Exoplanet Surveys at Five Microns with Direct and APP Imaging at the MMT Observatory

Matthew Kenworthy,
J.L. Codona, P.M. Hinz, J. Roger P. Angel, A. Heinze,
D. Apai, E. Mamajek, S. Sivanandam, M. Meyer

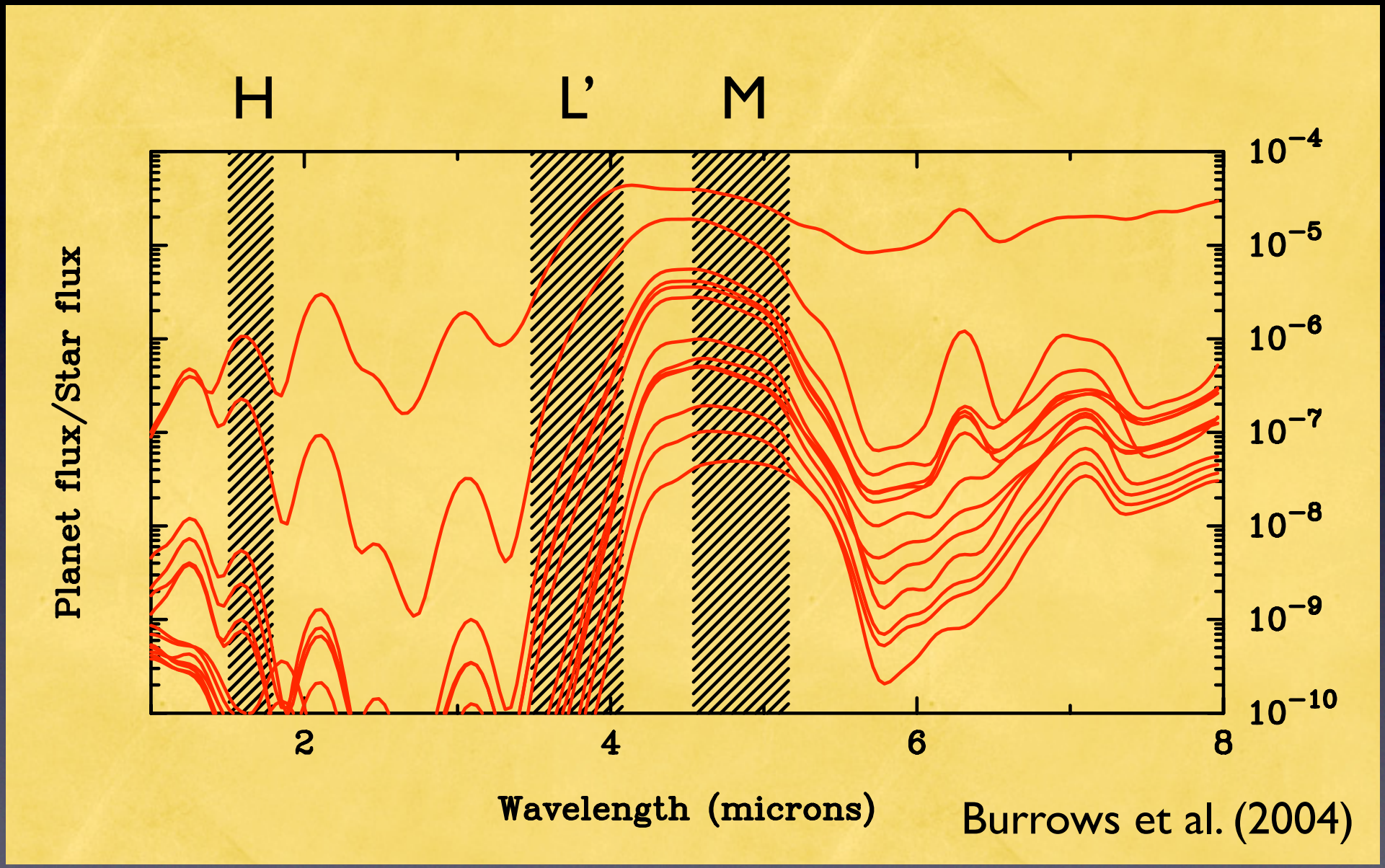
Steward Observatory, University of Arizona

The Spirit of Lyot, UC Berkeley, June 2007

Overview

- Why look for hot Jupiters at 5 microns?
- Why use the MMT AO?
- Status of the Direct Imaging Surveys
- Looking closer with an Apodizing Phase Plate

Where Planets Glow



Burrows et al. (2004)

MMTO 6.5m Telescope

Deformable Secondary Mirror

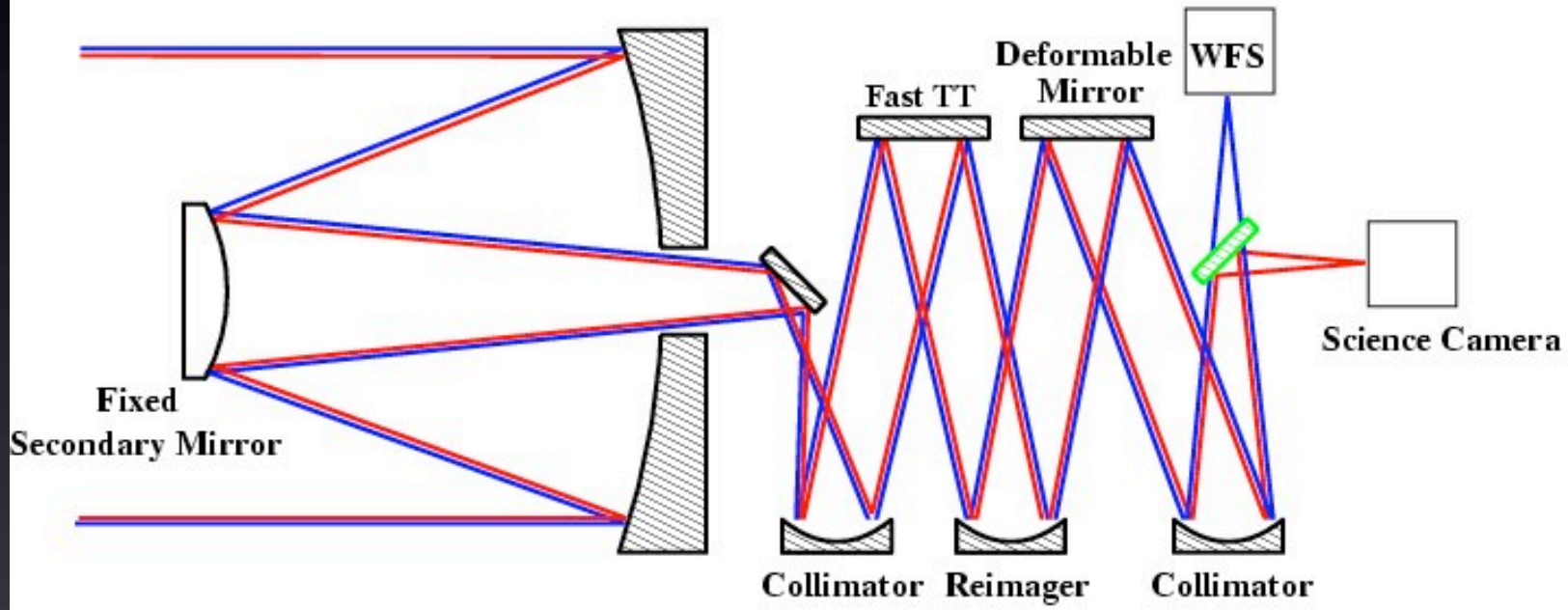
Thermal infrared optimized

2mm thick by 640 mm diameter

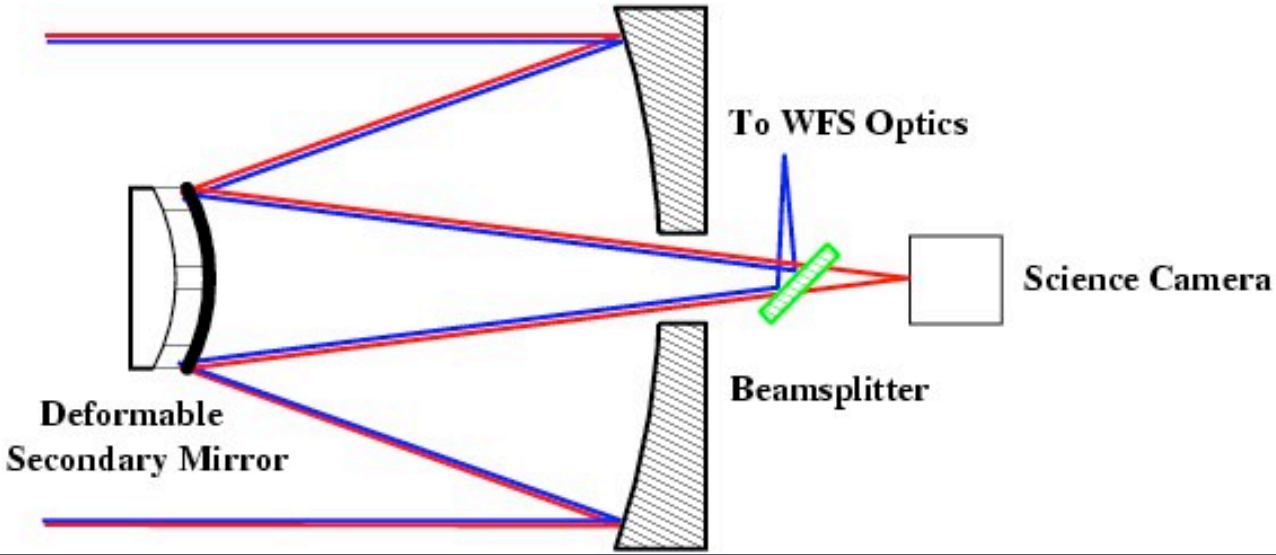
336 voice coil actuators

Undersized pupil
for IR observations
(effective D=6.35m)

