Chemical Signatures of the FU Ori Outbursts

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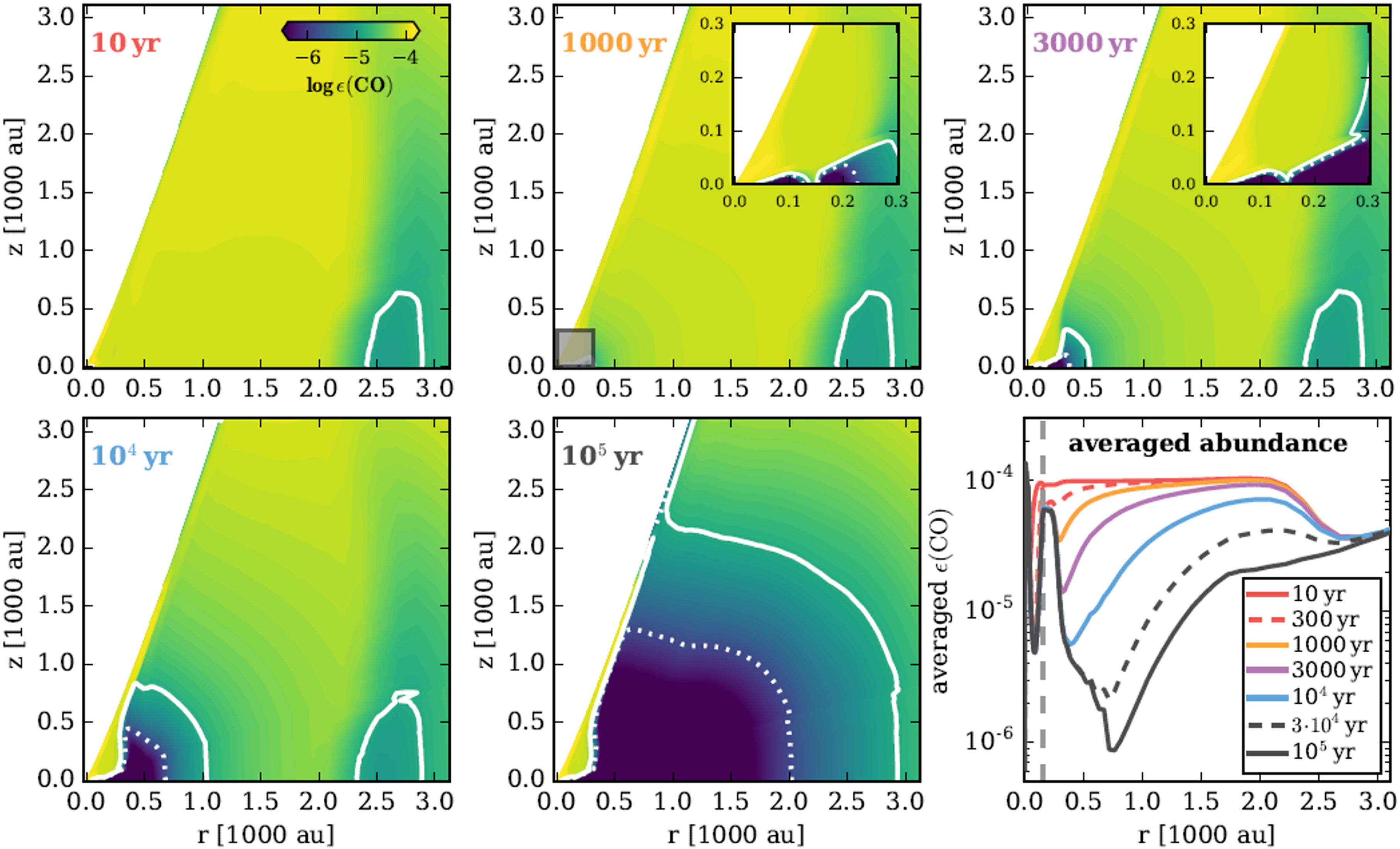
Accretion and luminosity bursts
across the stellar mass spectrum
Online workshop
December 15th 2020



Rab et al. 2017

CO distribution over the disk with envelope after the end of the outburst

Disk model

ANDES astrochemical code
(Akimkin et al. 2013)

Axisymmetric disk with the vertical structure determined by hydrostatic equilibrium

