Smoothed Particle Monte Carlo Radiative Transfer

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SPAMCART

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Outline

- Introduction to MCRT
- SPAMCART Algorithm
- Benchmark and examples

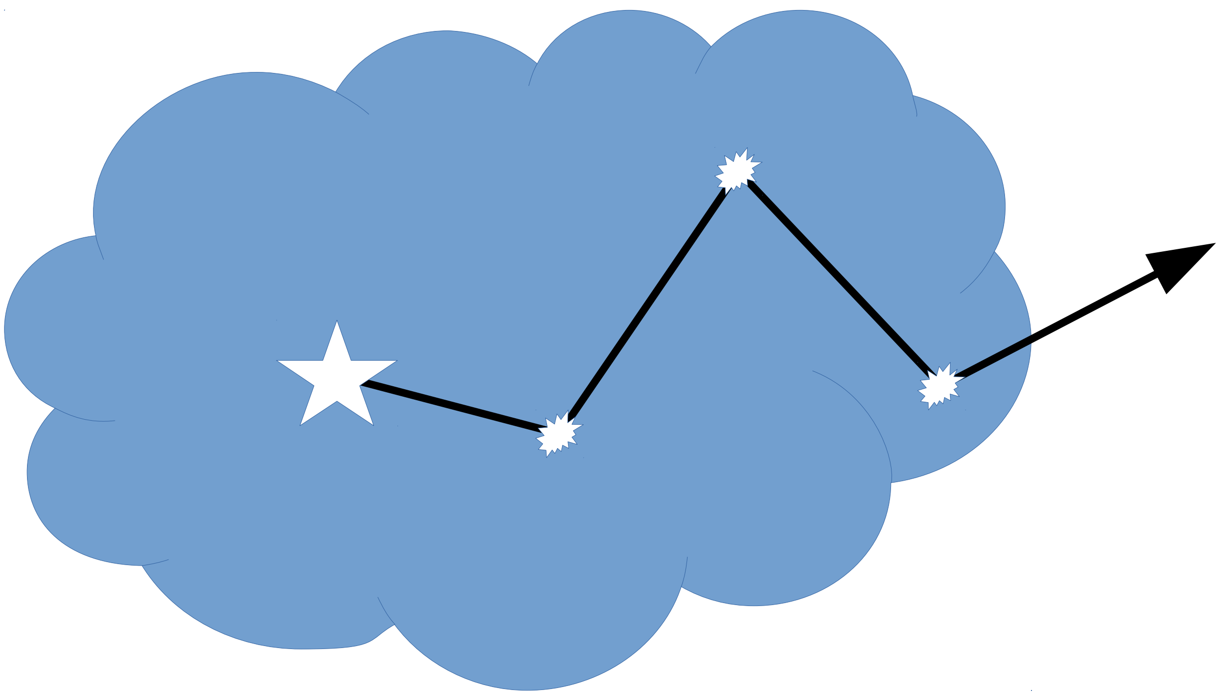
Introduction

- Radiation transport underpins observational inference.
- Also important in numerical modelling.
- Unfortunately, high-dimensional problem:

$$\frac{\mathrm{d}\,I}{\mathrm{d}\,s}(\boldsymbol{x},\boldsymbol{n},\lambda) = -\kappa(\boldsymbol{x},\lambda)\rho(\boldsymbol{x})\,I(\boldsymbol{x},\boldsymbol{n},\lambda) + j(\boldsymbol{x},\boldsymbol{n},\lambda)$$

MCRT

- Use random luminosity packets to model RT.



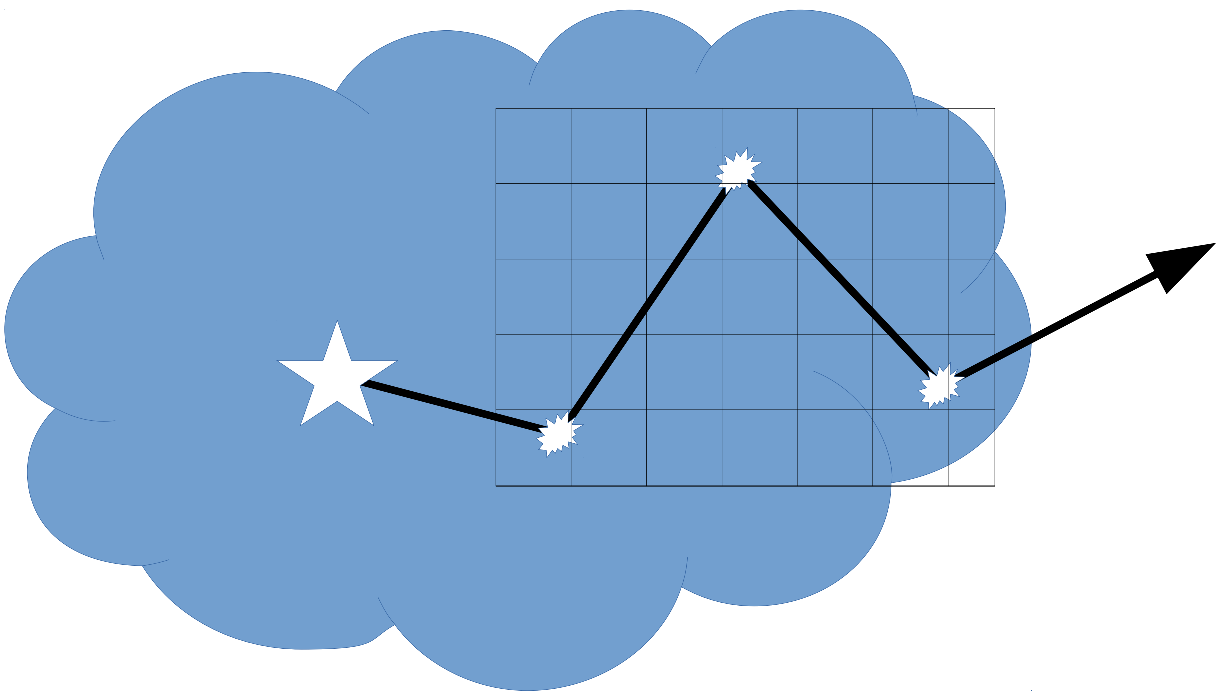
Random direction

$$\tau = -\ln(U)$$

$$\tau = \int_0^s \rho(\boldsymbol{x})\,\kappa(\boldsymbol{x},\lambda)\,\mathrm{d}s$$

MCRT

- Use random luminosity packets to model RT.



Random direction

$$\tau = -\ln(U)$$

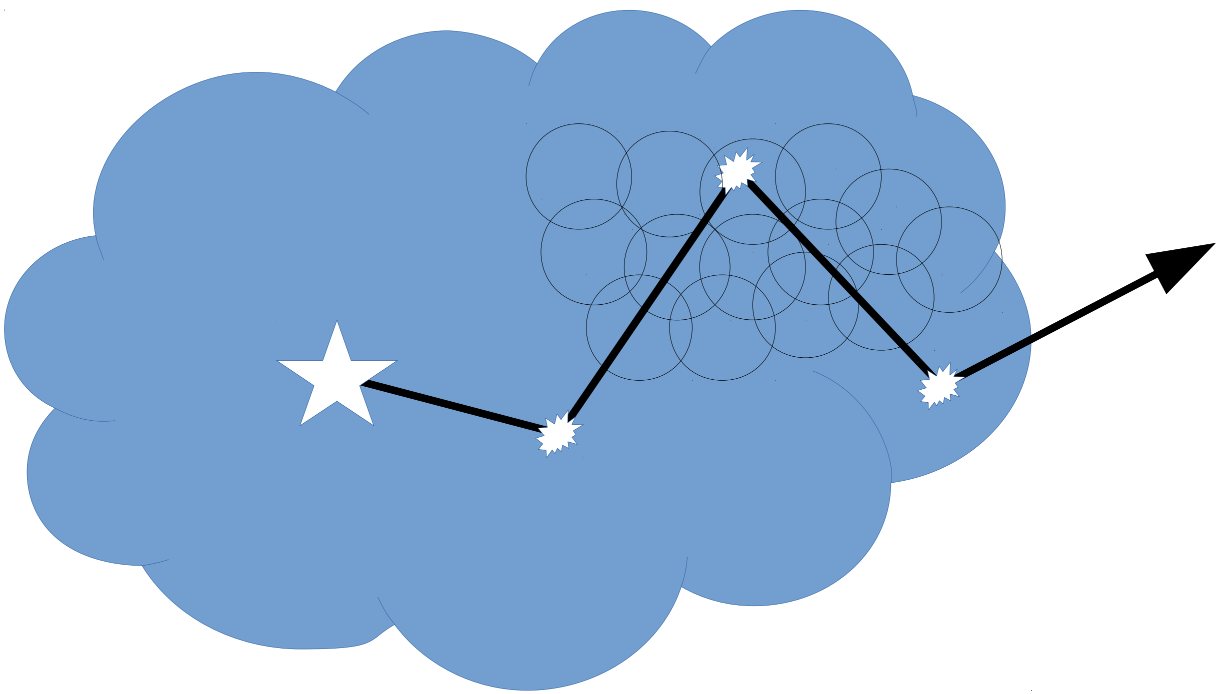
$$\tau = \int_0^s \rho(\boldsymbol{x})\,\kappa(\boldsymbol{x},\lambda)\,\mathrm{d}s$$

Relatively simple
to solve on grid

e.g. MOCASSIN, TORUS, HYPERION

MCRT

- Use random luminosity packets to model RT.



