Smart Instrument Technologies

Colin Cunningham / Lars Venema
WP 5
OPTICON Board
Lake Como, Oct 15th 2012

SPIE Modern Technologies in Space- and Ground-based Telescopes and Instrumentation II, July 2012, Amsterdam

- S. Pascal et al, “New Modelling of freeform surfaces for optical design of astronomical instruments”, Proc SPIE, (2012)
- Z. Challita et al: “Extremely aspheric mirrors: prototype development of an innovative manufacturing process based on Active Optics, Proc SPIE 8450(2012)
- Tibor Agócs et al: “Optimizing optical systems with active components”, Proc. SPIE 8450, (2012)
- Visa Korkiakoski et al, “Potential of phase-diversity for metrology of active instruments”, Proc. SPIE 8450 (2012)
- **Runner up: Best oral paper:** W. A. Cochrane, D. C. Atkinson, T. E. C. Bailie, C. Dickson, T. Lim, X. Luo, D. M. Montgomery, H. Schnetler, W. D. Taylor, B. Wilson “Recent testing of a micro autonomous positioning system for multi-object instrumentation” Proc. SPIE 8450 (2012)
- **Best Poster:** W. D. Taylor, H. Schnetler, W. A. Cochrane, M. Black, S. A. McLay “MAPS: where have the robots got to?” Proc. SPIE 8450 (2012)

Best poster award at SPIE Modern Technologies in Space and Ground-based Telescopes and Instrumentation

Dissemination : Public Outreach using Lego robots!

Robots under Concord at Robots Live Event in Scotland

a	Project Plan	feb-09	sep-09	UK ATC
b	Six monthly status reports	June 2009 Dec 2009 Jun 2010 Dec 2010 Jun 2011 Dec 2011 Jun 2012 Dec 2012		UK ATC
c	Smart Instrument Architecture	jun-09	mrt-10	UK ATC
d	Smart Technology Device Specifications	dec-09	apr-10	UK ATC
e	Zemax plug-in software module for extreme aspheric surfaces - analysis and design report	dec-09	jul-11	LAM
f	Zemax plug-in software module for extreme aspheric surfaces	dec-11	jun-12	LAM
g	Extreme aspheric mirror demonstrator analysis and design report, including a description of the manufacturing processes	dec-11		LAM
h	Extreme aspheric mirror prototype demonstrator	apr-12		LAM
i	Extreme aspheric mirror demonstrator Test Report	apr-12		LAM
j	Specifications of adjustable mirror	apr-11	jun-11	ASTRON
i	Report of prototype tests for principle exploration	okt-11	dec-11	ASTRON
ii	Preliminary analysis and report backtracking phase diversity to surface corrections on mirrors	mrt-12	dec-11	ASTRON
iii	Metrology for Active Instruments - cont.	mrt-12	jul-12	ASTRON
iv	Preliminary design report of the active mirror array	mrt-12	jul-12	ASTRON
	In Opticon FP 7 Contract			
5.2.5	Test report – Prototype Aspheric Mirror	apr-12		LAM
5.3.1	Cryogenic smart structures analysis, design and manufacturing report	aug-12		ASTRON

Final report will be setup/drafted in final team meeting in Marseille on Oct 22/23 (5.2.5 & 5.3.1)

Finance: changes to original plan

- Transfer of allocation from STFC to CSEM to pay for EngD student William Cochrane on secondment to Neuchatel for 6 months : working on rotating mirror mechanism for robots
- Purchase of Femtosecond laser for use in laser inscription at Heriot Watt University (astrophotonics): partly funded from underspend on STFC SIT and KTN allocation. Delivery expected 15th Oct
  - Fianium HE1060-1uJ-fs, High energy femtosecond fiber laser with integrated output modulator. 1064nm, 1uJ, <500fs, single-shot to 1MHz: Total cost: £42,792, EU claim will be 75% of this
- Other institutes will claim as planned

Final Financial prediction (TBC)

Baseline	€k			
	UK ATC	LAM	NOVA	CSEM
Total Effort Cost	128.48	128.39	97.59	90.84
Equipment Cost	60.00	30.00	60.00	30.00
Travel Cost	10.00	10.00	10.00	10.00
Subcontractor Cos	0.00	0.00	0.00	0.00
Total	198.48	168.39	167.59	130.84
EU	148.86	126.29	125.69	98.13
			Total	665.30
			TOTAL EU	500.00

Expected claims		€k		
	UK ATC	LAM	NOVA	CSEM
Total Effort Cost	85.00	128.00	97.00	146.00
Equipment Cost	40.00	30.00	60.00	40.00
Travel Cost	10.00	10.00	10.00	10.00
Subcontractor Cost	0.00	0.00	0.00	0.00
Total	135.00	168.00	167.00	196.00
EU	101.25	126.00	125.25	147.00
			Total	666.00
			TOTAL EU	499.50

- This will be confirmed following the final team meeting in Marseille on Oct 22/23

Key FP-7 Achievements

- Wireless Microrobots☑
- Zemax extension for aspherics☑
- Pressure formed mirrors☐ - getting close, but will be concluded in Phase 2
- Adjustable mirrors☑
- Metrology using Phase Diversity☑
- Postgrad Student experience: 2 in UK, 2 in France☑
- Good working partnership: UK ATC/Astron/LAM/CSEM leading to Phase 2 programme☑

