The Nearby Evolved Stars Survey

The dust and gas return to the Galactic interstellar medium

Peter Scicluna

ASIAA/ESO

JCMT Users' Meeting

Key collaborators: F. Kemper, A. Trejo, J. Marshall, S-Y. Liu, N. Hirano (ASIAA, Taiwan); S. Srinivasan (UNAM, Mexico); I. McDonald, A. Richards, A. Zijlstra (Manchester, UK); S. Wallström (KU Leuven); H. Shinnaga, H. Imai (Kagoshima, Japan); J. Greaves (Cardiff, UK); O. Jones, W. Holland (Edinburgh, UK); J. Wouterloot (EAO); J. He (YNAO & CASSACA, China); J. Cami (UWO, Canada); H. Kim, S.-H. Cho (KASI, Korea) and the NESS team

The Nearby Evolved Stars Survey

JCMT + APEX: 45 nearest dusty AGB stars + wedding-cake survey within 2 kpc (400 stars)

⇒ largest volume–limited survey of Galactic AGB stars

Open Science philosophy: aim to be fully reproducible and open source

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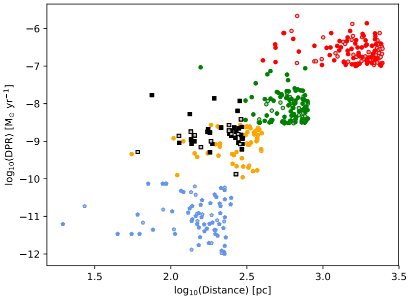
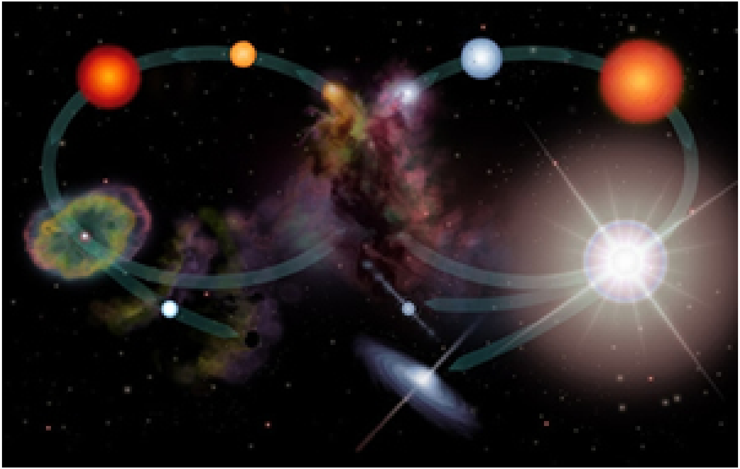
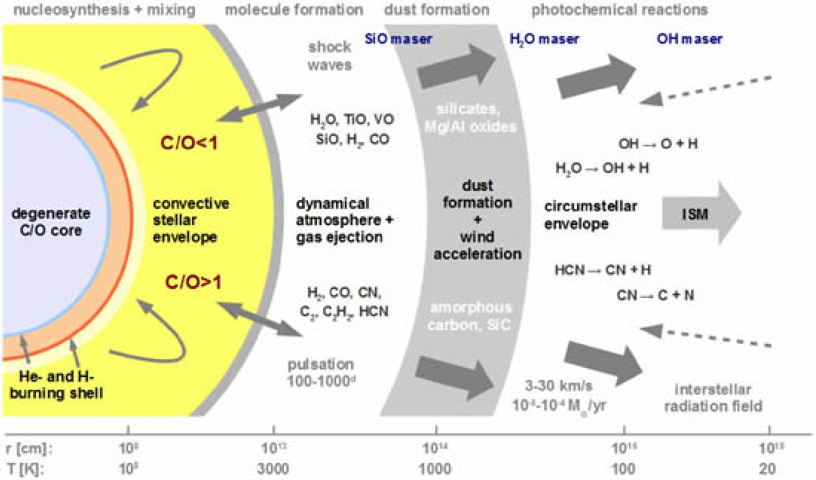


- ~ 600 hrs JCMT - continuum, CO(2–1), (3–2)
- ~ 60 hrs APEX - CO(2–1), (3–2)
- ~ 330 hrs Nobeyama - CO(1-0)
- lots of archival data

