



[flusser@utia.cas.cz](mailto:flusser@utia.cas.cz)

**Prof. Ing. Jan Flusser, DrSc.**

# **Digitální zpracování obrazu**

## **Lecture 4**

# Potlačení šumu v obraze

- **Modely šumu**
- **Lineární filtrace**
- **Nelineární metody**



# Image noise

Apparent in low-light scenes taken at high ISO and/or long exposure



## Noise sources

- Background electronic and thermal noise (additive Gaussian)
- Shot noise (photon noise) – Poisson, approx. multiplicative Gaussian
- Random errors of A/D converter, transmission errors (impulse noise)
- Wavefront interference noise (speckle noise)



Gaussian



Impulse

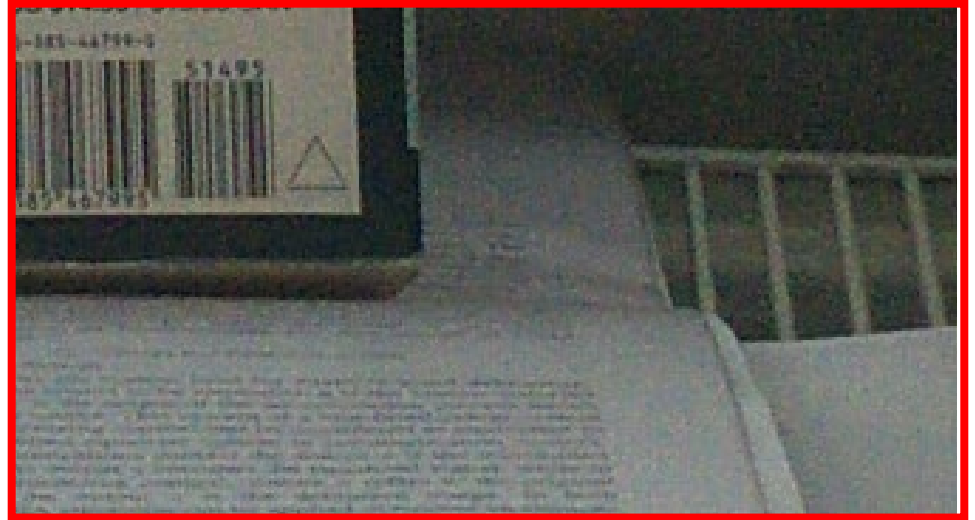
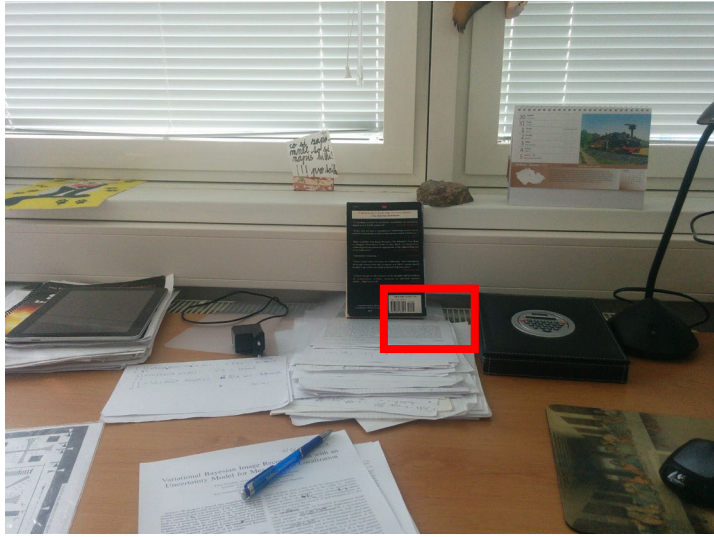


Poisson

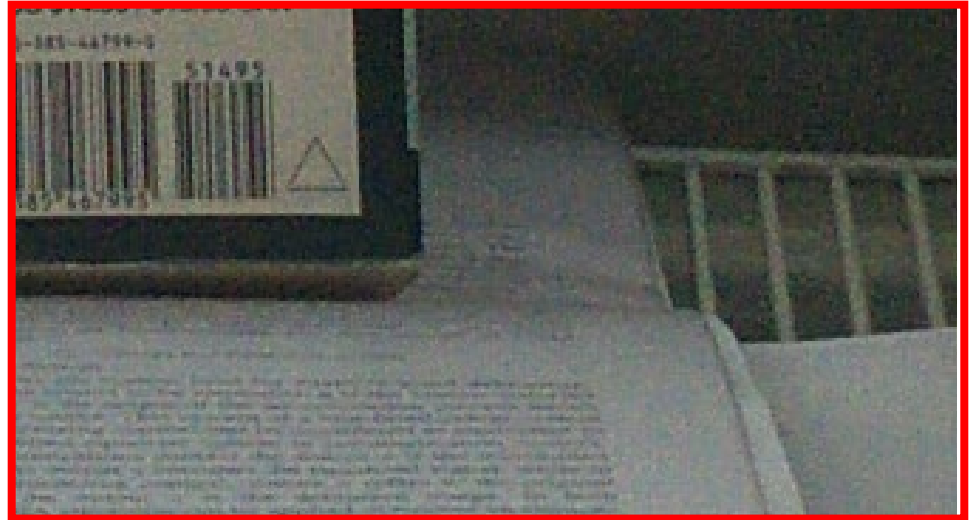
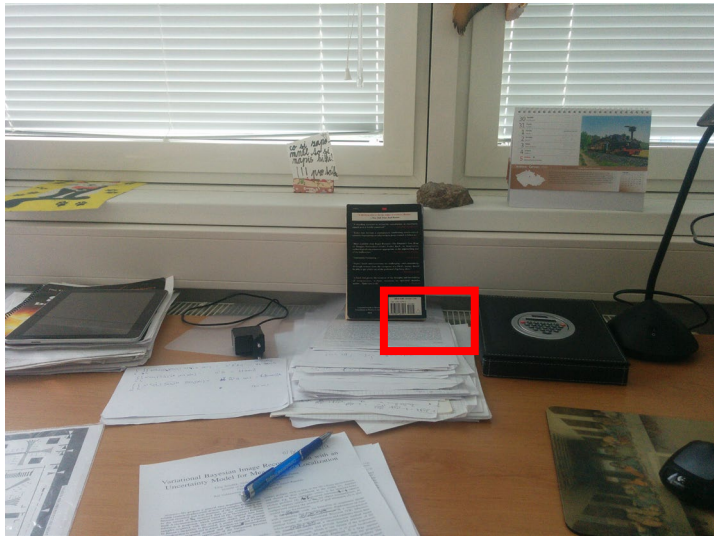


Speckle noise in satellite radar image

# Real camera compound noise



# Real camera compound noise



## Noise models

Non-specific or compound noise is mostly modelled as an additive, signal-independent white Gaussian noise (AWGN)

$$g = \mathcal{D}(f) + n$$

# Modely šumu

- **Aditivní náhodný šum**

$$g = f + n$$

- **Gaussovský bílý šum (AGWN)**
- **Impulsní šum (sůl a pepř)**



# Modely šumu

- **Gaussovský bílý šum (AGWN)**

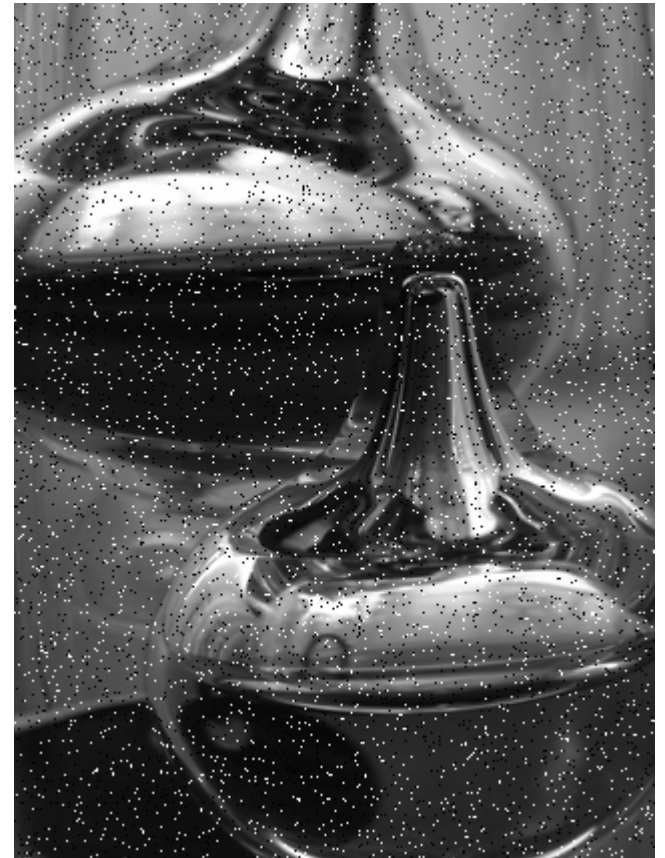
- frekvence ?

- korelovanost ?



