Concurrent Design with the Aid of High Performance Computers

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California Institute of Technology

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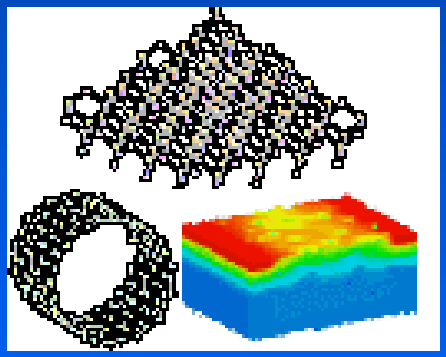
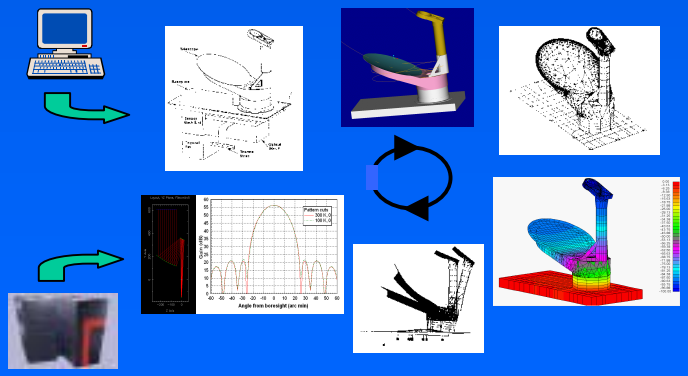
New Design Paradigms Workshop, Pasadena CA

The Need for Computational Resources ...

- **Scientific Data Processing**
  - Large data sets
  - Real-time results

- **Physics-based Models**
  - High-fidelity results
    - *Large memory*
    - *Long runtimes*





- **Design Environments**
  - Risk reduction
    - *Quick turn-around*

Design Motivation ...

- **LATE DESIGN**

  "One key goal of computer simulation is to limit and focus the number of physical experiments required in the design process."

  Uses high-fidelity discipline models

- **EARLY DESIGN**

  Real-time system trades for proposals, early design phases ...

  Uses collaborative environments

- **'FUTURE DESIGN'**

  Create parameterized designs that can exploit optimization, synthesis methods and be used for risk analysis

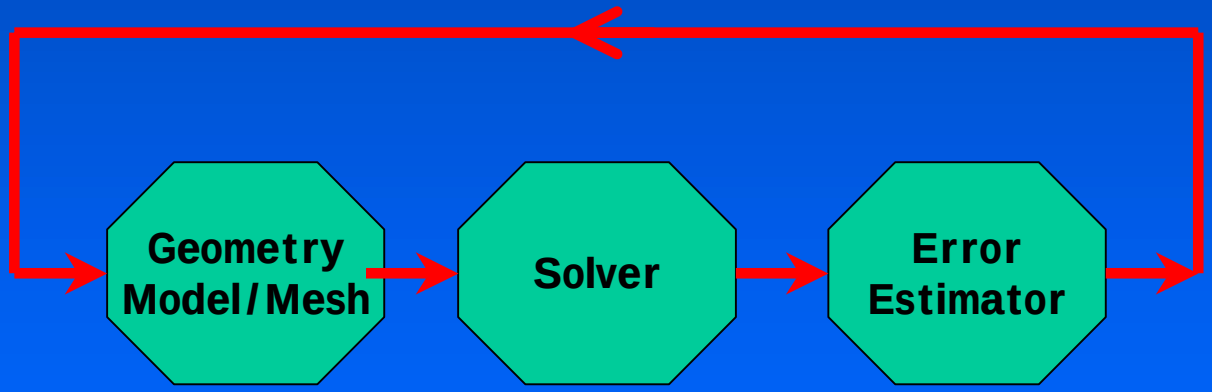
  Uses discipline models and collaborative environments

Evolution of Design ...

- From Discipline Model ...

  with solver, error control and mesh generator

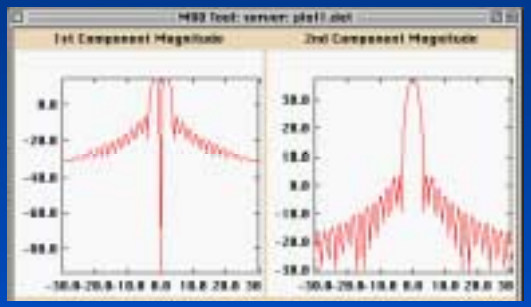
QuickTime™ and a
Microsoft Video 1 decompressor
are needed to see this picture.



...to design environment ...

