIONS
WATER	$H_2{}^{16}O$	556936.002	1(1,0)-1(0,1)
	$H_2{}^{17}O$	552020.96	1(1,0)-1(0,1)
	$H_2{}^{18}O$	547676.44	1(1,0)-1(0,1)
CARBON MONOXIDE	CO	576267.9305	J(5-4)
AMMONIA	NH_3	572498.3748	J(1-0)
METHANOL	CH_3OH	553146.296	8 1-7 0 (72.33 cm^{-1})
	CH_3OH	568566.054	3 2 - 2 1 (27.29 cm^{-1})
	CH_3OH	579151.005	12 1 - 11 1(129.19 cm^{-1})

Molecular Abundance Ratios in Comets

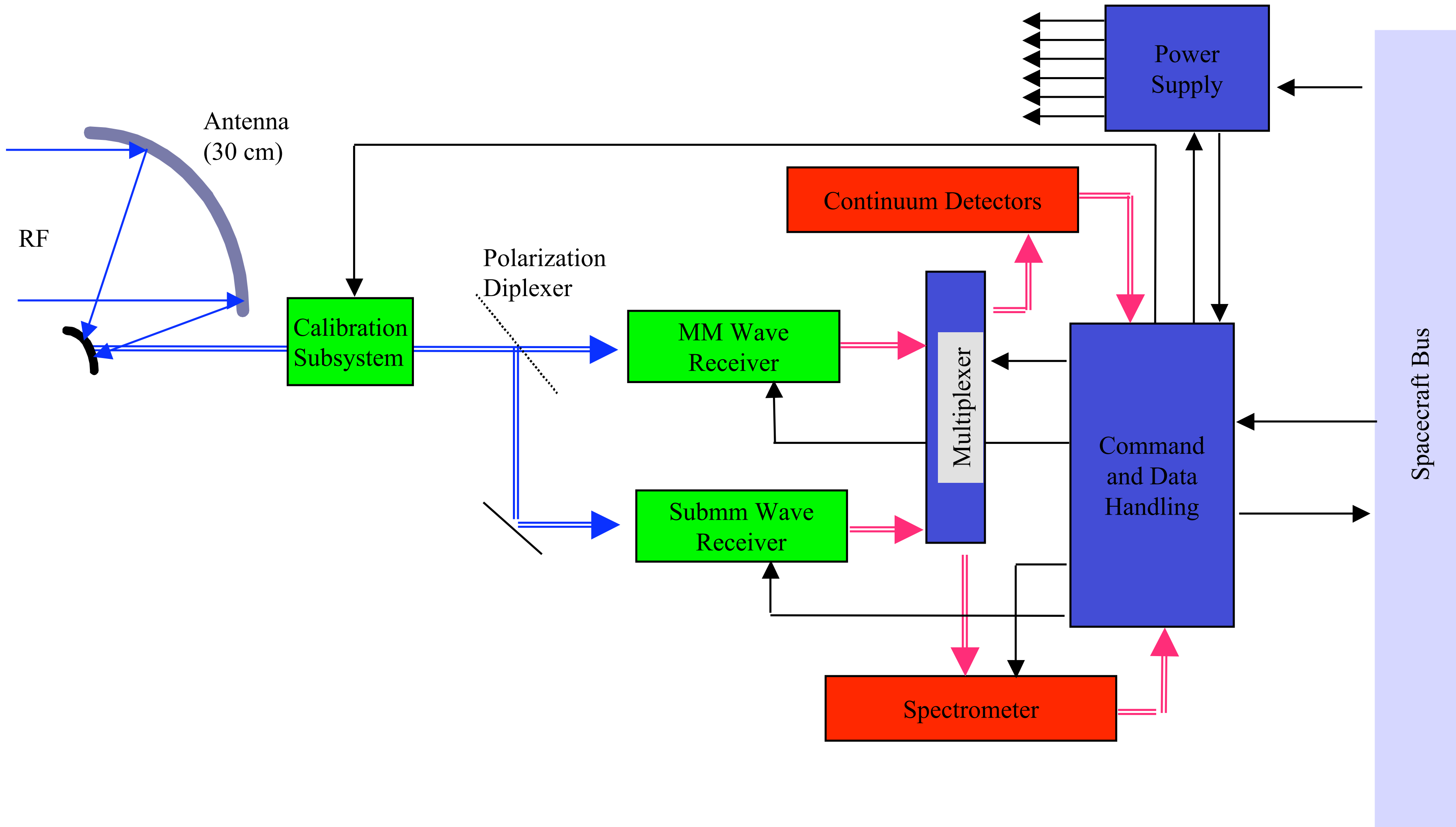
ABUNDANCE RATIOS RELATIVE TO WATER



Instrument Description

- **30 cm offset parabolic telescope**
- **mm wave continuum receiver**
- **smm wave continuum receiver**
- **4096 channel high resolution(44 kHz) spectrometer interfaced with smm heterodyne receiver (resolving power = 10^7)**
- **Internal hot and cold load calibration targets**
- **Fixed tuned to observe simultaneously H2O(isotopes 16,17,&18), CO, CH3OH(3 lines),NH3**
- **Frequency switched to improve gain stability**
- **Ultra stable oscillator for frequency control**
- **Mass less than 20 kg**

