BeatMark Software
to Reduce the Cost of X-Ray Mirror Fabrication by Optimization of Polishing and Metrology cycle
SBIR – II NNX16CM09C

Mirror Tech Days

11-01-2016

Second Star, LBNL, OptiPro

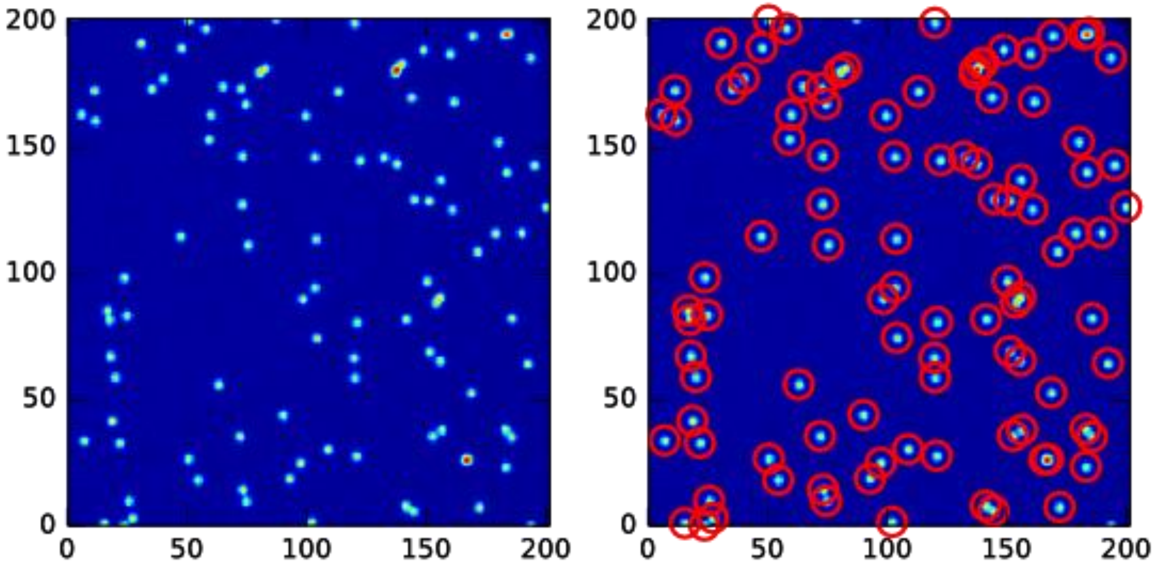
Second Star Algonumerics, LLC

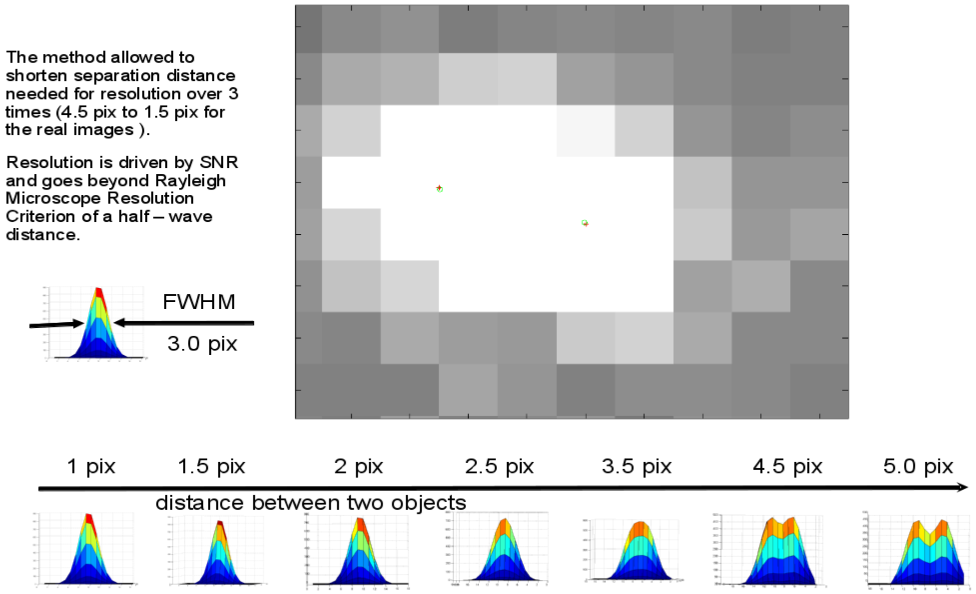
Second star to the right, and straight on till morning

Second Star Algonumerix LLC works in R&D, based in Boston MA

- Statistical Signal and Image Analysis and Pattern detection

One of our patented products is an image processing software specialized in detection of point sources with super-resolution accuracy beyond Raleigh Criterion.





Resolution beyond Rayleigh Criterion.

The method allowed to shorten separation distance needed for resolution over 3 times (4.5 pix to 1.5 pix for the real images).

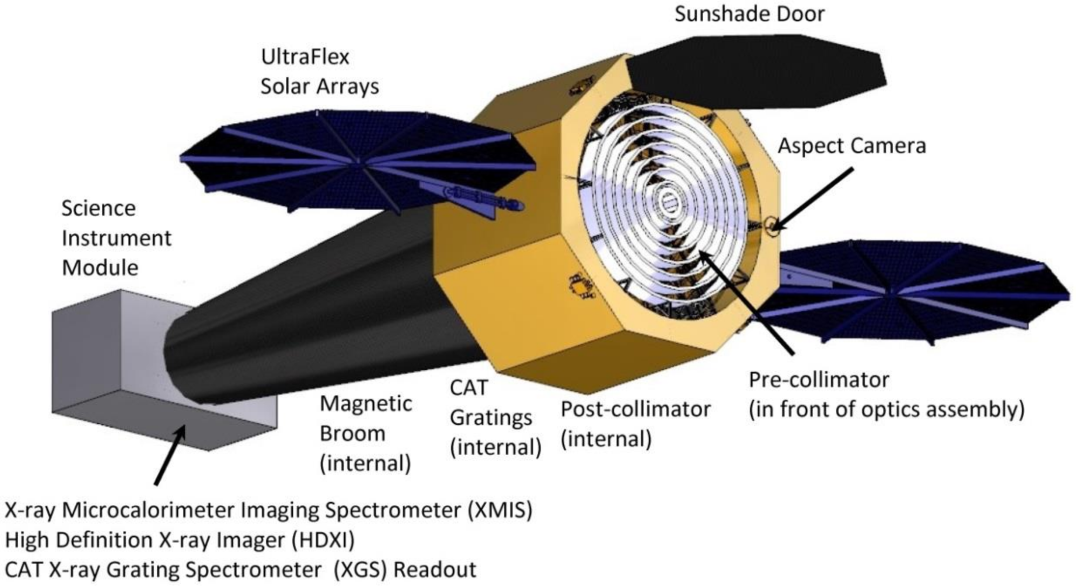
Resolution is driven by SNR and goes beyond Rayleigh Microscope Resolution Criterion of a half – wave distance.

