Protostellar and Planetary System Studies

The proposed interferometer's capability to probe < 100 milliarcsecond scales with exceptional sensitivity at submillimeter through far-infrared wavelengths makes it ideally suited for unique studies of protostellar & protoplanetary evolution. It will address fundamental questions associated with the earliest stages of star formation, the chemical and physical evolution of circumstellar disks, and the properties of the largest planets that form within them. These studies will:

1. **Establish the pivotal relationship between protostellar infall, thermal and rotational support, turbulence, and outflow in the formation of stars.**
2. **Provide detailed measurements of circumstellar disk structure and evolution**
3. **Constrain planet formation models by observing protoplanet formation directly**
4. **Test the ubiquity of Kuiper Belt and Oort clouds in the late evolution of star forming disks and post-main-sequence stars**
5. **Measure the oxygen content of the nearest Jovian-like extrasolar planet atmospheres, and yield a unique testbed for NASA Life Finder missions**

PROTOSTELLAR INFALL

One of the longest-standing problems in the field of star formation is the paucity of evidence for protostellar collapse. At low angular resolution, the signature of infall is dwarfed by the competing effects of cloud core rotation, turbulent and thermal velocity dispersion, outflow, the details of spectral line radiative transfer, and the depletion of gas-phase elements onto dust grains (Evans 1999 and references therein). Measurement of atomic oxygen at 63 μm and gas phase water (ex. 179, 538 μm) from space dramatically promotes the measurement of gas actually partaking in the gravitational collapse of a cloud core. The interferometer's high angular resolution will enable competing dynamical effects in protostellar envelopes, outflows and disks to be both spatially and kinematically disentangled from the signature and evolution of infalling material.

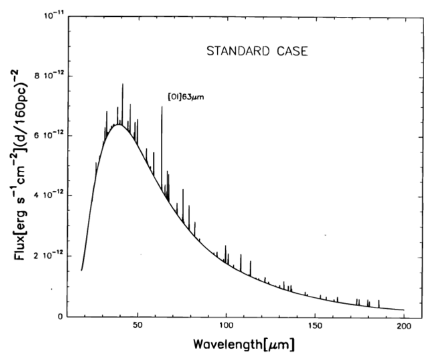

Figure 1: Model of protostellar envelope emission from Ceccarelli et al. (1996) demonstrates strong lines of atomic oxygen and water

EVOLUTION OF PLANET-FORMING DISKS

The innermost 50 AU of circumstellar disks are of paramount interest as all of the planets in our Solar System and all (>110) detected exoplanets are found there. The proposed interferometer provides <100 milliarcsecond resolution at the frequency of the bright 179 and 538 μm lines of water, allowing this planet-forming region to be spatially well-sampled in all of the nearest star forming regions within 300 pc (ex. Taurus, rho Oph, R CrA). The abundance of water relates the chemistry of disk dust and gas to their evolution and subsequent processing into planets (Ceccarelli et al. 1996, 1999). The high interferometric angular resolution allows these processes to be measured and spatially isolated in the disk, establishing chemical chronometers for the evolution of each protostellar system (van Dishoeck & Blake 1998). In contrast to water, the 15 milliarcsecond resolution afforded at the 63 μm fine structure line of atomic oxygen extends this reach to the Orion molecular cloud, and provides a chemically-insensitive thermometer and densitometer of disk gas. It also yields a critical measure of the accretion rate in deeply obscured protostellar systems where traditional optical and ultraviolet techniques are inapplicable.

MODELS OF PLANET FORMATION

Two principal classes of models have been invoked to explain the formation of planetary systems: core accretion and gravitational instability (Pollack 1996, Youdin & Shu, 2002). The extent to which each (or both) process may exist in circumstellar disks has not been established. Furthermore, recent theoretical work by Sari and Goldreich (2003, astro-ph:0307107) and others suggest there is a symbiotic relationship between the accretion of material in protostellar disks and the inward migration of planets. In this scenario most planets commit suicide by promoting the accretion of the disk material to which they are locked. It is only the last generation of planets that survive to form a long lasting planetary system. Observations of oxygen line emission will enable the search for signatures of planetary accretion during the earliest phases (Class 0, I, II) of protostellar evolution, and will test whether the episodic outbursts observed in protostellar objects are associated with planetary accretion. If the proposed link between accretion and planetary migration is correct, then this would indicate that planets are not only ubiquitous, but play an essential role in the early phases of stellar evolution.

COMETARY RESERVOIRS AROUND PRE- AND POST- MAIN SEQUENCE STARS

The surprising detection of water in the 1_{10}-1_{01} line at 538 μm toward the carbon-rich post-main-sequence star IRC+10216 by Melnick et al. (2001) suggests the use of water line emission in such objects as a probe of vaporized cometary systems in other stellar systems, and hence a measure of the frequency and nature of planetary systems like our own in the Solar neighborhood. Such measurements would be a natural complement to the radial-velocity planet finding methods (e.g. Marcy & Butler 2000) that are most sensitive to the detection of massive planets orbiting near their parent stars. The establishment of a technique to find analogs of "Kuiper Belts" and "Oort Clouds" around other stars is certainly exciting, intriguing and has far reaching consequences for the assessment of habitable planets in the Galaxy. The high angular and spectral resolution provided by the proposed interferometer will test this hypothesis, and will detect and resolve the envelope of liberated water from icy cometary material in a diverse sample of evolved stellar systems.

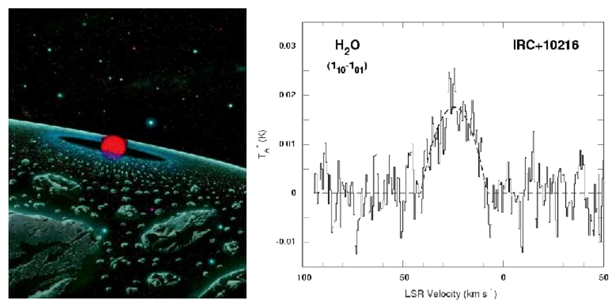

Figure 2: Artist's conception of vaporized water from comets in the IRC+10216 system; detection by Melnick et al. (2001) using SWAS

OXYGEN IN EXOPLANET ATMOSPHERES: A PRECURSOR TO LIFE FINDER MISSIONS

The evolution of life on Earth has led to an oxygen-rich atmosphere, the most prominent signature of the development of life on the planet. The high sensitivity and angular resolution of the proposed interferometer allows it to probe the oxygen (O_2, O_3) content of the nearest exoplanetary systems. At a distance of 10 pc, the continuum of a Jupiter-sized 300K blackbody is detectable at the >1 mK level at 300-600 μm, and saturated O_2 (615 μm) and O_3 (350 μm) absorption, using the Earth as a template, would be discernible by spectrally smoothing to 1-10 μm resolution. The detection of O_2 and O_3 in exoplanetary systems is an achievement of extraordinary implications! These observations would pave the way for Life Finder missions to extend the sensitivity and resolution of spaceborne interferometers to the observation of Earth-like planets around neighboring stars.

To utilize the full power of the proposed interferometer for star and planet formation studies, an instrument with a resolving power $\lambda/\Delta\lambda > 10^6$ is required. How such an instrument would be implemented within the SPECS mission concept is a key question that we will address in the proposed study.

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