[redacted]

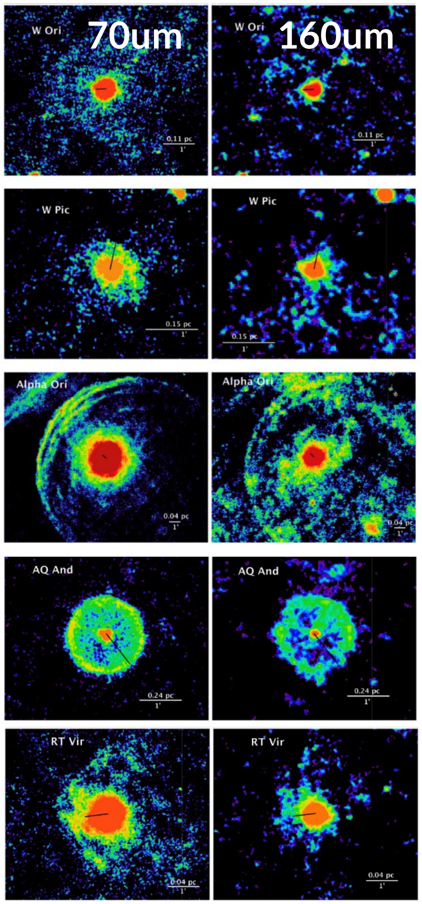
Strange Dust Properties & Super-Extended Dust Shells

Stacking Galactic Evolved Stars with Planck & IRAS

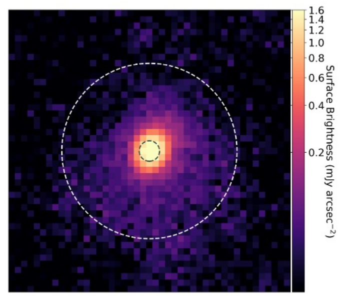
Chris Clark

with the Nearby Evolved Stars Survey team

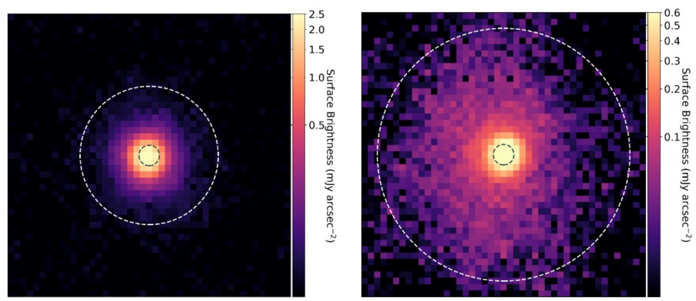
How Do We (Usually) Study AGB Dust?

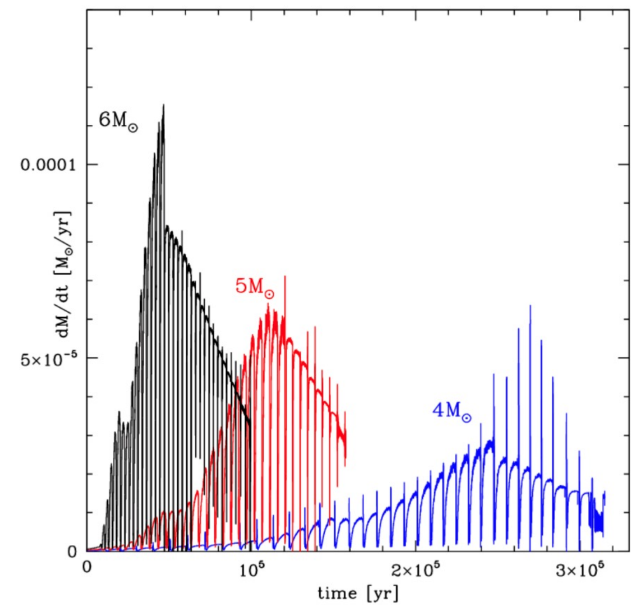


Dust around Galactic AGB stars in *Herschel* 70um and 160um data (Cox+ 2012)



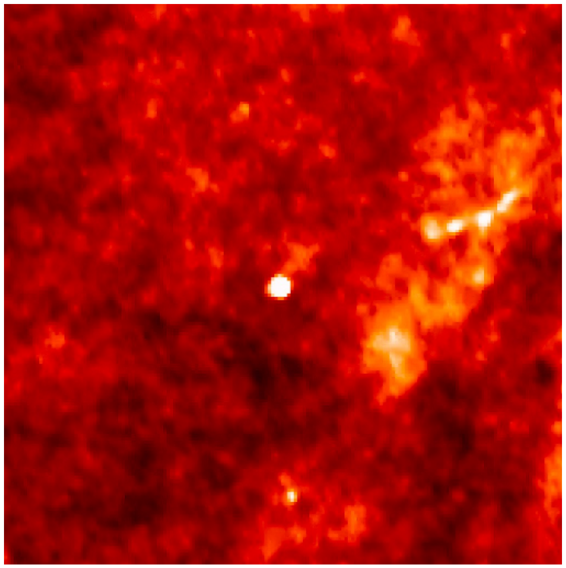
Dust around Galactic AGB stars in JCMT SCUBA-2 850um data (Dharmawardena + 2018)



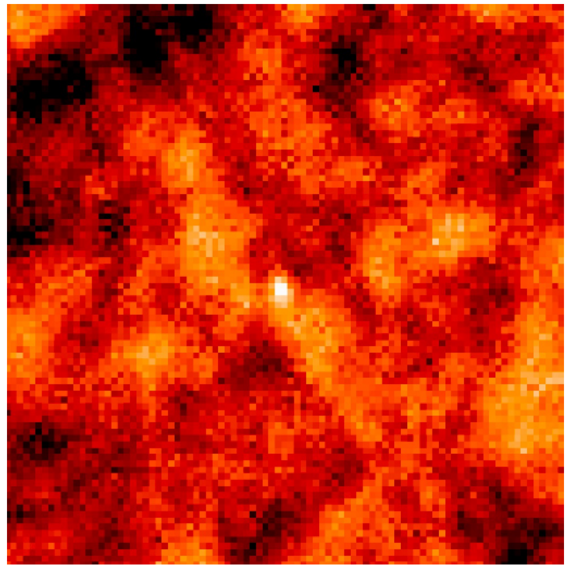


Theoretical models of AGB mass loss rate vs time (Marini+ 2023)

Extended & Long-λ Dust is Hard to Study

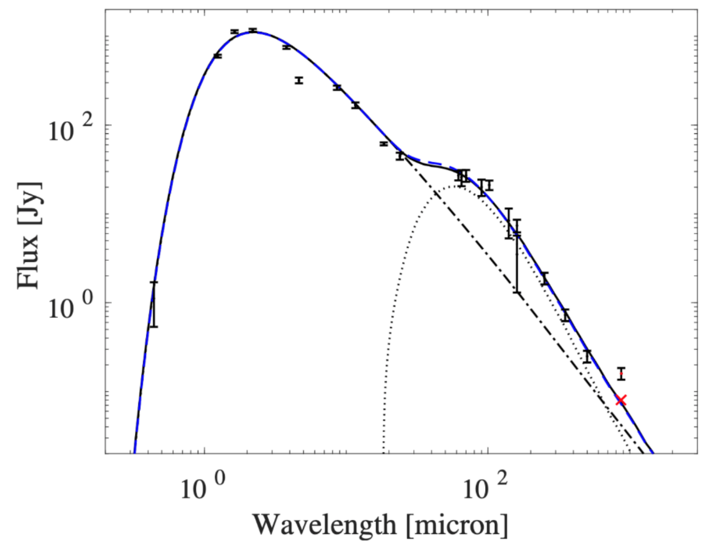


IRC+10216 at *Planck* 850 μm



IRC+10216 at *Planck* 3 mm

Example NIR–FIR SED of a dusty AGB star (Maercker+, 2018)



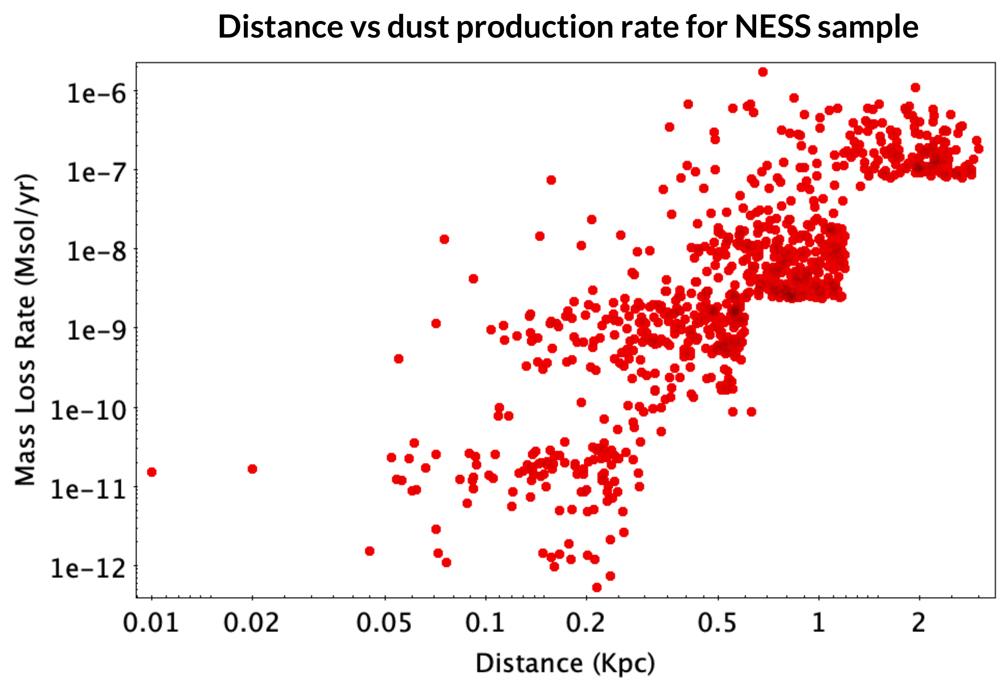
Nearby Evolved Stars Survey (NESS)

Nearby Evolved Stars Survey

Sample of 852 Milky Way evolved stars with well-constrained distances.

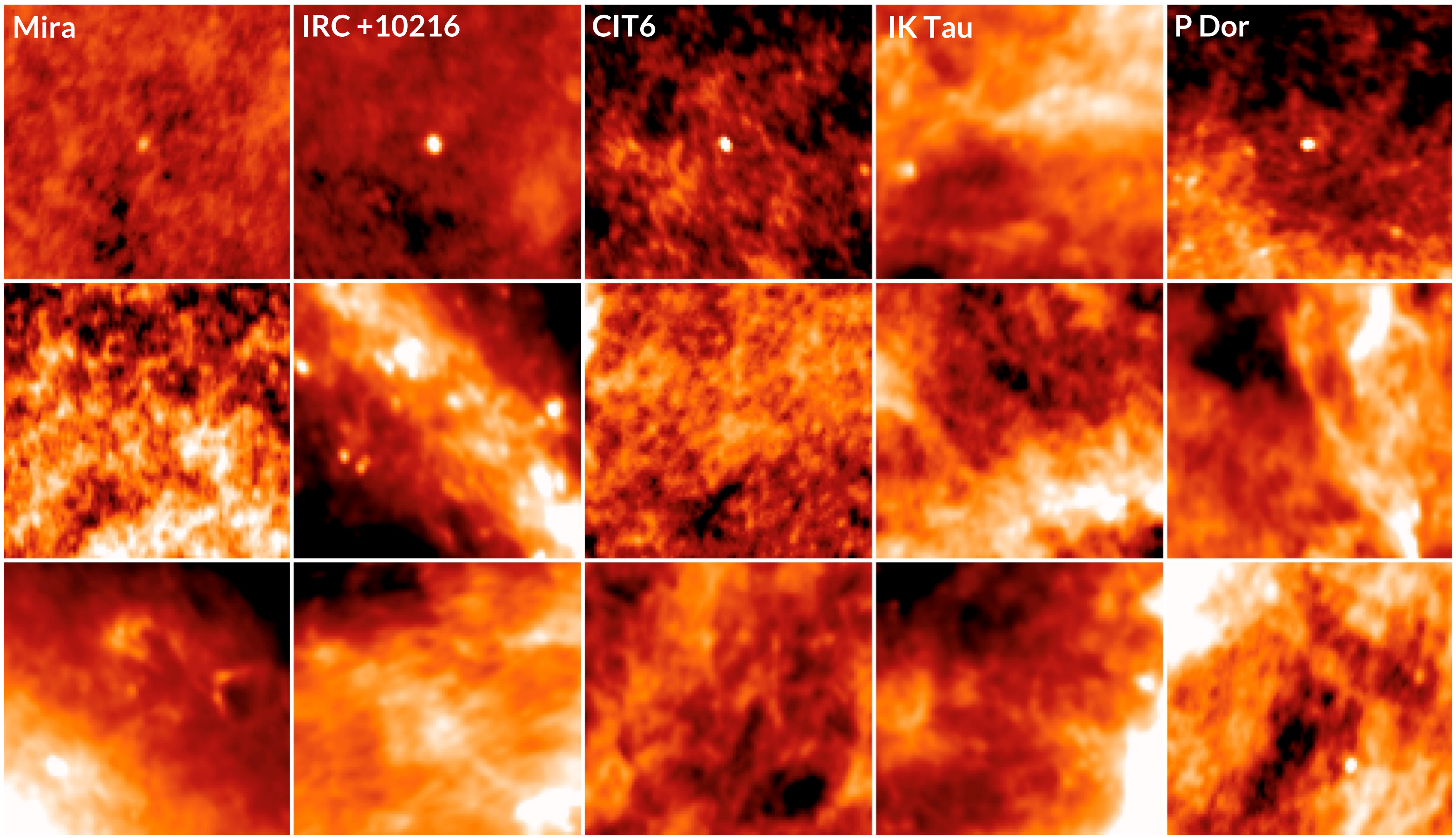
Centered around recent James Clerk Maxwell Telescope and APEX observations of CO and dust. (With data from Nobeyama and other facilities, too.)

