Mid-IR astronomy with the E-ELT: The case for evolved stars

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Overview

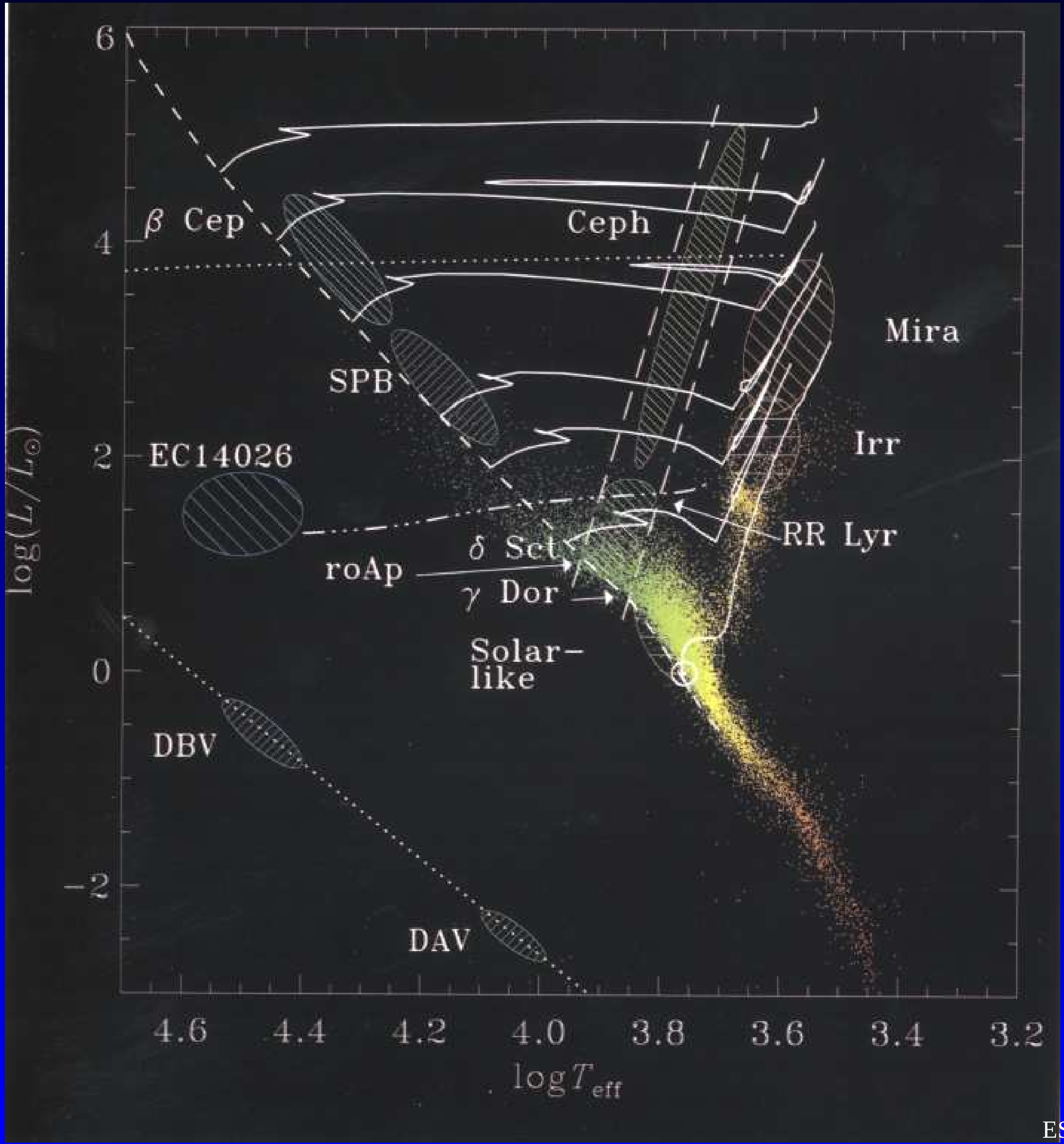
(JWST and the ELTs: An Ideal Combination, Garching, April 13-16, 2010)

- Introduction:
  current issues in evolved star research
- Science cases for E-ELT in the Mid-IR
  (HR & LR spectroscopy, imaging-broadband)
- Conclusions

Some caveats:

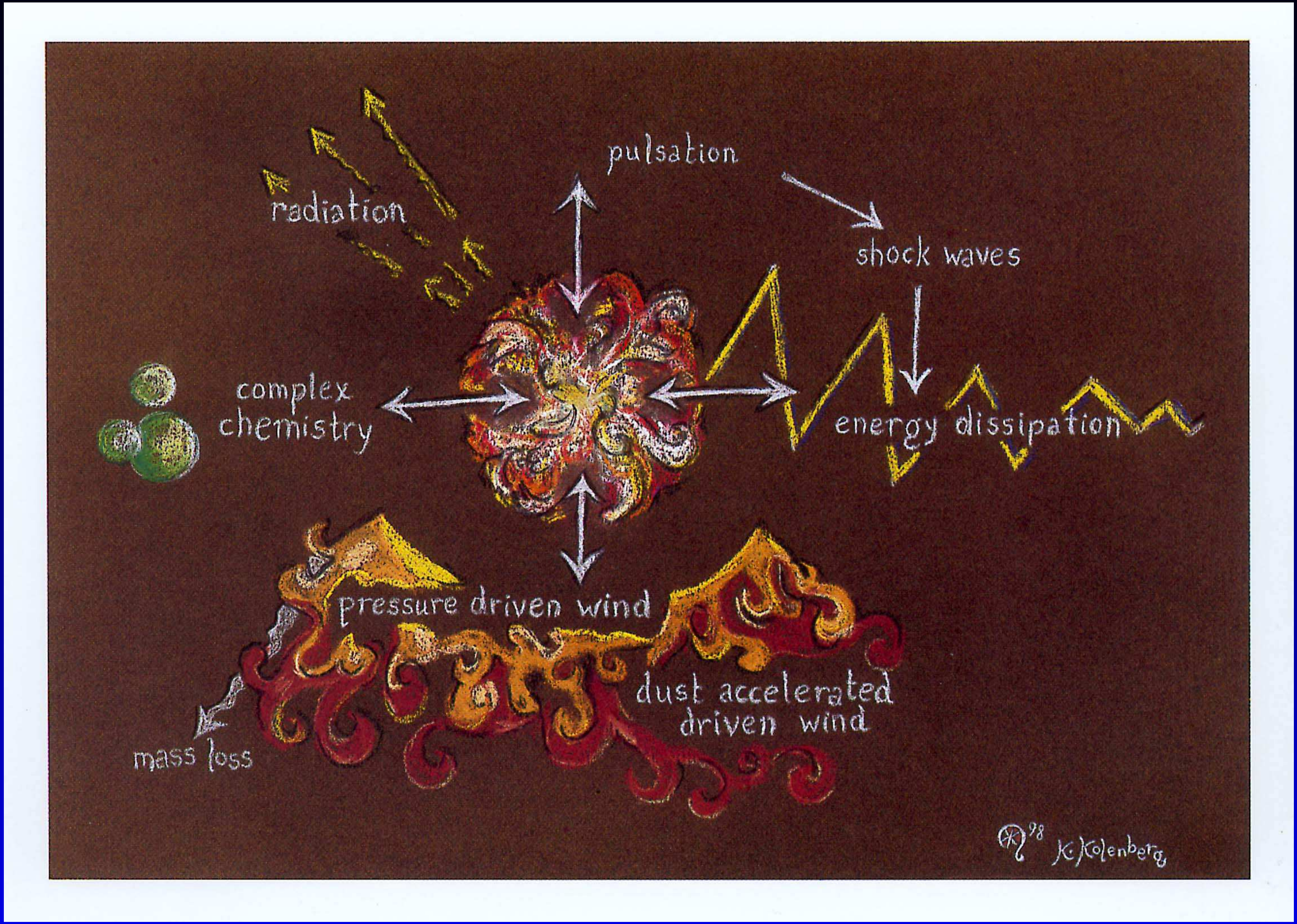
- Focus on AGB stars (not PN, LBV/WR, SN)
- No in depth comparison to other facilities that are relevant before 2023

