# CAMERA

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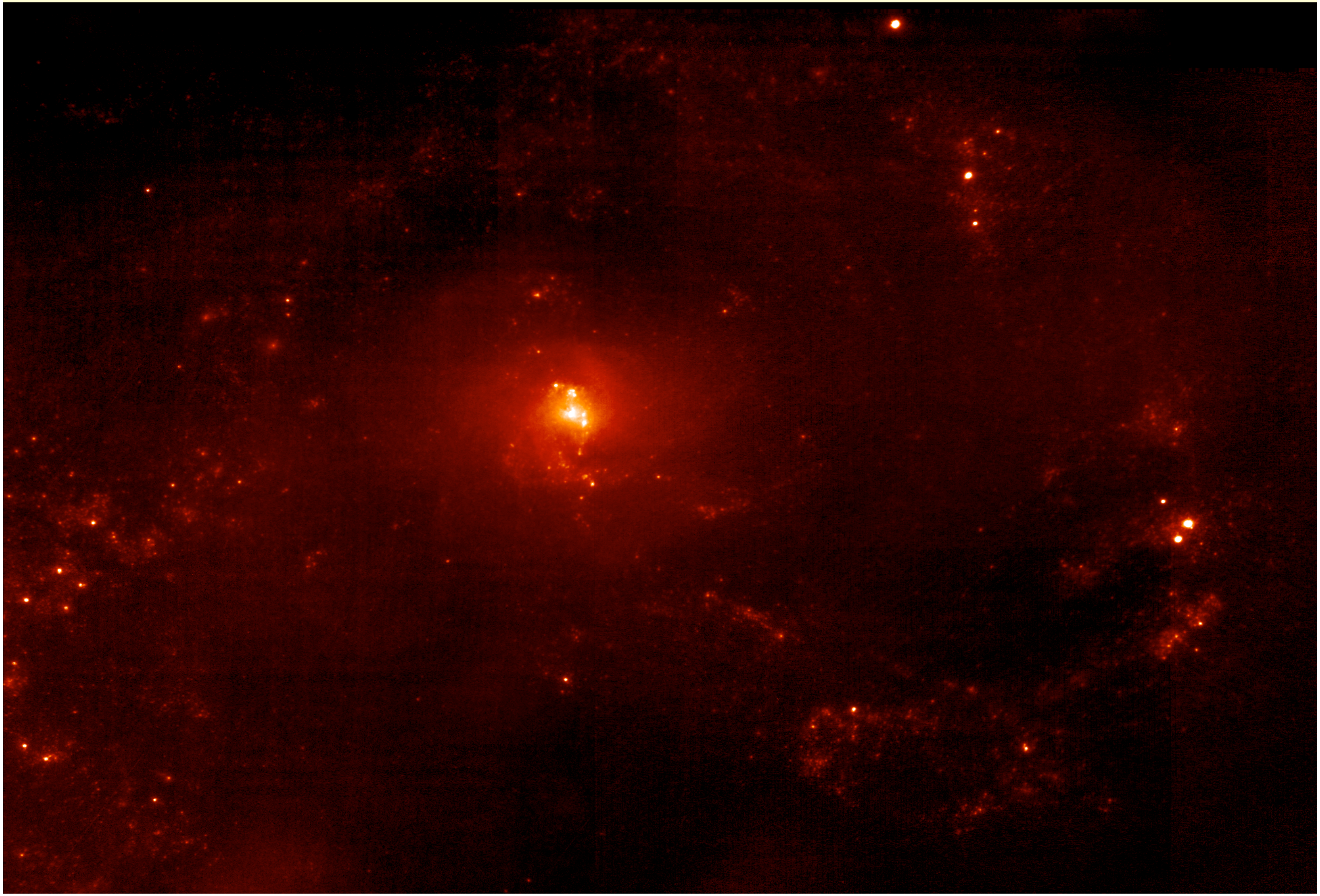
# Goal:

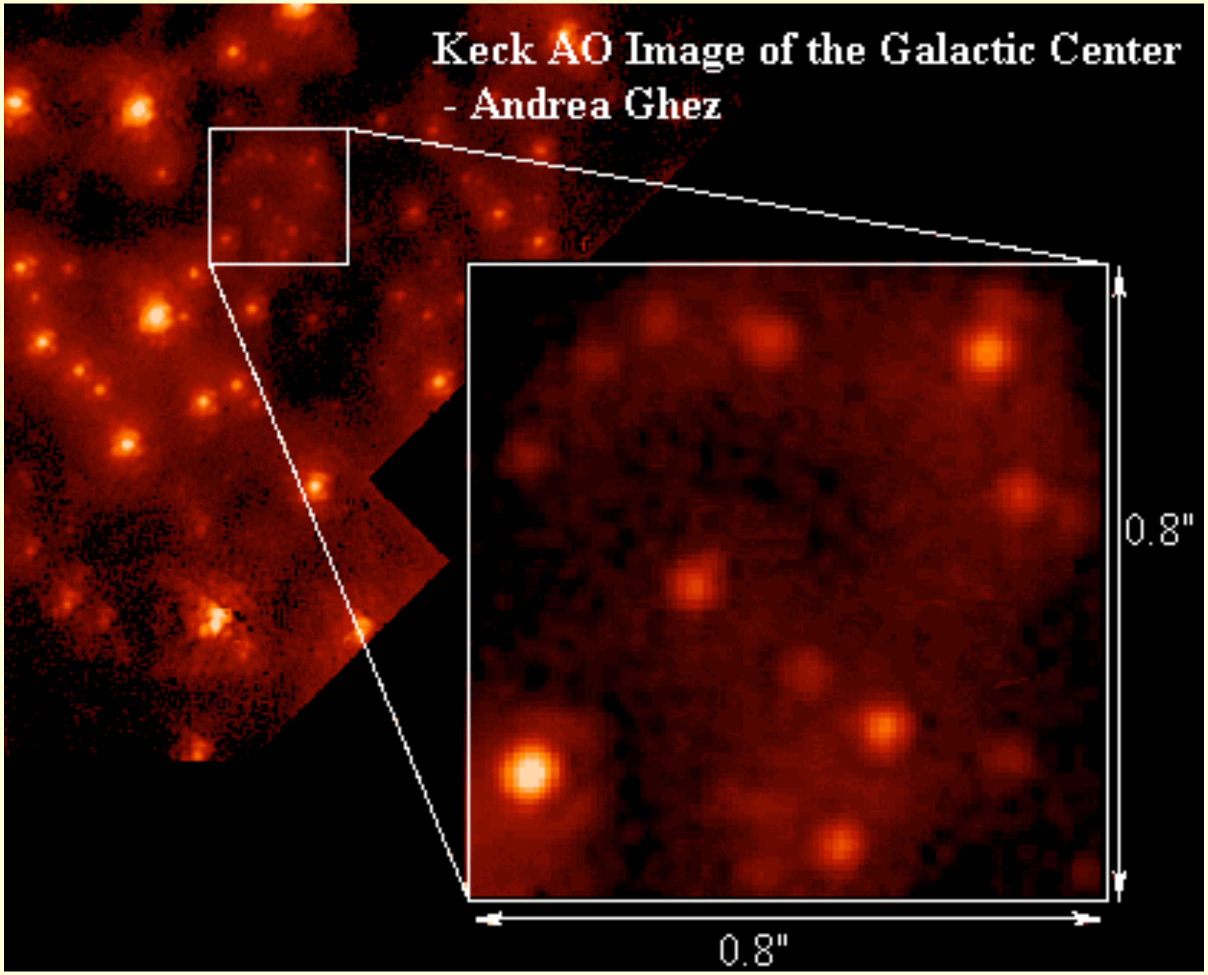
- Routine access to the sky with consistent good to high Strehl ratio in the near-IR
- High efficiency
  - Fully automated AO setup
  - Robotic telescope
- Optional seeing-limited observations in the optical

