Scintillation by Transparent Dark Matter

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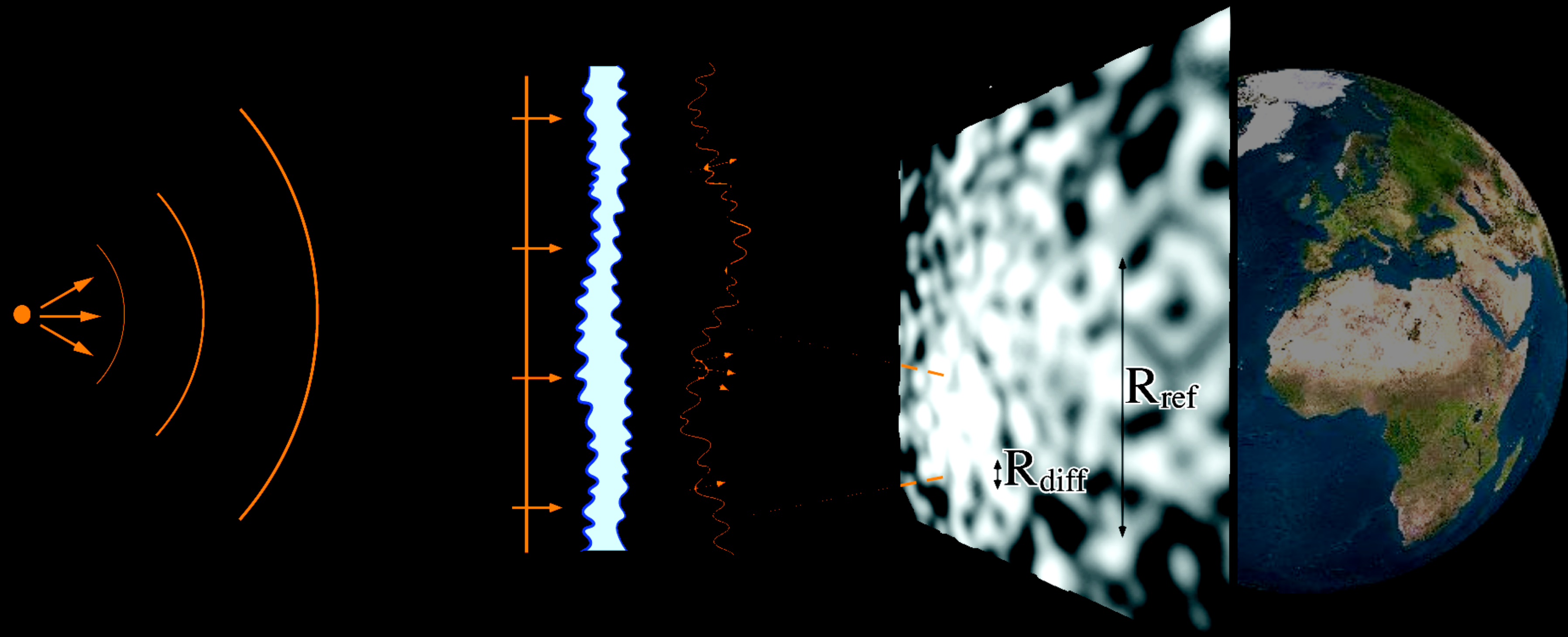
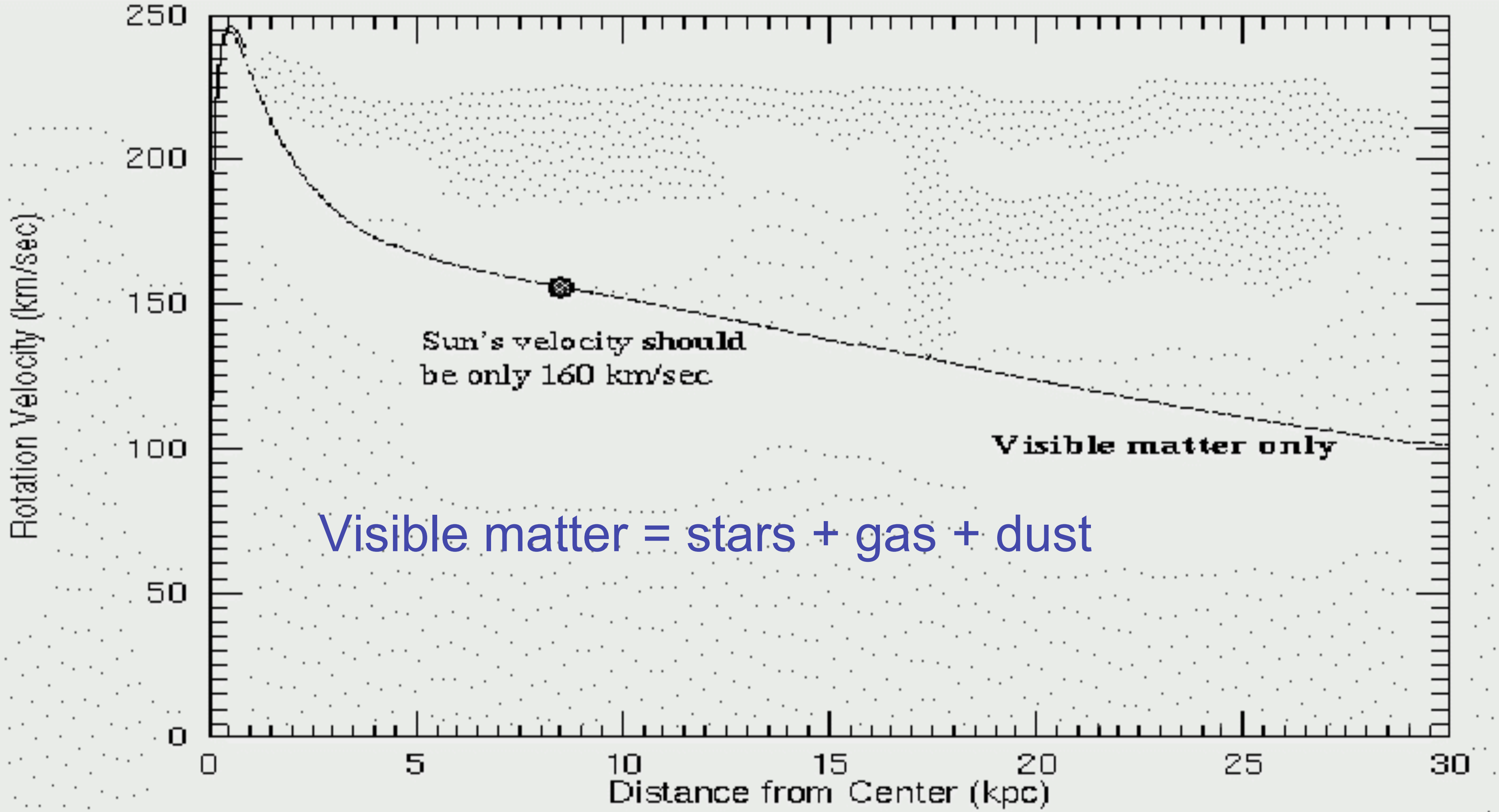


