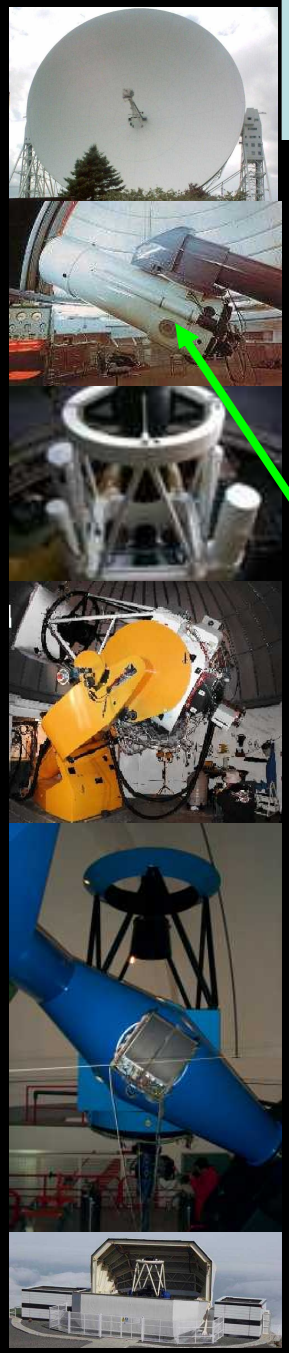


Monitoring Projects: Introduction

Dan Maoz, Tel-Aviv University

Wise Observatory

ON THE POSSIBILITY OF DETERMINING HUBBLE'S PARAMETER AND THE MASSES OF GALAXIES FROM THE GRAVITATIONAL LENS EFFECT*

Sjur Refsdal

(Communicated by H. Bondi)

(Received 1964 January 27)

Summary

The gravitational lens effect is applied to a supernova lying far behind and close to the line of sight through a distant galaxy. The light from the supernova may follow two different paths to the observer, and the difference Δt in the time of light travel for these two paths can amount to a couple of months or more, and may be measurable. It is shown that Hubble's parameter and the mass of the galaxy can be expressed by Δt, the red-shifts of the supernova and the galaxy, the luminosities of the supernova "images" and the angle between them. The possibility of observing the phenomenon is discussed.

1. *Introduction.*—In 1937 Zwicky suggested that a galaxy, due to the gravitational deflection of light, may act as a gravitational lens. He considered the case of a galaxy A lying far behind and close to the line of sight through a distant galaxy B. If the line of sight through the centre of B goes through A, the "image" of A will be a ring around B, otherwise two separated "images" appear, on opposite sides of B. The phenomenon has later been discussed by Zwicky (1957) and Klimov (1963), and they both conclude that the possibility of observing the

should be possible to observe every third year. The apparent magnitude of the "images" will be 21–23 for S_1 and 21–24 for S_2. For greater values of a $P(a)$ increase rapidly, in fact it is proportional to a^5.

It is possible that our estimate of the mass of galaxies is too great. If we consider only elliptical galaxies as possible gravitational lenses, the estimate of $\mathcal{M}$ is perhaps more realistic. About 20 per cent of all galaxies are elliptical, and the expected number of observable "double images" will be reduced by 80 per cent.

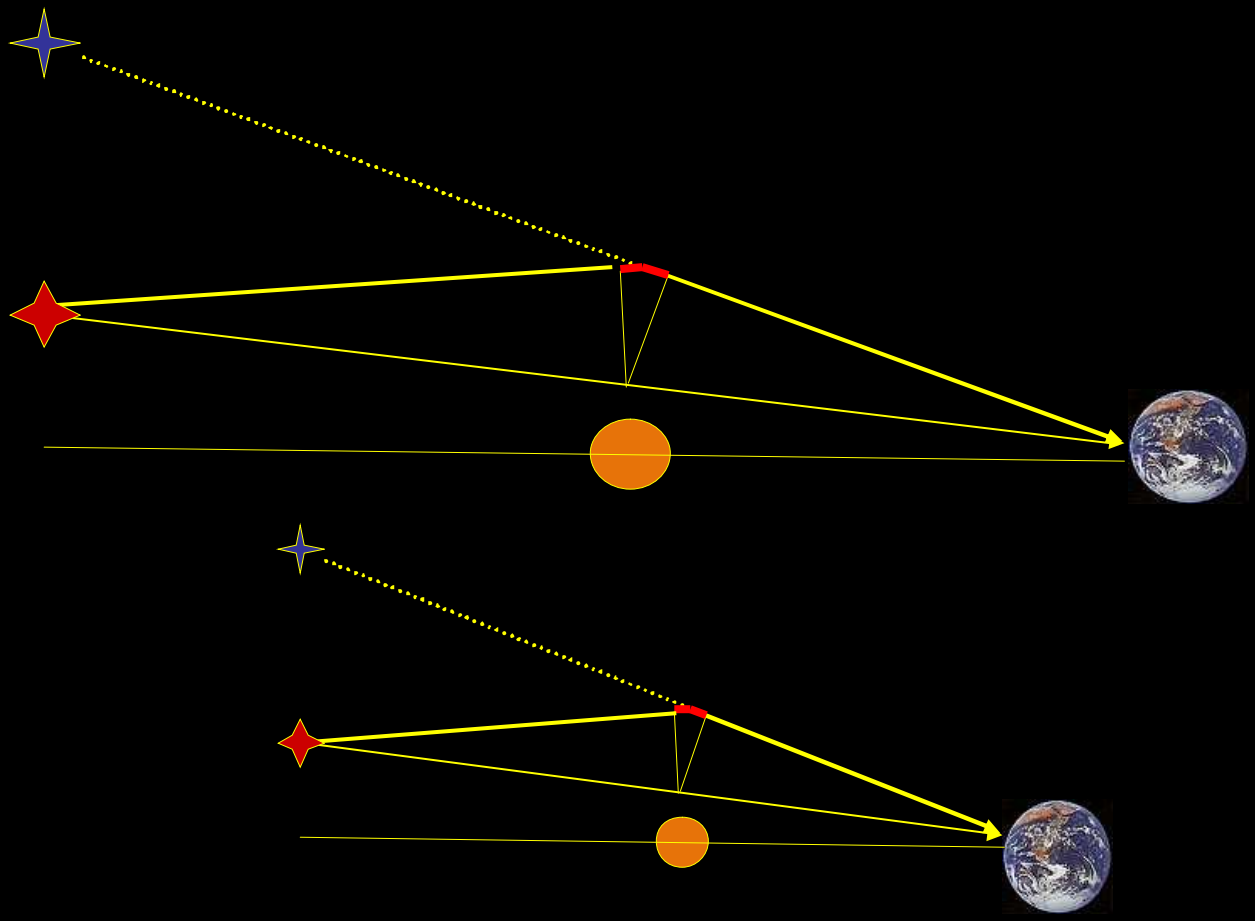
Star-like objects with intense emission both in the radio range and the optical range have recently been discovered (Greenstein 1963). Their absolute visual luminosity are of order -24, and it is possible that flashes occur in the optical region, lasting about one month, and with an amplitude about $0{\cdot}5^{m}$.

If so, observations at greater distances than with supernova will be possible. The distances may be so great that we can no longer assume Z to be small. The result of our calculations will then depend on the cosmological model we choose, giving a possibility of testing the different models. This will be discussed in a subsequent paper.

Acknowledgment.—An expression of gratitude is due to Dr E. Jensen for valuable help and encouragement.

Institute of Theoretical Physics,
University of Oslo, Blindern,
Norway:

