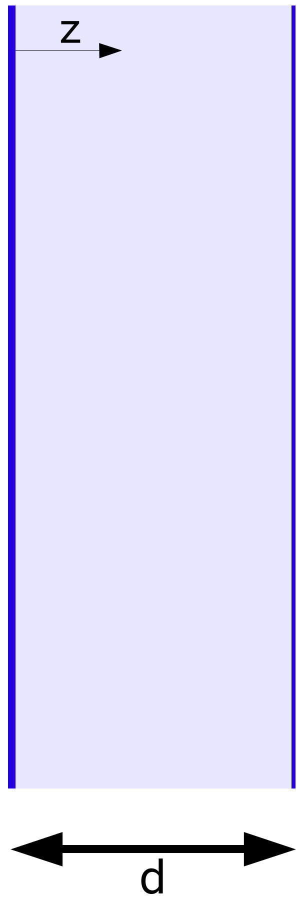
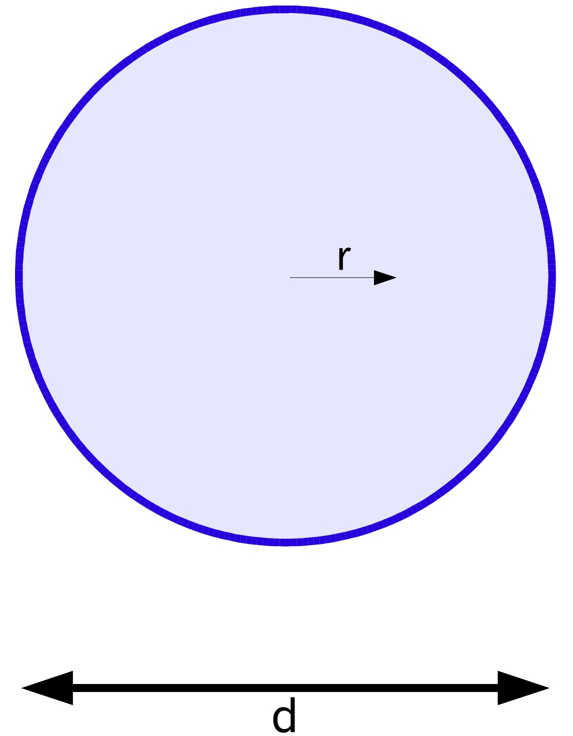
# PDR-models: geometry issues

- directed vs. isotropic illumination
- plane-parallel vs. spherical cloud geometry
- dust scattering
- clumpy clouds

# cloud geometry




<u>plane parallel</u>

$d \rightarrow \infty$ : semi-infinite

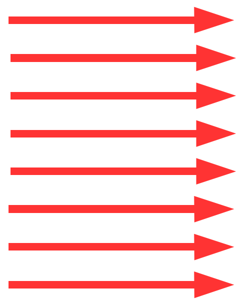
$\tau$ or $A_v \propto z$ (homogenous)

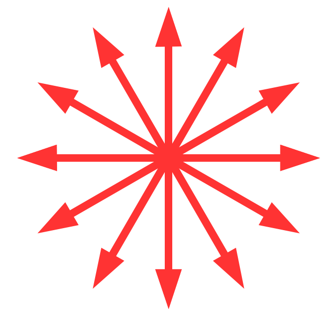
<u>spherical</u>

$d \rightarrow \infty$ : semi-infinite

$\tau$ or $A_v \propto (d/2-r)$ (homogenous)

# radiation field





**directed**
e.g. from sufficiently
far away young stellar cluster

**isotropic**
e.g. average interstellar radiation field

**for PDR models:**
**parametrization by mean intensity (or energy density)**

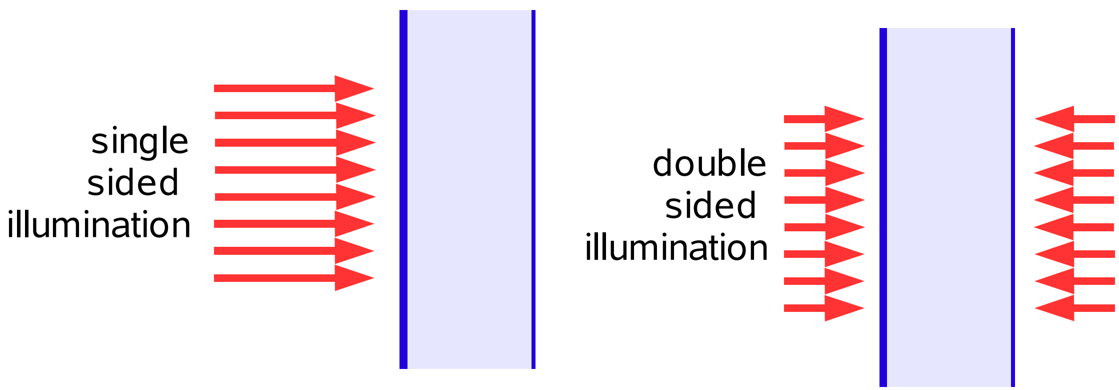
$$J = \frac{1}{(4\pi)} \int I \, d\Omega$$