# Keck Laser Guide Star AO is now Routine

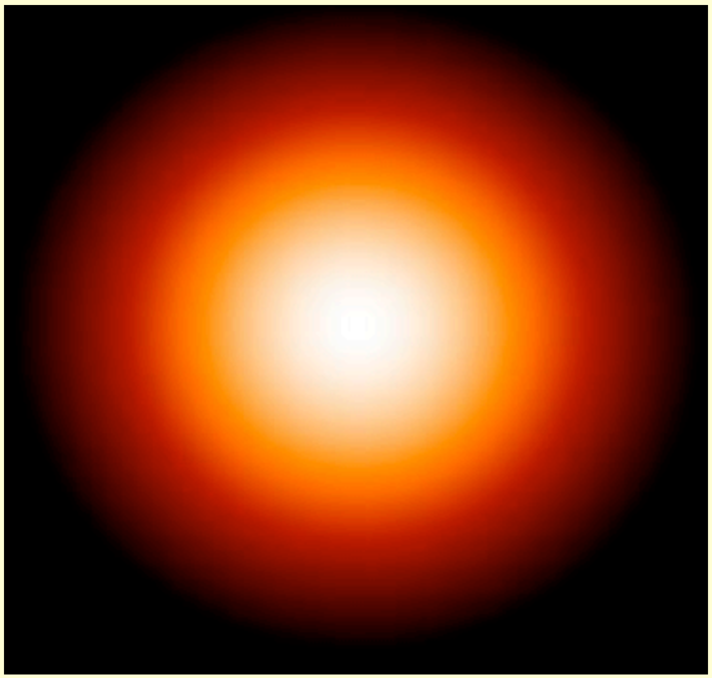
# Progenitors of Ibc SNe: A Hot Result

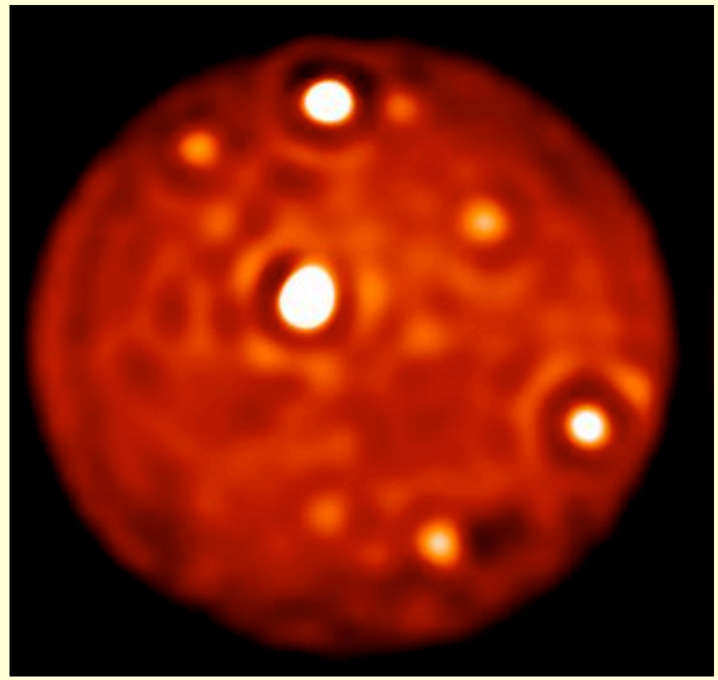


# Galactic Center



# Imaging of Io



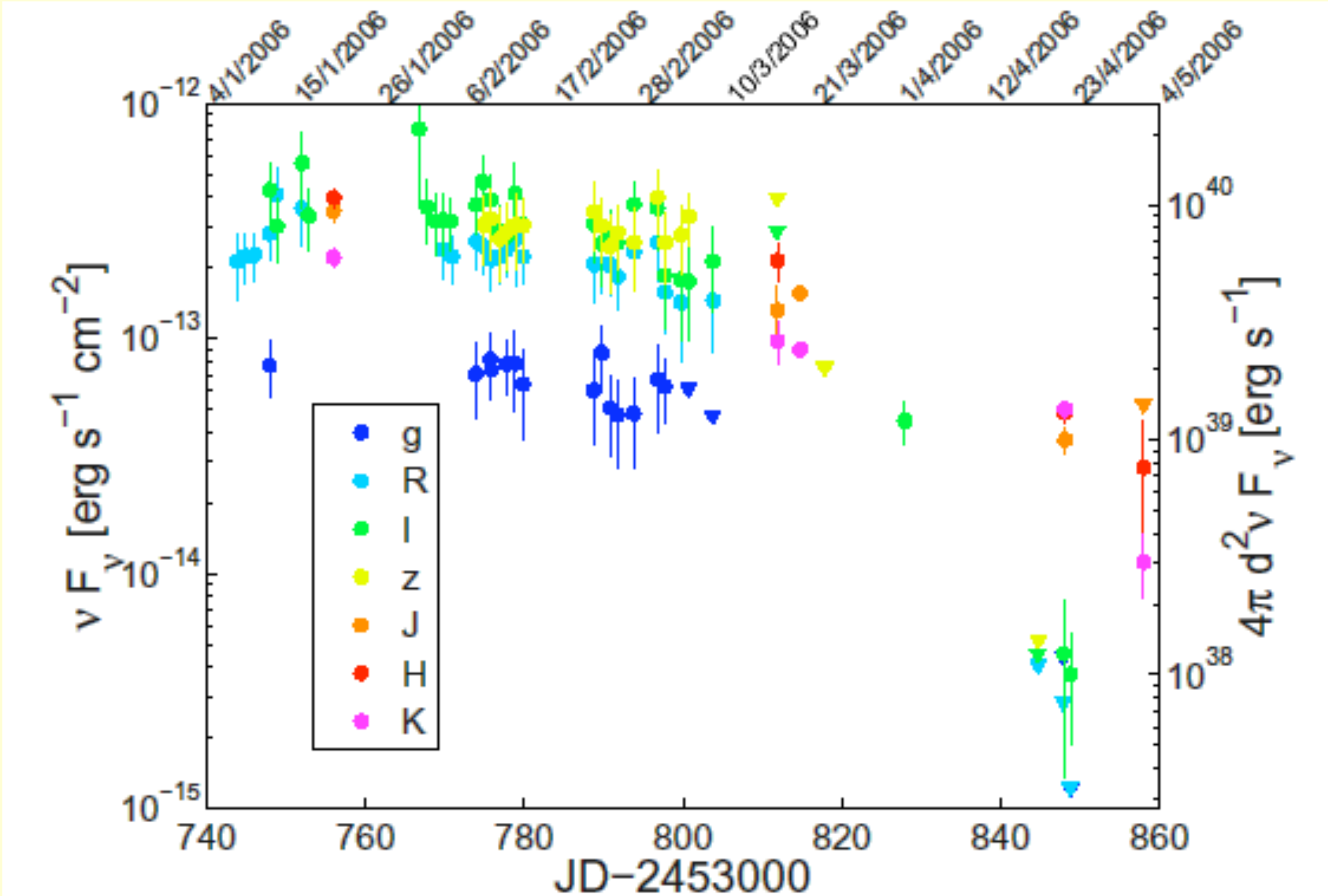


AO OFF

AO ON

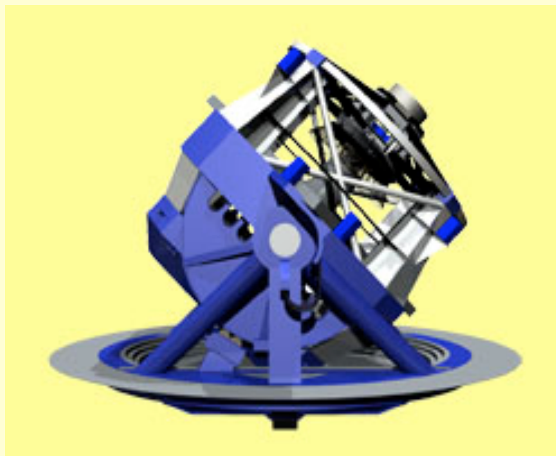
# Palomar Transient Factory

# Hyper-Eddington Red Nova




Kulkarni et al. 2007 (Nature)

