Stellar Population MIR Spectroscopy in the E-ELT era

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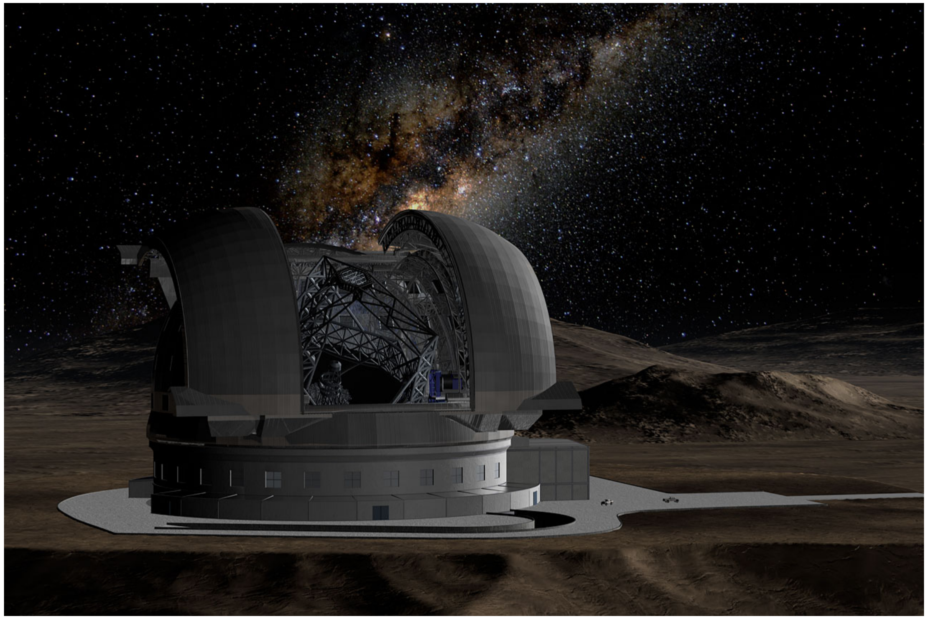
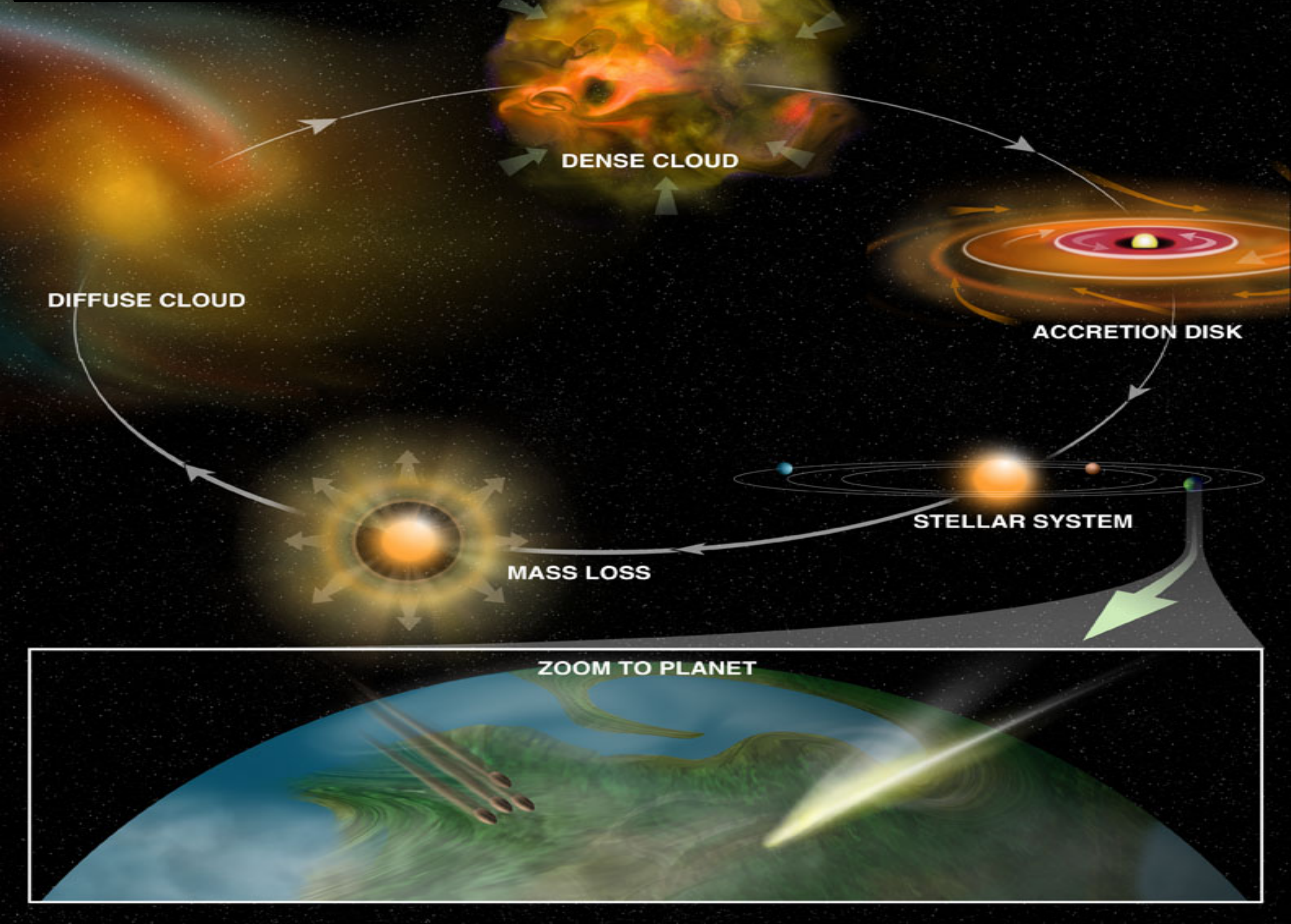
Outline

- Asymptotic Giant Branch (AGB) stars
  - Cosmic dust cycle
  - The atmosphere
  - The ELT era
- Applications
  - Low resolution spectroscopy
  - High resolution spectroscopy
- Synergy
- Summary



www.eso.org

http://www.nrao.edu/pr/2006/gbtmolecules/



The Small Magellanic Cloud

Why AGBs to study stellar populations?

