Instrumentation at the Caltech Submillimeter Observatory (CSO)

The CSO consists of a 10.4 m diameter Leighton telescope housed in a compact dome located at 4,100 m altitude near the summit of Mauna Kea, Hawaii (Fig. 1). Instruments are mounted at the Cassegrain and Nasmyth foci for spectroscopy and continuum imaging at wavelengths between 2 mm and 350 μm. Observations are carried out at night. The median zenith precipitable water vapor (PWV) is about 2 mm. Short wavelength (350 μm) observations are possible about 25% of the time, when the PWV is below 1 mm. The telescope is equipped with an active surface adjustment system that improves the surface accuracy to about 13 μm rms. Pointing is about 3″ rms. Observatory computers support both telescope operation and immediate data reduction. The CSO maintains a broad suite of instrumentation and associated data reduction software. Although the CSO staff will provide orientation, inexperienced observers are encouraged to collaborate with instrument teams or experienced observers.

Fig. 1—The Caltech Submillimeter Observatory at night. Photo: Serge Brunier.

Millimeter-wave Cameras: Bolocam and MUSIC

Bolocam is the CSO's existing millimeter-wave camera, with ≈115 functional detectors in an 8′ field of view and an instantaneous sensitivity at 1.1 mm of 100–200 mJy $s^{0.5}$ depending on weather and aggressiveness of filtering. Bolocam is mounted at the Cassegrain focus and is available in raster scan and Lissajous observing modes. An existing public analysis pipeline is available for data reduction. Bolocam has been used for photometry and surveys of dusty, star-forming galaxies and star-forming regions in our own Galaxy (including the Bolocam Galactic Plane Survey). Bolocam will be available until MUSIC is fully commissioned.

MUSIC, the Multicolor Submillimeter Inductance Camera, is the follow-on to Bolocam at the Cassegrain focus. It is designed to have 2304 microwave kinetic inductance detectors in 576 spatial pixels across its 14′ field of view. Each pixel observes in four bands simultaneously: 0.86 mm, 1.0 mm, 1.3 mm, and 2.0 mm. The angular resolutions are 22″, 25″, 31″, and 45″, respectively and expected sensitivities are 110, 55, 40, and 45 mJy $s^{0.5}$. MUSIC is currently being commissioned with approximately 30% of the array functional. Measured sensitivities are not yet available. When MUSIC is fully commissioned during 2013, it will initially be available with raster scan and Lissajous observing modes. Data reduction software will be derived from the existing public Bolocam analysis pipeline. MUSIC, with a mapping speed comparable to SCUBA-2, will be an ideal instrument for surveying for dusty, star-forming galaxies and star-forming regions in our own Galaxy and, with its unique, extended wavelength coverage, for studying galaxy clusters via the Sunyaev-Zeldovich effect. The MUSIC instrument team plans surveys covering many square degrees and roughly 200 galaxy clusters and welcomes inquiries about collaboration on these surveys.

Submillimeter Cameras

SHARC II is a second-generation 350/450 μm CSO camera with a 12×32 bolometer array. With its system quantum efficiency above 50% and background-limited performance, it takes full advantage of the CSO sensitivity at the shortest submillimeter wavelengths. SHARC II has been used for high-resolution imaging of debris disks, Galactic star formation, and the Galactic Center (Fig. 2); for resolved imaging of local galaxies; and for measuring the spectral energy distributions of galaxies at redshifts up to 6. SHARC II uses liquid helium economically and has been best used in a weather-flexed mode with a lower-frequency instrument. The

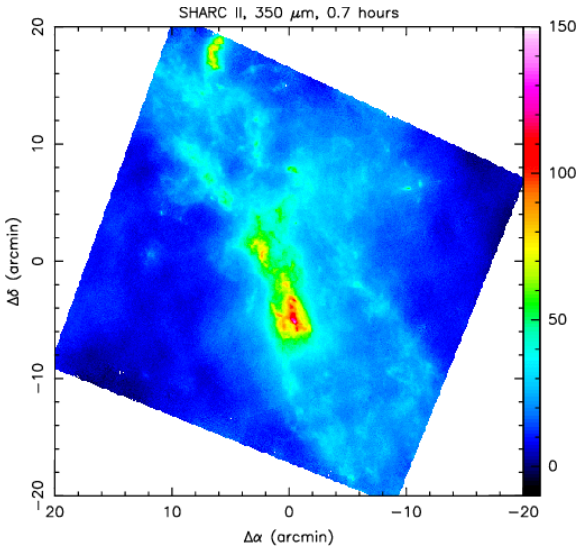

Fig. 2—CSO/SHARC II image of 350 μm dust continuum emission toward the Sagittarius A molecular cloud in the Galactic center.