Ancillary data from GALEX, SDSS, Skymapper, DSS, 2MASS, UKIRT, VISTA, WISE, **IRAS**, *Spitzer*, *Herschel*, ***Planck***



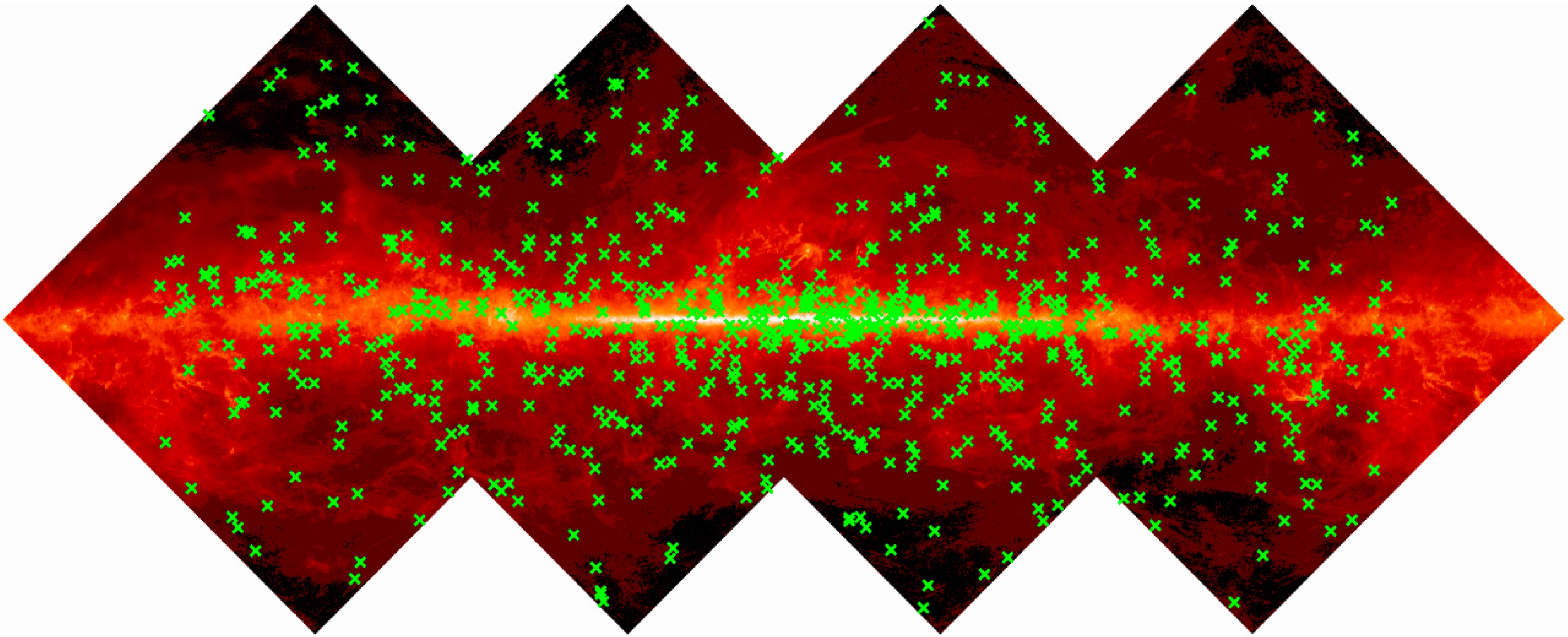
Scicluna+ (2022); McDonald+ (2025)

NESS Stars Mostly Undetected in *Planck*



5 deg x 5 deg *Planck* 350 µm cutouts, centered on 12 example NESS stars

Galactic Plane Dominates Background

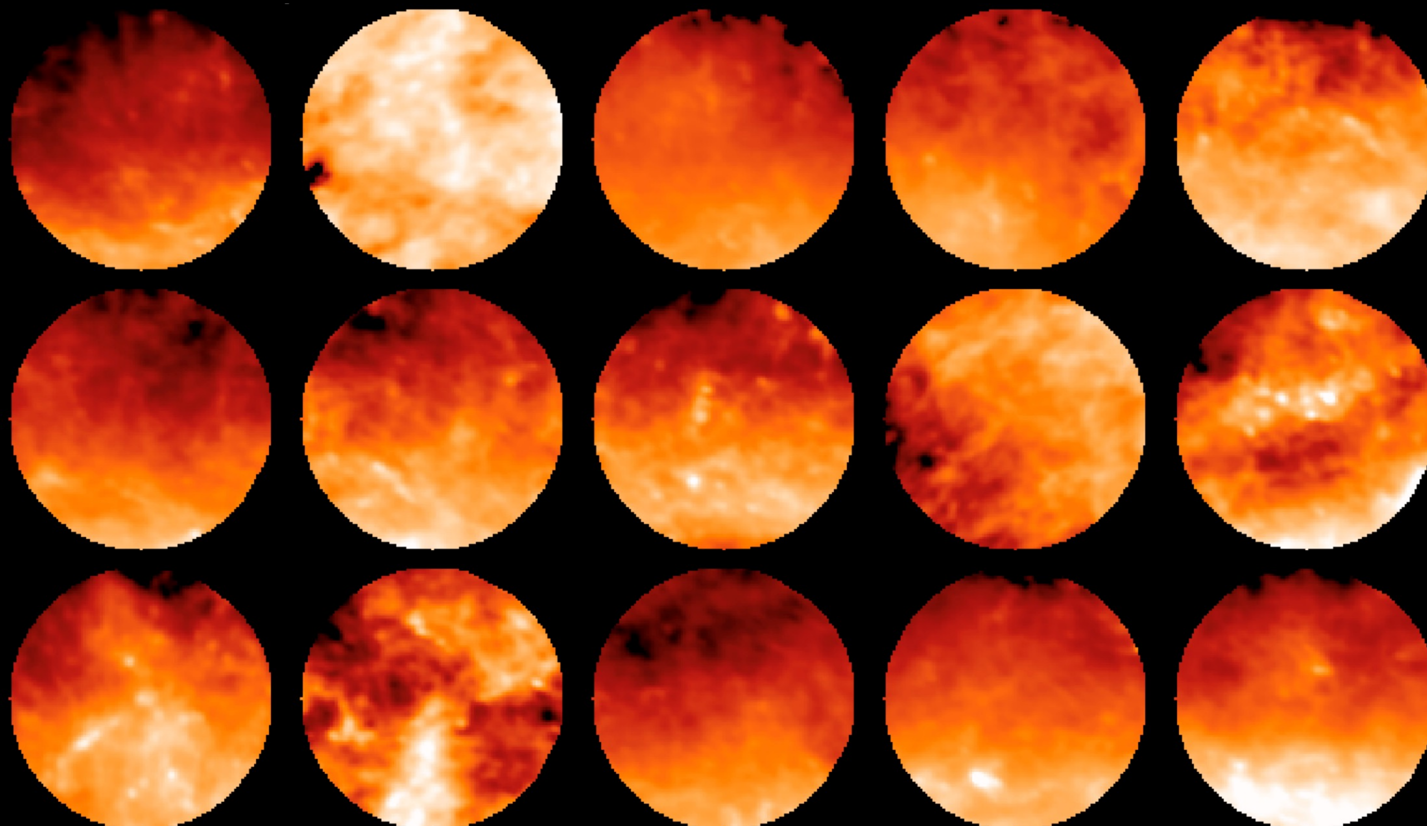


712 NESS sources plotted on *Planck* 350 μm all-sky data – sources within 1 deg of Galactic Plane have been removed

Cutouts Centred on Each NESS Star

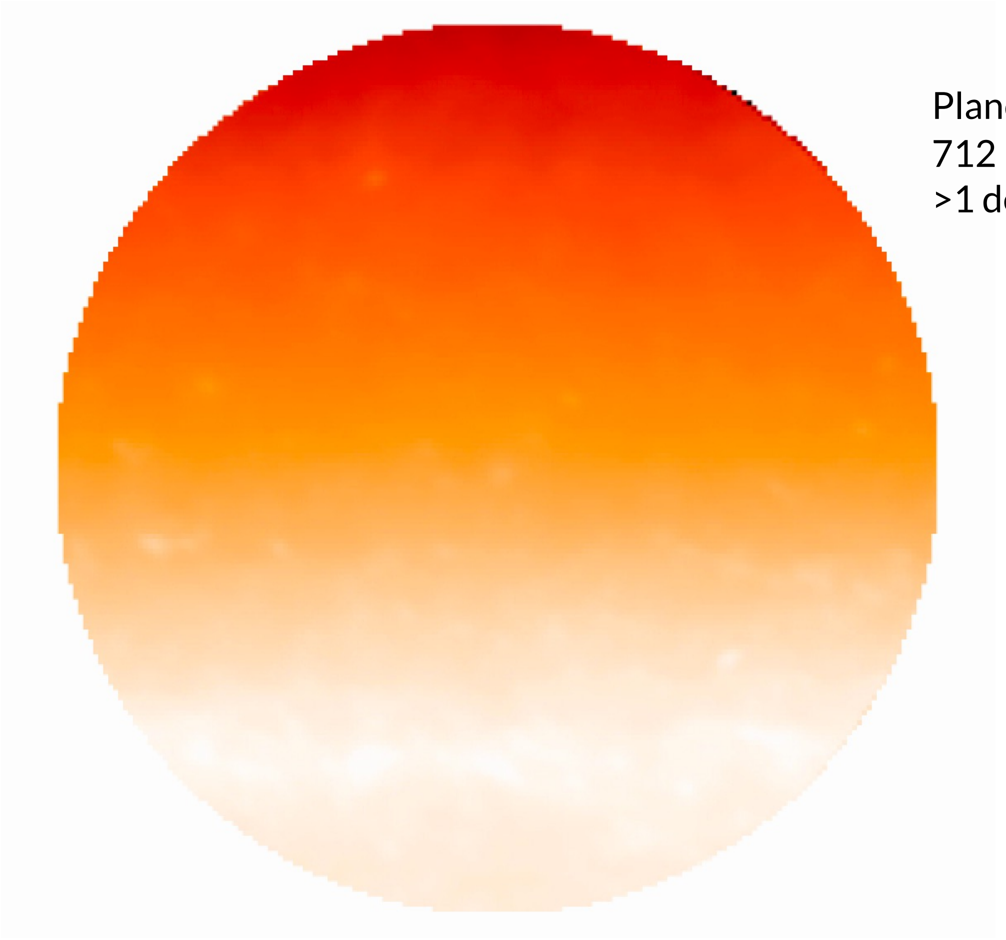
Example *Planck* 350 μm 5x5 degree cutouts, each centred on a Milky Way AGB star

All rotated such that Galactic plane is towards the bottom of the cutout



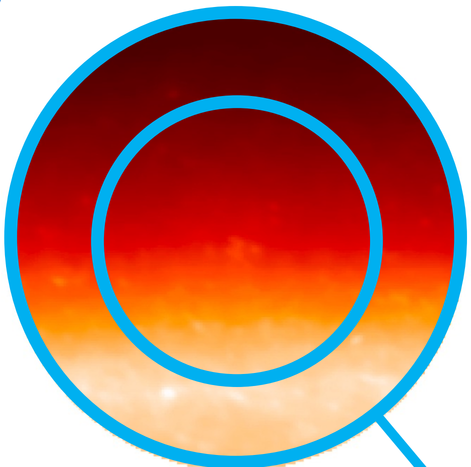
Clark+ (*in prep.*); Scicluna+ (2022)

An Actual Stack!



