Dust emission in an expanding supernova remnant in an inhomogeneous medium

Drozdov Sergey[1],

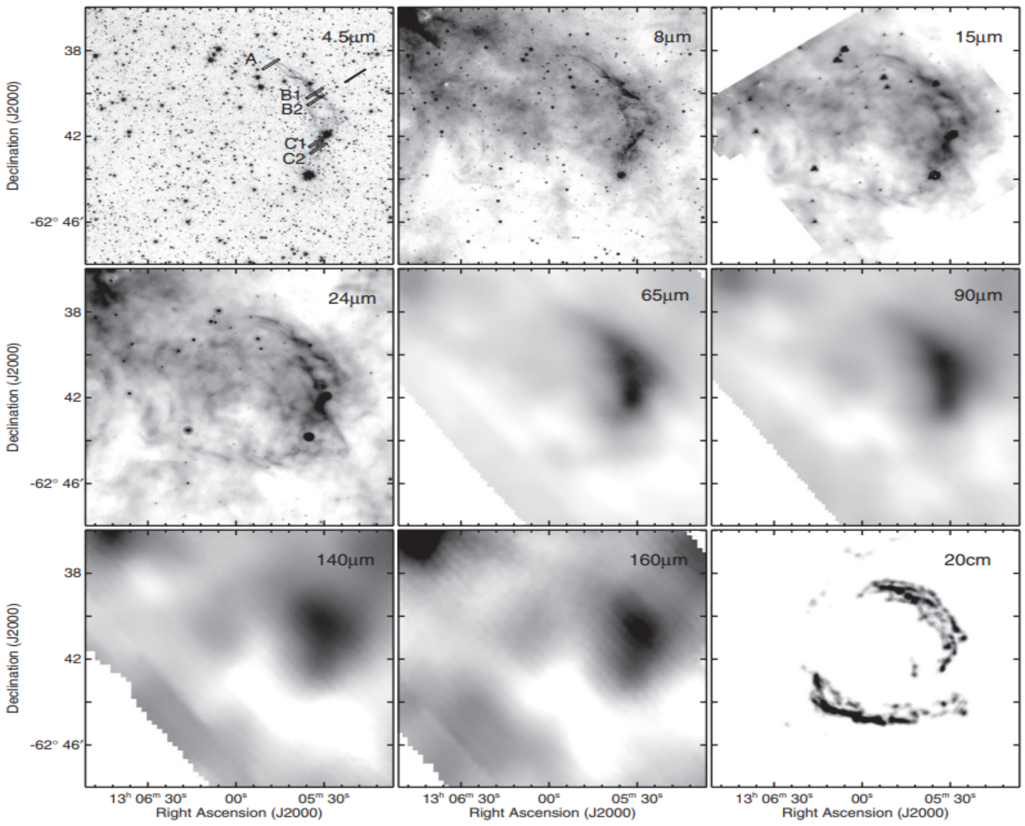
Dedikov Svyatoslav[1], Evgenii Vasiliev[1]

Drozdov et al. 2025

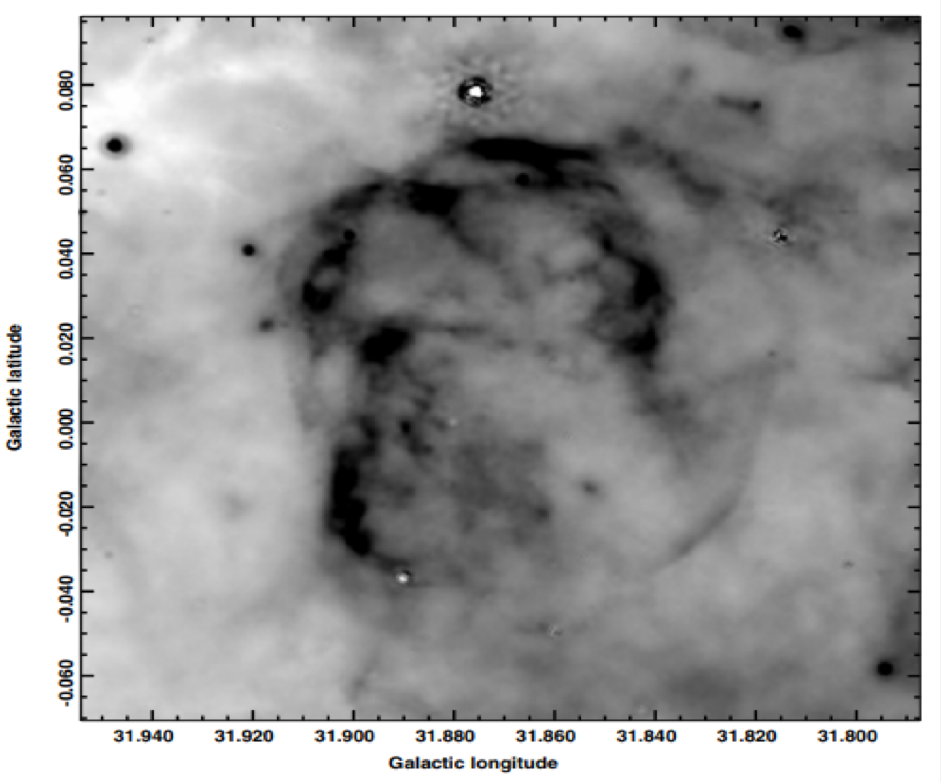
(grant RSF No. 23-22-00266)

Submillimeter and Millimeter Astronomy: Objectives and Instruments. Moscow, ASC LPI, 16.04.2025.