Laboratoire de l'Accélérateur Linéaire

Rotation Curve of the Milky Way



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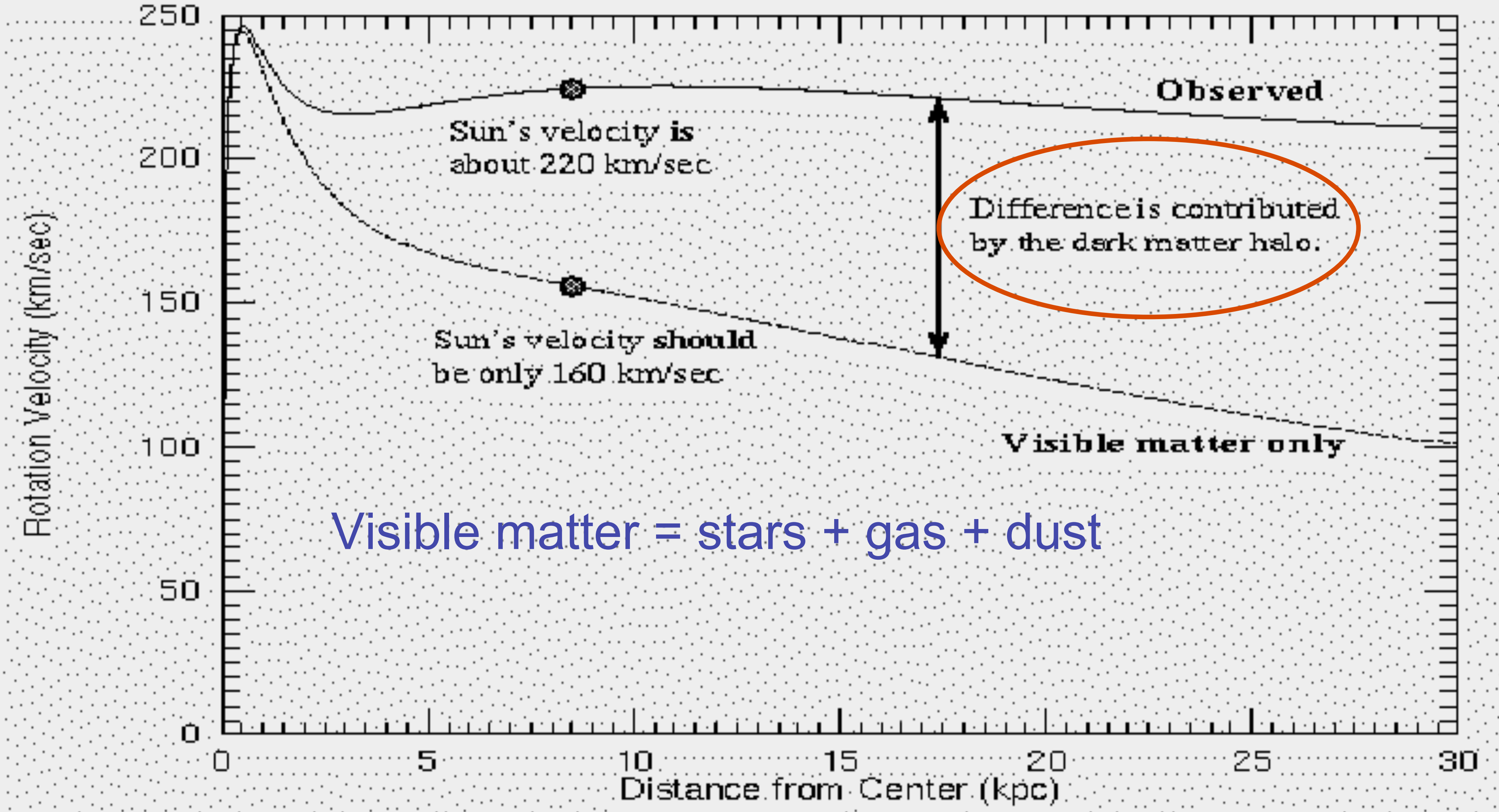
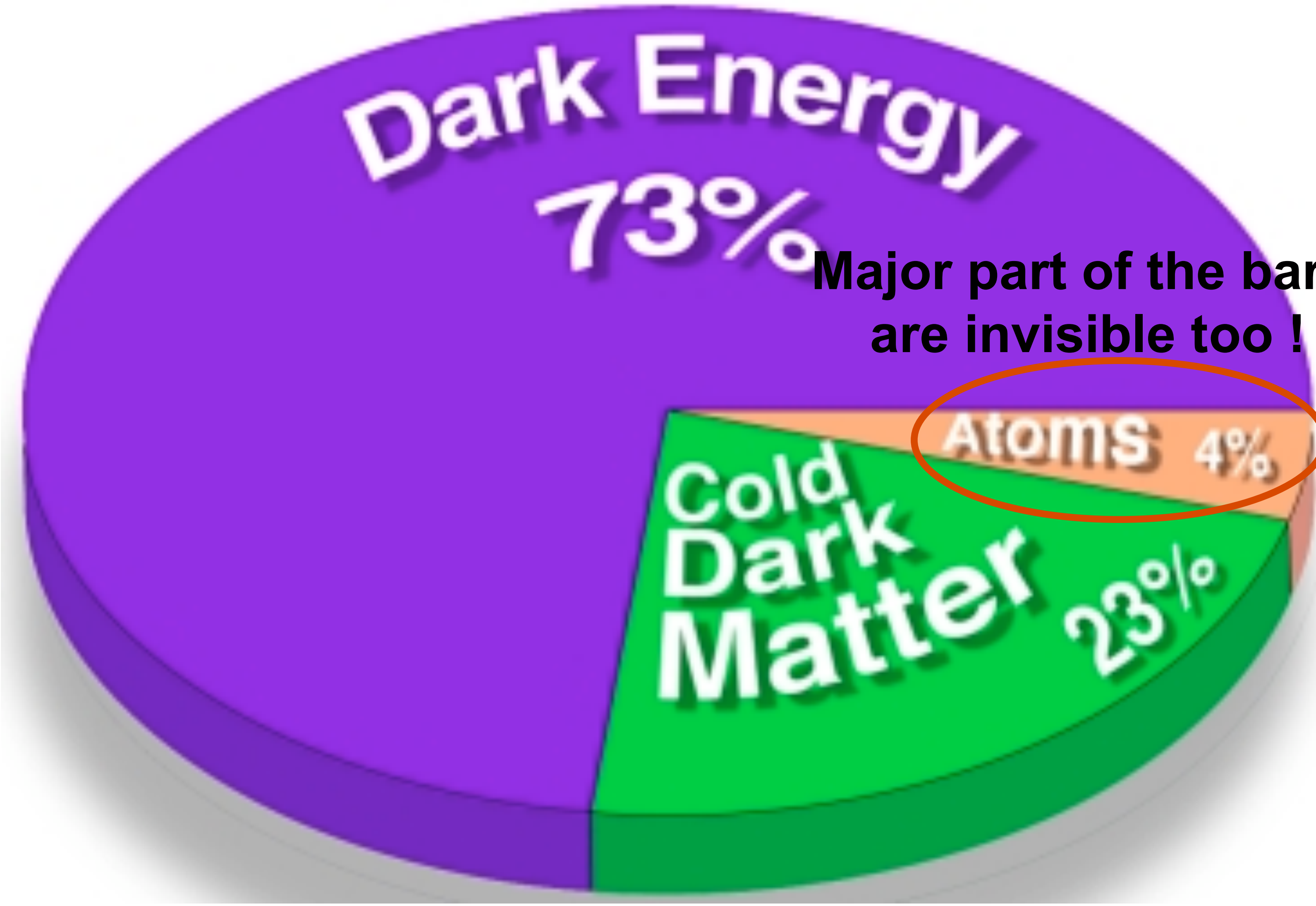


Content of the universe



Major part of the baryons are invisible too !

Content of the universe

- **Nucléosynthèse primordiale et CMB =>Ω_b = 0.044**
- **$\Omega_{visible}$ = 0.006 (unité $\Omega_{critique}$)**
- **Manque un facteur 7**
- **Essentiellement formé de H + 25% He en masse**

Where are the Galactic hidden baryons?

- **Compact Objects? ===> NO (microlensing)**
- **Gas**?
  - Atomic H well known (21cm hyperfine emission)

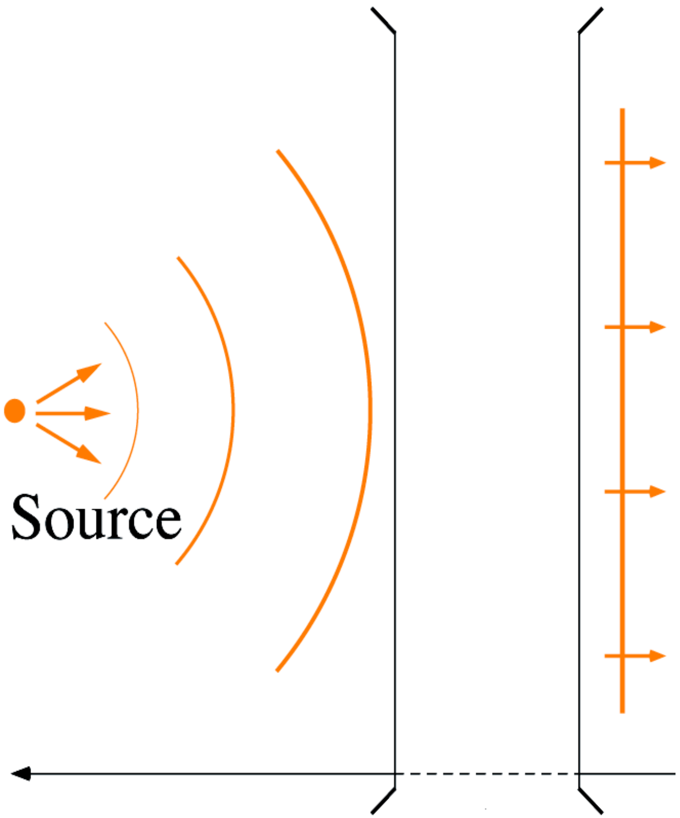
[redacted]

These Clouds Refract Light

[redacted]

    - Cold (**10K**) => no emission. Very transparent medium.
    - Primordial => low metalicity => no dust
    - In fractal structure covering **1%** of the sky. **clouds ~10 AU** (Pfenniger & Combes 1994)
    - Located in the **thick disc** or/and in the **halo**