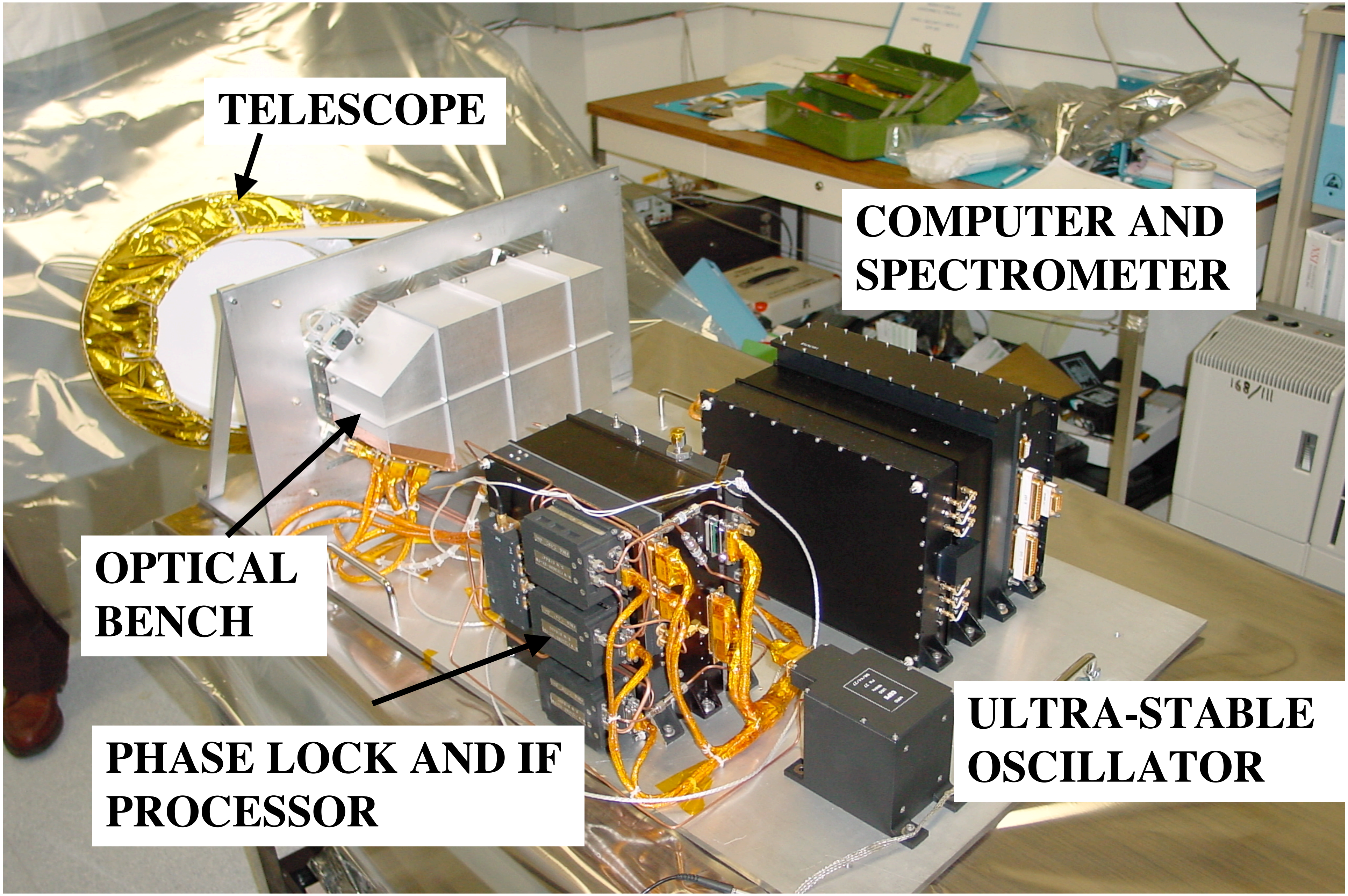
MIRO Instrument Concept



S. Gulkis

MIRO Structural Thermal Model - Sensor Unit

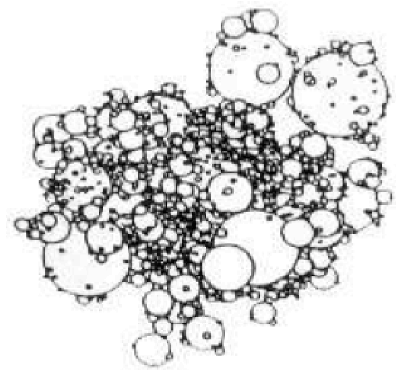
MIRO FLIGHT INSTRUMENT



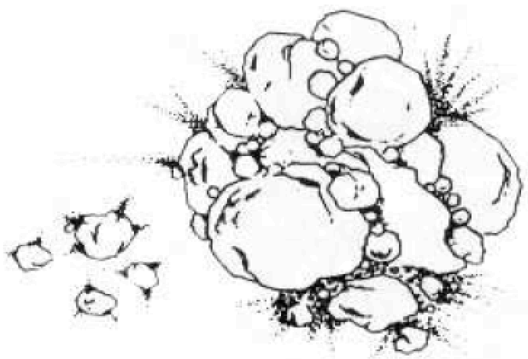
ROSETTA S/C & MIRO WITH DUST COVERS

Models of Cometary Nucleus(image Donn(1991))

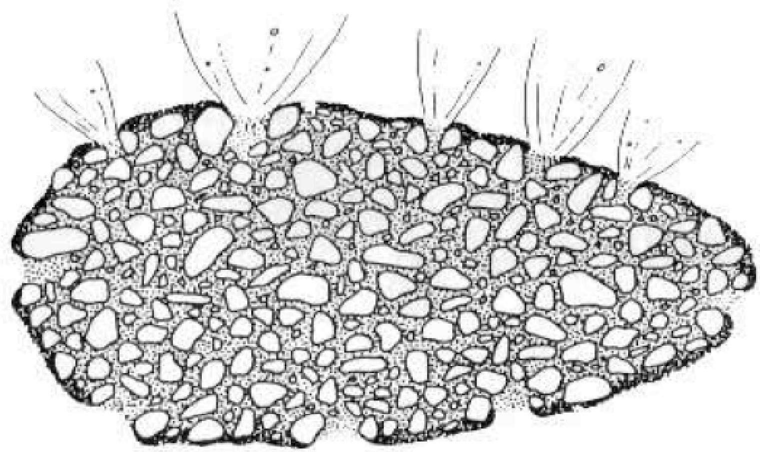
Dirty Snowball - Whipple(1950)



Fluffy Agregate - Donn(1986)

