



# Multiple Scattering Theory at the service of art

Simon Milcent

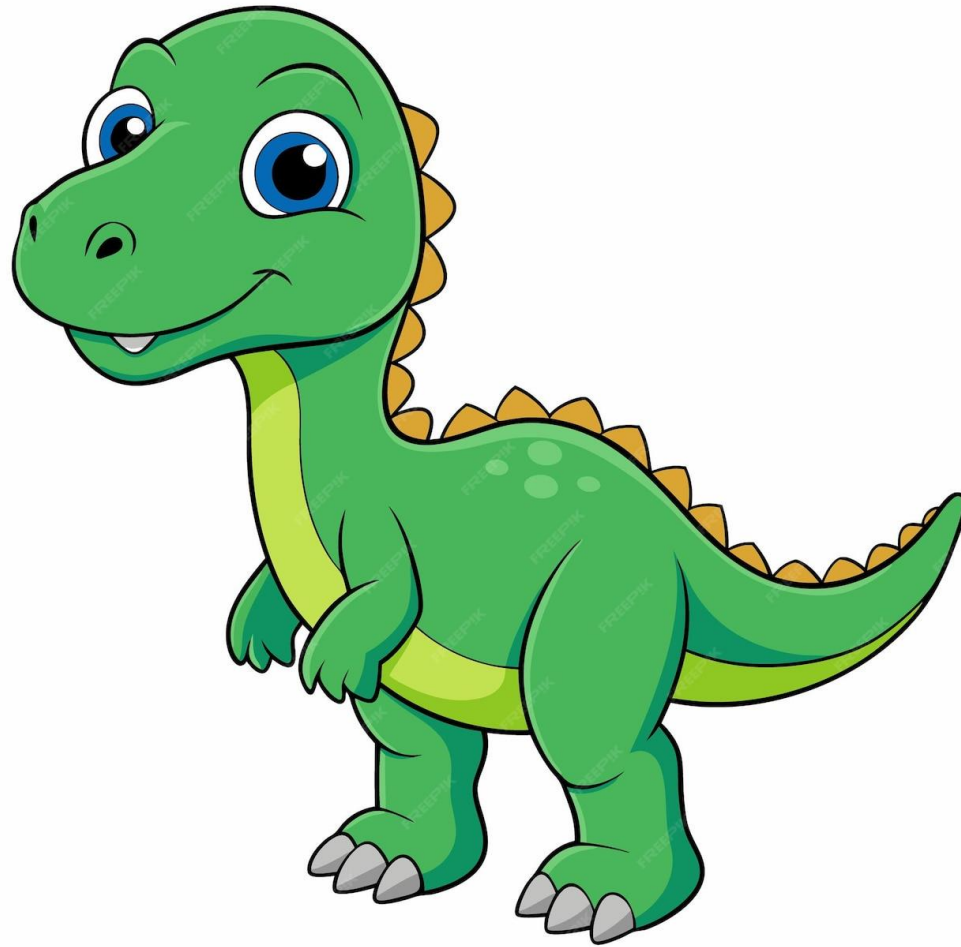
RJP

24 avr 2026

(MMCI)



# Jurassic parc



# Jurassic parc



No needs of windows

# Cave (wo)men



Hut made of bones

Entrance is the  
main source of  
light

THE CROODS (dreamWorks)



# First trace of sedentarity (Neolithic – Bronze age)



No sign of windows

<https://www.english-heritage.org.uk>



<https://www.nationalgeographic.com/>,  
Cristina Belmonte, 2019

# The need of light

Goal : Light  
Sources



# The need of light

Goal : Light  
Sources



A hole is enough

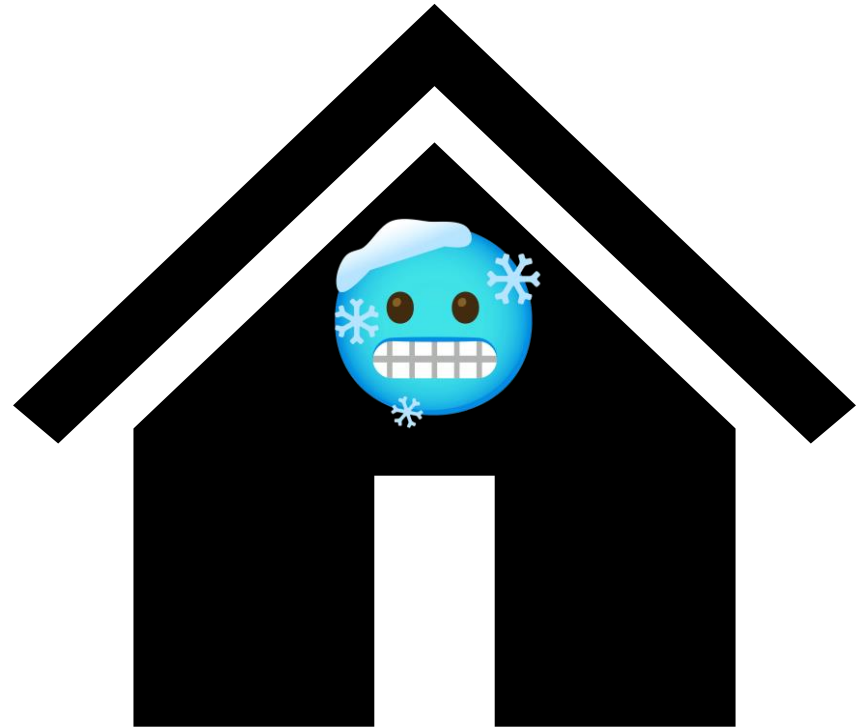
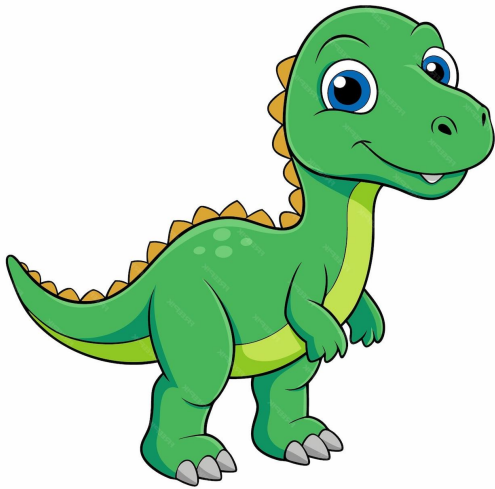


# The need of light

Goal : Light  
Sources



A hole is enough



# Ancient age

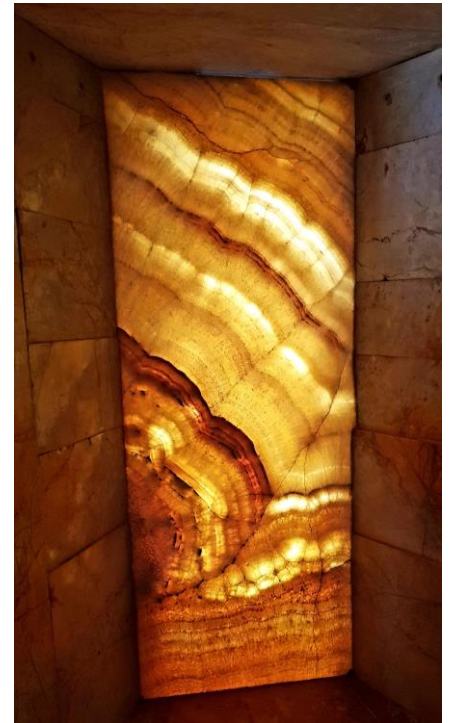
Egyptian windows



Oiled paper window



Alabaster window



# Antiquity

## First trace of glasses



## Glass beads



Tobias et al., <https://informatik.univie.ac.at/forschung/projekte/projekt/372/>, 2022

