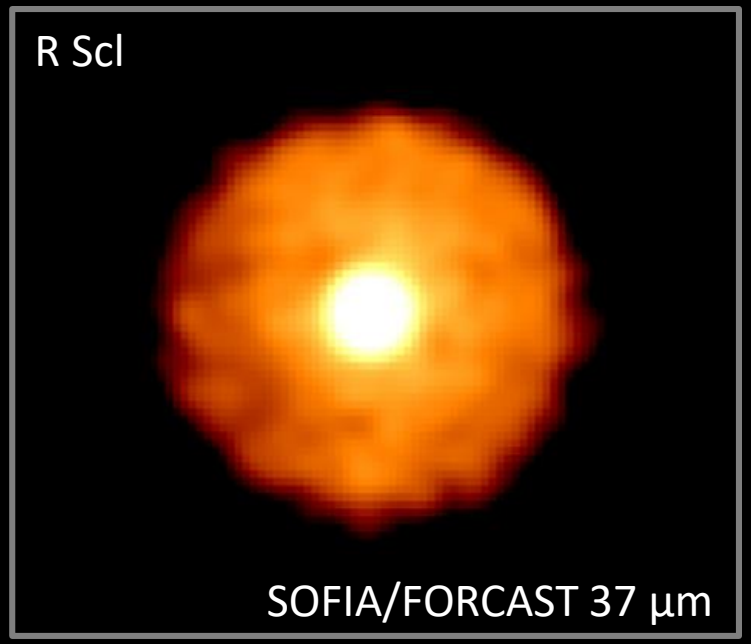


Constraining the Post-Thermal Pulse Mass-Loss History of R Scl with SOFIA/FORCAST

Matt Hankins

3/7/18

SOFIA Teletalk

Overview

- A short background on AGB stars, Thermal Pulses (TP), and circumstellar shells

- Observations of R Scl
  - Examining the multiwavelength morphology
  - Color-Temperature maps of dust emission

- Modeling the thermal dust emission
  - Examining the chemistry of R Scl
  - Constraining the mass loss history

- What about other post-TP AGB stars?
  - Future prospects

AGB Stars: A Few Simple Schematics

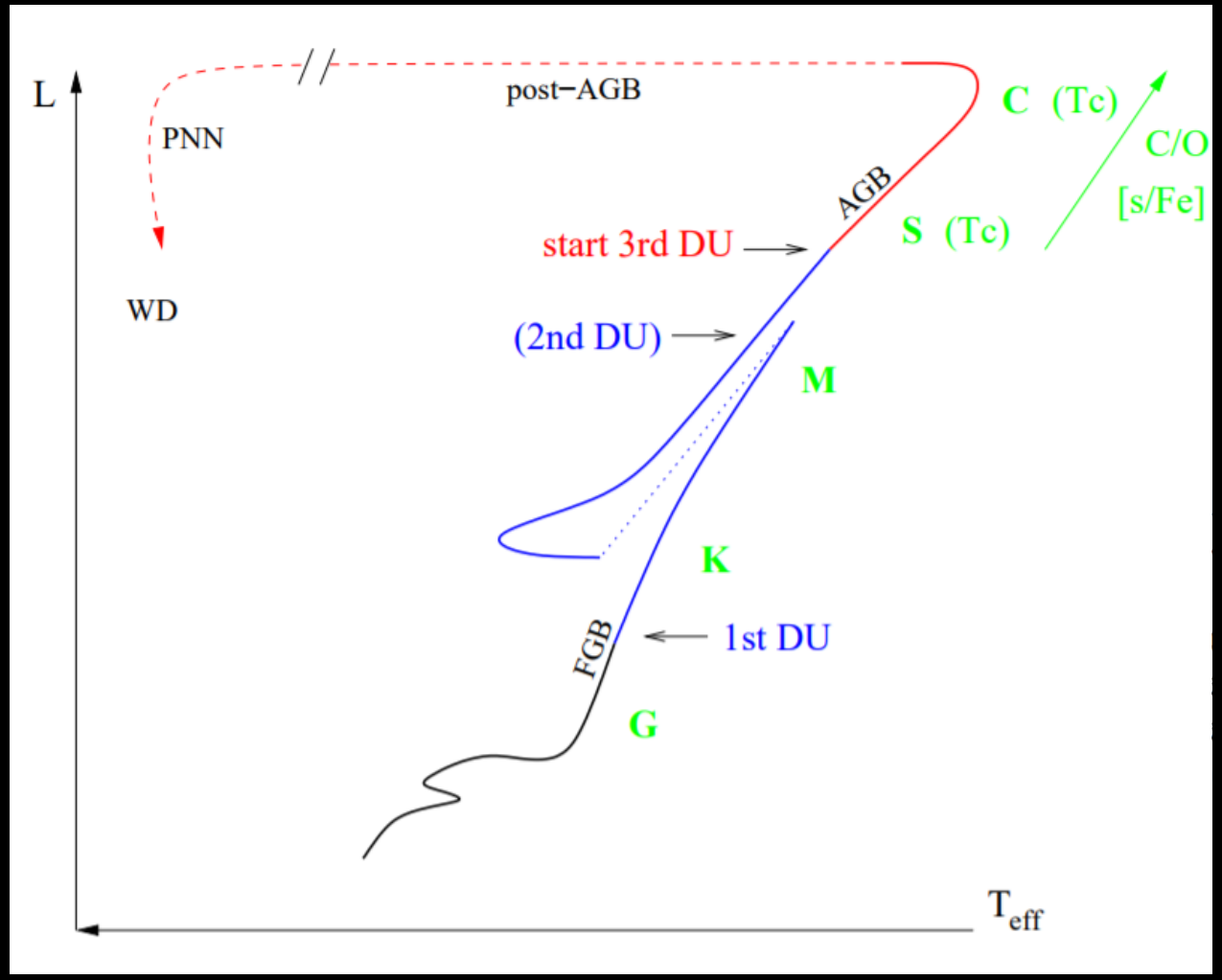


Image Credit: N. Langer

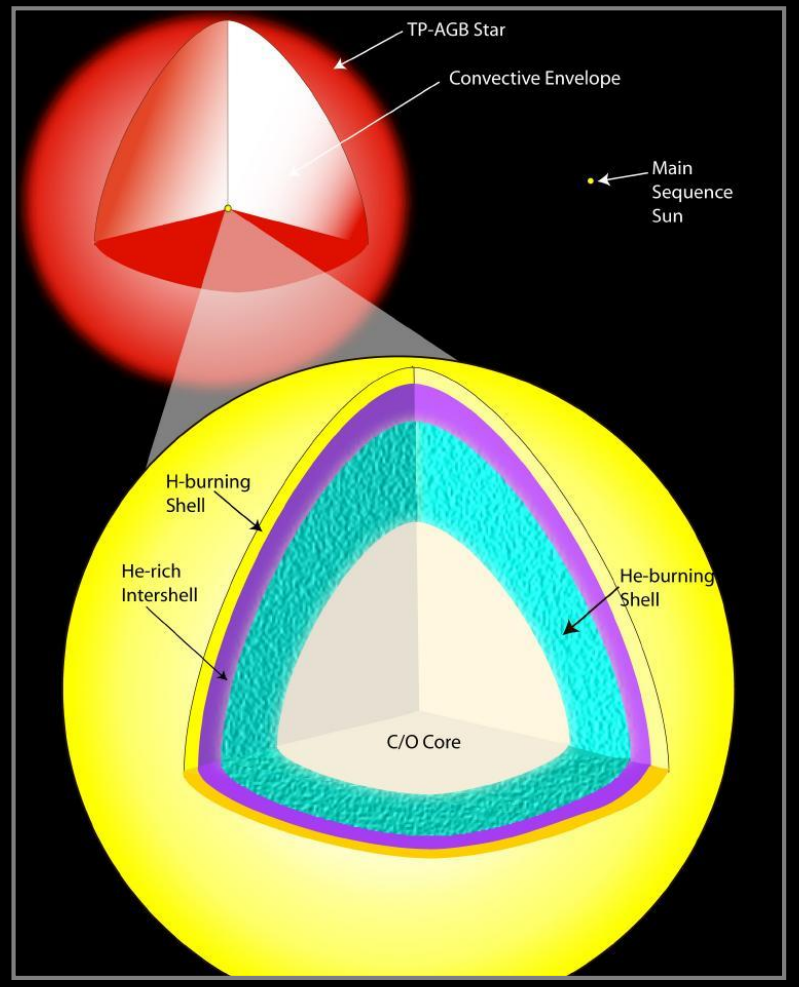


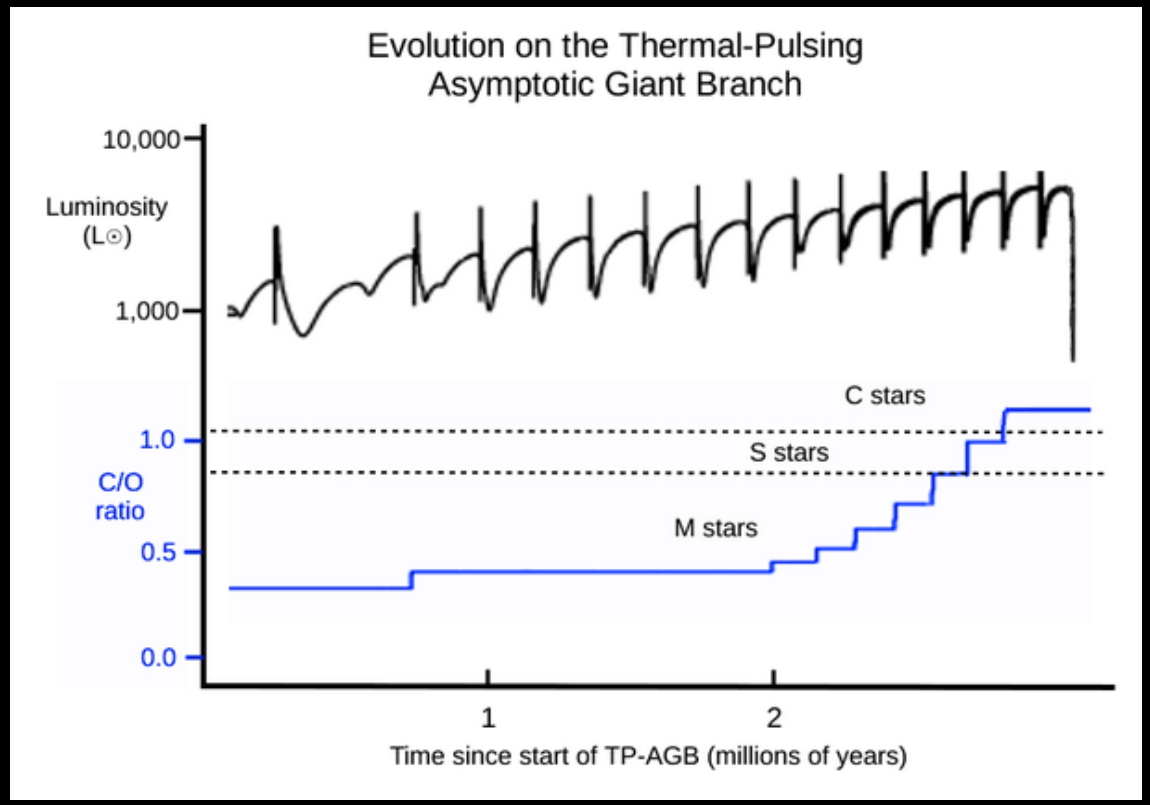
Image Credit: A. Karakas

AGB Stars: Thermal Pulse Behavior

- Events powered by He-shell burning in in Asymptotic Giant Branch stars (TP-AGBs)
  - He shell burning is very brief (years), but very powerful (~10^5-10^6 times the H-shell burning luminosity)

- Changes Caused by TPs:
  - Dredge-up and mixing of materials – production of carbon stars
  - Thought to increase mass-loss from the star- formation of circumstellar shells

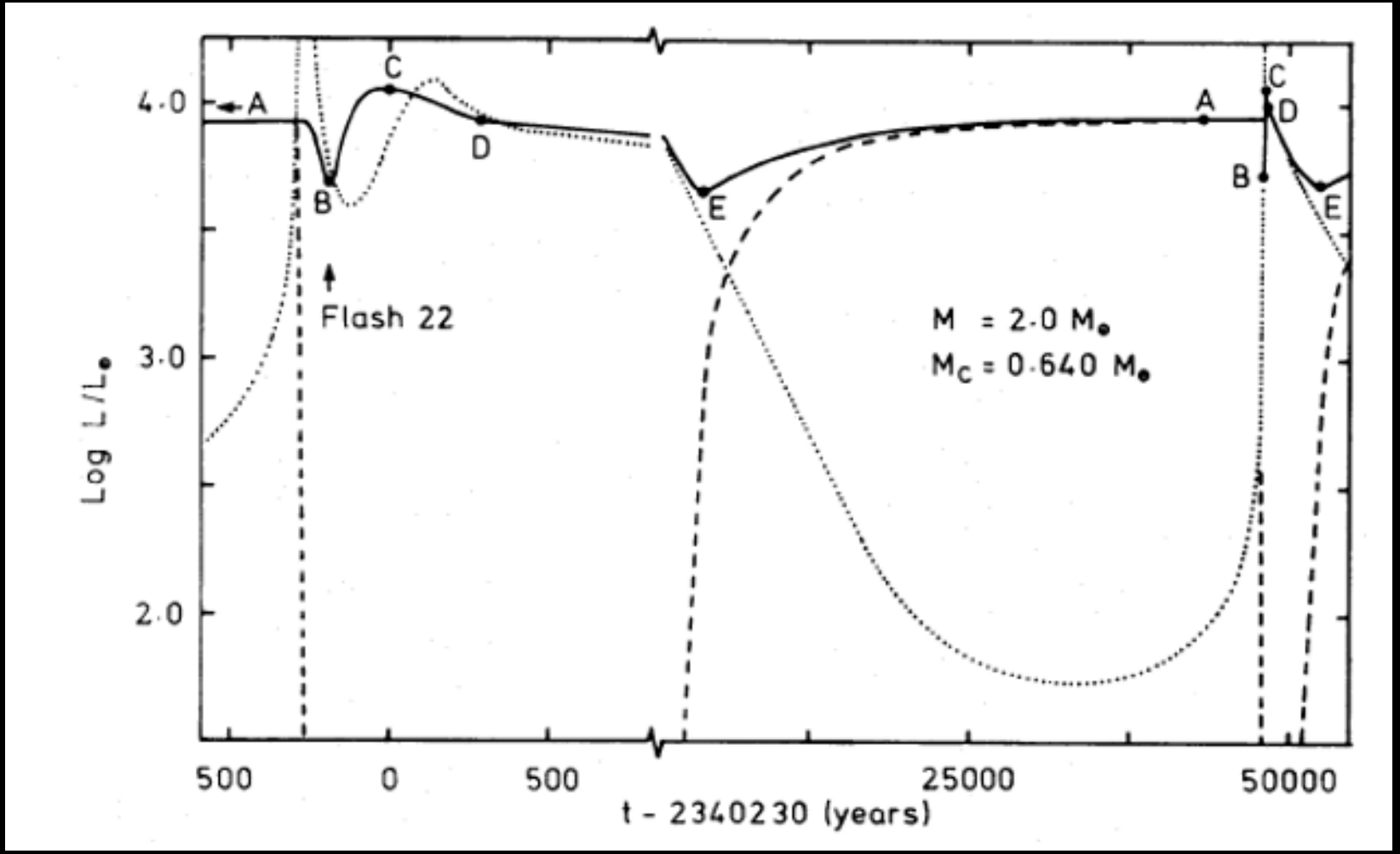
TP-AGB Stars: Thermal Pulse Behavior



Interpulse Period: ~10^4-10^5 yr

> Timescale depends on mass (lower mass -> longer timescale)

