# SUBMILLIMETER WAVE ASTRONOMY SATELLITE

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Abstract

The Submillimeter Wave Astronomy Satellite (SWAS) was selected in 1989 by NASA, for a scheduled Scout launch in 1993. The objectives of this mission within the Small Explorer Program are to study dense clouds in the interstellar medium via critically important transitions of molecular and atomic species which can be observed only at submillimeter wavelengths. SWAS will thus observe transitions of water vapor at 557 GHz, molecular oxygen at 487 GHz, atomic carbon at 492 GHz, and carbon–13 monoxide at 554 GHz. These frequencies are totally or largely opaque from the ground, and a space–based survey of molecular clouds throughout our galaxy will yield important new information about the chemistry in very dense clouds in the Milky Way, and the process of star formation. The SWAS instrument employs a 55–cm diameter offset Cassegrain antenna with a nutating secondary reflector. The receivers are second harmonic downconverters, using Schottky diodes as the mixing elements, with phase locked InP Gunn devices as the local oscillator sources. The receiver front ends are passively cooled to $\simeq$ 150 K. Spectral analysis is performed by an acousto–optical spectrometer with 1.4 GHz bandwidth, which covers the four lines simultaneously. SWAS represents the first space–borne system operating in the submillimeter range, and as such is providing considerable impetus for development of highly reliable, compact, components which have low mass and power consumption. We see SWAS as the precursor of more elaborate submillimeter astronomy missions, and complementing work done from airborne platforms and dry sites on the Earth's surface.

Participants in the SWAS project:

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P. Goldsmith, N. Erickson, R. Snell, University of Massachusetts, Amherst

D. Hollenbach, NASA Ames Research Center

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M. Harwit, National Air and Space Museum

D. Neufeld, University of California, Berkeley

Industry contractors:

Ball Aerospace Systems Group (antenna, pointing, thermal design,integration)

Millitech Corporation (submillimeter frontend)

# OBJECTIVES FOR SWAS PROJECT

SWAS IS AN OUTGROWTH OF INTEREST OF SCIENTISTS IN EXPLOITATION OF THE SUBMILLIMETER WAVELENGTH REGION FOR ASTRONOMY

IT WILL BE A PIONEERING STEP IN SUBMILLIMETER ASTRONOMY IN SPACE

SUBMILLIMETER <u>CONTINUUM</u> OBSERVATIONS, WHILE PAINFUL, CAN TAKE ADVANTAGE OF "WINDOWS"

THUS, THE FOCUS OF **SWAS** IS ON SUBMILLIMETER SPECTRAL LINES OF ASTROPHYSICAL SIGNIFICANCE WHICH CANNOT BE STUDIED USING GROUND–BASED TECHNIQUES

THE CHOICE OF FREQUENCIES IS ALSO IMPACTED BY REQUIREMENT THAT TECHNOLOGY BE AVAILABLE

* **Long wavelength submillimeter heterodyne receivers**
  - Schottky diode mixers
  - Solid state local oscillators
* **Acousto–optical spectrometer**

# SWAS SPECTRAL LINES

| Species | Transition | Frequency (GHz) | Wavelength (Microns) |
|---|---|---|---|
| $O_2$ | 3(3) – 1(2) | 487.249 | 615.7 |
| CI | $^3P_1 - {}^3P_0$ | 492.162 | 609.6 |
| $^{13}CO$ | 5 – 4 | 550.926 | 544.5 |
| $H_2O$ | $1_{10} - 1_{01}$ | 556.936 | 538.7 |
| $H_2{}^{18}O$ | $1_{10} - 1_{01}$ | 547.545 | 547.9 |

SPECIES SELECTED FOR OBSERVATION BY **SWAS** ARE IMPORTANT BECAUSE

(1) THEY ARE PREDICTED TO BE MAJOR RESERVOIRS OF CARBON AND OXYGEN IN DENSE INTERSTELLAR CLOUDS

(2) THEY SHOULD BE VALUABLE PROBES OF PHYSICAL CONDITIONS IN THESE REGIONS

(3) THEY *SHOULD* PLAY A MAJOR ROLE IN DETERMINATION OF TEMPERATURE IN INTERSTELLAR CLOUDS

(4) THEY PROVIDE IMPORTANT TESTS OF CHEMICAL MODELS OF WELL–SHIELDED REGIONS IN MOLECULAR CLOUDS AND OF REGIONS WHERE PHOTOCHEMISTRY IS IMPORTANT