# Next Generation Survey Telescopes



Pan-STARRS

LSST
Large Synoptic Survey Telescope

**Will generate thousands of transients per night:**

•GRB’s

•Novae, supernovae

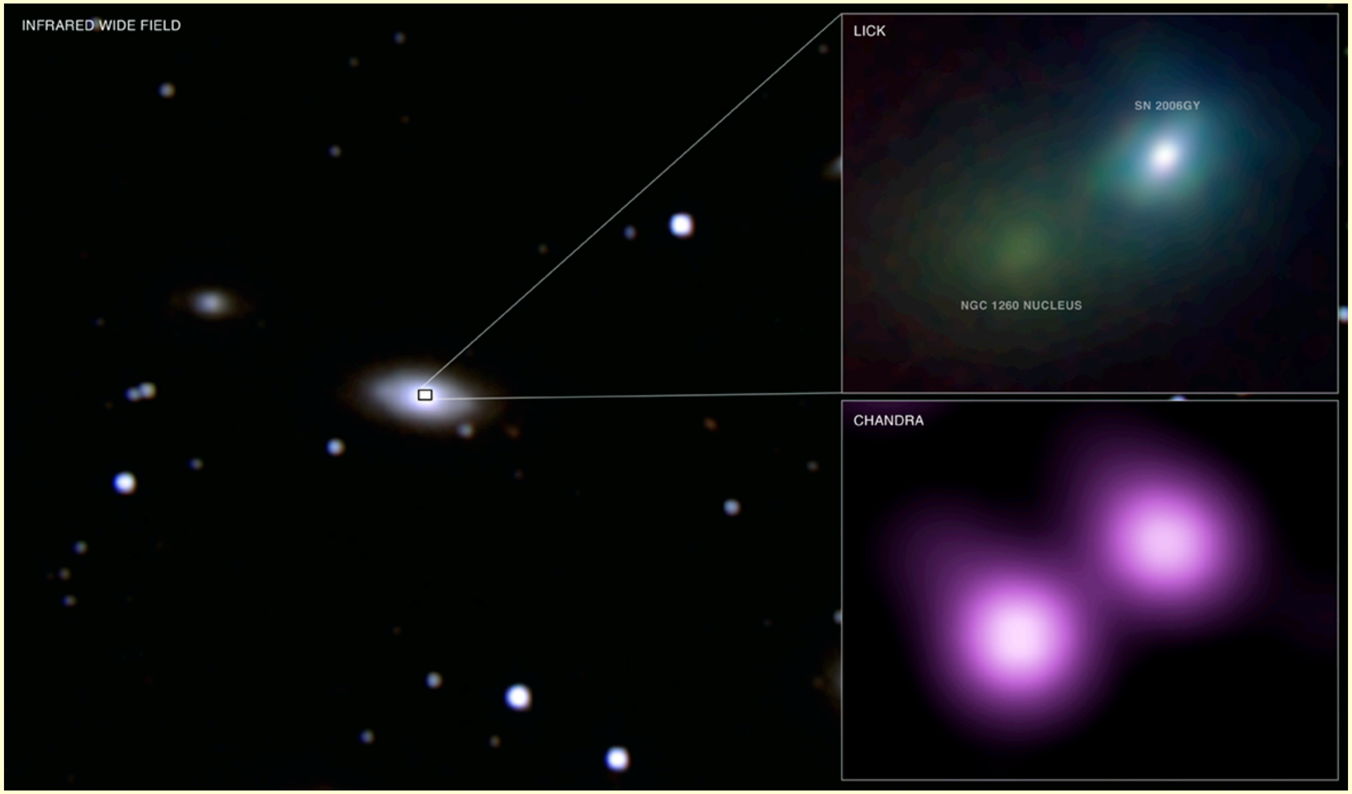
•Eclipses, microlensing

•New phenomena

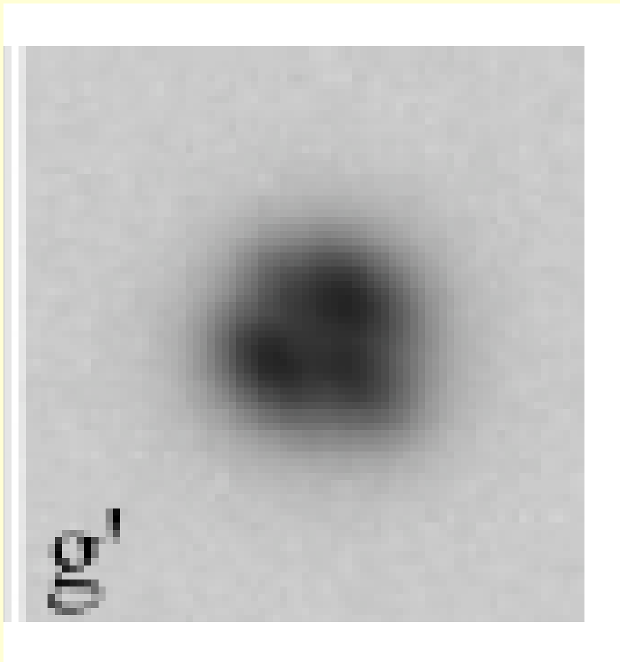
# Adaptive Optics Applications for Small Aperture Telescopes

- Rapid response capability for transient followup
- High angular resolution surveys of thousands of targets
- Regular monitoring observations of variable targets

