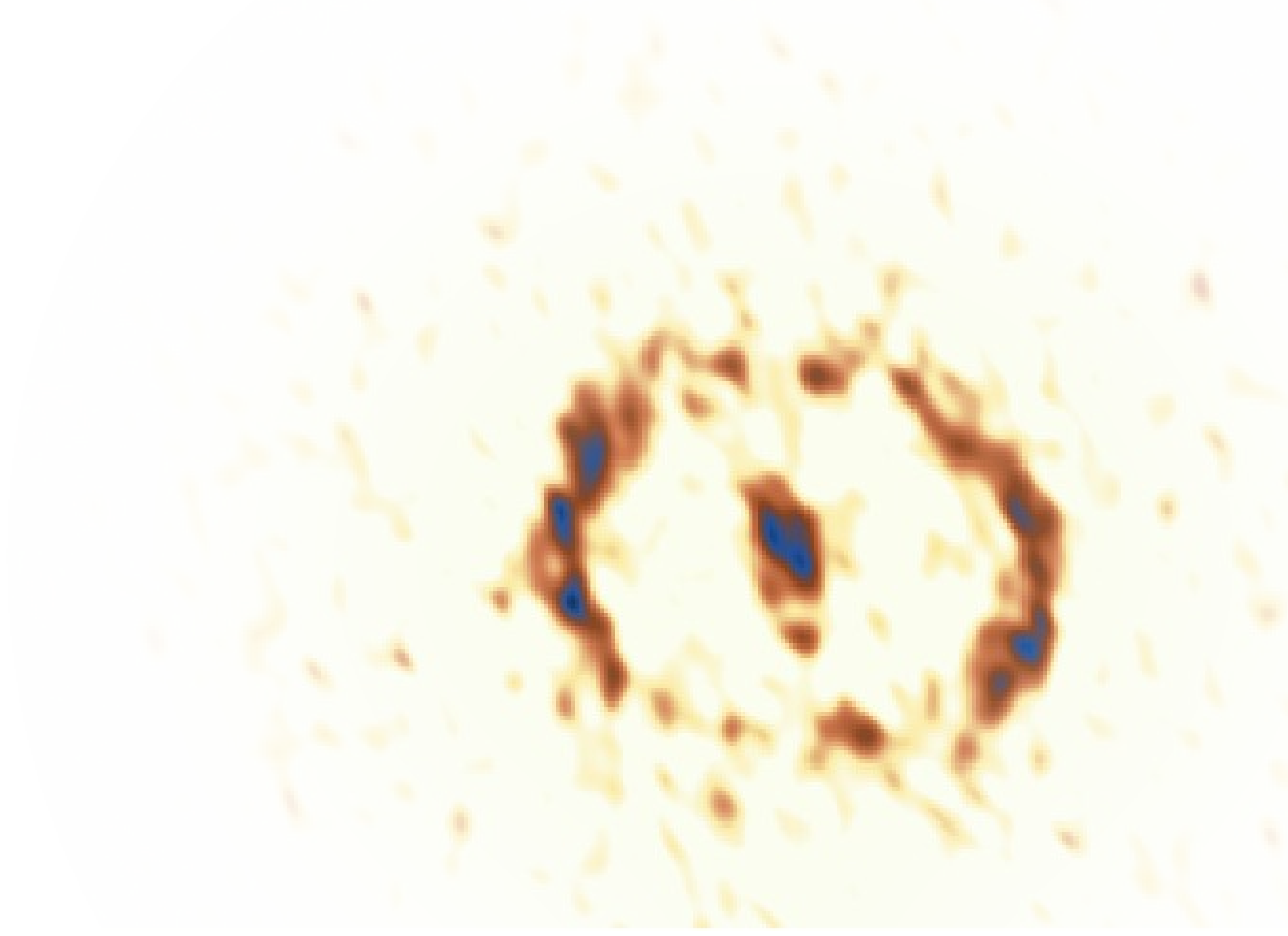
High-resolution observations of dust in SN 1987A



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POP QUIZ

In which direction is SN 1987A *right now*?