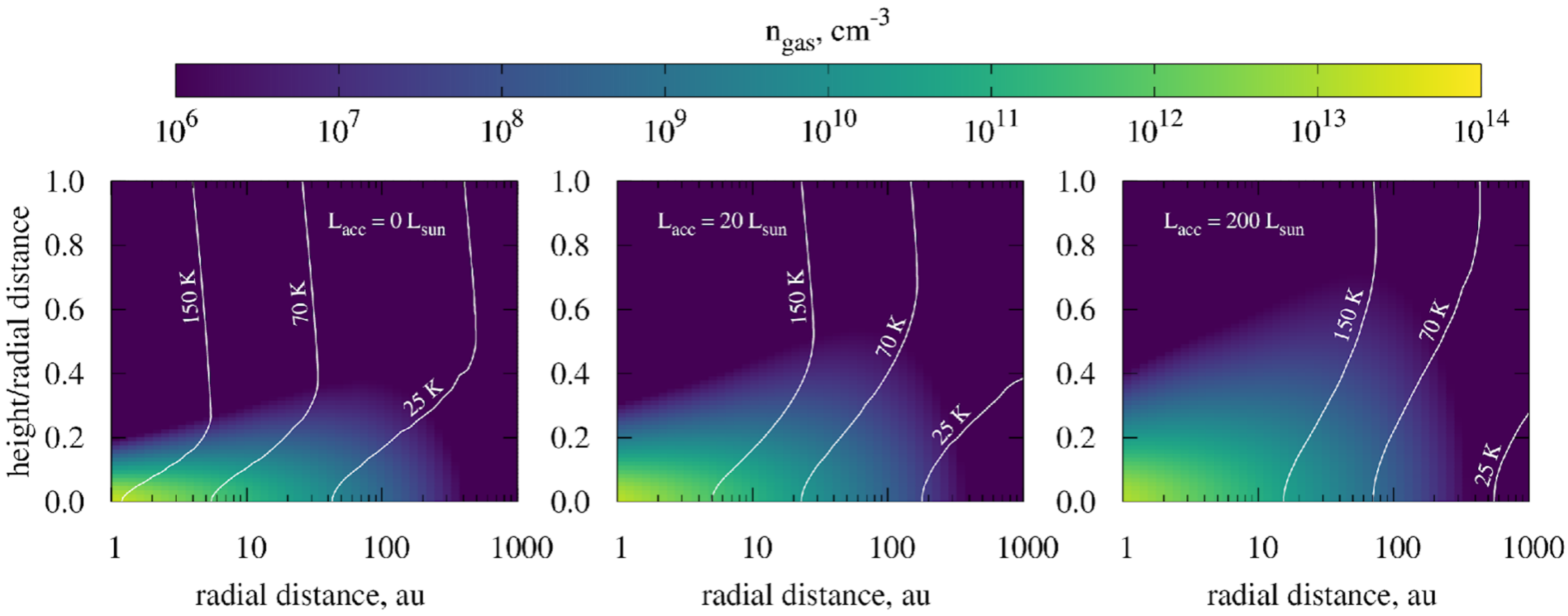
$$\frac{\partial P(R,z)}{\partial z} = -\rho(R,z)\,\frac{zGM_*}{(R^2+z^2)^{3/2}} \qquad P = \frac{k_B T(R,z)}{\mu m_p}\,\rho(R,z)$$

$$\Sigma(R) = \Sigma_0 \cdot \left(\frac{R}{R_c}\right)^{-\gamma} \cdot e^{-\left(\frac{R}{R_c}\right)^{2-\gamma}} \qquad T_m^4(R) = \frac{\varphi}{2}\left[T_\star^4\left(\frac{R_\star}{R}\right)^2 + T_{acc}^4\left(\frac{R_{acc}}{R}\right)^2\right]$$

$$T(R,z) = \begin{cases} T_a(R,z) + \big(T_m(R) - T_a(R,z)\big)\cos\left(\dfrac{\pi z}{2z_q(R)}\right)^2, |z| > z_q(R) \\ T_a(R,z), |z| \geq z_q(R) \end{cases}$$

R_c is the disk characteristic radius,
$T_\star$ is effective stellar temperature,
$R_\star$ is stellar radius,
γ is the steepness in radial distribution of surface density

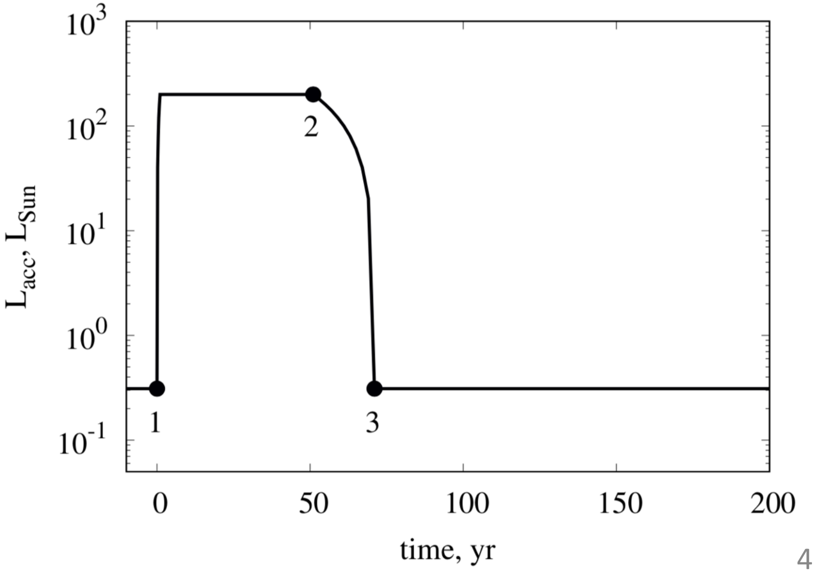
$T_\star$ and $R_\star$
are calculated from $M_\star$ using stellar evolution model by Baraffe et al. 2015.