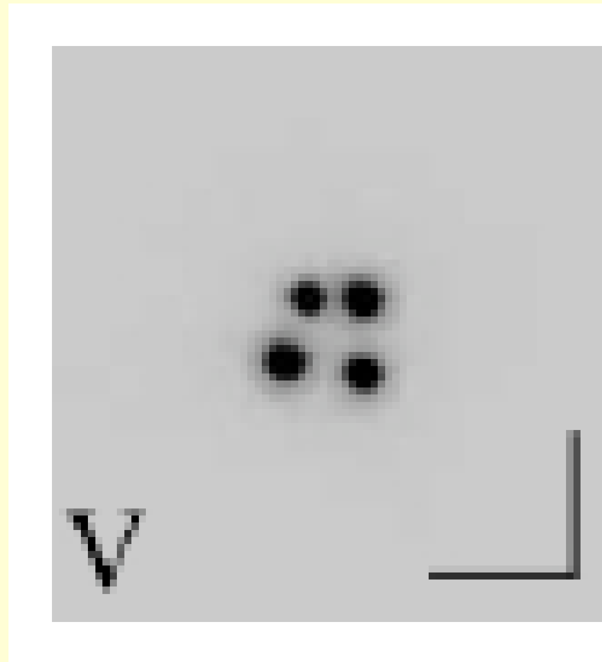
# Supernovae Followup



# Gravitational Lens Surveys

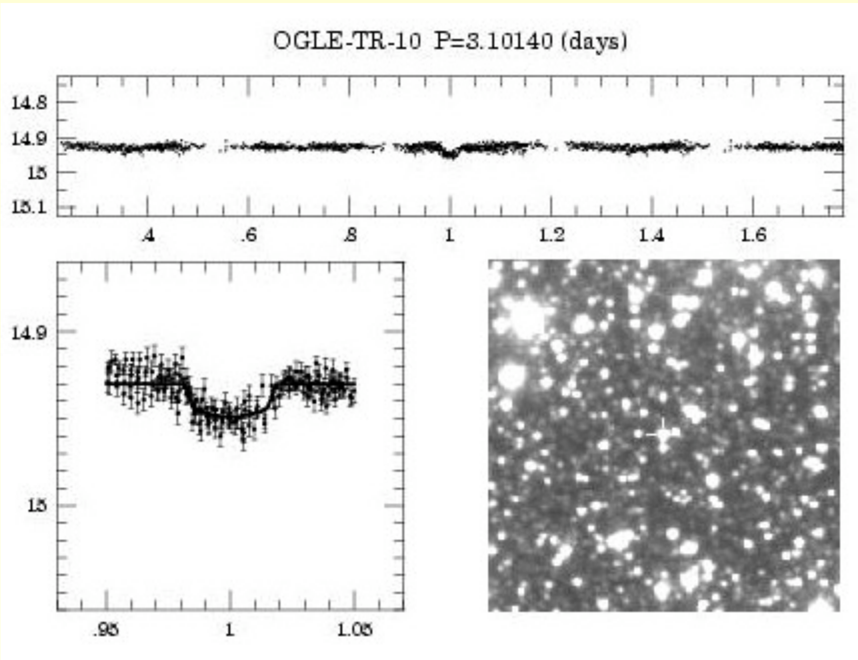


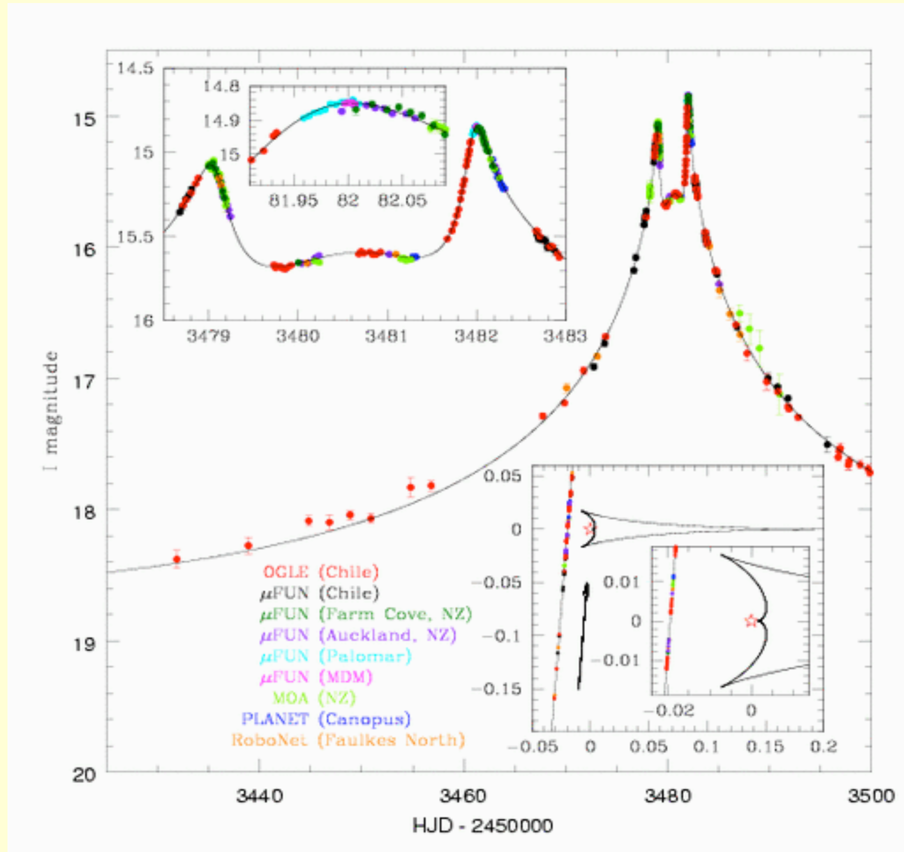

Seeing limited discovery image



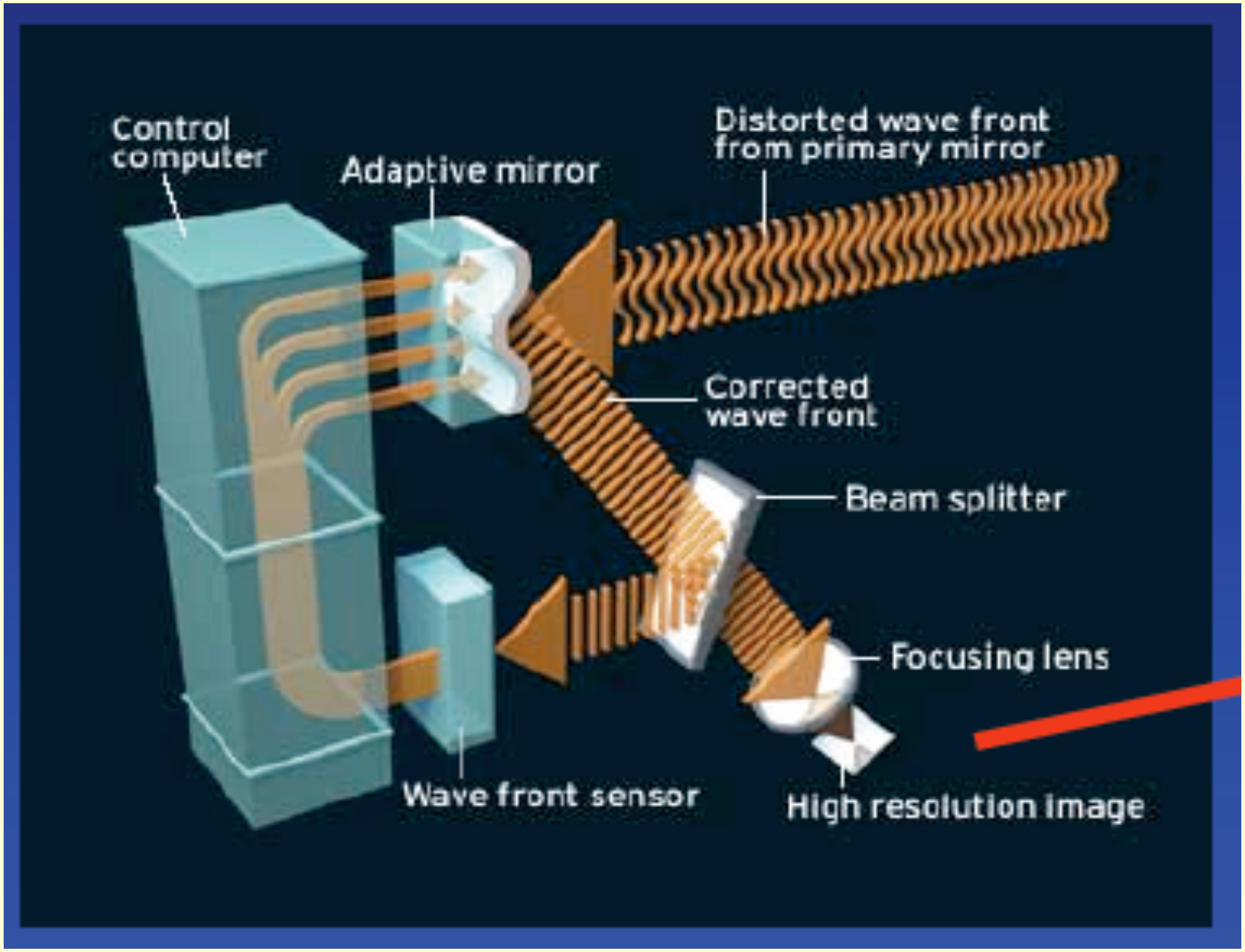

Hubble followup image

# Monitoring Photometric Light Curves



# AO in a nutshell



# The Cost Barrier

- Adaptive optics development financed largely through investment by the US military.
- Traditionally an extremely expensive technology, involving very specialized hardware and software.
- Sodium laser guide star requires very expensive lasers.
- Most of the AO effort has been directed towards the needs of large telescopes

# The Opportunity

- Commercial adaptive optics components and science grade detectors now available at modest cost.
- Modern, small format deformable mirrors permit a compact optical design suitable for small aperture telescopes.
- Rayleigh scattering is adequate to produce moderate Strehl images for small telescopes
- Commercial solid state lasers can be used to generate a guide star suitable for small aperture telescopes.
- Commodity multiprocessor servers provide sufficient computational resources to perform real time control.