AGB stars

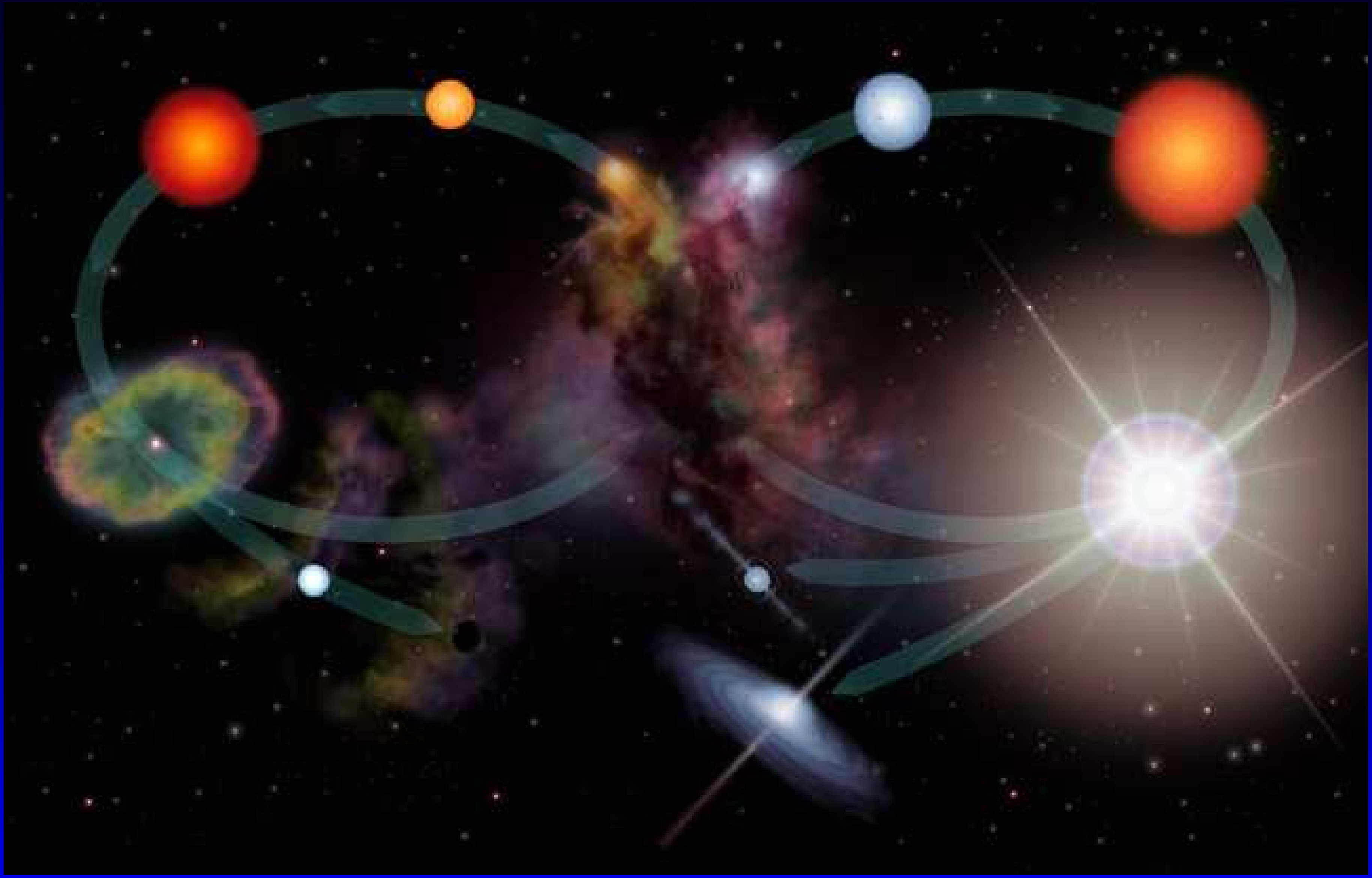

6
4
2
0
−2
$\log(L/L_\odot)$
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
$\log T_{\rm eff}$
β Cep
Ceph
Mira
SPB
Irr
EC14026
RR Lyr
δ Sct
roAp
γ Dor
Solar-like
DBV
DAV

Central Star

Betelgeuse. ESO press release 0927 (2009). Kervella, Ohnaka. AMBER, NACO

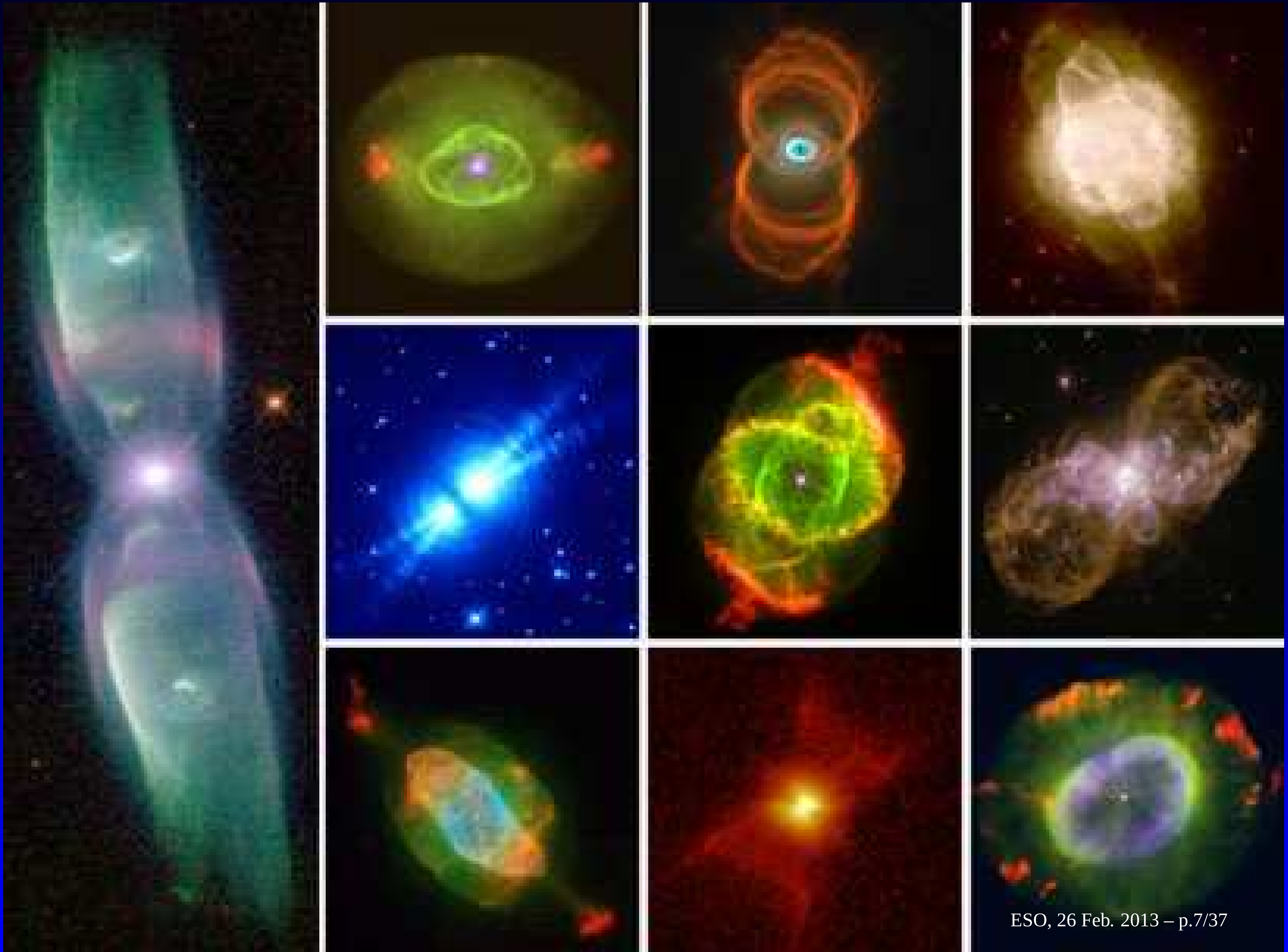

radiation
pulsation
shock waves
complex chemistry
energy dissipation
pressure driven wind
dust accelerated driven wind
mass loss
98 K. Kolenberg

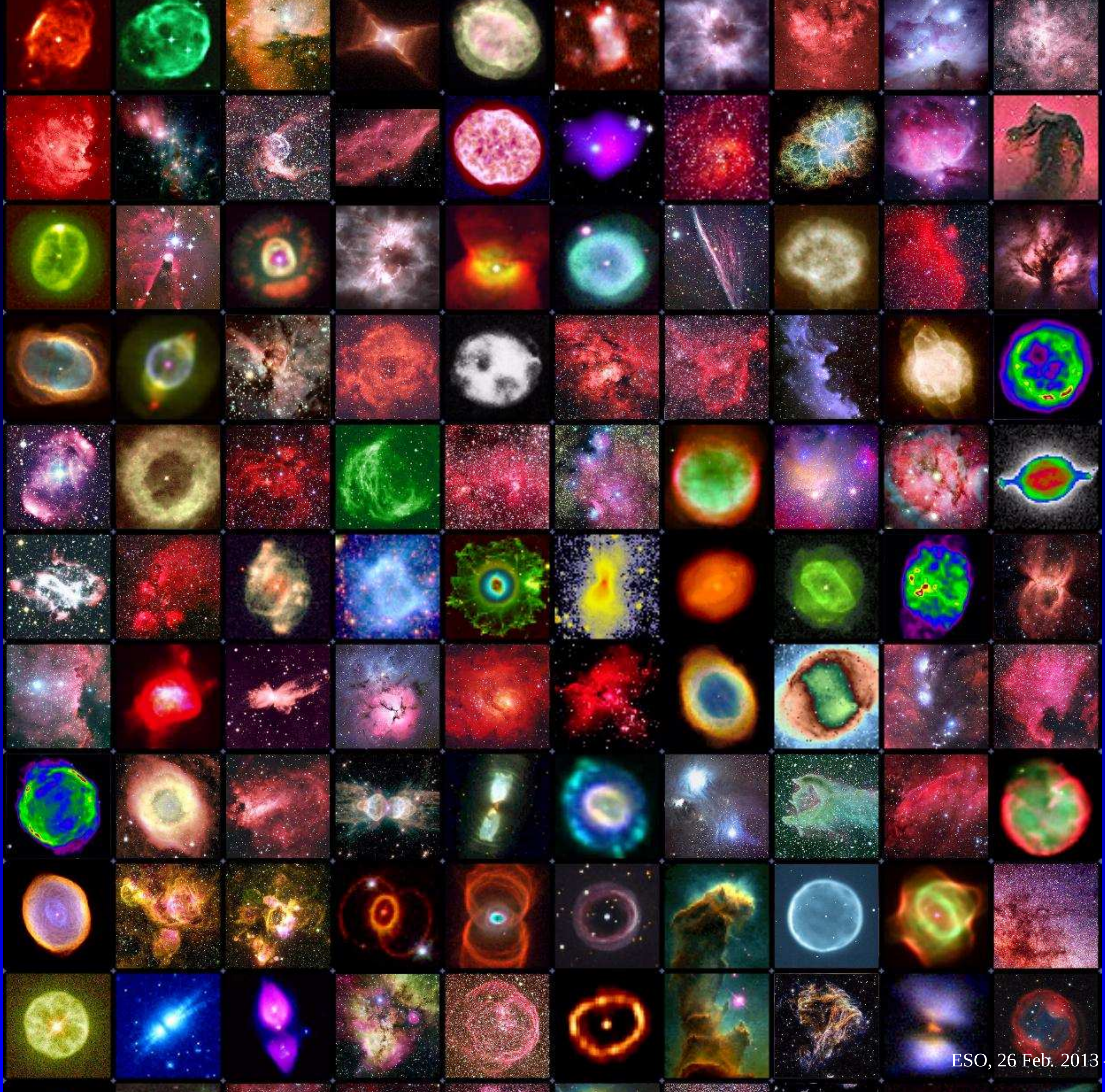
Lifecycle of dust and gas



http://hea-www.cfa.harvard.edu/CHAMP/EDUCATION/PUBLIC/starlifecycles_pics.html

Shaping PNe





Key Questions

What is the mass-loss return of dust and metal enrichment by AGB stars (versus SNe)

How does this depend on time, mass, metallicity ?

