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Radiative transfer: example of a radiative transfer model

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(Examples of) State-of-the-art radiative transfer models

International Research Track

2021

RADMC-3D

Outline

- scope
- method & algorithms
- applications
- conclusions

1. Scope - aims
2. Method & algorithms
3. Applications
4. Conclusions

Dynamical and chemical models

Outline

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- conclusions

| | Nautilus | Meudon PDR | CLOUDY | Paris-Durham shock | CHEMSES | RAMSES & KROME |
|-----------|----------|------------|--------|--------------------|---------|----------------|
| dimension | 0 | 1 | 1 | 1 | 3 | 3 |
| dynamical | | static | steady | ✓ | ✓ | free |
| thermal | | static | steady | ✓ | ✓ | free |
| chemical | | static | steady | ✓ | ✓ | free |

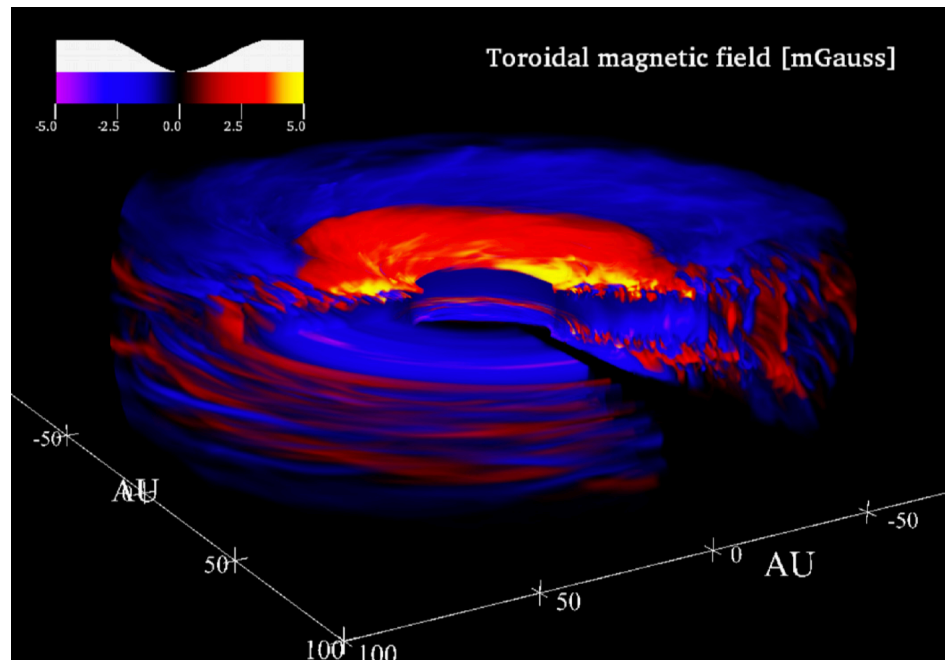
| | NAHOON | TDR | MAPPING | ENZO | ZEUS | NIRVANA |
|-----------|--------|--------|---------|------|--------|---------|
| dimension | 0 | 1 | 1 | 3 | 3 | 3 |
| dynamical | ✓ | steady | free | free | free | ✓ |
| thermal | steady | steady | free | ✓ | free | ✓ |
| chemical | steady | steady | free | free | static | free |

✓ diffusion

Simulations in astrophysics

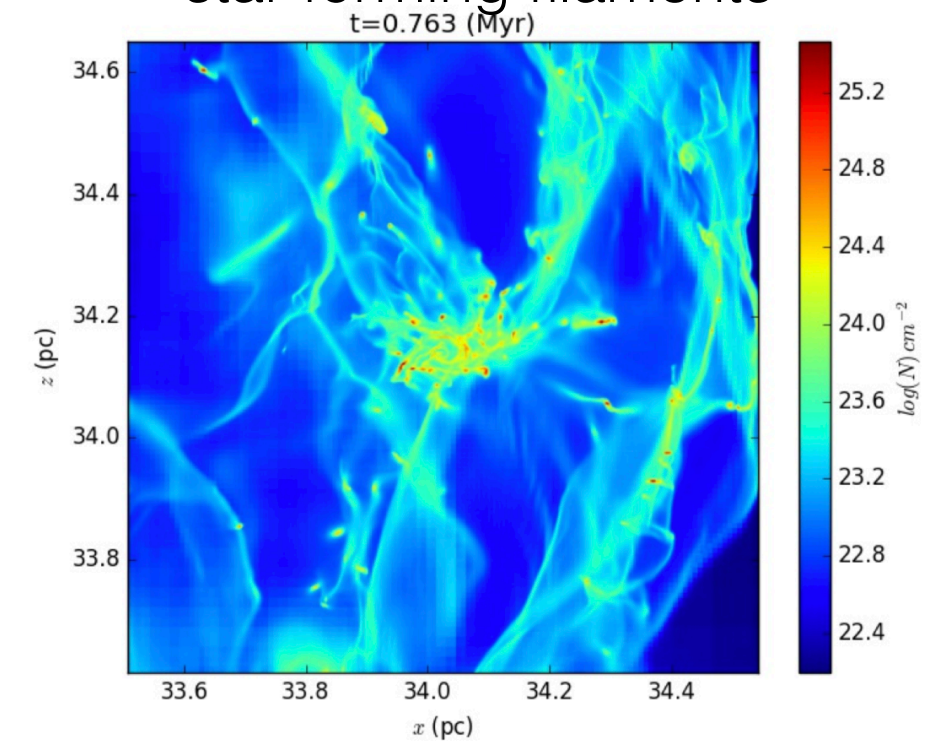
many 3D dynamical models of astrophysical environments

protoplanetary disk



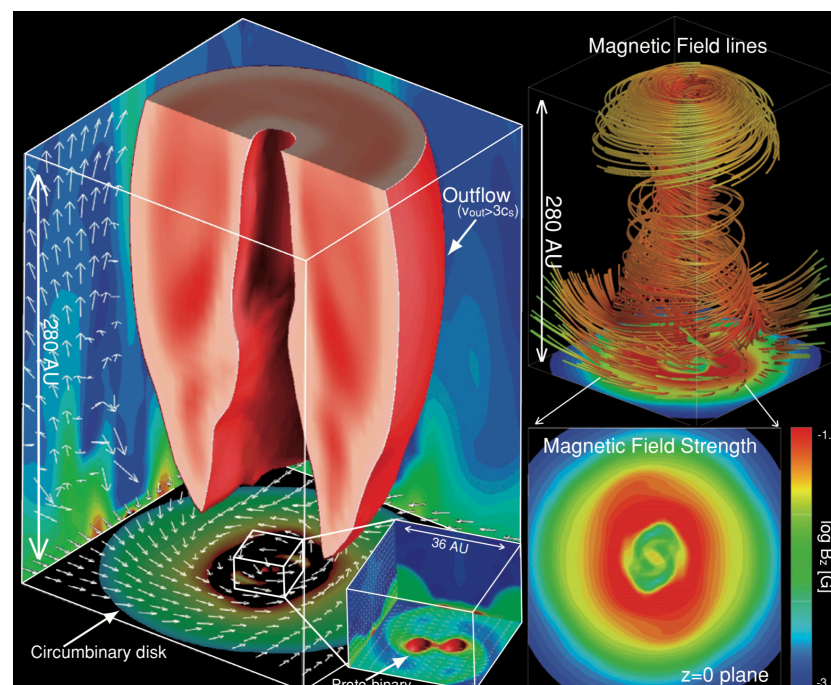
Flock et al. (2015)

star forming filaments



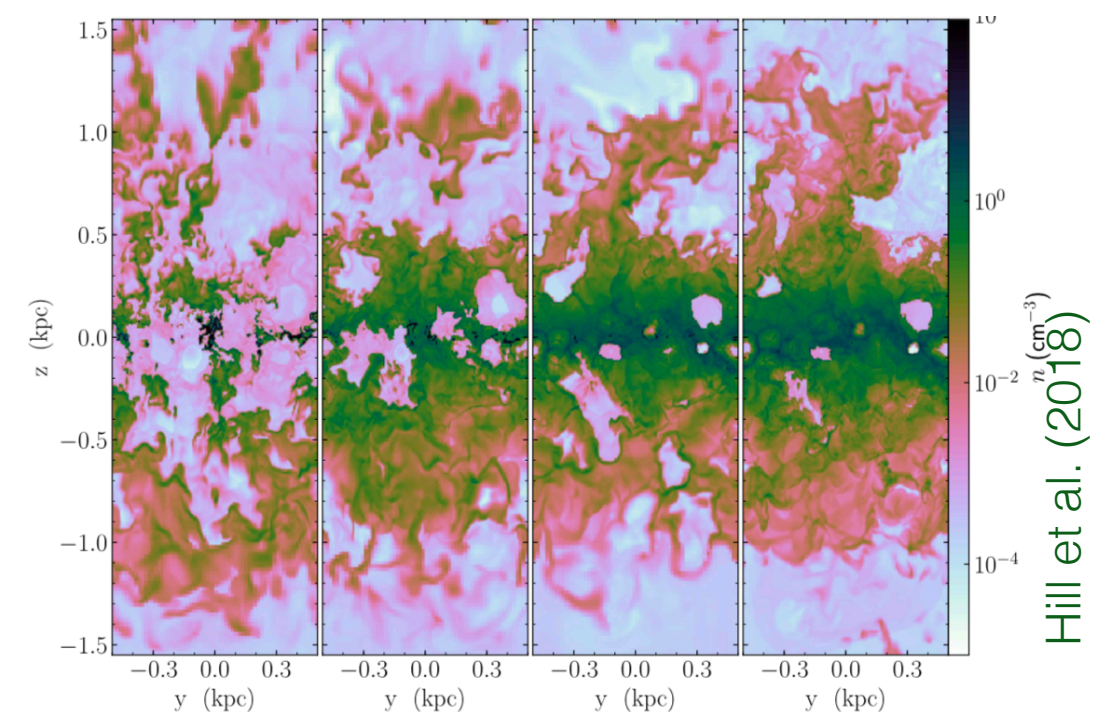
Ntormousi & Hennebelle (2018)

outflows



Machida et al. (2009)

multiphase galactic disk



Hill et al. (2018)

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Questions

- how to compute the line and continuum RT ?
- how to compute intensity maps ?
- full comparison of the 3D structure with observations ?

