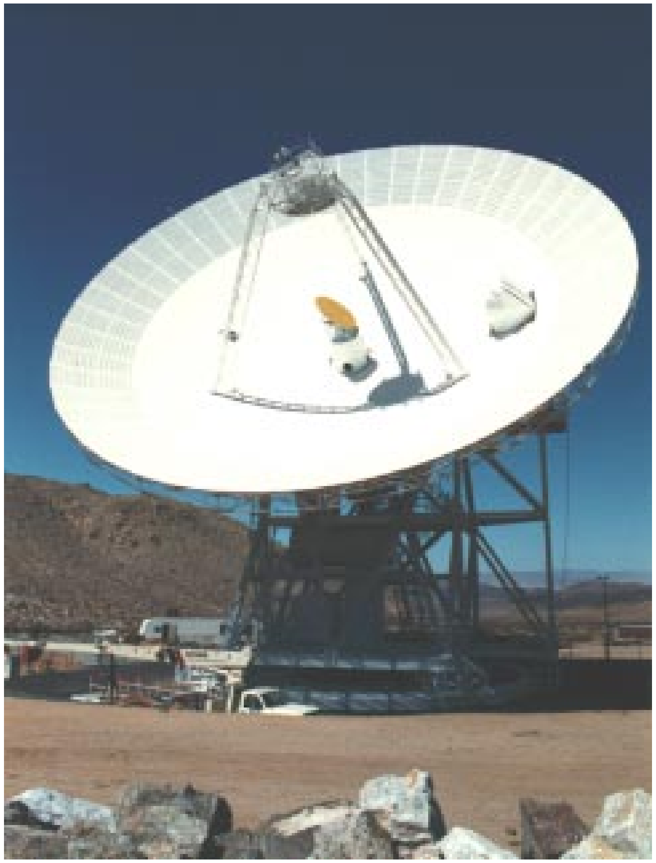
Large-Scale, Low-Cost Parallel Computers Applied to Reflector Antenna Analysis

