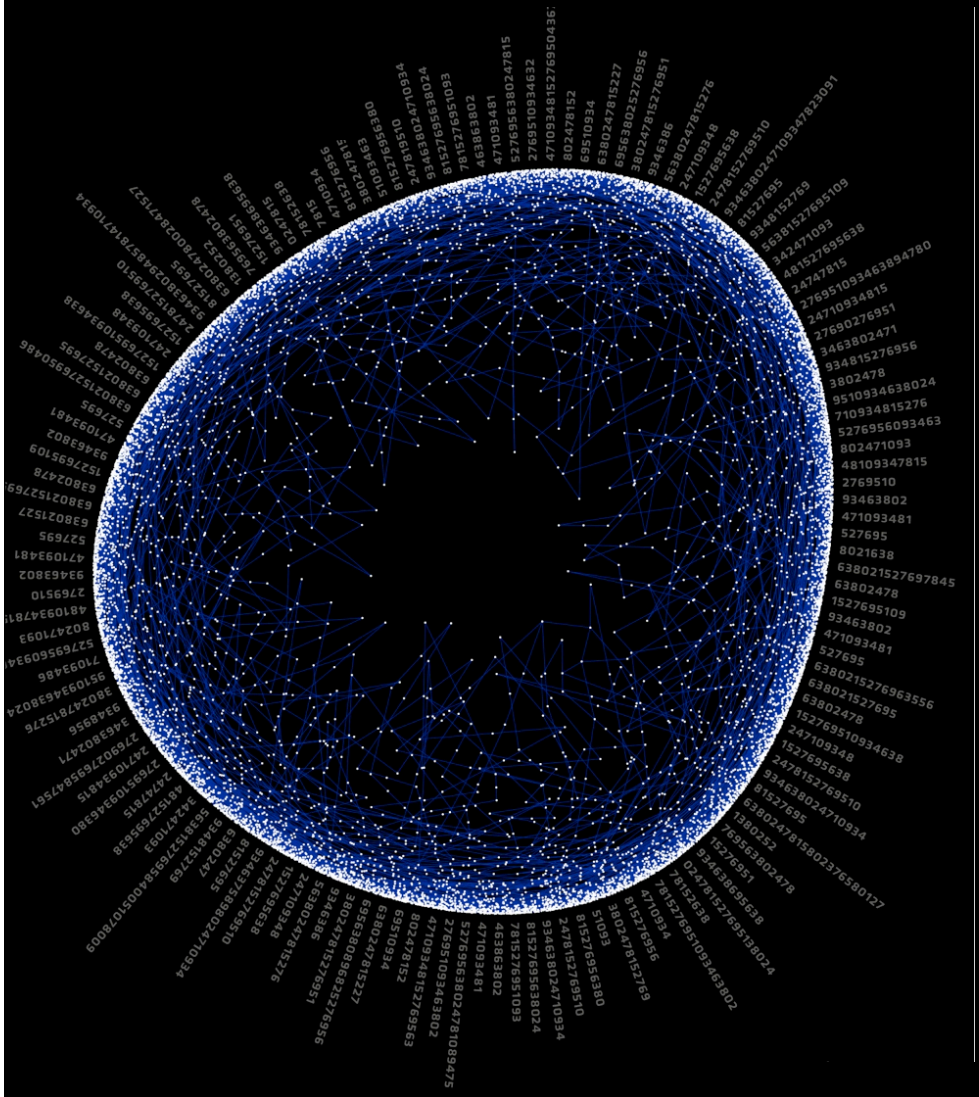
M4TEMOZIOA

Matematikaren hitzordua | Cita con las Matemáticas



Mathematical modeling: from the Galileo legacy to the environment, medicine and technology

Alfio Quarteroni

EPFL, Lausanne (Switzerland)
MATHICSE Mathematics Institute of Computational Science and Engineering

POLITECNICO di MILANO (Italy)
MOX Modellistica e Calcolo Scientifico

21/02/2012 | 19:00

BIZKAIA ARETOA | PARANINFO UPV/EHU

POLITECNICO DI MILANO

MOX

CMCS

MATHICSE

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Medicine,

Technology,

Environment

Why Math Matters?

Math is Pervasive

Two Instances fromm our daily life..

- Fast internet search thanks to efficient matrix computation
- Image transmission by fast and accurate compression algorithms


Searching
on the web

230.000.000

Two hundred thirty millions

Websites

1.000.000.000.000

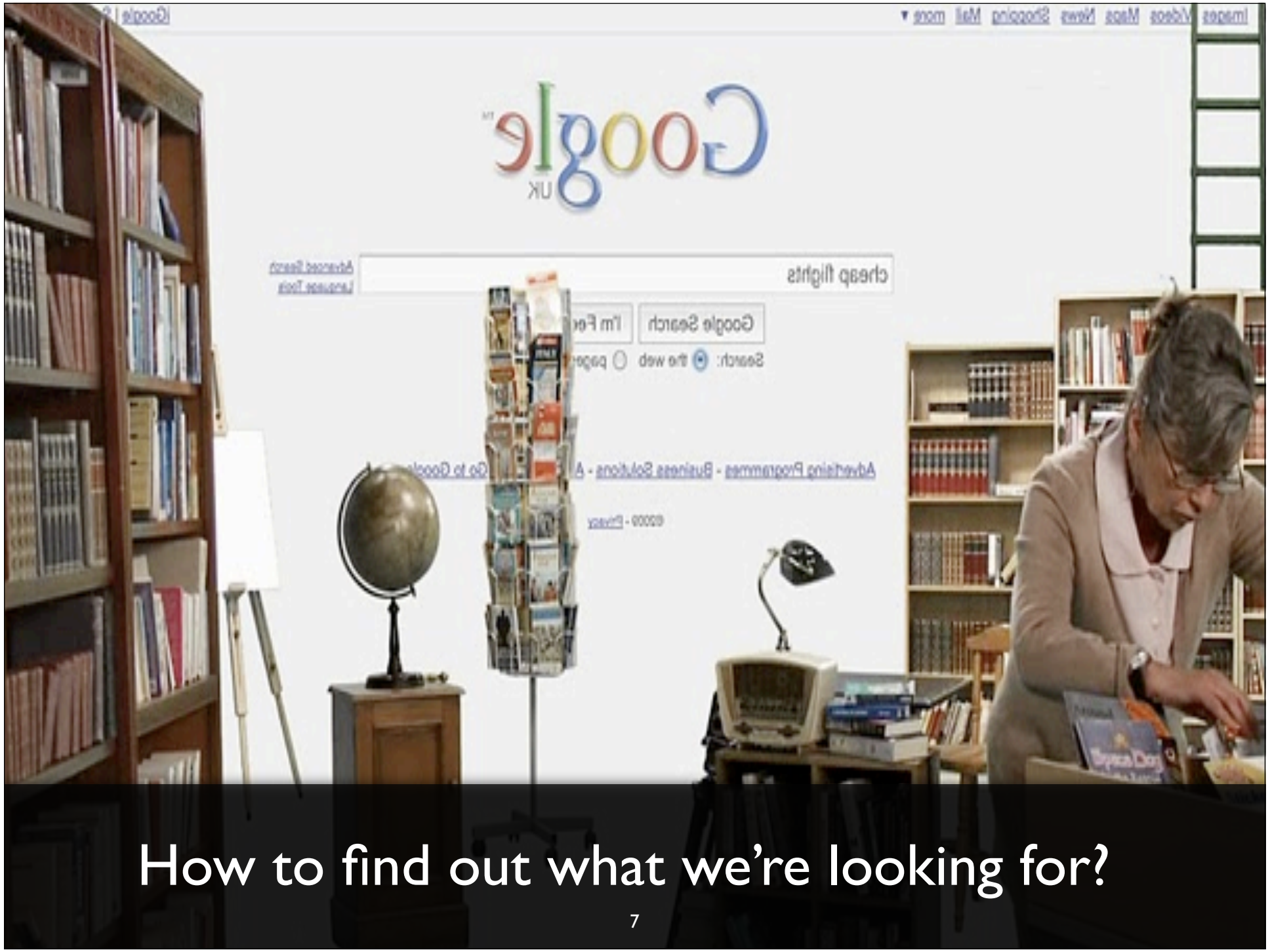
A thousand billions

Webpages

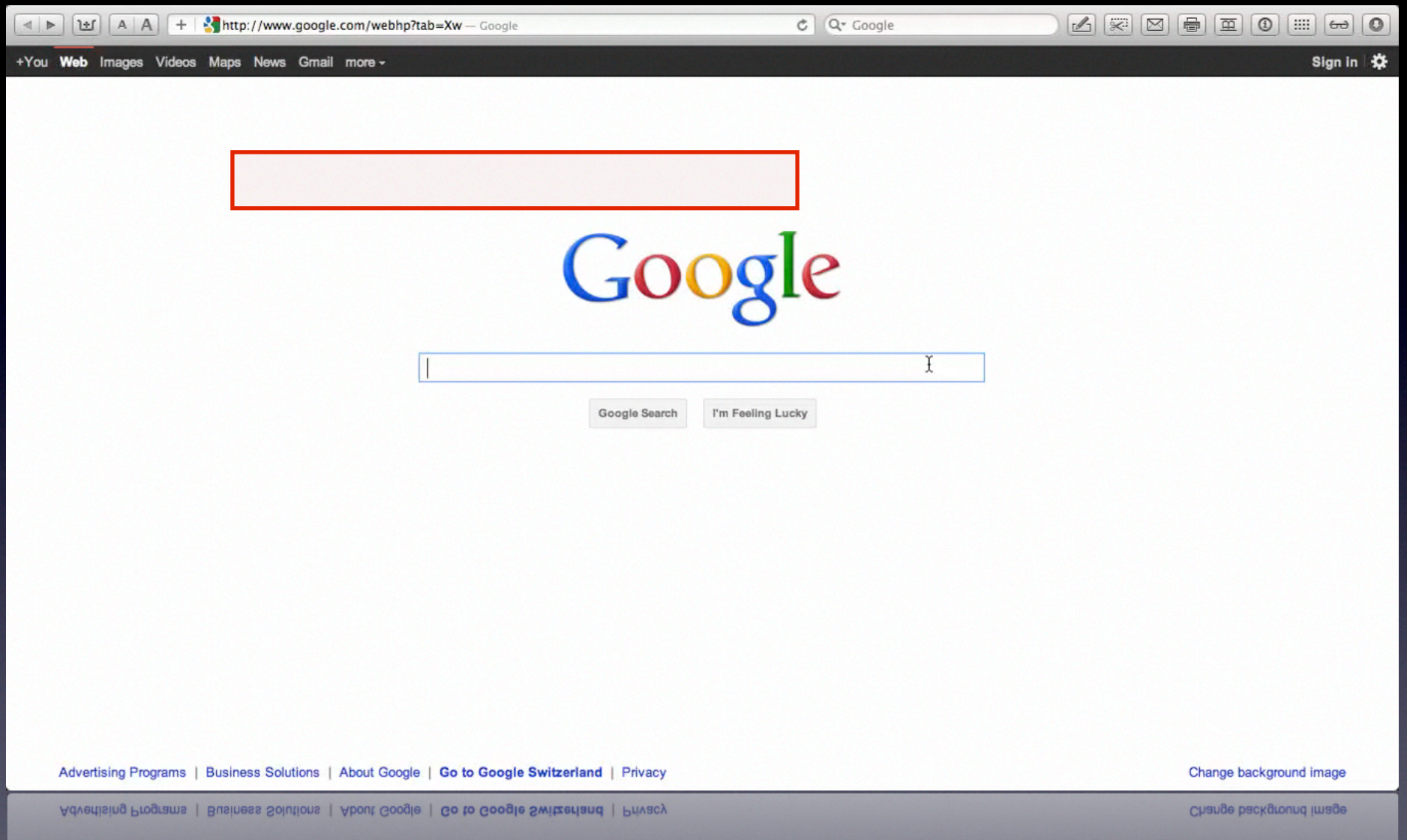
1.500.000.000

A billion and a half

Users


How to find out what we're looking for?

Search Engines



Googling for Isaac Newton

Among

1.000.000.000.000

Thousand Billion

Webpages

Google selects

10.000.000

Ten Million

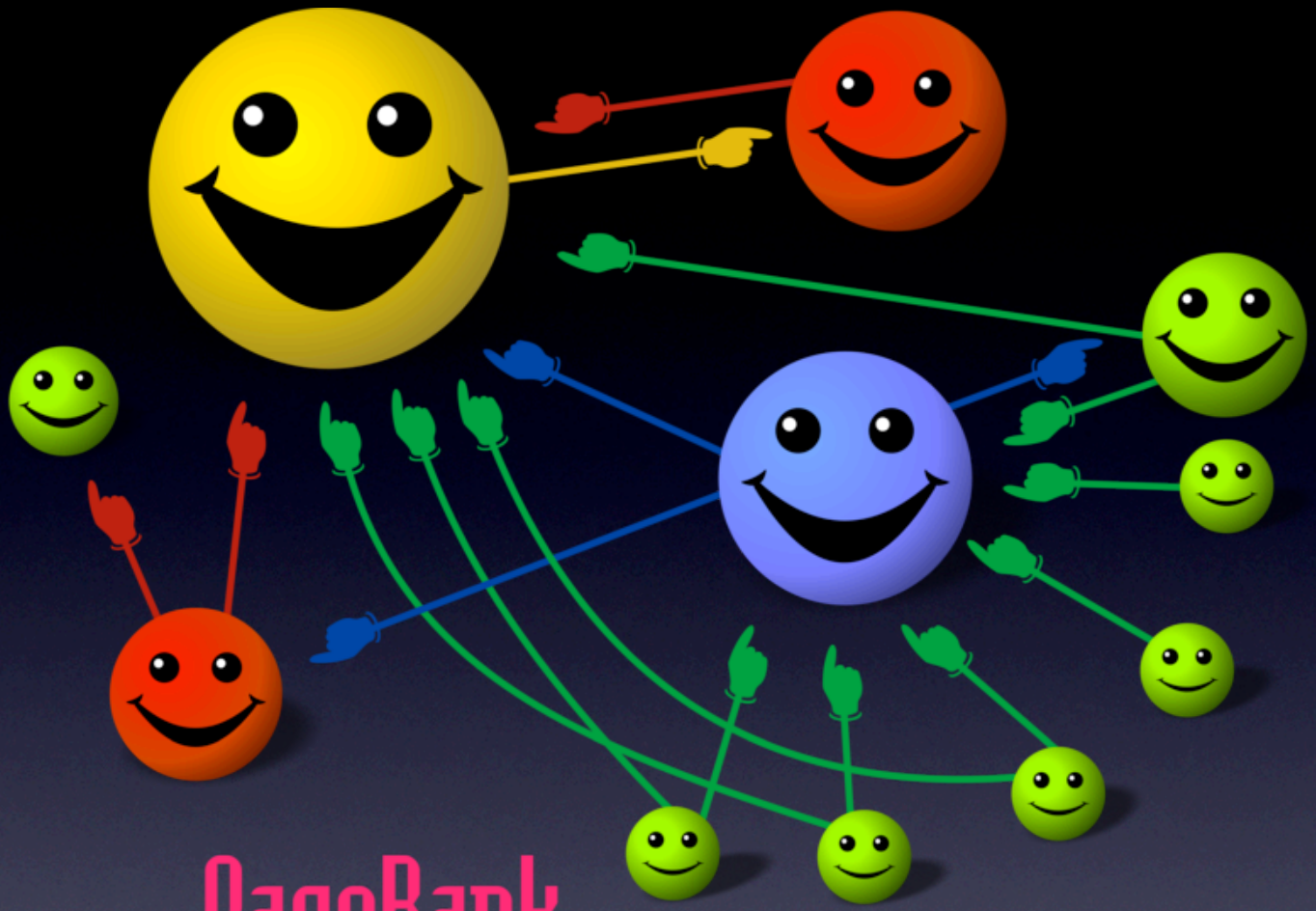
for us

in just

14

Fourteen

centiseconds



PageRank

$$PR(A) = \frac{1-d}{N} + d\left(\frac{PR(B)}{L(B)} + \frac{PR(C)}{L(C)} + \frac{PR(D)}{L(D)} + \cdots\right).$$

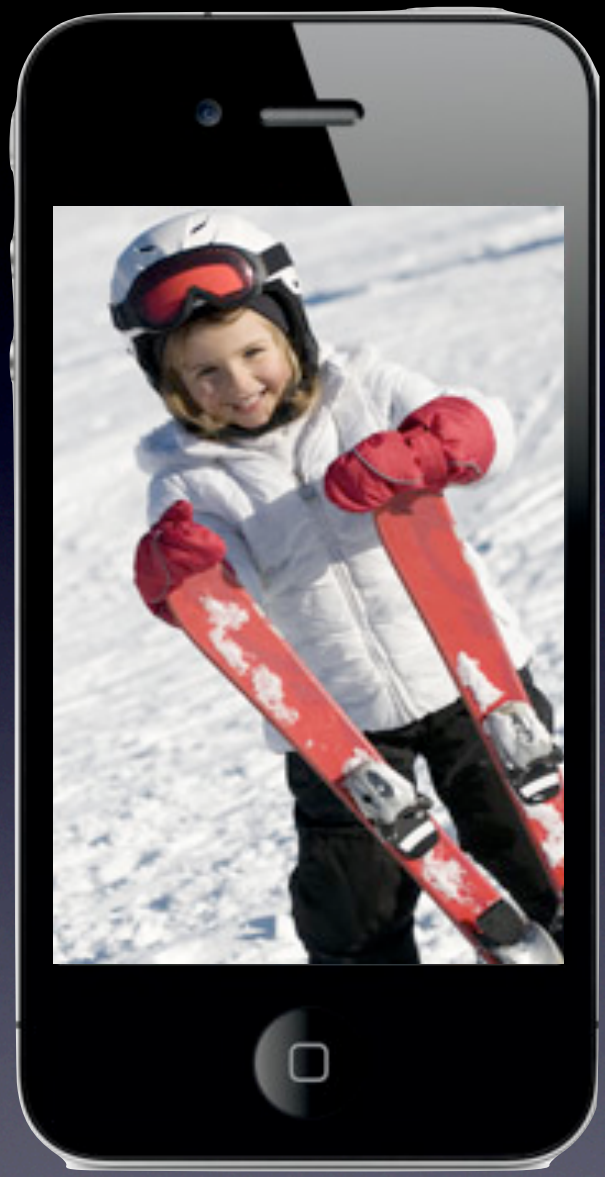
Google

is so fast thanks to

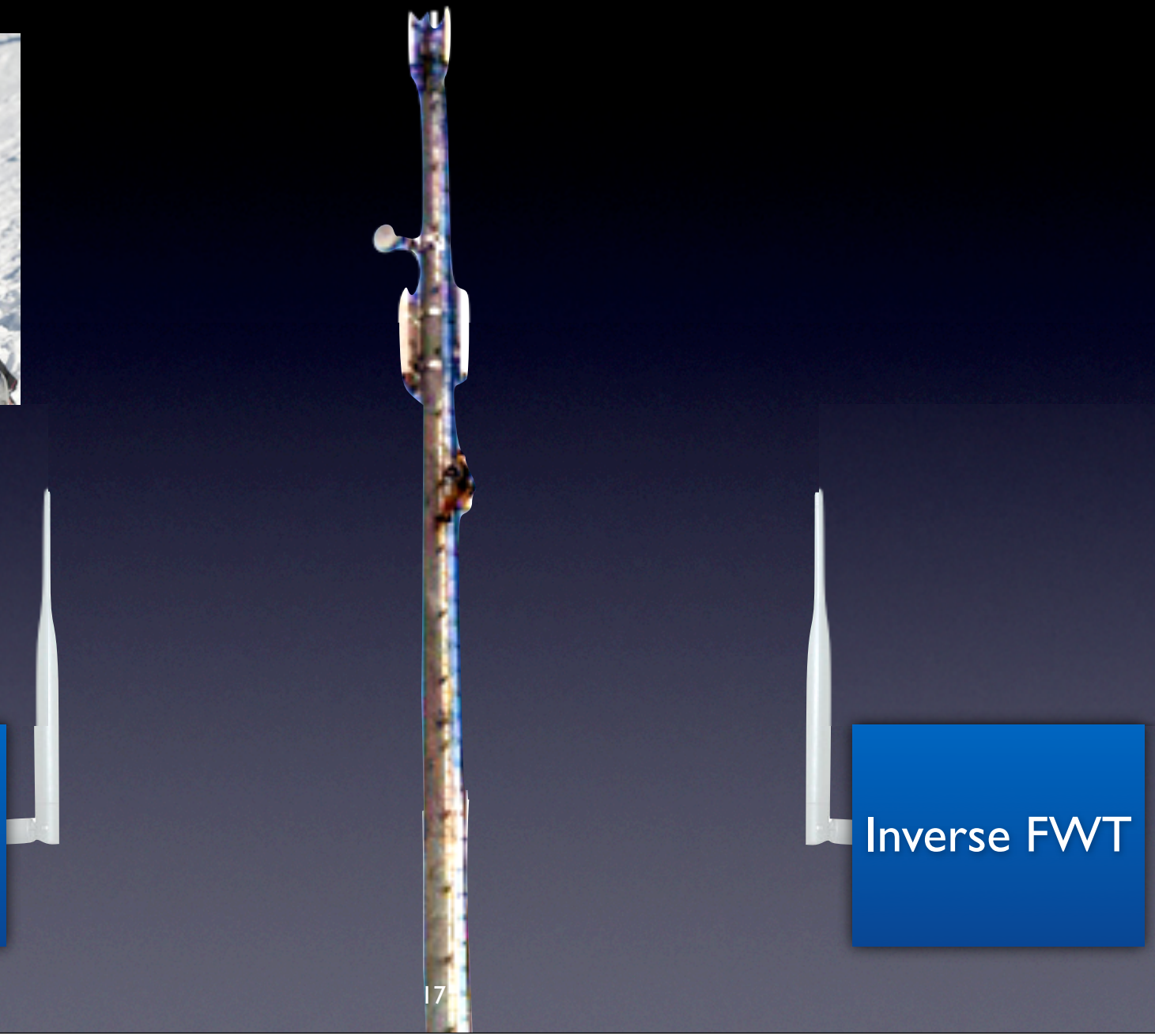
Mathematics!


Sending pictures
from our mobile phone

What you see..

