> **“How can low-metallicity cool giants drive substantial winds where we do not expect a signifciant amount of carbon- or silicate-rich dust?”**

The winds are fundamentally important for creating:

- Metal-enriched ISM
  - ➔ ISM then forms solar metallicity / Population I stars
    - ➔ Rocky planets
      - ➔ Us!

They also have implications for the high-redshift universe

"How can low-metallicity cool giants drive substantial winds where we do not expect a significant amount of carbon- or silicate-rich dust?"

Ingredients:

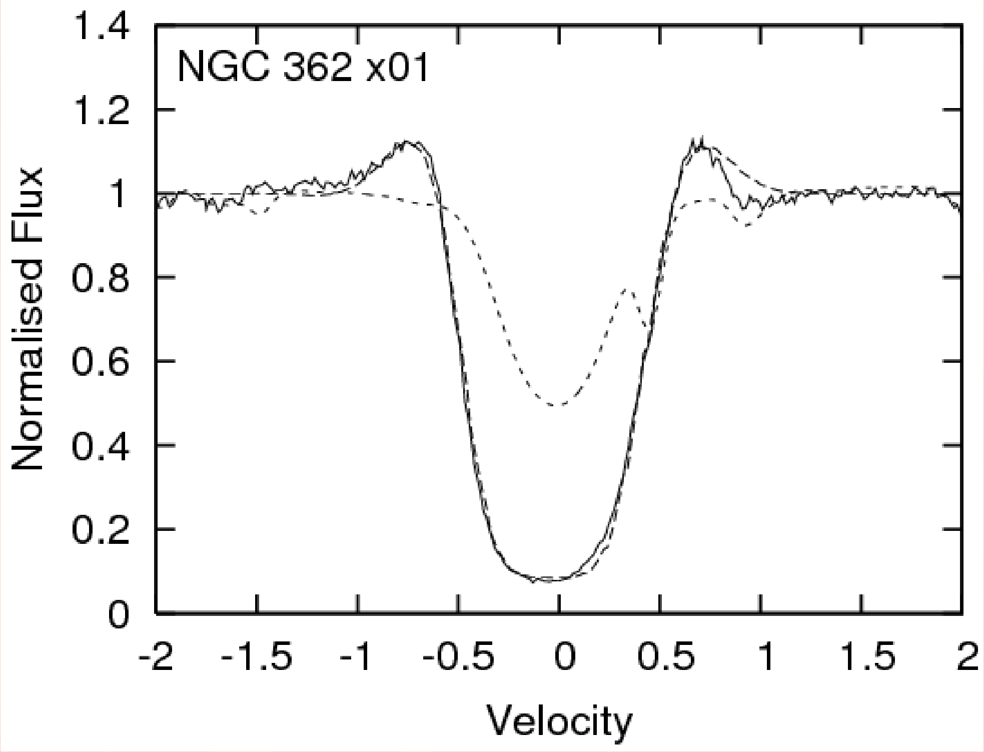
– Chromospheres –

– Pulsation –

– Dust –

Chromospheres

- Magnetic reconnection
  - ➔ Heating, outflows
- Also observed in low-metallicity giants[1].
  - ➔ emission in line wings (esp. Hα, Ca H & K)

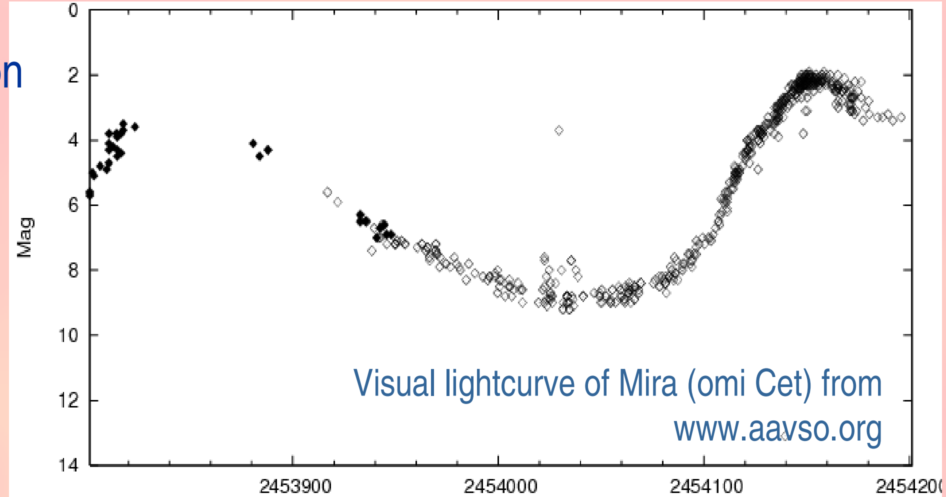


Hα emission (McDonald & van Loon, in prep.)

