DualDn: Dual-domain Denoising via Differentiable ISP

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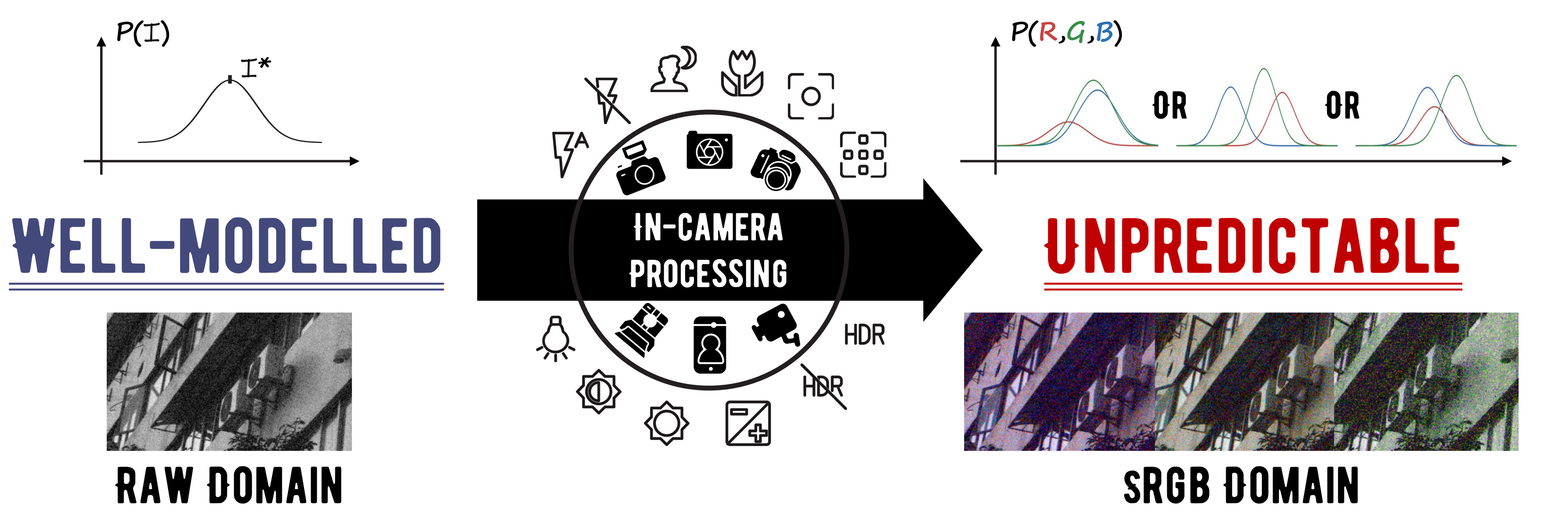
1. Noise Formulation

All digital images contain varying degrees of noise.

- Every pixel (**I**) in the unprocessed digital image within the raw domain typically follows a Poisson-Gaussian distribution†, with (**I***) representing the expected denoised counterpart.
- Due to the camera-specific and user-adjustable nature of the image signal processing (ISP), these variations make noise in (**R,G,B**) values unpredictable within the sRGB domain.