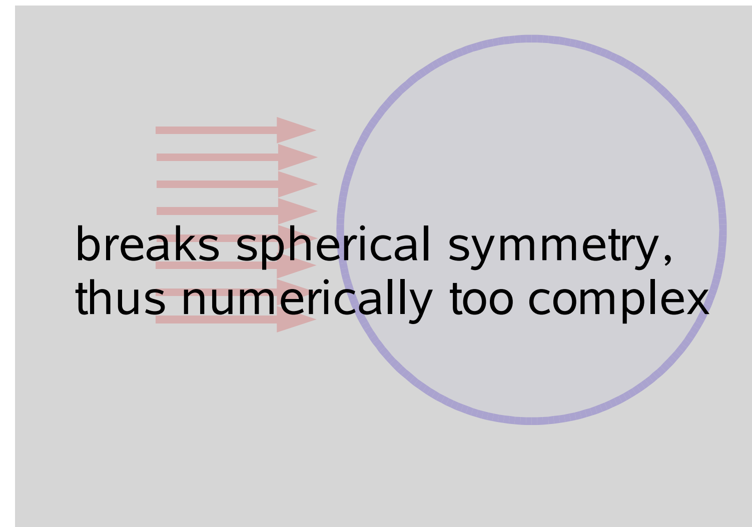
# cloud embedded in radiation field

plane-parallel cloud

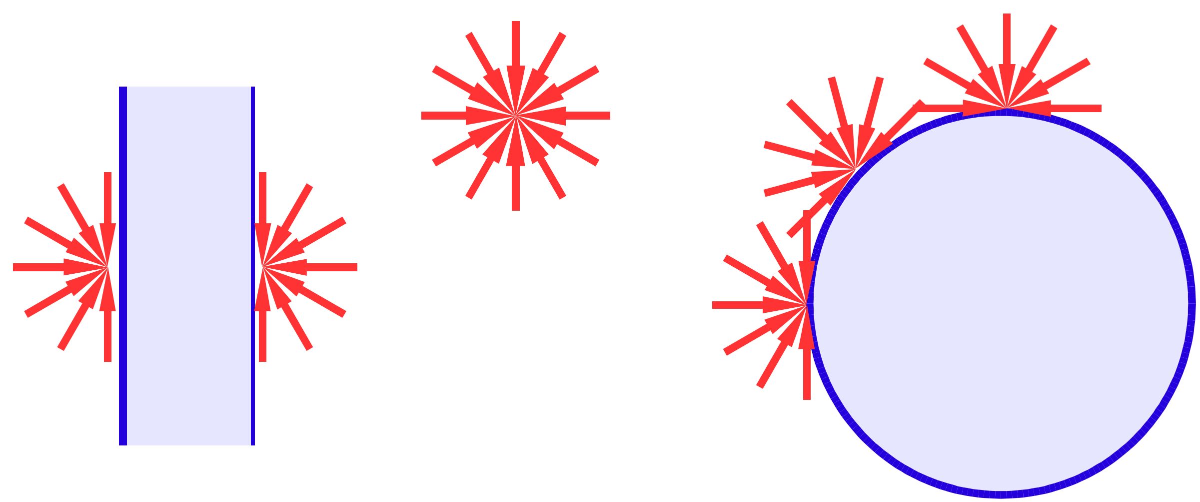
spherical cloud

directed illumination:




isotropic illumination:



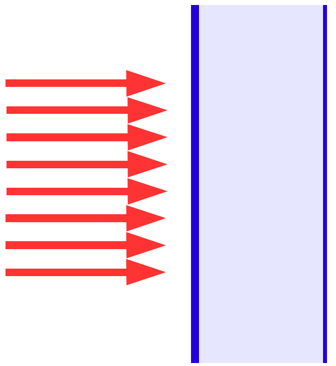
# cloud embedded in radiation field

plane-parallel cloud

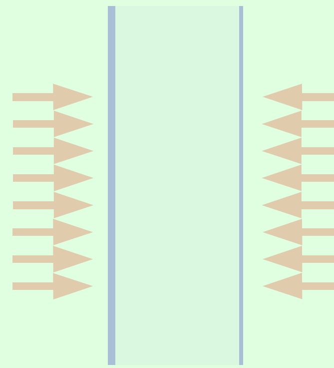
spherical cloud

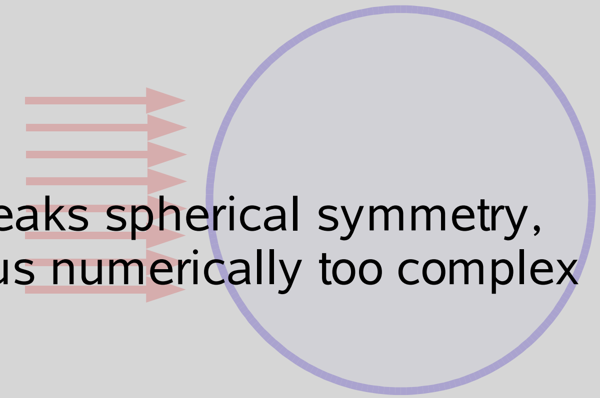
directed illumination:

single
sided
illumination



double
sided
illumination

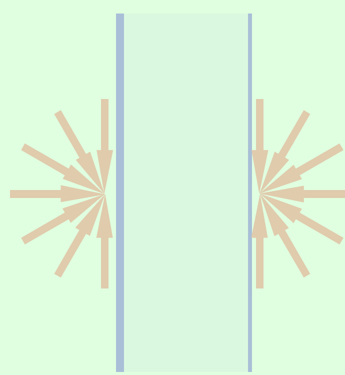


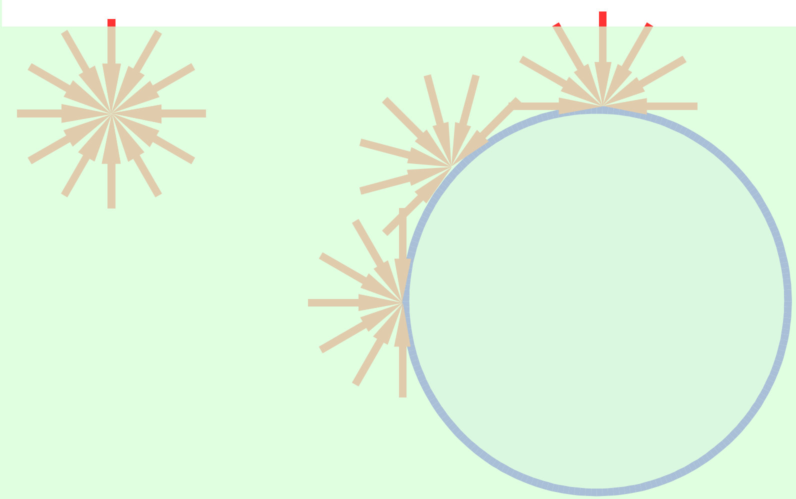


breaks spherical symmetry,
thus numerically too complex

isotropic illumination:

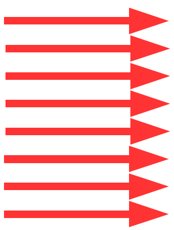
**Note:**
mean intensity at surface of optically thick cloud is half (no scattering!) of surface intensity of optically thin cloud!
(correspondingly for moderate optical depth and scattering)

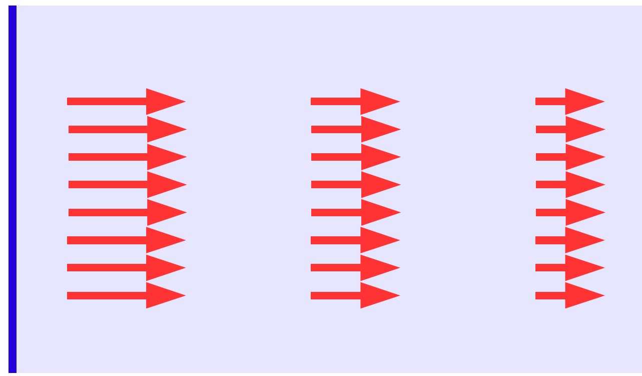




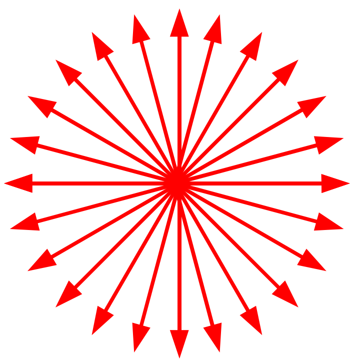
# directed vs. isotropic illumination

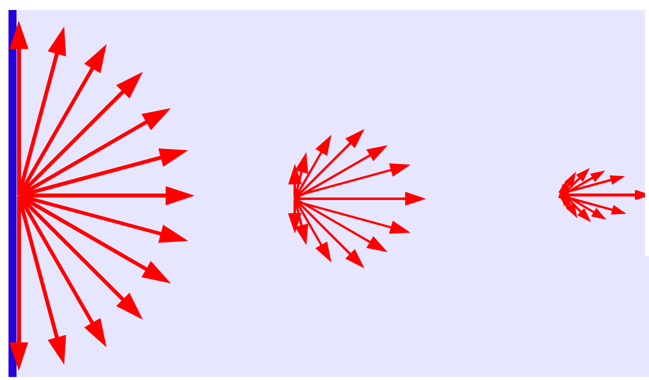
directed illum.



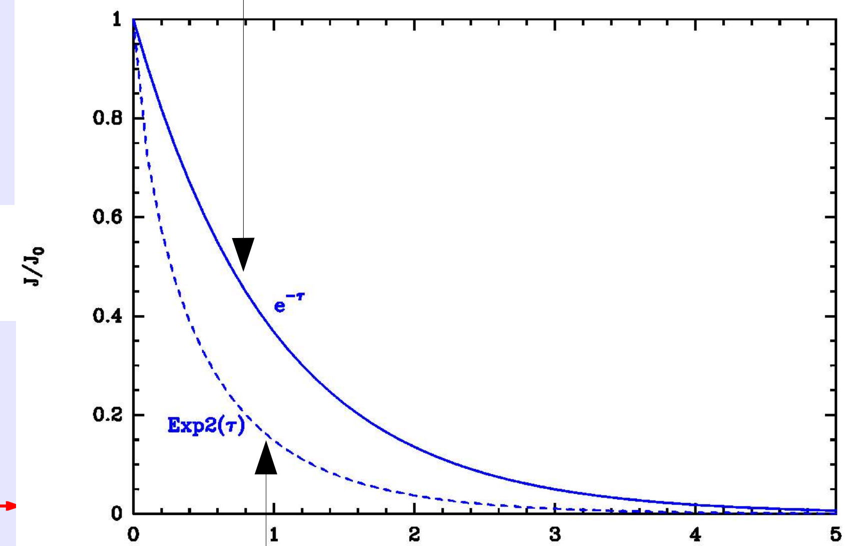


isotropic illum.





$$J/J_0 = \exp(-\tau)$$




$$J/J_0 = E_2(\tau) = \int_1^\infty \frac{\exp(-\tau\ z)}{z^2}\, dz$$

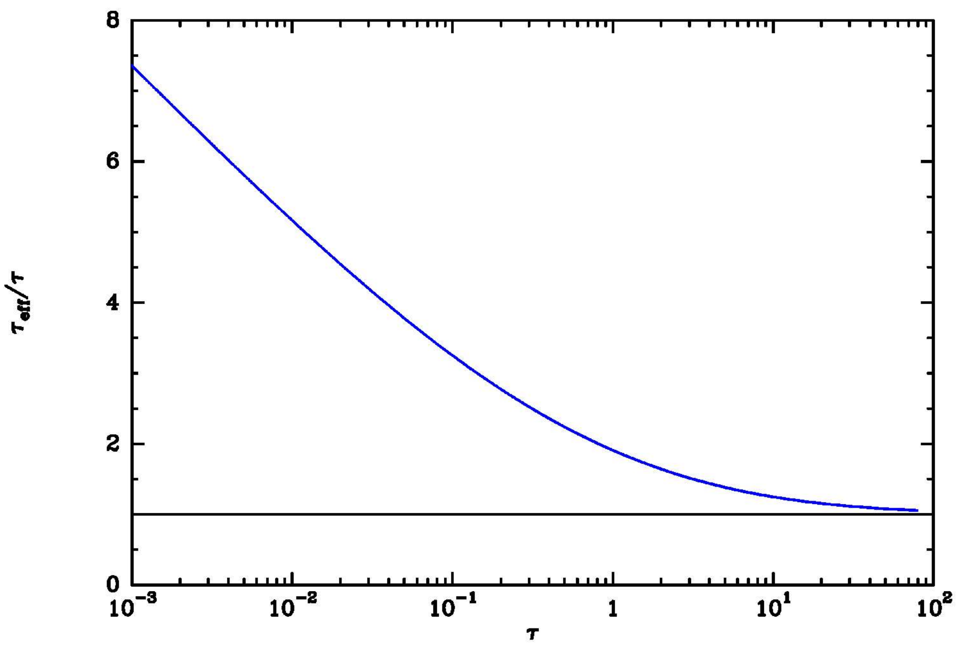
# directed vs. isotropic illumination [2]

