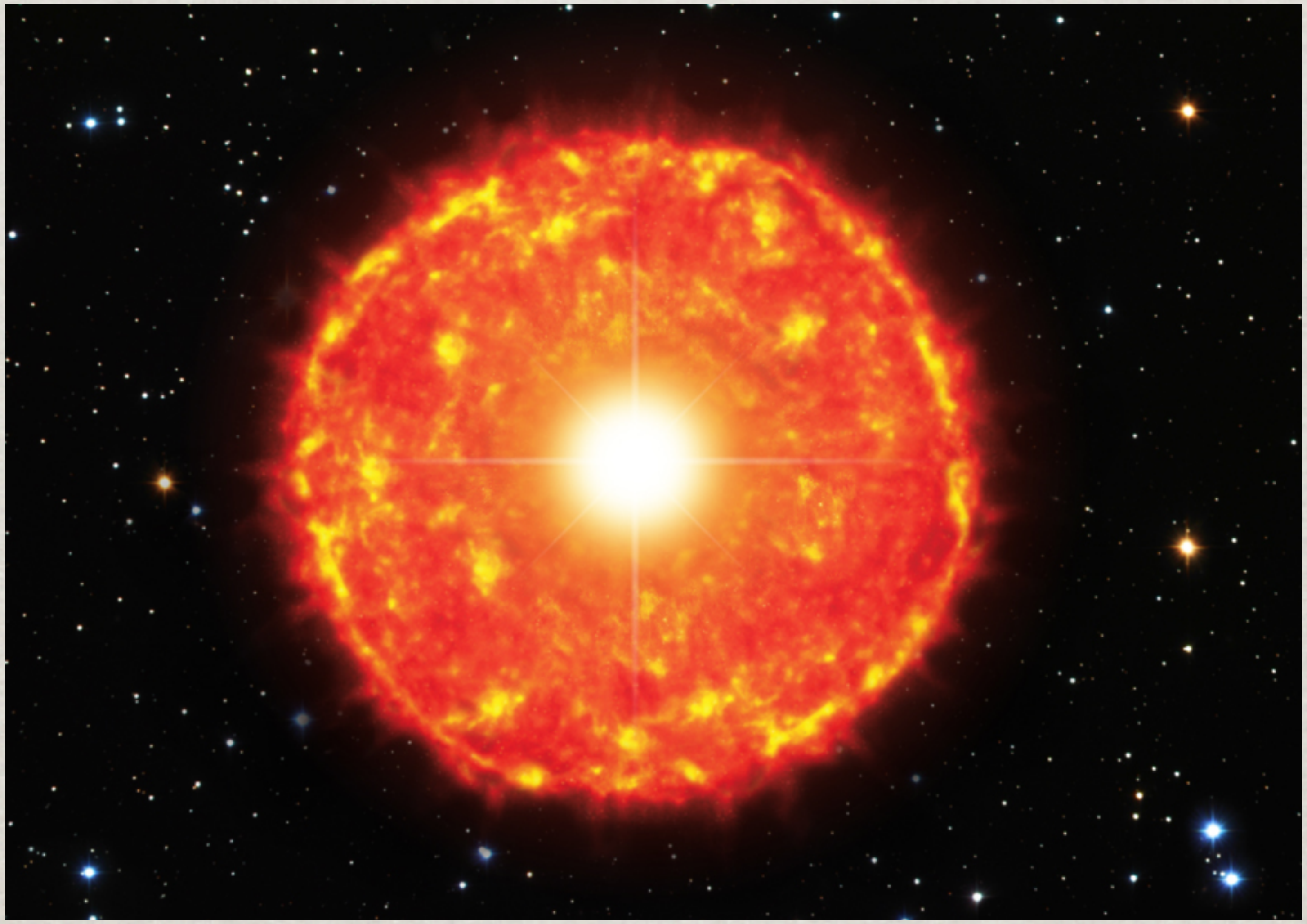
ALMA's first look at AGB stars: the secrets of thermal pulses and sculpted winds



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Asymptotic Giant Branch stars

