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Biophysical modeling of atrial signals

The Lausanne heart group

(www.lausanneheart.ch)

The Lausanne Heart Group

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Collaborators

- T.F. Oostendorp, Medical Physics, University of Nijmegen, The Netherlands
- R. Hoekema; Cardiology; University of Nijmegen, The Netherlands
- P. van Dam; Vitatron, Arnhem, The Netherlands
- Members of the CHUV/EPFL HEART TEAM Lausanne, Switzerland

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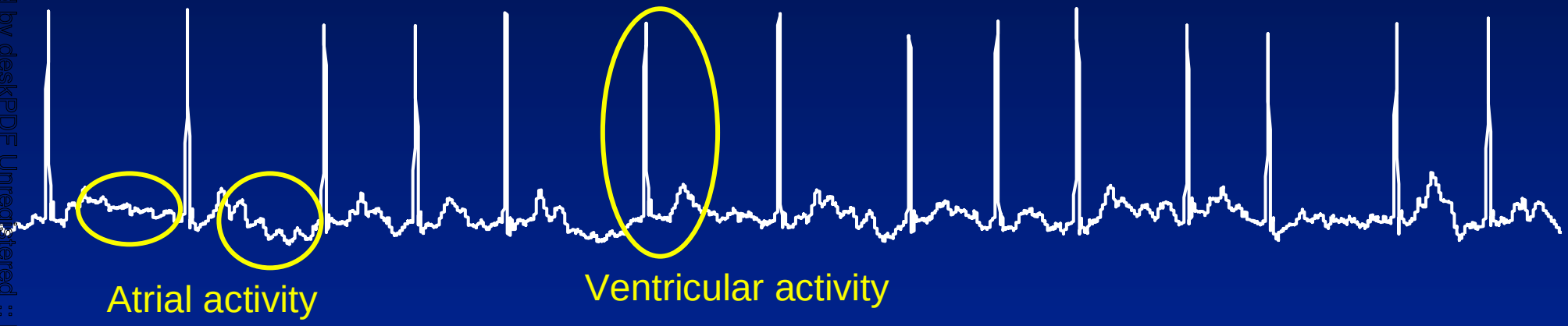
Problem Statement

Surface ECG during Atrial Fibrillation (AF)

The most common tool used for the clinical evaluation of arrhythmias



Can we extract from these signals any information about AF dynamics ?

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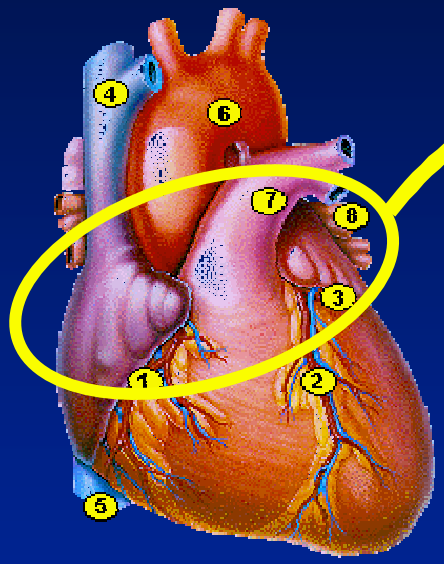
Approach

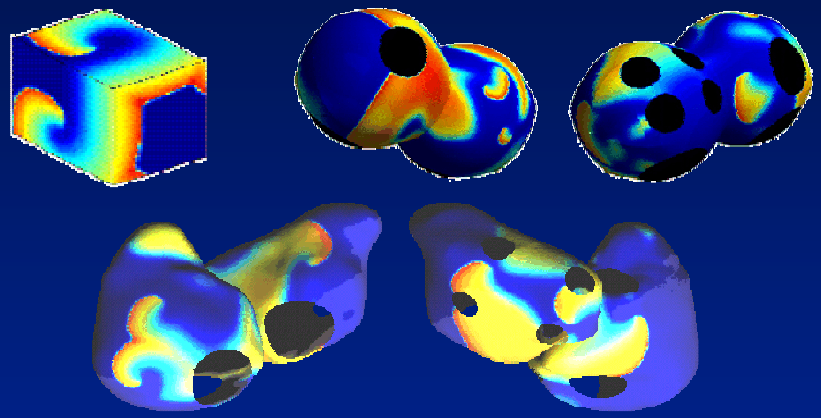
Human Heart

Virtual Heart

(Biophysical models)

Atria





Study of the initiation and the perpetuation of atrial arrhythmias

Compare with clinical signals

Evaluate; aim: to improve diagnostics and therapies

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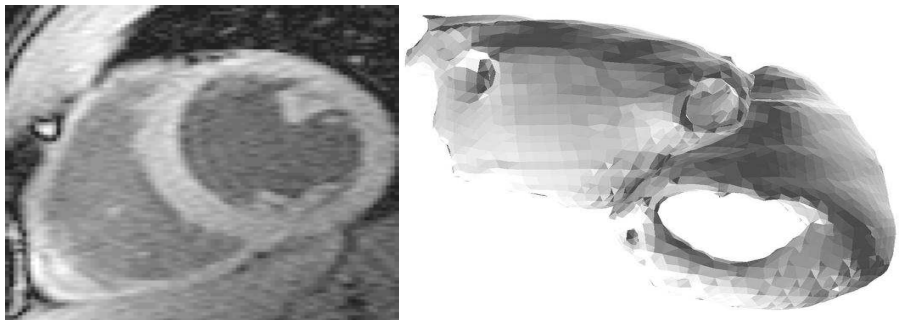
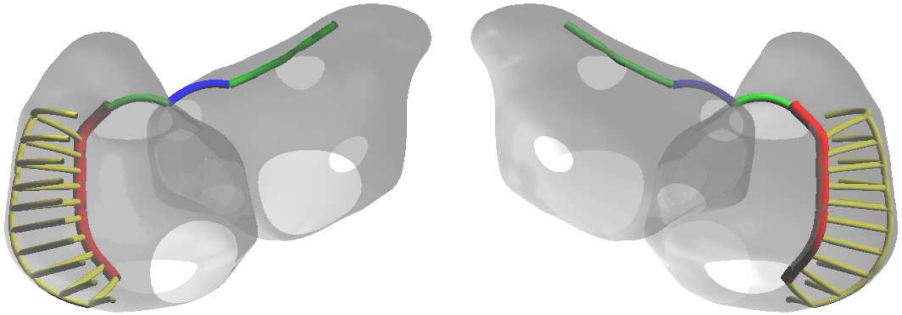
The Lausanne Atrial Model