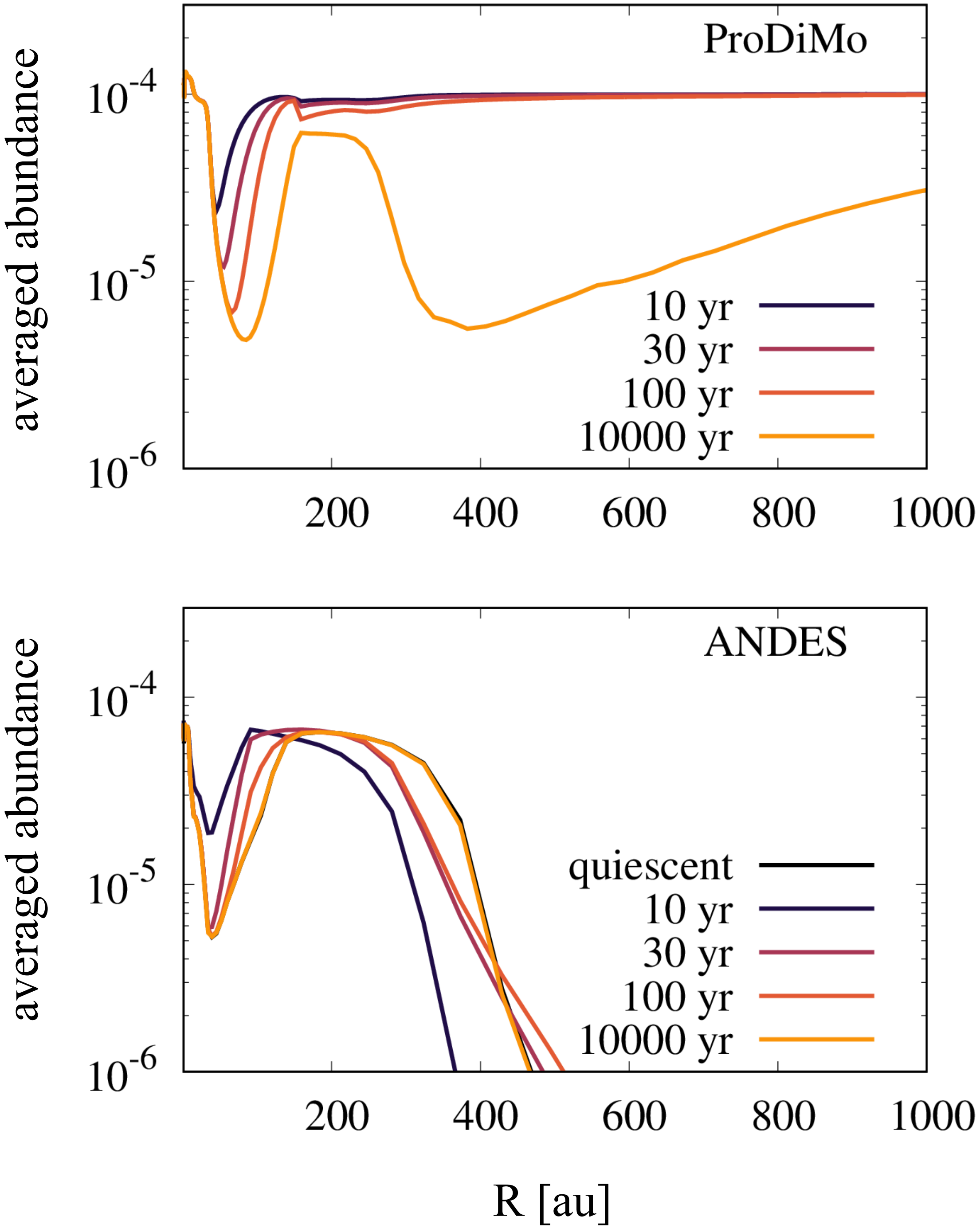


$$R_c = 100\ \text{au}$$

$$M_\star = 1.0 M_\odot$$

$$M_{disk} = 0.01 M_\odot$$

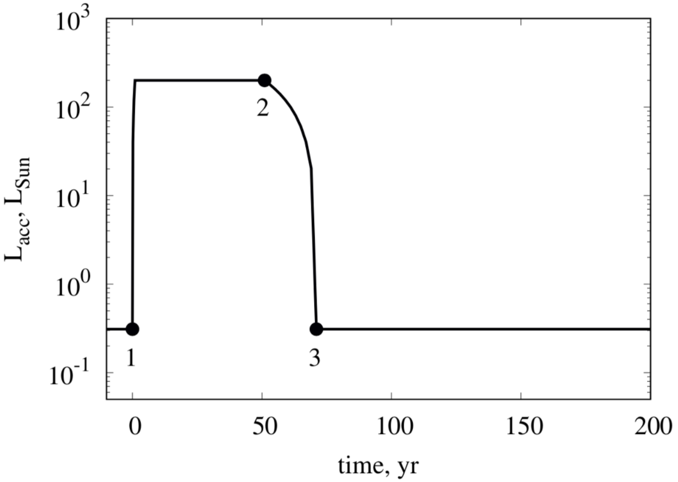




Rab et al. 2017

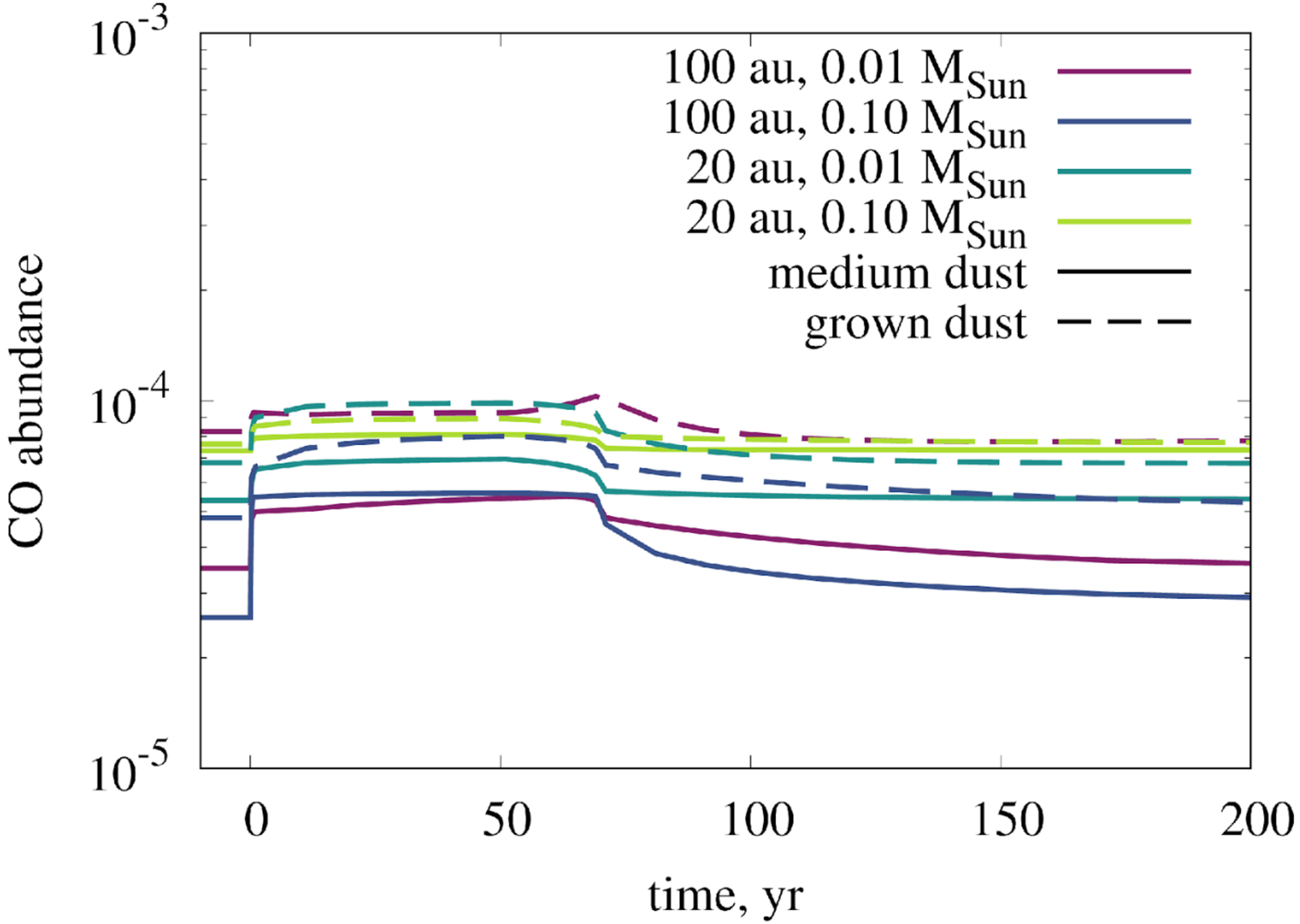
CO radial profile after the outburst

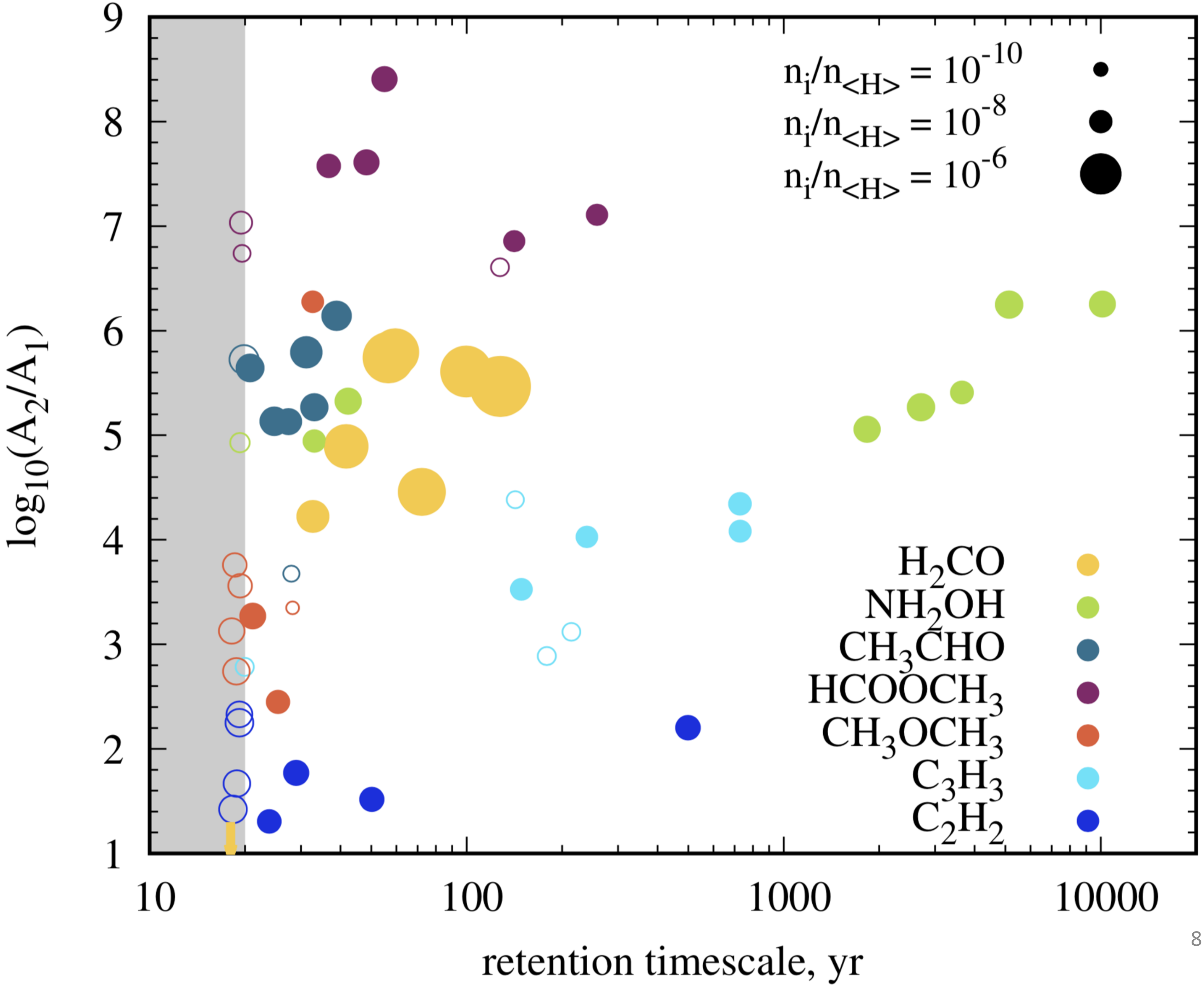
