

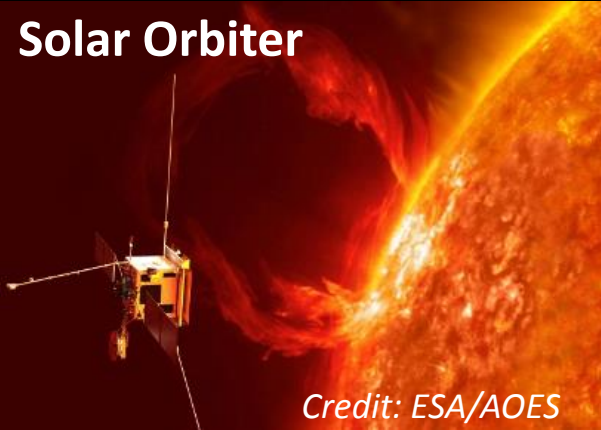
SUVITと地上(大型)望遠鏡

協調 or 競合?

京大理附属天文台 一本 潔

Coordinated Observations

Solar Orbiter



Credit: ESA/AOES

Solar Probe Plus

A NASA Mission to Touch the Sun



Credit: NASA/JHU APL

Solar Dynamic Observatory
or a mission of full-disk
observations



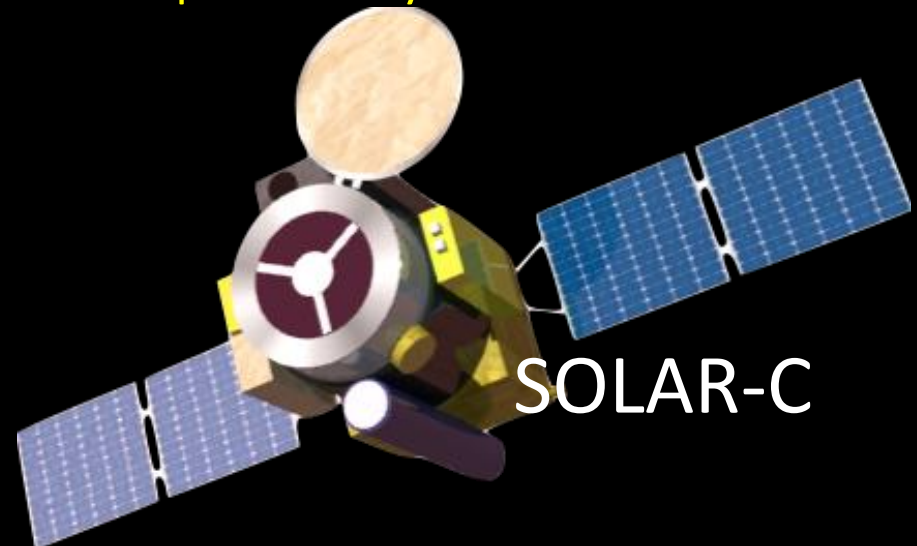
(Daniel K. Inouye Solar Telescope)
DKIST



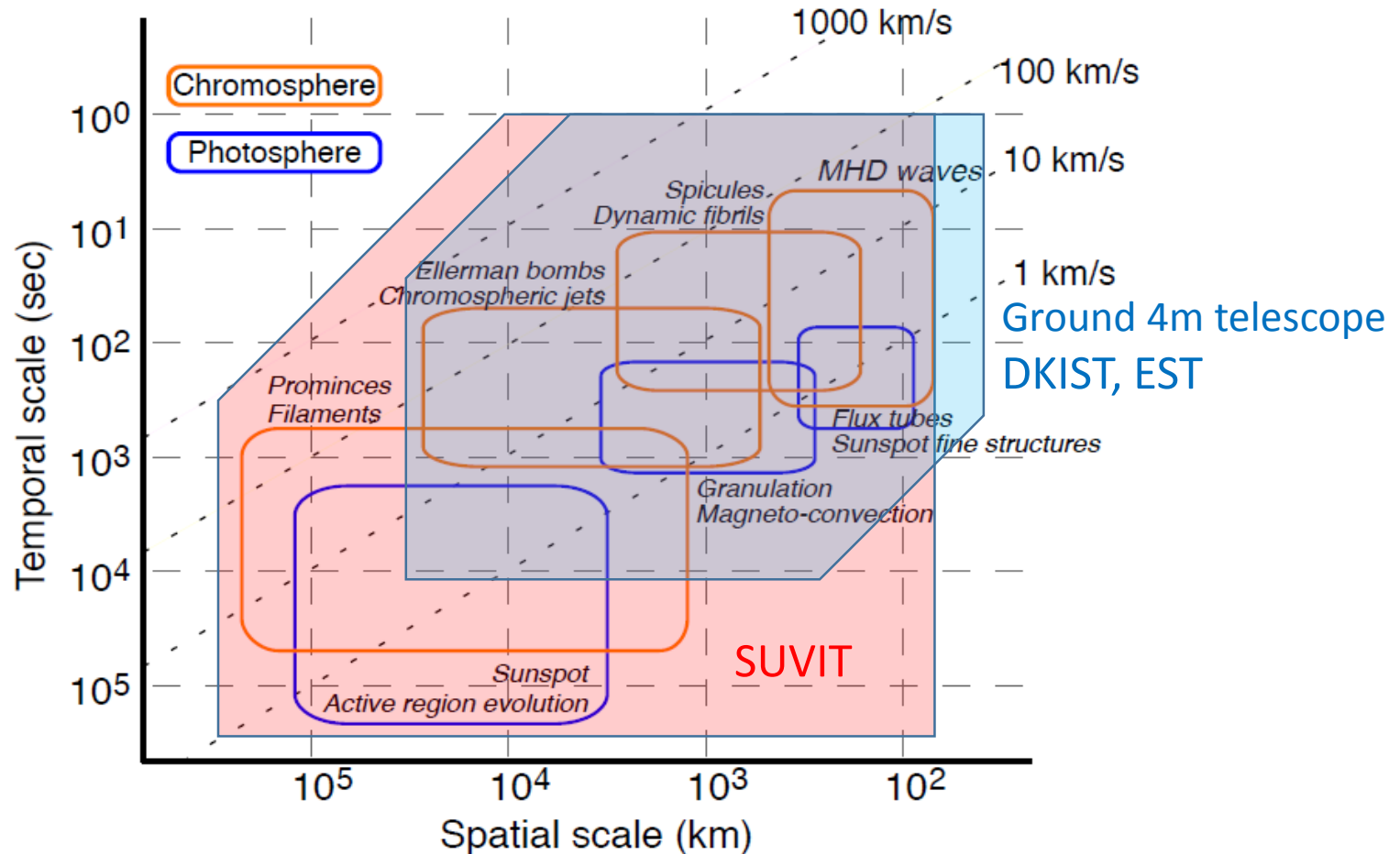
(European Solar Telescope)
EST



Solar-C is unique and highly
complementary to other missions



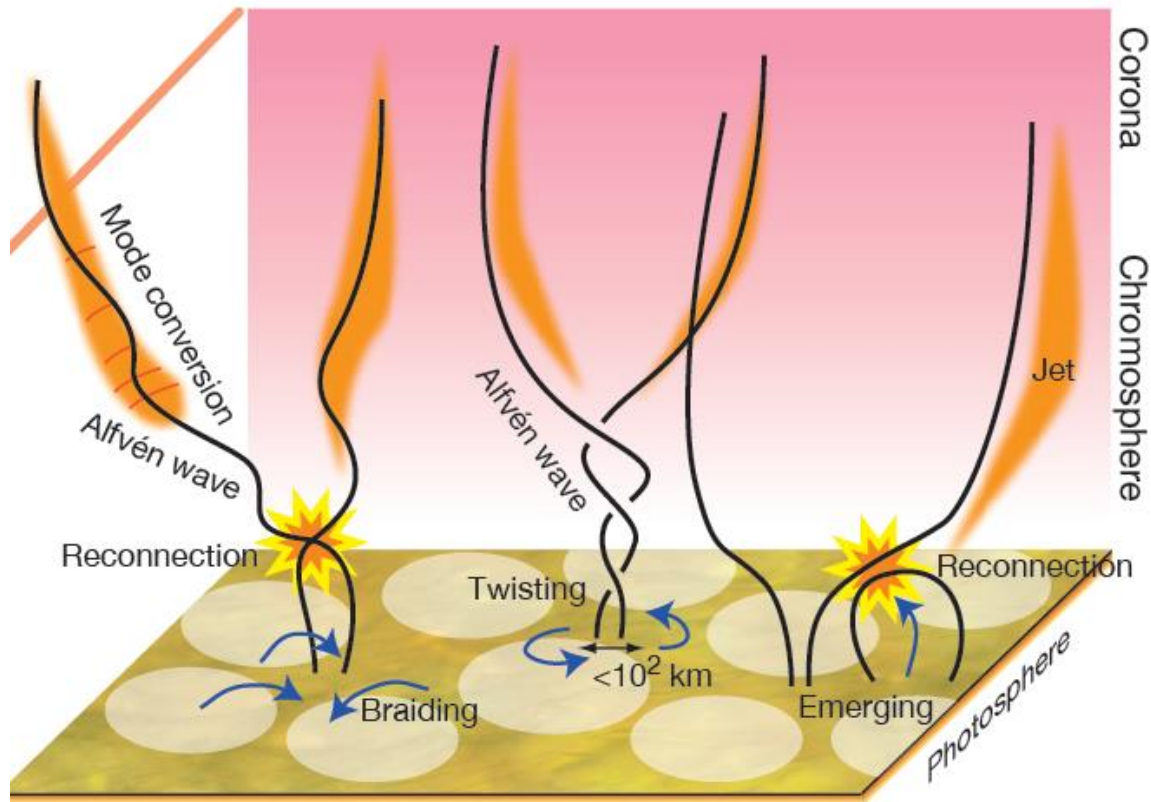
Time scale vs. Spatial scale of observation targets



Large aperture ground-based telescopes will meet the study of elementary process on the sun (small & short-timescale) in term of spatial resolution and time span.

Question:

- スピキュールの生成機構を説明するのは地上かSolar-Cか?



