Physics-based Noise Modeling for Extreme Low-light Photography

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TPAMI 2021

CVPR 2020 (Oral)

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Outline

- Introduction
- Method
- Experiment
- Conclusion

Introduction

$$N = KN_p + N_{read} + N_r + N_q,$$

Noise type	Formulation	Parameters
Photon shot noise N_p	Poisson distribution $(I + N_p) \sim \mathcal{P}(I)$	System gain K
Read noise N_{read}	Tukey lambda distribution $N_{read} \sim TL(\lambda; \mu_c, \sigma_{TL})$	Shape λ Color bias μ_c Scale σ_{TL}
Row noise N_r	Gaussian distribution $N_r \sim \mathcal{N}(0, \sigma_r)$	Scale σ_r
Quantization noise N_q	Uniform distribution $N_q \sim U(-1/2q, 1/2q)$	None

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K for photon shot noise

$$D = K(I + N_p) + N_o$$

$$\begin{aligned} Var(D) &= K^2 I + Var(N_o) \\ &= K(KI) + Var(N_o) \end{aligned}$$

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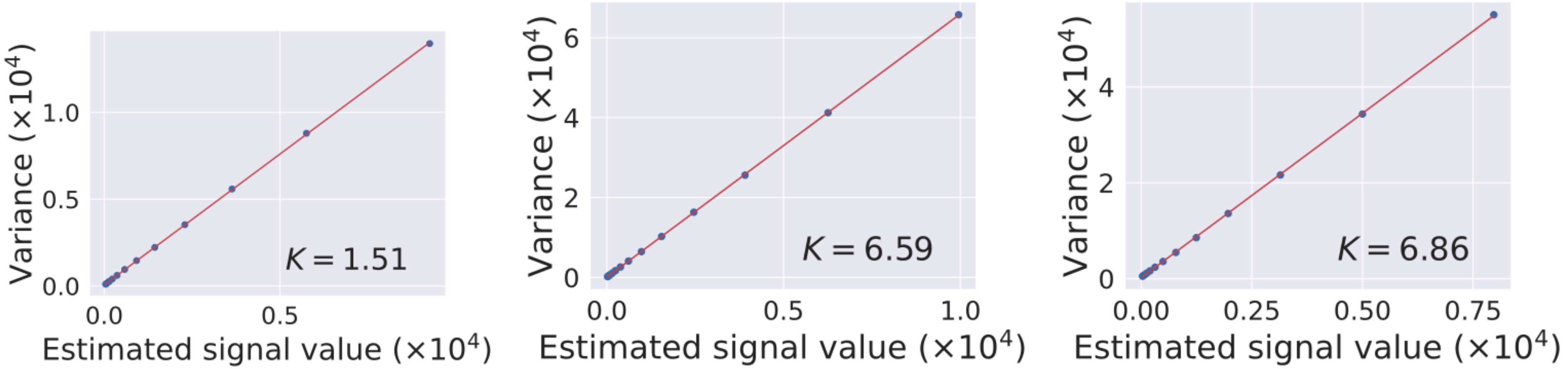
- true signal value KI can be approximated by the flat-field frame median



(a) SonyA7S2 (b) NikonD850 (c) CanonEOS70D

Estimating Noise Parameters

- Flat-field frames
  - uniformly illuminated
- Bias frames
  - lightless environment

