

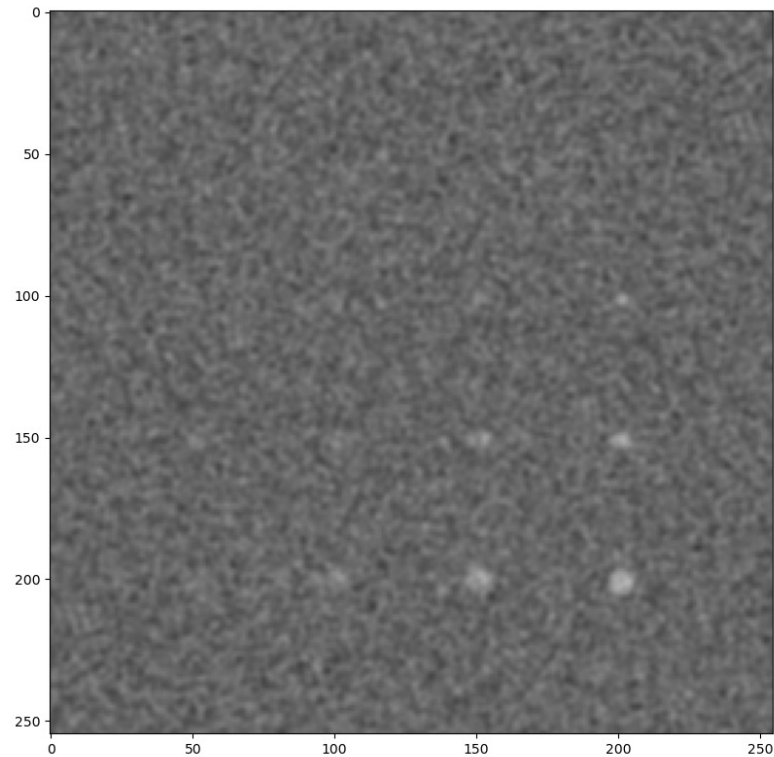
# Vlastnosti šumu CT obrazu u moderních rekonstrukčních algoritmů

DAVID KOZÁK

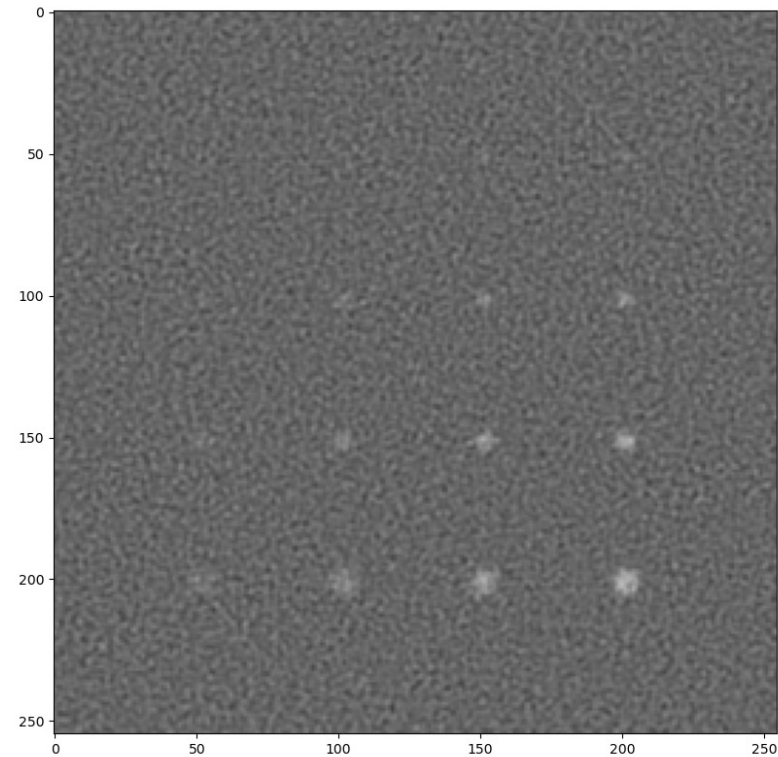
ODDĚLENÍ LÉKAŘSKÉ FYZIKY A RADIAČNÍ OCHRANY FNOL

# Motivace

*std = 15,00 HU*

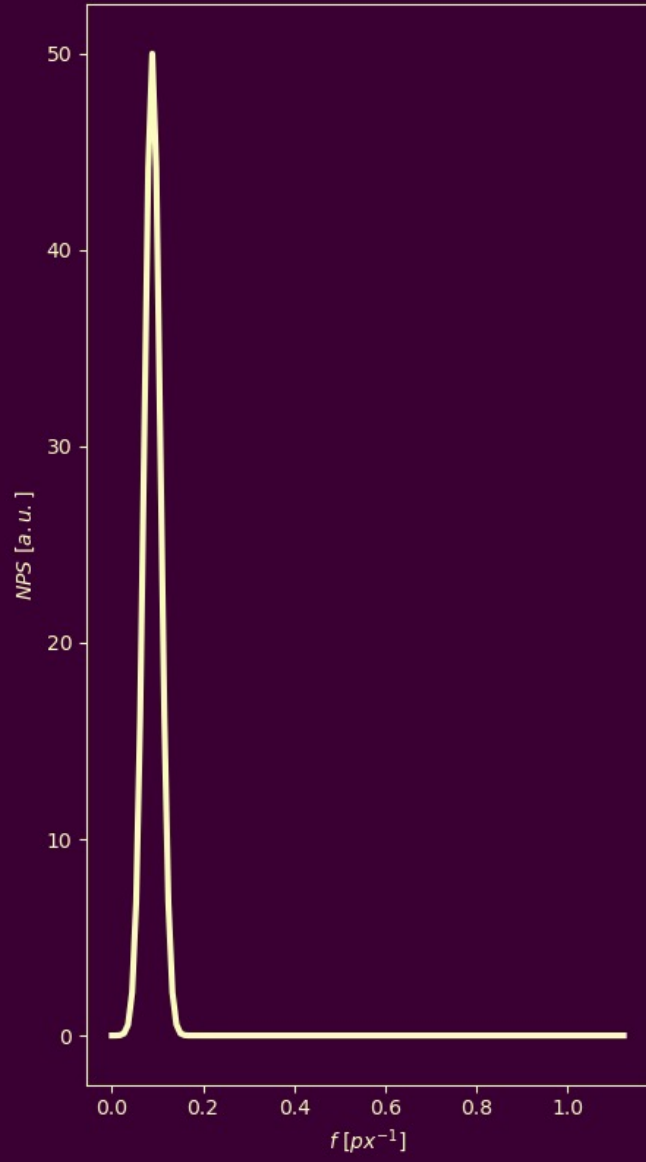


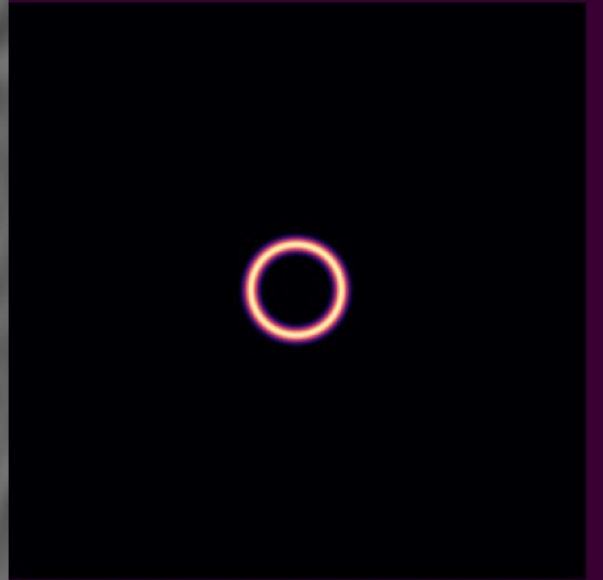
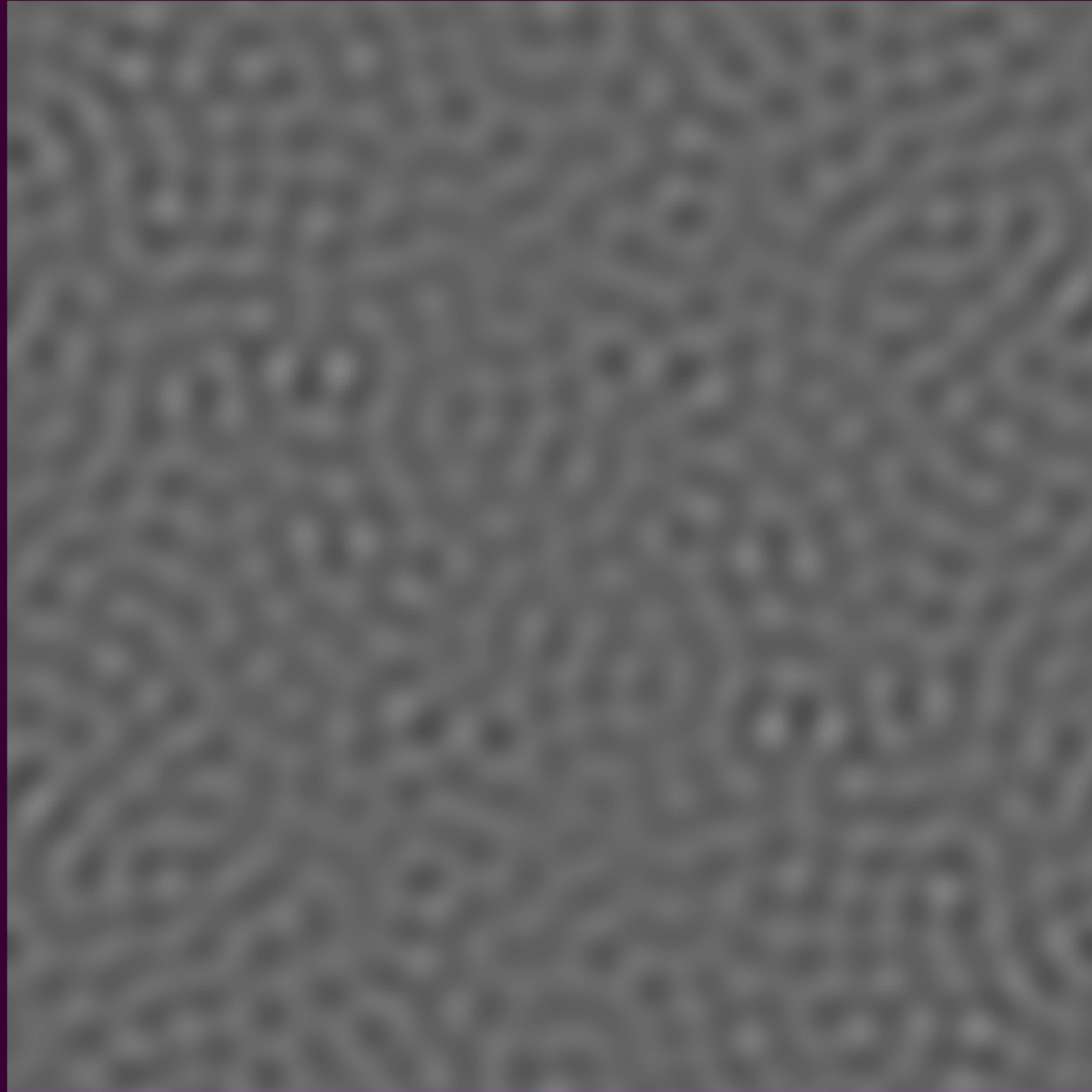
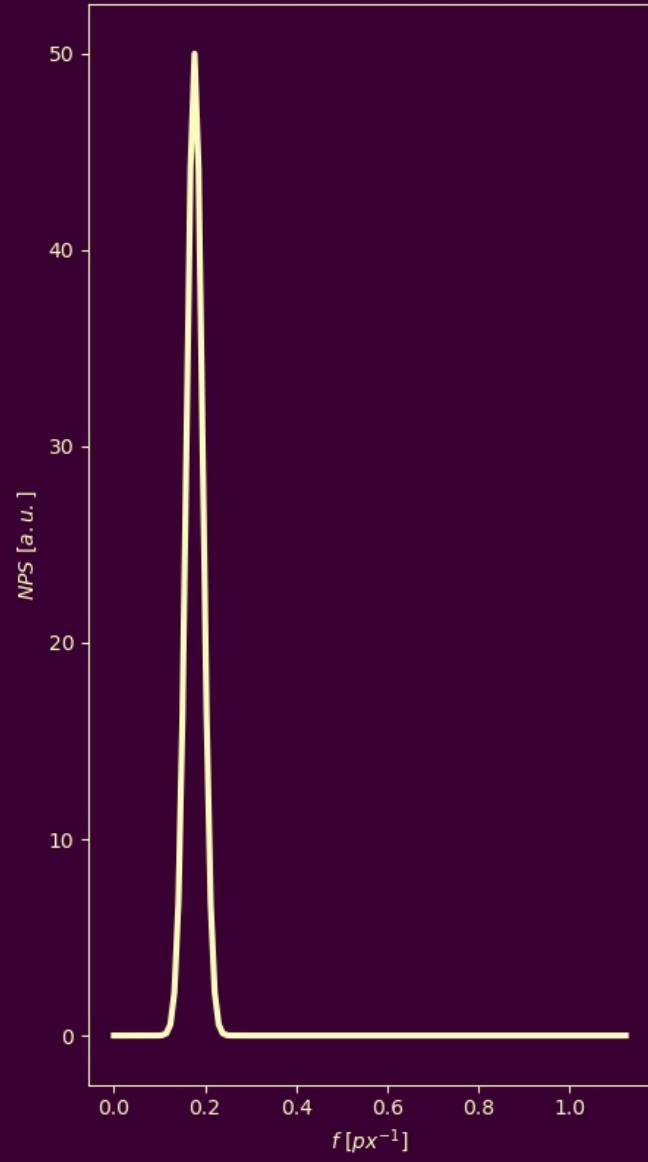
*std = 15,00 HU*

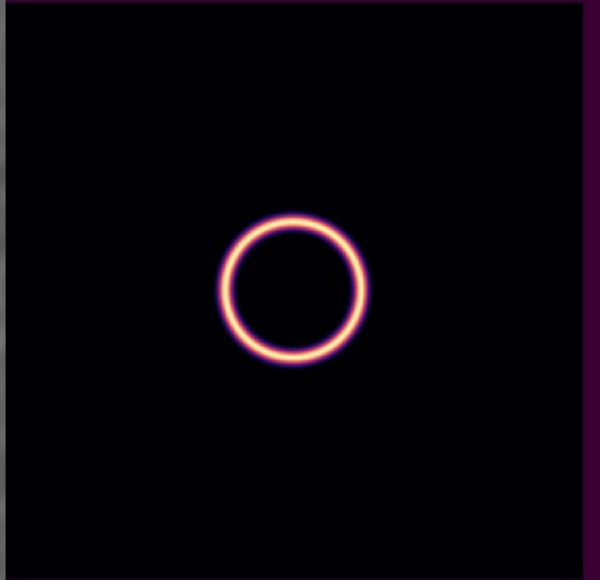
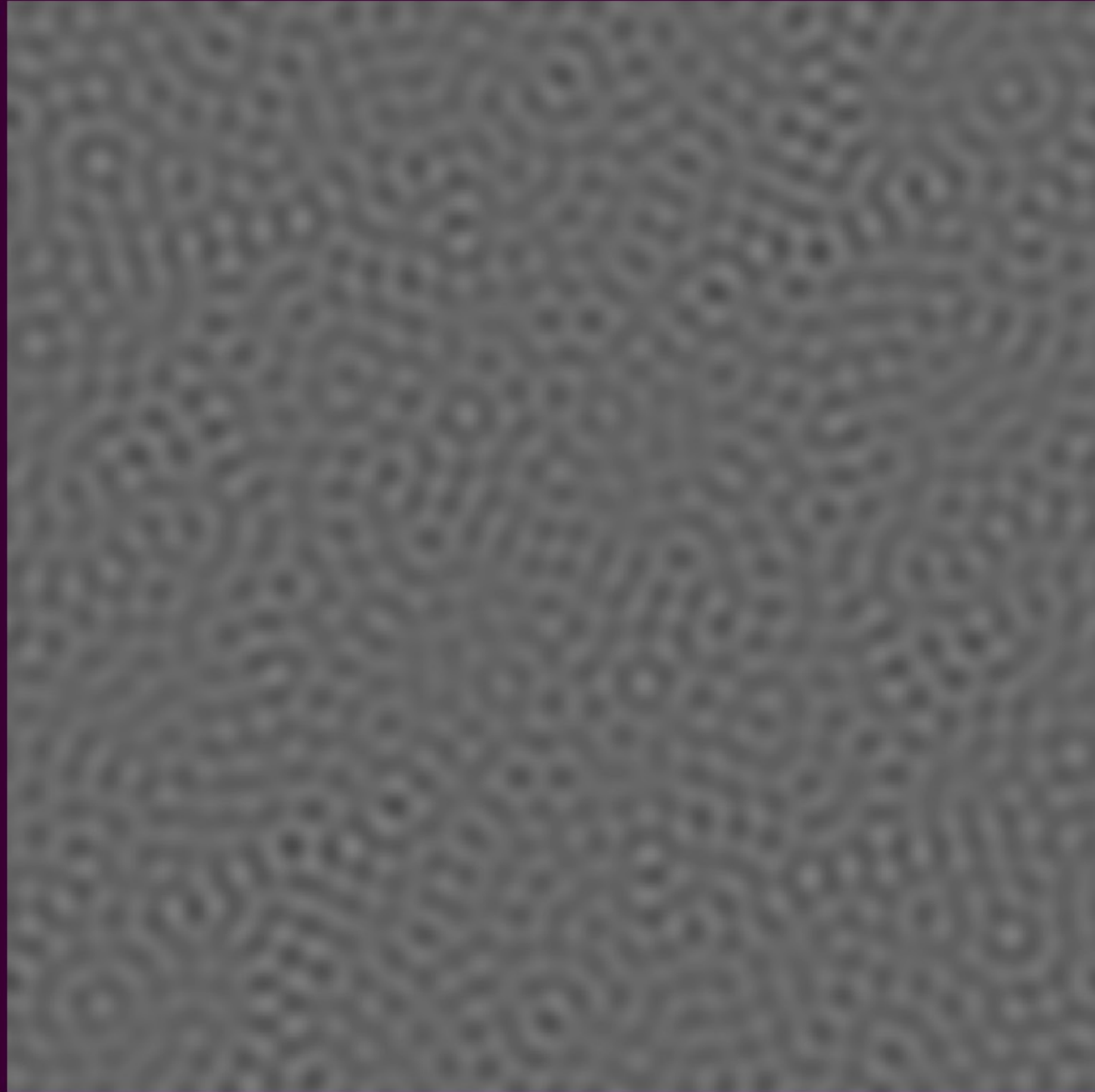
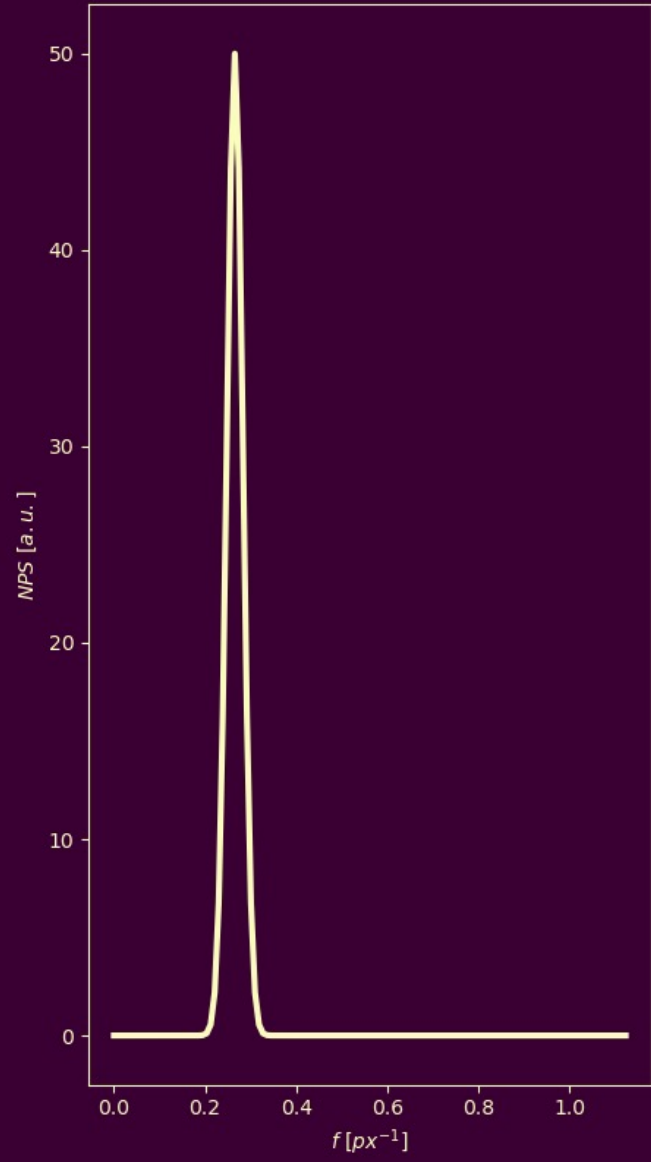


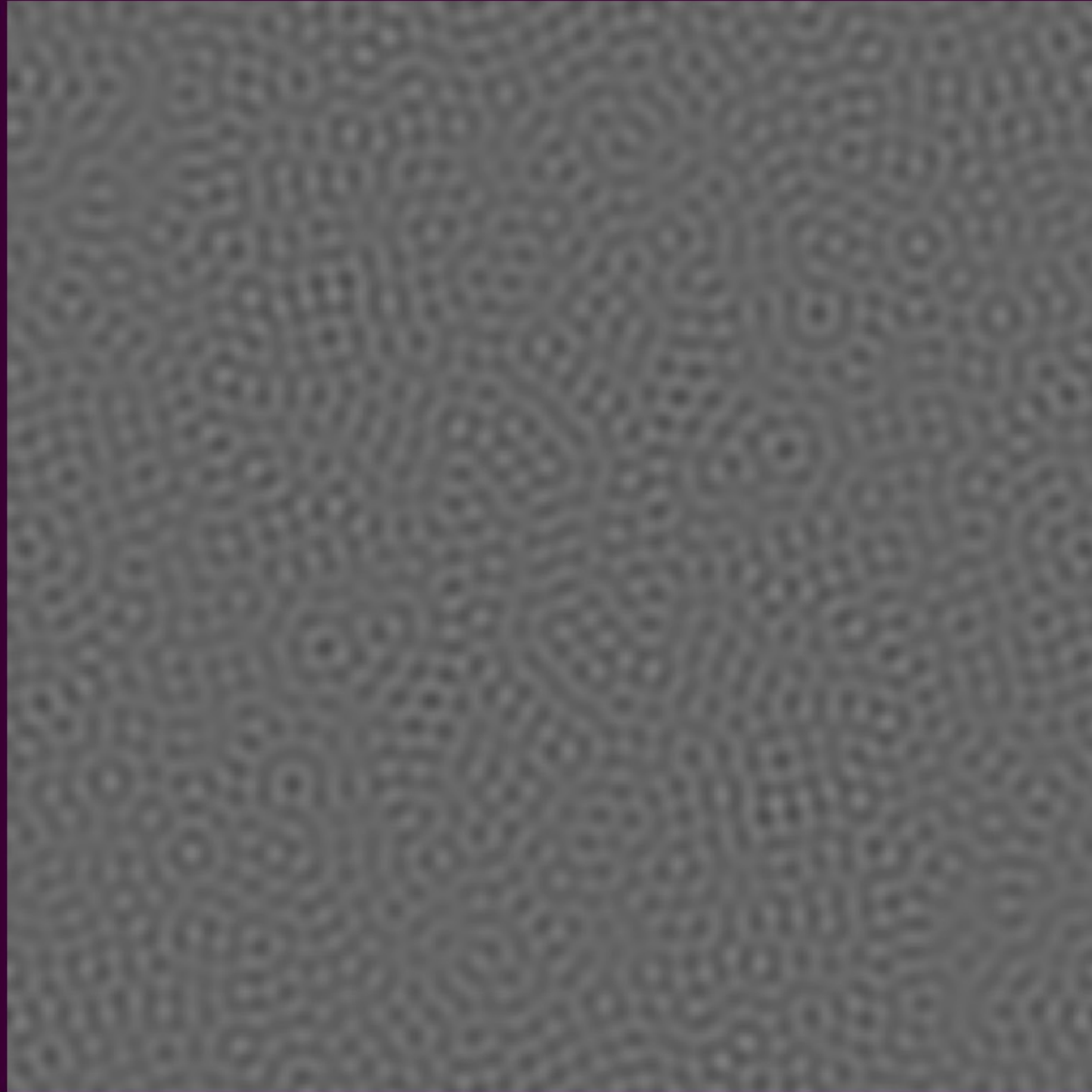
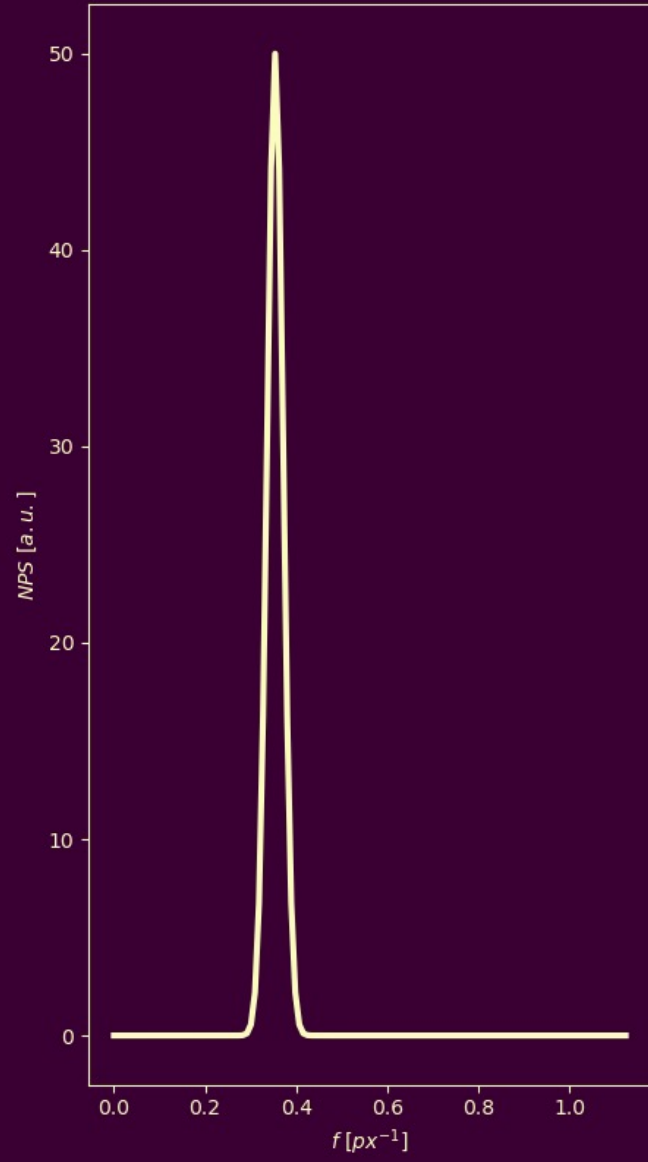
# Noise power spectrum

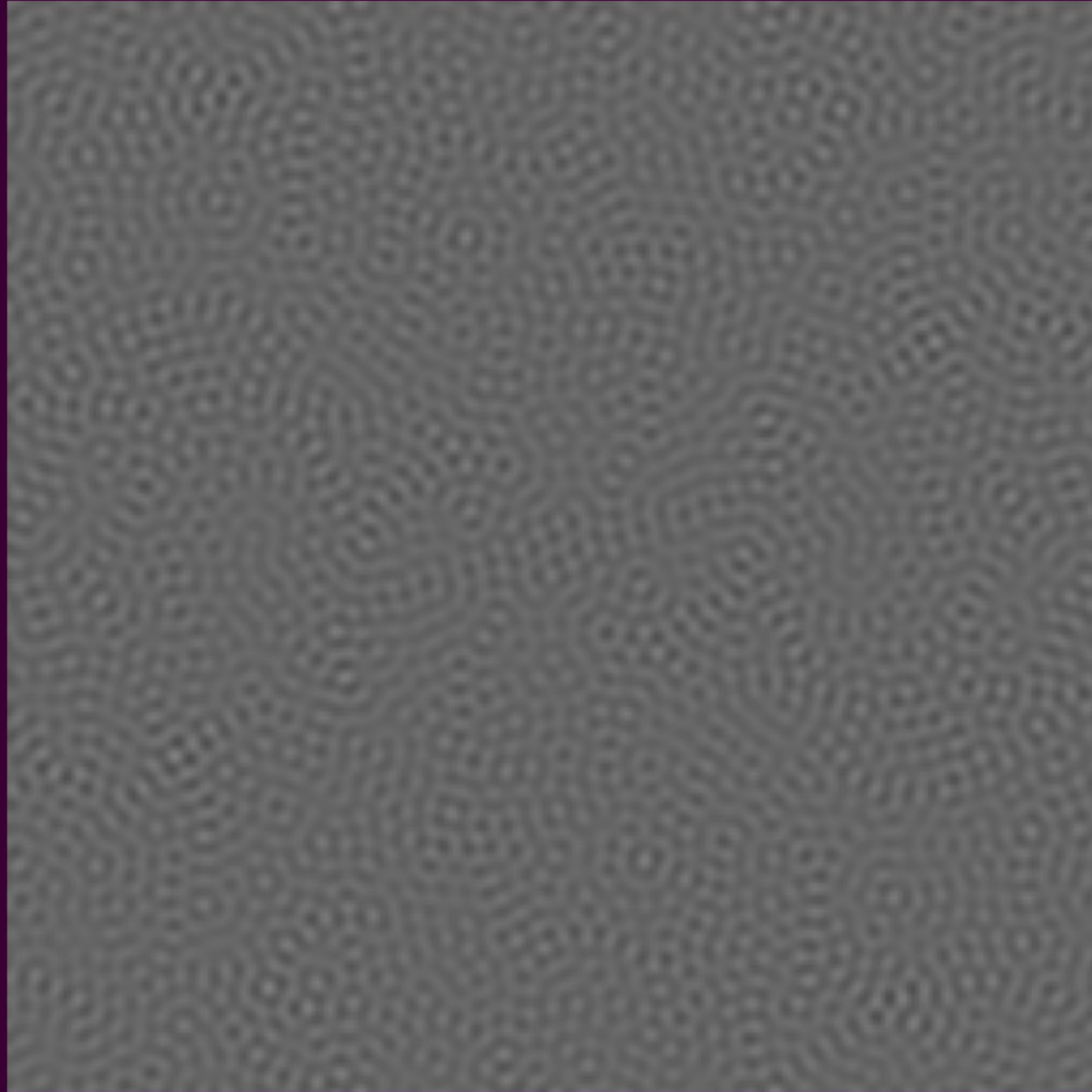
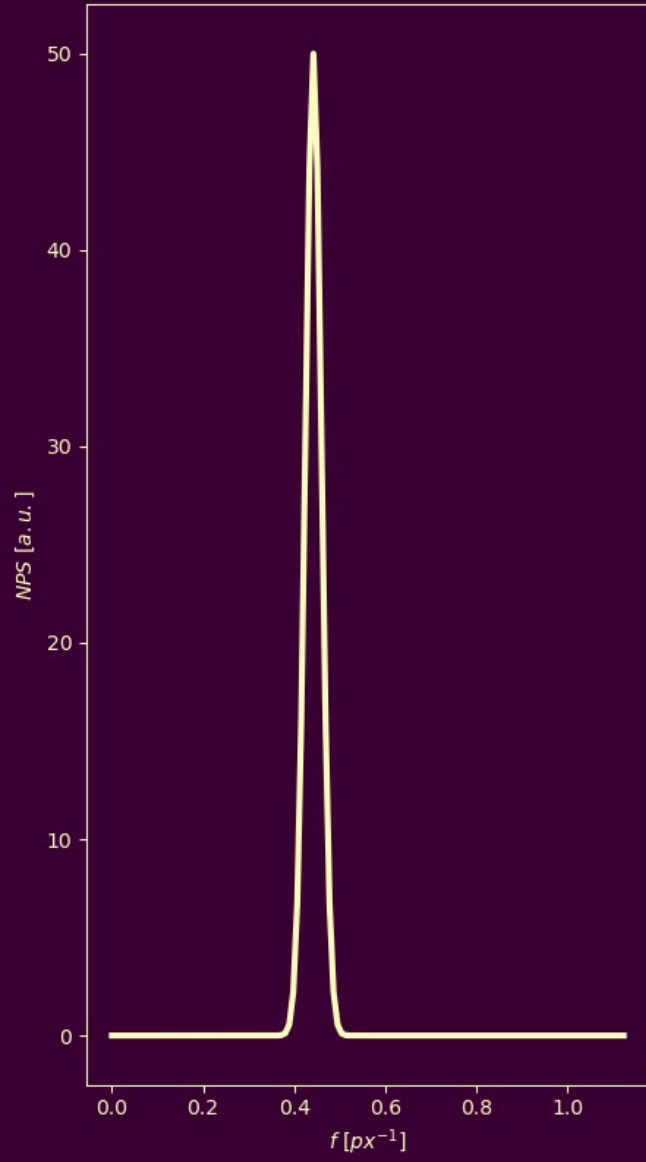
- ▶ Metrika pro zhodnocení šumu v obraze
  - ▶ Popisuje, jaké je zastoupení šumu pro různé prostorové frekvence
  - ▶ Díky tomu je možné zhodnotit nejen velikost šumu, ale i jeho texturu
  - ▶ Nízkofrekvenční, vysokofrekvenční šum