TP-AGB Stars: Variability



Solid – Surface luminosity

Dashed – H burning luminosity

Dotted – He burning luminosity

Wood & Zarro 1981

TP-AGB Stars & Circumstellar Shells

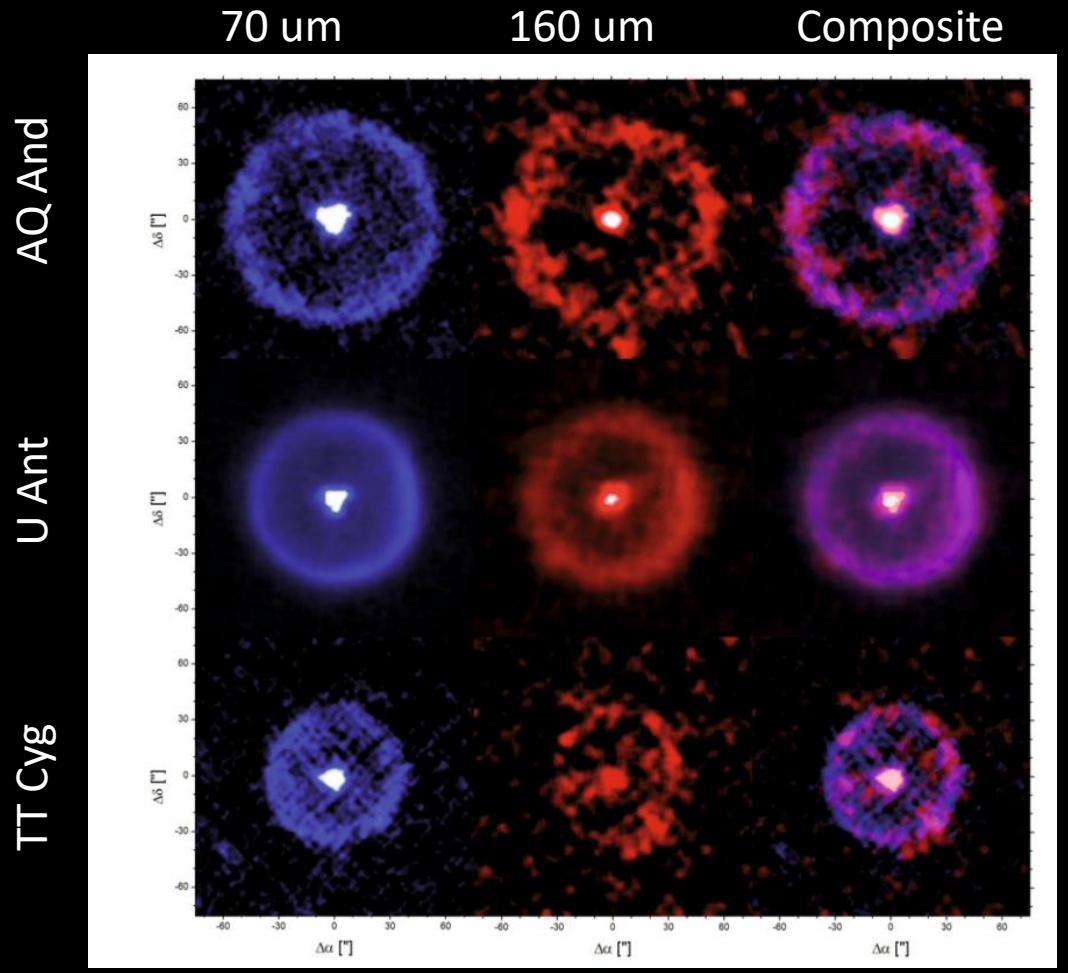
- Circumstellar shells thought to be produced as a byproduct of the thermal pulse
  - Two-wind interaction model (Schoier+2005)

- Only a handful of known objects: S Sct, U Ant, TT Cyg, R Scl, V644 Sco, U Cam, DR Ser

- Circumstellar shells known to be associated with C-type AGB stars

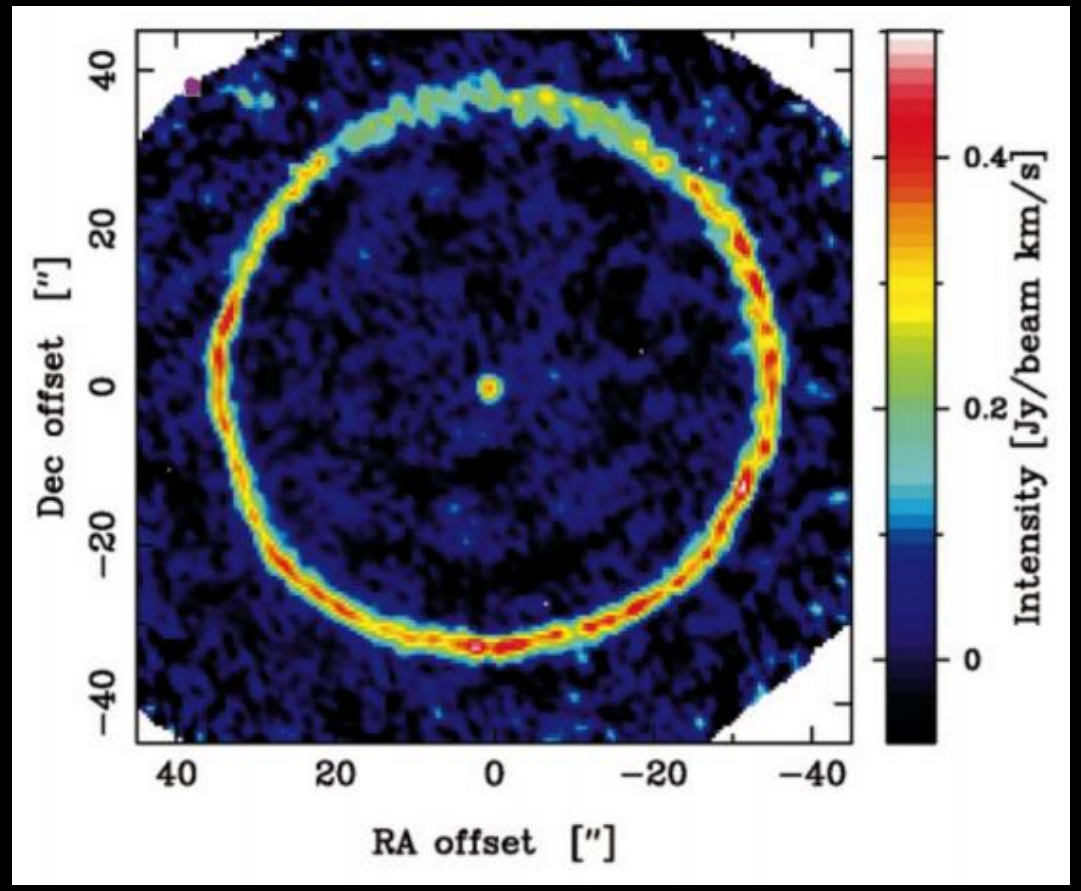
- Shells are geometrically thin (ΔR/R) with large radii (~10,000 AU)

Circumstellar Shells with TP-AGB Stars



Kerschbaum+ 2010

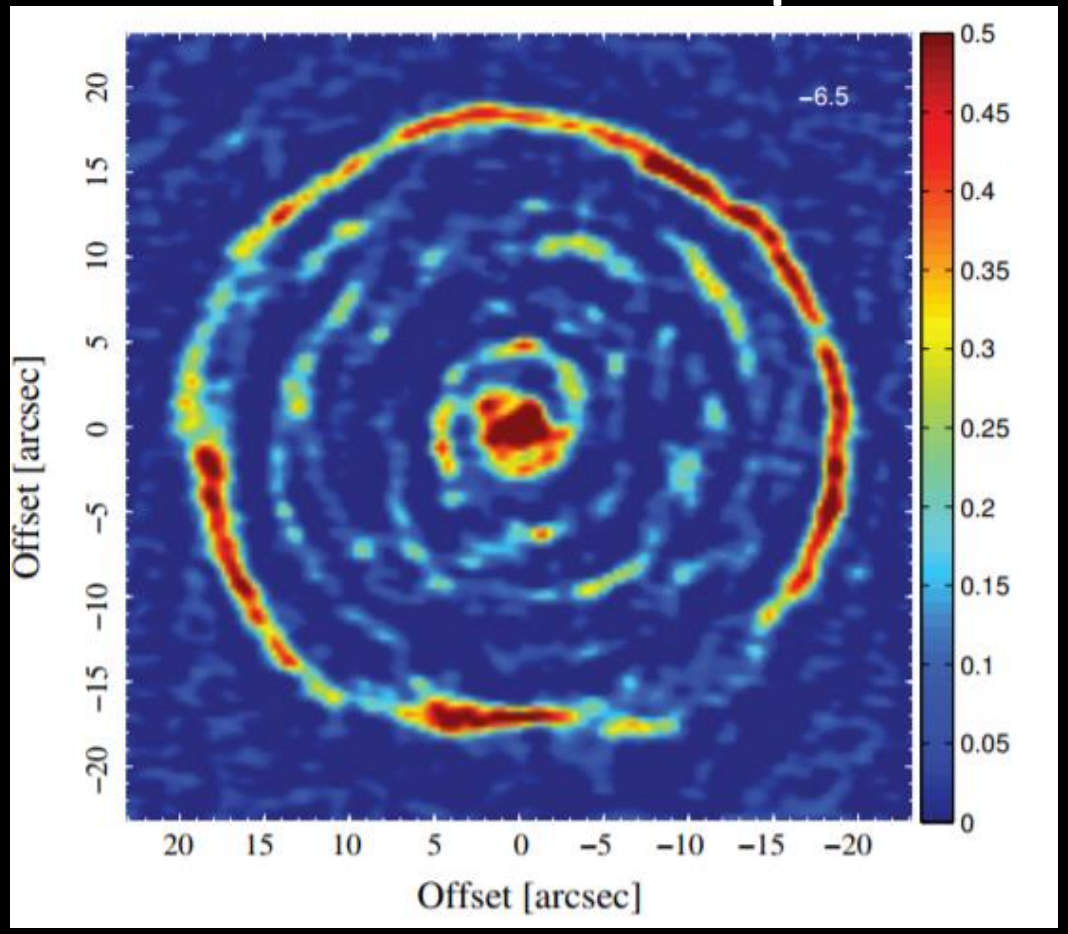
TT Cyg CO 1-0



Olofsson+ 2010

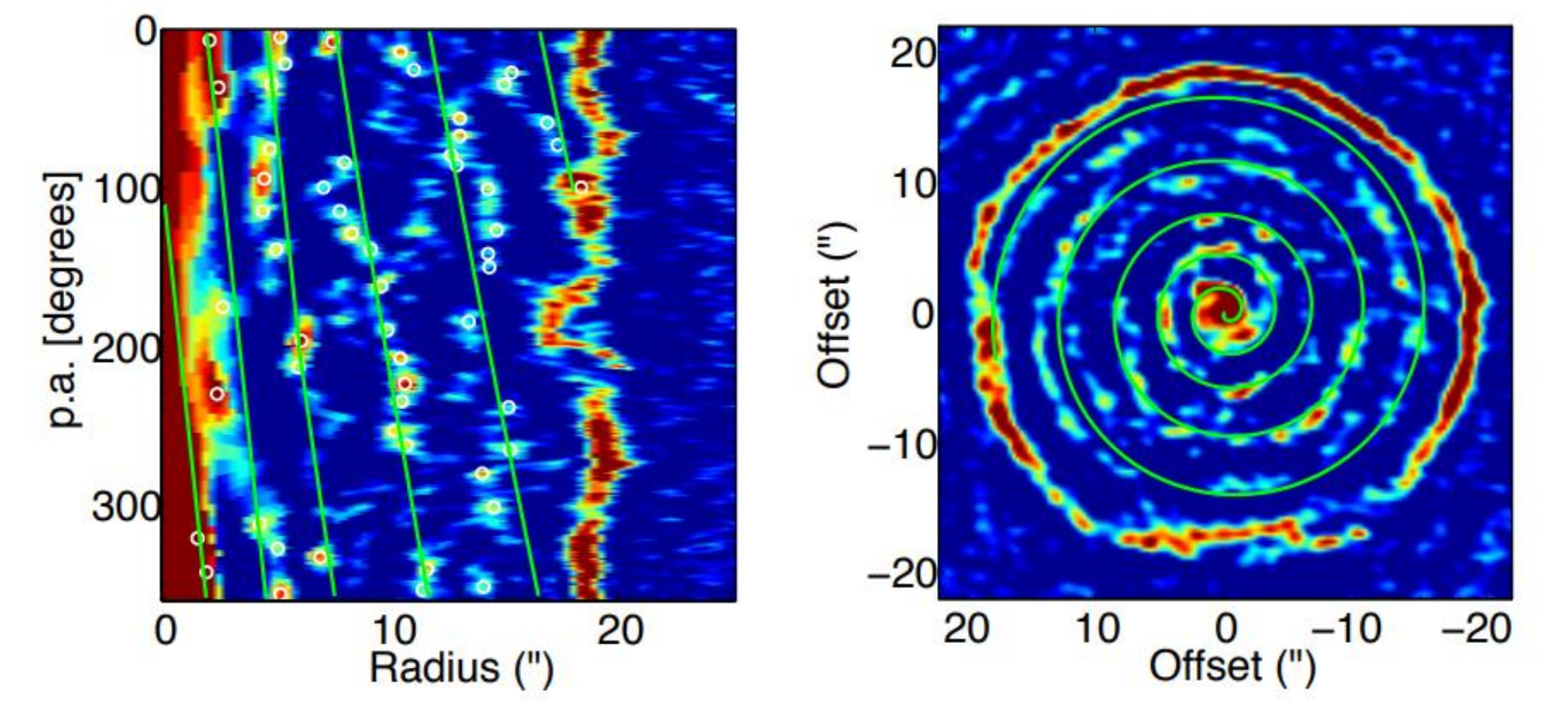
R Scl: A Well-Known Carbon Star with a Circumstellar Shell (and a surprise or two!)

