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The First Broadband Millimeter-wave Spectroscopic Study of the Warm Molecular Gas around the Cloverleaf Quasar

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We present the first broadband (λ=1–1.5mm) spectrum toward the z=2.56 Cloverleaf Quasar obtained with Z-Spec, a millimeter-wave grating spectrograph on the Caltech Submillimeter Observatory (CSO). The observation band corresponds to rest-frame 272 to 444 μm, and we measure the dust continuum as well as all four transitions of ^{12}CO lying in this range. The CO $J = 6 \rightarrow 5$, $J = 8 \rightarrow 7$, and $J = 9 \rightarrow 8$ measurements are the first, and now provide the highest-J CO information in this source. The power-law dust emission, $F_\nu = 14\,\mathrm{mJy}(\nu/240\mathrm{GHz})^{3.9}$ is consistent with the published continuum measurements.

We use all available transitions and our ^{13}CO upper limits to constrain the physical conditions in the Cloverleaf molecular gas disk. We find a large mass ($2 - 50 \times 10^9 M_\odot$) of highly-excited gas with thermal pressure $nT > 10^6\mathrm{Kcm}^{-3}$. The ratio of the total CO cooling to the far-infrared dust emission exceeds that in the local dusty galaxies. We conclude that both UV photons and X-rays likely contribute to the potential heating sources.

We also present the current performance of the Z-Spec on CSO, and discuss capability of detecting lines from high-z submillimeter galaxies. Finally, it is noteworthy that the Z-Spec instrument is a prototype for a planned far-infrared focal plane instrument onboard the next generation space infrared telescope SPICA.