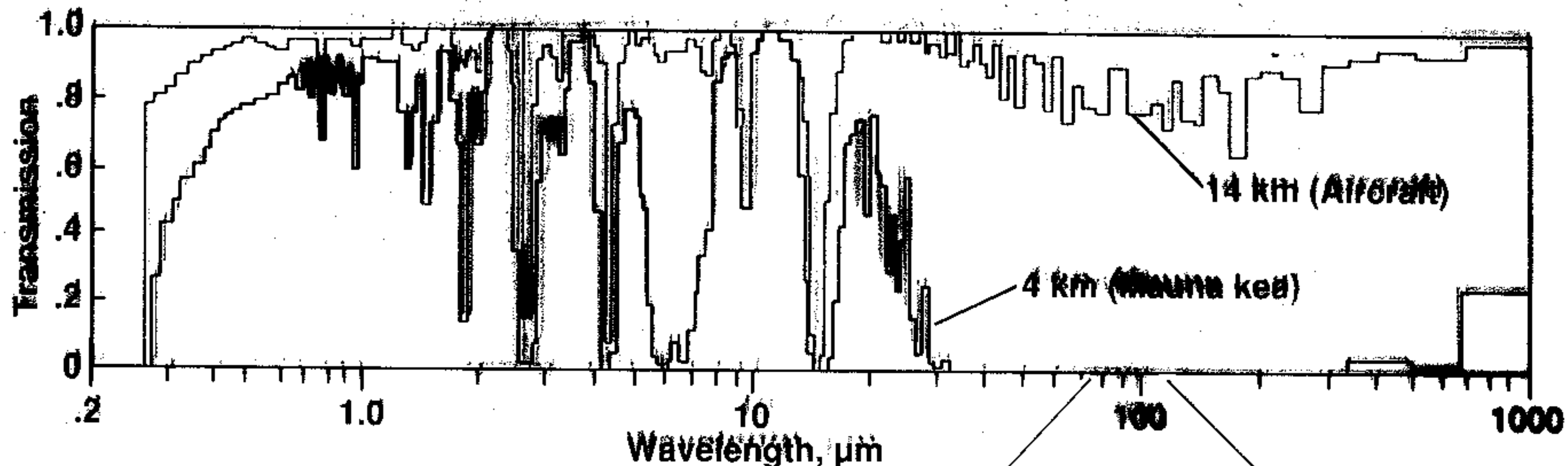
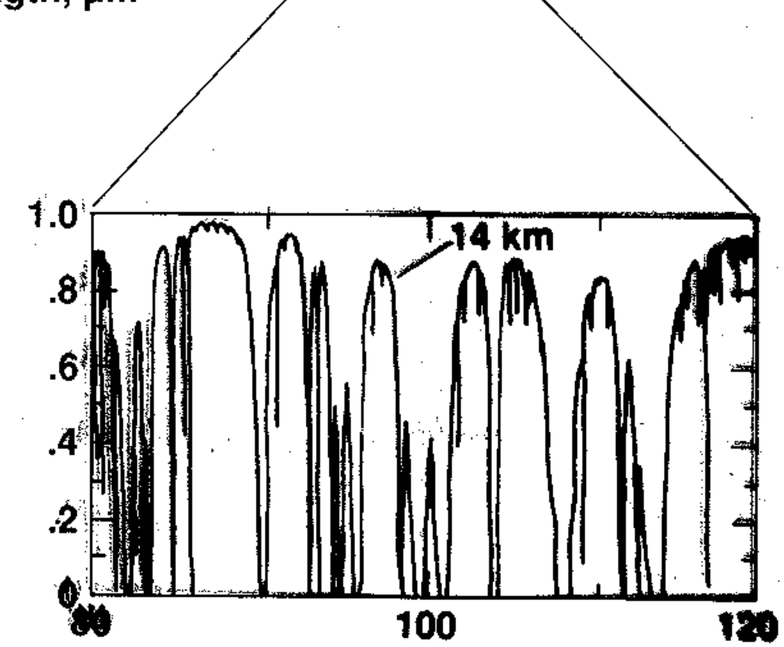
FAR INFRARED SPECTROSCOPY FROM SOFIA

E. F. ERICKSON, JULY 14, 1999

* OBSERVATORY CONSIDERATIONS
  - Atmospheric Transmission
  - Image Quality: Diffraction, Seeing
  - Pointing Stability
* CRYOGENIC SPECTROMETERS
  - EXES
  - AIRES
  - FIFI LS
  - SAFIRE
* THE REVOLUTION