# What is required?

- An AO system continuously mounted on a telescope
- High degree of system automation for rapid, autonomous response
- Good sky coverage
- Imaging capability in the visible and near-IR

# CAMERA

Compact

Automated

MEMS

Rayleigh

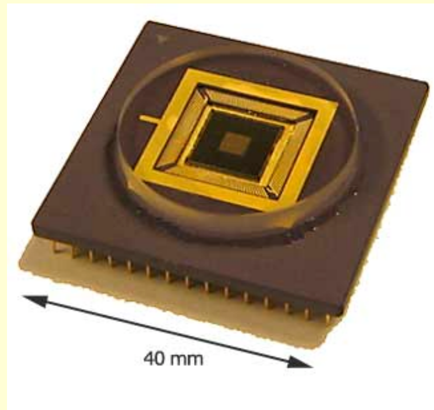
Adaptive optics system

# Design Philosophy

- Designed using commercially available components and detectors
- Employs a reliable solid state laser to generate a guide star
- Compact form factor
- Controlled using a multiprocessor server to facilitate automation

# CAMERA Components

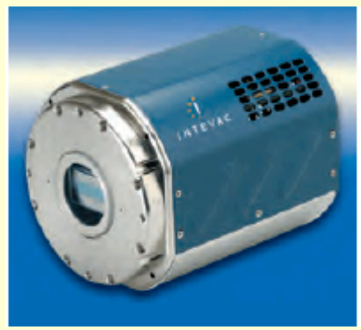