Driving of the wind (radiation pressure on dust, but....)

C-rich versus O-rich (different dust species, different wind driving ?)

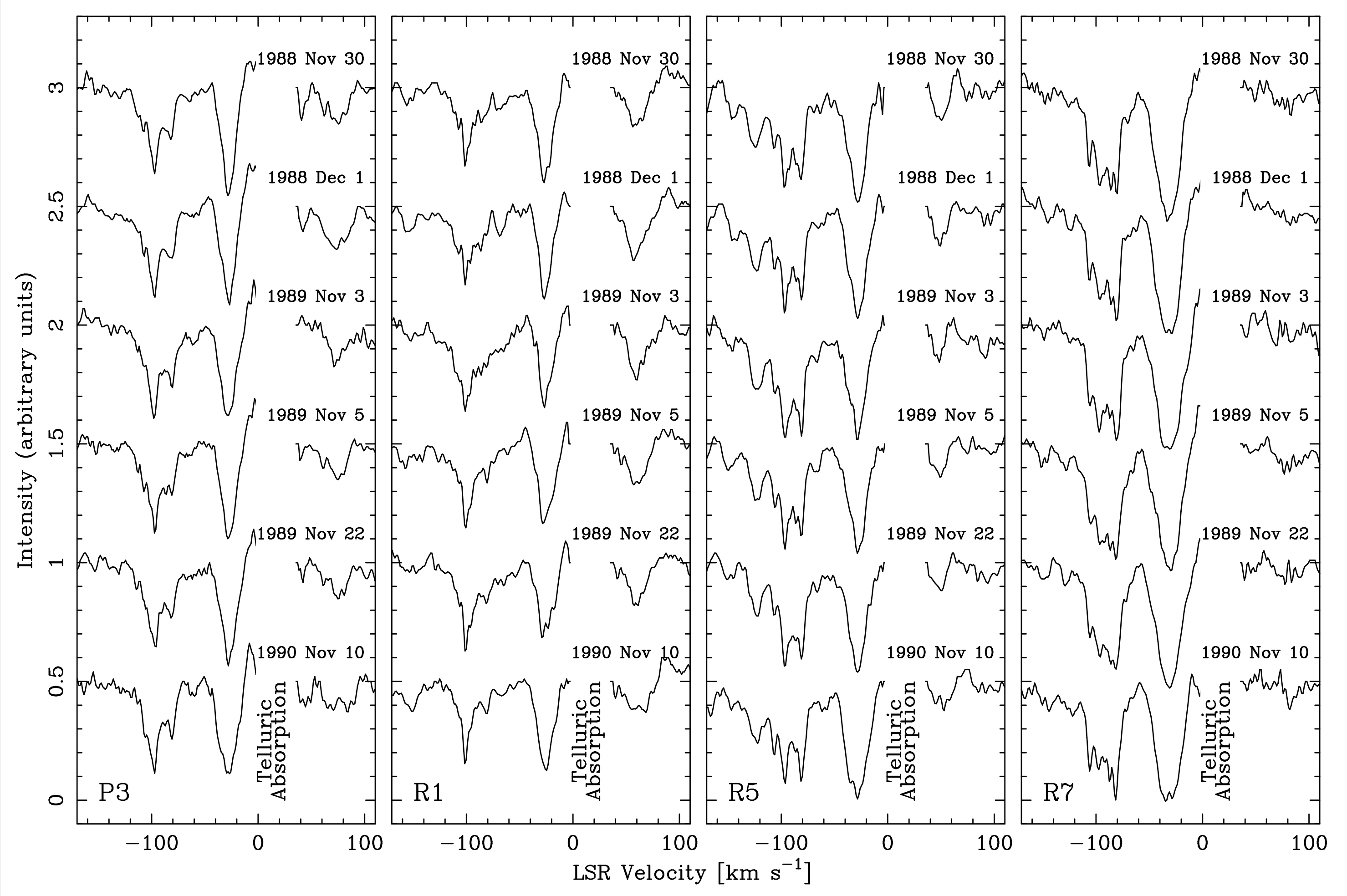
Thermal Pulses followed by nucleosynthesis near the core (convection)

Pulsation

non-spherical

role of binarity

HR Spectroscopy



Sahai et al. (2009), using FTS CO rot-vibr lines

2100-2200 cm^{-1} resolution of 0.02 cm^{-1}

4.55-4.76 μm, R= 107 000

4m telescope
no integration time, no S/N given, M = -2.3

"... these data, taken over 7 epochs, show that the circumstellar environment of V Hya consists of a complex high-velocity (HV) outflow containing at least six kinematic components with expansion velocities ranging between 70 and 120 km/s, together with a slow-moving normal outflow at about 10 km/s. Physical changes occur in the HV outflow regions on a time-scale as short as two days. The intrinsic line-width for each HV component is quite large ($6 - 8$ km/s) compared to the typical values (~ 1 km/s) appropriate for normal AGB circumstellar envelopes (CSEs), due to excess turbulence and/or large velocity gradients resulting from the energetic interaction of the HV outflow with the V Hya CSE."

CRIRES

Lebzelter et al. (2012) CRIRES-POP

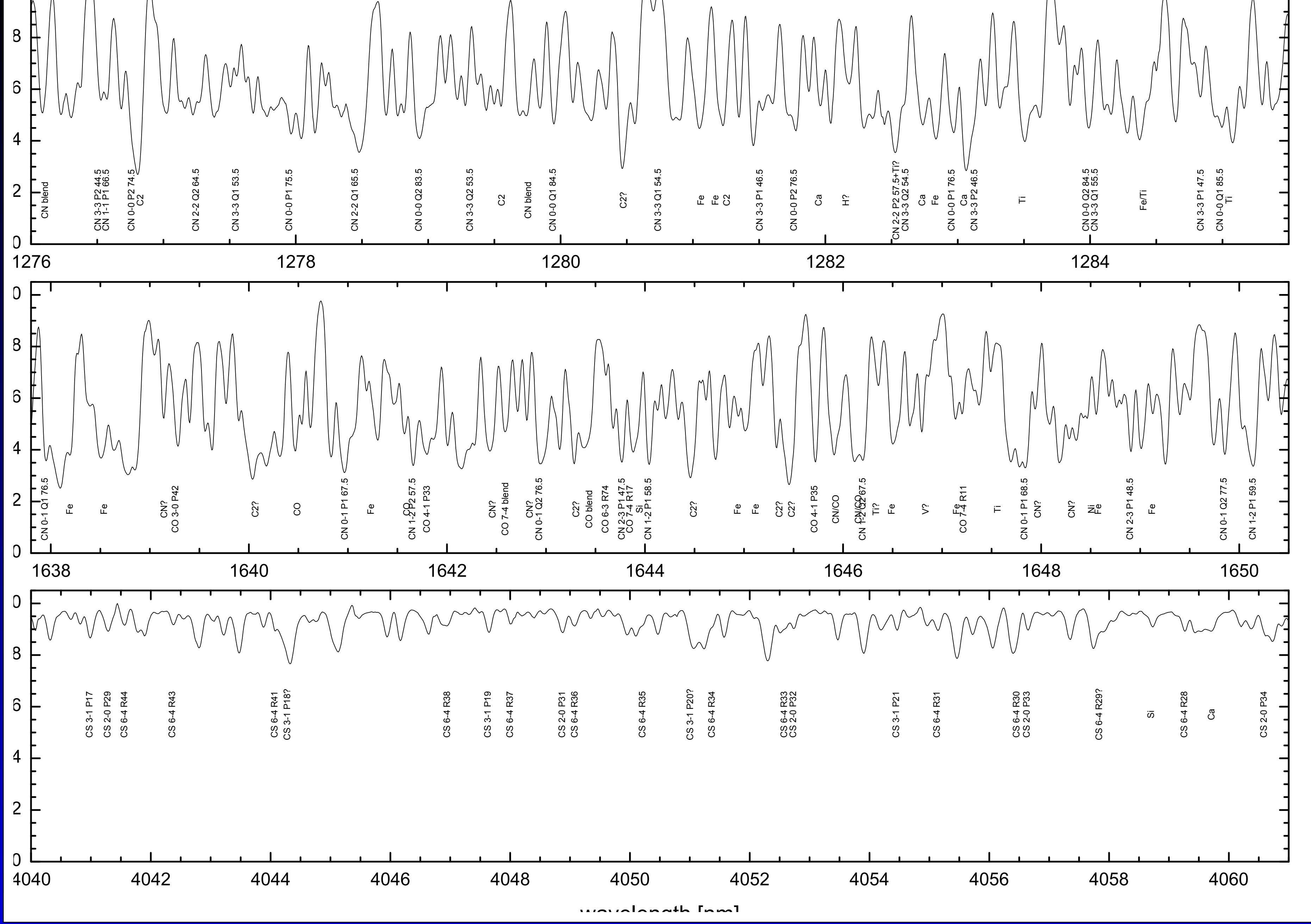
complete 0.97-5.3 μm region in 200 settings

R= 96 000 at 2.17 μm

"A complete scan of a star with K = 1 mag reaching a S/N of at least 200 throughout the entire spectral range takes almost nine hours and is strongly dominated by observational overheads (close to 80%)"

M-band: up to 20 min. per setting (K = M = 4.9)

25 objects (1 S, 1 C)