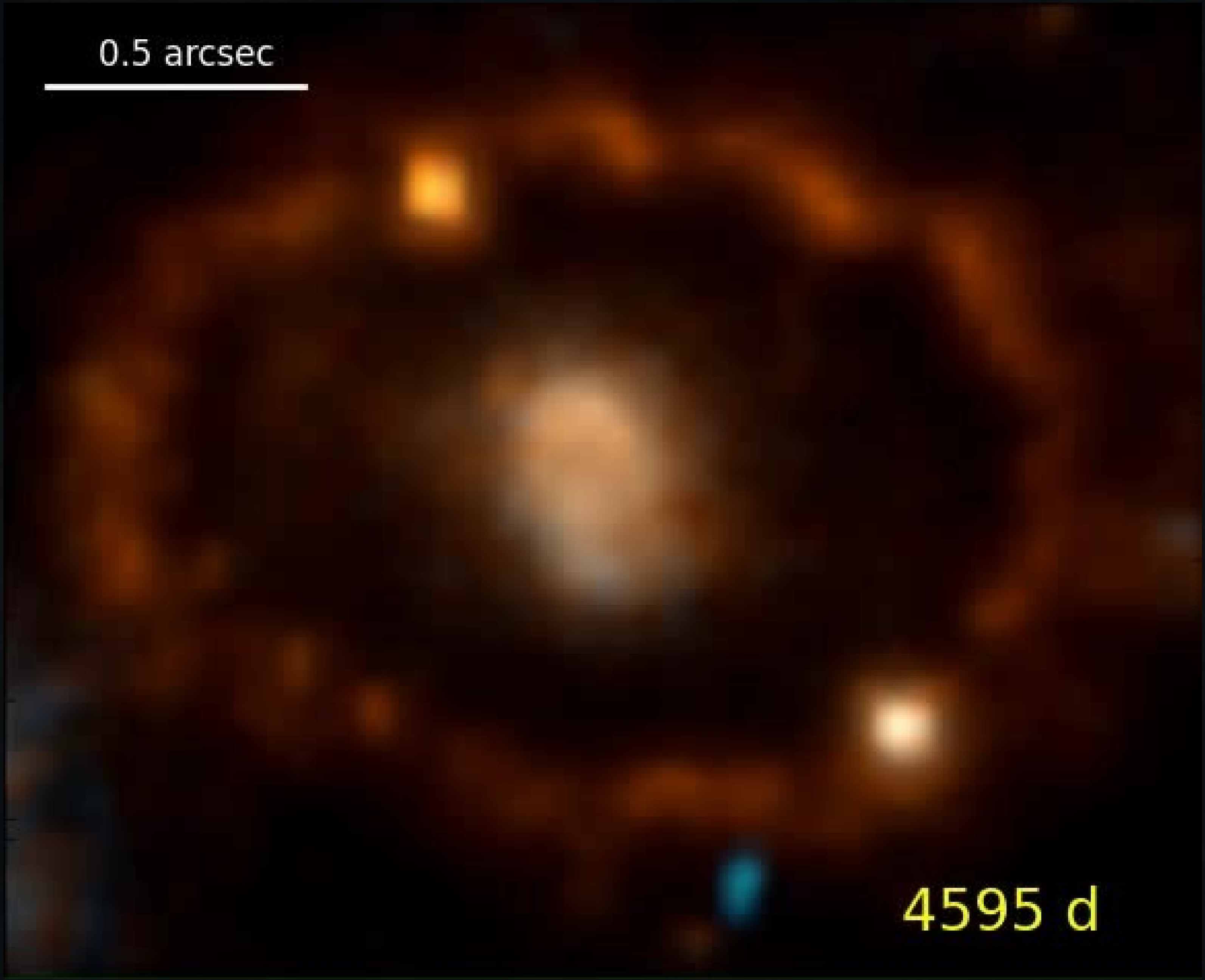
From the beach...