SECOND
STAR

For details, please, visit: http://www.secondstaralgonumerix.com

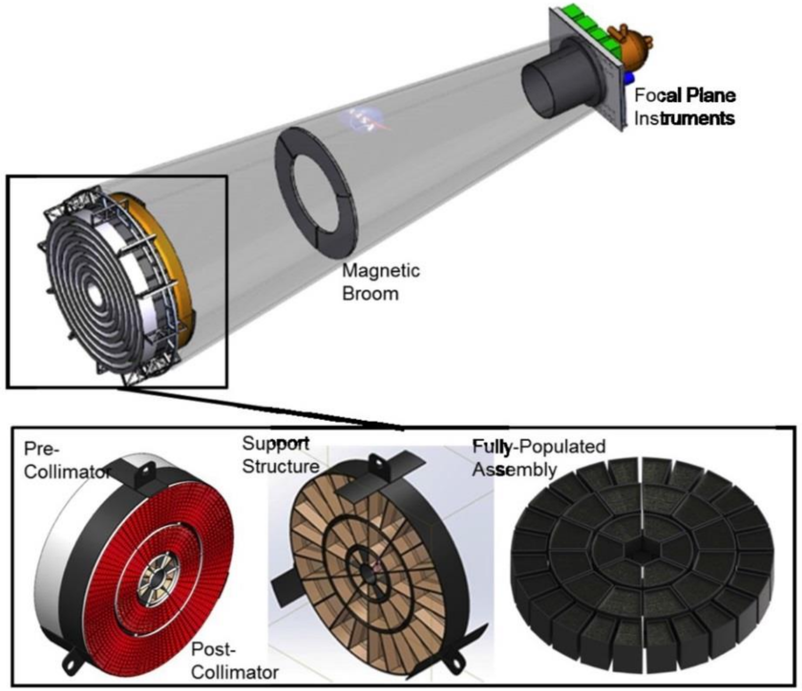
Objective of the project: *To reduce fabrication cost of x-ray mirrors*

X-ray Surveyor Mission Concept*



- ***292-segmented shells nested into 42 individual mirror modules with overall size of 3 m outer diam.;***
- ***~ 0.2 arcsec root-mean-square (rms) slope error;***
- ***$2,952M estimated total cost of the mission.***

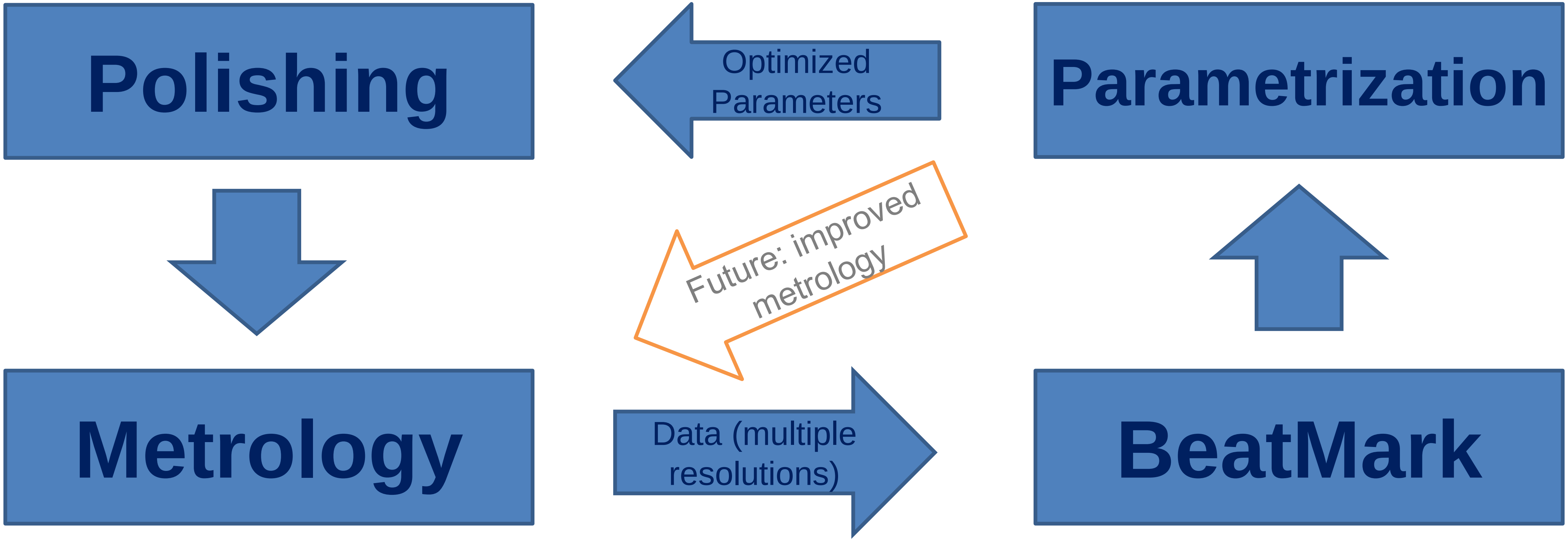
The X-ray Surveyor requires X-ray mirrors to achieve large throughput with high angular resolution (0.5 arcsec) in order to avoid X-ray source confusion and background contamination.
High angular resolution is critical for providing unique identifications of faint X-ray sources.