Evolved stars, mass loss and the lifecycle of matter

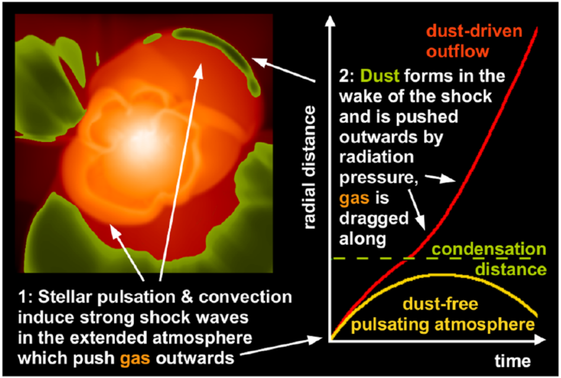


AGB stars



nucleosynthesis + mixing
molecule formation
dust formation
photochemical reactions
shock waves
SiO maser
H_2O maser
OH maser
silicates, Mg/Al oxides
H_2O, TiO, VO
SiO, H_2, CO
C/O<1
$OH \rightarrow O + H$
$H_2O \rightarrow OH + H$
degenerate C/O core
convective stellar envelope
dynamical atmosphere + gas ejection
dust formation + wind acceleration
circumstellar envelope
ISM
C/O>1
H_2, CO, CN,
C_2, C_2H_2, HCN
$HCN \rightarrow CN + H$
$CN \rightarrow C + N$
amorphous carbon, SiC
He- and H-burning shell
pulsation 100-1000d
3-30 km/s
interstellar radiation field
r [cm]:
T [K]:
10^{13}
10^{14}
10^{15}
3000
1000
100
20

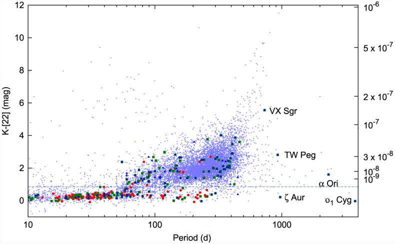
The physics of mass-loss

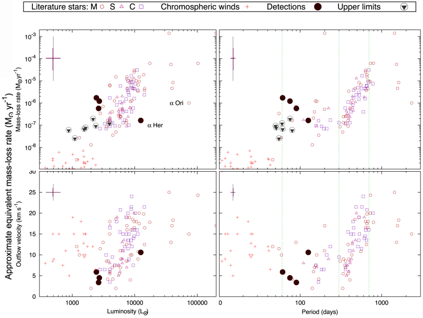


Höfner 2016

The physics of mass-loss

The importance of pulsation:

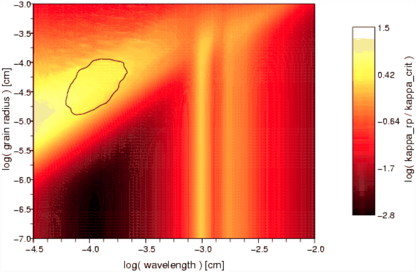


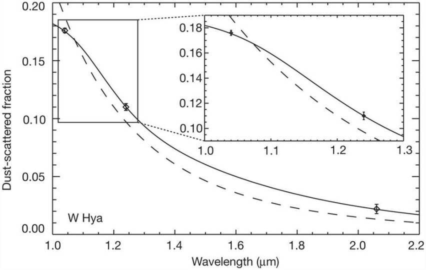


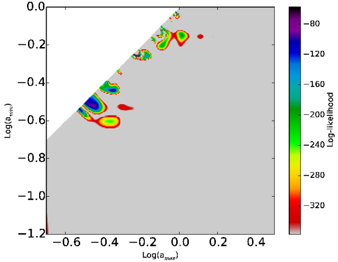
McDonald et al., (2016, 2019)

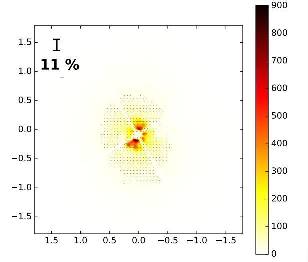
The physics of mass-loss

and grain properties:



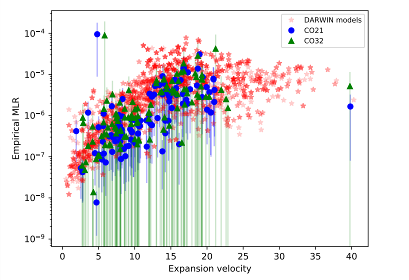


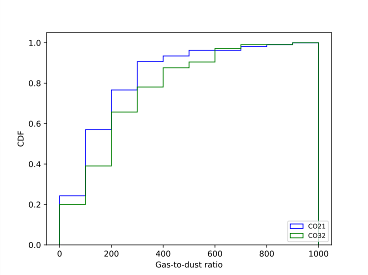




Höfner et al. (2008), Scicluna et al. (2015)   Norris et al. (2012), Scicluna et al., subm

The physics of mass-loss

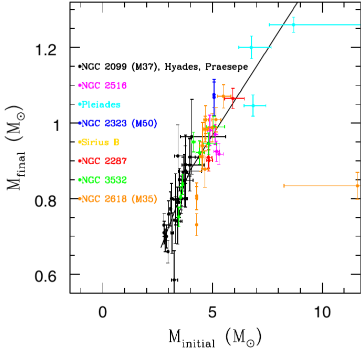




Wallström et al. (in prep)

