Note: This was an unusual seminar, in that Jeremy was unable to hear us! He proceeded anyway and invited questions by e-mail. So understand that there is no exchange of info and questions in this recording. He is available at jeremy.chastenet@ugent.be

GHENT UNIVERSITY

FACULTY OF SCIENCES

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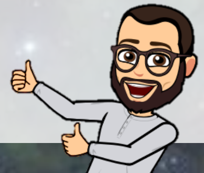
Far-IR dust polarisation in the Crab

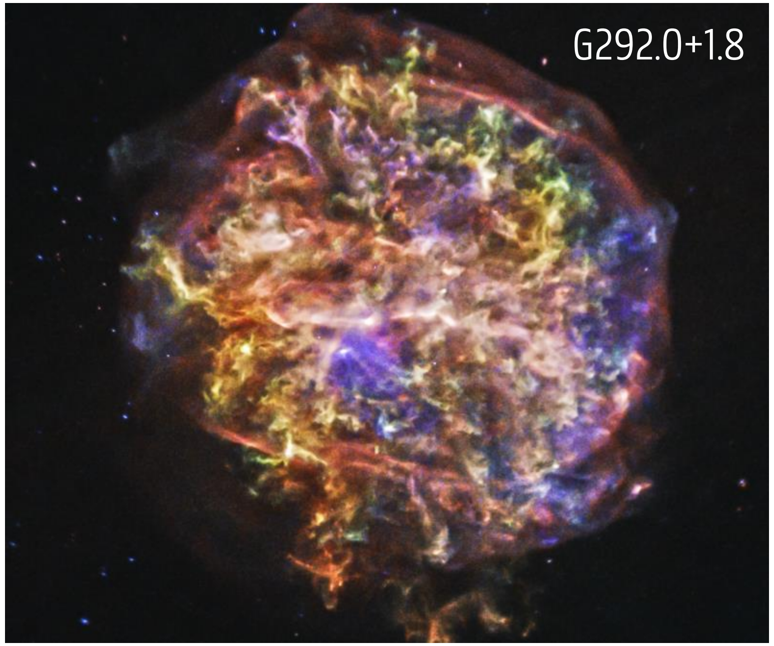
Link to the paper

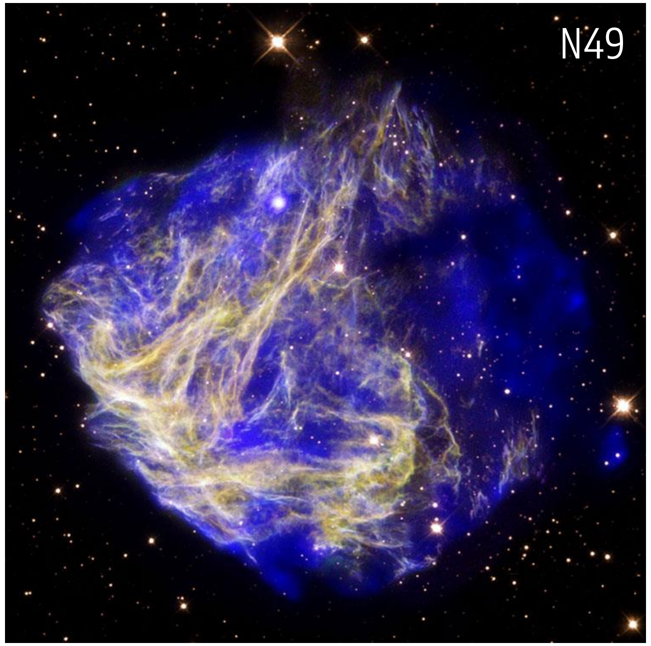
Jérémy Chastenet
with help from a lot of smart people.

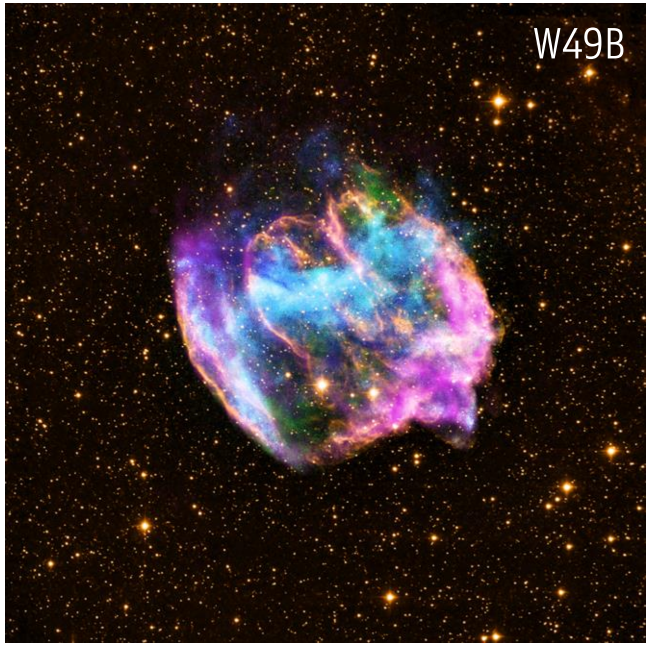


Dust Masses in SNRs (a very non-exhaustive list)

- Cassiopeia A: 0.02 – 0.6 $M_\odot$ (Rho et al. 2008, Arendt et al. 2014, Barlow et al. 2010, De Looze et al. 2017)
- G54.1+0.3: 0.06 – 1.1 $M_\odot$ (Temim et al. 2010, Temim et al. 2017, Rho et al. 2018)
- SN1987A: 0.5 – 0.7 $M_\odot$ (Matsuura et al. 2011)







