Dust production in low-mass stars

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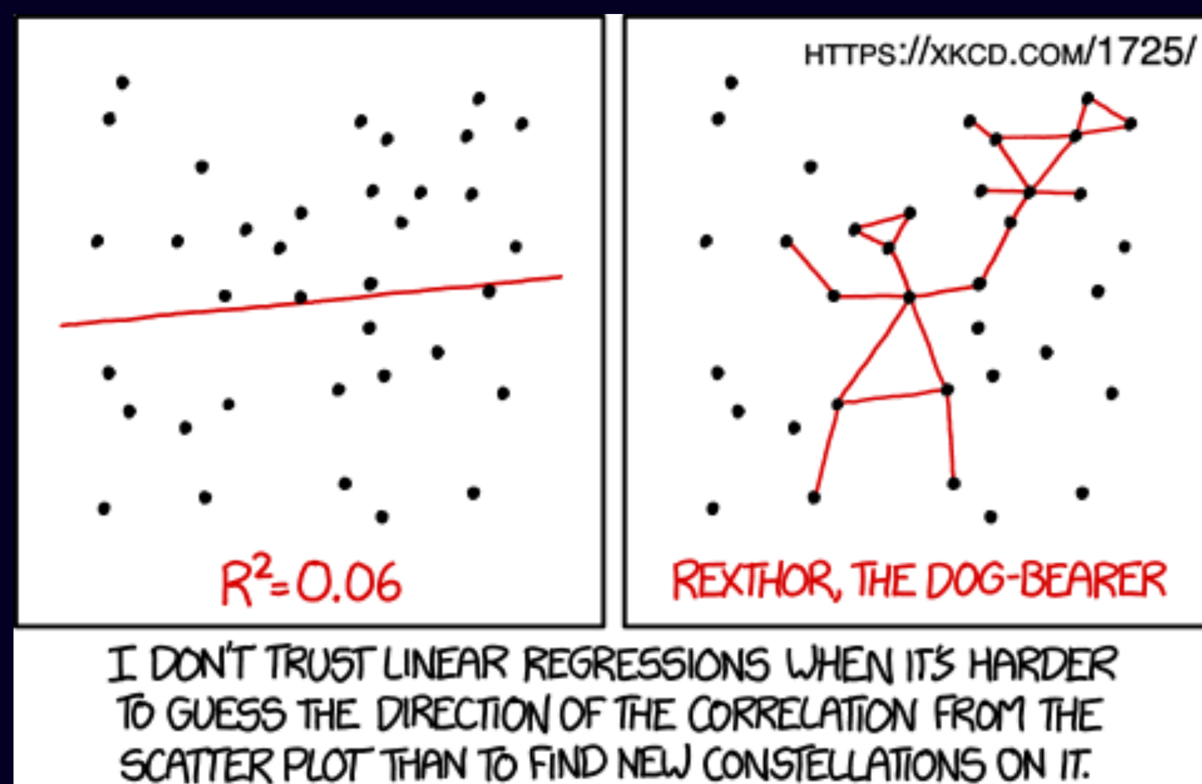
ASIAA, Taipei, Taiwan & IRyA/UNAM, Morelia, Mexico

CPHDUST2018, 11 June, 2018



This presentation has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562 [RadioNet]

Outline

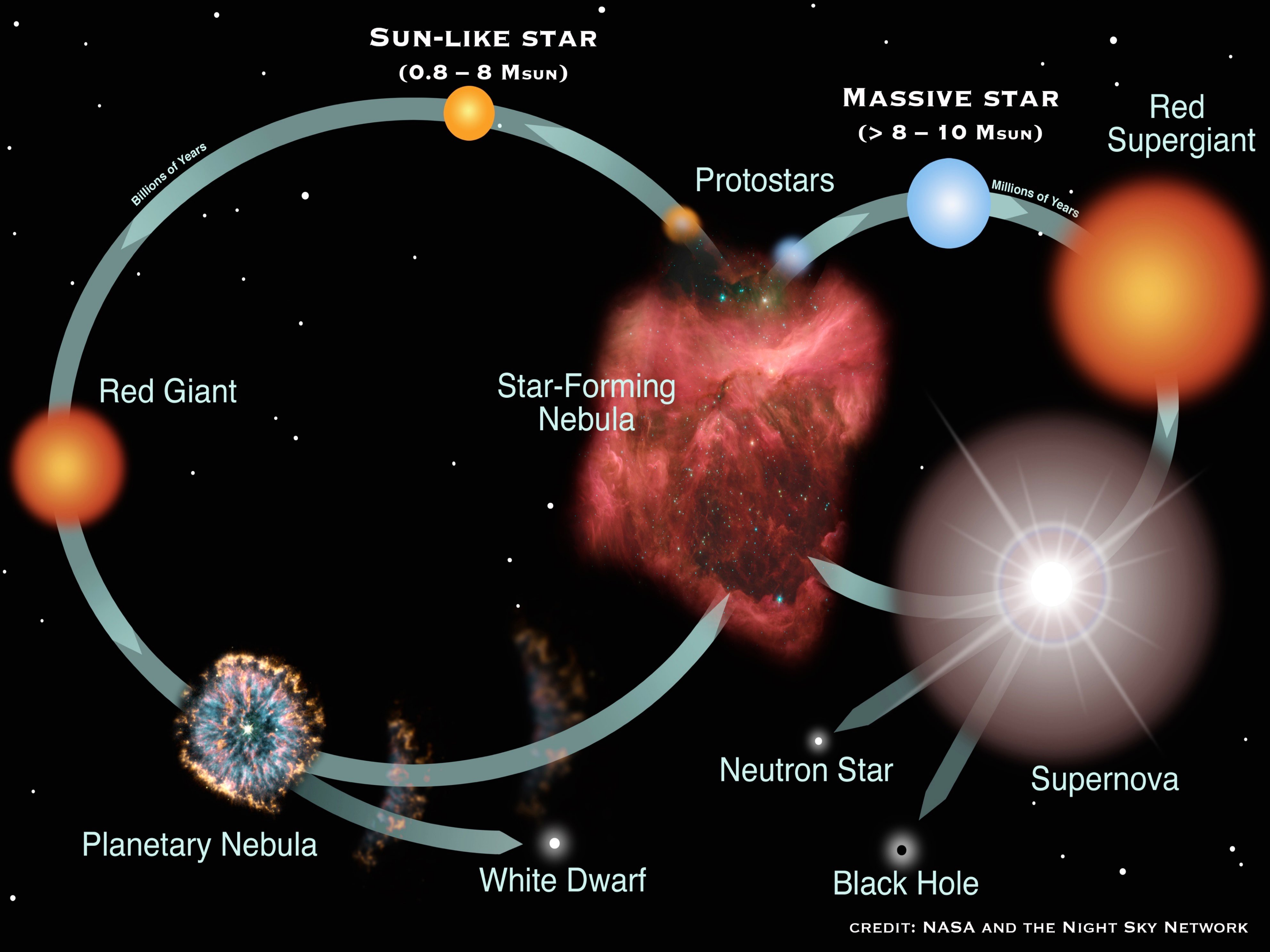
- Review: Sources of dust and AGB stars.
- The dust budget in nearby galaxies
    - GRAMS: A grid of RSG and AGB ModelS.
    - Computing the dust budget.
    - Results for nearby galaxies.
- The dust budget in our galaxy
    - The Nearby Evolved Stars Survey.

Review: why study dust?

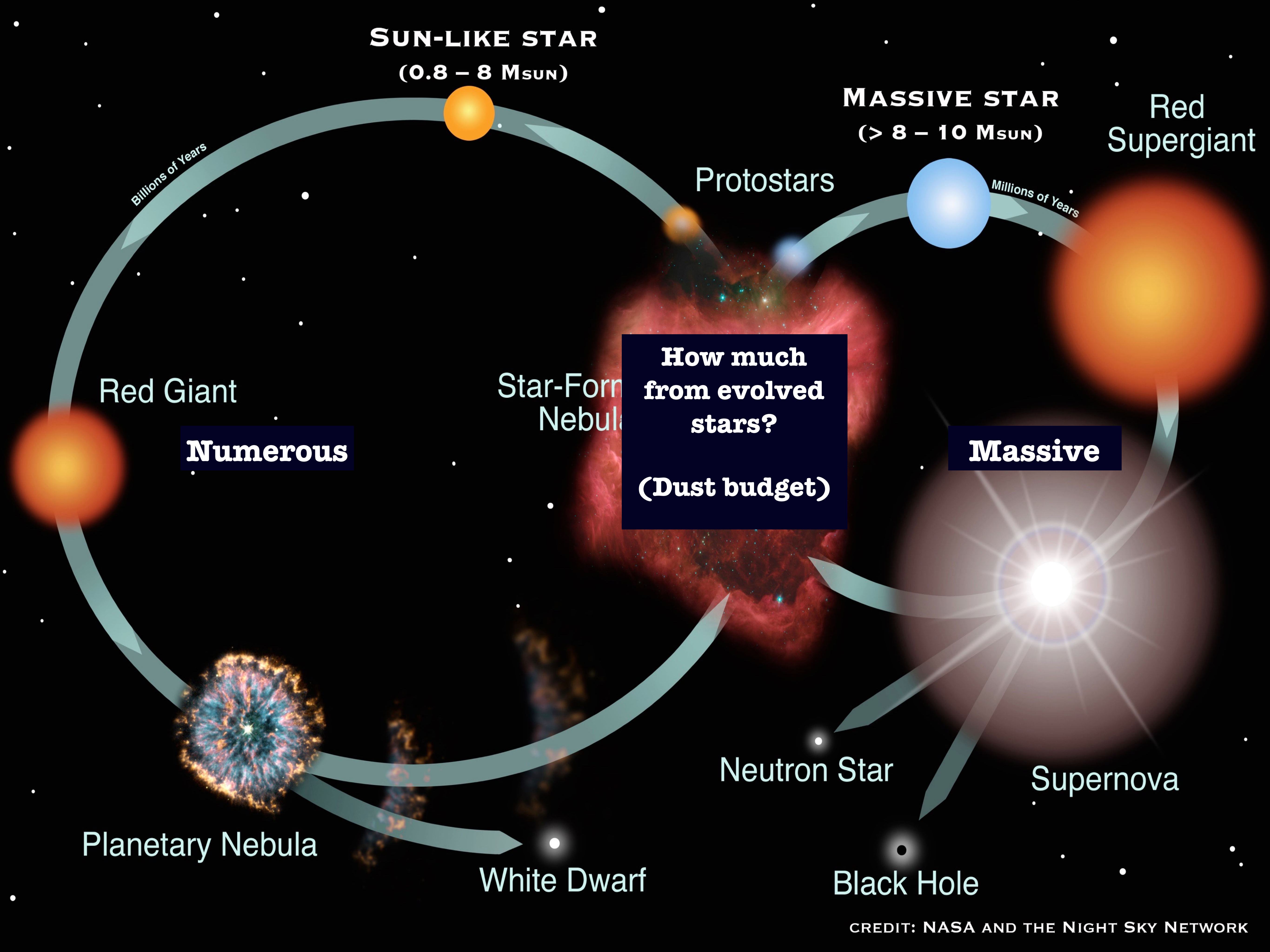
- Catalyst for H_2 formation.
- Efficient cooling of collapsing cores at higher densities (Evans 1999).
- "Dust remembers, gas forgets"
  Dust retains information in mineralogy and physical structure (e.g. crystallisation) for ~0.1 Gyr
  —> constraints on astrophysical processes.
- Star/planet formation, grain processing in ISM —> Galactic chemical evolution.

Review: sources of dust

- Stellar winds and explosions (This session and tomorrow).
- Growth in the ISM (Dwek 1988, Draine 2009; morning session).
- Tori of AGN (Elvis 2002, Elitzur & Shlosman 2006; Wednesday).



Sun-like star
(0.8 – 8 Msun)
Massive star
(> 8 – 10 Msun)
Red Supergiant
Billions of Years
Millions of Years
Protostars
Red Giant
Star-Forming Nebula
Supernova
Neutron Star
Planetary Nebula
White Dwarf
Black Hole
credit: NASA and the Night Sky Network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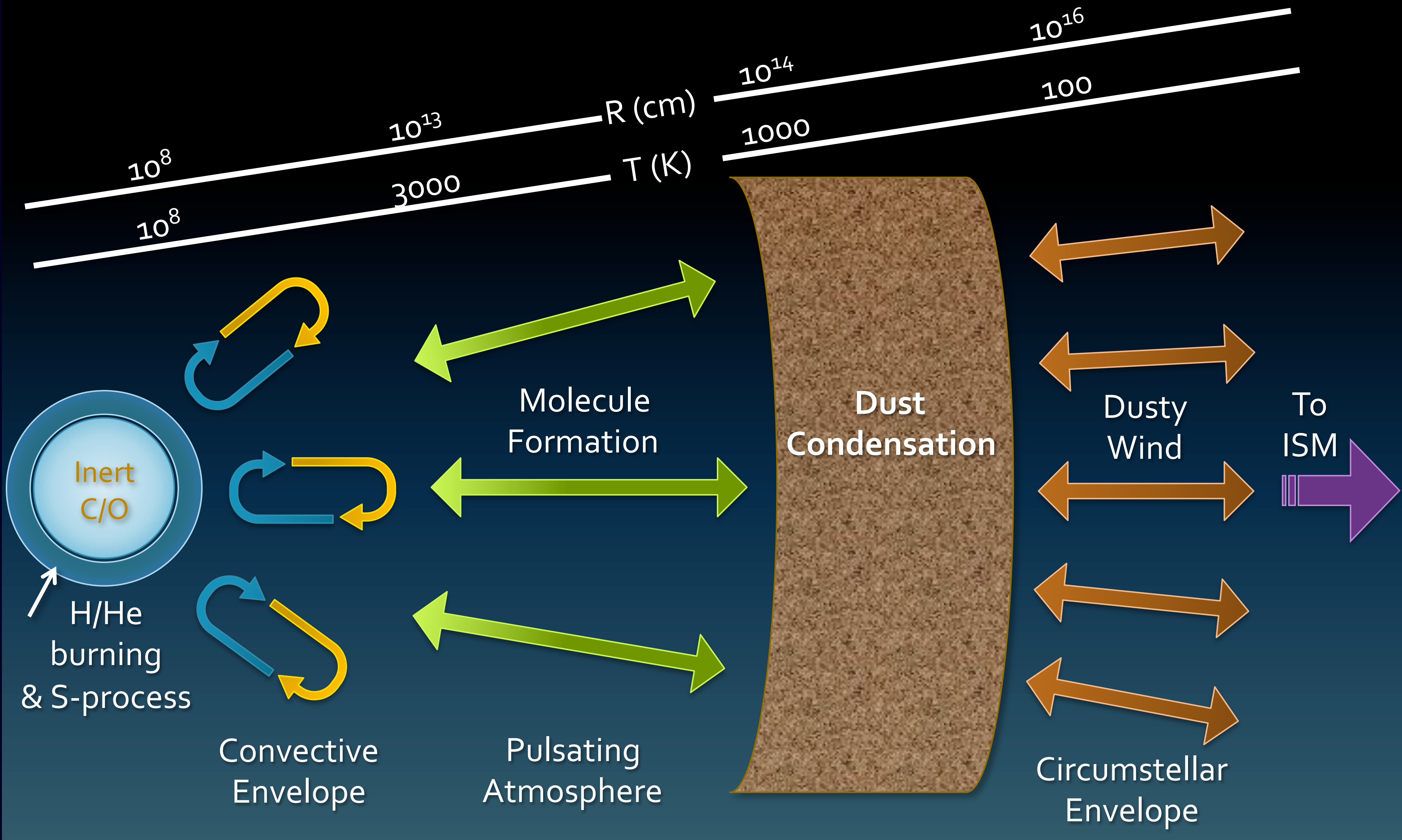
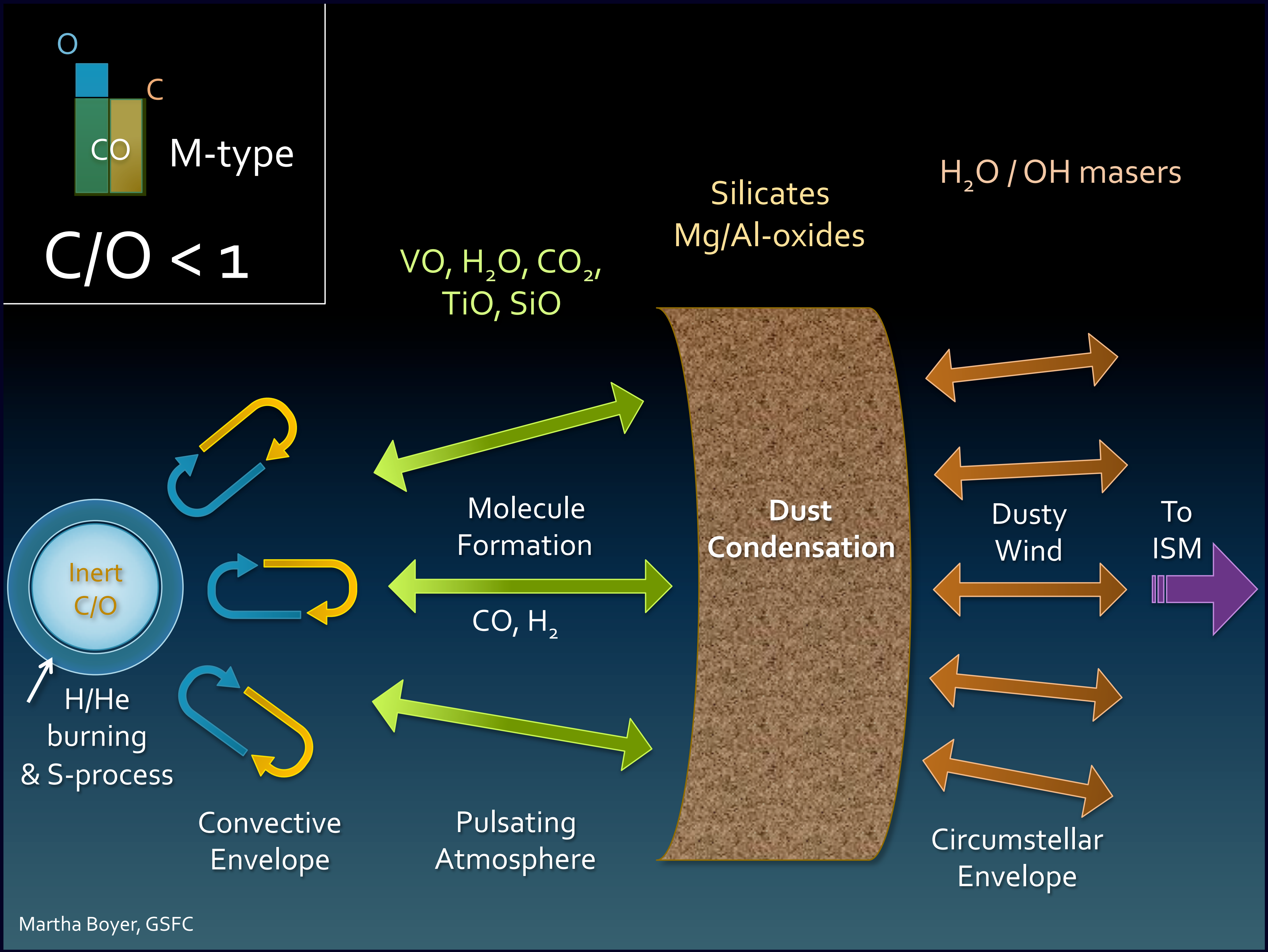
Red Supergiant
Protostars
Billions of Years
Millions of Years
Red Giant
Numerous
Star-Forming Nebula
How much from evolved stars?
(Dust budget)
Massive
Neutron Star
Supernova
Planetary Nebula
White Dwarf
Black Hole
credit: NASA and the Night Sky Network

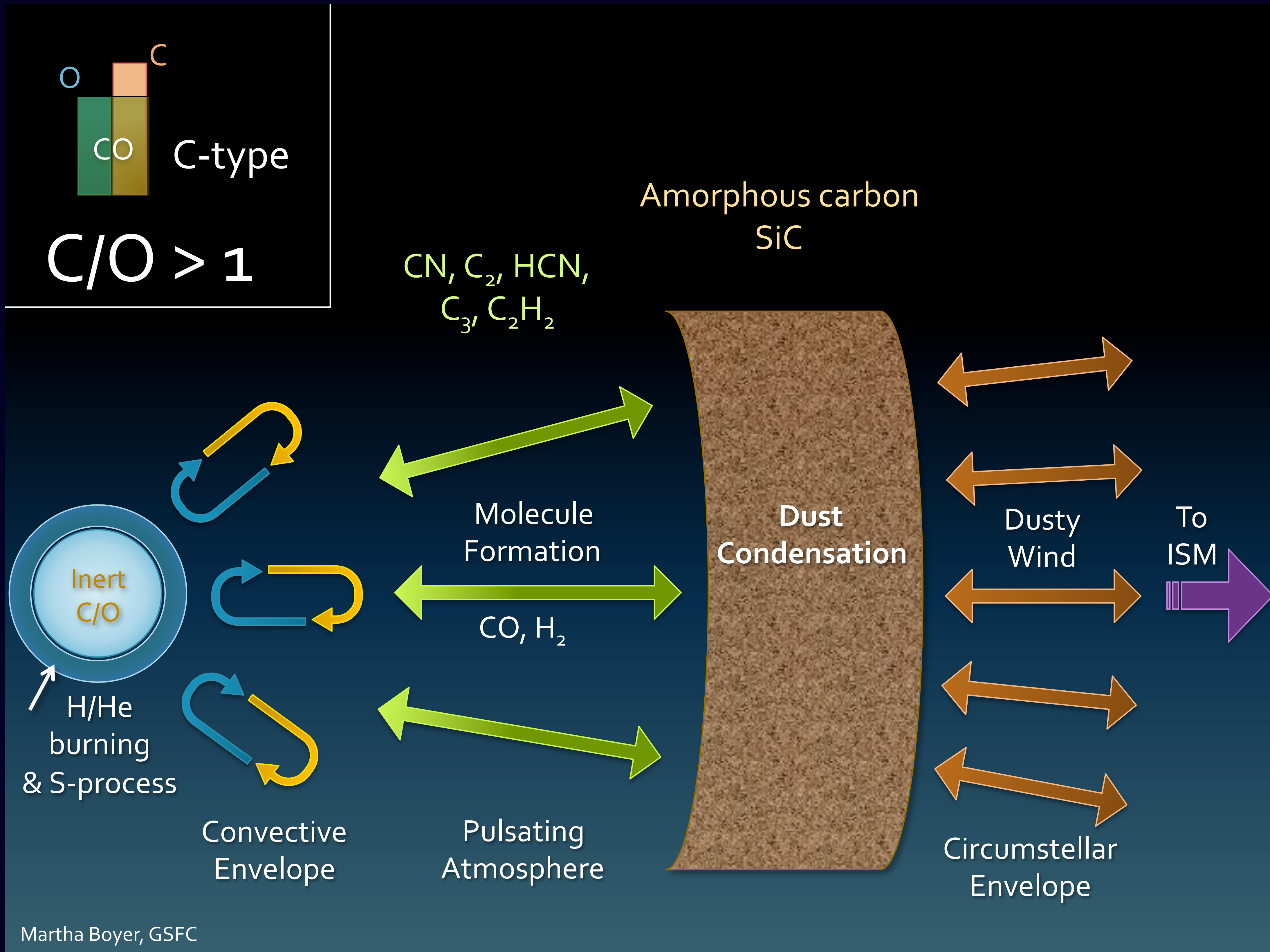
AGB Refresher



Martha Boyer, GSFC



O
C
CO
M-type
C/O < 1
VO, H_2O, CO_2,
TiO, SiO
Silicates
Mg/Al-oxides
H_2O / OH masers
Inert
C/O
H/He
burning
& S-process
Molecule
Formation
CO, H_2
Dust
Condensation
Dusty
Wind
To
ISM
Convective
Envelope
Pulsating
Atmosphere
Circumstellar
Envelope
Martha Boyer, GSFC