- Information about the history of a galaxy
- Most luminous red stars in any galaxy
- They are the brightest objects in the IR

⇒ Disadvantage: short live

Mass-loss one of the ingredients of stellar evolution codes

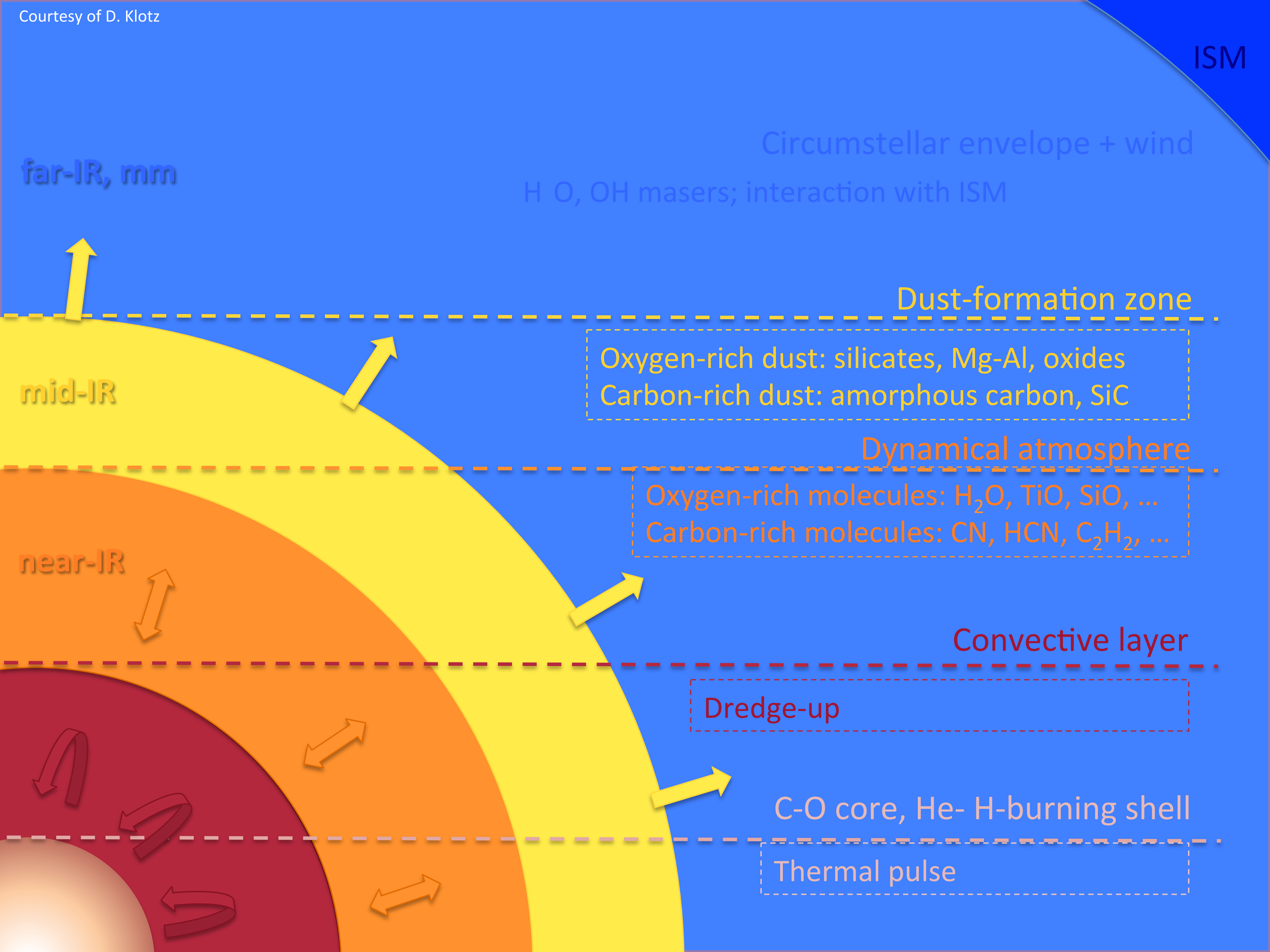
⇒ But we do not understand it!

Cit. Salaris

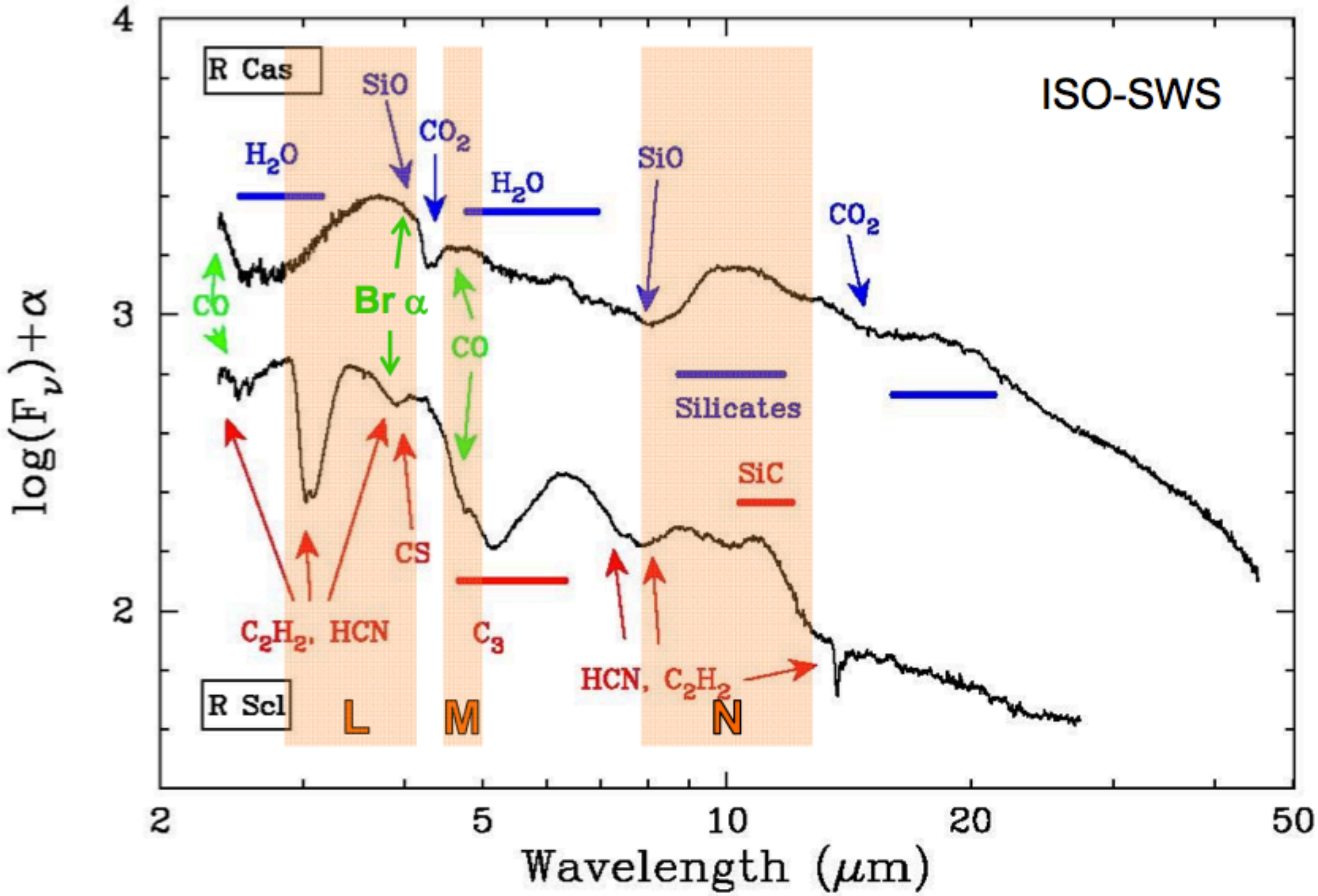
2MASS 2 MICRON ALL SKY SURVEY

Two Micron All Sky Survey
– Southern Facility –
2MASS Atlas Image Mosaic

Infrared Processing and Analysis Center/Caltech & University of Massachusetts


Courtesy of D. Klotz
ISM
Circumstellar envelope + wind
far-IR, mm
H O, OH masers; interaction with ISM
Dust-formation zone
Oxygen-rich dust: silicates, Mg-Al, oxides
Carbon-rich dust: amorphous carbon, SiC
mid-IR
Dynamical atmosphere
Oxygen-rich molecules: H_2O, TiO, SiO, …
Carbon-rich molecules: CN, HCN, C_2H_2, …
near-IR
Convective layer
Dredge-up
C-O core, He- H-burning shell
Thermal pulse