Random direction

$$\tau = -\ln(U)$$

$$\tau = \int_0^s \rho(\boldsymbol{x})\,\kappa(\boldsymbol{x},\lambda)\,\mathrm{d}s$$

Relatively simple
to solve on grid

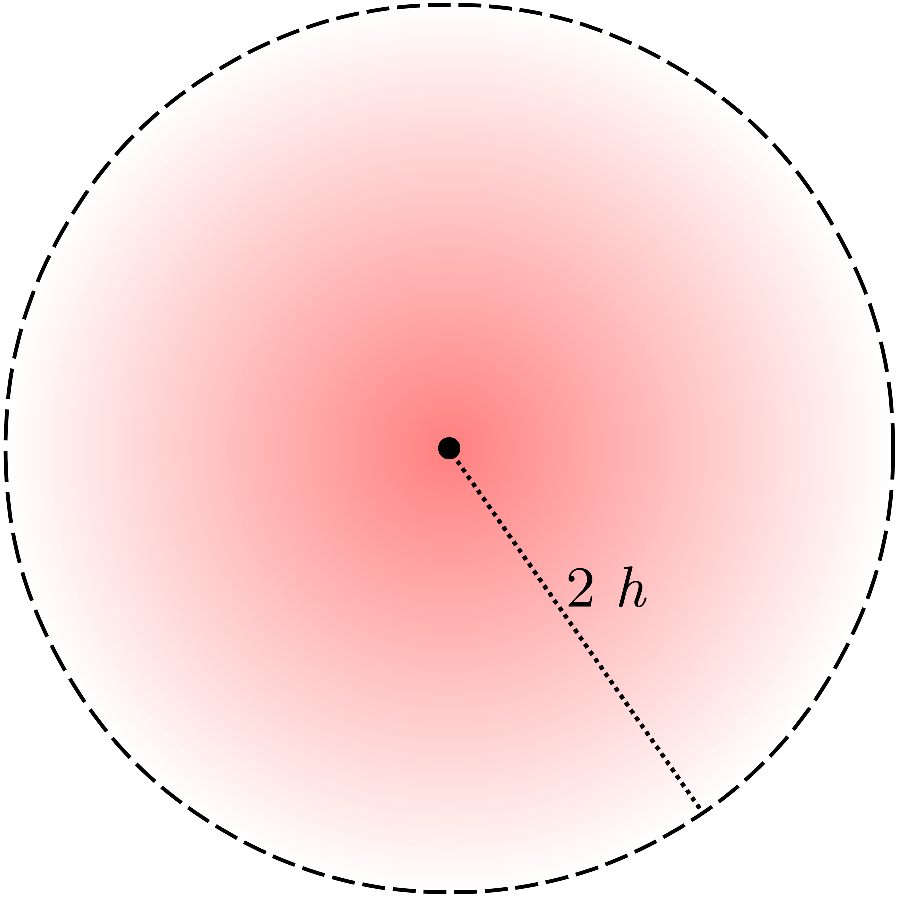
Less obvious for
smoothed particles

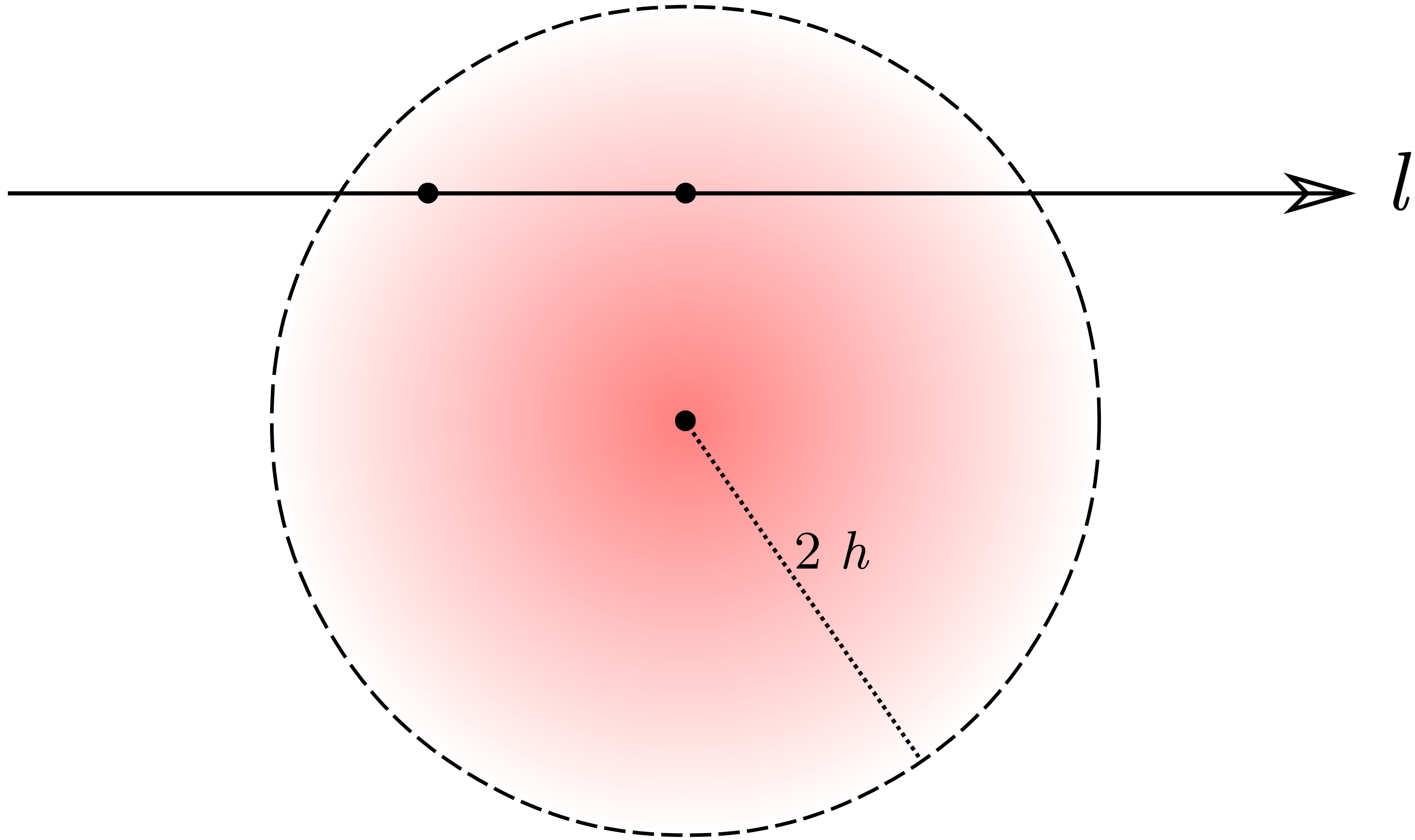
e.g. MOCASSIN, TORUS, HYPERION

Forgan and Rice, 2010

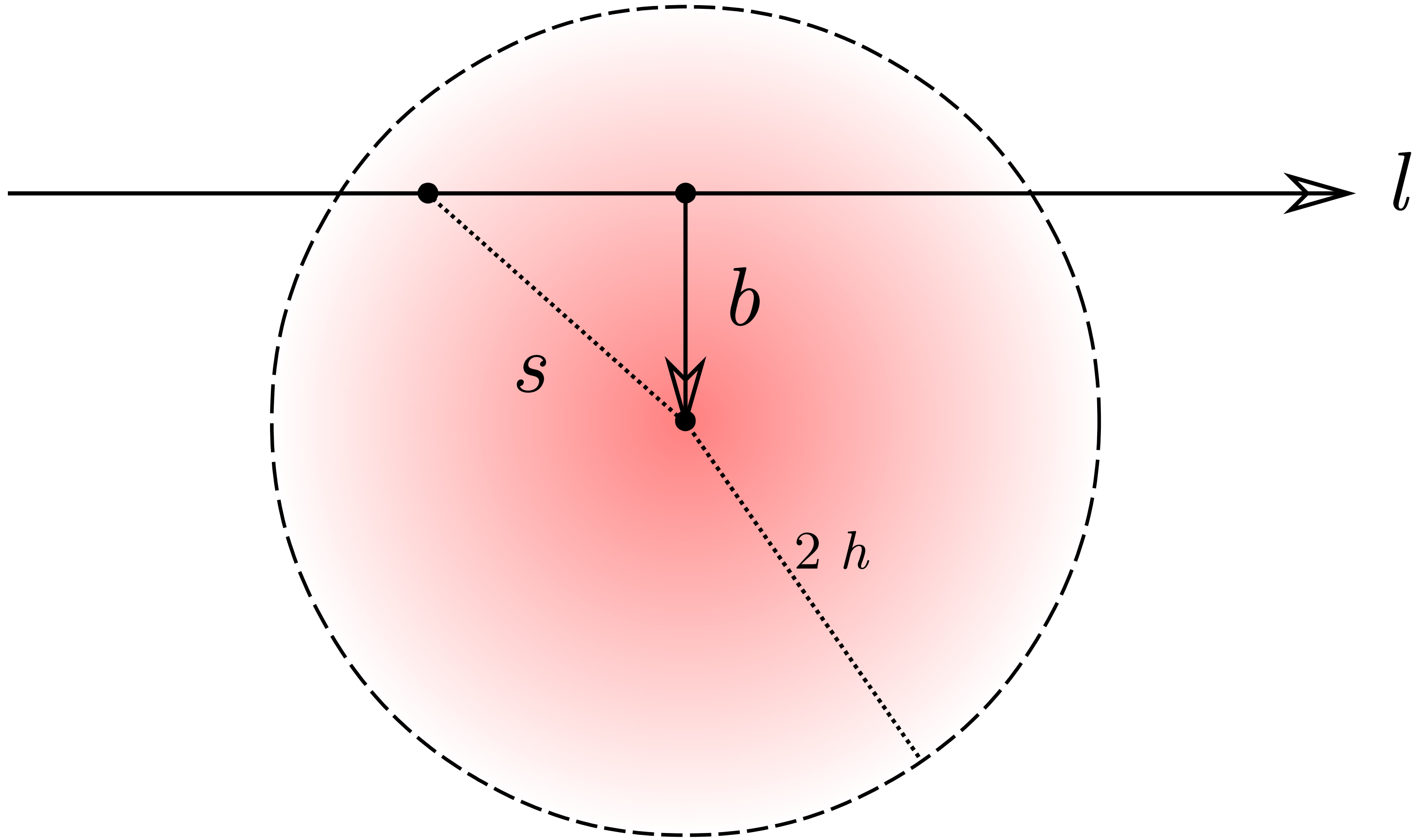
SPAMCART

- SPH exact Monte Carlo Radiation Transport
- Designed for post processing. Hydro timesteps may be possible in future
- Written in Fortran 2003/08
- Currently used to solve dust continuum RT. (Absorption and scattering)
- Easy to apply to other problems.

