Photoevaporation of molecular clumps in quasar outflows

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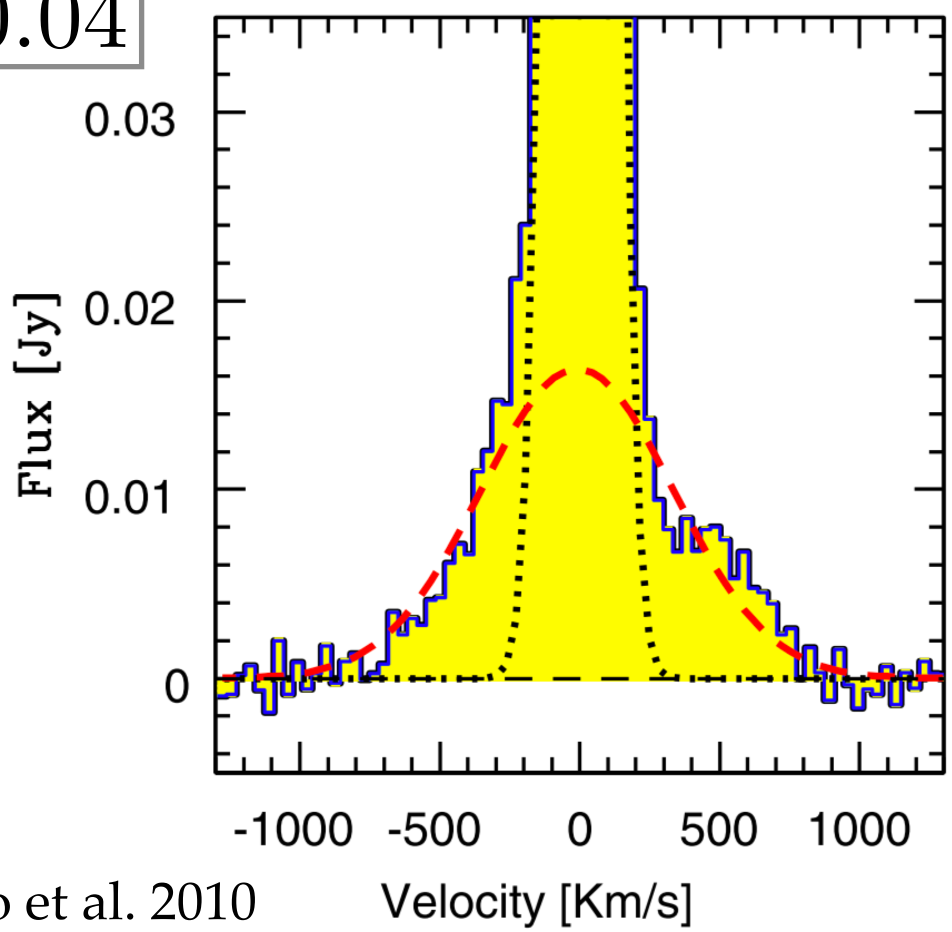
SCUOLA
NORMALE
SUPERIORE

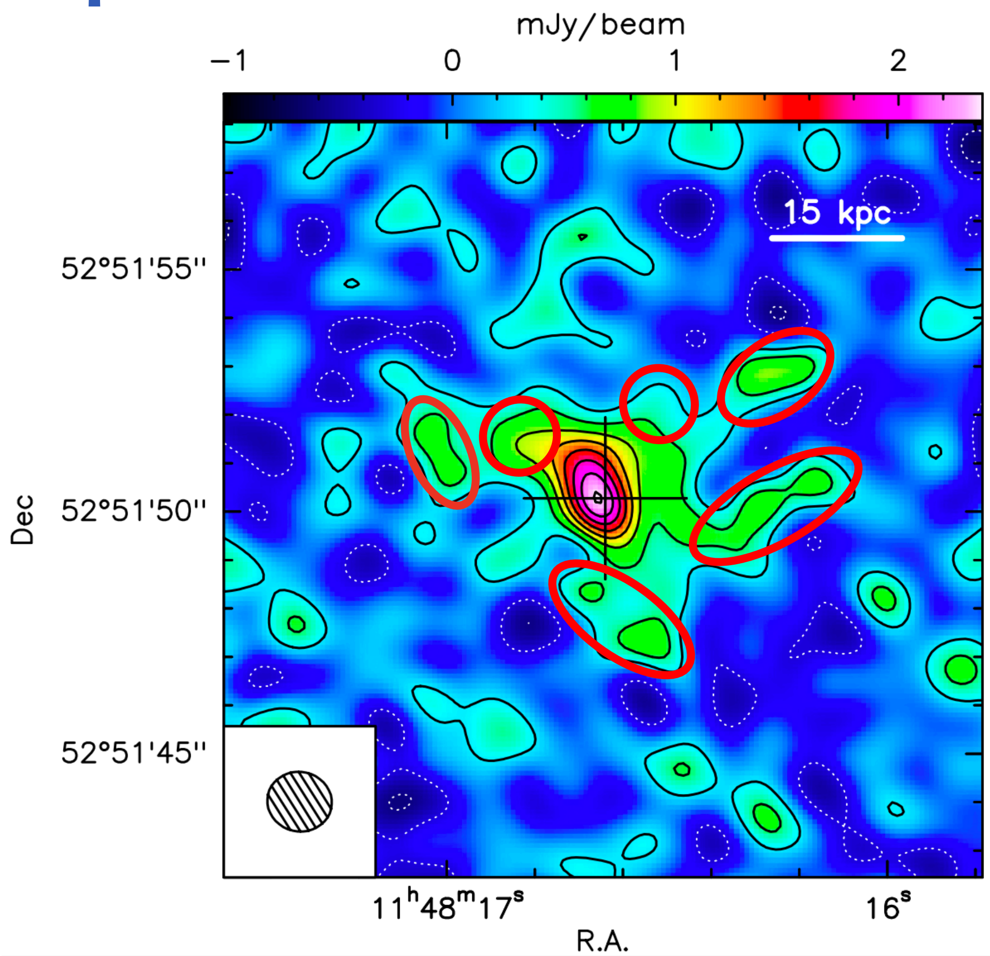
Molecular clumps in quasar outflows

$z \simeq 0.04$



Feruglio et al. 2010

$z \simeq 6.4$

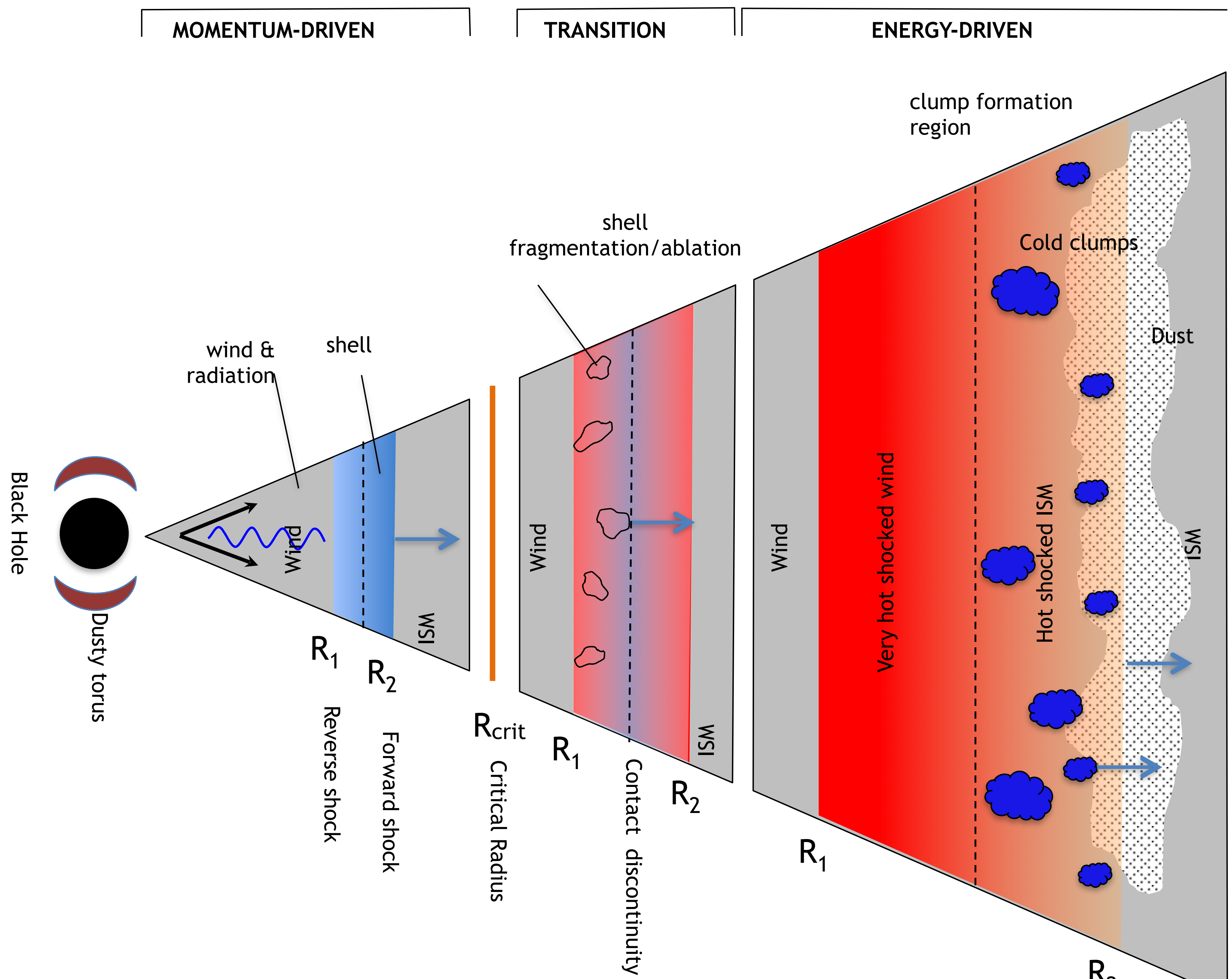


Cicone et al. 2015

- Detection of molecular outflows with [CII], CO, OH, HCN, …
- Estimate of outflow rate, size and geometry