1) Astrospace centre Lebev Physical Institute

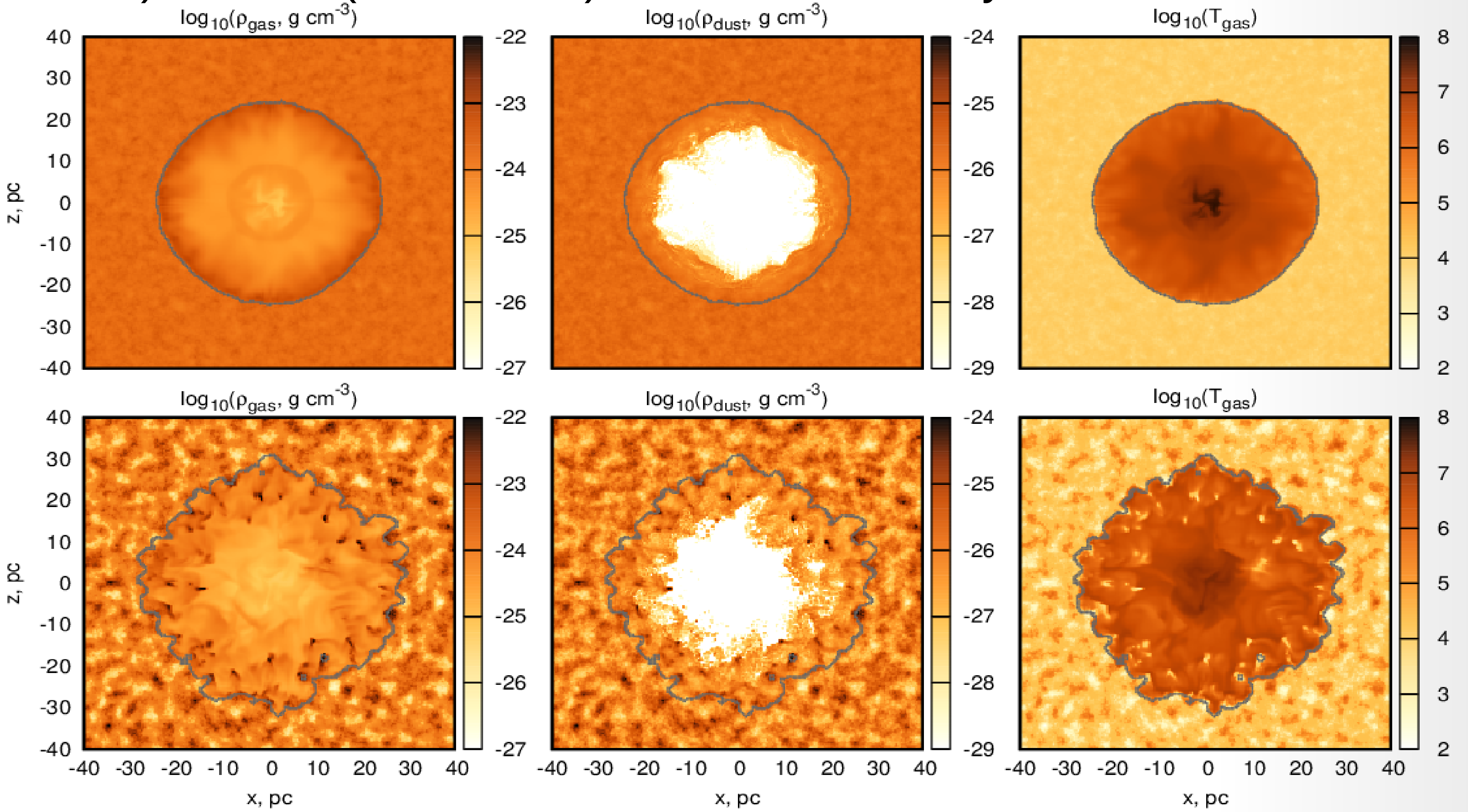


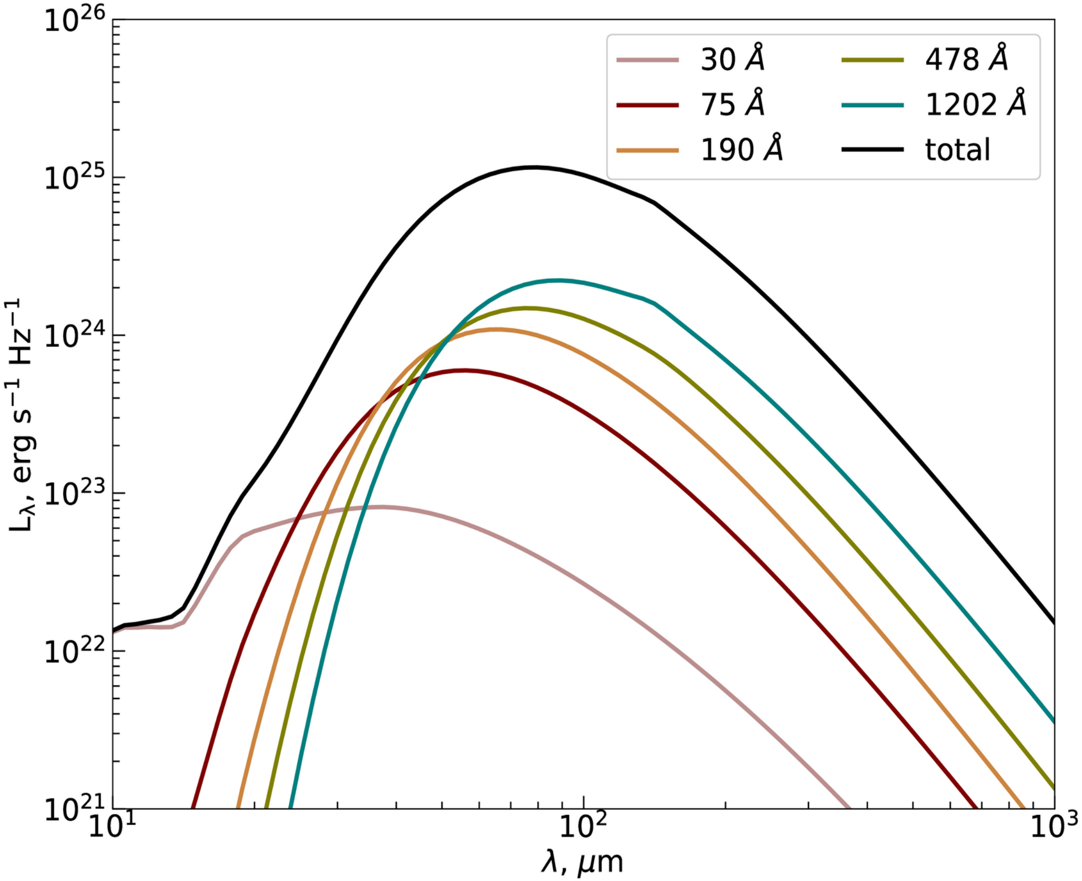
Kes 17 (G304.6)
Lee et al. 2011



3C391 (G31.9)
Gonc`alves et al. 2011

Distributions of the gas density, dust density, and temperature of the gas in the plane passing through the center of the SN remnant expanding in an inhomogeneous medium with average density ‹n› = 1 cm^{-3} and variance σ = 0.2 (upper line), σ = 2.2 (bottom line) at the time of 40 kyr.