UK-ATC Objectives in FP7

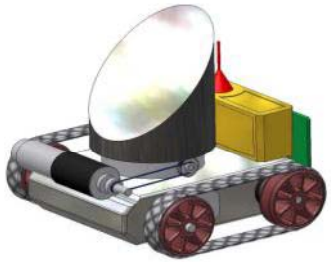
- **Definition of an Ideal Instrument**
  - Efficient self organising focal plane pick off → micro robots
  - Efficient spectrograph

- **Working in close collaboration with CSEM**
  1. *Accurate positioning of the pick off mirrors*
  2. *Development alignment metrology*
  3. *Development of next step optical train*

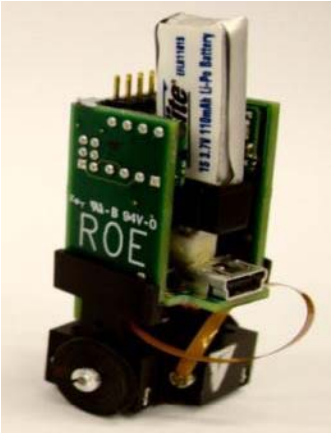
- **Results:**
  - Microrobots developed
  - Control software developed
  - Metrology done
  - Development tip/tilt follower system at CSEM

Evolution of the robots

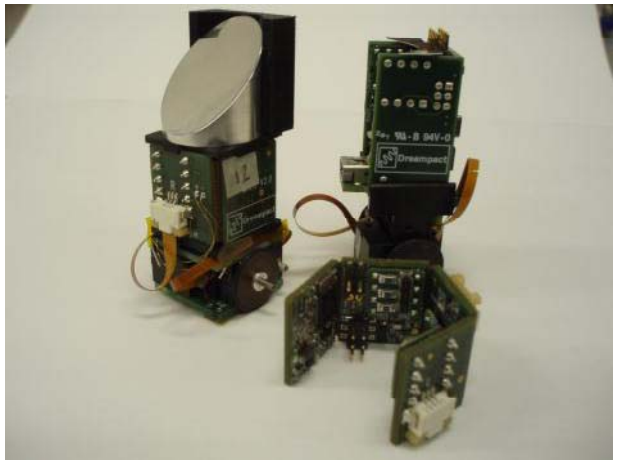