μc for color bias

- averaging all pixel values within each color channel of the bias frame

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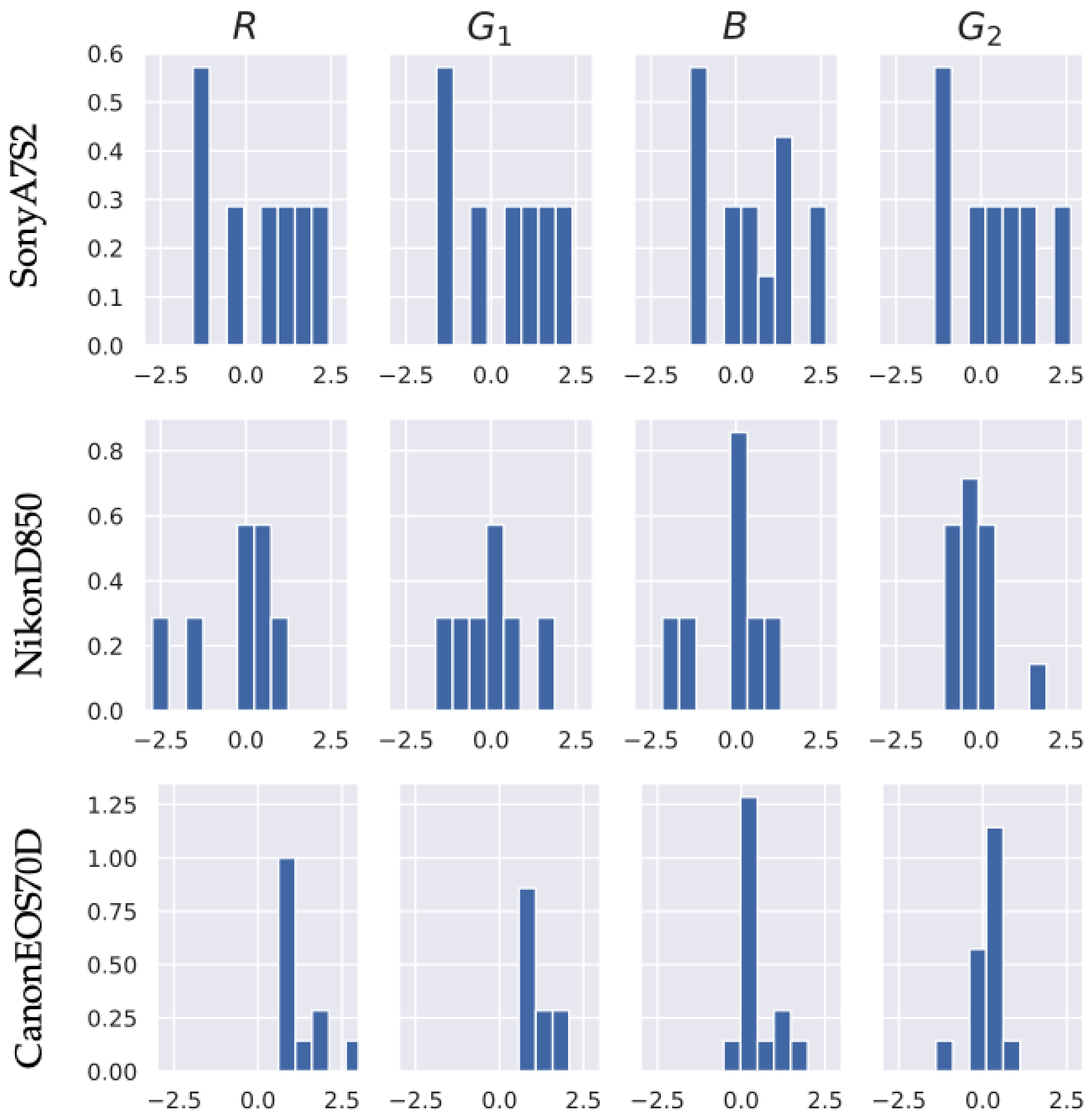

σr for row noise

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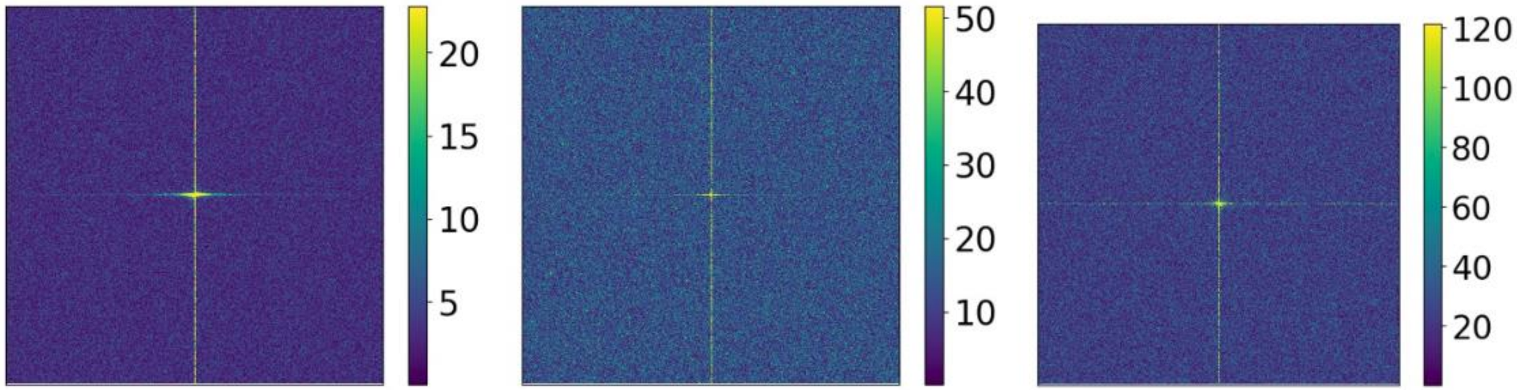