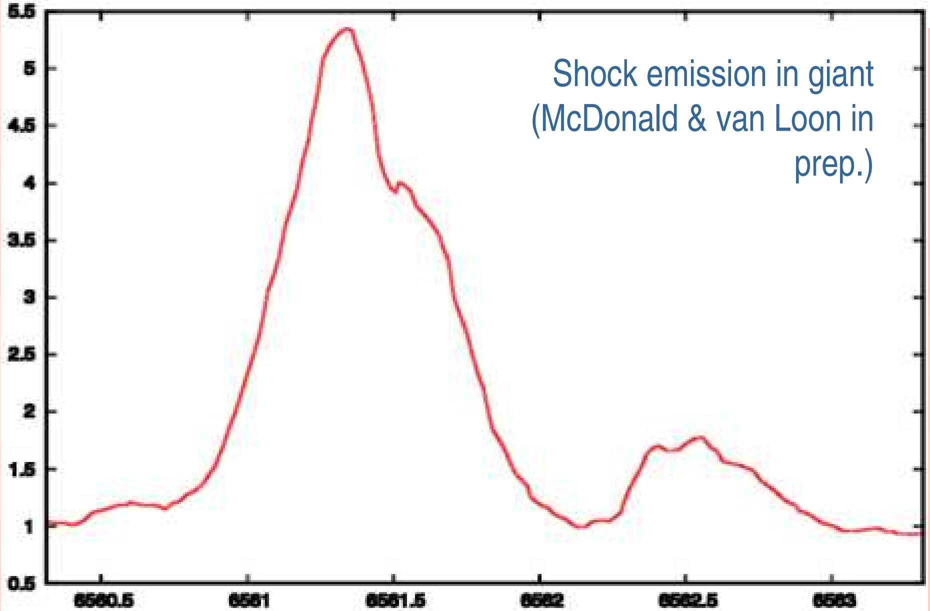
[1] – Reimers (1975), Cohen et al. (1976), Dupree et al. (1984,1990,1994), Mauas et al. (2006)

Pulsation

- AGB stars are unstable against radial pulsation
  - ➔ Variable atmospheric opacity
  - ➔ Pulsation
- Amplitude increases during AGB evolution
  - ➔ Provides 'kick' to material near surface
  - ➔ May help drive a wind from the surface[1]
- Observable through optical photometry
- Also creates shocks
  - ➔ Emission lines in spectra



Visual lightcurve of Mira (omi Cet) from www.aavso.org



Shock emission in giant (McDonald & van Loon in prep.)

[1] – Wilson & Bowen (1984)