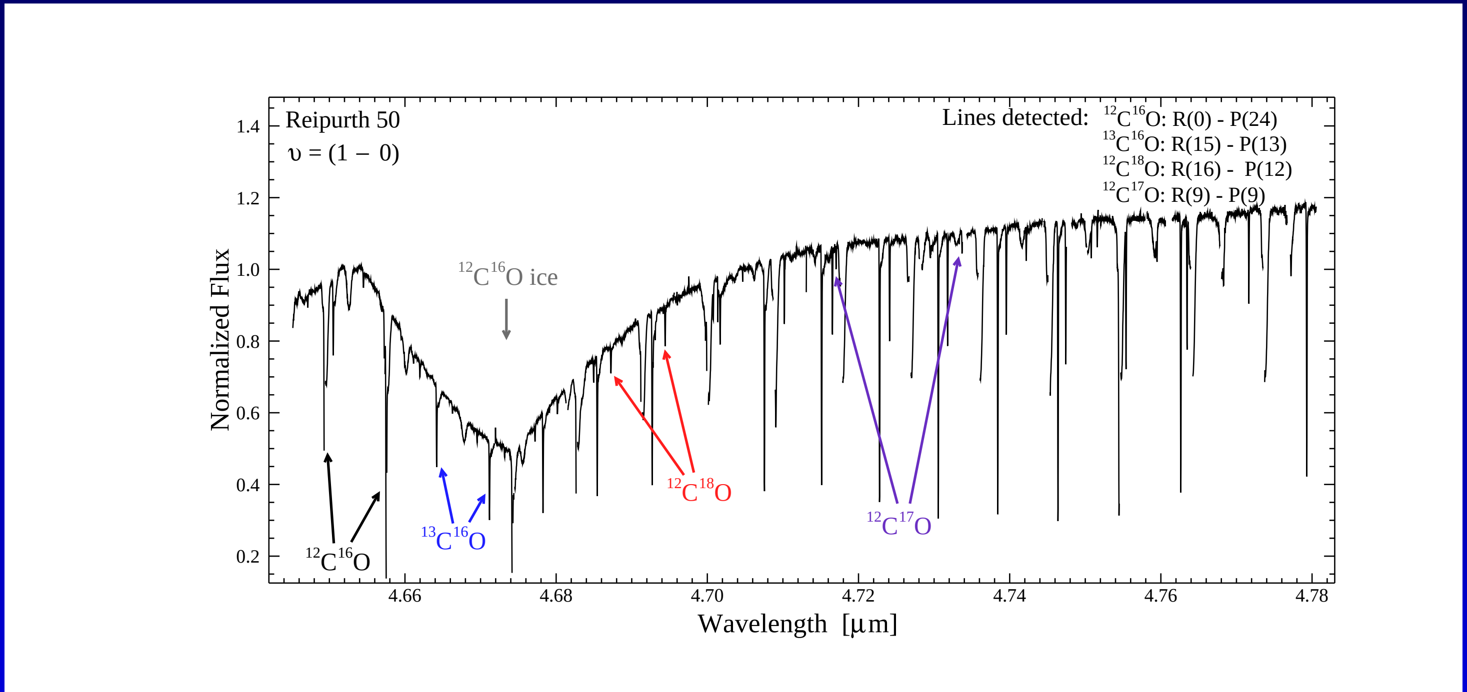
C-star X TrA CN, CS, C$_2$

CRIRES

Ryde et al. (2010) Bulge Giants

CNO, α elements, Fe, Si, S, and Ti

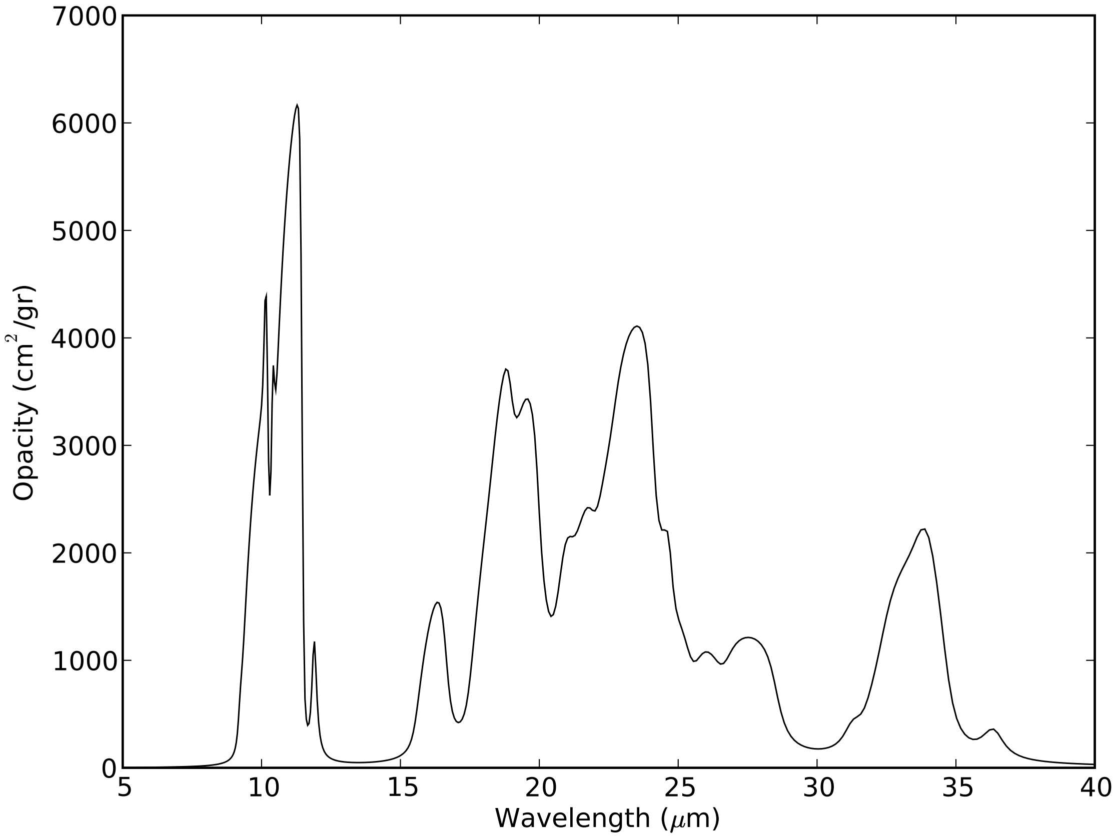
R= 70 000, H= 12.0, S/N= 90, t_{int} = 80 min