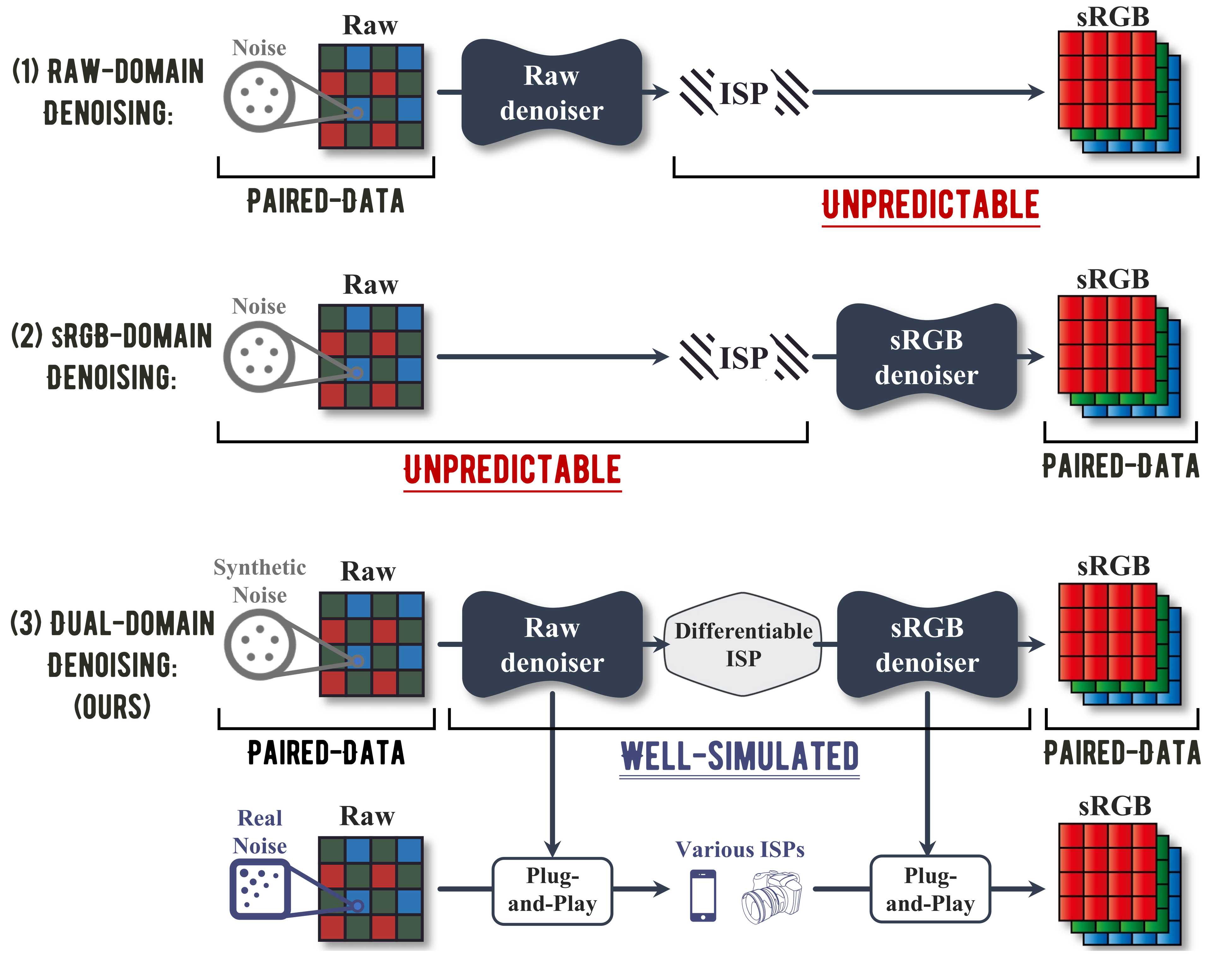
† Noise model in the raw domain can vary under specific conditions, such as low-light, but it is still well-studied.

2. Practical Denoising

▲ **Question:** How to denoising **sRGB** images without an exact noise model?

⇒ Generally, noisy-clean image pairs and a denoising neural network. Specifically, the way to properly prepare training data and apply denoisers.