O
C
CO
C-type
C/O > 1
Amorphous carbon
SiC
CN, C_2, HCN,
C_3, C_2H_2
Molecule
Formation
CO, H_2
Dust
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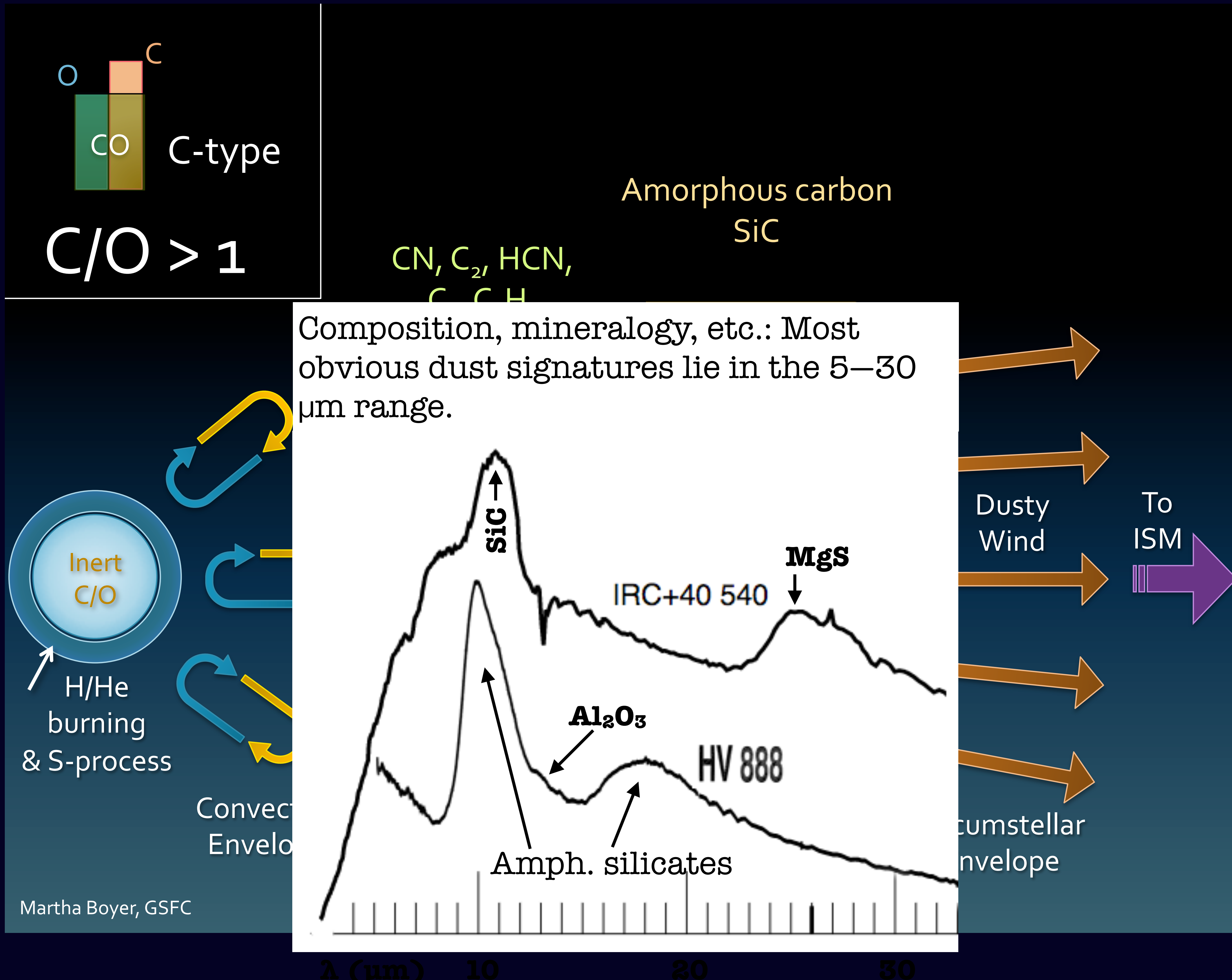
O
C
CO
C-type
C/O > 1
Amorphous carbon
SiC
CN, C_2, HCN,
Composition, mineralogy, etc.: Most obvious dust signatures lie in the 5—30 µm range.
SiC
MgS
IRC+40 540
Al_2O_3
HV 888
Amph. silicates
Inert
C/O
H/He
burning
& S-process
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Dusty
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To
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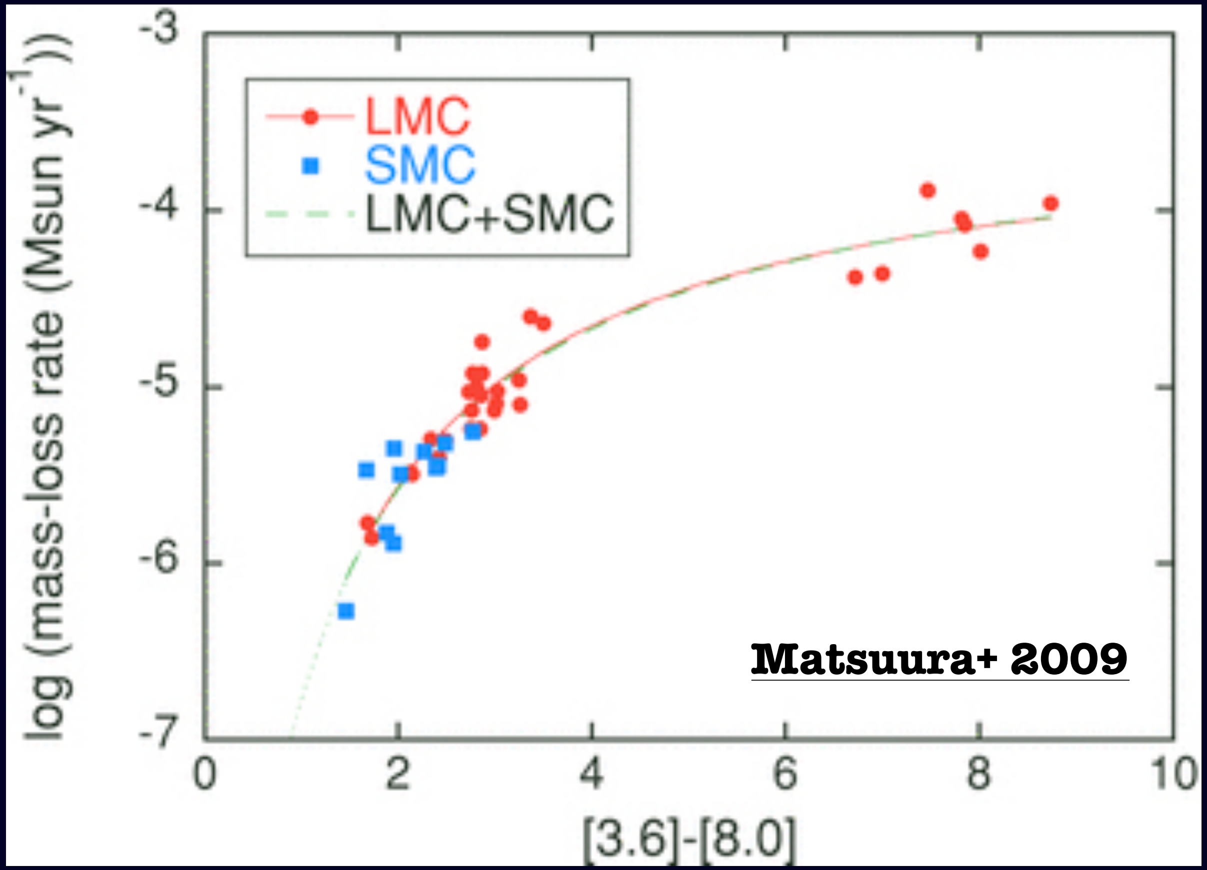
cumstellar
nvelope
Martha Boyer, GSFC

The dust budget in nearby galaxies

Requires us to know the dust-production rate (DPR, dust mass-loss rate) from each AGB/RSG star…

Computing the dust budget

- Use MIR color as proxy for DPR
- Use IR excess as proxy for DPR
- Fit SEDs with radiative transfer models



Mid-IR colors affected by dust, so should correlate with DPR.

Matsuura+ 2009,
Boyer, Srinivasan+ 2011,
Matsuura+ 2013, Boyer+ 2015

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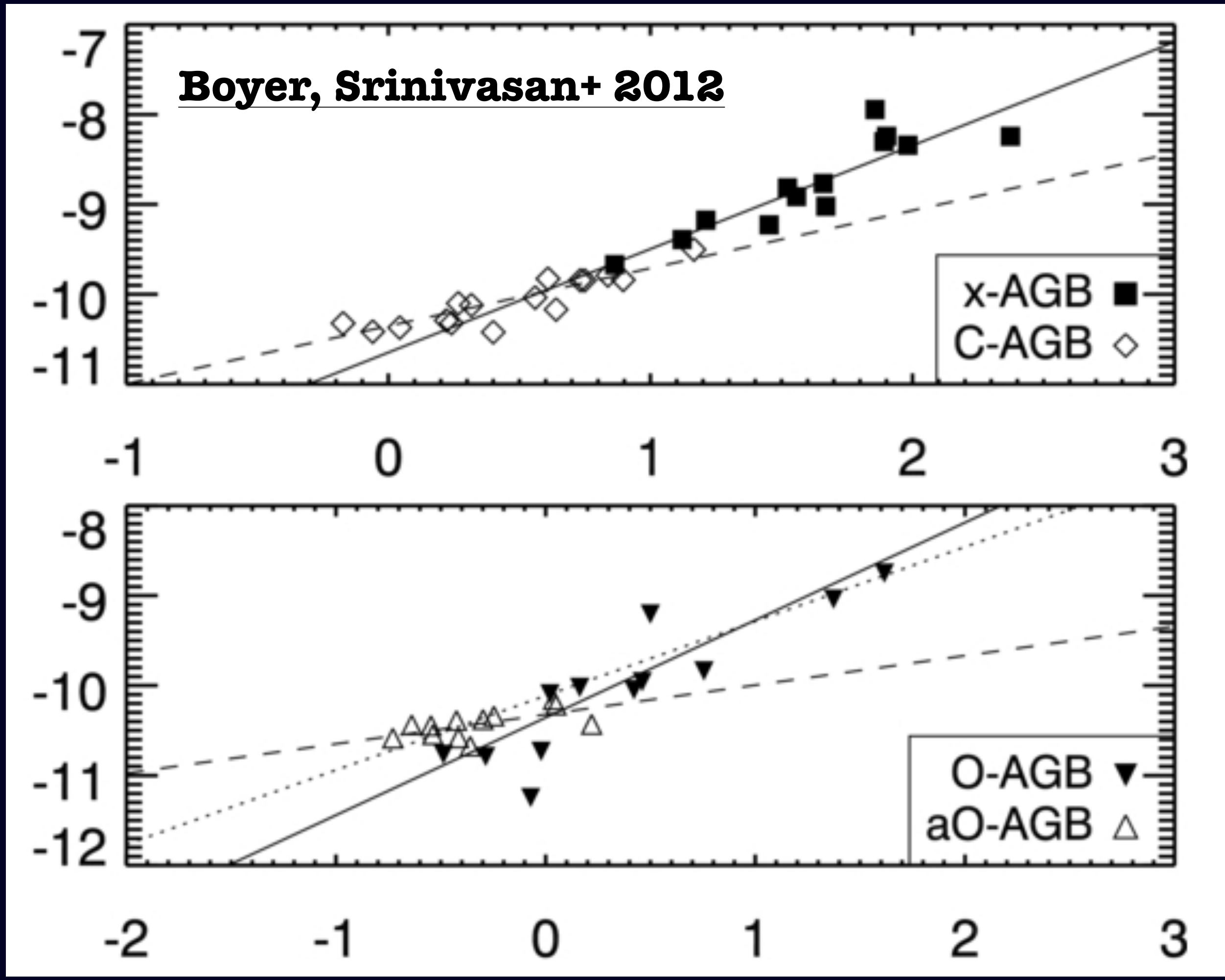

Dust contributes to mid-IR flux, so excess should correlate with DPR.

Srinivasan+ 2009,
Boyer, Srinivasan+ 2012

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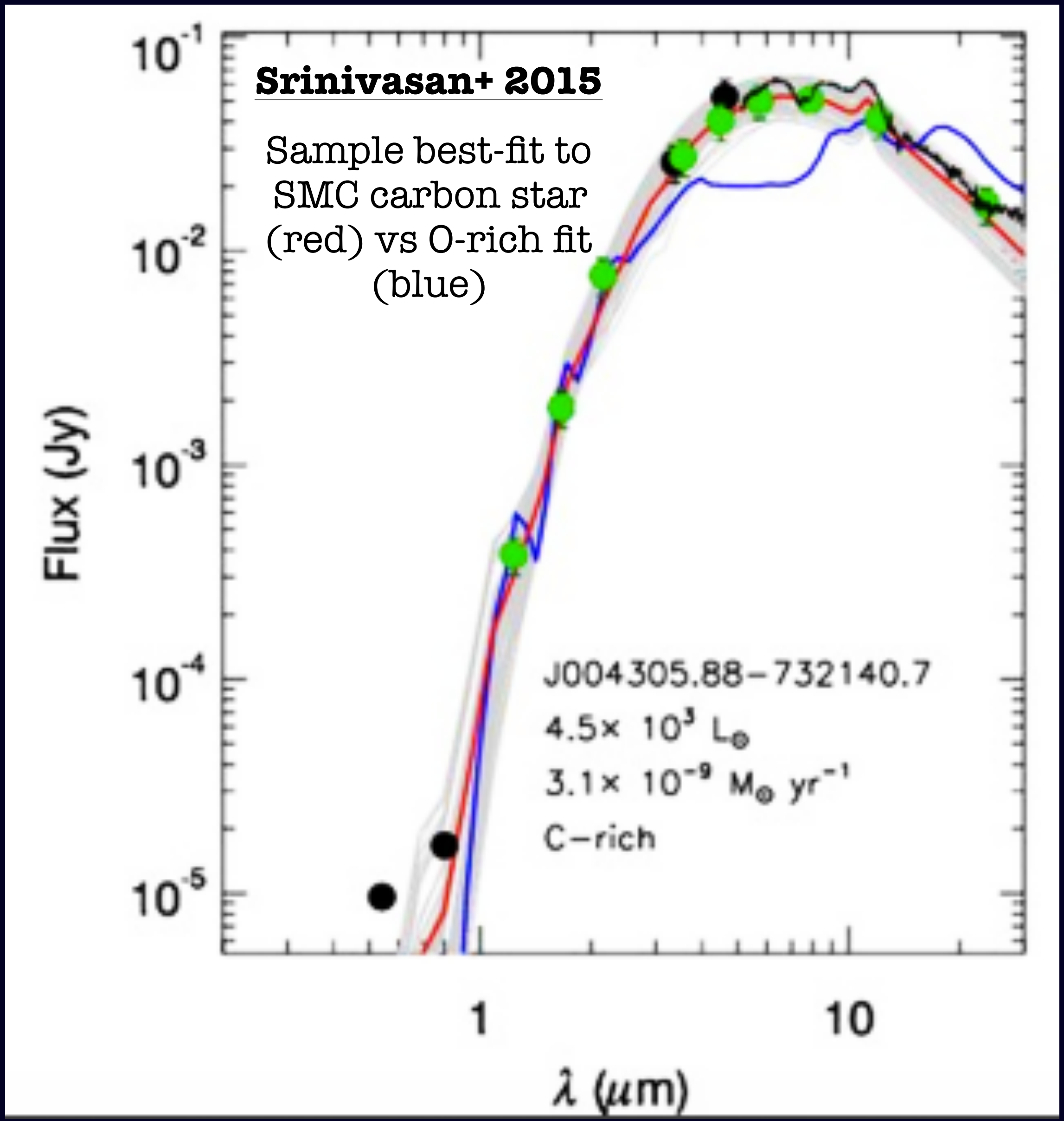

Detailed RT model fit to SED, get best fit parameters including chemical type.

van Loon+ 1999, Groenewegen+ 2009, Sargent, Srinivasan+ 2010, Srinivasan+ 2010, and many others

Computing the dust budget

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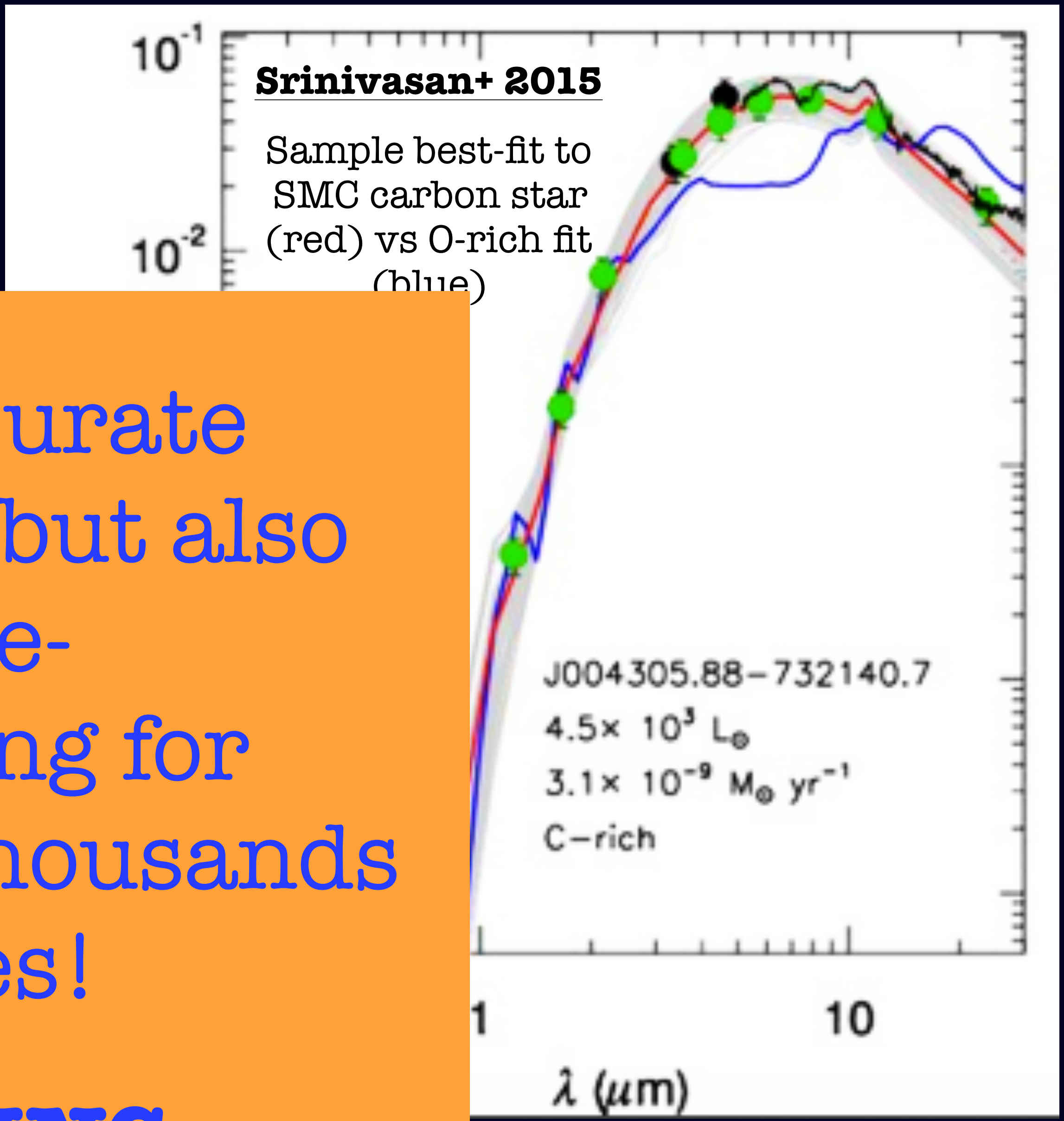

[…]l fit to SED, get best fit
[…]ding chemical type.

[…]van Loon+ 1999, Groenewegen+ 2009, Sargent, Srinivasan+ 2010, Srinivasan+ 2010, and many others

Most accurate method, but also very time-consuming for tens of thousands of sources!

ANYTHING FASTER?

GRAMS: A Grid of RSG and AGB ModelS

Sargent, Srinivasan & Meixner 2011 (O-rich), Srinivasan, Sargent & Meixner 2011 (C-rich)

Srinivasan+ 2016

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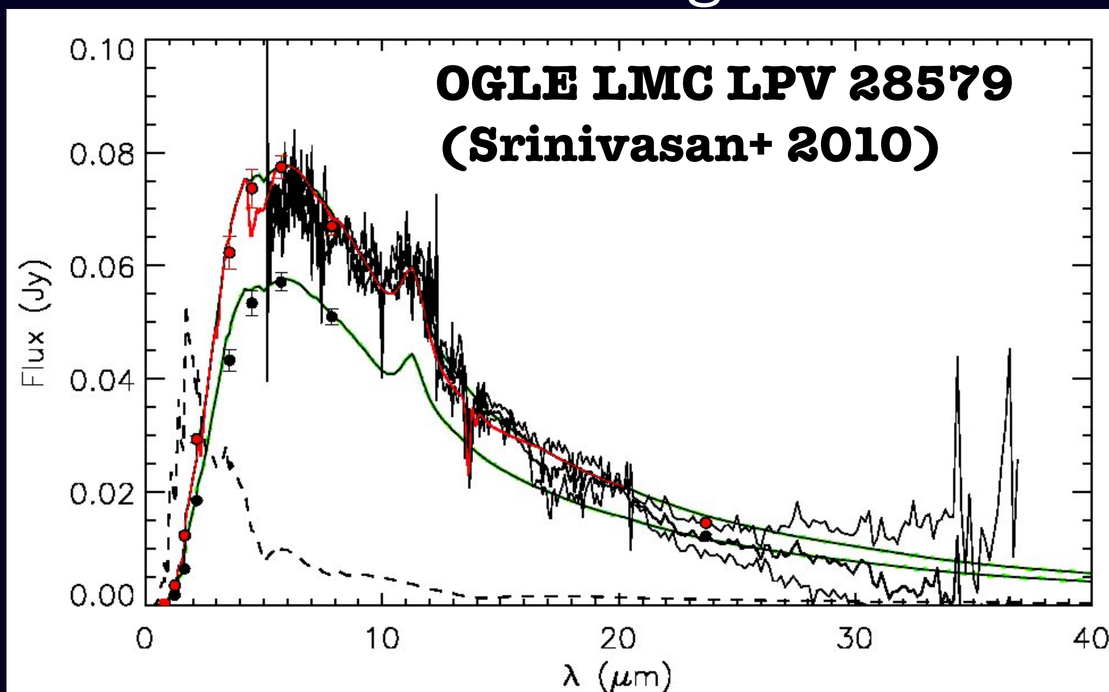
Detailed modelling takes time!



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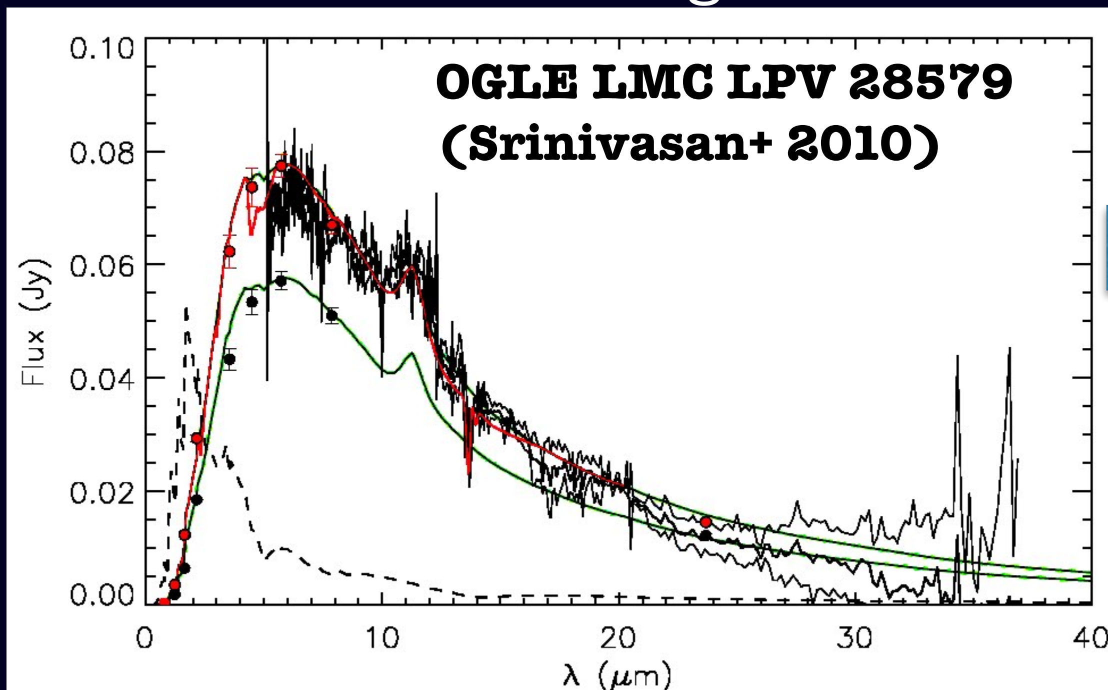

Srinivasan+ 2016

Model grid over range of expected parameter values.

