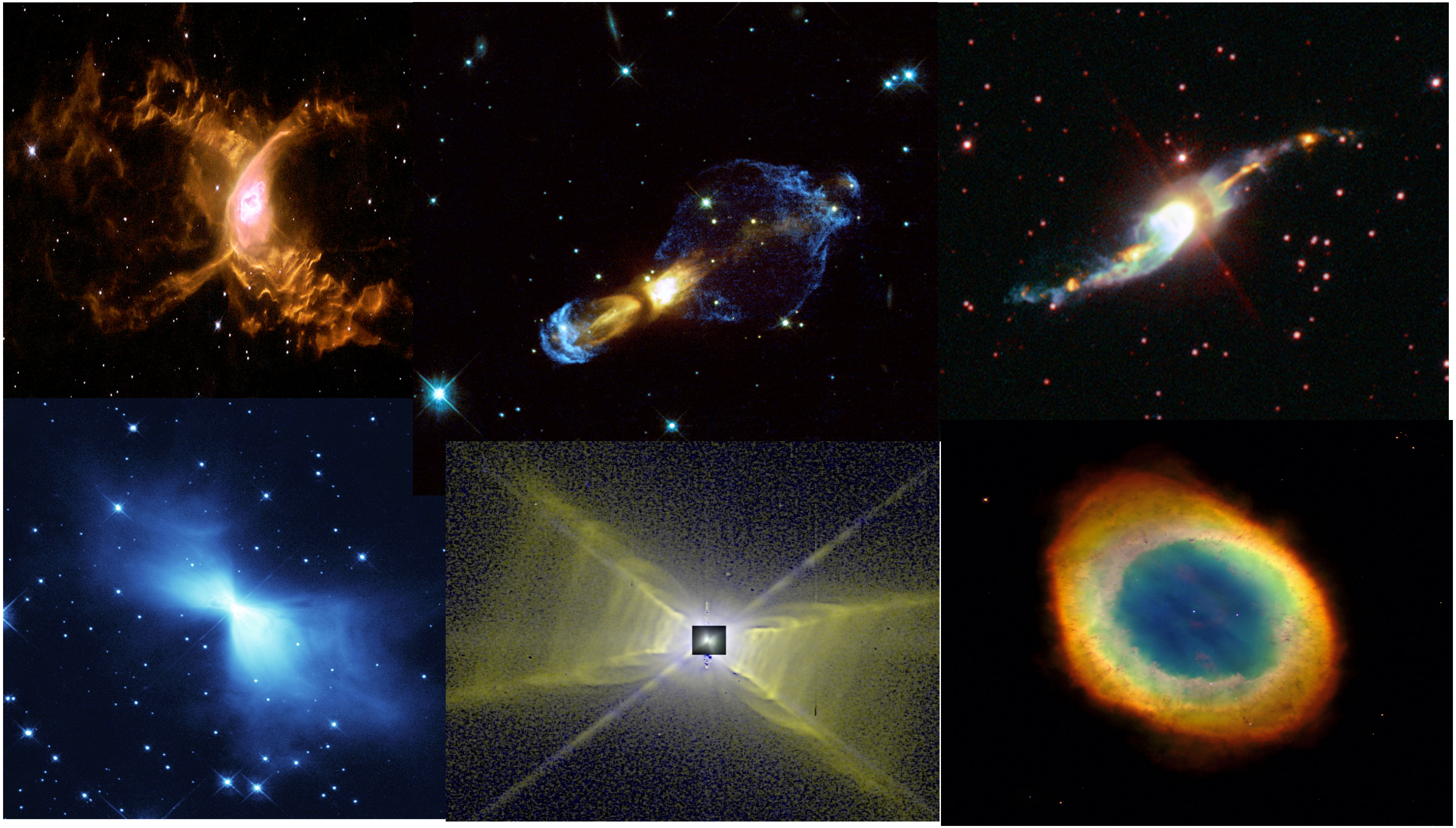
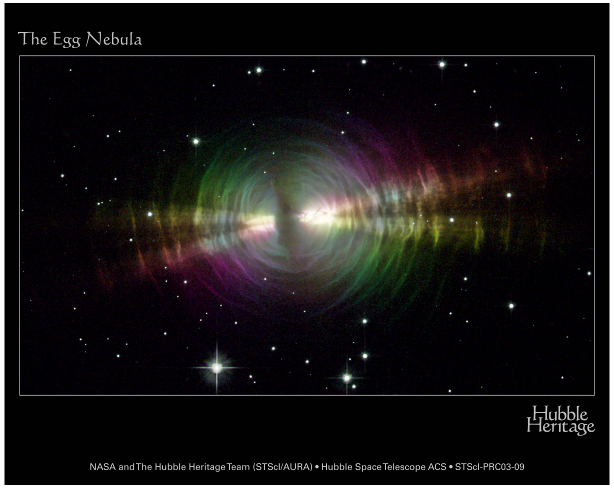
How do low-intermediate mass (binaries) evolve ?
The post-AGB connection



Post-AGB stars



Egg nebula
ADS: 727 ref (02/03/2010)

AFGL 618
ADS: 702

Calabash (OH231)
ADS: 403

No good statistical picture of Post-AGB evolution

What are the evolutionary channels connecting the individual objects ?

HD 56126: 218 ref.
HD 187885: 122 ref.
SAO 239853: 36 ref.

Outline

From AGB over post-AGB to PNe:
- enough riddles to keep us happy for still a while...

Binary connection:

Post-AGB connection:
- Stable disk formation is a mainstream process

LMC-SMC:
- selection of post-AGB stars with disks versus outflows
- preliminary results

Challenges in the future

Binary samples:

AGB → Post-AGB → Pne

Fast evolution !

4000K to 100 000K

R_* ~1 AU on the AGB to ~ R_sun

Variable often with Large Amplitudes

From very obscured to naked

Binary Detection Methods: Very diverse and prone to a large variety of observational biases...

Processes only (?) relevant in binaries: PNe

- Great majority of PNe are not spherical: axi symmetry; point symmetry jet-like structure are common (Balick&Frank, 2002; De Marco 2008, Zijlstra 07)

- which shaping mechanisms only relevant in binaries ?

- direct evidence for binarity is often poor/lacking

- central star mass distribution in very sharply peaked (crf. talk Zijlstra yesterday)

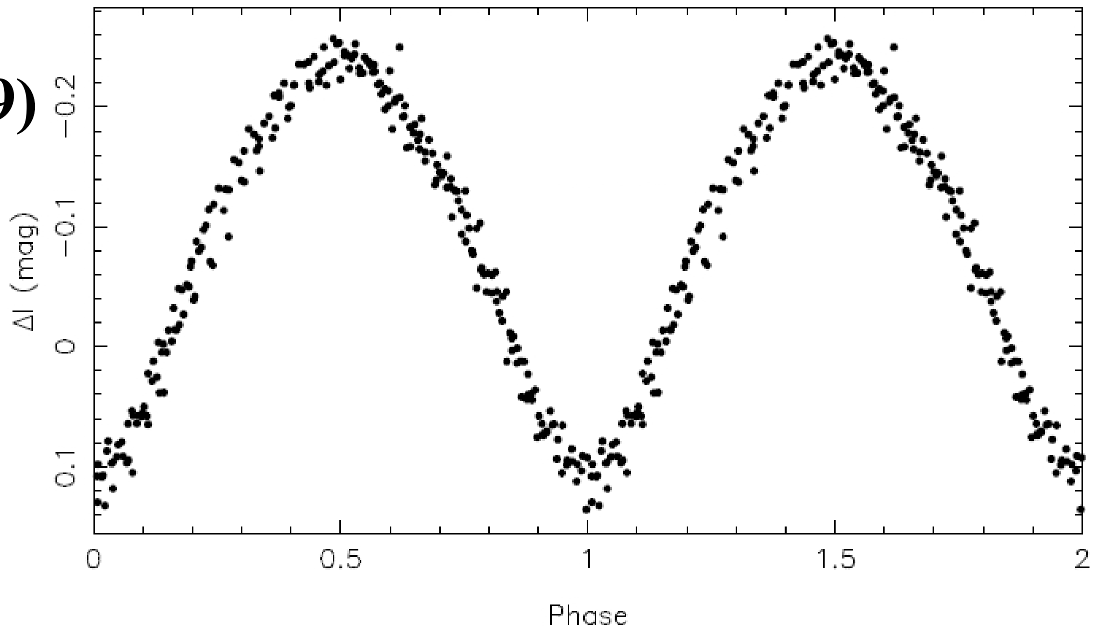
PNe and Binarity

- CSPN: photometric timeseries (Bond 2000, De Marco 2008, Miszalski 2008, 2009)

  12-21 % are close binaries with periods < 3d. Result of spiral-in

  When specific morphologies are selected (jets, rings, lobes, and symmetrical low-ionization structures): close binary rate is higher

Period = 0.1d



- visible binaries (Ciardiullo 1999) very wide orbits

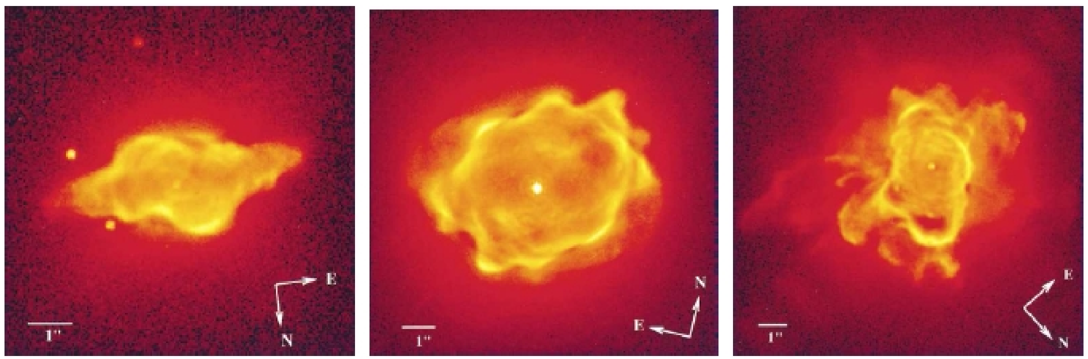
- rv orbits are missing: intermediate orbital range ?

Young PNe and Post-AGB nebulae

- shaping begins very early after the AGB (during superwind) !

- extremely complex geometries are legio: (multipolar) jets, point-symmetries

- seminal paper by Bujarrabal et al. (2001): 28/32 Post-AGB stars (PPne) showing CO emission, have outflow momenta in excess to what radiation can provide.

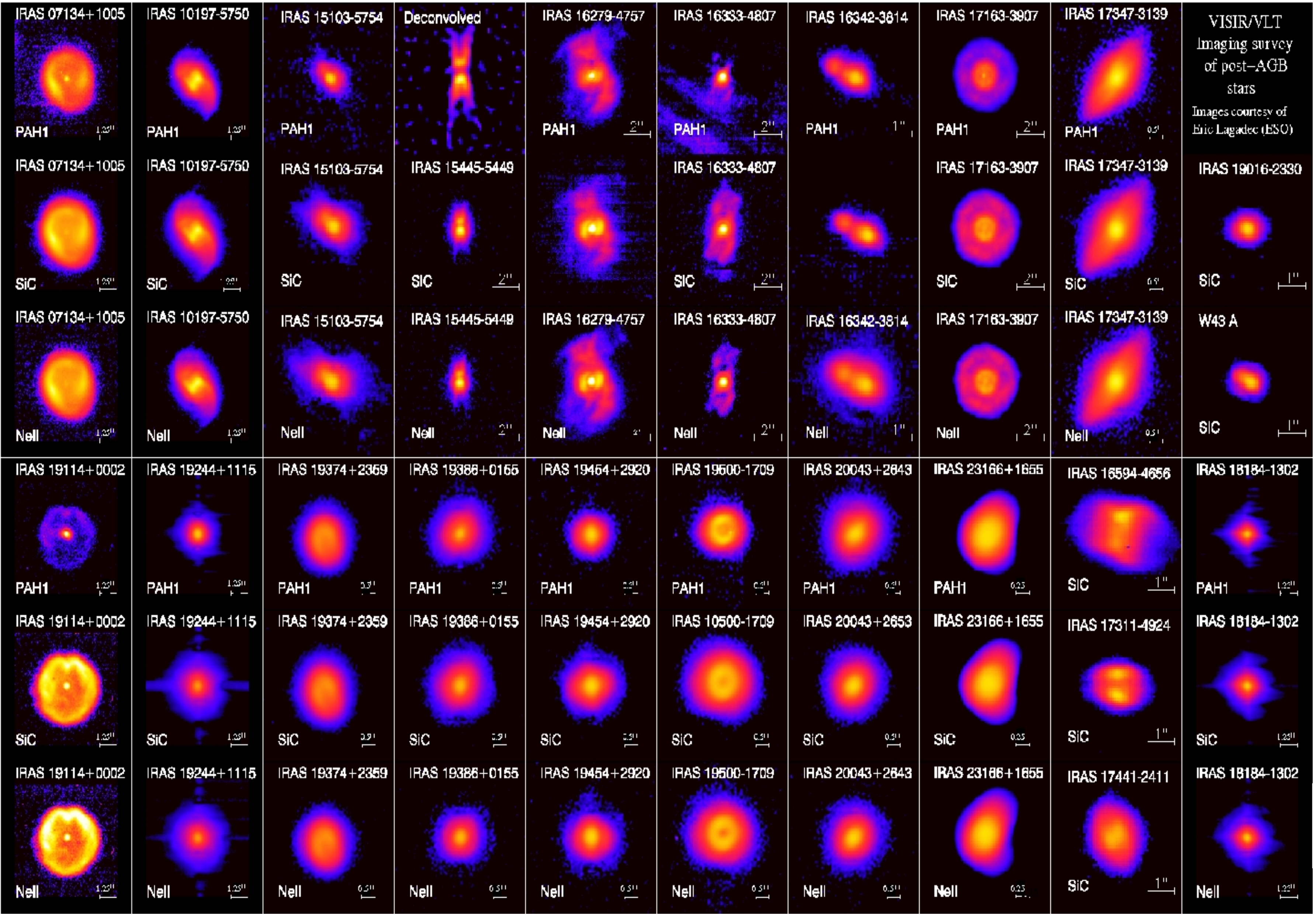


Sahai &Trauger 1998

Fig. 1.— HST Hα images of very young PNe (He 2-115, left, He 2-138, center and M 1-26, right) demonstrating the extreme morphologies exhibited by these objects. From Sahai & Trauger (1998), reproduced by permission of the AAS.

Mid-IR: surveys *Lagadec & Verhoelst, in prep*

Visir



85 stars
49 point sources
13 elliptical
8 bipolar
3 multiple
1 square
3 sphere

AGB stars

- P-L relation branches (Wood, 1999), Sequence E are ellipsoidal variables: **1-3% of all luminous giants.**

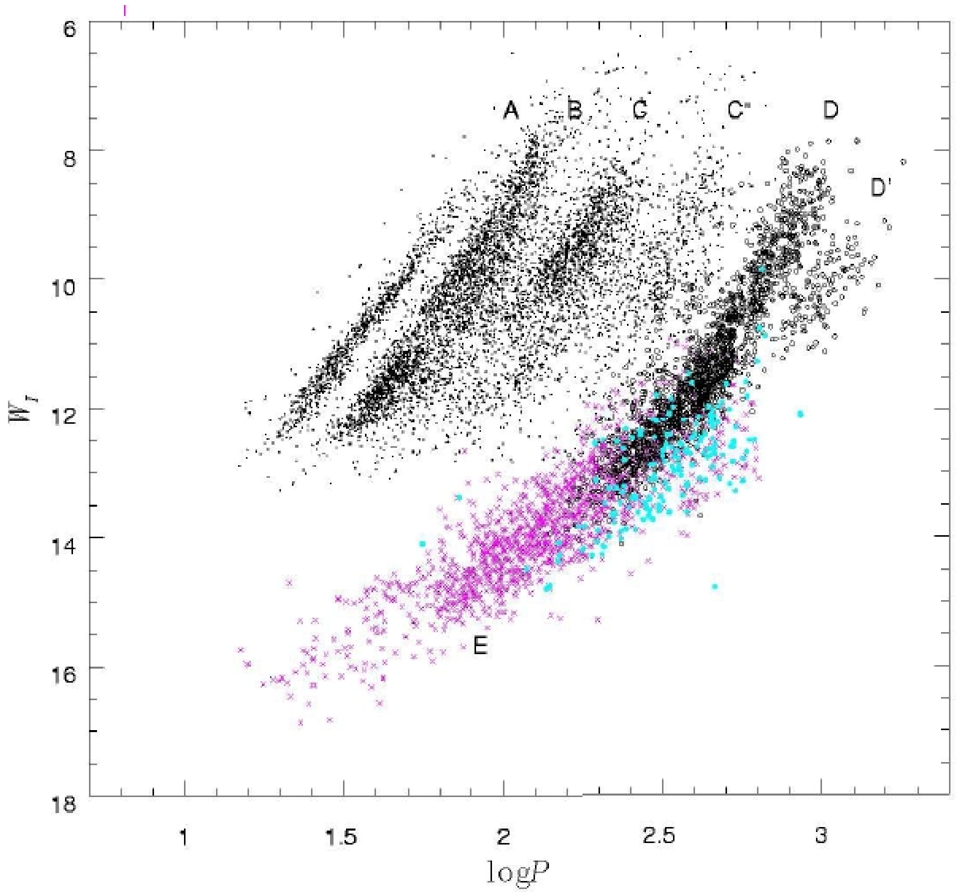
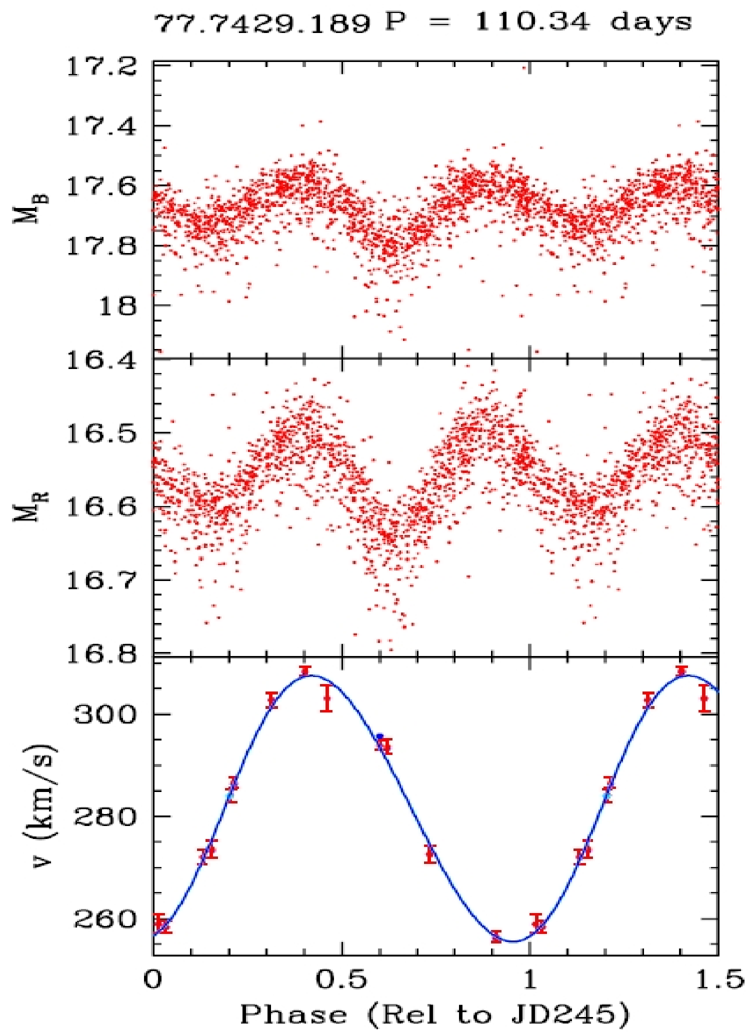


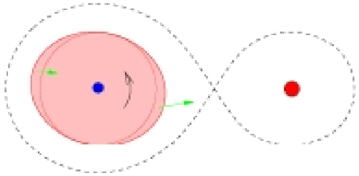
Fig. 5. Period–W_I diagram for variable red giants in the LMC. Magenta crosses mark candidates for ellipsodal variables, cyan dots show ellipsoidal variables with eccentric orbits, empty circles indicate LSPs, and small dots show other red giants.