Daniel S. Katz, Tom Cwik

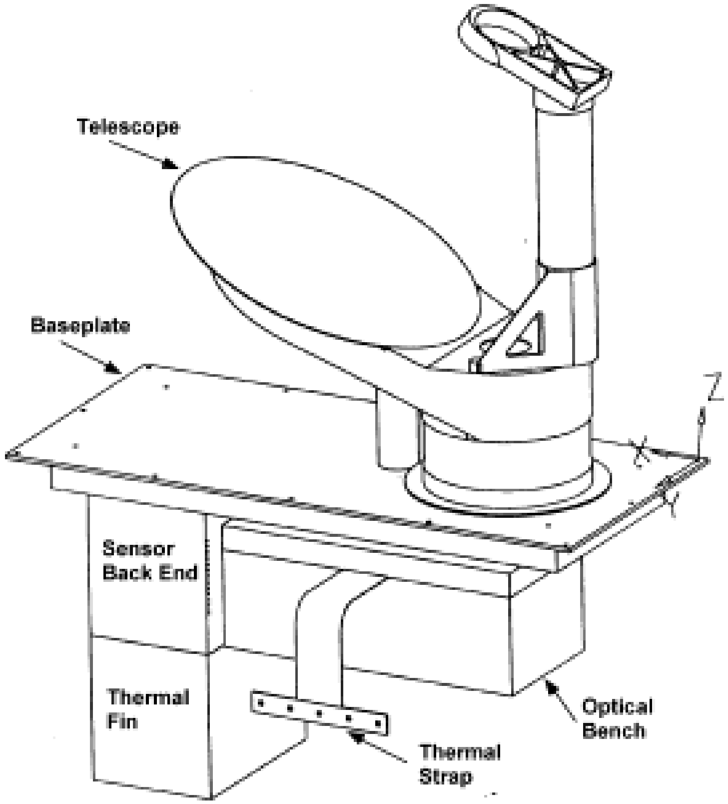
{Daniel.S.Katz, cwik}@jpl.nasa.gov

JPL

Physical Optics Application

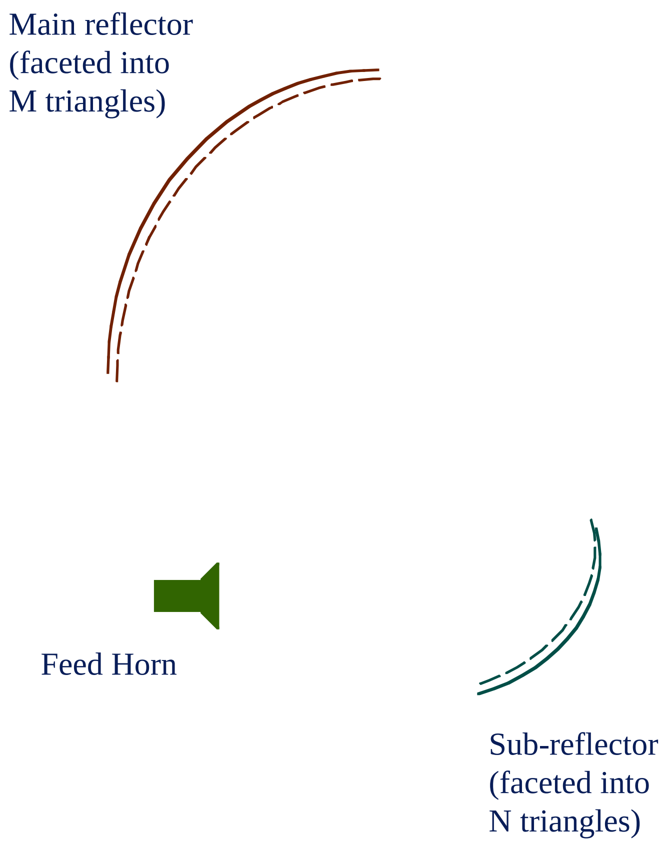


DSN antenna - 34 meter main



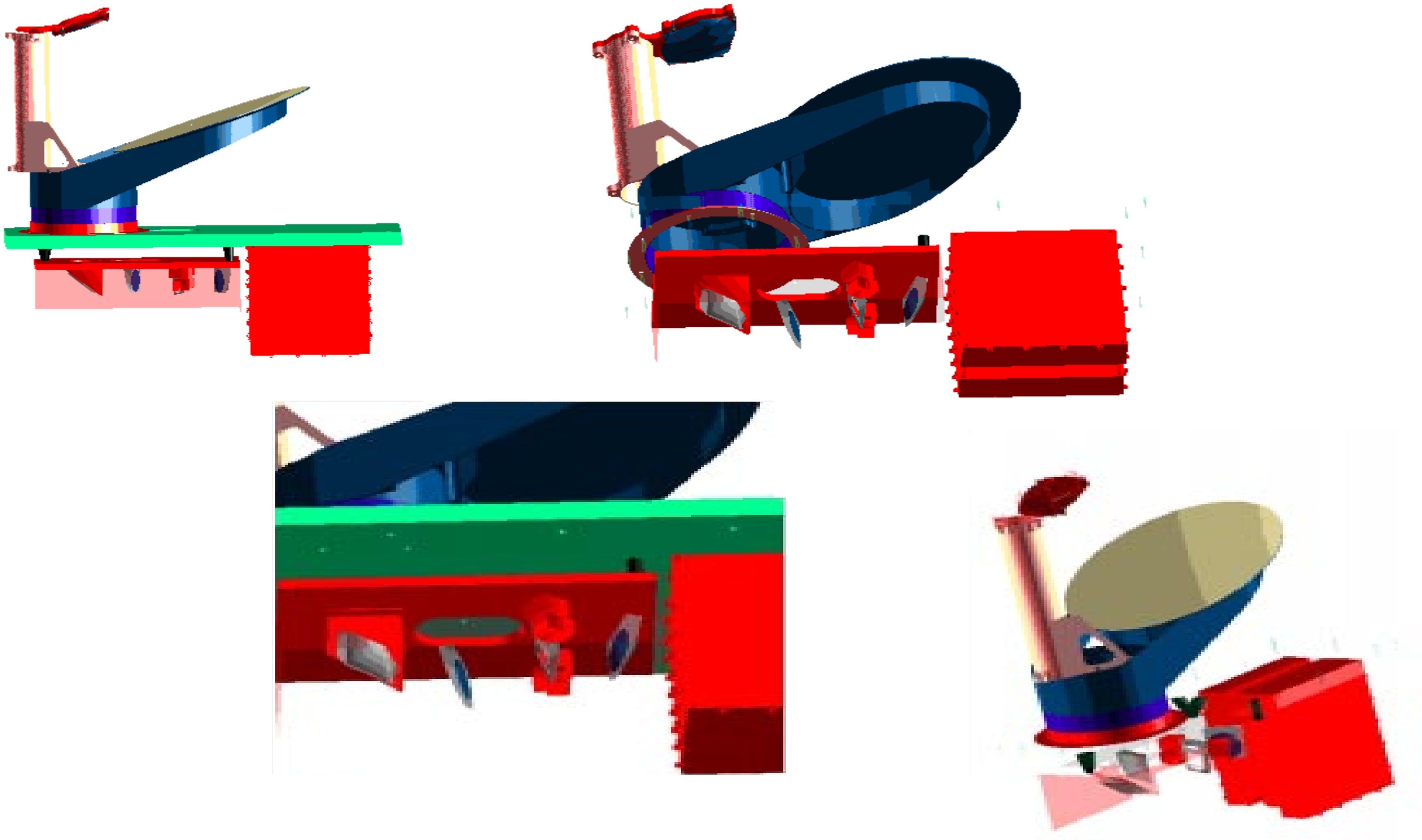
MIRO antenna - 30 cm main

Physical Optics Algorithm



1. Create mesh with N triangles on sub-reflector.
2. Compute N currents on sub-reflector due to feed horn (or read currents from file)
3. Create mesh with M triangles on main reflector
4. Compute M currents on main reflector due to currents on sub-reflector
5. Compute antenna pattern due to currents on main reflector (or write currents to file)

Microwave Instrument for the Rosetta Orbiter(MIRO)



PO Analysis of MIRO

190 GHz:

Element / Analysis time	# triangles
matching mirror	1,600
17 seconds	
turning mirror	1,600
57 seconds	
sub-reflector	6,400
1100 seconds	
main reflector	40,000

564 GHz:

Element / Analysis time	# triangles
matching mirror	6,400
193 seconds	
polarizer	6,400
193 seconds	
turning mirror	6,400
445 seconds	
sub-reflector	22,500
5940 seconds	
main reflector	90,000

Previous MIRO Analysis