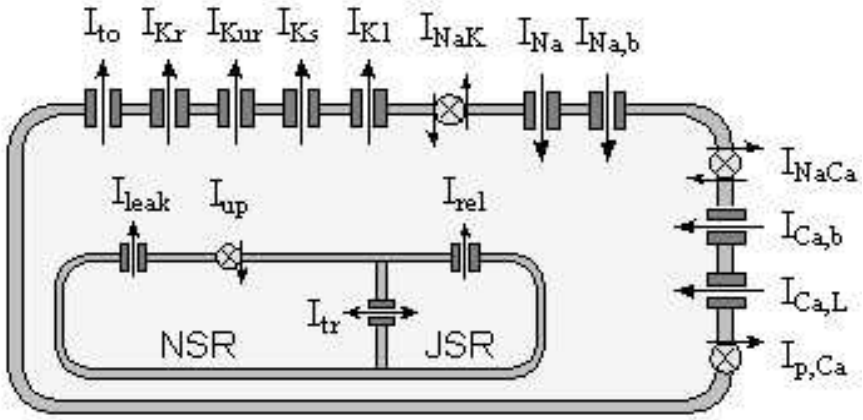
3D Geometry from MR images



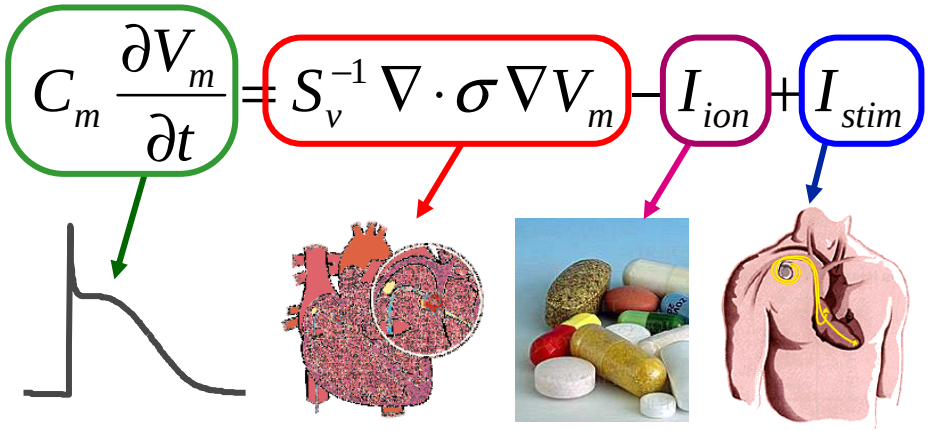
Special propagating bundles (?)



Membrane kinetics



Propagation of the electrical impulse



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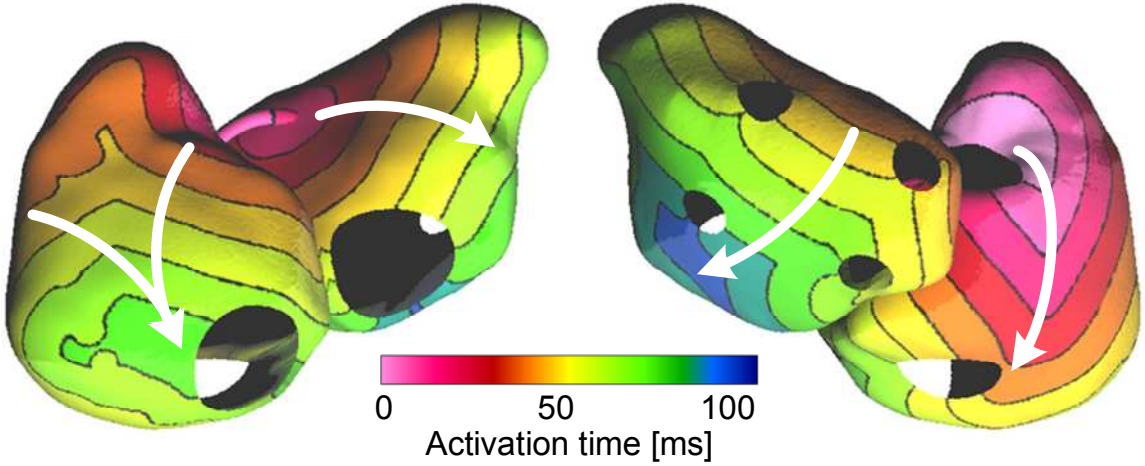
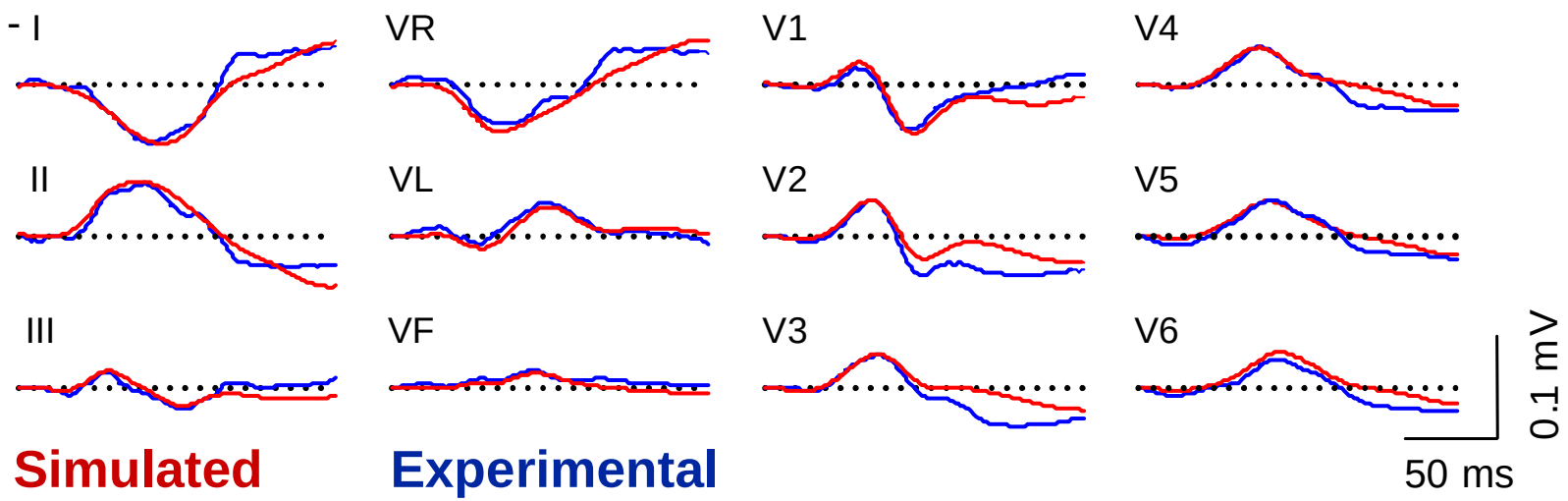
Normal Propagation



Isochrone map of spread of activation

12-lead ECG



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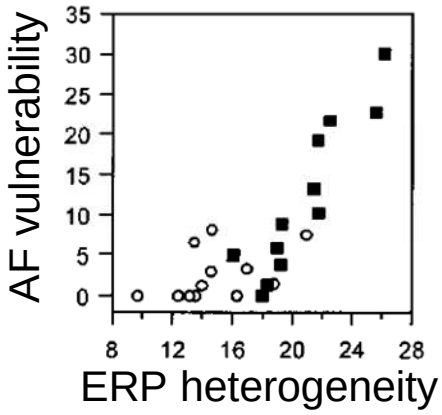
Arrhythmogenic Substrate

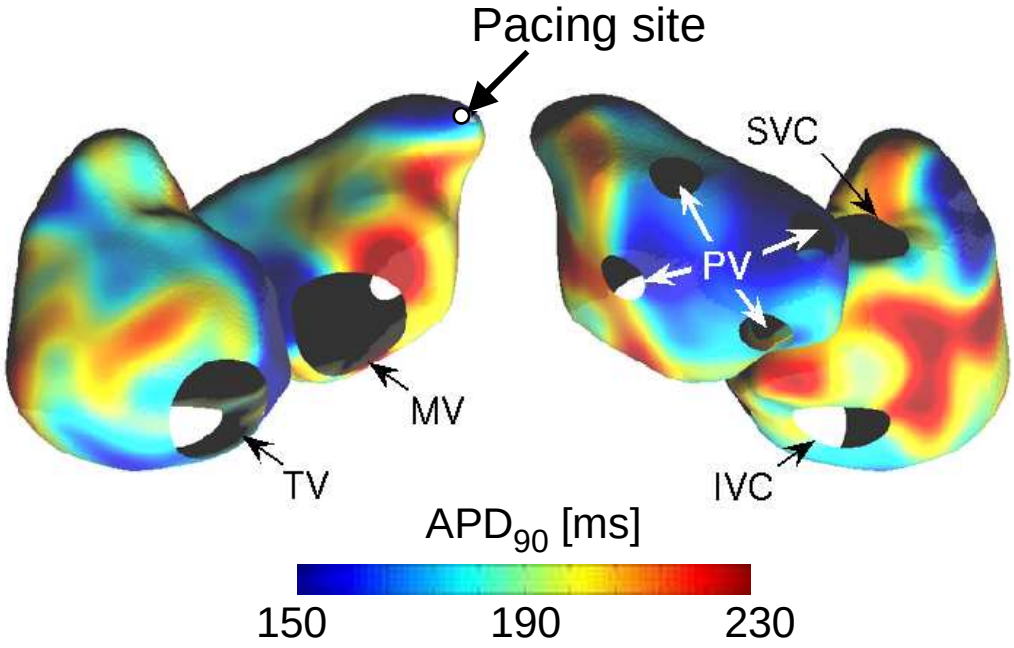
Fareh et al. Circulation 1998

ERP heterogeneity is an arrhythmogenic factor



ERP gradients facilitates wave breaks

Intrinsic heterogeneity in refractoriness



Initiation protocol :