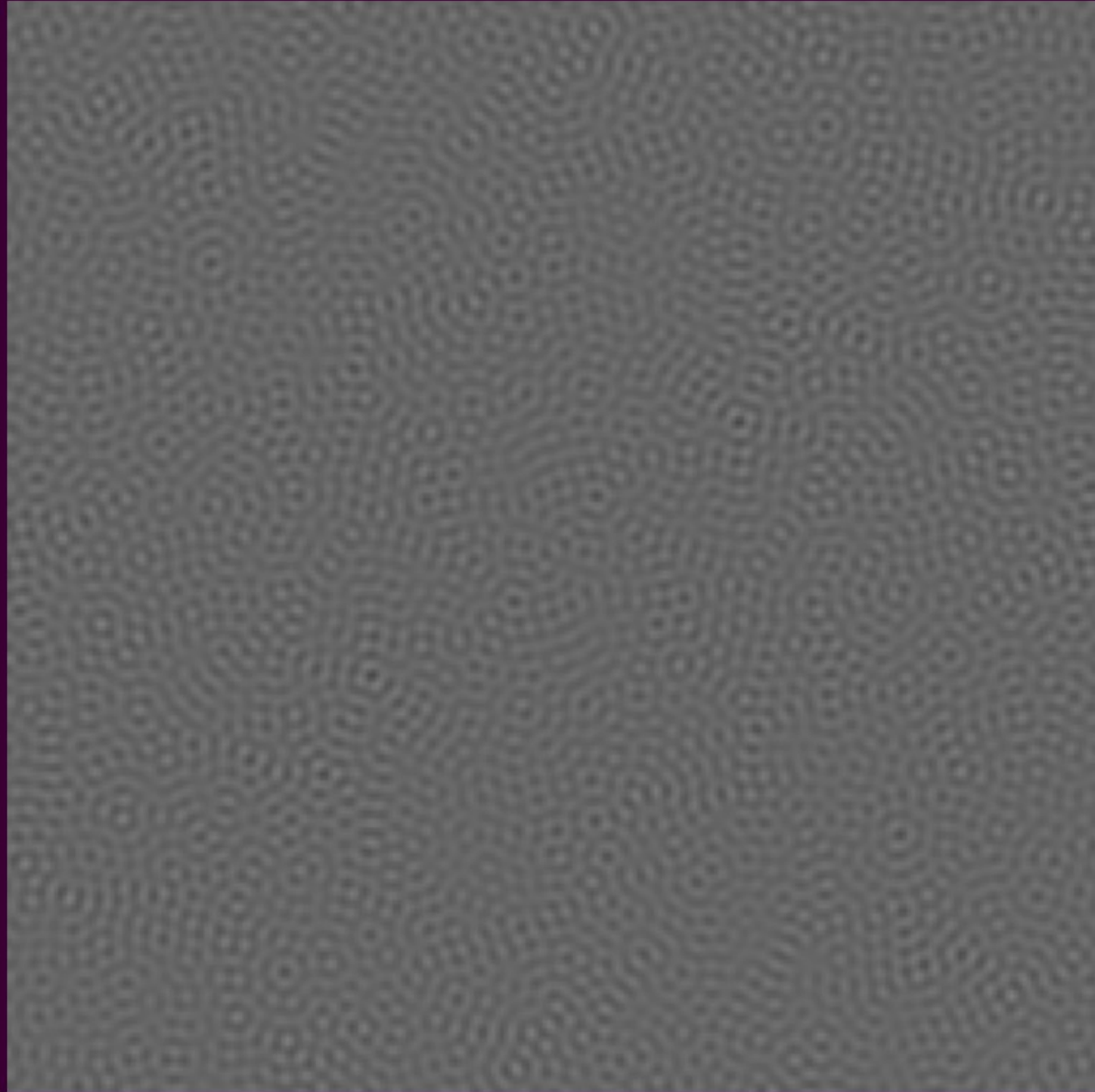
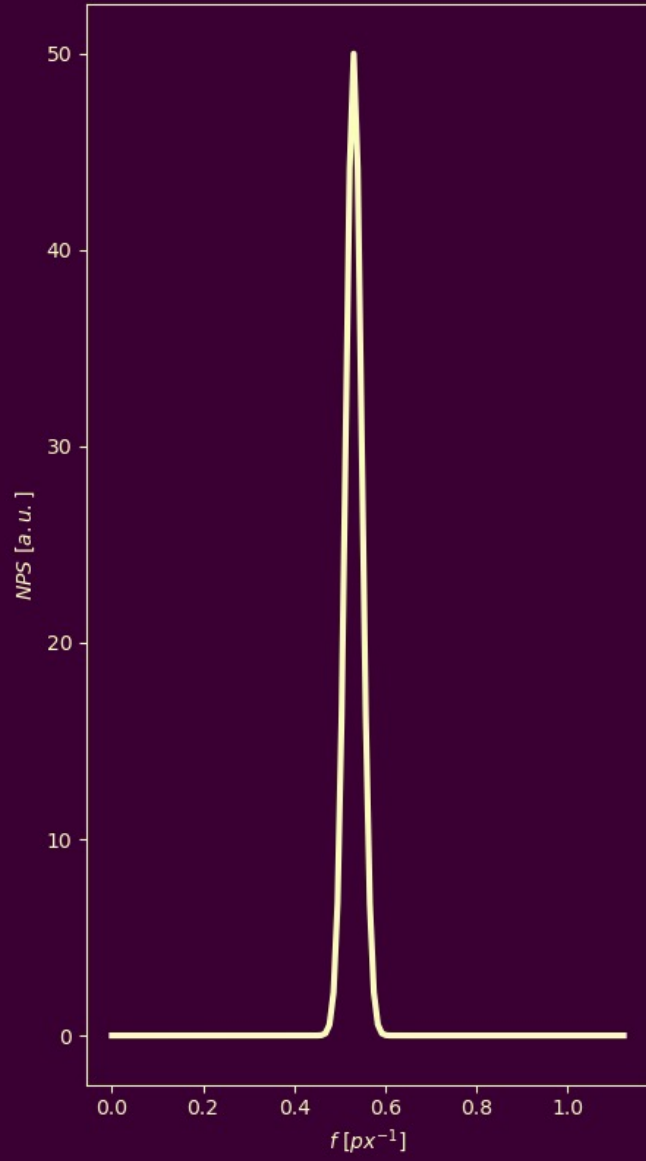


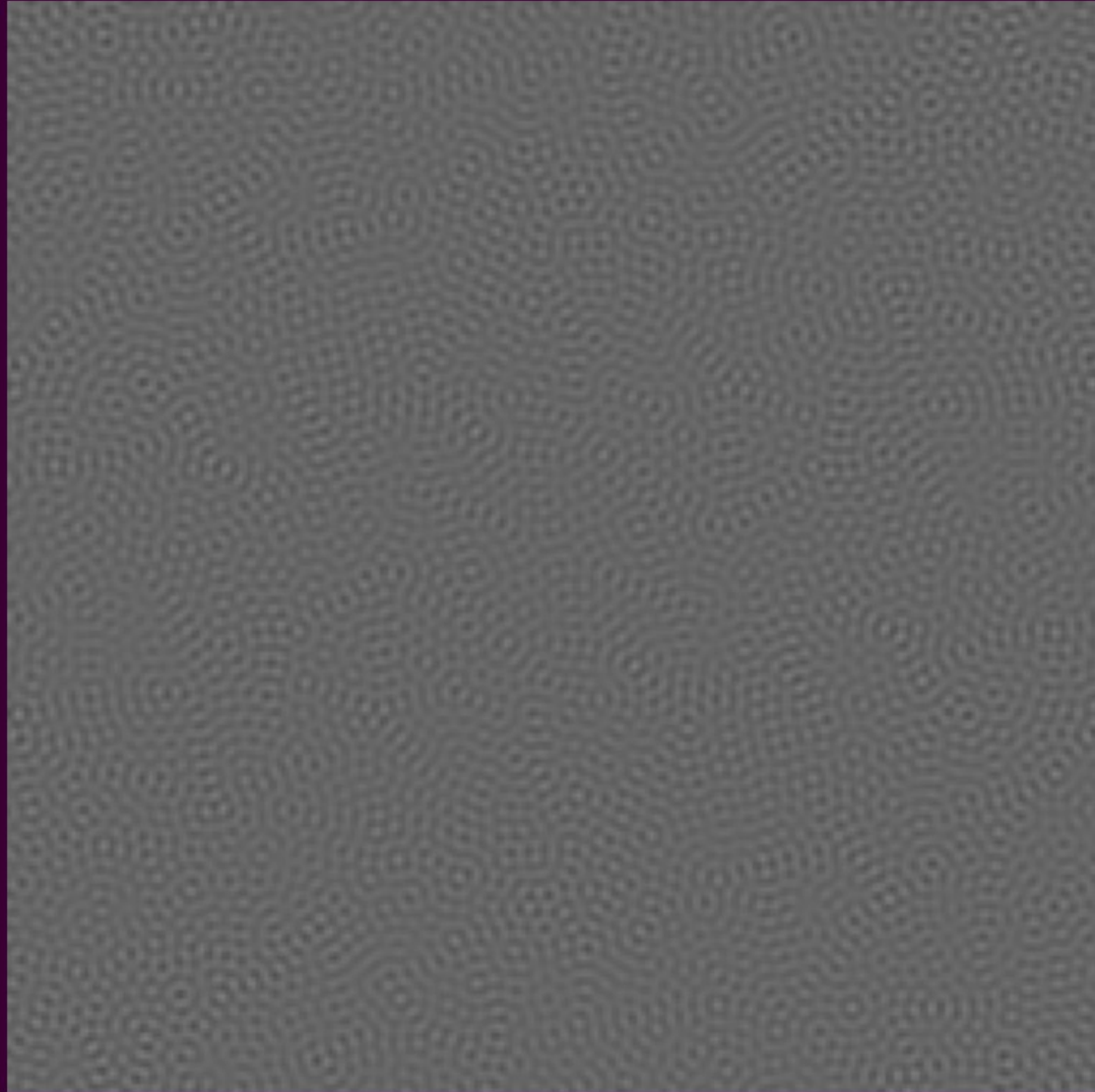
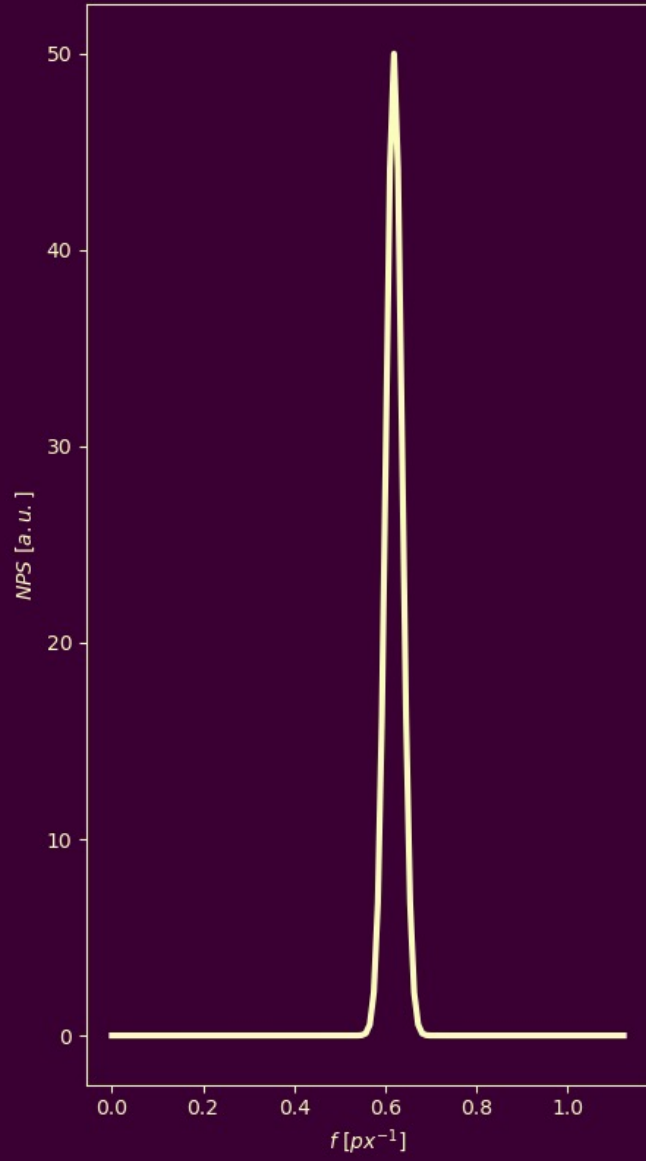


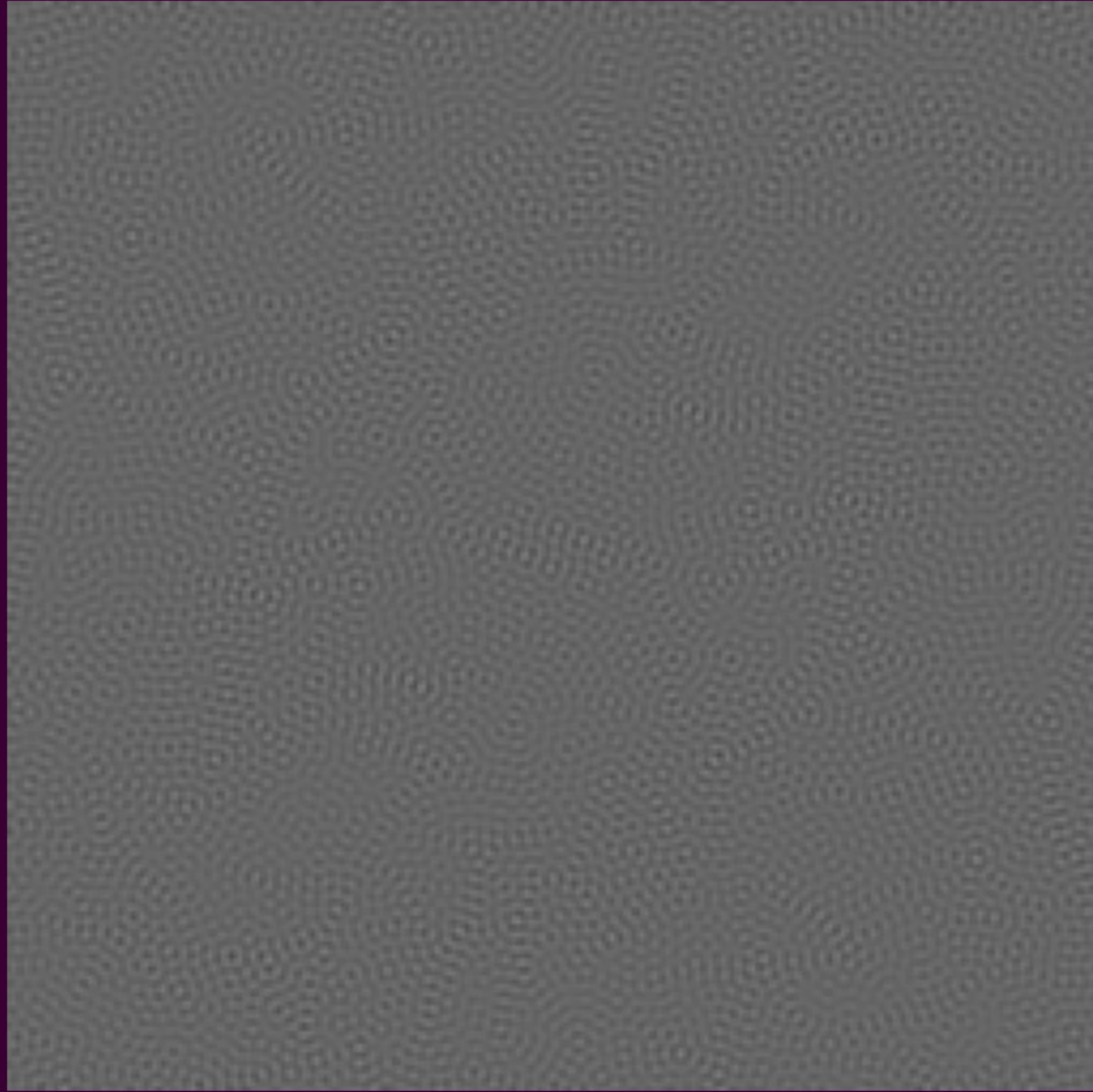
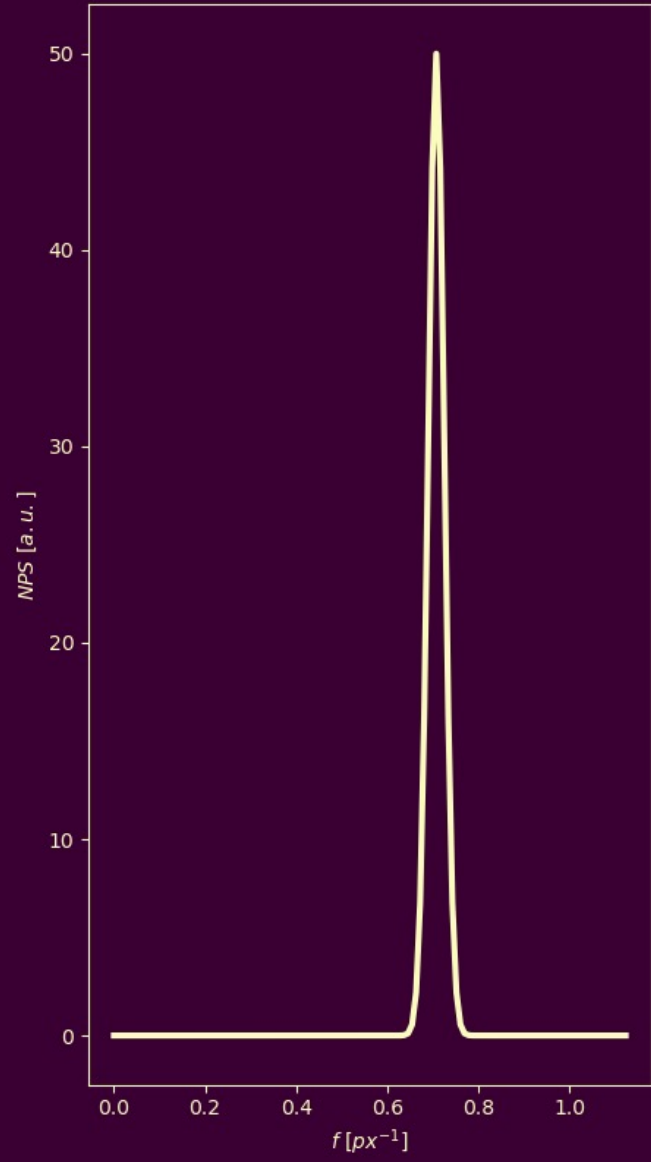


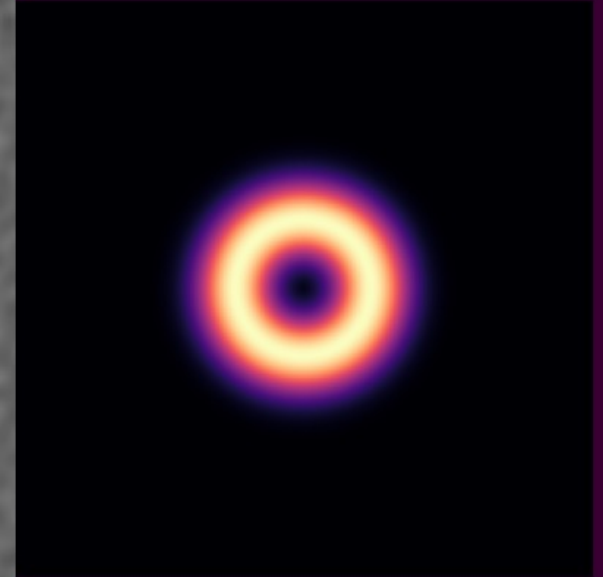
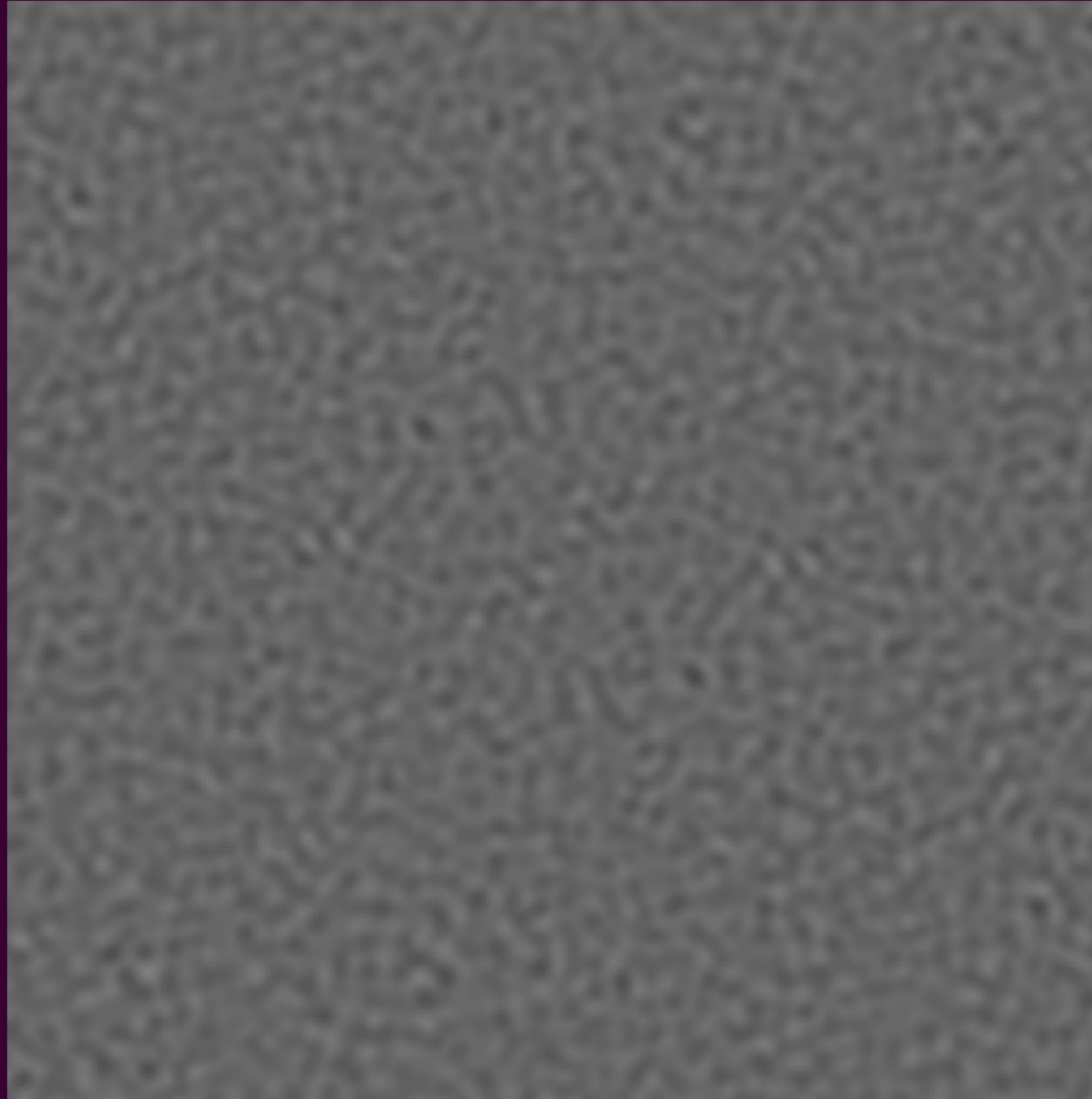
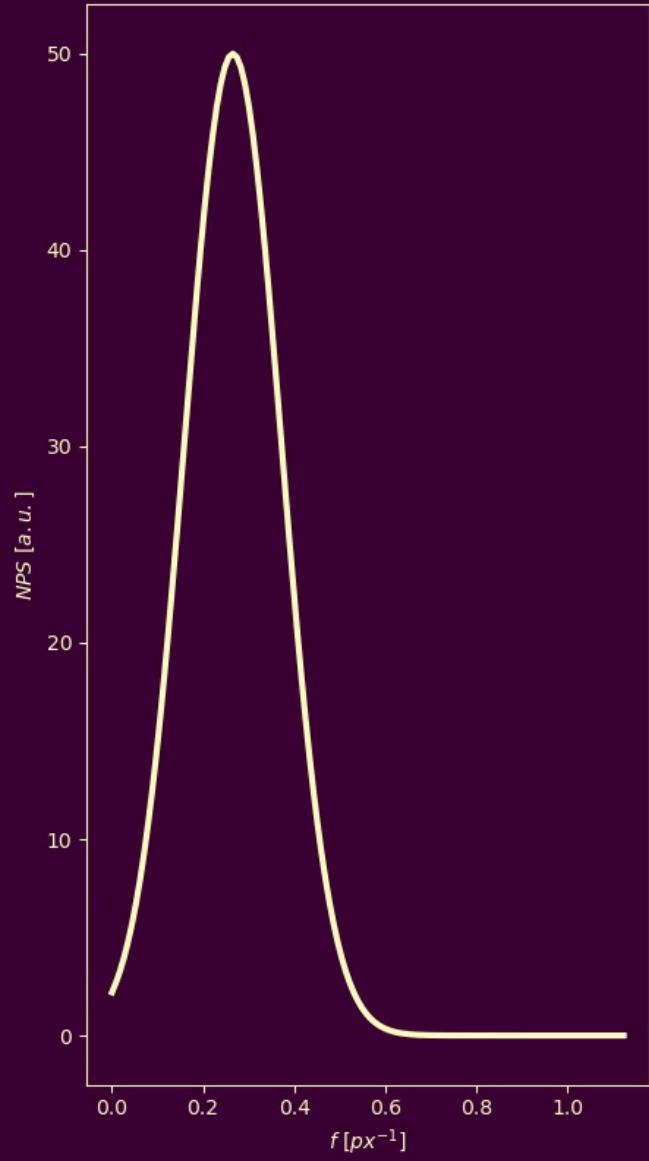


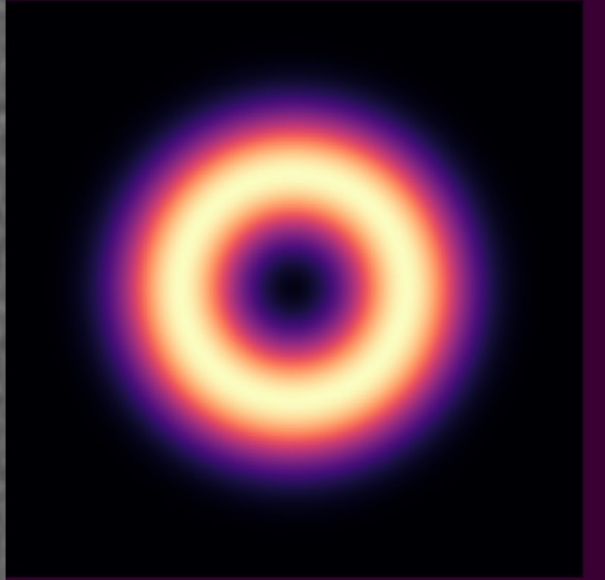
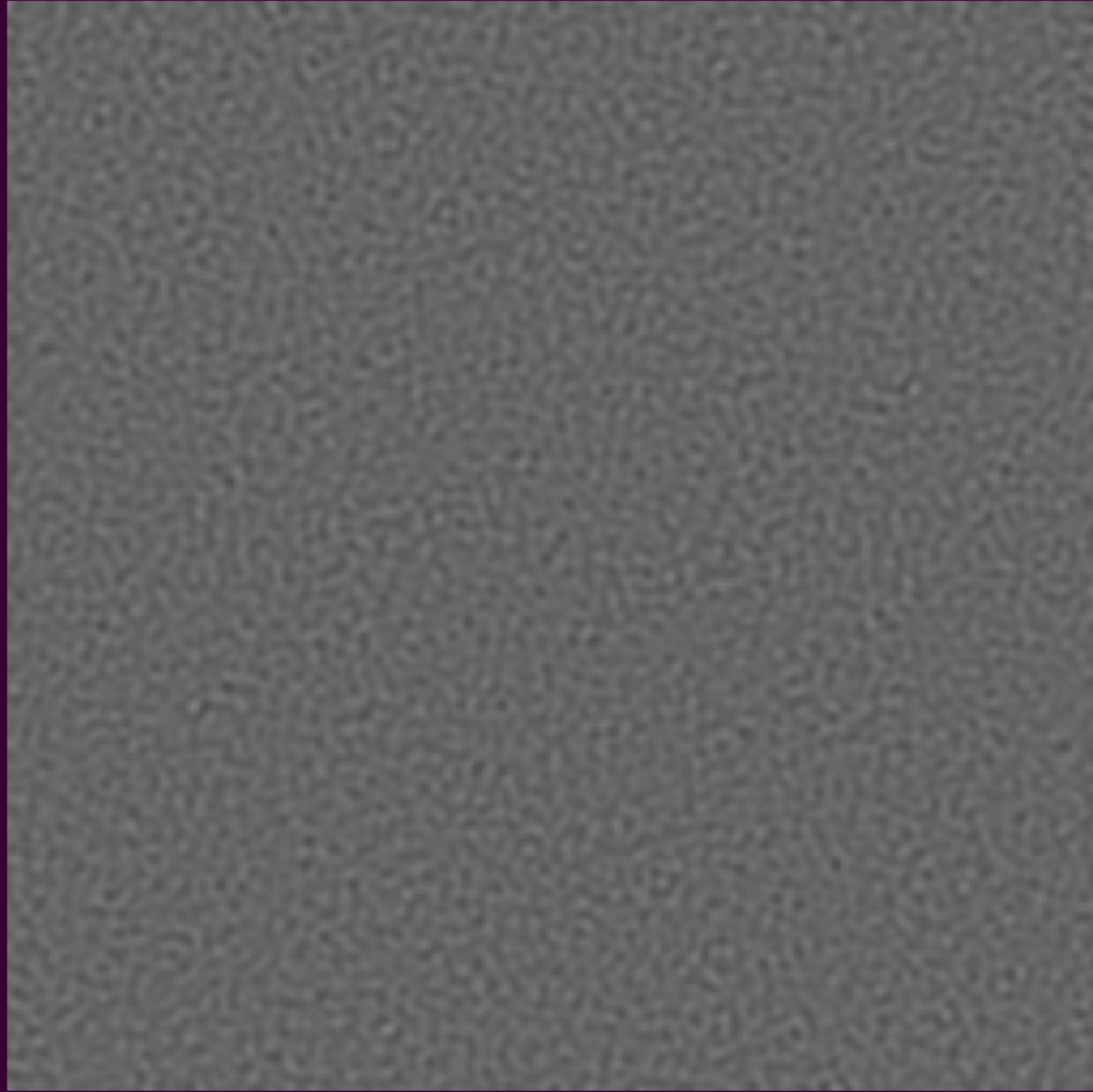
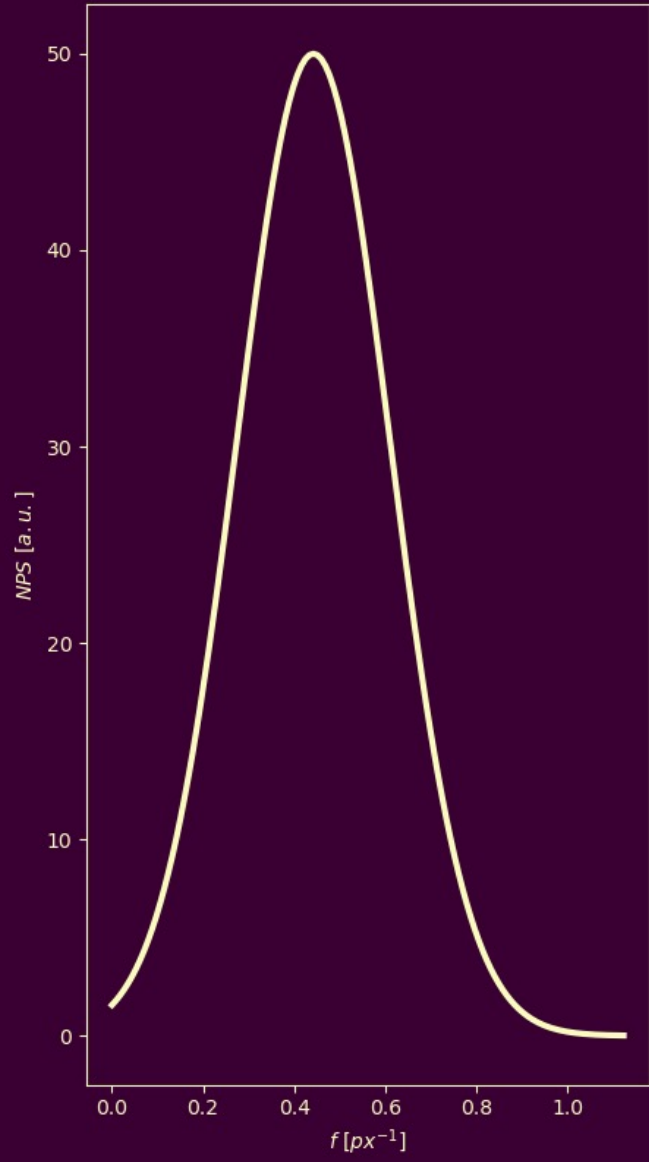