# Antiquity

First trace of glasses



Glass beads



Tobias et al., <https://informatik.univie.ac.at/forschung/projekte/projekt/372/>, 2022

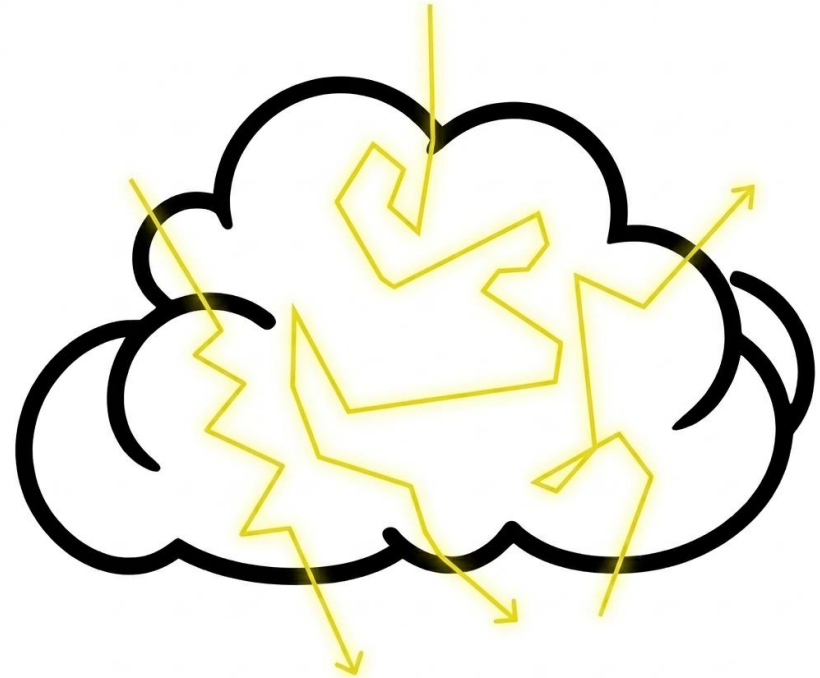
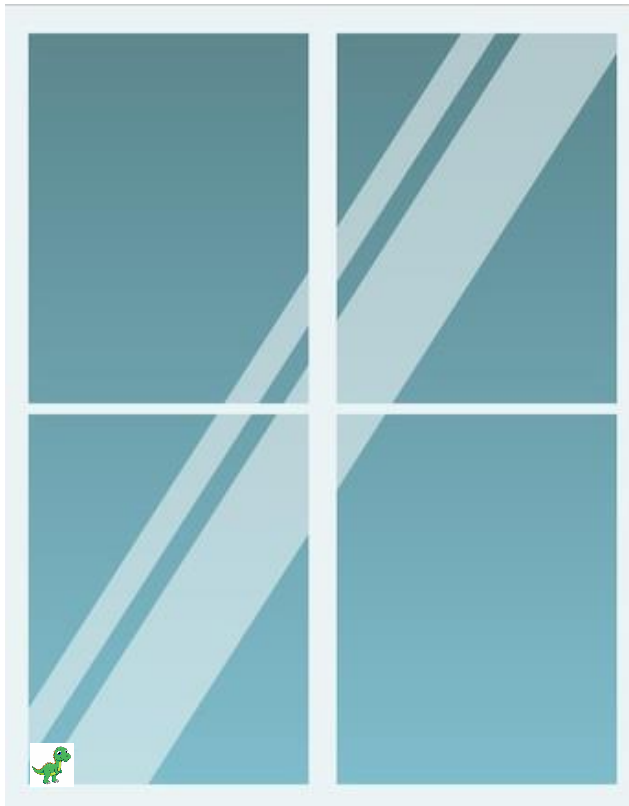
Universal discovery : Egyptian, Roman, Viking, ...

# What is transmitted ?



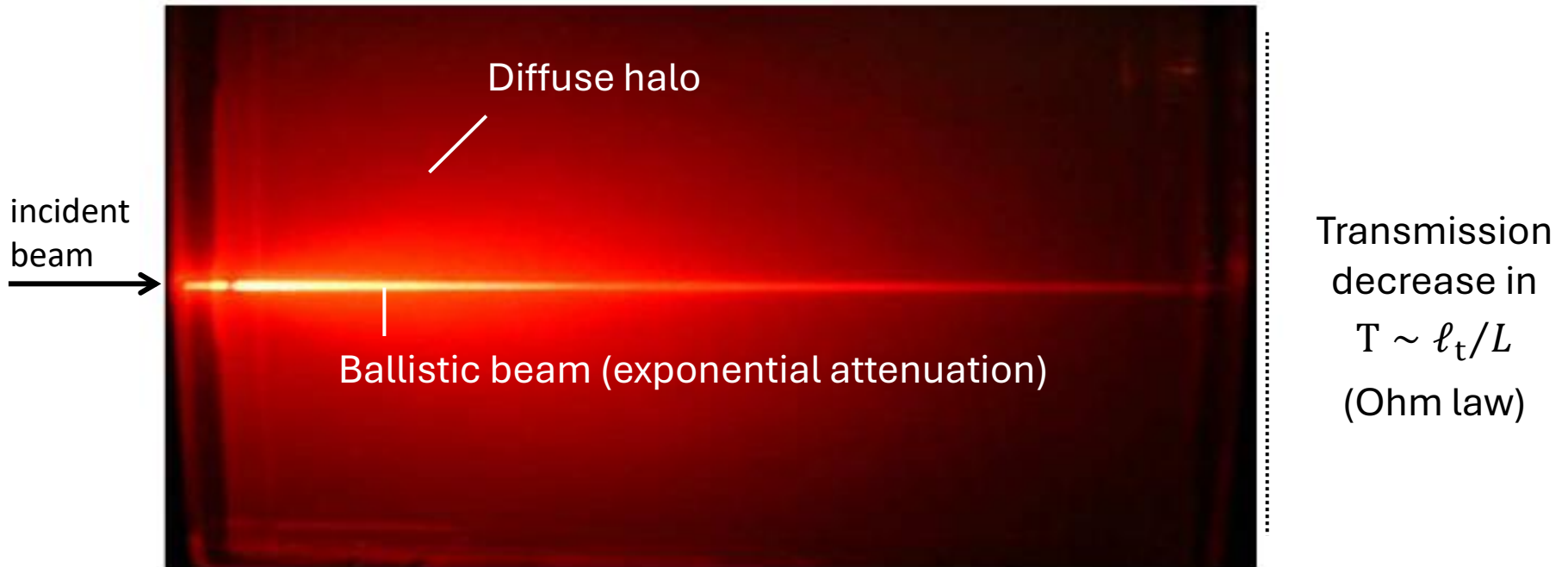
# Complex media vs Normal media

Light go through but no  
intimacy

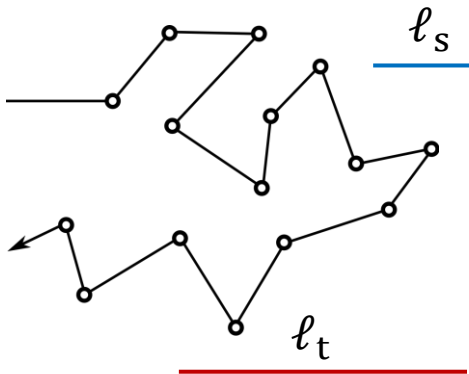


No image goes through, but a **lot**  
of energy is **lost** in the process

# Introduction to complex media



Romain Pierrat, *Propagation et émission du rayonnement en milieu diffusant. Application à l'imagerie des milieux complexes*. Thèse de doctorat, Ecole Centrale Paris, 2007.



