Gaseous Planet-Forming Disks

Ground-breaking work over the last 10+ years has shown that giant planets are common companions to nearby stars. Their orbital properties vary widely in mass, orbital radius, and eccentricity. This diversity, both remarkable and largely unanticipated, sparks a number of questions. How do planetary systems form? What are the physical mechanisms that govern the formation of such systems? Do they commonly produce solar systems like our own? How does life arise in these systems?

At the same time, studies of young stars carried out over the last few decades show that essentially all sun-like stars are surrounded at birth by a circumstellar disk, the material from which planets likely form. Thus we can study the process of planet formation by observing young disk systems that may be forming planets in the present era. The study of the *gaseous* component of these disks, currently in its infancy, has the potential to provide unique insights into disk dynamics and chemistry as well as the physical structure of gaseous disks (e.g., Najita et al. 2007; Bergin et al. 2007 for reviews).

Spectral Line Diagnostics of Gaseous Disks: We have now, through work carried out over the last 10+ years, identified a wide variety of gaseous diagnostics that probe the planet formation region of disks (e.g., Najita 2008 for a review). The range of disk radii probed by these diagnostics (<5 AU) complements the larger disk radii that will be well probed by *Herschel* and ALMA. The table below highlights some of the known diagnostics that are accessible to ground-based telescopes. Other entries (*in italics*) indicate potential diagnostics that can also be investigated.

Disk radii	**Wavelength**	**Diagnostic**
< 1AU	K-band L-band M-band	CO, H_2O OH, H_2O, C_2H_2, HCN, *CH_4, H_2CO, C_2H_6, CH_3OH…* CO
~few AU	N-band	H_2O, OH, HCN, C_2H_2, NH_3 *CH_3, HNCO, HC_3N, C_3H_4, SiO, SO_2, etc.*
> few AU	Optical K-band N-band	OI 6300A H_2 ro-vib NeII 12.8 μm Pure rotational (MIR) transitions

Most of the NIR diagnostics were discovered and characterized through ground-based spectroscopy at low and high spectral resolution. Low resolution spectroscopy with the *Spitzer Space Telescope* has shown that MIR molecular diagnostics are found in emission in nearly all accreting young stars (Carr & Najita 2008). The brightest MIR emission features can be studied at high spectral resolution with ground-based 8-m class telescopes. Some molecular bands (C_2H_2, HCN) have also been detected in absorption with *Spitzer*. The brightest sources among these can be studied from the ground at high spectral resolution, where the increased sensitivity to individual lines allows the detection of molecular species that are not detected by *Spitzer*.

High Spectral and Angular Resolution, High Sensitivity: High resolution spectroscopy (R>20,000) is critical not only to optimize the sensitivity to individual lines, but also to measure line profiles. Spectrally resolved lines can be used to determine whether a diagnostic arises in a disk and (under the assumption of Keplerian rotation) over what range of disk radii. When high resolution spectroscopy is combined with high angular resolution, as in spectroastrometry, the radial range from which a diagnostic originates can be probed more directly without having to assume Keplerian rotation. Several recent spectroastrometric studies have made use of the 4.7μm CO transitions to study the structure of gaseous disks (Pontoppidan et al. 2008; Brittain et al. 2008; van der Plas et al. 2008). The spectral resolution required to resolve individual lines (R>20,000) is unique to ground-based facilities and complements the lower spectral resolution that will be available with MIRI on *JWST*. High Sensitivity in the infrared is critical for such studies. The minimum requirements for real progress are capabilities such as NIRSPEC on Keck and TEXES on Gemini.

Example Questions: The above diagnostics and techniques can be used to probe planet formation processes and address questions of astrobiological interest such as the following.

Studies of the *evolution of the gas content* of disks probe the dominant pathways for giant planet formation and the origin of the masses and eccentricities of terrestrial planets, issues that are closely related to habitability and the likelihood of solar systems like our own. Considerable effort has therefore been devoted to developing a reliable tracer of dissipating gaseous disks. NeII is a promising tracer based on theory (Glassgold et al. 2007) and is commonly detected in *Spitzer* spectroscopy of T Tauri stars. The role of spectroscopy with 8-m class telescopes is to verify that the NeII line originates in a disk by measuring the line profiles of the brighter emission line sources. Observations like these provide the basis for interpreting (spectrally unresolved) NeII emission line surveys from *Spitzer* and *JWST*.