Nicholls et al., 2010

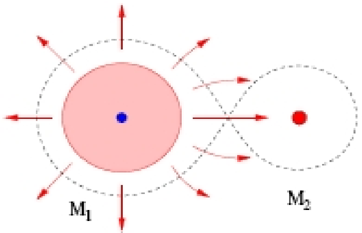


Binary Evolution

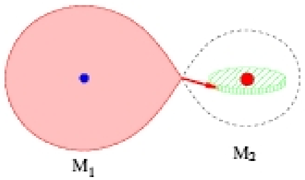
stars in binary systems can interact in various ways:



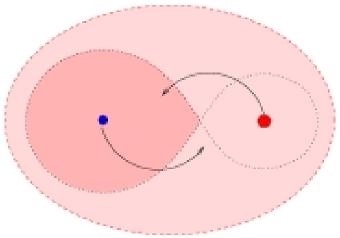
tidal interaction



wind accretion & tidally enhanced winds



Roche-lobe overflow

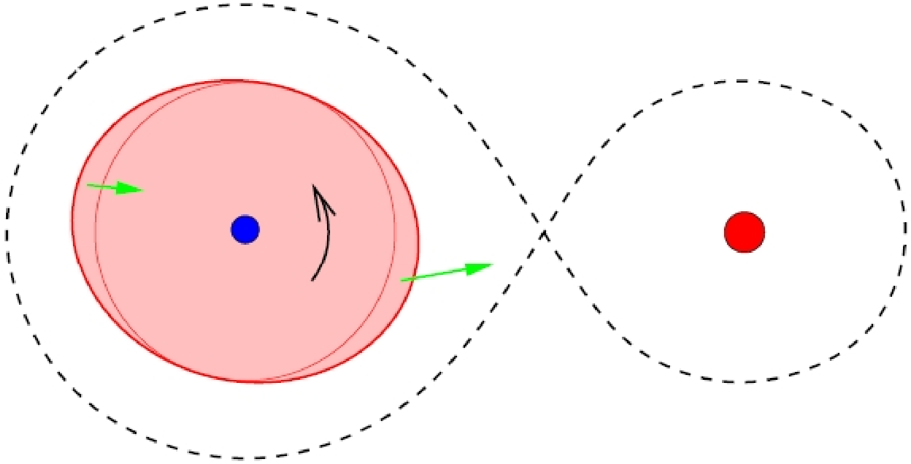


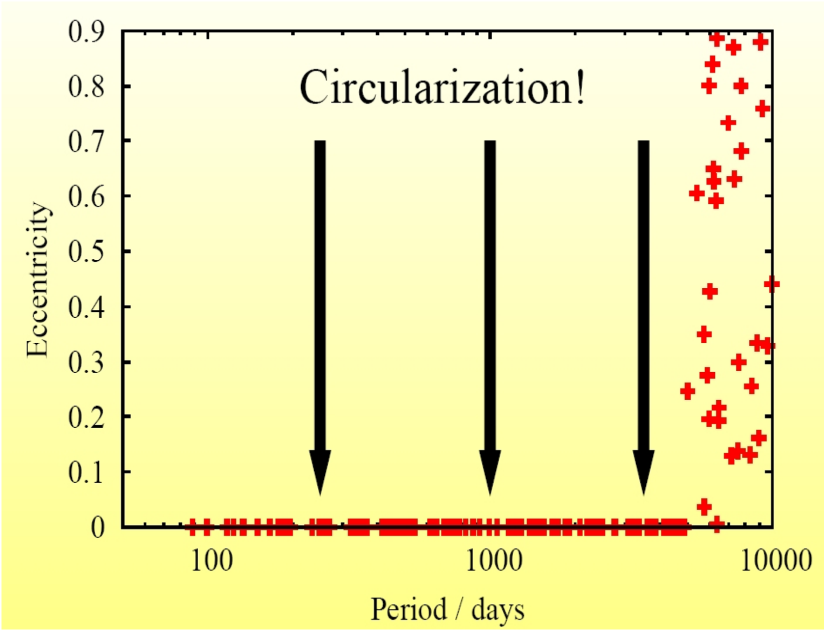
common envelope evolution

fig: Pols

(Webbink 1986, Jorissen 1998, Pols 2005 etc.)

Binary Evolution

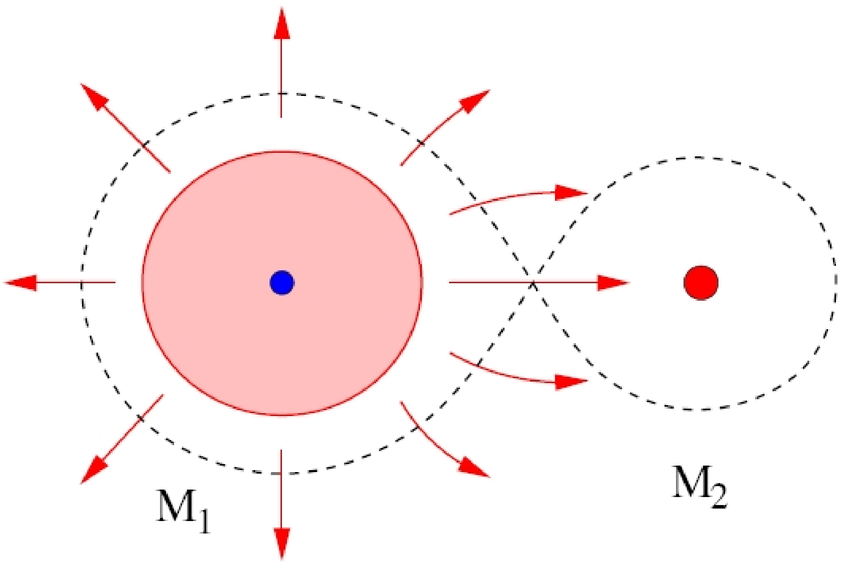


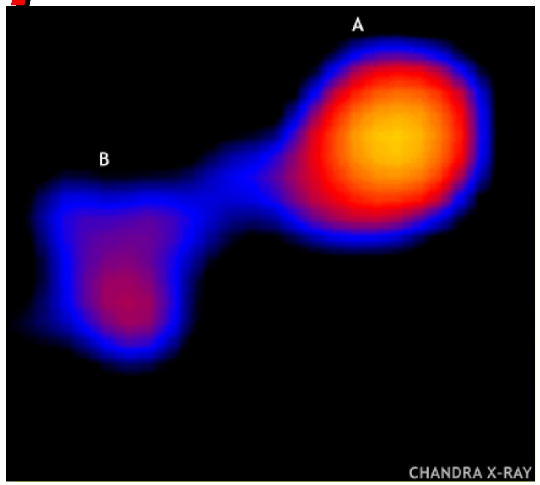


- differential gravitational field $\Rightarrow$ tidal bulges
- if $\Omega_{\rm spin} \neq \Omega_{\rm orb}$ or $e \neq 0$:
  frictional dissipation $\Rightarrow$ lag of tidal bulges $\Rightarrow$ torque
- minimum energy at constant $J_{\rm tot}$:
  $\Omega_{\rm spin} = \Omega_{\rm orb}$ and $e = 0$

fig: Pols, Izzard

Binary Evolution: wind accretion





Mira

- Bondi-Hoyle accretion:

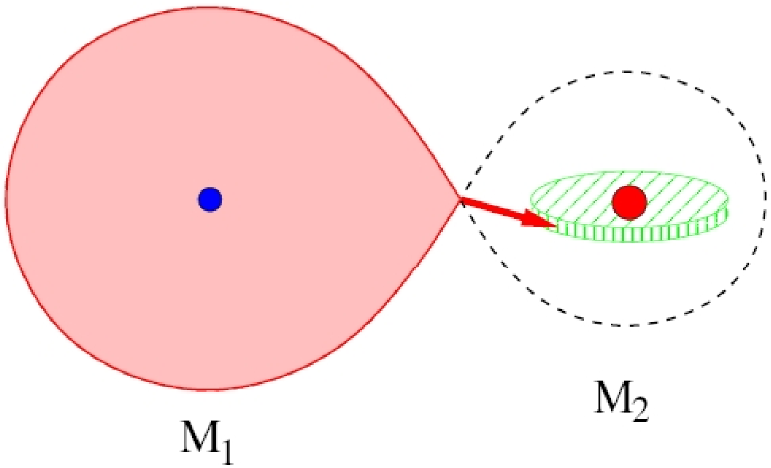
$$\dot{M}_{2\mathrm{acc}} = \alpha_{\mathrm{acc}} \times \dot{M}_{1\mathrm{wind}} \times \left(\frac{v_{\mathrm{wind}}}{v_{\mathrm{orb}}}\right)^{-4} \left(\frac{M_2}{M_1 + M_2}\right)^2$$

- caveat: Bondi-Hoyle only valid for $v_{\mathrm{wind}} \gg v_{\mathrm{orb}}$ ...
  not true for AGB winds!

Pols (2004), Nagae et al. (2004)

fig: Pols

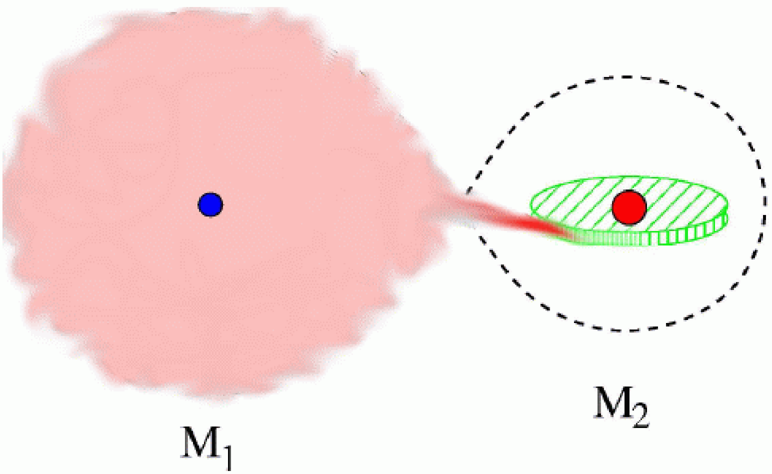
Binary Evolution: Roche Interaction



- stability of RLOF depends on $q = M_1/M_2$ and evolutionary state
- stars with radiative envelopes: stable mass transfer (thermal or nuclear timescale)
- stars with convective envelopes: dynamical instability if $q > q_{\rm crit} \sim 0.7$

fig: Pols

Binary Evolution: Roche Interaction

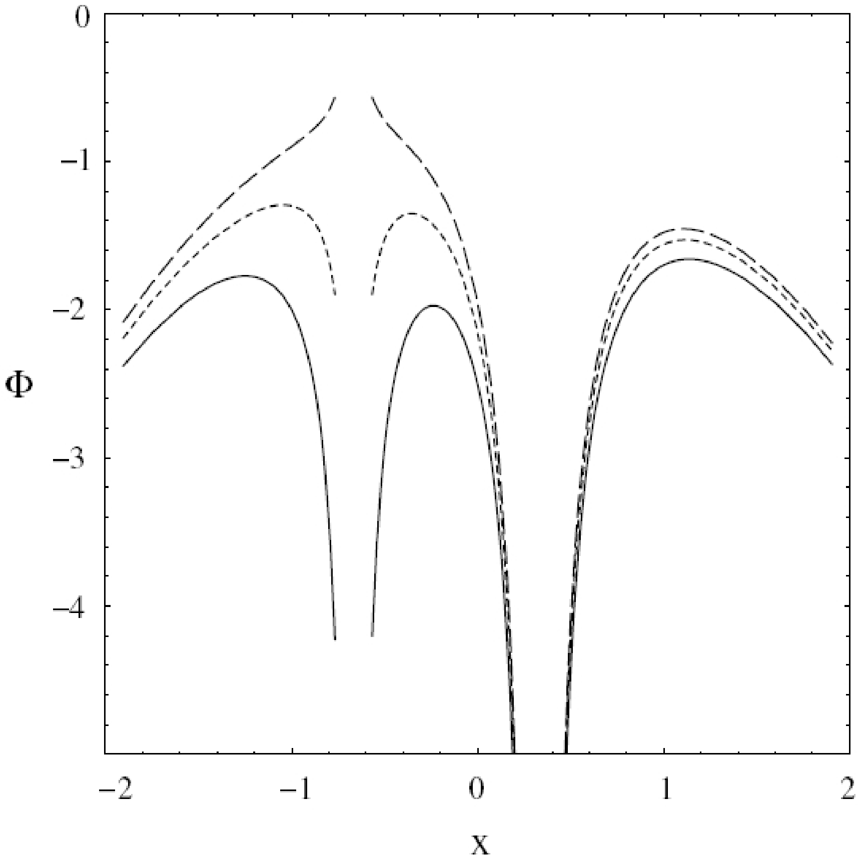


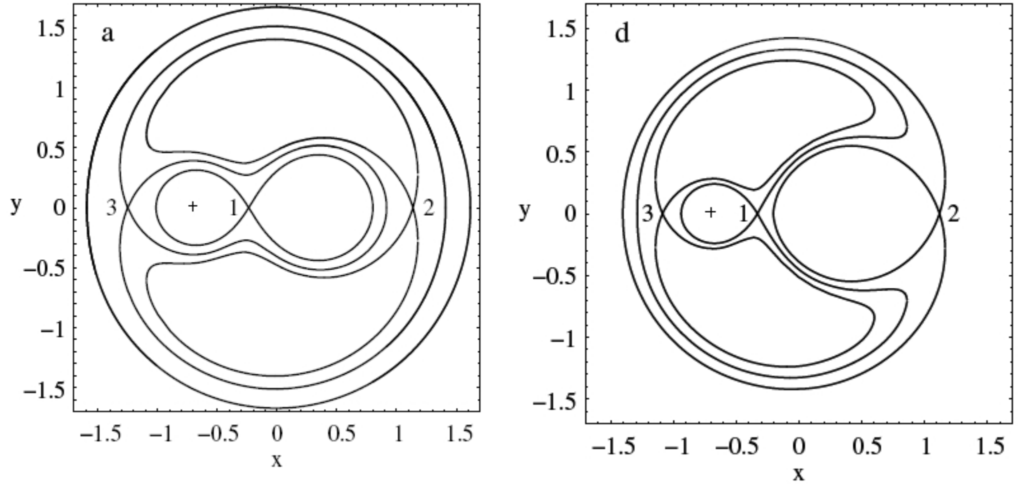
- exposes stellar core ⇒ CNO-processed material (or even He-burning material)
- response of companion to accretion: expansion, spin-up ⇒ mass and AM loss from binary system?
- caveat: assumes star has a sharp boundary... AGB stars are fluffy!

fig: Pols

Binary Evolution: Roche interaction

Radiation pressure reduced effective potential which can have a strong effect on the mass-flow in the system