Description of the Scintillation



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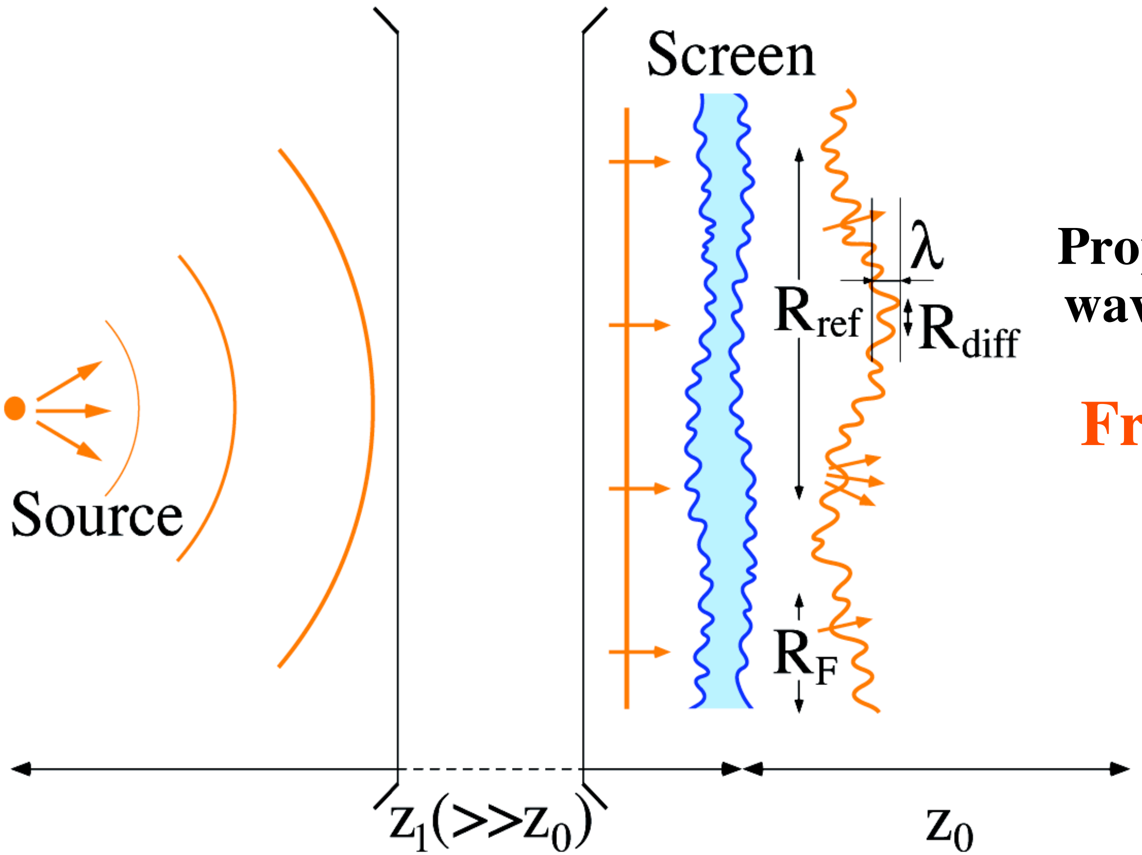


Propagation of distorted wave surface driven by:

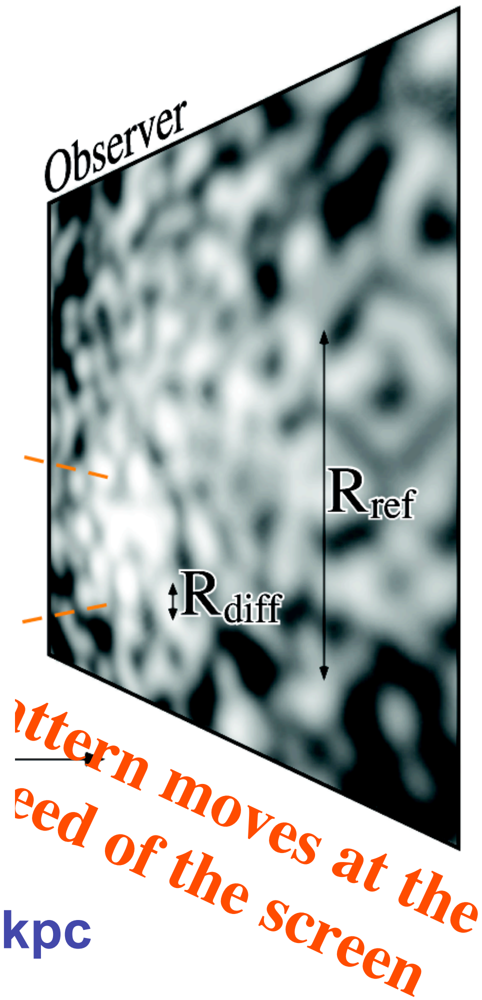
Fresnel diffraction

Description of the Scintillation

The observer sees

the *scintillation* of the

the star light.



Z1 ~ tens of kpc **Z0 ~ less than 1kpc**

Refraction

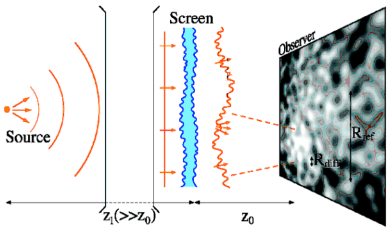
A medium causes extra optical path for light propagation :

$$\delta(x_1, y_1) \sim n(x_1, y_1)$$

The phase delay variation is directly proportion to the column density variations.

The corresponding phase delay is :

$$\phi(x_1, y_1) = \frac{2\pi}{\lambda}\delta(x_1, y_1)$$



Simulation Steps

We are going to …

1. Simulate an inhomogeneous screen which distorts the light wave front.

2. Compute the propagation of the light from the screen to the observer and the illumination pattern.

3. Study the statistical properties of the illumination pattern and the light curves for an extended source.

1. Simulation of an inhomogeneous screen

A transverse separation of 1 diffusion radius causes an average phase variation of 1 radian

$$D_\phi(x_1, y_1) = \langle (\phi(x_1 + x_1', y_1 + y_1') - \phi(x_1', y_1'))^2 \rangle_{(x', y')}$$

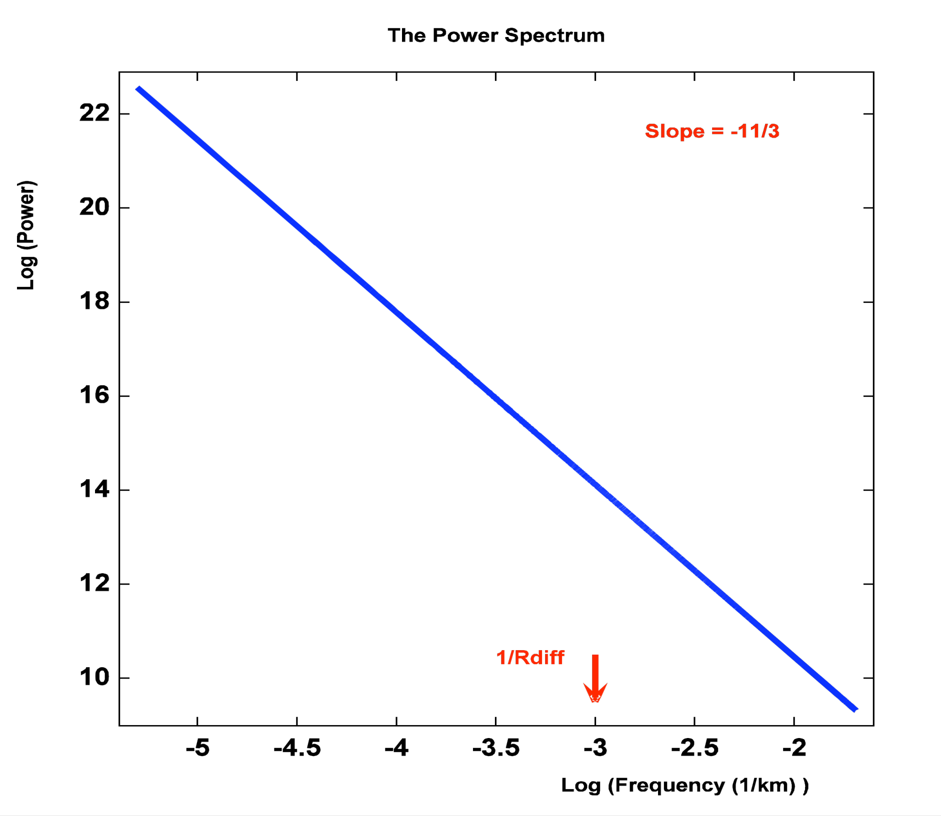
By the theory of isotropic turbulence :

$$D_\phi(r) = \left(\frac{r}{R_{diff}}\right)^{\frac{5}{3}} \qquad r = \sqrt{x^2 + y^2}$$