For a description of the method for constructing the TDF (Temperature distribution functions) of dust particles, see for more information *Drozdov 2021*

- An example of the total spectrum of a bubble in the IR range. The individual lines show the contributions from dust particles of various sizes.

- The heating of dust occurs due to collisions with gas

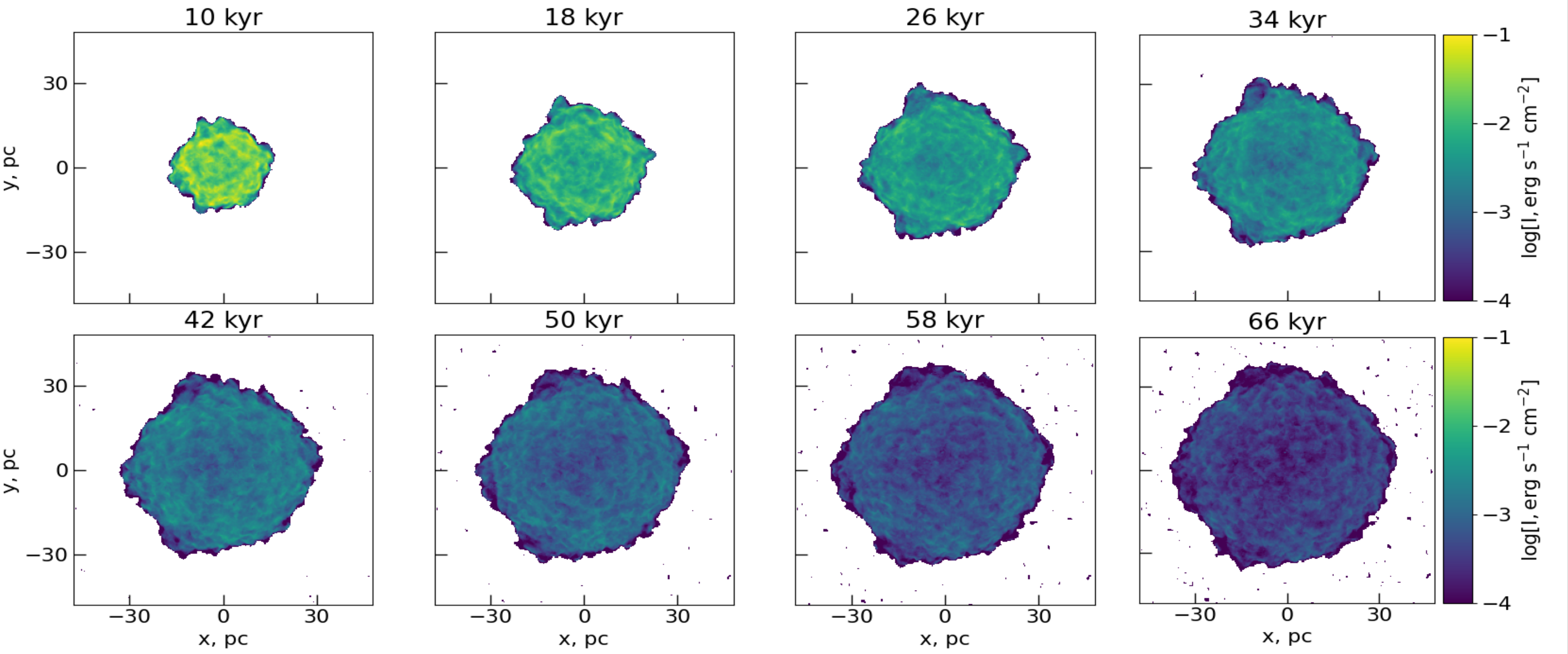
- The temperature of the dust calculation method is stochastic