Model parameters

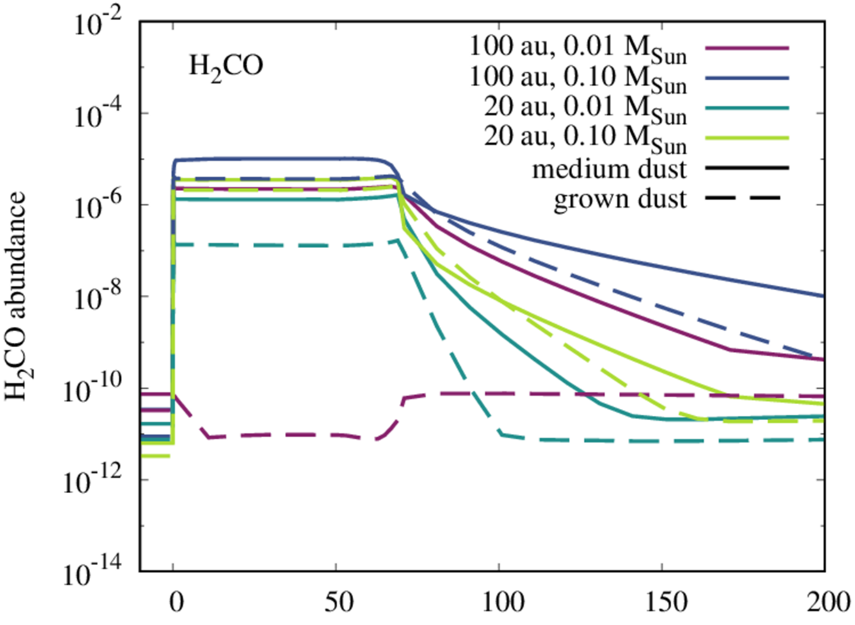


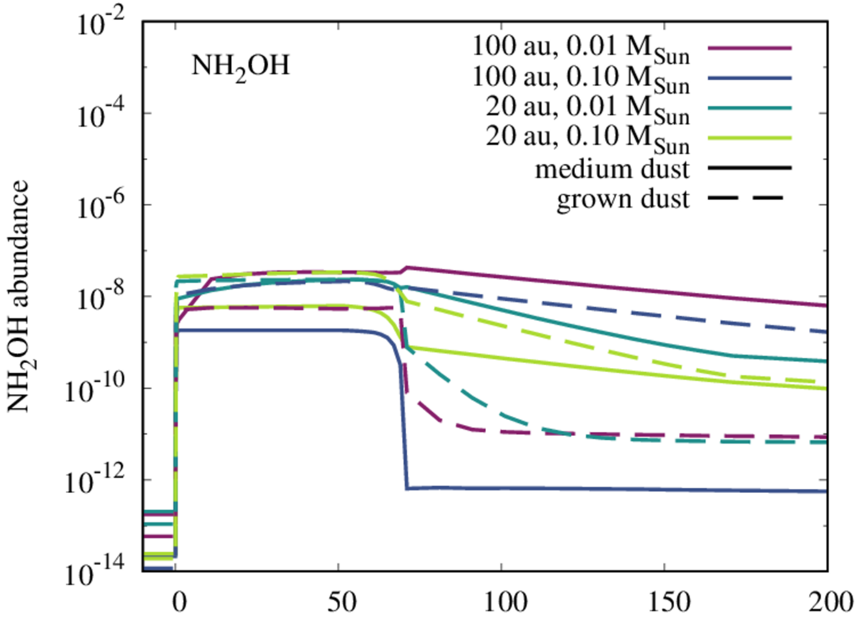
- Disk radii of 100 and 20 au,
  Disk mass of 0.1 and 0.01 $M_\odot$
- MRN-like power-law dust size distribution. Two dust sizes:
  $a_{min} = 0.005$ µm, $a_{max} = 25$ µm, $\bar{a} = 0.37$ µm – **medium dust**
  $a_{min} = 0.005$ µm, $a_{max} = 2500$ µm, $\bar{a} = 3.7$ µm – **grown dust**
- 500000 years before the outburst $L_{acc} = 0.3\ L_\odot$
  1 year growing up to $L_{acc} = 200\ L_\odot$
  50 years of outburst $200\ L_\odot$
  20 years damping to $0.3\ L_\odot$
  10000 years $L_{acc} = 0.3\ L_\odot$