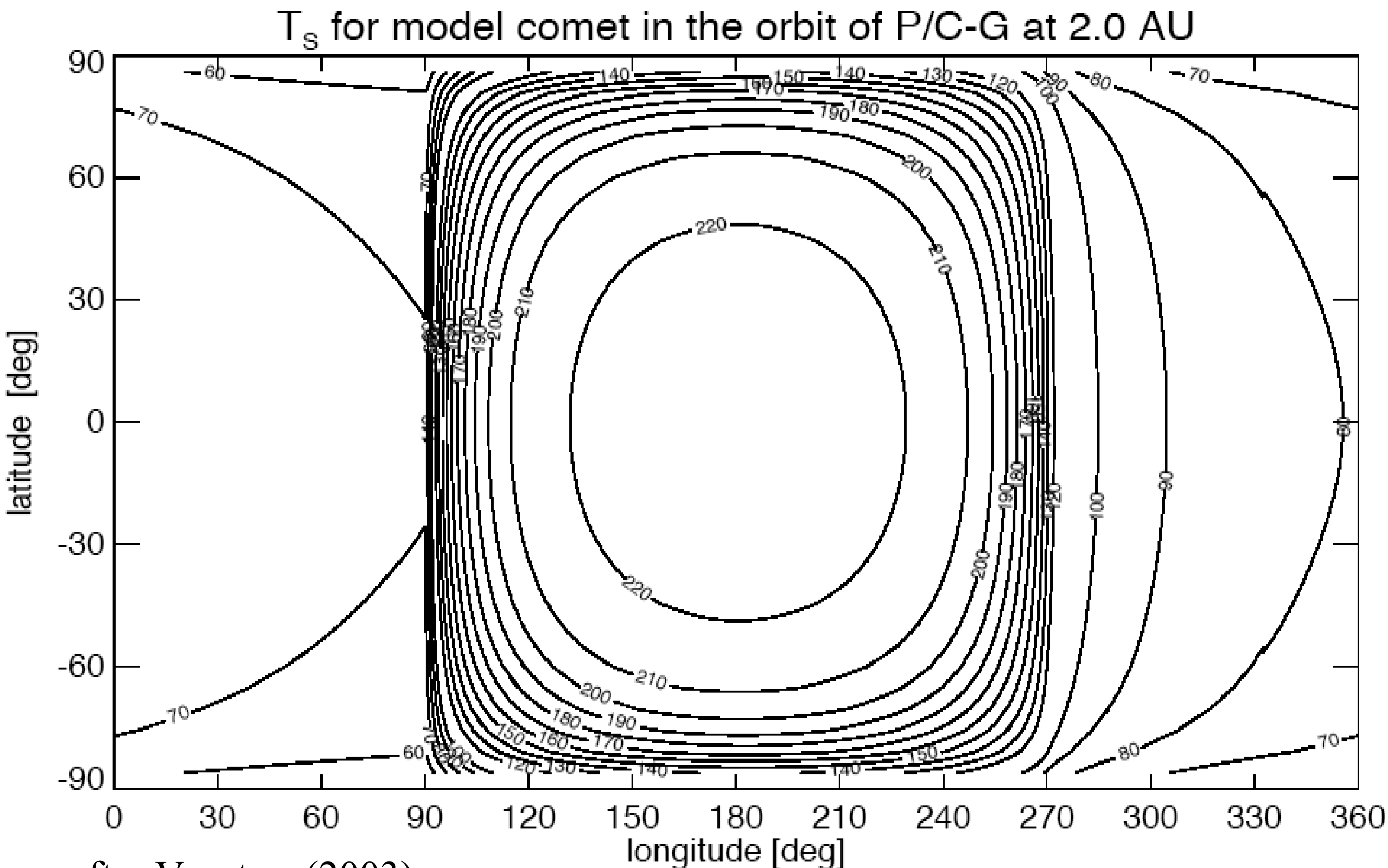


Rubble Pile - Weissman(1991)