X-ray Surveyor Telescope

*** J. A. Gaskin, M. C. Weisskopf, A. Vikhlinin, et. al., "The X-ray Surveyor Mission: A Concept Study," Proc. SPIE 9601, UV, X-Ray, and Gamma-Ray Space Instrumentation for Astronomy XIX, 96010J (August 24, 2015); doi:10.1117/12.2190837**

BeatMark concept:
Optimization of polishing and metrology process



Polishing optimization idea

- Ideal mirror surface (form-subtracted) deviates from a plane very slightly and in an absolutely random manner – white noise random
- White noise is an absolutely random process completely devoid of all pattern
- If the polishing tool left a pattern on a mirror and it can be detected the mirror can be improved. Our task is to detect and characterize the pattern so

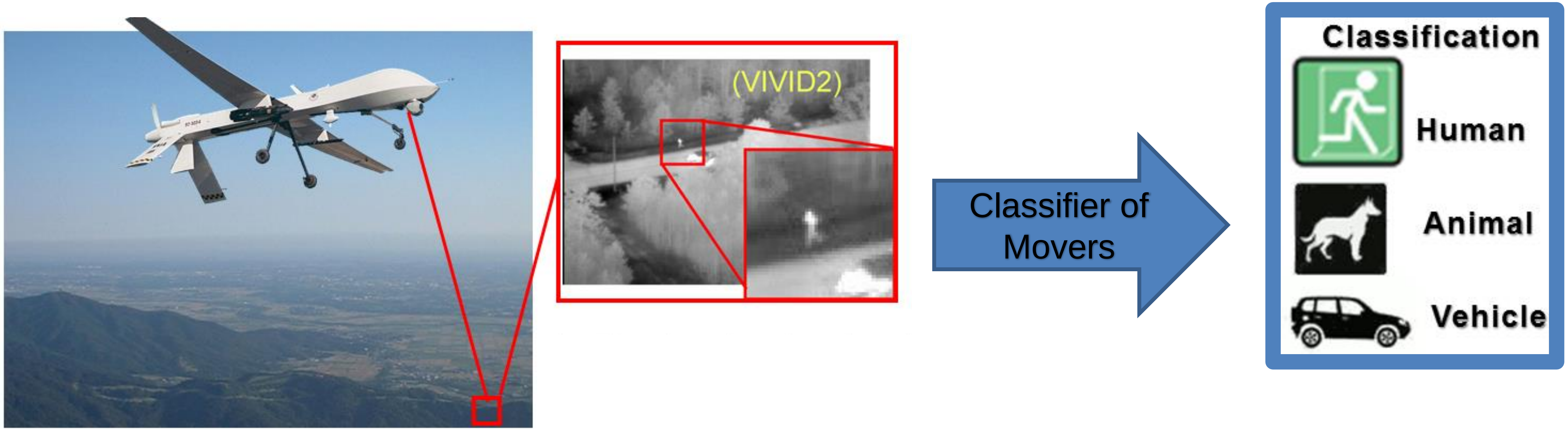
We are in search of a pattern

How to find a pattern 101

Easy pattern = a periodic function is analyzed with Fourier transform


Fourier Transform

Difficult pattern - stretch the idea pretty far to a very noisy signal example from DisSCER project – classification of moving objects in aerial video data