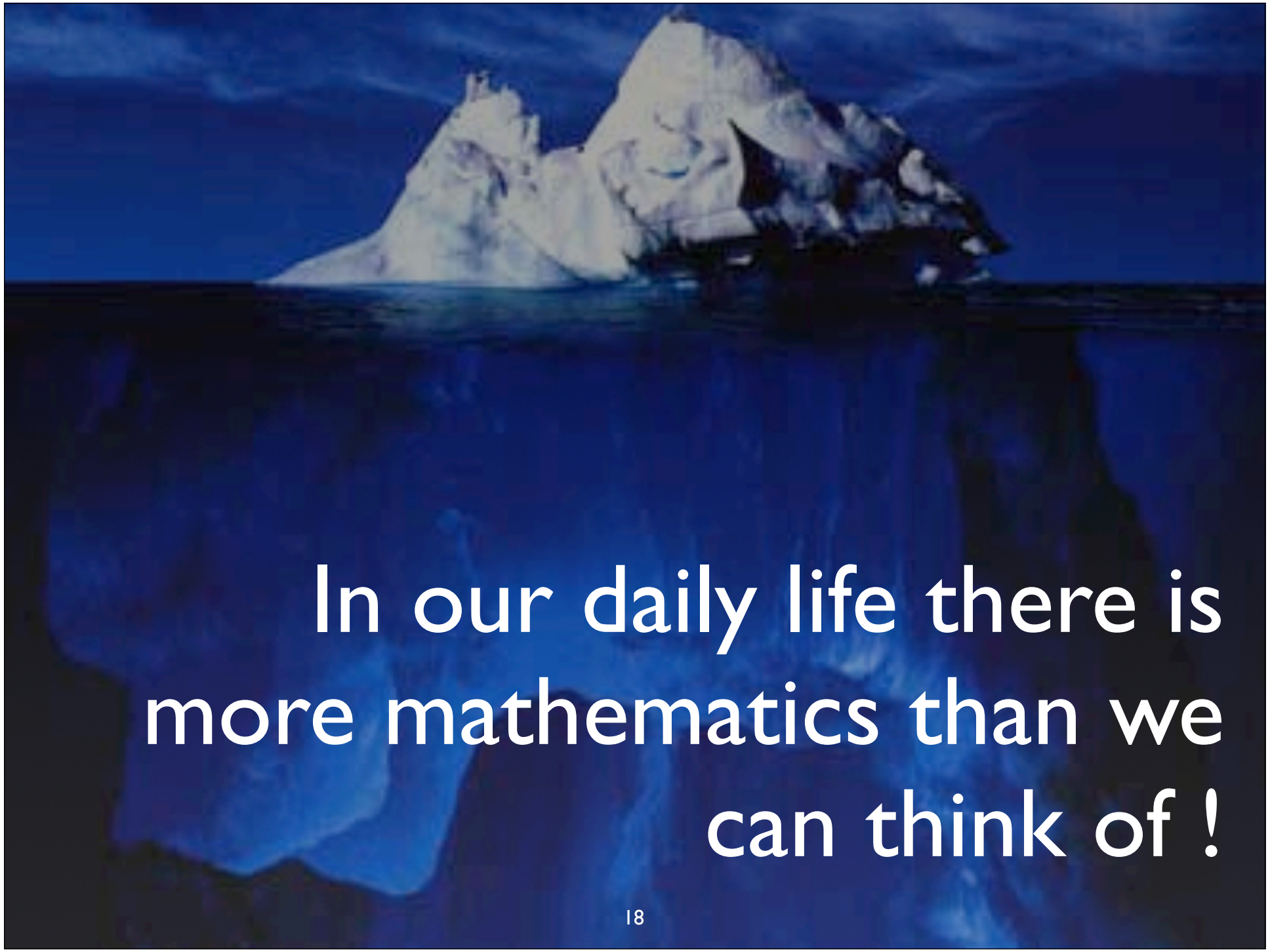


... and what does really happen

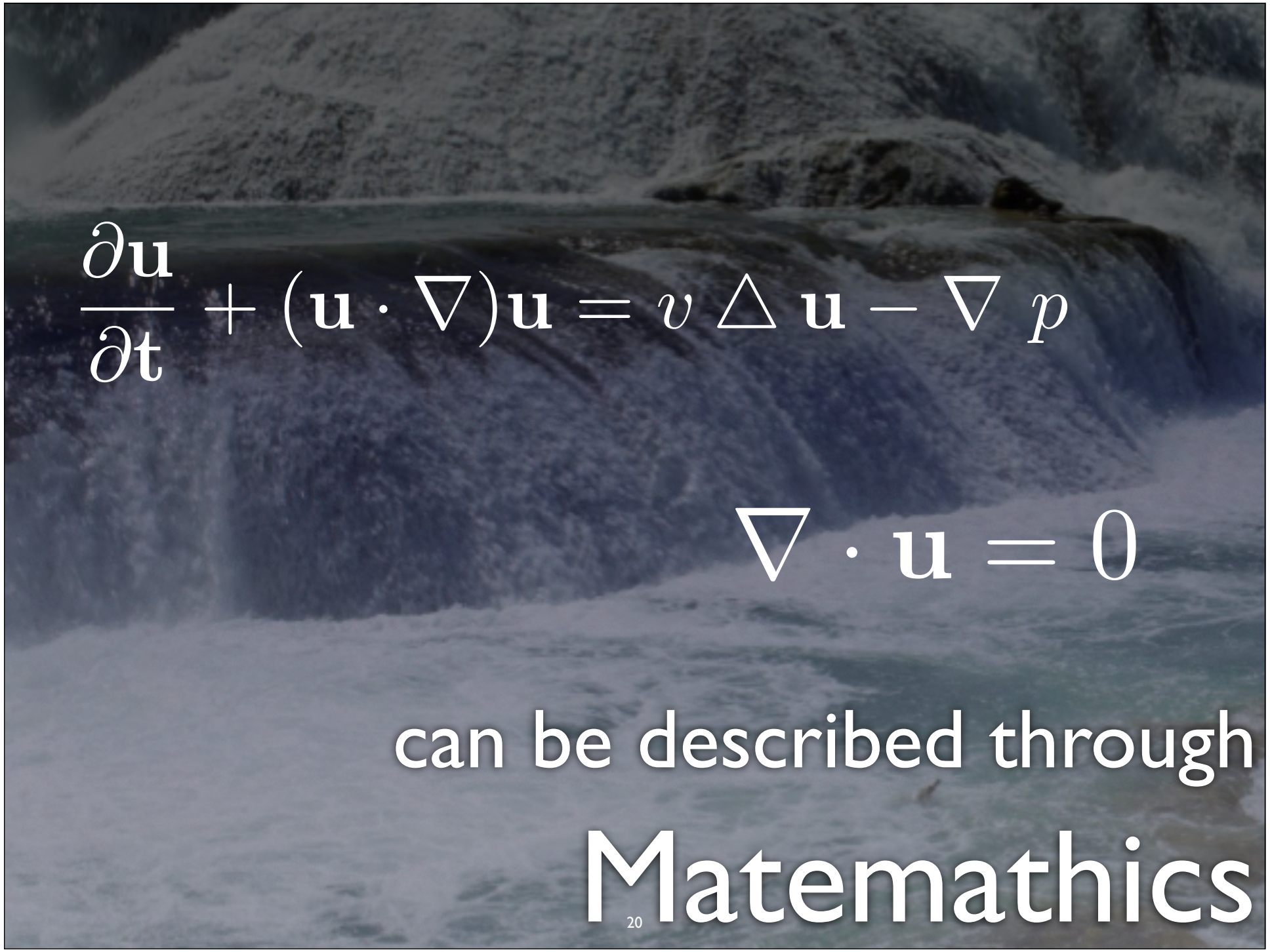


FWT
Fast Wavelet Transform

Inverse FWT


In our daily life there is
more mathematics than we
can think of !


water

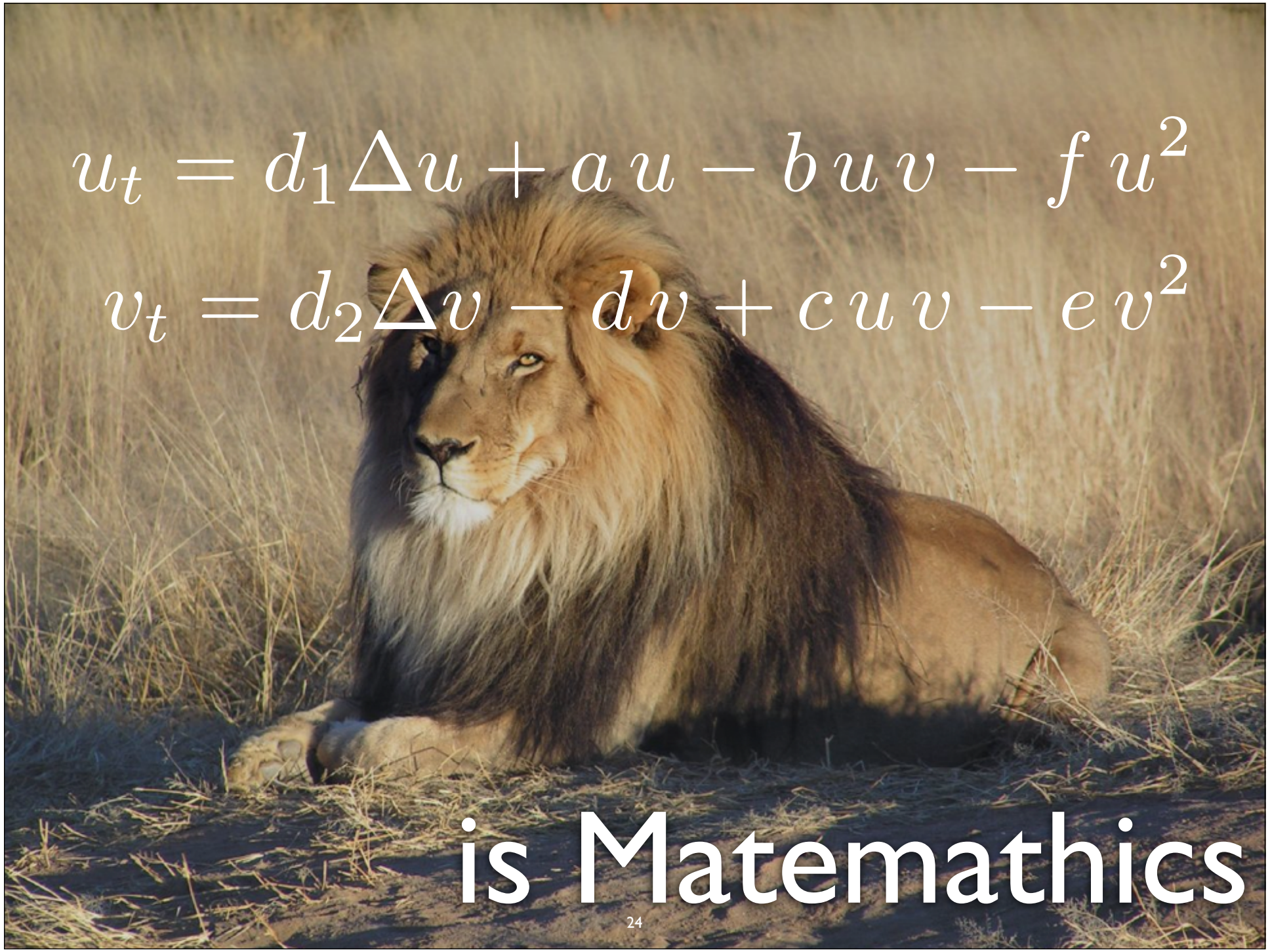

$\frac{\partial \mathbf{u}}{\partial \mathbf{t}} + (\mathbf{u} \cdot \nabla)\mathbf{u} = v \triangle \mathbf{u} - \nabla\, p$
$\nabla \cdot \mathbf{u} = 0$
can be described through
Matematics


sea waves

are Matemathics

$$u_t + \left(\frac{u^2}{2}\right)_x + \varepsilon^2 u_{xxx} = 0$$

predator-prey competition


$u_t = d_1 \Delta u + a\,u - b\,u\,v - f\,u^2$
$v_t = d_2 \Delta v - d\,v + c\,u\,v - e\,v^2$
is Matemathics


the stripes of
Zebras


the appearence of
Butterflyfish

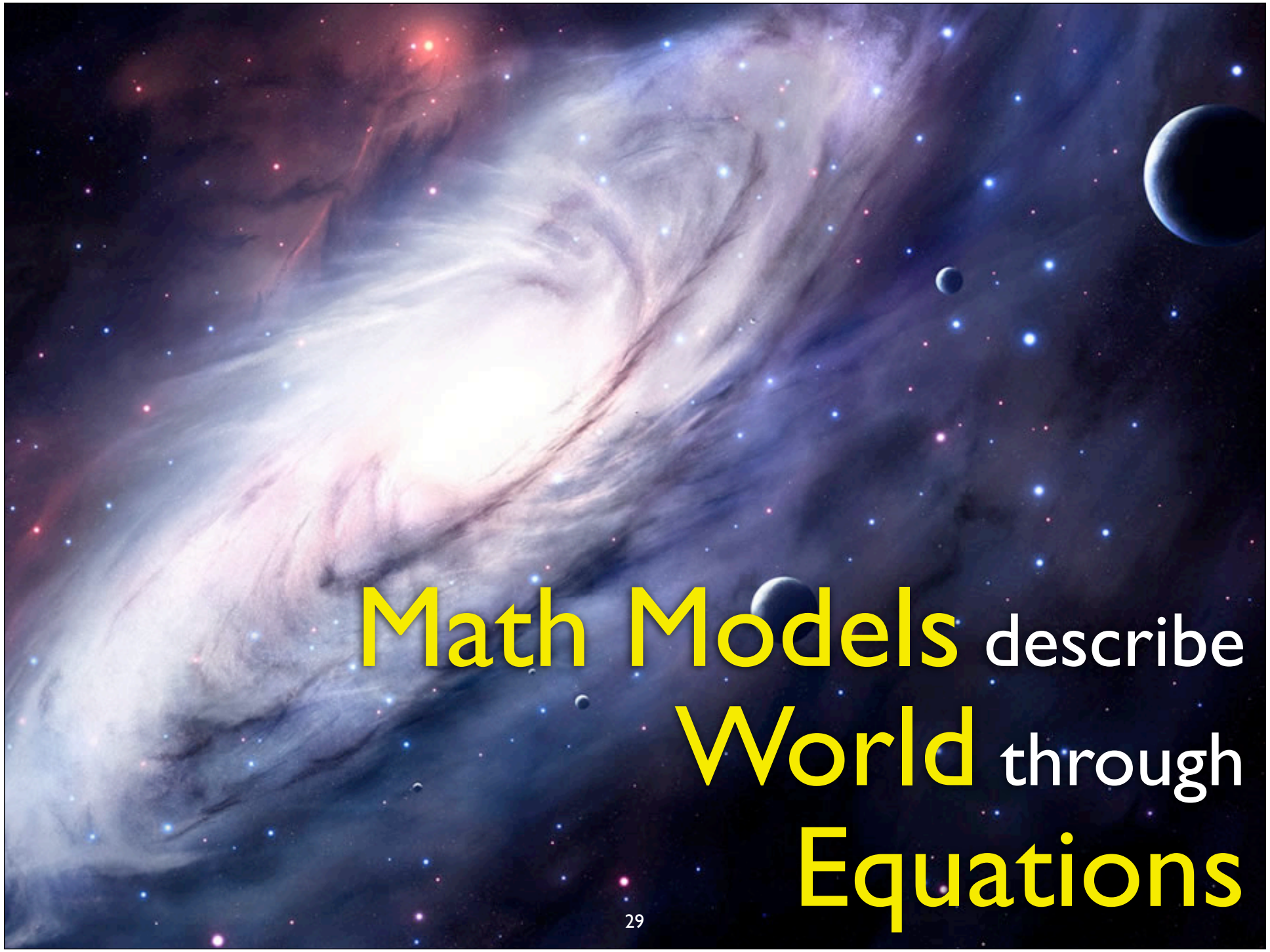
all that is Matemathics

$$u_t = \Delta u + \gamma f(u, v)$$

$$v_t = d\Delta v + \gamma g(u, v)$$

Key is

MATHEMATICAL MODELING


Math Models describe
World through
Equations


The real world
THE
MODEL

Galileo Galilei, 1564 - 1642

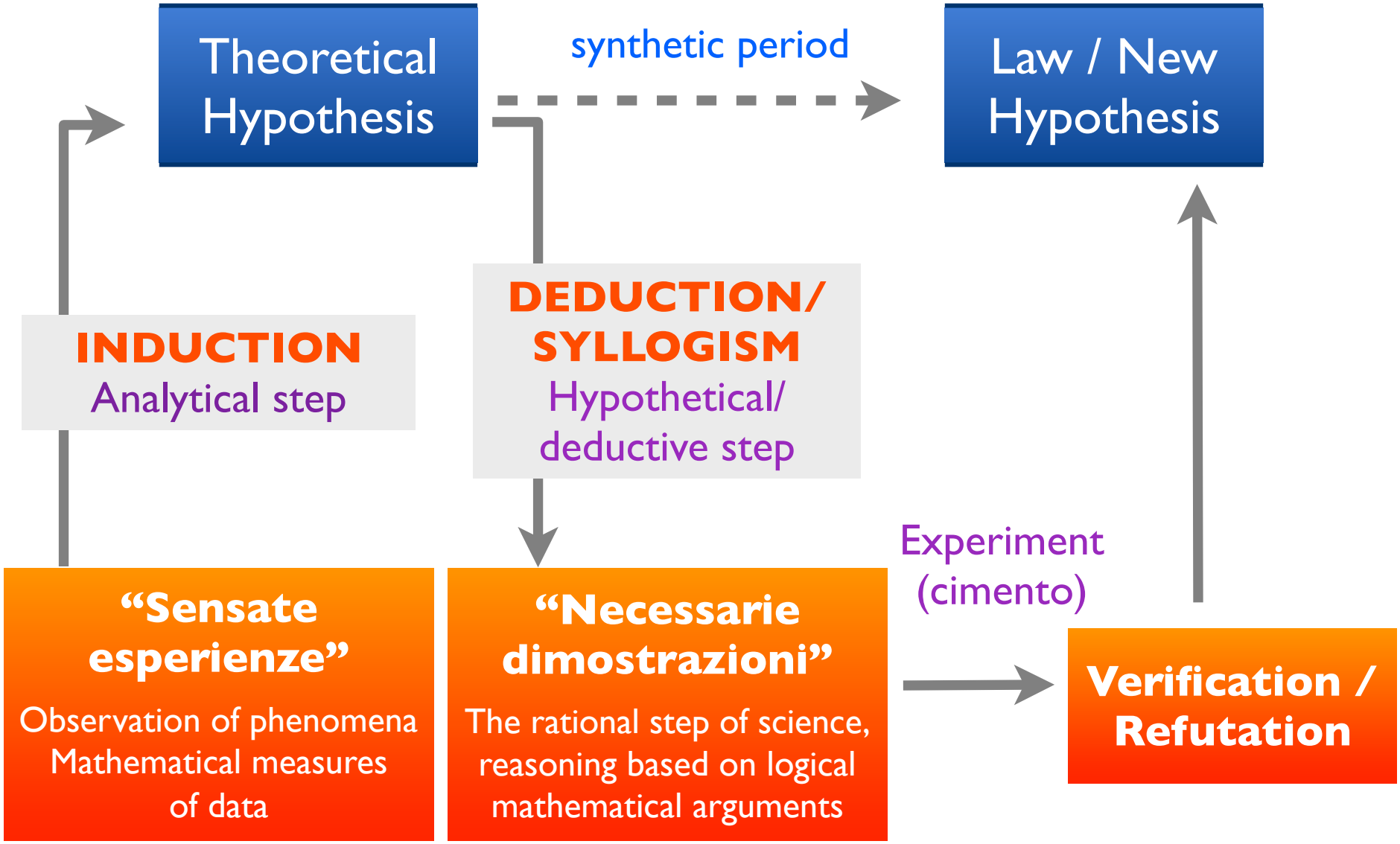
The Book of Nature (Il Saggiatore, 1623)

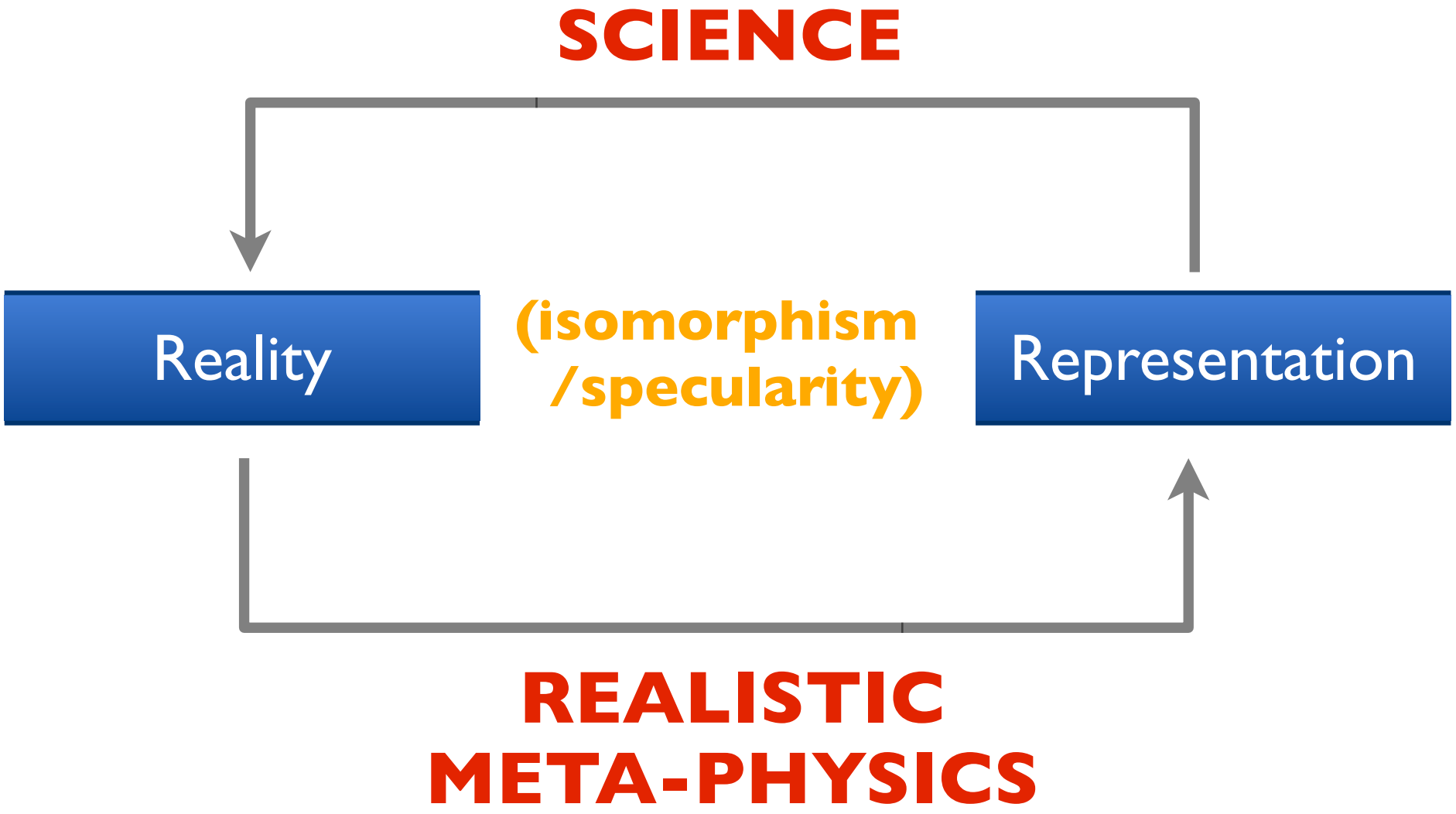
In 1623 Galileo crafted a famous metaphor (which he used to defend the work of scientists from religious authorities):

Nature - he wrote - *is a book written in*
"the language of mathematics".
If we cannot understand that language,
we will be doomed to wander about
as if "in a dark labyrinth".

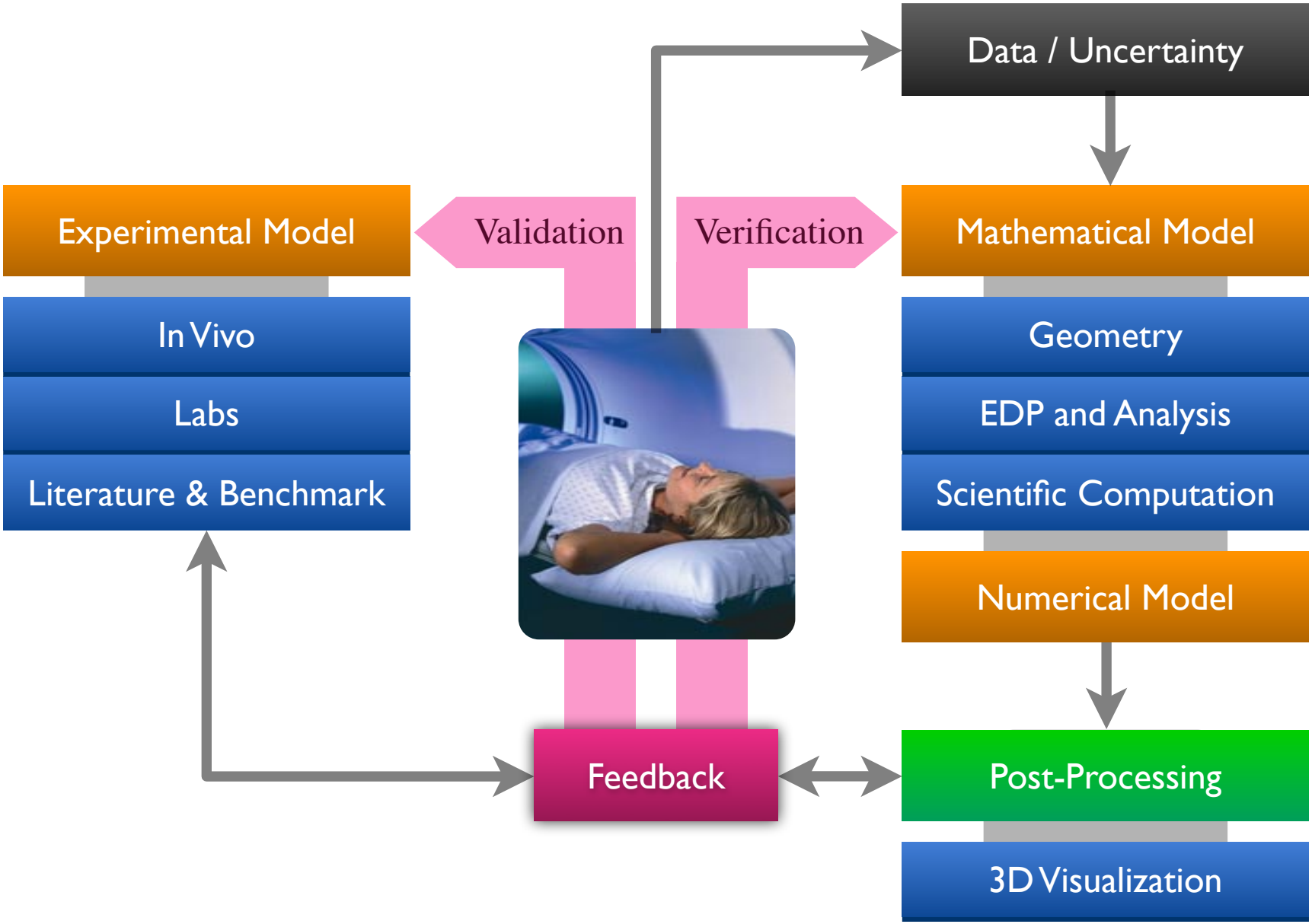
It captures our sense that nature's truths are somehow imposed on us – that they are already imprinted in the world – and underlines the key role played by mathematics in expressing those truths.