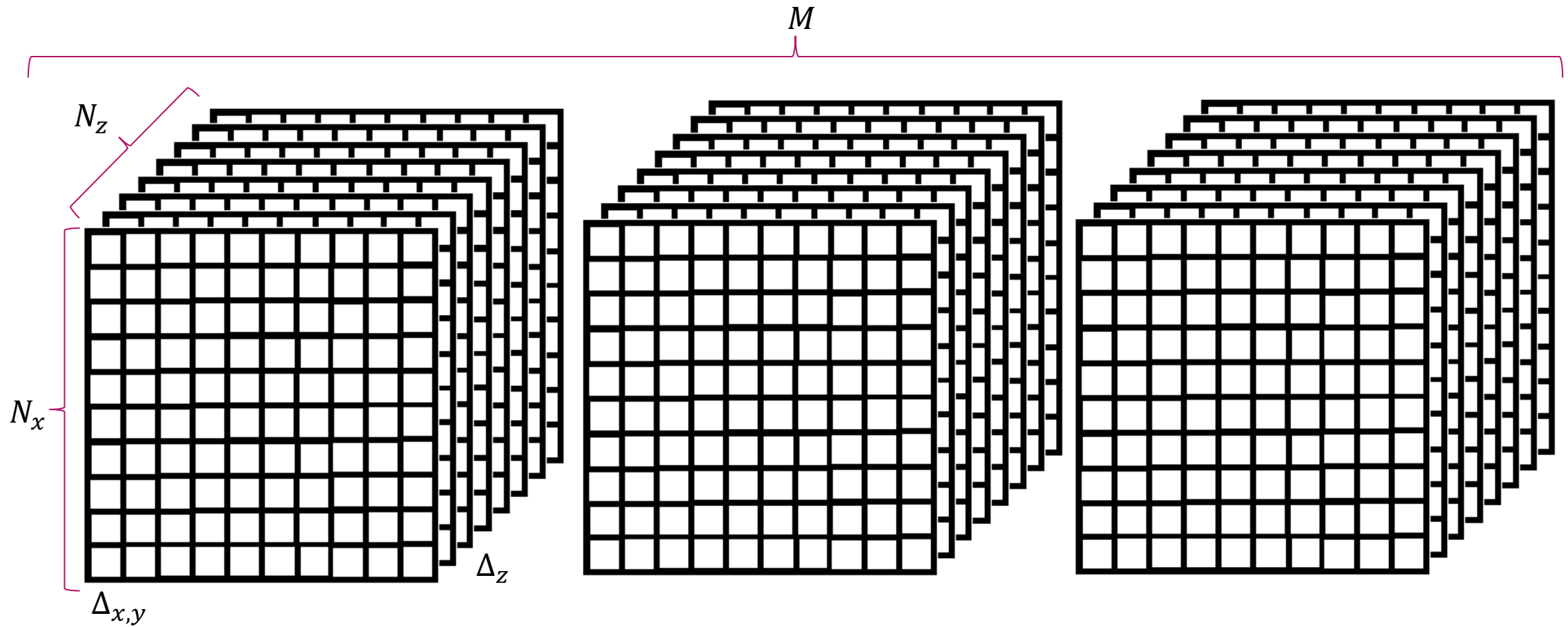


# Noise power spectrum

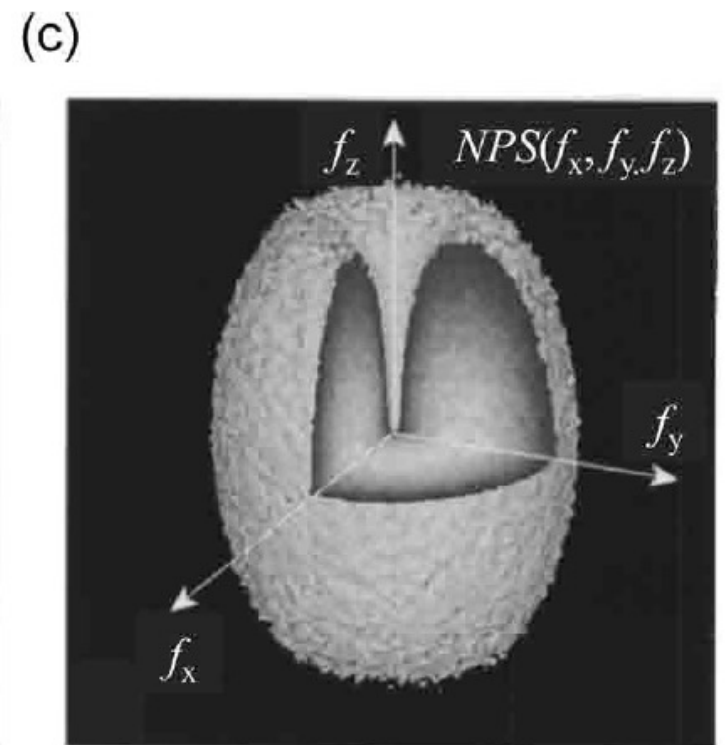
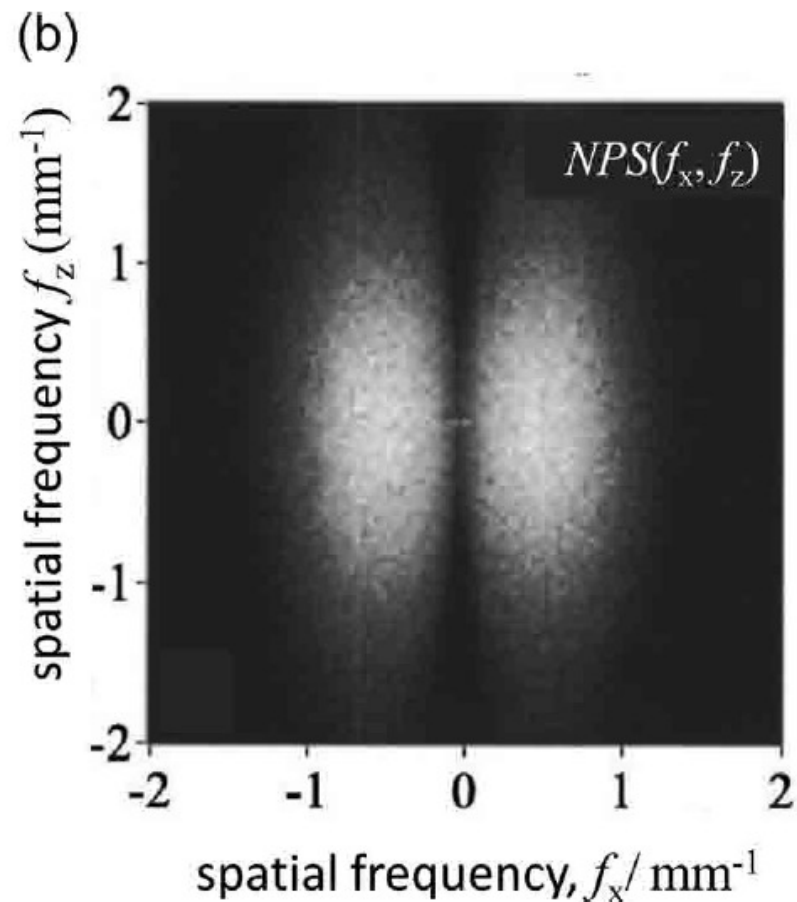
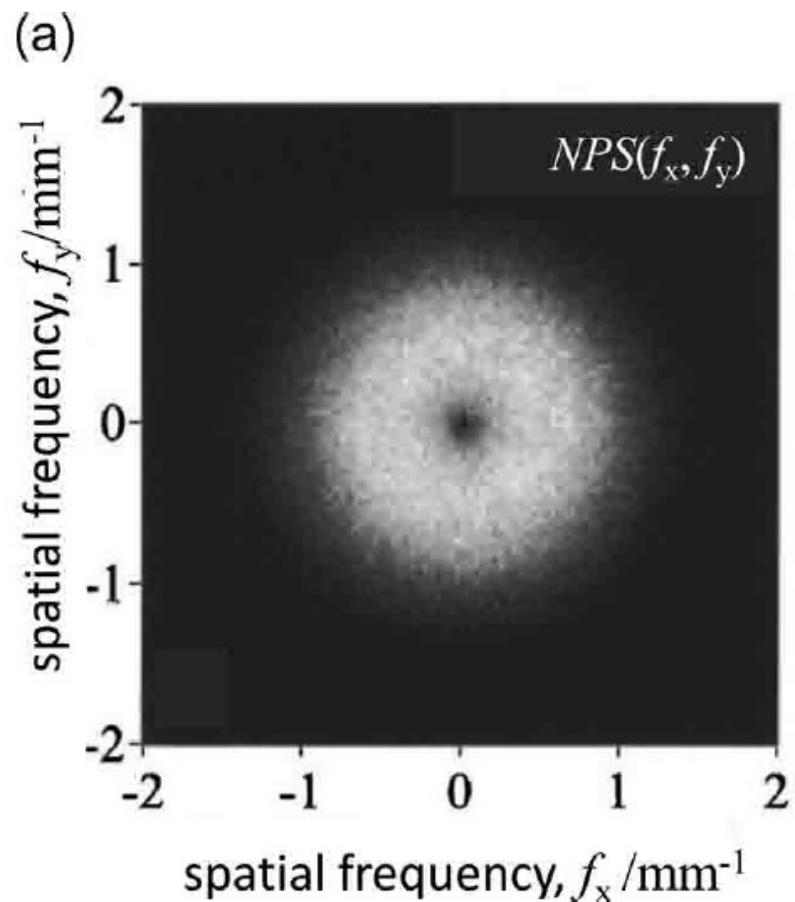
$$NPS(f_x, f_y, f_z) = \frac{\Delta_x \Delta_y \Delta_z}{N_x N_y N_z} \cdot \frac{1}{M} \sum_{i=1}^M |\mathcal{F}_{3D}(I_i(x, y, z))|^2$$

- ▶  $I_i(x, y, z)$  ... ROI šumu
- ▶  $\Delta_j$  ... velikost pixelu v ose  $j$  ( $\frac{DFOV}{Matrix\ size}$  nebo tloušťka řezu)
- ▶  $N_j$  ... počet pixelů v ose  $j$
- ▶  $M$  ... počet průměrovaných ROIs
- ▶ ICRU Report 87 – Radiation Dose and Image-quality assessment in computed tomography (2012)

# Noise power spectrum



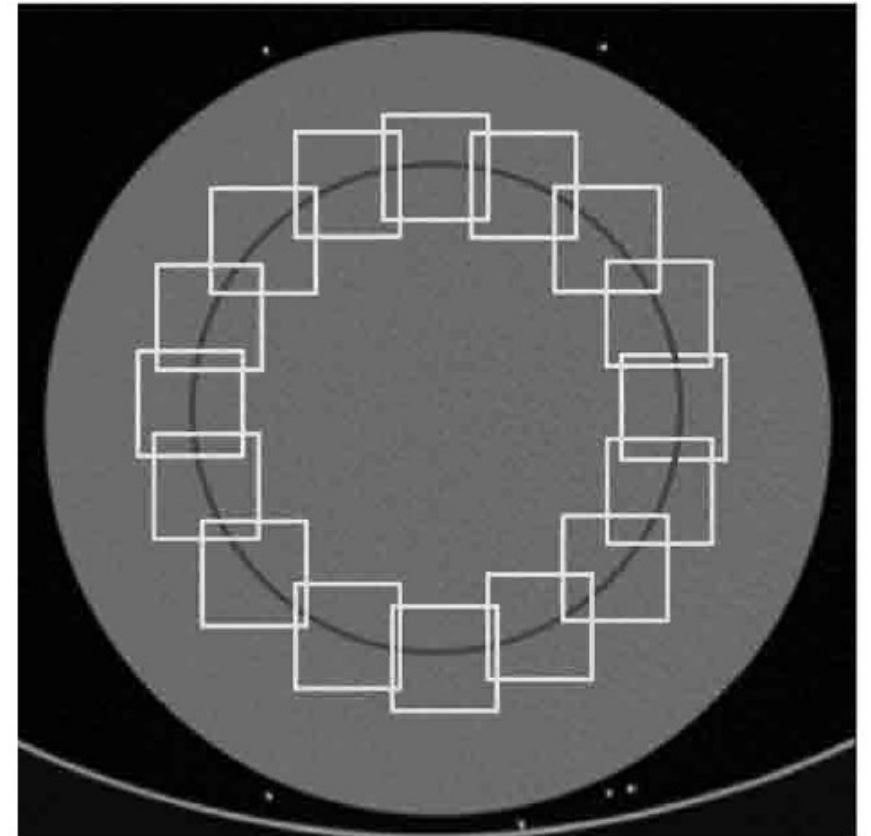
# Noise power spectrum





# Noise power spectrum

- ▶ Metoda měření
  - ▶ Dvě série naměřených dat, které jsou od sebe odečteny
  - ▶ Odečtené snímky vyděleny  $\sqrt{2}$  (odečtením se šum zvýšil)
  - ▶ Z těchto snímků vybírám ROI, ze kterých stanovím NPS, získávám  $I_i(x, y, z)$  členy ve výpočtu
  - ▶ Tyto ROI mohou být vybrány buď ze středu fantomu a poměrně velké (menší počet, dobré navzorkování v FFT), nebo menší, například po obvodu, fantomu (získám informaci o lokálním charakteru šumu, více ROI pro průměrování)



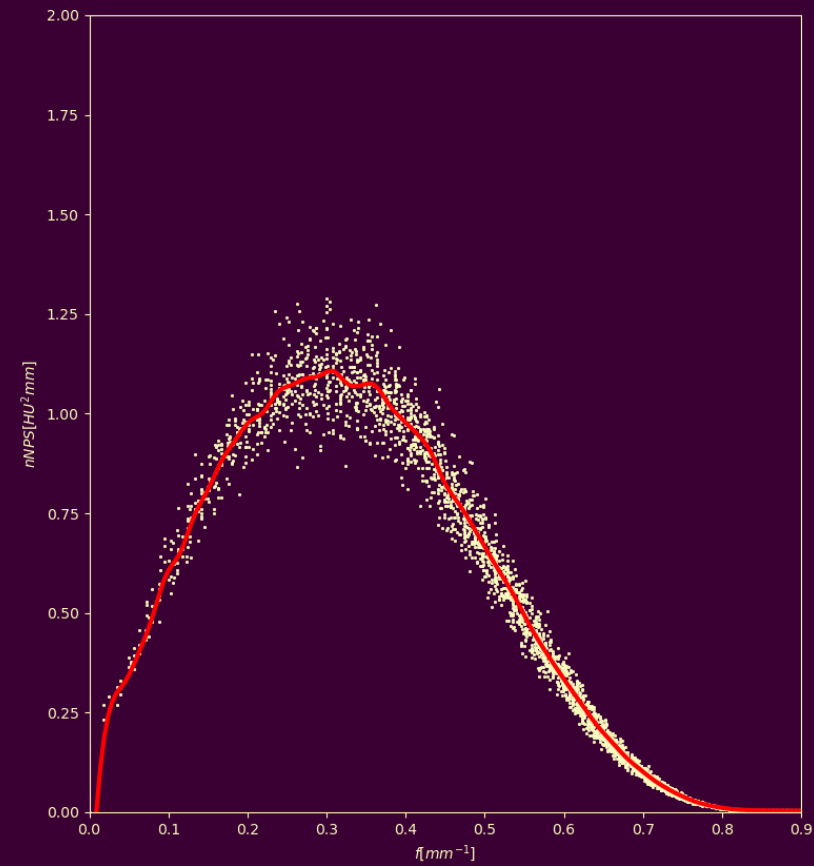
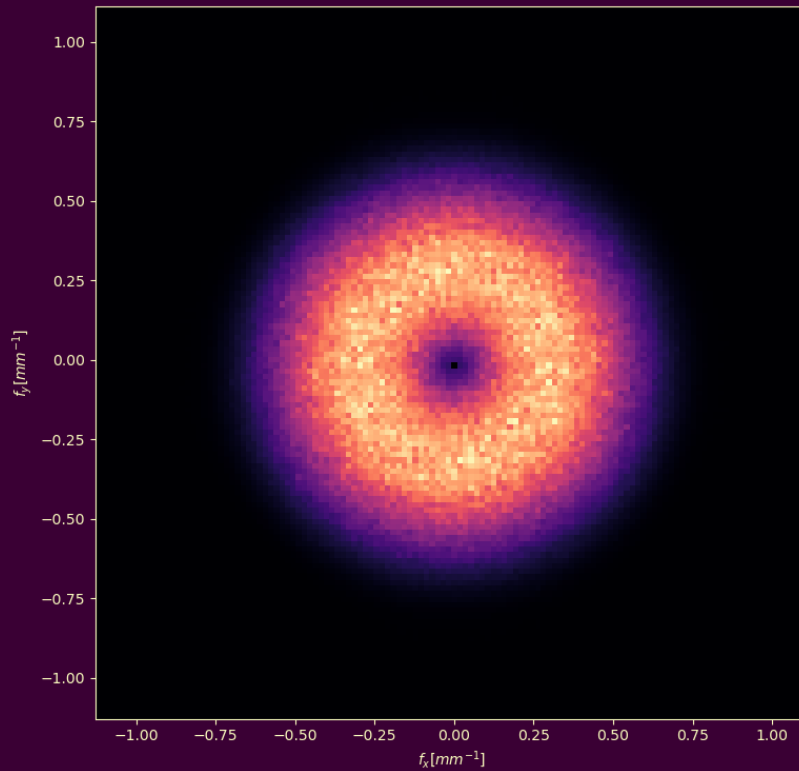
# Rekonstrukční algoritmus ASIR-V

- ▶ Dle slov výrobce kompromis mezi ASIR a Veo
- ▶ Nastavení síly 0 % až 100 % po 10% krocích (vážený průměr s FBP obrazem)
- ▶ Možnost zvolit různé rekonstrukční filtry (Soft, Standard, Lung, Bone, atd.)

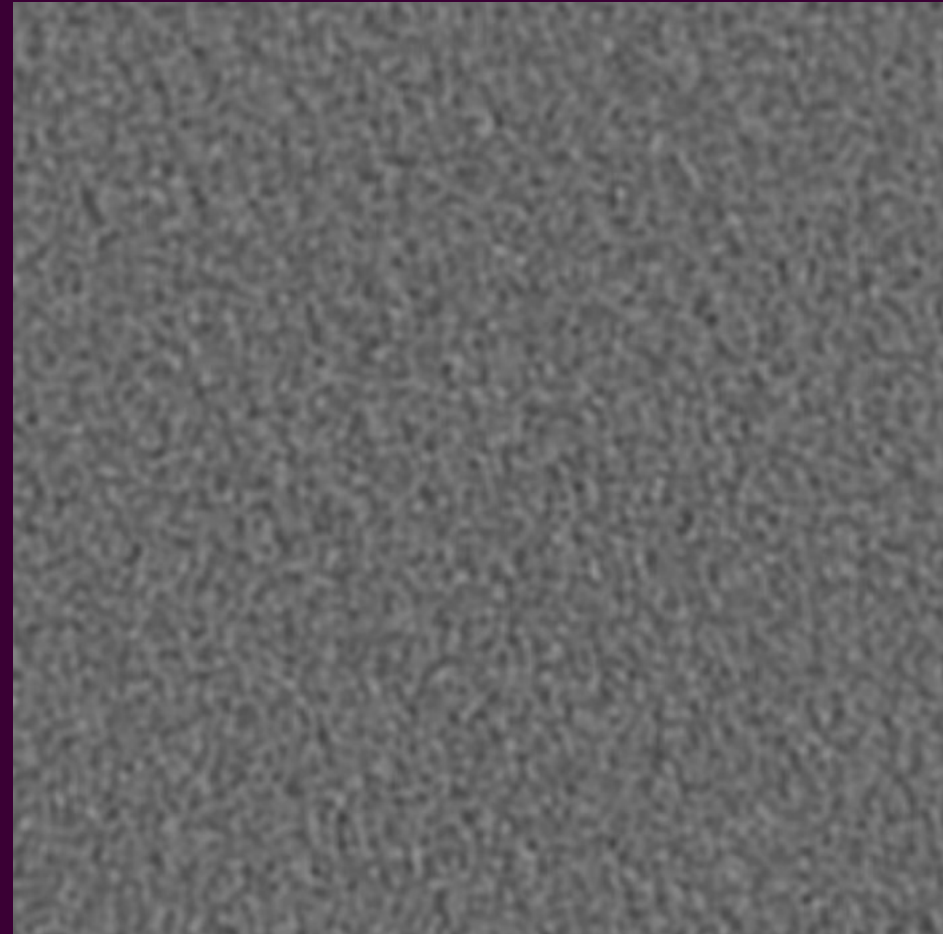
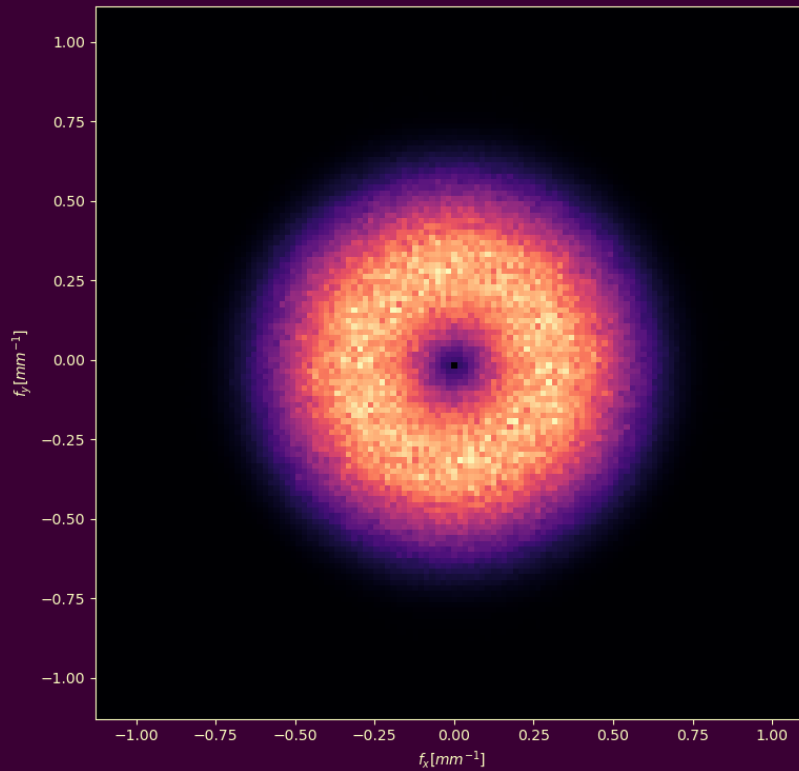
# Rekonstrukční algoritmus DLIR

- ▶ Využití AI v rekonstrukci obrazu
- ▶ Lze nastavit tři úrovně – Low, Medium, High
- ▶ Rekonstrukční filtr pouze Standard
- ▶ Možnost post-processingu obrazovými filtry – Soft, Edge, Lung

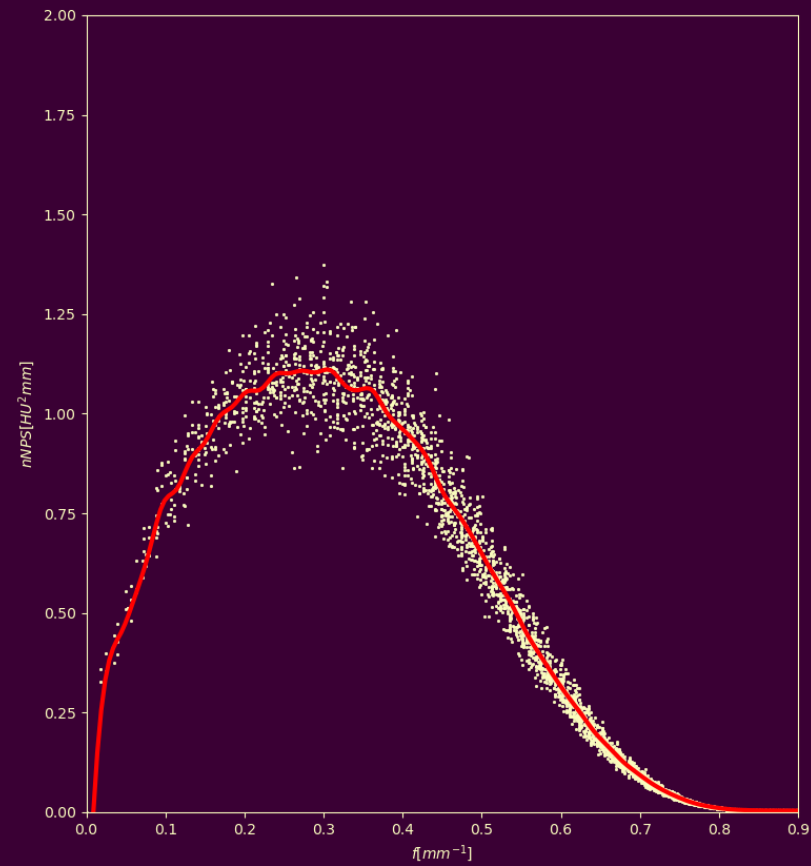
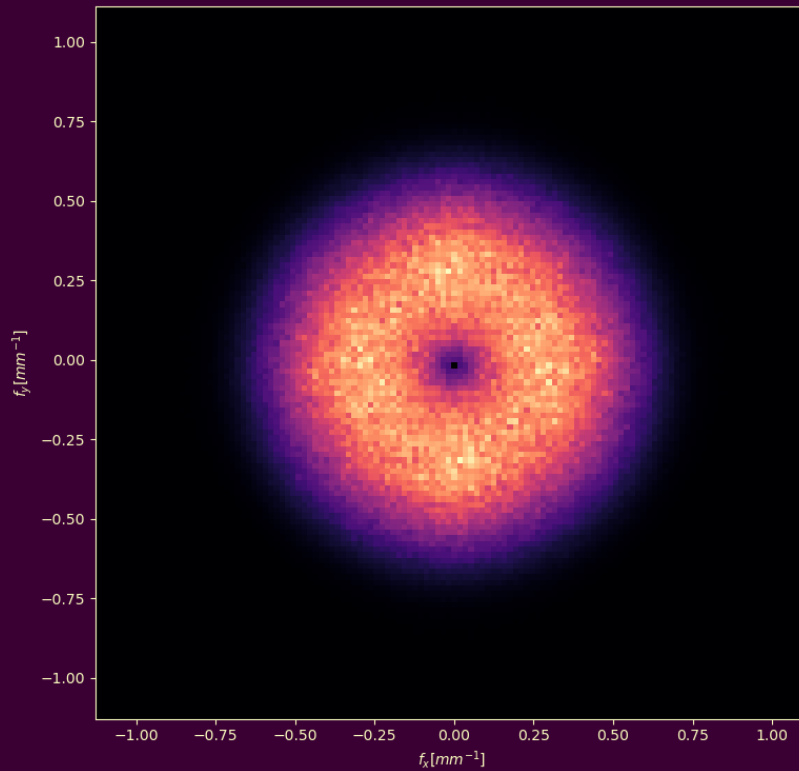
# Noise power spectrum – FBP



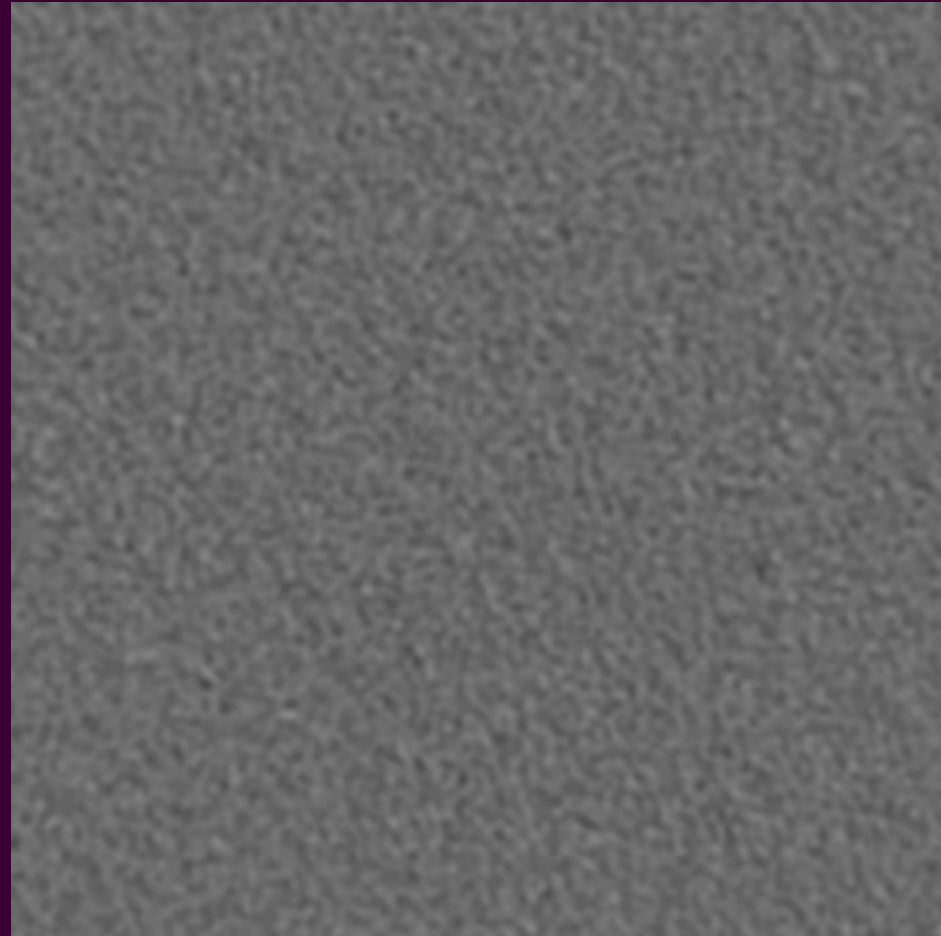
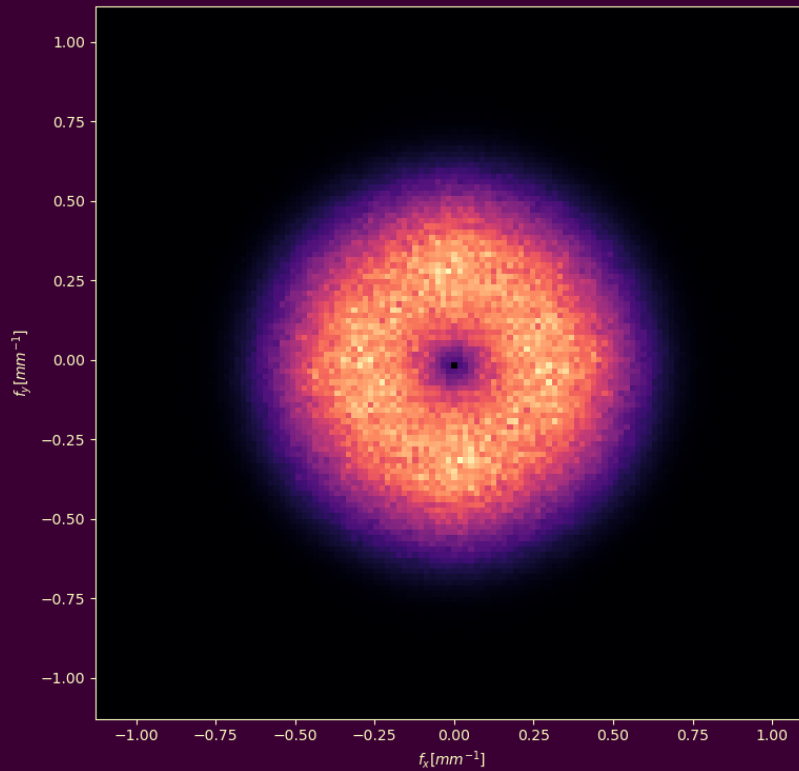
# Noise power spectrum – FBP



