A Submillimeter-wave Superheterodyne Camera (SuperCam) for the Heinrich Hertz Telescope

We propose to develop the world's most powerful, submillimeter-wave heterodyne array receiver for use at the Cassegrain focus of the Heinrich Hertz Telescope (HHT). The array will operate in the astrophysically rich, 870 μm atmospheric window. At this wavelength the HHT has the highest aperture efficiency of any submillimeter telescope in the world and excellent atmospheric transmission more than 50% of the time. The proposed Superheterodyne Camera (SuperCam) will be an 8x8, integrated receiver array fabricated using leading-edge mixer, local oscillator, low-noise amplifier, cryogenic, and digital signal processing technologies. When combined with the HHT, the array wil be an extremely powerful instrument for probing the history of star formation in our Galaxy and the distant Universe. Indeed, SuperCam will be an order of magnitude larger than any existing spectroscopic imaging array at submillimeter-wavelengths and will put the HHT in the forefront of research and tecnology in this wavelength regime for years to come.

Scientific Justification

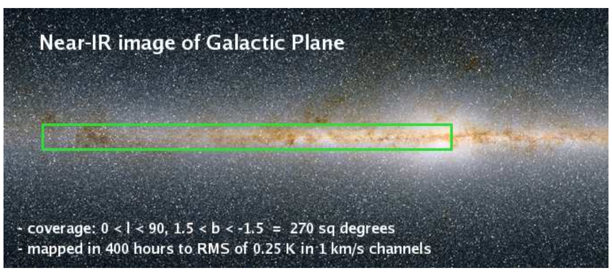

Figure 1: The power of SuperCam: a definitive chemical and kinematic survey of star forming clouds over 270 square degrees of the sky can be performed in 16 full days. The corresponding survey with contemporary single pixel receivers would take 4-5 years.

The submillimeter-wave portion of the electromagnetic spectrum contains the answers to many questions concerning the origin and evolution of the Universe, galaxies, stars, and planets. Over the past decade, advances in telescope and detector technology have for the first time made this regime available to a number of groundbased observers. The the Heinrich Hertz Telescope (HHT), the Caltech Submillimeter Observatory (CSO), the James Clerk Maxwell Telescope (JCMT), and, in the near future, the SMA provide the largest apertures for observing at these wavelengths. Due to the prevailing physical conditions in the interstellar medium, the 870 μm atmospheric window is one of the richest in the submillimeter portion of the spectrum. This window also has the highest atmospheric transmission of any submillimeter band. A large format array designed for this wavelength range would make excellent use of available telescope time and provide a new perspective on stellar, chemical, and galaxy evolution in both present and past epochs (Figure 1). Over the past few years, SORAL has constructed a small, currently 3 pixel, prototype 870 μm array to test the technologies for the proposed larger format system. The prototype array will go into regular operation on the HHT in November 2003 and be expanded to 7 pixels next summer. The sensitivity of the array is excellent, with individual mixers having a DSB noise temperature of ~ 55 K. This prototype array is now the largest in existence at these frequencies. The experience gained with this system puts the UofA in a unique position to carry array development to the next stage of evolution.

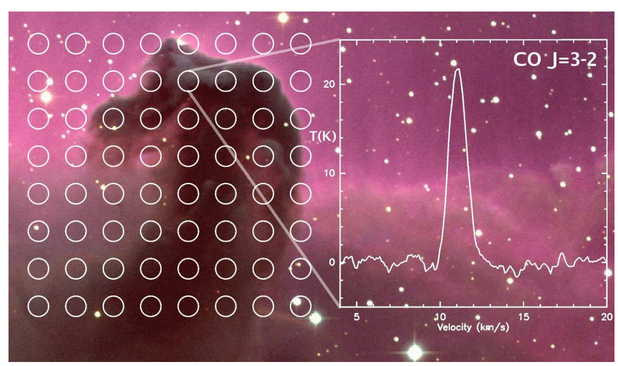

Figure 2: The 64 beams of SuperCam overlaid upon the Horsehead Nebula (B33). Each beam will measure a high-resolution spectrum, shown at right.