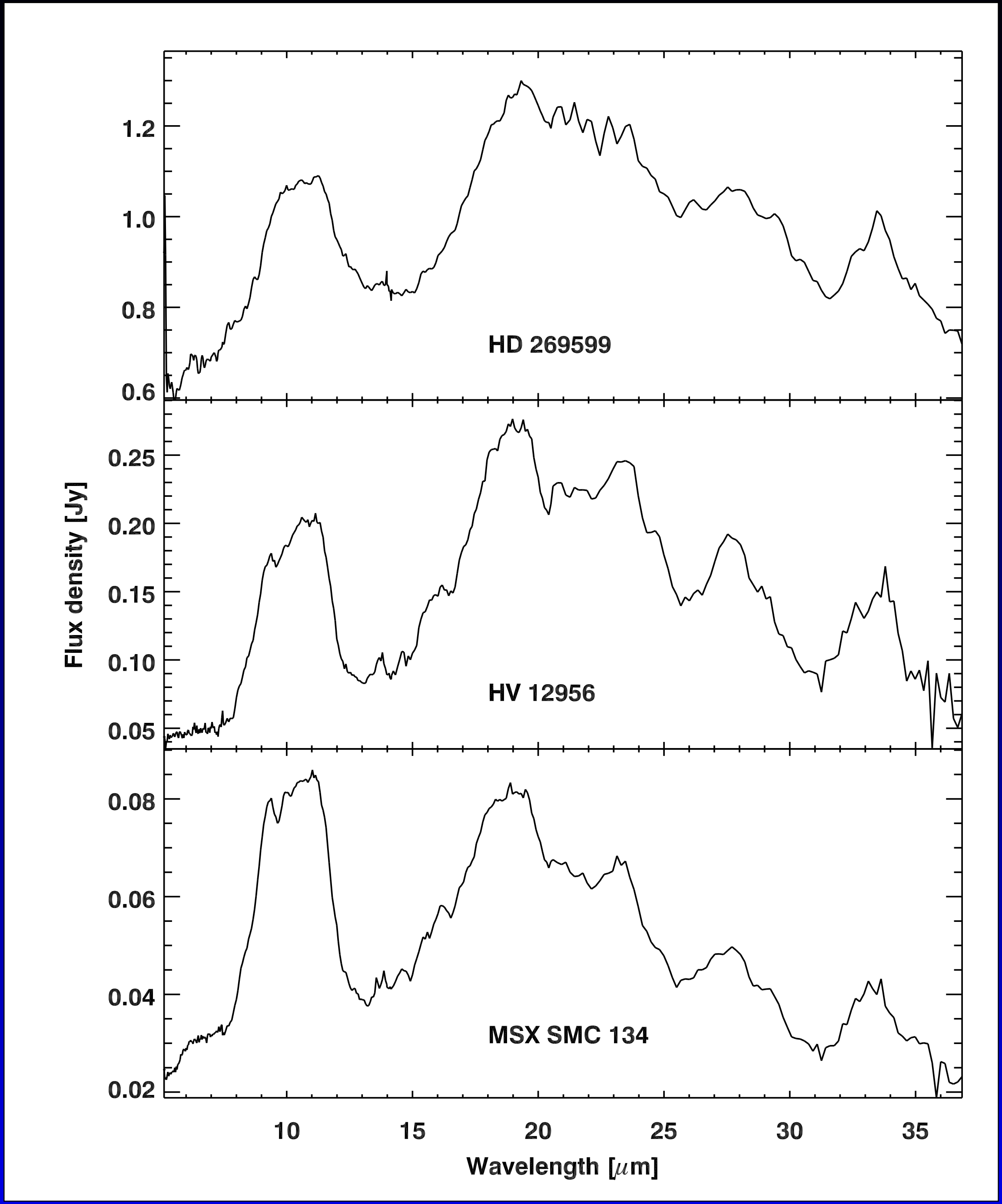
Smith et al. (2009), YSO

C^{16}O, C^{17}O, C^{18}O; 30 min., S/N= 300, M= +2.0

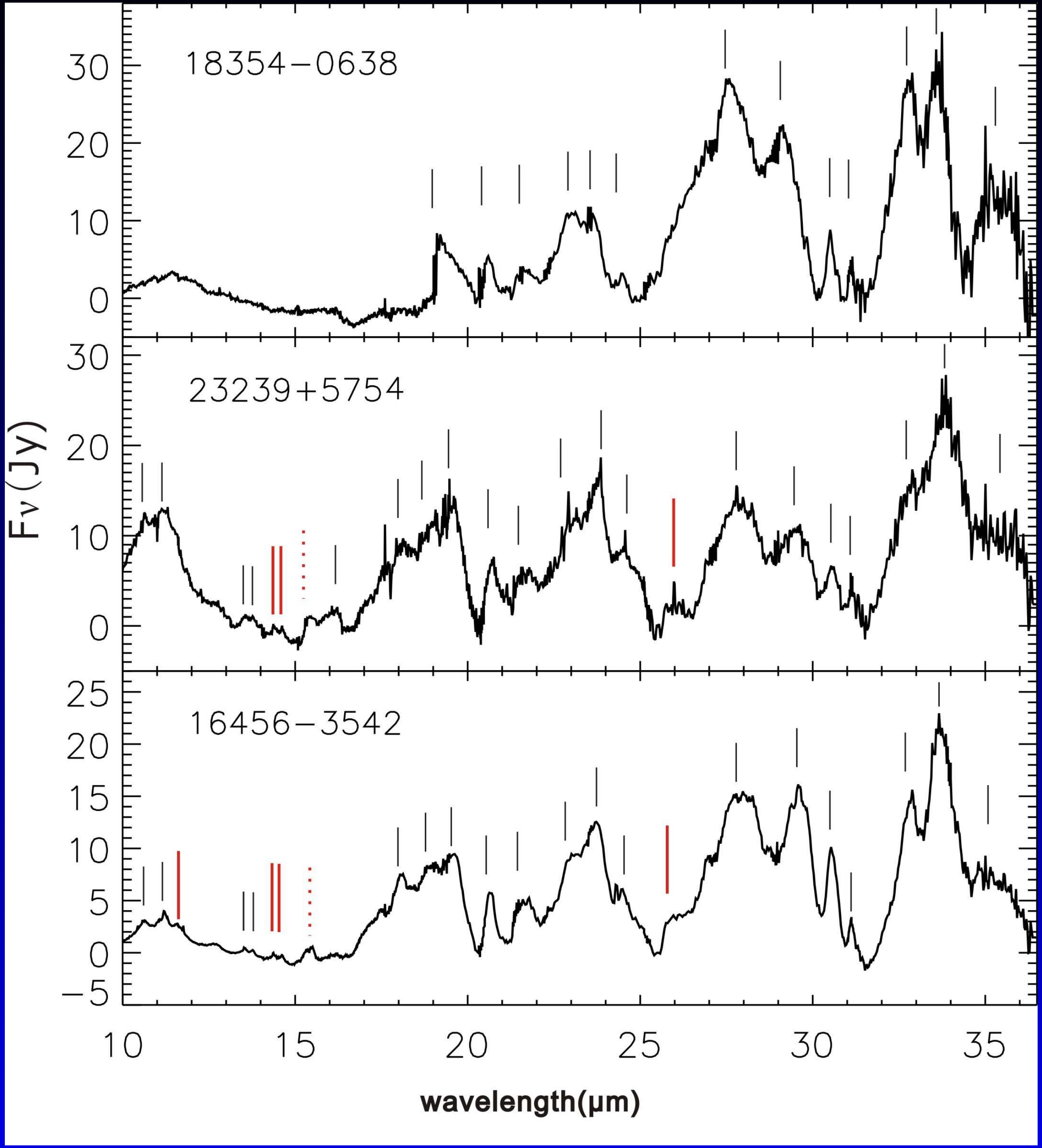
LR spectroscopy ⇒ Dust



de Vries et al. (2010)
The opacities of crystalline silicate forsterite



Jones et al. (2012) Q-band ~21 μm



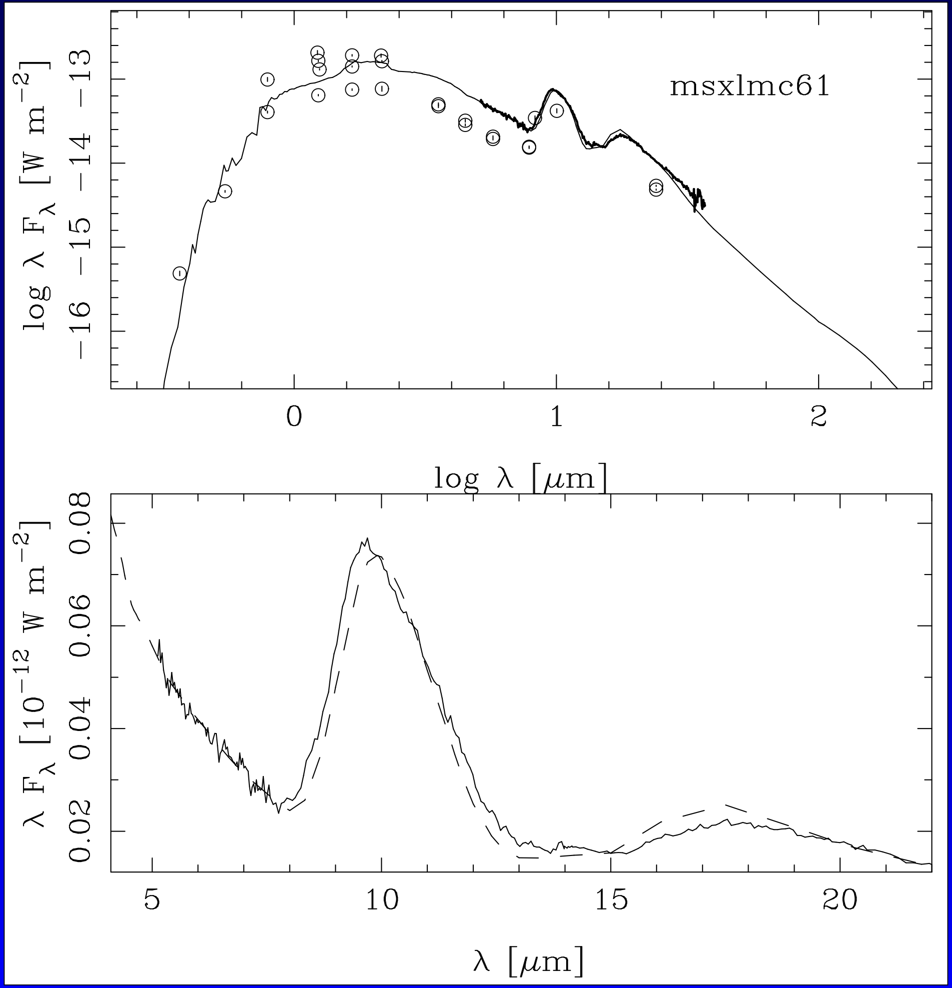
Jiang et al. (2013)

Spitzer IRS

LR spectroscopy

MSX LMC 61 (Groenewegen & Sloan, in prep.)

$L = 20\,800$ L$_\odot$, $\tau_{0.5} = 2.5$, $\dot{M} = 6.5 \cdot 10^{-7}$ M$_\odot$ yr^{-1}



210 mJy at 8.0 μm

ELT ETC

S/N= 30 R= 200

1hour F= 0.65 mJy

$L = 10\,000$ L$_\odot$

$\Rightarrow$ 0.6 Mpc

VISIR

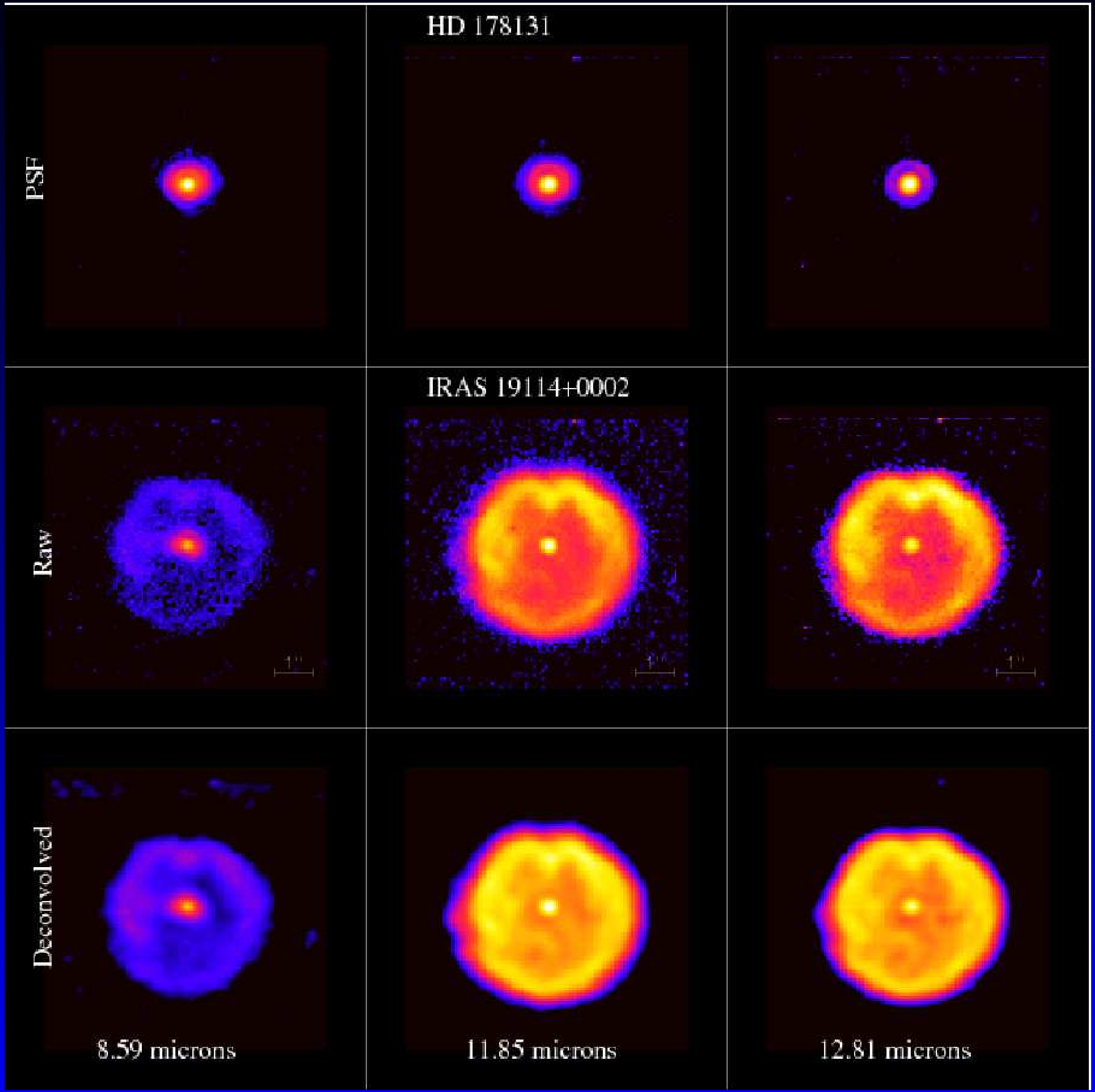
Lagadec et al. (2011)