Classifier of Movers

Classification

Human

Animal

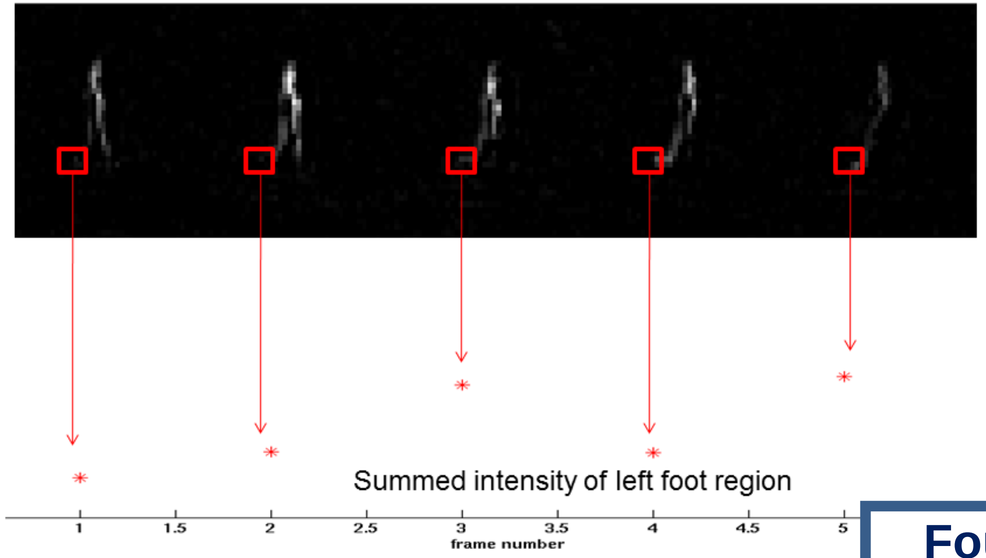
Vehicle

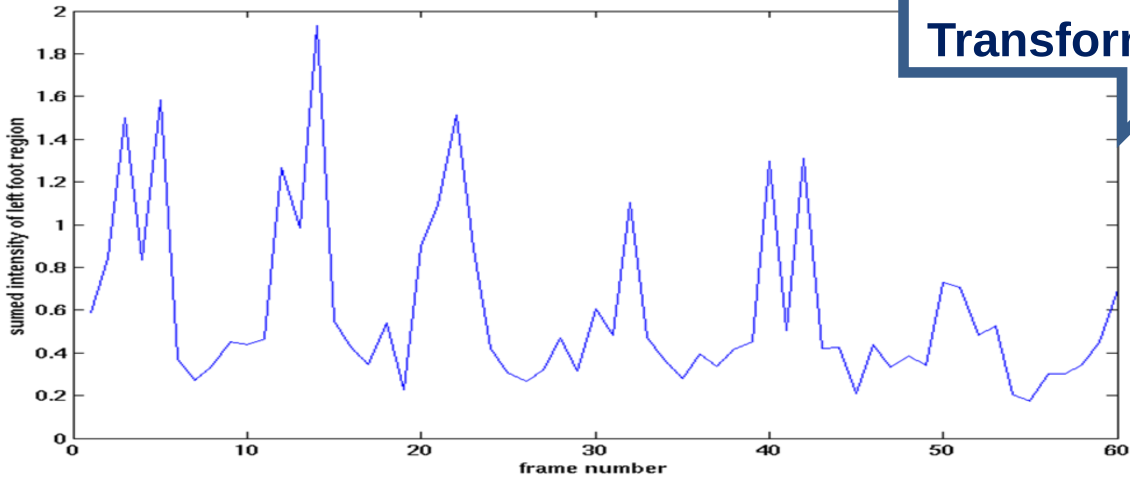
Aerial video data and moving objects

A sub frame movie for each mover

Fourier Analysis to see bipedal motion pattern

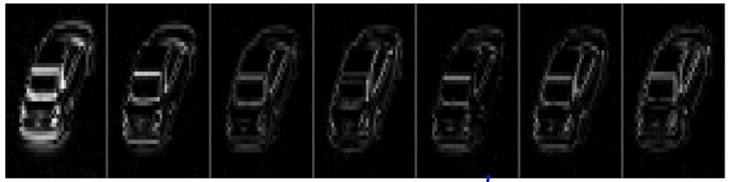
Summed intensity of left foot region

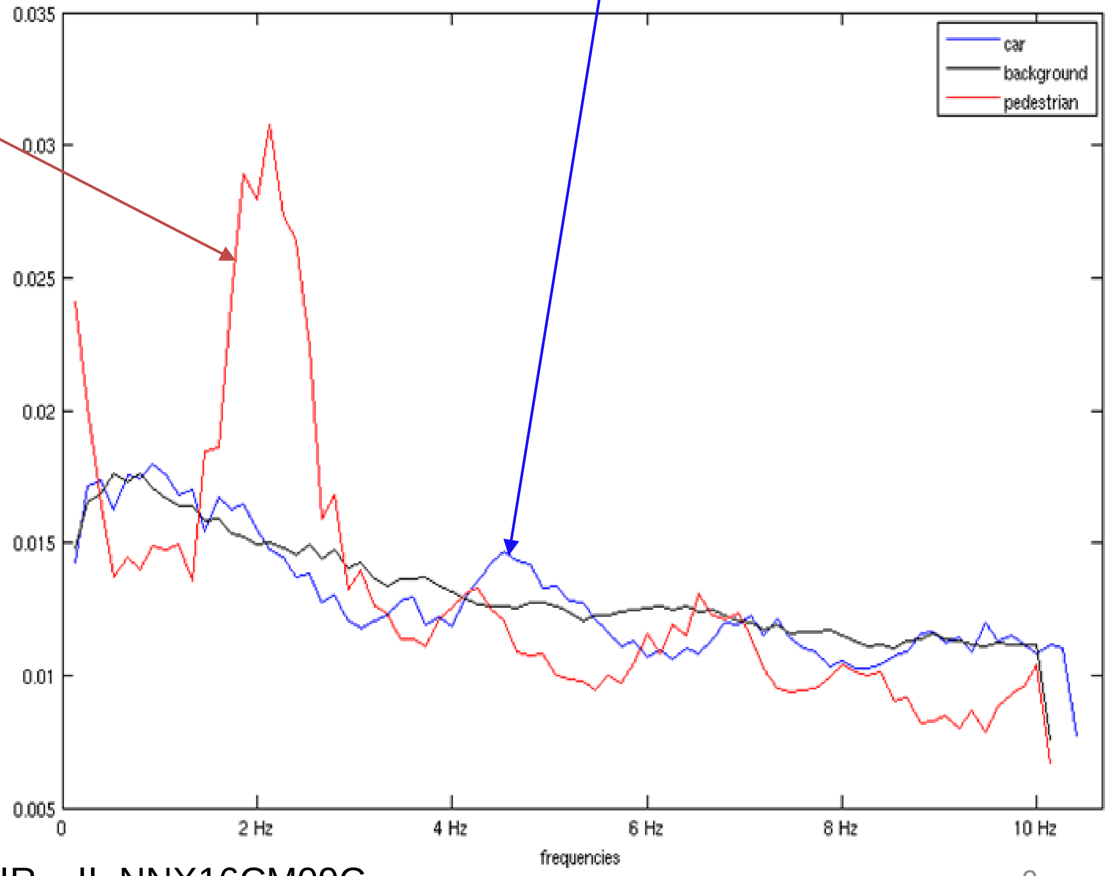




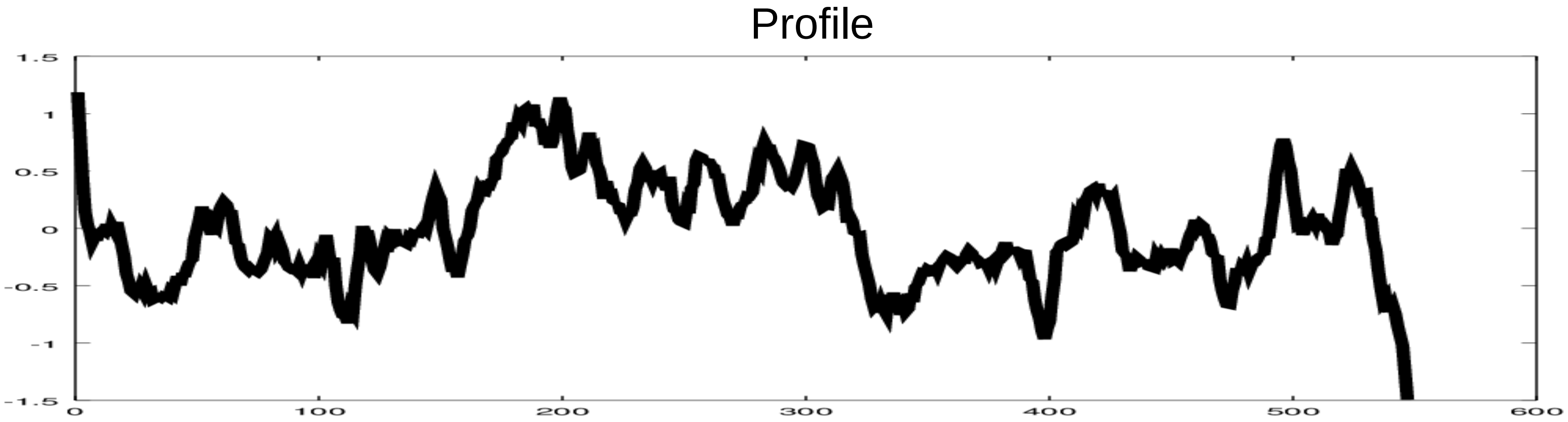
Fourier Transform

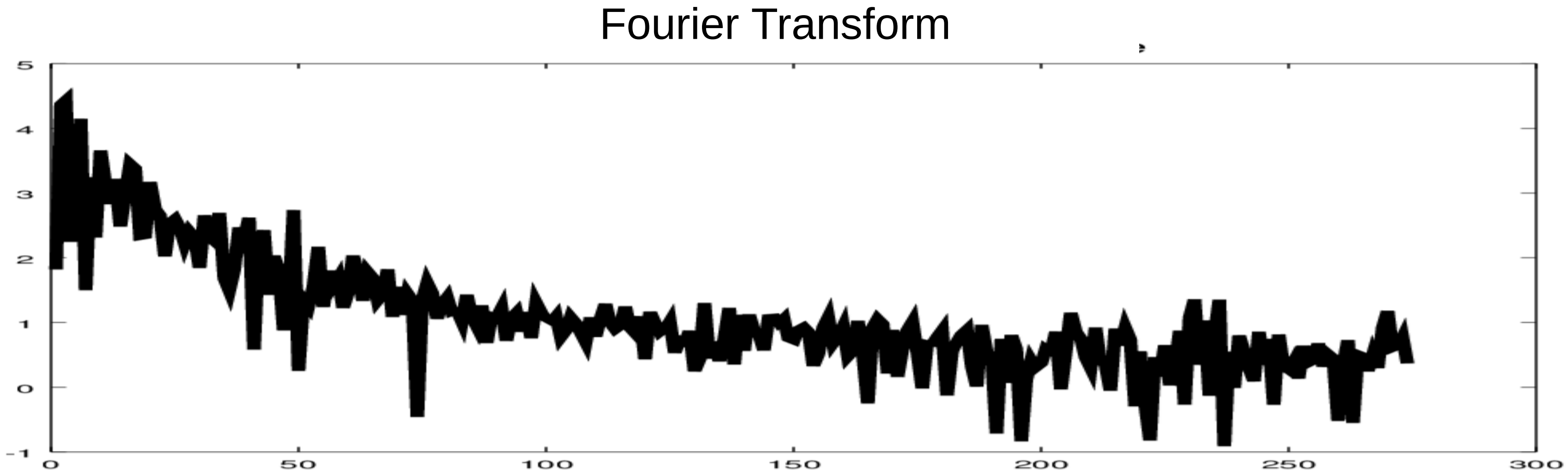
Chips made of non-dismounts moving objects





InTILF method looks for patterns not seen by Fourier Transform in stochastic signal


Profile