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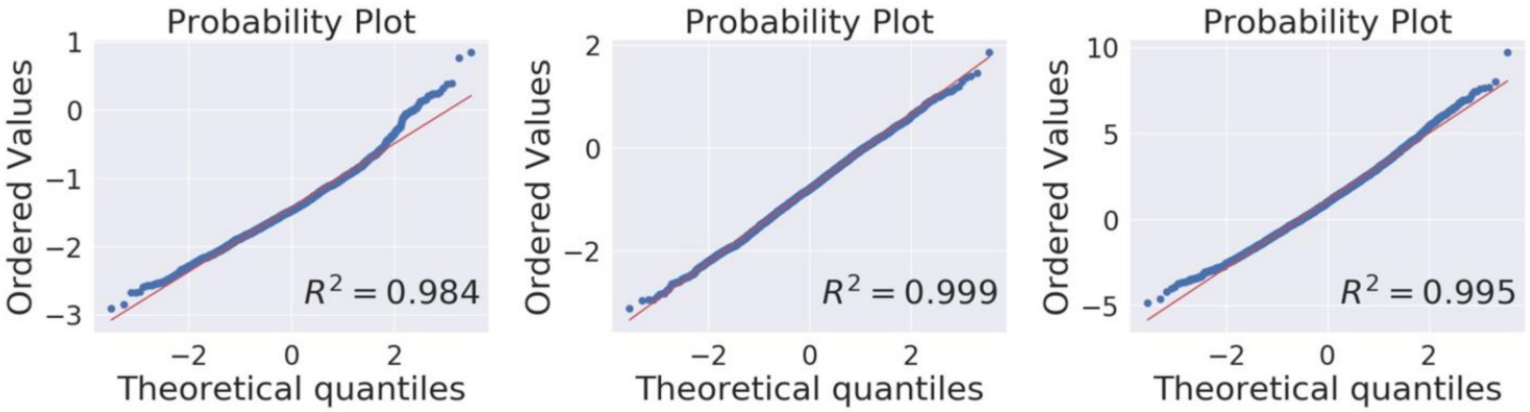