Problems of radiative transfer in dynamical models

- must be incredibly fast and parallelizable
- high accuracy not feasible

Solution offered by RADMC-3D

- RT done in postprocessing
- accurate treatment of complex RT physics (line, dust, scattering, ...)
- provide images and spectra and their combination
- applicable on many simulations and grid systems
- GUI for image production and volume rendering

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Fortran code

- developed over 20 years
- public access
- python interfaces

Programmers

Cornelis Dullemond

Attila Juhasz

Adriana Pohl

Michiel Min

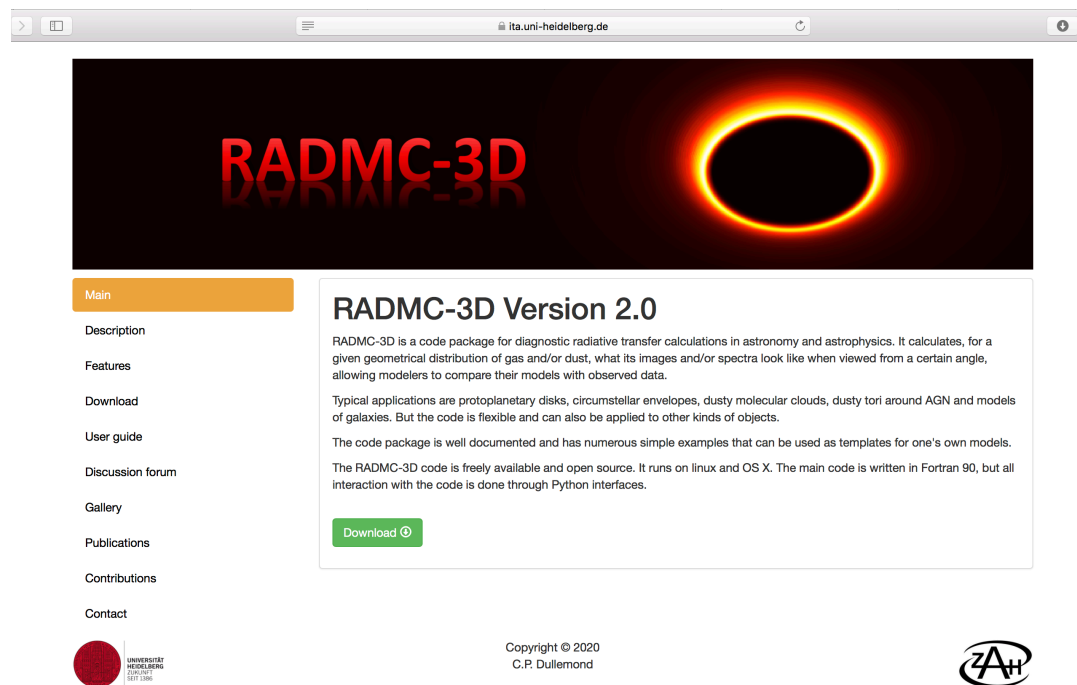
Farzin Sereshti

Rahul Shetty

Thomas Peters

Benoit Commercon

Mario Flock



<https://www.ita.uni-heidelberg.de/~dullemond/software/radmc-3d/index.php>

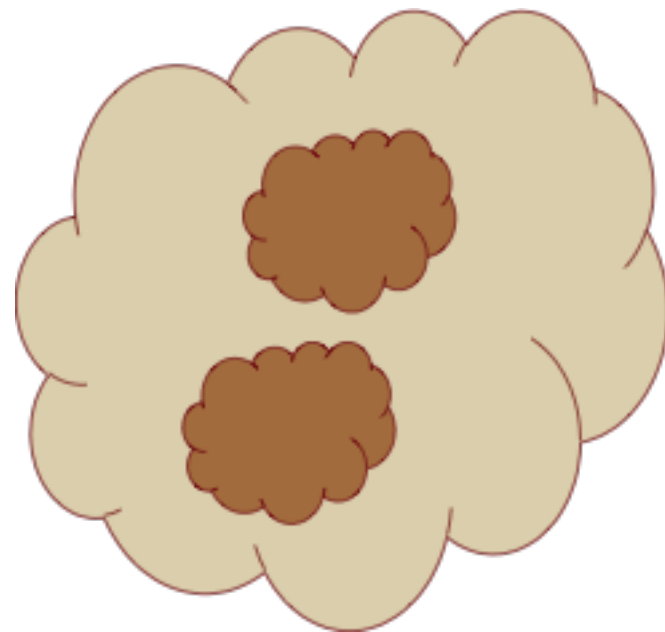
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Input data

- provide a density distribution (gas or dust)

Computation & output



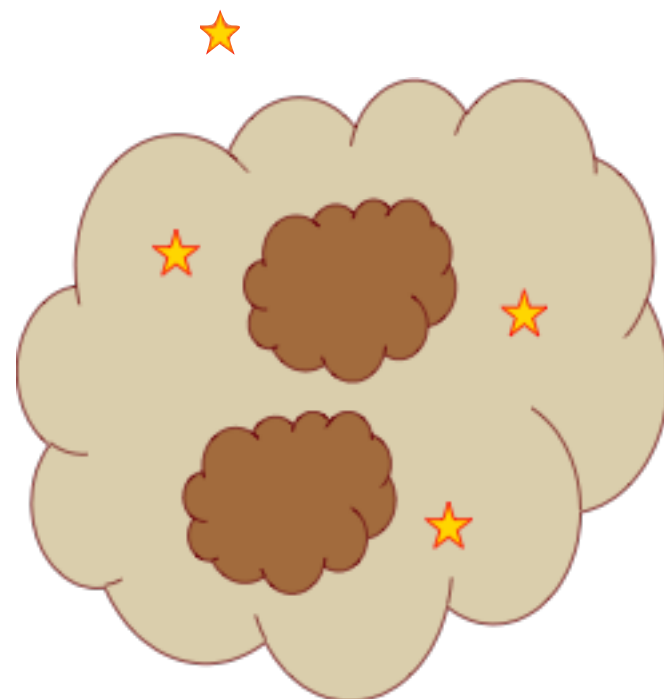
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Input data

- provide a density distribution (gas or dust)
- add stars & map over a grid

Computation & output



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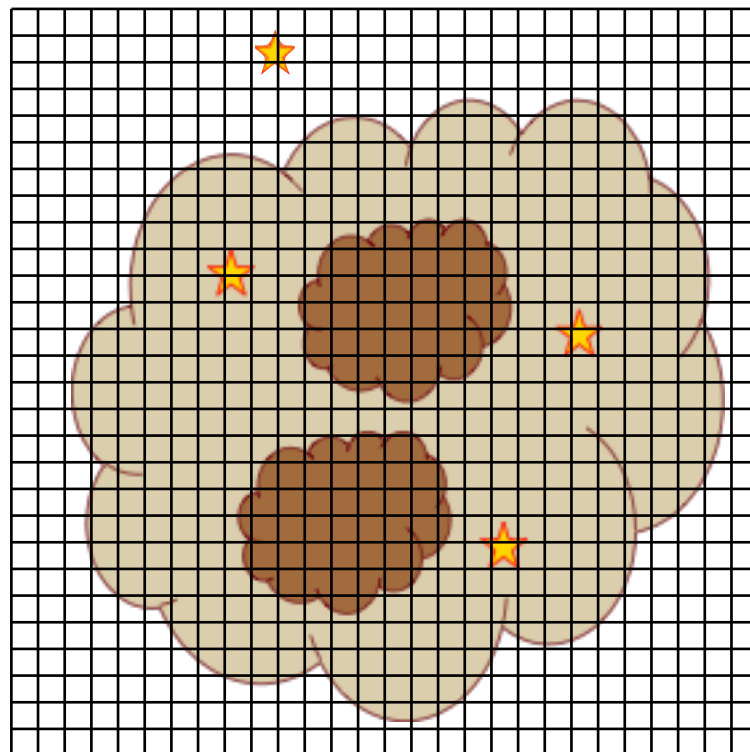
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Outline

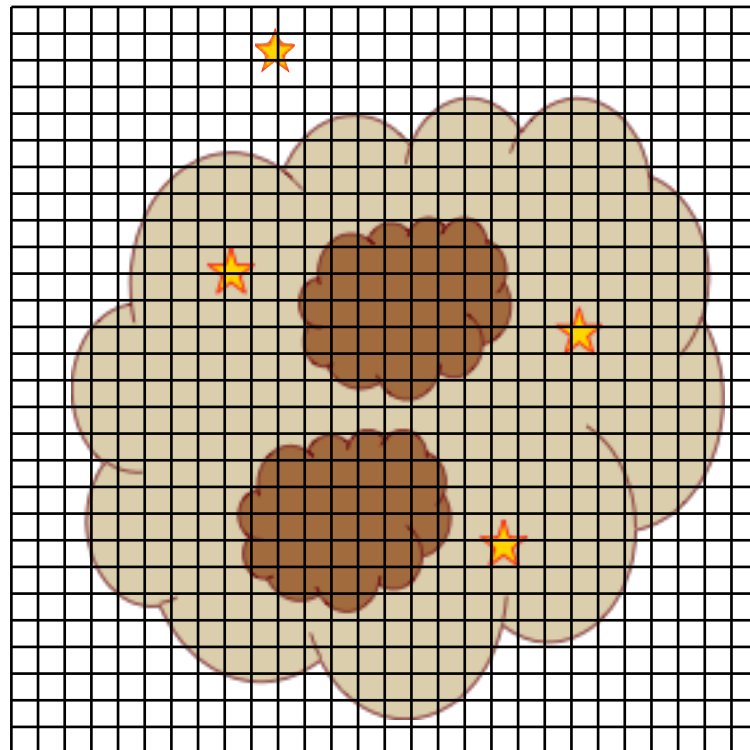
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Input data

- provide a density distribution (gas or dust)
- add stars & map over a grid
- provide physical data (atomic / molecular / dust)

Computation & output



Outline

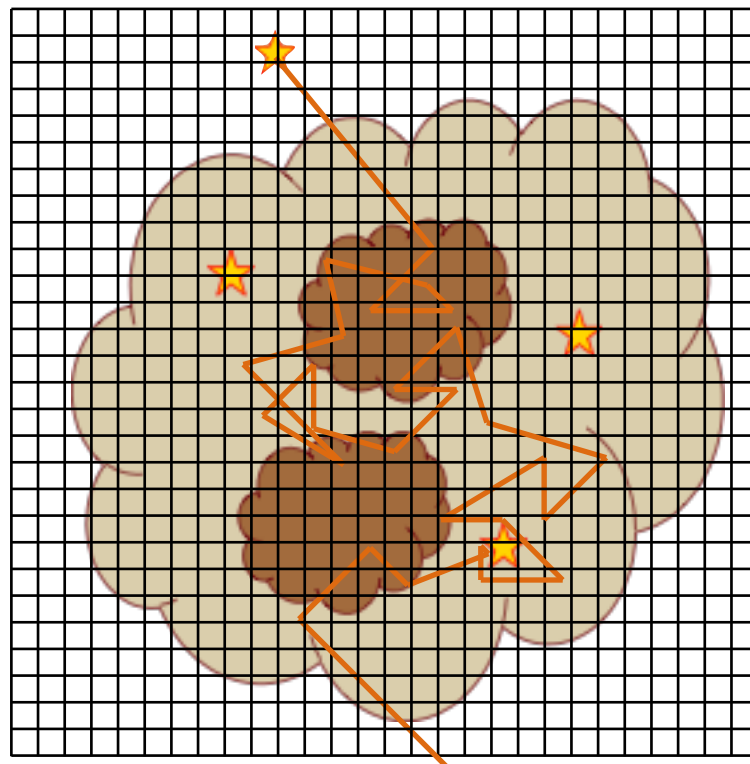
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Input data