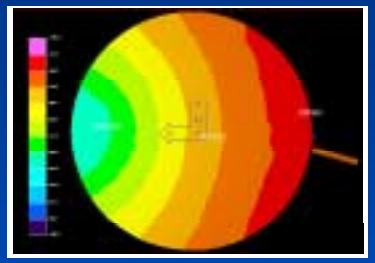
Concurrent Design using High Performance Computers

Physical Optics, MODTool



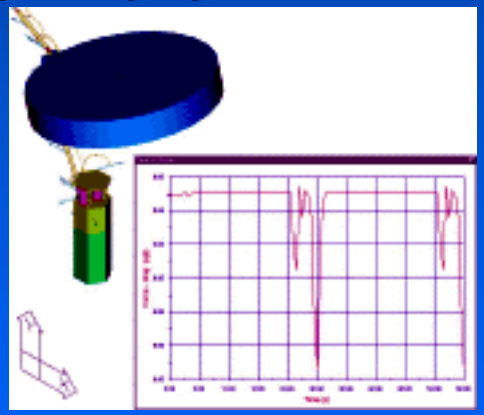
Def Data
NASTRAN

Thermal Desktop

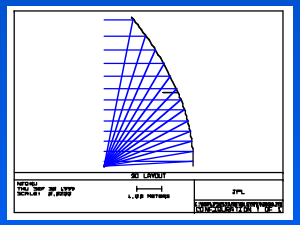


Mechanical Desktop

Rigid Body Dynamics, ADAMS



Ray Tracing, ZeMax/Code V



Apps Inside MDT

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Structural Dynamics, NASTRAN

Def Data
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SC Concept Drawing

SAIC

ASTRO Corp

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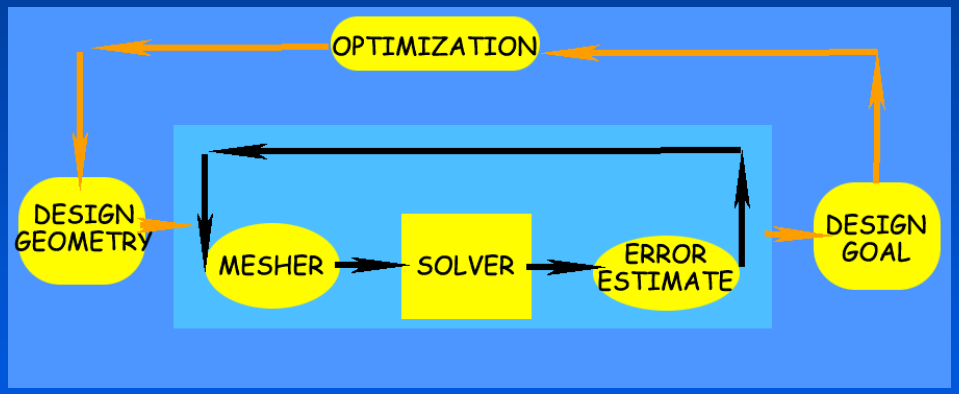
Def Data
Cwik 5 ZeMax

Evolution of Design … (Cont'd)

…to optimization, synthesis and risk reduction …



- Optimization driven by parameterized design
  - Local gradient search
  - Global stochastic (GA)
  - space mapping
- Databases of materials, designs, & measurements integrated into software

Use High Performance Computers When …

- Specific pieces of the design environment need more computational resources
  - Expensive discipline models

    Memory (10s-100s Gbytes) or CPU time (hours-days)
  - High-Fidelity models for resolution in geometry or measurables
  - Repeated 'smart' execution of models for optimization or risk reduction
  - High fidelity integrated simulations repeated over time parameter

One Solution: Commodity Clusters

- Beowulf cluster-class computers leverage
  - Commodity PCs
  - Internet switching and networking
  - Open source software
- Performance proportional to # of PCs
  - Just-in-time procurement
    Fastest cpu, RAM & disc sizing …
  - Extensible as needed
- Cost to requirements
  - Roughly $2K per node average
    Add for memory, disc farms, cpu …

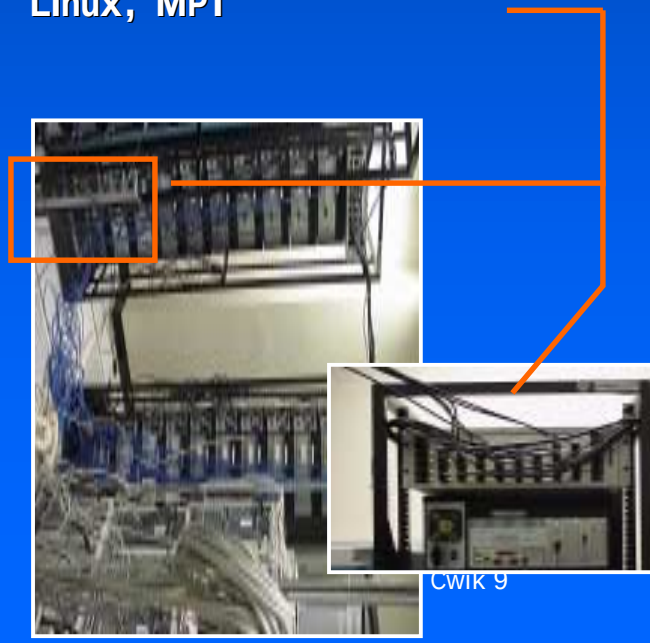
One Solution: Commodity Clusters (Cont'd)

- Three generations of experience …

Hyglac (1997)
16 Pentium Pros 200MHz
128 MB RAM per node
2 GB total
5GB Disc per node
80 GB total
100 Mb/s ethernet crossbar
Linux, MPI

Nimrod (1999)
32 Pentium IIIs 450MHz
512 MB RAM per node
16 GB total
8GB Disc per node
256 GB total
100 Mb/s ethernet crossbar
Linux, MPI