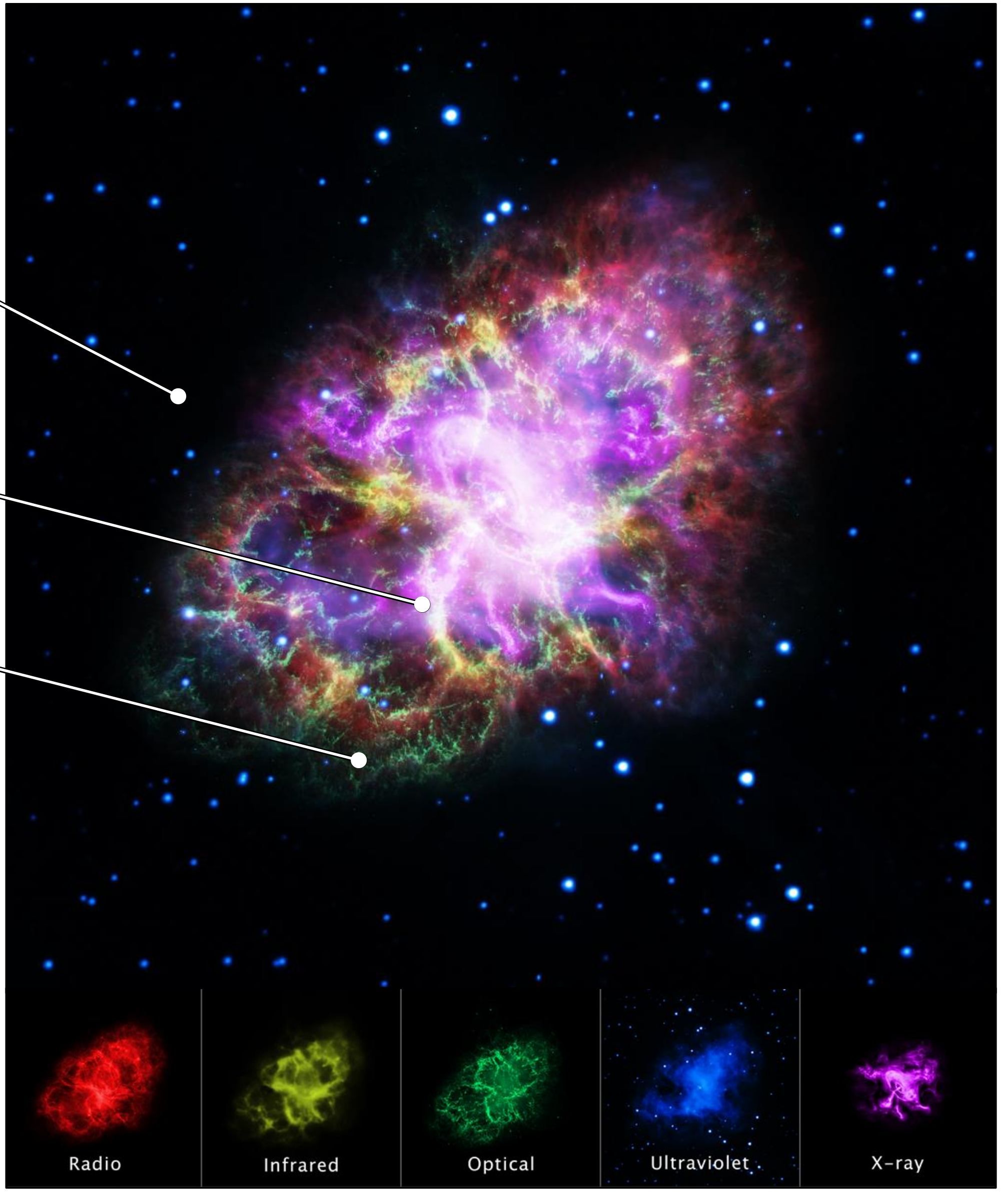
SNRs: Supernova Remnants

The Crab Nebula

Exploded in 1054 AD
2 kpc distance
Type II-P
8 – 11 $M_{\odot}$ progenitor

Pulsar Wind Nebula

85 – 90% He and lots of C, O, Ne, S, Ar



Jérémy Chastenet

Dust Masses in the Crab

- Gomez et al. (2012): 0.24 $M_\odot$ of 28 K carbon grains
  0.11 $M_\odot$ of 34 K silicate grains
  0.14 + 0.08 $M_\odot$ of both
- Temim & Dwek (2013): 0.019 $M_\odot$ of 56 K carbon grains
- Owen & Barlow (2015): 0.18 – 0.27 $M_\odot$ of carbon grains
  0.11 – 0.13 + 0.39 – 0.47 $M_\odot$ of both
- De Looze et al. (2019): 0.032 – 0.049 $M_\odot$ of 41 K carbon grains
  similar masses for $MgSiO_3$
  implausible masses for e.g. Fe or $Mg_{0.7}SiO_{2.7}$
- Priestley et al. (2019): 0.05 $M_\odot$ (0.026 – 0.076) of carbon grains
  0.076 – 0.218 $M_\odot$ of $MgSiO_3$

