ARTIST

Adaptive Radiative Transfer Innovations for Submillimeter Telescopes

Christian Brinch

on behalf of the ARTIST team:

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Motivation: Example question in future ALMA proposals

- What is the chemistry in the inner envelope/disk around protostars?

- What is the dynamical structure of low-mass protostars - e.g. infall vs. rotation on small scales?

- What is the distribution of matter in envelopes and disks?

- What is the kinematical structure of protoplanetary disks?

- Are the holes/gaps seen in transitional disks really empty?

- What is the structure of magnetic field in cloud cores and what is the role of magnetic field in the early phases of star formation?

Motivation: How can ALMA help to answer these questions?

ALMA is by far the most powerful telescope in three key areas;

Sensitivity

Spatial resolution

Dynamic range in spatial frequency

Model predictions should have the similar properties (e.g. image resolution, dynamic range, 3D), which is challenging.

The ARTIST project

Supported by national funding agencies within EU/ASTRONET framework(2009-2011).

“... supply a user-friendly 3D radiative transfer code that can be used to provide full detailed images (lines; continuum; polarization) given a physical/chemical structure of any object...”

“ ... provide a user-friendly *modeling environment* that can be used to make predictions for observations with current and future submillimeter telescopes given a physical/chemical model of any object...”

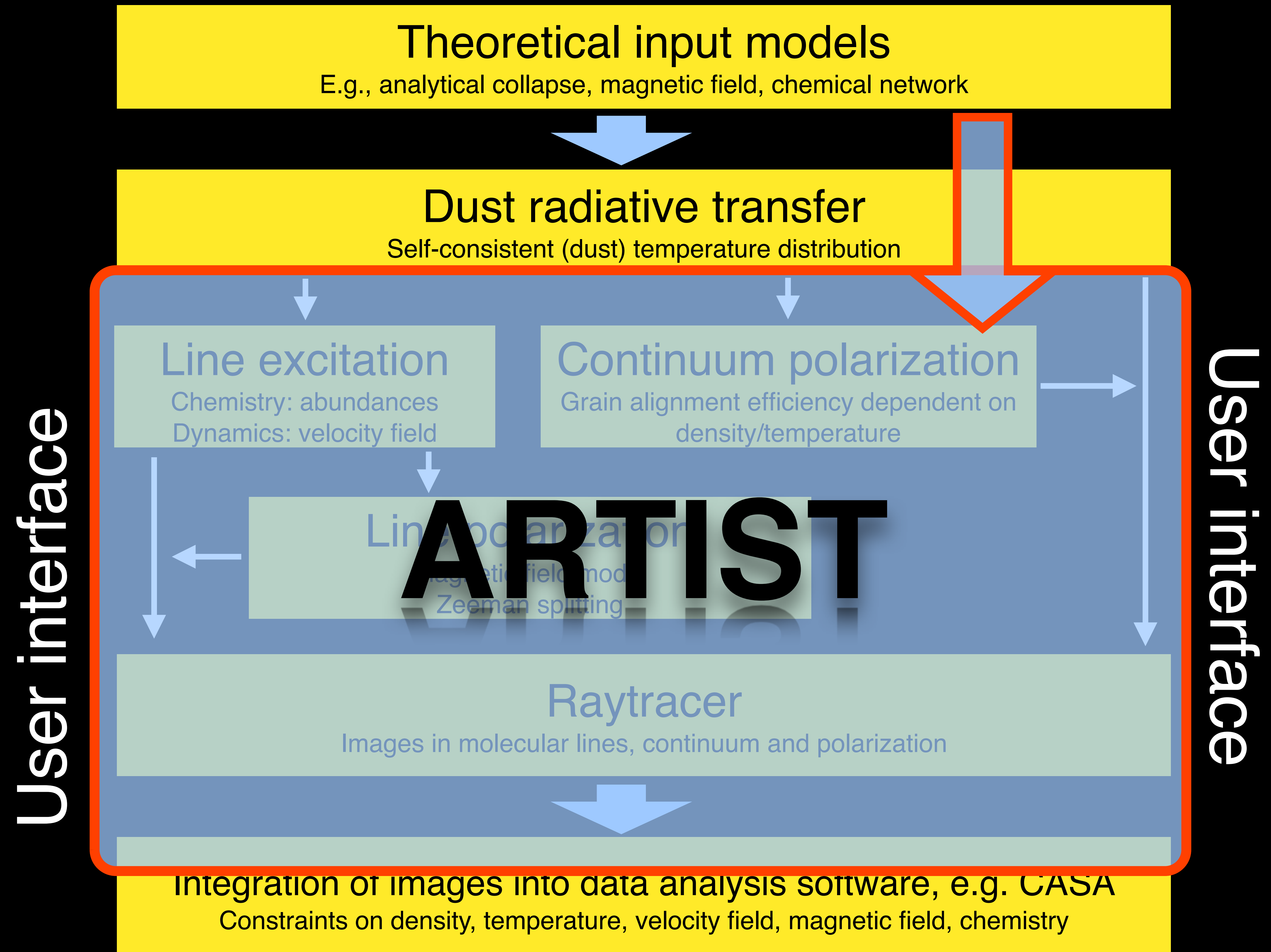
The ARTIST components

1) An innovative radiative transfer code using adaptive gridding that allows simulations of sources with arbitrary (3D) structures, ensuring rapid convergence - even for molecules with a complex level structure, e.g., H_2O

2) Tools for modeling the polarization of line and dust emission, information that will come with standard ALMA observations

3) A Python-based comprehensive interface with Graphcal User Interface connecting these packages and providing links to extrernal codes

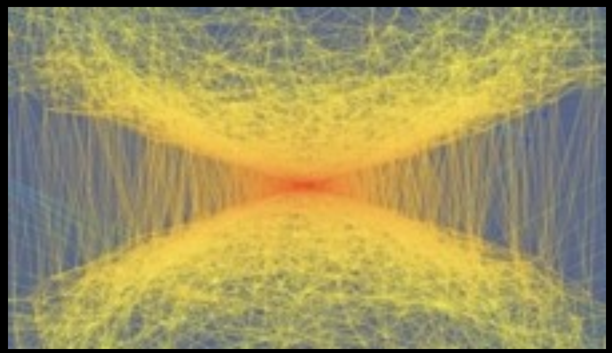
4) A library of pre-coded common models (e.g., Shu collapse model) for the user to browse.