Fourier Transform

Use statistical models to find patterns in stochastic data

MA –moving average – builds the process Y from White noise W – bends it (via operator B) to fit the statistical character of the original data

$$Y = B * W$$

AR – auto regressive – describes dependence (A) between neighboring data points in the data Y.

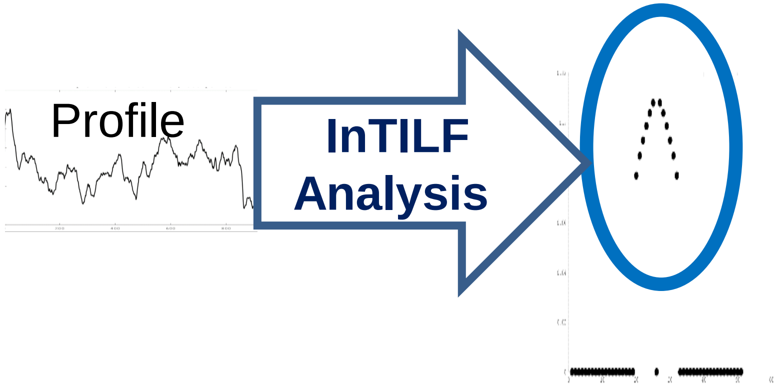
$$Y = A(Y - IdentityOperator)$$

ARMA – a combination model:

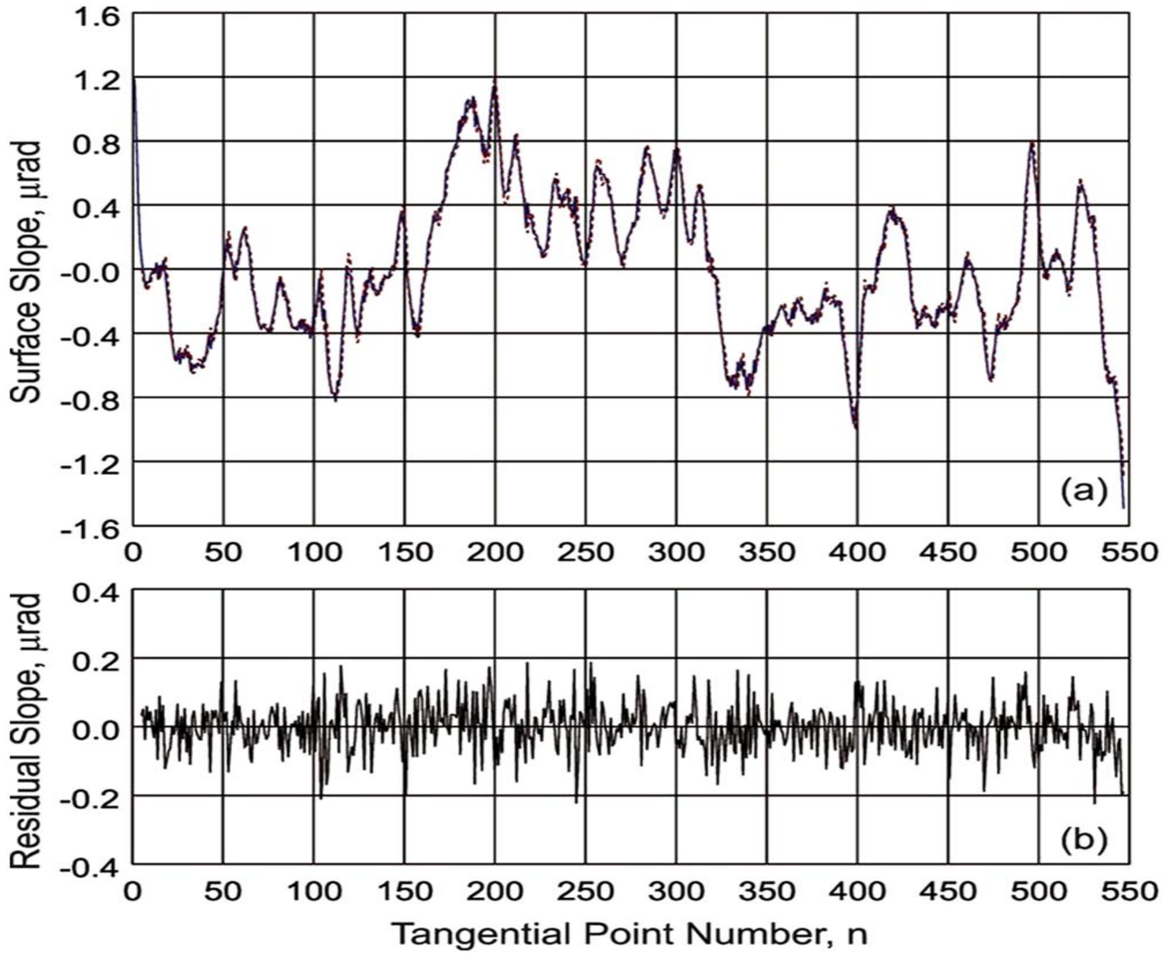
$$Y = A(Y - IdentityOperator) + C * W$$

These models are used for 1d predictions in time series we modified them to serve for description of 1d and 2d data