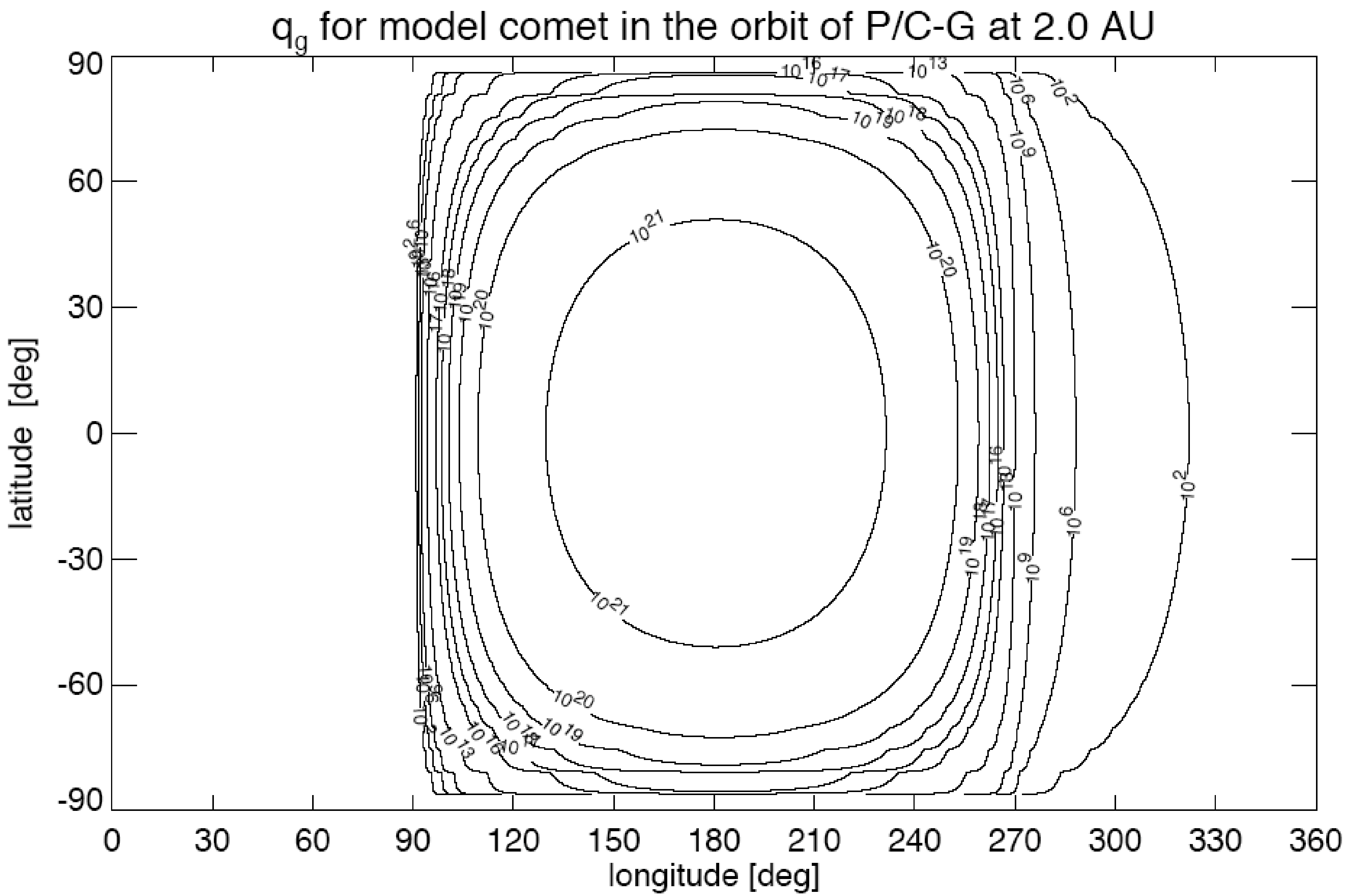
Icy-Glue -Gambosi and Houpis (1986)

Theoretical Surface Temperature at 2.0 AU



after Voertzen(2003)