ALMA CO 3-2 Map



Maercker+2012

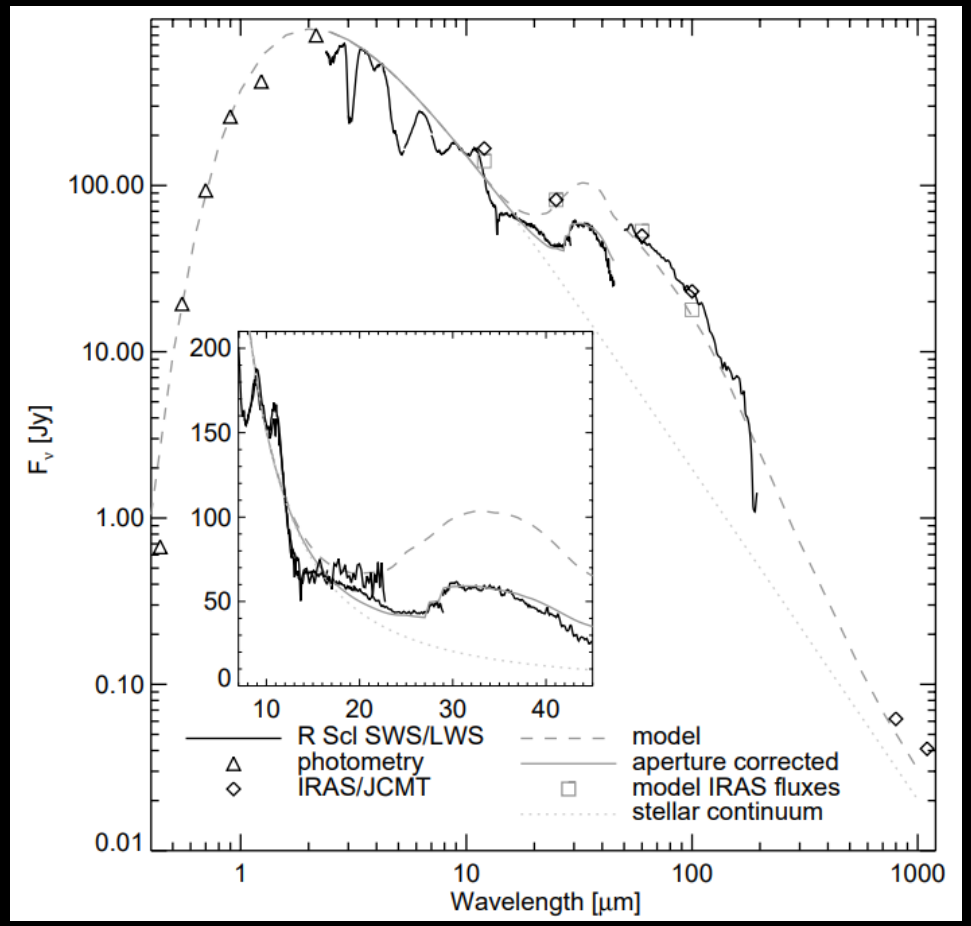
R Scl: The Surprising Spiral



Maercker+2012

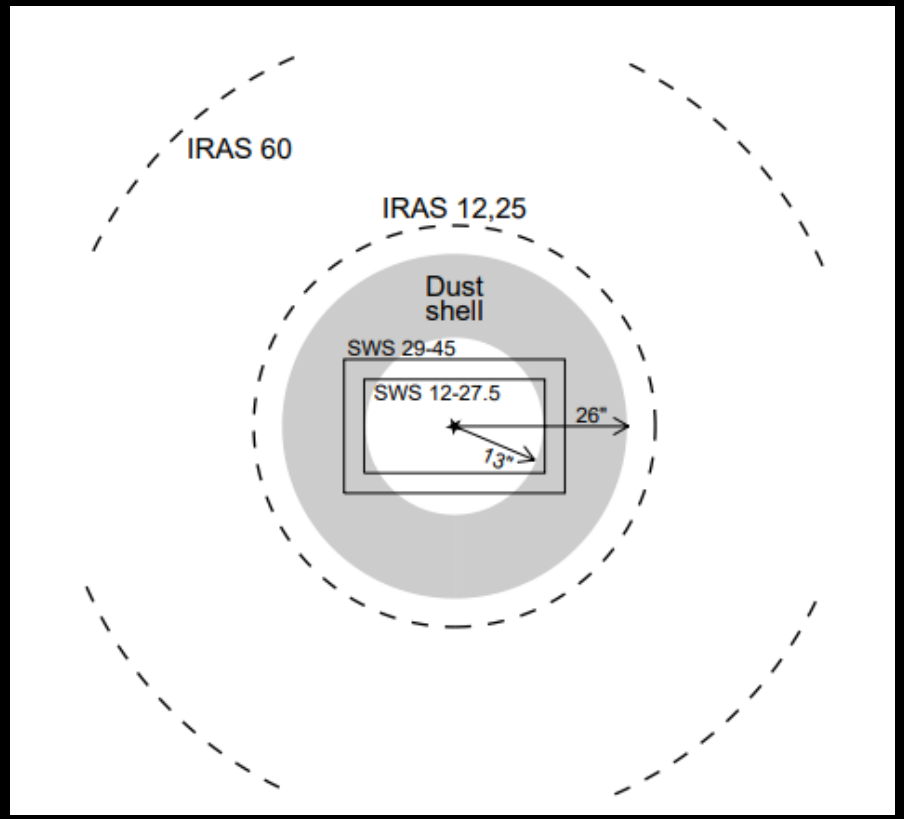
Earlier Works: Modeling the SED of R Scl