InTILF method (developed in Phase I)



Typical InTILF analysis results



Important result:

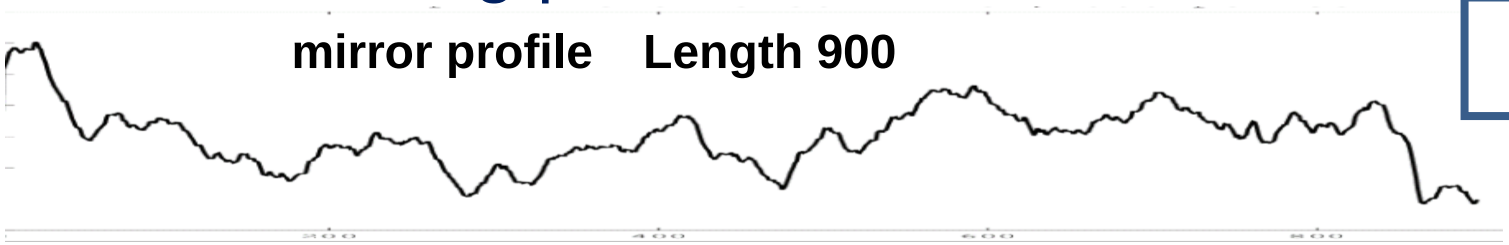
$$Profile - InTILF\ Filtered\ Profile\ =\ White\ Noise$$

The difference between Filtered and Original profile contains no pattern!

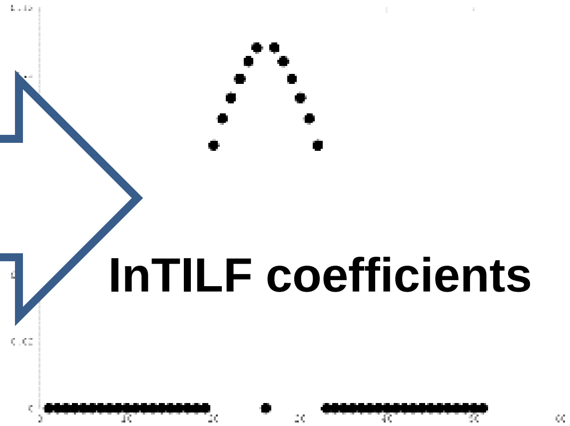
Metrology cost and time savings

Experiment :

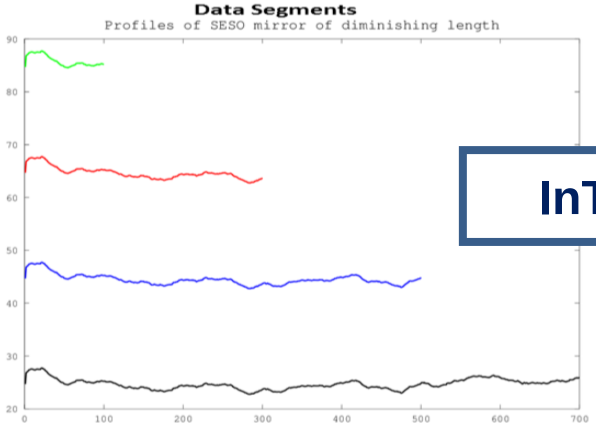
1. Take a long profile



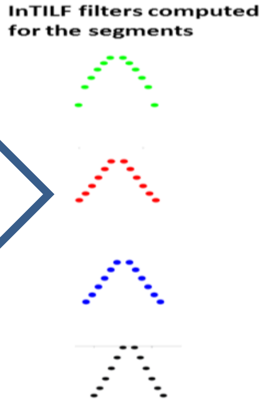
InTILF Analysis



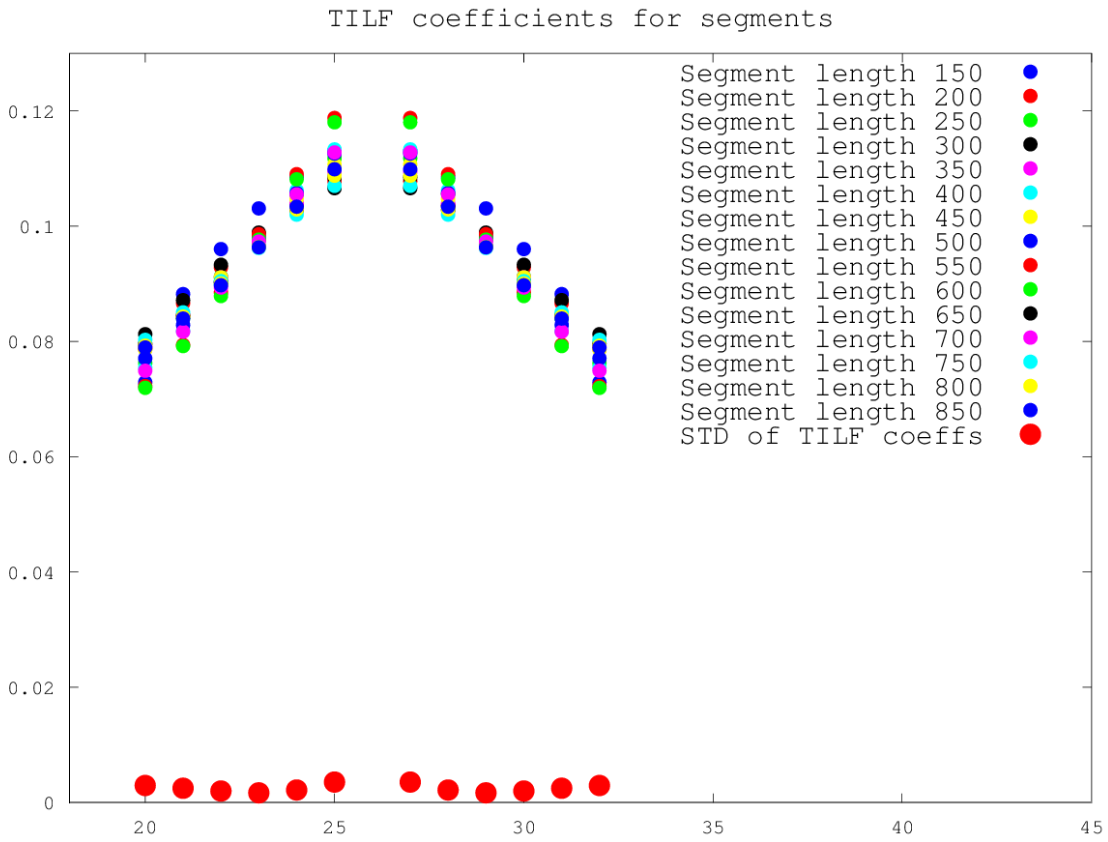
2. Take segments of the profile
3. For segments find InTILF filter