- The contribution to heating from UV photons is neglected

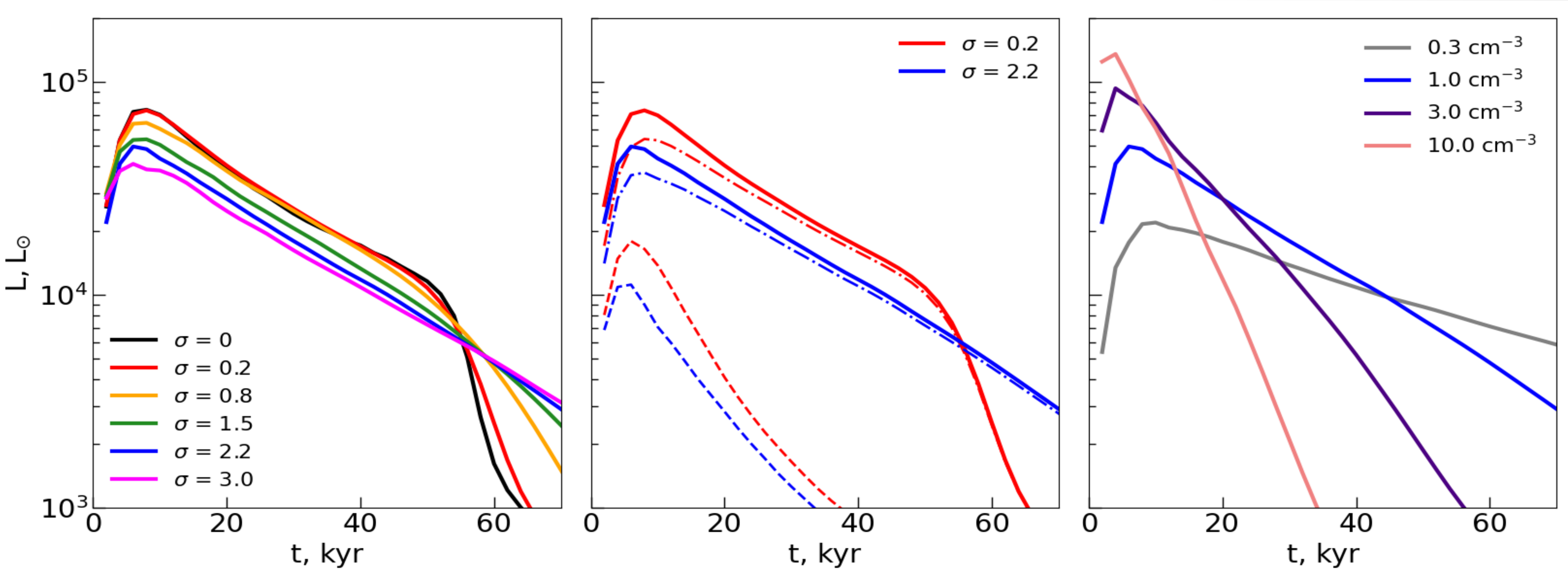
$$a_{gr} \in [30, 3000] \mathring{A}$$

$$a_{min} = 10 \mathring{A}$$

Evolution of the surface brightness of the remnant in the IR range, ‹n› = 1 cm^{-3} and variance σ = 2.2.



Evolution of the total IR dust luminosity in the remnants

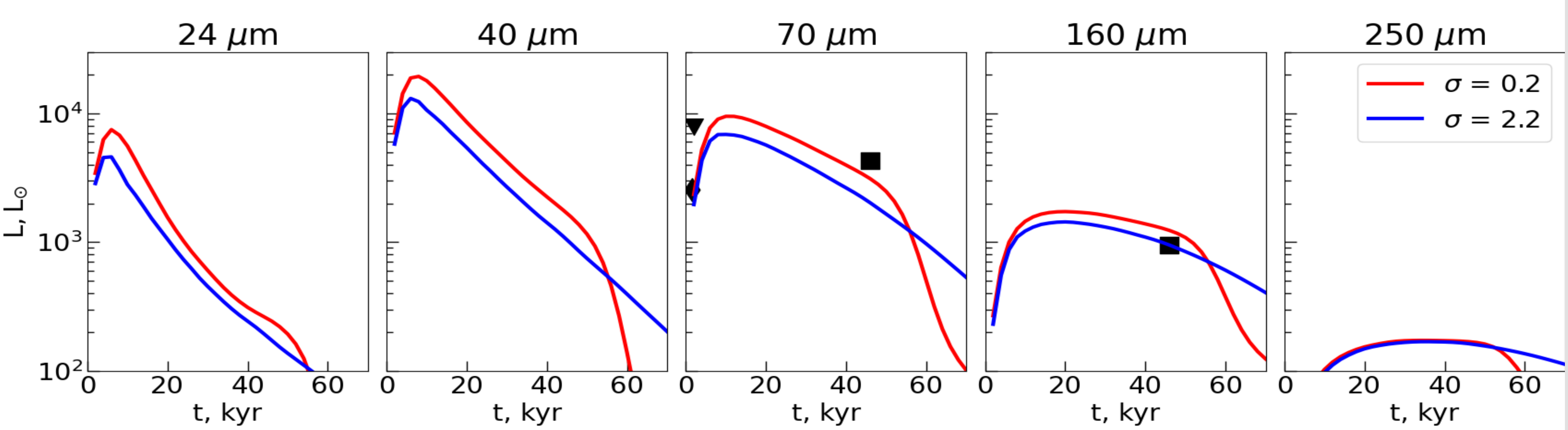


For different values of the density dispersion σ and with average density ‹n› = 1 cm^{-3}

$\lambda \leqslant 30\,\mu m$ -- dashed lines
$\lambda \geqslant 30\,\mu m$ -- dash-dotted lines
Total luminosity is a solid line

For different values of the background gas density ‹n› and with dispersion σ = 2.2

Evolution of the luminosity of the remnant in different photometric bands.