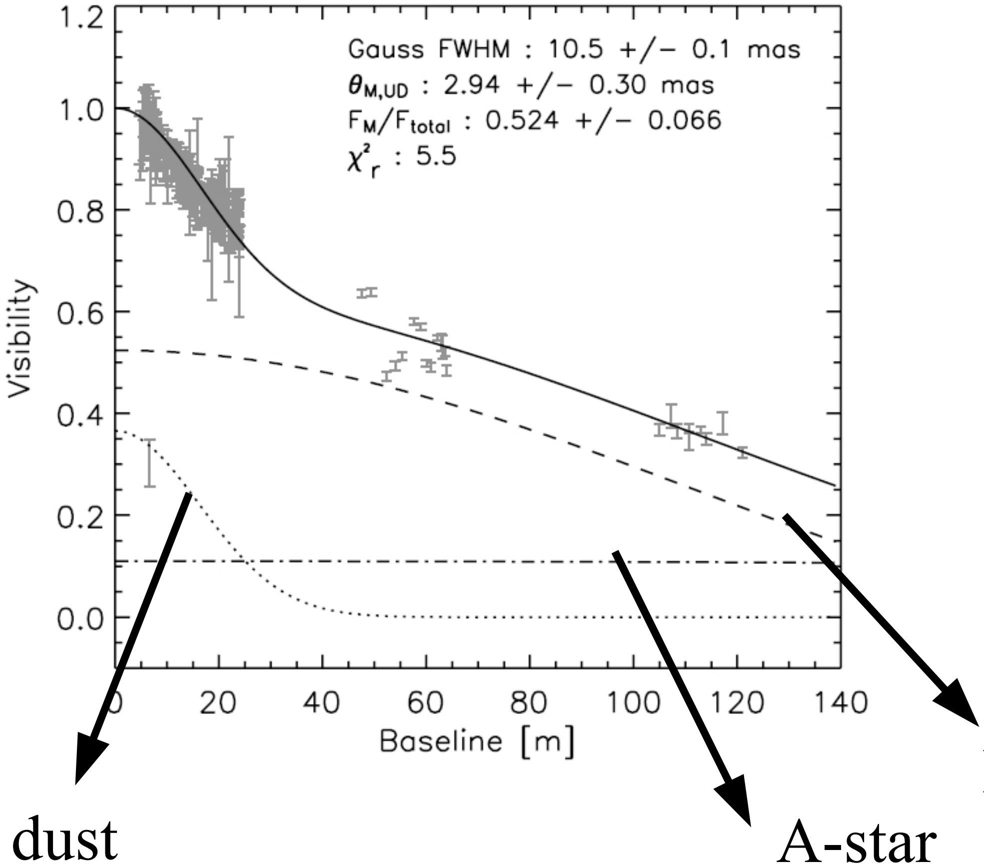


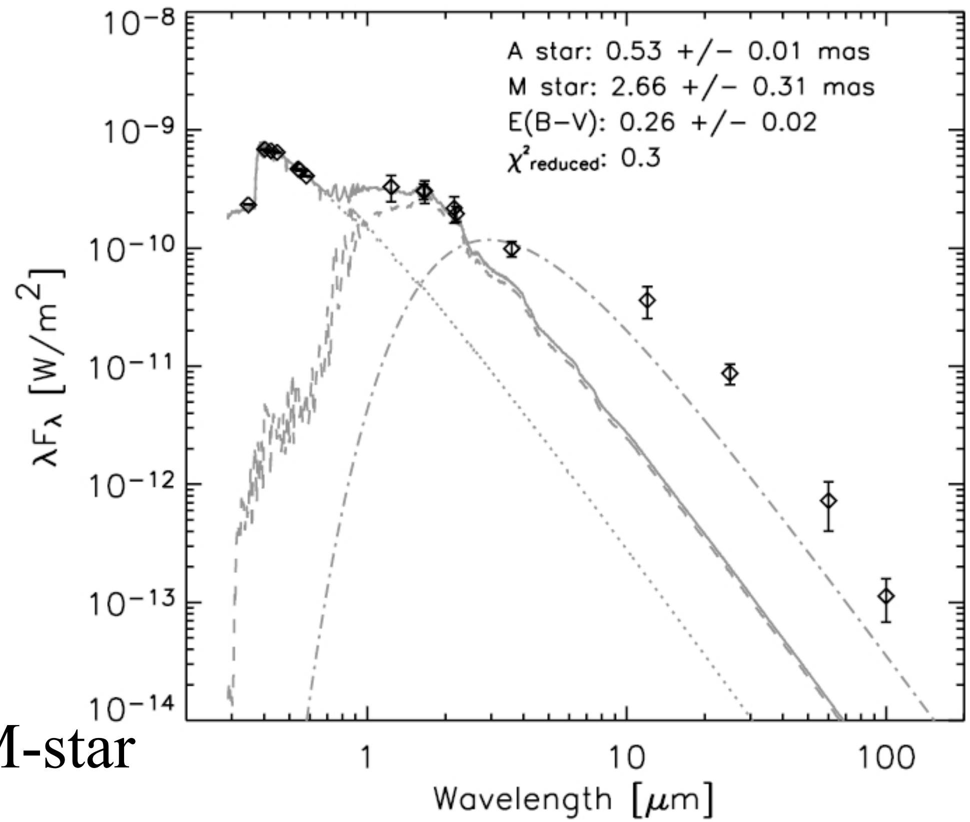
$$f \equiv -\frac{1}{\rho}\frac{\mathrm{d}P_{\mathrm{rad}}}{\mathrm{d}r}\bigg|_{r_1}\left(\frac{GM_1}{r_1^2}\right)^{-1}$$

Phillips & Podsiadlowski 2002, Dermine et al., 2009

SS Lep: ***Verhoelst et al., 2007***

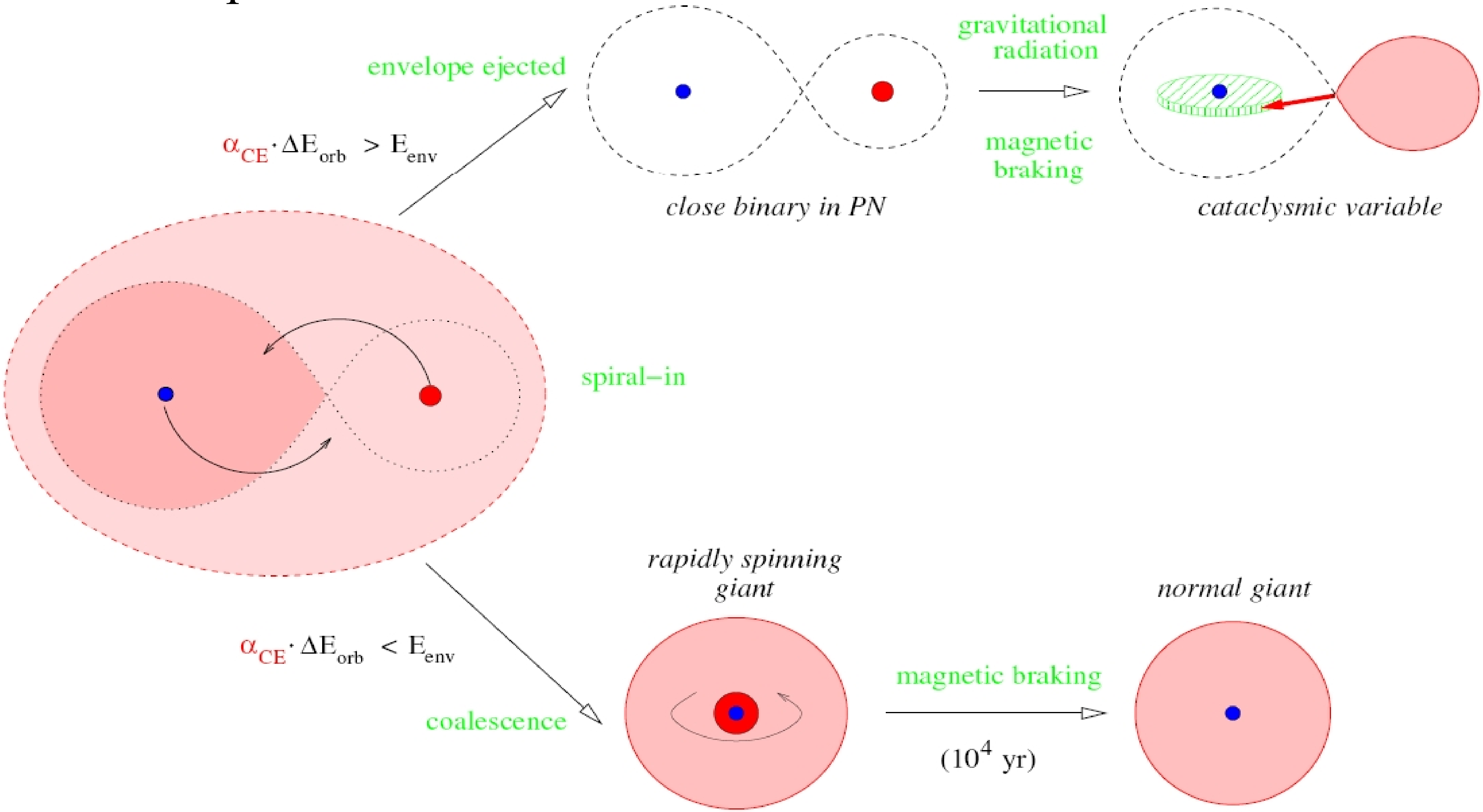
Algol Paradox: M-star + A-star (not in equilibrium)
M-star is resolved (Vinci) and filling its Roche-Lobe:
mass-transfer in action !





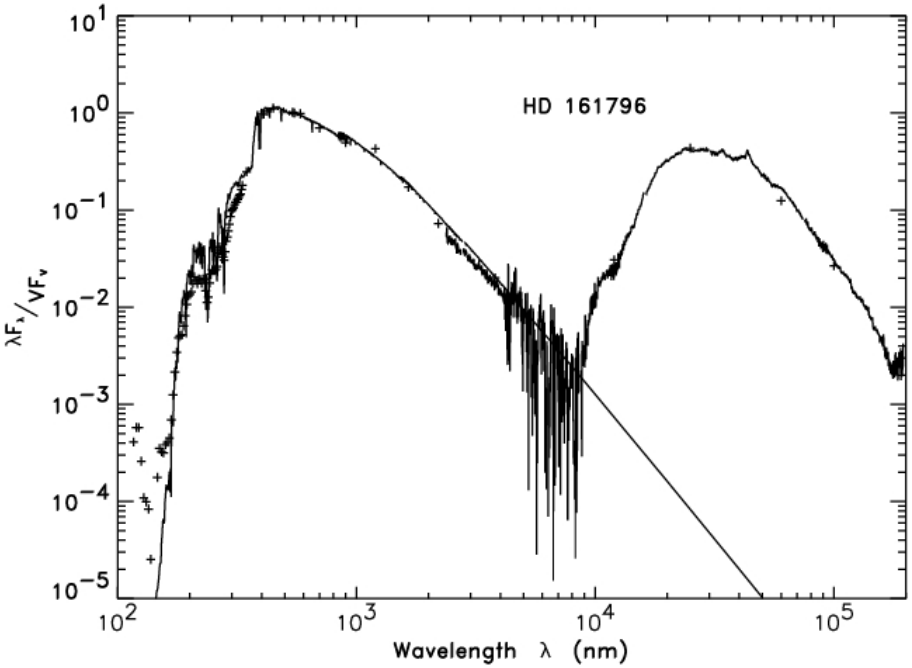
Binary Evolution: Common Envelope...

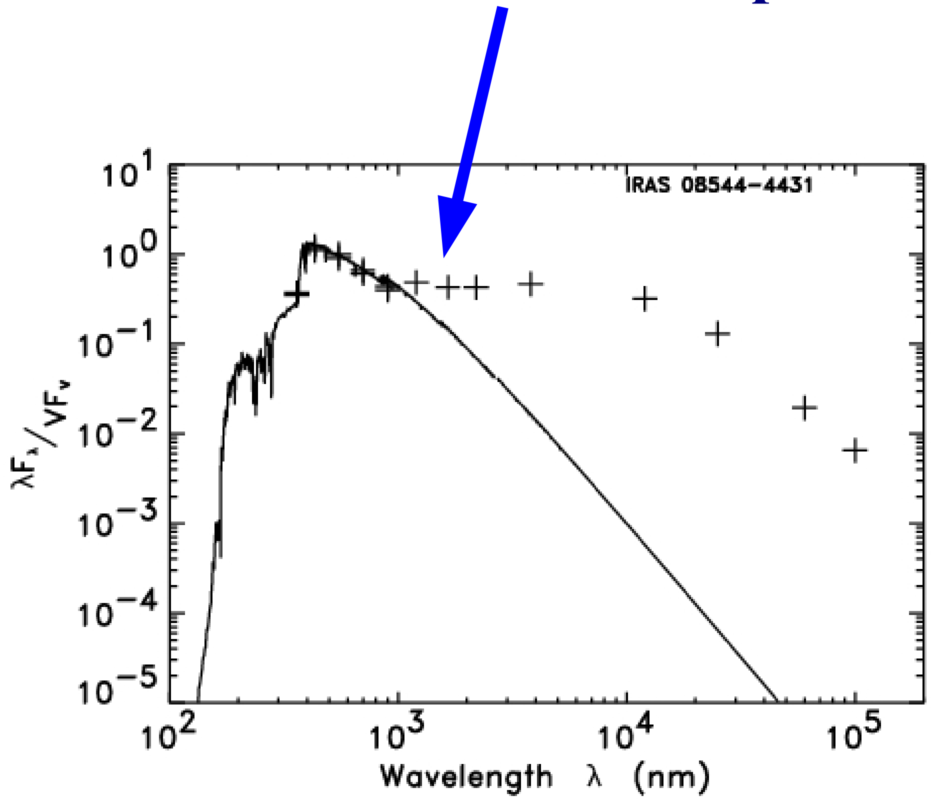
outcome is unpredictable....



The Post-AGB connection: near-IR excess

Luminosities ~ 1000-10000 L_sun
Dust at sublimation temperature

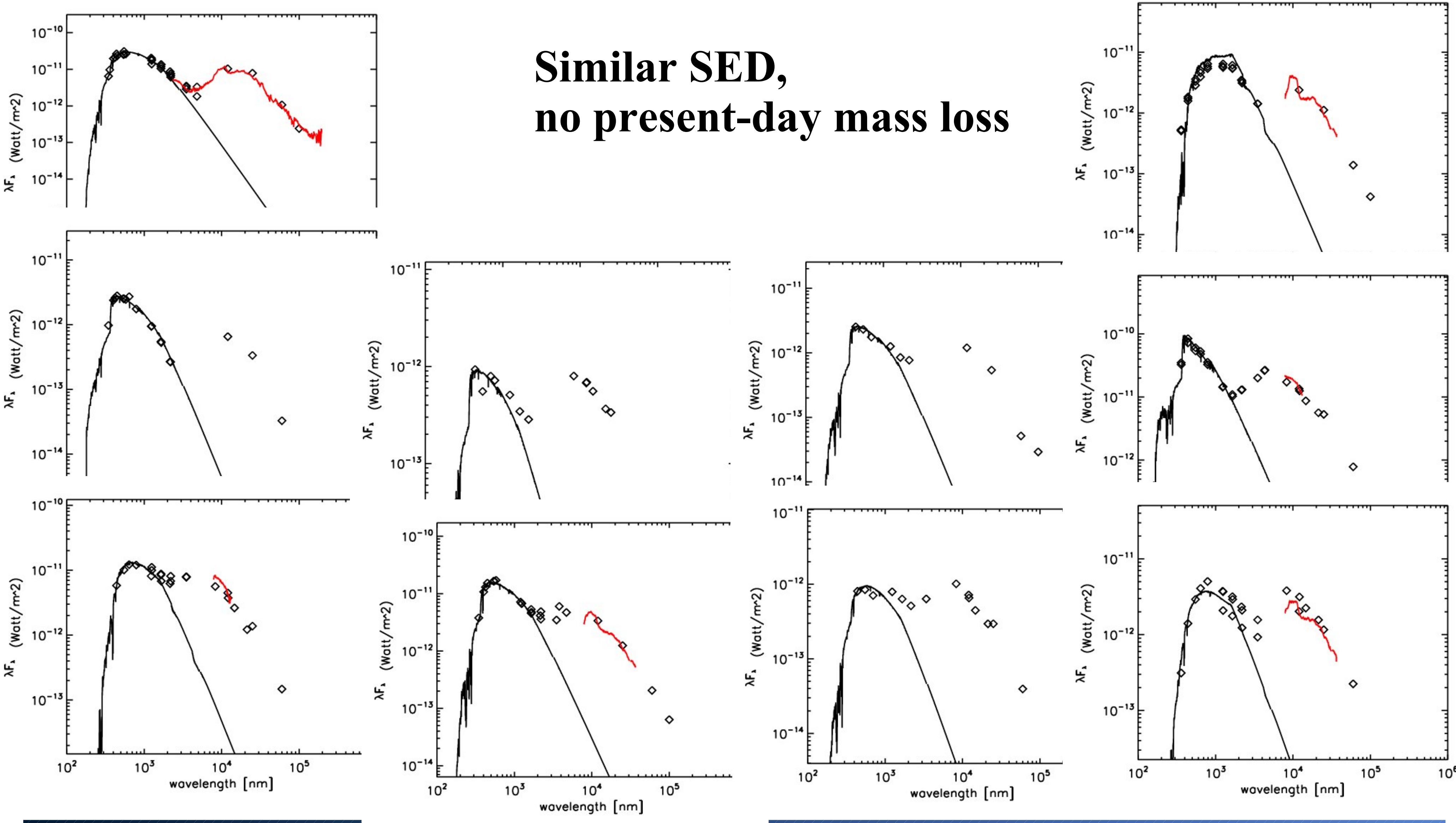




these are the binaries !