Srinivasan+ 2011, C-rich dust grid.

Photosphere model[a]	
L_* ($L_\odot$)	~1100 to ~26 000
T_{eff} (K)	2600 to 4000 (100)[b]
log g [cm s^{-1}]	−1.0 to 0.0 (0.1)[c]
M ($M_\odot$)	1, 2, 3 and 5
C/O	1.4, 2.0 and 5.0
Dust shell properties	
R_{in} (R_*)	1.5, 3, 4.5, 7, 12
R_{out} (R_{in})	1000
density profile	$\rho(r) \propto r^{-2}$
v_{exp}(km s^{-1})	10
Dust grain properties	
Species	AmC[d] + SiC[e]
SiC fraction	10%
τ(11 μm)	10^{-3} to 10^{-1} (5 per dex), 0.1 to 1 (0.1) and 1.5 to 4 (0.5)
Size distribution	KMH[f] a_{min}(μm) = 0.01 a_0(μm) = 1 γ = 3.5
Mass-loss rate and dust temperature	
$\dot{M}_{dust}$ ($M_\odot$ yr^{-1})	1.5×10^{-12} to 2.1×10^{-7}
$\dot{M}_{gas}$ ($M_\odot$ yr^{-1})[g]	3.0×10^{-10} to 4.3×10^{-5}
T_{in} (K)	710 to 1800[h]

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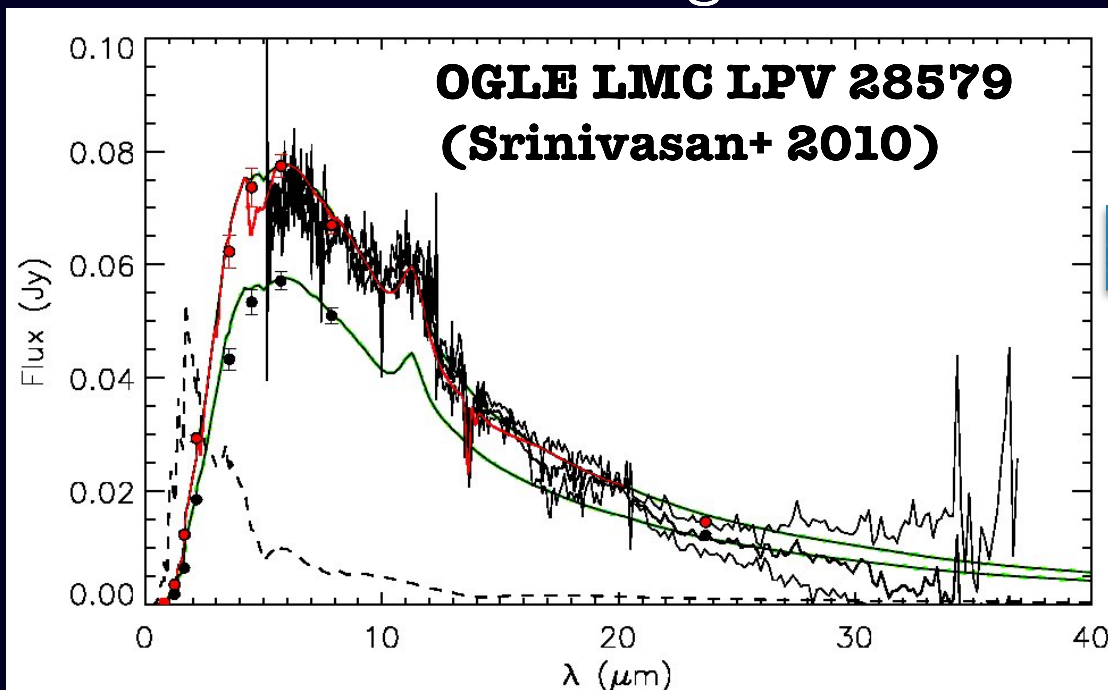

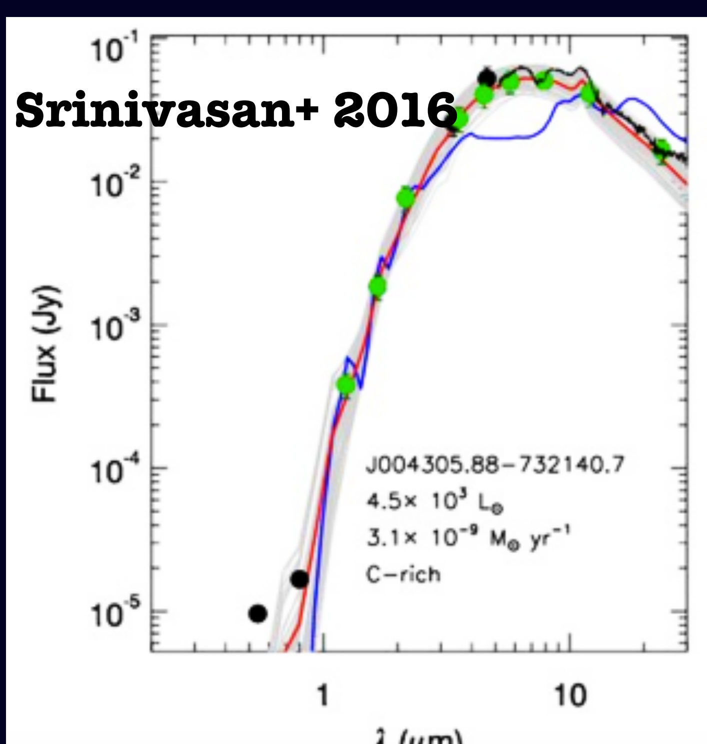

Method similar to Robitaille+ 2007 YSO grid.

Sample best-fit to SMC carbon star (red).

Model grid over range of expected parameter values.

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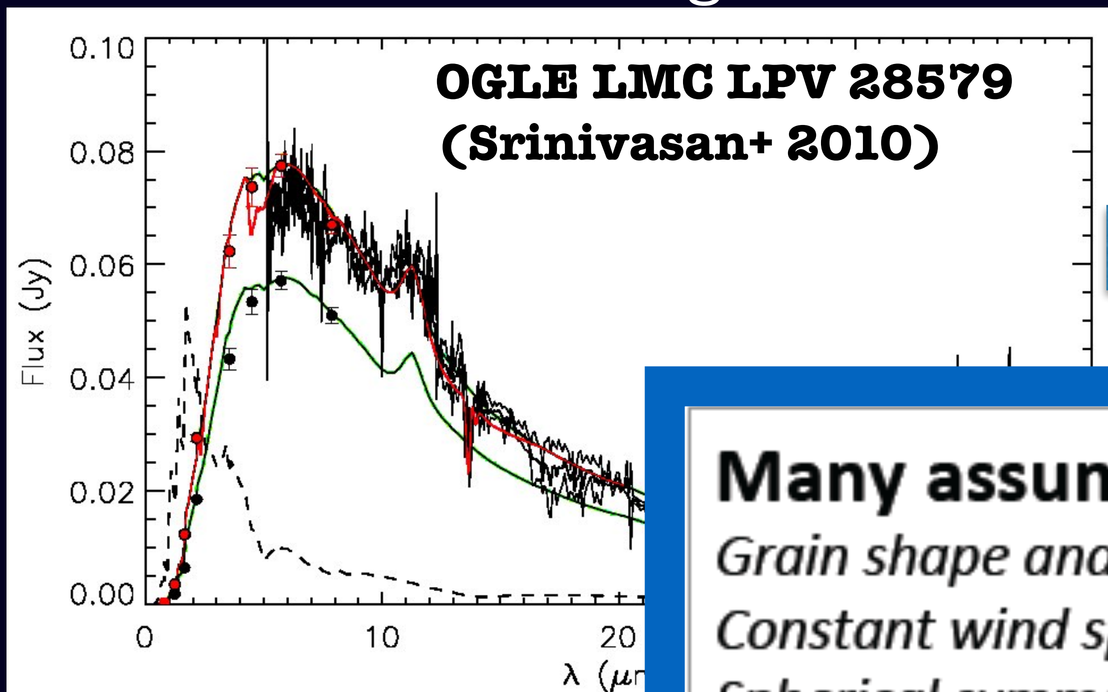

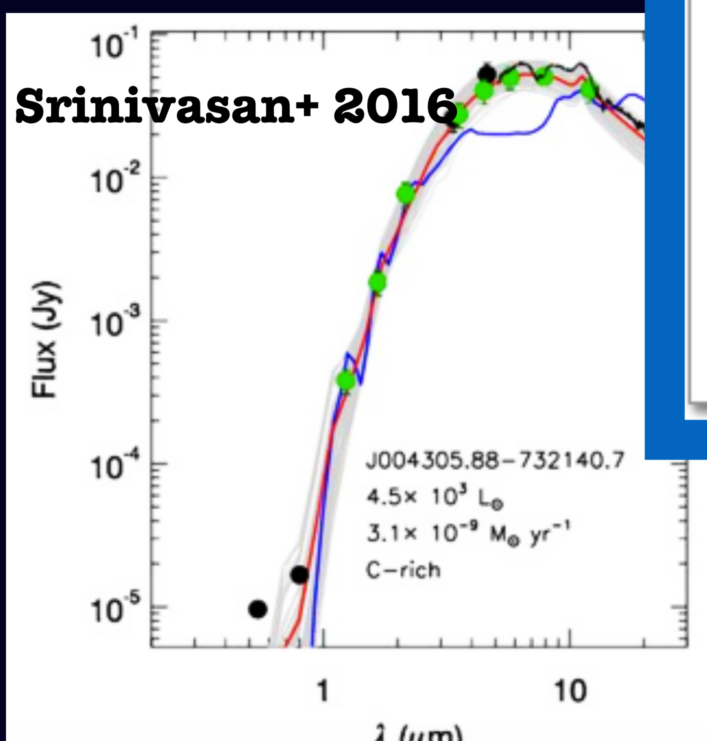

Many assumptions…

Grain shape and size distribution
Constant wind speed
Spherical symmetry
Single star
Dust optical constants (2-4x)
Wind speed (2x)
C vs. M dust (10x)
…

YSO grid.

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The dust budget in nearby galaxies

- CMD selection of AGB/RSG candidates.
- GRAMS model fits to each SED.
- Best 100 fits for each source used to determine chemical type, luminosity, DPR, and associated uncertainties.
- Results: luminosity function, DPR as a function of chemical type, population, etc.

The dust budget in the LMC/SMC

Spitzer data from the SAGE (Meixner+ 2006) and SAGE-SMC (Gordon+ 2010) programs.

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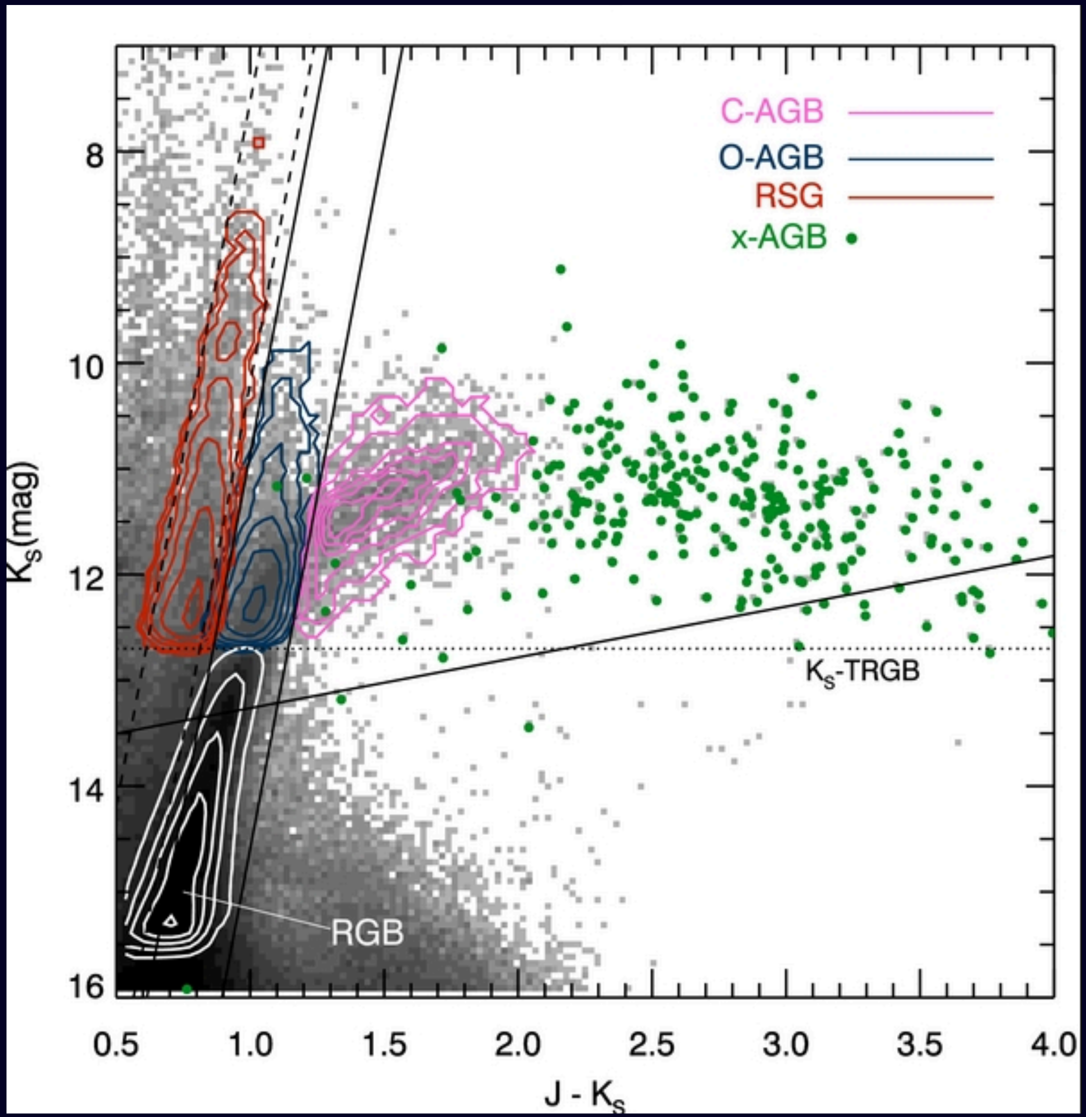

2MASS CMD for optically thin sources.

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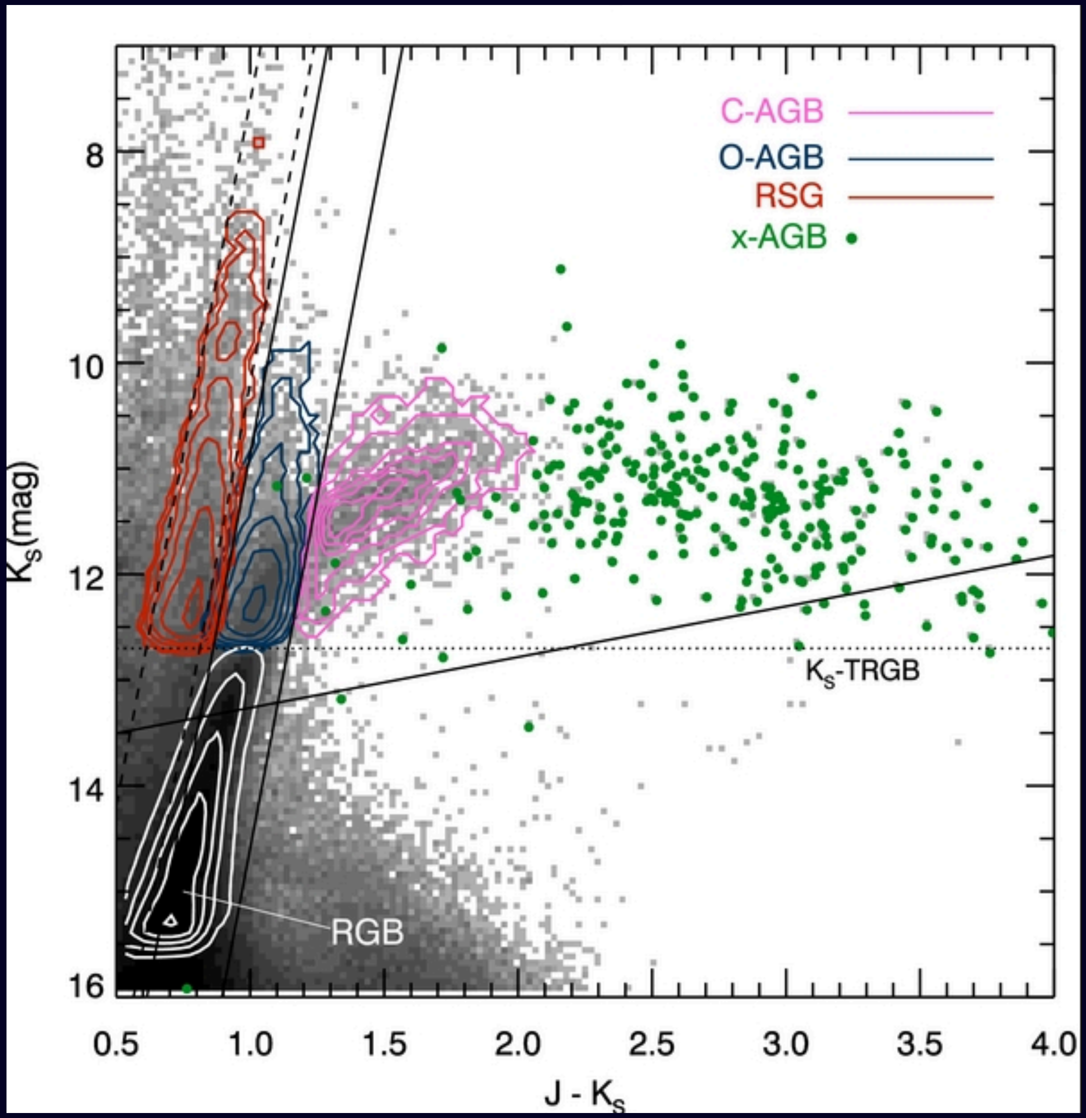

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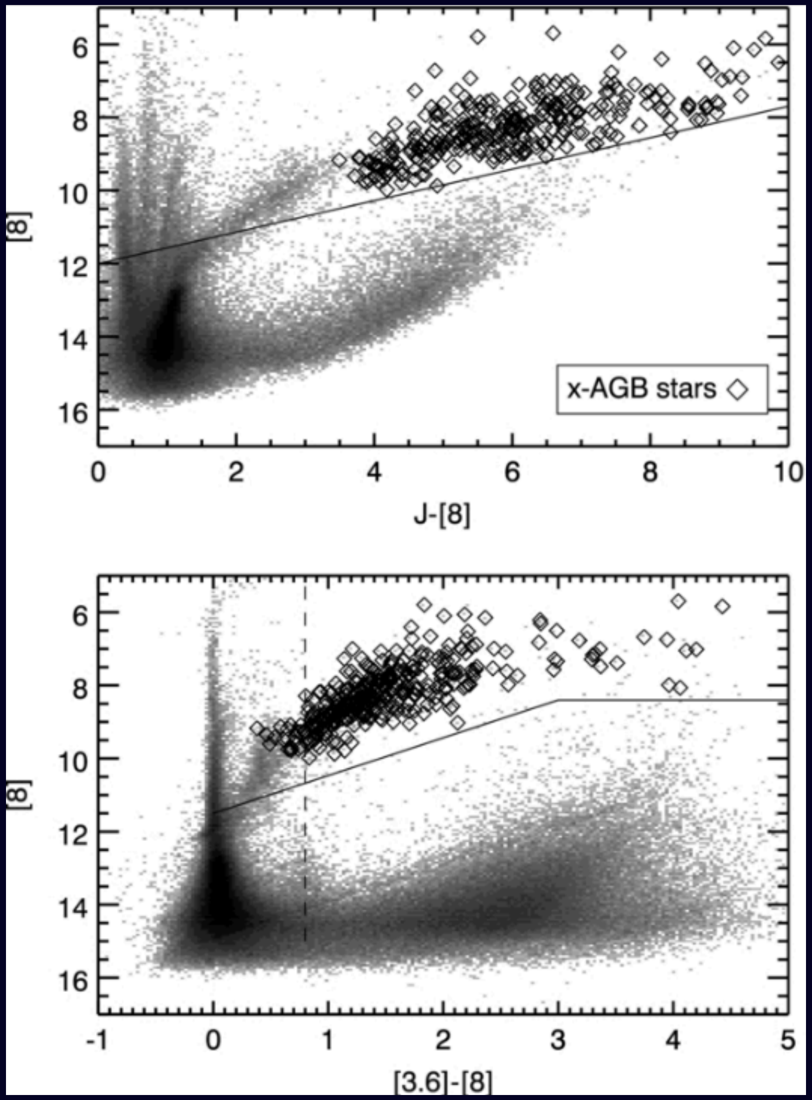


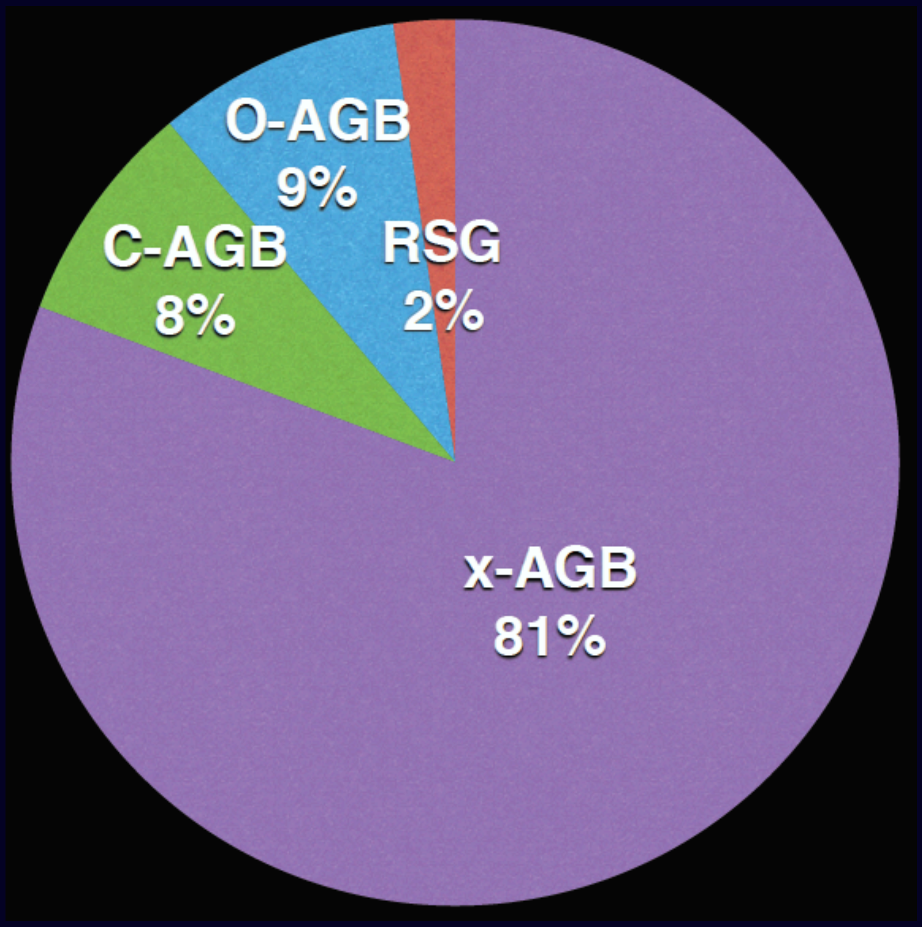
Spitzer CMDs for very dusty objects. (Boyer, Srinivasan+ 2011)