Theoretical input models
E.g., analytical collapse, magnetic field, chemical network
Dust radiative transfer
Self-consistent (dust) temperature distribution
Line excitation
Chemistry: abundances
Dynamics: velocity field
Continuum polarization
Grain alignment efficiency dependent on
density/temperature
ARTIST
Zeeman splitting
Raytracer
Images in molecular lines, continuum and polarization
Integration of images into data analysis software, e.g. CASA
Constraints on density, temperature, velocity field, magnetic field, chemistry
User interface
User interface

Components: Line excitation / Raytracing

LIME

Brinch & Hogerheijde, 2010



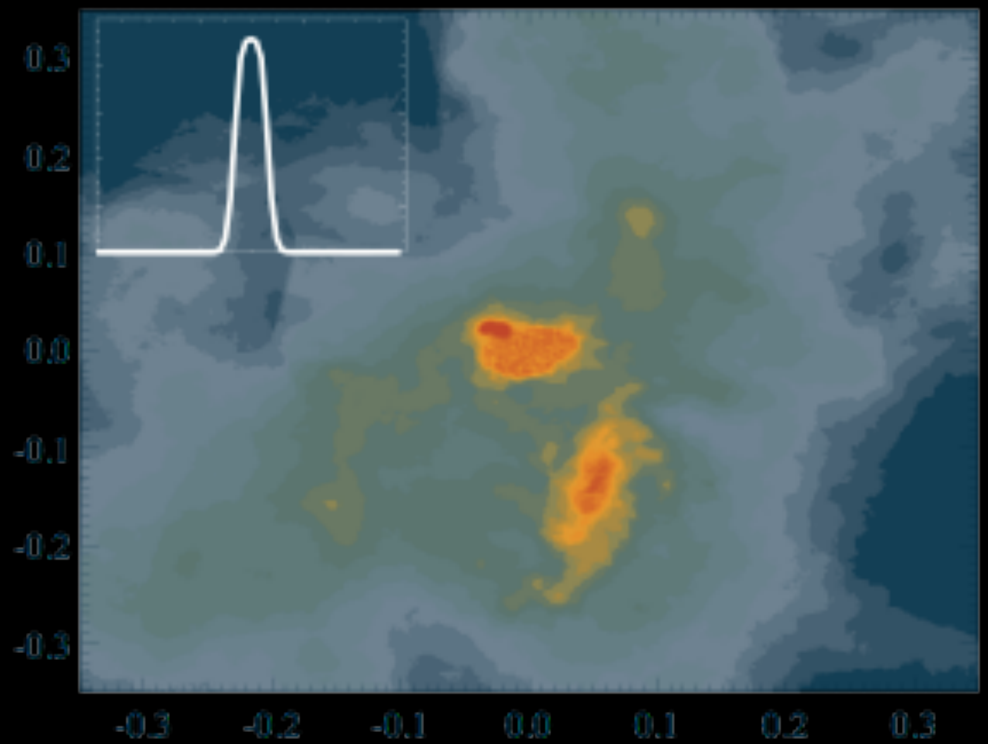
LIME is a new and innovative non-LTE spectral line radiation transfer code for 3D models in arbitrary geometries.

Instead of a 2D regular mesh (e.g. nested AMR) Lime transports photons along the edges of a 3D unstructured Delaunay-grid (Ritzerveld & Icke 2006)

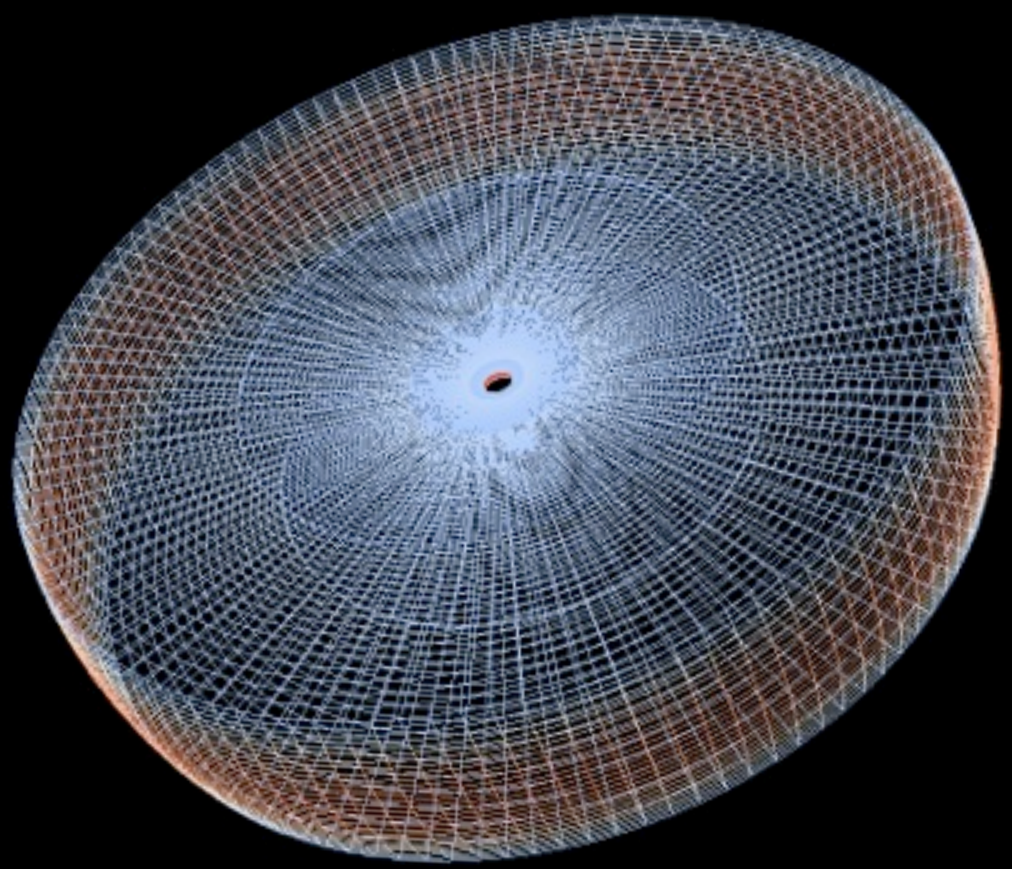
Grid points are placed semi-randomly but grid point distribution is well controlled
=> grid is very flexible