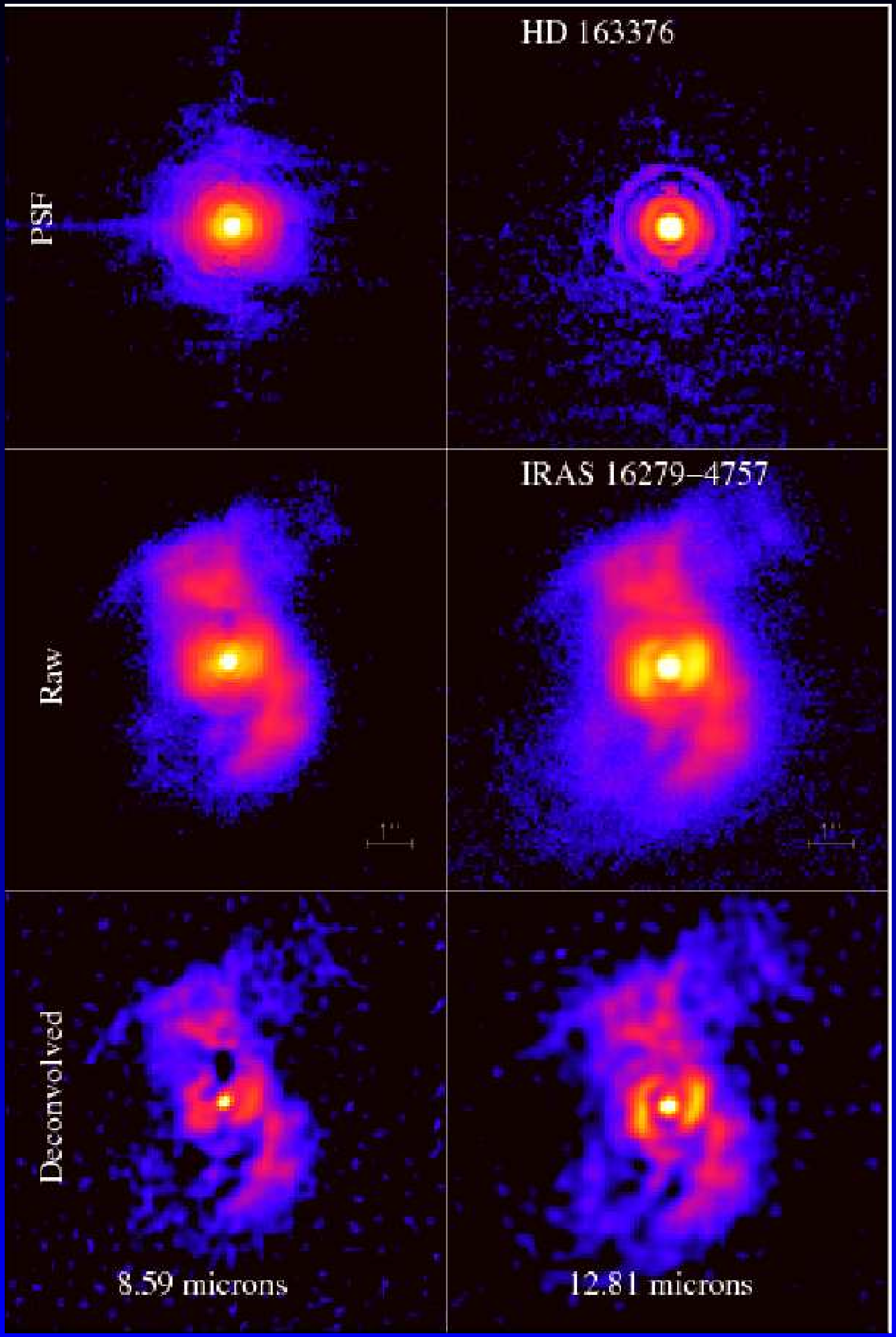
PAH (8.59 μm), SiC (11.85 μm), Ne II (12.81 μm)

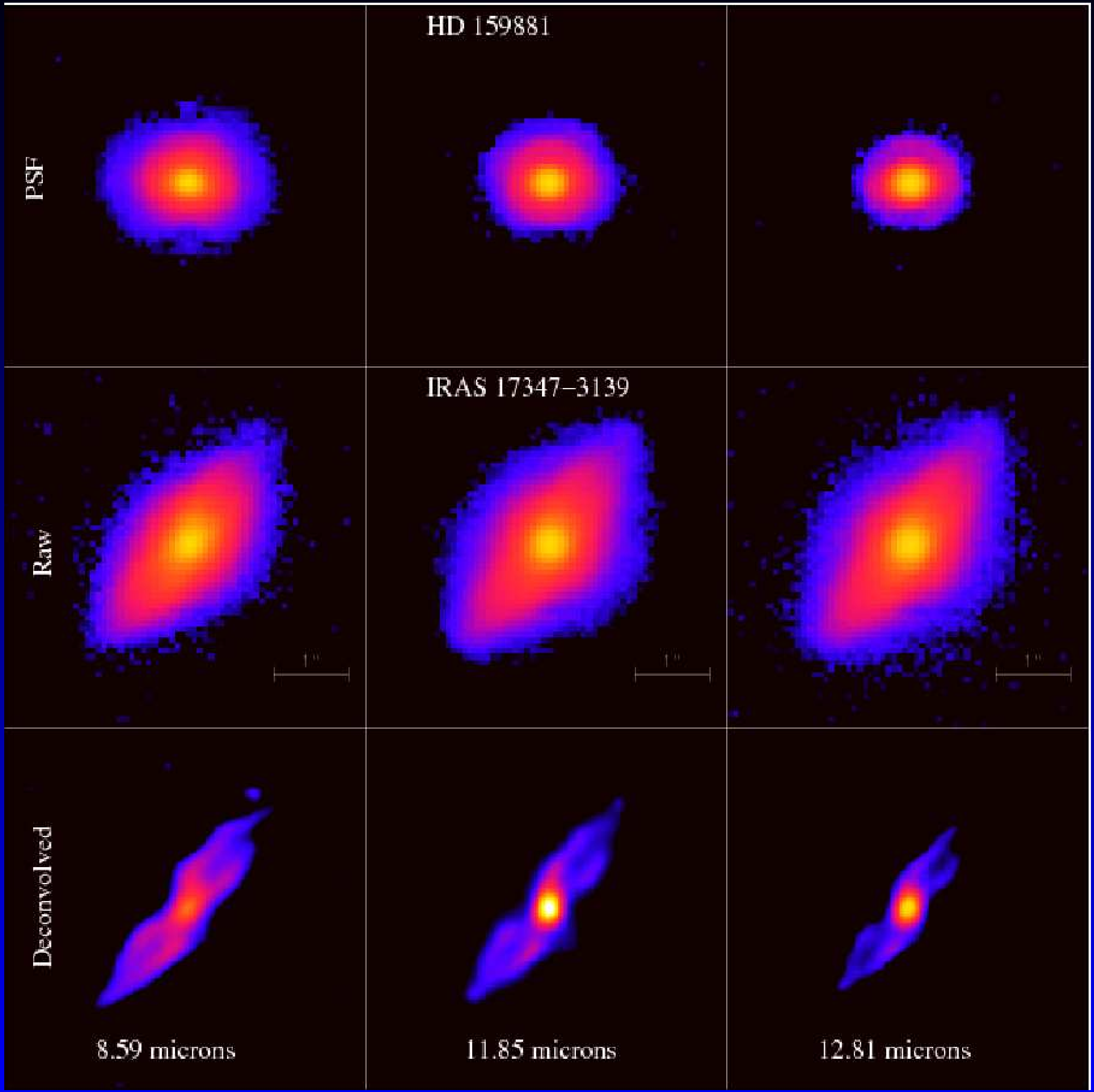
75 mas pixelscale, FoV= 19×19 arcsec^2, $t_{\rm int}$= 30 sec

FWHM from 250-500 mas

"We imaged a sample of 93 evolved stars and nebulae in the mid-infrared using VISIR/VLT, TRecs/ Gemini-South and Michelle/Gemini-North.We found that all the proto-planetary nebulae we resolved show a clear departure from spherical symmetry. 59 out of the 93 observed targets appear to be non-resolved."


HD 178131
PSF
IRAS 19114+0002
Raw
1''
1''
1''
Deconvolved
8.59 microns
11.85 microns
12.81 microns


HD 163376
PSF
IRAS 16279−4757
Raw
Deconvolved
8.59 microns
12.81 microns


HD 159881
PSF
IRAS 17347−3139
Raw
1″
1″
1″
Deconvolved
8.59 microns
11.85 microns
12.81 microns