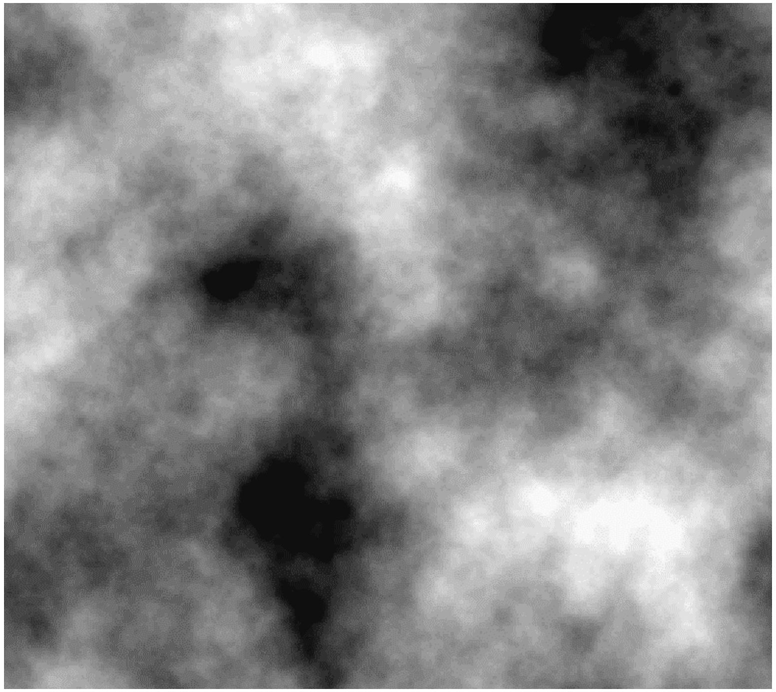
Diffusion radius is the characteristic length of the cloud and is the responsible of the distortion of the light wave front.

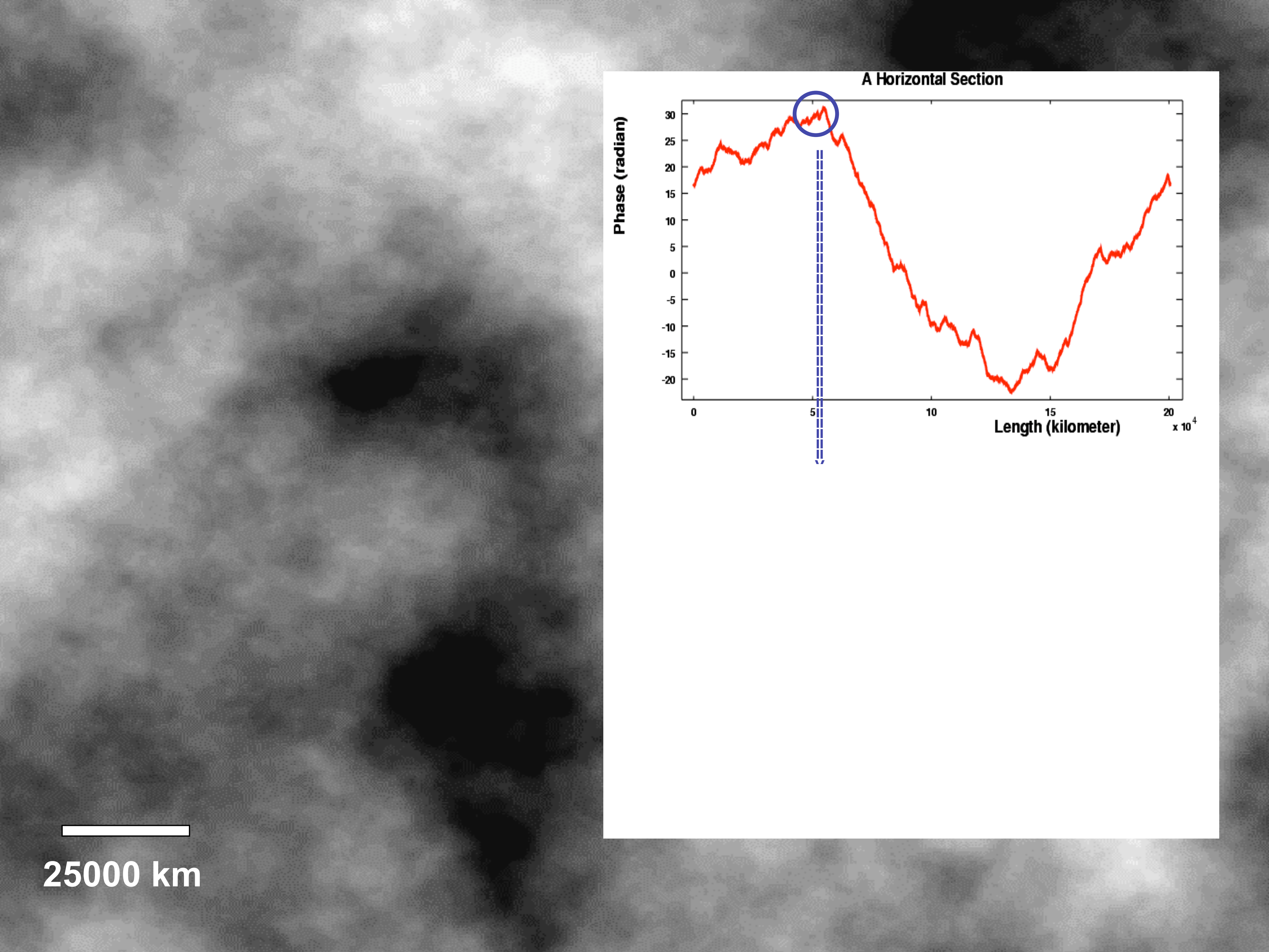
1. Simulation of an inhomogeneous screen

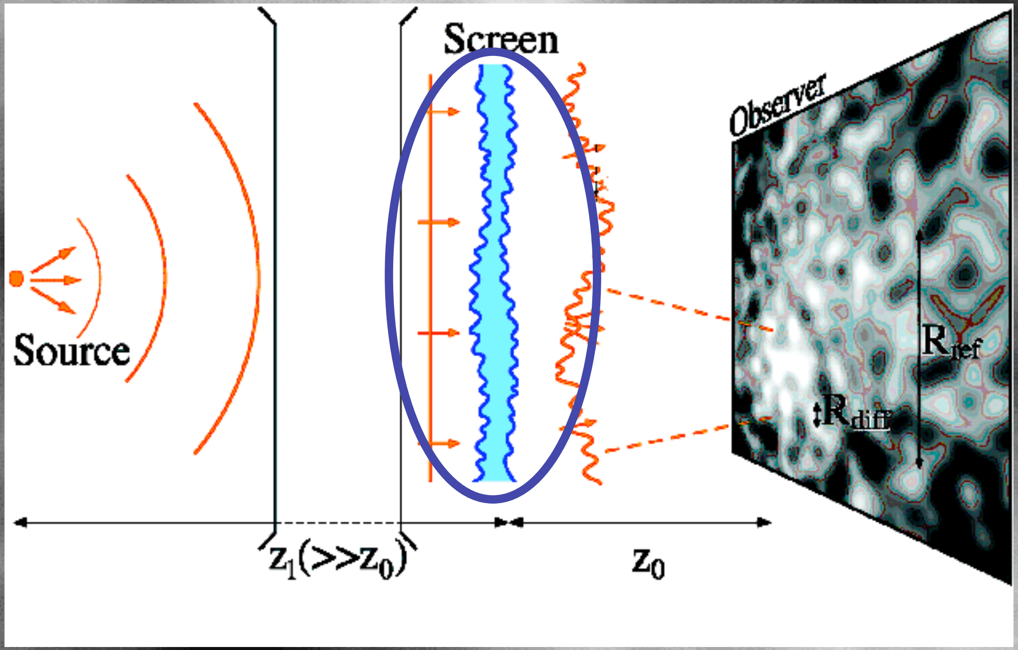
Corresponding power spectrum : $P(k) \sim R_{diff}^2 \, (R_{diff} \, k)^{-\frac{11}{3}}$



2D simulation of column density variation of the cloud in real space

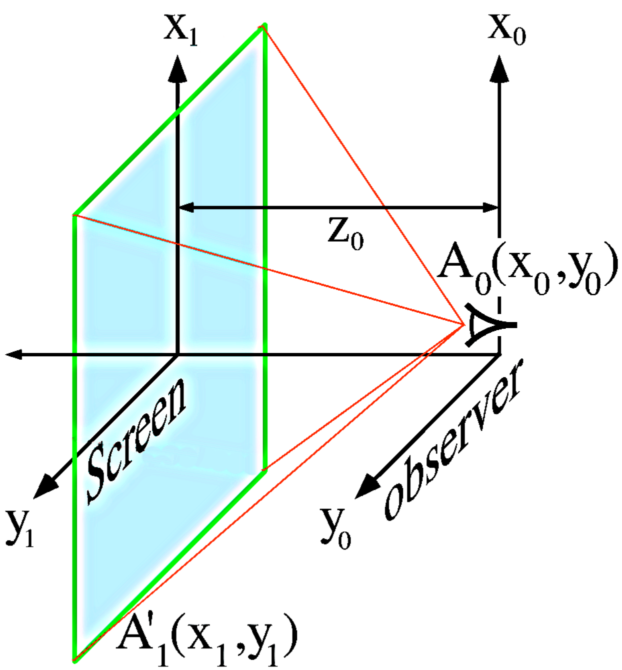



A Horizontal Section
Phase (radian)
30
25
20
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
Length (kilometer)
x 10^4
25000 km