SHARC II Polarimeter (SHARP) adds the capability for submillimeter continuum polarimetry. SHARP operates at the 9″ telescope diffraction limit, allowing resolved images of protostellar envelopes and determination of magnetic field strengths and geometries in molecular clouds.

Submillimeter detector technology continues to progress. A new 350 μm camera, with ≈500 kinetic inductance detectors, is under construction at Caltech and JPL. Continuing the CSO tradition of hosting state-of-the-art technology and more powerful instruments, this new camera will be demonstrated astronomically in 2013 as a step toward 100,000 pixel cameras for CCAT.

Heterodyne Receivers

A full complement of heterodyne receivers covers the atmospheric windows from 177 to 920 GHz. New receivers for the 230 GHz and 460 GHz bands have 4 GHz IF bandwidths and fully automated (synthesized) local oscillator tuning. Their balanced design, tunerless mixers provide excellent sensitivity and superb instrumental stability. Older receivers, with 1 GHz IF bandwidths, are available for the 345 GHz, 650 GHz, and 850 GHz atmospheric windows. Two FFTS spectrometers are available. The high-resolution FFTS1 provides 8192 channels across a selectable bandwidth of 1 GHz or 500 MHz, which is tunable across the 4 GHz IF band. The new wide-band FFTS2 provides 16384 channels across the full 4 GHz IF band.

Low-Resolution Spectrometers—ZEUS-2 and Z-Spec

Z-Spec is a broadband grating spectrometer that covers the full 190–310 GHz atmospheric window instantaneously. Z-Spec is designed to measure redshifts of distant galaxies using the CO rotational ladder—at least two ^{12}CO lines are redshifted into the Z-Spec bandpass for galaxies at $z > 0.9$ (Fig. 3). The broadband capability also allows fast line surveys of local galaxies to measure HCN, CN, CS, SO, and other molecular species. Z-Spec will be available at the CSO beginning in mid- to late-summer, 2013.

ZEUS-2 is a long slit echelle grating spectrometer that delivers large bandwidth ($\Delta\lambda/\lambda$ up to 5%) spectra in the 350 μm, 450 μm, and 650 μm telluric windows with a resolving power R ~ 1000. Spectra can be obtained simultaneously in the different windows and the long slit provides 9 spatial pixels. The array layout and order of the echelle grating are such that the instrument can simultaneously observe—and map—the (arguably) four most important diagnostic lines in the submillimeter windows—CO (7–6), ^{13}CO (6–5), and [CI] 370 μm and 609 μm—in nearby extended sources. Furthermore, over much of the redshift 1–2 interval the [CII] 158 μm and [NII] 205 μm lines can be observed simultaneously from dusty star forming galaxies, thereby characterizing both the diffuse ionized and PDR gas. ZEUS-2 will not be available in 2013 but is expected to reside half of the time at the CSO in 2014 and onwards.

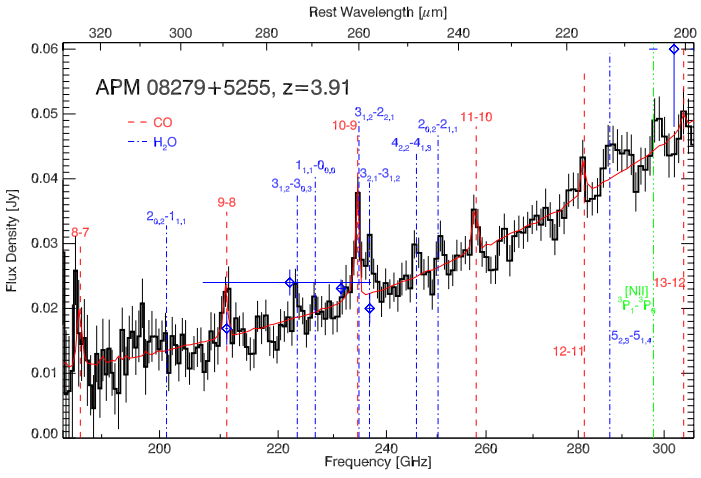

Fig. 3—Z-Spec spectrum of the lensed quasar APM 08279+5255 at z=3.91, obtained in a total of 25 hours of observation. Six water transitions are convincingly detected between 220 GHz and 255 GHz.