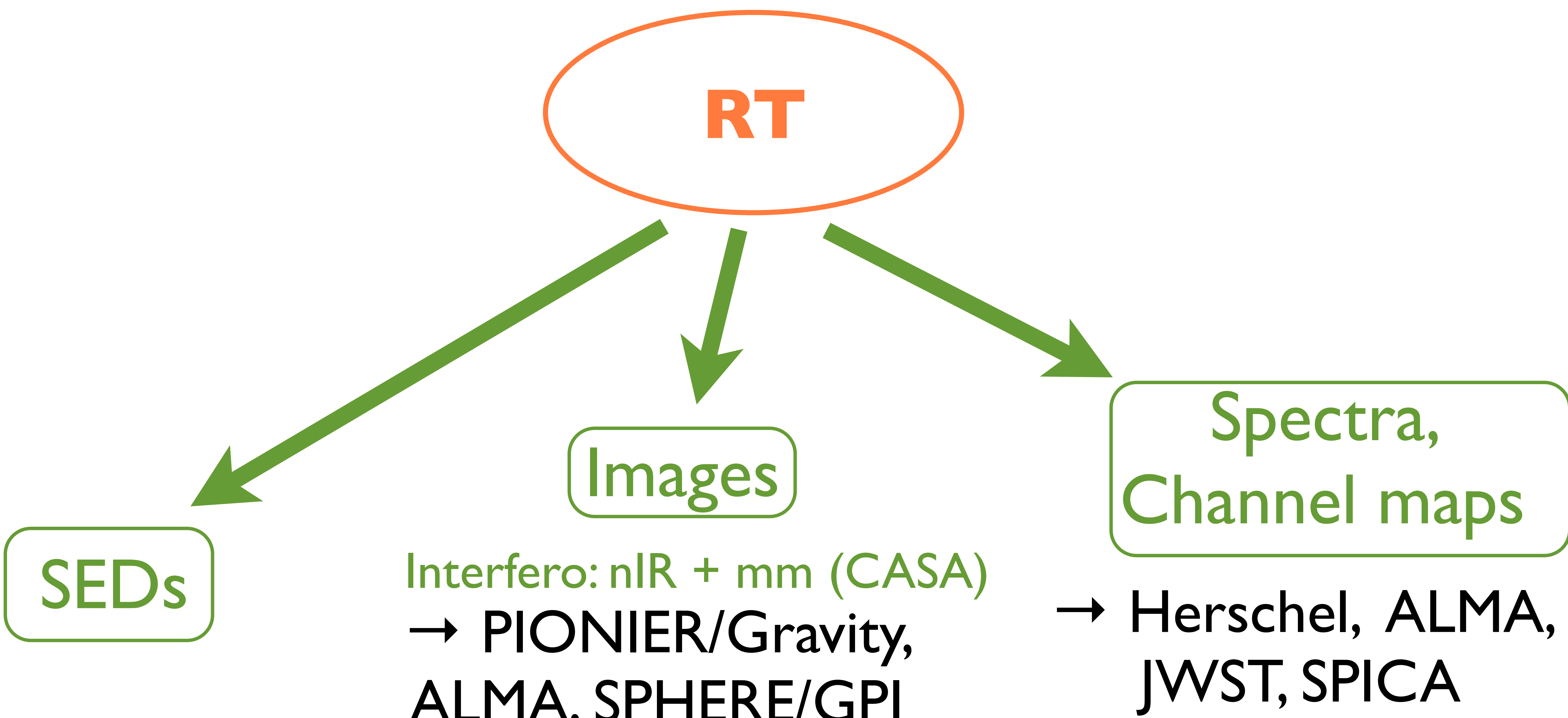
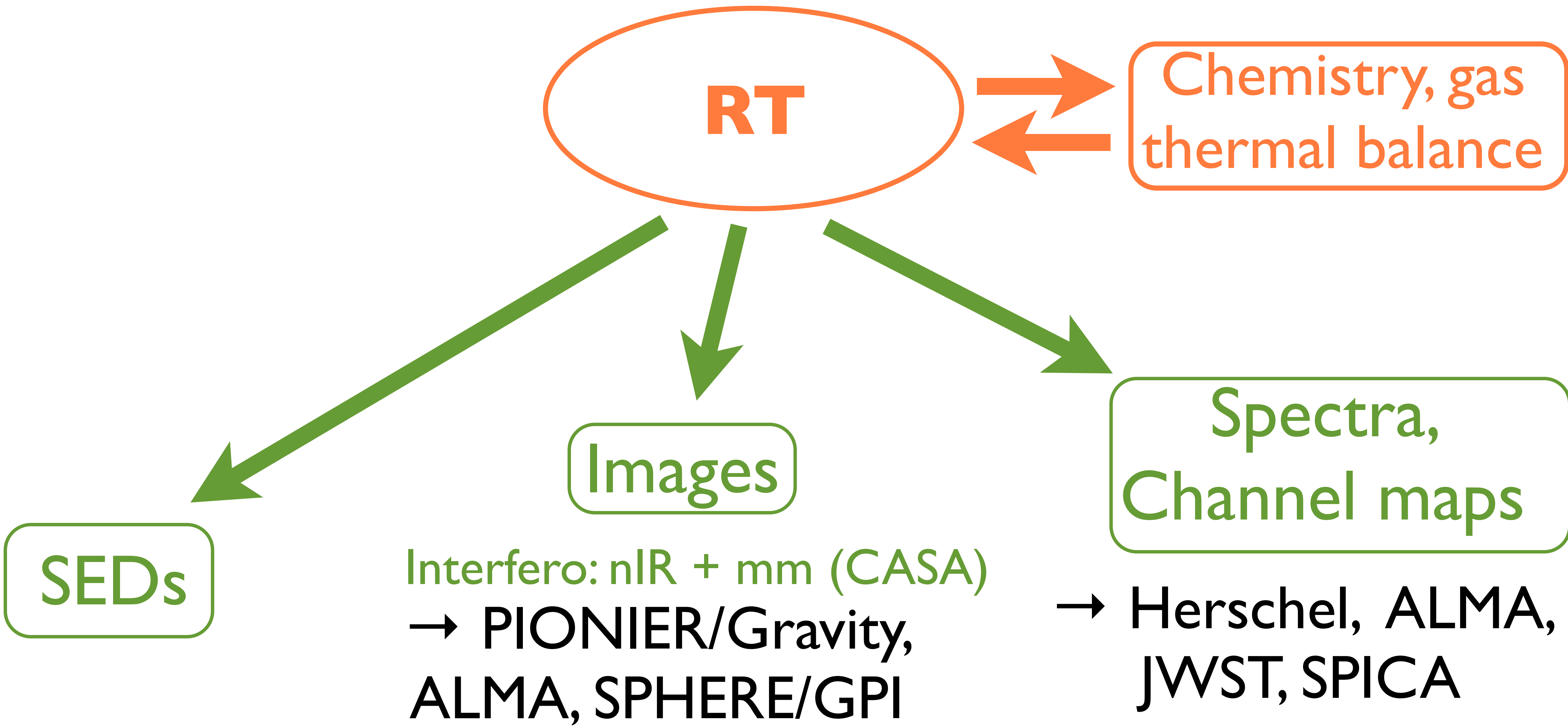
Can we build a **complete** set of tools ?

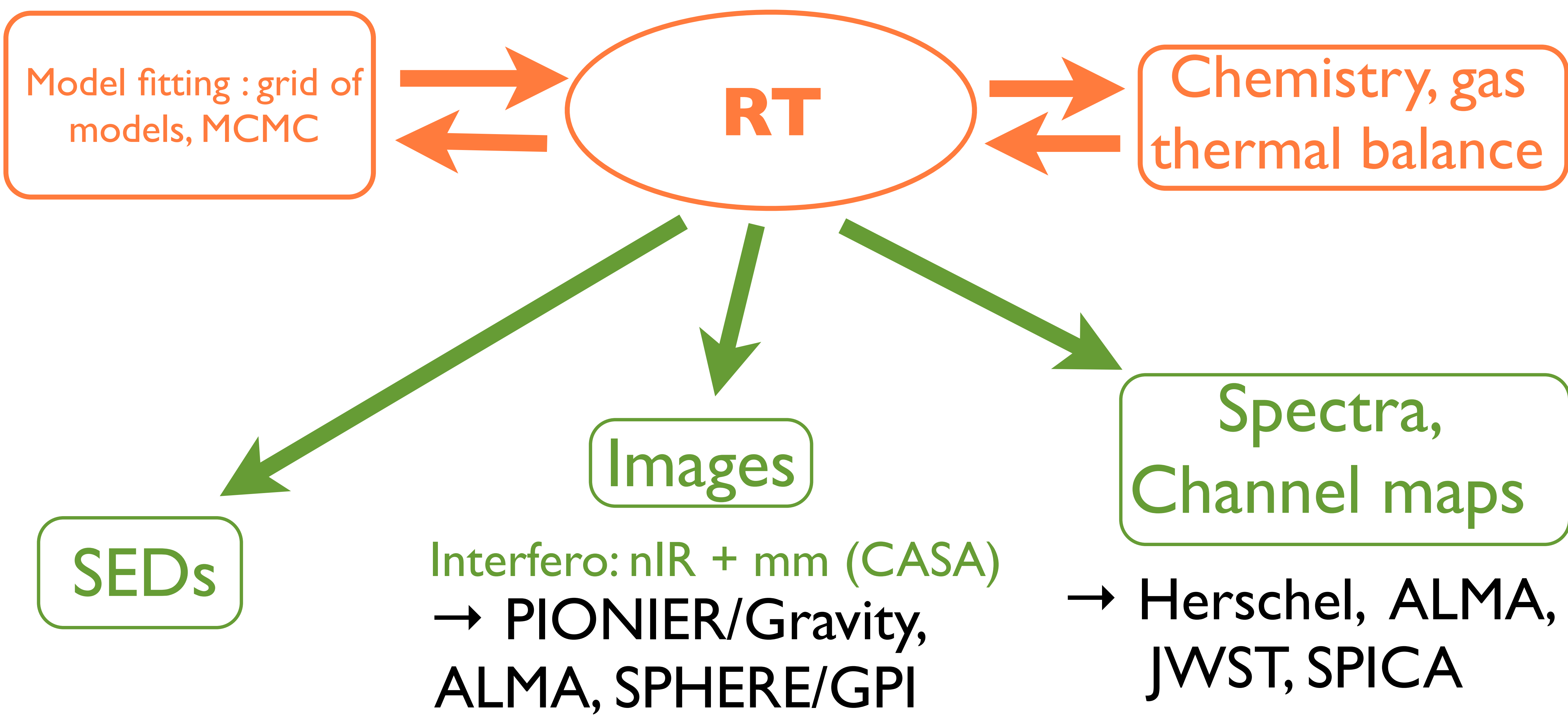
Can we build a **complete** set of tools ?



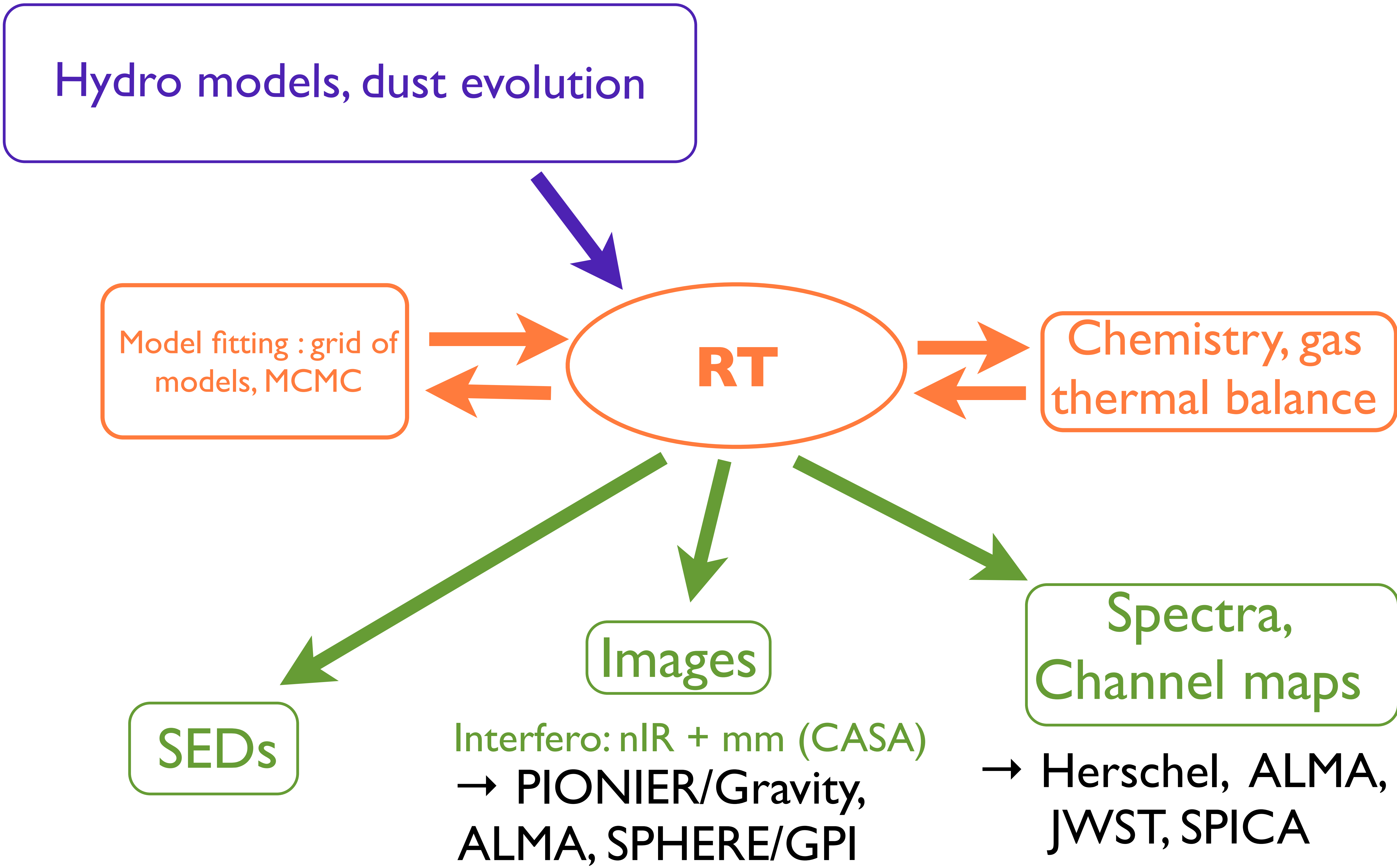
Can we build a **complete** set of tools ?