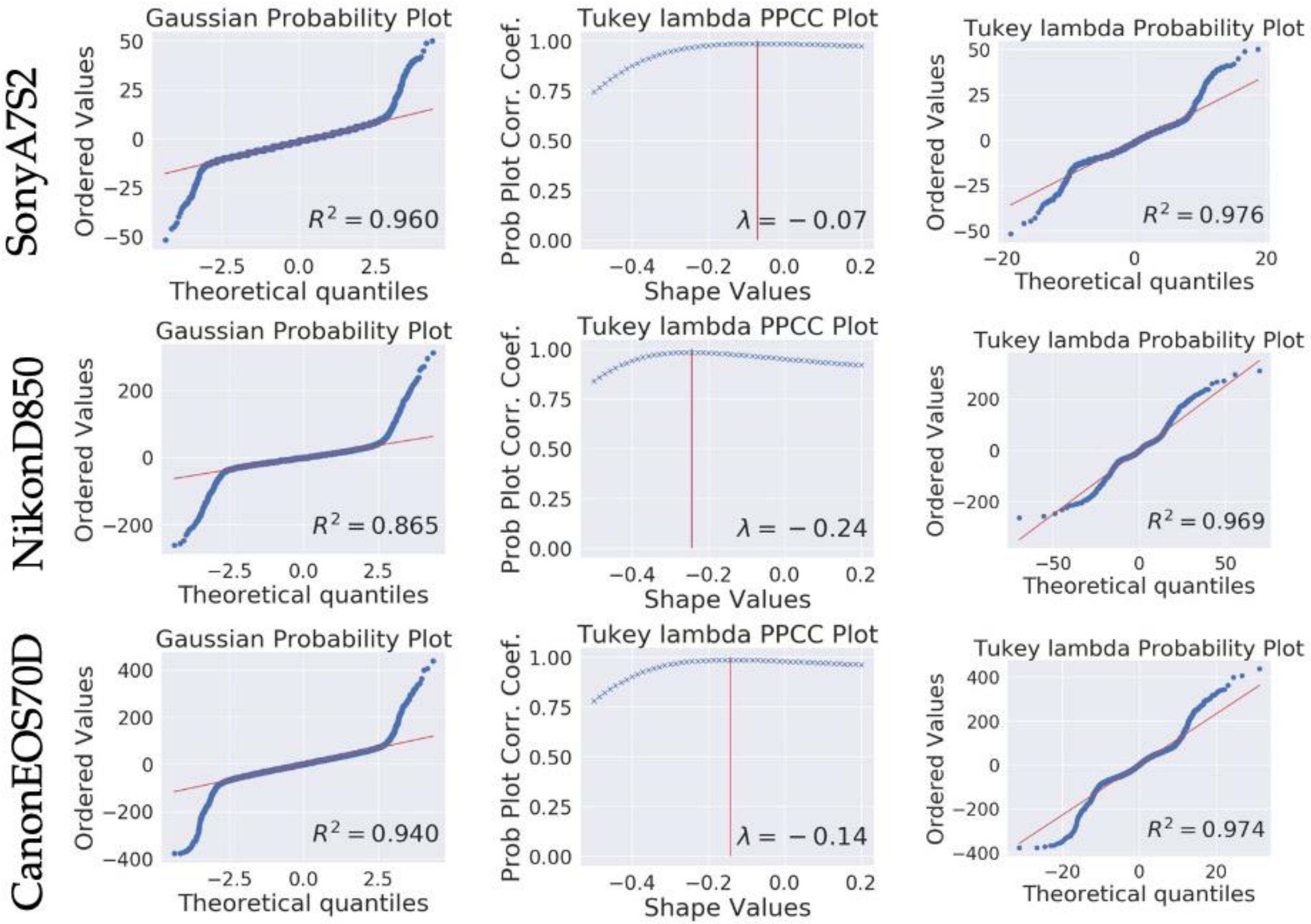
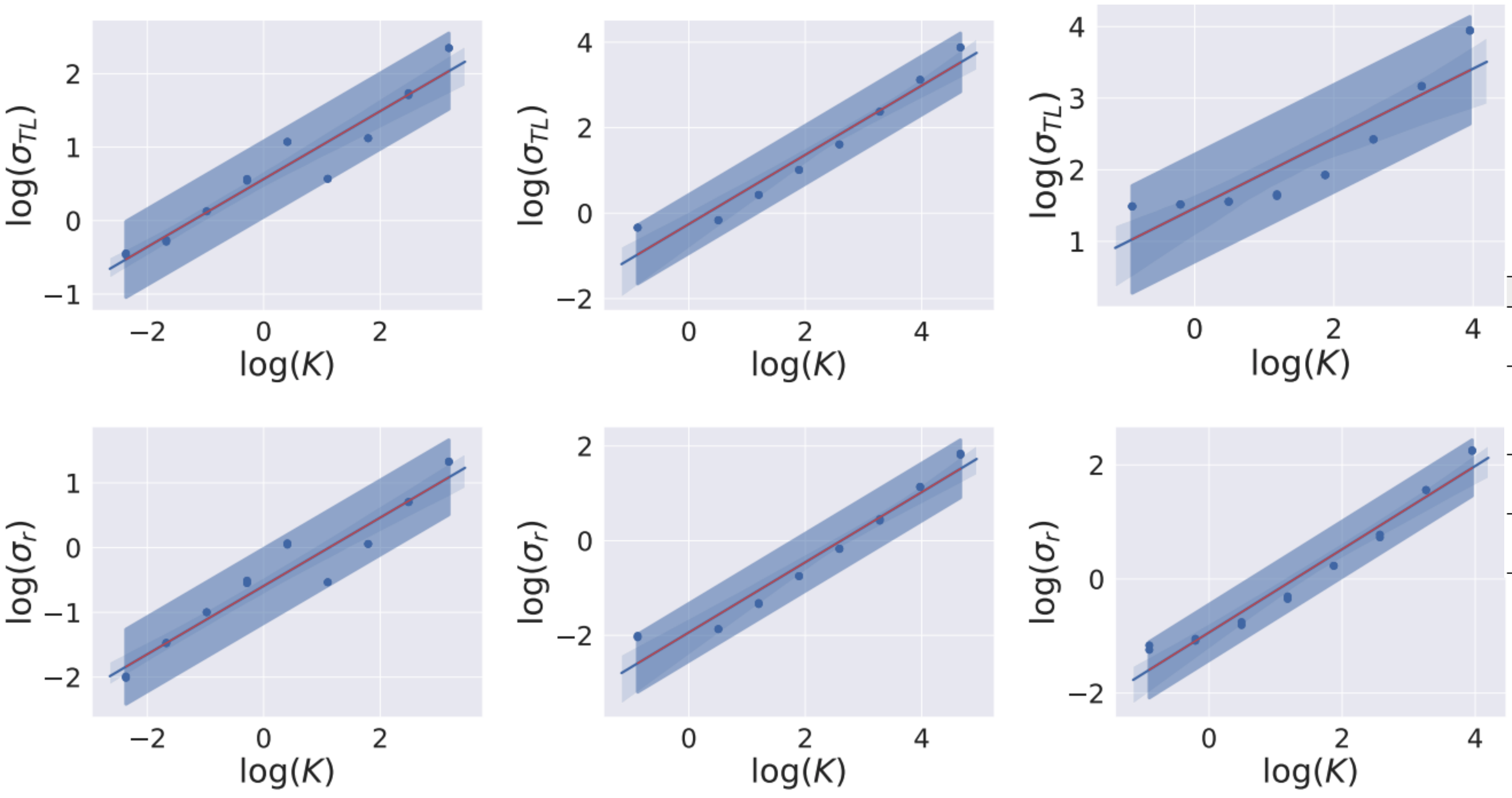