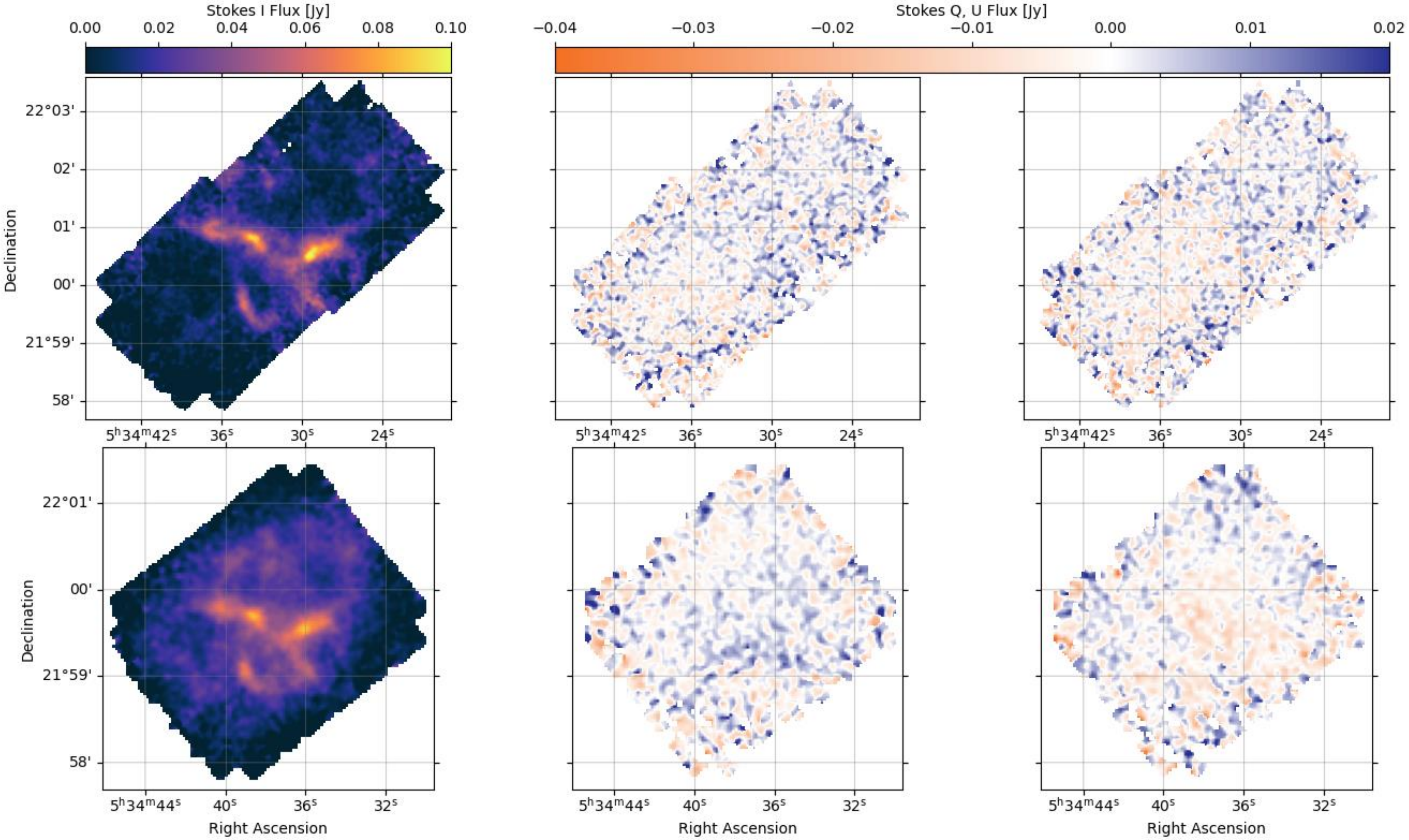
near-IR – radio fitting

radiative transfer

mid- – far-IR fitting

New data: far-IR SOFIA/HAWC+

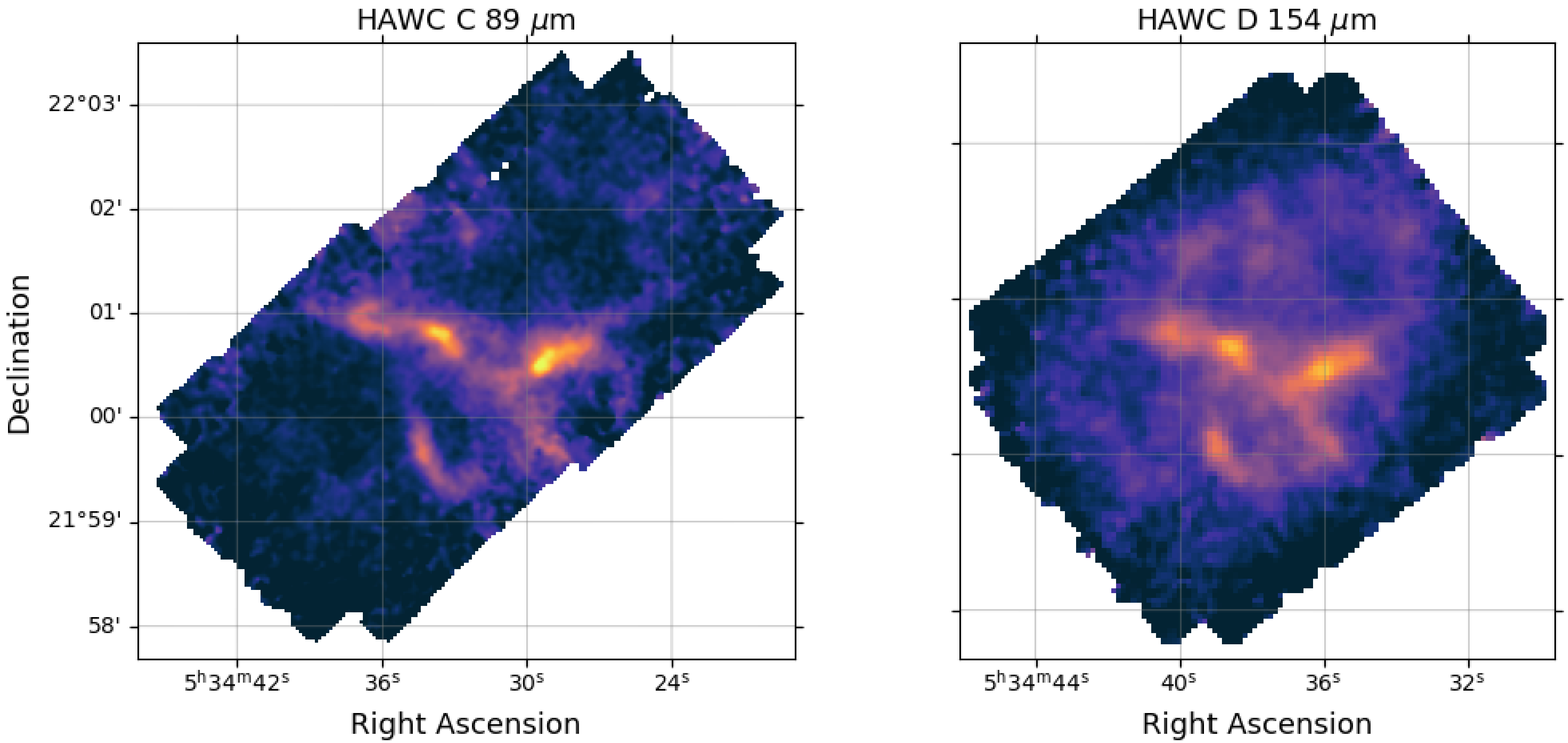
STOKES VECTOR IN THE CRAB, WITH SOFIA



HAWC+ C
89 µm

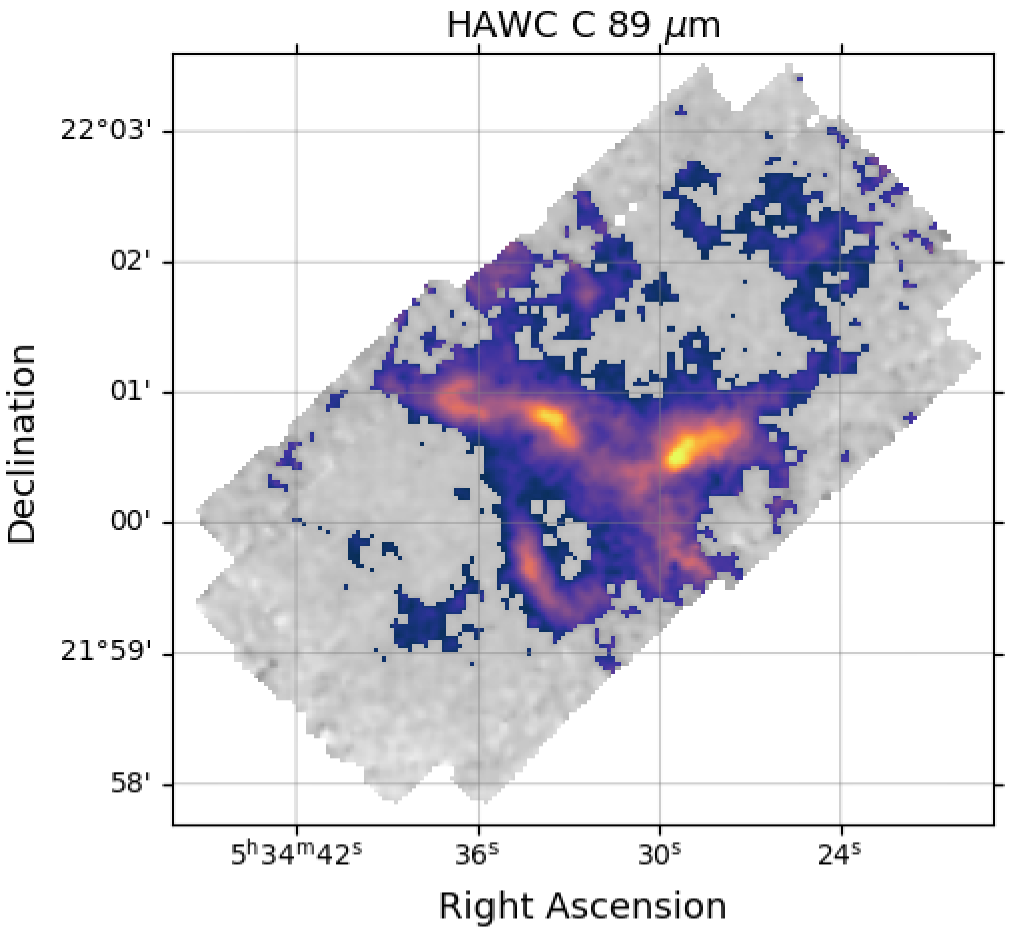
HAWC+ D
154 µm

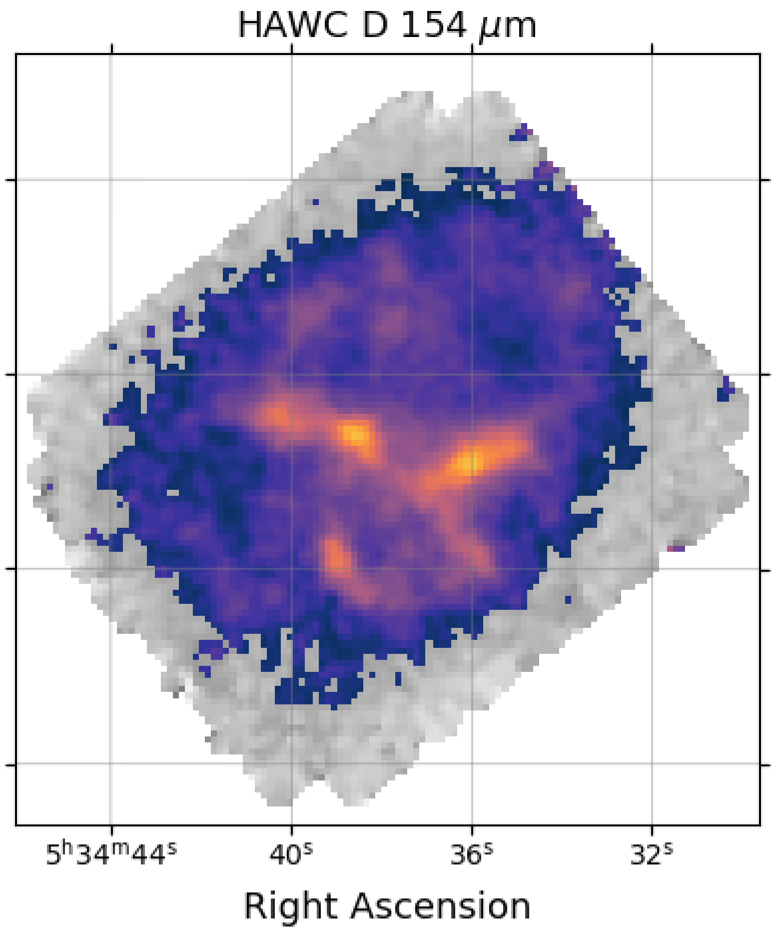
Quality Checks



In the literature, Crab M_{dust}: 0.019 – 1.0 $M_{\odot}$