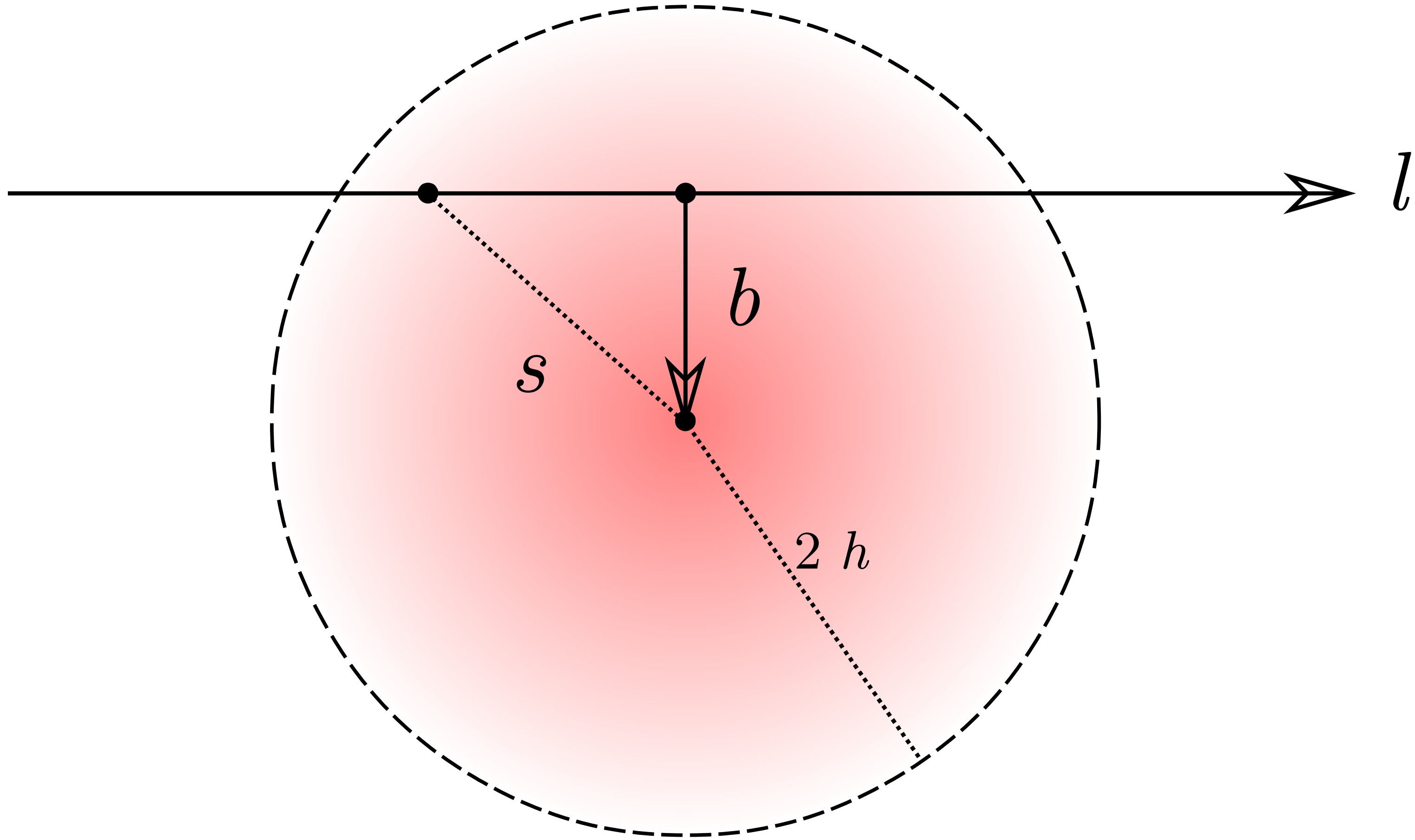

$2\ h$



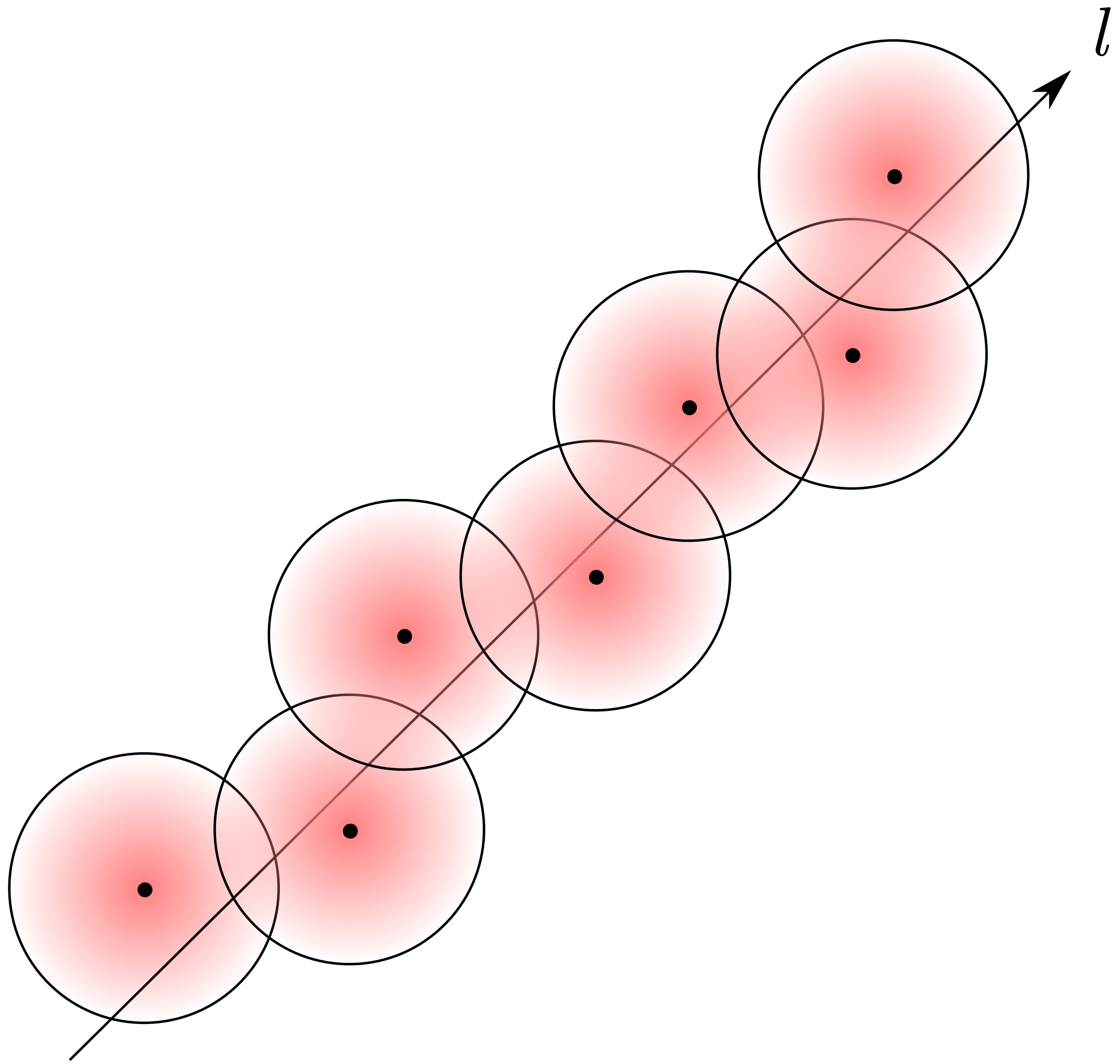
l
2 h



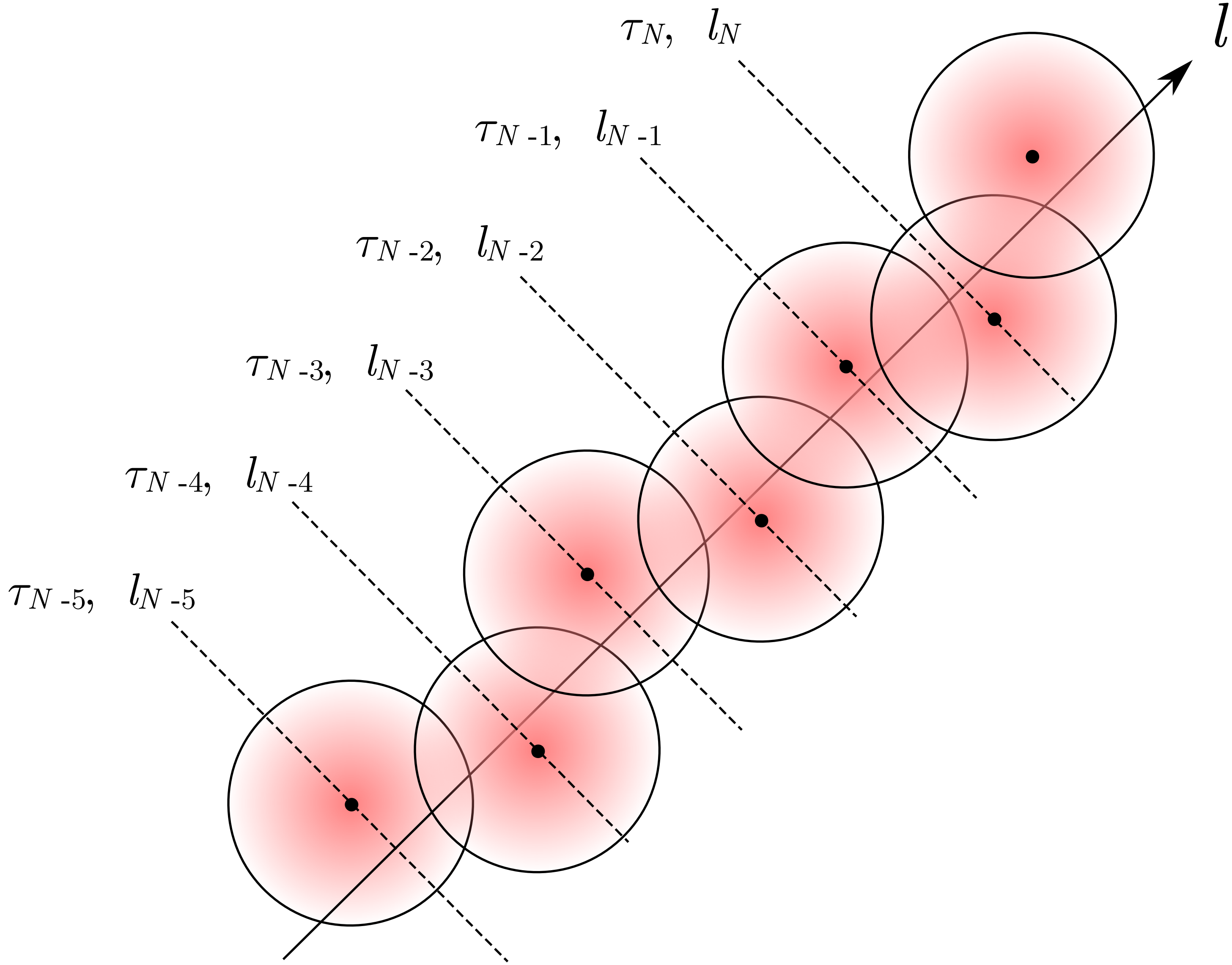
l
b
s
$2\ h$

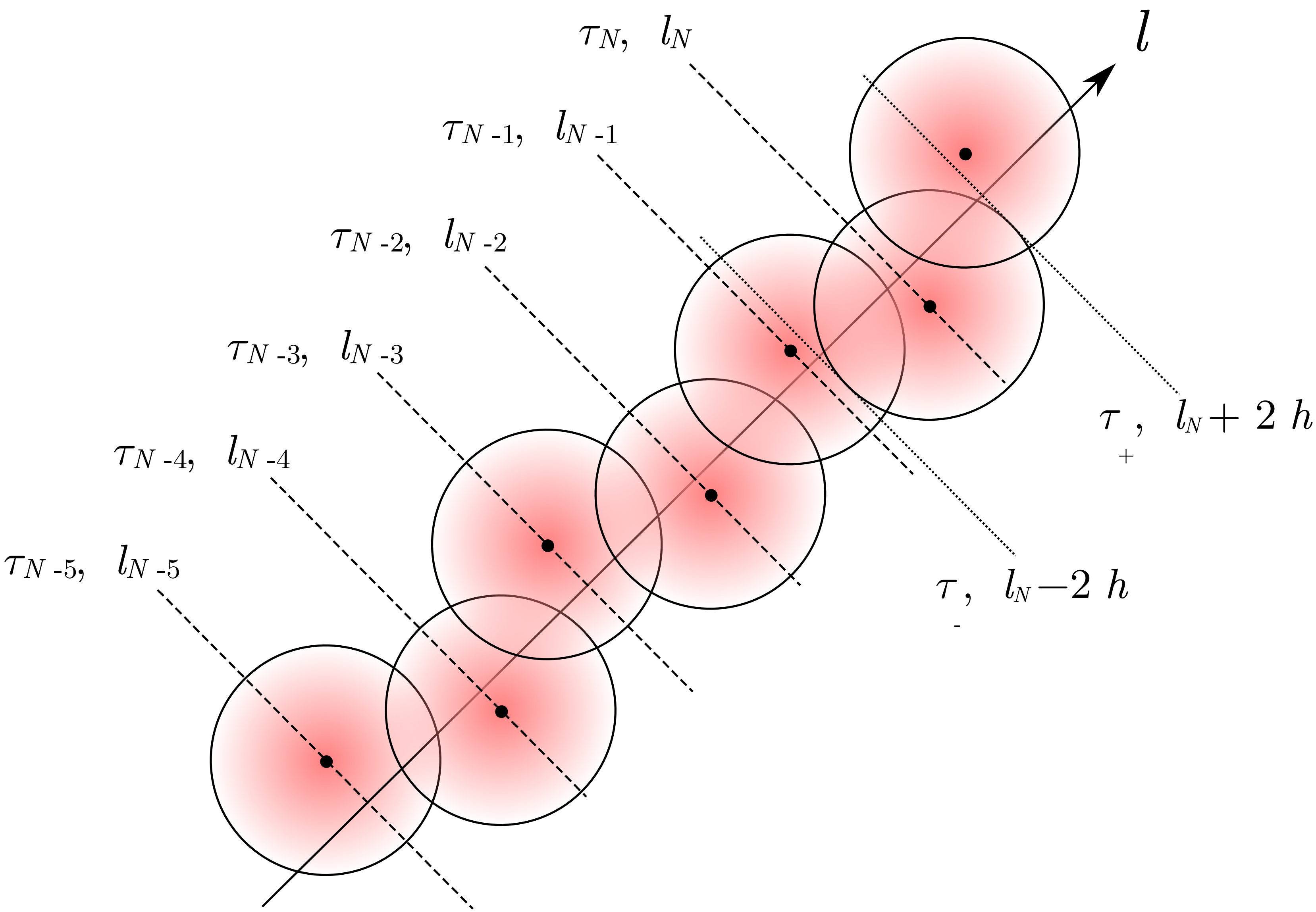


$$\varsigma(b,s) = \int_b^s \frac{W(s)\,s}{\sqrt{s^2 - b^2}}\,\mathrm{d}s.$$



l


l
τ_N, l_N
$\tau_{N\text{-}1}$, $l_{N\text{-}1}$
$\tau_{N\text{-}2}$, $l_{N\text{-}2}$
$\tau_{N\text{-}3}$, $l_{N\text{-}3}$
$\tau_{N\text{-}4}$, $l_{N\text{-}4}$
$\tau_{N\text{-}5}$, $l_{N\text{-}5}$



l
τ_N, l_N
τ_{N-1}, l_{N-1}
τ_{N-2}, l_{N-2}
τ_{N-3}, l_{N-3}