太陽磁場観測への要求

高空間(時間)分解能と高精度の同時達成

SUVITの目標 → $0.1'' + 3 \times 10^{-4}$

2020年代の達成空間分解能 @500nm;

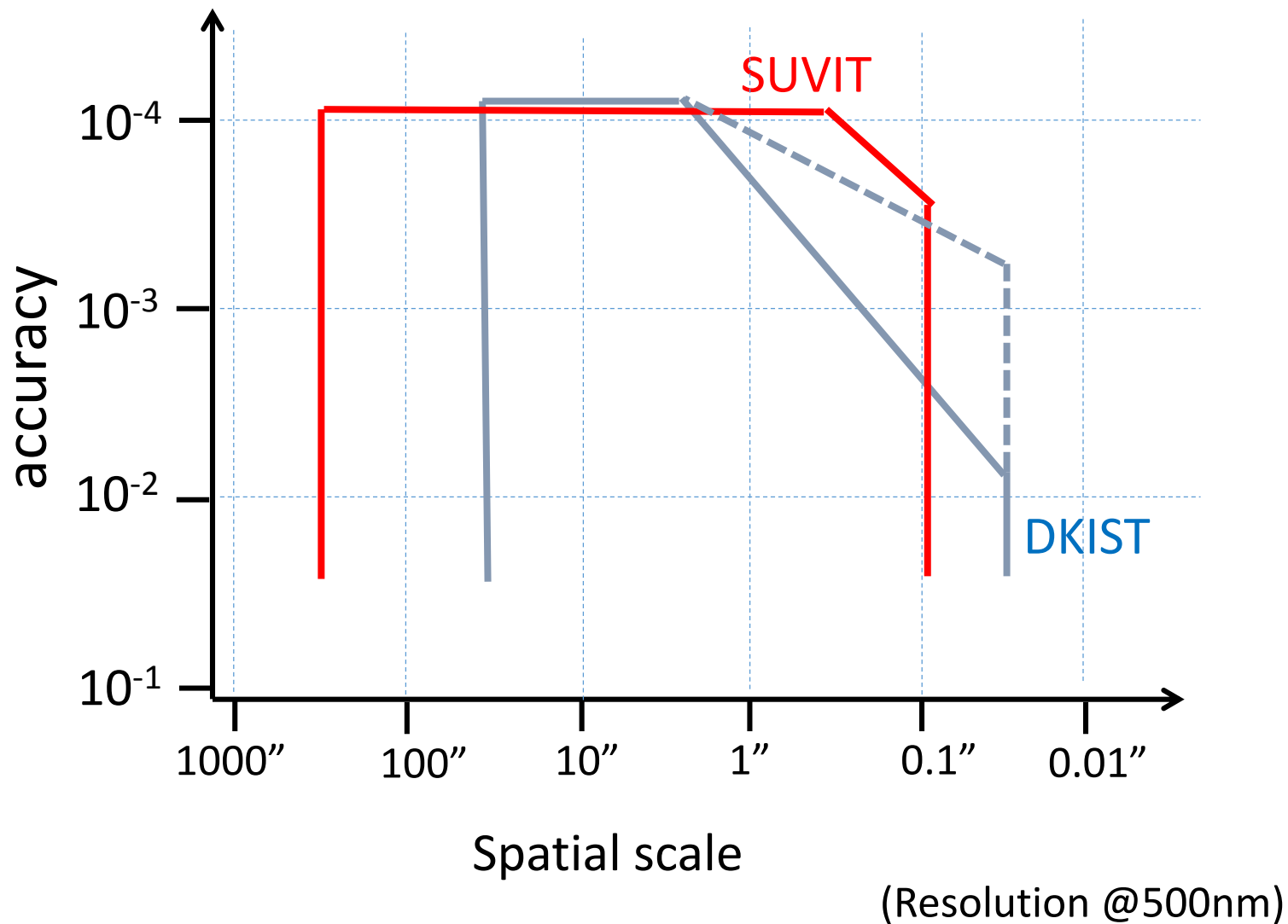
地上大型望遠鏡 $D = 0.5 - 4\text{m}$ $0.2 \sim 0.026''$

Solar-C SUVIT $D = \sim 1.4\text{m}$ $\sim 0.08''$

空間分解能(Δx)と測光精度(δI)の積 $\delta I \propto \Delta x^2$

→ 要素エネルギー(熱、運動、磁場)の検出限界

地上観測とスペースで達成できる検出限界の極限とは?



シーイングのシミュレーション

‘Kolmogorov phase screen’

Power spectral density of wavefront error, Φ ,

$$\Phi(\kappa) = 0.023 r_0^{-5/3} \kappa^{-11/3} \quad [\text{rad}^2 / (\text{d}\kappa)^2, \text{ex. cm}^2]$$

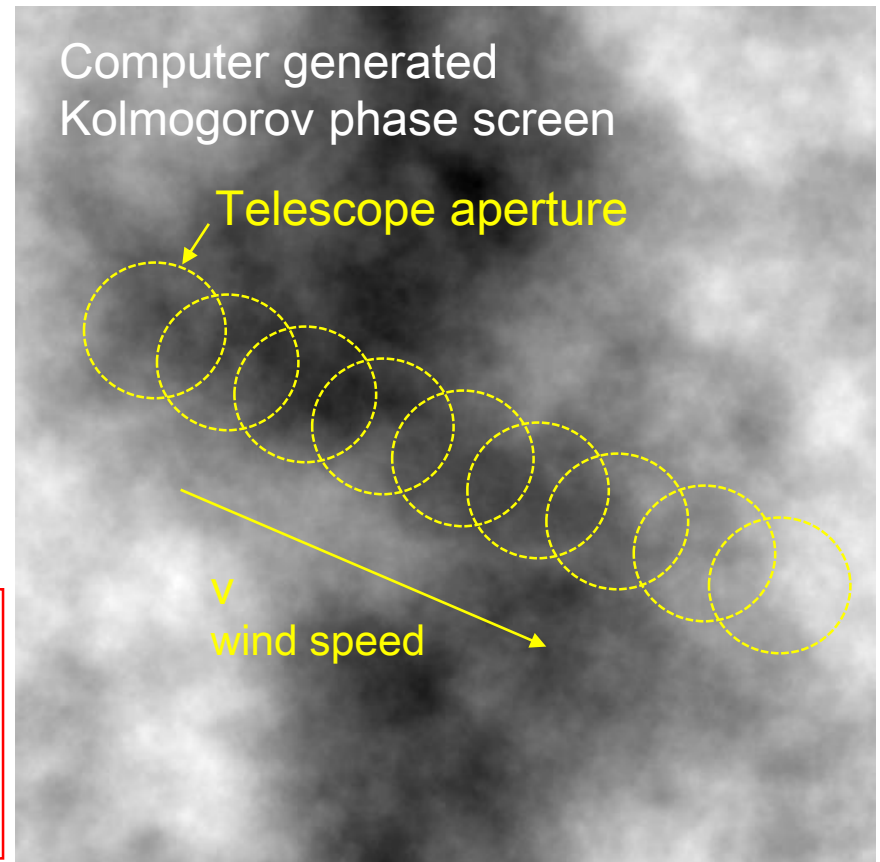
where r_0 : Fried param. [cm]
 κ : spatial freq., [cm⁻¹]

時々刻々変化する波面誤差は風速 v で流れるphase screenを望遠鏡開口で切り取って得られる(テイラーの凍結)

シーイングを特徴付けるパラメータ
 r_0 and v .

$$r_0 \propto \lambda^{6/5}$$

$$\sigma_{\text{tiltcomp}}^2 = 0.134 (D / r_0)^{5/3}$$

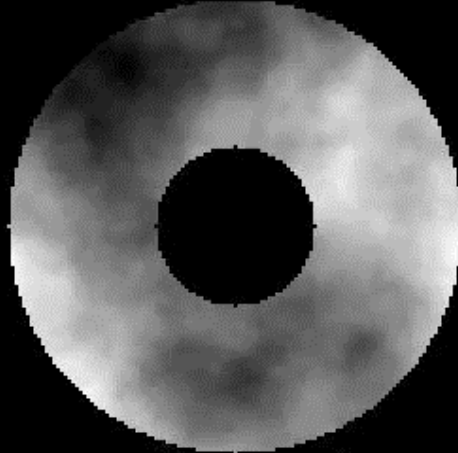


Seeing simulation ($D=60\text{cm}$, $v=10\text{m/s}$)

example

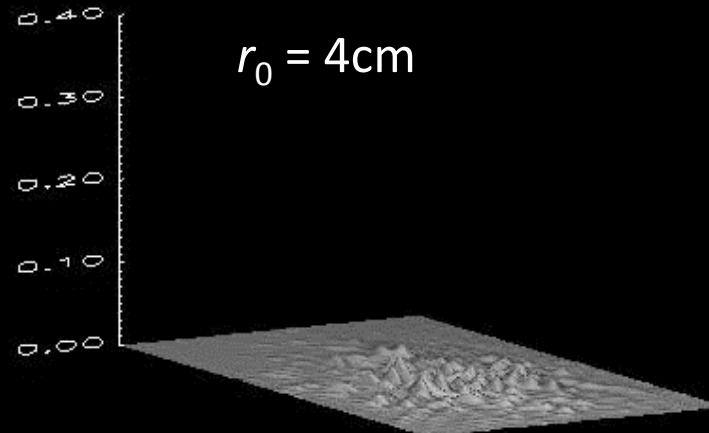
original: Hinode G-band

$r_0 = 4.0\text{cm}$, $D = 60\text{cm}$, $V_w = 10\text{m/s}$, $t = 0000\text{ms}$
wavefront error



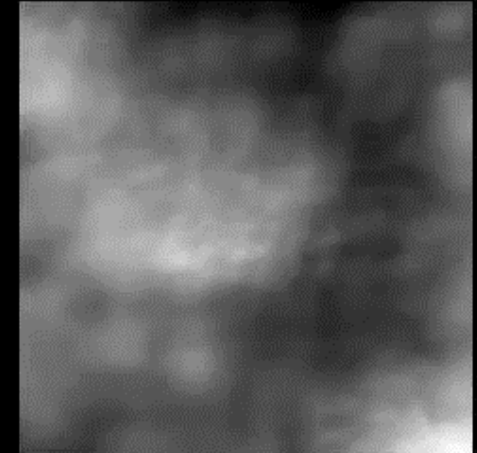
0.78λ rms (tilt removed)

Point spread func.