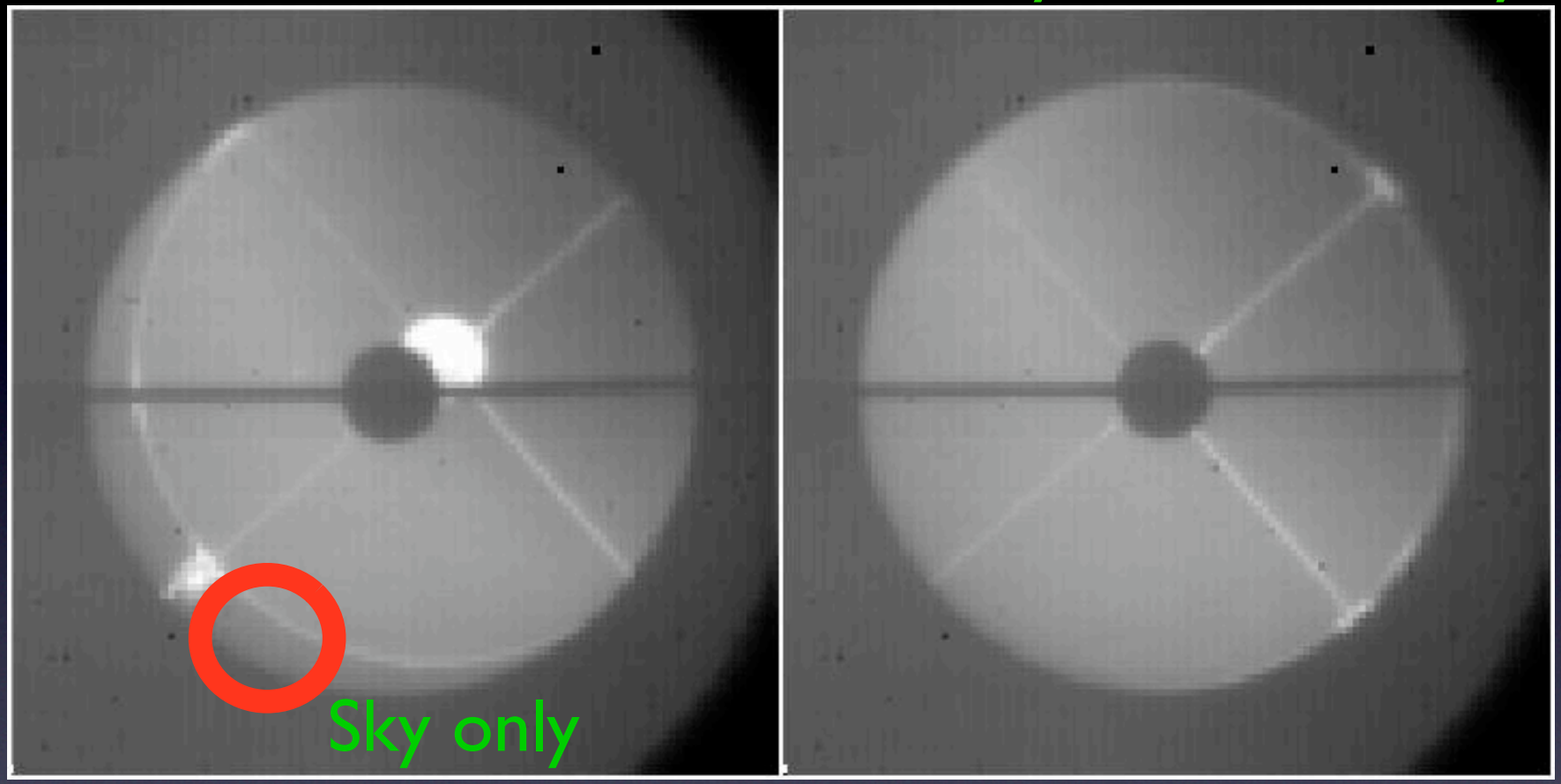
Typical AO System



Deformable Secondary AO System



Sky imaged with
Primary and secondary



7% emissivity

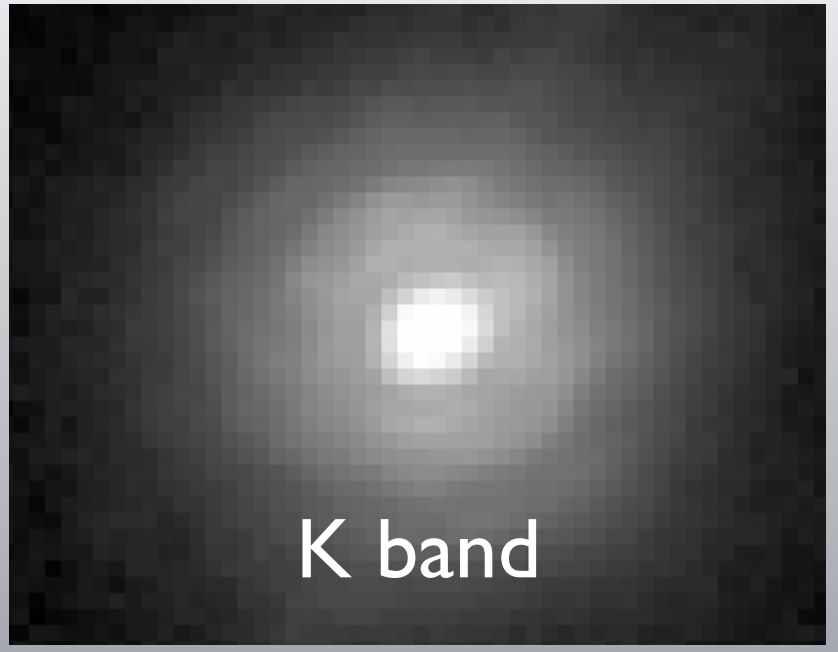
Thermal Imaging with Clio

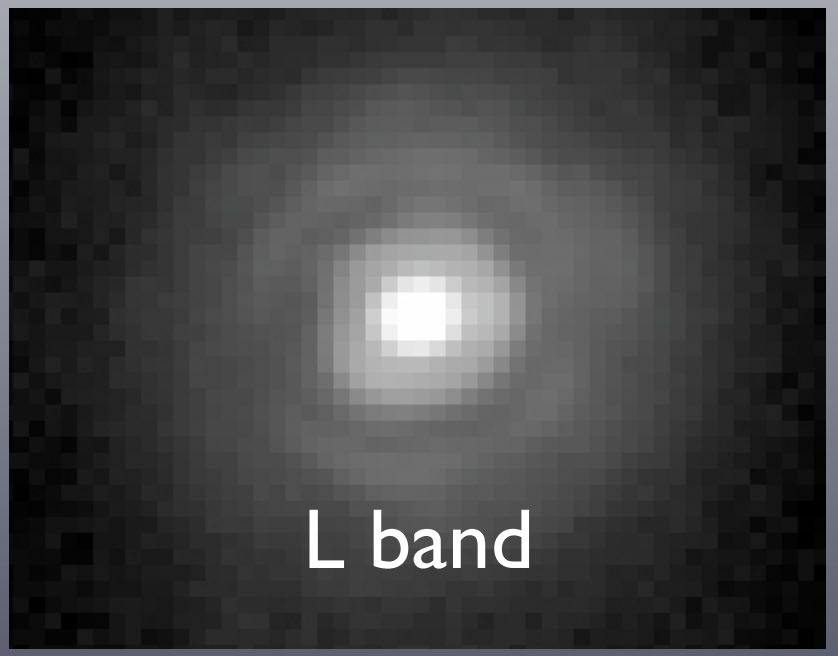
PI: Phil Hinz

- 3 to 5 micron imaging camera/coronagraph
- 12 by 15 arcsec FOV

Longer Wavelength Imaging

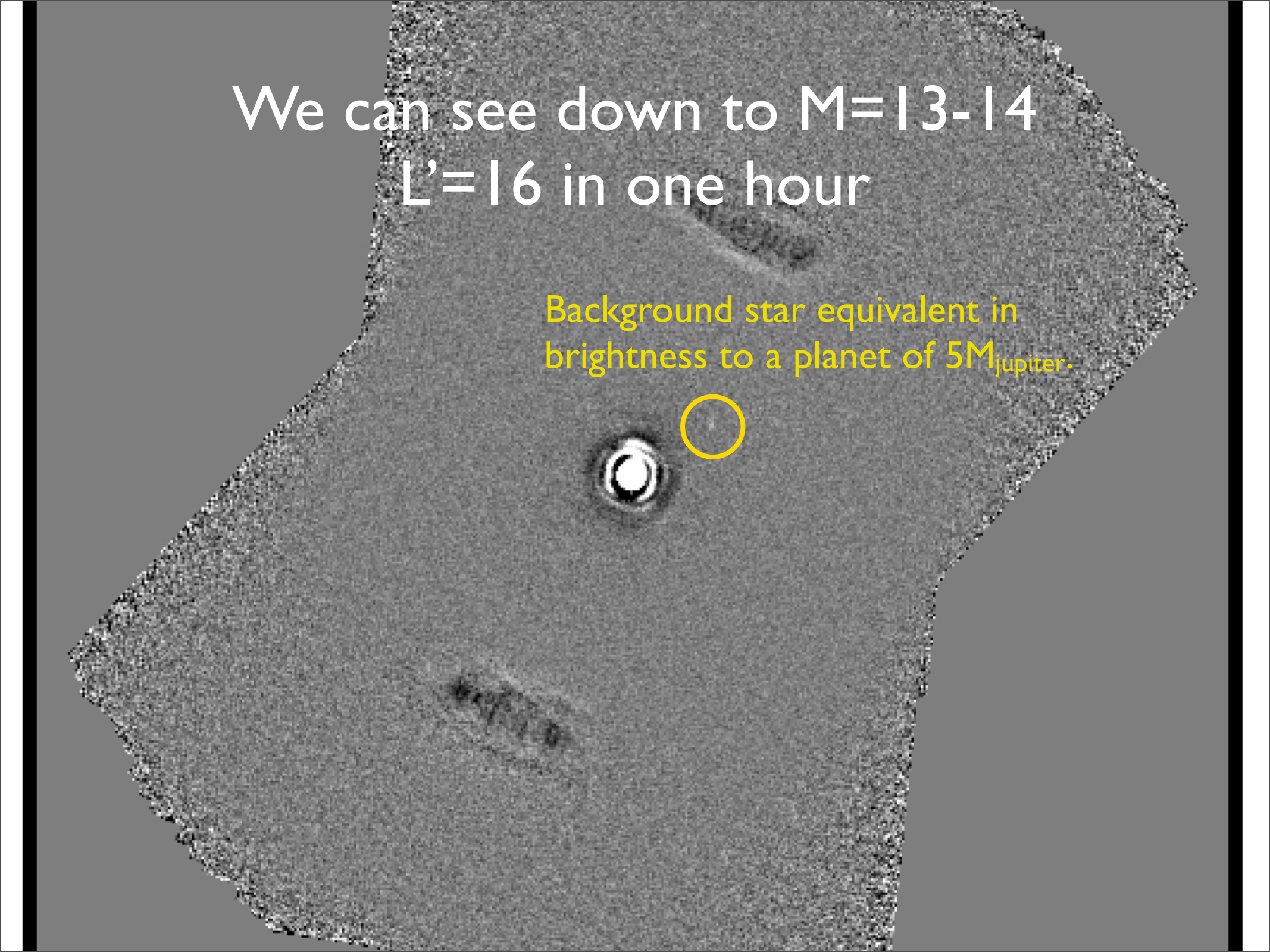
Band	Wavelength	Strehl
H	1.65	30%
K	2.00	40%
L’	3.8	70%
M	4.8	90%