# Modely šumu

- Impulsní šum (sůl a pepř)
- $P(f) = 1 - K$
- $P(1) = K/2$
- $P(0) = K/2$



# Míra šumu v obraze

- **Rozptyl**
- **Signal-to-noise ratio (SNR)**

$$\text{SNR} = 10 \log (D(f)/D(n)) \quad [\text{dB}]$$

# Gaussovský bílý šum

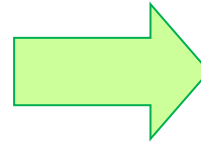


20 dB

10 dB

0 dB

# Průměrování v čase



# Průměrování v čase

4

8

šum



16

32

64

# Průměrování v čase

$g_1, \dots, g_N$  – nezávislá pozorování

$$g_k = f + n_k$$

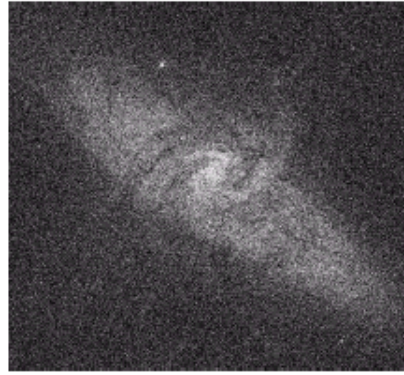
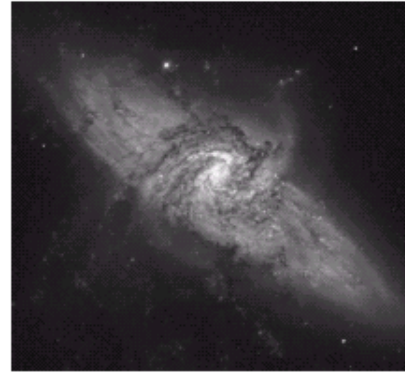
$$n_k \sim p(0, \sigma^2)$$

$$g = \frac{1}{N} \sum_{k=1}^N g_k = f + n$$

$$n \sim p(0, \sigma^2/N)$$

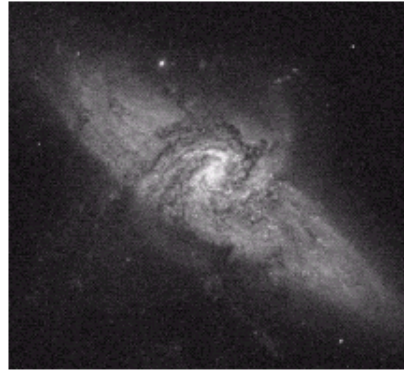
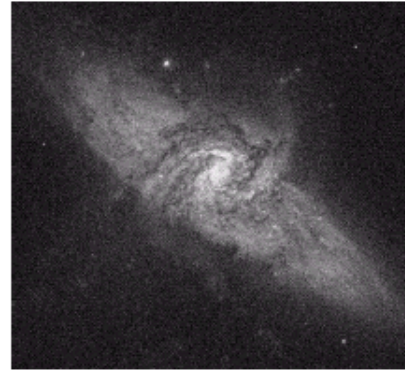
# Průměrování v čase

orig



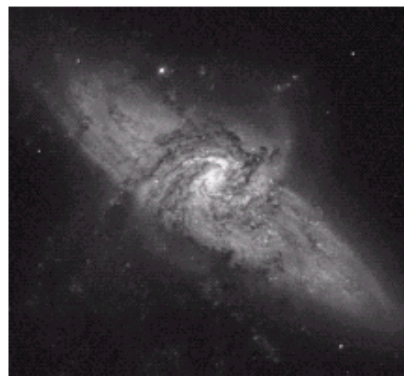
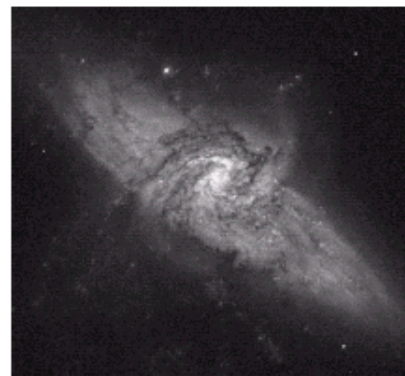
šum

8



16

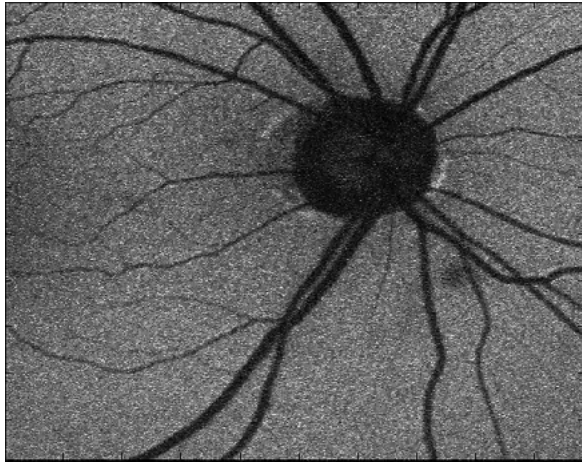
64



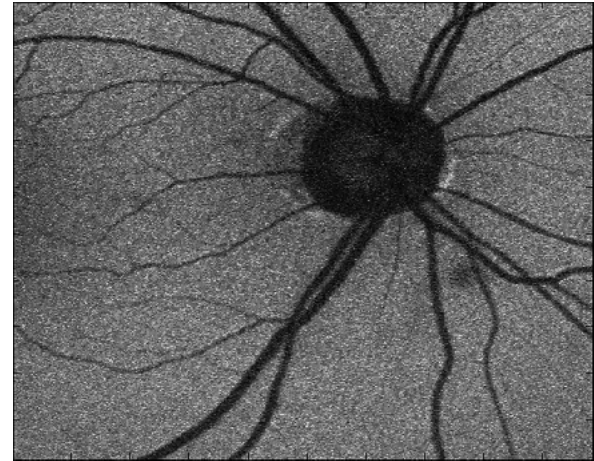
128



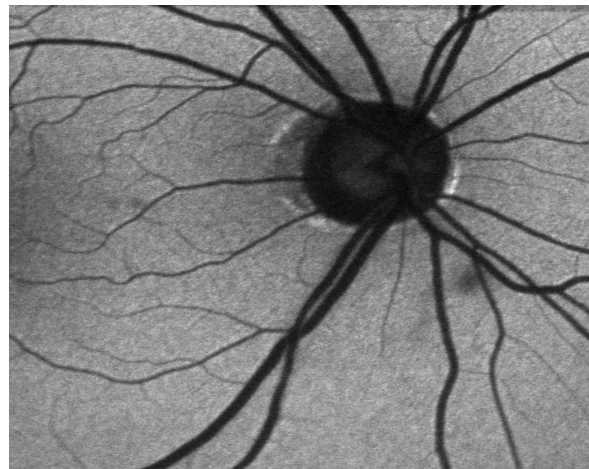
# Průměrování v čase



Before registration



After registration



Averaging

# Konvoluční filtry

- **Průměrování (prosté a vážené)**
- **Průměrování podél hran**
- **Rotující okno**
- **Filtry ve frekvenční oblasti**

# Průměrování v obraze

šum



3x3


5x5



7x7

# Průměrování v obraze

Original Image      Corrupted Image      Filtered Image


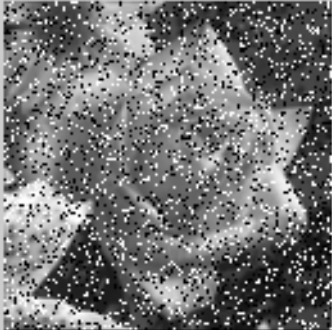
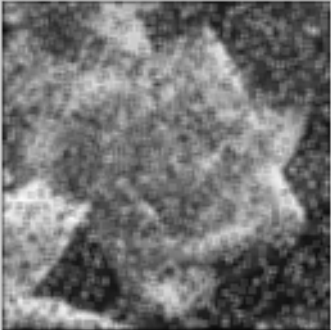


Select an Image:  Image Noise Type:  Noise Removal Filter:

Mean:  Filtering Neighborhood:

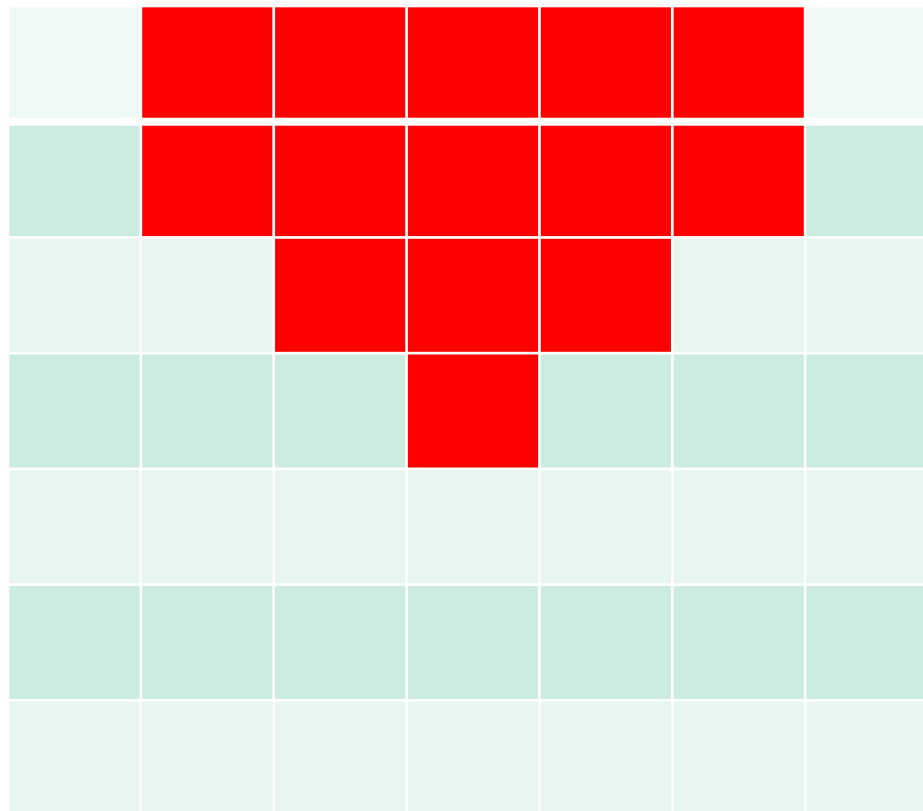
Variance:

# Průměrování v obraze

Original Image	Corrupted Image	Filtered Image
		
Select an Image:	Image Noise Type:	Noise Removal Filter:
Flower <input type="button" value="v"/>	Salt & Pepper <input type="button" value="v"/>	Averaging <input type="button" value="v"/>
	Density: <input type="text" value="0.2"/>	Filtering Neighborhood:
		3-by-3 <input type="button" value="v"/>