- provide a density distribution (gas or dust)
- add stars & map over a grid
- provide physical data (atomic / molecular / dust)

Computation & output

- compute dust temperature & radiative transfer
- compute line rad transfer



Outline

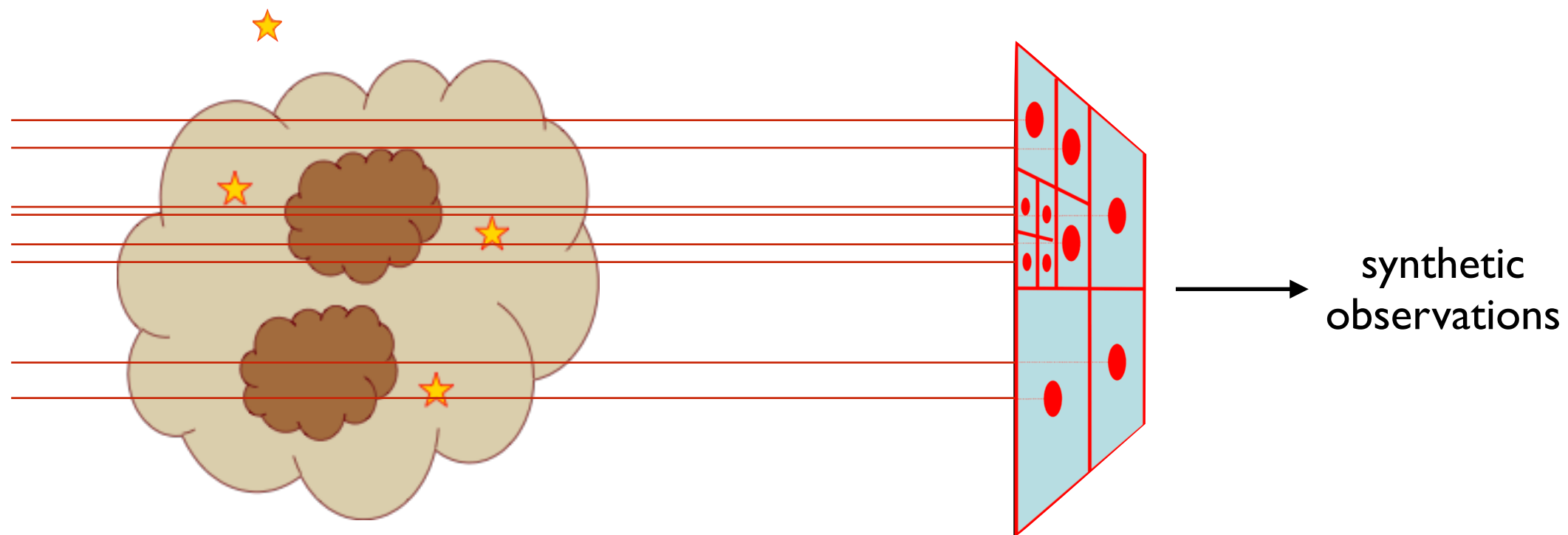
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Input data

- provide a density distribution (gas or dust)
- add stars & map over a grid
- provide physical data (atomic / molecular / dust)

Computation & output

- compute dust temperature & radiative transfer
- compute line rad transfer
- images and spectra from ray tracing towards observer



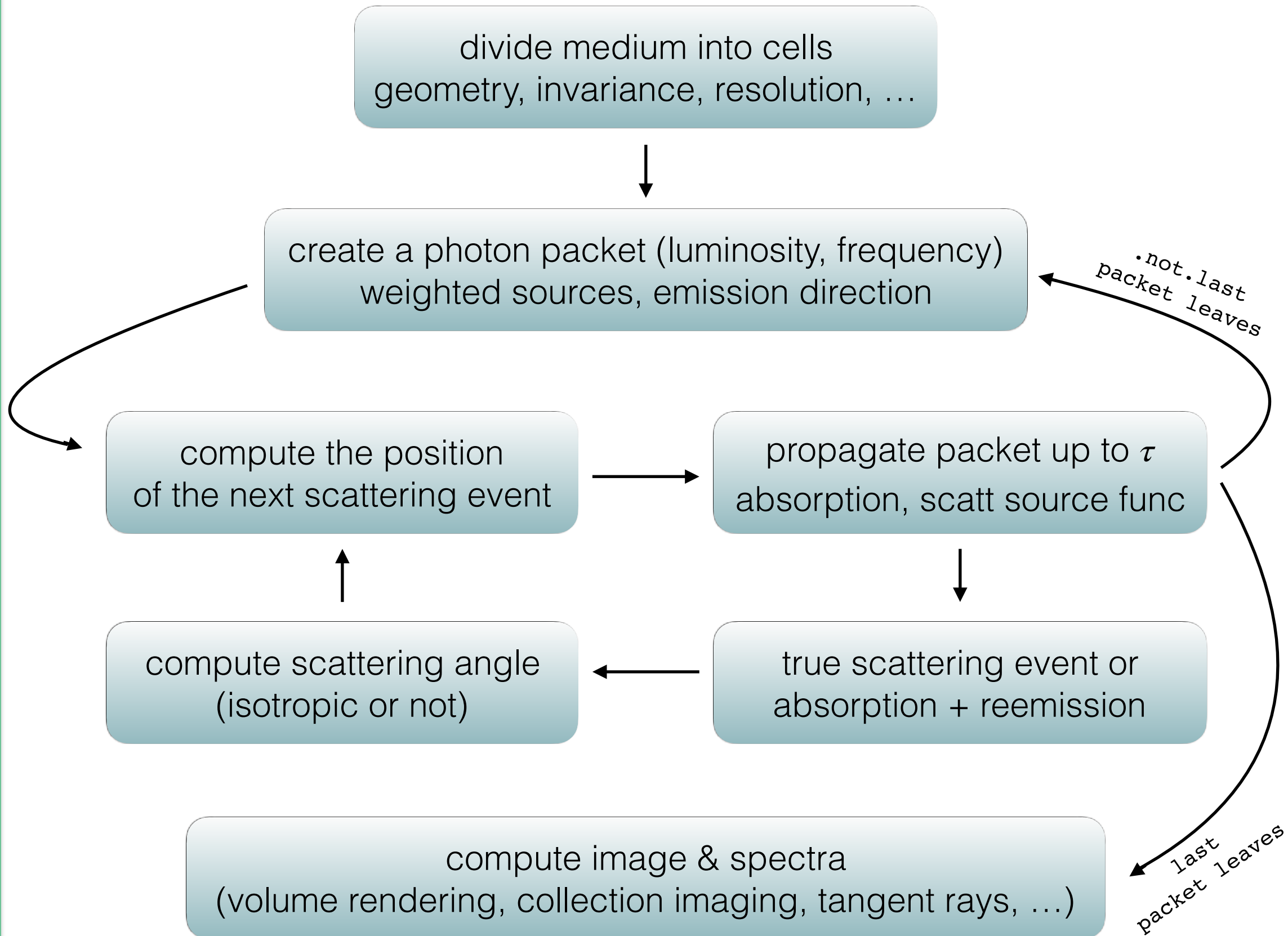
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Monte-Carlo algorithm

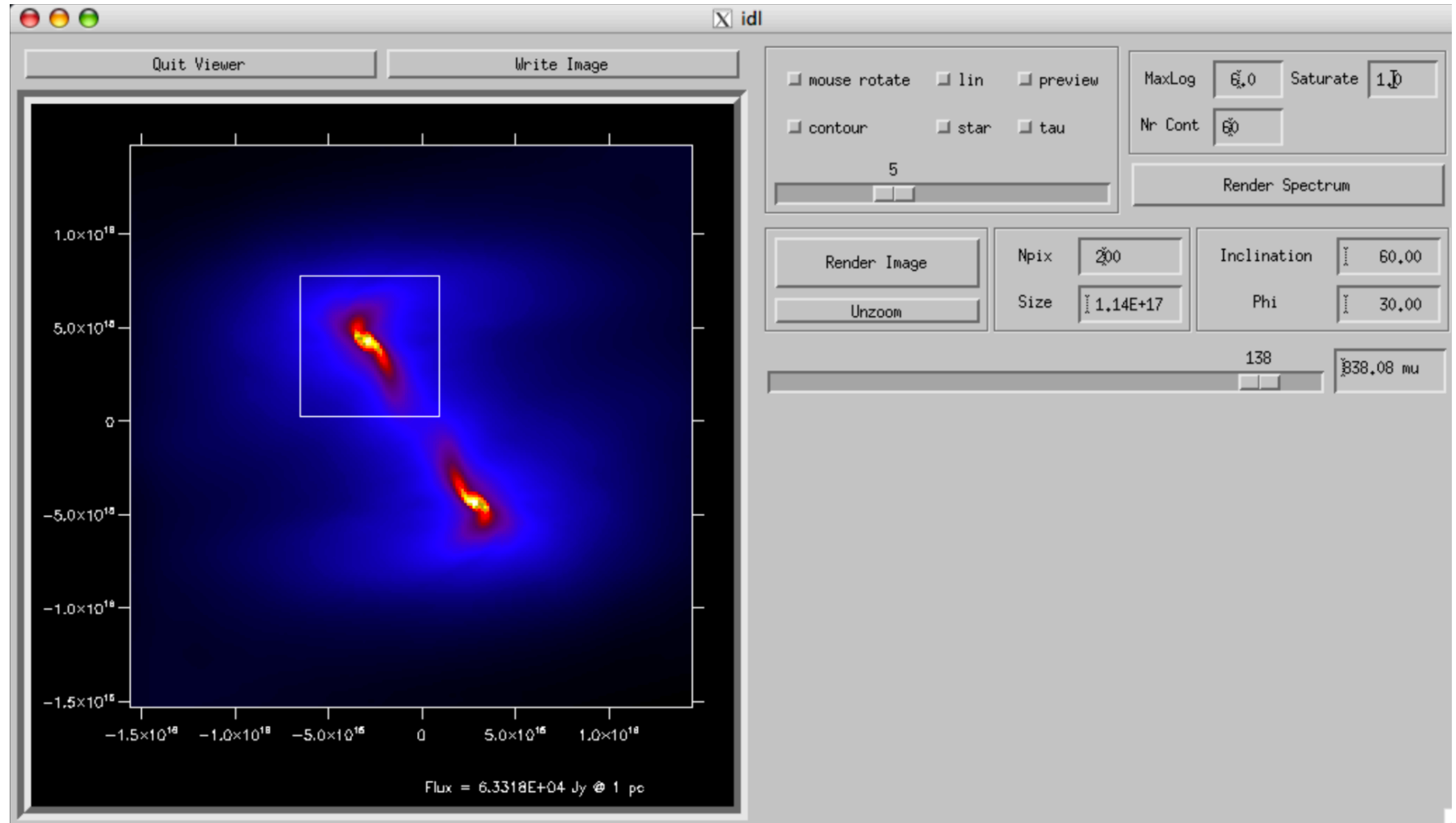
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Graphical User Interfaces

