Is respiration the major regulator of CSF flow?

A computational study based on in vivo pressure measurements

Vegard Vinje
Simula Research Laboratory

P. K. Eide
K-A. Mardal
M. Rognes

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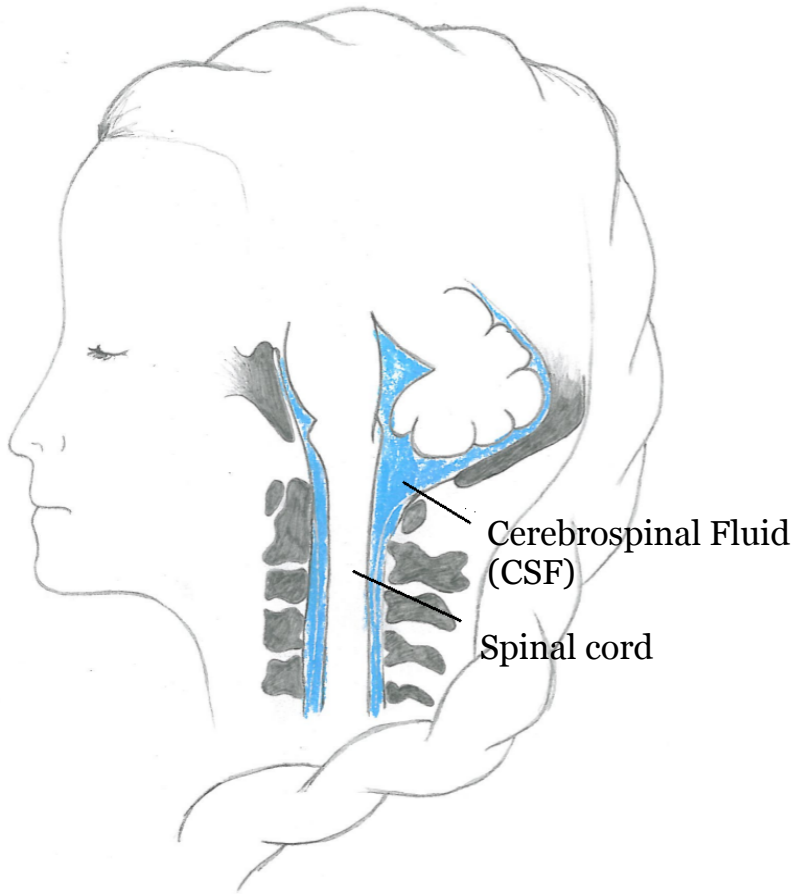

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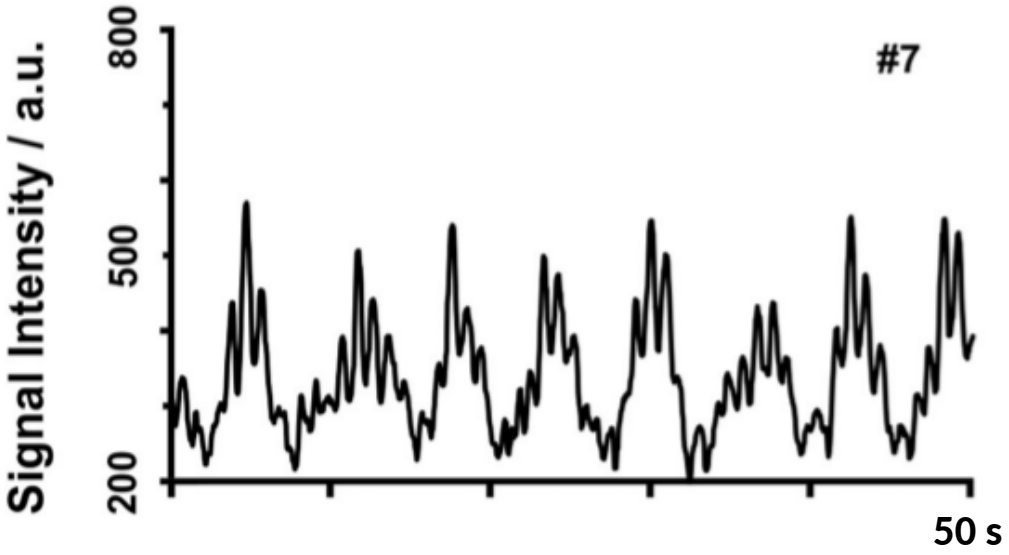
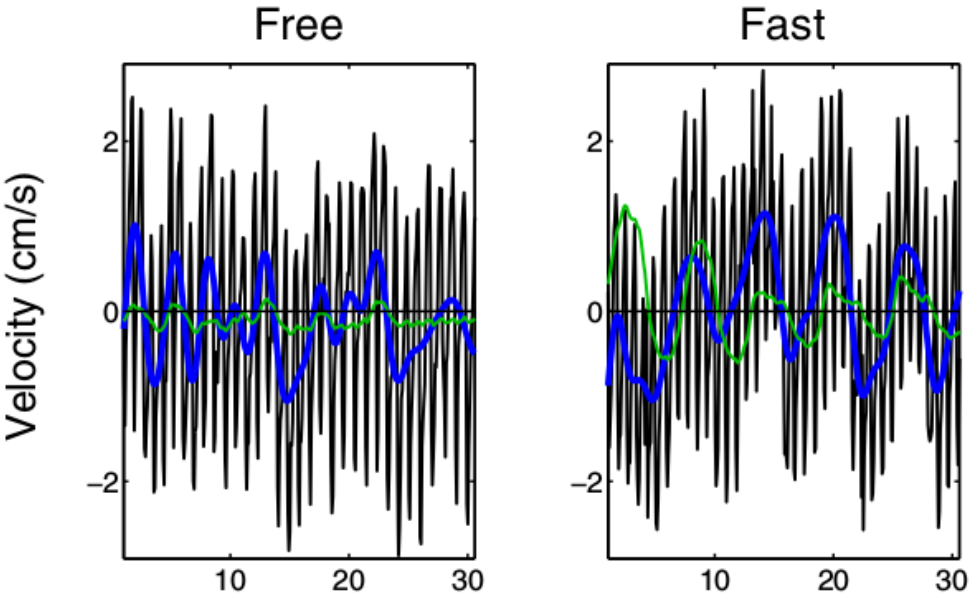
UiO : University of Oslo

MRI studies have revealed respiratory CSF motion in the aqueduct

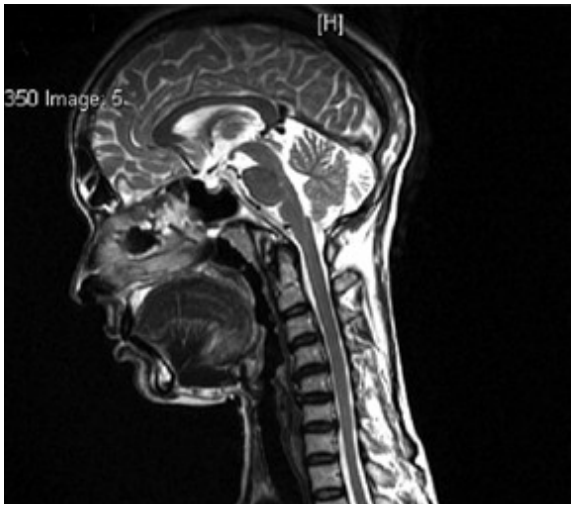


Dreha-Kulaczewski et al., 2015

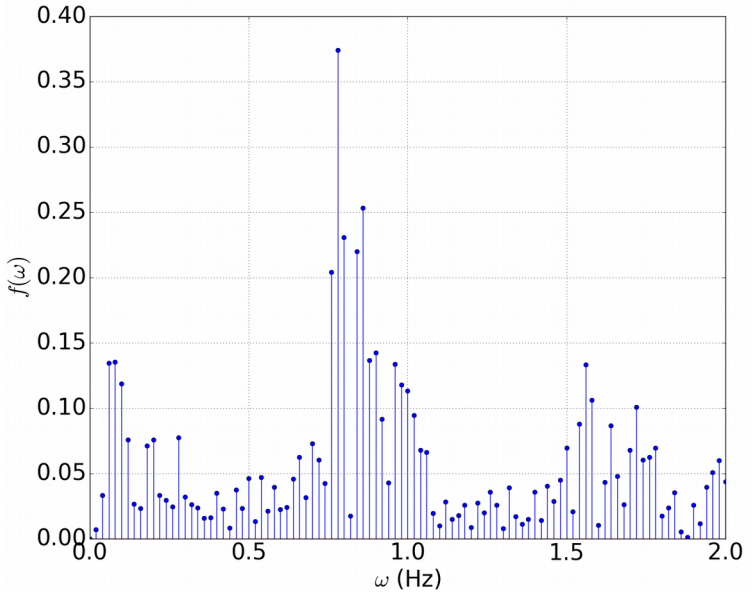


Chen et al., 2015

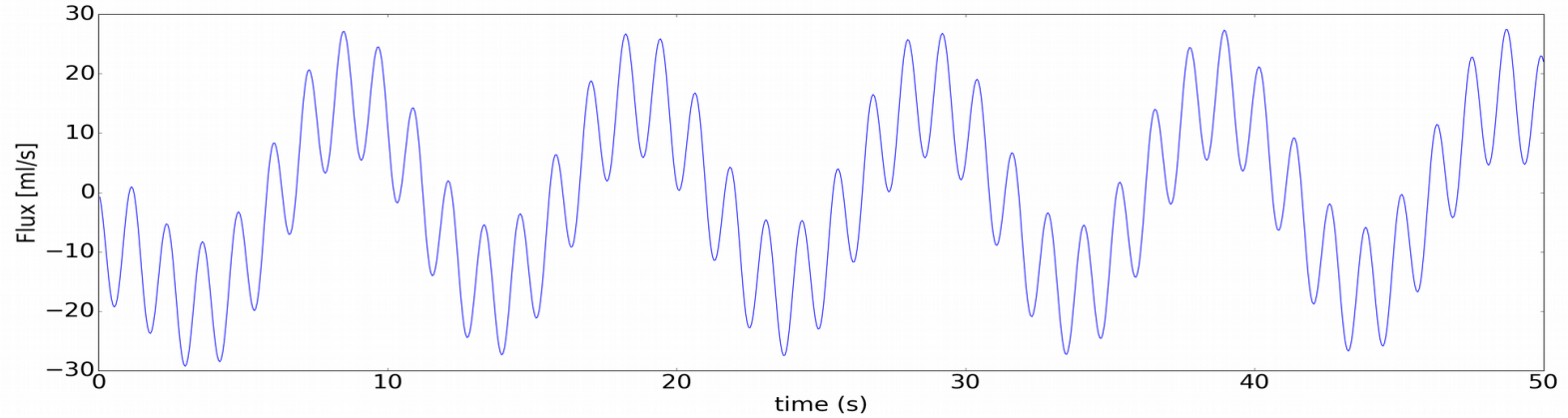
In this study we calculate CSF flow based on in vivo pressure measurements