Young Suns - Heinze

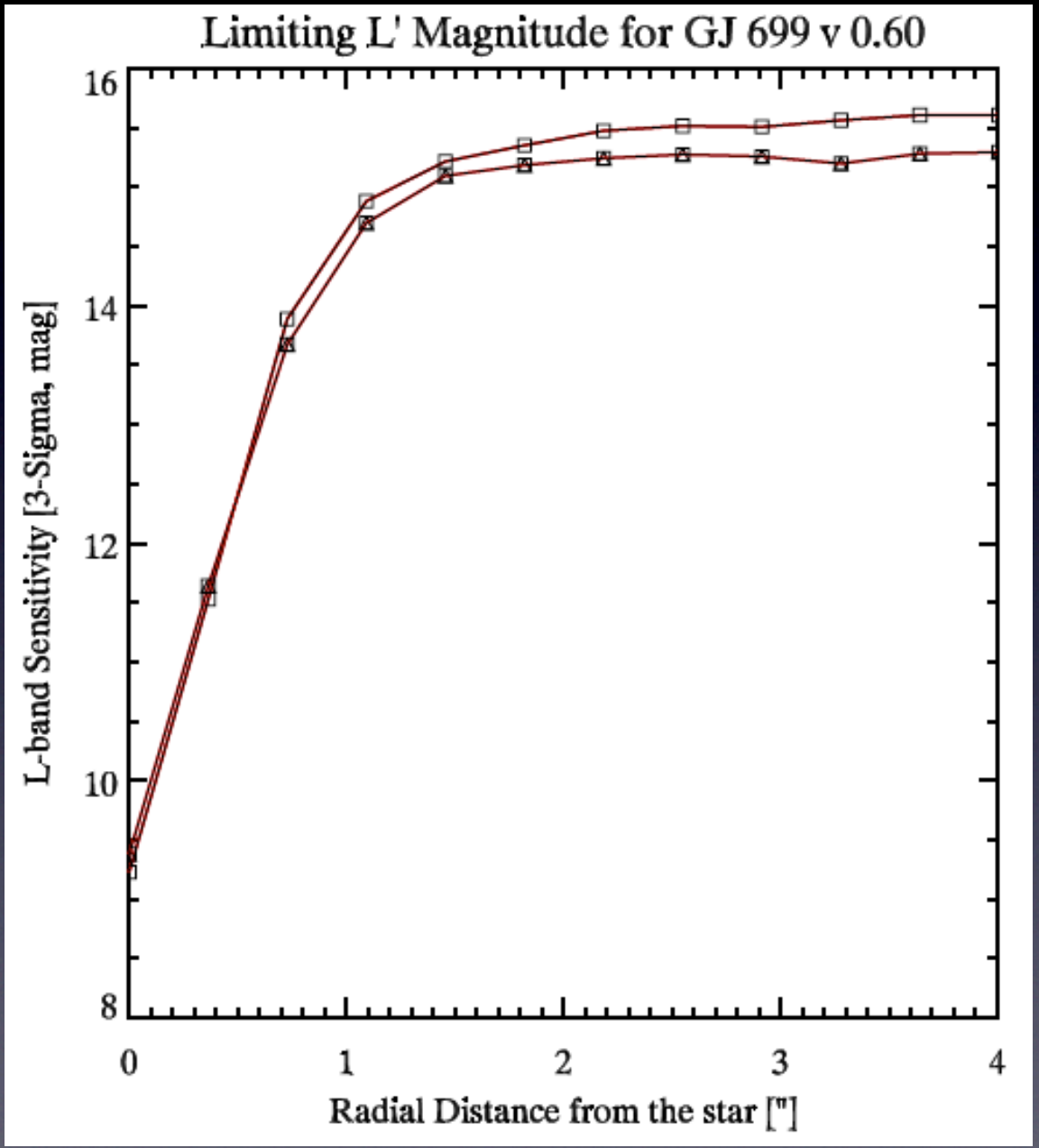
- 50 stars in 43 systems surveyed
- 7 to 10 below $5M_{jup}$ (10 sigma limits)
- Many below $7M_{jup}$
- A few below $3M_{jup}$
- No planet candidates found


We can see down to M=13-14
L'=16 in one hour
Background star equivalent in
brightness to a planet of 5M$_{jupiter}$.

M dwarfs - Apai

- 6 pc survey
- 20 out of 36 systems observed
- L' band limit is 15.3 to 15.8 sky background
- Typically < 5 AU distances

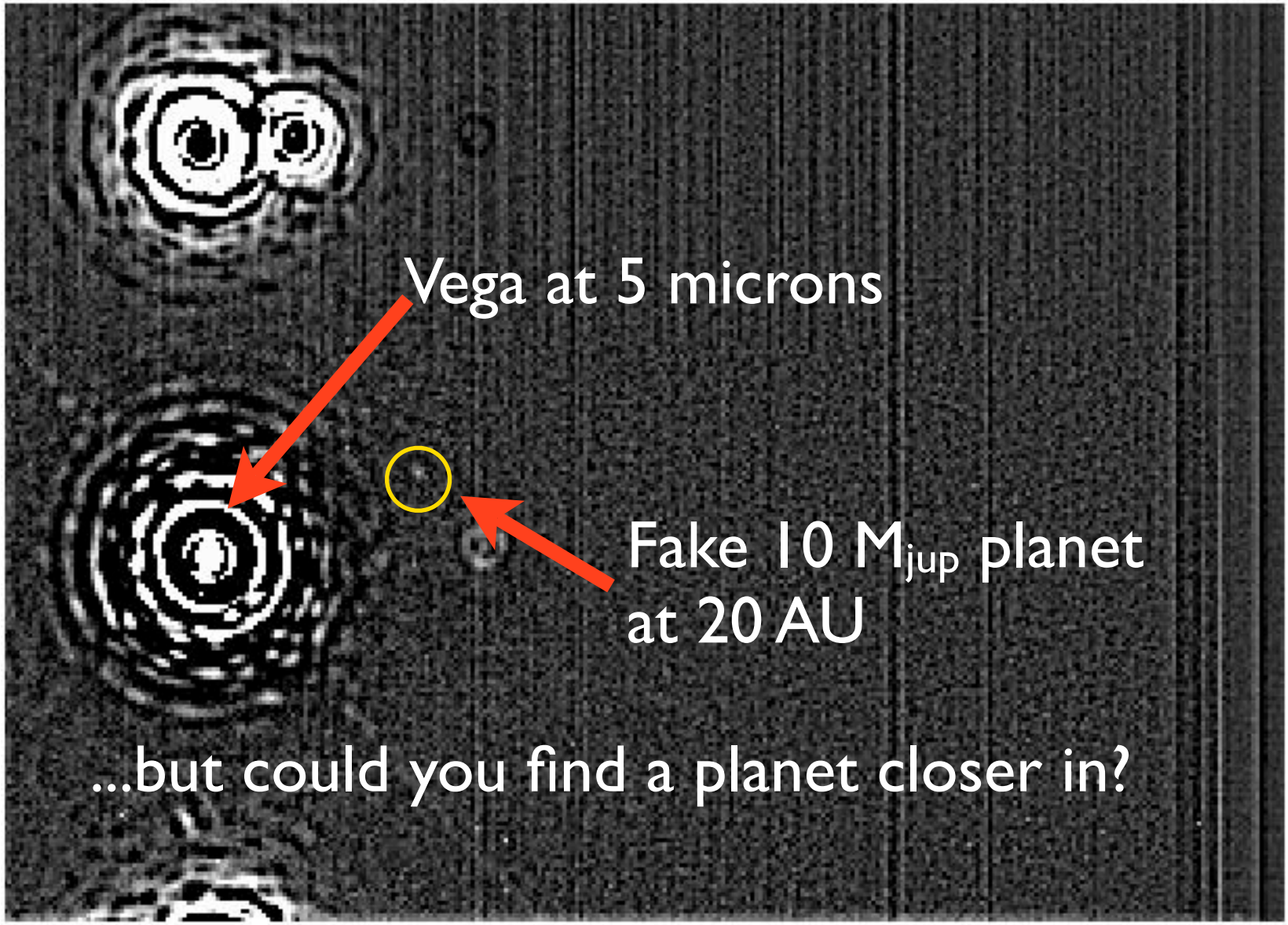
M dwarfs - Apai



A stars - Mamajek

- A stars out to 25pc
- 15 out of 25 stars observed
- 12M_{jup} typical (2M_{jup} for Sirius...)
- 25M_{jup} for Ursa Major group at ~25pc

Diffraction Effects

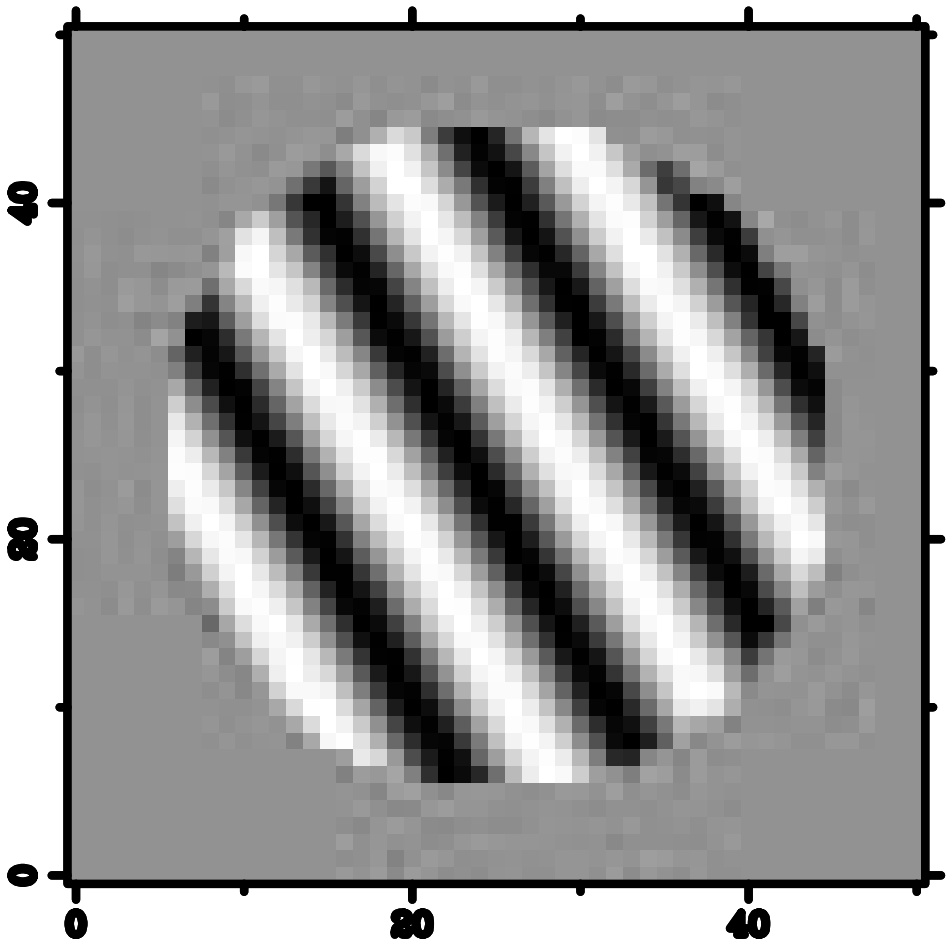


Why does Image Subtraction not work?

