Destriping MODIS data using the FOV Overlapping Method (FOM)

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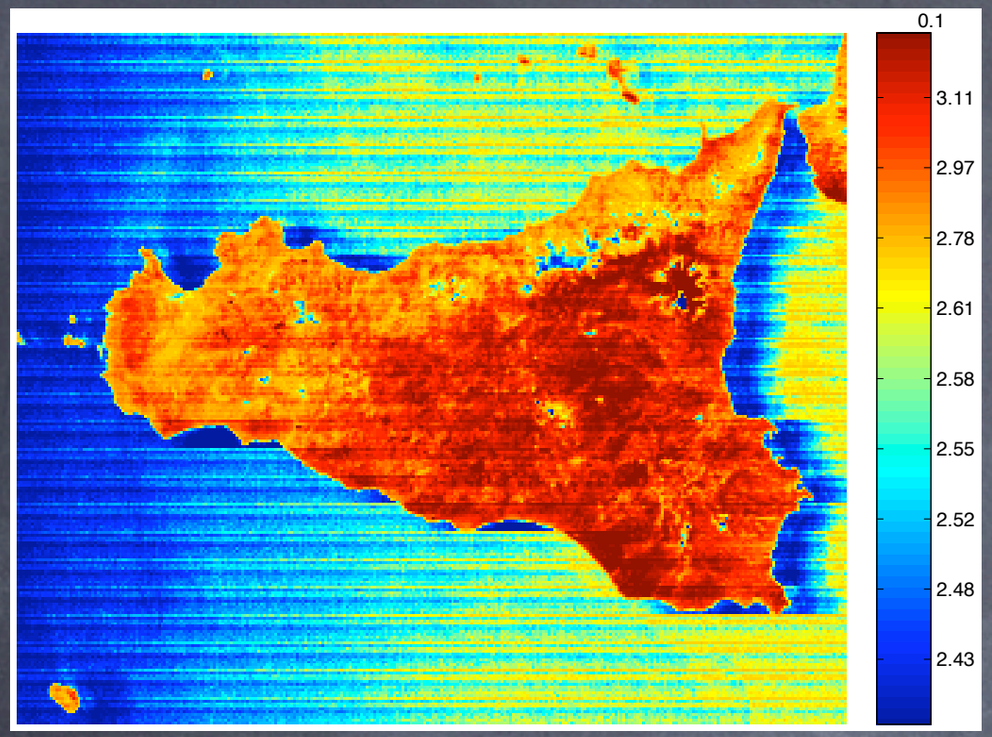
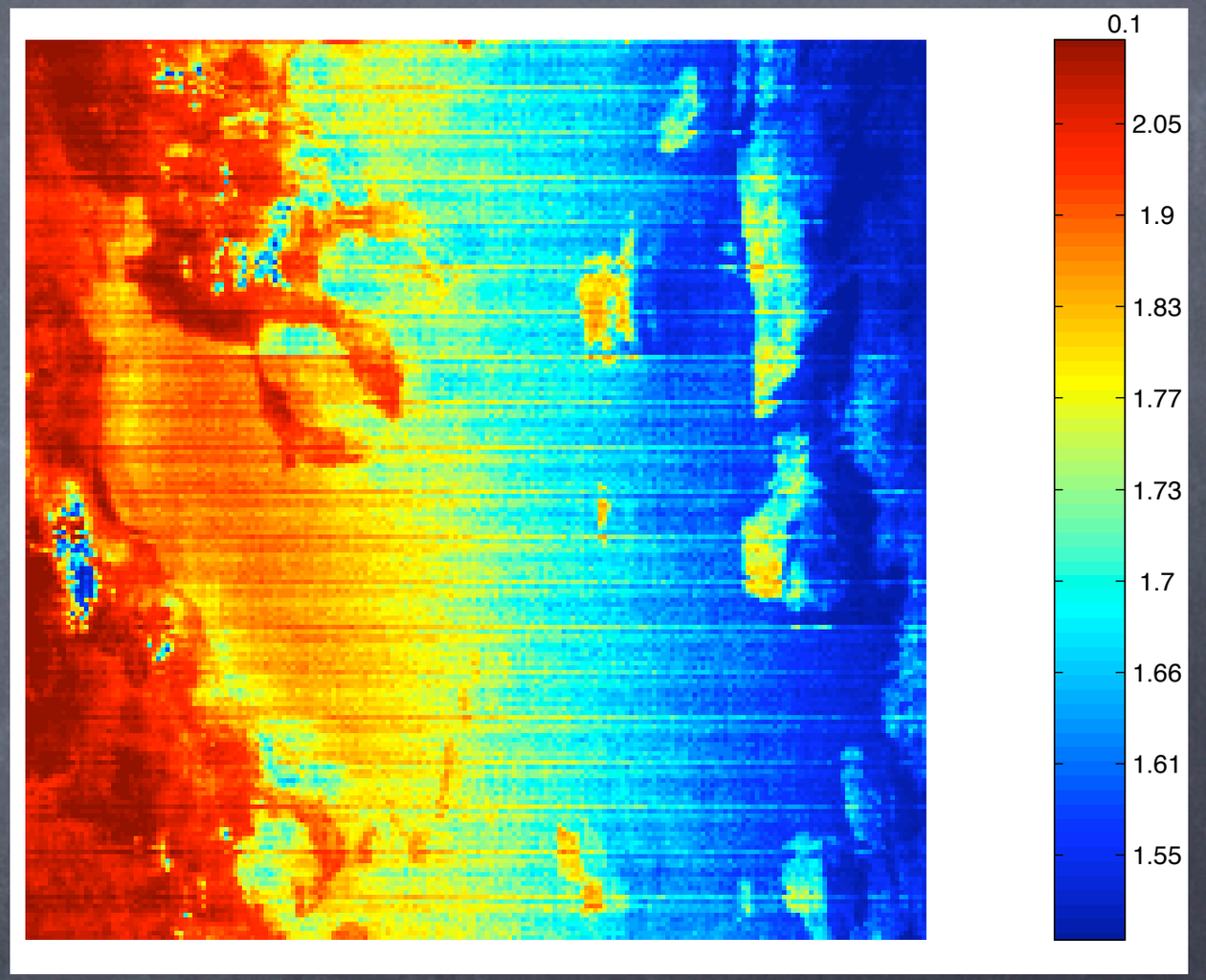
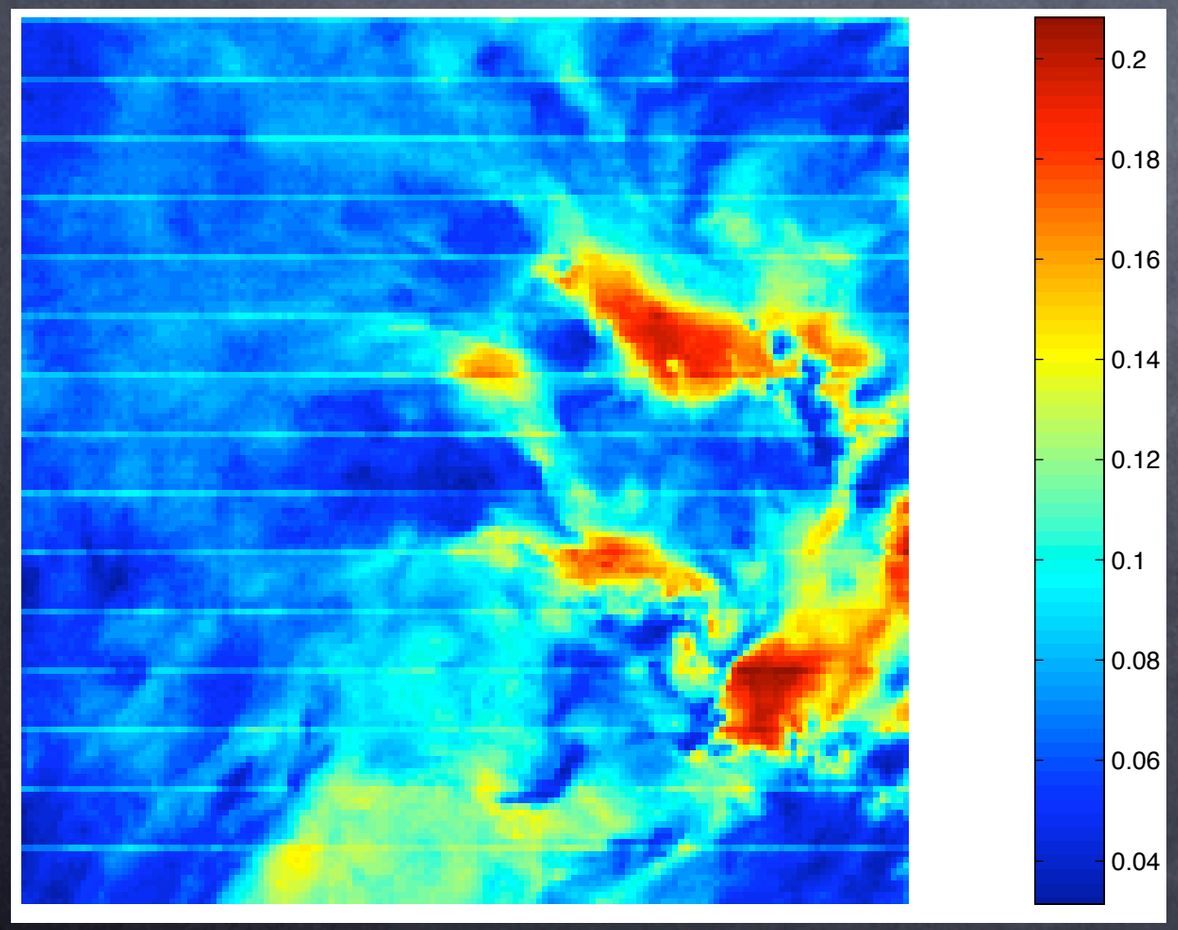
Outline

- Stripes: how they appear
- MODIS: a quick look at the instrument
- Review of the "open literature" solutions
- The FOV Overlapping Method (FOM)

Stripes







MODIS/Terra - Band 24 - 2004.07.21 09:45

MODIS

MODerate resolution Imaging Spectroradiometer

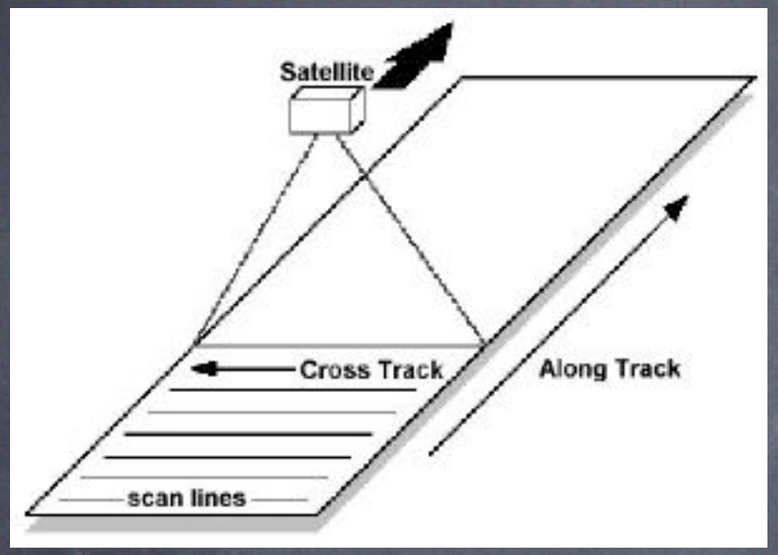
Stripes
MODIS
Review
FOM

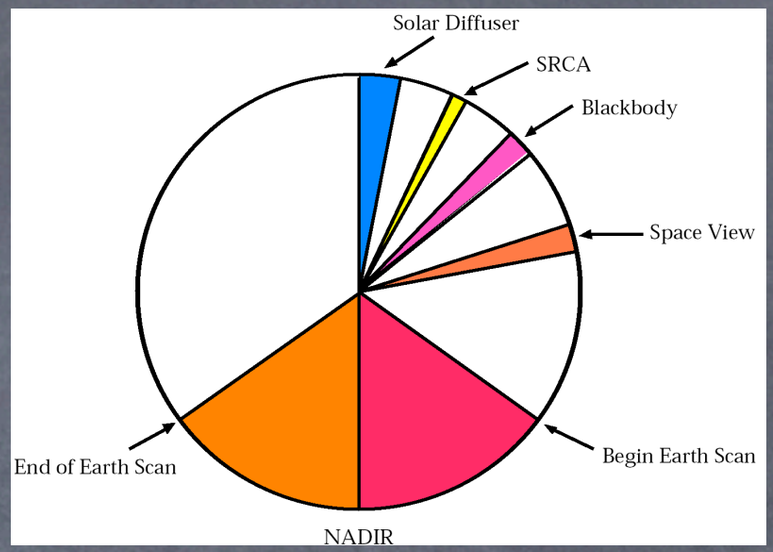
Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

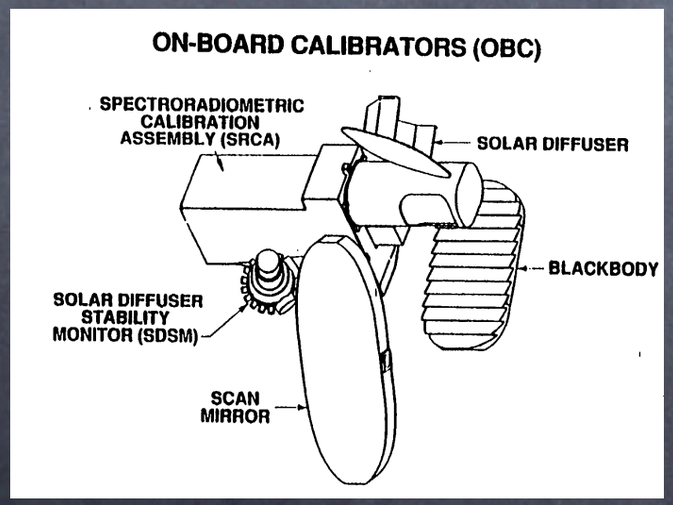
Primary Atmospheric Application	Band	Bandwidth[1]	$T_{typical}$ (K)	Radiance[2] at $T_{typical}$	$NE^{\Delta}T$ (K) Specification	$NE^{\Delta}T$ (K) Predicted
Surface Temperature	20	3.660-3.840	300	0.45	0.05	0.05
	22	3.929-3.989	300	0.67	0.07	0.05
	23	4.020-4.080	300	0.79	0.07	0.05
Temperature profile	24	4.433-4.498	250	0.17	0.25	0.15
	25	4.482-4.549	275	0.59	0.25	0.10
Moisture profile	27	6.535-6.895	240	1.16	0.25	0.05
	28	7.175-7.475	250	2.18	0.25	0.05
	29	8.400-8.700	300	9.58	0.05	0.05
Ozone	30	9.580-9.880	250	3.69	0.25	0.05
Surface Temperature	31	10.780-11.280	300	9.55	0.05	0.05
	32	11.770-12.270	300	8.94	0.05	0.05
Temperature profile	33	13.185-13.485	260	4.52	0.25	0.15
	34	13.485-13.785	250	3.76	0.25	0.20
	35	13.785-14.085	240	3.11	0.25	0.25
	36	14.085-14.385	220	2.08	0.35	0.35

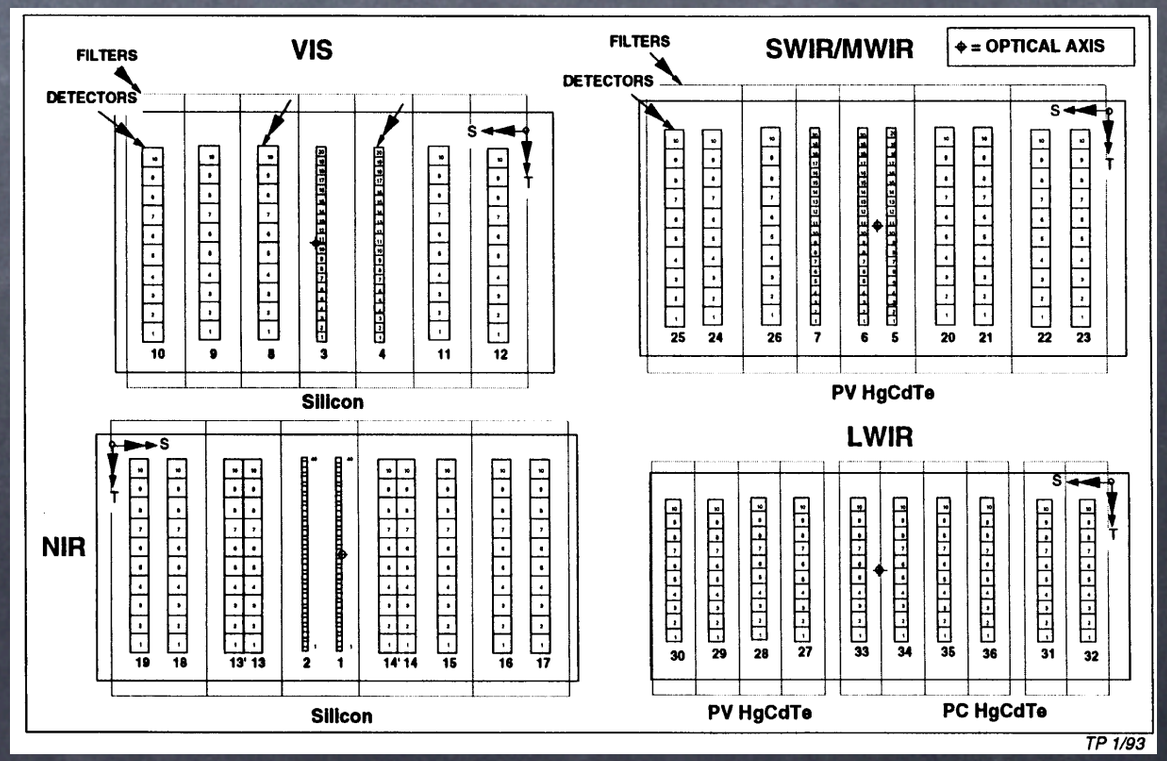
MODIS

MODerate resolution Imaging Spectroradiometer



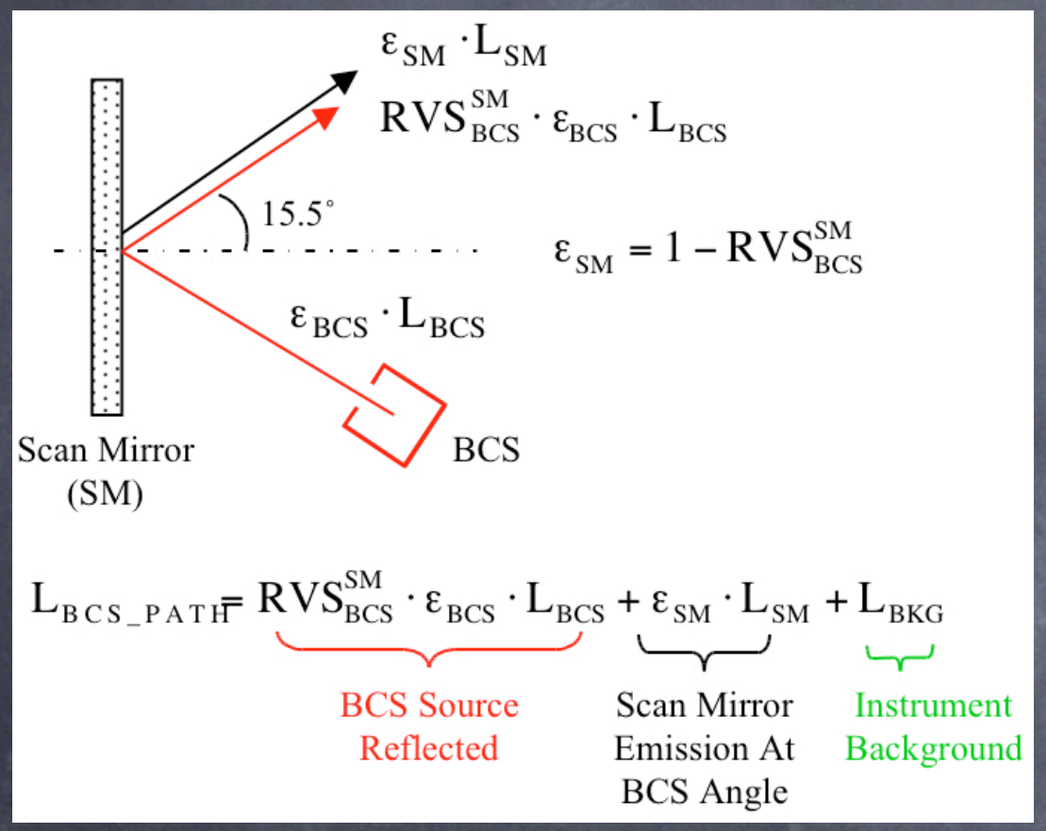




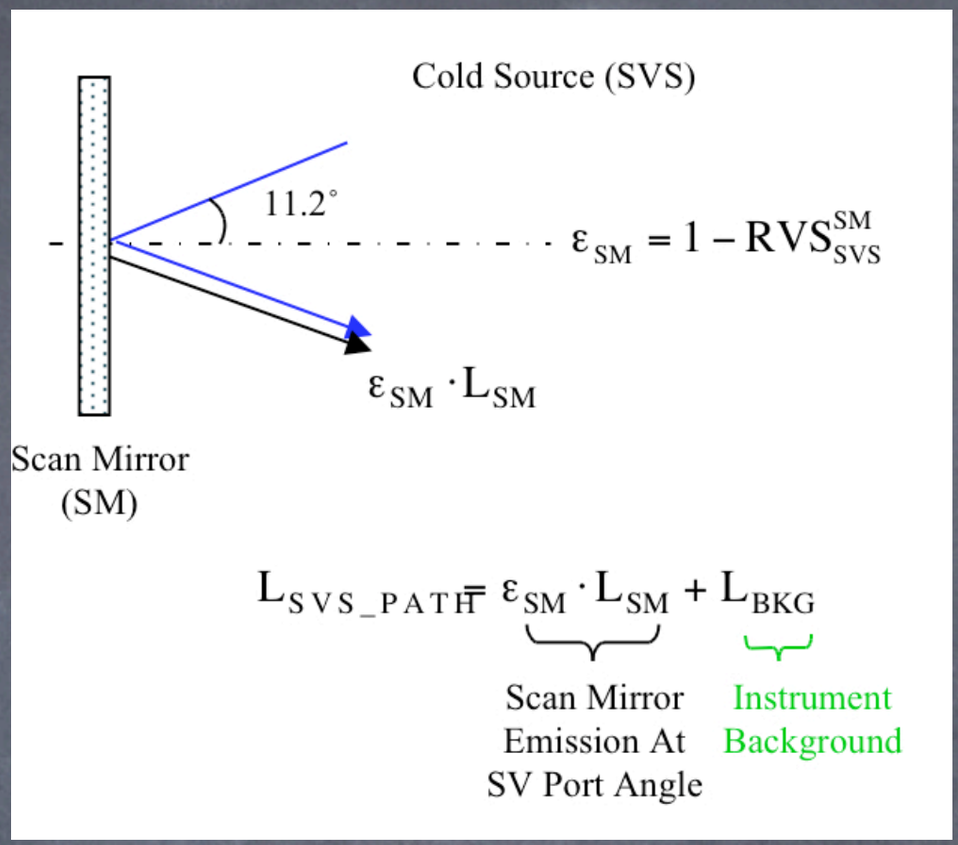


MODIS

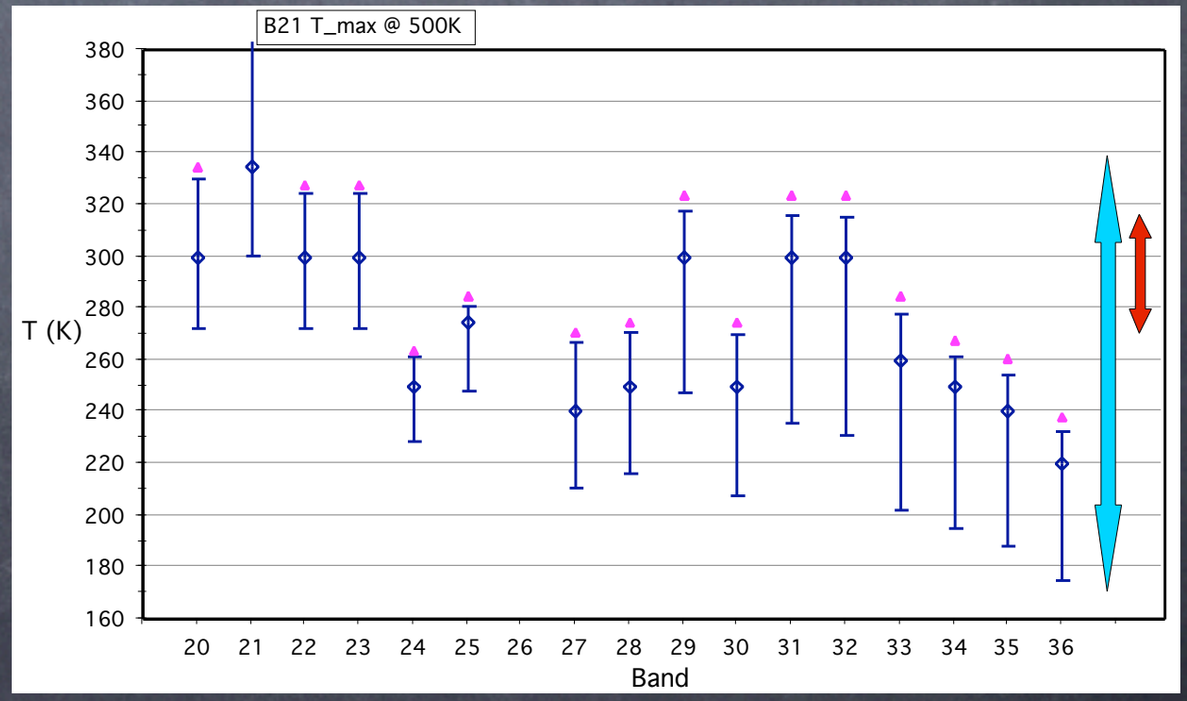
MODerate resolution Imaging Spectroradiometer