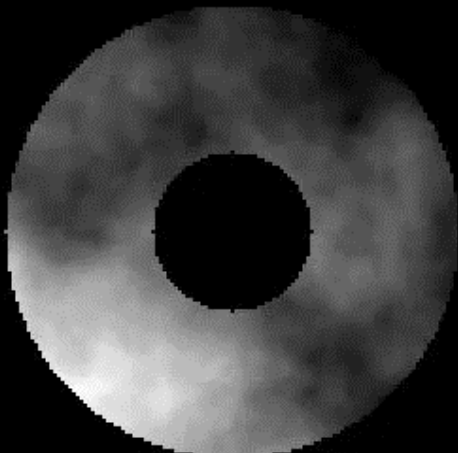


$r_0 = 4\text{cm}$

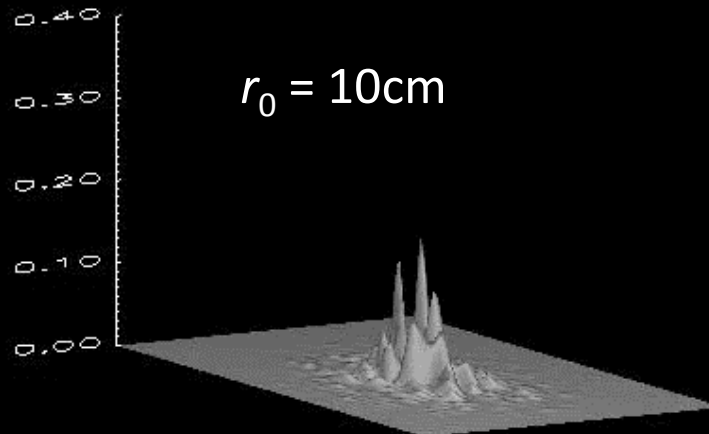
Degraded image



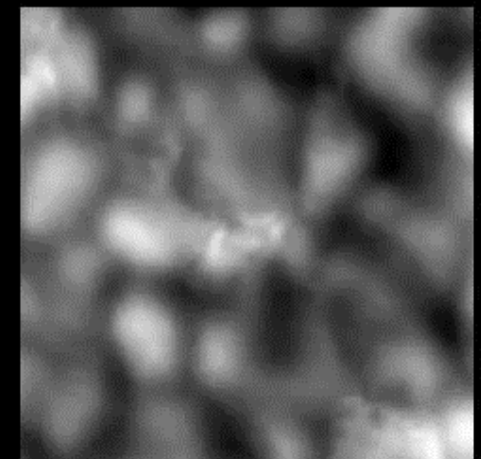
$r_0 = 10.0\text{cm}$, $D = 60\text{cm}$, $V_w = 10\text{m/s}$, $t = 0000\text{ms}$



0.28λ rms (tilt removed)



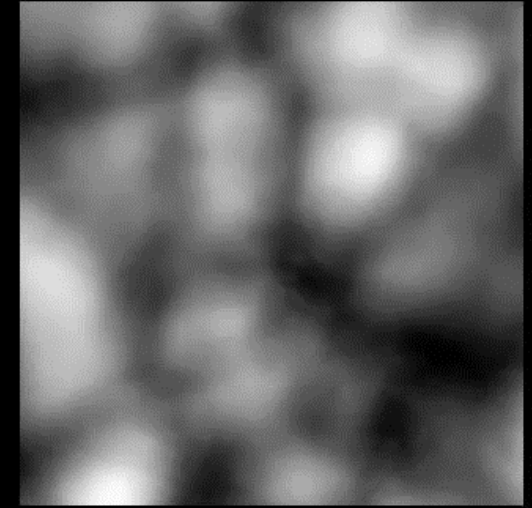
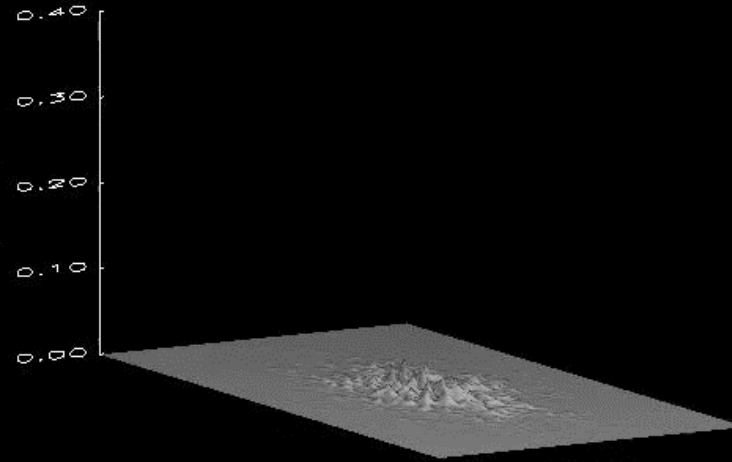
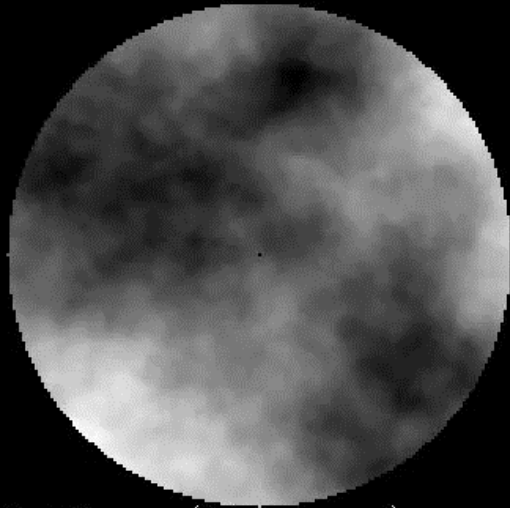
$r_0 = 10\text{cm}$



Seeing simulation

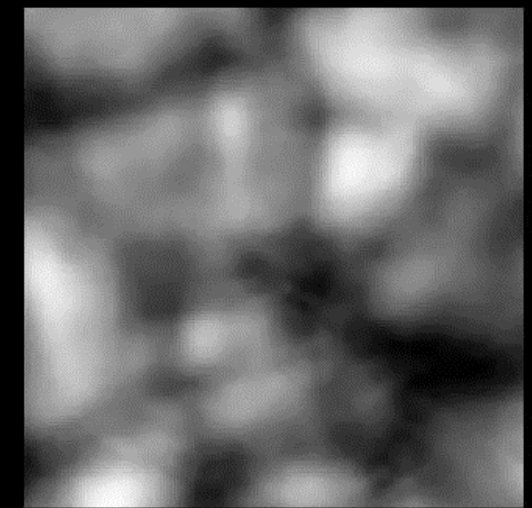
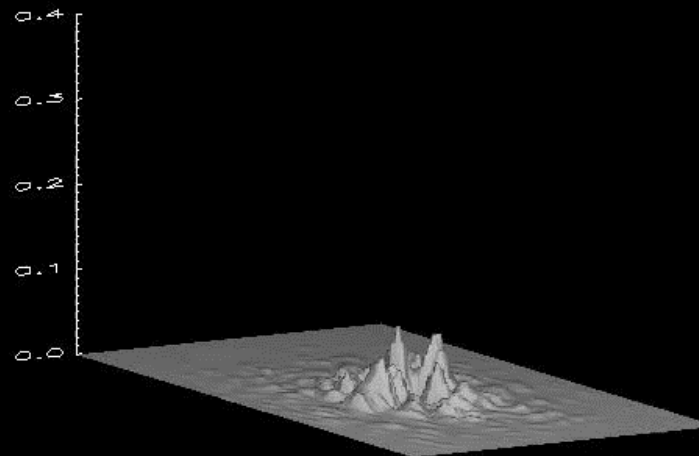
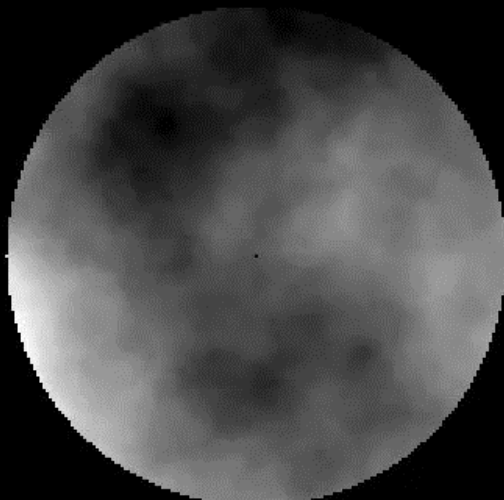
original: Rempel MHD

$r_0=10.0\text{cm}$, $D=160\text{cm}$, $V_w=10\text{m/s}$, $\lambda=500\text{nm}$, $t=0000\text{ms}$



0.67λ rms (tilt removed)