Screen
Source
Observer
R_{ref}
R_{diff}
$z_1(>>z_0)$
z_0

2. Computation of the illumination pattern



Spheric wave

$$A_0(x_0,y_0) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} A'_1(x_1,y_1)\frac{e^{ikr_{01}}}{i\lambda r_{01}}dx_1dy_1$$

$$r_{01} \simeq z_0\left[1+\frac{1}{2}\left(\frac{x_0-x_1}{z_0}\right)^2+\frac{1}{2}\left(\frac{y_0-y_1}{z_0}\right)^2\right]$$

- **Fresnel approximation**
- **Stationary phase approximation**
- **Point-like source on axis at ∞**
- **Phase screen described by $\delta(x_1,y_1)$**

$$A_0(x_0,y_0) = \frac{Ae^{ikz_0}}{2i\pi {R_F}^2}\iint_{-\infty}^{+\infty} e^{ik\delta(x_1,y_1)}e^{i\frac{(x_0-x_1)^2+(y_0-y_1)^2}{2{R_F}^2}}dx_1dy_1$$

$R_F = \sqrt{z_0/k} = \sqrt{\lambda z_0/2\pi}$
is the **FRESNEL RADIUS**

A few 1000 km at λ = 500 nm
if z_0 = a few kparsecs

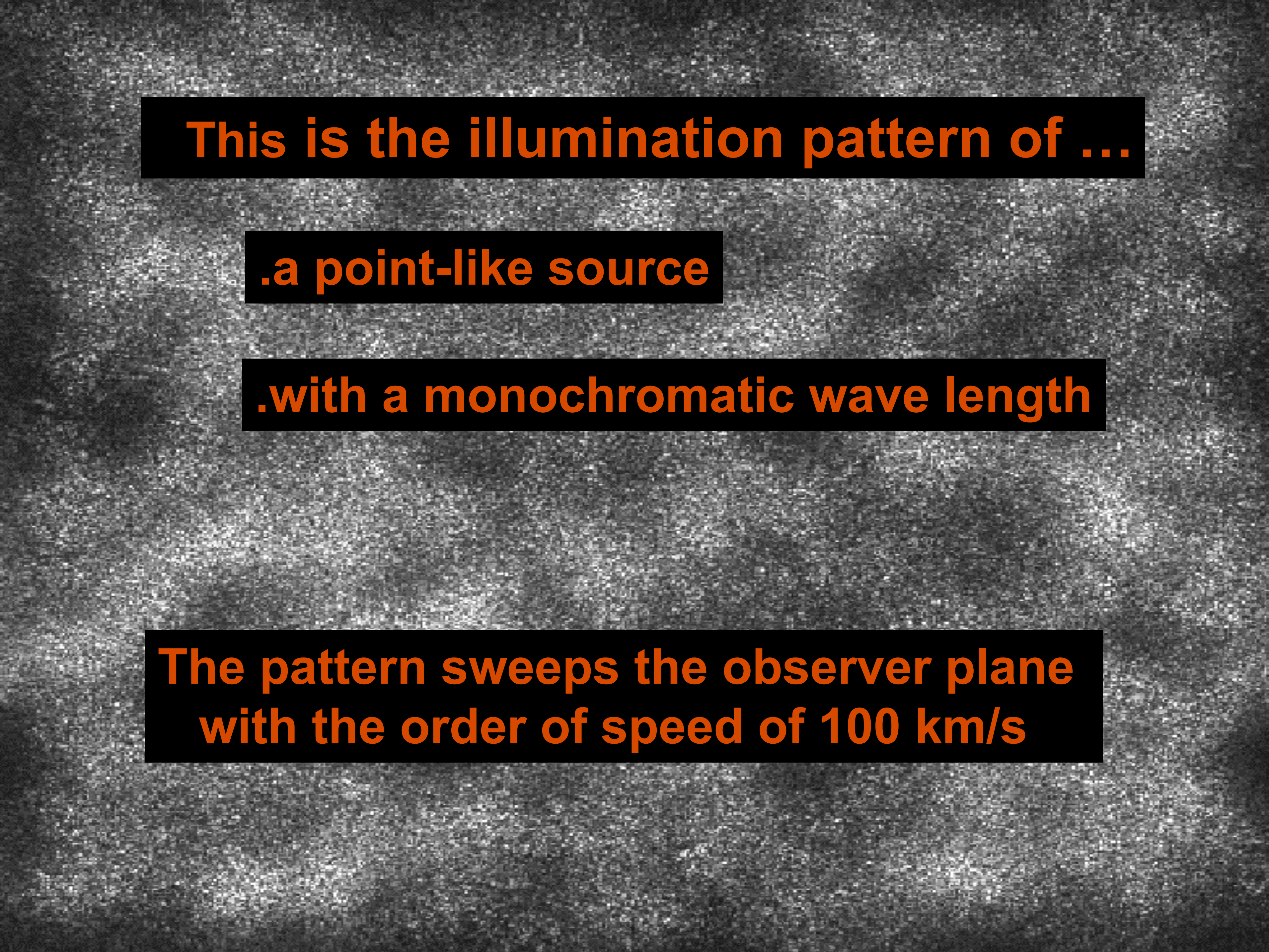
2. Computation of the illumination pattern

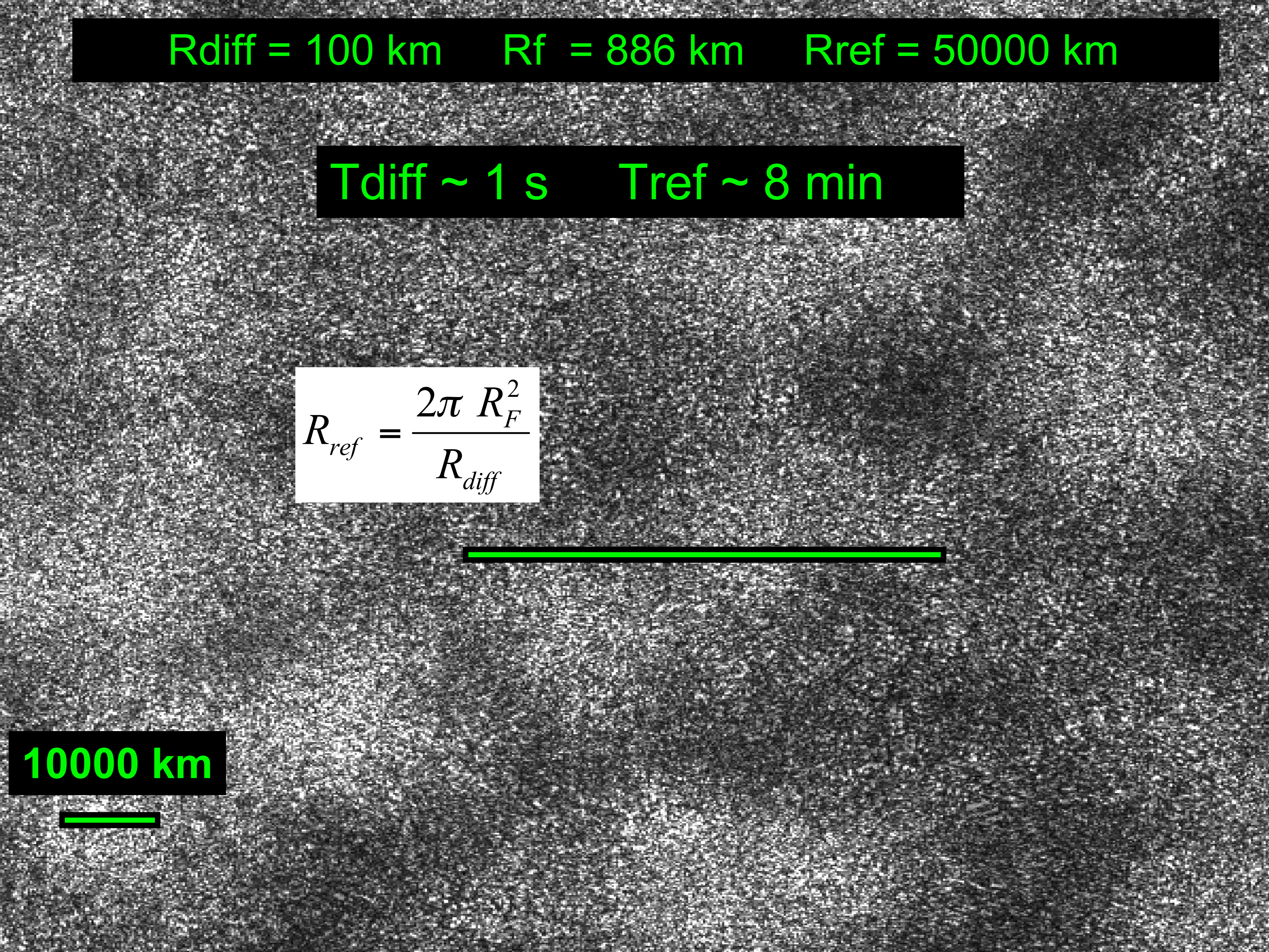
The relative Intensity which is going to be computed:

FFT is our tool to compute the illumination pattern

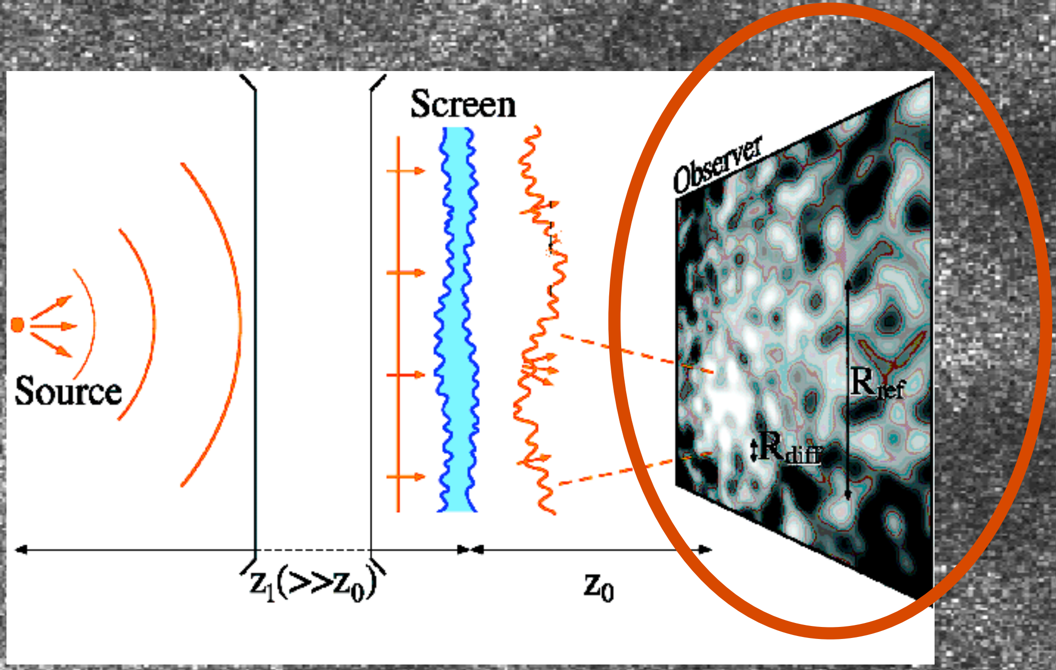
Which can be considered as :

$$I(x_0, y_0) = \left| \frac{1}{2\pi i\, R_F^2} FT\left(e^{i\phi(x,y) + \frac{x^2 + y^2}{2R_F^2})}\right) \right|^2$$


This is the illumination pattern of …
.a point-like source
.with a monochromatic wave length
The pattern sweeps the observer plane with the order of speed of 100 km/s



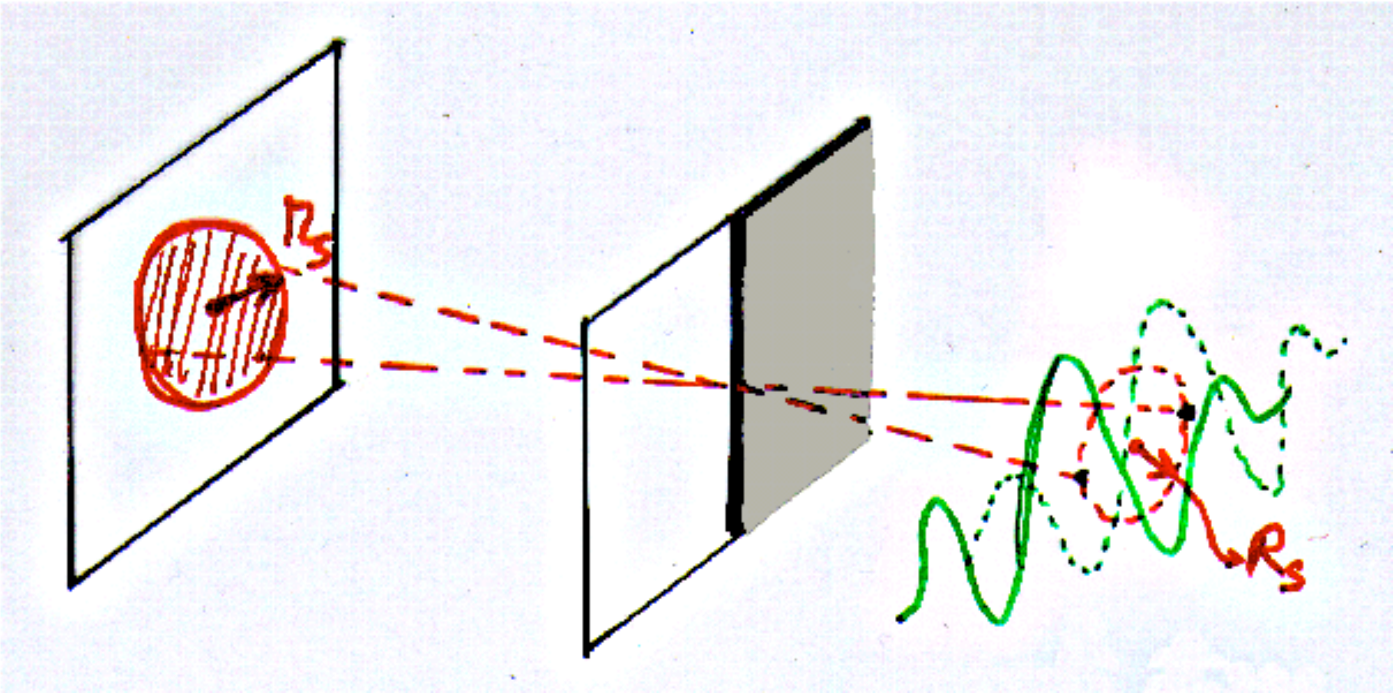
Rdiff = 100 km Rf = 886 km Rref = 50000 km
Tdiff ~ 1 s Tref ~ 8 min
$$R_{ref} = \frac{2\pi\ R_F^2}{R_{diff}}$$
10000 km



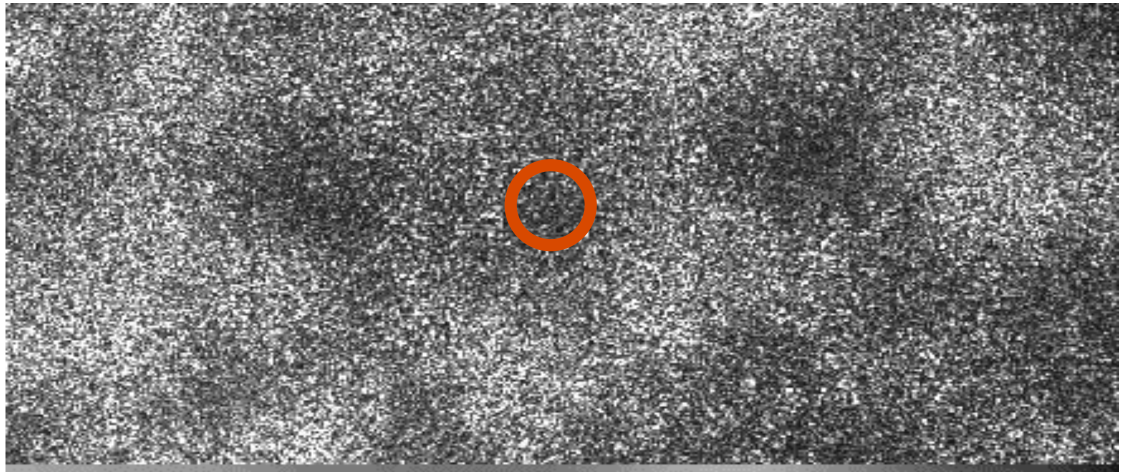
Screen
Observer
Source
R_{ref}
R_{diff}
$z_1(>>z_0)$
z_0

