CfAO-Related Activities at Gemini Observatory

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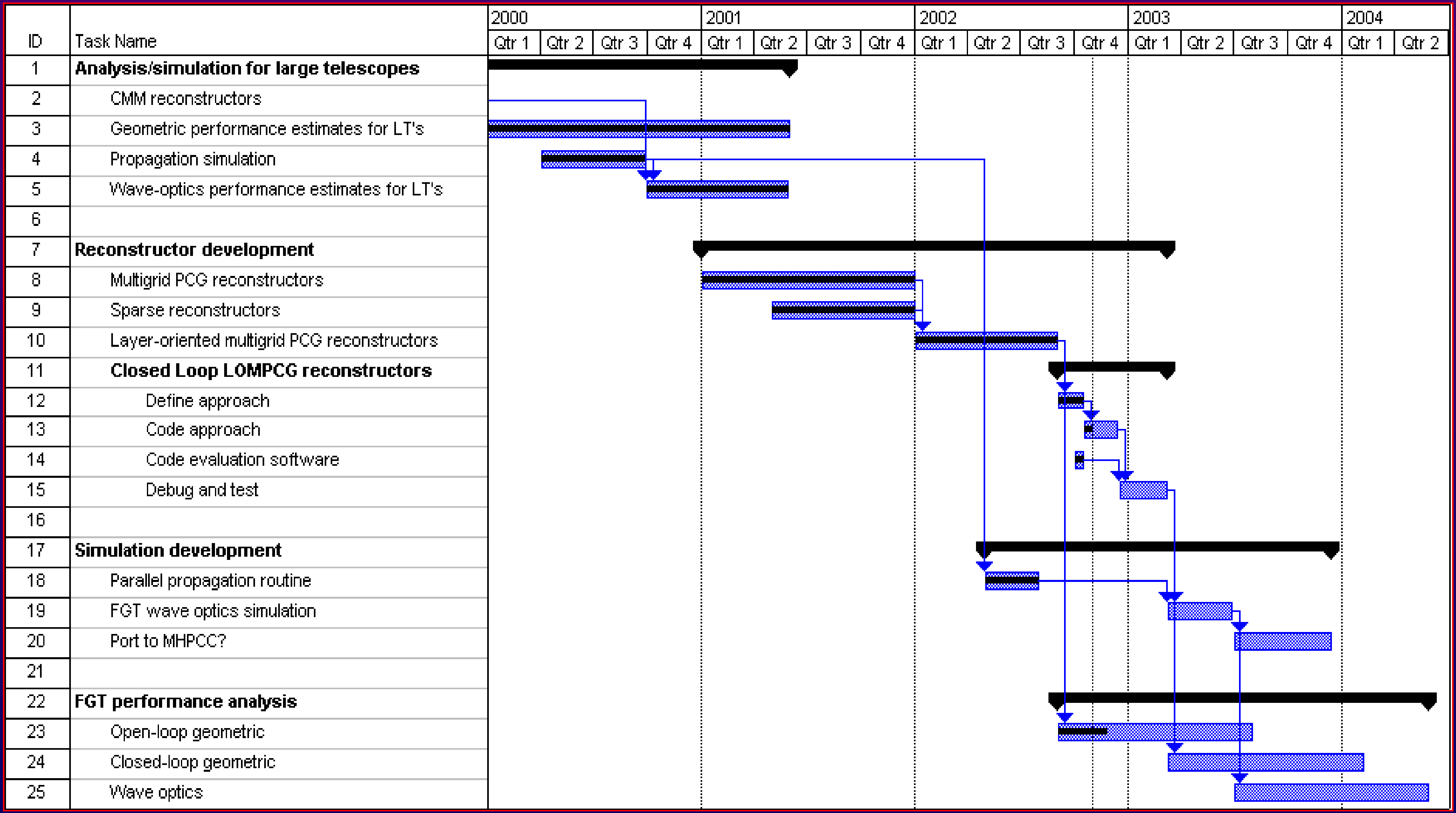
Gemini Observatory

Outline

- Overview
- Altair LGS upgrade at Gemini-North
- New wavefront reconstruction simulations for MCAO on future giant telescopes
- Parallel simulation status
- Parallelizing sparse matrix wavefront reconstructors for ExAO

Progress and Plans



ID	Task Name
1	**Analysis/simulation for large telescopes**
2	CMM reconstructors
3	Geometric performance estimates for LT's
4	Propagation simulation
5	Wave-optics performance estimates for LT's
6	
7	**Reconstructor development**
8	Multigrid PCG reconstructors
9	Sparse reconstructors
10	Layer-oriented multigrid PCG reconstructors
11	**Closed Loop LOMPCG reconstructors**
12	Define approach
13	Code approach
14	Code evaluation software
15	Debug and test
16	
17	**Simulation development**
18	Parallel propagation routine
19	FGT wave optics simulation
20	Port to MHPCC?
21	
22	**FGT performance analysis**
23	Open-loop geometric
24	Closed-loop geometric
25	Wave optics

Calculations to Do as Time Permits

- Evaluate more MCAO configurations for FGT’s
  - Additional guide star and DM configurations
  - Additional turbulence profiles
- Geometric analysis of boundary layer AO
- Wave optics analysis of ExAO PSF
- Sodium LGS WFS measurement accuracy for FGT’s with measured sodium layer profiles
- Extensions to infinite aperture MCAO analysis
  - Integrated analysis of turbulence estimation and correction
  - Servo lag effects for classical control laws