- Cray J90 timings:
  - » 190 GHz:

    Complete run (3 mirror pairs): 20 minutes
  - » 564 GHz:

    Complete run (4 mirror pairs): 120 minutes
- Turnaround time of 2 hours is too long to do effective design work.
- Use parallel computing to decrease time to obtain results

Beowulf System at JPL (Hyglac)

- 16 Pentium Pro PCs, each with 2.5 Gbyte disk, 128 Mbyte memory, Fast Ethernet card.
- Connected using 100Base-T network, through a 16-way crossbar switch.
- Theoretical peak: 3.2 GFLOP/s
- Sustained: 1.26 GFLOP/s

Hyglac Cost

- Hardware cost: $54,200 (as built, 9/96)
  $22,000 (estimate, 4/98)
  - » 16 (CPU, disk, memory, cables)
  - » 1 (16-way switch, monitor, keyboard, mouse)
- Software cost: $600 (+ maintainance)
  - » Absoft Fortran compilers (should be $900)
  - » NAG F90 compiler ($600)
  - » public domain OS, compilers, tools, libraries

Beowulf System at Caltech (Naegling)

- ~120 Pentium Pro PCs, each with 3 Gbyte disk, 128 Mbyte memory, Fast Ethernet card.
- Connected using 100Base-T network, through two 80-way switches, connected by a 4 Gbit/s link.
- Theoretical peak: ~24 GFLOP/s
- Sustained: 10.9 GFLOP/s