$$L_{BCS\_PATH} = \underbrace{RVS^{SM}_{BCS} \cdot \varepsilon_{BCS} \cdot L_{BCS}}_{\text{BCS Source Reflected}} + \underbrace{\varepsilon_{SM} \cdot L_{SM}}_{\text{Scan Mirror Emission At BCS Angle}} + \underbrace{L_{BKG}}_{\text{Instrument Background}}$$



$$L_{SVS\_PATH} = \underbrace{\varepsilon_{SM} \cdot L_{SM}}_{\text{Scan Mirror Emission At SV Port Angle}} + \underbrace{L_{BKG}}_{\text{Instrument Background}}$$



$$\Delta L_{BCS} = L_{BCS\_PATH} - L_{SVS\_PATH}$$

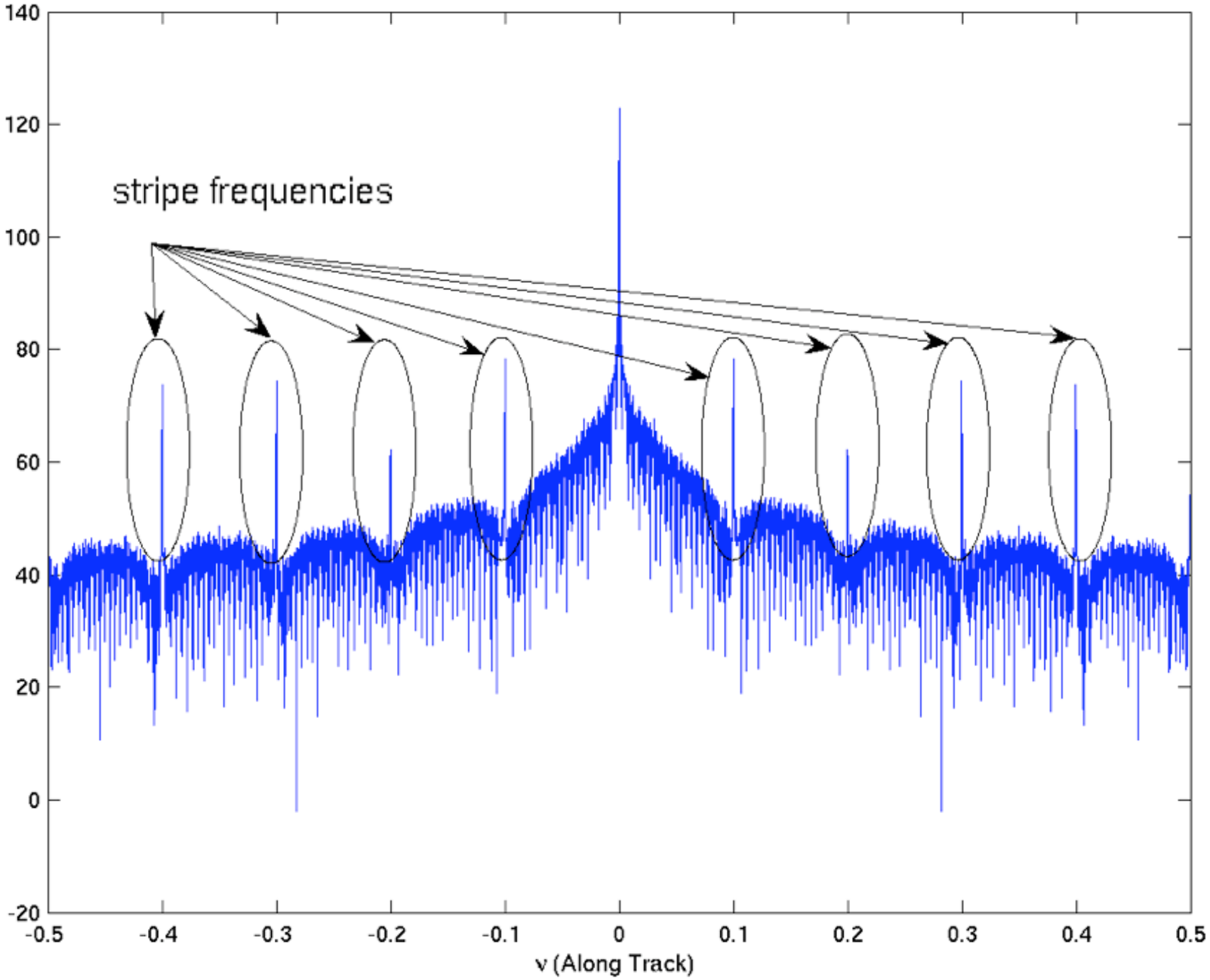
$$\Delta L_{BCS}(B, T_{instr}) = a_0^{BCS}(B, T_{instr}) + a_1^{BCS}(B, T_{instr}) \cdot dn_{BCS} + a_2^{BCS}(B, T_{instr}) \cdot dn_{BCS}^2$$

Review of the open literature solutions

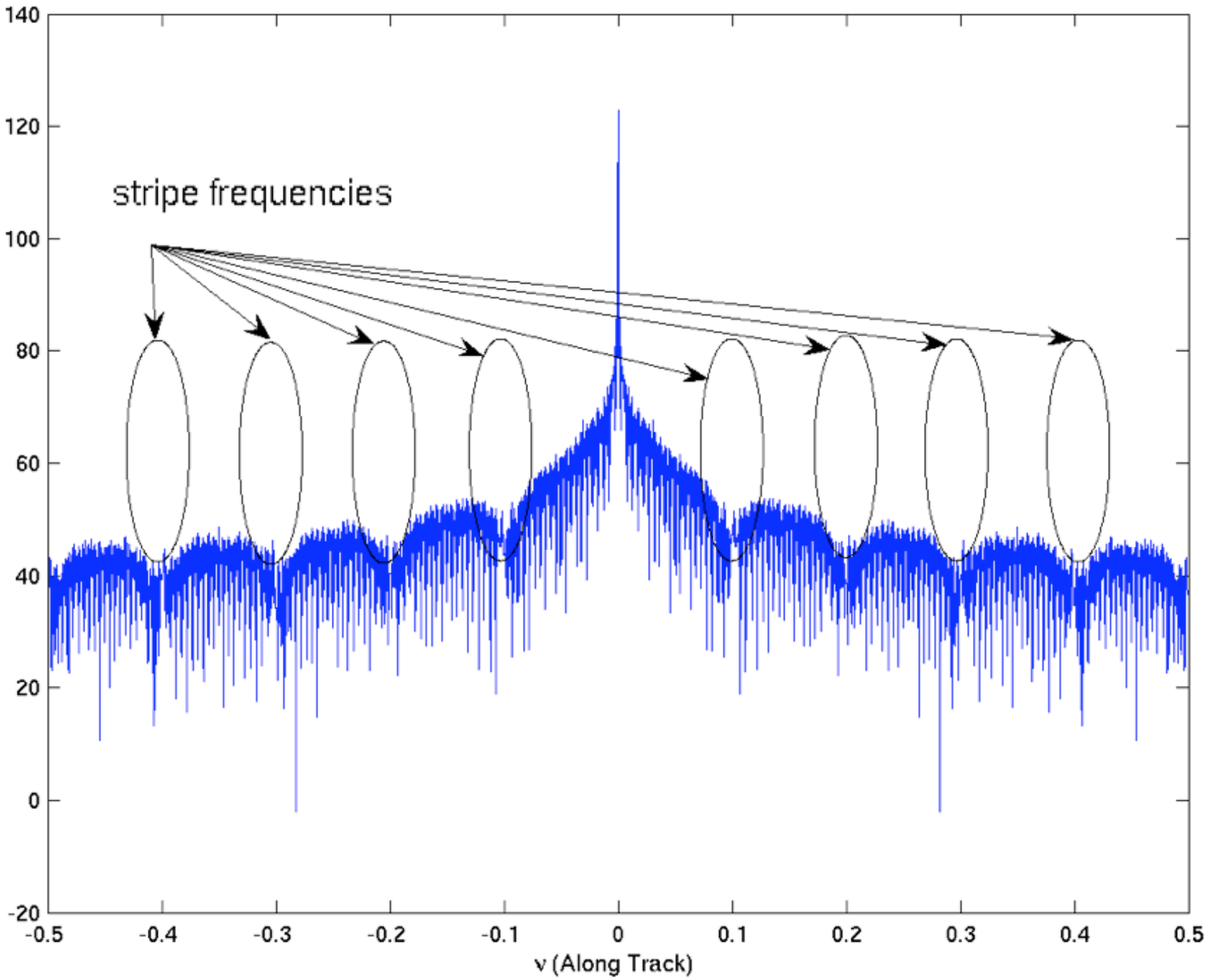
Stripes
MODIS
Review
FOM

- Spatial filtering
- Statistics matching
- Equalization

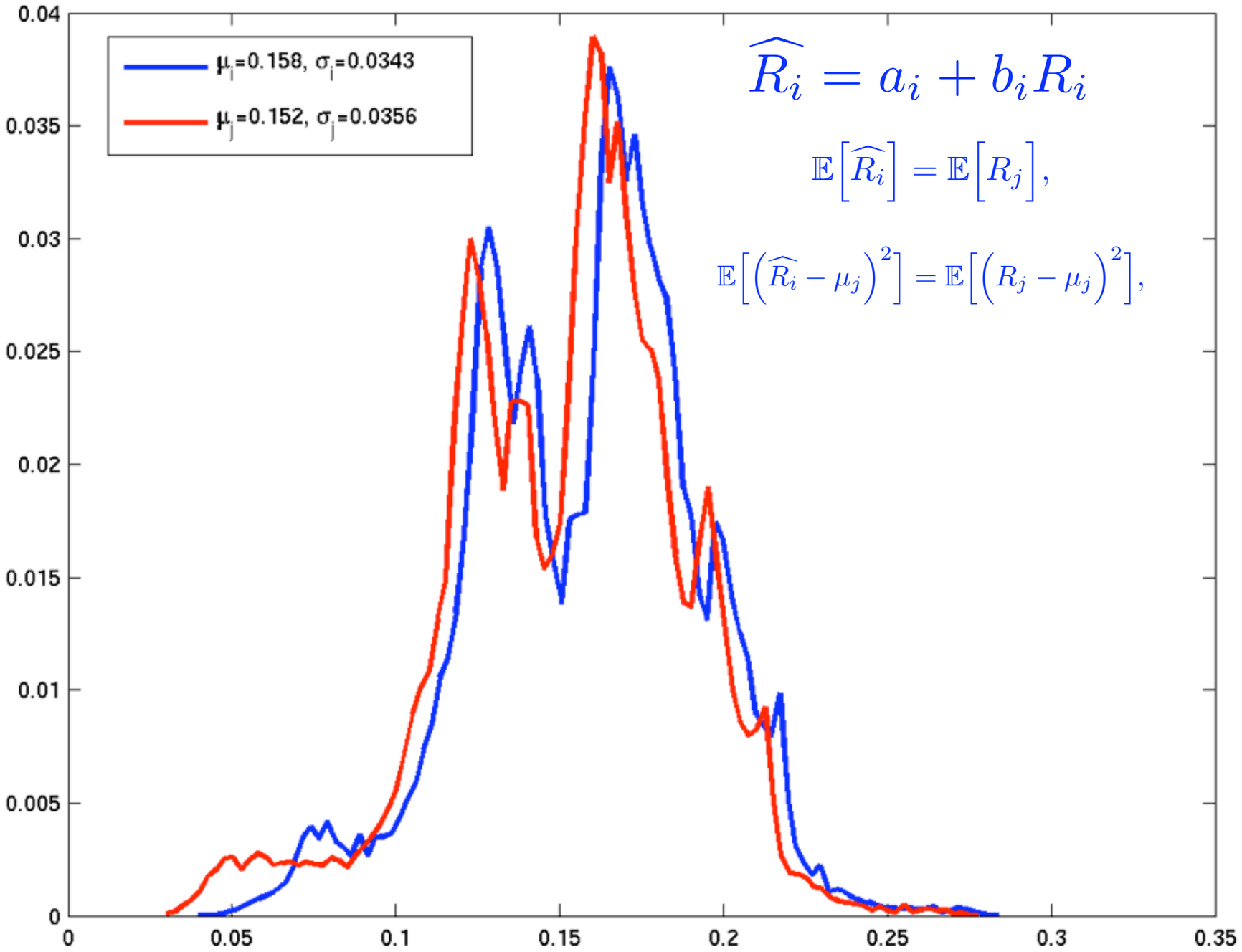
Spatial filtering



Spatial filtering



Moment matching

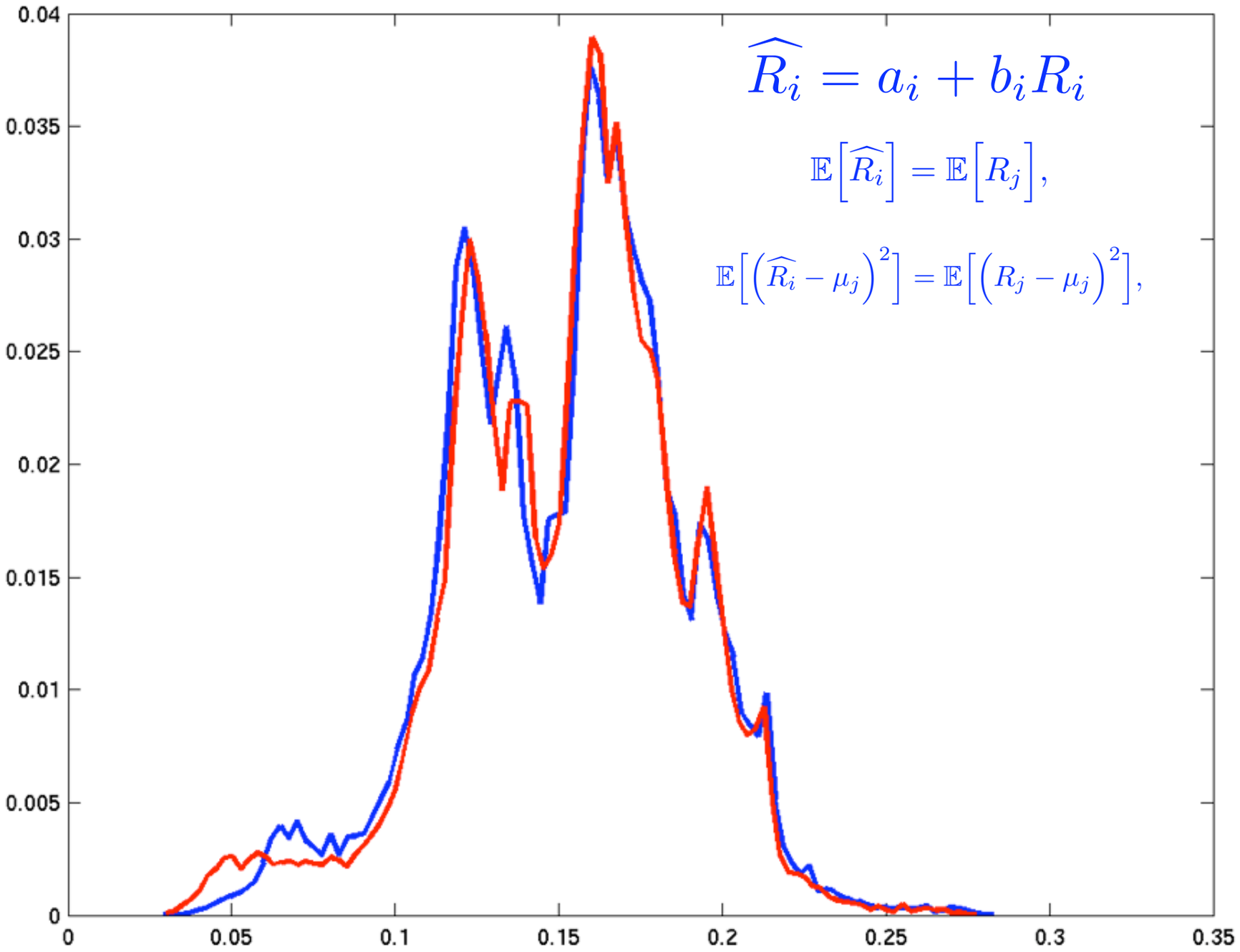


$$\widehat{R_i} = a_i + b_i R_i$$

$$\mathbb{E}\left[\widehat{R_i}\right] = \mathbb{E}\left[R_j\right],$$

$$\mathbb{E}\left[\left(\widehat{R_i} - \mu_j\right)^2\right] = \mathbb{E}\left[\left(R_j - \mu_j\right)^2\right],$$

Moment matching



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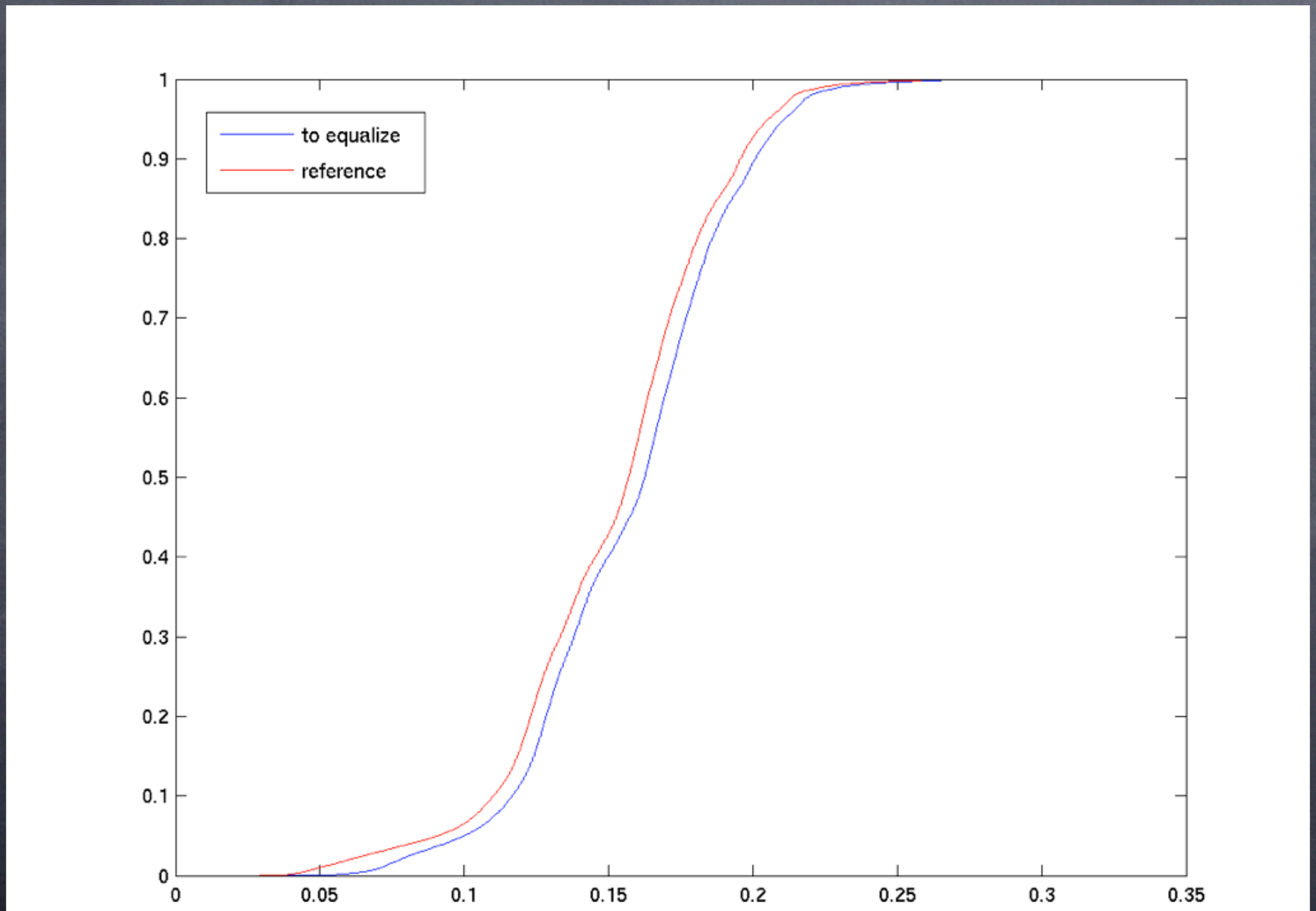
$$\mathbb{E}\left[\left(\widehat{R_i} - \mu_j\right)^2\right] = \mathbb{E}\left[\left(R_j - \mu_j\right)^2\right],$$

