NESS – The Nearby Evolved Stars Survey:
CO observations, mass-loss rates, and dust/gas ratios

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I. McDonald (U. Manchester); and the NESS collaboration
NESS – The Nearby Evolved Stars Survey

- Largest volume-limited and statistically representative survey of AGB stars in the Solar neighbourhood
  - ~ 850 sources within 3 kpc
  - “Wedding-cake” survey in tiers based on distance and dust-production rate (DPR)
  - Observations of CO and submm continuum
  - Open Science philosophy: aim to be fully reproducible and open source

http://evolvedstars.space/
The NESS sample

Tier 0
Tier 1
Tier 2
Tier 3
Tier 4

Outlined points = mapping sample
NESS observations

• Successful proposals
  • ~1400 hrs JCMT – continuum, CO (2–1), (3–2)
  • ~200 hrs APEX – CO (2–1), (3–2)
  • ~450 hrs Nobeyama 45m – CO (1-0)
  • ~80 hrs IRAM 30m
  • ~100 hrs ALMA/ACA – higher resolution maps

• Lots of archival data
  • JCMT archival data can be incorporated automatically through pipeline reduction at CADC
  • Archival data from other sources generally requires manual reduction

• Current heterodyne reduction: JCMT RXA3 and HARP data as of July 2021, initial APEX sample of sources out to 2 kpc with Dec < -30°
JCMT data reduction pipeline

• Python script calling Starlink functions, will be made available with paper publication
• Run on CADC servers, easy download of JCMT data
• For each source:
  • Find all matching archival JCMT data of the source, searching by coordinates and frequency range
  • Correct raw files for sideband offset and convert TA* -> Tmb
  • Reduce the data with ORACDR in batches grouped by receiver and backend
  • Output a FITS image and spectrum from the reference pixel
  • Fit all observed CO & $^{13}$CO lines together with a soft parabola function, using MCMC to estimate errors on each parameter
  • Output a table of values including total observing time, rms, and line fit parameters: peak, central velocity, width, and beta (shape factor)
## Detection statistics – CO in JCMT and APEX

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>JCMT</th>
<th>APEX</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of sources</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[CO (2-1); CO (3-2)]</td>
<td>540 [322; 437]</td>
<td>435 [250; 354]</td>
<td>105 [72; 83]</td>
</tr>
<tr>
<td><strong>CO (2-1) detections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>211 (66%)</td>
<td>173 (69%)</td>
<td>38 (53%)</td>
</tr>
<tr>
<td><strong>$^{13}$CO (2-1) detections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>72 (29%)</td>
<td>52 (29%)</td>
<td>20 (28%)</td>
</tr>
<tr>
<td><strong>CO (3-2) detections</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>215 (49%)</td>
<td>157 (44%)</td>
<td>58 (70%)</td>
</tr>
<tr>
<td><strong>$^{13}$CO (3-2) detections</strong></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>53 (15%)</td>
<td>27 (10%)</td>
<td>26 (31%)</td>
</tr>
</tbody>
</table>

Note: $^{13}$CO only observed towards sources with sufficiently strong $^{12}$CO detection
[Preliminary results] – Empirical mass-loss rates vs DPR

- ~ 430 CO detections so far
- Empirical MLR formula from Ramstedt et al. 2008
  - Based on modeling of 10 sources
  - Valid for $10^{-7} - 10^{-5} \, M_\odot \, yr^{-1}$
- Mostly consistent with canonical gas-to-dust ratio (within large uncertainties)
- More outliers at very low and high mass-loss

Wallström et al., in prep
[Preliminary results] — Gas-to-dust ratios

Wallström et al., in prep
[Preliminary results] – Gas-to-dust ratios

Range: 0.34 to 16871.53
Mean: 452.52 +/- 49.18
Median: 259.41
[Preliminary results] – MLR vs velocity by tiers

Wallström et al., in prep
[Preliminary results] – Comparison with literature samples

Wallström et al., in prep
[Preliminary results] – Comparison with literature samples

- Samples from
  - Loup et al. 1993
  - Schöier & Olofsson 2001
  - Olofsson et al. 2002
  - Gonzalez-Delgado et al. 2003
  - Ramstedt et al. 2009
  - De Beck et al. 2010
  - Total = 616 data points

- Median values of both samples similar:
  - NESS MLR = 1.3e-6, $v_{exp} = 12$
  - Lit. MLR = 2.0e-6, $v_{exp} = 12.5$
[Preliminary results] – Comparison with literature samples

- Directly comparing MLR and $v_{\text{exp}}$ values for sources common to both samples
  - Divided mean NESS value by mean literature value

<table>
<thead>
<tr>
<th>Number of sources</th>
<th>164</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean MLR (NESS/literature)</td>
<td>$1.17 \pm 0.08$</td>
</tr>
<tr>
<td>mean $v_{\text{exp}}$ (NESS/literature)</td>
<td>$0.97 \pm 0.01$</td>
</tr>
</tbody>
</table>

Wallström et al., in prep
[Preliminary results] – $^{12}$CO/$^{13}$CO ratios

- Most $^{12}$CO lines optically thick, so ratios are lower limits
- 199 sources with both $^{12}$CO and $^{13}$CO detected
  - Range: -0.28 to 78.72
  - Mean: 6.13 +/- 0.58
  - Median: 4.11
- De Beck et al 2010 from a sample of 27 stars find
  - Mean: 10.27 ± 1.98
  - Median: 8.1

Wallström et al., in prep
[Preliminary results] – Optically thin $^{12}\text{CO}/^{13}\text{CO}$ ratios

• Student project at IRyA-UNAM in Mexico
  • Dayra Torres working with Prof. Sundar Srinivasan (and me)

• Identified lines that appear to be optically thin
  • Eg. IRAS 05524+0723 [Betelgeuse] in CO 3-2, ratio 8.01
[Preliminary results] – Optically thin $^{12}\text{CO}/^{13}\text{CO}$ ratios

- NESS total: 199 sources
  - Range: -0.28 to 78.72
  - Mean: 6.13 +/- 0.58
  - Median: 4.11

- Optically thin: 54 sources
  - Range: 2.51 to 61.20
  - Mean value: 12.71 ± 1.33
  - Median: 11.56

Wallström et al., in prep
Ongoing work

• Data collection and analysis continues
  • Upper limits on non-detections
  • CO maps of ~ 50 sources
  • Line shapes
  • Time variation

• Paper on JCMT pipeline and initial heterodyne data in prep
  • Data, tables, and scripts will be released alongside publication on NESS website, CDS, github and/or observatory archives

http://evolvedstars.space/