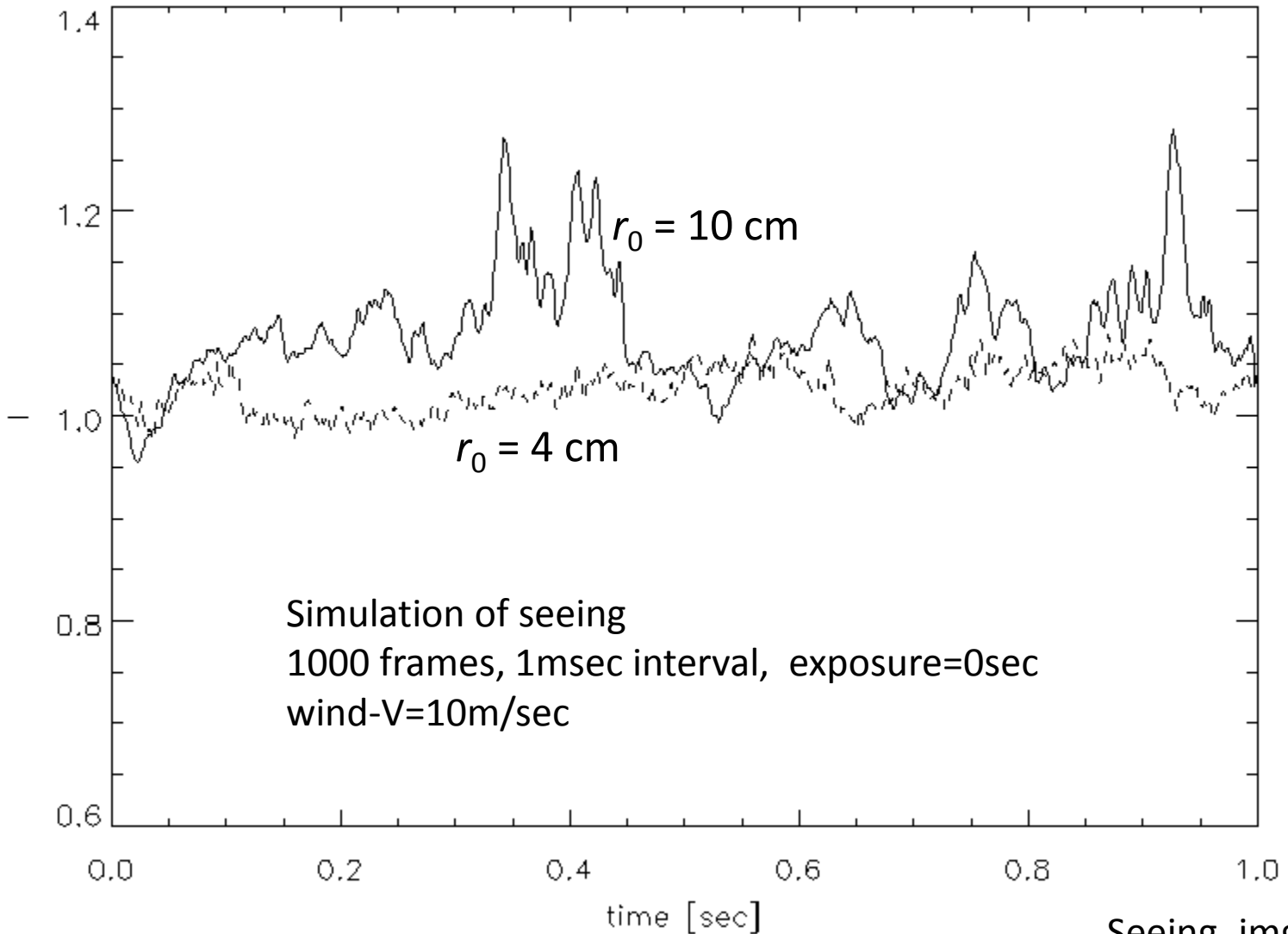
$r_0=25.0\text{cm}$, $D=160\text{cm}$, $V_w=10\text{m/s}$, $\lambda=1083\text{nm}$, $t=0000\text{ms}$



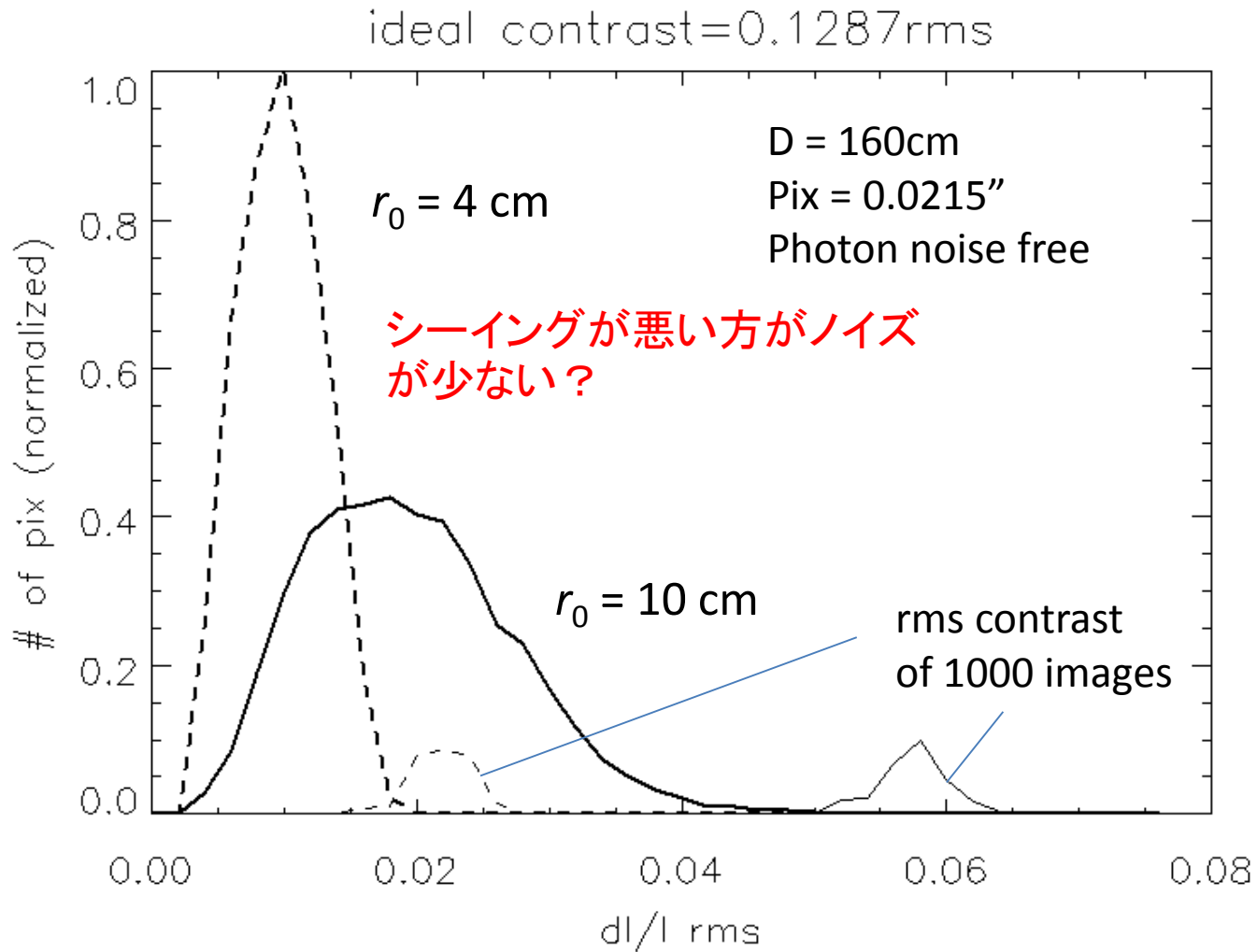
0.39λ rms (tilt removed)

Seeing noise

Intensity profile of central bright point (sun is stationary)