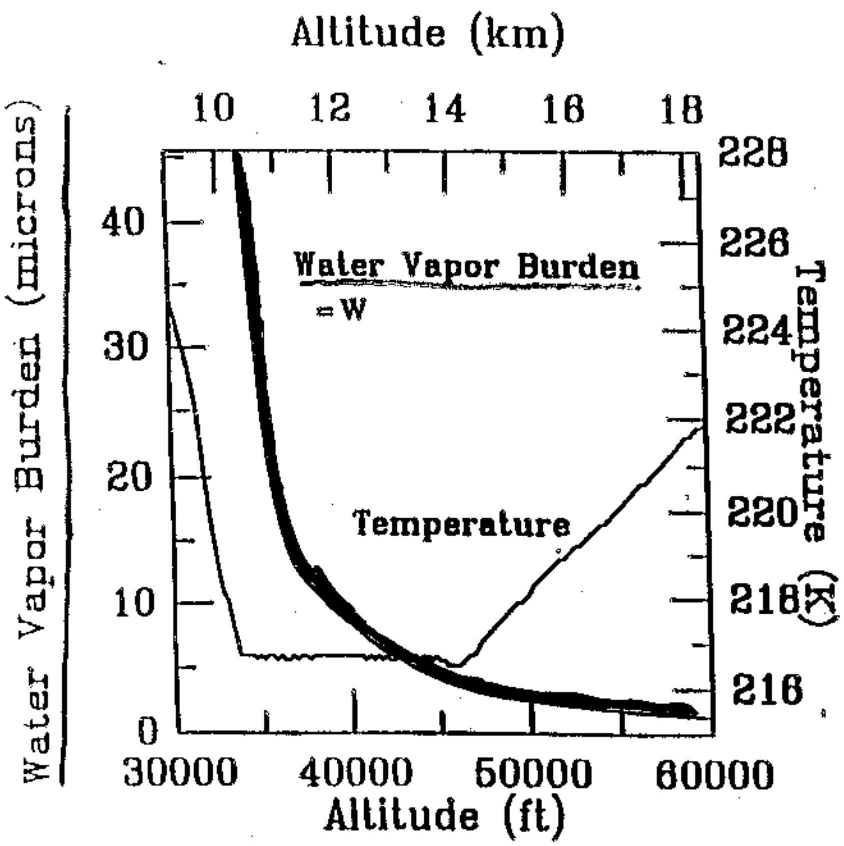
ATMOSPHERIC TRANSMISSION VERSUS WAVELENGTH





- Many wavelength bands obscured from earth are accessible from aircraft

ATMOSPHERIC PARAMETERS VERSUS ALTITUDE

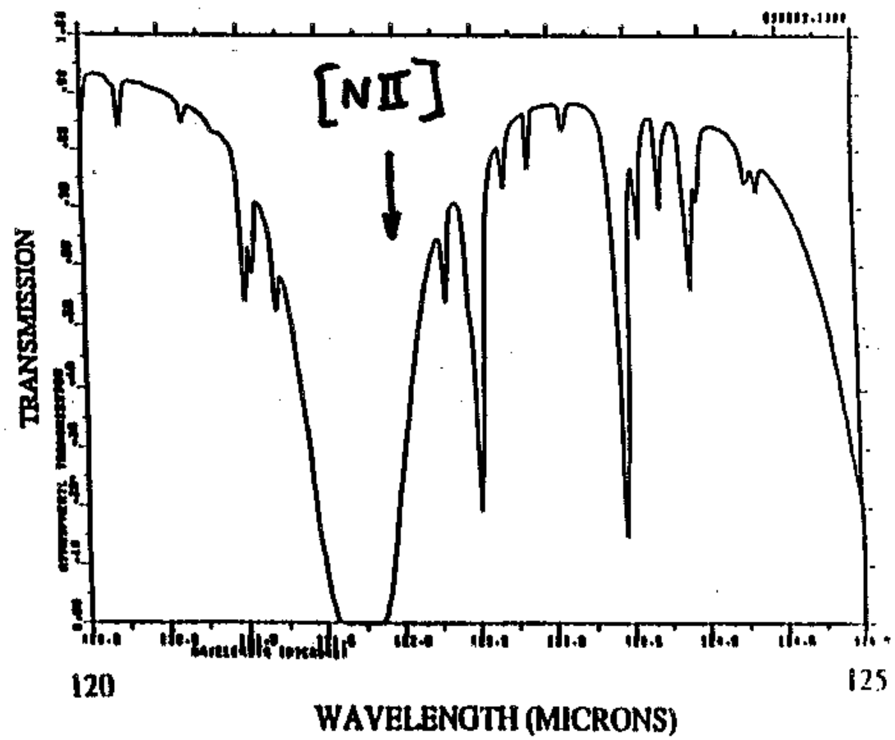


W = WATER COLUMN DENSITY ABOVE A GIVEN ALTITUDE

- W CONTINUES TO DECREASE THROUGHOUT THE TROPOPAUSE AND INTO THE STRATOSPHERE