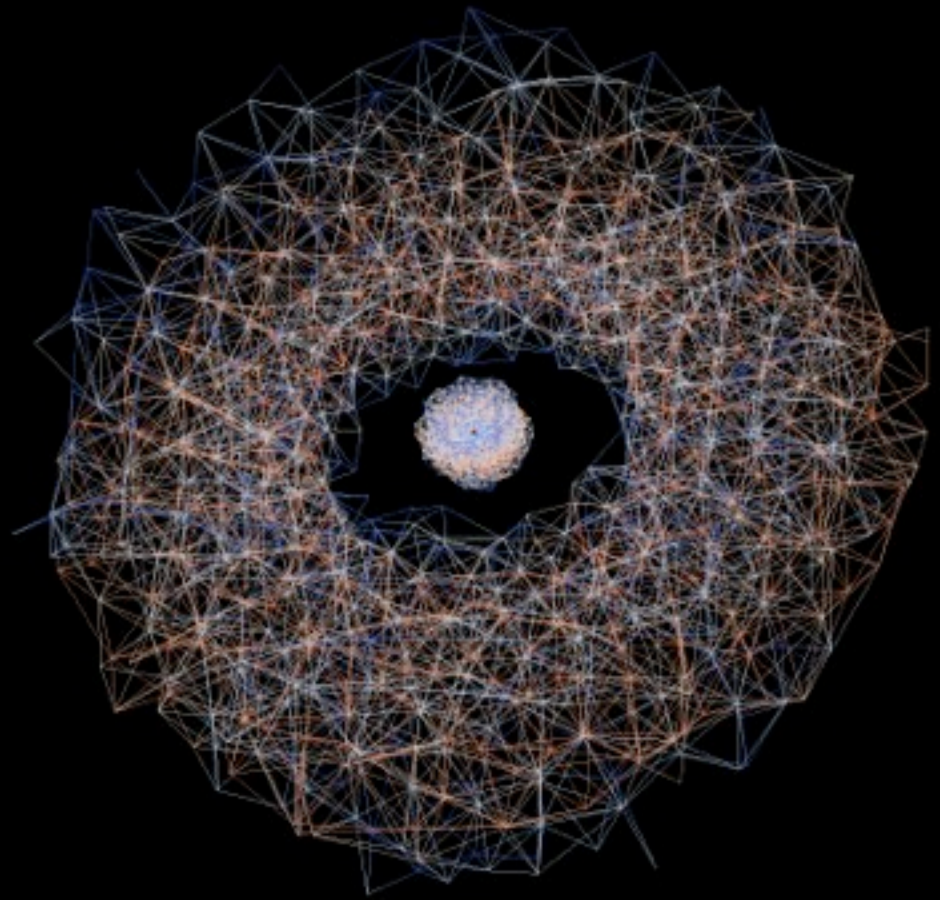
Visualization with VTK

Image data are written in FITS format that can be used in directly in CASA (simdata).