Quality Checks

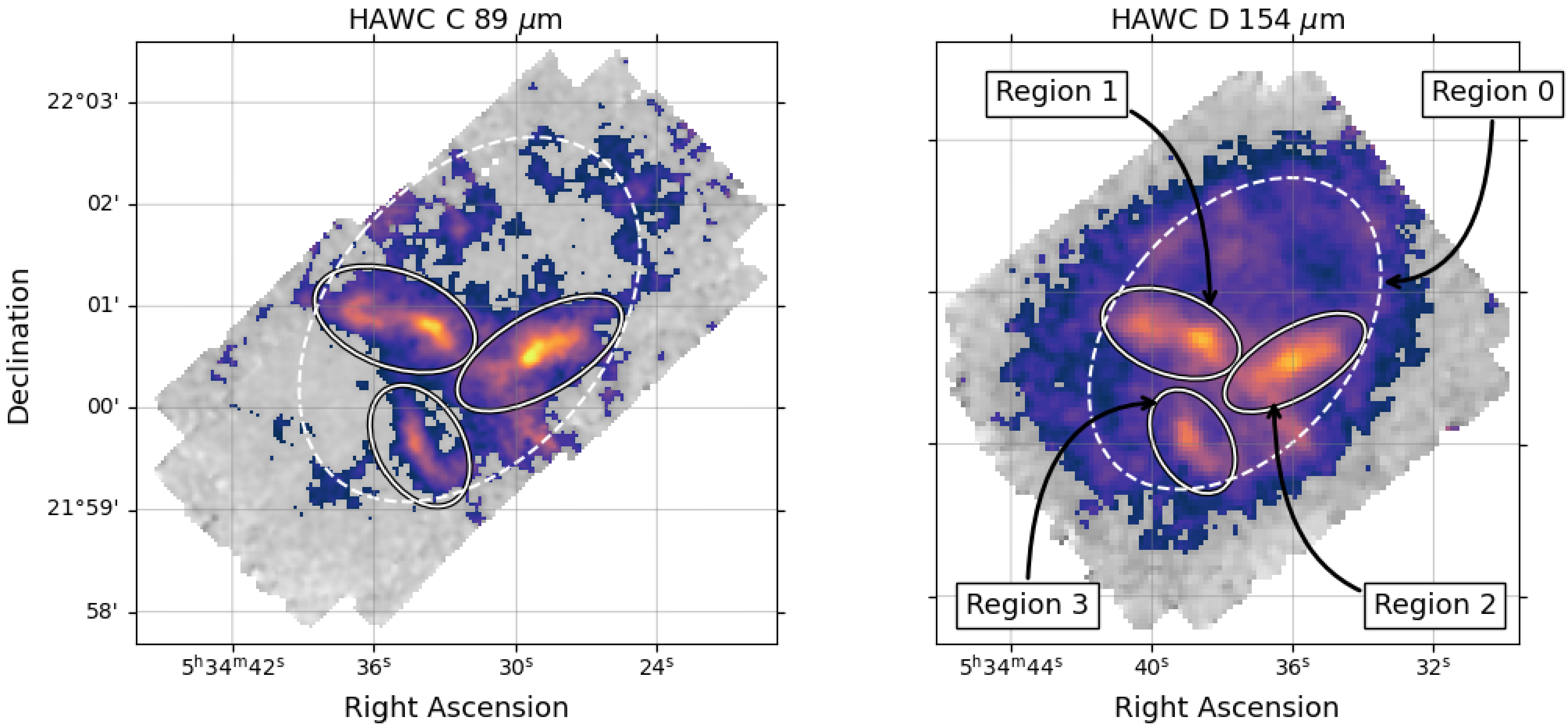




S/N ≥ 3

In the literature, Crab M_{dust}: 0.019 – 1.0 $M_{\odot}$

Quality Checks



S/N ≥ 3

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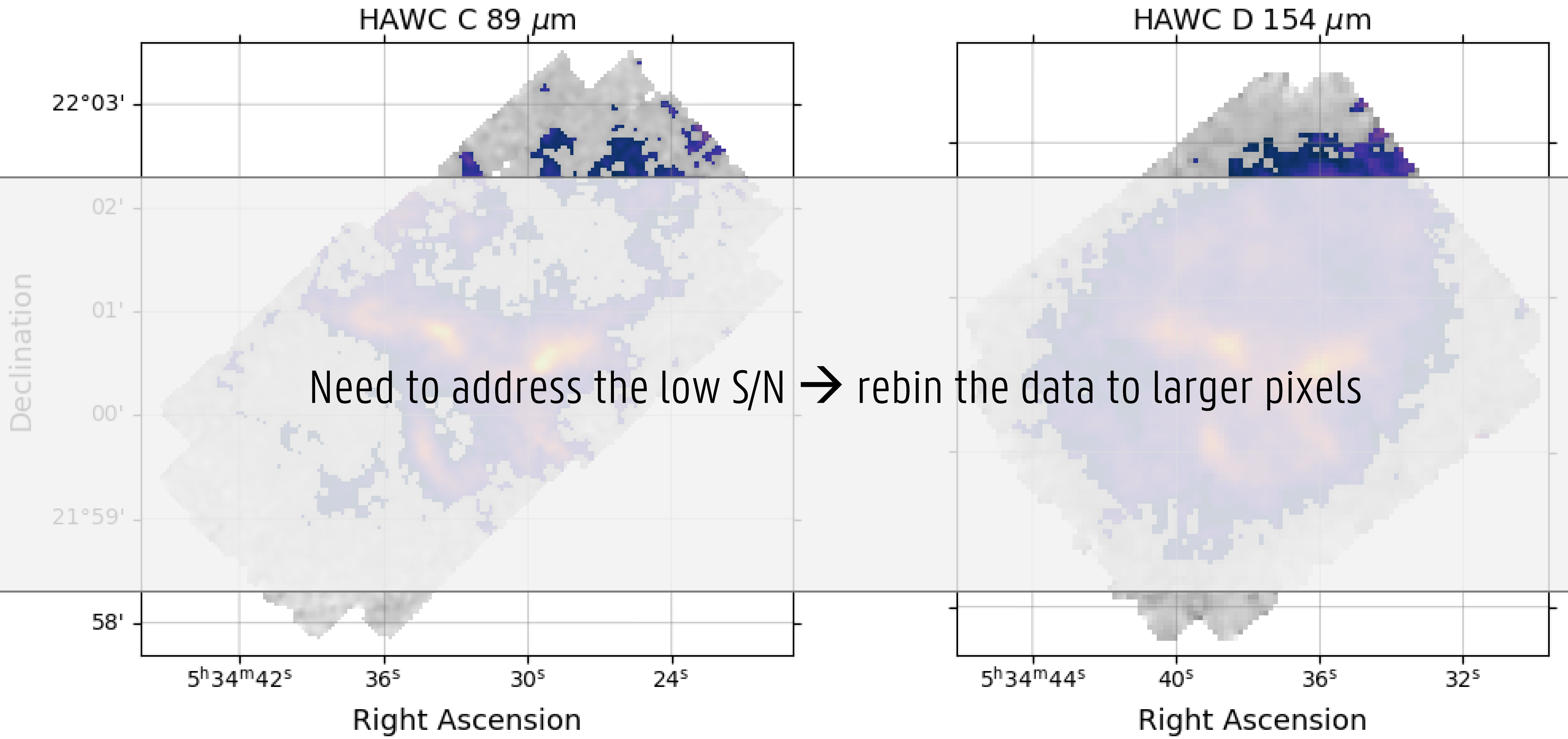
Quality Checks



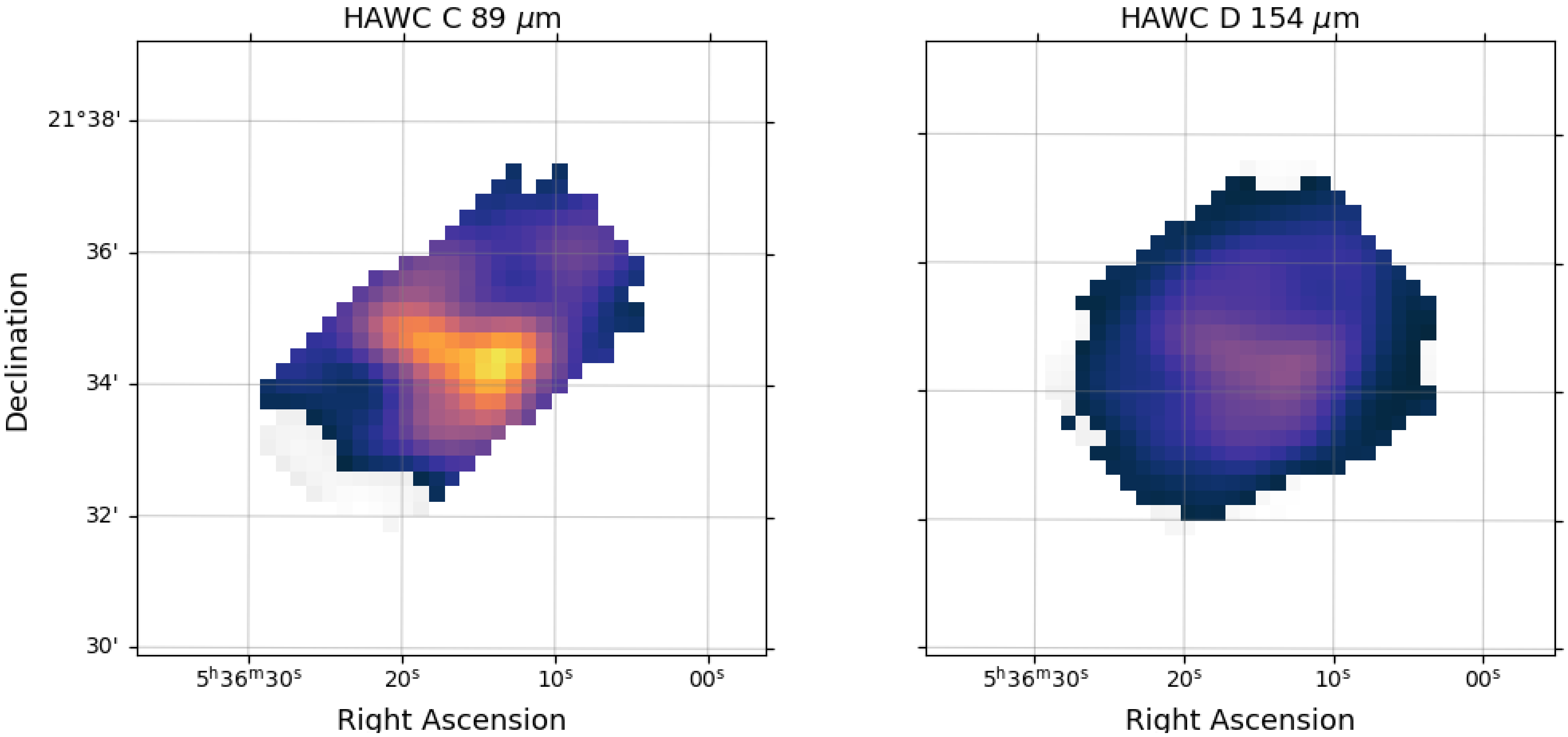
Need to address the low S/N → rebin the data to larger pixels

