Dust & Gas around Stars
Young & Old, Near & Far

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…
Stellar Evolution

- protostar
- stellar nursery
- mass
- time
- blue supergiant
- supernova (SN)
- interstellar medium
- black hole
- neutron star
- planetary nebula
- red giant
- type II SN
- type Ia SN
- sun
- yellow dwarf
- yellow giant
- red dwarf
- brown dwarf
IR Astronomy Surveys

η Car – luminous blue variable & nebula

IRAS 1983  VISIBLE

Image credits: NASA, DSS, AFRL, NASA
Spitzer Space Telescope

- Mapping Projects
  - Cygnus-X
    - MIPS 24 & 70 μm
    - IRAC 4-band
  - MIPSGAL
    - MIPS 24 & 70 μm

- Spectroscopy Projects
  - Small Magellanic Cloud
  - Large Magellanic Cloud
  - Local Group Galaxies
  - Cygnus-X

- Infrared Spectrograph (IRS)
  - 5.2-38 μm
- Infrared Array Camera (IRAC)
  - 3.6, 4.5, 5.8, 8.0 μm
- Multiband Imaging Photometer for Spitzer (MIPS)
  - 24, 70, 160 μm
- Cryo: 2003-2009
- Post-cryo: 2009-2014

Cygnus-X
Massive Star Forming Region
<2 kpc
> $10^3$ OB stars
> $10^4$ protostars
$M_* > 10^5 \, M_\odot$
$M_{\text{tot}} > 10^6 \, M_\odot$

• **blue** = $3.6 \, \mu m$
  ~ stars
• **green** = $8 \, \mu m$
  ~ warm gas/dust
• **red** = $24 \, \mu m$
  ~ cool dust

Hora et al. 2009
Infrared Dark Clouds

IRDCs
• discovered by *MSX* & *ISO*
• very dense cold dust lanes
• youngest, most deeply embedded YSOs

LDN 896 near AFGL 2636 near G078.0+00.6
The Spitzer Cygnus-X Legacy Survey

Cygnus-X Evolved Stars

<table>
<thead>
<tr>
<th>Evolved Object Type</th>
<th># in 24μm Region</th>
<th># Det’d at 24μm</th>
<th>Det’n Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNe</td>
<td>7</td>
<td>5</td>
<td>71%</td>
</tr>
<tr>
<td>WRs</td>
<td>9</td>
<td>9</td>
<td>100%</td>
</tr>
<tr>
<td>pAGBs</td>
<td>2</td>
<td>2</td>
<td>100%</td>
</tr>
<tr>
<td>C*s</td>
<td>52</td>
<td>51</td>
<td>98%</td>
</tr>
<tr>
<td>S*s</td>
<td>6</td>
<td>5</td>
<td>83%</td>
</tr>
<tr>
<td>SNRs</td>
<td>10</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Miras</td>
<td>4</td>
<td>4</td>
<td>100%</td>
</tr>
<tr>
<td>semi-reg</td>
<td>4</td>
<td>4</td>
<td>100%</td>
</tr>
<tr>
<td>Cepheids</td>
<td>4</td>
<td>4</td>
<td>100%</td>
</tr>
<tr>
<td>RR Lyr</td>
<td>1</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>cont. bin</td>
<td>19</td>
<td>4</td>
<td>21%</td>
</tr>
<tr>
<td>Dw. Nov.</td>
<td>3</td>
<td>1</td>
<td>33%</td>
</tr>
<tr>
<td>other V*s</td>
<td>85</td>
<td>61</td>
<td>72%</td>
</tr>
</tbody>
</table>

Kraemer et al. 2010
Evolved Stars

- **BD+43 3710**: Carbon star with a bipolar outflow
- **HBHA 4202-22**: Moving Wolf-Rayet star with shell
- **G79.29+0.46**: Luminous blue variable near IRDC
• He-shell flashes & dredge-ups
  ▪ create C, N etc. & move it out
  ▪ C/O>1 → carbon star
  ▪ molecule & dust formation, wind

Adapted from Karakas & Lattanzio 2008 and Habing & Olofsson 2004
Evolved Stars: Models

HBHA 4202-22

Line through peak: 30°
Space motion: 31°
Evolved Stars: Models

Radiative transfer model with 3 carbon-rich dust shells
MIPSGAL 24 μm Survey

blue= 3.6 μm ~stars  green=8 μm ~warm gas/dust  red=24 μm ~cool dust

Carey et al. 2009, Benjamin et al. 2003
Evolved Stars

- Catalog of >400 disks & rings in MIPSGAL
- Little or no emission at other wavelengths
- ~15% previously ID’d as evolved objects
- Likely planetary nebulae or other evolved objects – missing population

Mizuno et al. 2010, Flagey et al. 2009
Magellanic Clouds

Visible Image credit: ESO
Magellanic Clouds

IRAS 100 µm
The Small Magellanic Cloud

- low metallicity: $\sim0.2\times$solar
- nearby: $\sim60$ kpc
- local surrogate for galaxies in the earlier Universe

- SKY model & LMC to predict object types for brightest MSX objects
- *Spitzer*’s IRS spectra to verify
The plan

- The plan: observe several of each type of evolved star
- These stars create:
  - dust – energy balance
  - C & N – planets, life

What happened

- The result: many, many carbon stars!

