Signal-to-noise properties of correlation plenoptic imaging with chaotic light

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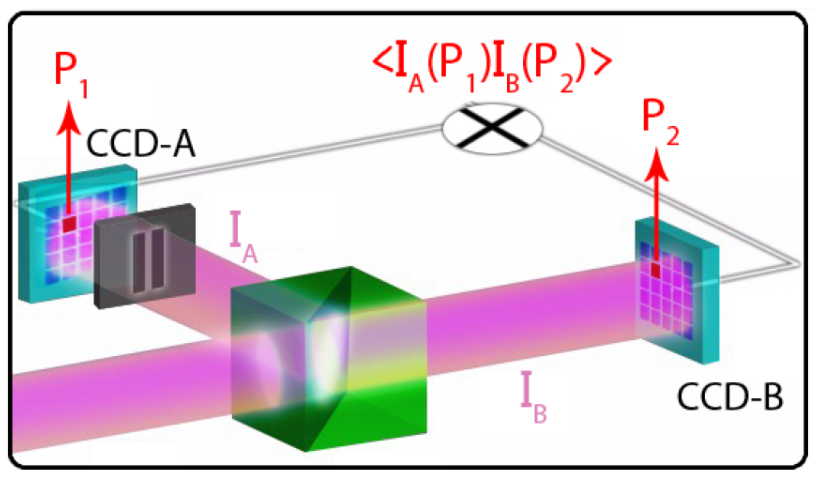
Abstract

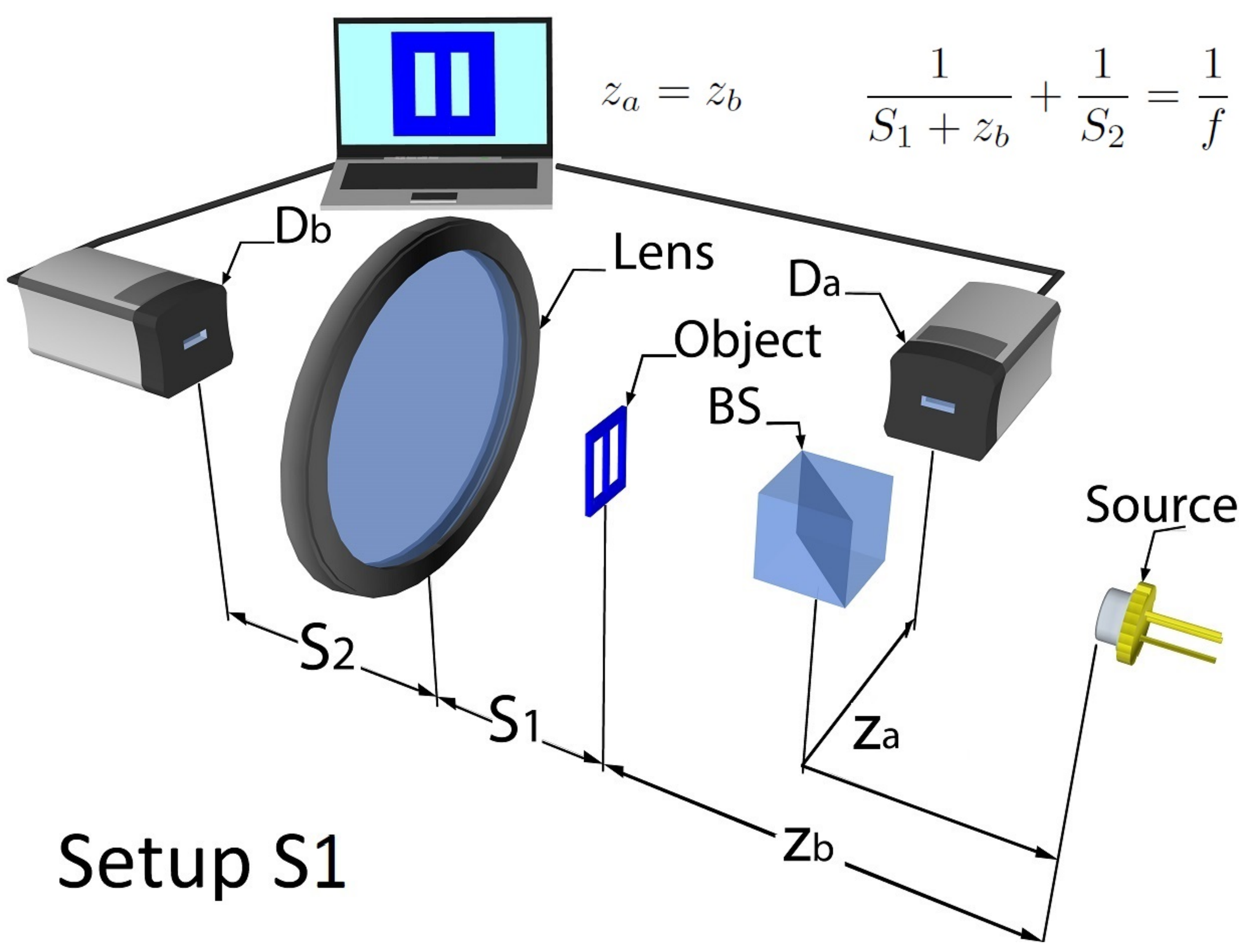
Correlation Plenoptic Imaging (CPI) is a novel imaging technique, that exploits the correlations between the intensity fluctuations of light to perform the typical tasks of plenoptic imaging, namely refocusing out-of-focus parts of the scene, extending the depth of field, and performing 3D reconstruction. We characterize the signal-to-noise ratio, of two setups in which CPI hinges upon the intensity correlations of chaotic light.