for images



Outline

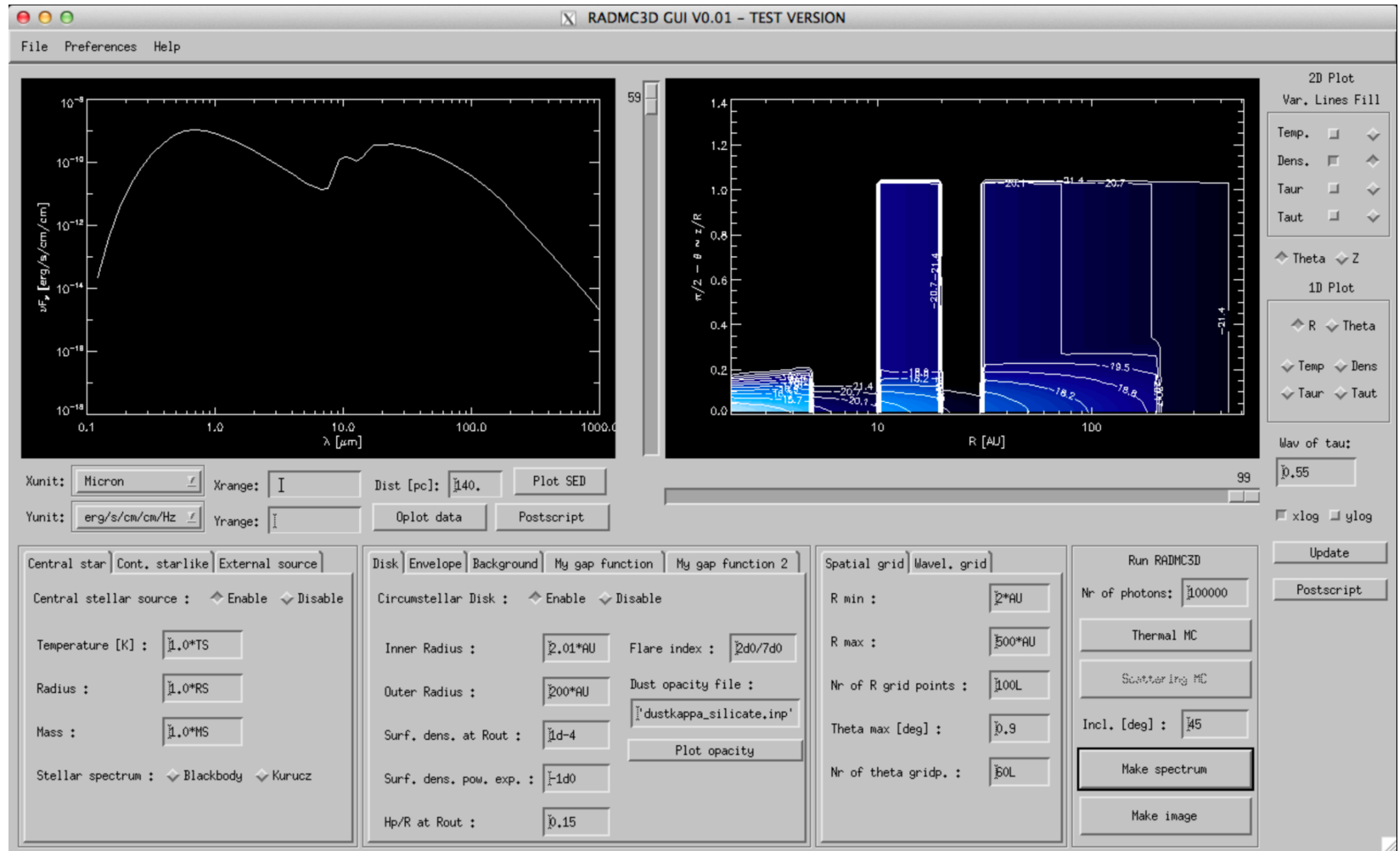
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Graphical User Interfaces

for disk models

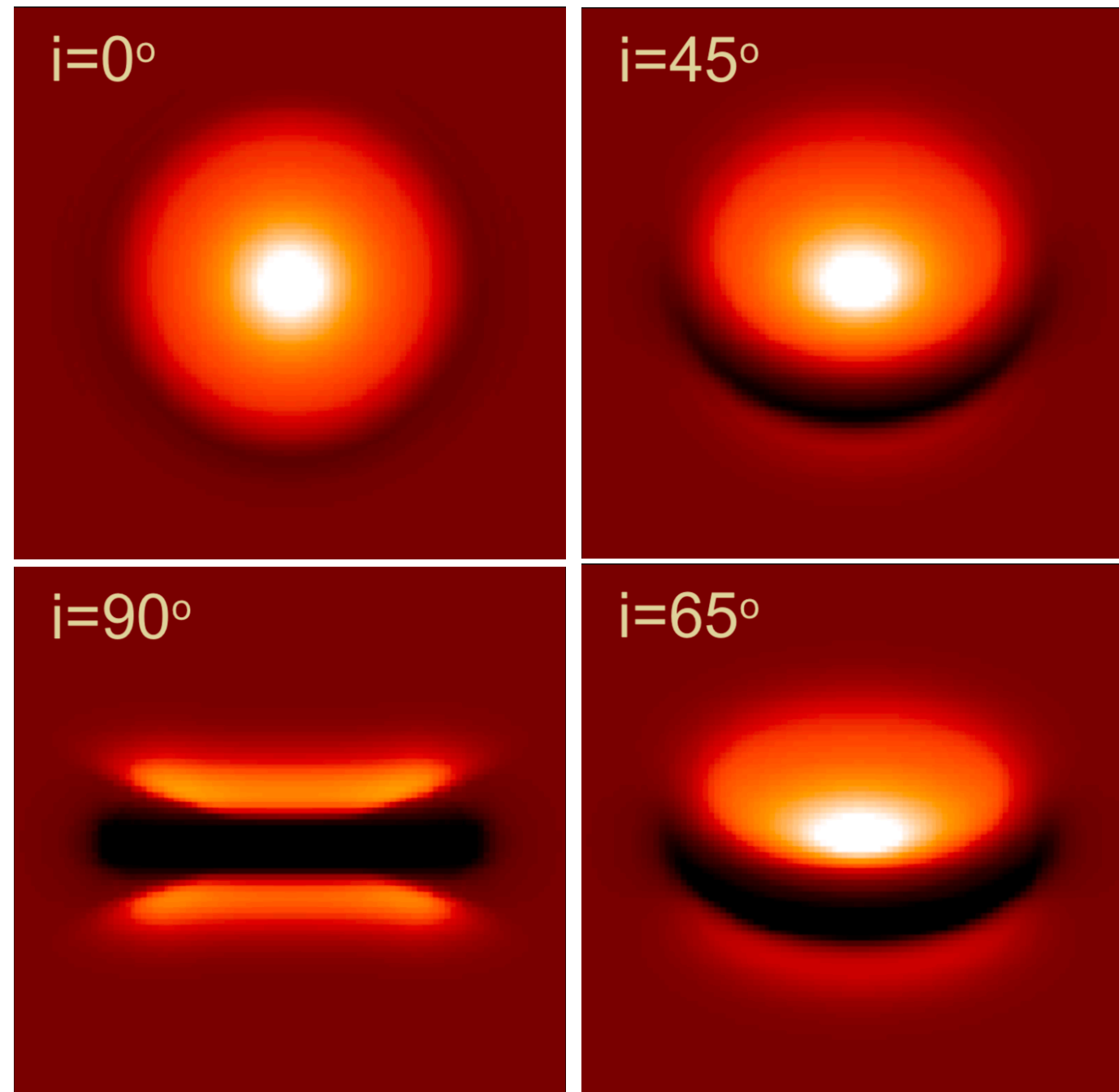
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Attila Juhasz (IoA Cambridge)

Dust in protoplanetary disk (Dullemond & Dominik 2004)