Pluto (2001)
52 Pentium IIIs 800MHz
dual CPUs
2 GB RAM per node
52 GB total
10 GB Disc per node
260 GB total
2 Gb/s Myricom crossbar
Linux, MPI

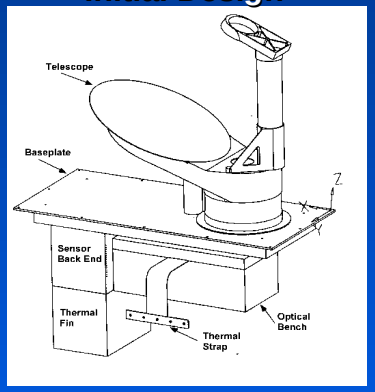


Where We Have Used the Clusters …

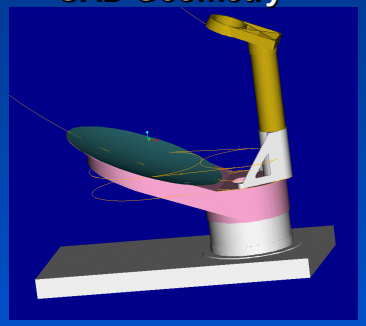
Millimeter-wave Optics Design Tool (Modtool)

Desktop

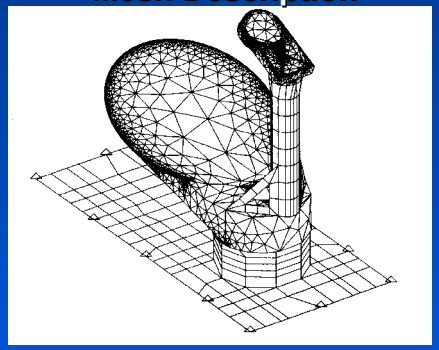
Initial Design



CAD Geometry

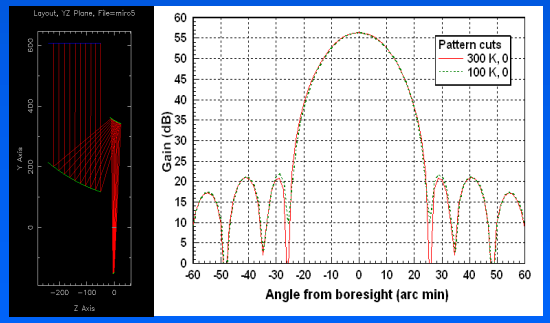


Mesh Description

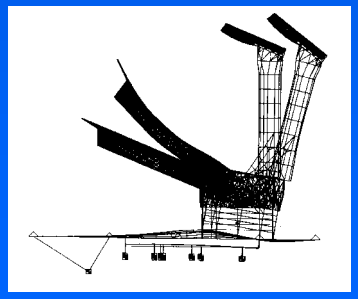


Common Geometry

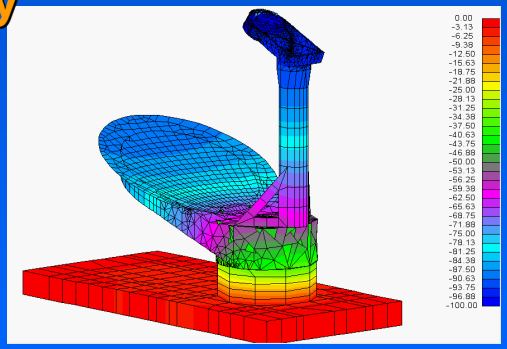
Supercomputer



Diffraction Calculation



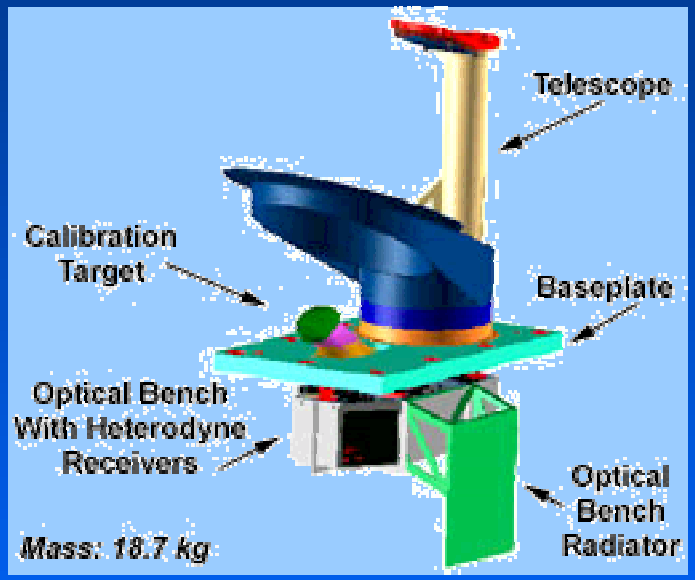
Structural



Thermal

Motivation (1998)

- For the foreseeable future, JPL is proposing, and building microwave and millimeter wave instruments
- Instruments meet design criteria obtained from science mission goals
  - Beamwidth, sidelobes
  - Pointing
  - Gain
- Design criteria are functions of space environment
  - Fluctuating thermal (deep space and earth orbiting) or dynamical loads
  - Mechanical distortion due to loads