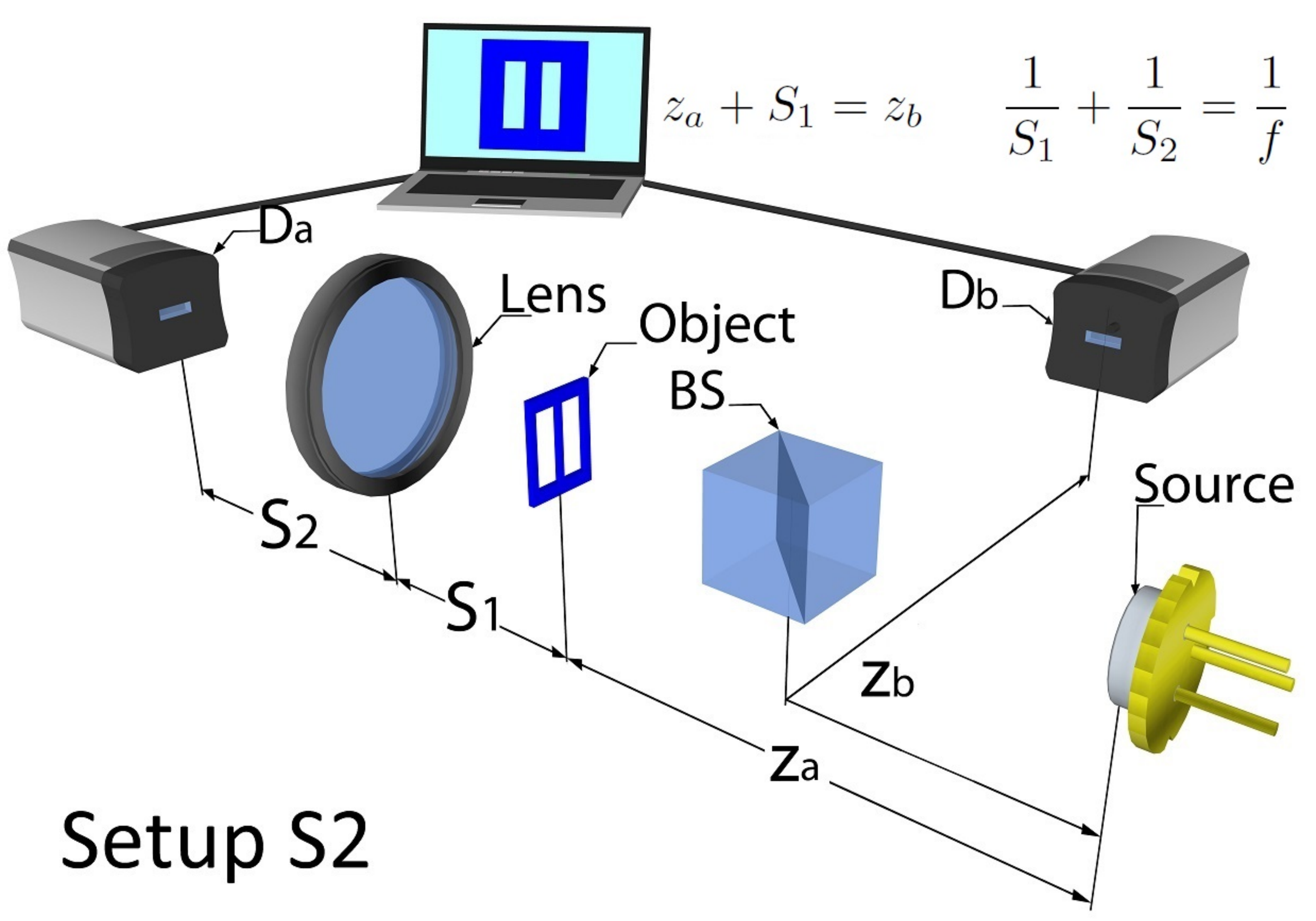
Keyword and target

- Second-order imaging;
- Plenoptic
- Depth of field vs Resolution;
- **signal-to-noise ratio control**



Comparison between two setups





Correlation Plenoptic Imaging (CPI)

Correlation function

The intensity patterns $I_A(\boldsymbol{\rho}_a)$ and $I_B(\boldsymbol{\rho}_b)$ are recorded for the correlation function

$$\Gamma_{AB}(\boldsymbol{\rho}_a,\boldsymbol{\rho}_b)=\langle \Delta I_A(\boldsymbol{\rho}_a)\Delta I_B(\boldsymbol{\rho}_b)\rangle\,, \tag{1}$$

CPI encodes the images of two distinct planes in order to capture directional information.

Signal and Fluctuation function

The signal and its noise come from the collection of images from (1) integrating over D_b,

$$\Sigma_{\mathrm{ref}}(\boldsymbol{\rho}_a)=\left\langle \mathcal{S}_{(\alpha,\beta)}(\boldsymbol{\rho}_a)\right\rangle, \quad \mathcal{F}(\boldsymbol{\rho}_a)=\left\langle \mathcal{S}_{(\alpha,\beta)}(\boldsymbol{\rho}_a)^2\right\rangle-\left\langle \mathcal{S}_{(\alpha,\beta)}(\boldsymbol{\rho}_a)\right\rangle^2 \tag{2}$$

with

$$\mathcal{S}_{(\alpha,\beta)}(\boldsymbol{\rho}_a)=\int \mathrm{d}^2\boldsymbol{\rho}_b \Delta I_A(\alpha\boldsymbol{\rho}_a+\beta\boldsymbol{\rho}_b)\Delta I_B(\boldsymbol{\rho}_b). \tag{3}$$

The parameters (α,β) approach to $(1,0)$ at focus.