S/N ≥ 3

In the literature, Crab M_{dust}: 0.019 – 1.0 $M_{\odot}$

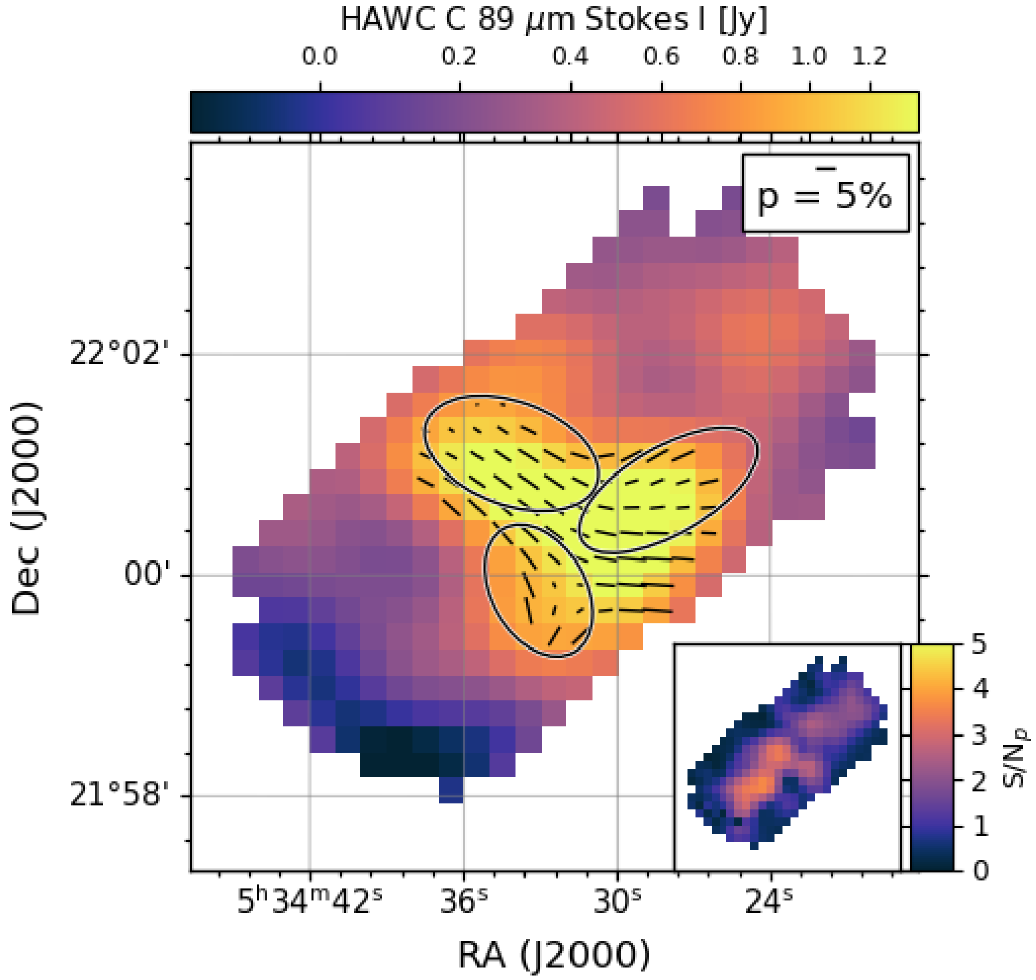
Jérémy Chastenet

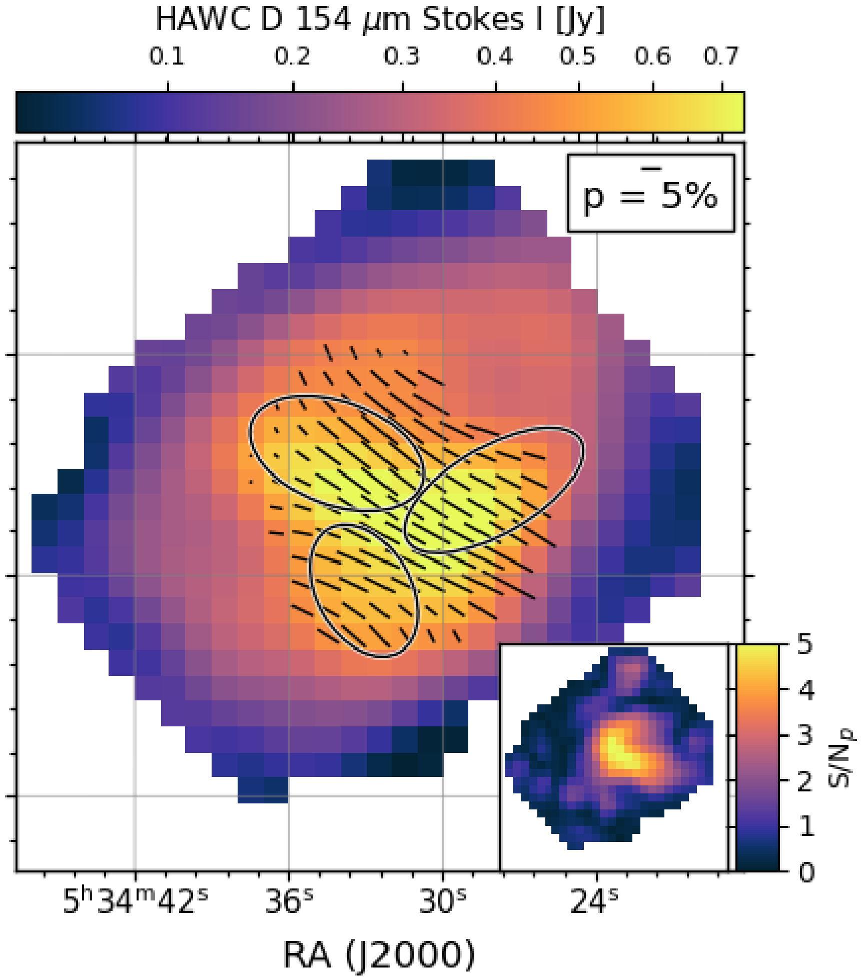
Quality Checks – Rebinned Data to SPIRE 500



In the literature, Crab M_{dust}: 0.019 – 1.0 $M_{\odot}$
SOFIA/HAWC+ data: low S/N

Data Polarisation

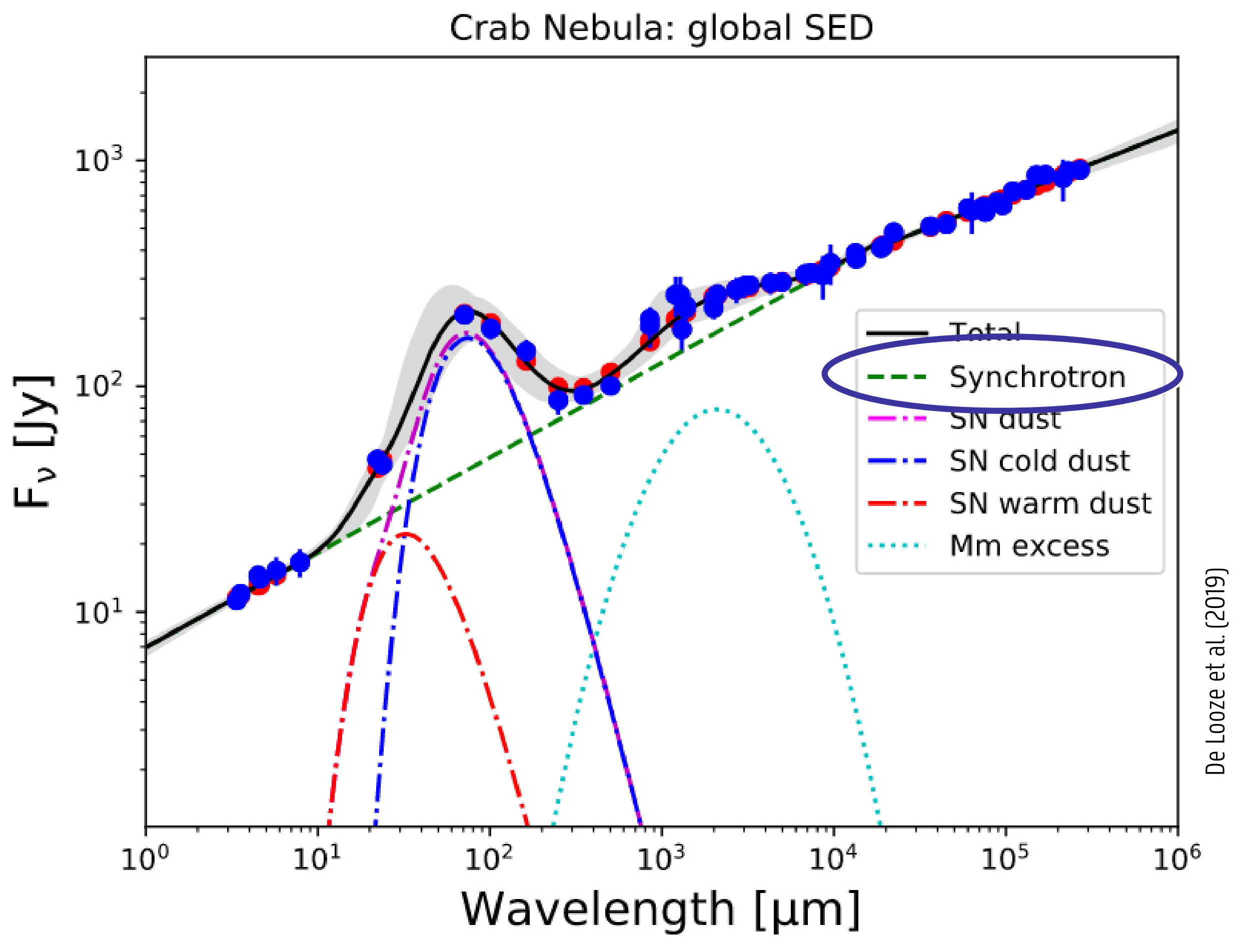




In the literature, Crab M_{dust}: 0.019 – 1.0 $M_{\odot}$
SOFIA/HAWC+ data: low S/N