R Scl SED



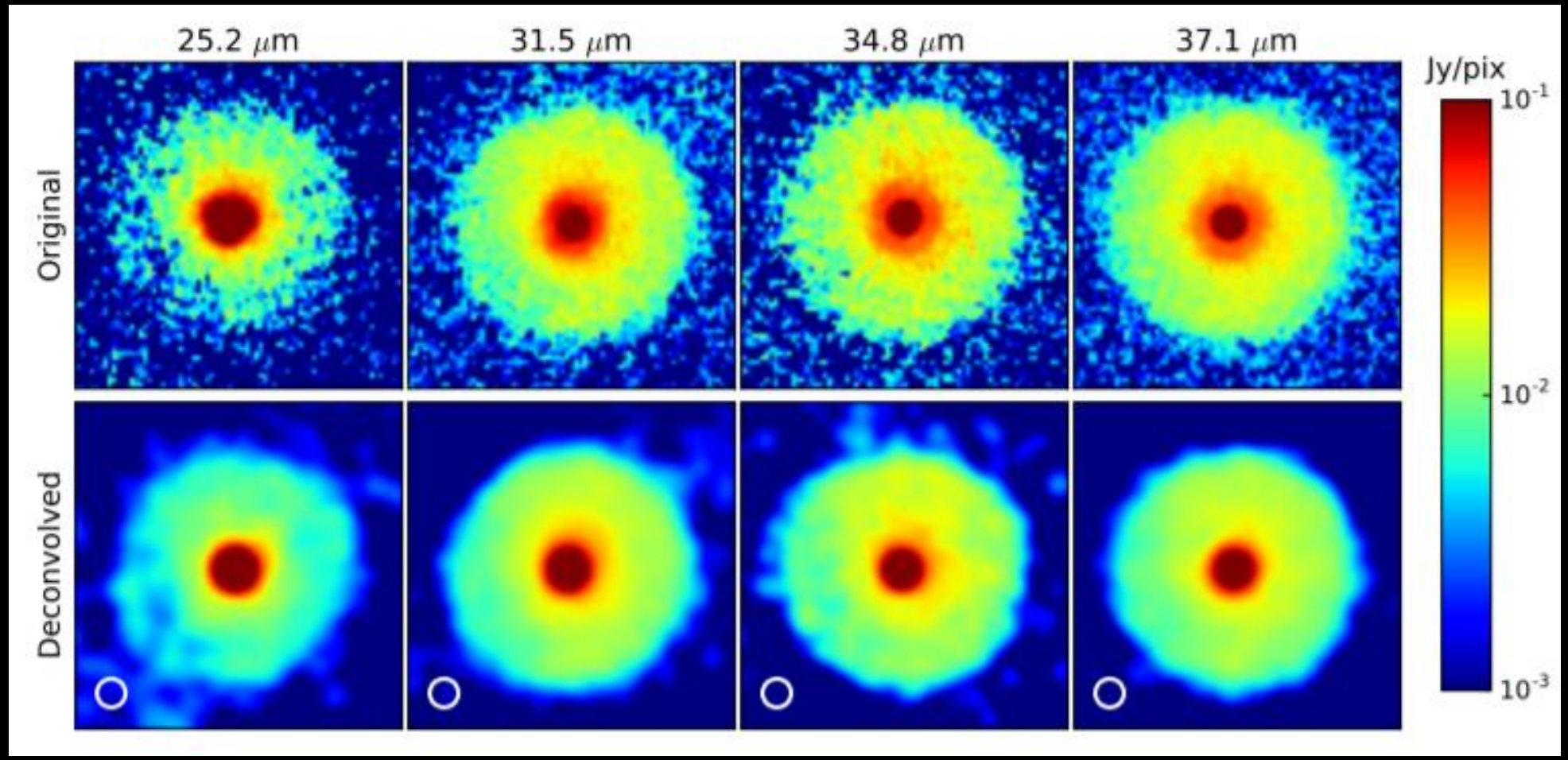
Hony & Bouwman 2004

Issue with the Footprint of the ISO/SWS



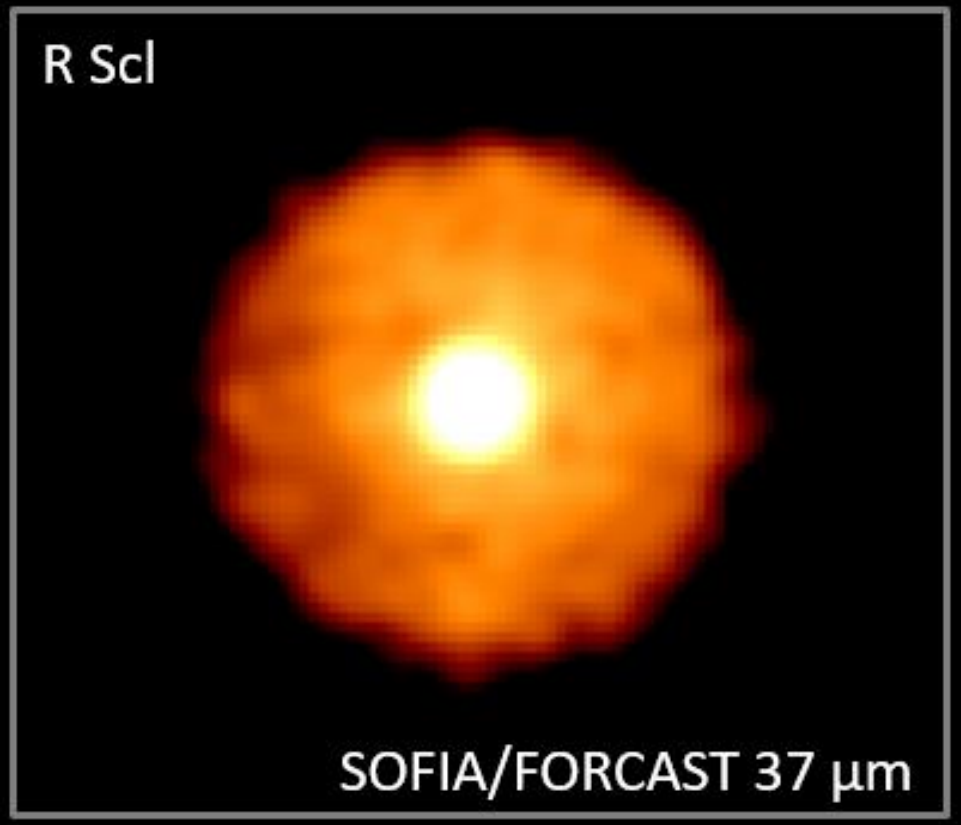
Hony & Bouwman 2004

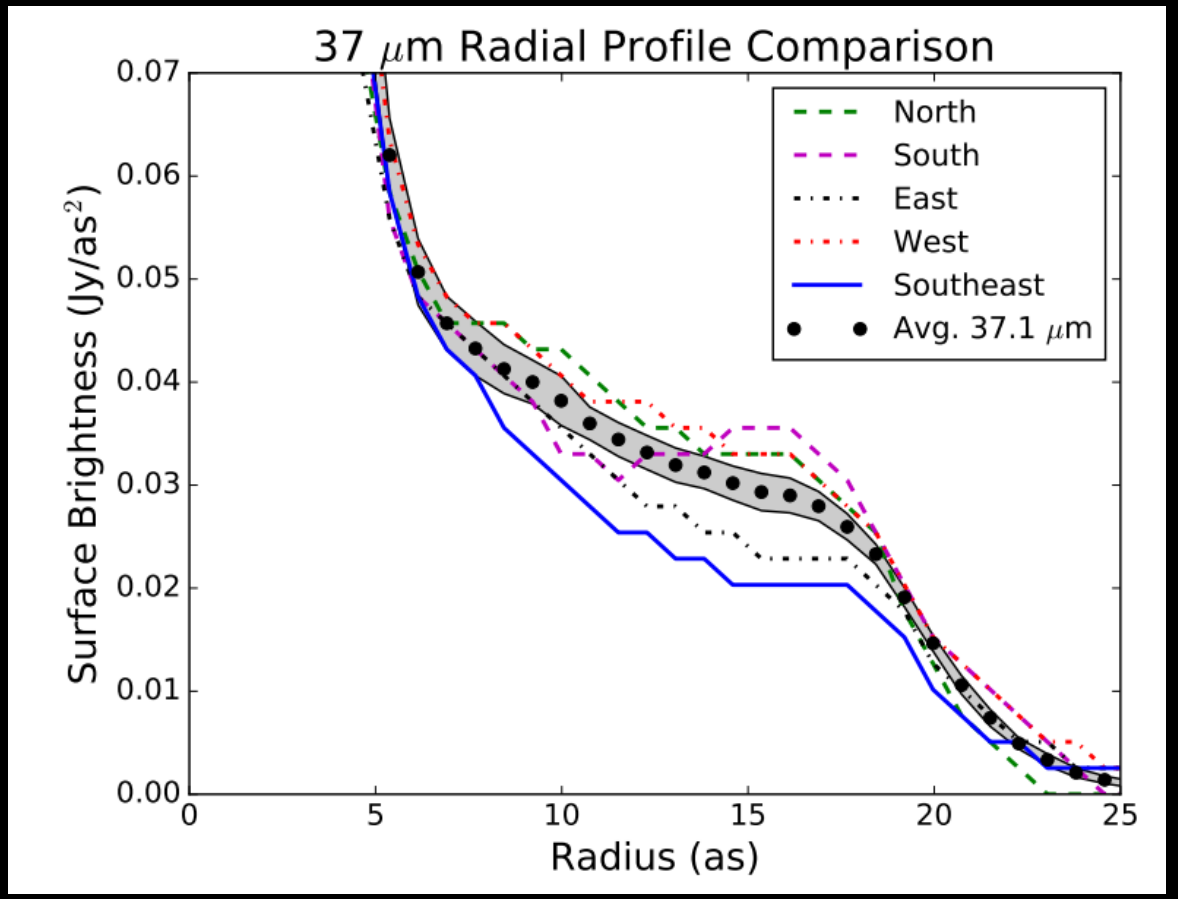
SOFIA/FORCAST Observations of R Scl



Hankins+ 2018

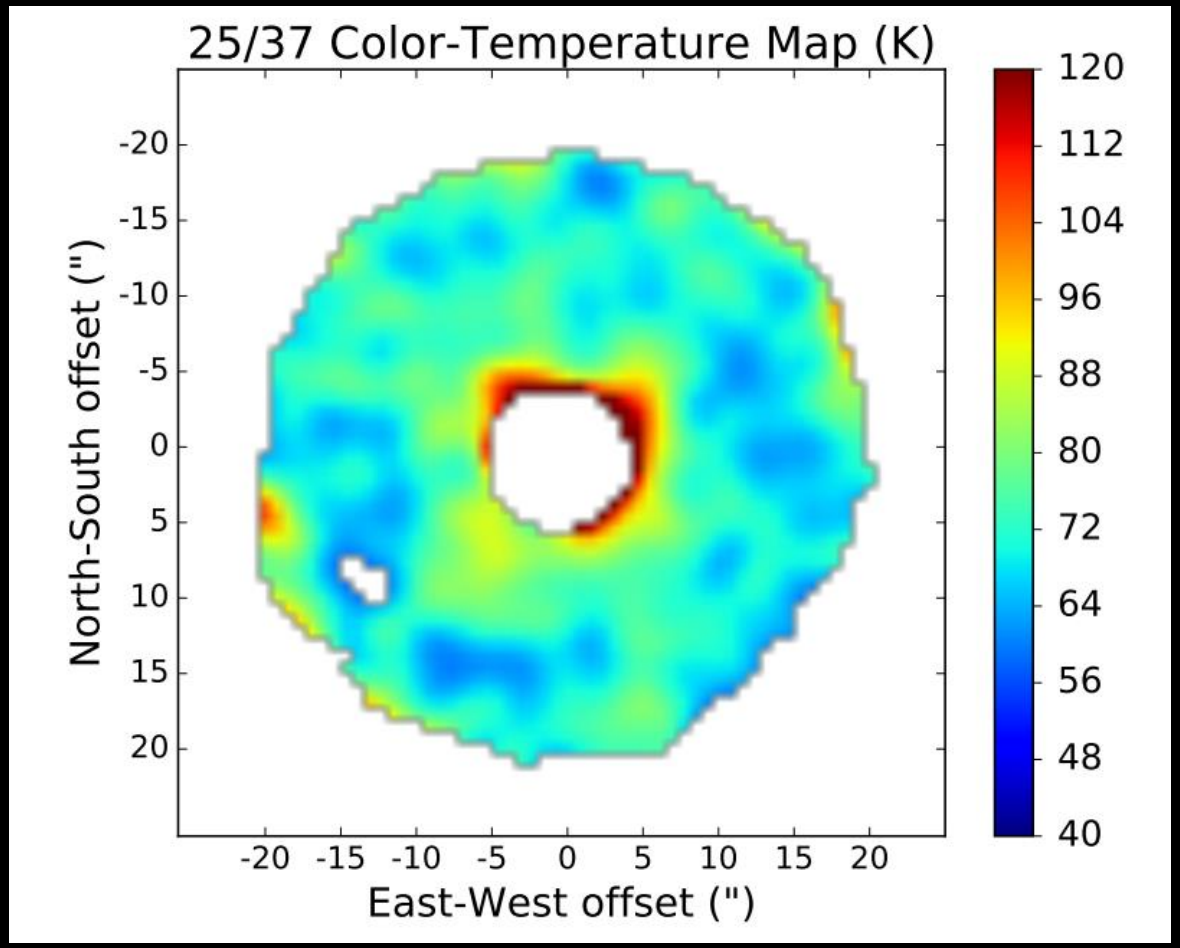
Morphology: An Unusual Dimming in the East





Hankins+ 2018

Color-Temperature Analysis



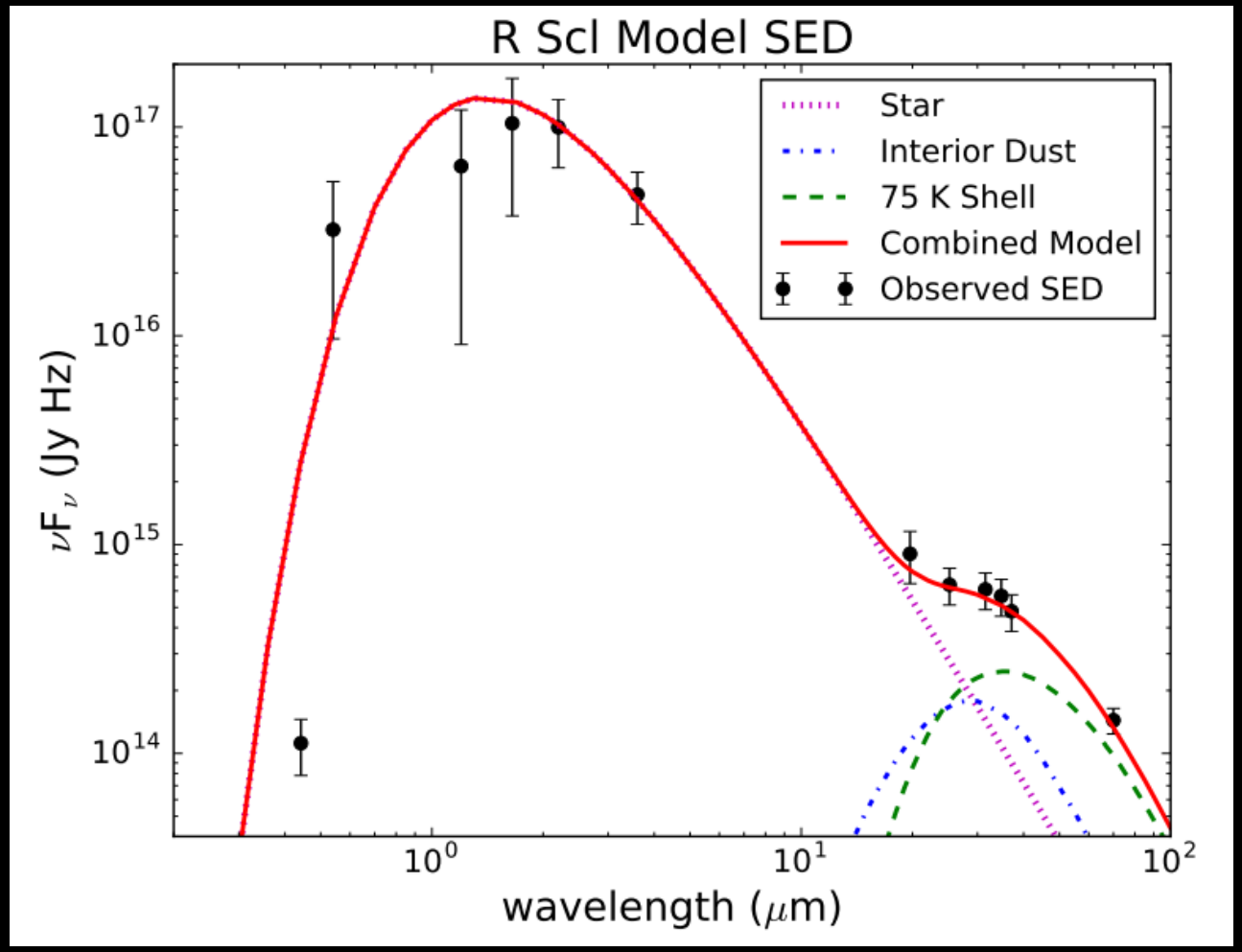
- Temperature is fairly uniform at ~75 K
  - Consistent with SED fit of the dust temperature

Hankins+ 2018

Modeling R Scl's Circumstellar Dust Emission with DUSTY

- Fit the SED
  - Done in previous works
- Fit the radial profile of the extended dust emission
  - This gives our greatest constraints on the models
- Fit the composition of the dust
  - R Scl is a known carrier of the 30 μm MgS feature

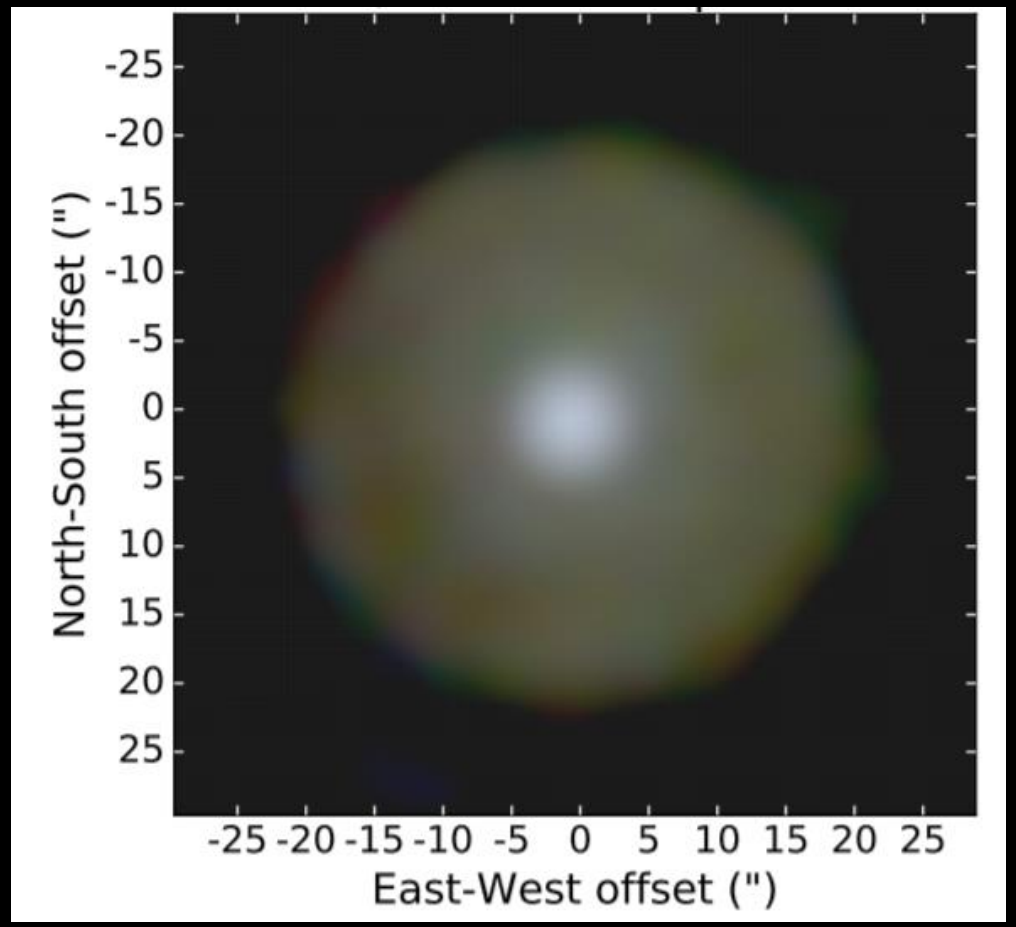
DUSTY SED Model



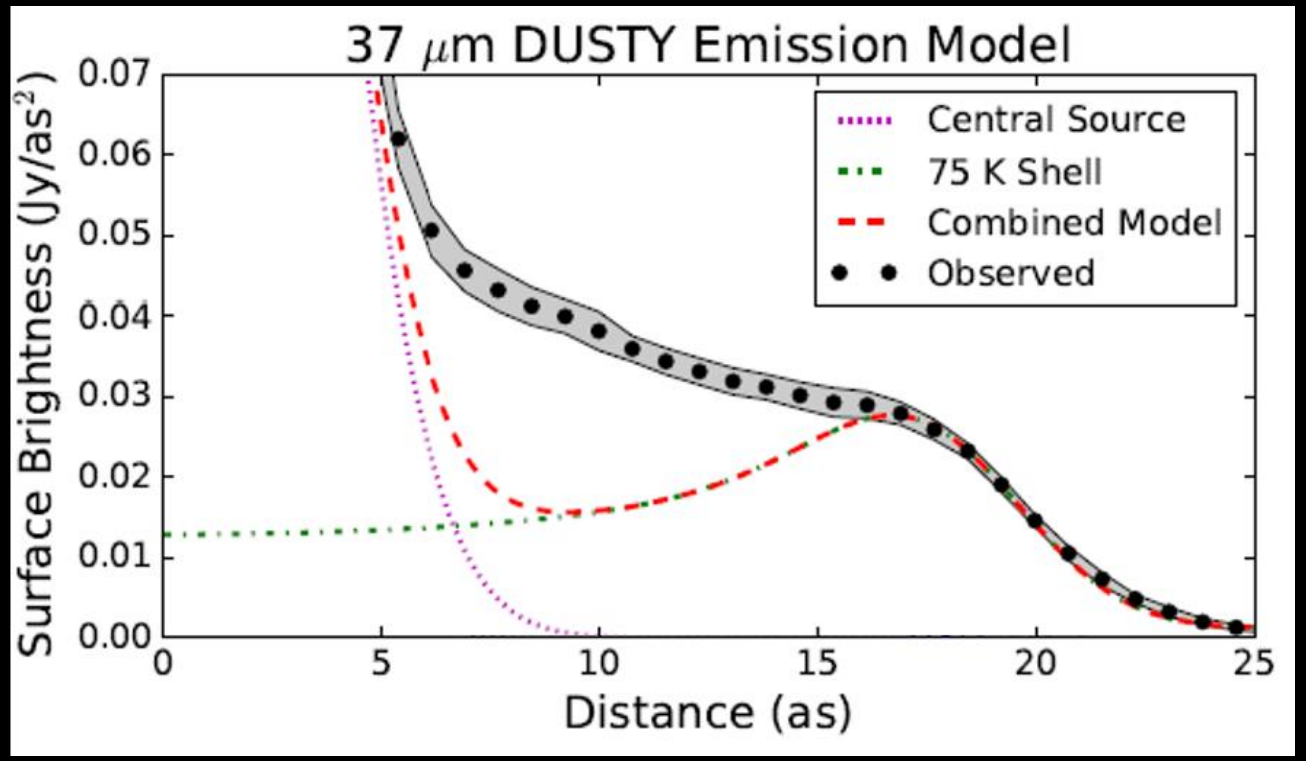
- Started with 2 component model (Star + Shell)
  - Need an additional component to fit the radial profile