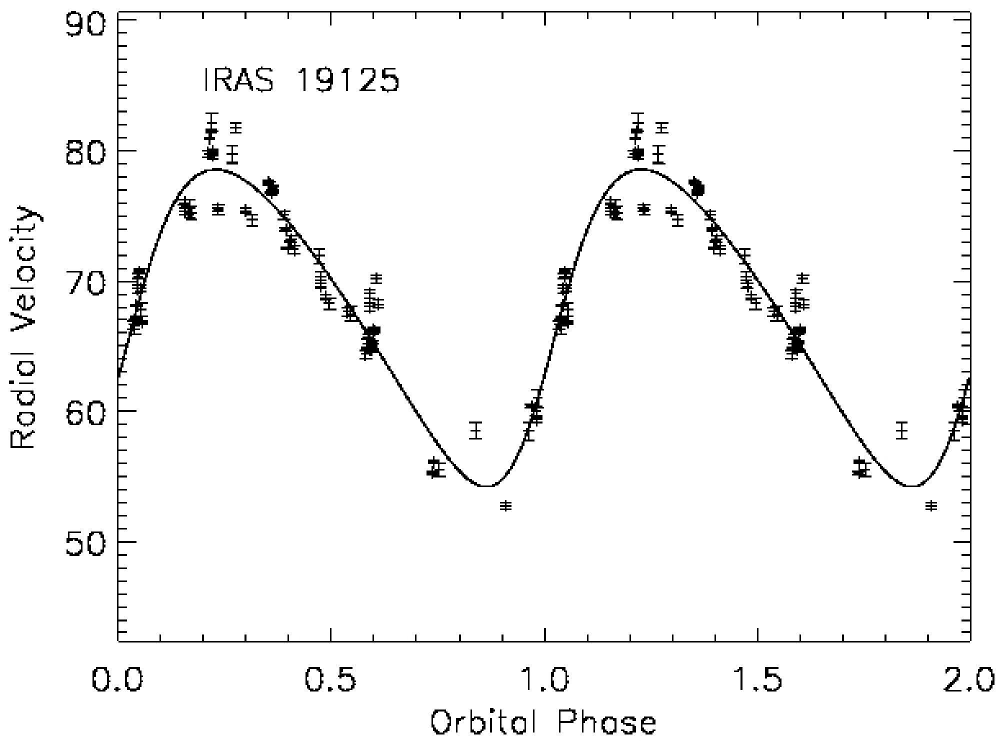
Galactic Sample ~ 80 objects

Similar SED,
no present-day mass loss



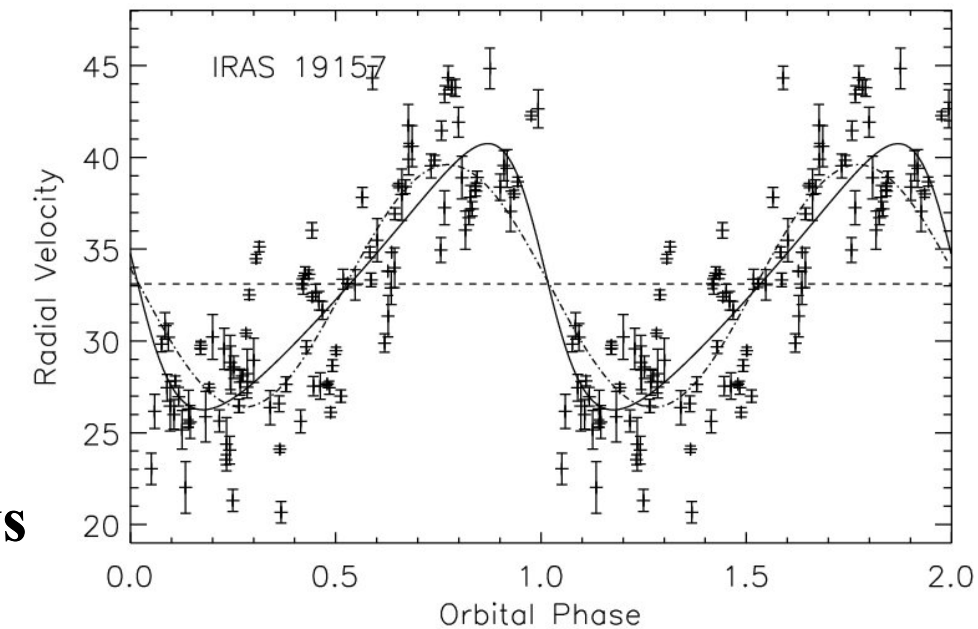
De Ruyter et al., 2006; Gielen et al., 2008, 2009

Binarity rate: non-pulsating one : 100%



P = 520 +/- 2 d
e = 0.25 +/- 0.03
f(M) = 0.097 solar mass

P = 119.5 +/- 0.2 d
e = 0.31 +/- 0.07
f(M) = 0.0041 solar mass

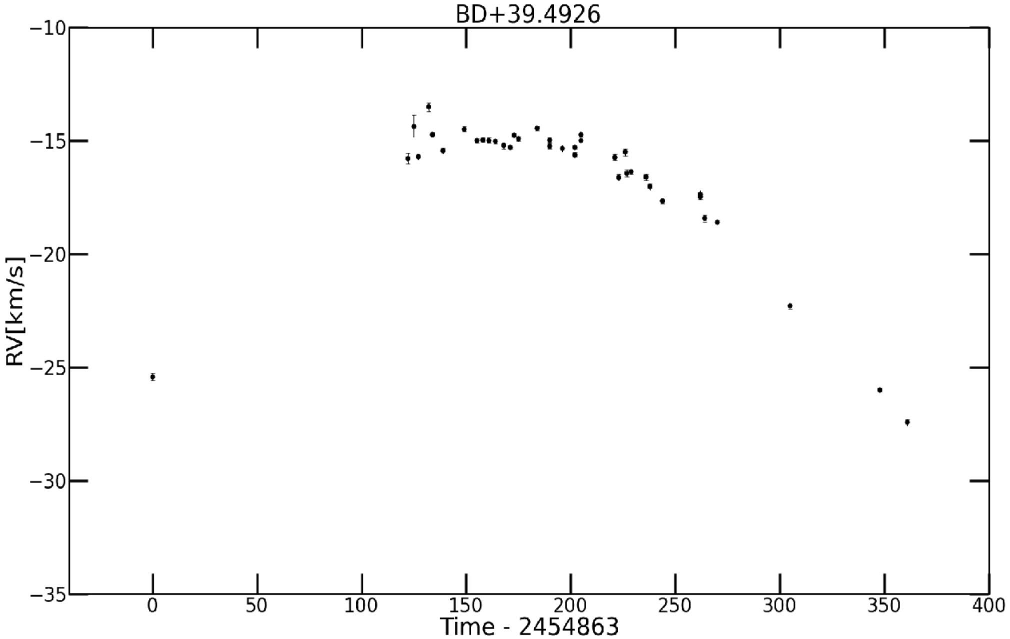


Van Winckel et al., 2009, A&A 505, 1221

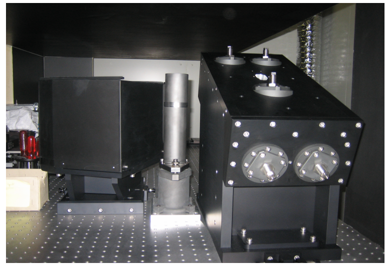
6/6 binaries, P between 120-1800 days

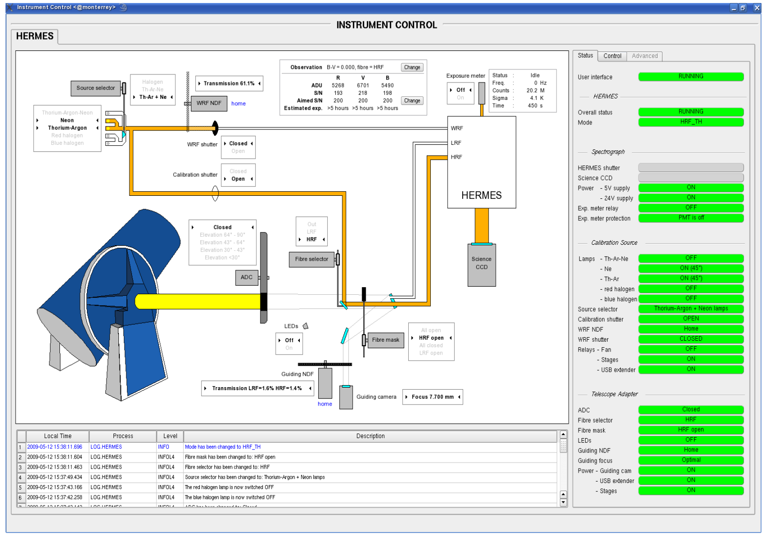
Mercator Telescope Hermes spectrograph

regular monitoring, CCF routine



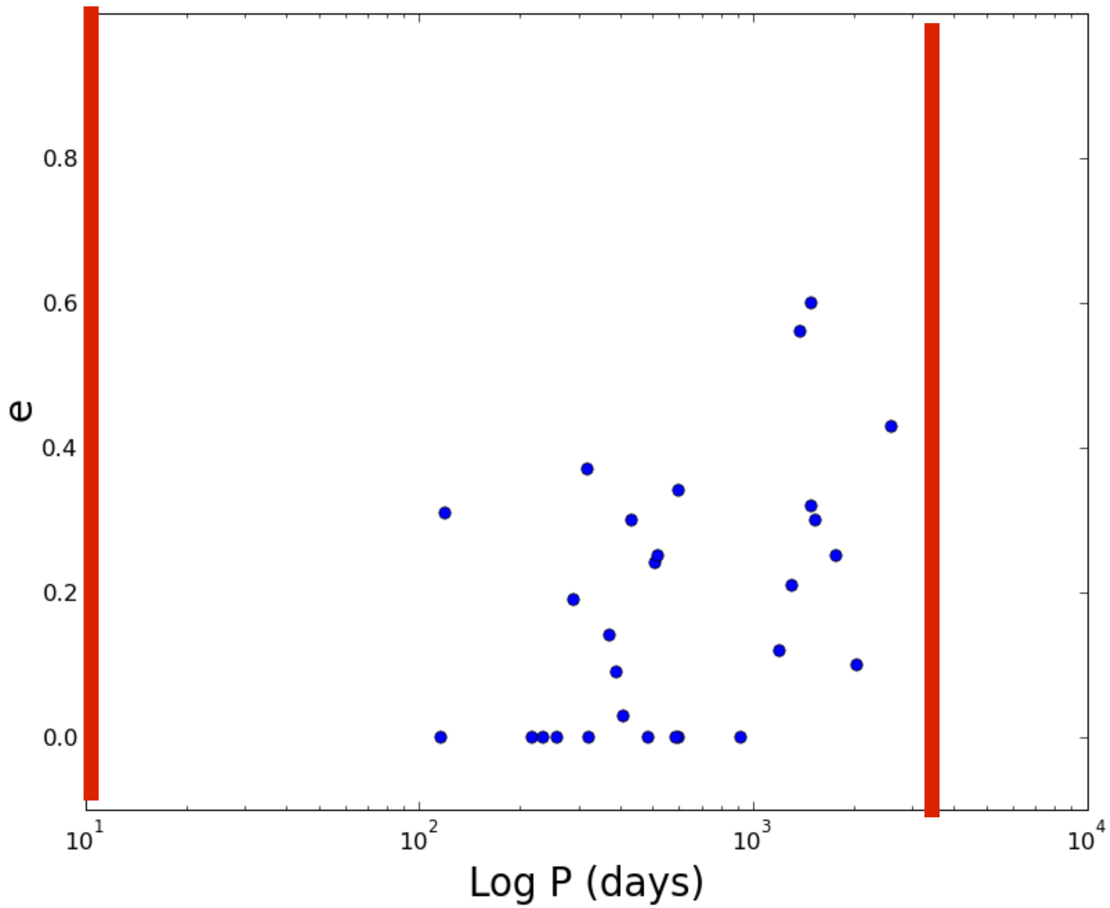
R~90 000
fibre fed
370-900 nm





V.-A. Jacobs

e-log(P) diagram: post-AGB stars: 28 orbits so far



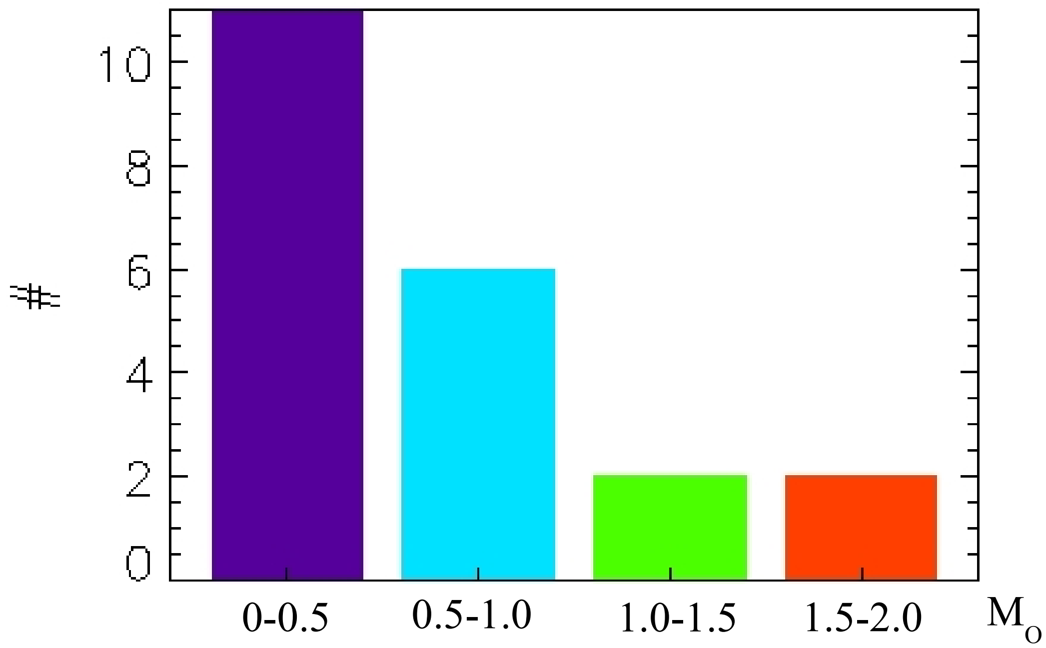
Periods AND high eccentricities are NOT expected !

Phase of strong binary interaction in the past.

Now all objects are within the Roche lobes

binary evolutionary tracks !!

Mass estimates: companion-mass under limits



Inclinations are uncertain

Mass functions: 0.0008 to 0.95

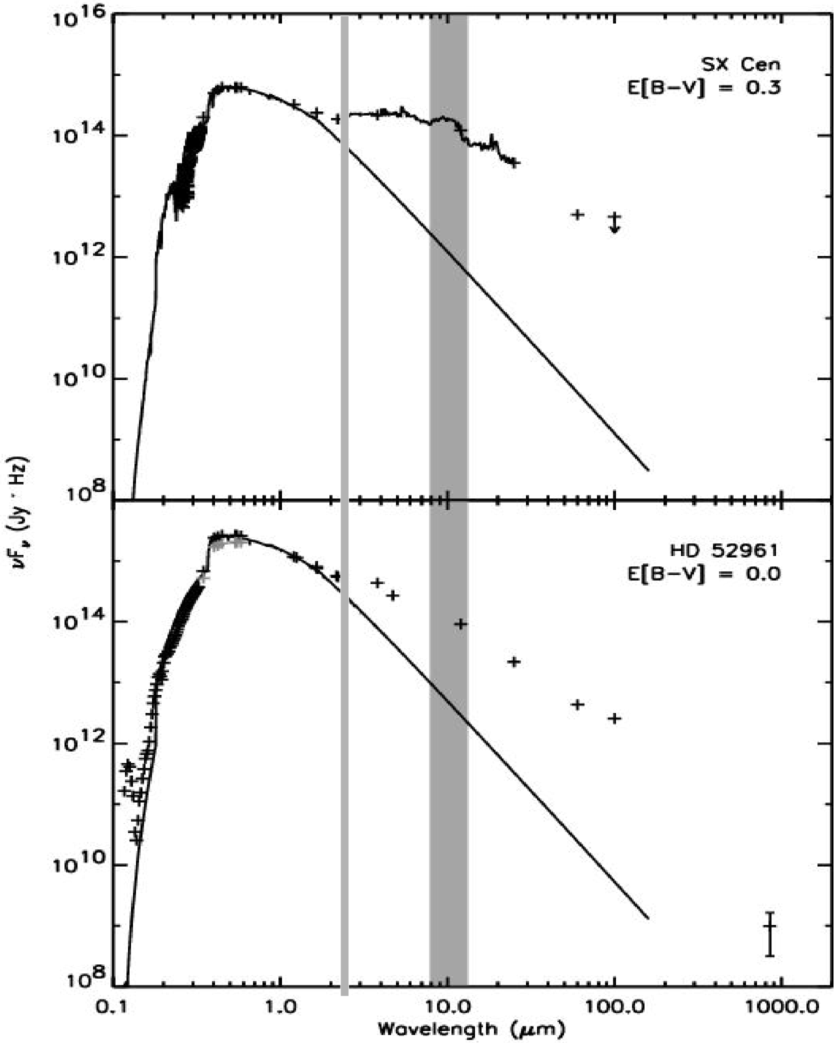
Assuming inclination of 90 degrees

Assuming M1 = 0.6 solar mass

Intrinsic metallicity: -1.0 to solar

In none of the systems symbiotic activity : M2 likely unevolved
parent population of these objects has a wide range of properties

Interferometry: resolving the processed CS environment



The VLT Array on the Paranal Mountain

ESO PR Photo 14a/00 (24 May 2000)

MIDI : N-band: near peak SED

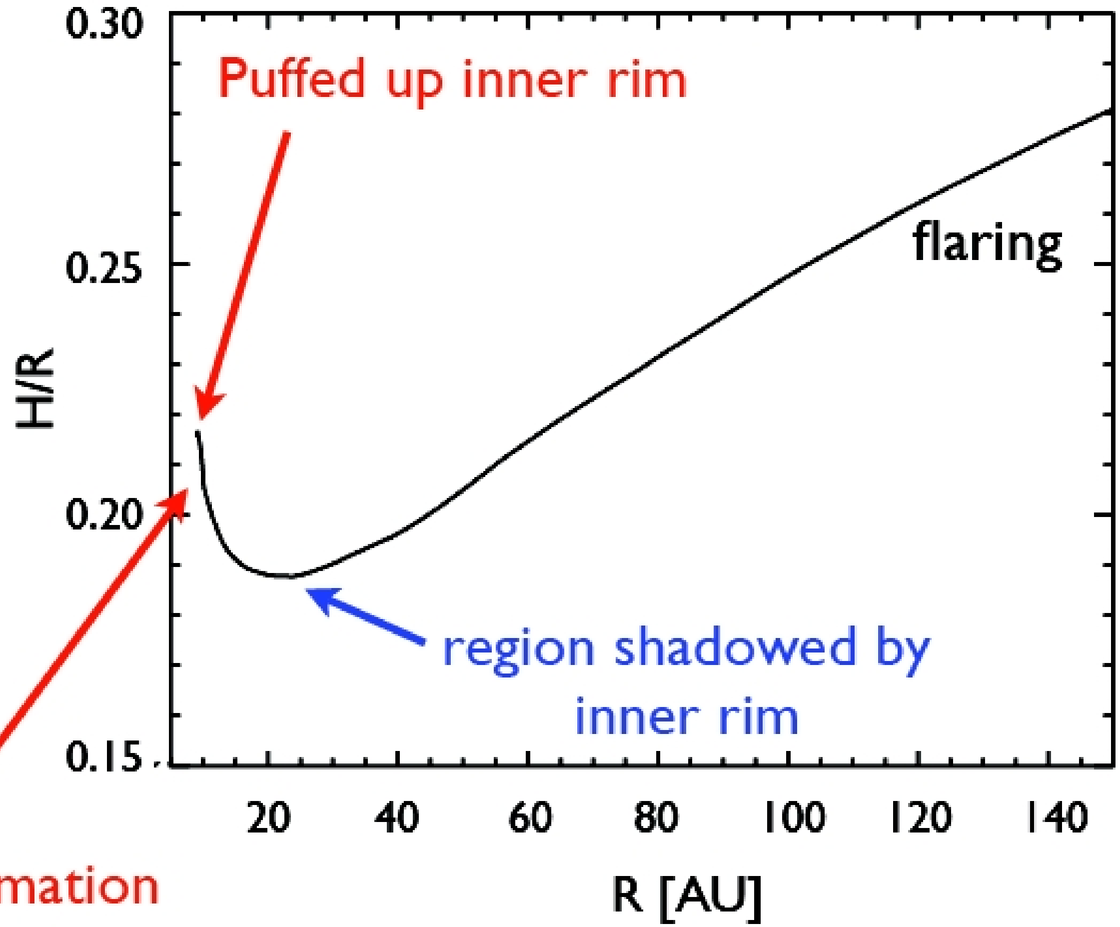
AMBER: photosphere-hot dust region

Flash-Back: Tuesday 2/3/2010

Basic Disk structure:

passive **disc** radiative transfer model: Dullemond et al., 2002; 2004

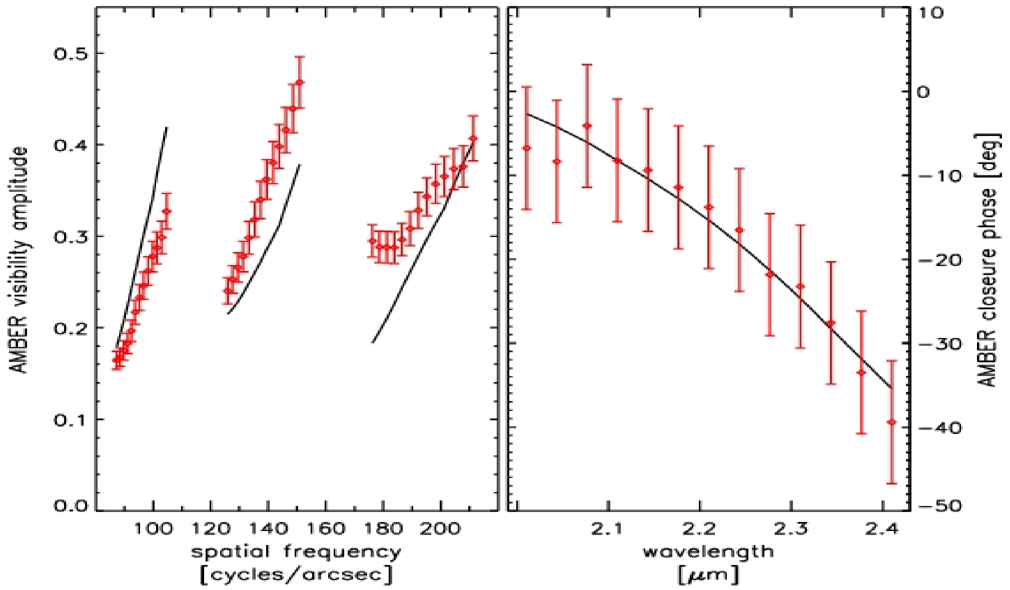
- mixture of gas and dust
- dust irradiated by central star
- structure:
  hydrostatic equilibrium
- dimensions:
  SED constrained
  - ➡ large and processed grains
  - ➡ R_{in} = 9 AU
  - ➡ H/R_{in} = 0.22
    (total height = 4.0 AU)