Rapid pacing in the left atrium appendage

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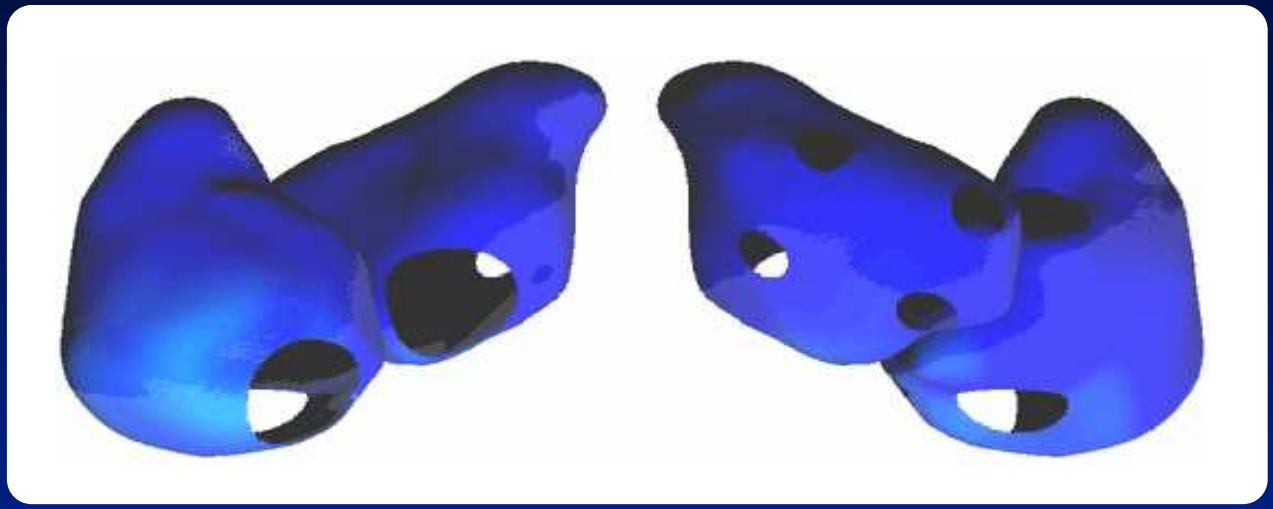
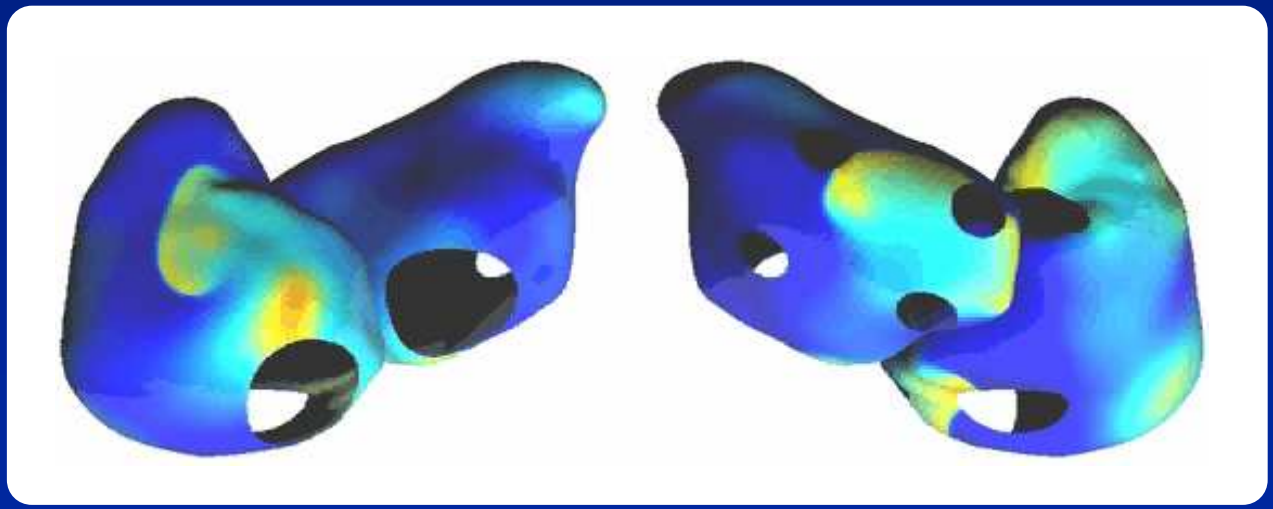
Simulated AF



Initiation

Pacing in the left appendage;

Self-Terminating



Self-Perpetuating

Multiple wavelets

Wavebreaks due to heterogeneities

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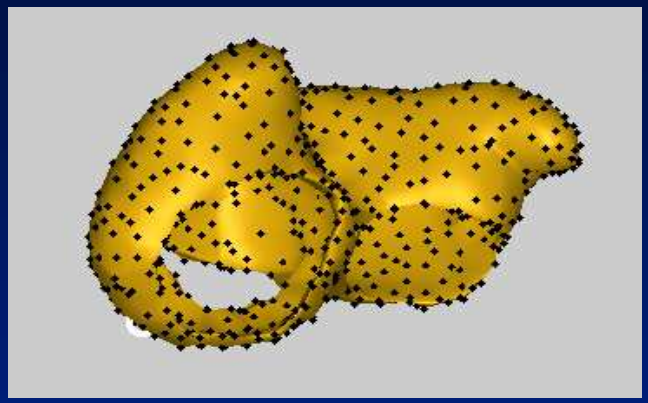
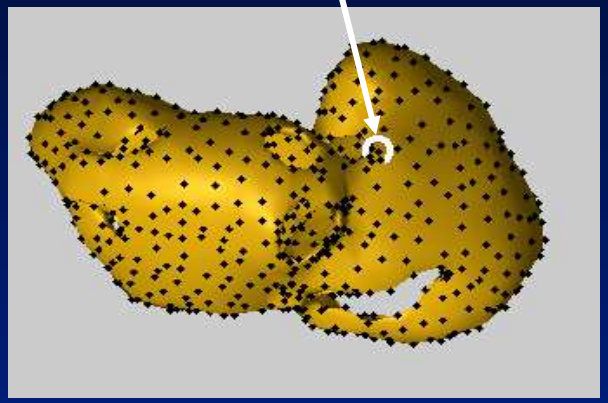
Conversion to EDL source model



anterior view



posterior view

Thick wall variant; MRI based geometry

- wall thicknes approx. 2 mm
- 1300 nodes on closed surface
- topology: 6th order doughnut