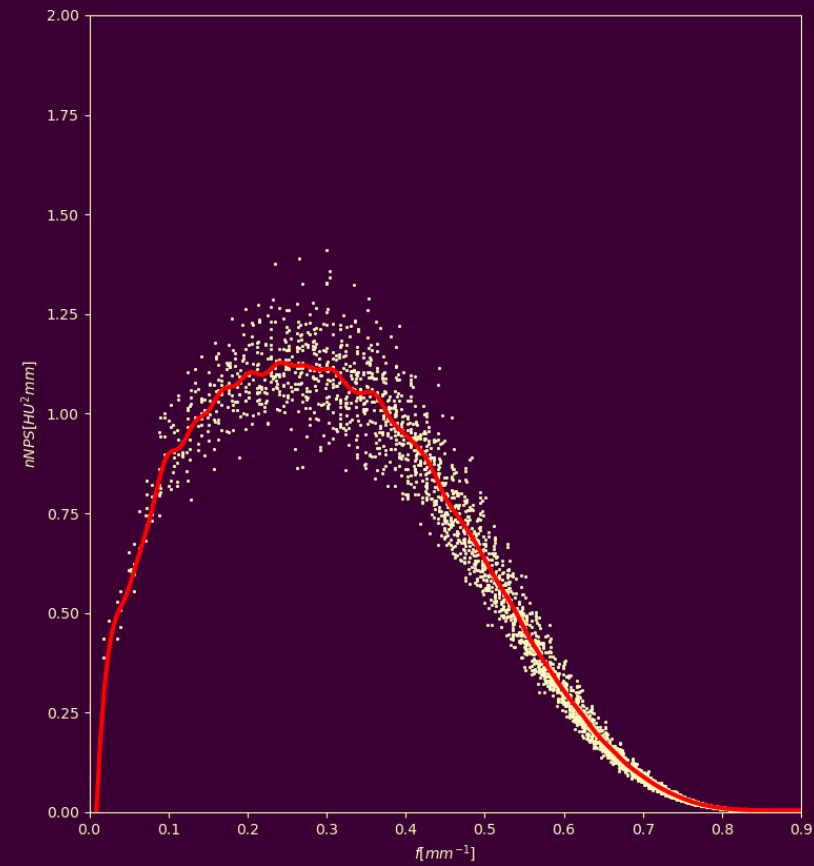
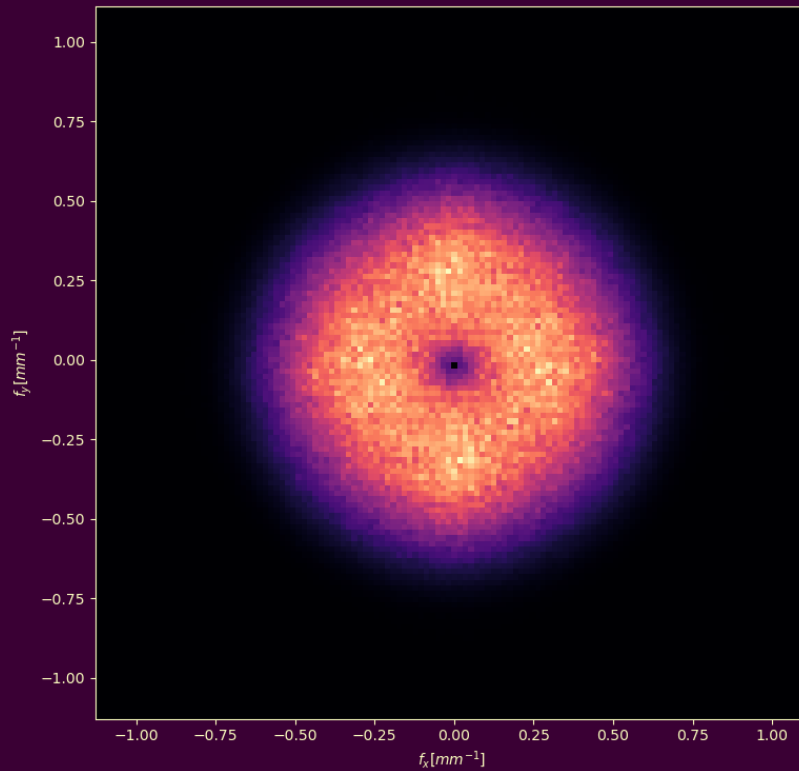
# Noise power spectrum – DLR-L



# Noise power spectrum – DLR-L

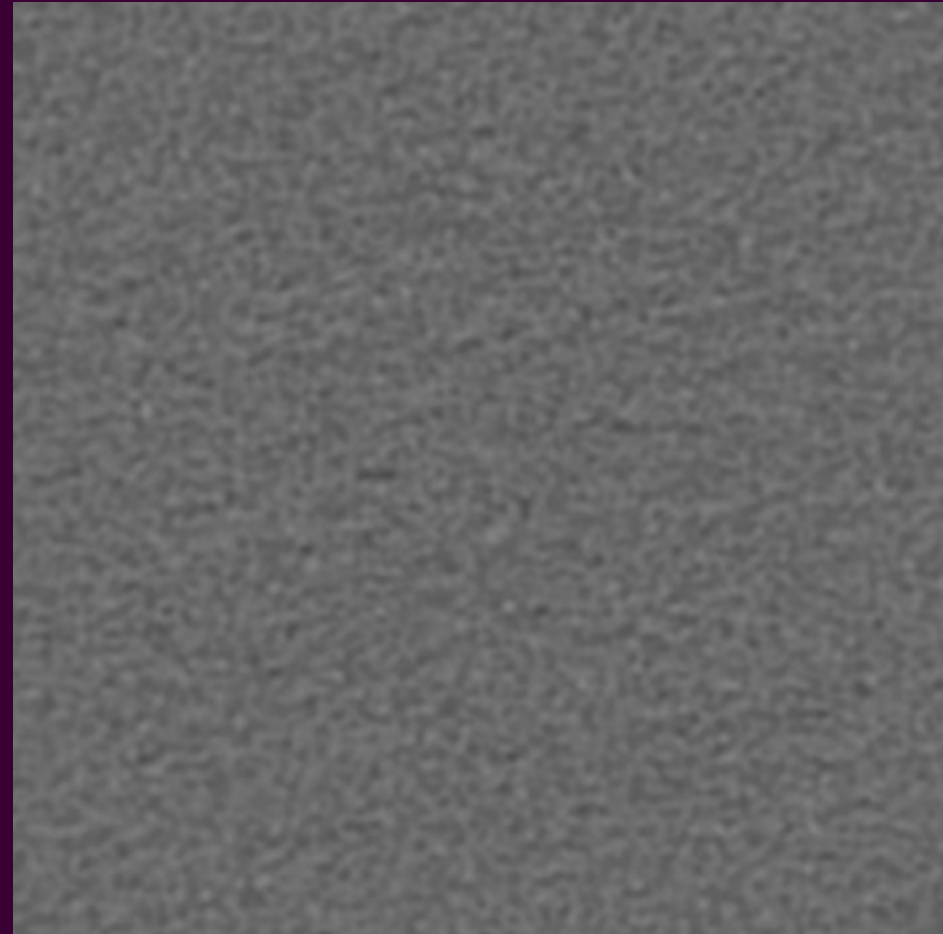
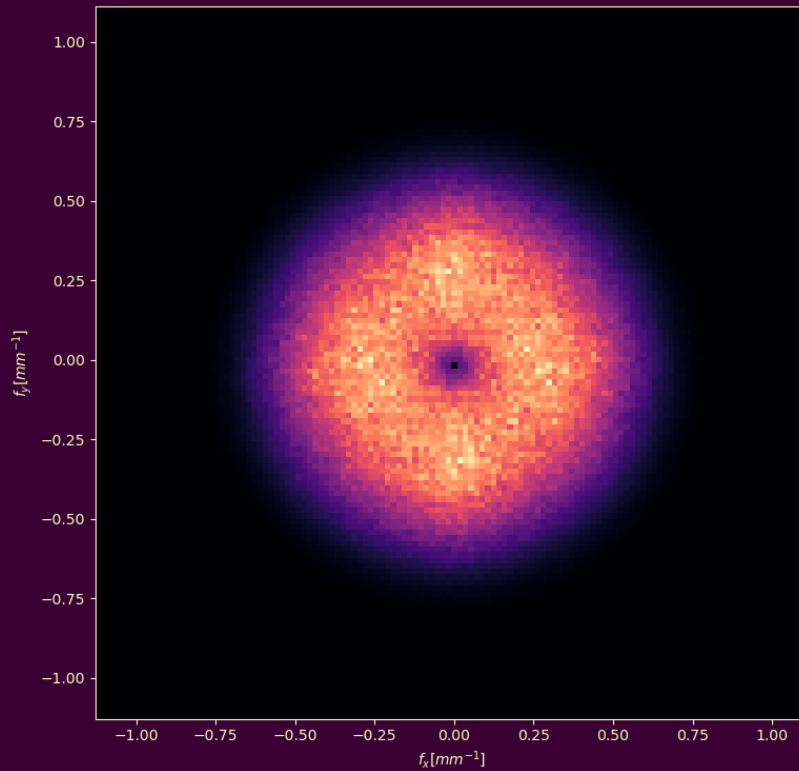


# Noise power spectrum – DLR-M

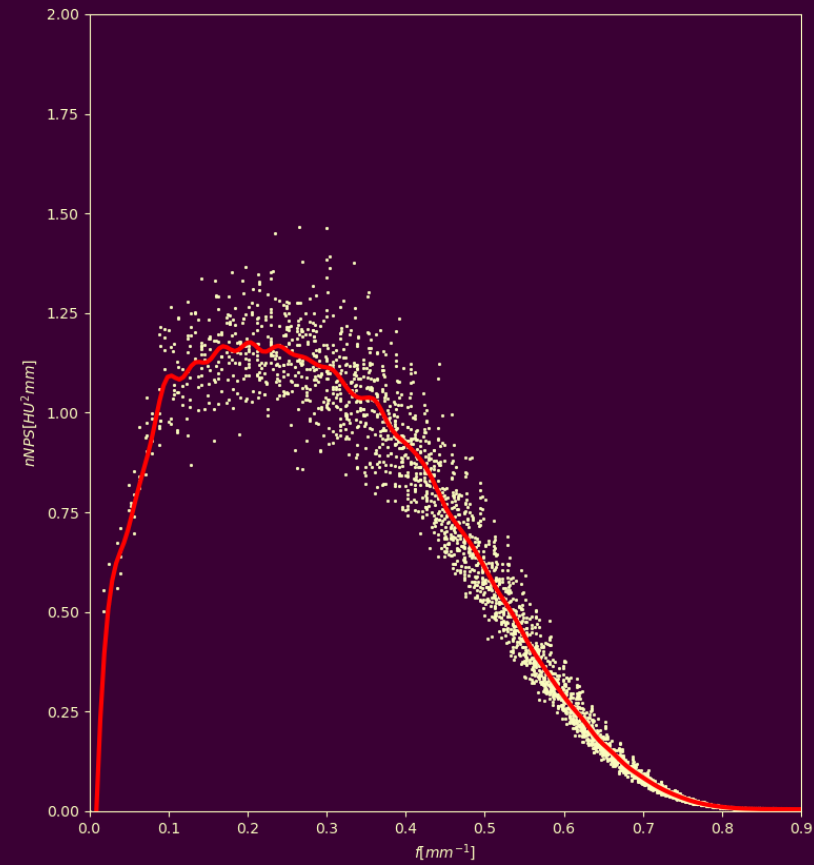
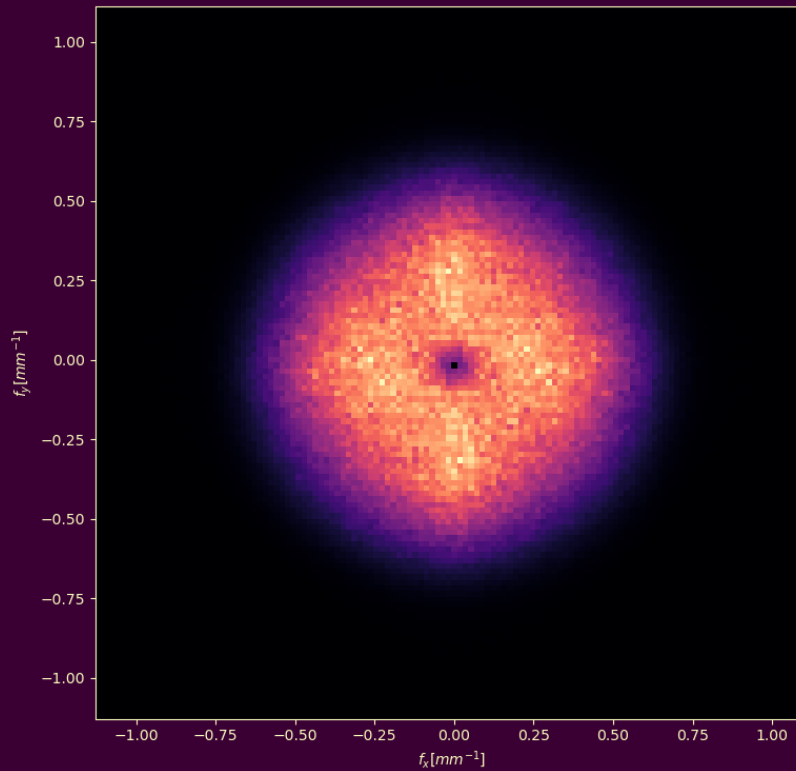




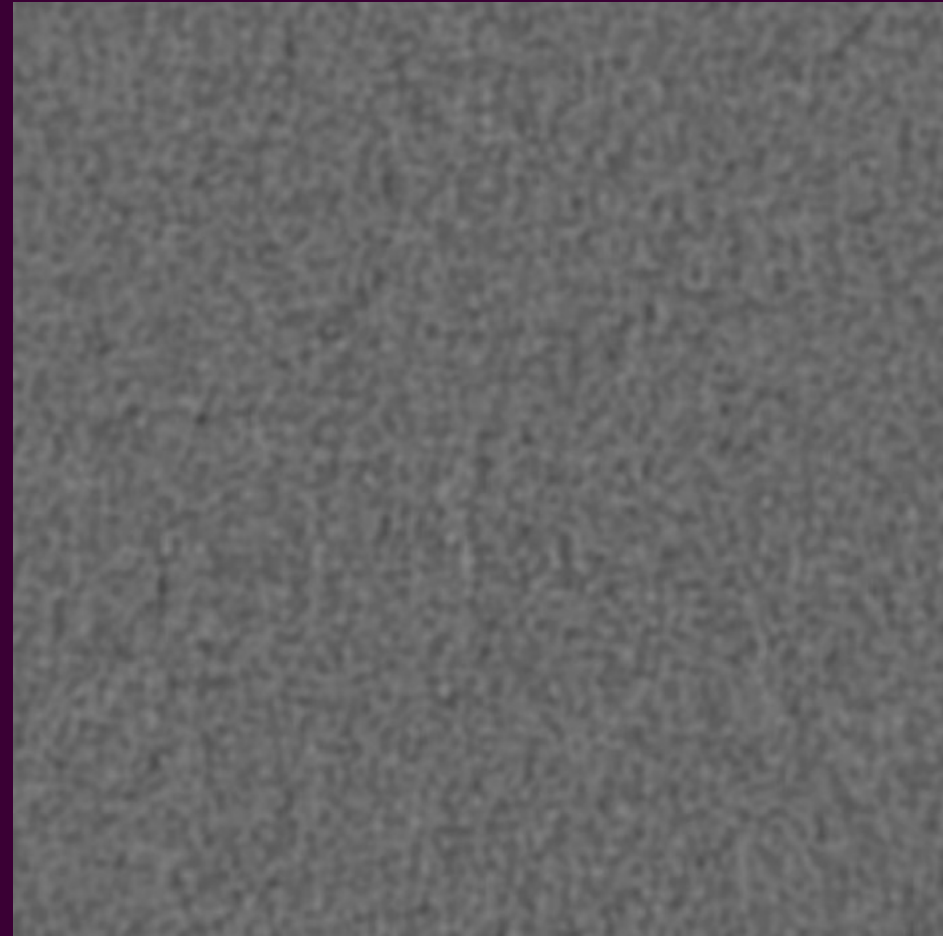
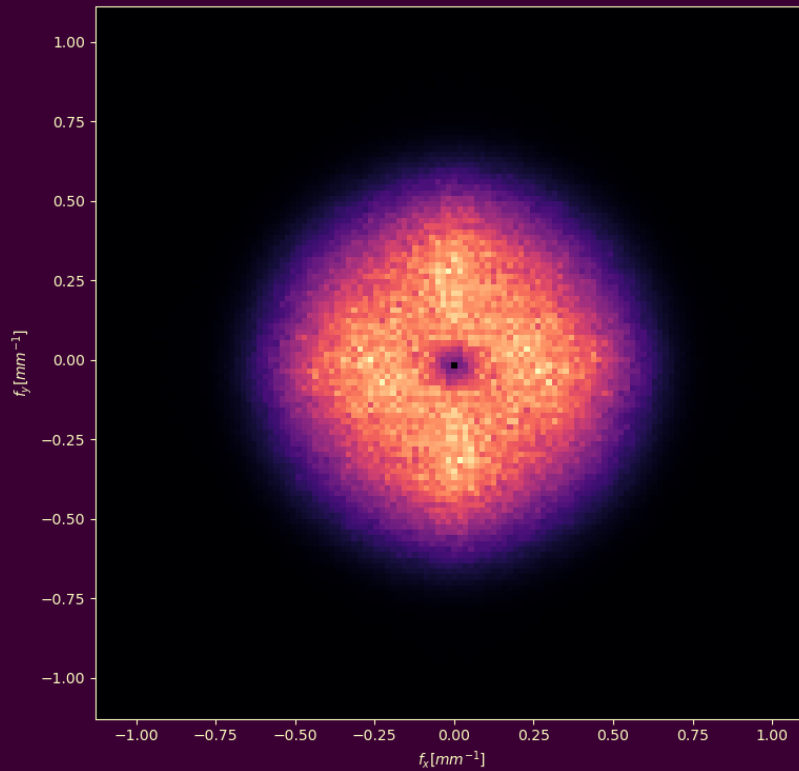
# Noise power spectrum – DLR-M



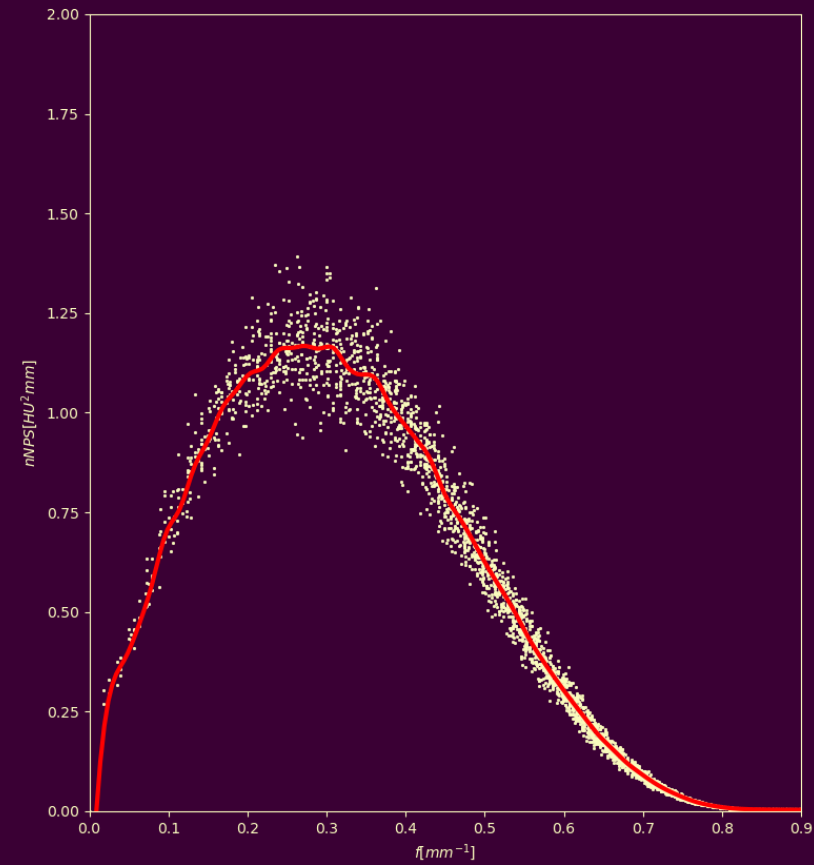
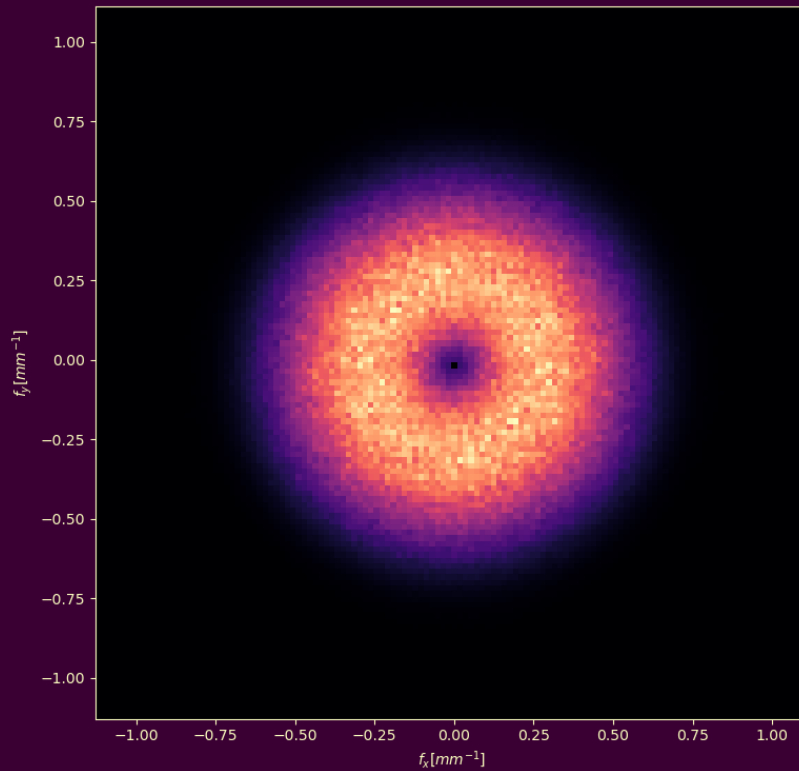
# Noise power spectrum – DLR-H



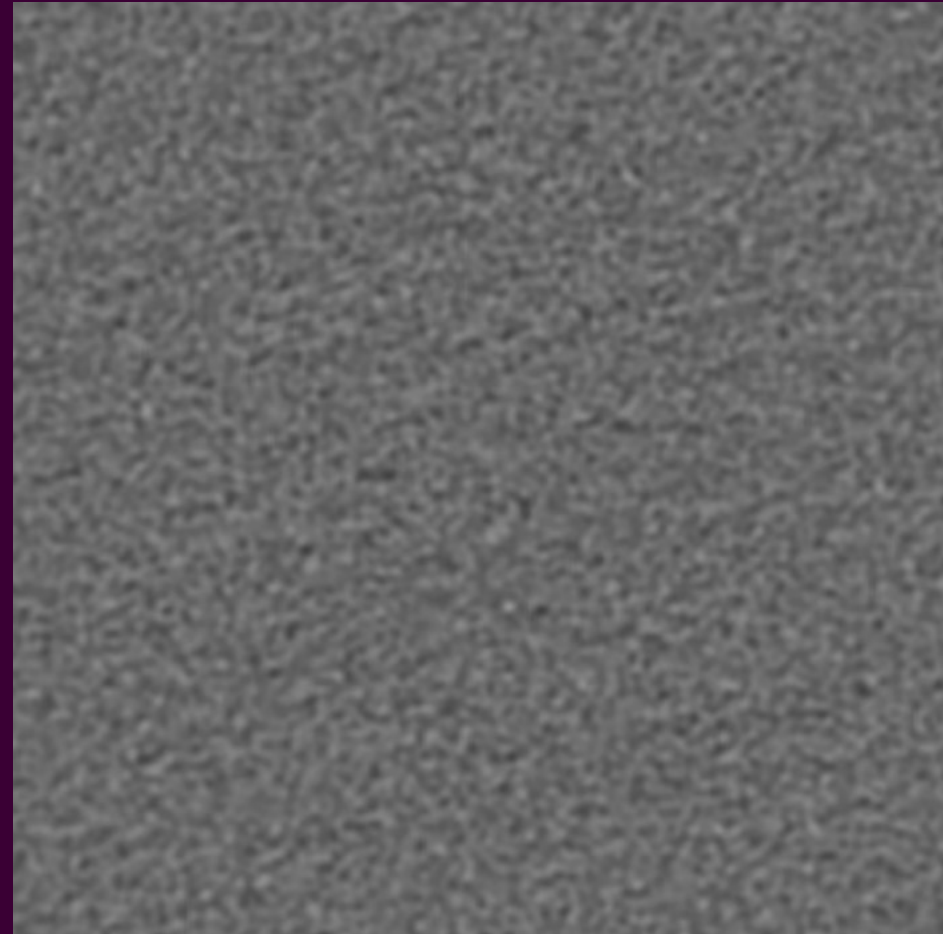
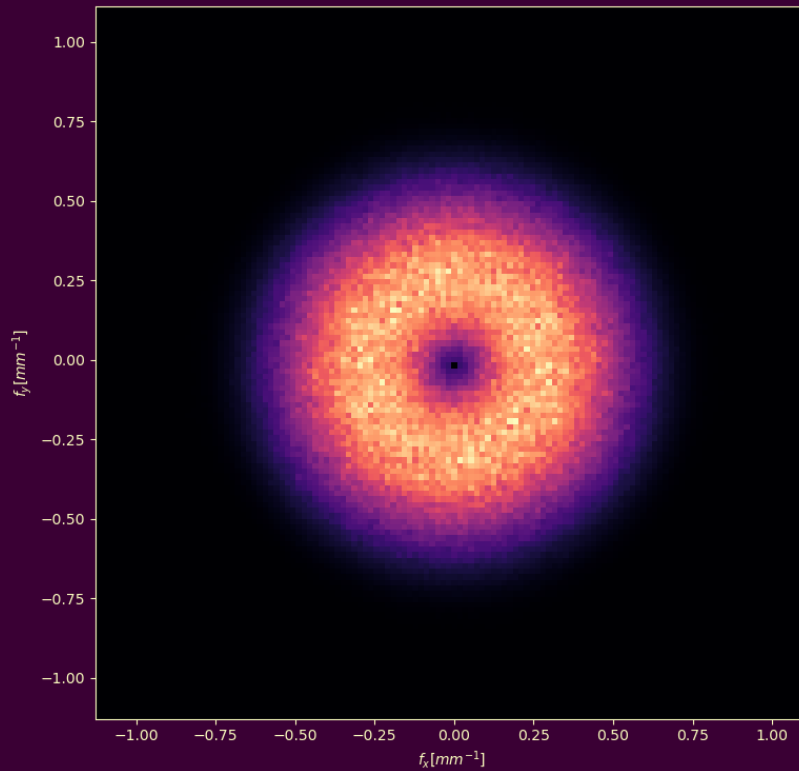
# Noise power spectrum – DLR-H



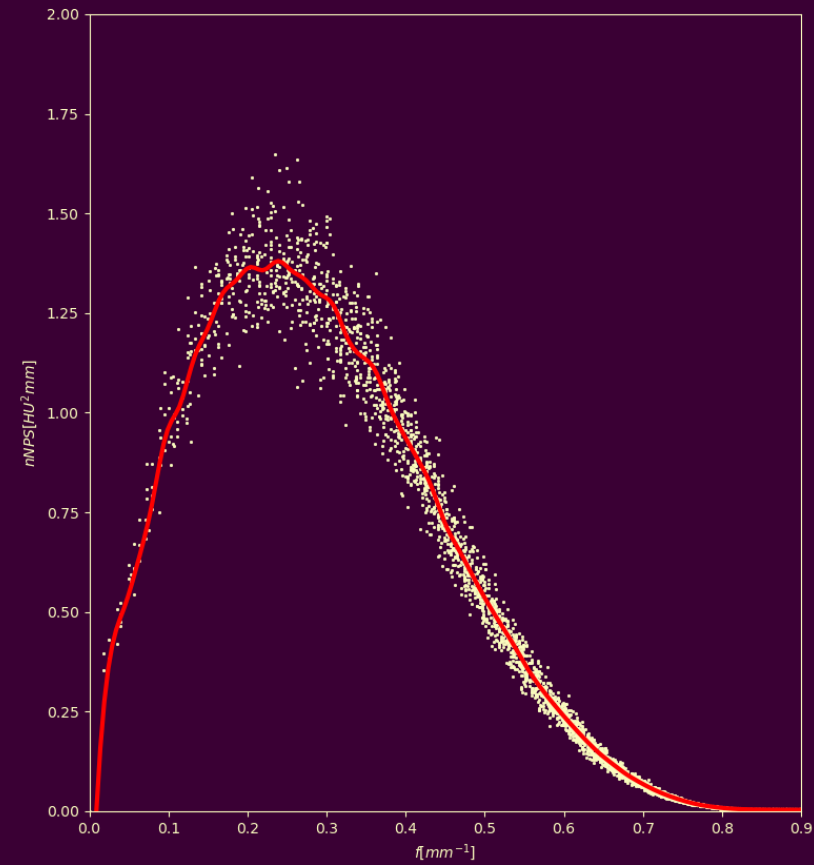
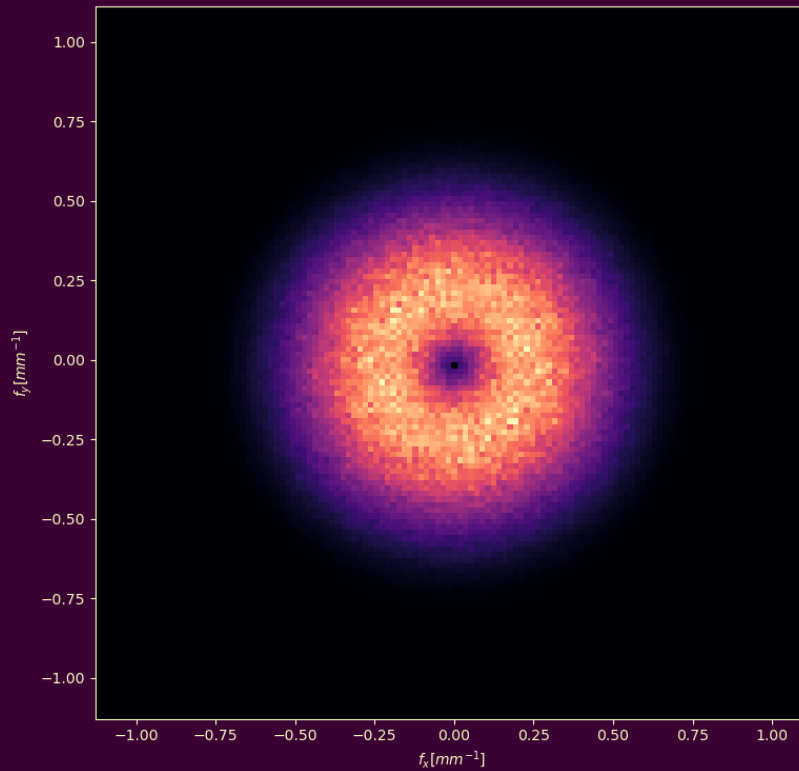
# Noise power spectrum – ASIR-V 20%



