Search for Hidden Baryons Through Scintillation

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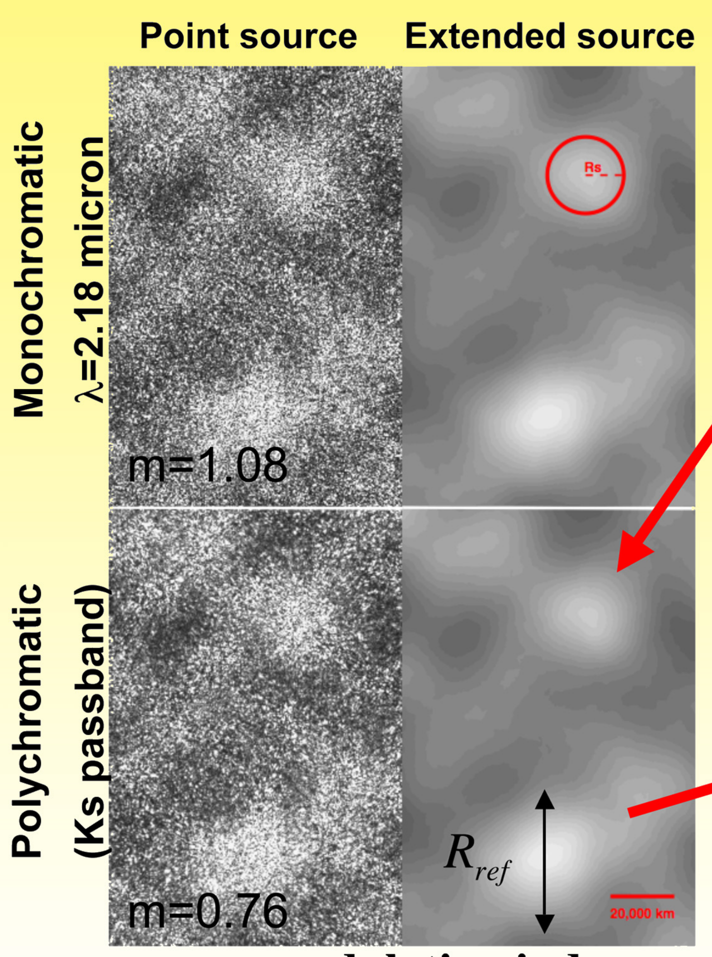
Where Are the Hidden Baryons?

- **Compact Objects? ===> NO (microlensing)**
- **Gas**?
  - Atomic H well known (21cm hyperfine emission)
  - Poorly known contribution: **molecular H_2** (+25% He)
    - Cold (**10K**) => no emission. Very transparent medium.
    - In fractal structure covering **1%** of the sky. **Clumpuscules ~10 AU** (Pfenniger & Combes 1994)
    - In the **thick disc** or/and in the **halo**
    - Thermal stability with a liquid/solid hydrogen core
    - **Detection of molecular clouds** with quasars (Jenkins et al. 2003, Richter et al. 2003) and **indication of the fractal structure** with clumpuscules from CO lines in the galactic plane (Heithausen, 2004).

How can we detect H_2?

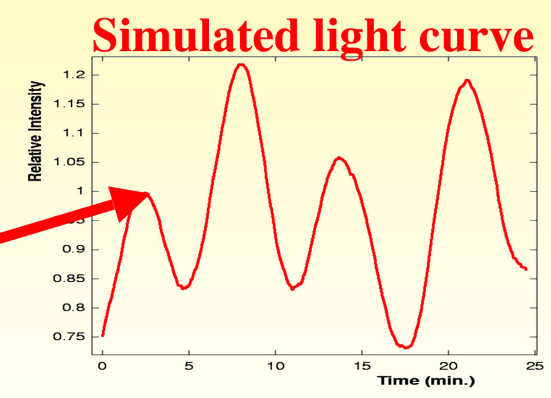
- **Through scintillation due to the refraction of light**
- Elementary process involved: **polarizability** α
  - far from resonance => classical forced oscillator formalism
  - close to initial propagation direction => collective effect even with low molecular density ~ 10^9 cm^{-3}
- Extra optical path due to H_2 medium
  - On average ~800λ @ λ=500nm => varies from **0** (99% of the sky) to **80,000** λ (1%)