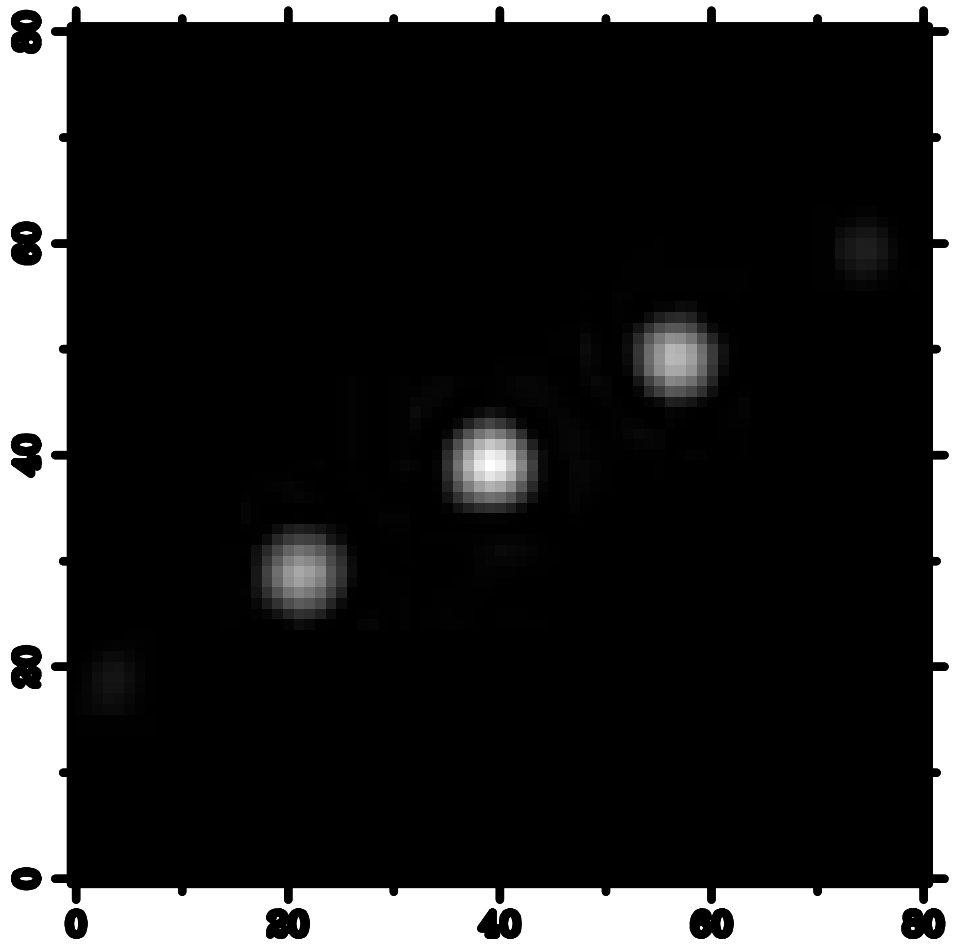
- Two images taken about 20 minutes apart are not identical
- Quasi-static ‘speckles’ are present in all images
- Small differences amplified by diffraction rings
- Squash the diffraction down with a coronagraph

Apodzing **101**

Phase ripple at Pupil Plane...

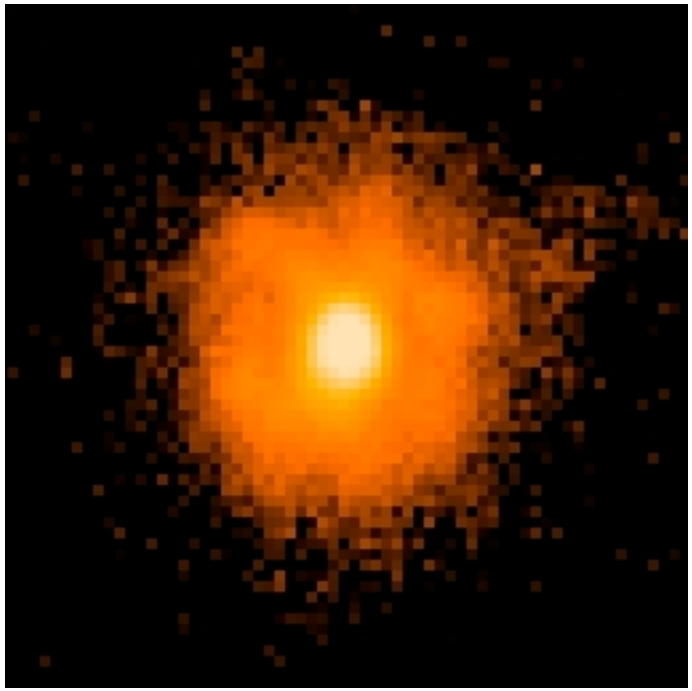


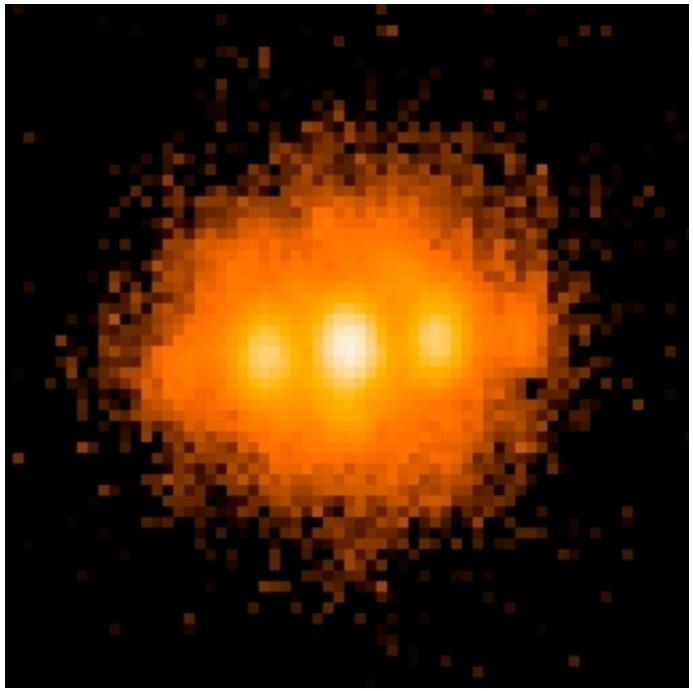
...this is the result



Apodzing in Closed Loop

Tried it using the Deformable Mirror at MMT



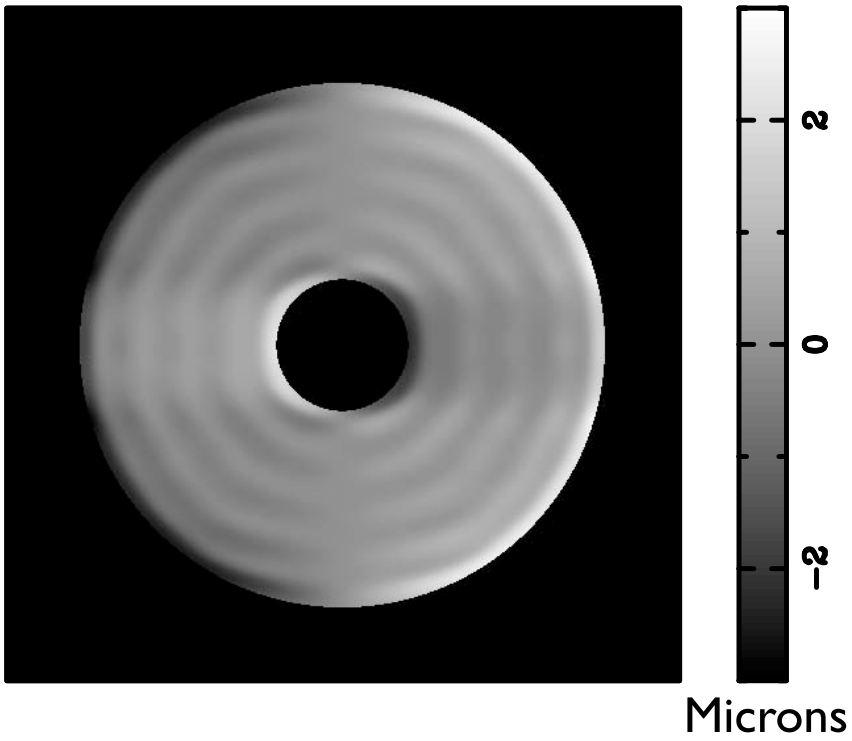


ARIES at H Band - May 2005

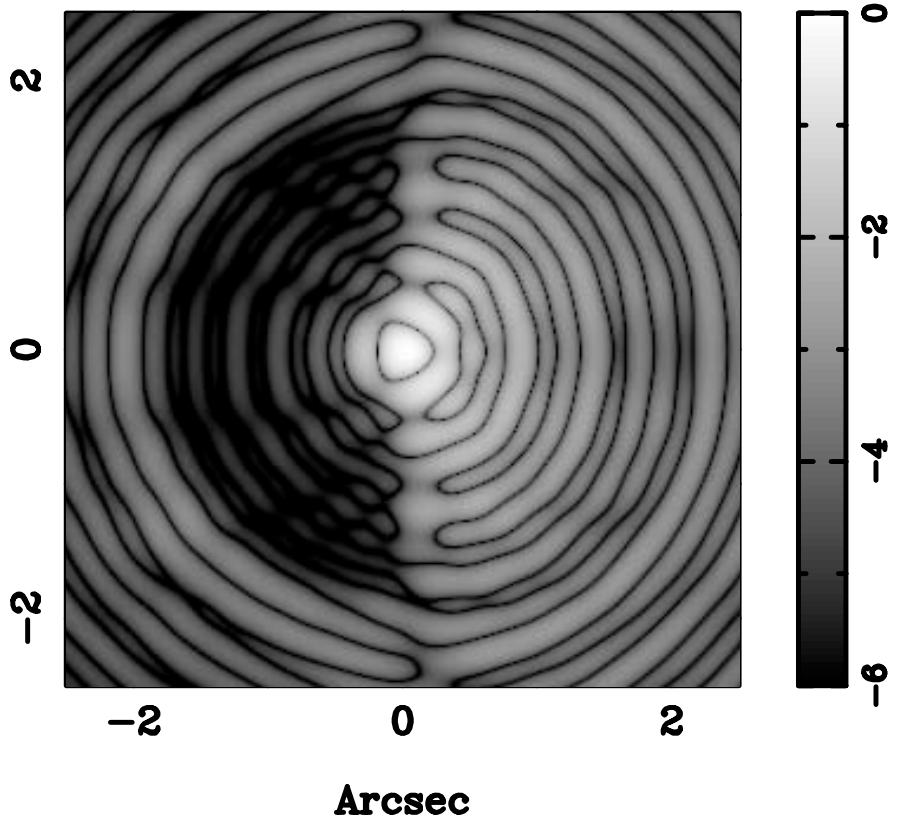
(Kenworthy et al. 2006, SPIE 6272)