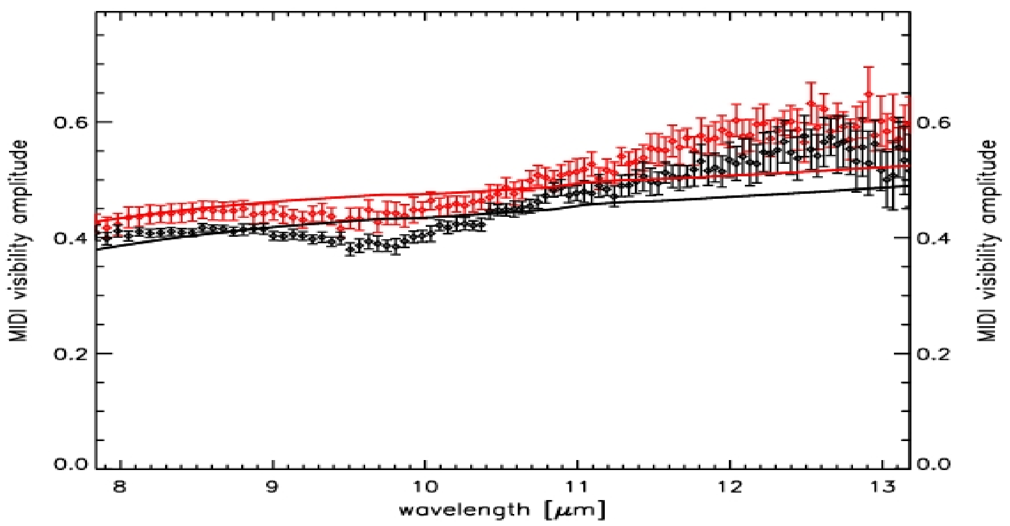


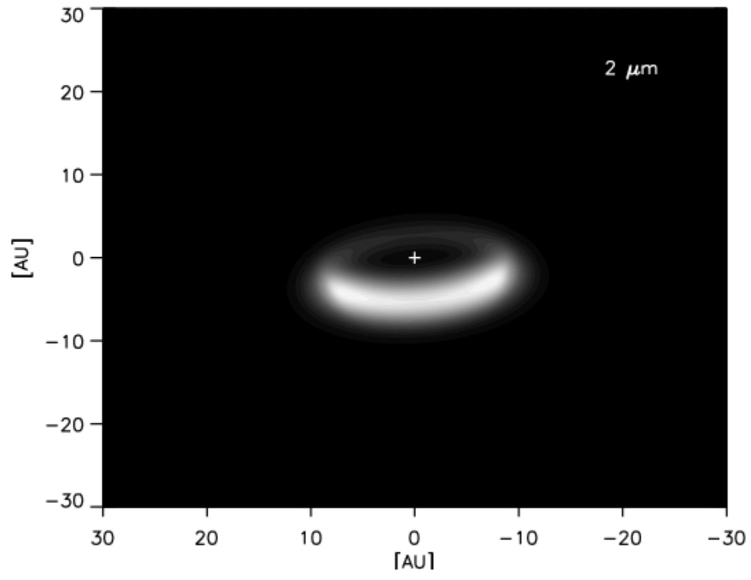
dust at sublimation temperature

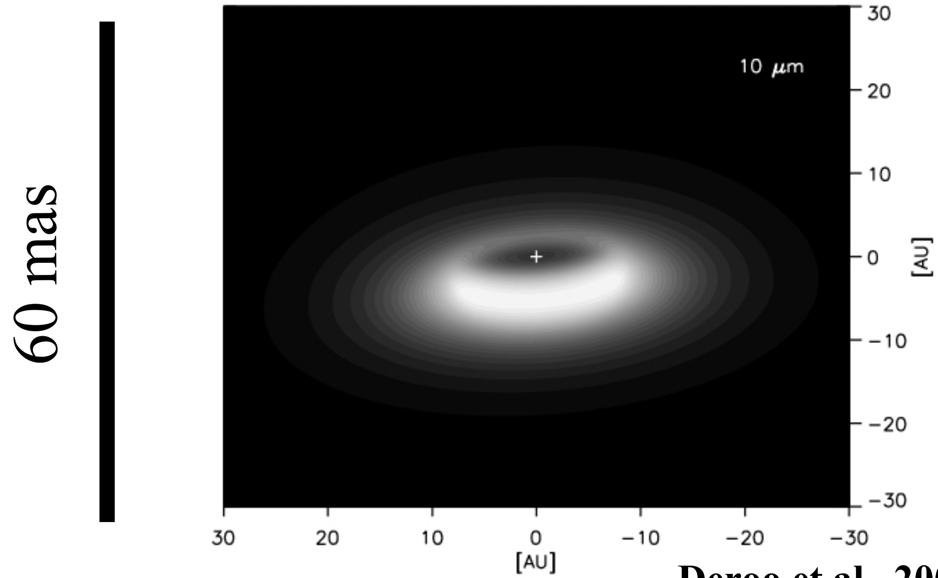
main difference with YSO: effective gravity is lower

