Exploring the Structure of Evolved Stars' Extended Atmospheres:
SKA Capabilities and Observation Opportunities

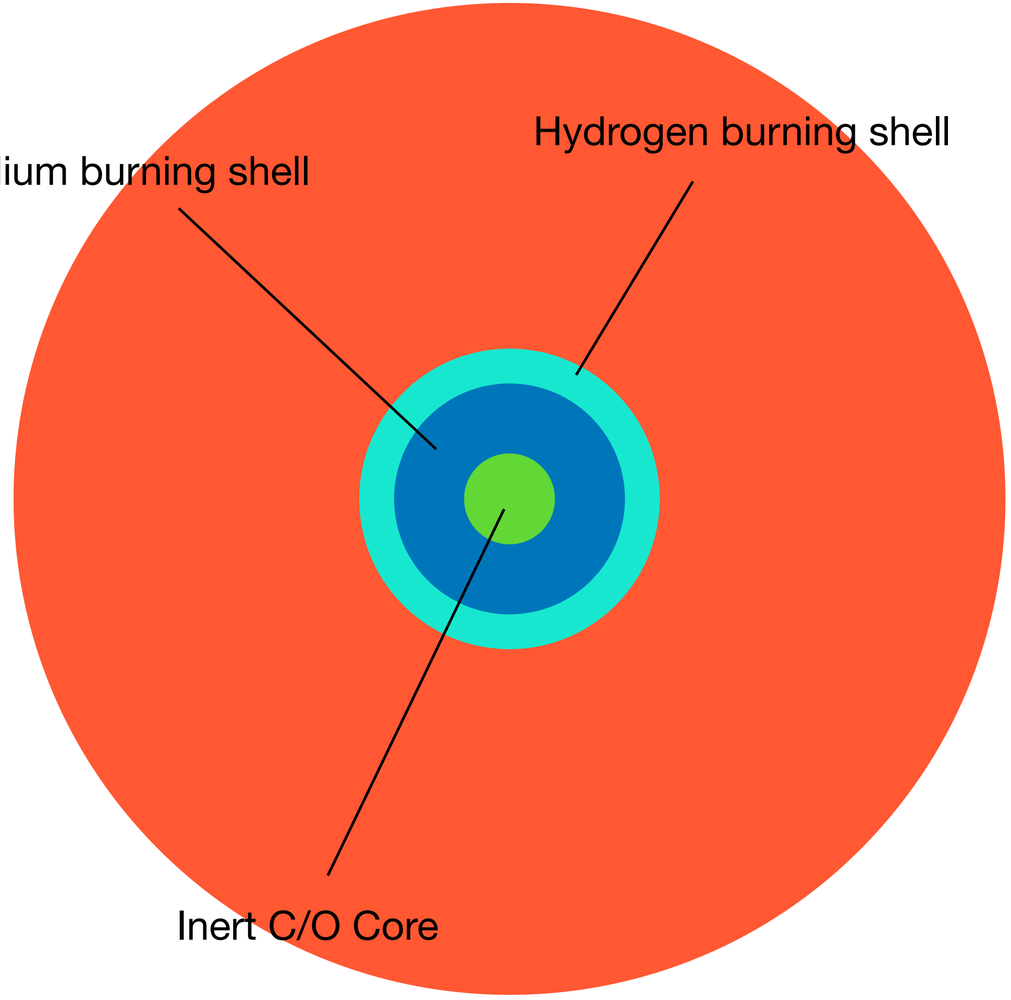
Behzad Bojnordi Arbab

Wouter Vlemmings

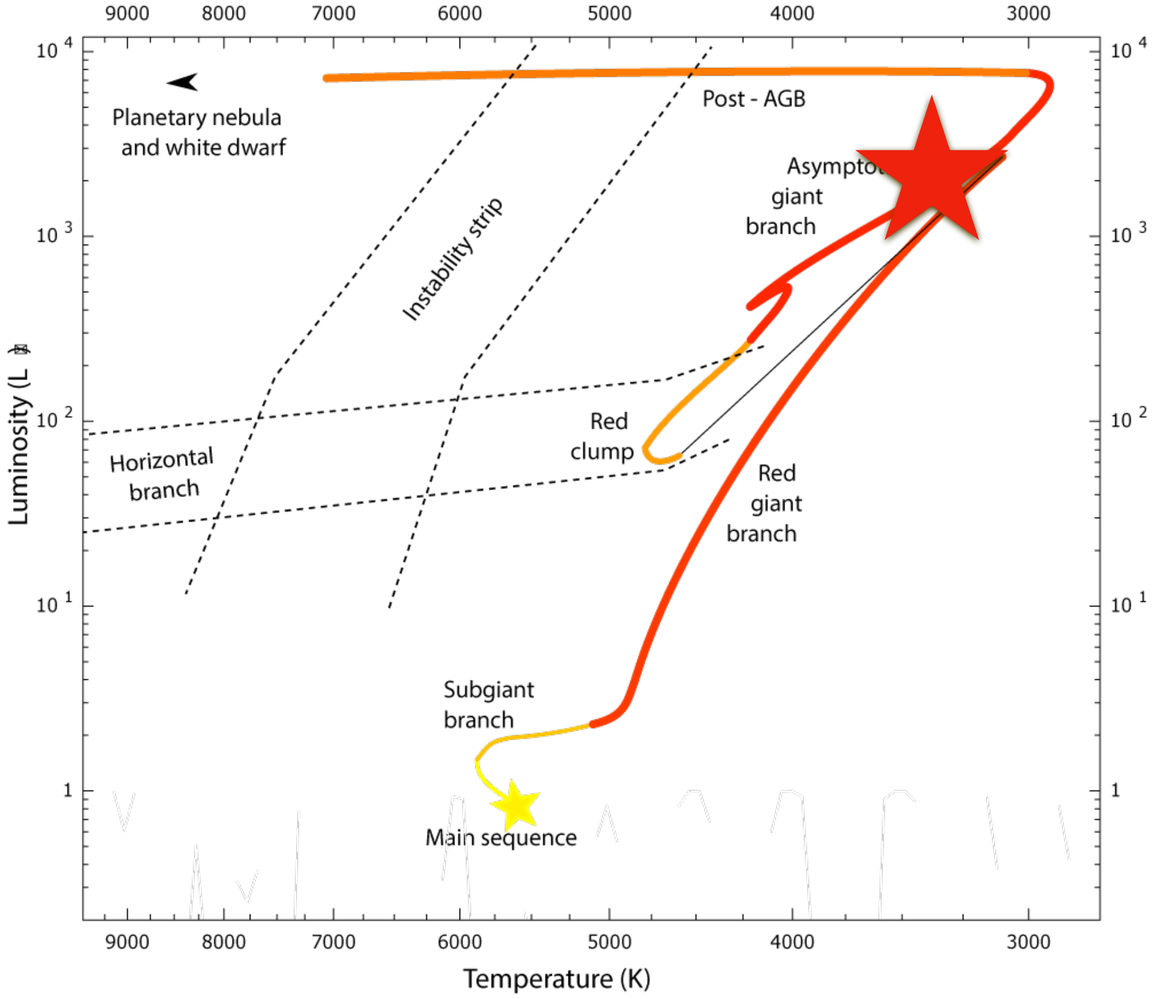
Theo Khouri

Sussanne Höfner

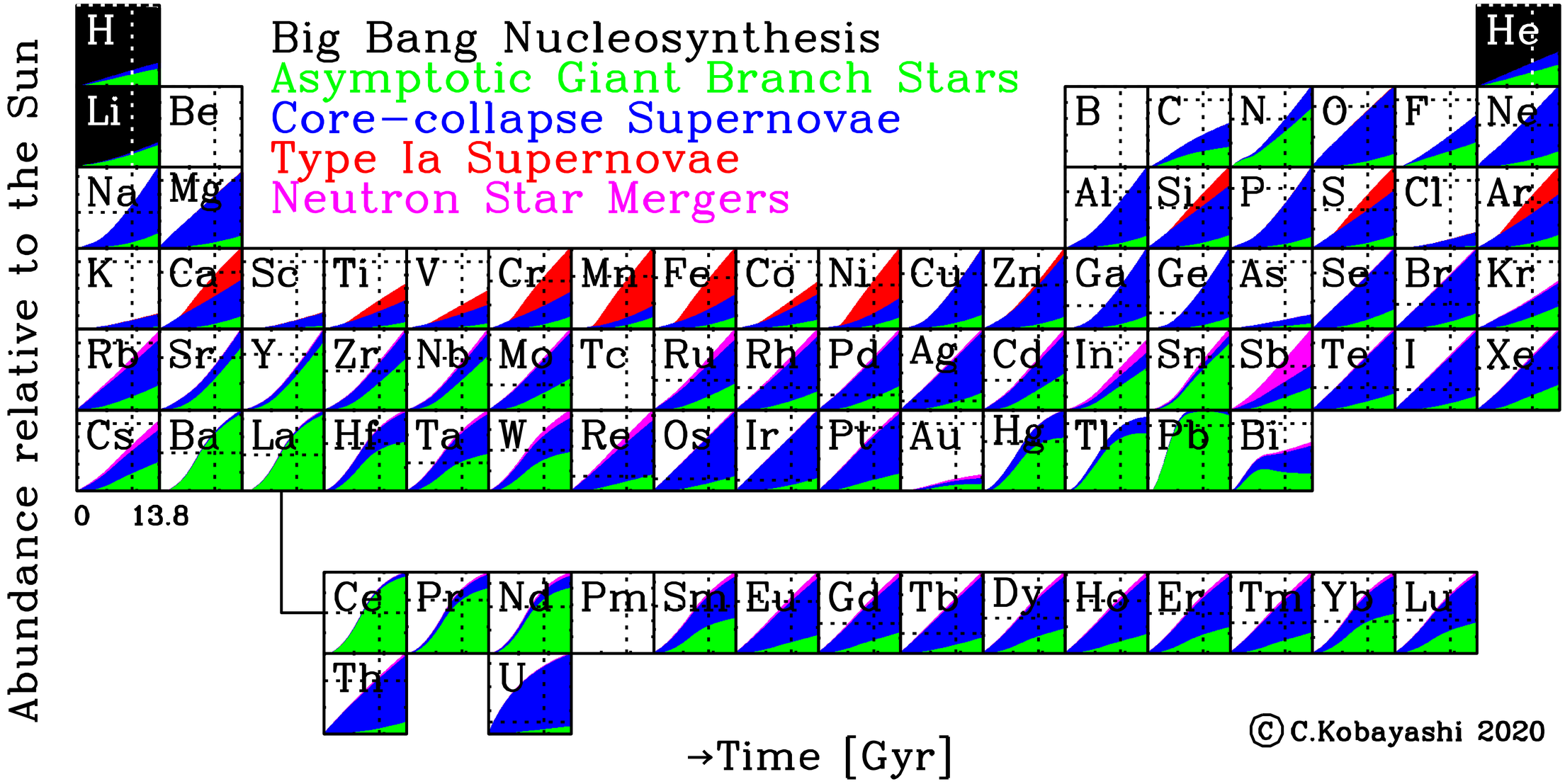
Asymptotic Giant Branch (AGB) stars



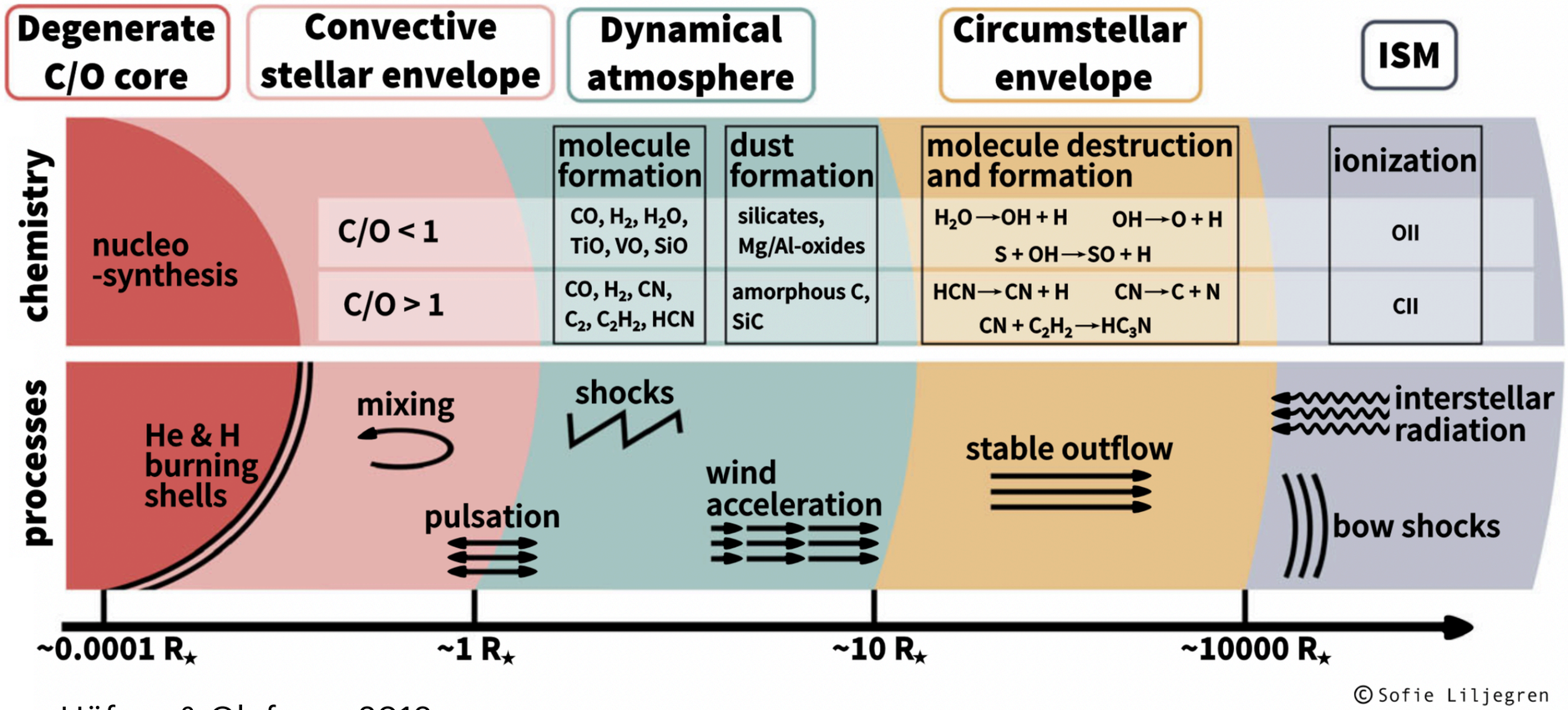
$$\approx 200R_{\odot} - 500R_{\odot}$$



Why are AGB stars important?