- Can be modeled by a **random walk** of *photons*
- **Statistically homogeneous** media approximation

# Roman age and early middle age

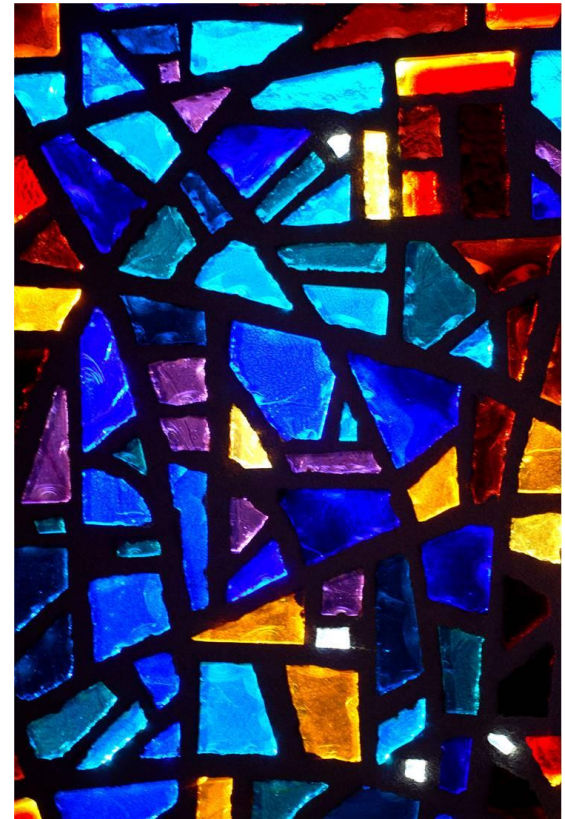
First trace of windows



<https://en.villumwindowcollection.com/all-about-windows/glass/roman-cast-glass/>



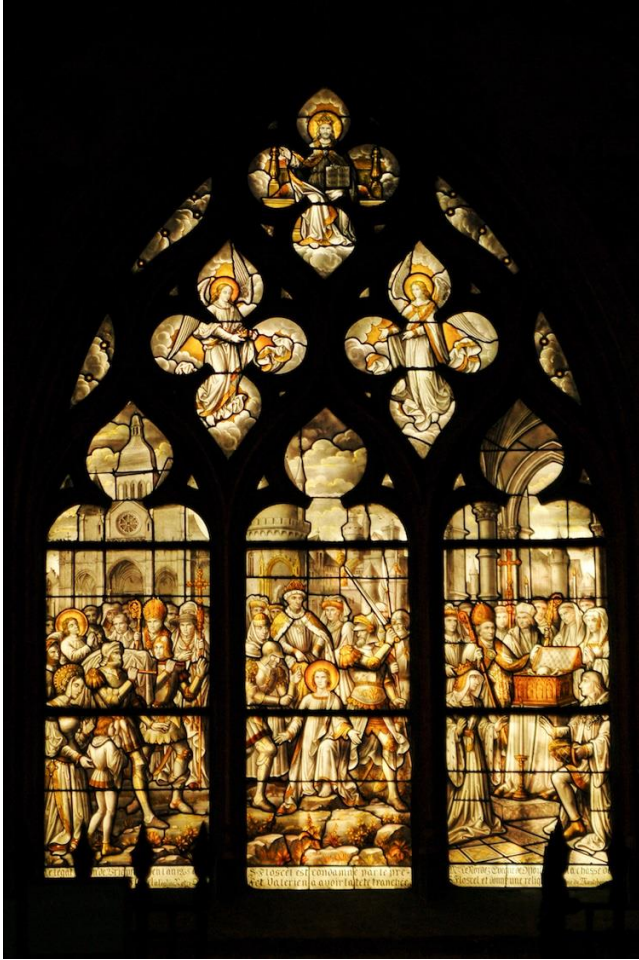
First stain glasses windows arround  
600AD



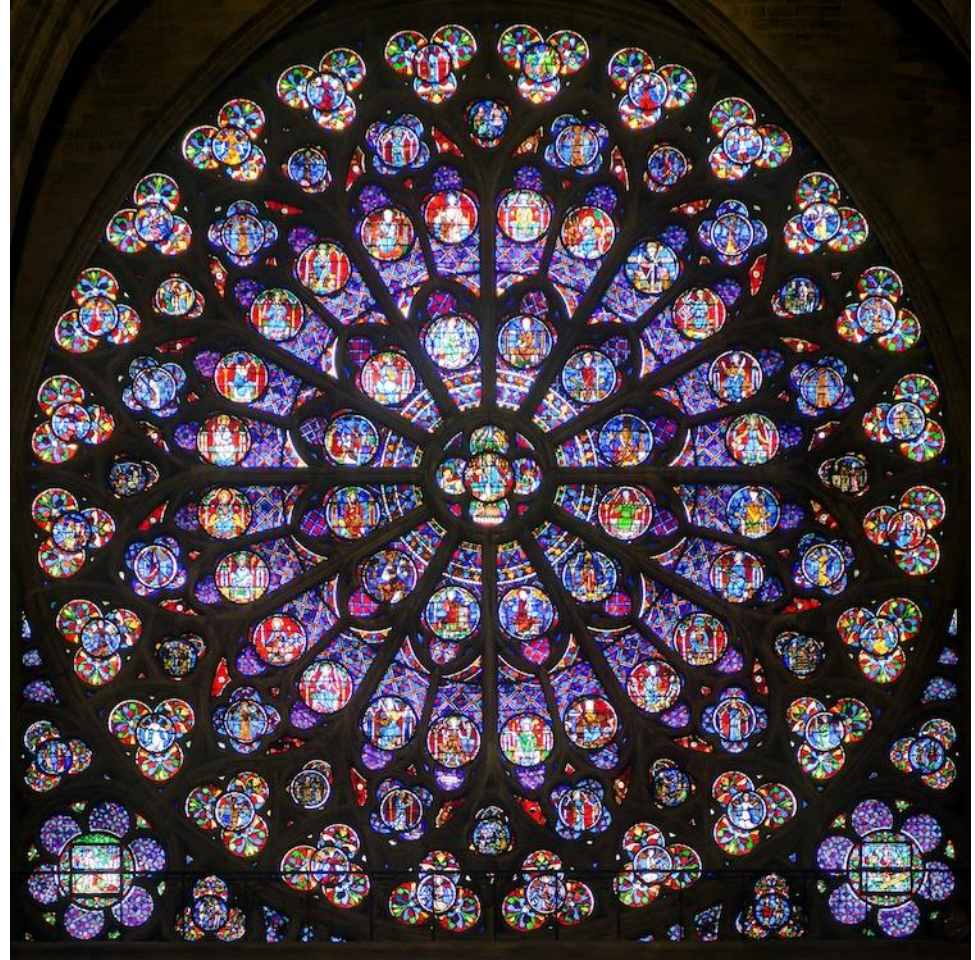
Sowers, Robert W.. "stained glass". Encyclopedia Britannica, 4 Jul. 2025, <https://www.britannica.com/art/stained-glass>. Accessed 21 April 2026.