PDR chemical and physical properties are dominated by UV mean intensity.

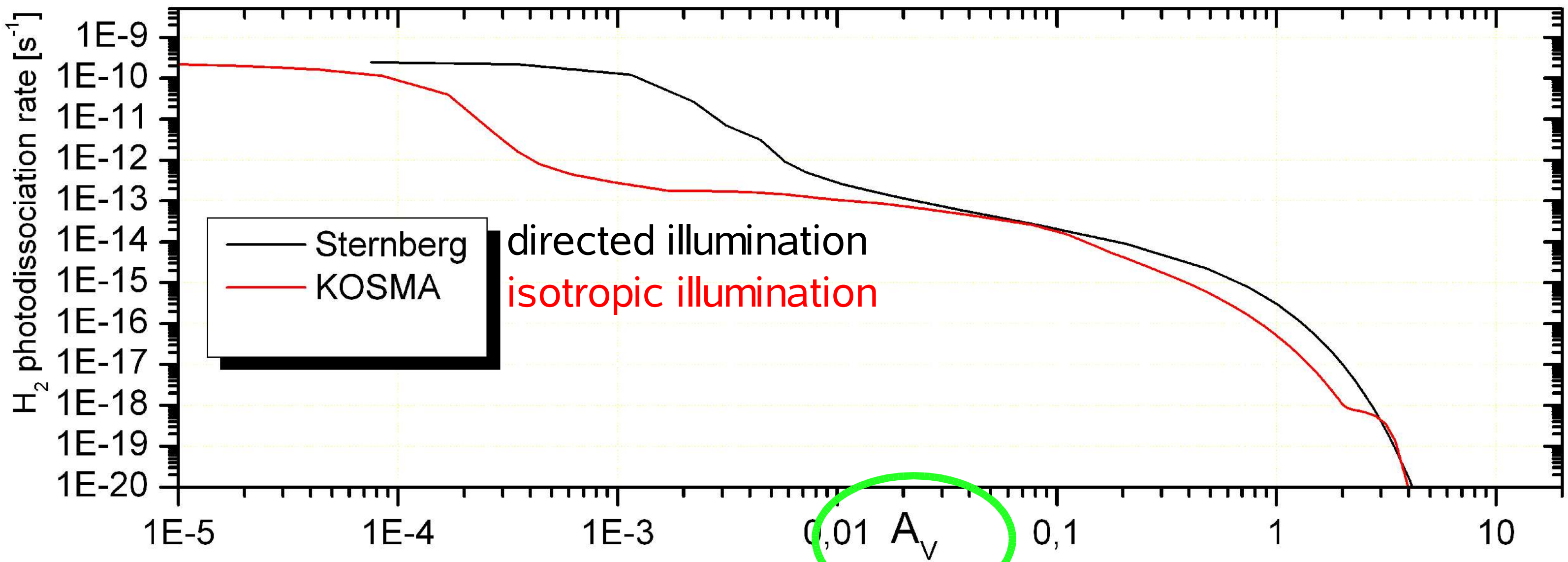
Thus,

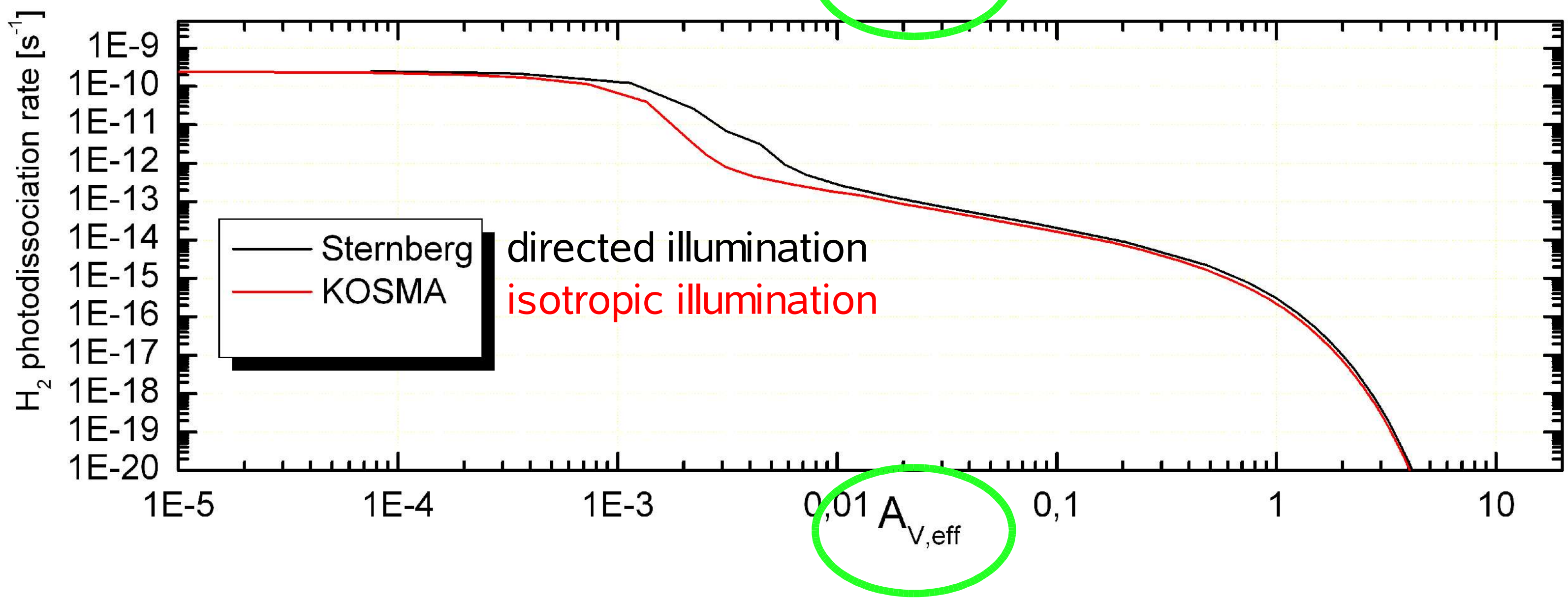
- we use $A_v$ (i.e. optical depth normal to surface) to plot depth variation of relevant quantities, which characterizes exponential attenuation of UV mean intensity
- to compare plane-parallel problem with isotropic illumination vs. directed illumination, we should plot the latter vs