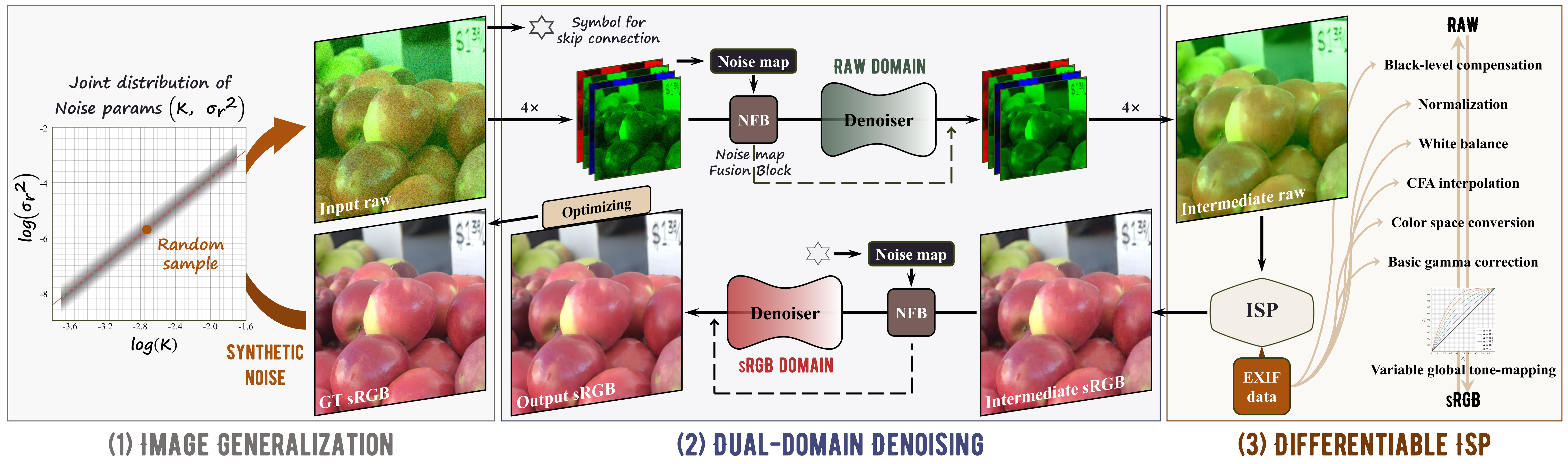
⋆ **Solutions:**



⇒ Only (3) can **well-simulate** noise formation pipeline **without unpredictable** variables.

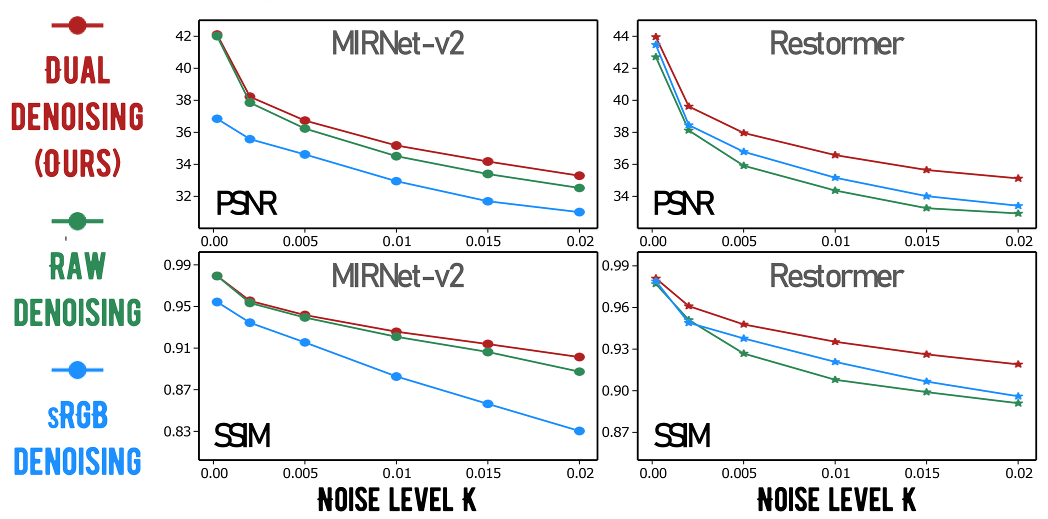
3. Our Pipeline

DualDn consists of 3 key components. (1) Image generalization with various noise, (2) Dual-domain denoising with noise map fusion, (3) Differentiable ISP with corresponding EXIF data and variable ISP parameters.