Lensed quasar time delays for measuring H_0

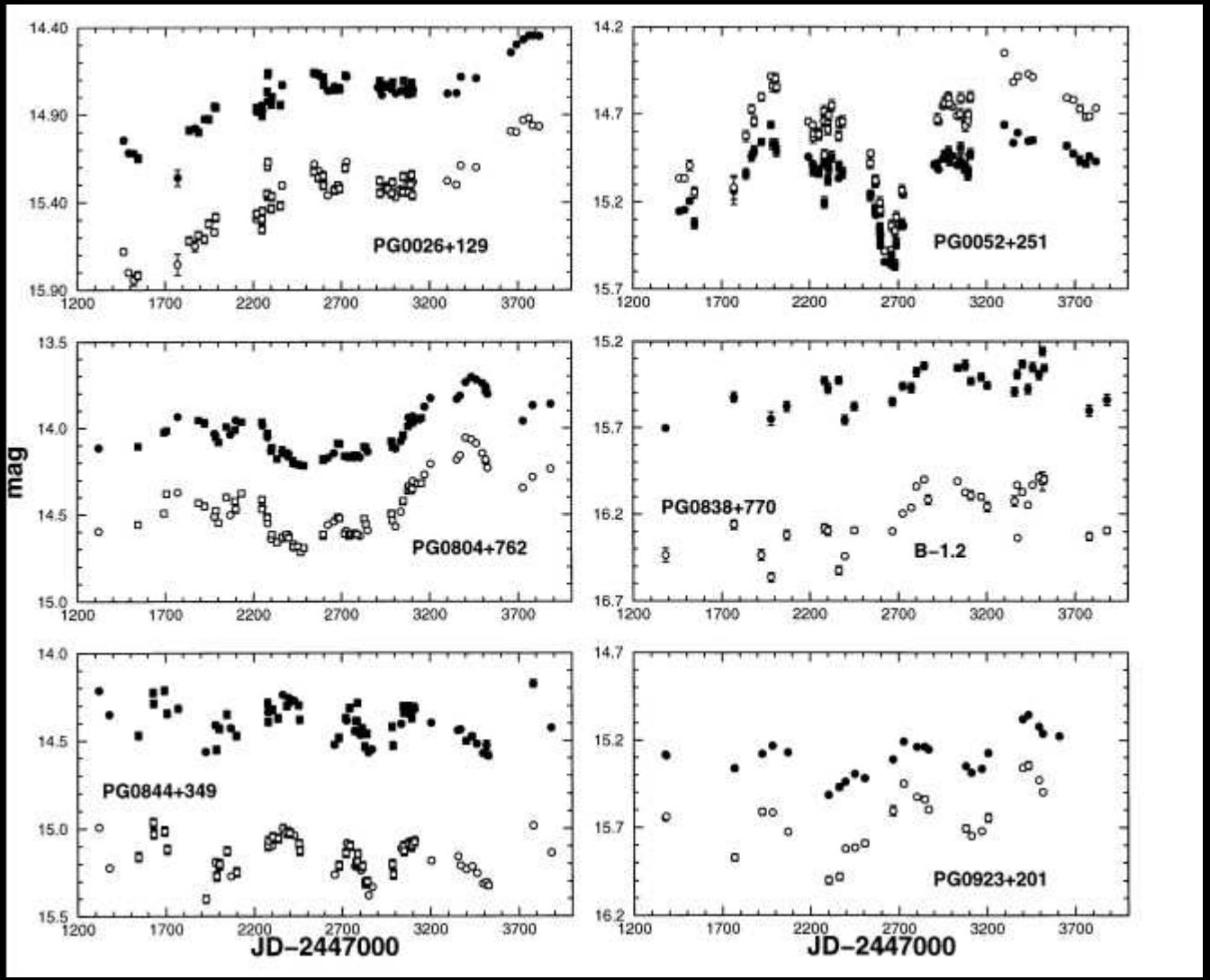


small H_0

large H_0

$$\tau(\boldsymbol{\theta}) = \frac{D_d D_s}{c D_{ds}} \left[\frac{1}{2} (\boldsymbol{\theta} - \boldsymbol{\beta})^2 - \Psi(\boldsymbol{\theta}) \right]$$

