1. Introduction
Disks surrounding protostars are the birthplaces of planets. Knowledge of the dynamics and chemistry in disks is thus crucial to understanding planet formation. Disks typically have radii of at most 1000 AU. The ro-vibrational transitions of CO are good tracers of disks, and are thus less affected by extinction than optical and near-IR tracers. We are conducting a high-resolution (R=25,000; $\Delta\nu=12\text{ km s}^{-1}$) 4.7 $\mu$m spectroscopic survey of 100 protostars visible from the northern hemisphere. Here we present the first results from this survey.

2. Observations
All observations were obtained over several observing sessions from 2000–2003 using the NIRSPEC spectrometer (McLean et al. 1998) at the Keck II telescope on the summit of Mauna Kea, HI, USA. NIRSPEC was used in its high resolution mode, R=25,000, providing a Nyquist sampled velocity resolution of 12 km/s. Typically 4-6 spectral orders per source were observed in the wavelength ranges 4.64-4.83 and 4.93-5.13 $\mu$m.

3. A Shrinking Disk?
L1489 IRS is a low mass protostar (0.65 $M_\odot$) in the Taurus Molecular Cloud, surrounded by a large, 2000 AU radius, disk seen at millimeter wavelengths (top left) and in scattered NIR light (top right). The kinematics of the disk, derived from high resolution HCO+ line emission, correspond to Keplerian rotation with an infall component. At the infall site deduced, the disk would collapse within 2000 years (Hogerheijde 2000). It is hypothesized that this protostar is in a short-lived stage between Class I protostars with large disks and T Tauri stars with smaller, centrifugally supported disks.

We observed L1489 IRS at R=25000 in the 4.7 $\mu$m fundamental transition of CO. Absorption by gas phase 12CO, 13CO, and CO+ is detected as well as the deep band of solid CO (see Section 4). The gas phase lines show a prominent red-shifted absorption wing, that we interpret as disk material infalling towards the star, thus confirming the shrinking disk picture. However, a power law disk model (red line, figure below) overestimates the mass accretion rate near the star. Thus, in this picture, only a portion of the disk is collapsing, most likely the surface layers.

4. Direct Observations of Ices in Disks
Large depletions of gas phase species are expected in circumstellar disks. Under favorable edge-on inclinations the ices can be directly observed in the IR. Here we show 4.7 $\mu$m observations of frozen CO in such edge-on disks and an example face-on (emission) source on top of the data. These are the ONLY case known with directly detected ices in disks. The sources are ordered from top to bottom with an increasing CO depletion factor, and are likely increasingly edge-on. SPITZER should tell as much more.

The high quality Keck/NIRSPEC 4.7 $\mu$m observations have allowed the most detailed band profile analysis of the solid CO band. Even at the very top, where the CO band is observed toward L1489 IRS (see also Section 3), the broad central peak, from highly volatile CO-rich ices (green), is accompanied by red and blue wings due to less volatile inclusions of CO in H2O and CO-rich ices. The abundance of volatile CO-rich ices is remarkably low and we conclude that these have evaporated in the upper layers of this slightly inclined – edge-on – Disk (see also Pontoppidan et al. 2003).

5. Discovery of the $^{13}$CO Isotopologue in Interstellar Ices
As part of our survey we discovered the absorption band of $^{13}$CO (top) in the ices in the envelope surrounding the massive protostar NGC 7538 IRS9. The band profile strongly limits the ice composition: an excellent fit is obtained for pure CO ices (red). Simultaneously fitting the $^{13}$CO band indicates these pure CO ices must reside on ellipsoidal grains. Thus we conclude that simultaneous observations of solid 12CO and 13CO provides a new tool to study the composition and chemistry of ices, also in disks.

6. Tracing the Inner Regions of Herbig Ae and T Tauri Disks
We have also observed a sample of older, isolated Herbig Ae (top) and T Tauri (bottom right) stars with significant IR excesses. The 12CO $v=0$ emission is detected at 5-20% of the continuum up to the J=4-3 level (top left), but any vibrationally excited emission is weak at best. The much broader HI lines observed indicate that accretion continues in these stars.

When corrected for distance and estimated inclination angles, the CO rotation diagrams of these disks are remarkably alike (figure to right). The curvature is attributed to highly optically thick 13CO lines, as verified by the detection of 13CO in AB Aur, and to the large temperature gradients in disks.

While isothermal emission models (dashed curve in rotation diagram, c.f. Britain et al. 2003, Najita et al. 2003) can account for the observed line intensities, they fail to reproduce the narrow, single peaked profiles observed in moderate inclination sources such as MWC 480 (i=38$^\circ$). Fits based on the shadowed disk models of Natta, Dullemond and co-workers (see figure above), that include BOTH resonance fluorescence driven by the 4.7 $\mu$m dust continuum radiation and thermal emission, can successfully fit the rotation diagrams (solid curve in rotation diagram) and the observed line profiles (top right). The disk shadowing also naturally explains the lack of vibrationally excited emission that would be produced by UV excitation.

7. General Conclusions and Future Work
We conclude that high resolution observations of the CO fundamental in the 4.6-5.15 $\mu$m spectral region provide a wealth of information on the structure and composition of circum-protopstellar disks over a wide range of radii and physical conditions. The appearance of the features, both in solid and gas phase, depends strongly on the disk inclination and radial structure. A selection of the first results is shown in this poster. Work on a flux-limited sample of protostars (i<100$^\circ$) is in progress. Many of these sources will be observed in the 5.3-8 $\mu$m wavelength range with the IRS spectrometer on board of NASA’S Spitzer Space Telescope in the near future, providing spectral energy distributions and additional spectral features (silicates, ices). The combined data sets will provide fundamental properties of disks surrounding low mass protostars.

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9. References
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