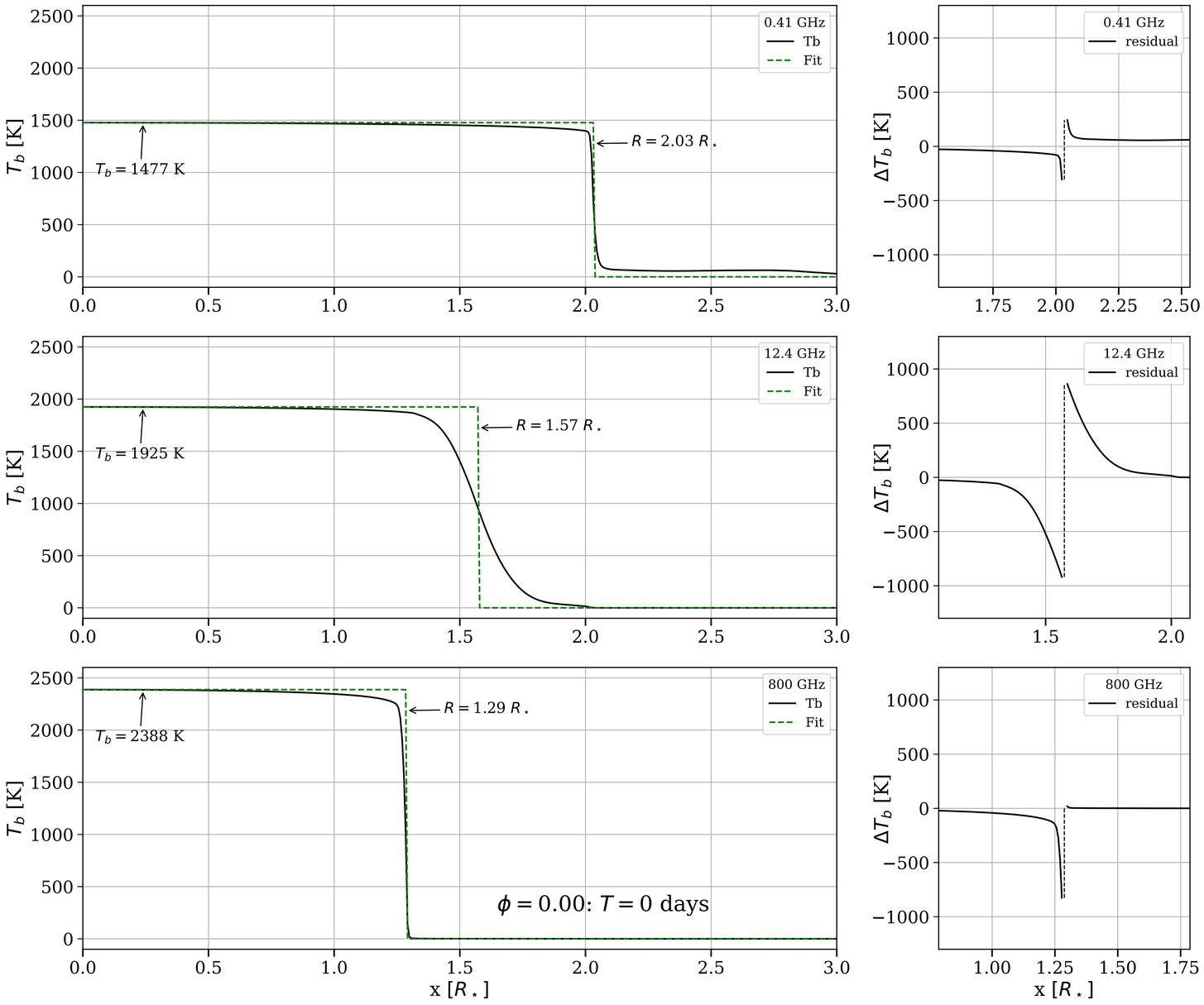
Structure of AGB stars



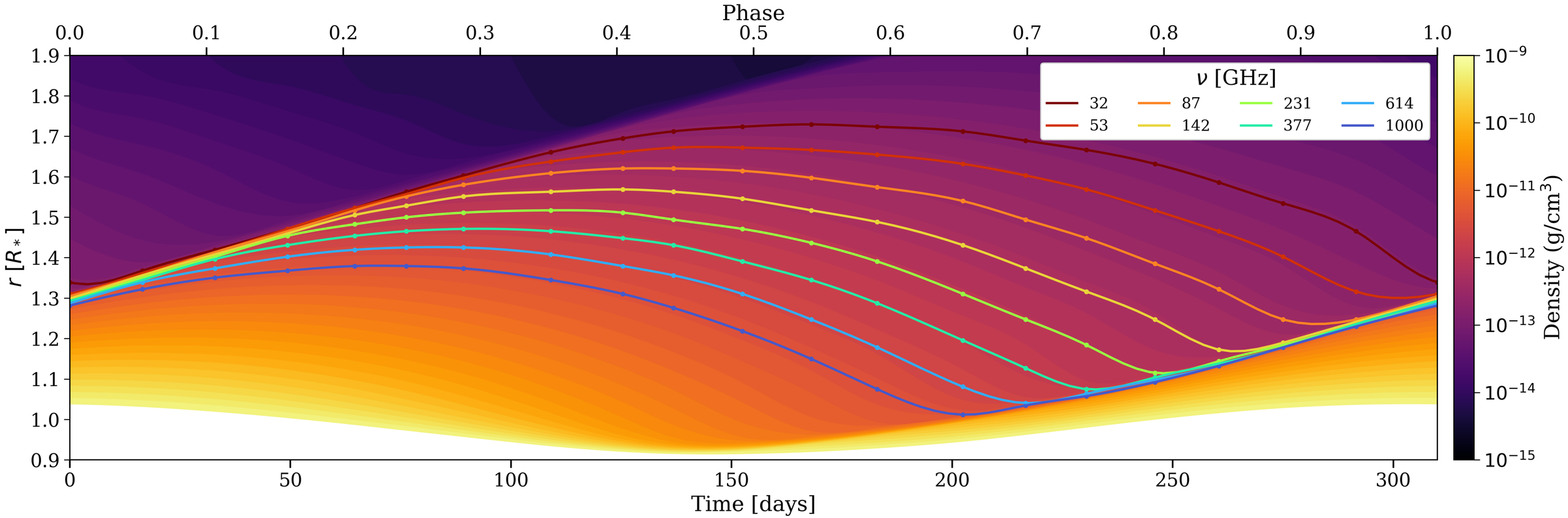
Höfner & Olofsson 2018

Model and Radiative transfer

- Radiation-hydrodynamical DARWIN model An315u3 (Höfner 2022)
- LTE, free-free emission of free electrons and atomic Hydrogen
- Free electron sources: K^+, Na^+, Ca^+, and Al^+
- Fit the brightness temperature profile