87A here

Optical Evolution of SN 1987A

Hubble *B*, *R*
Fransson+2015,
Larsson+2013

At 50 kpc, SN 1987A is the nearest SN explosion detected in 400 years



Motivation

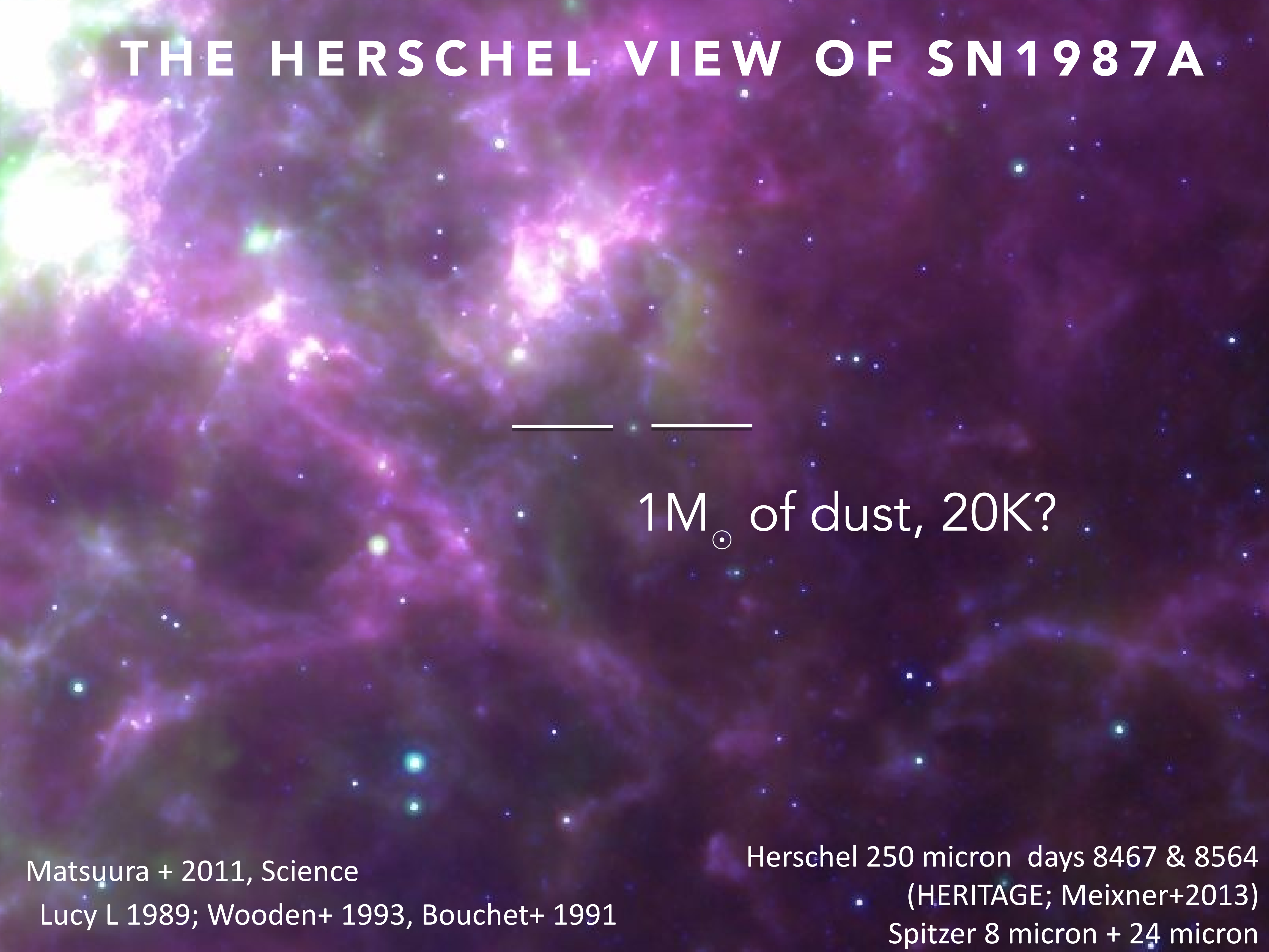
- Spatially resolved images of dust and molecules can reveal the chemistry resulting in dust formation in SNe
- Models predict core-collapse SNe are important source of dust in galaxies if they produce 0.1-1.0 $M_{\odot}$ (Morgan & Edmunds 2003; Nozawa et al. 2003; Gomez+2012, Gall+2014, Dwek & Cherchneff 2011)
- CCSNe could be major source of ISM dust (e.g., Matsuura+2009; Dwek & Cherchneff 2011…)
- Low-Z galaxies: low DGR from low condensation rates. Need dust from stars (e.g., Zhukovska 2014)
- Making dust in the early universe is hard: dust budget crisis
  - Need more than just AGB stars (Morgan & Edmunds 2003; Rowlands+2014; Shaerer+2015…)

→ How is dust distributed in SN ejecta?
→ How much dust do SNe really produce?

History of Dust in SN 1987A

- Days 260-1316: MIR thermal emission (Wooden+1993; Bouchet+1991)
  - ~10^{-4} $M_\odot$ dust, presumed to be in ejecta

THE HERSCHEL VIEW OF SN1987A



$1M_{\odot}$ of dust, 20K?

Matsuura + 2011, Science

Lucy L 1989; Wooden+ 1993, Bouchet+ 1991

Herschel 250 micron days 8467 & 8564
(HERITAGE; Meixner+2013)
Spitzer 8 micron + 24 micron

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- 23 yr later, days 8467, 8564: FIR (100-350μm) (Matsuura+2011)
  - 0.4-0.7 $M_\odot$ dust (!). Confirmed from ejecta (Indebetouw+2014)
    - Debated – larger than Spitzer MIR masses
    - BUT Herschel Cas A and Crab obs. also showed $M>0.1M_\odot$