Stars between 0.8-8 M$_\odot$

dormant C/O-core

He-burning shell

H-burning shell

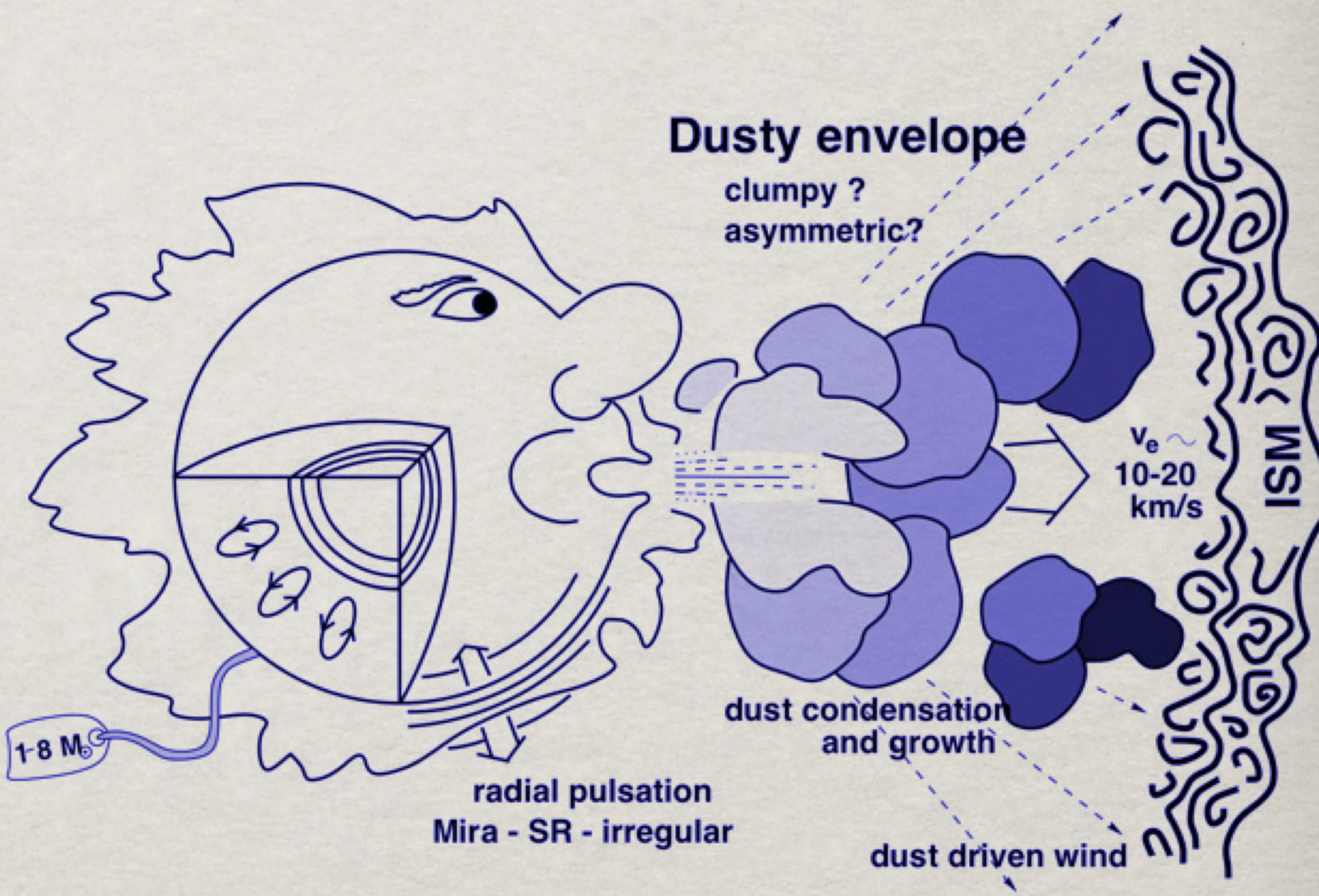
convective envelope

pulsating atmosphere

Mass-loss rates of 10^{-7}-10^{-4} M$_\odot$yr^{-1}

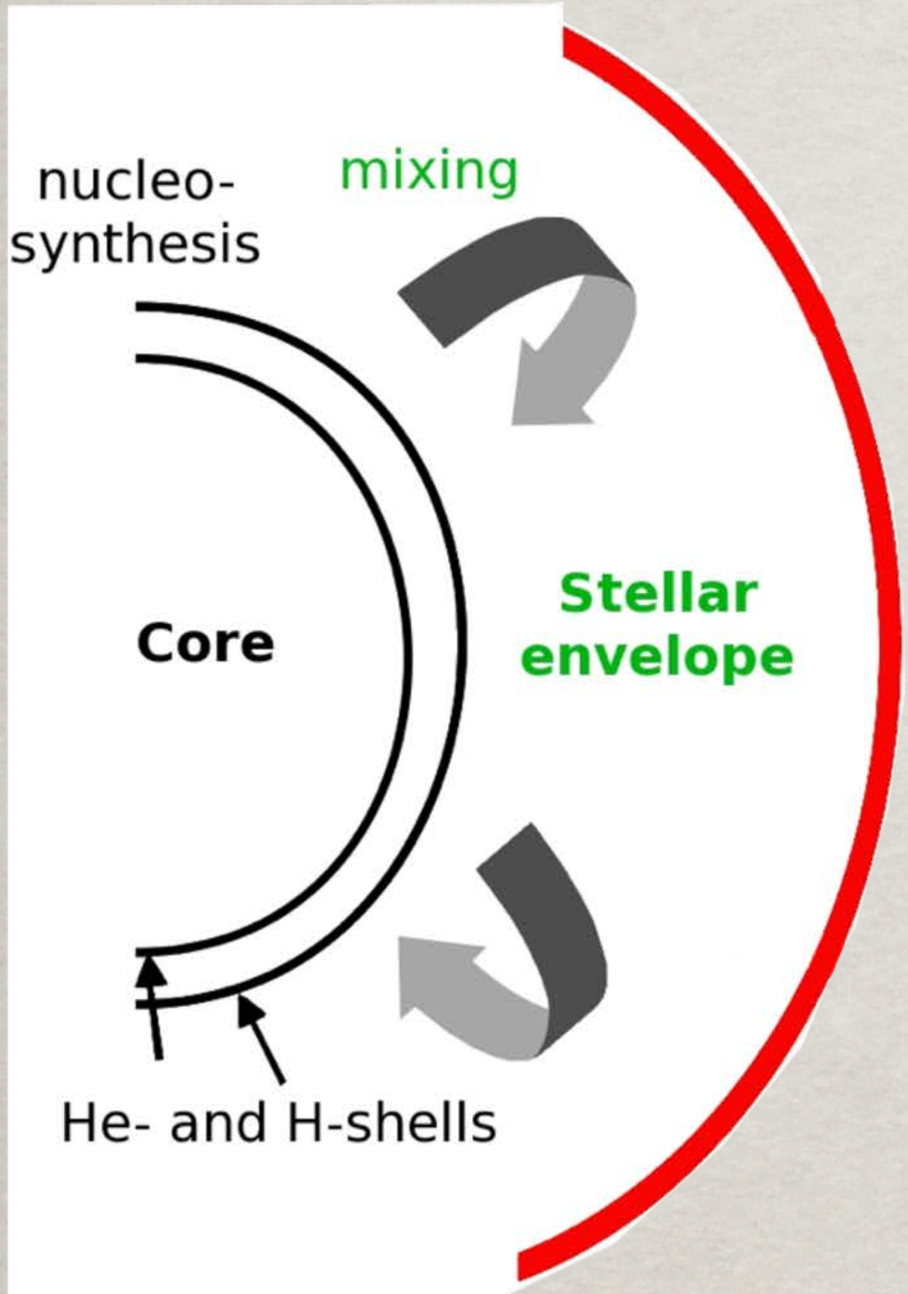
Expansion velocities of 10-20 km/s

build-up of large, circumstellar envelope (CSE)