Histogram matching



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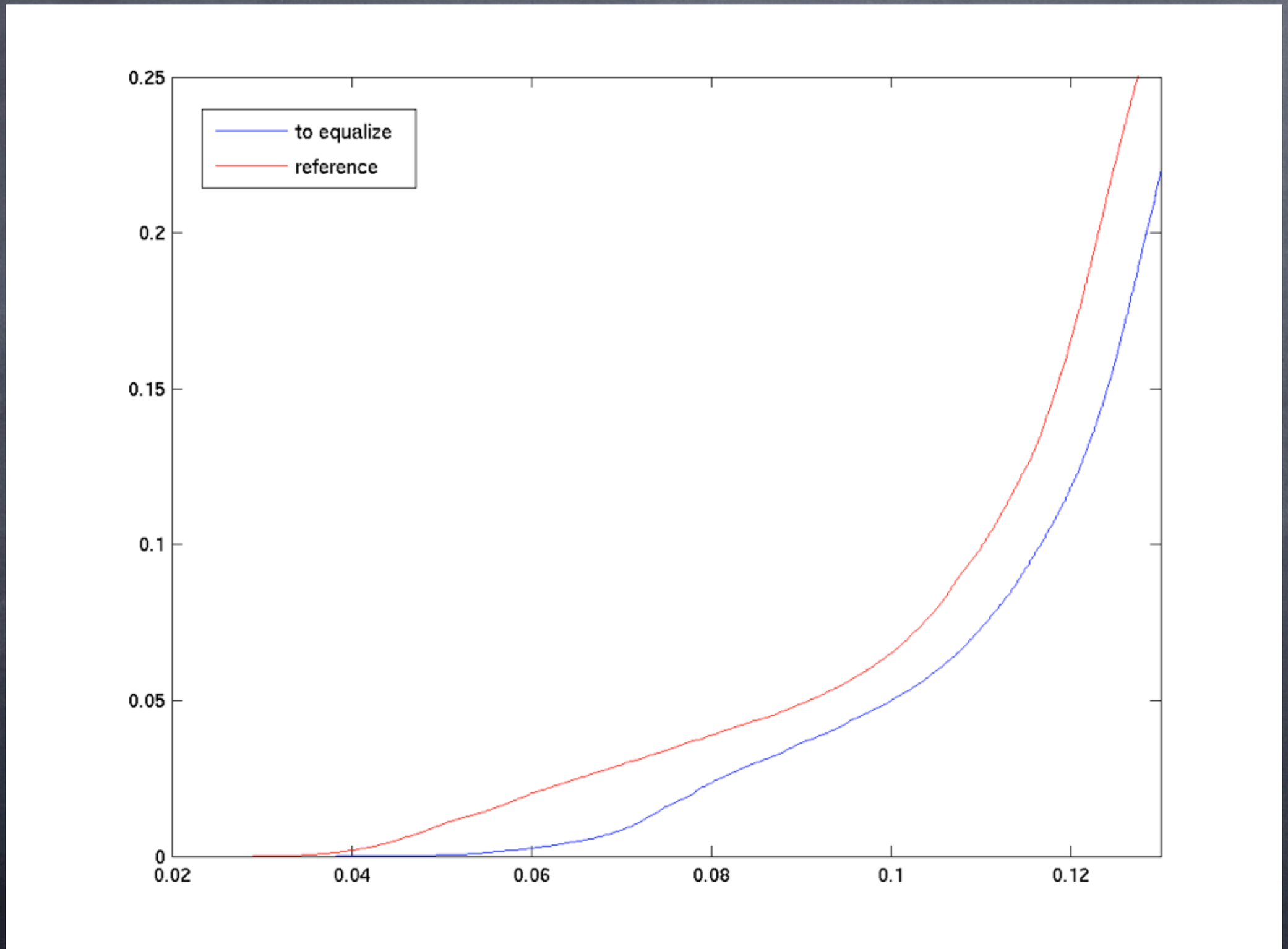

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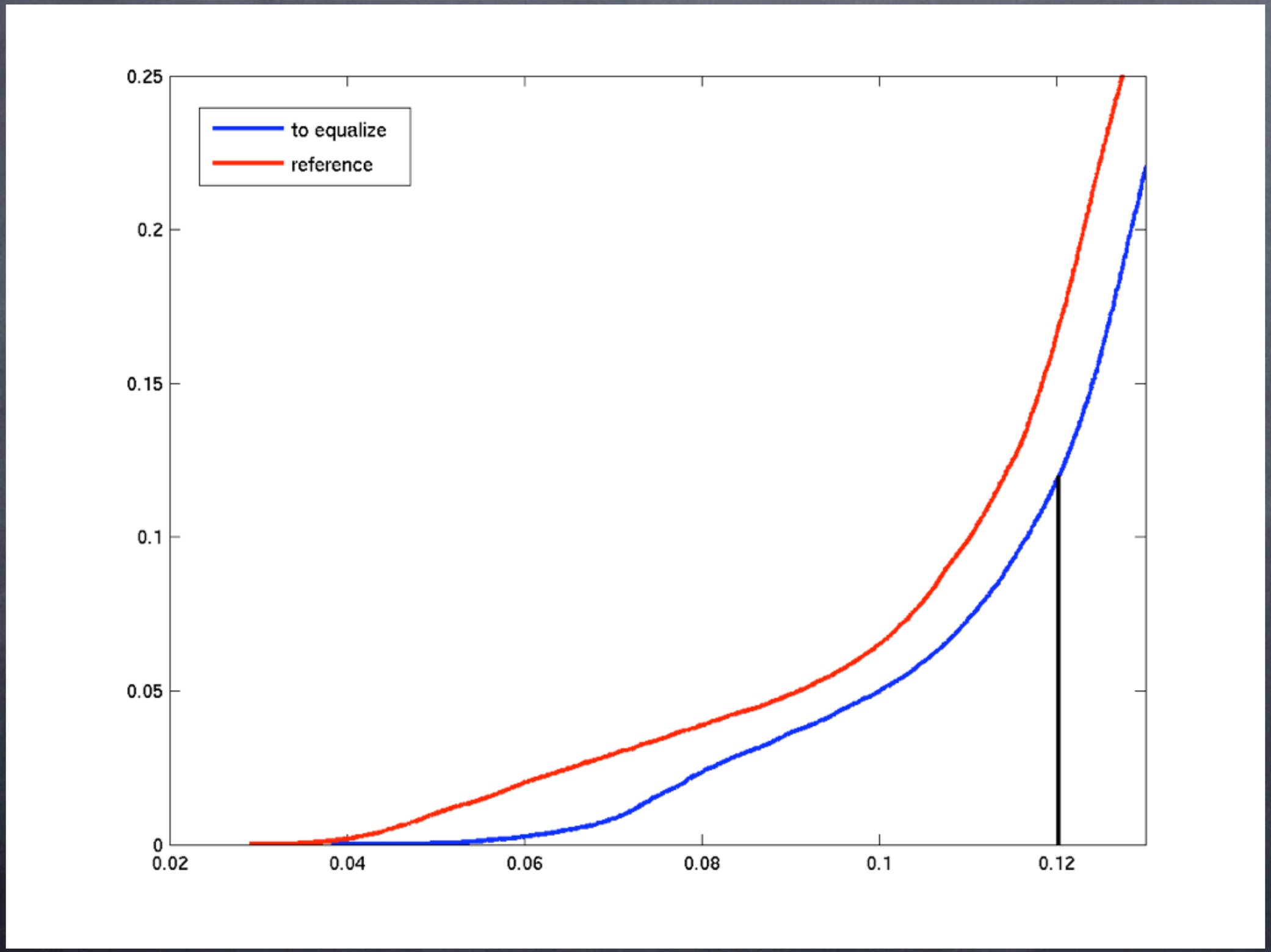
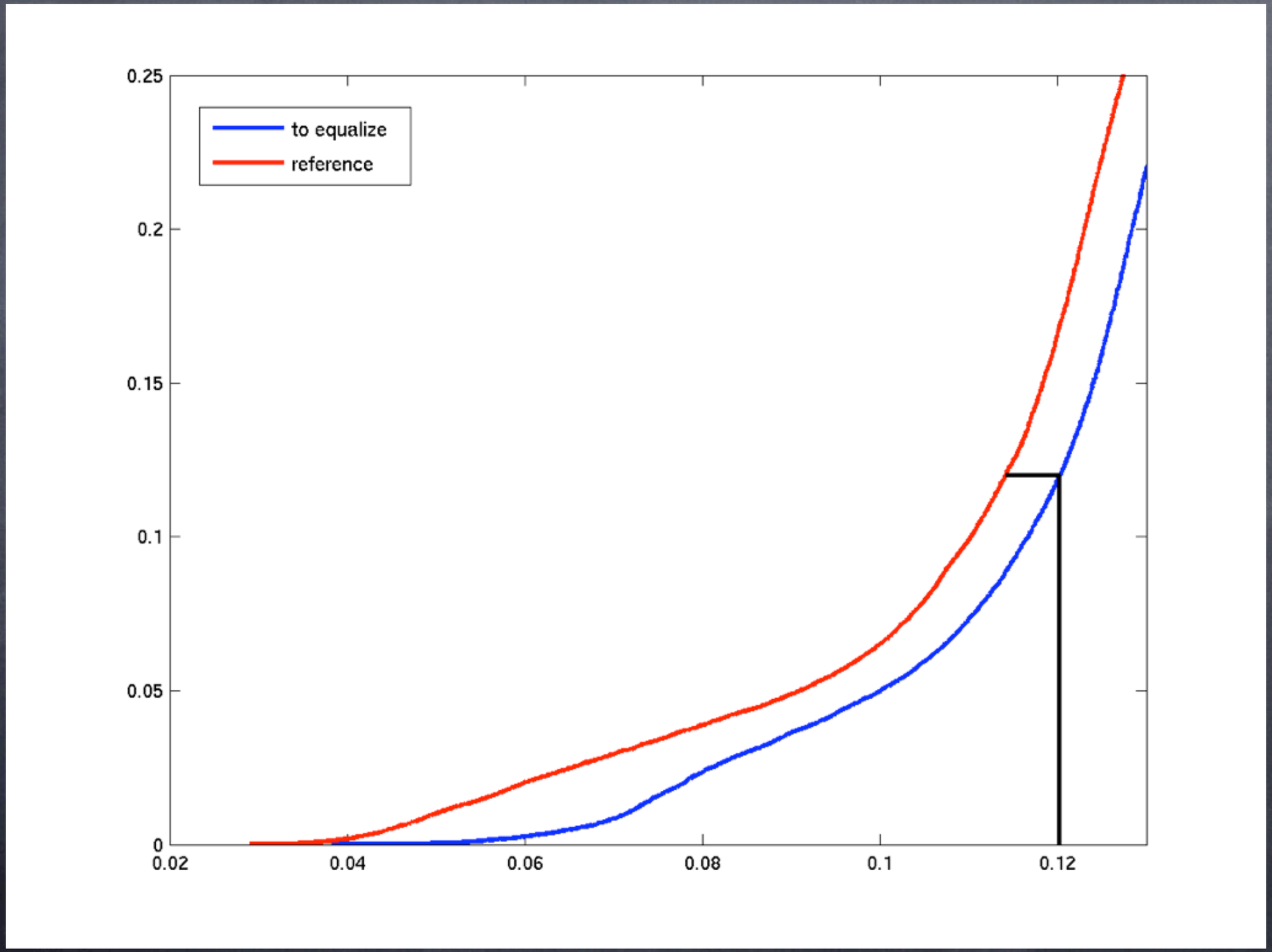
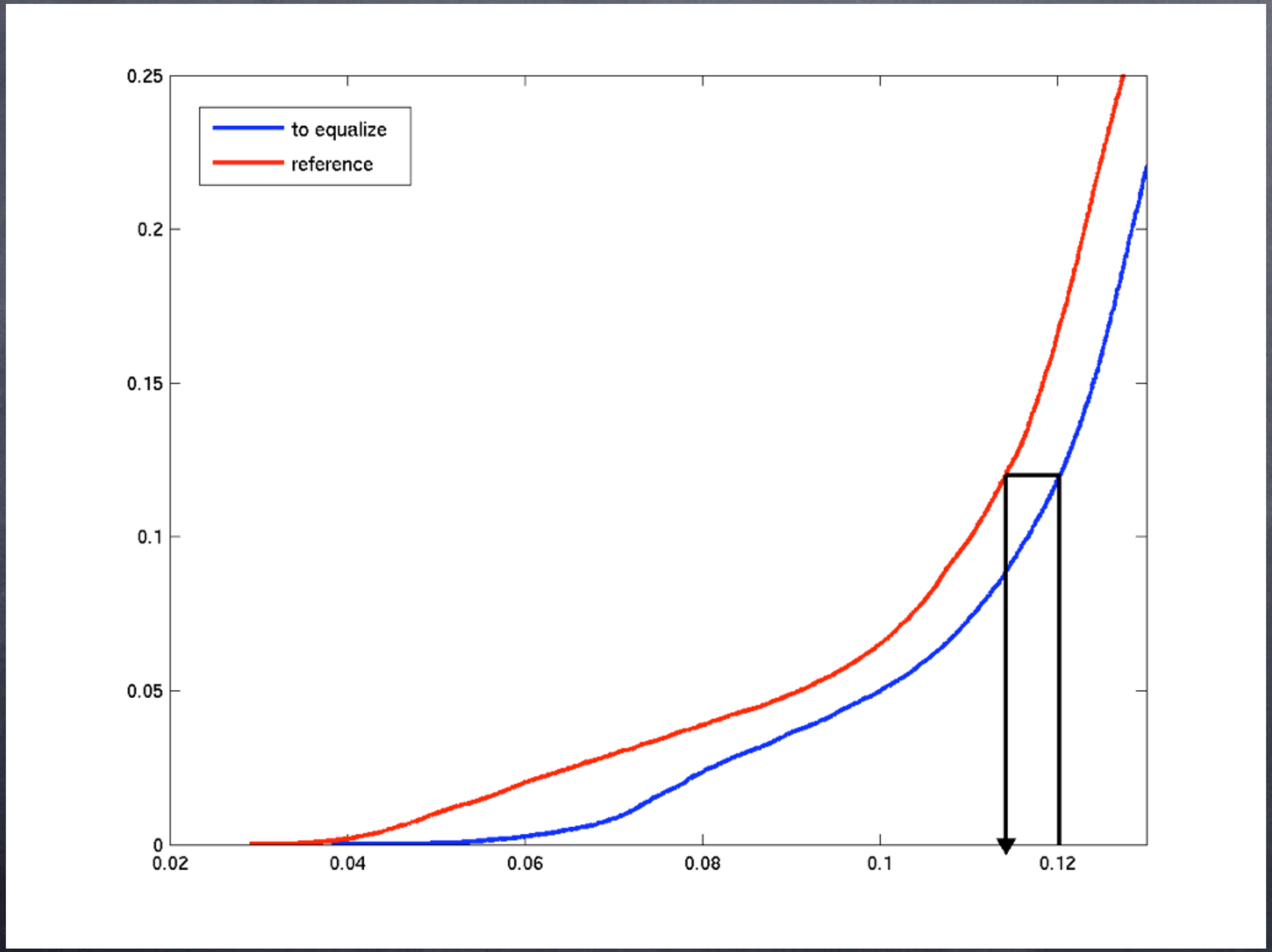


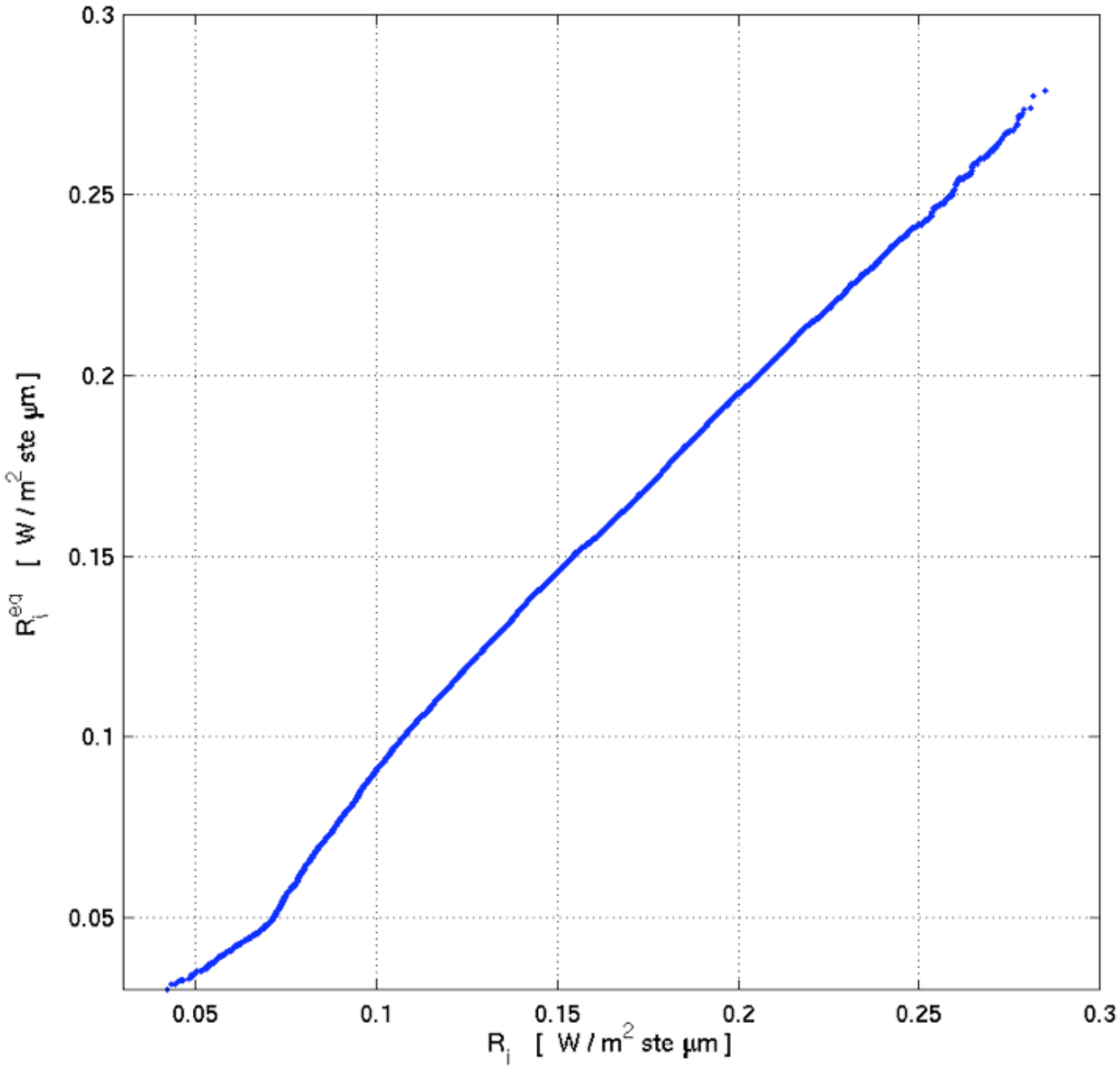
Histogram matching



Histogram matching



Histogram matching



The FOV Overlapping Method

Stripes
MODIS
Review
FOM

- the "bow-tie" effect as calibration side information
- the simple idea
- the multistage design
  - metrics and classification
  - pre-equalization
  - destriping model
  - mirror side dependance
- results
- the time variation issue

the "bow-tie effect"