(a) SonyA7S2 (b) NikonD850 (c) CanonEOS70D

λ and σTL for read noise



Modeling Joint Parameter Distributions



(a) SonyA7S2 (b) NikonD850 (c) CanonEOS70D

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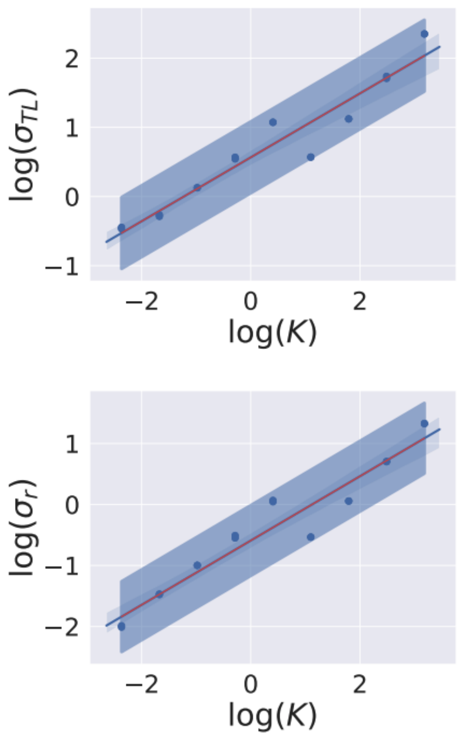
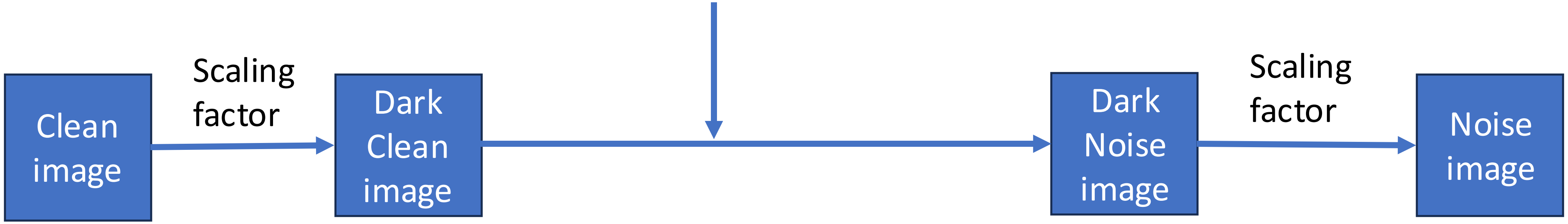
Noisy Image Synthesis