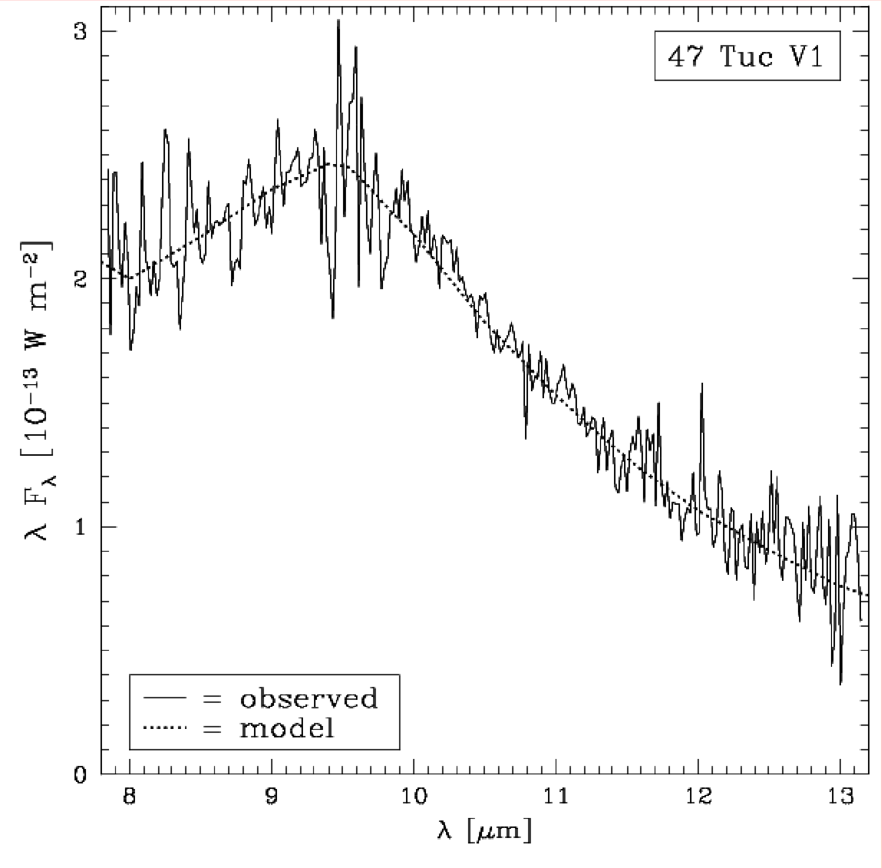
Dust

- AGB star winds are very cool
  - ➔ Molecular seeds (e.g. Al_2O_3, C_2H_2)
  - ➔ Dust grains condense around seeds.

- Radiation pressure on grains accelerates wind away from star.

- Collisional coupling can occur
  - ➔ Dust helps accelerate gas

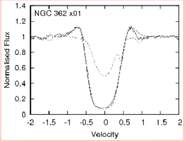
- Low metallicities → difficult to get enough seeds and/or dust to create a strong wind.



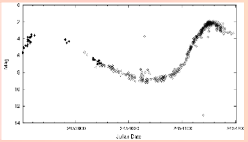
TIMMI2 spectrum – van Loon, McDonald et al. (2006)

- Mass-loss rates inferred from spectral energy distributions (SEDs).
  - ➔ But we *do* see dust at low metallicities.

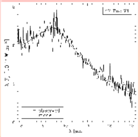
Chromospheres



Pulsation



Dust



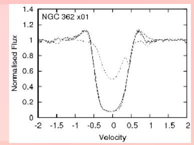