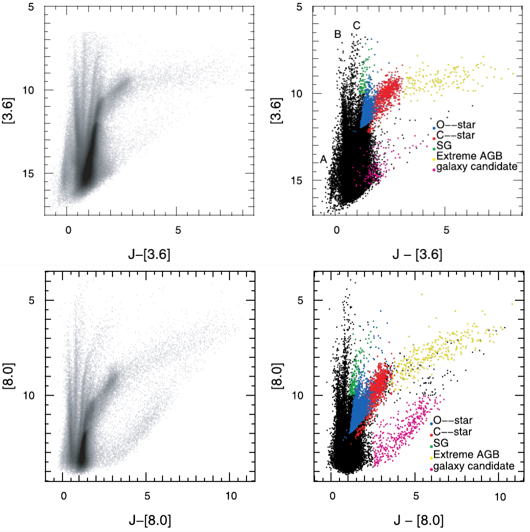
The physics of mass-loss

- How much mass do they lose?
- How is it enriched?
- How does this depend on the fundamental properties of the stars?



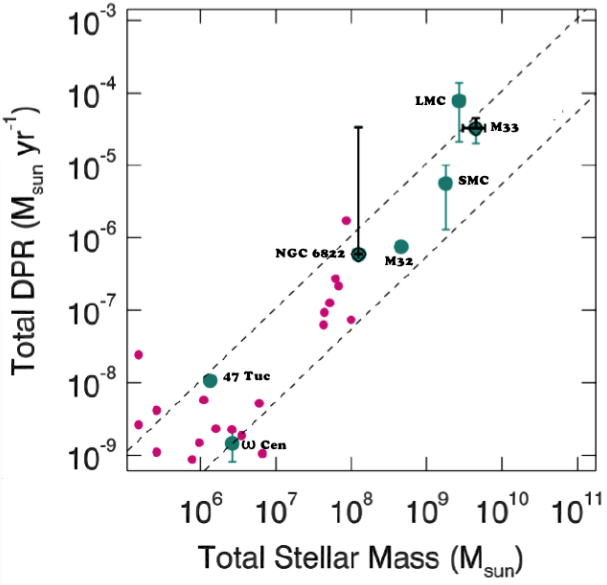
Cummings et al. (2016)

Measuring mass return

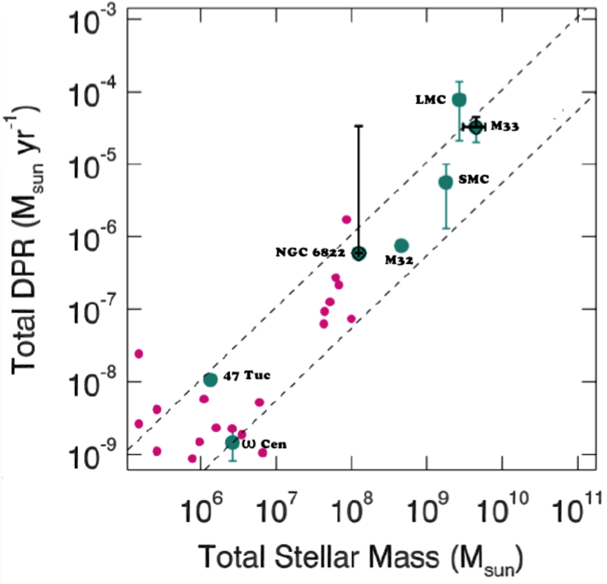


Blum et al. 2006

- E.g. SAGE
- Find dusty (MIR-bright) sources
- Classify - YSOs/AGB/RSG etc. & chemisty
- Compute DPR
  - Empirical relations
  - radiative transfer
- Add up all contributors
- Dominated by extreme AGBs



S. Srinivasan



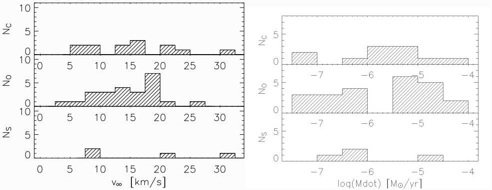
S. Srinivasan

- Solar Neighbourhood/MW missing
- Need for volume-limited study of nearby sources

