- DIGITAL IMAGE RECONSTRUCTION: Deblurring and Denoising (Puetter et al. ARA&A, 2005)

Self2Self With Dropout: Learning Self-Supervised Denoising From Single Image

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2.1. Blur

The image formed in the focal plane is blurred by the imaging instrument and the atmosphere. It can be expressed as an integral over the true image, denoted symbolically by $\otimes$:

$$M(\mathbf{x}) = P \otimes I = \int P(\mathbf{x}, \mathbf{y})I(\mathbf{y})\,d\mathbf{y}. \qquad (1)$$

PSF (y) 和图像 (x) 独立

$$M(\mathbf{x}) = P * I = \int P(\mathbf{x} - \mathbf{y})I(\mathbf{y})\,d\mathbf{y}.$$

傅立叶变换：频域

Convolutions have the added benefit that they translate into simple algebraic products in the Fourier space of wave vectors $\mathbf{k}$ (e.g., Press et al. 2002):

$$\tilde{M}(\mathbf{k}) = \tilde{P}(\mathbf{k})\tilde{I}(\mathbf{k}). \qquad (3)$$

图像采样：离散化

2.7. Noise

A major additional factor limiting image reconstruction is noise due to measurement errors. The measured data actually consist of the expected data M_i plus measurement errors:

$$D_i = M_i + N_i = (H \otimes I)_i + N_i = \int H(\mathbf{x}_i, \mathbf{y}) I(\mathbf{y}) \, d\mathbf{y} + N_i. \qquad (10)$$

噪声来源：光子涨落，探测器读出噪声，天光背景

噪声：空间上各点独立，近似为高斯分布，最大熵，无信息量，不可预测

- 天文图像的噪声通常是已知的！PSF也是已知的
- 但是退卷积还是困难的
- ill-posed problem

传统的图像退卷积方法

$$\tilde{I}(\mathbf{k}) = \Phi(\mathbf{k})\frac{\tilde{D}(\mathbf{k})}{\tilde{H}(\mathbf{k})}. \tag{13}$$

- 频域空间滤波 （抑制噪声）

  It can be shown (e.g., Press et al. 2002) that the optimal filter, which minimizes the difference (in the least squares sense) between the filtered noisy data and the true signal, is the Wiener filter, expressed in Fourier space as

  $$\Phi(\mathbf{k}) = \frac{\langle|\tilde{D}_0(\mathbf{k})|^2\rangle}{\langle|\tilde{D}_0(\mathbf{k})|^2\rangle + \langle|\tilde{N}(\mathbf{k})|^2\rangle} = \frac{\langle|\tilde{D}_0(\mathbf{k})|^2\rangle}{\langle|\tilde{D}(\mathbf{k})|^2\rangle}. \tag{14}$$

  - Wiener滤波

- 图像域的迭代过程
  - Up-sampling and PSF Deconvolution Coaddition （Wang et al. 2022,2025）
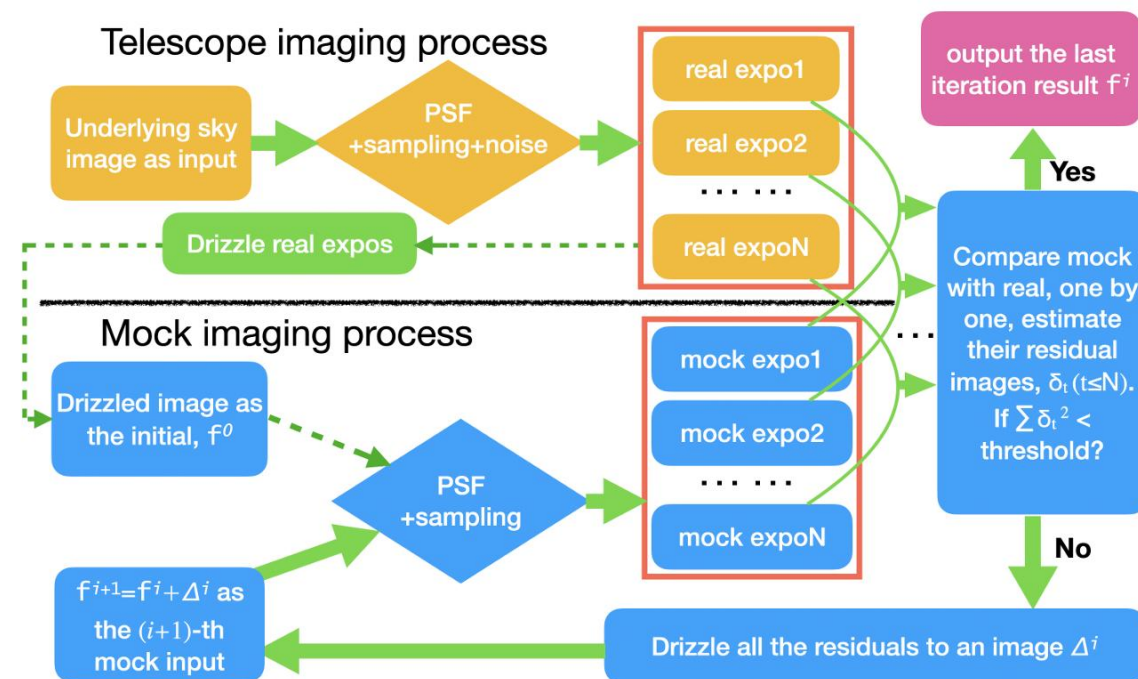
AI (万能的拟合函数)

- 能否直接猜出来真实图像信息？
  - 原则上可以，实际（技术）上有挑战
  - ill-posed problem，可以用先验概率来克服

- CV领域：去噪和退卷积似乎是两个独立的问题
  - 通常不知道噪声和PSF的具体模型

Self2Self: 一幅图直接去噪

- 原理

  - 图像进行随机Mask，由图像其余部分预言Mask区域
    - 图像信息是相关，冗余的

  - 噪声是不可预测（独立）的，预言的Mask区域的值是期望值（去噪）

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