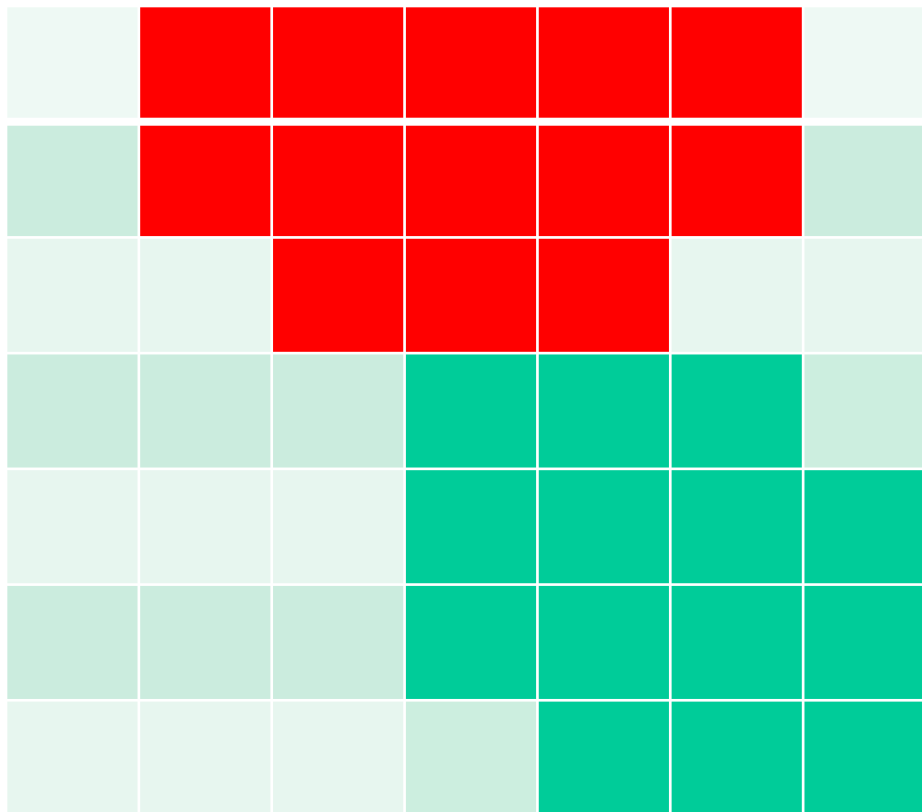
# Konvoluční filtry

- **Rotující okno**

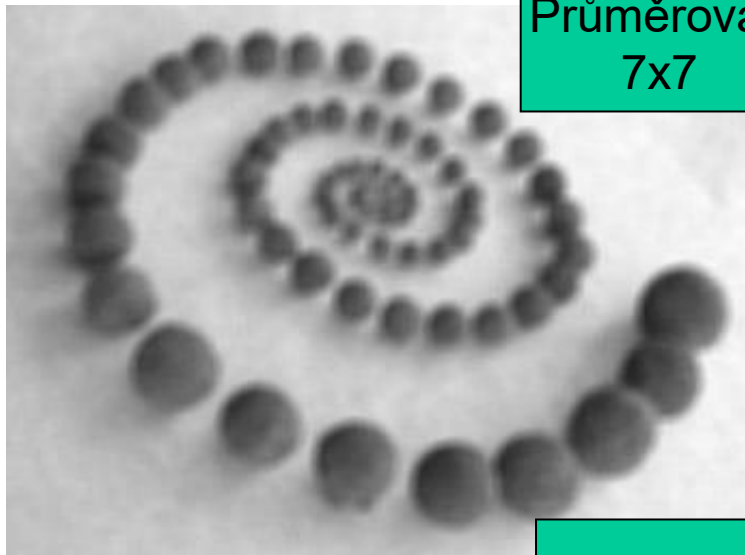


# Konvoluční filtry

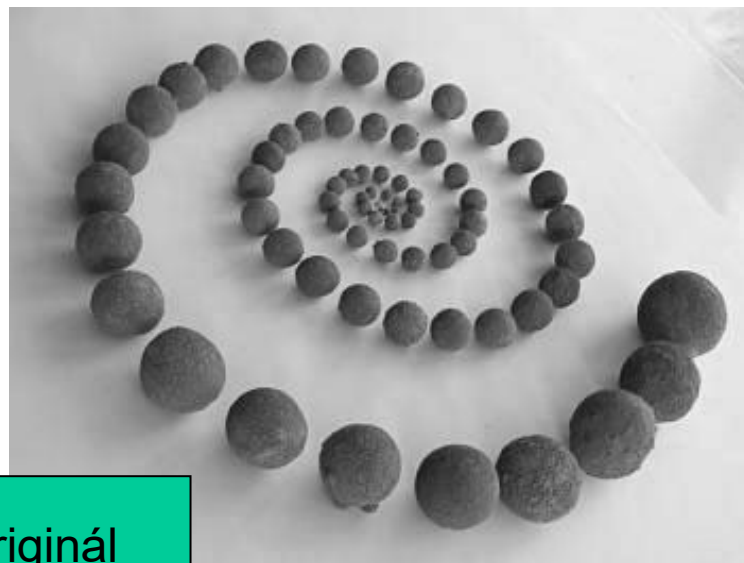
- **Rotující okno**



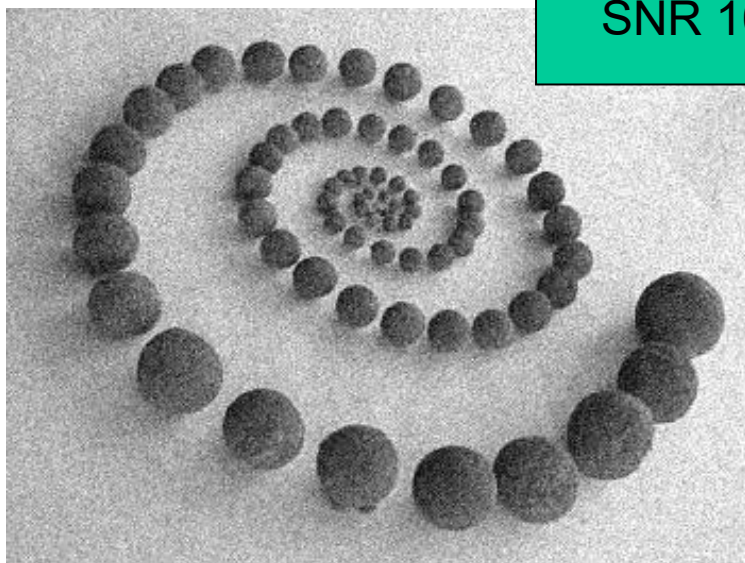
# Rotující okno



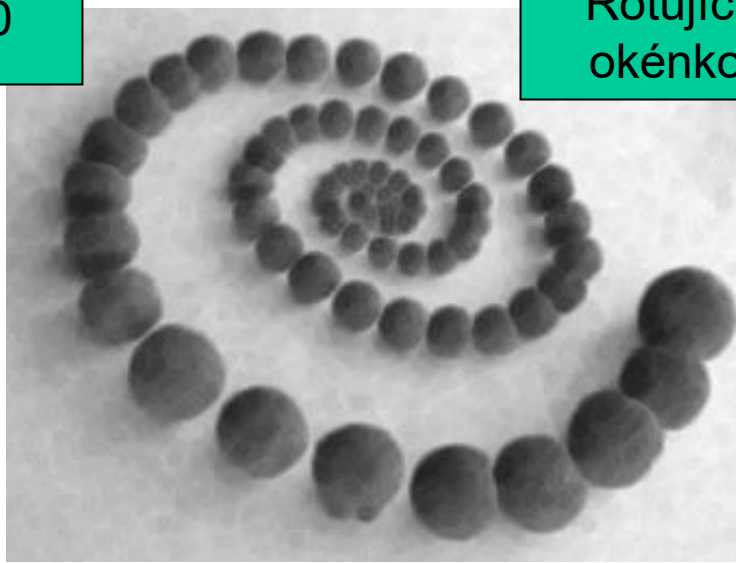
Průměrování  
7x7



Originál



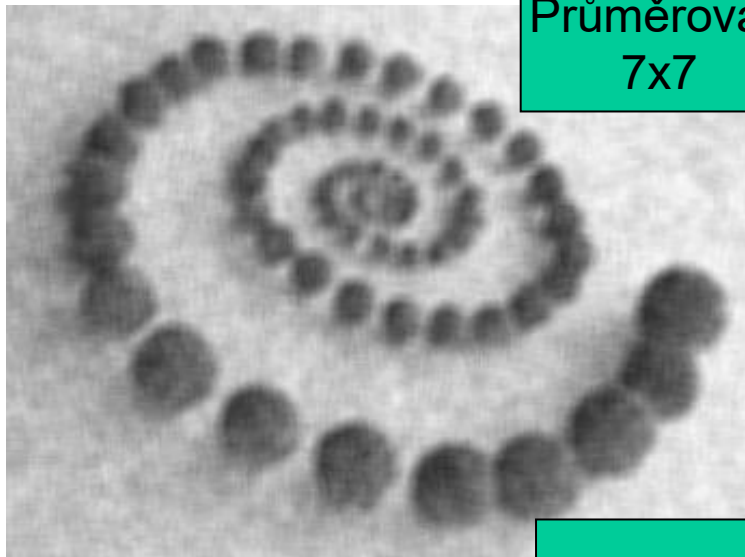
SNR 10



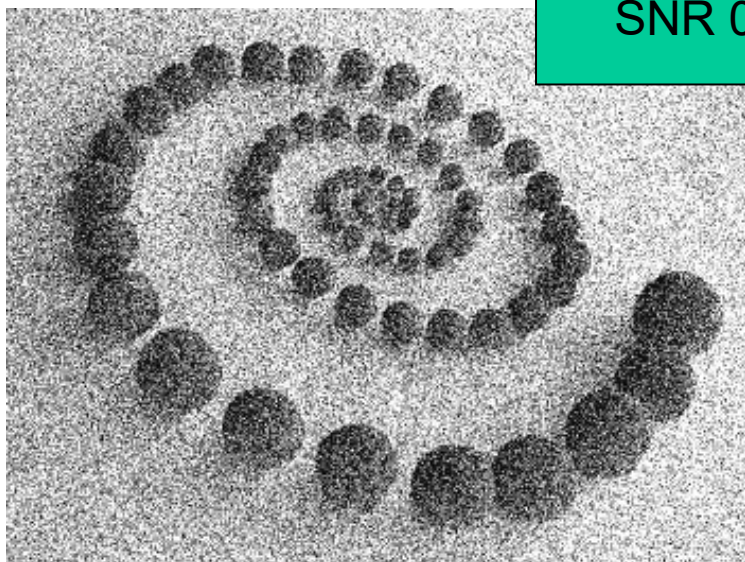
Rotující  
okénko



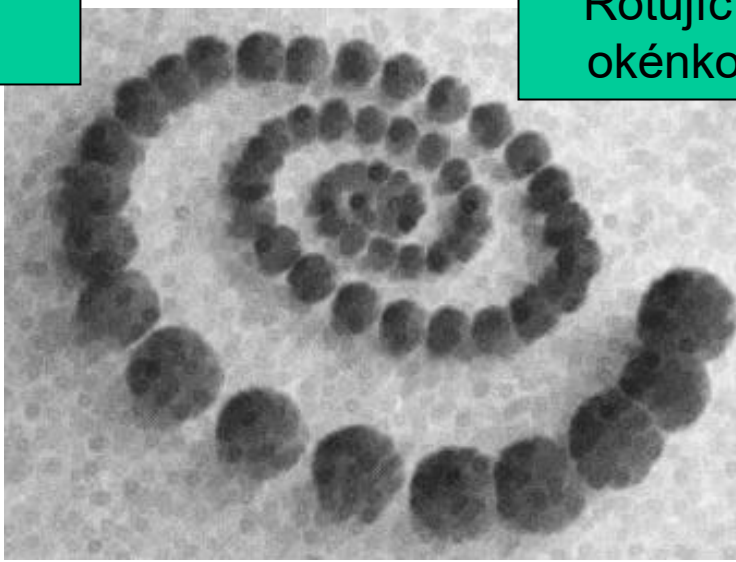