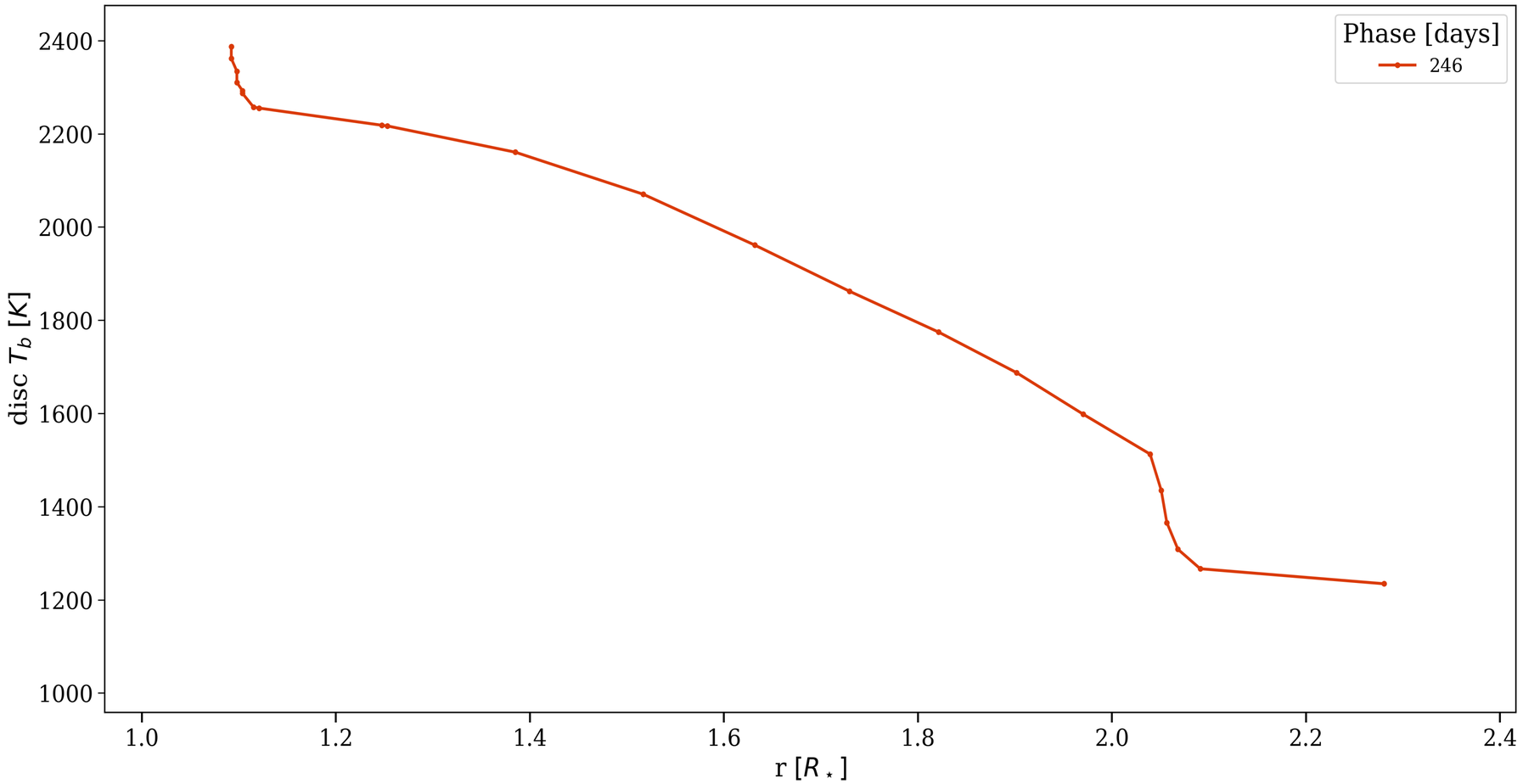


Frequency- and phase-dependent photosphere radius

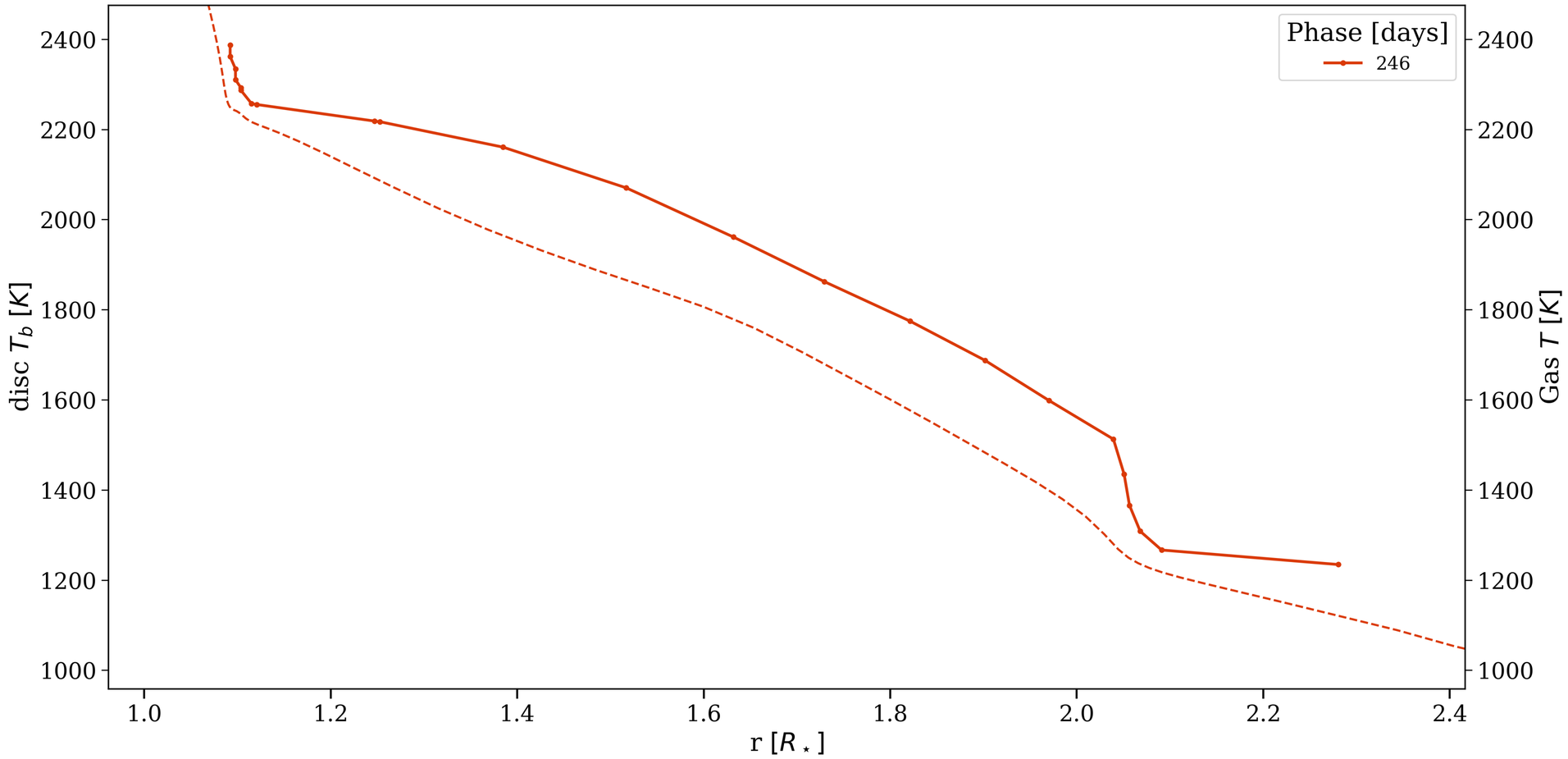


- The photosphere radius mostly follows density profiles
- We see deeper with higher frequencies → we see generally hotter regions
- On the shock, the measured radius for a wide range of frequencies merge
- The radius increases with shock then falls to the next shock

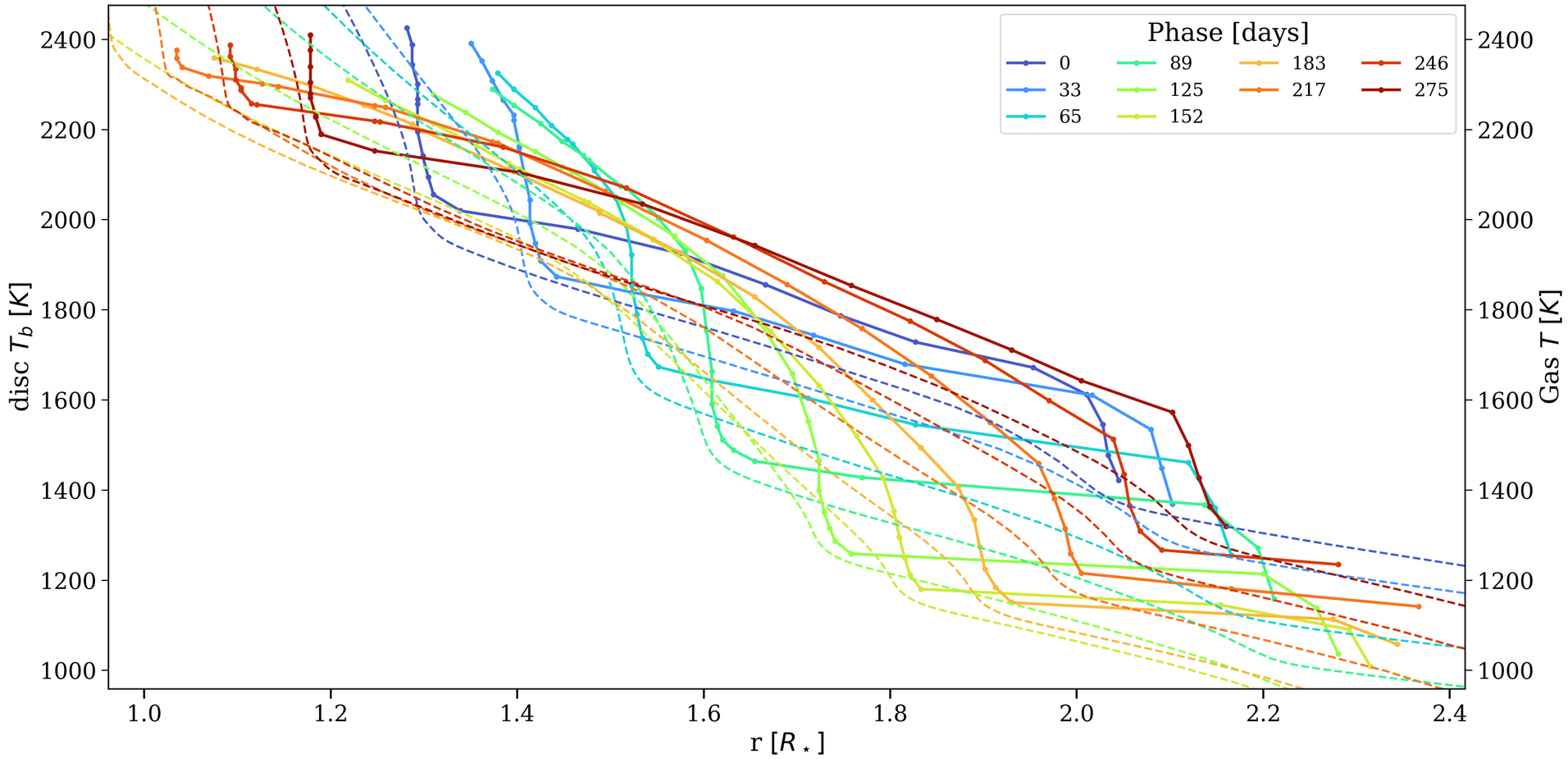
Some features in resolved observations: Brightness temperature and gas temperature



Some features in resolved observations: Brightness temperature and gas temperature

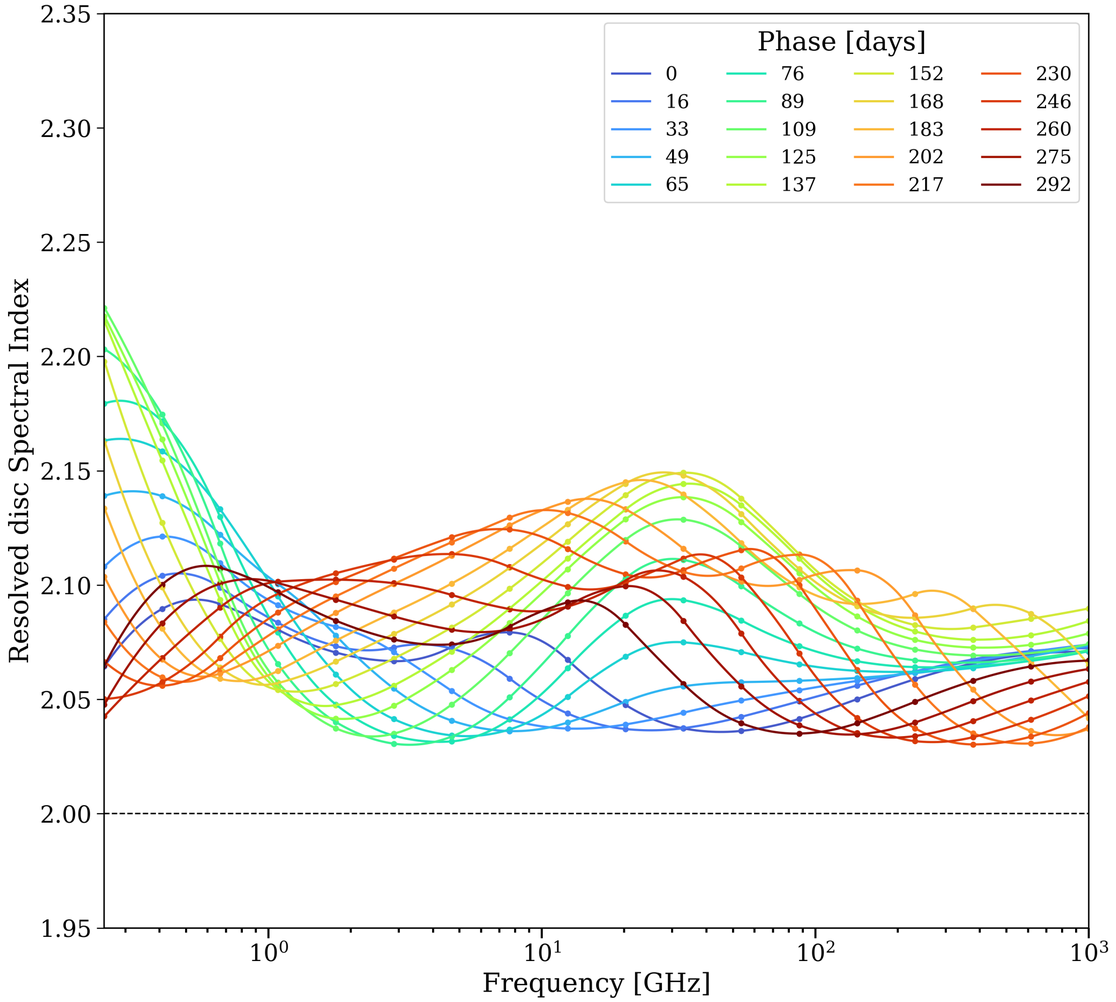


Some features in resolved observations: Brightness temperature and gas temperature