effective producers of
new elements and dust

Thermal pulses on the AGB



thermally unstable He-shell

He-shell flash (thermal pulse)

nucleosynthesis in intershell zone

Stellar yields critically dependent on

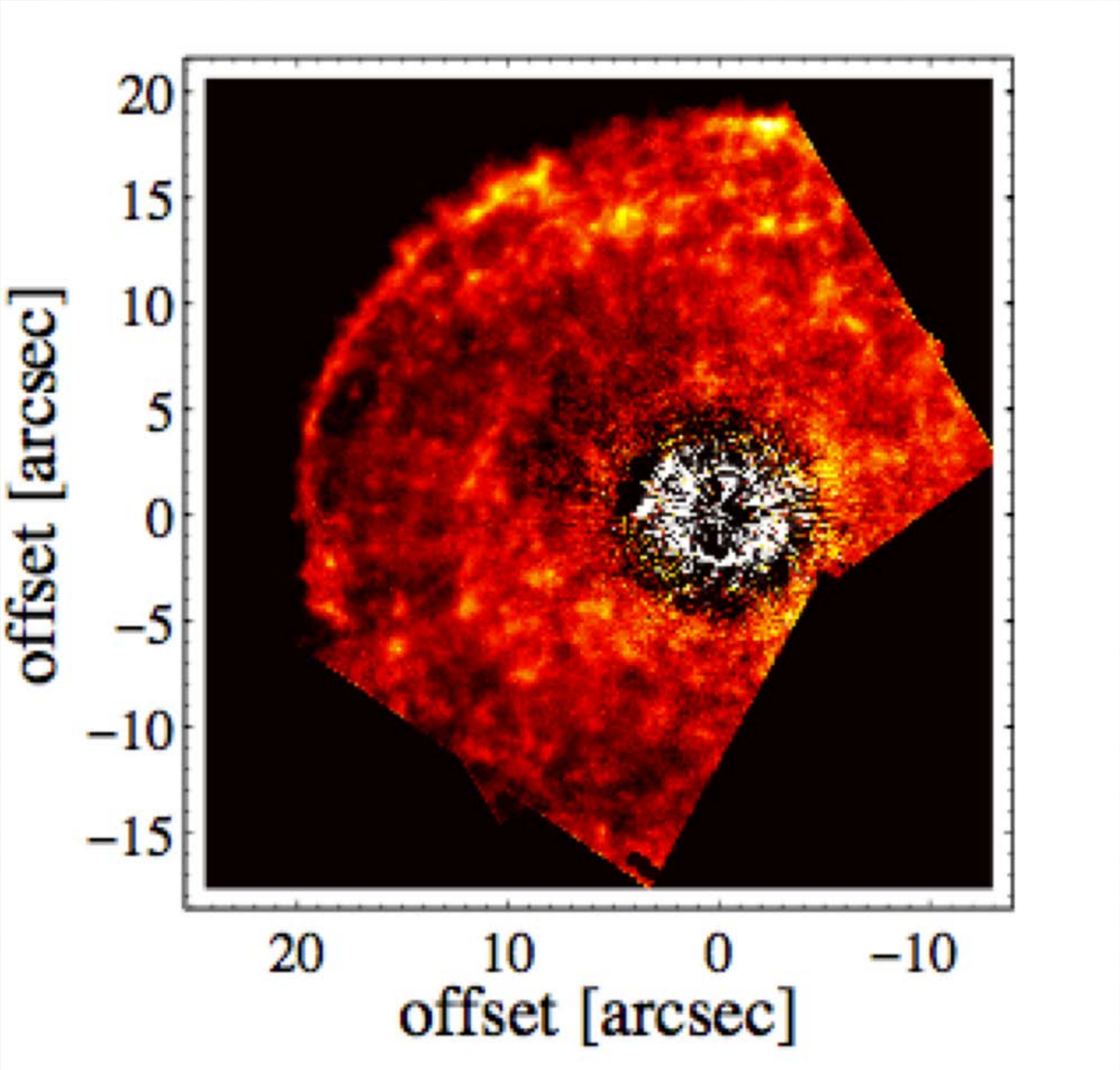
physical properties of subsequent pulses:

- ✓ pulse duration
- ✓ luminosity variation (energy output)
- ✓ increase in mass-loss rate
- ✓ increase in expansion velocity

chemical evolution of stars, the ISM, and galaxies

Detached shells around carbon AGB-stars

increase in mass-loss rate and expansion velocity forms detached shells



R Scl, Hubble Space Telescope
Olofsson et al. 2010

likely connected to thermal pulses

previous observations

basic physical properties of the shells

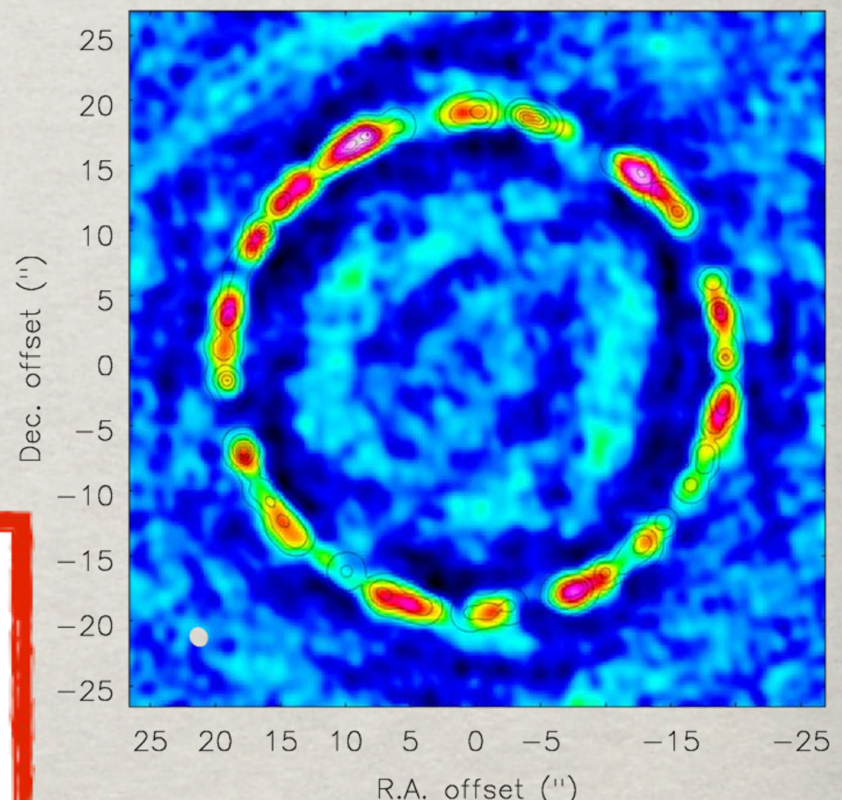
no direct information on thermal pulse properties

