Mid-IR astronomy with the E-ELT: The case for evolved stars

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Overview

(JWST and the ELTs: An Ideal Combination, Garching, April 13-16, 2010)

• Introduction: current issues in evolved star research
• Science cases for E-ELT in the Mid-IR (HR & LR spectroscopy, imaging-broadband)
• Conclusions

Some caveats:

• Focus on AGB stars (not PN, LBV/WR, SN)
• No in depth comparison to other facilities that are relevant before 2023
AGB stars
Central Star

Lifecycle of dust and gas

Shaping PNe
Key Questions

What is the mass-loss return of dust and metal enrichment by AGB stars (versus SNe)?

How does this depend on time, mass, metallicity?

Driving of the wind (radiation pressure on dust, but....)

C-rich versus O-rich (different dust species, different wind driving?)

Thermal Pulses followed by nucleosynthesis near the core (convection)

Pulsation

non-spherical

role of binarity
Sahai et al. (2009), using FTS CO rot-vibr lines 2100-2200 cm$^{-1}$ resolution of 0.02 cm$^{-1}$ 4.55-4.76 $\mu$m, $R= 107\,000$
4m telescope
no integration time, no S/N given, $M = -2.3$

"... these data, taken over 7 epochs, show that the circumstellar environment of V Hya consists of a complex high-velocity (HV) outflow containing at least six kinematic components with expansion velocities ranging between 70 and 120 km/s, together with a slow-moving normal outflow at about 10 km/s. Physical changes occur in the HV outflow regions on a time-scale as short as two days. The intrinsic line-width for each HV component is quite large ($6 - 8$ km/s) compared to the typical values ($\sim 1$ km/s) appropriate for normal AGB circumstellar envelopes (CSEs), due to excess turbulence and/or large velocity gradients resulting from the energetic interaction of the HV outflow with the V Hya CSE."
Lebzelter et al. (2012) CRIRES-POP
complete 0.97-5.3 \( \mu m \) region in 200 settings
\( R = 96 \, 000 \) at 2.17 \( \mu m \)

"A complete scan of a star with \( K = 1 \) mag reaching a S/N of at least 200 throughout the entire spectral range takes almost nine hours and is strongly dominated by observational overheads (close to 80%)"

\( M \)-band: up to 20 min. per setting (\( K = M = 4.9 \))
25 objects (1 S, 1 C)
C-star X TrA CN, CS, C₂
CRIRES

Ryde et al. (2010) Bulge Giants
CNO, $\alpha$ elements, Fe, Si, S, and Ti
$R = 70000$, $H = 12.0$, $S/N = 90$, $t_{\text{int}} = 80\text{ min}$

Smith et al. (2009), YSO
$^{16}\text{C}O$, $^{17}\text{C}O$, $^{18}\text{C}O$; 30 min., $S/N = 300$, $M = +2.0$
LR spectroscopy ⇒ Dust

devries et al. (2010)
The opacities of crystalline silicate forsterite
Jones et al. (2012)  Q-band $\sim$21 $\mu$m
Jiang et al. (2013)  

*Spitzer* IRS
LR spectroscopy

MSX LMC 61 (Groenewegen & Sloan, in prep.)

\( L = 20\,800\, L_\odot, \ \tau_{0.5} = 2.5, \ \dot{M} = 6.5 \cdot 10^{-7}\, M_\odot\, yr^{-1} \)

210 mJy at 8.0 \( \mu \)m

ELT ETC

S/N= 30 \( \quad R= 200 \)

1hour \( F= 0.65\, mJy \)

\( L = 10\,000\, L_\odot \)

\( \Rightarrow 0.6\, Mpc \)
Lagadec et al. (2011)

PAH (8.59 \( \mu \text{m} \)), SiC (11.85 \( \mu \text{m} \)), Ne II (12.81 \( \mu \text{m} \))

75 mas pixelscale, FoV = 19 \( \times \) 19 arcsec\(^2\), \( t_{\text{int}} = 30 \) sec

FWHM from 250-500 mas

"We imaged a sample of 93 evolved stars and nebulae in the mid-infrared using VISIR/VLT, TRecs/Gemini-South and Michelle/Gemini-North. We found that all the proto-planetary nebulae we resolved show a clear departure from spherical symmetry. 59 out of the 93 observed targets appear to be non-resolved."
Dusty red giants and asymptotic giant stars are confined to the 47 Tuc [MG: at 5 kpc] long period variables population. In particular, dusty red giants are limited to the upper one N8.6$\mu$m magnitude below the giant branch tip. This particular luminosity level corresponds to $\sim 1000 L_\odot$ in previous determinations to mark the onset of dusty mass-loss.
(upper) 2MASS with pointings; (lower) VISIR
HRD, combined with ACS
$N_{8.6} = 10$ corresponds to about 5 mJy
Of brightest object
$R = 300, 9.8 \mu m + 11.4 \mu m$ central wavelength
**Broadband**