(a) SonyA7S2



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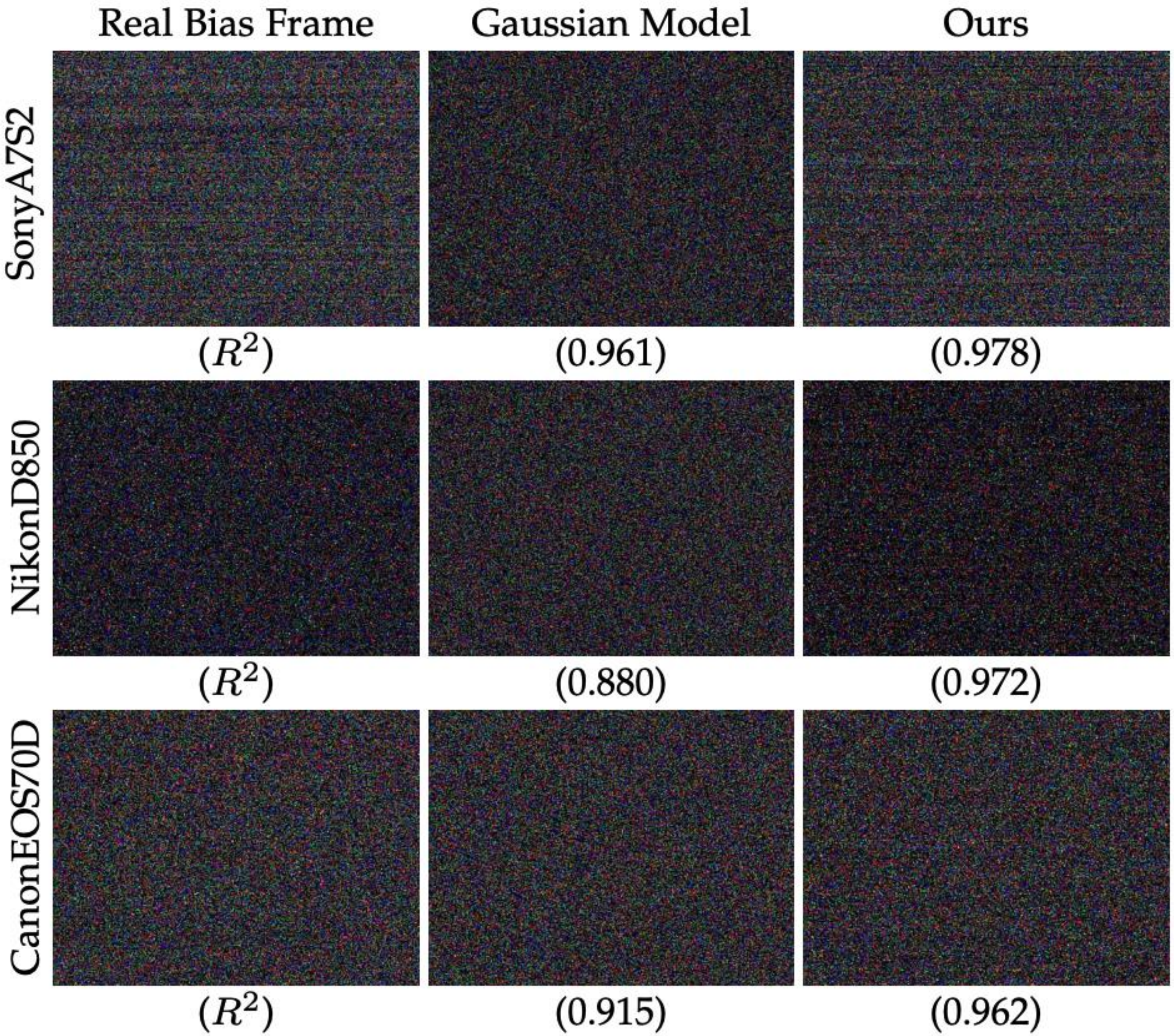
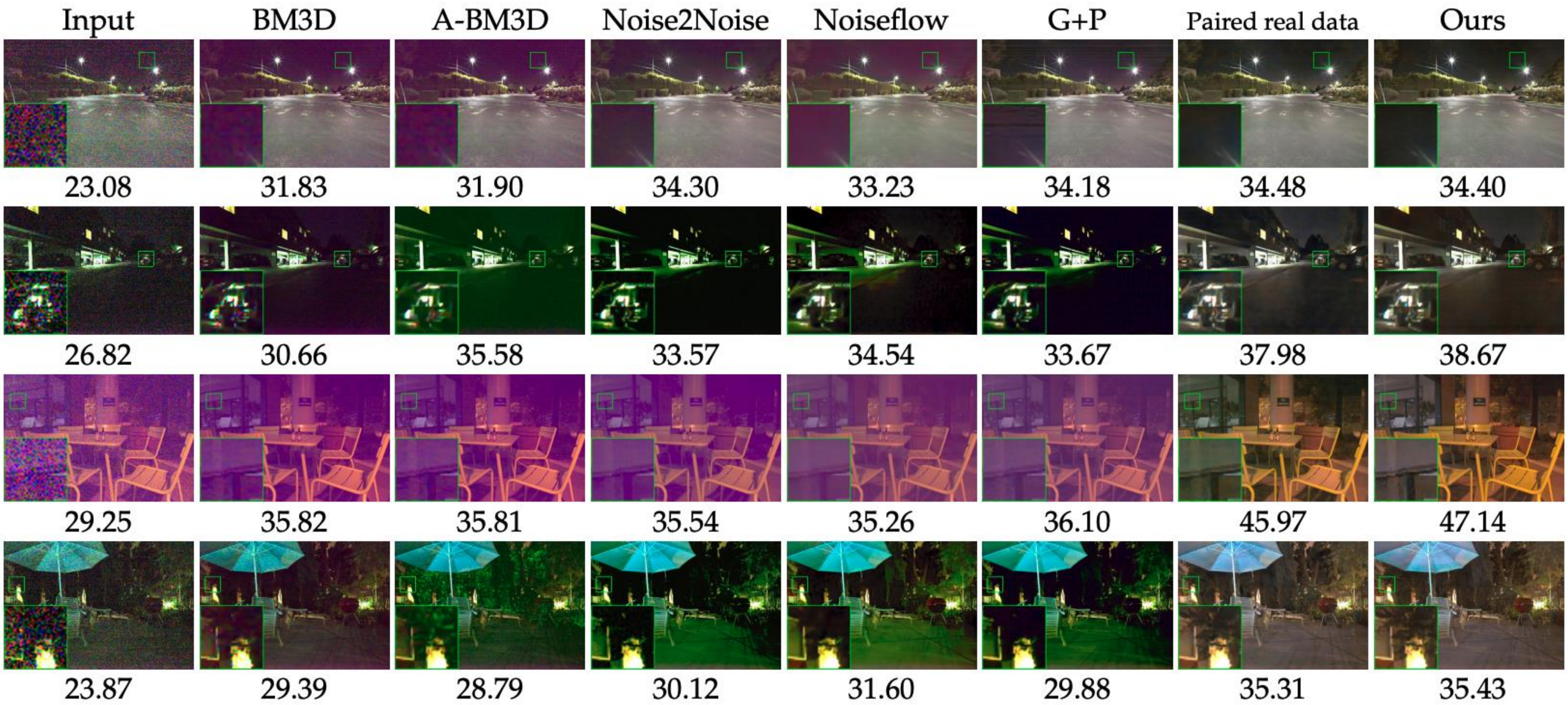
Experiment

