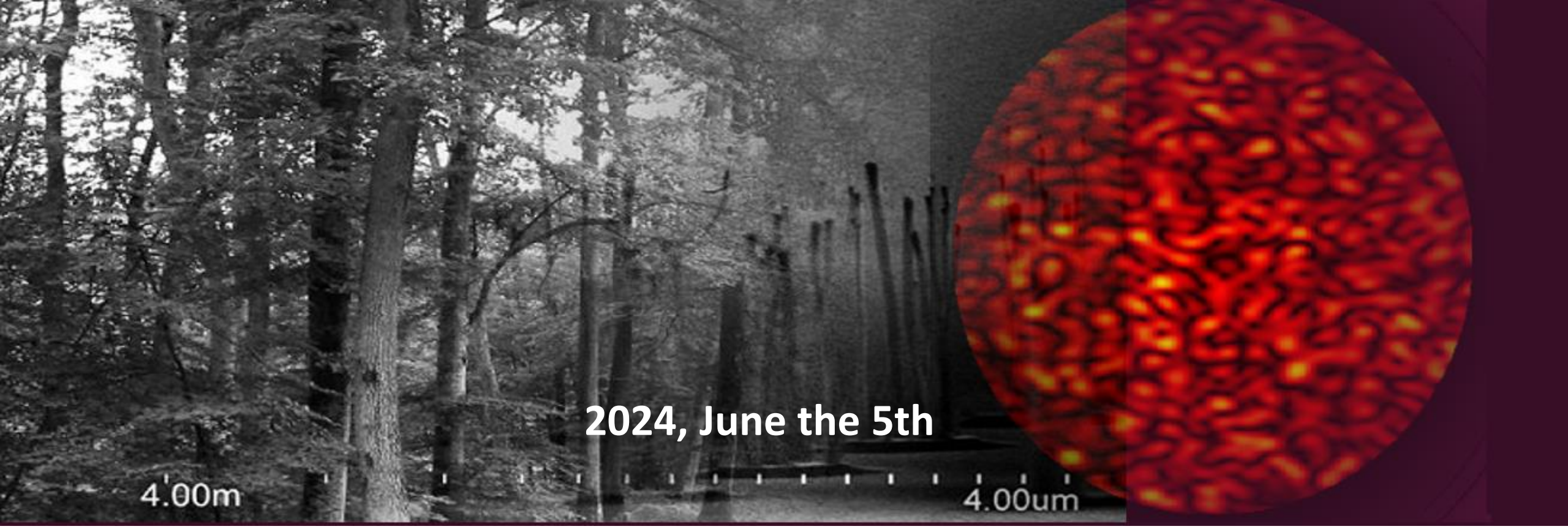


Depolarized Dynamic Speckle

From our planet to the laboratory

Elise Colin

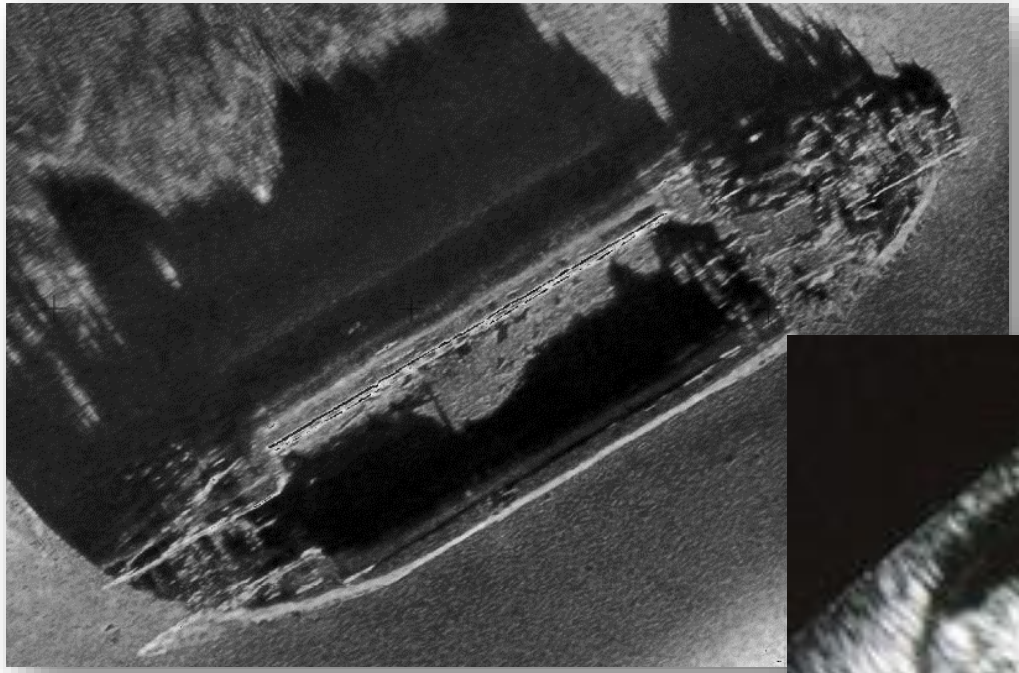
ONERA
THE FRENCH AEROSPACE LAB

Hôpital Marie Lannelongue,
Groupe Hospitalier Paris St Joseph, Université Paris Saclay

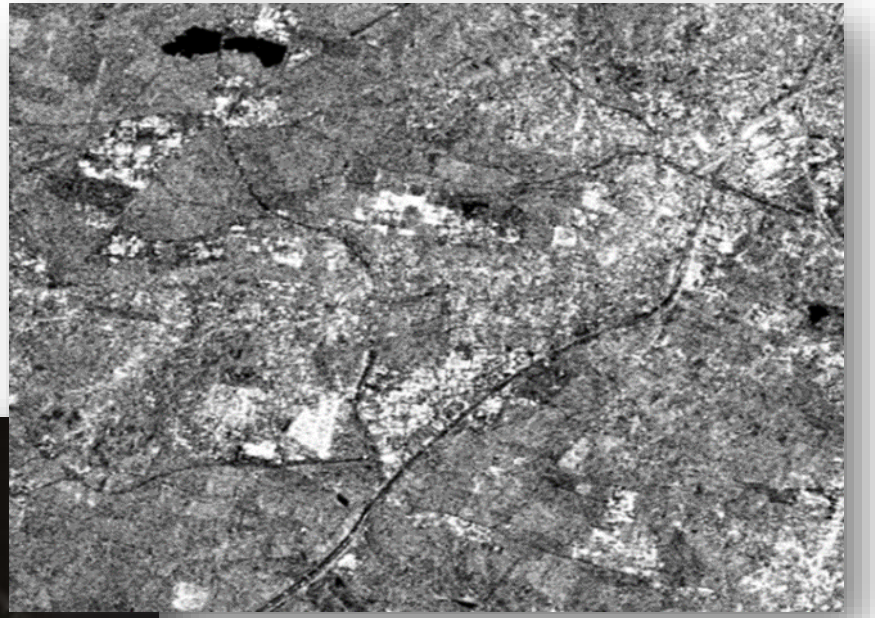
Financial support:

- Physic Cancer Plan
  Inserm, ESCAPADS Project
- Fondation Cœur et Recherche

What is speckle?



Sonar

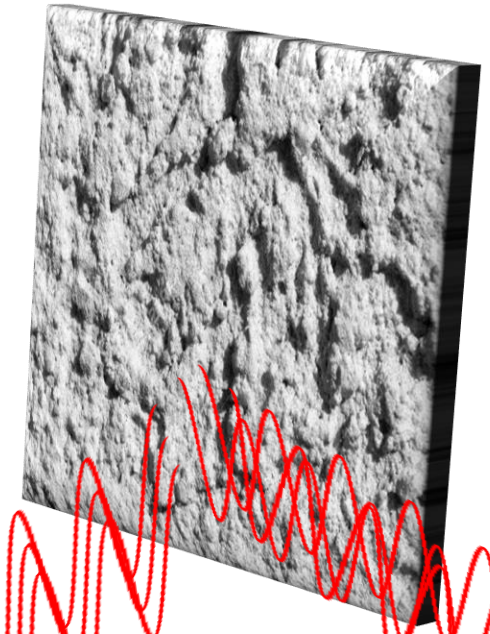


SAR (radar) images

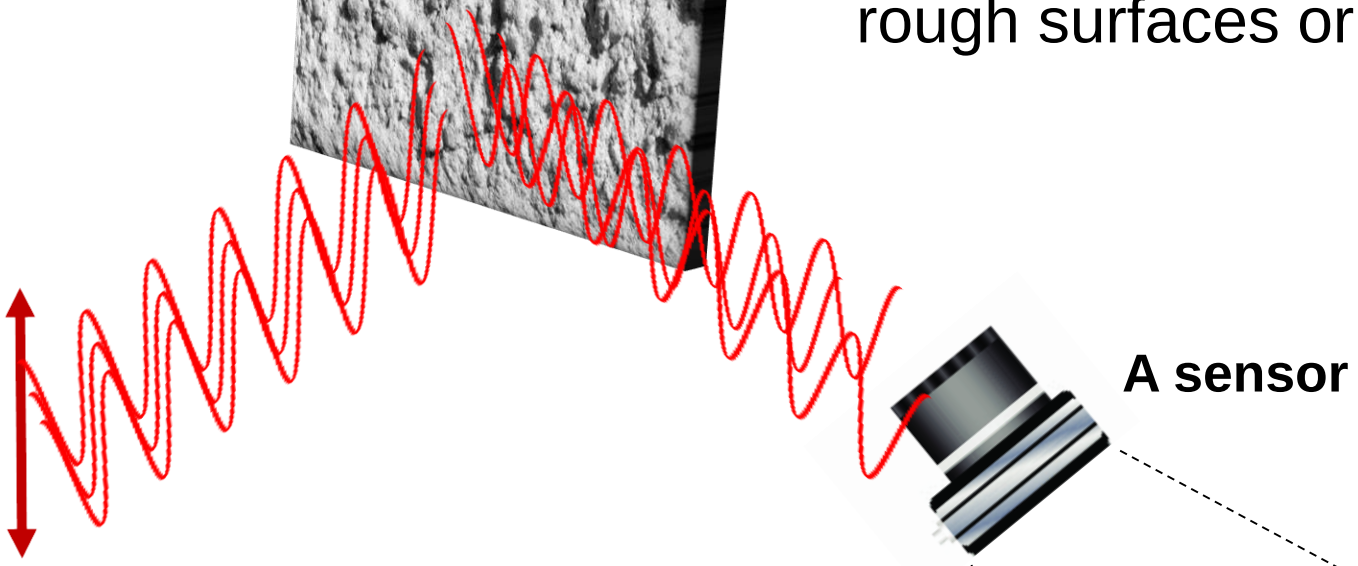
Echography

What is speckle?

A rough surface or a diffusing volume

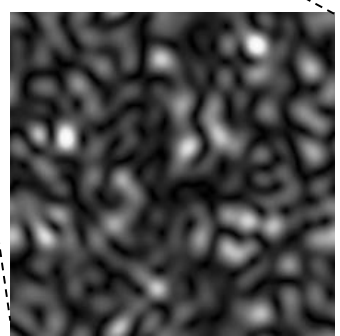


Interference phenomenon observable in images obtained by coherent imaging systems observing rough surfaces or volumes