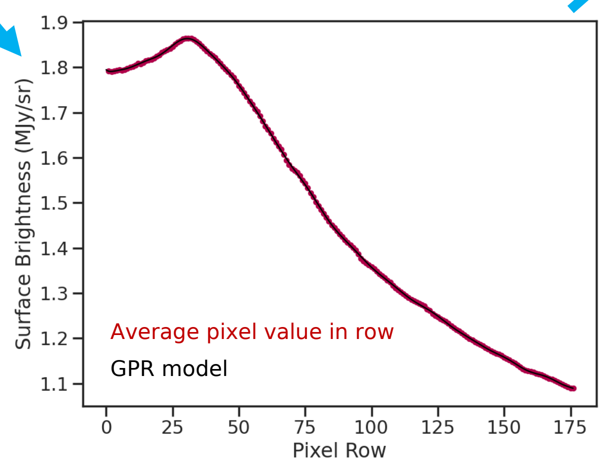
Planck 350 μm stack of
712 NESS sources located
>1 deg from Galactic Plane

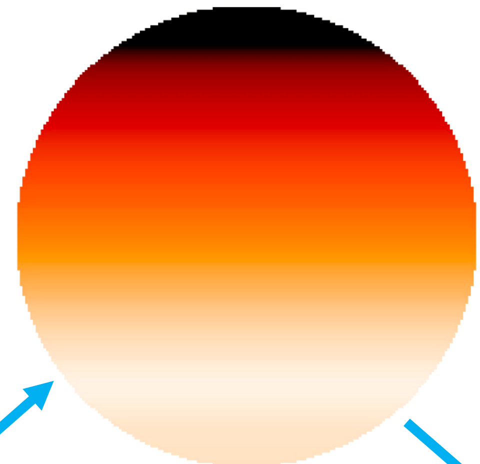
Removing Milky Way Emission



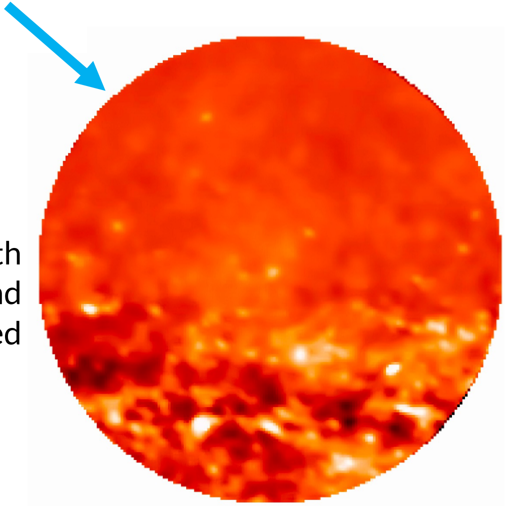
Mean Planck 350 µm stack; 1.5–2.5 deg annulus defined as sly region

Gaussian process regression model of pixel row vs surface brightness



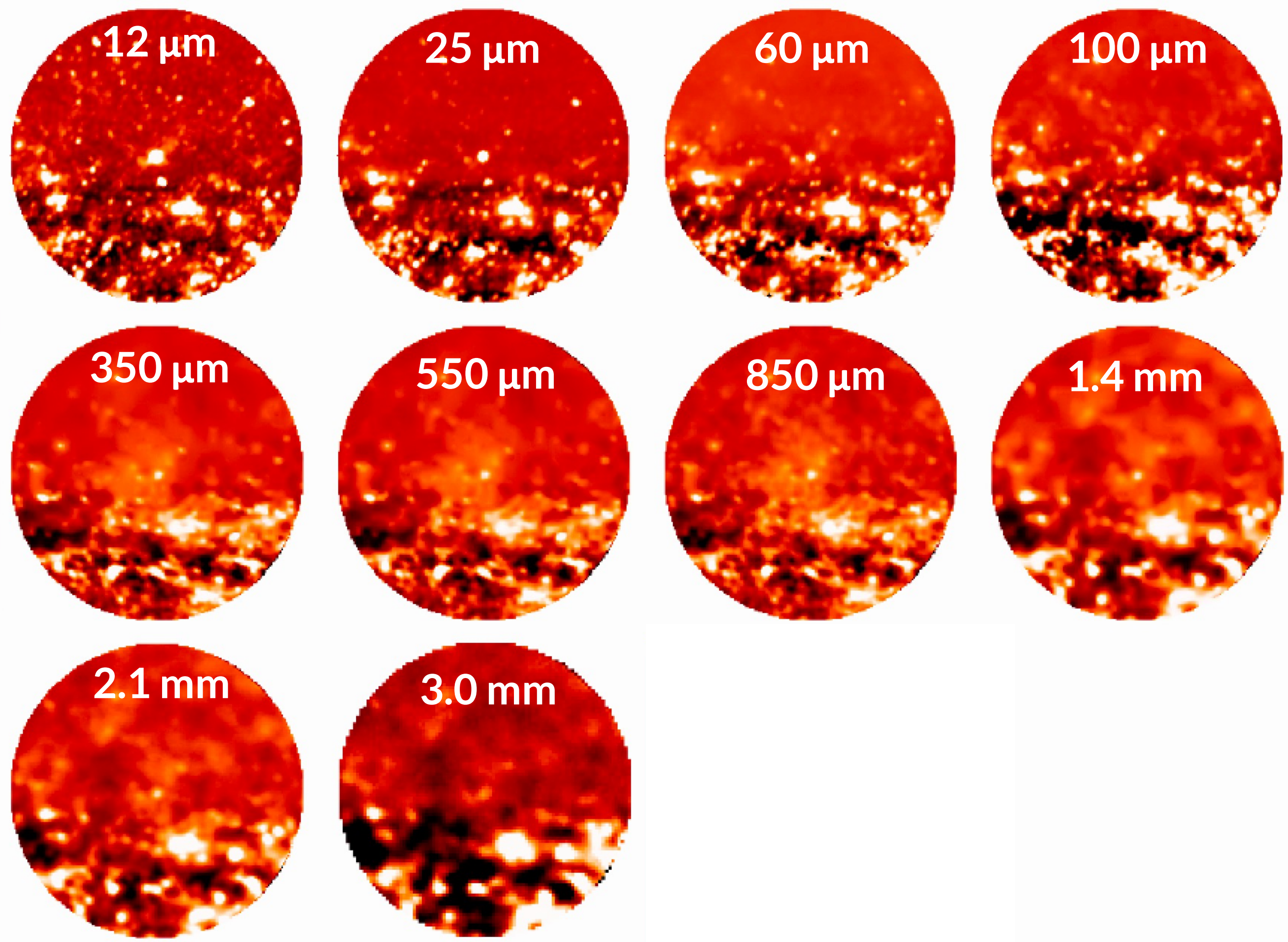


Modelled Milky Way foreground/background emission

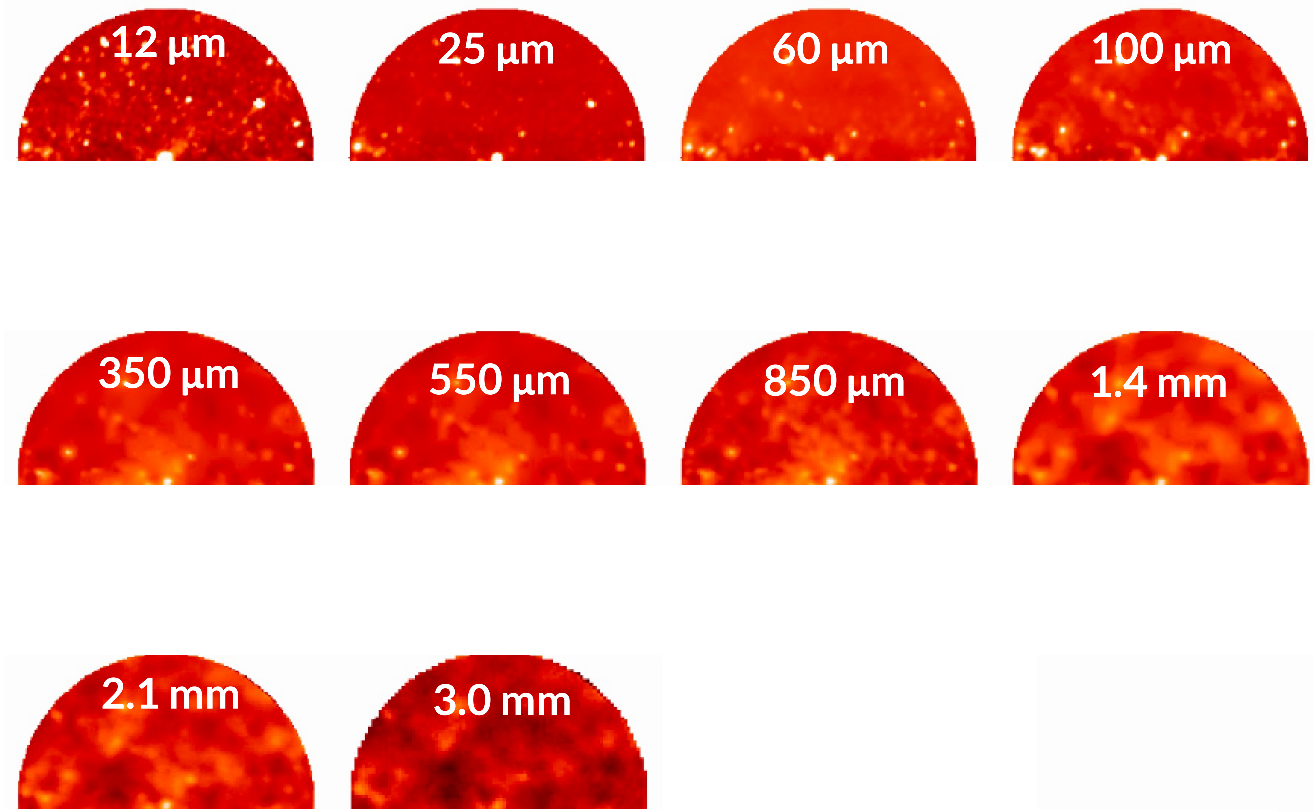


Planck 350 µm stack with foreground/background emission subtracted

Detections in Most IRAS & *Planck* Bands...?



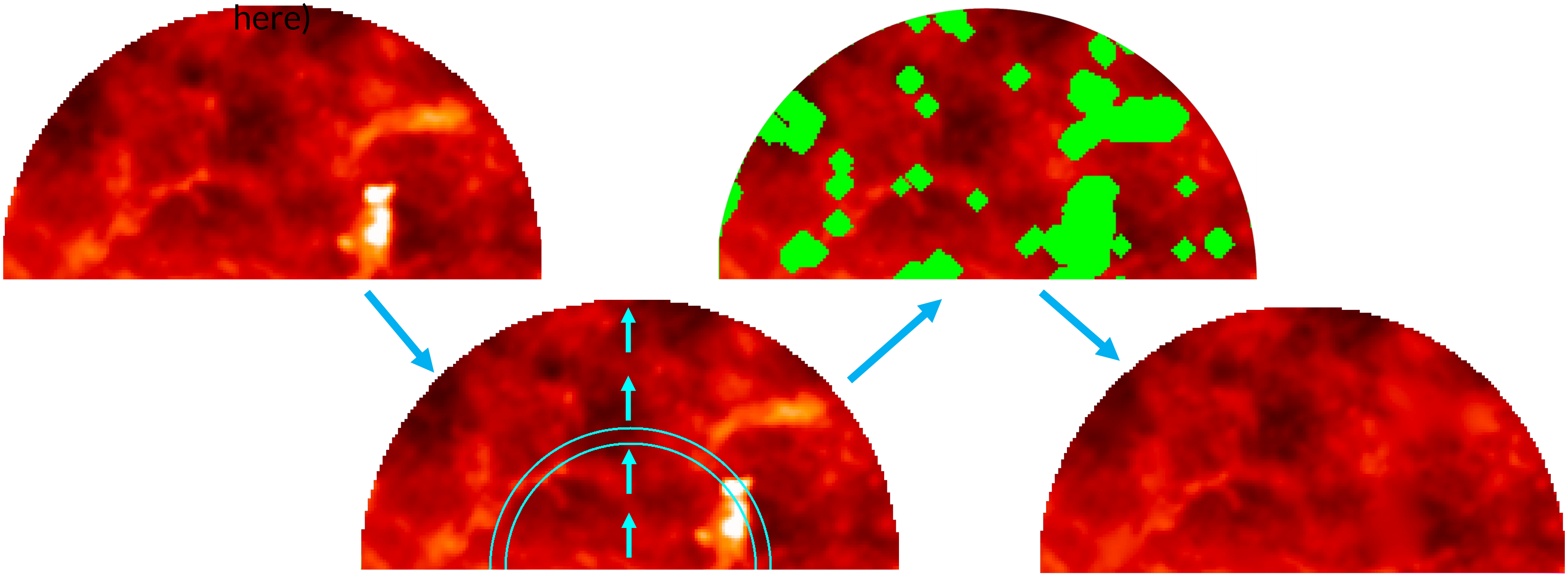
Detections in Most IRAS & *Planck* Bands…?