■ -- G304.6 Lee et al. 2011

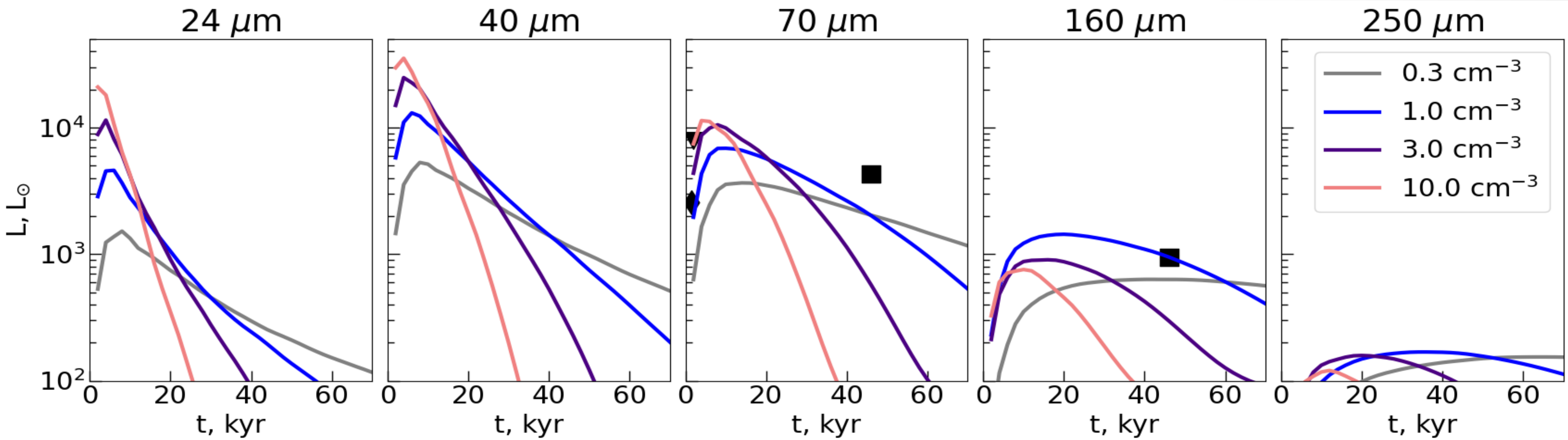
▼ -- G34.7 Koo et al. 2016

♦ -- 3C 397 Koo et al. 2016

For different values of the background gas density dispersion

$$\frac{\lambda}{\Delta\lambda} = 3$$

Evolution of the luminosity of the remnant in different photometric bands.