Case Study: IRAS08544



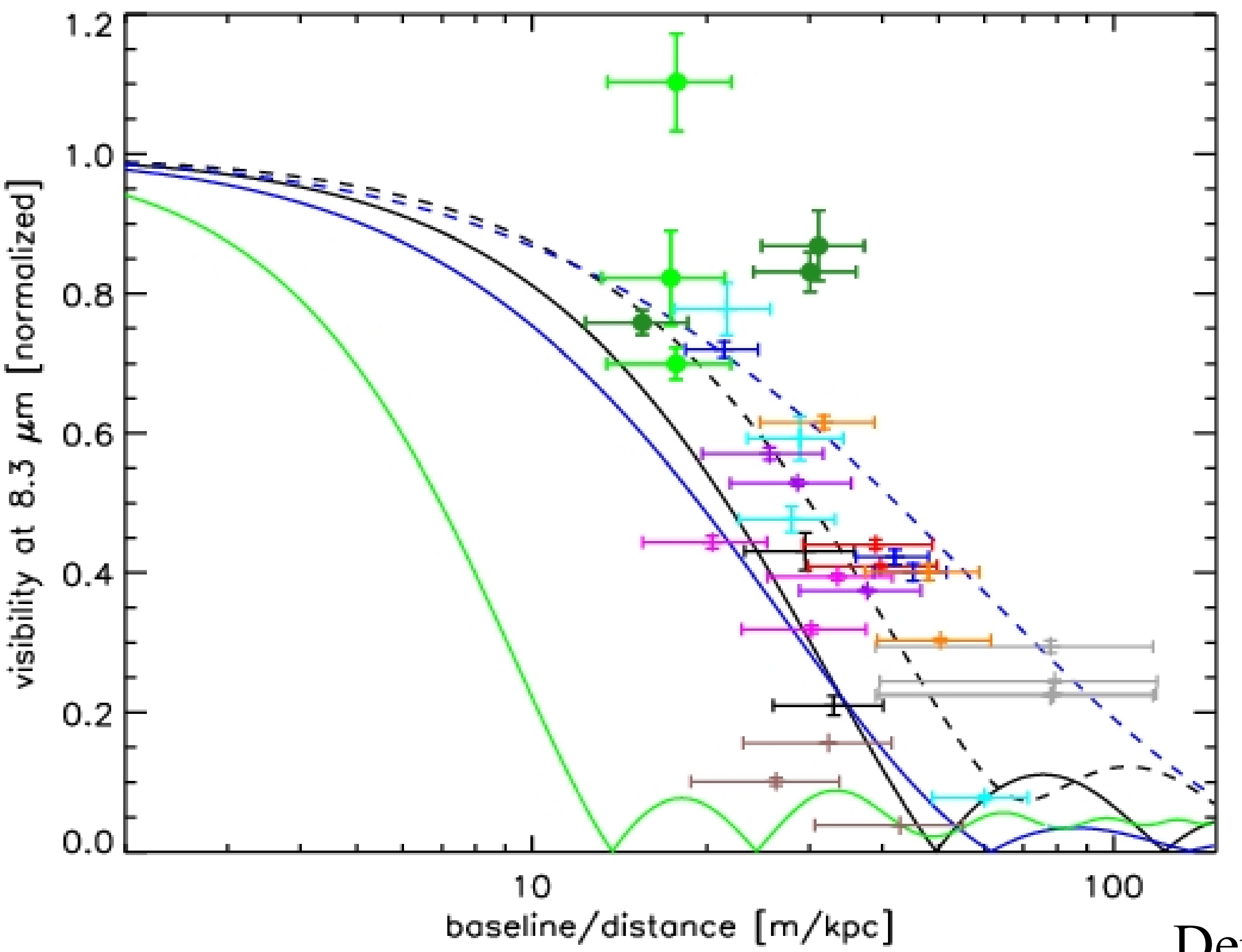






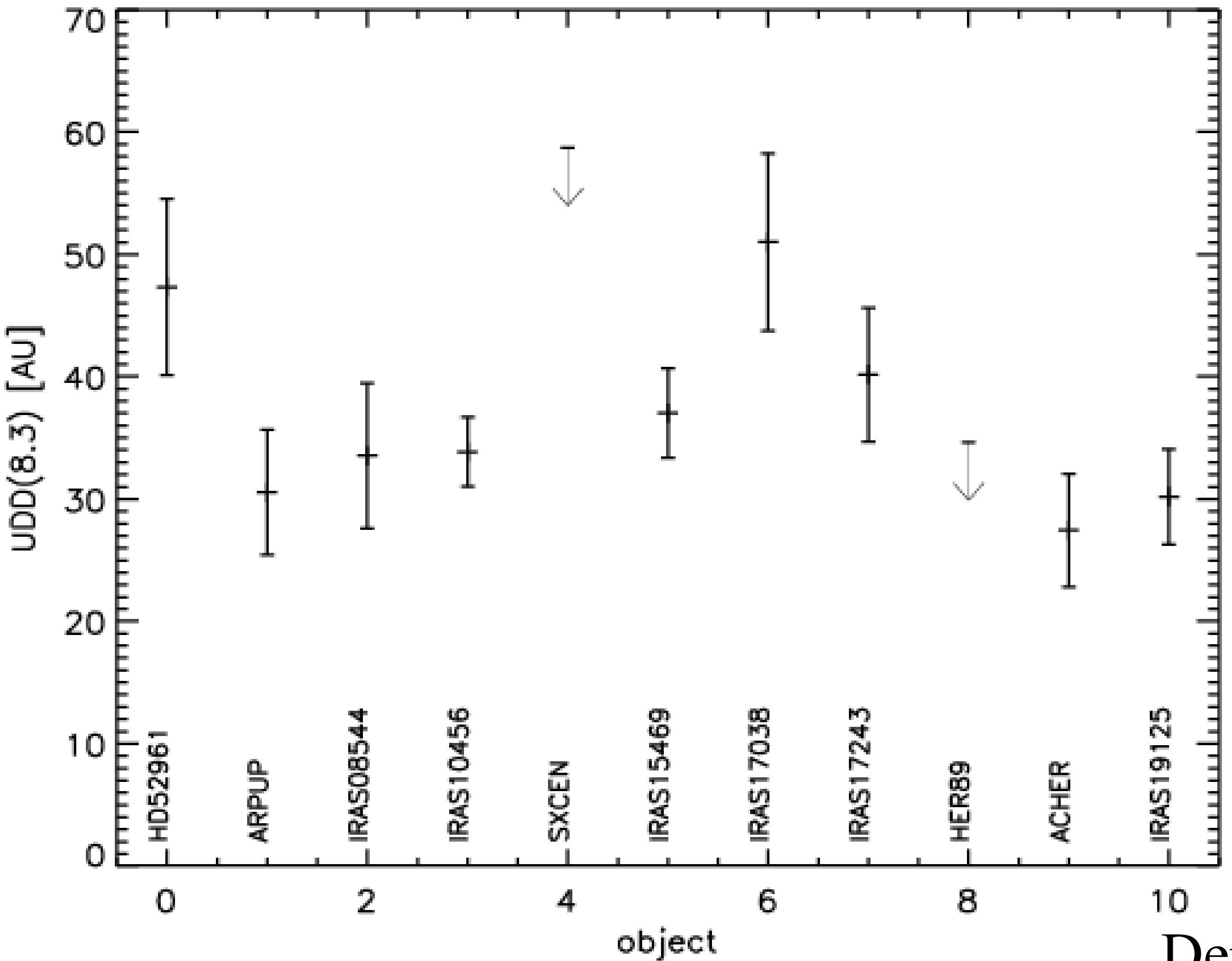
Deroo et al., 2007

Sample Results



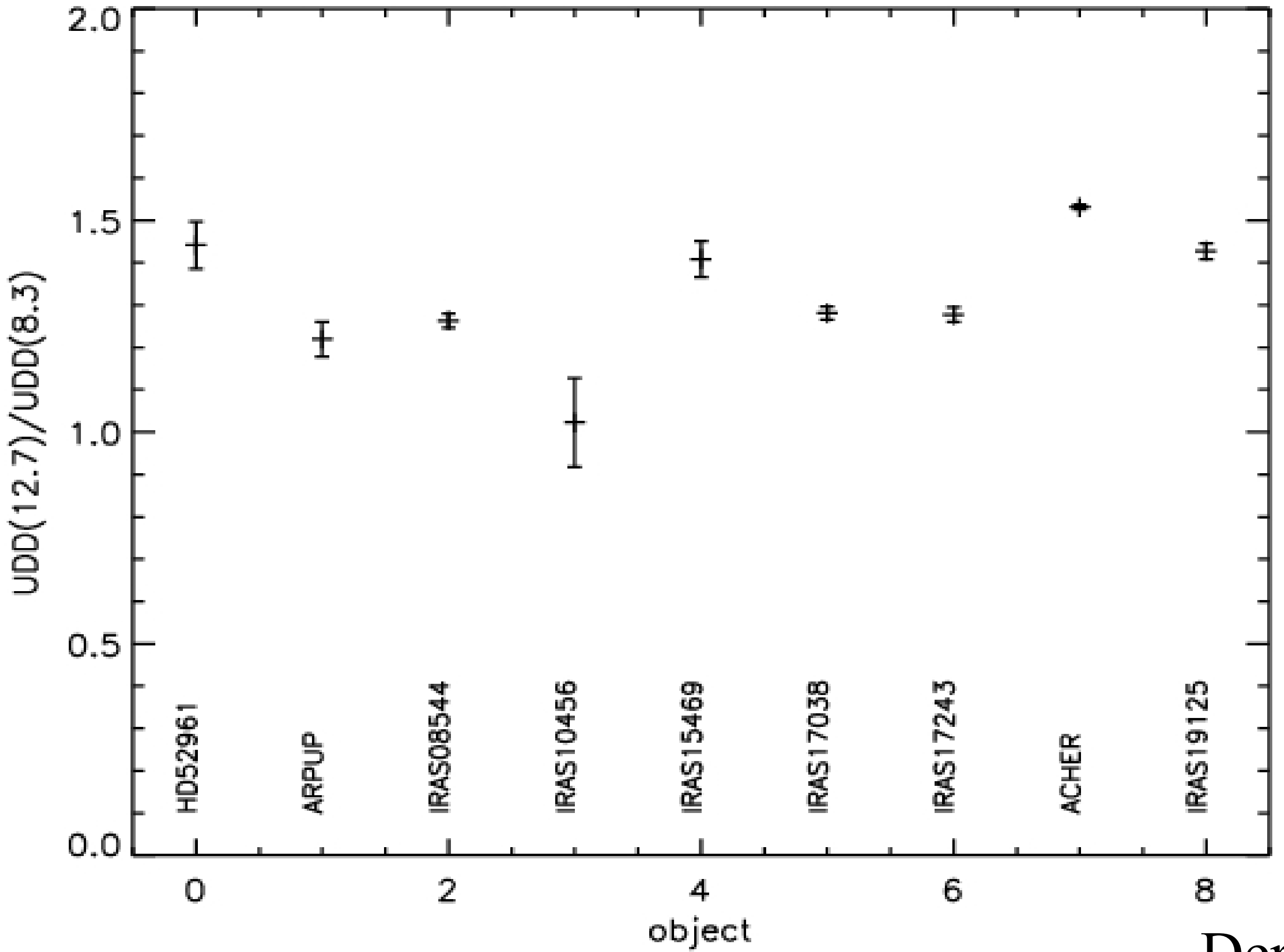
Deroo et al. 06

Overview Results



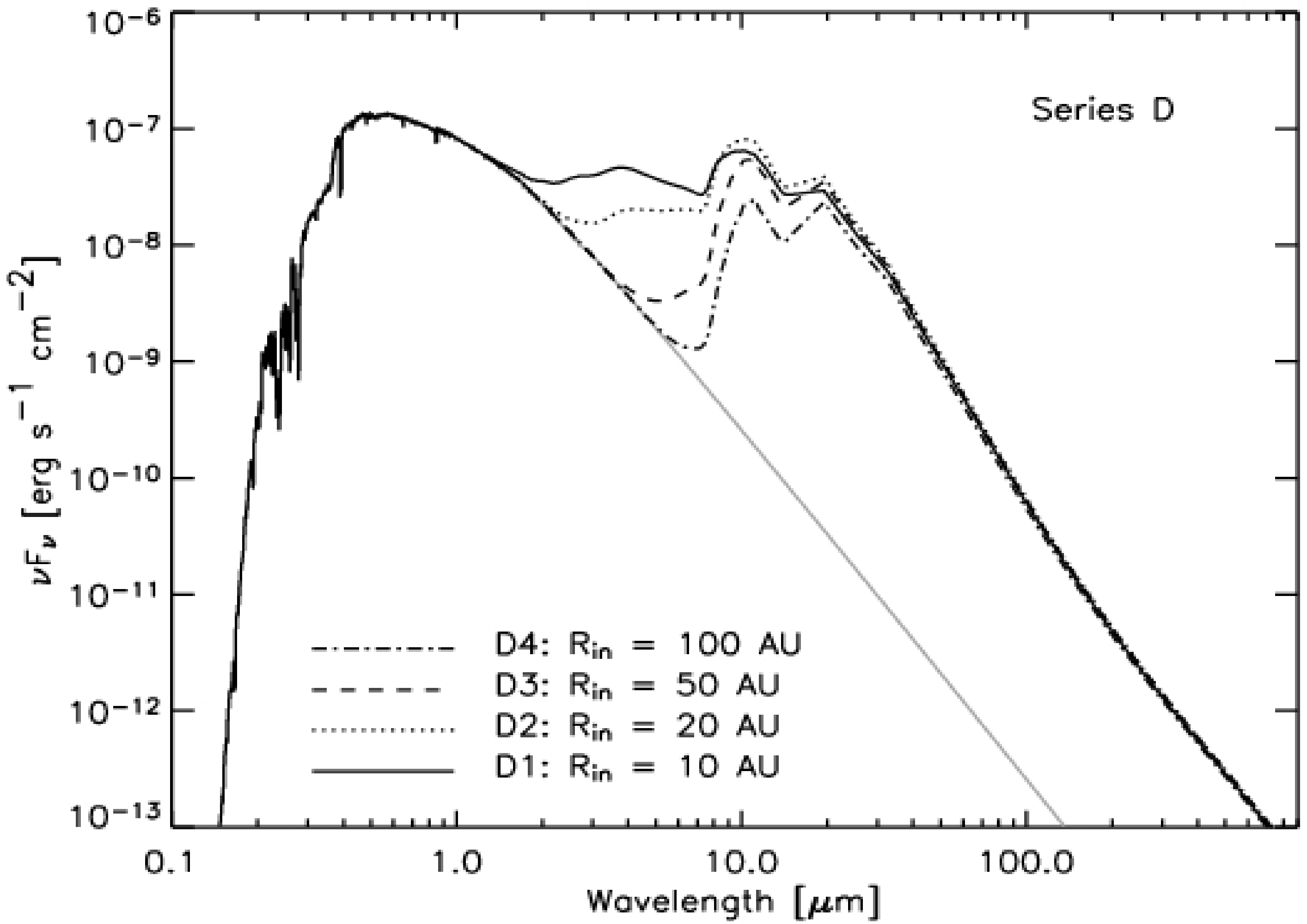
Deroo et al. 06

Overview: Results



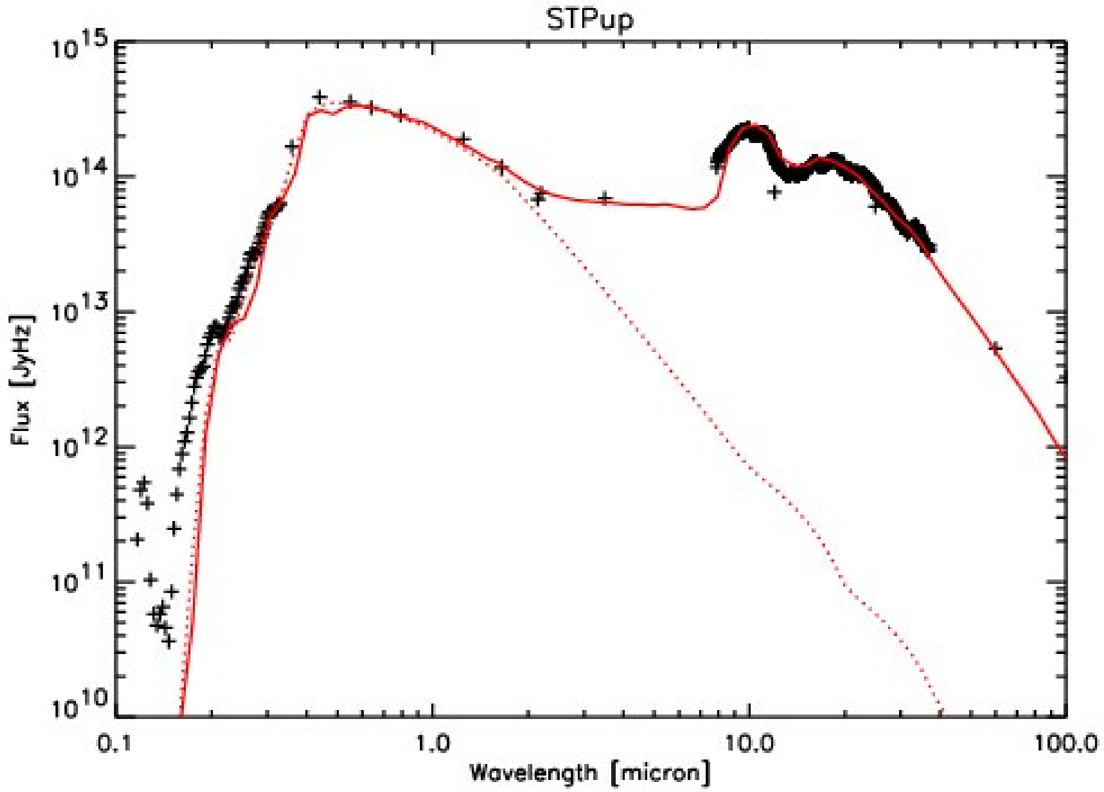
Deroo et al. 06

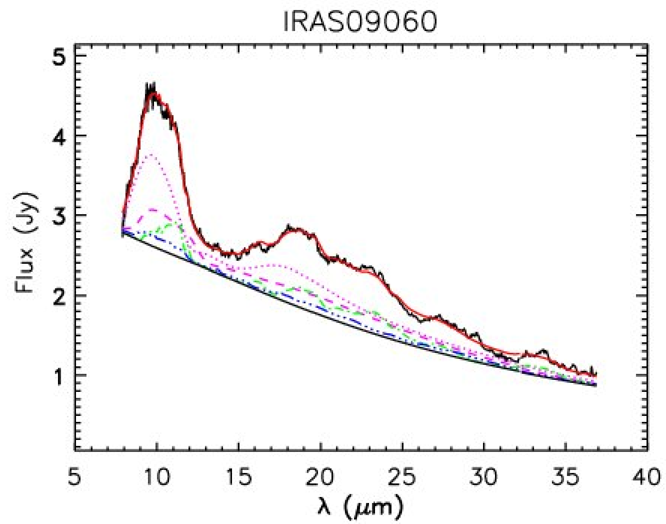
Model: SED+interferometric constraints

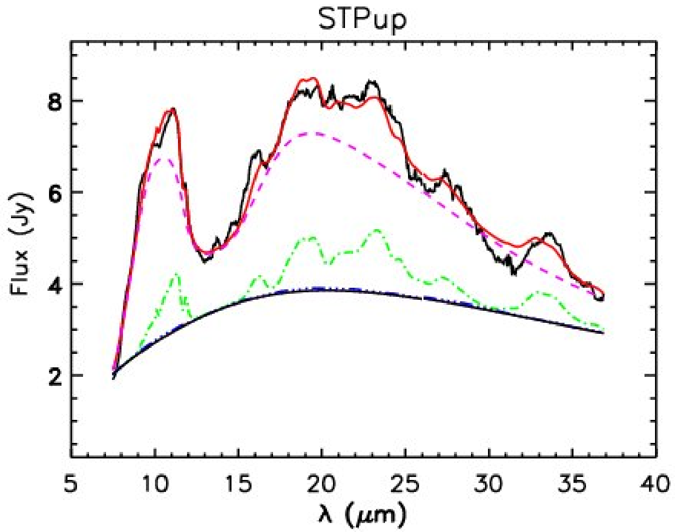


Example Spectra

- wide variety in observed spectra



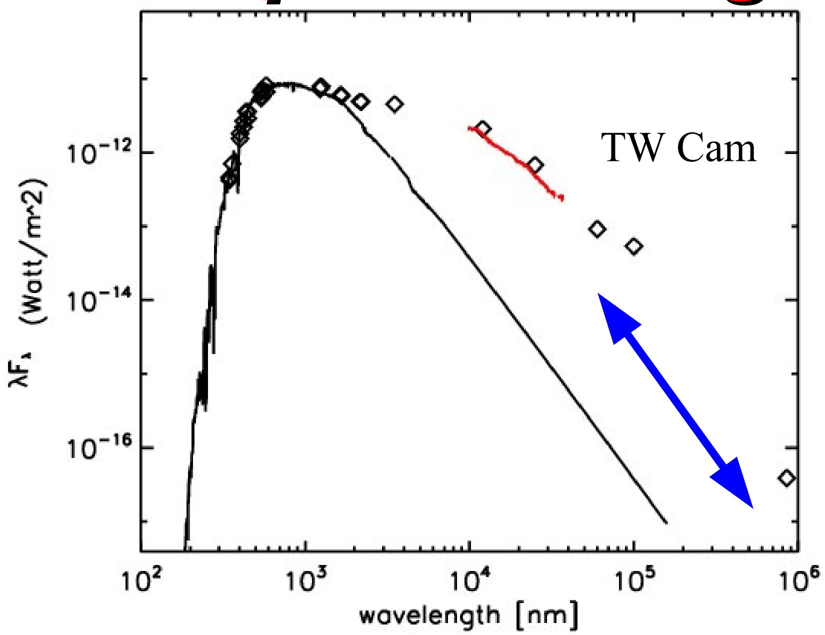


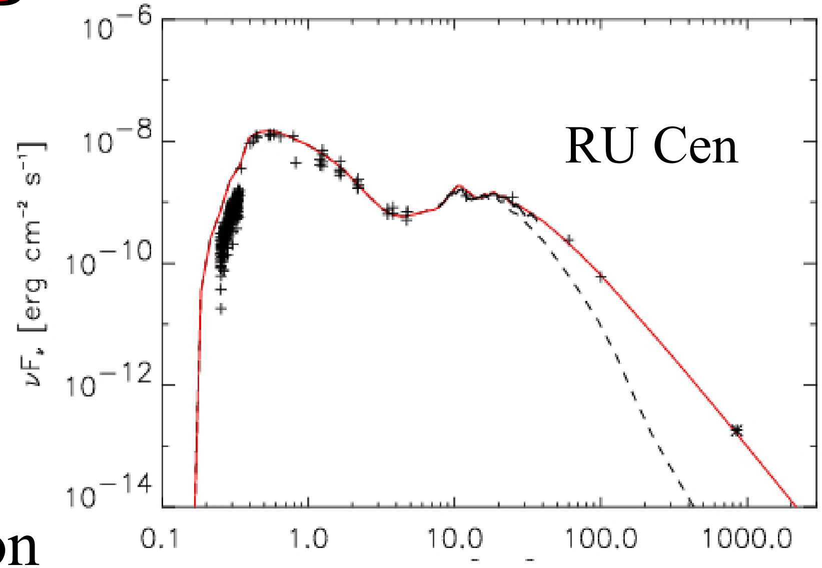


strong crystallinity

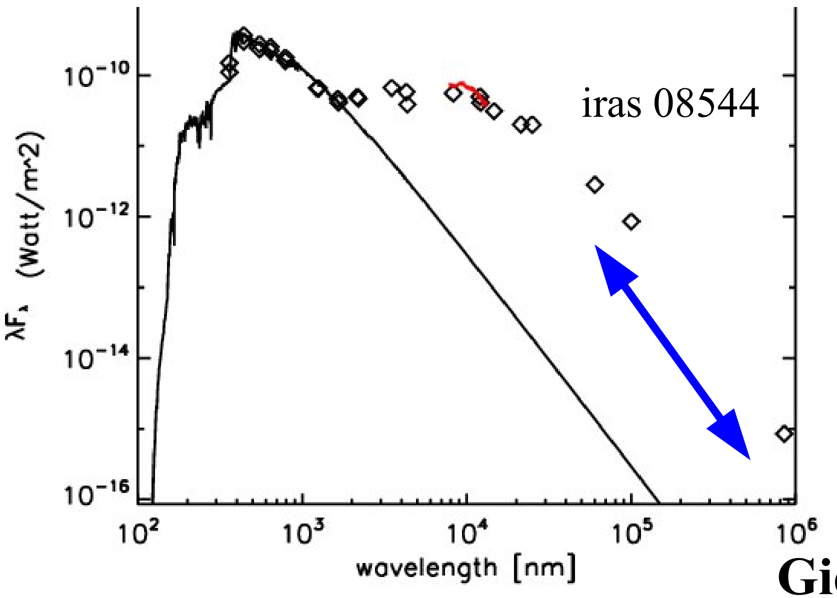
Gielen et al. 2009 + in prep

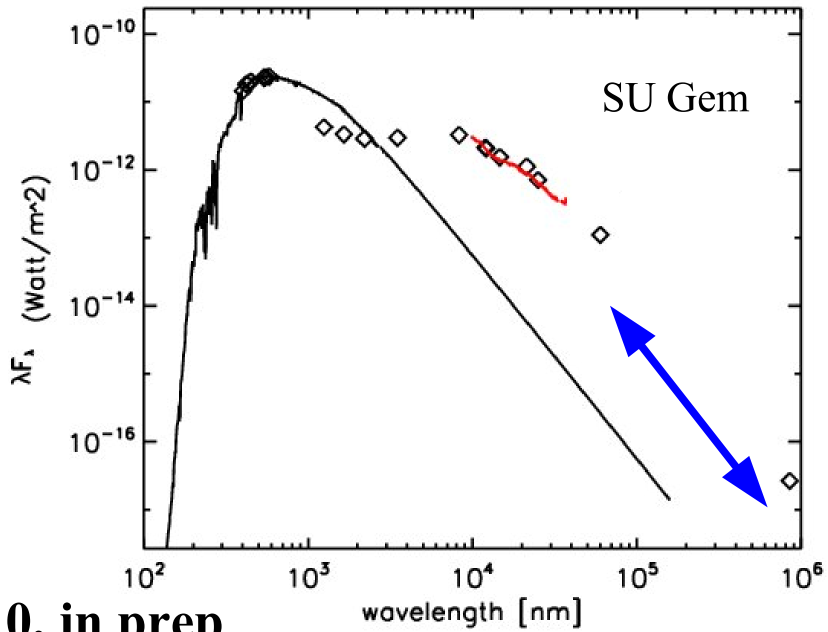
Dust processing: large grains !