theoretical models of pulses largely without observational constraints

R Sculptoris with ALMA Cycle 0

Observe the detached shell using the compact configuration of Cycle 0

- bands 3, 6, and 7, mainly target CO(1-0), CO(2-1), and CO(3-2)
- 7, 23, and 45 pointed mosaics, 50”x50” fields
- spatial resolution of 4.3” to 1.4”



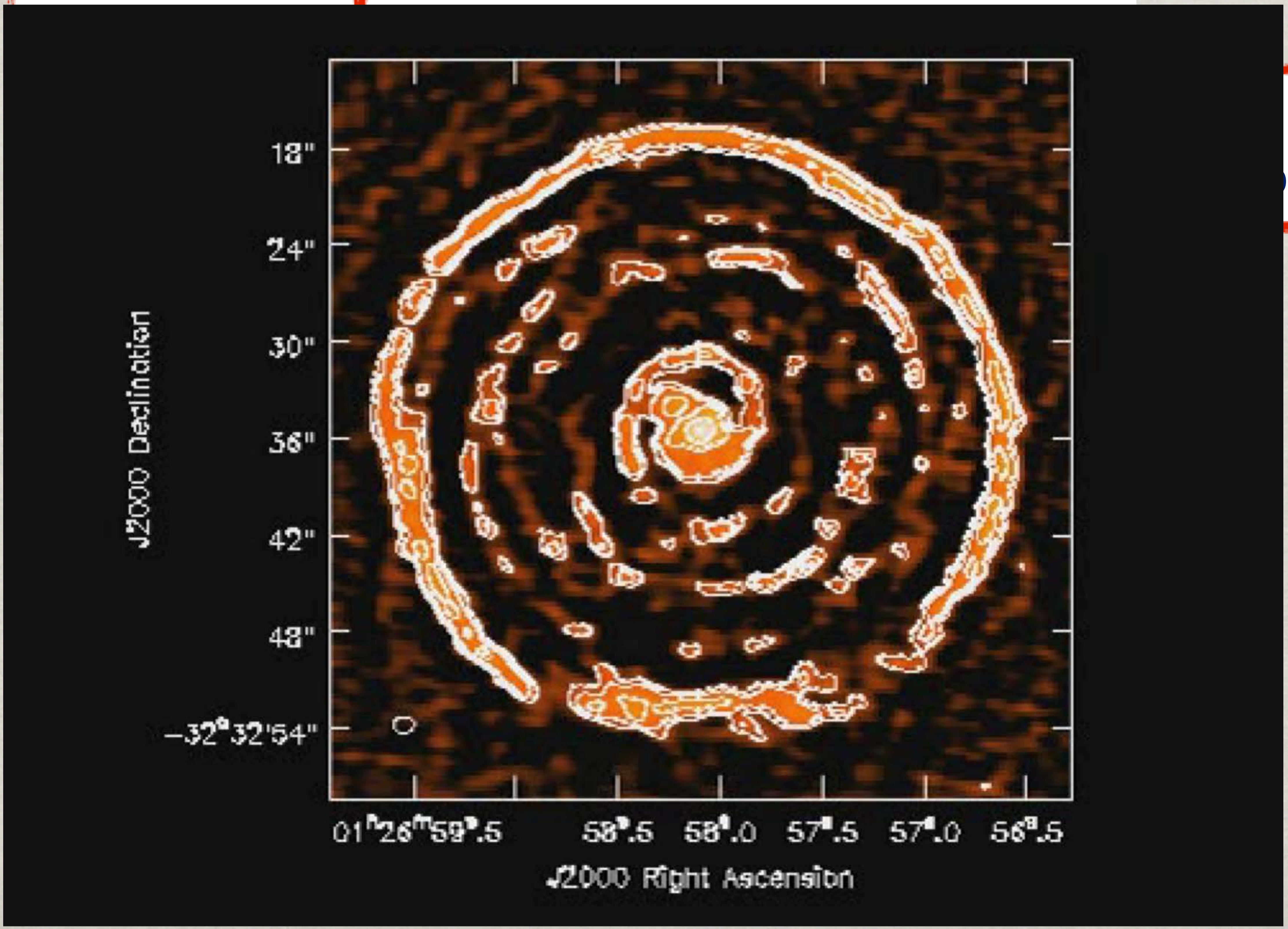
CO(3-2) with simdata

Observe the detached shell of gas in unprecedented detail

- gas mass, and temperature structure
- gas distribution and clumpiness (angular resolution)
- velocity structure (spectral resolution)
- information on scales comparable to dust observations