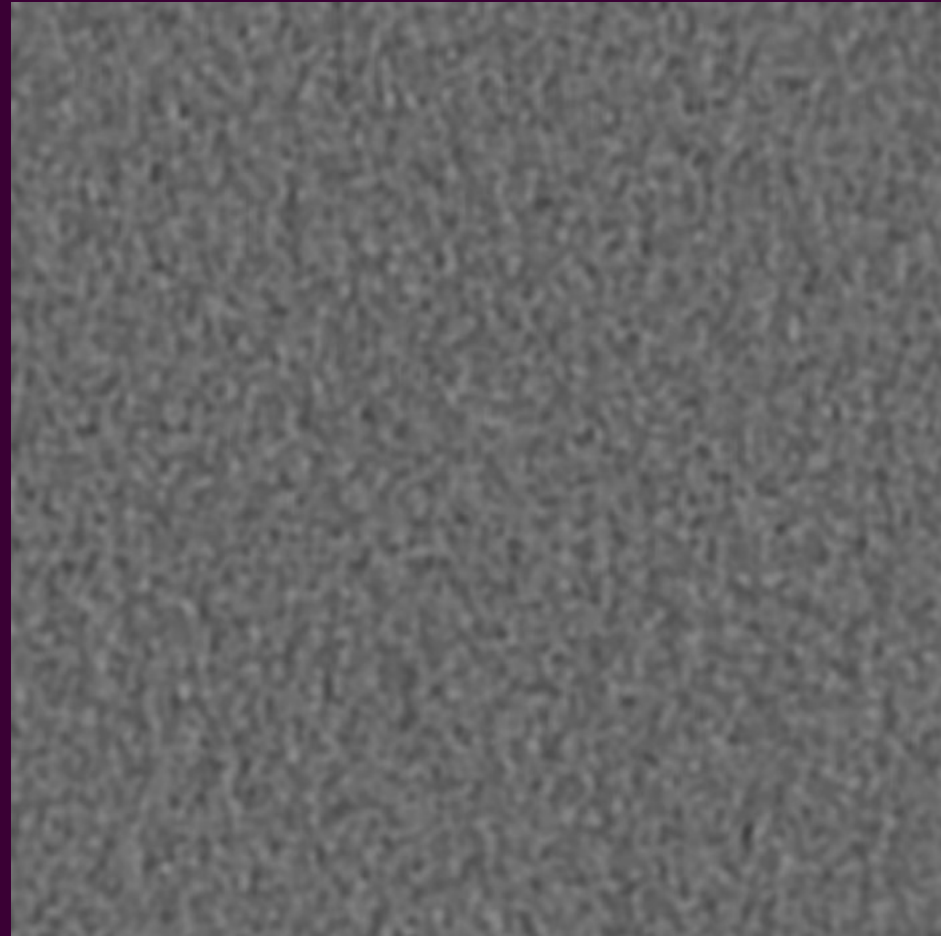
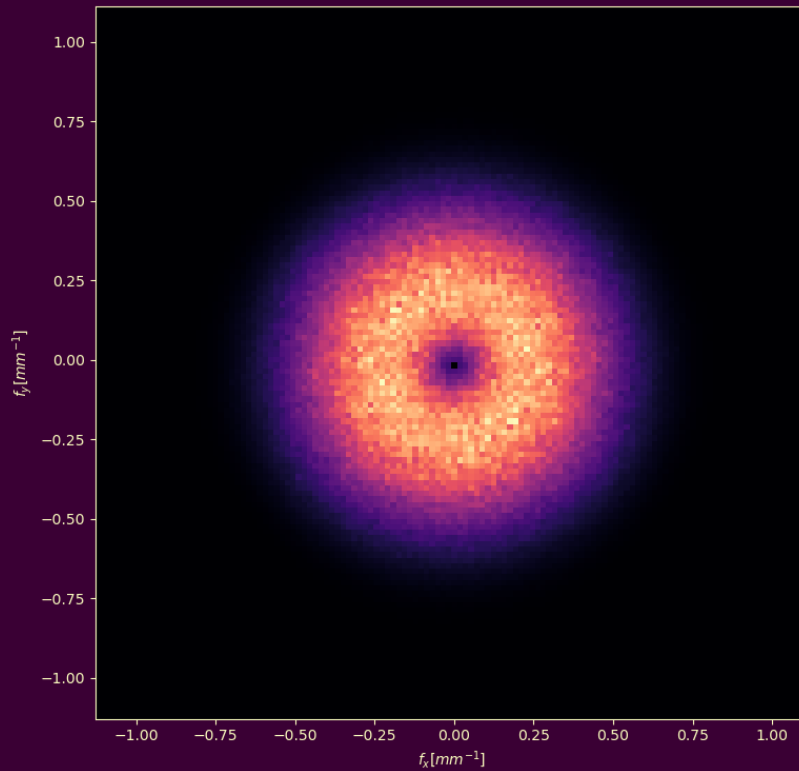
# Noise power spectrum – ASIR-V 20%



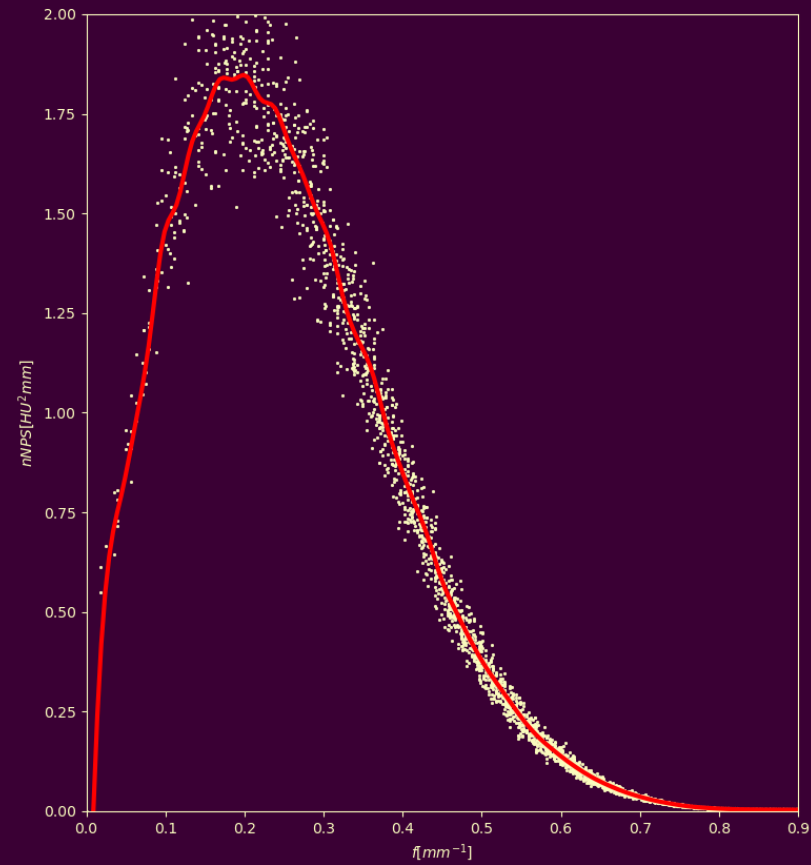
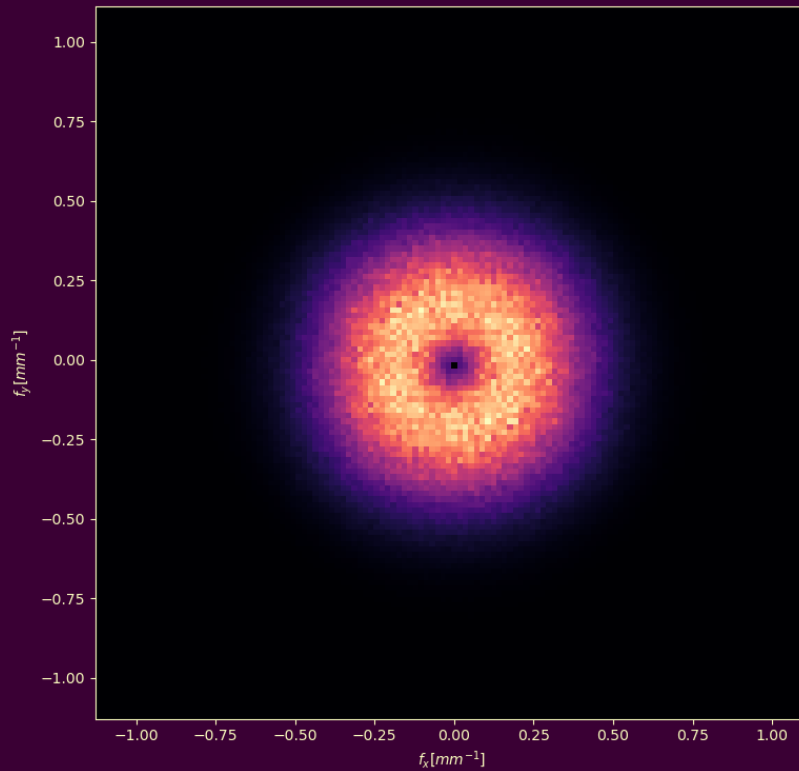
# Noise power spectrum – ASIR-V 50%



# Noise power spectrum – ASIR-V 50%

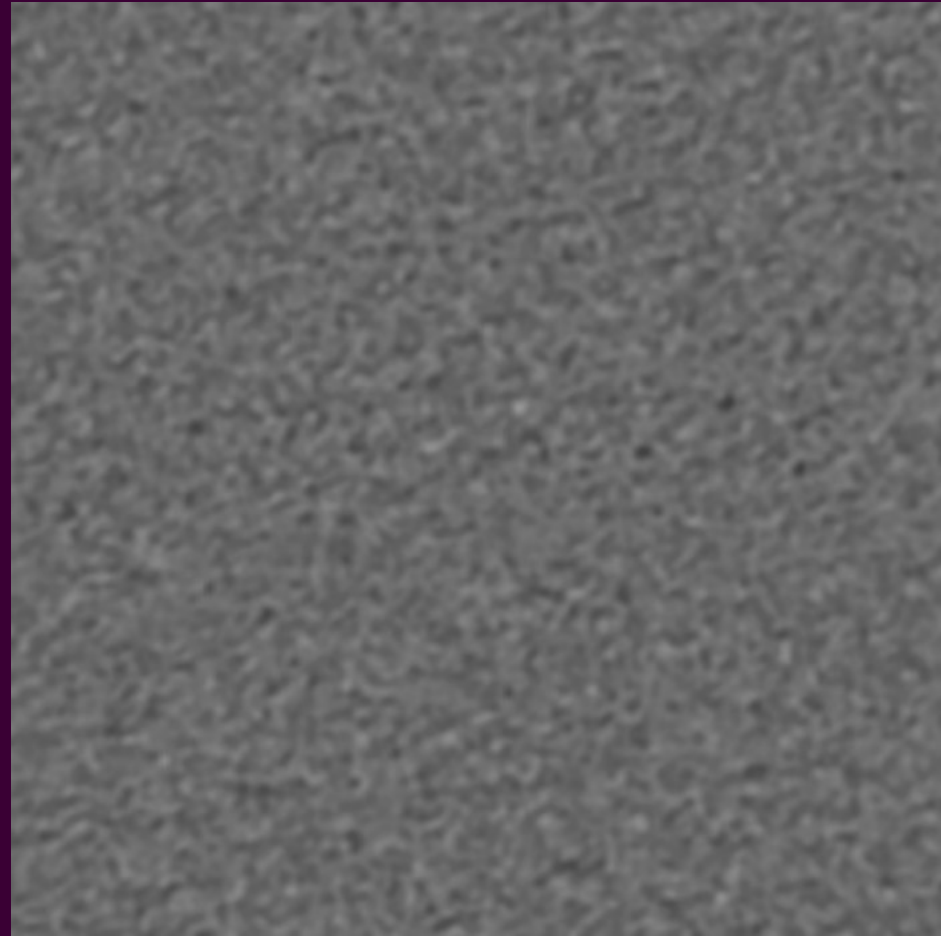
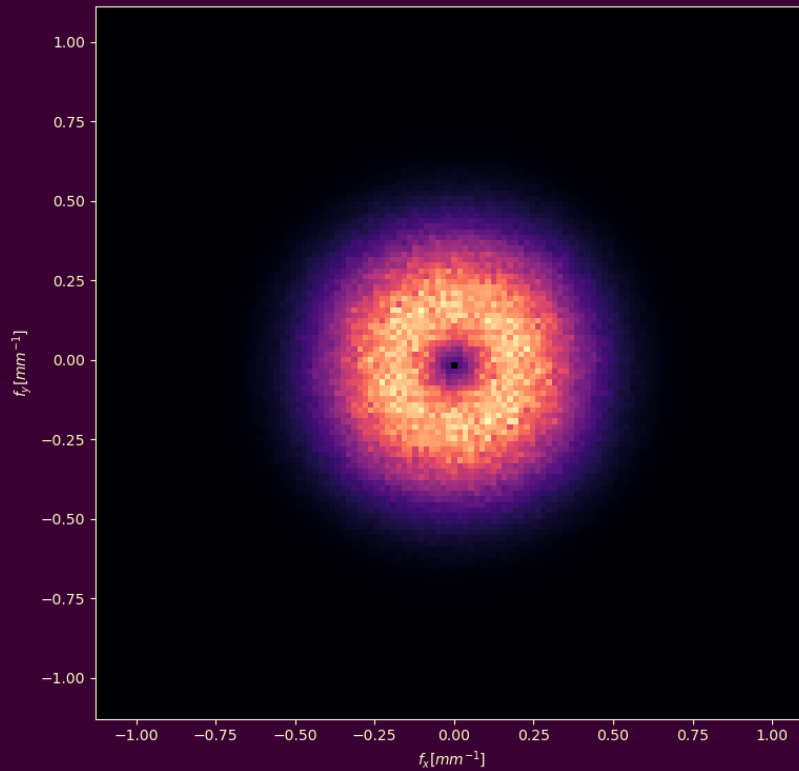


# Noise power spectrum – ASIR-V 80%





# Noise power spectrum – ASIR-V 80%



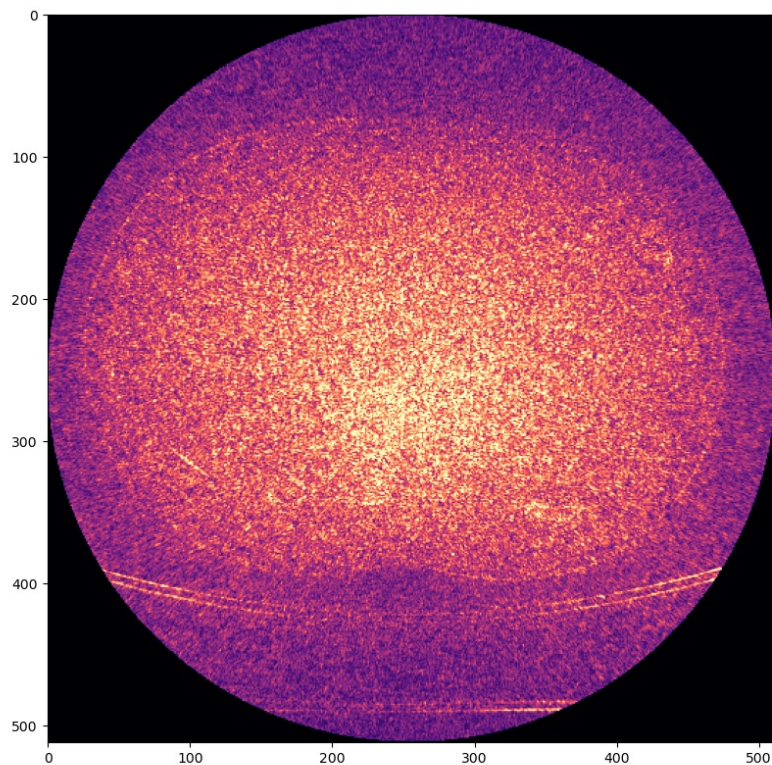


# Variabilita šumu

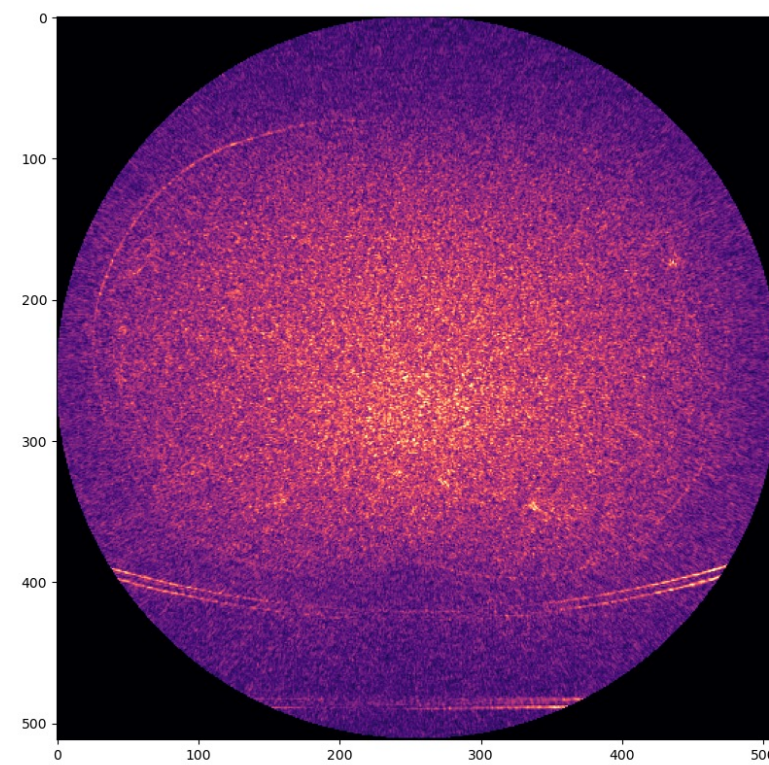
- ▶ FBP, ASIR-V a DLIR rekonstrukce pro játra a plíce antropomorfního fantomu
- ▶ Deset opakovaných měření stejné oblasti
- ▶ Pixel-wise směrodatná odchylka těchto desíti sérií
- ▶ Hodnocení toho, která místa v obraze zvládne algoritmus rekonstruovat s nějakou přesností