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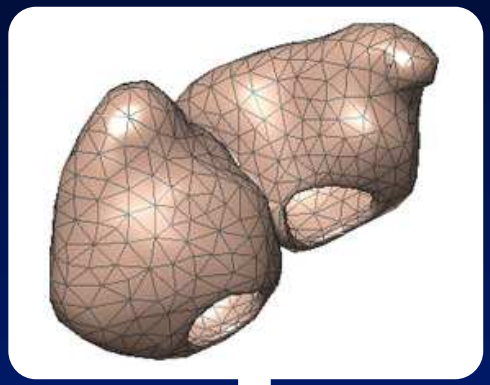
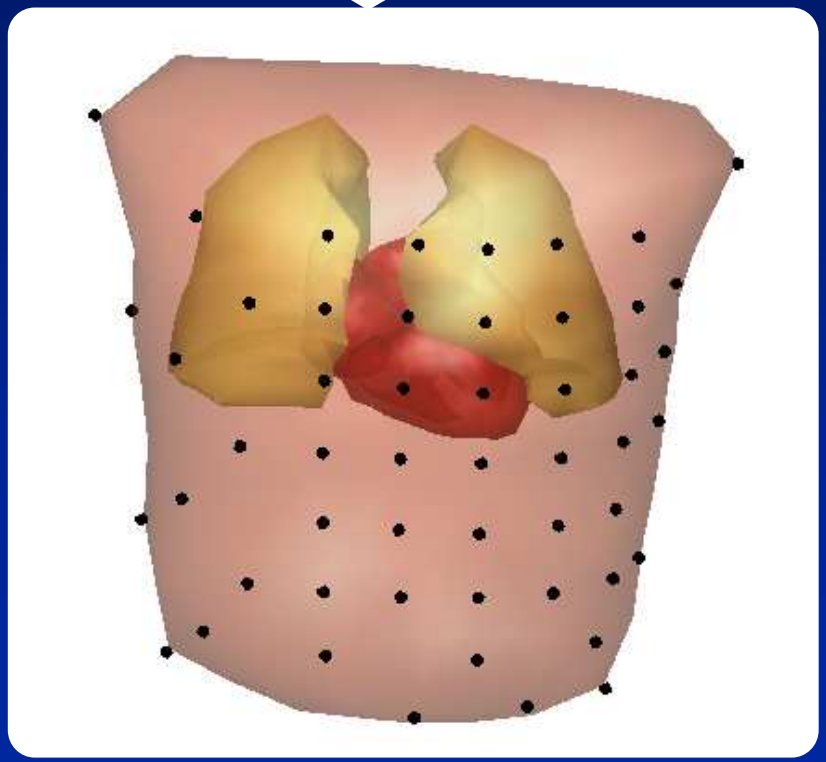
Volume Conductor Model





The atrial tissue as a current source for a volume conduction problem

$$\nabla \cdot \sigma \nabla \phi = I_{src}$$

Tissue conductivity

Electric potential

Membrane currents

- Compartmental torso model (lungs, blood cavities)
- Boundary element method
- Nijmegen 64-lead system
- Standard 12-lead system

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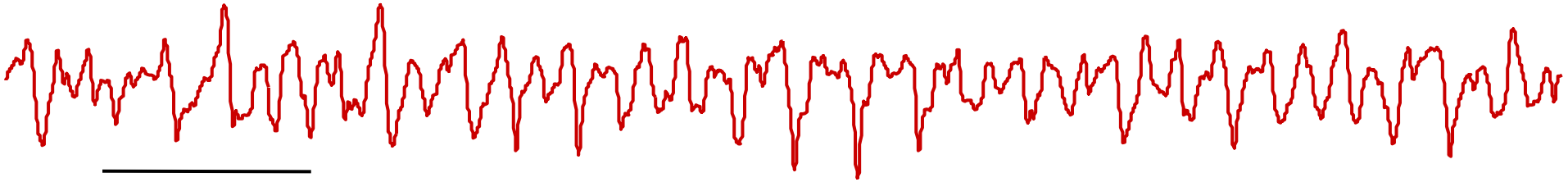
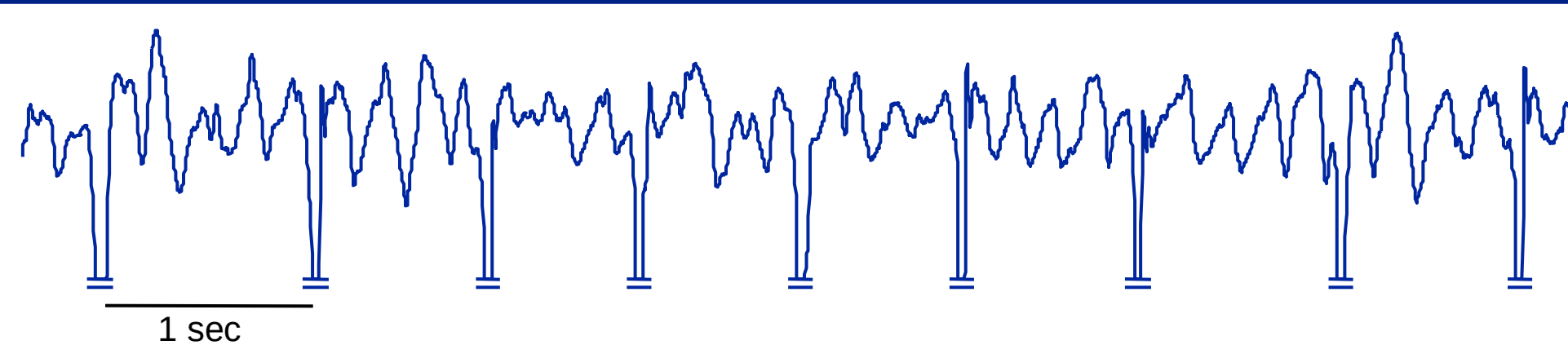
Comparison of ECGs during AF

Simulated ECG (lead V1)



Example of clinical ECG (lead V1)



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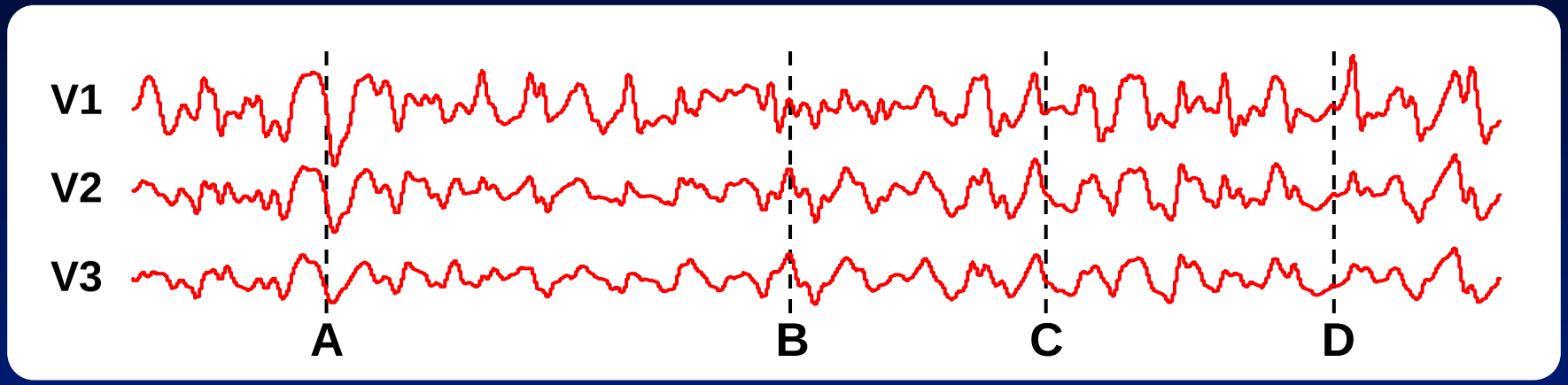
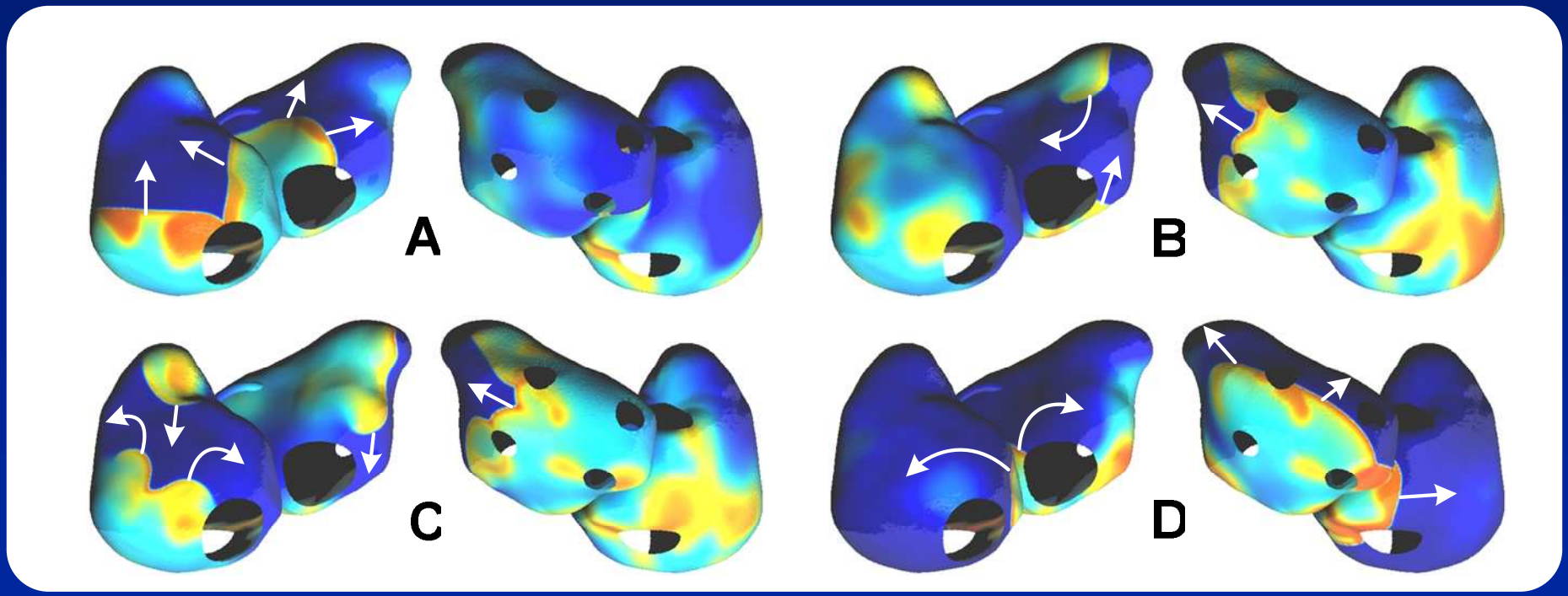
Link Between ECGs and Atrial Wavelets