Stripes
MODIS
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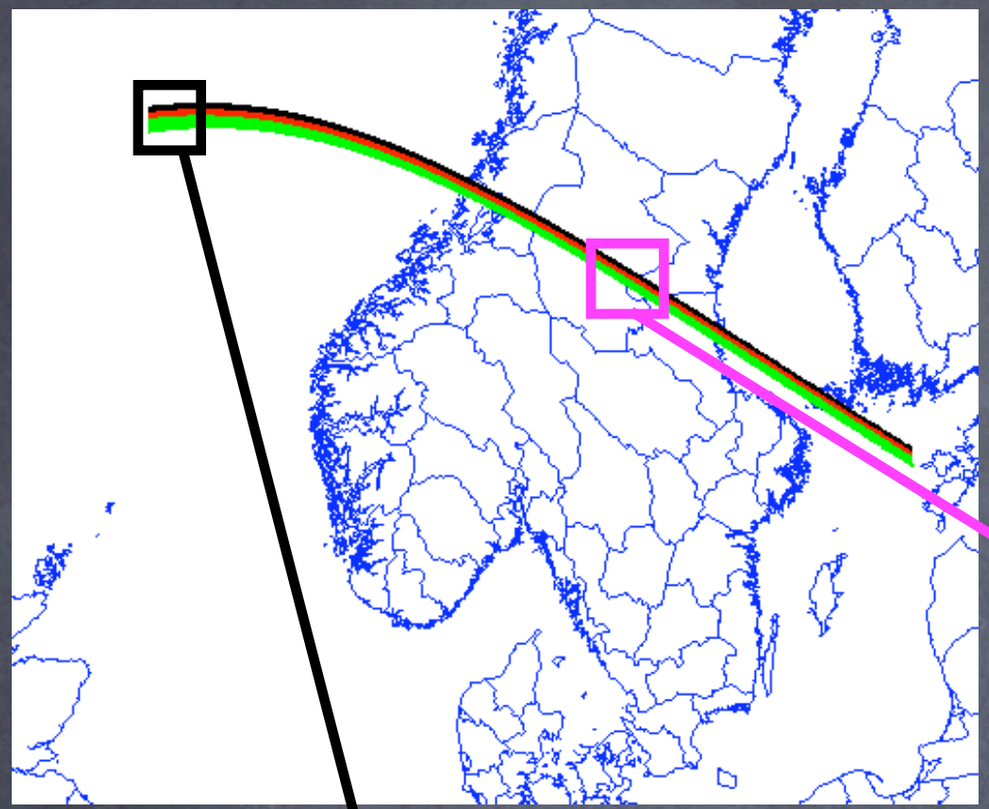
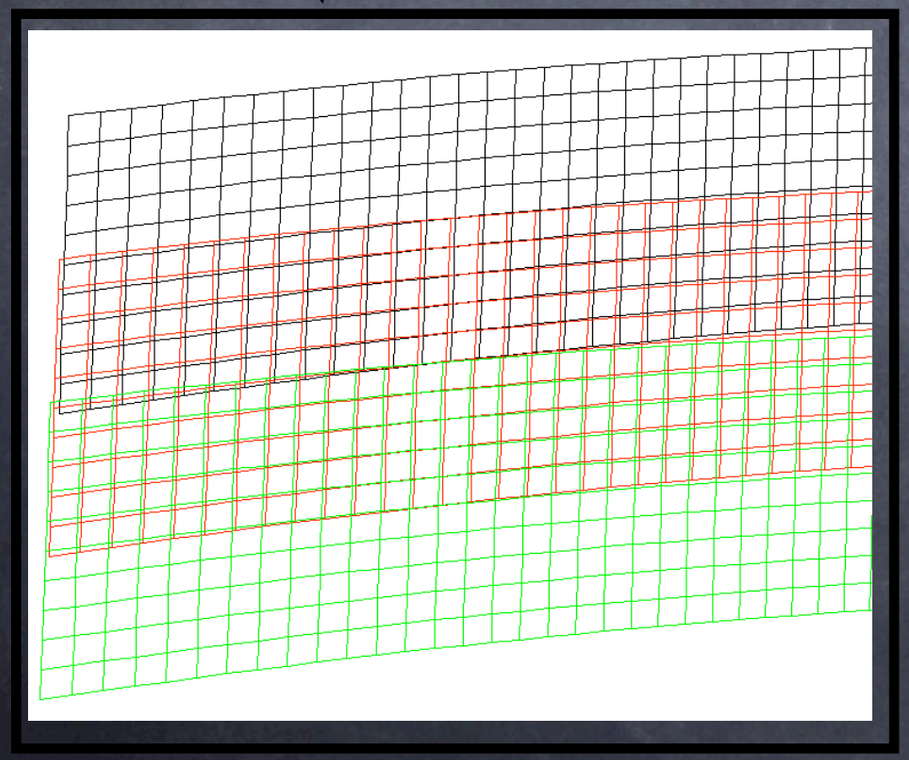
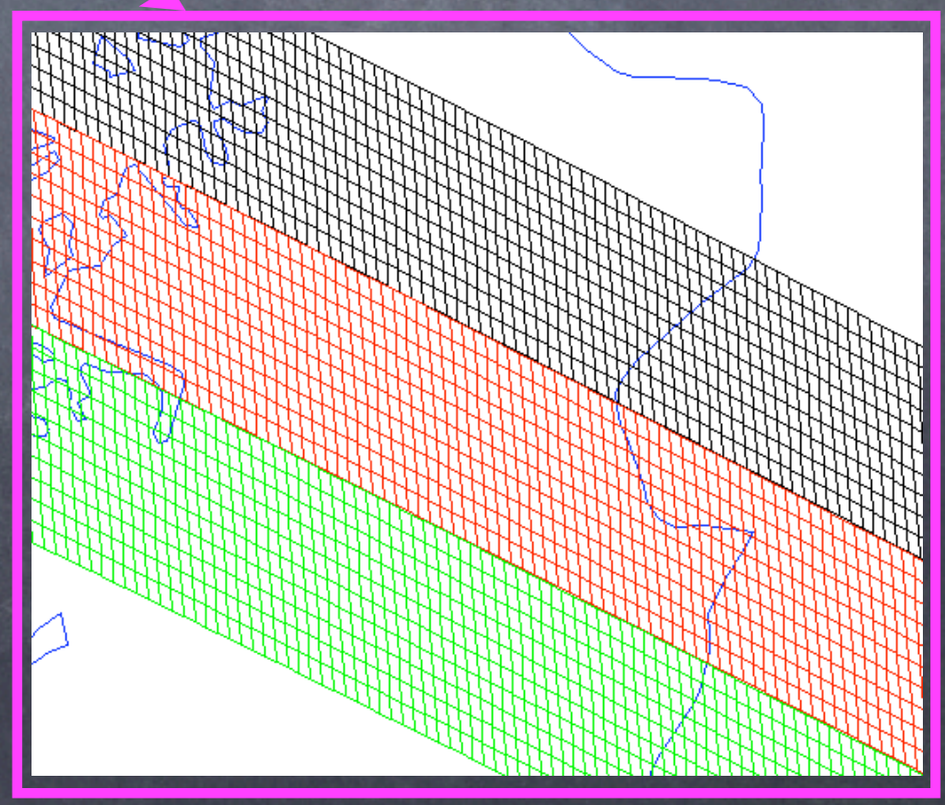
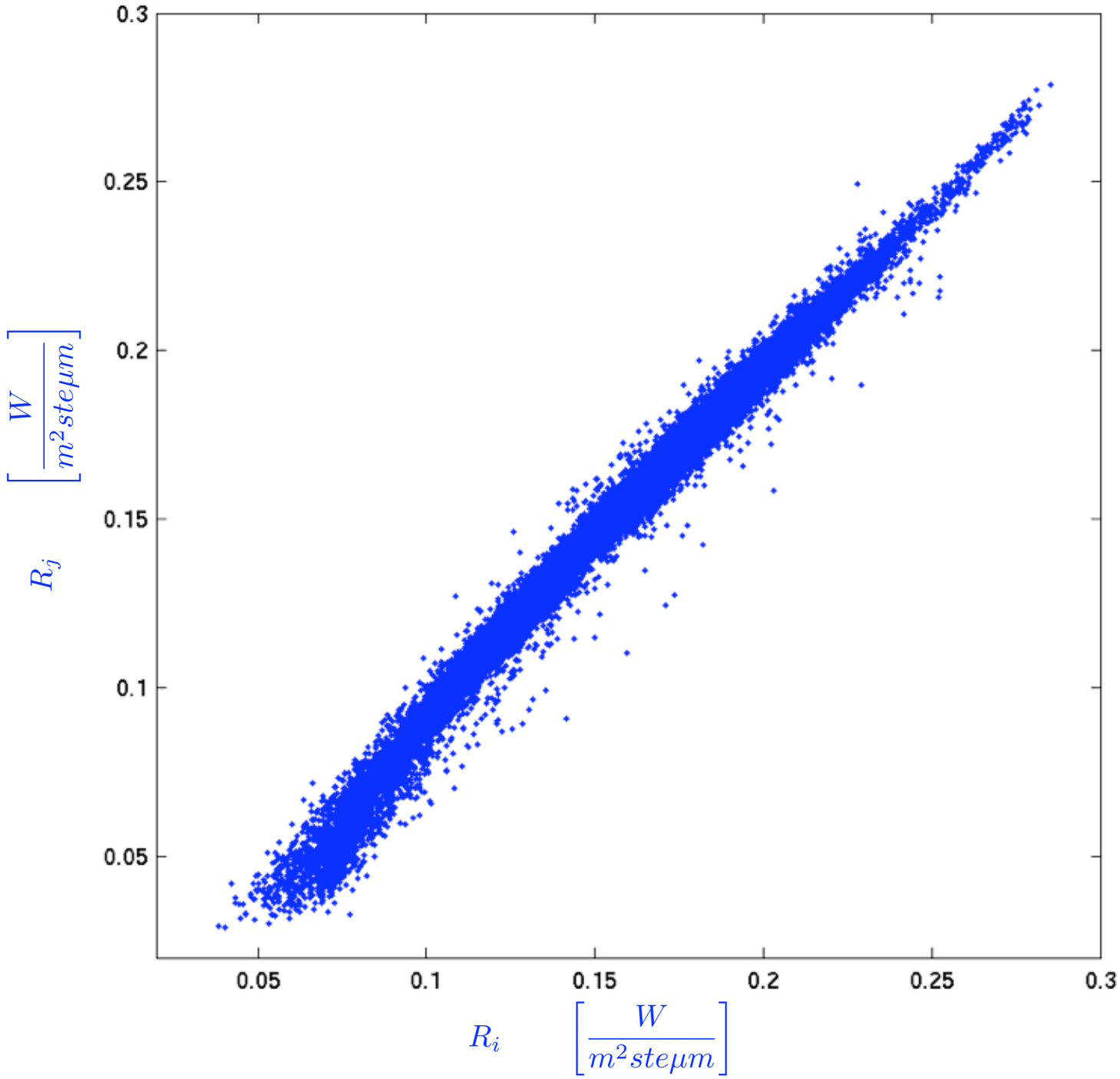






the simple idea



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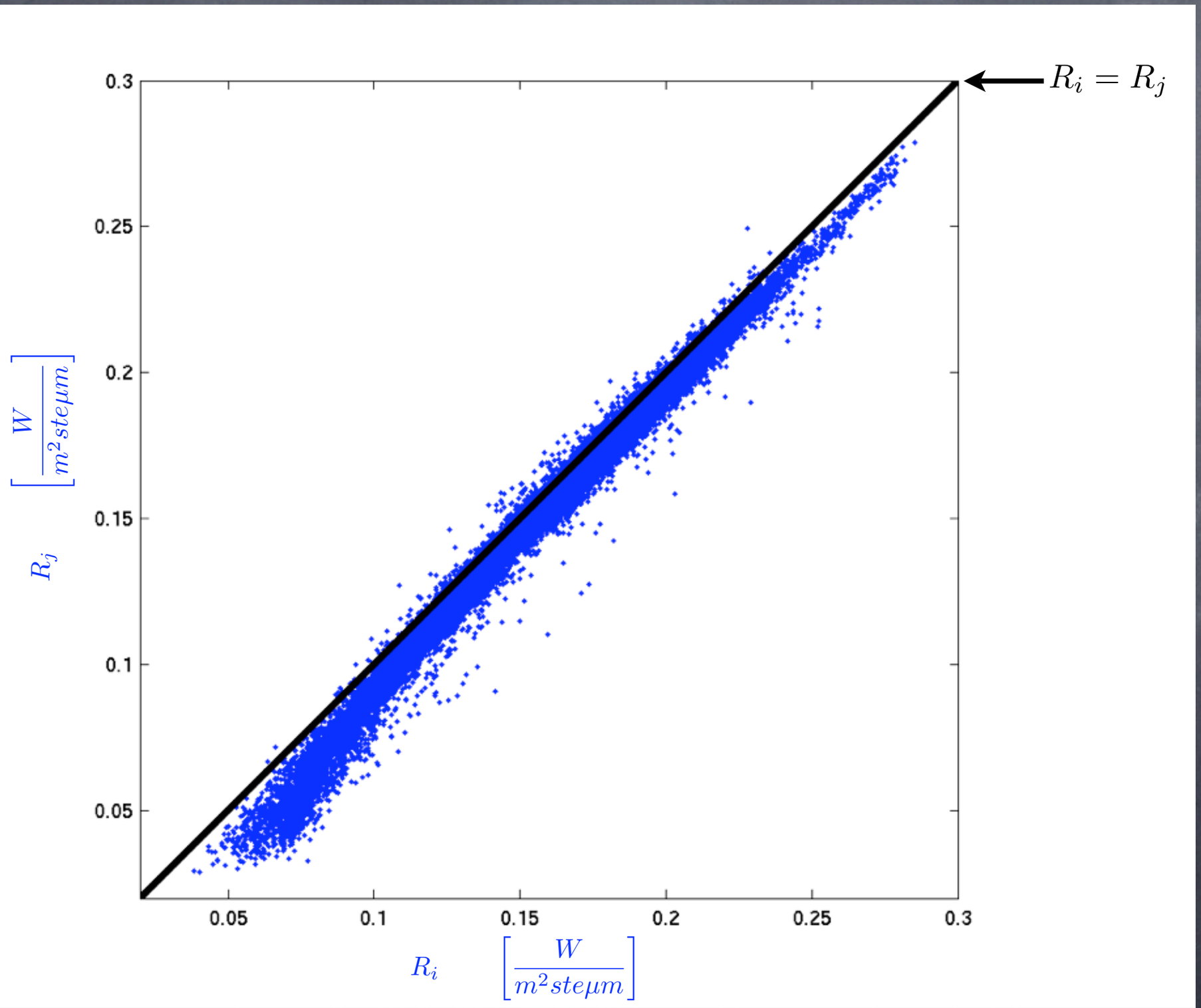

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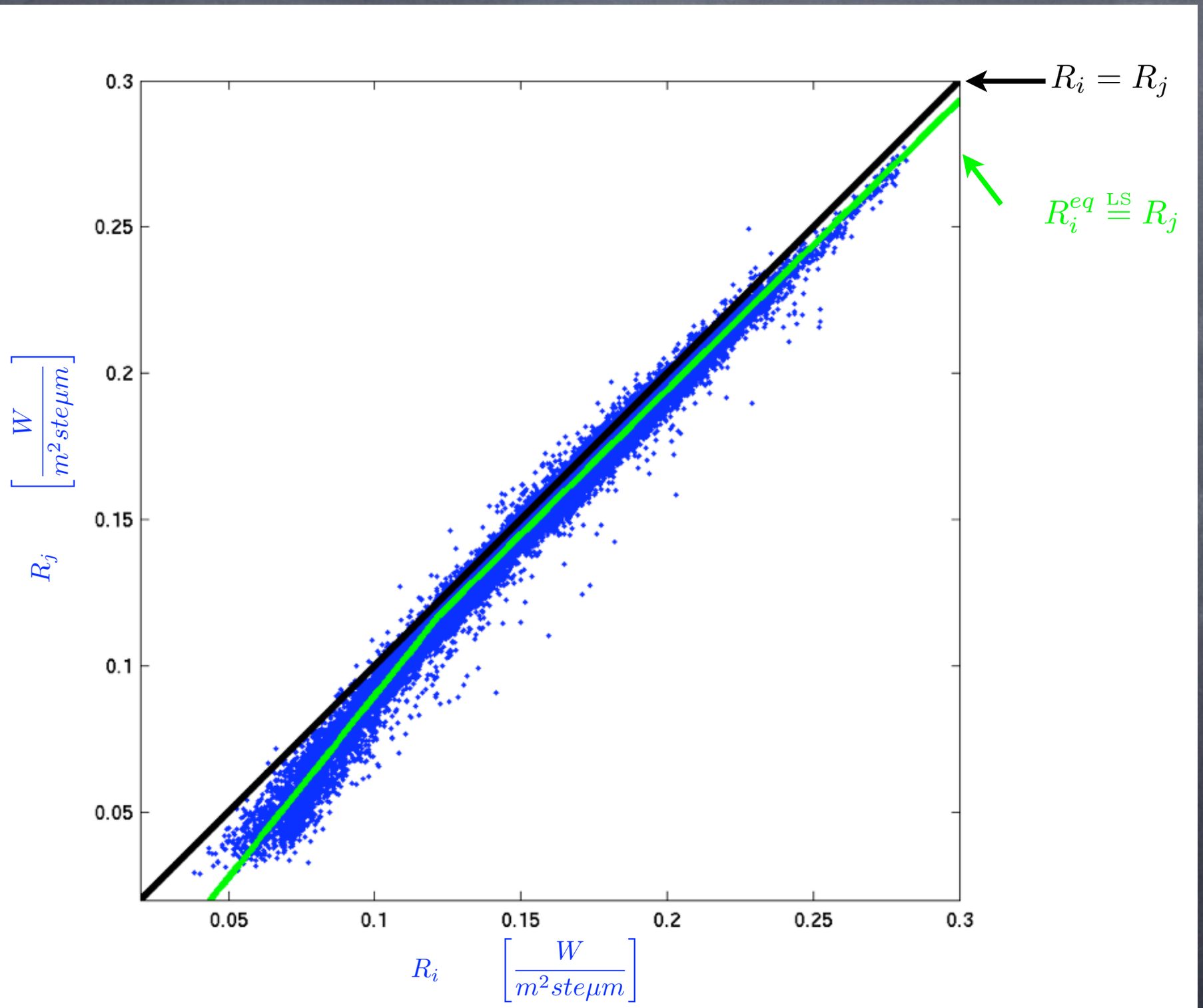
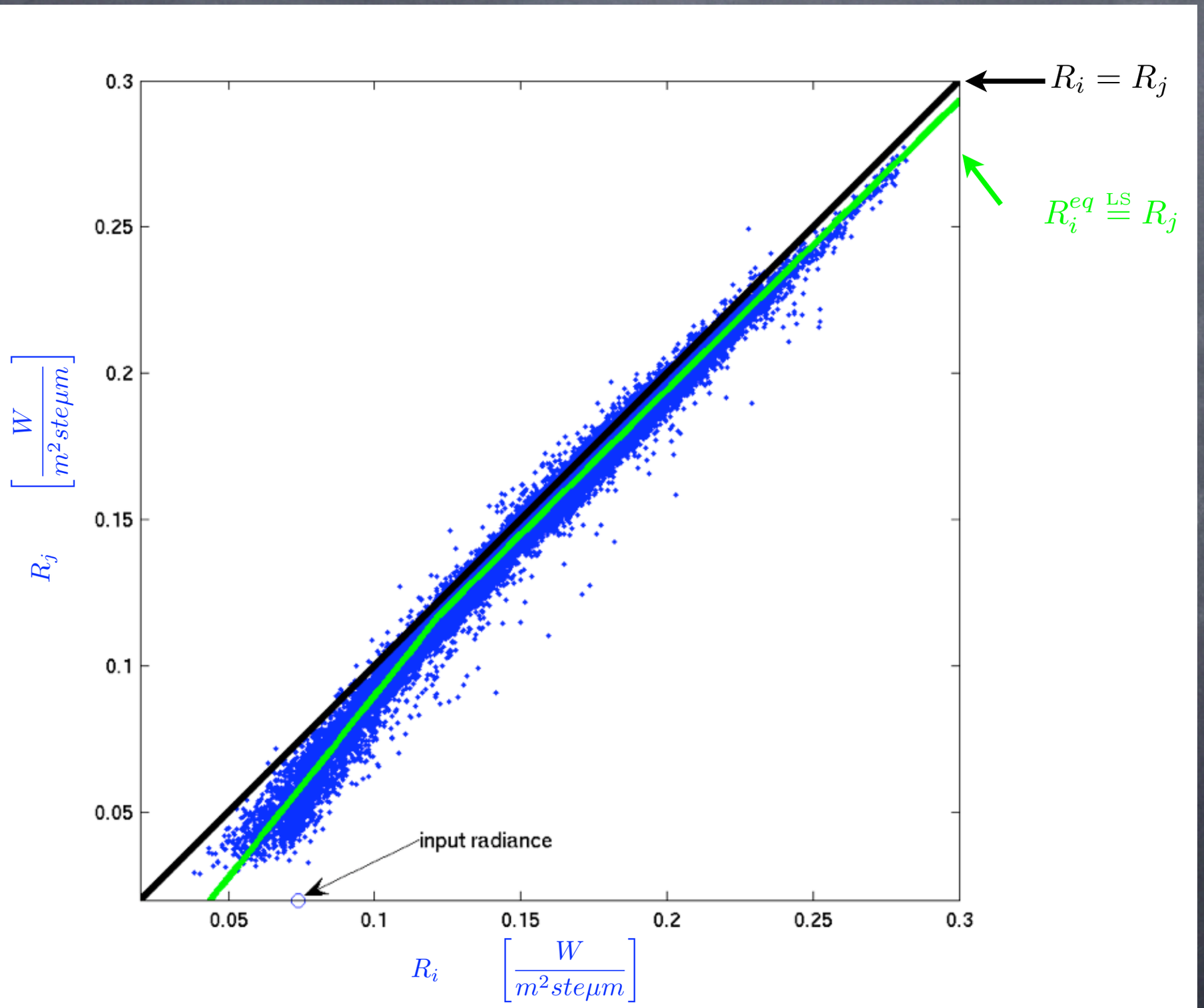
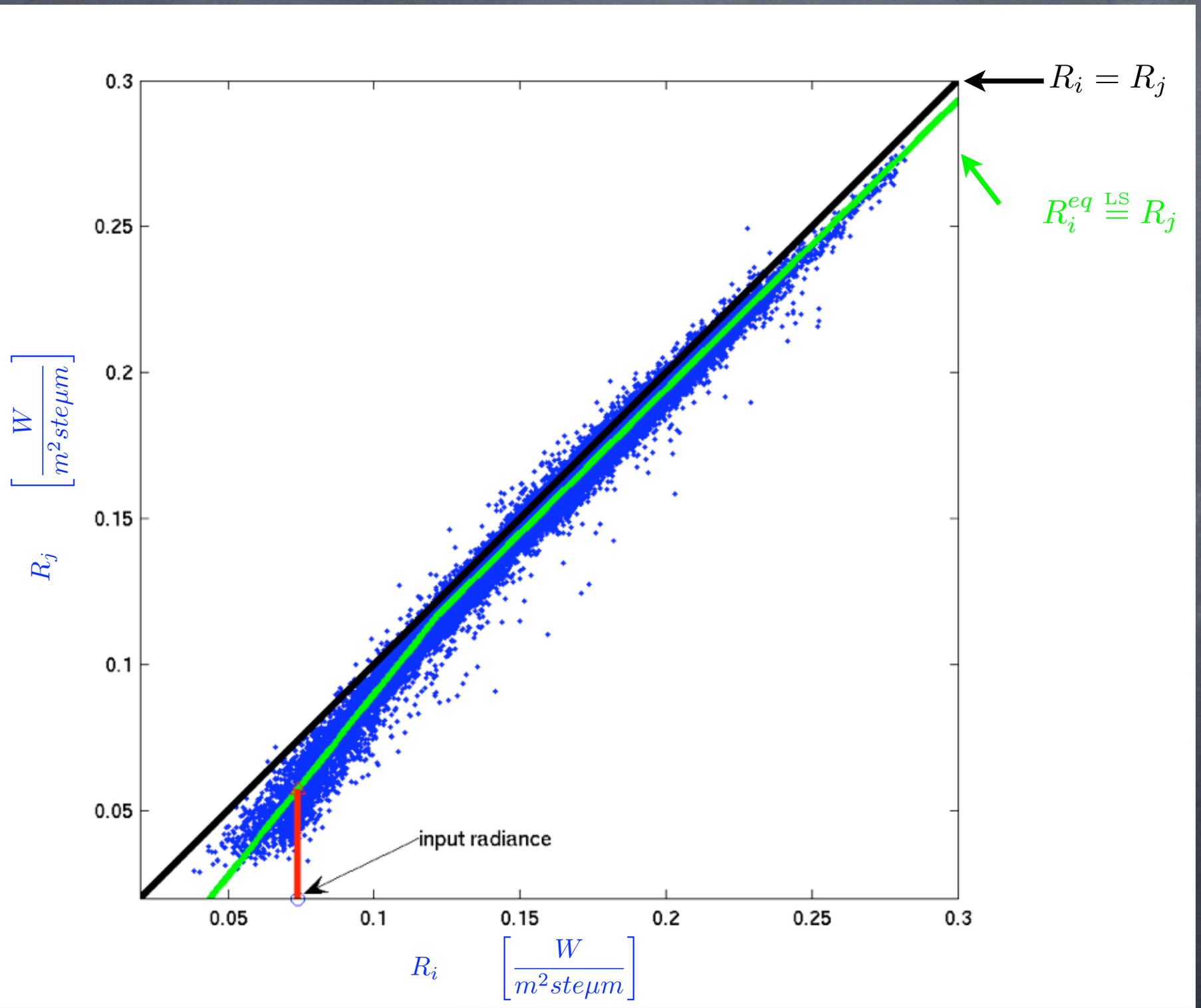