Studies of the *molecular abundances* of disks probe disk chemical synthesis. The possibility of an extra-terrestrial origin for the precursor molecules that led to the emergence of life on Earth is under serious consideration in astrobiology today. Were the chemical building blocks of life synthesized in circumstellar disks and delivered to planetary surfaces by comets and asteroids? The molecular diagnostics listed above can measure the molecular abundances of important chemical precursors and thereby constrain the pathways and products of disk chemical synthesis.

Spectroscopy with 8-m class telescopes is needed to demonstrate that a given molecular diagnostic arises in a disk. For example, high resolution spectroscopy of bright water lines detected with *Spitzer* shows that the emission line profiles are consistent with emission from a disk within a few AU of the star (Knez et al. 2007; Carr et al., in preparation). Bright sources that show molecular absorption from an edge-on disk are unique opportunities to search for rare molecular species, as they likely probe larger column densities of gas in absorption. Recent studies of this kind do indeed detect molecular species not detected by *Spitzer* (e.g., NH_3) and show that the absorption arises (at least partly) in an edge-on disk (Lahuis et al. 2006; Doppmann et al. 2008; Gibb et al. 2007; Najita et al., in preparation).

Studies of the *physical structure* of disks may enable the indirect detection of giant planets in the process of formation. Forming Jovian and supra-Jovian mass planets are expected to carve gaps and inner holes, respectively, in the gaseous disks from which they form. The above diagnostics can be used to probe the radial distribution of the gaseous disk in order to search for gaps and inner holes. Measurements of this kind can be used to infer what kinds of disks (i.e., what initial disk masses) lead to what kinds of planets (i.e., what outcome planetary masses and orbital radii). This issue can be addressed by combining ground-based observations with those made by *Spitzer* and *JWST*.

[Note: The description above includes input from survey respondents 381, 436, 437, and 626.]

Dusty Galaxies and 10 m telescopes : Tom Soifer

Over the last decade, surveys undertaken with MIPS on Sptizer, SCUBA on JCMT, and many other platforms have made it clear that much of the star formation and AGN luminosity in the distant universe is occurring in extremely dusty galaxies that are hidden from view at optical wavelengths. The galaxies hosting this activity are highly luminous, with emergent luminosities of 10^{12} - 10^{14} Lo, comparable to the luminosities of quasars. Their peak space density appears to occur at z~2, with high comoving densities of such systems extending out to at least z=4. The high redshift limit for these systems is defined by the search techniques, rather than any physical processes.

While these systems are comparatively bright at their discovery wavelengths (i.e. few - 10 mJy at submm wavelengths, 0.1 - 10 mJy at 24um from Spitzer), by their very nature such galaxies are extremely faint in the optical and Near IR. Understanding the characteristics of these galaxies, what are their power sources, and how they fit into the overall evolutionary history of galaxies requires substantial investments in large (6.5-10m class) telescope time to probe their natures.

These systems are simply too faint to allow meaningful observations on smaller telescopes. even in the near IR these systems are faint, i.e. ~ 20mag at K and fainter, while in the optical 24 mag is considered a bright counterpart. The identification process is difficult, requiring deep images at optical and/or near infrared wavelengths. This is most efficiently done with 8-10m imaging. The follow-on spectroscopy at optical and near infrared wavelengths that is necessary to establish properties as basic as redshifts, as well as spectral classifications, require many hours of 8-10 m telescope time. Probing other properties, e.g. morphology and dynamics requires sub-kpc spatial resolution. This angular resolution and sensitivity is afforded only by adaptive optics fed imagery and spectroscopy on 8-10m telescopes.

Tens of such galaxies have been observed to date. To address the deeper questions posed by these heavily dust enshrouded systems require studies of hundreds to thousands of such systems. To accomplish this requires hundreds of nights of 8-10 m class telescopes.

Galactic Archaeology from High Resolution Detailed Chemical Abundance Studies: Andy McWilliam
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An important probe for understanding galaxy evolution, with large telescopes, is obtained through detailed chemical abundance studies made with high resolution optical and infrared spectrographs.

The chemical composition of long-lived stars in Galactic components (i.e. in the bulge, halo, thin and thick disks) provide an important tool for understanding the star formation history and evolution of the Galaxy. Particular elemental abundance ratios are sensitive to the mass and metallicity of the progenitor stars that were the sites of nucleosynthesis. Thus, these diagnostic abundance ratios provide information on the history of the star formation rate (SFR), the formation timescale, and the initial mass function (IMF). In the context of chemical evolution, the abundance ratios also provide information on the role of mass inflows and outflows during Galactic formation.