Globular clusters provide a good location in which to study these:

- Co-eval population
- Stars at similar, known distance
- Wide range of sub-solar metallicities

Mass-Losing Stars in Globular Clusters

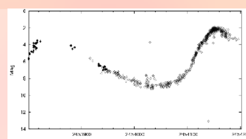
Iain McDonald – NAM 2007

Chromospheres



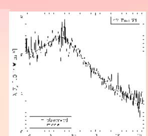
→ Very-high-resolution optical spectra in four clusters

Pulsation



→ Photometric monitoring for undiscovered variables, focussing on M15

Dust



→ SED modelling of dusty objects in ω Centauri

Chromospheres…

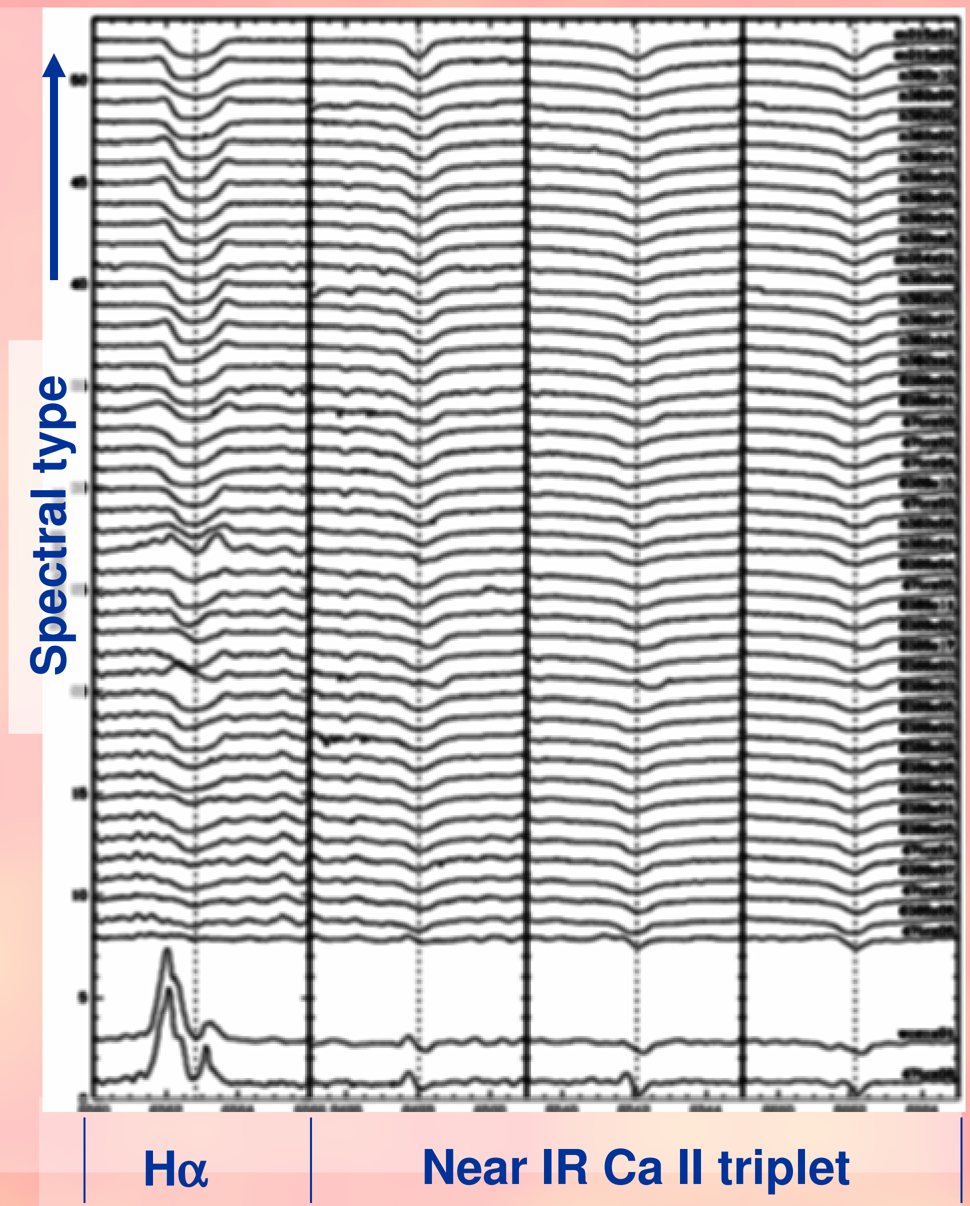
- VLT/UVES
- 46 giants, 4 clusters
- –2.3 < [Z/H] < –0.5
- Resolution: R > 100,000 ~ 3km/s
- Highest R spectra of GC giants
- 6100–9900 Angstroms