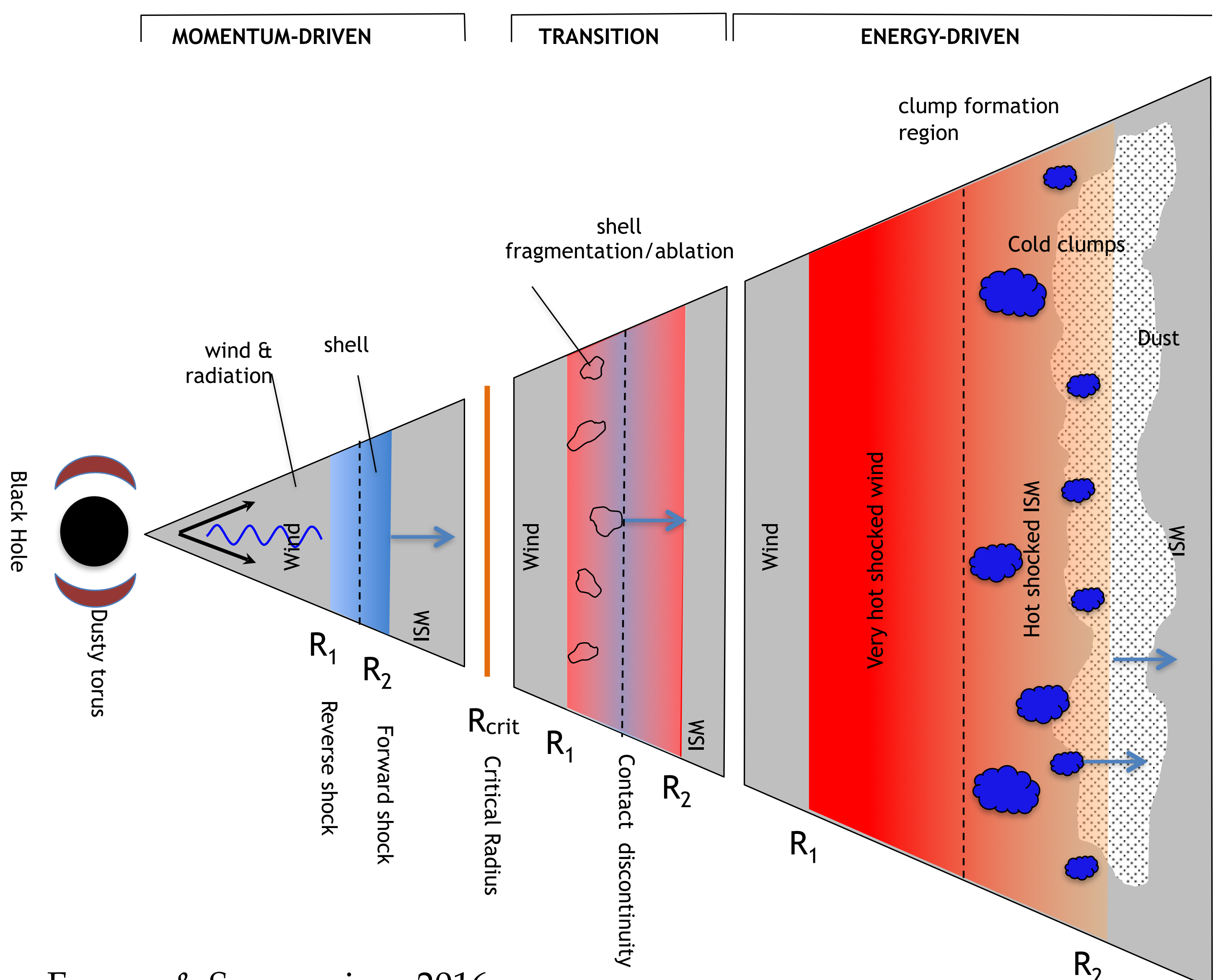
Velocity ~ 500 - 1000 km/s   Radial extension ~ kpc

Outflow model: what we need to investigate



Ferrara & Scannapieco 2016

Outflow model: what we need to investigate



Ferrara & Scannapieco 2016

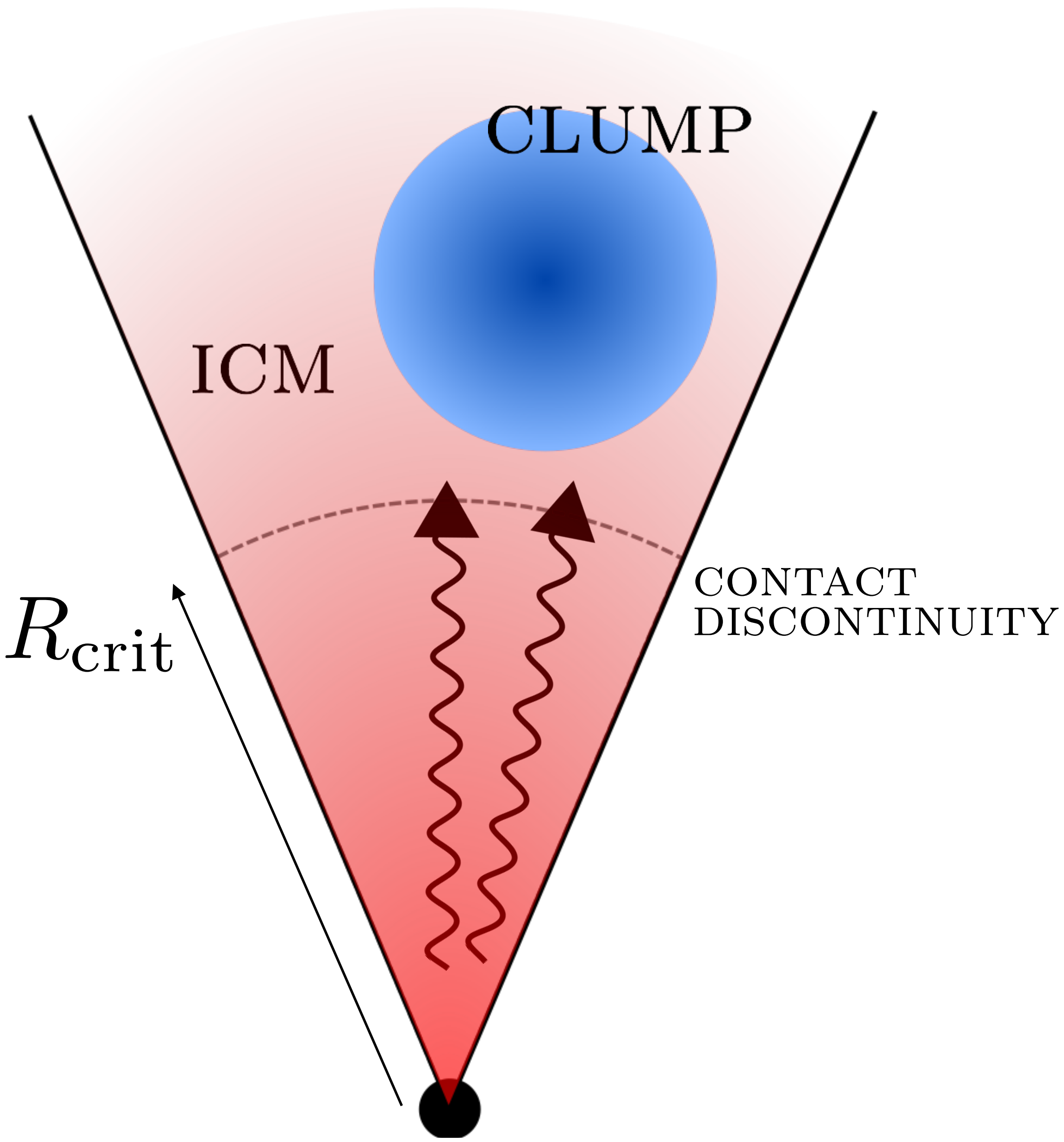
Origin of molecules:

- Acceleration of existing MCs ?
- Formation in-situ by instabilities ?

Fate of molecules:

- Shock ablation of clumps
- Photoevaporation

Set-up of the problem



$$L_{bol} = 10^{45} - 10^{47}\,\mathrm{erg\,s^{-1}}$$

$$T_{\rm ICM} \simeq 2.2 \times 10^{7}\mathrm{K}$$

$$n_{\rm ICM} \simeq 60\,\mathrm{cm^{-3}}$$

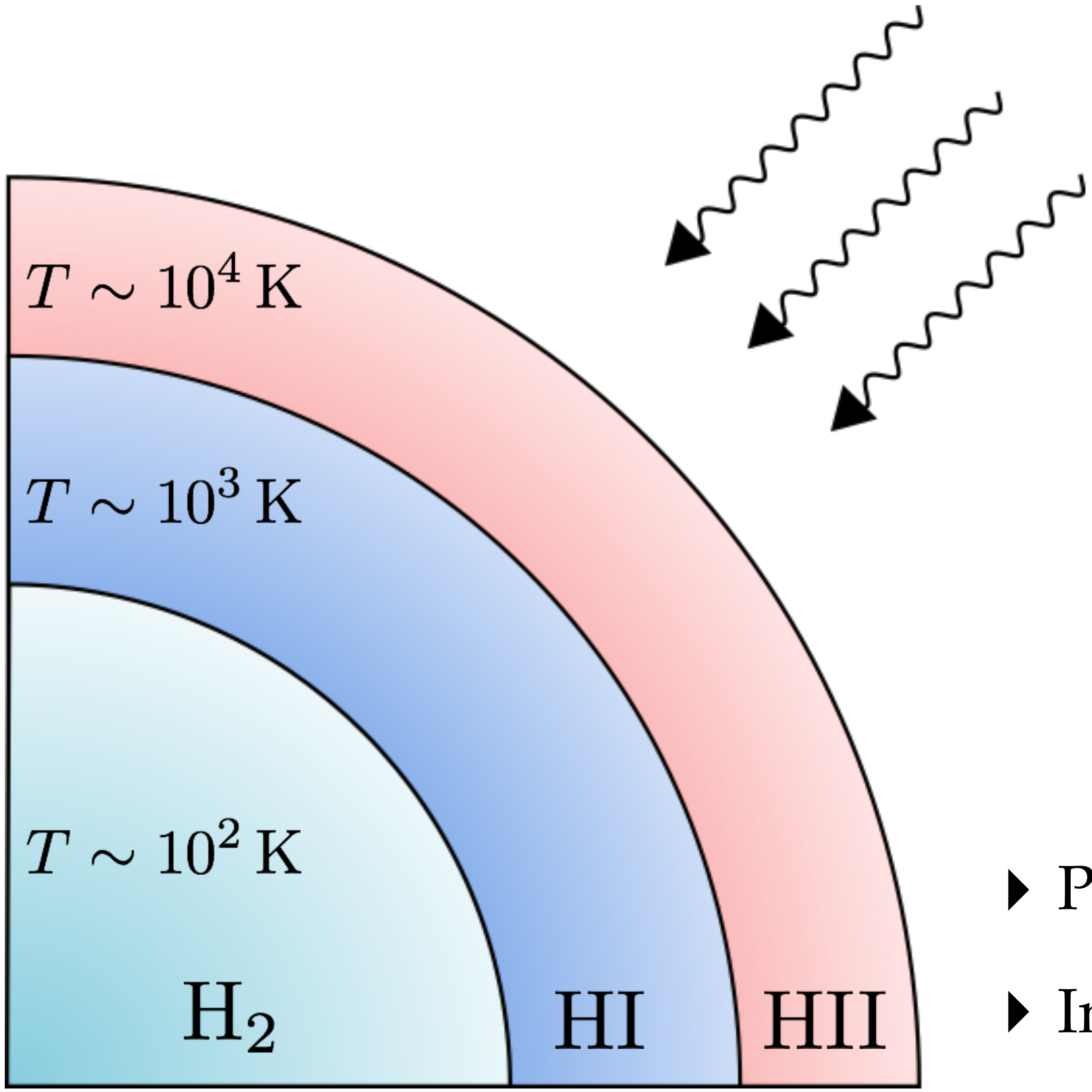
$$M_{\rm CLUMP} = 10 - 10^{4}\,\mathrm{M_{\odot}}$$

$$T_{\rm H_2} \simeq 100\,\mathrm{K}$$

$$R_{\rm crit} \simeq 500\,M_8^{1/2}\,\mathrm{pc}$$

from King (2010) outflow model

Effect of radiation on the clump structure



Decataldo et al. 2017

- Ionizing spectrum:

  $L_\nu \propto \nu^{-1.5}$

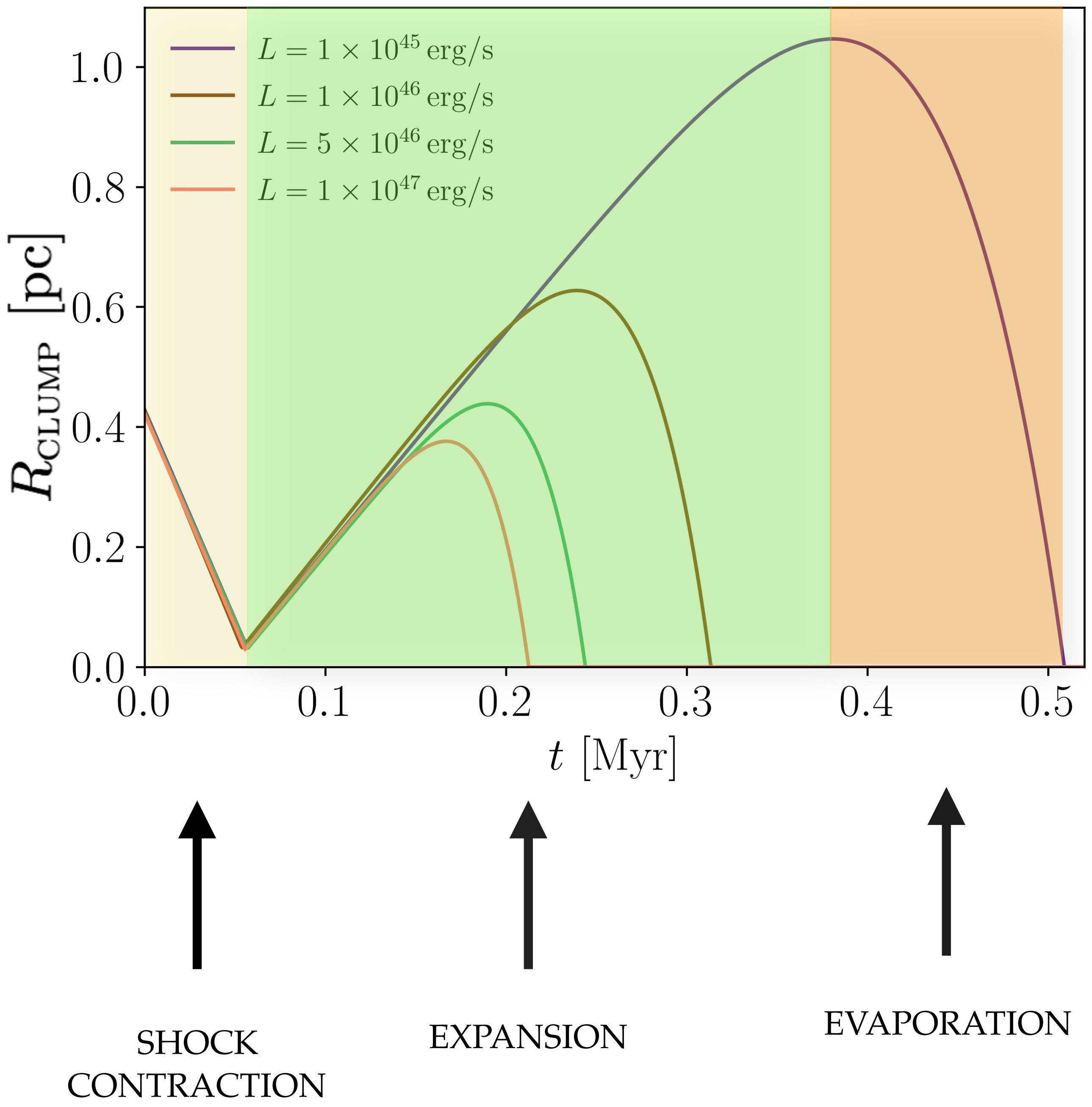
- FUV flux:

  $G_0 \simeq 10^{3-5}$

- Propagation of shocks at interfaces
- Interactions of shocks and rarefactions
- Spherical convergence

Clump evolution

Decataldo et al. 2017



$D = 1\,\mathrm{kpc}$

$M_{\rm CLUMP} = 10^3\,\mathrm{M}_\odot$

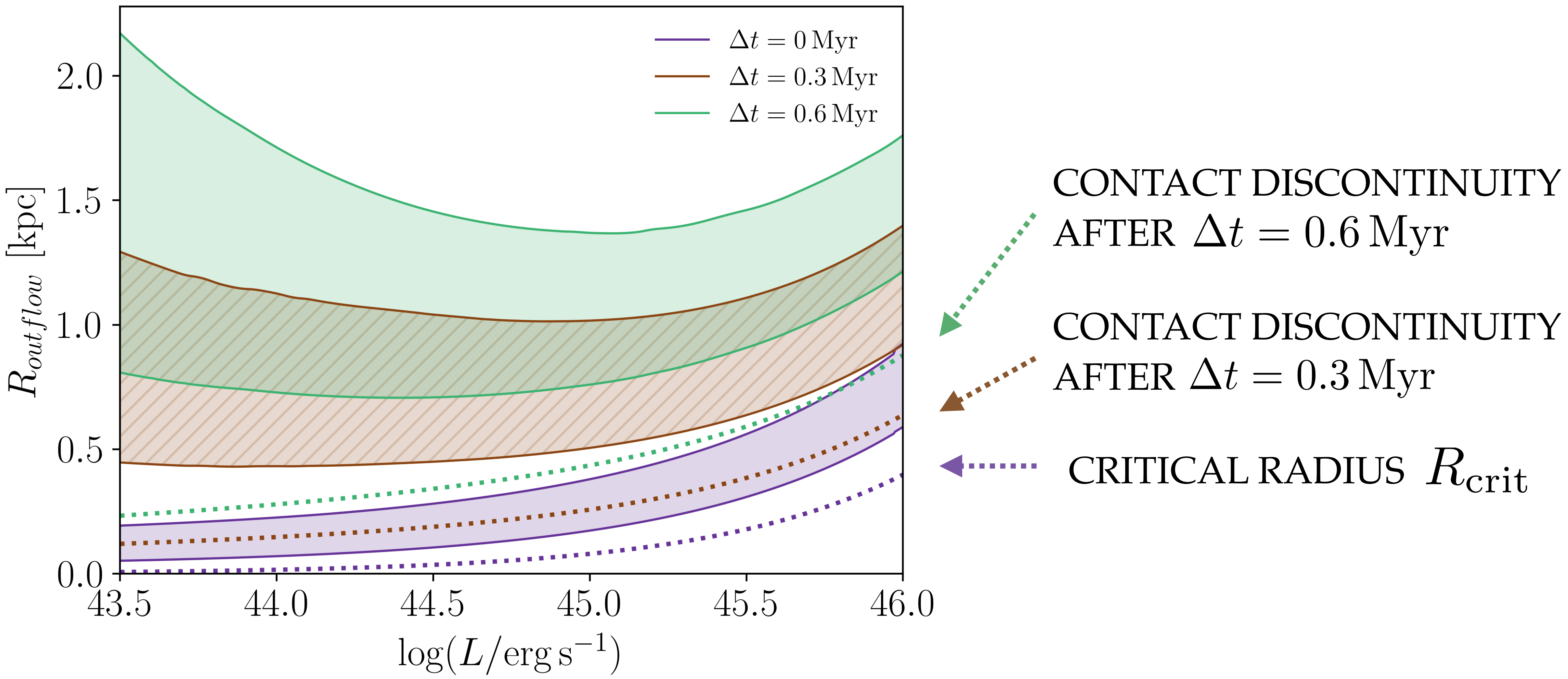
During the contraction phase:

$R_{\rm CLUMP}$ $\downarrow$ of a factor 10

ρ $\uparrow$ of a factor 10^3

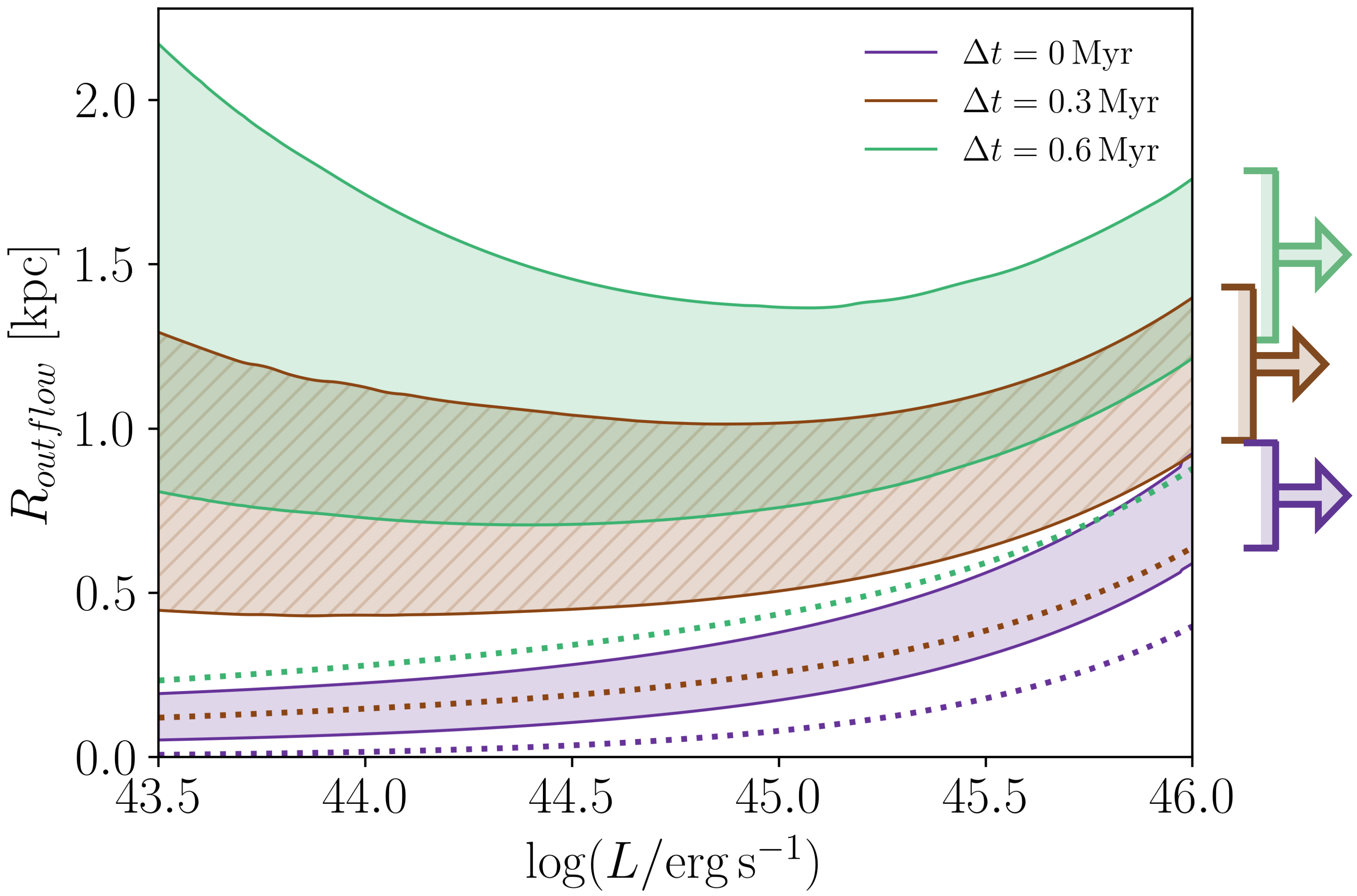
Maximum outflow extension

Decataldo et al. 2017



Maximum outflow extension

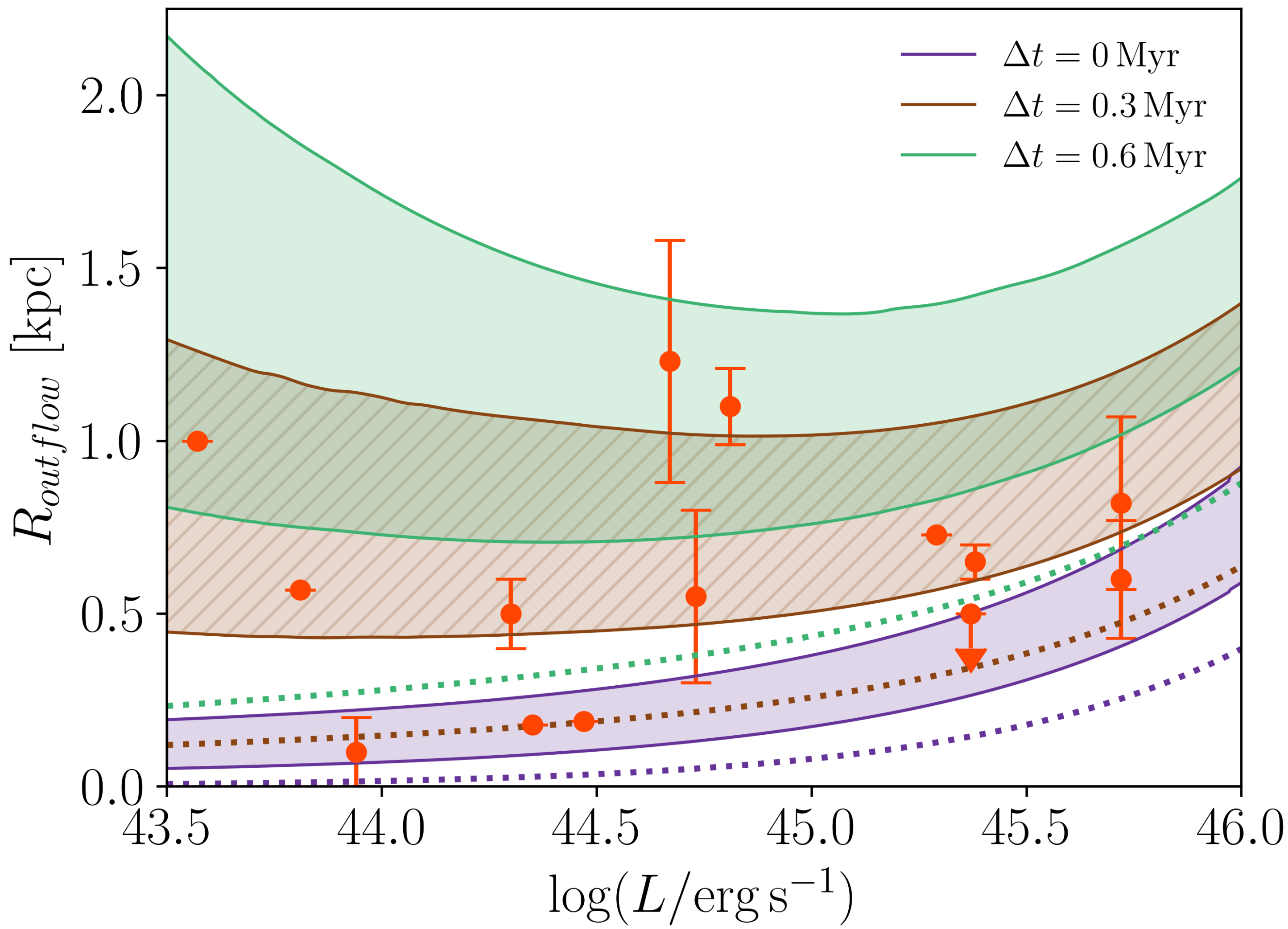
Decataldo et al. 2017



Maximum distances covered by clumps with masses in the range $10 - 10^4\ M_\odot$ formed at the corresponding position of the contact discontinuity