AGB Infrared spectrum



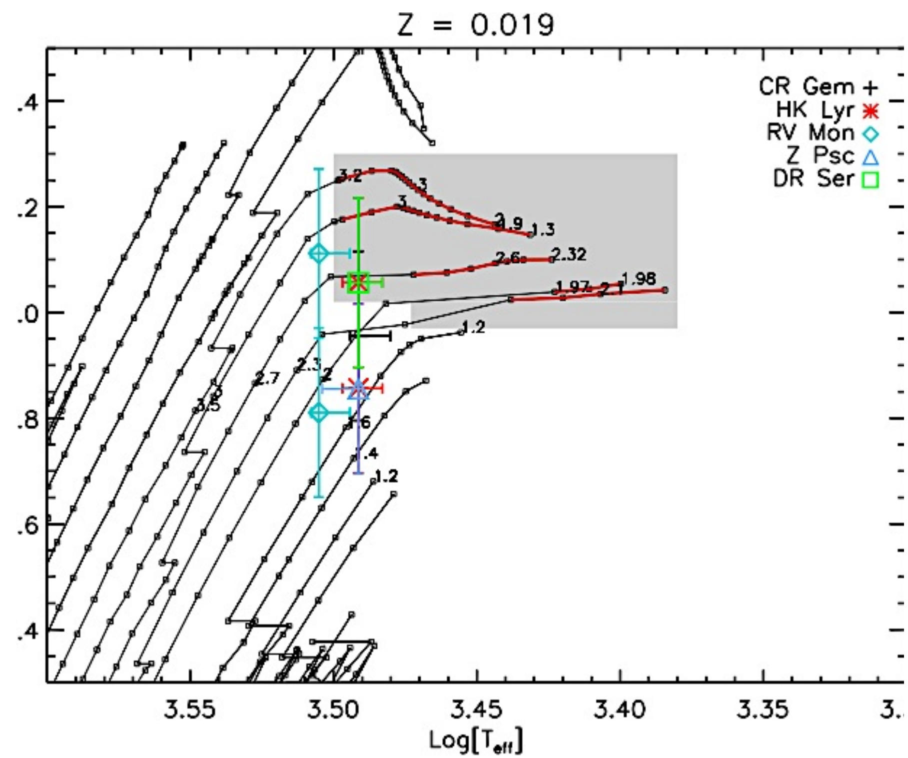
Constraining stellar evolution

Paladini et al. (2011); Klotz, et al. (2013); van Belle et al. (2013); Wittkowski et al. (2006)

- Spectroscopy
- Interferometry

⇒ Stellar parameters

⇒ Constrain stellar evolution for solar metallicity



Paladini et al. 2011

Relevant questions

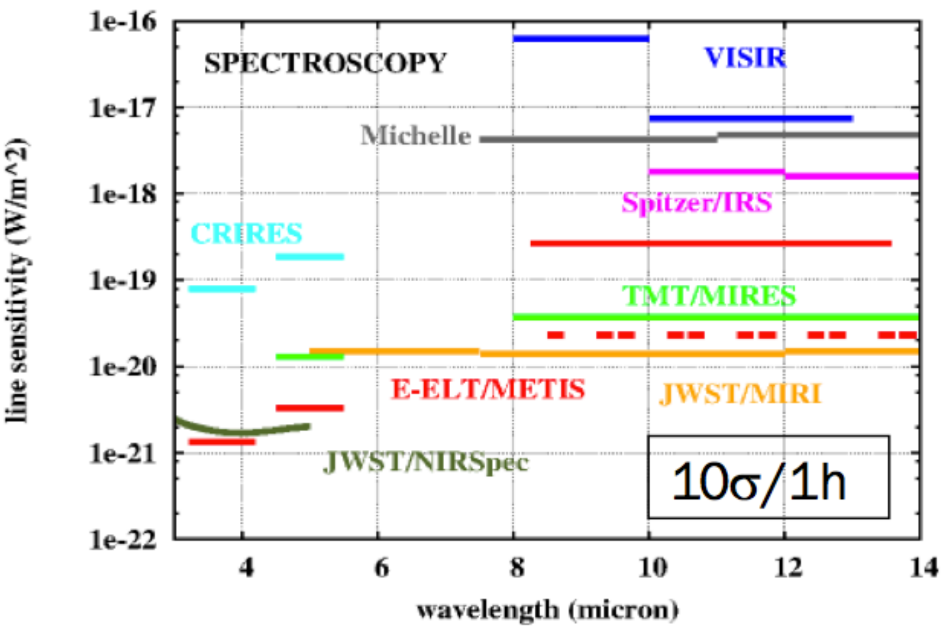
Once you resolve A LOT of AGBs:

- What are the seeds for dust formation?
- What drives the wind in AGB stars?
- How does the dust evolution depends on metallicity?
- What is the mechanism shaping the wind?
  - And how does this affect the shape of Planetary Nebulae…

Tools to answer

In the mid-infrared (L+M+N+Q…)

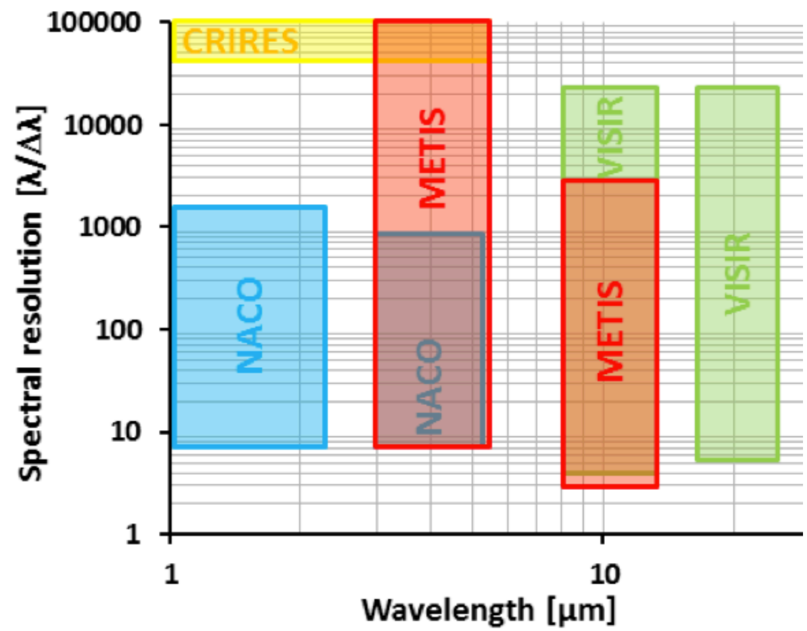
- Future E-ELT competitors:
  - MIRI: max resolution 3000; 5-28 microns
  - SPICA: resolution ~2000; 20-37 micron
  - …