ALMA Cycle 0 band 7 CO(3-2) data

detached shell



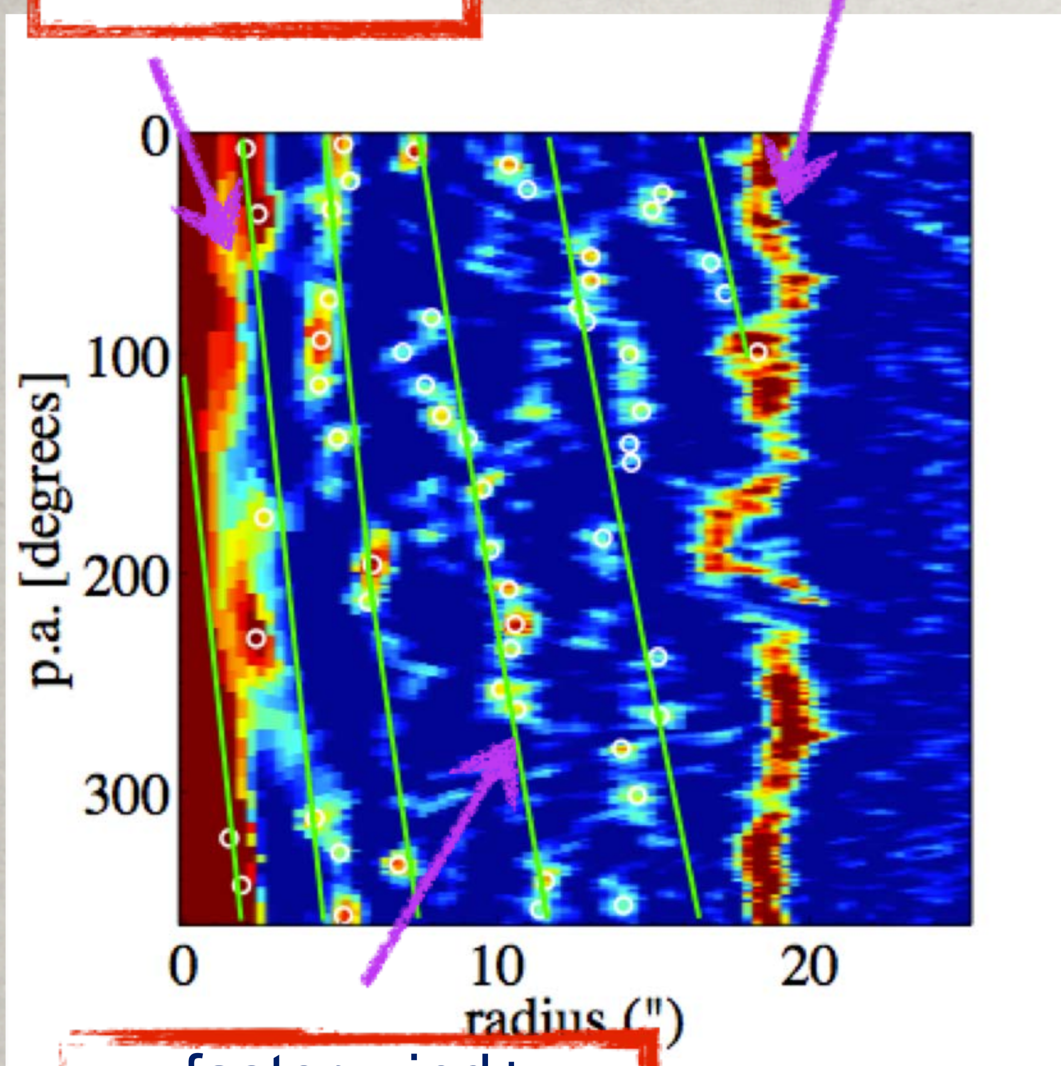
What do we believe has happened?

1) Detached shell due to thermal pulse

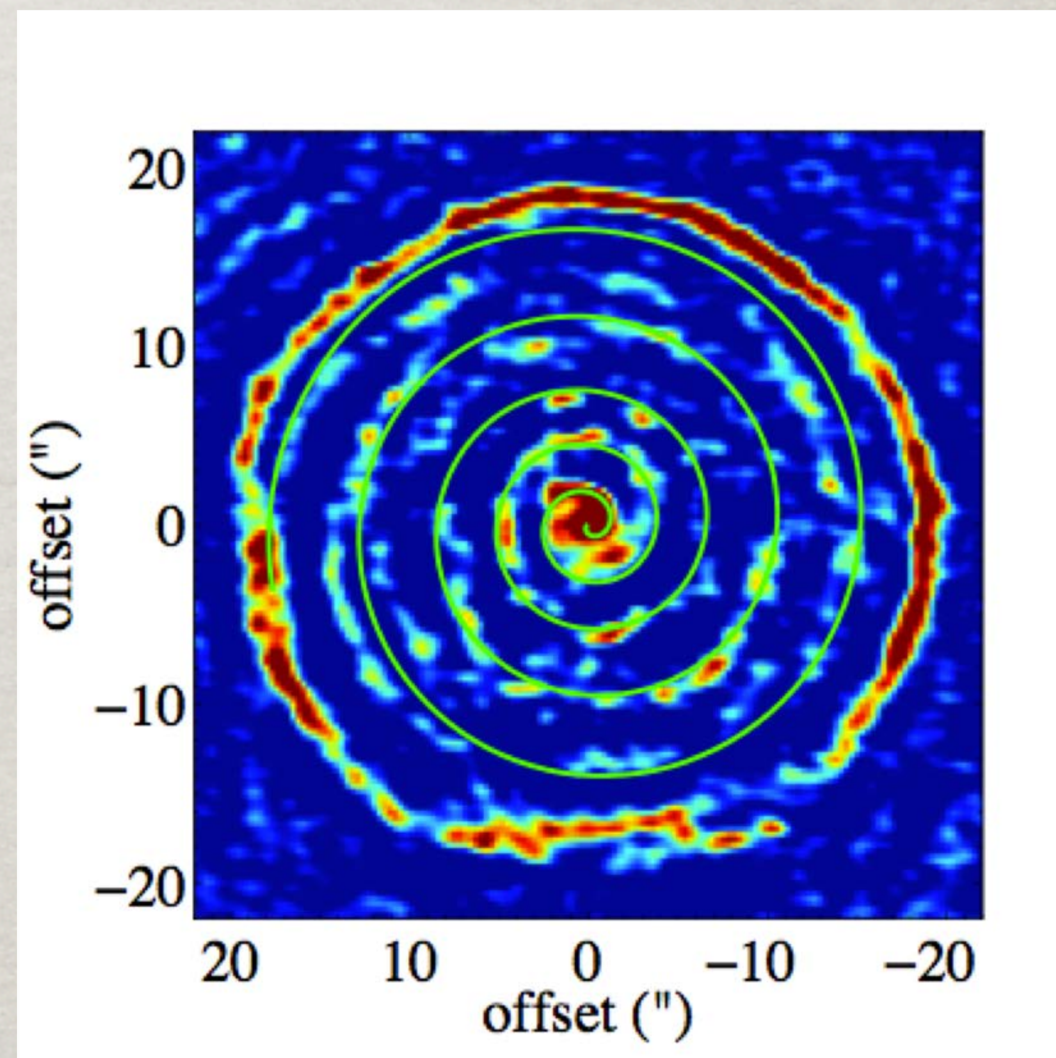
2) Spiral structure due to binary interaction