WATER AND CARBON MONOXIDE ARE THOUGHT TO BE THE MOST

IMPORTANT COOLANTS OF GAS IN INTERSTELLAR MOLECULAR CLOUDS

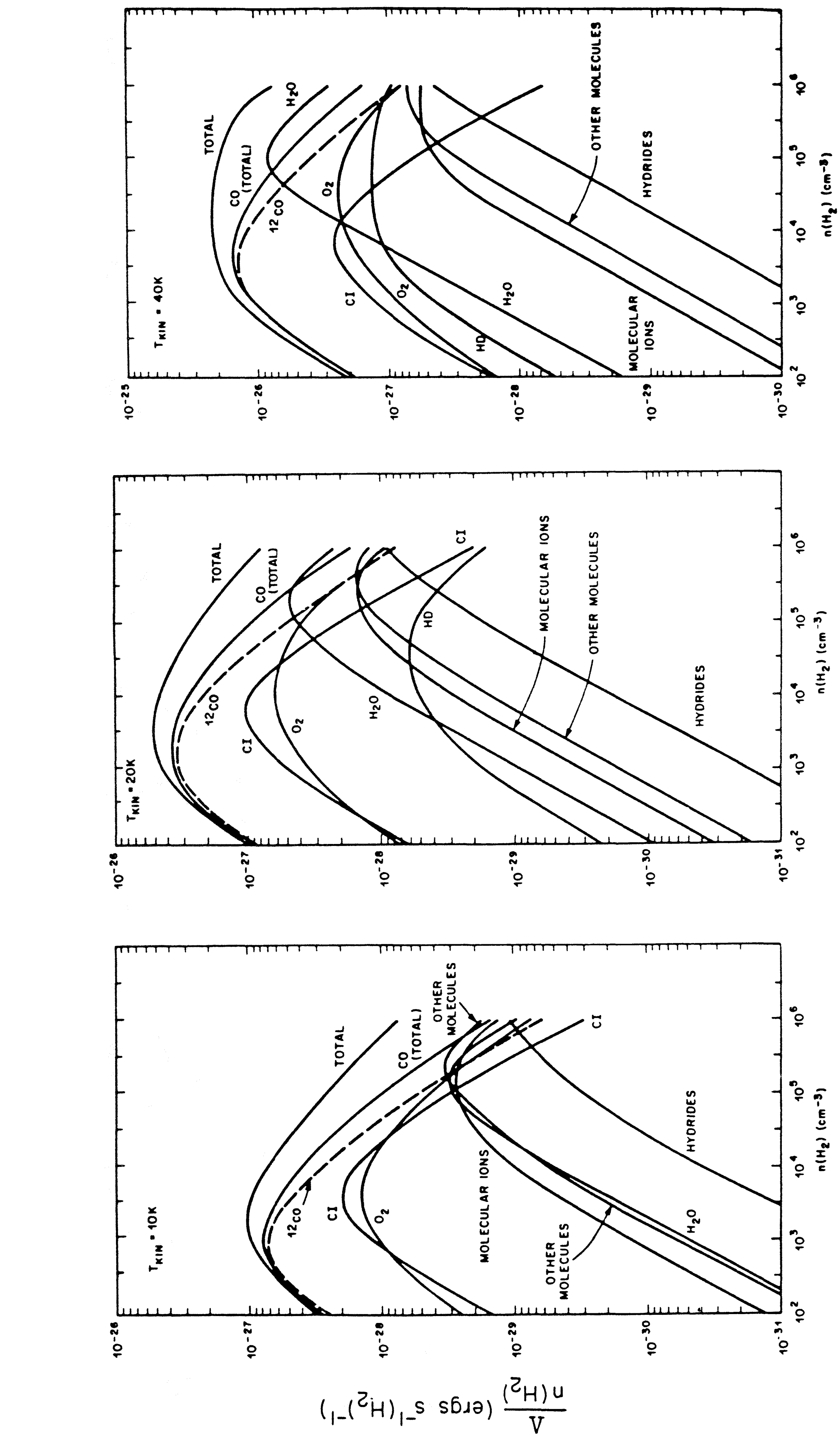
AT HIGH DENSITIES IN CLOUD CORES $n(H_2) \geq 10^5$ $CM^{-3}$