E-ELT/METIS

Brandl et al. (2014, SPIE)

- IFU
  - L, M bands
  - Resolution = 100,000
  - FOV = 1.5” x 0.4”
- Long slit
  - L, M, N bands
  - R ~ 2000

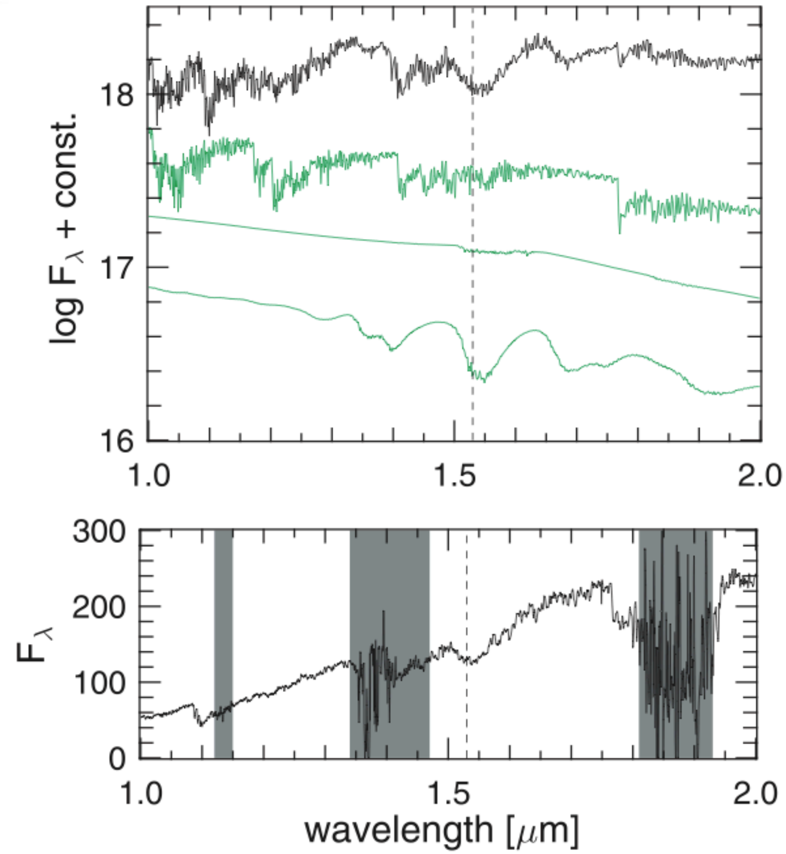


More spectral and angular resolution!

Low resolution spectroscopy
R < 3000

Building block of dust: C_2H_2

- 1.53 micron feature
  - J-K >2, evolved AGBs
  - Dependence on pulsation phase
- 3 micron feature (+5 micron C_3)
  - T_{eff} & C/O indicator
  - Dynamics
- 14 micron feature
  - Not explained by current models
  - NLTE?



Gautschy-Loidl et al. 2004; Groenewegen et al. 2009

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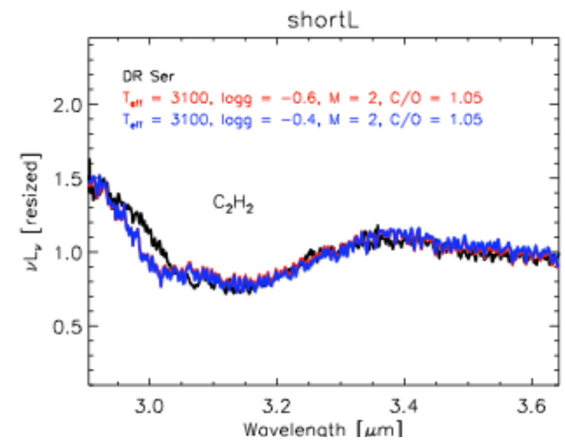