constant v_{exp}
orbital period

detached shell



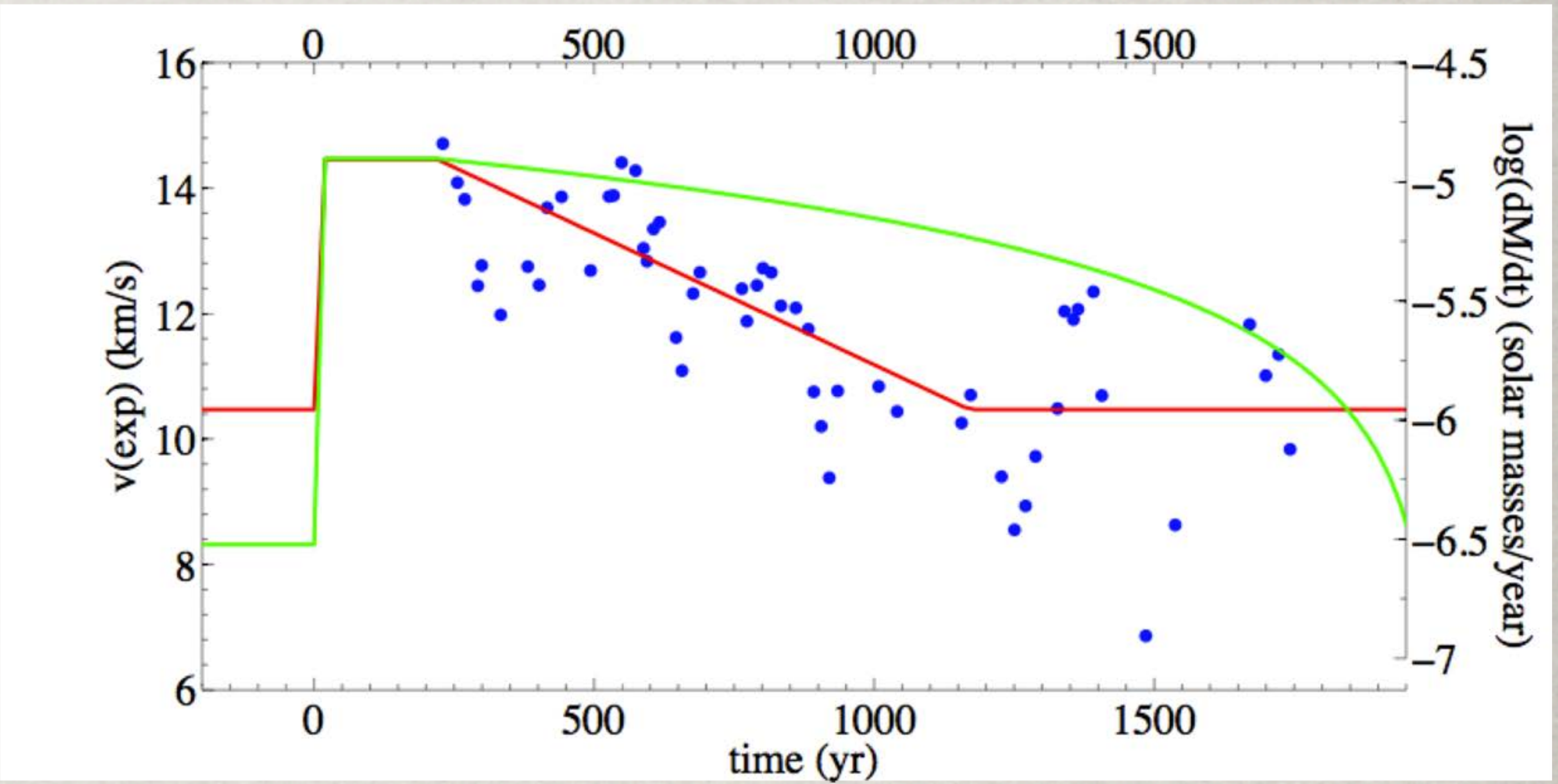
faster wind+
velocity variations



What do the observations tell us directly?

inner 2.5 windings and present-day v_{exp} = 10.5 km/s (from HCN modelling)