The detailed chemical abundance patterns also permit "chemical labelling" to identify and estimate the fraction of distinct subsystems present in the Galaxy (in addition to kinematic signatures). This is important for testing the role of accretion and hierarchical structure formation in the evolution of the Galaxy.

In addition, our knowledge of the astrophysical sites of nucleosynthesis is improved by comparing chemical composition across a variety of systems (galaxy type or galactic sub-component). Both the chemical evolution history and the physics of nucleogenesis must be solved simultaneously.

Numerous projects to be pursued with current large telescopes fall under the umbrella of Galactic archaeology, for example:

1. Detailed chemical abundance studies of stars in the Galactic bulge. The bulge constitutes the nearest spheroid, that can be studied in great detail. Thus, the bulge provides a template for understanding spheroid systems, such as extra-galactic bulges and giant elliptical galaxies; in particular, for understanding their evolution from low resolution spectra.

2. Detailed abundance studies of stars in nearby galaxies of the Local Group (Magellanic Clouds, the bright dwarf Spheroidals, and the Irregulars). The results provide information on chemical evolution under a variety of galactic environments, for testing predictions based on our current understanding of chemical enrichment from studies of the Galaxy. While some detailed abundance studies have already been undertaken, the number and spectral quality of the spectra could be greatly increased, in order to measure many more elements, and better define these systems. The abundances also constrain the fraction of such systems that could have contributed to the Galaxy.

3. Studies of the abundance ratios stars and GCs in the Galactic halo. The abundance ratios and the inhomogeneity implied by the dispersion constrain the role of dwarf galaxy accretion during halo formation.

4. The search for, and abundance study of, extremely metal-poor (EMP) stars, below [Fe/H]$\sim$$-$3, provides clues to the earliest phase of chemical evolution. The dispersion of element ratios in some EMP stars are evidence that certain elements in those stars were dominated by individual supernova events

(SNe). Thus, the measured abundance ratios in EMP stars constrain SN yields at low metallicity. Furthermore, some systematic element trends at low metallicity (e.g. Co/Cr) may be the chemical fossil of population III stars. Systematic study of EMP stars to examine these possibilities is currently limited by the small number known. However, ongoing and future surveys (e.g. SEGUE, SDSS, PANSTARRS and LSST) will likely produce many more candidates.

5. New low-luminosity dwarf companions to the Galaxy have recently been found by the Sloan survey. Detailed chemical of the Her dwarf galaxy has found a very unusual composition, which suggests enrichment by a small number of massive SNe, and possibly an unusual enhancement of the putative population III composition. It is not known whether the low luminosity dwarf galaxies have unusual composition as a group, perhaps due to their physical characteristic (e.g. high dark matter content), or if the small SNe numbers led to an incomplete sampling of the SN IMF. In addition, these objects may be important source of the EMP stars in the halo field. To address these issues, detailed studies of stars in the extant group of low luminosity galaxies is warranted. Future surveys, such as LSST, are expected to find more of these systems. While these galaxies are relatively close, the RGB is not well populated, so typical stars are very faint. Therefore, multi-object, high resolution, spectra should greatly improve the data acquisition efficiency. These systems are typically less than 10 arc minutes across.

6. High resolution abundance and kinematic studies of thin and thick disk stars to understand the evolution of the Galaxy and disk galaxies.

7. High resolution abundance studies of globular clusters in their integrated-light (GCIL) is a new technique to obtain chemical abundances of extra-galactic GCs. The power of this technique is that it can be used to study the chemical composition of old systems at large distances, which was previously unobtainable. Detailed chemical abundances of red giant stars are currently limited to only stars in nearby galaxies. With current spectrograph efficiencies even the next generation of large telescopes will be limited to the Local Group.

However, in order to fully understand galaxy and chemical evolution, from detailed chemical abundance ratios, it will be necessary to study all galaxy types, including giant elliptical galaxies. While acquisition of the necessary spectra will be challenging the efficiency would be aided enormously with multi-object, high resolution, spectrographs. The typical field size for galaxies at $\sim$5Mpc is $\sim$10--20 arc minutes.

8. Spectral stacking. In order to obtain detailed chemical abundances of stars to the edge of the Local Group (e.g. M31, M33) the use of multi-object, high resolution spectrographs could be employed to stack many low S/N spectra, obtained simultaneously. These spectra would be stacked according to approximate metallicities obtained either photometrically, or by cross-correlation techniques. Integrated-light abundance techniques would be used to measure abundances from the combined spectra. In this way abundance ratio trends with metallicity could be obtained, and used to infer evolutionary history.