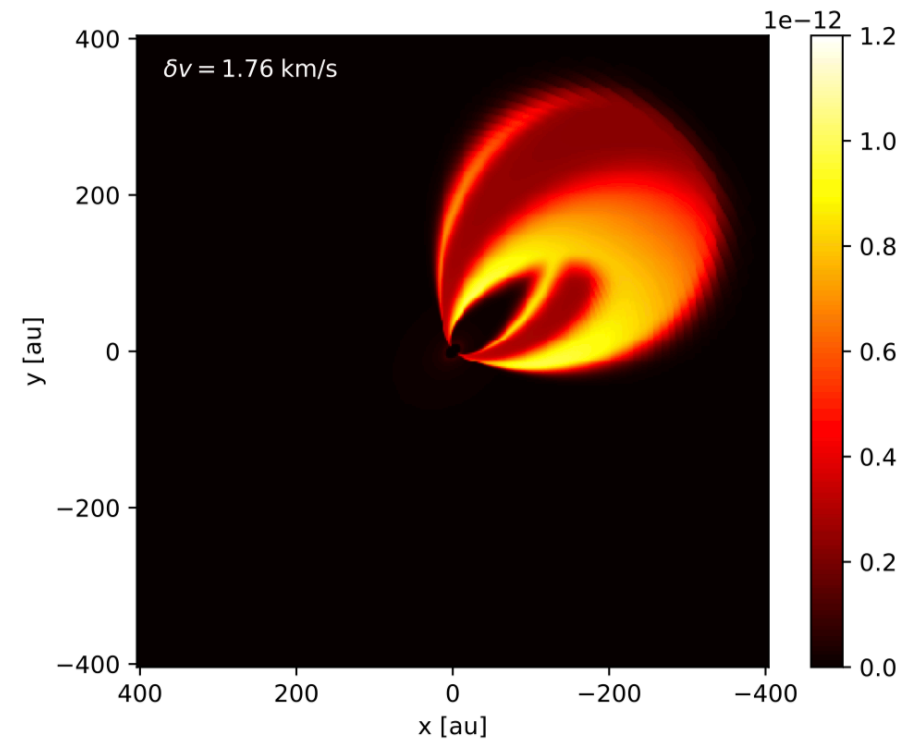
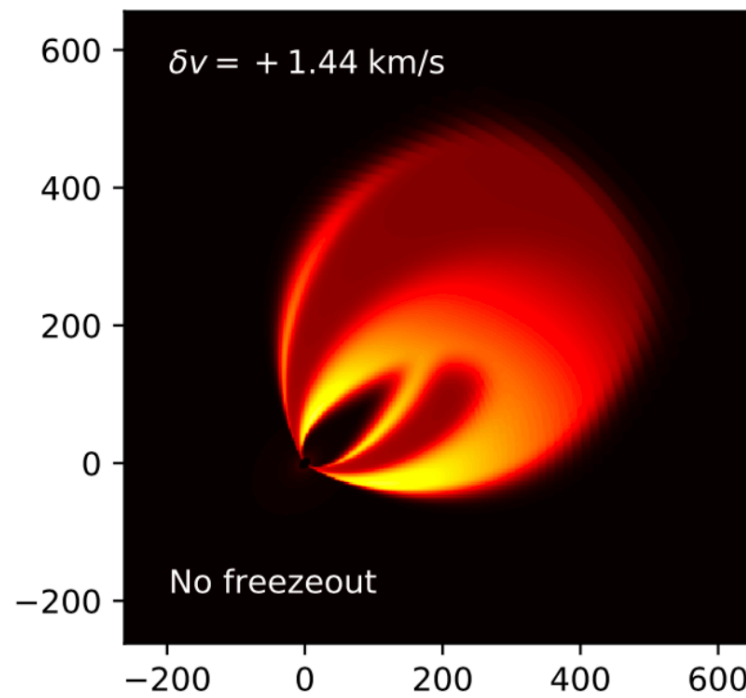
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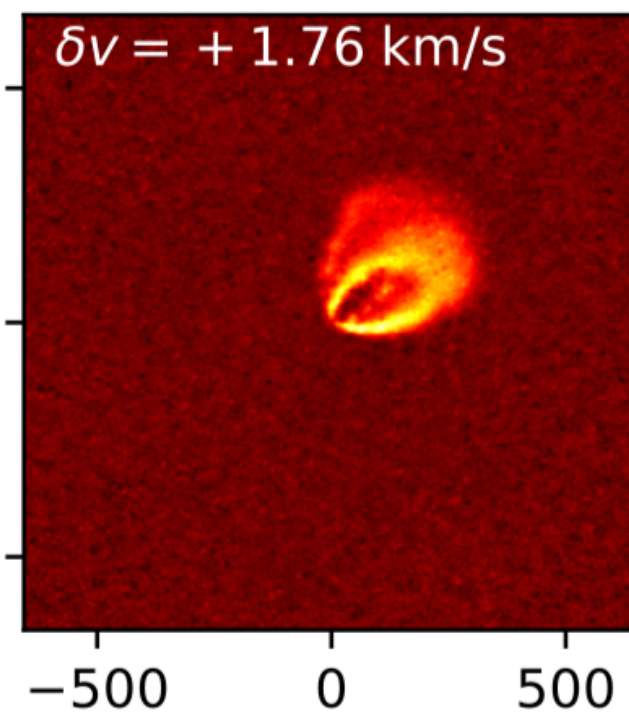
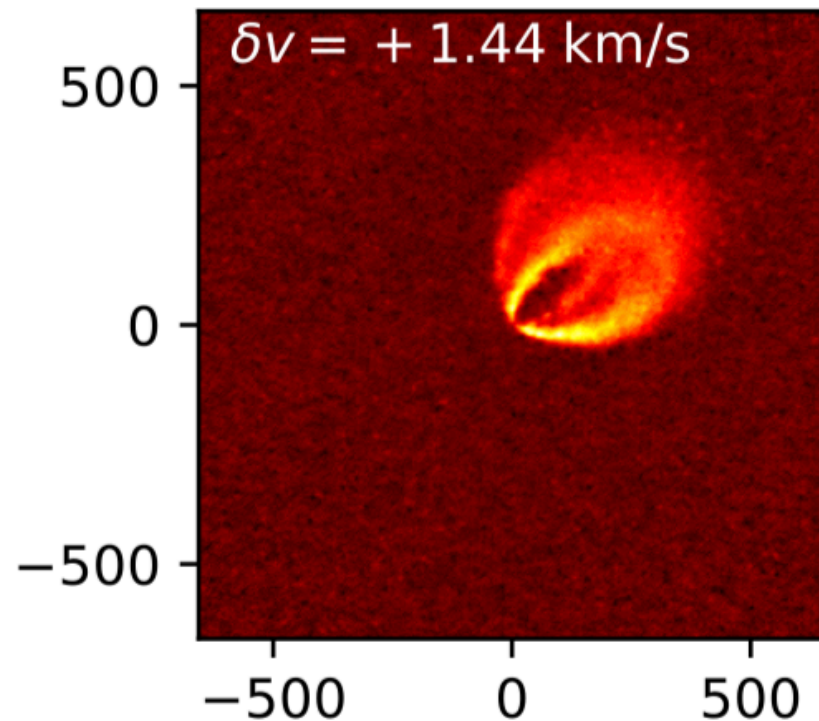
Protoplanetary disks

Line emission in protoplanetary disks (Dullemond et al. 2020)

RADMC-3D



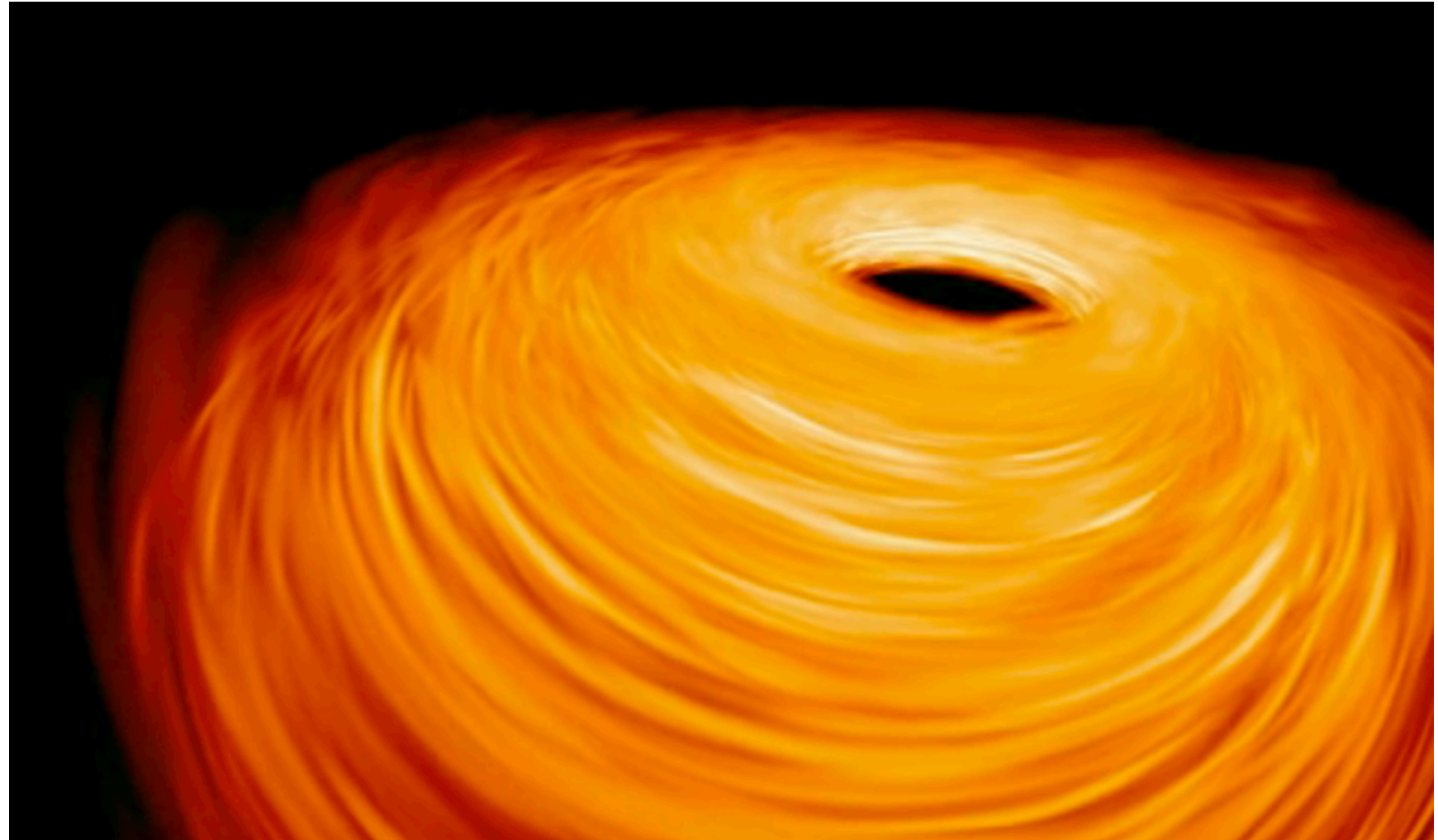
ALMA observations



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Magnetic pressure in protoplanetary disk (Flock)