Components: Line excitation / Raytracing





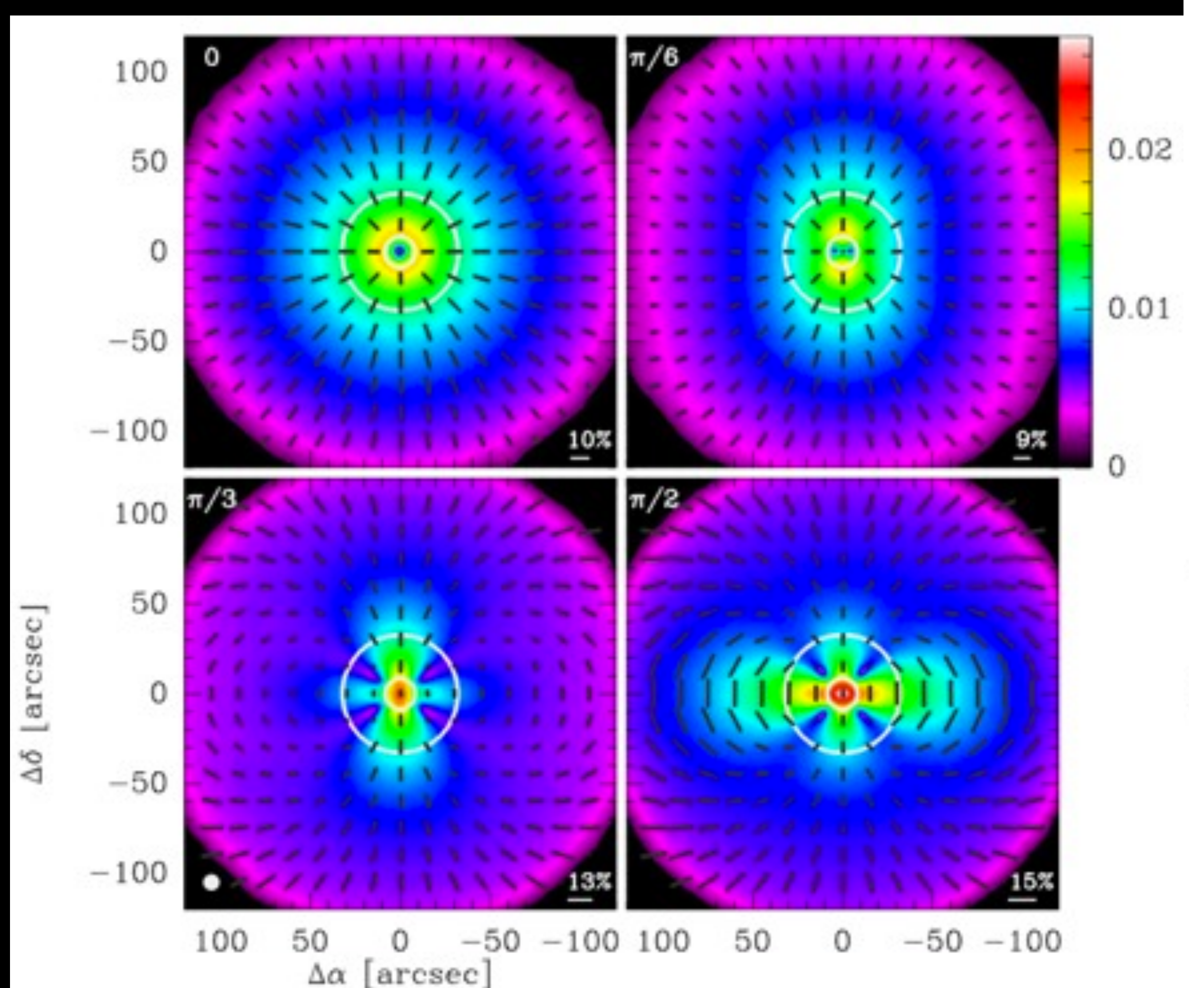
Components: Continuum polarization

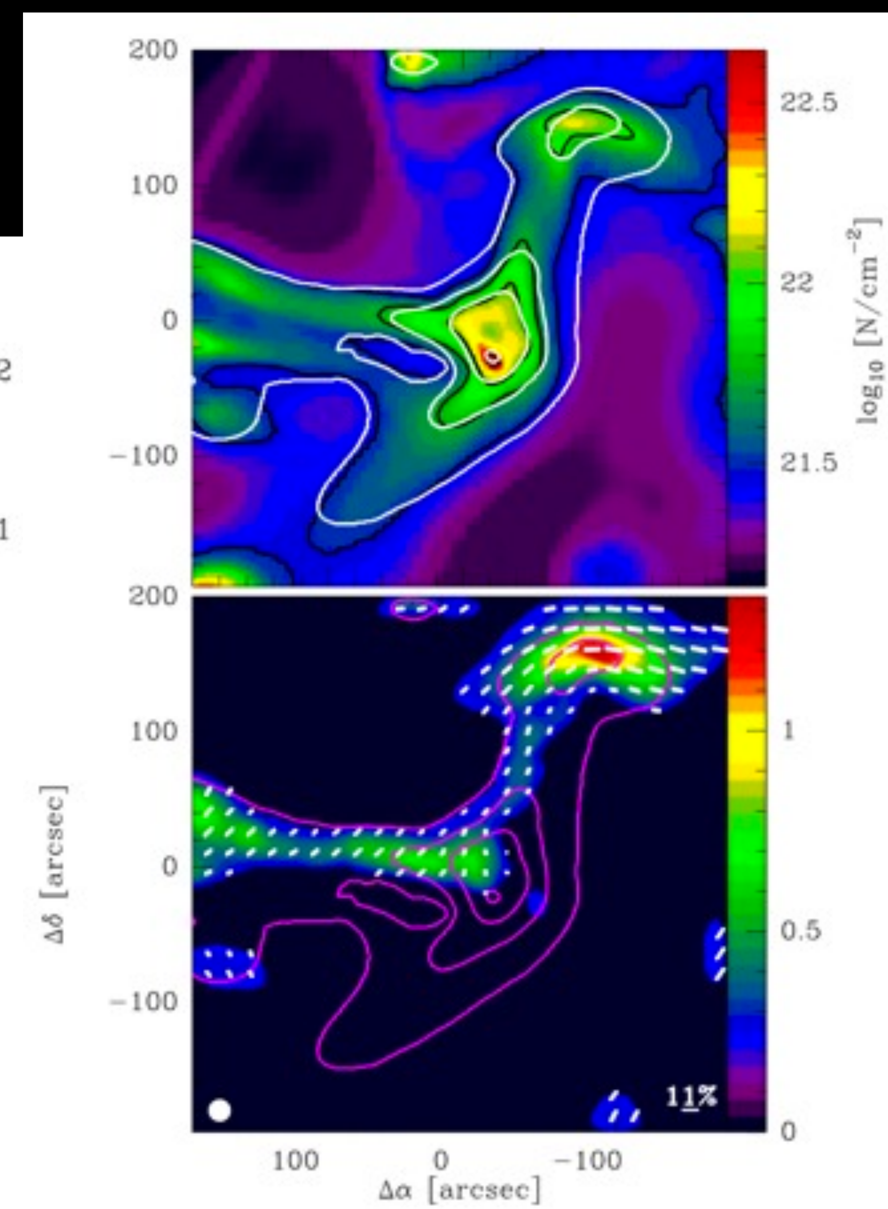
Dustpol (Padovani et al. 2012, in press.)

Calculates Stokes parameters on the basis of Lee & Draine 1985, Padoan 2011

Grain alignment efficiency (function of density/temperature)
3D magnetic field structure

=> Synthetic stokes vectors





Components: Line polarization

Line polarization (Kuiper et al. in prep) is in the testing/benchmarking phase

Full stokes radiative transfer using a modified version of LIME

Goldreich-Kylafis effect (Unequal population of magnetic-substates in an anisotropic velocity/radiation field)

Components: Interface

Two level interface

- Command line tools (Python/C++)
- Graphical User Interface (Python) (see demo)