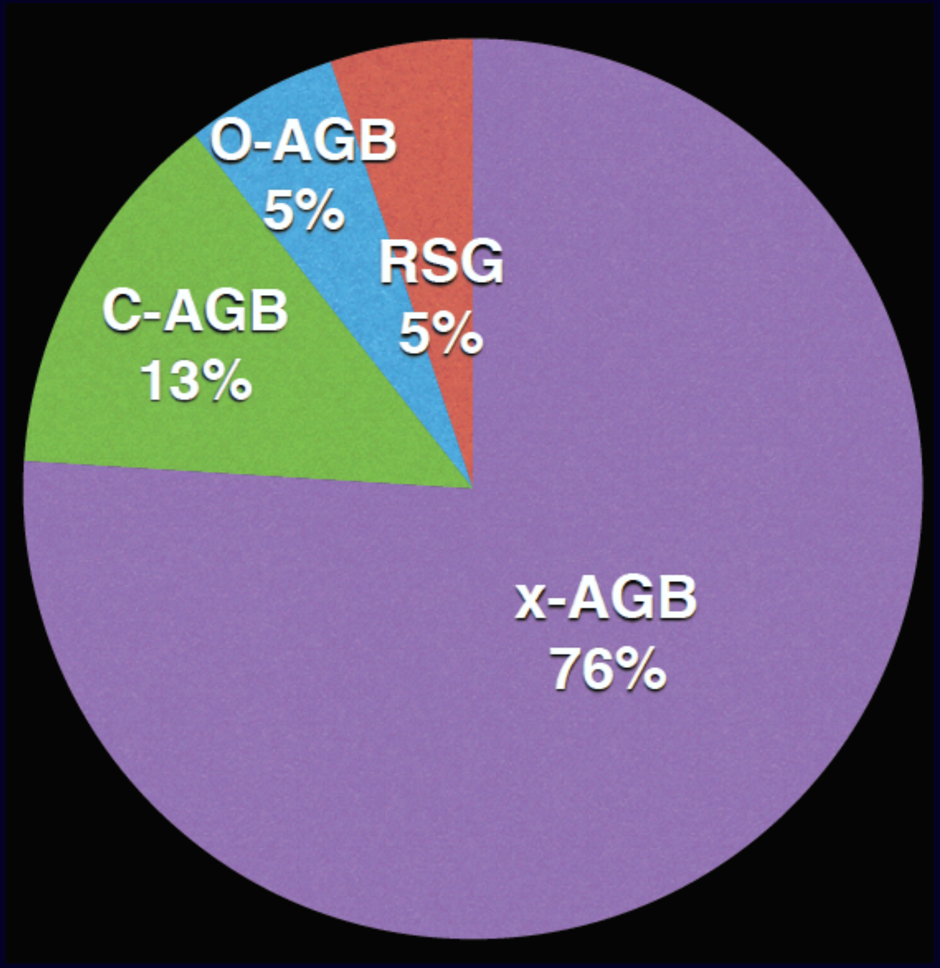
The dust budget in the LMC/SMC

Breakdown by dust mass contribution

The dust budget in the LMC/SMC

Breakdown by dust mass contribution





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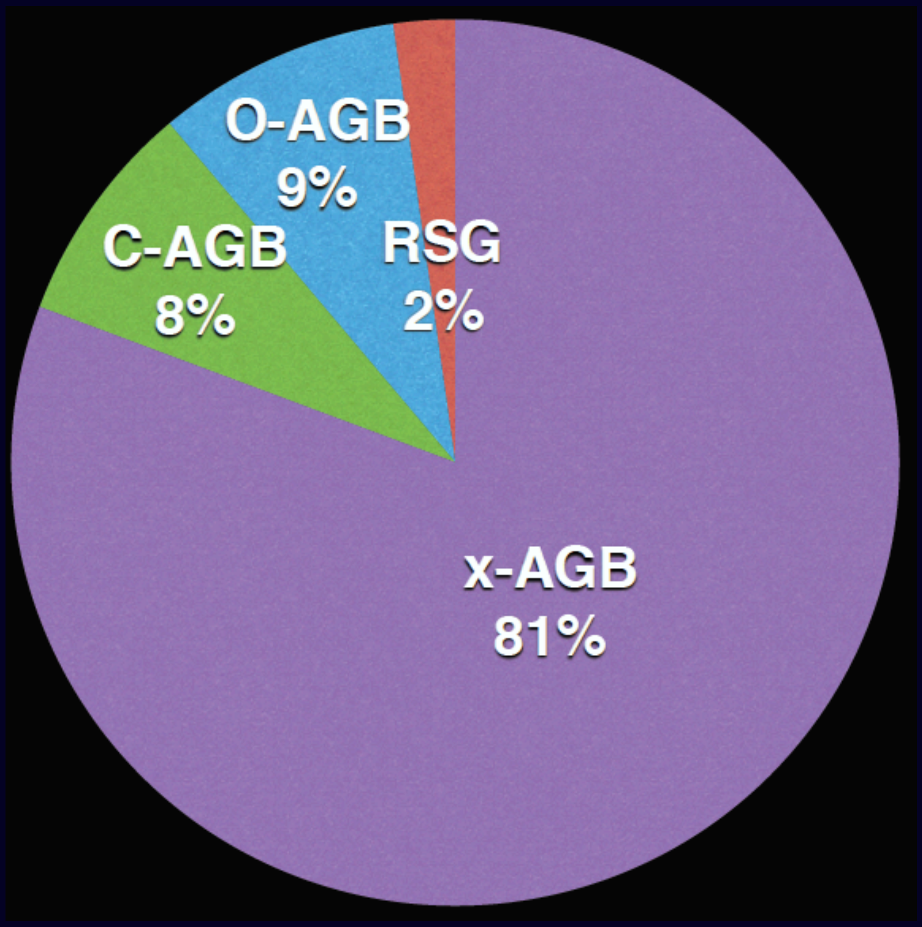

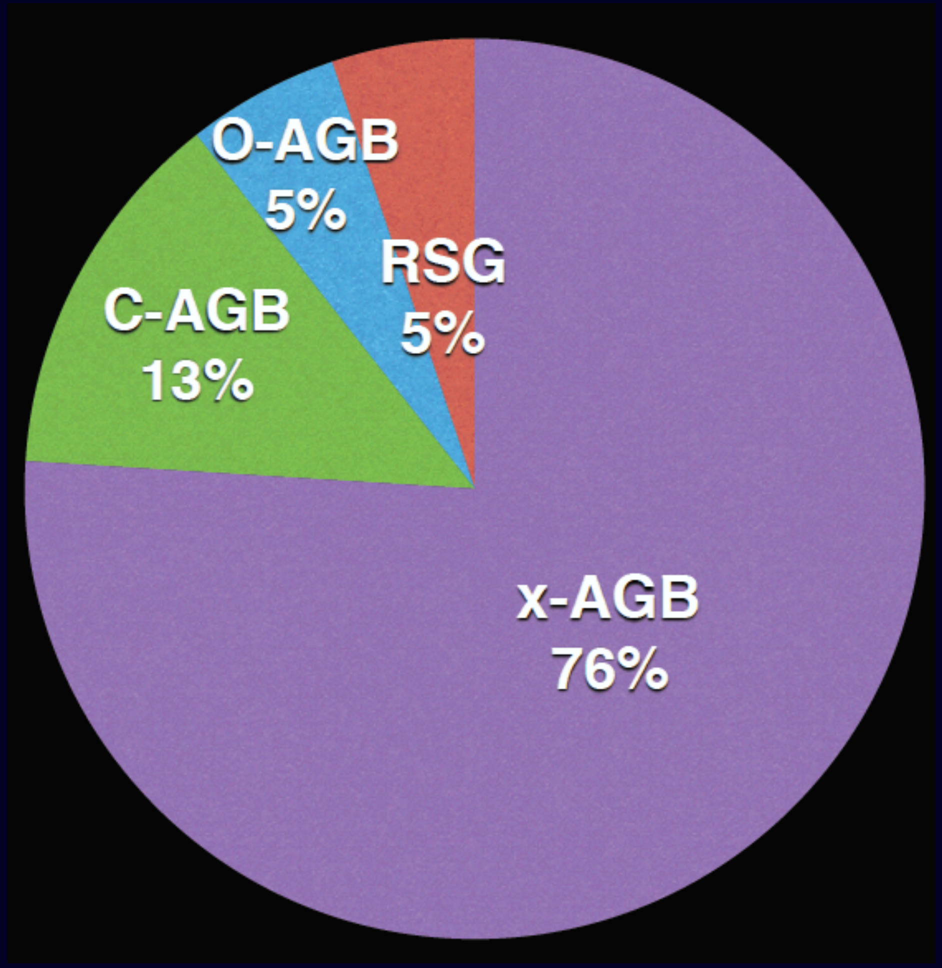

LMC
Total: (2–6) x 10^{-5} M_{sun} yr^{-1}
(Riebel, Srinivasan+ 2012)

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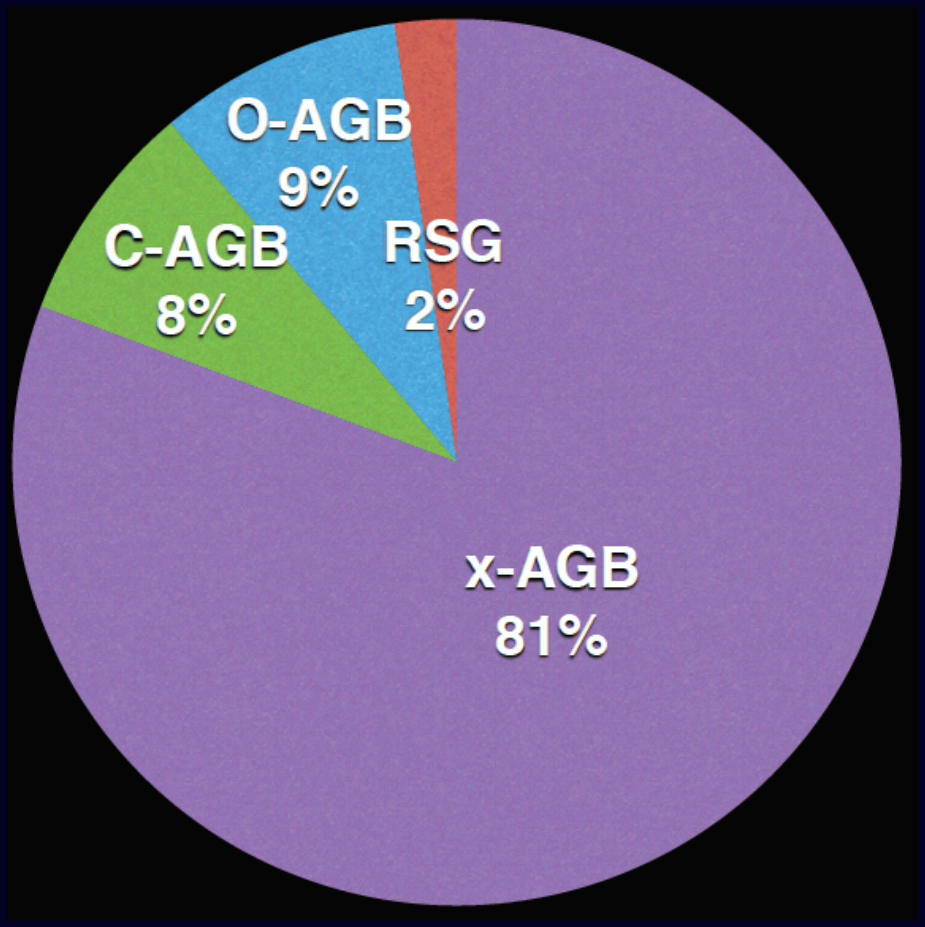

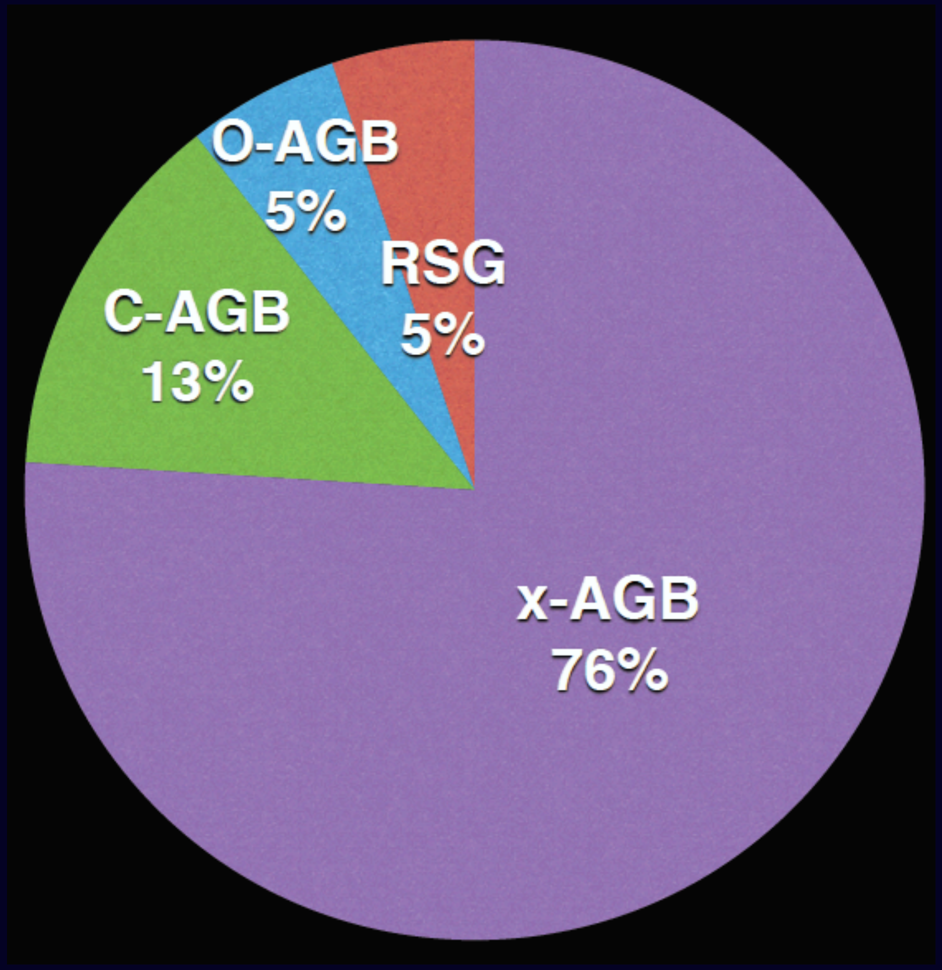

LMC
Total: (2–6) x 10^{-5} M_{sun} yr^{-1}
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SMC
Total: (0.1–1.3) x 10^{-5} M_{sun} yr^{-1}
(Srinivasan+ 2016)

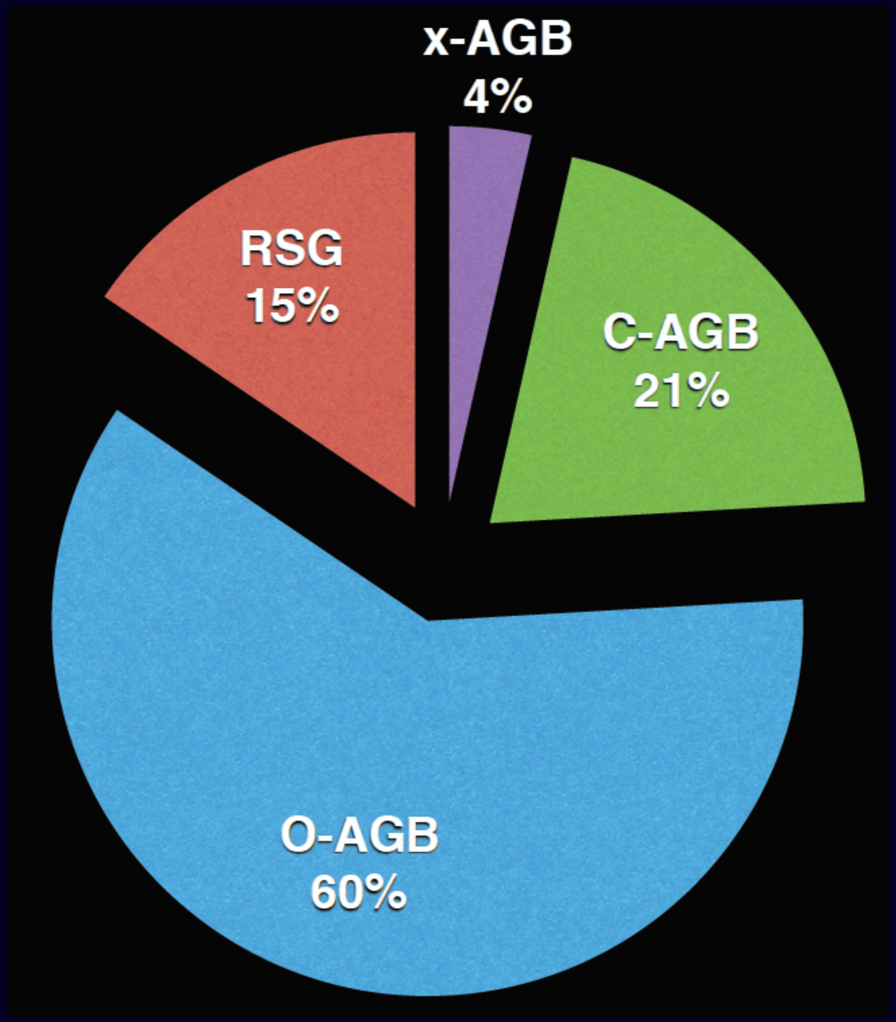
The dust budget in the LMC/SMC

Breakdown by number

The dust budget in the LMC/SMC

Breakdown by number

- Dominant contribution from a very small population of very dusty sources (extreme AGB stars).



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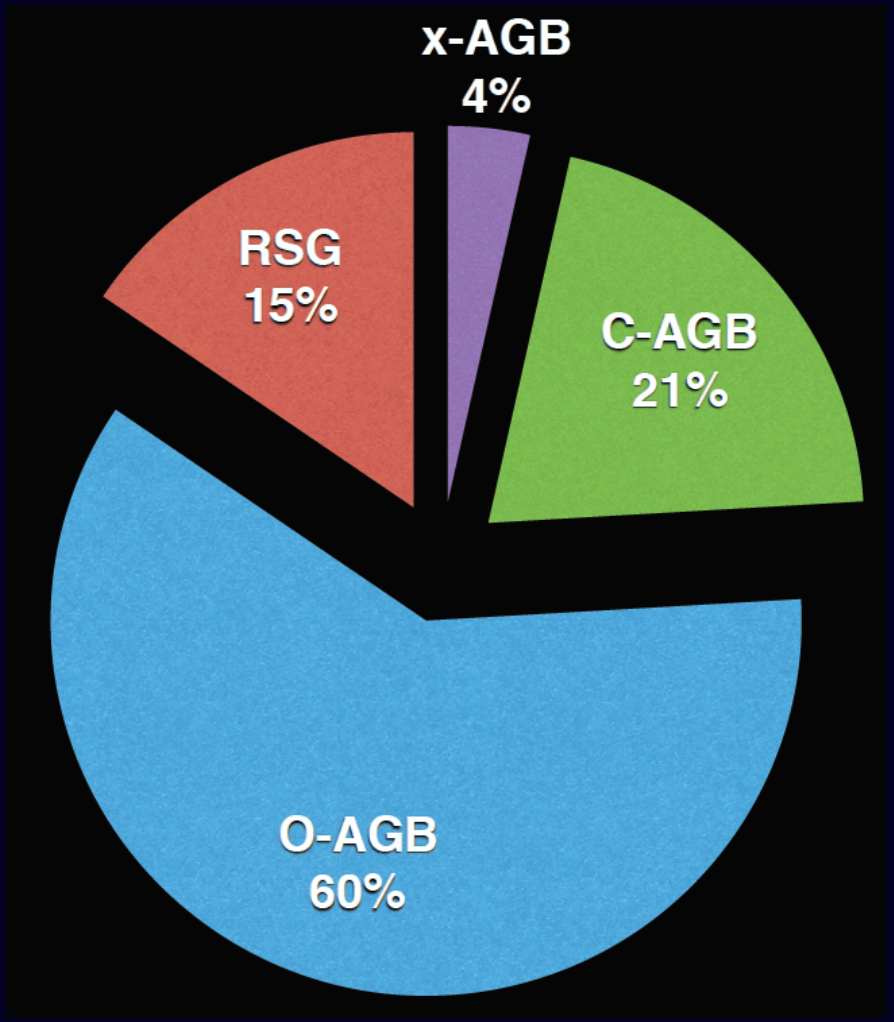

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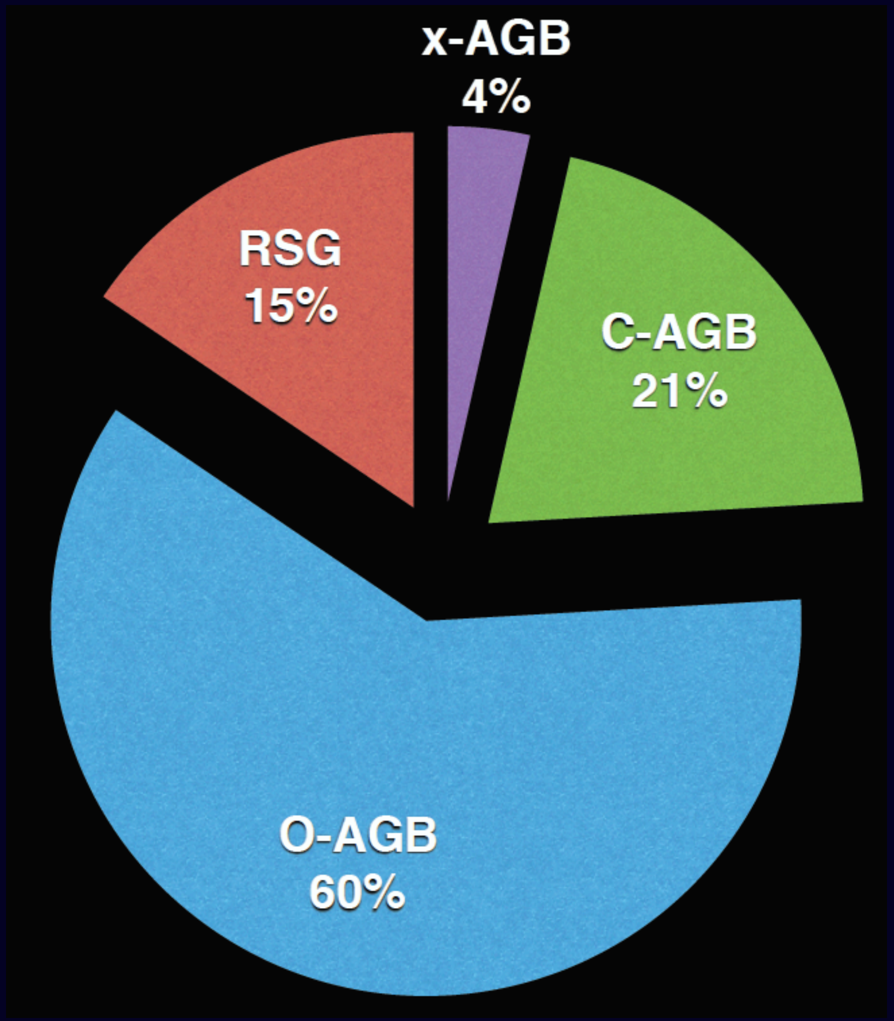
Breakdown by chemistry

The dust budget in the LMC/SMC



Breakdown by number

- Dominant contribution from a very small population of very dusty sources (extreme AGB stars).