# Rotující okno



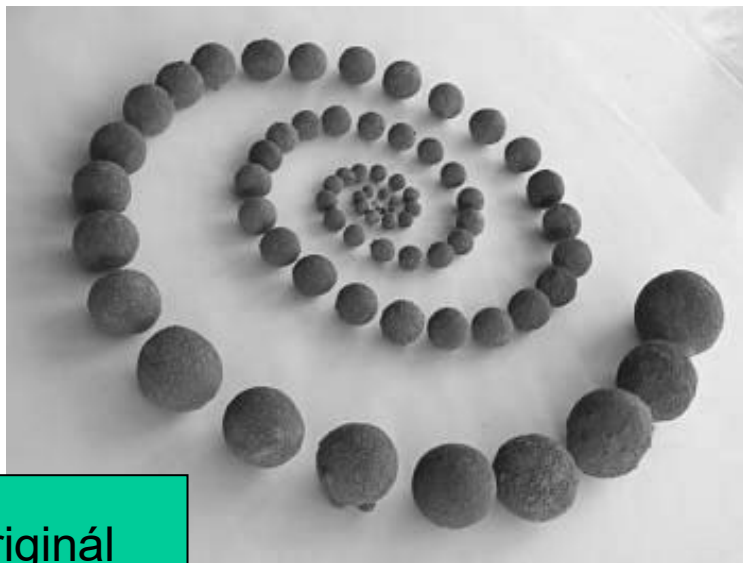
Průměrování  
7x7



SNR 0



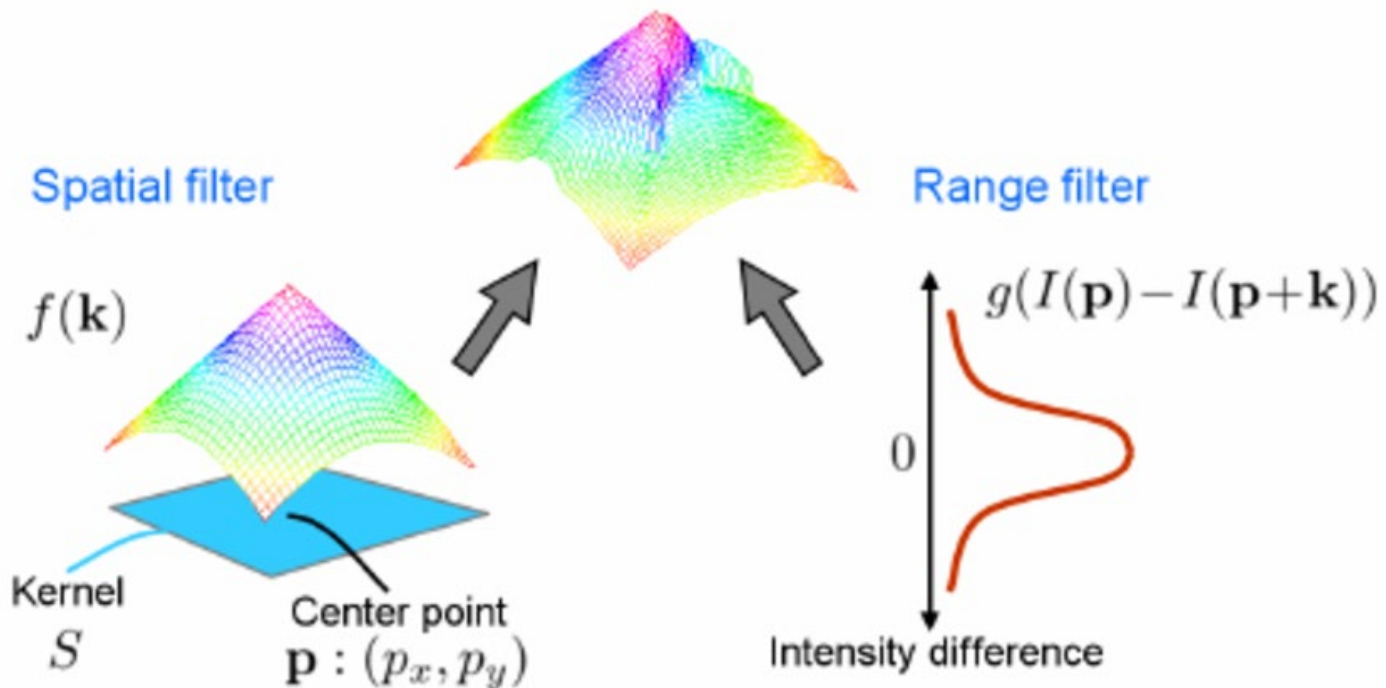
Rotující  
okénko



Originál

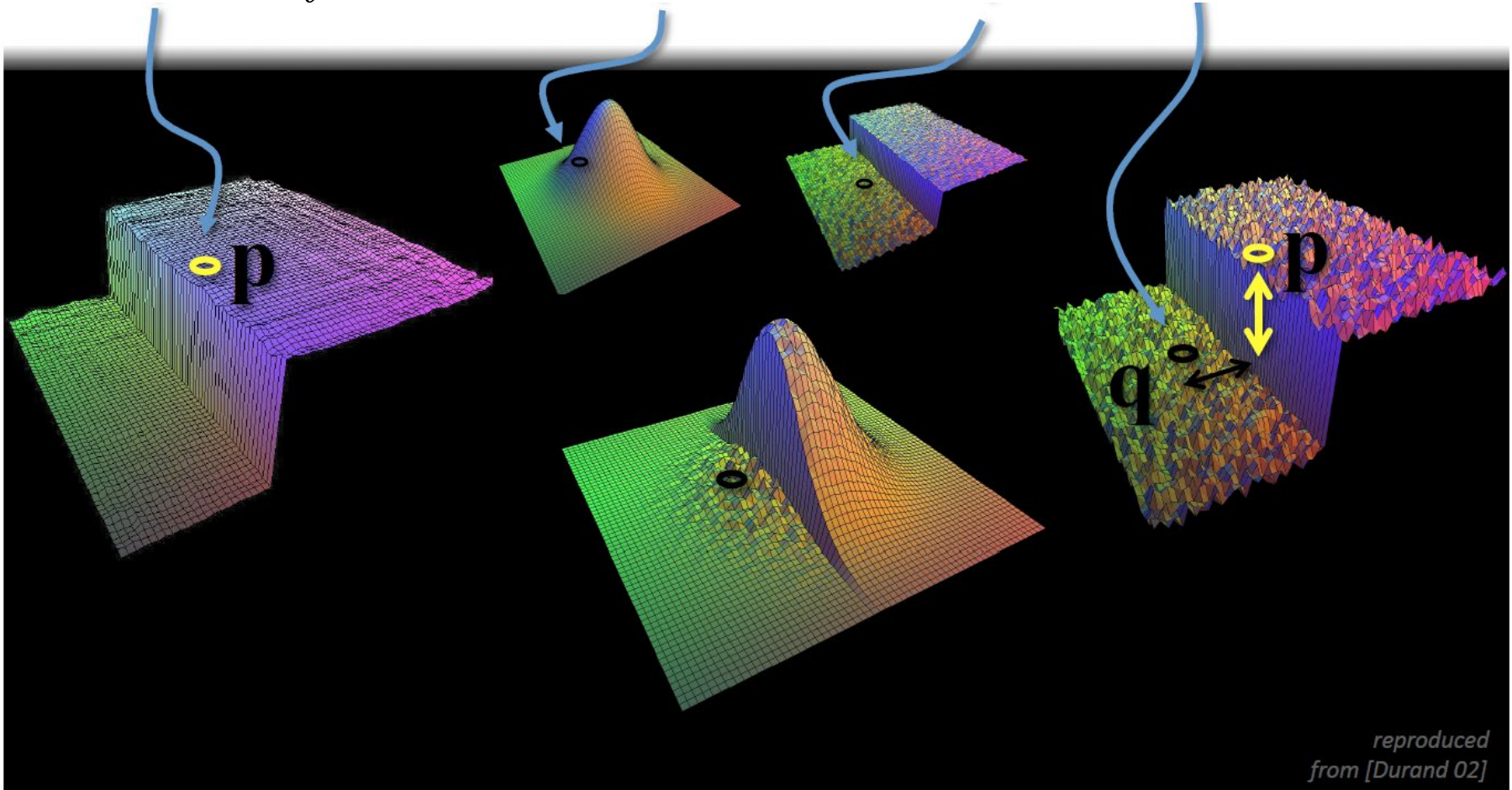
# Bilaterální filtr

- Průměrování v okolí přes podobné intenzity (bilaterální filtr)



$$\hat{g}(x) = \sum_t G_{\sigma_s}(\|x - t\|) G_{\sigma_r}(\|g(x) - g(t)\|) g(t)$$

$$\hat{g}(x) = \sum_t \underbrace{G_{\sigma_s}(\|x - t\|)}_{\text{spatial}} \underbrace{G_{\sigma_r}(\|g(x) - g(t)\|)}_{\text{range}} g(t)$$



reproduced  
from [Durand 02]