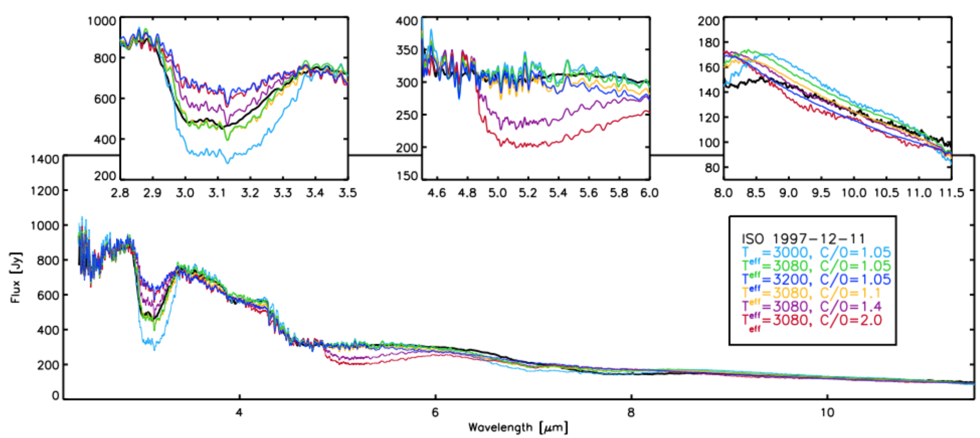

Paladini et al., 2011; Klotz et al., 2012

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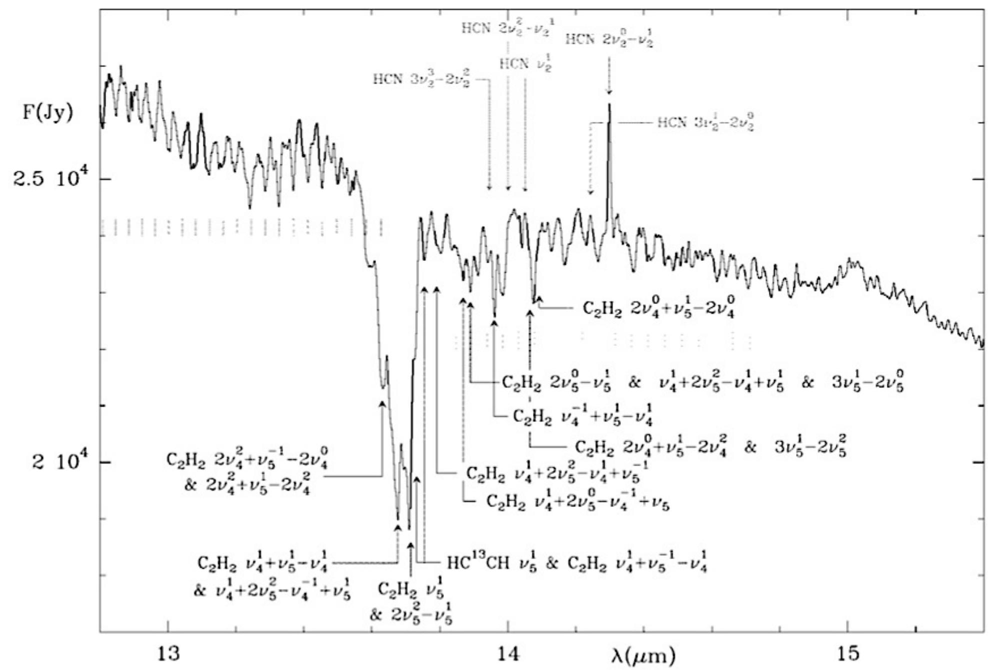
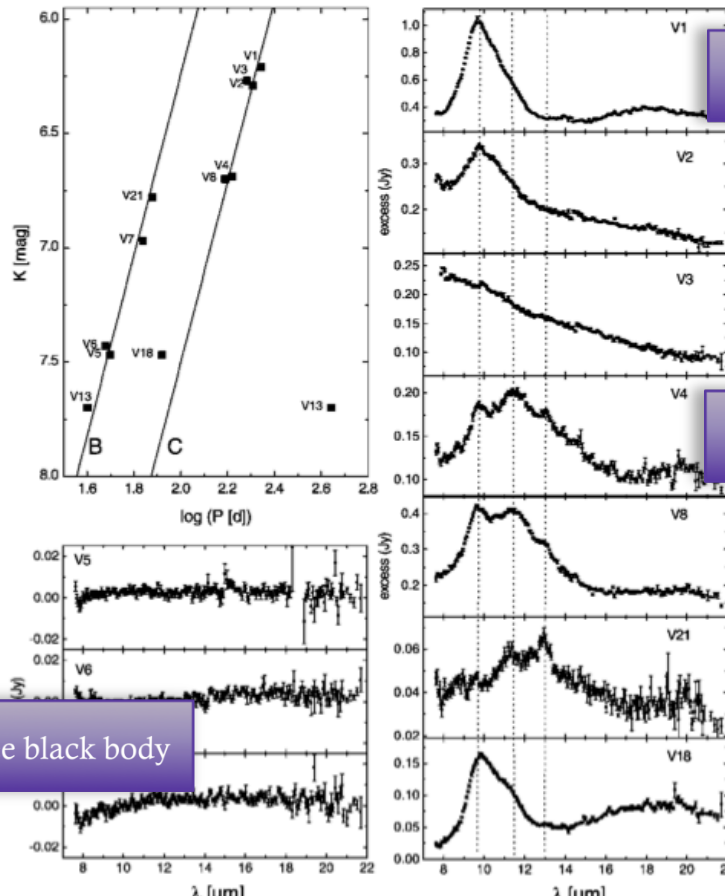


Gautschy-Loidl et al. 2004; Cernicharo et al. 1999

C_2H_2, C_3, C_2H line lists are incomplete!

Oxygen dust

- Several dust species
- What drives the wind not yet accepted
  - Scattering on micron size grains (Hoefner et al., 2008)
- Comparison with model predictions needed!
- Study of mass-loss with metallicity



Am. silicates Mg, Fe, SiO

Am. Al_2O_3
Spinel $MgAl_2O_4$

Dust free black body

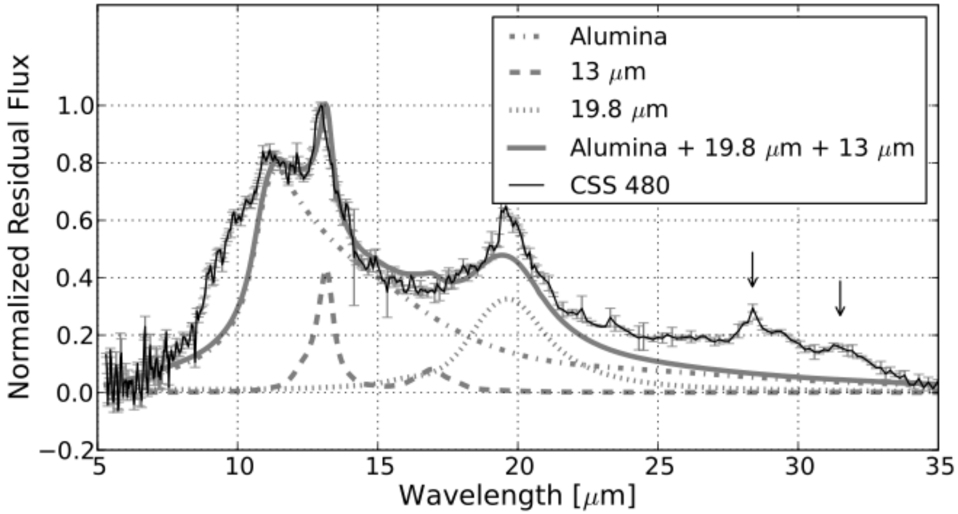
Lebzelter et al. 2006

Credit: J. Hron

S-type stars?

87 (Galactic) S-type AGBs

- Stellar parameters: Photometry + Visible spectra + MARCS models
- Study of dust species: Spitzer spectra