■ -- G304.6 Lee et al. 2011

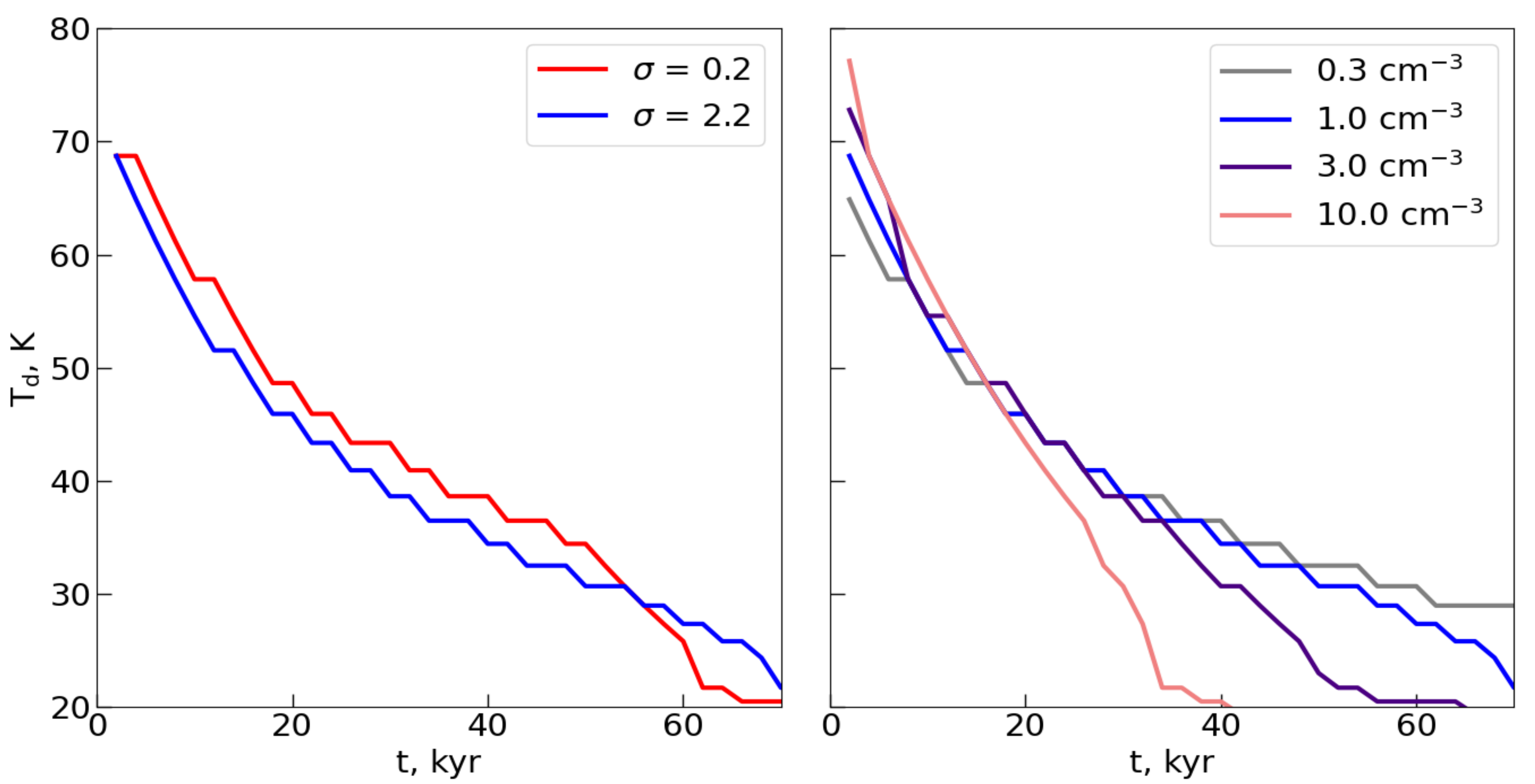
▼ -- G34.7 Koo et al. 2016

♦ -- 3C 397 Koo et al. 2016

For different values of the background gas density

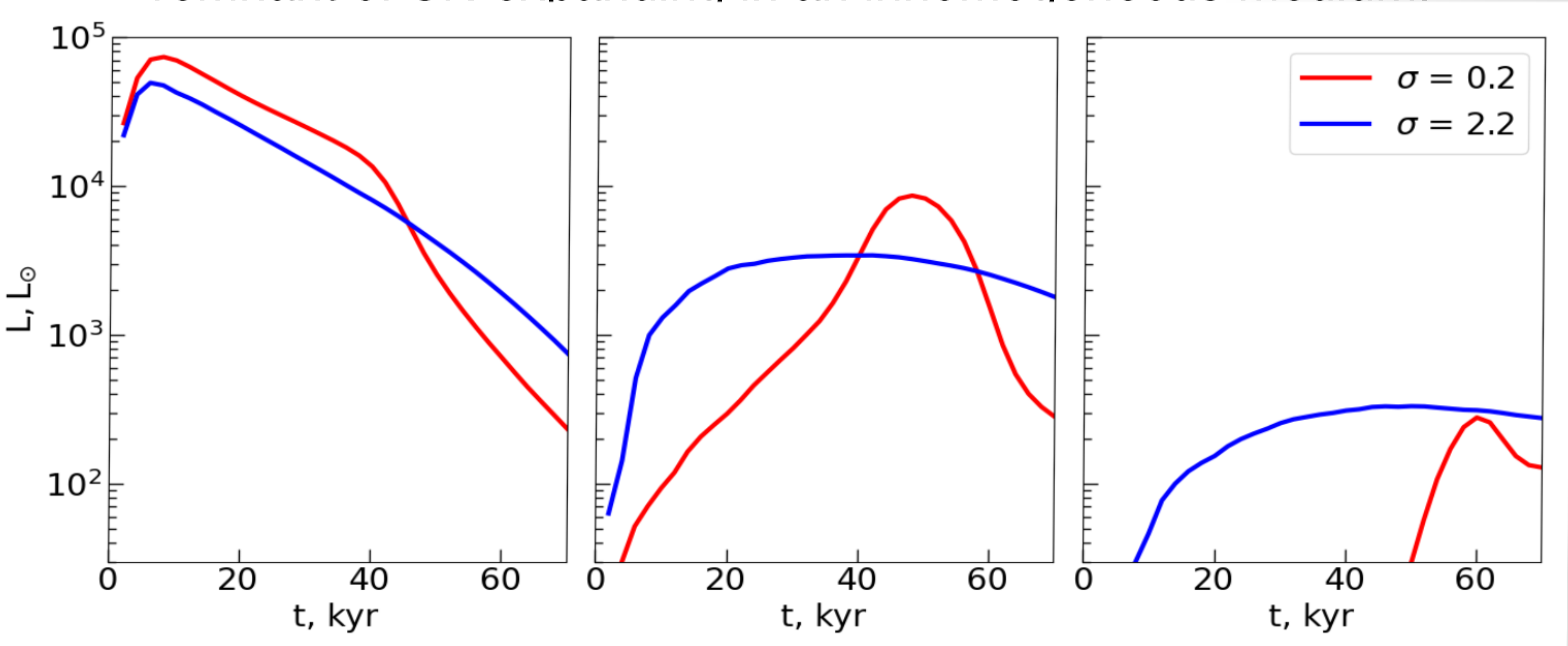
$$\frac{\lambda}{\Delta\lambda} = 3$$

Evolution of the observed temperature of dust in the remnant



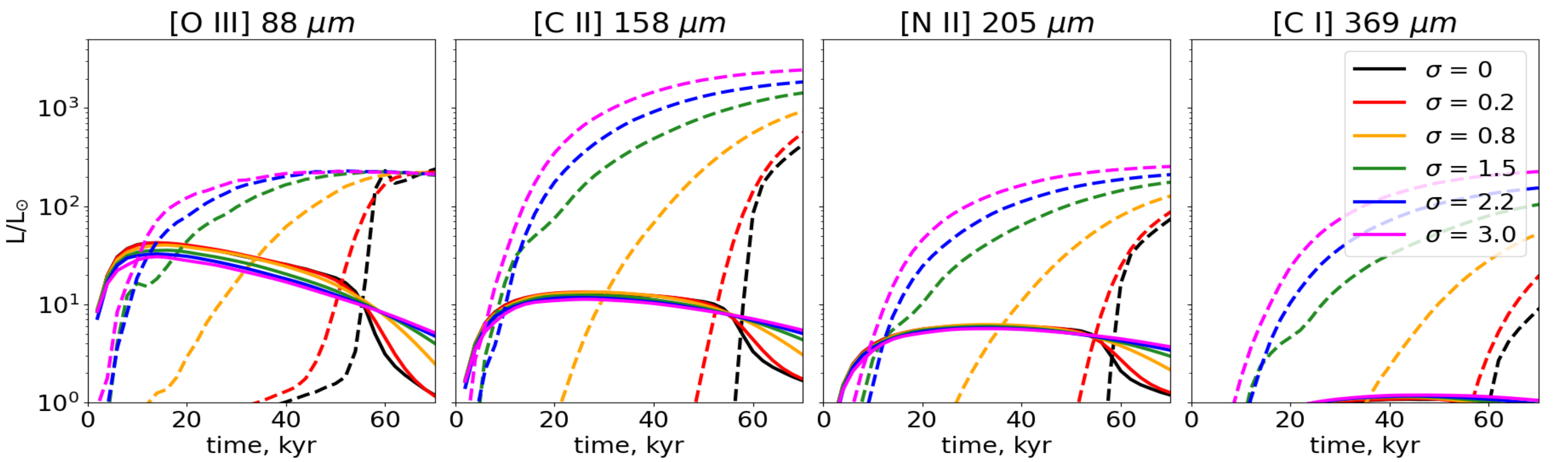
$$\lambda_{max}(\beta, T_d) = \frac{hc}{k_B T_d} \frac{1}{(4+\beta) + W[-(4+\beta)exp(-(4+\beta))]}$$

IR luminosity of dust in gas with different temperature in the remnant of SN expanding in an inhomogeneous medium.