355 nm Laser




MEMS DM

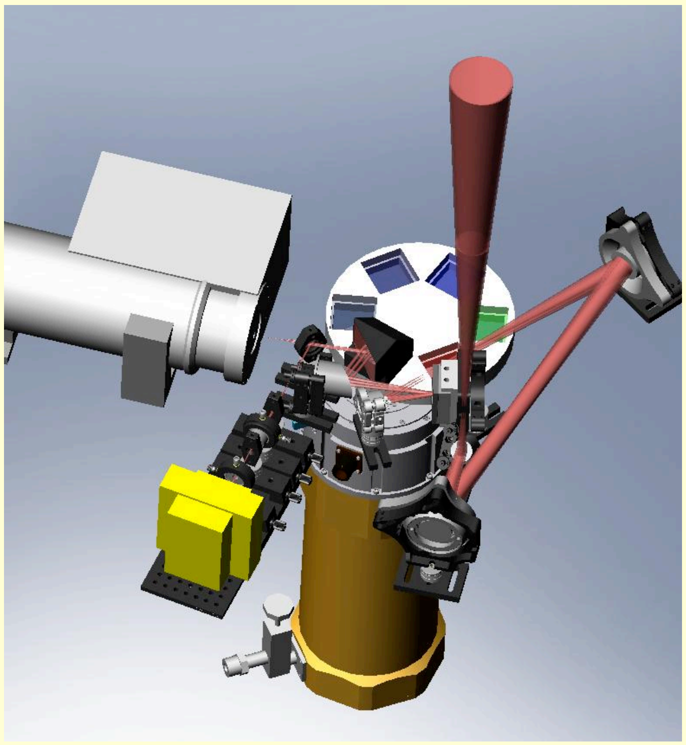

Tip tilt stage

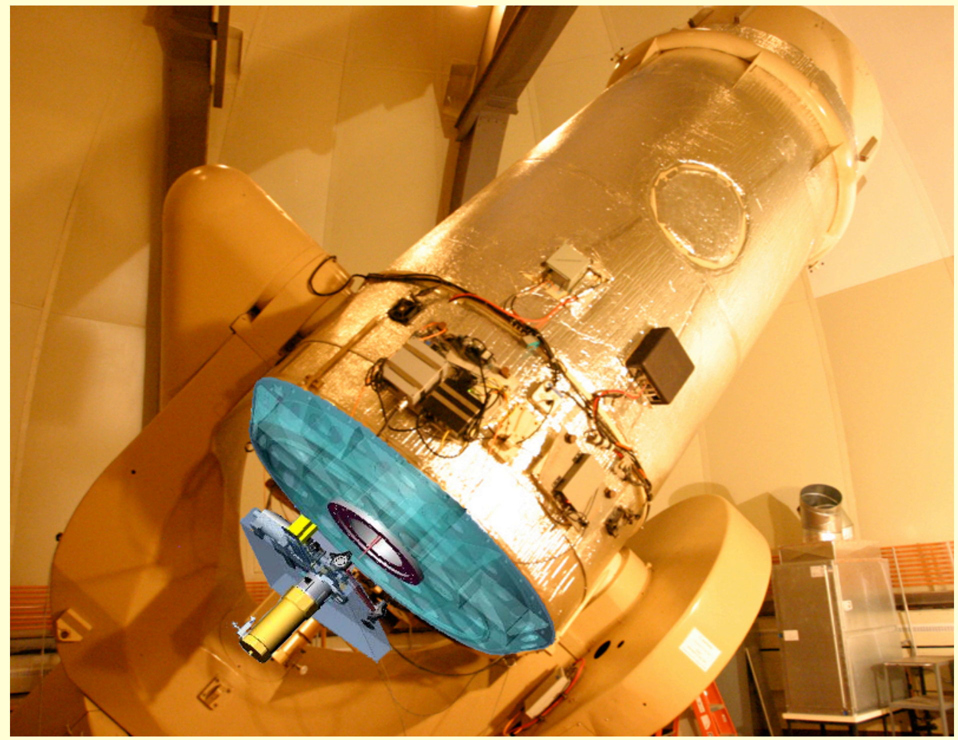

L3 CCD

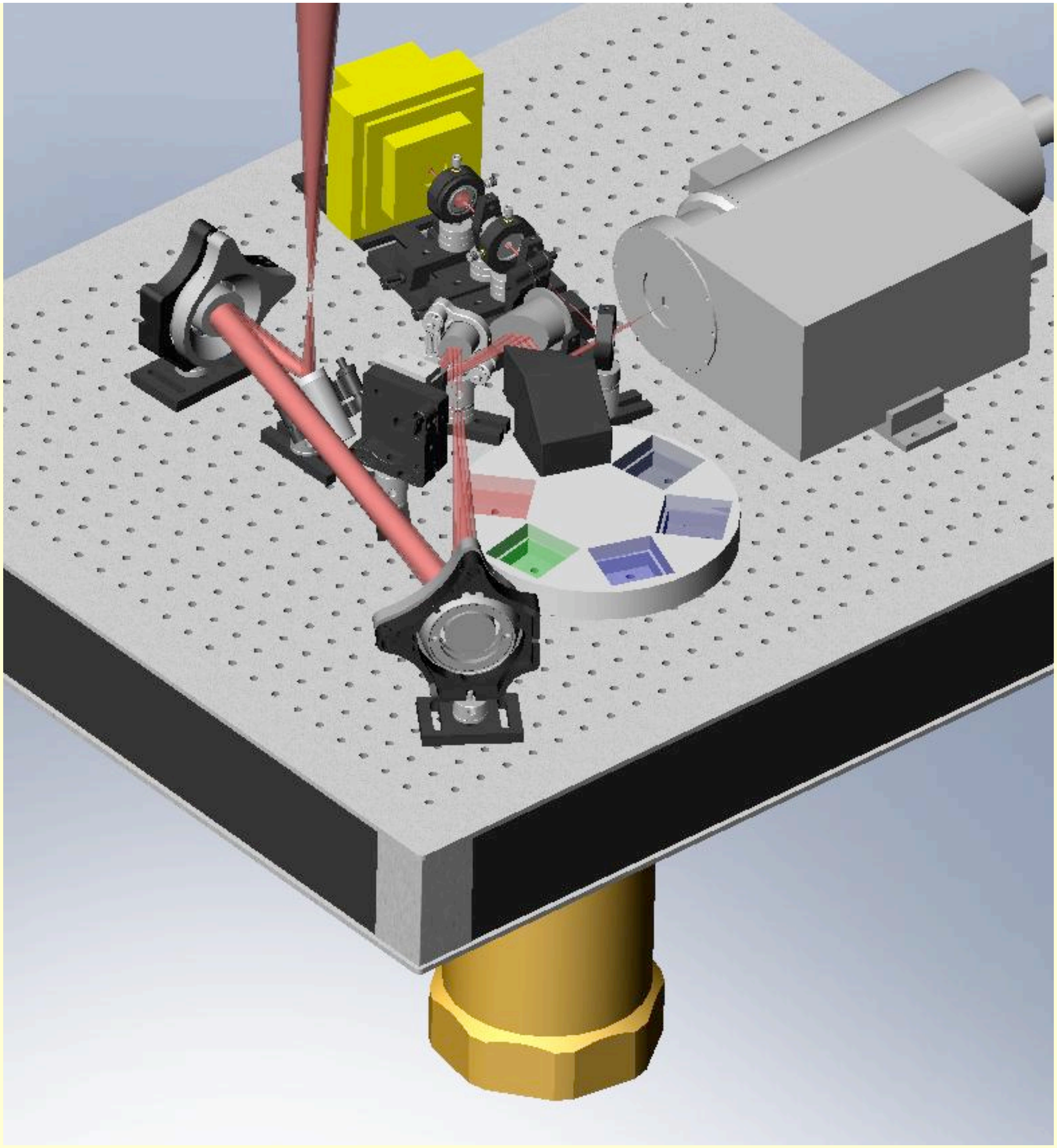


IR Array

# Optical Design
# (Palomar 60-inch)



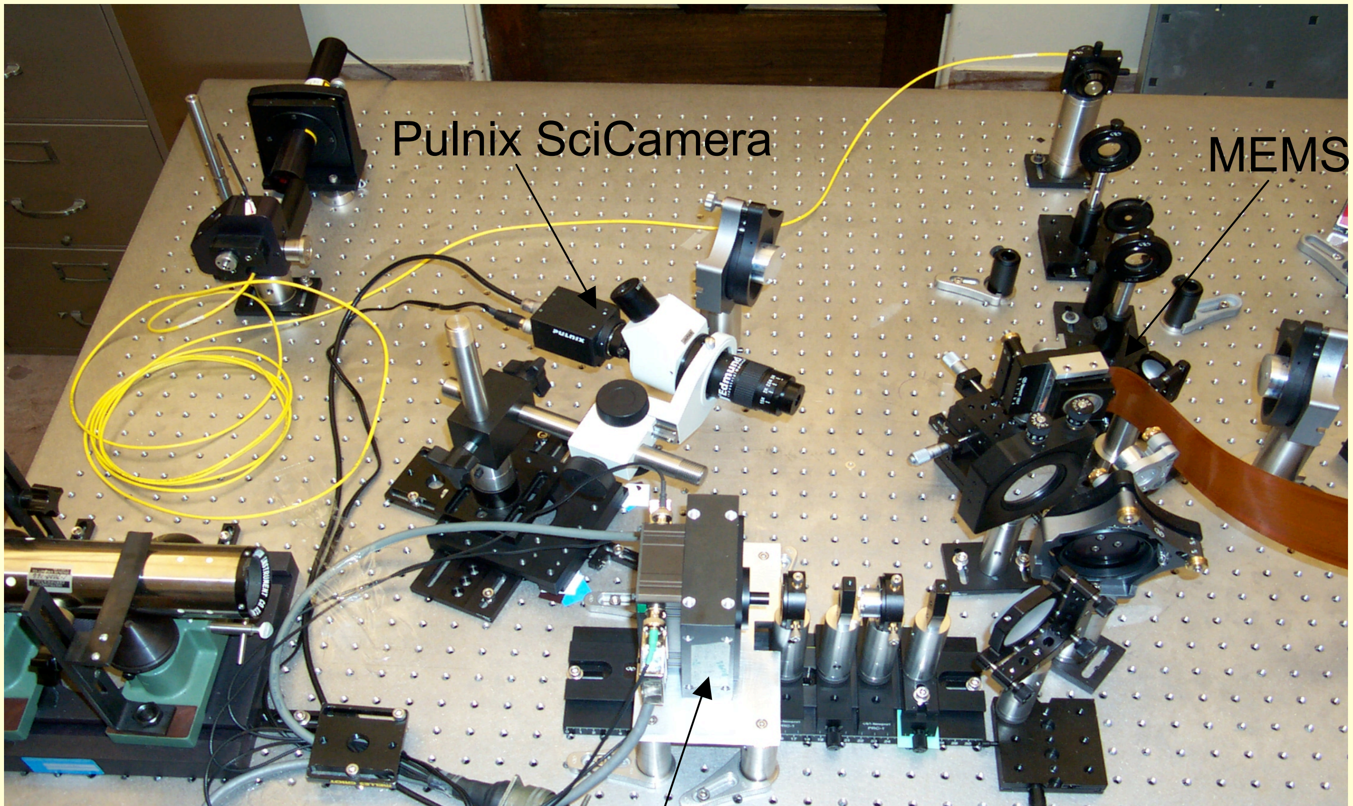


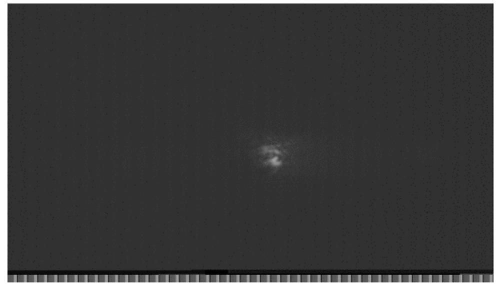


# A Server and Clever Software

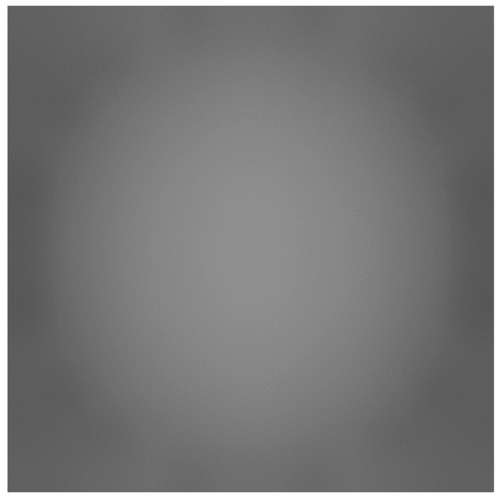
- Wavefront sensing and control through a multiprocessor server
- Observations executed autonomously
- Targets selected from a queue
- Monitors VOEvent feeds on the internet to provide transient followup capability