Correlations:

Early-type { Chromospheric emission

Late-type { Infilling, Pulsation-shocked emission

- Transition metallicity related?



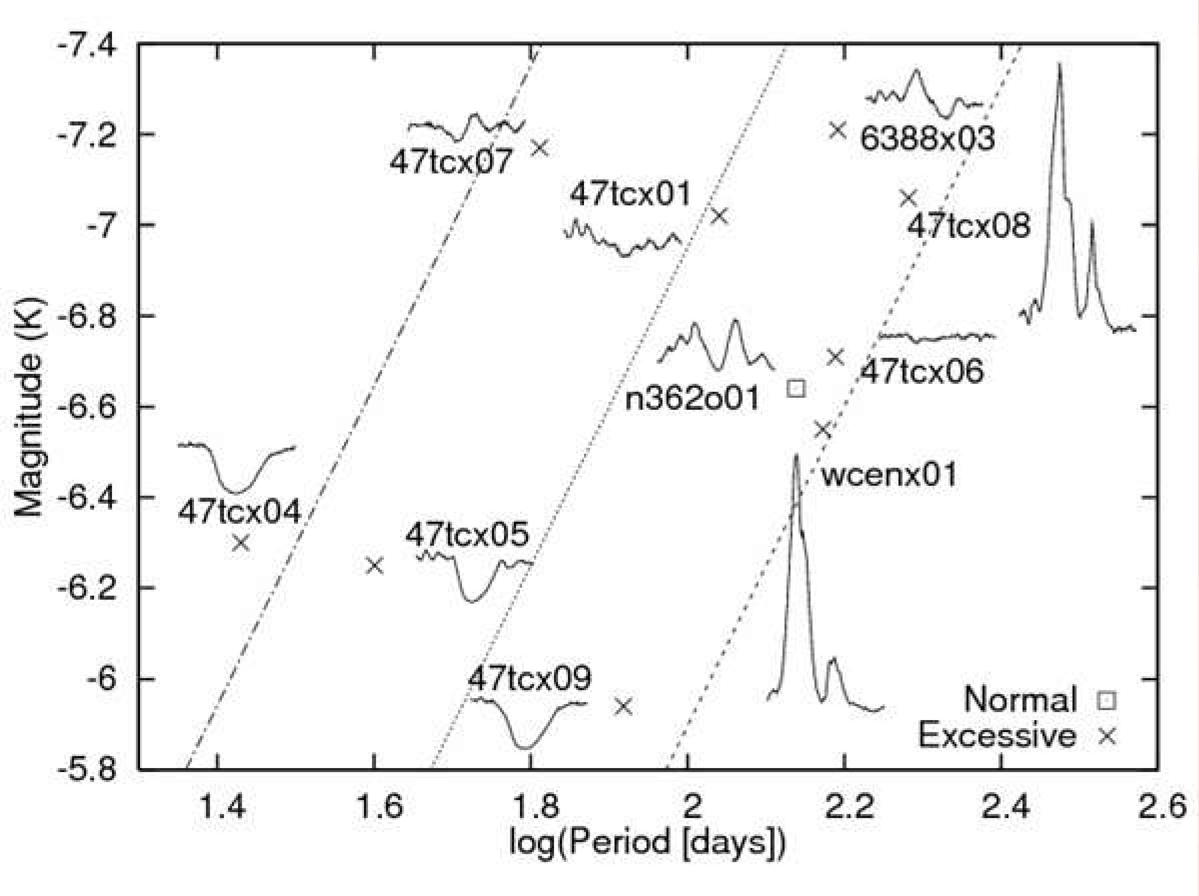
…& pulsation

Longer pulsation periods →

- Stronger pulsation shocks

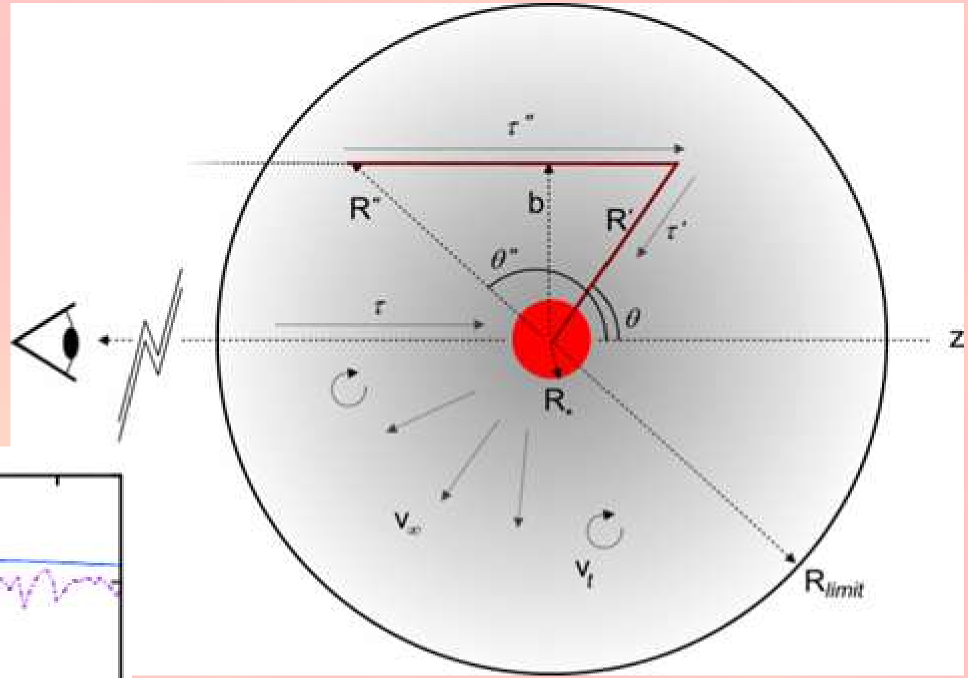
Higher luminosity →

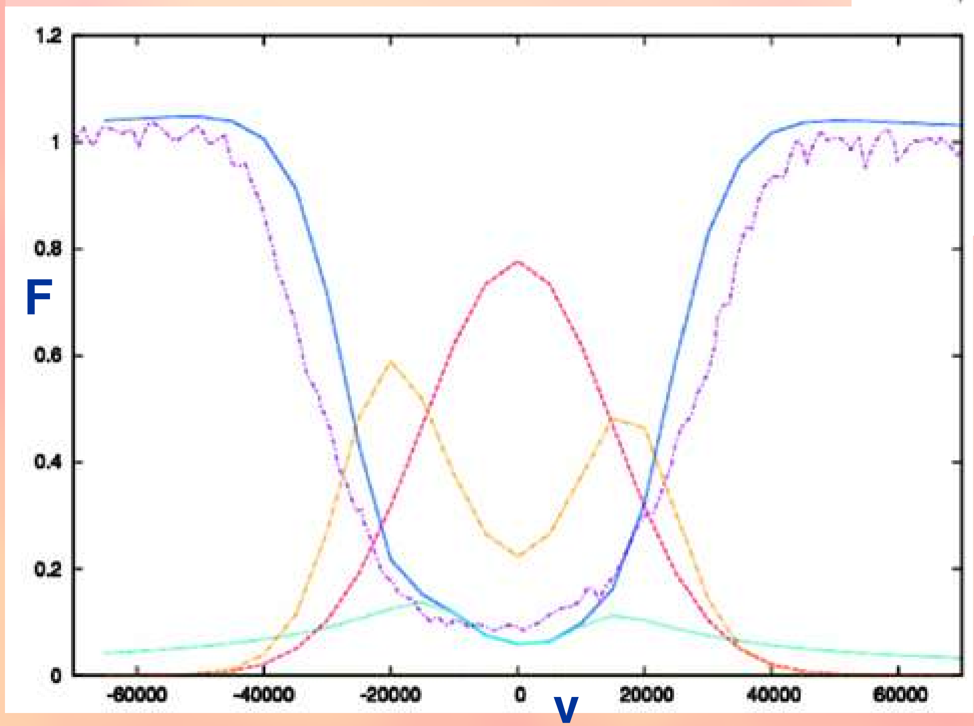