In vivo measurements of intracranial (ICP) and lumbar (LP) pressure

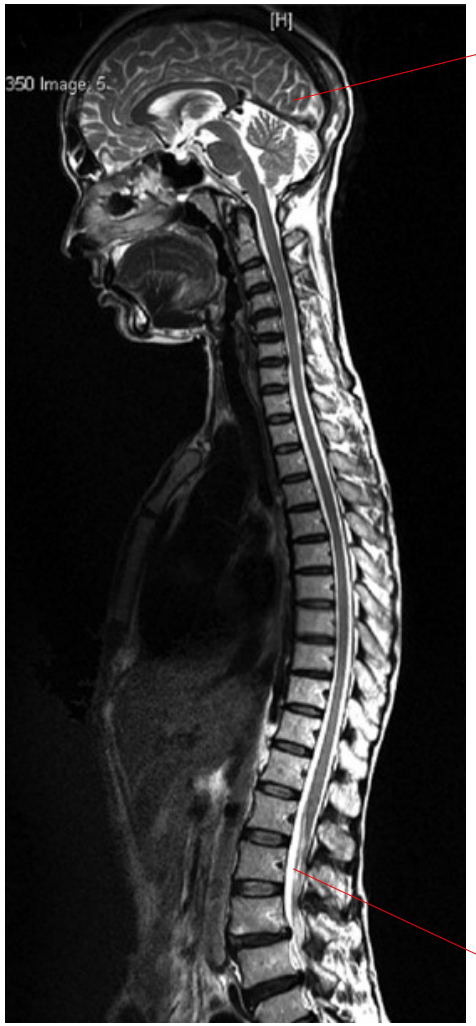


Extract frequency and amplitudes from fourier transform of $\Delta p = ICP - LP$



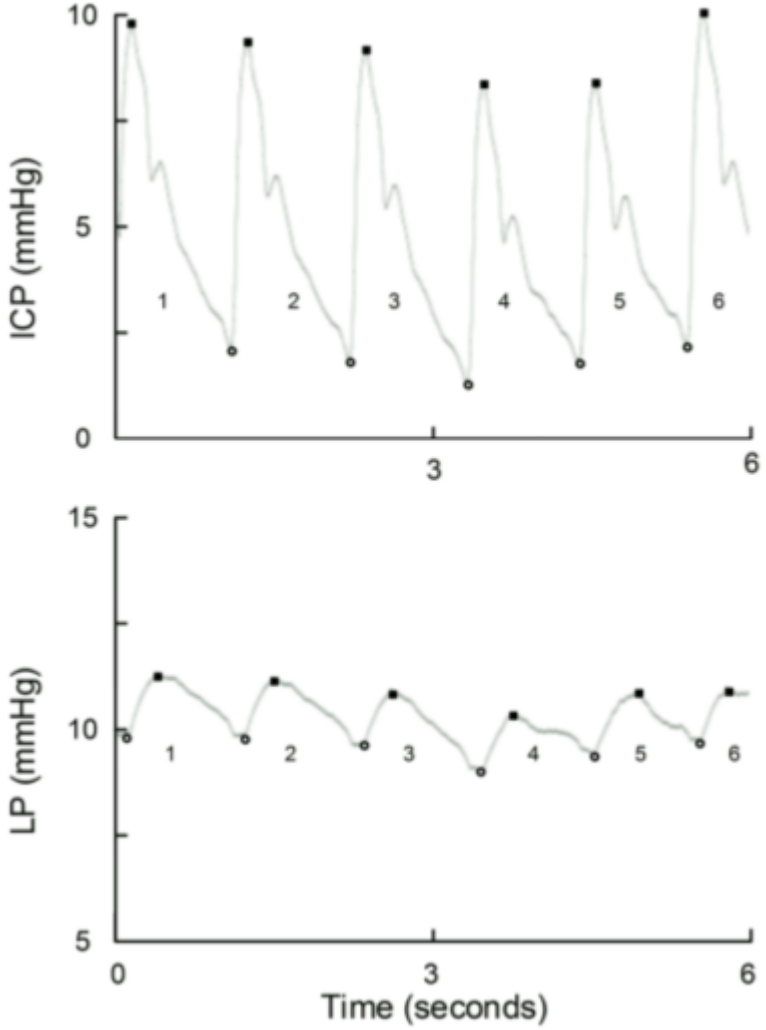
CFD calculations of flow resulting from the dominant pressure frequencies

Simultaneous measurements of intracranial (ICP) and lumbar (LP) pressure



ICP(t)

LP(t)

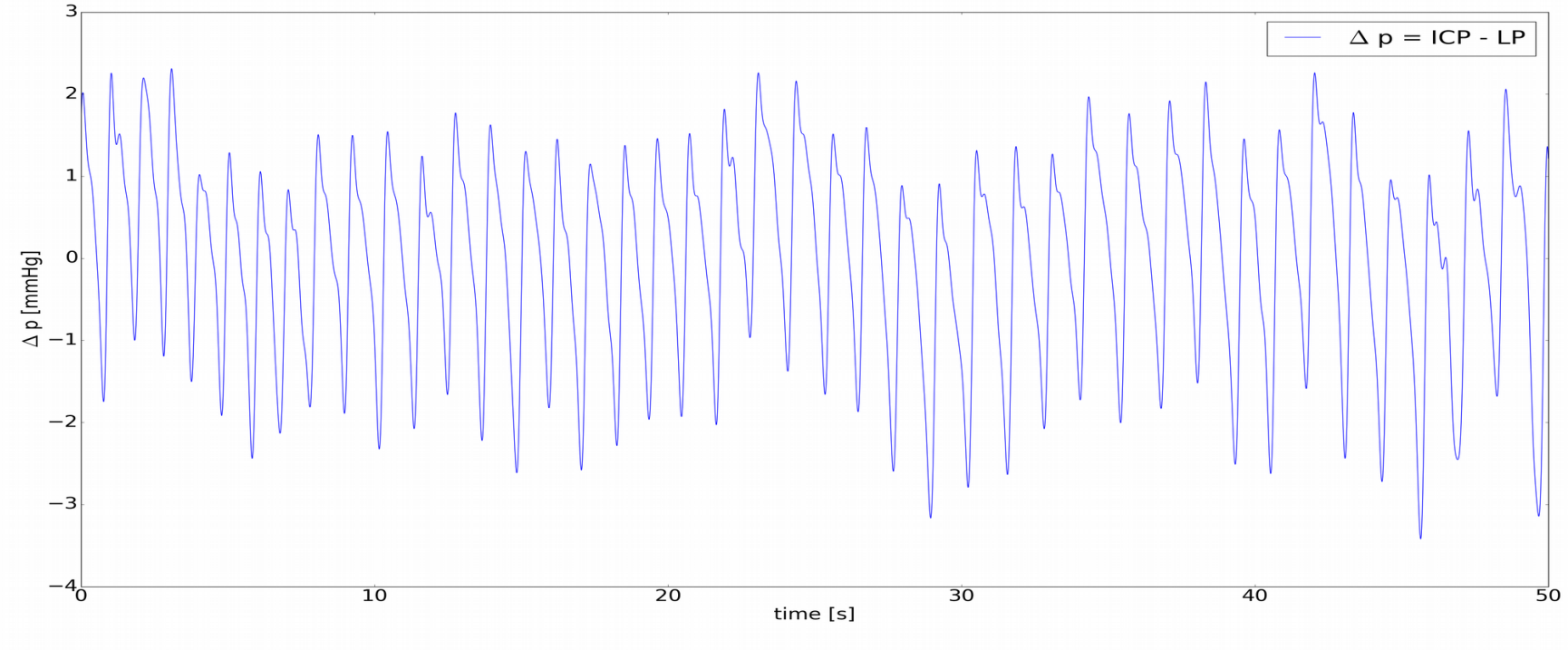


Friĉ and Eide, 2015

Pressure *differences* drive CSF flow

$$\frac{\partial v}{\partial t} + v \cdot \nabla v = -\frac{1}{\rho}\nabla p + \nu \nabla^2 v$$

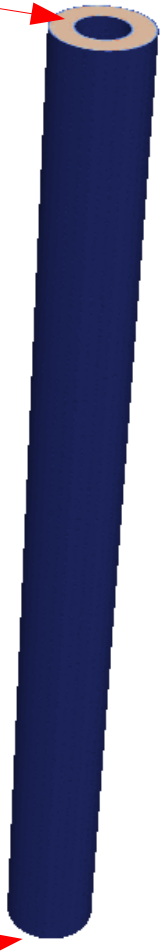
$$\nabla \cdot v = 0$$



Experimental data from a Chiari patient, by Fric & Eide (2015)

CFD simulations are used to calculate cervical CSF flow in the subarachnoid space

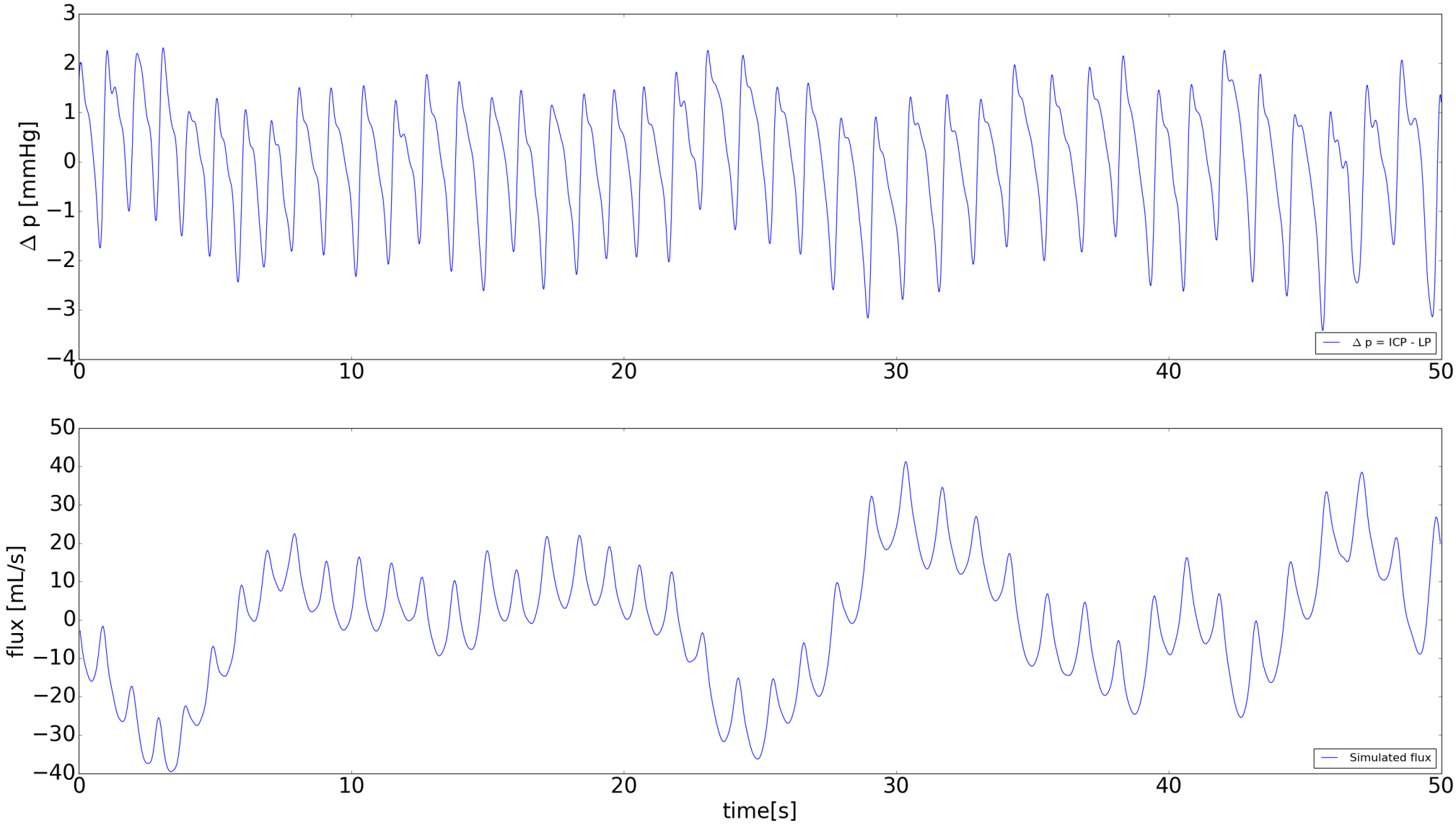
ICP(t)