TRANSMISSION THROUGH TELLURIC LINE PROFILES

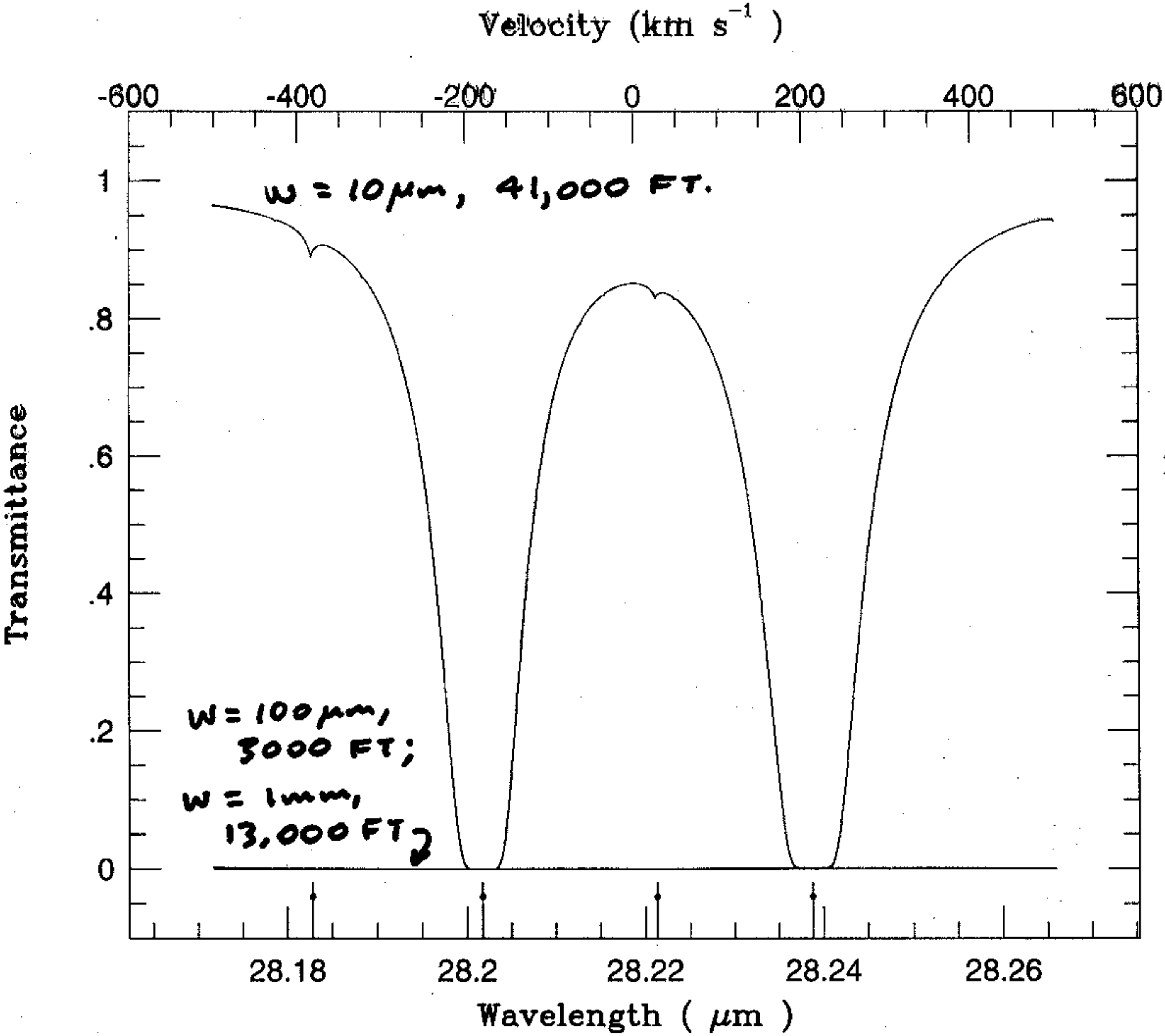
41,000 FEET ALTITUDE
10 MICRONS PRECIPITABLE WATER



TRANSMISSION = EXP (- W * K_λ),
K_λ = ATOMIC (MOLECULAR) LINE SHAPE

- THE TRANSMISSION IN ANY PART OF A LINE DEPENDS EXPONENTIALLY ON W

0 km/s => H_2 S(0)