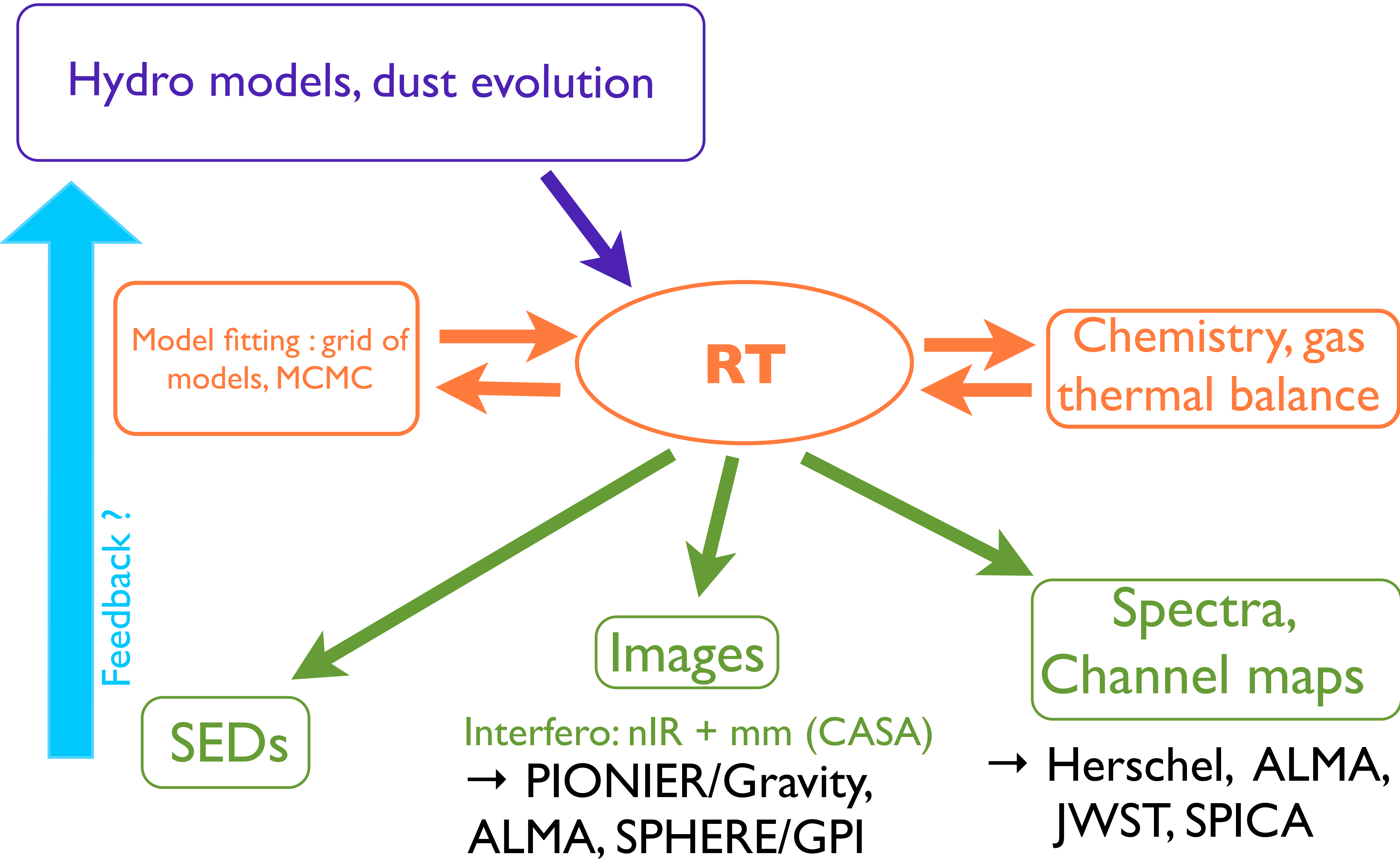
Can we build a **complete** set of tools ?



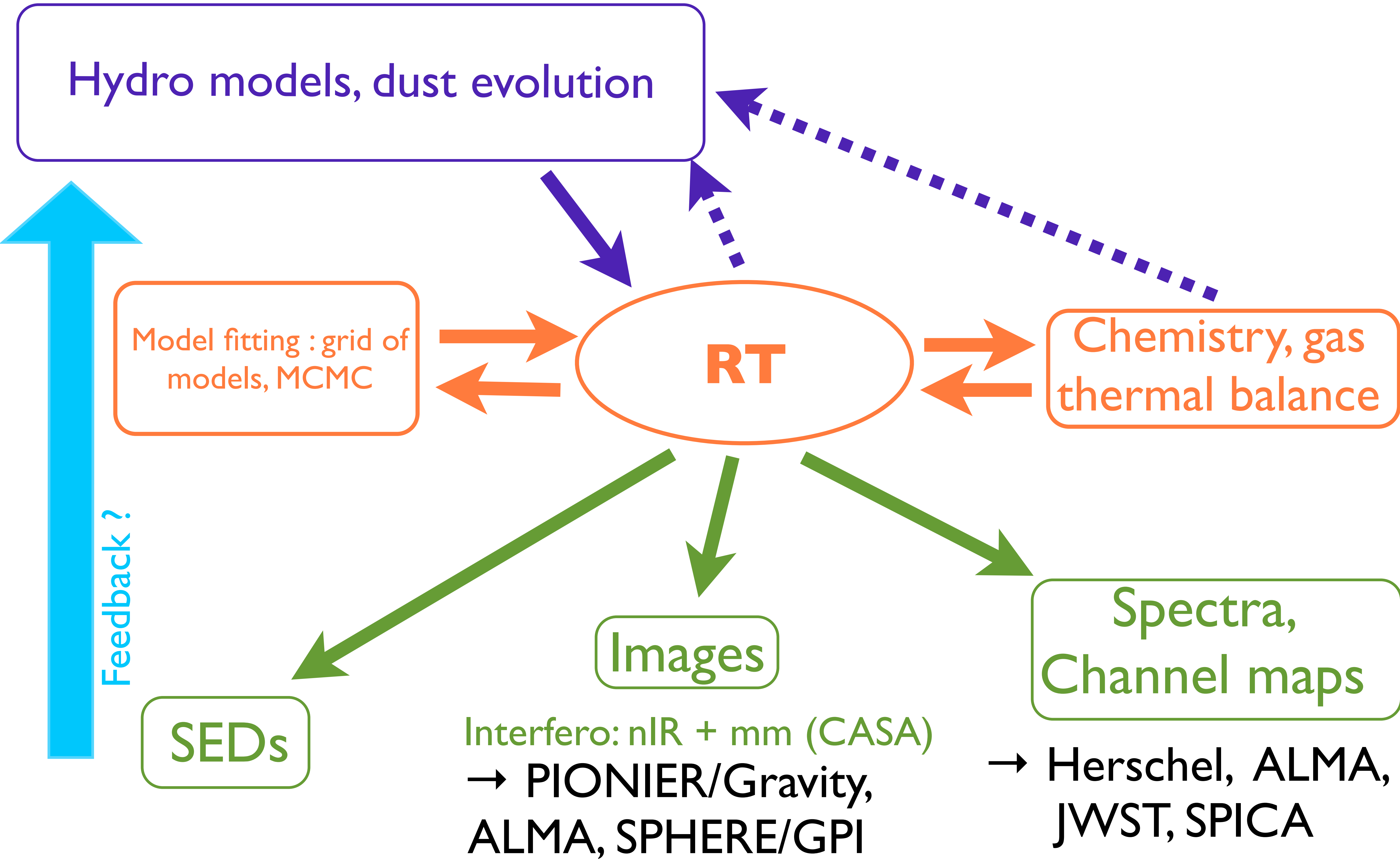
Can we build a **complete** set of tools ?



Can we build a **complete** set of tools ?



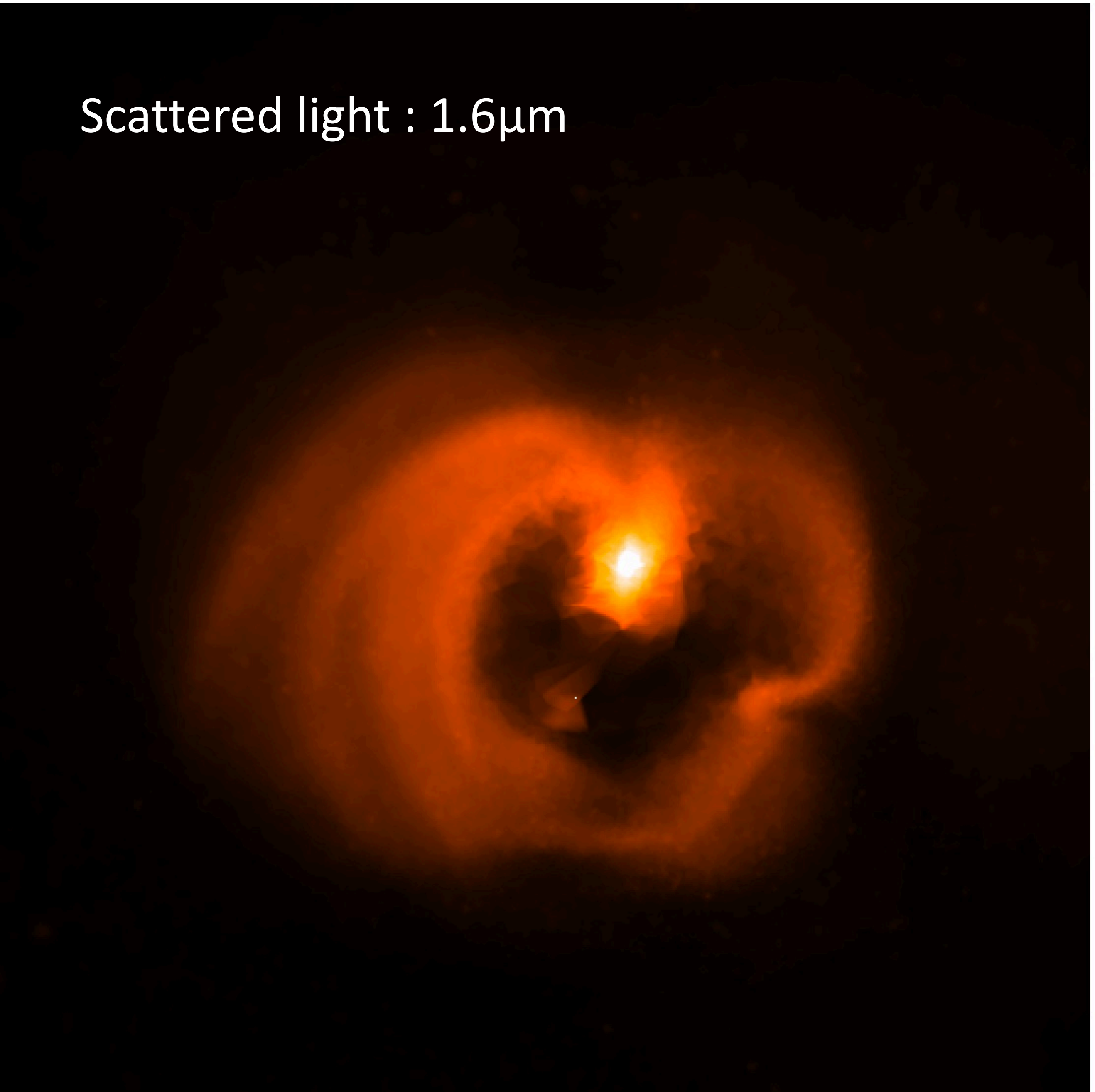
Can we build a **complete** set of tools ?