$H_2O$ IS THE MOST IMPORTANT GAS COOLANT

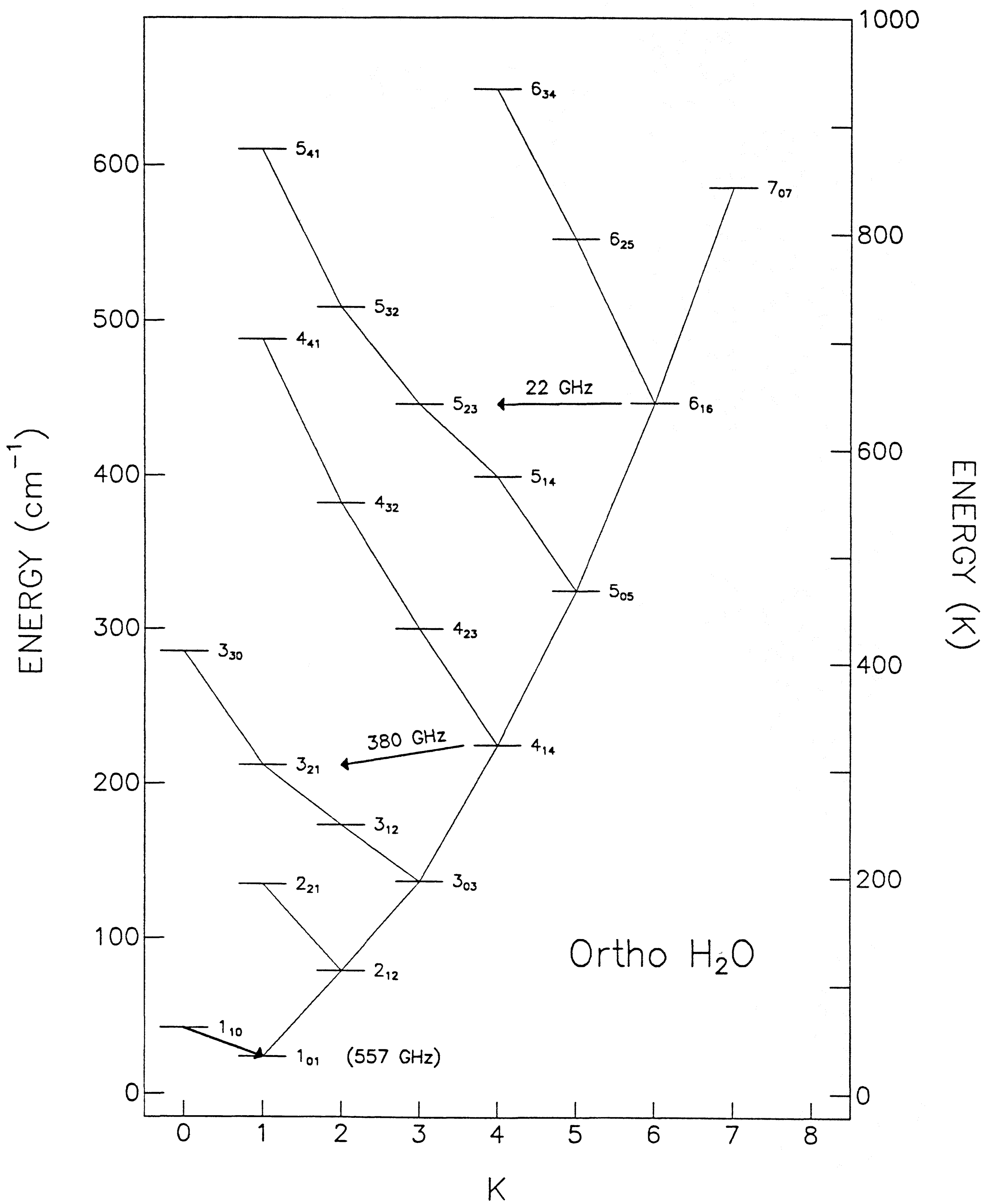
THE **557 GHZ $1_{10} - 1_{01}$ GROUND STATE TRANSITION** PLAYS A KEY ROLE

THIS TRANSITION SHOULD BE READILY OBSERVABLE WITH **SWAS**

IN GMC CORES THROUGHOUT MILKY WAY

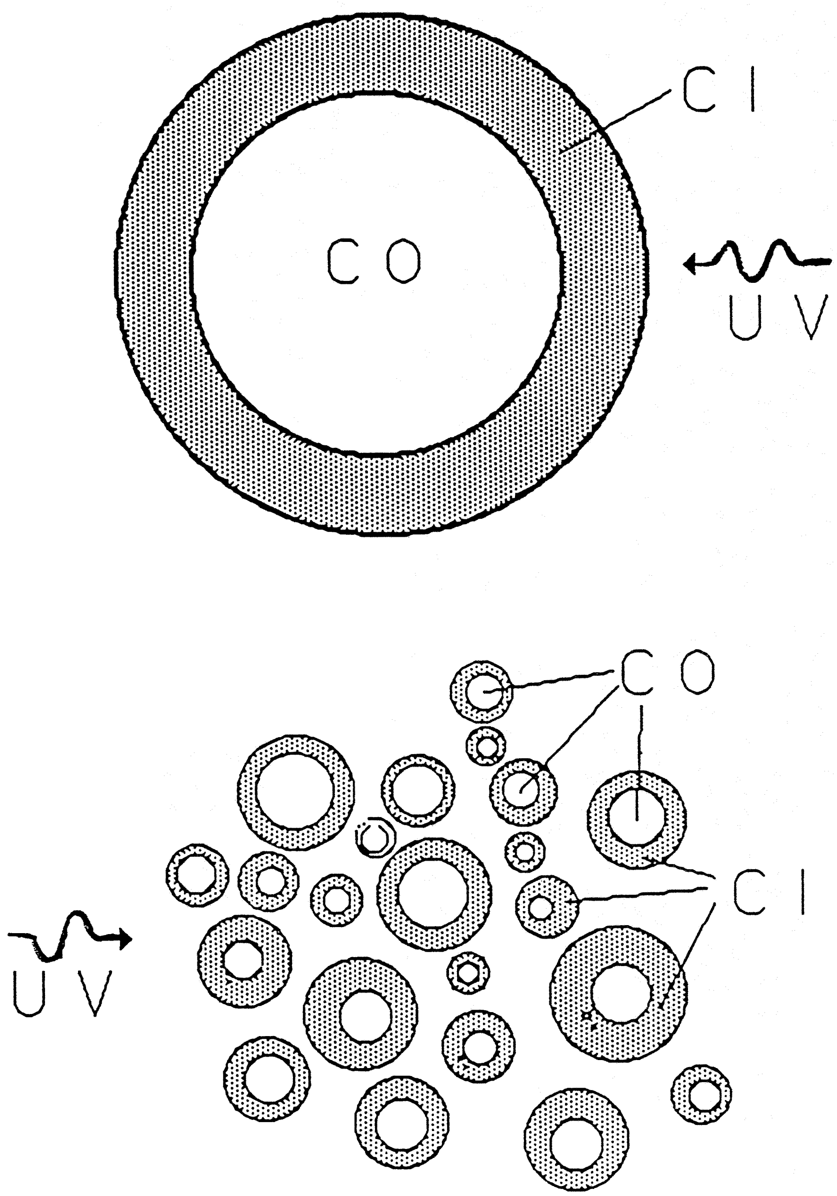



COOLING FROM ATOMS AND MOLECULES IN DENSE CLOUDS IN THE INTERSTELLAR MEDIUM


ENERGY (cm^-1)
ENERGY (K)
K
0
100
200
300
400
500
600
0
200
400
600
800
1000
0
1
2
3
4
5
6
7
8
6_34
5_41
7_07
6_25
5_32
4_41
22 GHz
5_23
6_16
5_14
4_32
5_05
4_23
3_30
380 GHz
4_14
3_21
3_12
2_21
3_03
Ortho H2O
2_12
1_10
1_01
(557 GHz)

# NEUTRAL CARBON IS A VERY VALUABLE PROBE OF THE EFFECTS OF PHOTOCHEMISTRY ON THE STRUCTURE OF MOLECULAR CLOUDS

THIS MAY NOT BE RESTRICTED TO CLOUD EDGES, BUT IF DENSITY OF A CLOUD IS VERY NON–UNIFORM (HIGHLY CLUMPED), THERE MAY BE PHOTOCHEMICALLY–DOMINATED REGIONS THROUGHOUT A LARGE FRACTION OF CLOUDS' VOLUME. THIS WILL HAVE A PARTICULARLY IMPORTANT EFFECT WHEN THERE ARE HII REGIONS NEARBY