Mask Interlopers From Each Input Cutout

Process each of the ~700 input cutouts (one example shown here)

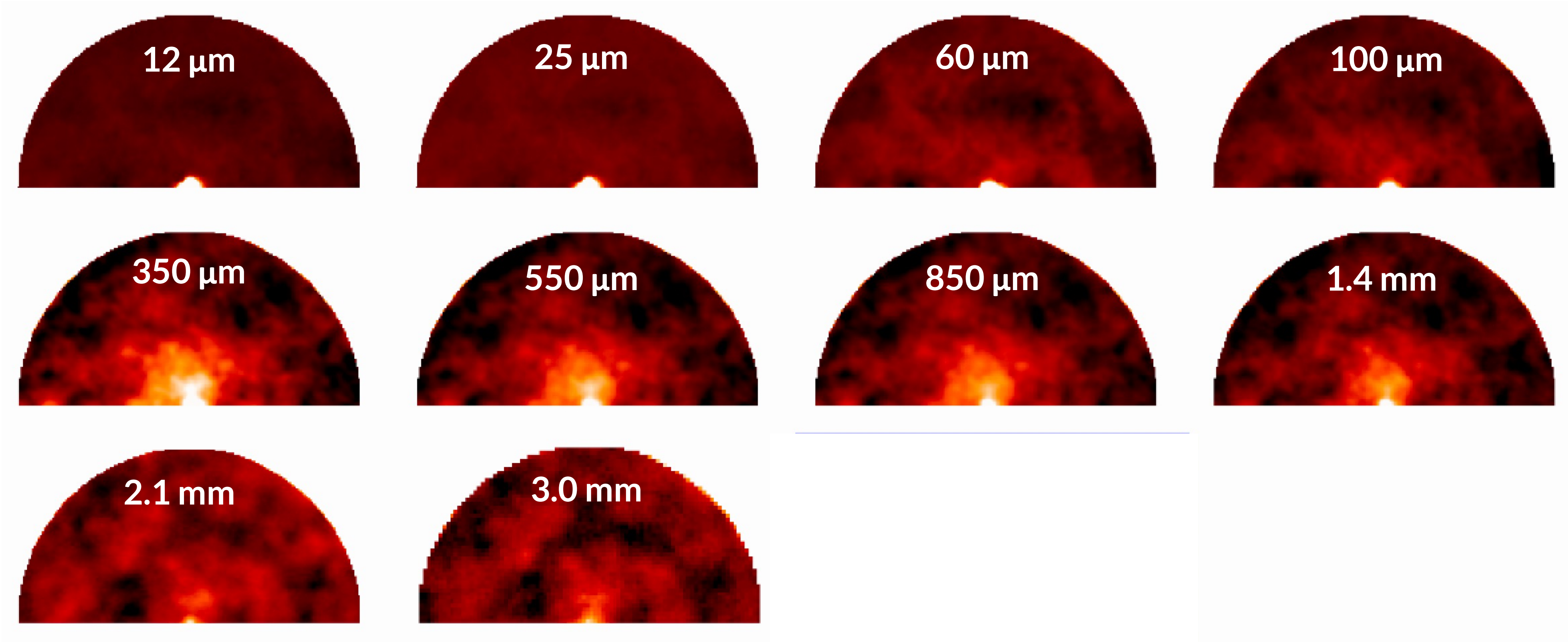
Assume bright compact sources are interlopers, and mask them out



Sigma-clip in moving annular window, to identify bright compact sources

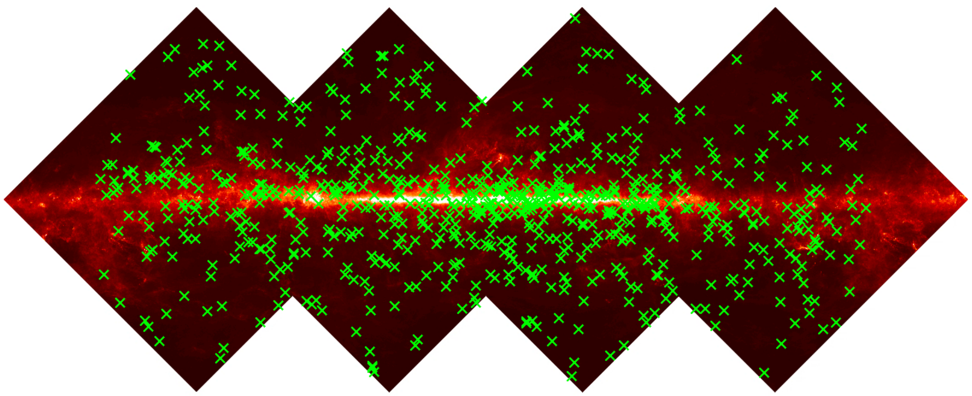
Smoothly in-paint masked regions; cutout now ready for stacking

Diffuse Emission in *Planck* 350 μm – 1.4 mm

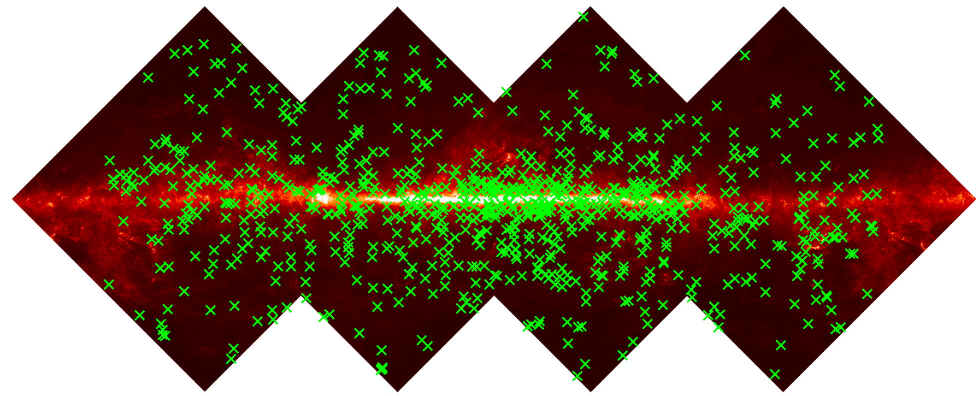


100 Control Stacks on Random Offset Coords

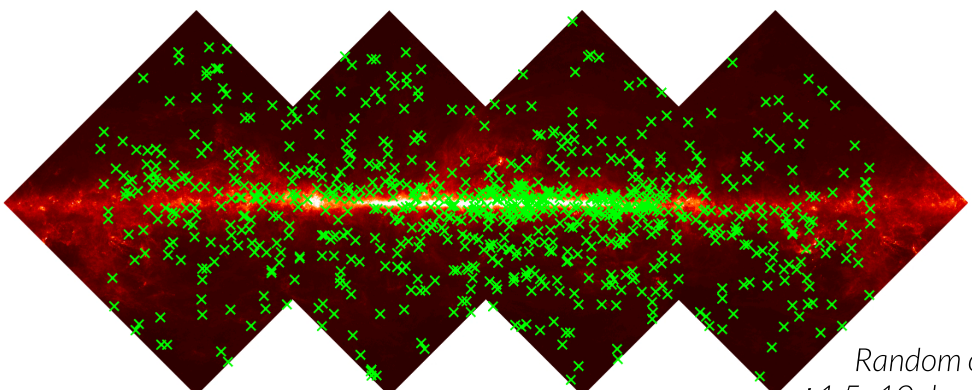
Actual positions of evolved stars in sample



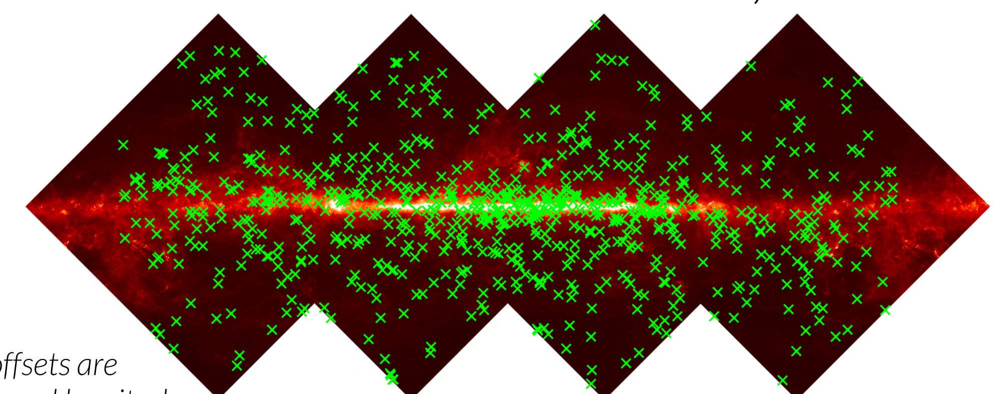
Random offset coordinate set 1



Random offset coordinate set 2



Random offset coordinate set 3, etc…



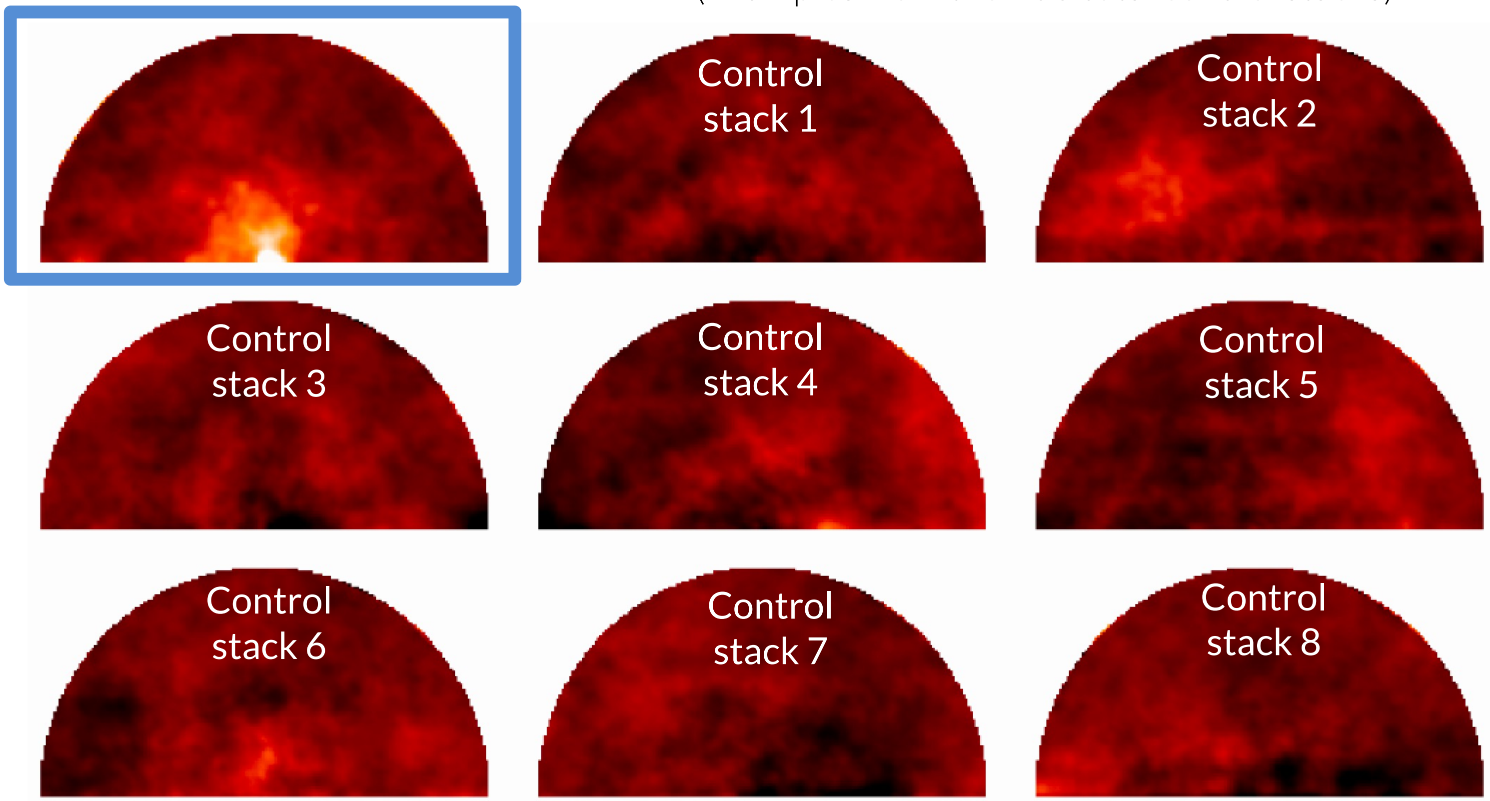
Random offsets are ±1.5–10 deg in gal longitude