Modeling the Extended Dust: Two Components

SOFIA/FORCAST 25, 31, 37 μm



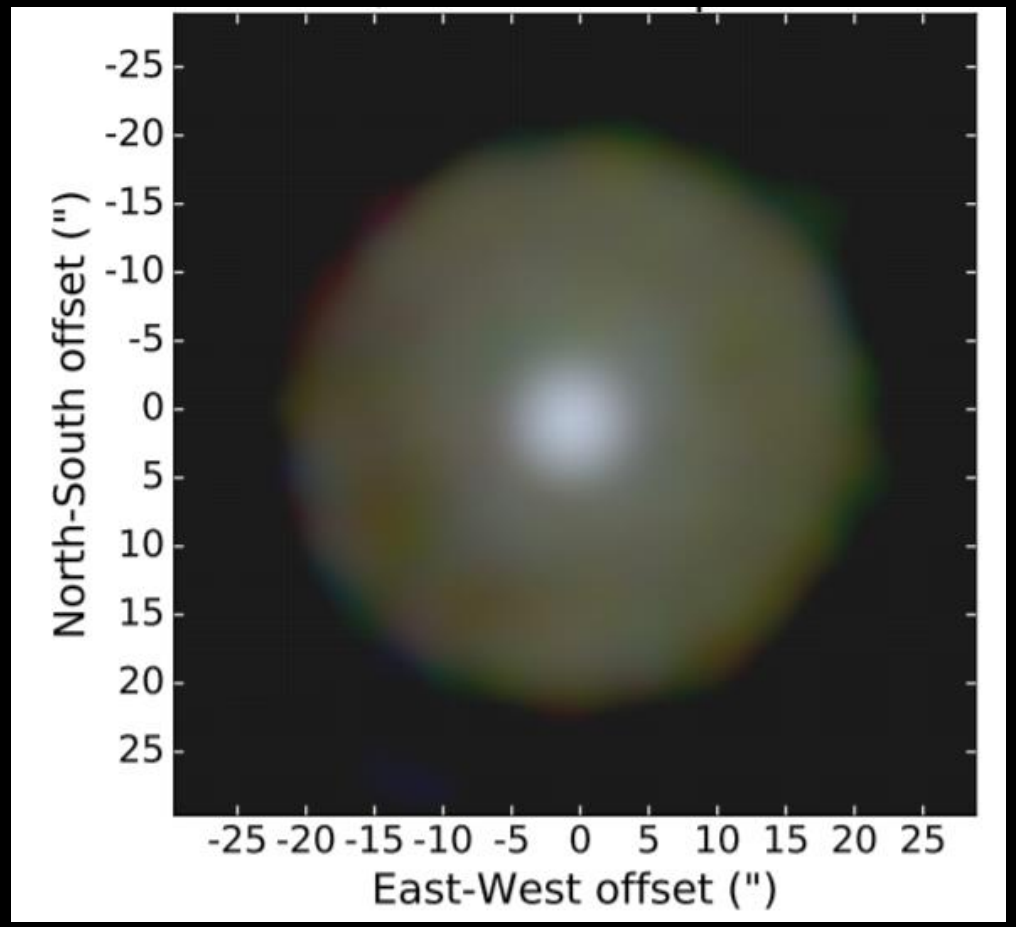
Hankins+ 2018



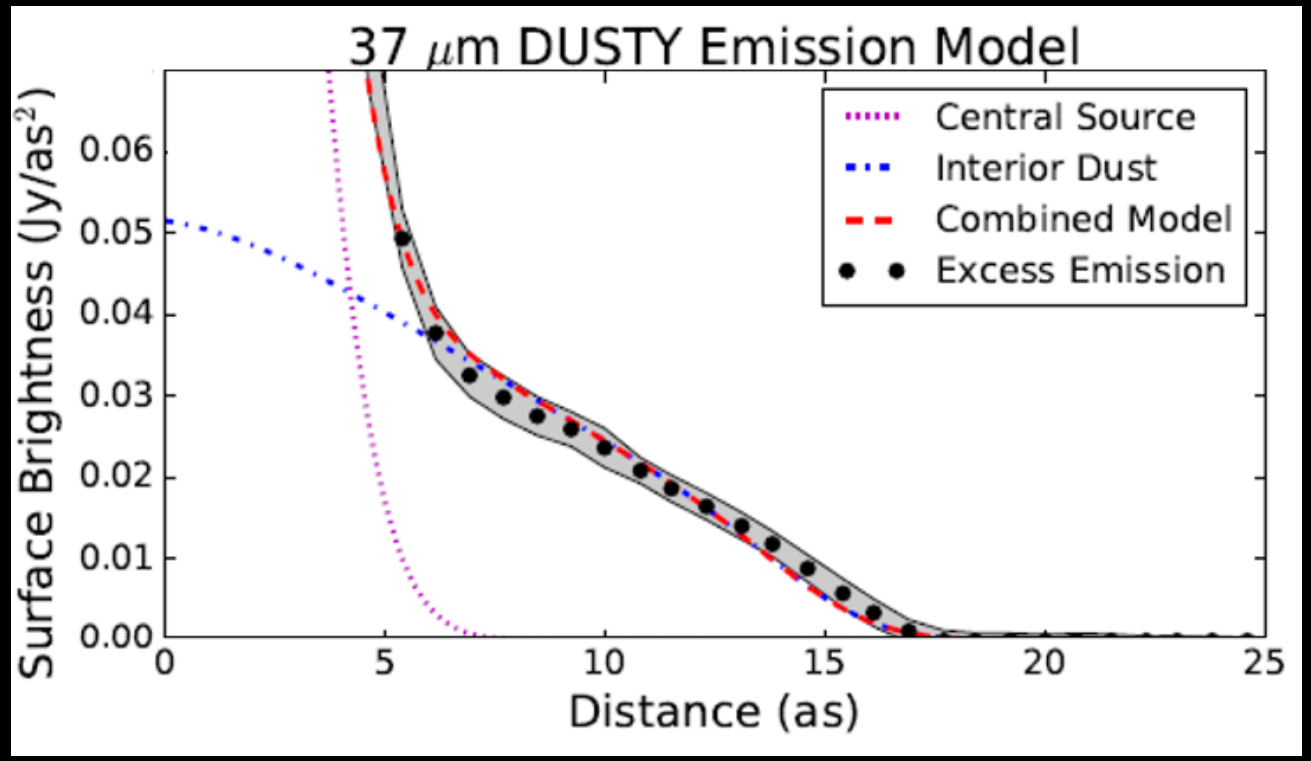
Hankins+ 2018

Modeling the Extended Dust: Interior Emission?

SOFIA/FORCAST 25, 31, 37 μm



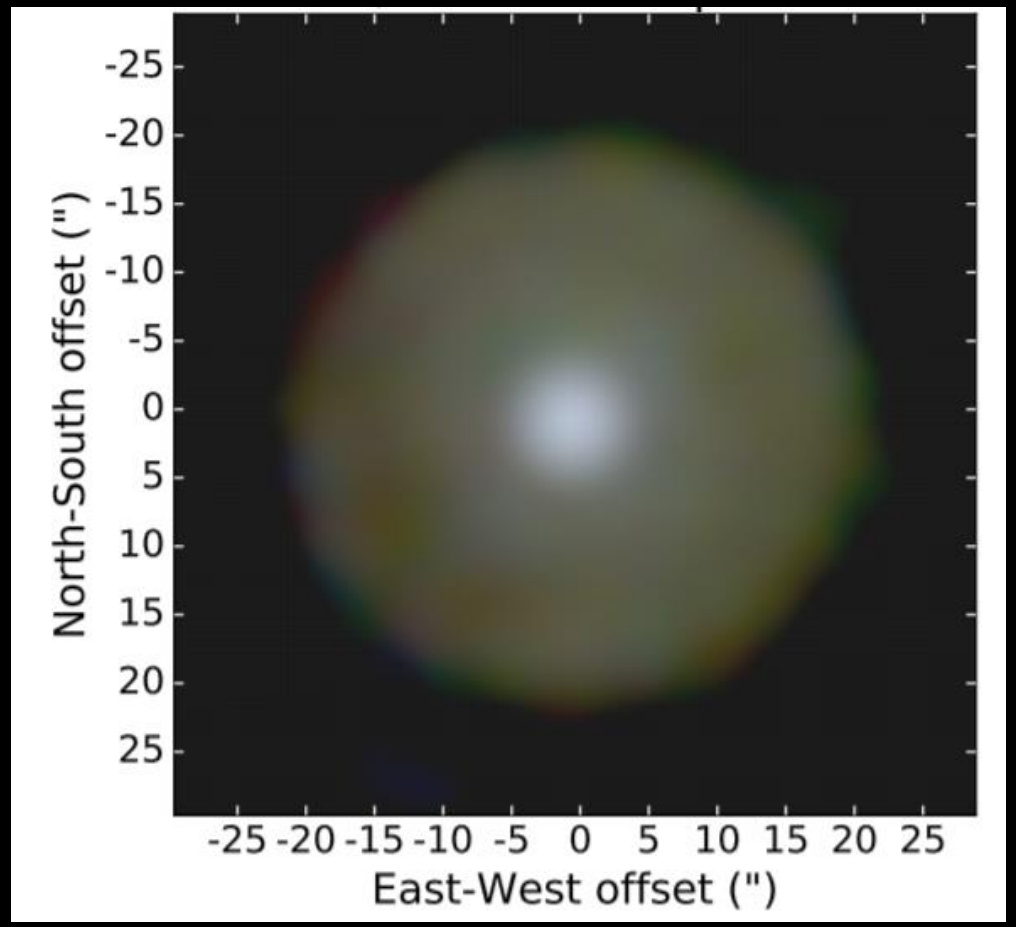
Hankins+ 2018



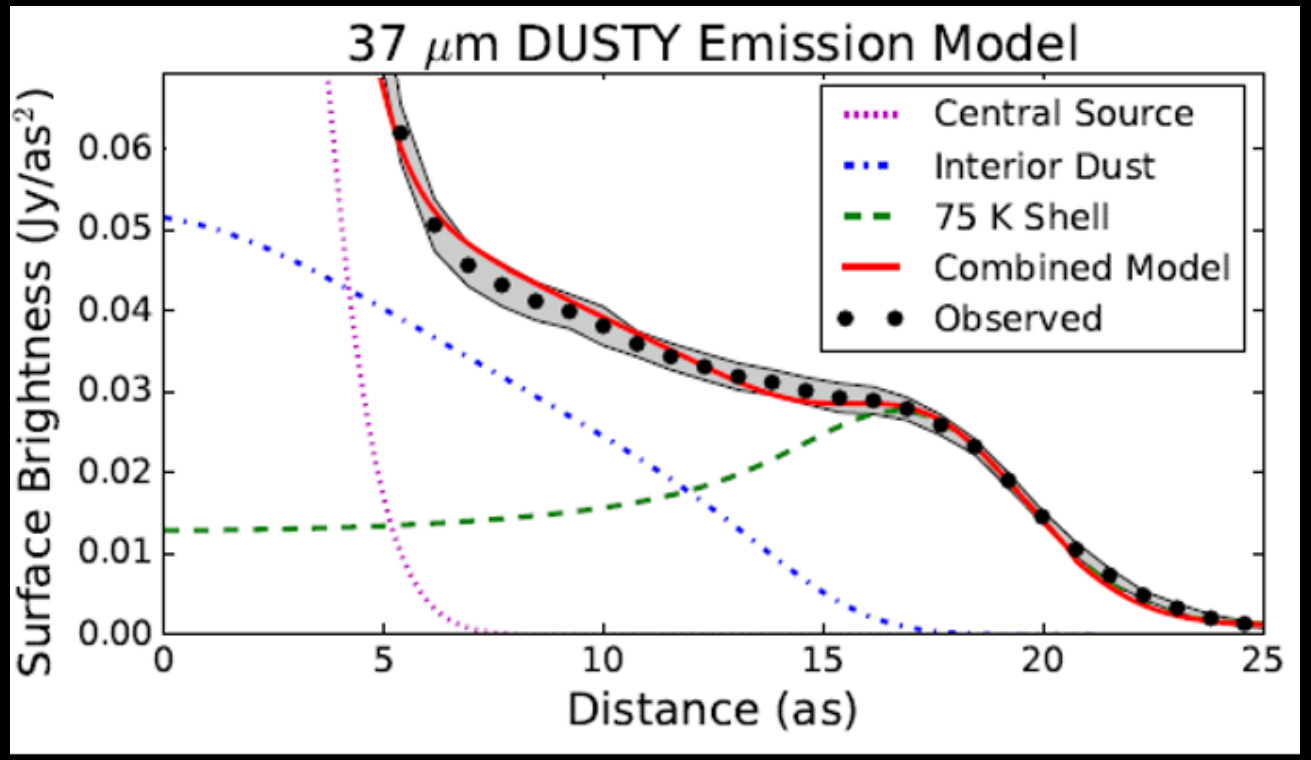
Hankins+ 2018

Modeling the Extended Dust: A Combined Model

SOFIA/FORCAST 25, 31, 37 μm

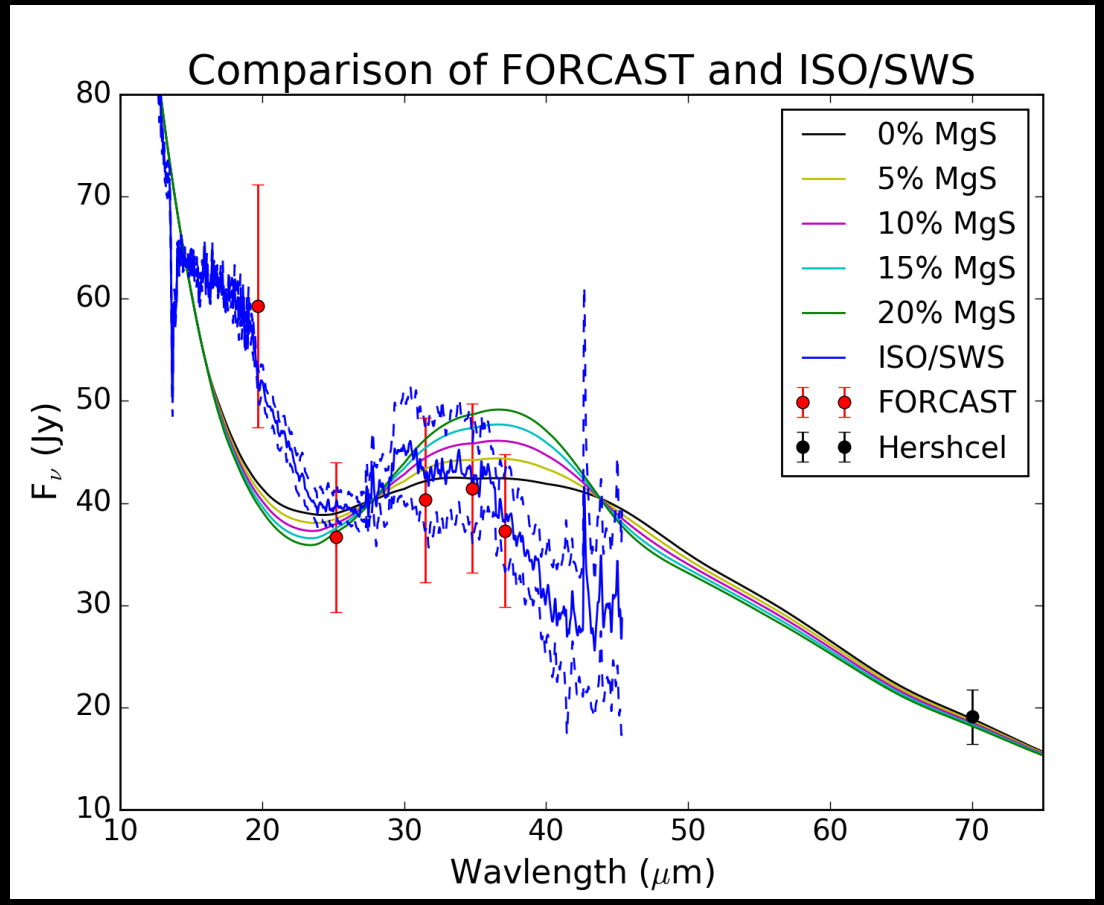


Hankins+ 2018



Hankins+ 2018

Issues Modeling the MgS Dust



- ISO/SWS has a known issue with hysteresis in the detector at its longer wavelengths
  - 5 observations of R Scl show very different shape & strength of the 30 um feature
- MgS models are difficult to constrain with photometry alone
  - FORCAST Grisims and/or HERMES may be promising here!