Initial vision



First Prototype

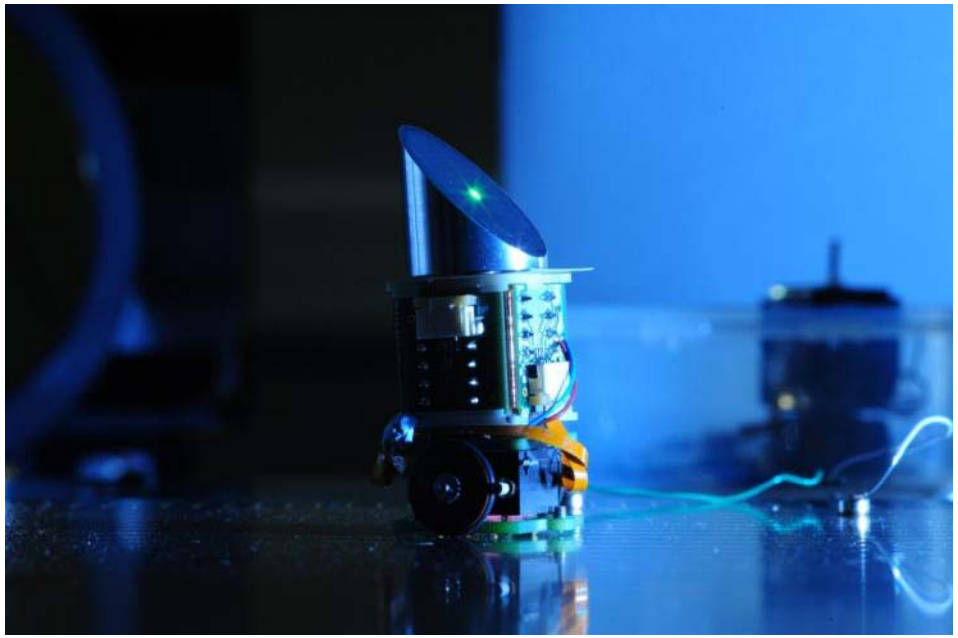


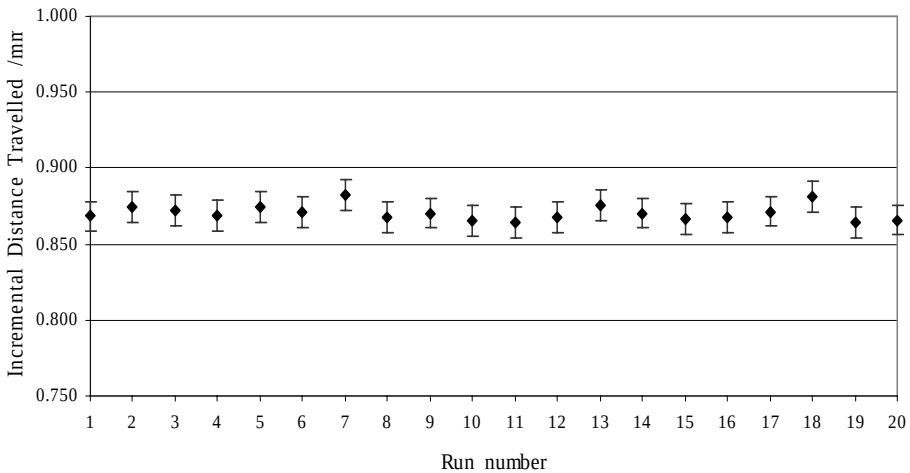
Second Prototype

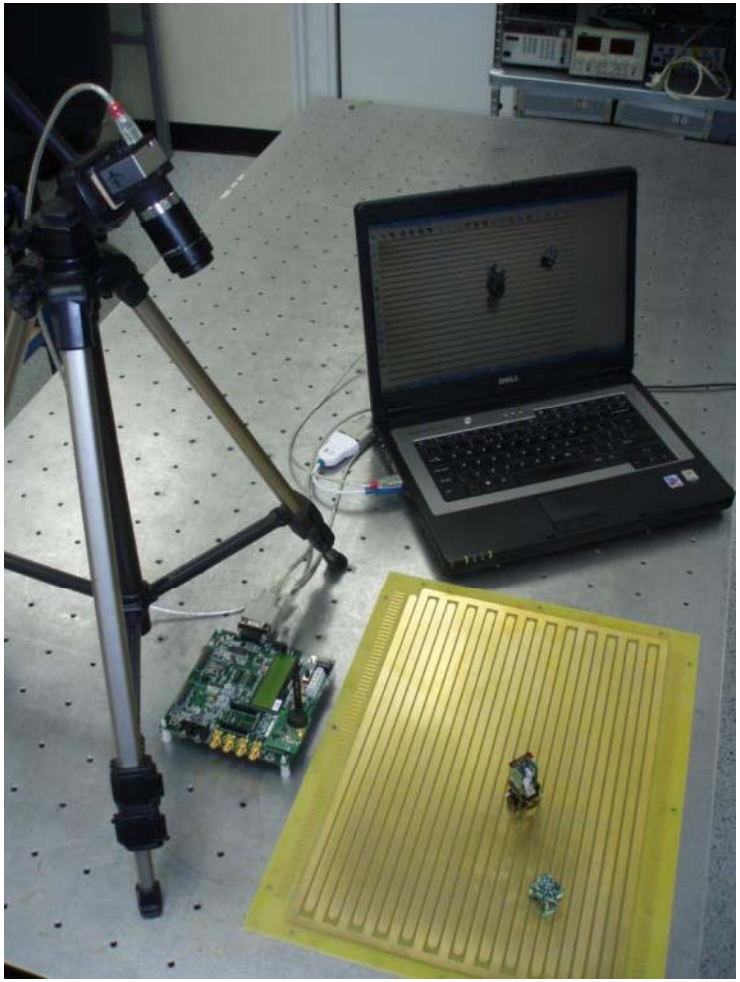


Current Robot

Robots: 3rd model & metrology: 6μm SD

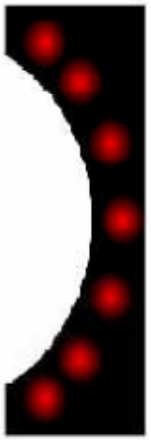


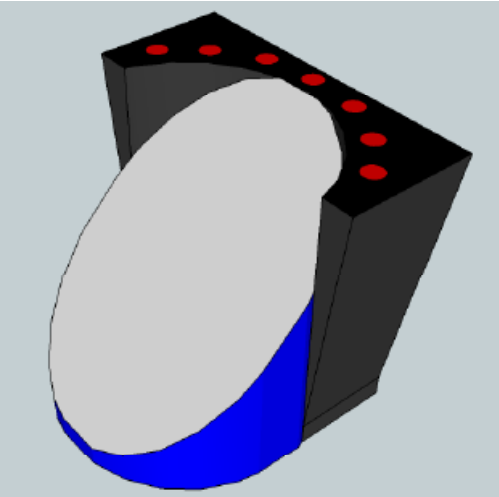


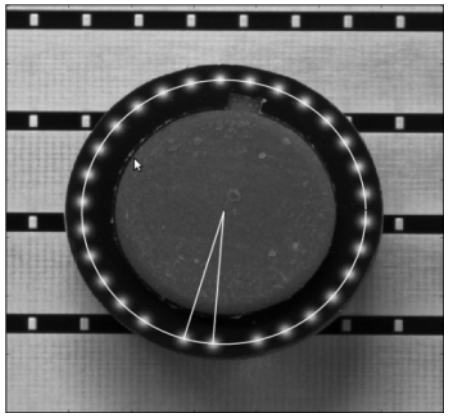


Metrology Module

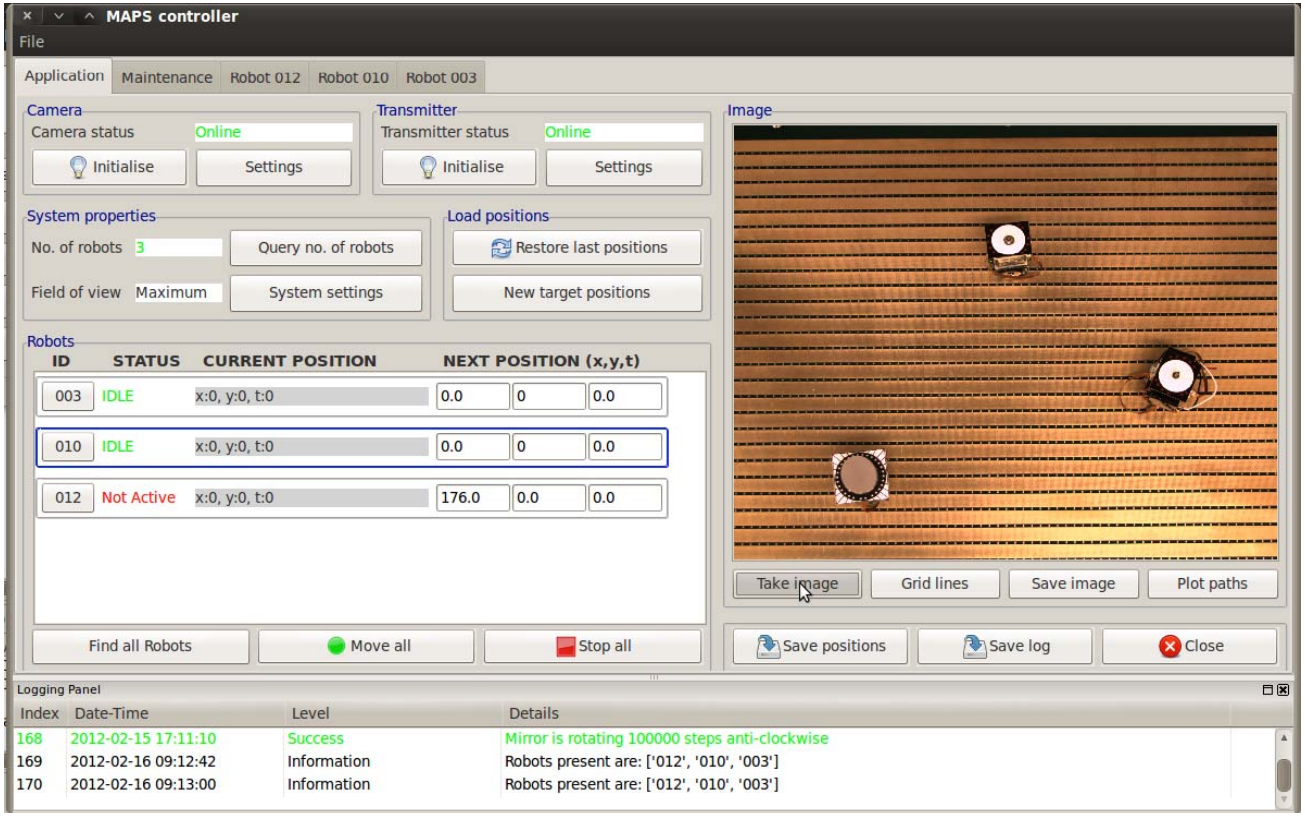
- Phase 1 targets replaced by phase 2 targets
  - Improved precision – more points better results
  - Used to determine orientation and location of robots







Command & Control GUI