MIRO Instrument (JPL)
wwwmiro.jpl.nasa.gov

- PROVIDE HIGH-FIDELITY SIMULATIONS IN DESIGN SPACE EARLY IN PROJECT (PROPOSAL)

Current Design Tools And Process

- Disciplines/Tools:
  - CAD
    - *MDT*
    - *Pro/Engineer*
    - *IDEAS*
  - Meshing
    - *FEMAP*
  - Structural
    - *NASTRAN*
  - Thermal
    - *TRASYS*
    - *SINDA*
  - Antenna/Optics
    - *ZEMACS*
    - *POPO*

- Each tool is used by an analyst/designer, who works in one discipline
- When one analyst completes a model, it is passed to the next

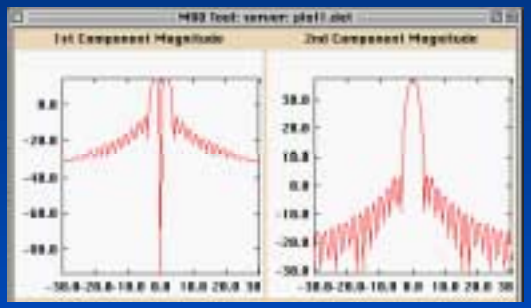
- The current work focuses on antenna electromagnetic design, and how it is connected to the other disciplines through a common digital geometry

MODTool GOALS

- Develop new code only if necessary
  - Try to use/reuse:
    - *Commercial applications*
    - *Previously developed JPL applications*
  - Try to develop code so that it can be used for other future projects
    - *Use standard packages/tools*
    - *Always think beyond this project*
- Ensure users on multiple platforms can easily use tool (client-server)
  - Client written in Tcl/Tk
    - *Freely available over the web*
    - *Available for Unix, PC, Mac*
  - Server also written in Tcl/Tk, but on a specific type of machine
    - *Uses compiled C code using Unix libraries for user authentication*

Concurrent Design using High Performance Computers

Physical Optics, MODTool



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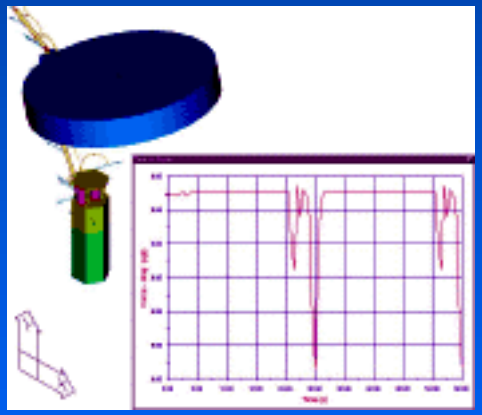

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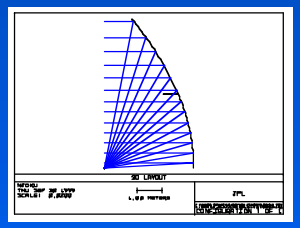

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ZeMax

Instrument: Osiris Mesh Antenna (N. Njoku, Jpl)

- **Real-time analysis of spinning antenna system on spacecraft**
  - *Deployable Mesh Antenna on boom; dual beam, 1.4 GHz;*
  - *Rotates 6RPM*
  - *Dynamic loading causes 'wobble' with resultant beam shift*

QuickTime™ and a
Video decompressor
are needed to see this picture.

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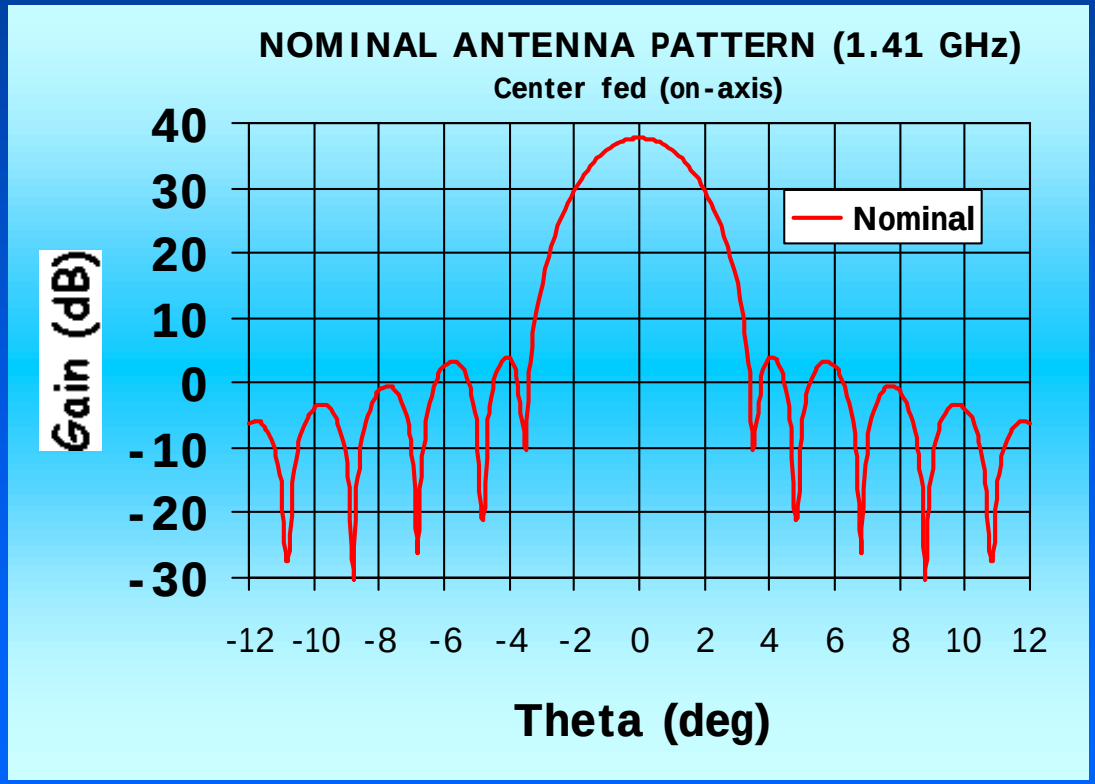
Microsoft Video 1 decompressor
are needed to see this picture.