Altair LGS Upgrade—Laser System

- Contract now awaiting final approval from NSF
  - Delivery 20 months after contract award
- Diode-pumped Nd:YAG sum frequency design
  - To be mounted on telescope center section
  - 21W design, with a requirement for 14W
- Reliability and alignment
  - Some degree of daily alignment adjustments anticipated
  - Early lab demos and prototyping to reduce risk
    - Optional active alignment systems for Nd:YAG cavities and SFG crystal already priced
  - 5 months of on-site support provided after delivery

Altair LGS Upgrade—other Major Subsystems

- Altair AO system
  - LGS WFS installed on bench; final alignment required
  - System-level and real-time control software upgrades in progress
- Laser Launch Telescope (LLT)
  - CDR scheduled at EOST on 12/19/02
  - Delivery scheduled for 3Q 2003
- Beam Transfer Optics (BTO)
  - CDR scheduled for in-house design on 03/03/03
- SALSA aircraft safety system
  - All sky camera selected, detection software under development
  - Boresighted thermal IR camera selected and tested at sea-level
- Laser Traffic Control System (LTCS)
  - Fine-tuning underway for operational system at Keck

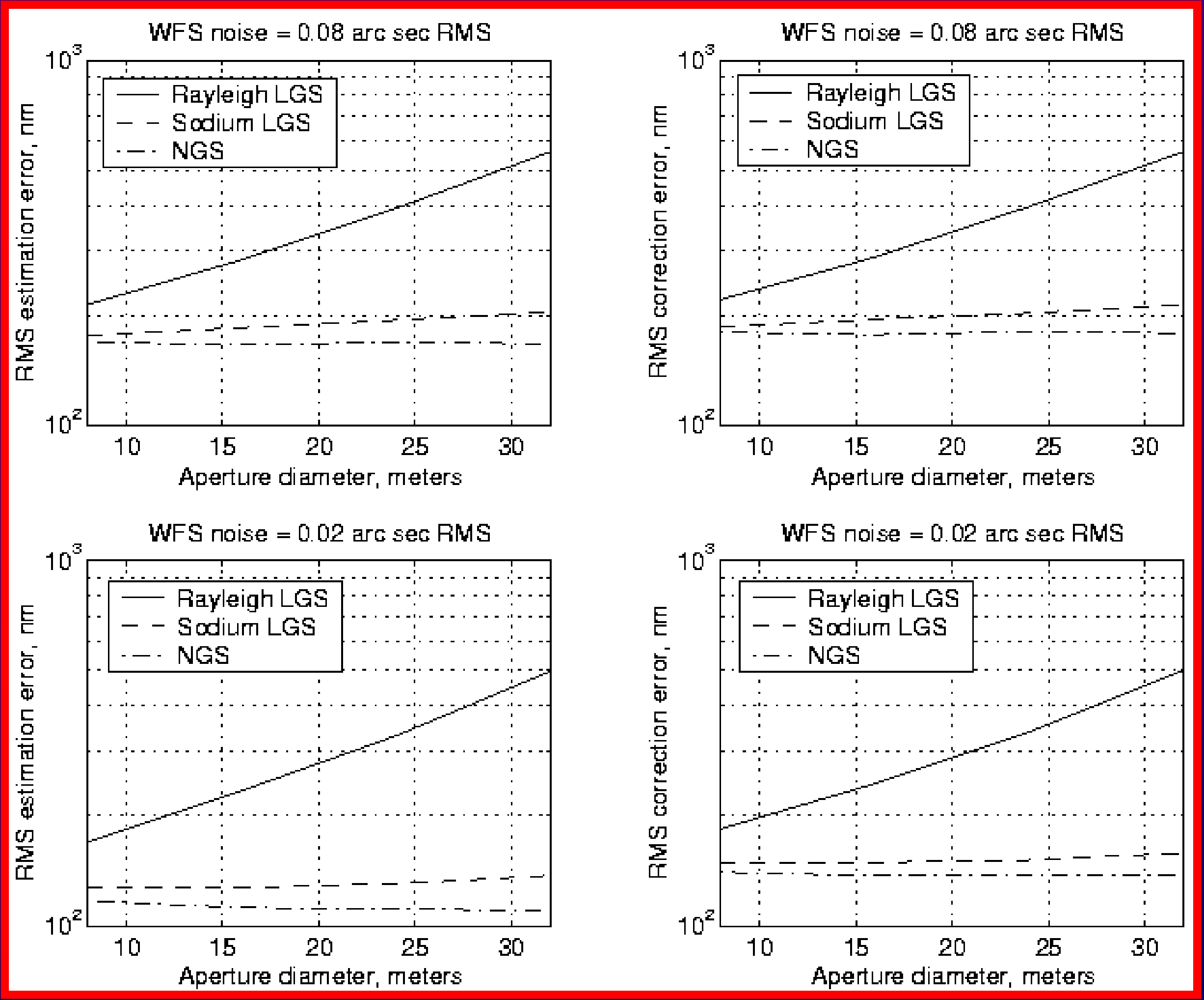
Simulations of MCAO on FGT's

- Goal: Evaluate performance scaling with aperture
- Simulation parameters:
  - 6-layer Cerro Pachon turbulence profile
  - 1 arc minute square science field-of-view
  - 3 DM's conjugate to 0, 5.15, and 10.30 km
    - Actuator pitches of 0.5, 0.5, and 1.0 m
  - 5 higher order guidestars at corners and center of 1' field
    - NGS, Sodium LGS, or Rayleigh LGS at 30 km
    - 0.5 m subapertures, 0.02 or 0.08 arc sec measurement noise
  - 4 tip/tilt NGS WFS for LGS MCAO systems
  - 10 simulation trials using 64 m screens with 1/32m pitch