Smolders et al. 2012

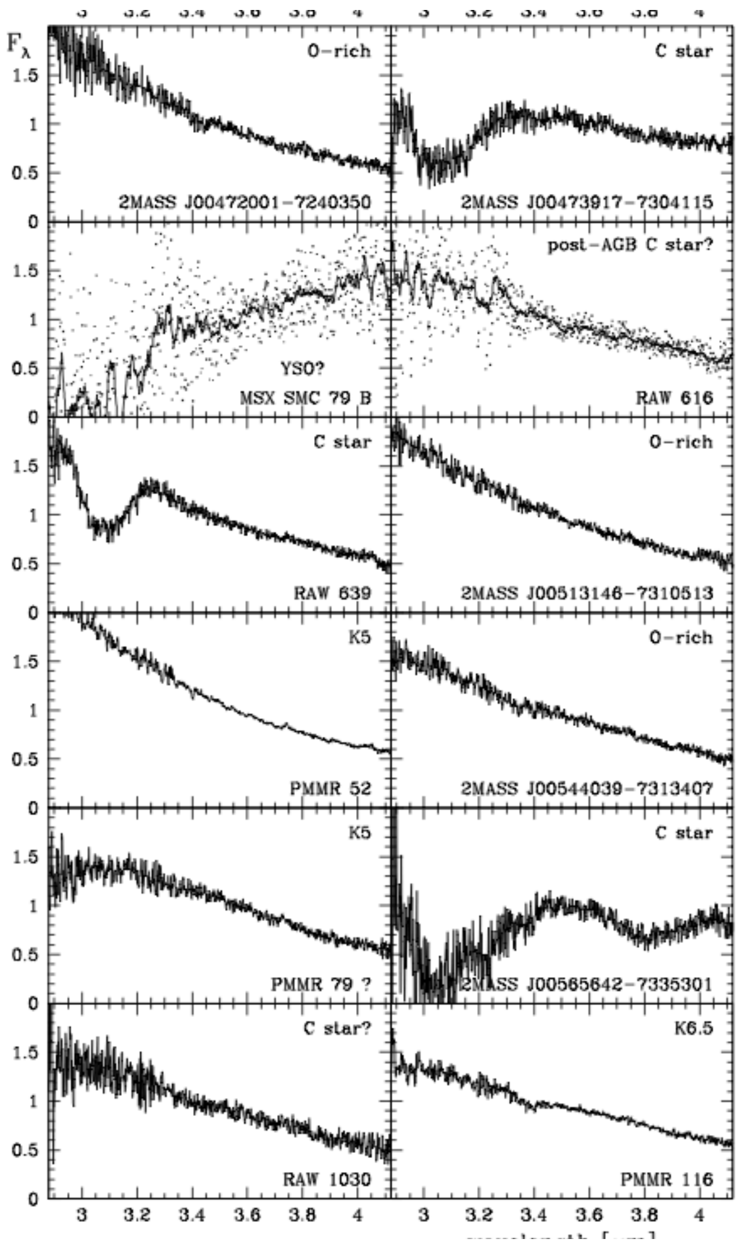
SiS band dependent on C/O ratio
3 groups of dust
Dust condensation cut short for low mass-loss objects

Dust production vs. metallicity

van Loon et al. (2013)

Studied SMC & LMS targets

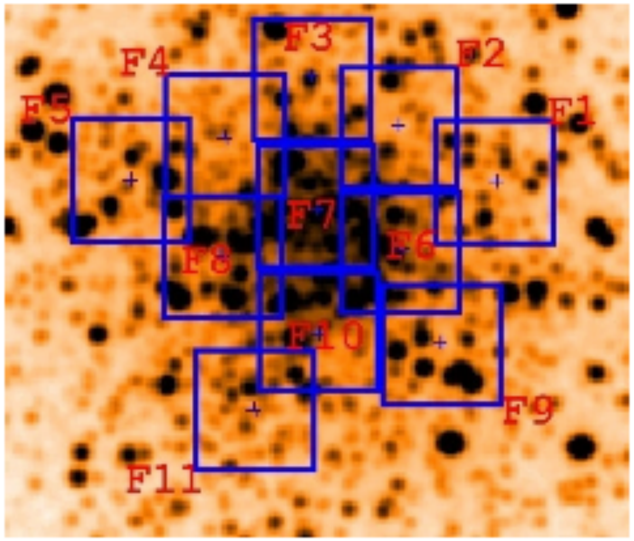
=> Dust formation less efficient at low metallicity

