Balloon Borne Molecular Oxygen Search: SIS Spectrometer

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ABSTRACT

Oxygen is the third most abundant element in our galaxy. The oxygen bearing molecules that have been detected do not account for the expected oxygen abundance in Molecular Clouds. Molecular oxygen (O_2) could be a major reservoir for the missing oxygen. We at UCSB in conjunction with JPL and AT&T have designed, built, and tested a balloon borne radio telescope with the capability to observe O_2 ($118750MHz$) and CO ($115271MHz$). Using an SIS mixer from NRAO[4] and a digital auto-correlator from JPL, the SIS Spectrometer (SISS) has achieved double sideband receiver temperature of $50K$ and a spectral resolution of $1km/s$. Using the 1 meter primary mirror on the UCSB balloon borne gondola, the SISS has a $10'FWHM$ beam.

1. INTRODUCTION

We know that oxygen is the third most abundant element in our galaxy from observations of atomic oxygen in stellar atmospheres and ionized nebulae. Molecular line studies of oxygen bearing molecules, CO, OH, H_2O, etc, cannot account for all the oxygen that is expected in Molecular Clouds. Measurements in highly doppler shifted extra-galactic sources and of the $O^{18}O$ isotope have set limits of $x(O_2) = n(O_2)/n(H_2) \sim 8 \times 10^{-6}$ and $\sim 10^{-5}$ respectively (Lizst 1992). The abundance of H_3O^+, the chief precursor of O_2, implies $x(O_2) \sim 10^{-5} - 10^{-6}$ (Phillips 1992). Using a simple radiative transfer model and an oxygen abundance 10^{-6}, we expect $T_{ant}(O_2) \sim T_{ant}(C^{18}O)$ if the CO abundance is $\sim 4 \times 10^{-5}$, and the isotope ratio in the galactic disk is $n(^{16}O)/n(^{18}O) \sim 675$ (Penzias 1981). Antenna temperatures for our beamsize for $C^{18}O$ are typically 0.1-1K.

2. THE MEASUREMENT

The reason O_2 has not been observed is that the terrestrial O_2 line is opaque and pressure broadened to $> 5GHz\ FWHM$ near the ground. At

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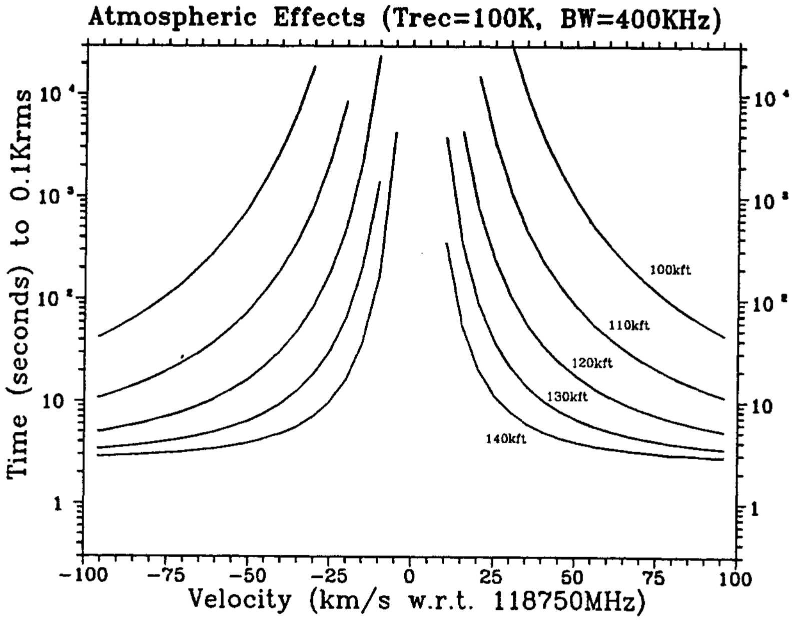

Fig. 1. Integration time to reach 0.1Krms per channel.

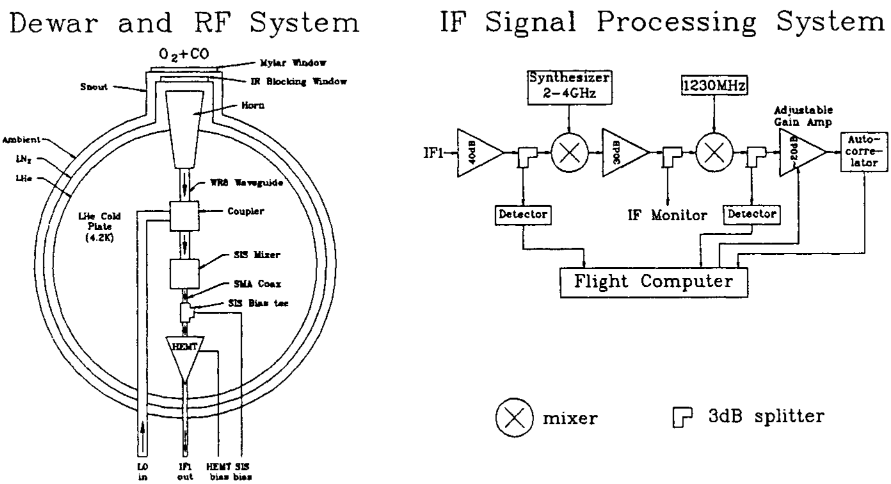

Fig. 2. Schematic Representation of the Dewar and IF Signal Processing.