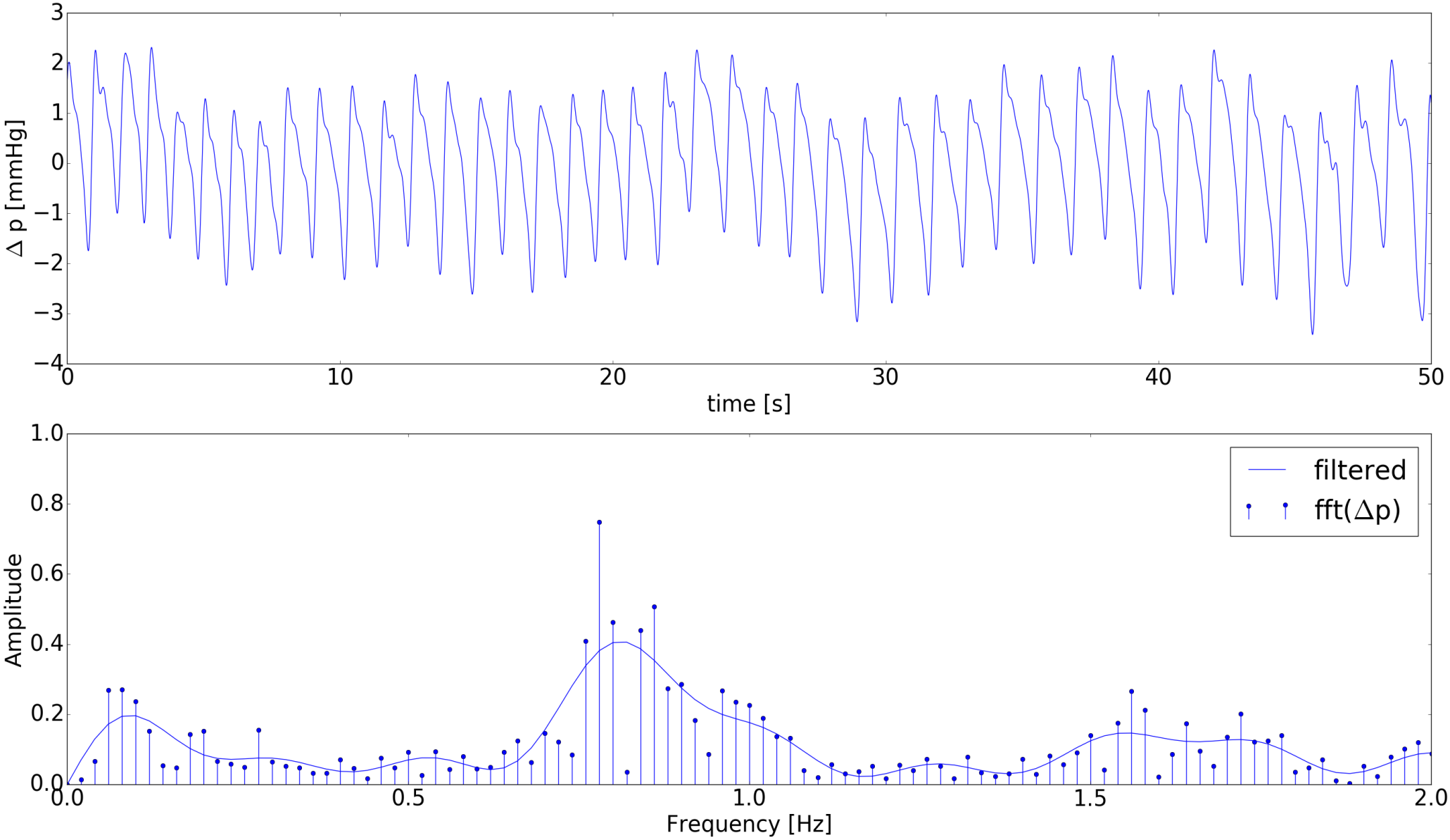
LP(t)

L = 60 cm
r0 = 5 cm
r1 = 9 cm

Experimental pressure data results in irregular flow



Frequencies in dP(t) can be quantified by a Fourier transform



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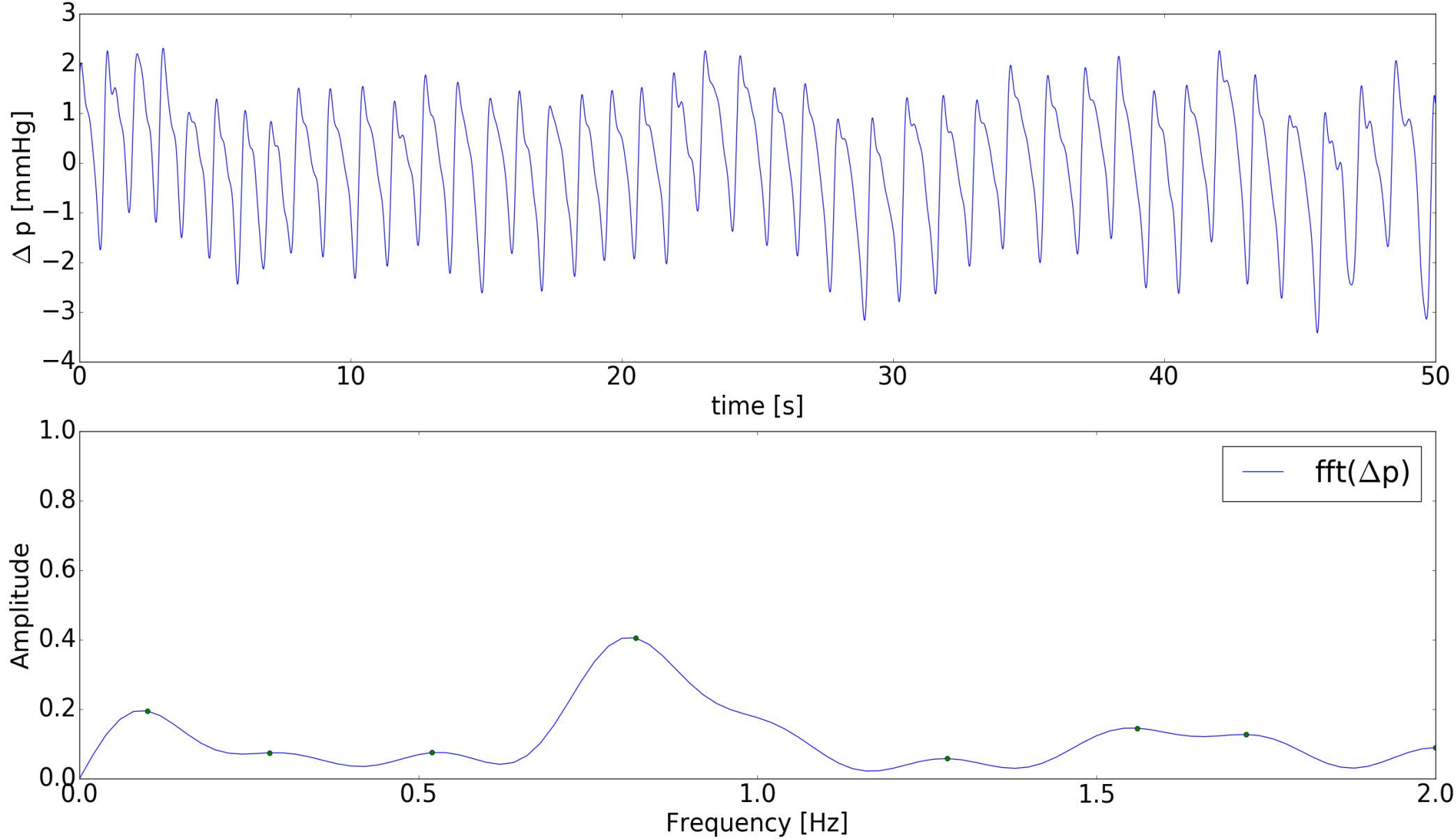
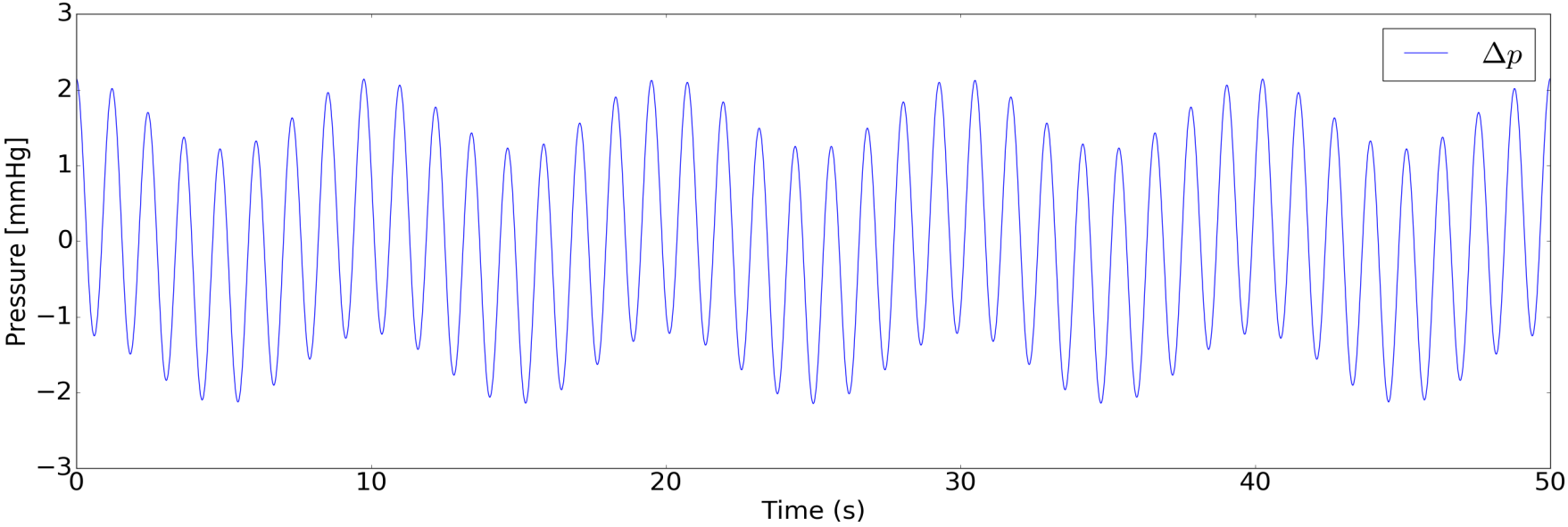