2. Computation of the illumination pattern

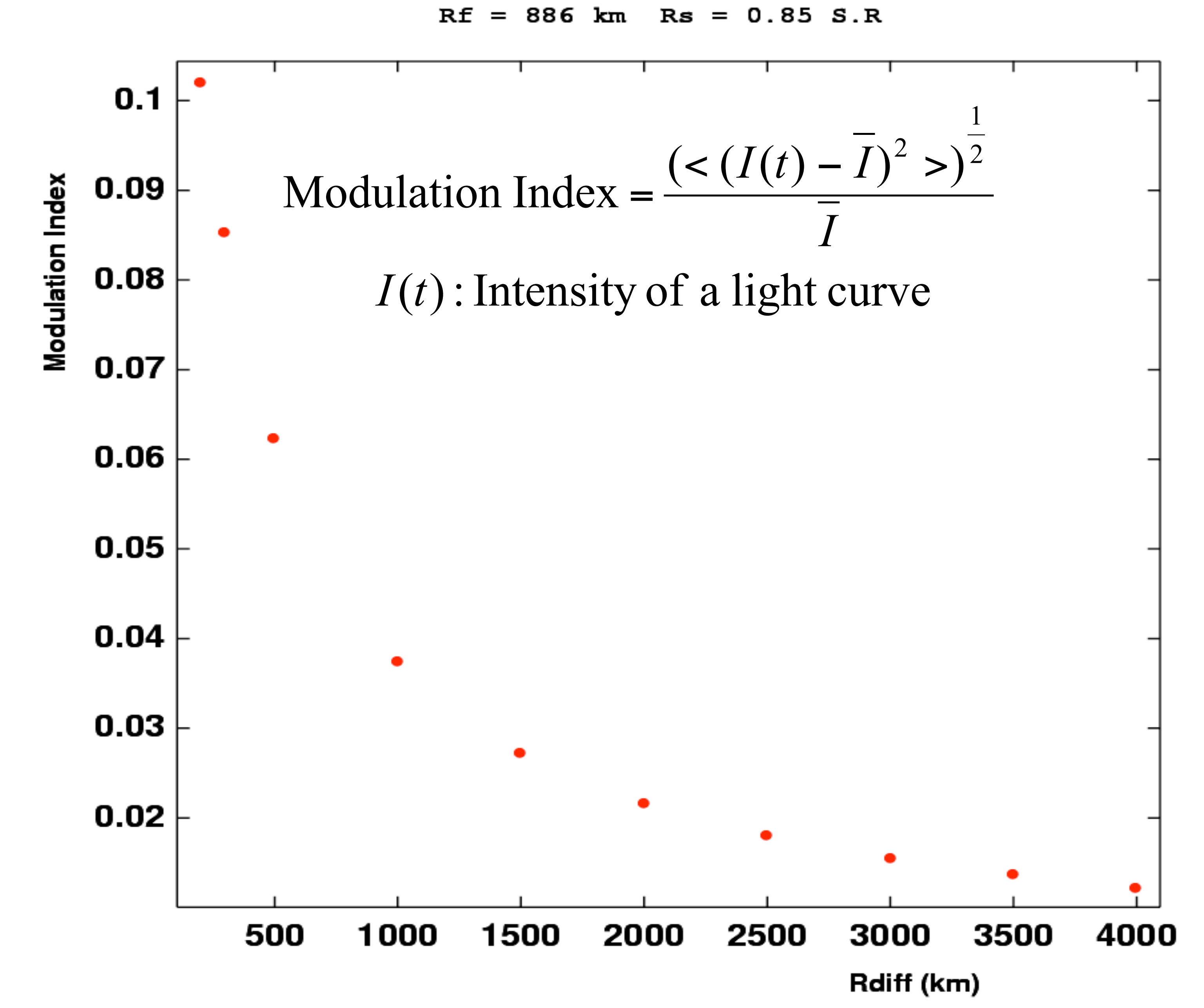
From the point-like source to the extended source :