balloon altitudes the terrestrial O_2 line is much narrower ($\sim$60MHz=150km/s), although still opaque at the center. By using the motion of the Earth and choosing sources with high doppler velocities, we can shift the extra-terrestrial lines to reduce the atmospheric emission and attenuation. Figure 1 shows the integration time necessary to reach 0.1Krms per channel (400kHz) outside the atmosphere as function of doppler velocity w.r.t. the center of the terrestrial O_2 line. We have several sources available with total doppler velocities of greater than 50km/s that will allow us to fly at 37km and reach 0.1Krms in less than 5 minutes.

3. THE INSTRUMENT

The UCSB 1 meter balloon borne gondola, ACME (Advanced Cosmic Millimeter-wave Explorer), has flown two different Cosmic Microwave Background Radiation (CMBR) detectors on four flights in the last four years. A gyro based inertial guidance system provides pointing information. By using a simple ballscrew for elevation and reaction wheel for azimuth control, this platform has demonstrated arc-minute pointing in flight.

The heart of the SISS is a six junction niobium SIS mixer block from NRAO (Kerr 1990). This brings CO (115271MHz) from the lower sideband and O_2 (118750MHz) from the upper sideband down to the first IF (1500 *to* 2000MHz) by mixing it with a phase-stabilized Gunn oscillator at 117160MHz. Mounted on the liquid helium cold plate with the SIS mixer is a low noise, HEMT (High Electron Mobility Transistor) amplifier that boosts the signal by $\sim 30dB$ before it leaves the dewar. Typically, the double sideband noise temperature over the entire first IF is 50K. Further warm IF signal processing *via* one computer controlled and one fixed local oscillator (Fig. 2) brings a 20MHz bandwidth signal down to DC where it is fed into a 52 channel digital auto-correlator built at the Jet Propulsion Laboratory (JPL). This gives us a velocity resolution of $\sim 1km/s$ at 118750MHz. An on-board 80286-based computer collects and integrates spectra from the auto-correlator as it directs and monitors all other aspects of the experiment: position/frequency chopping, calibration, thermal control, local oscillator lock conditions, *etc.* The spectra and house keeping data are sent down a radio link provided by NSBF (National Scientific Balloon Facility) during the flight as well as saved on board on an 80MB hard-disk for later recovery.

4. PRE-FLIGHT TESTS

Beam tests were performed using the a Gunn diode source at 125 meters. With the 1 meter primary mirror on ACME the SISS has a $10' FWHM$ beam. At the same distance, measurements of an LN_2 load show the telescope efficiency to be $\sim 80\%$. We tested system stability by hanging in the lab with the pointing system tracking and the detector looking at the ambient load. We integrated the system temperature of 350K DSB and a chopped noise of $1.3K\sqrt{sec}$ per channel, down to theoretical noise levels for more than an hour. The detector and new electronics (without the gondola) have been tested under flight pressure and temperature conditions at JPL. An exaggerated pressure and temperature profile harsher than what is expected in flight was used. One pressure sensitive oscillator was found and a simple pressure box has been constructed.

5. "OBSERVATIONS"

Of course the definitive pre-flight test for our telescope is to use its ability to look at CO in the lower sideband. With the gondola hanging from the awning outside our lab and with system temperature of $\sim 250K$ DSB, dominated by the completely saturated O_2 line which fills the upper sideband, we have been able to measure CO spectra in sources such as NGC7538, DR21, W51, *etc*, within minutes.

6. CONCLUSIONS

In flight we hope to have a system temperature of $100K$ DSB or less and to reach a chopped noise level per channel of less than $10mK$rms on several sources. Because of scheduling conflicts for the use of the ACME gondola, we were unable to fly August 1992. We are building "ACME-II", a nearly duplicate platform, as a backup for our next flight opportunity in June-August 1993. We are refining our observing strategy for this period with $C^{18}O$ maps from the Bell Labs 7m telescope which will allow us to concentrate on lines of sight with the highest column density. JPL is also working on a higher resolution, 128 channel, CMOS auto-correlator with the same $20MHz$ total bandwidth.

7. ACKNOWLEDGMENTS

At JPL, Bill Langer provided help with source selection, Bill Wilson advised on spectrometers and calibration, and Paul Batelaan contructed electronics and supervised the thermal/vacuum test. In Santa Barbara, Mark Lim pilots the gondola and Brad Pendleton helped in mechanical and electronic construction. We are very grateful to Anthony Kerr at the National Radio Astronomy Observatory for loaning us the SIS block and Arthur Lichtenberger of University of Virginia for providing the junctions. This research was performed in part at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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