H2 v=0–0 S(0)

Zenith WV	10.0
Zenith Ang	40.0
L.O.S. WV	13.1
Atm. Type	Std.&H$_2$O Adj.
Layers	10
Altitude	41000

H_2O

Lambda 1	28.172
Lambda 2	28.266
Sampling	0.000018
Res(FWHM)	0.000000
Instr. Fn.	None
Line Ctr	28.219
Num. Pts.	5242
Ozone	9.13E+18

Tue Jul 13 20:43:02 1999

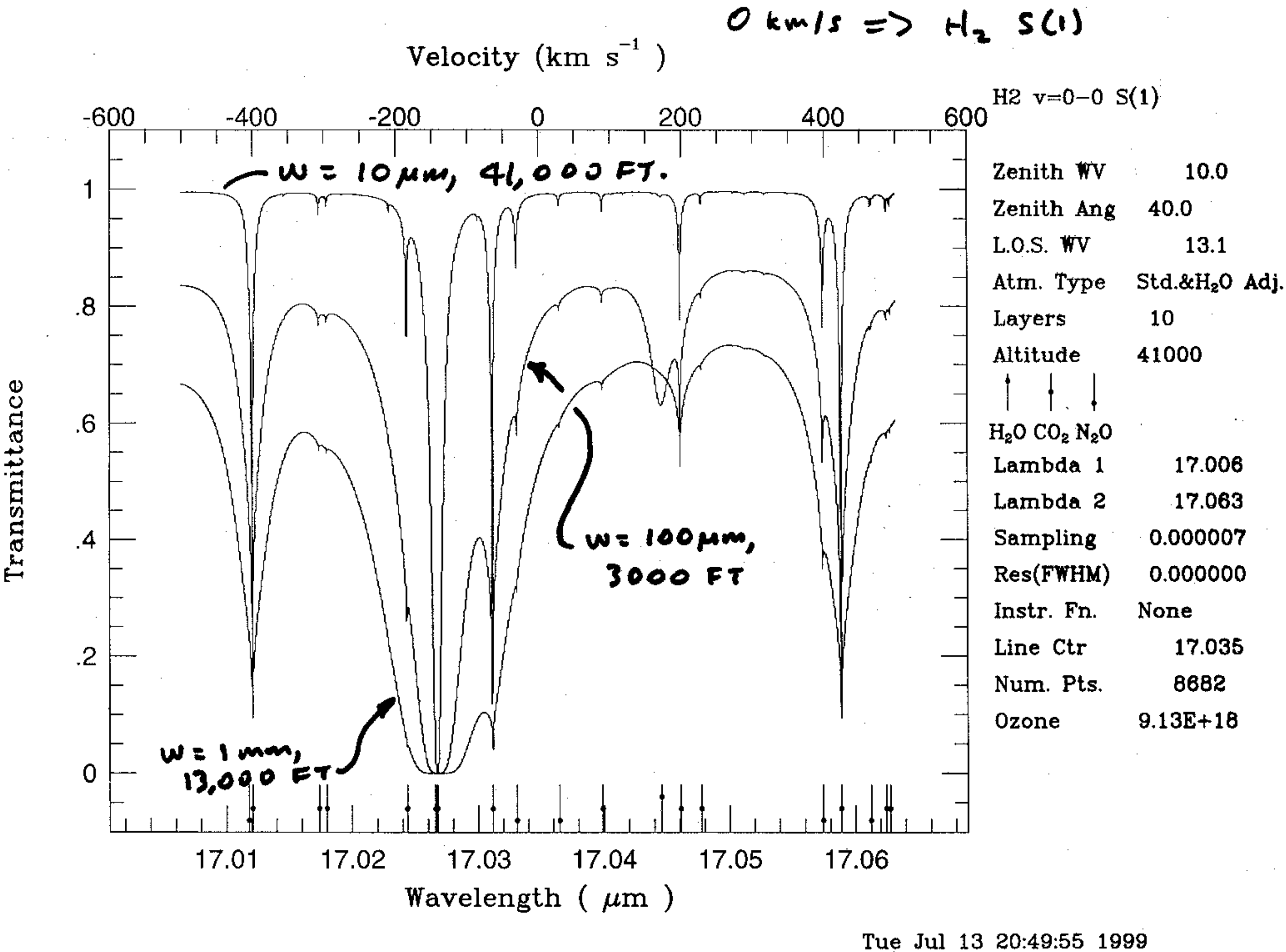
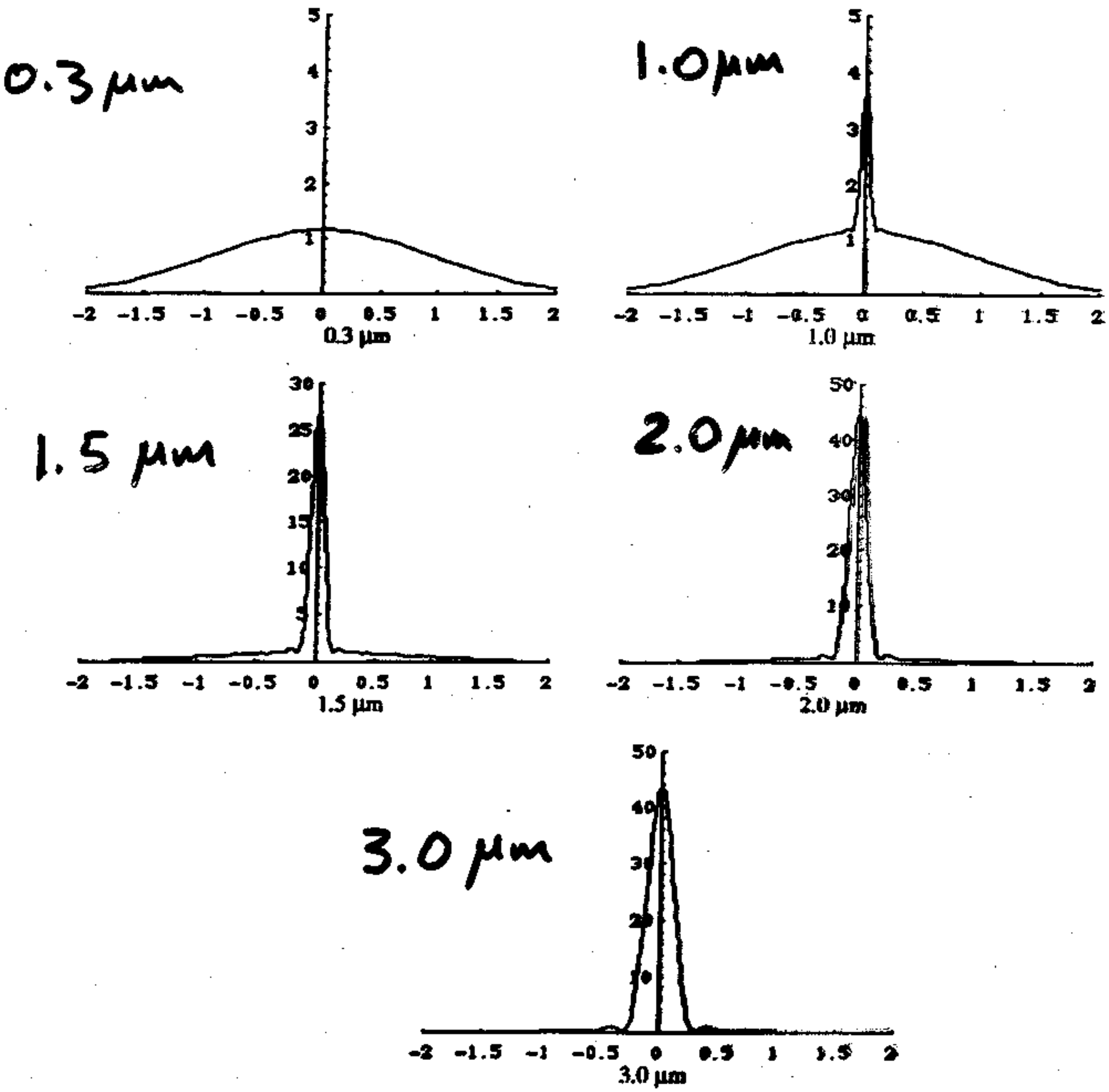