the simple idea



the simple idea



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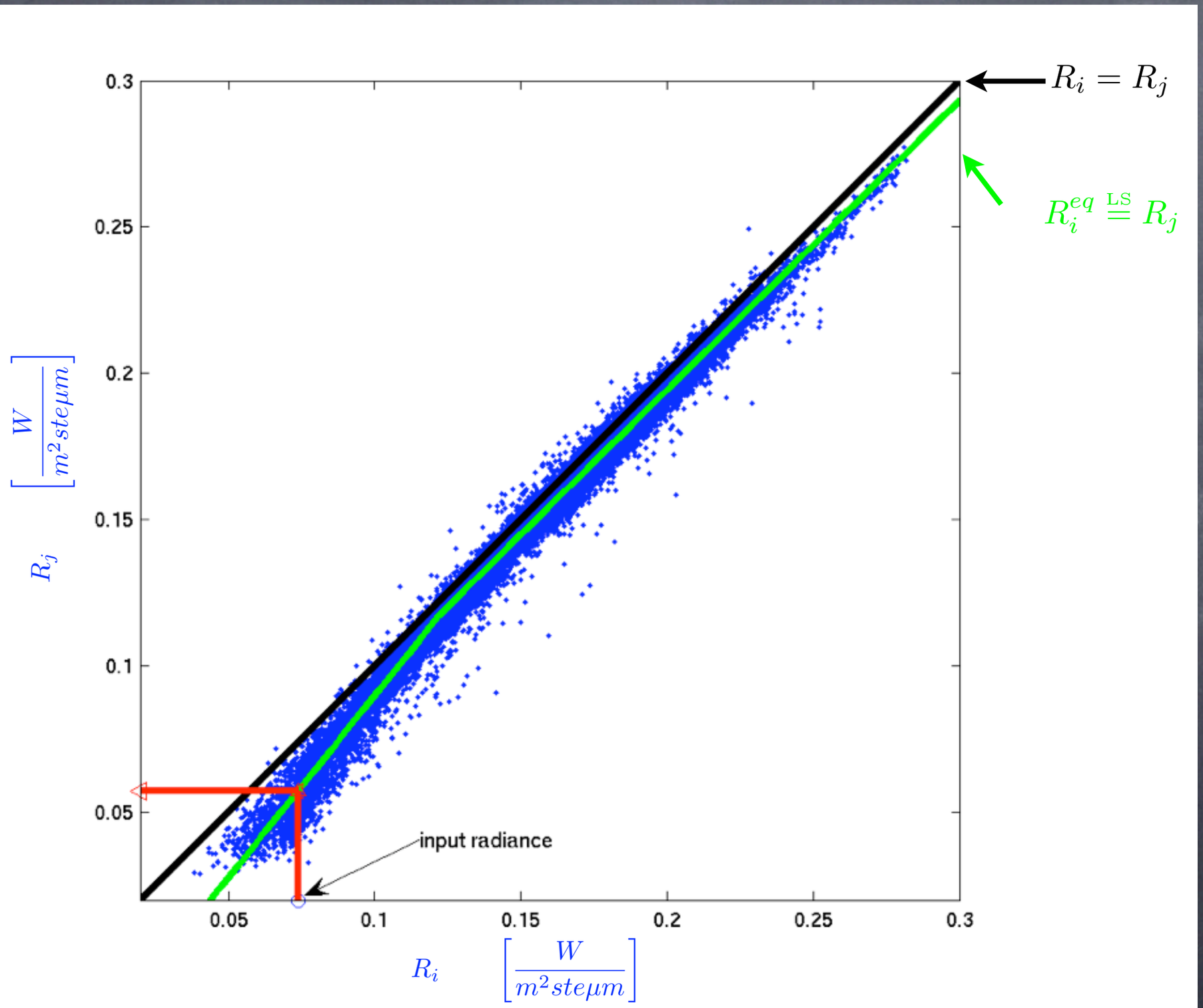

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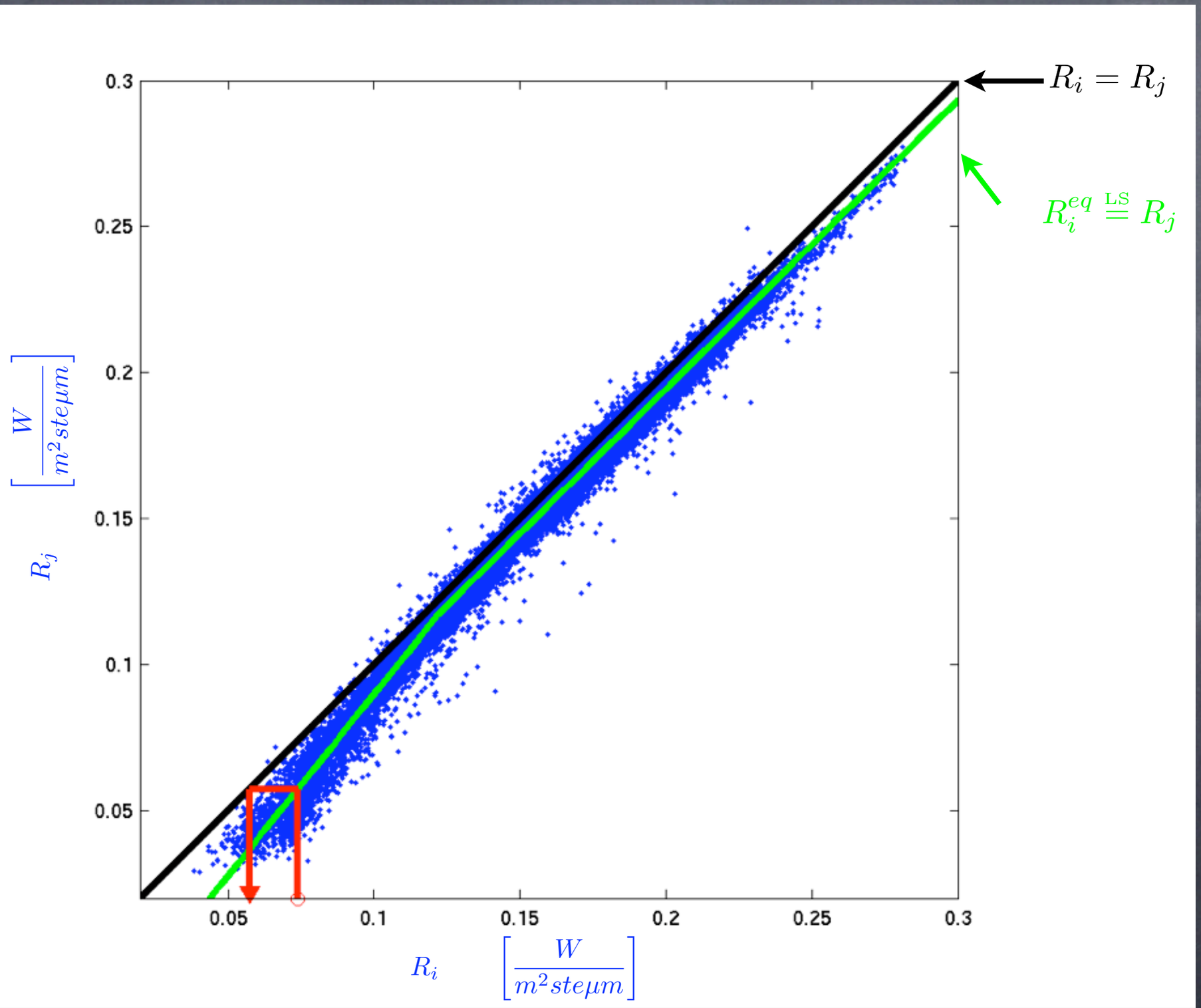

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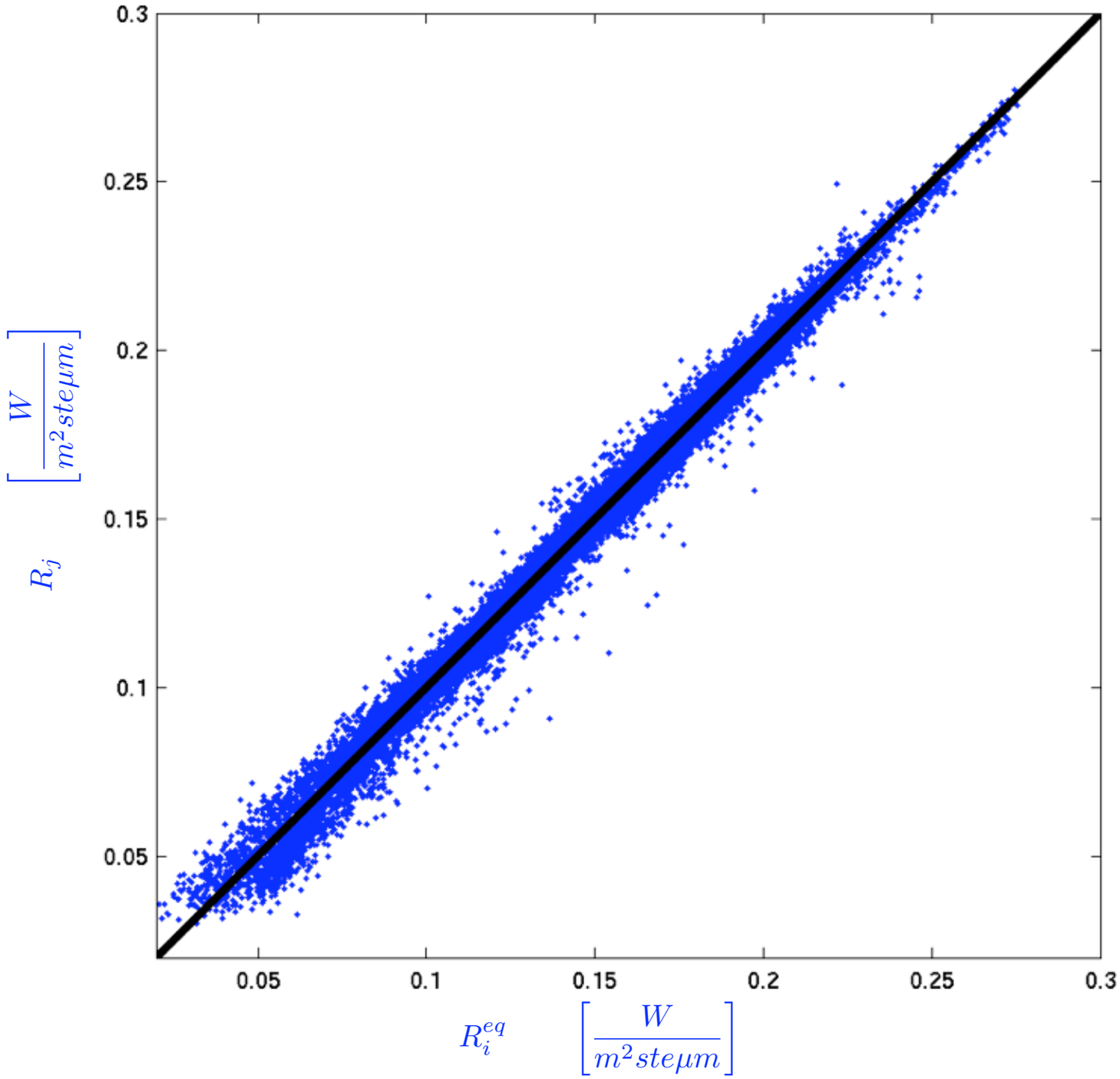

the simple idea

- Identify the reference detector
- Define a model for the striping
- Equalize the detectors

The FOV Overlapping Method

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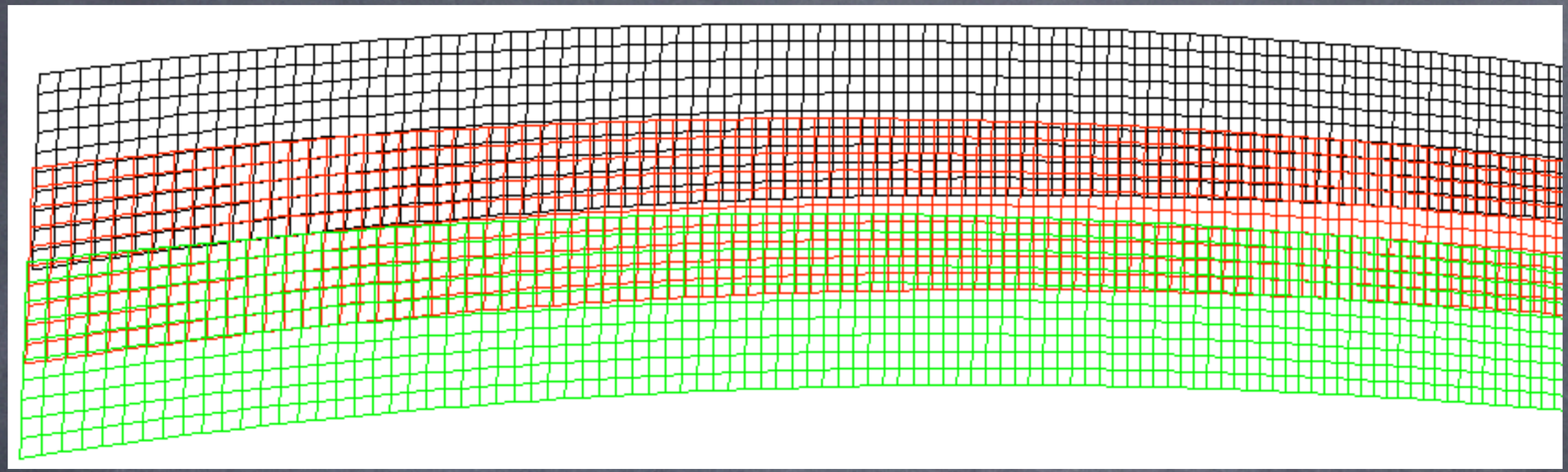
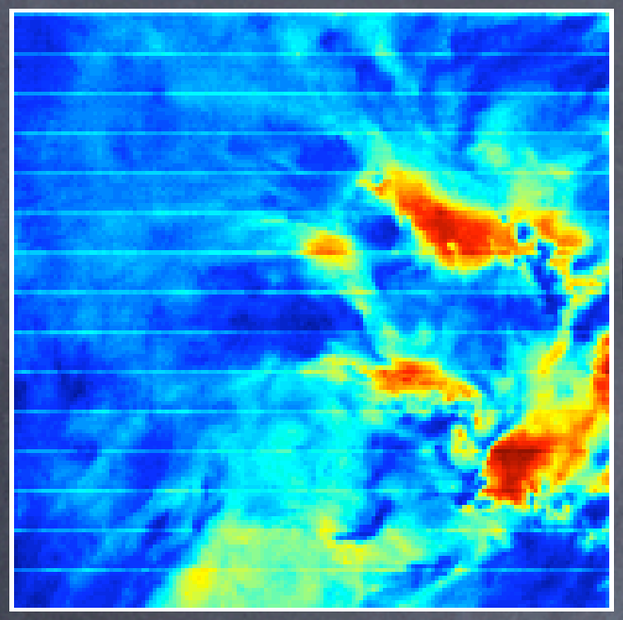
  - mirror side dependance
- results
- the time variation issue

the multistage design



$n \backslash^{n+1}$	d_6	d_7	d_8	d_9	d_{10}
d_1	X	X	X	X	X
d_2		X	X	X	X
d_3			X	X	X
d_4				X	X
d_5					X



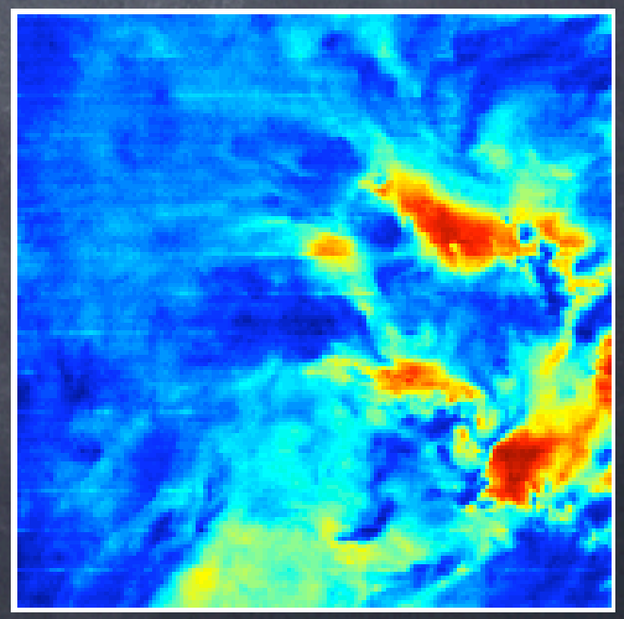
Stage 0: Identify the Overlapping

Stage 1: Classify the detectors (DIF e OOF)

Stage 2: Compute the reference (Pre-equalization)

Stage 3: Destripe the OOF detectors

Stage 4: Equalize excluded detectors



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the multistage design

the multistage design

metrics and classification

Local metric

$$d_{i,j}^{btb} = \sqrt{\frac{(\mathbf{R_i} - \mathbf{R_j})^T \mathbf{W}_{i,j} (\mathbf{R_i} - \mathbf{R_j})}{trace(\mathbf{W}_{i,j})}}$$

overlapping percentage

Global metric

$$D_{i,j} = \frac{1}{N_{obs}} \sum_{n=1}^{N_{obs}} |F_i(r(n)) - F_j(r(n))| \; ;$$

Empirical CDF

the multistage design

metrics and classification

Stripes
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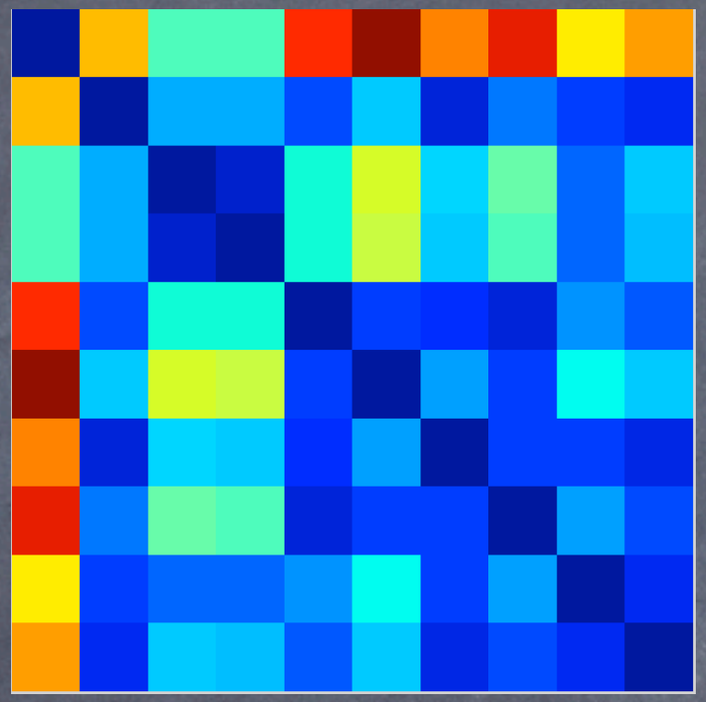
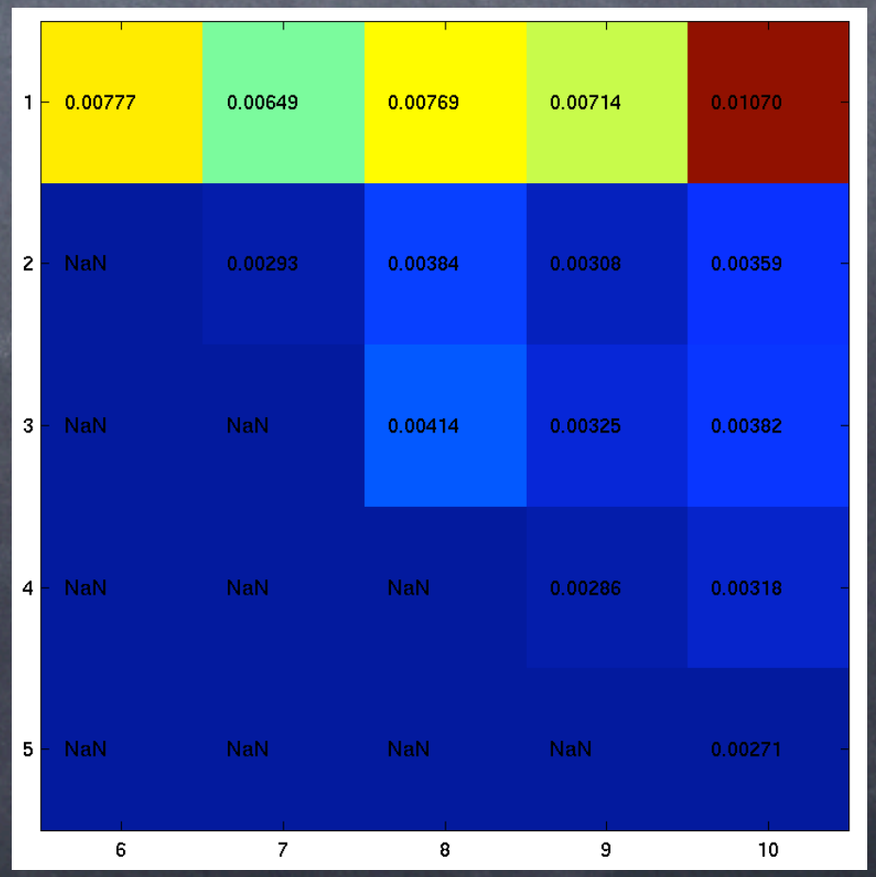
KS
distances



detector "i" is classified as OOF if its distances are larger that a specified threshold.
The procedure is iterative and is computed, at each iteration, on a reduced set.