$$A_{v,eff} = -\ln\left[E_2(A_v)\right]$$



# directed vs. isotropic illumination [3]



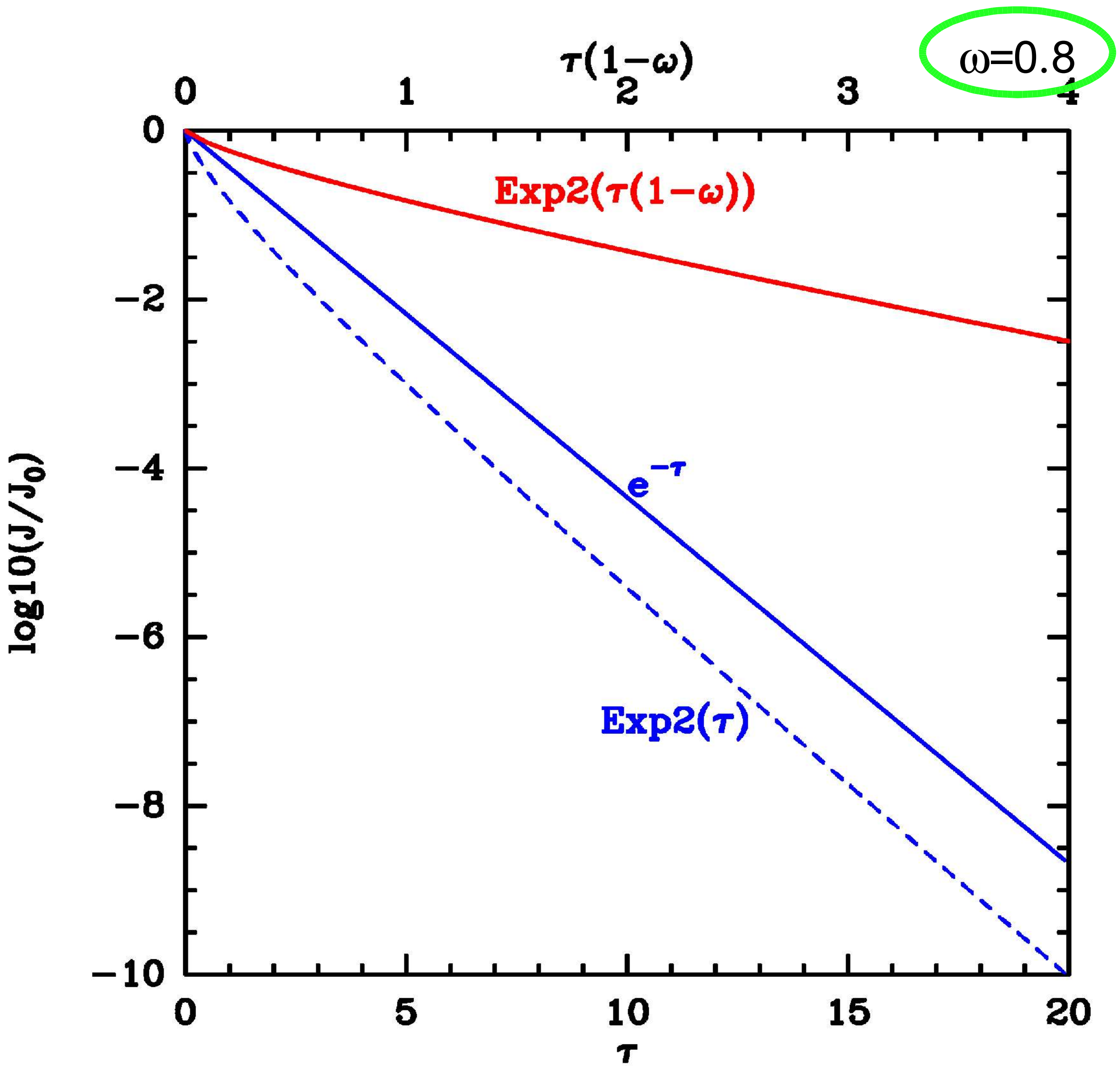
# scattering on dust

- most PDR-models neglect scattering on dust
- exceptions: Le Bourlot, Leiden, CLOUDY, ... ?
- dust scattering characterized (Henvey-Greenstein) by
  - albedo $\omega = 0,...,1$
  - mean cosine of scatter angle g = 0 (isotropic), ... , 1 (forward)
- 'analytic' solution via Legendre-Polynom expansion (Flannery et al. 1980)
- typical UV dust properties: $\omega = 0.8$, g = 0.75
- note: for g=1 solution scales from no-scatter case as $\tau' = \tau\,(1-\omega)$