Real Stack vs Control Stacks

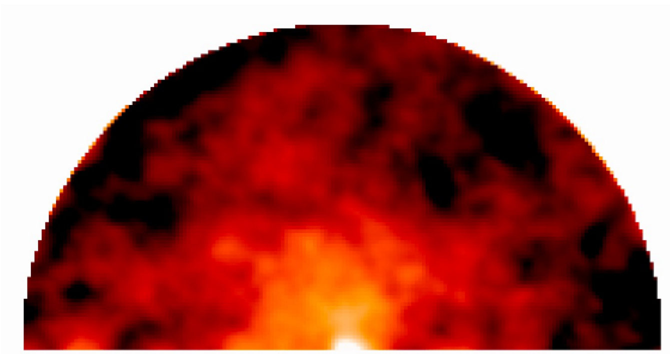
Real *Planck* 350 µm stack

8 of the Planck 350 µm control stacks

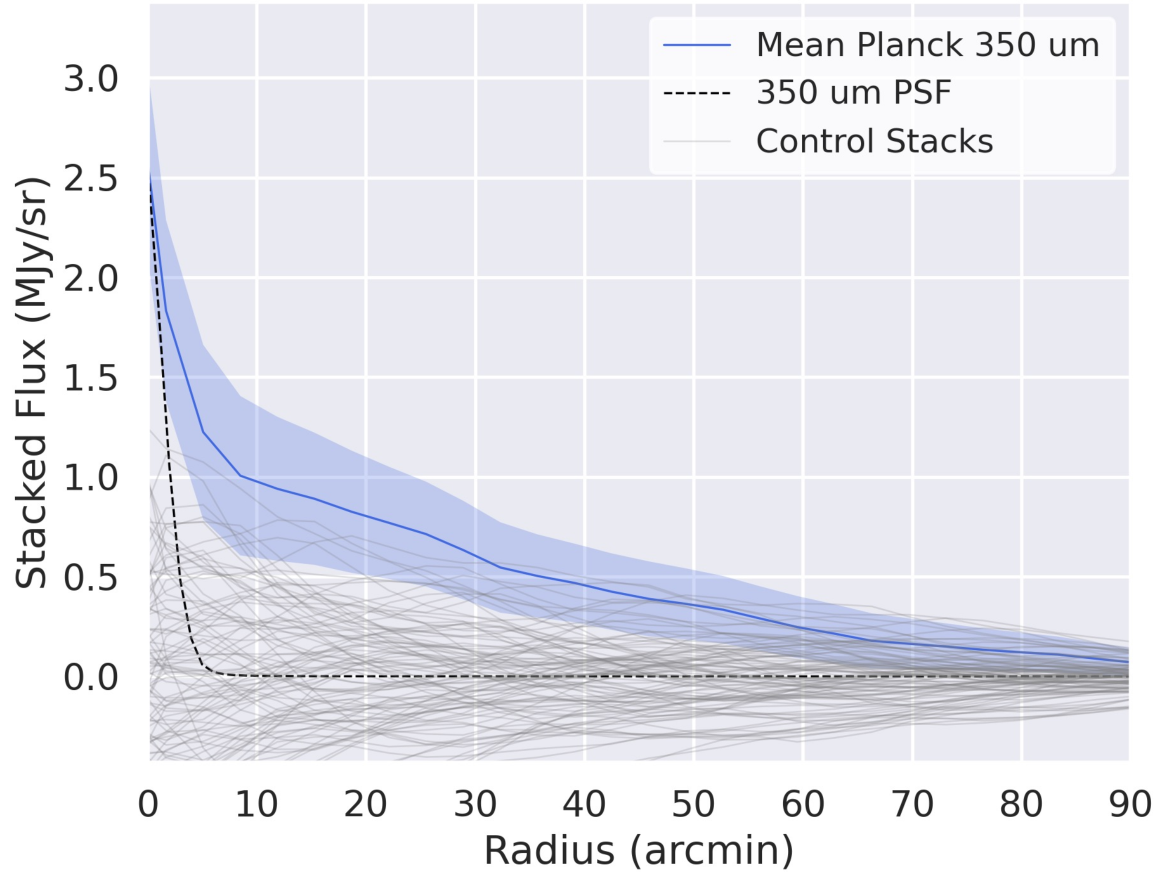
(Examples from the 100 total control stacks)



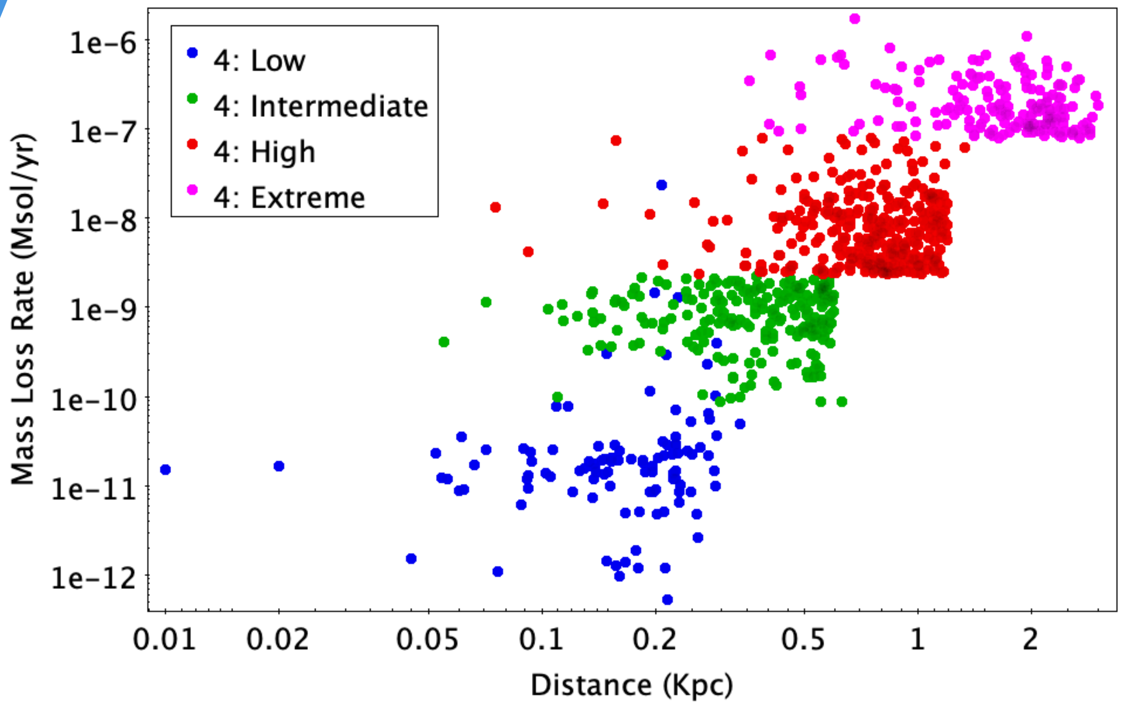
Extended AGB Star Dust Envelopes

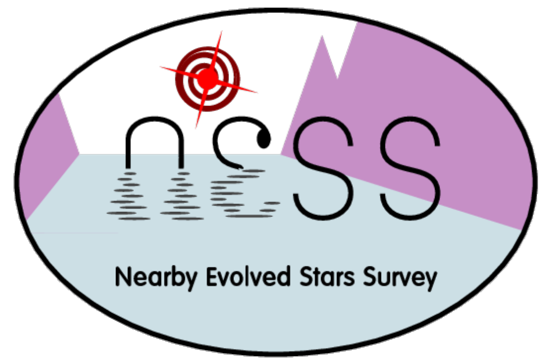


Planck 350 μm stack



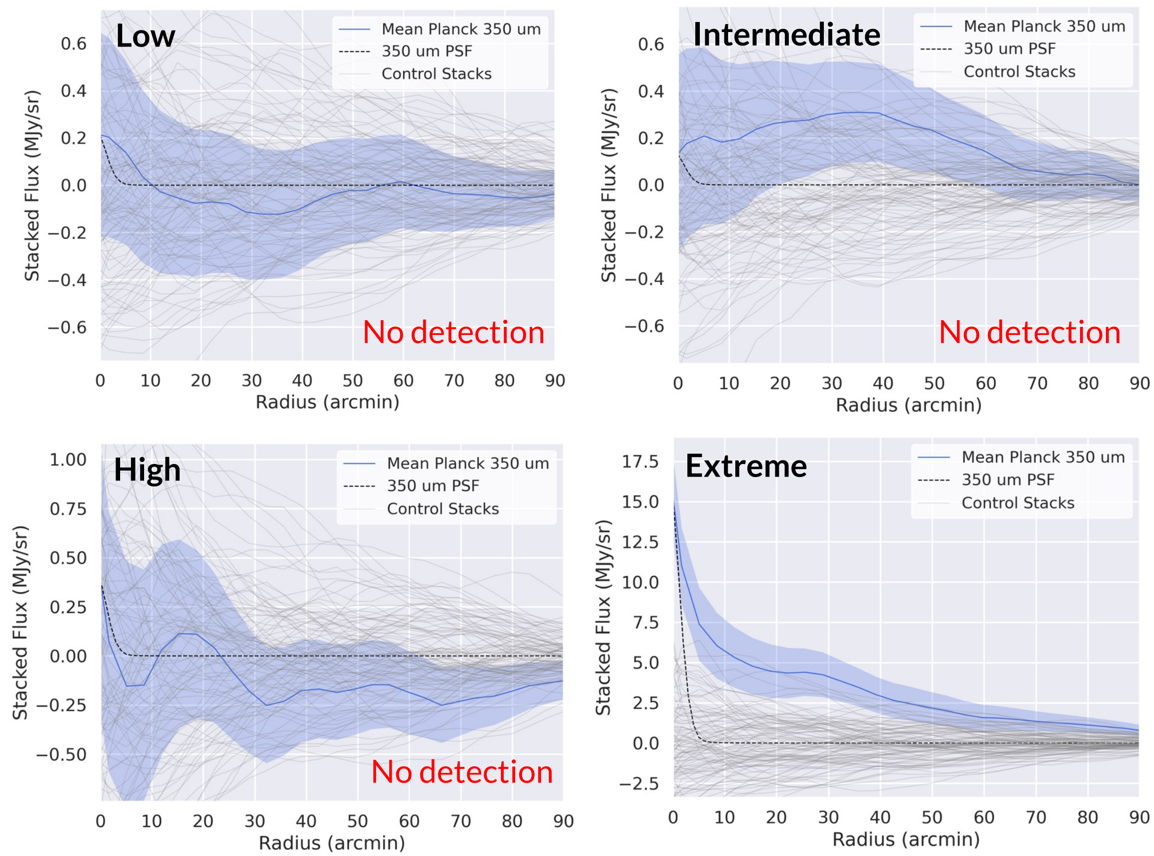
Sub-Stacks Based on Mass-Loss Rate





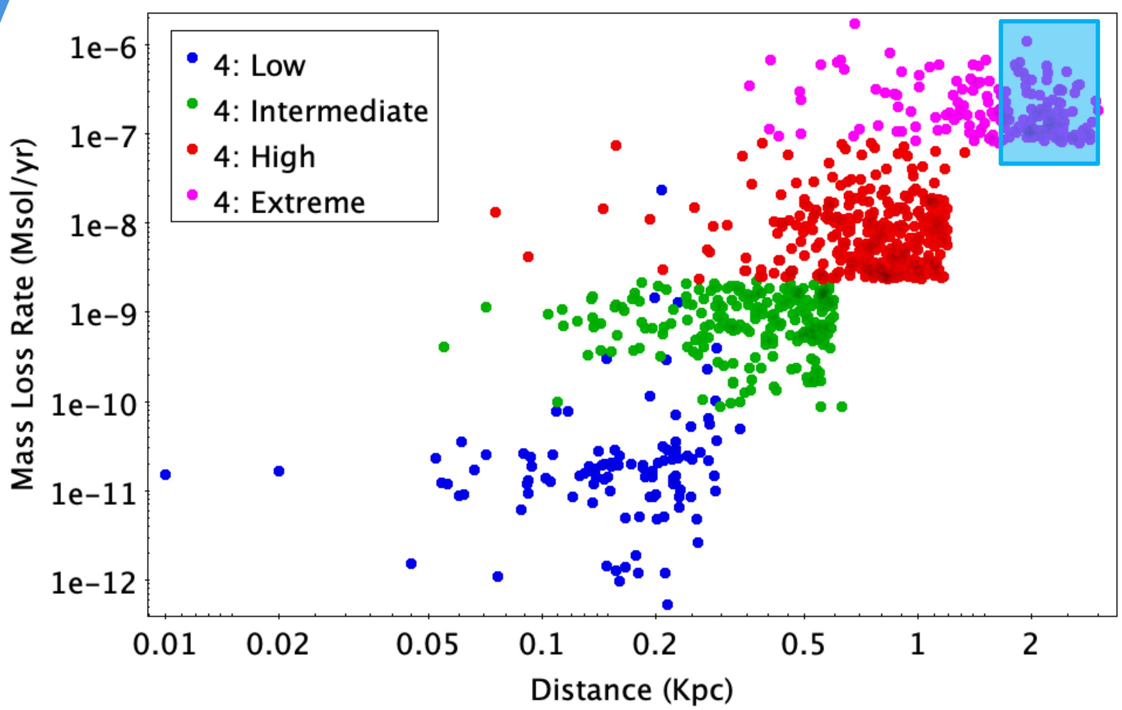
NESS is built out out 4 volume-limited sub-samples, each sampling a different range of dust production rates

Sub-Samples Based on Mass-Loss Rate



Extreme mass-loss-rate stars account for ≈all the emission in the full-sample stack.