2. Computation of the illumination pattern



3.Illumination pattern and light curves statistics

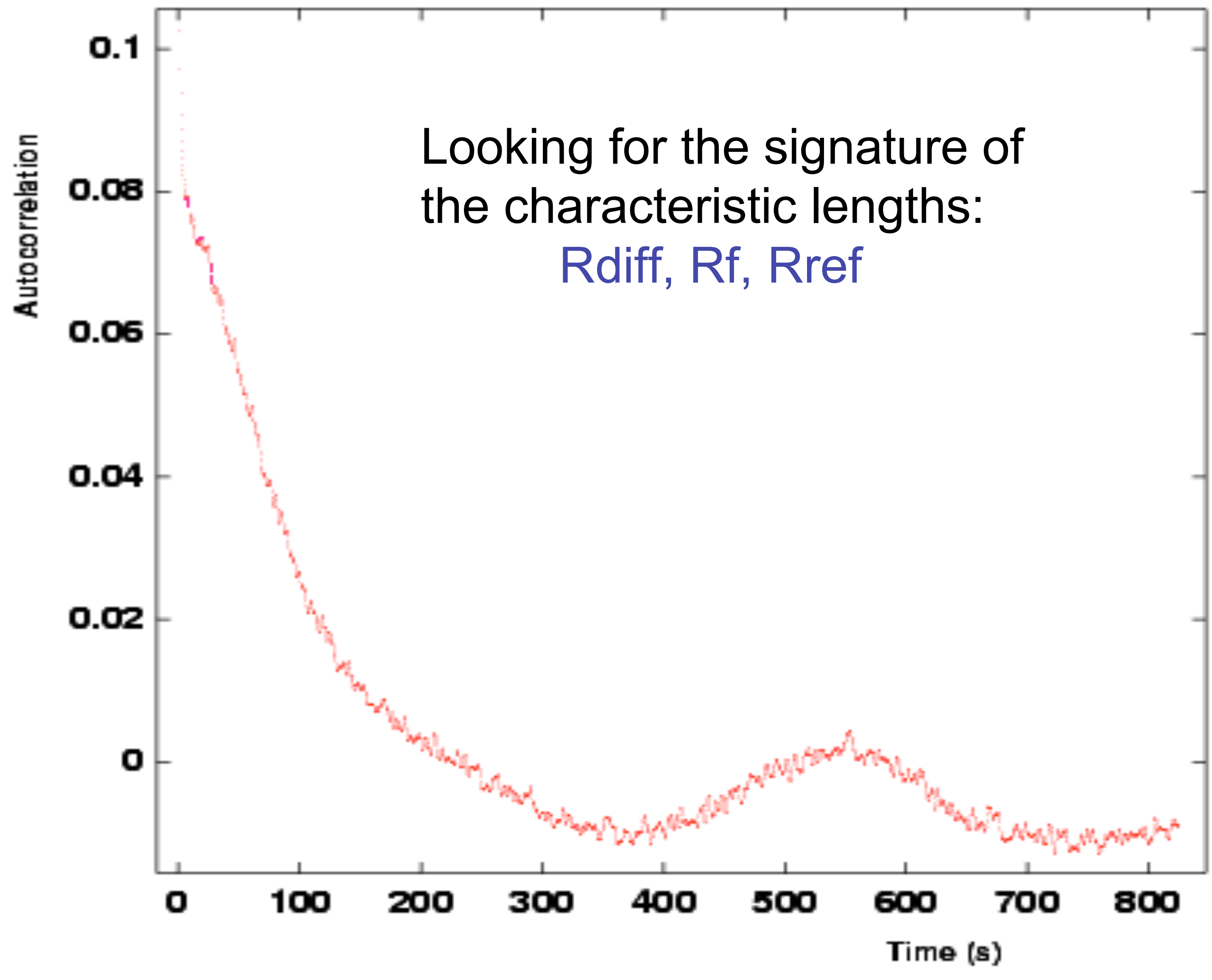


$$\text{Modulation Index} = \frac{(<(I(t)-\bar{I})^2>)^{\frac{1}{2}}}{\bar{I}}$$

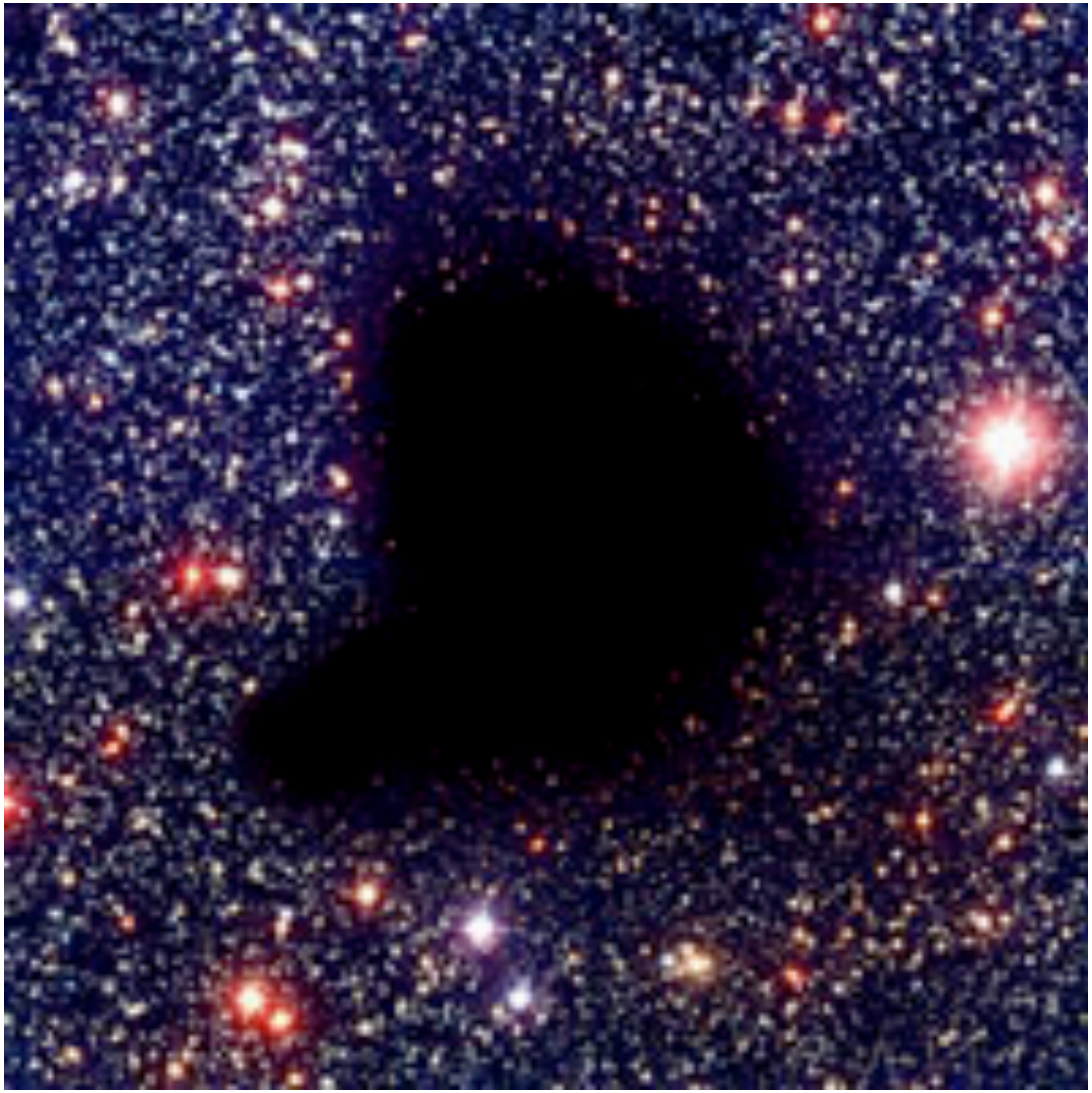
$I(t)$: Intensity of a light curve

The characteristic lengths / time scales appear in variation of the autocorrelation function of the light curve

3.Illumination pattern and light curves statistics



Test towards Bok globule B68
NTT IR (2 nights in june 2004)

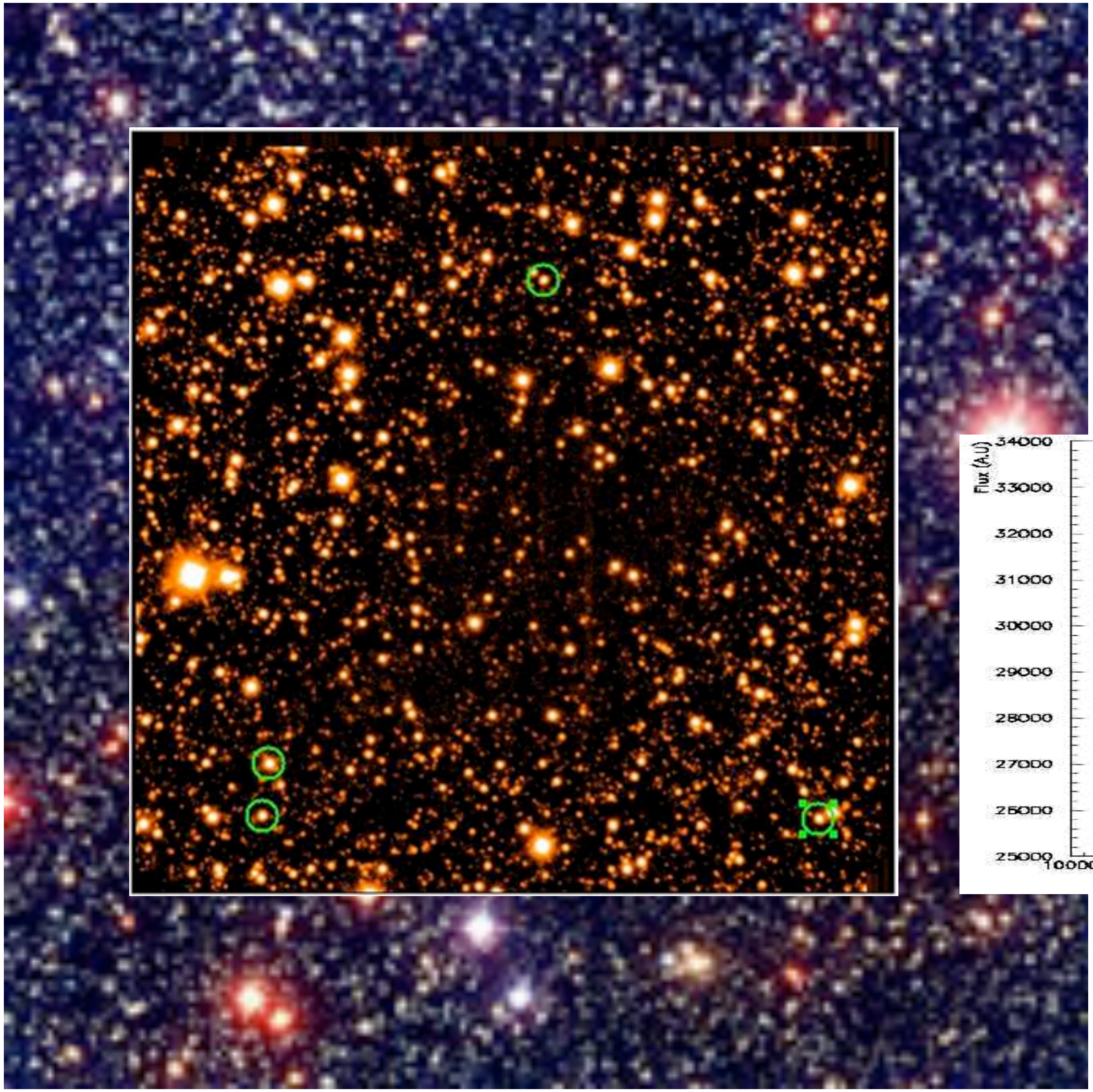


- 2873 stars monitored
- ~ 1000 exposures/night
- Z0 ~ 160 pc, Rf = 886km

Signal if $\Delta n/n \sim 10^{-4}$ per < 1000 km

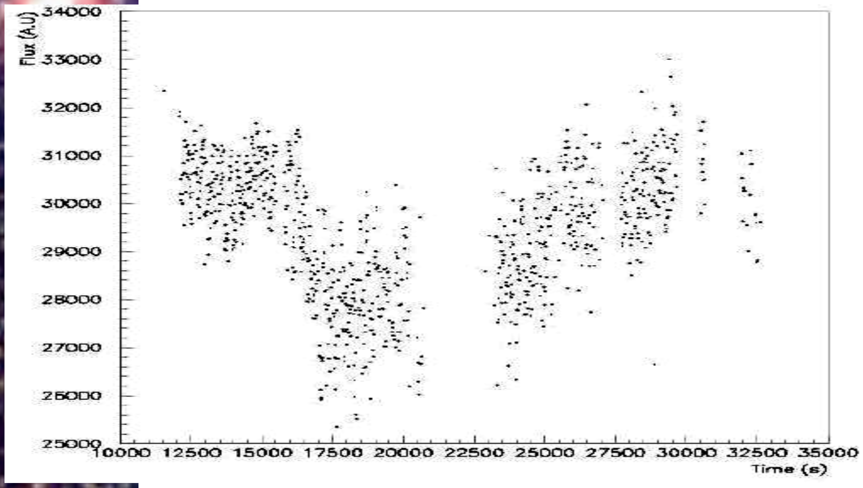
- Mainly test for back-ground and feasibility

Test towards Bok globule B68
NTT IR (2 nights in june 2004)



4 fluctating stars

(other than known artifacts)



Future Observations

- This simulation will be used in LSST strategy of observation and will be a guide in data analyzing of GAIA project.

Merci :-)