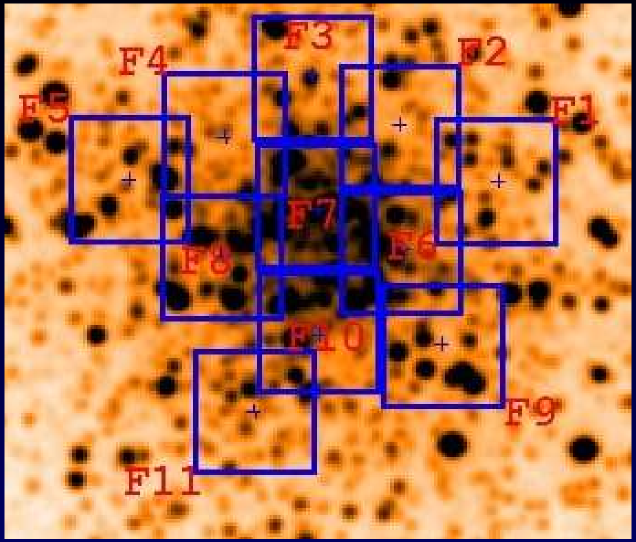
VISIR

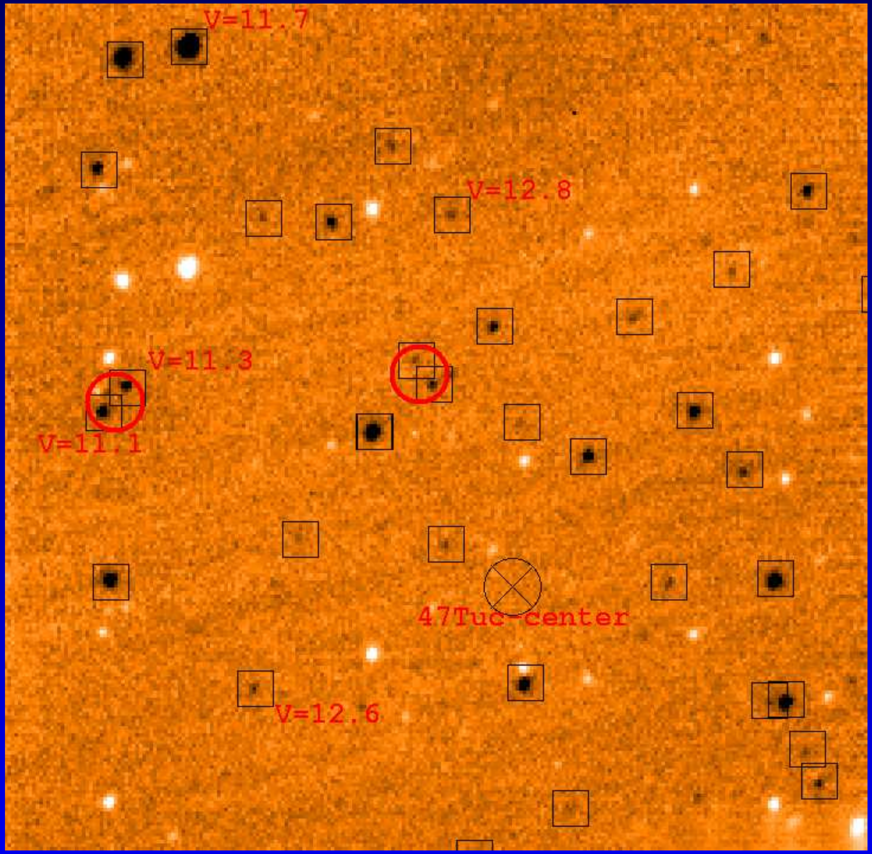
Momany et al. (2012)

PAH (8.59 μm)

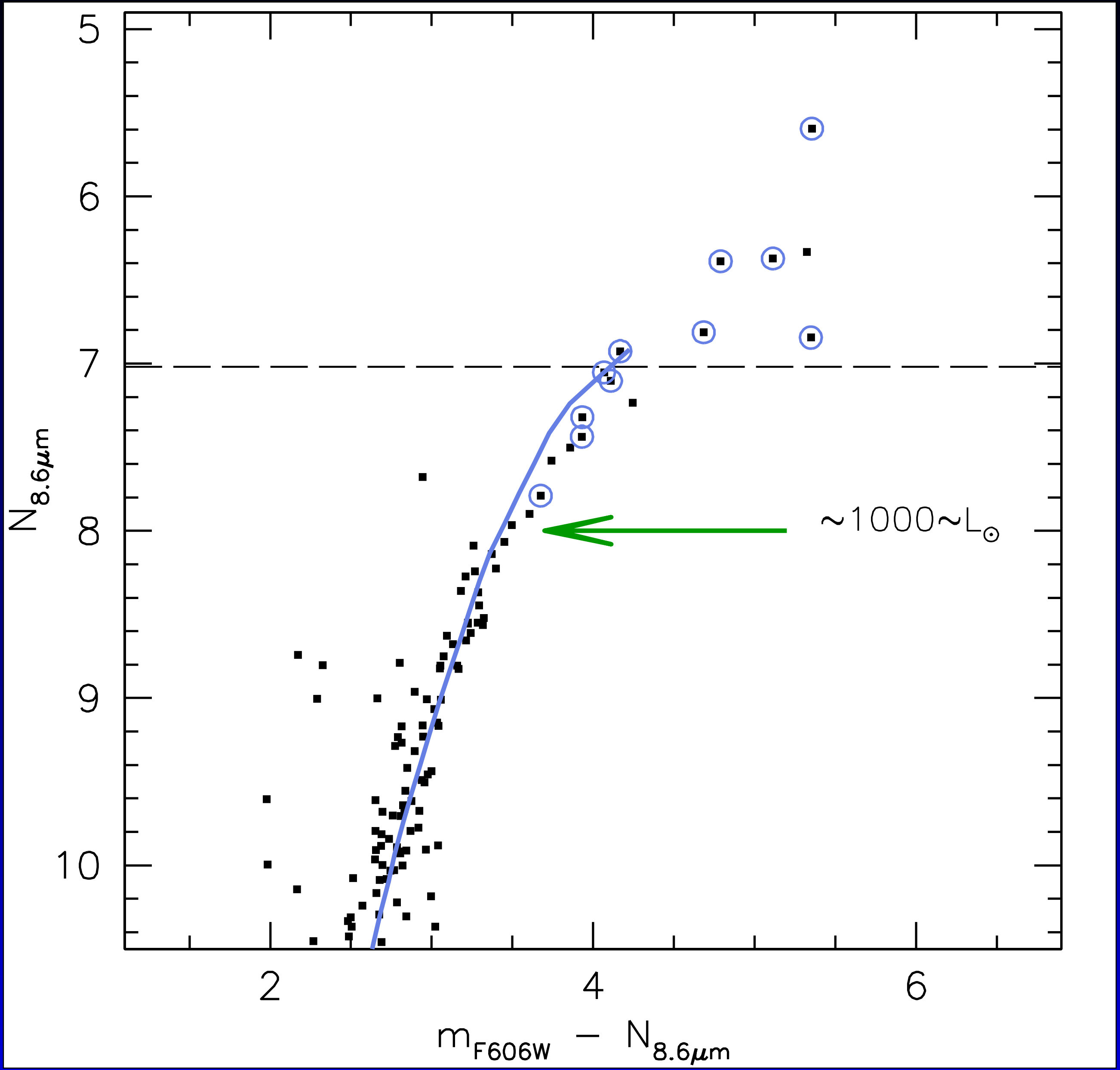
127 mas pixelscale, FoV= 32×32 arcsec^2,
1.8h per pointing

"Dusty red giants and asymptotic giant stars are confined to the 47 Tuc [MG: at 5 kpc] long period variables population. In particular, dusty red giants are limited to the upper one N8.6μm magnitude below the giant branch tip. This particular luminosity level corresponds to $\sim$ 1000 L$_\odot$ in previous determinations to mark the onset of dusty mass-loss"