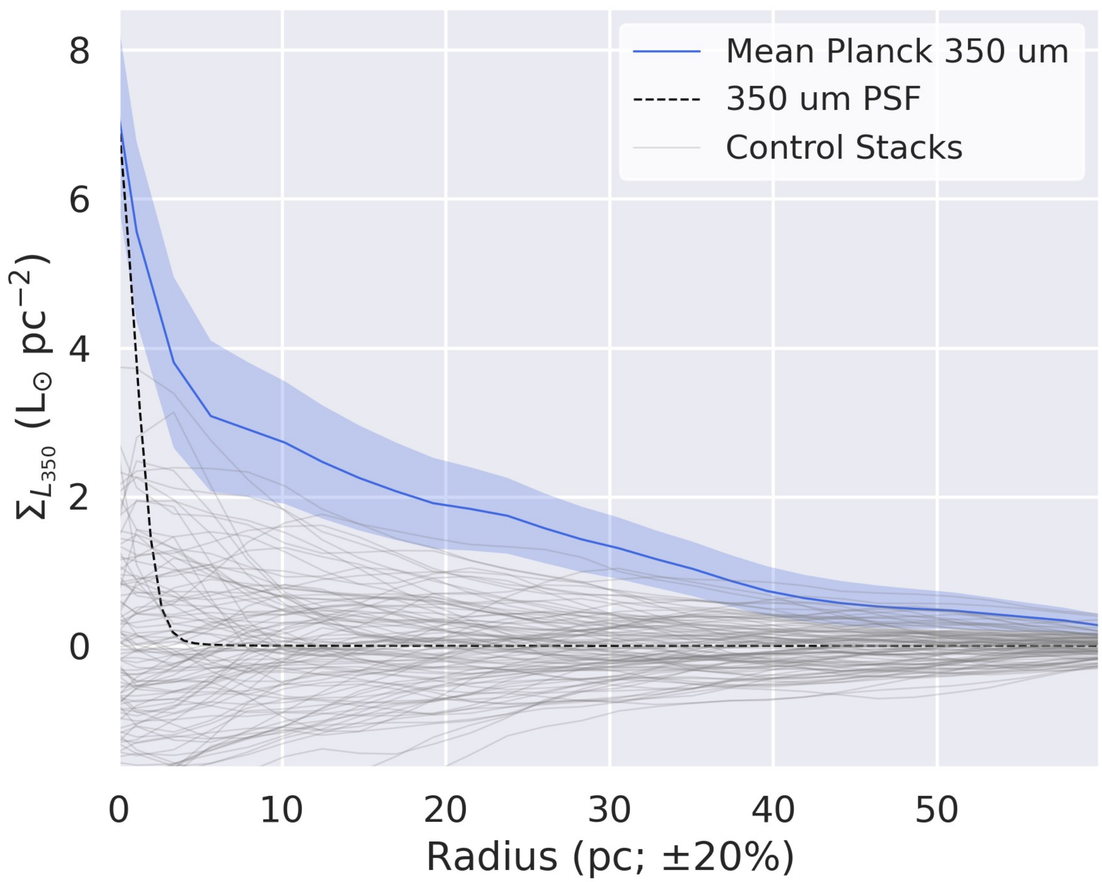
Stack Only Stars In Limited Distance Raage

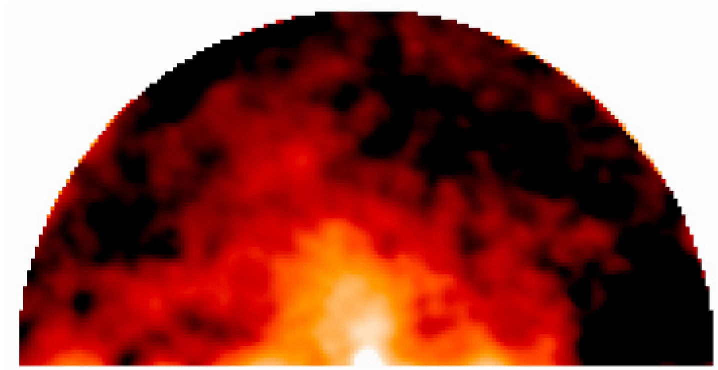


Stack only the 91 extreme-mass-loss stars that are at 1.6–3.2 kpc

NESS is built out out 4 volume-limited sub-samples, each sampling a different range of dust production rates

Highly Extended Dust Envelopes



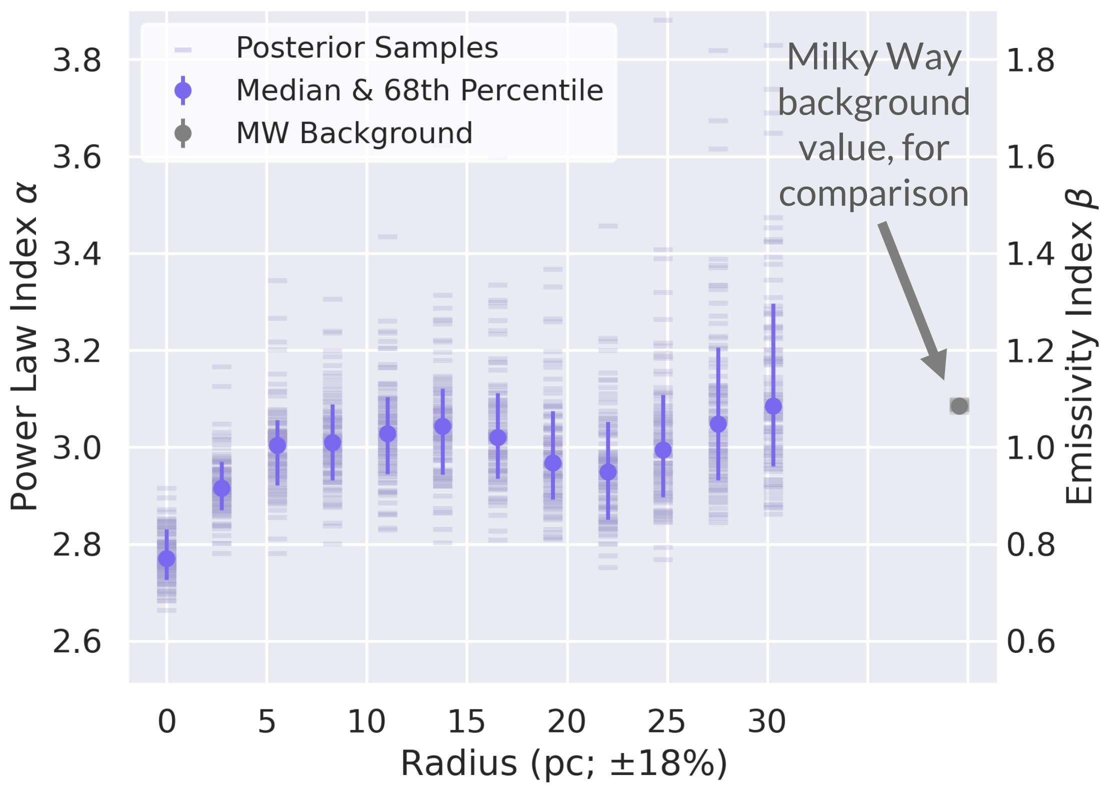


Physical extent of emission corresponds to >30 pc.

Previous detections only out to <0.5 pc (100,000 AU)!

(From NESS study of U Ant; Dharmawardena+, 2018)

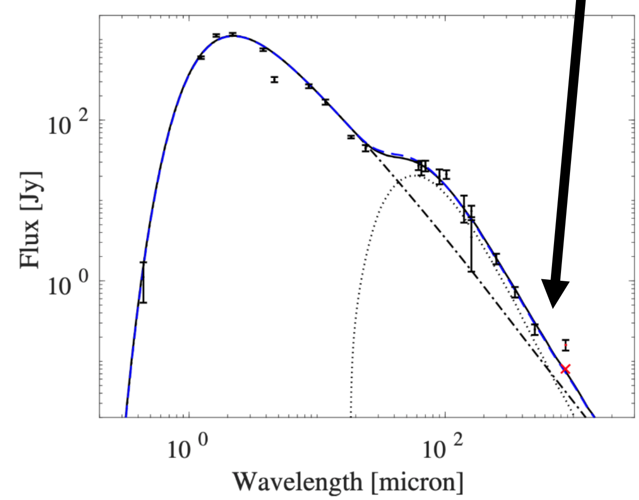
Dust Properties Evolve With Radius



α is power law index of long-λ SED slope

At the Rayleigh-Jeans limit, α ⟶ β +2

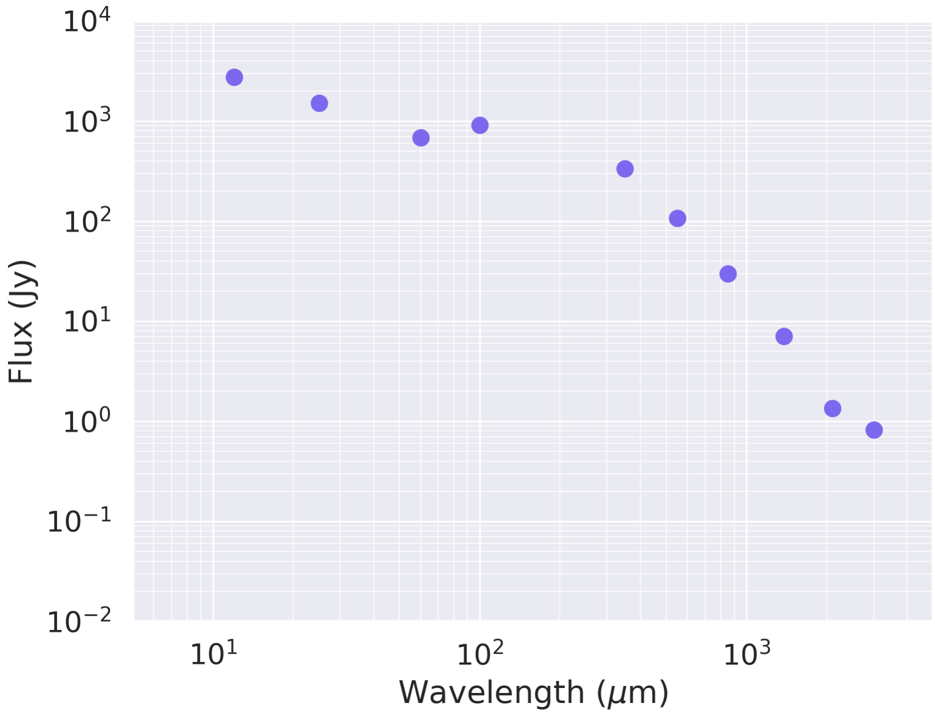
α set by properties of dust grains



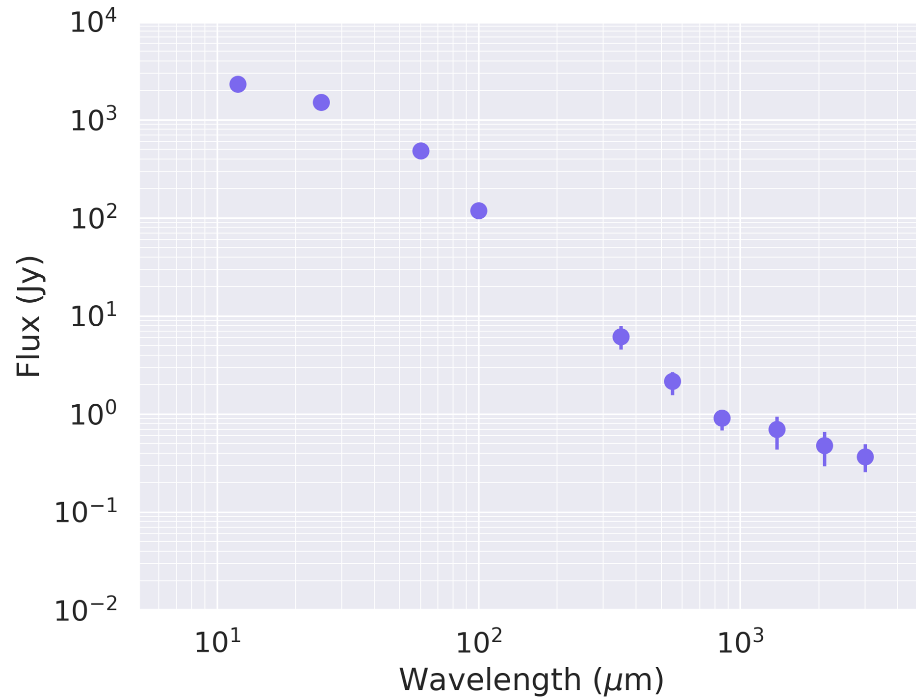
Example SED of a dusty AGB star (Maercker+, 2018)

SEDs Differ By Chemistry – C is Shallow

Stacked SED of bright O-rich stars
(34 sources, all individually detected at 350 μm)

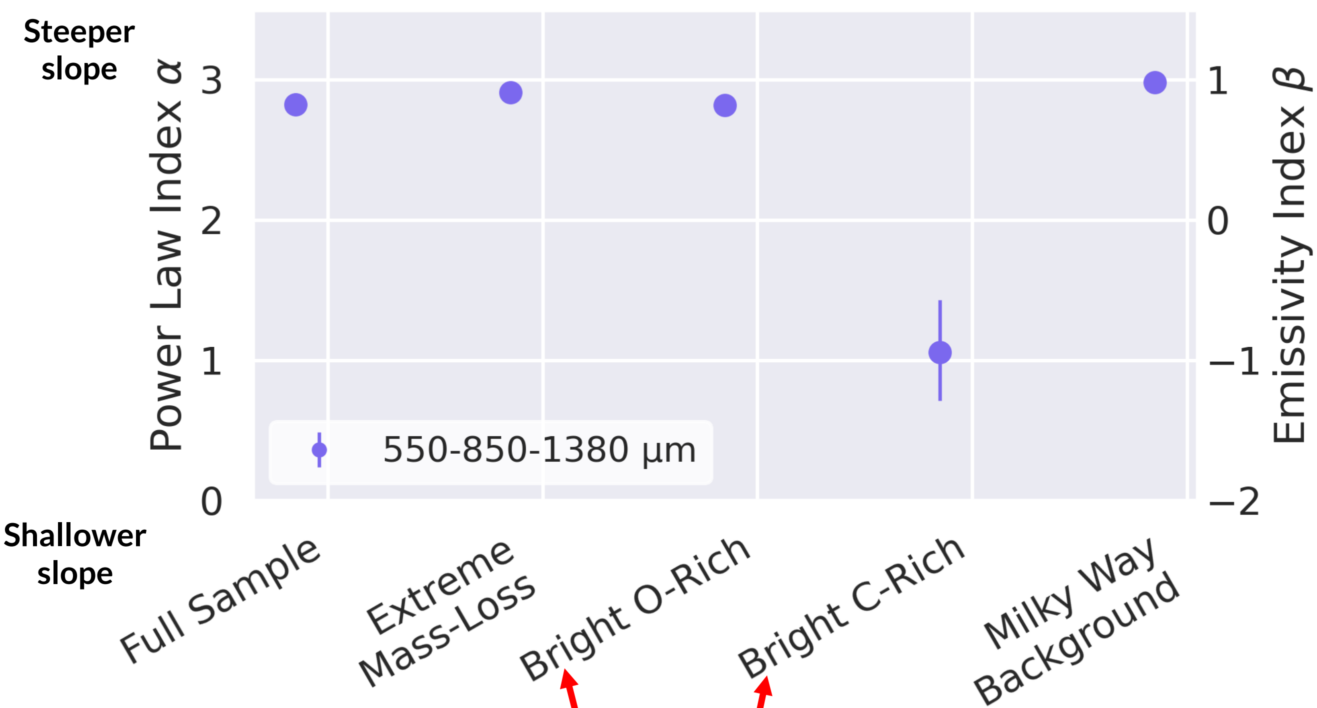


Stacked SED of bright C-rich stars
(13 sources, all individually detected at 350 μm)