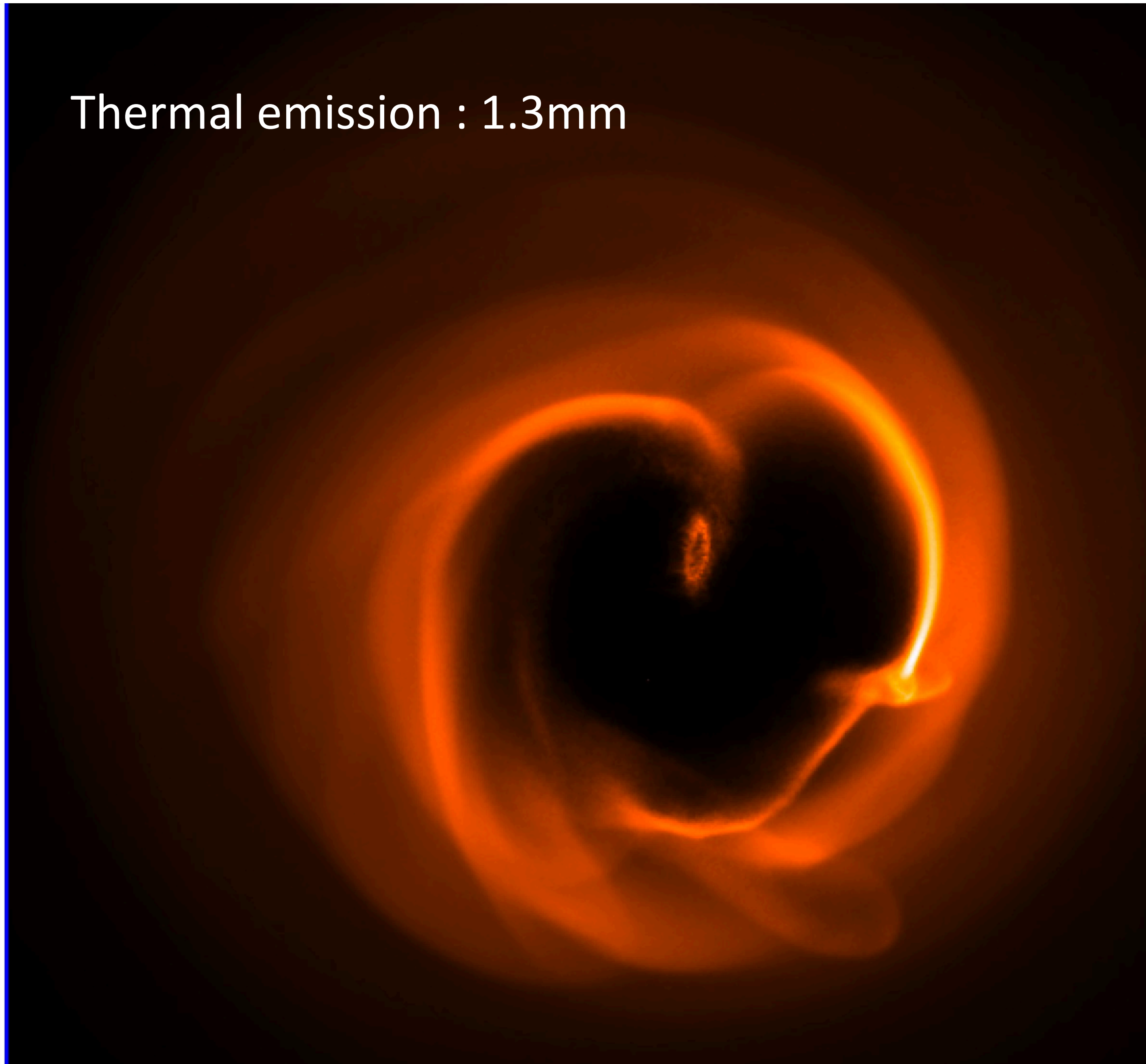


Example of post-processing

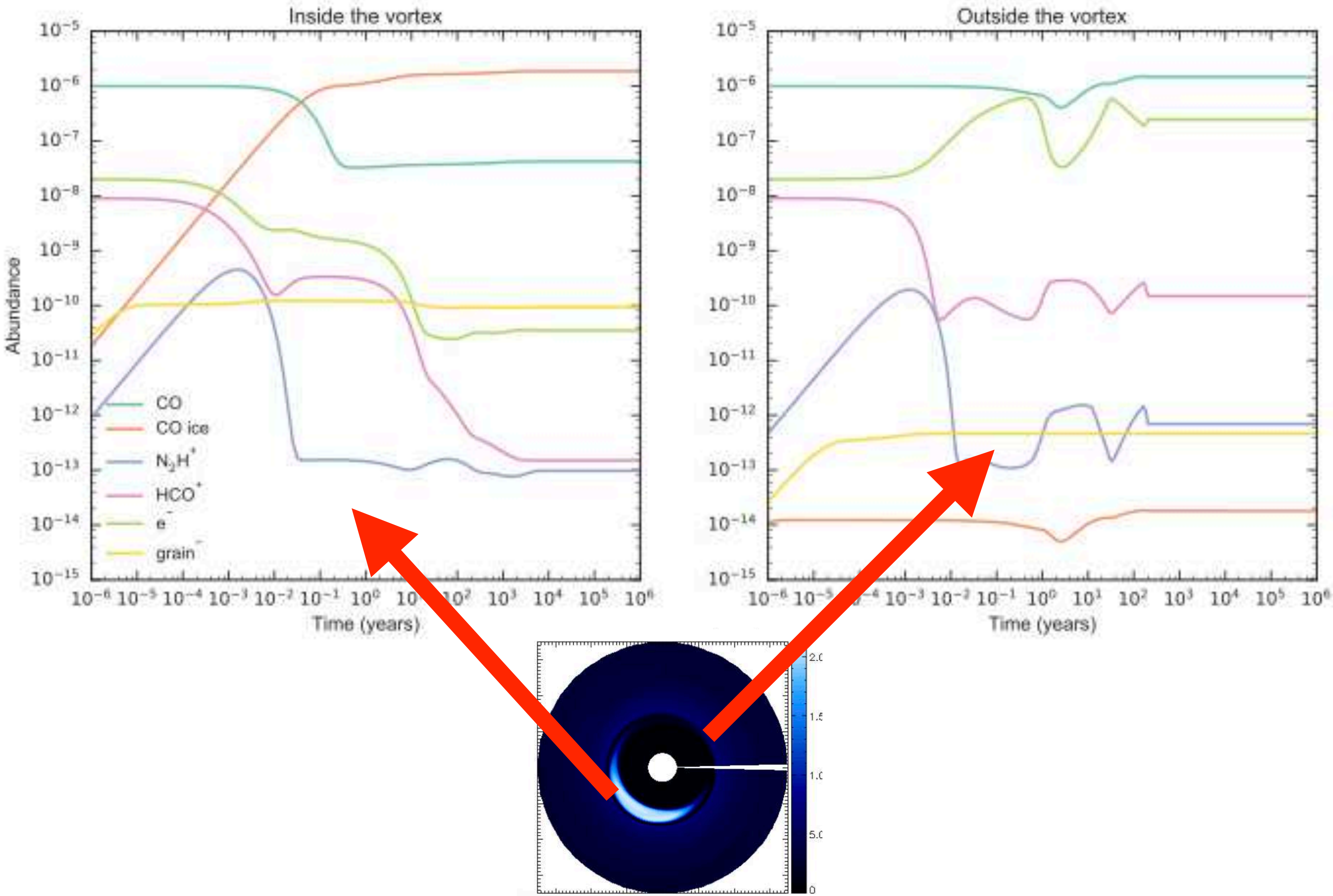
Inclined binary with a disc:
1 million phantom SPH particules → 1 million MCFOST Voronoi cells

mcfost <para_file> -phantom <dump>



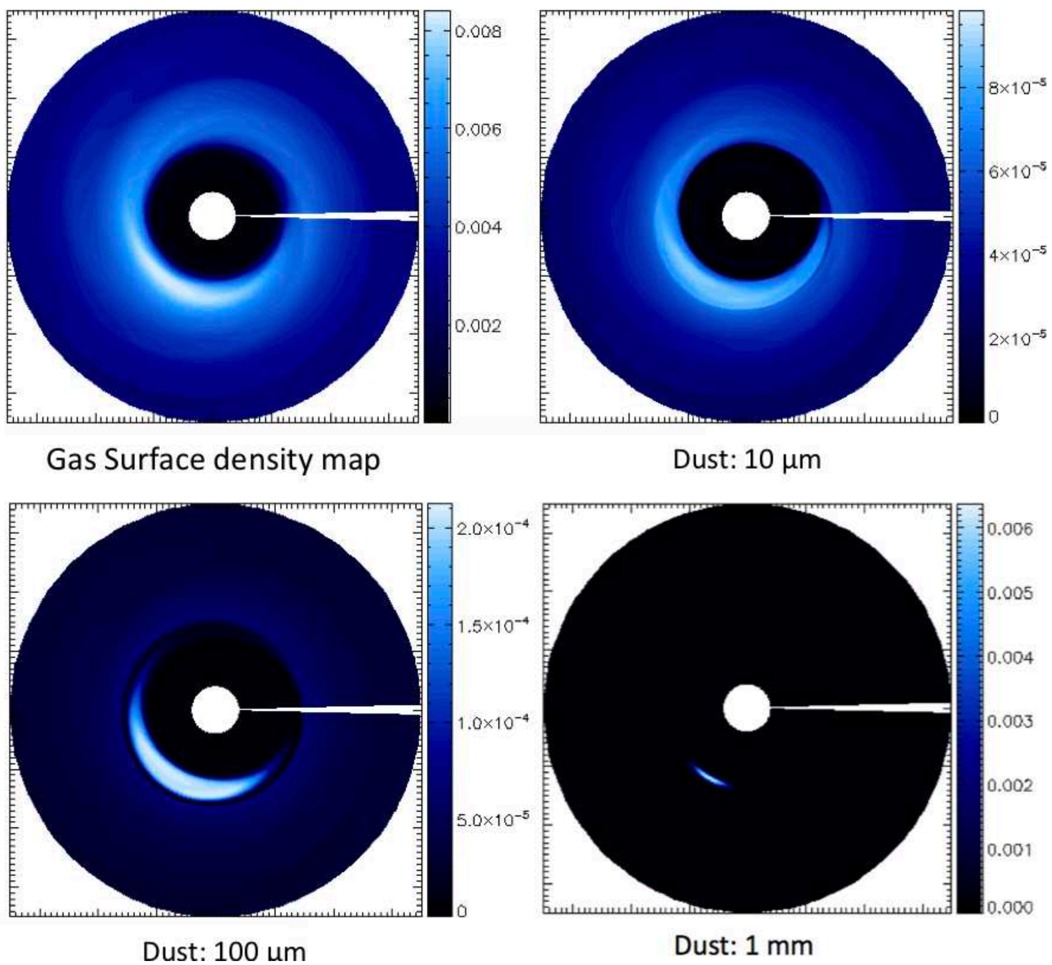


Dust trapping : effect on lines



Dust: 100 um

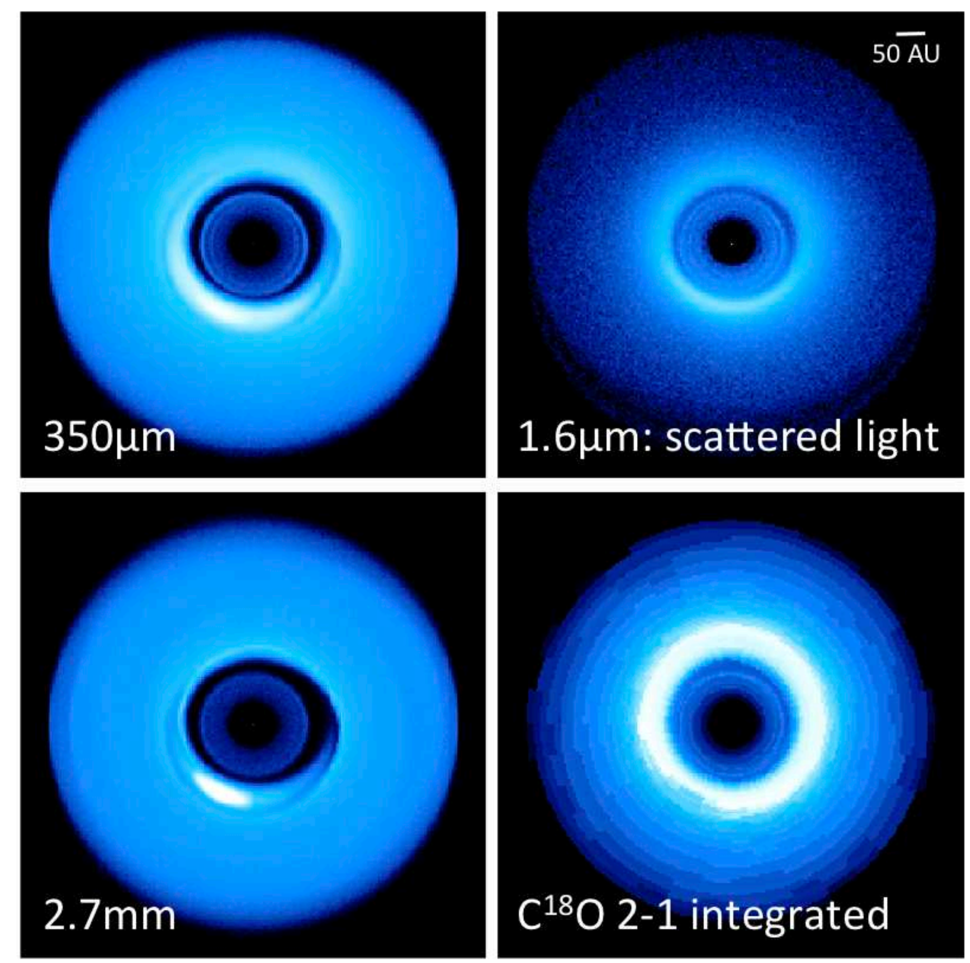
Coupling hydro + chemistry + RT



MCFOST

+

Astrochem



Fargo model

Live coupling hydro + RT

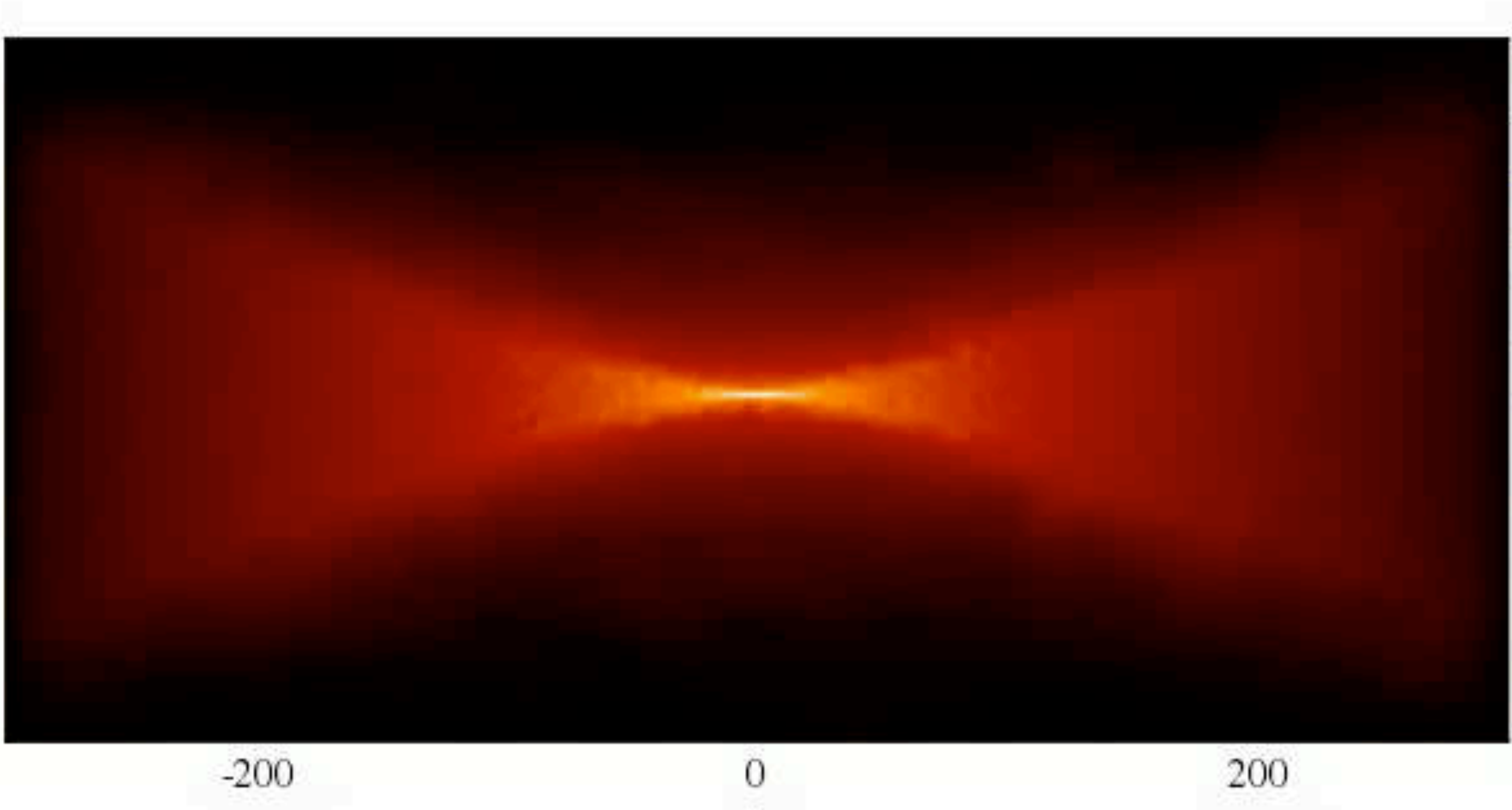
- mcfost is now available as a library (libmcfost.a)

  syntax specific to phantom (thanks Daniel) so far,
  but trivial to extend to other code

