Time-domain spectroscopy at moderate spectroscopic resolution: What can we learn?

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Abstract: With the advent of multi-fibre spectrographs it is natural to explore what can be learned if the same objects are observed multiple times. What kinds of new time dependent phenomena could be discovered from multiple epoch spectroscopic observations?

At moderate spectral resolution (R = 5000 to 20000) and focusing on stars, two areas seem to be particularly exciting:
1) radial velocity variability. 2) Young star variability.

Radial velocity (RV) variability. Stars can vary in radial velocity without varying photometrically. Such objects would be missed from a spectroscopic follow up program that only chose objects via photometric variability. Many binary and triple systems are not strongly photometrically variable, however if observed at multiple binary and triple systems can be identified via the accelerations of features in the spectrum. For the F- and G-type Population I stars that 58% are non-single and 21% are in triple or higher level systems (Fuhrmann+17). The statistics of binary and triple systems and how they depend on stellar population could be quantified via a multiple epoch radial velocity survey. As 3D space motions depend on radial velocity measurements, better understanding of binary and triple system populations will help us improve derived 3D velocity distributions based on single epoch RV measurements. Binary and triple systems are interesting for their own sake as the statistics of drifts in radial velocity constrain the numbers of large planets in the outer parts of solar systems and the number of brown dwarfs in the brown dwarf desert (e.g., Quillen 2008). The APOGEE survey routinely observes stars more than once to reach a required S/N criterion for each star. This has let them discover substellar companions via radial velocity variations and explore binary statistics (see Troup+16). Interpretation of interesting objects discovered via their odd abundances such as the young high alpha abundance stars (Chiappini+15, Martig+15) can be influenced by binarity (Jofre+16,Perets14) as abundance variation can be caused by binary or triple evolution scenarios. Likewise for the large number of blue stragglers identified in SDSS (Santucci+15). With statistical binary information mechanisms for blue straggler formation can be constrained in the thick disk and other environments. We expect that radial velocity measurements from APOGEE are improved because they have constraints on binary induced motions from the subsample of stars with multiple epoch observations. RV measurements of stars in streams can be used to study the shape of the Galactic halo, however these measurements are hampered by errors caused by binaries. Identification of binaries can improve the radial velocity measurements and so the constraints on halo shape and cluster evaporation. RV measurements of stars in faint halo dwarf galaxies or clusters can be used to measure the dark matter fraction in these objects. However if binaries are present in the sample then these measurements give only a limit (the dispersion is overestimated giving a larger dark matter fraction than should be measured). In the galaxy disk cluster and stream membership is also dependent on RV precision, and so also hampered by uncertainties in binarity. One could argue that all RV surveys should plan a cadence of repeat observations so as to improve RV measurements and enable statistical corrections based on binary statistics. To carry out a multiple cadence RV survey, there may not be a need for high resolution (~20,000) spectroscopy for repeat observations as some surveys have argued that R=2000 is sufficient (the LAMOST survey?)

Background: Are there other proposed time domain spectroscopic surveys? Yes. The Time Domain Spectroscopic Survey (TDSS; Morganson+15) is proposed at fairly low spectroscopic resolution (R~2000) and while the point of this survey is to study variable objects, 90% of targets likely to be observed only once. The name of the survey arises because the targets are selected via their photometric variability. A focus of this survey is study of AGNs. APOGEE co-adds multi-epoch spectra to achieve a desired S/N (Majewski+17) but individual spectra can also be used to look for spectroscopic variability. In stellar physics numerous studies have used multi-epoch and high spectral resolution spectra (R>100000) however most of these studies necessarily have focused on single and very bright stars. For example to study their magnetic fields (along with polarization) and differential rotation using starspots. Only a few T-Tauri stars have been studied spectroscopically with multi-epoch observations (e.g., Bouvier+1999,+2003).

Young star spectroscopic variability: Young stars are photometrically variable. In fact variability is one way to pinpoint young stars in the field (Plavchan+08). Variable stars discovered in the 2MASS calibration database and K2 light curves were later identified to be young (Parks +14, Plavchan+08, Ansdell+16). Photometric studies (those mentioned about) and a series of papers dubbed CSI-2264 by a CoRot team (e.g., Alencar+2010; Cody+14), and the Palomar transit factory, (e.g., Findeisen+13) have identified a number of mechanisms for young star variability including star spots, flares, variations in accretion rate, accretion hot spots and shocks, disk warps, binarity, disk clumps and occultations by disk material (e.g., Parks+14) or intervening accretion streams (e.g., Bodman+17). Photometric variability alone is often not sufficient to tell these mechanisms apart. Numerous mechanisms are proposed to account for variability in photometric surveys but often only light curve slopes and sometimes color variations are available to help differentiate between variability mechanisms. We would hope that multi-epoch spectroscopic observations may break degeneracies and so actually differentiate between mechanisms. Clusters and moving groups of different ages can be studied probing accretion dynamics during the age of planet formation and early exoplanet system evolution. For low mass stars with magnetospherically truncated disks, periods are typically 2--8 days and spectroscopic monitoring a few dozen stars over a period of a week would catch a sample in a variety of orientation angles, accretion states and phases, and during an epoch when planet formation would be taking place. Variations in atomic lines associated with intervening gas would pin-point the location of absorbing gas via temperature, density and ionization state diagnostics. Variations in emission associated with accretion hot-spots and shocks would constrain accretion models and allow time dependent measurements of accretion dynamics. Accretion flows can reach velocities of a few hundred km/s so velocity information in the time domain could be interesting. A multi-epoch survey that included many young stars might also make serendipitous discoveries of rare events such as occulting planetary disks (J1407; Mamajek+12) and occultations of evaporating or disrupting planetesimals (transient atomic absorption lines on stars such as Beta Pic, (e.g., Lecavelier des Etangs+99), or help pin down the nature of absorbing material in Boyajian's (Taby's) star; Boyajian+16).