# Variabilita šumu – FBP

$std_{avg} = 21,08 HU$

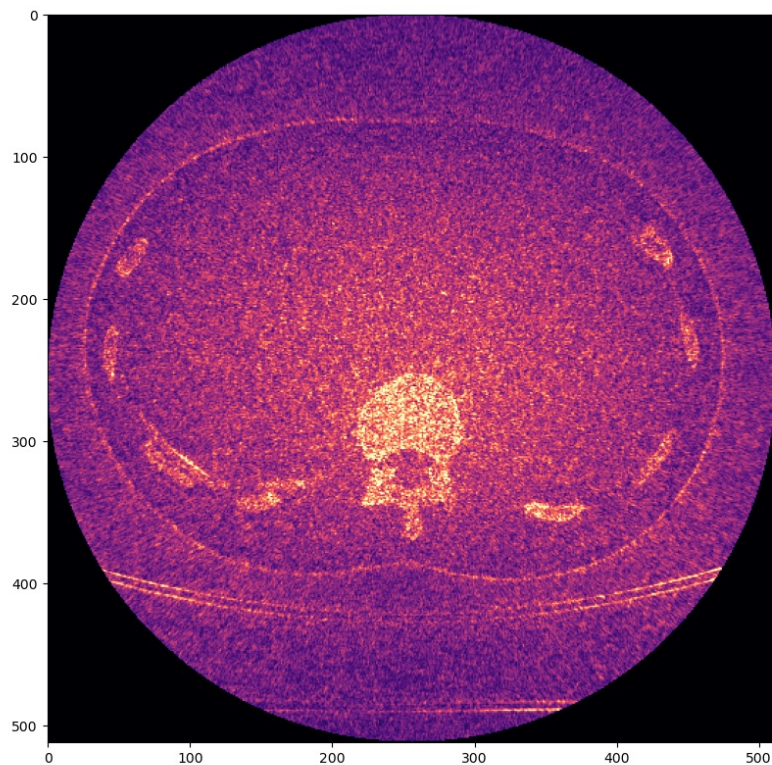


$std_{avg} = 15,41 HU$

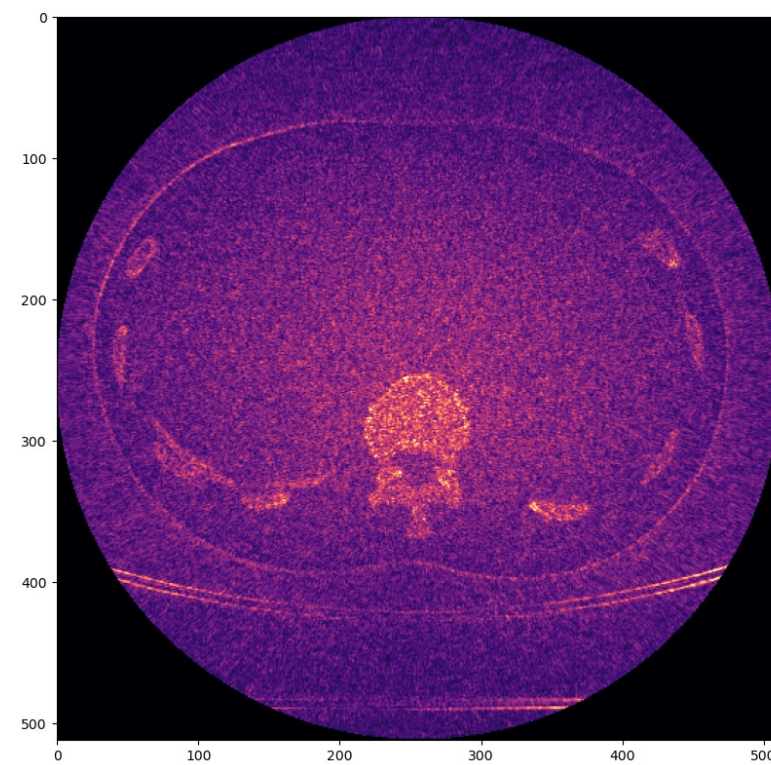


# Variabilita šumu – ASIR-V 20%

$std_{avg} = 16,93 HU$

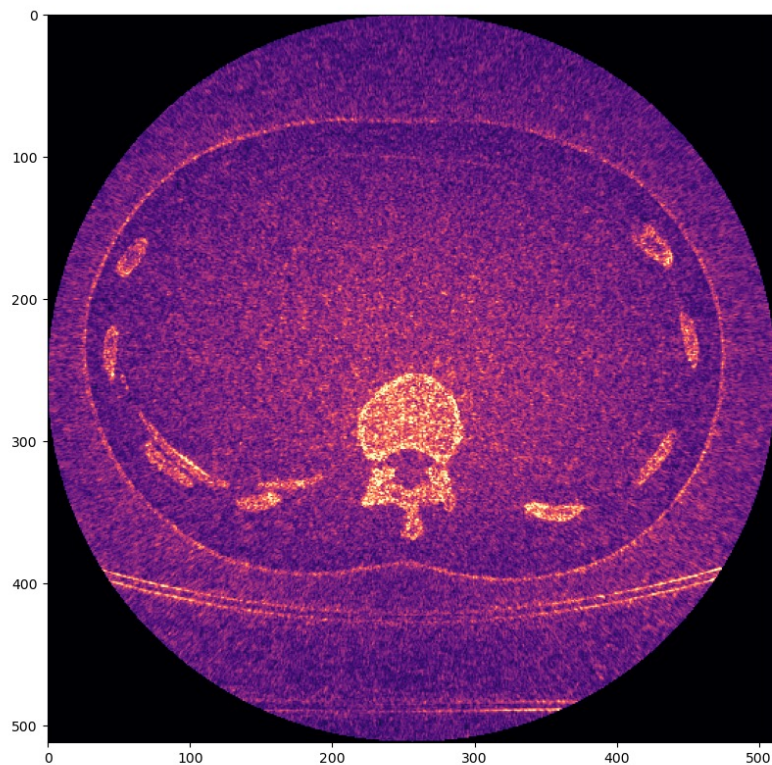


$std_{avg} = 12,61 HU$

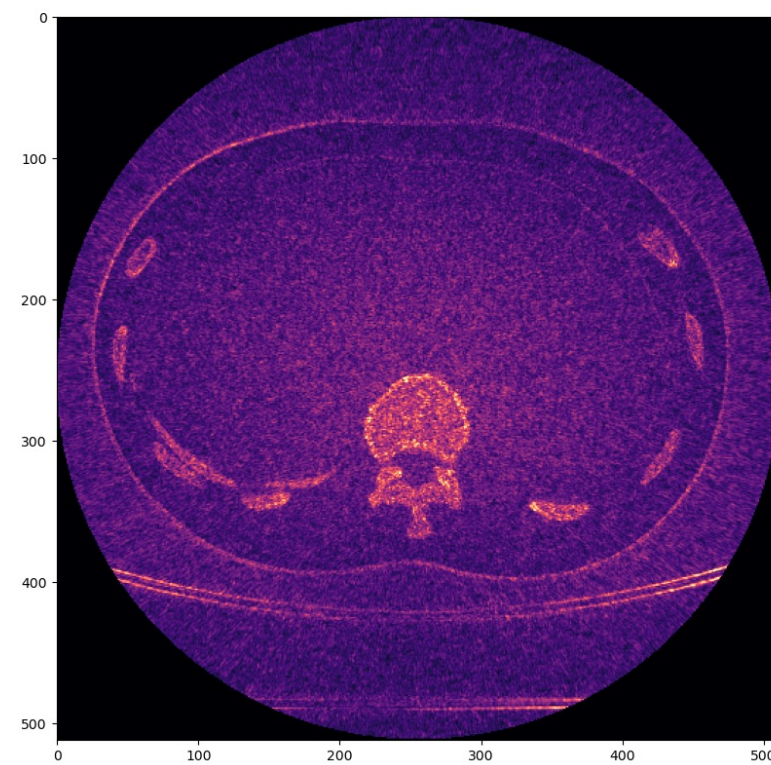


# Variabilita šumu – ASIR-V 50%

$std_{avg} = 14,23 HU$

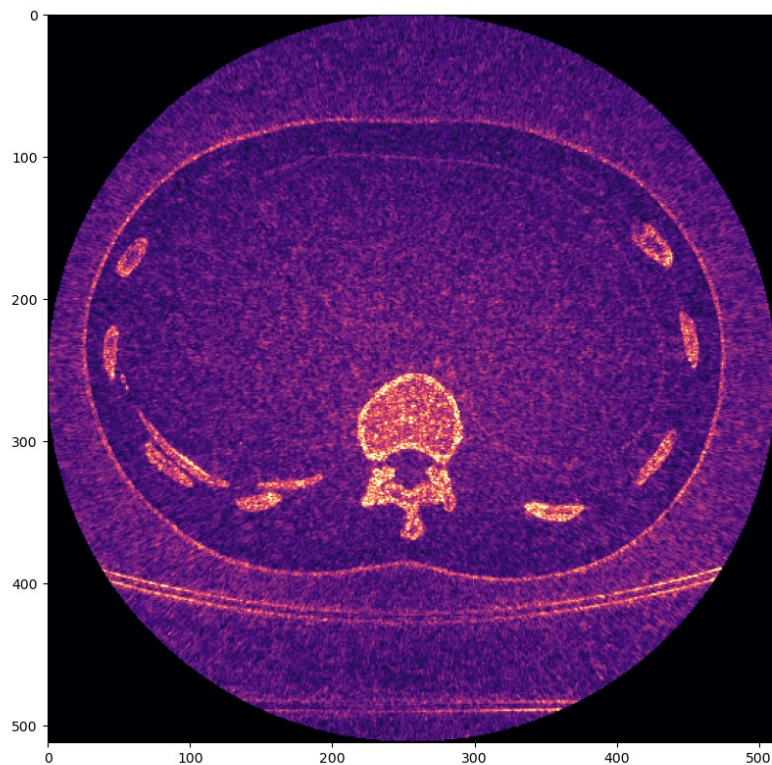


$std_{avg} = 10,54 HU$

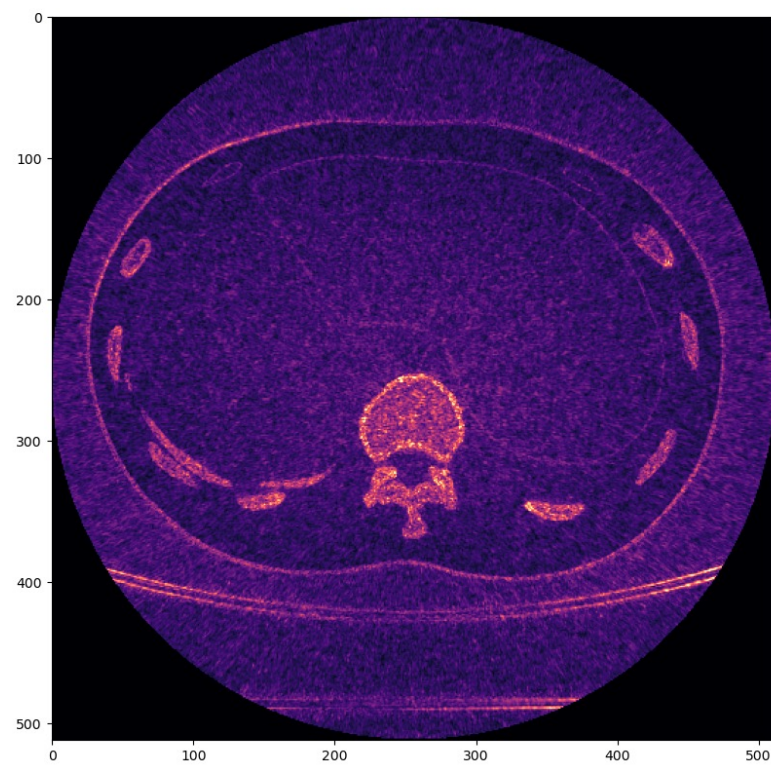


# Variabilita šumu – ASIR-V 80%

$std_{avg} = 11,59 HU$

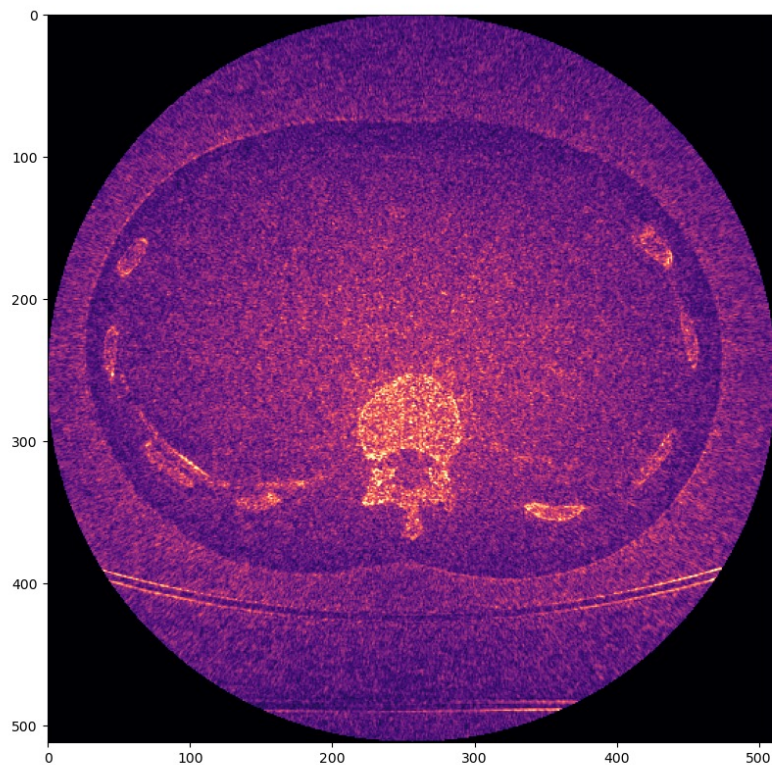


$std_{avg} = 8,54 HU$

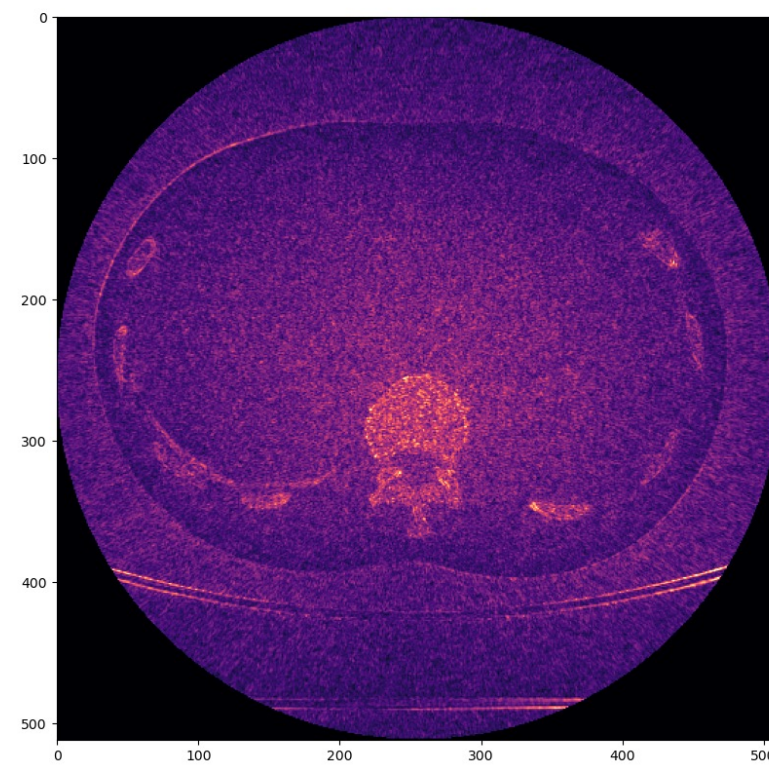


# Variabilita šumu – DLR-L

$std_{avg} = 13,99 HU$



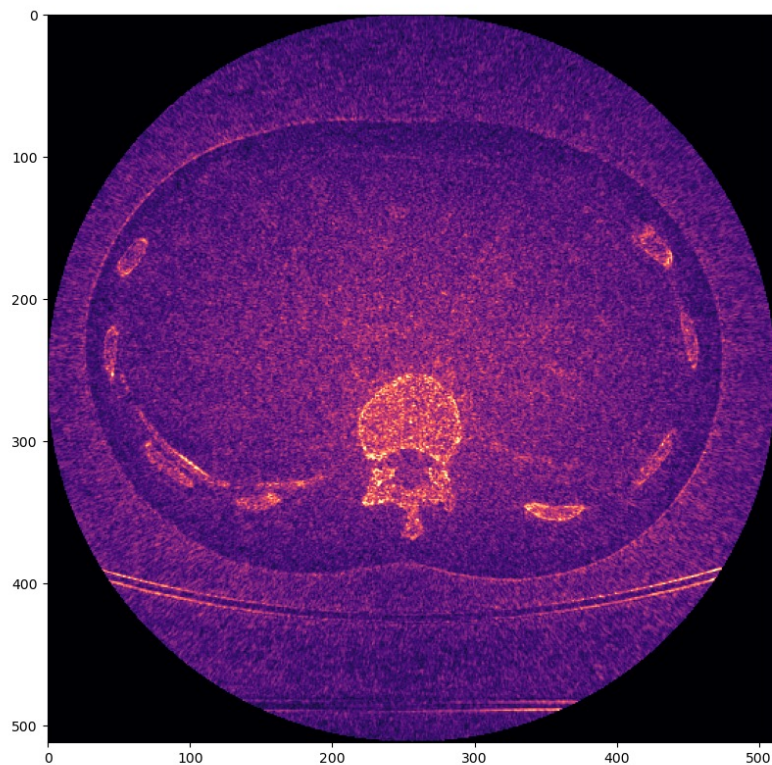
$std_{avg} = 10,95 HU$



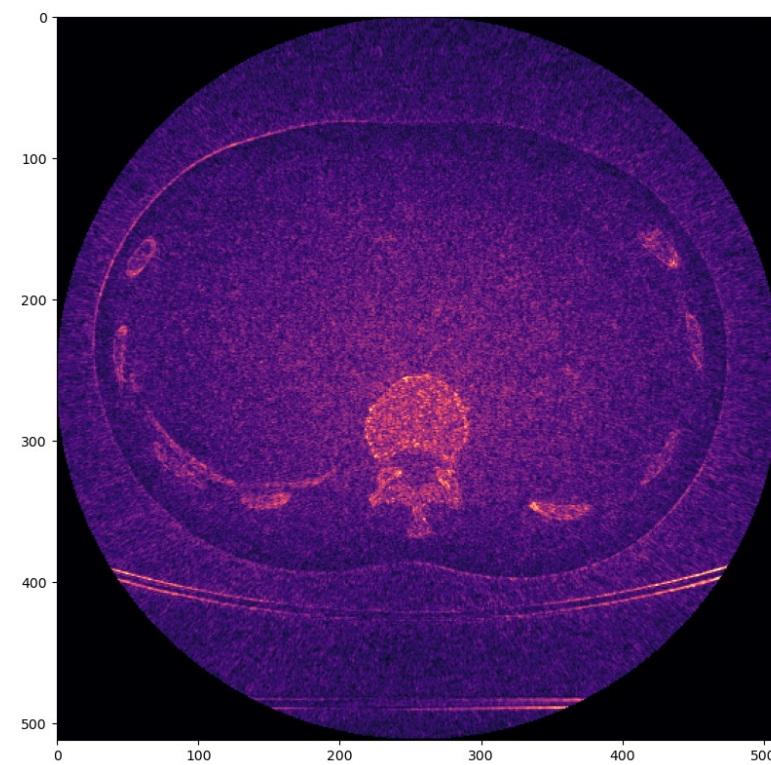


# Variabilita šumu – DLR-M

$std_{avg} = 11,88 HU$

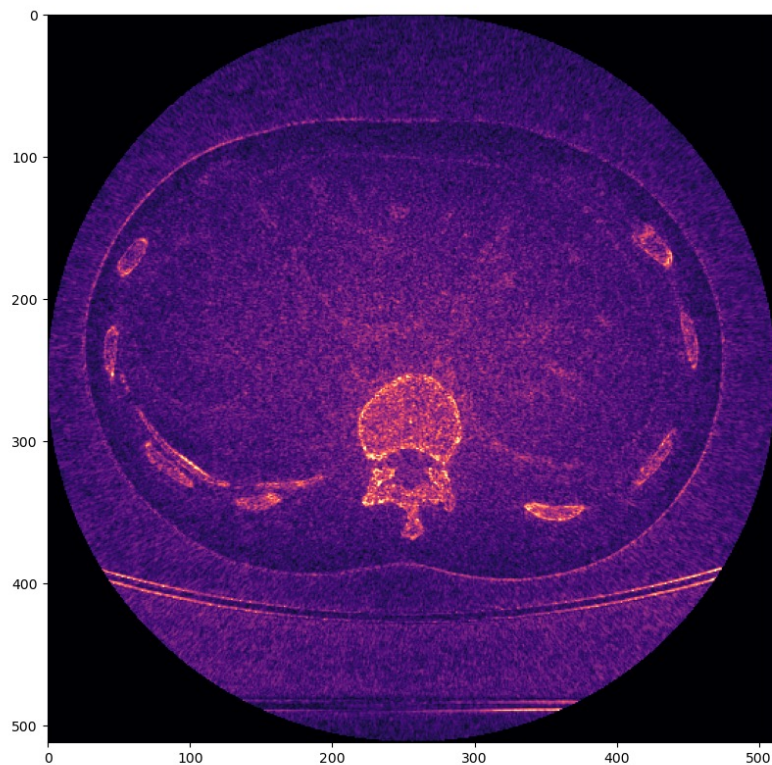


$std_{avg} = 9,47 HU$

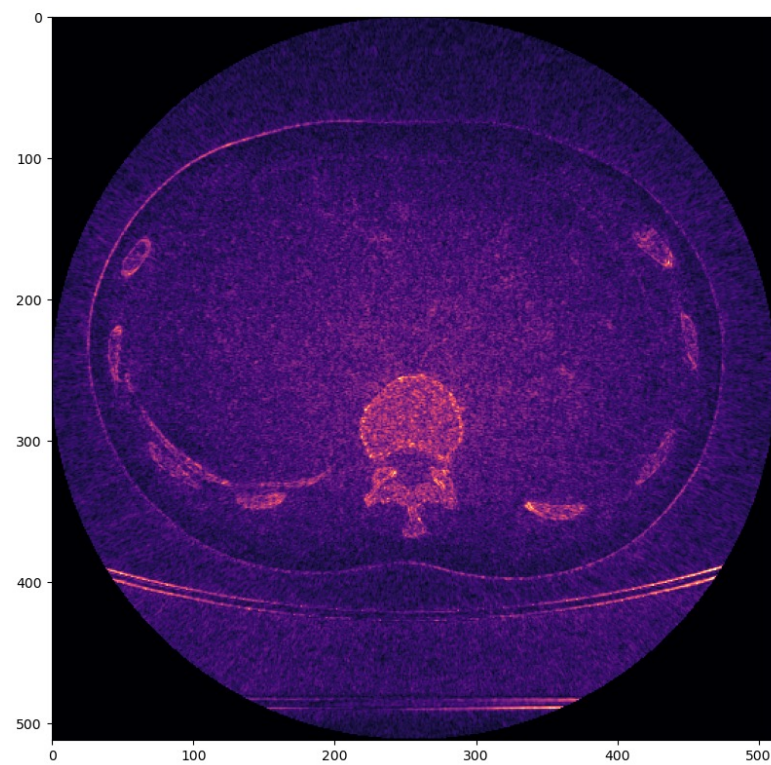


# Variabilita šumu – DLR-H

$std_{avg} = 9,74 HU$

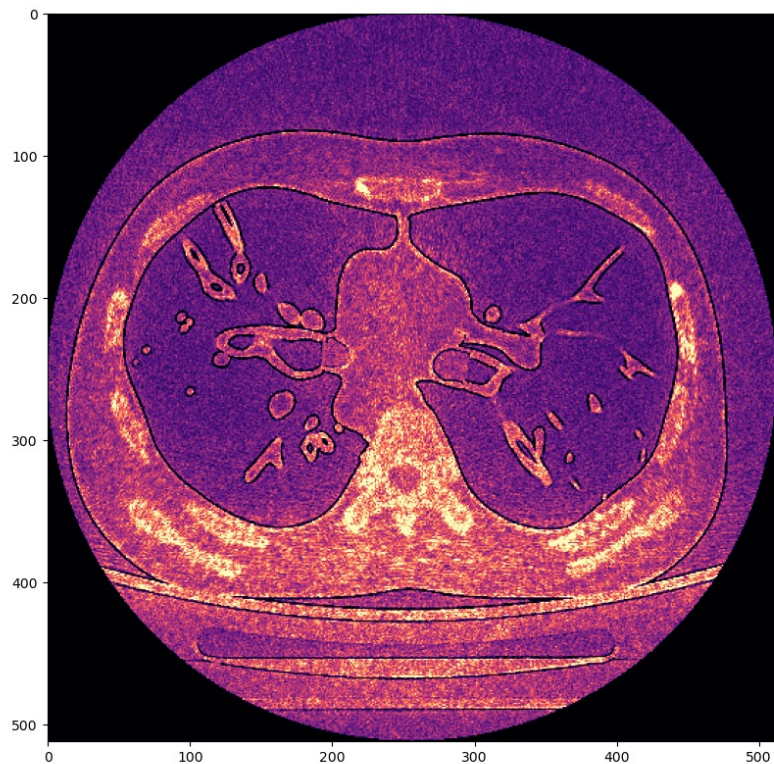


$std_{avg} = 8,02 HU$

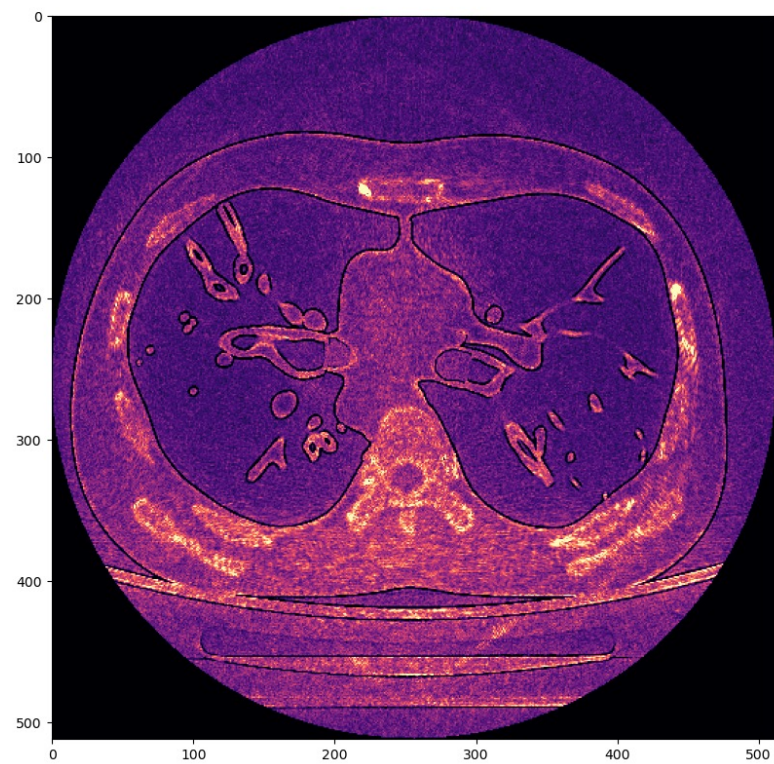


# Variabilita šumu – ASIR-V 20%

$std_{avg} = 35,31 HU$

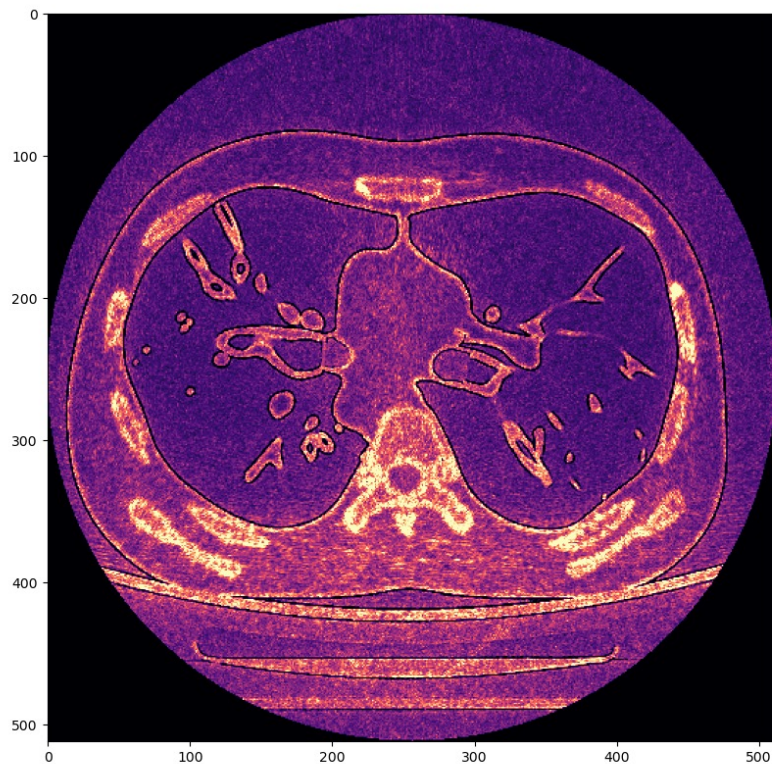


$std_{avg} = 27,84 HU$

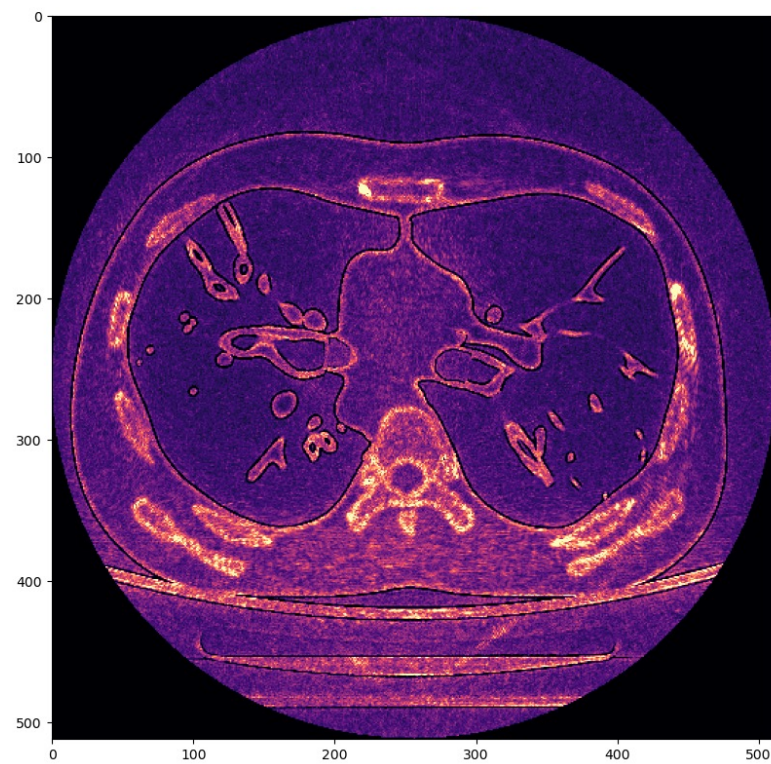


# Variabilita šumu – ASIR-V 50%

$std_{avg} = 30,80 HU$

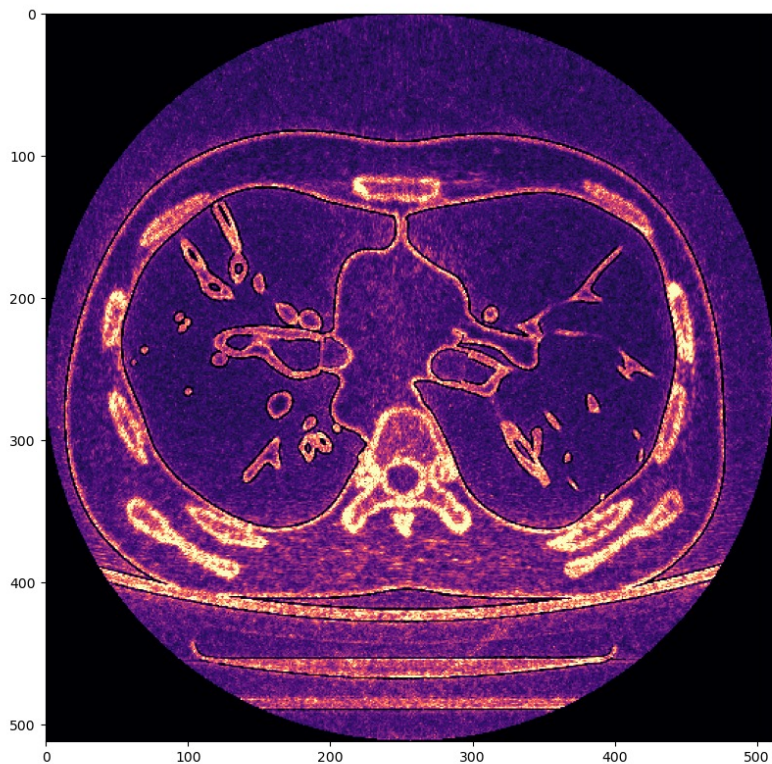


$std_{avg} = 24,44 HU$

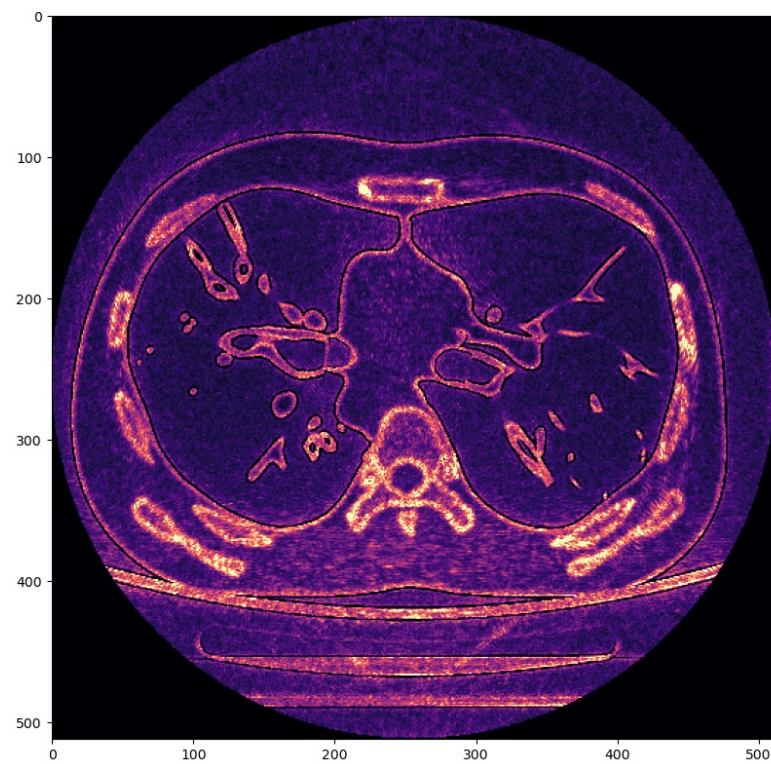


# Variabilita šumu – ASIR-V 80%

$std_{avg} = 26,08 HU$

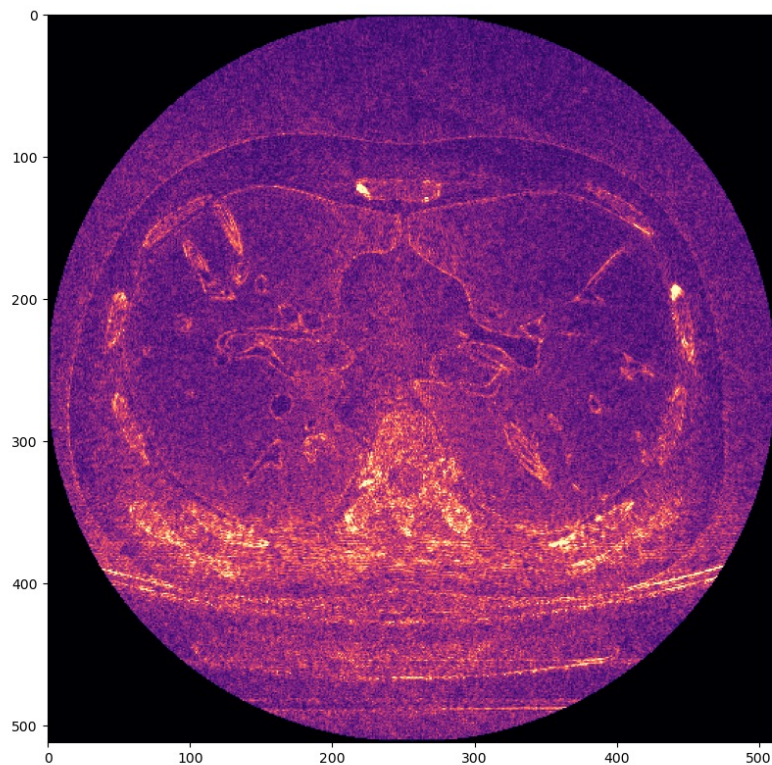


$std_{avg} = 20,85 HU$

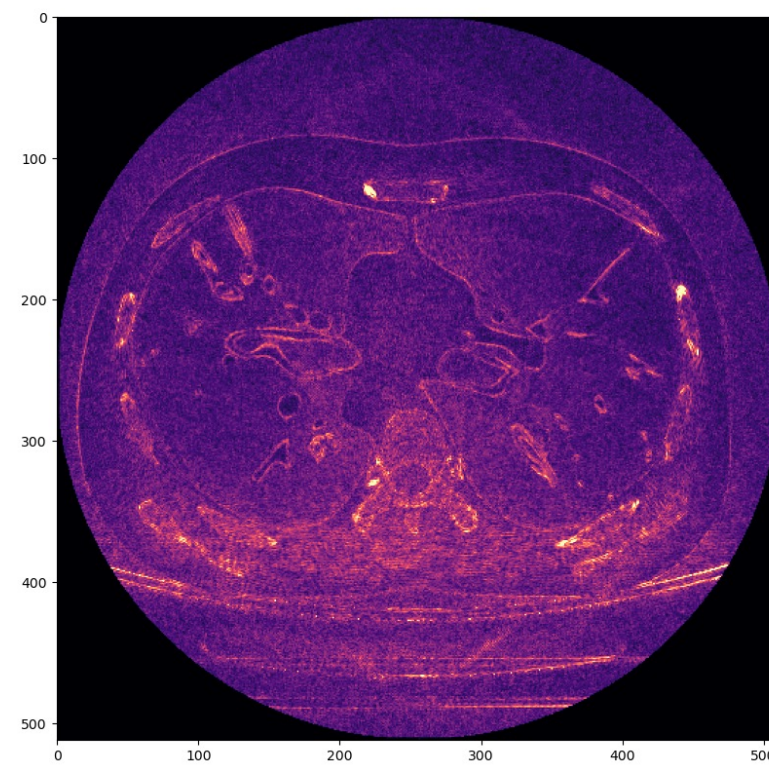


# Variabilita šumu – DLR-L

$std_{avg} = 31,29 HU$

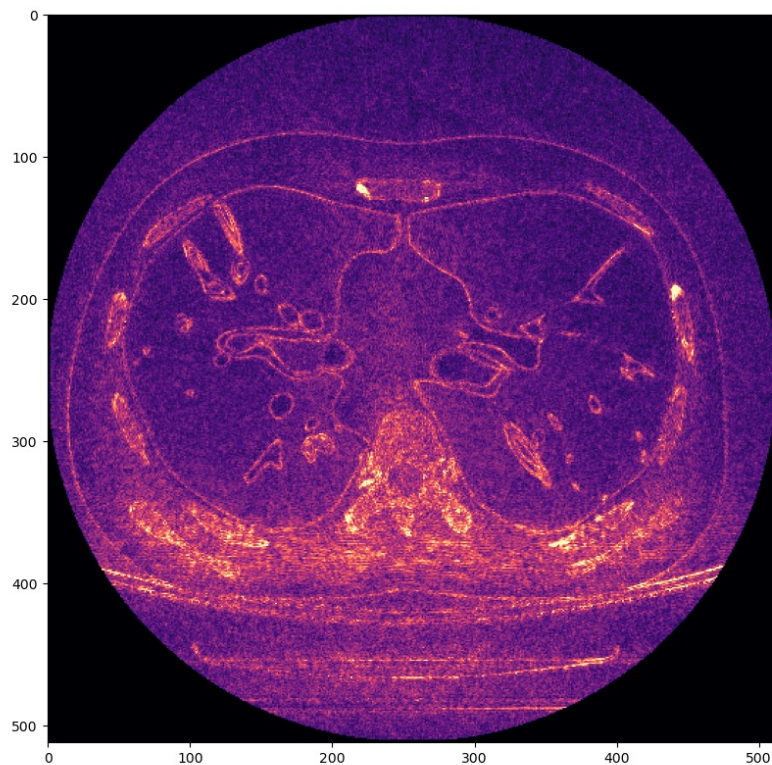


$std_{avg} = 23,79 HU$

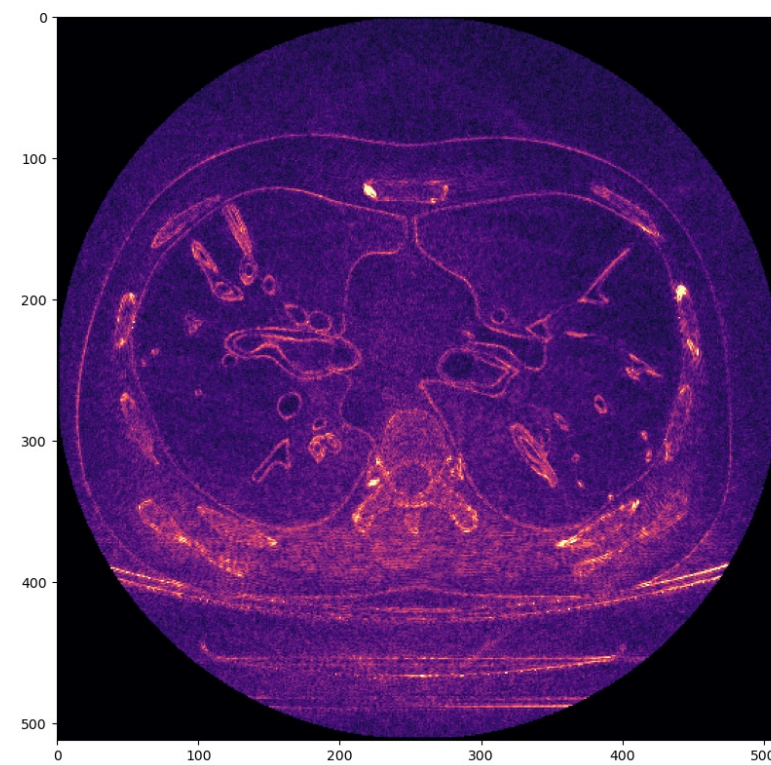


# Variabilita šumu – DLR-M

$std_{avg} = 26,91 HU$

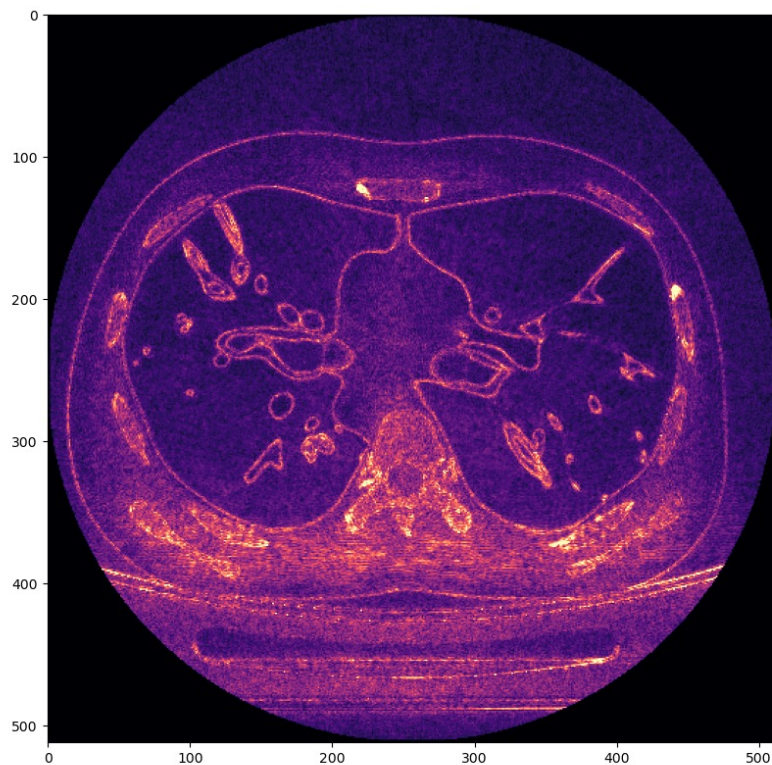


$std_{avg} = 20,41 HU$

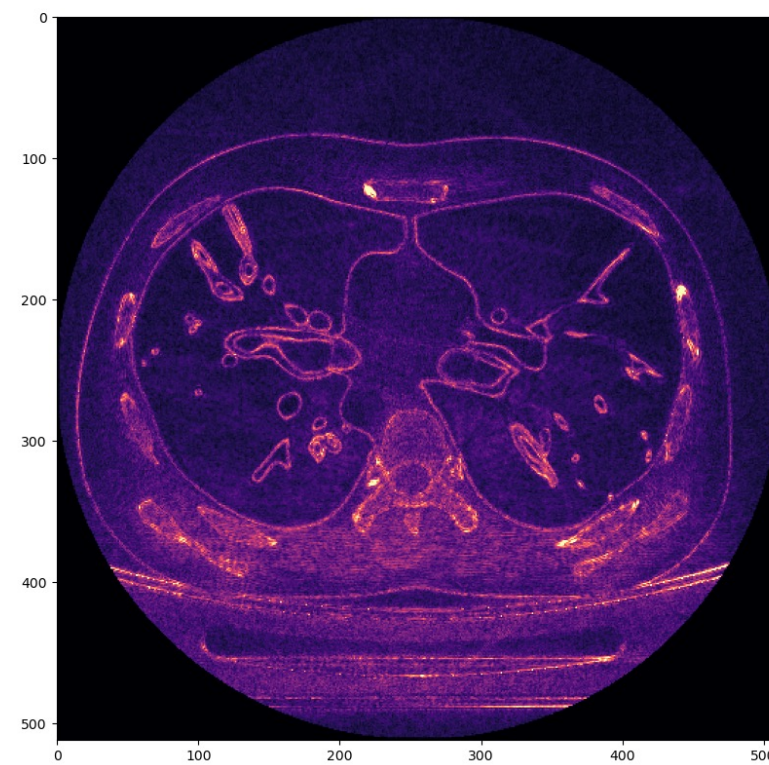


# Variabilita šumu – DLR-H

$std_{avg} = 23,03 HU$