τ_{N-4}, l_{N-4}
τ_{N-5}, l_{N-5}
τ_+, $l_N + 2h$
τ_-, $l_N - 2h$

Dust Continuum Calculation

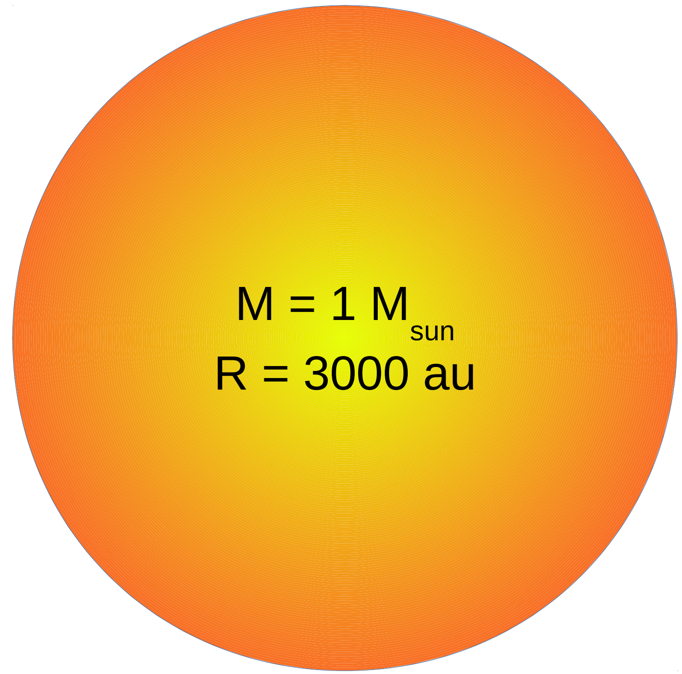
Lucy, 1999

$$J_{\rm cell} = \frac{1}{4\pi} \frac{\varepsilon_\gamma}{\Delta t} \frac{1}{V_{\rm cell}} \sum \ell_\gamma$$

$$\dot{A}_{\rm cell} = \frac{\varepsilon_\gamma}{\Delta t} \frac{1}{V_{\rm cell}} \sum \kappa_\nu \ell_\gamma$$

$$J_i = \frac{1}{4\pi} \frac{\varepsilon_\gamma}{\Delta t} \frac{1}{m_i} \sum s_\gamma$$

$$\dot{A}_i = \frac{\varepsilon_\gamma}{\Delta t} \frac{1}{m_i} \sum \kappa_\nu s_\gamma$$