Data correction: Synchrotron removal

SIGNAL CONTAMINATION

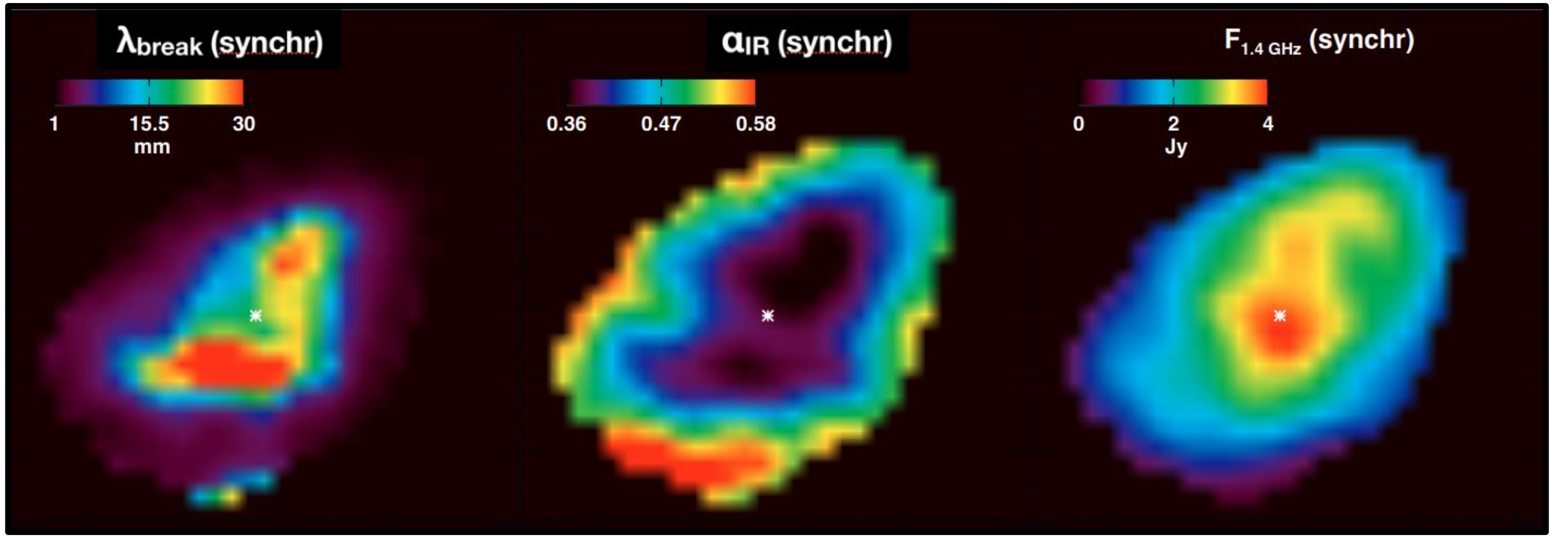


De Looze et al. (2019)

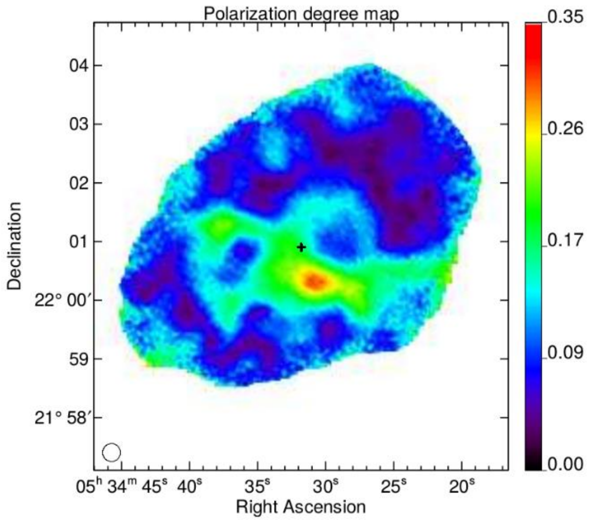
In the literature, Crab M_{dust}: 0.019 – 1.0 $M_\odot$
SOFIA/HAWC+ data: low S/N

Signal (de)Contamination

NIKA 150 GHz



De Looze et al. (2019)



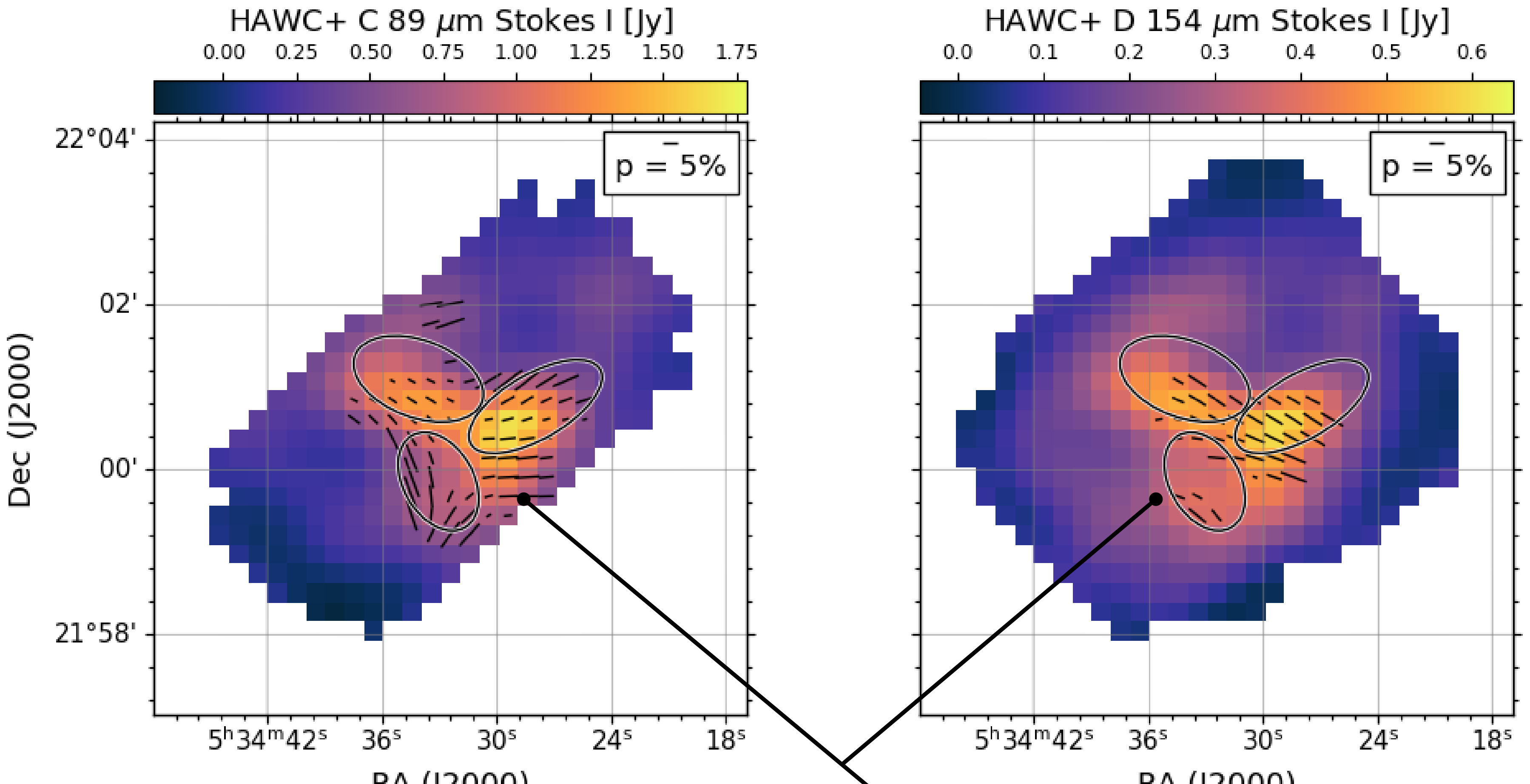
Ritacco et al. (2018)