Towards Mathematical Modeling: the Galilean Method

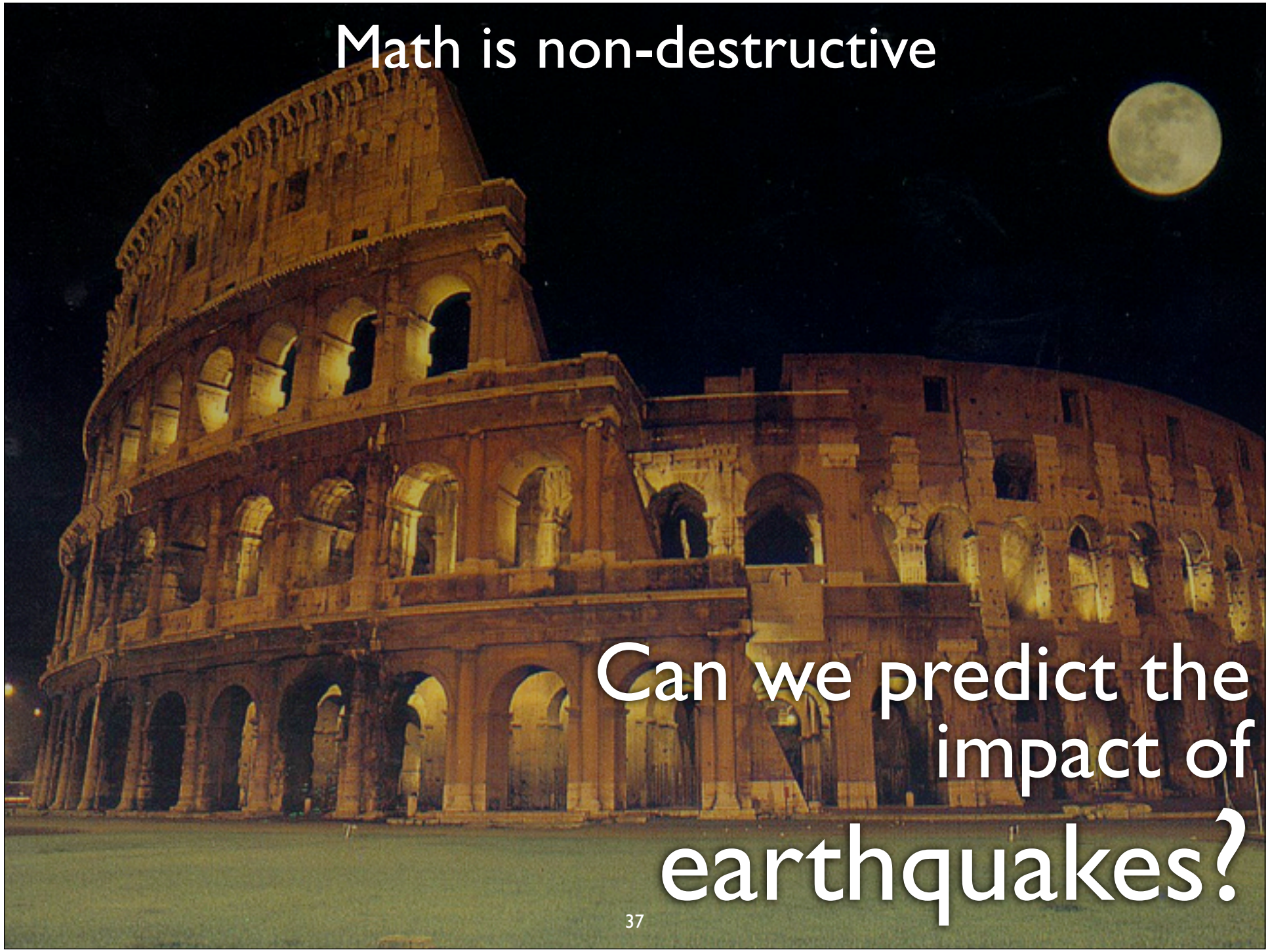


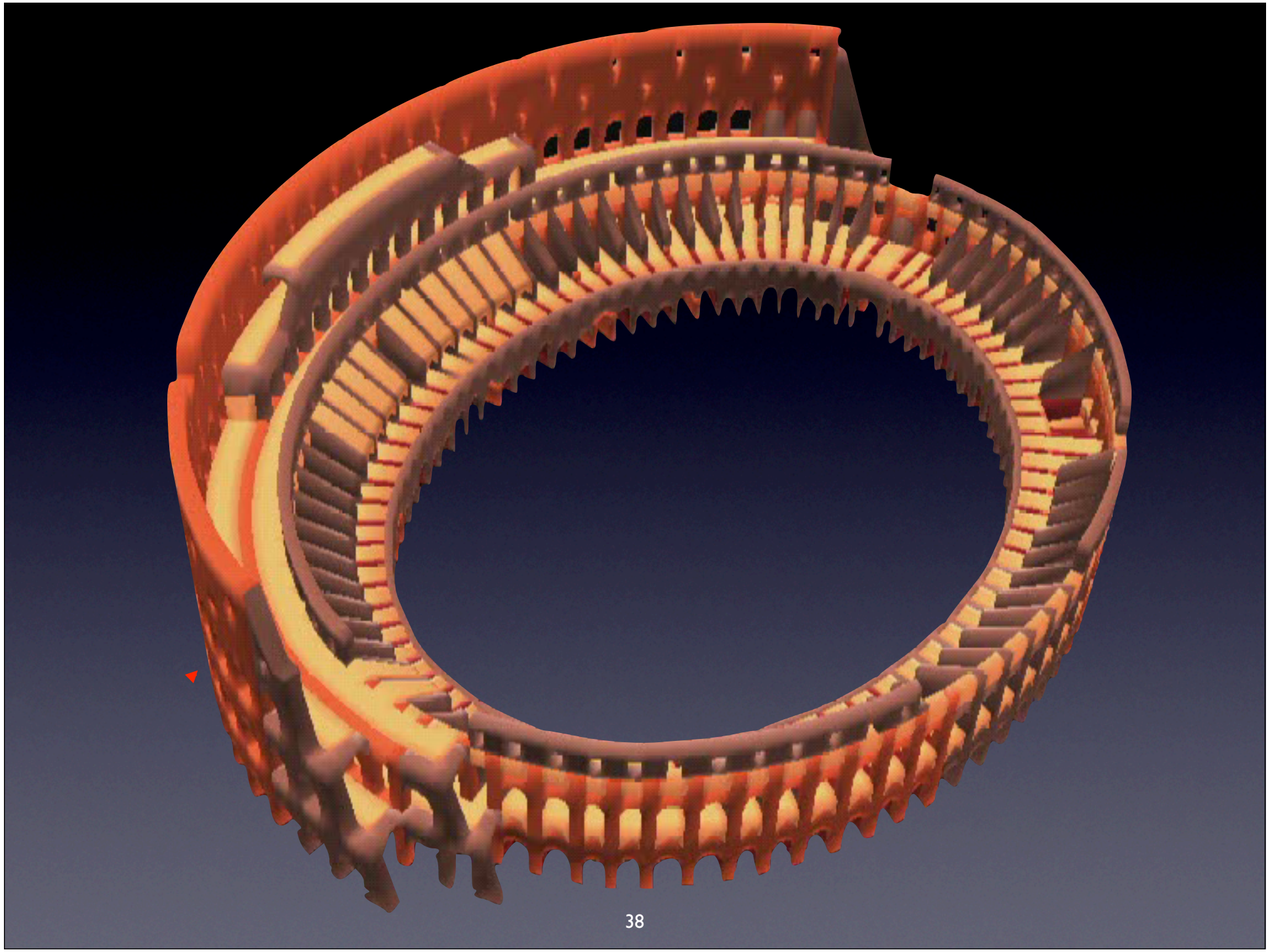

SCIENCE
Reality
(isomorphism
/specularity)
Representation
REALISTIC
META-PHYSICS

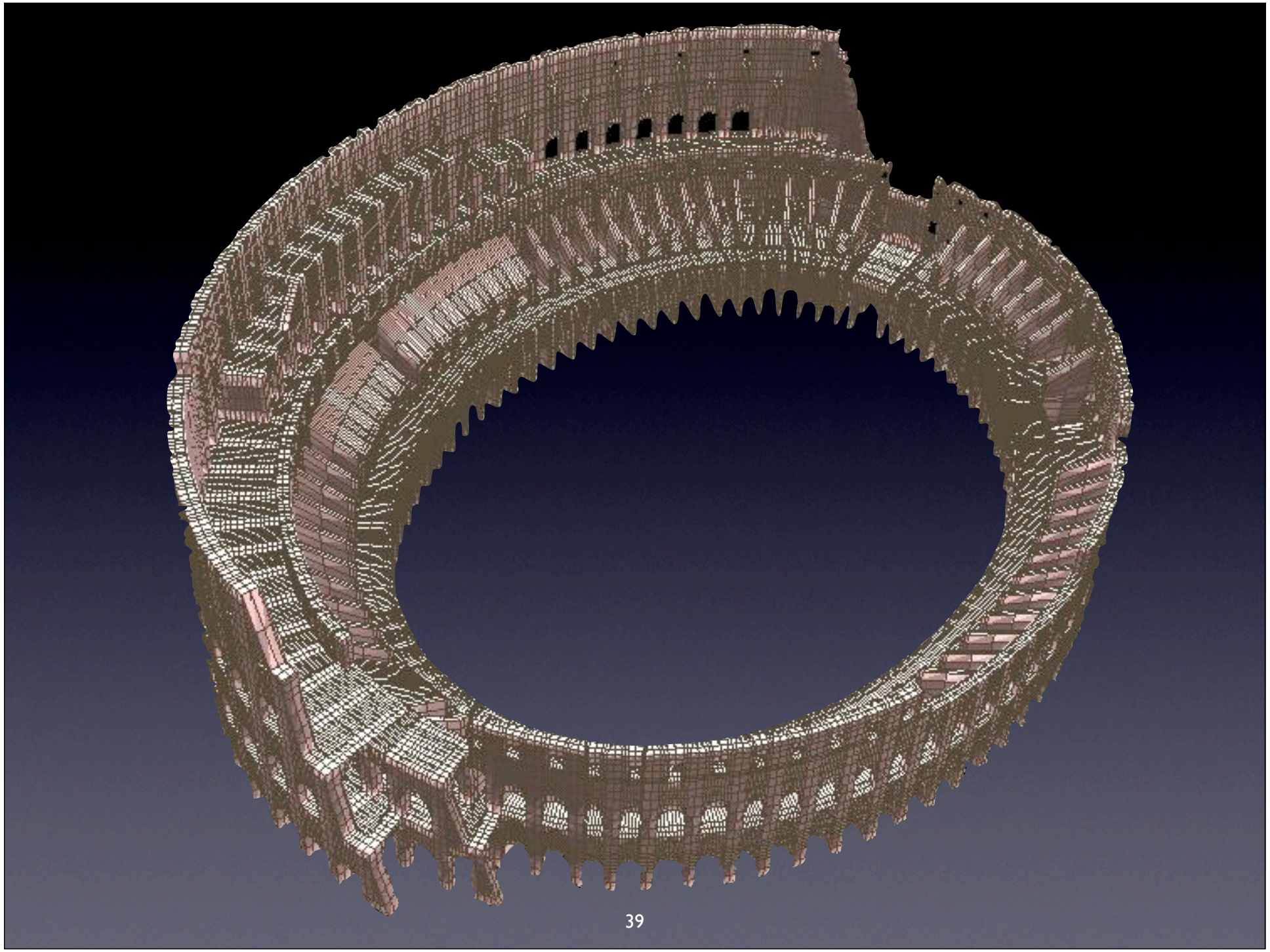
Mathematical Modeling and Simulation: an Outlook

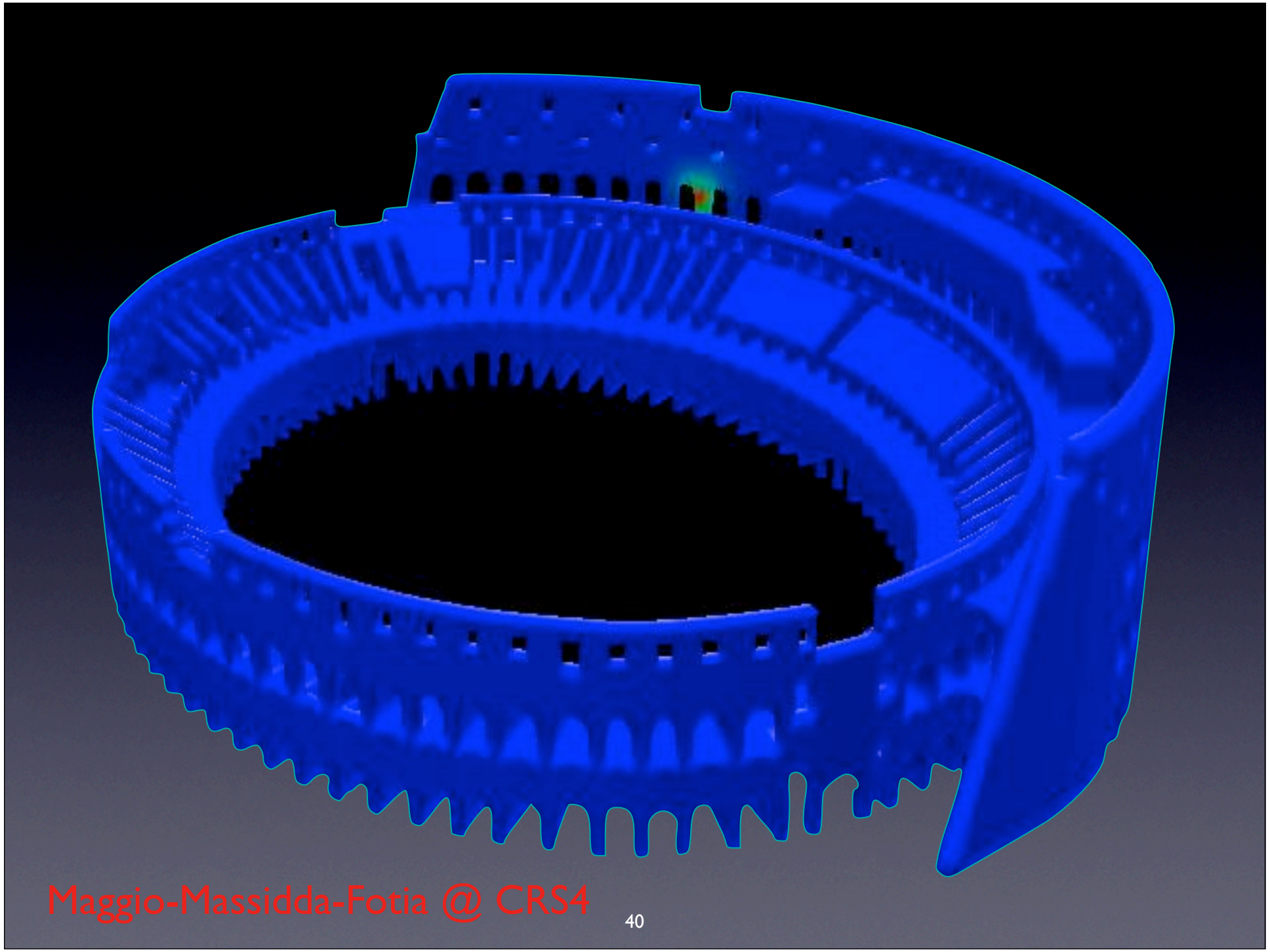


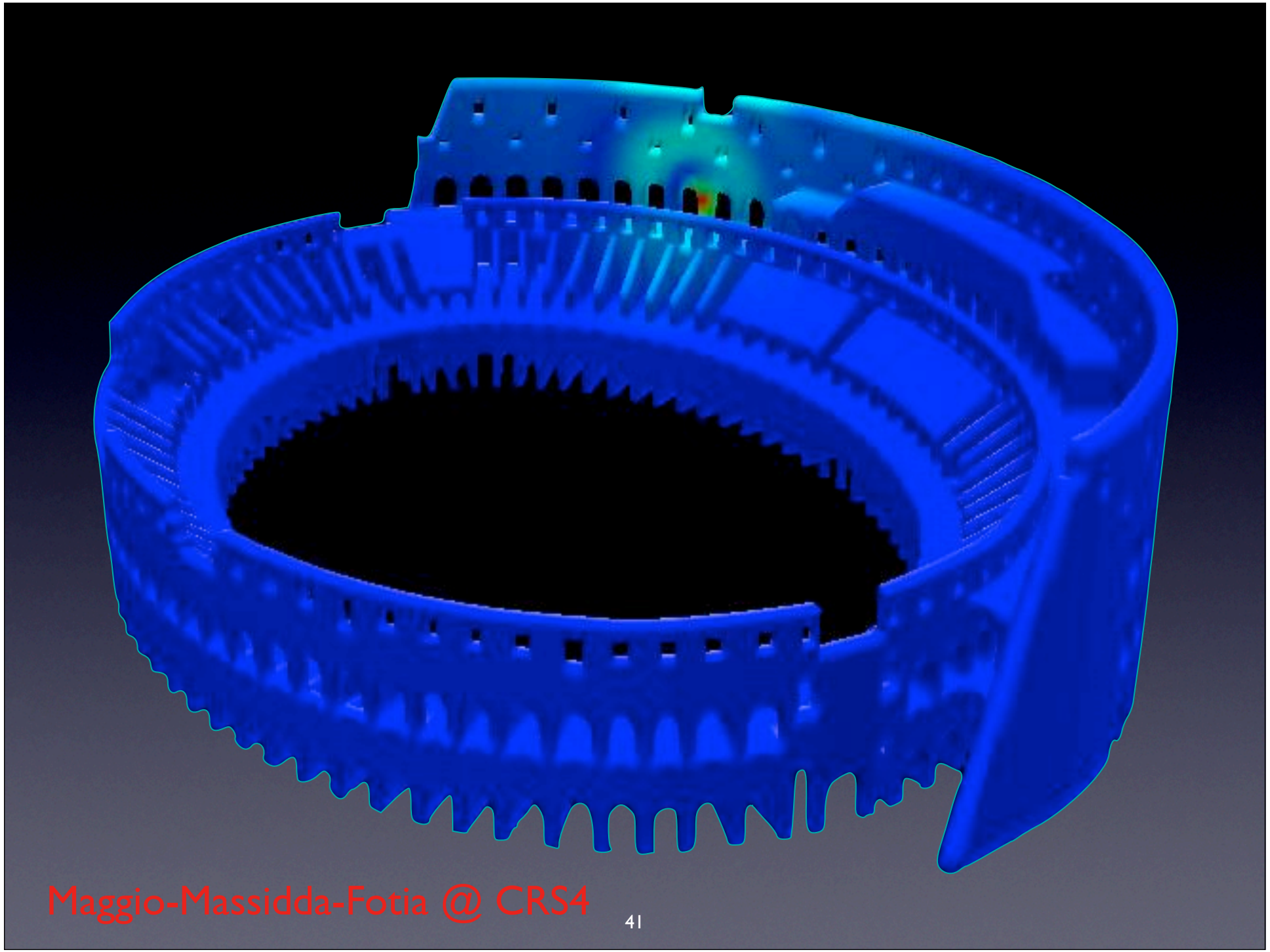
Mathematics
is our
Immaterial Lab

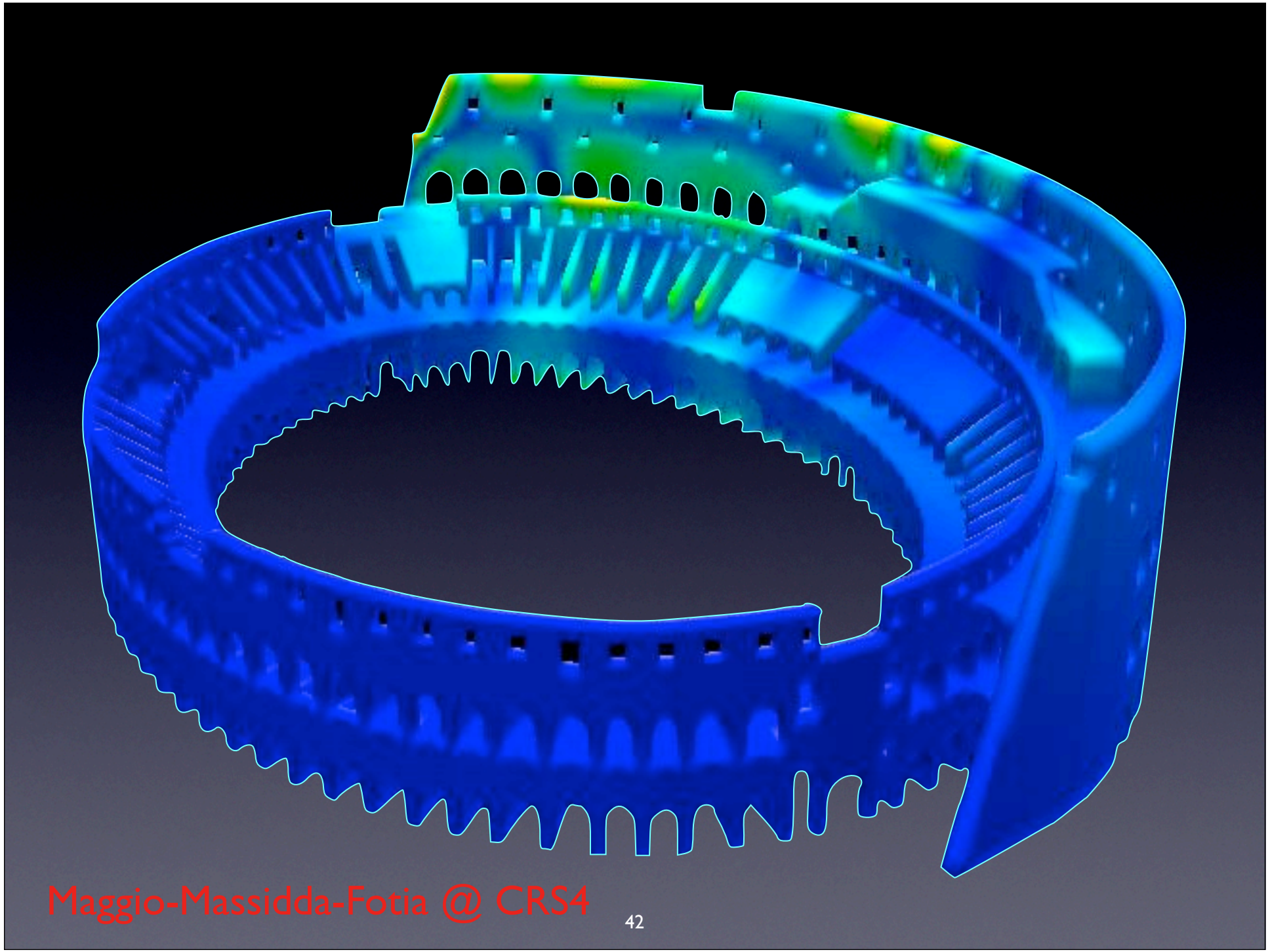

Math is non-destructive
Can we predict the impact of earthquakes?





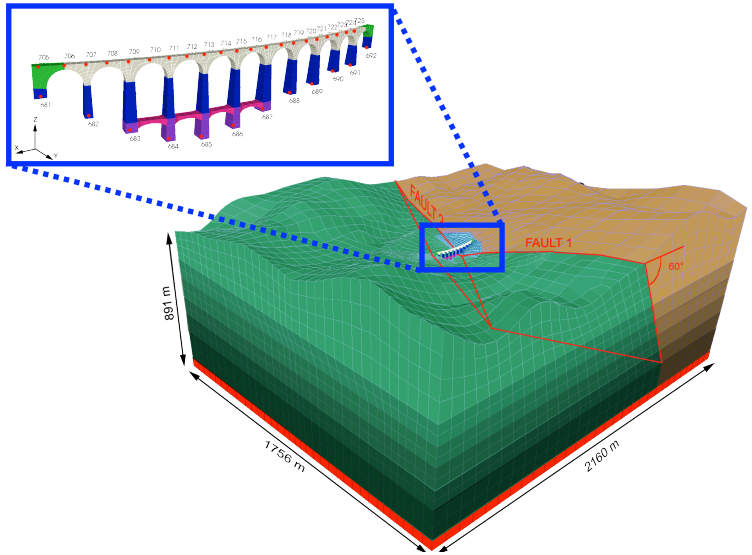

Maggio-Massidda-Fotia @ CRS4


Maggio-Massidda-Fotia @ CRS4

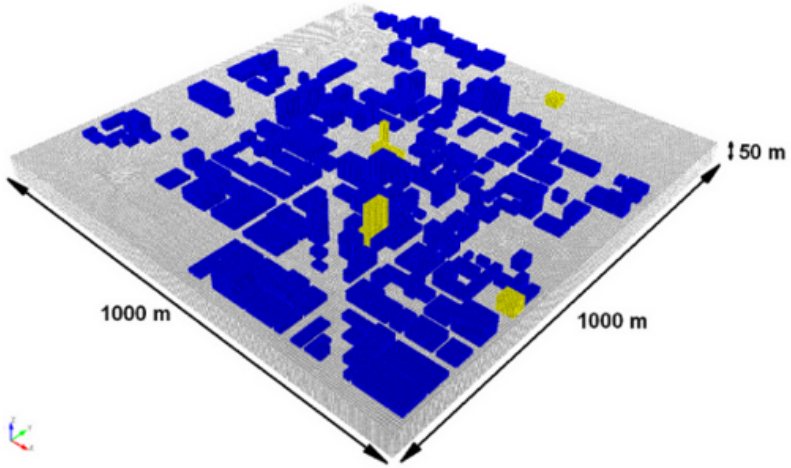

Maggio-Massidda-Fotia @ CRS4

Seismic Waves Simulation
by high order methods

Seismic response of the
Acquasanta Viaduct
(Liguria - Italy)