2

0.1



$\sigma_r$

0.25



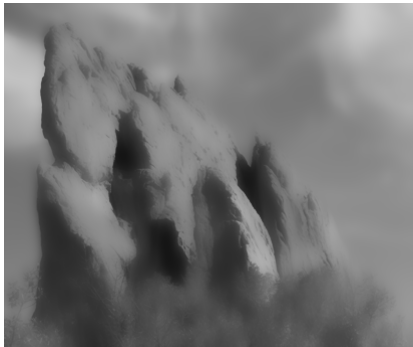
Gaussian blur

$\infty$

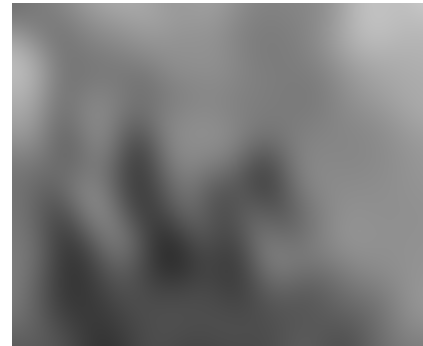
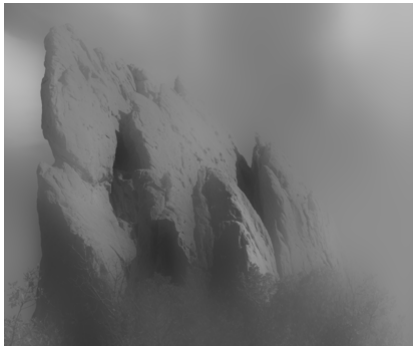


$\sigma_s$

6



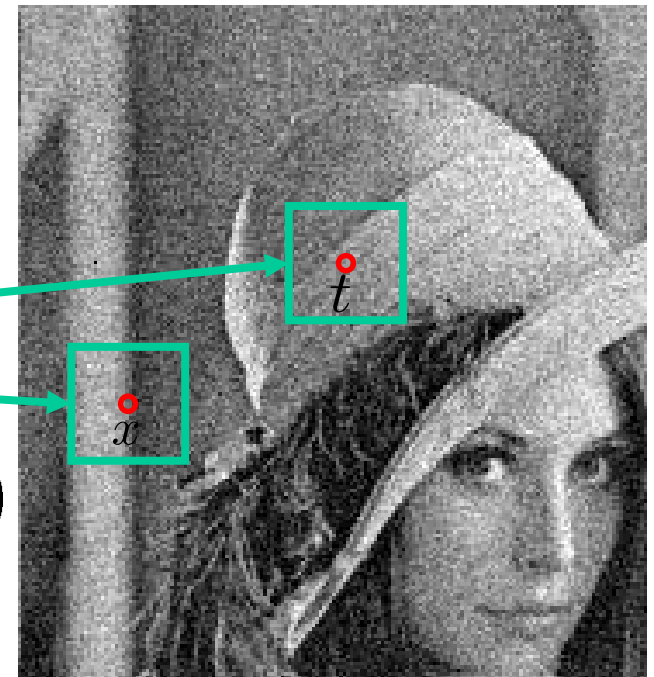
18



# Non-local Means filtr

- Průměrování přes všechny pixely s váhou, která je dána podobností okolí

$$\hat{g}(x) = \sum_t \cancel{G_{\sigma_s}(\|x - t\|)} G_{\sigma_r}(\|\mathcal{N}(x) - \mathcal{N}(t)\|^2) g(t)$$



- BM3D (2007)