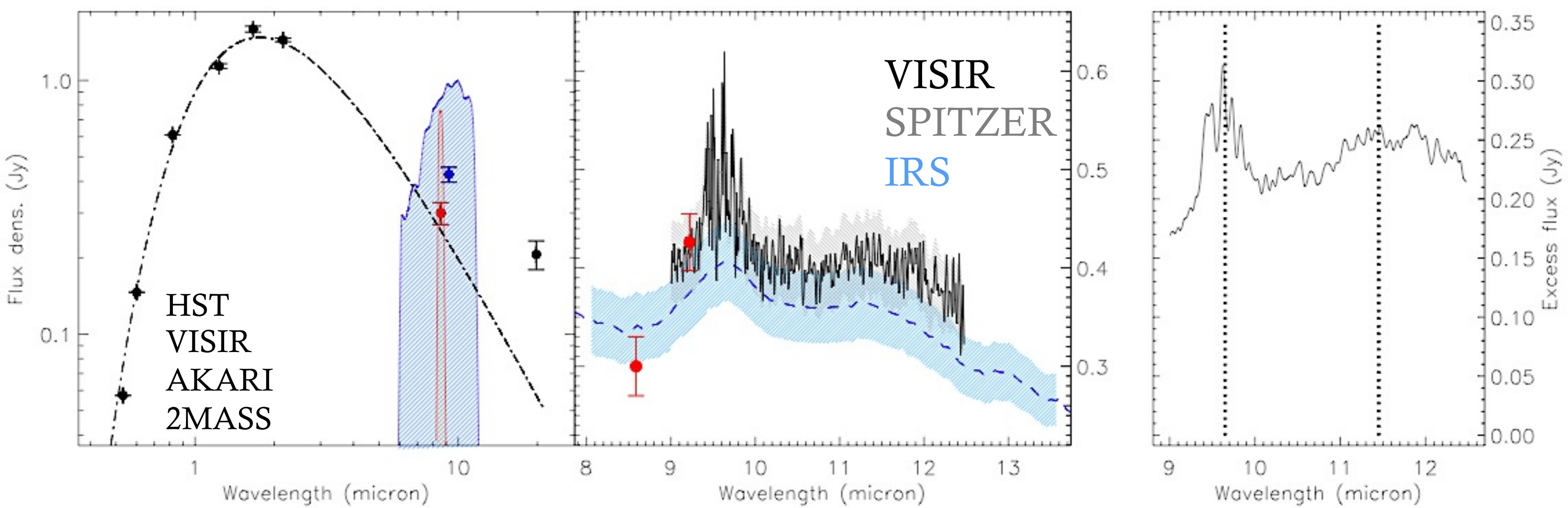


47 Tuc

Momany et al. (2012)
mid-IR view on 47 Tuc

Photometry
But also… Spectroscopy



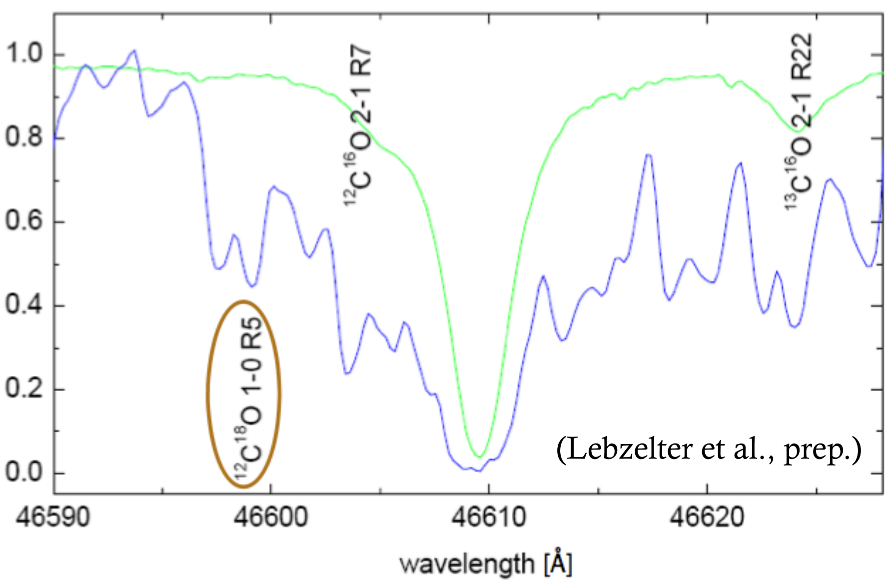


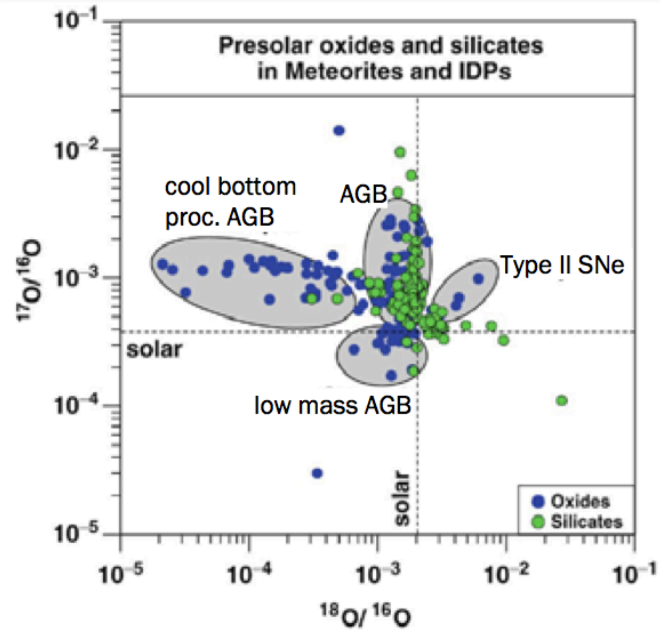
High resolution spectroscopy (the higher the better…)

Molecules & stellar evolution

- Nucleosynthesis & mixing
  - $^{12}C/^{13}C$
  - $^{16}O/^{18}O$
  - $^{24}Mg/^{25}Mg$

$^{16}O/^{18}O$ used to discriminate presolar grains of different origin





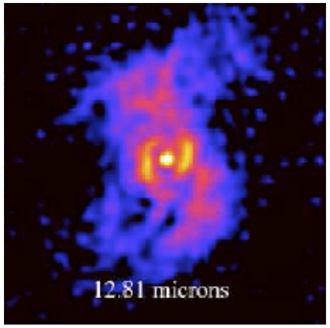
(Henning, 2011,„Astromineralogy")

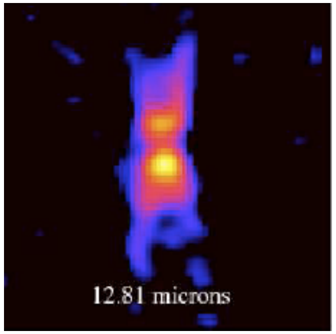
Credit: J. Hron

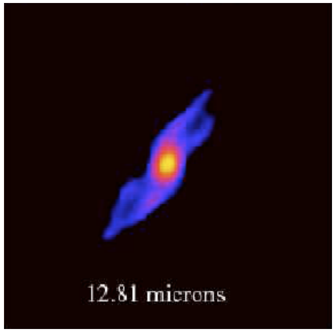
The geometry of the mass-loss process

- Many Post-AGB stars show departure from spherical symmetry
- Asymmetries should develop in the previous stage but…

  on the AGB the picture remains uncertain.







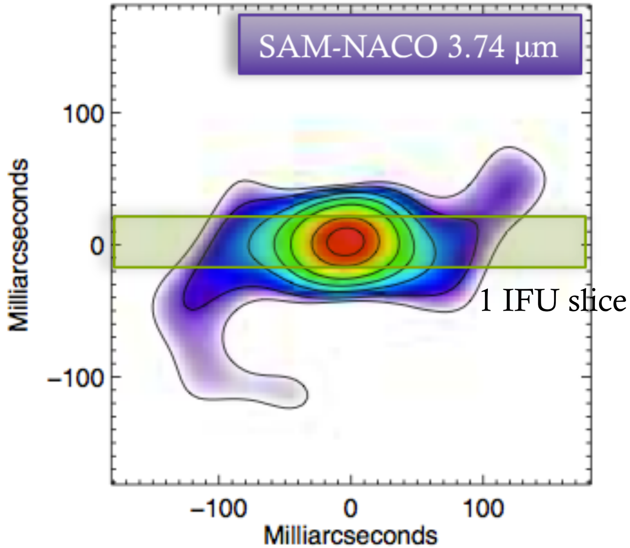
Lagadec et al., 2011

On the AGB the picture remains uncertain.

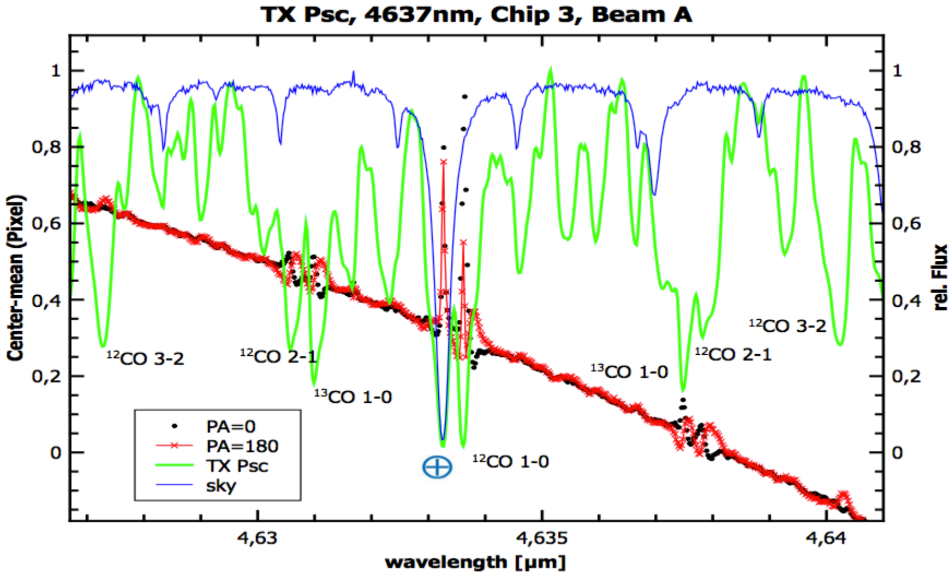
Shaping mechanisms?

- Linking the envelope to the central star:
  convection, blobs, inner wind structure, companions ?

Lykou et al. (subm.)