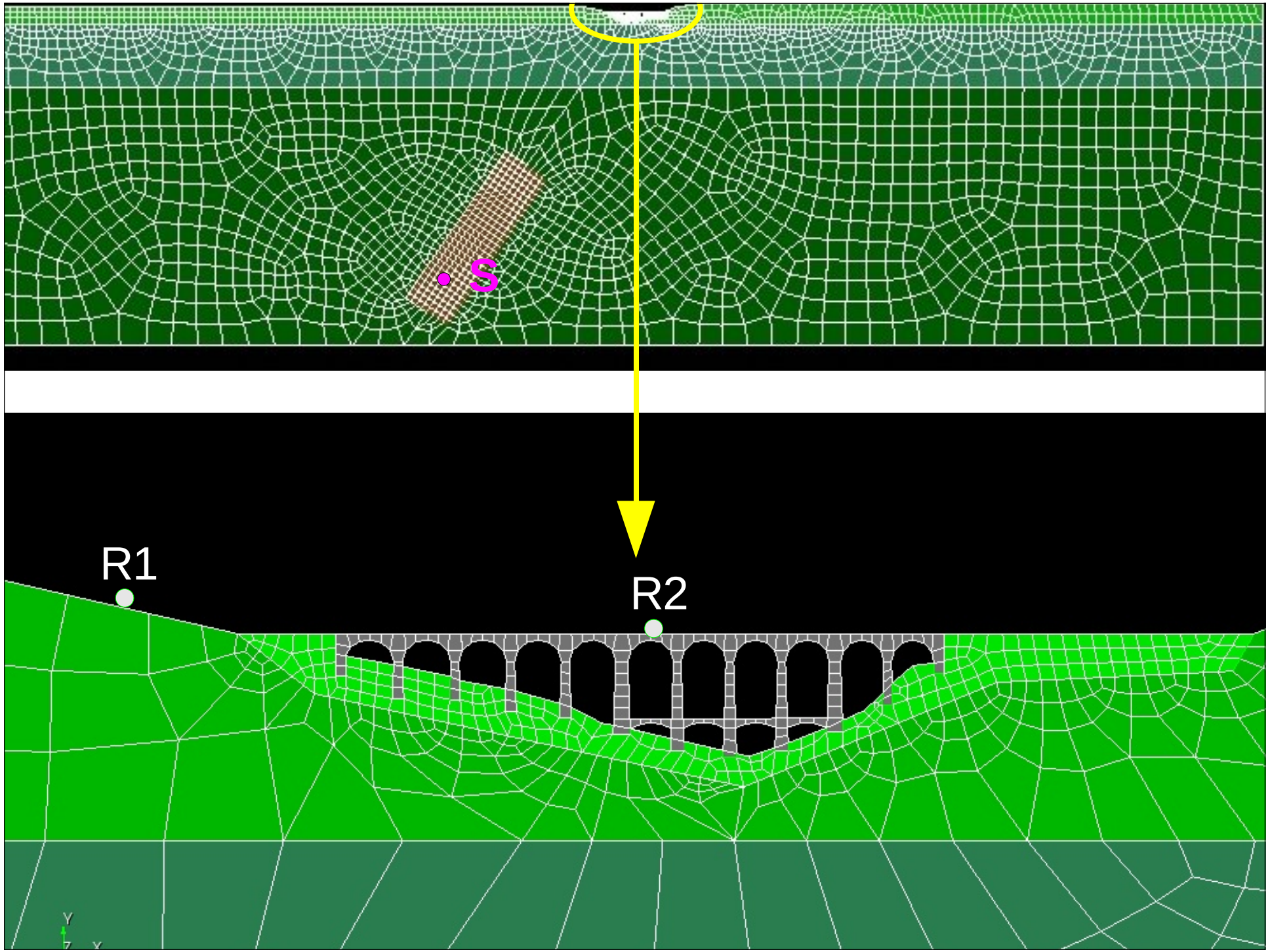


Seismic waves propagation in
Christ Church, New Zealand

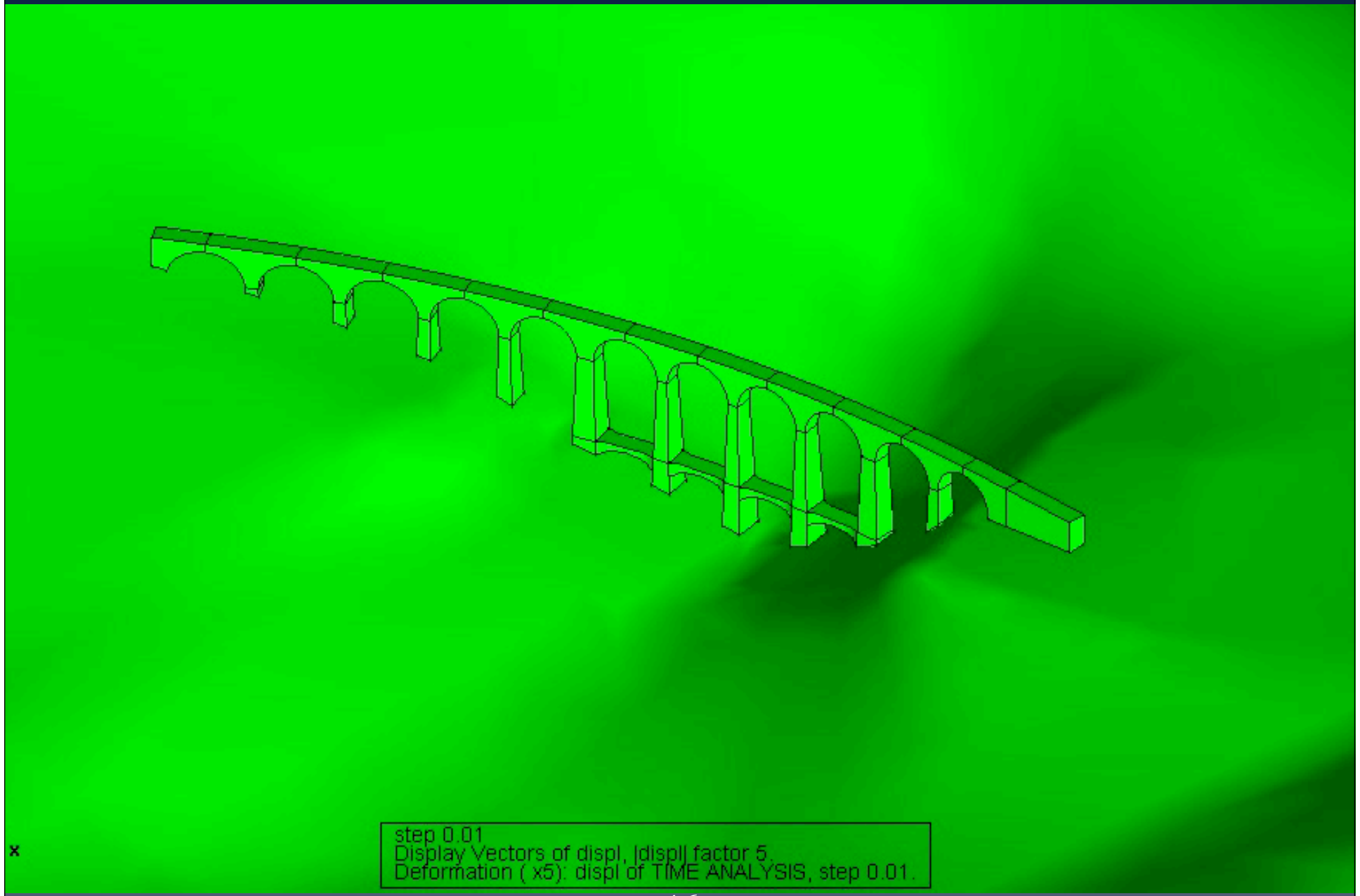


Acknowledgments:
R.Paolucci, Ch.Smerzini, DIS - Politecnico di Milano
M.Stupazzini, Munich RE
P.Antonietti, I.Mazzieri, MOX - Politecnico di Milano
F.Rapetti, Université de Nice

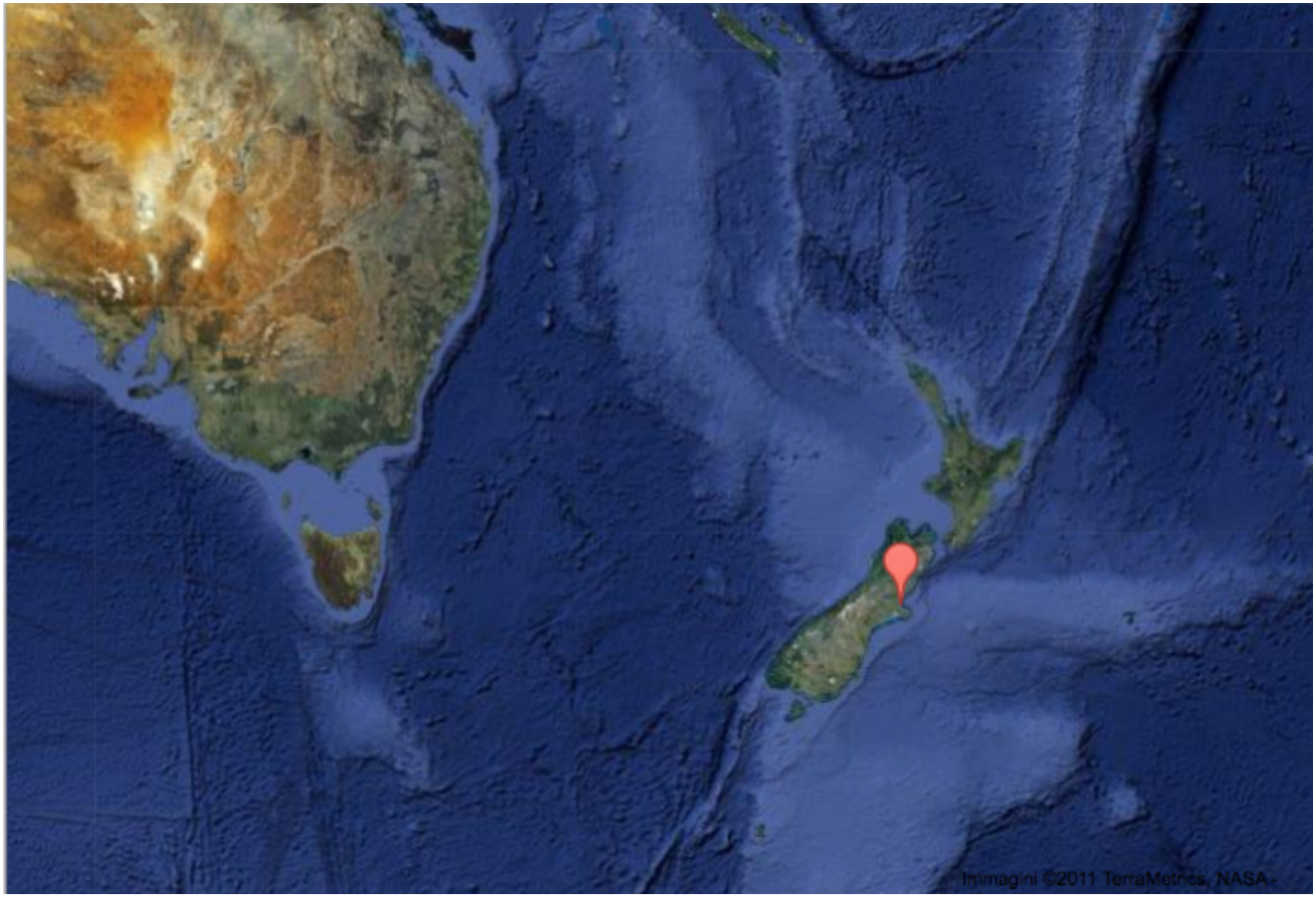
Acquasanta Bridge, Liguria, Italy


S
R1
R2

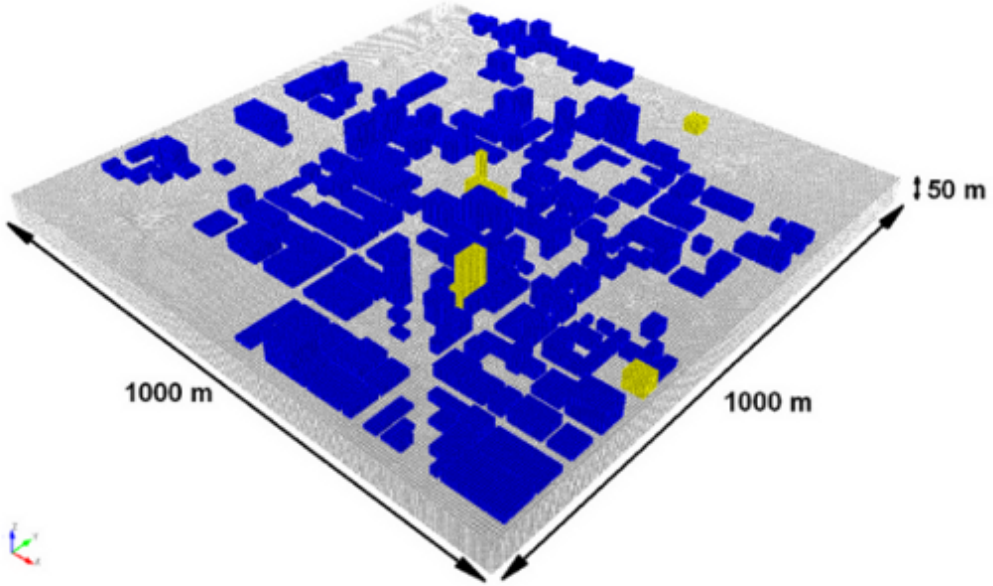
Acquasanta Viaduct, Liguria, Italy

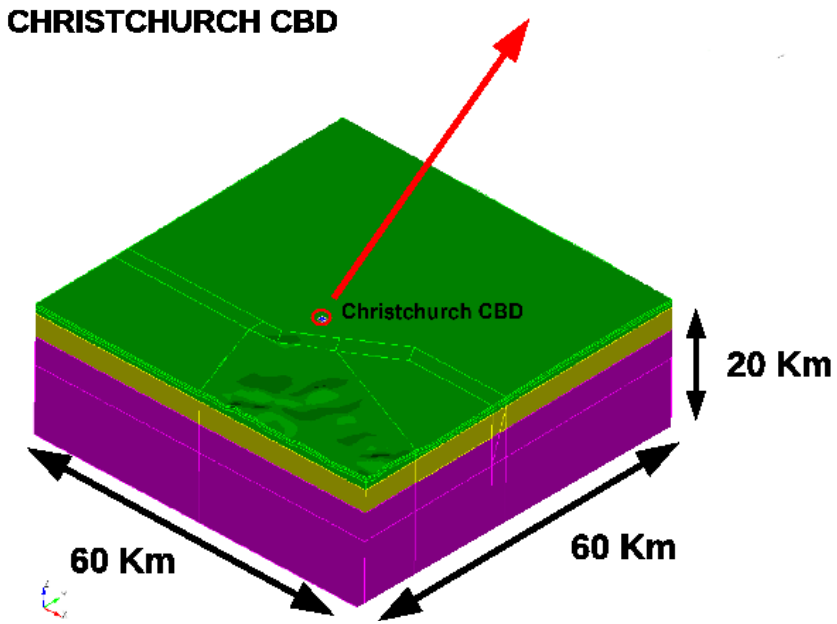


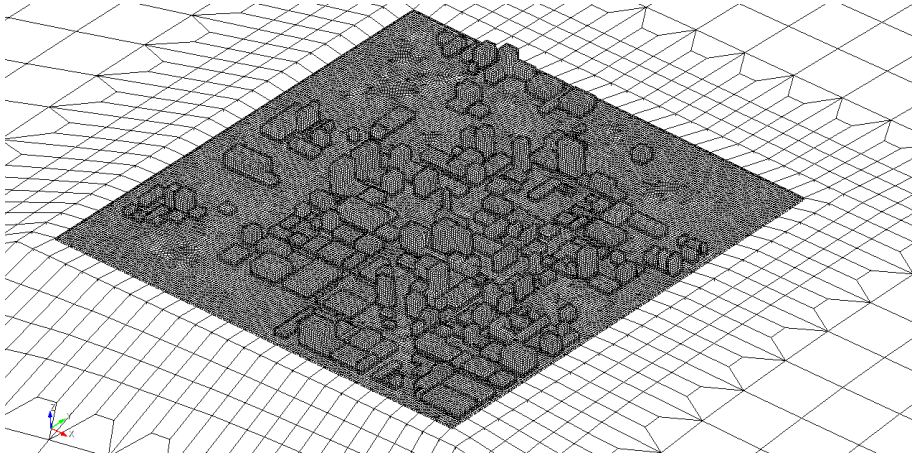
Christ Church NZ (6.2 Richter - 22 February 2011)



Christchurch Central Business District







Christ Church NZ (6.2 Richter - 22 February 2011)