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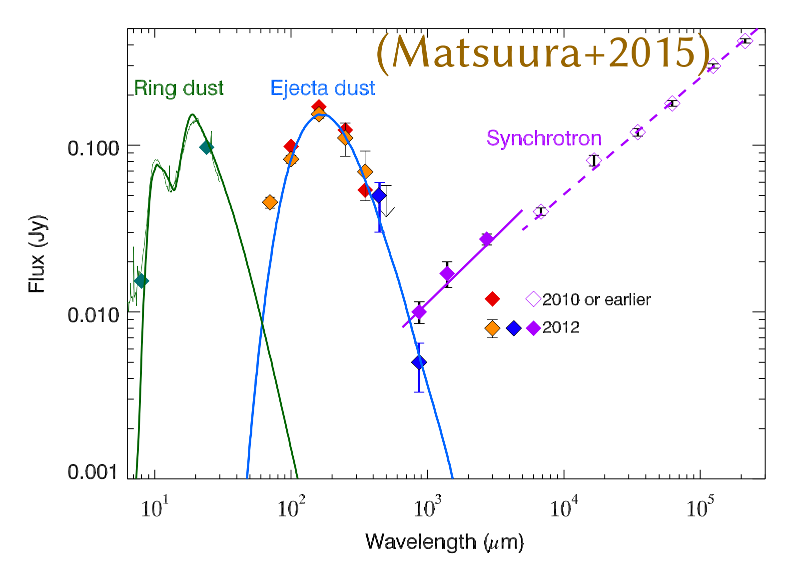
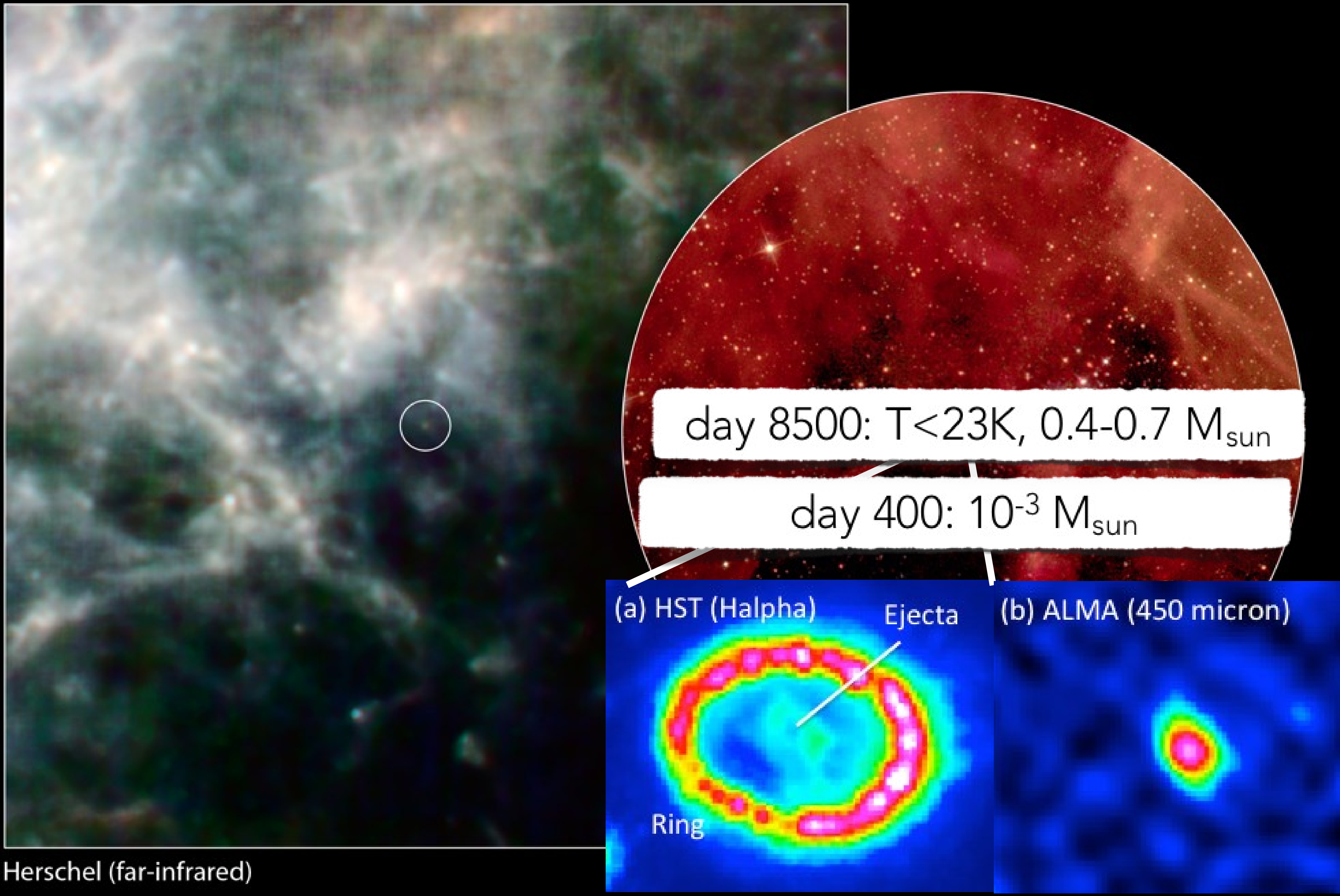
- 2012, day 9090: New Herschel obs.
  - Confirmed large mass (0.8 $M_{\odot}$) of dust
    - 0.3 $M_{\odot}$ ACAR, 0.5 $M_{\odot}$ silicates
    - Crucially, used 70μm data to show T<30K