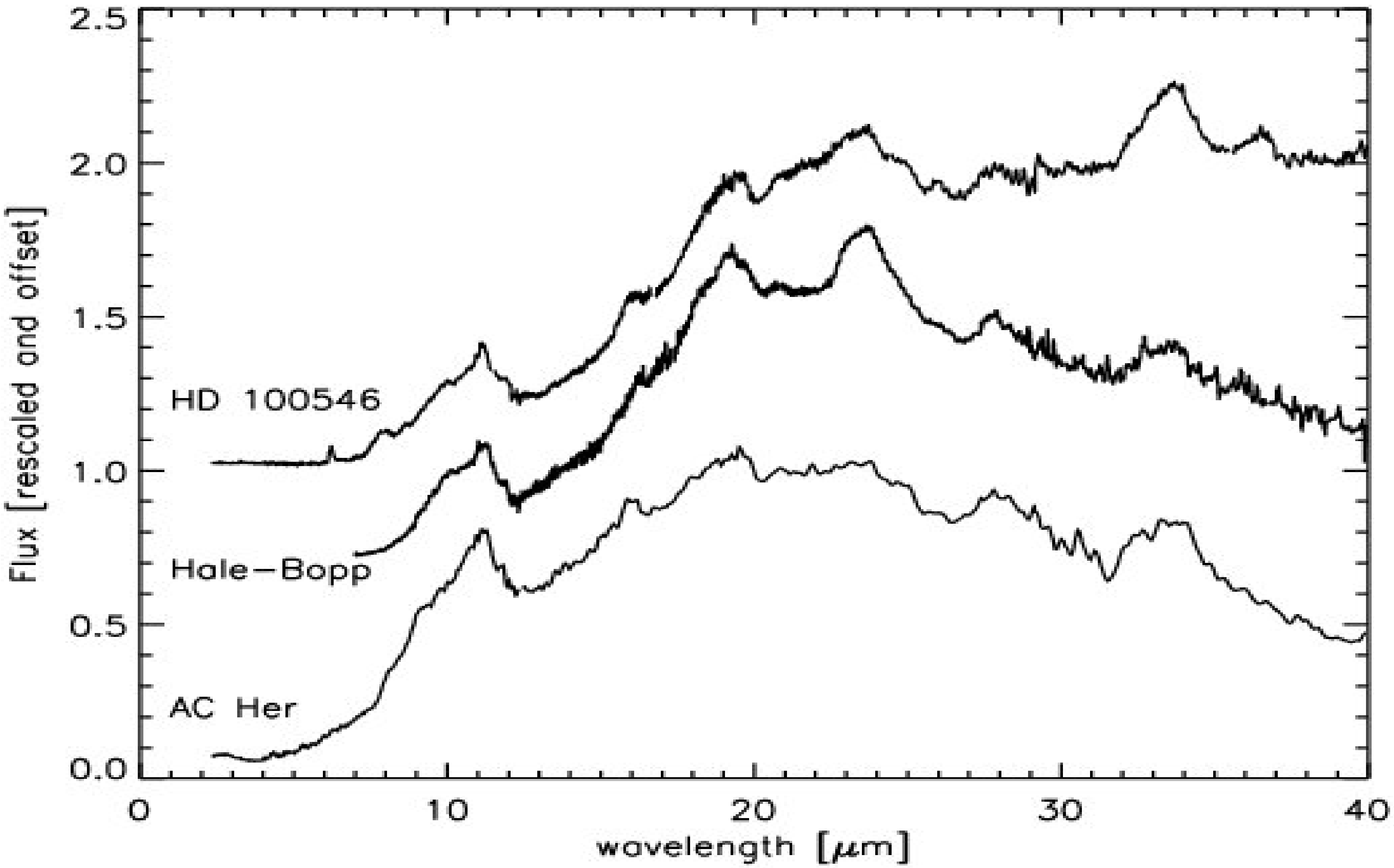
870 micron Data (Laboca)





Gielen et al., 2010, in prep

Proto-Planetary disks

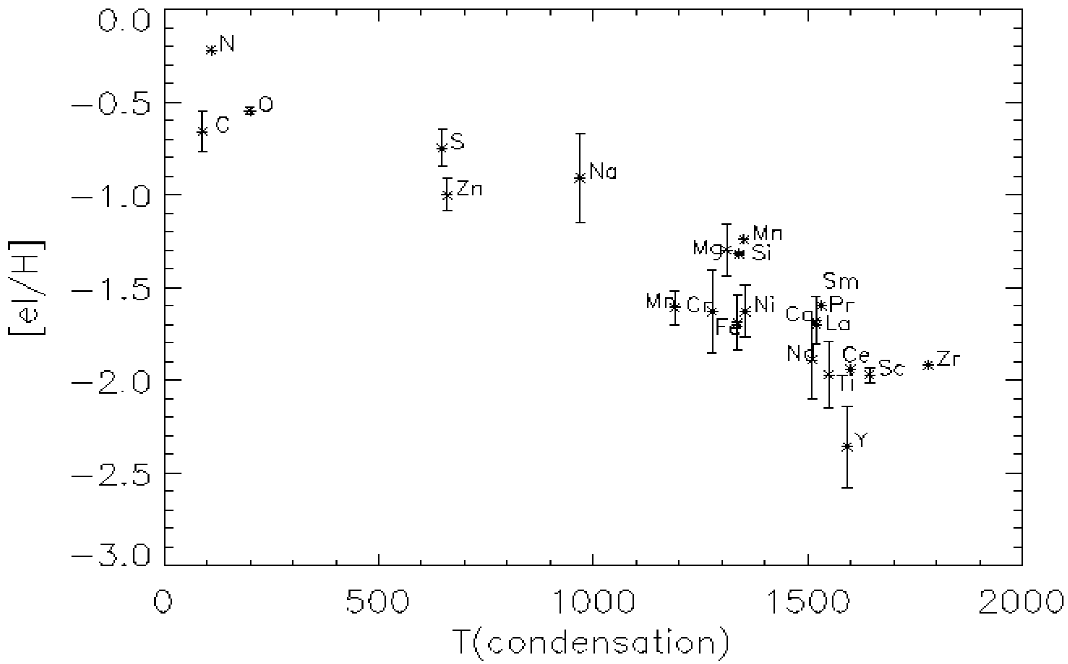


Flash-Back finished...

Photospheric Depletion: Feedback from disk

cfr. talk Gustafsson on the Solar analogues

AC Her



Abundance patterns ~ gas phase abundance of ISM

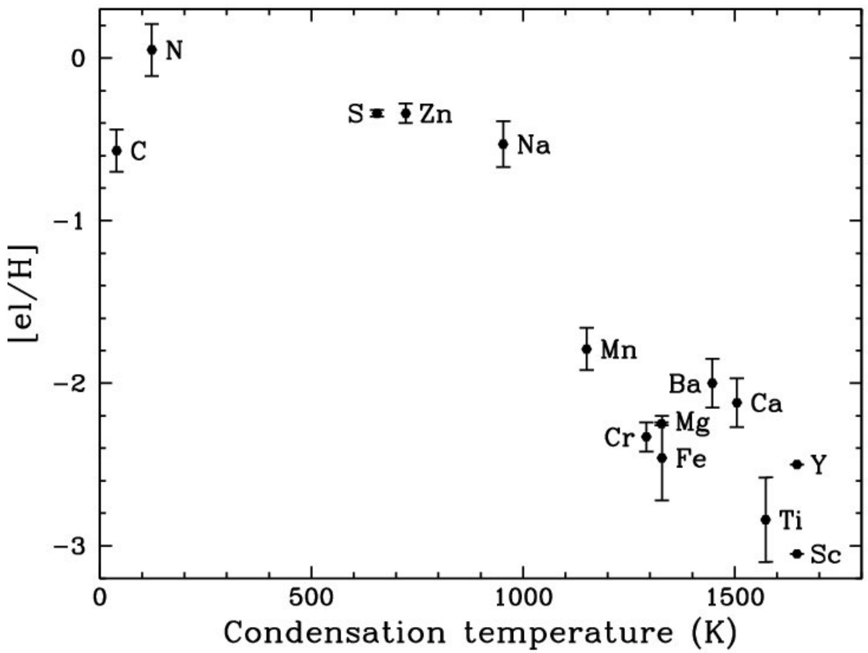
You **lose the nucleosynthetic history**

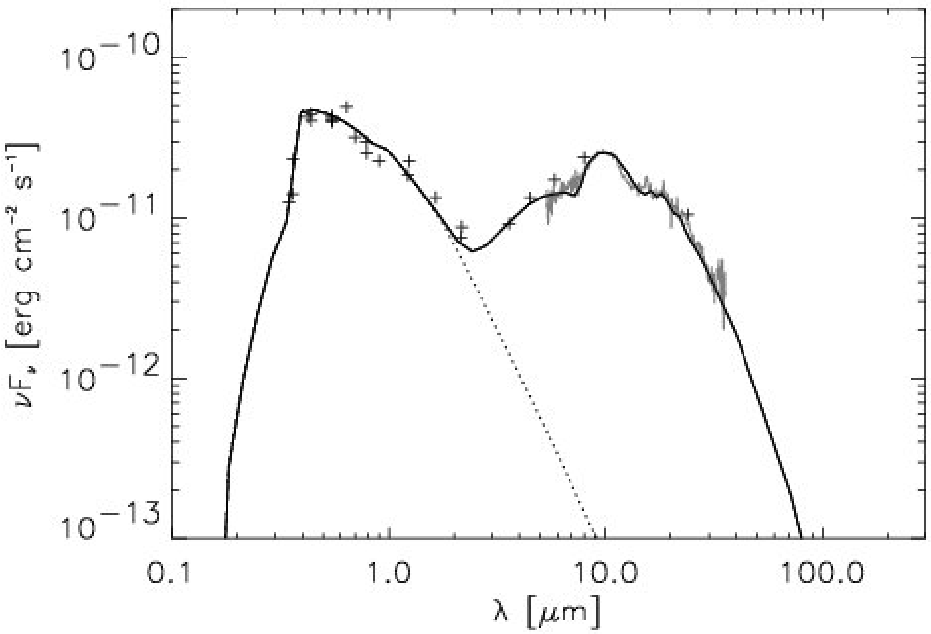
Can be very efficient (down to [Fe/H]=-4.8)

Accretion of circumstellar gas

Disc is needed to guarantee low density and long timescale (Waters et al., 1992)

Depletion in the LMC RV Tauri stars

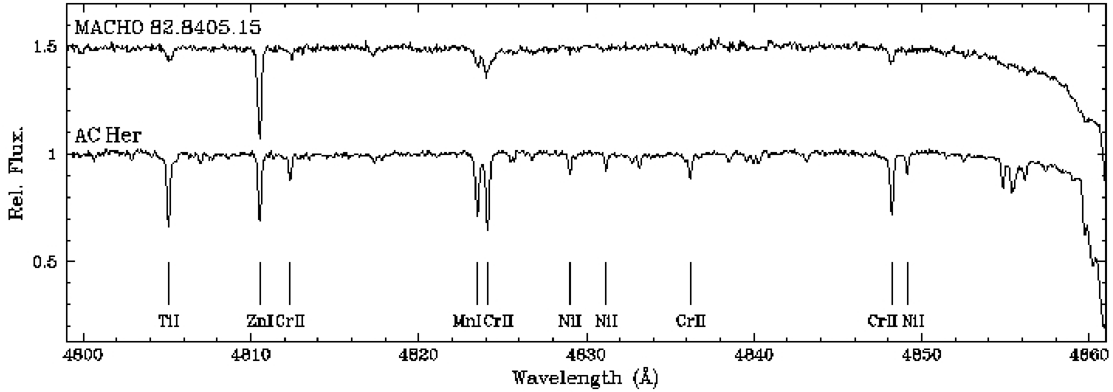


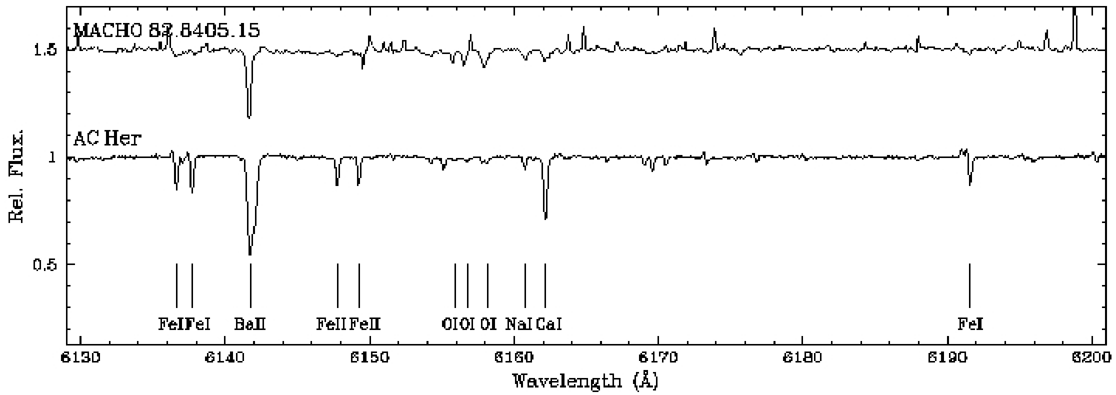


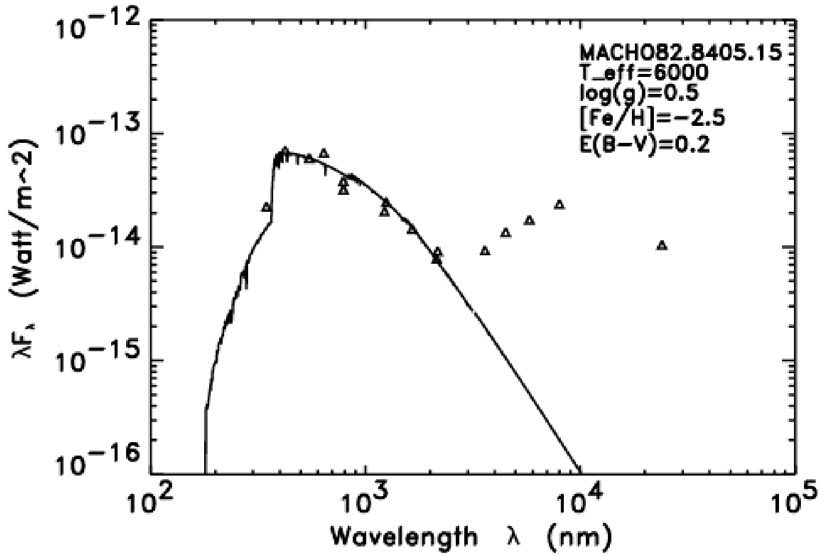
Macho 82.8405.15: [Fe/H] = -2.1 ; [Zn/Fe]=+2.2; [S/Ti]=+2.2

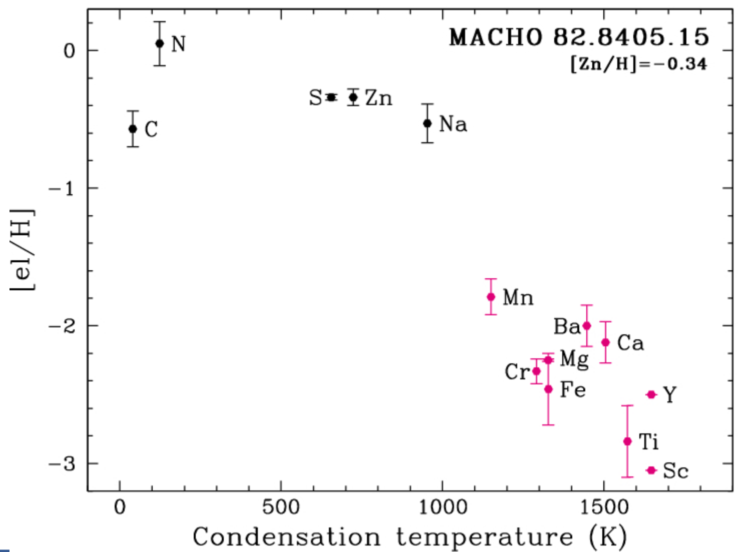
(Reyniers et al., 2007; Gielen et al., 2009)

Post-AGB stars in the LMC: RV Tauri stars





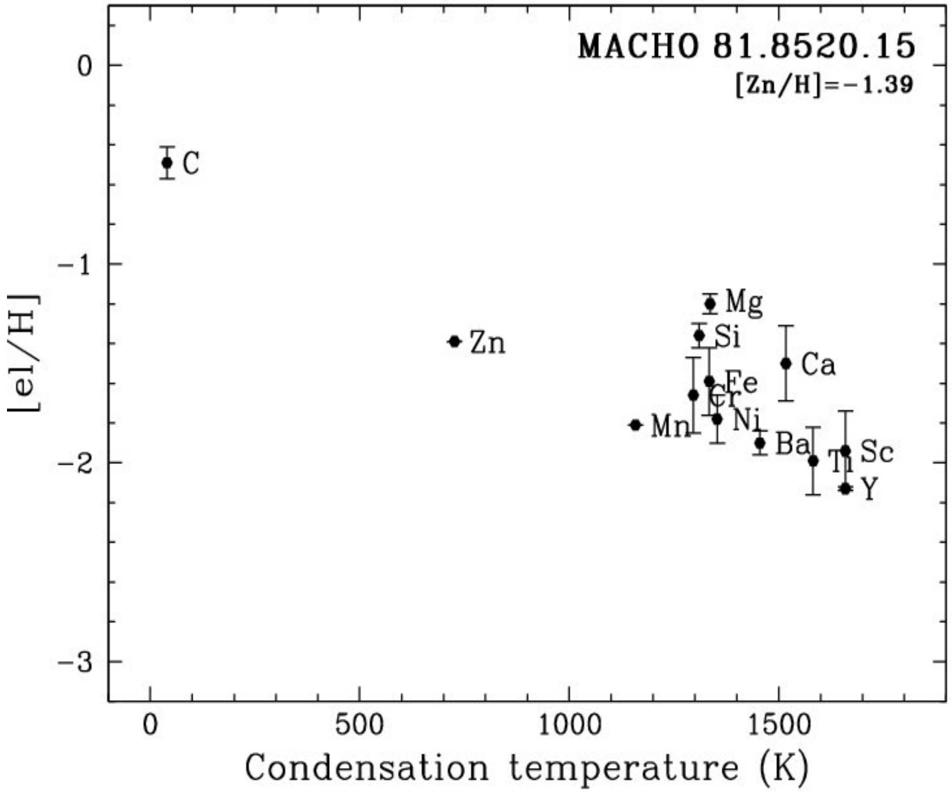


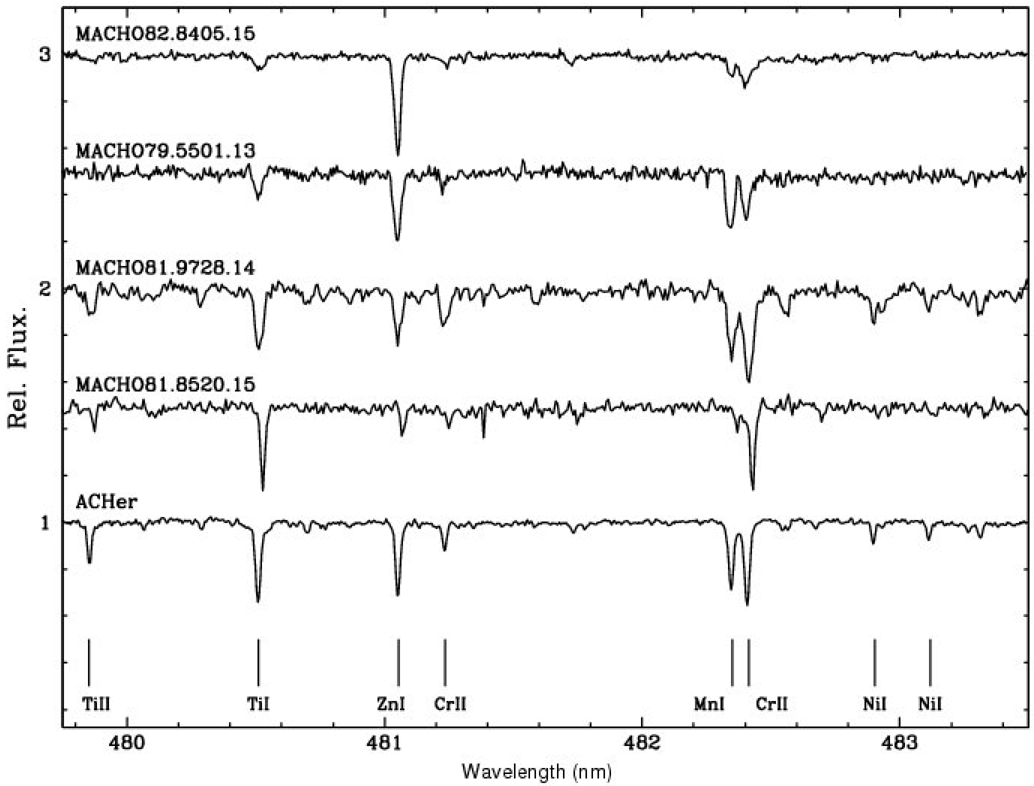


Macho 82.8405.15: [Fe/H] = -2.1 ; [Zn/Fe]=+2.2; [S/Ti]=+2.2: strongly depleted !