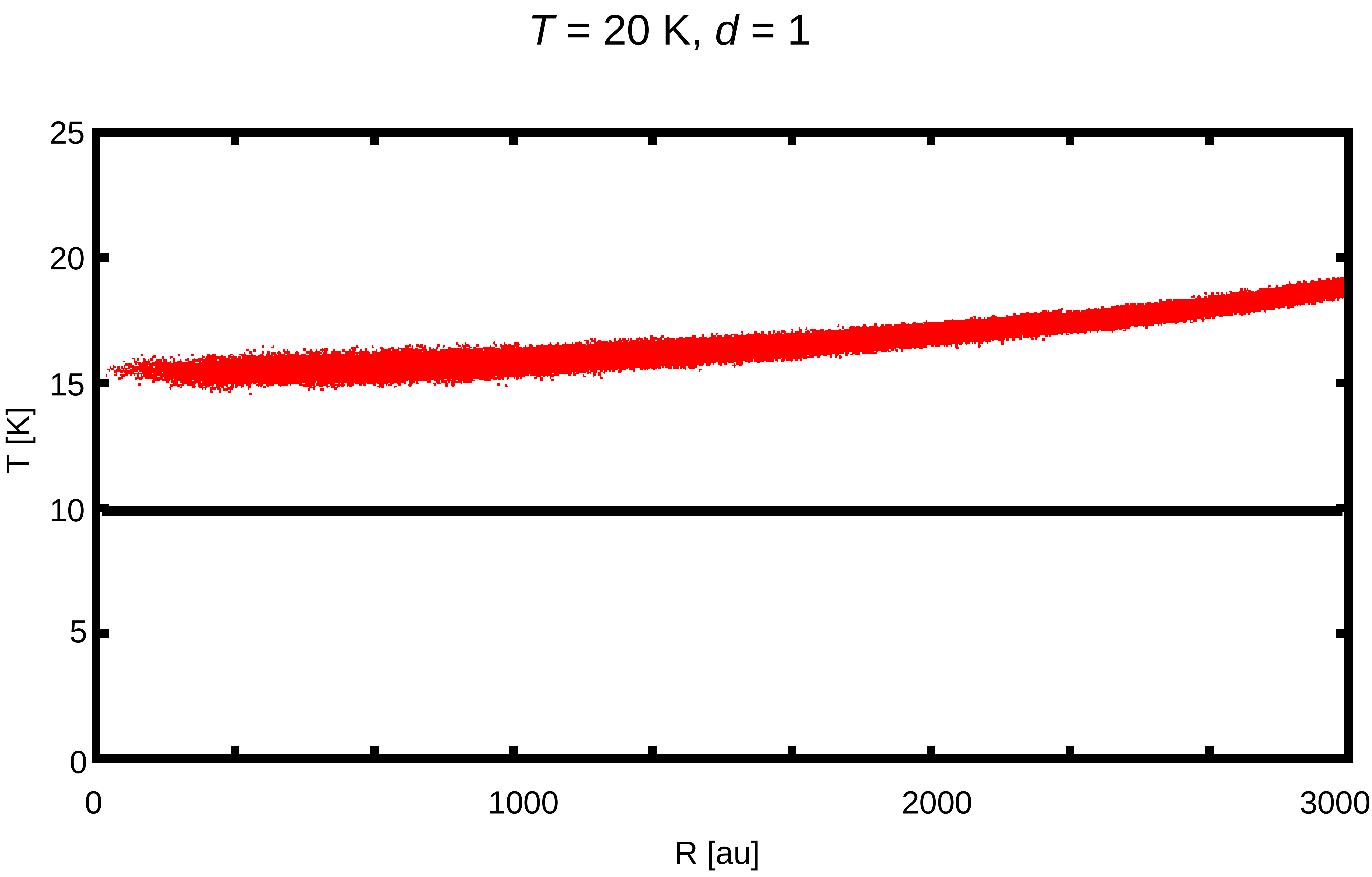


$N_{\rm sph} = 2 \times 10^5$

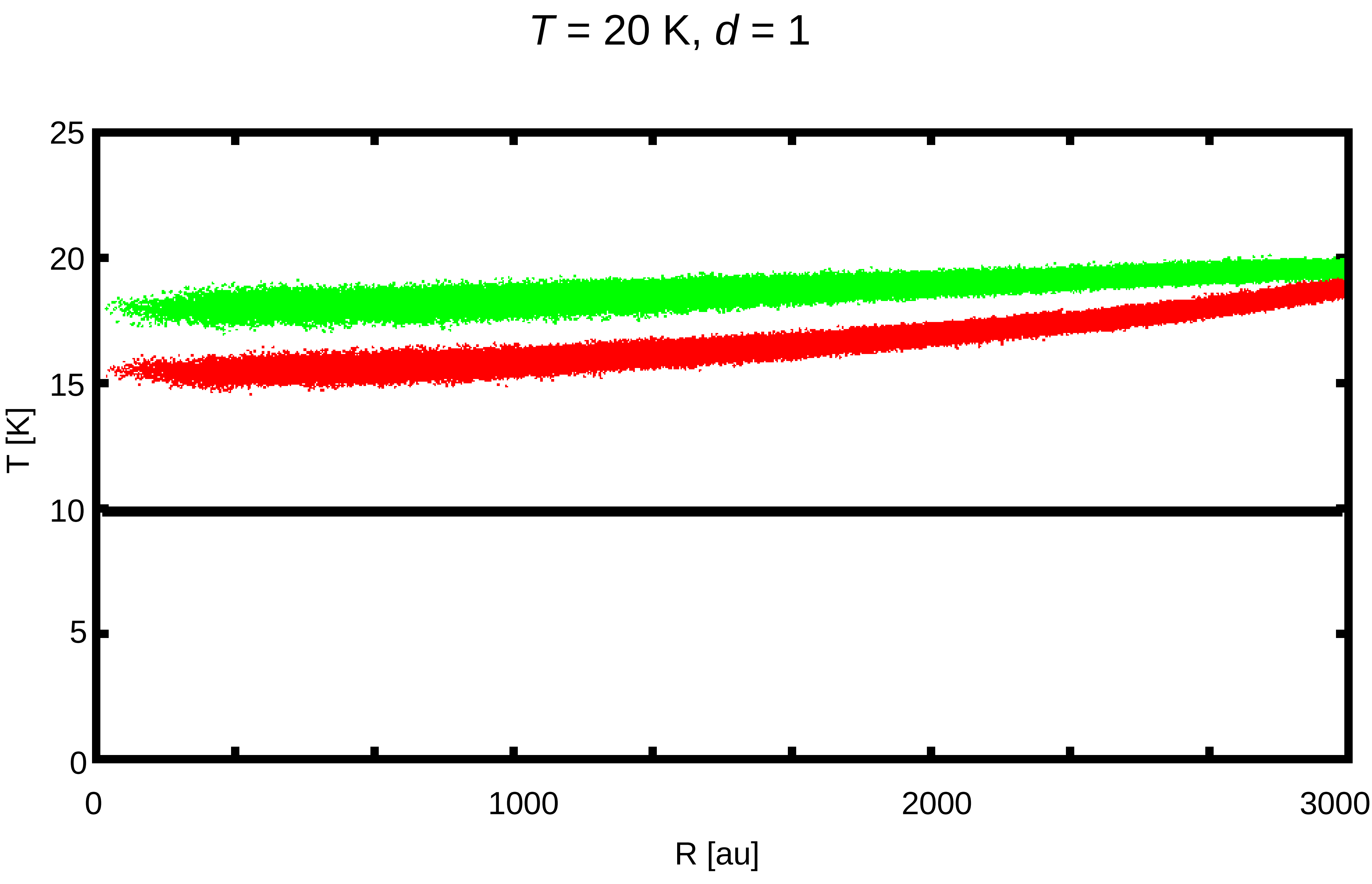
$N_\gamma = 10^6$

20 K blackbody radiation field

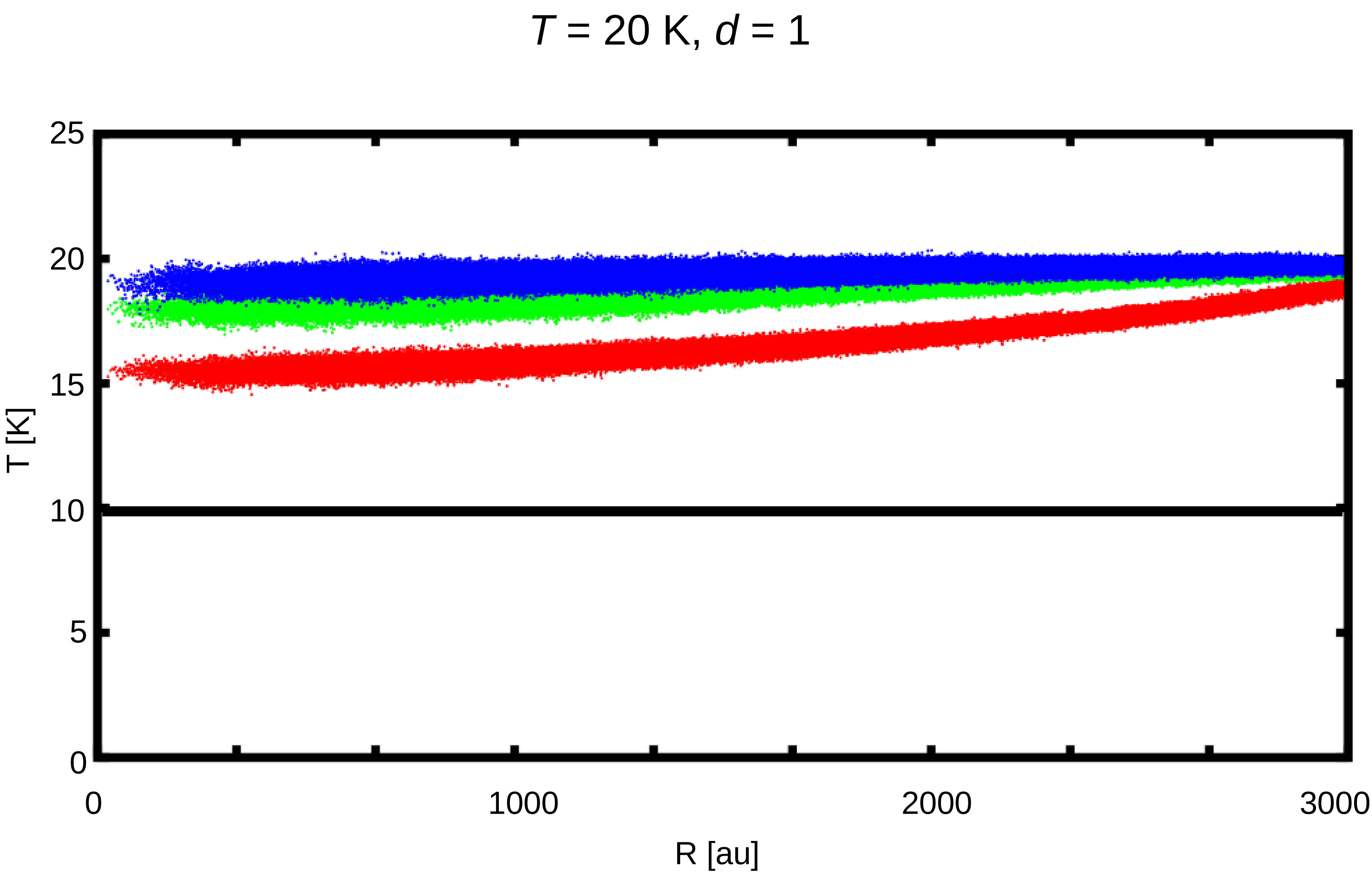
40 K diluted blackbody radiation field



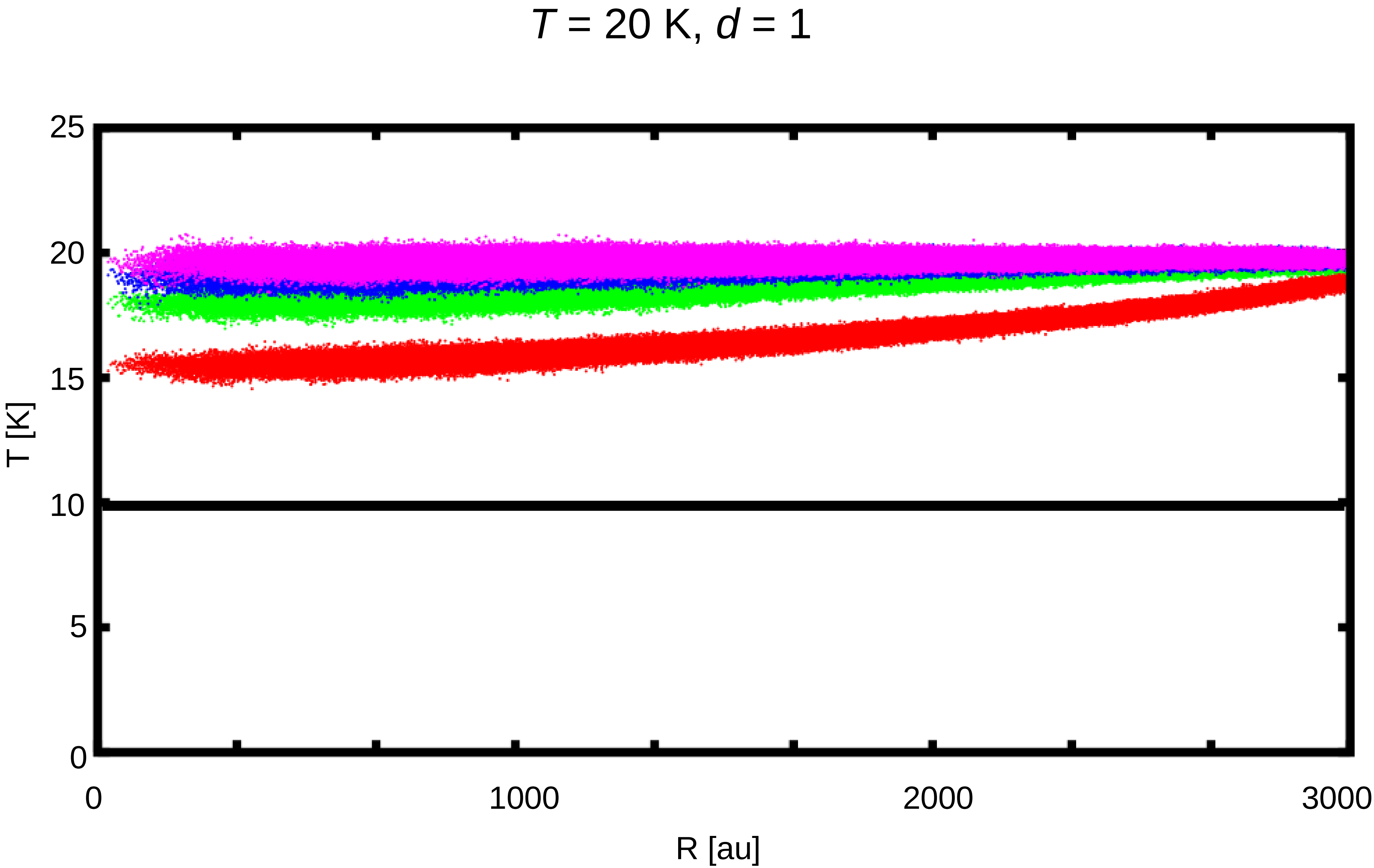
T = 20 K, d = 1
25
20
15
10
5
0
T [K]
0
1000
2000
3000
R [au]