**Deployed mesh antenna;
NASTRAN model imported**

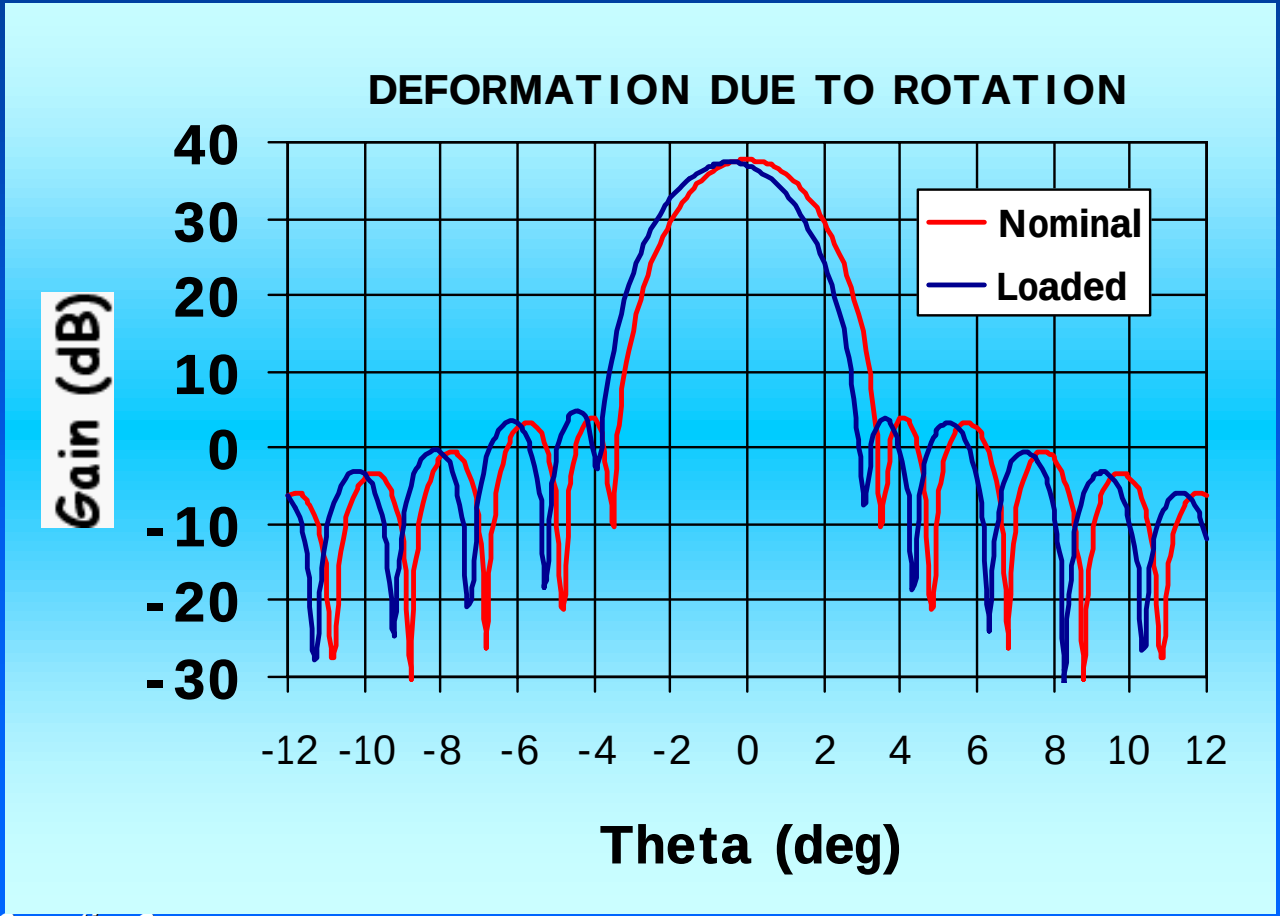
Instrument: Osiris Mesh Antenna (Cont'd)

- Calculate nominal antenna pattern
  - Prescribed solid surface
  - No distortions