- More infilling



…& gas

- Modelling Hα stellar line profiles using a simple wind model.
- Spherically-symmetric wind with constant outflow with up to two scatterings and micro-turbulence.



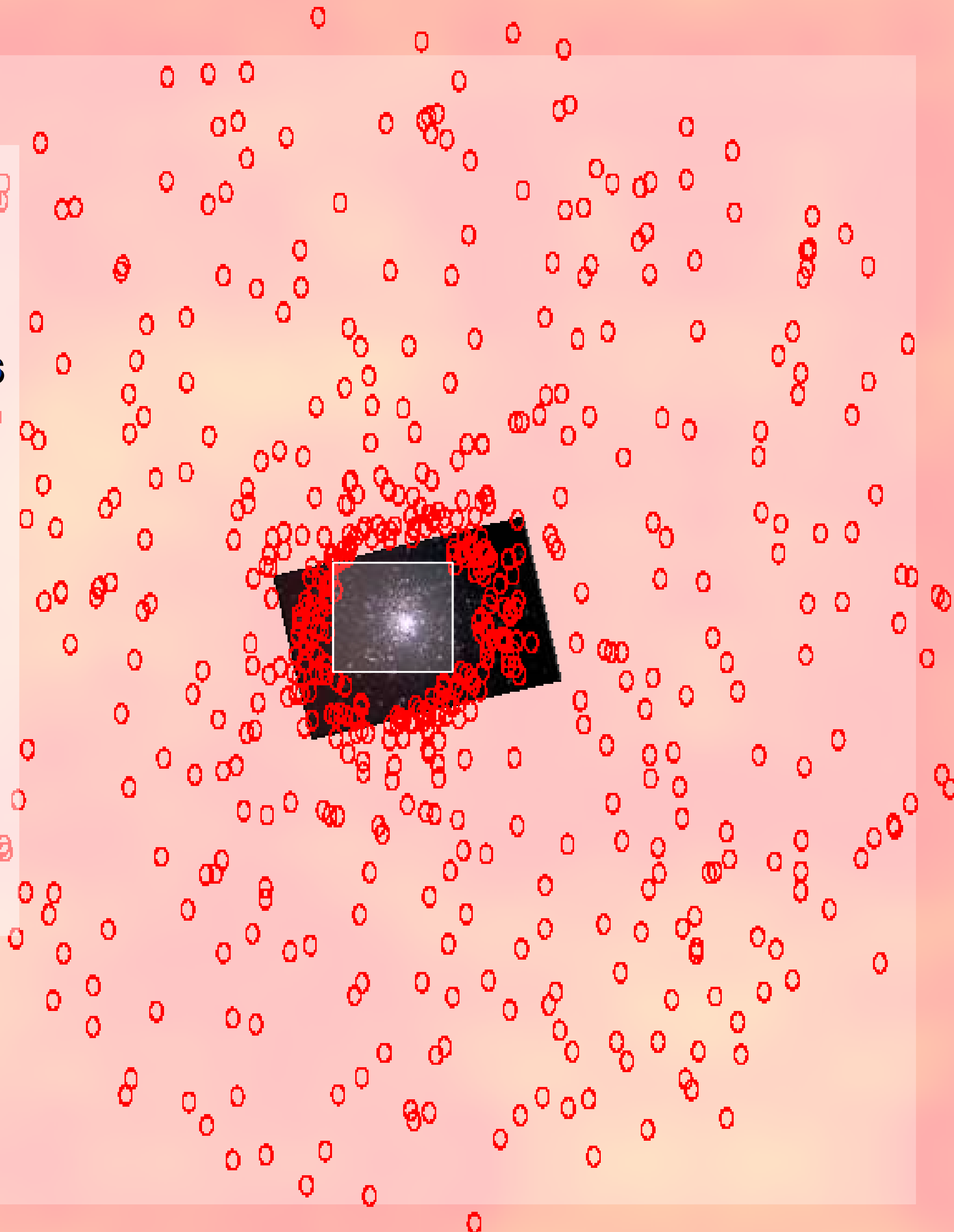


Early results:

- Isothermal wind
- Speed: 1–3 km/s
- Turbulence ~10 km/s in excess of thermal broadening.