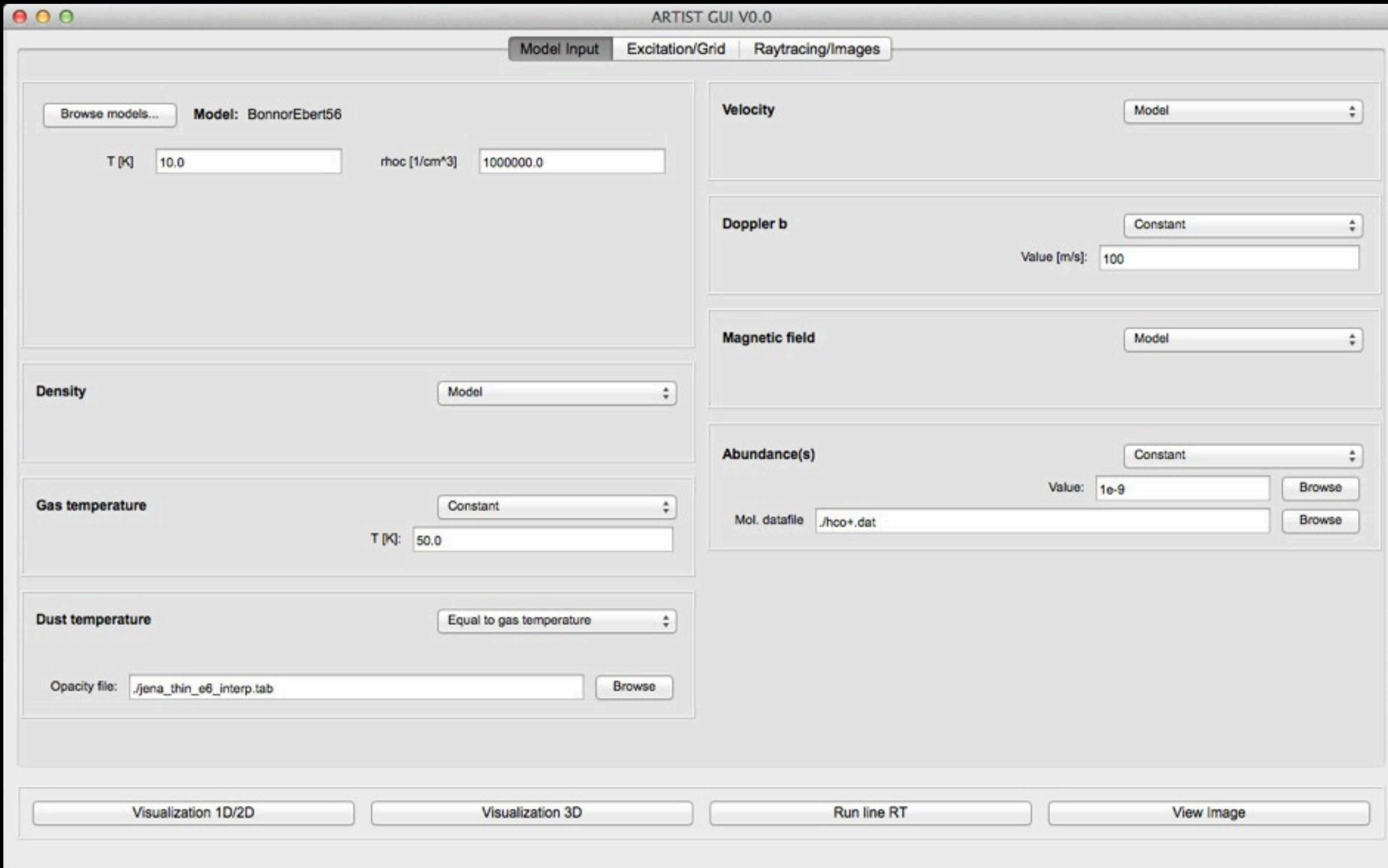
Model setup

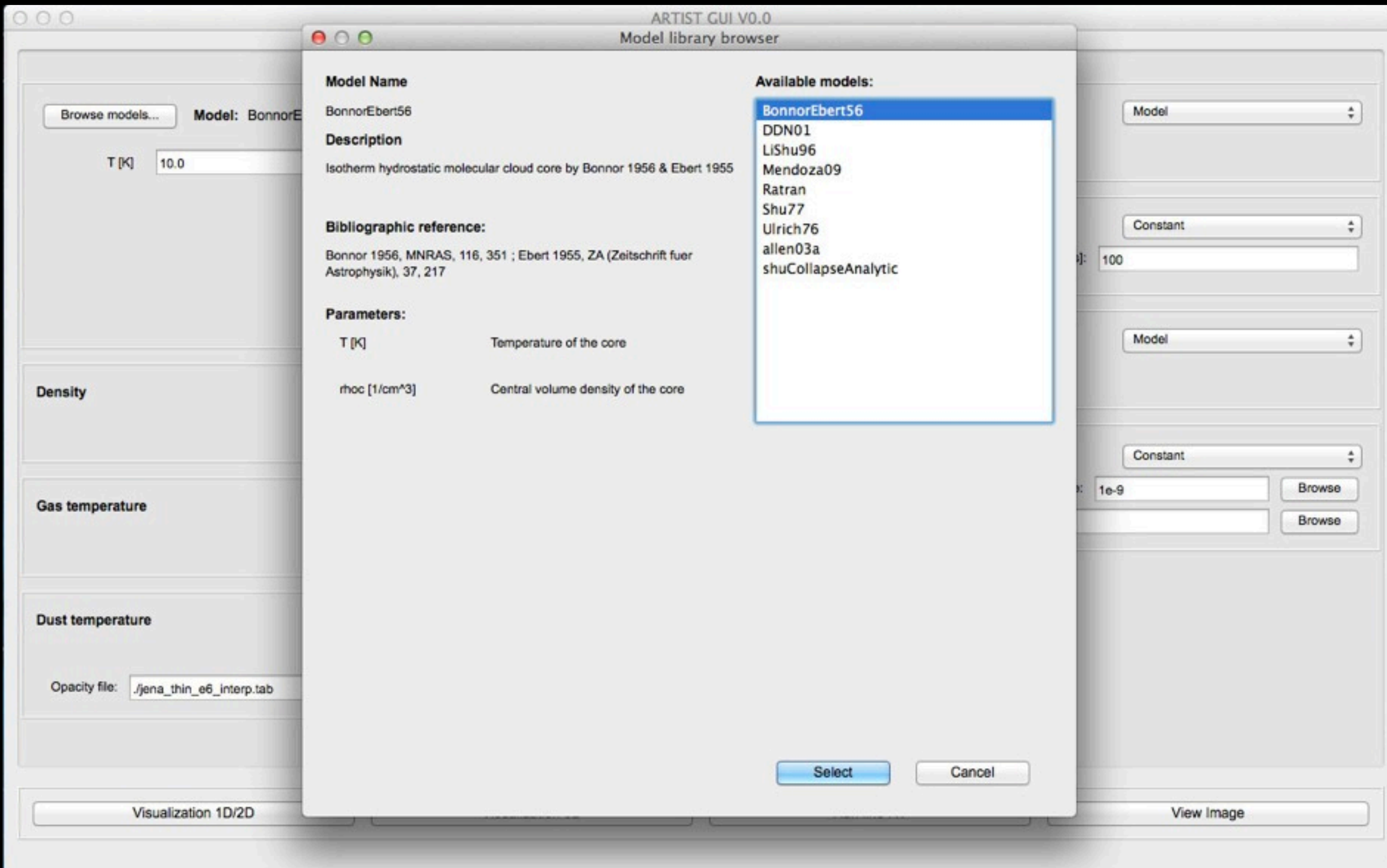
- Set physical variables (density, abundance, velocity, etc)
  - Simple polynomial user-defined functions
  - Library of analytical models
  - Tabulated output of external numerical codes (e.g. RADMC-3D, StarFormat)
- Set grid properties (number of grid points, point distribution, etc)
- Set image properties (image size, pixel size, velocity resolution,etc)

Visual inspection of model (1D/2D within the interface, 3D requires external software - Paraview)