Breakdown by chemistry

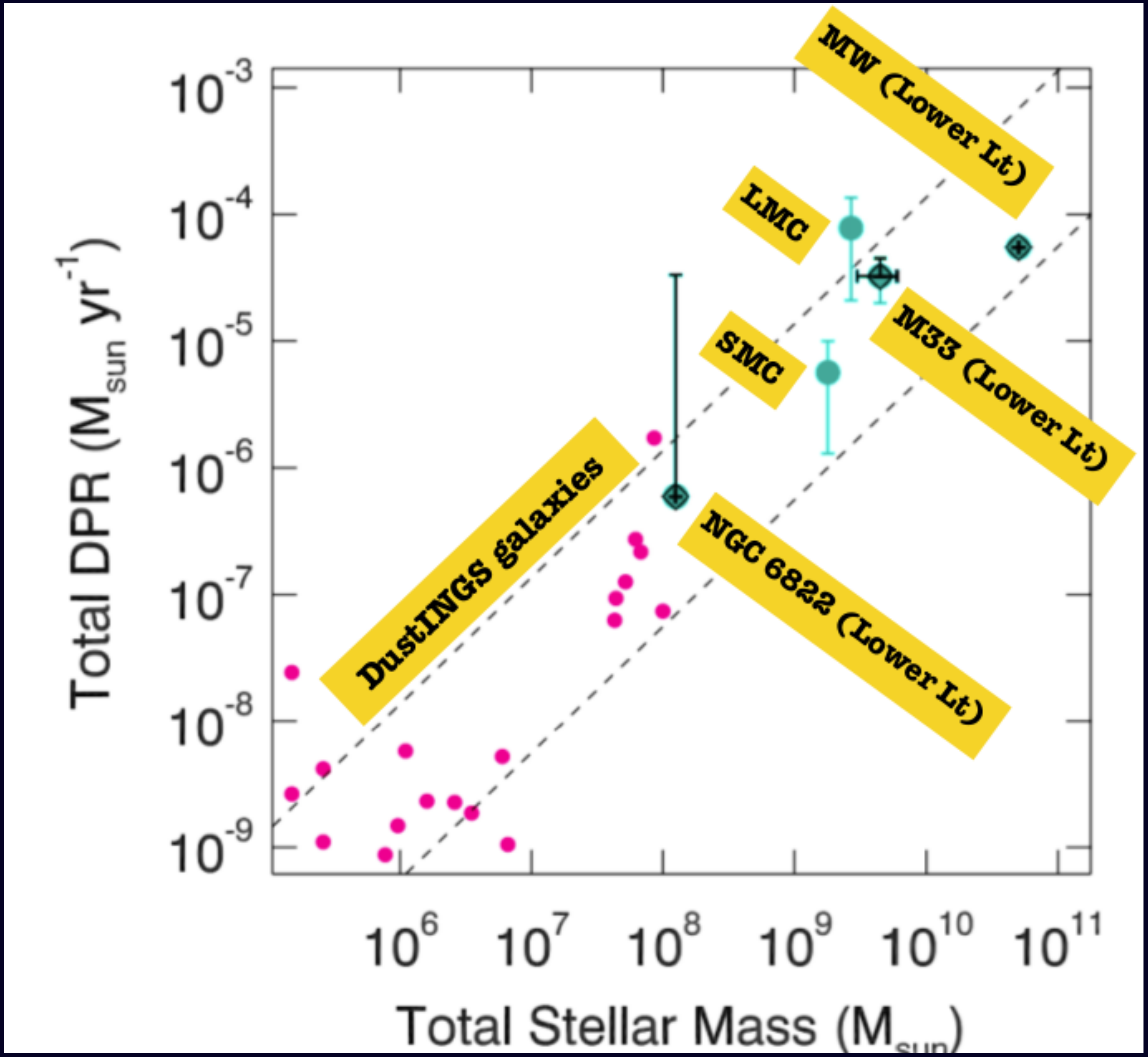
- Carbon stars dominate evolved-star dust production in the Magellanic Clouds (Riebel, Srinivasan+ 2012, Boyer, Srinivasan+ 2012, Srinivasan+ 2016).

The dust budget in nearby galaxies: the story so far

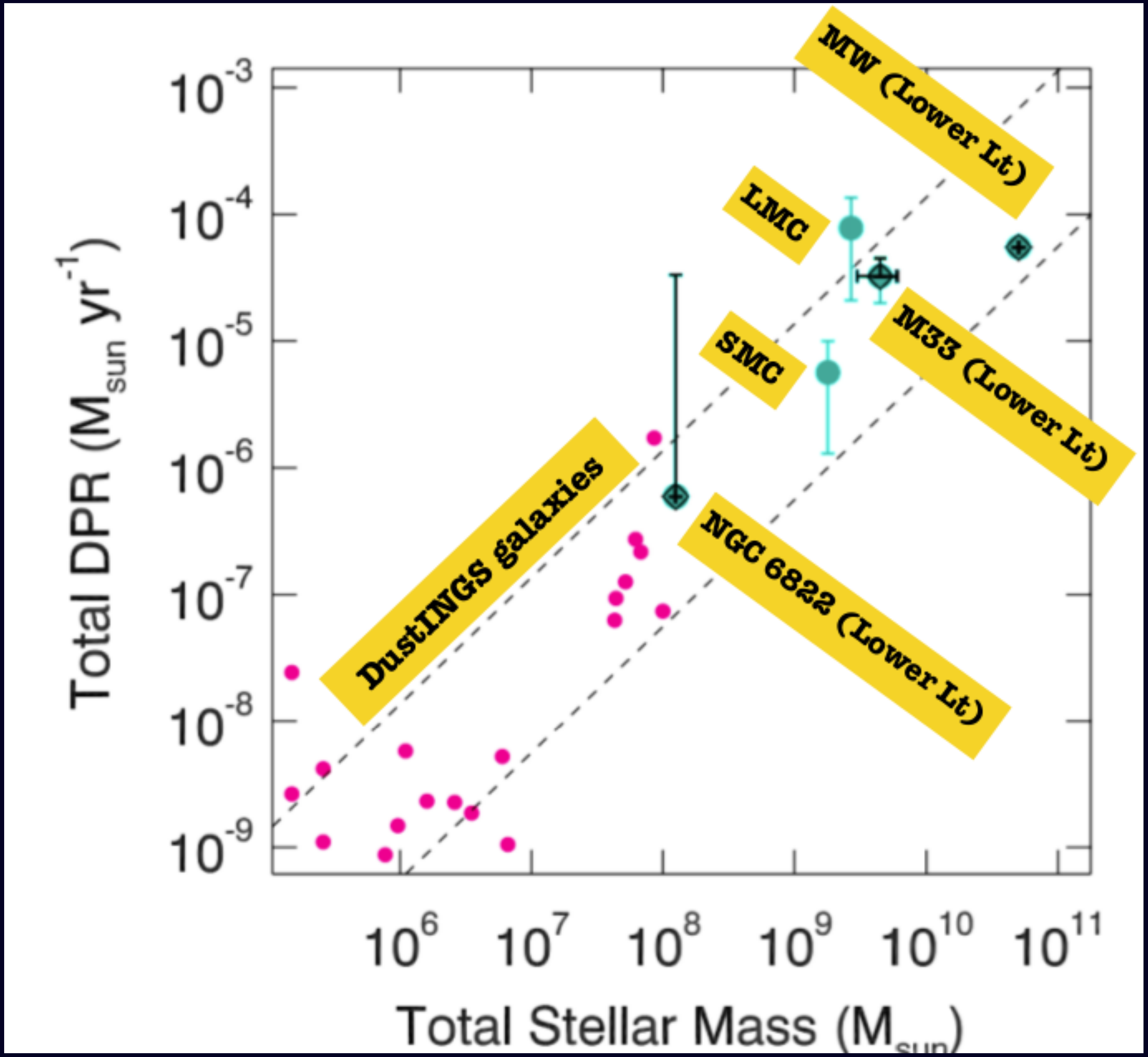
Sundar Srinivasan

2018-06-11

The dust budget in nearby galaxies: the story so far

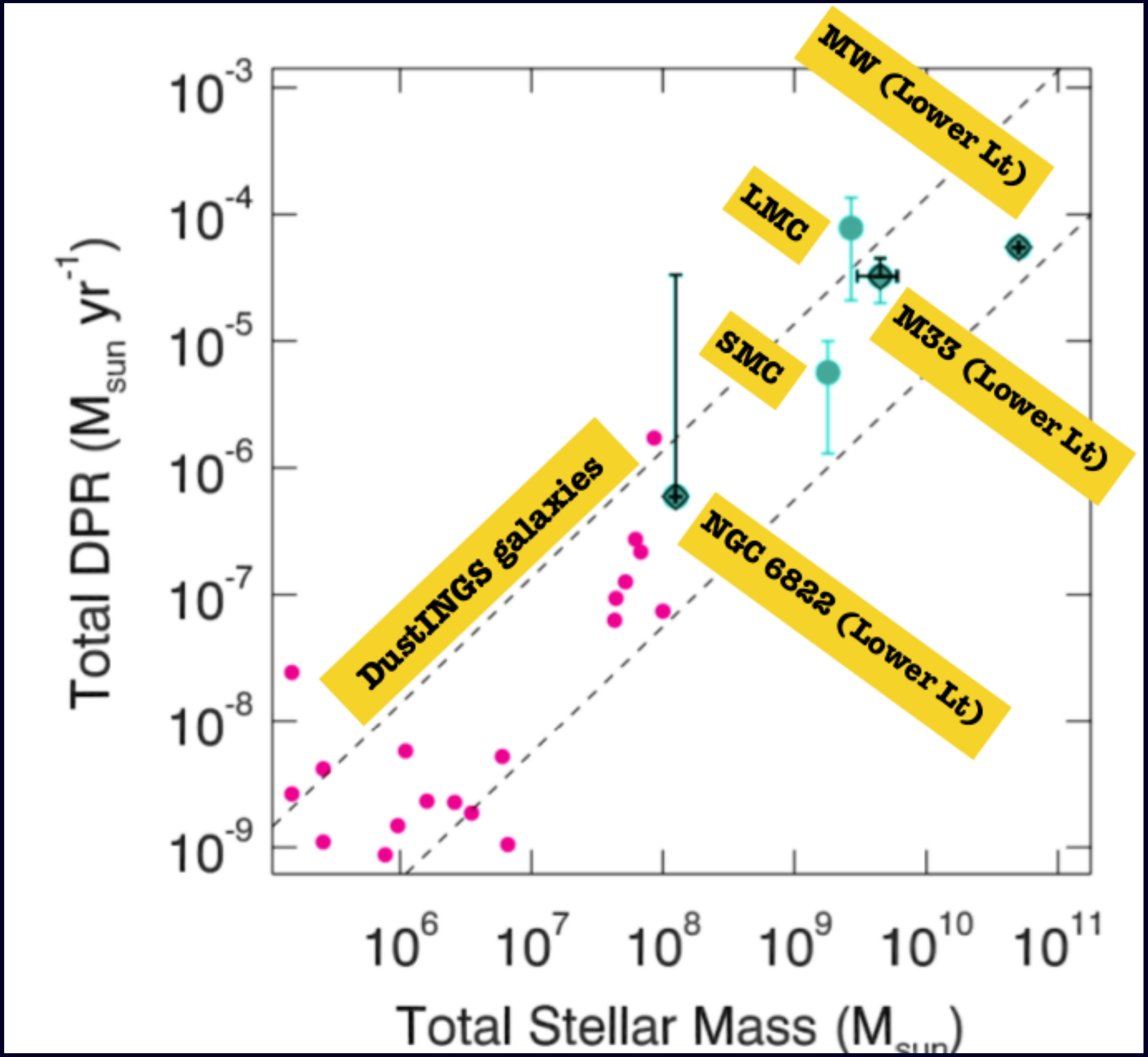


The dust budget in nearby galaxies: the story so far



Papers in prep for:

The dust budget in nearby galaxies: the story so far



Papers in prep for:

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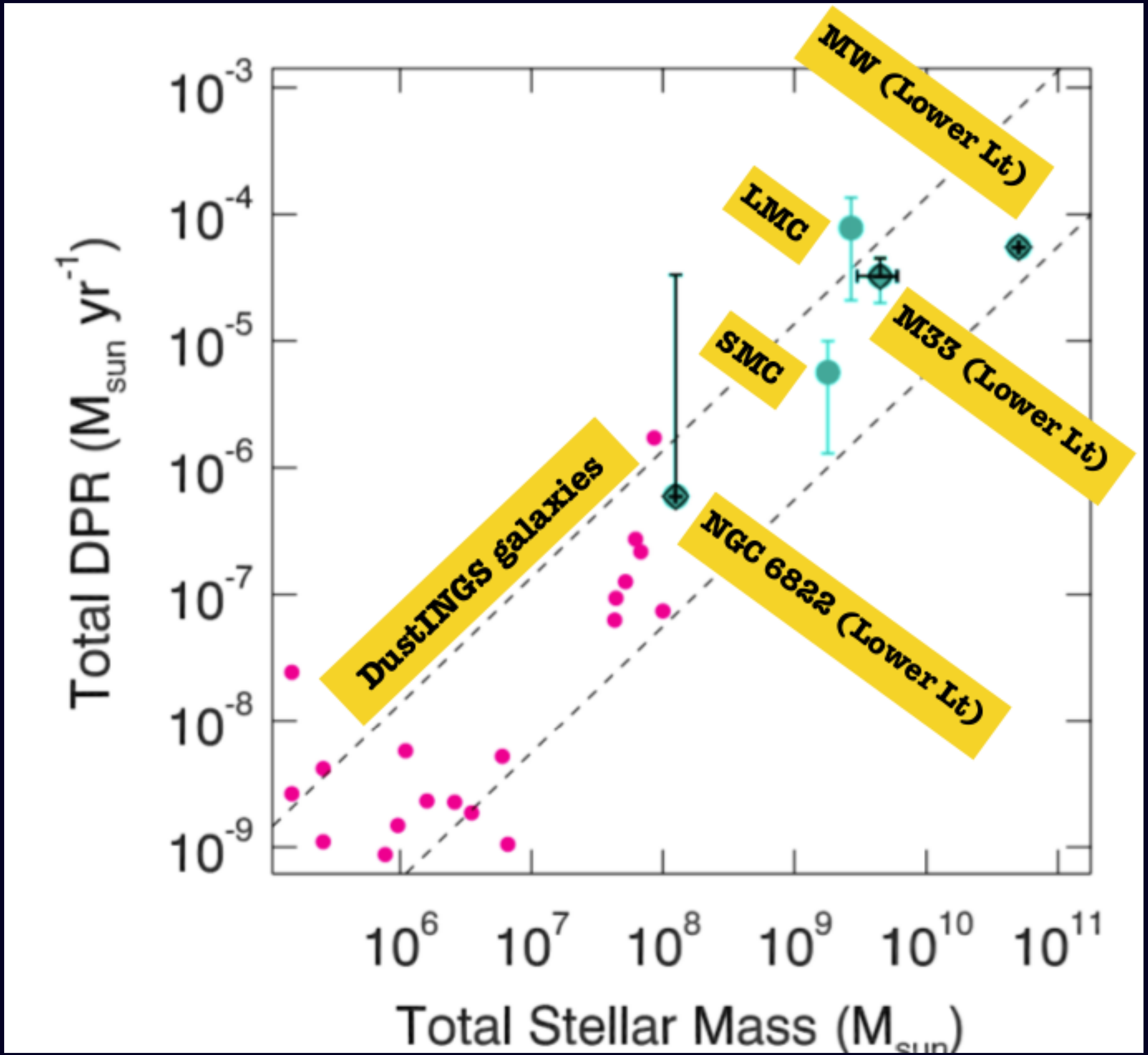

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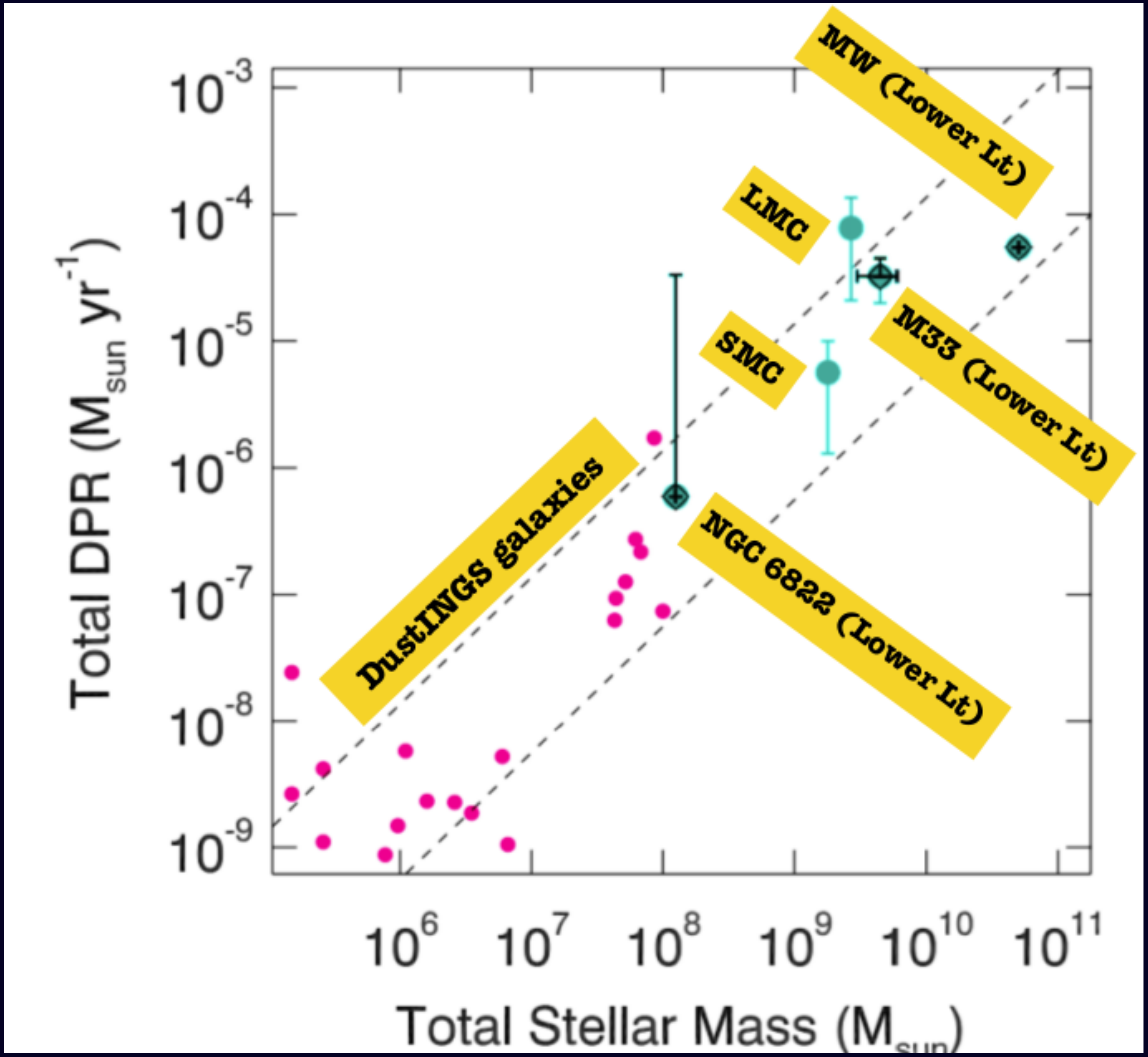

Papers in prep for:

- M33 (Srinivasan+).
- NGC 6822 (Srinivasan+).
- Solar Neighbourhood (Trejo, Srinivasan+ 2015, also in prep — see poster by Ciska Kemper).

Balancing the dust budget in the LMC/SMC

Balancing the dust budget in the LMC/SMC

- AGB/RSG dust input to the SMC: (0.1–1.3) x 10^{-5} M_{sun} yr^{-1}
  (Srinivasan+ 2016)
- SNe dust input (w/o destruction): (0.1–51) x 10^{-5} M_{sun} yr^{-1}
  (Temim+ 2015)
- ISM dust mass: (8.3 ± 2.1) x 10^{4} M_{sun}
  (Gordon+ 2014)

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==> A significant fraction of ISM dust originates from stellar sources.

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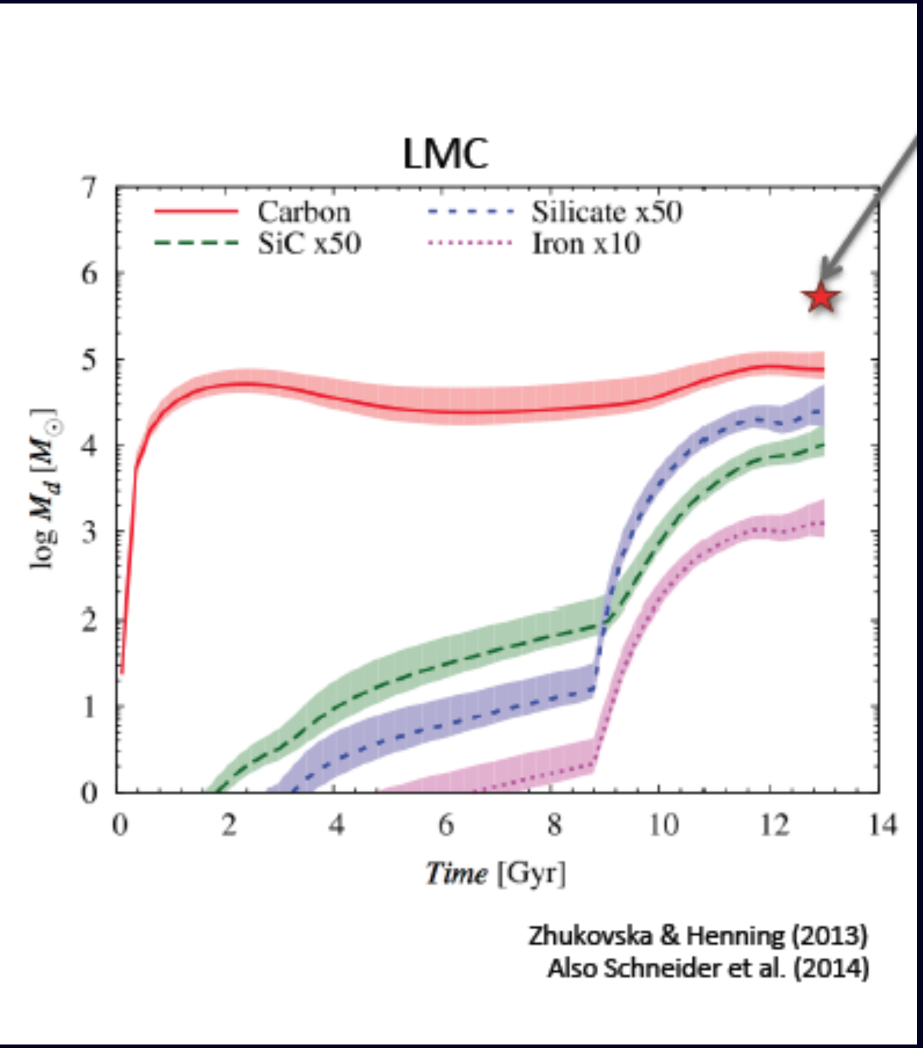
Similar result in the LMC.