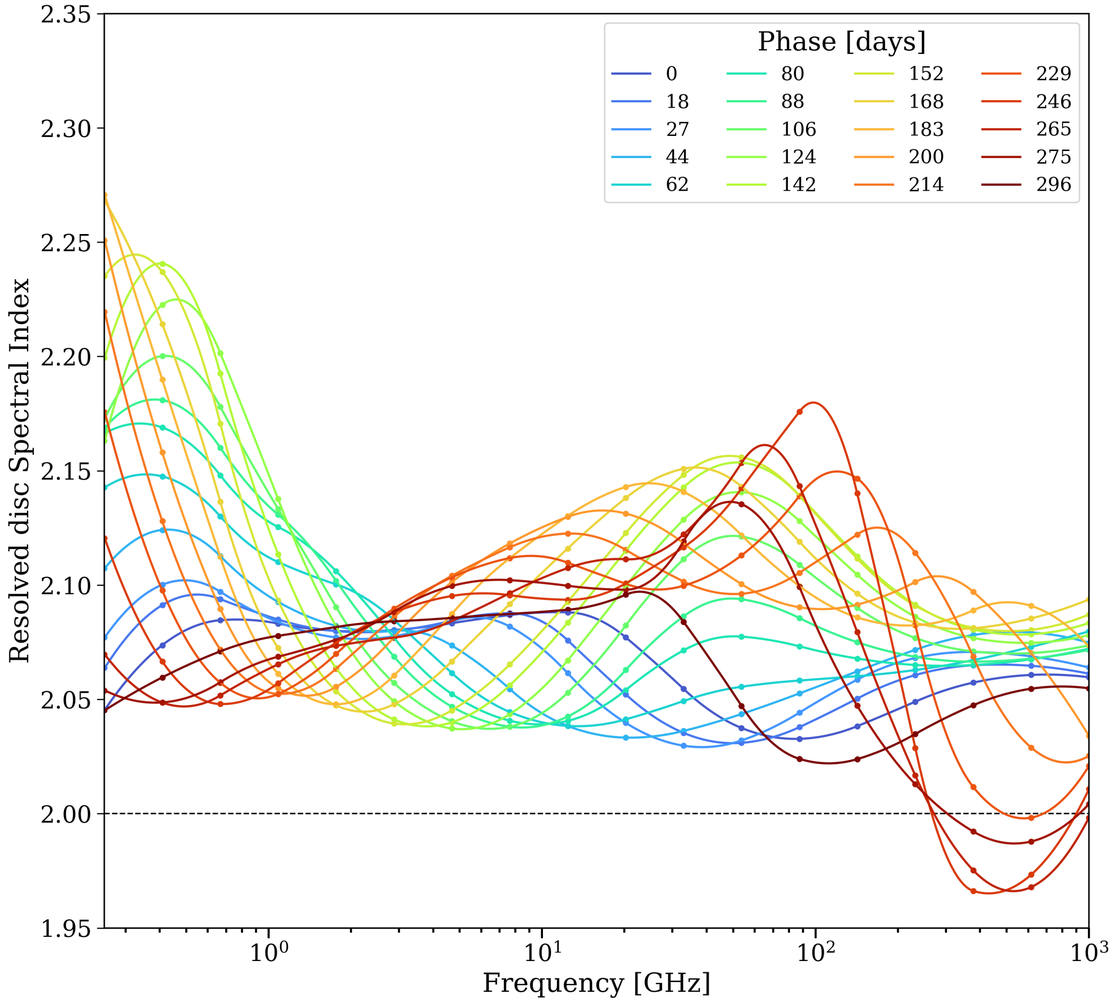


Some features in resolved observations:
Resolved Spectral Index

An315u3

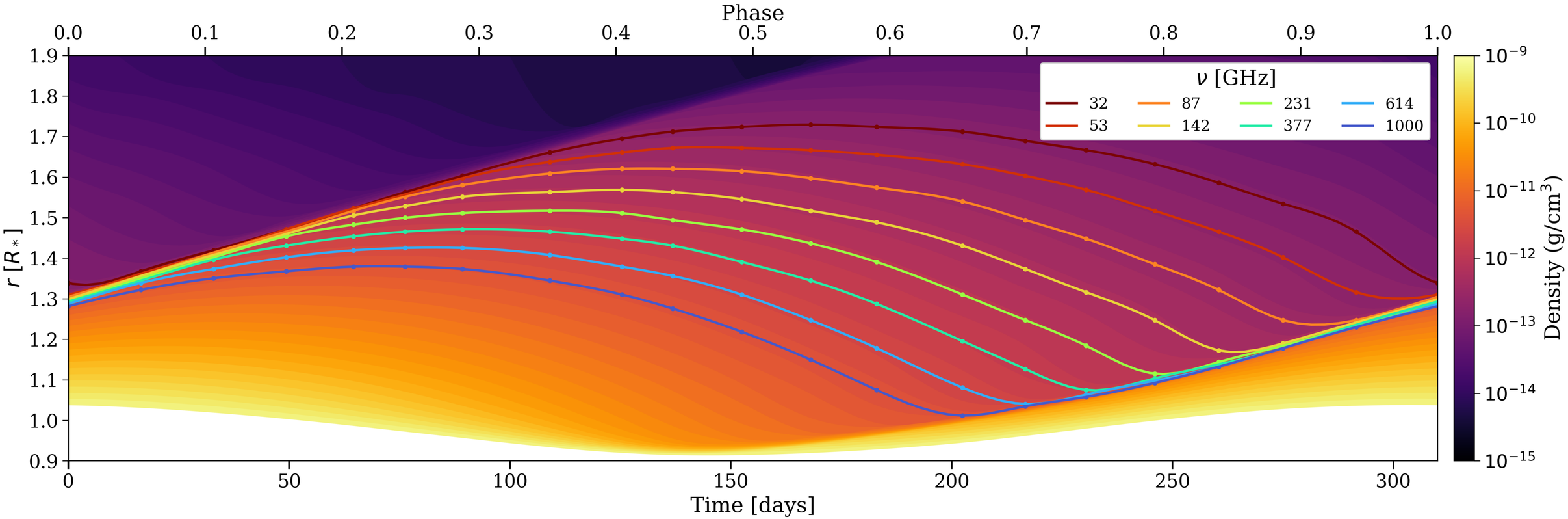


An315u4

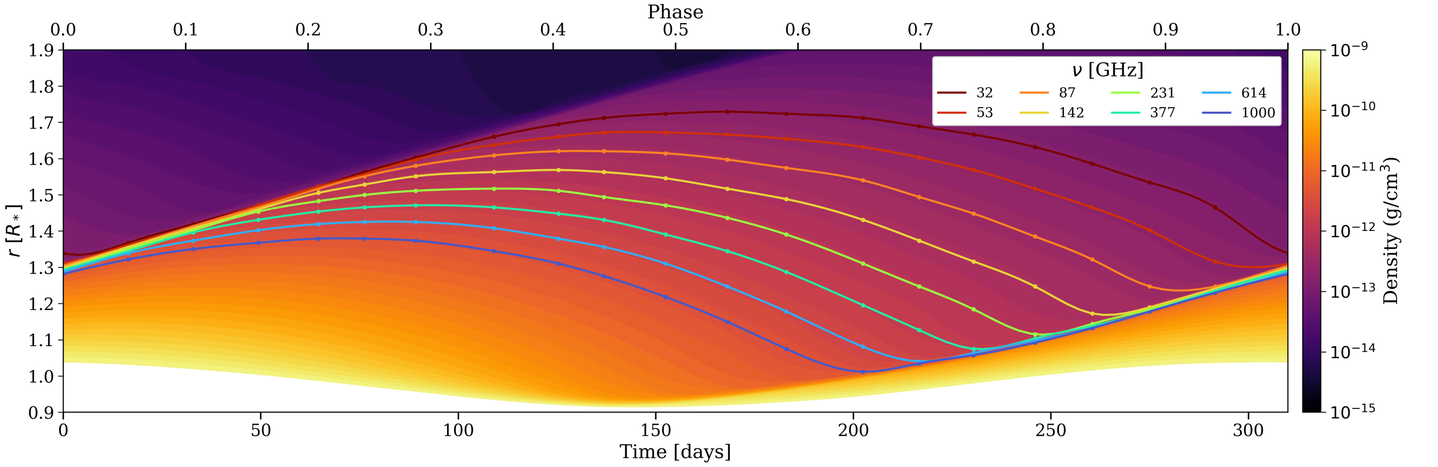


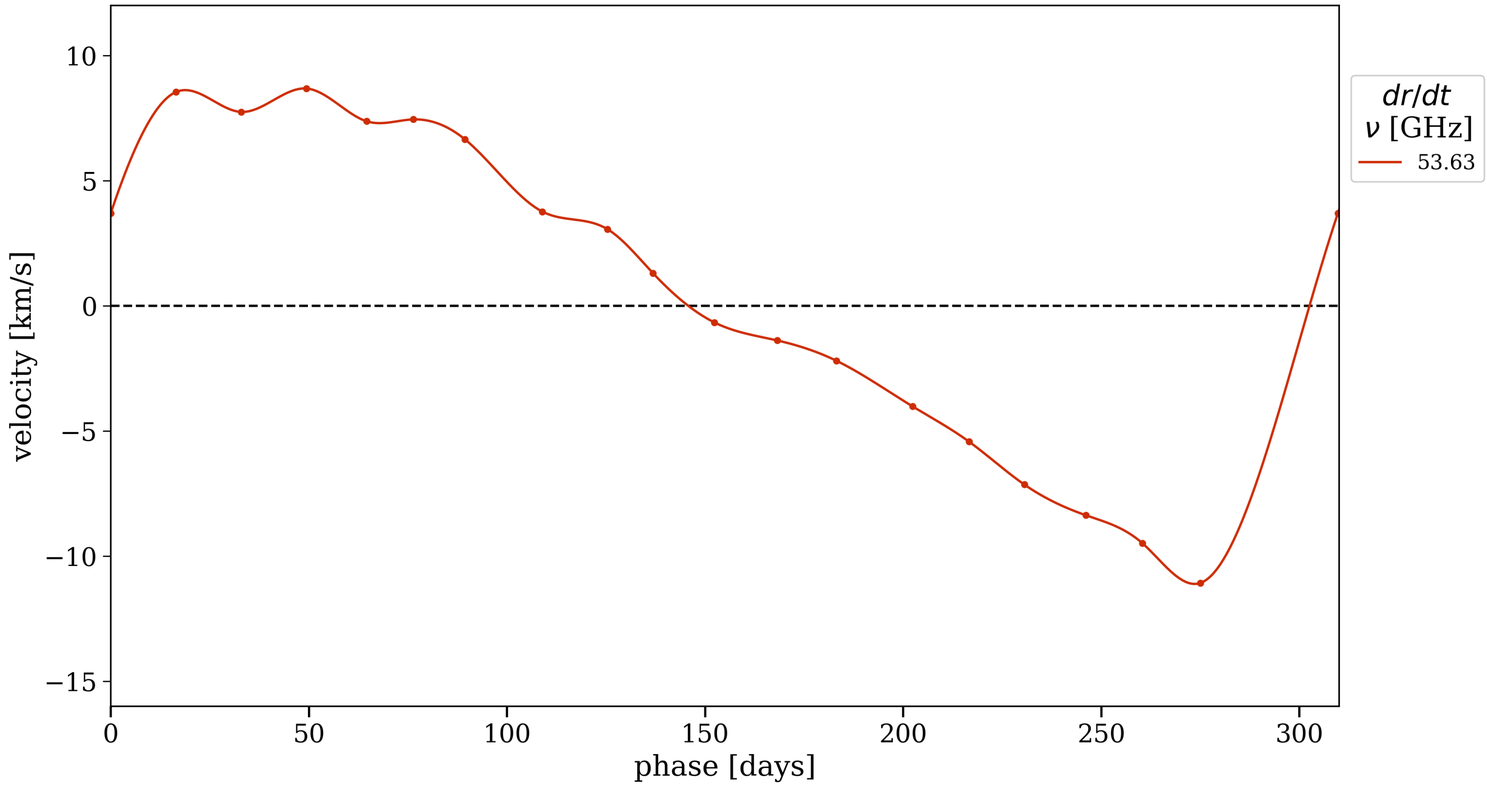
Some features in resolved observations:

Photosphere radial velocity

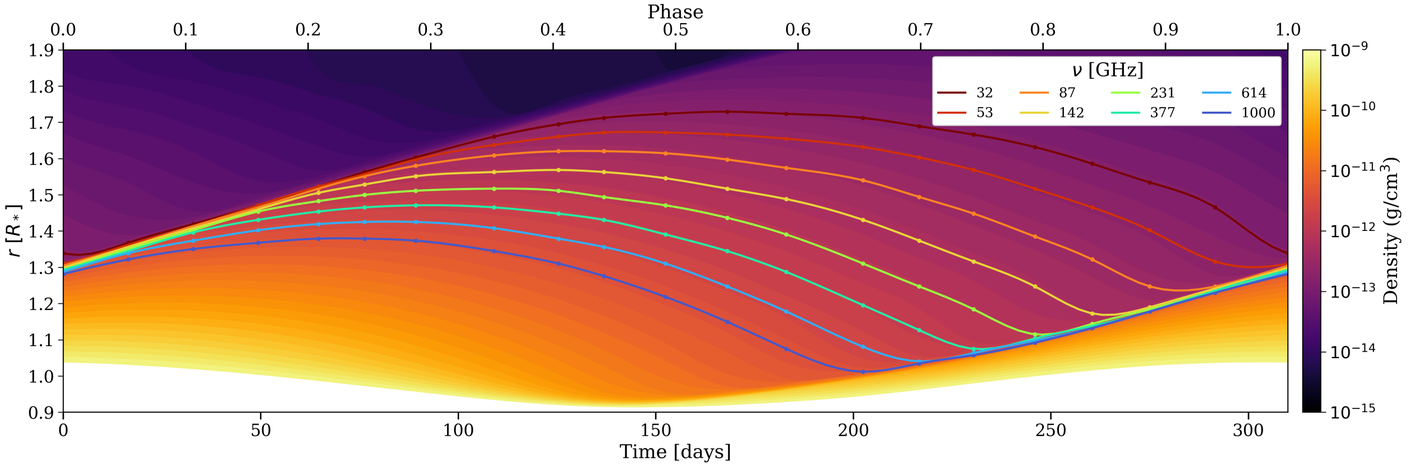


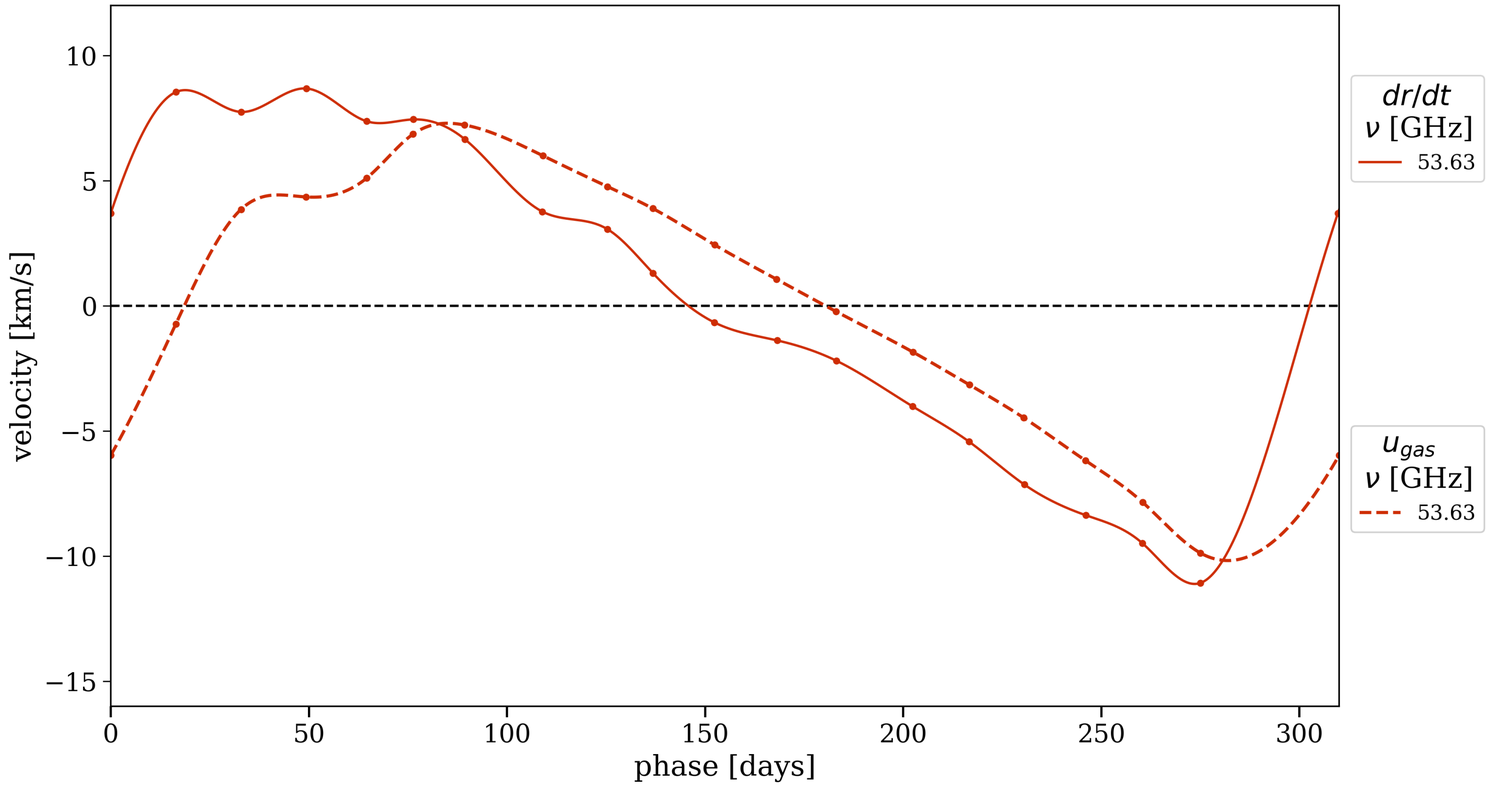
Photosphere radial velocity





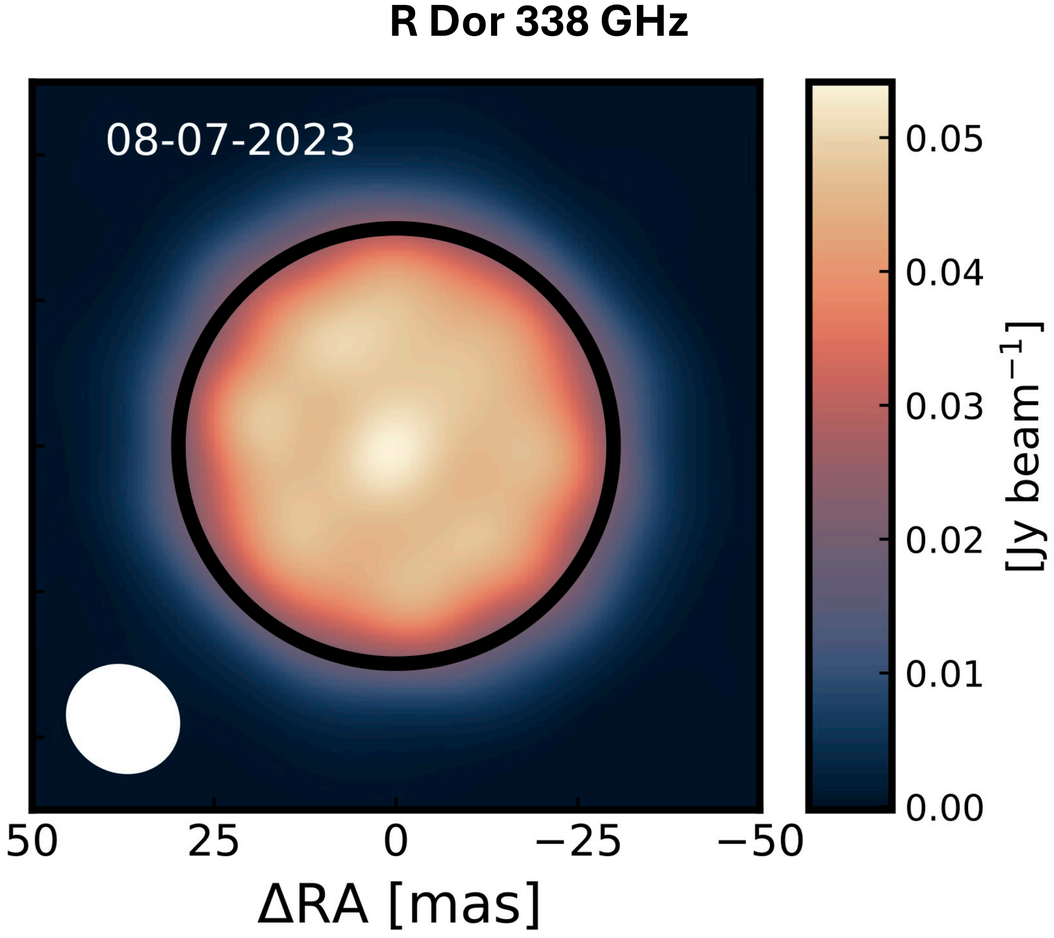
Photosphere radial velocity





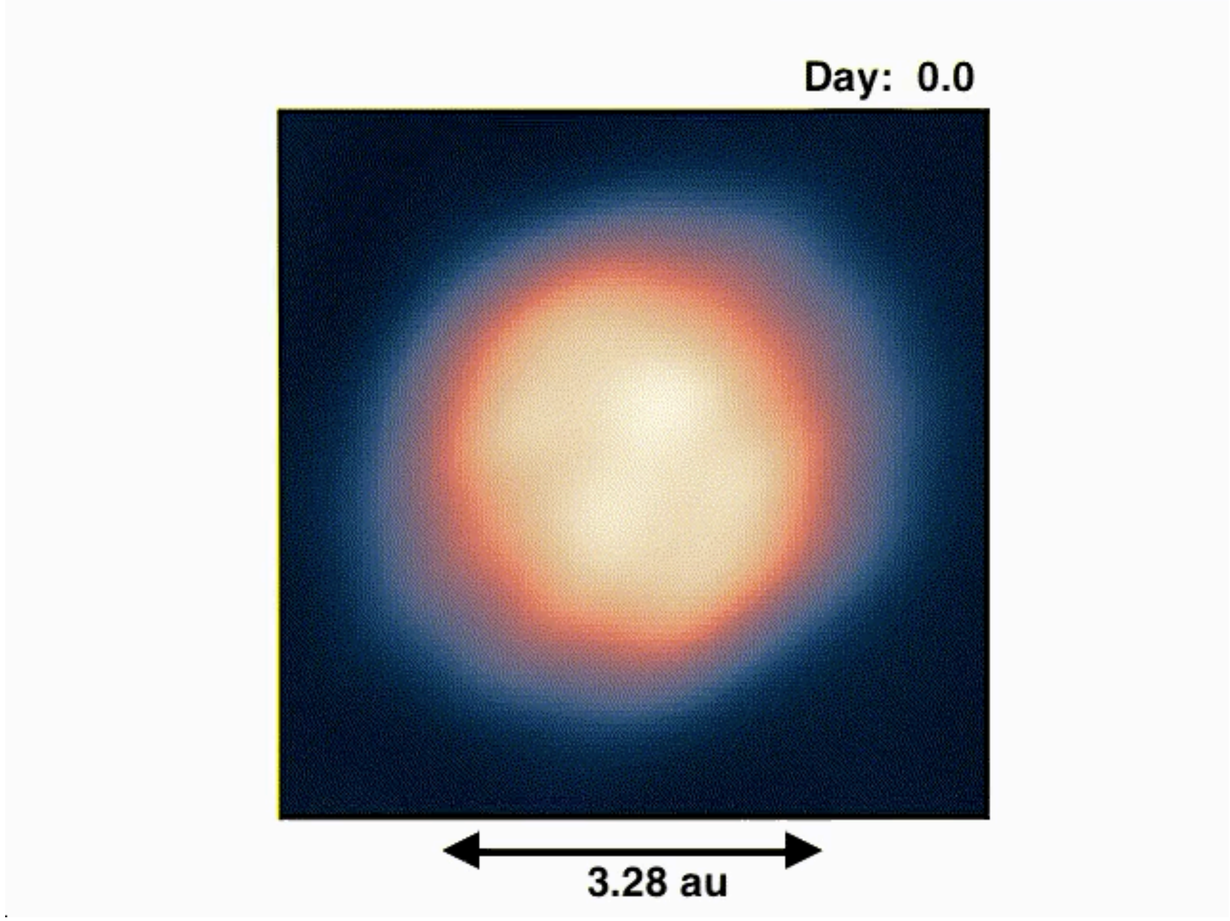
ALMA Observation of Convection on AGB stars

- Vlemmings et al 2024 (Nature)
- R Doradus at 55 ± 3 pc
- Pulsation periods of 362 and 175 days
- Largest configuration of ALMA and bands 6 (≈ 225 GHz) and band 7 (≈ 338 GHz)
- Shows a stellar disc with a radius of 1.64 ± 0.09 au at 338 Ghz

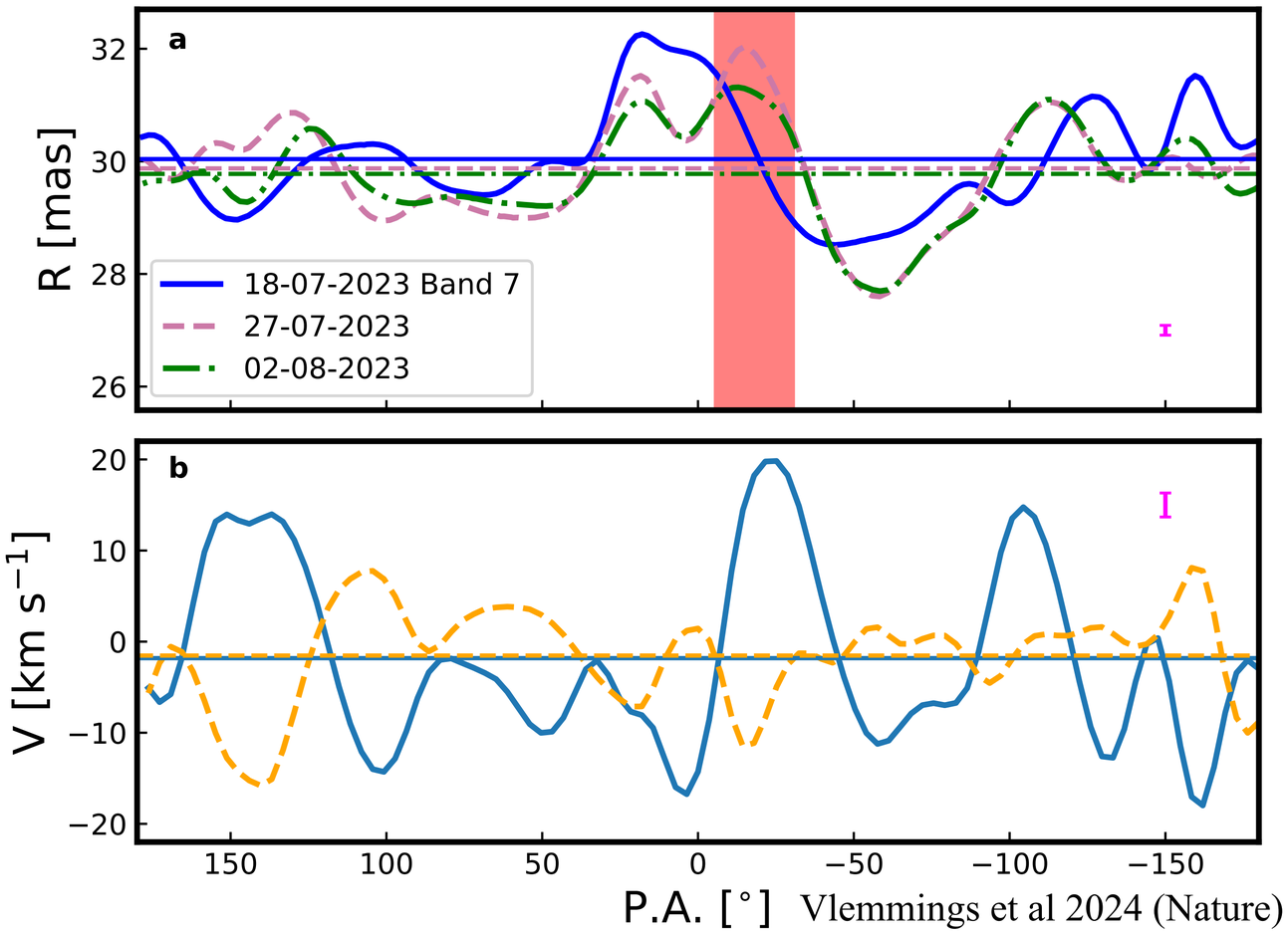


Vlemmings et al (2024)

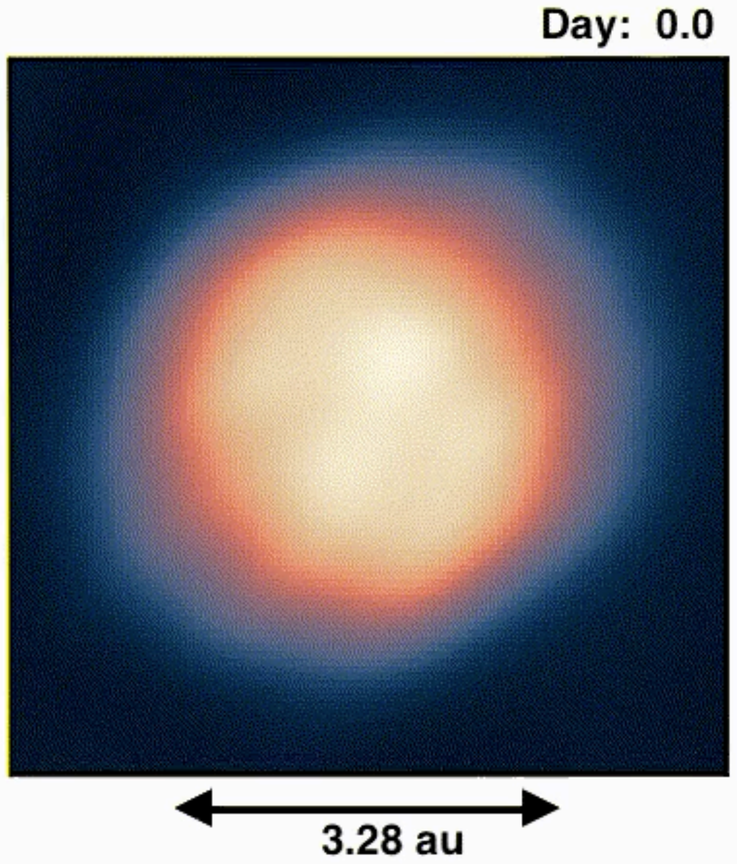
ALMA Observation of Convection on AGB stars