⟶ Convolution to *Herschel* / SPIRE 500

⟶ $p_{\mathrm{radio}}, \theta_{\mathrm{radio}}$

In the literature, Crab M_{dust}: 0.019 – 1.0 $M_{\odot}$
SOFIA/HAWC+ data: low S/N + synchrotron removal

Synchrotron-corrected Polarisation

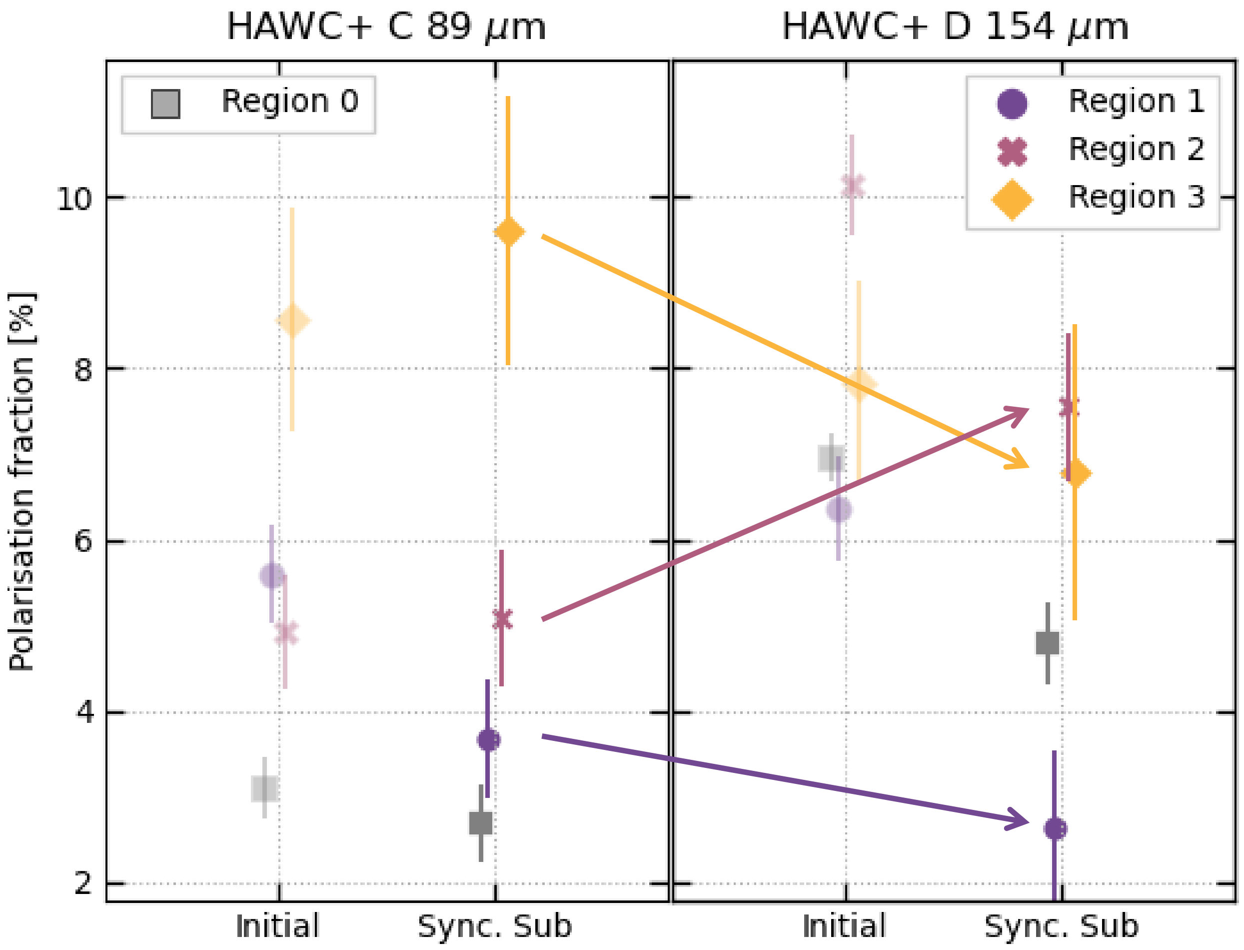


few to no S/Np > 3 vectors → work on integrated sales

In the literature, Crab M_{dust}: 0.019 – 1.0 $M_{\odot}$

SOFIA/HAWC+ data: low S/N + synchrotron removal → convolution/projection to SPIRE 500

SYNCHROTRON-CORRECTED POLARISATION



In the literature, Crab M_{dust}: 0.019 – 1.0 $M_{\odot}$

SOFIA/HAWC+ data: low S/N + synchrotron removal → convolution/projection to SPIRE 500 | Integrated scales analysis

Doing science: Deriving dust properties!

Deriving Dust Properties: Flowchart

Assumptions

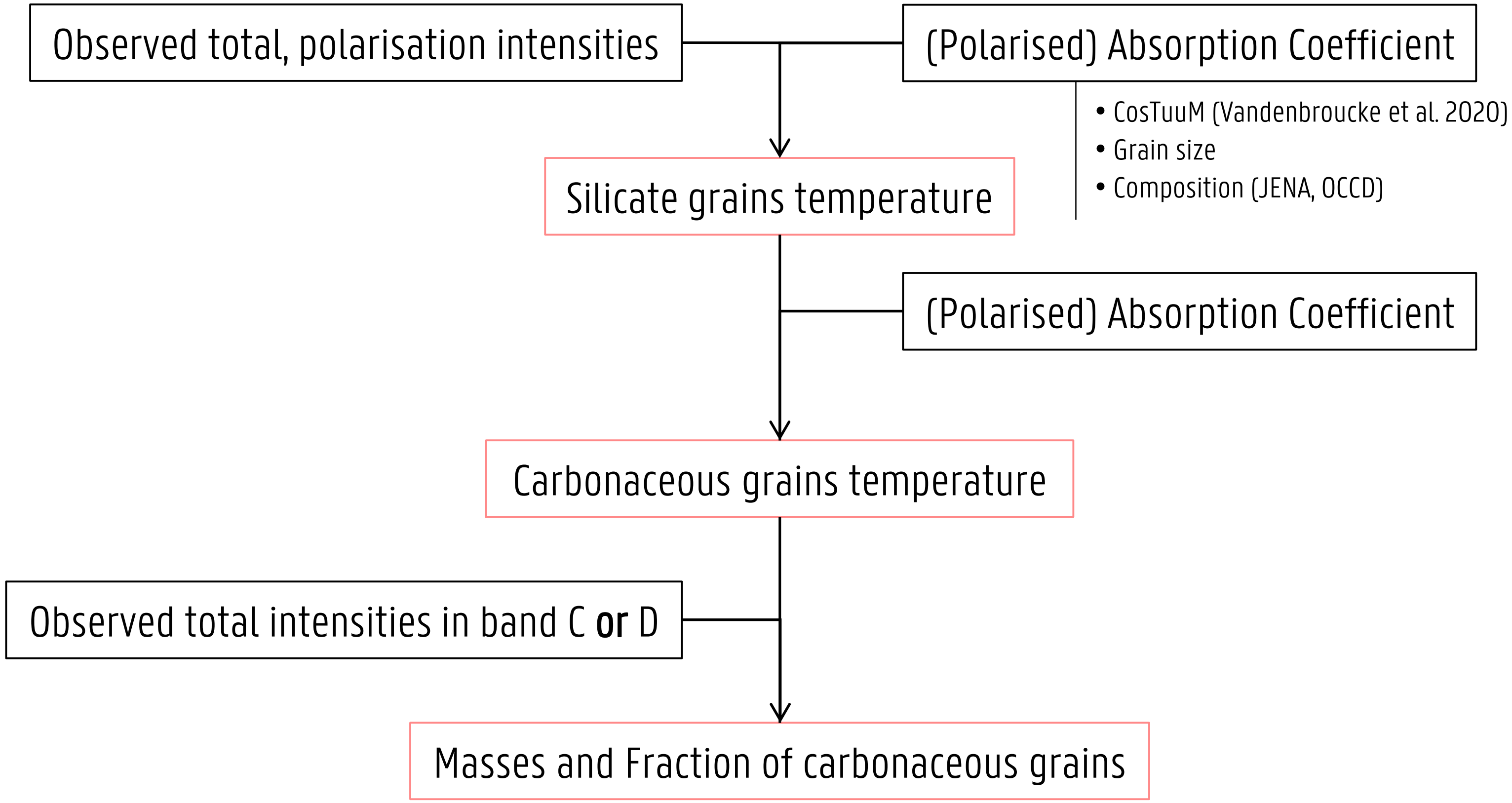
- Dust = carbonaceous + silicates
- Big enough to have steady state temperature
  → blackbody emission
- Grains with a < 0.1 µm do not polarise
- Alignment due to magnetic field, using a single zenith angle
- Only silicate grains polarise light