Giveon et al. 1999: 7-year light curves for 42 PG QSOs



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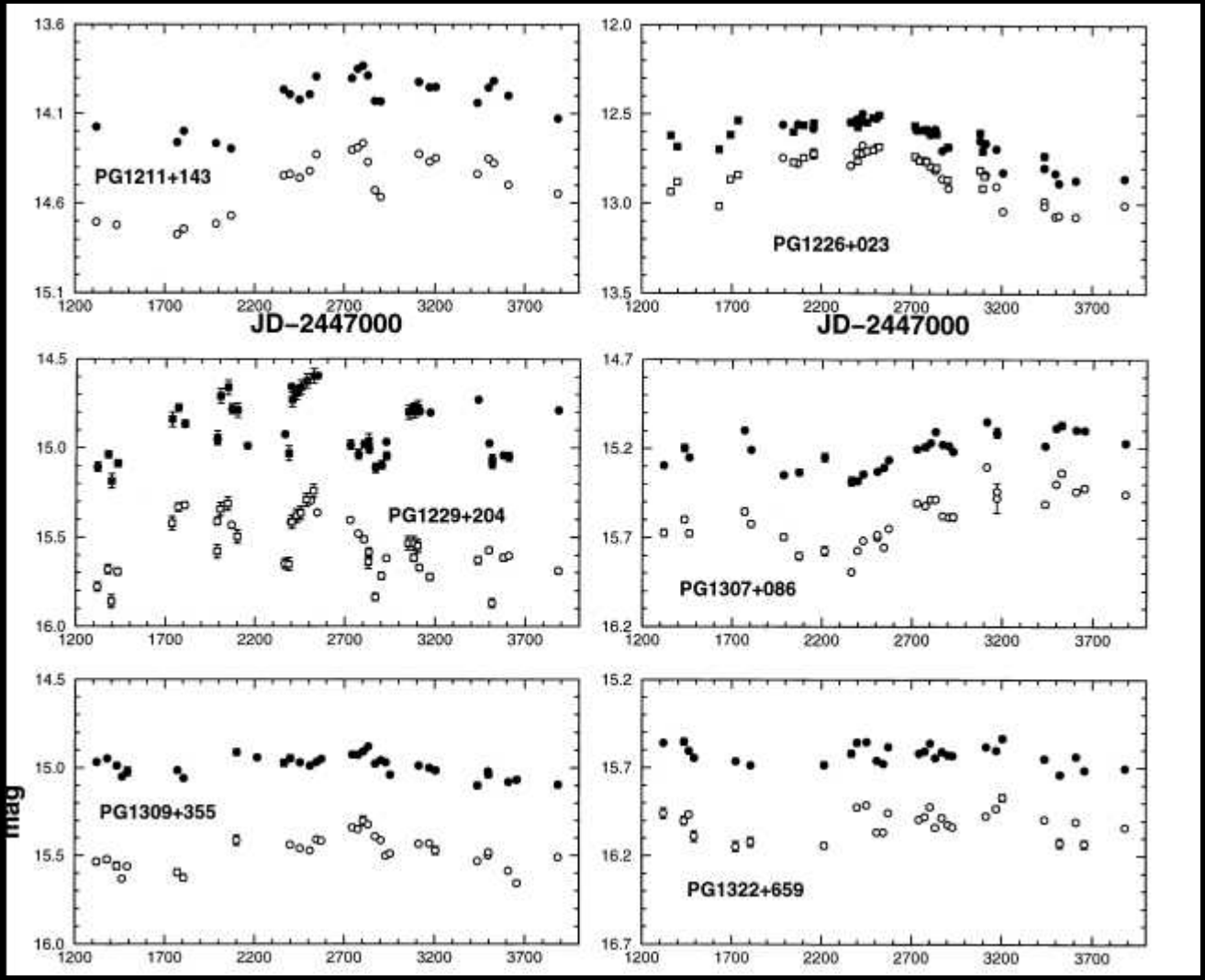
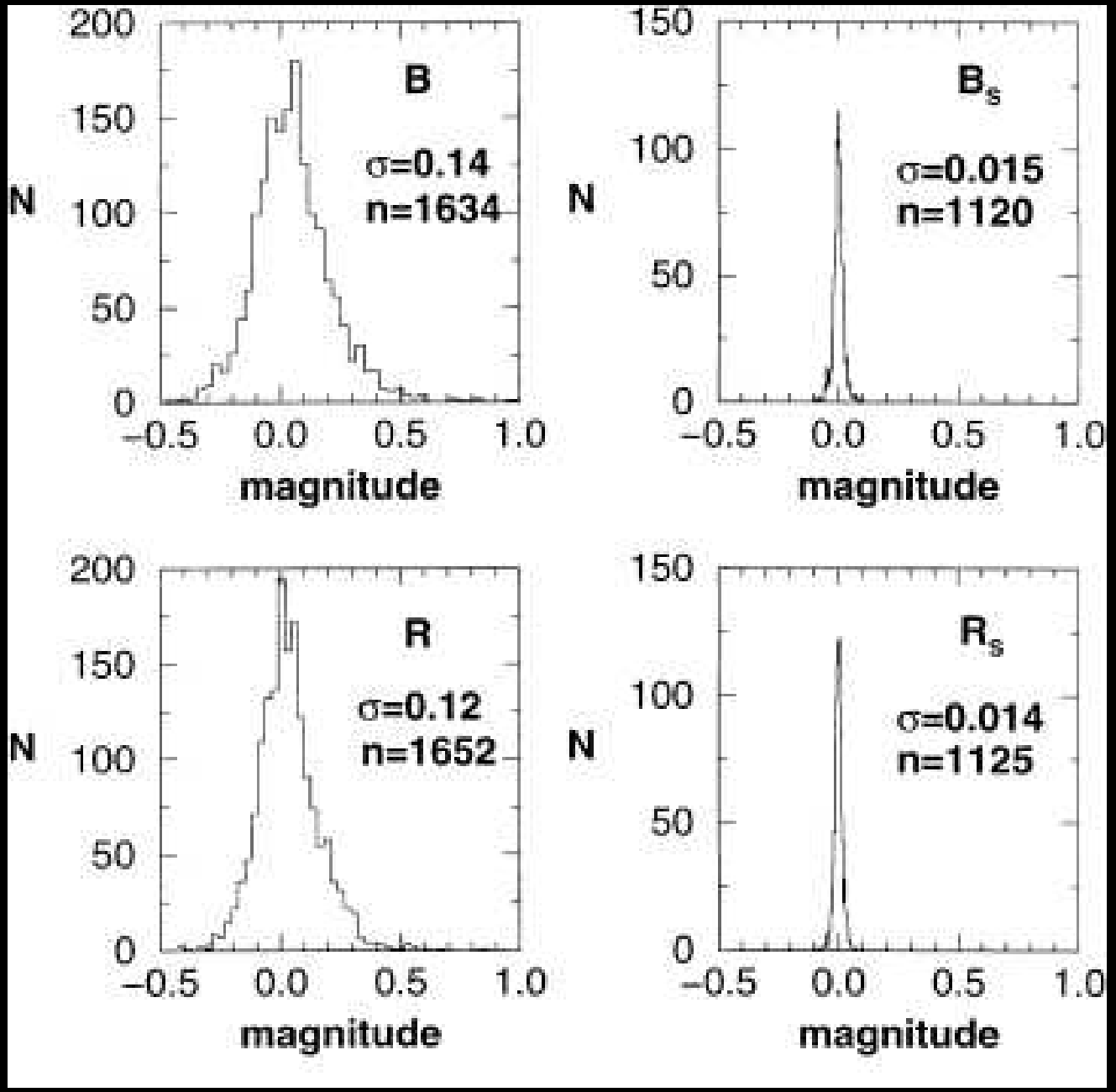
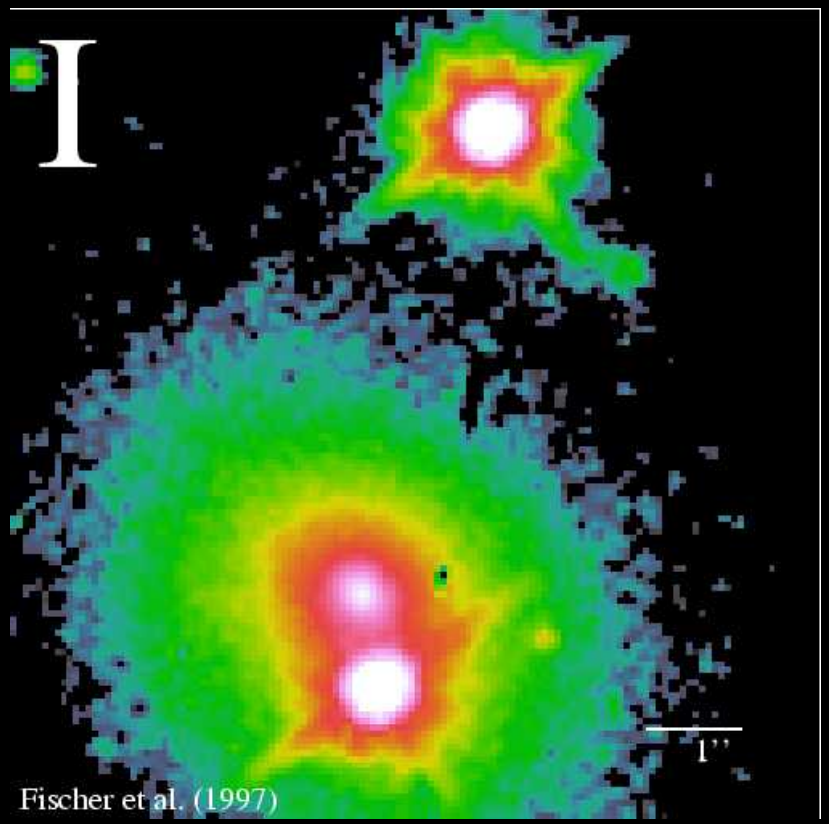