InTILF

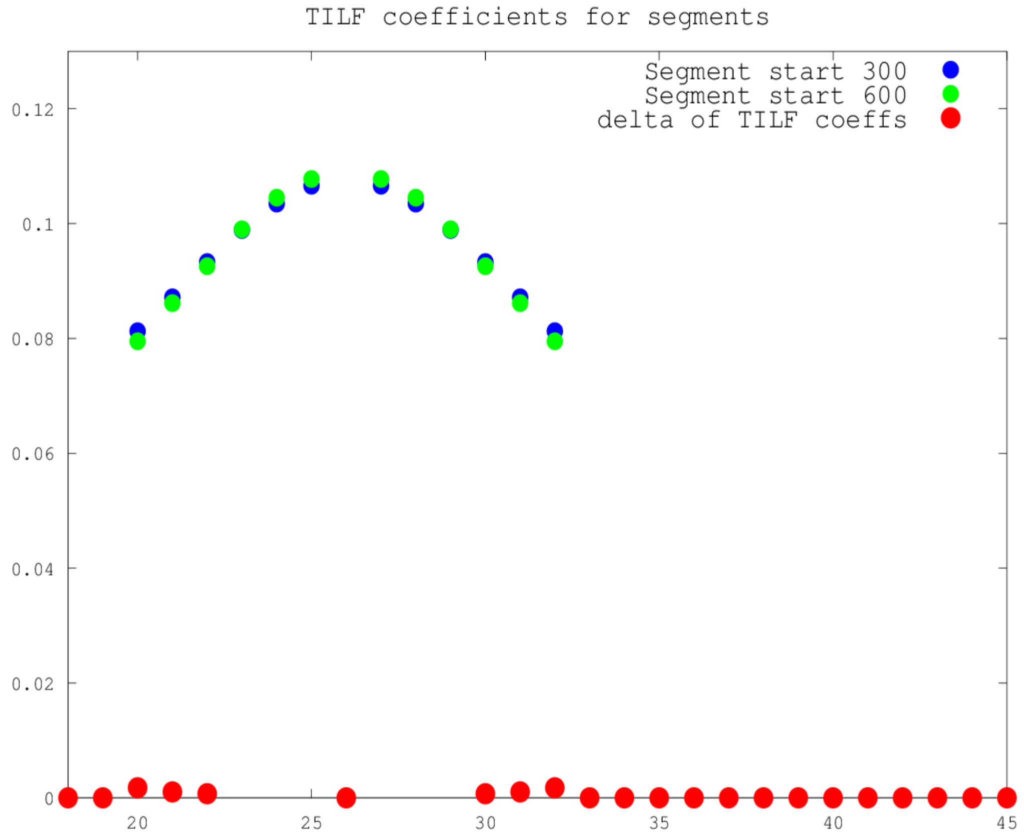


InTILF coefficients are very stable up to short length of 150 data points in observed data



InTILF coefficients of disjoint short segments

Segment length = 300



The notion of ideal mirror as of surface with no discernable pattern

Define Quality indicator as portion of the data not described by any pattern:

100% – (Pattern in data)%

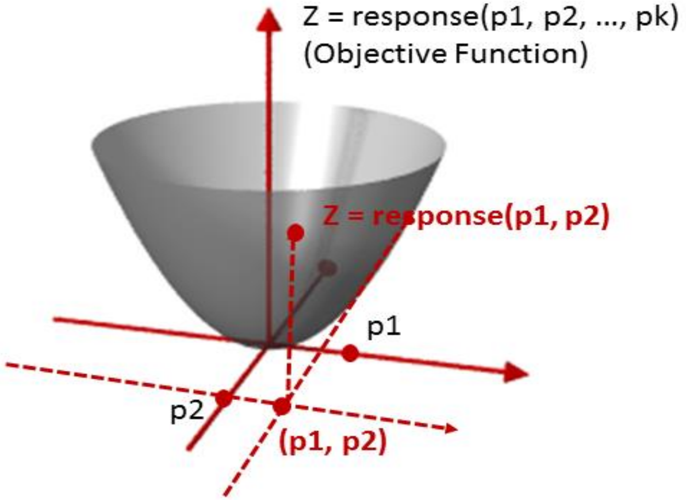
Polishing parameters optimization

Produce surfaces with different sets of machining parameters like pressure, speed, shape of the tool etc.

A quality measure or objective function is computed for each surface based on Beatmark Analysis:

$$response(p_1, p_2, \dots, p_k) = ObjectiveFunction(p_1, p_2, \dots, p_k)$$
$$response(\widetilde{p_1}, \widetilde{p_2}, \dots, \widetilde{p_k}) = ObjectiveFunction(\widetilde{p_1}, \widetilde{p_2}, \dots, \widetilde{p_k})$$