All bands convolved to Planck 3 mm resolution;
fluxes from point source photometry

Dust Properties Vary with Chemistry

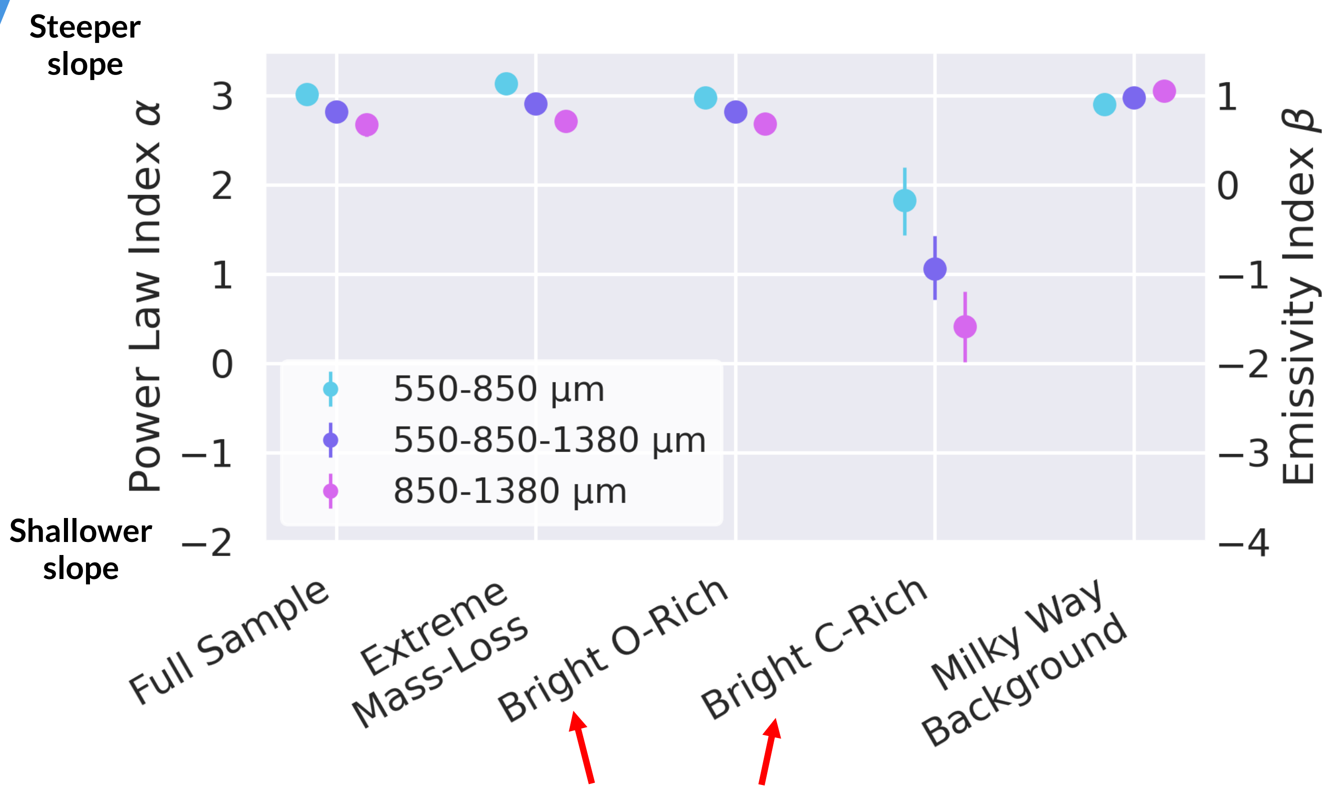


"Bright" stacks only include sources that are individually detected at Planck 350 µm, to maximise S/N at longer wavelengths

Very different power-law for oxygen-rich vs carbon-rich stars

(At the Rayleigh-Jeans limit, $\alpha \rightarrow \beta + 2$)

Dust Properties Vary with Chemistry



"Bright" stacks only include sources that are individually detected at Planck 350 μm, to maximise S/N at longer wavelengths

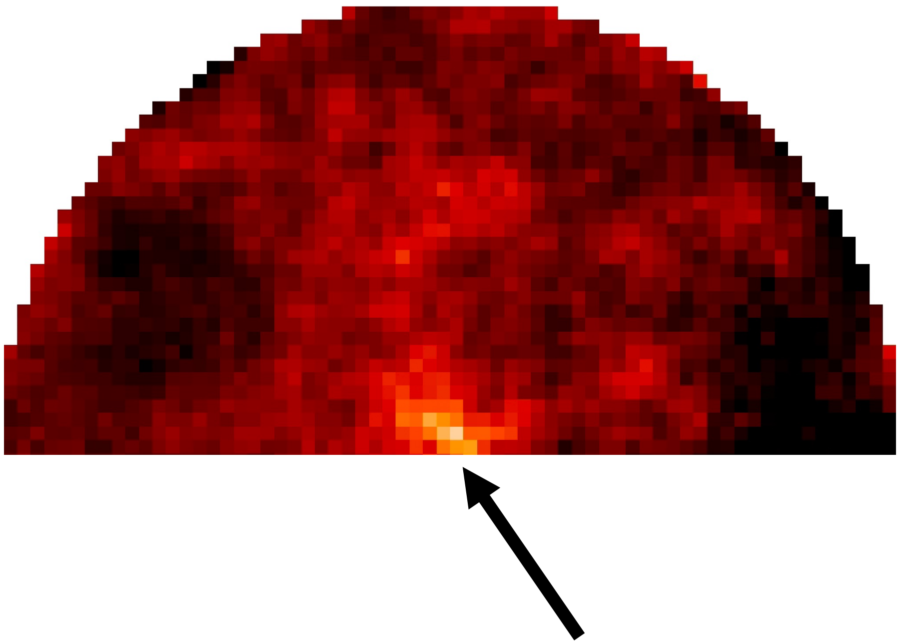
Very different power-law for oxygen-rich vs carbon-rich stars

Power law gets shallower at longer wavelengths:

We don't see this for general Milky Way dust (which has constant α to within errors)

(At the Rayleigh-Jeans limit, $\alpha \rightarrow \beta + 2$)

Sneak Preview of Future Work…



A_V = 0.08 mag at peak

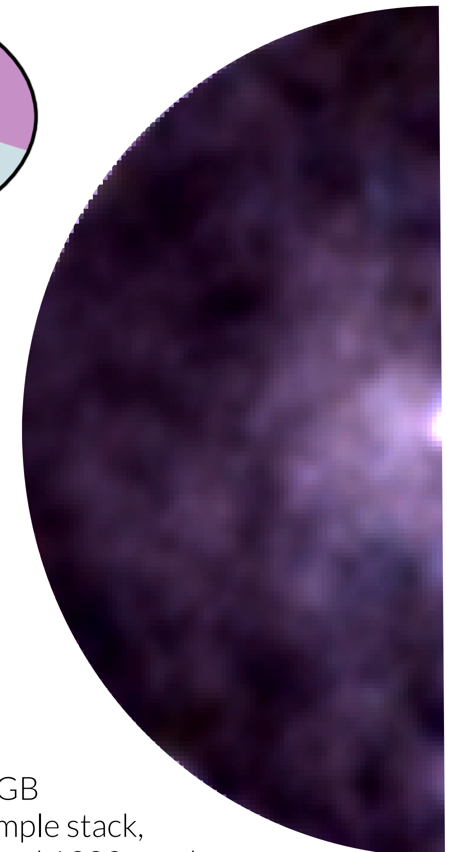
Stack produced using `Bayestar` 3D dust map

(Using all 428 NESS stars in Bayestar footprint and >1 deg from Galactic plane)

Very preliminary!

Questions!

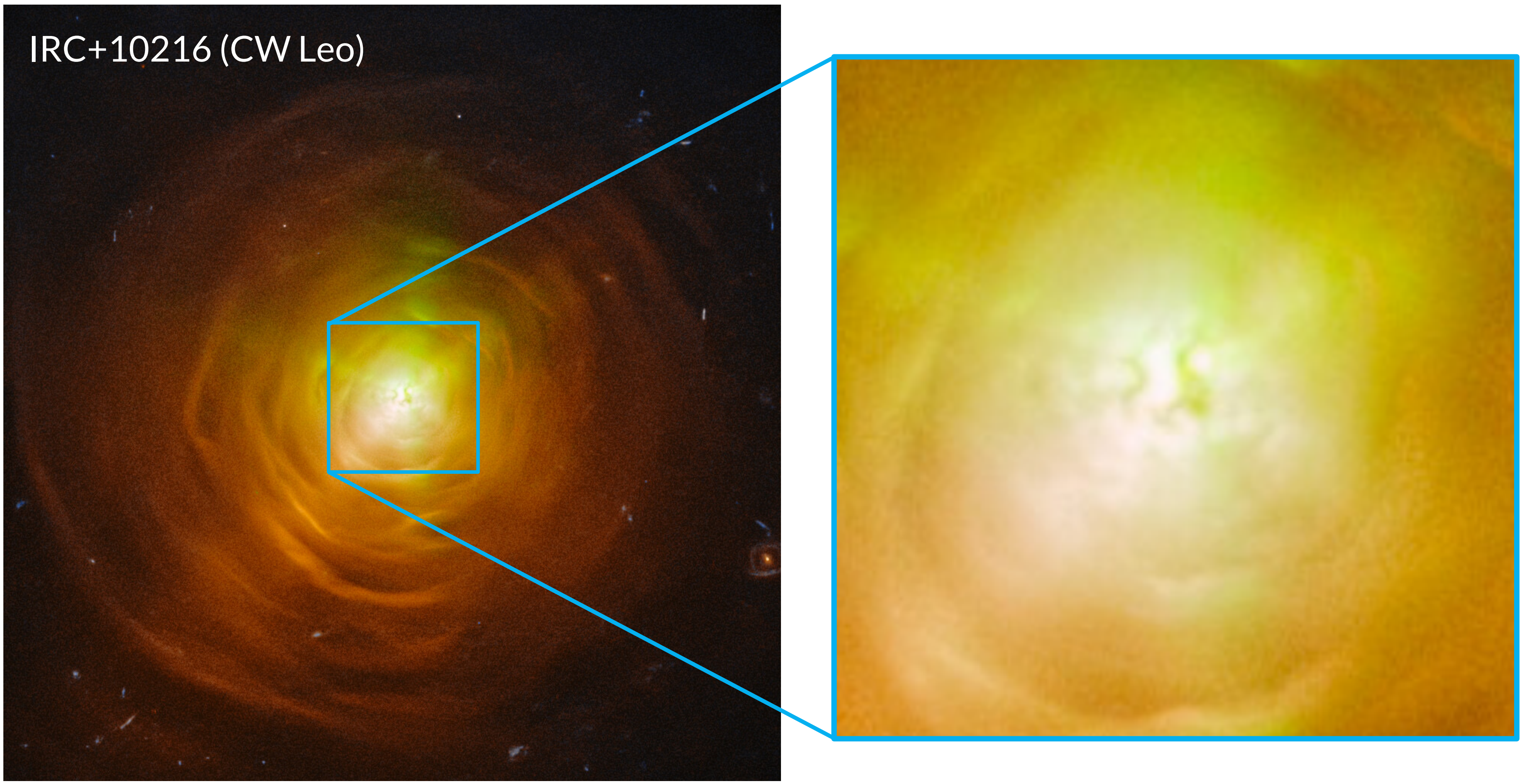
- Stacked dust emission from 712 Milky Way evolved stars from the Nearby Evolved Stars with *Planck* & IRAS.
- Detected stacked emission from 100 μm to 3 mm.
- Very extended dust emission detected in stack, with S/N > 2 out to radius of >30 arcmin.
- By stacking subsamples of stars within constrained distances, we detect dust out to radius of >40 pc; a factor of 60 further out than previously possible!
- Dust properties evolve with radius; suggests processing? (Bow shocks? Exposure to UV ISRF?)
- Dust around AGB stars has different FIR–mm properties than standard Milky Way dust; implies rapid dust processing in ISM.
- We see very different FIR–mm emission properties from dust around carbon-rich vs oxygen-rich stars