Main method

- Use the color ratio $I_\nu(89\ \mu m)/I_\nu(154\ \mu m)$

In the literature, Crab M_{dust}: 0.019 – 1.0 $M_\odot$
SOFIA/HAWC+ data: low S/N + synchrotron removal → convolution/projection to SPIRE 500 | Integrated scales analysis

Deriving Dust Properties: Flowchart



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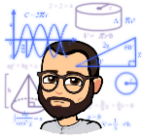
Assumptions: big grains + BBody emission + only aSil polarise

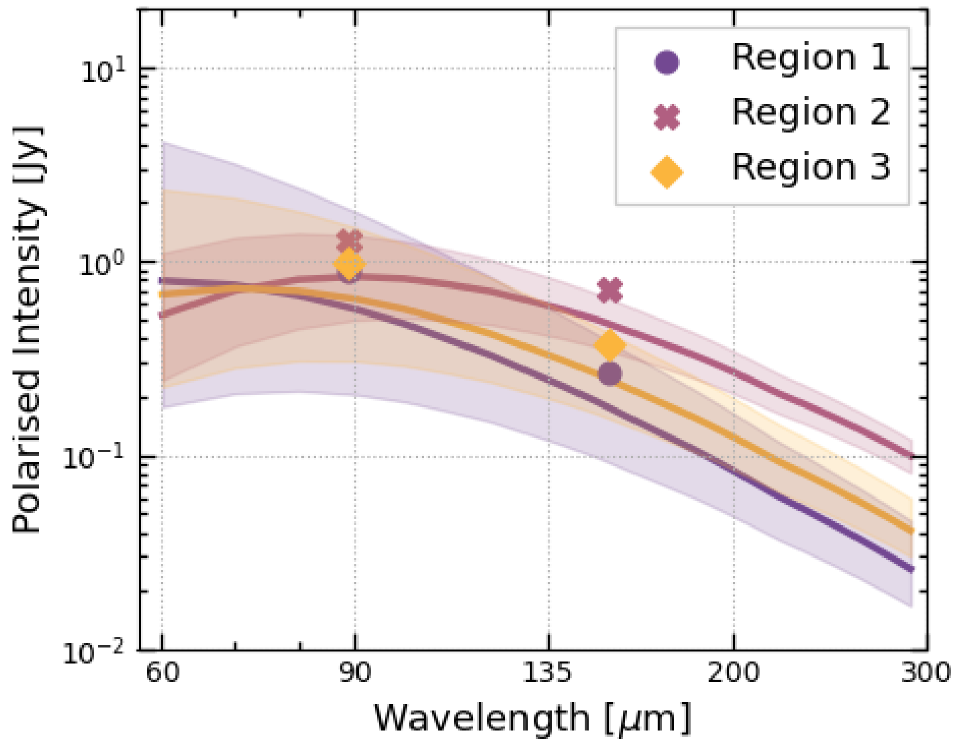


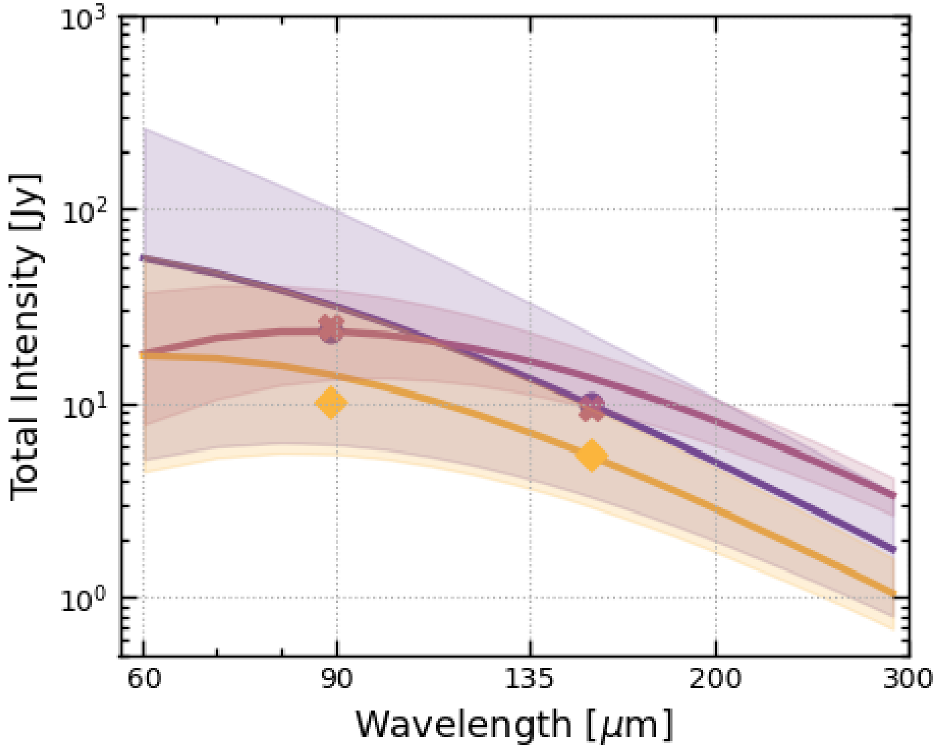
DUST PROPERTIES IN THE CRAB WITH FAR-IR POLARIMETRY

	$MgSiO_3$ amorphous	$MgSiO_3$ glassy	$MgSiO_4$	$Mg_{0.7}SiO_{2.7}$	$Mg_{0.5}Fe_{0.5}SiO_3$
Temperatures, in K					
of Silicates	31.8 – 46.9	33 – 50	31.8 – 46.9	31 – 45.1	33.4 – 50.9
of Carbonaceous	39 – 67.7	38.8 – 67.1	38.9 – 67.5	38.8 – 67	38.8 – 67
Upper limits, in $M_\odot$					
Estimate 1	0.040 – 0.059	0.026 – 0.032	0.037 – 0.054	0.27 – 0.53	0.027 – 0.034
Estimate 2	0.11	0.061	0.10	1.0	0.065
f_{aC}, in %					
	6 - 50	17 – 70	9 – 53	0.2 – 8	17 - 68

In the literature, Crab M_{dust}: 0.019 – 1.0 $M_\odot$
SOFIA/HAWC+ data: low S/N + synchrotron removal → convolution/projection to SPIRE 500 | Integrated scales analysis
Assumptions: big grains + BBody emission + only aSil polarise | Sequential analysis

Dust Properties in the Crab with Far-IR Polarimetry





In the literature, Crab M_{dust}: 0.019 – 1.0 $M_\odot$
SOFIA/HAWC+ data: low S/N + synchrotron removal → convolution/projection to SPIRE 500 | Integrated scales analysis
Assumptions: big grains + BBody emission + only aSil polarise | Sequential analysis

Conclusions

- **Confirmed polarisation detection in the Crab Nebula**, the second SNR after Cassiopeia A!
  → implies the existence of large grains (0.05 – 0.1 μm)
- We **remove the synchrotron-emission** from the SOFIA/HAWC+ far-IR emission
  → contributes up to $\sim$ 30% to the total signal
- We find averages of ***p* = 2.7% and 4.8%**, at 89 and 154 μm, and values ranging 3.7 – 9.6% and 2.7 – 7.6% in three dusty filaments.
- With laboratory data, and several assumptions, we find:
  - Silicate temperatures ranging from $\sim$ 30 to 50 K,
    carbonaceous grain temperatures ranging from $\sim$ 39 to 68 K
  - Upper limits on dust masses ranging from $\sim$ 0.0026 to 0.53 $M_{\odot}$ or 0.065 to 1.0 $M_{\odot}$
  - **Fractions of carbonaceous grains ranging from 0.2 to 70%**

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Extra: Synchrotron Removal

- Interpolation of the (resolved) synchrotron radiation at 89 and 154 µm

- Synchrotron polarisation fraction and angle from NIKA 150 GHz

$$p_{\text{radio}}, \theta_{\text{radio}}$$

- Synchrotron Stokes vectors:

$$P_{\text{sync}} = p_{\text{radio}}\, I_{\text{sync}}$$
$$Q_{\text{sync}} = P_{\text{sync}} \cos(2\, \theta_{\text{radio}})$$
$$U_{\text{sync}} = P_{\text{sync}} \sin(2\, \theta_{\text{radio}})$$

- Synchrotron-free Stokes vectors:

$$I_{\text{final}} = I_{\text{HAWC}} - I_{\text{sync}}$$
$$Q_{\text{final}} = Q_{\text{HAWC}} - Q_{\text{sync}}$$
$$U_{\text{final}} = U_{\text{HAWC}} - U_{\text{sync}}$$

Extra: Synchrotron Removal