Schöier et al. 2005



orbital period = 345 years

spherical expanding shell

R_{sh} = 18.5” and v_{sh} = 14.5 km/s

shell age t_{age}<1800 years

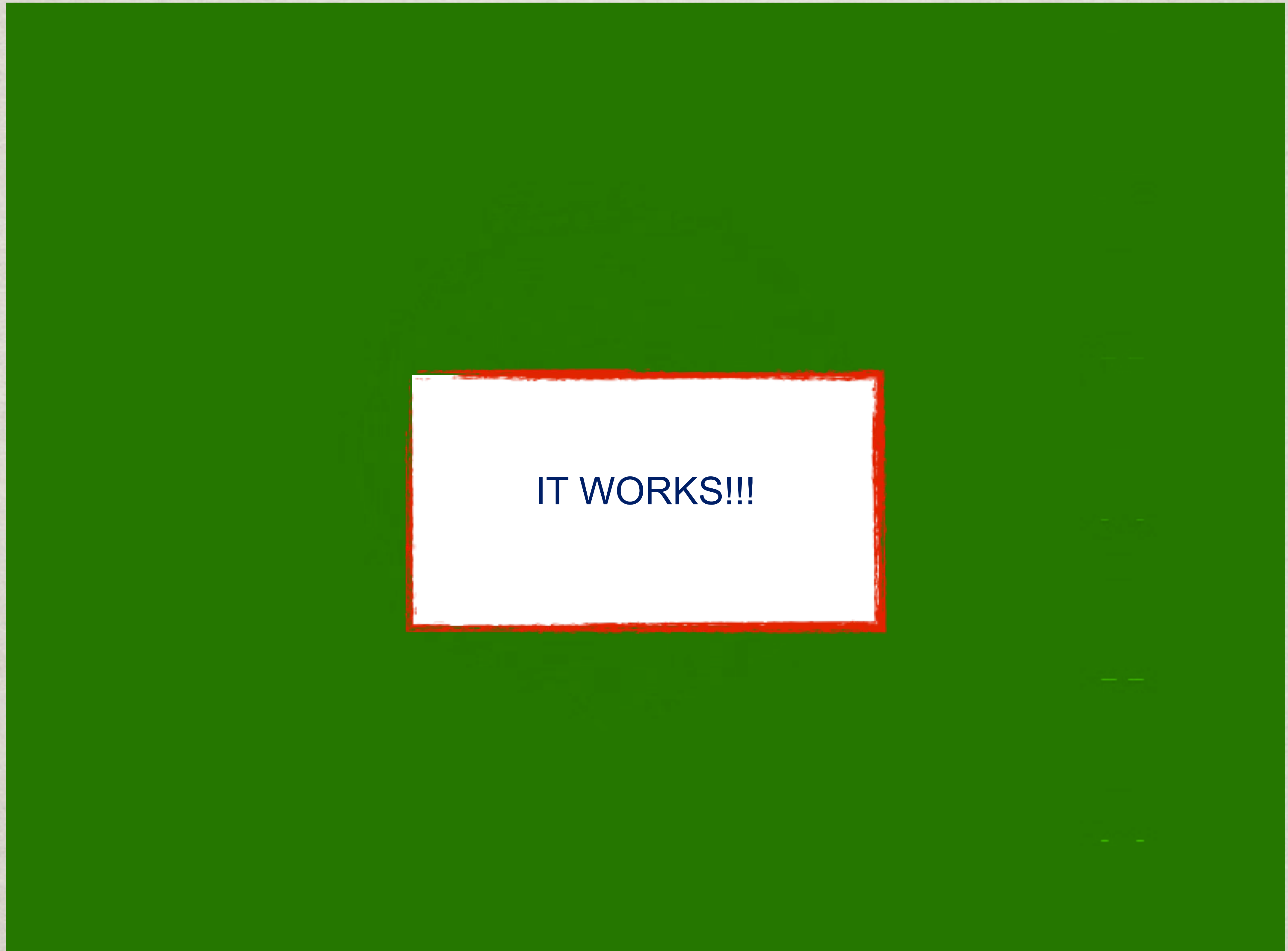
no deceleration of shell

pulse duration t_{pulse} = 345 years

pulse expansion velocity v_{pulse} = 14.5 km/s

pulse mass-loss rate = $7\times10^{-6}\ M_\odot yr^{-1}$, $3\times10^{-7}\ M_\odot yr^{-1}$ (present-day)

Testing the pulse + binary theory



What do the observations tell us directly?

theoretical models of thermal pulses in a binary system

- explain detached shell and spiral

However

- more complicated behaviour of expansion velocity and mass-loss rate
- no deceleration of detached shell

ALMA observations of R Sculptoris

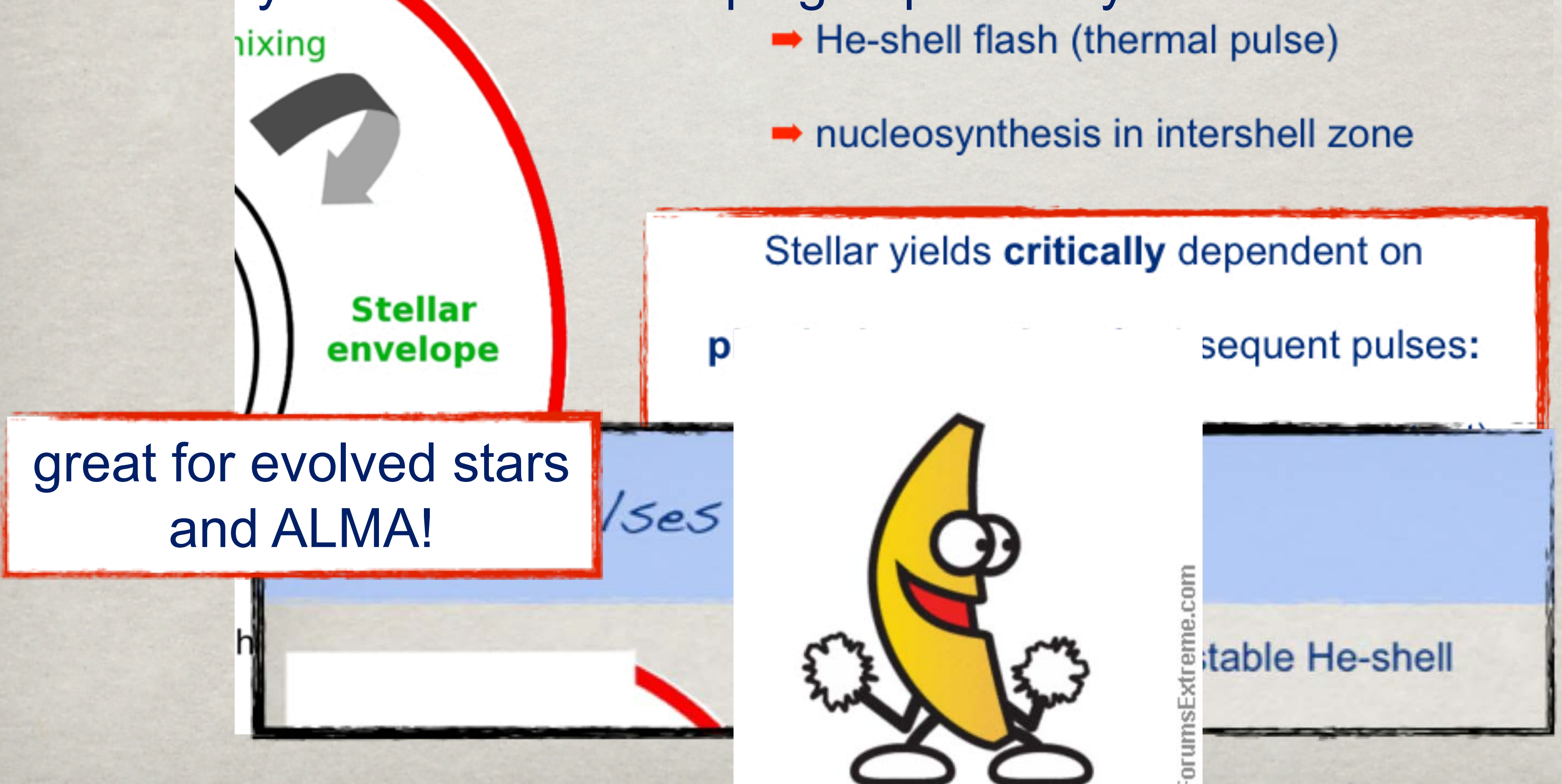
likely discovery of a previously unknown binary companion