Molecular Production Rates at 2.0 AU

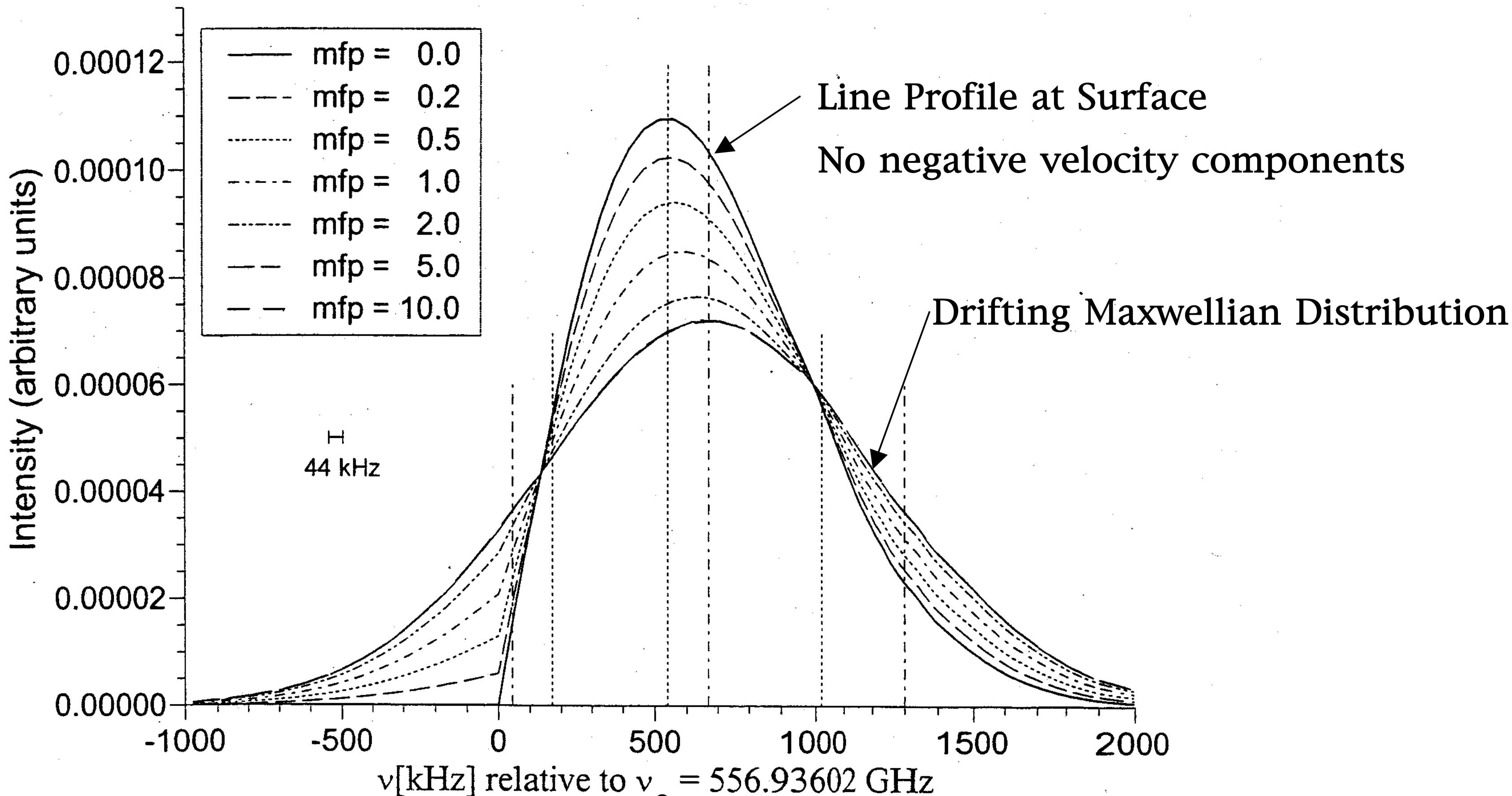


after Voertzen(2003)