Balancing the dust budget in the LMC/SMC

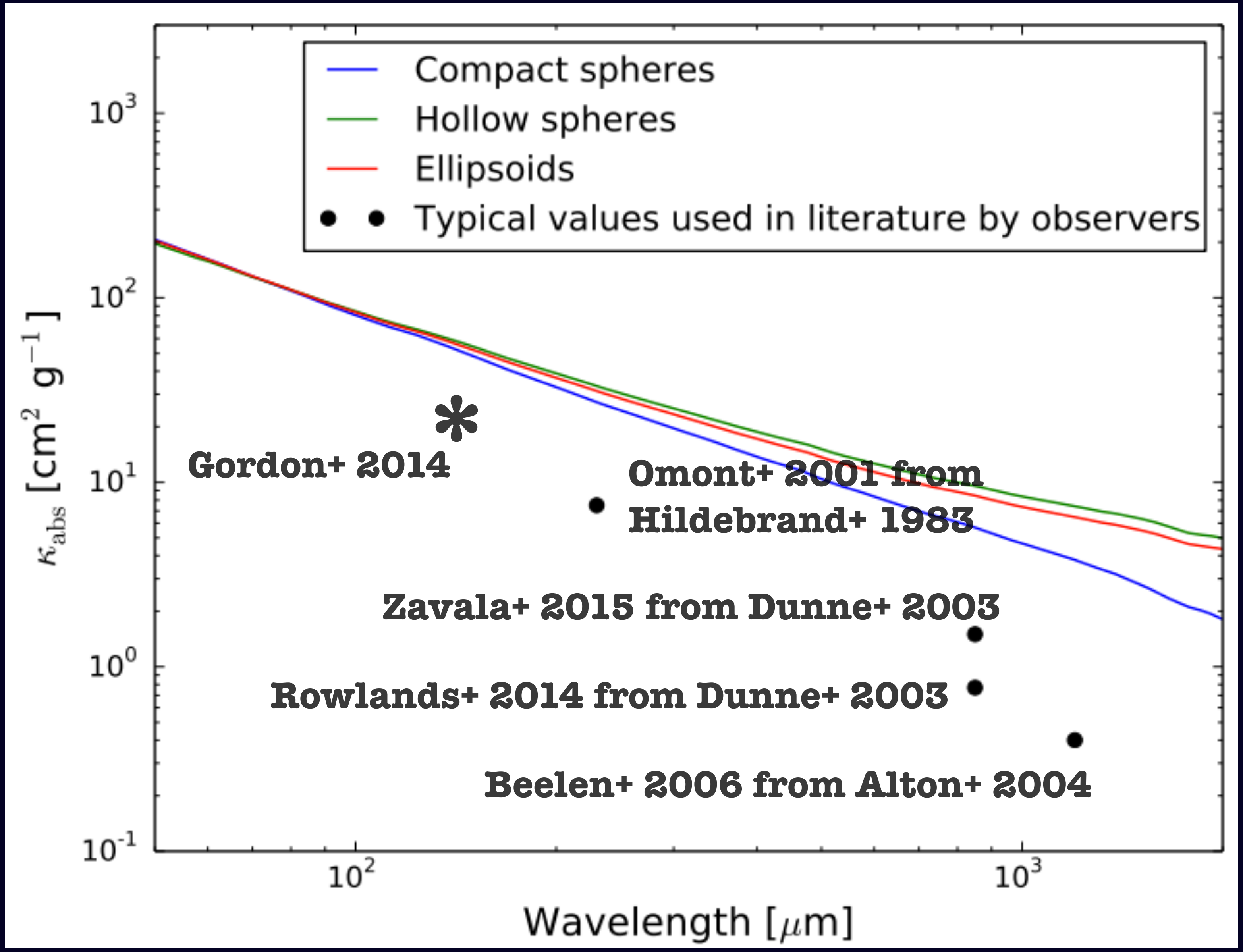
- AGB/RSG dust input to the SMC: (0.1–1.3) x 10^{-5} M_{sun} yr^{-1} (Srinivasan+ 2016)
- SNe dust input (w/o destruction): (0.1–51) x 10^{-5} M_{sun} yr^{-1} (Temim+ 2015)
- ISM dust mass: (8.3 ± 2.1) x 10^{4} M_{sun} (Gordon+ 2014)

==> Replenishment timescale > 0.4 Gyr (w/o dust destruction)
==> A significant fraction of ISM dust originates from stellar sources.

Similar result in the LMC.



Sub-mm dust opacities may be overestimated by up to 20x! (Fanciullo et al. in prep, see Lapo's talk)



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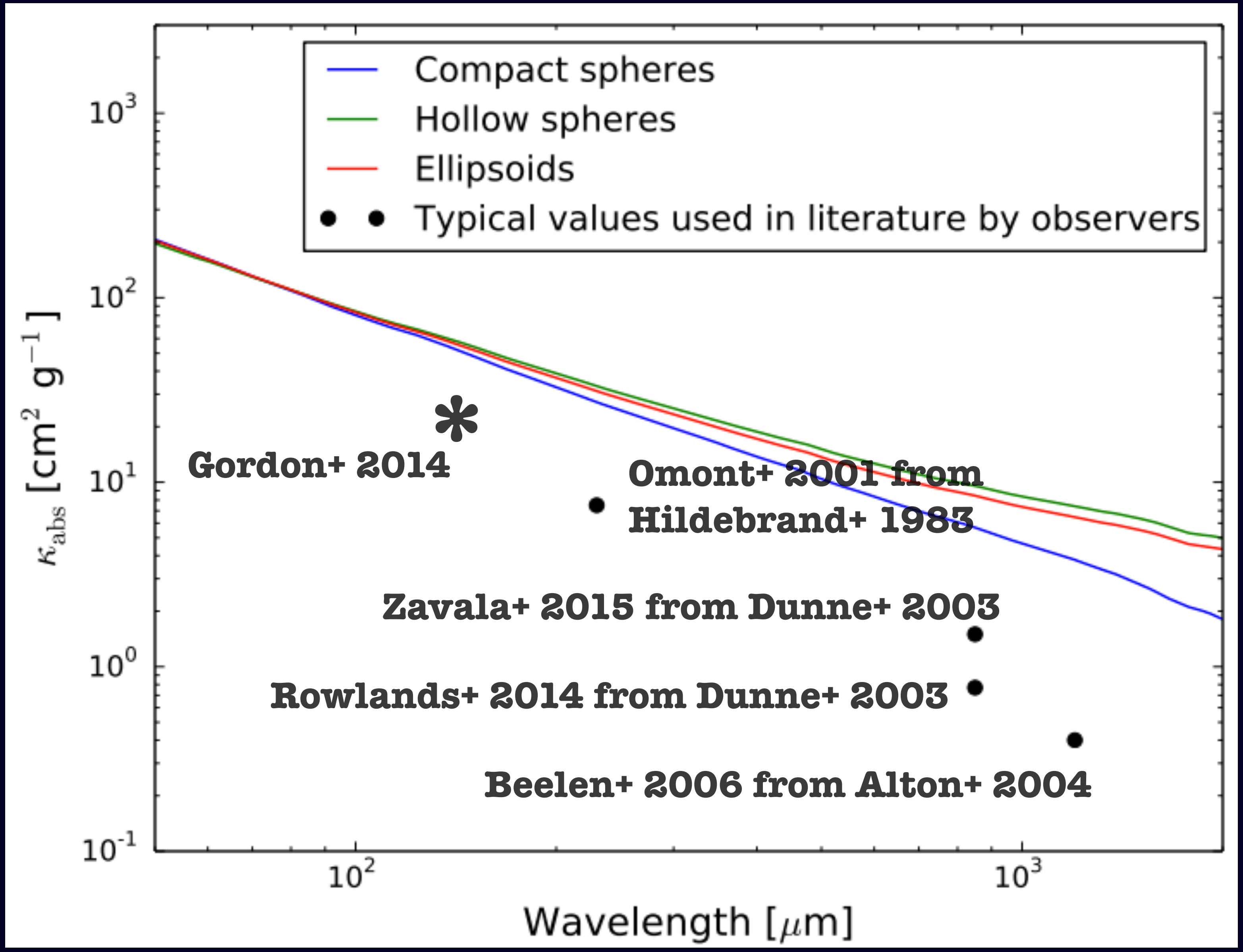

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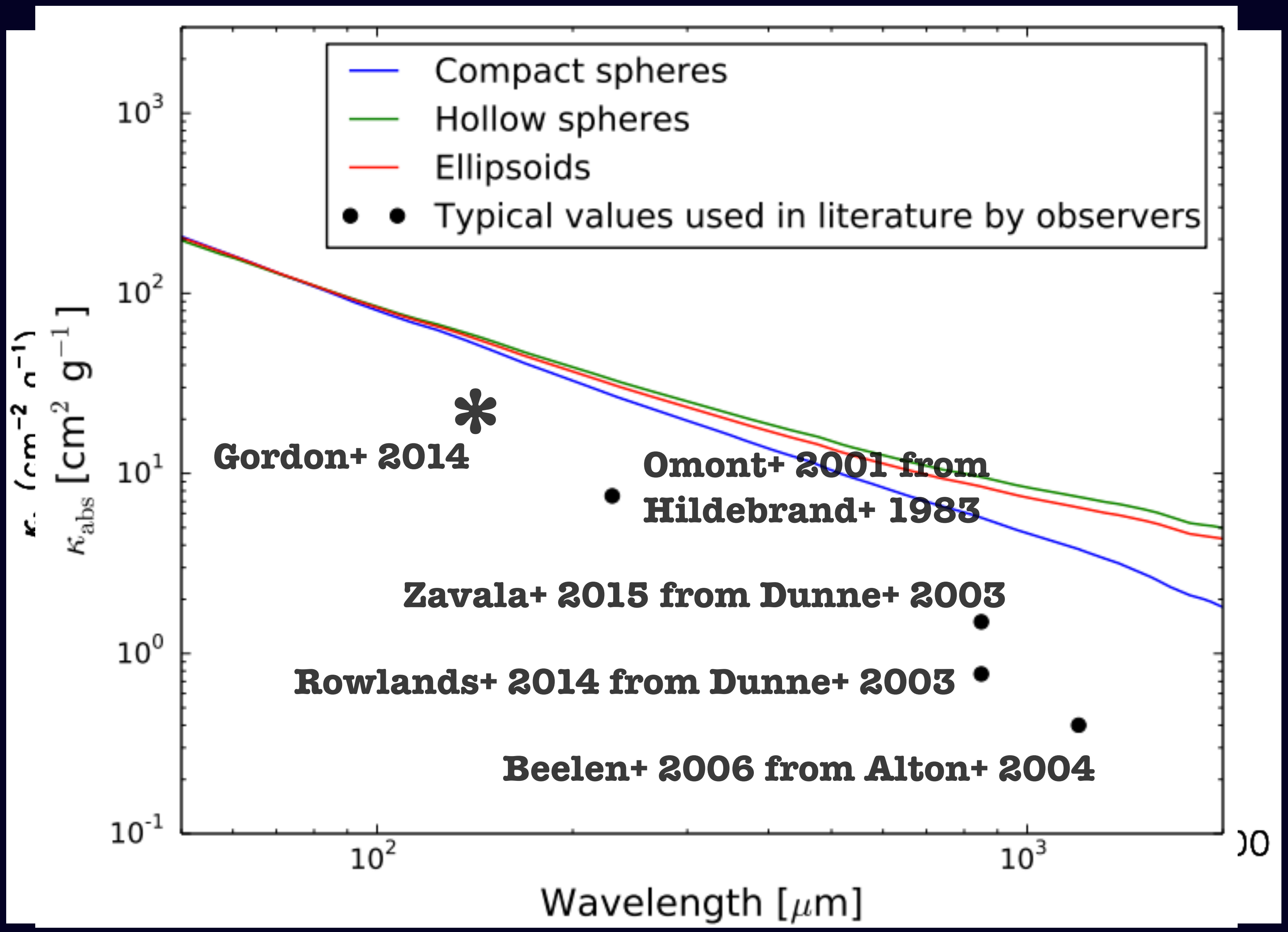

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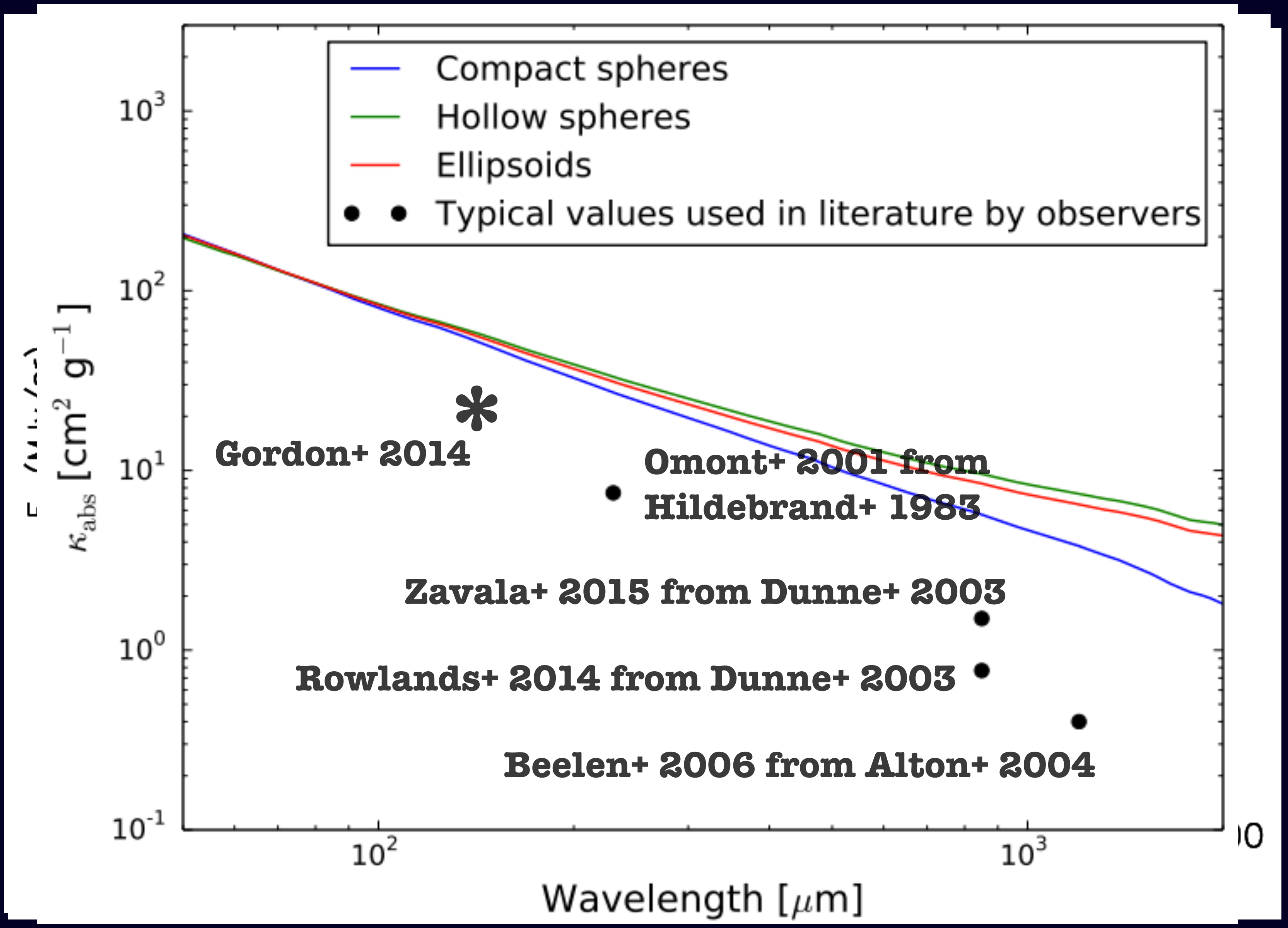

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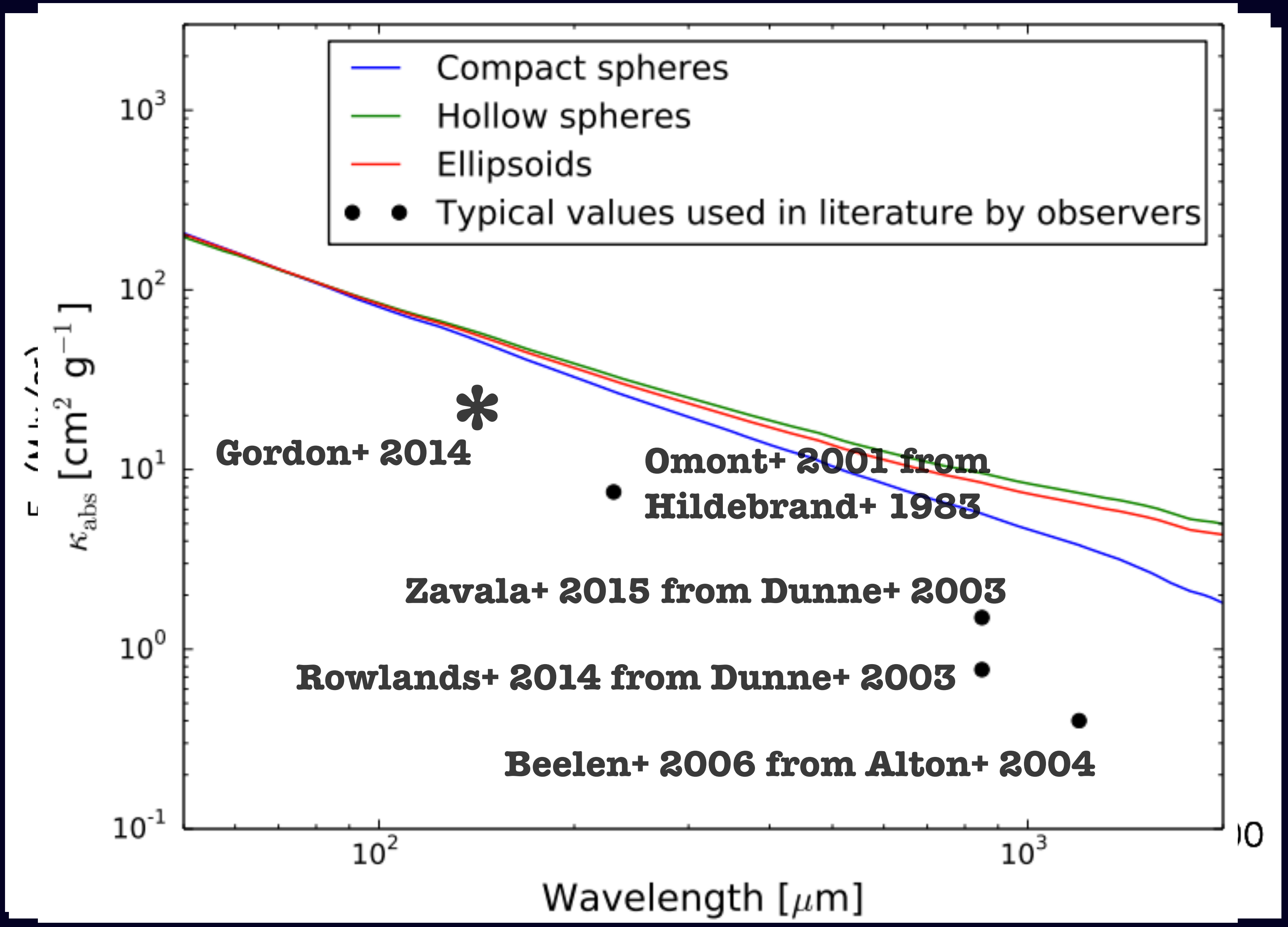

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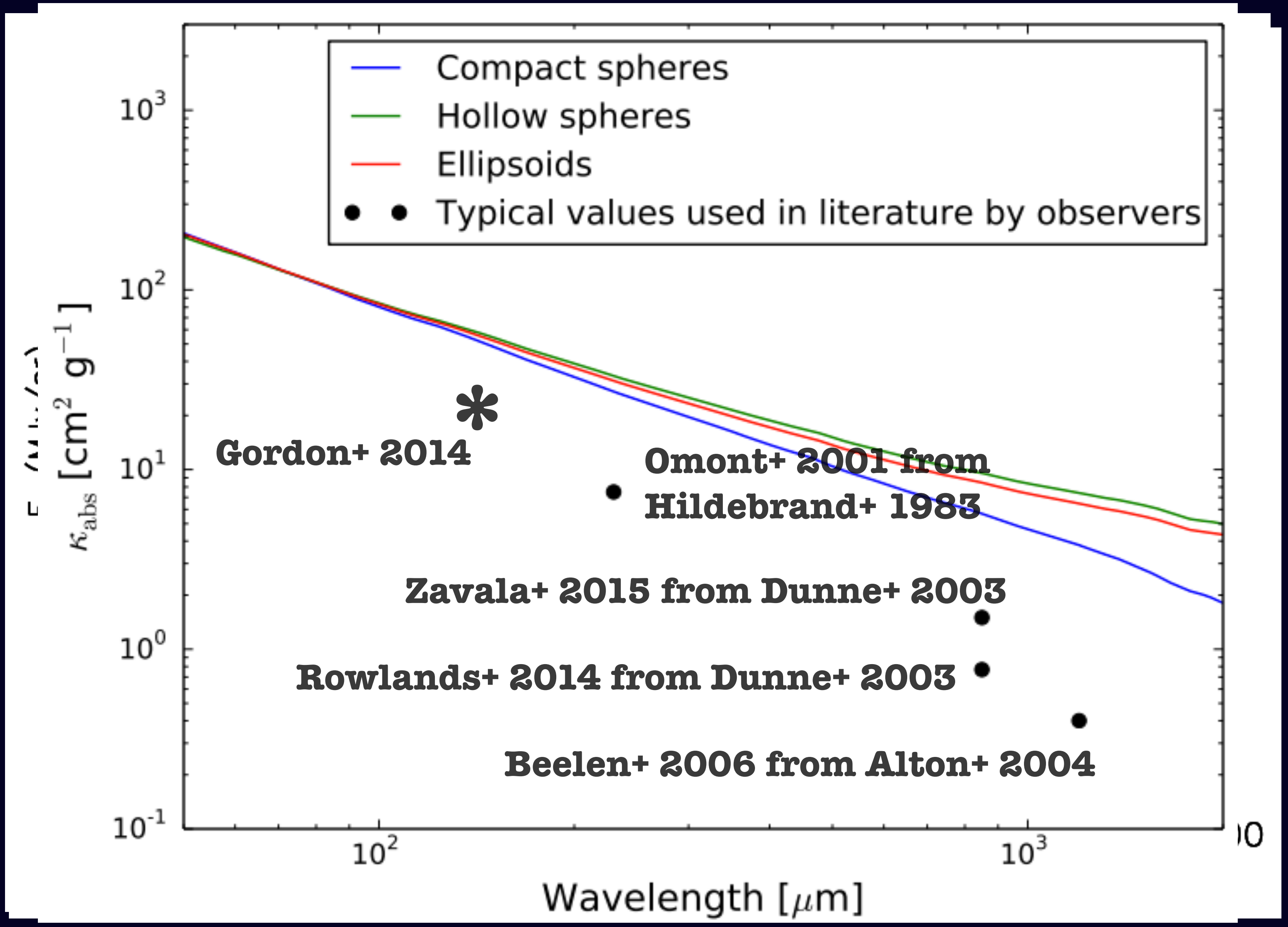
- Lab opacities compared with those derived from observations.
- Lower lab opacities ==> lower dust masses.
- Could resolve the high-z "dust budget crisis"! Less burden on ISM.