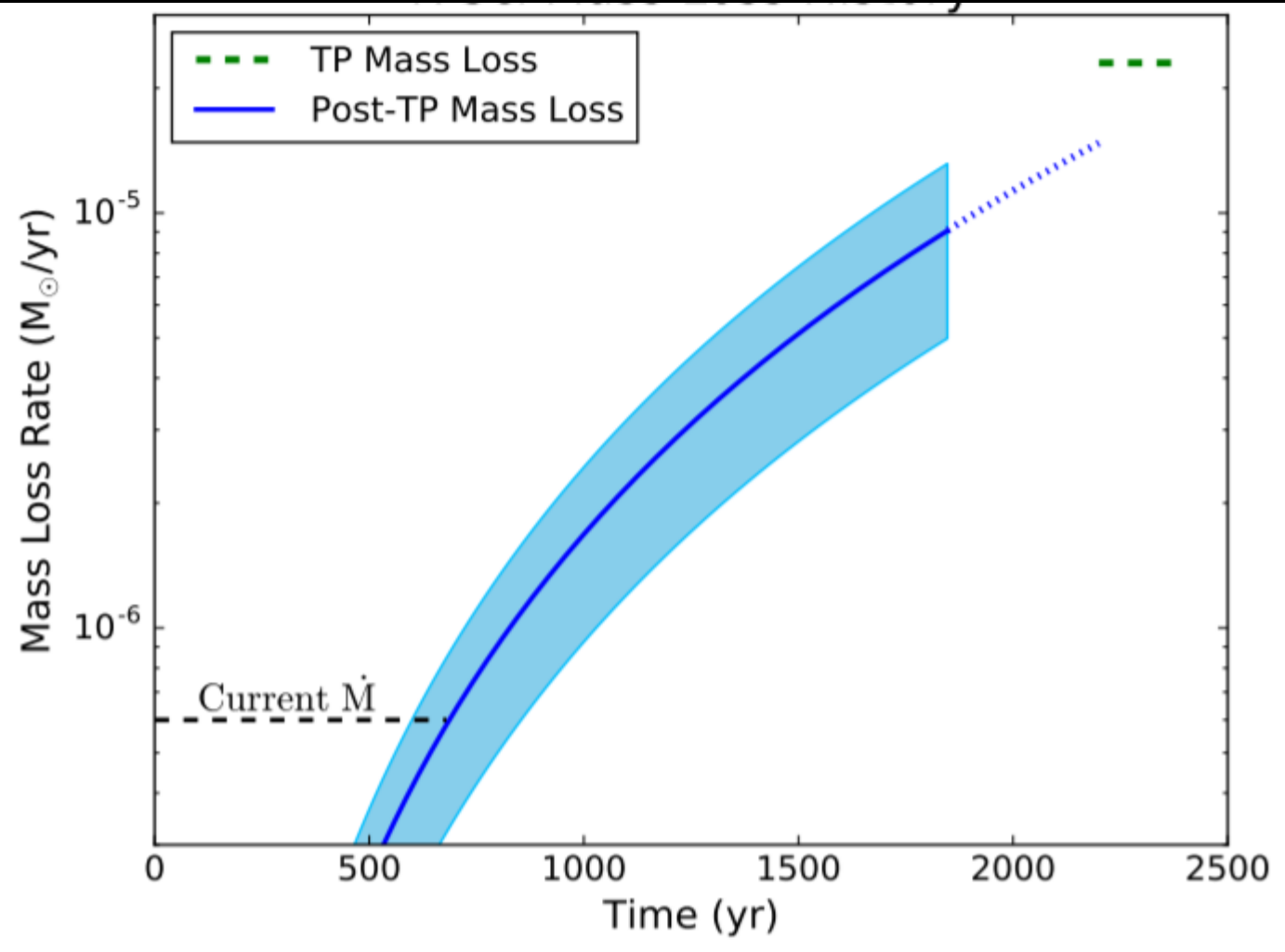
Best-Fit Parameters from DUSTY

DUSTY Model Parameters

Parameter	Value	Type	Source
Stellar Temperature	2600 K	adopted	Cruzalèbes et al. (2013)
Stellar Luminosity	$10^{4.0\pm0.2}\ L_{\odot}$	fitted	this work
Distance	370 pc	adopted	Maercker et al. (2016)
Dust Size Distribution	$dn/da \propto a^{-3.5}$	adopted	this work
Fractional Dust Composition	0.86 AmC	adopted	this work
	0.10 SiC	adopted	Sacuto et al. (2011)
	0.04 MgS	adopted	Hony & Bouwman (2004)
Shell Dust Temperature (T_{shell})	75 K	adopted	Schöier et al. (2005)
Shell Radius	6950 AU (18.8")	fitted	this work
Shell Thickness	0.1	adopted	González Delgado et al. (2003)
Shell Dust Mass	$3.7 \times 10^{-5} M_{\odot}$	adopted*	Schöier et al. (2005)
Interior Dust Temperature (T_{in})	1200 K	adopted	Sacuto et al. (2011)
Inner Radius (R_{in})	10 AU (27 mas)	adopted	Determined from T_{in}
Outer Radius (R_{out})	5550 AU (15")	fitted	this work
Relative Thickness (Y)	550	fitted	Y=R_{out}/R_{in}
Density Power Law (α)	$0.75^{+0.45}_{-0.25}$	fitted	this work
Interior Dust Mass	$9.0^{+2.3}_{-4.1} \times 10^{-6}\ M_{\odot}$	fitted	this work

*For consistency, the dust shell mass has been scaled from the original value quoted in Schöier et al. (2005) to our adopted distance of 370 pc.

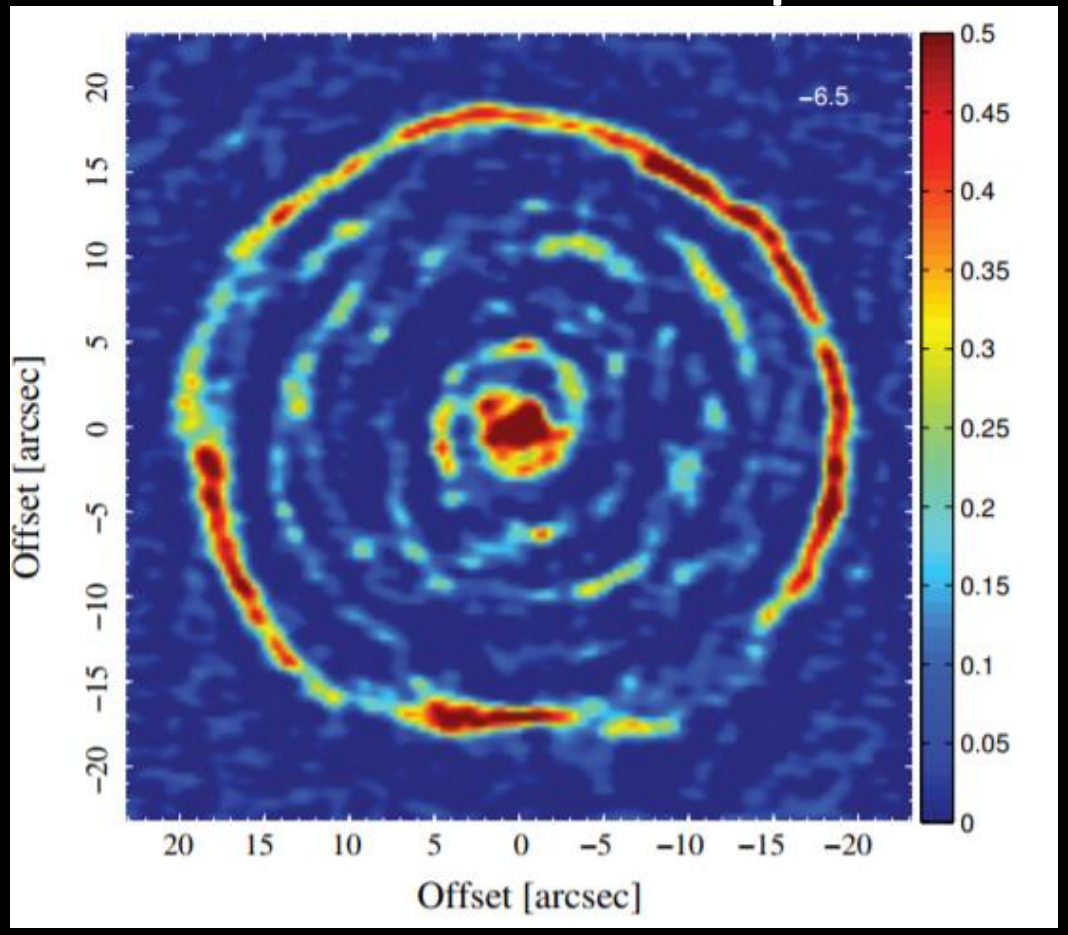
Constraining the Post-TP Mass Loss History of R Scl