The signal is decomposed into two sinusoidal waves



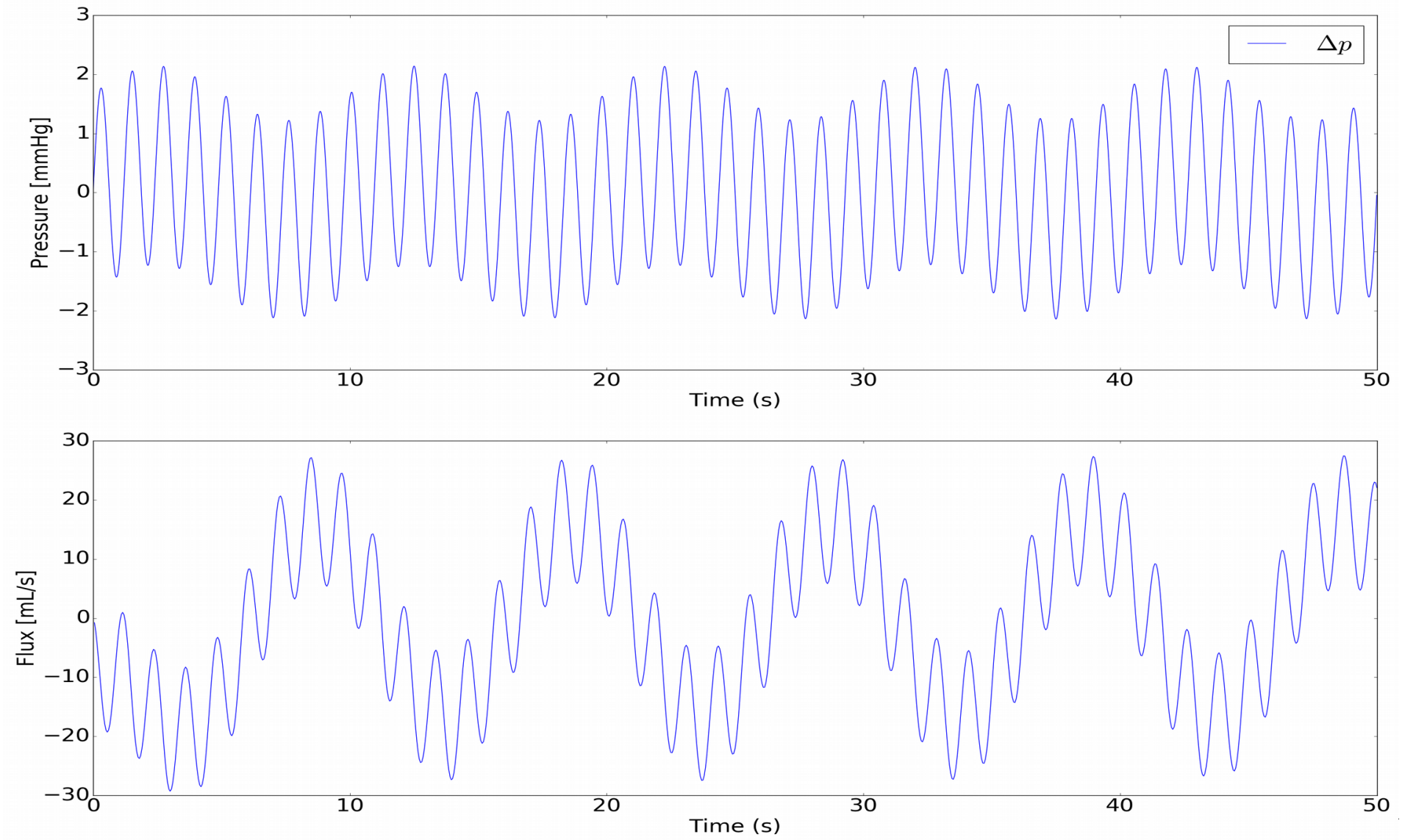
$$\Delta p = a_0 \sin(2\pi t f_0) + a_1 \sin(2\pi t f_1)$$

where

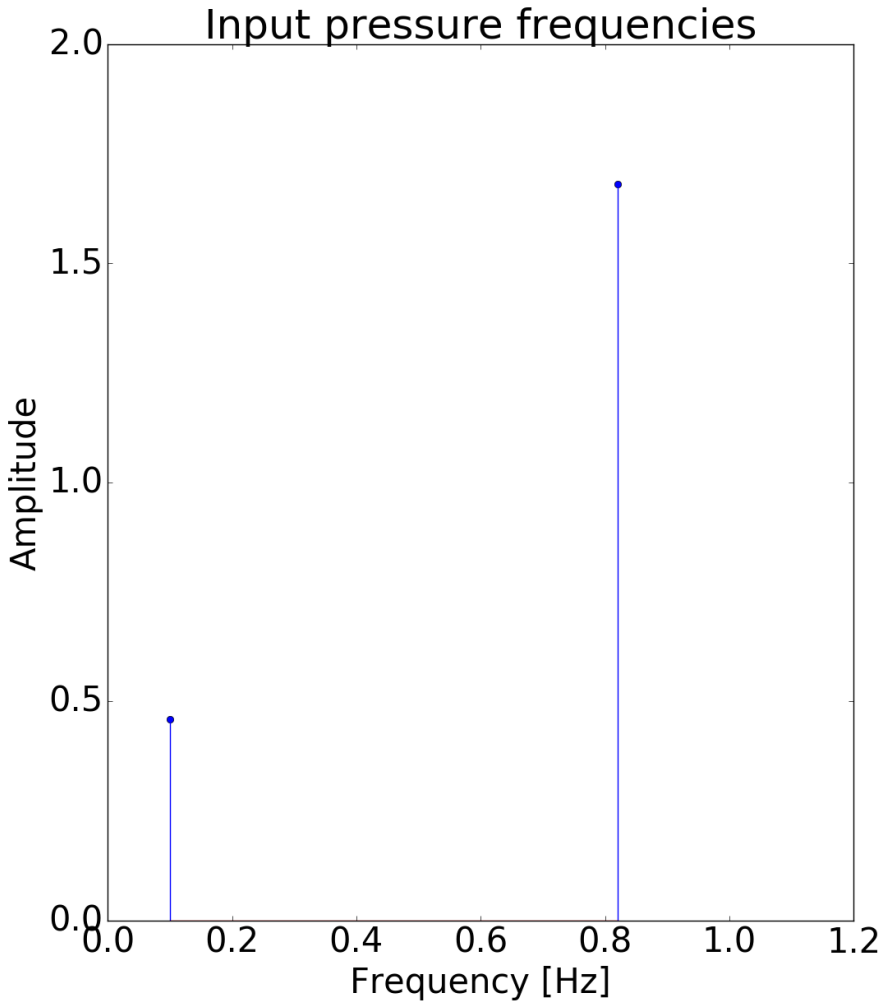
$f_0 = 0.10, a_0 = 0.46$ **Respiratory**

$f_1 = 0.82, a_1 = 1.68$ **Cardiac**

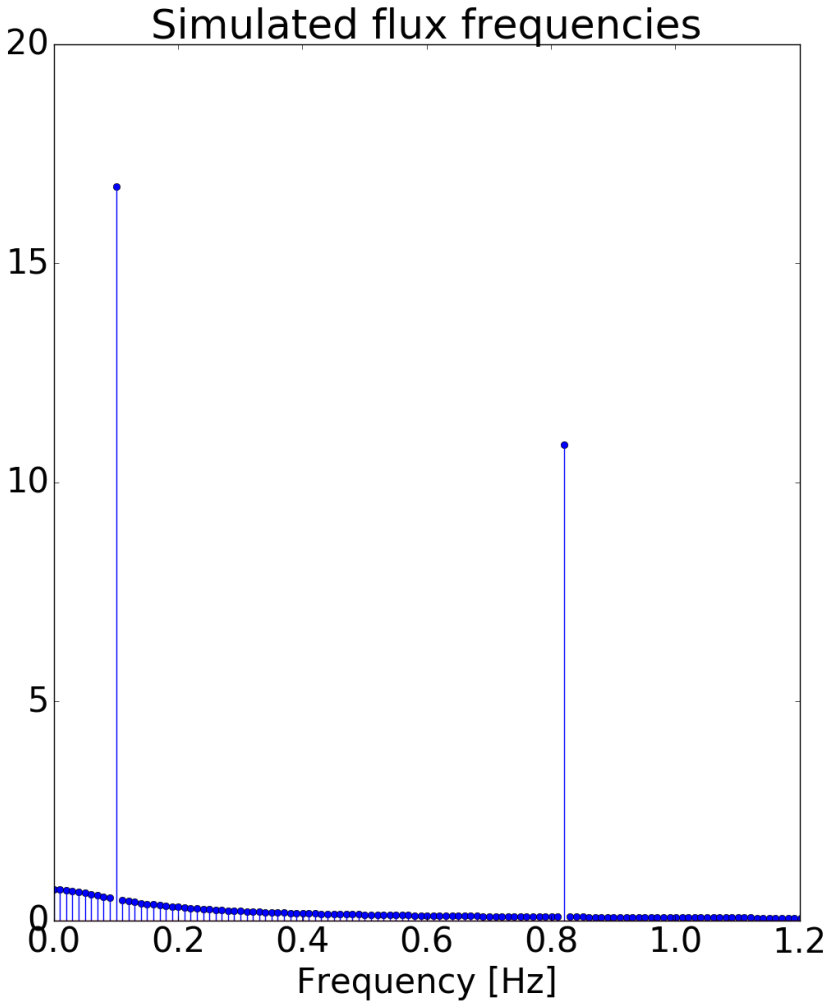
Frequencies due to respiration (10s) and cardiac activity (0.8s) are most prominent