- Position converted from pixel space to coordinates
- User defines desired pick-off locations
- Computer determines robots path
- Robots sent series of commands
- Continuous monitoring and path planning

LAM Objectives in FP7

- **Global objective: towards an Ideal Instrument**
  - Based on freeform optics
  - Will allow a gain in compactness, transmitted flux, performance, integration time, etc…

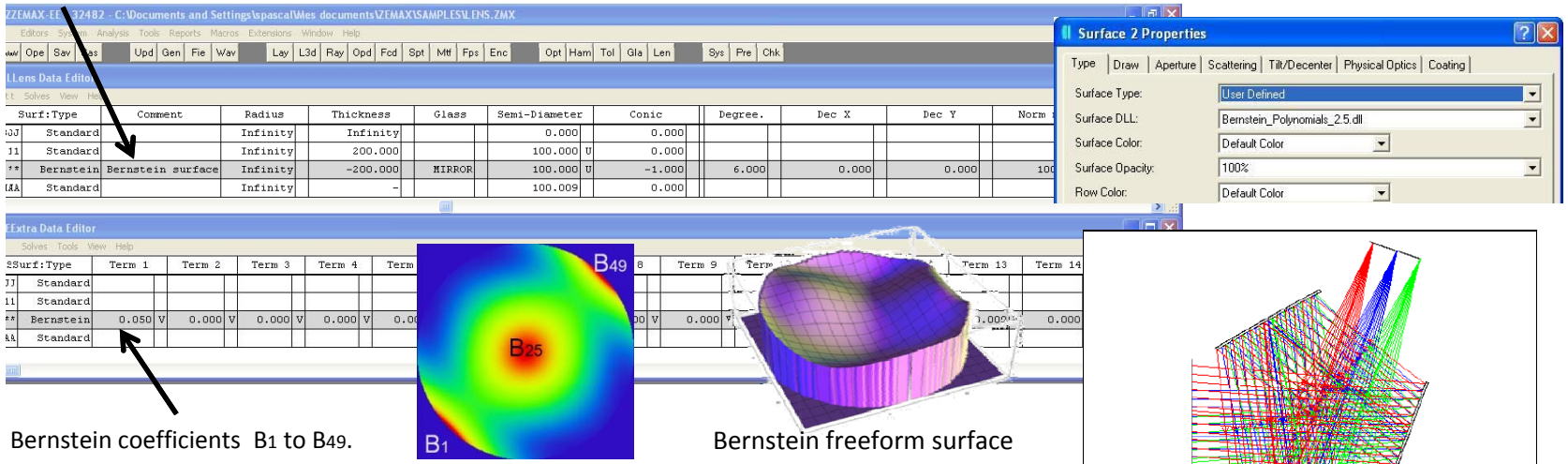
- **Method: Two main axis**
  1. *Freeform modelling*: development of a specific ray-tracing plug-in
  2. *Freeform manufacturing:* Development of an innovative manufacturing method