**MSX LMC 1298 (→ SED peaks near \( M \)-band)**

\[ L = 29 \, 200 \, \text{L}_\odot, \ \tau_{0.5} = 10, \ \dot{M} = 4.4 \cdot 10^{-6} \, \text{M}_\odot \, \text{yr}^{-1} \]
Broadband

ERO 0550261
$L = 11\,000\,L_\odot$, $\tau_{0.5} = 120$, $\dot{M} = 3.6 \cdot 10^{-5}\,M_\odot\,yr^{-1}$
## Dust Production in the LMC

<table>
<thead>
<tr>
<th>Type</th>
<th>N</th>
<th>$\sum \dot{D}$ ((M_\odot/\text{yr}))</th>
<th>%</th>
<th>$&lt; \dot{D} &gt;$ ((M_\odot/\text{yr}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>x-AGB</td>
<td>313</td>
<td>$6.26 \times 10^{-7}$</td>
<td>65.9</td>
<td>$2.0 \times 10^{-9}$</td>
</tr>
<tr>
<td>C-AGB</td>
<td>1559</td>
<td>$1.21 \times 10^{-7}$</td>
<td>12.7</td>
<td>$7.8 \times 10^{-11}$</td>
</tr>
<tr>
<td>O-AGB</td>
<td>1851</td>
<td>$0.52 \times 10^{-7}$</td>
<td>5.5</td>
<td>$2.8 \times 10^{-11}$</td>
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<tr>
<td>aO-AGB</td>
<td>1243</td>
<td>$0.26 \times 10^{-7}$</td>
<td>2.7</td>
<td>$2.1 \times 10^{-11}$</td>
</tr>
<tr>
<td>RSG</td>
<td>2611</td>
<td>$0.31 \times 10^{-7}$</td>
<td>3.3</td>
<td>$1.2 \times 10^{-11}$</td>
</tr>
<tr>
<td>FIR*</td>
<td>50</td>
<td>$0.96 \times 10^{-7}$</td>
<td>10.1</td>
<td>$1.9 \times 10^{-9}$</td>
</tr>
<tr>
<td>Total, no FIR</td>
<td>7577</td>
<td>$8.6 \times 10^{-7}$</td>
<td>90.5</td>
<td>$1.1 \times 10^{-10}$</td>
</tr>
</tbody>
</table>

Remarks:
FIR= contaminants (YSO, PNe); quoted are \textit{DUST} MLR, so multiply by $\sim 200$.

Boyer et al. (2012)
Matsuura et al. (2009, 2012)
<table>
<thead>
<tr>
<th>Filter</th>
<th>magnitude</th>
<th>Flux (mJy)</th>
<th>magnitude</th>
<th>Flux (mJy)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>MSX LMC 1298</td>
<td></td>
<td>ERO 0550261</td>
<td></td>
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<tr>
<td>Z</td>
<td>19.97</td>
<td>0.02</td>
<td></td>
<td></td>
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<tr>
<td>Y</td>
<td>18.24</td>
<td>0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>15.47</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>12.47</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>10.22</td>
<td>54</td>
<td>22.1</td>
<td>0.001</td>
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<tr>
<td>L</td>
<td>7.28</td>
<td>296</td>
<td>12.29</td>
<td>3.0</td>
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<tr>
<td>M</td>
<td>6.53</td>
<td>412</td>
<td>10.05</td>
<td>16</td>
</tr>
<tr>
<td>N</td>
<td>4.89</td>
<td>413</td>
<td>5.49</td>
<td>240</td>
</tr>
<tr>
<td>Q</td>
<td>4.41</td>
<td>204</td>
<td>3.47</td>
<td>480</td>
</tr>
<tr>
<td>MIPS 24</td>
<td>4.19</td>
<td>152</td>
<td>2.86</td>
<td>517</td>
</tr>
<tr>
<td>350 µm</td>
<td>–</td>
<td>0.16</td>
<td>–</td>
<td>1.2</td>
</tr>
</tbody>
</table>

$N$-band 0.05 mJy S/N= 30 1hour (ETC for 42m)  
(METIS 0.03 mJy S/N= 10 1hour)