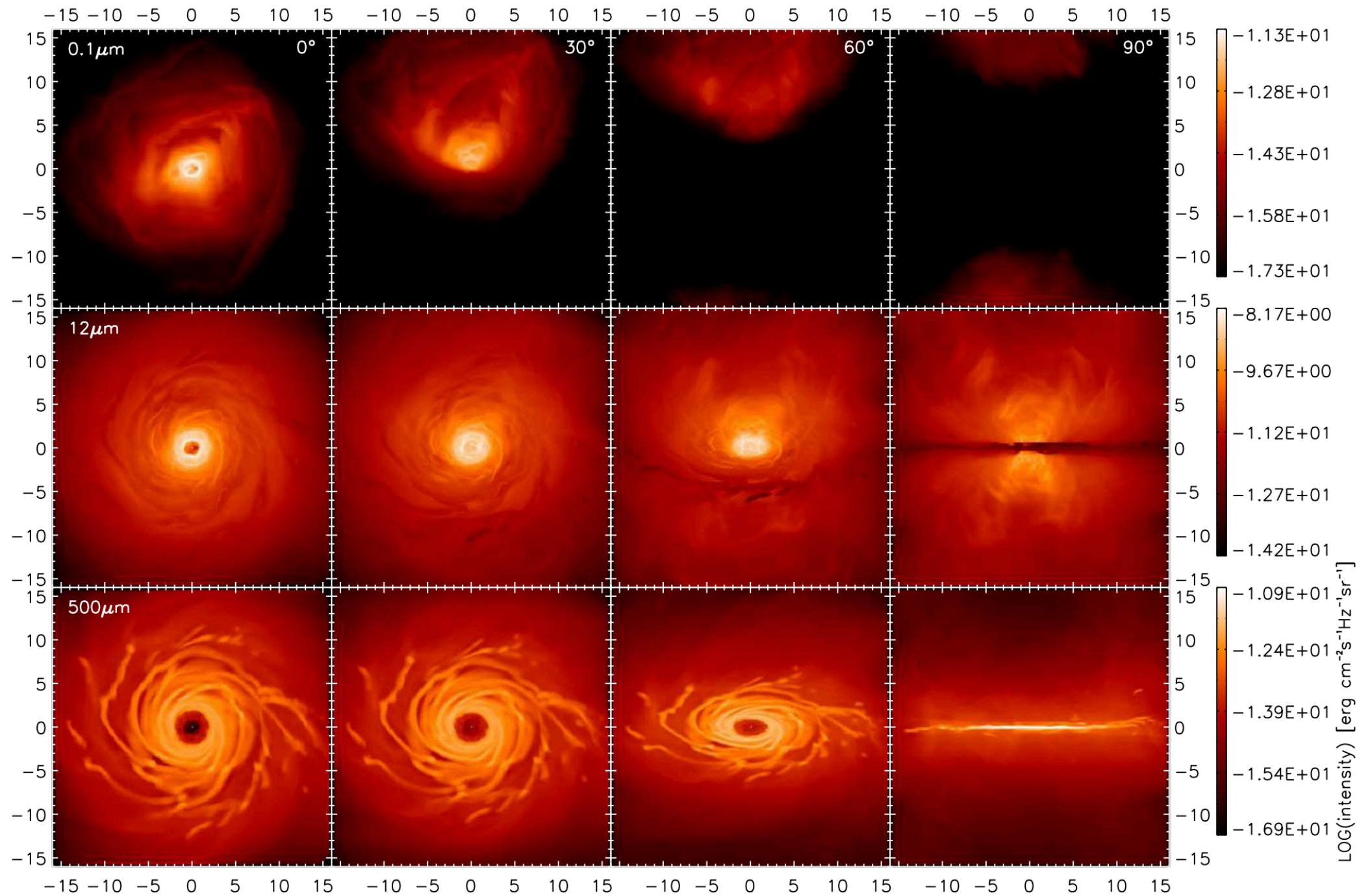
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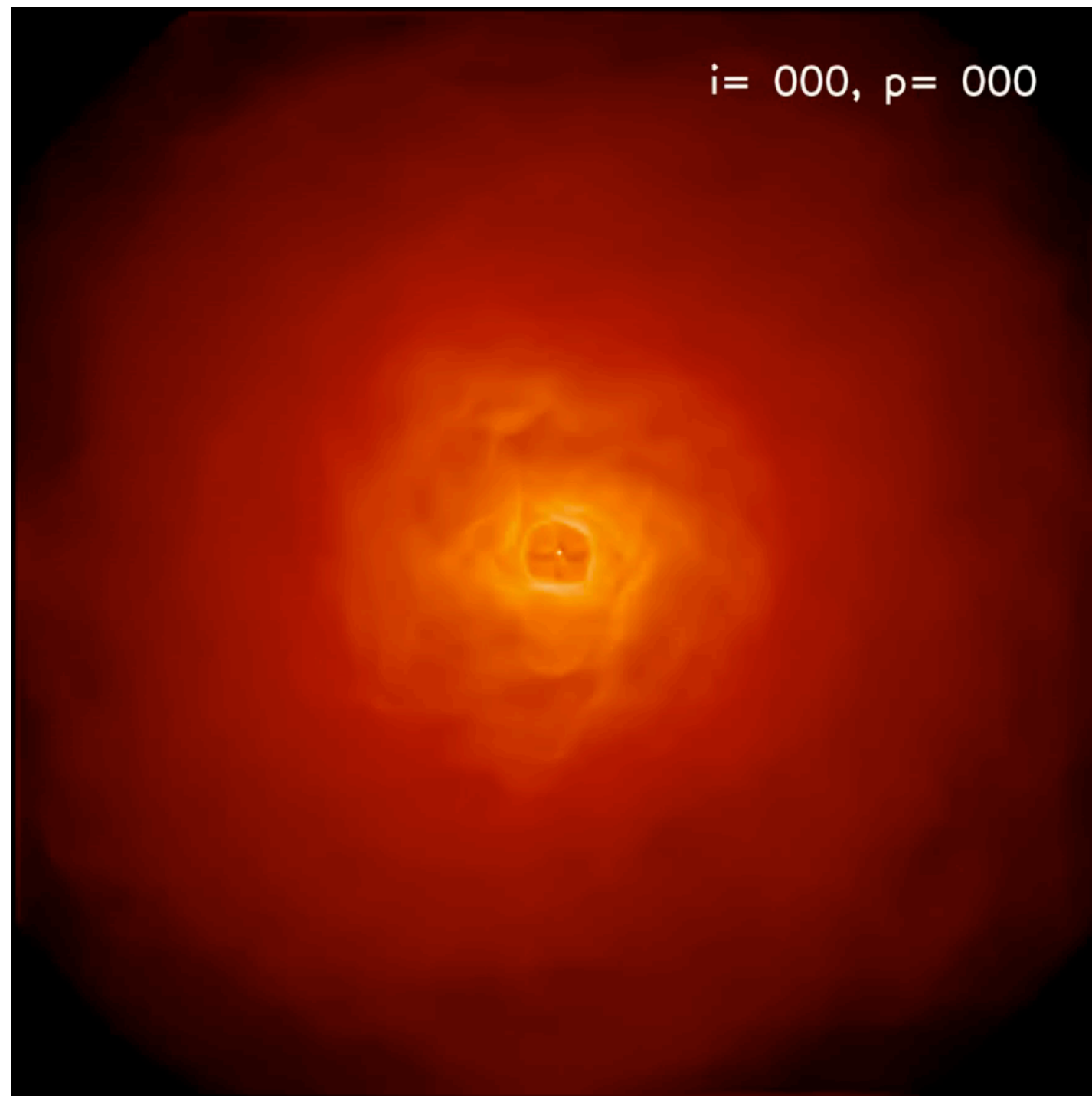
Dust in 3-D hydrodynamics model of an AGN torus (Schartmann et al. 2014)

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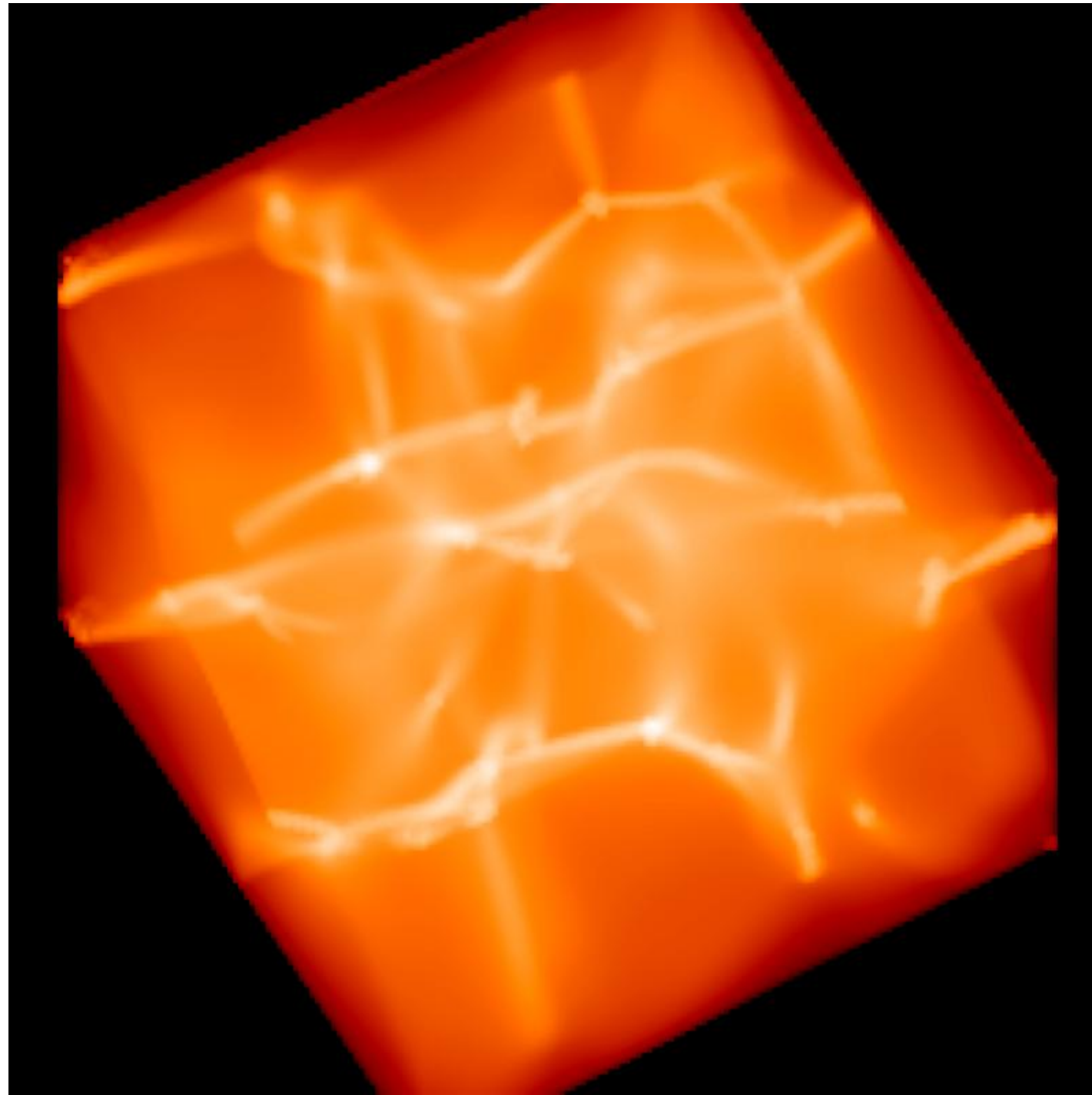
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Dust emissivity from star forming region