Find the parameters minimizing the Quality measure



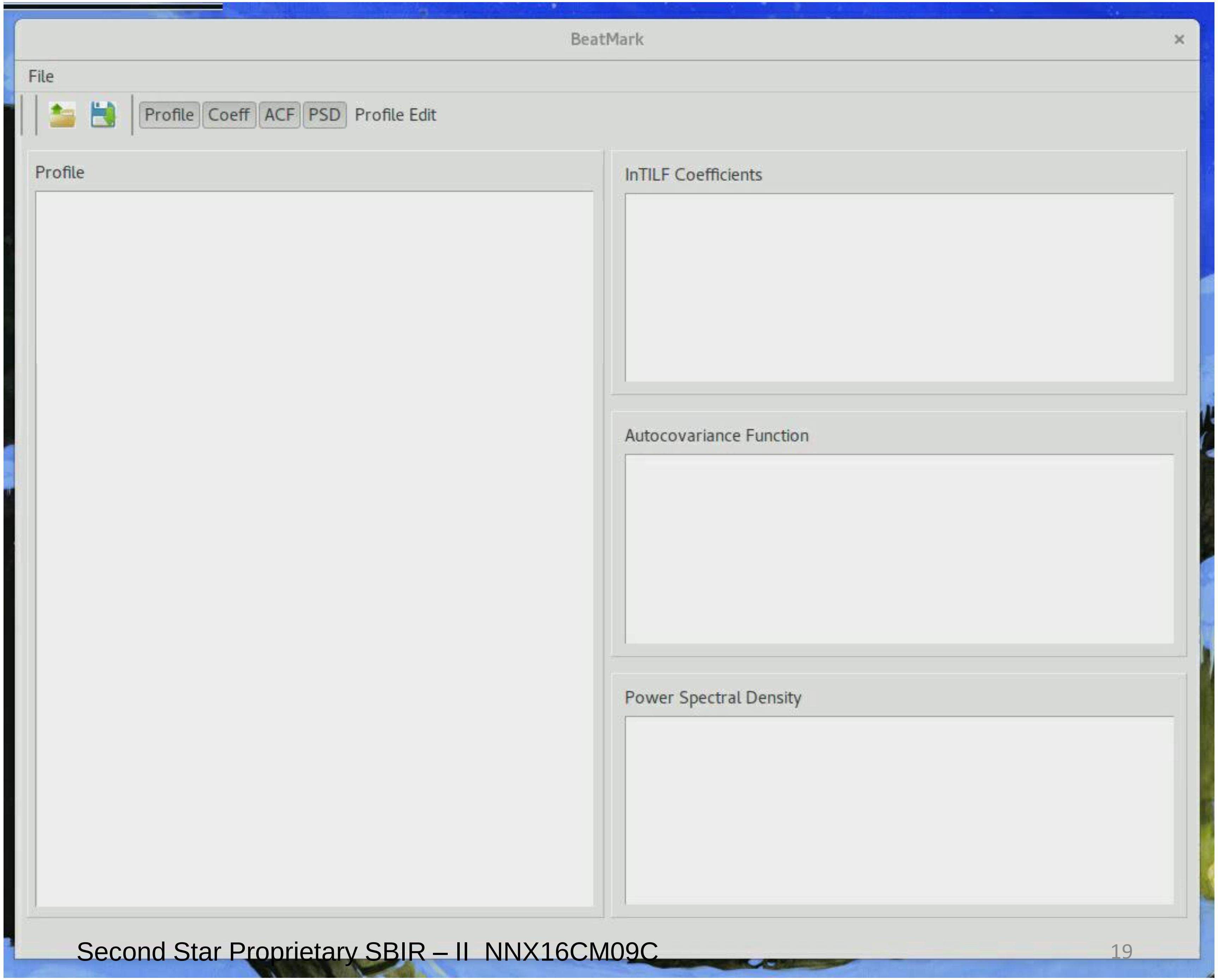
Propose Phase II technical Objectives

Develop an Analytical Software Tool BeatMark™

Parametrization (analysis and generation) of 2-D data and Recommendations for re-polishing based on analysis results

- intuitive user interface
- analysis of the data from existing x-ray mirror producers
- compact statistical 1D and 2D metrology data analysis and parametrization:
- description of the metrology data with a small number of parameters
- generation of statistically equivalent data
- develop an optimal mirror quality indicator
- provide polishing feedback using the quality indicator

BeatMark prototype demo

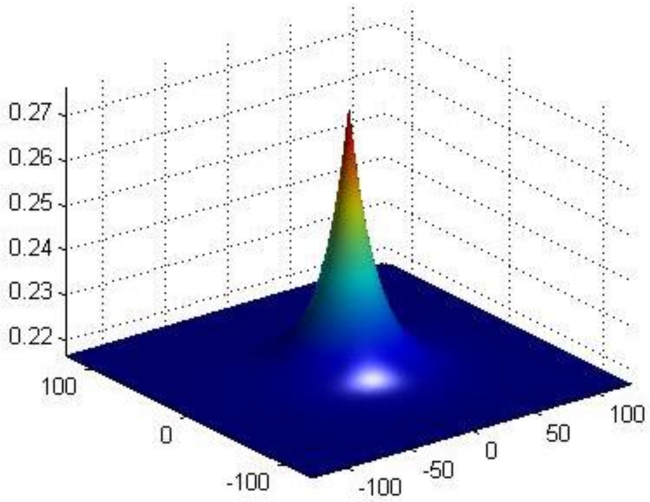


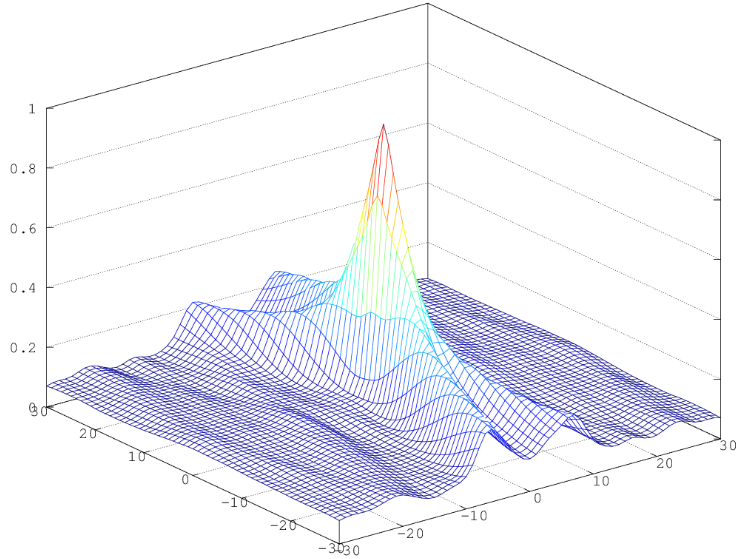
Thank you for your attention!

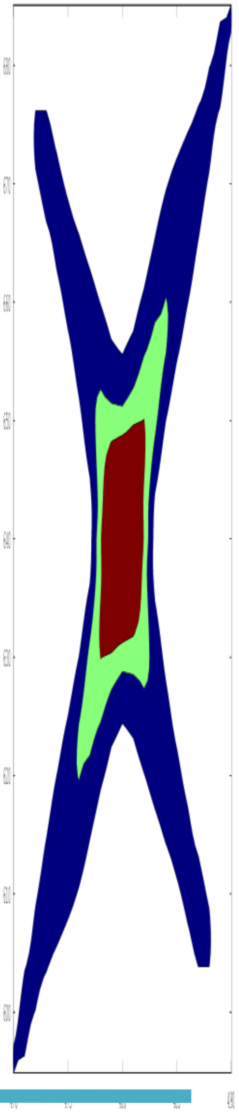
Appendix

The importance of 2D analysis

Compare the delta-like ACF of white noise (left) to a real x-ray mirror example (right)







Level sets of the ACF

Analitical Derivation of 2D InTILF models is completed.

2D Software development is planned for Phase II

InTILF software analysis application example 4

spasial resolution (step) ~1.5 mm