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Applications (so far)

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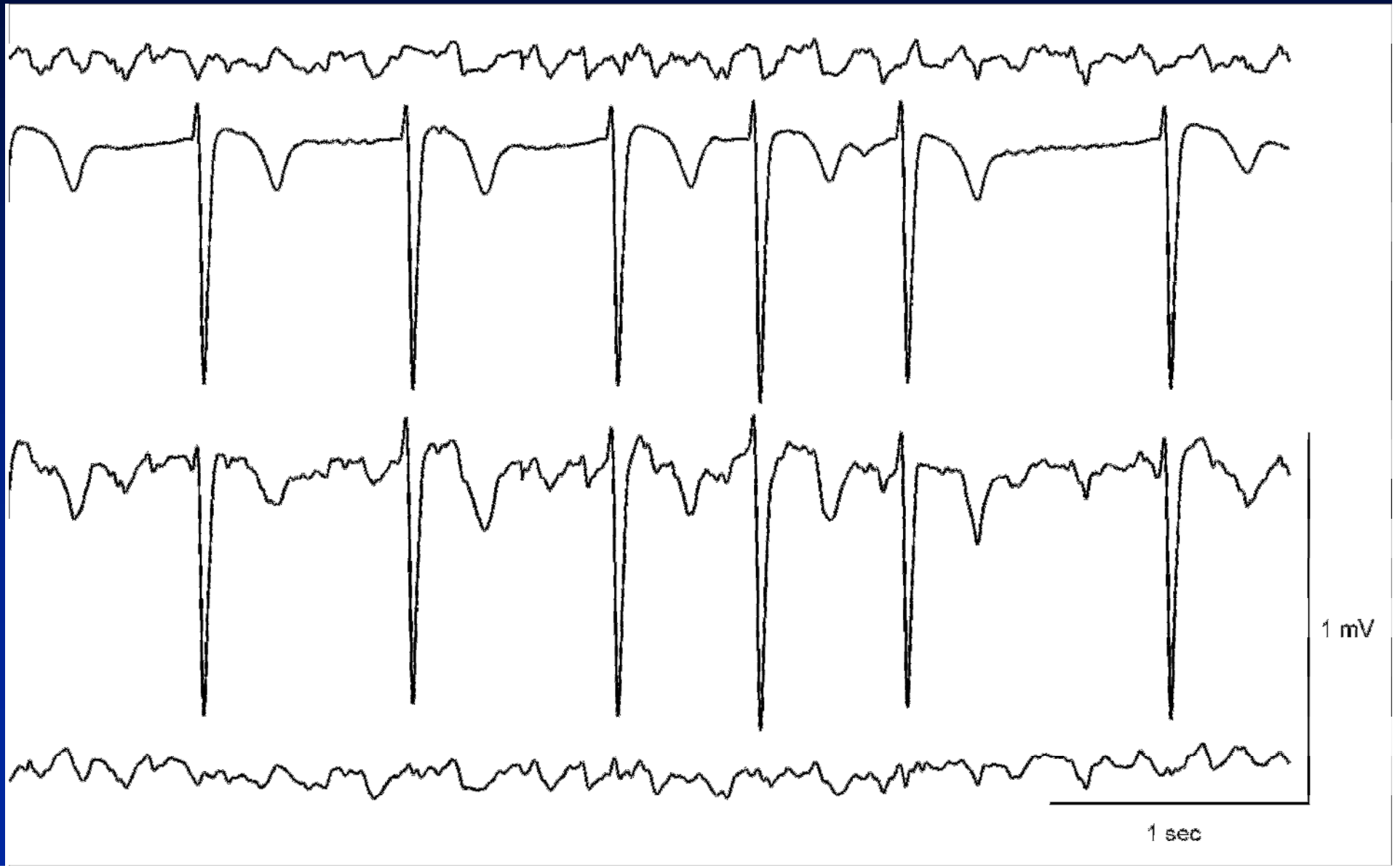
1) QRST suppression (V1)