<https://www.stainedglass.org/about-stained-glass/history-stained-glass>,  
2026

# From Roman to Gothic Architecture



Beaune Notre-dame, France (Photo: Stock Photos from lynnlin/Shutterstock)



Notre-Dame Cathedral in Paris (Photo: Stock Photos from Viacheslav Lopatin/Shutterstock)

# Middle age : Apparition of clear glass

In parallel of the development of stained glasses the first transparent window make their apparition in Venetia (Murano)



"The Glassblowing Process". Sugar Hollow Glass. Retrieved June 15, 2009



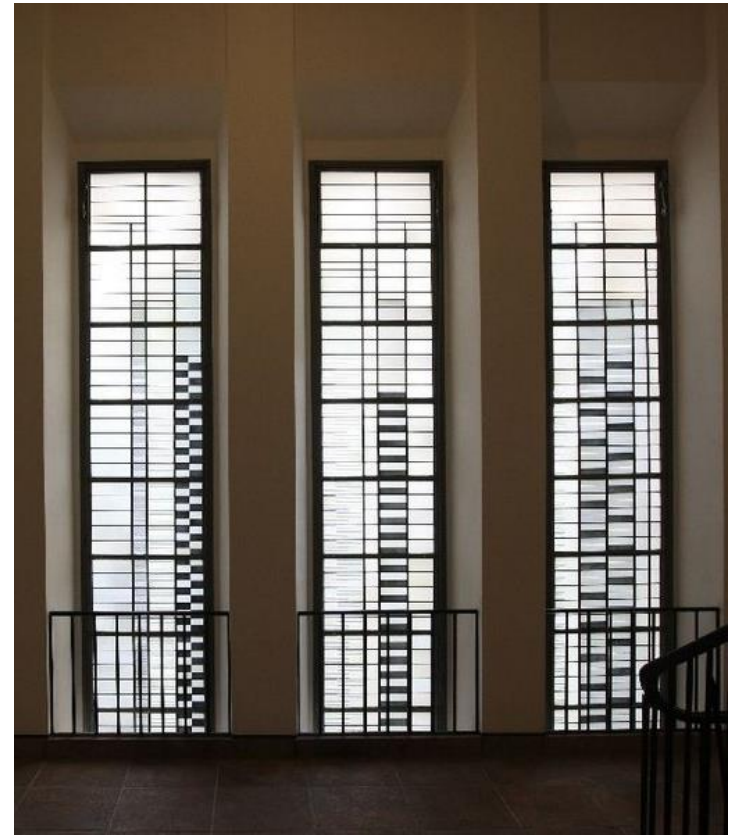
Hugh Wakefield,  
<https://www.britannica.com/art/glassware/Mid-15th-to-mid-19th-century>

# Contemporary age

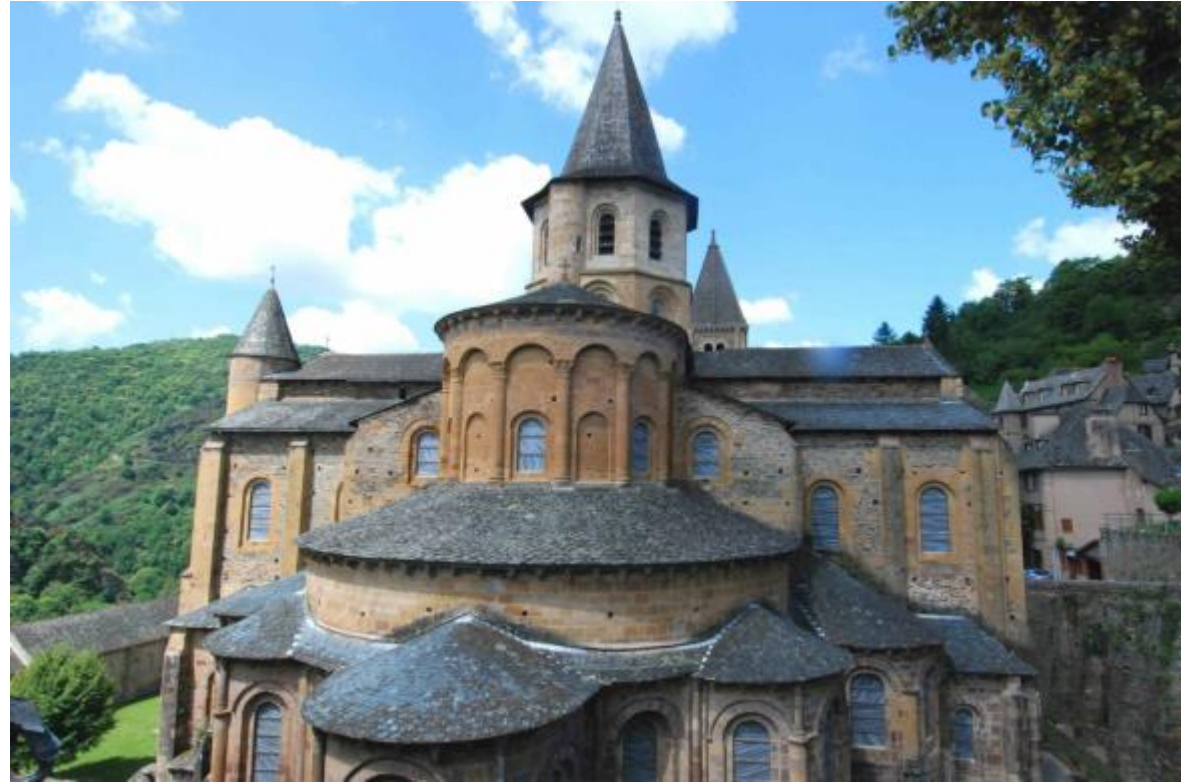
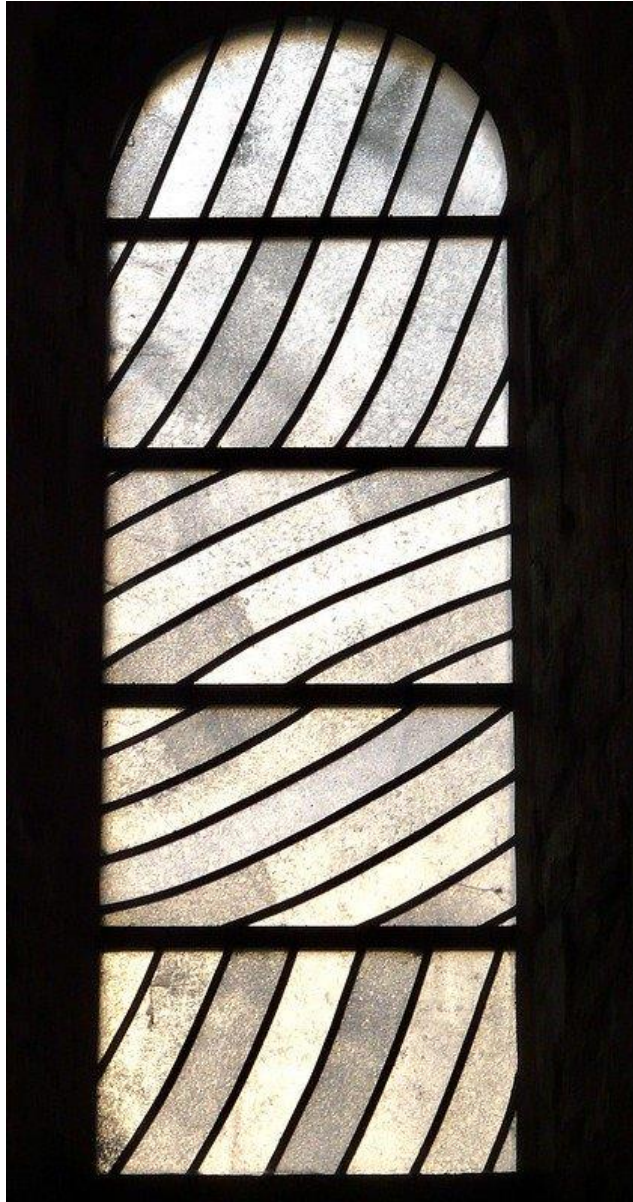
Art deco stain glasses