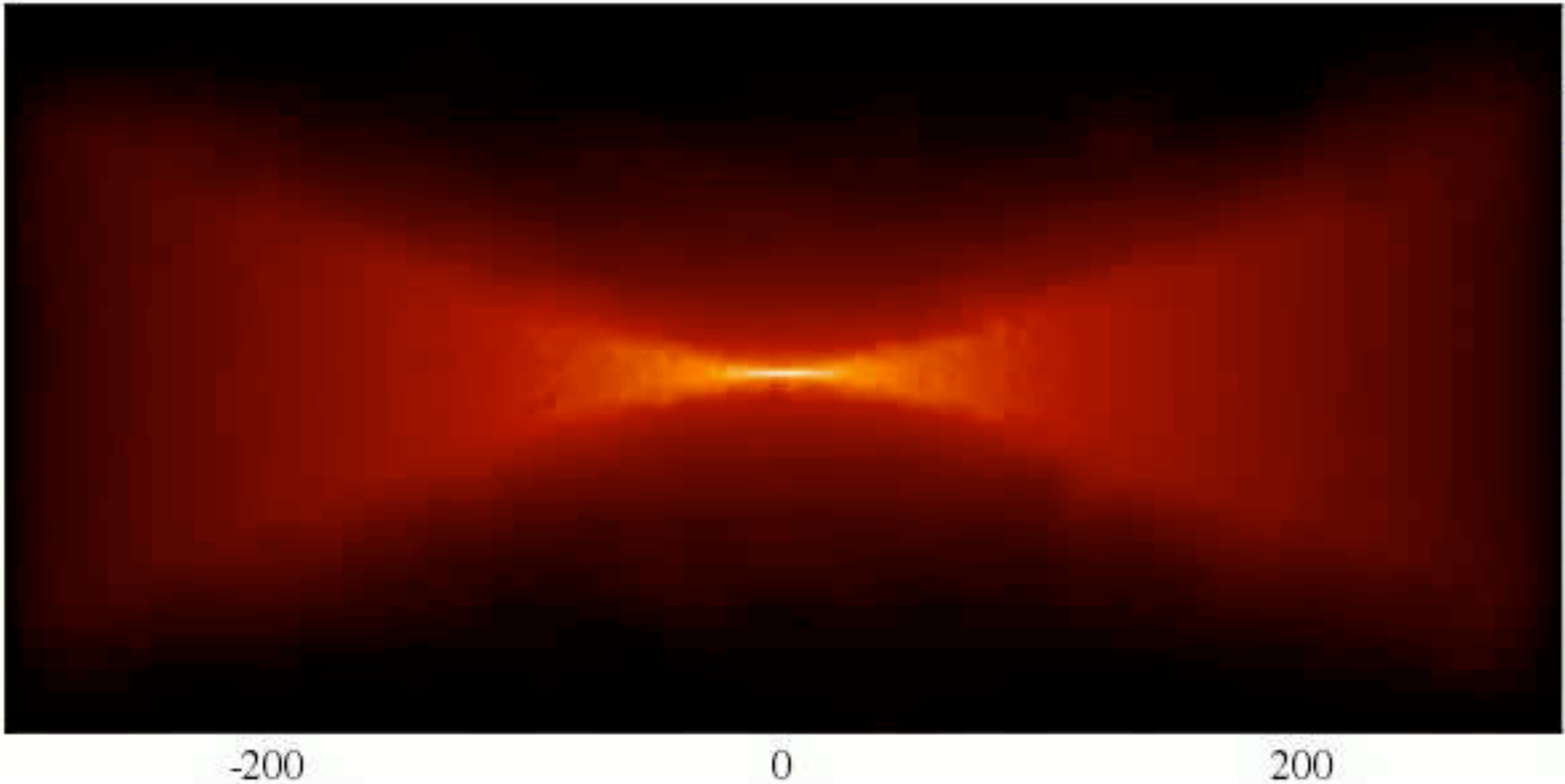
```
subroutine run_mcfost_phantom(np,nptmass,ntypes,ndusttypes,npoftype,xyzh,iphase,grainsize,&
     dustfrac, massoftype,xyzmh_ptmass,hfact,umass,utime,udist,graindens,compute_Frad, Tdust, Frad,mu_gas,ierr)
```

- pass SPH particles (position, velocity, n(a))
- MCFOST performs Voronoi tessellation + radiative transfer and returns T_{dust} + radiation pressure vectors without interpolation
- takes ~ few minutes for 10^6 particles :
  - can be performed every few time steps yo get full hydro+RT simulations

MCFOST + phantom :
recovering hydrostatic equilibrium



MCFOST + phantom : recovering hydrostatic equilibrium



Gas temperature

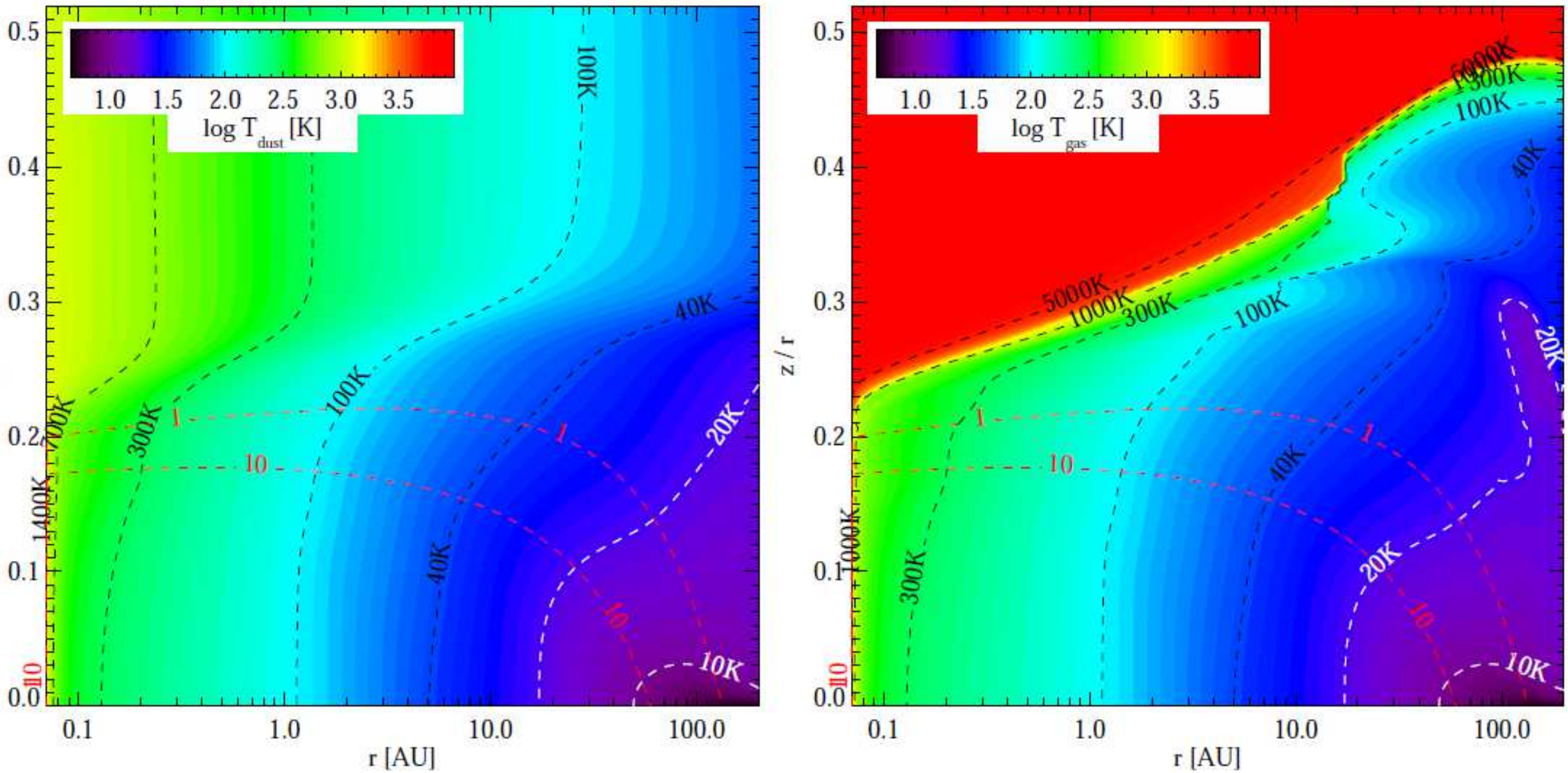


Figure 4: Resulting dust and gas temperature structures.

mcfost + ProDiMo (Woitke 2009) model

Gas heating & cooling

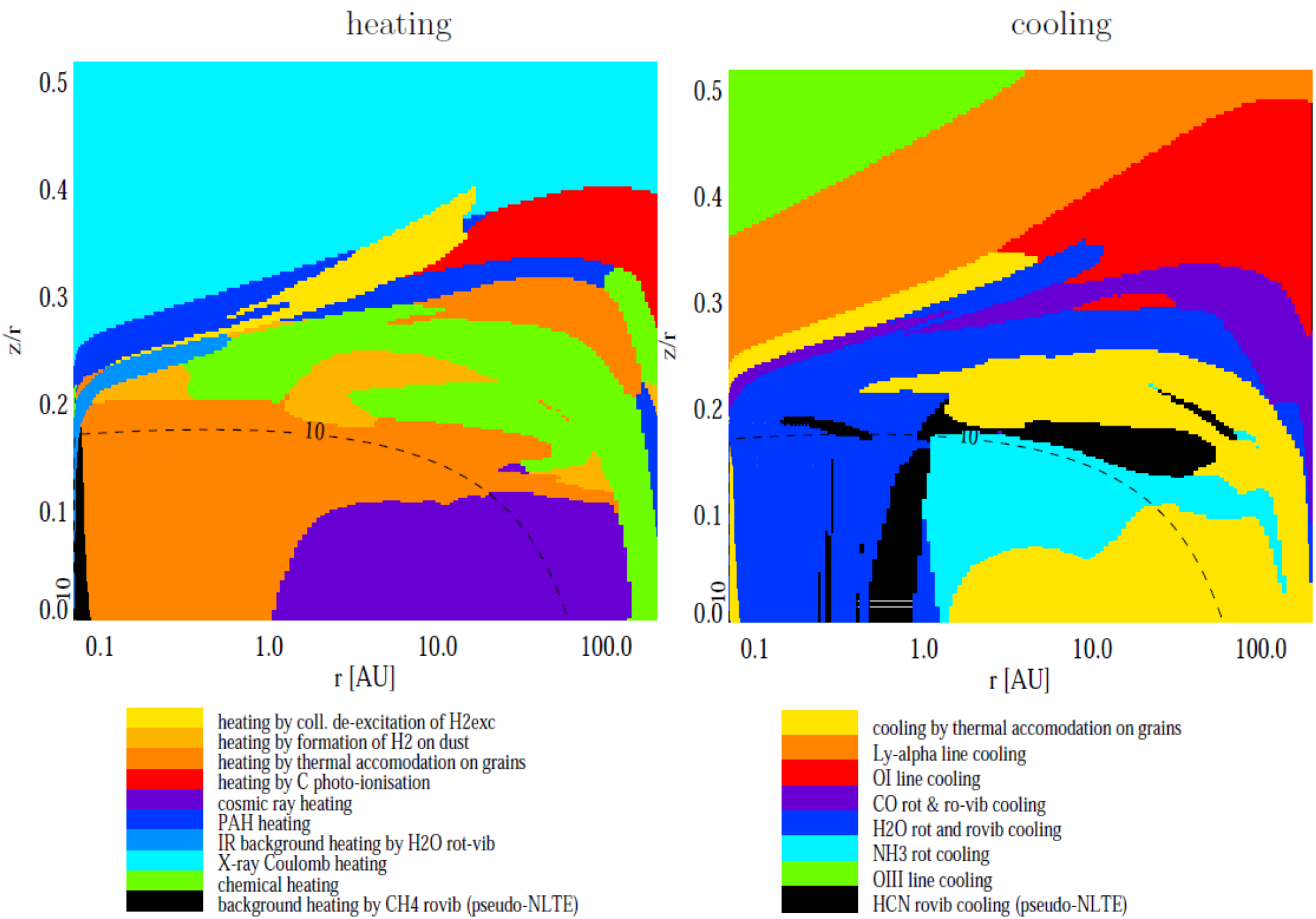
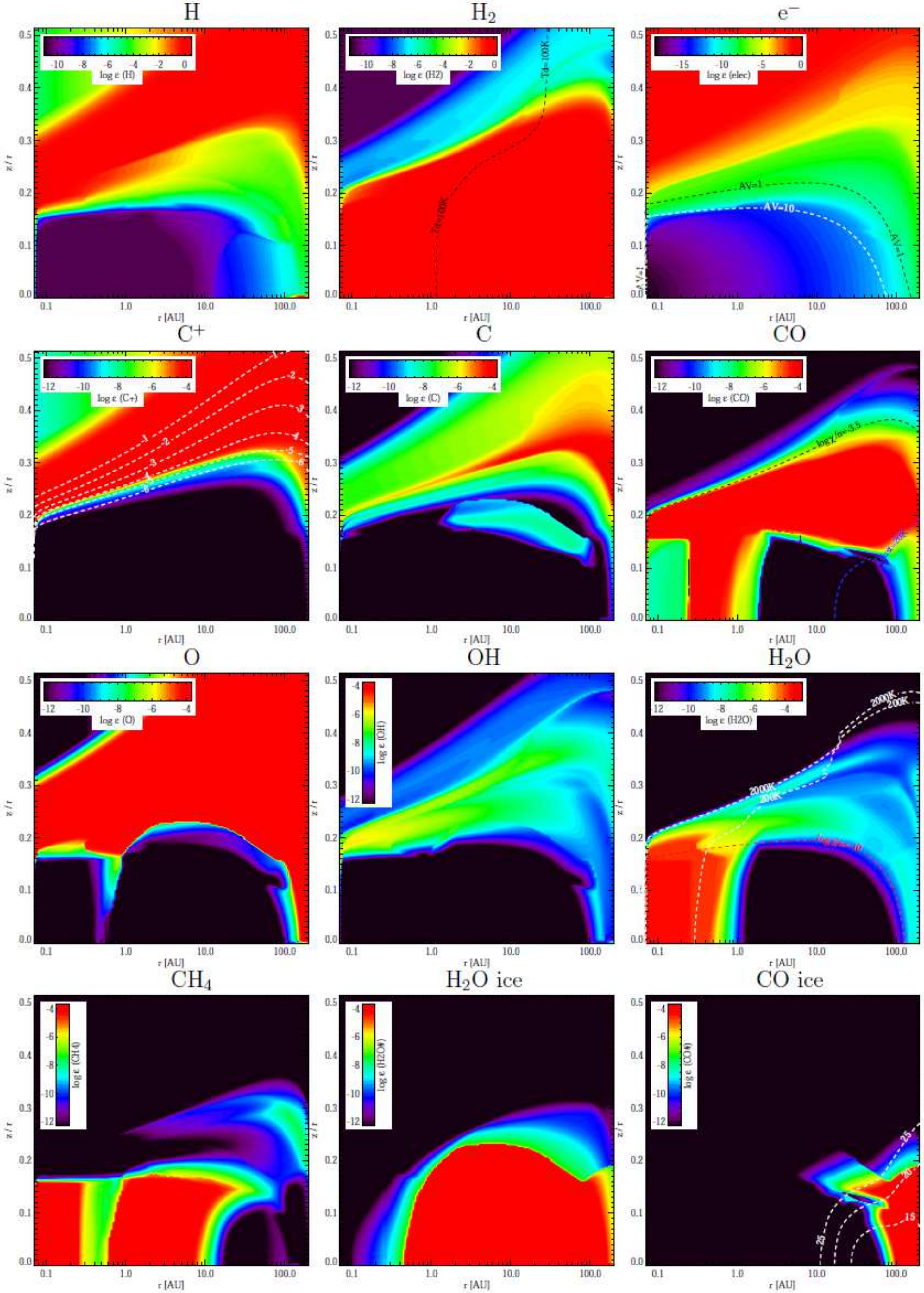