HIGHLY CLUMPED MODEL OF INTERSTELLAR CLOUD WHICH

ALLOWS PENETRATION OF UV

# $^{13}CO$ J = 5–4 TRANSITION AT 551 GHZ IS SENSITIVE TO REGIONS WITH HIGH TEMPERATURE AND DENSITY

THE UPPER LEVEL IS **80 K** ABOVE GROUND STATE

SPONTANEOUS DECAY RATE IS **$1.1 \times 10^{-5}$ s$^{-1}$**

IN CONJUNCTION WITH OTHER PROBES, IT SHOULD BE A VERY EFFECTIVE TRACER OF WARM MATERIAL IN GMC's

# MOLECULAR OXYGEN IS AN IMPORTANT SPECIES TO OBSERVE BECAUSE FORMATION AND DESTRUCTION PATHWAYS ARE INTIMATELY LINKED WITH OTHER MAJOR CARBON– AND OXYGEN– BEARING SPECIES INCLUDING CI, CO, AND $H_2O$

## FORMATION OF $O_2$

$H_2 + CR \rightarrow H_2^+ + e^-$

$H_2^+ + H_2 \rightarrow H_3^+ + H$

$H_3^+ + O \rightarrow OH^+ + H_2$

$OH^+ + H_2 \rightarrow H_2O^+ + H$

$H_2O^+ + H_2 \rightarrow H_3O^+ + H$

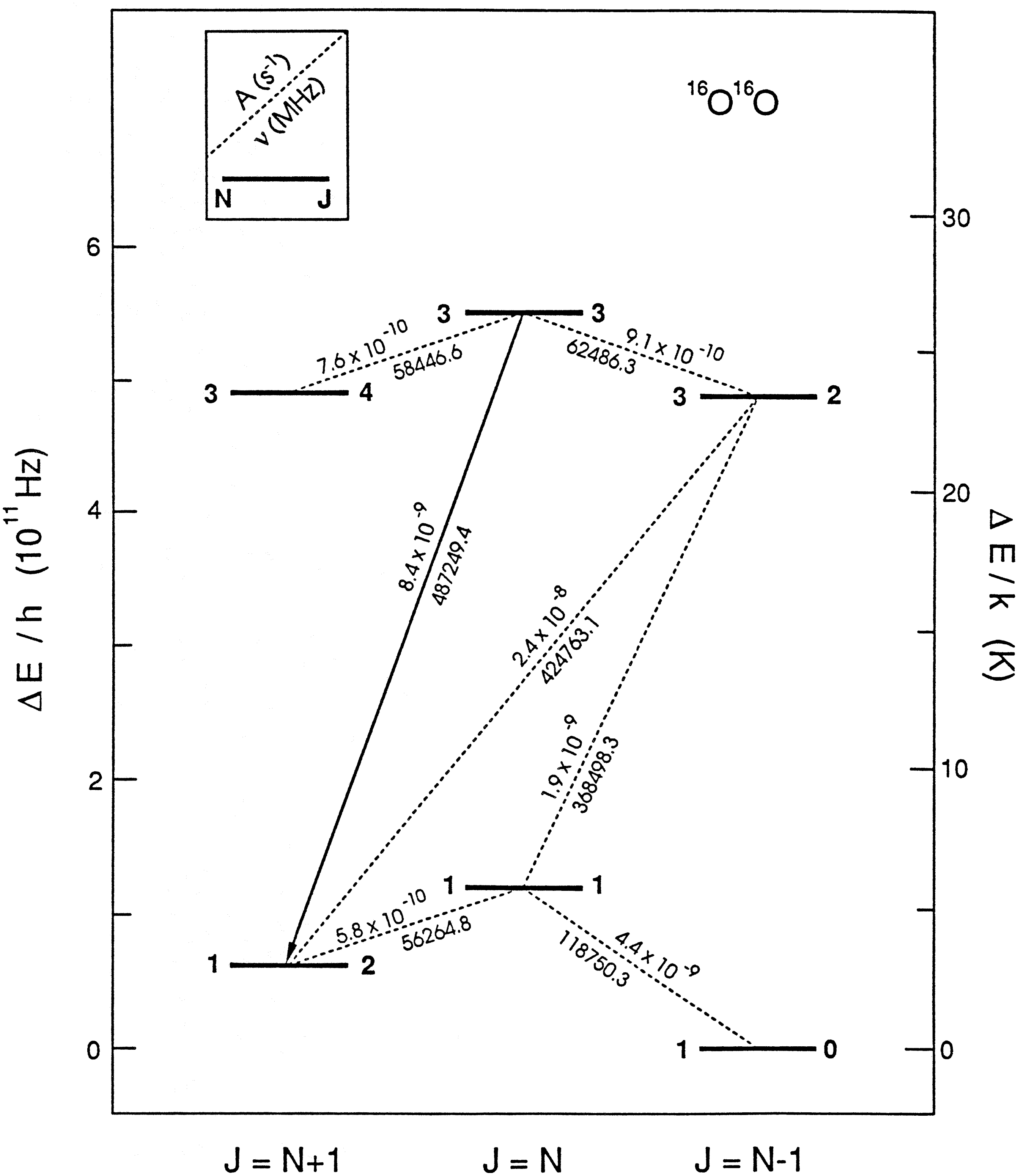
$H_3O^+ + e^- \rightarrow \mathbf{H_2O} + H$