$T_g > 10^6 K$ $10^5 < T_g < 10^6 K$ $T_g < 10^5 K$

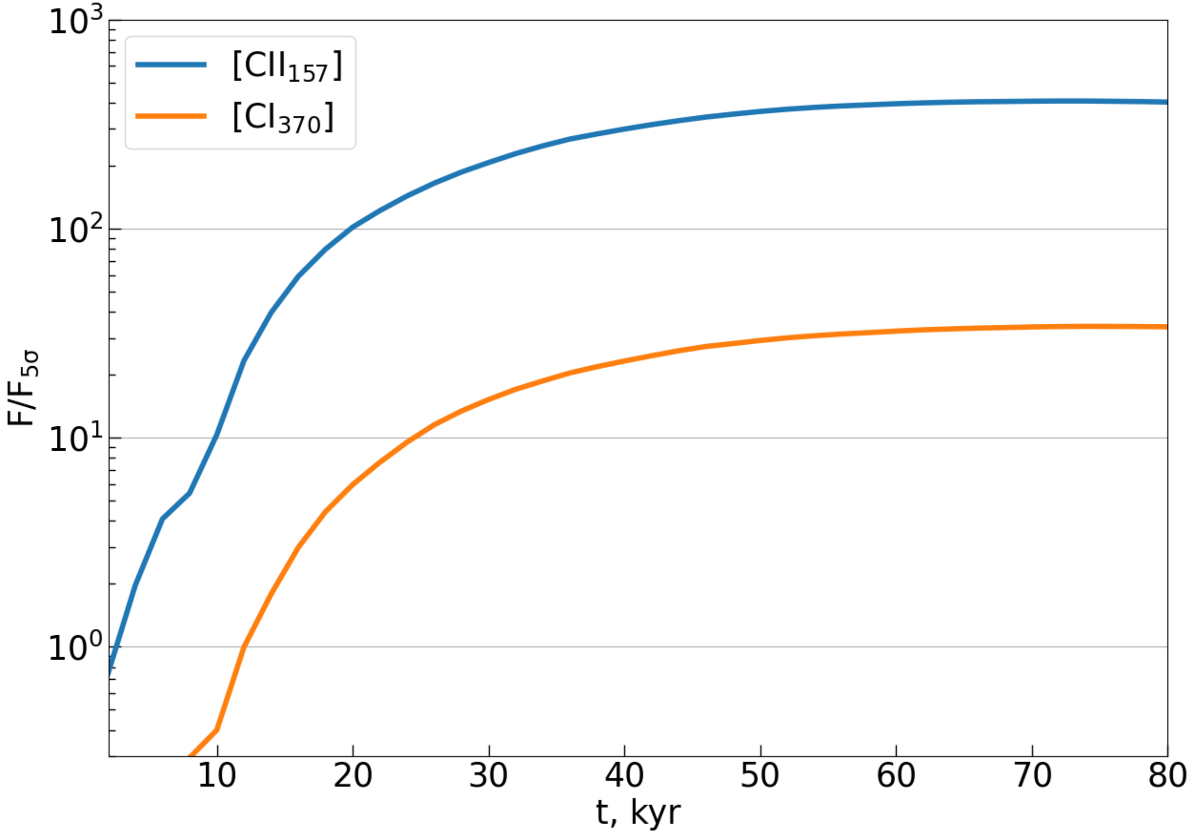
Evolution of the luminosity of spectral lines and the dust continuum under them



$\Delta\nu = 8\,GHz$

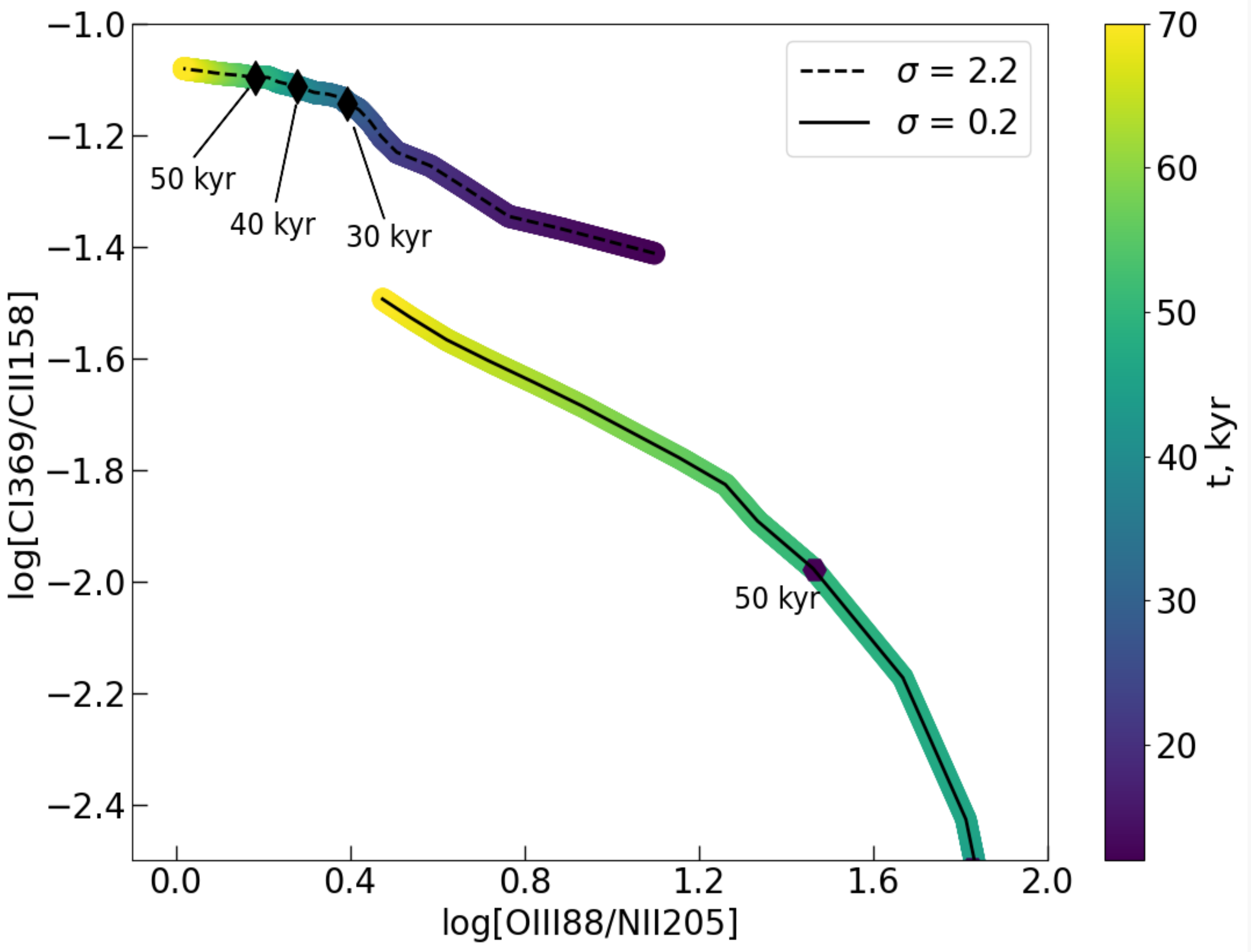
The luminosity of the lines is calculated based on the data *Vasiliev 2013*