CO Lines as a mass-loss tracer

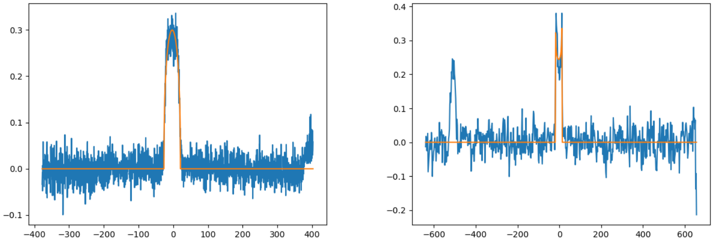
e.g. Knapp & Morris 1985

- Multiple CO line profiles
- Radiative transfer (comoving frame)
- fit $T(R)$, v & $\dot{M}$
- Still need assumptions, e.g. $\frac{CO}{H_2}$
- Low-J lines → colder gas, not comparable with IR dust
- Only really possible for Galactic sources



De Beck et al., 2010

… and with NESS



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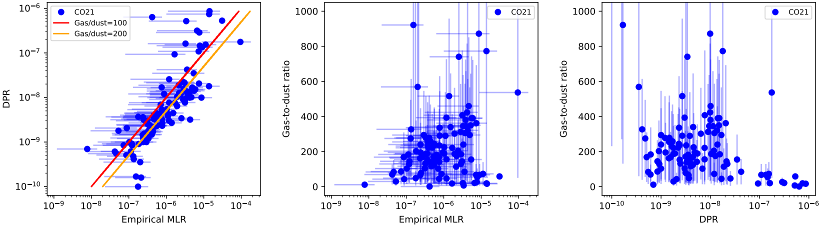
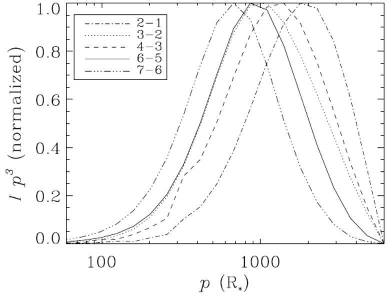
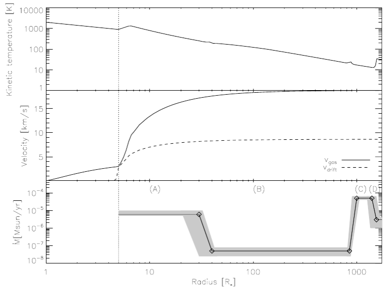


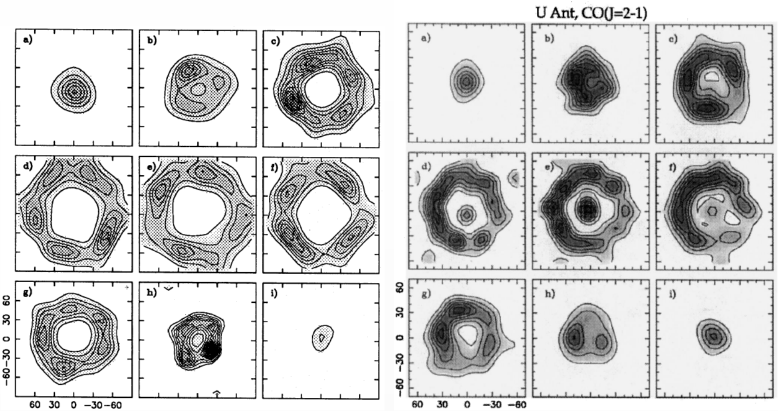
Wallström et al. (in prep)

Mass-loss history





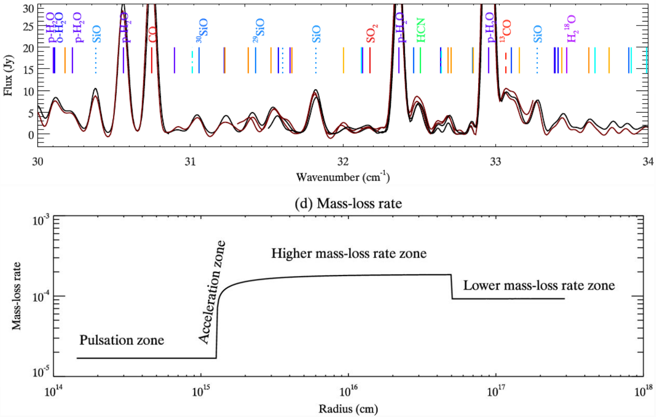
Kemper et al., 2003; Decin et al., 2007



Left: S Sct - Olofsson et al. 1992 *Right*: U Ant - Olofsson et al. 1996

Extended emission from AGB stars

Progress with Herschel:



Matsuura et al., 2014

Extended emission from AGB stars

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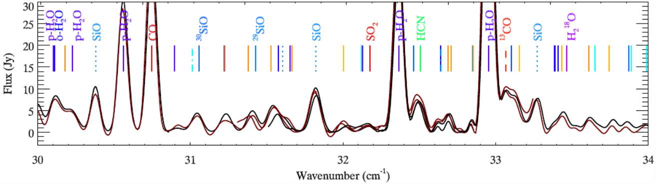
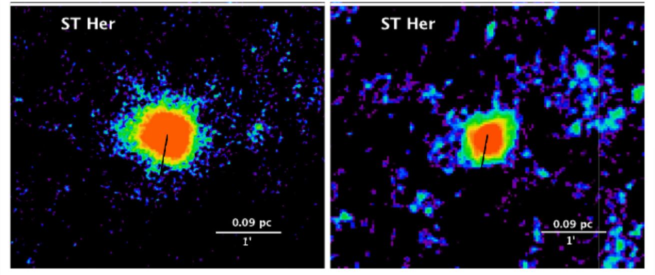


Matsuura et al., 2014

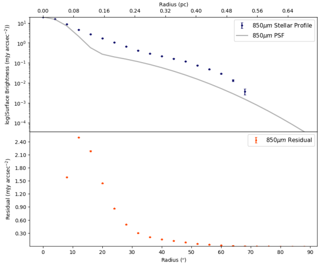
MESS:

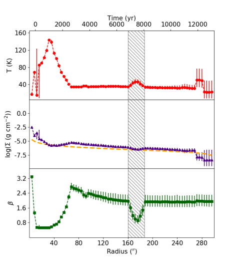


Cox et al., 2012

Extended emission with the JCMT

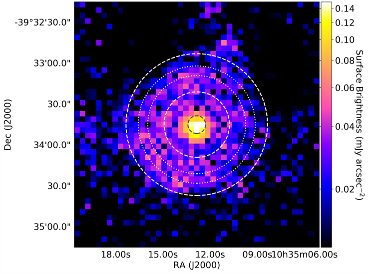
Dharmawardena et al. (2018) - CW Leo, SCUBA2 850

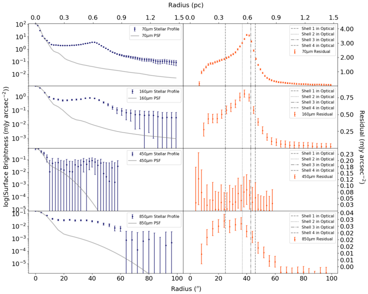




- lots of cold dust!
- $\dot{M}_{\rm d}$ variations
- resolved gas-to-dust ratios
- deviations from symmetry?

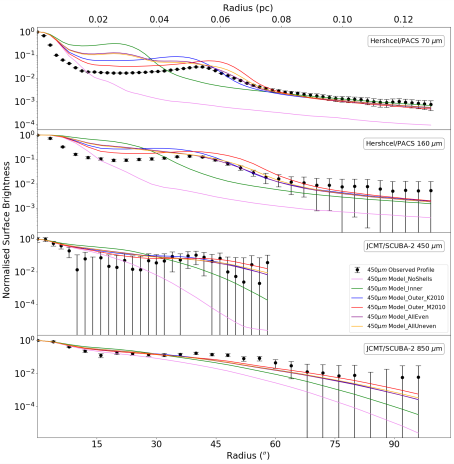
Extended emission with the JCMT





Dharmawardena et al. (2019)

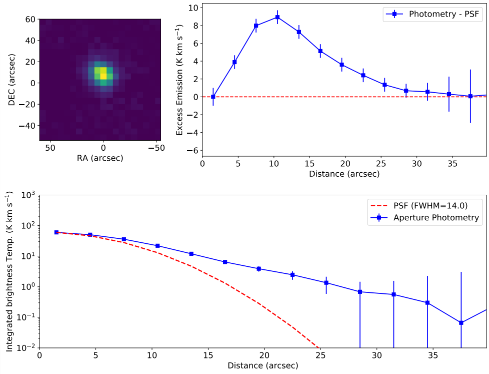
Extended emission with the JCMT

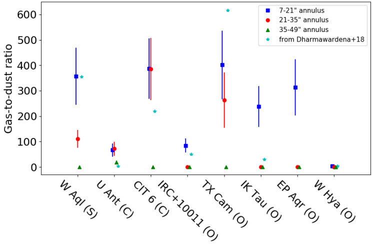


Dharmawardena et al. (2019)

- Models all fail to reproduce data
- But in different ways at different wavelengths!
- Flux at 850 μm 3× higher than expected

Extended emission with the JCMT

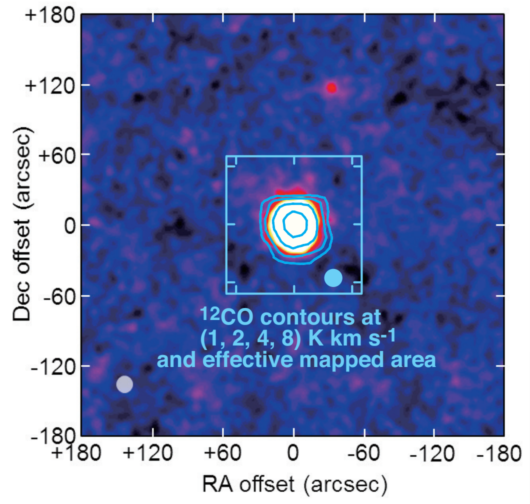




Wallstrom, Trejo, Cami et al., (in prep)