- **Tool and results:**
  - Analytic definition of a new polynomial basis
  - Implementation with Zemax ray tracing software

  - Finite element analysis in non-linear cases using Marc/Mentat
  - Material characterisation
  - Design of specific manufacturing machine
    - Tests to be performed early 2013

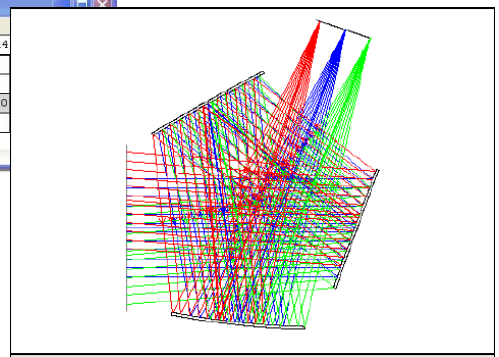
Freeform optics modelling

UDS : Bernstein surface



Bernstein coefficients B1 to B49.

Bernstein freeform surface



FoV : 9°×9°
F / 3.5
M1 M2 M3 diameter : ~200 mm
Pupil position : M1

- ✓ Based on a new polynomial base (Bernstein polynomials)
- ✓ Implemented in Zemax as a DLL,
- ✓ First simulations showing excellent results (good convergence, fast calculation time, good optical quality…)

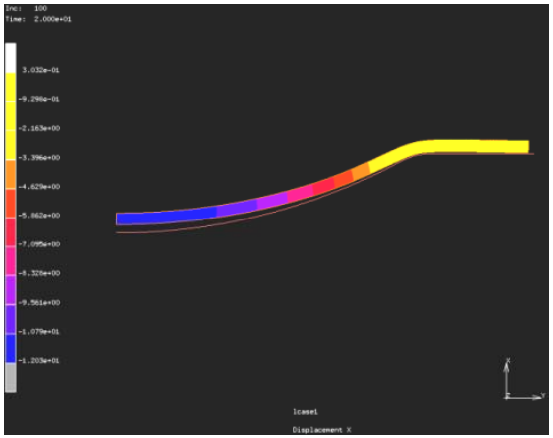
LAM DLL to be distributed in a forthcoming Zemax release!

S. Vives et al "Modelling highly aspherical optical surfaces using new polynomial formalism into Zemax" Proc SPIE 8172, (2011)
S. Pascal et al, "New Modelling of freeform surfaces for optical design of astronomical instruments", Proc SPIE, (2012)

Freeform optics manufacturing

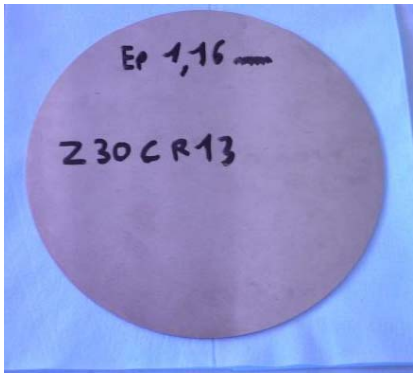
- **Innovative manufacturing method** developed with a combined approach:
  - Based on metal hydro-forming
  - Finite Element Analysis in non-linear case, experiment, material characterisation

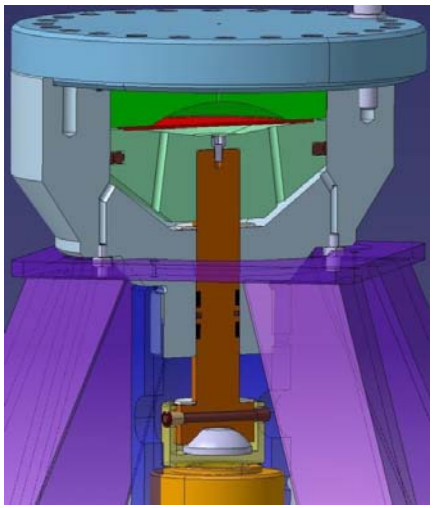
- **Work done so far**
  - FEA optimisation taking into account non-linear plastic behaviour of metallic substrates
  - Hydro-forming engine: design completed, to be received in October 2012
  - Characterisation of metallic substrates parameters



Axi-symmetric analysis of a thin circular metallic substrate under plasticization. An asphericity of about 6000µm is generated.