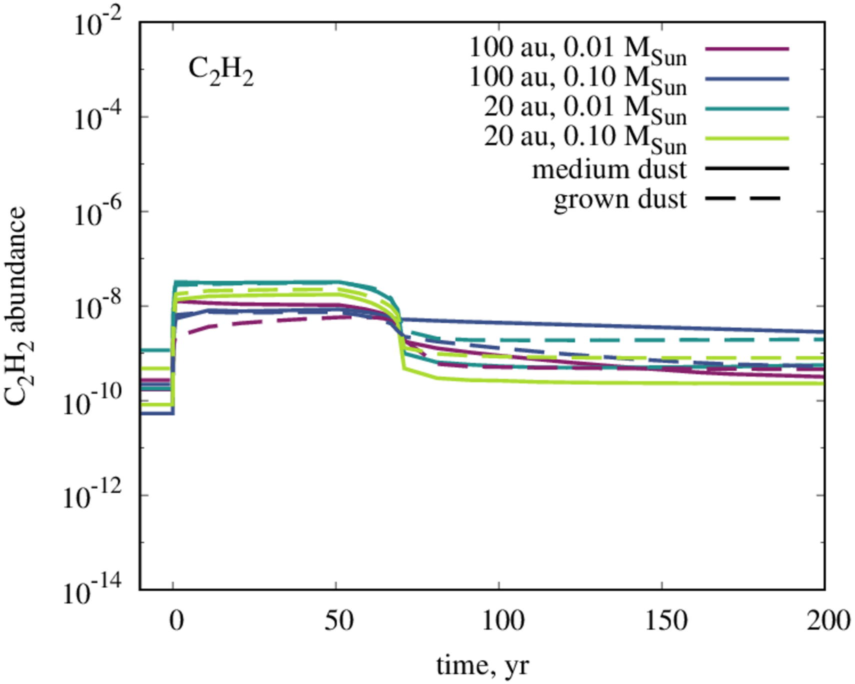
The goal is to find out the gas-phase species that can stay overabundant after the end of the outburst

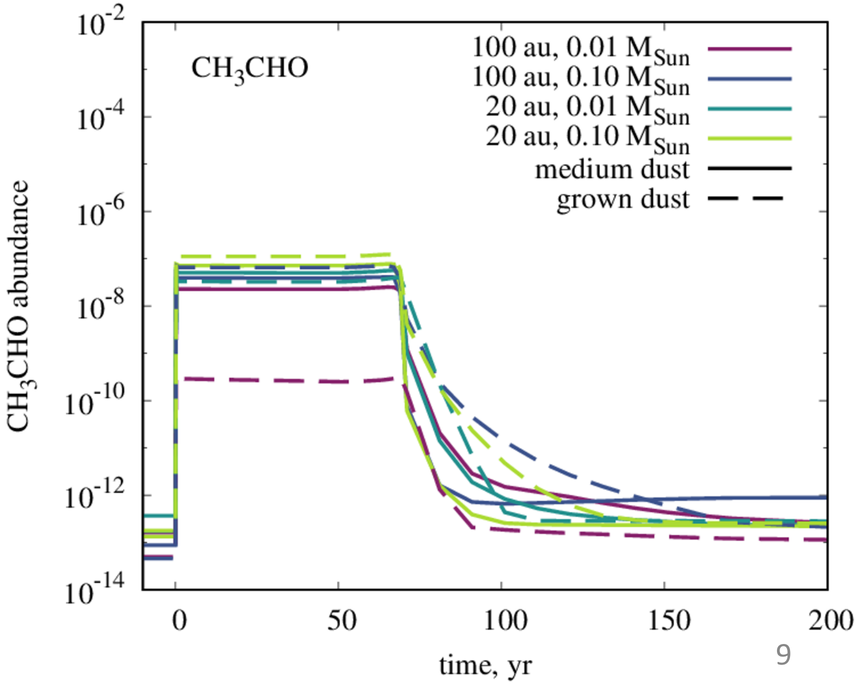

100 au, 0.01 M_{Sun}
100 au, 0.10 M_{Sun}
20 au, 0.01 M_{Sun}
20 au, 0.10 M_{Sun}
medium dust
grown dust
CO abundance
10^{-3}
10^{-4}
10^{-5}
0
50
100
150
200
time, yr