Christchurch Business District

Math Models for Human Life

1. From clinical imaging to volume reconstruction

2. Mathematical Modeling

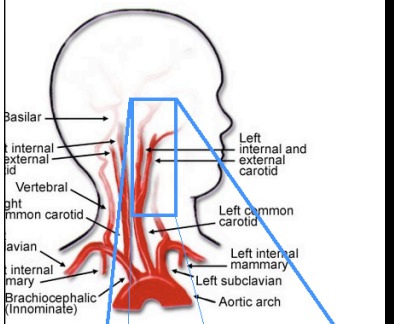
3. Computing

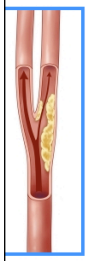
4. Clinical Applications

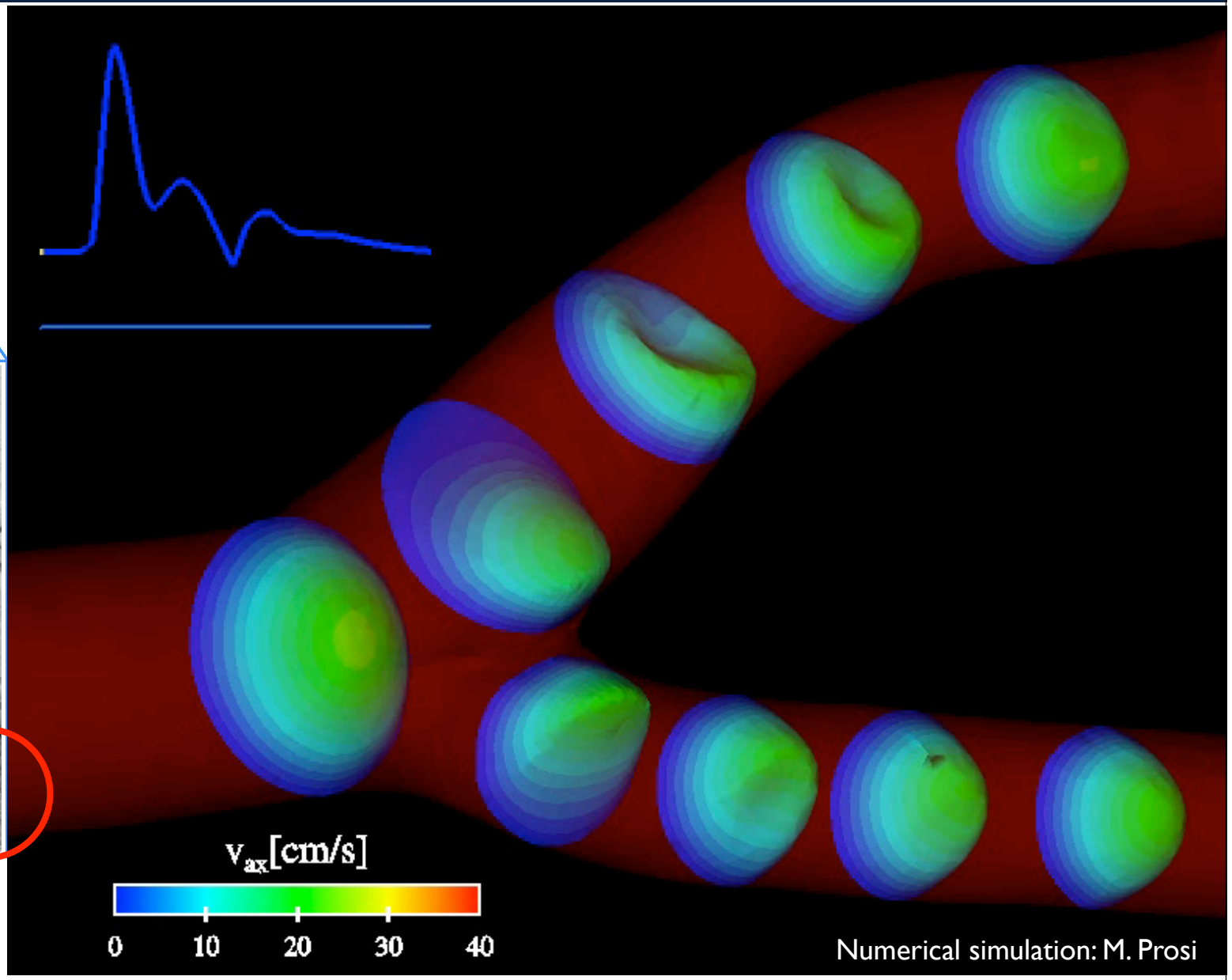
5. Virtual Surgery

6. Prosthetic Design

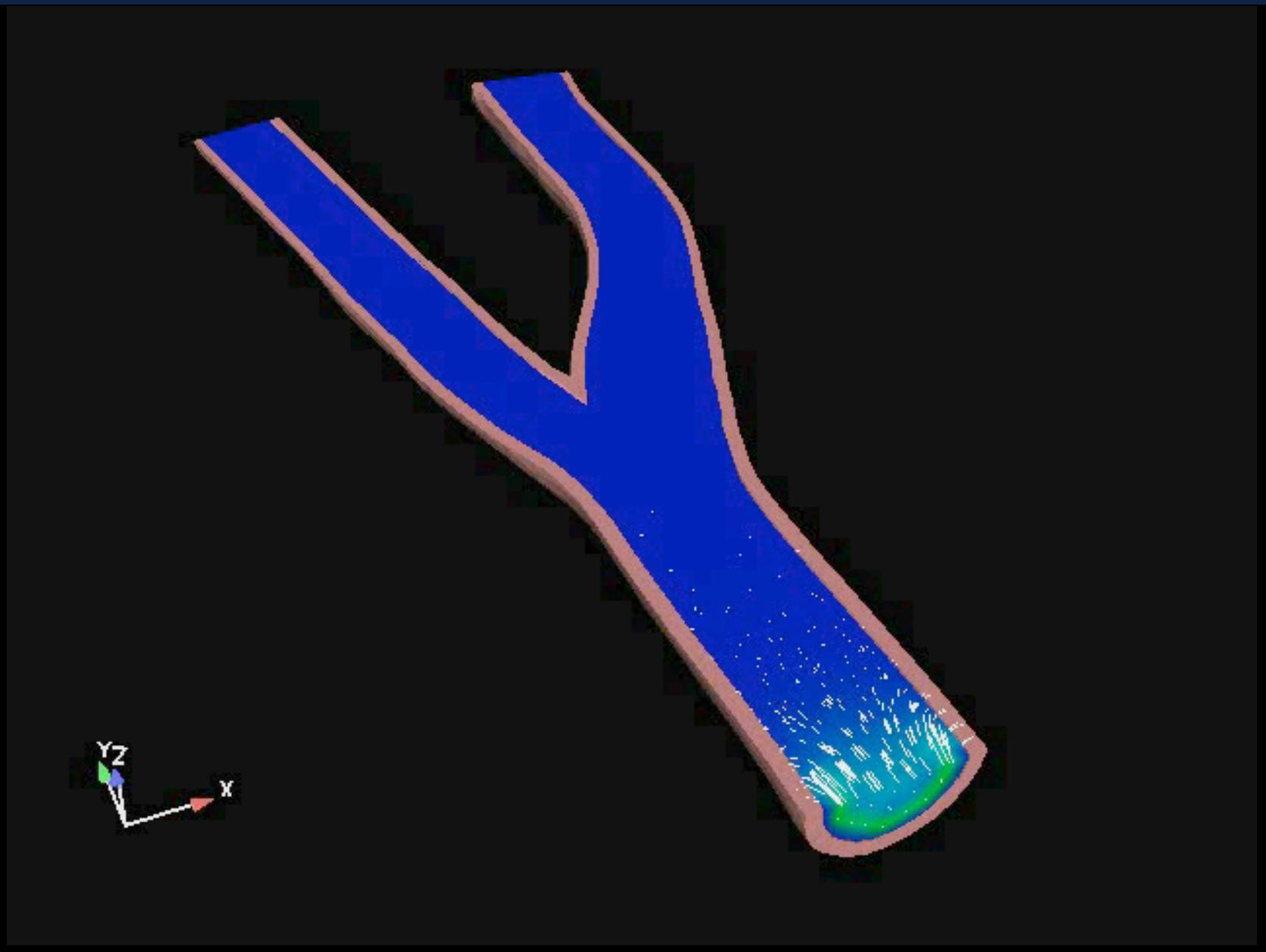
Blood flow in a carotid bifurcation



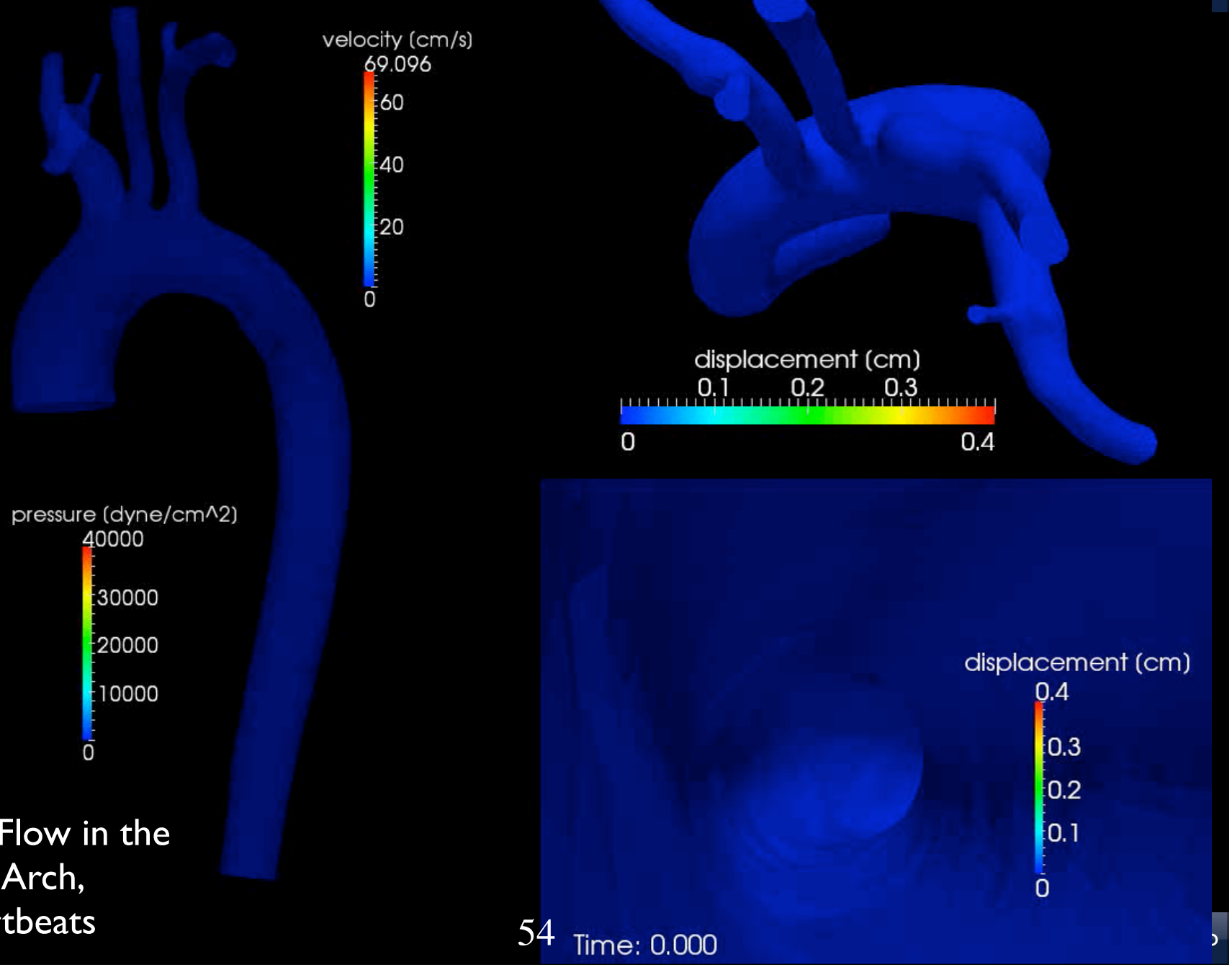




Carotid wall deformation

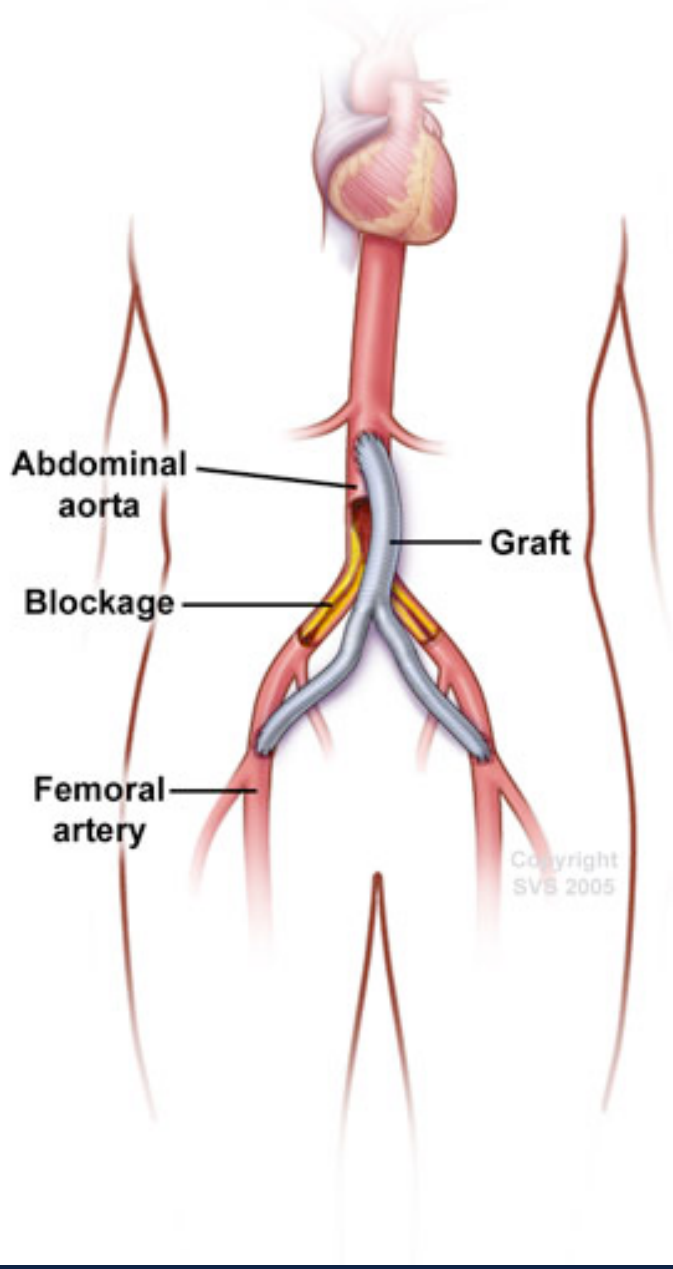


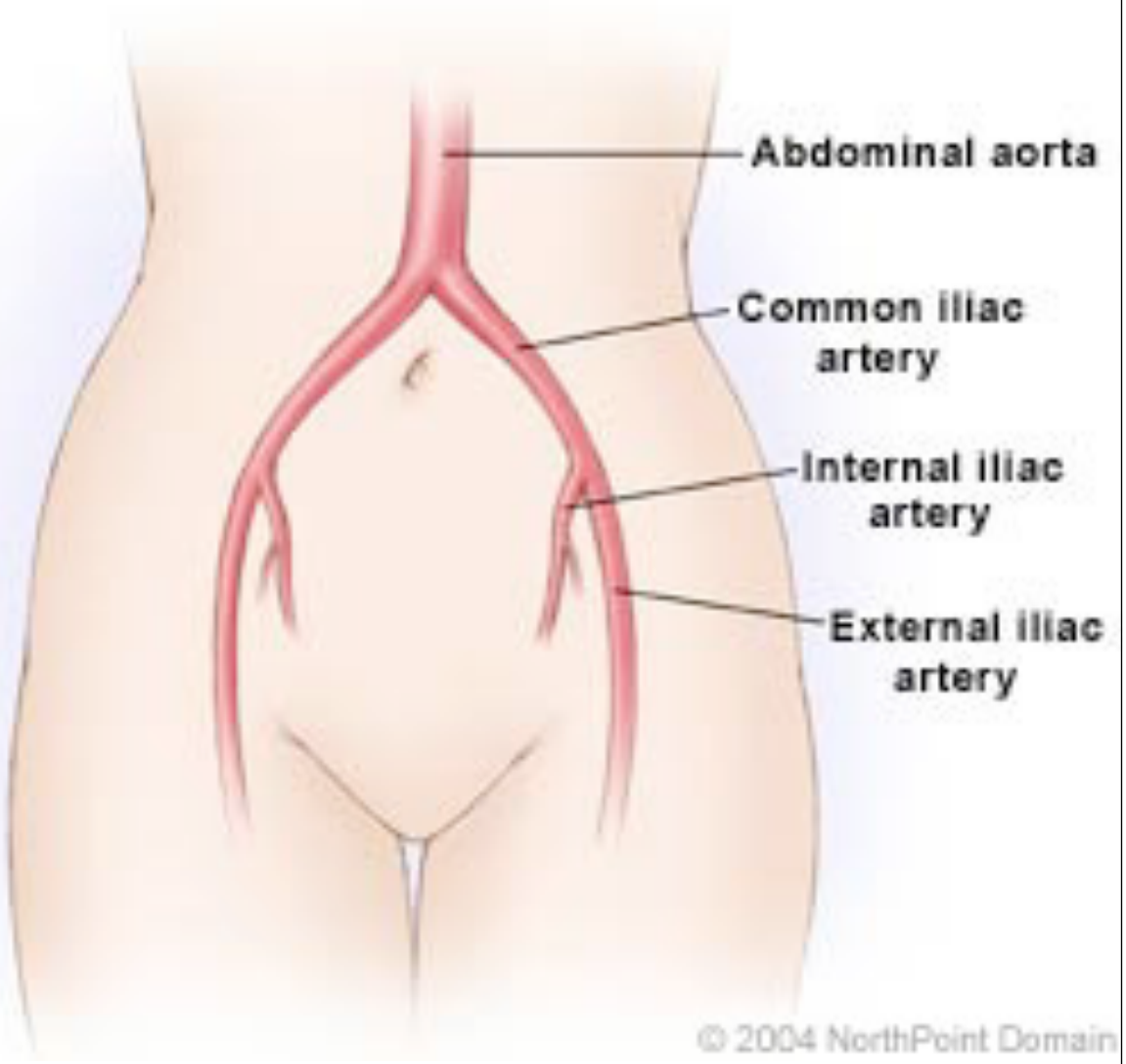
Aorta modeling: flowfield and wall pressure



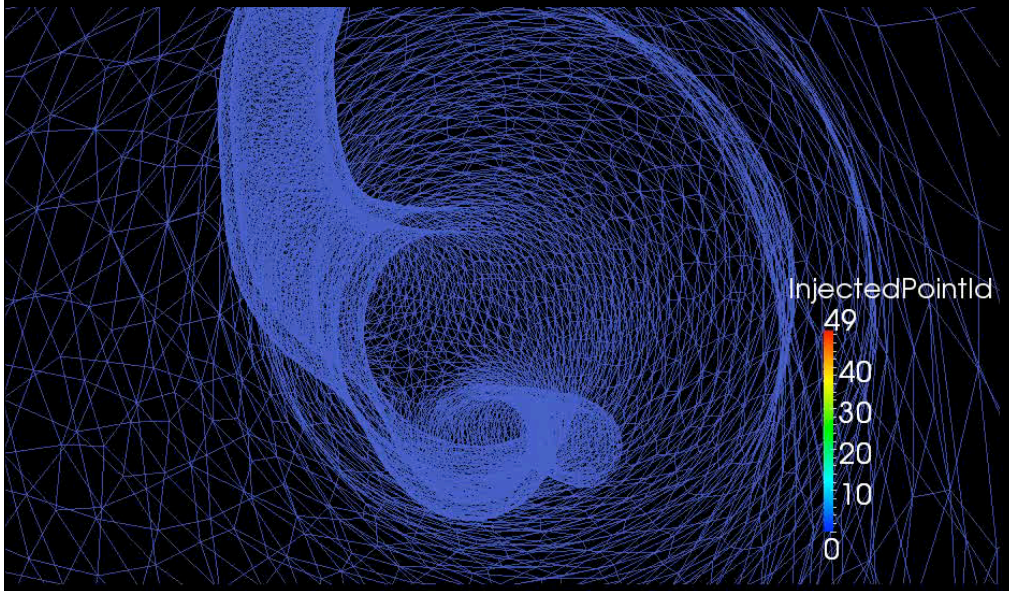
Blood Flow in the Aortic Arch, 2 Heartbeats

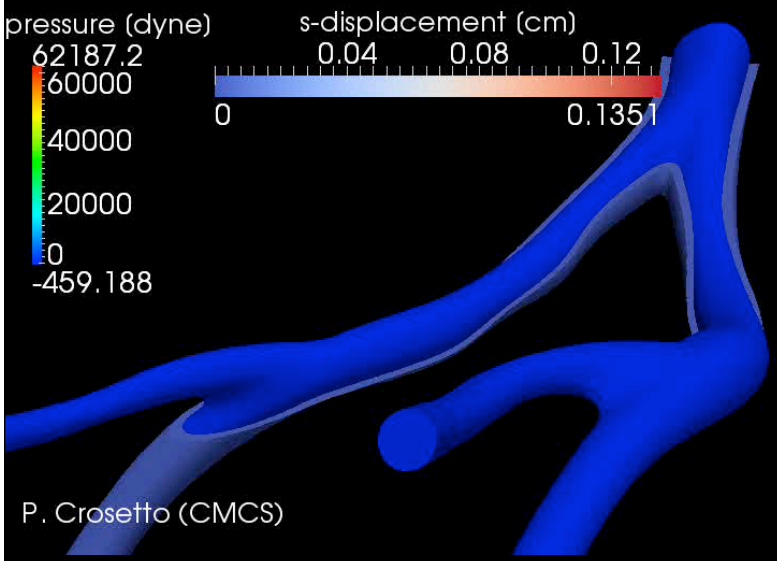
Iliac bifurcation modeling: flowfield and wall pressure

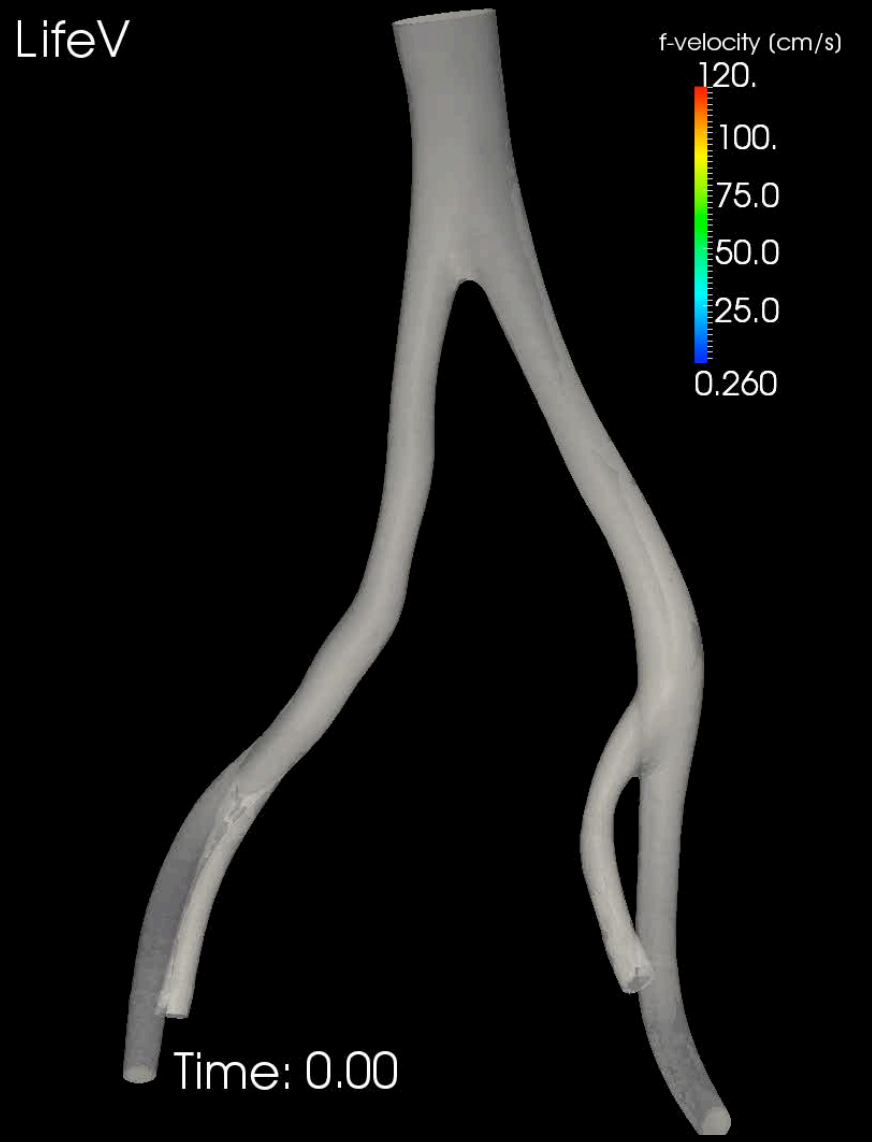




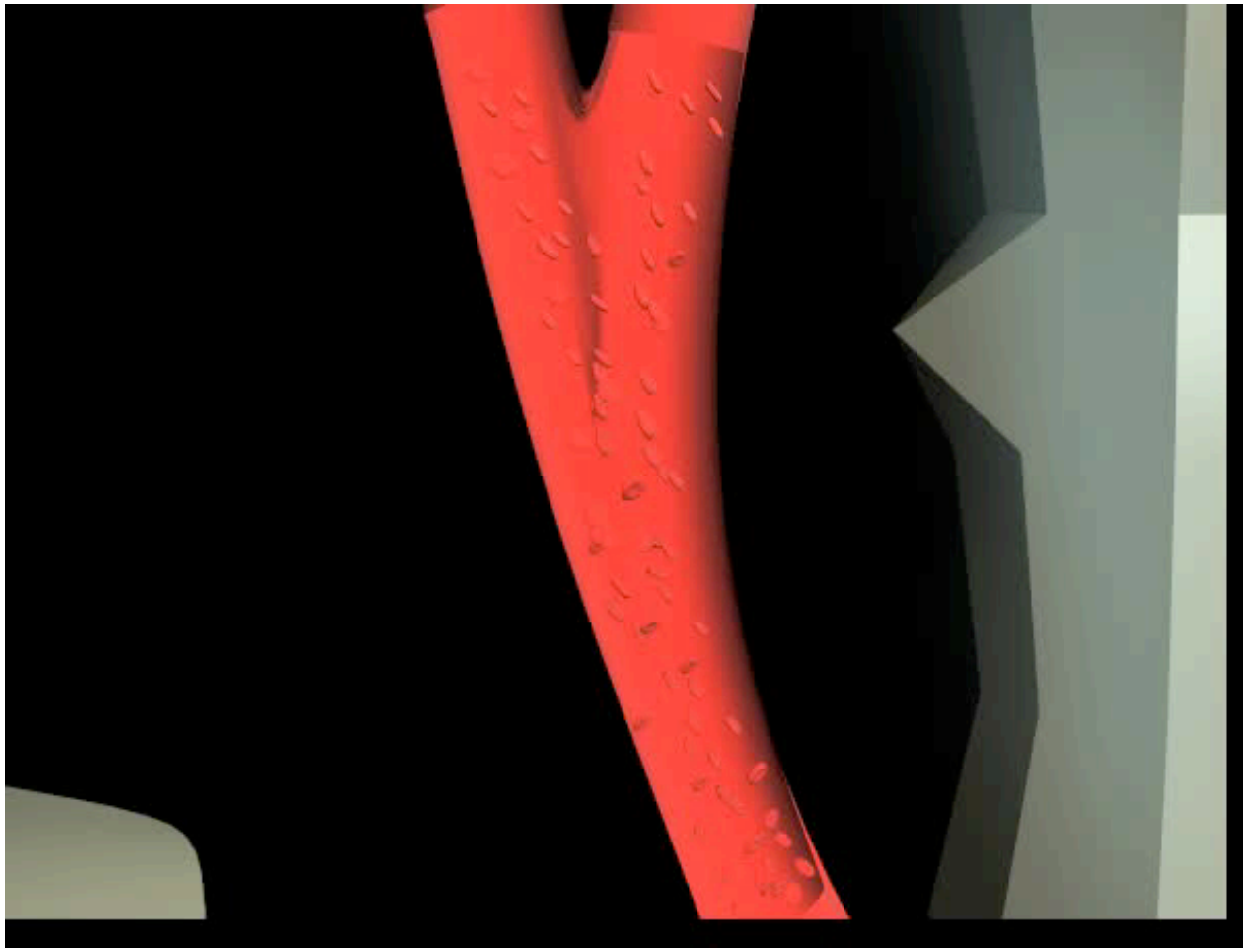
Iliac bifurcation modeling: flowfield and wall pressure







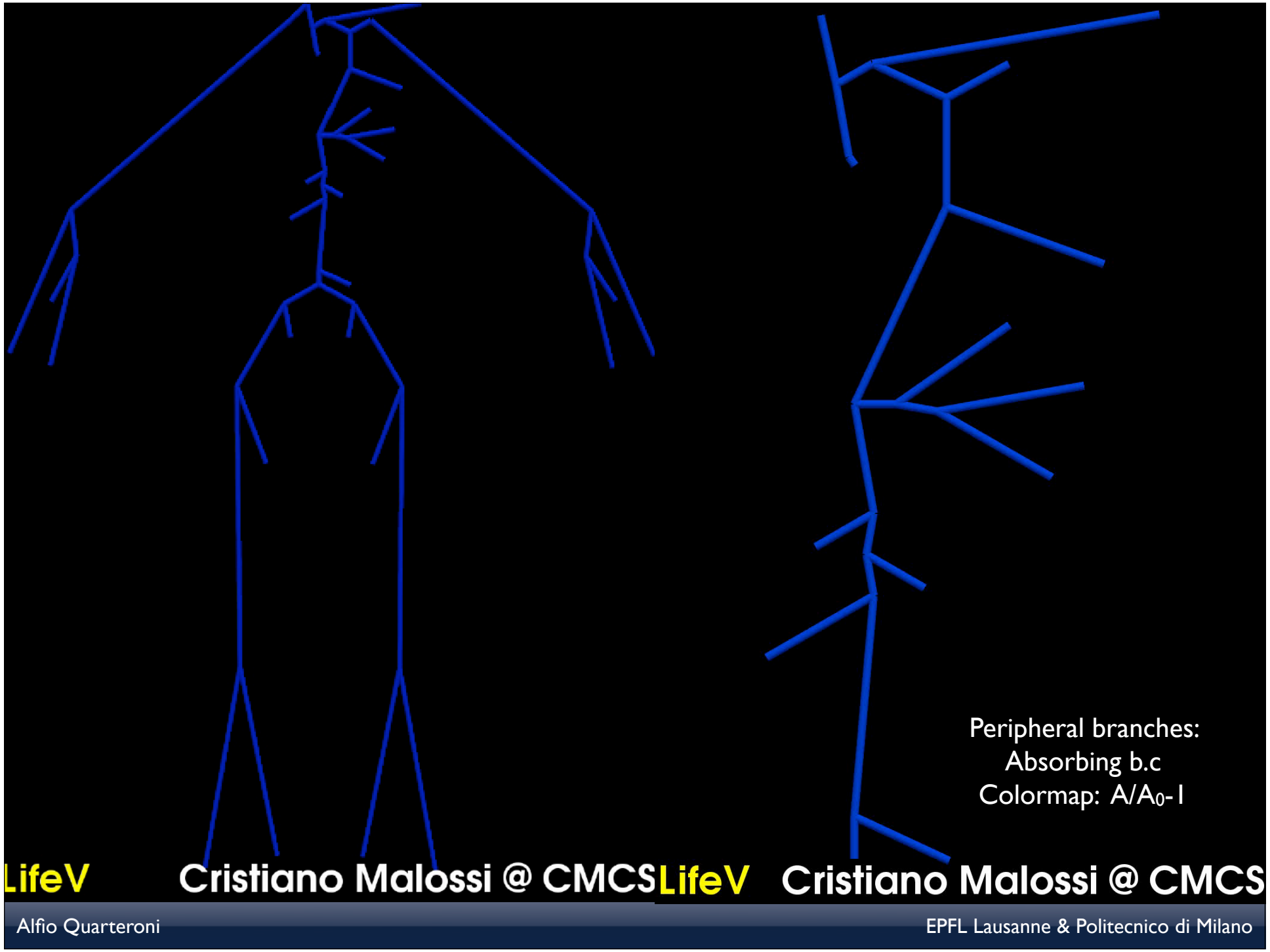
A geometric multiscale approach for the circulatory system



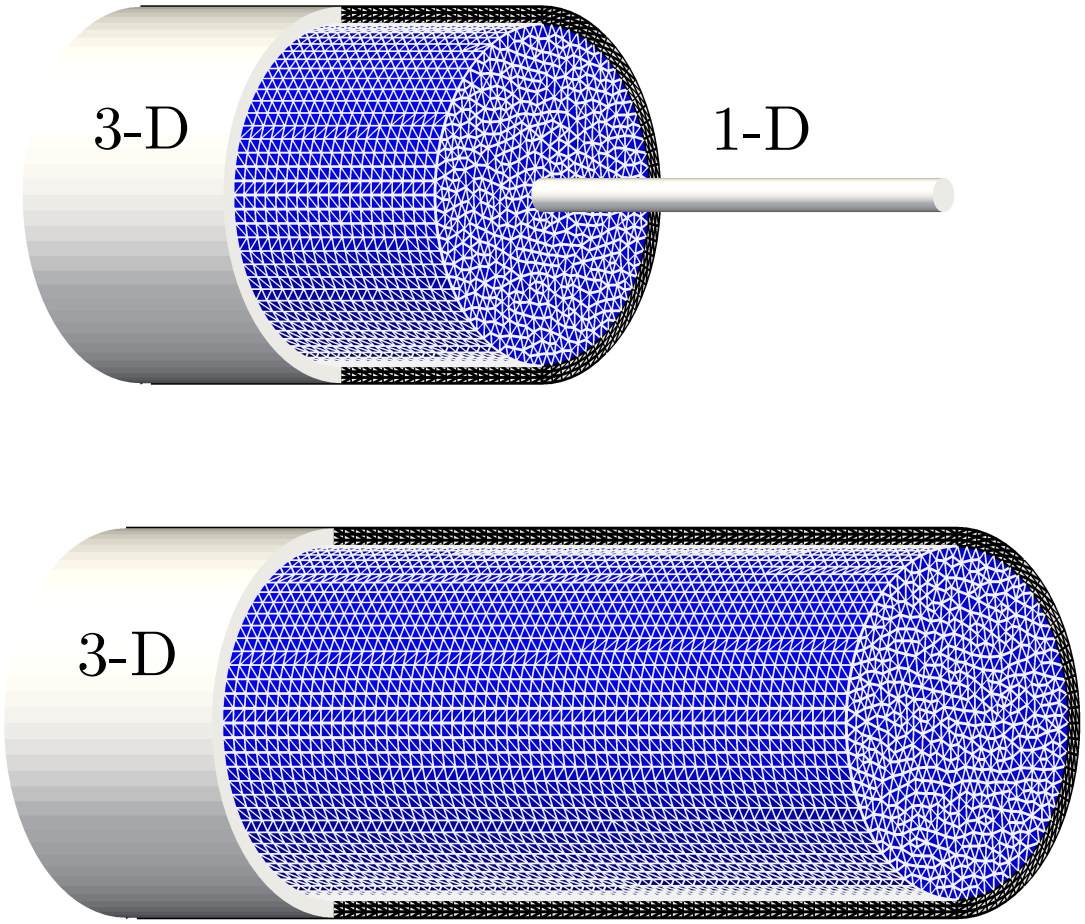
Local (level 1): 3D flow model (FSI between NS equations and elastodynamic eqs)

Global (level 2): 1D network of major arteries and veins (Euler hyperbolic system)