0 km/s => H2 S(1)
Velocity (km s⁻¹)
-600
-400
-200
0
200
400
600
H2 v=0−0 S(1)
w = 10 μm, 41,000 FT.
w = 100 μm, 3000 FT
w = 1 mm, 13,000 FT
Transmittance
1
.8
.6
.4
.2
0
17.01
17.02
17.03
17.04
17.05
17.06
Wavelength (μm)
Zenith WV 10.0
Zenith Ang 40.0
L.O.S. WV 13.1
Atm. Type Std.&H2O Adj.
Layers 10
Altitude 41000
H2O CO2 N2O
Lambda 1 17.006
Lambda 2 17.063
Sampling 0.000007
Res(FWHM) 0.000000
Instr. Fn. None
Line Ctr 17.035
Num. Pts. 8682
Ozone 9.13E+18
Tue Jul 13 20:49:55 1999

Figure 7. Predicted Point Spread Functions for Different Wavelengths 2

NOTE: The horizontal axes are arcseconds in each case, and the vertical axis is relative surface brightness.



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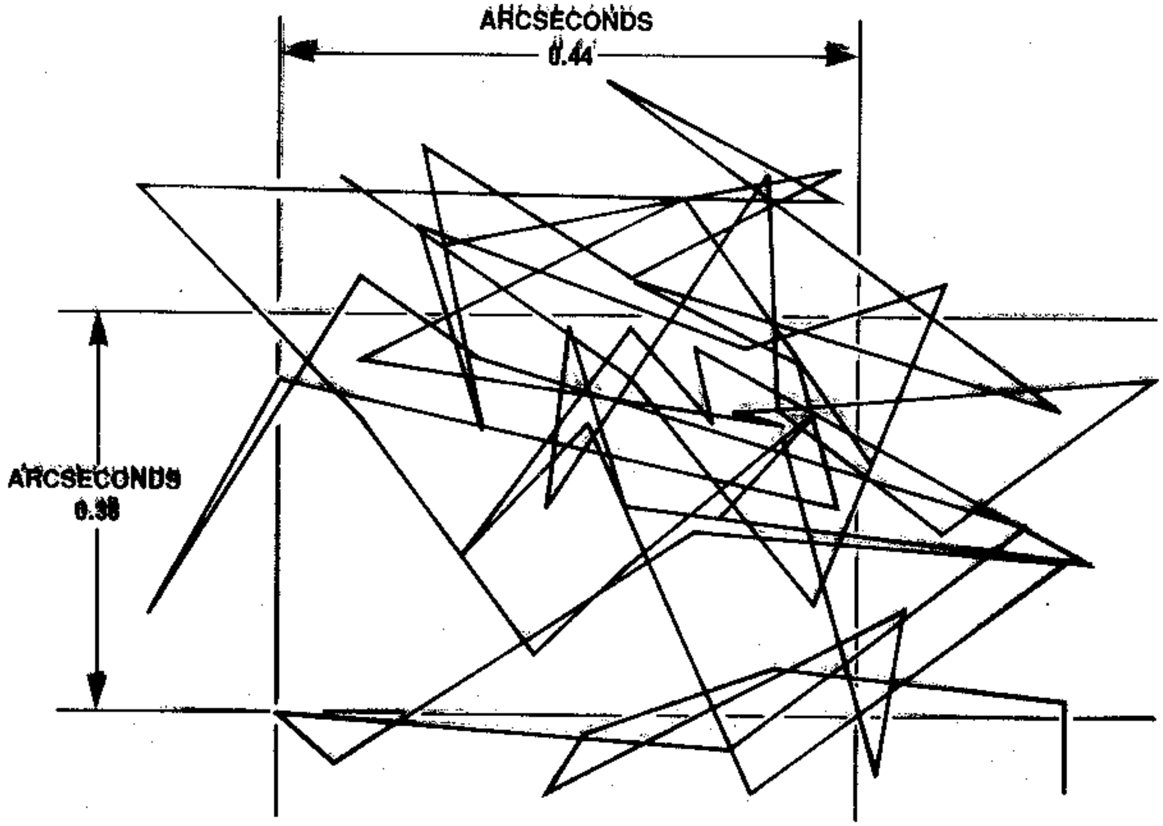
Possible Airborne Telescope Pointing Stability



Motion measured on KAO of the centroid of a stellar image while focal plane tracking under optimal conditions (11/20/90). Resulting RMS stability equals 0.2 arcseconds after 1 second and 60 positions.