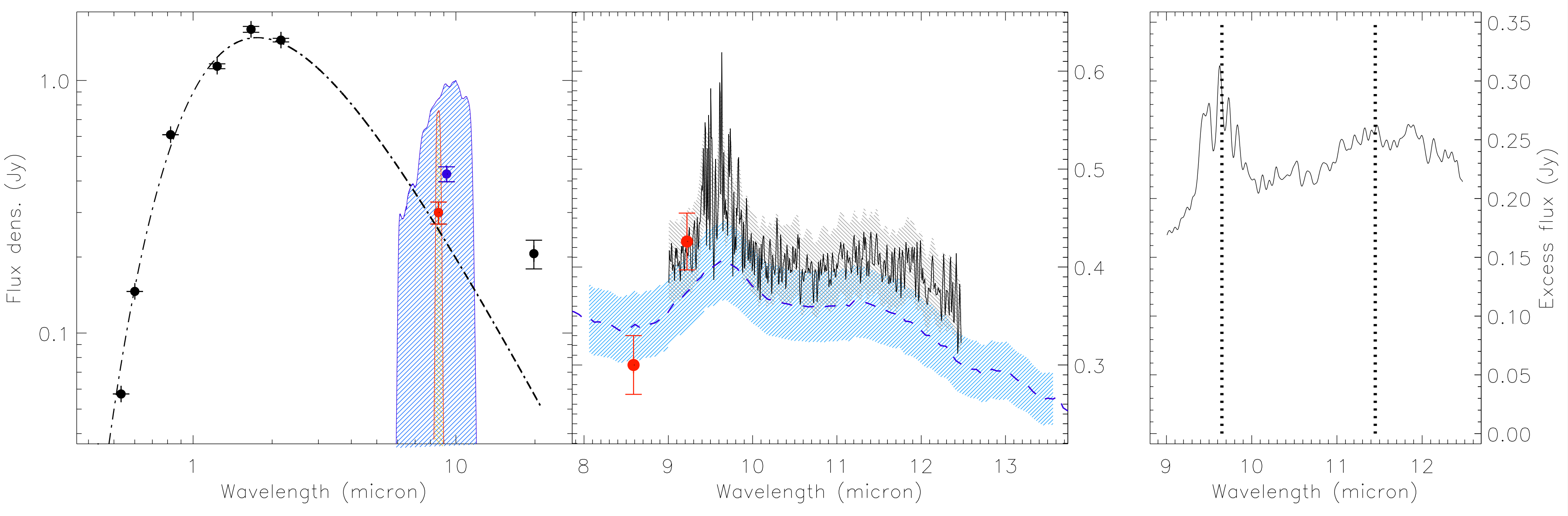


(upper) 2MASS with pointings; (lower) VISIR



HRD, combined with ACS

*N*8.6= 10 corresponds to about 5 mJy



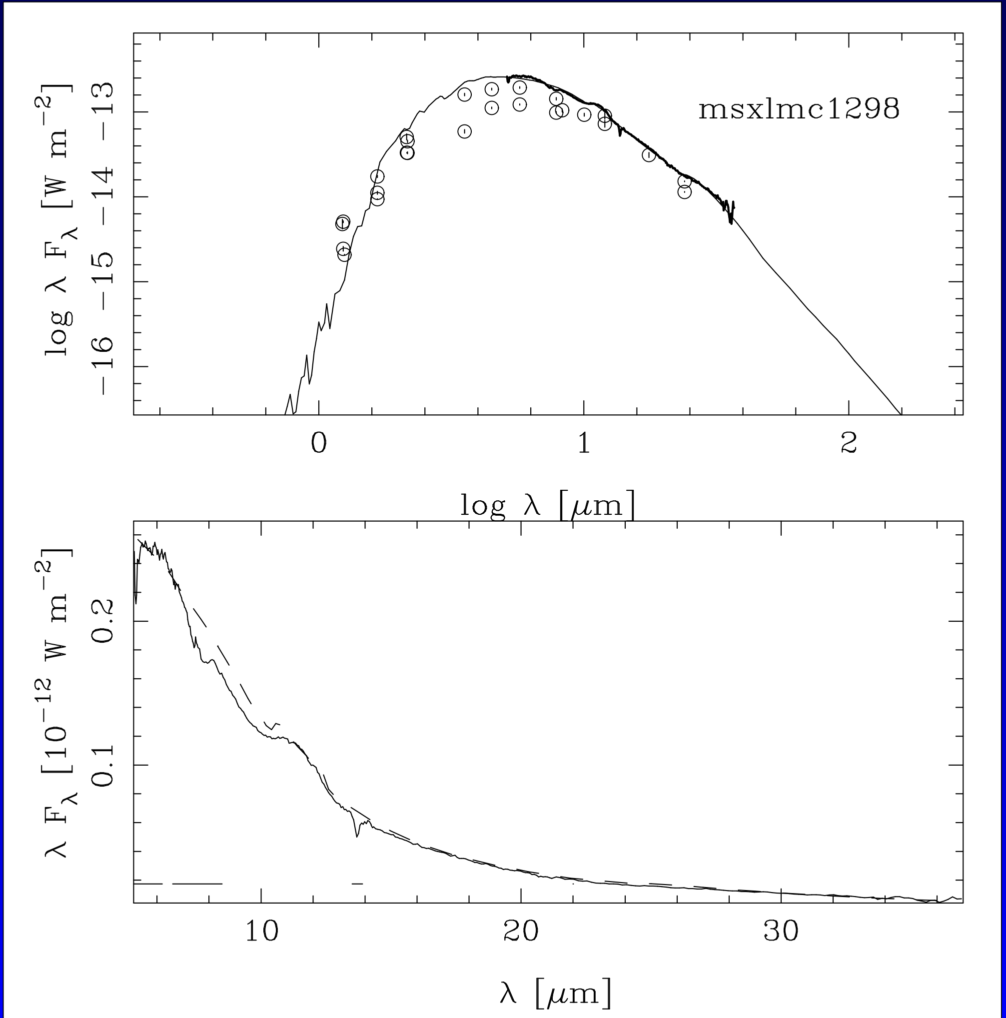
Of brightest object

R= 300, 9.8 μm + 11.4 μm central wavelength

Broadband

MSX LMC 1298 ($\rightarrow$ SED peaks near M-band)

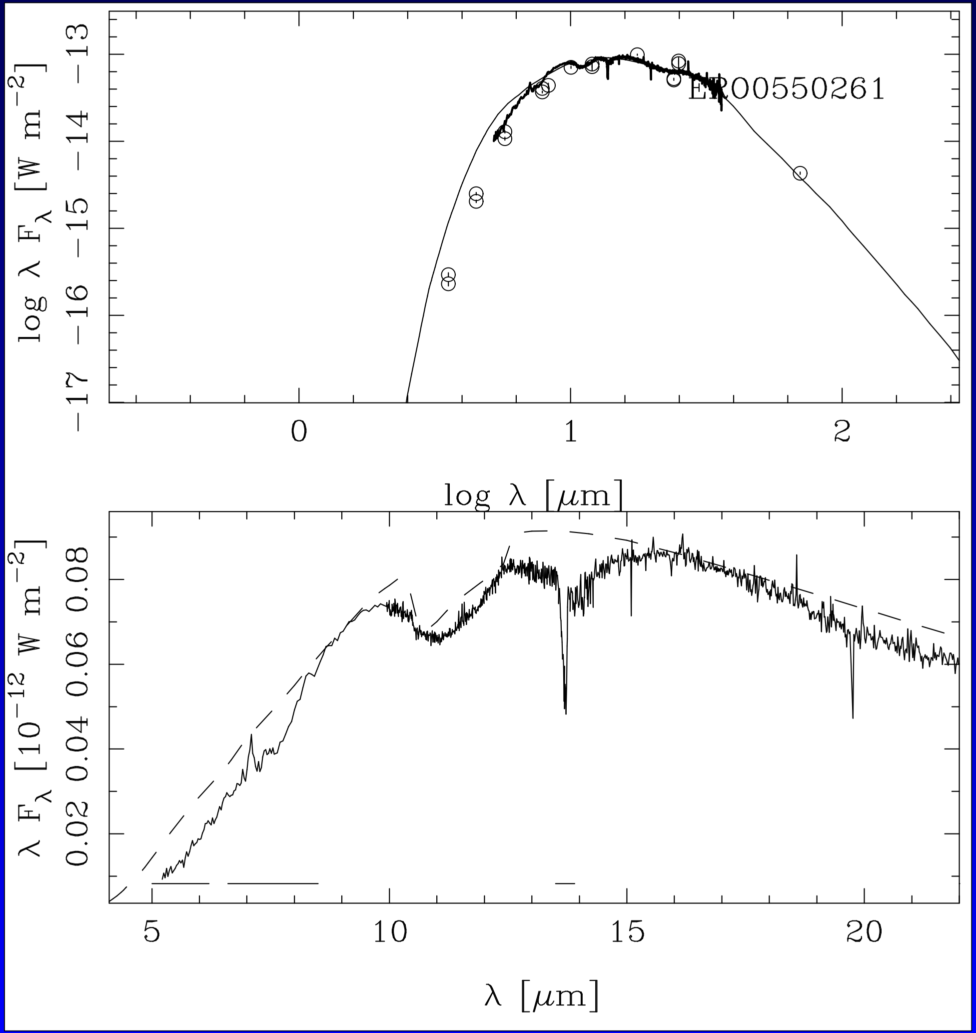
$L = 29\,200$ L$_\odot$, $\tau_{0.5} = 10$, $\dot{M} = 4.4 \cdot 10^{-6}$ M$_\odot$ yr^{-1}



Broadband

ERO 0550261

$L = 11\,000$ L$_\odot$, $\tau_{0.5} = 120$, $\dot{M} = 3.6 \cdot 10^{-5}$ M$_\odot$ yr^{-1}



Dust Production in the LMC

Type	N	$\Sigma\dot{D}$ ($M_\odot$/yr)	%	$<\dot{D}>$ ($M_\odot$/yr)
x-AGB	313	6.26×10^{-7}	65.9	2.0×10^{-9}
C-AGB	1 559	1.21×10^{-7}	12.7	7.8×10^{-11}
O-AGB	1 851	0.52×10^{-7}	5.5	2.8×10^{-11}
aO-AGB	1 243	0.26×10^{-7}	2.7	2.1×10^{-11}
RSG	2 611	0.31×10^{-7}	3.3	1.2×10^{-11}
FIR*	50	0.96×10^{-7}	10.1	1.9×10^{-9}
Total, no FIR	7 577	8.6×10^{-7}	90.5	1.1×10^{-10}

Remarks:
FIR= contaminants (YSO, PNe); quoted are *DUST* MLR, so multiply by $\sim$ 200.

Boyer et al. (2012)
Matsuura et al. (2009, 2012)

Filter	magnitude	Flux (mJy)	magnitude	Flux (mJy)
	MSX LMC 1298		ERO 0550261	
Z	19.97	0.02		
Y	18.24	0.11		
J	15.47	0.9		
H	12.47	11		
K	10.22	54	22.1	0.001
L	7.28	296	12.29	3.0
M	6.53	412	10.05	16
N	4.89	413	5.49	240
Q	4.41	204	3.47	480
MIPS 24	4.19	152	2.86	517
350 μm	–	0.16	–	1.2

N-band 0.05 mJy S/N= 30 1hour (ETC for 42m)
(METIS 0.03 mJy S/N= 10 1hour)

$L = 5\,000$ L$_\odot \Rightarrow$ 1.9 Mpc
outer radius of 1000 inner radii $\Rightarrow$ 20 mas @ 1.9 Mpc

Some famous AGB+SGs

Star	Radius (mas)	Distance (kpc)	M-mag	N-mag
R Dor	31.5	0.055	-4.4	-5.0
α Ori	23.2	0.15	-4.3	-5.0
CW Leo	17.7	0.12	-5.5	-7.7
o Cet	15.6	0.09	-3.4	-4.4
R Cas	9.9	0.13	-2.3	-3.6
VY CMa	6.9	1.2	-4.2	-6.1
U Hya	6.7	0.2	-1.3	-1.8
R Scl	5.6	0.3	-1.2	-1.8
U Ant	4.8	0.3	-0.9	-1.4
R For	2.9	0.7	-0.9	-2.0
S Sct	2.6	0.4	0.5	-0.0
V CrB	2.5	0.7	0.3	-1.0
AFGL 3116	2.3	0.7	-0.4	-3.0
AFGL 3068	2.0	1.2	1.6	-3.0
OH 26.5	1.9	1.6	0.3	-2.0
TT Cyg	1.5	0.5	1.5	1.0
AFGL 190	0.93	2.9	4.1	-0.8
IRC +10 420	0.48	7.0	2.2	-3.3
AFGL 2343	0.22	5.0	4.8	1.3

Concluding remarks

+ HR spectroscopy: abundances, isotope ratios, in (nearby) LG galaxies

– NIR will be better/sufficient in most cases

+ HR spectroscopy: kinematics (shaping of PNe)

– To study the acceleration of wind, resolution of 100 000 is low-ish ($<$1 km/s desirable).

ALMA in most extended configuration with
16 km baseline:
6 mas @ 675 GHz, 37 mas @ 110 GHz
0.01 km/s @ 110 GHz

Concluding remarks

$+$ LR spectrocopy: dust in LG galaxies

$-$ JWST more sensitive, and larger wavelength coverage, but at lower spatial resolution.
Case for Q-band

$+$ Imaging: shape of CSE, shaping of P-AGB, PNe

$-$ Saturation limit?
Neutral Density filter versus Coronograph
Need to probe as close as $\sim 1.5 R_\star$

$+$ Imaging: SED of dustiest AGB stars in LG

$-$ JWST more sensitive, but at lower spatial resolution.
Case for Q-band

THE END