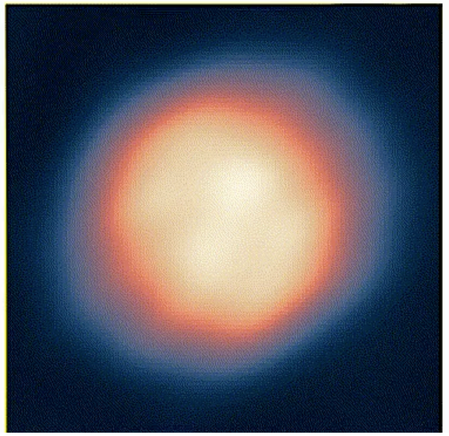
ALMA Observation of Convection on AGB stars



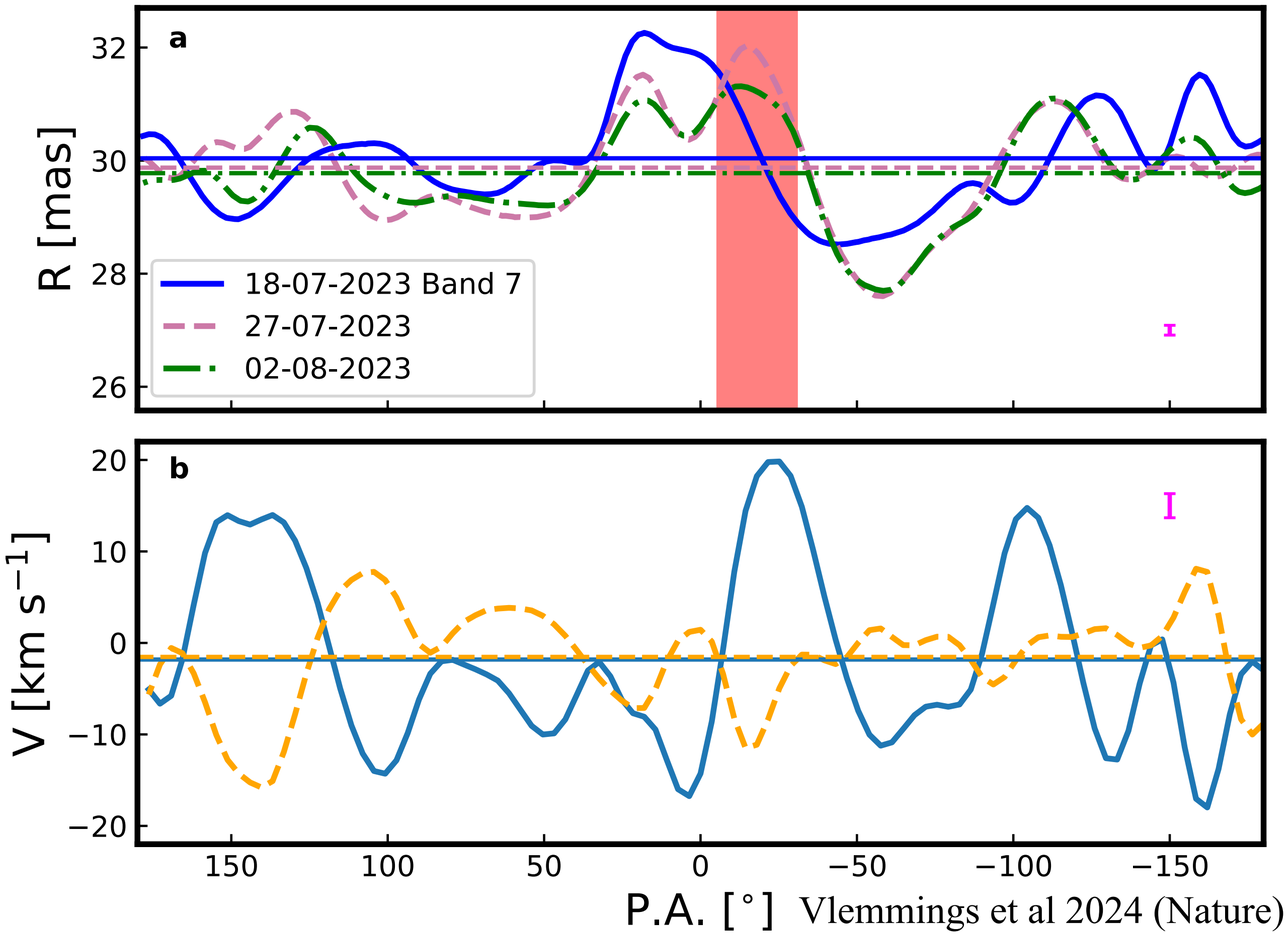
Vlemmings et al 2024 (Nature)



ALMA Observation of Convection on AGB stars

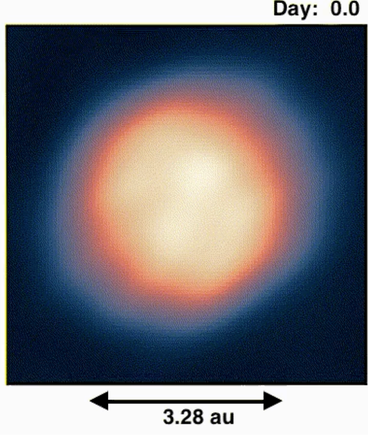


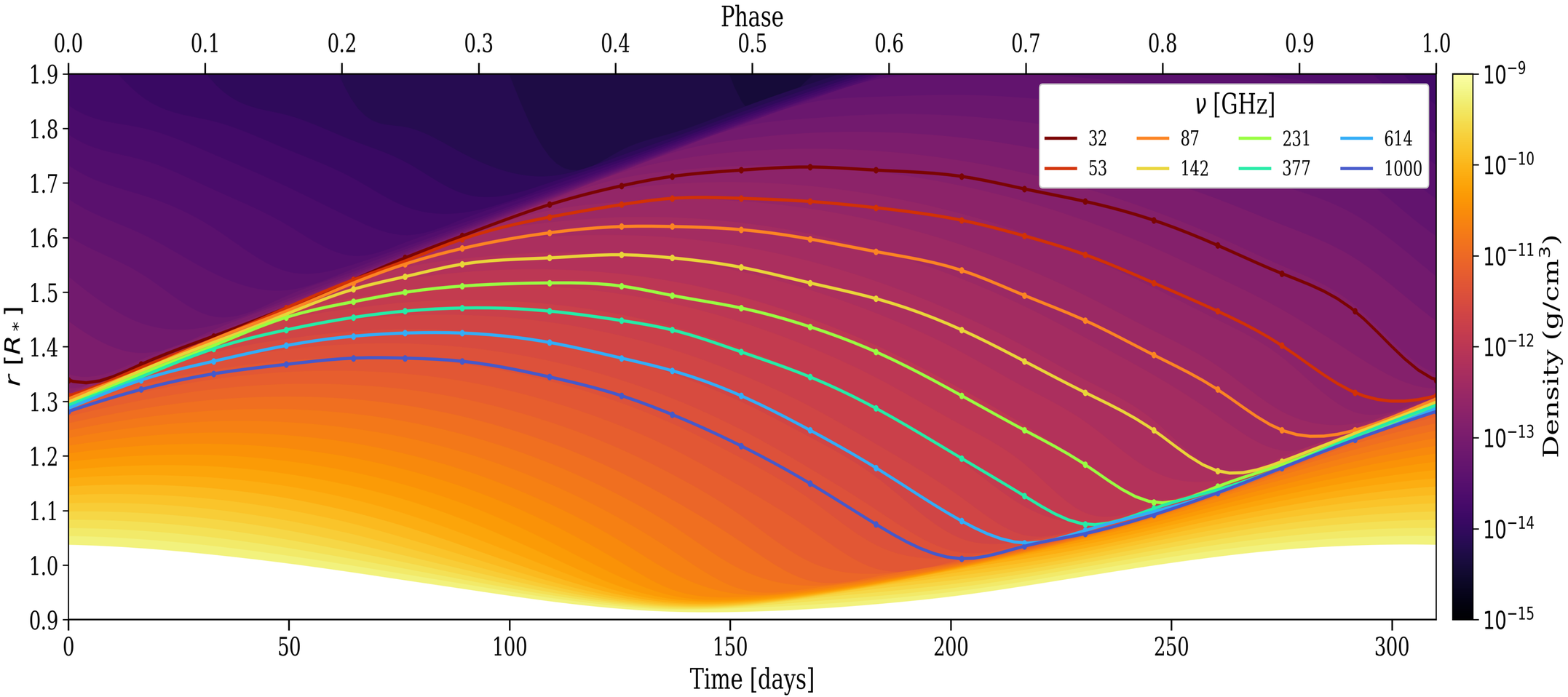
- Variations are significant
- Granule size (Red bar) estimated from spatial PSD → structure on the disc
- Structure sizes on the limb are comparable to the disc granule size
- Compared to the local sound speed of ≈ 6 km/s, the variations are consistent with supersonic shocks resulting from convection
- The time scale of surface granule variations $\approx 33 \pm 3$ days



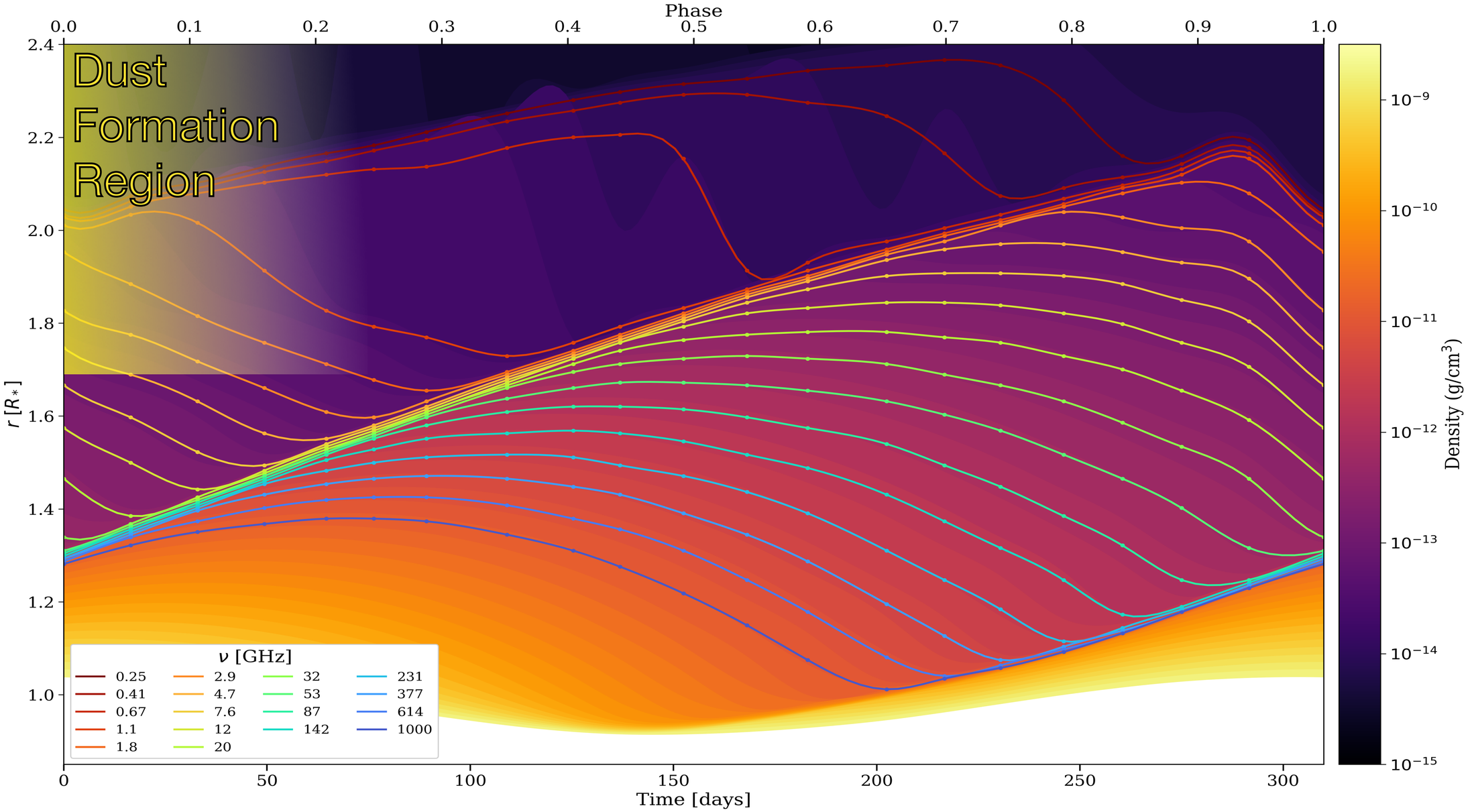
Vlemmings et al 2024 (Nature)

What does SKA see?