Simulation towards B68



m = modulation index

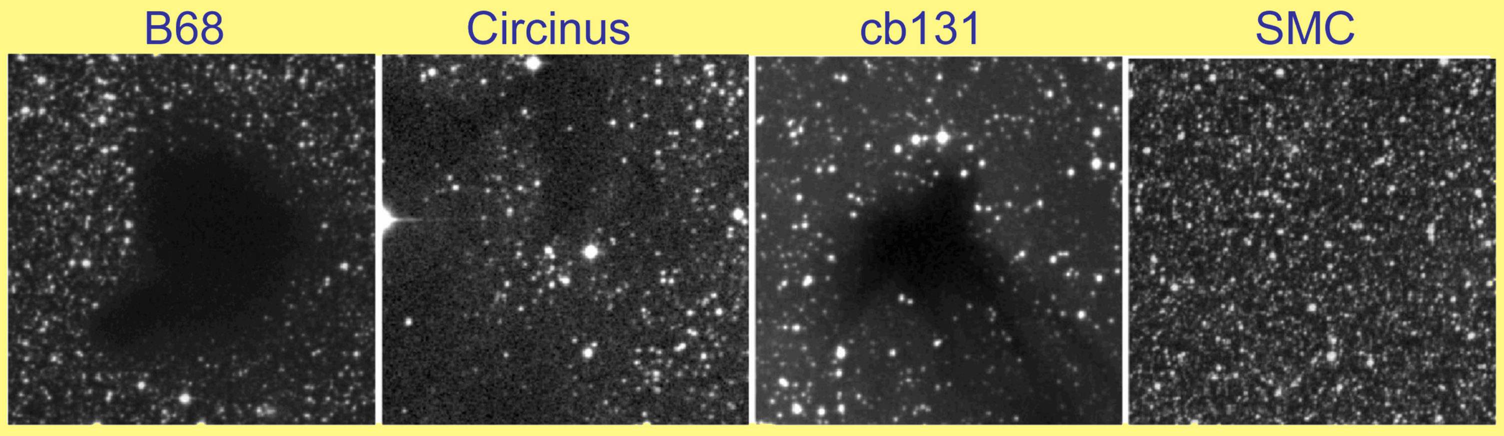
Illumination in **Ks** by a **K0V** star@8kpc through a cloud@160pc with R_{diff}=150km



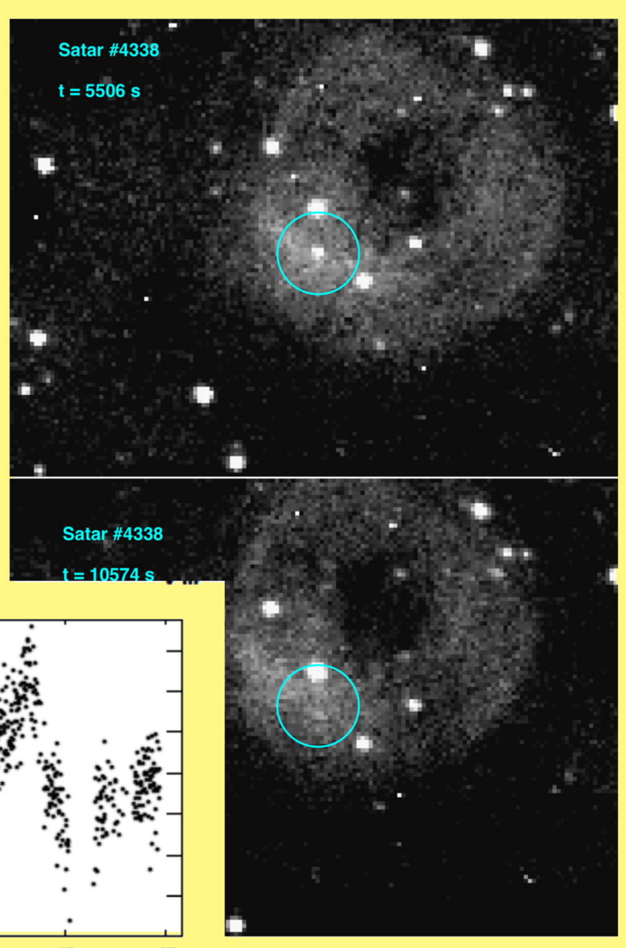
Stochastic with characteristic length: R_{ref}