Maximum outflow extension

Decataldo et al. 2017

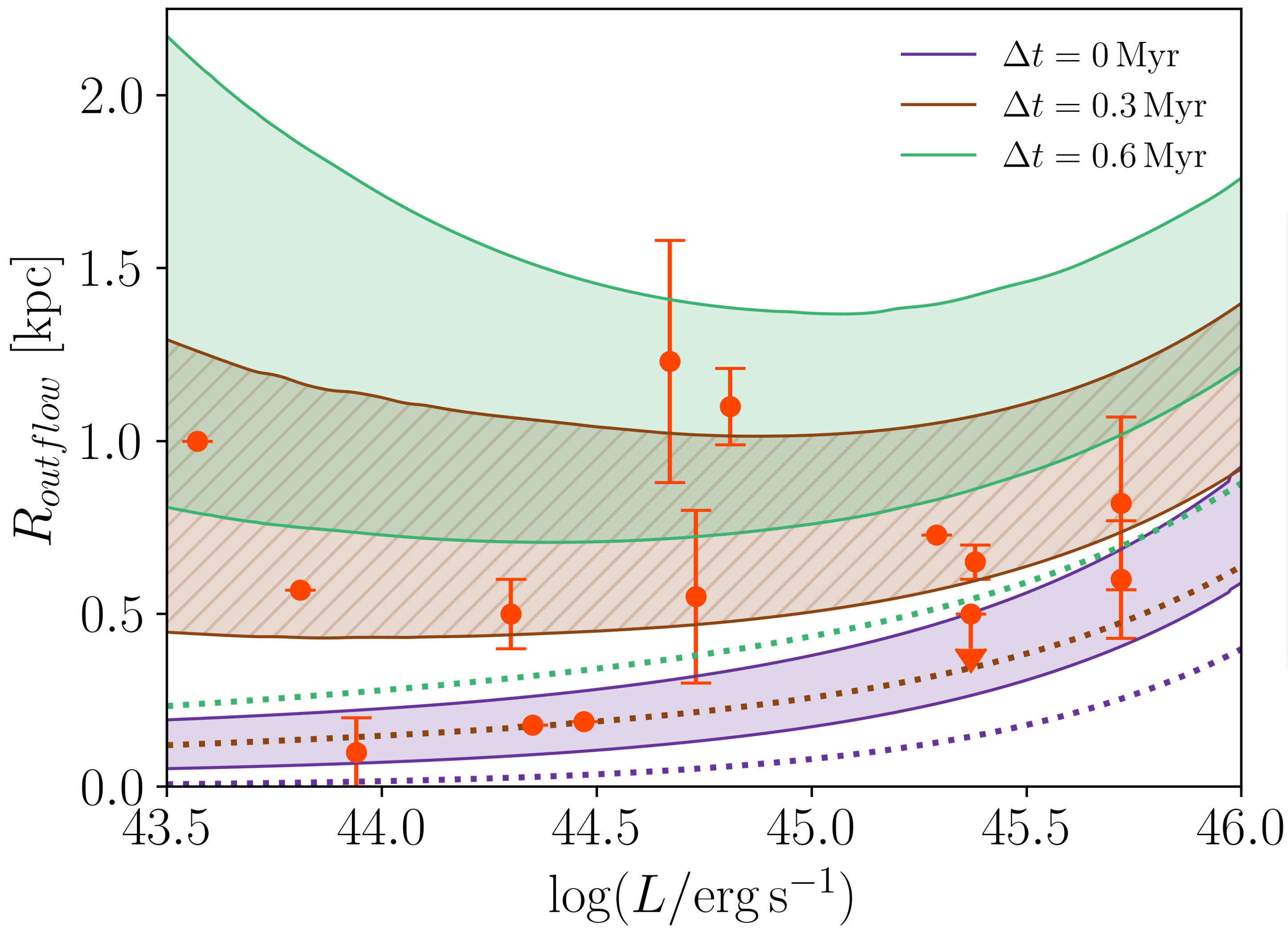


Object	$\log(L\,[\mathrm{erg\,s^{-1}}])$	R_{H_2} [kpc]
NGC 1068	43.94	0.10
IC 5063	44.30	0.50 ± 0.10
IRAS 23365+3604	44.67	1.23 ± 0.35
Mrk 273	44.73	0.55 ± 0.55
IRAS F10565+2448	44.81	1.10 ± 0.11
I Zw 1	45.37	< 0.50
NGC 6240	45.38	0.65 ± 0.05
IRAS F08572+3915	45.72	0.82 ± 0.17
Mrk 231	45.72	0.60 ± 0.25
Circinus	43.57	1.0
PG 0157+001	45.29	0.73
IRAS 05189-2524	44.47	0.19
NGC 4418	43.81	0.57
IRAS 13120-5453	44.35	0.18

Cicone et al. 2015 ; Fluetsch et al. 2018

Maximum outflow extension

Decataldo et al. 2017



- Observed points lie above distance travelled by clumps formed at R_{crit}
- Clumps must also form at subsequent positions of the contact discontinuity

Analytical model

→

- ✗ NO cloud self-gravity
- ✗ NO radiative transfer

New simulation suite

- Poisson solver for gravity
- Radiation coupled with hydro
- Complex chemical network