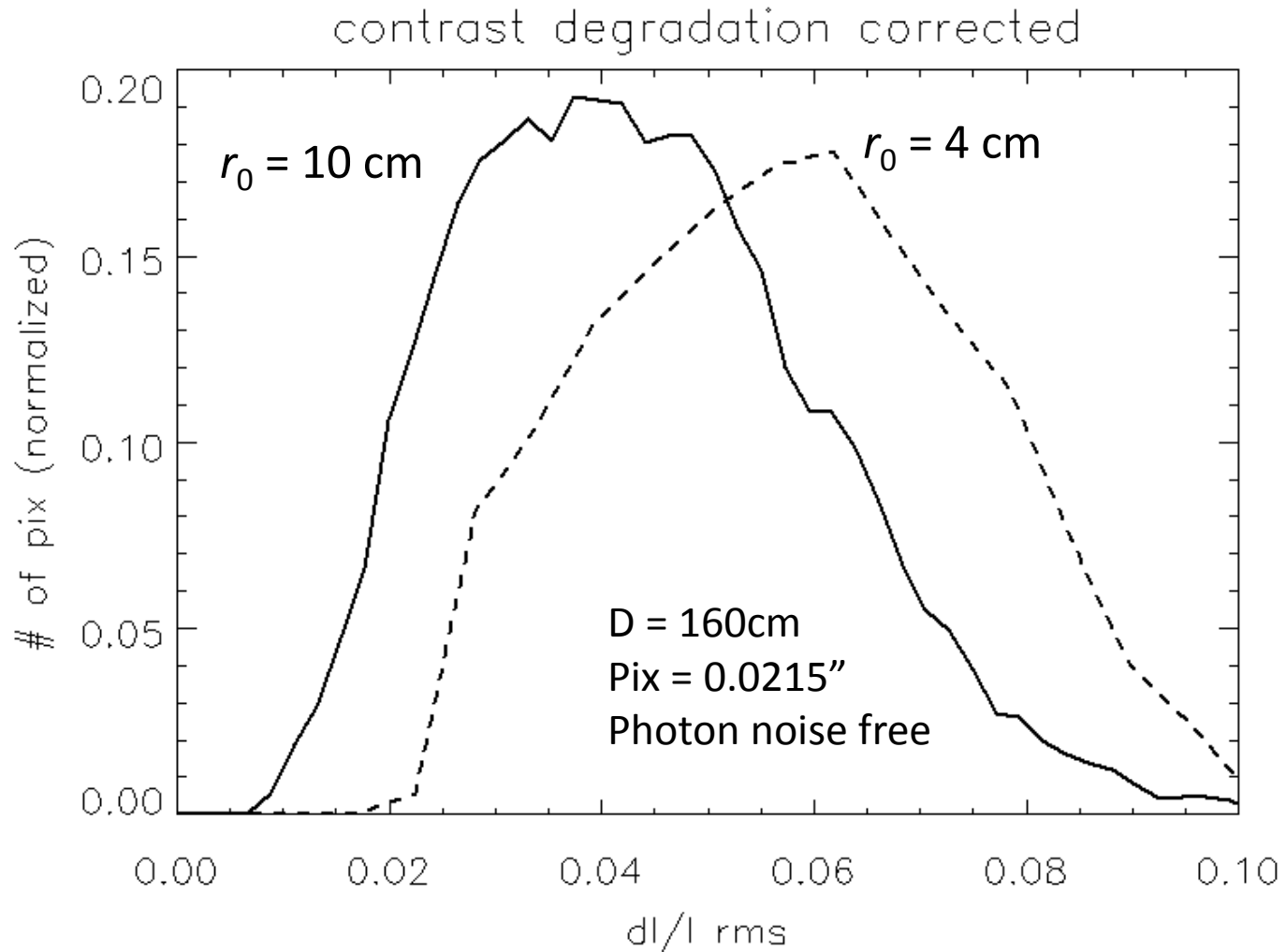


Seeing noise



シーイングが悪い方がノイズ
が少ない？

Seeing noise

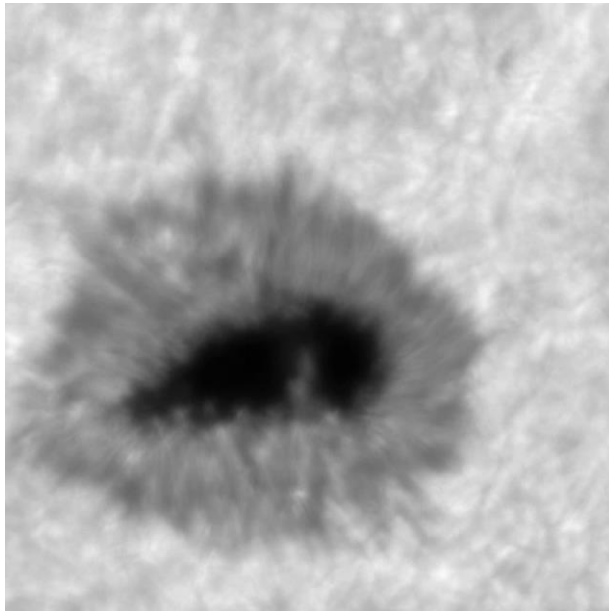


$\frac{\delta I}{I} = 0.01 \sim 0.05$ under a good seeing

シーイングを克服する技術

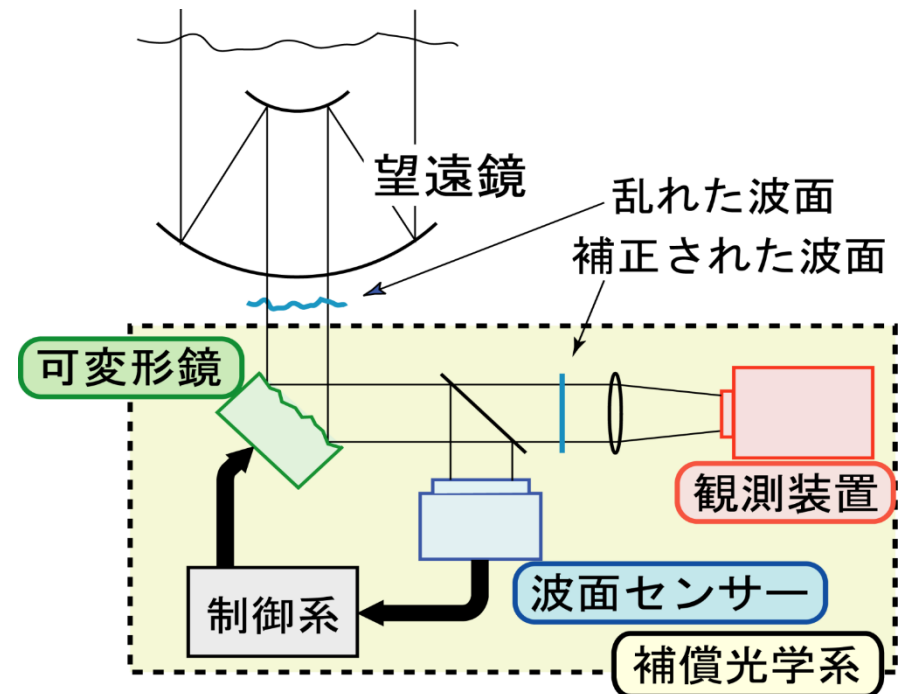
1. 画像回復処理

多数の瞬間画像から真値を推定
ex. Speckle masking



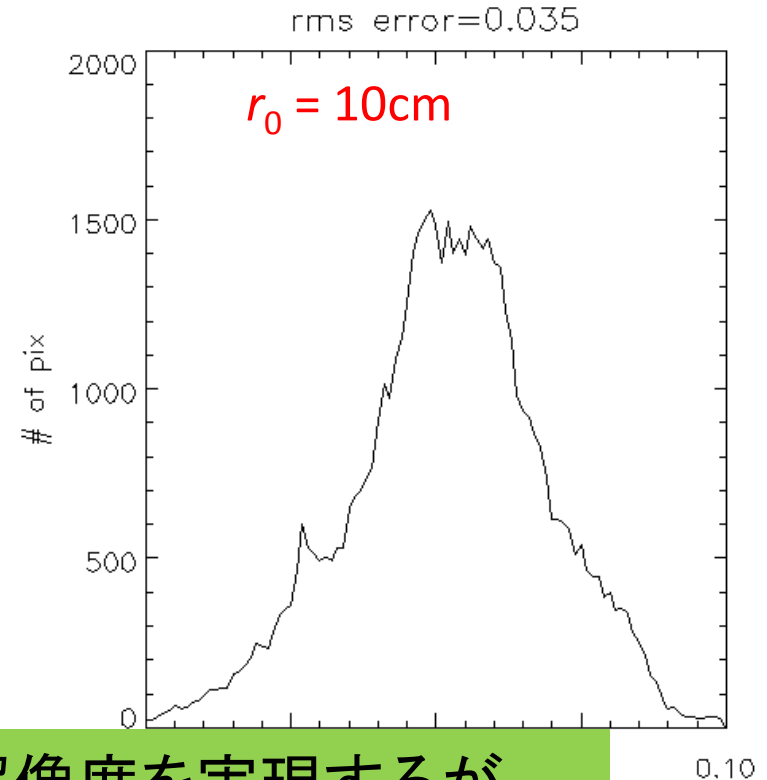
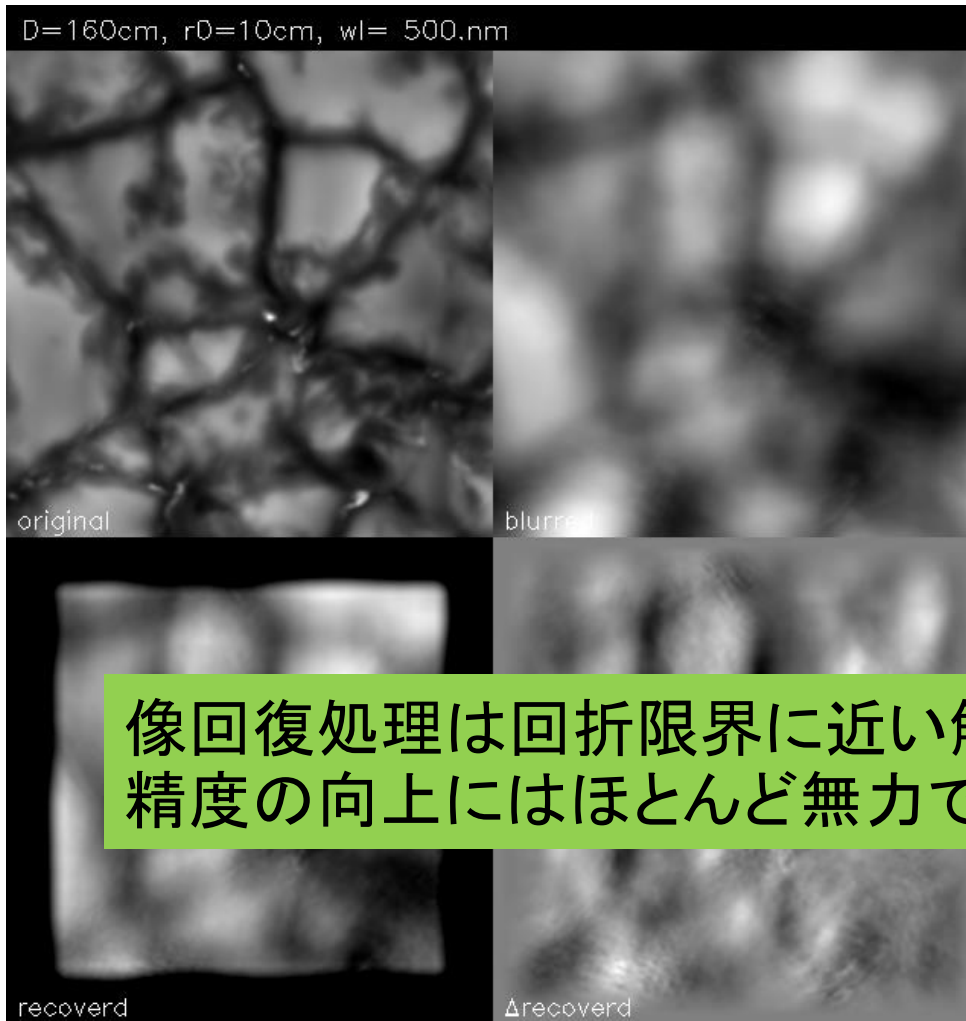
2. 補償光学