Feasibility Test in NIR with ESO NTT

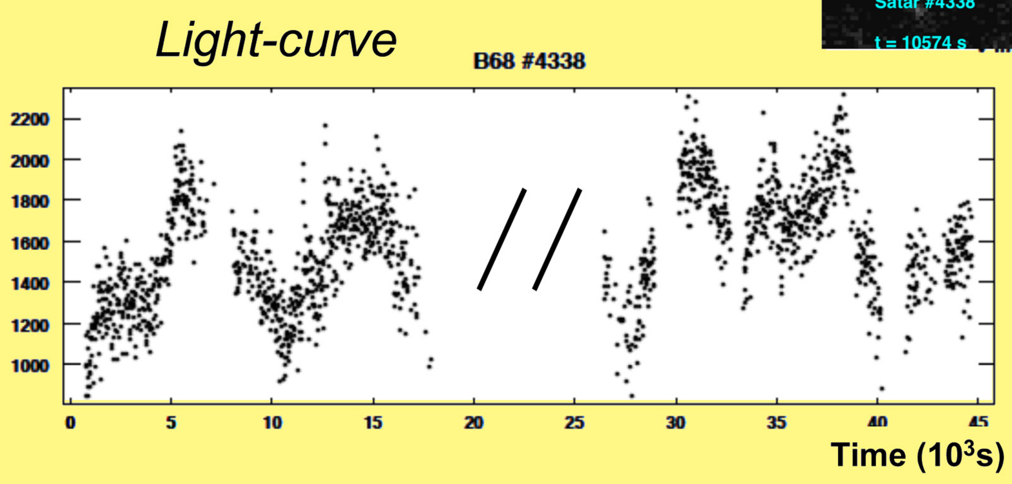
Targets



- **Total ~ 5000 images**
- **Sampling ~ 15s**

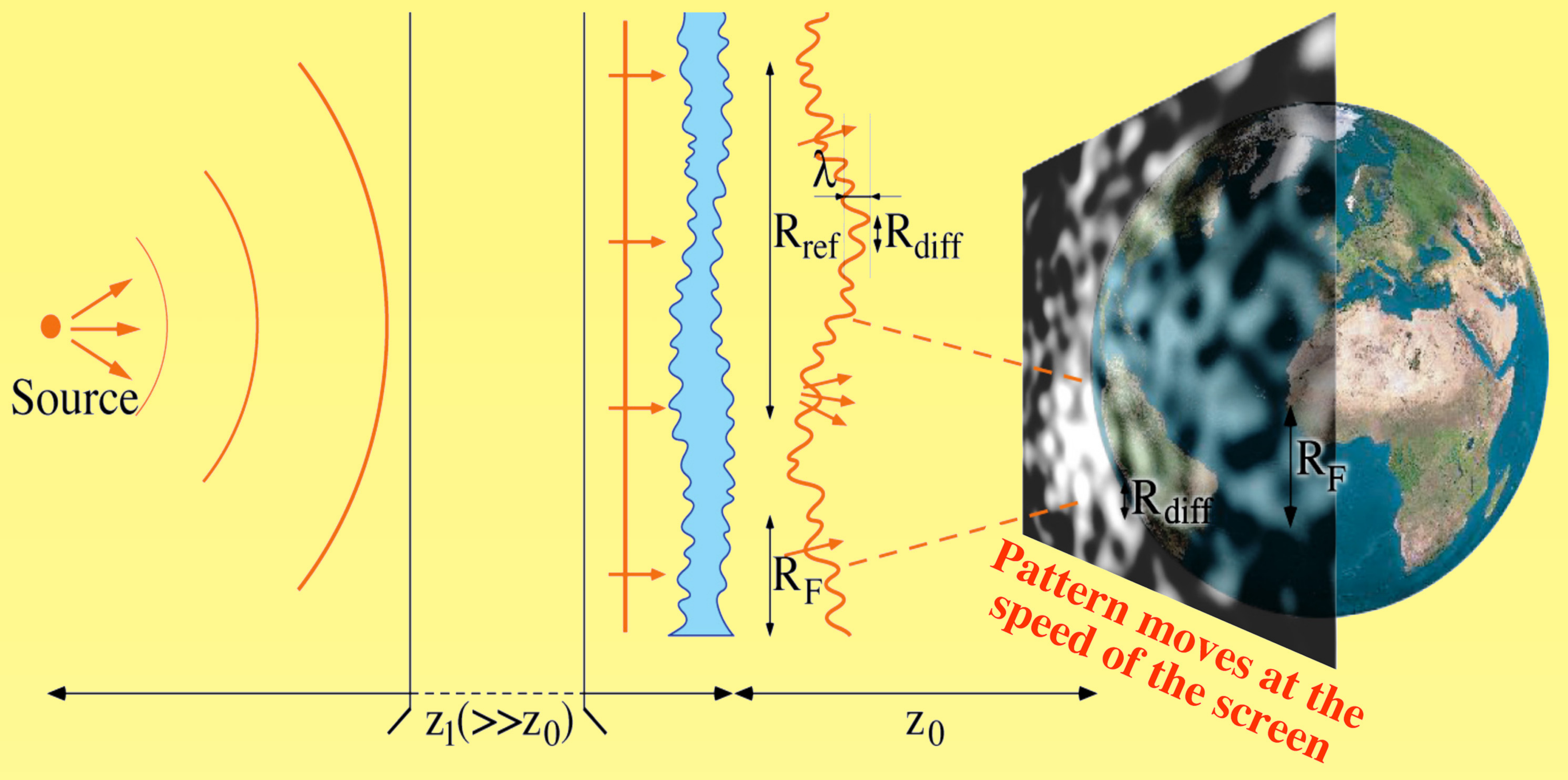


one scintillating star?