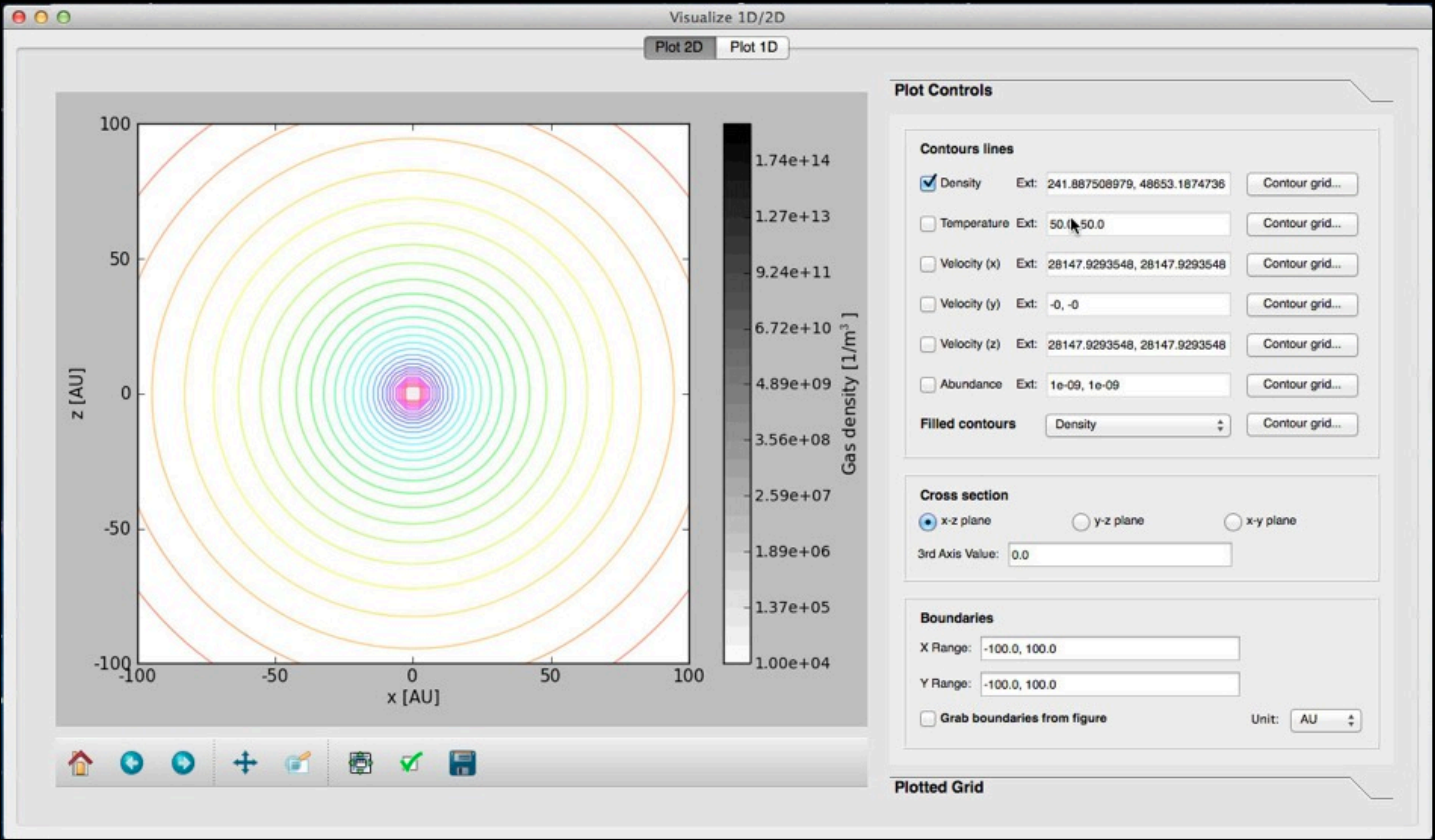
Excitation calculation / raytracing

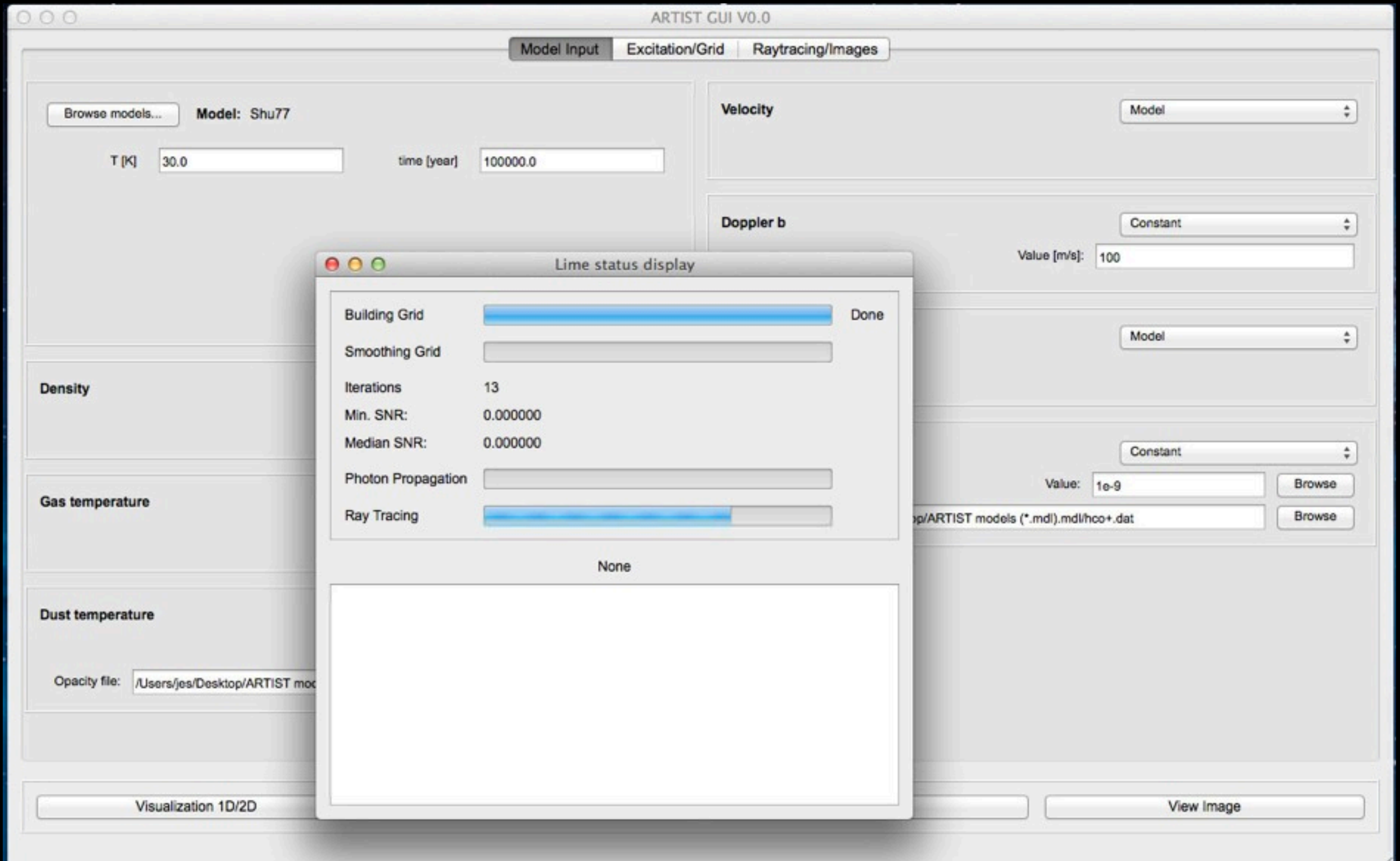
Post-processing
(e.g. image convolution, moment maps)