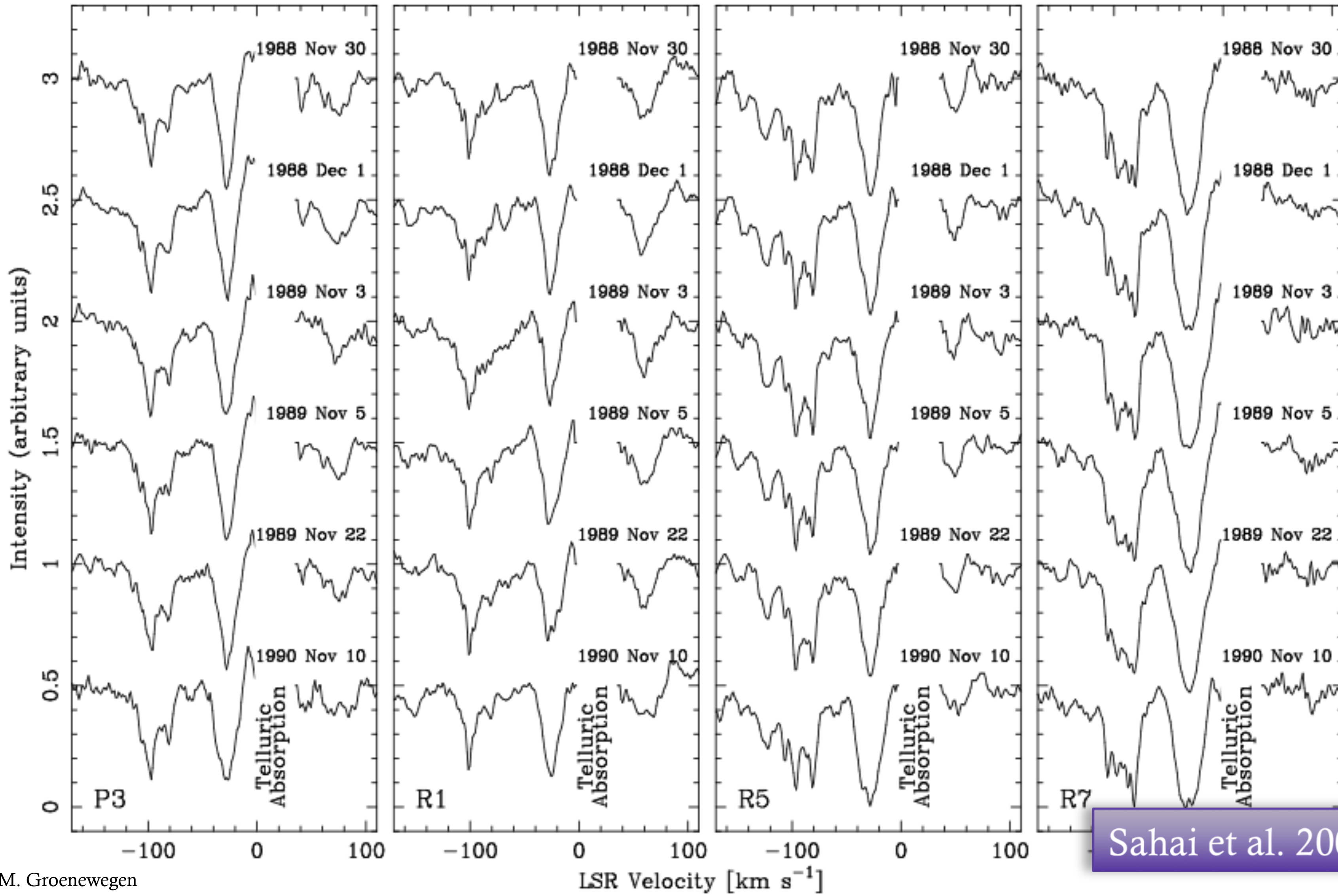


Spectro-astrometry: Hron et al. (2014)



Credit: J. Hron

Kinematic studies

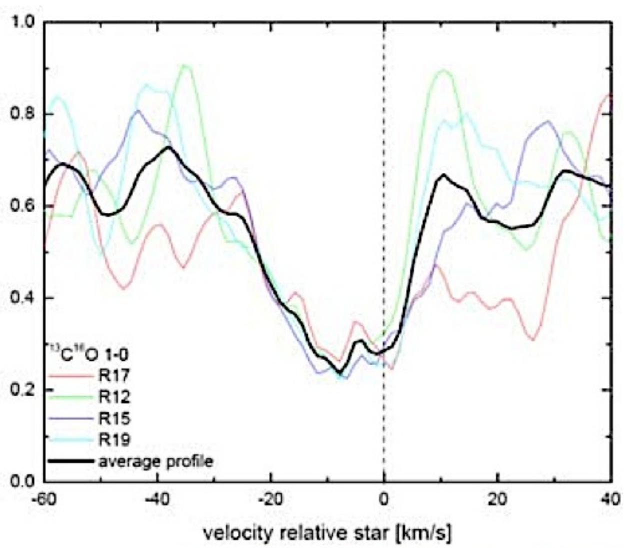


Sahai et al. 2009

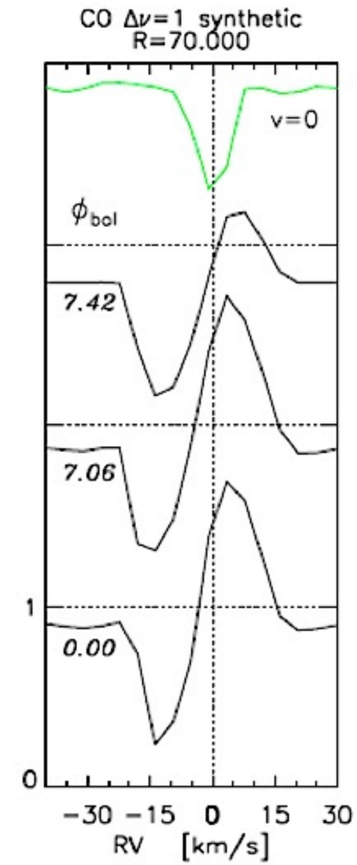
Credit: M. Groenewegen

Gas enrichment of Galaxies

- CO tracing the velocity field
- CO @ L+M bands + submm to estimate gas mass-loss rates?



(Lebzelter et al., prep.)



Nowotny et al. (2005)

Credit: J. Hron

Synergies

- mid-IR + near-IR spectroscopy
  - Stellar parameters+ dust formation
- ALMA
  - Probing different parts of the star
  - Shaping mechanism
- VLTI (interferometry in general)
  - AGB Shaping mechanism
  - Calibrate evolutionary tracks (Solar neighborhood for the moment)
  - Understanding convection
- GAIA, TMT, JWST…

Credit: www.eso.org

Summary

The thermal IR contains a wide range of diagnostic features for these objects and also poorly explored spectral regions

After photometric campaign: mid-infrared+near-infrared campaign

- stellar parameters => New prescription for mass-loss rates
- gas+dust studies

- Mass-loss dependency on metallicity

- Study of the stellar atmosphere
  - mass-loss mechanism
  - Shaping agents

- high spectral and/or spatial resolution observations in the thermal IR are an excellent complement to JWST & ALMA &VLTI/MATISSE

Thank you

Useful literature

- ^van Loon et al.
- ^Lebzelter et al.
- Ramdani & Jorissen 2001
- Origlia et al. 2002
- Vandenbussche et al 2002
- Decin et al. 2008

Vandenbussche et al (2002)