- **On going work**
  - Integration of the HyFo engine
  - Fine polishing and plasticization of the thin polished substrates
  - Characterisation and fine tuning of FEA parameters





Thin metallic substrates (AISI 420, diameter 140mm) and Hydro-forming engine CAD

PhD (Z. Challita) to be defended end 2013

Z. Challita et al: “Extremely aspheric surfaces: toward a manufacturing process based on Active Optics, Proc SPIE 8169 (2011)
Z. Challita et al: “Extremely aspheric mirrors: prototype development of an innovative manufacturing process based on Active Optics, Proc SPIE 8450(2012)

NOVA ASTRON Objectives in FP7

- **Global objective: towards Active Instruments**
  - Based on active structures
  - Requires metrology

- **Collaboration: Extreme Optics LAM benefits/requires Active Elements**
  - Active alignment
  - Shape correction

- **Method: Two main axis**
  1. *Metrology:* Development of an WFE corrections using science channel "without" metrology devices
  2. *Active Structure*: first focus development of active array to correct shape residuals

- **Tool and results:**
  - Metrology based on phase diversity – only defocus at detector
  - Implementation of Phase Diversity – Reverse Optimization – Linear algebra forward optimization (SVD)

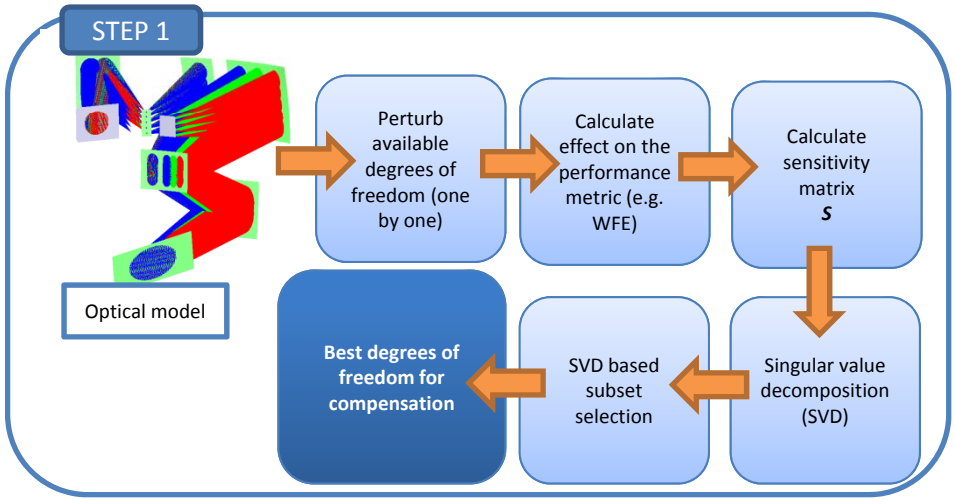
  - Finite element analysis in non-linear cases using Marc/Mentat
  - Material characterisation
  - Design of specific manufacturing machine
    - Tests to be performed early 2013

Active Arrays workpackage was performed in collaboration with the Konkoly Observatory in Budapest, H

Introduction Metrology

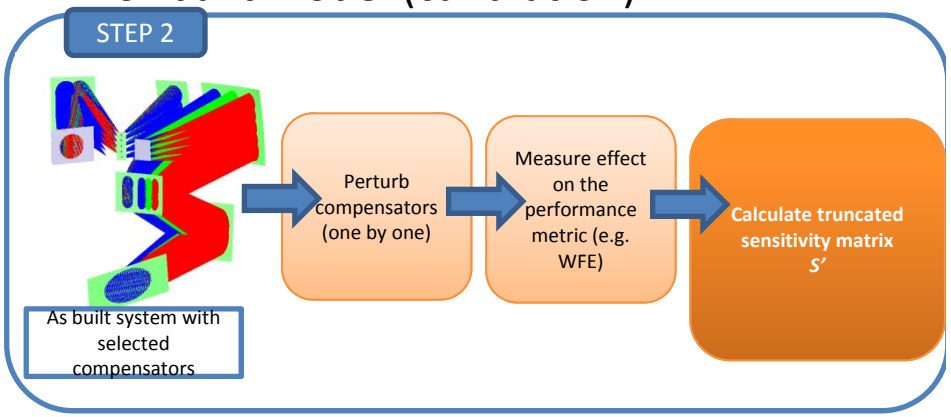
- Active optical components
  - Reduce manufacturing and alignment residuals
  - Correct environmental influences on the instrument
- New methods were developed to design and operate instruments with active components
  - Based of linear algebra methods
  - Based on reverse optimization
  - Metrology: Phase Diversity (PD)