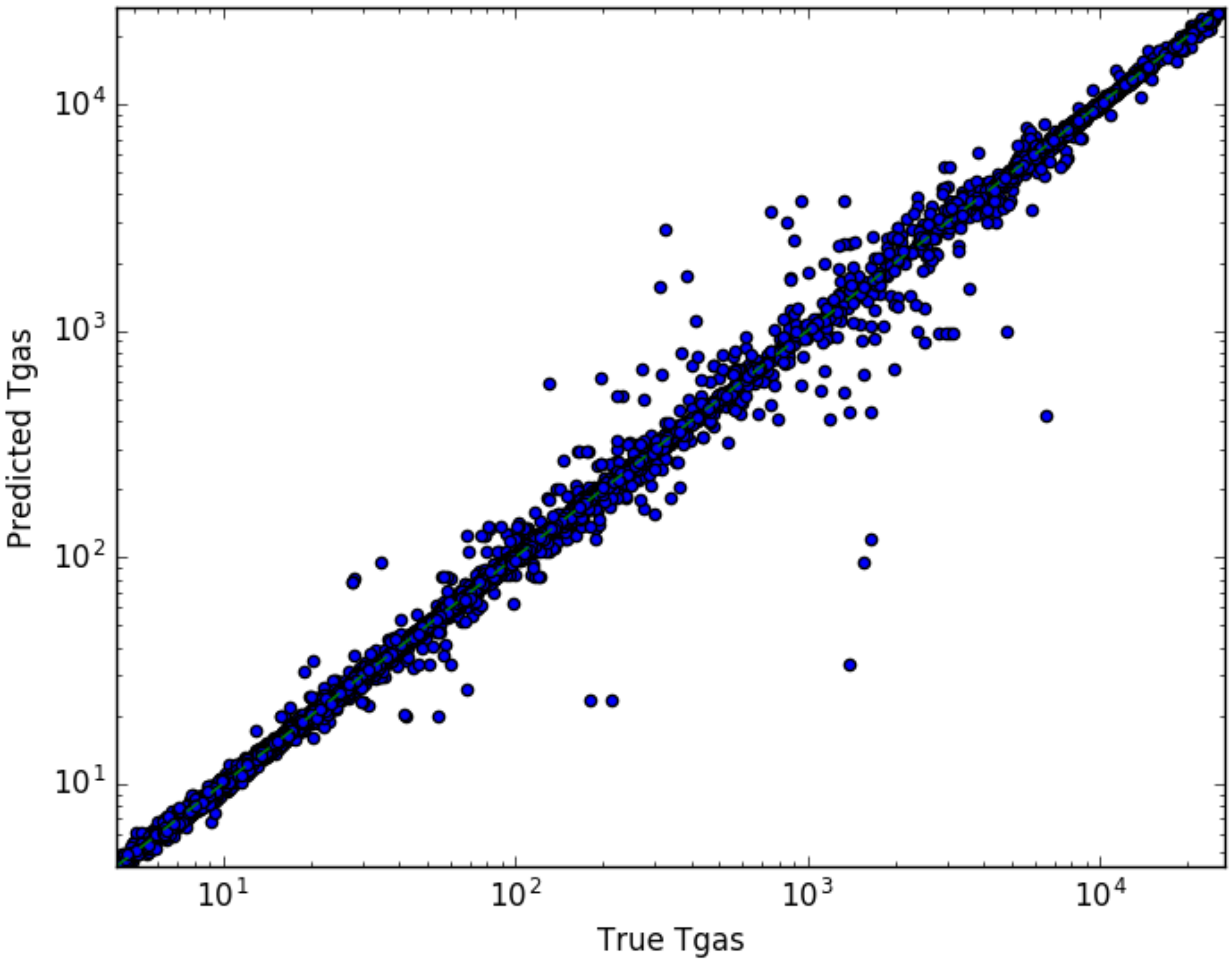
Figure 5: Most important heating and cooling processes for the gas.

Chemical abundances



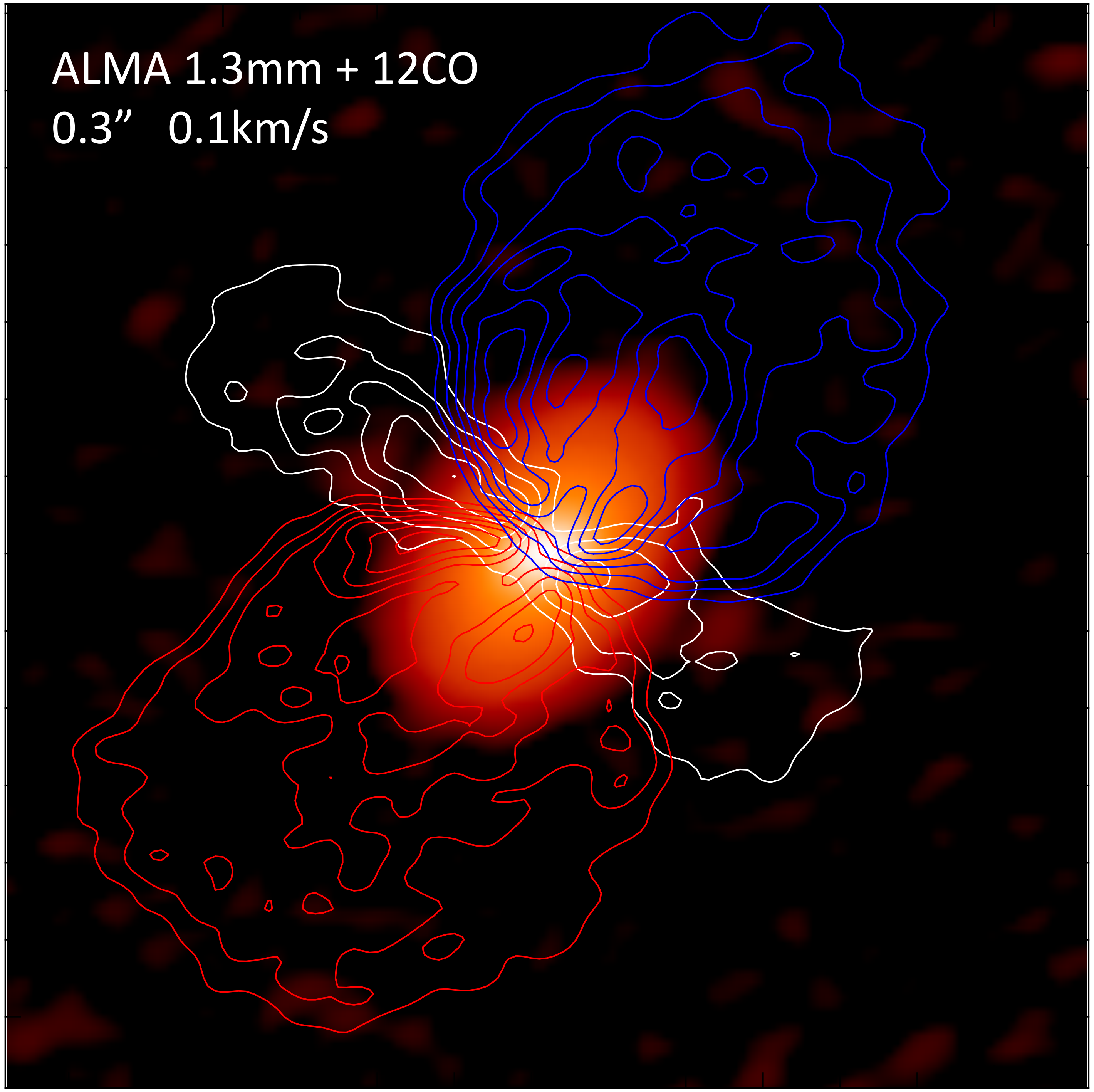
Estimating Tgas via Machine Learning

Prediction from 100 ProDiMo models training set



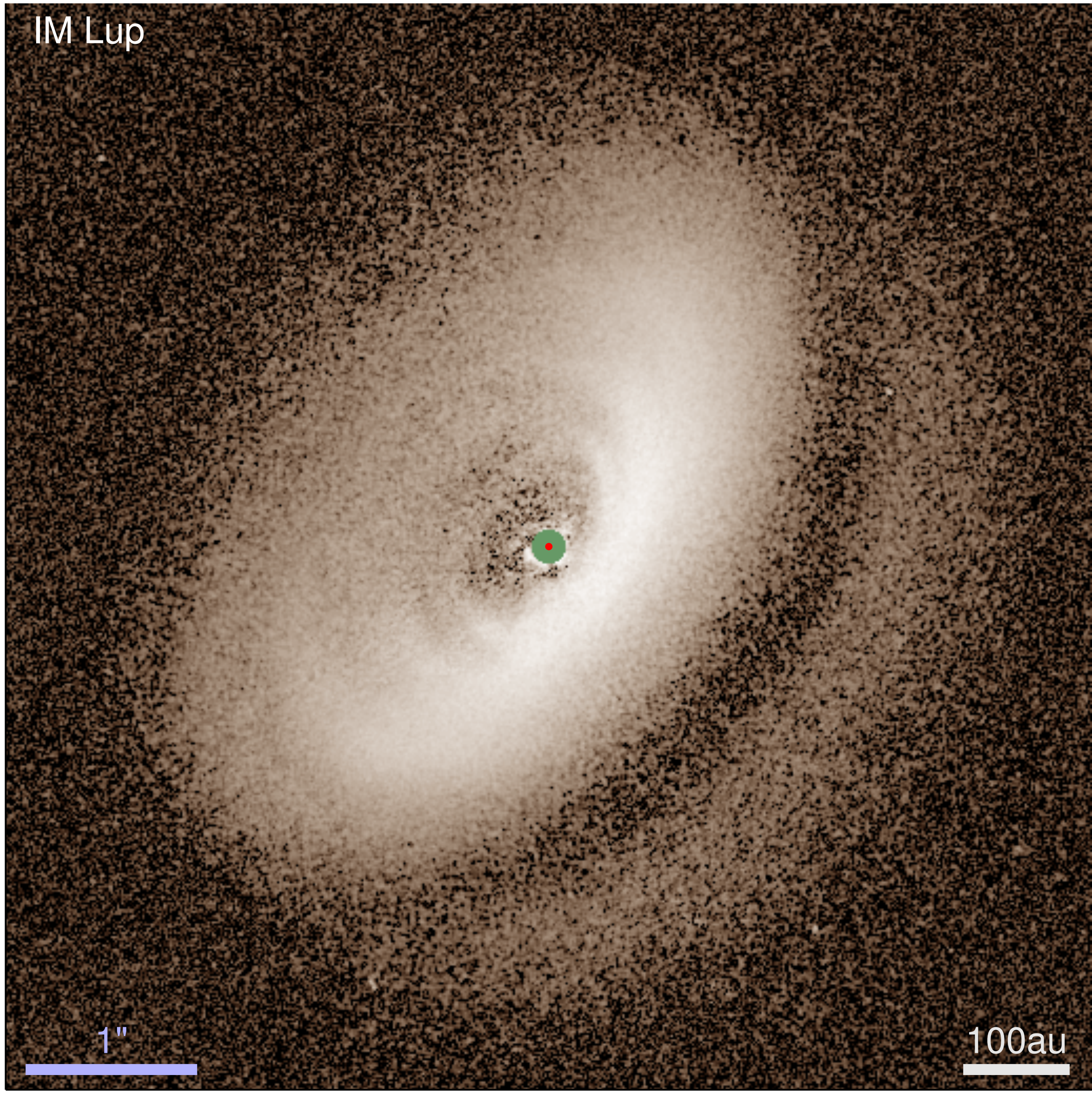
Also predicts election density (-> MHD), molecular abundances