ALMA PROVIDES A SHARPER VIEW

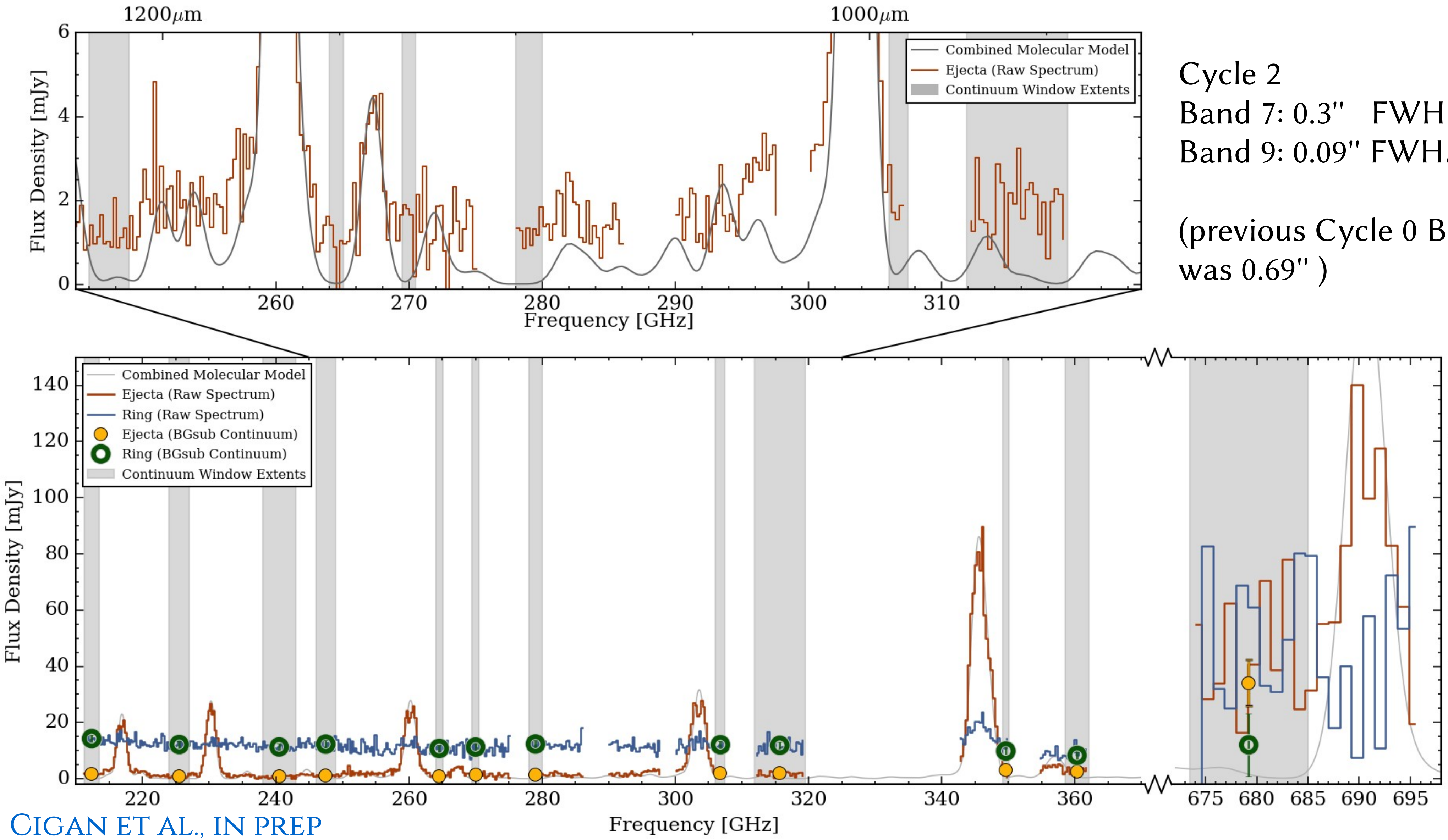


Matsuura+2011, Science; Matsuura+2015, ApJ

Indebetouw+ 2014

New ALMA Observations

Combined molecular model from Matsuura+2017 (submitted)



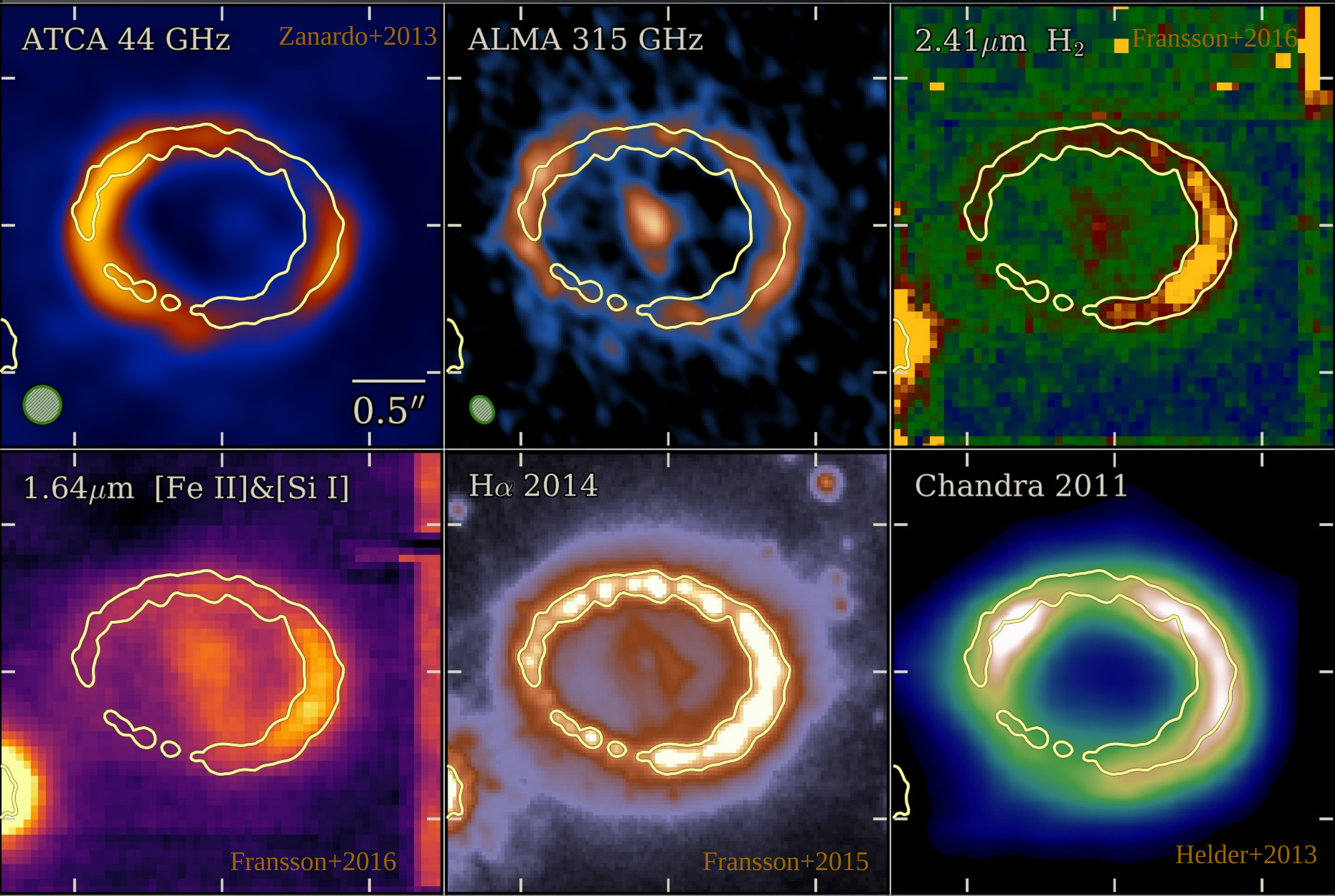
Cycle 2
Band 7: 0.3" FWHM
Band 9: 0.09" FWHM