detector "i" is classified as OOF if its distances are larger that a specified threshold.
The procedure is iterative, detector classification order is based on the number of available overlap with in-family detectors

btb
distances

the multistage design

metrics and classification

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FOM

KS / btb	DIF	OOF
DIF	DIF	OOF
OOF	As It Is	
EXC	EXC	

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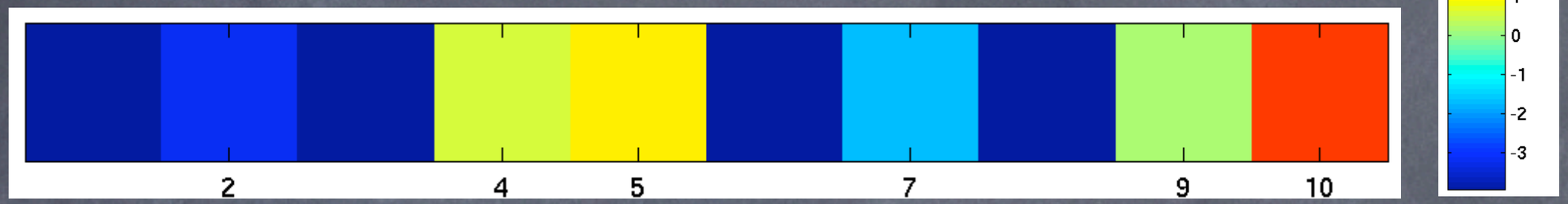
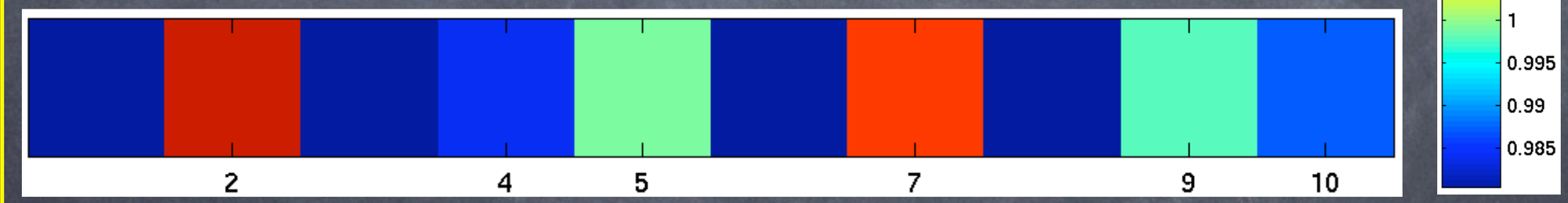
the multistage design

pre-equalization

$$\mathbf{a_0} = \left[a_0(d_{dif(1)}), \cdots, a_0(d_{dif(N_{dif})})\right]^T$$



$$\mathbf{a_1} = \left[a_1(d_{dif(1)}), \cdots, a_1(d_{dif(N_{dif})})\right]^T$$



$$\begin{cases} a_0(d_{dif(1)})\mathbf{1} + a_1(d_{dif(1)})\,\mathbf{R}_{d_{dif(1)}} \overset{\text{LS}}{=} \widetilde{\mathbf{R}} \\ \vdots \\ a_0(d_{dif(N_{dif})})\mathbf{1} + a_1(d_{dif(N_{dif})})\,\mathbf{R}_{d_{dif(N_{dif})}} \overset{\text{LS}}{=} \widetilde{\mathbf{R}} \end{cases}$$

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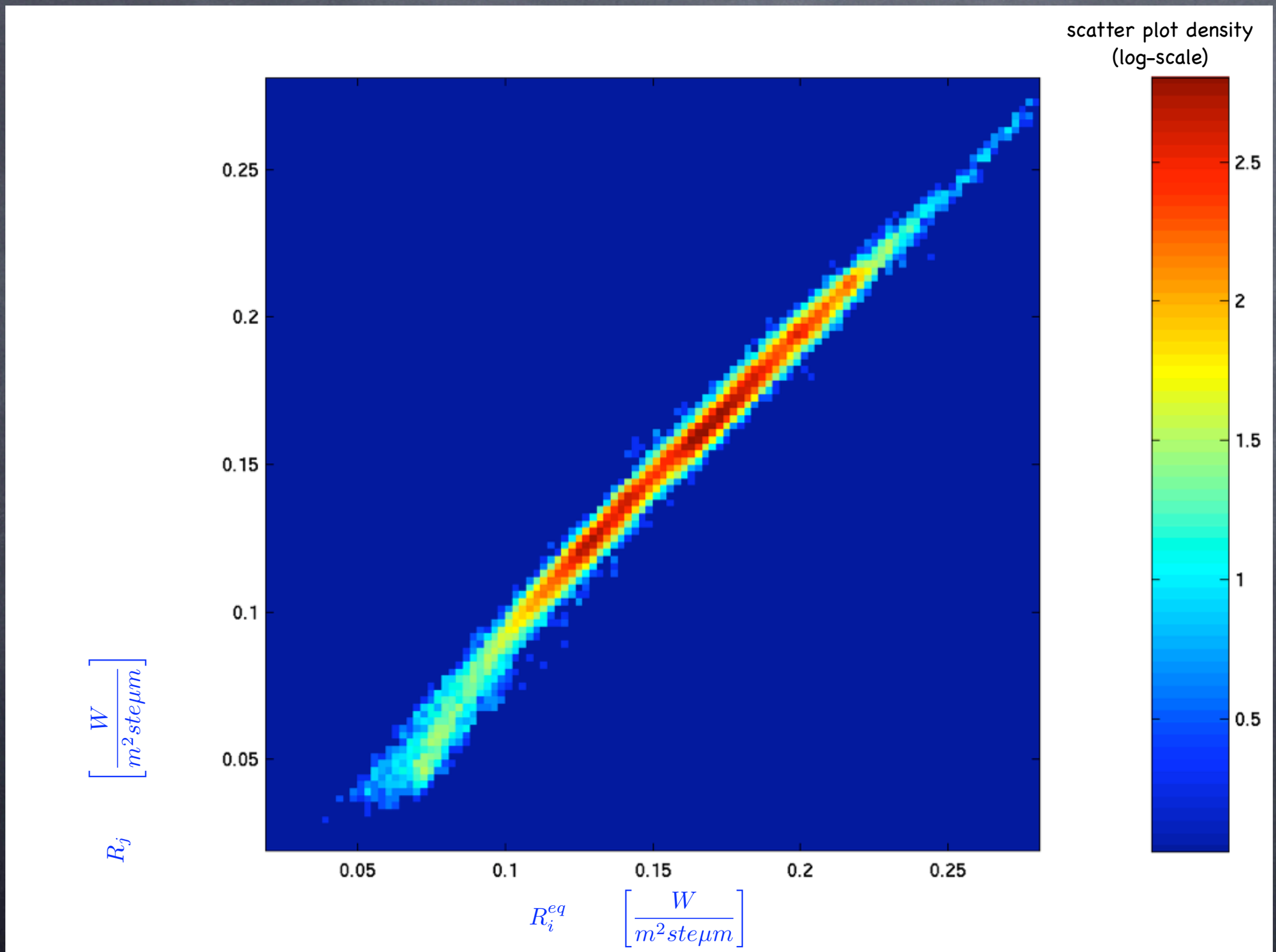
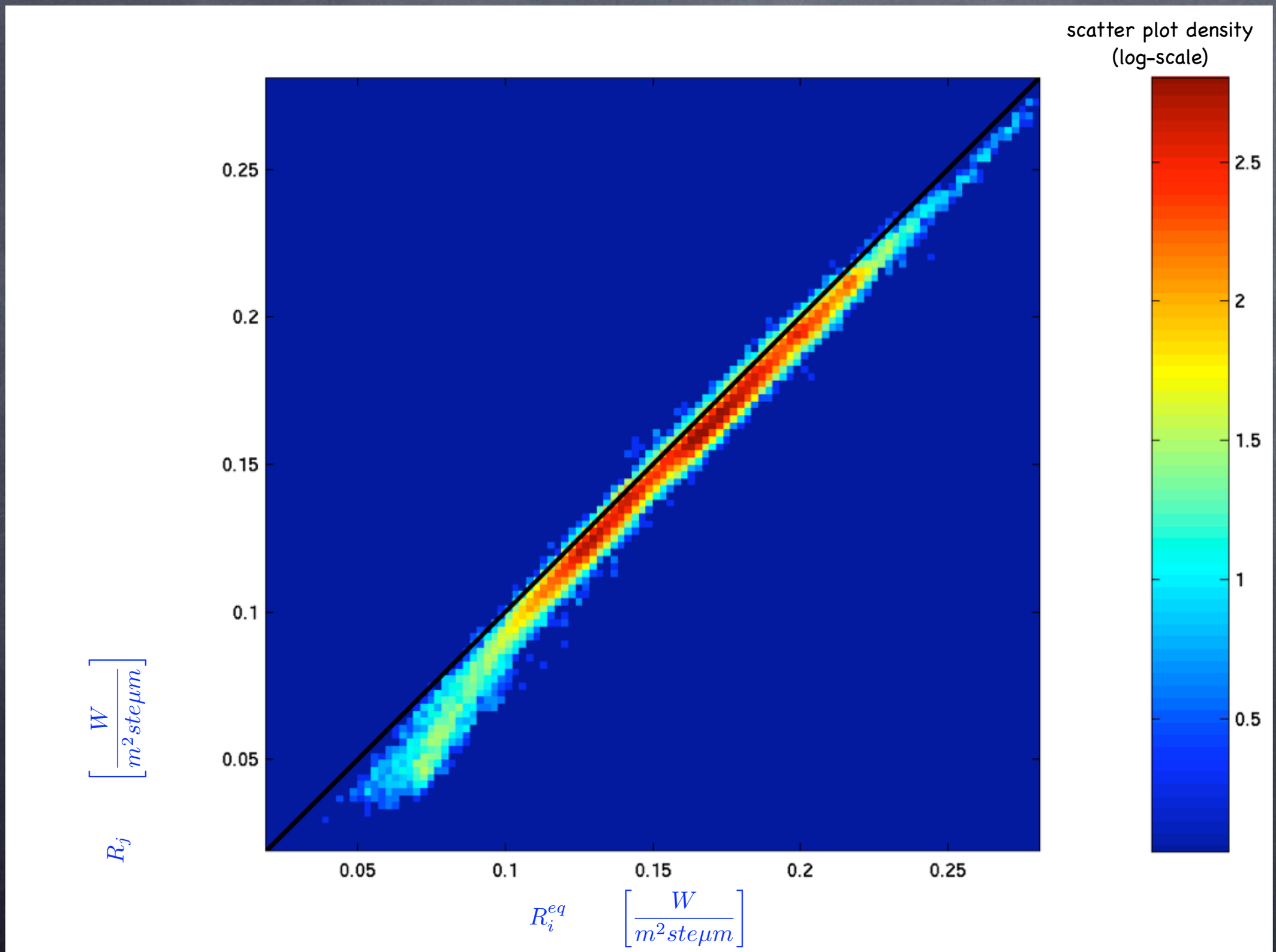
the multistage design

destriping model



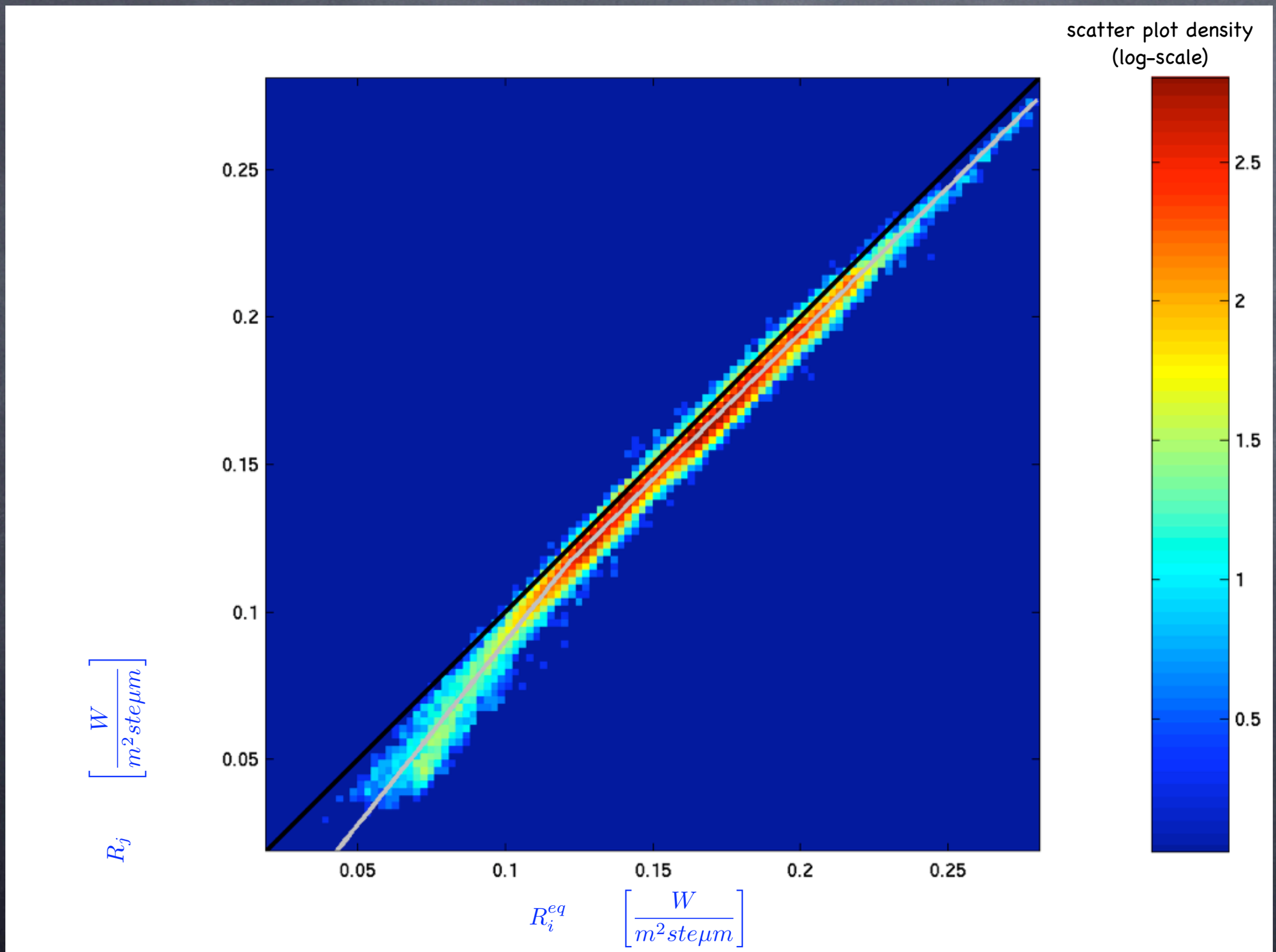
the multistage design

destriping model



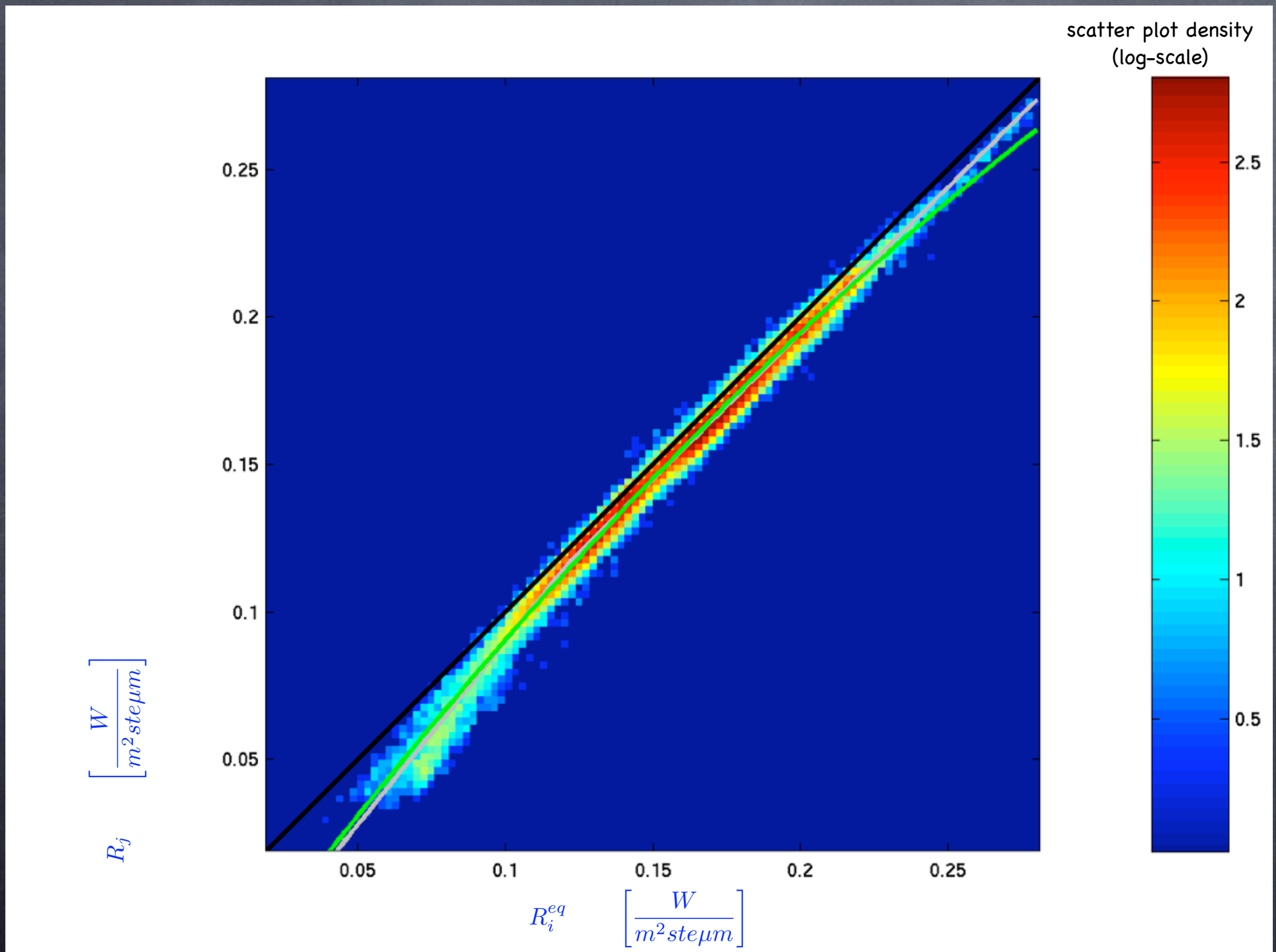
the multistage design

destriping model



the multistage design

destriping model



the multistage design

destriping model

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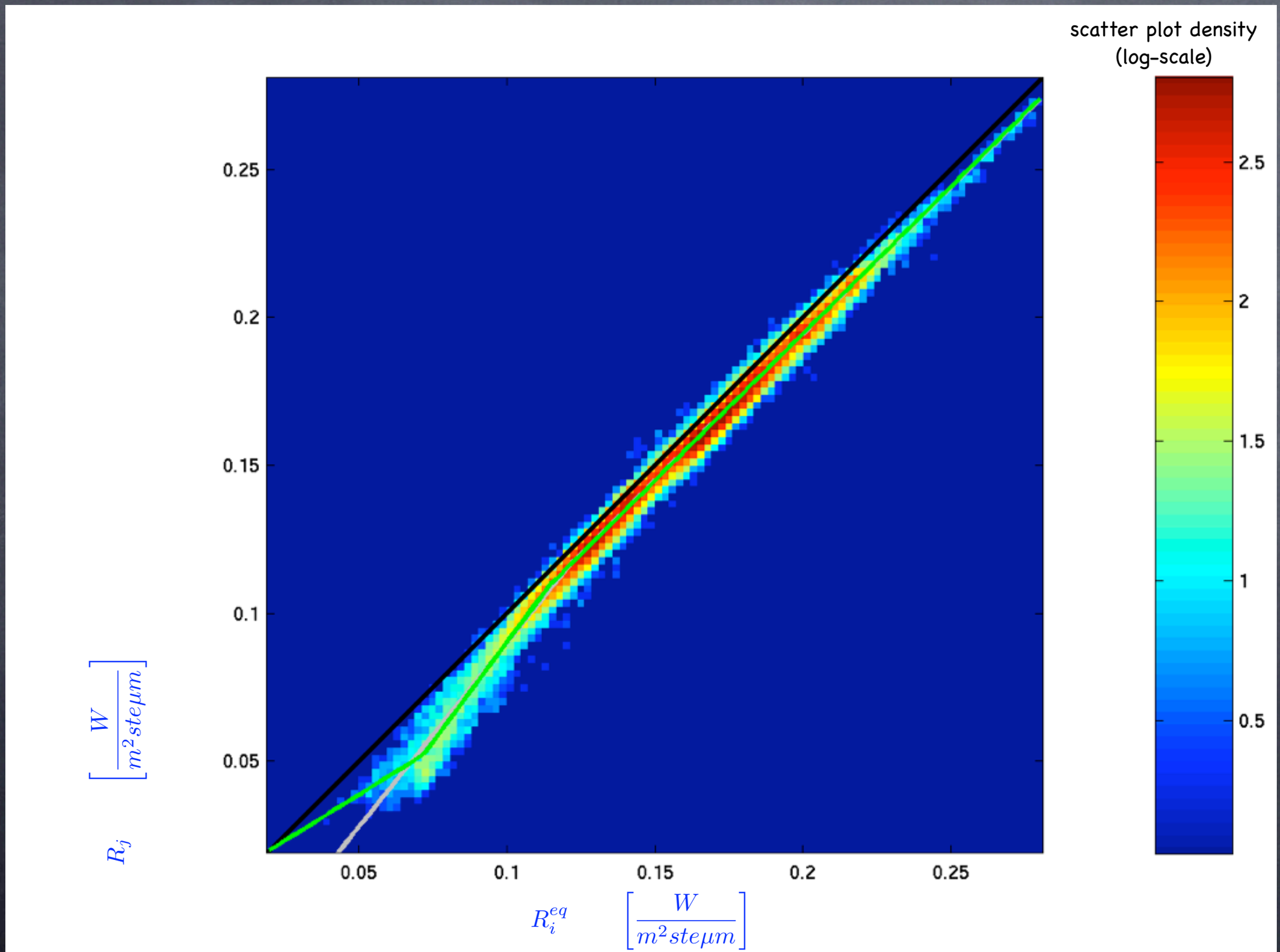
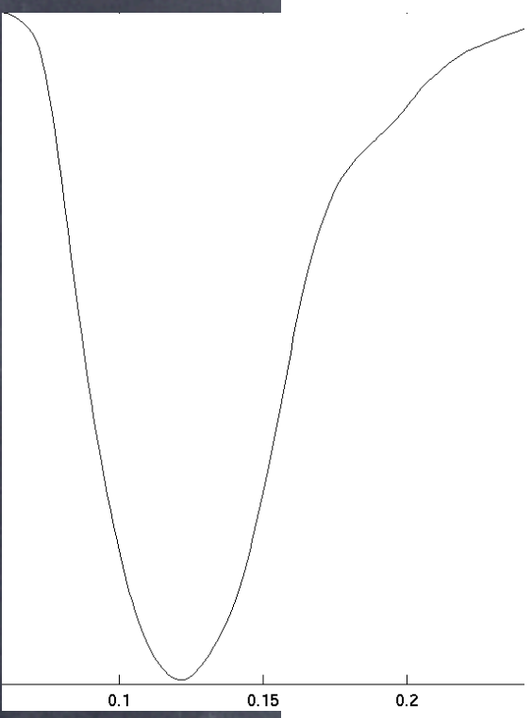