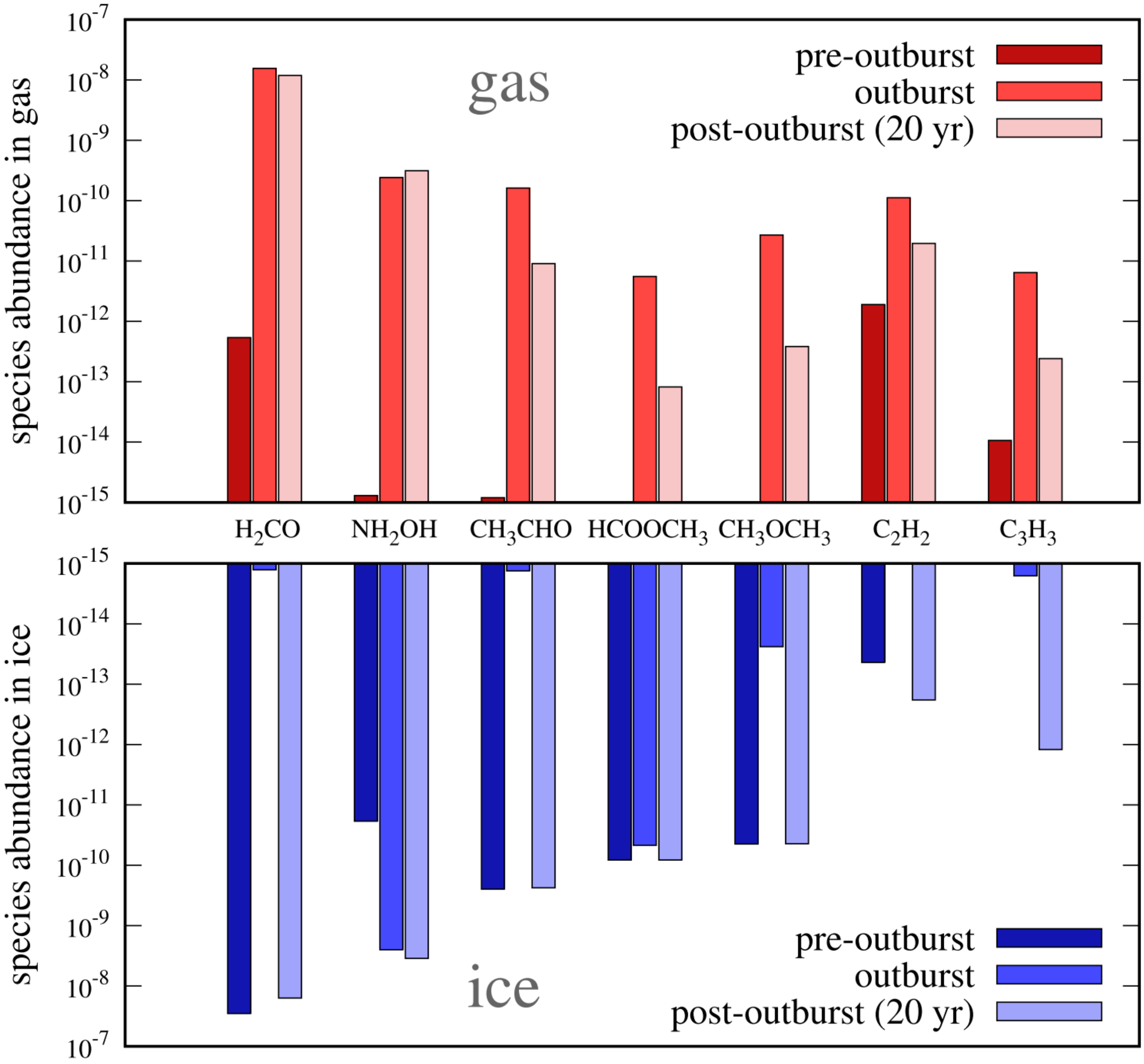

$n_i/n_{<H>} = 10^{-10}$
$n_i/n_{<H>} = 10^{-8}$
$n_i/n_{<H>} = 10^{-6}$
H_2CO
NH_2OH
CH_3CHO
$HCOOCH_3$
CH_3OCH_3
C_3H_3
C_2H_2
$\log_{10}(A_2/A_1)$
retention timescale, yr
1
2
3
4
5
6
7
8
9
10
100
1000
10000


H$_2$CO
100 au, 0.01 M$_{Sun}$
100 au, 0.10 M$_{Sun}$
20 au, 0.01 M$_{Sun}$
20 au, 0.10 M$_{Sun}$
medium dust
grown dust
H$_2$CO abundance
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
0
50
100
150
200


NH$_2$OH
100 au, 0.01 M$_{Sun}$
100 au, 0.10 M$_{Sun}$
20 au, 0.01 M$_{Sun}$
20 au, 0.10 M$_{Sun}$
medium dust
grown dust
NH$_2$OH abundance
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
0
50
100
150
200


C$_2$H$_2$
100 au, 0.01 M$_{Sun}$
100 au, 0.10 M$_{Sun}$
20 au, 0.01 M$_{Sun}$
20 au, 0.10 M$_{Sun}$
medium dust
grown dust
C$_2$H$_2$ abundance
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
0
50
100
150
200
time, yr