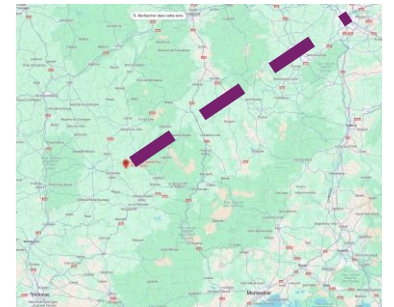
Behaus stain glasses



# Conques glasses



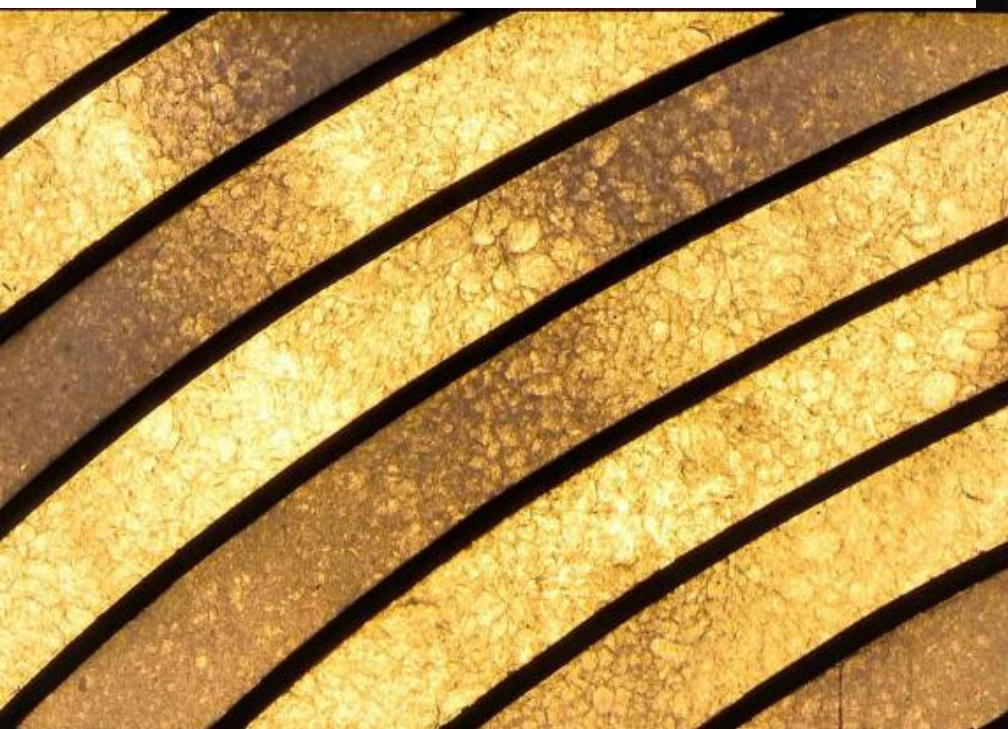
Installed in 1994 those glasses are very interesting in the point of view of the physicist