Sloan et al. 2006
SMC IRS Project

**Carbon rich**

Blue SMC carbon stars

- Source (F$_{12}$ in mJy)
- MSX SMC 202 (25)
- MSX SMC 142 (11)
- MSX SMC 066 (60)
- MSX SMC 200 (30)
- MSX SMC 162 (31)
- MSX SMC 033 (72)
- MSX SMC 105 (69)
- MSX SMC 044 (50)
- MSX SMC 198 (36)
- MSX SMC 232 (34)

Red SMC carbon stars

- Source (F$_{12}$ in mJy)
- MSX SMC 091 (26)
- MSX SMC 062 (47)
- MSX SMC 163 (76)
- MSX SMC 209 (88)
- MSX SMC 054 (58)
- MSX SMC 036 (36)
- MSX SMC 159 (56)
- MSX SMC 060 (144)

C$_2$H$_2$, HCN, CS, C$_3$, CN

**Oxygen rich**

- MSX SMC 134 (44) 3.SEC
- MSX SMC 18 (215) 3.SEC
- MSX SMC 55 (660) 3.SE
- MSX SMC 181 (102) 2.SEc
- MSX SMC 149 (99) 2.SEc
- MSX SMC 168 (22) 2.SEc
- MSX SMC 109 (54) 2.SEc
- MSX SMC 96 (23) 2.SEb:
- MSX SMC 24 (71) 2.SEb:
- HV 12122 (9) 1.N/NO

Silicates

- crystalline silicates

C$_2$H$_2$, CN, oxides – Si, Al, Mg, Fe
Extended IRS Projects

Carbon rich

• initial study: 36 objects
• extending to other IRS programs
  • ~250+ SMC
  • ~1000+ LMC
  • ~dozens Local Group

\[ \text{C}_2\text{H}_2, \text{HCN, CS, C}_3, \text{CN} \]
• Mid-IR selection, isolated, ~uniform sky coverage
• Non-variable to <<10% at 12 & 25 μm (IRAS)
• 600+ calibration stars, 1-35 μm spectral templates

• Moderate spectral resolution & photometric accuracy
• Limited actually measured spectra
Spectra for Calibration

Upgrades current calibration network to improve:

- absolute accuracy (*MSX*)
- spectral resolution (*ISO*)
- wavelength coverage (*ISO, MSX, DIRBE, Tycho/Hip, Kurucz, Pickles*)
- dynamic range (*ISO, MSX, Spitzer*)
- variability assessments (near-IR, visible)

Variability Assessments

\[ \beta\ UMi \]

\[ \text{Flux (Jy)} \]

\[ t \text{ (weeks)} \]

\[ 1.25 \mu m \]

\[ \text{Lomb-Scargle periodogram} \]

\[ \text{T Cep} \]

\[ \text{Flux (Jy)} \]

\[ t \text{ (weeks)} \]

\[ 1.25 \mu m \]

\[ \text{Lomb-Scargle periodogram} \]

Price et al. 2010
IR Periodogram Results

"Expected" Variables
- 199; 88%
- 16; 7%
- 12; 5%

Non-variables; 1457; 82%

Control Sample
- Variables; 266; 15%
- Candidates; 58; 3%
- Non-variables; 1457; 82%

IR Standards
- 589; 97%
- 17; 3%
- 1; 0%

IR Bright
- 36; 62%
- 19; 33%
- 3; 5%

Visible assessment in-progress

Kraemer et al. 2010
ΔT, shocks, molecular formation cause a lag between the visible peak & the IR peaks
TODAY: Last transit of Venus til 2117

I: 1st contact ~6:05pm
II: 2nd contact ~6:23pm
Sunset ~8:18pm

Boston University & Harvard-Smithsonian observing from rooftops & other locations (incl. indoors if cloudy)
www.bu.edu/astronomy/events/venustransit
www.cfa.harvard.edu/events.mon.html
NH Astro.Soc & McAuliffe-Shepard Disc.Ctr.
nhastro.com/events/transit.php
starhop.com/ ($)
sunearthday.nasa.gov/2012/transit/webcast.php
www.exploratorium.edu/venus/

Thanks!