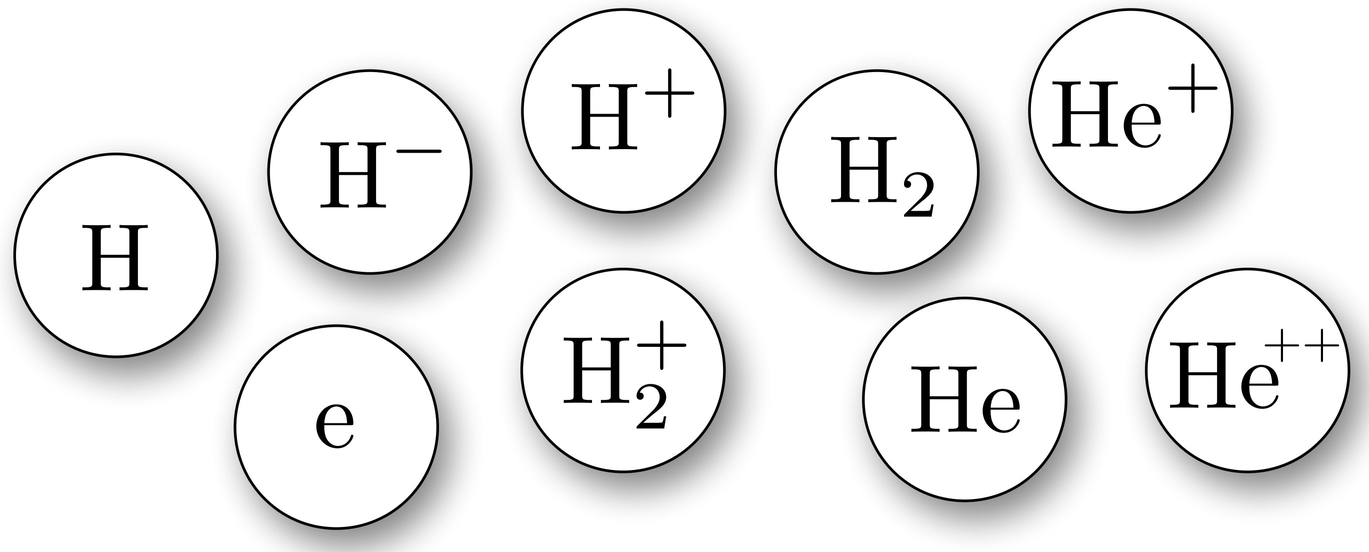
RAMSES-RT

+

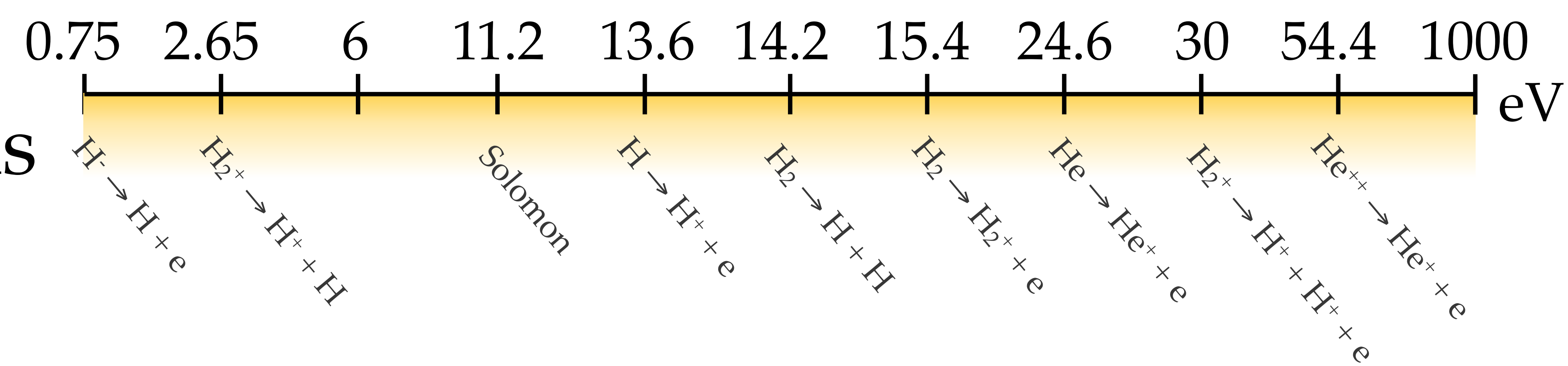
KROME

Coupled RT & Chemistry

9 Chemical Species

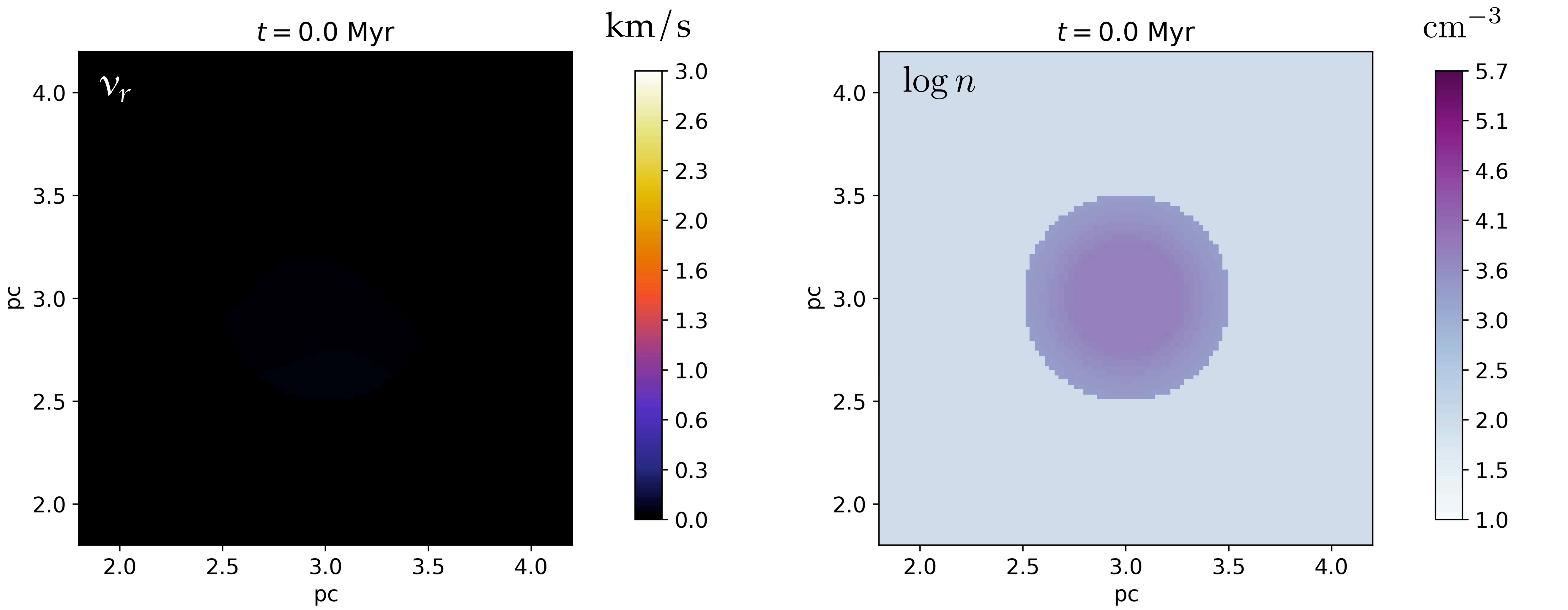


10 Photon Bins



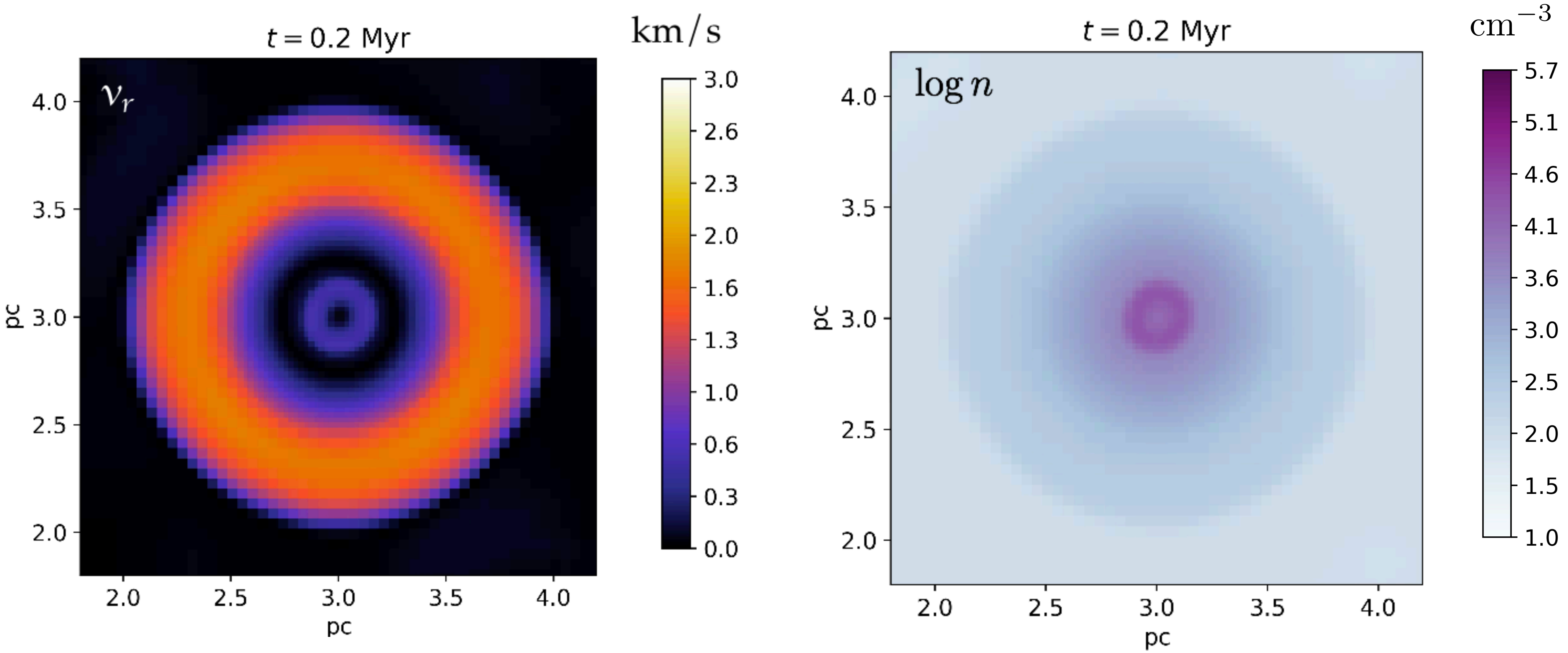
Chemical network: 53 reactions

Simulation with stellar radiation



$$M_{\rm cl} = 50\,{\rm M}_\odot \qquad R_{\rm cl} = 0.5\,{\rm pc} \qquad G_0 = 2 \times 10^4$$

Simulation with stellar radiation



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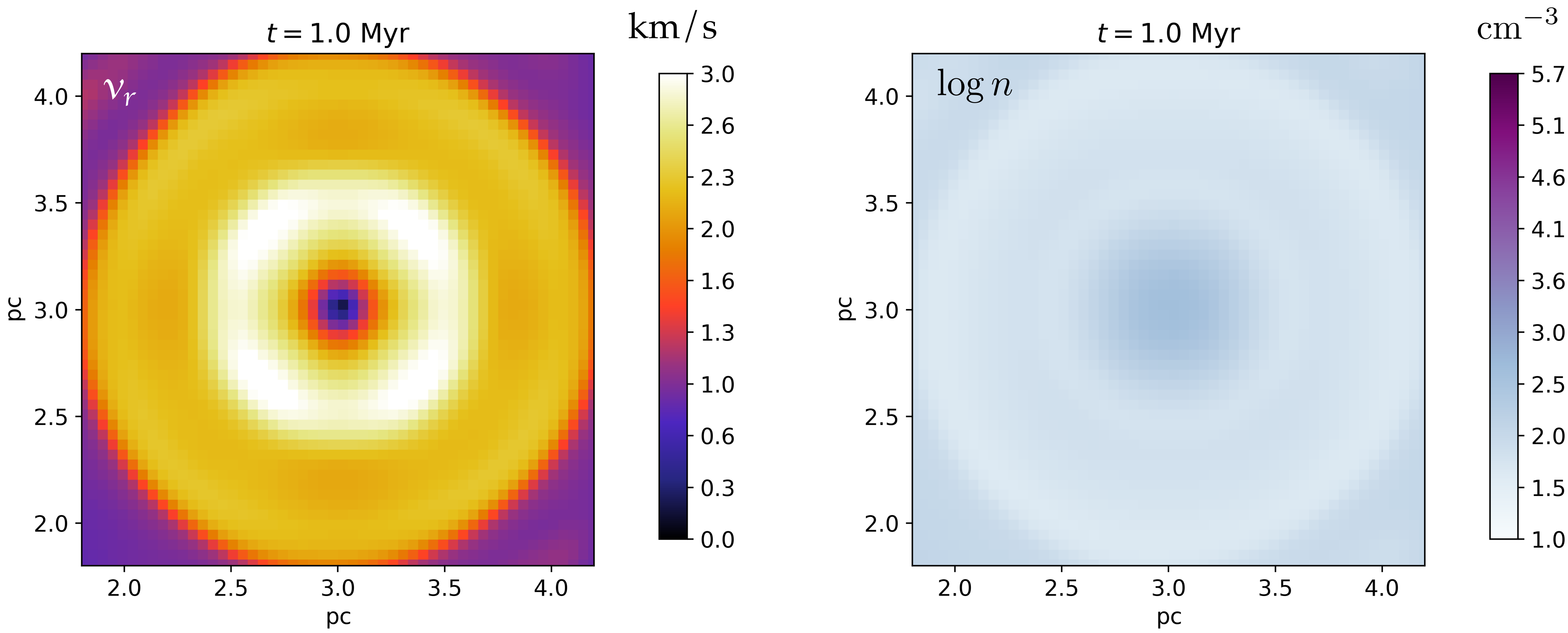

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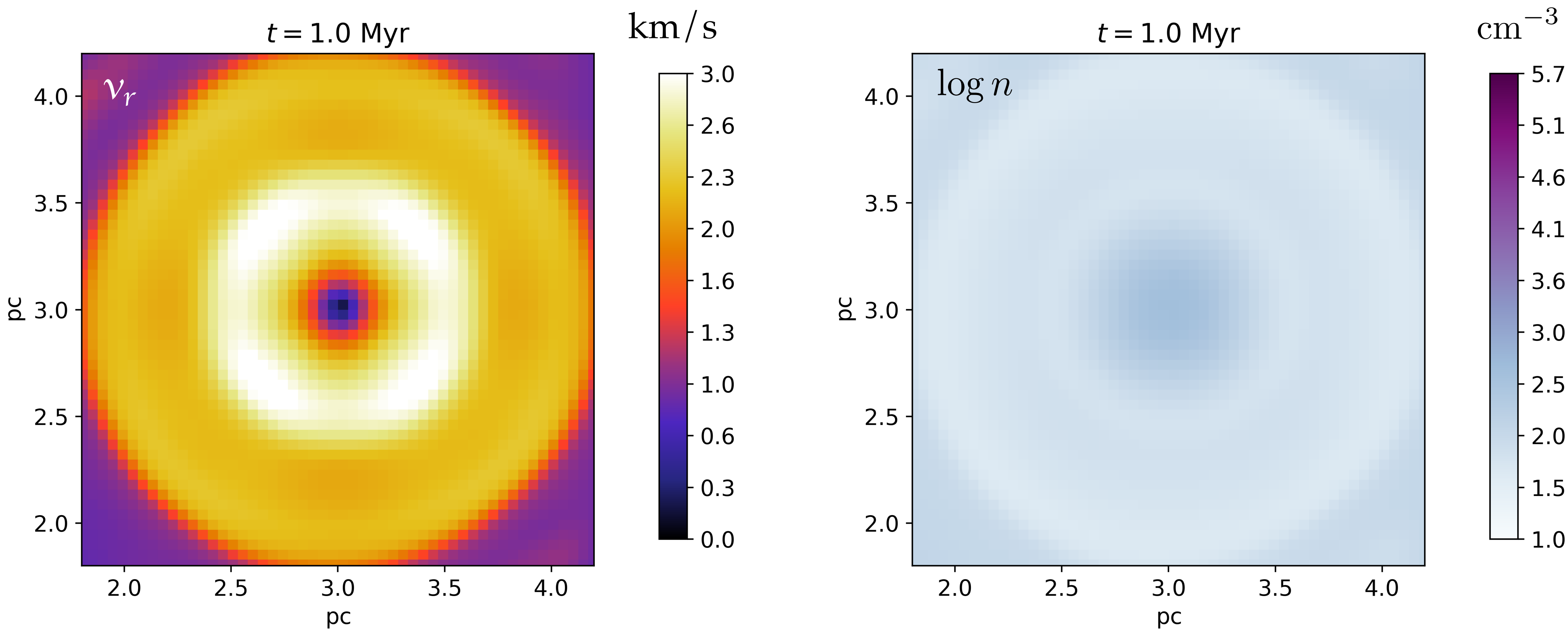