# Soulages' project

**Stained Glass Windows** of the Abbey Church of Conques by the artist Pierre Soulages (1919–2022)

7 years of empirical work



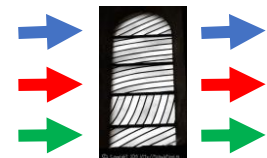
- Bright



- Diffusive

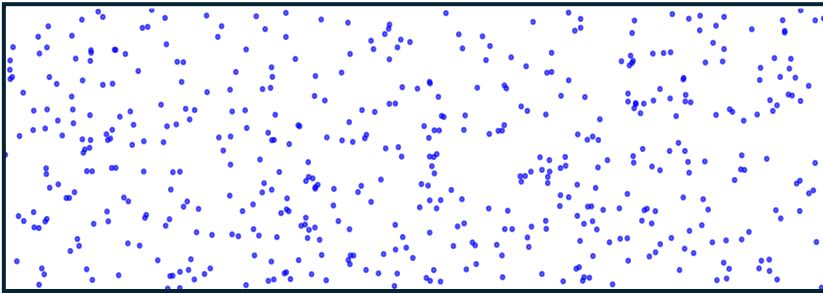


- Achromatic

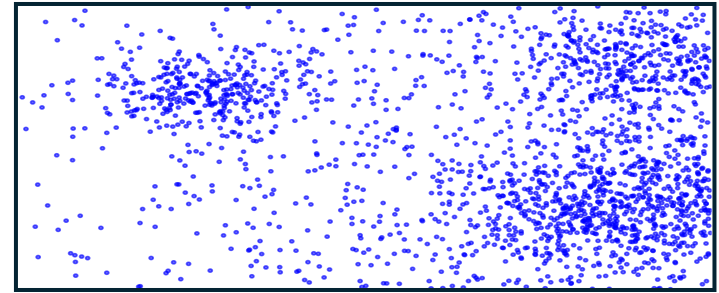


# What is the meaning of very heterogeneous ?

## HOMOGENEOUS MEDIA



## HETEROGENEOUS MEDIA

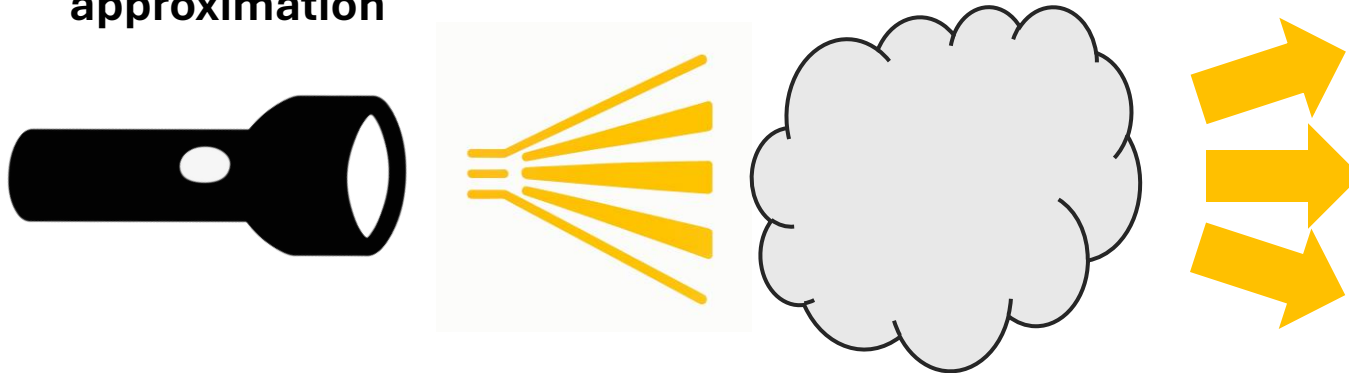


# Unusual diffusive properties

## Soulage's stained glasses

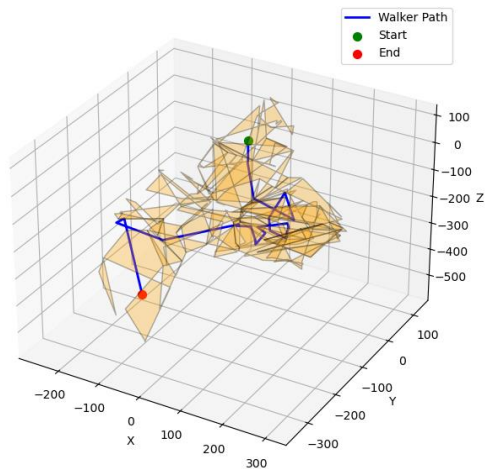
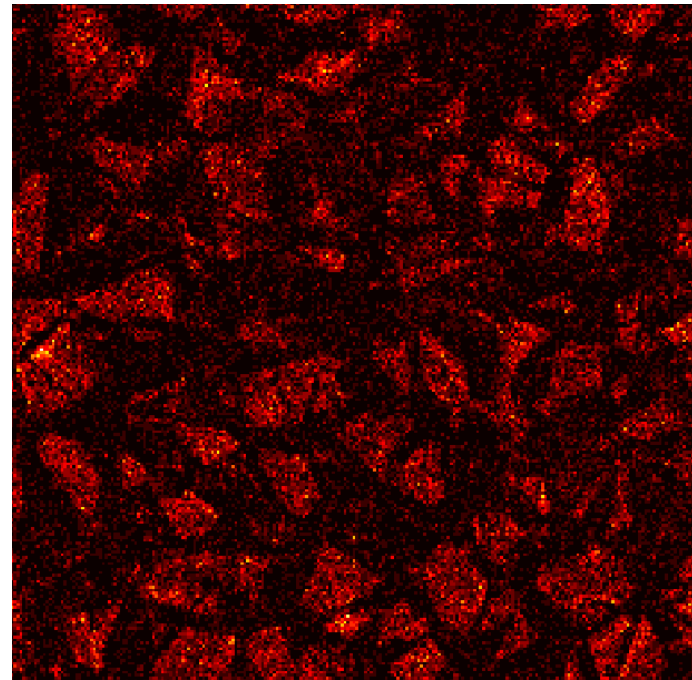
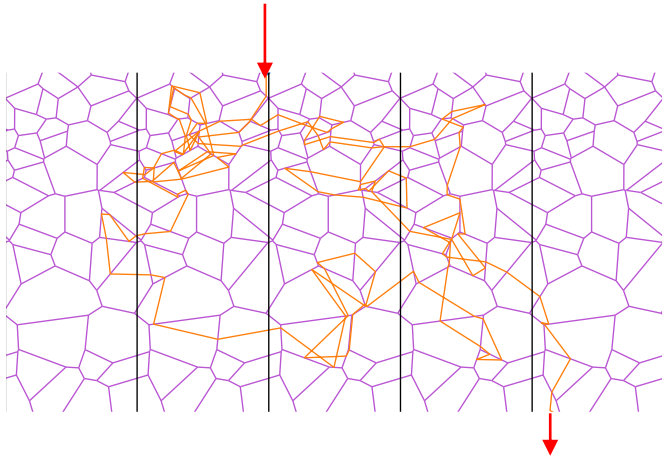


## Statistically homogeneous approximation

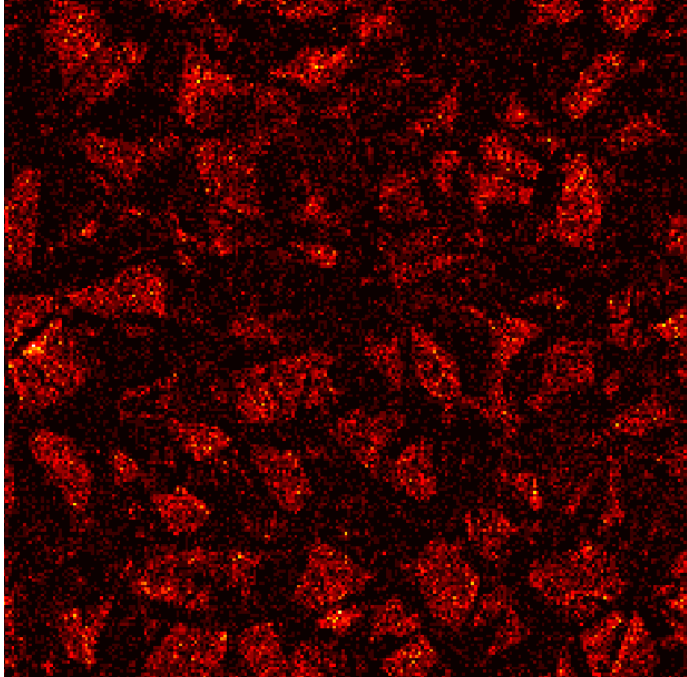


# A random walk process

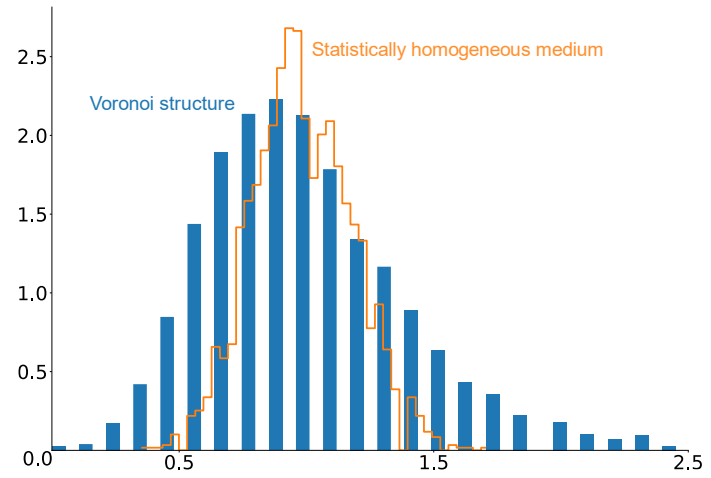
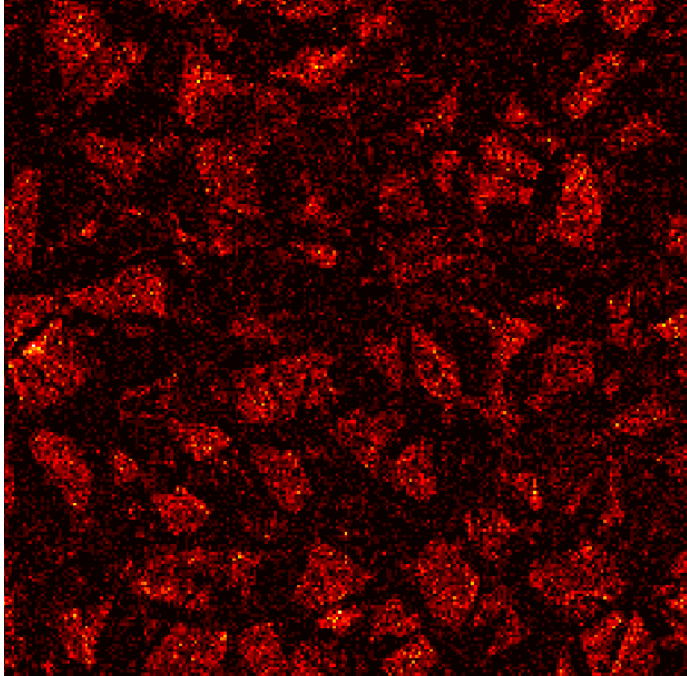
## Random walk in a Voronoi Diagram