波面誤差の実時間補正



Simulation of image reconstruction error

D=160cm, r0=10cm @500nm



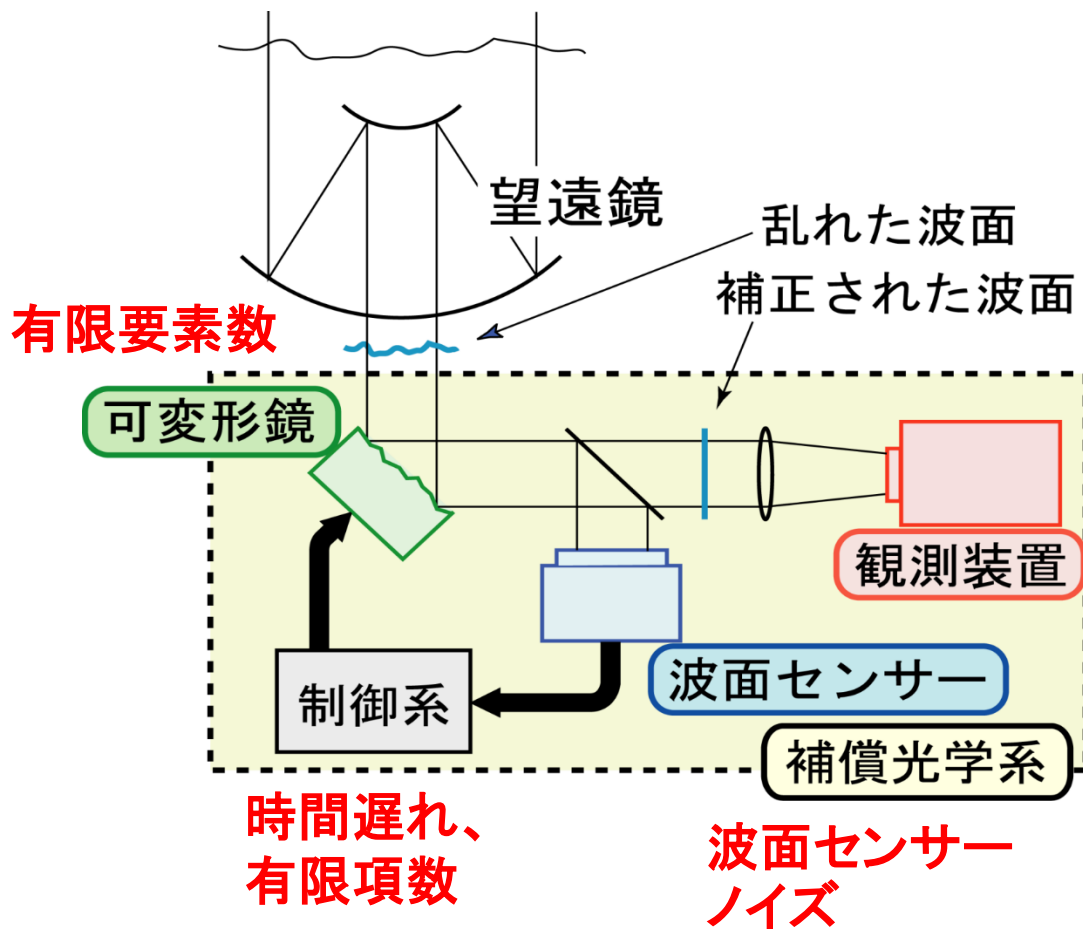
像回復処理は回折限界に近い解像度を実現するが、精度の向上にはほとんど無力である。

reconstructed images using different sets of 100 frames out of 1000 frame,
Set-1 – frame# = [0 - 99]
Set-2 – frame# = [100 - 199]

Contrast 0.129 → 0.062

AO シミュレーション by 三浦

AO の限界



NST-AO:

Diameter: 1.6m

WFS 素子数: 308

DM 素子数: 357

制御帯域: (DM & TT): 1.5k Hz

KL 項数: 192

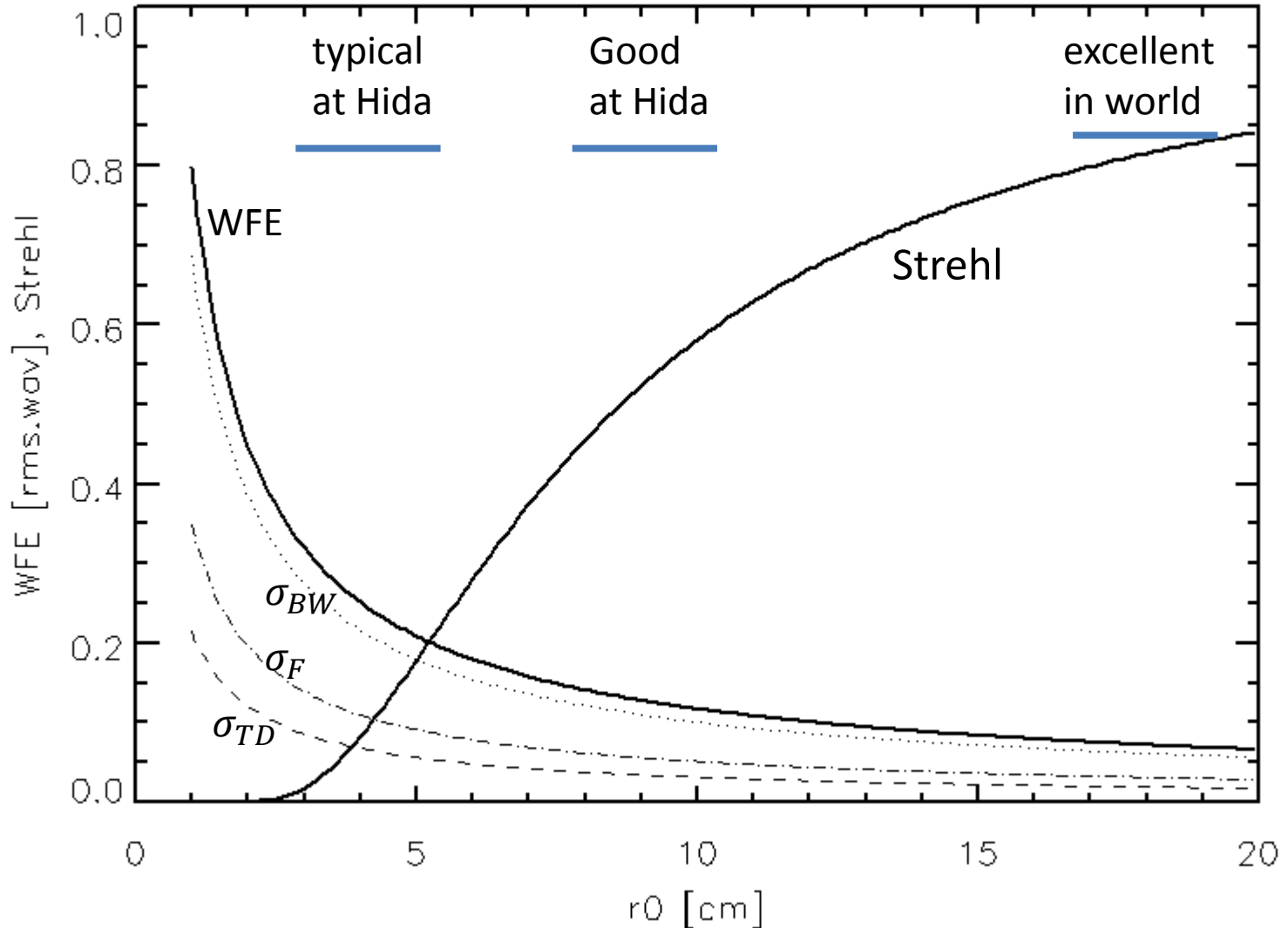
波面センサーノイズ:

半値半幅0.8" Gaussian

AO residual wavefront error

Hida DST; Good performance AO

$v_{\text{wind}}=10\text{m/sec}$, $d=5.5\text{cm}$, $f_s=74.0\text{Hz}$

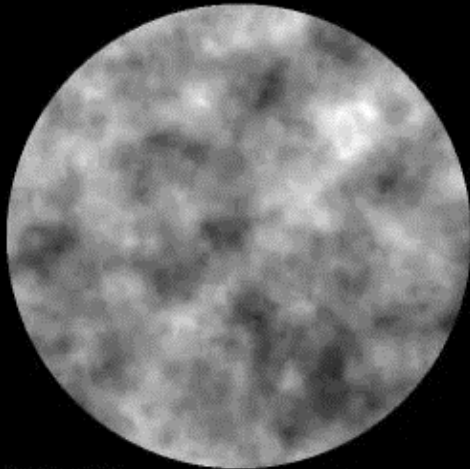


AO simulation (1.6m NST)

NST—AO: Diameter: 1.6m
WFS: 308, DM: 357
Control Freq (DM & TT): 1.5k Hz
KL term: 192, w/ noise by N. Miura

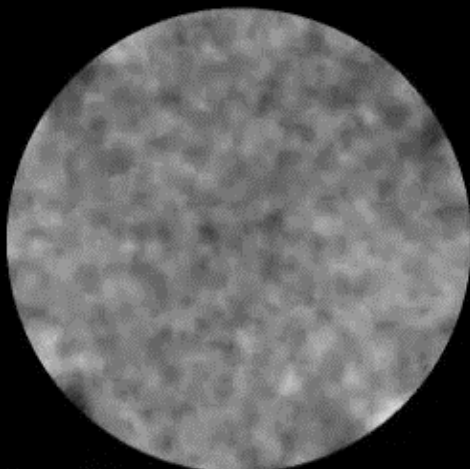
$r_0 = 9.6\text{cm}$, $D = 160\text{cm}$, $V_w = 10 \text{ \& } 20\text{m/s}$, $t = 0.0\text{ms}$