(previous Cycle 0 B7 was 0.69")

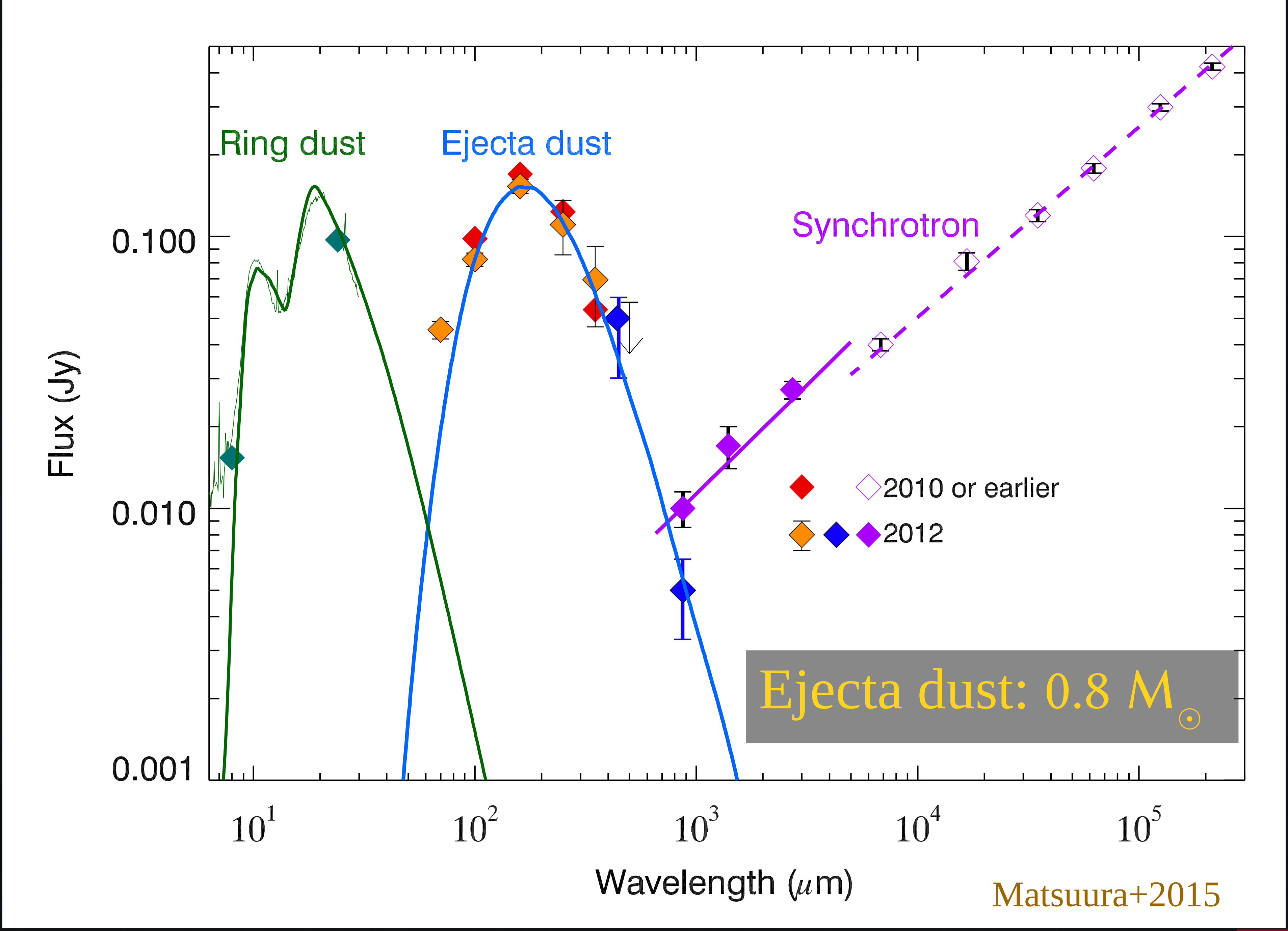
Cigan et al., in prep

Multi-Wavelength Overview

Cigan et al., in prep

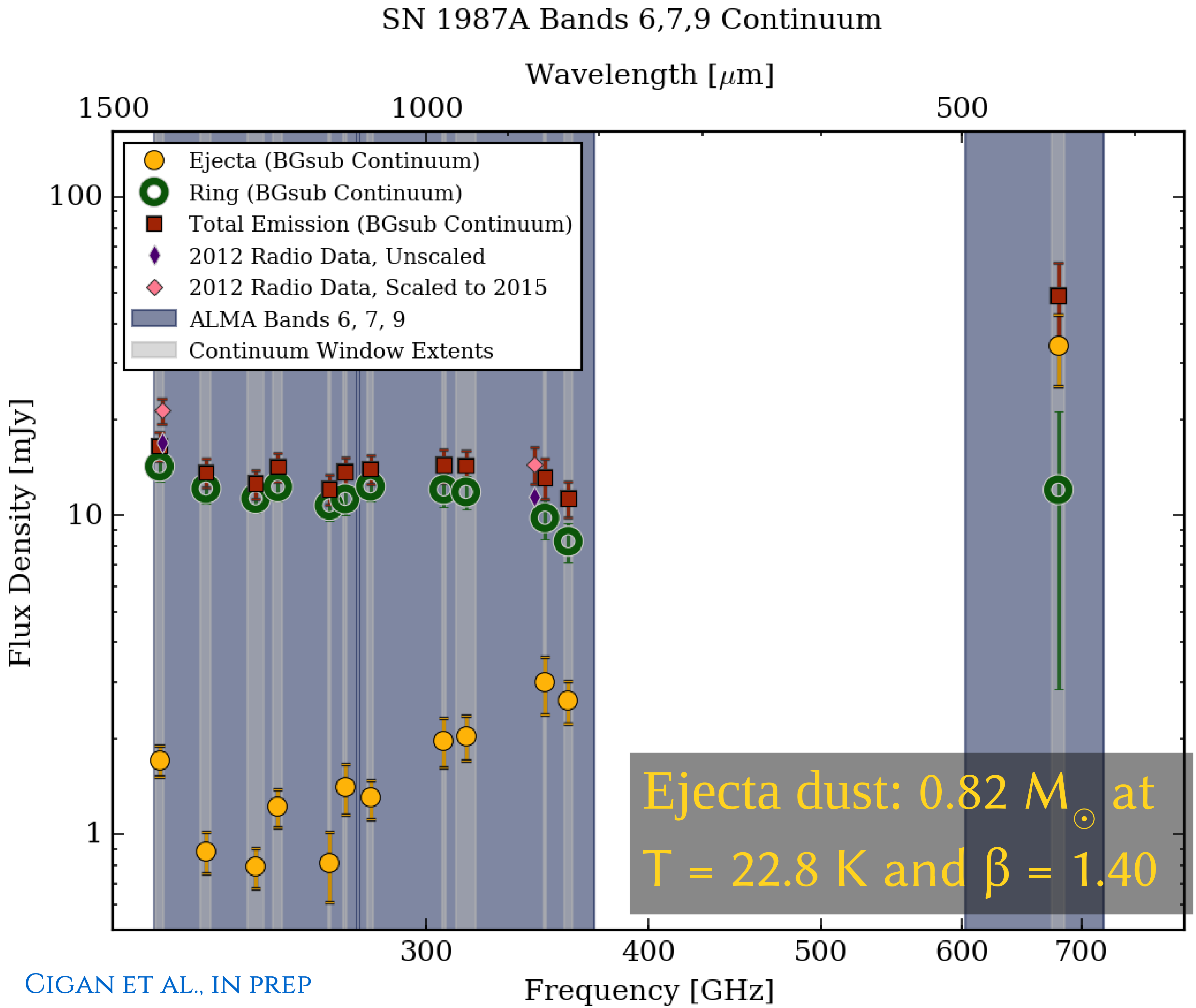


SED



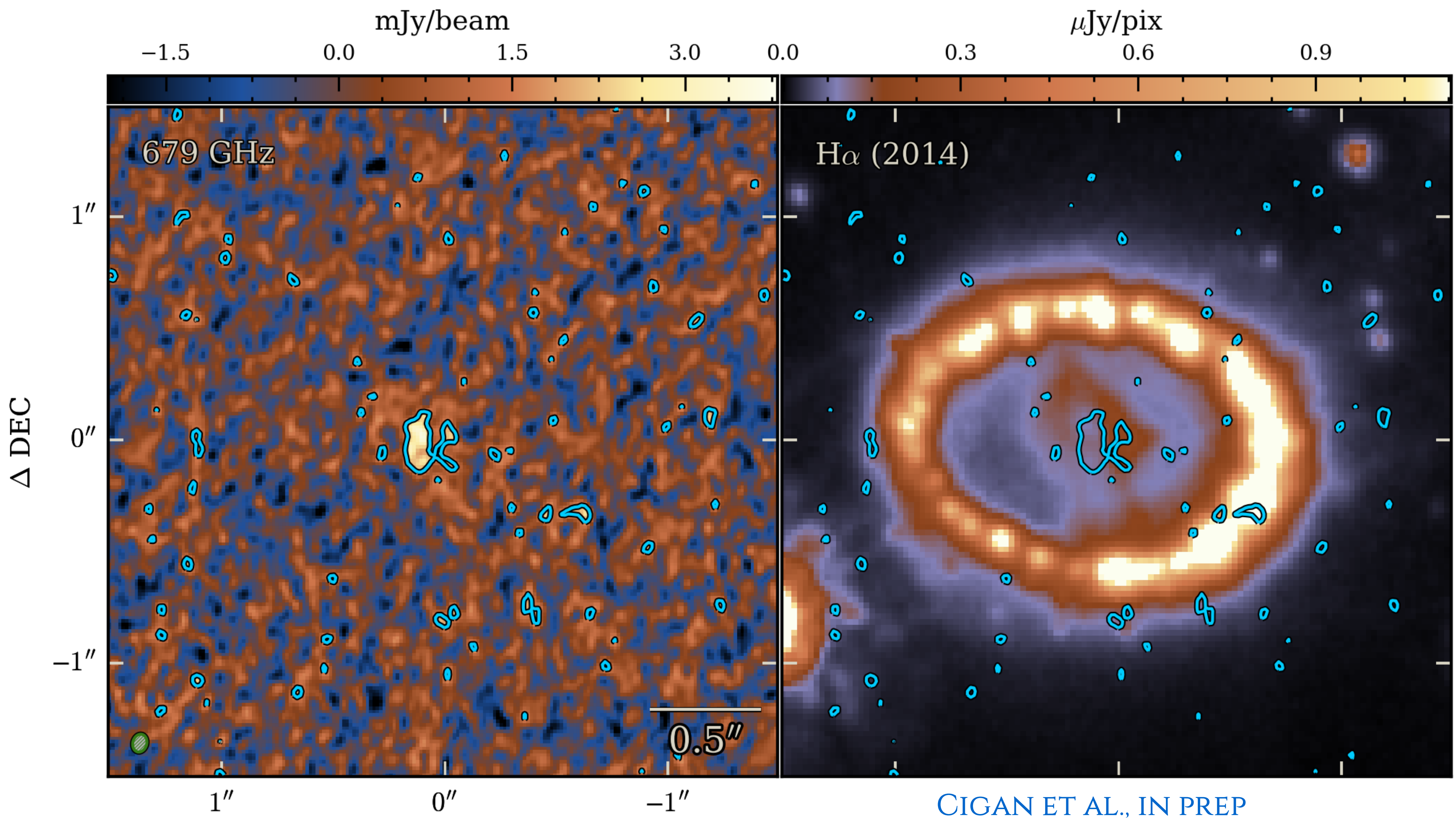
Ring dust
Ejecta dust
Synchrotron
2010 or earlier
2012
0.100
0.010
0.001
Flux (Jy)
10^1
10^2