ARTIST GUI V0.0
Model Input
Excitation/Grid
Raytracing/Images
Browse models...
Model: BonnorEbert56
T [K]
10.0
rhoc [1/cm^3]
1000000.0
Density
Model
Gas temperature
Constant
T [K]:
50.0
Dust temperature
Equal to gas temperature
Opacity file:
./jena_thin_e6_interp.tab
Browse
Velocity
Model
Doppler b
Constant
Value [m/s]:
100
Magnetic field
Model
Abundance(s)
Constant
Value:
1e-9
Browse
Mol. datafile
./hco+.dat
Browse
Visualization 1D/2D
Visualization 3D
Run line RT
View Image

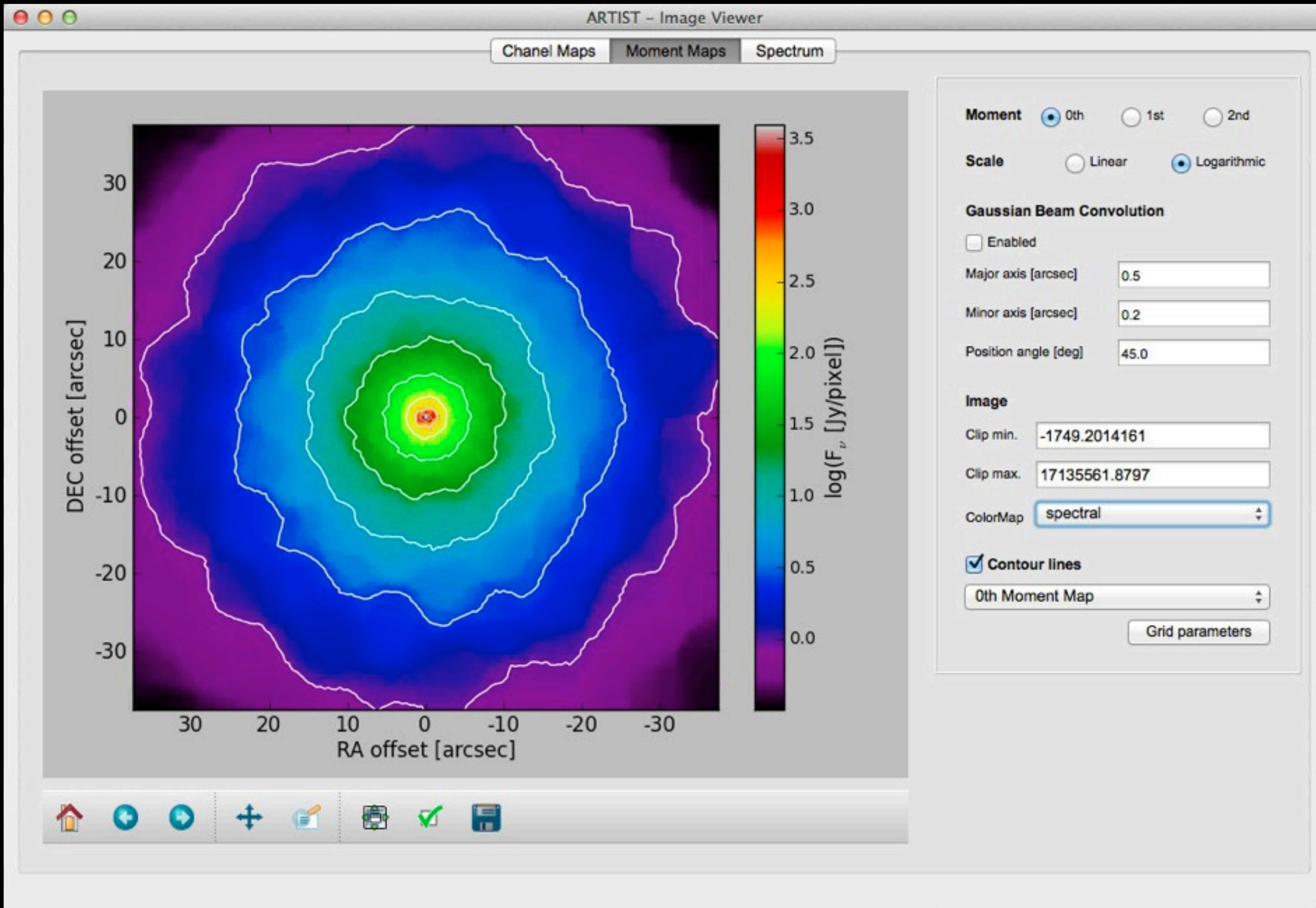


ARTIST GUI V0.0
Model library browser
Model Name
BonnorEbert56
Description
Isotherm hydrostatic molecular cloud core by Bonnor 1956 & Ebert 1955
Bibliographic reference:
Bonnor 1956, MNRAS, 116, 351 ; Ebert 1955, ZA (Zeitschrift fuer Astrophysik), 37, 217
Parameters:
T [K]
Temperature of the core
rhoc [1/cm^3]
Central volume density of the core
Available models:
BonnorEbert56
DDN01
LiShu96
Mendoza09
Ratran
Shu77
Ulrich76
allen03a
shuCollapseAnalytic
Select
Cancel
Browse models...
Model: BonnorE
T [K]
10.0
Density
Gas temperature
Dust temperature
Opacity file:
./jena_thin_e6_interp.tab
Model
Constant
100
Model
Constant
1e-9
Browse
Browse
Visualization 1D/2D
View Image


Visualize 1D/2D
Plot 2D
Plot 1D
100
50
0
-50
-100
z [AU]
-100
-50
0
50
100
x [AU]
1.74e+14
1.27e+13
9.24e+11
6.72e+10
4.89e+09
3.56e+08
2.59e+07
1.89e+06
1.37e+05
1.00e+04
Gas density [1/m³]
Plot Controls
Contours lines
Density Ext: 241.887508979, 48653.1874736 Contour grid...
Temperature Ext: 50.0, 50.0 Contour grid...
Velocity (x) Ext: 28147.9293548, 28147.9293548 Contour grid...
Velocity (y) Ext: -0, -0 Contour grid...
Velocity (z) Ext: 28147.9293548, 28147.9293548 Contour grid...
Abundance Ext: 1e-09, 1e-09 Contour grid...
Filled contours Density Contour grid...
Cross section
x-z plane
y-z plane
x-y plane
3rd Axis Value: 0.0
Boundaries
X Range: -100.0, 100.0
Y Range: -100.0, 100.0
Grab boundaries from figure
Unit: AU
Plotted Grid