Simulation Dimensionality

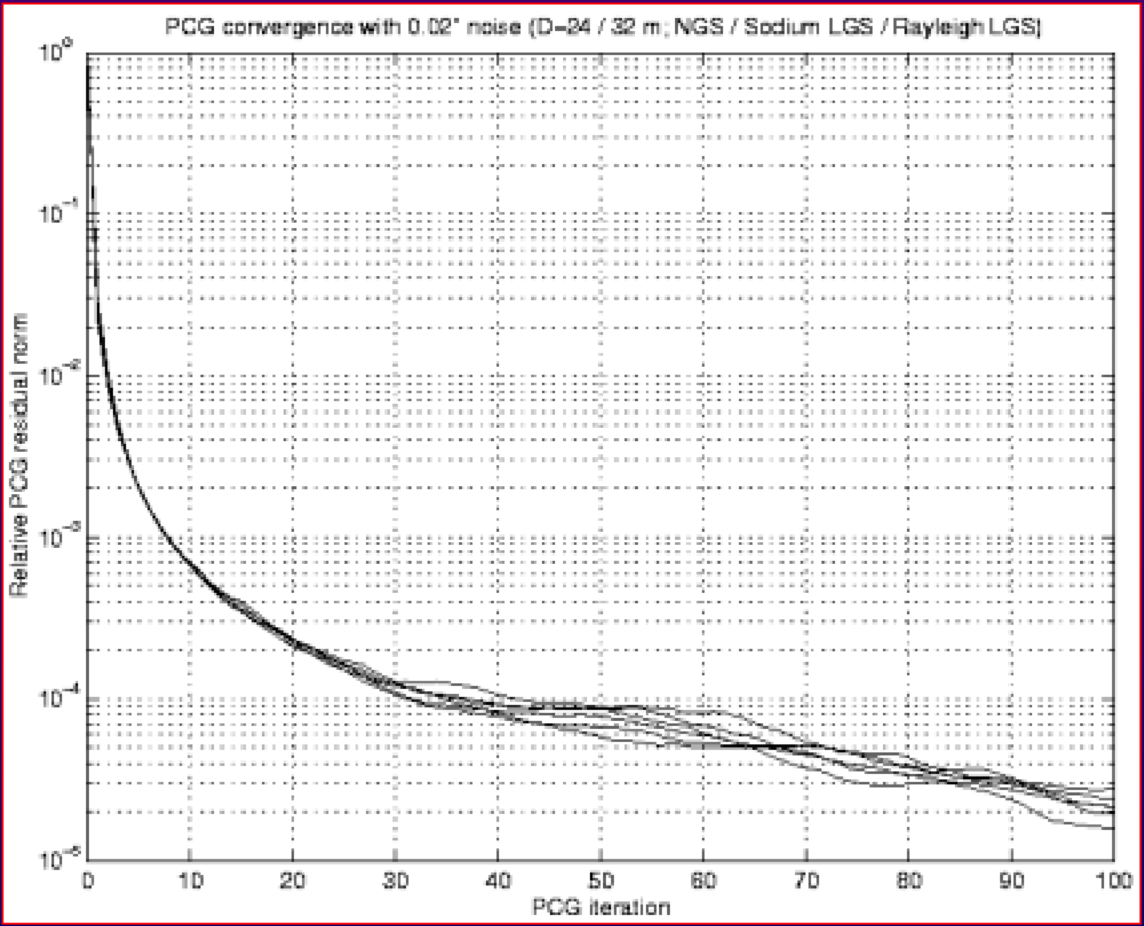
Aperture, m	8	16	24	32
WFS measurements	2240	8560	18840	33320
Phase points estimated	7270	21226	42334	70838
DM actuators	789	2417	4957	8449