Apodizing over half the FOV

Apodizing Phase Plate

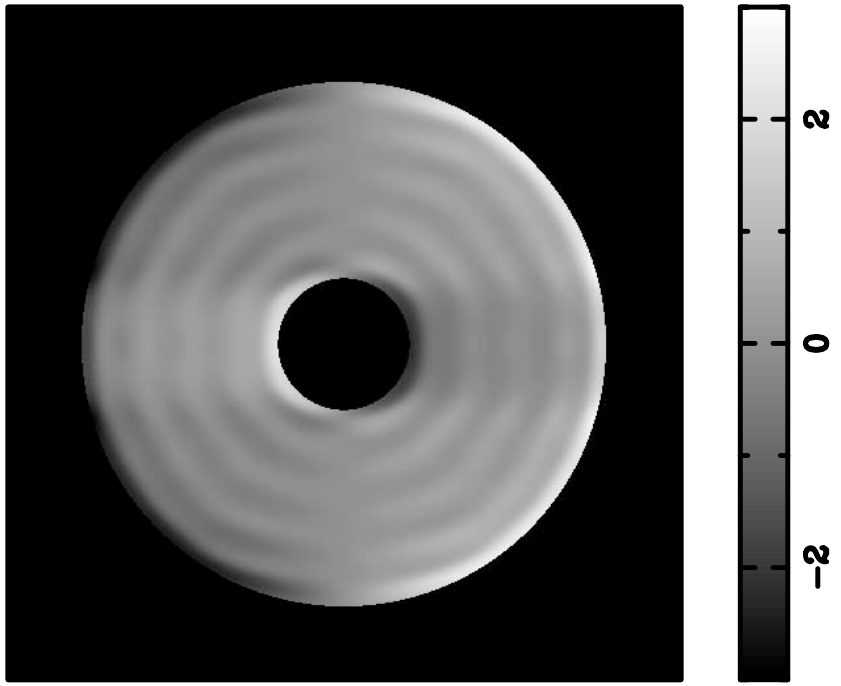


PSF (log scale)

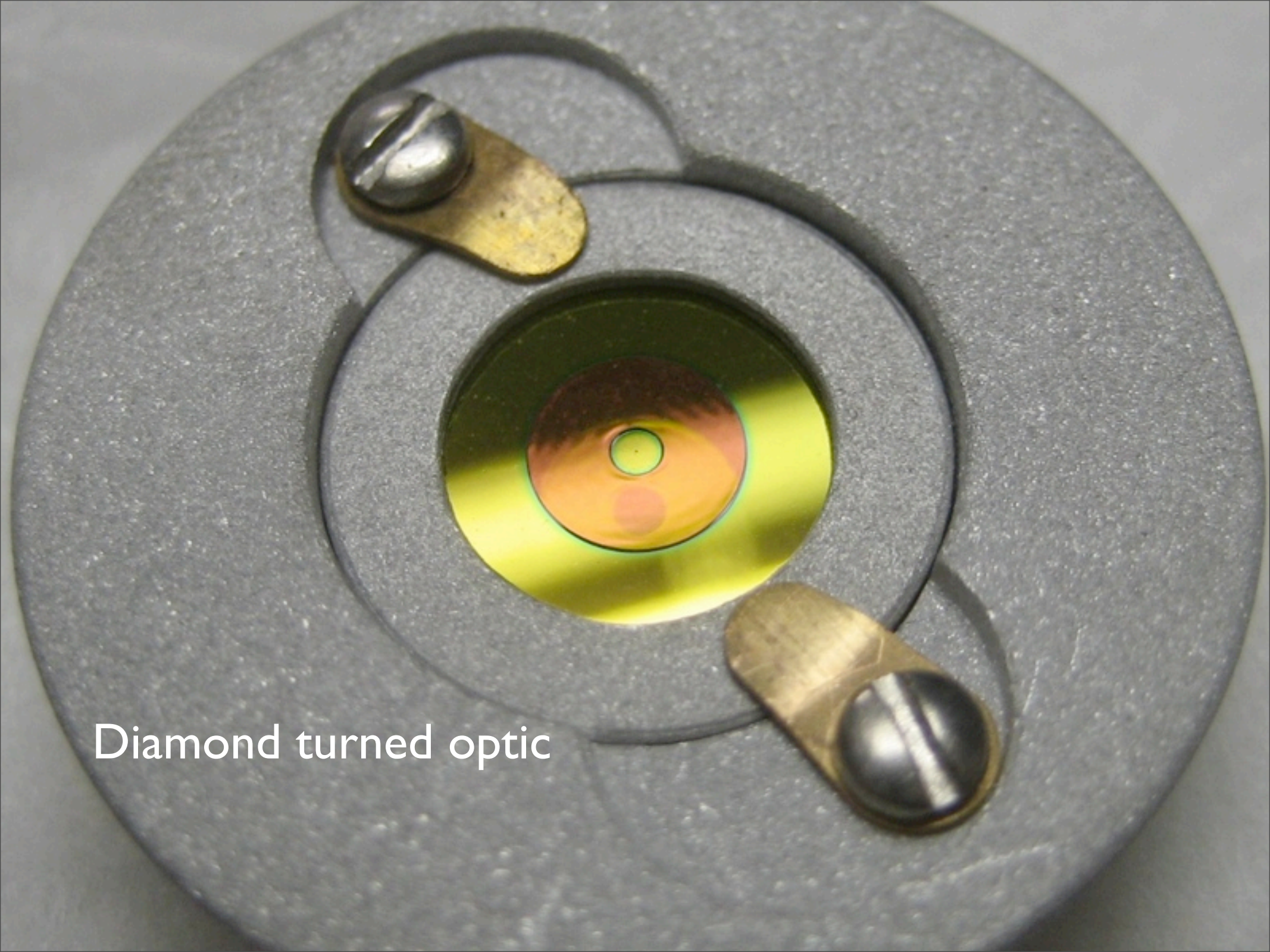


Codona algorithm - see John's talk later today

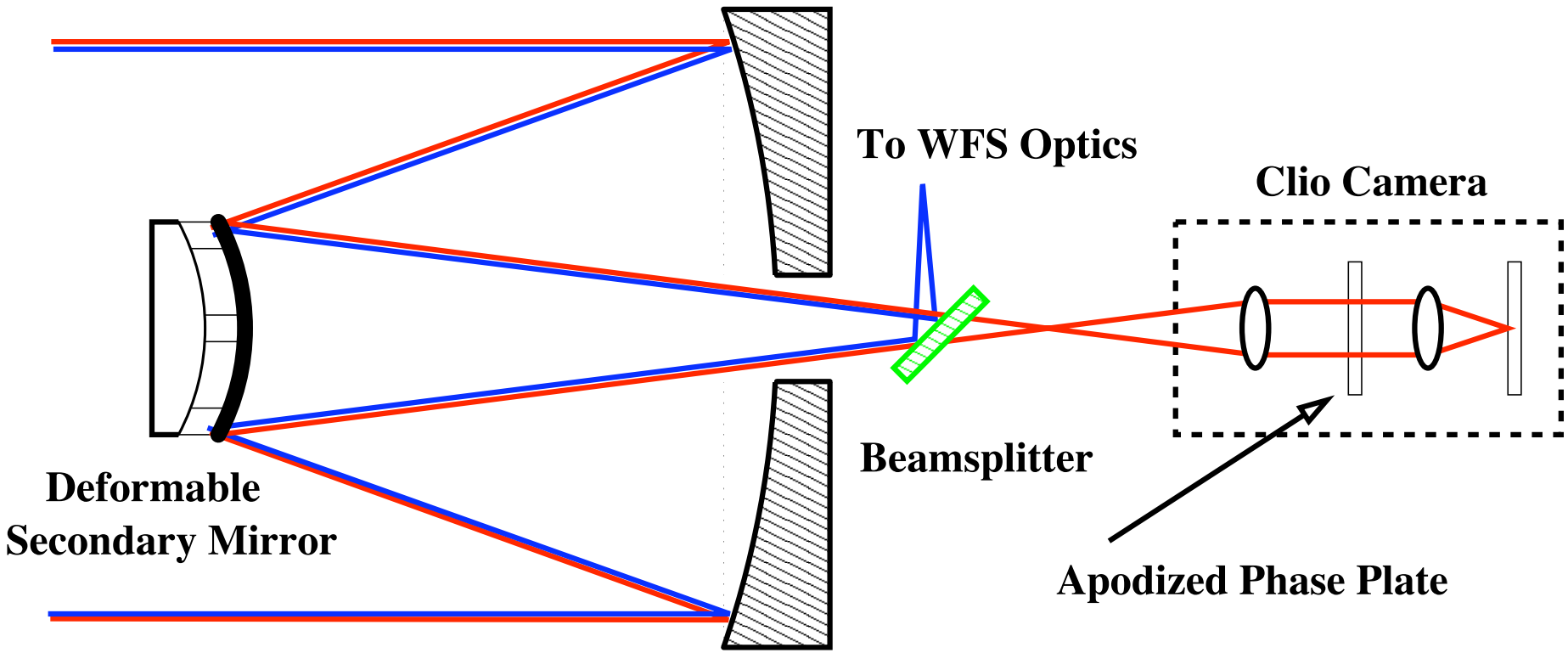
- >99% transmission
- NO focal plane mask
- 69% Strehl
- Increase in FWHM <5%
- IWA = 2.2 l/D
- OWA = 9 l/D