Naegling Cost

- Hardware cost: $190,000 (as built, 9/97)
  $154,000 (estimate, 4/98)
  - » 120 (CPU, disk, memory, cables)
  - » 1 (switch, front-end CPU, monitor, keyboard, mouse)
- Software cost: $0 (+ maintainance)
  - » Absoft Fortran compilers (should be $900)
  - » public domain OS, compilers, tools, libraries

Performance Comparisons

	Hyglac	Naegling	T3D	T3E600
CPU Speed (MHz)	200	200	150	300
Peak Rate (MFLOP/s)	200	200	300	600
Memory (Mbyte)	128	128	64	128
Communication Latency (μs)	150	322	35	18
Communication Throughput (Mbit/s)	66	78	225	1200

(Communication results are for MPI code)

Message-Passing Methodology

- Receiver issues (non-blocking) receive calls:

```
CALL MPI_IRECV(…)
```

- Sender issues (non-blocking, synchronous send calls:

```
CALL MPI_SSEND(…)
```

- Receiver issues (blocking) wait calls (to wait for receives to complete):

```
CALL MPI_WAIT(…)
```

Parallelization of PO Algorithm

- Distribute (M) main reflector currents over all (P) processors
- Store all (N) sub-reflector currents redundantly on all (P) processors
- Creation of triangles is sequential, but computation of geometry information on triangles is parallel, so 1 and 3 are partially parallel
- Computation of currents (2, 4, and 5) is parallel, though communication is required in 2 (MPI_Allgetherv) and 5 (MPI_Reduce).
- Timing:
  - » Part I: Read input files, perform step 3
  - » Part II: Perform steps 1, 2, and 4
  - » Part III: Perform step 5 and write output files
- Algorithm:
  1. Create mesh with N triangles on sub-reflector.
  2. Compute N currents on sub-reflector due to feed horn (or read currents from file)
  3. Create mesh with M triangles on main reflector
  4. Compute M currents on main reflector due to currents on sub-reflector
  5. Compute antenna pattern due to currents on main reflector (or write currents to file)

Physical Optics Results (Two Beowulf Compilers)

Number of Processors	Part I	Part II	Part III	Total
1	0.0850	64.3	1.64	66.0
4	0.0515	16.2	0.431	16.7
16	0.0437	4.18	0.110	4.33

Time (minutes) on Hyglac, using gnu (`g77 -O2 -fno-automatic`)

Number of Processors	Part I	Part II	Part III	Total
1	0.0482	46.4	0.932	47.4
4	0.0303	11.6	0.237	11.9
16	0.0308	2.93	0.0652	3.03

Time (minutes) on Hyglac, using Absoft (`f77 -O -s`)

M = 40,000 N = 4,900

Physical Optics Results (T3D Optimization)

Change main integral calculation from:

```
      CEJKR = (AJ*AK*1./R)*CDEXP(-AJ*AKR)/R2
```

to:

```
      CEJKR = DCMPLX(
     .          (R*AK*DSIN(AKR)+DCOS(AKR))/(R*R2),
     .          (R*AK*DCOS(AKR)+DSIN(AKR))/(R*R2))
```

Number of Processors	Part II (no opt.)	Part II (w/ opt.)	Part III (no opt.)	Part III (w/ opt.)
1	85.8	48.7	1.90	0.941
4	19.8	12.2	0.354	0.240
16	4.99	3.09	0.105	0.0749

Time (minutes) on T3D, N=40,000, M=4,900

Physical Optics Results

Number of Processors	Naegling	T3D	T3E-600
4	95.5	102	35.1
16	24.8	26.4	8.84
64	7.02	7.57	2.30

Time (minutes), N=160,000, M=10,000

- Cray J-90 Time : about 2 hours

Expected new analysis times for MIRO

- Using Beowulf-class computers
  - » Can run 190 GHz case (3 paired mirrors):
    - – 16 processors: about 1 minute
    - – 64 processors: less than 20 seconds
  - » Can run 564 GHz case (4 paired mirrors):
    - – 16 processors: about 25 minutes
    - – 64 processors: about 7 minutes

Conclusions

- Beowulf-class computers can fit individual projects, such as MIRO, quite well
- They can enable a project with a limited budget to improve the time required to obtain results
- Reflector antenna analysis using Physical Optics is well-suited for these computers