MCAO Performance vs. Aperture



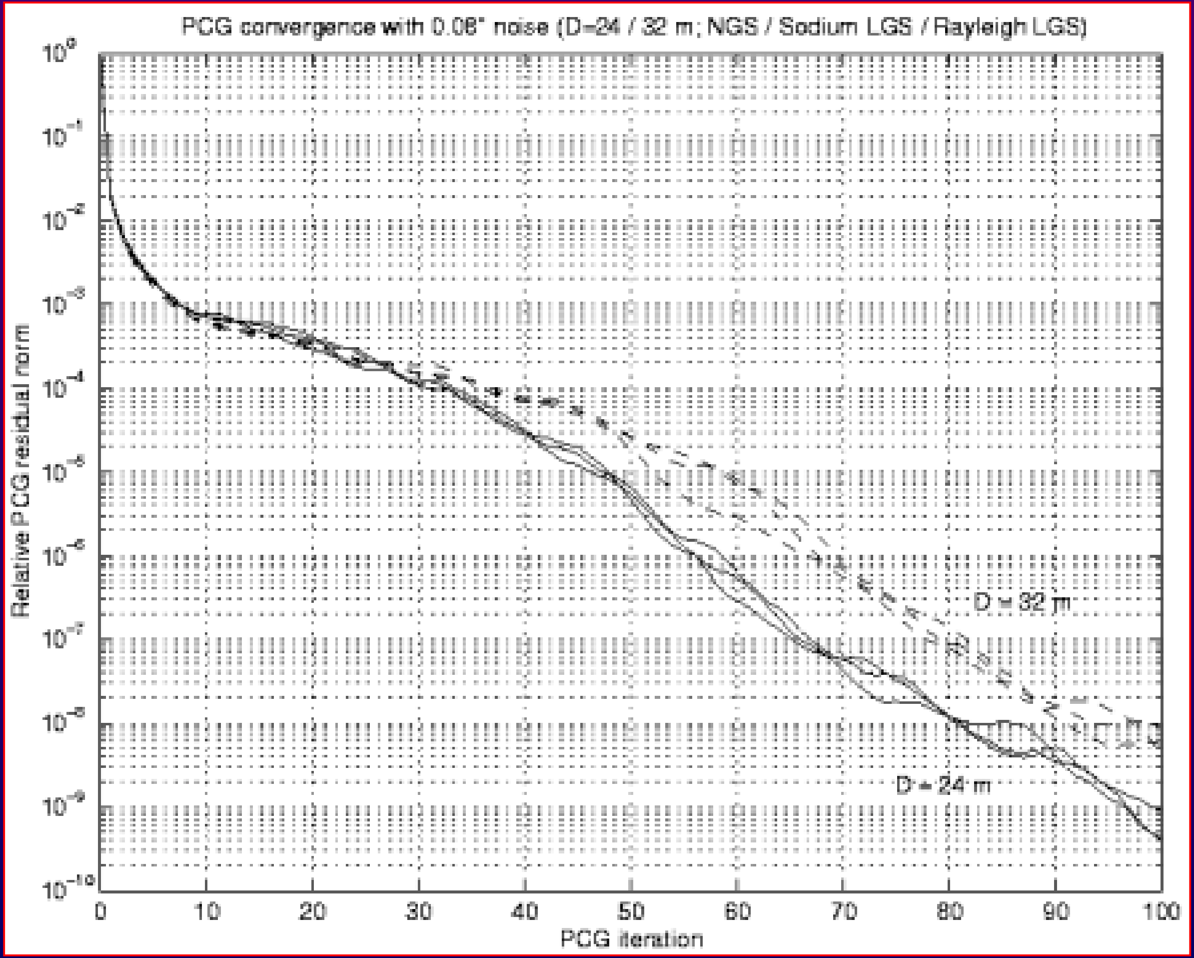
PGC Convergence Histories for Optimistic WFS SNR

- Rapid convergence for first ~20 iterations
- Convergence than slows due to wide range of eigenvalues
- Results effectively independent of aperture diameter and guide star type



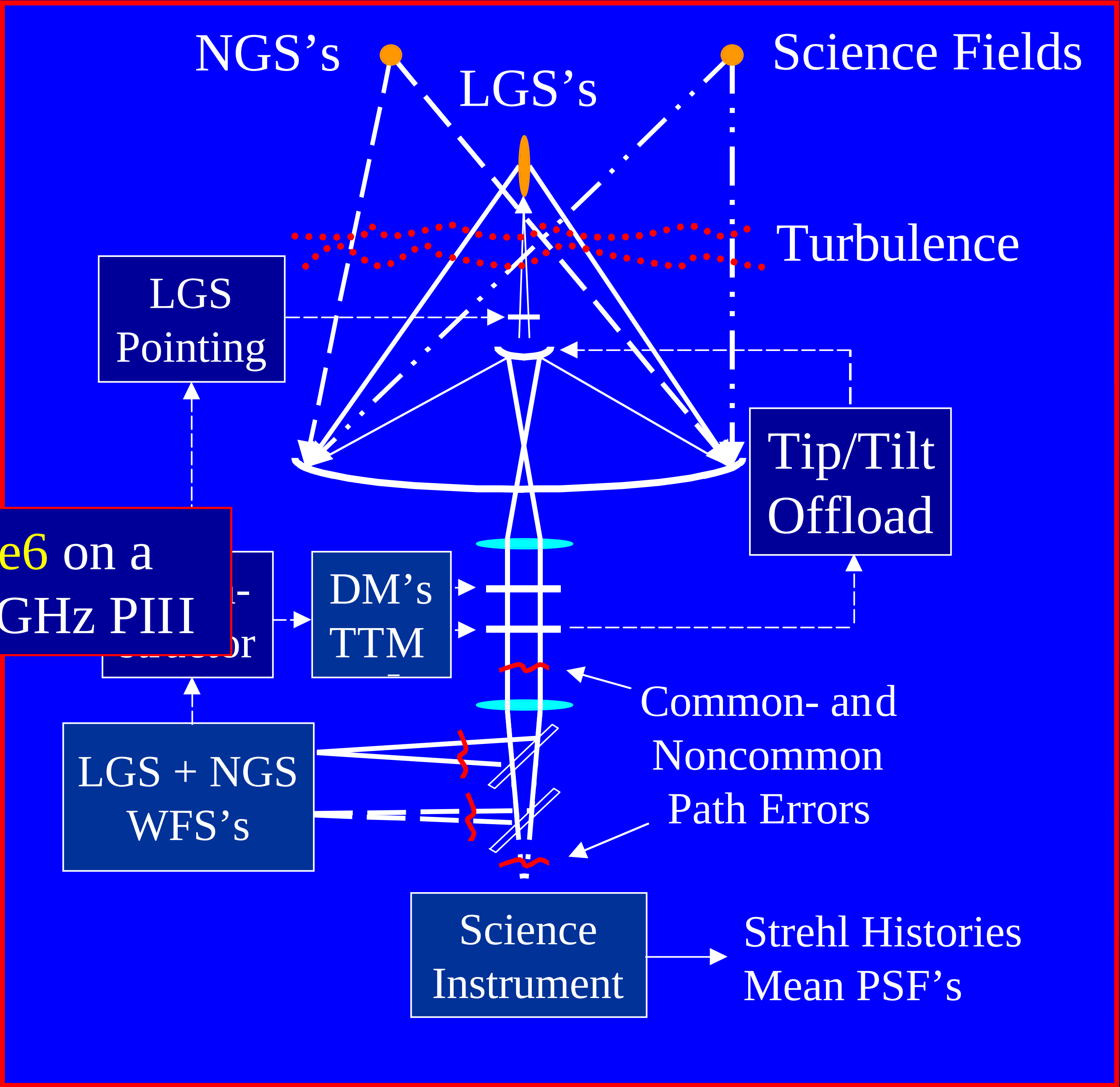
PCG Convergence Histories for Pessimistic WFS SNR