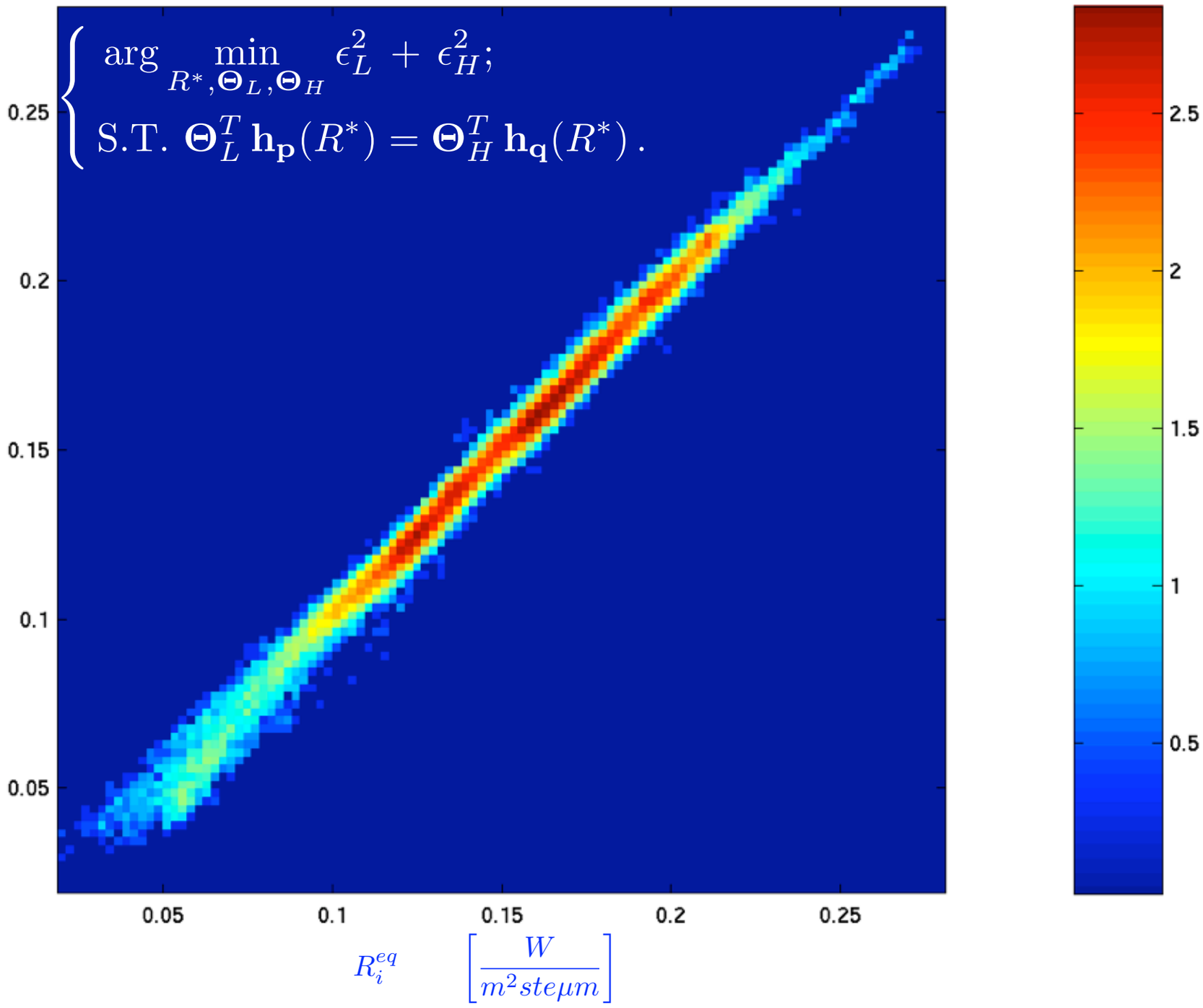
the multistage design

destriping model



$$\begin{cases} \arg \min_{R^*, \boldsymbol{\Theta}_L, \boldsymbol{\Theta}_H} \epsilon_L^2 + \epsilon_H^2; \\ \text{S.T. } \boldsymbol{\Theta}_L^T \mathbf{h_p}(R^*) = \boldsymbol{\Theta}_H^T \mathbf{h_q}(R^*) . \end{cases}$$

scatter plot density
(log-scale)



$R_j \quad \left[\frac{W}{m^2 ste \mu m}\right]$

$R_i^{eq} \quad \left[\frac{W}{m^2 ste \mu m}\right]$

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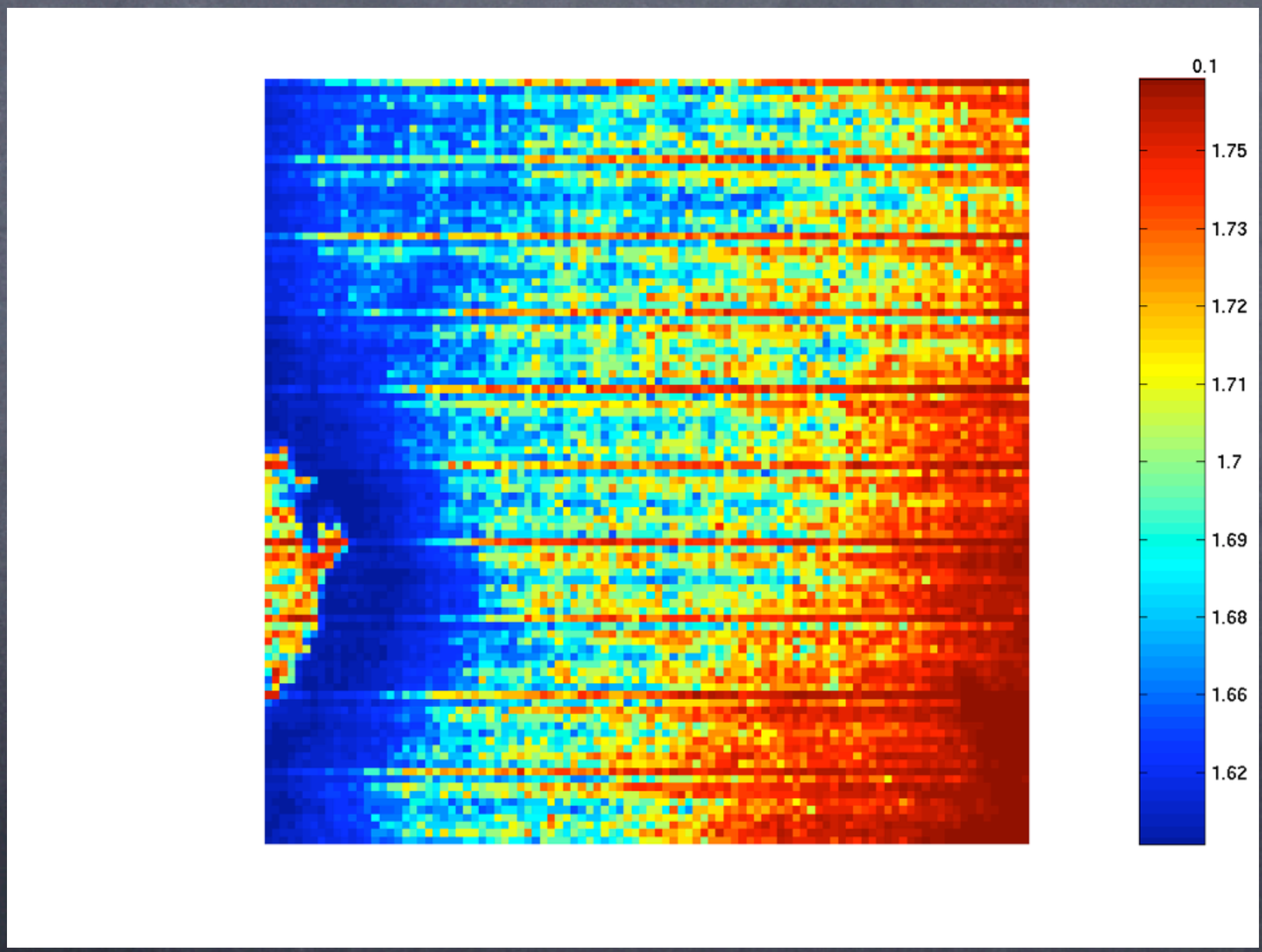
  - > ~~pre-equalization~~
  - > ~~destriping model~~
  - – mirror side dependance
- results
- the time variation issue

the multistage design

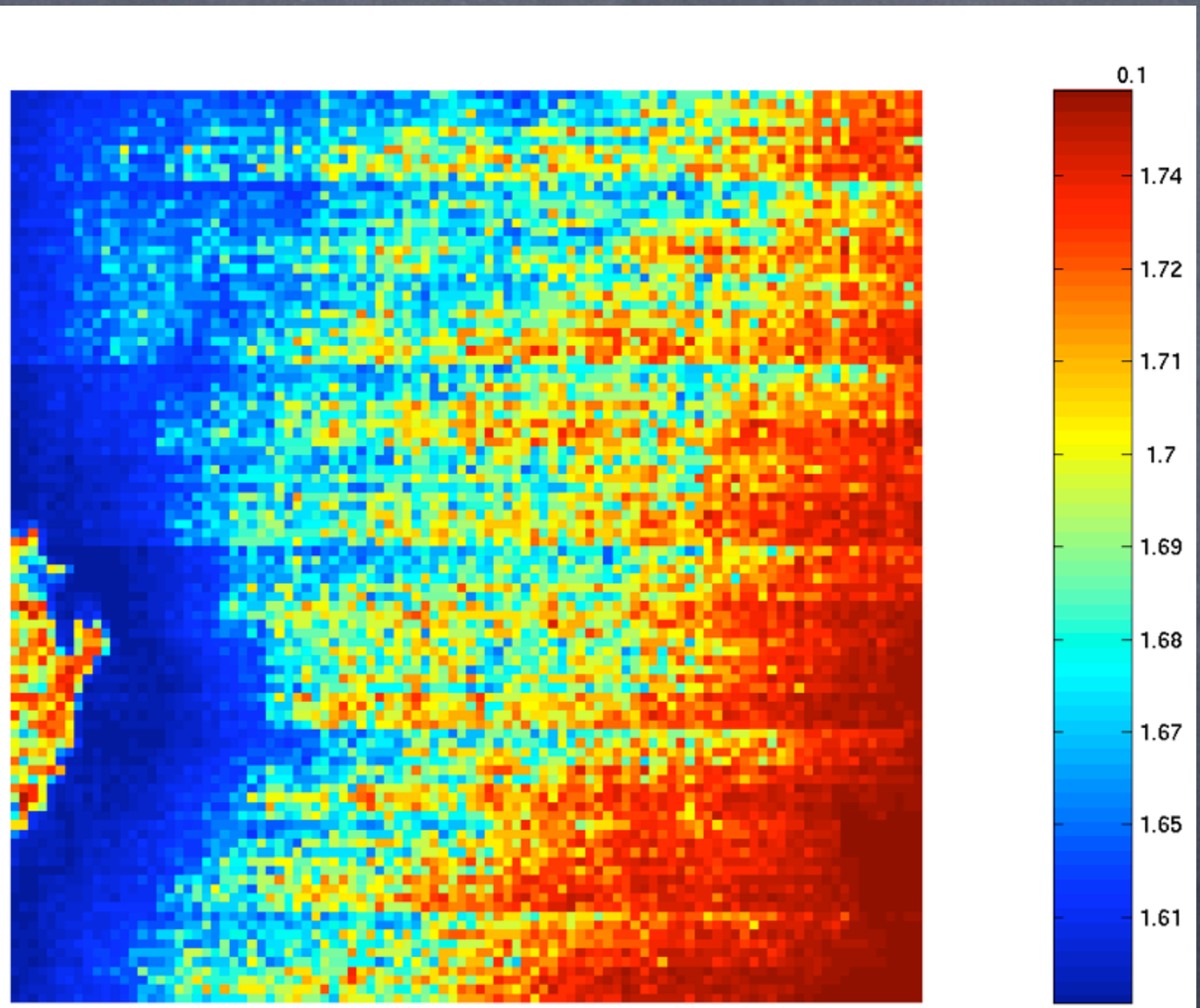
mirror side dependance



original sub-set

the multistage design

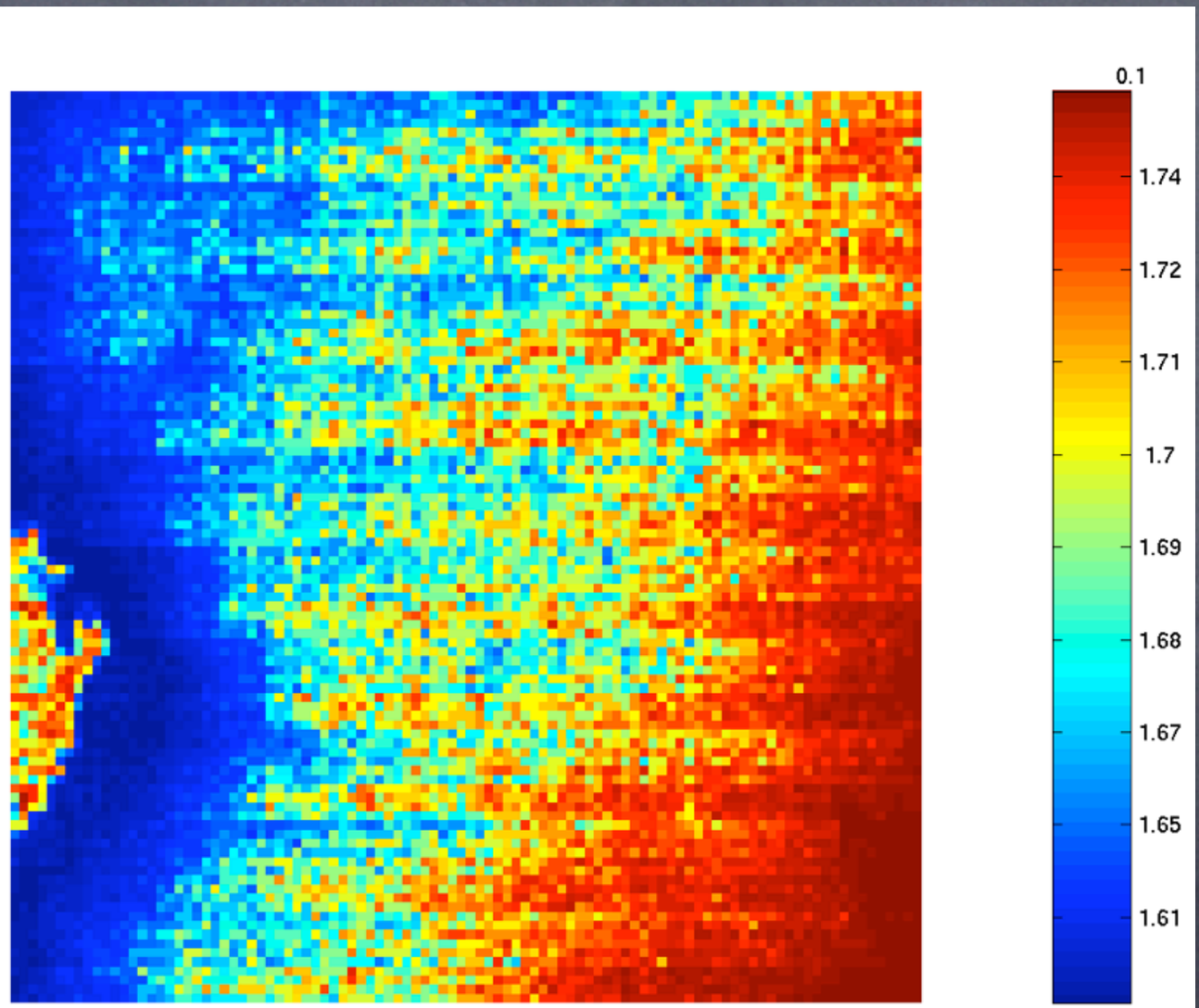
mirror side dependance



without de-banding

the multistage design

mirror side dependance



with MS dependance applied

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results

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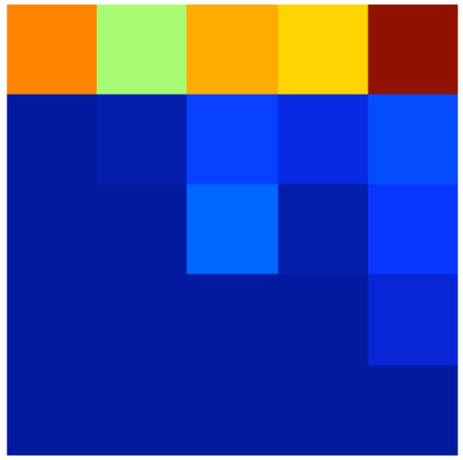
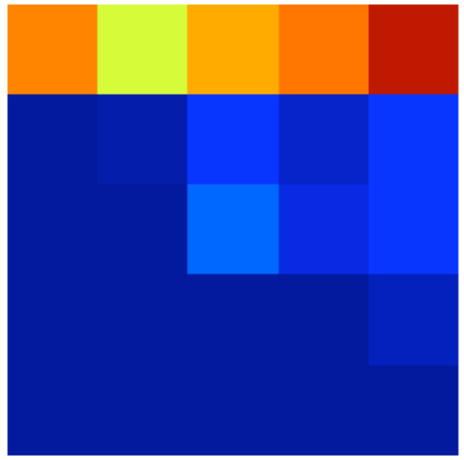
btb
A side

4.2800



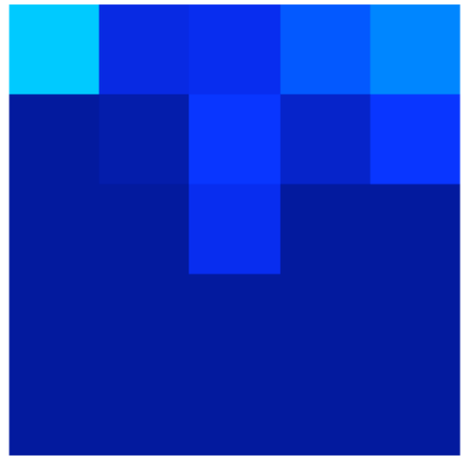
original

4.2917



pre-equalized

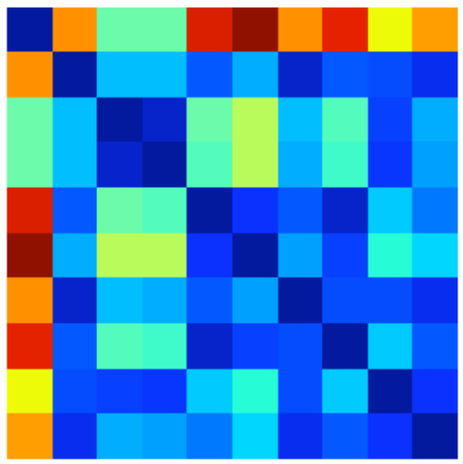
3.0671



destriped

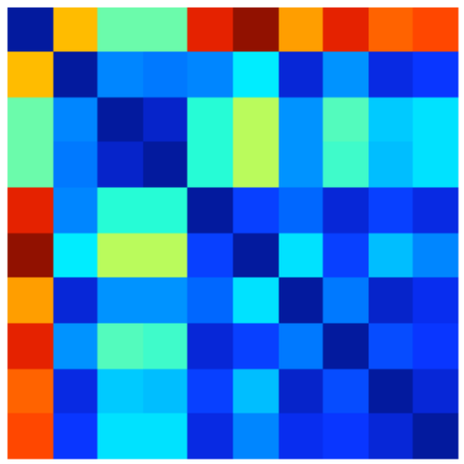
KS
A side

8.1346



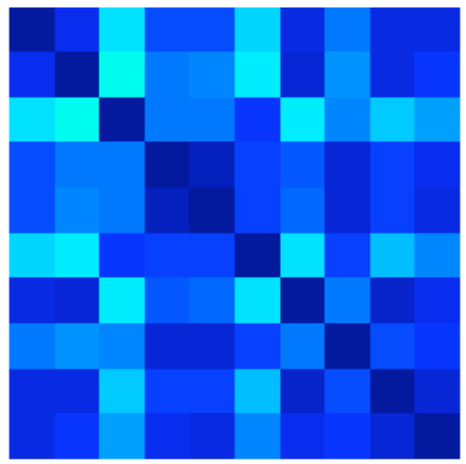
original

8.0560



pre-equalized

4.2228



destriped

results

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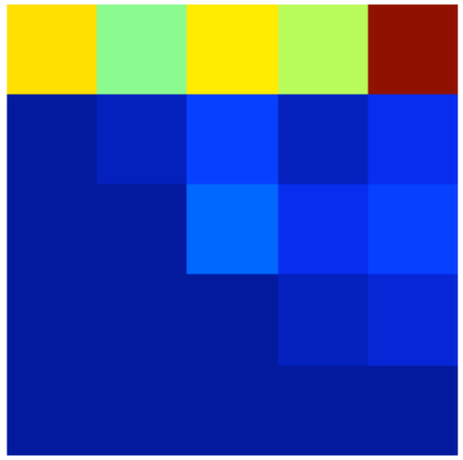
btb
B side