ALMA and SPHERE views of IM Lupi



Pinte et al, 2017

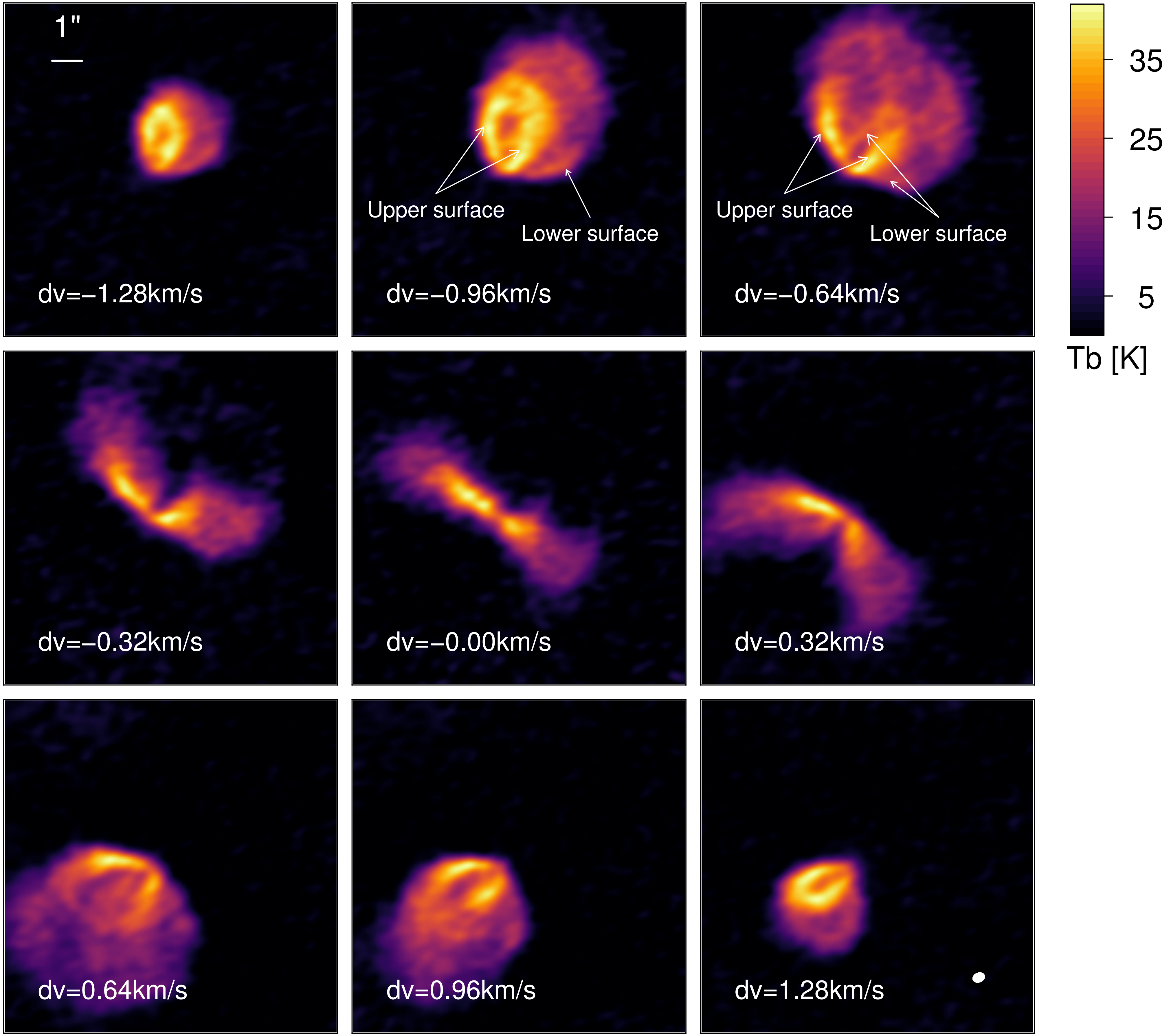
SPHERE H band DPI   ~ 0.03”



Avenhaus et al, in prep.

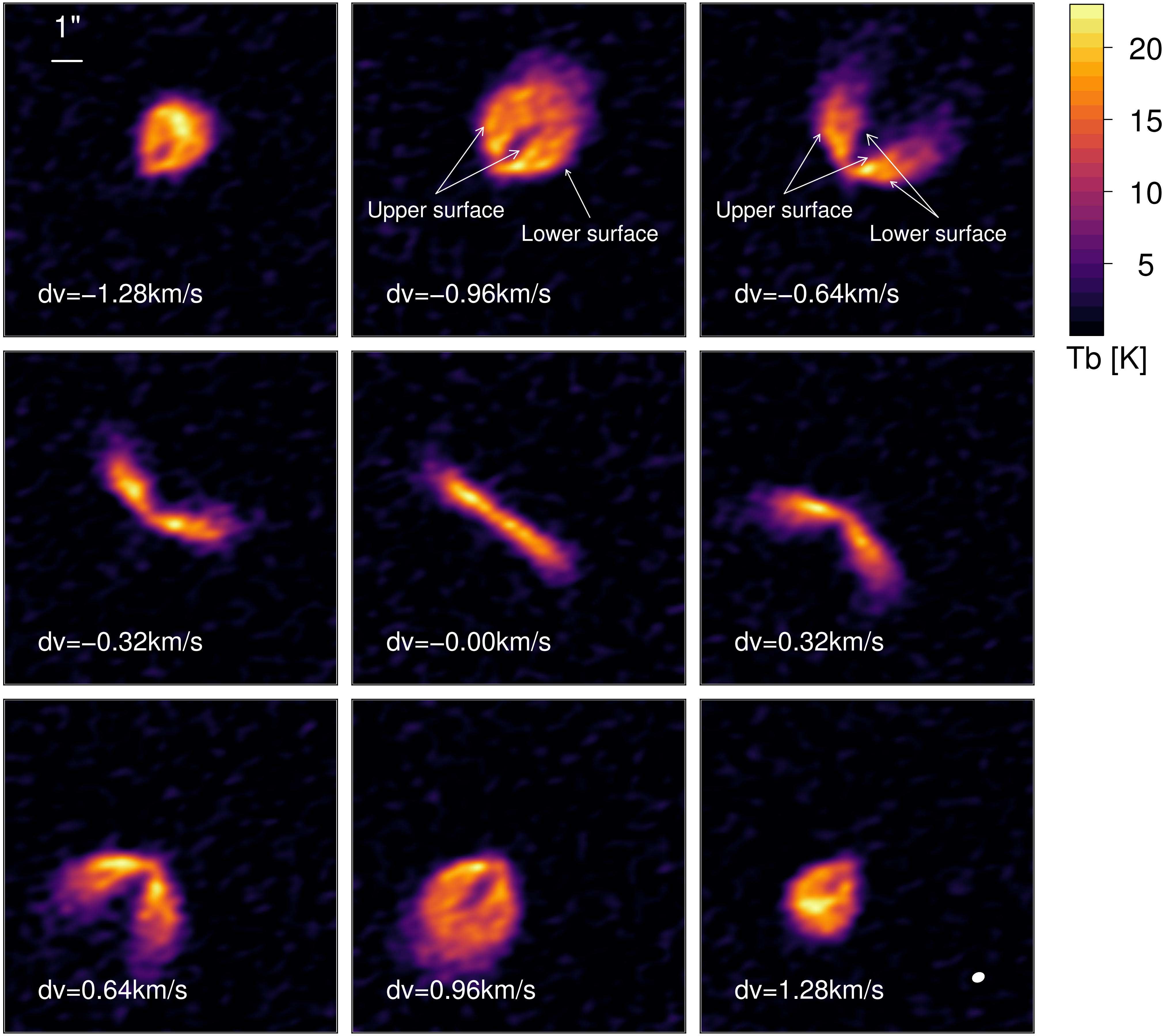
i = 50 deg

12CO (2-1)

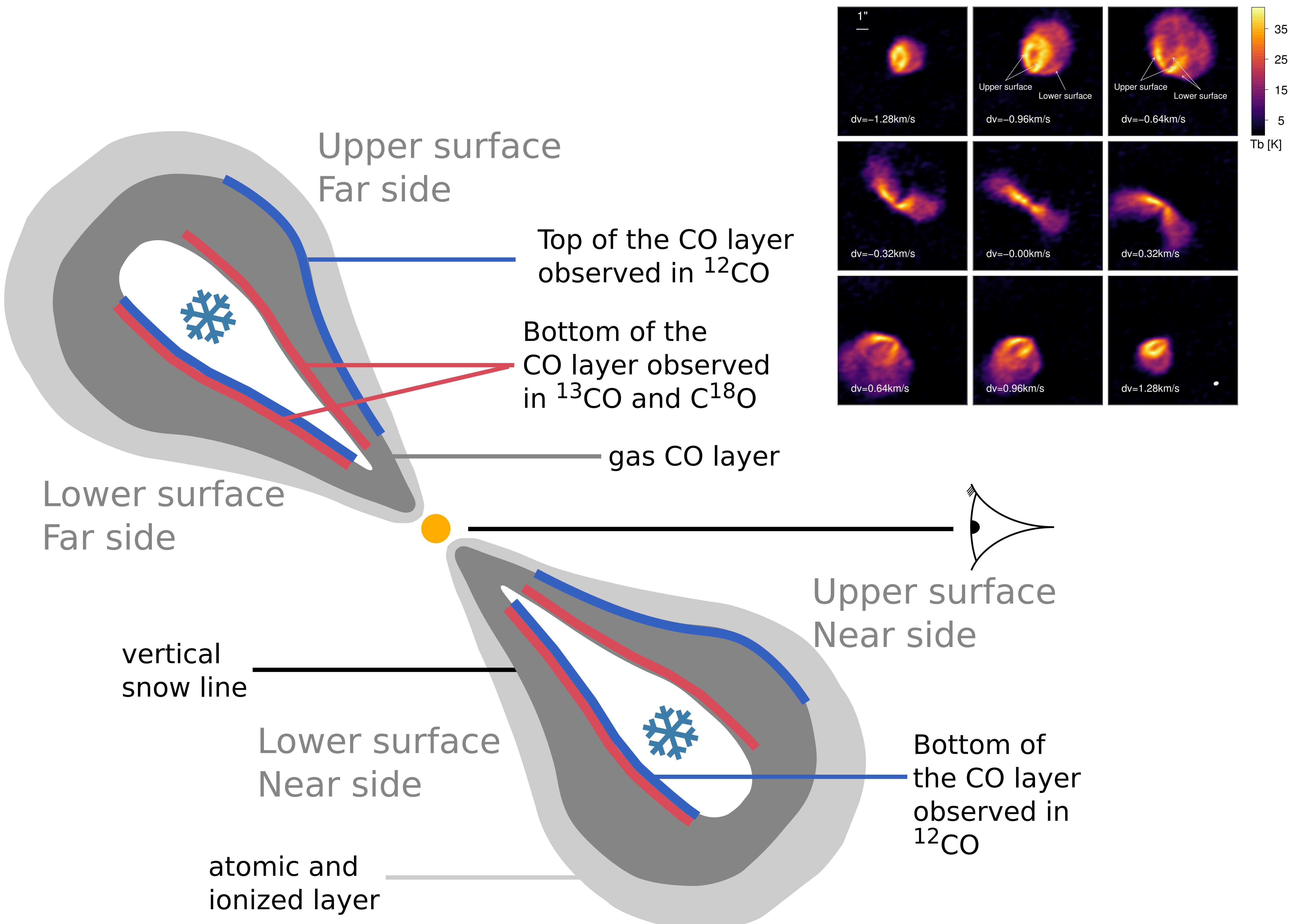


1"
Upper surface
Lower surface
Upper surface
Lower surface
dv=–1.28km/s
dv=–0.96km/s
dv=–0.64km/s
dv=–0.32km/s
dv=–0.00km/s
dv=0.32km/s
dv=0.64km/s
dv=0.96km/s
dv=1.28km/s
35
25
15
5
Tb [K]