Distribution of mag differences





Q0957+561 Kundic et al. 1997

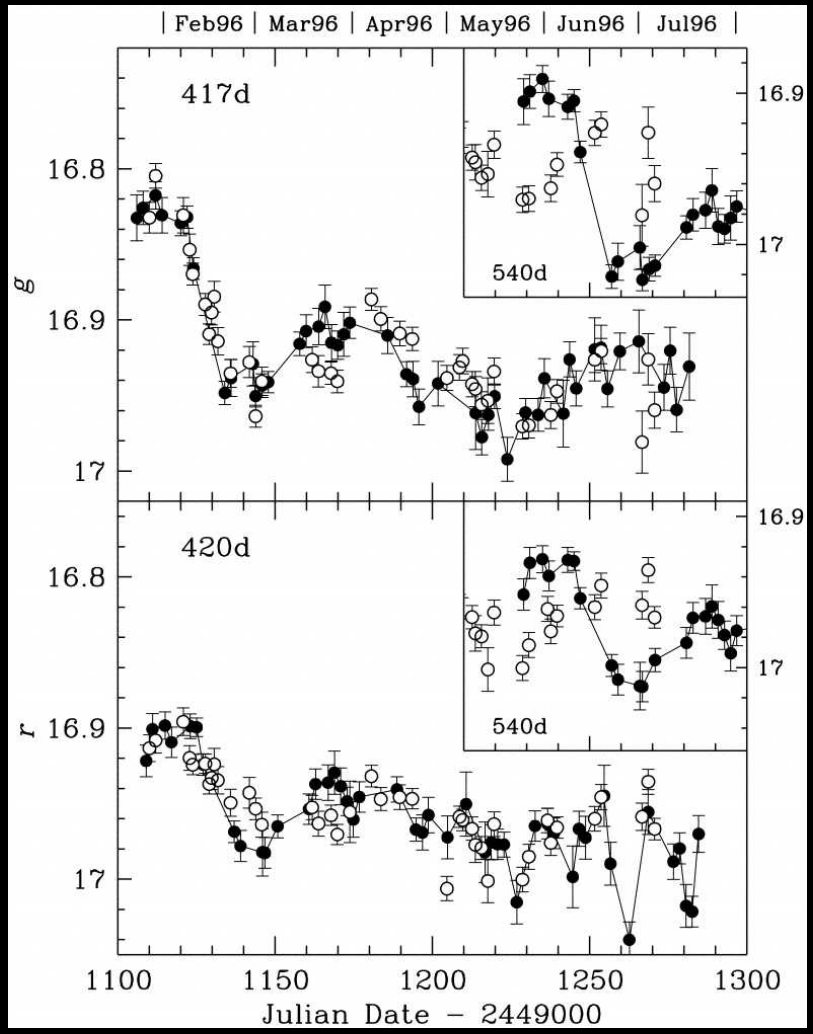


Table B.1. Time Delay Measurements

System	N_{im}	Δt (days)	Astrometry	Model	Ref.
HE1104–1805	2	161 ± 7	+	"simple"	1
PG1115+080	4	25 ± 2	+	"simple"	2
SBS1520+530	2	130 ± 3	+	"simple"	3
B1600+434	2	51 ± 2	+/−	"simple"	4
HE2149–2745	2	103 ± 12	+	"simple"	5
RXJ0911+0551	4	146 ± 4	+	cluster/satellite	6
Q0957+561	2	417 ± 3	+	cluster	7
B1608+656	4	77 ± 2	+/−	satellite	8
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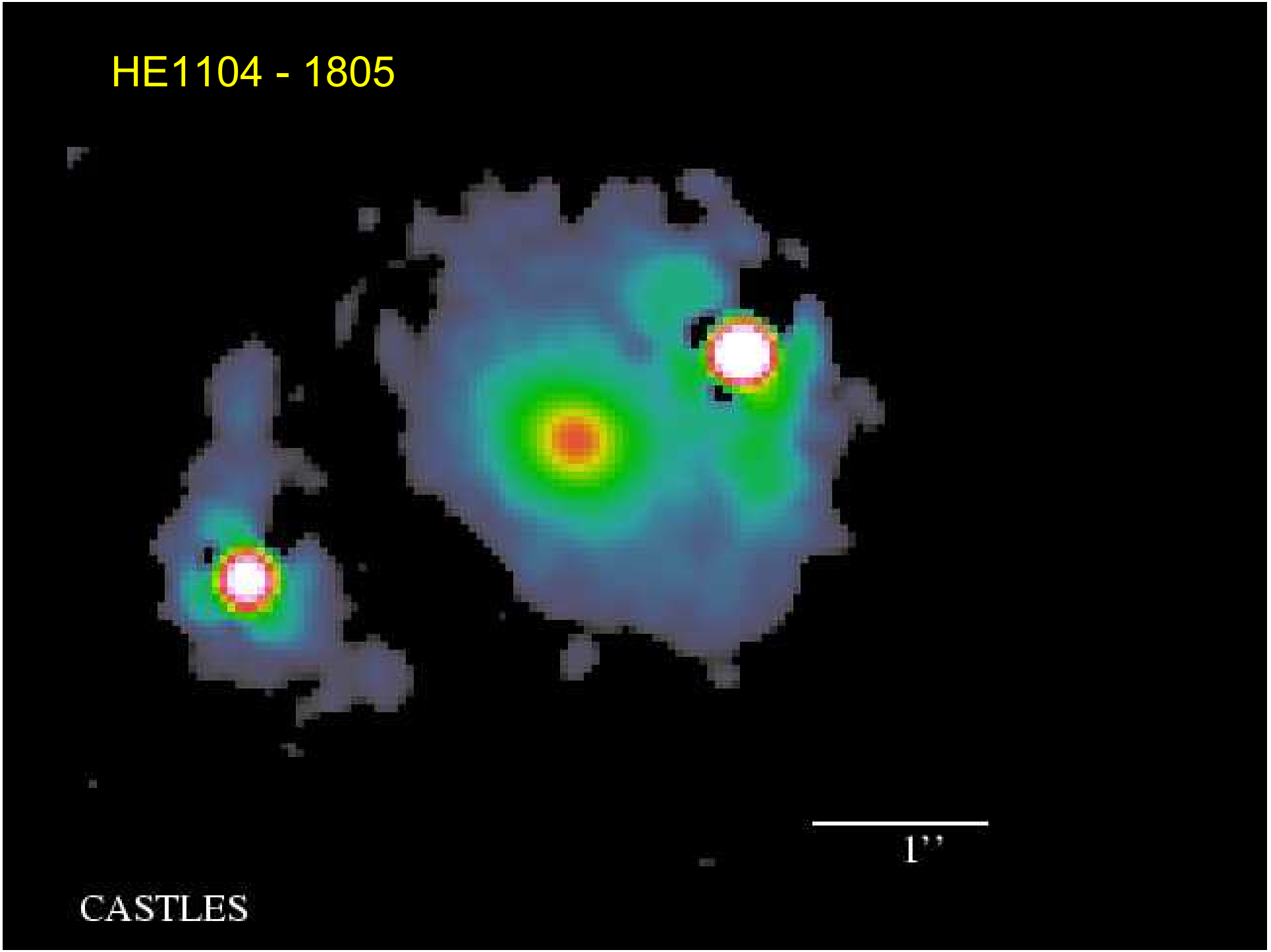
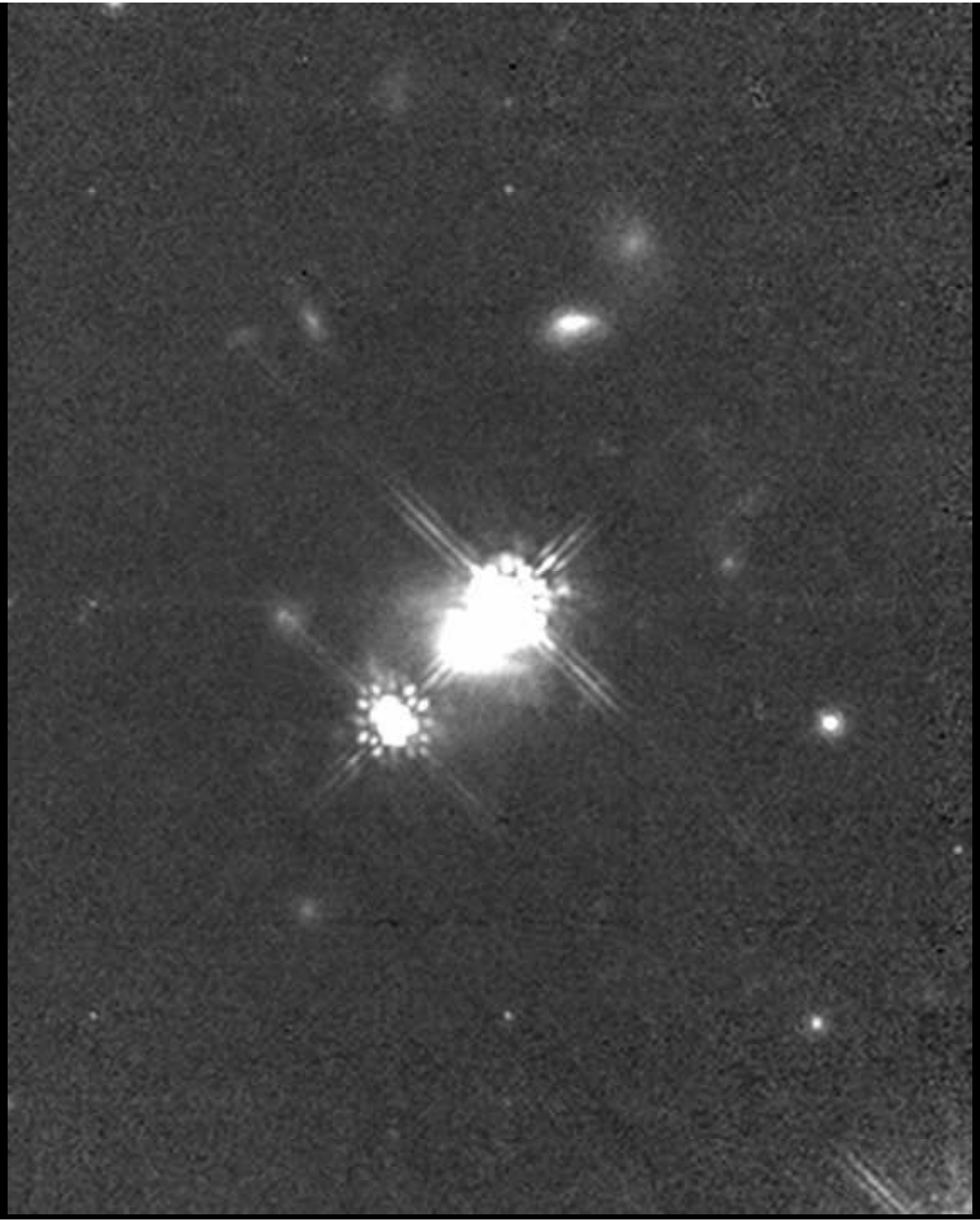
12. 0951+2635