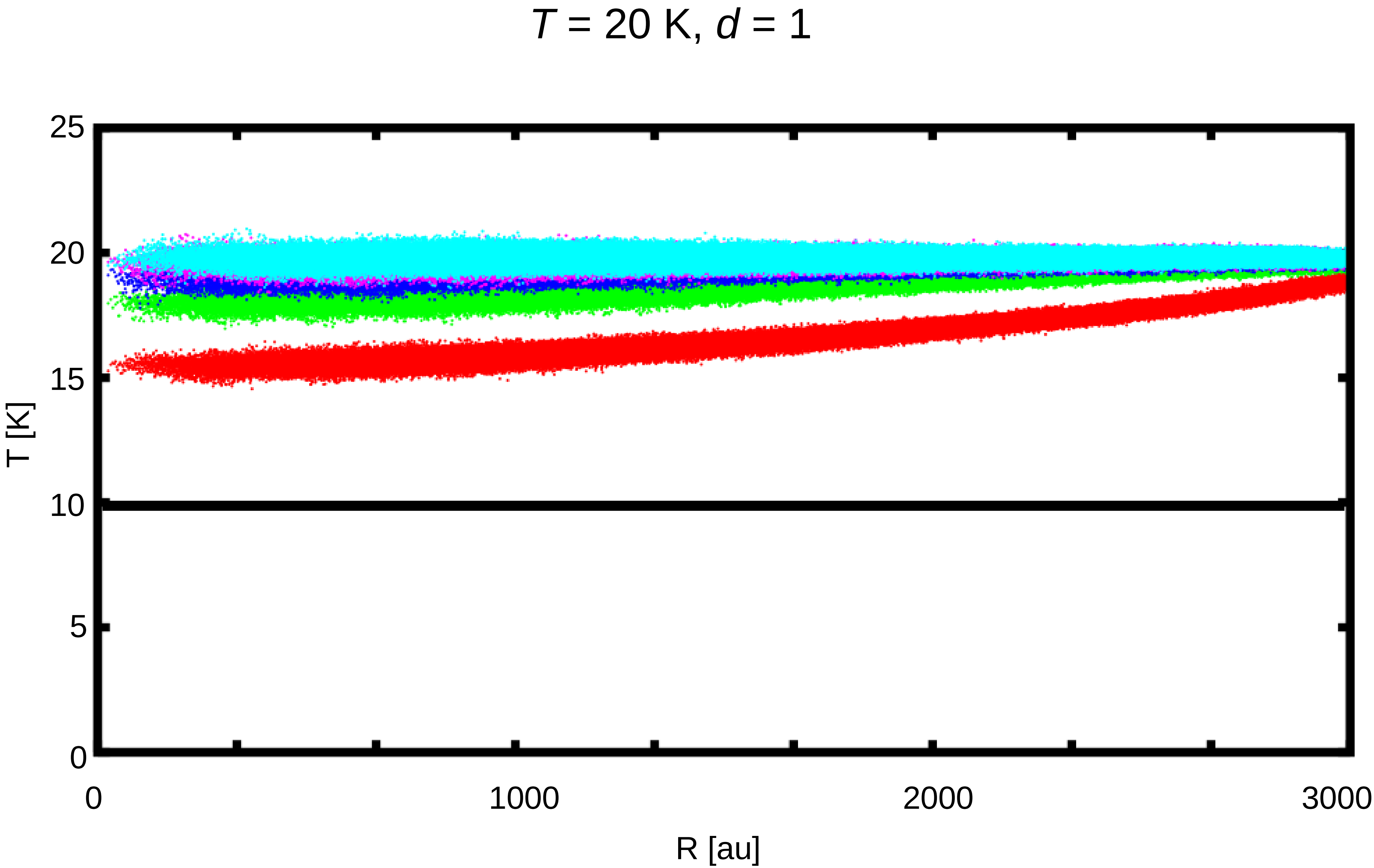


T = 20 K, d = 1
25
20
15
10
5
0
T [K]
0
1000
2000
3000
R [au]

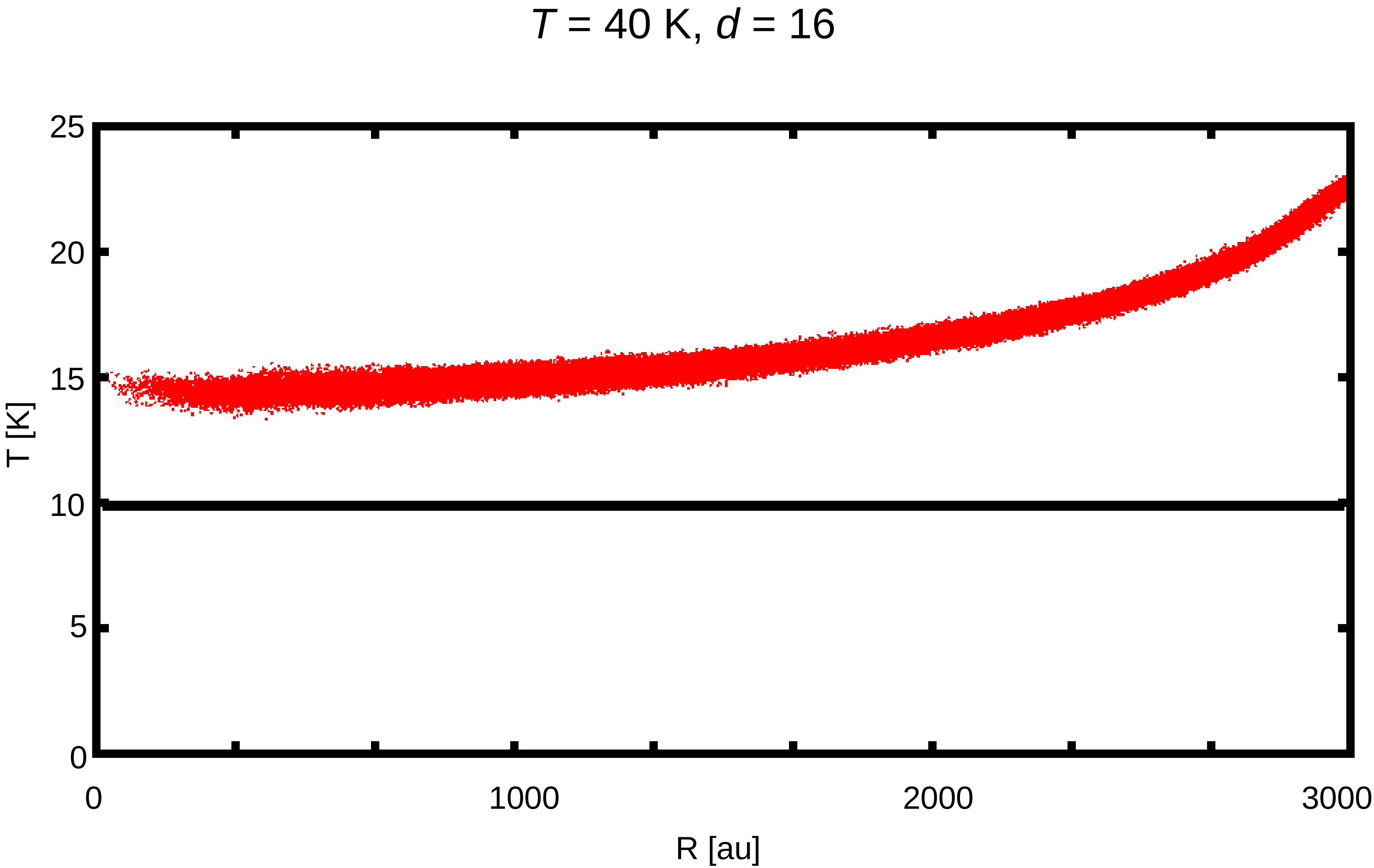


T = 20 K, d = 1
25
20
15
10
5
0
T [K]
0
1000
2000
3000
R [au]

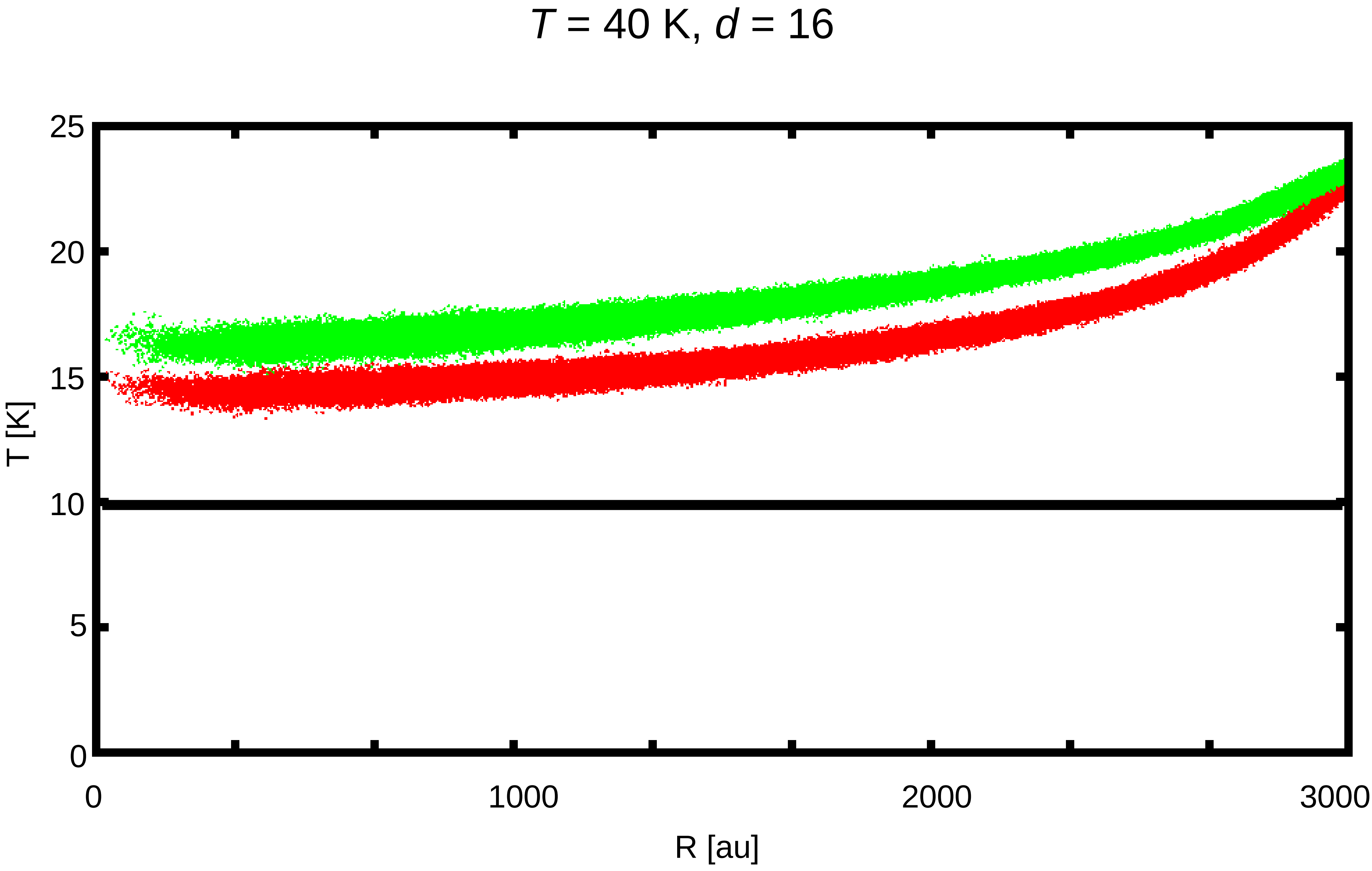

T = 20 K, d = 1
25
20
15
10
5
0
T [K]
0
1000
2000
3000
R [au]