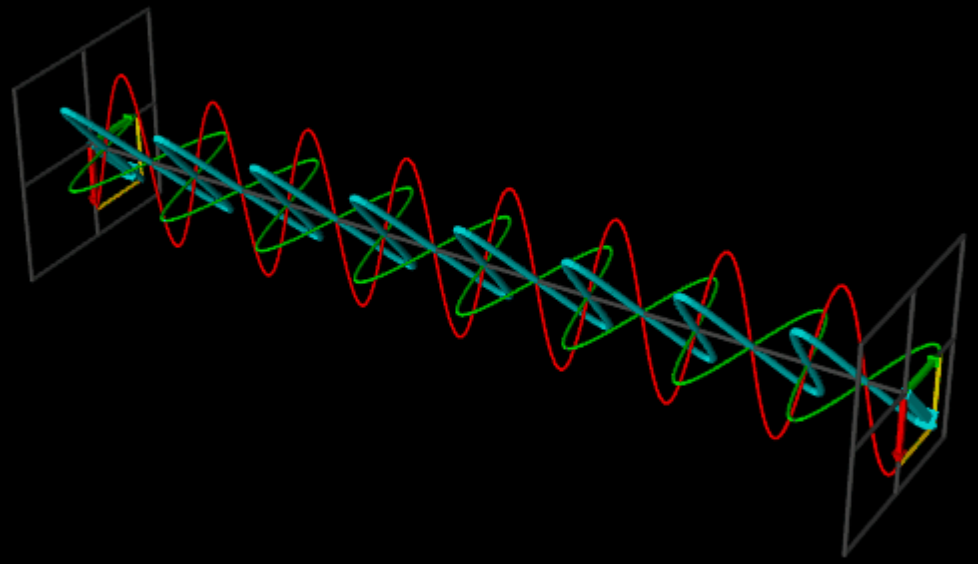


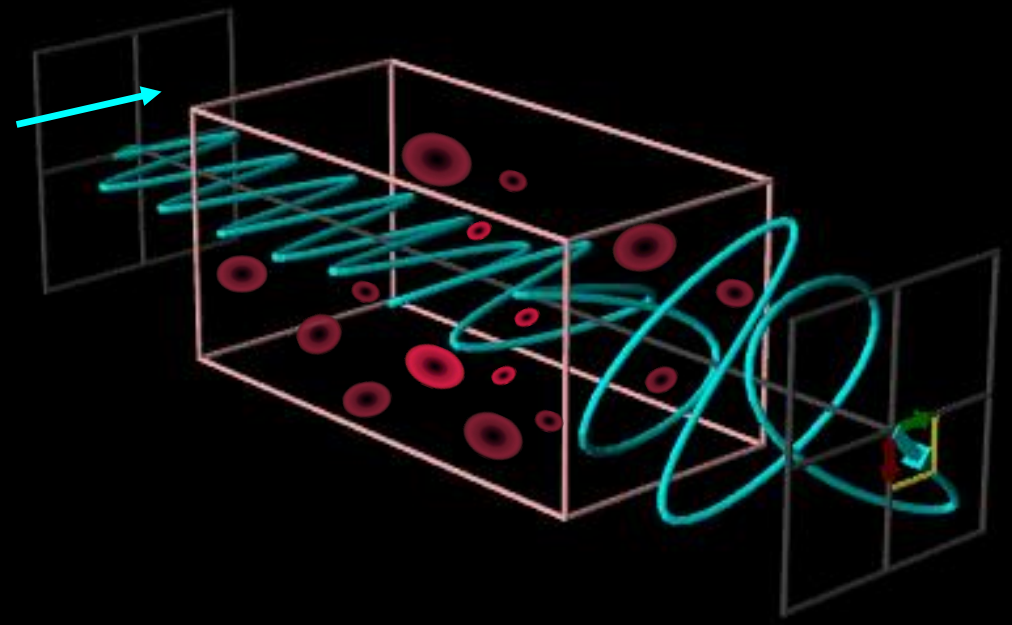
A sensor

A coherent source

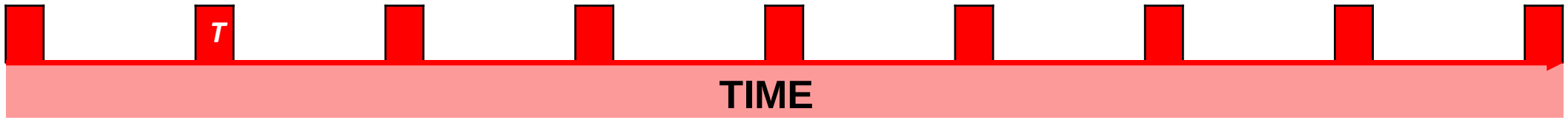


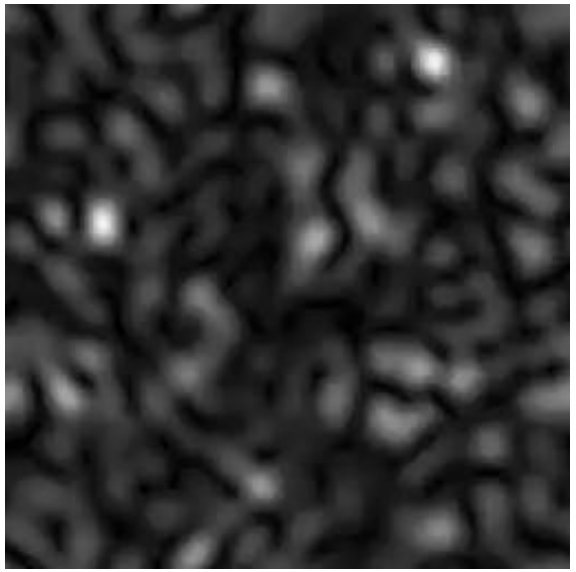
polarization





What is dynamic speckle

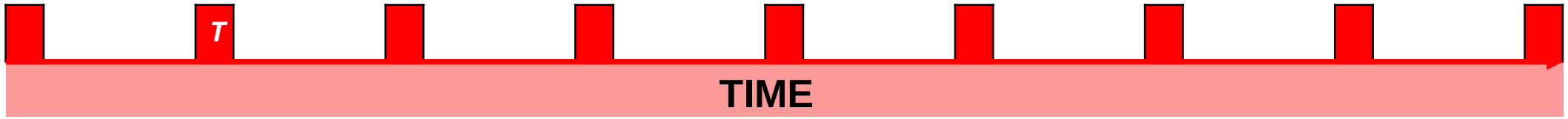


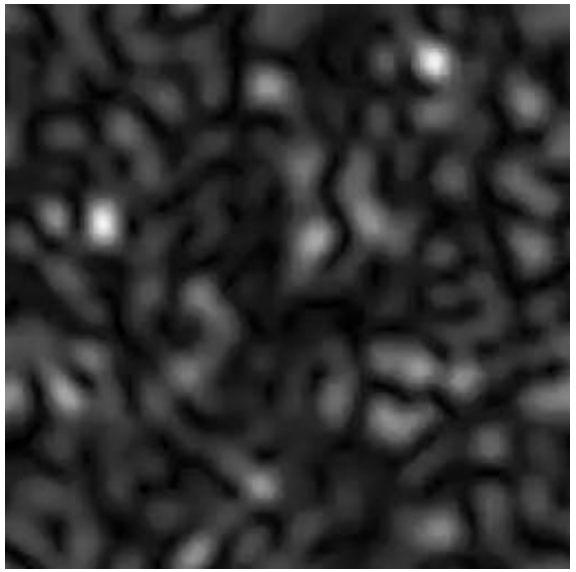


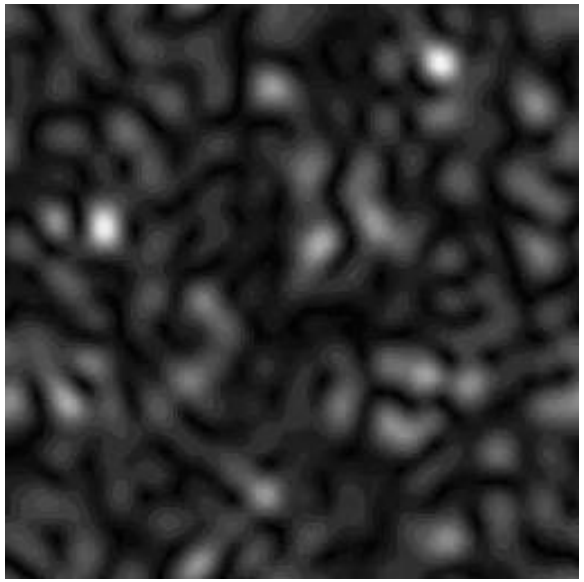
$$\mathbf{A}(\mathbf{x}, t)$$

Physical Phenomenon

What is dynamic speckle







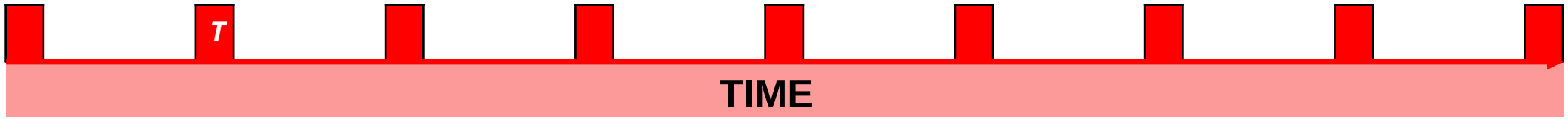
$\mathbf{A}(\mathbf{x}, t)$

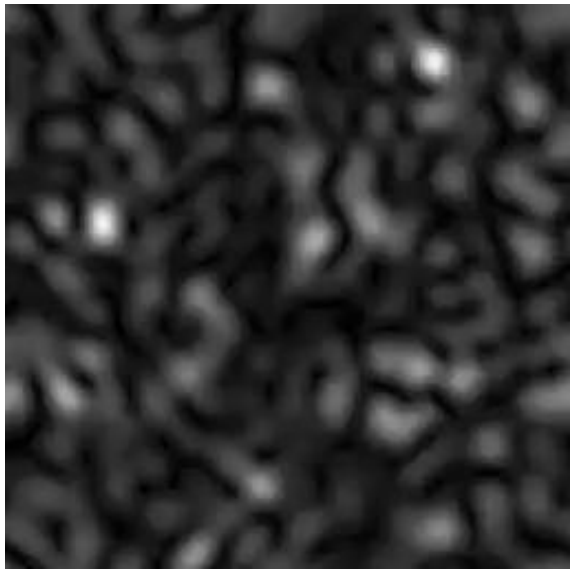
$$I_k(\mathbf{x}) = \int_{t_k - \frac{T}{2}}^{t_k + \frac{T}{2}} \mathbf{A}\mathbf{A}^*(\mathbf{x}, \tau) d\tau$$

Physical Phenomenon

Measurement

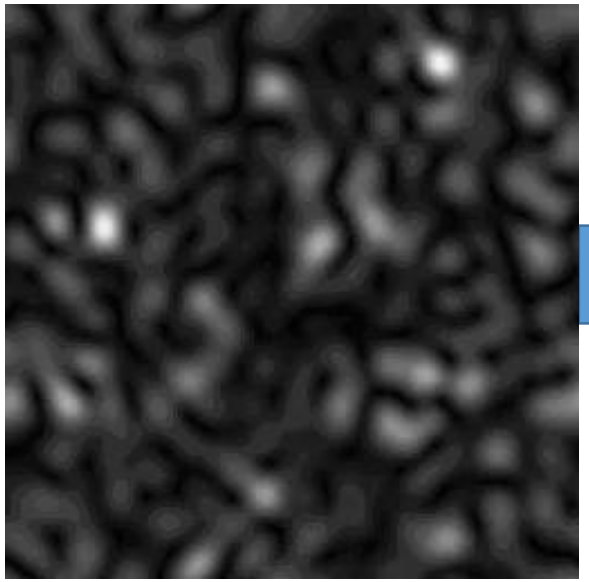
What is dynamic speckle





$\mathbf{A}(\mathbf{x}, t)$

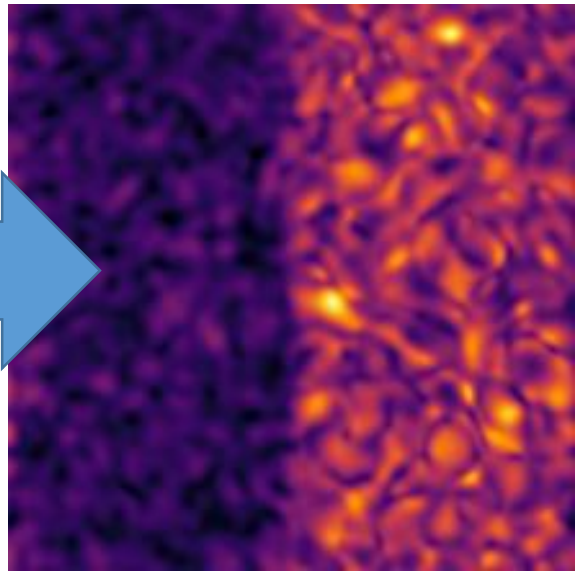
Physical Phenomenon



$$I_k(\mathbf{x}) = \int_{t_k-\frac{T}{2}}^{t_k+\frac{T}{2}} \mathbf{AA^*}(\mathbf{x}, \tau) d\tau$$

Measurement

My job



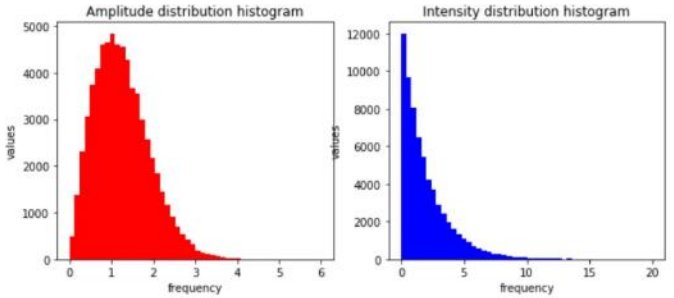
Construction of an index

High Activity

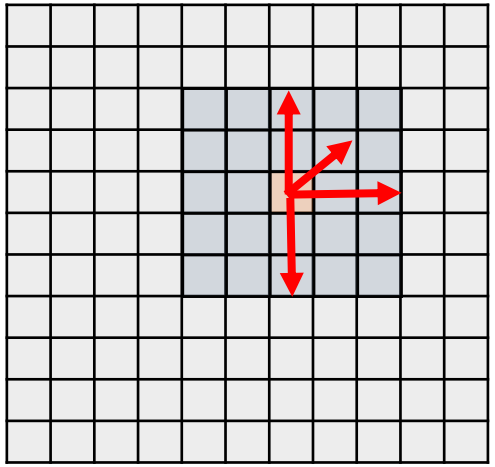
Low Activity

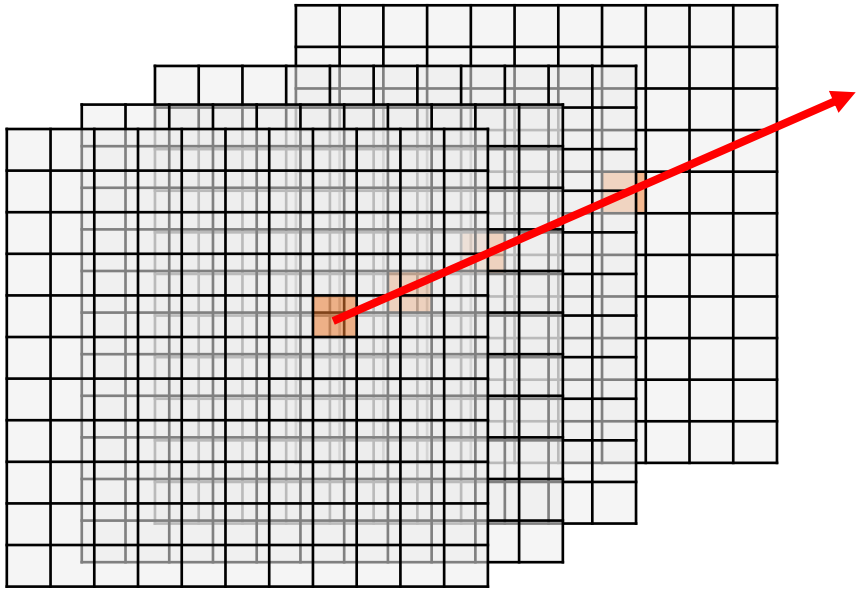
Statistics

The speckle constitutes a distinct field of statistics



- A reference model: the Godman speckle. $Z = \frac{1}{\sqrt{N}} \sum_{n=1}^{N} a_n e^{i\theta_n}$
- Study of the distribution laws of positive real magnitudes or complex signals
- Widely employed ergodic properties:

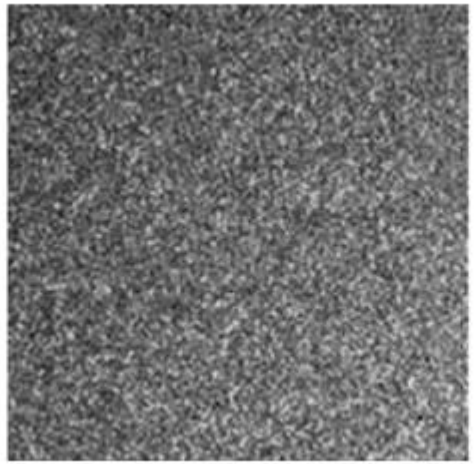




T=1s

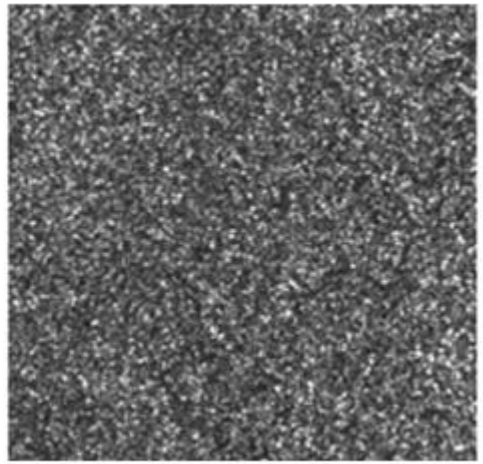
TD=1 year (30 000 000s)