$\rightarrow OH + H_2$

$OH + O \rightarrow \mathbf{O_2} + H$

## DESTRUCTION OF $O_2$

$C + O_2 \rightarrow CO + O$



A (s⁻¹)
ν (MHz)
N
J
¹⁶O¹⁶O
ΔE / h (10¹¹ Hz)
ΔE / k (K)
6
4
2
0
30
20
10
0
3
3
7.6 x 10⁻¹⁰
58446.6
9.1 x 10⁻¹⁰
62486.3
3
4
3
2
8.4 x 10⁻⁹
487249.4
2.4 x 10⁻⁸
424763.1
1.9 x 10⁻⁹
368498.3
1
1
5.8 x 10⁻¹⁰
56264.8
4.4 x 10⁻⁹
118750.3
1
2
1
0
J = N+1
J = N
J = N-1

# SWAS MISSION PROFILE

## I. QUICK–LOOK CHEMISTRY

10 POSITIONS IN EACH OF 5 GIANT AND DARK CLOUD CORES FOR 1200 s

4 POSITIONS IN EACH OF 5 GIANT AND DARK CLOUDS FOR 45,000 s

Total time approximately 10 days

## II. MINI–SURVEY OF GMC's in GALAXY

1000 POSITIONS FOR 5000 s PER POSITION

NEUTRAL CARBON MAPPED THROUGHOUT REGIONS

EXPECT TO DETECT ALL GMC CORES IN $H_2O$, $^{13}CO$, AND $O_2$

Total time approximately two months

## III. MAPS OF LOCAL CLOUDS

10 LOCAL CLOUDS FOR SPATIAL DISTRIBUTION OF VARIOUS SPECIES

TRACE VARIATIONS AS FUNCTION OF $\tau$, RADIATION FIELD, etc.

Orion, Monoceros, Taurus, Perseus, Chamaeleon, Ophiuchi, Cygnus...

Total time approximately four months

## IV. ADDITIONAL STUDIES

DEPEND ON INTENSITIES AND ABUNDANCES FROM PHASES I – III

HIGH SPATIAL RESOLUTION STUDIES– –NYQUIST–SAMPLED MAPS

FULL SURVEY OF CLOUDS IN THE GALAXY

EXTRAGALACTIC SOURCES

Nominal mission lifetime is 2 years

# SWAS ANTENNA AND OPTICS

**Observe Four Spectral Lines Simultaneously**

* Two Receivers operating in orthogonal polarizations
* Wire Grid Diplexer sends two lines to each mixer
* Local Oscillator frequencies fold a pair of lines into each IF
* Two IF's diplexed into spectrometer