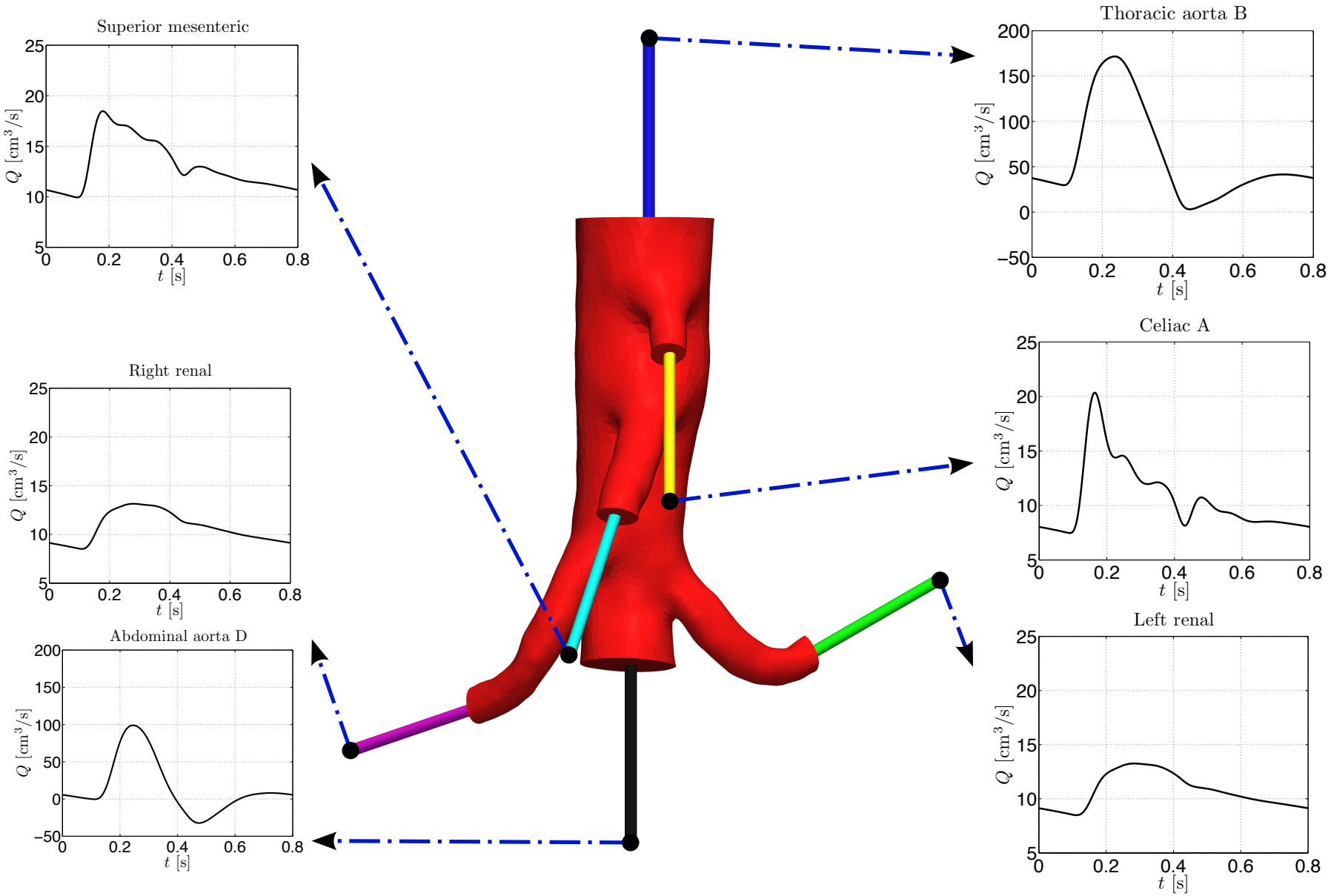
Global (level 3): 0D capillary network (DAE system)


Peripheral branches:
Absorbing b.c
Colormap: A/A_0-1
LifeV Cristiano Malossi @ CMCS
LifeV Cristiano Malossi @ CMCS

A geometric multiscale approach for the circulatory system



A geometric multiscale approach for the circulatory system



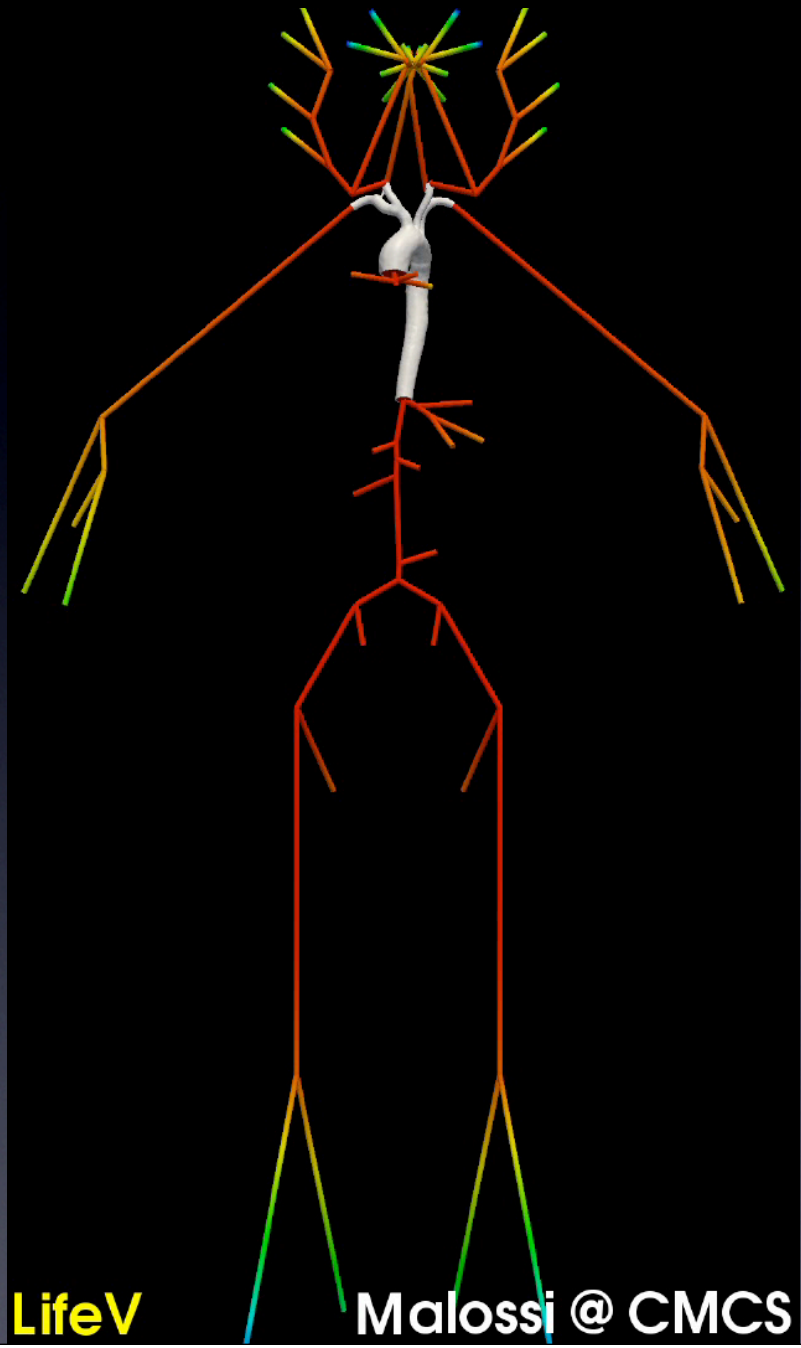
Geometric Multiscale - The Aortic Arch

Models:

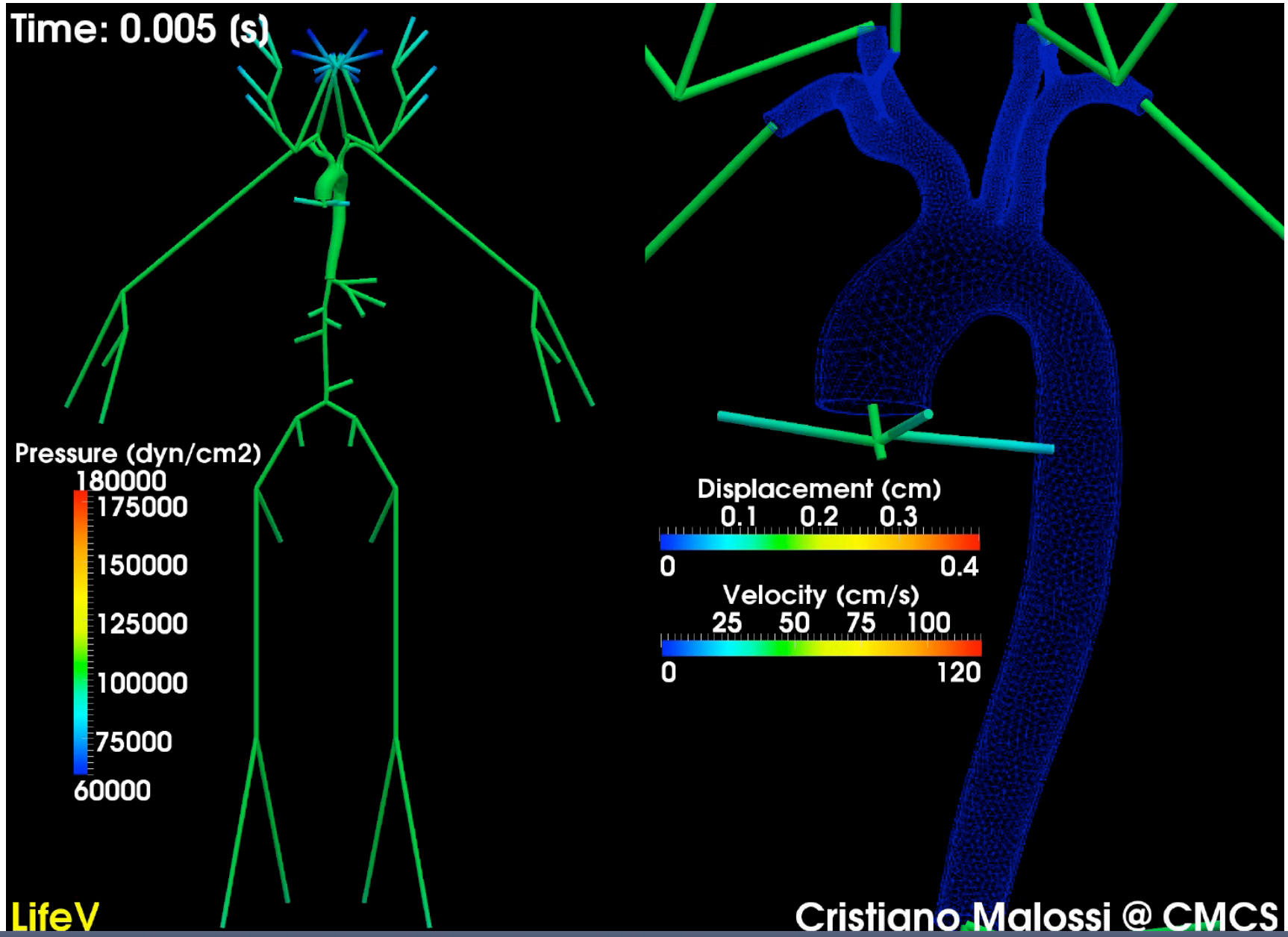
- 3-D FSI Aorta
- 1-D arterial tree
  - 92 tapered elements
  - viscoelastic wall
- 0-D terminals
  - 47 Windkessel elements (RCR)

Coupling:

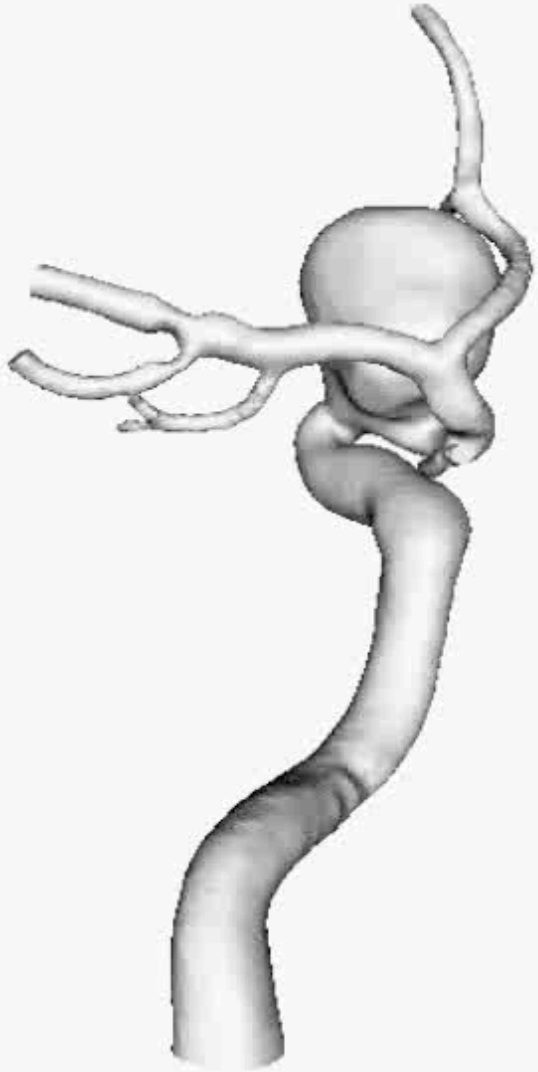
- averaged/integrated quantities at the interfaces (flow rate or normal stress)
- segregated approach for the solution of the coupled problem (Newton, inexact-Newton, or Broyden methods)

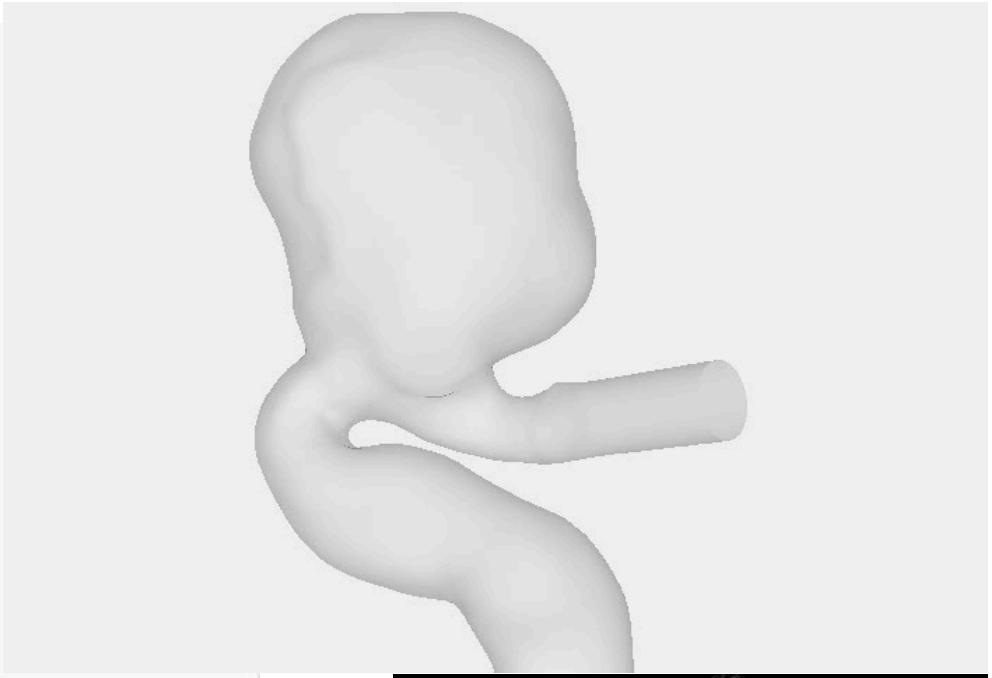


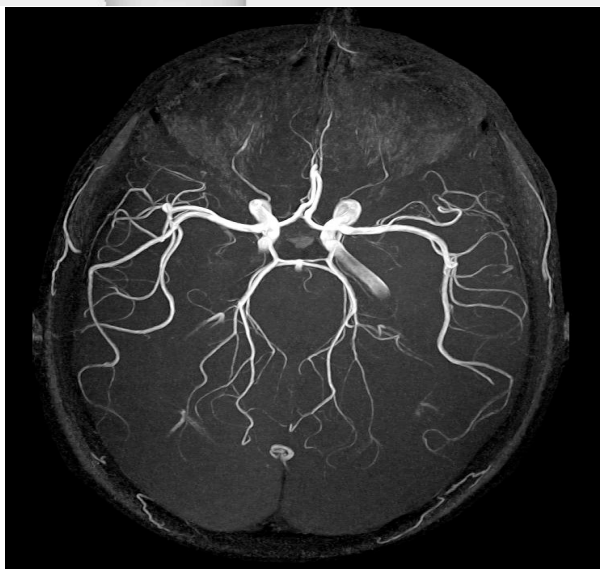
Flowfield in aortic branch and carotid arteries



Flow in a cerebral aneurysm during a full cardiac pulse

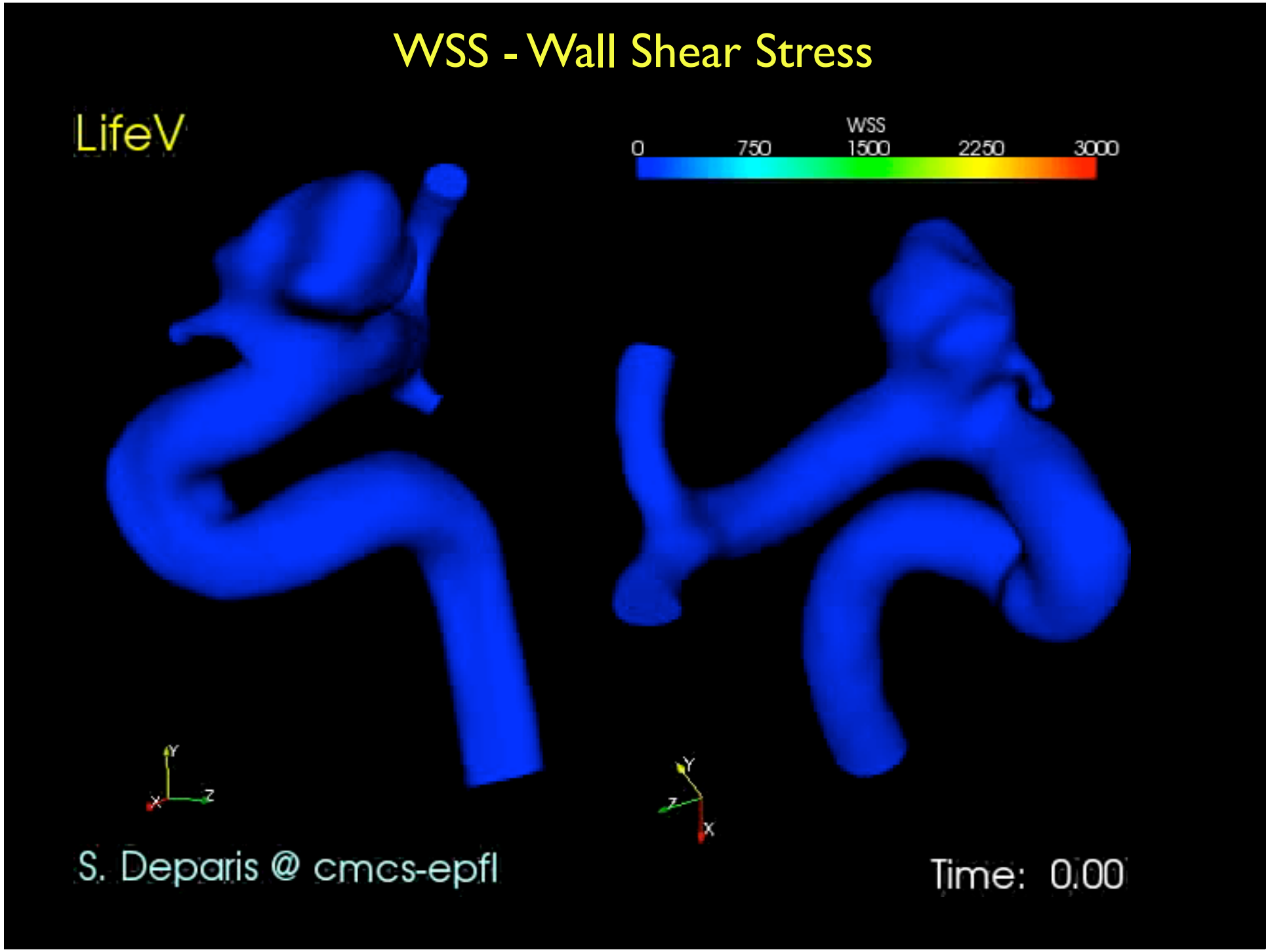






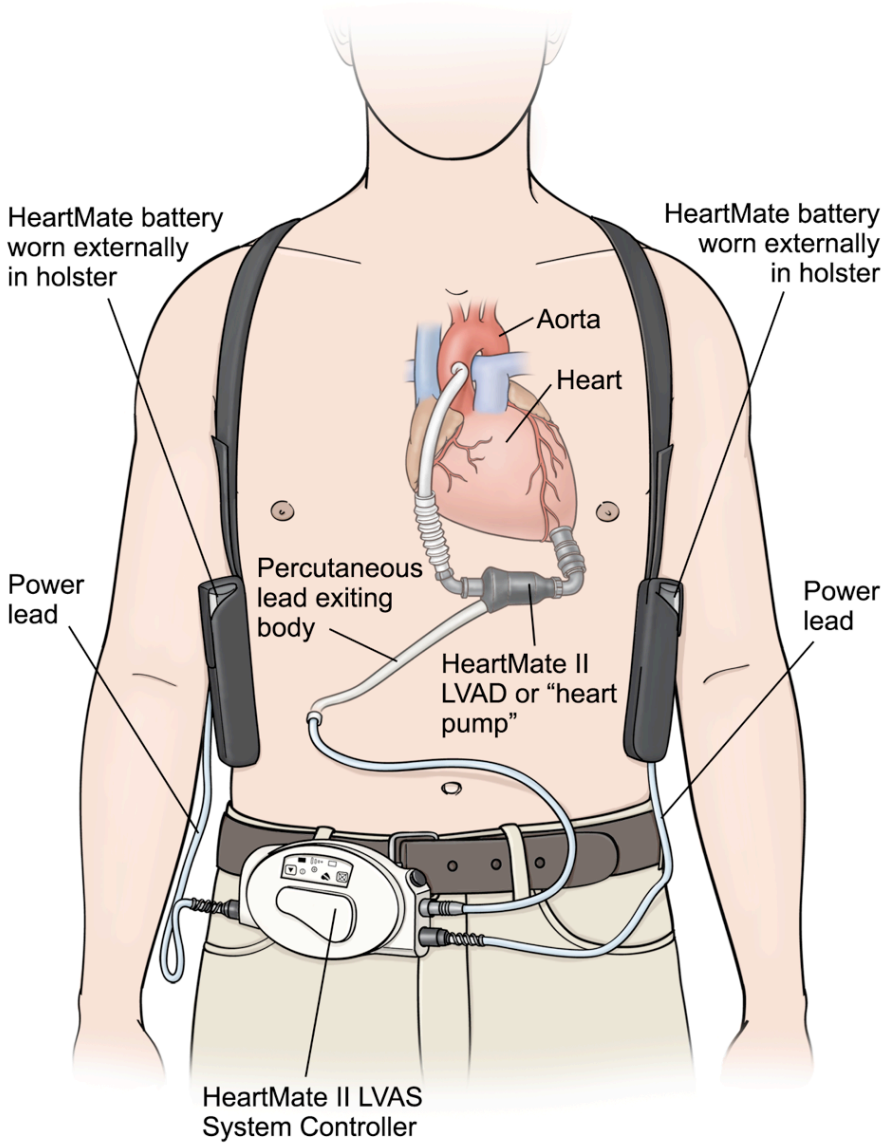
Simulation carried out by T. Passerini

WSS - Wall Shear Stress

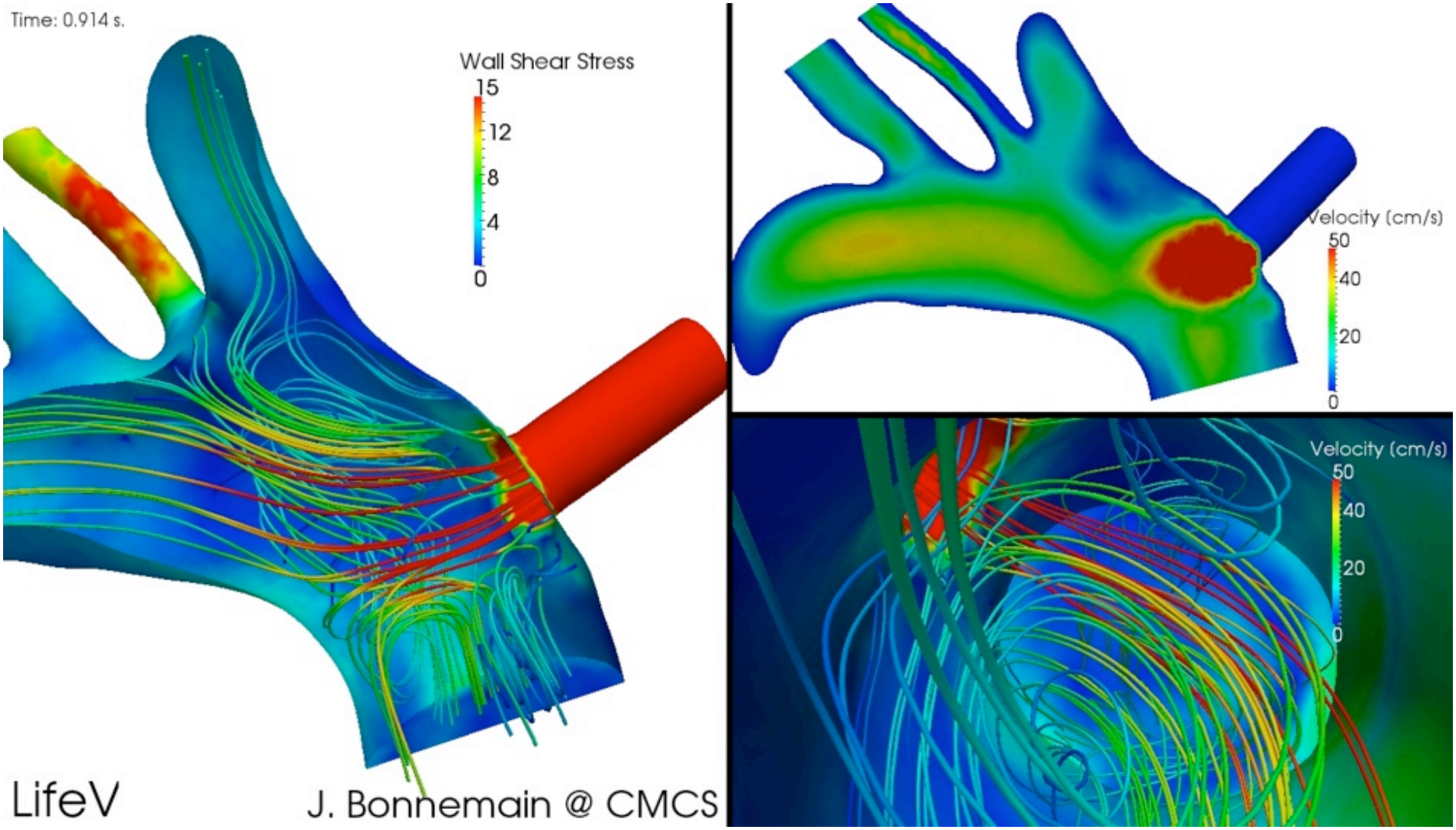


Ventricular Assisted Device (VAD)