Pressure is dominated by cardiac pulsations, flow is dominated by respiration

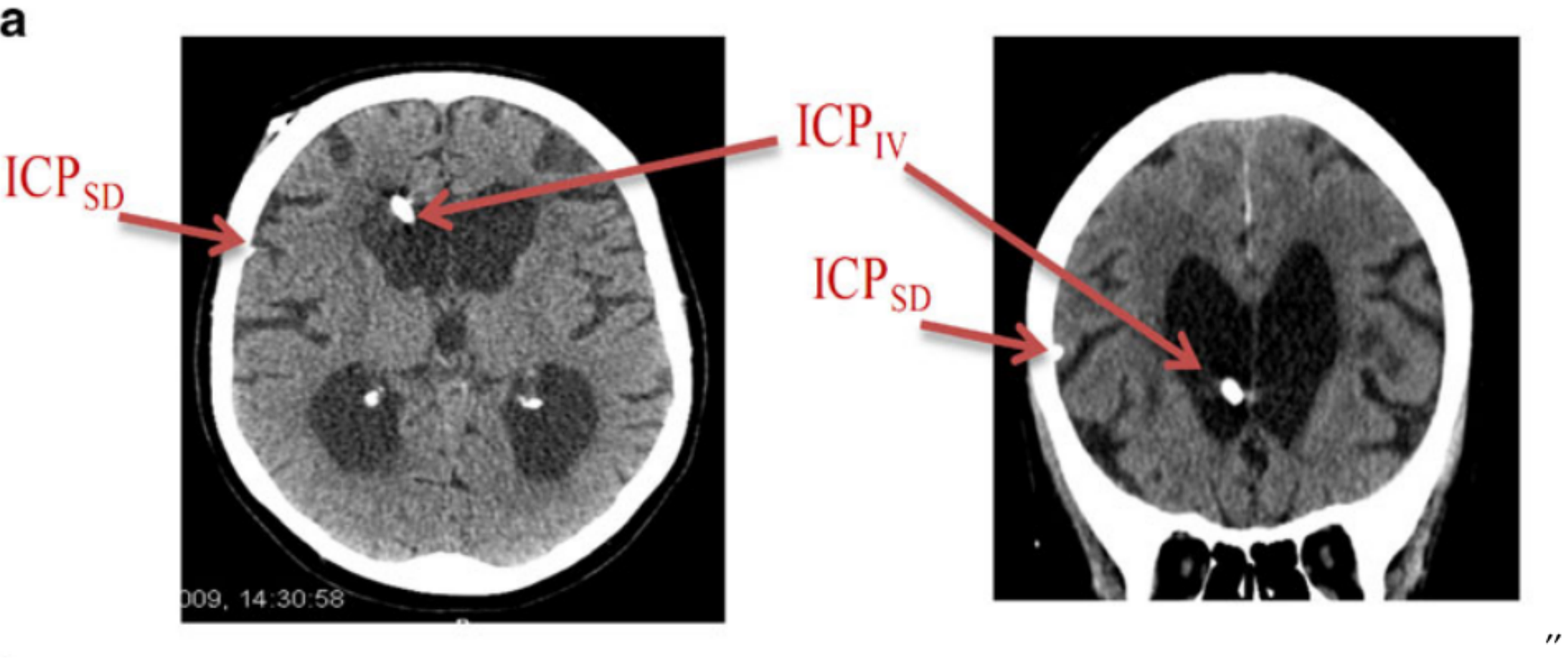


FFT of input pressure difference



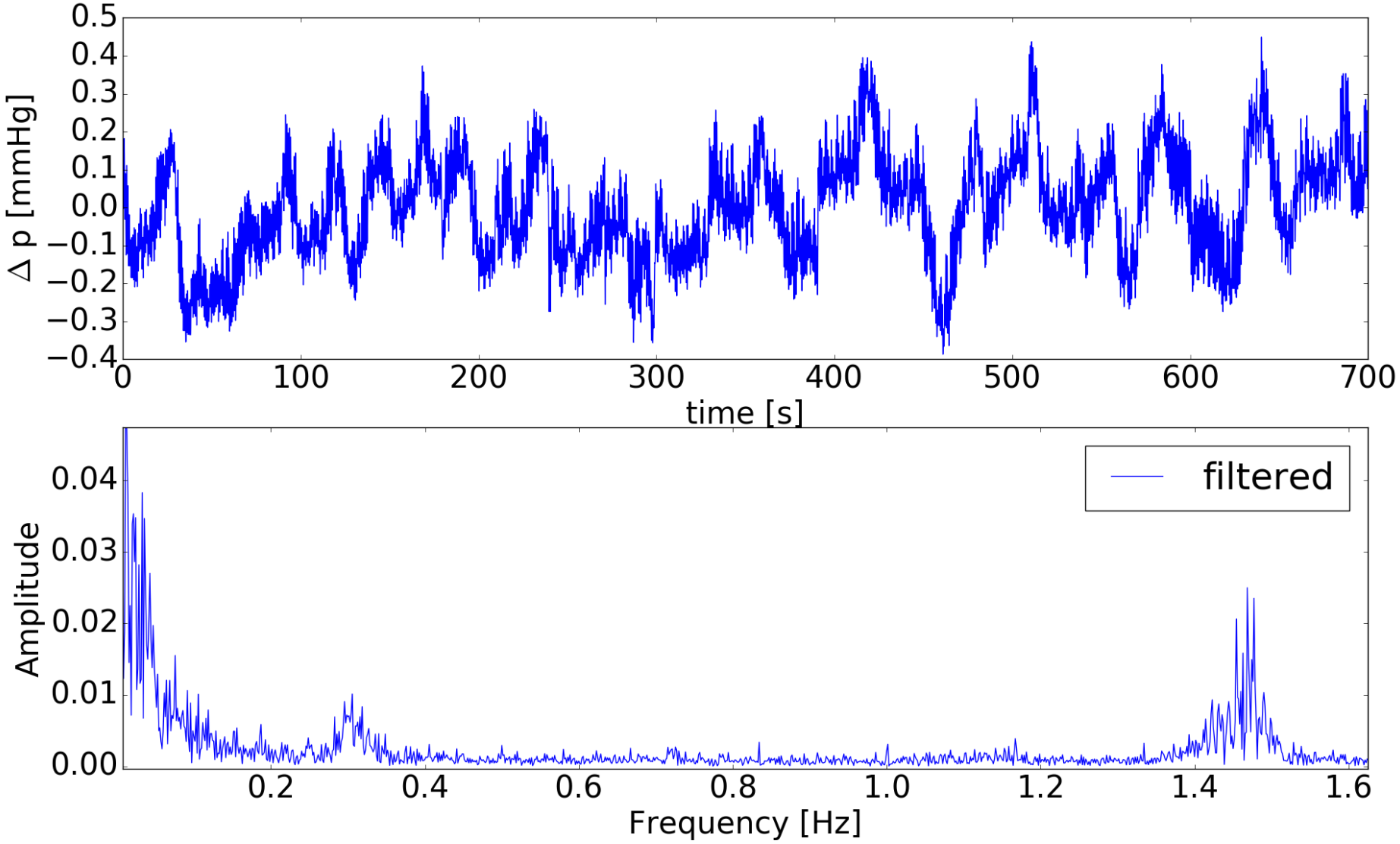
FFT of simulated flux

Aqueductal flow can be investigated in the same manner

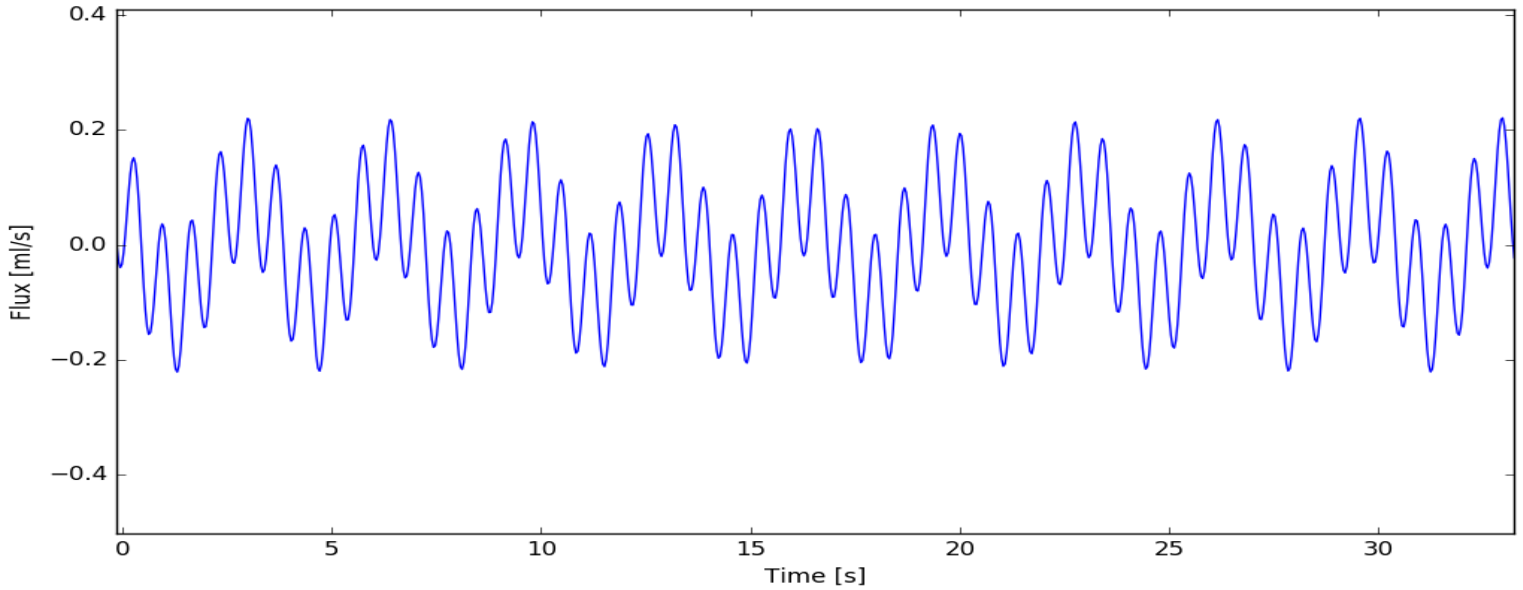


Eide and Sæhle, 2016

More relative noise in the difference between *ventricular* and *subdural* pressure