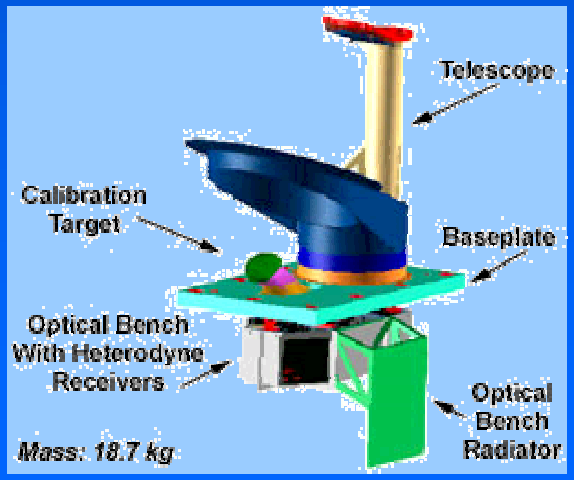
Instrument: Osiris Mesh Antenna (Cont'd)

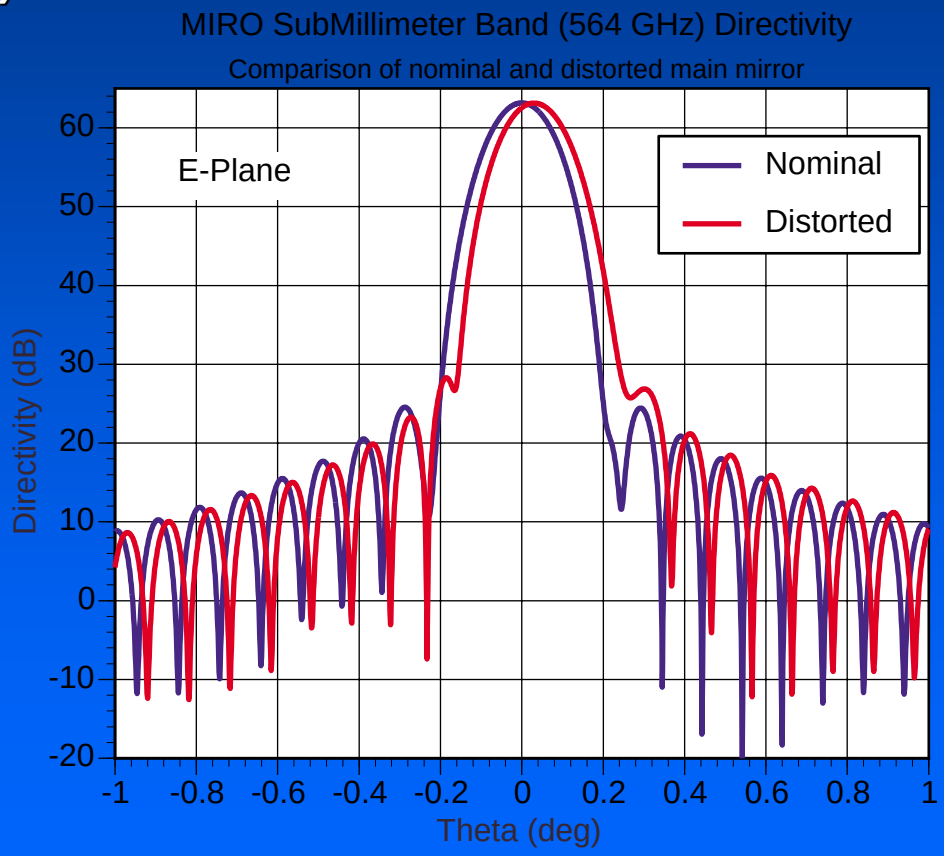
- Design cycle closed -> distorted mesh fed to PO calculation
  Nominal and deformed surface pattern calculations



Using As-Built Measured Data

- Coordinate Measuring machine (CMM) data (MIRO main reflector surface)
  - Data fit to polynomial or used directly in PO code (local/global interpolations)
  - Calculate pattern of as-built surface





