Things I Never Imagined Spitzer Would Do

A Summary Talk at the Spitzer Science Conference
Michael Werner
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Spectacular Images of Large Scale Star Formation
Thousands of Young Stellar Objects, permitting powerful statistical conclusions [Neal Evans, c2d]
IF Time is the only variable AND IF star formation continuous for $t > t(\text{II})$ AND IF Class II lasts 2 Myr, THEN

Class I lasts 0.57 Myr
Flat lasts 0.38 Myr
(longer than most previous estimates)

Caveats:
GB clouds extincted (decrease by ~0.1 Myr)
Class III census incomplete
Class III not included in timescale Depends on how $\alpha$ is calculated
Class 0 mixed with Class I
Combined starless core mass distribution leads to well-constrained estimate of the IMF

\[ T_D = 10^K \kappa = 0.0114 \text{ cm}^2/\text{g} \]

**Best fit power law:** \( n \sim p \sim 2.5 \) or Lognormal

**IMF:**
- Salpeter (\( p \sim 2.4 \))
- Chabrier \( 03 \) (\( p \sim 2.7 \) \( M > 1 \text{M}_\odot \))

⇒ "Not inconsistent" with a scenario in which stellar masses are determined during core formation. If so, >25% goes into star.

\[ p = -2.5 \pm 0.2 \]
\[ \sigma = 0.3 \pm 0.03, \text{M}_\odot = 1.0 \pm 0.1 \]

Enoch et al. 2008
10,000 YSOs in Cygnus X – Joe Hora et al

Cyg OB2

Cyg OB9

AFGL 2591

IRAS 20305+4005

3.6μm=Blue, 5.8μm=Green, 24μm=Red
In Cygnus X, the Youngest Objects are found in filamentary structures. A similar result is found by Tereby for Taurus.
Further evidence for episodic accretion – how might this affect disk appearance and evolution? [Watson]
It seems that many fundamental issues about disk evolution and dissipation are still poorly understood….perhaps consideration of theoretical dissipation mechanisms, as shown in the calculation below by Hollenbach, could be helpful.
The Ubiquity and Hardiness of Protoplanetary Disks – and Perhaps of Planetary Systems:

RCW49 – GLIMPSE Image
The central star of the Helix Nebula, a hot, luminous White Dwarf, shows an infrared excess attributable to a planetary debris disk around the white dwarf central star (Su et al).
Asteroidal debris around white dwarfs implies survival of solar system throughout the evolution of the original star [Jura et al]

Fig. 3.—Comparison between photospheric-subtracted observations and predicted fluxes for the model disk described in the text. The points represent the IRAC and MIPS data listed in Table 1, while the IRS data from Fig. 1 are shown as the magenta line. The solid blue curve shows the total flux from the model, while the fluxes from regions I, II, and III are shown as dashed lines of cyan, red, and green, respectively.

Fig. 1.—IRS spectrum of GD 362. The errors are shown as the dotted black line; the feature near 14 μm is a detector/instrument artifact. For comparison, we display the scaled profiles of interstellar silicates (Kemper et al. 2004) as a dashed red line and the emission from BD +20 307 (Song et al. 2005) as a dashed blue line.
Planetary systems around white dwarfs

Prior to Spitzer, there was some evidence for infrared excesses around white dwarfs GD 362 and G29-38.

Spitzer has dramatically confirmed and extended these results:

• Crystalline silicate emission seen around 362 and 29-38
• Similar results for several other white dwarfs
• All such objects amongst small fraction of WD which show atmospheric metals
  • Metals should sink gravitationally in WD atmosphere
  • Presence of metals implies external pollution
  • Suggest common origin for circumdwarf dust and atmospheric pollution in tidal break up of asteroidal object
• Comparison of abundance pattern in white dwarf atmospheres allows study of asteroidal composition – comparative exoplanetology
Brown Dwarfs Form Like Stars: Can “Planets” have Planets?

A Brown Dwarf With a Planet-Forming Disk
Spitzer spectrum of ejecta from Deep Impact event in which a refrigerator-sized projectile collided with a small cometary nucleus.
Crystalline silicates - from the green sand beaches of Hawaii to the outer solar system to nearby stars and beyond.....
Spectral Studies By Abraham et al. (2009) & Van Boekel et al. (2004) have suggested flares as the source of crystallization and radial gradients in crystallization towards the primary.
**HD172555**, like β Pic, is an A5V star in the BPMG (~12 My old), with a highly unusual circumstellar dust spectrum rich in emission from amorphous silica and SiO gas. Unlike any other system modeled to date, tektite & obsidian thermal emission spectra are required to fit the data. A combination of olivines and pyroxenes cannot make a good fit. In fact, there are almost no pyroxenes present, suggesting these have been destroyed to make silica.