- Converge identical to optimistic SNR case for first 20 iterations
- Faster convergence thereafter because higher WFS noise improves matrix conditioning (!!)
- Results effectively independent of guide star type, weakly dependant on aperture diameter



What are We Simulating?

t_{sim}/t_{real} = 2e5 to 2e6 on a dual processor, 1 GHz PIII



NGS's

LGS's

Science Fields

Turbulence

LGS Pointing

Tip/Tilt Offload

DM's
TTM

Common- and Noncommon Path Errors

LGS + NGS WFS's

Science Instrument

Strehl Histories
Mean PSF's

Simulation Models

- Atmospheric phase screens: Filtered white noise with a Kolmogorov or von Karman spectrum
  - Periodic
  - Taylor hypothesis (frozen flow)
- Fresnel propagation through atmosphere and optics
- Fraunhofer propagator for PSF evaluation
- DM model: linear superposition of zonal influence functions and temporal dynamics
  - Misregistration in five degrees of freedom

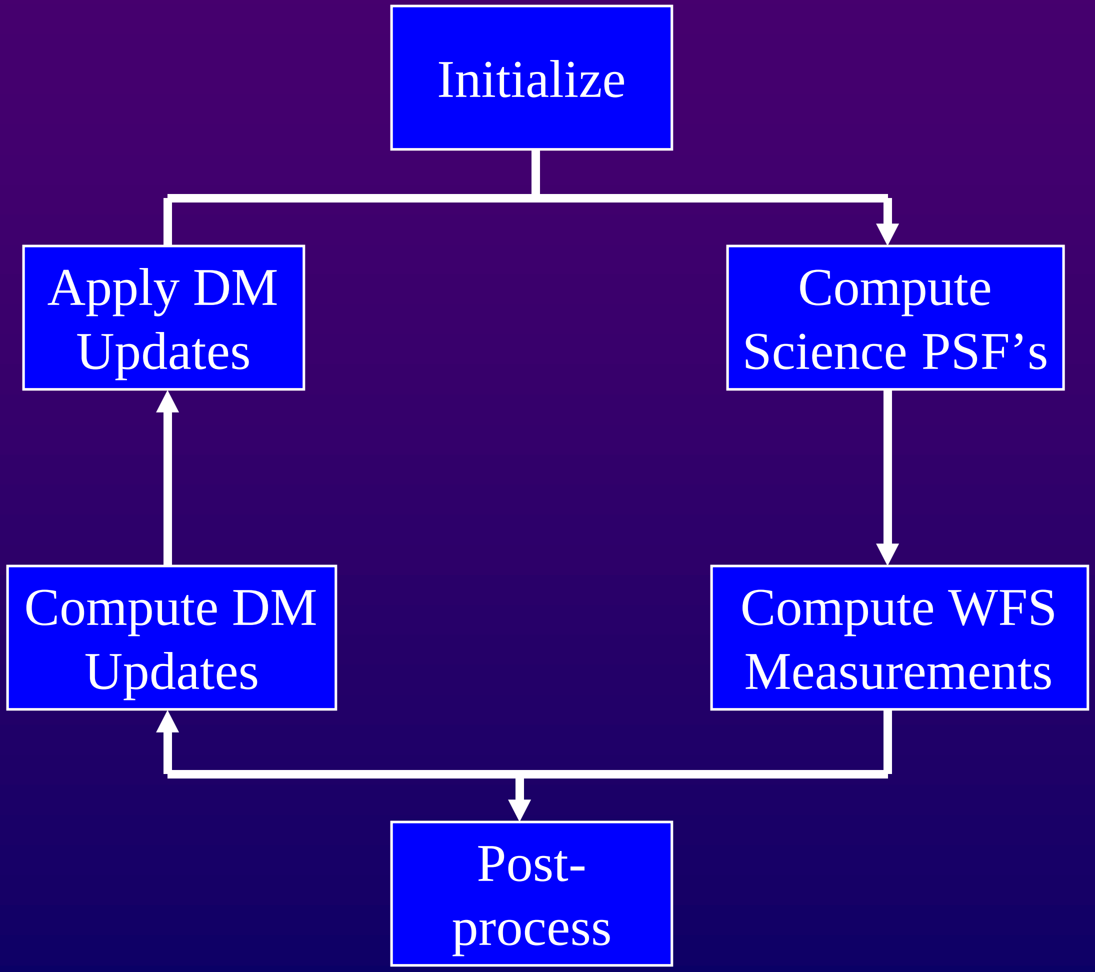
Simulation Models II

- Shack-Hartman WFS’s

  Idealized phase gradient measurements, or