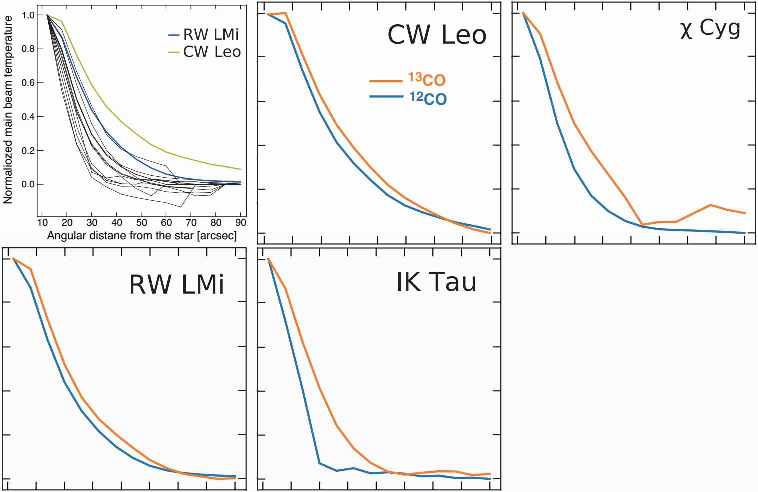
… and NRO

Nobeyama 45-m



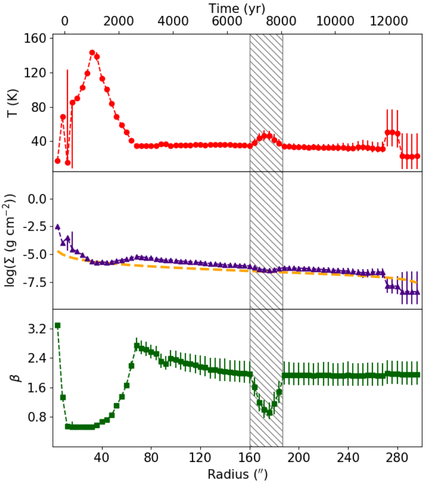
As expected from similar temperatures, CO(1–0) and 850 μm probe similar region
Amada, Imai, et al. (in prep)

... and NRO

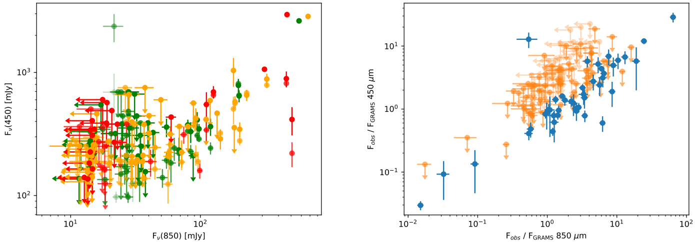


Normalized main beam temperature
1.0
0.8
0.6
0.4
0.2
0.0
10 20 30 40 50 60 70 80 90
Angular distane from the star [arcsec]
RW LMi
CW Leo
CW Leo
^{13}CO
^{12}CO
χ Cyg
RW LMi
IK Tau

Dust properties in evolved stars



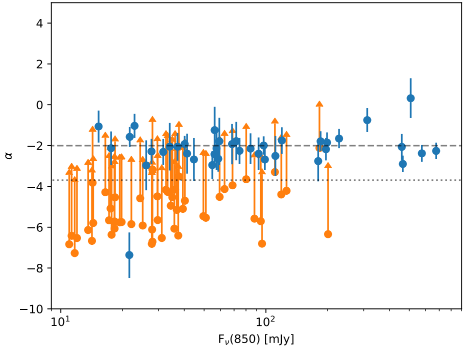
Dust properties in evolved stars



- High (distance-dependent) detection fraction (∼ 75%)
- Lots more emission than models suggest
- ⇒ lots of cold dust or different dust properties (or both!)

Scicluna et al. (subm)

Dust properties in evolved stars



Evolved stars are mostly consistent w/ blackbody emission in sub-mm continuum - large dust grains?

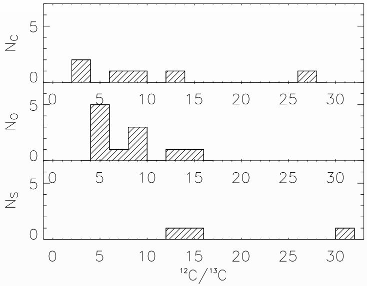
Unlikely, probably tracing combination of things: Different emission mechanisms, different source sizes, and data-reduction artefacts.