**vstup**



**jednoduché  
průměrování**



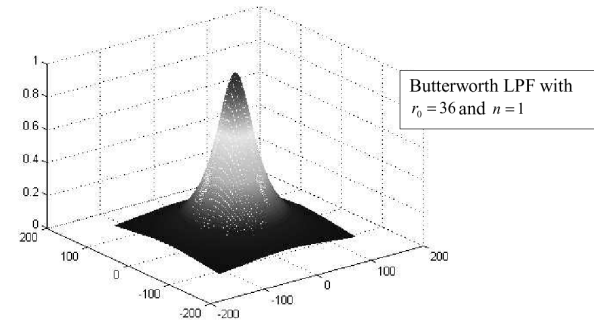
**schody**

**bilaterální  
filtr**



**NL-means  
filtr**

# Hladký low-pass filtr ve frekvenční oblasti



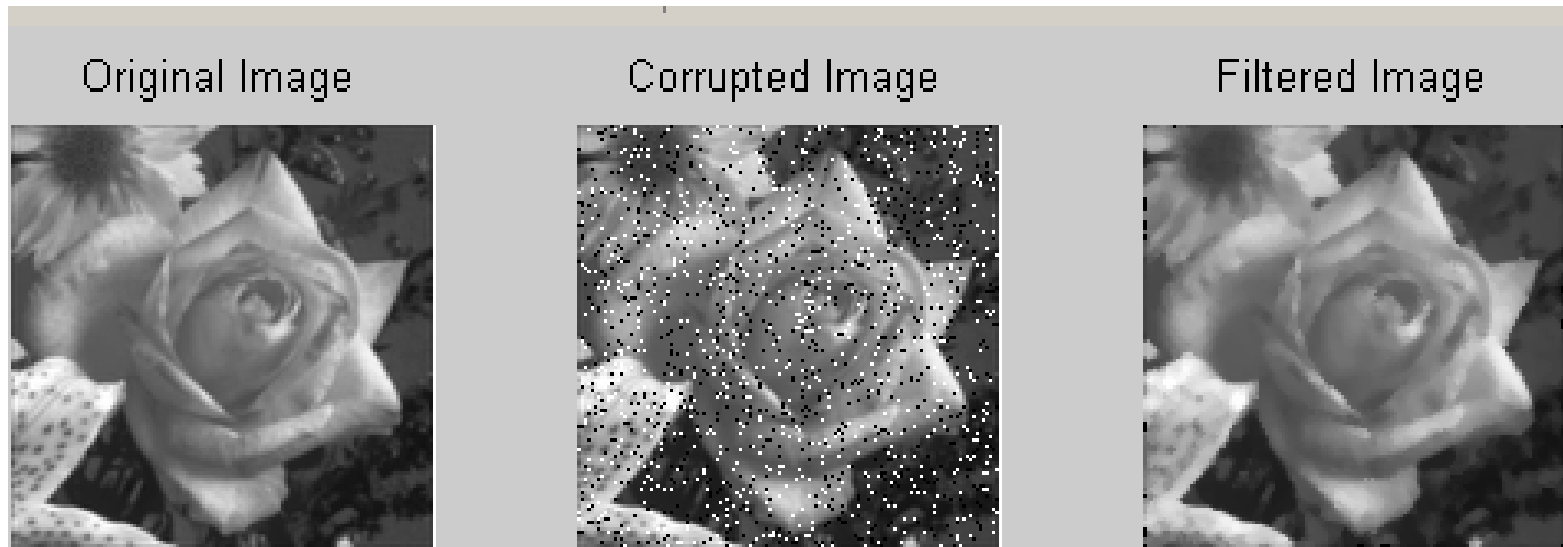
LPF image,  $r_0 = 13$



LPF image,  $r_0 = 10$

# Nelineární filtry

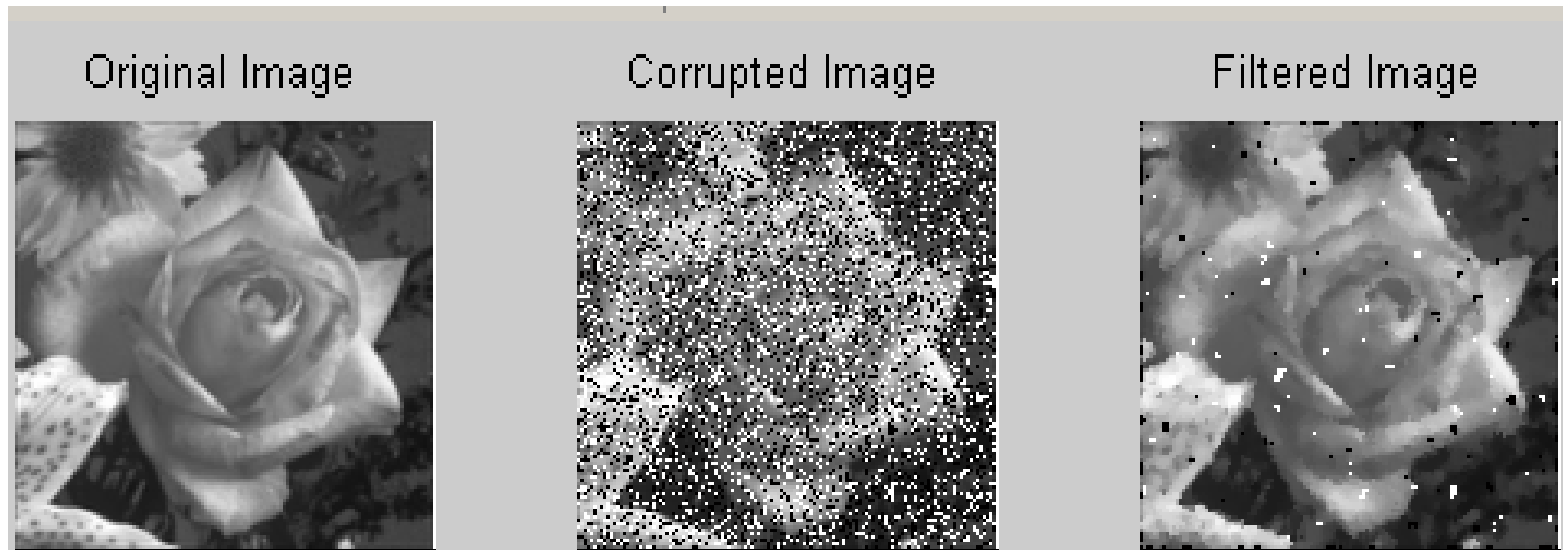
- **Medián**



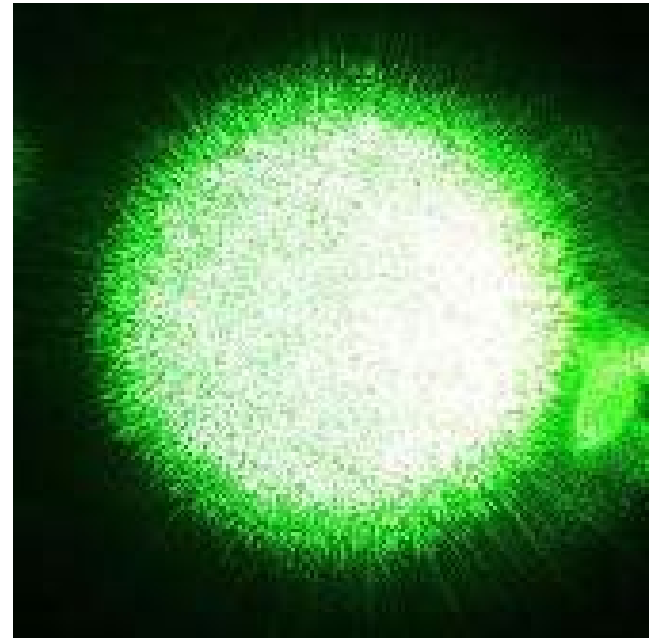
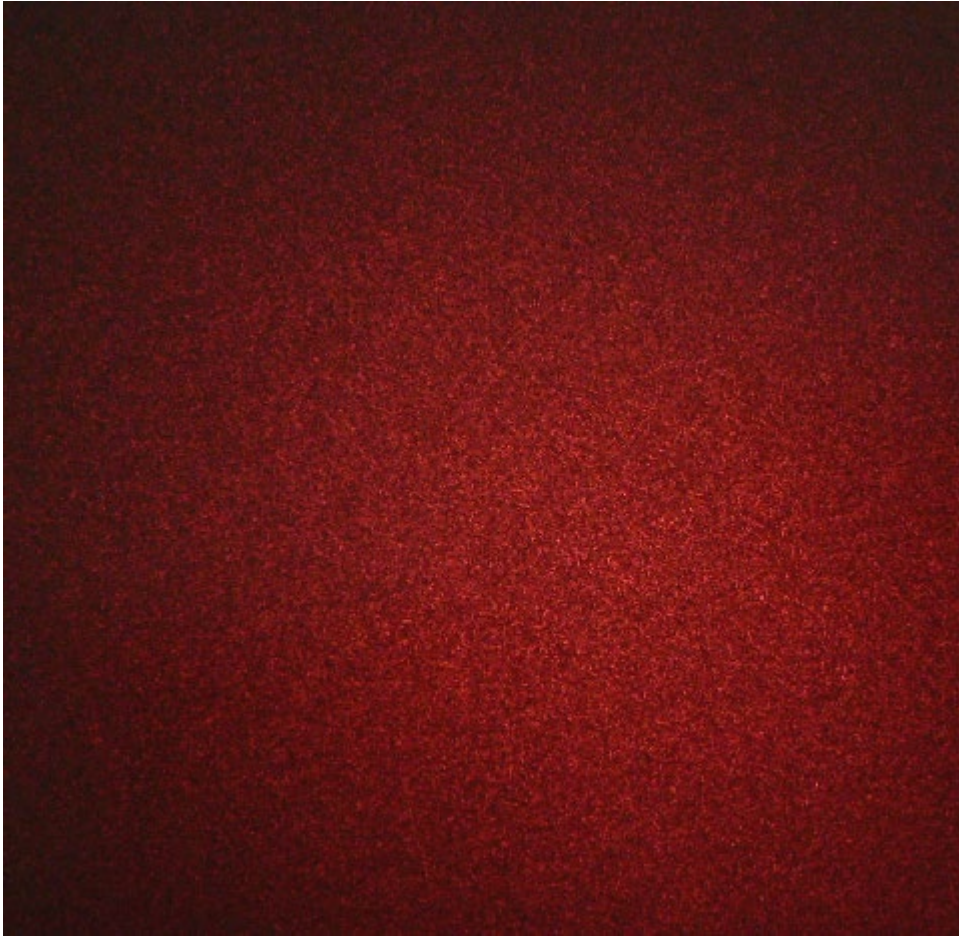


# Nelineární filtry

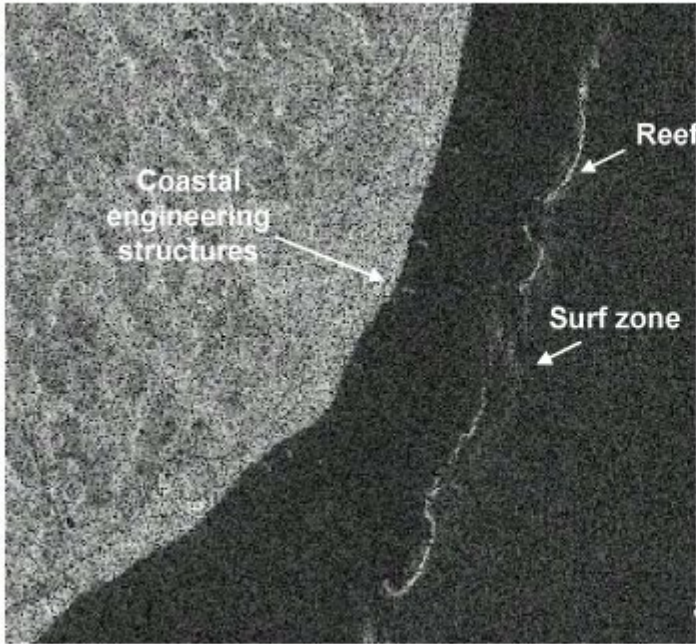
- **Medián**



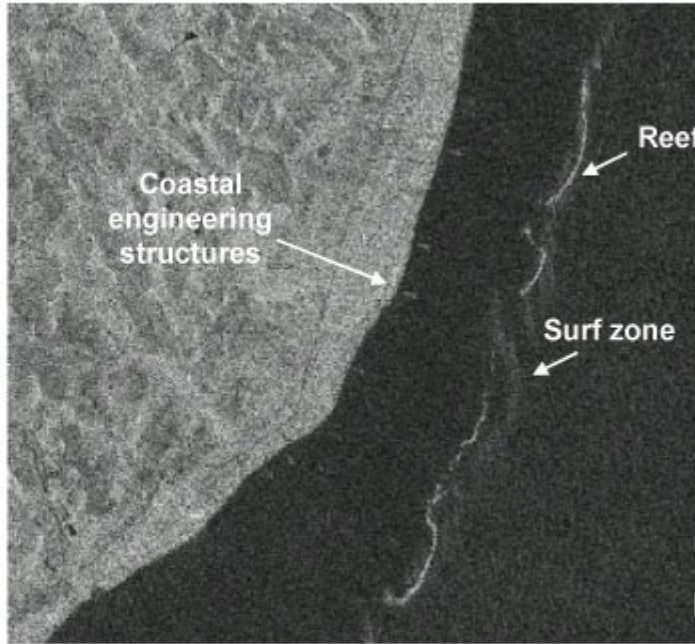
# Speckle noise



**A**



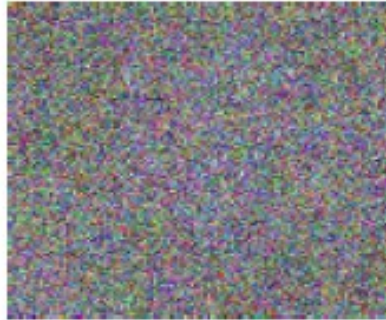
**B**



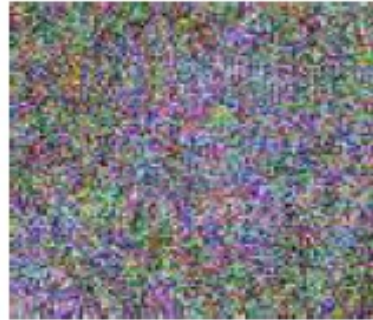
# Color median filter



(a)



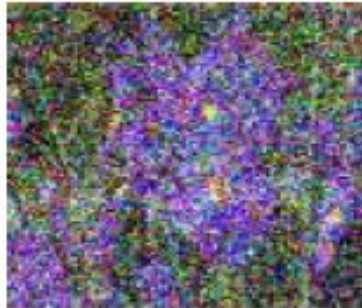
(b)



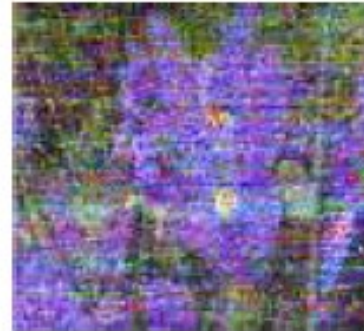
(c)



(d)



(e)



(f)



(g)