(other than known artifacts)



Scintillation through a Diffusive Screen

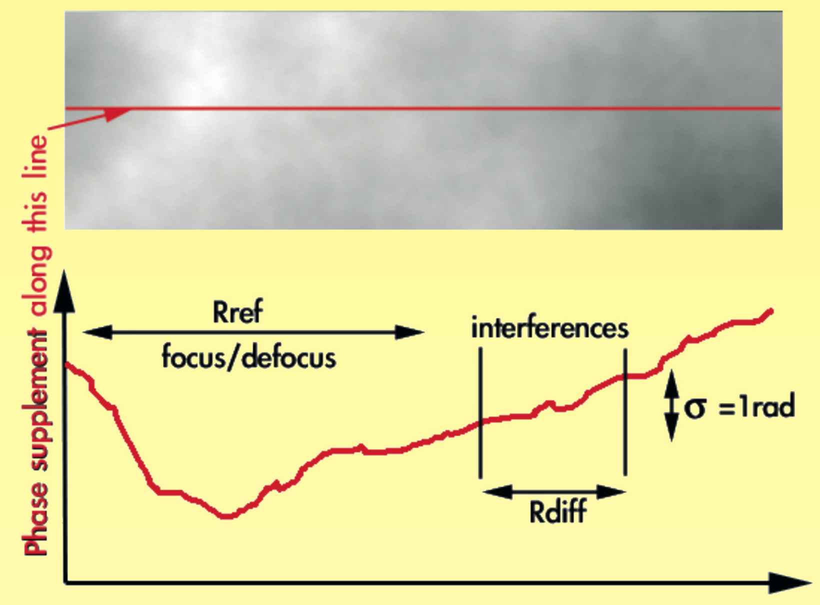
Propagation of distorted wave surface driven by:
Fresnel diffraction + « global » refraction