HE1104 - 1805
1''
CASTLES

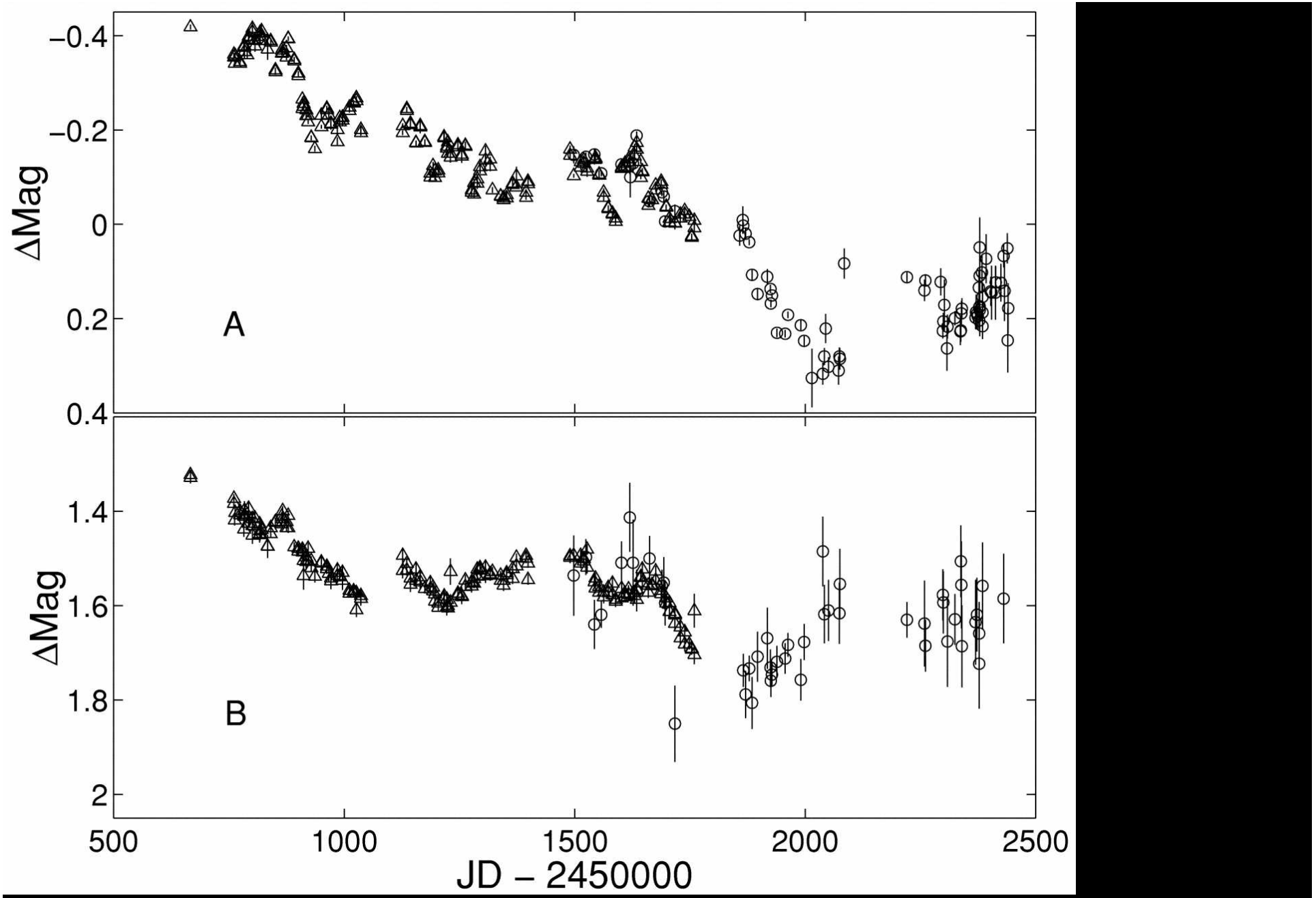
HST/NICMOS F160W

Kochanek et al., in prep.

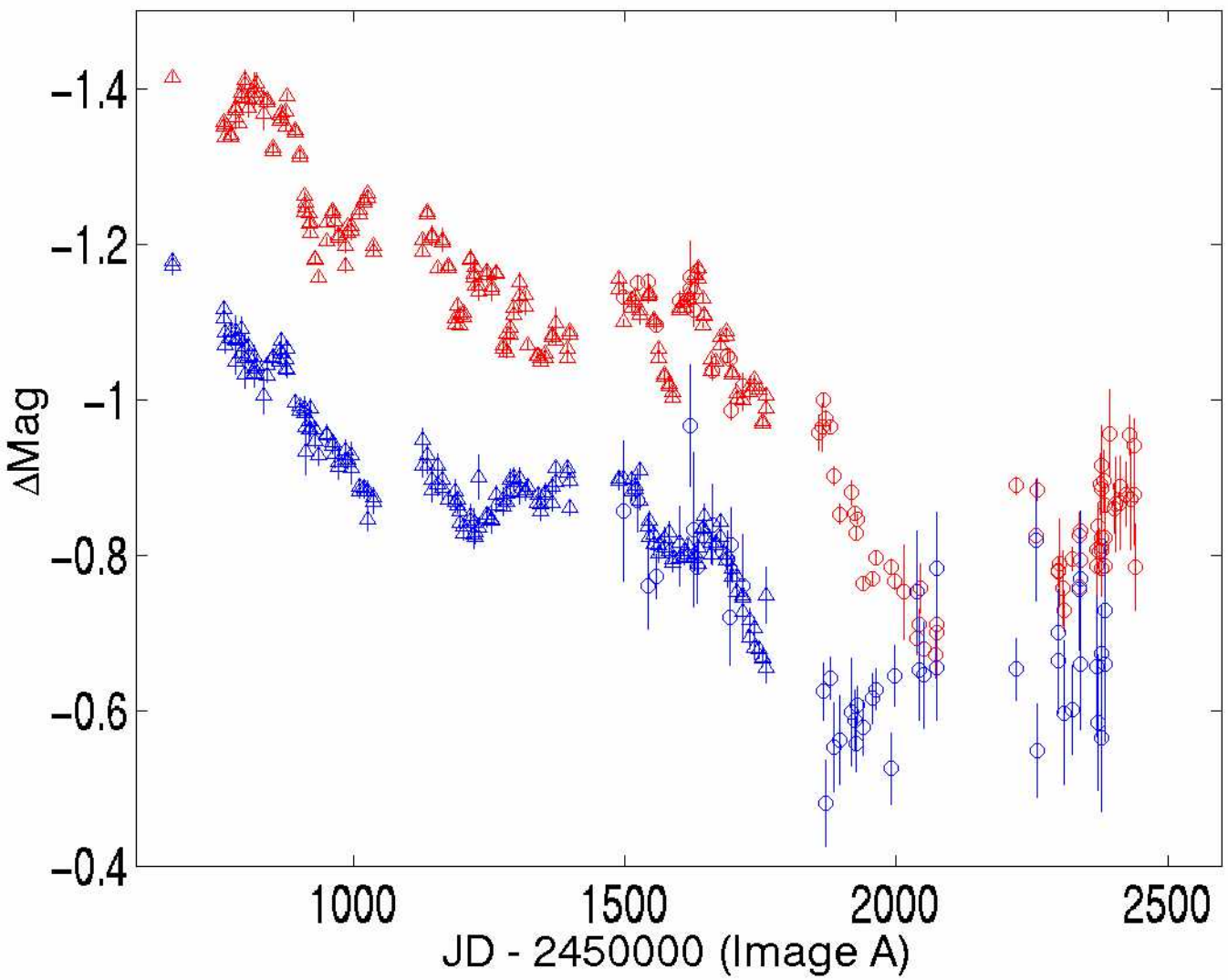


HE1104-1805 Time Delay History

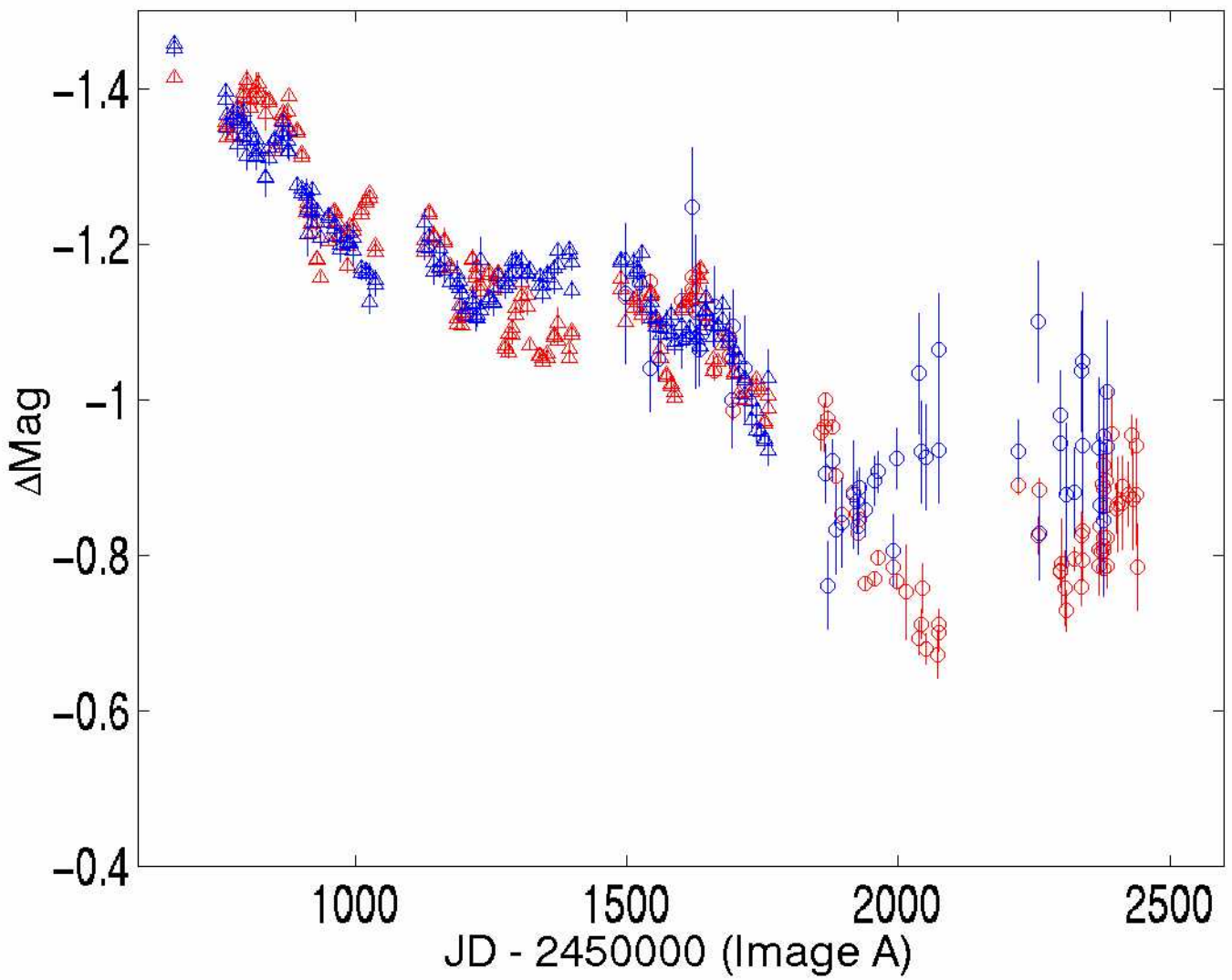
Wisotski et al. (1998)	-270 days, but -100 possible
Gil-Merino, Wisotski, & Wambsganss (2002)	-310+/- 20 days
Pelt, Refsdal, & Stabell (2002)	-255 to 330 days
Schechter et al. (2003)	no clear delay