# Minimalizace funkcionálu



# Průměrování v obraze

šum



3x3

5x5



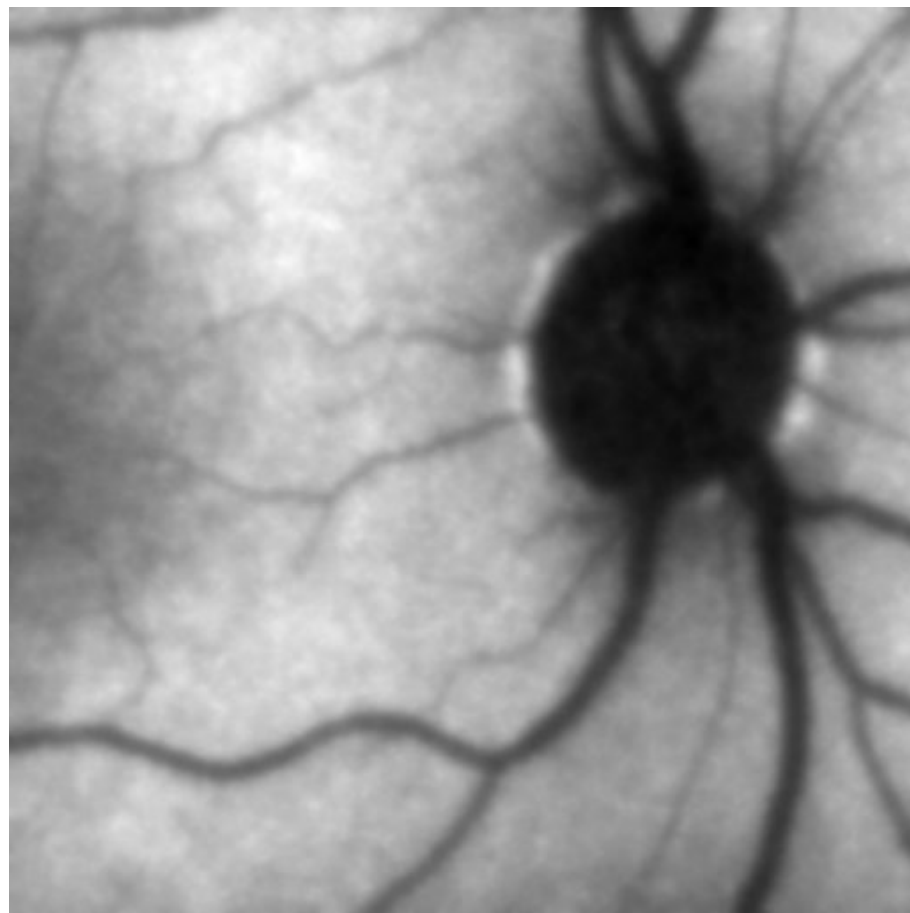
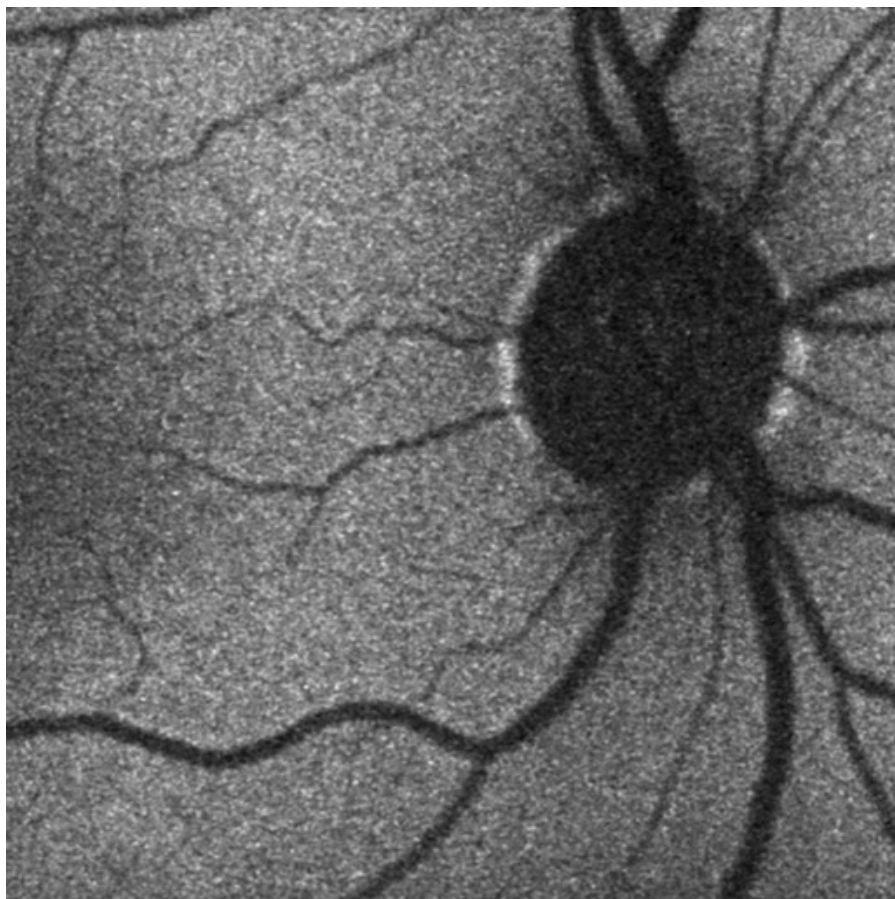
7x7