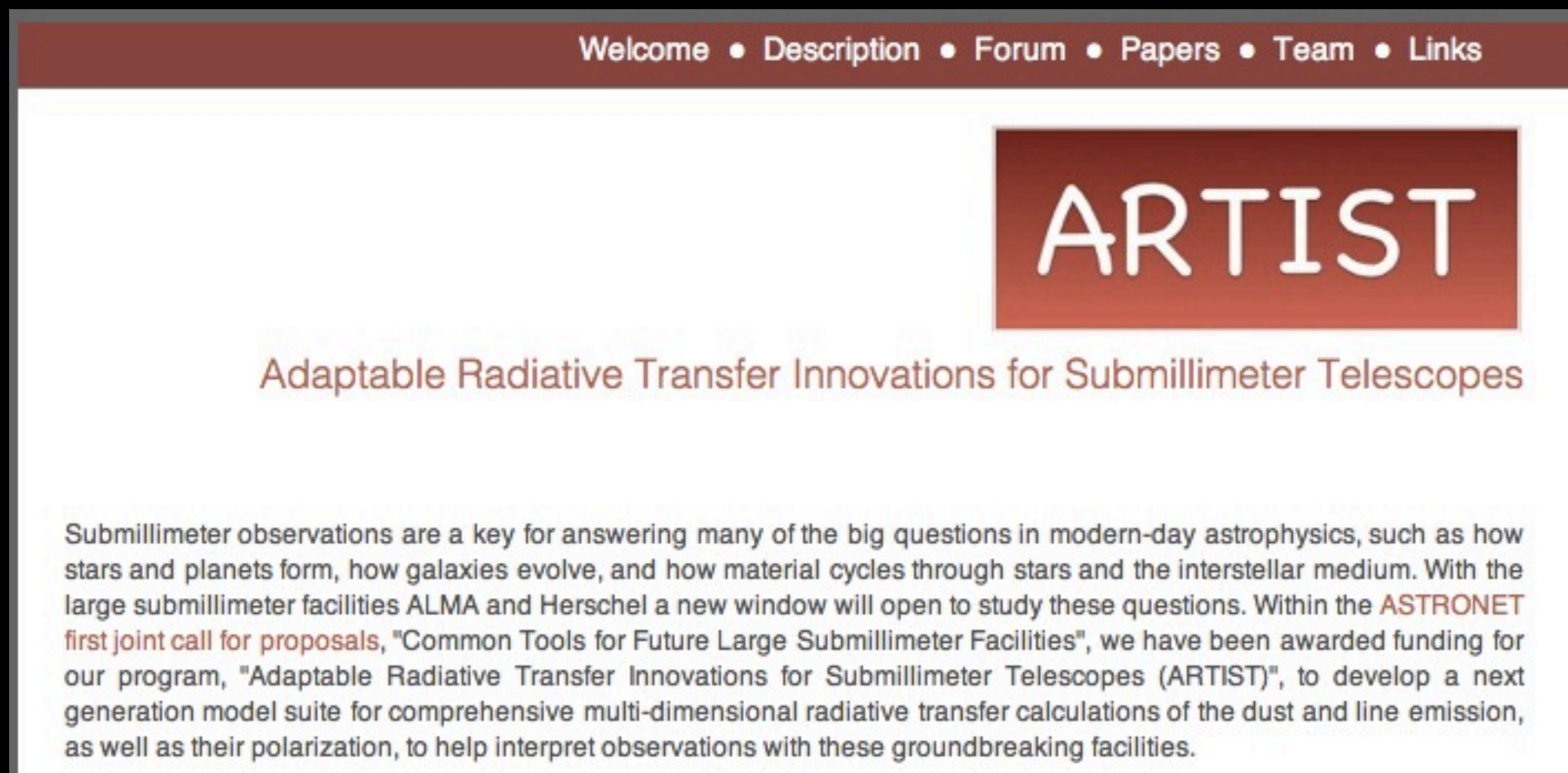
ARTIST GUI V0.0
Model Input
Excitation/Grid
Raytracing/Images
Browse models...
Model: Shu77
T [K]
30.0
time [year]
100000.0
Velocity
Model
Doppler b
Constant
Value [m/s]:
100
Model
Density
Gas temperature
Dust temperature
Opacity file:
/Users/jes/Desktop/ARTIST mod
Constant
Value:
1e-9
Browse
p/ARTIST models (*.mdl).mdl/hco+.dat
Browse
Visualization 1D/2D
View Image
Lime status display
Building Grid
Done
Smoothing Grid
Iterations
13
Min. SNR:
0.000000
Median SNR:
0.000000
Photon Propagation
Ray Tracing
None


ARTIST – Image Viewer
Chanel Maps
Moment Maps
Spectrum
DEC offset [arcsec]
30
20
10
0
-10
-20
-30
30
20
10
0
-10
-20
-30
RA offset [arcsec]
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
log(F_ν [Jy/pixel])
Moment
0th
1st
2nd
Scale
Linear
Logarithmic
Gaussian Beam Convolution
Enabled
Major axis [arcsec]
0.5
Minor axis [arcsec]
0.2
Position angle [deg]
45.0
Image
Clip min.
-1749.2014161
Clip max.
17135561.8797
ColorMap
spectral
Contour lines
0th Moment Map
Grid parameters

ARTIS - contact

ARTIST website :

http://youngstars.nbi.dk/artist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Adaptable Radiative Transfer Innovations for Submillimeter Telescopes

Submillimeter observations are a key for answering many of the big questions in modern-day astrophysics, such as how stars and planets form, how galaxies evolve, and how material cycles through stars and the interstellar medium. With the large submillimeter facilities ALMA and Herschel a new window will open to study these questions. Within the ASTRONET first joint call for proposals, "Common Tools for Future Large Submillimeter Facilities", we have been awarded funding for our program, "Adaptable Radiative Transfer Innovations for Submillimeter Telescopes (ARTIST)", to develop a next generation model suite for comprehensive multi-dimensional radiative transfer calculations of the dust and line emission, as well as their polarization, to help interpret observations with these groundbreaking facilities.

ARTIS - contact

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