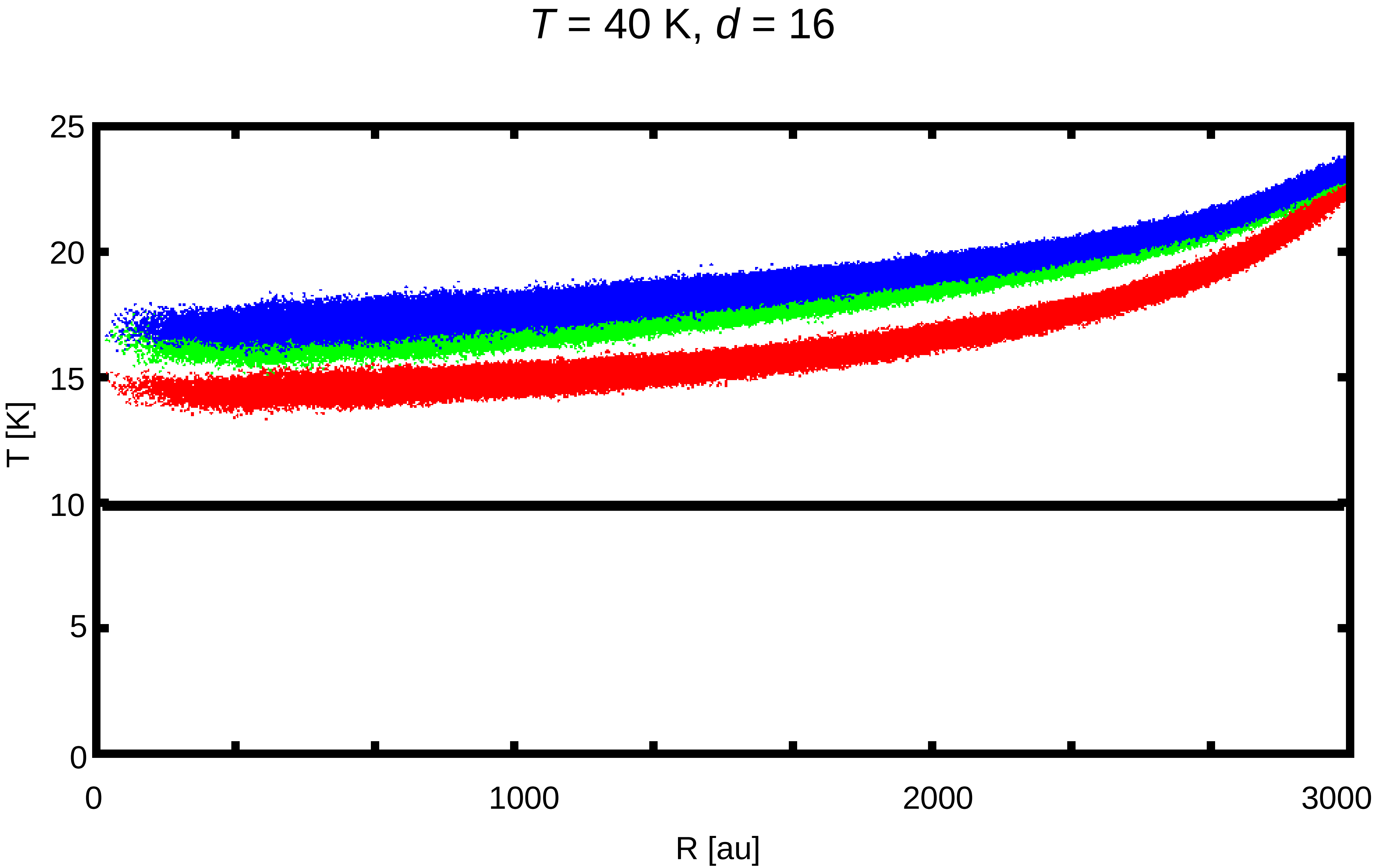
T = 20 K, d = 1
25
20
15
10
5
0
T [K]
0
1000
2000
3000
R [au]



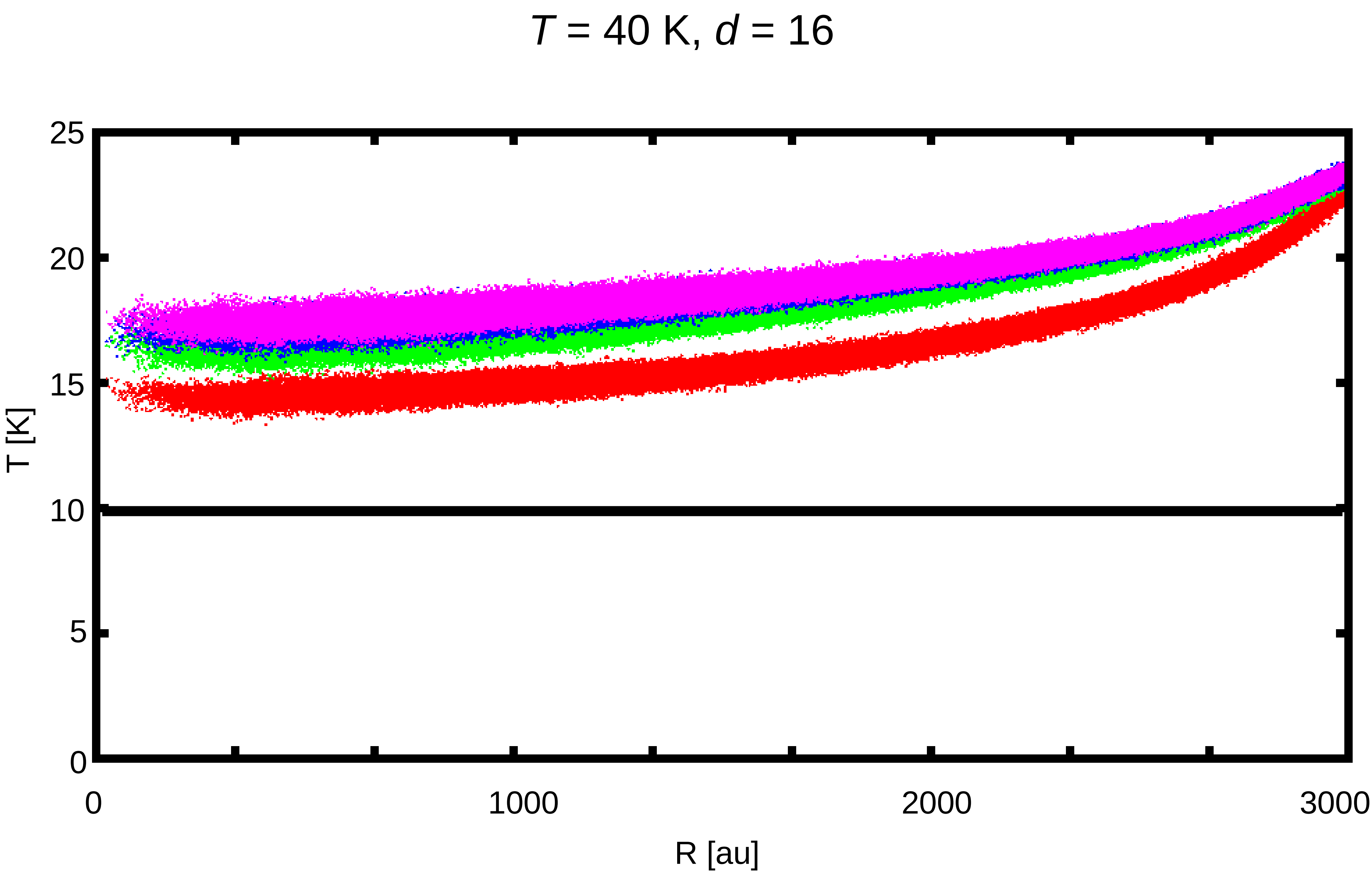
T = 40 K, d = 16
25
20
15
10
5
0
T [K]
0
1000
2000
3000
R [au]