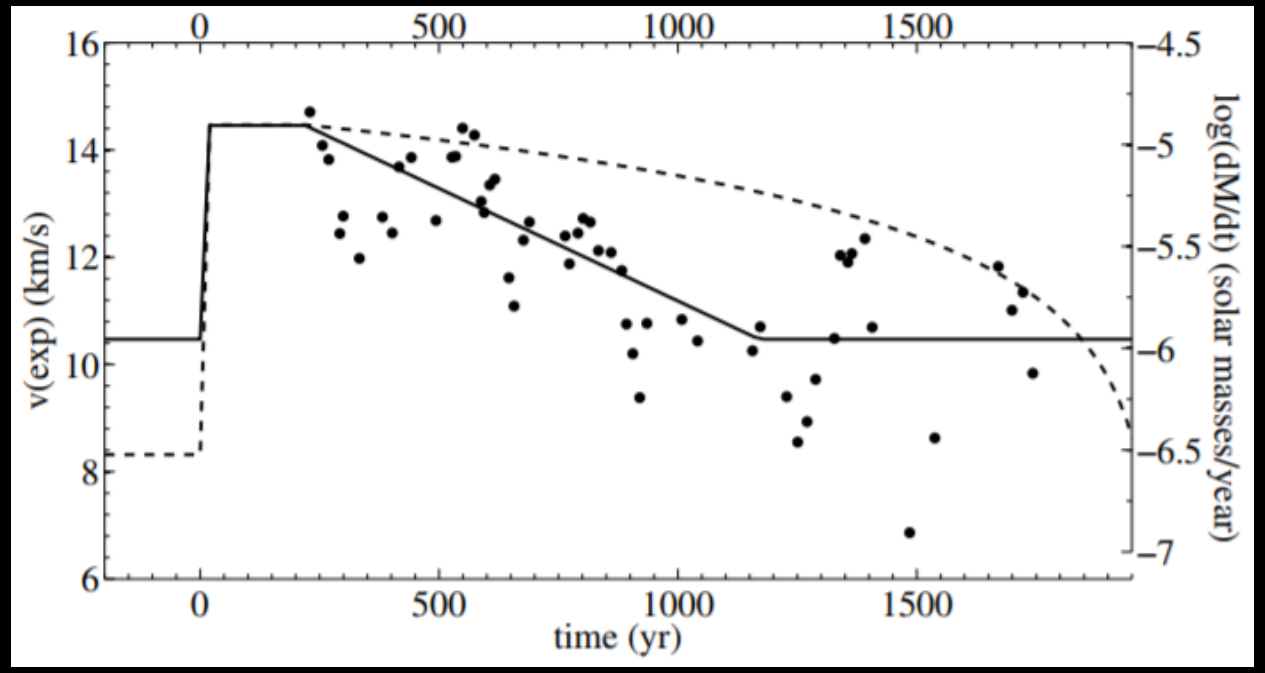
Hankins+ 2018

Constraining R Scl's Circumstellar Material

ALMA CO 3-2 Map



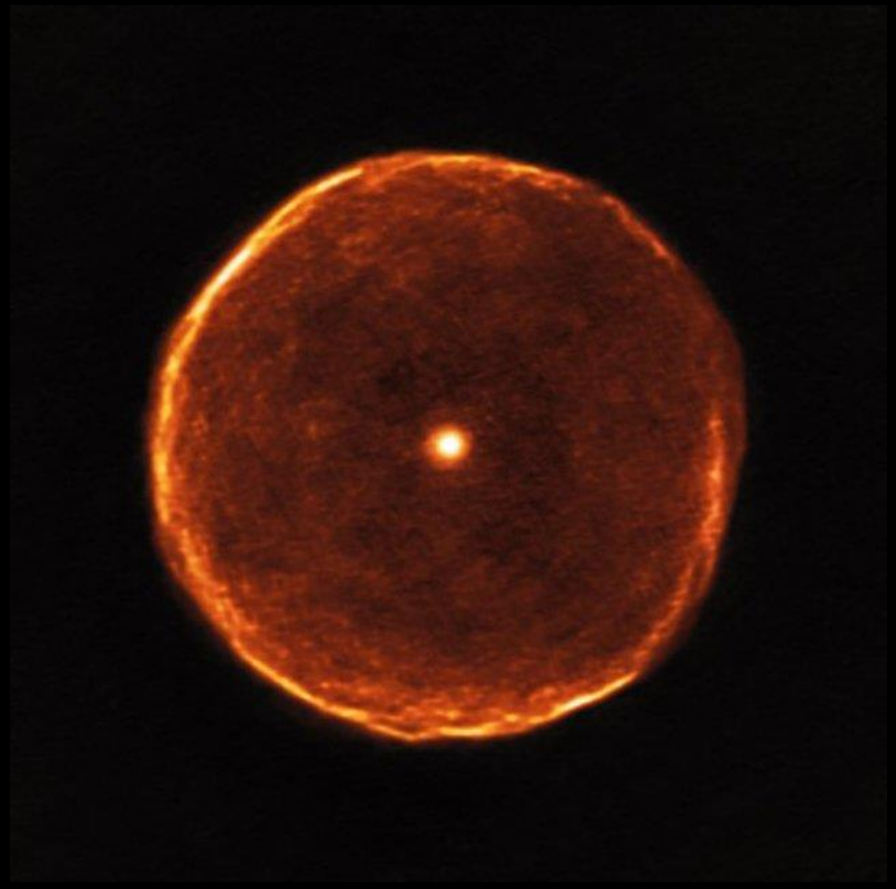
Maercker+2012

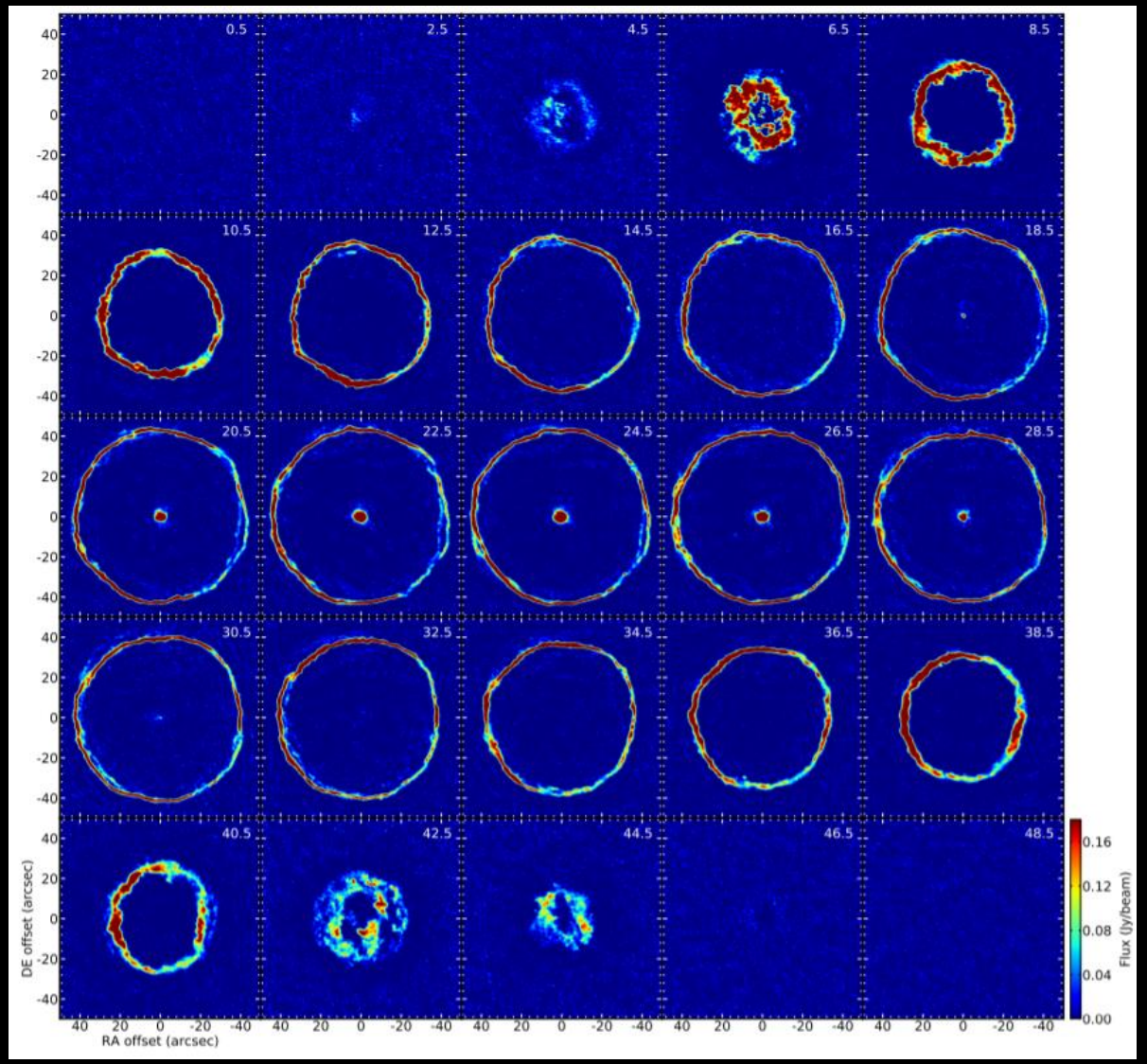


Maercker+2012

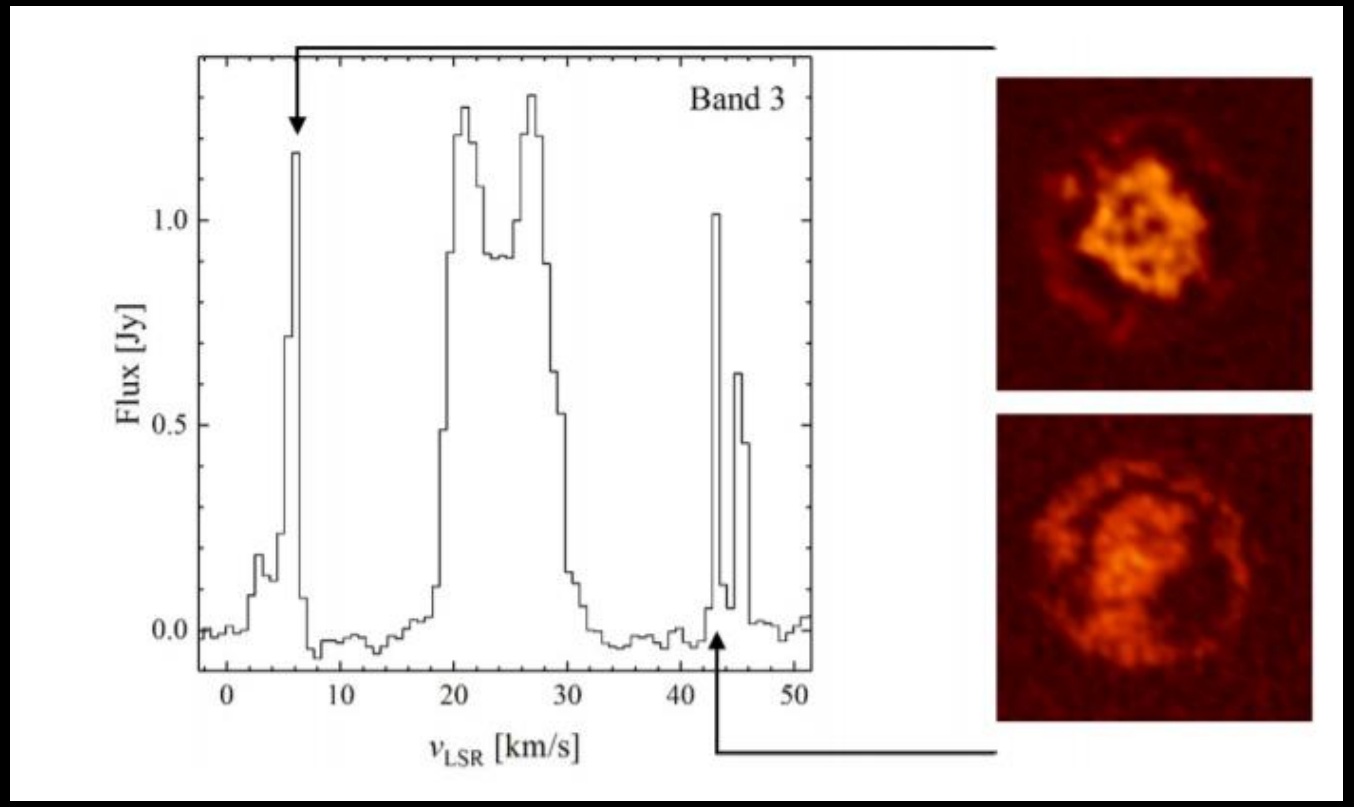
What about other post-TP carbon stars?

ALMA Observations of U Ant (Kershenbaum+2017)



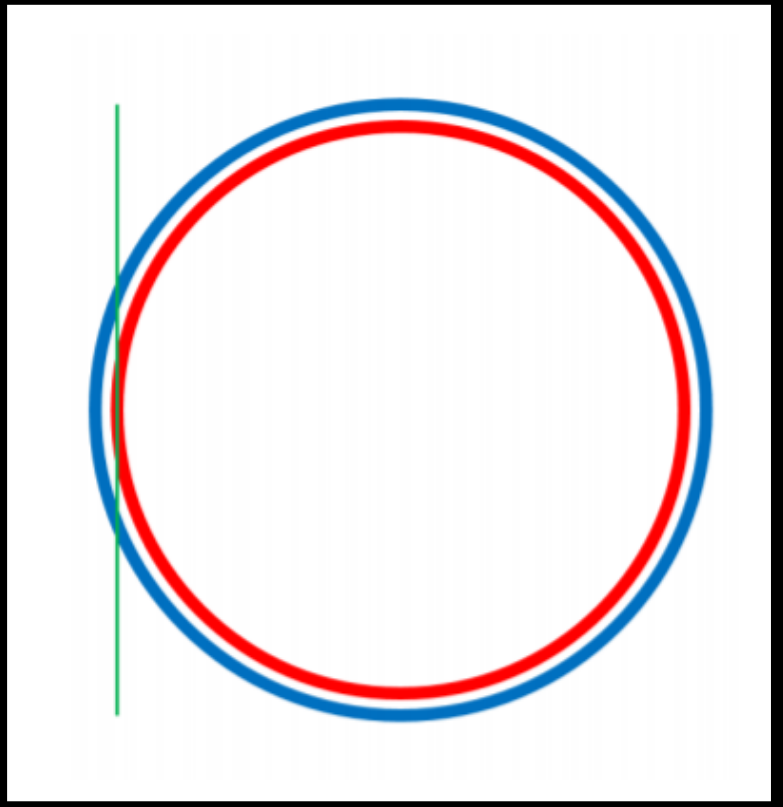


ALMA Observations of U Ant



Kershenbaum+2017

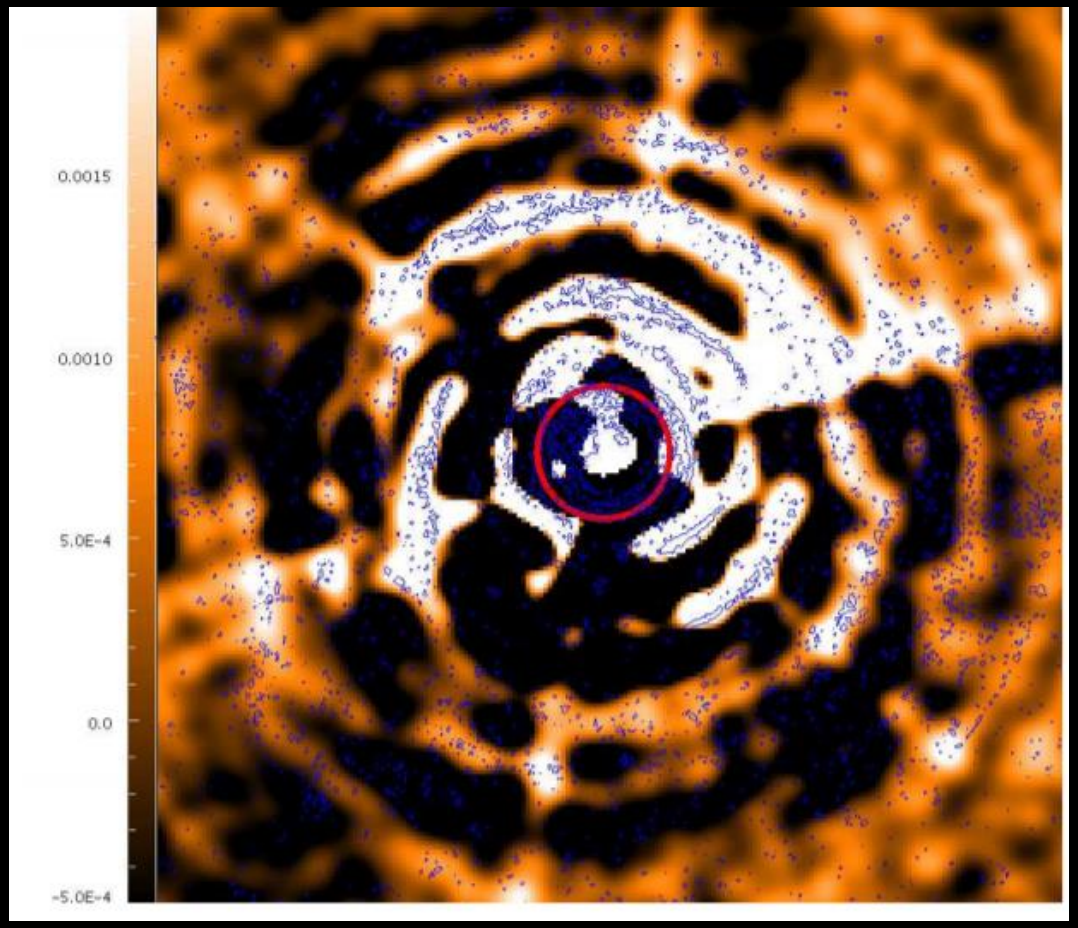
A Simple Emission Model



Kershenbaum+2017

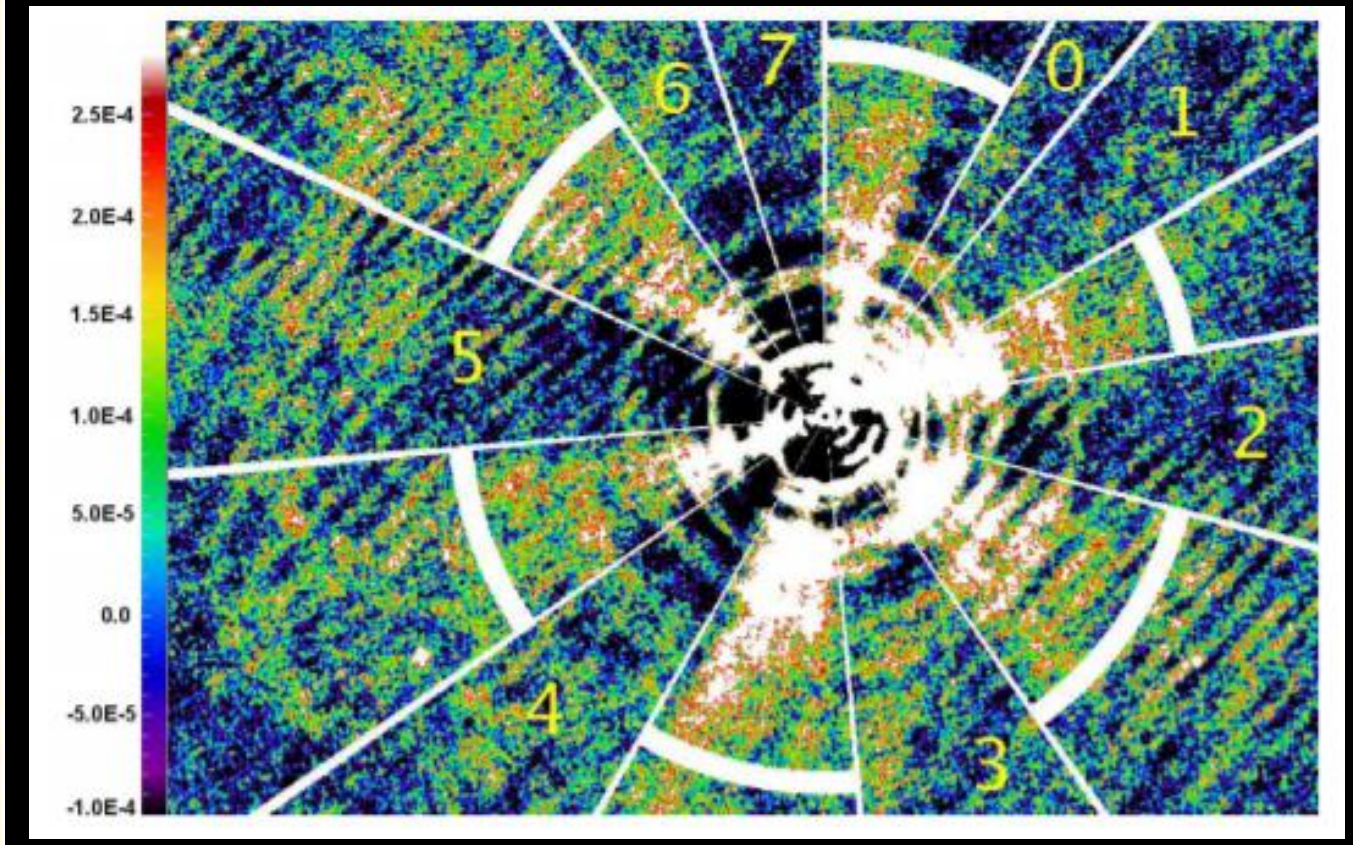
What About More Exotic Sources?