Pulsation

1. Narrow-angle monitoring on the metal-poor cluster M15 for pulsating stars using the Liverpool Telescope (first results due this week!).
2. Medium-angle monitoring and follow-up using Keele 24” telescope.
3. Wide-angle search for variables around 28 clusters using SuperWASP photometry.



- New variable stars

   ➔ New mass-loss candidates

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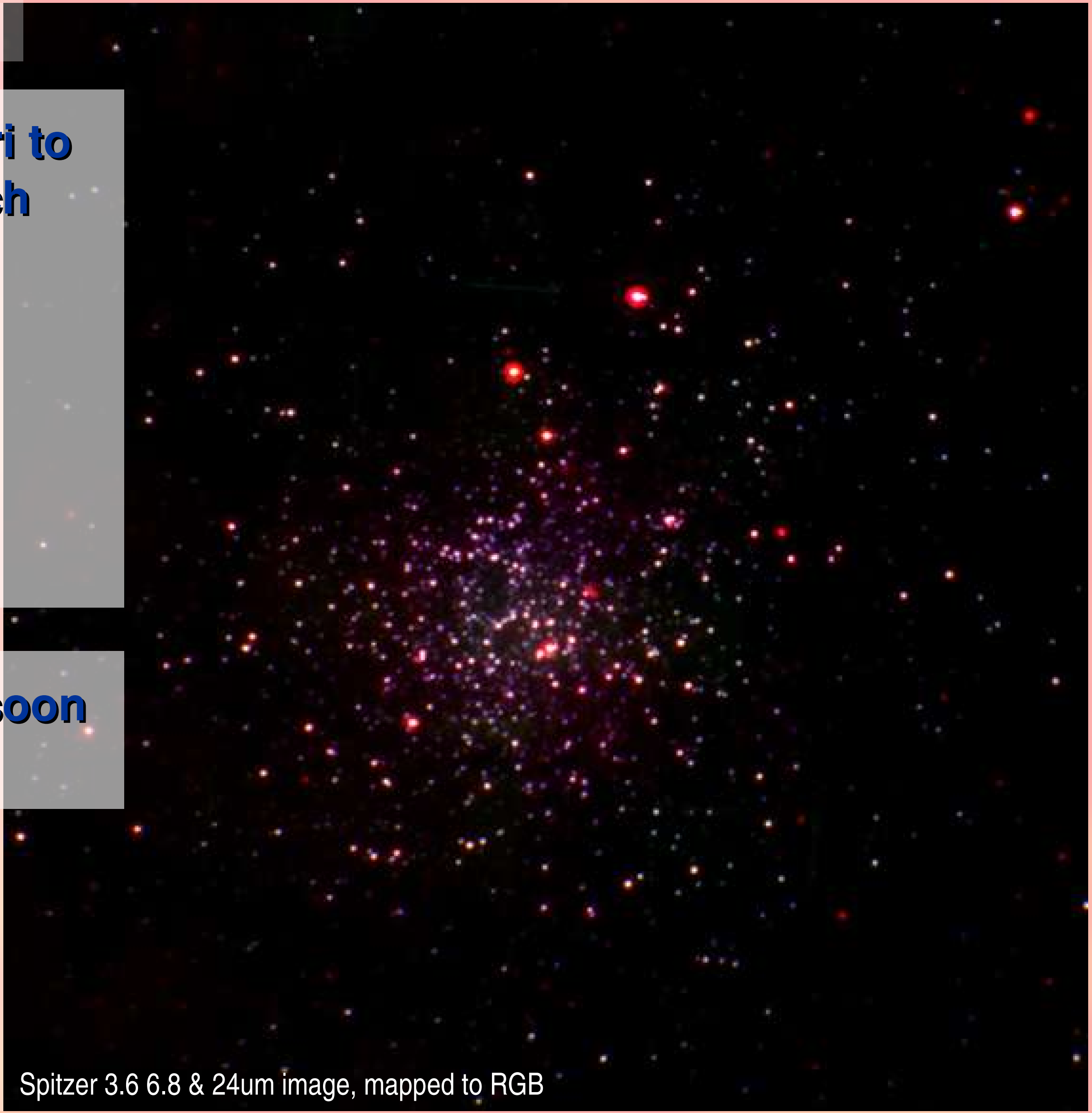
Dust

- Spitzer atlas of ω Centauri to below the horizontal branch
- 16700 stars detected in 2+ bands (IRAC/MIPS)
- Cluster members identified through proper motion[1].