R_{diff} : Statistical characterization of a stochastic screen

Size of domain where
$\Delta\phi$ **= 1 radian**

- i.e. (λ = 500 nm)
ΔN_l **= 1.8x10^{18}** molecules/cm^2
- This corresponds to
  - $\Delta N_l / N_l$ **~ 10^{-6}** for disk/halo clumpuscule
  - $\Delta N_l / N_l$ **~ 10^{-4}** for Bok globule (NTT search)



$$R_{diff} = 744\,km \times \left[\frac{\lambda}{1\mu m}\right]^{\frac{6}{5}} \left[\frac{L_z}{10A.U.}\right]^{-\frac{3}{5}} \left[\frac{L_{out}}{10A.U.}\right]^{\frac{2}{5}} \left[\frac{\sigma_{3n}}{10^9 cm^{-3}}\right]^{-\frac{6}{5}}$$

L_z : Cloud's size $\quad$ L_{out} : Turbulence's outer scale

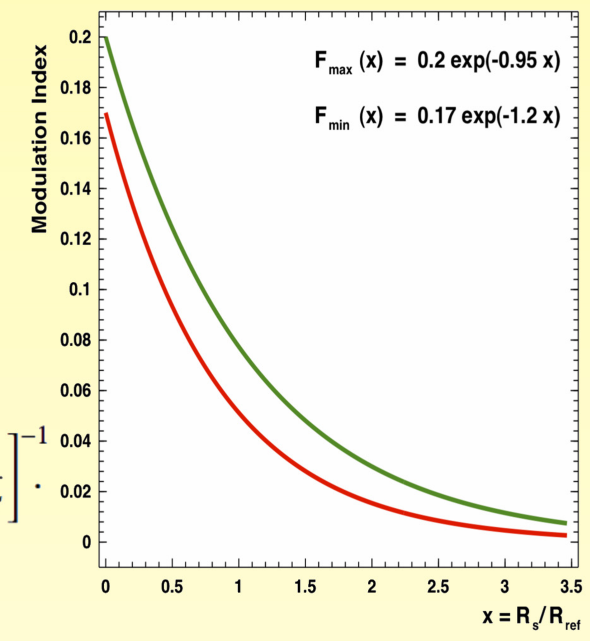
Scaling Laws in Scintillation of a Star

Scale of large structures:

$$R_{ref}(\lambda) = \frac{\lambda z_0}{R_{diff}} \sim 30,860\,km \left[\frac{\lambda}{1\mu m}\right]\left[\frac{z_0}{1\,kpc}\right]\left[\frac{R_{diff}(\lambda)}{1000\,km}\right]^{-1}$$

Characteristic Scintillation time:

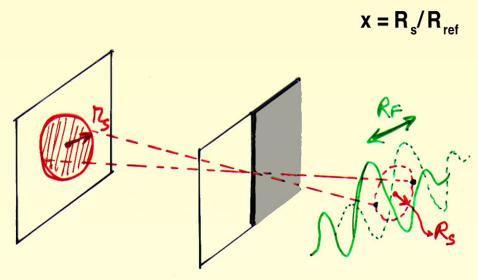
$$t_{ref}(\lambda) = \frac{R_{ref}(\lambda)}{V_T} \sim 5.2\,minutes \left[\frac{\lambda}{1\mu m}\right]\left[\frac{z_0}{1\,kpc}\right]\left[\frac{R_{diff}(\lambda)}{1000\,km}\right]^{-1}\left[\frac{V_T}{100\,km/s}\right]^{-1}.$$



Modulation index: $m = \frac{\sigma_I}{\bar{I}}$

Essentially depends on $\mathbf{R_S/R_{ref}}$

$$\frac{R_S}{R_{ref}} = \frac{r_s R_{diff}}{\lambda z_1} \sim 2.25\left[\frac{r_s}{R_\odot}\right]\left[\frac{R_{diff}}{1000\,km}\right]\left[\frac{\lambda}{1\mu m}\right]^{-1}\left[\frac{z_1}{10\,kpc}\right]^{-1}$$