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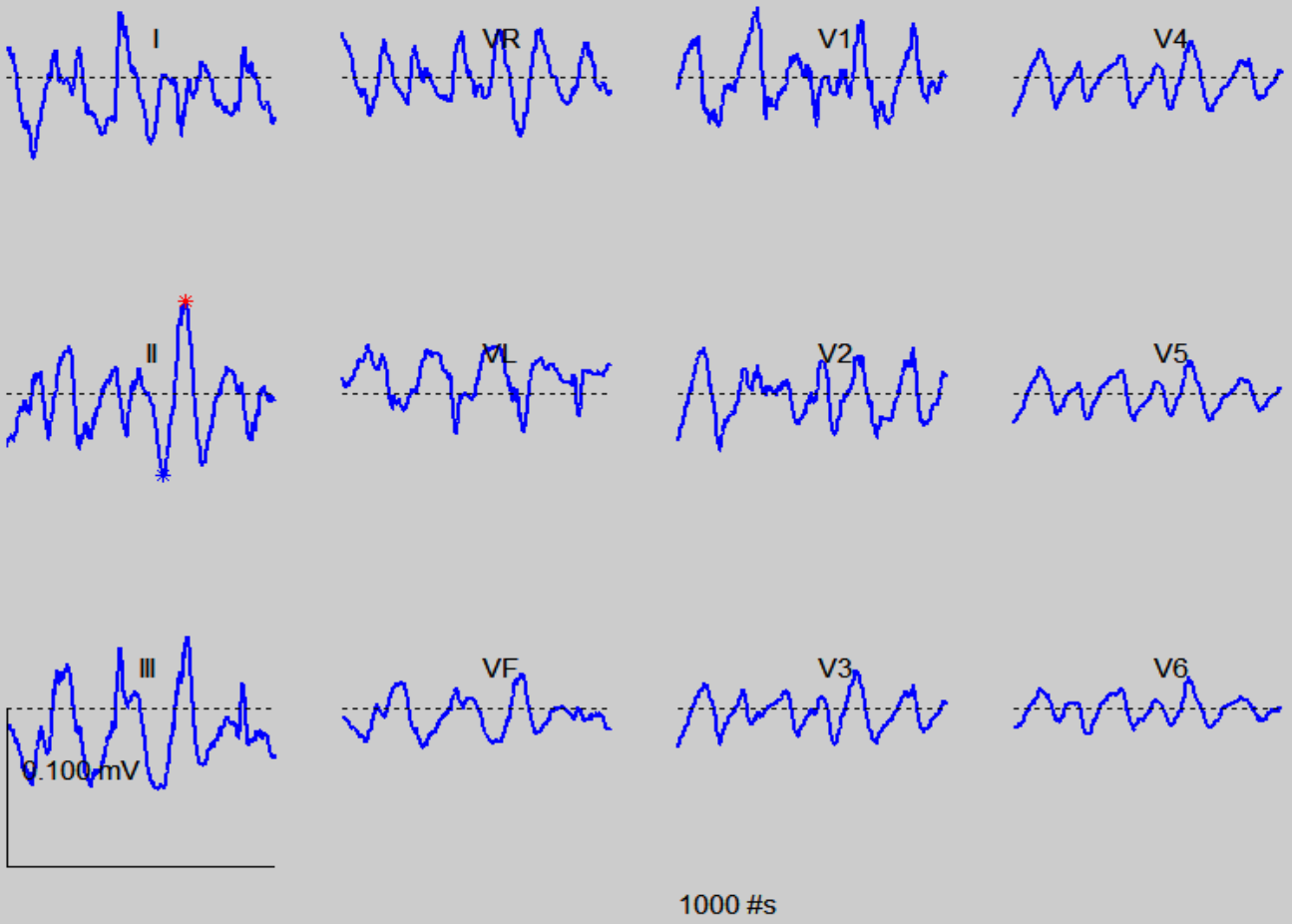
2) Optimal lead systems

Simulated AF in the standard 12-ld ECG



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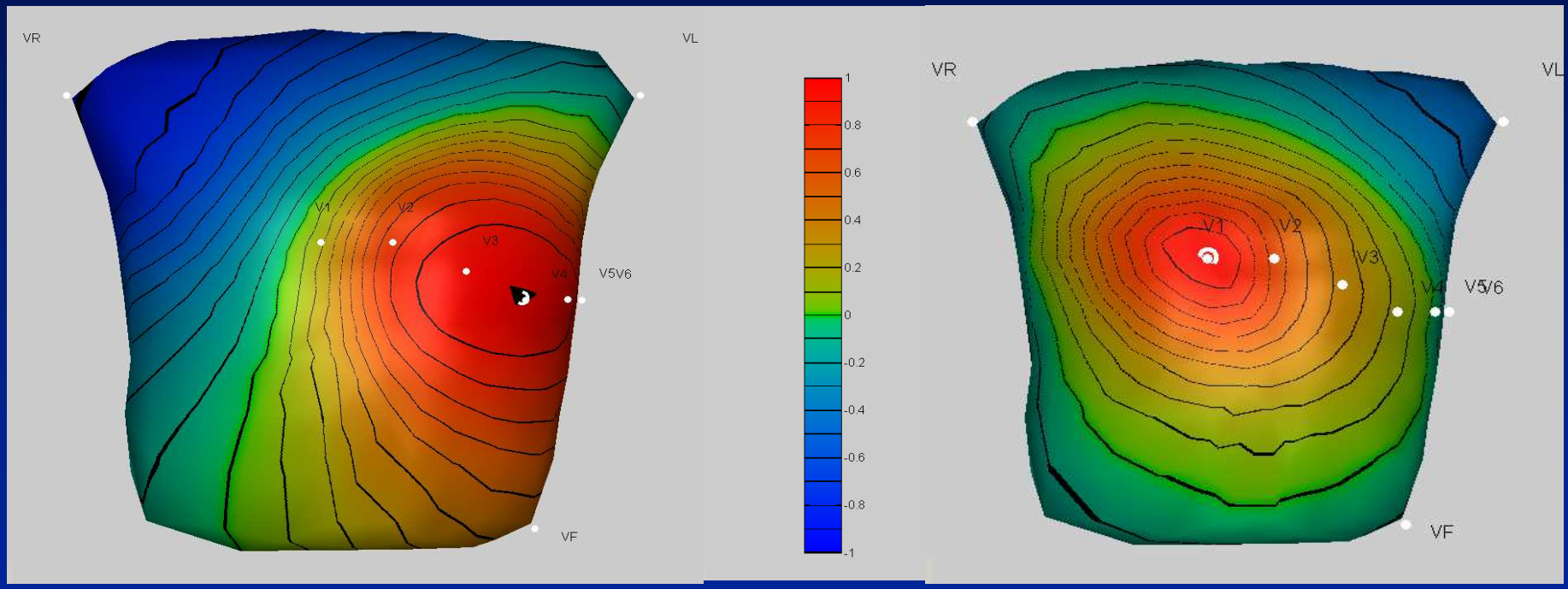
Correlation maps during AF



V_4 V_1

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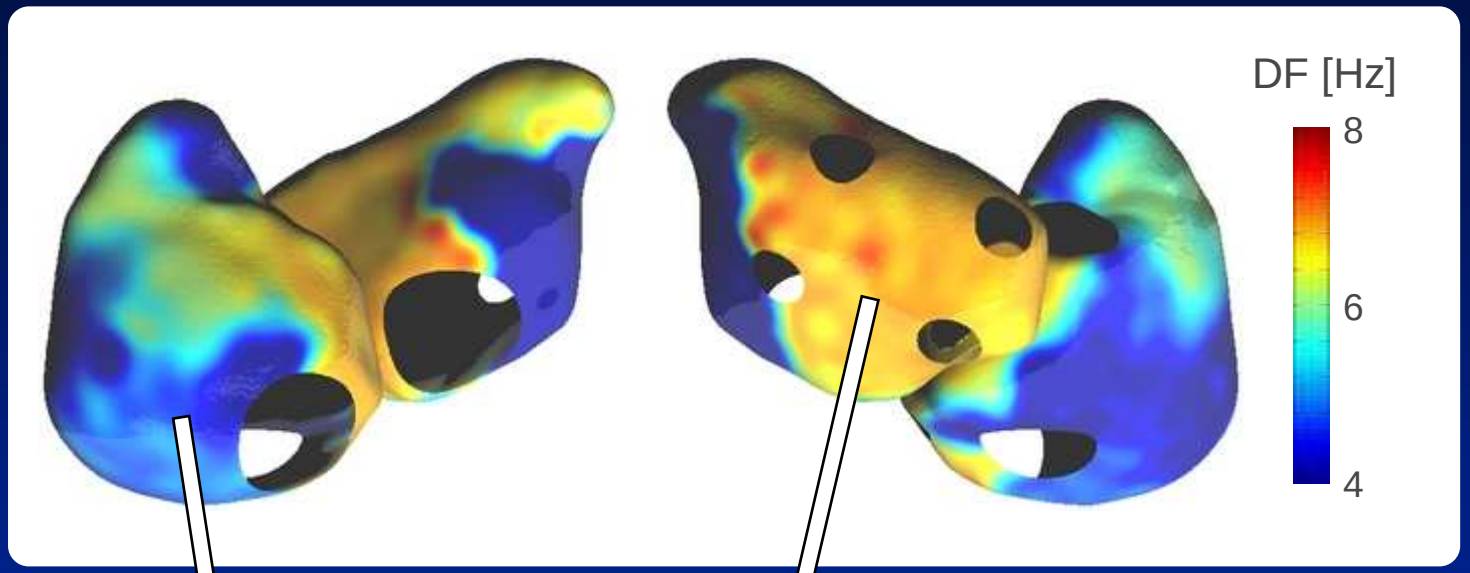
3) Frequency Analysis of Atrial Electrograms