T=5ms



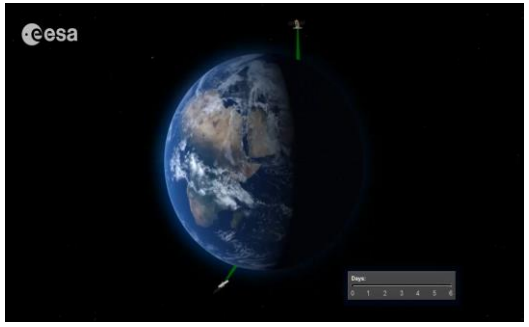
TD=1s

T=10ms



TD=5s

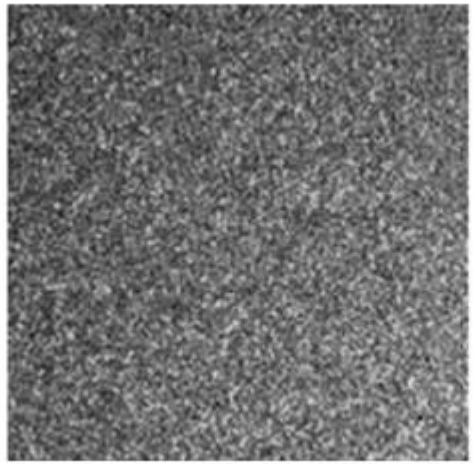
Total Duration TD



T=1s

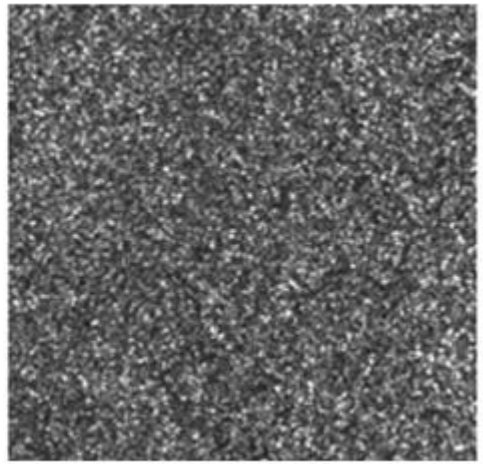
TD=1 year (30 000 000s)