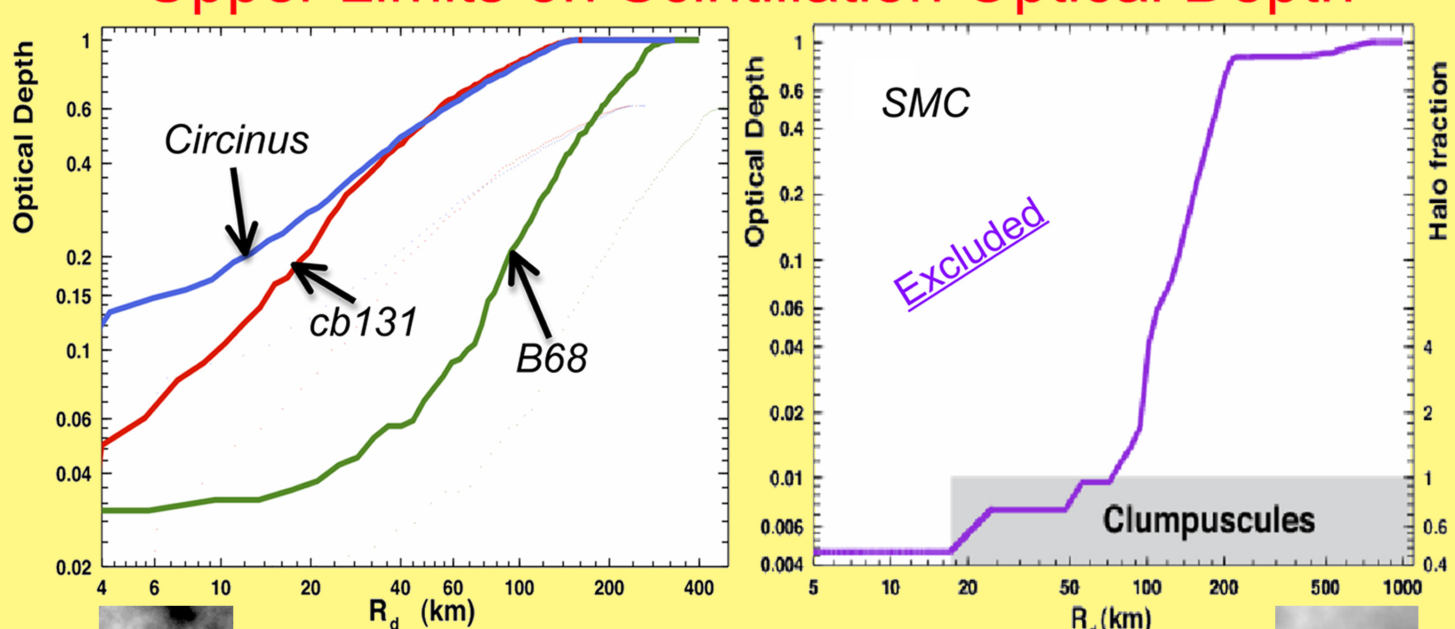


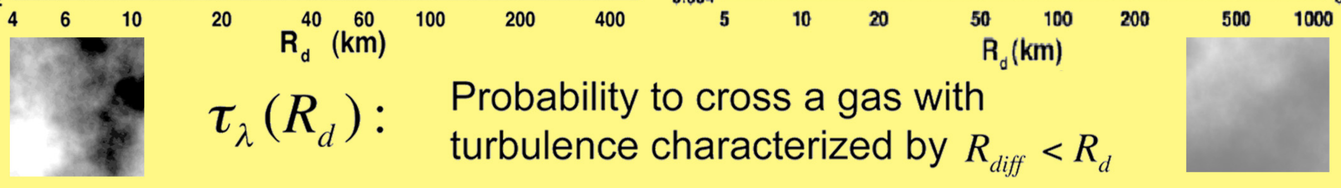
z_1 is the cloud-source distance

What can we learn from detection or non-detection?

- **If detection**
  - Get details on the clumpuscule (structure, column density -> mass) through modelling (reverse problem)
  - Measure contribution to galactic hidden matter
- **If no detection**
  - Get max. contribution of clumpuscules as a function of their structuration parameter R_{diff} (fluctuations of column density)

Upper Limits on Scintillation Optical Depth




$\tau_\lambda(R_d)$: Probability to cross a gas with turbulence characterized by $R_{diff} < R_d$

Perspectives

- 100 times more statistics needed to constrain significantly the Galactic turbulent hidden gas
  - Dedicated telescope
  - Wide field fast read-out camera
  - Multi-wavelength complementary observations for clear signature of scintillation
- LSST movie-mode
- 2-4 m class telescope could do the job before!