Codona algorithm - see John's talk later today

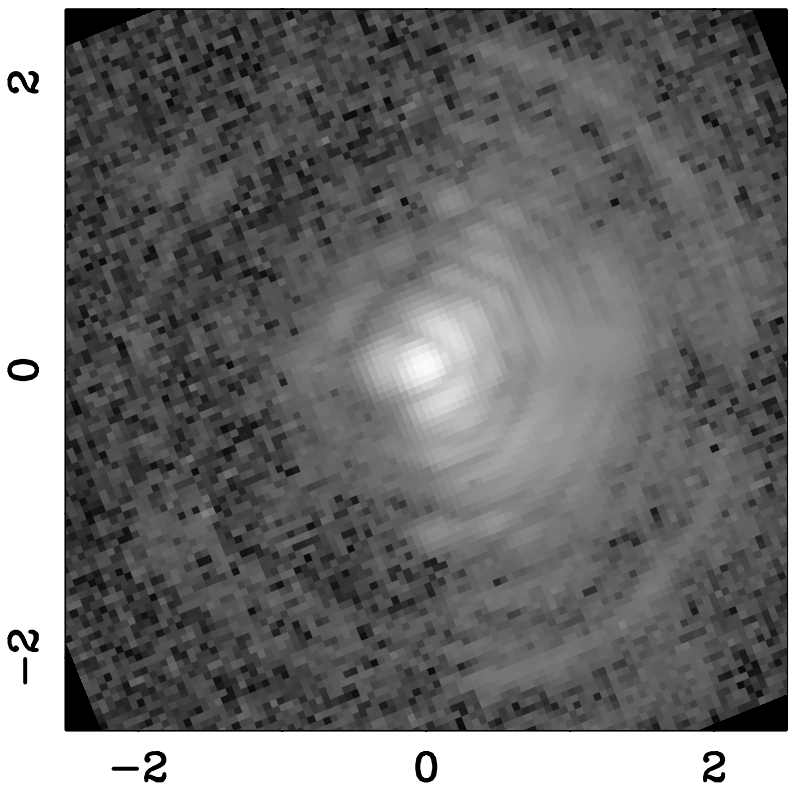

Diamond turned optic

MMTAO + Clio

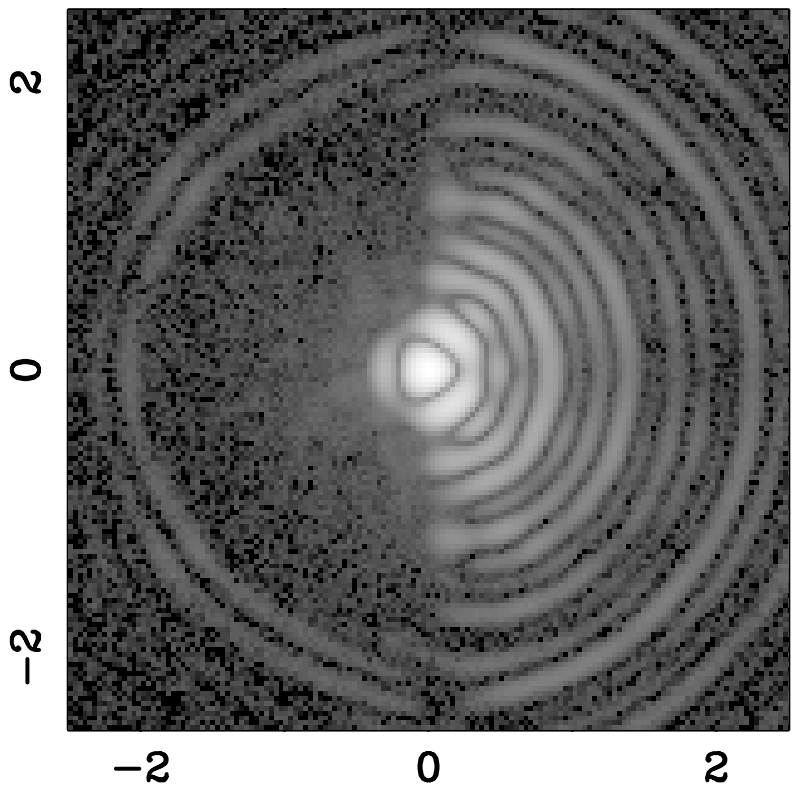

To WFS Optics
Clio Camera
Beamsplitter
Deformable
Secondary Mirror
Apodized Phase Plate

It works!

Real Image with Phase Plate



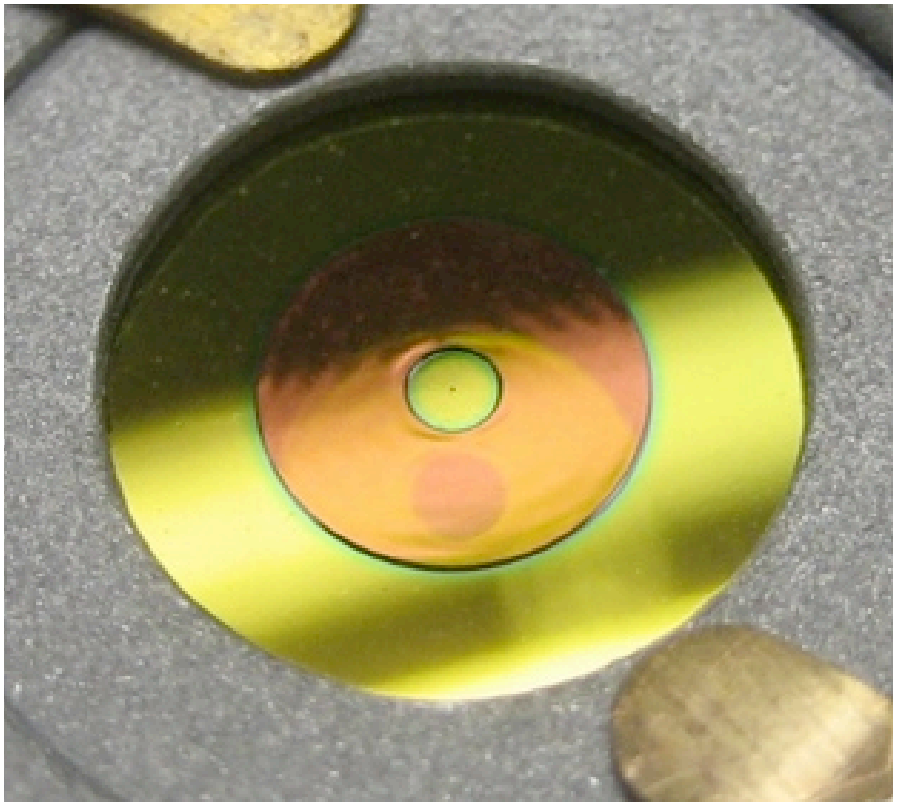
Modeled Image



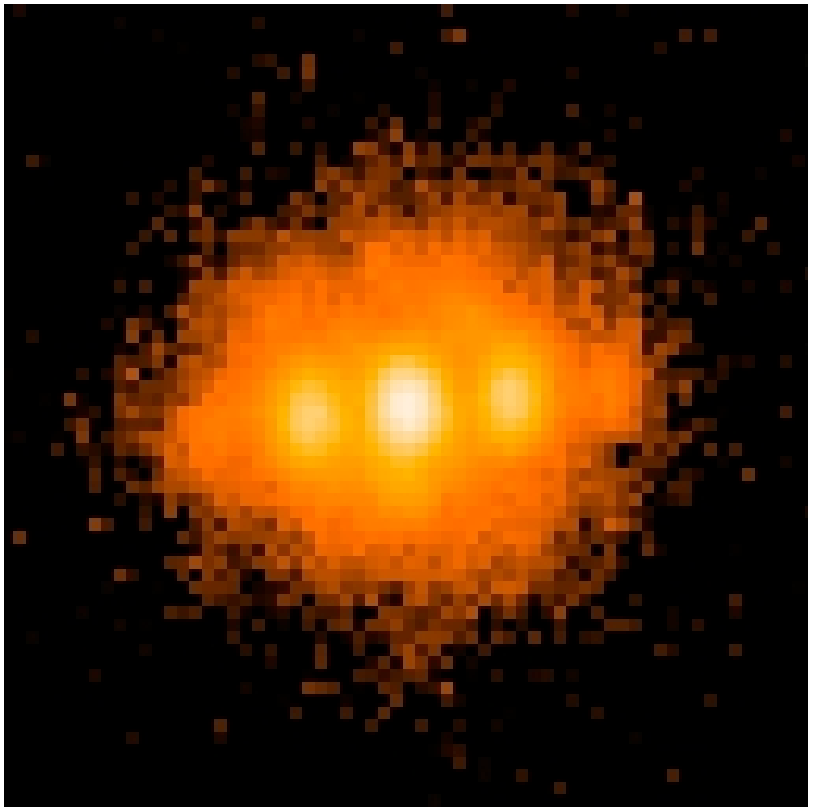
April/May 2006

Testing for Incoherence

Suppress diffraction...