T=5ms



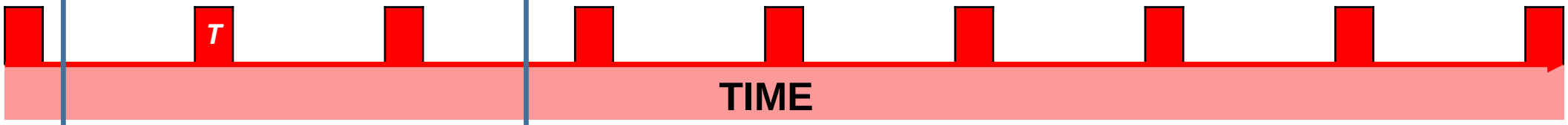
TD=1s

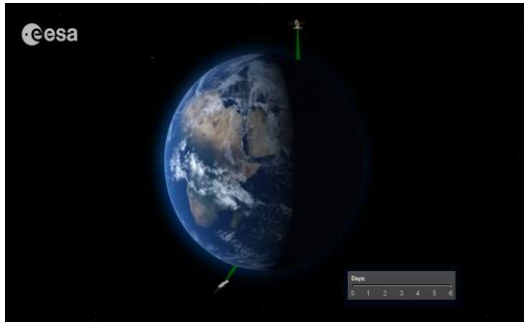
T=10ms



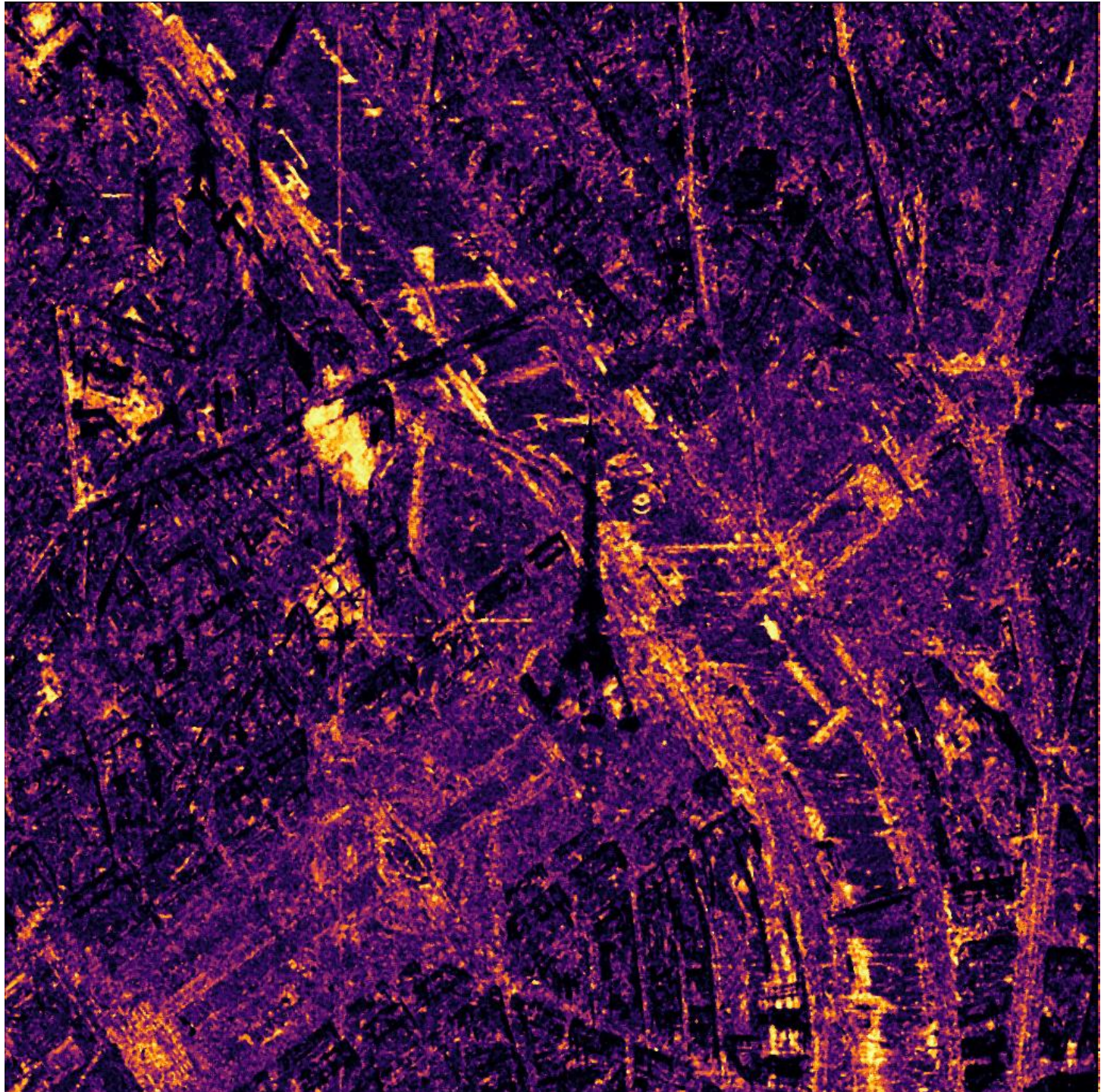
TD=5s

Total Duration TD

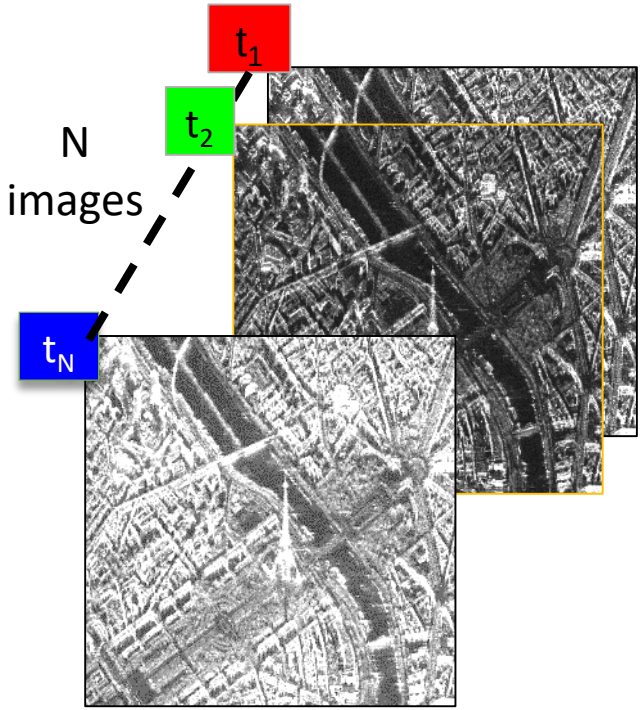


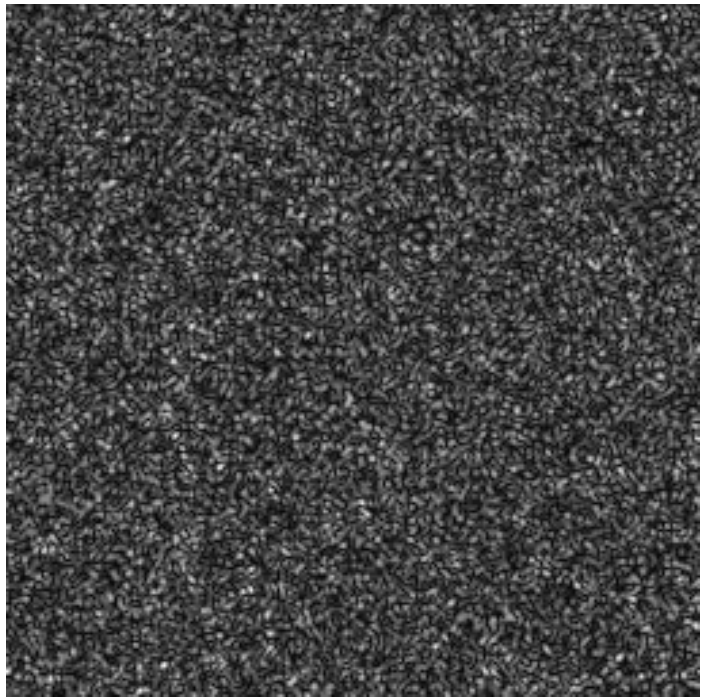


$$C_A(\mathbf{x}) = \frac{\sigma(A_k(\mathbf{x}))}{\mu(A_k(\mathbf{x}))}$$

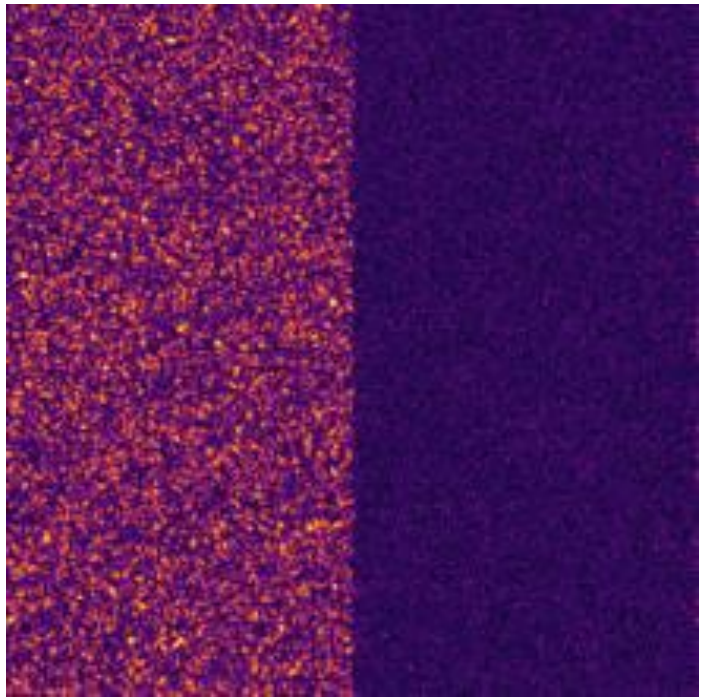


Change detection in radar for Earth Observation

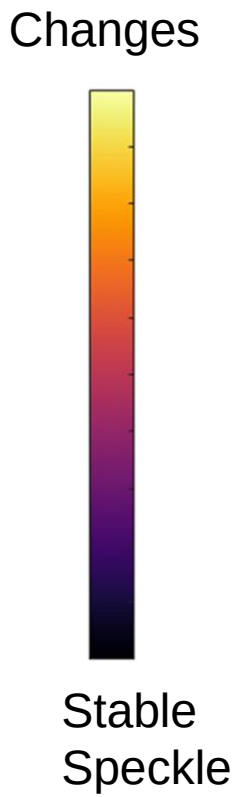




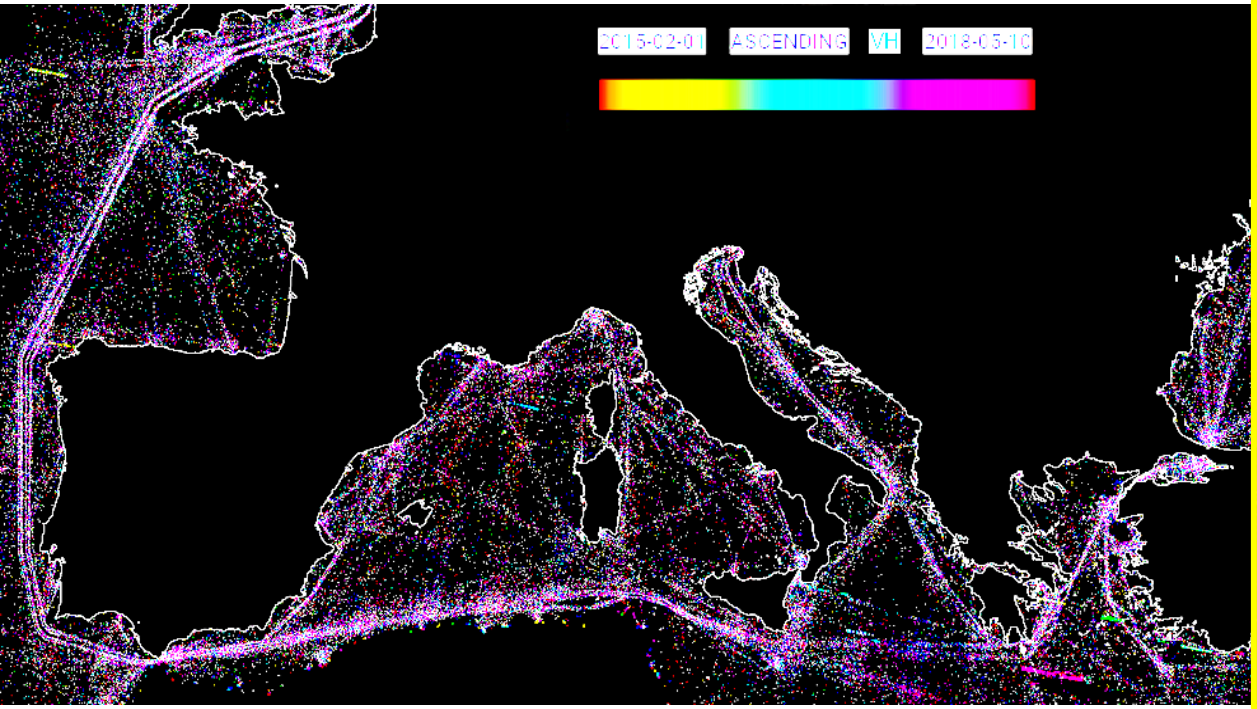
$$\mathbf{A}(\mathbf{x}, t)$$

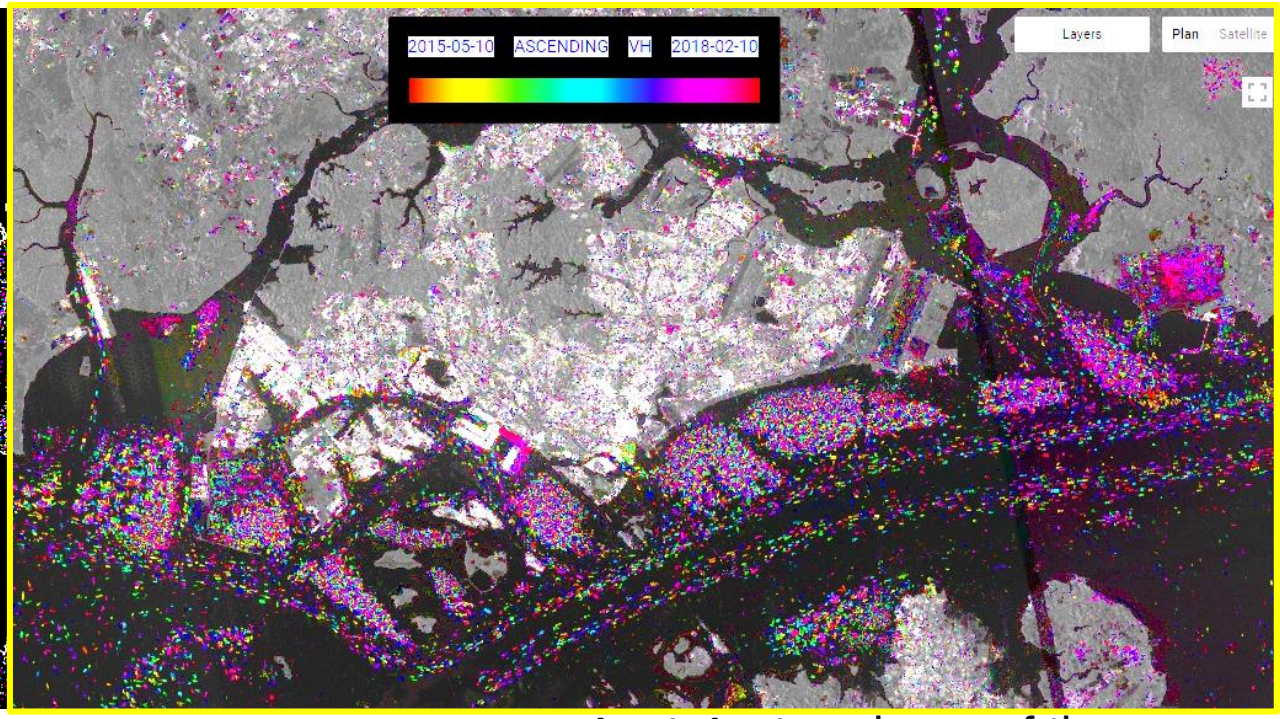


$$C_A(\mathbf{x}) = \frac{\sigma(A_k(\mathbf{x}))}{\mu(A_k(\mathbf{x}))}$$



Applications to surveillance





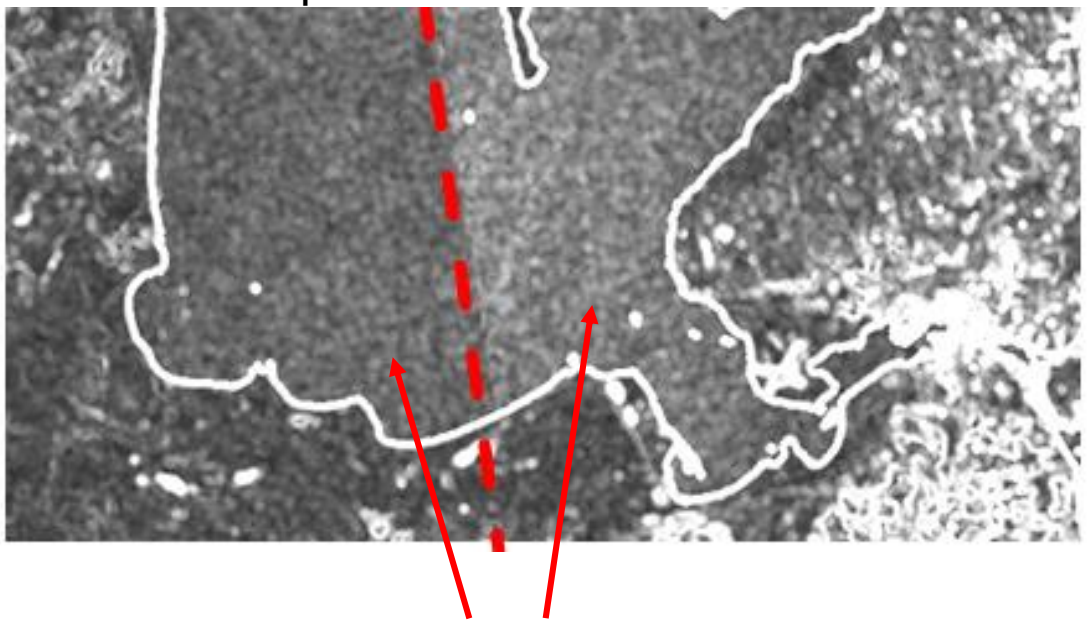
Best paper award: "Visualisation des changements sur séries temporelles radar : méthode REACTIV évaluée à l'échelle mondiale sous Google Earth Engine" CFPT/RFIAP 2018 workshop

Early Bird Prize winner of the @sentinel_hub Hub Custom Script Contest **(2020, October)**

First Place: @sentinel_hub 3d Custon Script Contest **(2021, January)**

And now…towards a new video mode

speckle contrast



Images captured on different dates on a Lake.

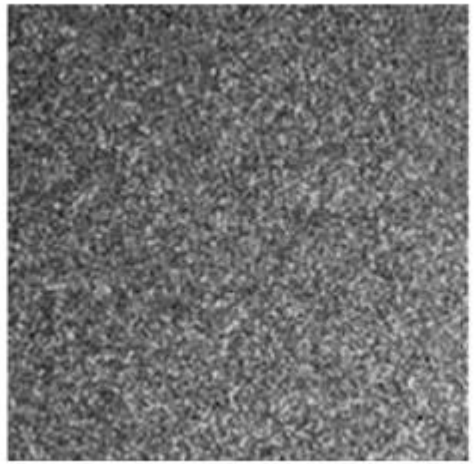
- identical speckle contrast was anticipated
- but noticeable differences were measured.

What is going on when movement during the Time of Integration can not be neglected?

T=1s

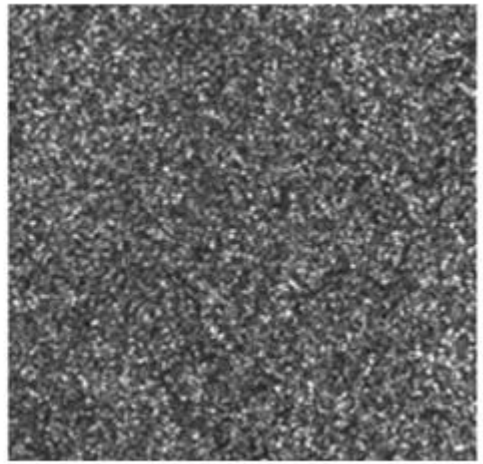
TD=1 year (30 000 000s)