(Reyniers et al., 2007; Gielen et al., 2009)

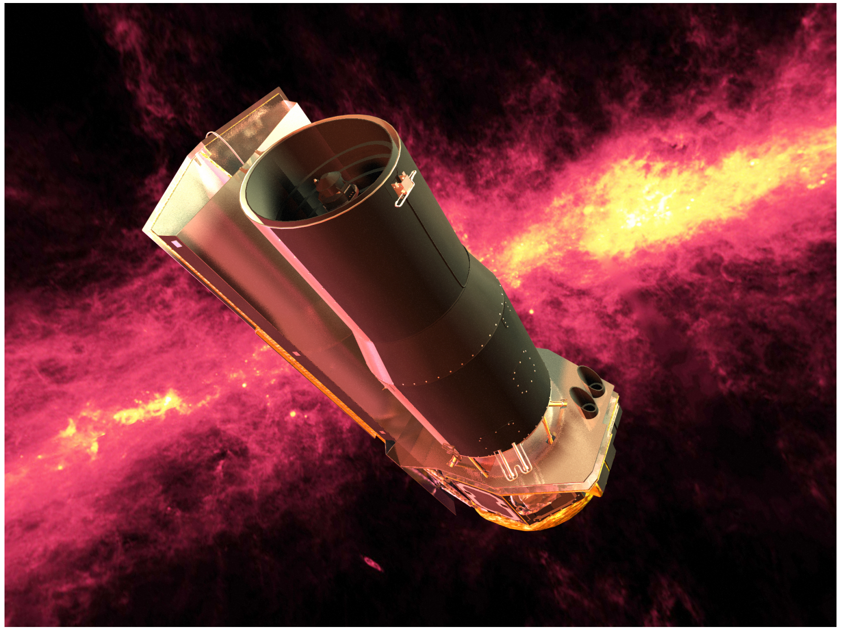
Depletion in the LMC





Gielen et al., 2009

SAGE-post-AGB project



Sage dataproduct (Meixner et al. 2006)

2 epoch IR photometry LMC

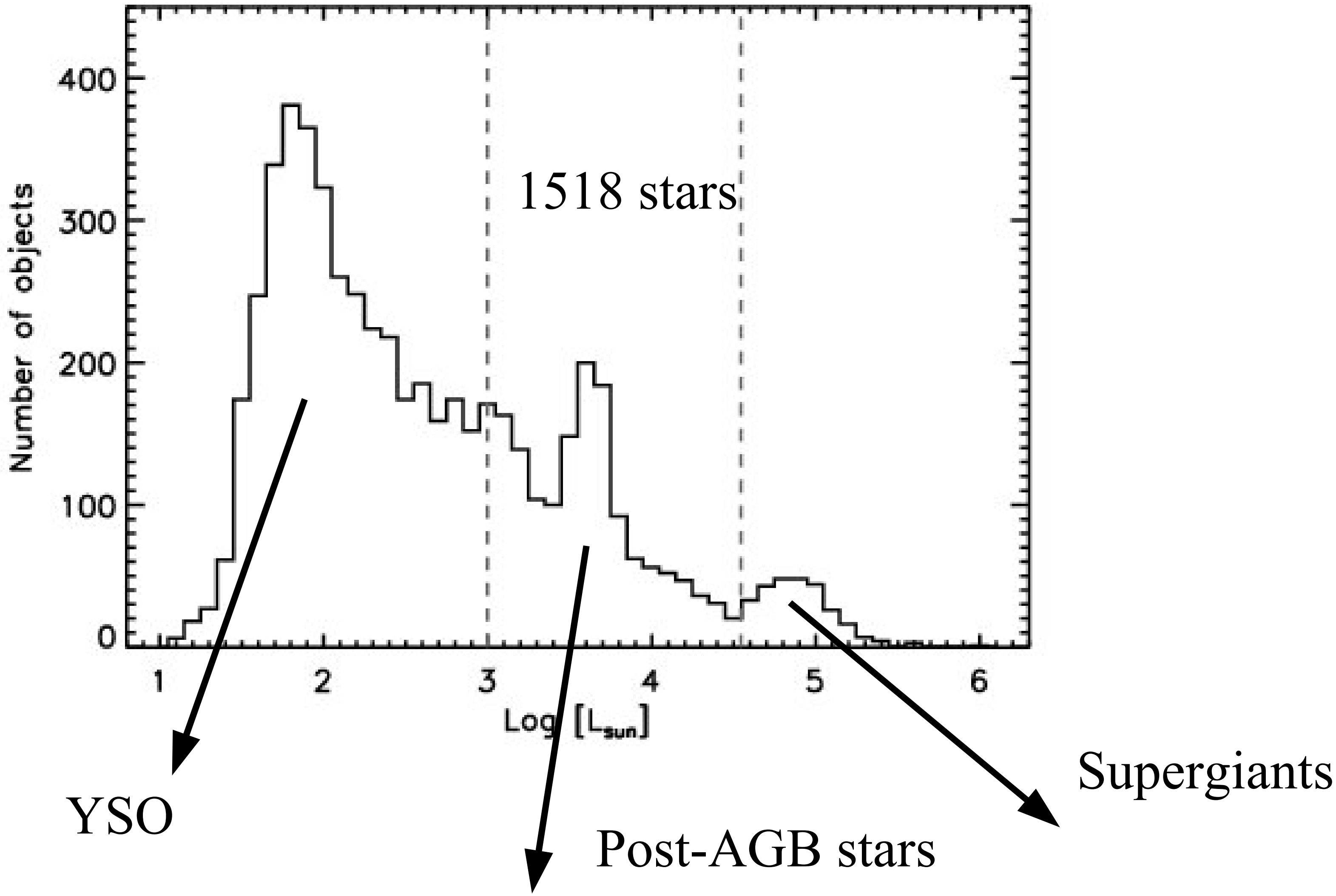
- 6.9 million sources observed with IRAC
- 40 000 with MIPS

- Selection criteria tuned to find optically visible post-AGB stars with IR excesses (discs + outflows) :

  8 & 24 micron detection
  F(24) > 0.4 x F(8)
  Cross-correlation with 3 optical catalogs: → **5613 objects**

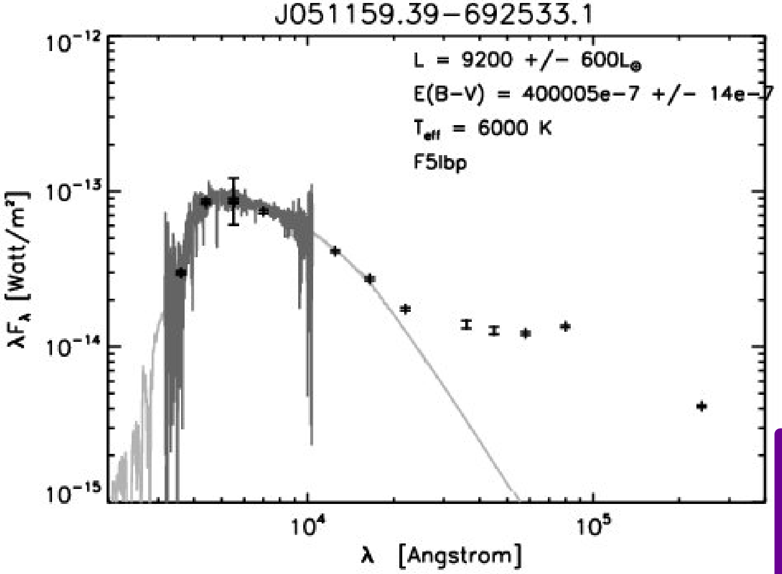
van Aarle et al. 2010 in prep.

LMC Sample post-AGB stars: L-cut

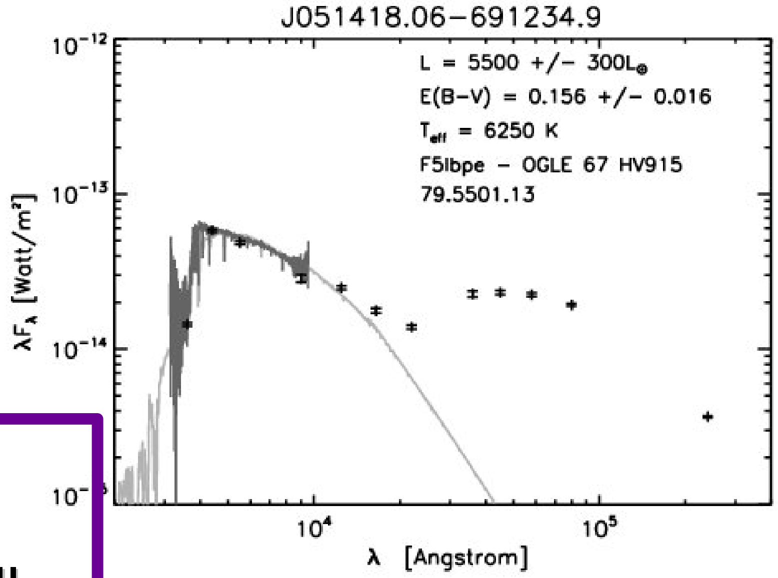


van Aarle et al. 2010 in prep.

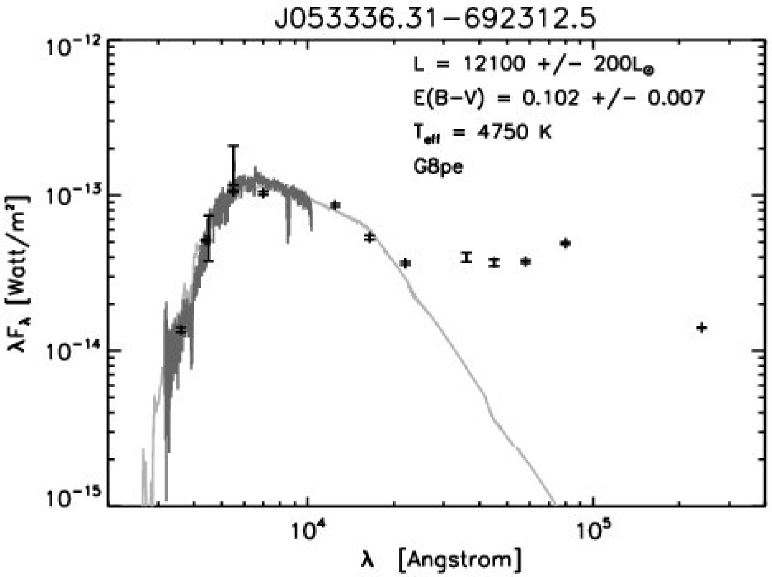
Also in the LMC discs are detected

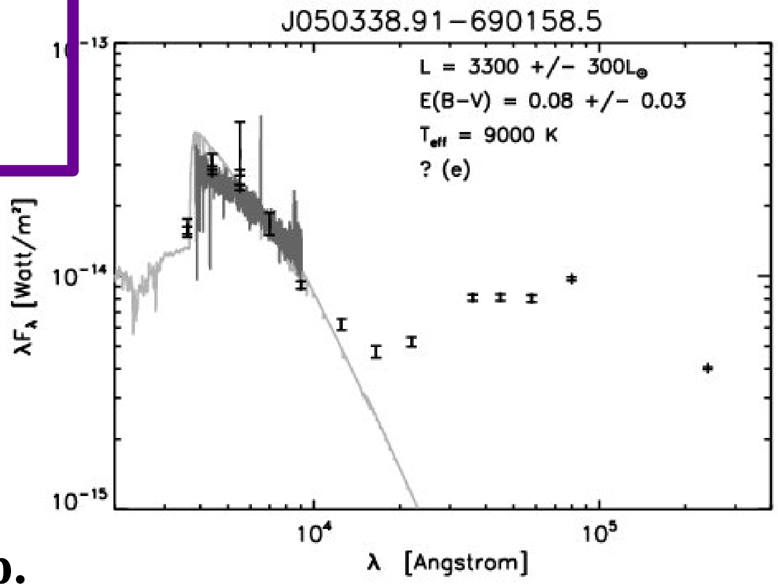


SAGE LMC Survey



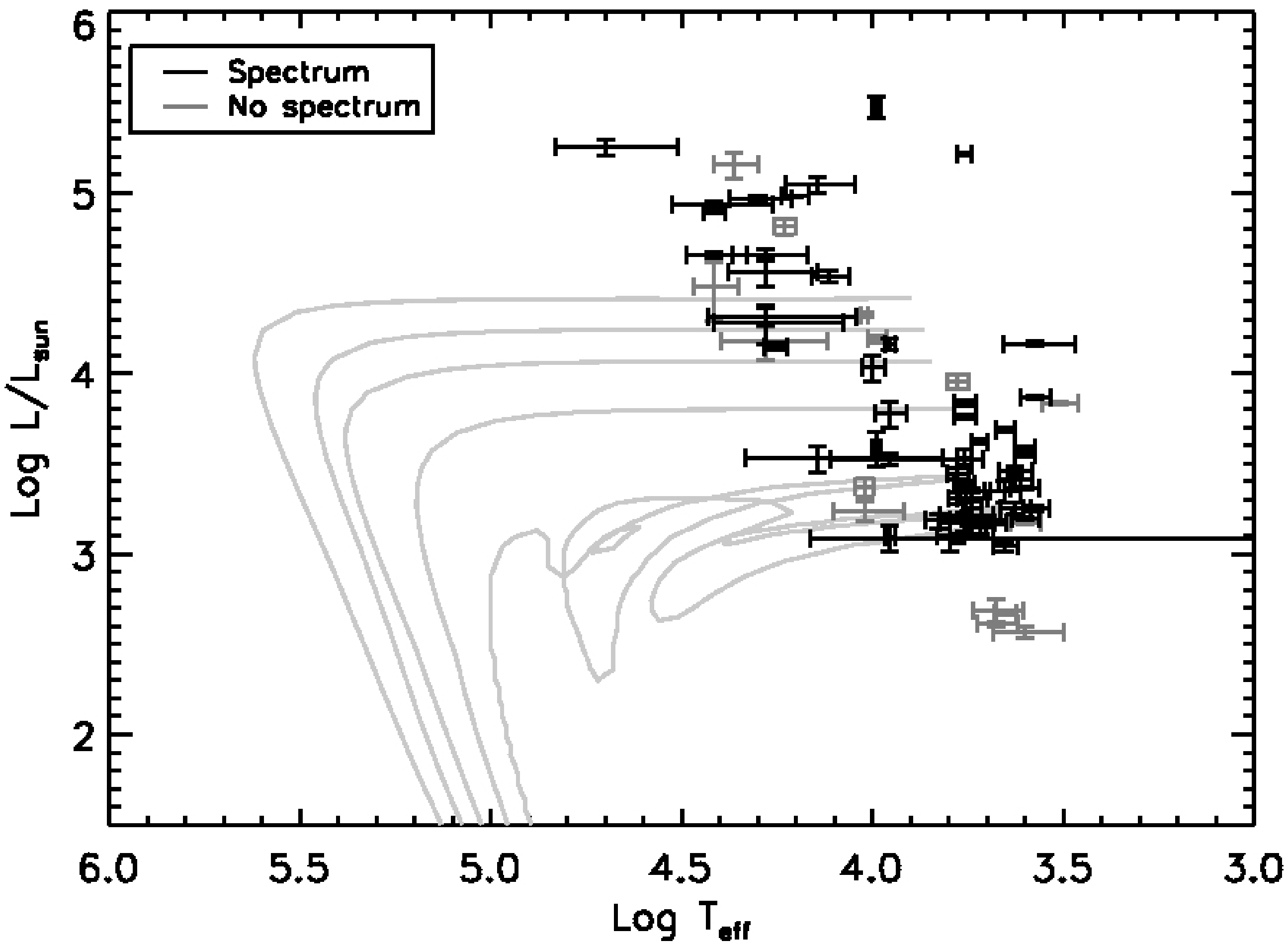
- 625 discs
- 536 detached shells
- 350 can be both





van Aarle et al. 2010 in prep.

HR-diagram of disc sources: half (?) of post-AGB candidates have a disc (prelim.)



van Aarle et al., in prep

Post-AGB stars with hot dust:

- SEDs of post-AGB stars with near-IR excess are connected to stable circumbinary disks
- The disks are passive (protoplanetary)
- They avoid very efficiently spiral-in despite CE.
- Disk formation is a mainstream process
- Strong dust processing (crystallinity, growth)
- All discs contain O-rich dust
- Long IR lifetime
- Disk-Binary interaction: e-pumping ? (Bonacic-Martinovic et al. 08)
  accretion ! (depletion)
  mass-loss ! (P-Cygni profiles)
  will determine evolution
- Disks prevail : important ingredient in any binary evolution model

Future challenges:

Combine all data into **one complete picture of the current disk structures**

How do those disks **form** ? How do the disks **evolve** ? Does it impact on the evolutionary timescale ?

Is there a connection to **(asymmetric) PNe** ?

What is the **impact of the disk** on the evolution of the central star ?
(depletion; mass-loss history etc.)

What is the **relation** between binary post-AGB stars and other objects like Ba-stars, symbiotics, CH-stars, sdBs, bipolar Pne, CV's etc. etc. (long term dedicated rad.vel.monitoring: orbital connection)

Detailed comparison between **YSO and post-AGB disks**

LMC post-AGB sample:

- Thanks to SAGE: come to a **complete picture of disc and outflow sources** in the LMC-SMC with well constraint Luminosities.

- Place the objects in HR-diagram, and connect them to tailored (binary) evolutionary tracks.
- Detailed chemical analysis for **3rd dredge-up/depletion** processes
- Get **statistics** correct with respect to outflow sources
- Get good constraints on **formation and evolution of the discs**

- **Get orbital distribution of LMC stars.... the hard way**

Potential of LMC stars: nucleosynthesis