  - Imaging of 3-d guide star for LGS AO (no saturation)
  - Photon arrival statistics, detector read noise
  - Gain and bias calibration
  - Centroid detection with *n* by *n* pixels
  - Misregistration and pupil distortion
- Minimal variance wave front reconstruction
- Temporal filtering
  - Higher-order and tip/tilt control loops
  - LGS pointing loops

Serial Simulation Architecture



Initialize

Apply DM Updates

Compute Science PSF's

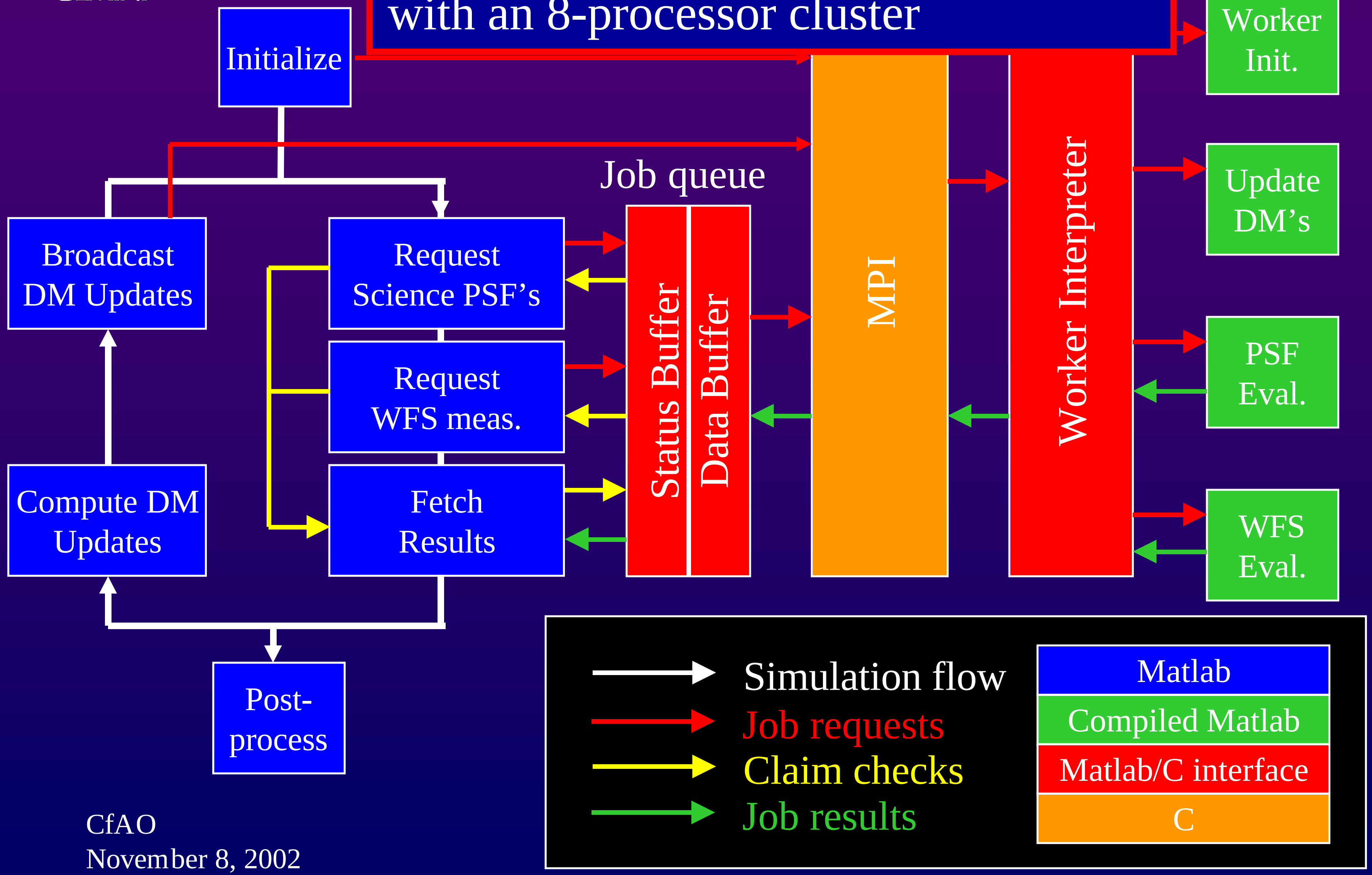
Compute DM Updates

Compute WFS Measurements

Post-process

Parallel Simulation Architecture

Factor of 5.8 improvement in speed with an 8-processor cluster



- Simulation flow
- Job requests
- Claim checks
- Job results

Matlab
Compiled Matlab
Matlab/C interface
C

Sparse Matrix Wavefront Reconstruction for ExAO

- Algorithm of the form

  $a = F[\text{itting}]E[\text{stimation}]s$

- Operators F and E both take the form $x=A^{-1}By$
  - B sparse, A sparse and symmetric positive definite (SPD)
- Solution obtained by factoring