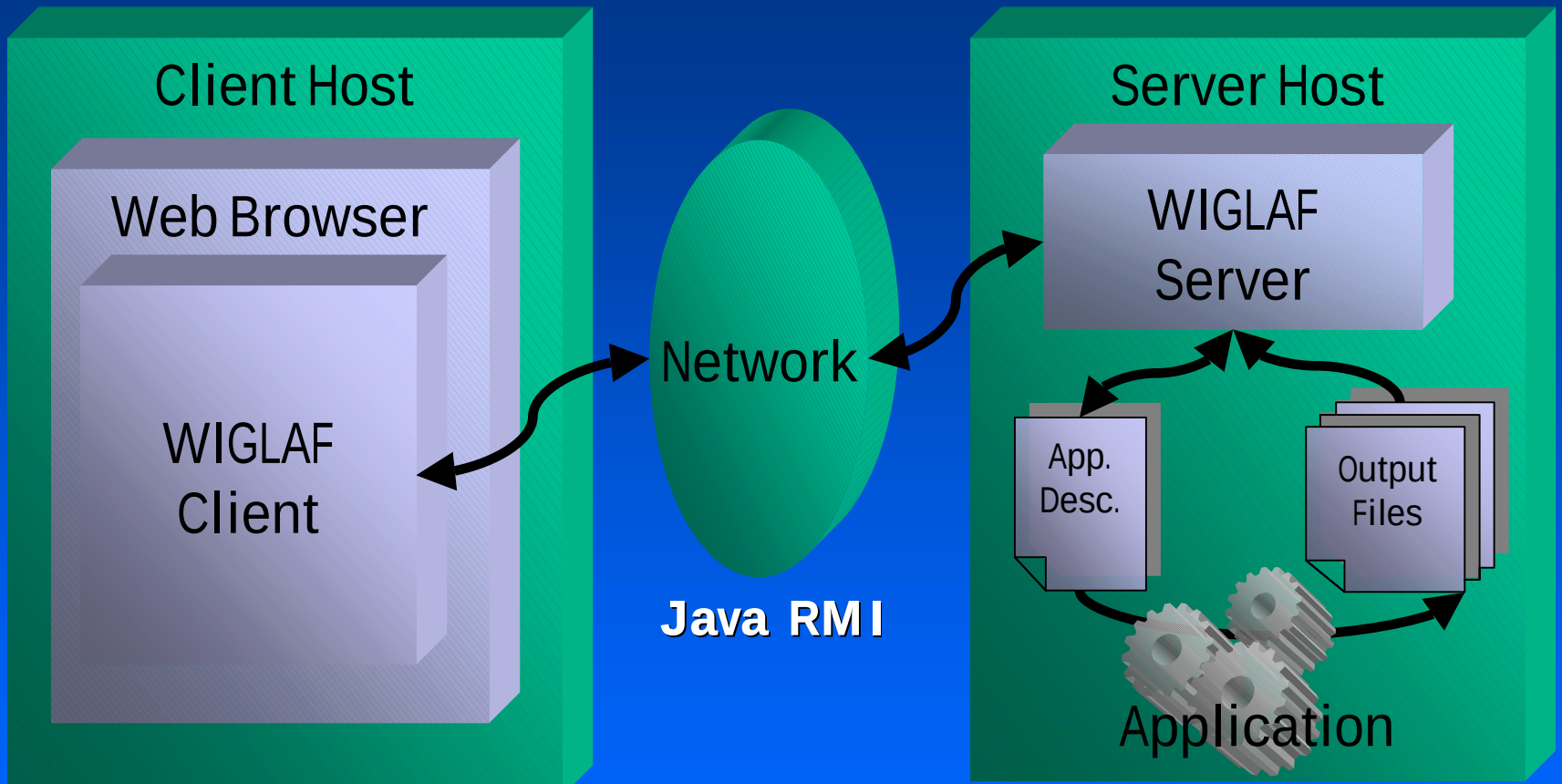
Lessons Learned

- Use of cluster computers can enable
  - Realtime turn-around for design iterations
  - The use of high fidelity models
- The high-performance computer needs to be invisible to the user
  - Make the cluster look like a typical workstation
  - No additional computational skills needed to perform analysis or design

Making the Cluster Invisible - WIGLAF

- **Cluster applications can be difficult to use.**
  - Input files must be formatted carefully.
  - Output files must be located and examined.
  - Remote logins and data transfer needed.
  - The difficulty is due to *inconsistency*.
- **WIGLAF: a facade for cluster applications.**
  - Input and output are presented in a consistent interface.
  - Web-based – *All you need is a web browser.*
  - *Internal codename WIGLAF- warrior who sent messenger to tell of Beowulfs death.*