AGB studies in

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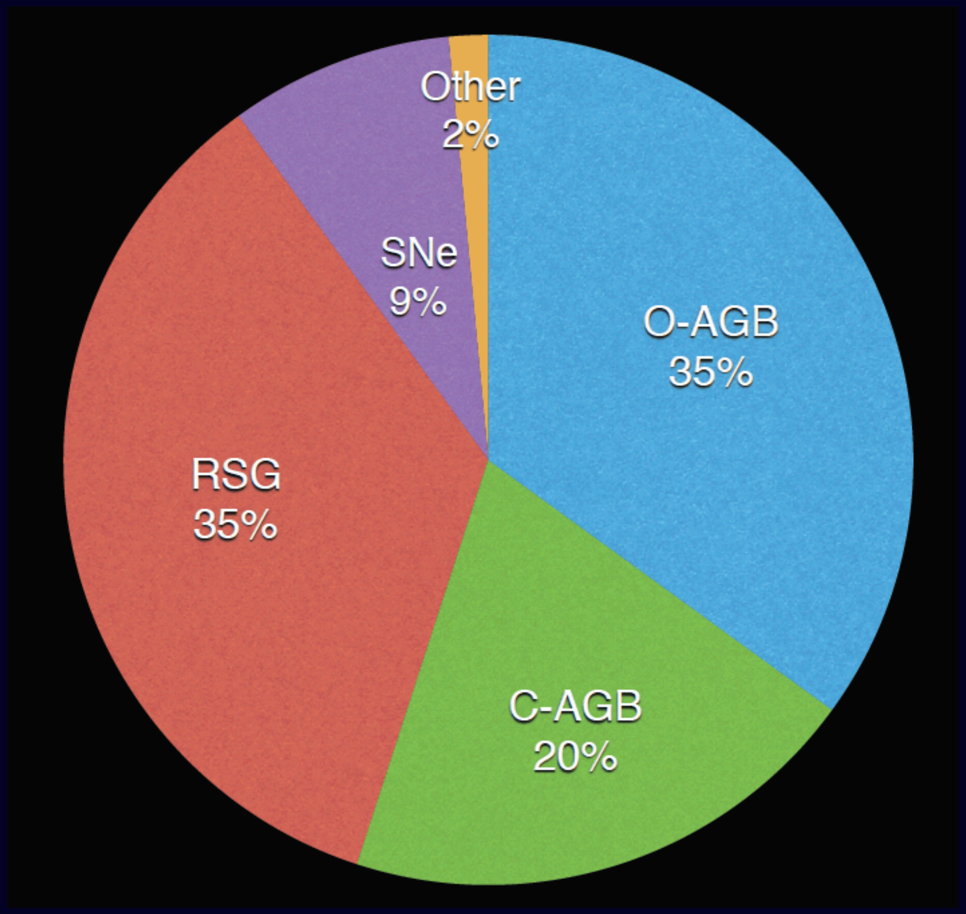

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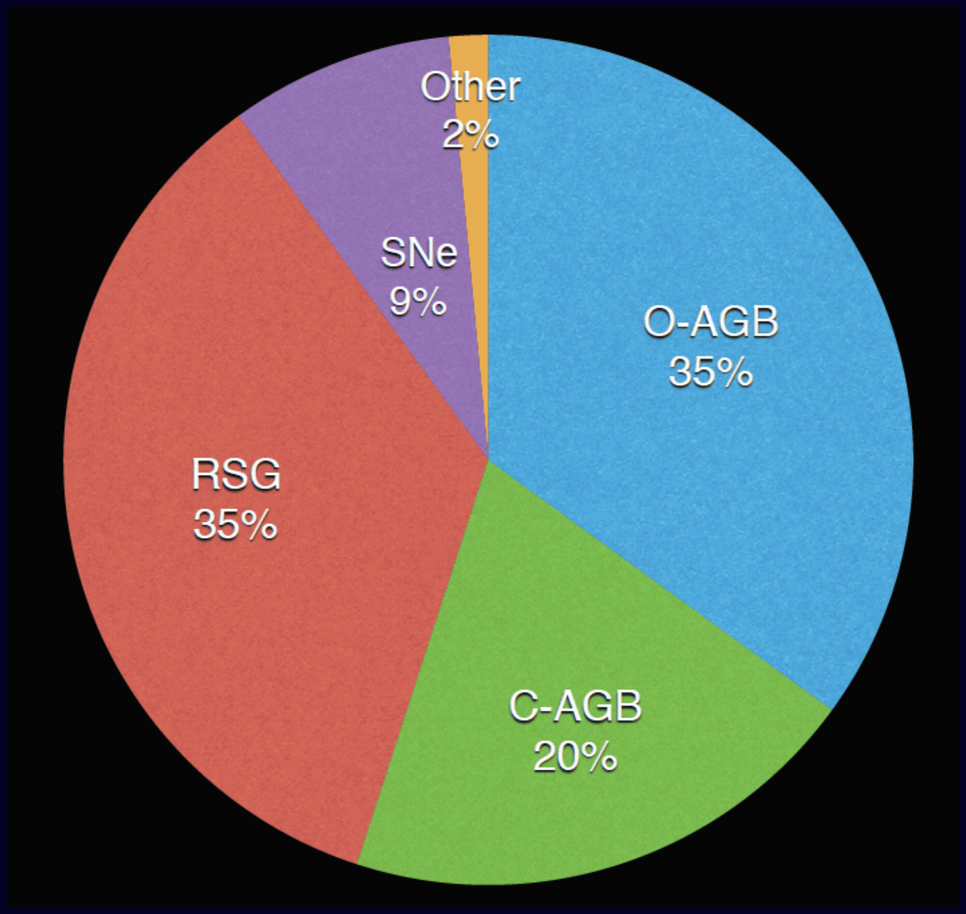

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- See Ciska Kemper's poster on Alfonso's work.

AGB studies in the Milky Way:
The Nearby Evolved Stars Survey (NESS)

Nearby Evolved Stars Survey

http://evolvedstars.space

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- Volume-limited survey of mass-losing AGB stars in the Solar Neighbourhood.
- Study dust and gas return, resolved mass-loss histories, dust:gas ratio, departure from spherical geometry.
- sub-mm data (dust continuum and CO line emission) combined with other data to produce what will be the **authoritative dataset for Galactic evolved-star studies in the next decade.**

AGB studies in the Milky Way: The Nearby Evolved Stars Survey (NESS)

Nearby Evolved Stars Survey

http://evolvedstars.space

- **NESS will be fully reproducible!**
  In the interest of open science, the NESS program aims to be fully reproducible. All raw, processed and auxiliary data, scripts, and outputs will be made available to the scientific community.

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AGB studies in the Milky Way:
The Nearby Evolved Stars Survey (NESS)

Sundar Srinivasan

2018-06-11

AGB studies in the Milky Way: The Nearby Evolved Stars Survey (NESS)

- JCMT Large Program (~500h, ~300 sources, PI: P. Scicluna) already 43% complete.

- APEX (~80h) and NRO (~80h) time also acquired.

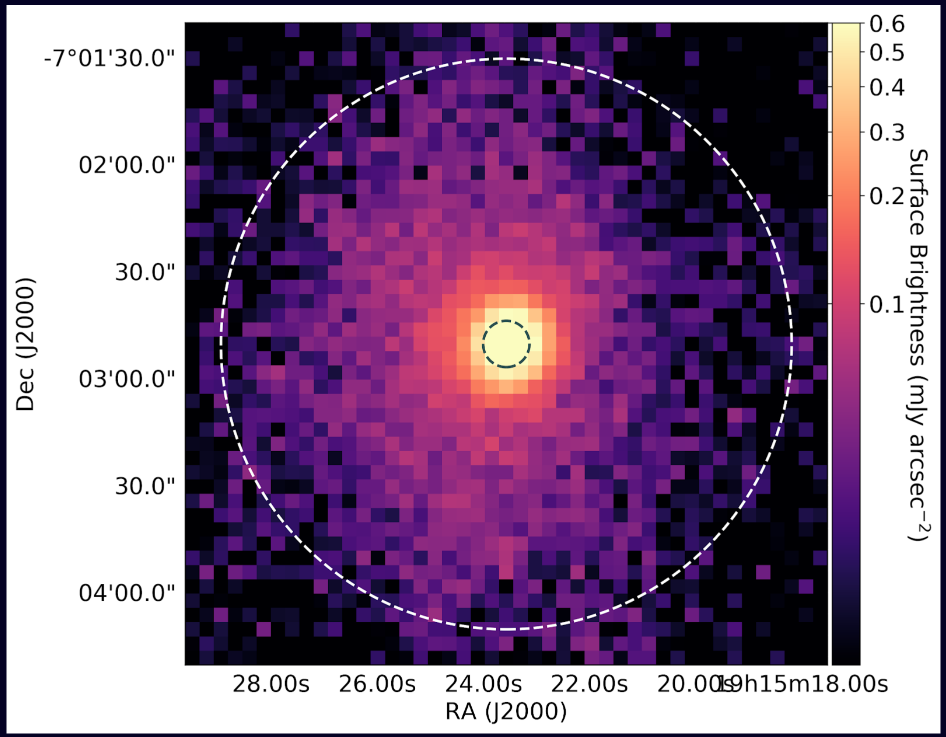
- SMA and ALMA proposals in prep (PI: Srinivasan).

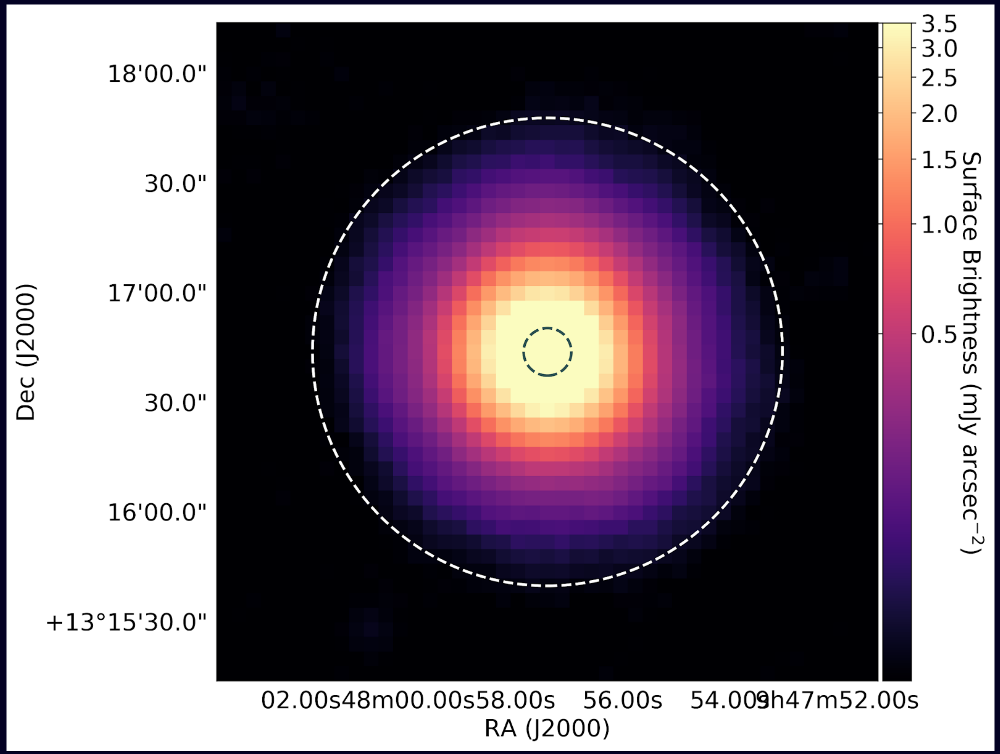
- Team of > 70 scientists across Asia, Europe, the UK, and North America.

- And you? (Talk to me, Peter, or Ciska)

AGB studies in the Milky Way: The Nearby Evolved Stars Survey (NESS)

Mass-loss history





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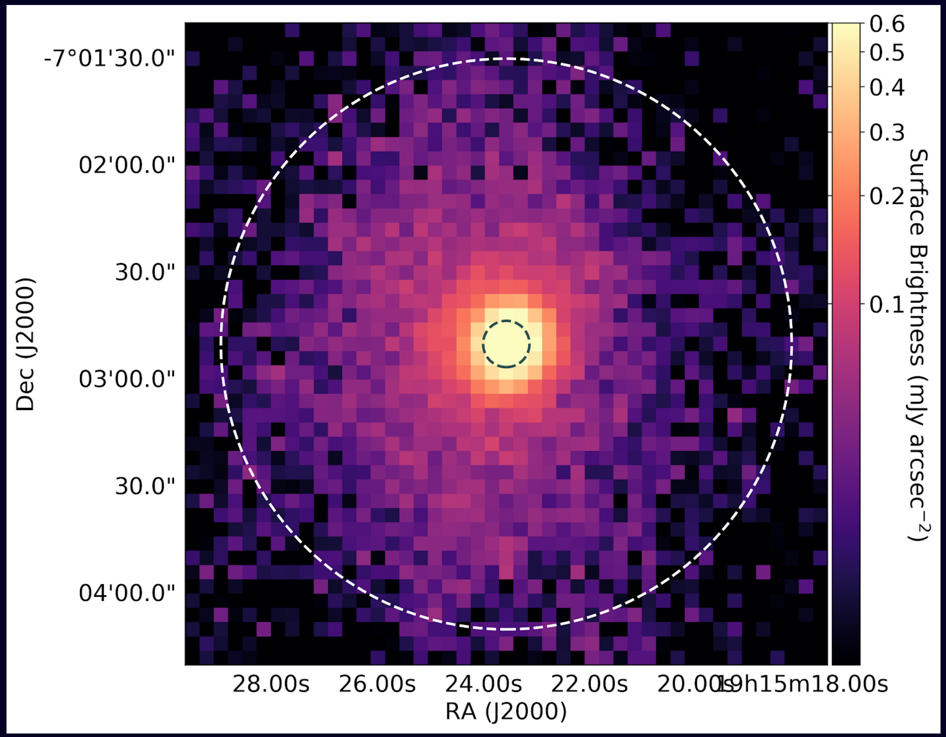

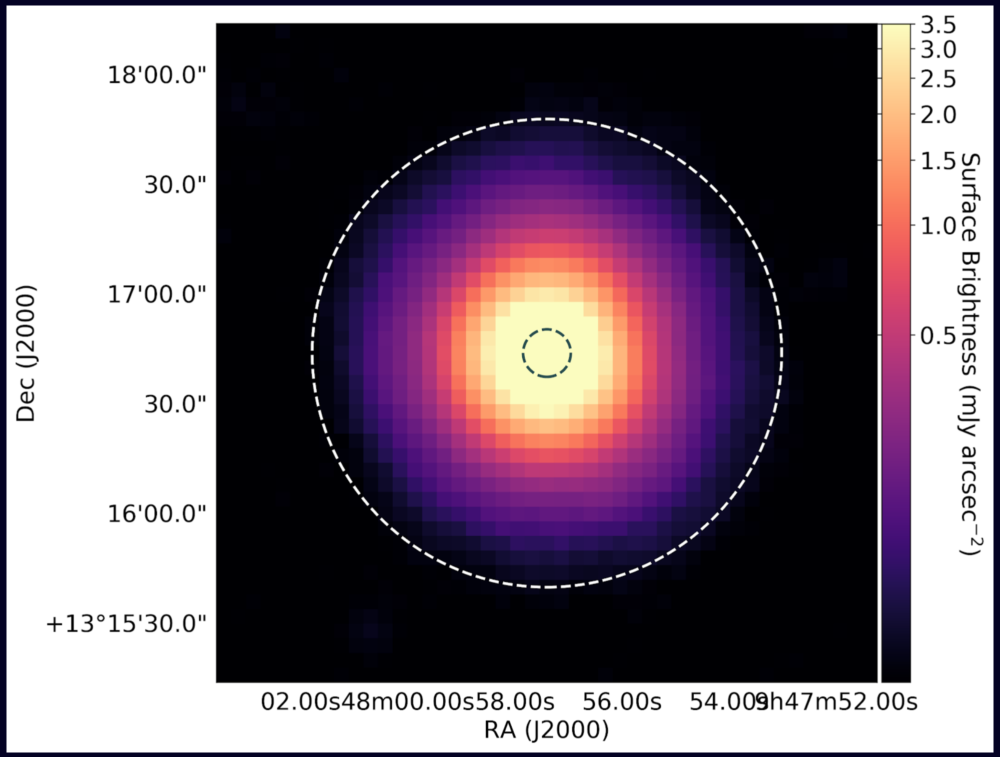

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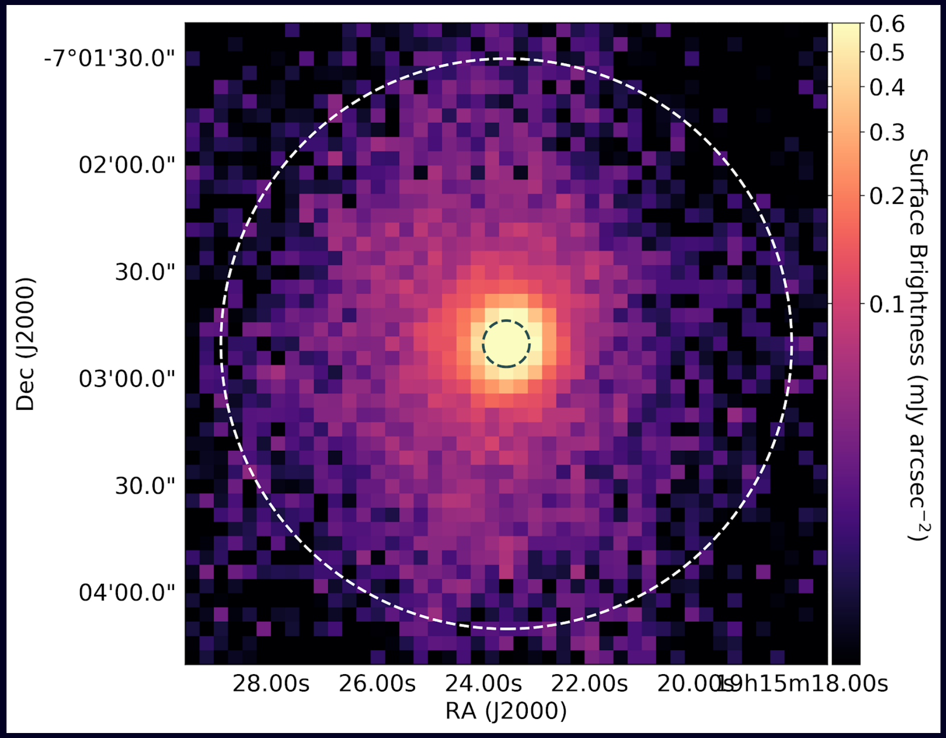

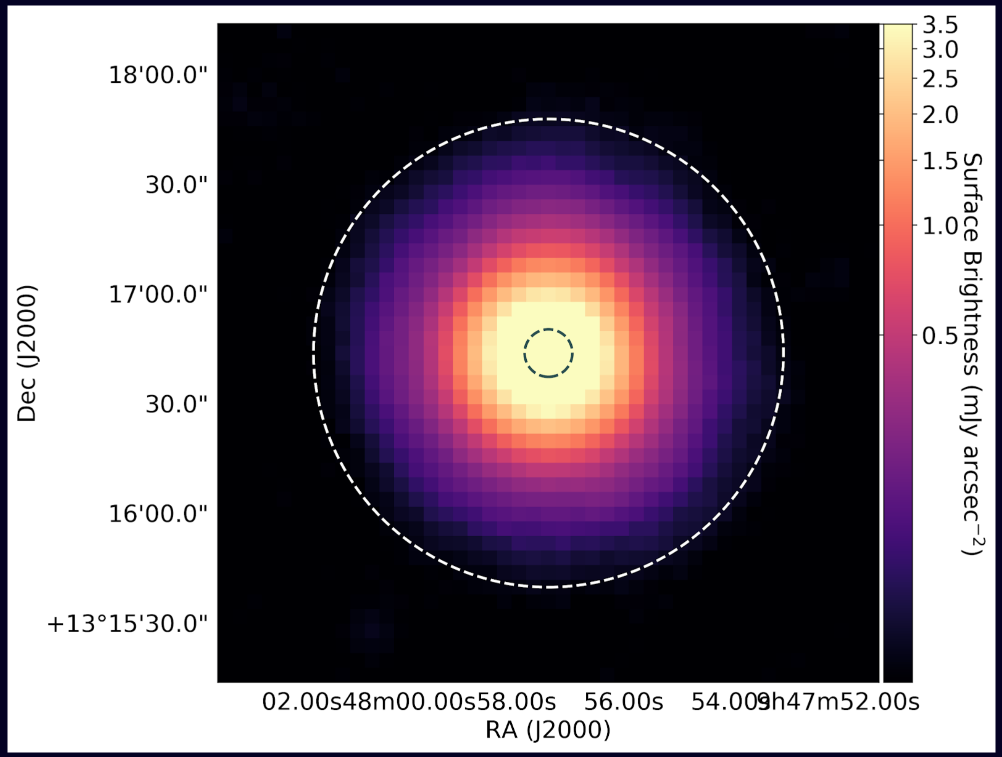

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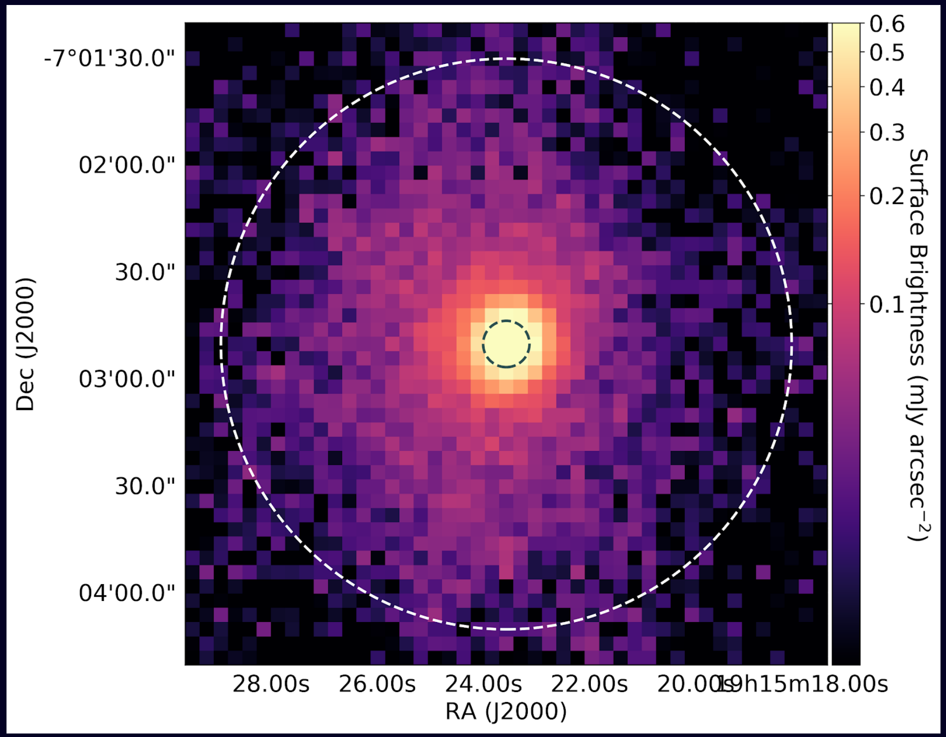