TOP VERTICAL

INTERSTELLAR SPECTRAL FEATURES MEASURED FROM THE KUIPER AIRBORNE OBSERVATORY

ATOMS		MOLECULES		DUST GRAINS	
Wavelength (μm)	SPECIES	Wavelength (μm)	SPECIES	Wavelength (μm)	SPECIES
1.88, 2.62, 2.67, 2.76, 4.65, 5.91, 6.6, 7.5, 52.5, 88.8, 169.4	H I	1.4, 1.8a	C_2	2.95?, 6.3, 7.1a	NH_3 Ice
3.1, 7.5	Ni I	2.0, 2.6, 7.5a	C_2H_2	5.2, 5.6, 6.2, 6.9, 7.6, 7.8	PAH
4.5	MgIV, Ar VI (?)	2.3, 4.6, 77, 84, 87, 97, 103, 119, 124, 153, 163, 174, 186, 200, 289, 302, 650	CO	5.5a	HCO in Ice
5.6	Mg V	2.9a	C_2H	6.0, 45a/e, 62	H_2O Ice
6.6	Ni II	3.0, 3.5, 7.5a	HCN	6.8a	Hydrocarbon
6.98	Ar II	5.0a	C_3	19.0a/e	Silicate
7.63	Ne VI	8.5	SiO	24-30+	MgS (?)
8.99, 21.8	Ar III	17.0	H_2	45, 62a/e	H_2O
17.9, 26.0	Fe II	53.4, 84.4, 84.69, 119.3, 119.5, 149, 163.1, 164.4, 202a/e	OH		
18.7, 33.4	S III	154, 308	^{13}CO		
22.9	Fe III	120.0, 120.2a/e	^{18}OH		
24.3	Ne VI	125, 166, 524	NH_3		
25.2	S I	149.1, 149.4, 203	CH		
25.9	O IV	479	HCl		
34.8	Si II	790, 1600	H_2O		
36.0	Ne III	805	H_2D^+		
51.8, 88.4	O III				
57.3	N III				
63.2, 146	O I				
121.9, 205	N II				
158	C II				
158	^{13}C II				
370, 609	C I				

Almost all of these features were first detected from NASA's airborne observatories, and cannot be studied from ground-based sites. Features seen in absorption are indicated with "a", and seen in both emission and absorption with "a/e". Whereas the dust features typically originate in regions cooler than a few hundred degrees Kelvin, the various gaseous lines originate in regions ranging in temperature from 10^5K down to 10K. Thus there are infrared material in all phases of interstellar medium: solid particles, molecules, neutral atoms, and ionized atoms.