In the aqueduct, flow is evenly regulated by cardiac and respiratory cycle



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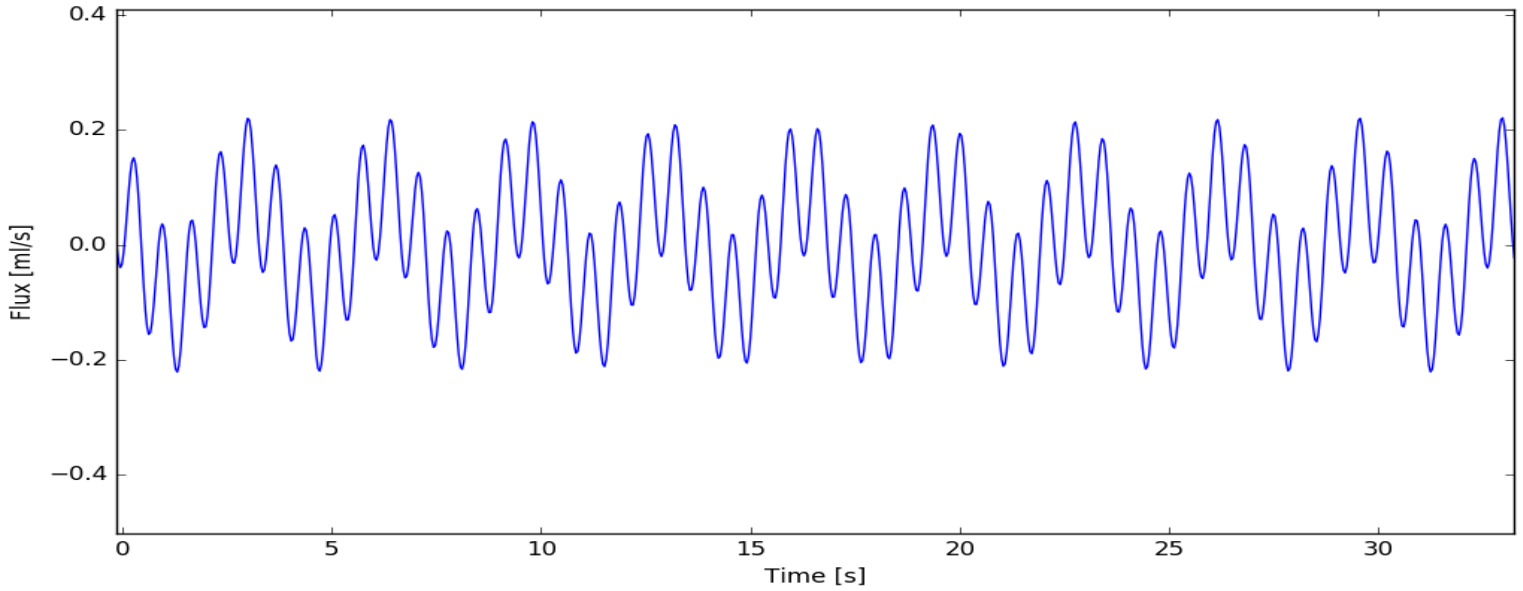

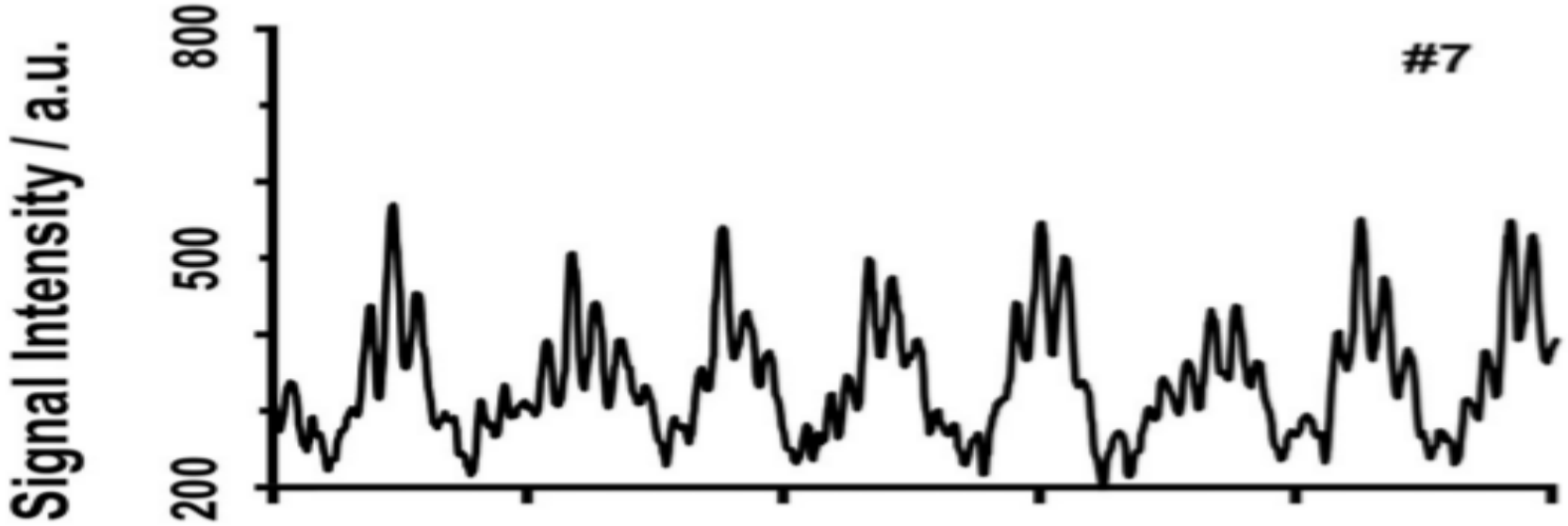

Dreha-Kulaczewski et al., 2015

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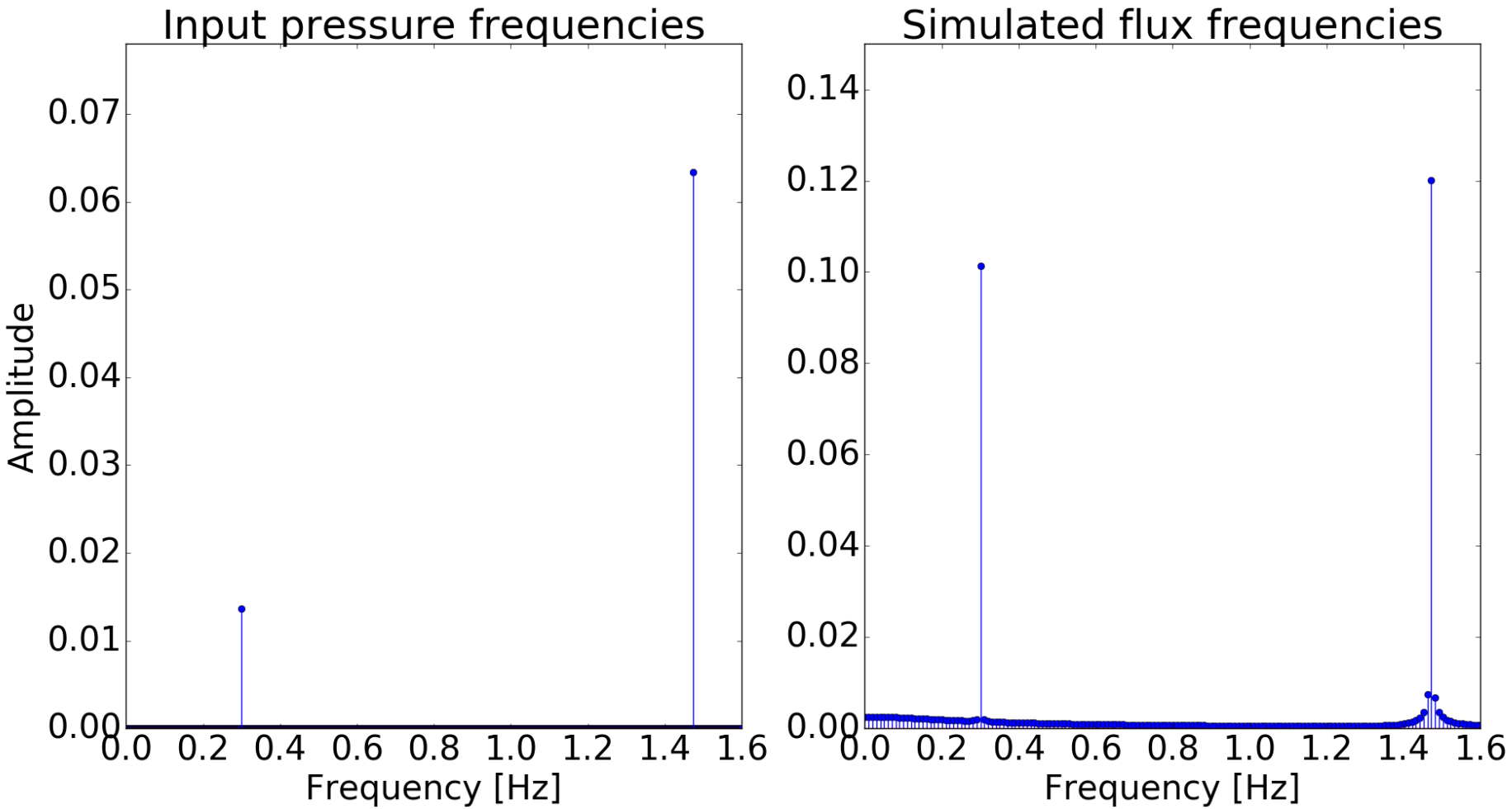
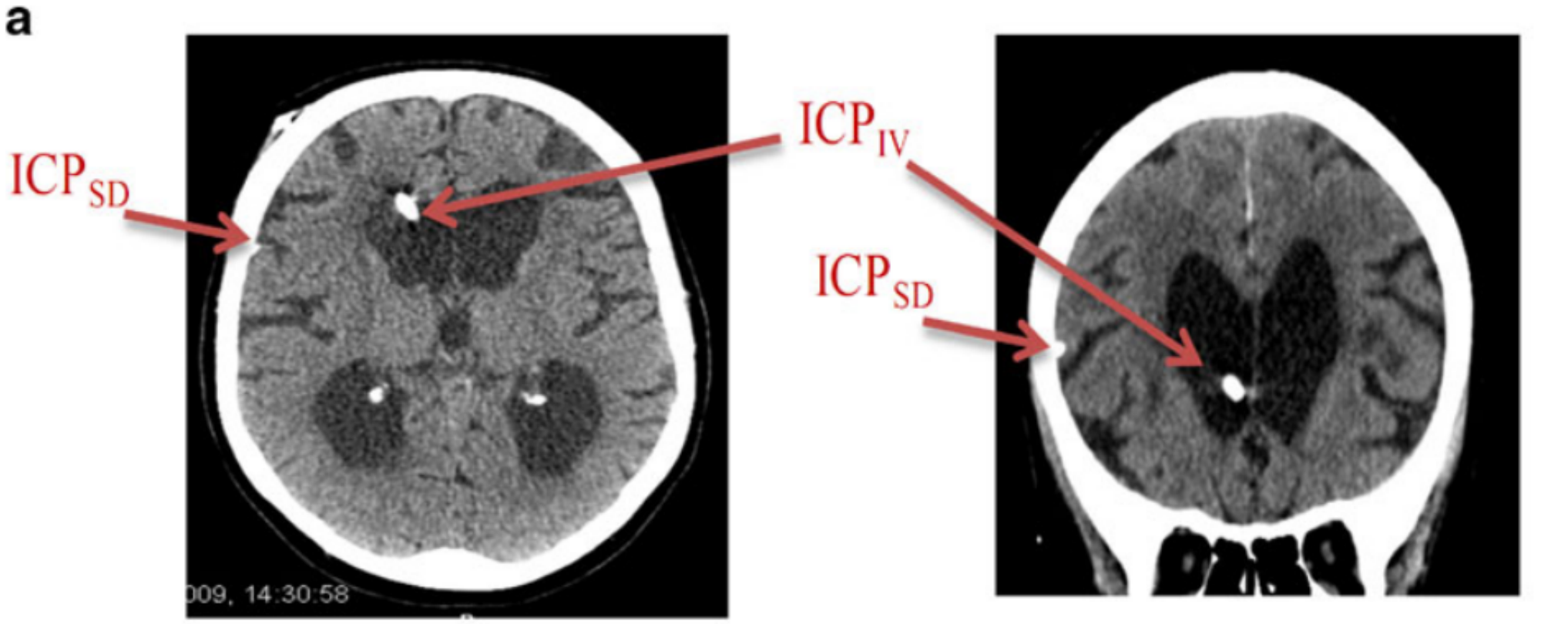