  $A=LL^{T}$

  with L lower triangular, and computing

  $y'=By$ (sparse matrix multiply)

  $Ly''=y'$ (sparse matrix backsolve)

  $L^{T}x=y''$ (sparse matrix backsolve)

Computational Scaling

- Similar for fitting and estimation steps, except that $N_{\mathrm{estim}} \sim 4\, N_{\mathrm{fit}}$
  - Higher resolution phase estimation reduces fitting error by ~10-20% -- is this necessary?
- Cost to compute/store/apply B is $O(N)$
- Cost to store/apply L is $O(N^{3/2})$
- Cost to compute L is $\sim O(N^{3/2})$

N	257	921	1981	3641
t, sec	0.25	1.17	3.60	8.94

1 Ghz Pentium III

Can Sparse Algorithms be Parallelized?

- Best payoff for the backsolves $Ly''=y'$ and $L^{T}x=y''$
  - Highest computational complexity
- Approach: as each $y''(i)$ computed, substitute

  $y'(j) \rightarrow y'(j) - L_{ji}y''(i)$

  in parallel for all $y'(j)$ that depend on $y''(i)$
- If L were a full lower triangular matrix…
  - N-1processors would be needed
  - N-1 computational cycles would be needed
  - No improvement over a conventional matrix multiply!
- Fewer processors/steps needed when L is sparse

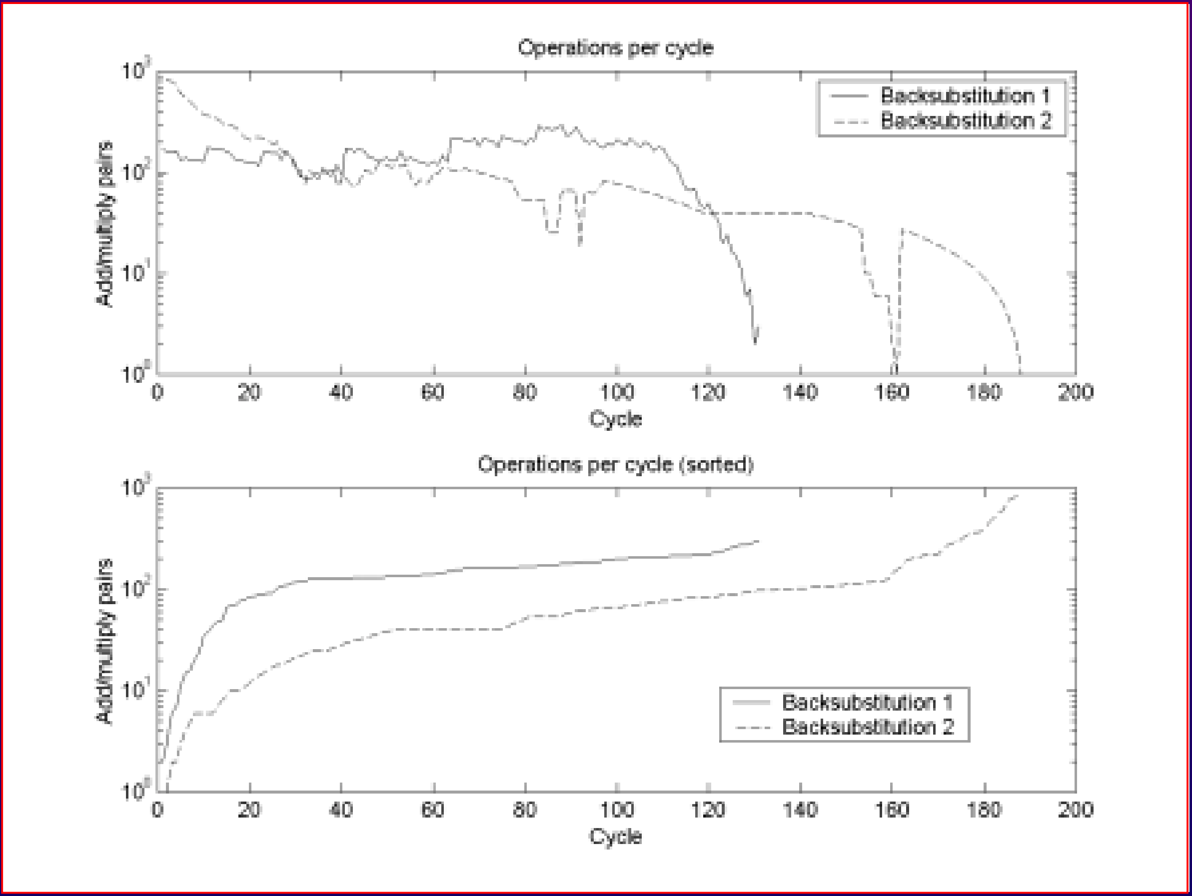
Sample Comparison against Conventional a Matrix Multiply