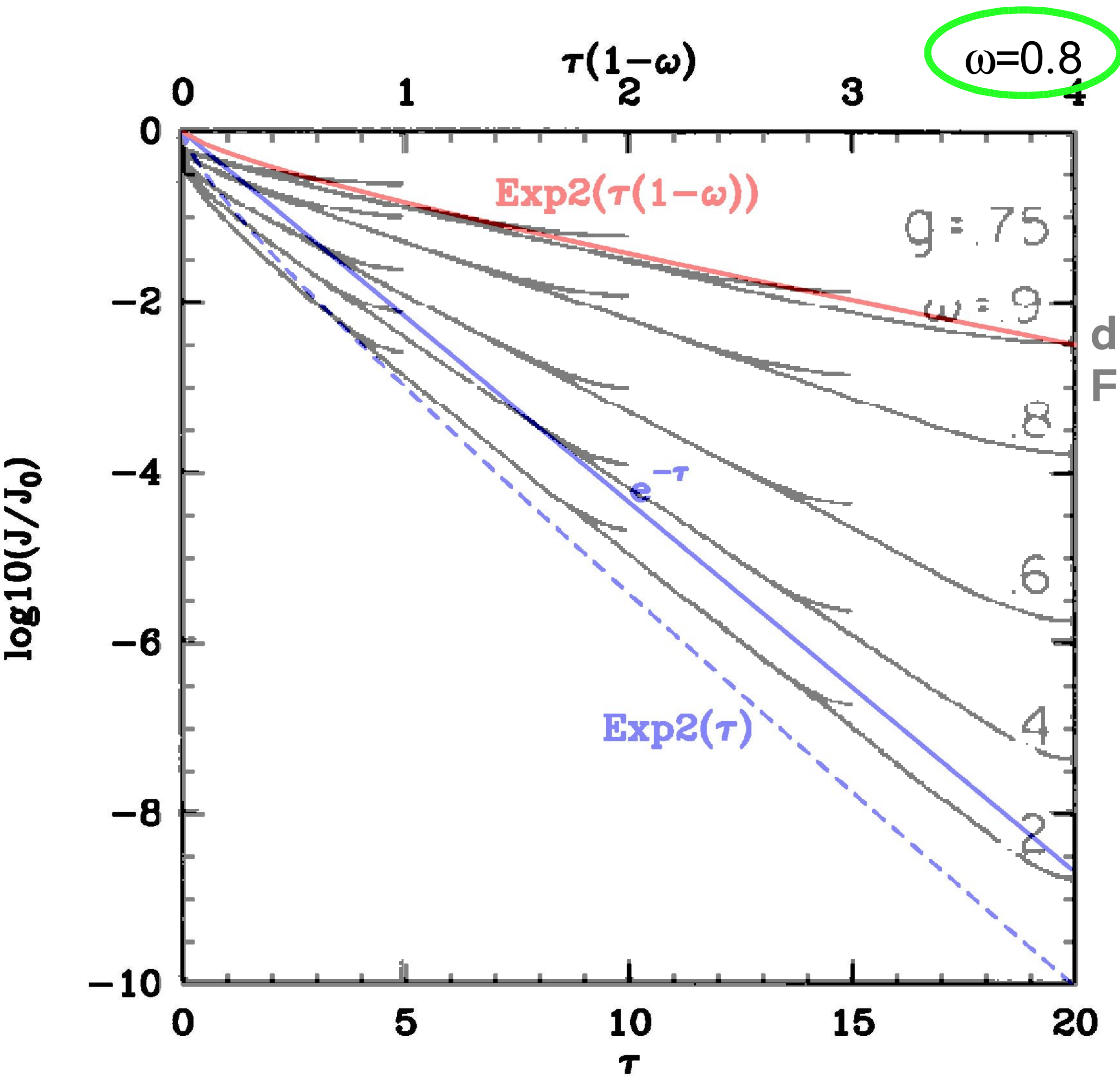
issues:

- scattering decreases effective attenuation: more material needed to reach the same UV-attenuation $\Rightarrow$ proper $A_v$ / $H_2$-scaling
- scattering changes angular characteristic of rad. field (how important is this for PDR models?)

