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

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### NESS – The Nearby Evolved Stars Survey

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



### 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
  - $\sim$ 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°</li>

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### 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 & <sup>13</sup>CO lines together with a soft parabola function, using MCMC to estimate errors on each parameter

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• 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

	Total	JCMT	ΑΡΕΧ
Number of sources	540	435	105
[CO (2-1); CO(3-2)]	[322; 437]	[250; 354]	[72; 83]
CO (2-1)	211	173	38
detections	(66%)	(69%)	(53%)
<sup>13</sup> CO (2-1)	72	52	20
detections	(29%)	(29%)	(28%)
CO (3-2)	215	157	58
detections	(49%)	(44%)	(70%)
<sup>13</sup> CO (3-2)	53	27	26
detections	(15%)	(10%)	(31%)

Note: <sup>13</sup>CO only observed towards sources with sufficiently strong <sup>12</sup>CO detection

### [Preliminary results] – Empirical mass-loss rates vs DPR



- $\sim$  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



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### [Preliminary results] – Gas-to-dust ratios



Range: 0.34 to 16871.53 Mean: 452.52 +/- 49.18 Median: 259.41

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### [Preliminary results] – MLR vs velocity by tiers



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## [Preliminary results] – Comparison with literature samples



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# [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<sub>exp</sub> = 12
  - Lit. MLR = 2.0e-6, v<sub>exp</sub> = 12.5



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# [Preliminary results] – Comparison with literature samples

- Directly comparing MLR and v<sub>exp</sub> values for sources common to both samples
  - Divided mean NESS value by mean literature value

Number of sources	164	
mean MLR (NESS/literature)	1.17 ± 0.08	
mean v <sub>exp</sub> (NESS/literature)	$0.97 \pm 0.01$	



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### [Preliminary results] – <sup>12</sup>CO/<sup>13</sup>CO ratios

- Most <sup>12</sup>CO lines optically thick, so ratios are lower limits
- 199 sources with both <sup>12</sup>CO and <sup>13</sup>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



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### [Preliminary results] – Optically thin <sup>12</sup>CO/<sup>13</sup>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



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## [Preliminary results] – Optically thin <sup>12</sup>CO/<sup>13</sup>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/