T=5ms



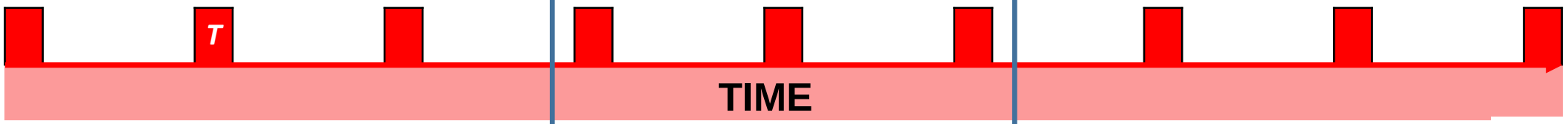
TD=1s

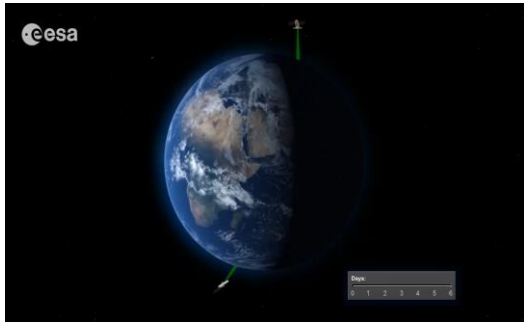
T=10ms

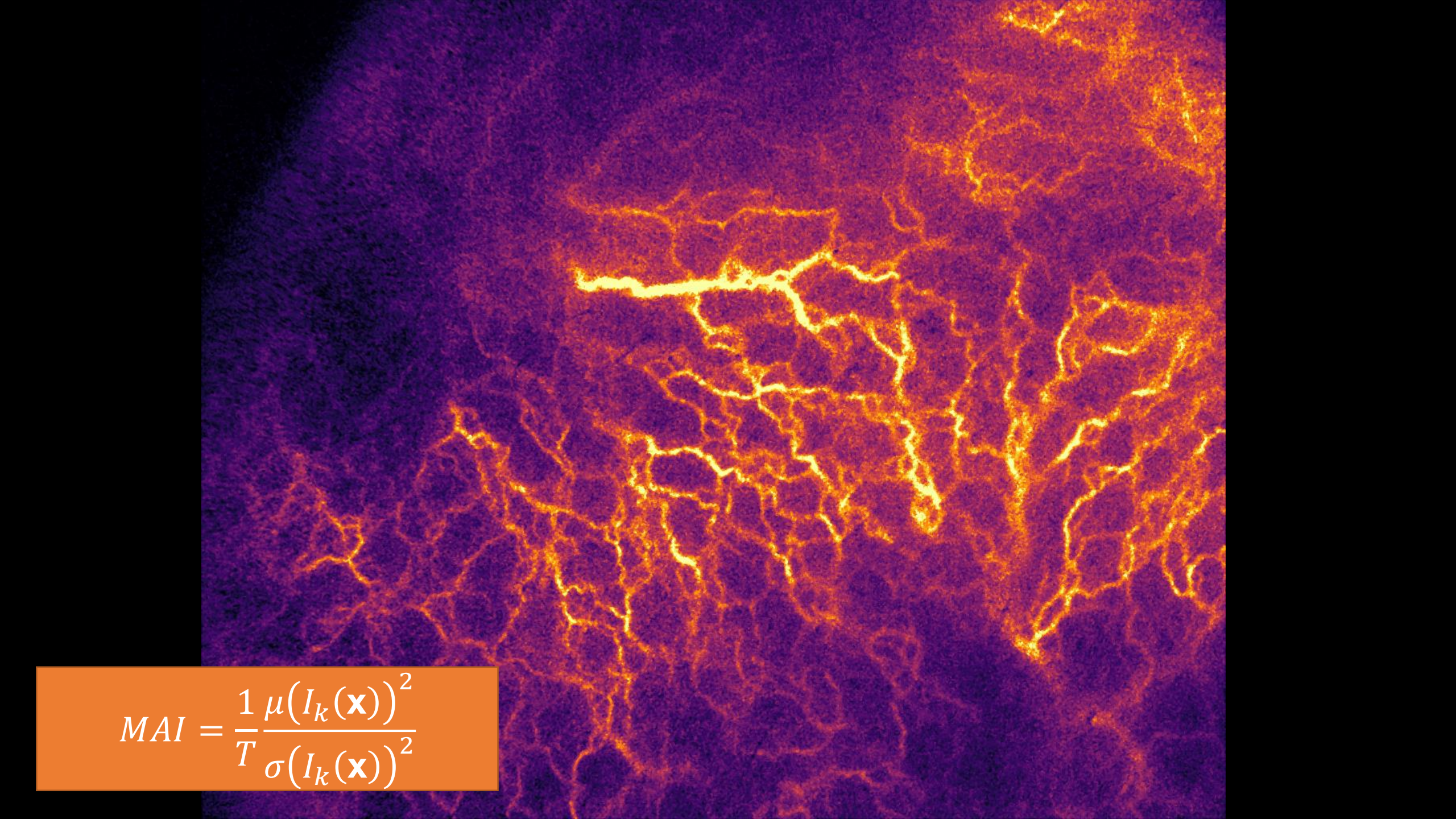


TD=5s

Total Duration TD

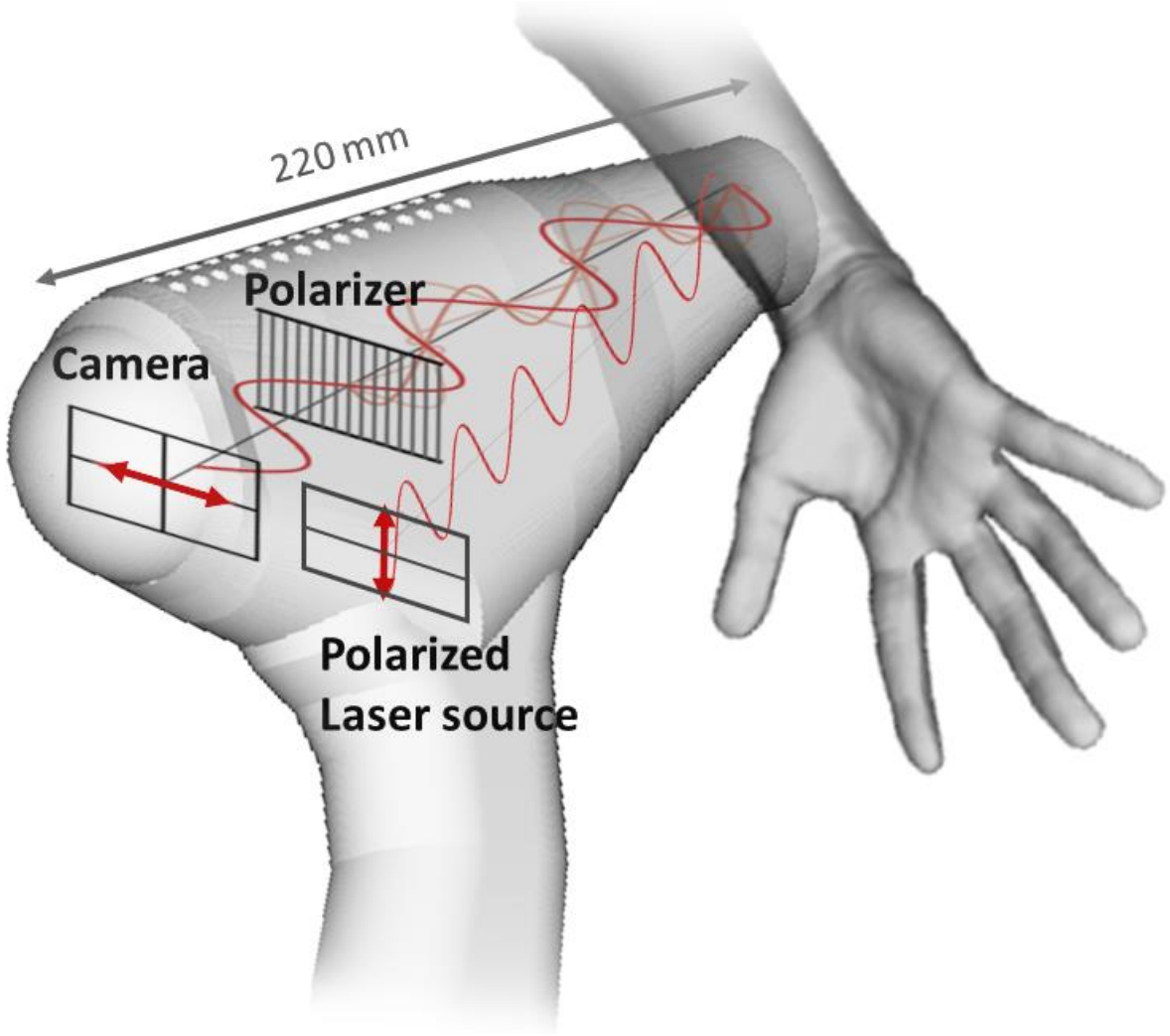






$$MAI = \frac{1}{T}\frac{\mu\left(I_k(\mathbf{x})\right)^2}{\sigma\left(I_k(\mathbf{x})\right)^2}$$

The Vasculoscope : depolarized dynamic speckle

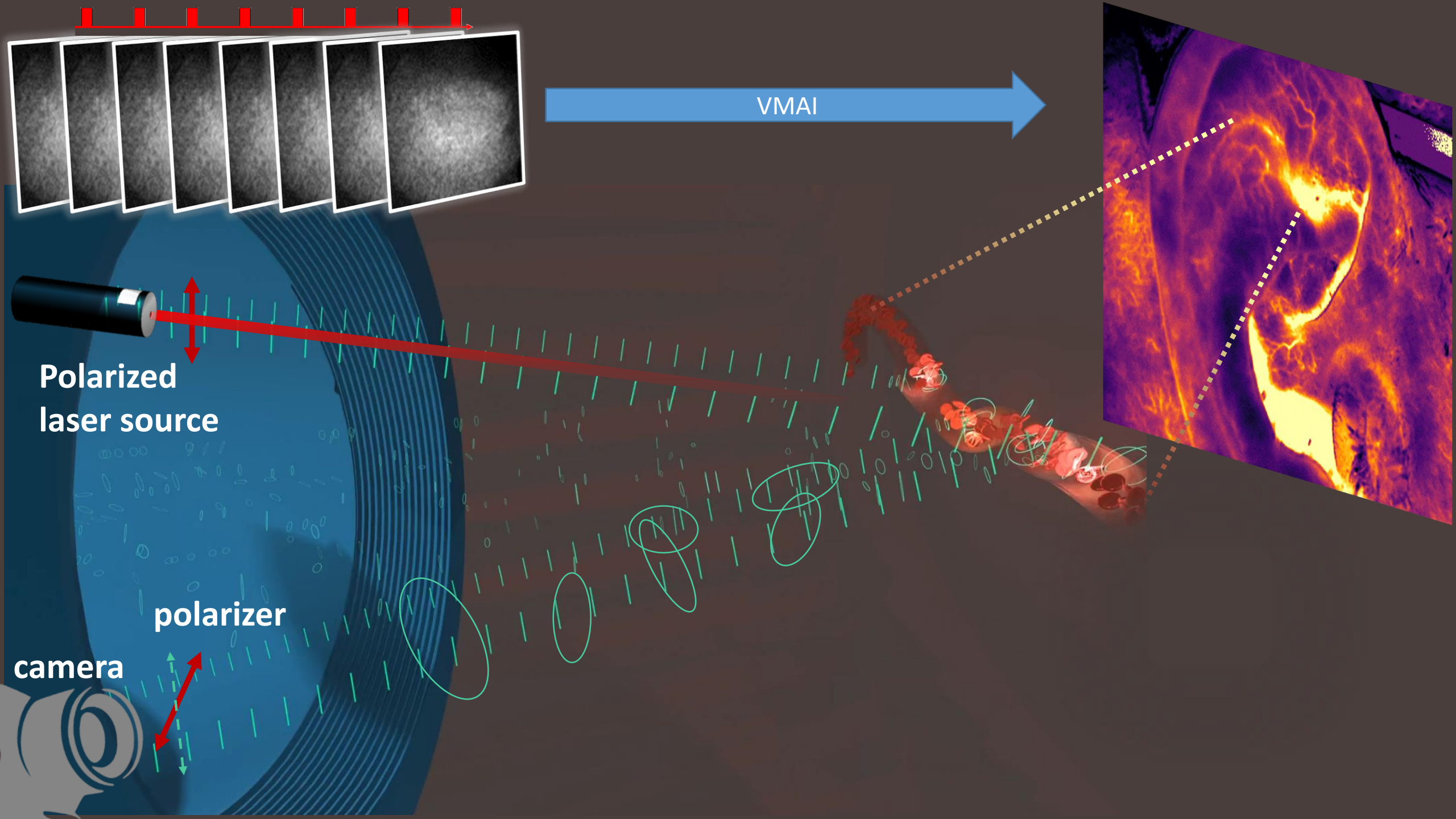


Orthogonal Polarizer filter (patent):

Attenuate first-order scattering

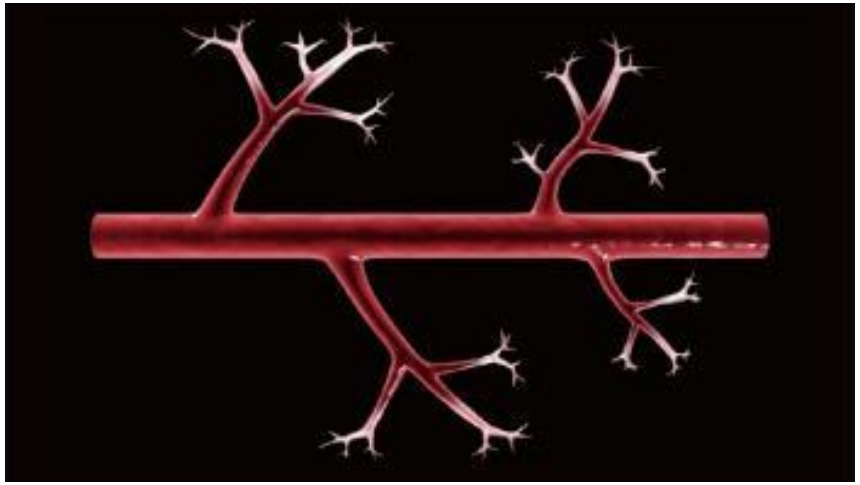
Encourage multiple scattering

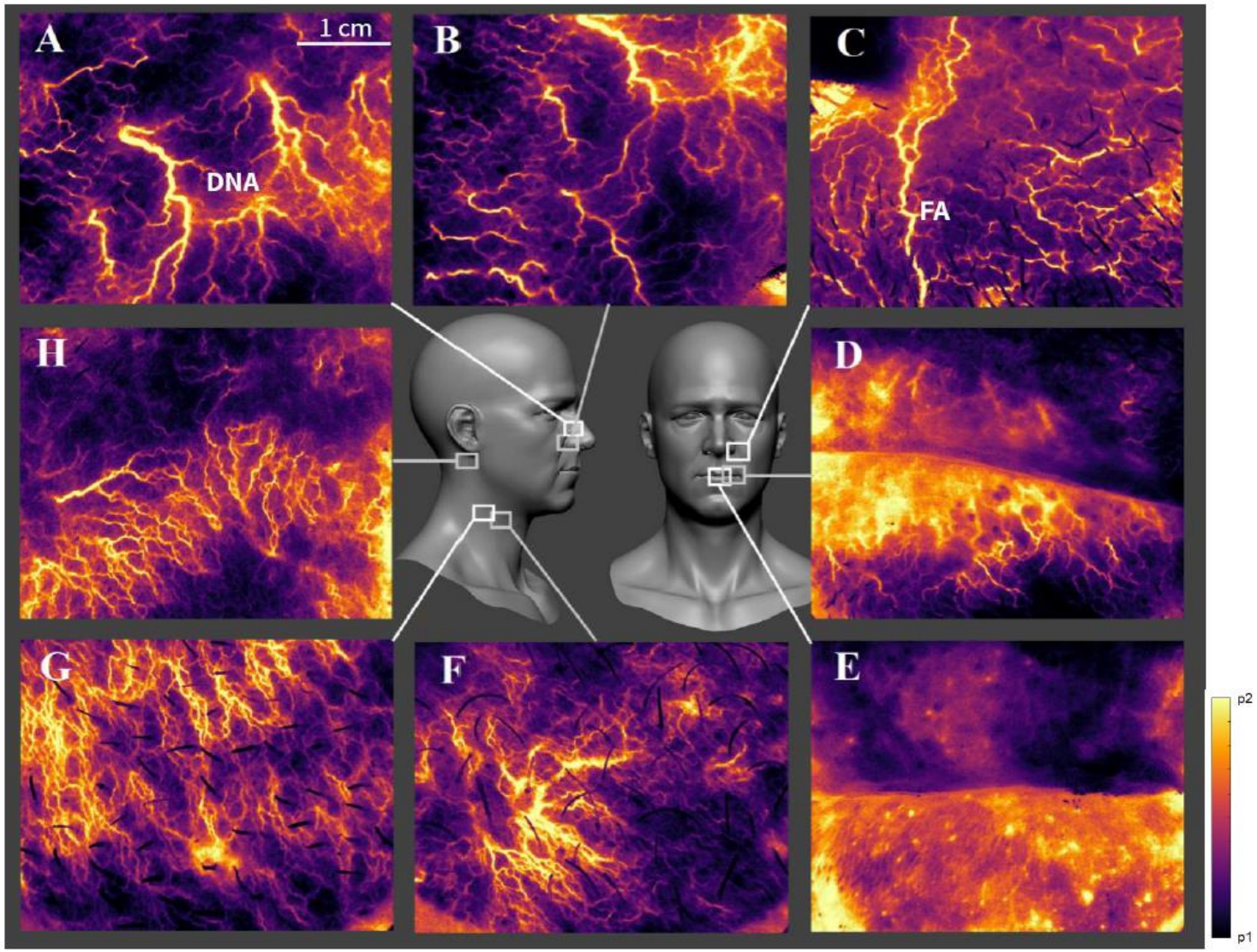
- which take place at greater depths
- Could amplify perceptible activity