$$t_{\rm evap} \simeq 0.96\,\mathrm{Myr}$$

SIMULATION

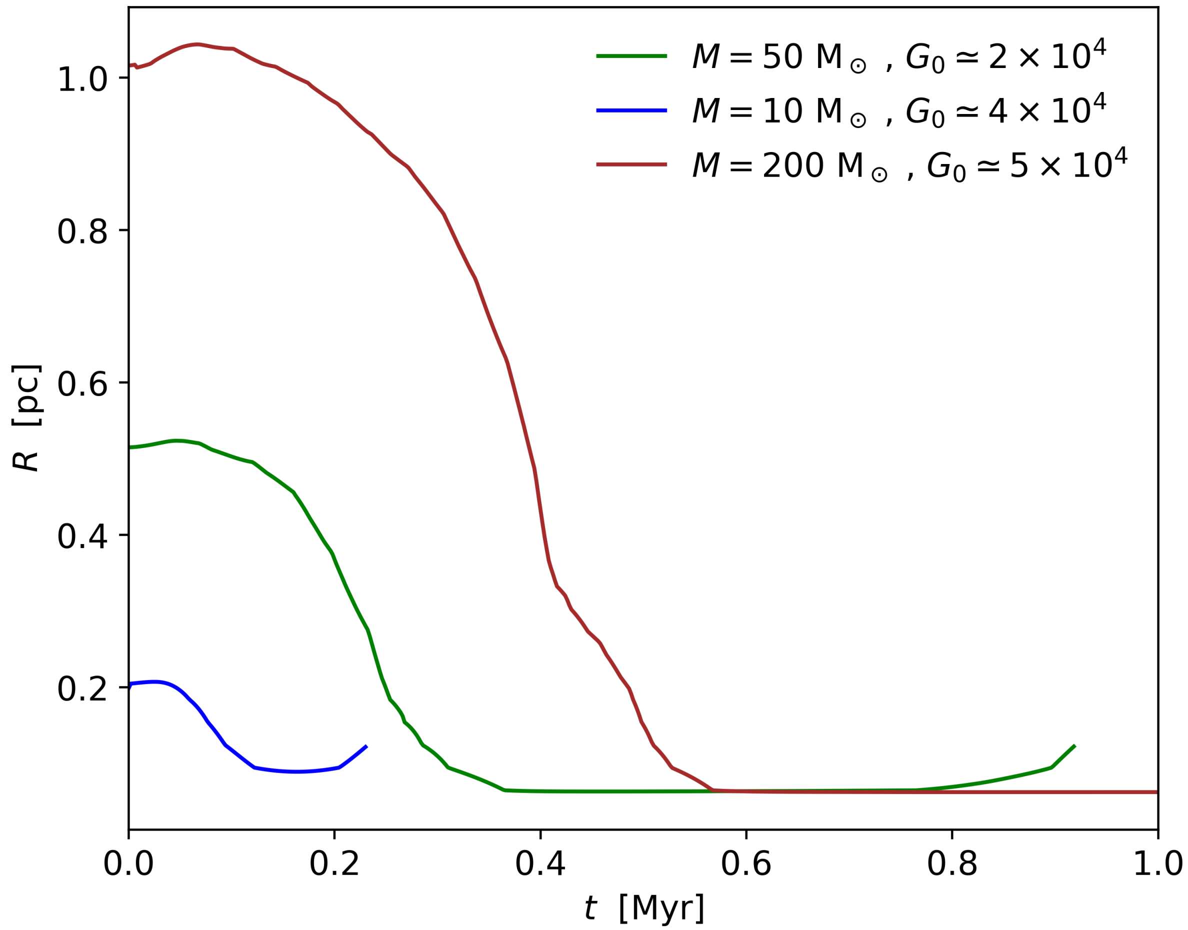
VS

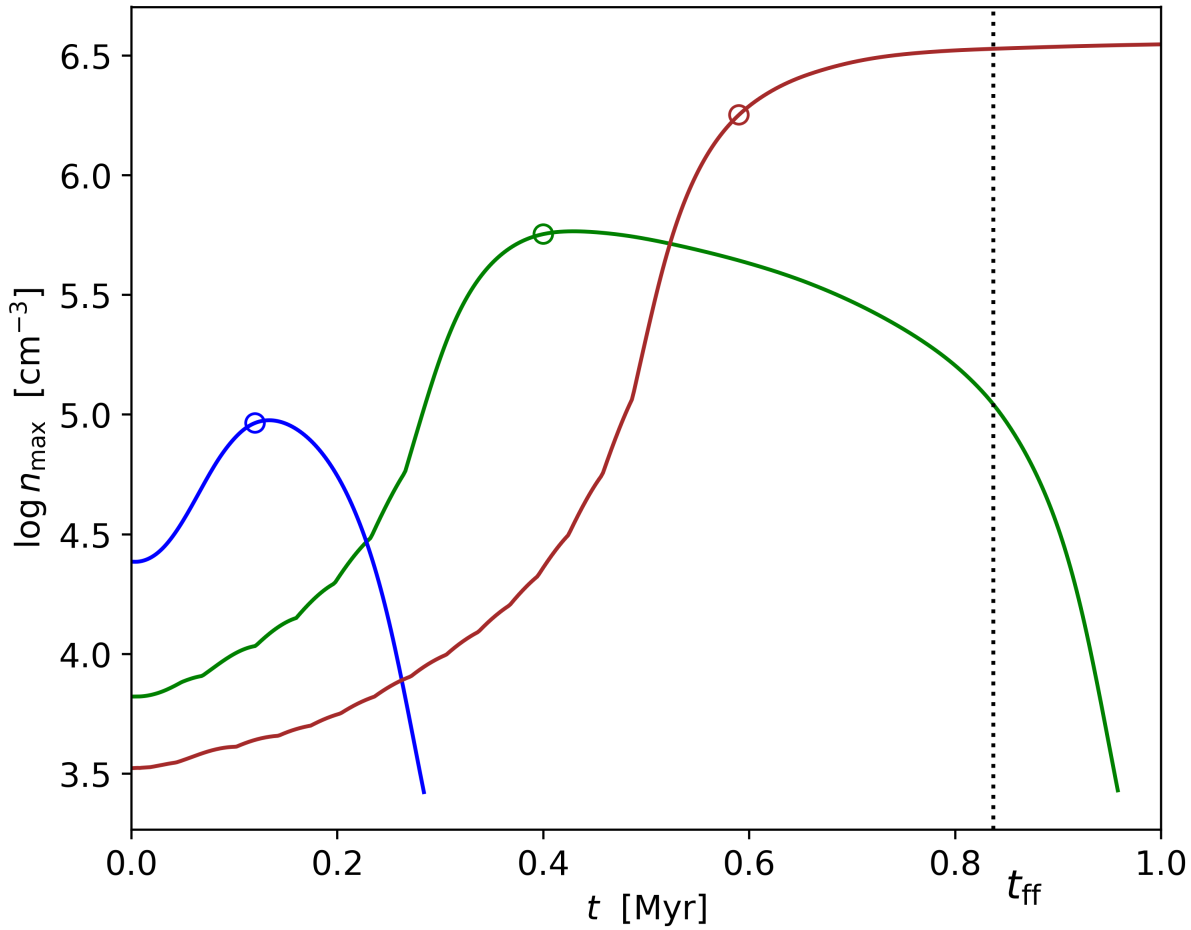
$$t_{\rm evap} = 0.65\,\mathrm{Myr}$$

ANALYTICAL MODEL

R, n_{max} and M_{H2} time evolution

Decataldo et al., in prep.