AO—off

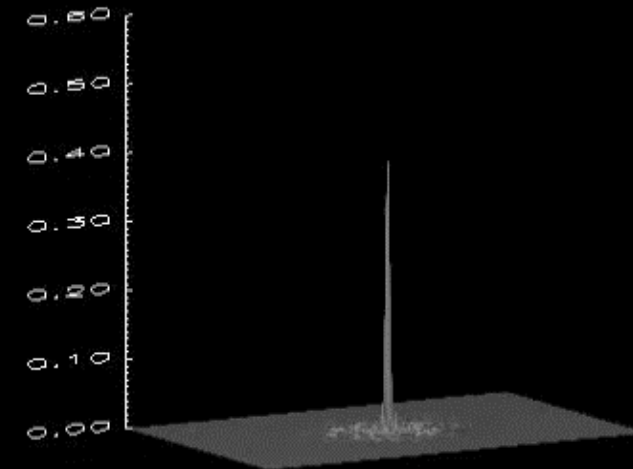
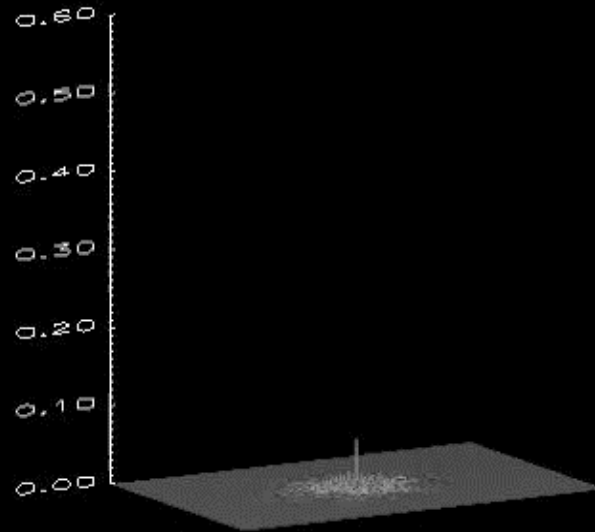


0.284λ rms

AO—on

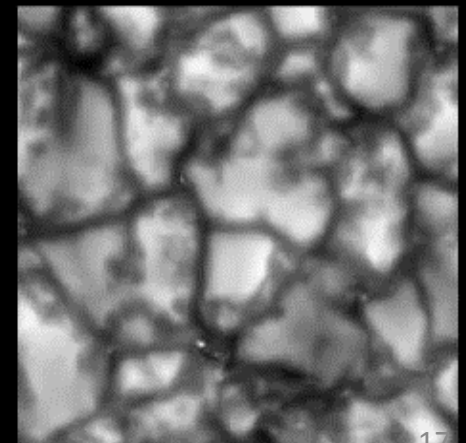
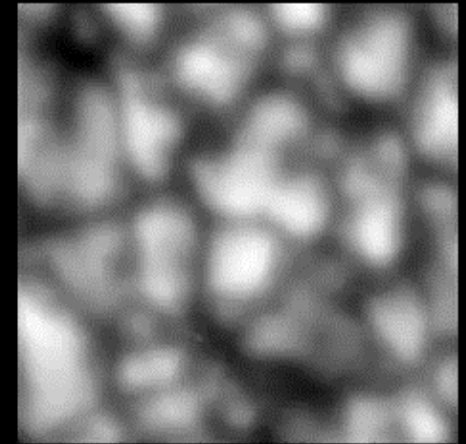


0.159λ rms

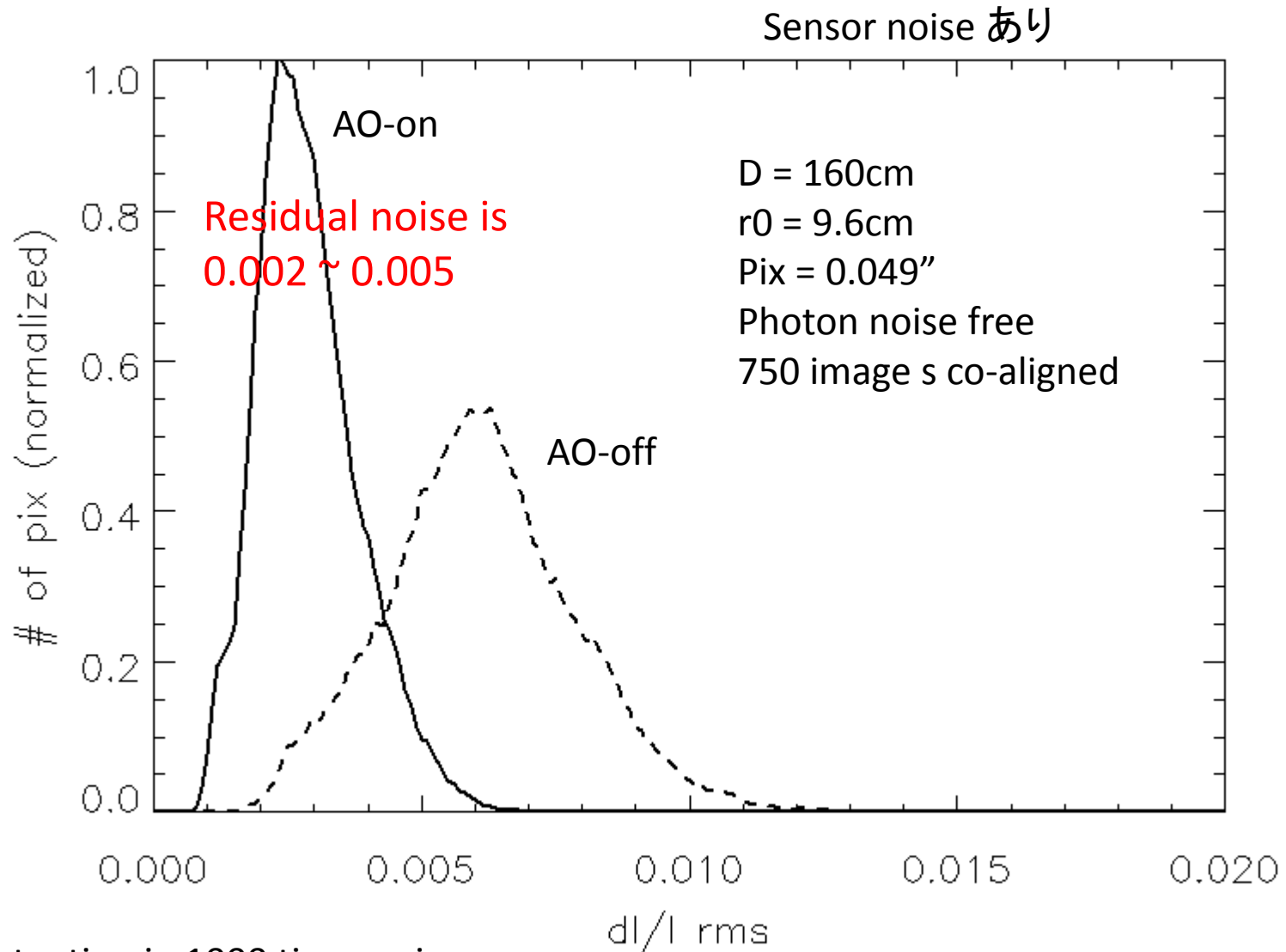


Original image

RMHD simulation by Rempel



Intensity fluctuation from AO sim.



Fluctuation in 1000 time series

AO simulation (1.6m NST)

$r_0 \sim 12\text{cm?}$

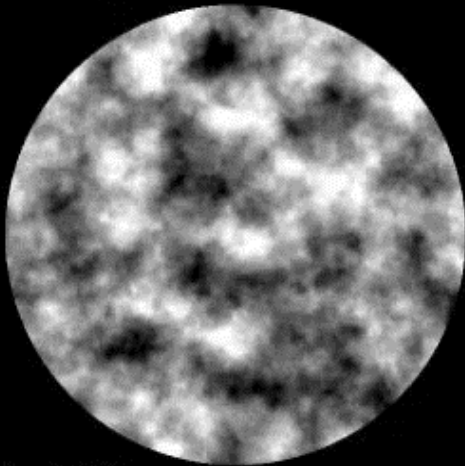
Original image

RMHD simulation by Rempel

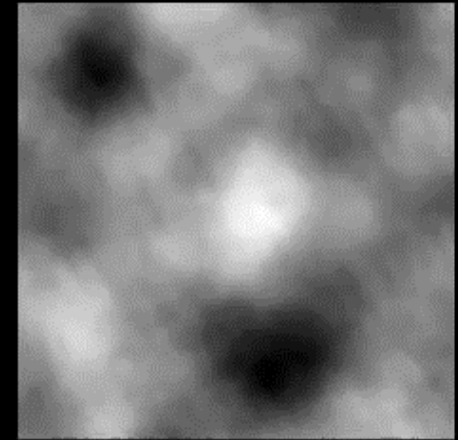
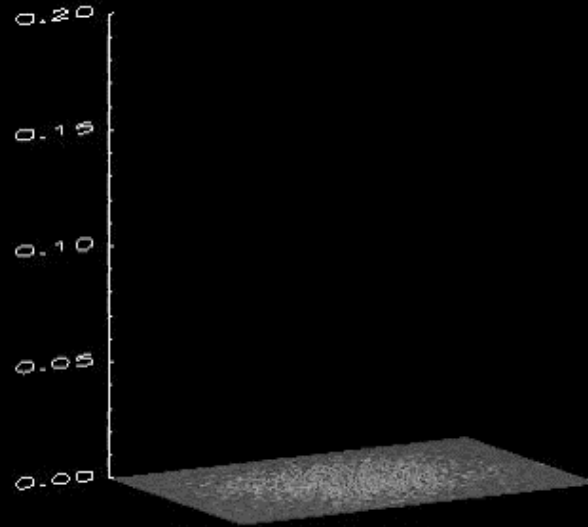
$r_0 = 4.0\text{cm}$, $D = 160\text{cm}$, $V_w = 10 \& 20\text{m/s}$, $\lambda = 500\text{nm}$, $t =$