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

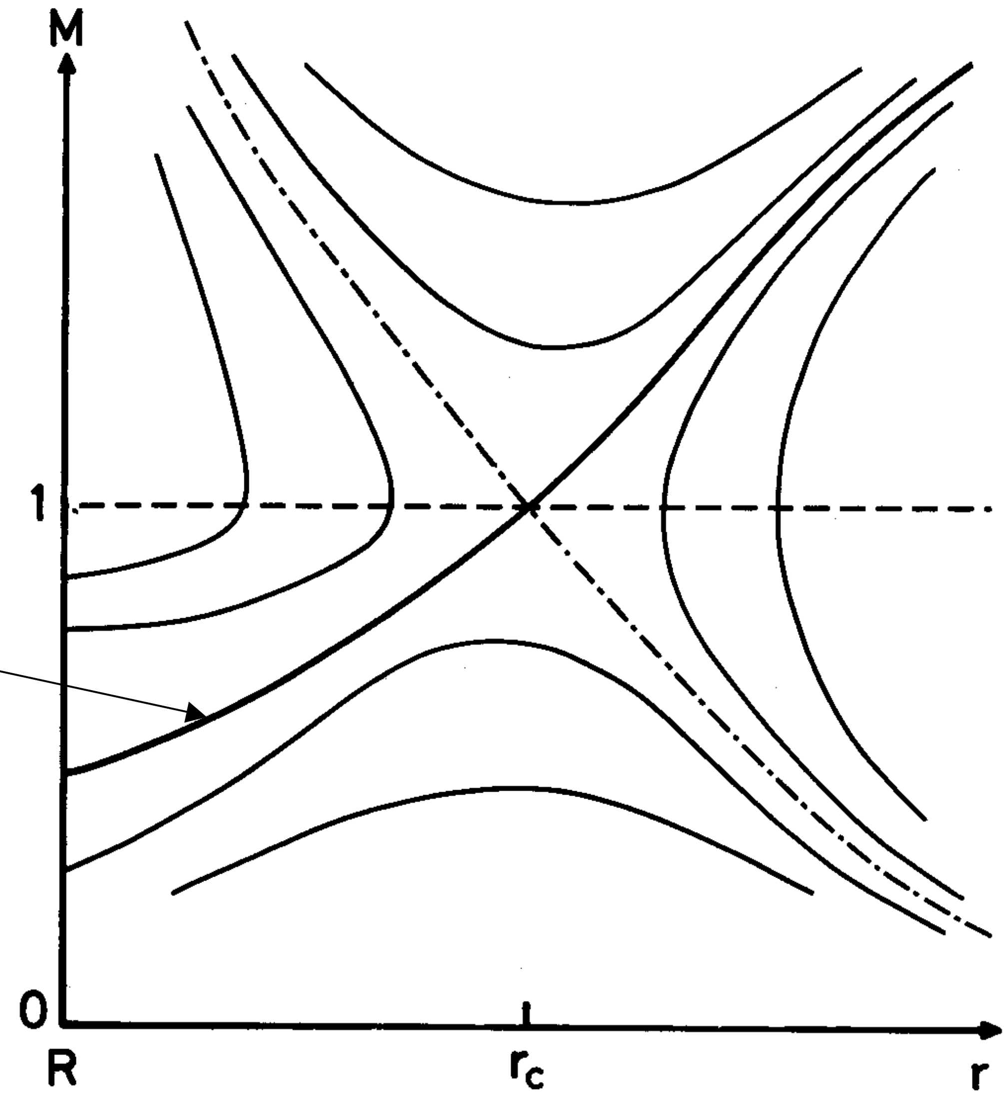
Figure shows evolution of line shape as a function of mfp