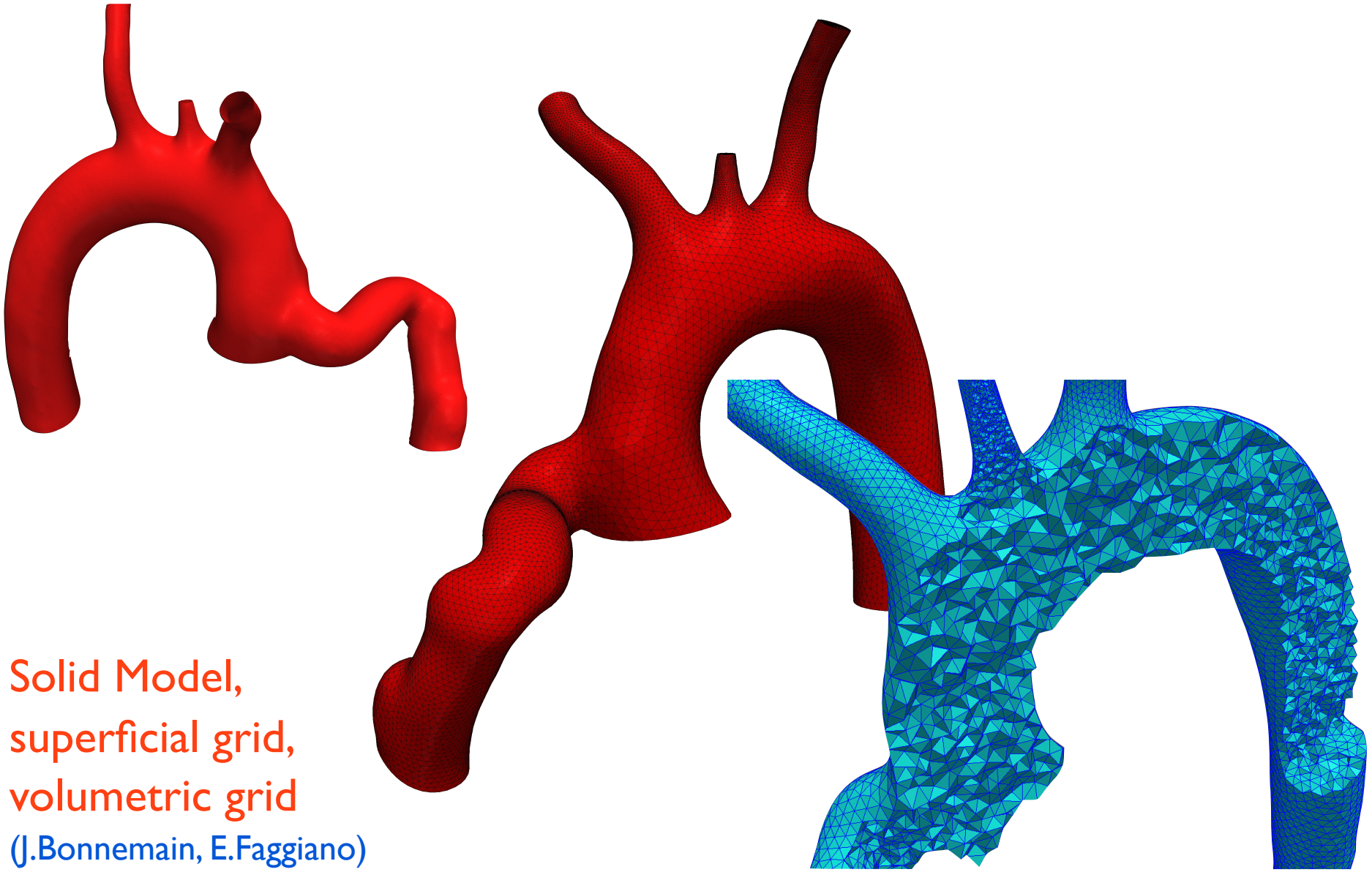
- Treatment of terminal heart failure
- Left ventricle and / or right ventricle assistance
- For patients awaiting heart transplantation
- Also for patients ineligible for transplantation



Cannula of a Ventricular Assisted Device (VAD)

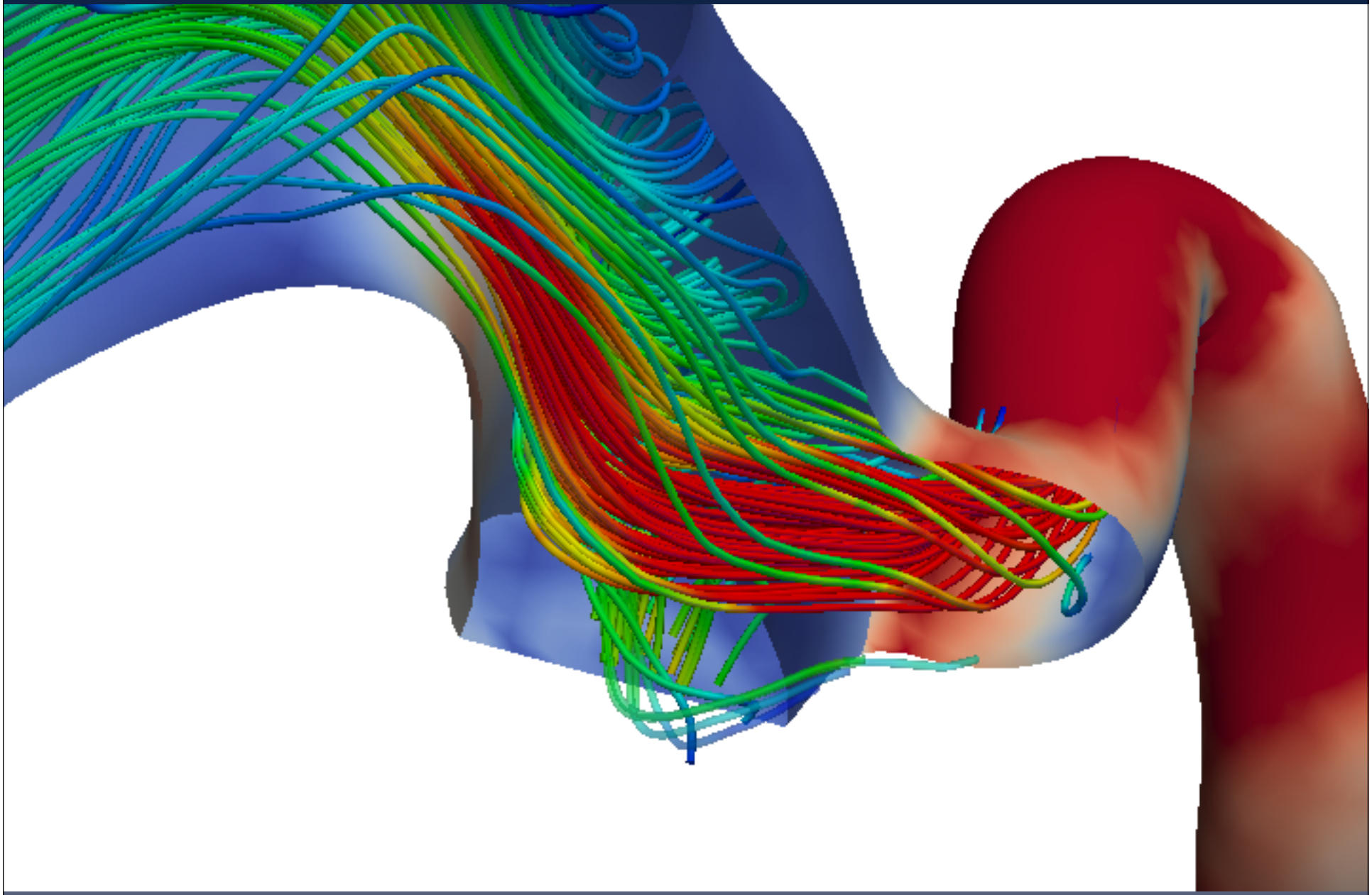


Cannula of a Ventricular Assisted Device (VAD)

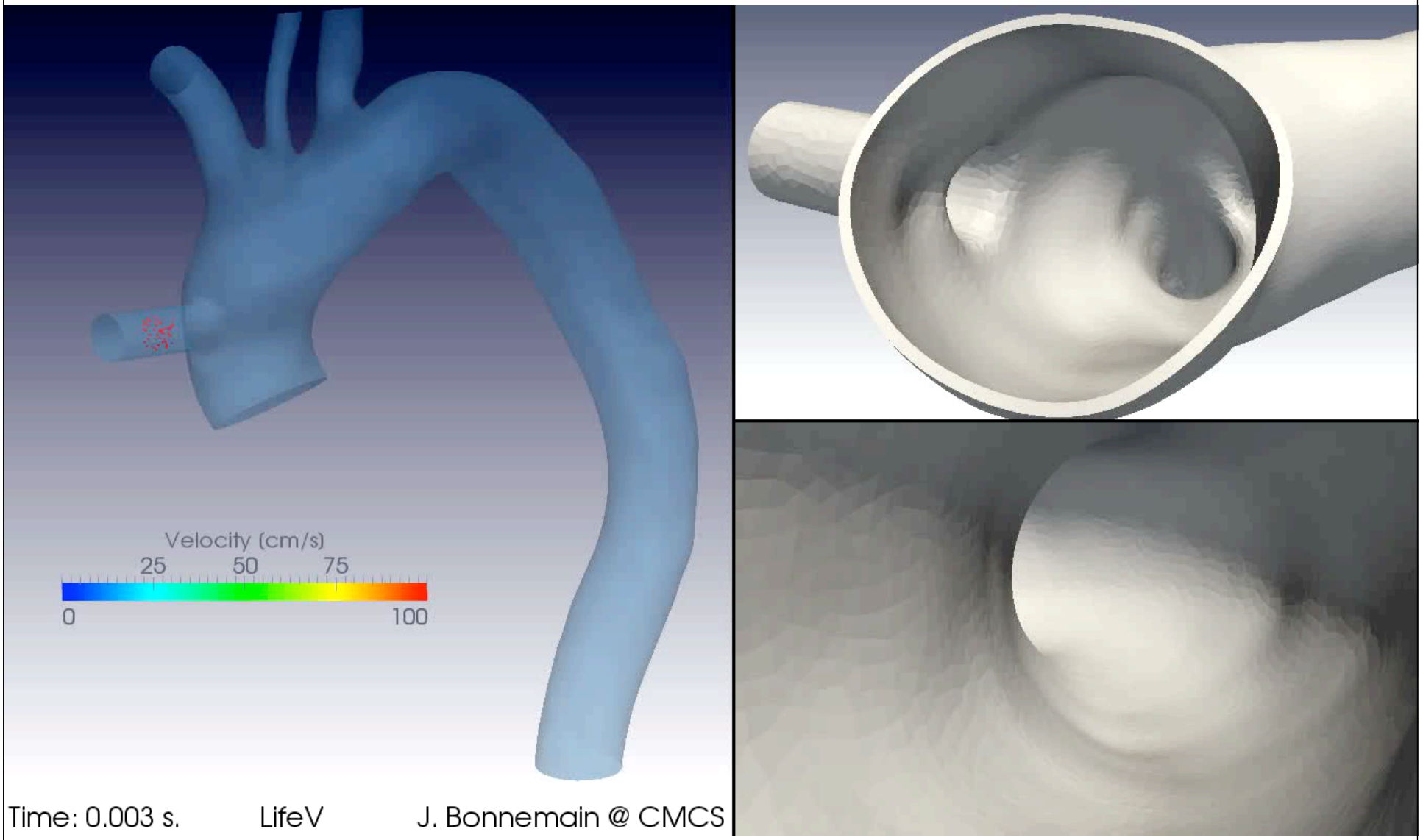


Solid Model,
superficial grid,
volumetric grid
(J.Bonnemain, E.Faggiano)

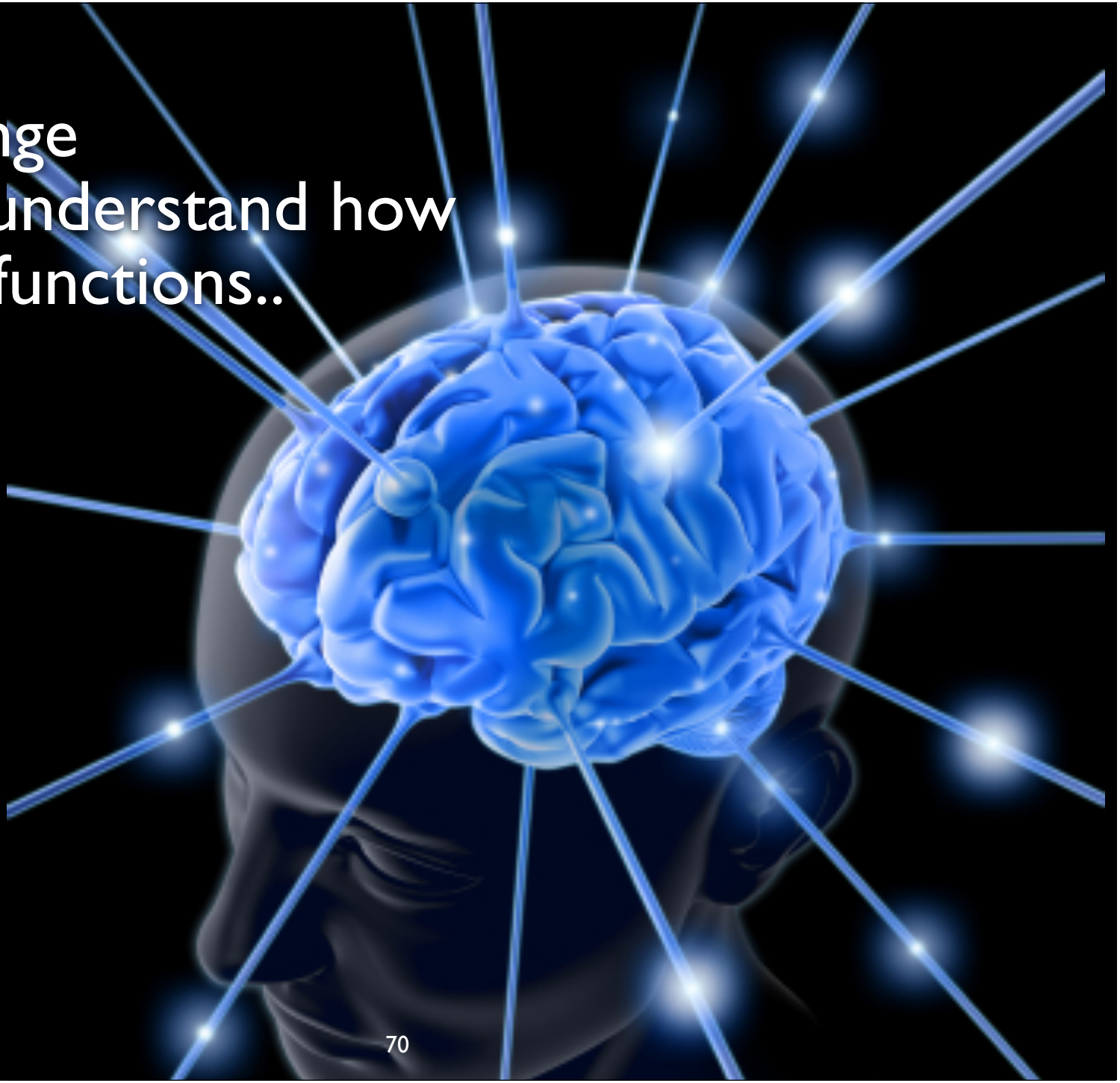
Cannula of a Ventricular Assisted Device (VAD)



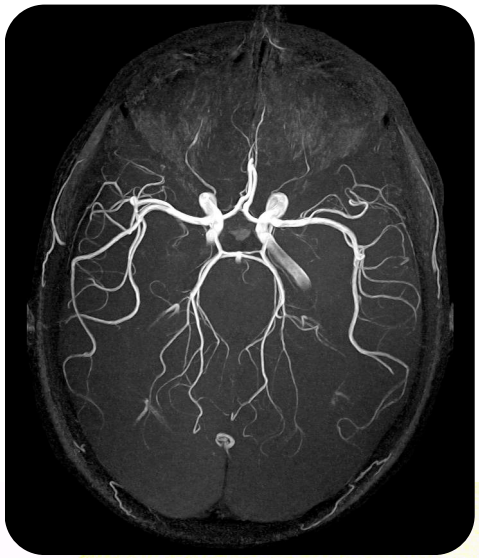
Cannula of a Ventricular Assisted Device (VAD)

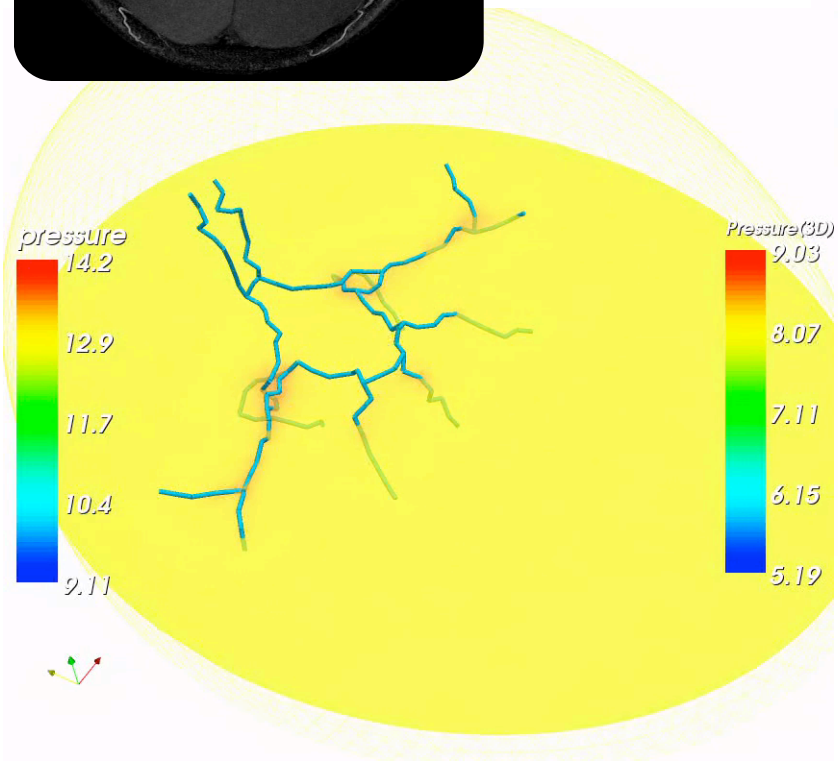


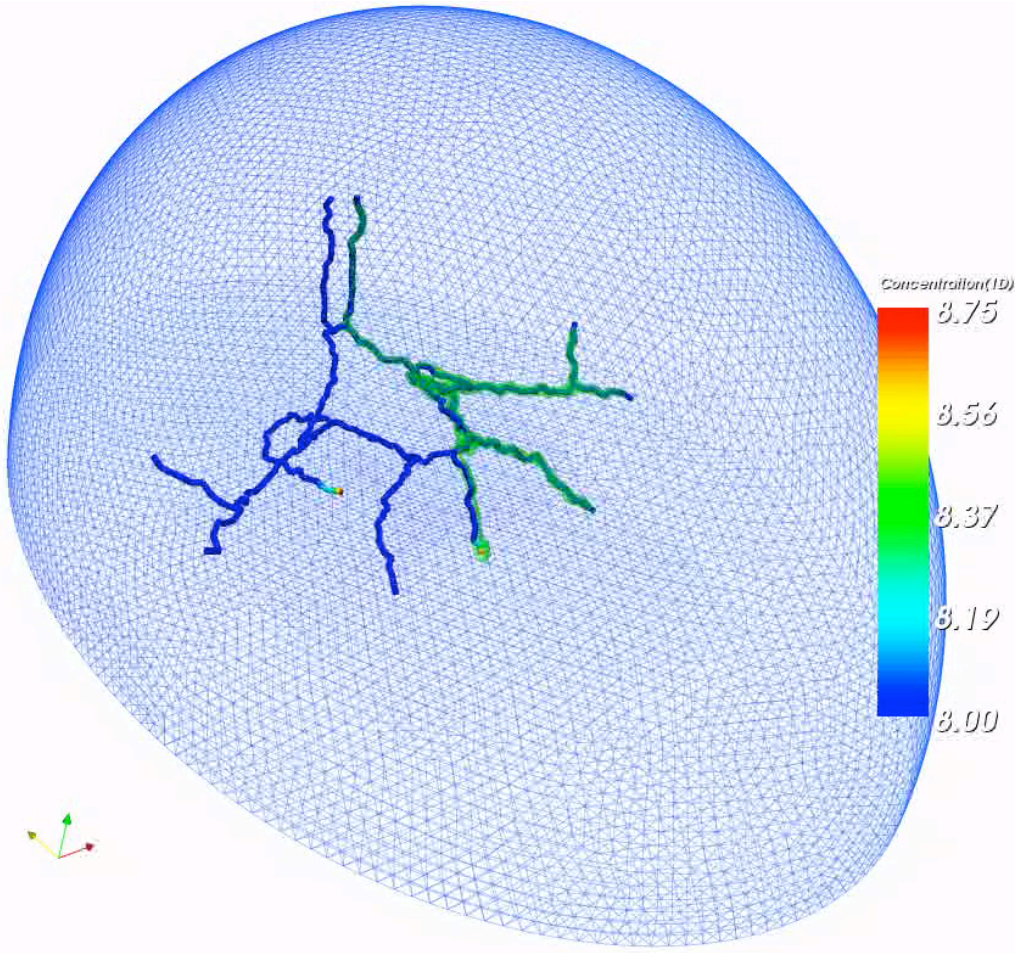
Math is
the challenge
to better understand how
our brain functions..