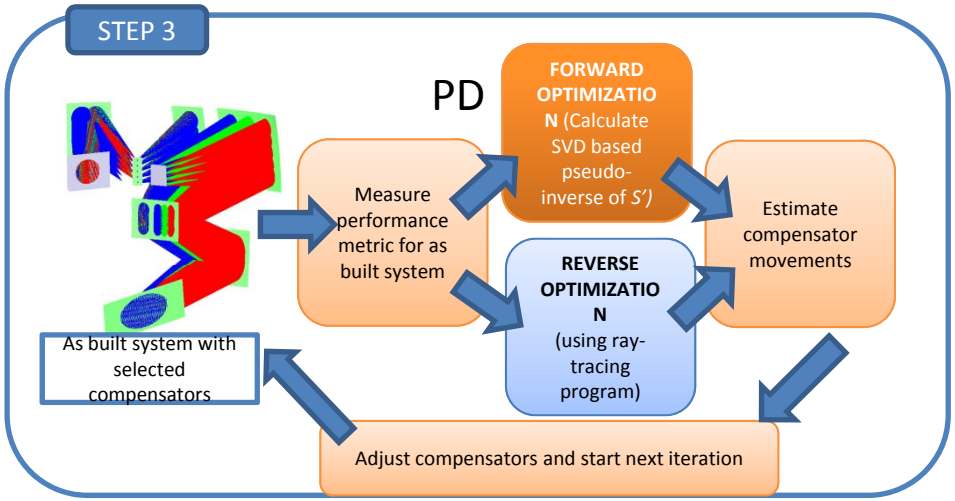
Flow chart of the methods



Limit degrees of freedom in system in design

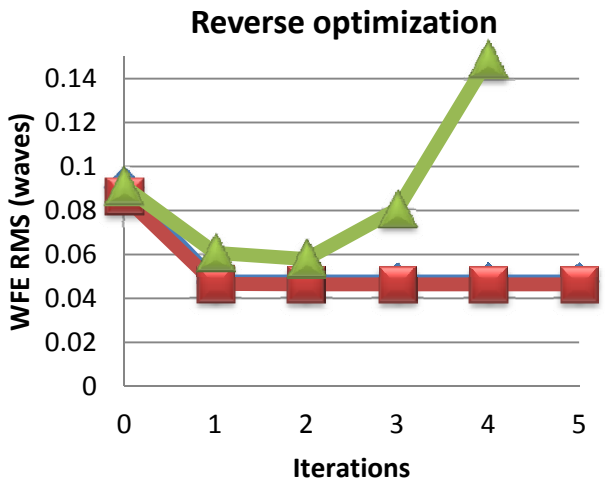
Determine Sensitivity matrix by ZEMAX or built model (calibration)

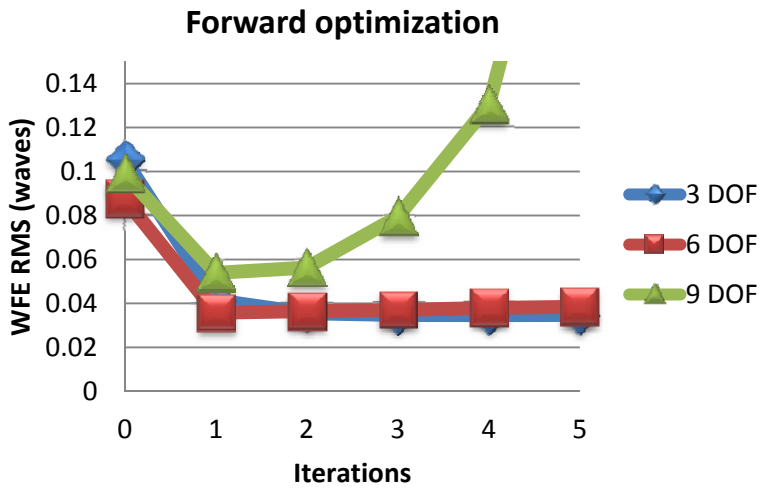




Perform controlled adjustment based on performance measurements

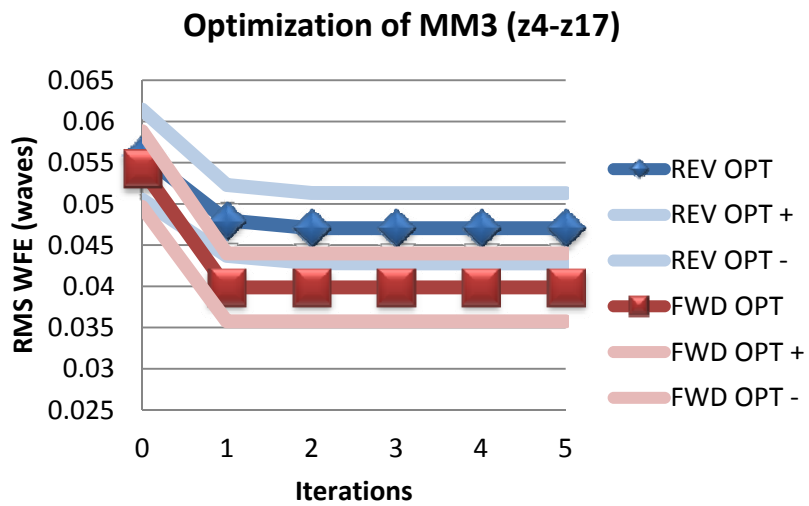
Results





TT & transl. active elements

- Randomly misaligned systems
- Presel. DOF → convergence
- Without presel. → divergence