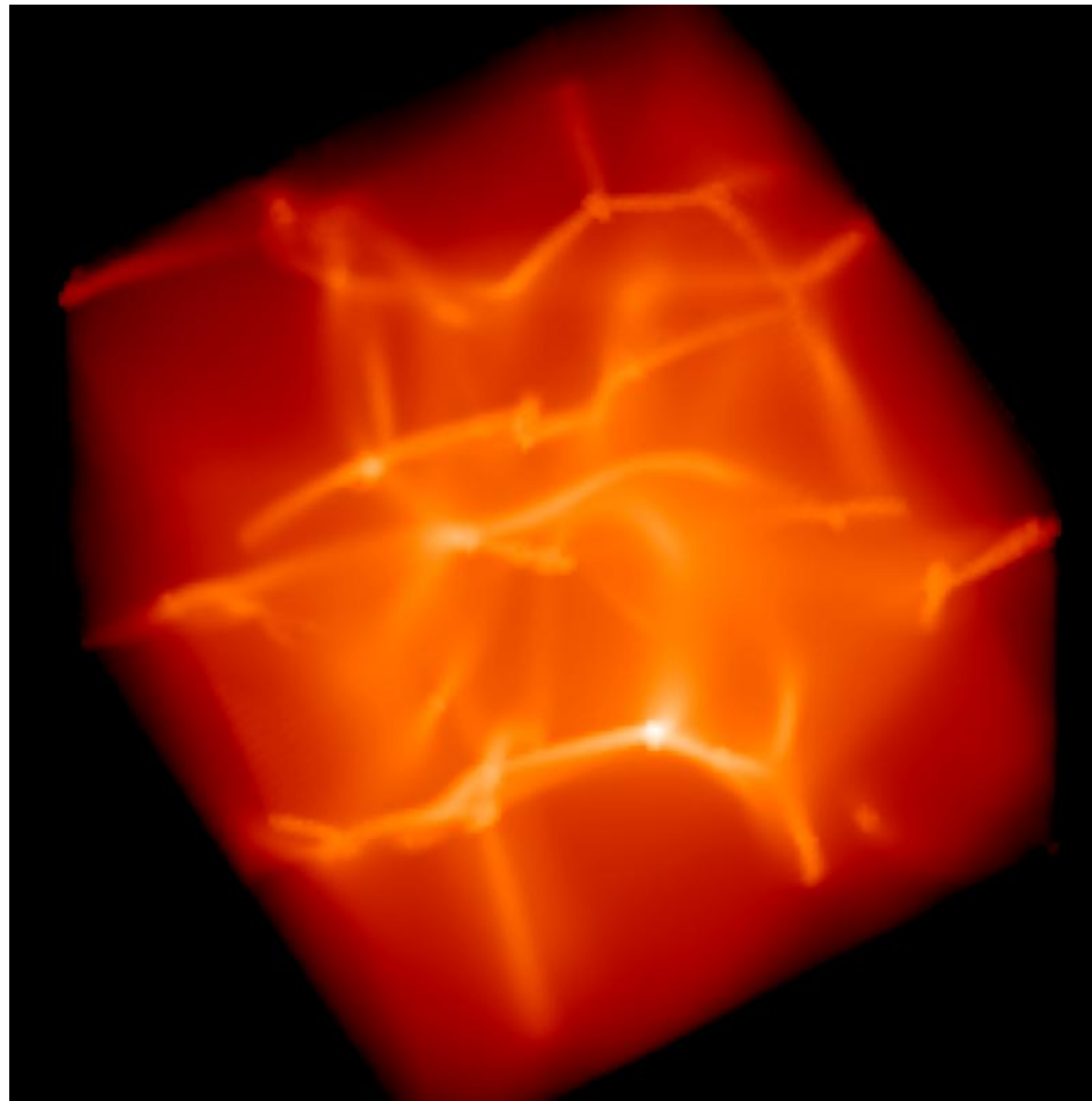


$\lambda = 1000 \mu\text{m}$

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Dust emissivity from star forming region

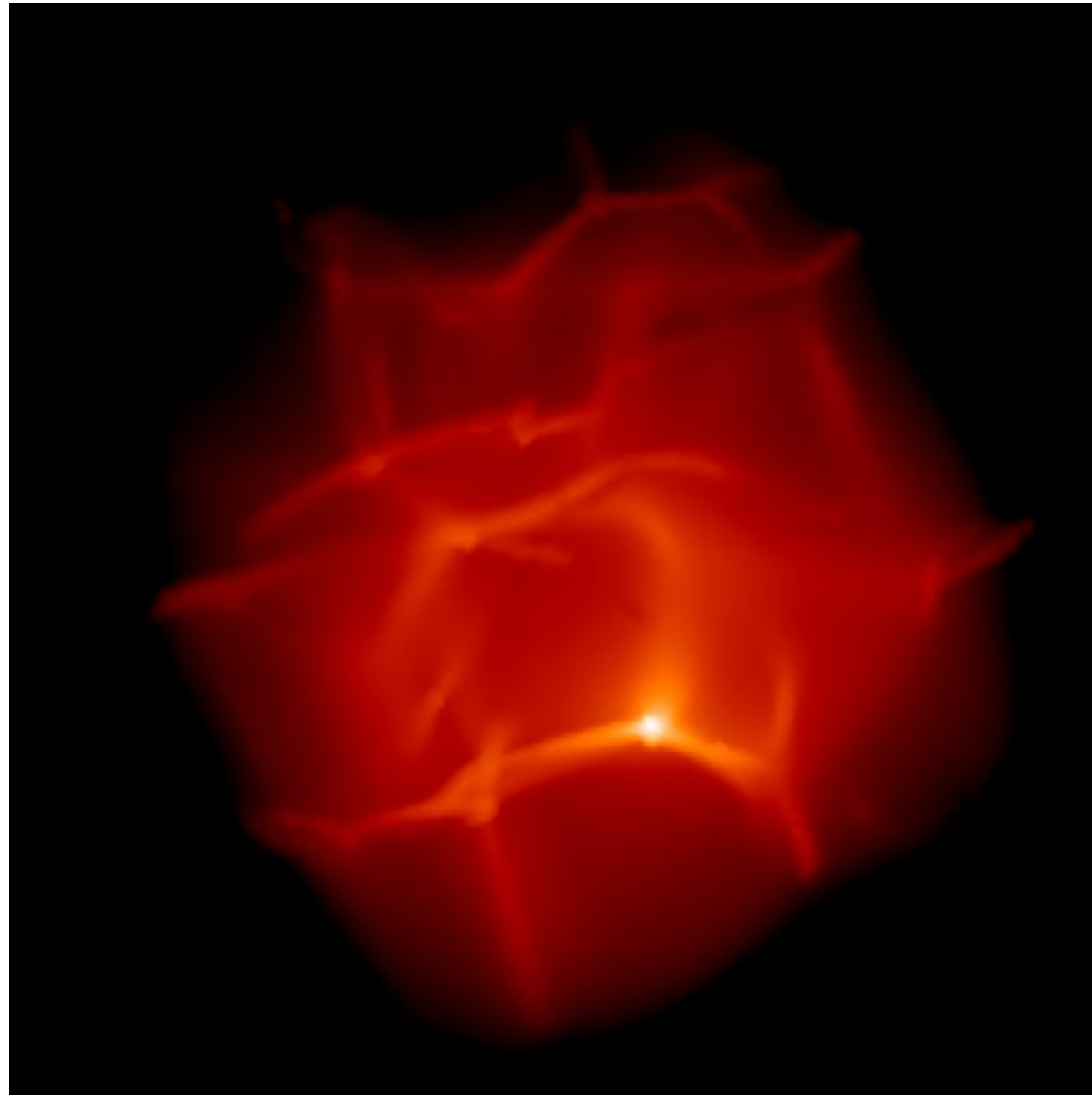


$\lambda = 100 \mu\text{m}$

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Dust emissivity from star forming region

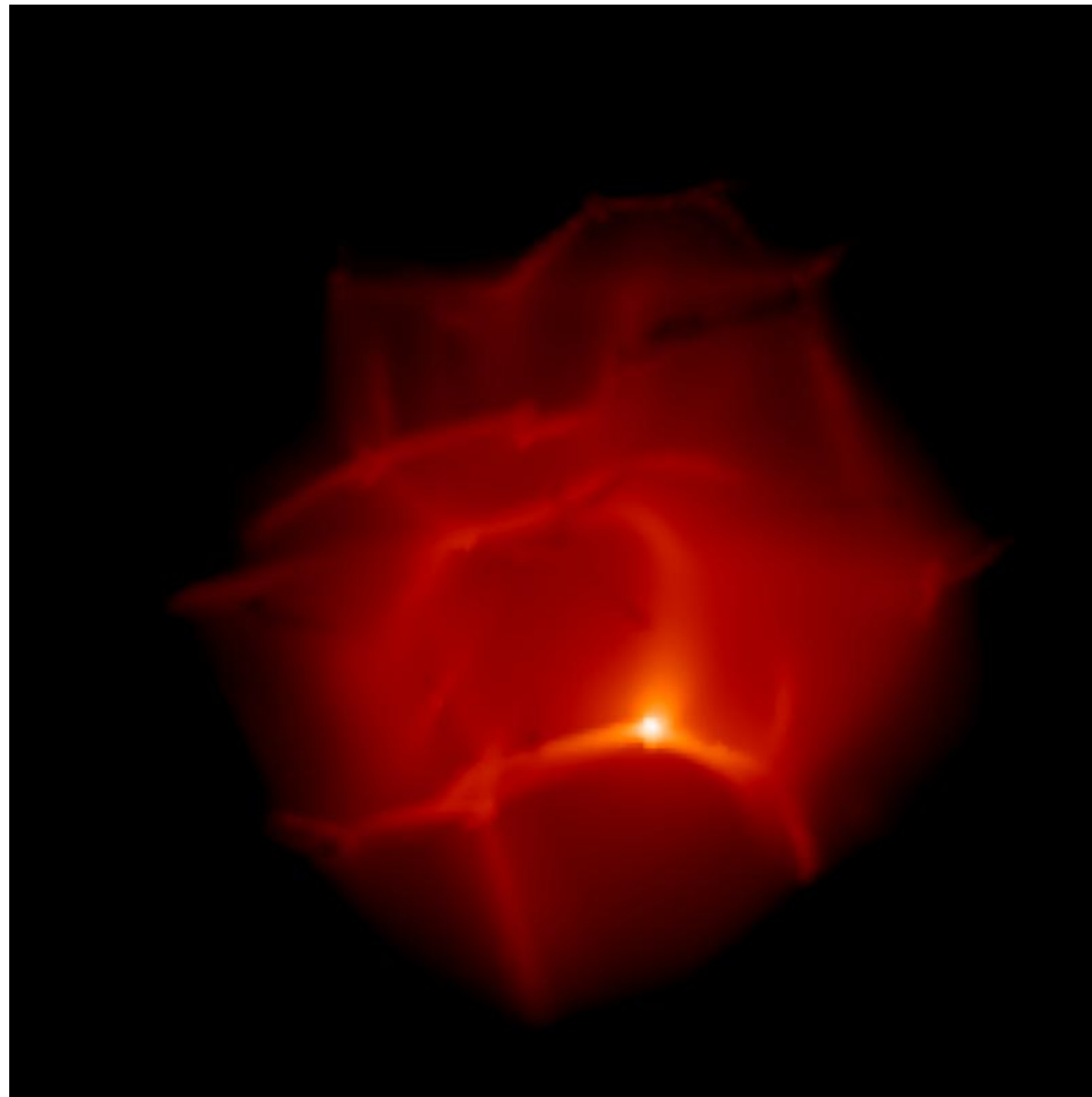


$\lambda = 50 \mu\text{m}$

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Dust emissivity from star forming region