Three-colour RGB image of full-sample stack, with 350, 850, and 1380 μm data

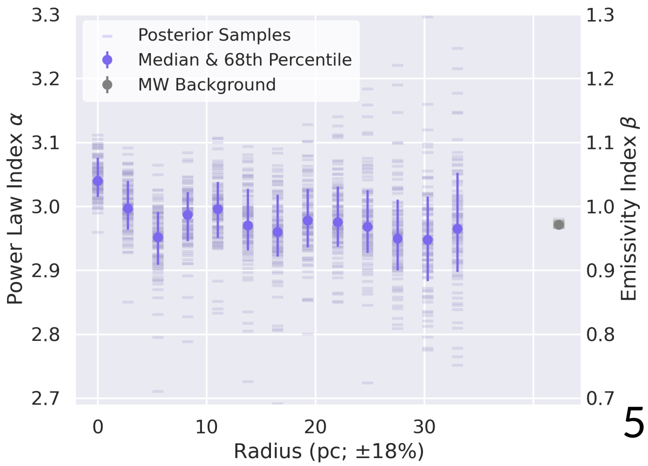
Bonus Slides

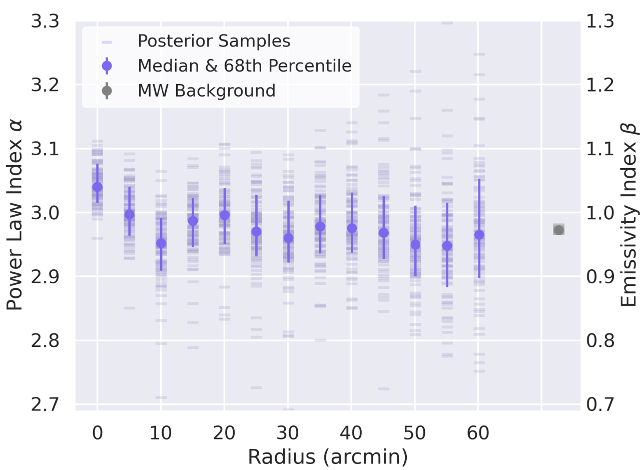
Messy Photocentres Bad for Gaia



ESA/Hubble & NASA, Ueta, Kim

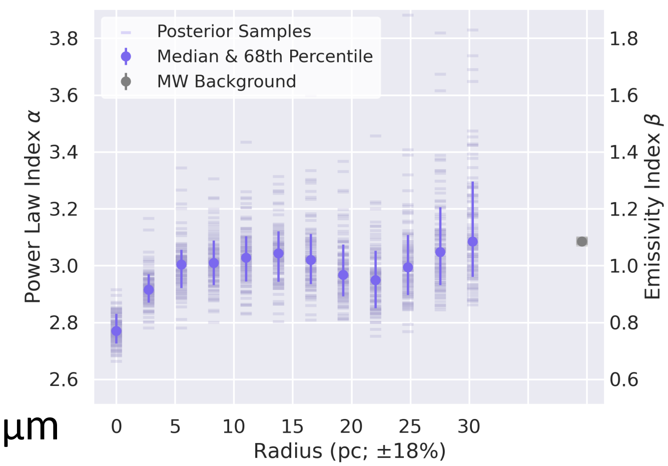
Wavelength-Dependent Slope Evolution

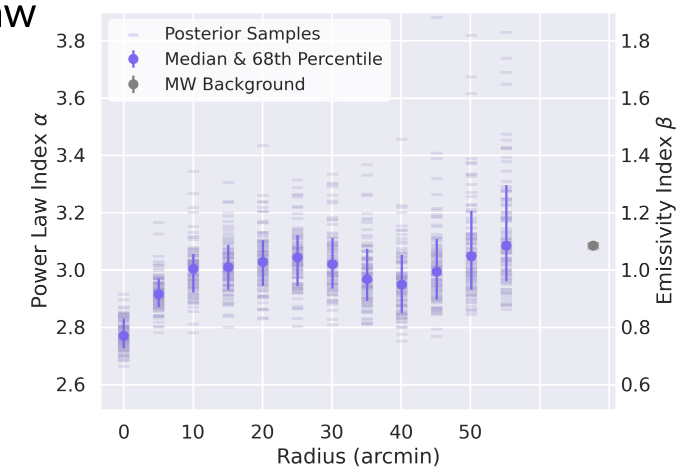




550–850 μm
power law

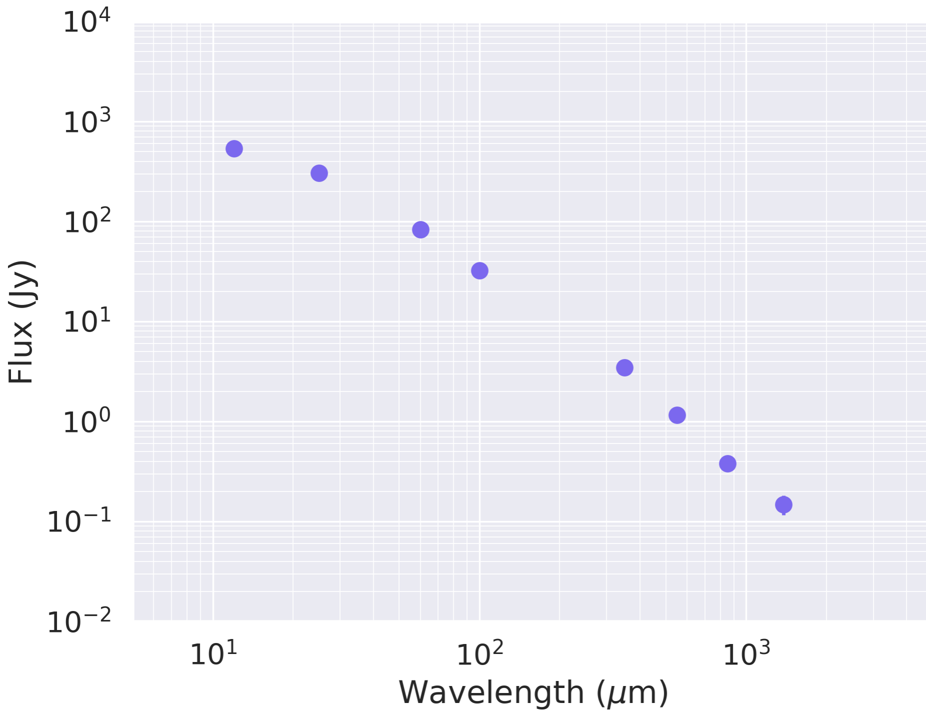
850–1380 μm
power law





SEDs Differ By Chemistry

Stacked SED of bright O-rich stars
(34 sources, all individually detected at 350 μm)



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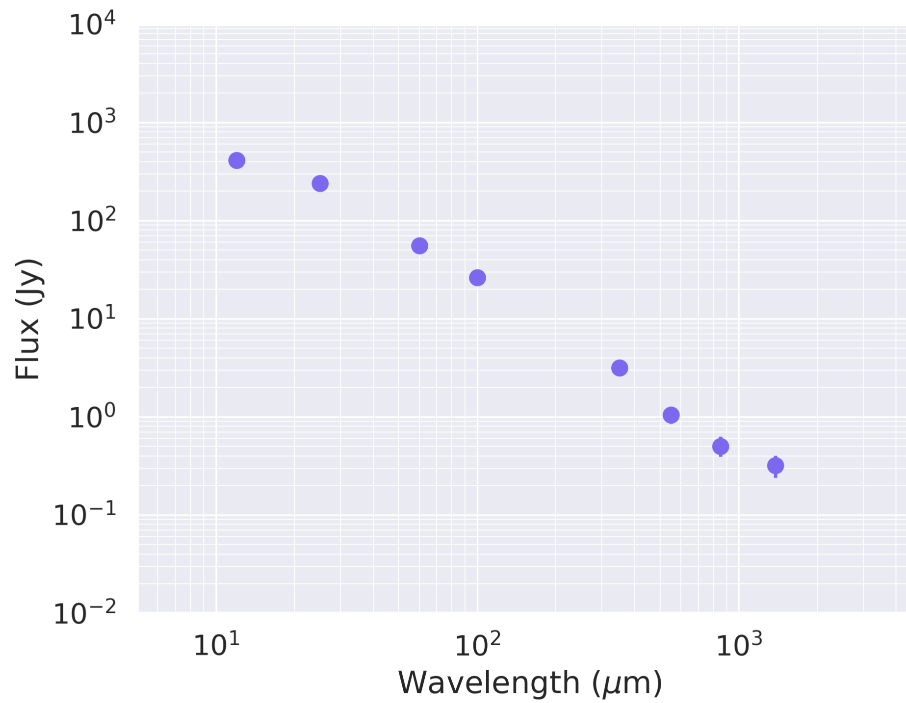

***Median* stacks**

PSF photometry, all bands convolved to Planck 1.38 mm resolution

SEDs Differ By Chemistry

Stacked SED of bright O-rich stars
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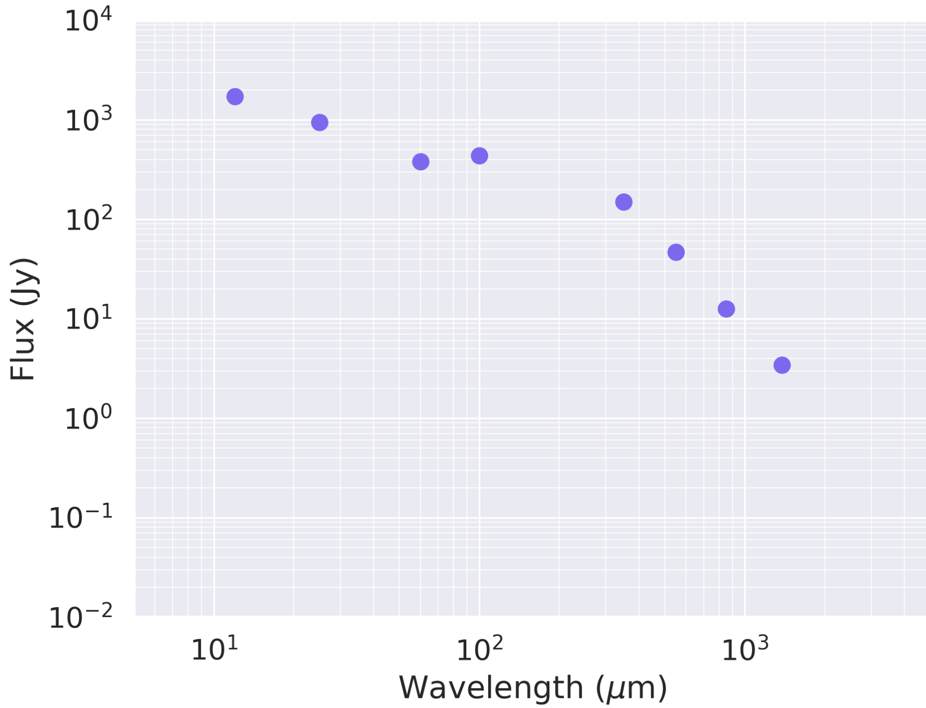

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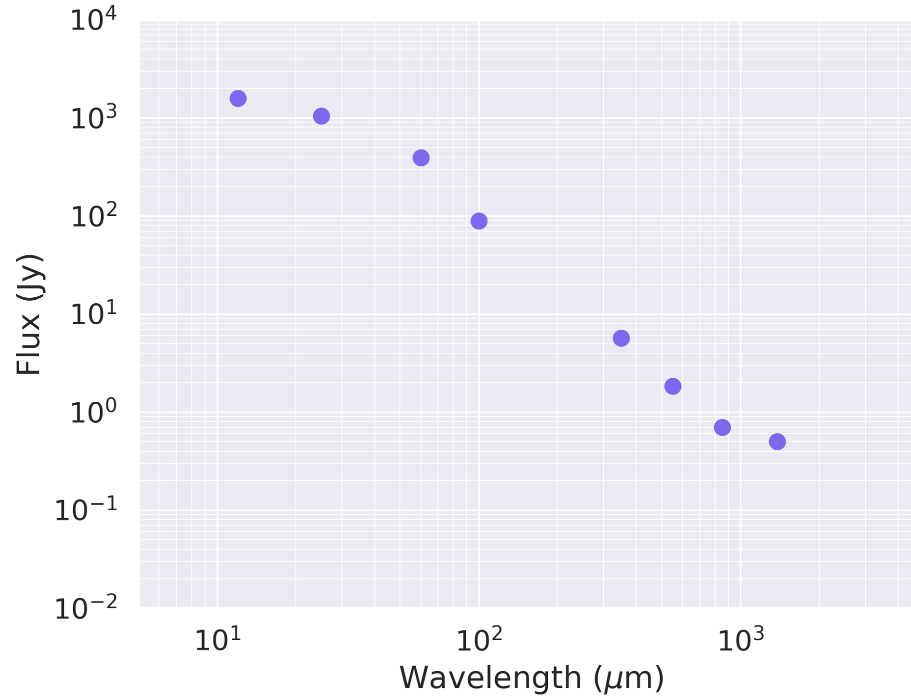

All bands convolved to Planck 1.38 mm resolution;
fluxes from point source photometry

Bias Correction