One possible outlier with $\alpha = -7.4 \pm 1.1$, SMA follow up at 230 GHz

Scicluna et al. (subm)

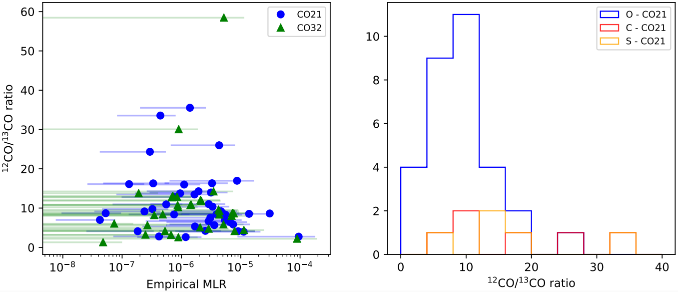
CO isotopologues

- AGB stars produce ^{12}C
- Massive AGB stars convert ^{12}C to ^{13}C
- Mass-loss alters ISM abundance
- traces nucleosynthesis



De Beck et al., 2010

CO isotopologues



Wallström et al, (in prep)

Some of the challenges

SCUBA-2

- Evolved stars in sub-mm continuum:
  - Bright point source with faint extended halo
  - $\Rightarrow$ Dynamic range problem!

Some of the challenges

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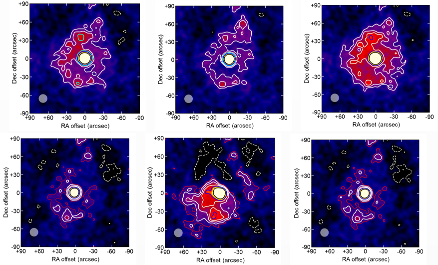
  - ⇒ Dynamic range problem!
- Pushing SCUBA-2 DR to the limit



Some of the challenges

SCUBA-2

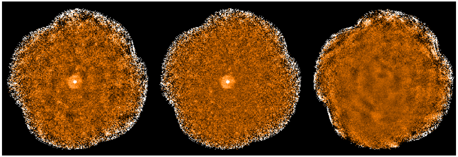
- Evolved stars in sub-mm continuum:
  - Bright point source with faint extended halo
  - ⇒ Dynamic range problem!
- Pushing SCUBA-2 DR to the limit
- More data doesn't always help

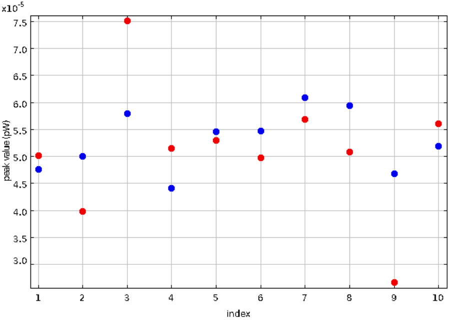
Date	Obs no	450µm		850µm	
		Peak flux (Jy/beam)	Integrated flux (Jy)	Peak flux (Jy/beam)	Integrated flux (Jy)
20180118	10	69.2 ± 7.3	-1.756 (!)	34.5 ± 1.5	195
	11			24.9 ± 1.4	153
	15			44.1 ± 1.4	610 (!)
	16			29.4 ± 1.4	120
20181209	58			33.3 ± 1.8	66 (!)
	60			31.4 ± 1.6	156
	68			37.1 ± 1.9	298 (!)
20181210	56			33.5 ± 1.5	195
	57			21.0 ± 1.5	−31 (!!)
	68			36.9 ± 1.5	268
Average (std dev)				32.6 ± 6.5	202 ± 171 (!)

Some of the challenges

SCUBA-2

- Evolved stars in sub-mm continuum:
  - Bright point source with faint extended halo
  - ⇒ Dynamic range problem!
- Pushing SCUBA-2 DR to the limit
- More data doesn't always help
- Maybe PCA would?
  - but that's slow
  - and perhaps a self-fulfilling prophecy?





Some of the challenges

RxA3m

- $\sim$ half our time is for 230 GHz
  - used just over half of that

Some of the challenges

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Some of the challenges

RxA3m

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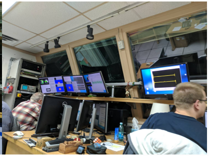
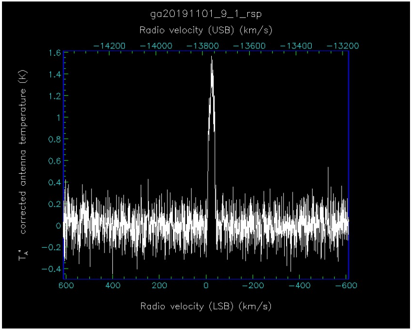
- but that all changed last week!