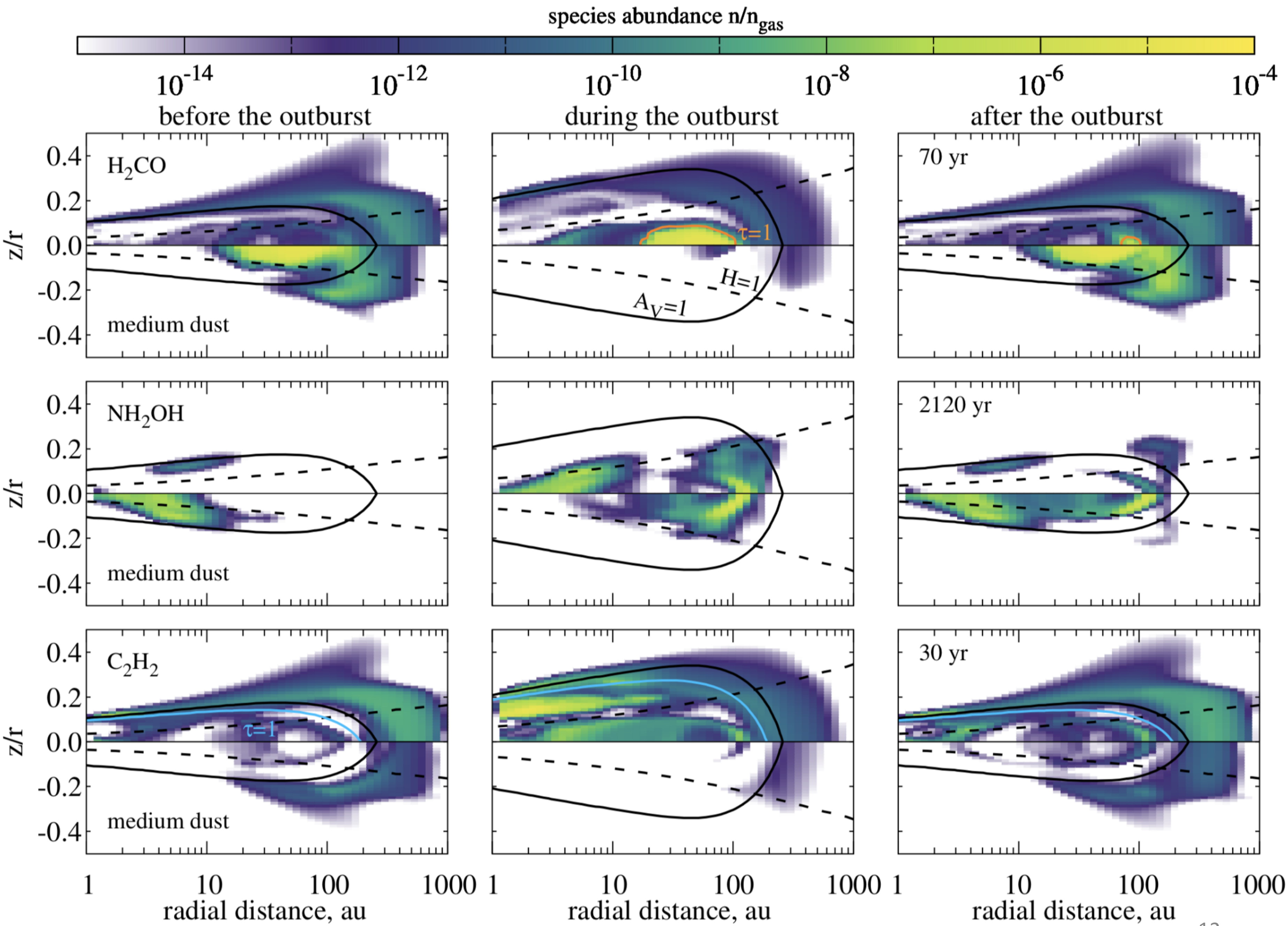

CH$_3$CHO
100 au, 0.01 M$_{Sun}$
100 au, 0.10 M$_{Sun}$
20 au, 0.01 M$_{Sun}$
20 au, 0.10 M$_{Sun}$
medium dust
grown dust
CH$_3$CHO abundance
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
0
50
100
150
200
time, yr


gas
pre-outburst
outburst
post-outburst (20 yr)
species abundance in gas
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
H_2CO
NH_2OH
CH_3CHO
$HCOOCH_3$
CH_3OCH_3
C_2H_2
C_3H_3
species abundance in ice
10^{-15}
10^{-14}
10^{-13}
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
ice
pre-outburst
outburst
post-outburst (20 yr)

Three formation scenarios

- Thermal desorption of the ice pre-formed during the quiescent stage: H_2CO, $HCOOCH_3$, CH_3OCH_3, $CHOCH_3$.
- Formation in the gas from thermally desorbed molecules or through new enhanced reaction chains: C_2H_2, C_3H_3.
- Formation in the ice phase followed by reactive desorption: NH_2OH

Wiebe et al. 2019


species abundance n/n_{gas}
10^{-14}
10^{-12}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
before the outburst
during the outburst
after the outburst
H_2CO
medium dust
$\tau=1$
H=1
$A_V=1$
70 yr
NH_2OH
medium dust
2120 yr
C_2H_2
$\tau=1$
medium dust
30 yr
z/r
0.4
0.2
0.0
-0.2
-0.4
1
10
100
1000
radial distance, au

Conclusions

- CO abundance does not retain the outburst influence for a long time after the outburst in the absence of an embedding envelope.
- Some species can be used to identify past outbursts in quiescent disks. H_2CO and NH_2OH are the most promising species, their abundances remain orders of magnitude above their pre-outburst values for tens and hundreds of years after the outburst, respectively.
- Chemical composition of the disk during the outburst and timescales to return to the quiescent chemical composition are sensitive to disk physical parameters and dust properties.

Molyarova et al. (2018)

Thank you for your attention!