Clinical aspects

- ICP monitoring and PC-MRI measure different types of pulsatility
- Is cardiac gated MRI sufficient for clinical use?
- Pressure and flow studies, regulate/monitor breathing and **motion**?

ICP gradients may also affect brain motion and possibly interstitial fluid flow



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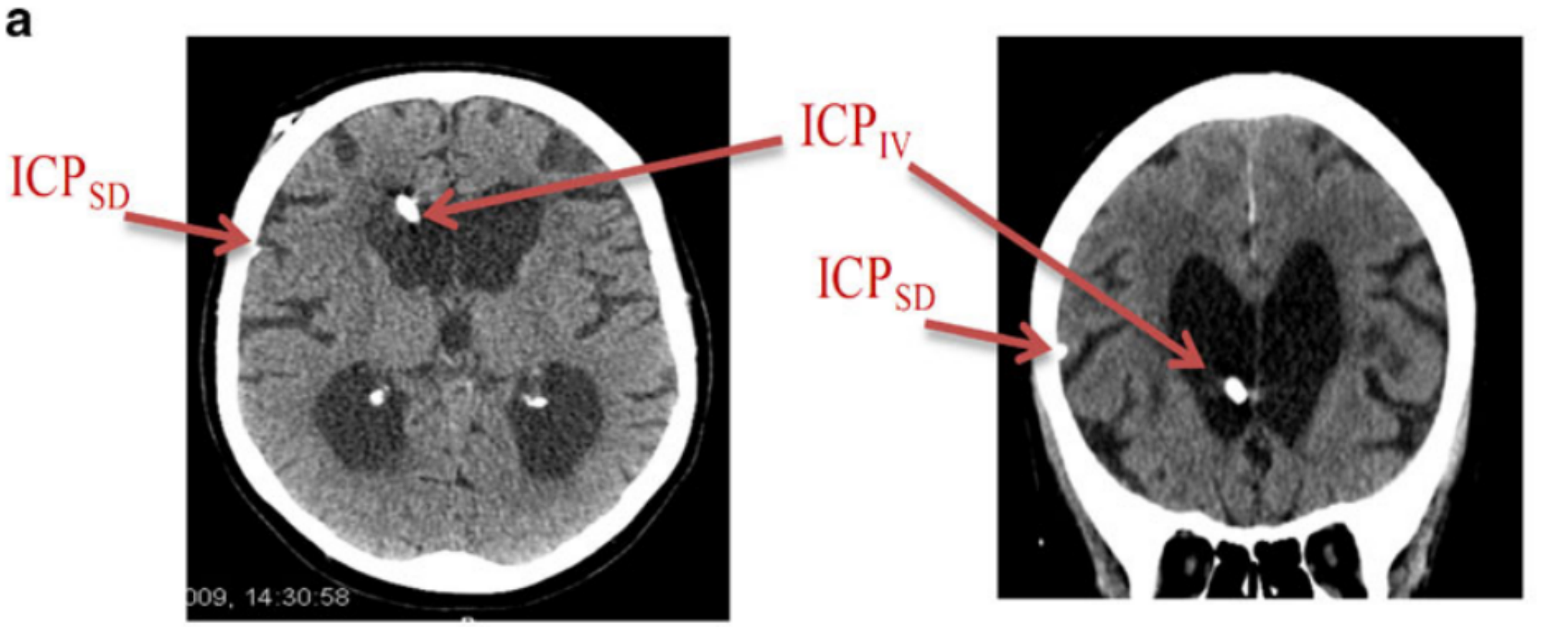
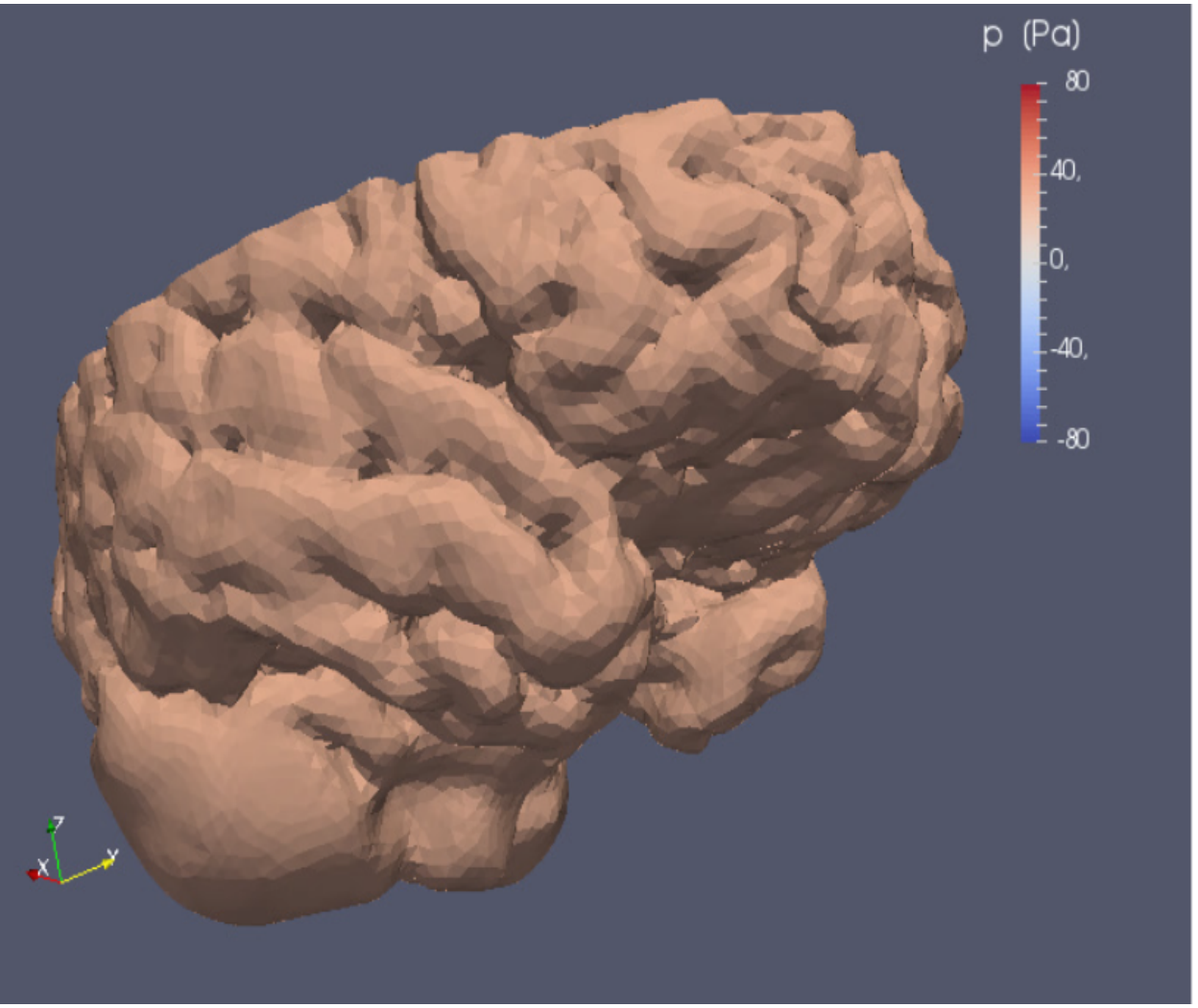
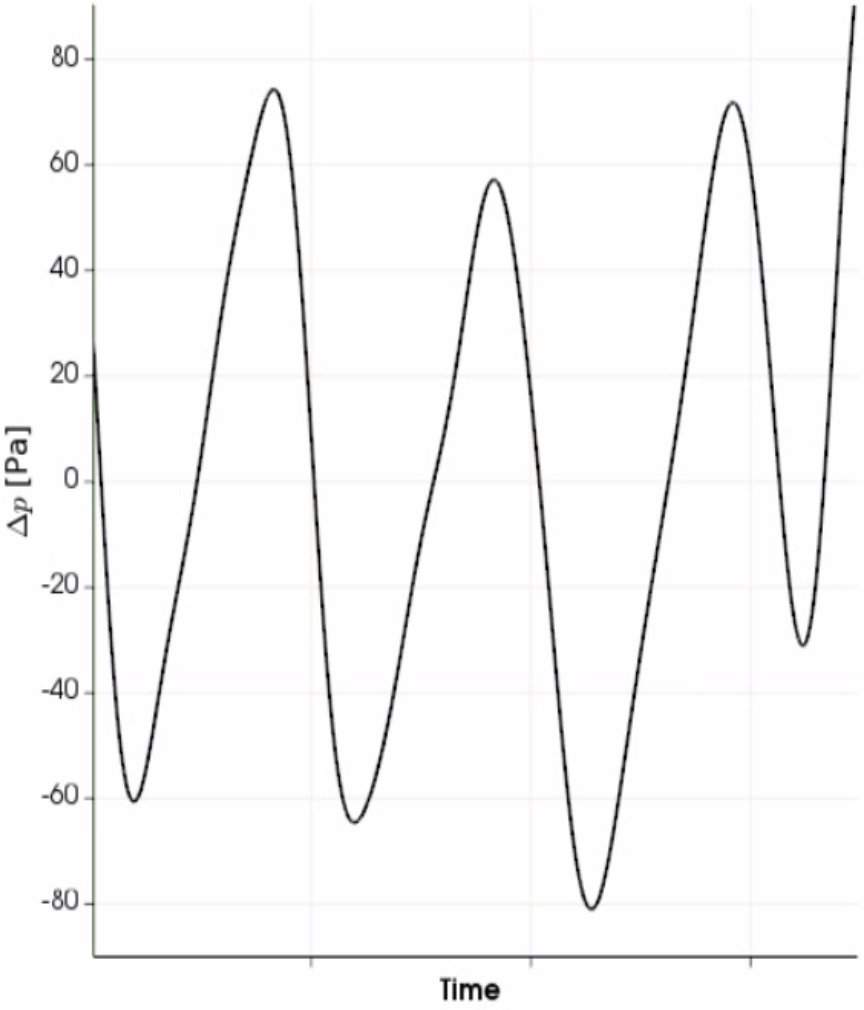
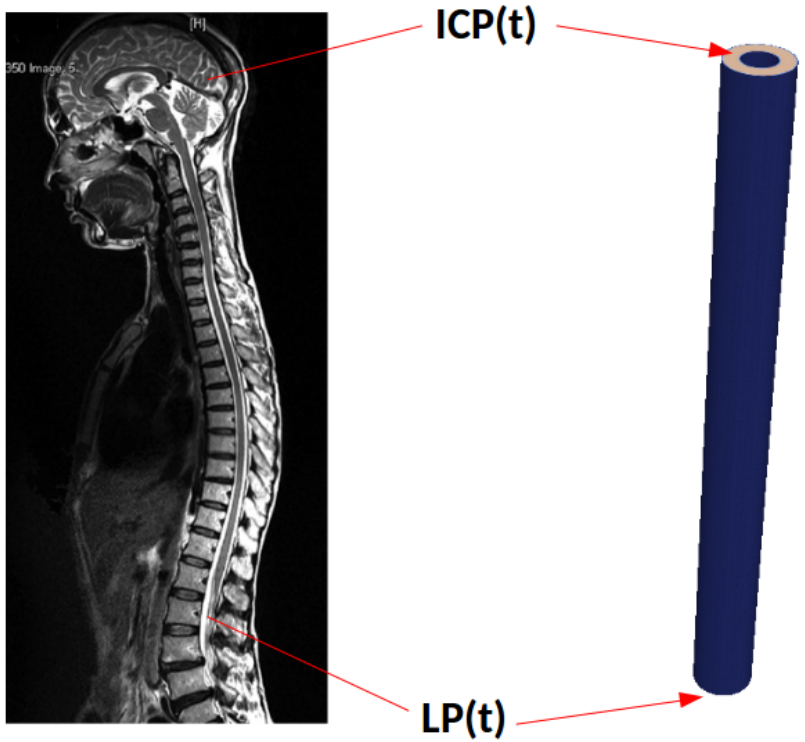