$std_{avg} = 17,47 HU$



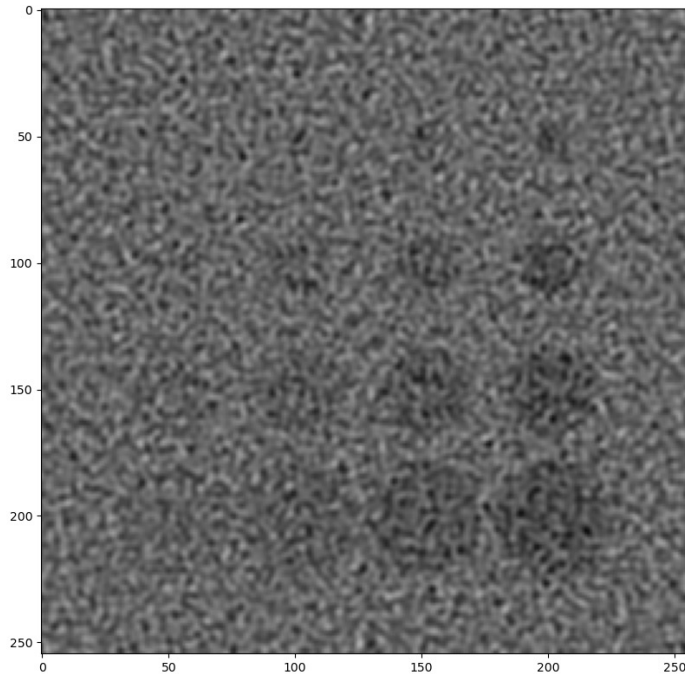


# Simulace šumu

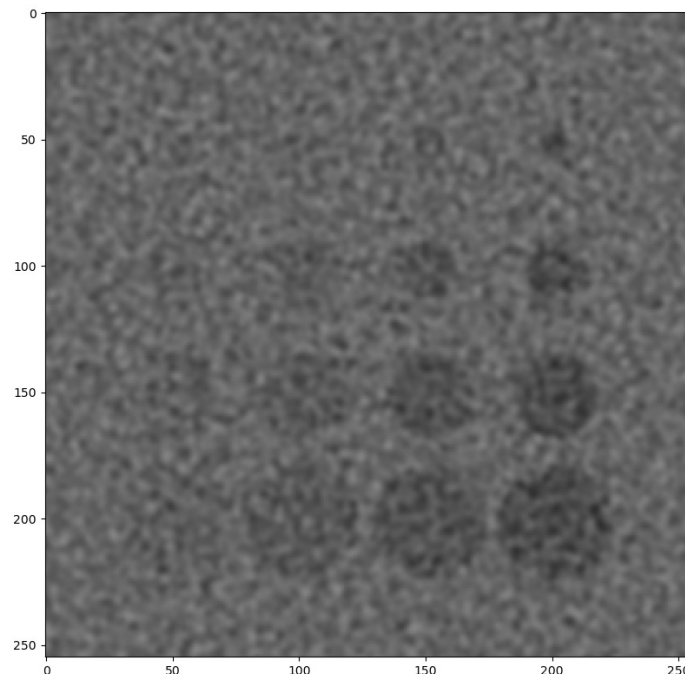
- ▶ Naměřené NPS mohou využít k získání simulovaných obrazů šumu (pro různé rekonstrukční algoritmy a hodnoty dávky/šumu)
- ▶ Je možné si vytvořit fantom simulující nějaký objekt a hodnotit viditelnost (nebo jinou metriku) pro různé hodnoty dávky/šumu

# Simulace šumu – CTDI = 2,53 mGy

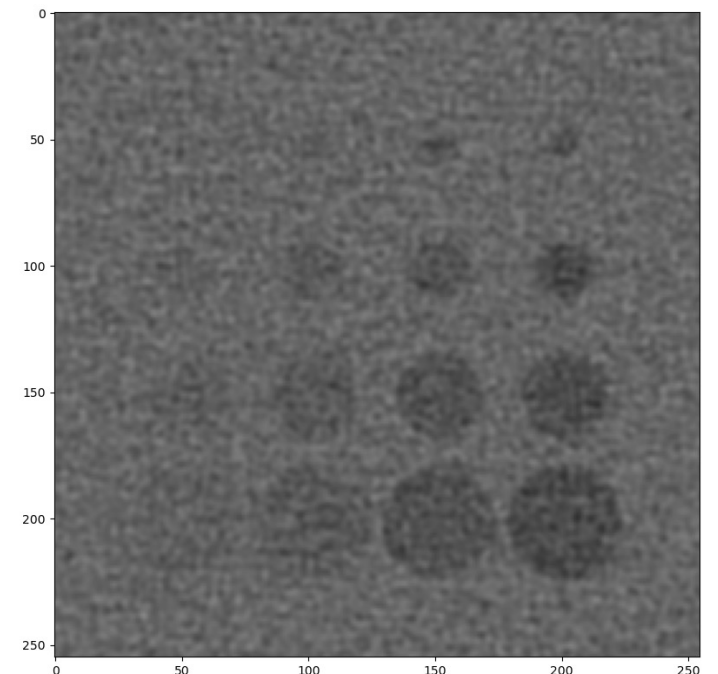
FBP, std = 29,16 HU



ASIR 80%, std = 15,18 HU

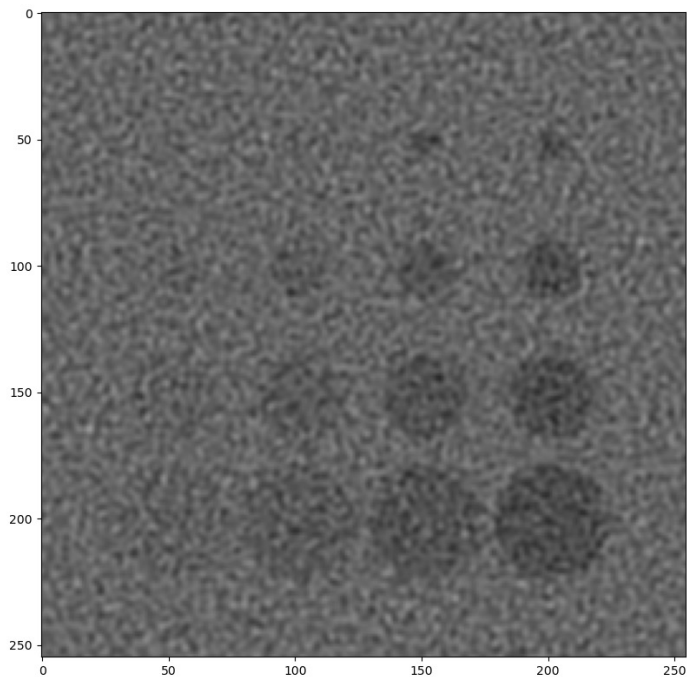


DLR High, std = 12,69 HU

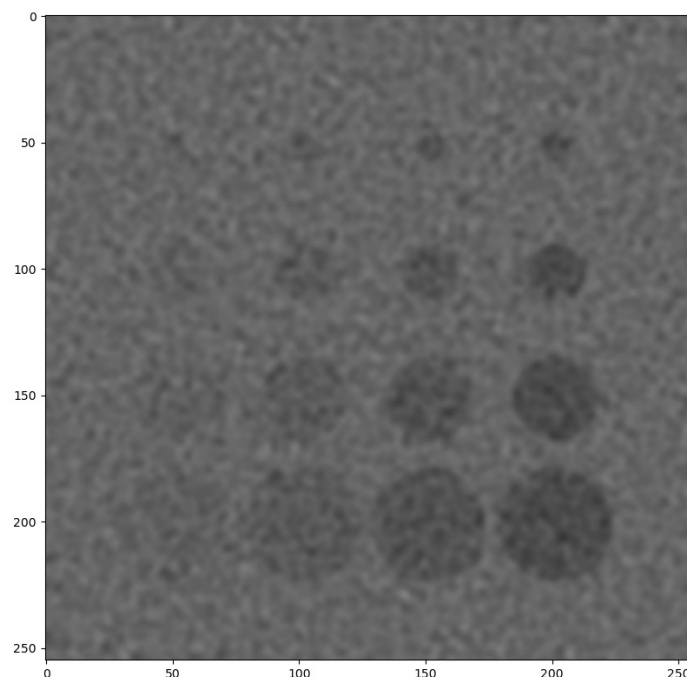


# Simulace šumu – CTDI = 6,32 mGy

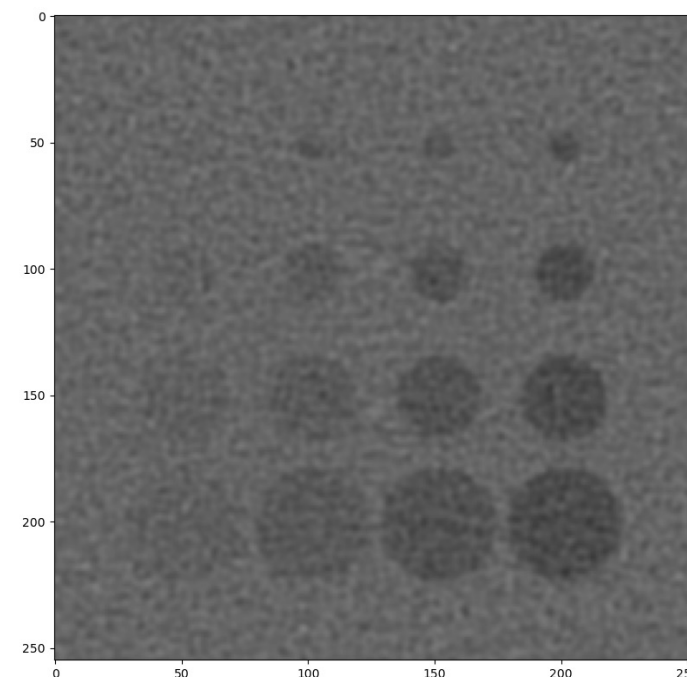
FBP, std = 18,04 HU



ASIR 80%, std = 9,41 HU

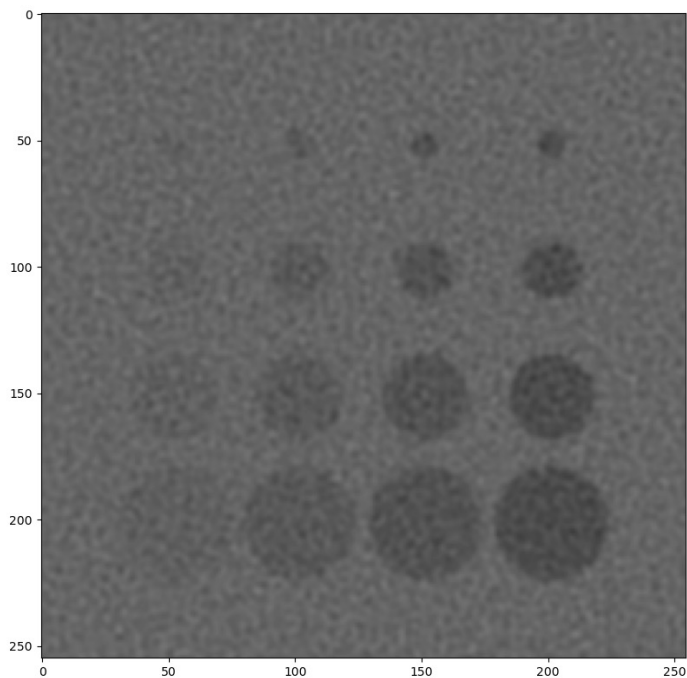


DLR High, std = 9,14 HU

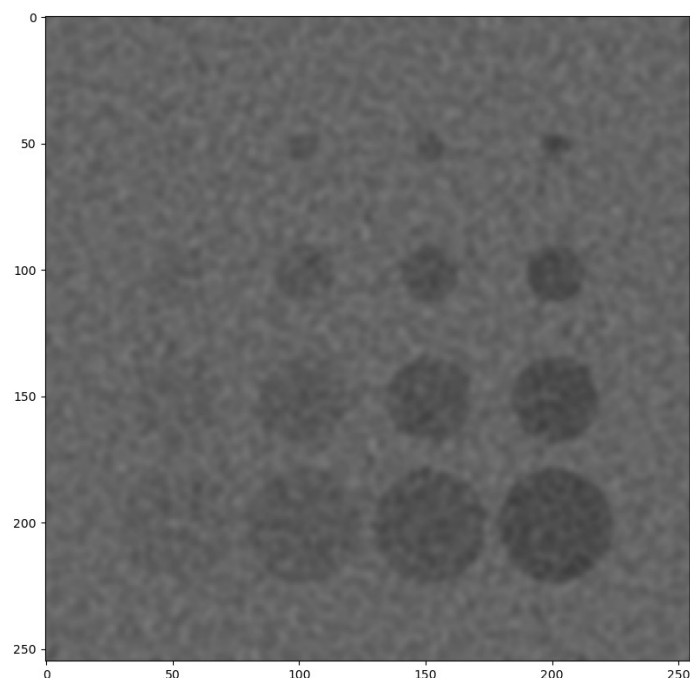


# Simulace šumu – konstantní std

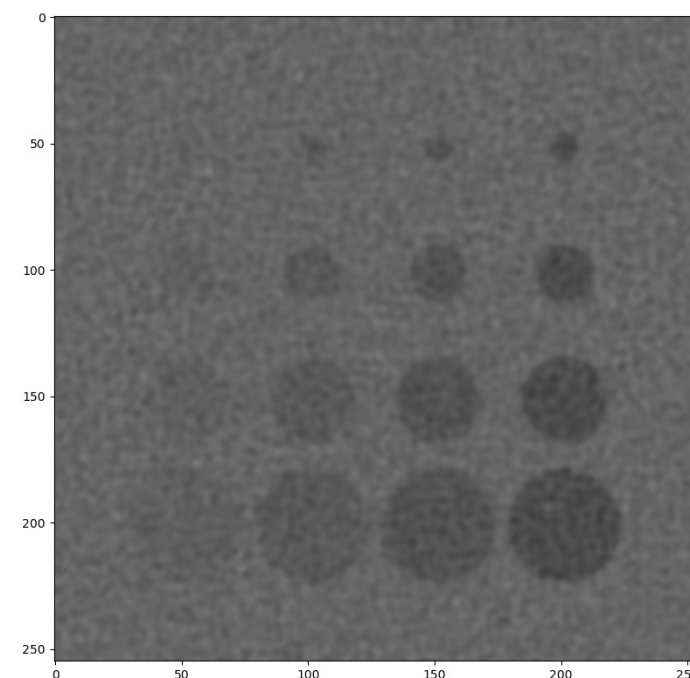
FBP, std = 7,50 HU



ASIR 80%, std = 7,50 HU

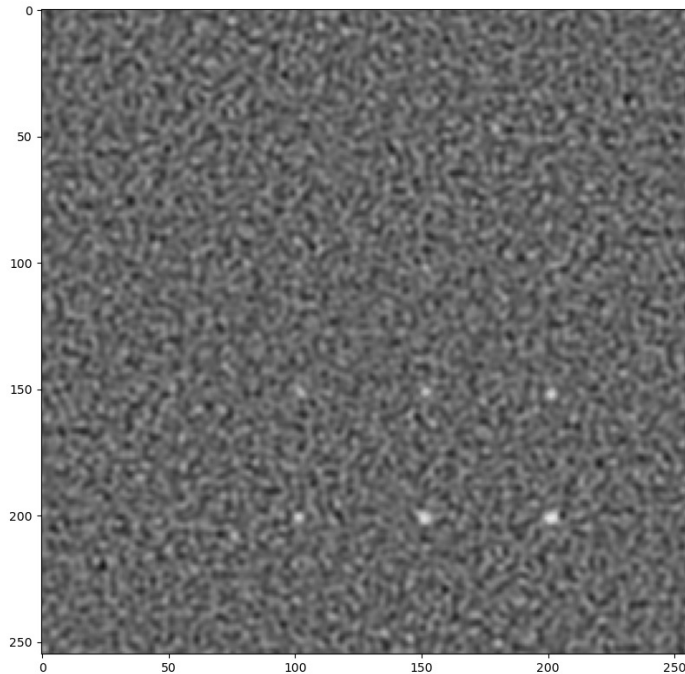


DLR High, std = 7,50 HU

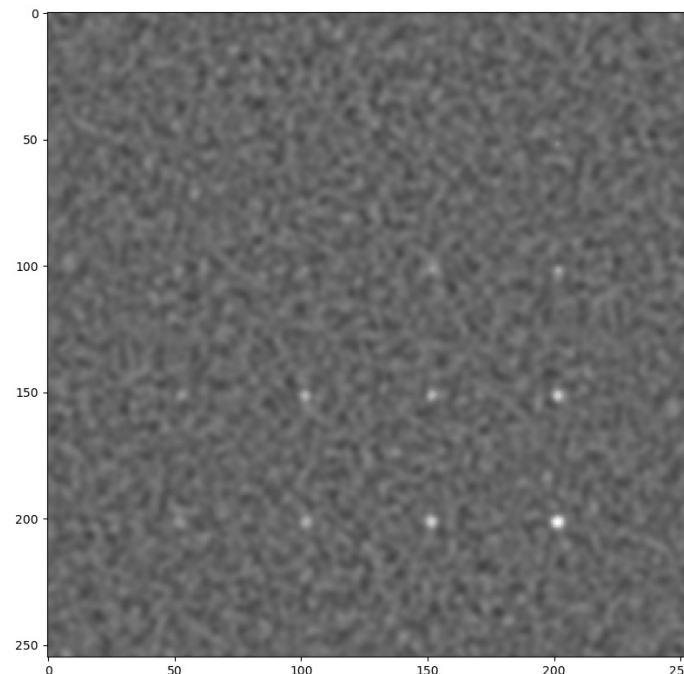


# Simulace šumu – CTDI = 2,53 mGy

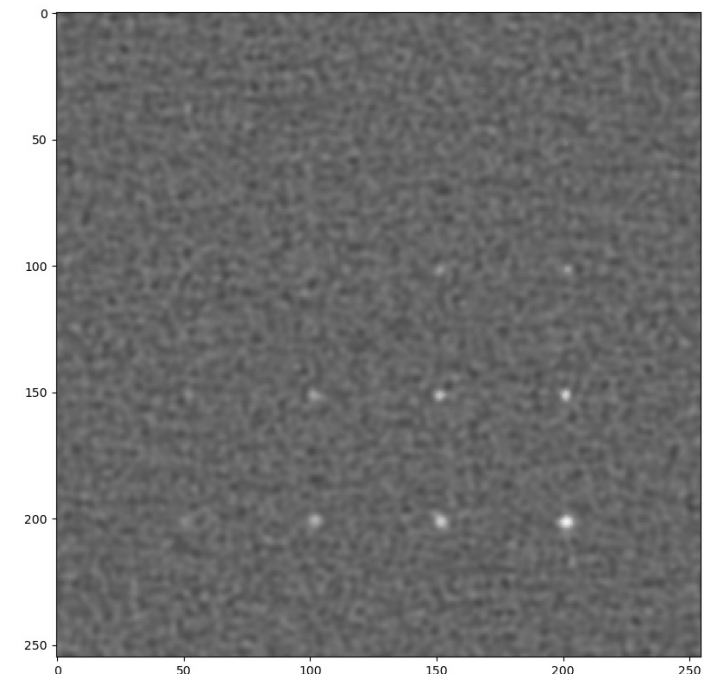
FBP, std = 29,16 HU



ASIR 80%, std = 15,18 HU

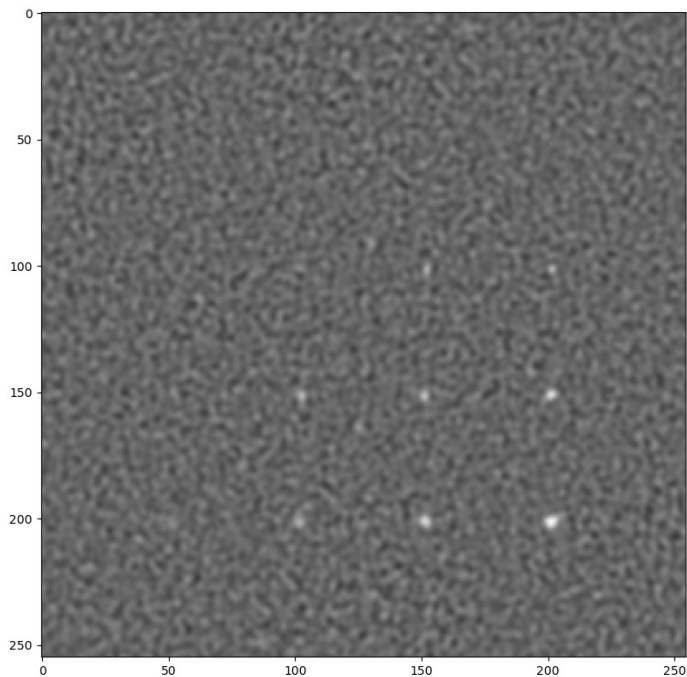


DLR High, std = 12,69 HU

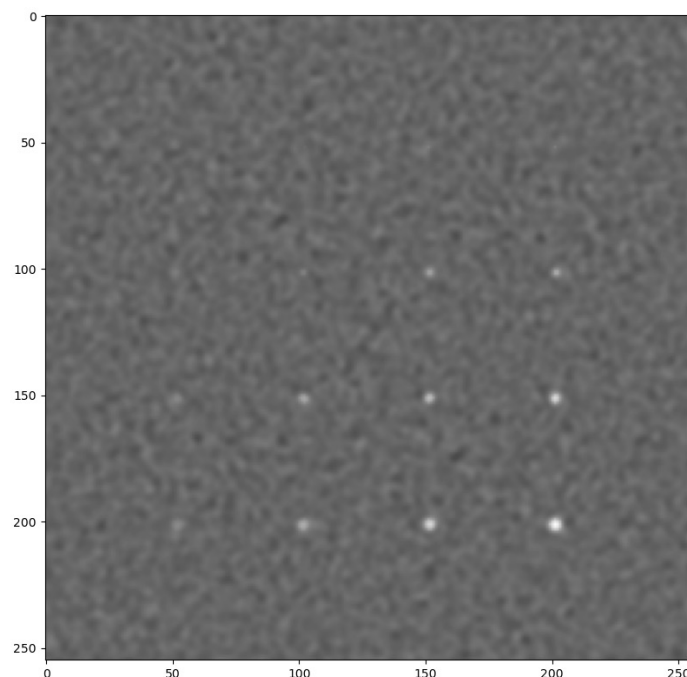


# Simulace šumu – CTDI = 6,32 mGy

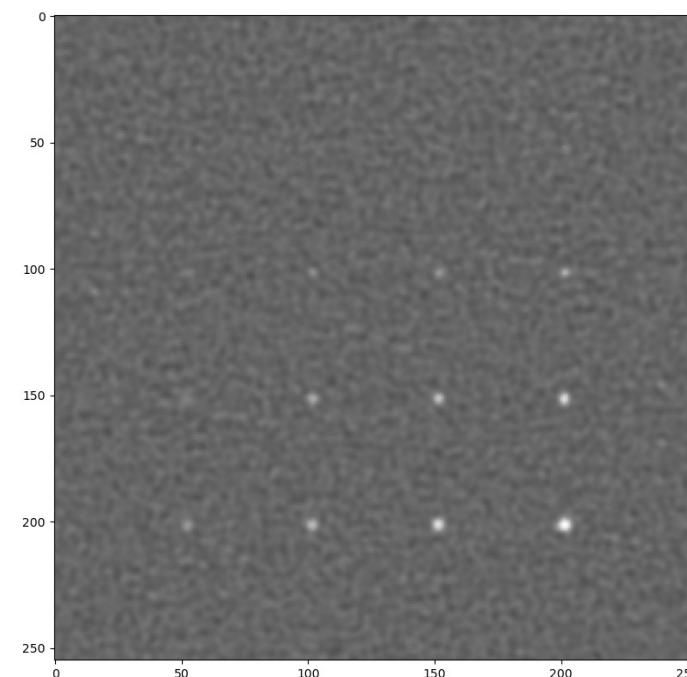
FBP, std = 18,04 HU



ASIR 80%, std = 9,41 HU

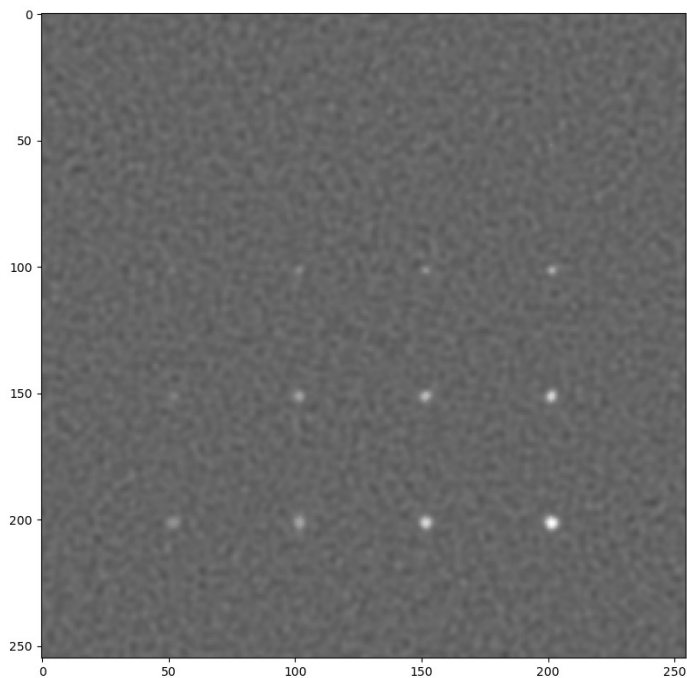


DLR High, std = 9,14 HU

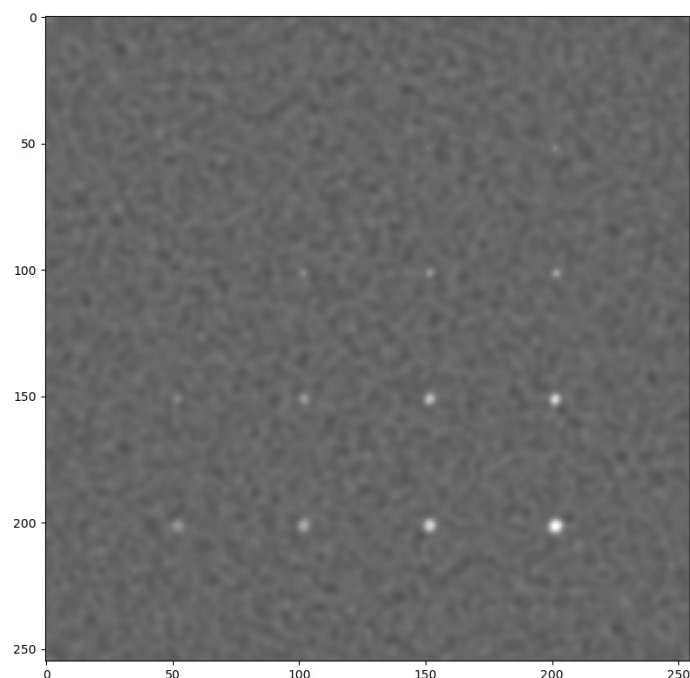


# Simulace šumu – konstantní std

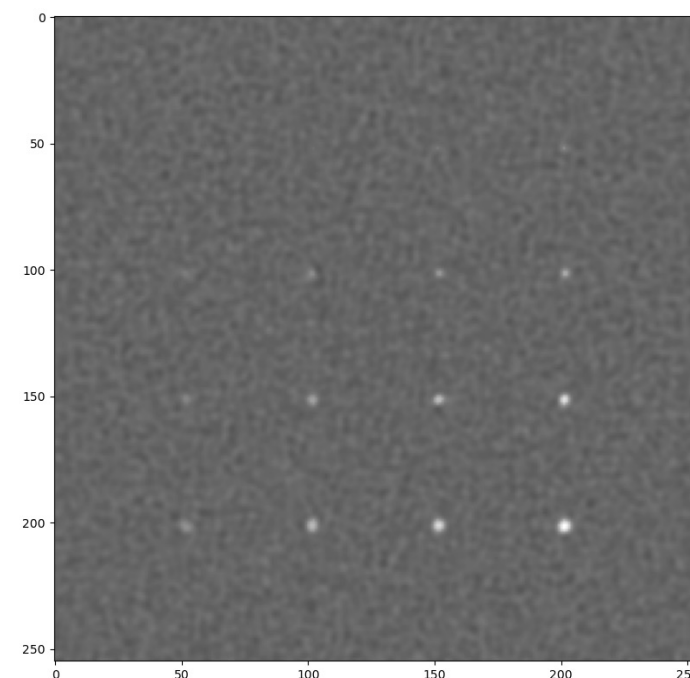
FBP, std = 7,50 HU



ASIR 80%, std = 7,50 HU



DLR High, std = 7,50 HU



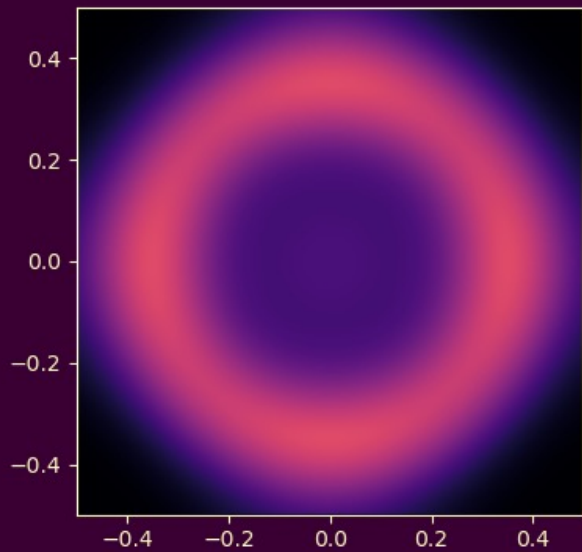
# Aliasing šumu

- ▶ Šum obrazů, které jsou rekonstruovány ostrými filtry s velkým DFOV, se vyznačuje aliasingem
- ▶ Ten se projevuje jednak zvýšením směrodatné odchylky, ale také změnou textury šumu
- ▶ K aliasingu šumu dochází, když NPS nabývá nenulových hodnot za Nyquistovou frekvencí