Dominant Frequency Map

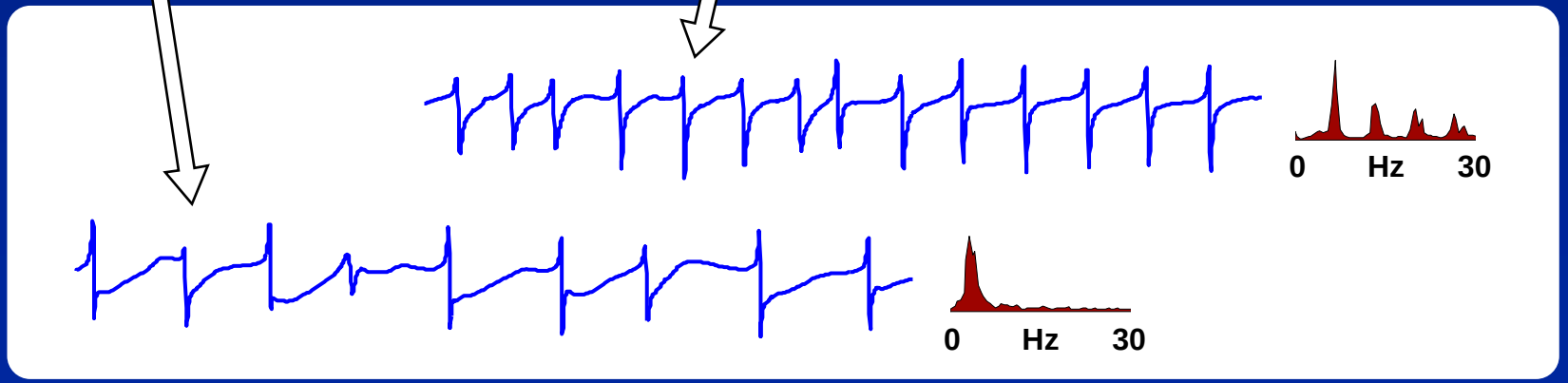


Average DF

Left atrium
6.3 ± 1.1 Hz

Right atrium
5.7 ± 0.8 Hz

Overall
6.0 ± 1.0 Hz



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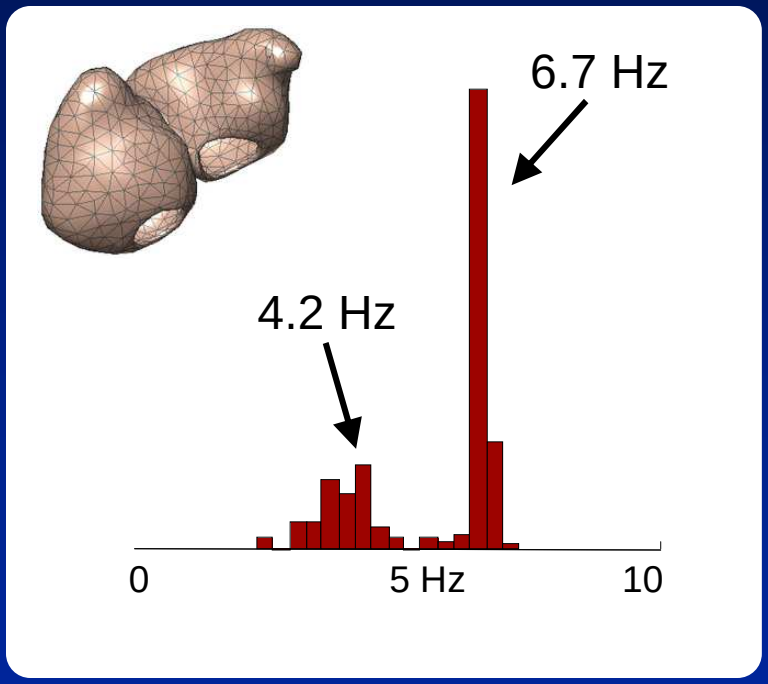
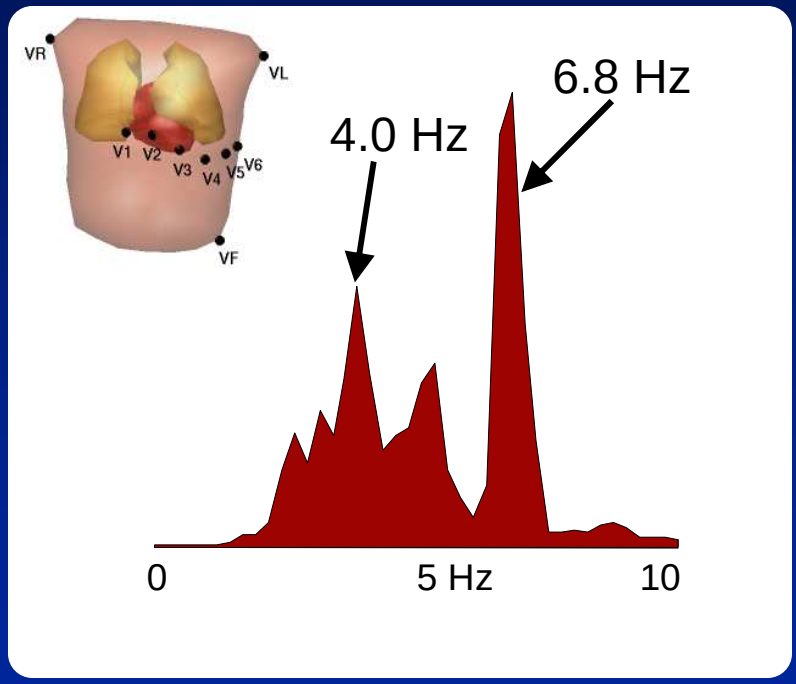
Atrial Electrograms vs ECGs

Histogram of atrial dominant frequencies



Frequency spectrum of Lead V2



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Summary

- model based analysis of the atrial signals in the ECG
- focus on AF
- multi-unit model of atrial myocytes, involving membrane kinetics
- expression of atrial sources in the ECG by means of volume conduction models of the thorax
- 1) development of dedicated preprocessing tools
- 2) search for optimal lead placement
- 3) search for signal processing methods for the characterization of AF

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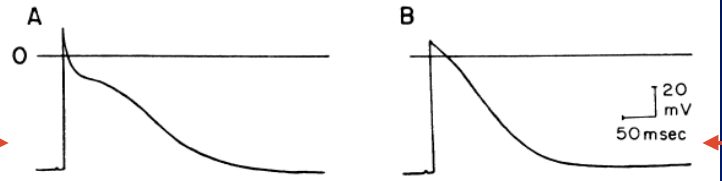
Atrial TMPs, early data

atrial specialized fibers



atrial contractiles fibers

FIGURE 1

Transmembrane action potentials (TAP) recorded from two types of atrial fibers. Top trace in each panel is line of zero potential. **A:** *Typical TAP recorded from an atrial specialized fiber. There is a prominent overshoot, followed by a period of rapid repolarization and then a prolonged phase of slow repolarization (plateau).* **B:** *TAP from an atrial contractile fiber. In contrast to A, separate phases of repolarization cannot be distinguished in contractile fibers.*

Circulation Research, Vol. XXX, March 1972

Electrophysiologic Properties of Isolated Preparations of Human Atrial Myocardium

By Henry Gelband, Harry L. Bush, Michael R. Rosen, Robert J. Myerburg, and Brian F. Hoffman