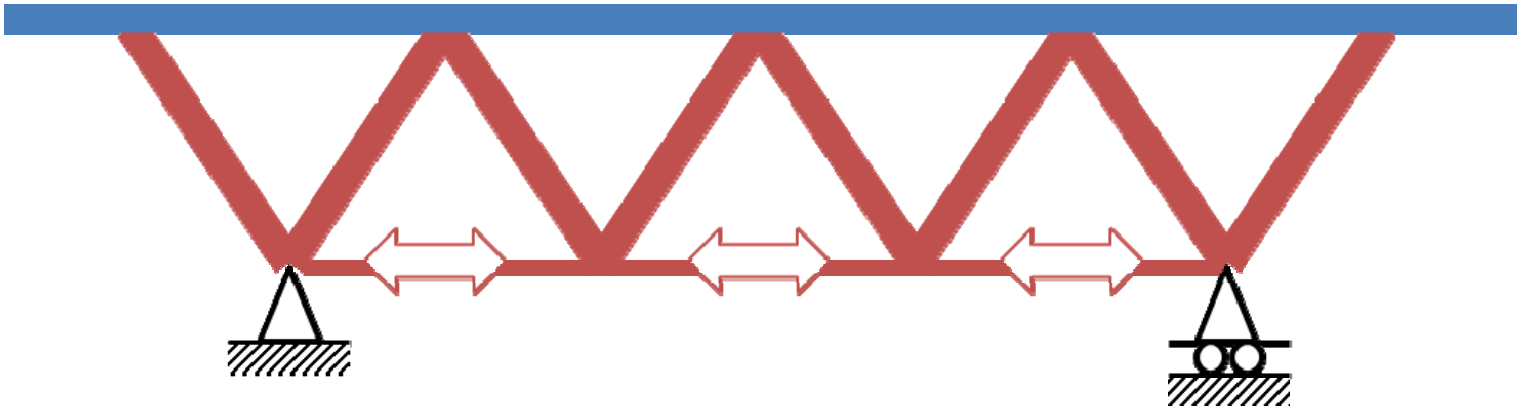


Surface deformation of MM3

- Random surface figuring errors
- Standard Zernike (z4-z17) coefficients are 'active' on MM3
- Convergence is achieved in all cases

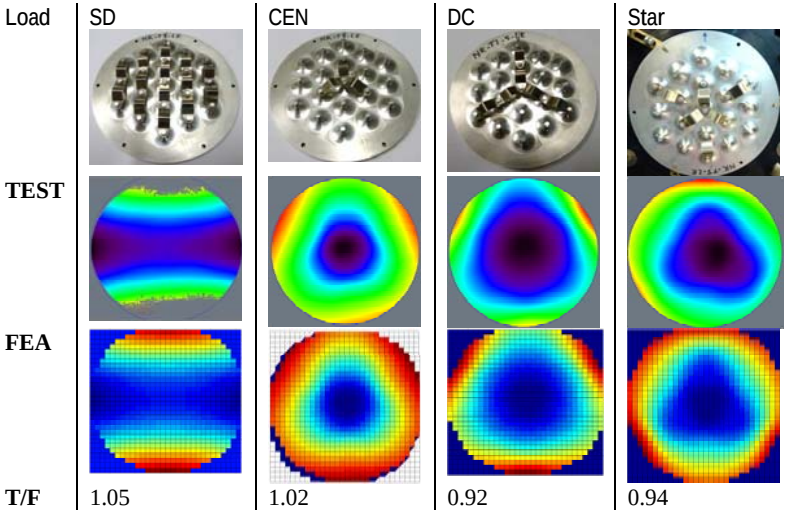
Introduction Active Array

- Literature study
  - Many developments ongoing – most seem to fail in transfer to engineering solutions
- Zero based design strategy
  - Requirements (stable, reliable, slow)
- Conclusions
  - Global stiffness – no external loading
  - Local adjustments



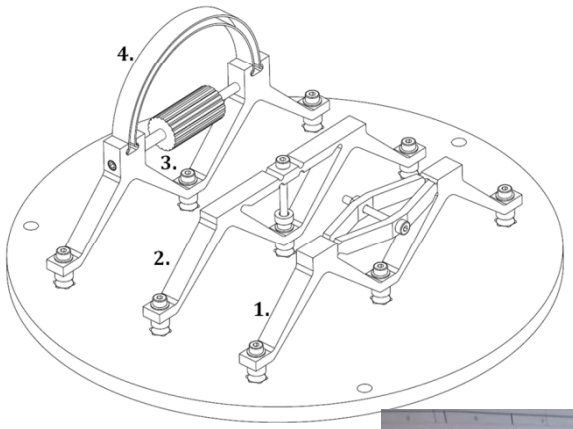
Prototypes

1: Test and FEA



2: Better control

- Loading & location



- Good agreement between FEM and test samples
- Smooth transition to mirror plane, provides good starting point for next phase

G. Kroes et al: “A new generation active arrays for optical flexibility in astronomical instrumentation”, Proc SPIE 8450(2012)

End