$L = 5 000 L_\odot \Rightarrow 1.9$ Mpc
outer radius of 1000 inner radii $\Rightarrow$ 20 mas $\theta$ 1.9 Mpc
## Some famous AGB+SGs

<table>
<thead>
<tr>
<th>Star</th>
<th>Radius (mas)</th>
<th>Distance (kpc)</th>
<th>$M$-mag</th>
<th>$N$-mag</th>
</tr>
</thead>
<tbody>
<tr>
<td>R Dor</td>
<td>31.5</td>
<td>0.055</td>
<td>-4.4</td>
<td>-5.0</td>
</tr>
<tr>
<td>α Ori</td>
<td>23.2</td>
<td>0.15</td>
<td>-4.3</td>
<td>-5.0</td>
</tr>
<tr>
<td>CW Leo</td>
<td>17.7</td>
<td>0.12</td>
<td>-5.5</td>
<td>-7.7</td>
</tr>
<tr>
<td>ω Cet</td>
<td>15.6</td>
<td>0.09</td>
<td>-3.4</td>
<td>-4.4</td>
</tr>
<tr>
<td>R Cas</td>
<td>9.9</td>
<td>0.13</td>
<td>-2.3</td>
<td>-3.6</td>
</tr>
<tr>
<td>VY CMa</td>
<td>6.9</td>
<td>1.2</td>
<td>-4.2</td>
<td>-6.1</td>
</tr>
<tr>
<td>U Hya</td>
<td>6.7</td>
<td>0.2</td>
<td>-1.3</td>
<td>-1.8</td>
</tr>
<tr>
<td>R Scl</td>
<td>5.6</td>
<td>0.3</td>
<td>-1.2</td>
<td>-1.8</td>
</tr>
<tr>
<td>U Ant</td>
<td>4.8</td>
<td>0.3</td>
<td>-0.9</td>
<td>-1.4</td>
</tr>
<tr>
<td>R For</td>
<td>2.9</td>
<td>0.7</td>
<td>-0.9</td>
<td>-2.0</td>
</tr>
<tr>
<td>S Sct</td>
<td>2.6</td>
<td>0.4</td>
<td>0.5</td>
<td>-0.0</td>
</tr>
<tr>
<td>V CrB</td>
<td>2.5</td>
<td>0.7</td>
<td>0.3</td>
<td>-1.0</td>
</tr>
<tr>
<td>AFGL 3116</td>
<td>2.3</td>
<td>0.7</td>
<td>-0.4</td>
<td>-3.0</td>
</tr>
<tr>
<td>AFGL 3068</td>
<td>2.0</td>
<td>1.2</td>
<td>1.6</td>
<td>-3.0</td>
</tr>
<tr>
<td>OH 26.5</td>
<td>1.9</td>
<td>1.6</td>
<td>0.3</td>
<td>-2.0</td>
</tr>
<tr>
<td>TT Cyg</td>
<td>1.5</td>
<td>0.5</td>
<td>1.5</td>
<td>1.0</td>
</tr>
<tr>
<td>AFGL 190</td>
<td>0.93</td>
<td>2.9</td>
<td>4.1</td>
<td>-0.8</td>
</tr>
<tr>
<td>IRC +10 420</td>
<td>0.48</td>
<td>7.0</td>
<td>2.2</td>
<td>-3.3</td>
</tr>
<tr>
<td>AFGL 2343</td>
<td>0.22</td>
<td>5.0</td>
<td>4.8</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Concluding remarks

+ HR spectroscopy: abundances, isotope ratios, in (nearby) LG galaxies
  - NIR will be better/sufficient in most cases

+ HR spectroscopy: kinematics (shaping of PNe)
  - To study the acceleration of wind, resolution of 100 000 is low-ish (<1 km/s desirable).

ALMA in most extended configuration with 16 km baseline:
6 mas @ 675 GHz, 37 mas @ 110 GHz
0.01 km/s @ 110 GHz
Concluding remarks

+ LR spectroscopy: dust in LG galaxies
  - JWST more sensitive, and larger wavelength coverage, but at lower spatial resolution. Case for $Q$-band

+ Imaging: shape of CSE, shaping of P-AGB, PNe
  - Saturation limit?
    Neutral Density filter versus Coronograph
    Need to probe as close as $\sim 1.5 R_\star$

+ Imaging: SED of dustiest AGB stars in LG
  - JWST more sensitive, but at lower spatial resolution.
    Case for $Q$-band
THE END