**Antenna**

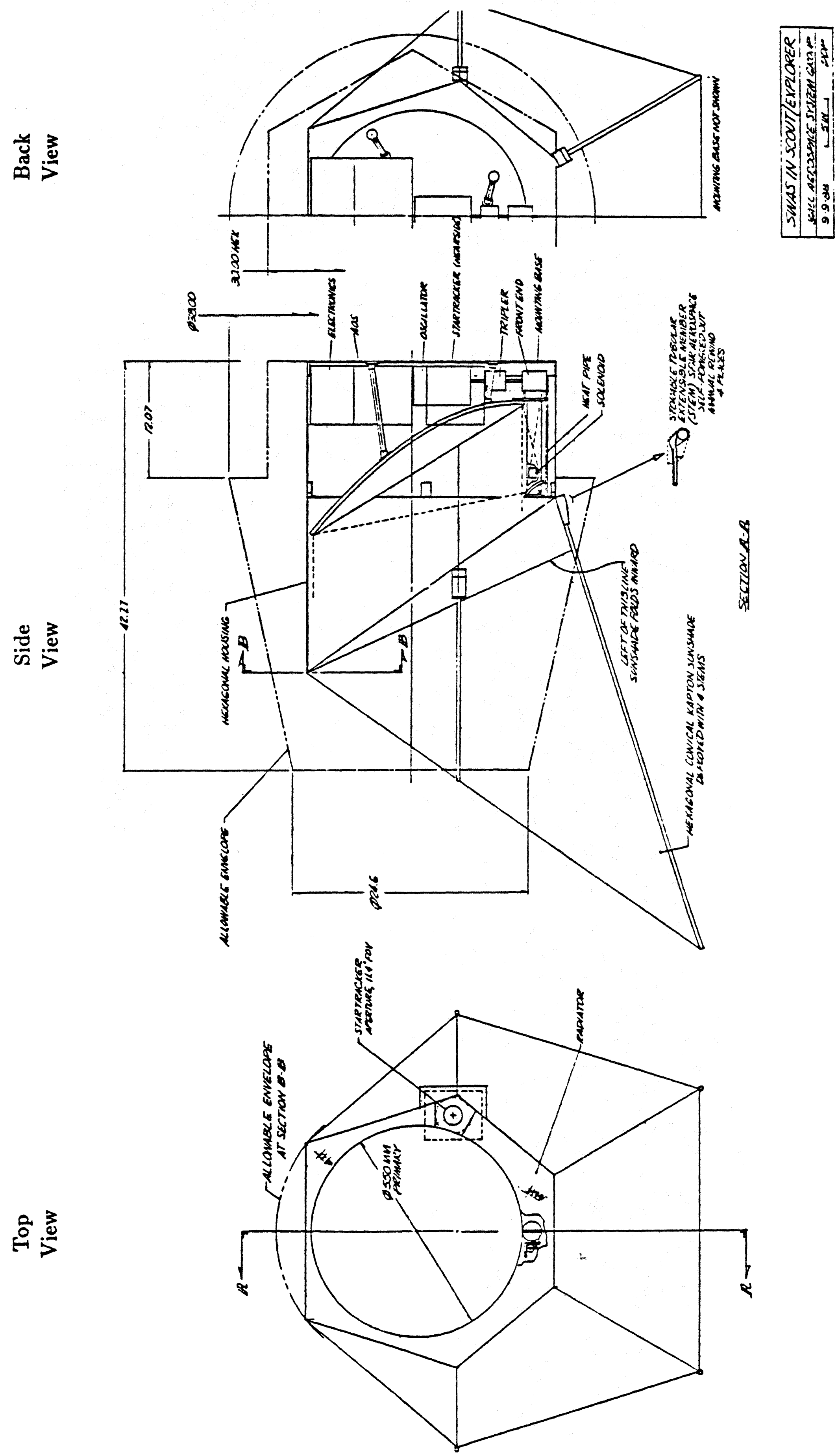
* 55 cm diameter offset Cassegrain
* $\Delta\theta_{fwhm} = 4.4$ arcmin at 610 $\mu$m and 3.9 arcmin at 540 $\mu$m
* $f_e/D_m = 4.8$
* Nutating secondary mirror (1 degree chop at 1/60 Hz)
* Approximately Gaussian illumination with conical feedhorns

**Calibrations**

* Internal using ambient load and cold sky: $\Delta T \simeq 160$ K
* External using planets (unresolved) and Moon

**Spectrometer**

* Acousto–Optical Spectrometer (AOS)
* 1400 elements covering 1.4 GHz
* Redundant laser diodes and CCD readouts




Layout of the SWAS intrument relative to the payload envelope.

# SWAS RECEIVERS

* **Second harmonic mixers pumped by frequency–tripled Gunn oscillators**

  Oscillator frequencies are 81.5 GHz and 92.3 GHz for the two receivers

  The two Gunn oscillators are phase locked to a single (but redundant) reference oscillator at 5.114 GHz

  Doppler tracking is obtained by synthesizer employed for PLL loop reference

* **HEMT amplifiers for first IF stages**

  2.1–2.8 GHz for low band ($O_2$–CI) receiver and 2.7–3.4 GHz for high band ($H_2O$–$C^{13}O$ receiver)

* **Input optics, mixers, and first IF amplifiers are passively cooled to a temperature of between 120 and 160 K** (the value depends on thermal design)