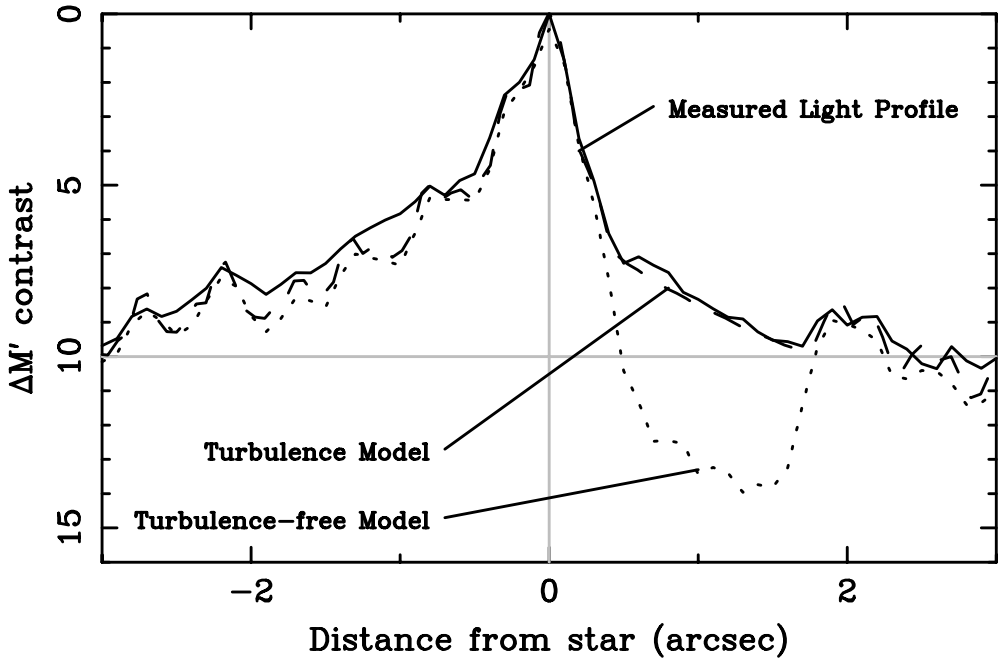


+

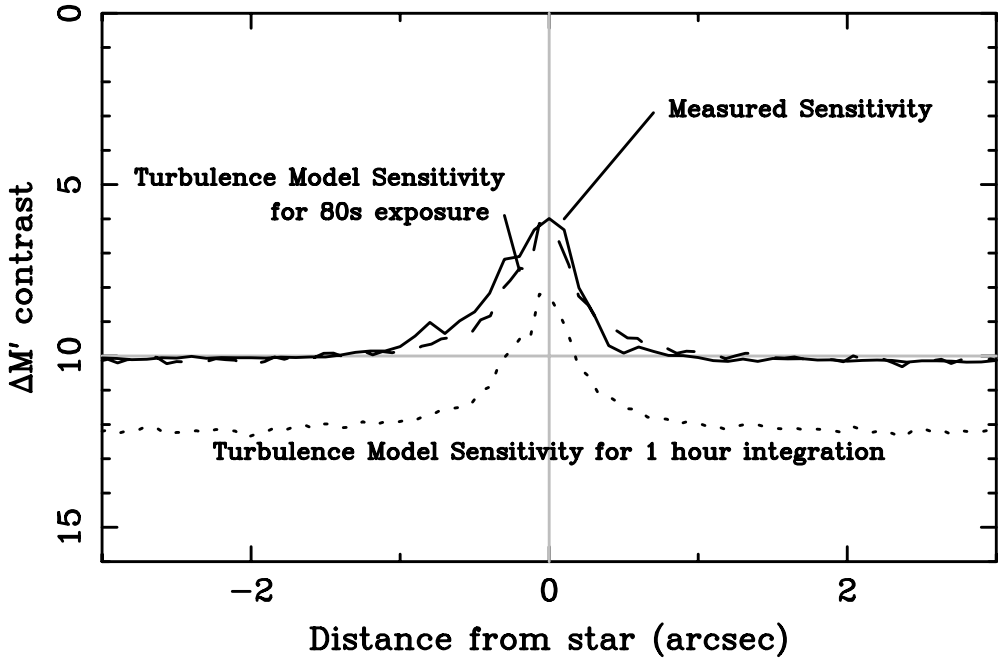


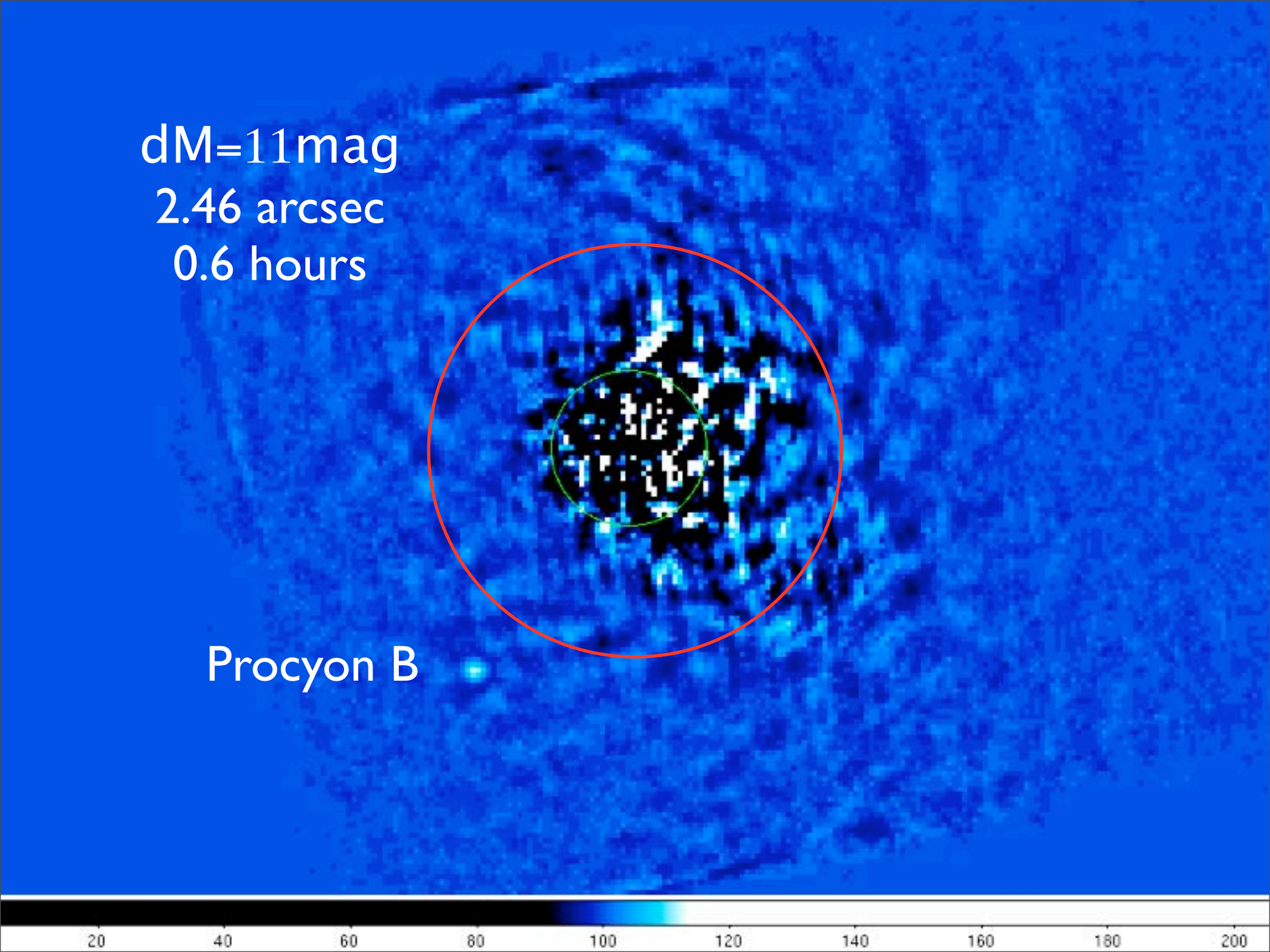
...use DM to clear residuals

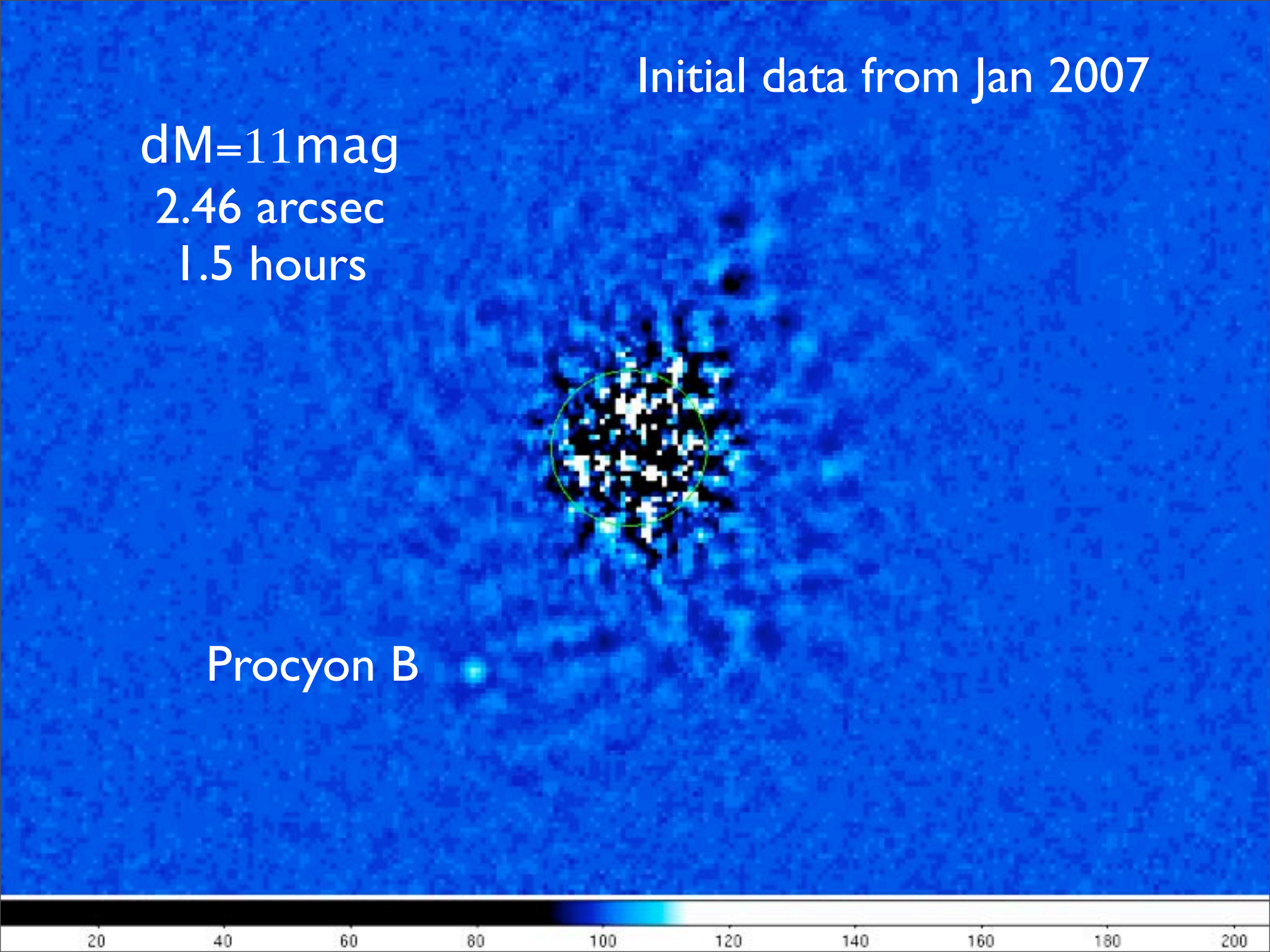
Companions can't be nulled out with DM

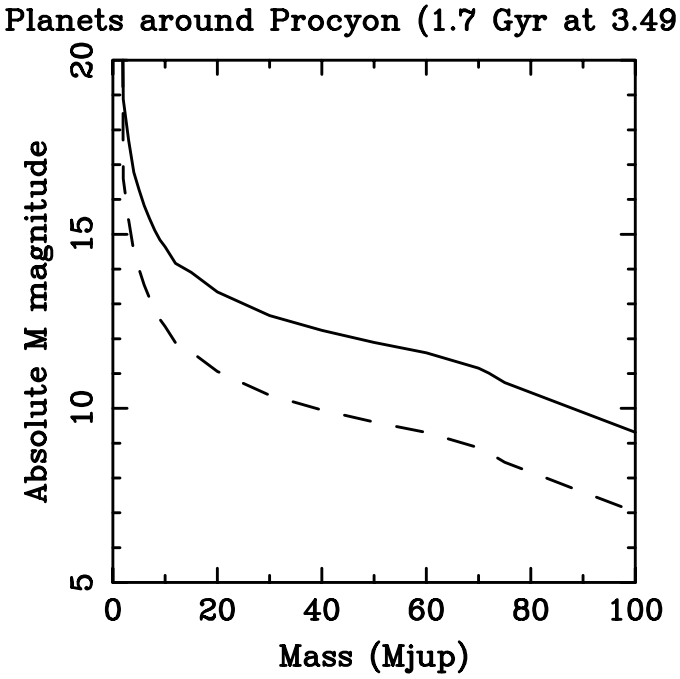


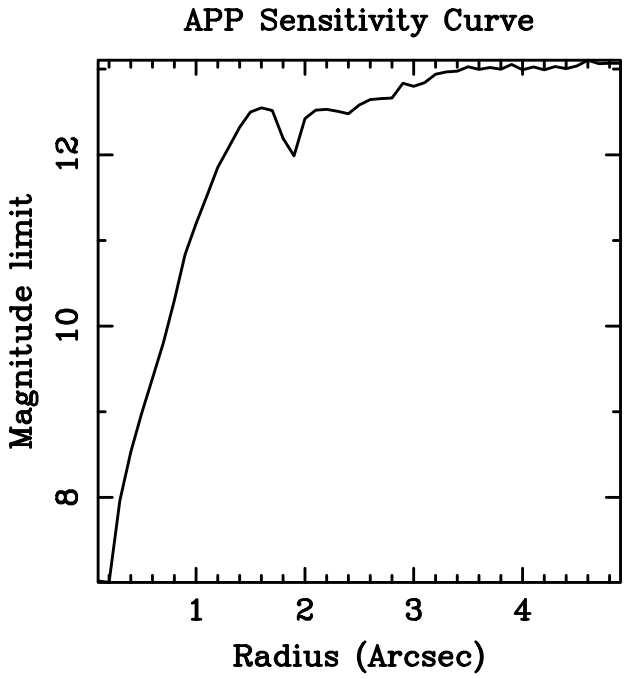
Sensitivity curve

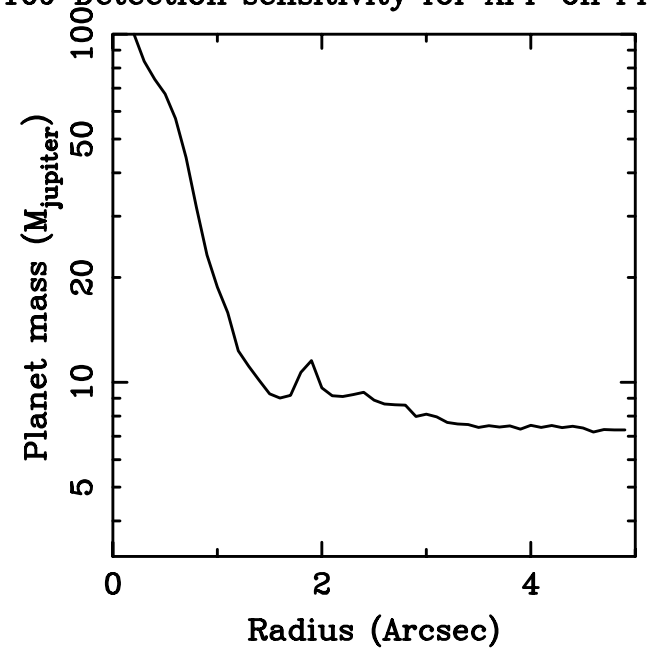


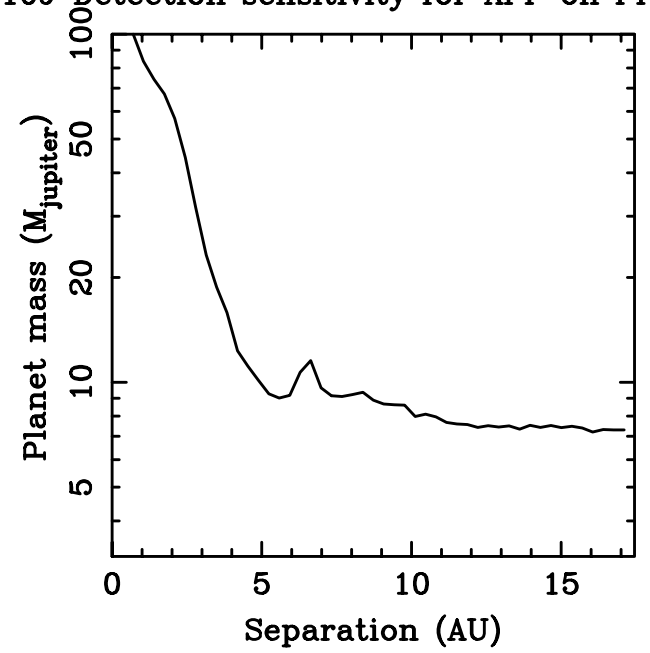

dM=11mag
2.46 arcsec
0.6 hours
Procyon B
20
40
60
80
100
120
140
160
180
200


Initial data from Jan 2007
dM=11mag
2.46 arcsec
1.5 hours
Procyon B
20
40
60
80
100
120
140
160
180
200


Planets around Procyon (1.7 Gyr at 3.49 pc)
Absolute M magnitude
Mass (Mjup)
5
10
15
20
0
20
40
60
80
100


APP Sensitivity Curve
Magnitude limit