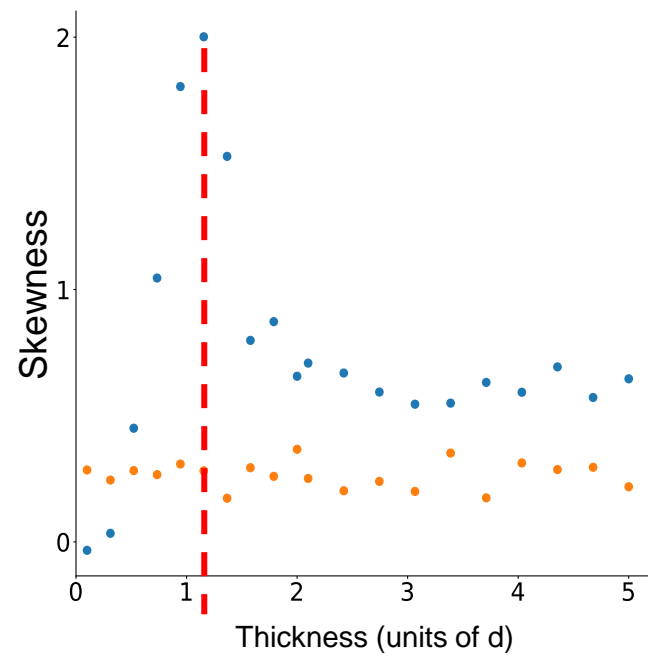
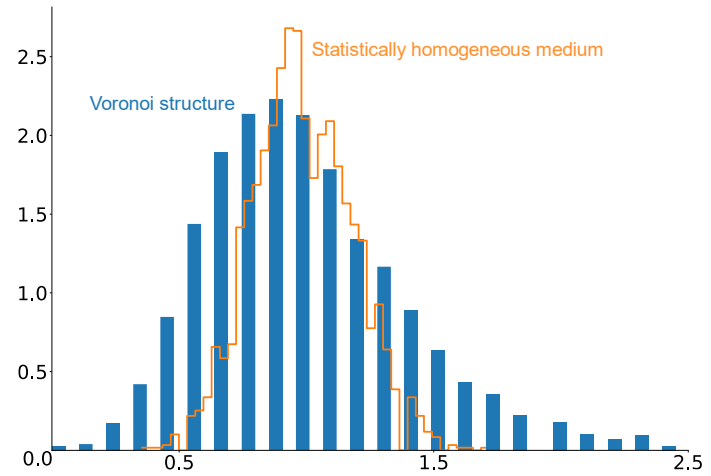
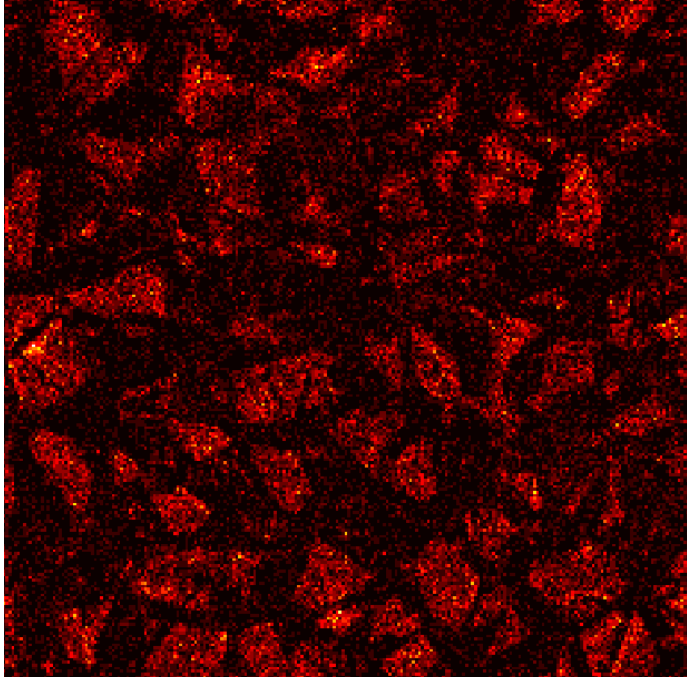
# Some results



# Some results



# Some results



# A tiny bit of theory


$$\frac{1}{c} \frac{\partial L(\mathbf{r}, \hat{\mathbf{s}}, t)}{\partial t} + \hat{\mathbf{s}} \cdot \nabla L(\mathbf{r}, \hat{\mathbf{s}}, t) + \mu_t L(\mathbf{r}, \hat{\mathbf{s}}, t) = \mu_s \int_{4\pi} p(\hat{\mathbf{s}}, \hat{\mathbf{s}}') L(\mathbf{r}, \hat{\mathbf{s}}', t) d\Omega' + S(\mathbf{r}, \hat{\mathbf{s}}, t)$$

$$\nabla^2 u(\mathbf{r}) + k^2 u(\mathbf{r}) = 0$$

$$G = G_0 + G_0 \Sigma G$$

$$\frac{1}{c} \frac{\partial \Phi(\mathbf{r}, t)}{\partial t} - \nabla \cdot (D \nabla \Phi(\mathbf{r}, t)) + \mu_a \Phi(\mathbf{r}, t) = S_0(\mathbf{r}, t)$$

$$\langle E(\mathbf{r}) E^*(\mathbf{r}') \rangle = \langle E(\mathbf{r}) \rangle \langle E^*(\mathbf{r}') \rangle + u k_0^4 \int G(\mathbf{r} - \mathbf{r}_1) G^*(\mathbf{r}' - \mathbf{r}'_1) \Gamma(\mathbf{r}_1 - \mathbf{r}'_1) \langle E(\mathbf{r}_1) E^*(\mathbf{r}'_1) \rangle d\mathbf{r}_1 d\mathbf{r}'_1$$



$$\begin{array}{l|l} \nabla \cdot \mathbf{D} = \rho_v & \nabla \cdot \mathbf{B} = 0 \\ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} & \nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J} \end{array}$$


$$\frac{1}{c} \frac{\partial \psi(\mathbf{r}, \boldsymbol{\Omega}, s, t)}{\partial t} + \boldsymbol{\Omega} \cdot \nabla \psi(\mathbf{r}, \boldsymbol{\Omega}, s, t) + \frac{\partial \psi(\mathbf{r}, \boldsymbol{\Omega}, s, t)}{\partial s} + \Sigma_t(s) \psi(\mathbf{r}, \boldsymbol{\Omega}, s, t) = \delta(s) \left[ \int_{4\pi} \int_0^\infty \Sigma_s(s', \boldsymbol{\Omega}' \rightarrow \boldsymbol{\Omega}) \psi(\mathbf{r}, \boldsymbol{\Omega}', s', t) ds' d\boldsymbol{\Omega}' + q(\mathbf{r}, \boldsymbol{\Omega}, t) \right]$$