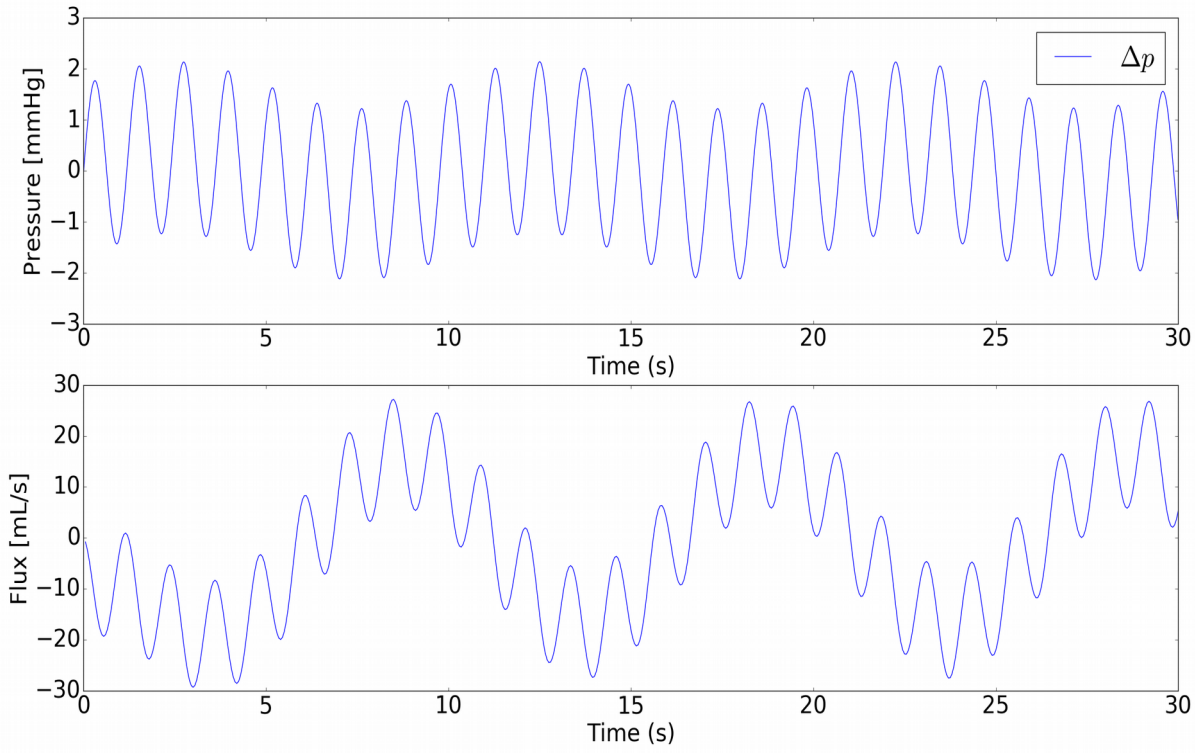
Biot's equations relate pressure to displacements in a porous medium. We use pressure boundary conditions on the brain surface and the ventricles


p (Pa)
80
40,
0,
-40,
-80
Z
X
Y


80
60
40
20
0
-20
-40
-60
-80
Δp [Pa]
Time

CSF flow may be dominated by respiration, even though pressure is dominated by the cardiac cycle

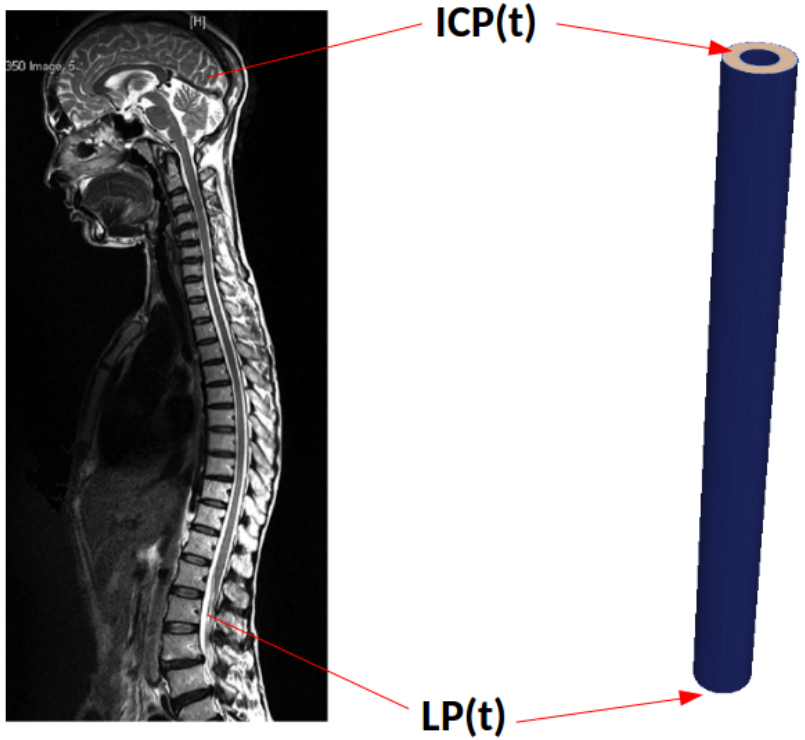


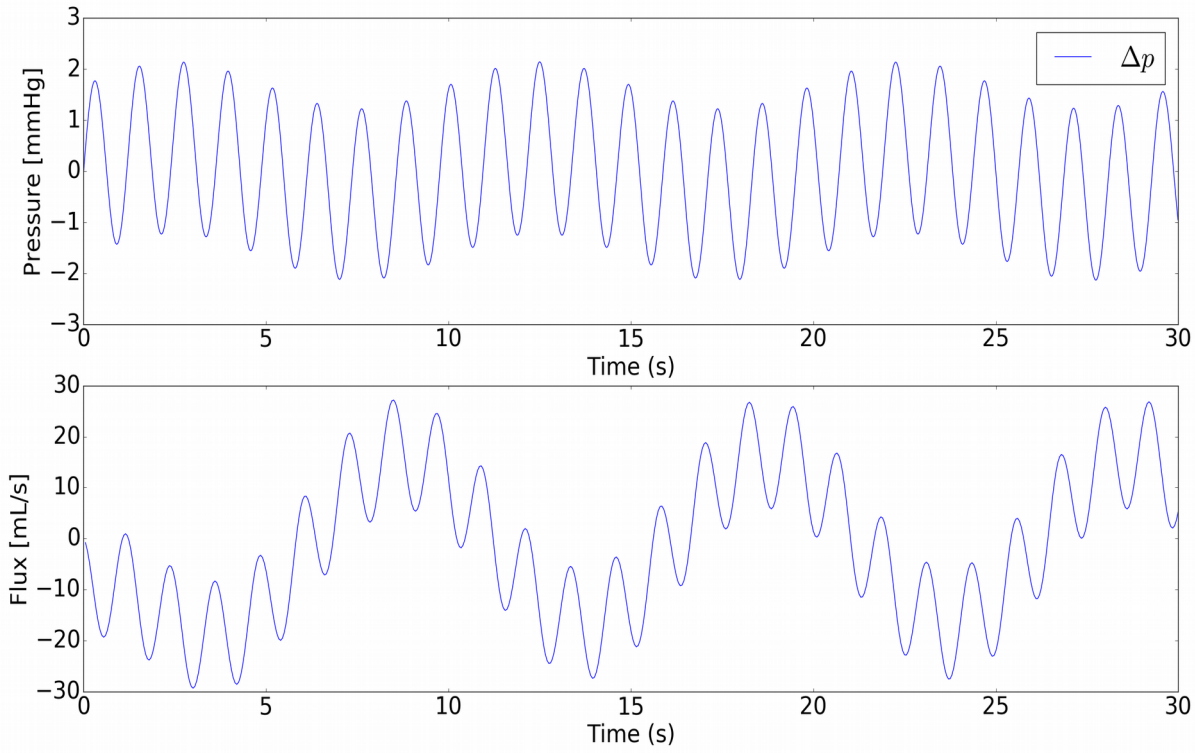


In vivo pressure measurements

CFD experiment, quantifying flow from a simplified input pressure function

CSF flow may be dominated by respiration, even though pressure is dominated by the cardiac cycle





In vivo pressure measurements

CFD experiment, quantifying flow from a simplified input pressure function

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Thank you!

UiO : University of Oslo