the observed spiral allows to verify model results observationally for the first time!

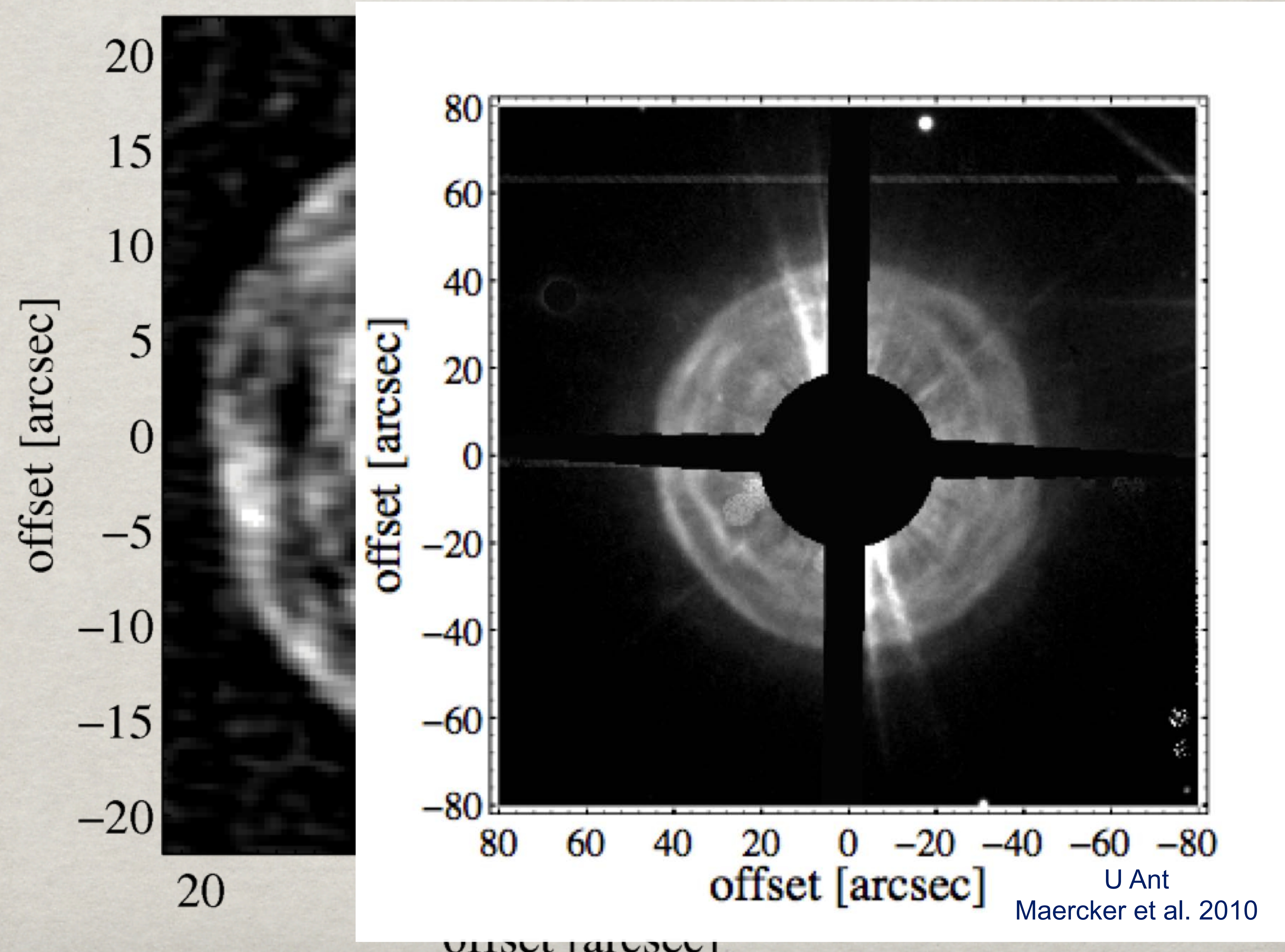
observational constraints on pre-pulse, thermal pulse, and post-thermal pulse evolution

refined models of thermal-pulses and nucleosynthesis

binary evolution and shaping of planetary nebulae



Why didn't we know about this before?



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Maercker et al. 2010