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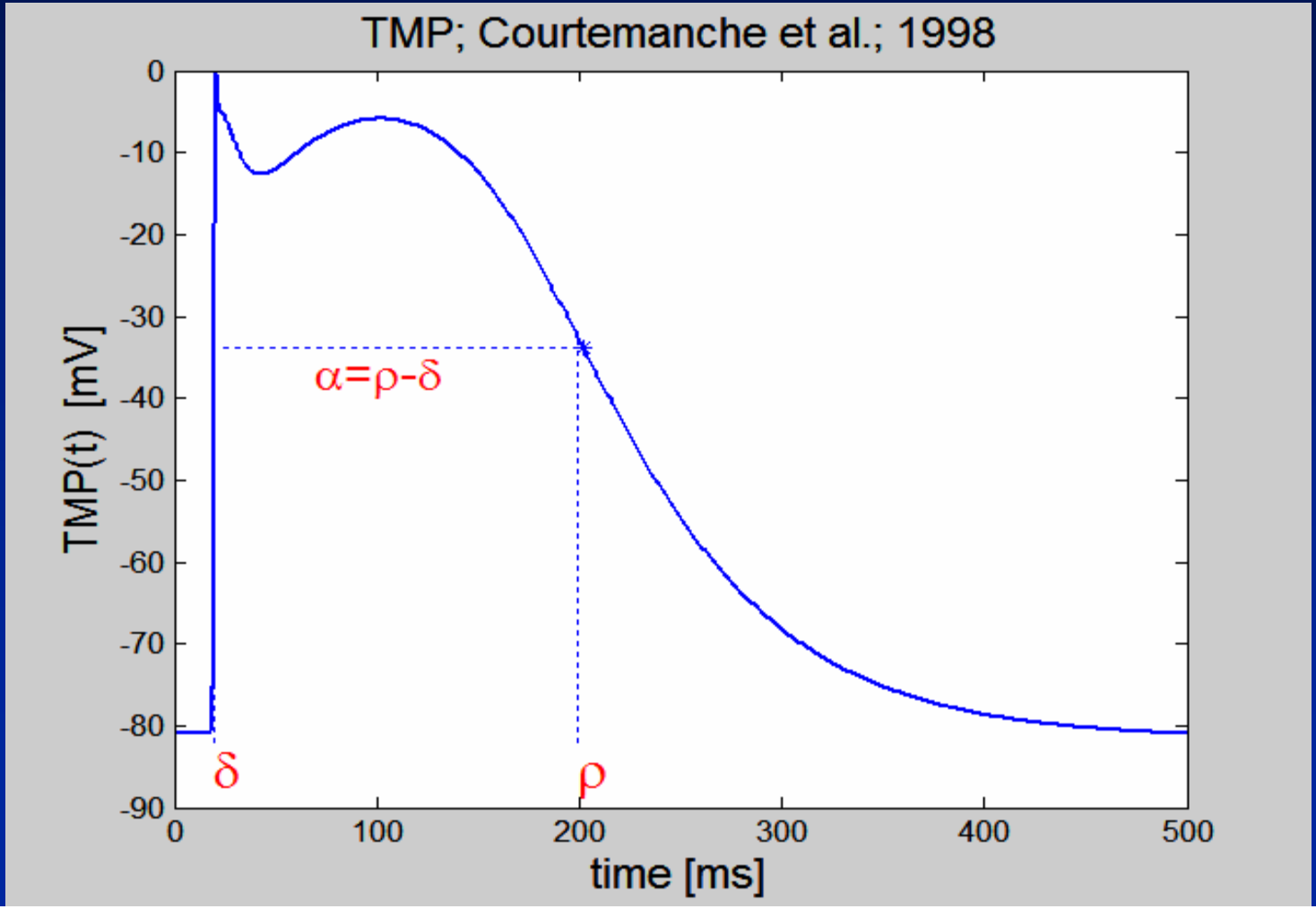
The timing of TMPs

depolarization: δ_n repolarization: ρ_n

wave form set by: $\alpha_n=\rho_n-\delta_n=ARI_n$



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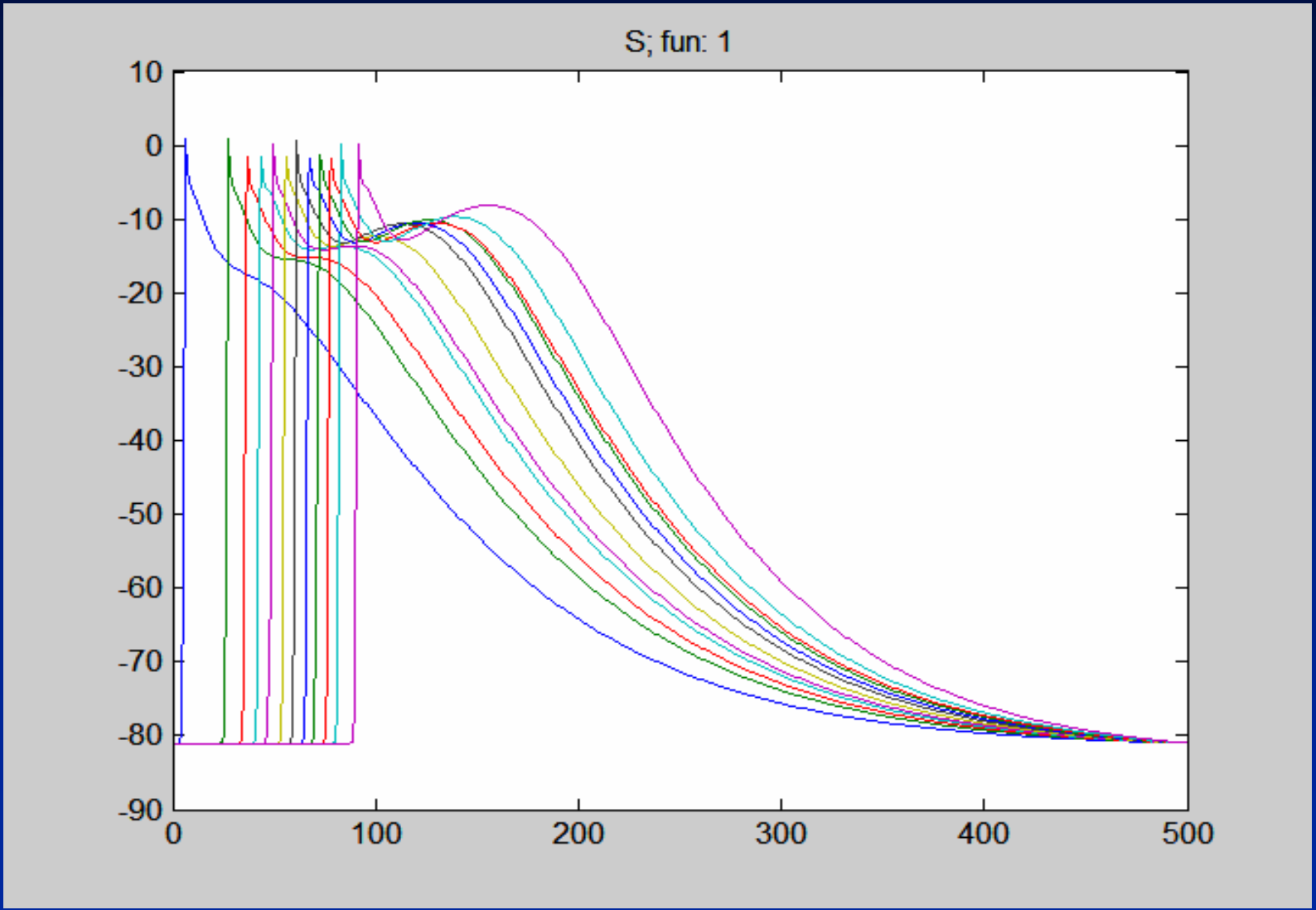
wave forms for different δ_n ,ρ_n values



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