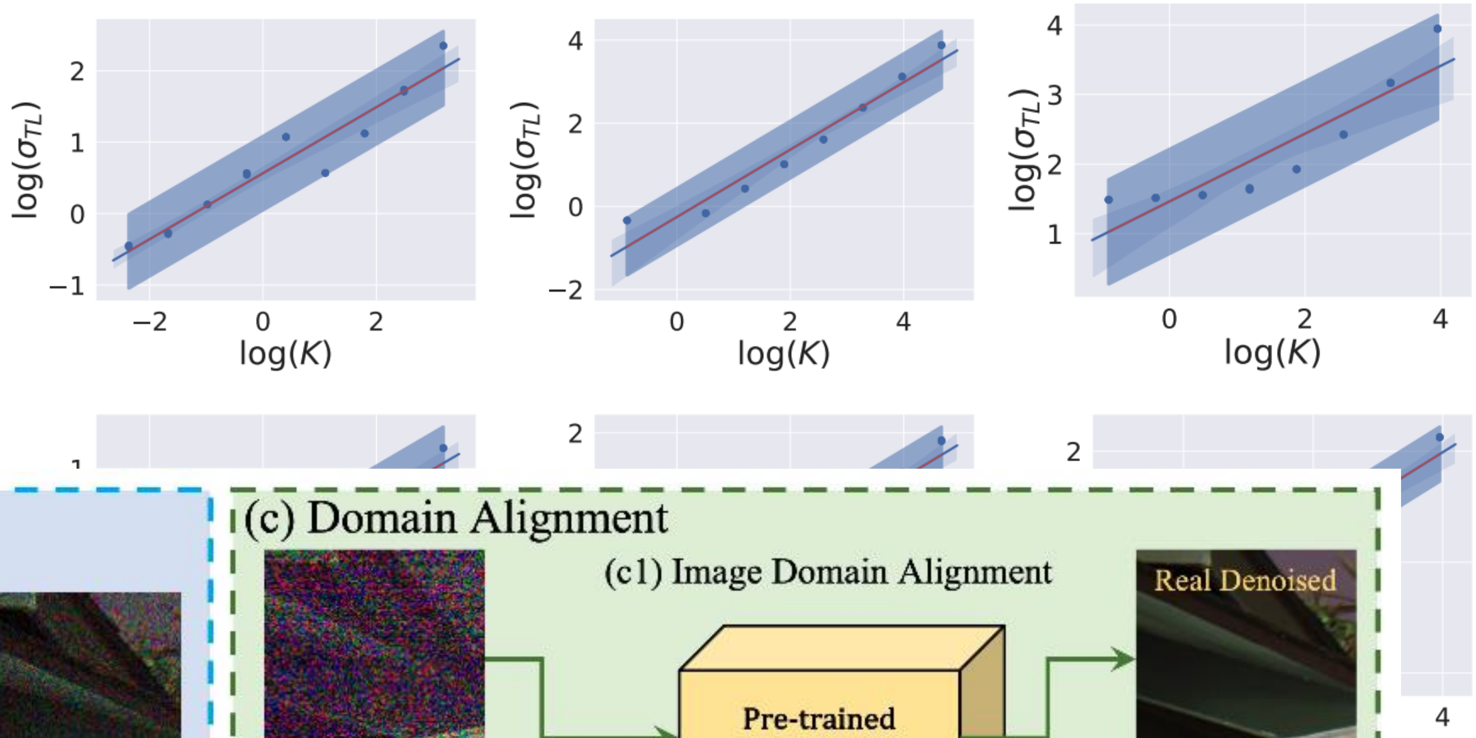


Real Bias Frame
Gaussian Model
Ours
SonyA7S2
(R^2)
(0.961)
(0.978)
NikonD850
(R^2)
(0.880)
(0.972)
CanonEOS70D
(R^2)
(0.915)
(0.962)