4. Quantitative and Qualitative Experiments

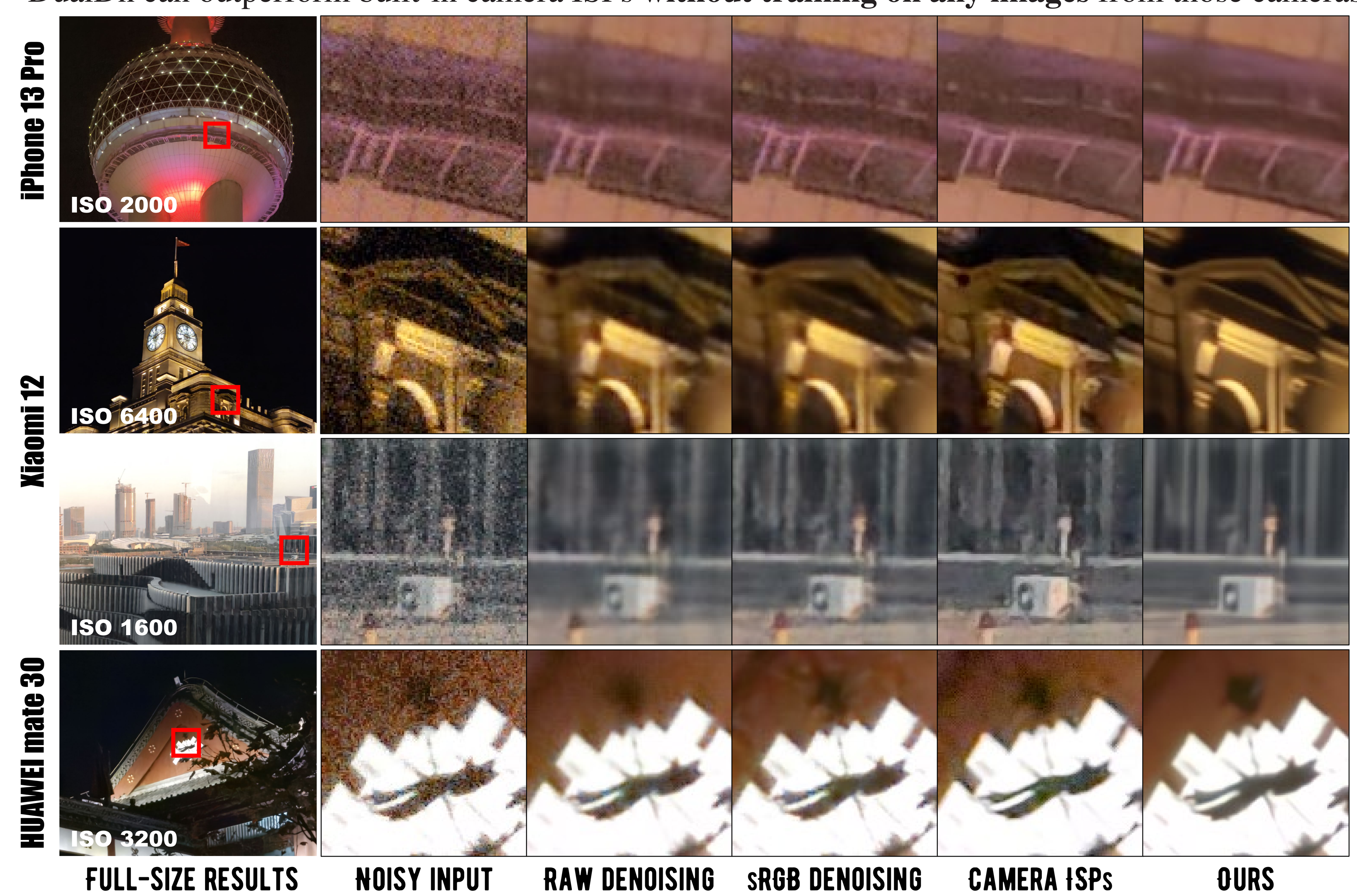
Denoising Performance on various [noise level K] and [ISP amplification ratio α].