Instrument Description

SuperCam will be located in the Apex room of the HHT, just behind the primary. A pair of retractable, off-axis parabolic mirrors will transform the incoming light from f#/13.8 to f#/4. Scalar feedhorns will efficiently couple the f#/4 beams into eight, 1x8 waveguide mixer arrays. The separation between adjacent pixels will be $2f\lambda$. When projected on to the sky, the 64 pixel array will produce the beam footprint shown in Figure 2. Each diffraction limited beam will have a full-width-half-maximum width of $\sim 22''$. State-of-the-art Superconductor-Insulator-Superconductor (SIS) mixing devices will be used in a balanced arrangement to provide the lowest possible noise performance for each array pixel. This arrangement advantageously allows 100% of the available local oscillator (LO) power to be injected into each mixer using an efficient waveguide coupler. The downconverted, intermediate frequency (IF) output of each mixer is then amplified before further processing. The mixer arrays, LO power splitter, and 1st stage IF amplifiers all reside in a closed-cycle cryostat. The mixers and LO power splitter are cooled to $\sim$ 4 K by a closed-cycle JT refrigerator. The 1st stage IF amplifiers are cooled to $\sim$ 15 K by a second closed-cycle refrigerator. A 3D CAD drawing of the SuperCam array cryostat and reimaging optics is shown in Figure 3. A block diagram of the instrument is provided in Figure 4. The 64 IF outputs from the array cryostat enter an IF processor where they are further amplified and downconverted to a baseband frequency appropriate for the autocorrelator spectrometer (ACS). The ACS is composed of 8 commercially available correlator chips, each capable of producing power spectra over a 1.5 GHz bandwidth. For our application, each 1.5 GHz spectrum is divided into eight, 187 MHz sub-bands. One sub-band is assigned to each array pixel. At the design center frequency of the instrument (345 GHz), each array pixel will have 163 km s^{-1}of velocity coverage at a velocity resolution of 0.64 km s^{-1}. This velocity coverage and resolution are an excellent match to the vast majority of Galactic astronomy projects. For investigations requiring greater bandwidth (e.g. surveys of external galaxies), the number of pixels can be traded for increased bandwidth. The computer controlled bias system for the proposed instrument is essentially identical to that developed for Desert STAR.

As part of the proposed effort, we will augment the existing capabilities of Steward Observatory by purchasing a high performance micromilling machine, which will be used to frabricate all the required mixer and optical components. This machine will continue to be a valuable asset to the department and University after the proposed project is completed. All components for SuperCam (LO's, low-noise amplifiers, correlators, SIS mixing devices, closed-cycle cryostats) are available commercially or through subcontracts to other universities.

With the implementation of SuperCam, the HHT will have a new, powerful capability for exploring the origin of stars, galaxies, and planetary systems like our own. We look forward both to the exciting science that will come from SuperCam and the challenge of making it a reality.

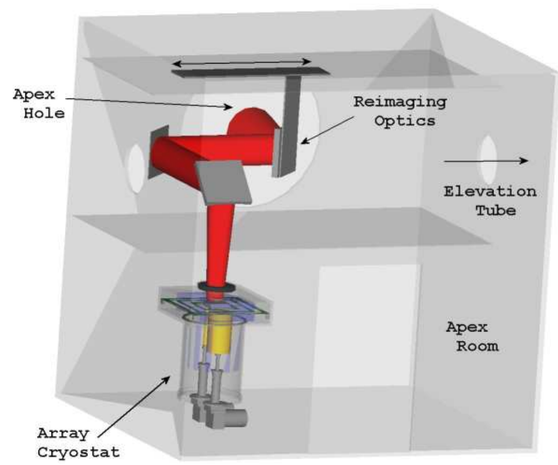

Figure 3: 3D CAD image of the optical arrangment of SuperCam within the Apex room of the HHT.

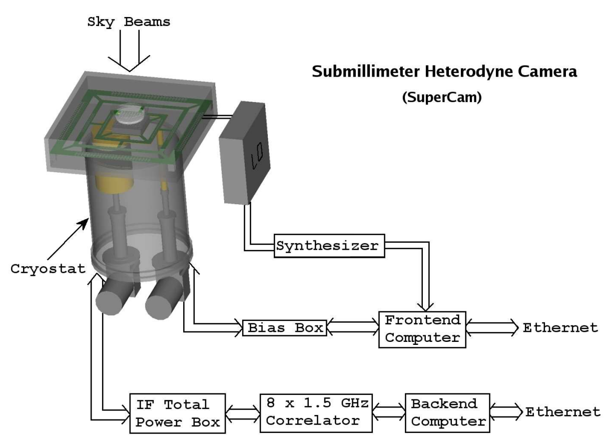

Figure 4: Block Diagram of SuperCam subsystems.