- Order 40 by 40 system with Hudgens geometry
- Least squares wavefront reconstruction
  - $a = (G^T G)^{-1} G^T s$ phase estimation step
  - Trivial fitting step (identify matrix)
- Requirements for parallel solution to $x=(G^T G)^{-1} y$:

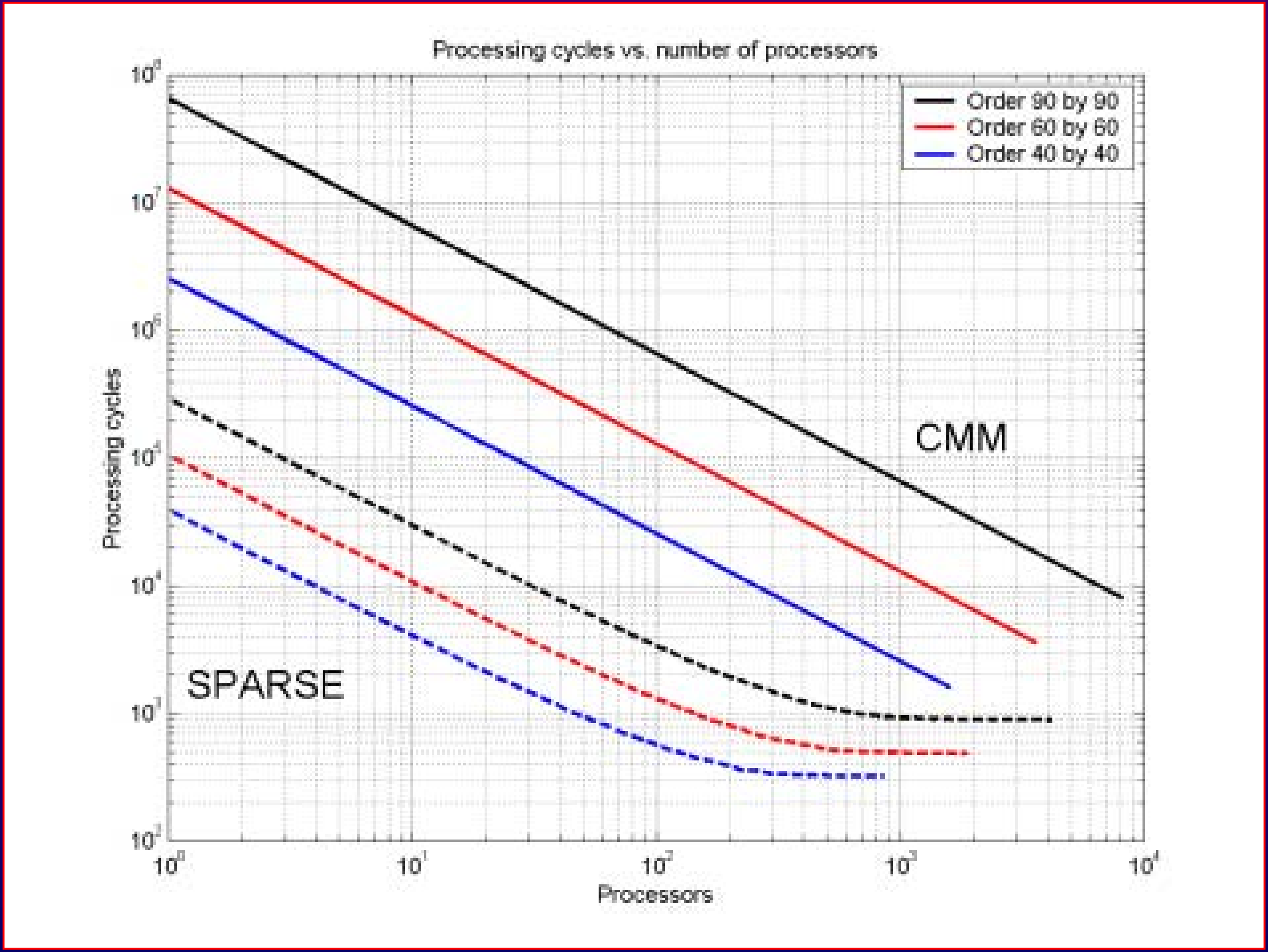
	VMM	Ly'=y	LTx=y'	Total sparse
Adds/mults	2.56e6	21173	21173	42346
Processors	1600	291	854	854
Cycles	1600	132	189	321

Processors Required each Cycle for Full Parallelization

- Relatively few cycles require the maximum number of processors
- Total number of cycles required increases gradually as the number of processors is decreased



Processing Time vs. Number of Processors for Partial Parallization



Other Issues

- Supervisory Processes: Analogous to other systems
  - Hartmann spot size estimation (WFS gain)
  - Control loop bandwidth optimization
  - Invisible mode removal (piston/waffle)
- Optimization parameter: (Seeing)/(RMS WFS noise)
- Mode removal: Linear projection operators, $O(NM)$
- Predictive control: Hard to predict (that’s my prediction)
- Closed loop control:
  - No modifications necessary for least squares reconstruction
  - Experiment with regularization parameter for minimum variance
- Experimental validation:
  - Least squares implementation fully equivalent to existing VMM systems