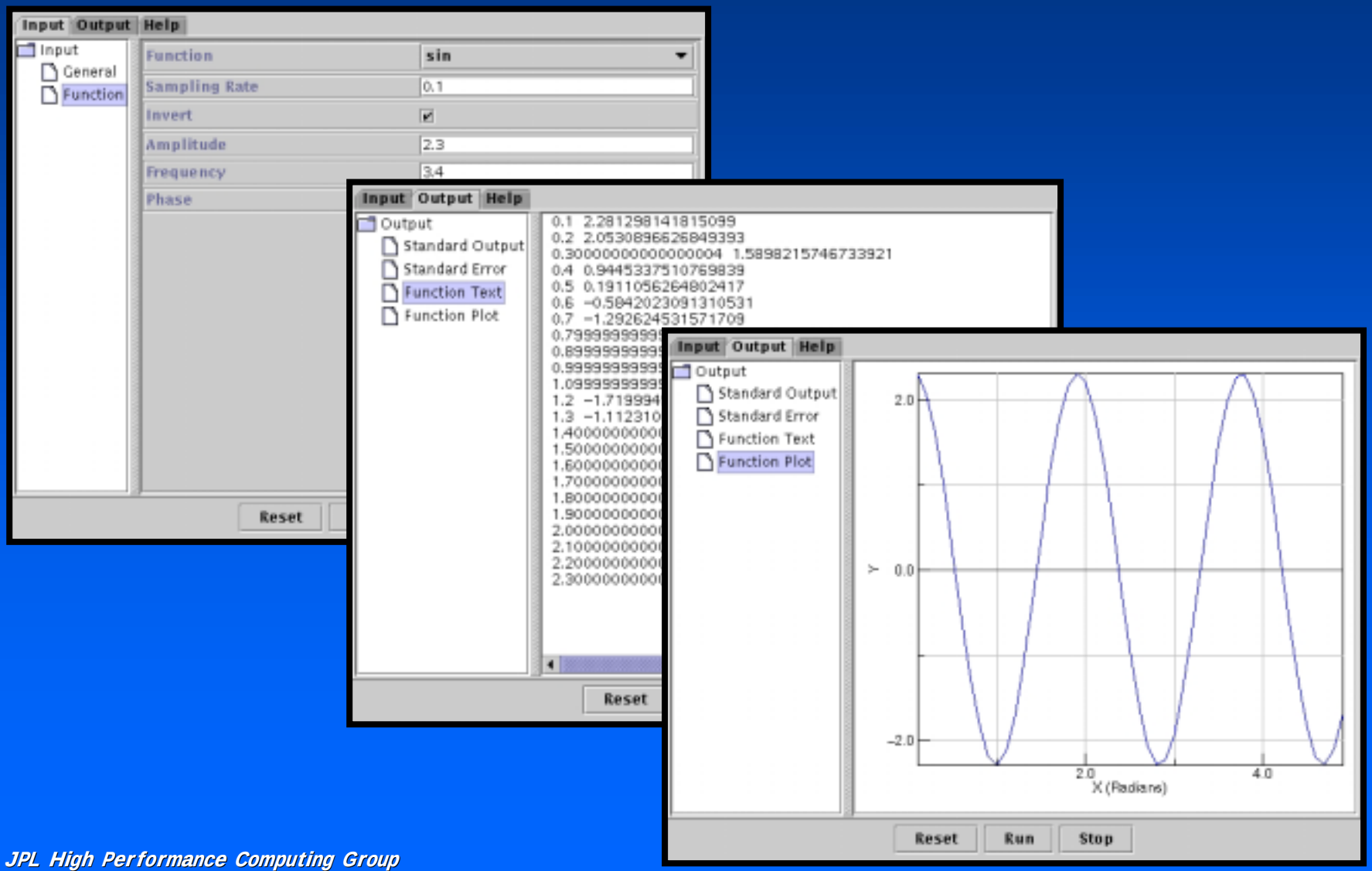
WIGLAF – Deployment



On the Desktop
Only your browser

On the Cluster
Java, XML,
application language (c, Fortran …)

WIGLAF - Screenshots



Optimization, Synthesis and Risk Reduction

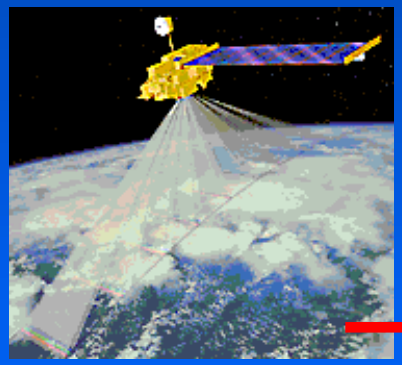
- Parameterized designs, mature models and high performance computers lead to
  - Optimization and design synthesis through local search or global methods (Genetic Algorithms)
  - Risk reduction using Monte Carlo or related methods

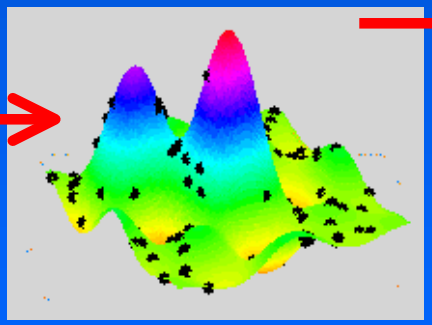
Compliments Genetic Programming Inc. http://www.genetic-programming.com/

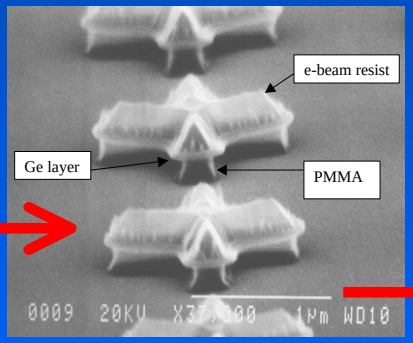
Optimization, Synthesis and Risk Reduction (Cont'd)

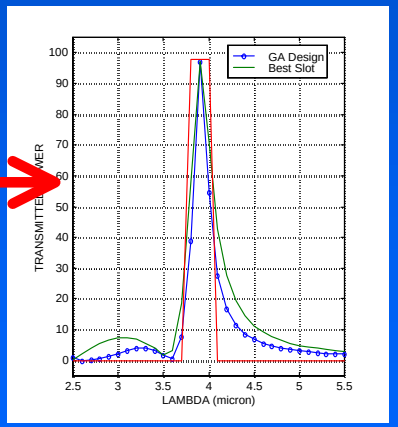
- **Prescribe fitness function to optimize**
  - Parameterize model and provide parameter ranges
  - Distribute computation to nodes; each node receives single parameter set

    master node orchestrates individual simulations









- **Filter design, antenna design, nanotechnology modeling**