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



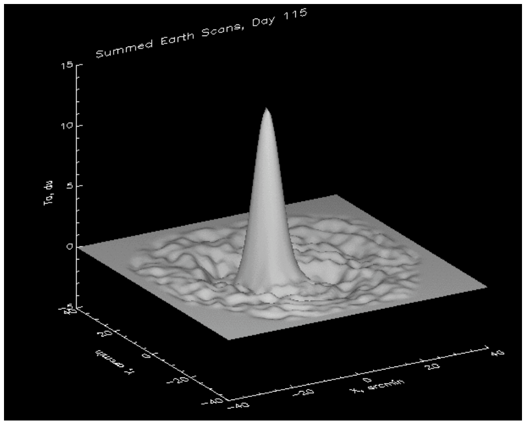
Possible Solutions to flow away from the surface of a comet

(Wallis, 1982, see also Probstein, 1969)



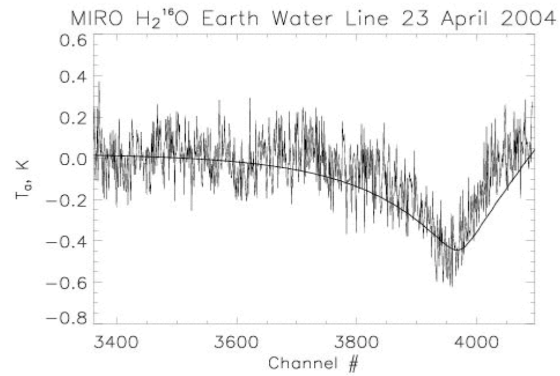
MIRO COMMISSIONING MEASUREMENTS

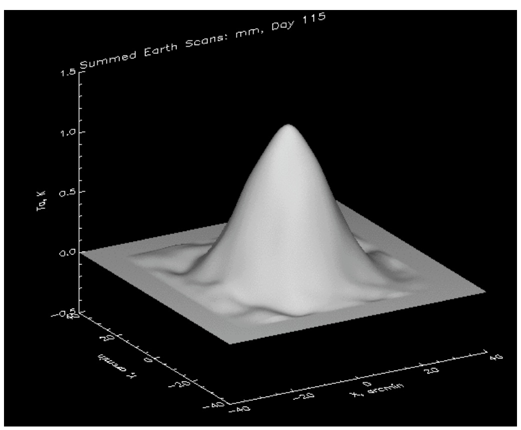
556.936 GHz Water Line



Submillimeter Beam

Earth

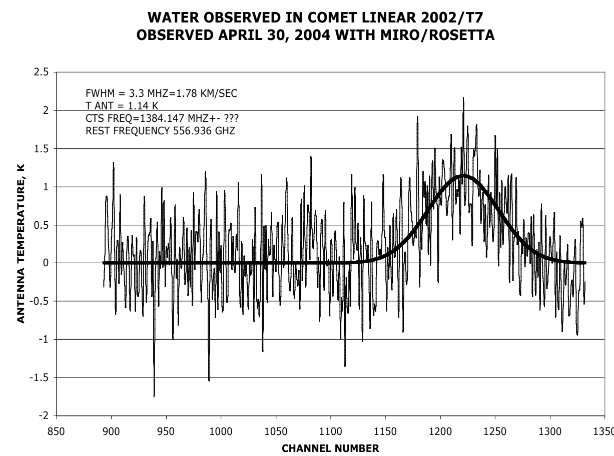