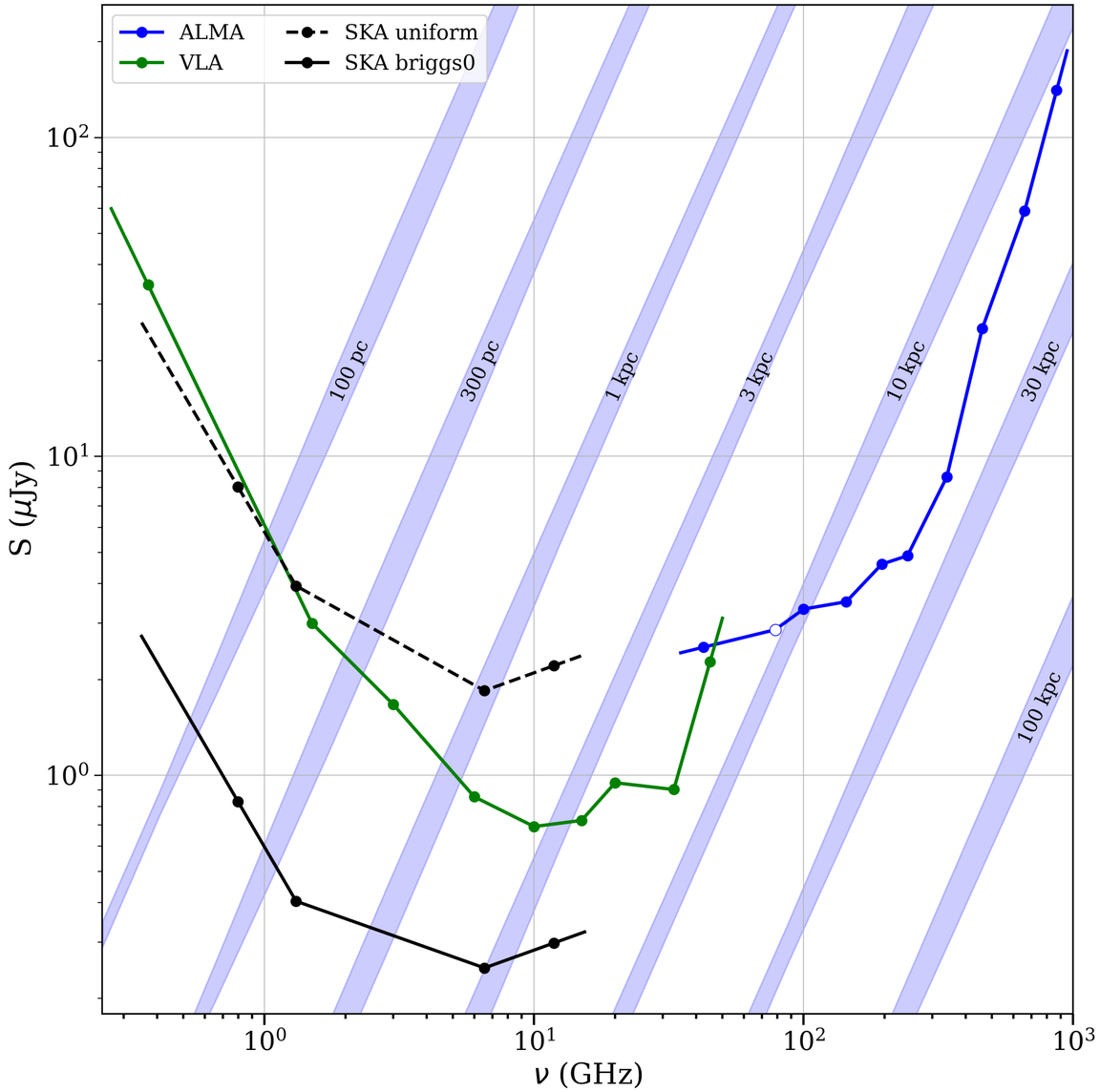


What does SKA see?



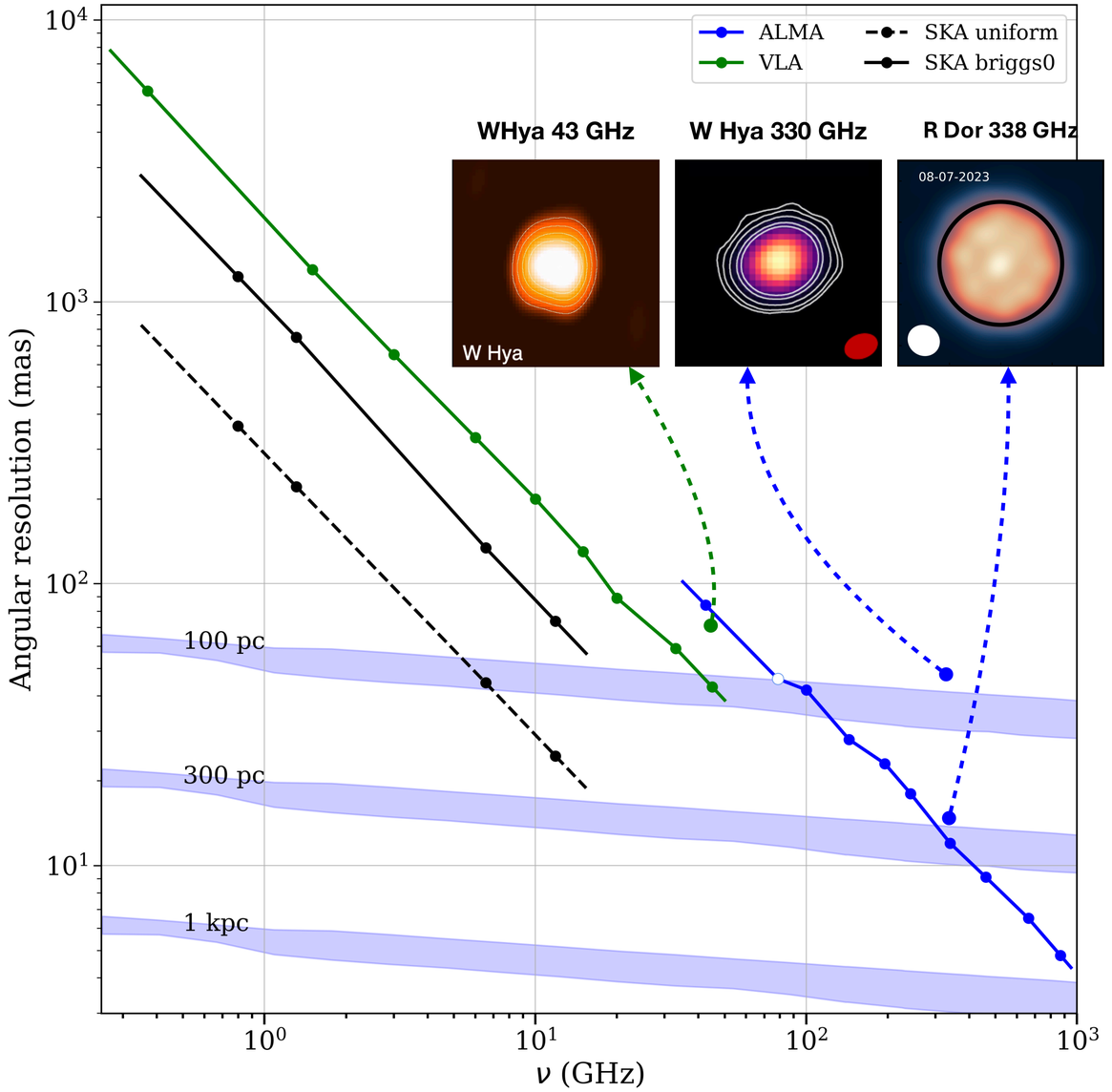
Capabilities of SKA in unresolved observations

- Flux density profile for stars within 3kpc
- Higher signal-to-noise compared to VLA
- Detect AGB stars within 1kpc with only a few minutes of observing time
- Recurring unresolved visits of AGBs as far as 1kpc as dedicated projects and piggy-back on survey projects

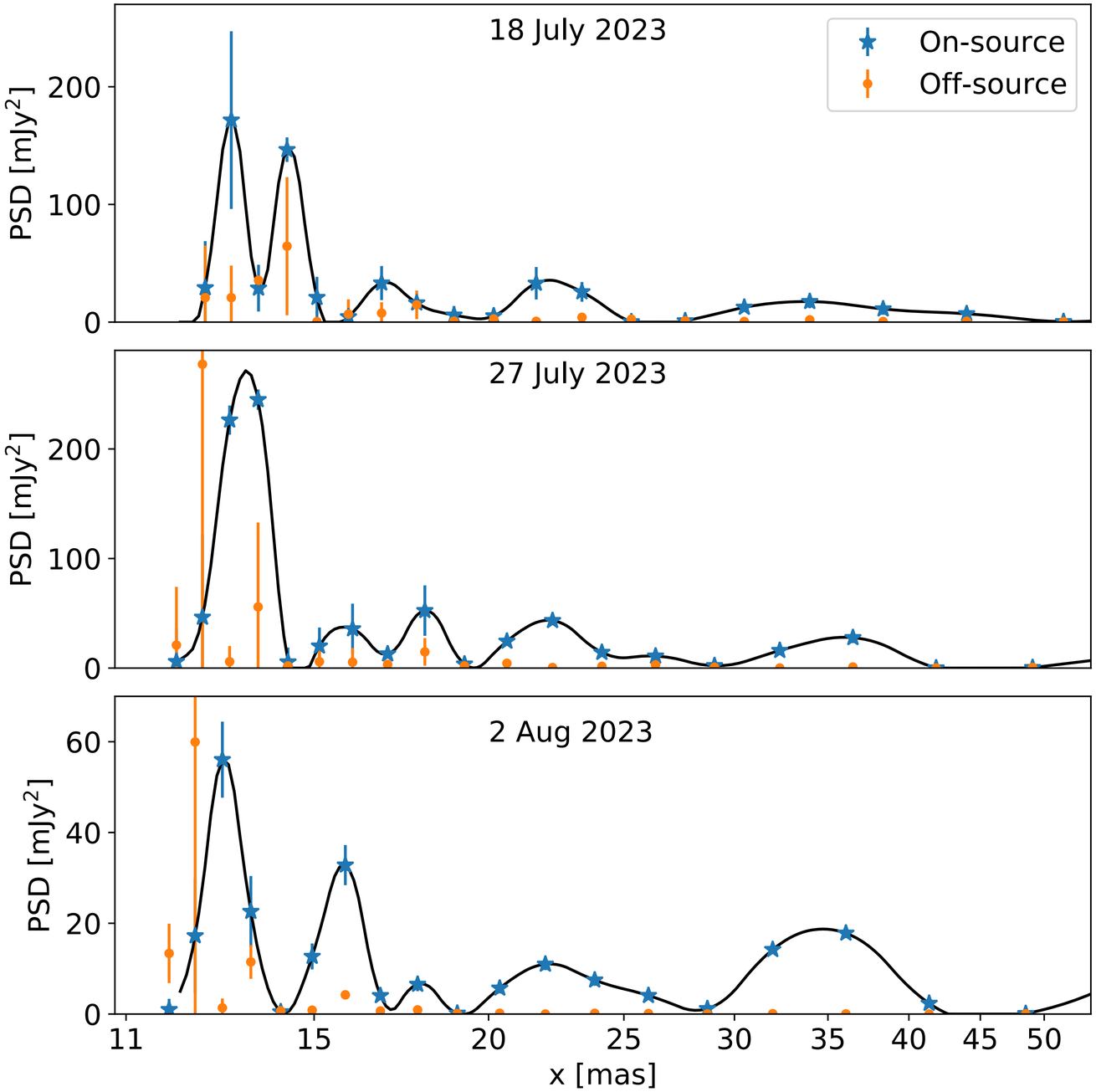


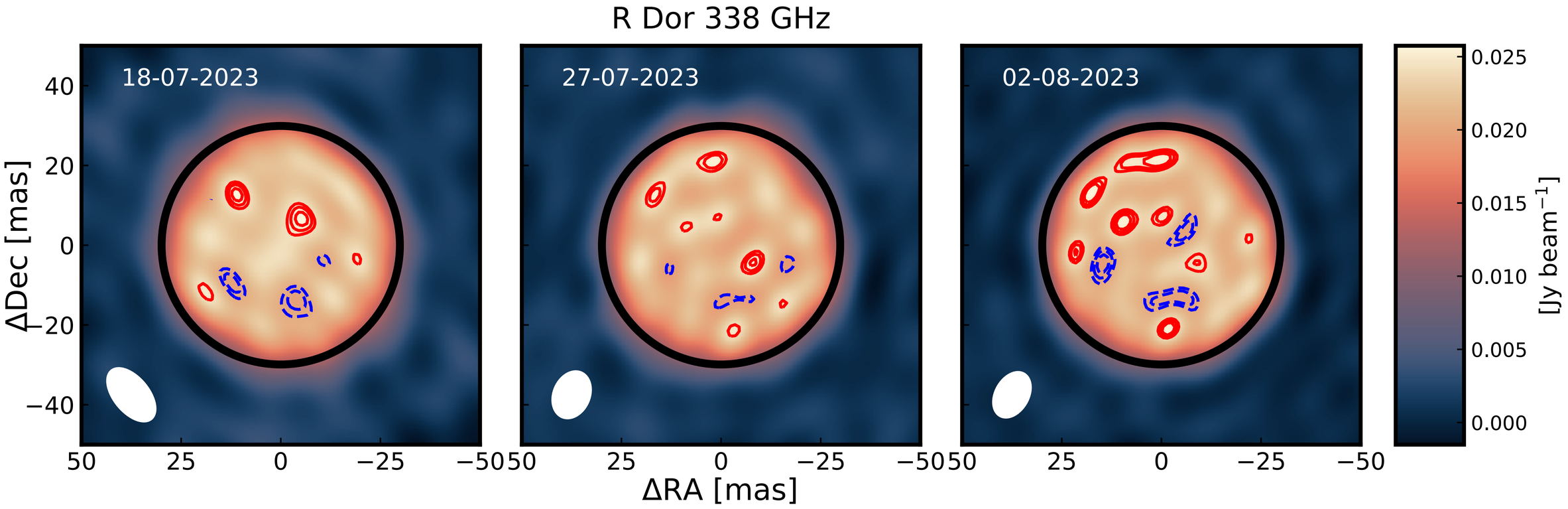
Capabilities of SKA in resolved observations