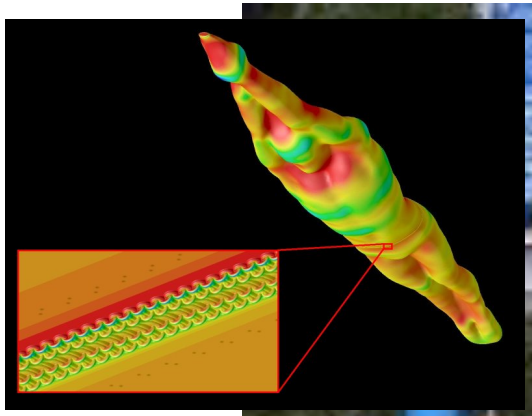
Oxygen Diffusion and Blood Pressure in the Brain



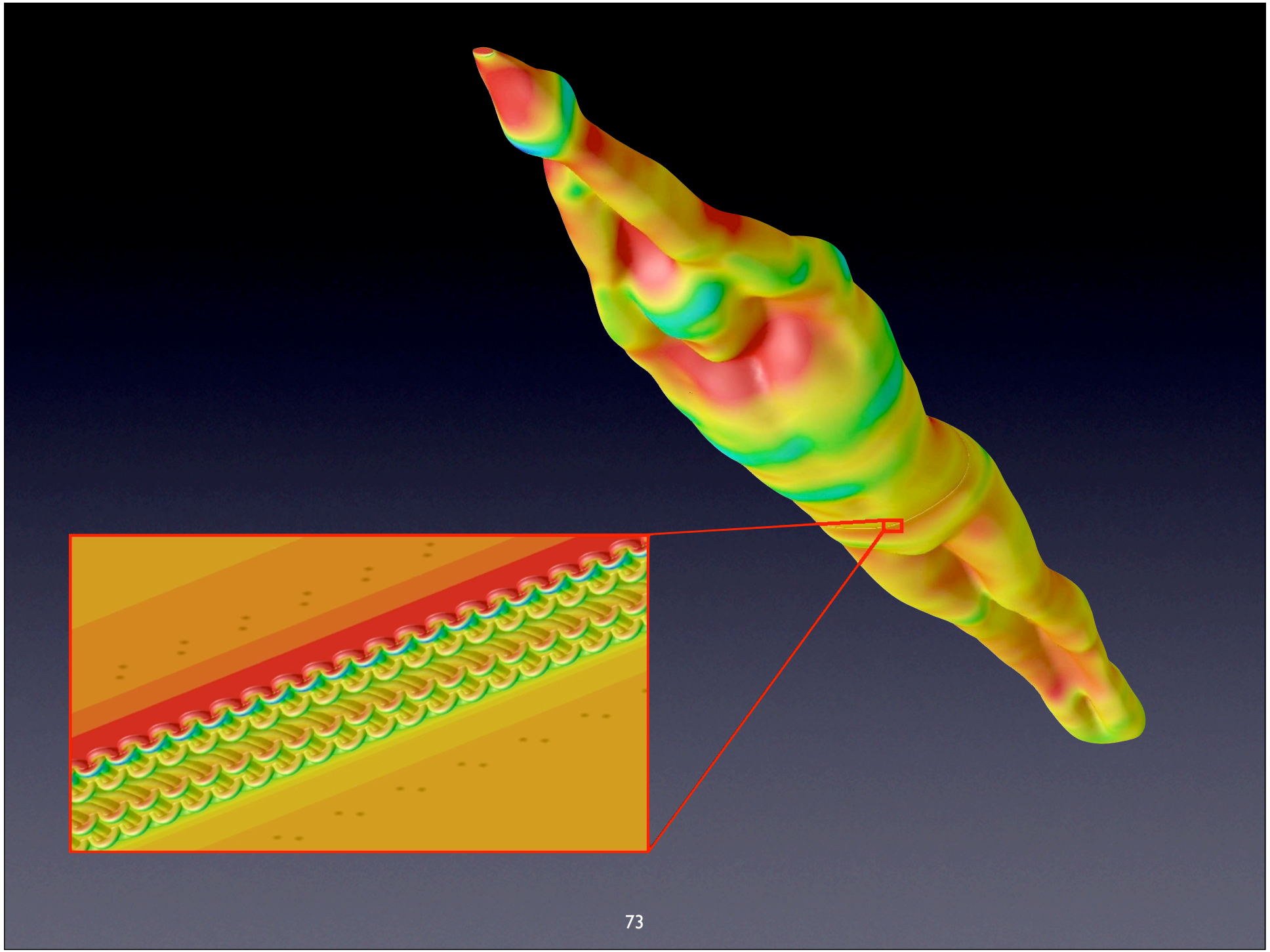




Real and virtual swimmers



(N.Parolini, A.Veneziani)



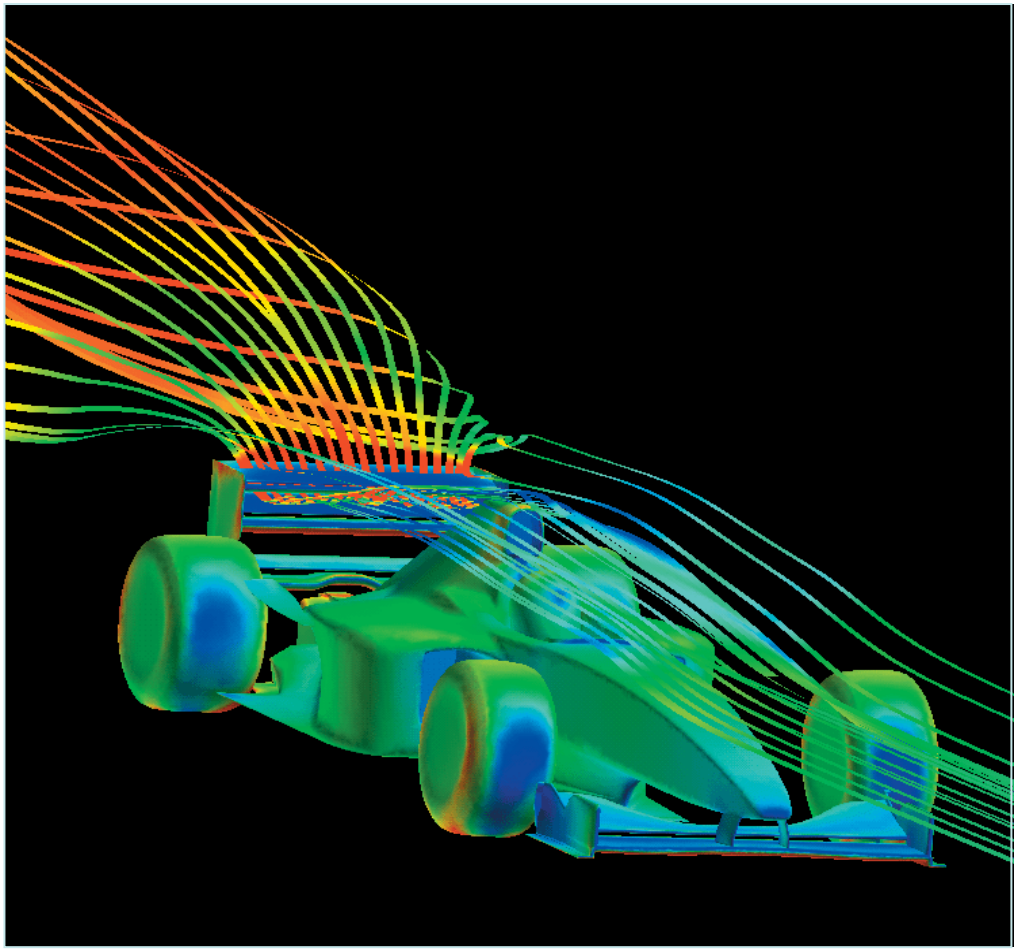
Racing cars: facts and figures

Performance due to:

15% engine

35% weight

50% aerodynamics



Time:

8 months for virtual design

(virtual models are built up through CFD-CSD-Vehicle dynamics facts and behaviors are understood through wind tunnel experimental quantities are measured)

1 month for assembling

Math is our Lab

- cheap
- fast
- optimal

The SOLAR IMPULSE Airplane

Math Modelling and AMERICA'S CUP

alinghi

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

OFFICIAL SCIENTIFIC ADVISOR
ALINGHI DEFENDER 32nd AMERICA'S CUP

(N.Parolini, D.Detomi)

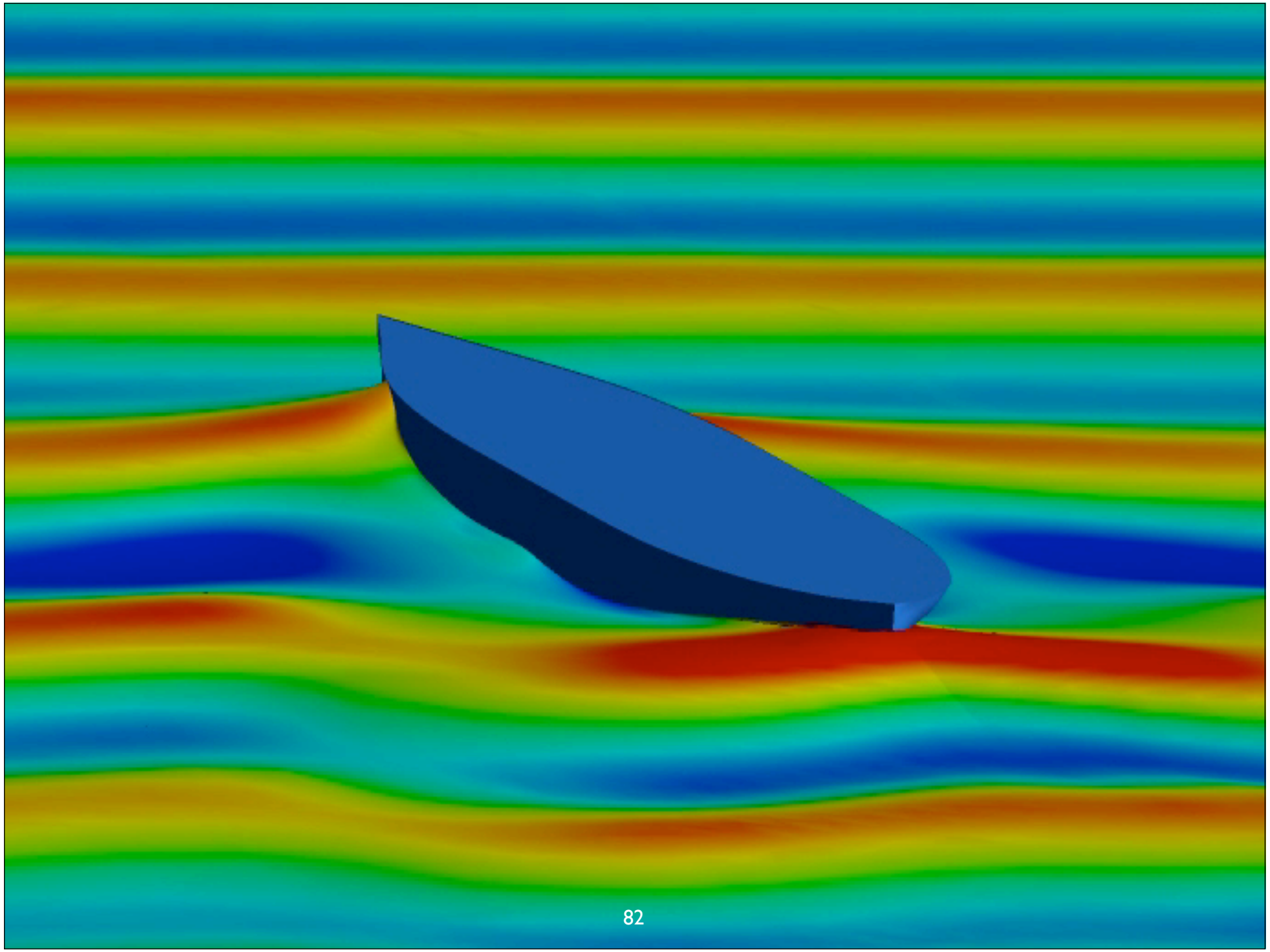

AC31 -2003
infonet
AUDEMARS PIGUET
riri
ALINGHI.COM
UBS
alinghi
(G.Cowles,M.Sawley,N.Parolini,A.Q.)

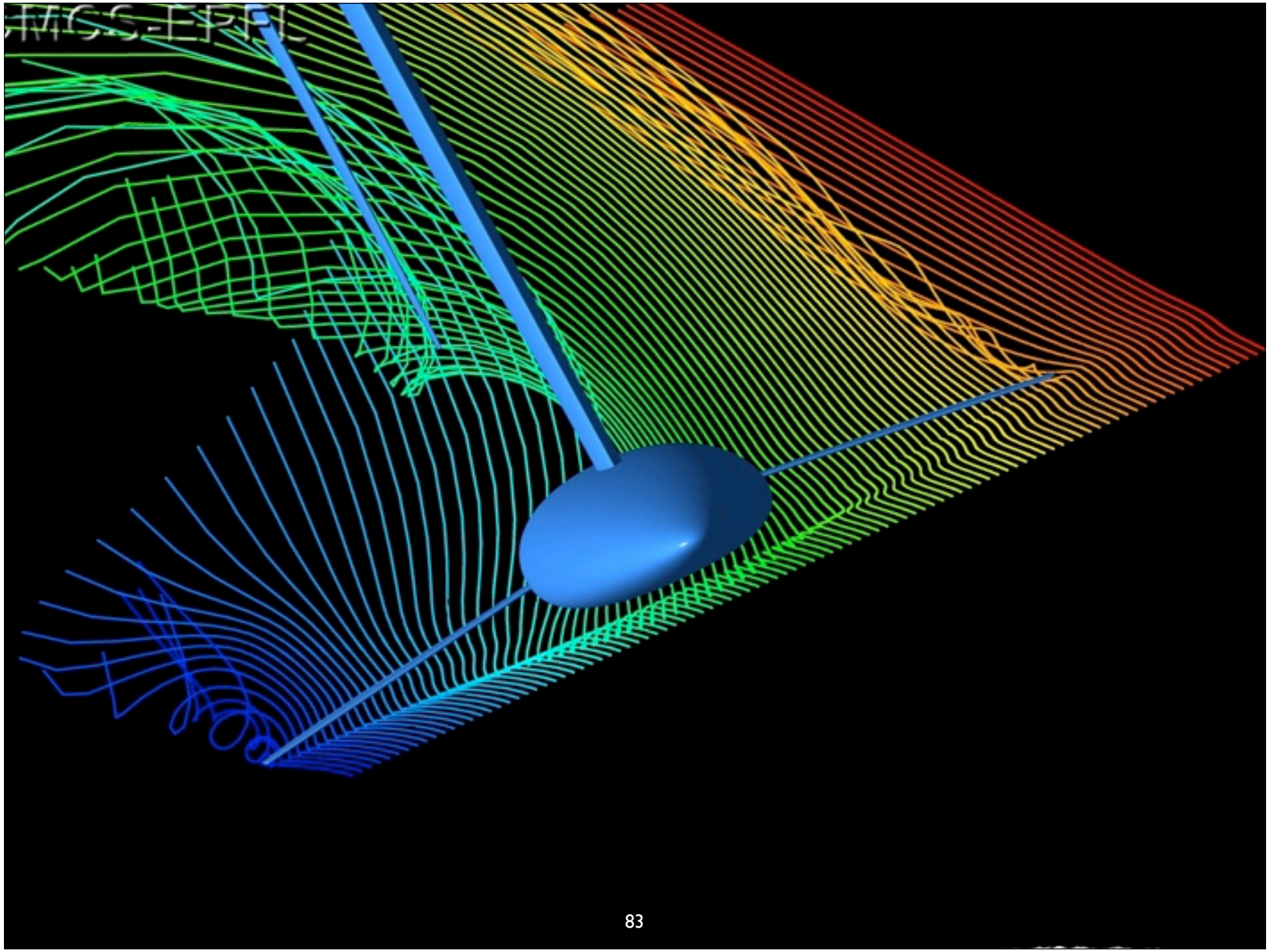
AC32-2007

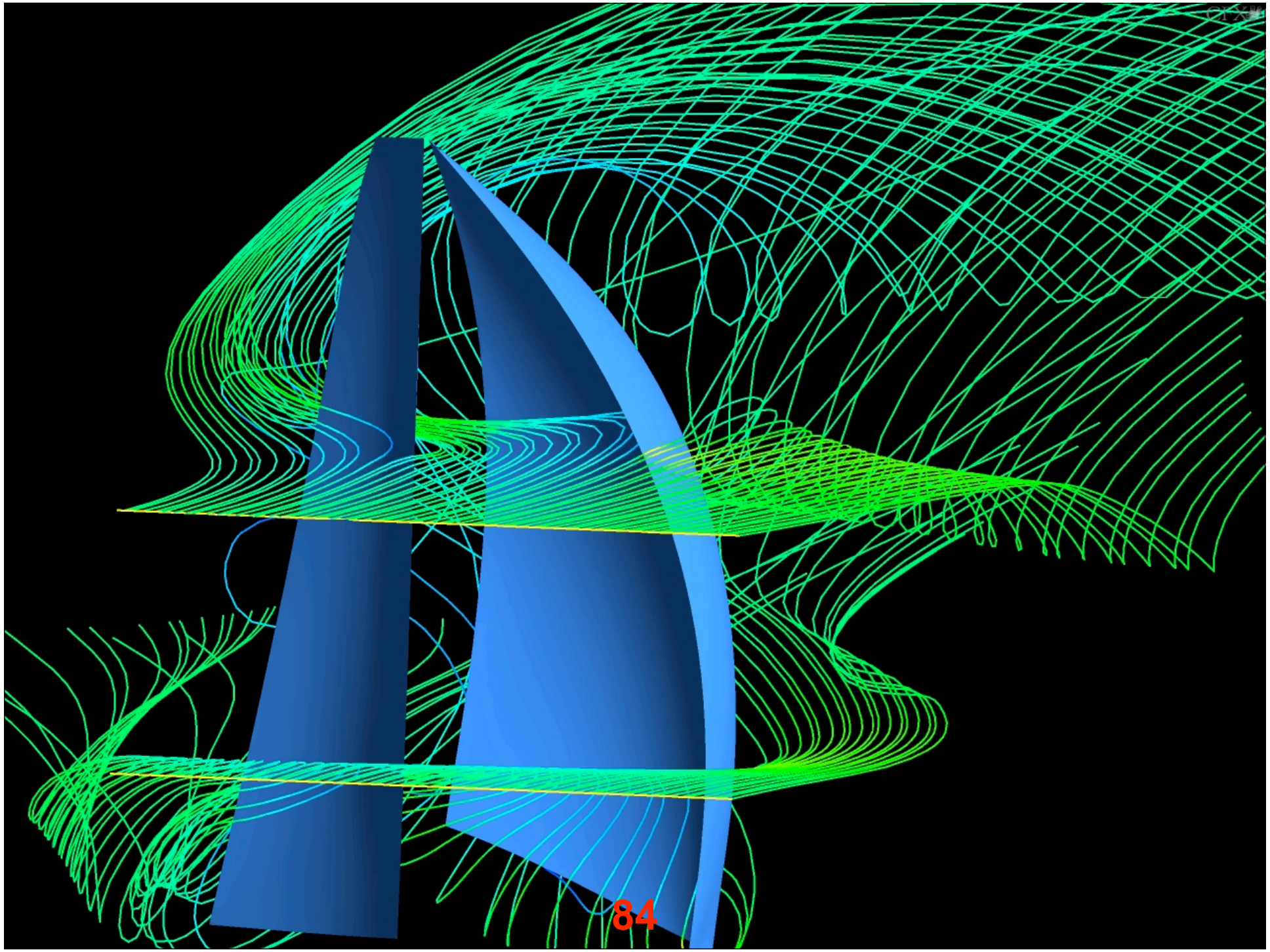
(N.Parolini, D.Detomi, A.Q.)


Pressure
(FWDBeam2)
6.000e+01
-5.500e+01
-1.700e+02
-2.850e+02
-4.000e+02
[Pa]
0
10.000
20.000 (m)
5.000
15.000
AC33-2010
AC 2010
ALINGHI 5
the Multihull
33RD AMERICA'S CUP
ALINGHI 5
HISSE LES VOILES ∂ SETS SAIL
HUBLOT
PHOTO
80

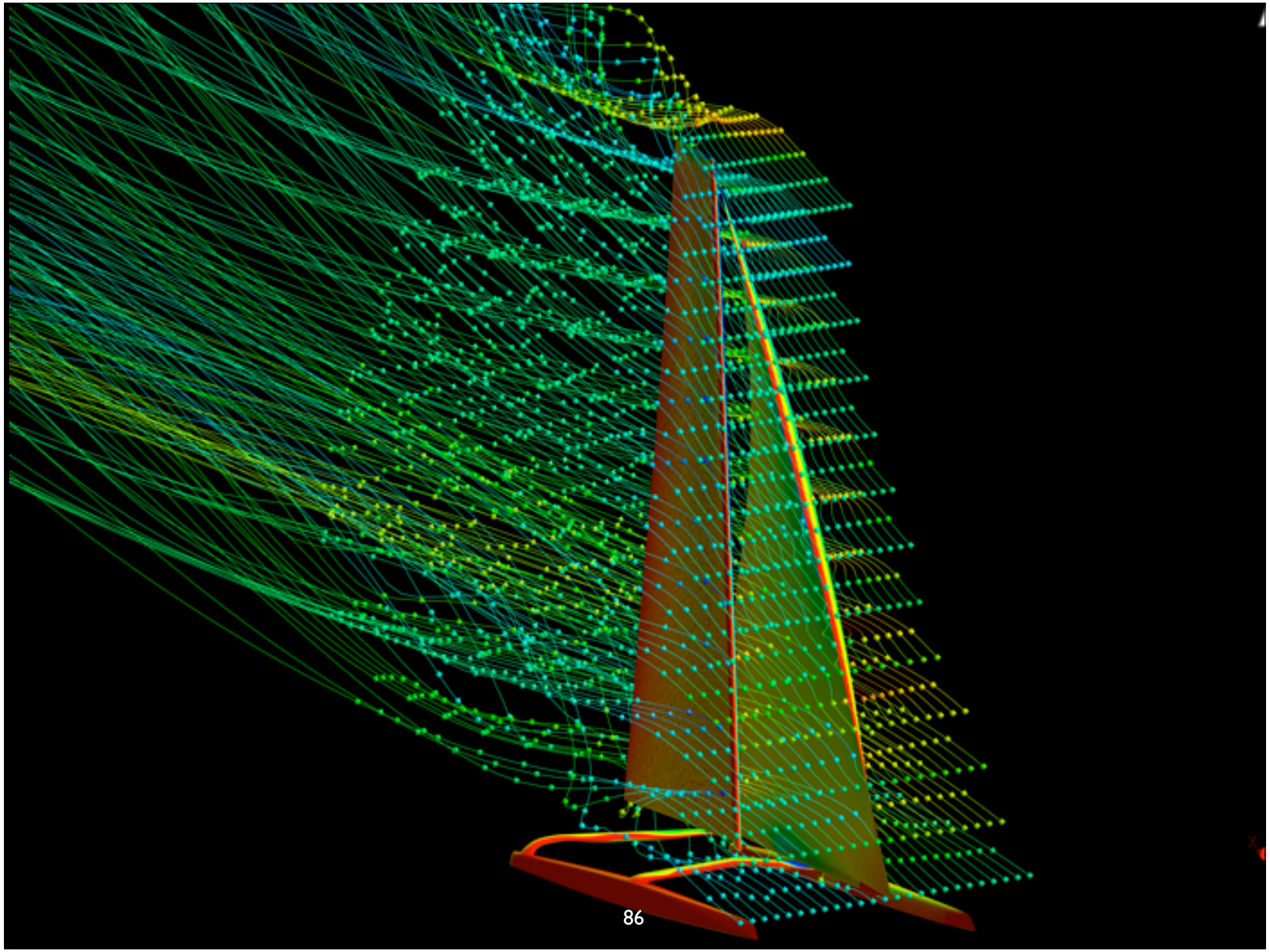

UBS

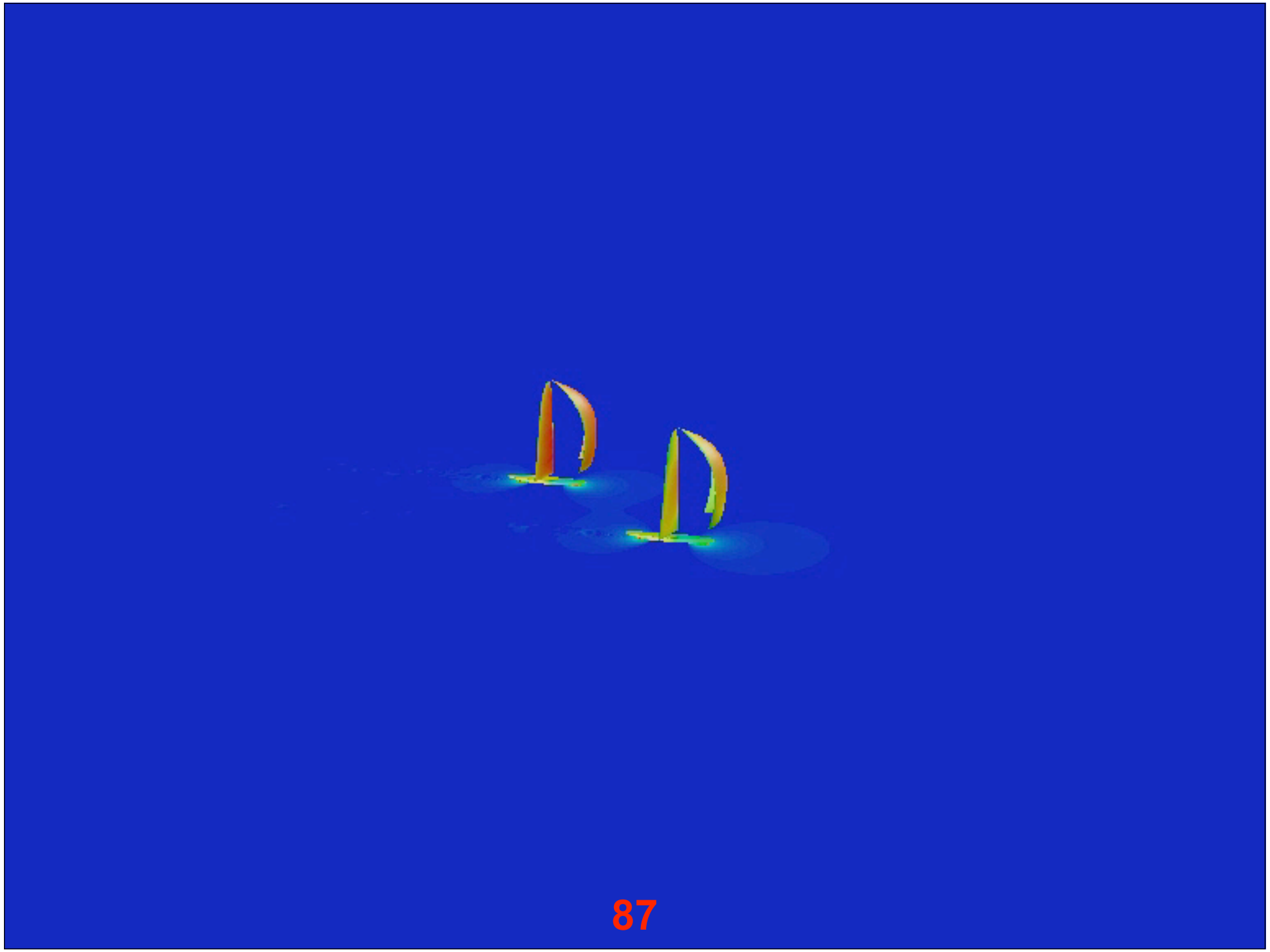







VD 915





Muchas Gracias