VMAI
Polarized
laser source
polarizer
camera

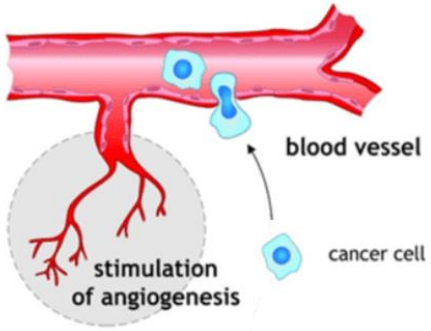
Applications to dermatology

- Activity is linked to blood micro-circulation

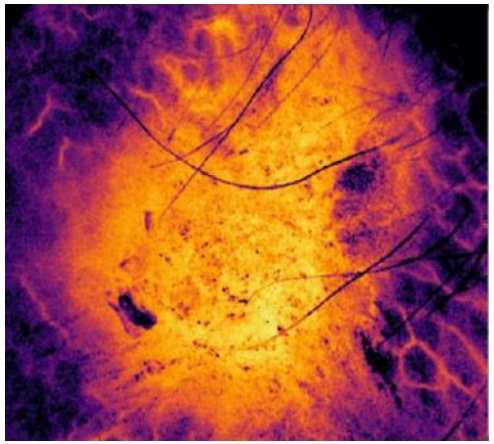




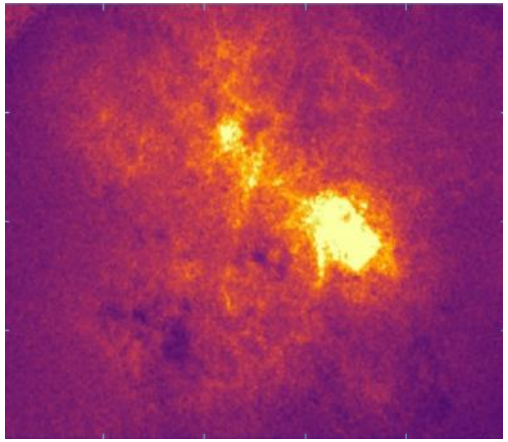
Study of a therapy

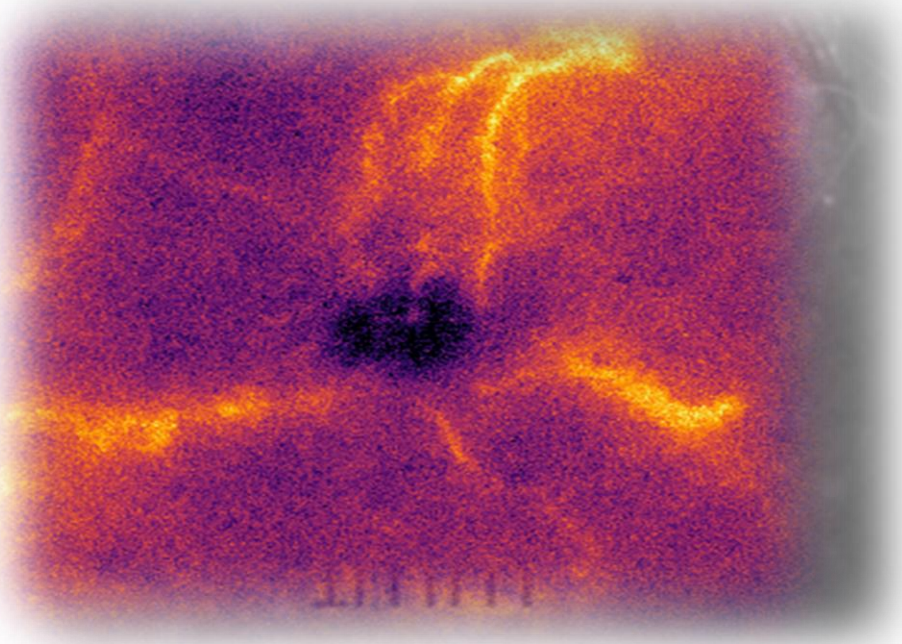


carcinoma



melanoma



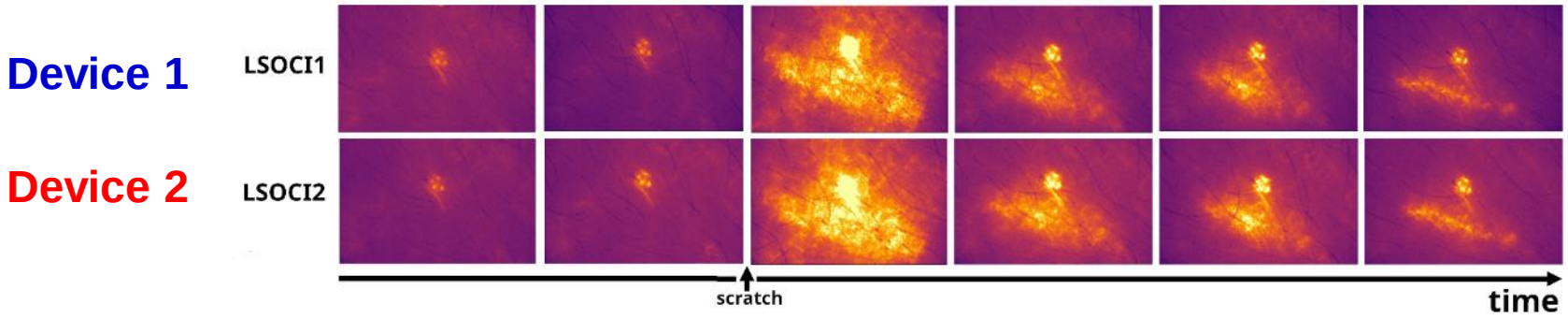


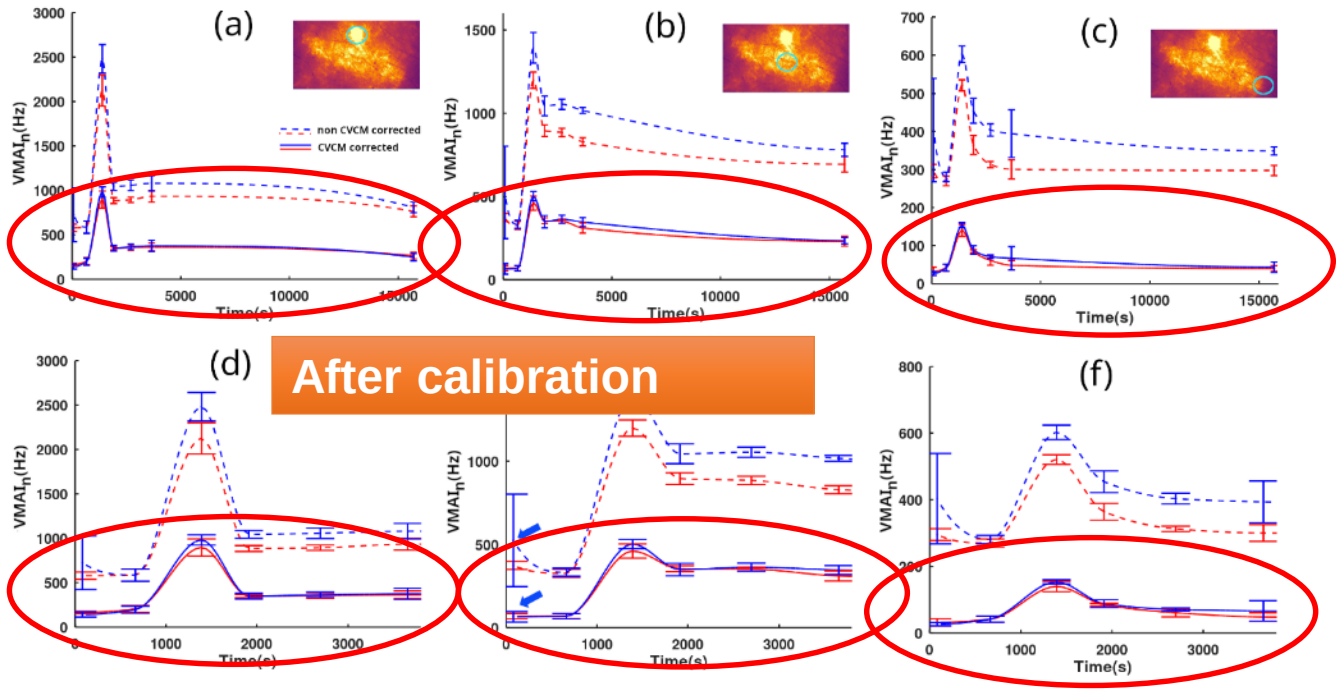
Melanoma cells
inside a mouse

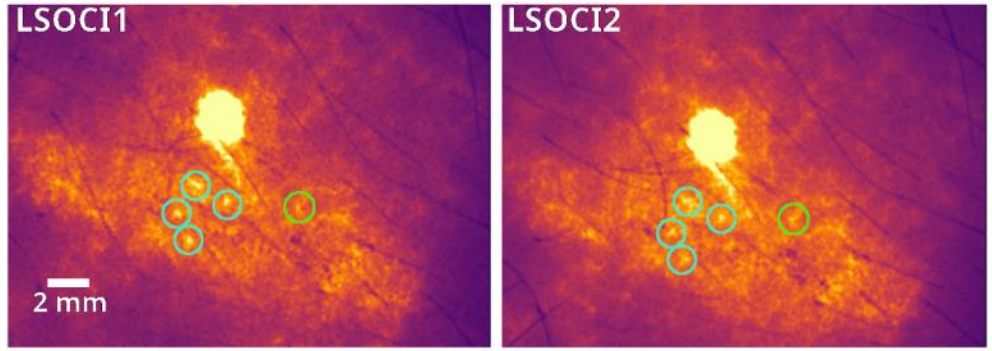
IPBS (CNRS)

Towards quantification

Comparison of dynamics for two independent devices







$$Activity\ index\colon \frac{1}{T}\left(\left(\frac{C}{C_{\max}}\right)^2 - 1\right)$$

Patent on laser stability check for calibration

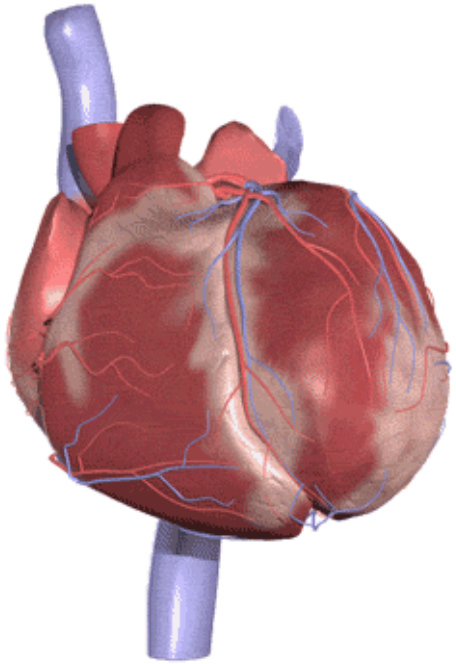
Compensate macro movements

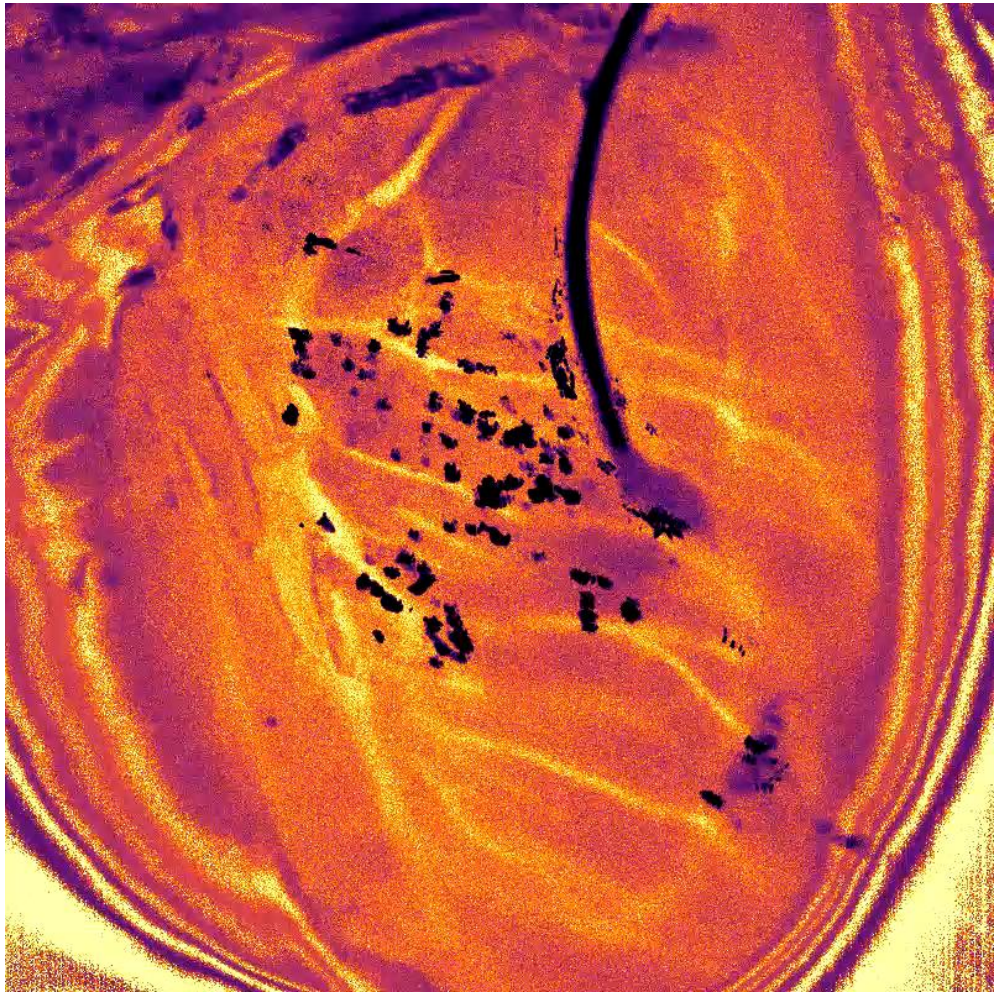
Project Echoronex, Hôpital Marie Lannelongue,
Groupe Hospitalier Paris St Joseph,
Université Paris Saclay