# A tiny bit of theory

$$\frac{1}{c} \frac{\partial L(\mathbf{r}, \hat{\mathbf{s}}, t)}{\partial t} + \hat{\mathbf{s}} \cdot \nabla L(\mathbf{r}, \hat{\mathbf{s}}, t) + \mu_t L(\mathbf{r}, \hat{\mathbf{s}}, t) = \mu_s \int_{4\pi} p(\hat{\mathbf{s}}, \hat{\mathbf{s}}') L(\mathbf{r}, \hat{\mathbf{s}}', t) d\Omega' + S(\mathbf{r}, \hat{\mathbf{s}}, t)$$

$$\nabla^2 u(\mathbf{r}) + k^2 u(\mathbf{r}) = 0$$

$$\langle E(\mathbf{r}) E^*(\mathbf{r}') \rangle :$$



$$\begin{array}{l|l} \nabla \cdot \mathbf{D} = \rho_v & \nabla \cdot \mathbf{B} = 0 \\ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} & \nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J} \end{array}$$



$$\nabla^2 \Phi(\mathbf{r}, t) + \mu_a \Phi(\mathbf{r}, t) = S_0(\mathbf{r}, t)$$

$$-\mathbf{r}'_1 \langle E(\mathbf{r}_1) E^*(\mathbf{r}'_1) \rangle d\mathbf{r}_1 d\mathbf{r}'_1$$

$$\frac{1}{c} \frac{\partial \psi(\mathbf{r}, \Omega, s, t)}{\partial t} + \Omega \cdot \nabla \psi(\mathbf{r}, \Omega, s, t) + \frac{\partial \psi(\mathbf{r}, \Omega, s, t)}{\partial s} + \Sigma_t(s) \psi(\mathbf{r}, \Omega, s, t) = \delta(s) \left[ \int_{4\pi} \int_0^\infty \Sigma_s(s', \Omega' \rightarrow \Omega) \psi(\mathbf{r}, \Omega', s', t) ds' d\Omega' + q(\mathbf{r}, \Omega, t) \right]$$

# A tiny bit of theory

$$\frac{1}{c} \frac{\partial L(\mathbf{r}, \hat{\mathbf{s}}, t)}{\partial t} + \hat{\mathbf{s}} \cdot \nabla L(\mathbf{r}, \hat{\mathbf{s}}, t) + \mu_t L(\mathbf{r}, \hat{\mathbf{s}}, t) = \mu_s \int_{4\pi} p(\hat{\mathbf{s}}, \hat{\mathbf{s}}') L(\mathbf{r}, \hat{\mathbf{s}}', t) d\Omega' + S(\mathbf{r}, \hat{\mathbf{s}}, t)$$

Radiative transfert theory for statistical homogeneous media.

Amazing because : **valid in multiple field of physics**, (particle transport, light, earthquake,...)

# A tiny bit of theory

$$\frac{1}{c} \frac{\partial L(\mathbf{r}, \hat{\mathbf{s}}, t)}{\partial t} + \hat{\mathbf{s}} \cdot \nabla L(\mathbf{r}, \hat{\mathbf{s}}, t) + \mu_t L(\mathbf{r}, \hat{\mathbf{s}}, t) = \mu_s \int_{4\pi} p(\hat{\mathbf{s}}, \hat{\mathbf{s}}') L(\mathbf{r}, \hat{\mathbf{s}}', t) d\Omega' + S(\mathbf{r}, \hat{\mathbf{s}}, t)$$

Radiative transfert theory for statistical homogeneous media.

Amazing because : **valid in multiple field of physics**, (particle transport, light, earthquake,...)

**BUT** : Strong  
Aproximation  
**not** valid in our  
case

# A tiny bit of theory

$$\frac{1}{c} \frac{\partial L(\mathbf{r}, \hat{\mathbf{s}}, t)}{\partial t} + \hat{\mathbf{s}} \cdot \nabla L(\mathbf{r}, \hat{\mathbf{s}}, t) + \mu_t L(\mathbf{r}, \hat{\mathbf{s}}, t) = \mu_s \int_{4\pi} p(\hat{\mathbf{s}}, \hat{\mathbf{s}}') L(\mathbf{r}, \hat{\mathbf{s}}', t) d\Omega' + S(\mathbf{r}, \hat{\mathbf{s}}, t)$$

Radiative transfert theory for statistical homogeneous media.

Amazing because : **valid in multiple field of physics**, (particle transport, light, earthquake,...)

**BUT** : Strong  
Aproximation  
**not** valid in our  
case



A **Generalized** version  
shown without the Maxwell  
equation

$$\frac{1}{c} \frac{\partial \psi(\mathbf{r}, \boldsymbol{\Omega}, s, t)}{\partial t} + \boldsymbol{\Omega} \cdot \nabla \psi(\mathbf{r}, \boldsymbol{\Omega}, s, t) + \frac{\partial \psi(\mathbf{r}, \boldsymbol{\Omega}, s, t)}{\partial s} + \Sigma_t(s) \psi(\mathbf{r}, \boldsymbol{\Omega}, s, t) = \delta(s) \left[ \int_{4\pi} \int_0^\infty \Sigma_s(s', \boldsymbol{\Omega}' \rightarrow \boldsymbol{\Omega}) \psi(\mathbf{r}, \boldsymbol{\Omega}', s', t) ds' d\Omega' + q(\mathbf{r}, \boldsymbol{\Omega}, t) \right]$$

# Humanity Timeline

## Prehistory

3 millions years  
to 3000 BC

PALEOLITHIC

NEOLITHIC

## History

3000 BC to nowadays

ANCIENT  
AGE

MEDIEVAL  
AGE

MODERN  
AGE

CONTEMPORARY  
AGE

3 millions  
10000 AC

10000 BC

3000 BC to  
476 AC

476 AC to  
1492 AC

1492 to  
1789 AC

1789 AC  
2011AC

Use of fire  
1 million years  
BC



Agriculture  
begins  
10000 BC



Invention of  
Writing  
3.000BC



Fall of Western  
Roman Empire  
476 AC



Columbus  
discovered  
America  
1492 AC



French Revolution  
1789 AC



First human species  
2.5 millions years BC



# Windows Timeline

## Prehistory

3 millions years to 3000 BC

PALEOLITHIC

NEOLITHIC

ANCIENT AGE

MEDIEVAL AGE

MODERN AGE

CONTEMPORARY AGE

3 millions to 10000 AC

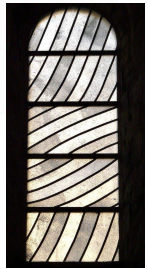
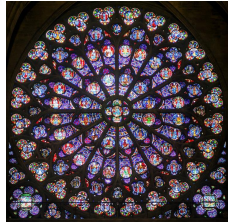
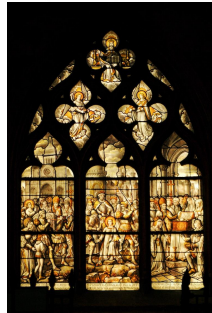
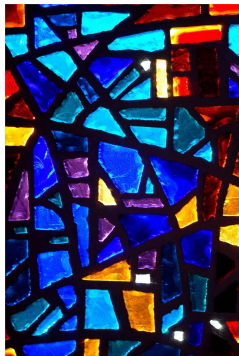
10000 BC

3000 BC to 476 AC

476 AC to 1492 AC

1492 to 1789 AC

1789 AC to 2011 AC



Thanks for you time an I am open to question