5.2537

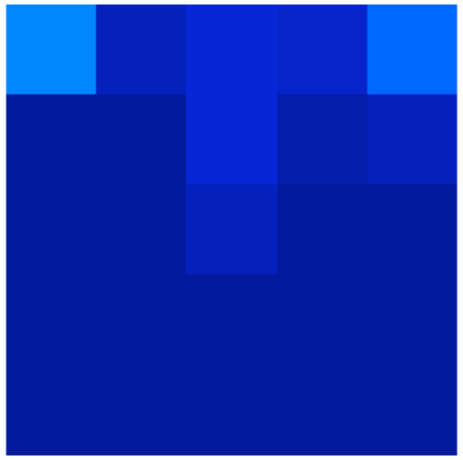


original

5.0507

pre-equalized

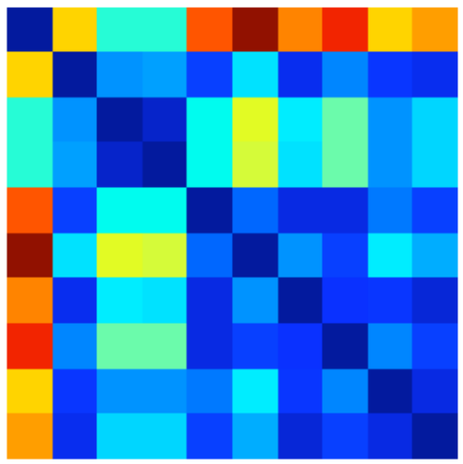
3.1238



destriped

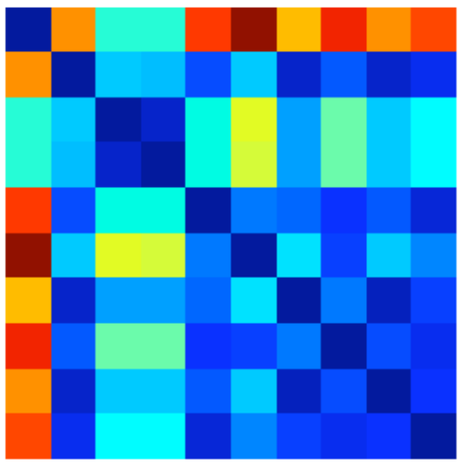
KS
B side

8.3686



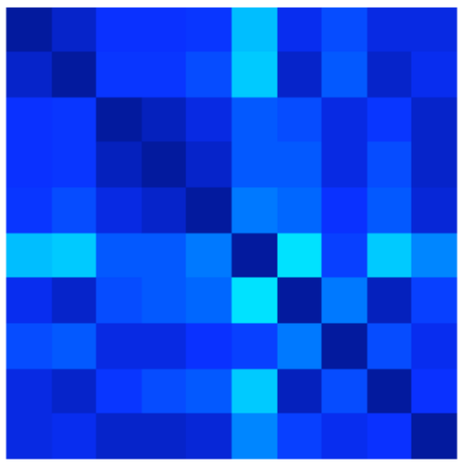
original

9.5527



pre-equalized

3.0974



destriped

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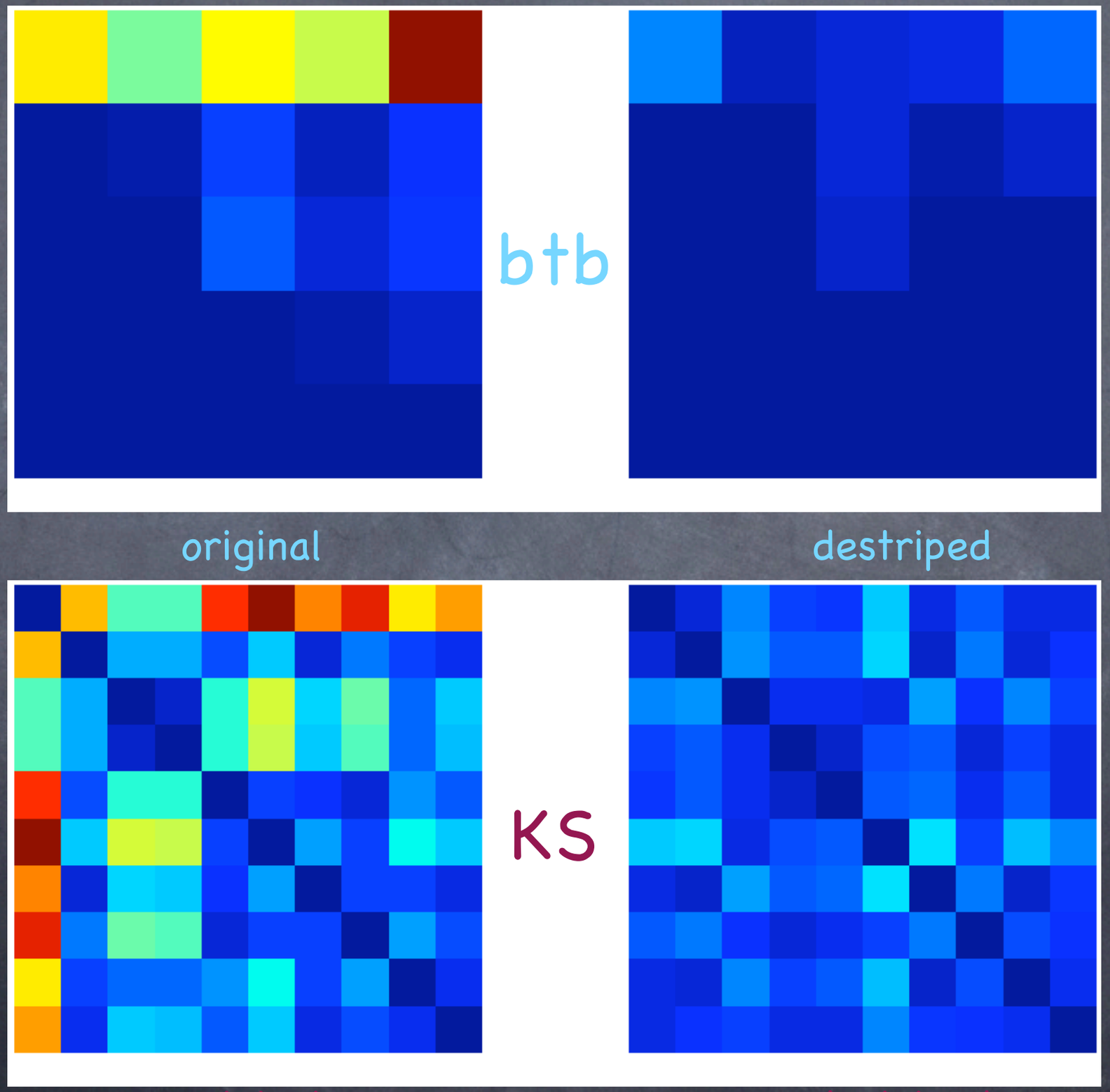
4.8784



3.1024

8.4902

3.9015

results

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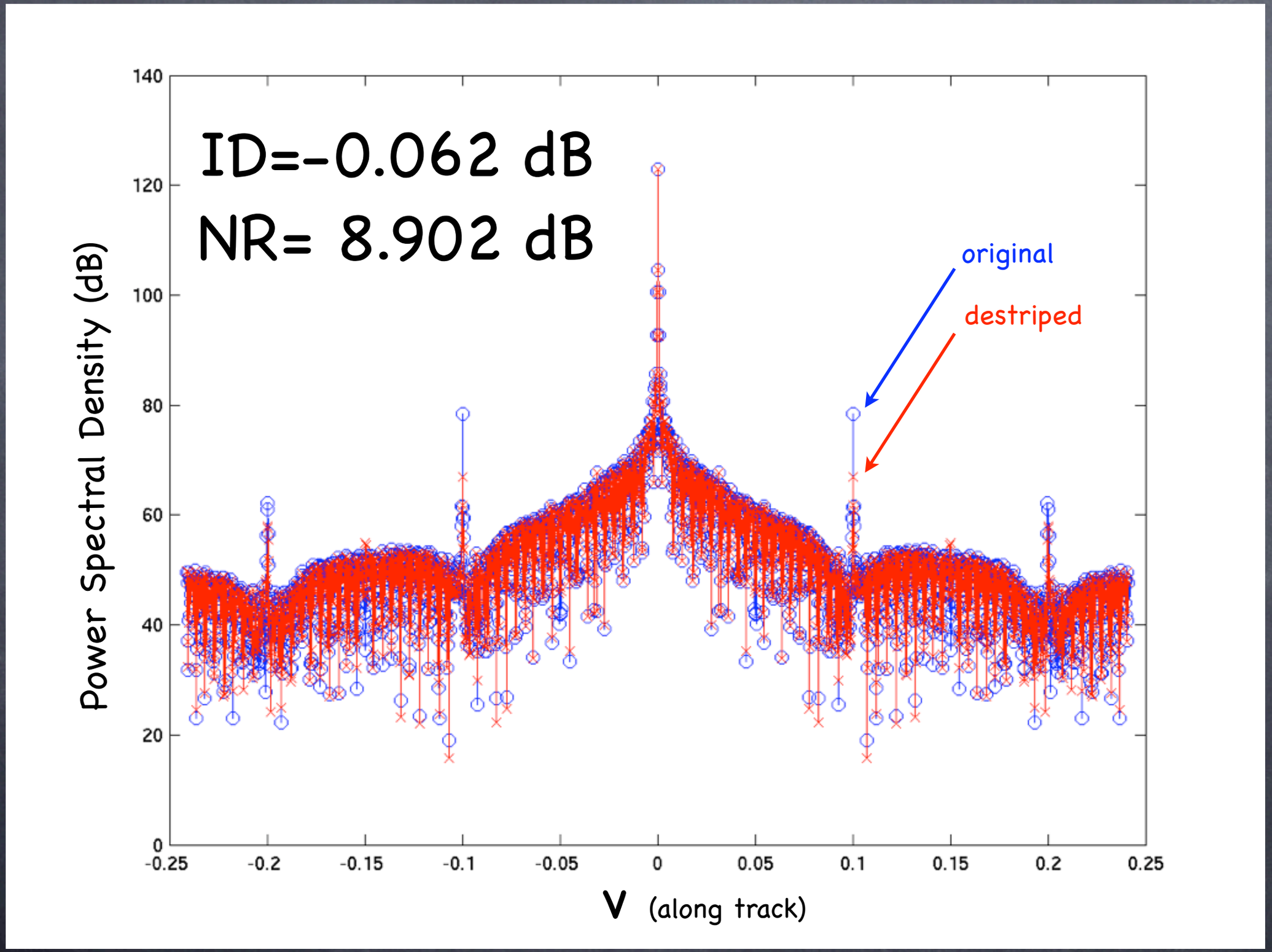

results

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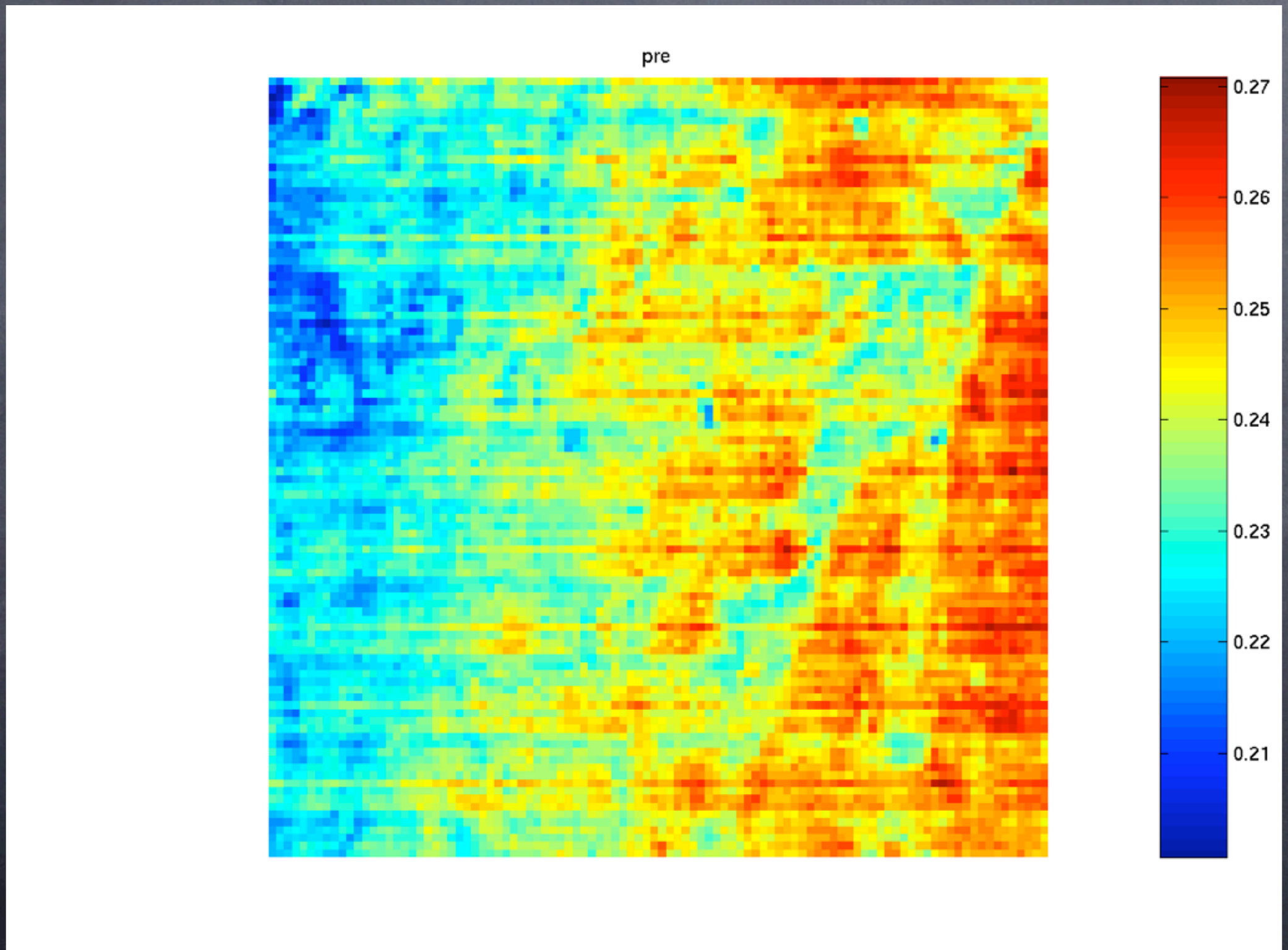
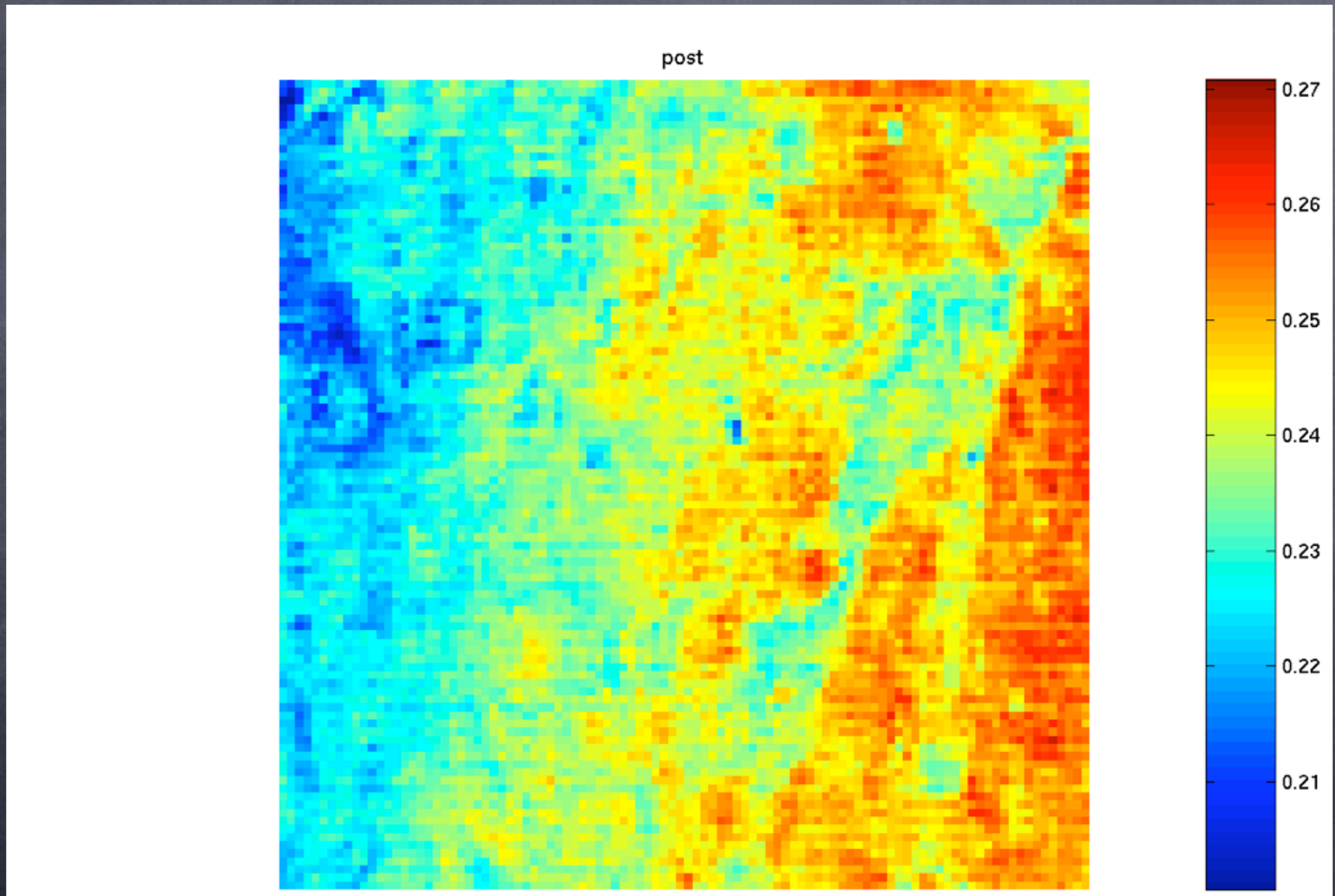


results



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- ✓ ~~results~~
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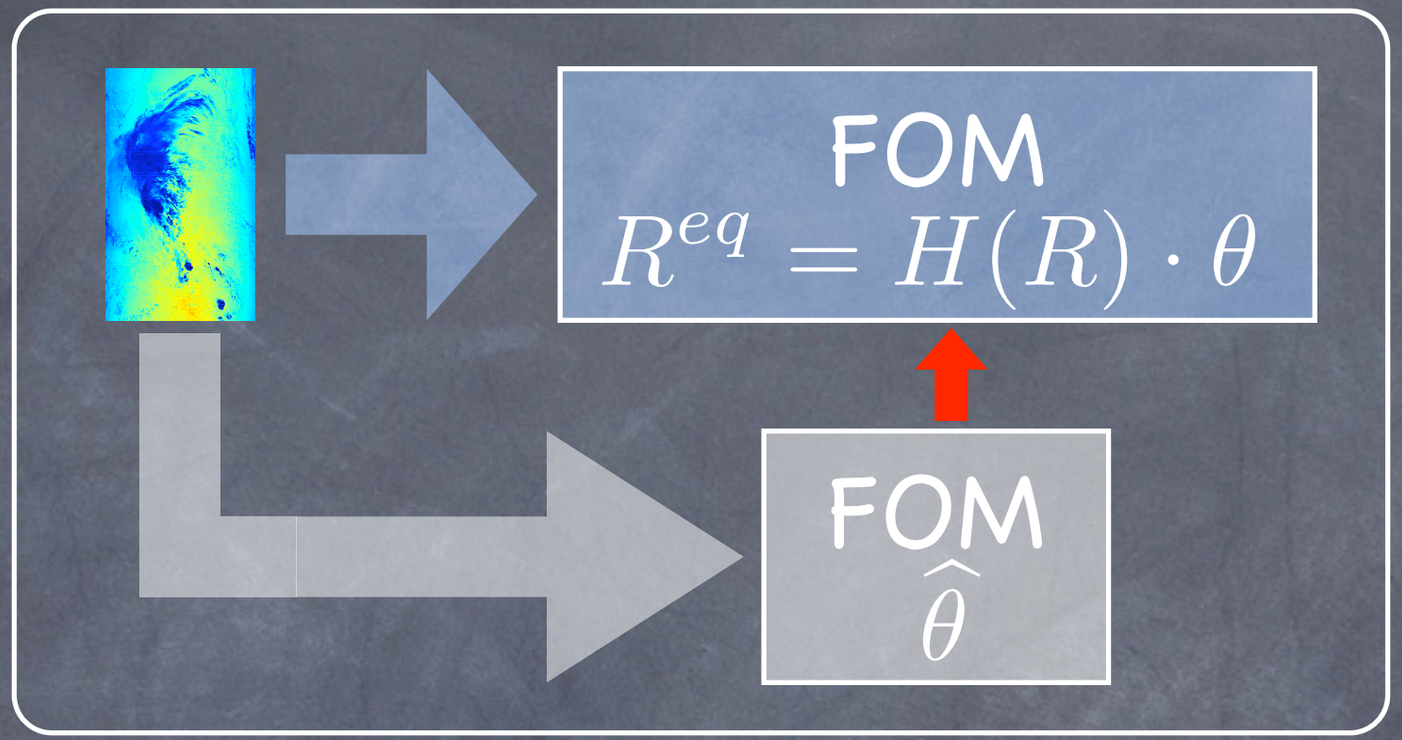
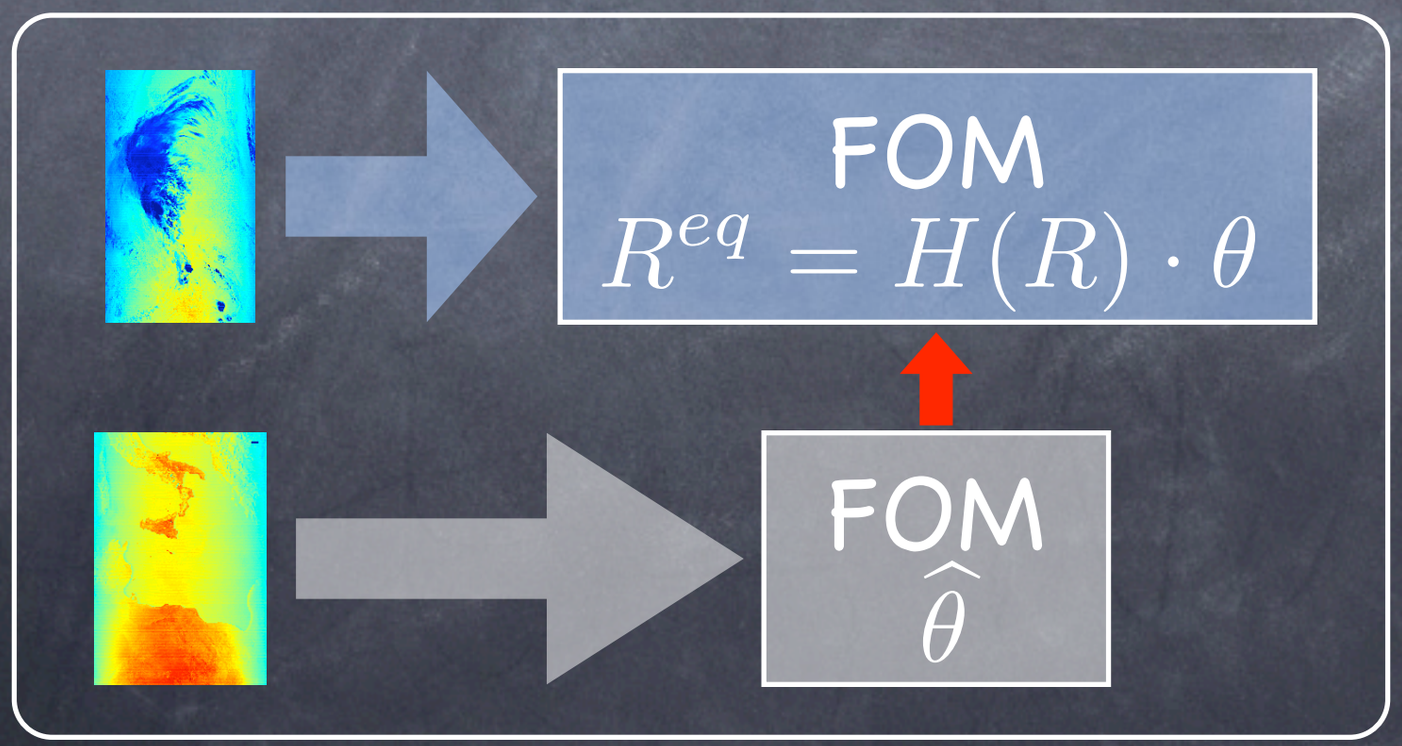
time variation scale





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