## Infračervený obrázek - splajny





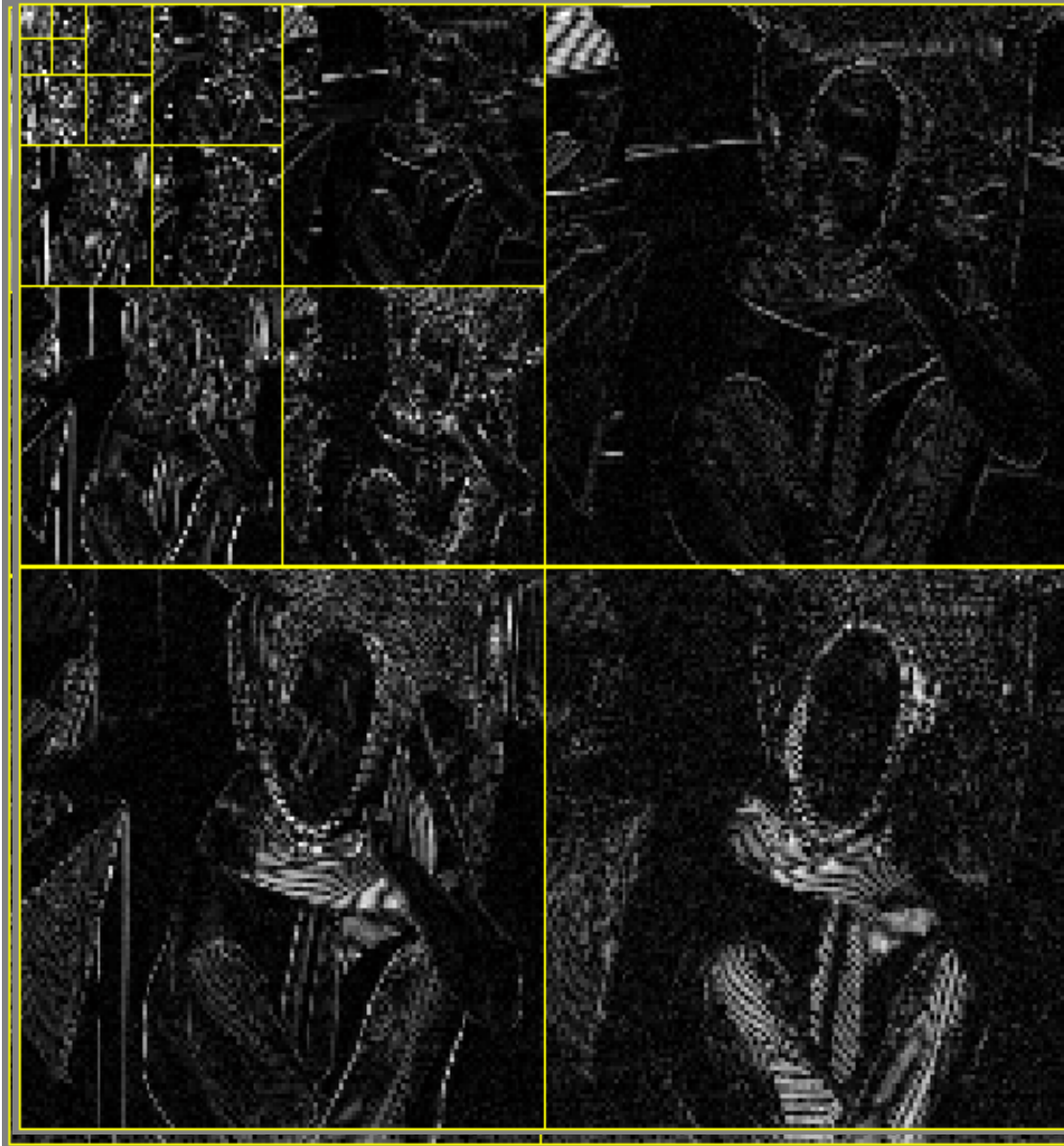
# Autofluorescenční snímky oka



# Anizotropní difuze

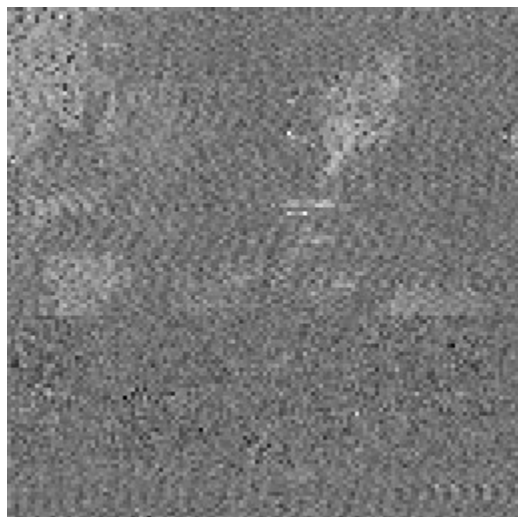


# Wavelety

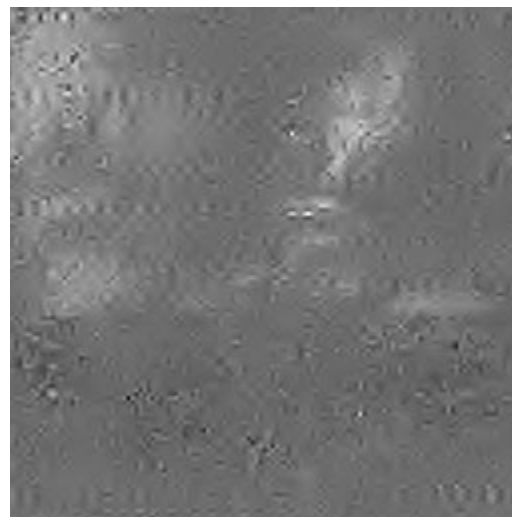


# Wavelety

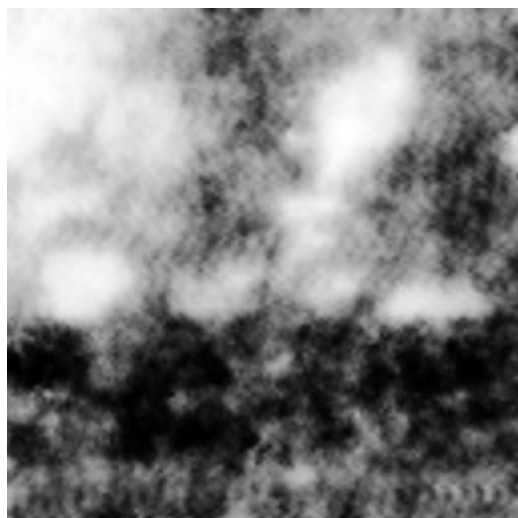




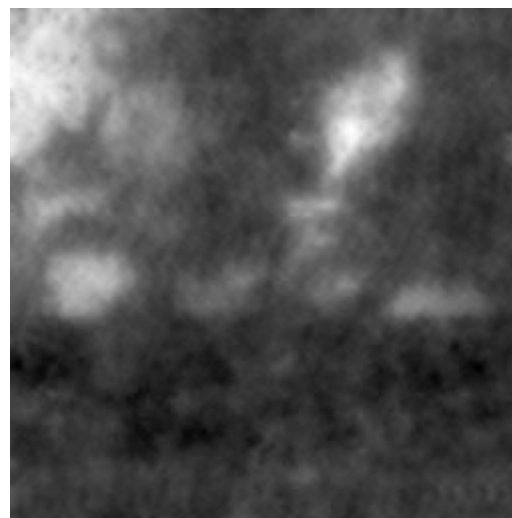
noisy BEEM image



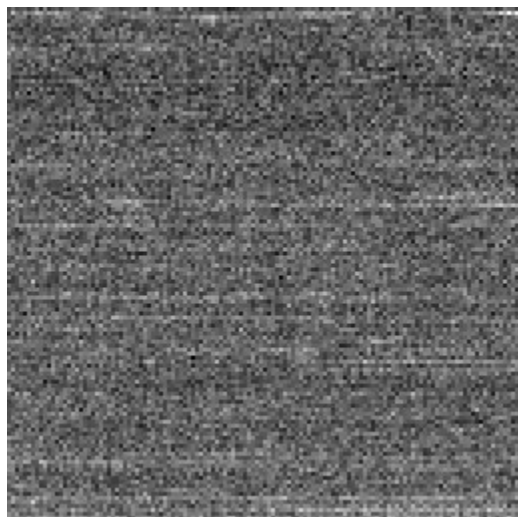
wavelet-based denoising



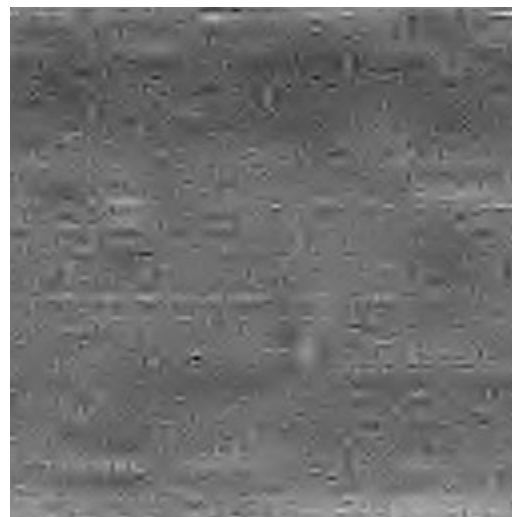
TV + histogram equalization



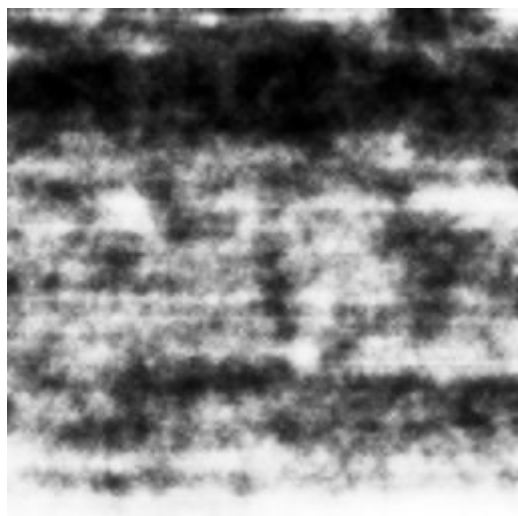
TV-based denoising



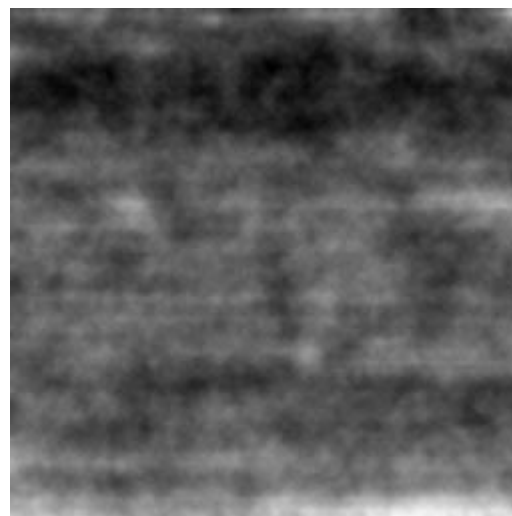
noisy BEEM image



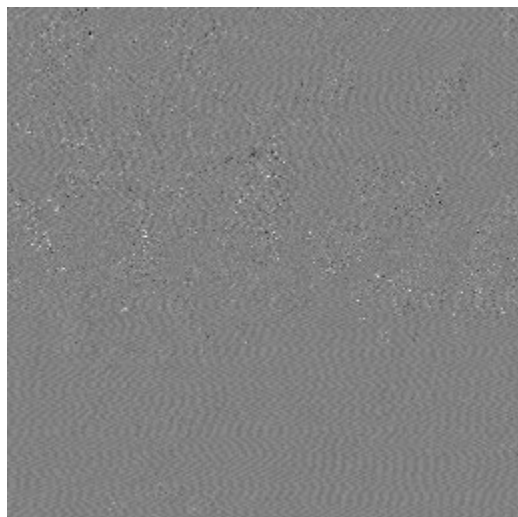
wavelet-based denoising



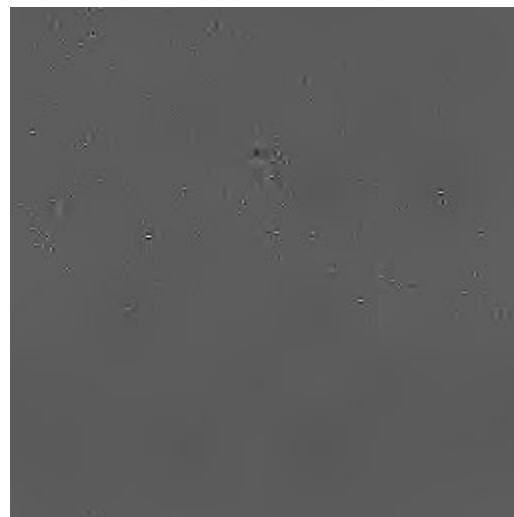
TV + histogram equalization



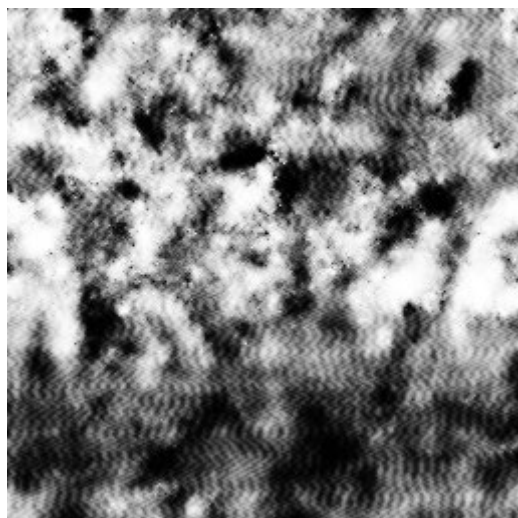
TV-based denoising



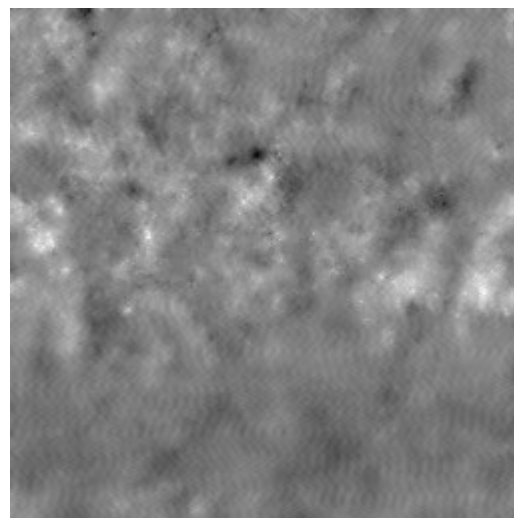
noisy BEEM image



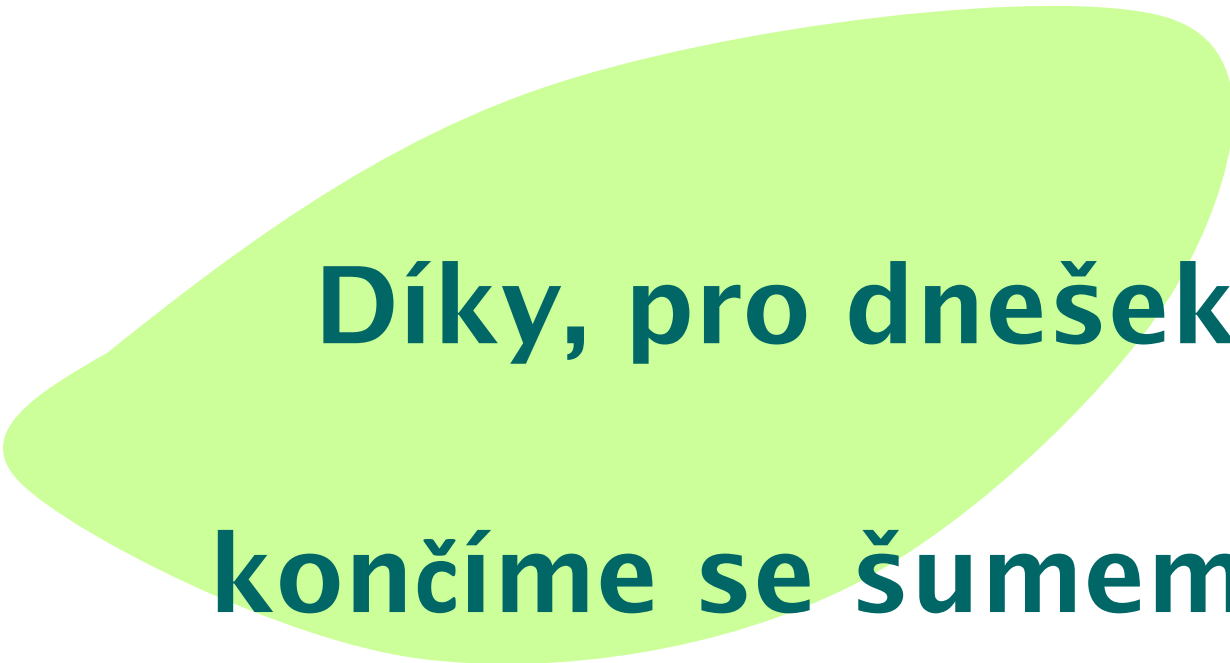
wavelet-based denoising



TV + histogram equalization



TV-based denoising



**Díky, pro dnešek  
končíme se šumem!**

**Nějaké otázky ?**