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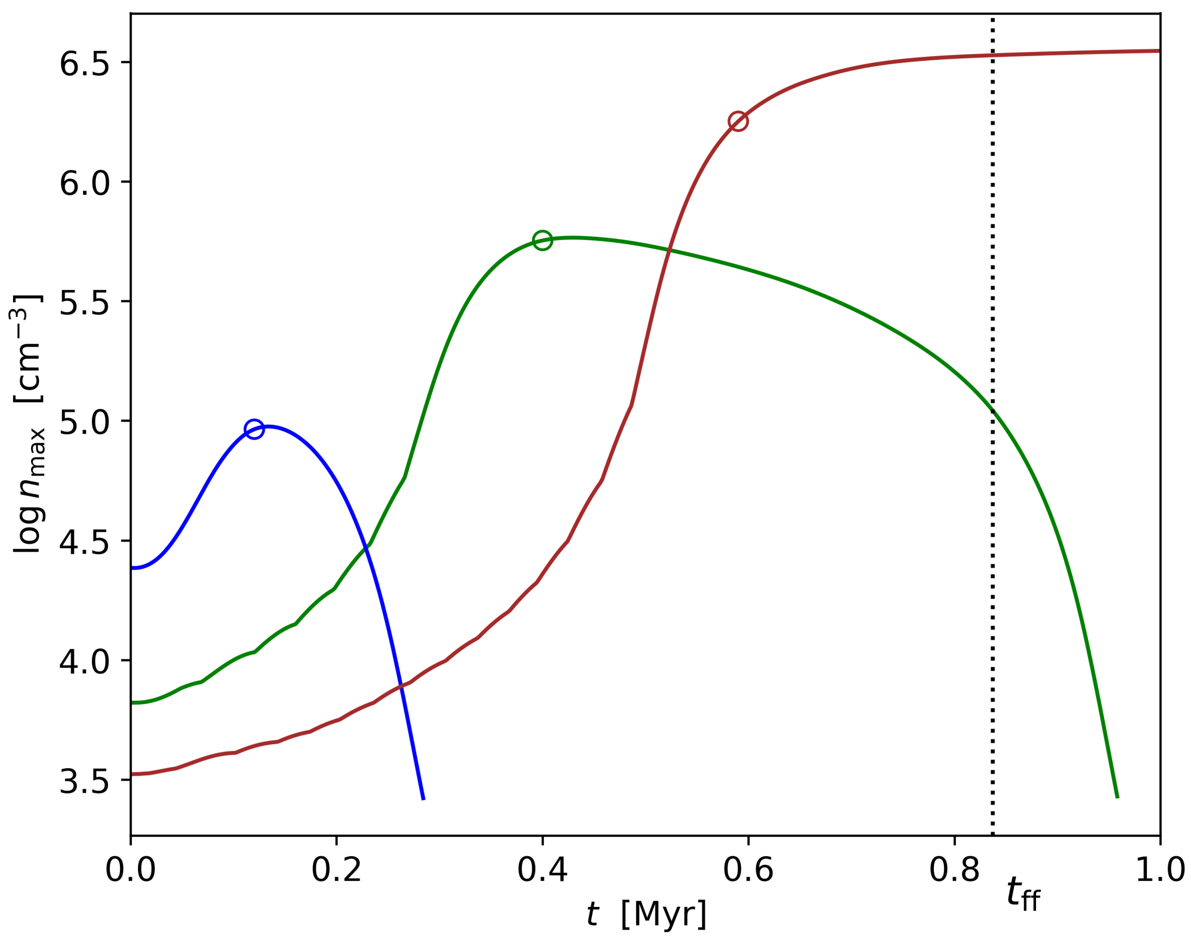
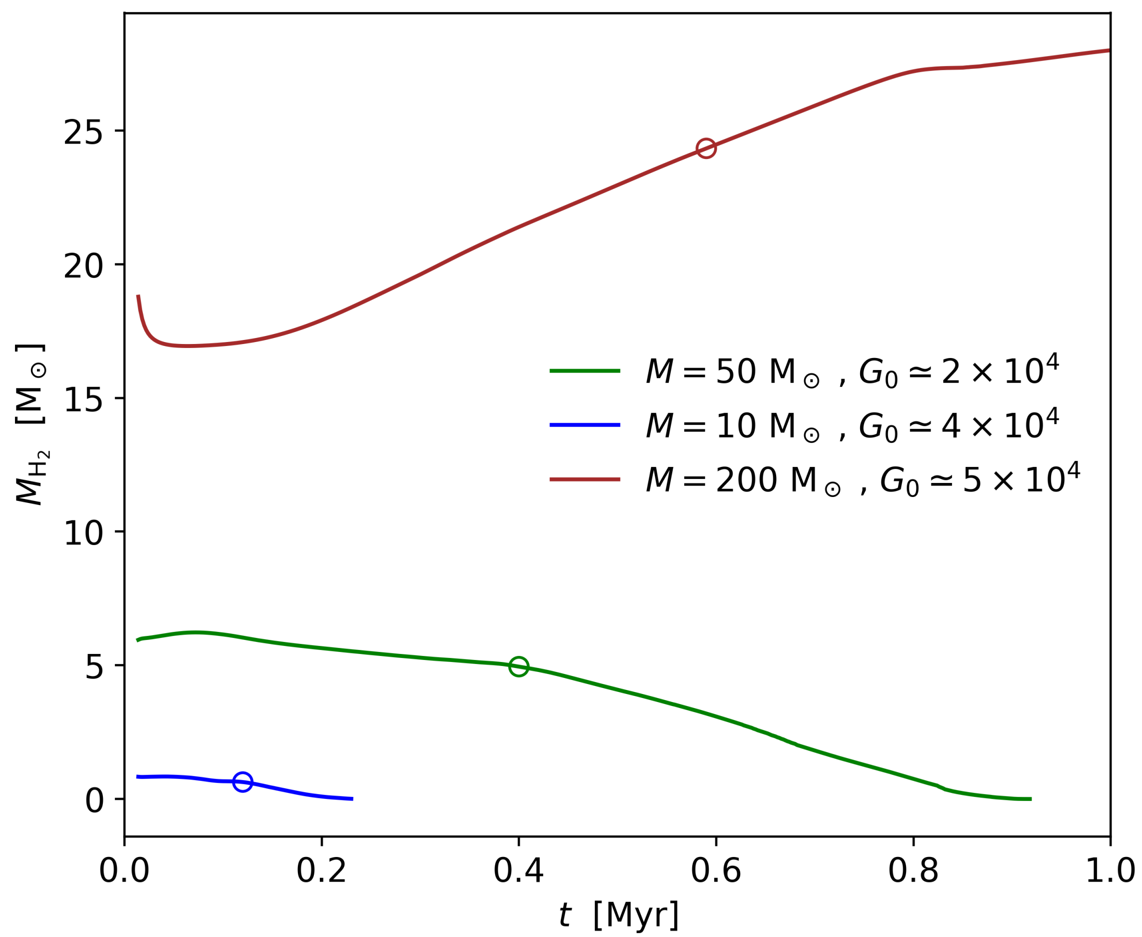
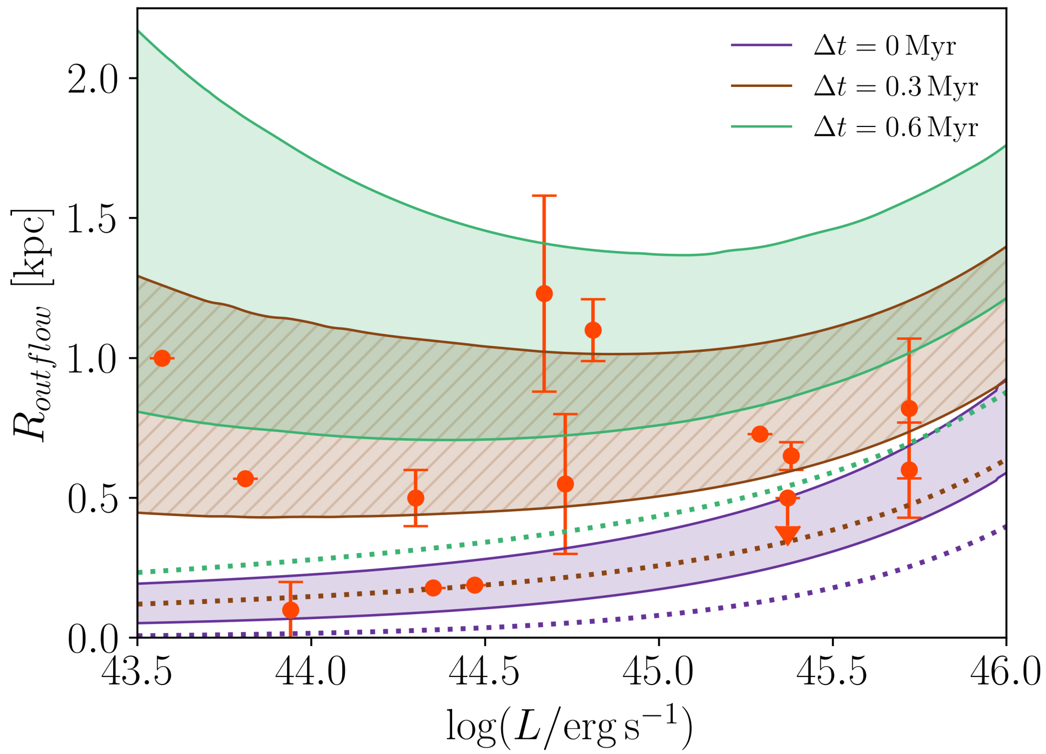




New features:

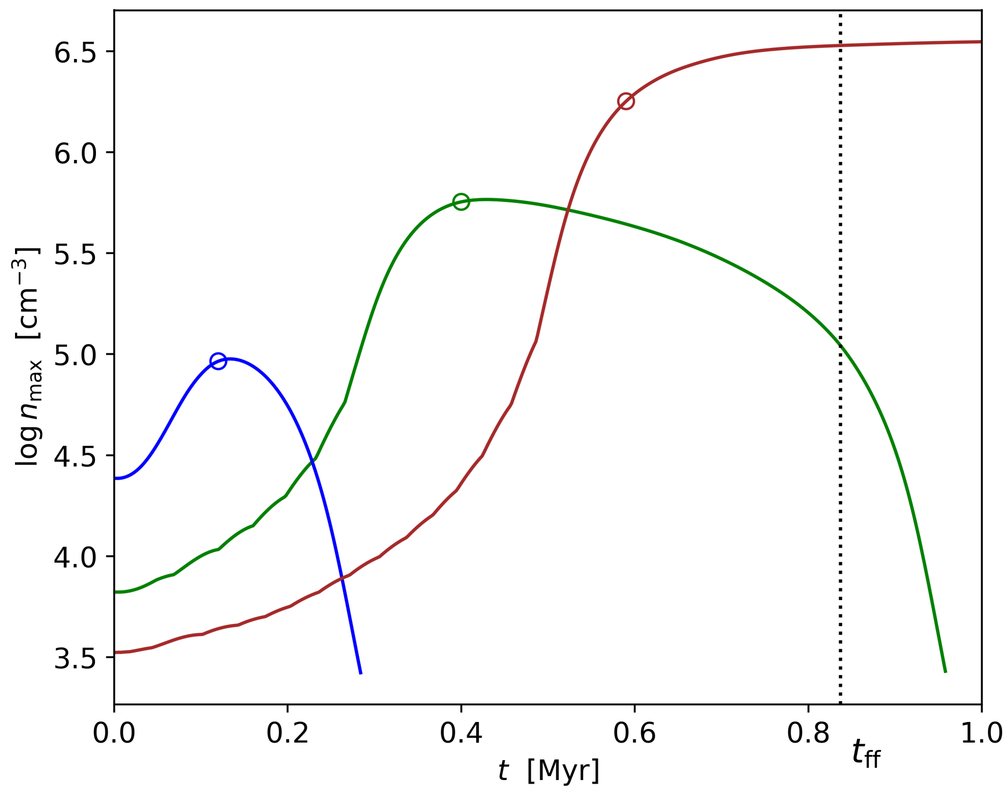
- NO expansion phase after implosion
- Massive clumps do NOT evaporate → TRIGGERED STAR FORMATION ?

Conclusions



- Clumps can survive AGN radiation

- Photoevaporation is compatible with molecular outflow extension



- New simulation suite for studying photoevaporation

FUTURE PROSPECT

Simulation of clumps in molecular outflows, including star formation