# comparison: with/without scattering



# comparison: with/without scattering




dust scattering
Flannery et al. 1980

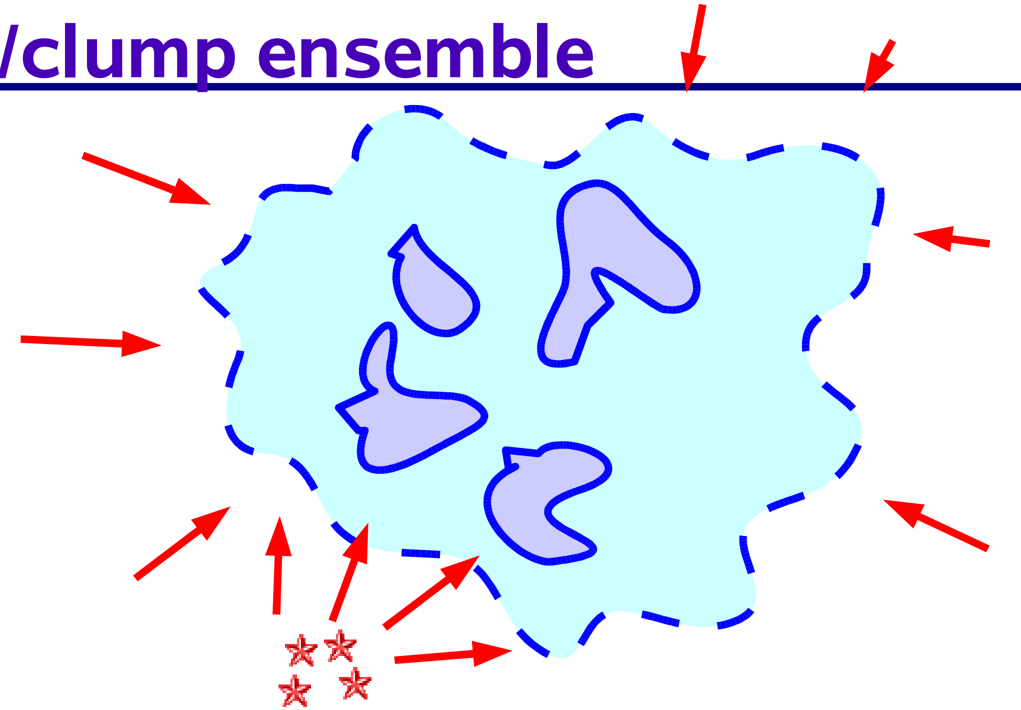
# line radiative transfer

- cooling lines & mean intensity inside cloud:
  escape probability (or similar) treatment properly accounts for geometry (check!)
- topics to discuss:
  - how is directed vs. isotropic irradiation treated in self-schielding against dissociation of molecules?
  - emergent intensities: normal to surface / angular average?

# overall cloud structure: fractal/clump ensemble

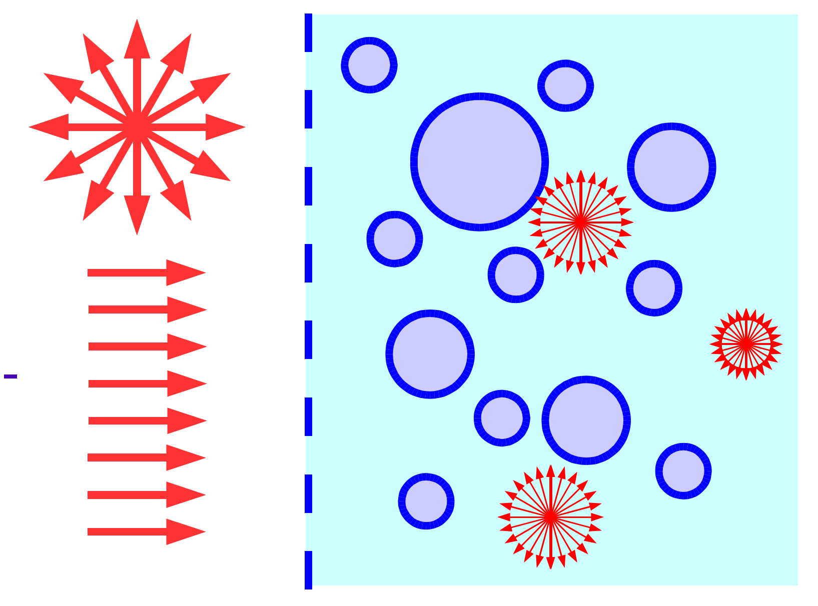
real clouds:

- fractal or clump ensemble
- diffuse interstellar radiation field plus local young stellar clusters



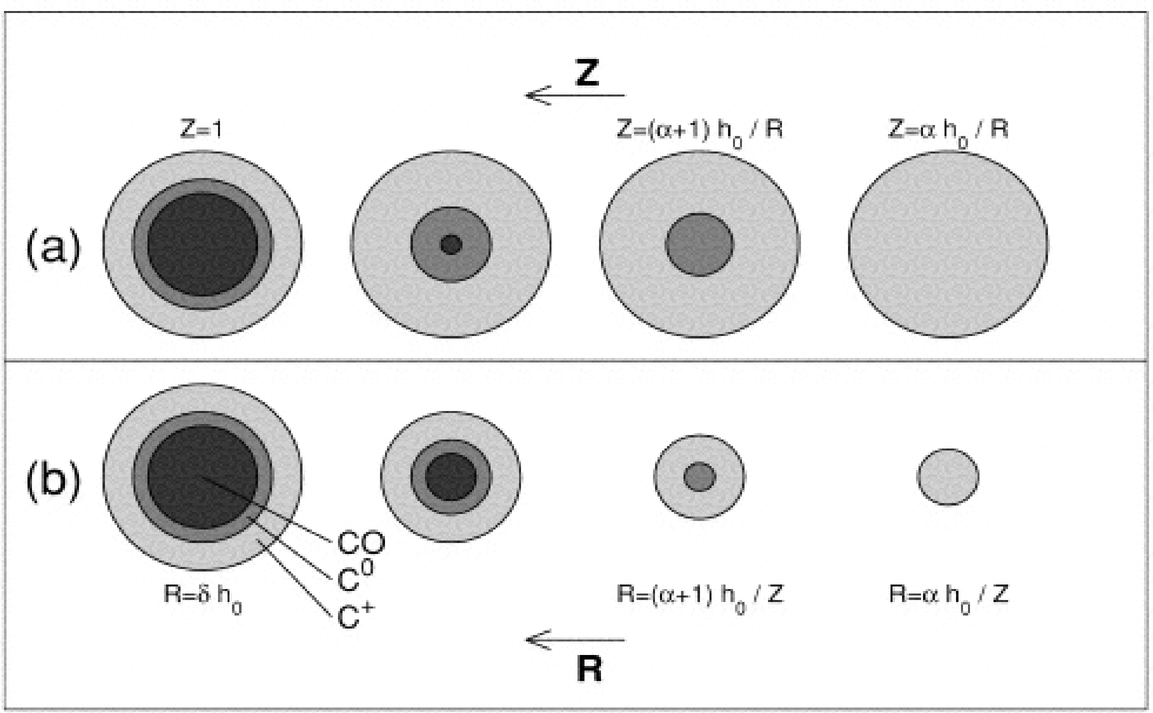
modelling:

- 3D density/velocity structure and Monte-Carlo rad. transfer plus PDR physics
- sperical clump ensemble
  - directed and/or isotropic illumination
  - interclump p.p. PDR
  - pre-shielding of clumps by inter-clump medium



# clumpy cloud: example

- Bolatto et al 1999: spherical clumpd **and metallicity**
- lower metallicity:
  - both dust and "metals" (i.e. atoms, molecules except for HI and $H_2$) reduced
  - dust shieldung and "self-shielding" reduced
  - PDR structure scales up $\propto 1/Z$




ad hoc semi-analytic model (Bolatto et al. 1999):

a) CII- and CI- layer thickness in-creases inversely with metallicity

b) CII $\propto$ 1/Z, but CI-layer stays con-stant with metallicity

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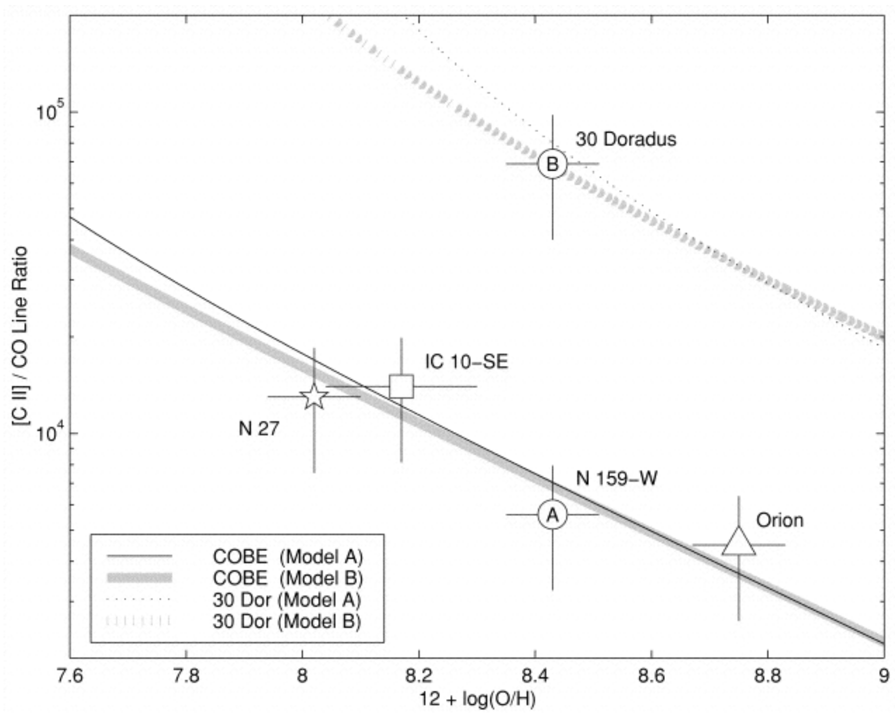


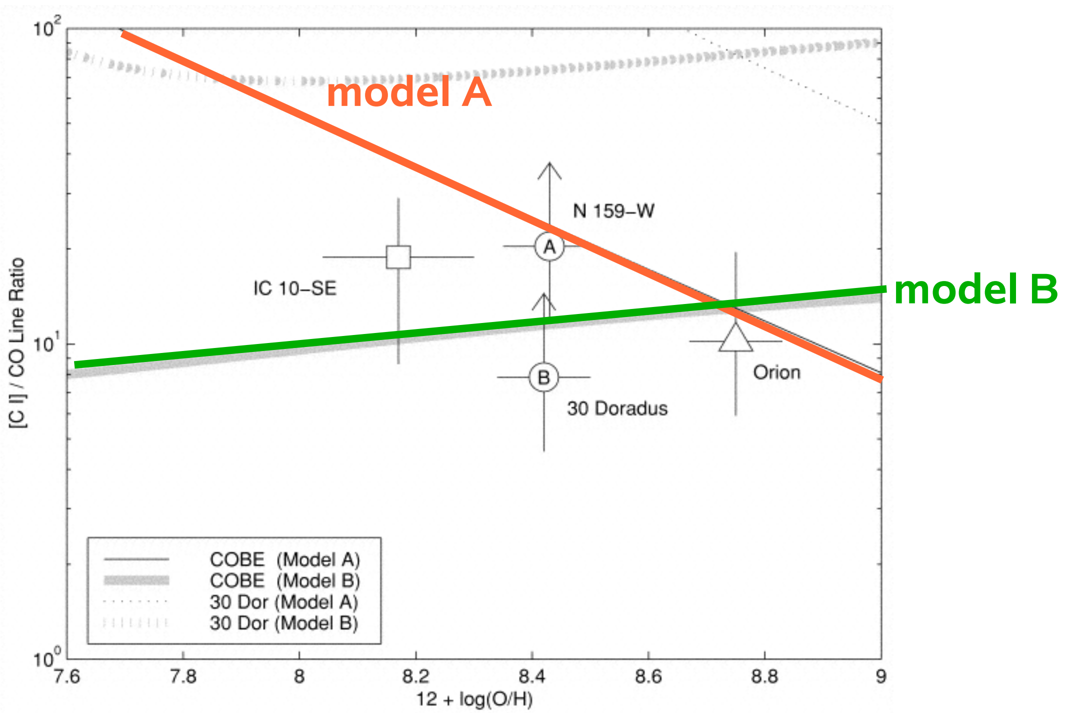

# not covered

- planetary nebulae:
  - spherically symmetric shell structure with central UV source
  - embedded in isotropic interstellar radiation field
- ...
- ...