10^3
10^4
10^5
Wavelength (μm)
Ejecta dust: 0.8 M☉
Matsuura+2015

SED



CIGAN ET AL., IN PREP

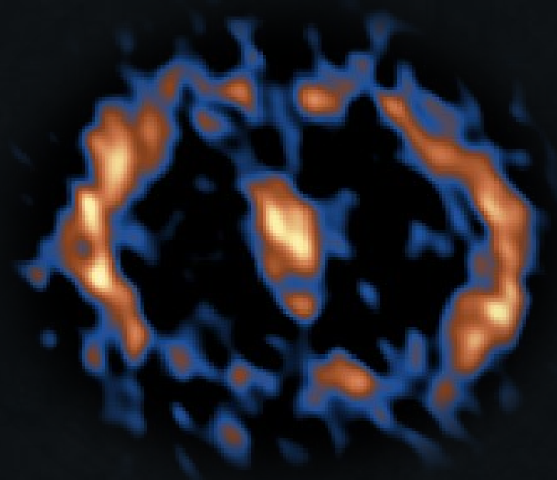
Dust Morphology



Cigan et al., in prep

Summary

- SN dust production can be important for ISM studies
- First resolved observations of SN ejecta dust!
- SN 1987A ejecta dust mainly falls in optical gaps
- ALMA confirms large ejecta dust mass from FIR
  - Ejecta emission is thermal
  - Around 0.8 solar masses of dust observed
  - T ~23 K, β = 1.40



- Center pos. ~63 mas SE from 1995 VLBI
- Exciting new views of the relation between dust and molecules in SN ejecta
  - Also keep an eye out for Abellan, Indebetouw, et al.