Herschel/PACS 100 µm of IRC+ 10216



FOV 200”x200”

Same data, different stretch



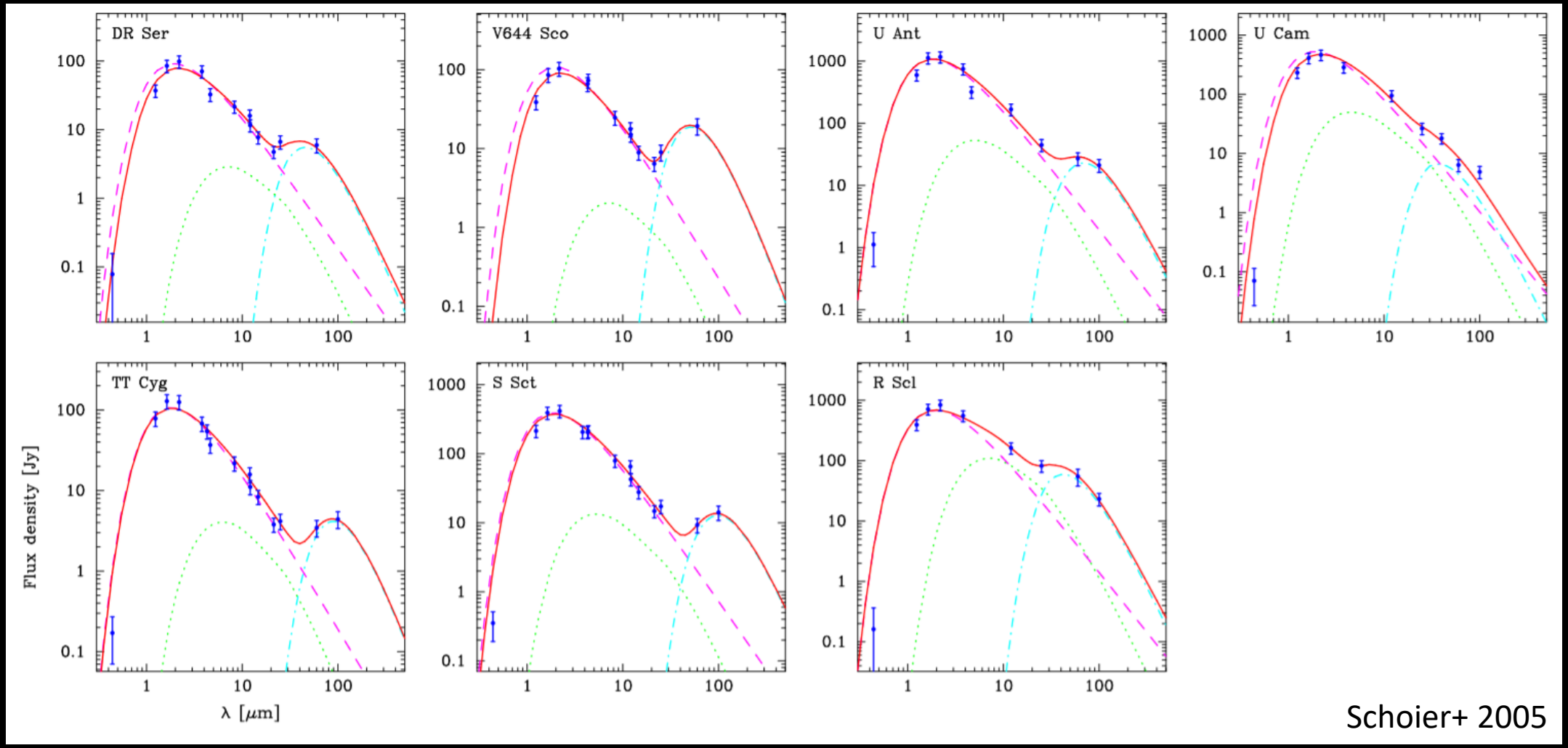
Decin+ 2011

Considering TP & Post-TP Behavior Further

So there are a few odd objects out there, why does it matter?

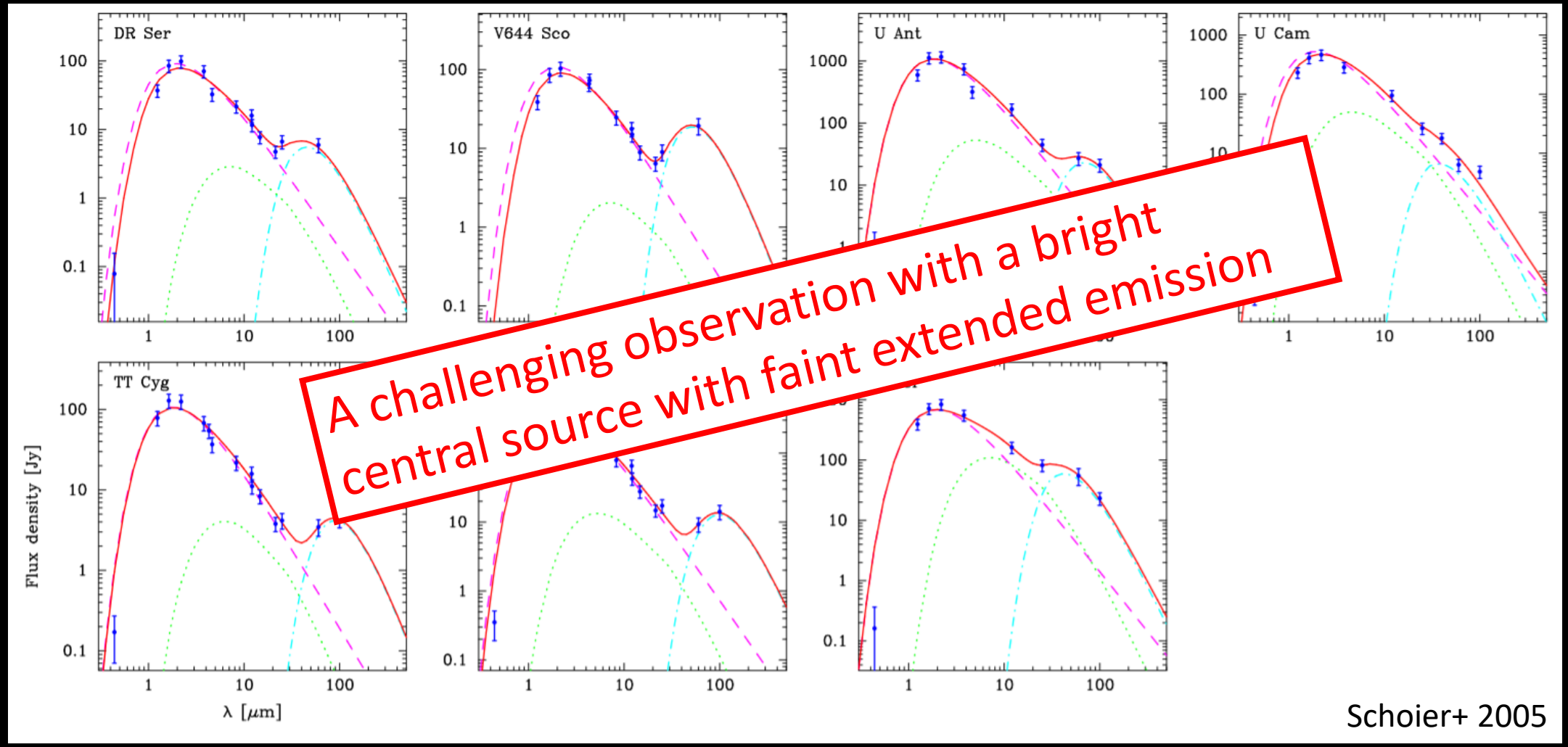
- Mass loss also sets a star's lifetime of the AGB
  - More mass-loss, fewer TP's, shorter lifetime on the AGB
- AGBs are also important sources of dust in the ISM
  - Issues with dust in the local universe like the LMC Dust Budget (Matsuura+ 2009)

What's next?- Several Sources for JWST



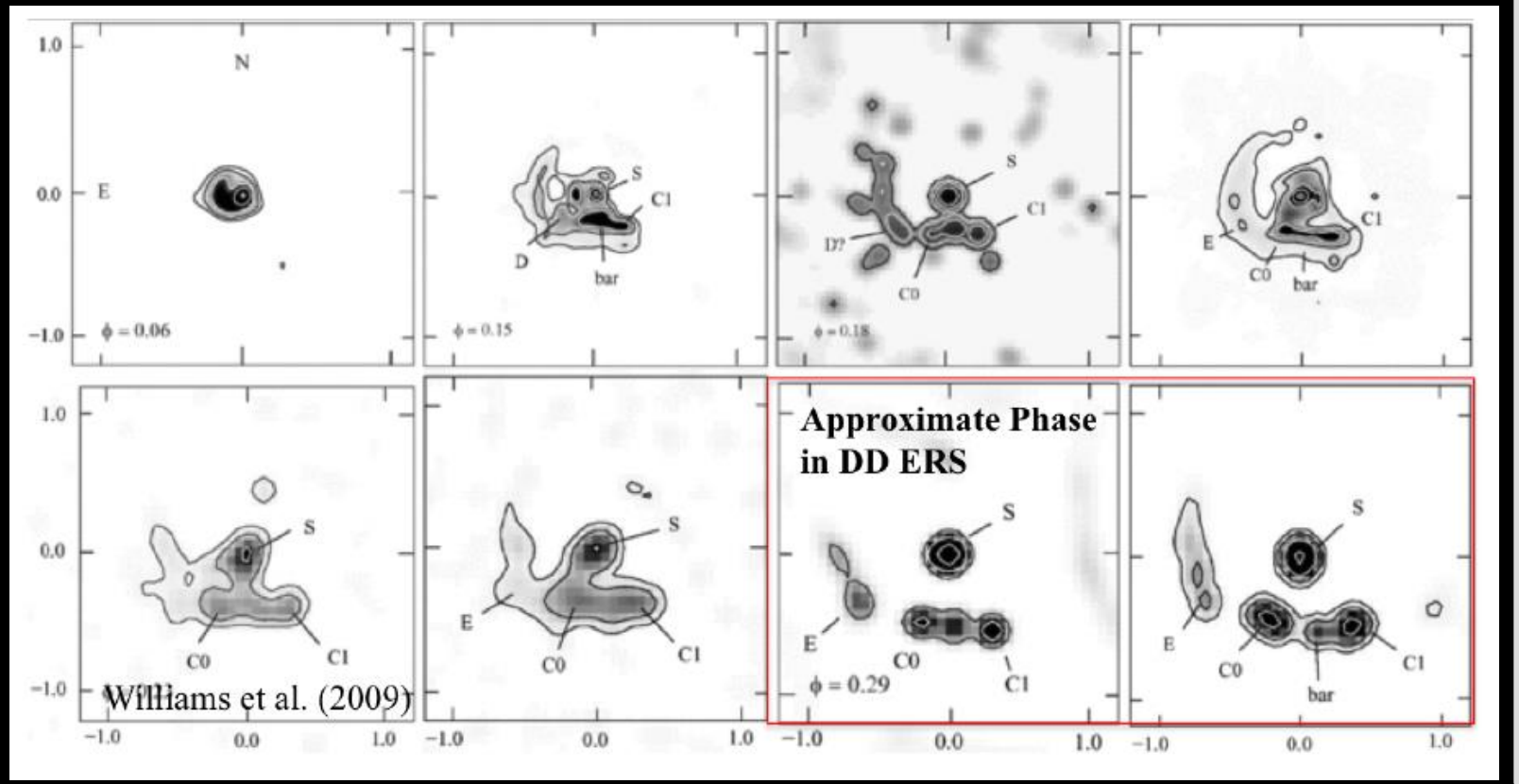
Schoier+ 2005

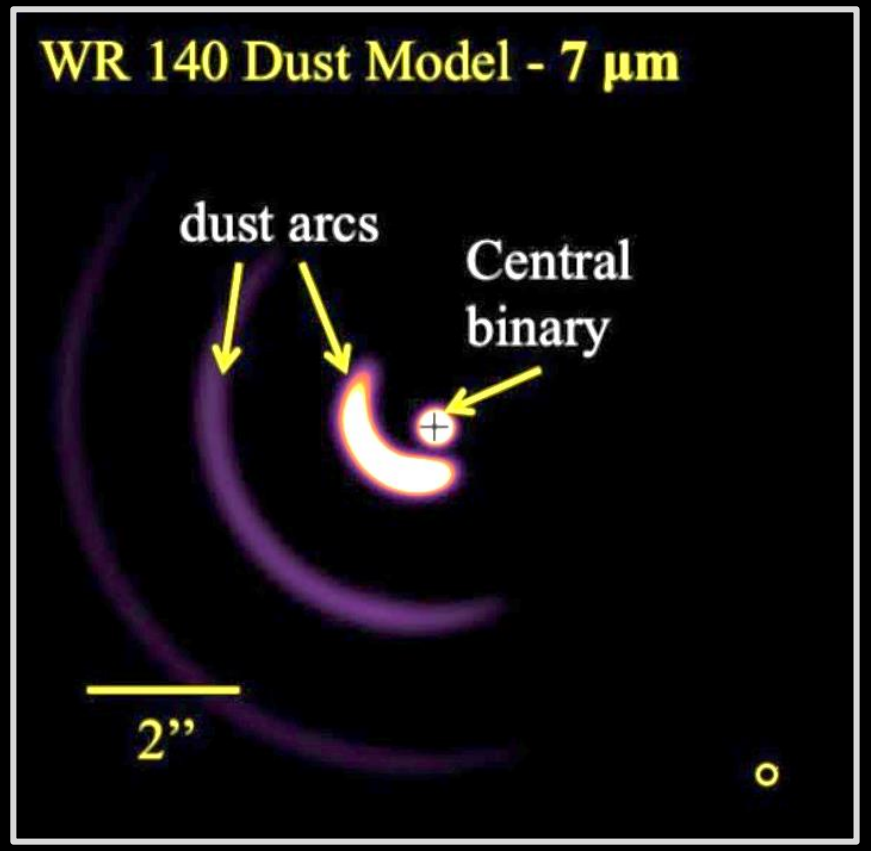
What's next?- Several Sources for JWST



Schoier+ 2005

JWST Early Release Science Program: WR 140





PI: R. Lau, Co-I: M. Hankins

Summary

- R Scl is an intriguing carbon star with interesting circumstellar material
  - Provides evidence for a slow decline in post-TP mass loss history
  - Still work to be done understanding the dust composition

- Examine other carbon stars with circumstellar shells
  - Is R Scl unusual or do more objects also show a slow decline in mass loss?

Thanks for Joining!

Questions?

Collaborators: Terry Herter (Cornell), Matthias Maercker (Chalmers University), Ryan Lau (Caltech), Greg Sloan (UNC/STSci)