**Tektite and Obsidian Dust**: products of quick quenching of molten rock at high T, low P.

**SiO gas**: produced by vaporizing rock.

$M_{Dust} > M_{Pluto}$: 150 - 200 km radius asteroid’s worth (4×10^{19} – 2×10^{20} kg) of fine silica rich material; ~500 km radius worth (10^{21} – 10^{22} kg) of large rubble; and ~10^{22} kg of SiO gas at ~5.6 AU.

**Mineralogy**: Parent object does not seem like any known taxonomy, asteroid or comet. If one has to be selected, the parent appears to be closest to an A-type igneous asteroid: there is copious metal sulfide and olivine-type rock. However, it is not easy to show where the sizeable silica content originates - A-types are not known for this.
Fomalhaut Images [above] look nothing like Vega, although their SEDs are virtually identical.
HR8799 and its planets:  A5V star:  
M~1.5 Msun  
40 pc  
from Earth  
Estimated age  
20-160MY  
Marois et al imaged three planets: 
8799b, r=68au, M~7Mjup 
8799c, r=38au, M~11Mjup 
8799d, r=24au. M~10Mjup 
“a scaled up version of our solar system”
This image, not quite to scale, was prepared by George Rieke based on Spitzer data combined with direct imaging of the three planets. It shows the star HR8799, its three known planets, and the complex dust disk surrounding it. It is totally amazing. Like the Vega images and some of Lisse’s results, it is suggestive of dynamical episodes which mirror similar processes in our Solar System.
Continuum-subtracted T Tauri Star Spectrum – Prevalence of planets heightens interest in these and other spectra

Lines of water throughout (*)
Temperatures and emitting areas consistent with an origin in the terrestrial planet region of the disk

<table>
<thead>
<tr>
<th>Molecule</th>
<th>T (K)</th>
<th>N (10^{16} cm^{-2})</th>
<th>R (AU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$O</td>
<td>575</td>
<td>65</td>
<td>2.1</td>
</tr>
<tr>
<td>OH</td>
<td>525</td>
<td>8.1</td>
<td>2.2</td>
</tr>
<tr>
<td>HCN</td>
<td>650</td>
<td>6.5</td>
<td>0.6</td>
</tr>
<tr>
<td>C$_2$H$_2$</td>
<td>650</td>
<td>0.81</td>
<td>0.6</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>350</td>
<td>0.2–13</td>
<td>1.2</td>
</tr>
<tr>
<td>CO</td>
<td>900</td>
<td>49</td>
<td>0.7</td>
</tr>
</tbody>
</table>
C$_2$H$_2$ HCN CO$_2$

See also Salyk et al. (2008)
Spectra of YSOs provide evidence for grain growth and disk settling (Furlan)
4. Galactic Structure: Summary

1. Long Bar confirmed and (partially) mapped.

2. Tangencies confirm Drimmel (2000) and Drimmel & Spergel (2001) based on K band light from COBE, but provide more precise information.

3. Lack of stellar tangencies for other arms indicates qualitative difference between spiral arms.

4. Vigorous star formation detected at near end of Long Bar.

5. Part of Scutum Centaurus arm mapped!
On diffuse sightlines, more extinction at 4.5, 6, 8 μm than expected:

- WD01 $R_V = 3.1$ model (not shown, but was expected to be appropriate for diffuse regions) falls short from 3.6 – 8 μm

- WD01 $R_V = 5.5B$ model seems OK – but this model does not reproduce the optical-UV extinction in diffuse ISM.
Some Coming Attractions….

<table>
<thead>
<tr>
<th>Band</th>
<th>S9W</th>
<th>L18W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>9 µm</td>
<td>18 µm</td>
</tr>
<tr>
<td>Detection limit (5σ)</td>
<td>~50 mJy</td>
<td>~120 mJy</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>~5″</td>
<td>~5″</td>
</tr>
<tr>
<td>Source number</td>
<td>~851,000</td>
<td>~195,000</td>
</tr>
</tbody>
</table>

Akari [above] and WISE all sky surveys

Warm Spitzer – YSO Variability Program [cf. Muzerolle et al, 2009]
Finally, words of thanks

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