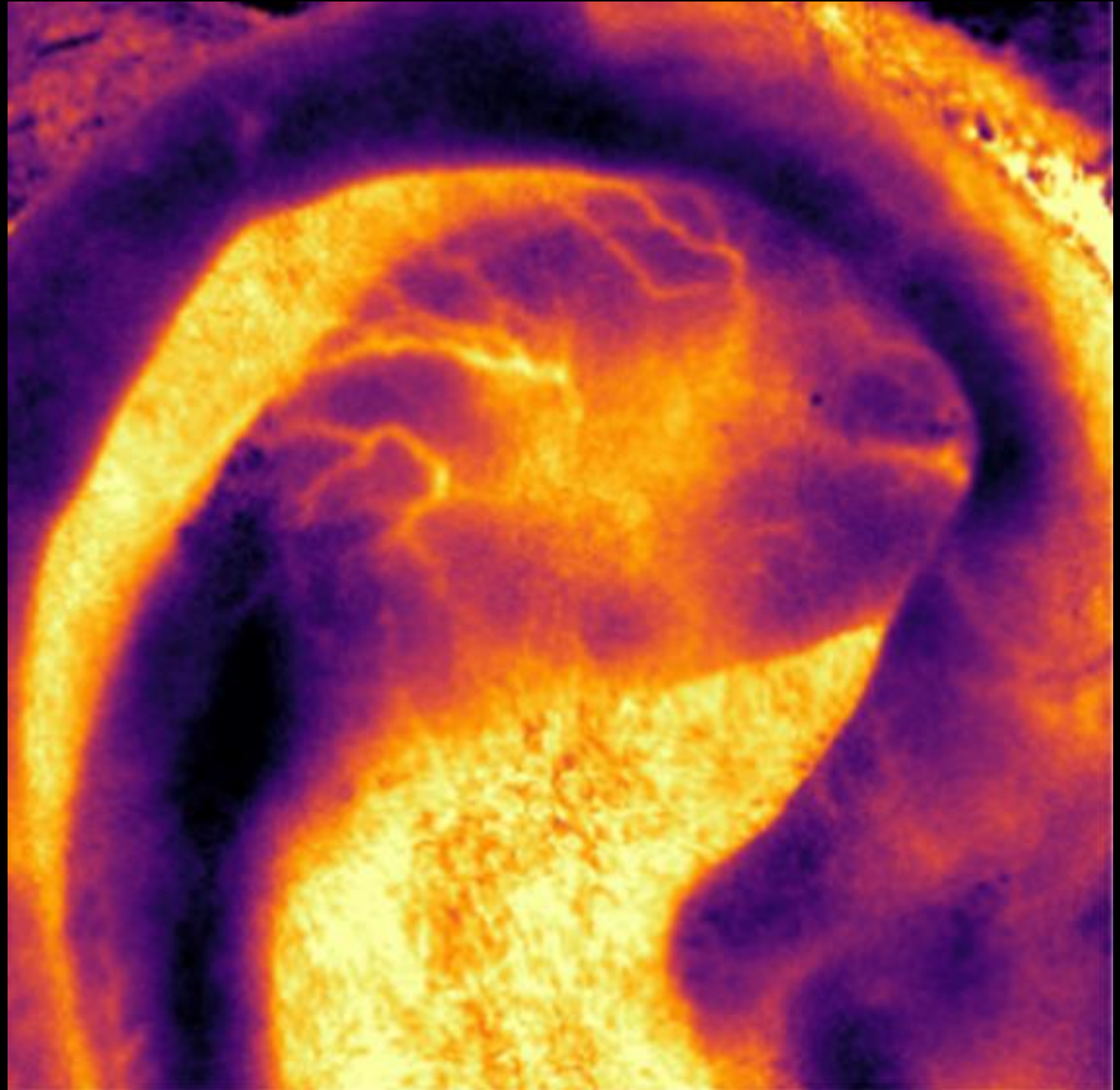
Subject: Study of a perfused heart

Objectif :

- Propose a non-invasive imaging method for graft activity under perfusion







$$1 - r_1 = \frac{m_2 - P}{m_2 - m_1^2}$$

$$m_1 = \frac{1}{N}\sum_{k=1}^{N} I_k$$

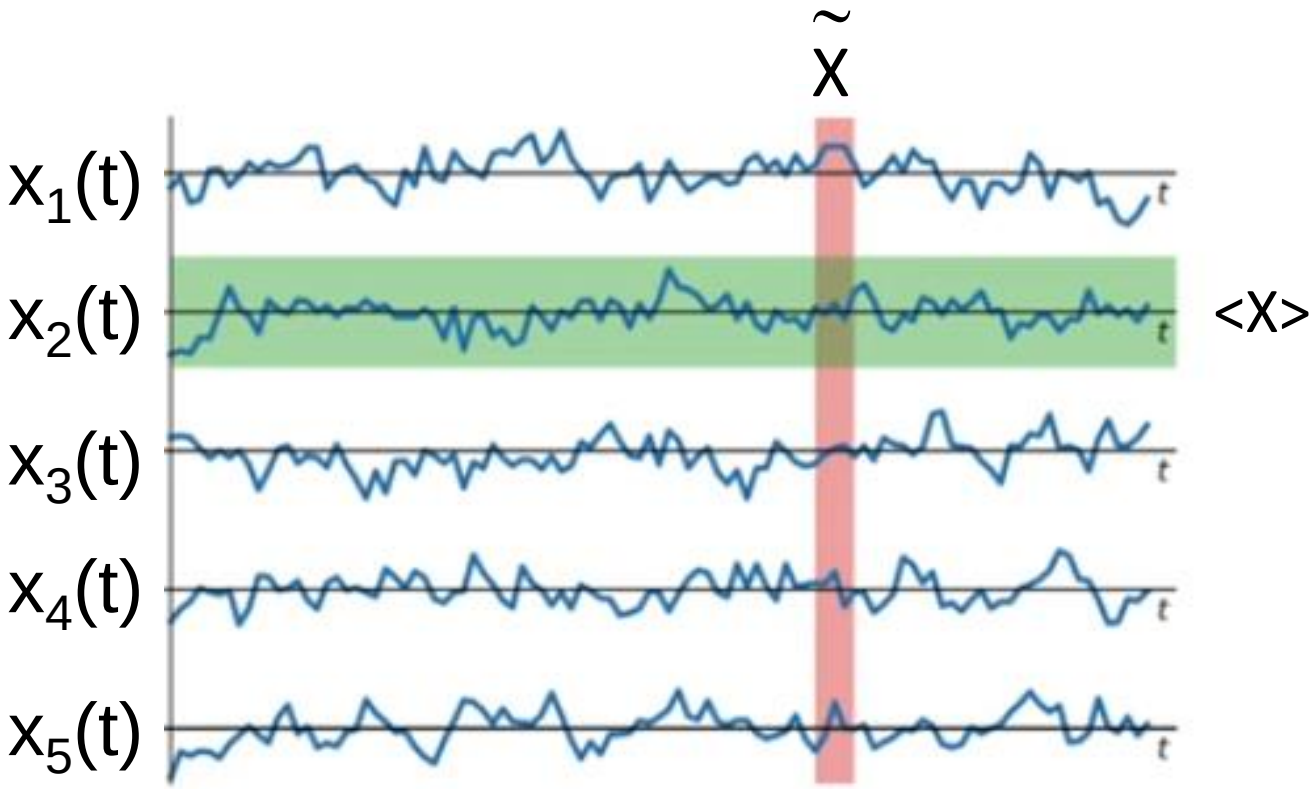
$$m_2 = \frac{1}{N}\sum_{k=1}^{N} I_k^2$$

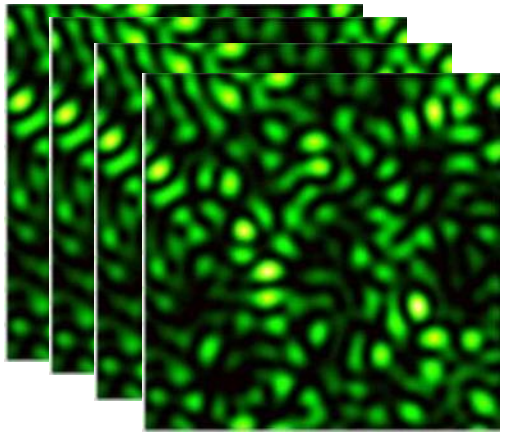
$$P = \frac{1}{N}\sum_{k=1}^{N} I_k I_{k+1}$$

When ergodicity fails

time average ≠ ensemble average

$\langle X \rangle \neq \tilde{x}$





Very low movement

Spatial Contrast ≈ 1

Temporal Contrast ≈ 0

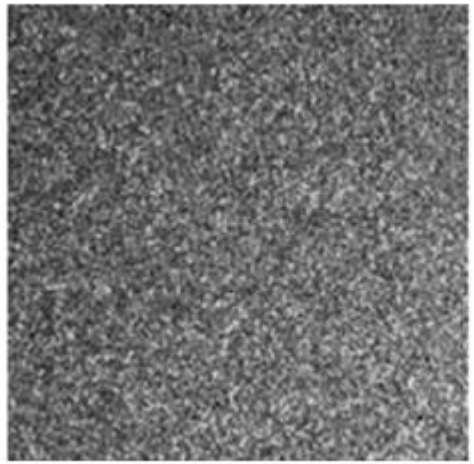
Question

Where ergodicity?

T=1s

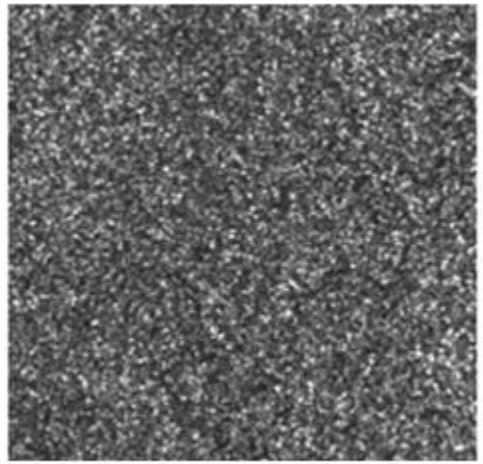
TD=1 year (30 000 000s)