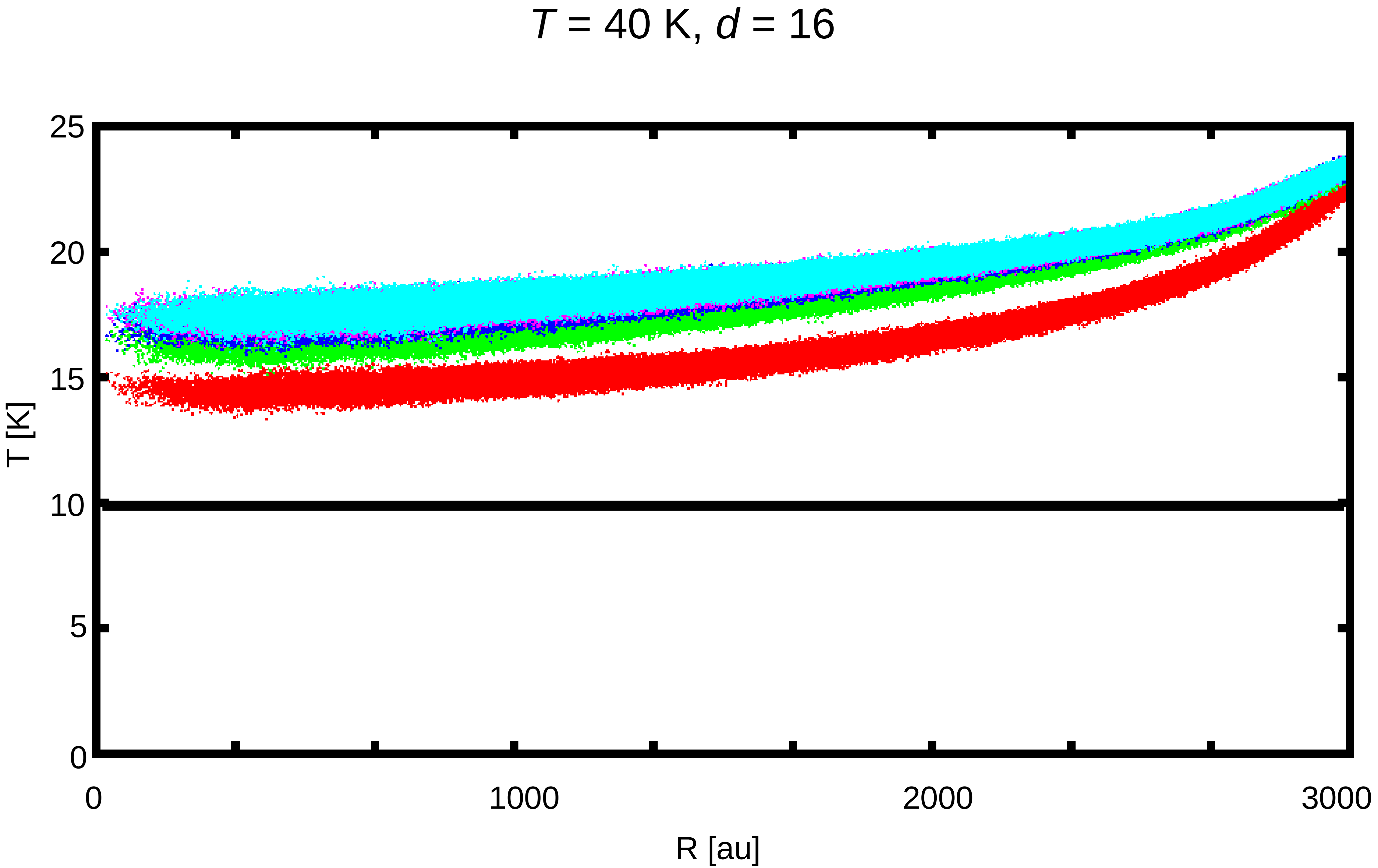
T = 40 K, d = 16
25
20
15
10
5
0
T [K]
0
1000
2000
3000
R [au]



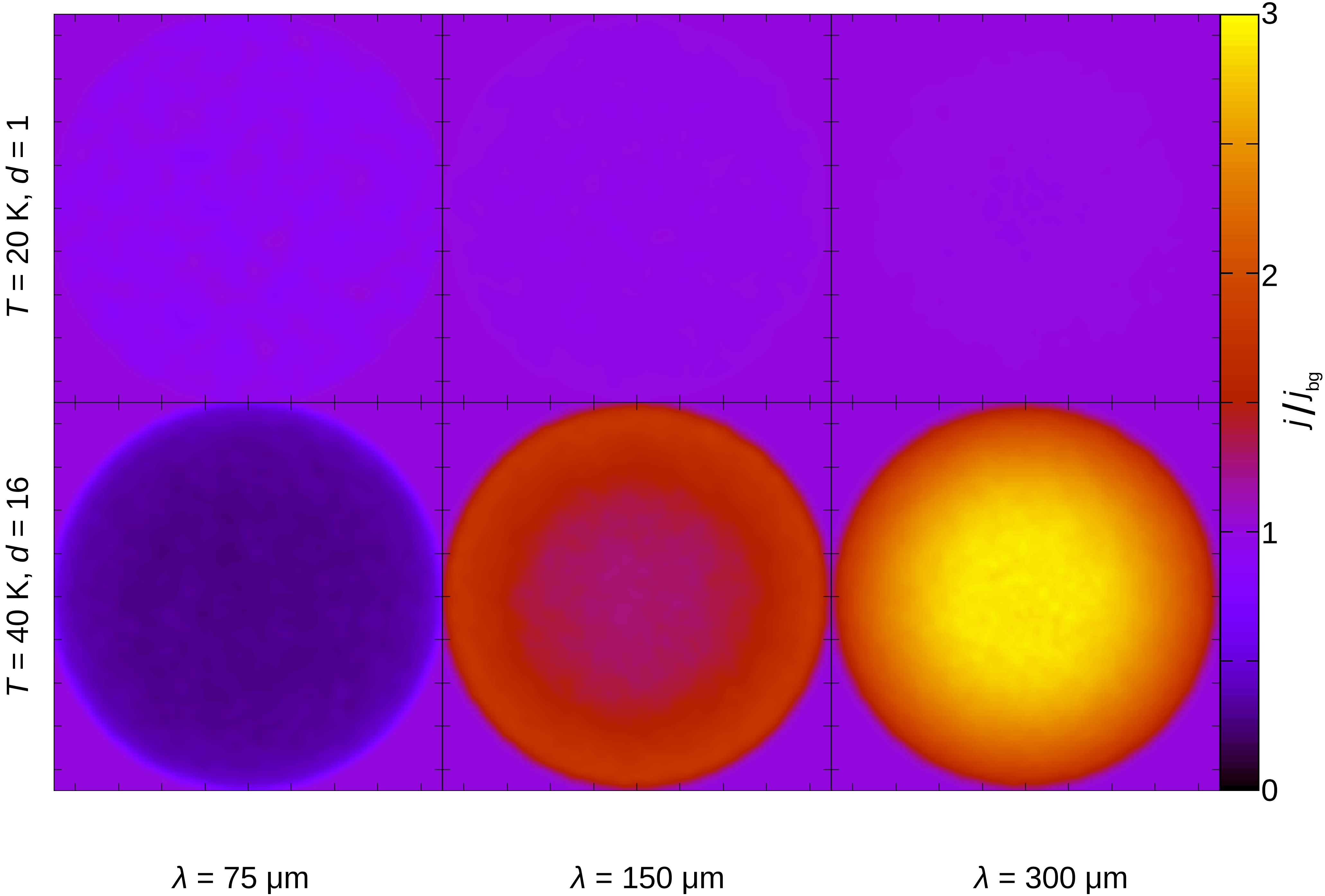
T = 40 K, d = 16
25
20
15
10
5
0
T [K]
0
1000
2000
3000
R [au]



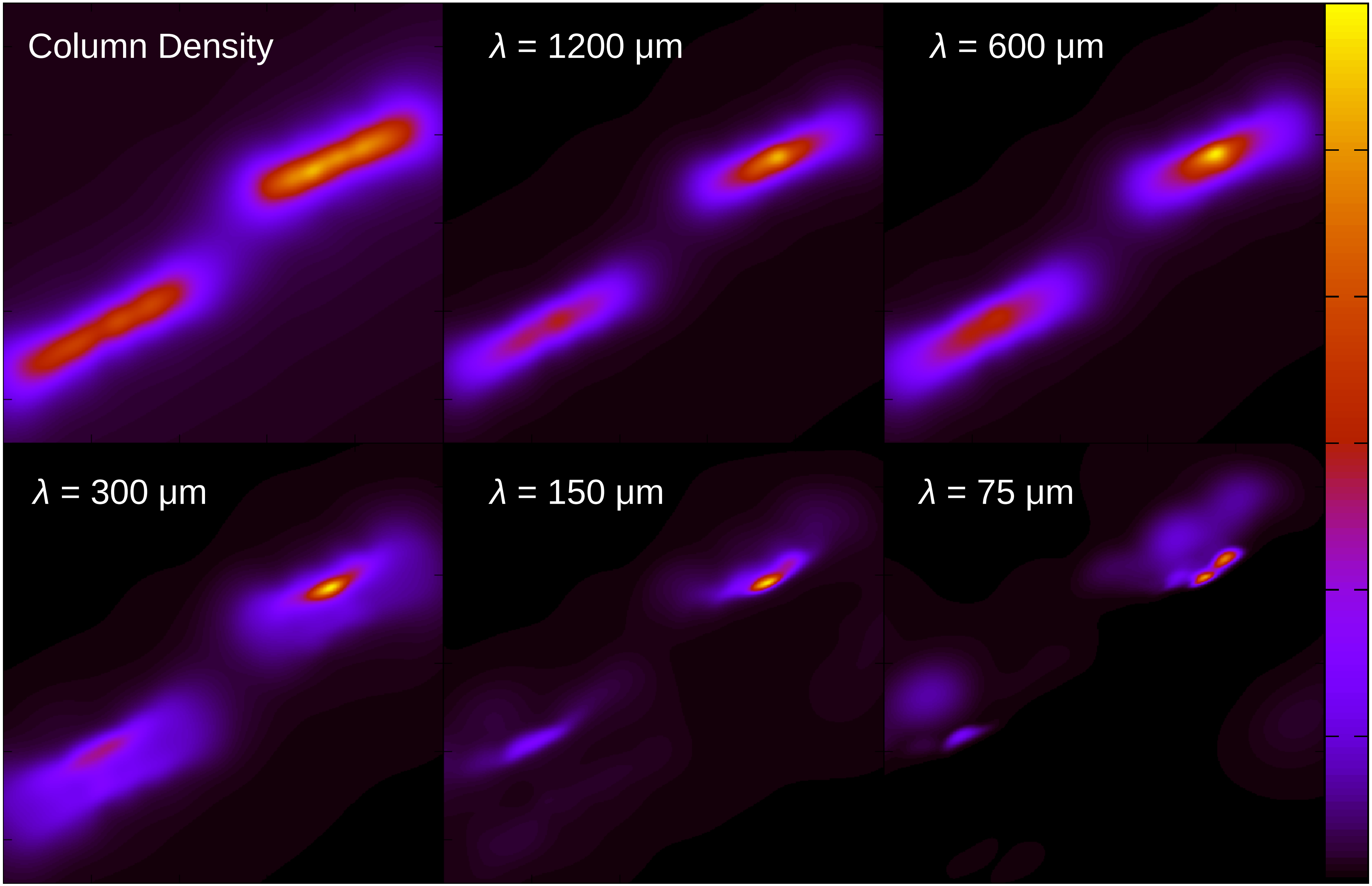
T = 40 K, d = 16
T [K]
R [au]
25
20
15
10
5
0
0
1000
2000
3000



T = 40 K, *d* = 16
25
20
15
10
5
0
T [K]
0
1000
2000
3000
R [au]



T = 20 K, d = 1
T = 40 K, d = 16
λ = 75 μm
λ = 150 μm
λ = 300 μm
j / j_bg
0
1
2
3



Simulation data from:
Lomax et al., 2014, MNRAS, 439, 3039
Lomax et al., 2015, MNRAS, 447, 1550

Conclusions

- Smoothed particles can be use to perform MCRT calculations, equivalent to grids.
- Able to post process SPH simulations at identical resolution.
- Can be applied to other physics (e.g. line emission, ionisation)
- Algorithm is optimisable (e.g. vectorisation, MRW)