Radius (Arcsec)
8
10
12
1
2
3
4


10σ Detection sensitivity for APP on Procyon
Planet mass (Mjupiter)
Radius (Arcsec)
5
10
20
50
100
0
2
4

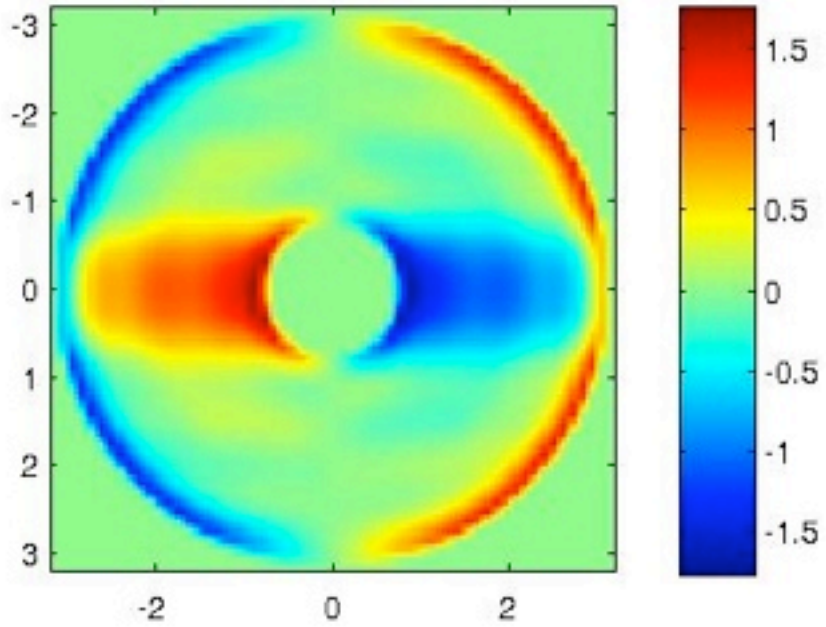

10σ Detection sensitivity for APP on Procyon
Planet mass (Mjupiter)
Separation (AU)
5
10
20
50
100
0
5
10
15

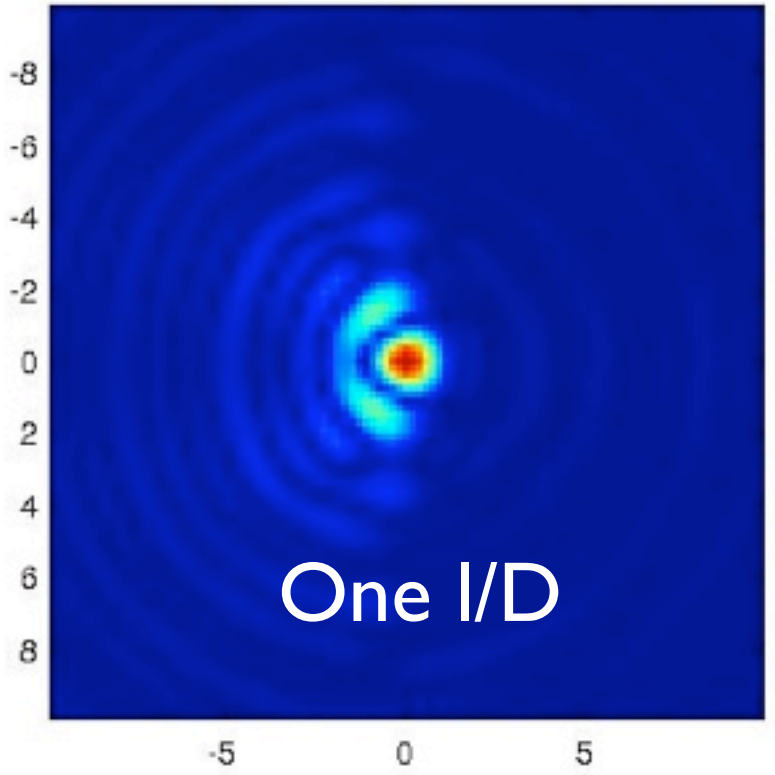
Conclusions

- Thermal imaging is sensitive enough
- No planets so far...but watch for the A star survey
- APP can be generalised for **ANY** pupil, e.g. JWST and GMT

(one more slide before lunch...)

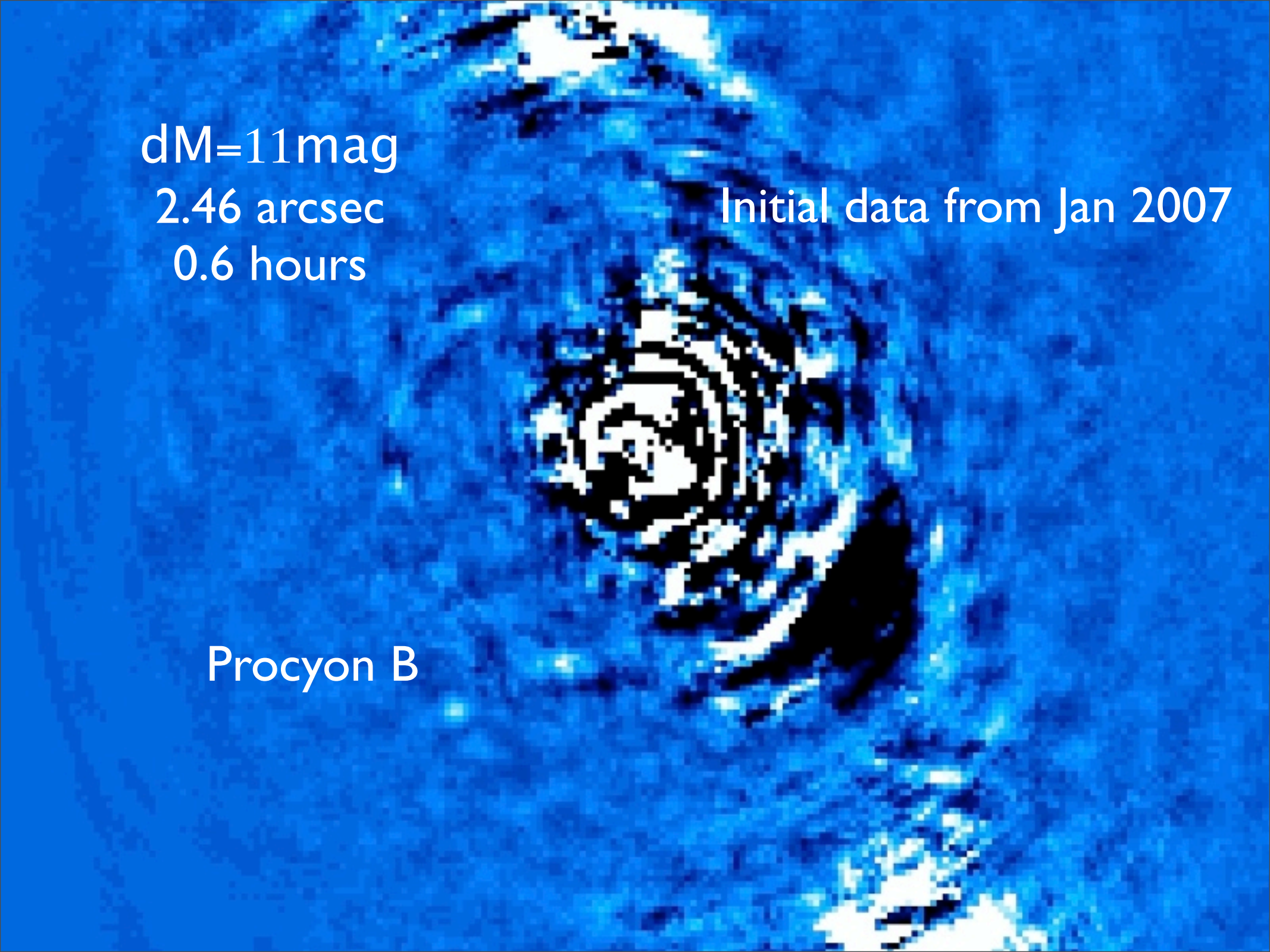
New APP Algorithm





- >50% Strehl
- <5% increase in FWHM
- See John Codona talk later today

Spare Slides


dM=11mag
2.46 arcsec
0.6 hours
Initial data from Jan 2007
Procyon B