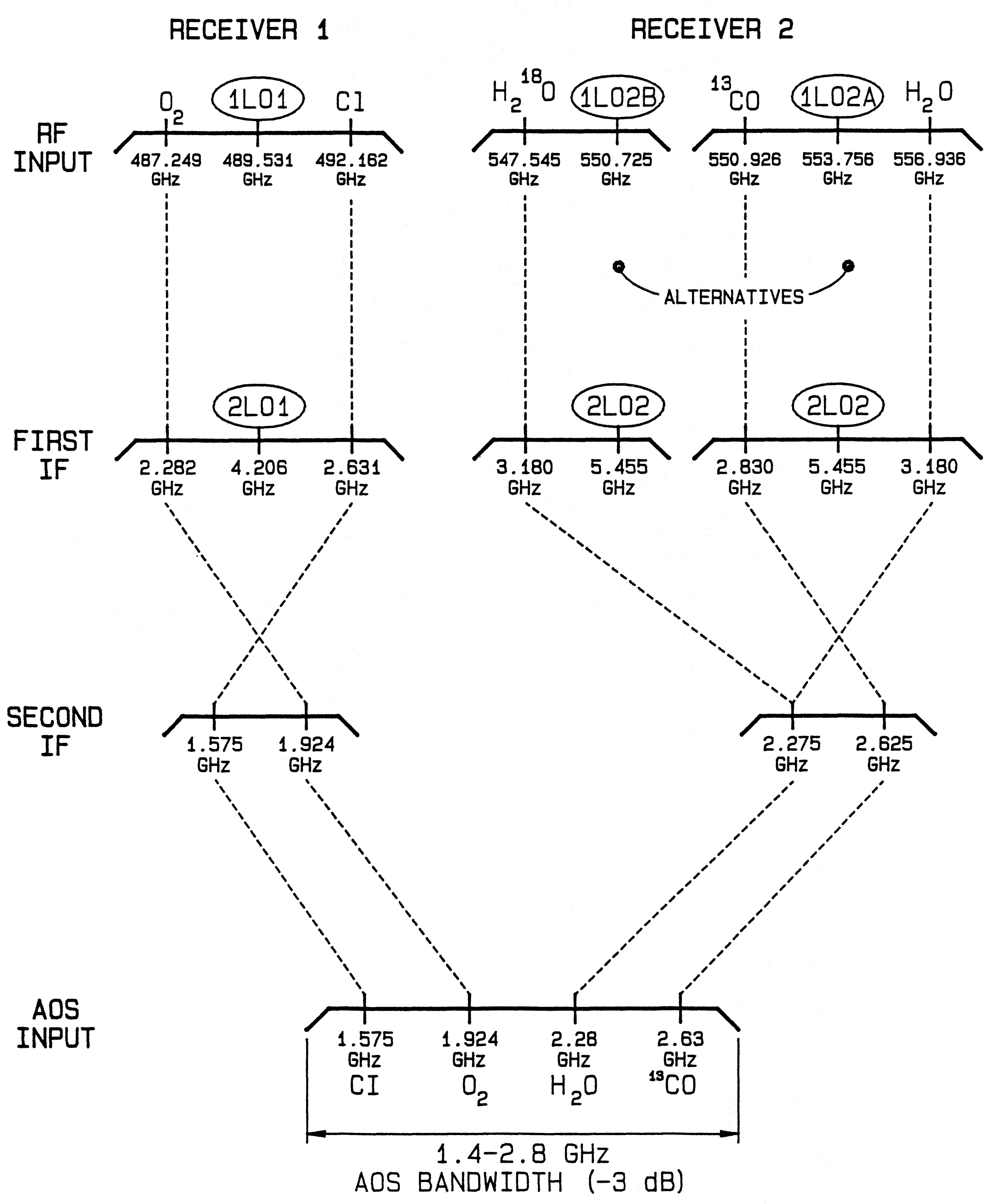
* **Use of harmonic mixers significantly reduces system complexity**