CRYOGENIC FIR SPECTROMETERS

EXES, AIRES, FIFI LS, SAFIRE

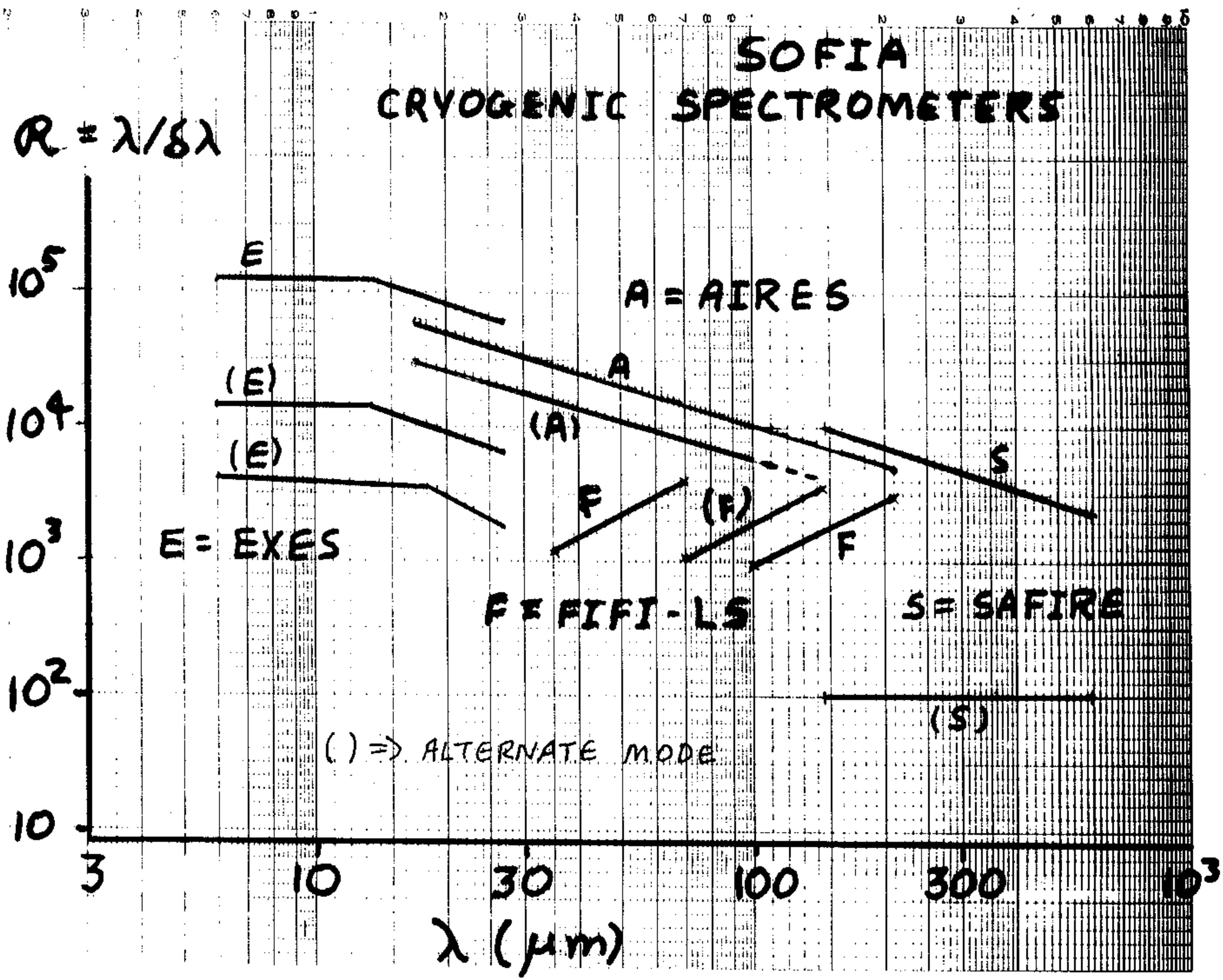
Instrument descriptions are located at:

http://sofia.arc.nasa.gov

CRYOGENIC SPECTROMETERS FOR SOFIA
- SIMPLIFIED COMPARISON -

	$\lambda_{min} - \lambda_{max}$	$\mathcal{R} = \lambda/\delta\lambda$	BANDPASS	FOV
EXES	6 - 27 μm	120,000 - 60,000	1200 - 420 km/s	1.3"x10" - 2.6"x44"
		(4200 - 1800)	3800 - 4300 km/s	1.8"x95" - 3.7"x40"
AIRES	17 - 210 μm	70,000 - 4000	220 - 290 km/s	2"x150" - 23"x150"
FIFI LS	42 - 210 μm	1200 - 3000	1500 - 3000 km/s	35"x35" - 70"x70"
SAFIRE	145 - 655 μm	10,000 - 2200	150 ••• 2000 km/s (?)	340"x65"
		(100 - 100 (?))		

EFE 7/99


SOFIA
CRYOGENIC SPECTROMETERS
R = λ/δλ
10^5
10^4
10^3
10^2
10
E
(E)
(E)
A
(A)
F
(F)
F
S
(S)
A = AIRES
E = EXES
F = FIFI-LS
S = SAFIRE
( ) ⇒ ALTERNATE MODE
3
10
30
100
300
10^3
λ (μm)

The Revolution

This date, July 14 is known as Bastille Day in France, marking the overt beginning of the French revolution. Last year a similar if less remarked event occurred in astronomy, with the start of development of SIRTF and SOFIA.

These facilities, and the instruments which we are now building, are revolutionary compared to the tools we had (what seems like) just a few years ago. The picture here shows Ian Gatley, Eric Becklin, Gerry Neugebauer, and Gordon Forester on a KAO flight in 1976, during which they made the first far infrared maps of M17 (after fixing a minor instrument problem).

In those days science productivity was limited in large degree by our instruments. With these new capabilities, such as EXES, AIRES, FIFI LS and SAFIRE on SOFIA, the science we can do will be more limited by our capacity to plan investigations and interpret results than by our capacity to get the data — a - revolution indeed. To fully succeed we will need much help.