Ofek & Maoz (2003); long-term trend in A → microlensing



Ofek & Maoz (2003)



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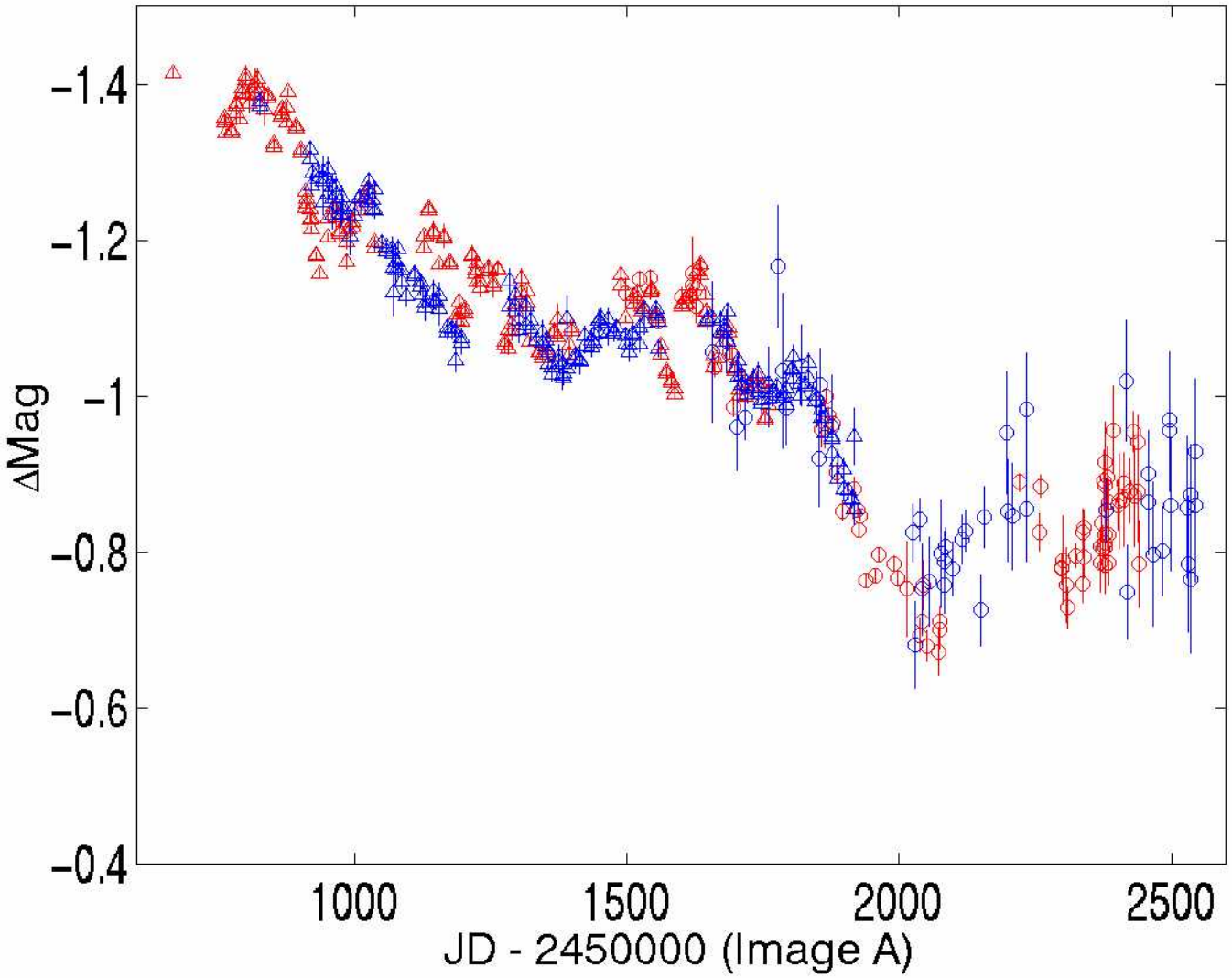


Delay = -160 +/- 7days

Ofek & Maoz (2003)

Geometric delay

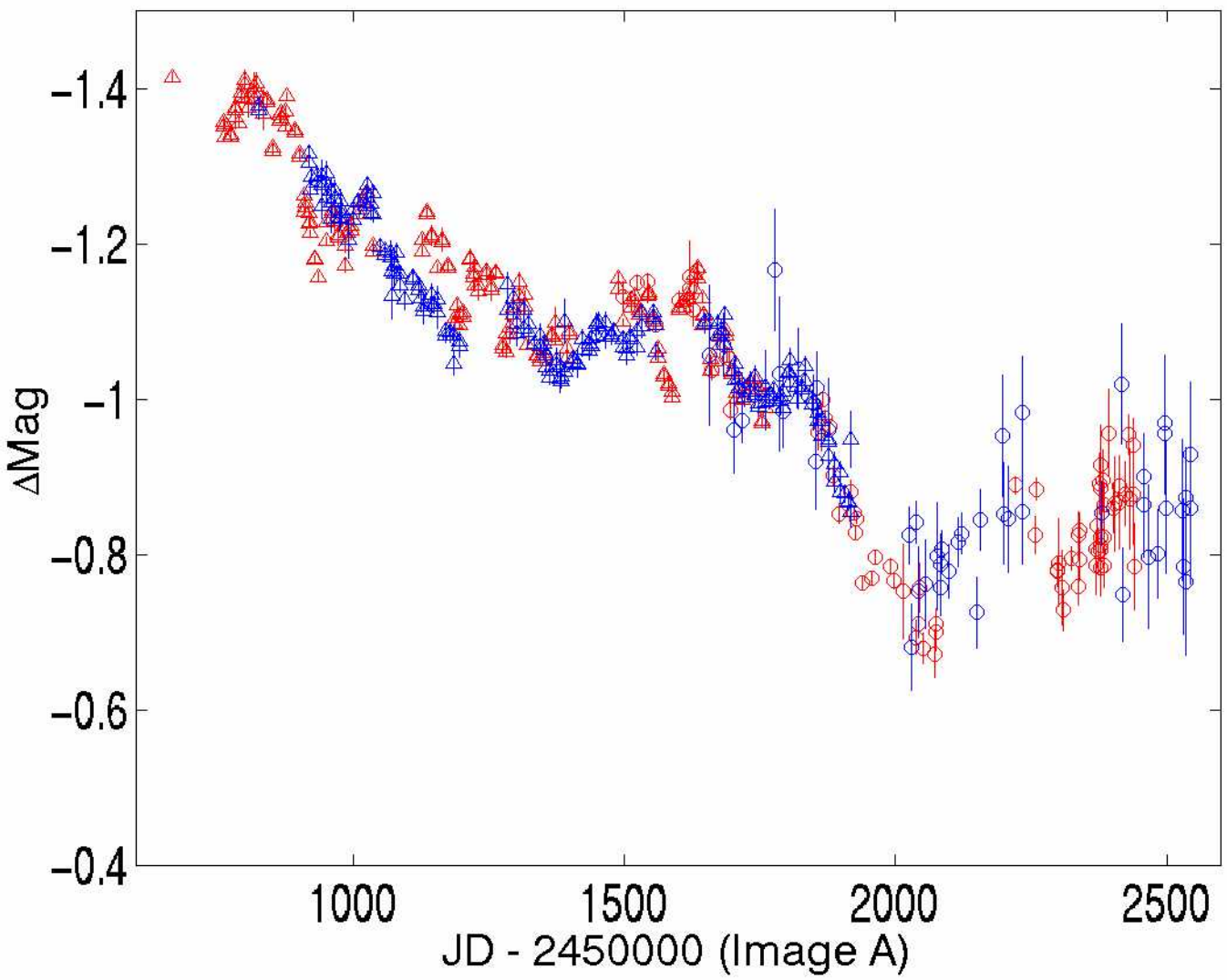
gravitational (Shapiro) delay

$$\tau(\theta) = \frac{D_d D_s}{c D_{ds}} \left[\frac{1}{2} (\theta - \beta)^2 - \Psi(\theta) \right]$$

$$\Delta t_{SIS} = \tau_B - \tau_A = \frac{1}{2} \frac{D_d D_s}{c D_{ds}} \left(\theta_A^2 - \theta_B^2 \right)$$

e.g., Kochanek 2002:

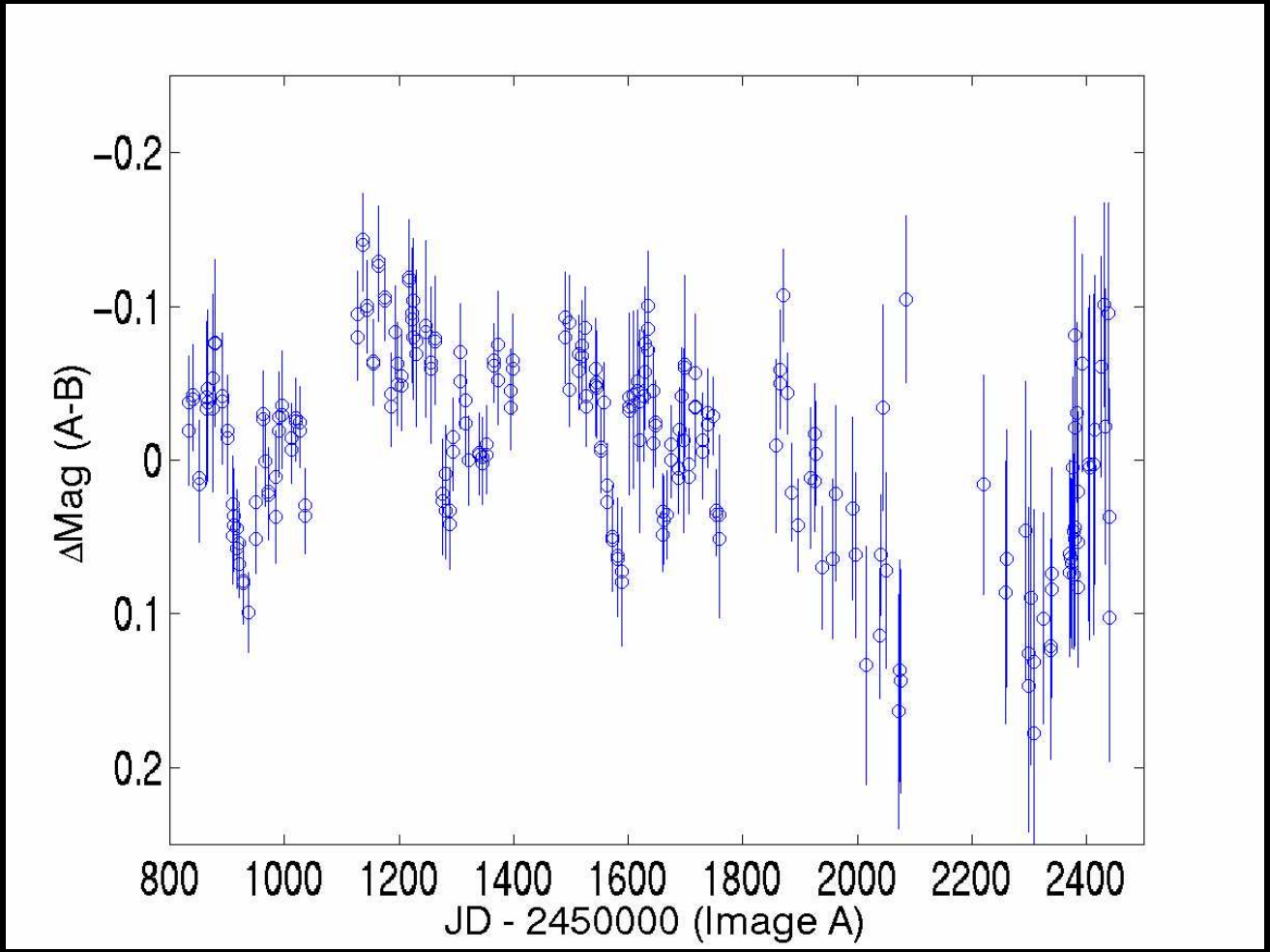
$$\Delta t(n) = (n-1) \Delta t_{SIS} \left[1 - \frac{(2-n)^2}{12} \left(\frac{\delta\theta}{\langle\theta\rangle} \right)^2 + \cdots \right]$$



Delay = -160 +/- 7days

Ofek & Maoz (2003) → H_0=90? (Lehar et al. 2000)

Residuals in A – (delayed B):



1-month timescale, 0.07 mag amplitude

Microlensing by Jupiters? (Wythe & Loeb 2002)

Microlensing of relativistic motion in accretion disk? (Miralda-Escude & Gould□□□□)

Challenges and Problems:

1. Blending of images, lens galaxi(es)
2. Low amplitude variations
3. Sampling, gaps, intercalibration of diff. data sets
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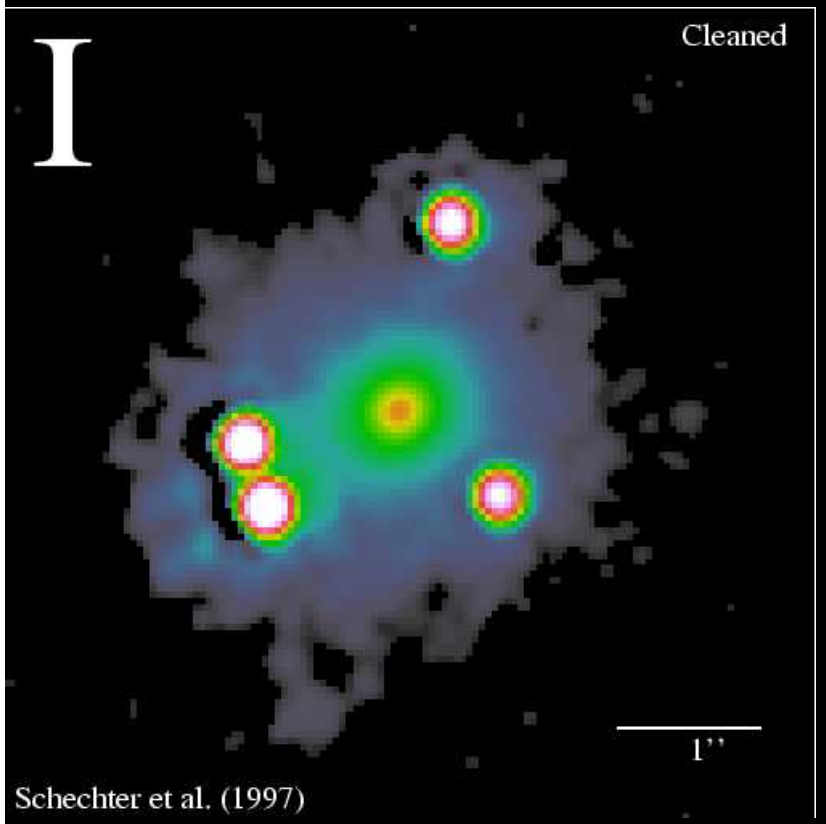
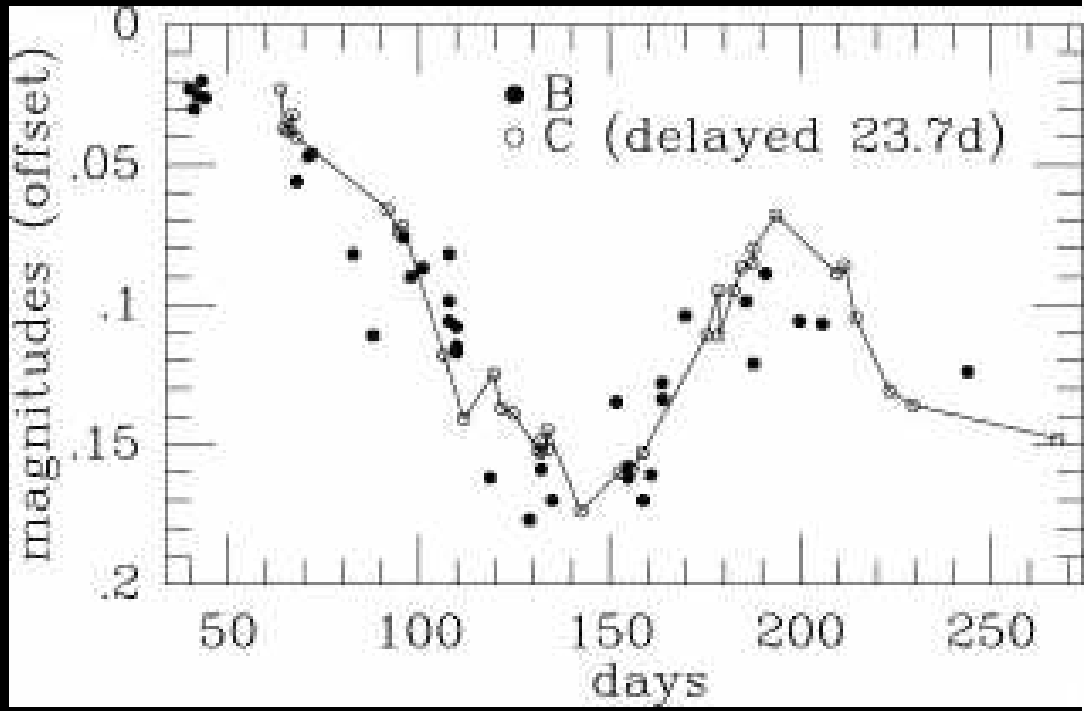
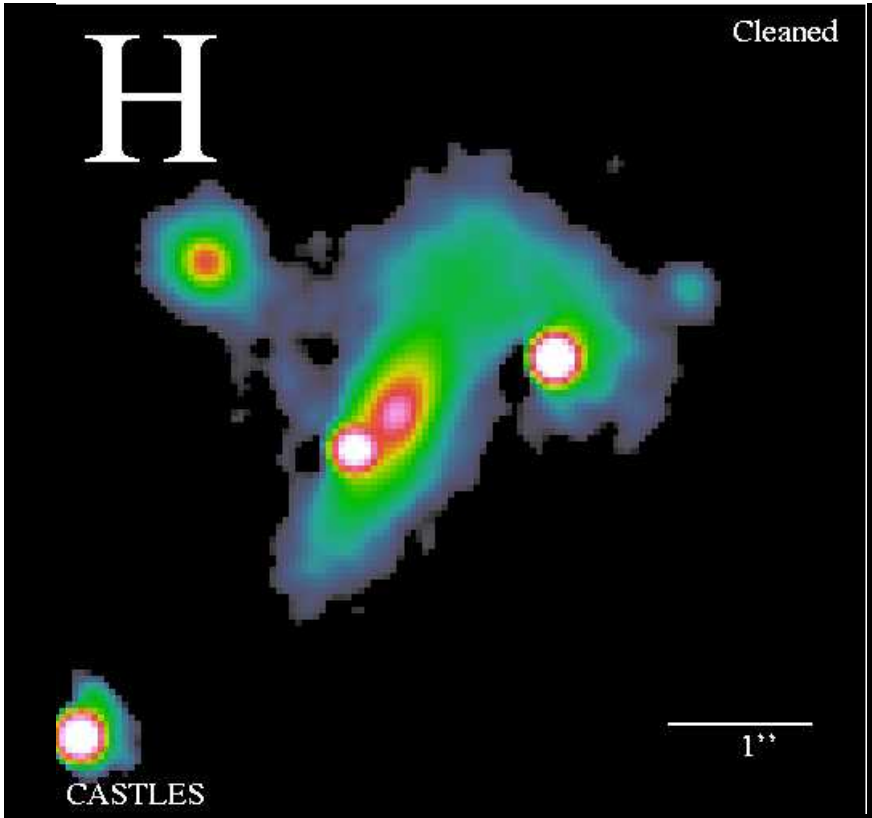
PG 1115+080 Schechter et al. 1997