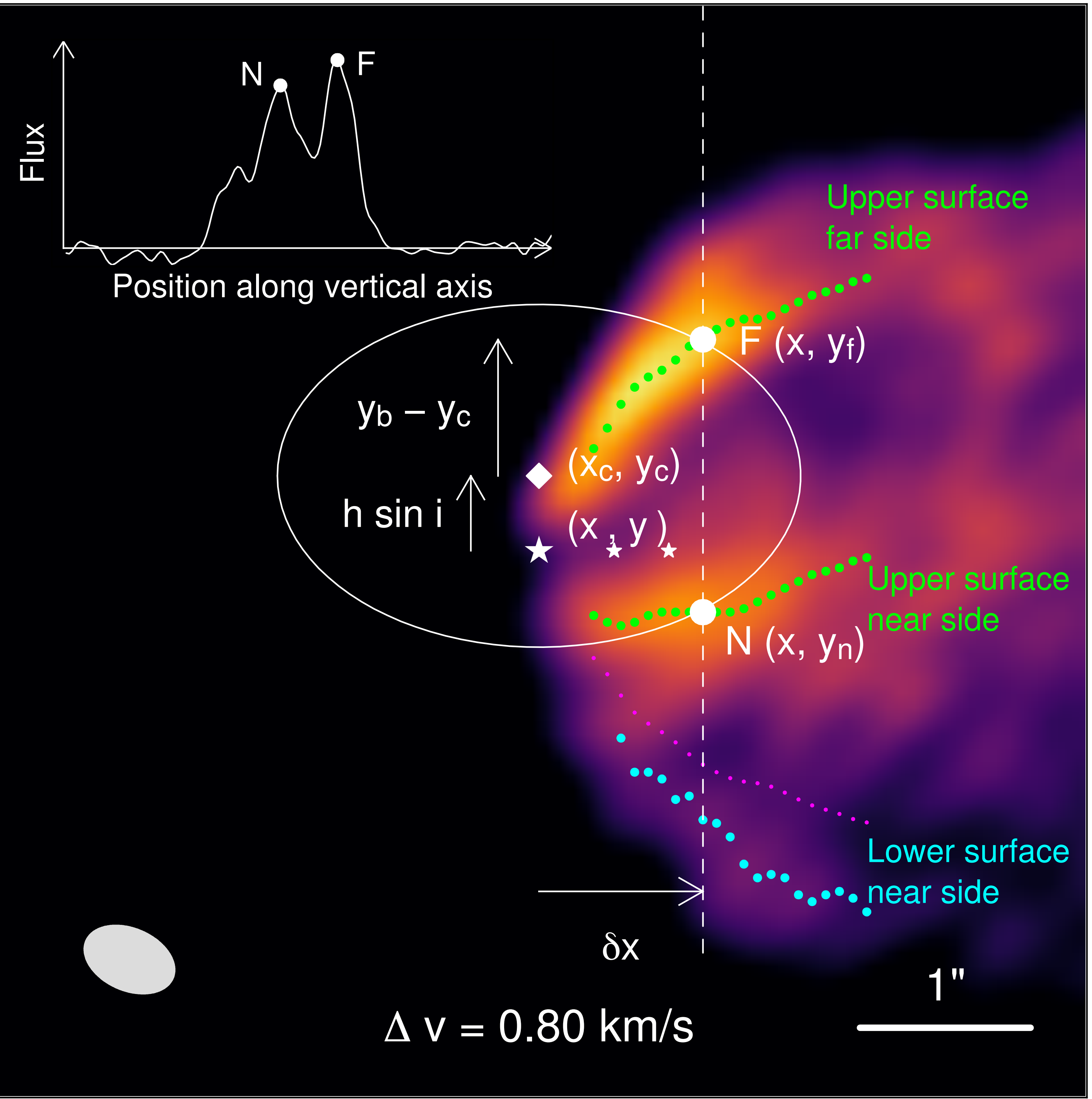
13CO (2-1)



1"
Upper surface
Lower surface
Upper surface
Lower surface
dv=−1.28km/s
dv=−0.96km/s
dv=−0.64km/s
dv=−0.32km/s
dv=−0.00km/s
dv=0.32km/s
dv=0.64km/s
dv=0.96km/s
dv=1.28km/s
20
15
10
5
Tb [K]


Upper surface
Far side
Top of the CO layer
observed in ^{12}CO
Bottom of the
CO layer observed
in ^{13}CO and $C^{18}O$
gas CO layer
Lower surface
Far side
Upper surface
Near side
vertical
snow line
Lower surface
Near side
Bottom of
the CO layer
observed in
^{12}CO
atomic and
ionized layer
1"
Upper surface
Lower surface
dv=−1.28km/s
dv=−0.96km/s
dv=−0.64km/s
dv=−0.32km/s
dv=−0.00km/s
dv=0.32km/s
dv=0.64km/s
dv=0.96km/s
dv=1.28km/s
35
25
15
5
Tb [K]

Reconstructing the altitude, velocity and temperature of the CO emitting layers



$$r = \sqrt{(x - x_\star)^2 + \left(\frac{y_f - y_c}{\cos i}\right)^2}$$

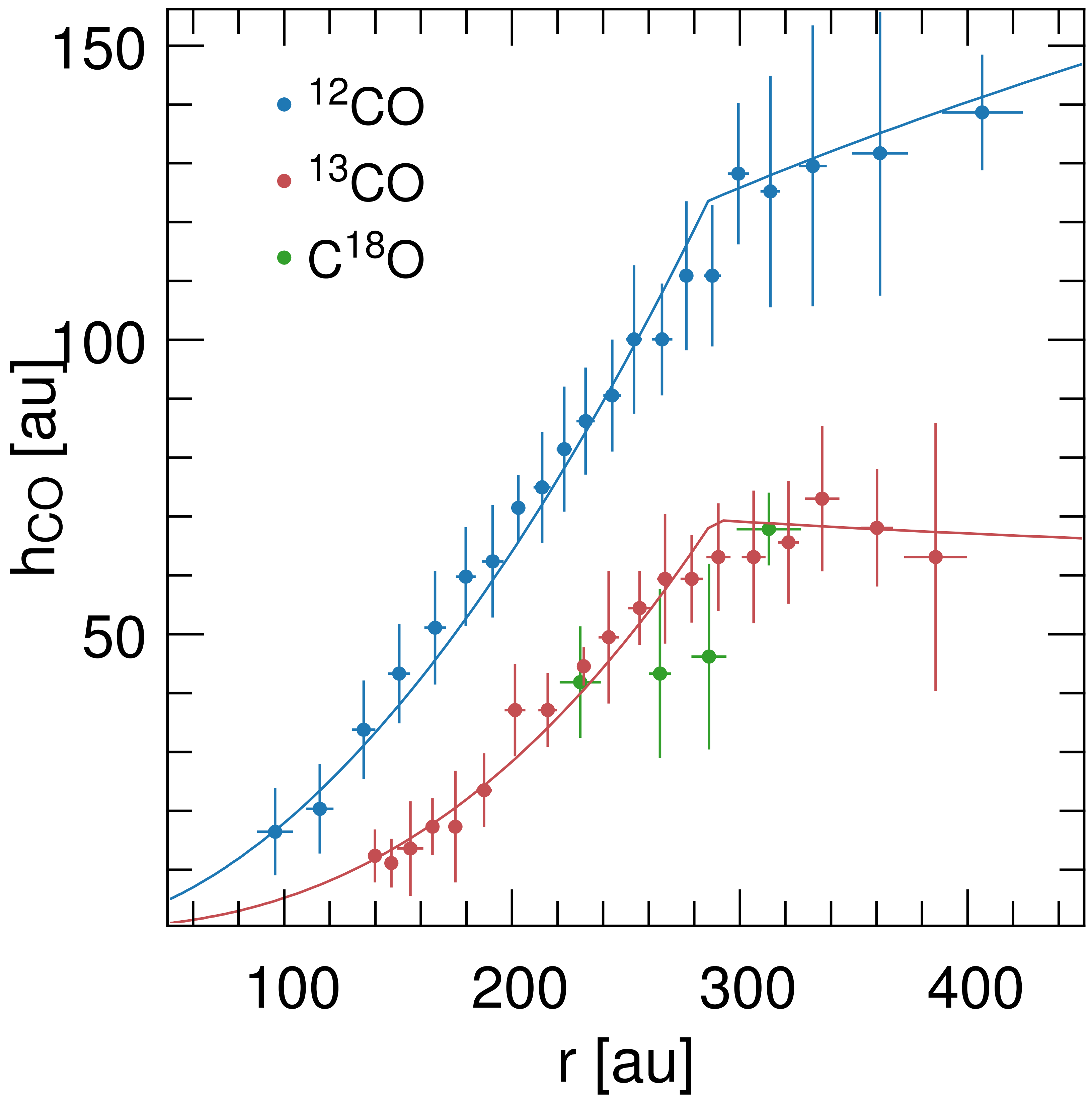
$$h = \frac{y_c - y_\star}{\sin i}$$

$$v = (v_{\rm obs} - v_{\rm syst})\,\frac{r}{(x - x_\star)\,\sin i}$$

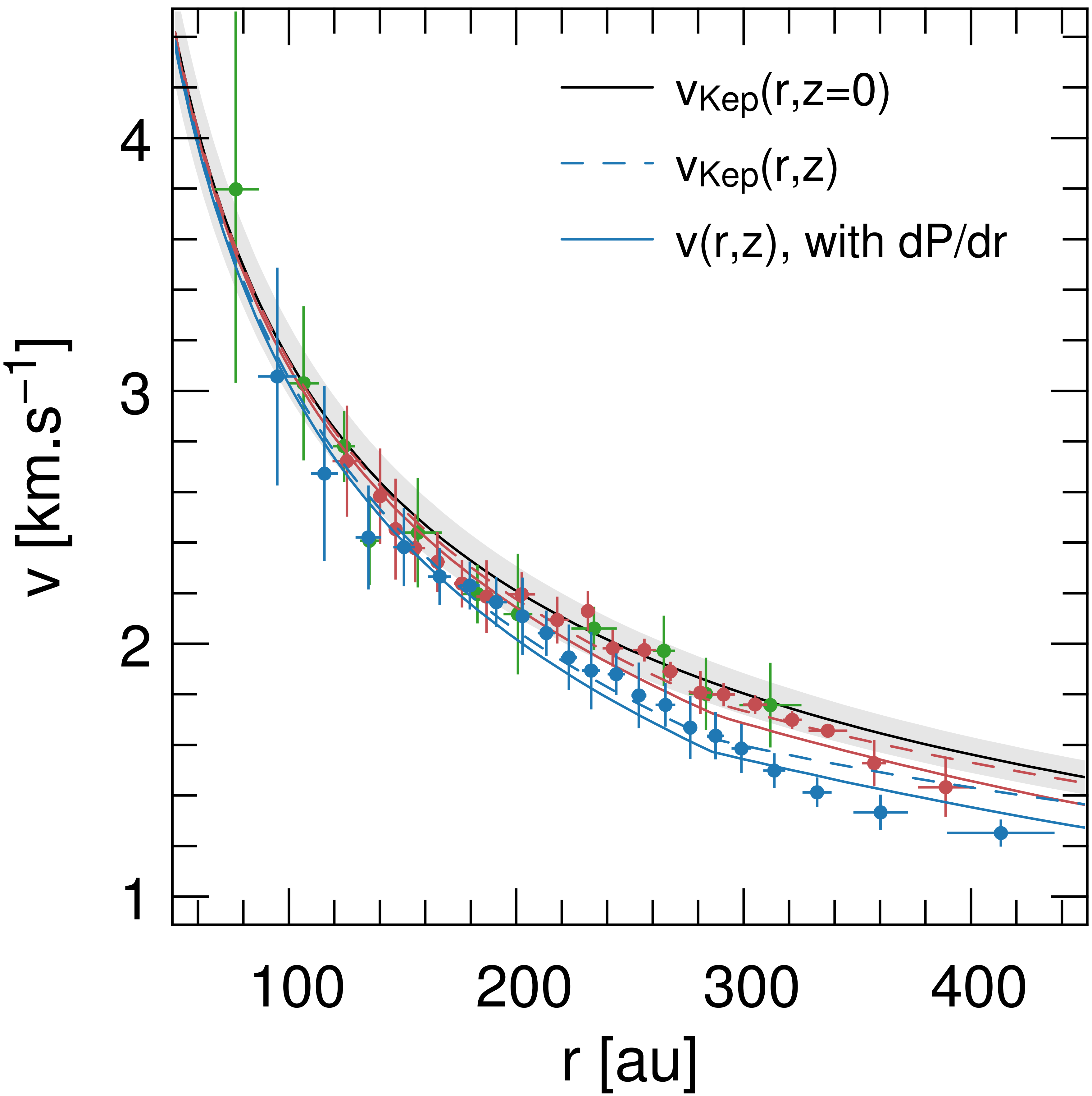
$$T_{\rm b} = T_{\rm ex}(1 - e^{-\tau})$$