0.0ms

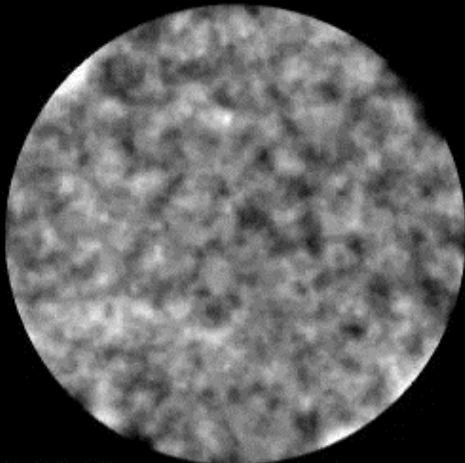
AO-off



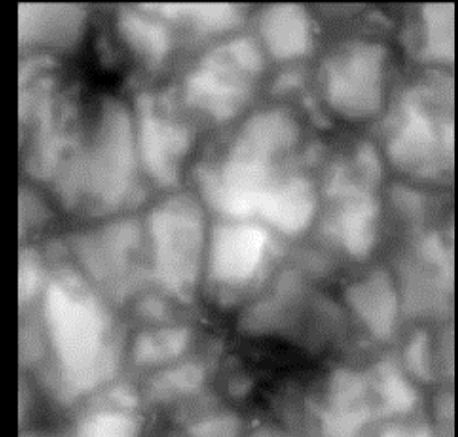
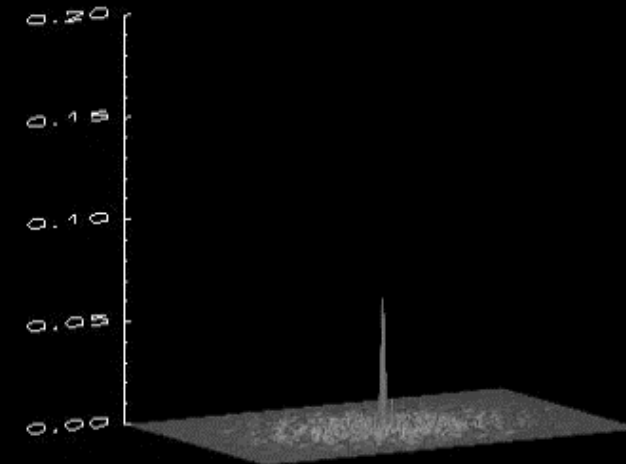
0.487λ rms



AO-on

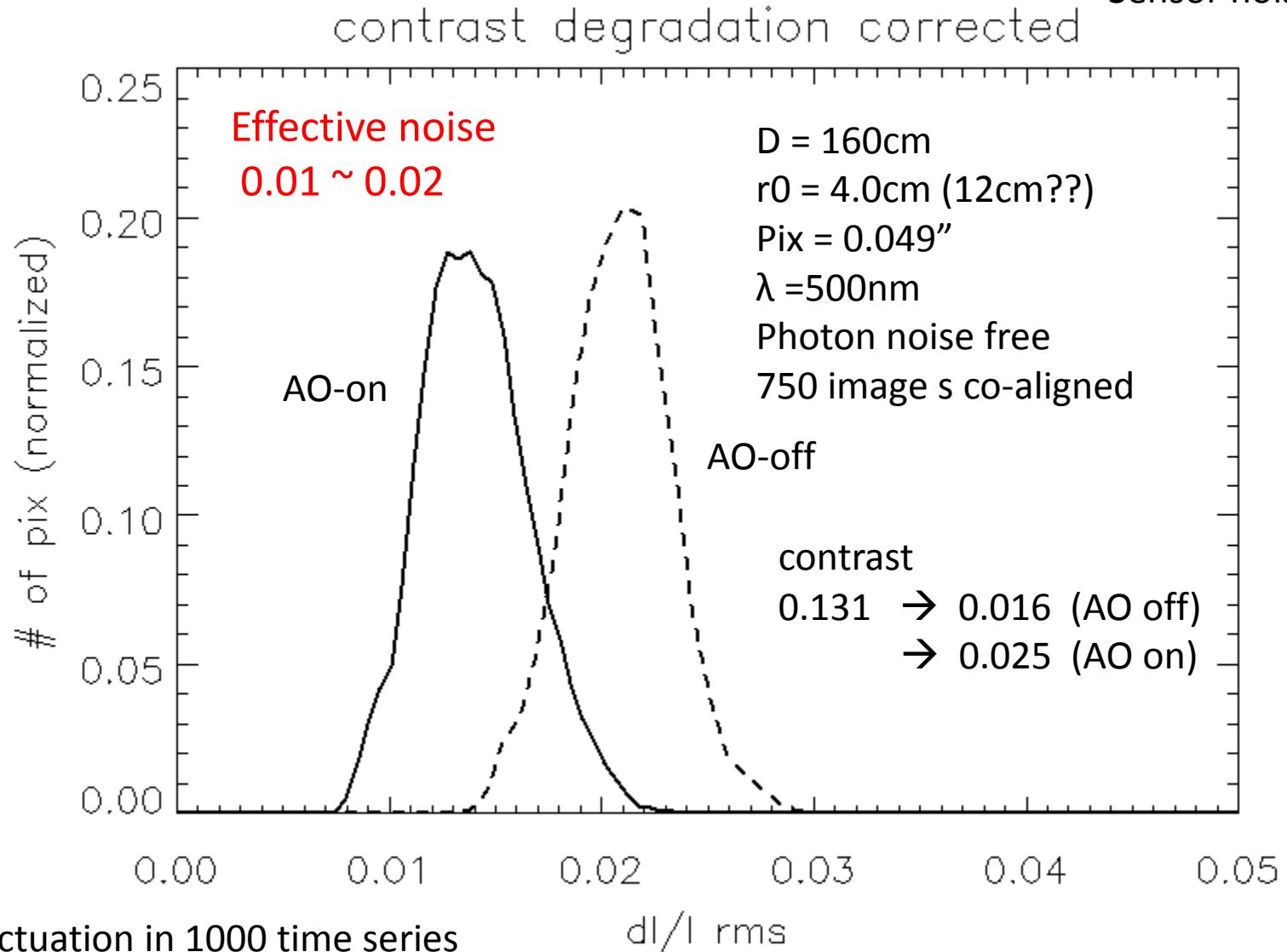


0.292λ rms

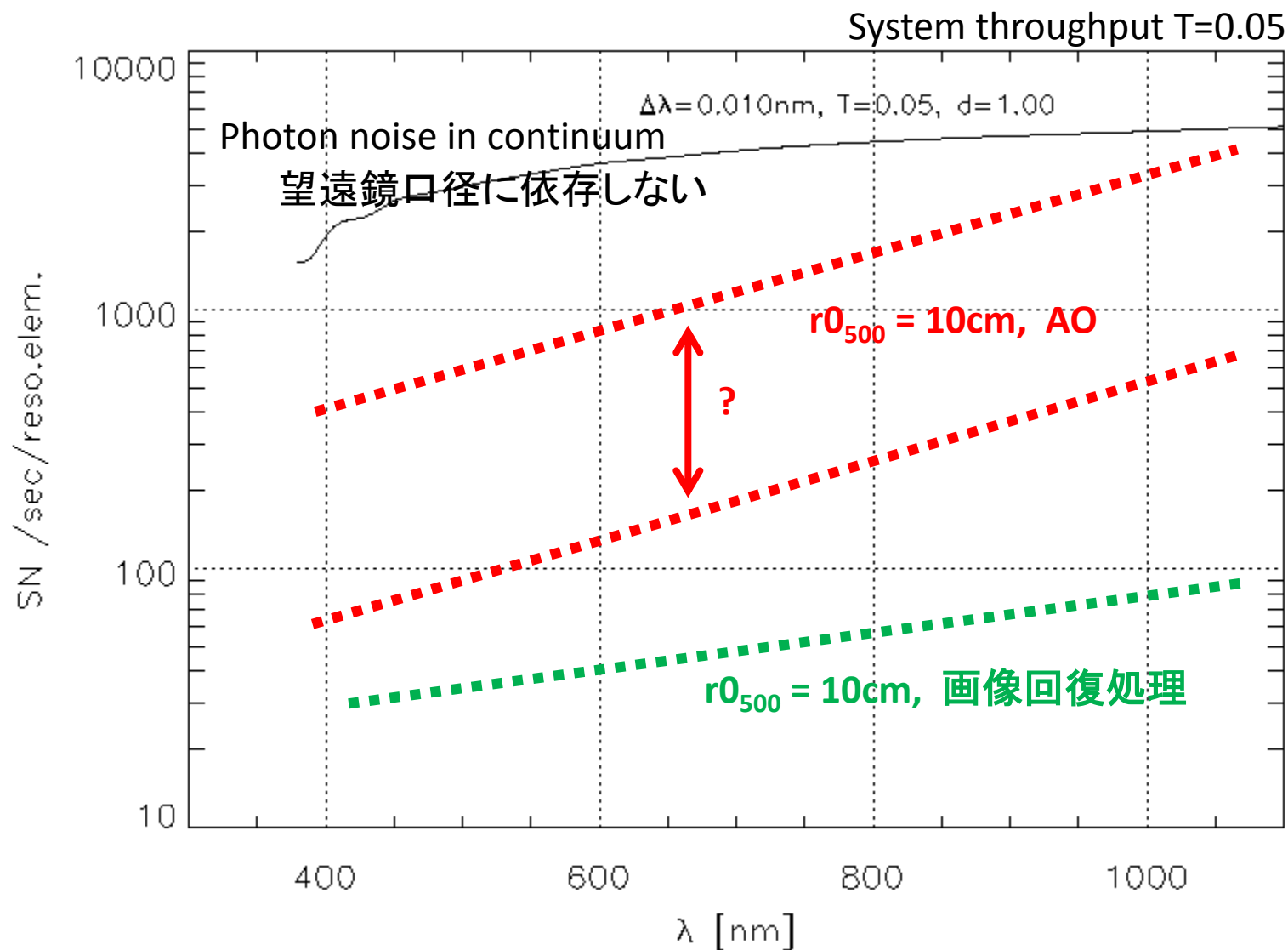


Intensity fluctuation from AO sim.

Sensor noise あり



回折限界分解要素のSN



まとめ

- 2020年代、最高空間分解の撮像は地上大型望遠鏡
 - 時間~1hr, 視野~20" -- スピキュールの研究には十分
- 検出限界(分解能×精度)は画像処理やAOを考慮しても(少なくとも)可視域ではSUVITが上。
- ただし $1.1\mu\text{m}$ では両者が拮抗する可能性あり
- スピキュールの研究; SUVITによる下部磁場構造と地上大型による高解像ダイナミクスの協調観測
- SUVIT(とくに1083nm)は、広視野長時間安定観測が圧倒的な強み。
- シーイングシミュレーションを完成させる必要あり