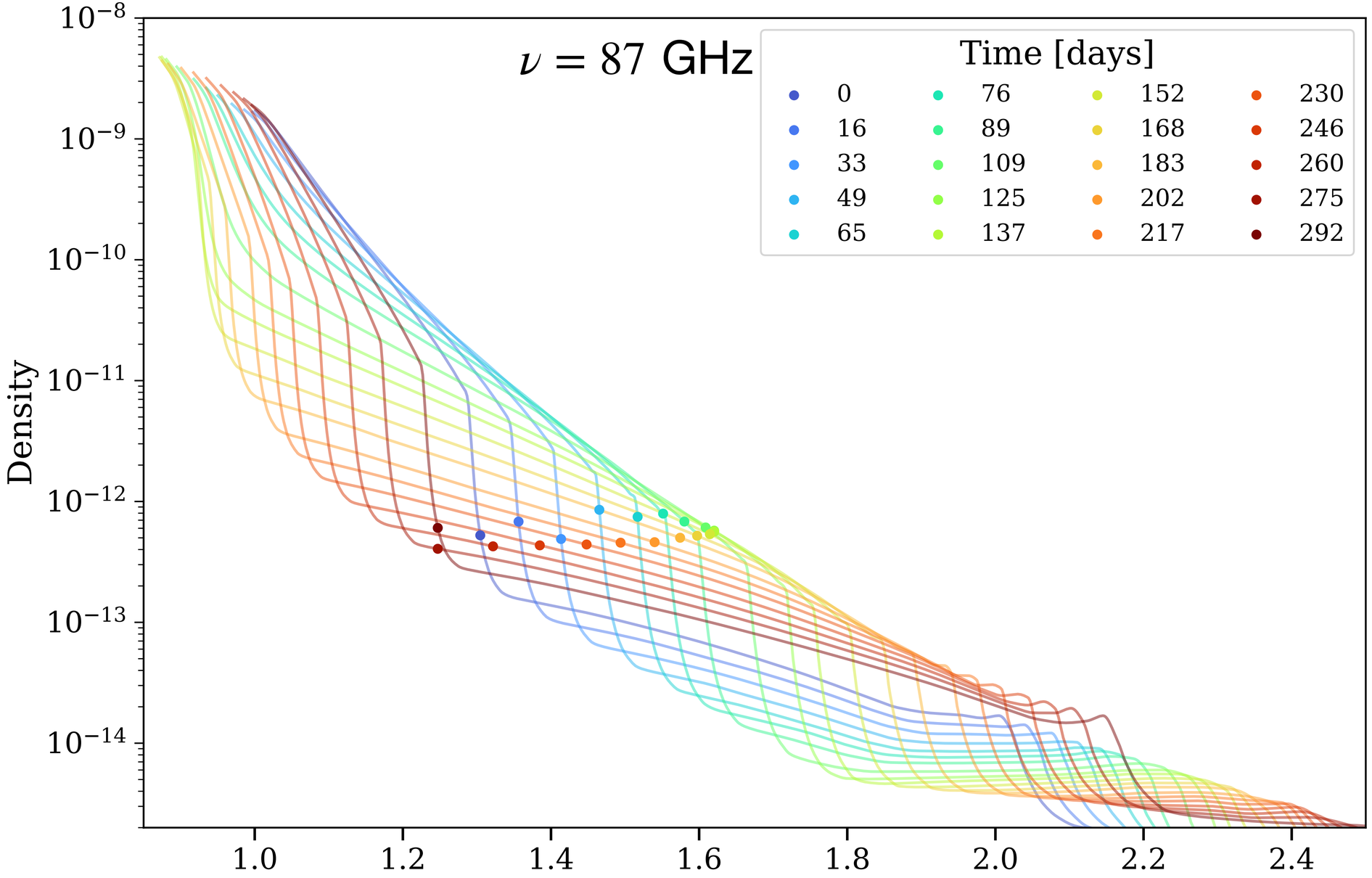
- The highest bands (5a and 5b) are suitable for resolved observations of nearby AGB stars
- Resolving in the dust-forming region
- Brightness temperature measurements of the disc in a wide range of frequencies → constrain temperature and density profile in the extended atmosphere
- The wide field of view of SKA provides opportunities to revisit nearby AGBs several times during one period

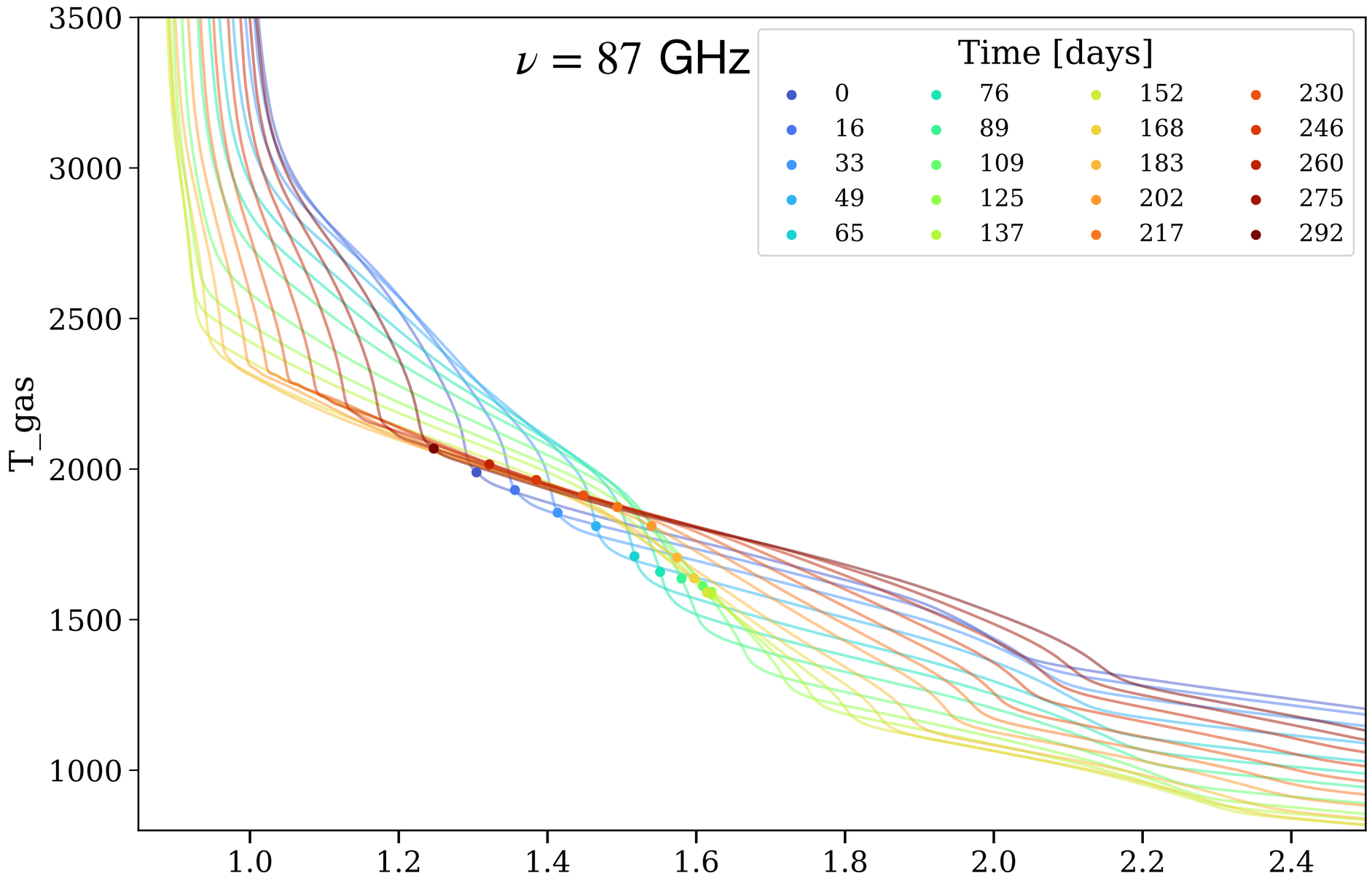


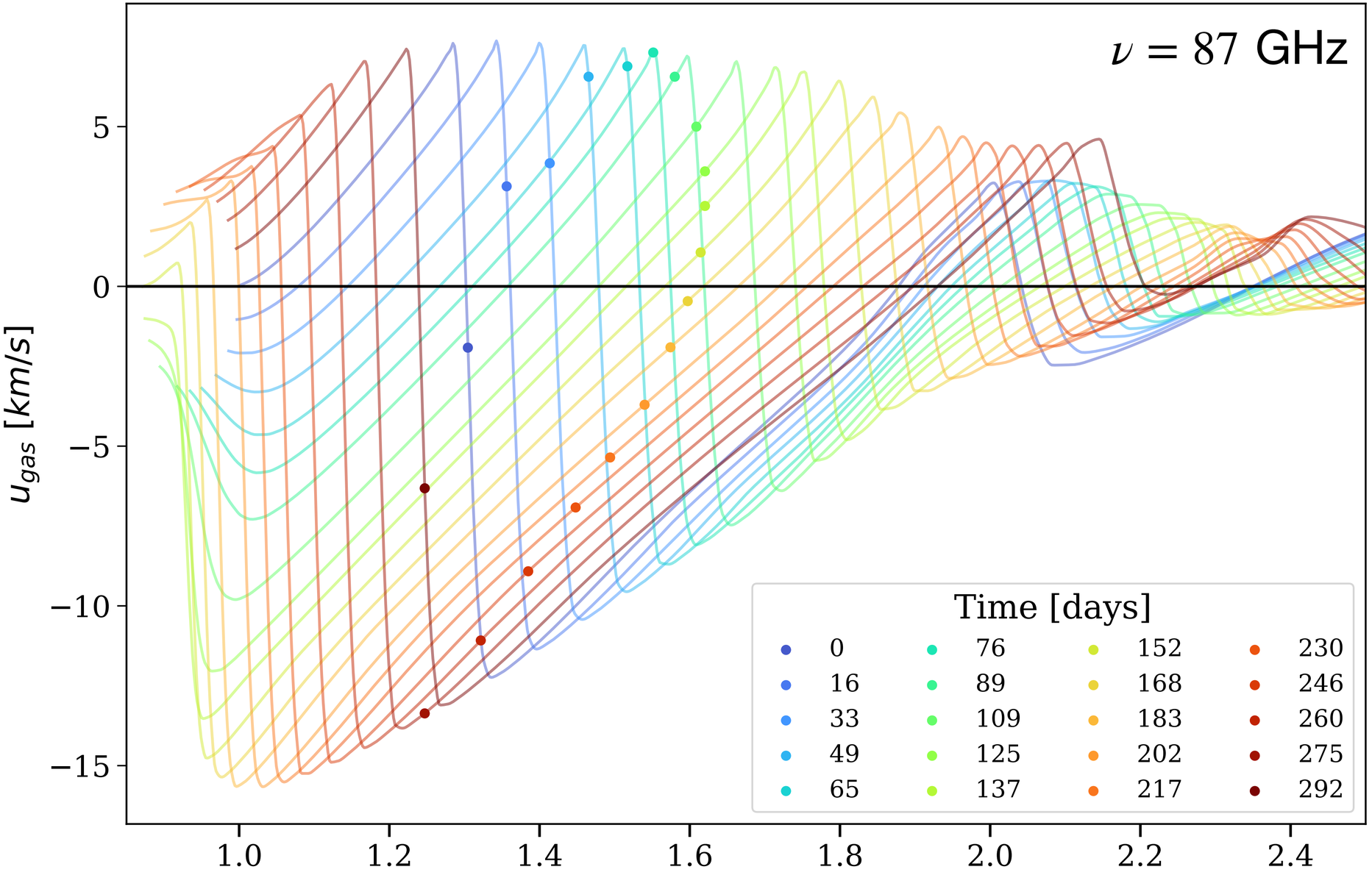
Thank you for your attention


18 July 2023
On-source
Off-source
PSD [mJy^2]
200
100
0
27 July 2023
PSD [mJy^2]
200
100
0
2 Aug 2023
PSD [mJy^2]
60
40
20
0
11
15
20
25
30
35
40
45
50
x [mas]


R Dor 338 GHz
18-07-2023
27-07-2023
02-08-2023
ΔDec [mas]
ΔRA [mas]
40
20
0
−20
−40
50
25
0
−25
−50
0.025
0.020
0.015
0.010
0.005
0.000
[Jy beam^{-1}]


$\nu = 87$ GHz
Time [days]
0
16
33
49
65
76
89
109
125
137
152
168
183
202
217
230
246
260
275
292
Density
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4


$\nu = 87$ GHz
Time [days]
0
16
33
49
65
76
89
109
125
137
152
168
183
202
217
230
246
260
275
292
T_gas
3500
3000
2500
2000
1500
1000
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4


$\nu = 87$ GHz
u_{gas} [km/s]
5
0
−5
−10
−15
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Time [days]
0
16
33
49
65
76
89
109
125
137
152
168
183
202
217
230
246
260
275
292