Local Group: Searching for the Origins of Stars, Planets, and Life

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The Origins of Stars, Planets, and Life…

- What is the initial mass function of stars and sub-stellar objects?
- What physical variables control the assembly of stars?
- Are planetary systems like our own common or rare in the Milky Way?
- How do elements evolve into complex organic molecules that could give rise to life?
Tearing Away the Cosmic Veil: Infrared Imaging and Spectroscopy
Measuring Gas Phase ISM Abundances:

First detection of H3+ and H2 in same source (Phoenix at KPNO)
Courtesy Craig Kulesa (U. Arizona)
Aromatic emission features (PAHs)
Spitzer Space Telescope/IRAC
NGC 7023

Courtesy Kris Sellgren.
2.4 - 45 μm spectrum of interstellar ices

Follow the carbon...
Kinematics and Chemistry of Collapsing Protostars

GMT Resolution will be 2.5 AU for 4 µm of nearest targets at 50 parsecs (e.g. TW Hya).

Yorke & Bodenheimer (1999)
Herbig Haro 212 in Orion

H. Zinnecker et al. H2 Emission from the VLT. Kinematics required!
Spitzer Space Telescope
3.6-8.0 µm
Images of Protostars In NGC 1333
LBT-I can study Forming Protostars with *HST Resolution* in the Thermal IR

\[ \sim 1 \text{ arcmin diameter.} \]

Andersen, Meyer, Oppenheimer, Dougados, and Carpenter (2006)
Pre-Main Sequence Stellar Astrophysics Machine

• Rotational Properties (vsini)
• Magnetic Field Strength (Zeeman splitting)
• Accretion Rates (Brackett Line Profiles)
• Cluster Kinematics (radial velocities)
• Fundamental Parameters (Teff, log-g, abundances)

• Courtesy K. Covey (U. Washington/CfA)
From Active Accretion to Planetary Debris Disks...

Images courtesy of K. Stapelfeldt, P. Kalas, and NASA.

Planetary debris disk ~ 100 Myr old

Solar system debris disk 4.65 Gyr old!

Gas-rich disk ~ 1 Myr old
Blackbody Disk with Dynamically Cleared Gap
Diversity in Primordial Disks: Masses and Lifetimes

Haisch et al. 2001; see also Hillenbrand (2002).
Warm Gas disk lifetimes appear to be < 10 Myr.

=> No gas rich disk (> 0.1 Mjup) detected.

Spitzer IRS 11-37 um

Science of the Cold and Slow: Ground-based Mid-IR Echelle Wins!

TEXES on Gemini  Lacy et al. (2006); Richter et al. (2004)
Gas content as a function of radius and age.

Velocity resolved CO emission at 4.7 microns from Blake and Boogert (2004)
Spitzer Observations of Warm Debris Frequency Around Normal Stars: Clues to Terrestrial Planet Formation?

Meyer et al. (in preparation).

CAIs      Vesta/Mars                                            LHB
Chondrules       Earth-Moon

FEPS
Spitzer Early Release Observations


Fomalhaut Circumstellar Disk

NASA / JPL-Caltech / K. Stapelfeldt (JPL)
Resolved Spectroscopy of Debris Surrounding Sun-like Stars

Beichman et al. (ApJ, 2005); Song et al. (Nature, 2005); Weinberger et al. (2003); Telesco et al. (2004).
Direct Detection of Planets: The Problem
Direct Detection: Show me a planet!

NACO/VLT (Chauvin et al. 2004).

MMT-AO with CLIO Courtesy Phil Hinz (Kenworthy et al. 2006).

MMT-AO with CLIO/VLT with NACO

Courtesy Daniel Apai (see also Heinze et al. 2006).
No Natural Guide Stars in Key Dark Cloud Targets, But *Tip-Tilt Stars Available*. 


$m_I < 18^m$

$\sim 1$ arcmin

Diameter.
Near-IR Spectra can Distinguish Candidate Planetary Companions from Background Stars

Chauvin et al. (2005)
McLean et al. (2003)
H-R Diagrams for Planetary Mass Objects in NGC 1333

No local variations in stellar IMF (e.g. Meyer et al. 2000).
Is the IMF different in super-star clusters?
Star Formation Rate of the Universe?

Assumes a Salpeter IMF that is constant in time!
Milky Way Cluster Westerlund 1

The Super Star Cluster Westerlund 1
(2.2m MPG/ESO + WFI)

VLT NACO Observations:
Andersen et al. (2006)
IFU Spectra of Stars With 75 mas resolution

Eclipsing Binary IRS 16SW in the Galactic Center: radial velocity curve from He I line

Courtesy Kris Sellgren.
Extreme Star-Formation in NGC 604 in M 33 at 1 Mpc
Capabilities Needed in the System:

1) **Cross-dispersed echelle spectrographs in NIR at R > 30,000 and mid-IR at R > 50,000 required on 6-10 meter telescopes.**

2) **Multi-object near-IR spectroscopy 2-4 arcminute fields at R > 2000 required for characterization of young stellar pops (OH fibers with GLAO?). R > 10,000 would provide tremendous break-through in PMS Astrophysics (6-10m).**

3) **Diffraction-limited thermal IR imaging/spectroscopy (0.5-2’) on 6-10m probes the initial conditions with resolution comparable to HST and enables compositional studies of disks where planets form.**

4) **All-sky adaptive optics required for high spatial resolution imaging/spectroscopy of unique objects (6-10m).**

5) **High contrast imaging (> 10^{-7}) for debris disks and planets.**
Capabilities Needed in the System:

6) **Near-IR spectral imagery of star clusters in nearby galaxies over 2-20 arcsecond FOV will enable determination of the IMF down to solar mass stars in regions of extreme star formation (LBT-I).**

7) **MOAO targets of < 1” over 1-2’ fields of view of interest (6-10m).**

8) **Wide-field narrow-band imaging in OIR (2-4 meter).**

9) **Acquisition of OIR photometry of bright sources using 1-2 meter telescopes as well as R > 500 spectra for variable sources crucial.**

10) **Synoptic monitoring programs with 1-2 meters in UBVRIJHK can yield valuable insights into processes of star and planet formation.**
Strategies for Success?

- Community access to OIR facilities is a fundamental principle of the system.
- Public/private partnership can create a whole greater than the sum of the parts (avoid redundancy).
- Universities can provide innovation in instrumentation, and training opportunities for students.
- National Centers can provide base capabilities (standard data products of high quality) and portals for community access to rest of system.
- Future investments in programs of scale require flexibility during development, buy-in from entire community, and commitments for life-cycle costs.