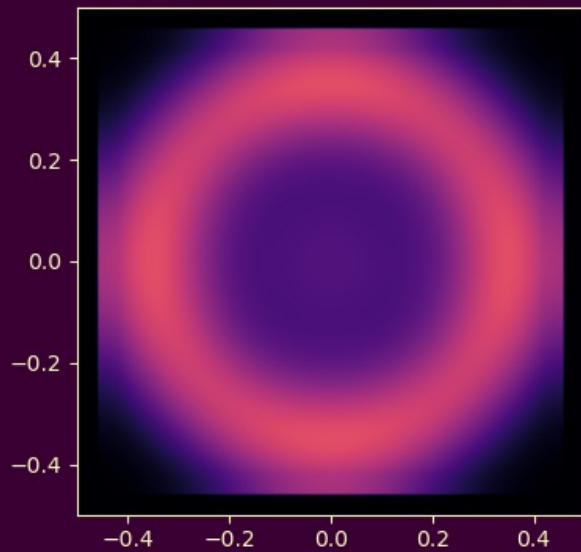
$$f_{Nyquist} = \frac{1}{2 \cdot \Delta_j}$$

- ▶ Analýza NPS tak umožňuje určení maximálního DFOV pro daný rekonstrukční kernel

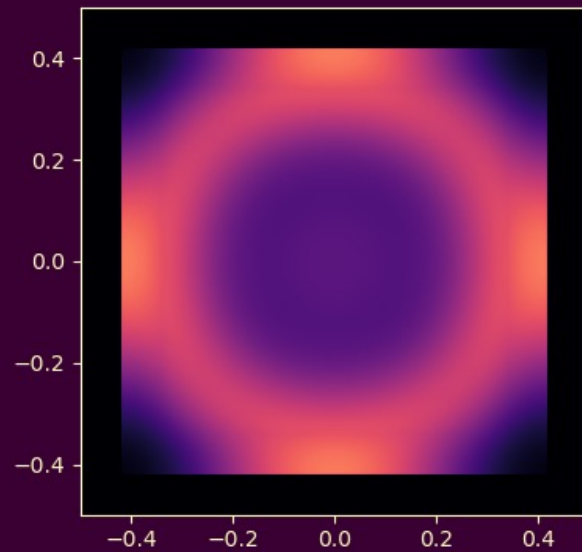




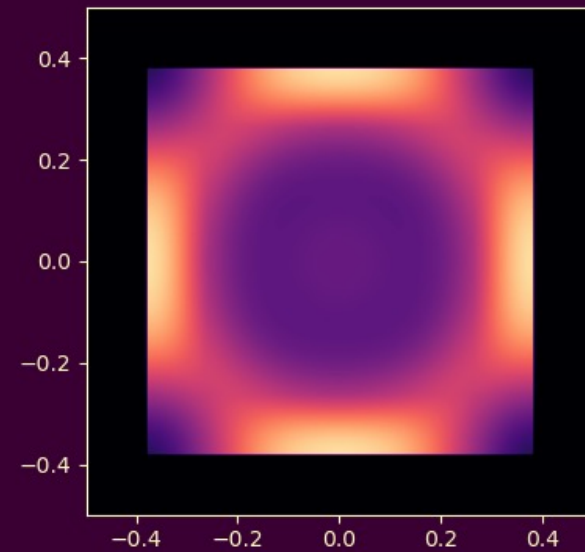
STD = 99.21



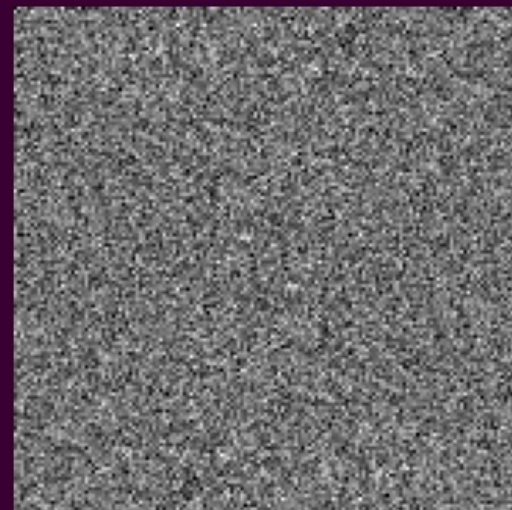
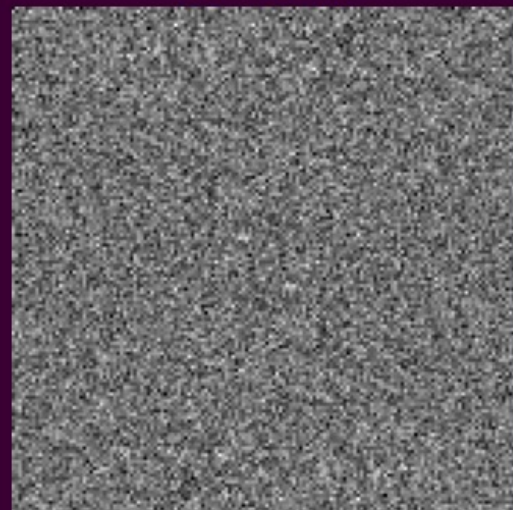
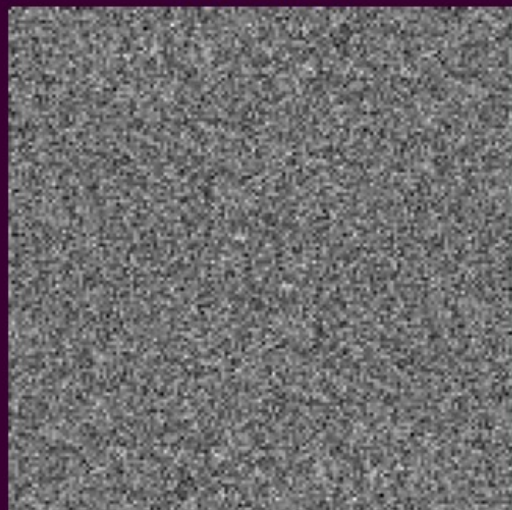
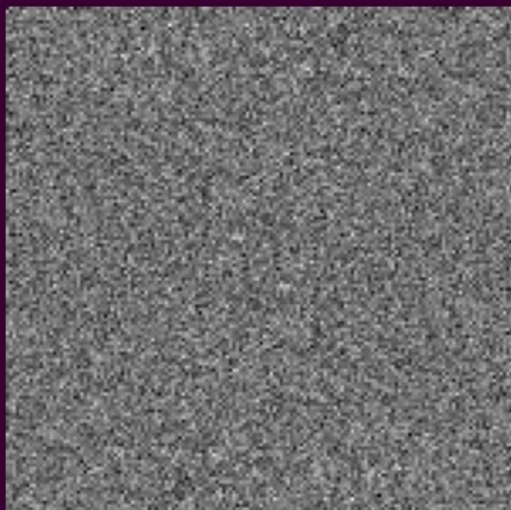
STD = 106.38



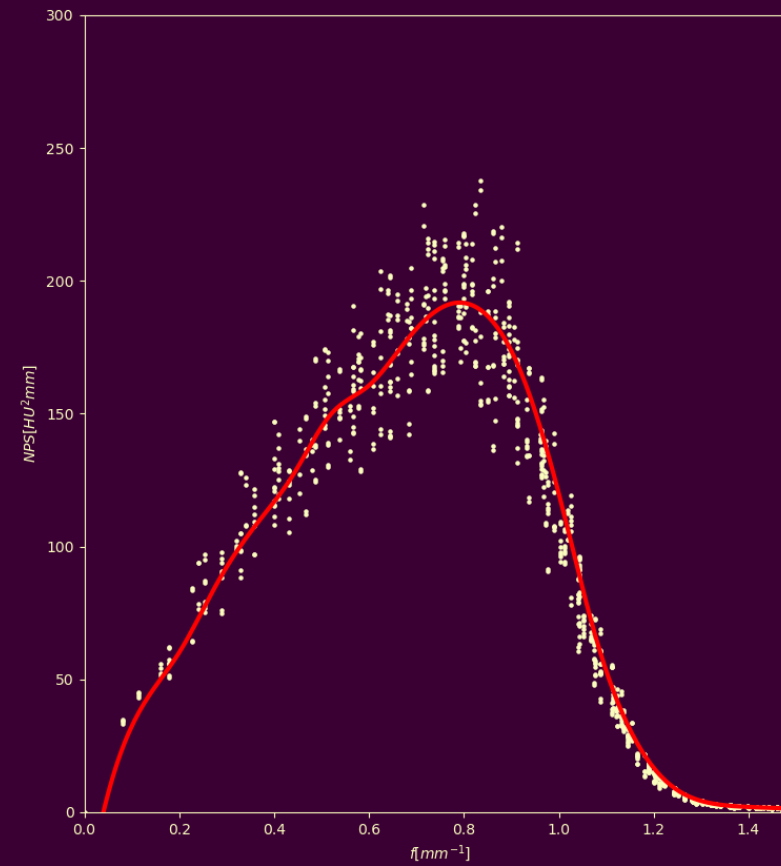
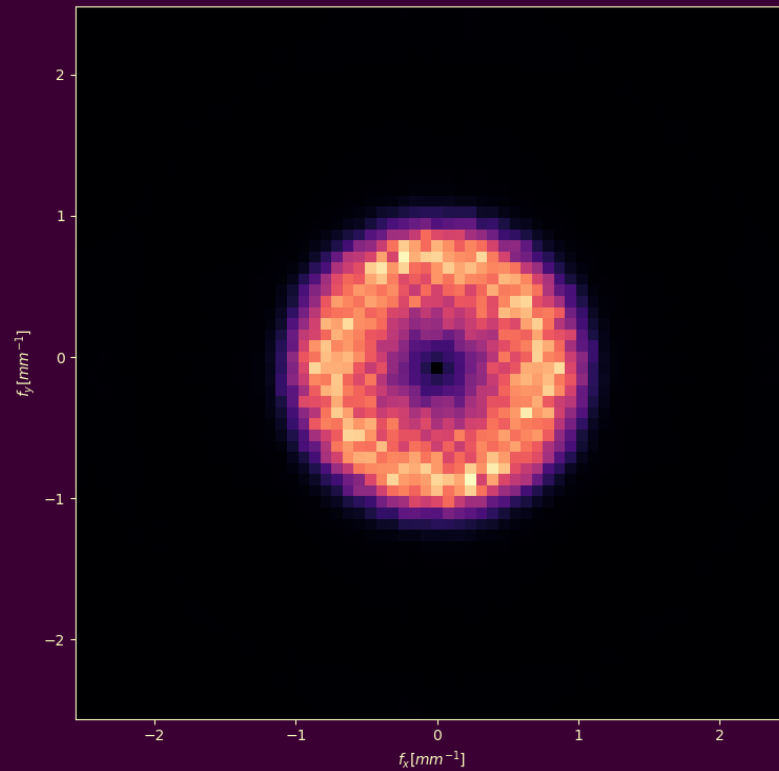
STD = 114.91



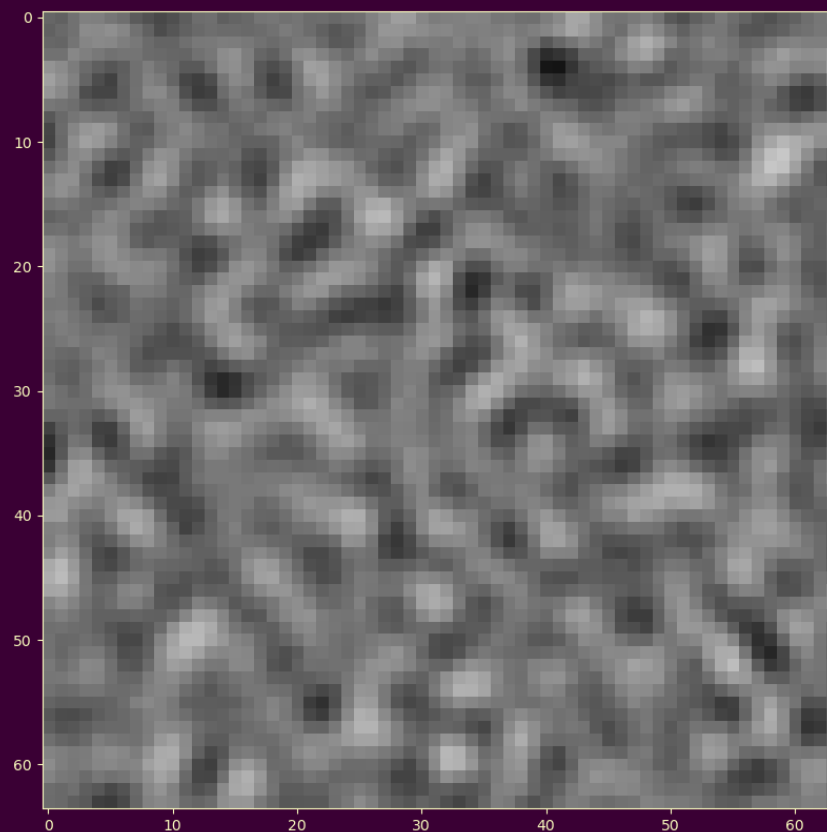
STD = 125.22



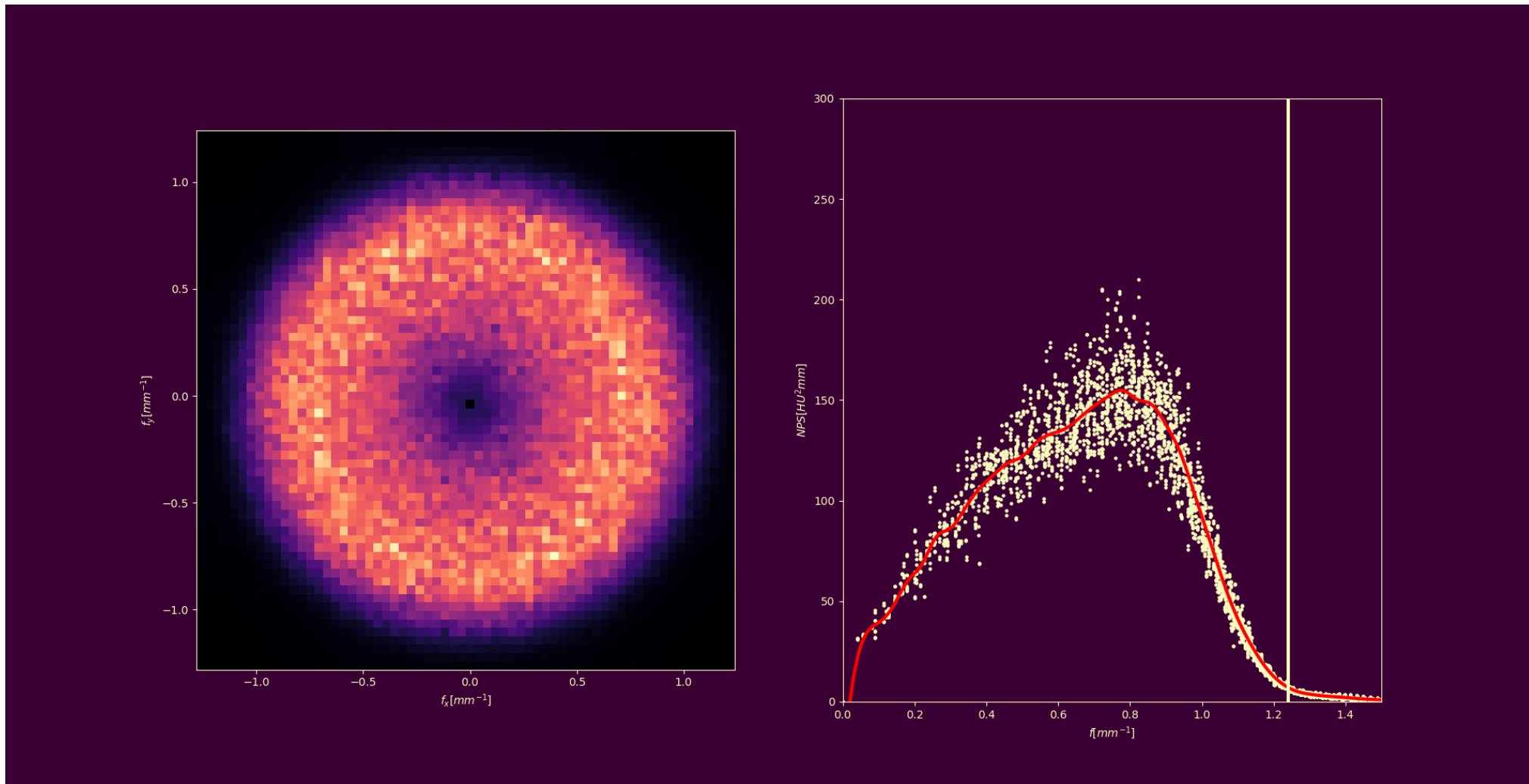
# Aliasing šumu – DFOV 100 mm



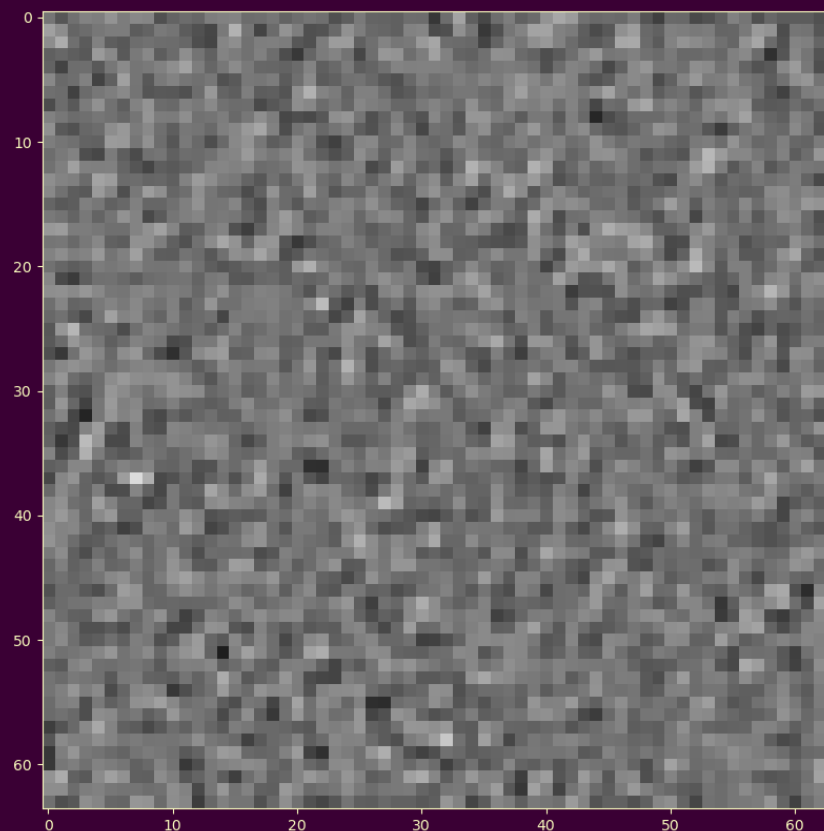
# Aliasing šumu – DFOV 100 mm



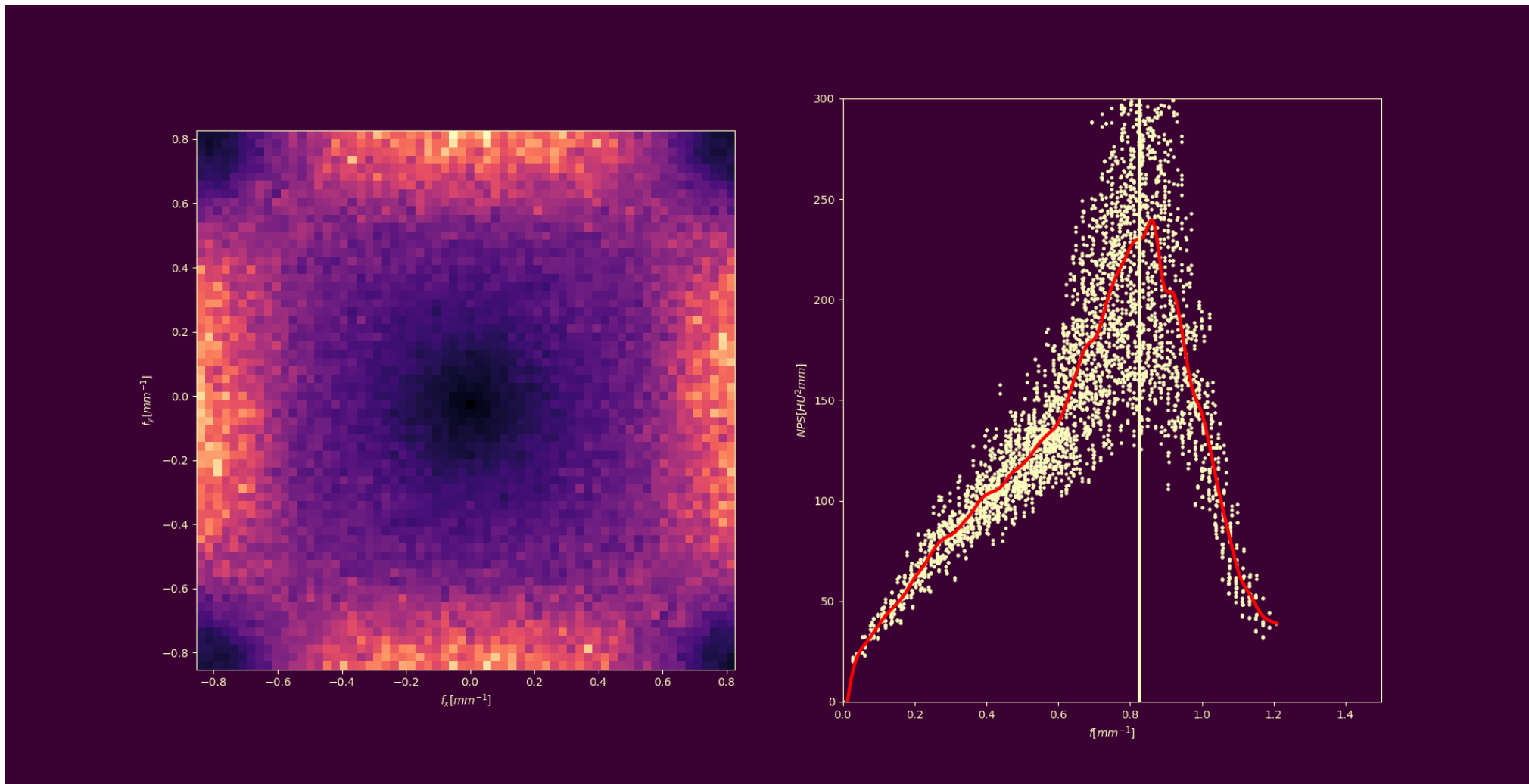
# Aliasing šumu – DFOV 200 mm



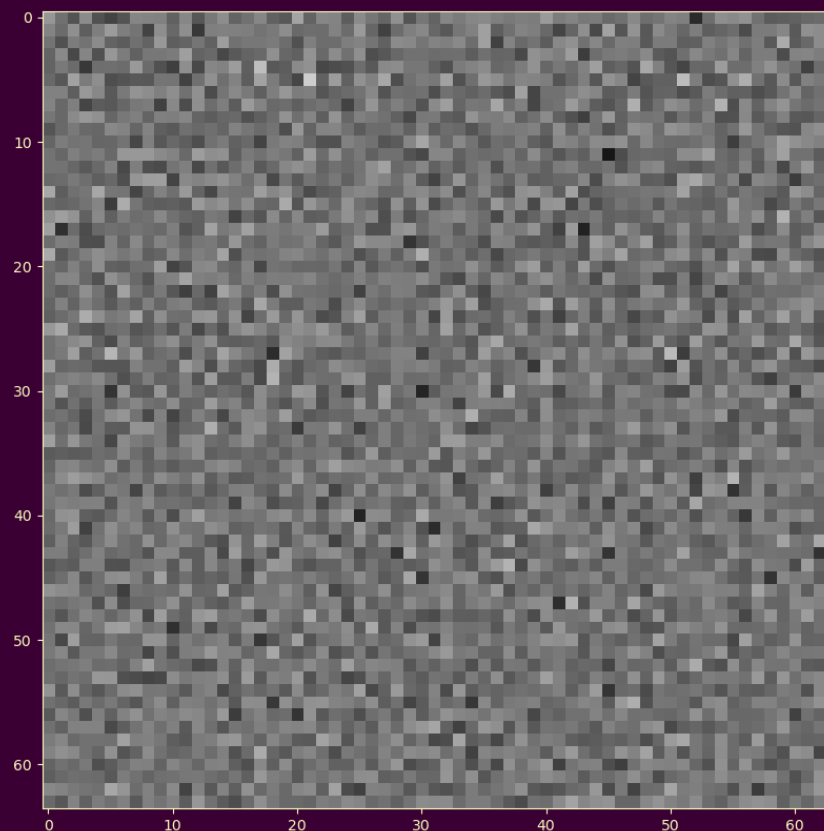
# Aliasing šumu – DFOV 200 mm



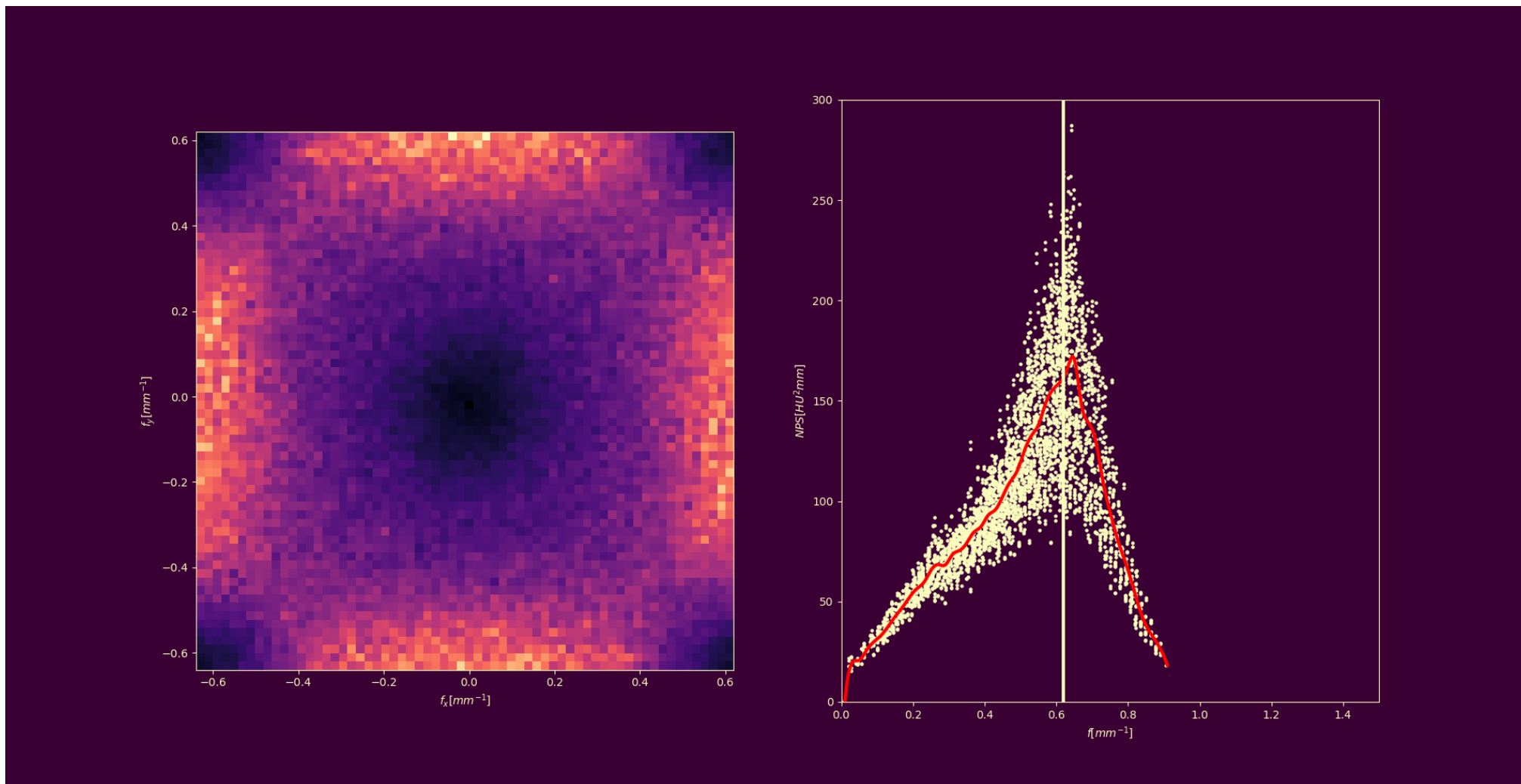
# Aliasing šumu – DFOV 300 mm



# Aliasing šumu – DFOV 300 mm

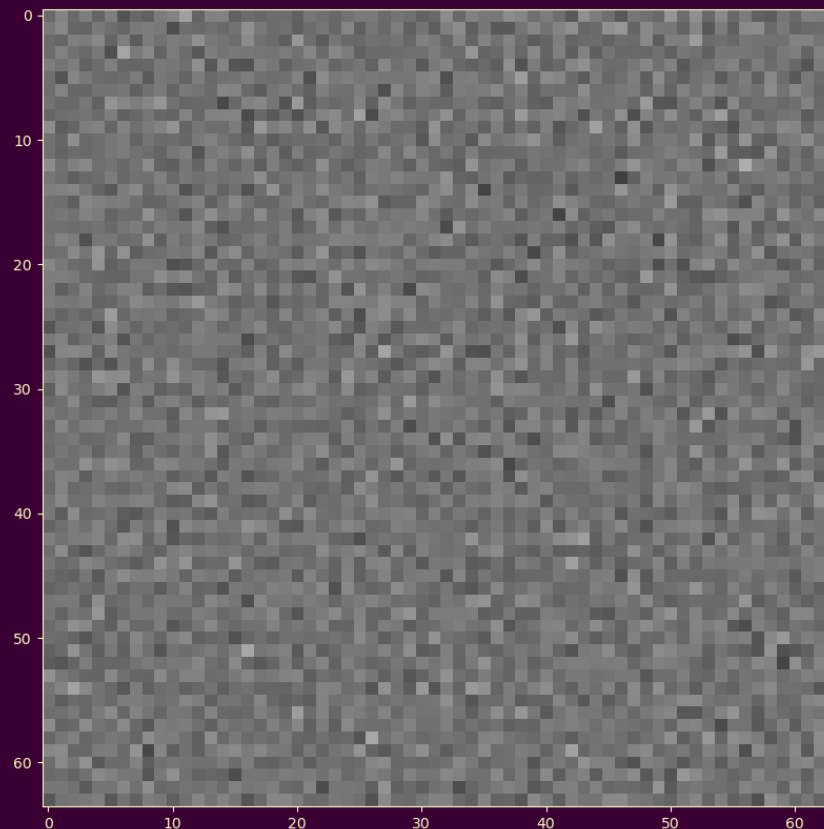


# Aliasing šumu – DFOV 400 mm





# Aliasing šumu – DFOV 400 mm



# Závěrem

- ▶ Šum je v obraze ovlivněn několika parametry – největší vliv má rekonstrukční jádro (a další parametry) a samozřejmě dávka
- ▶ Analýzou NPS získám další informace o šumu v obraze (na jaké frekvenci je šum nejvyšší, jestli je orientován v nějakém směru)



Děkuji za pozornost