Signal-to-noise ratio

Fluctuations function

The signal-to-noise ratio is

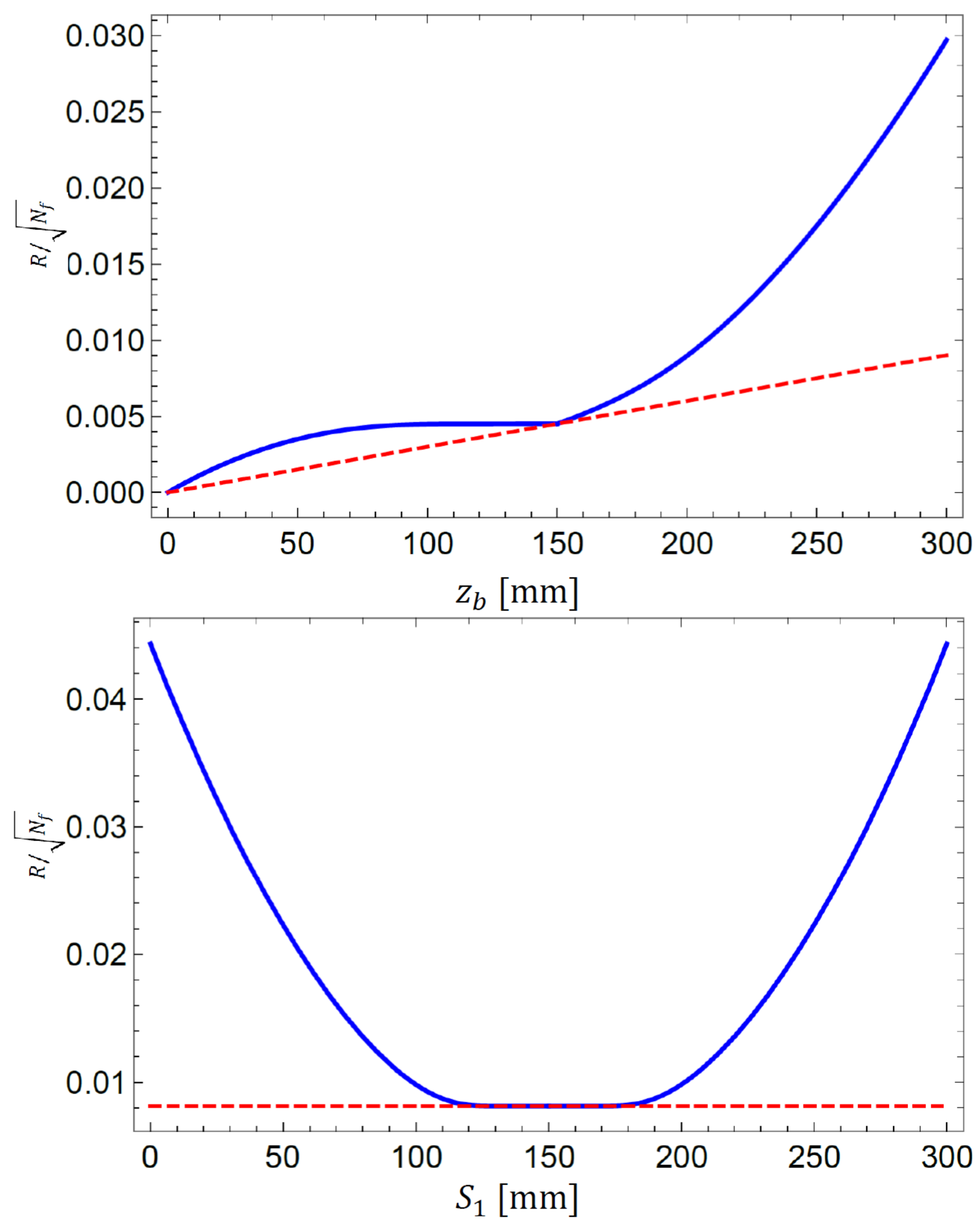
$$R(\boldsymbol{\rho}_a)=\sqrt{N_f}\frac{\Sigma_{\mathrm{ref}}(\boldsymbol{\rho}_a)}{\sqrt{\mathcal{F}(\boldsymbol{\rho}_a)}}. \tag{4}$$

For SETUP1

$$R^{(g)}(\boldsymbol{\rho}_a)\simeq\sqrt{\frac{N_f}{2}}\lambda z_b\left|1-\frac{z_b}{z_a}\right|\frac{|A(\boldsymbol{\rho}_a)|^2}{\int \mathrm{d}^2\boldsymbol{\rho}|A(\boldsymbol{\rho})|^2}, \tag{5}$$

For SETUP2

$$\frac{R^{(g)}(\boldsymbol{\rho}_a)}{\sqrt{N_f}}\sim\left(\frac{S_2/S_1}{1-S_2/S_2^f}\right)^2\sqrt{\frac{\sigma_B^2}{A_{\mathrm{lens}}}\frac{A_{\mathrm{lens}}}{A_{\mathrm{obj}}}}\left|A\left(-\frac{\boldsymbol{\rho}_a}{\mu}\right)\right|^2, \tag{6}$$



SNR for the refocused image (2) (solid blue line), and for a ghost image (red dashed line) for SETUP1 (up) and SETUP2 (down) taken at $z_a = z_b$ (for S1) and at $S_2^f = (1/f - 1/S_1)^{-1}$ (for S2) as a function respectively of z_b and S_1.

Conclusion

SETUP1 **results more advantageous than** SETUP2**:** e.g. at $z_b = S_1 = 80\,\mathrm{mm}$ one tenth of the frames is needed in SETUP2 to reach the same SNR as in SETUP1.

References

[1] G. Scala, M. D'Angelo, A. Garuccio, S. Pascazio, and F. V. Pepe, Phys. Rev. A 99, 053808 – (2019)