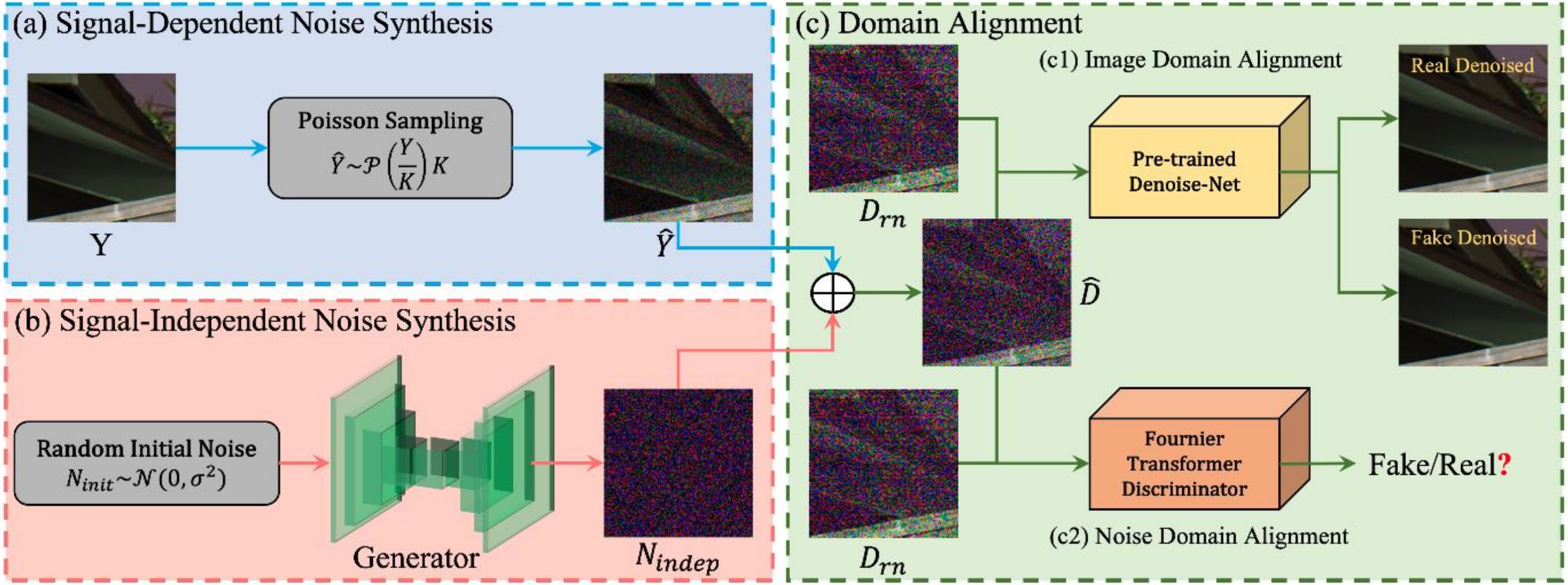
Experiment


Input
BM3D
A-BM3D
Noise2Noise
Noiseflow
G+P
Paired real data
Ours
23.08
31.83
31.90
34.30
33.23
34.18
34.48
34.40
26.82
30.66
35.58
33.57
34.54
33.67
37.98
38.67
29.25
35.82
35.81
35.54
35.26
36.10
45.97
47.14
23.87
29.39
28.79
30.12
31.60
29.88
35.31
35.43

Conclusion



log(σ_TL)
log(K)



(a) Signal-Dependent Noise Synthesis
Poisson Sampling
$\hat{Y} \sim \mathcal{P}\left(\frac{Y}{K}\right) K$
Y
$\hat{Y}$
(b) Signal-Independent Noise Synthesis
Random Initial Noise
$N_{init} \sim \mathcal{N}(0, \sigma^2)$
Generator
N_{indep}
(c) Domain Alignment
(c1) Image Domain Alignment
D_{rn}
Pre-trained Denoise-Net
Real Denoised
Fake Denoised
$\hat{D}$
Fournier Transformer Discriminator
Fake/Real?
D_{rn}
(c2) Noise Domain Alignment