  Eliminates frequency doubler for second harmonic mixer and input diplexer

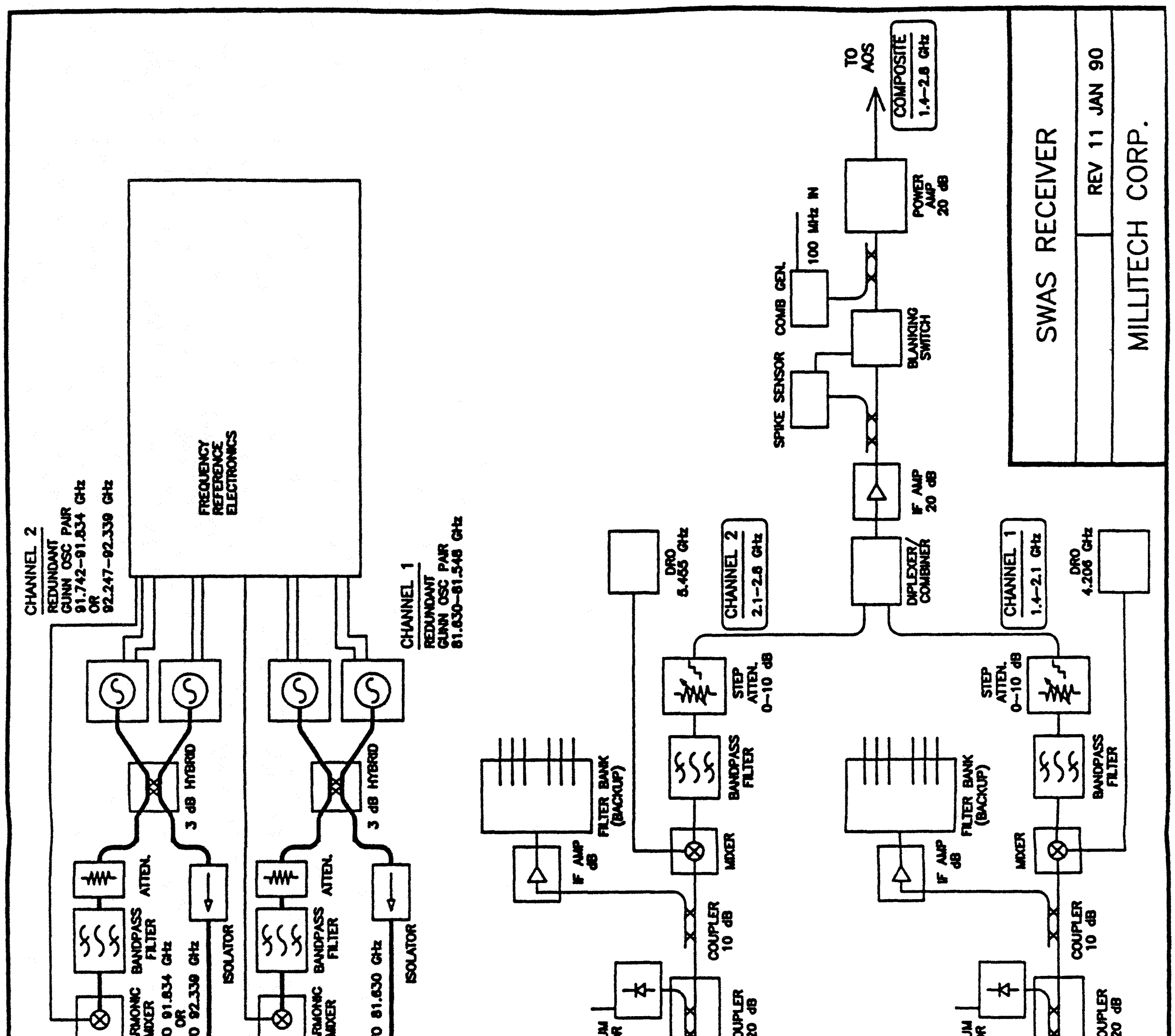
  Approximately 1 dB (1.26x) higher conversion loss for second harmonic mixer than for fundamental mixer

* **557 GHz (modified for 547 GHz) prototype successfully flown on KAO**

* **Expected receiver temperatures when cooled < 2500 K Single Sideband**




SWAS SUBMM RECEIVER FREQUENCIES


SWAS RECEIVER
REV 11 JAN 90
MILLITECH CORP.
TO AOS
COMPOSITE 1.4–2.8 GHz
POWER AMP 20 dB
100 MHz IN
COMB GEN.
SPIKE SENSOR
BLANKING SWITCH
IF AMP 20 dB
DIPLEXER/ COMBINER
DRO 8.455 GHz
CHANNEL 2 2.1–2.8 GHz
CHANNEL 1 1.4–2.1 GHz
DRO 4.206 GHz
STEP ATTEN. 0–10 dB
BANDPASS FILTER
FILTER BANK (BACKUP)
MIXER
IF AMP dB
COUPLER 10 dB
COUPLER 20 dB
CONTINUUM DETECTOR
IF AMP 45 dB
ISOLATOR
CHANNEL 2 2.7 – 3.4 GHz
CHANNEL 1 2.1 – 2.8 GHz
FREQUENCY REFERENCE ELECTRONICS
CHANNEL 2 REDUNDANT GUNN OSC PAIR 91.742–91.834 GHz OR 92.247–92.330 GHz
CHANNEL 1 REDUNDANT GUNN OSC PAIR 81.630–81.548 GHz
3 dB HYBRID
ATTEN.
HARMONIC MIXER
91.742 TO 91.834 GHz OR 92.247 TO 92.330 GHz
81.548 TO 81.630 GHz
THERMAL WG BREAK
THERMAL COAX BREAK
2–STAGE HEMT IF AMP 25 dB
TRIPLER
CHANNEL 2
2ND HARMONIC MIXER
RADIATIVELY COOLED 100–200? K
WIRE GRID POLARIZER
CHANNEL 1
CALIBRATION LOAD
MOVABLE MIRROR
TO ANTENNA
MOLECULE | FREQ GHz | RECEIVER CHANNEL #
O2 | 487.249 | 1
C(I) | 492.162 | 1
H2 18O | 547.545 | 2
13CO | 550.926 | 2
H2O | 556.936 | 2

# SWAS MISSION AND SPACECRAFT

* **Two year lifetime to accomplish scientific objectives**

  requires perigee altitude $\geq$ 530 km

  An equatorial orbit is most favorable for lifetime, but has problems including telemetry stations and launch site status. Still under discussion

* **Pointed observations using solid state star tracker — 0.01 deg pointing accuracy**

* **Mass minimized by use of**

  deployable metallized plastic sunshade
  ribbed graphite epoxy primary mirror (1.5 kg)

* **Overall instrument mass is 60 kg**

  includes antenna, receiver, and spectrometer

  with spacecraft, the total mass is 200 kg

  may be reduced by lightening of AOS support structure

* **Power consumption is 50 W**

  allowing for converter efficiency, this is just within SMEX limit

* **Launch vehicle has not been definitely selected**; it could be a Scout, an Augmented Scout, or a new launcher such as Pegasus

* **Launch currently scheduled for August 1994**