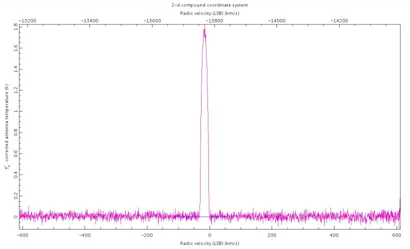


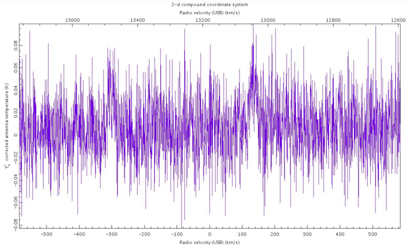


Some of the challenges

RxA3m

- ~ half our time is for 230 GHz
  - used just over half of that
- Since it's been gone . . .
- but that all changed last week!
- Very nice spectra, depth as expected





Some of the challenges

RxA3m

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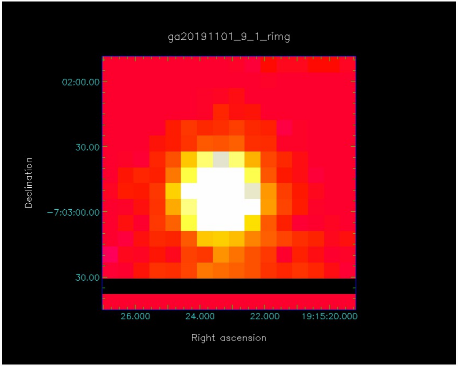
  - used just over half of that
- Since it's been gone ...
- but that all changed last week!
- Very nice spectra, depth as expected
- And maps too!

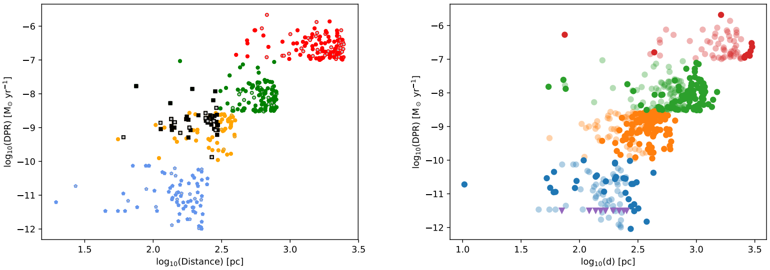


The future of NESS

1. The onset of mass loss and its evolution in sun-like stars
2. Mass-loss histories

The future of NESS

1. The onset of mass loss and its evolution in sun-like stars
   - When (and how) do stars start losing mass?
   - Evolution at $M \leq 2\ M_\odot$?
   - More sources needed, larger distances
   - JCMT extension for ~ 660 hours submitted
2. Mass-loss histories

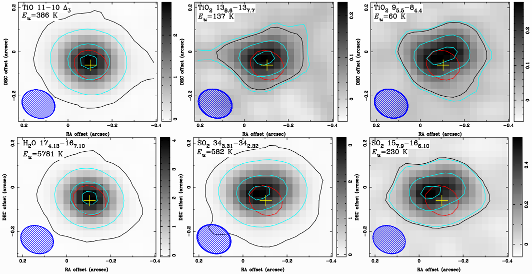


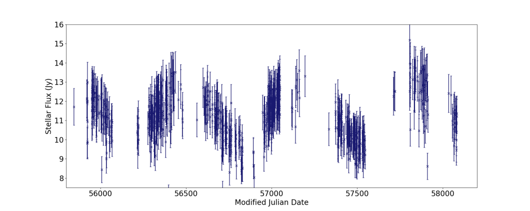
The future of NESS

1. The onset of mass loss and its evolution in sun-like stars
2. Mass-loss histories
   - How does mass-loss vary over $t \sim$ centuries – millenia?
   - Statistics of variations of different amplitudes
   - Resolve envelopes of many sources → interferometric survey
   - SMA and ACA (or most compact ALMA config) well suited - proposals submitted
   - ... or future JCMT continuum camera for larger scales

Beyond NESS

- Chemistry of dust formation: ALMA/VLT(I)
- Role of $\vec{B}$-fields: ALMA, JCMT
- Time domain: Sub-mm variability (Future 850 instrument) Atmospheric dynamics (Various hi-res OIR spectrographs)





Summary

- Objectives:
  - Total mass return to Solar Neighbourhood
  - Statistically-robust studies of evolved-star physics
  - Go-to database for nearby evolved stars
- JCMT observing ~58% complete
- Processing data for science
- Still lots to do
- Exploring options for follow up
- Everyone is welcome to get involved:
  - Get in touch!

See http://evolvedstars.space for more