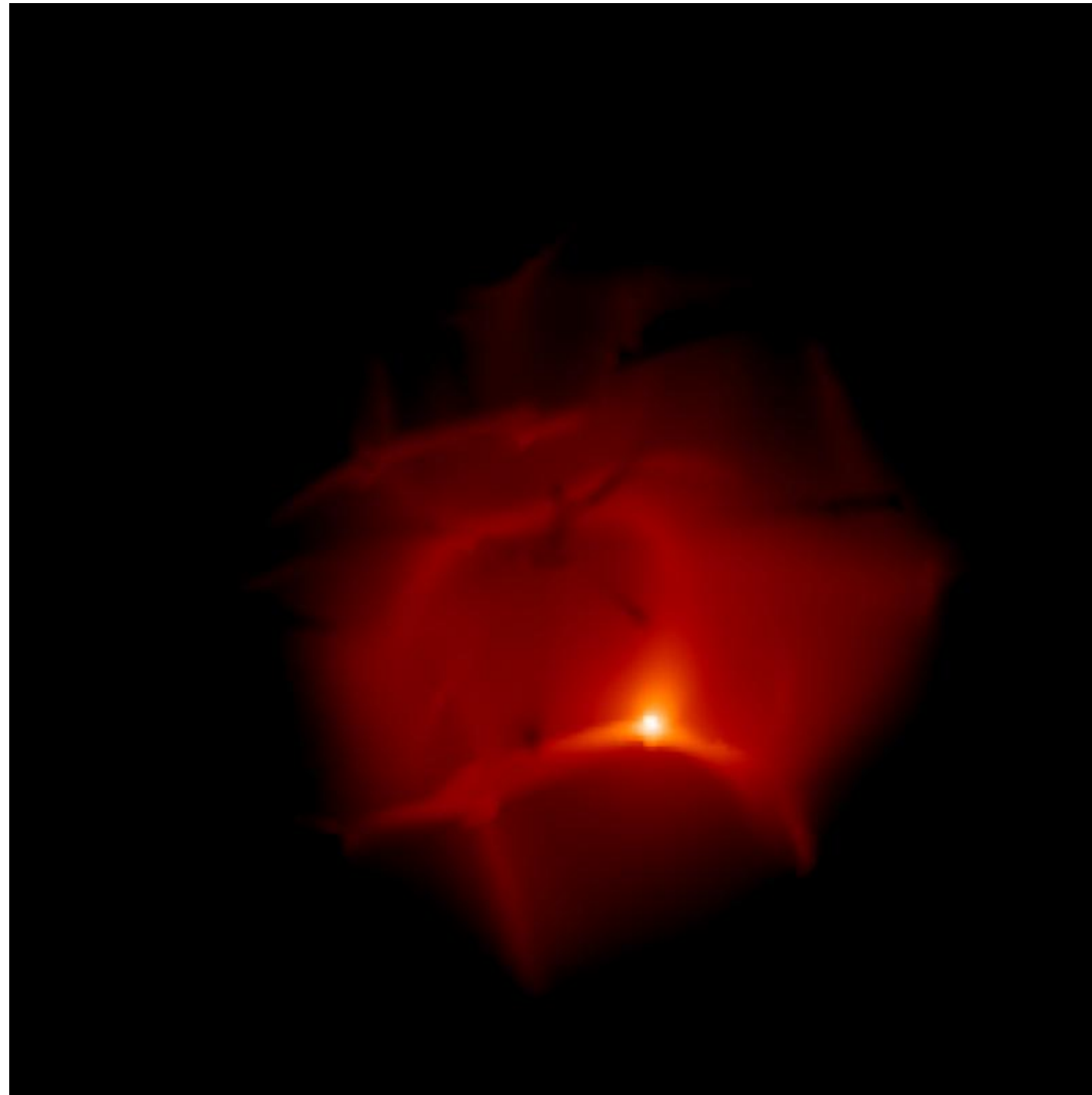


$\lambda = 40 \mu\text{m}$

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Dust emissivity from star forming region

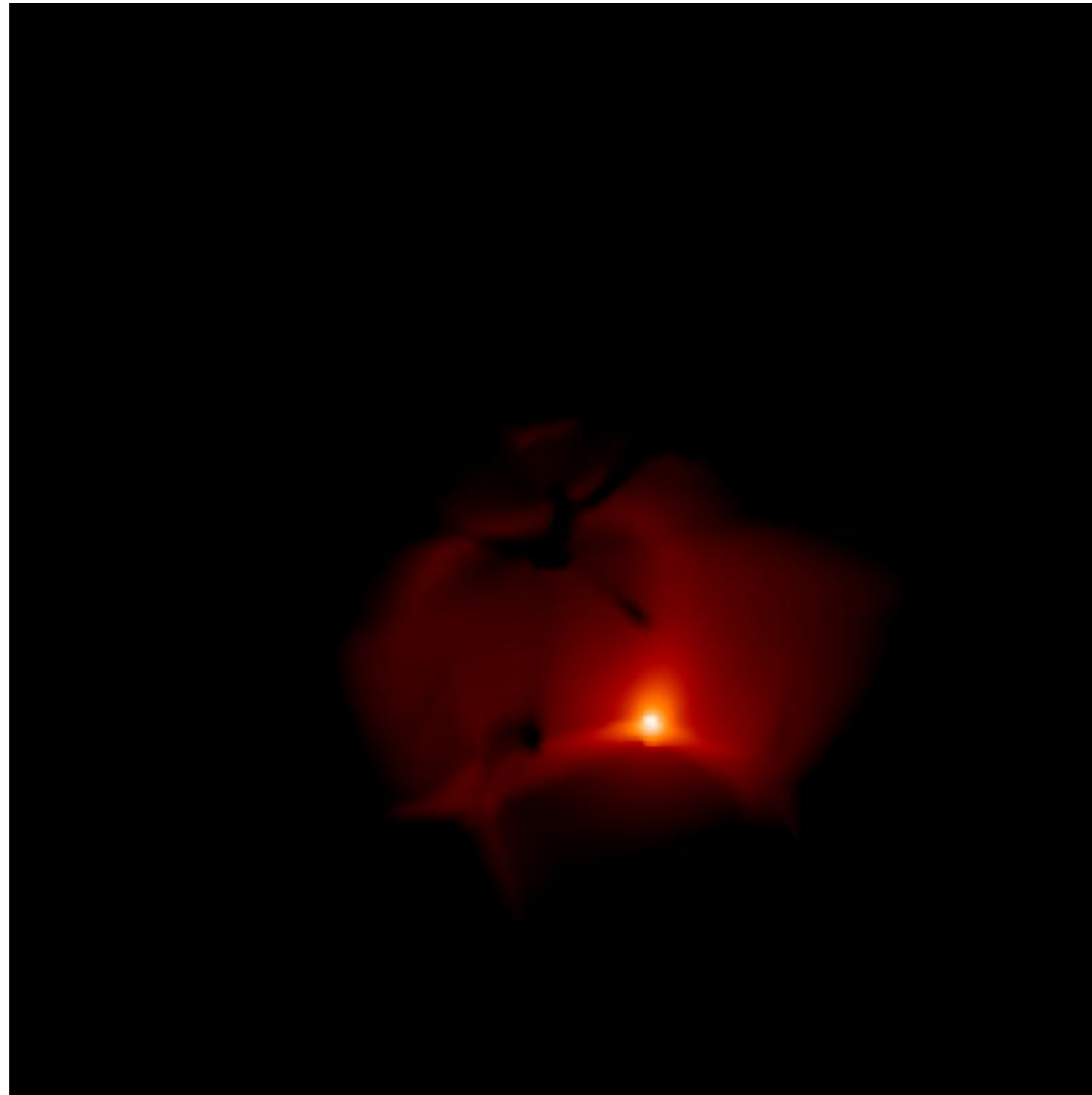


$\lambda = 30 \mu\text{m}$

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Dust emissivity from star forming region

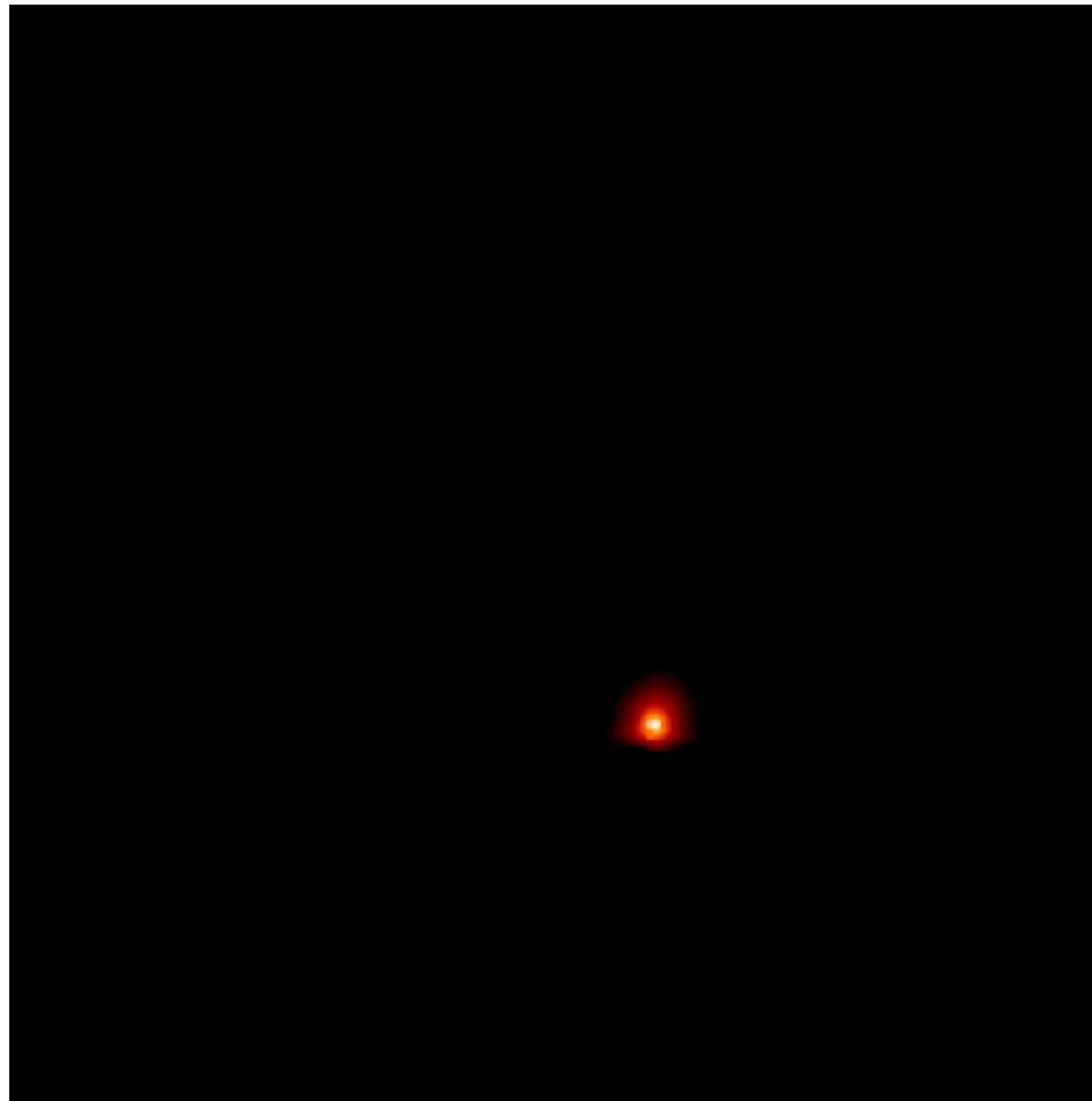


$\lambda = 20 \mu\text{m}$

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Dust emissivity from star forming region



$\lambda = 10 \mu\text{m}$

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Limitations

- RADMC 3D is not a model
- currently parallelized with OpenMP
- exact radiative transfer in line not available yet

Advantages

- large domain of application
 - various coordinates, grids
 - versatile & well documented
 - easy to use
- complex RT physics
 - dust abs /emi / scattering
 - polarized emi and scattering
 - atomic and molecular lines
- produce maps & spectra
 - high accuracy & resolution
- many imaging options
 - perspective, zoom-in
 - observer at infinity or local
 - recursive pixel refinement
 - multi-wavelength images
 - movie mode

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