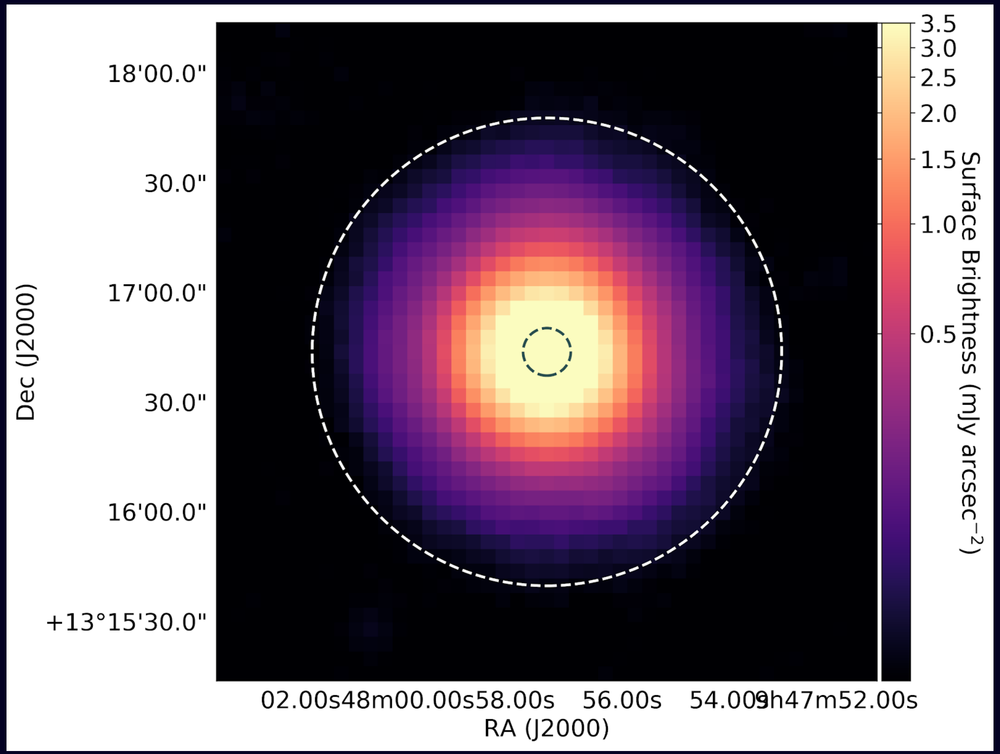

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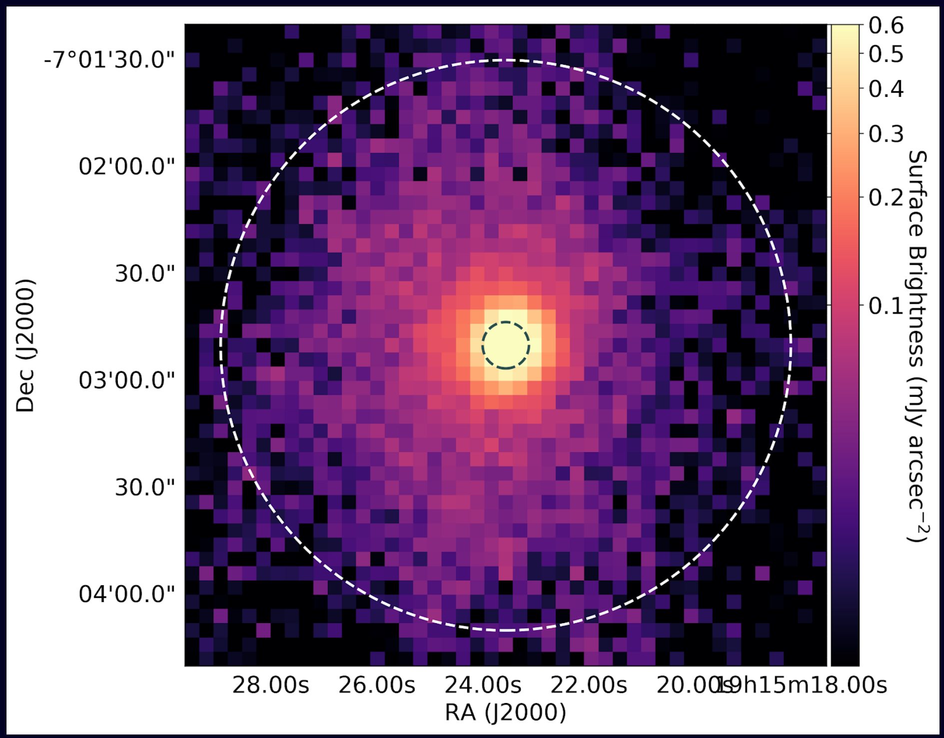

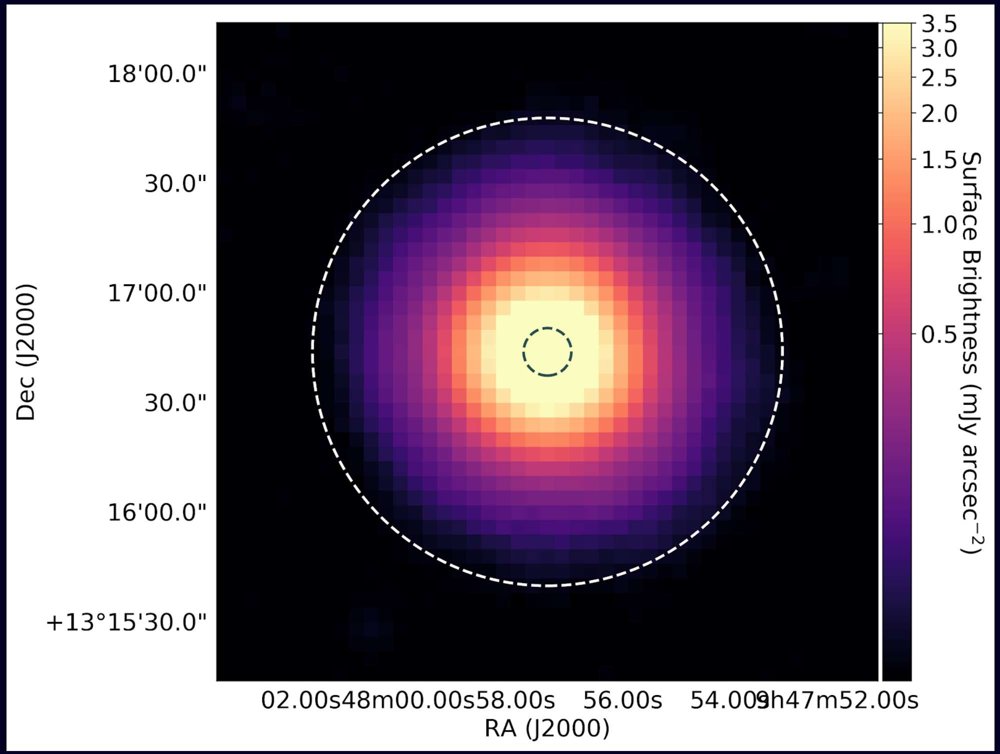

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  - Up to 40% of total flux is in the extended component.

AGB studies in the Milky Way: The Nearby Evolved Stars Survey (NESS)

Sundar Srinivasan

2018-06-11

AGB studies in the Milky Way: The Nearby Evolved Stars Survey (NESS)

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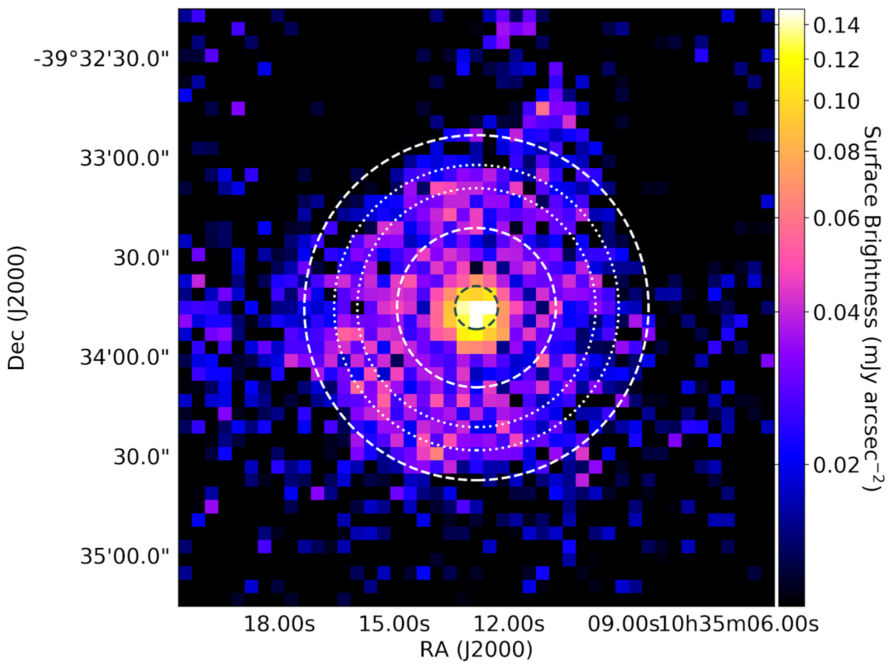

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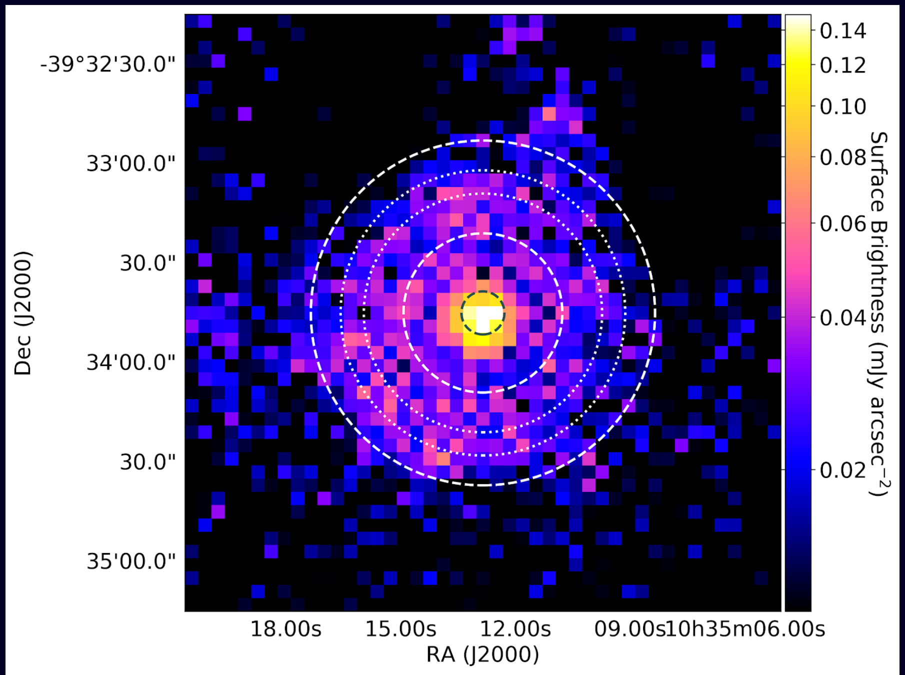

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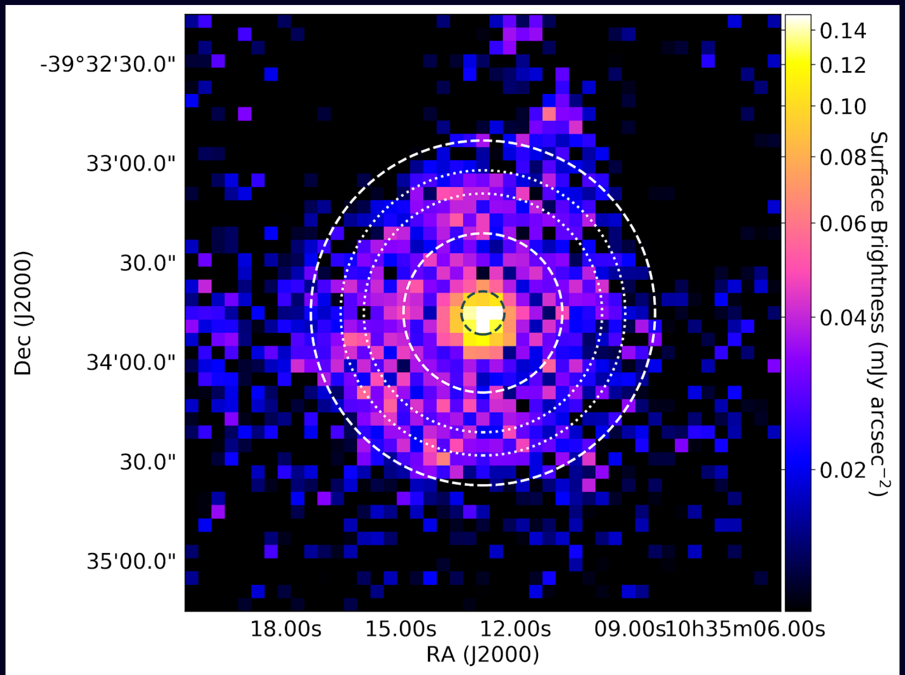

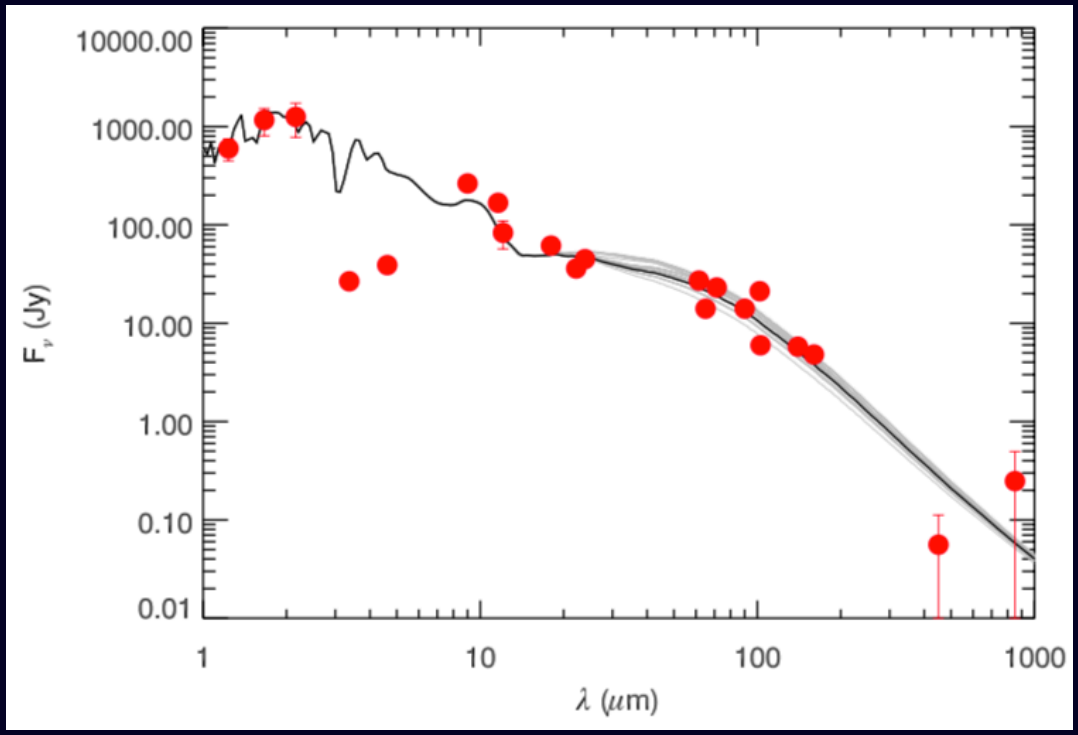

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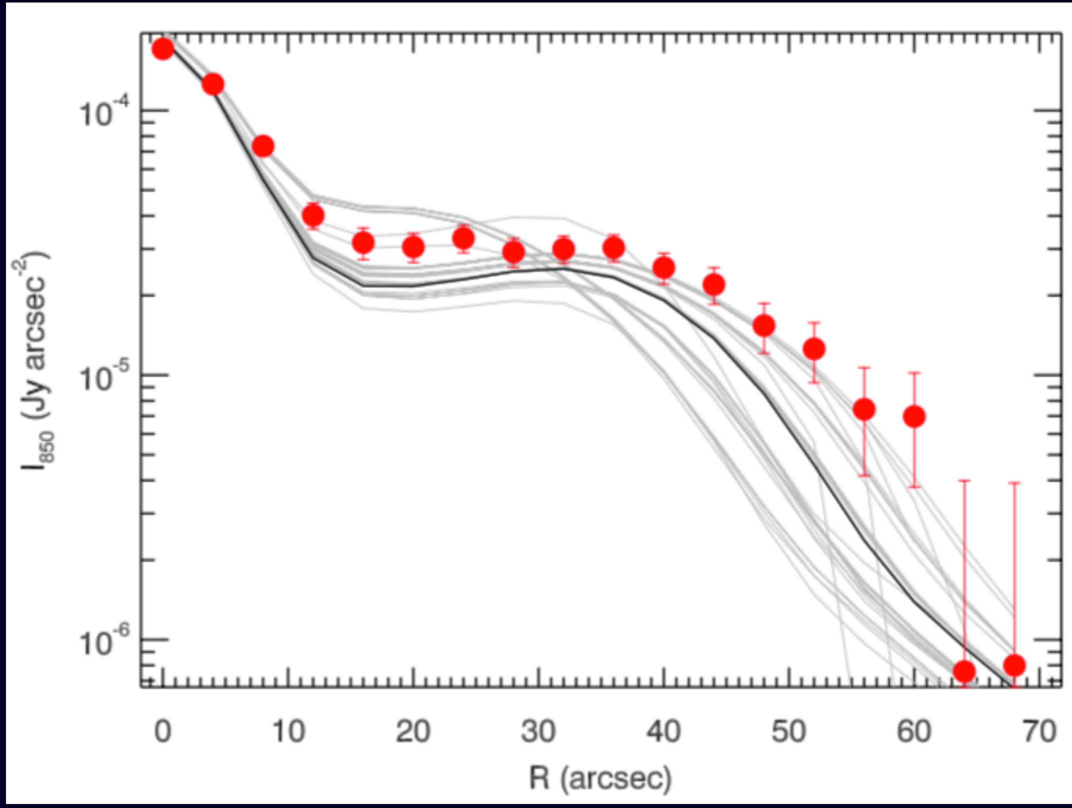

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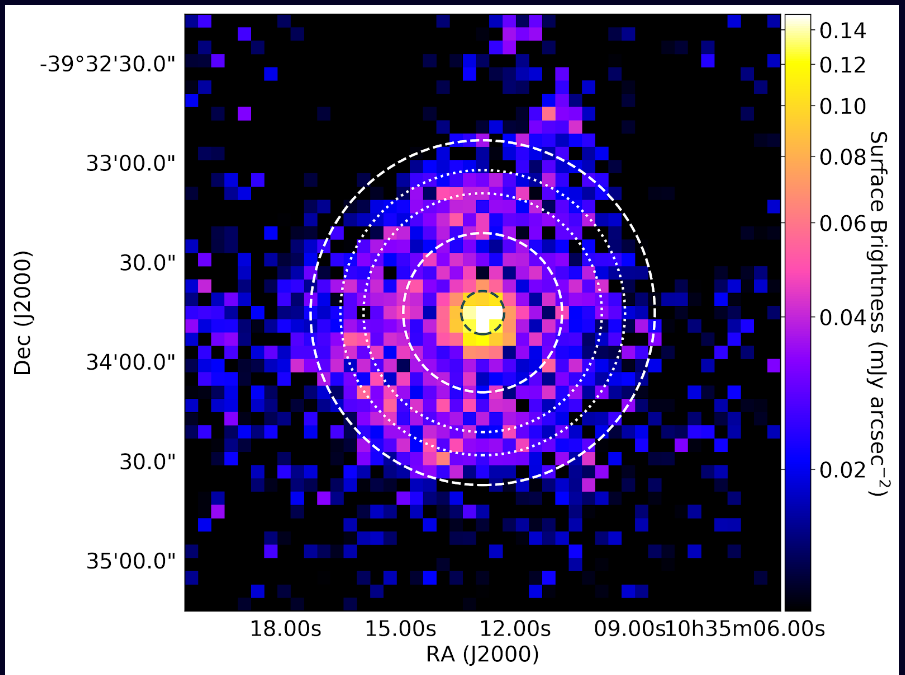

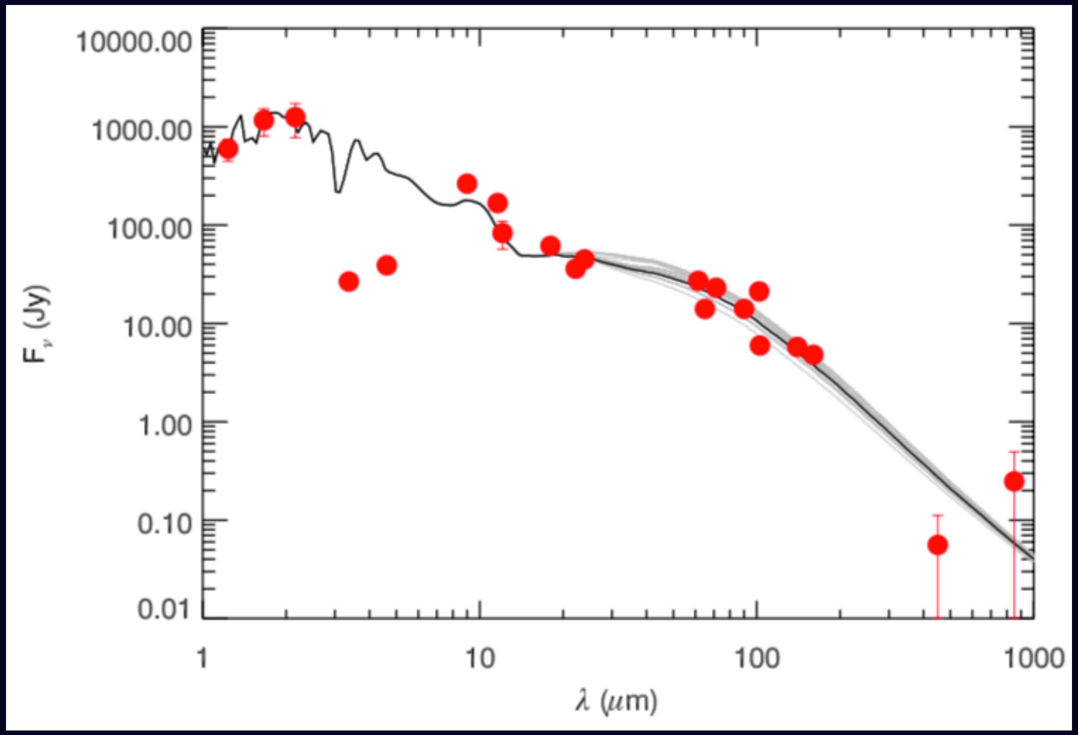

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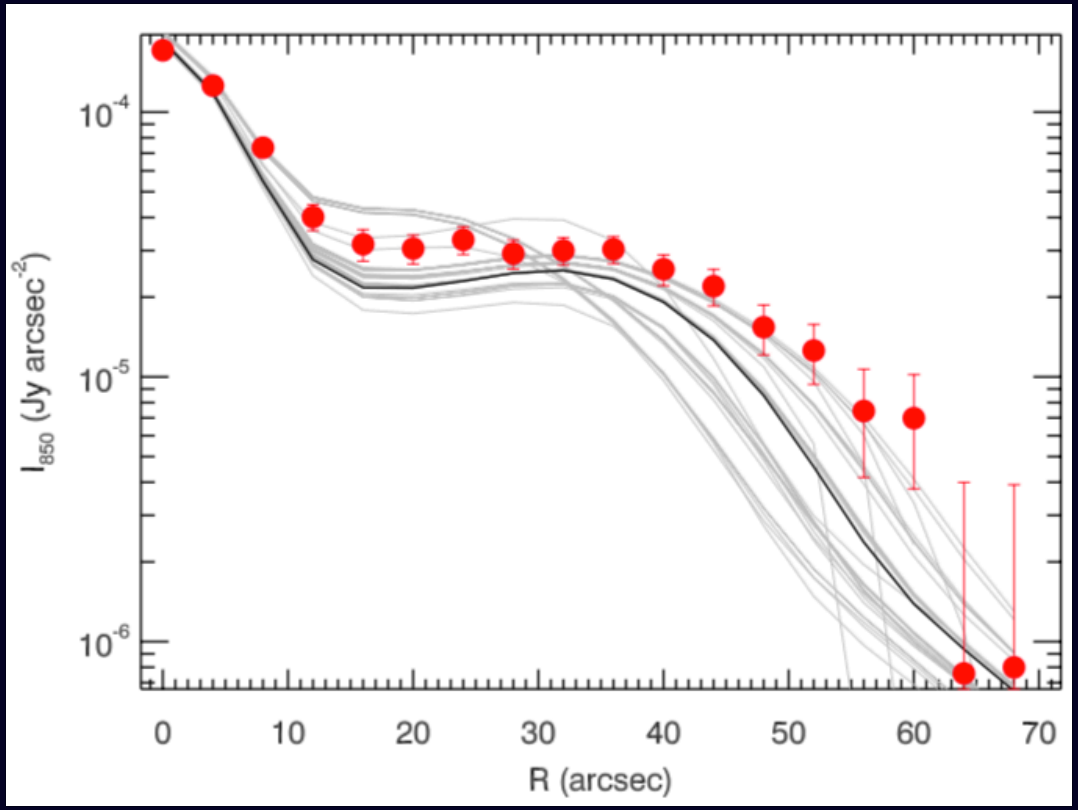
  - See poster P102 on Wednesday.



Summary

- We have a tested method to derive the global dust budget in resolved evolved-star populations, and to provide statistical results on their dust production.
- The AGB contribution in nearby galaxies is well determined [systematic model uncertainties dominate].
  - Reddest sources contribute most of the dust.
  - Relative contributions from O-/C-rich stars can be estimated.
  - 12 orders of magnitude in DPR over 6 orders of magnitude in stellar mass!
- We have an ongoing massive collaboration, NESS, that will investigate the entire mass-losing population within 2 kpc. This will result in more robust results for evolved stars.

Thanks to the organisers!

This presentation has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730562 [RadioNet]