T=5ms



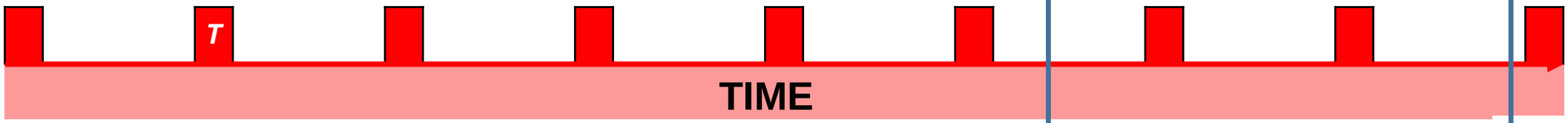
TD=1s

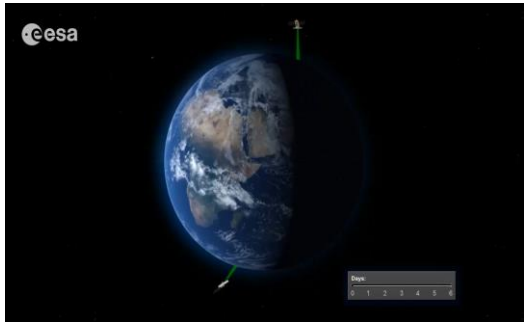
T=10ms

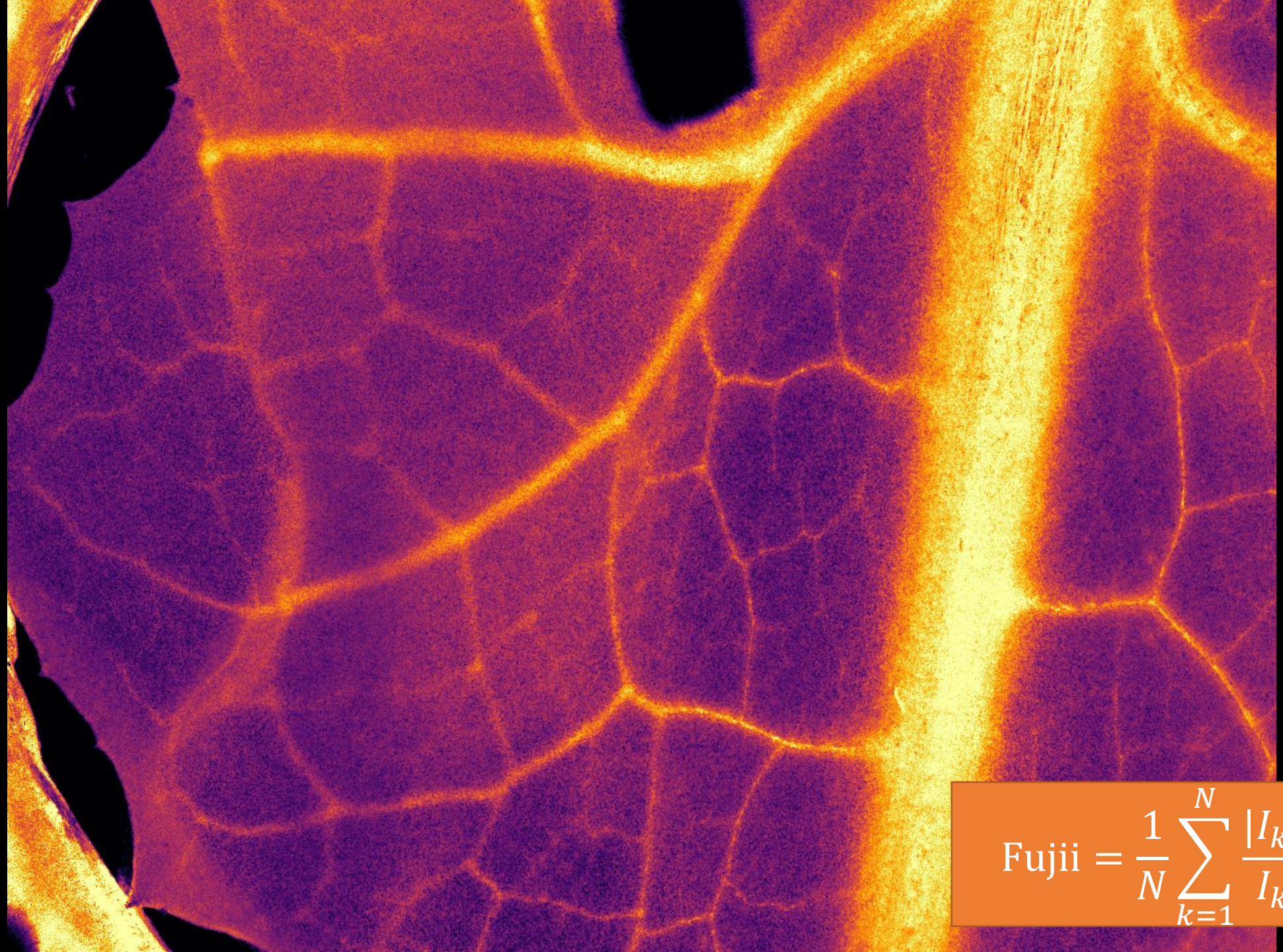


TD=5s

Total Duration TD







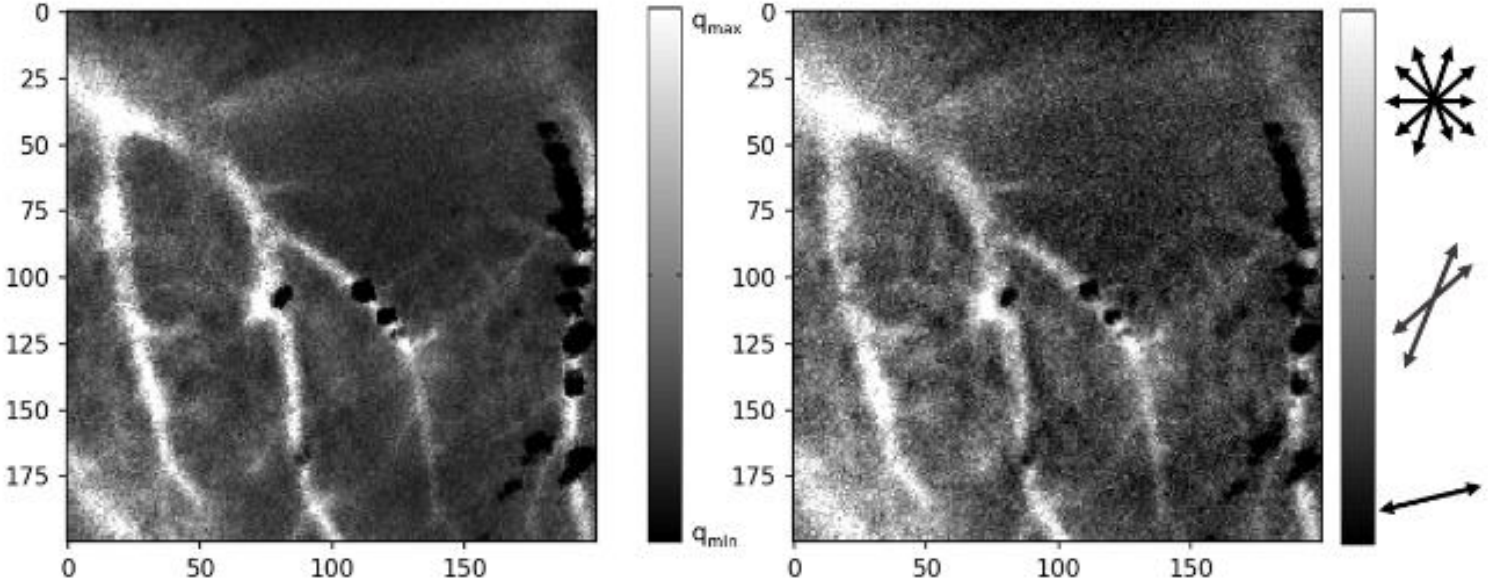
$$\text{Fujii} = \frac{1}{N}\sum_{k=1}^{N}\frac{|I_k - I_{k+1}|}{I_k + I_{k+1}}$$

How to understand better non erdodicity domain?

By controlled measurement (optical)

innovative optical setup for conducting polarized dynamic speckle measurements in either Stokes or Mueller polarimetric modes, with LPICM

By including polarimetric studies



speckle contrast

depolarization

Preprint - The speckle contrast extended to the polarimetric case: applications to radar and Laser images (E. Colin)

Submitted- ***Towards a Unified Formalism of Multivariate Coefficients of Variation*** *-- Application to the Analysis of Polarimetric Speckle Time Series (E. Colin, R. Ossikovski)*

Synthesis

From Micro to Macro: A Holistic View of Speckle Dynamics Across Optics and Radar

- **Diverse Applications**:

health, planetary environment, biology, materials, and flow in wind tunnels

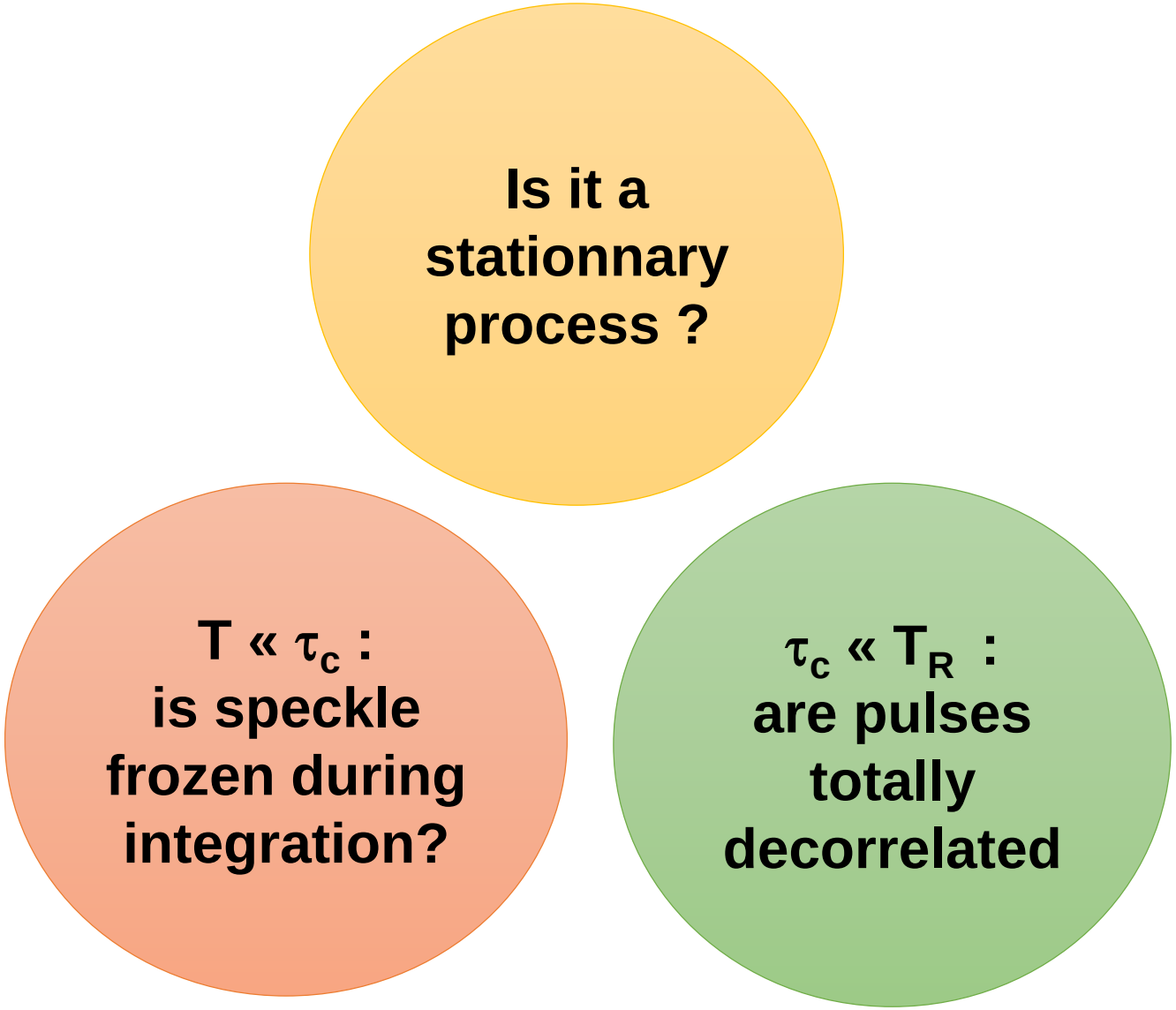
- **Extreme Spatial and Temporal Scales**:

Measurements spanning scales with ratios up to one million,

- **Diversity of Physical Hypotheses**:

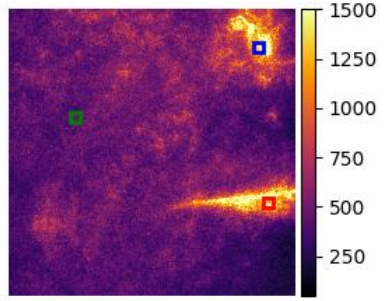
Identification and clarification of physical hypotheses that vary across application areas, crucial for accurate measurement interpretation.

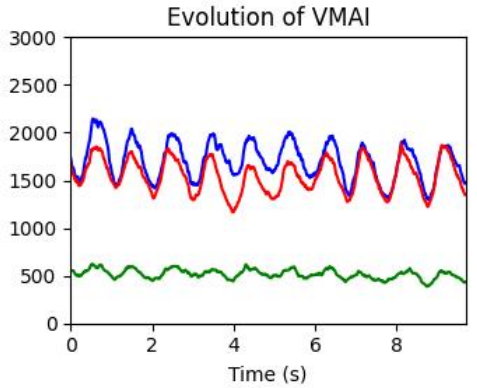
Identification and clarification of physical hypotheses



New domains to explore for new applications

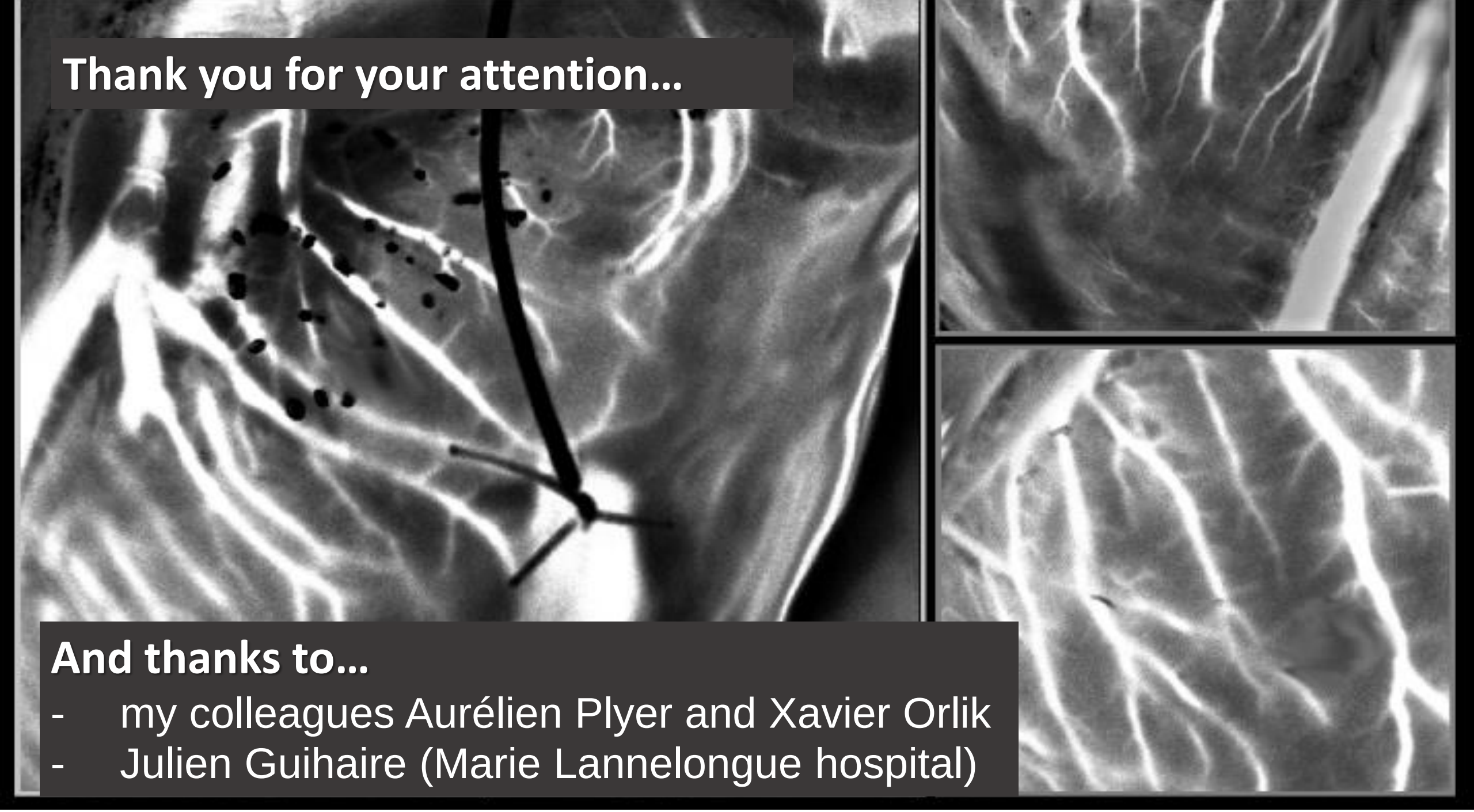
Is it a stationnary process ?





$T \ll \tau_c$: is speckle frozen during integration?

$\tau_c \ll T_R$: are pulses totally decorrelated



Thank you for your attention…

And thanks to…

- my colleagues Aurélien Plyer and Xavier Orlik
- Julien Guihaire (Marie Lannelongue hospital)

Publication International peer-reviewed journals

- *Plyer, A., Colin, E., Orlik, X., Akamkam, A., Guihaire, X - Imaging the vasculature of a beating heart by dynamic speckle: the challenge of a quasi-periodic motion, Journal of biomedical Optics, under review, 2022 October*
- *Colin, E., Plyer, A., Golzio, M., Meyer, N., Favre, G., & Orlik, X. (2022). Imaging of the skin microvascularization using spatially depolarized dynamic speckle. Journal of Biomedical Optics, 27(4), 046003.*
- *Erdmann, S., Weissgerber, F., Koeniguer, É. C., & Orlik, X. (2022). Dynamic speckle imaging of human skin vasculature with a high-speed camera. Optics Express, 30(7), 11923-11943.*
- *Preprints, submitted under review*

Workshop

- **JIONC 2023 -** Imagerie de la **circulation** de **sève** d'une feuille par **speckle dynamique**
- **JIONC 2022 -** Le vasculoscope : **speckle dynamique polarisé** pour l'imagerie d'un indice d'activité microvasculaire volumique
- **NIH / IRSN Meeting 2022** – The vasculoscope : Depolarized dynamic speckle
- **GSO17th** - The transcutaneous Microvasculoscope: Observation of the tumoral microvasculature
- **EBTT 2021** - New non-invasive and real-time imaging modality to evaluate the effects of electrochemotherapyon melanoma

National Journals

- **Revue des Mines, 2023**
- **Aerospatium, 2023**

Awards

Nomination Prix Jerphagnon 2023, Société Française d'Optique
Jury présidé par Alain Aspect, Prix Nobel 2022

Video ressources

TED-X Paris Saclay 2022
Cohérence de la lumière, de notre planète à la vascularisation.
https://youtu.be/6_rR3DDTGjU

Prix Jean Jerphagnon - Nominée 2023 - Elise COLIN
https://youtu.be/y9UfQzymESI?si=M8F9x-1hMF5fxF0x

ITAE au forum des Innovations Paris Saclay 2022
https://youtube.com/clip/UgkxIsJEZredRNzDBff23fFtJecd2Eto5X18?si=lXROH0vIBTfw4dM2