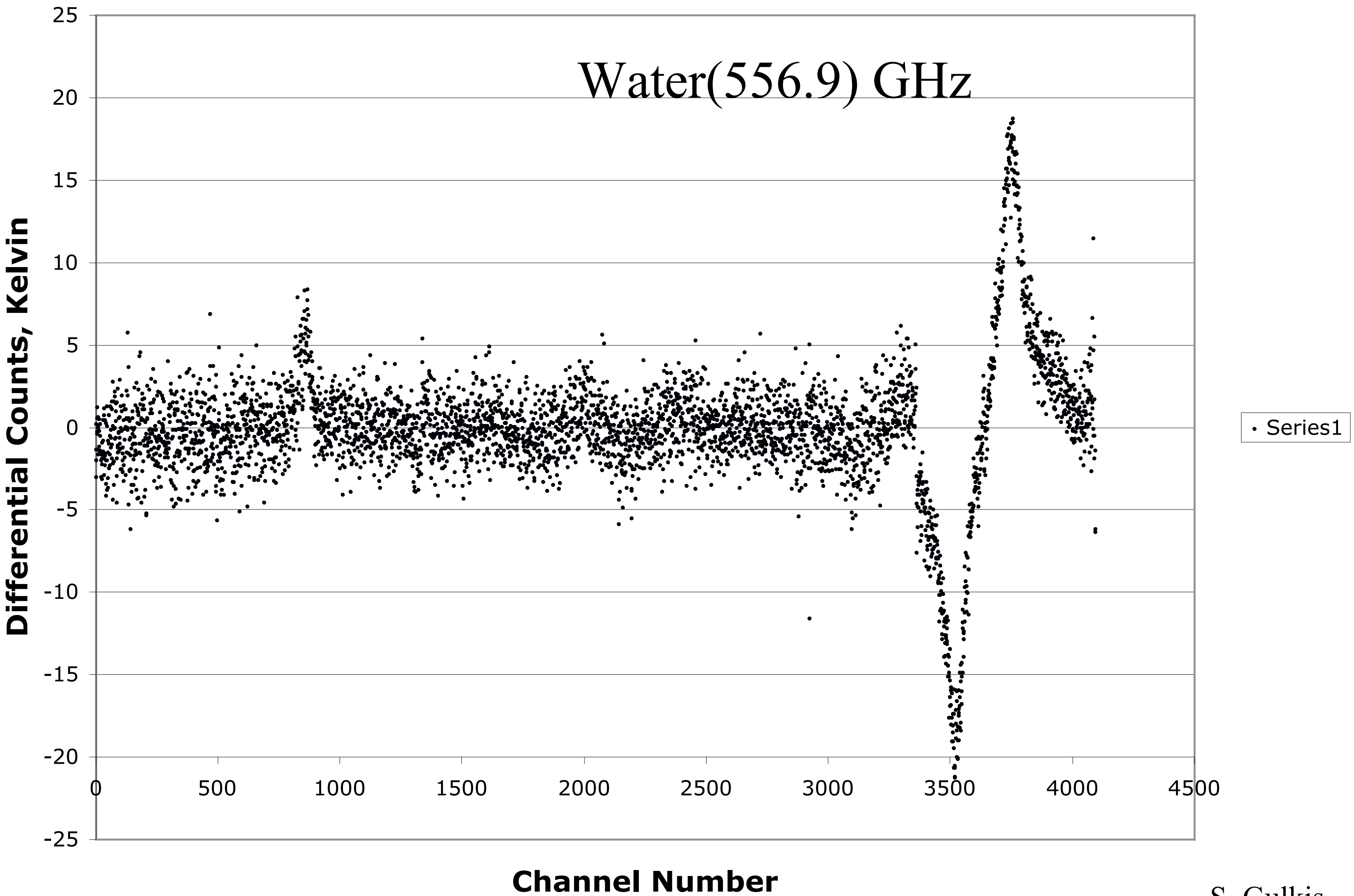
Millimeter Beam

Comet

Linear 2002



MIRO Spectrum of Earth at 1st Flyby



Performance Parameters

	Millimeter	Submillimeter
Telescope		
Diameter	30 cm	30 cm
Beam-Size (FWHM)	23.7x24.7 arc min	7.6 arc min
Foot-Print (2 km nadir distance)	15 m	5 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	0.1-1.92 kbps	

Last Modified - October 2004