Tex ≈ Tgas for low J CO lines

The CO layers

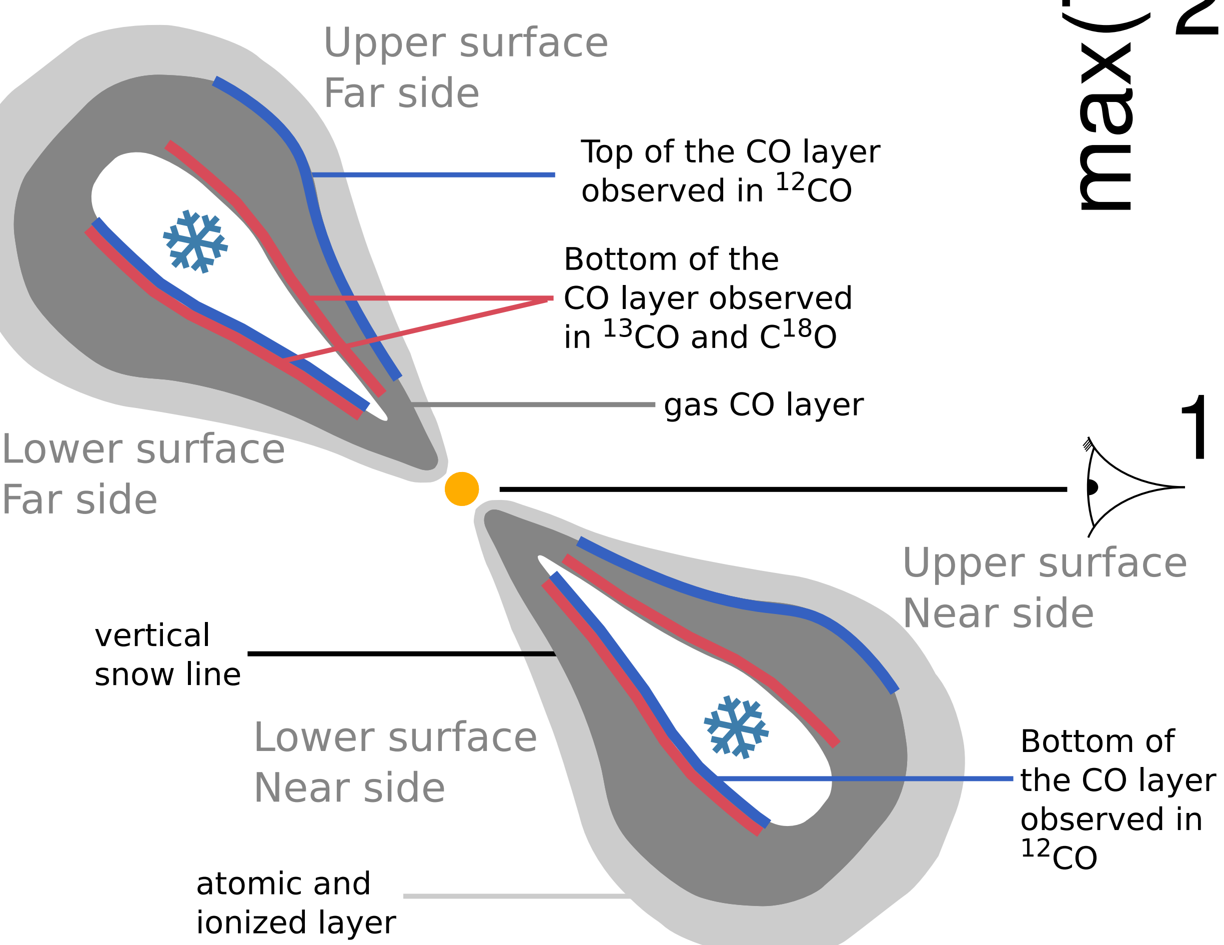


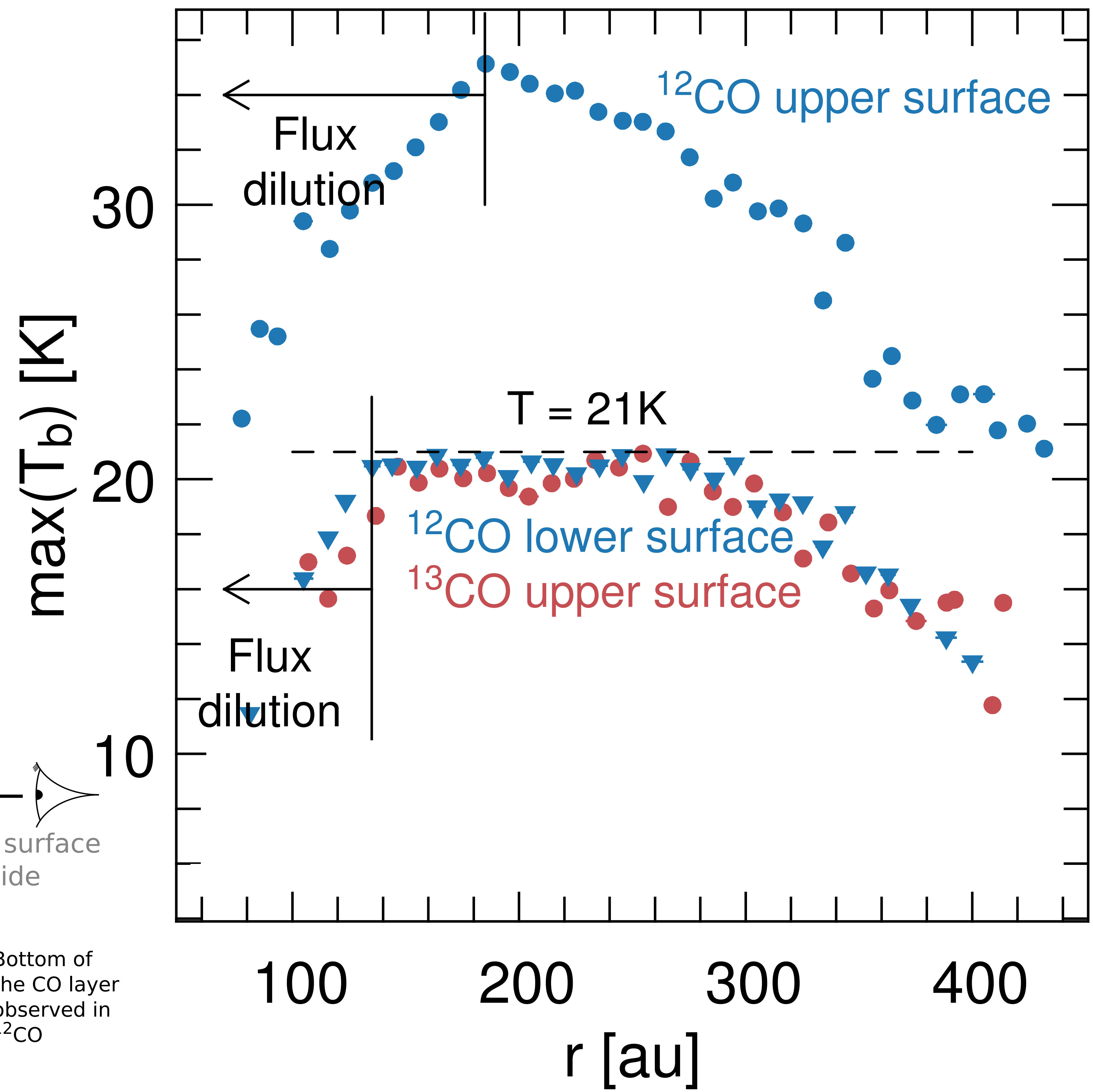
Vertical velocity gradient & sub-Keplerian rotation



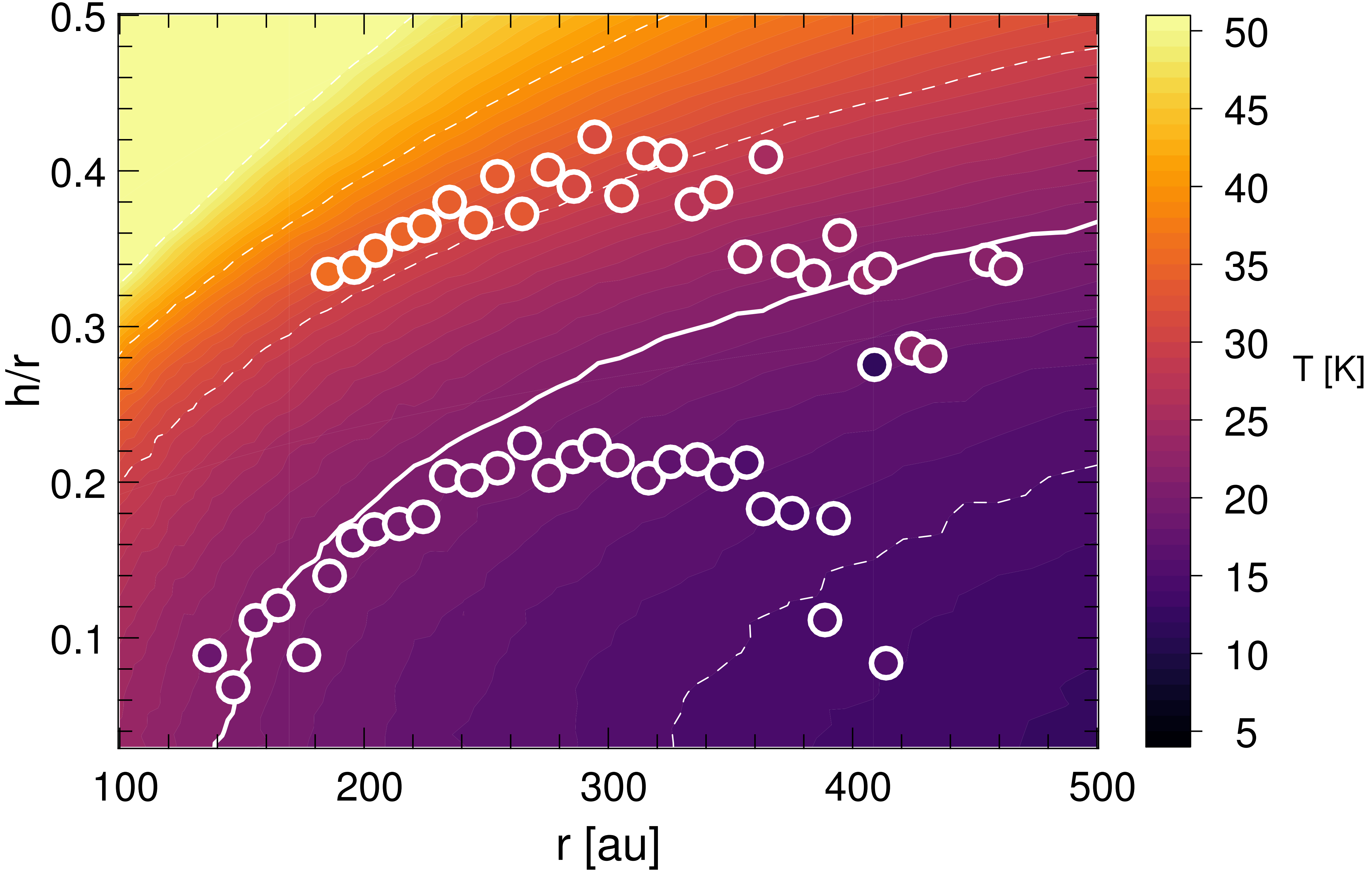
$$\frac{v^2}{r} = \frac{GM_\star r}{(r^2 + h^2)^{3/2}} + \frac{1}{\rho_{\rm gas}} \frac{\partial P}{\partial r}$$

Mapping the vertical snow line

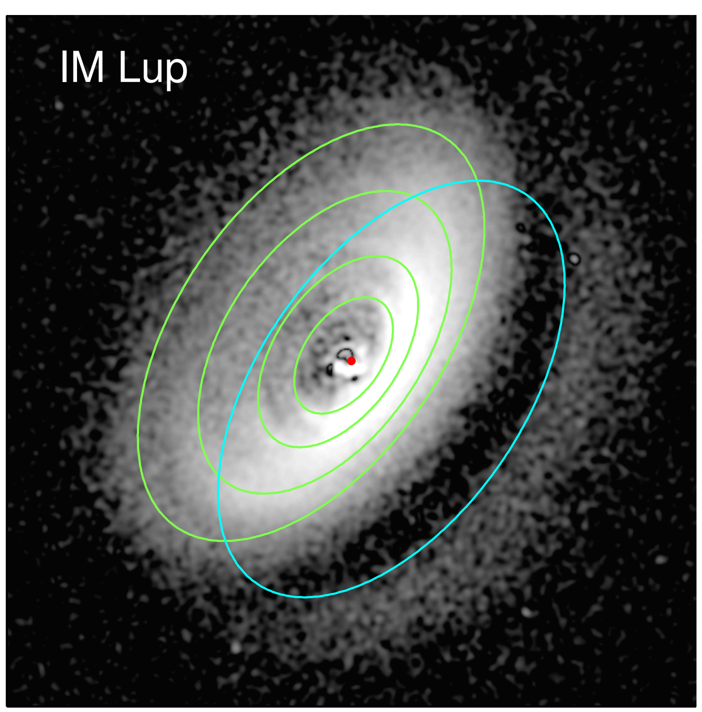




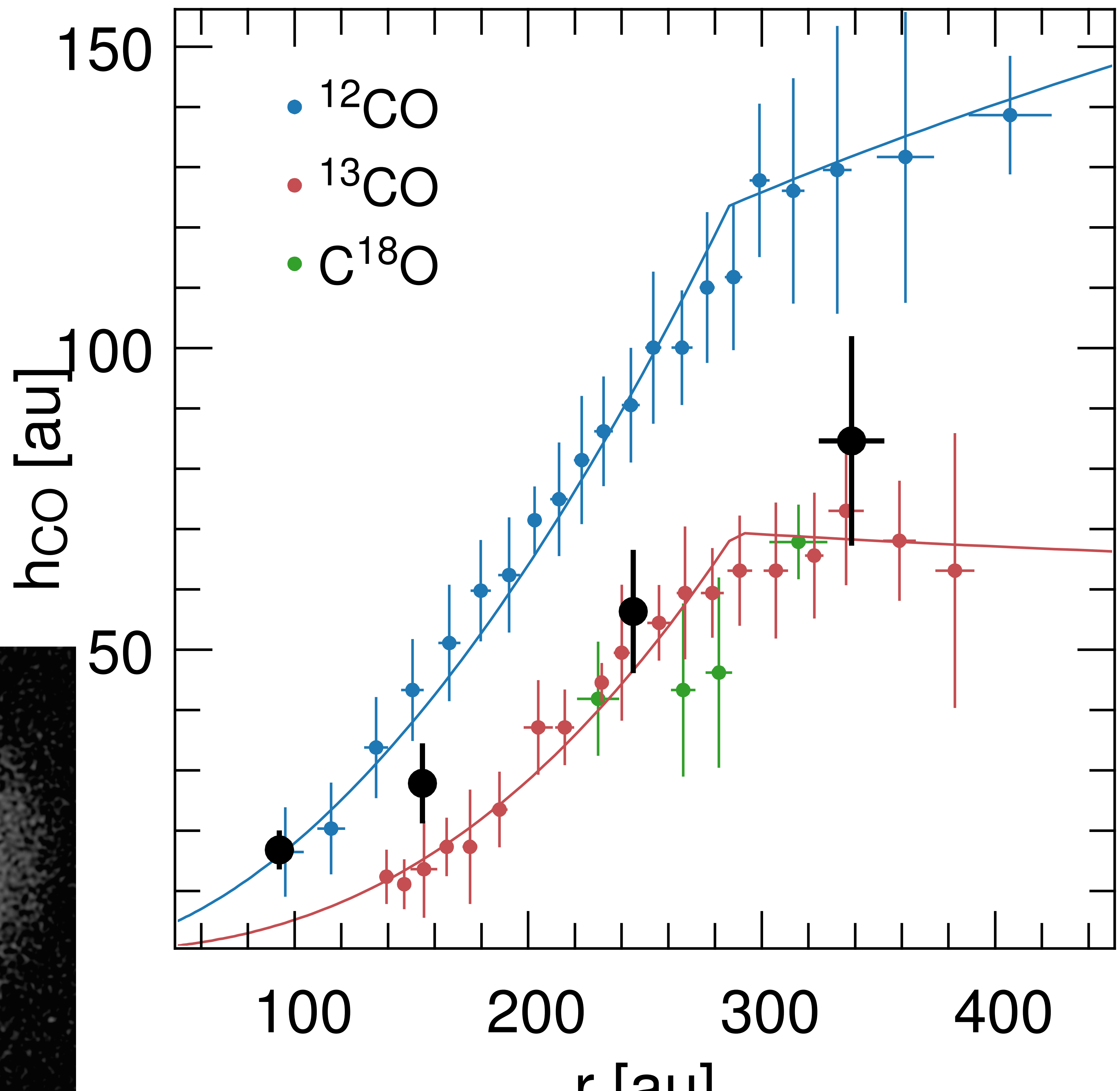
Comparison with models



CO layers vs scattered light layer



Avenhaus et al, in prep.



Concluding remarks

- New ALMA and adaptive optics observations require advanced models coupling hydro + RT + chemistry
- Modern continuum RT codes can be coupled efficiently with hydro codes
- T_{gas}, ionisation chemistry can be estimated via Machine Learning trained on databases of thermo-chemical models