The ratio of the emission flux in the line to the sensitivity of the MM in HRS
R = 3000, τ = 1h, 5σ

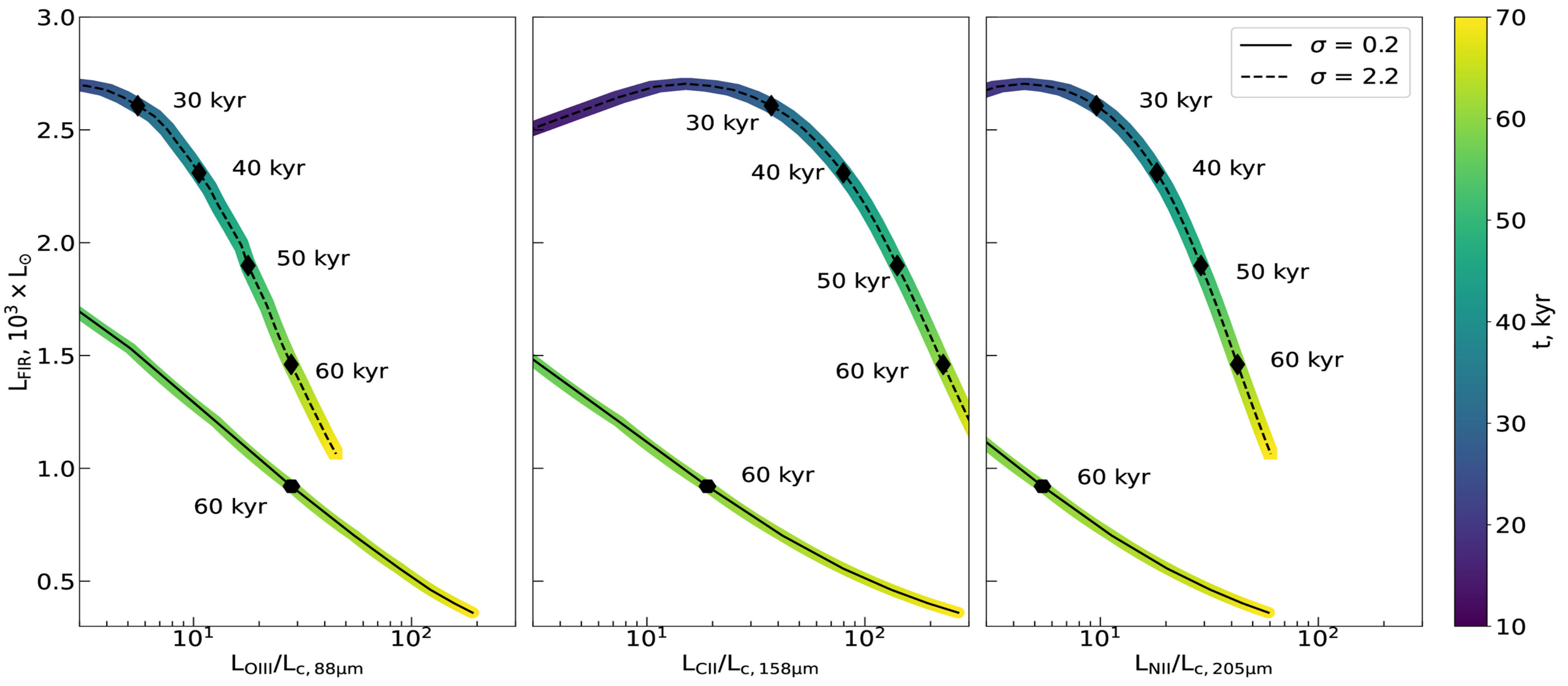


- M1: 500 — 600 μm
- M2: 330 — 400 μm
- M3: 244 — 277 μm
- M4: 214 — 231 μm
- M5: 157.1 — 158.7 μm
- M6: 124.5 — 125.52 μm
- M7: 111.9 — 112.8 μm

Luminosity ratios in spectral lines. The average gas density is ‹n› = 1 cm^{-3} . Symbols mark different moments in time.



Dependence of the ratio of luminosity in different spectral lines L_i to the luminosity of the continuous spectrum of dust emission under the line in the 8 GHz band $L_{c,i}$ on the luminosity in the far-IR range L_{FIR} (λ = 100 — 1000 μm). The color shows the age of the remnant in thousands of years.



$L_{FIR}(\lambda > 100\mu m)$

$\Delta\nu = 8\,GHz$

Results:

- The total IR luminosity of the dust reaches a maximum: $L_{IR} \sim (4-8) \times 10^4 L_\odot$ primarily due to the swept-up dust.

- The high inhomogeneity of the gas makes it possible to maintain the high temperature of the gas for longer (after 50 thousand years), and as a result -- the high luminosity of the dust.

- The maximum IR luminosity is achieved when the age of the SN remnant is about 10 kyr in the band with a central wavelength of 40 μm, and after 20–30 kyr it shifts to a longer wavelength range with 70 μm.

- The dust temperature changes from almost 70 K to about 20 K during the evolution process and its value depends weakly on the magnitude of inho-mogeneity of the medium, however, for remnants older than 40 kyr, the dust temperature decreases rapidly with an increase in the average density of the medium.

- The values of the intensities of the dust continuum under the ion lines ([OIII], [CII], [NII]) and the values of the intensities of the lines themselves make it possible to study the remnants of SN using the planned space project Millimetron.

Numerical modeling of shell emission was carried out with the support of the Russian Science Foundation (grant No. 23-22-00266).