- Results to be published soon as Boyer, McDonald et al.



Spitzer 3.6 6.8 & 24um image, mapped to RGB

[1] – van Leeuwen et al. (2000)

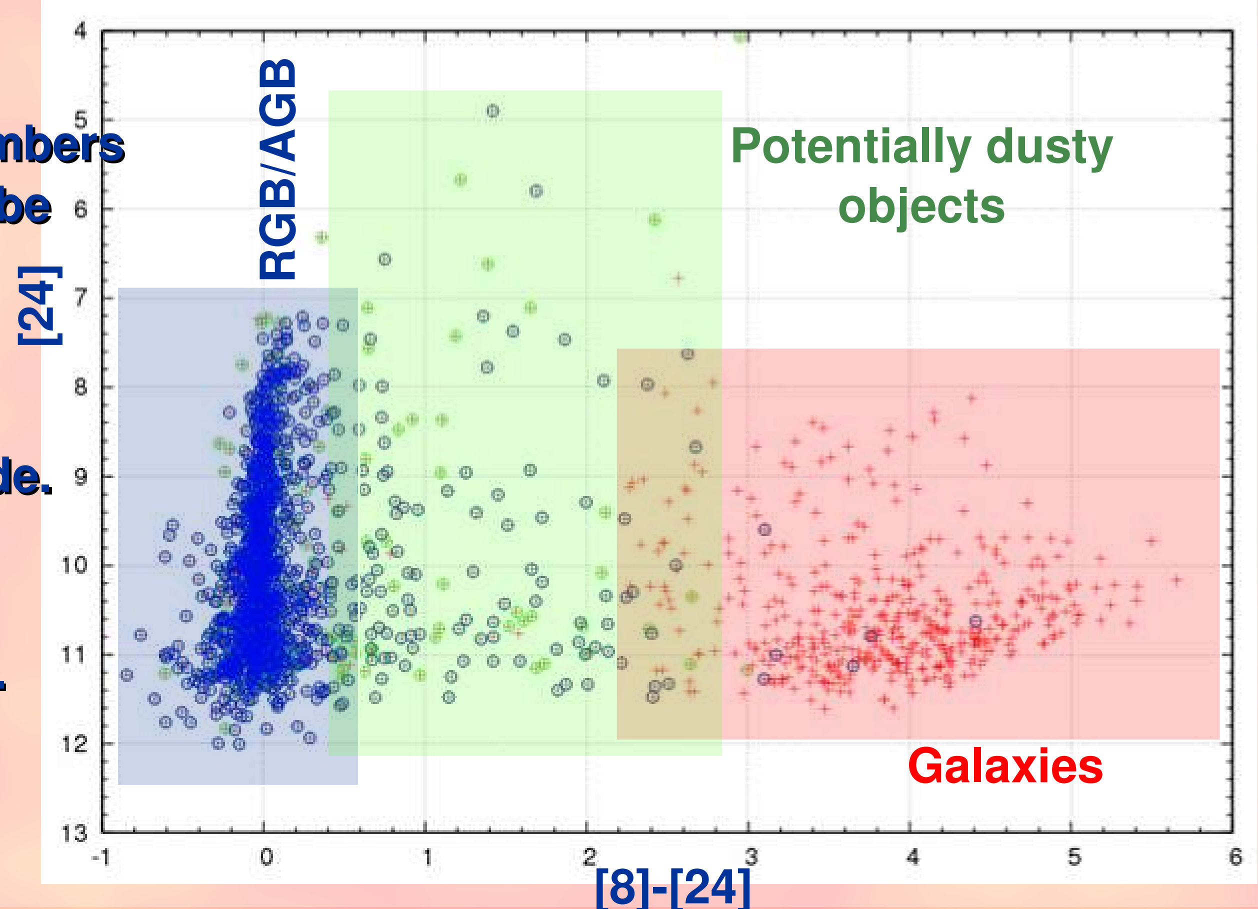
Dust

- 8µm vs. 24µm colour-magnitude diagram (CMD) can identify objects with dust.

- SEDs of cluster members with 24µm excess to be constructed.

- Modelling with the DUSTY synthesis code.

- Mass loss rates and temperatures of dust.



Bringing it all together

AGB Evolution

Chromospheres

Mass-loss through magnetic reconnection

Pulsation

Pulsation & gas/dust coupling drives wind

Dust

Pulsation also drives shock waves, assisting expulsion

Typical stellar values in globulars

Hydrogen 10^{-8}

4500K

4000K

TiO 10^{-7}

3500K

Al_2O_3 10^{-6}

3000K

Complex dust 10^{-5}

Cooler

Superwind