# CAMERA Testbed at Caltech





Iteration number 0



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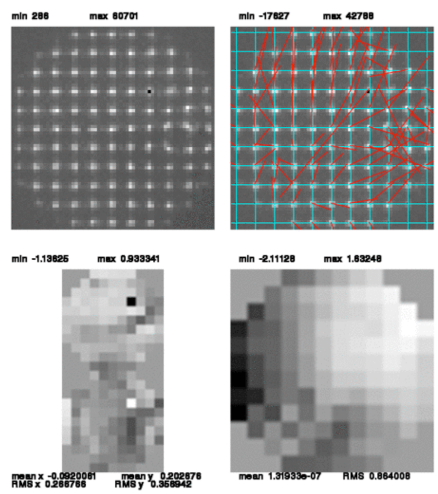
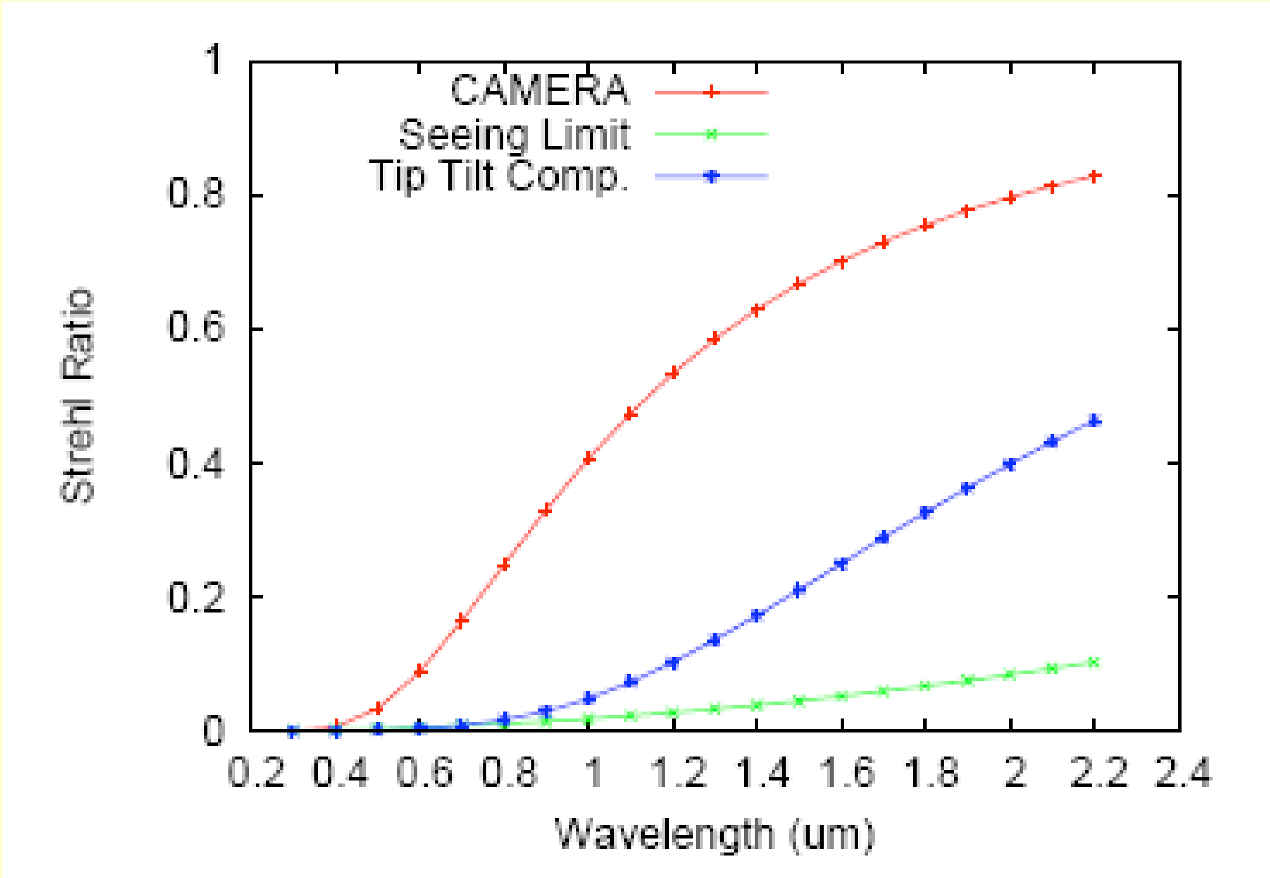


# CAMERA Strehl vs. Wavelength on a 60" Telescope (Prediction)



# CAMERA Sensitivity on a 60” Telescope

| Band | 5 min Limiting Magnitude | 5 min CAMERA SNR | 5 min SL SNR | $t_{int}$ ratio | $\lambda/D$ (mas) |
|---|---|---|---|---|---|
| V | 22.5 | 10 | 10 | 1.0 | 72 |
| R | 23.2 | 10 | 5.3 | 3.5 | 81 |
| I | 24.1 | 10 | 1.9 | 27.7 | 122 |
| J | 23.5 | 10 | 1.0 | 100.0 | 169 |
| H | 22.6 | 10 | 1.2 | 69.4 | 223 |

# Costs

- *JDS Uniphase* Laser $ 100K
- Laser Launch Telescope $ 50K
- *Boston MicroMachines* MEMS $ 30K
- *SciMeasure* WFS $ 50K
- *Andor* L3 CCD $ 50K
- *IR Lab* IR Camera $ 100K
- *Optics, Bench, TT etc* $ 60K
- Computer *etc* $ 15K
- Software, I&T $ 300K
- NRE $ 300K

# Conclusions

- Adaptive optics has reached a price point that places this technology within reach of small aperture telescopes.
- Such a system mounted on a 2m class telescope can generate high profile astronomical results, particularly in the emerging field of transient astronomy.