Backbone	Amplification ratio:	$\alpha = 0.2$ PSNR↑	SSIM↑	LPIPS↓	$\alpha = 0.5$ PSNR↑	SSIM↑	LPIPS↓	$\alpha = 0.8$ PSNR↑	SSIM↑	LPIPS↓	Params (G)	Runtime (ms)
SwinIR	Raw denoising	26.96	0.595	0.62	25.84	0.576	0.62	24.82	0.584	0.60	11.50	45
	sRGB denoising	26.32	0.513	0.65	25.41	0.519	0.63	23.95	0.500	0.64	11.50	212
	Dual denoising (Ours)	**28.95**	**0.709**	**0.50**	**27.89**	**0.694**	**0.50**	**26.53**	**0.664**	**0.50**	11.79	121
MIRNet-v2	Raw denoising	31.47	0.865	**0.26**	30.03	0.838	**0.27**	28.80	0.817	**0.27**	37.48	47
	sRGB denoising	30.20	0.806	0.48	28.88	0.777	0.49	27.60	0.754	0.48	37.48	55
	Dual denoising (Ours)	**32.35**	**0.883**	**0.26**	**31.05**	**0.862**	**0.27**	**29.93**	**0.845**	0.28	38.97	54
Restormer	Raw denoising	32.08	0.873	0.23	30.65	0.850	0.24	29.44	0.831	0.25	46.23	65
	sRGB denoising	33.01	0.889	**0.20**	31.84	0.870	**0.20**	30.59	0.845	**0.20**	46.23	90
	Dual denoising (Ours)	**33.98**	**0.906**	0.22	**32.64**	**0.888**	0.23	**31.48**	**0.872**	0.23	53.05	71

Generalization ability under [unseen ISPs] and [in-the-wild scenes].

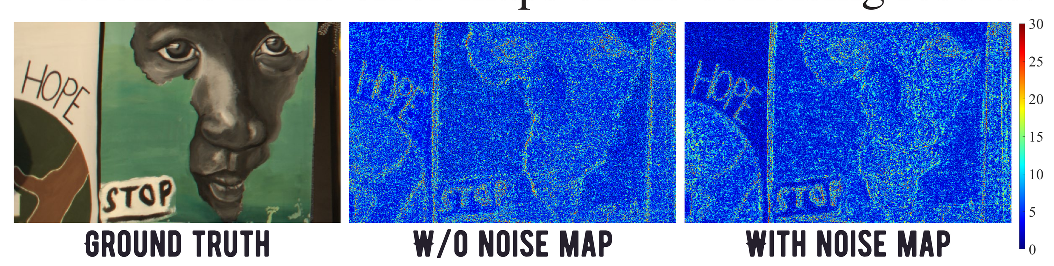
- DualDn can outperform built-in camera ISPs **without training on any images** from those cameras.



Ablation study of individual modules.

- **Raw and sRGB denoiser have distinct functions**, handling noise and ISP variations separately.

- **Noise map mechanism in DualDn** reduces the differences in the error maps of the denoising results.



- **Quantitative contributions** of different modules.

Skip connection	Raw noise map	sRGB noise map	Supervision	PSNR	SSIM
	✓	✓	$\lambda = 1$	34.54	0.914
✓			$\lambda = 1$	34.79	0.917
✓		✓	$\lambda = 1$	34.84	0.918
✓	✓		$\lambda = 1$	34.88	0.918
✓	✓	✓	$\lambda = 0$	34.74	0.916
✓	✓	✓	$\lambda = 1$	**34.92**	**0.919**