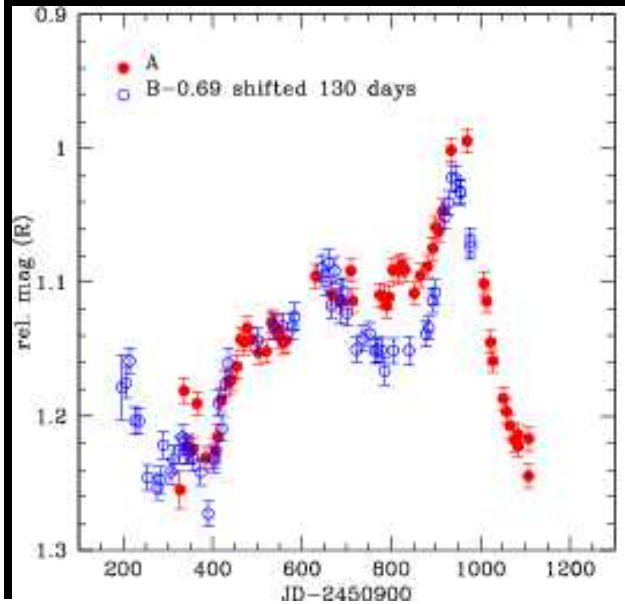


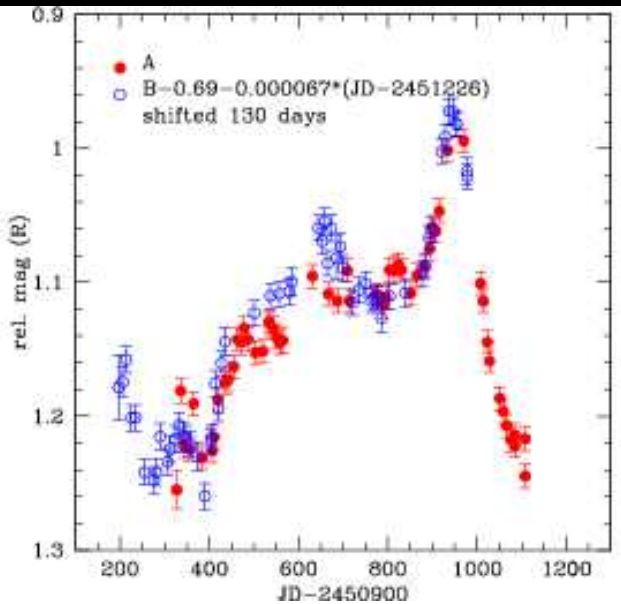


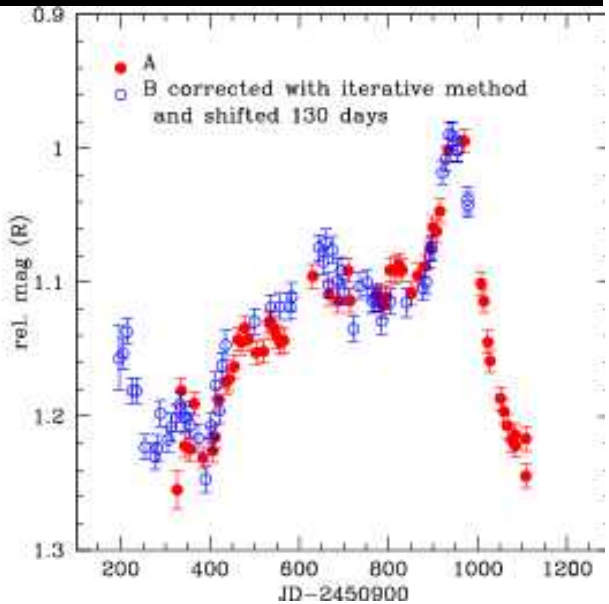


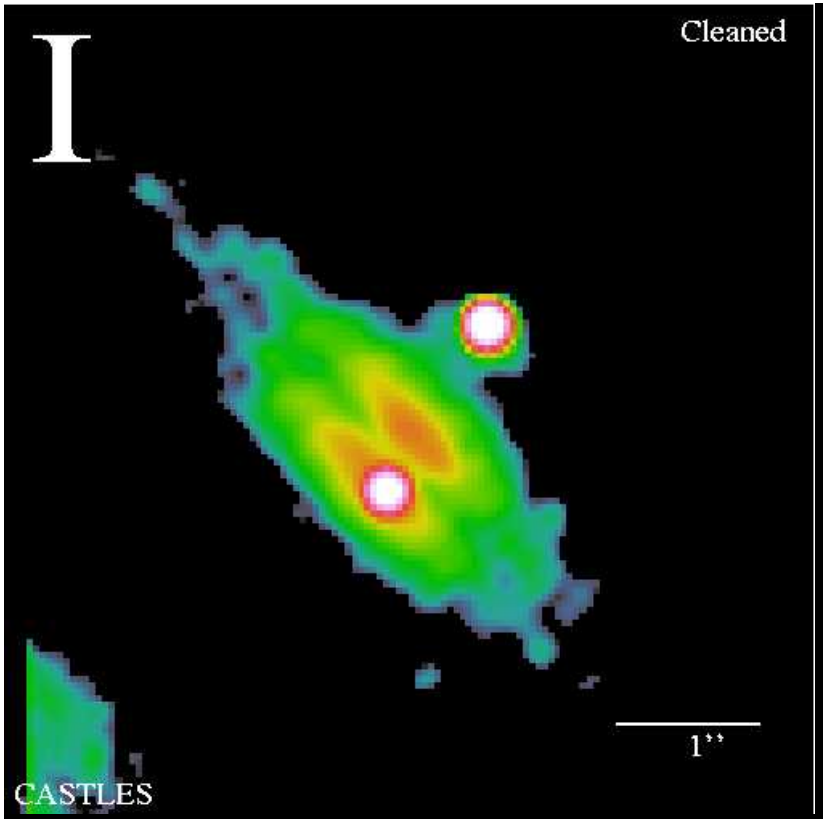
SBS 1520+530

Burud et al. 2002



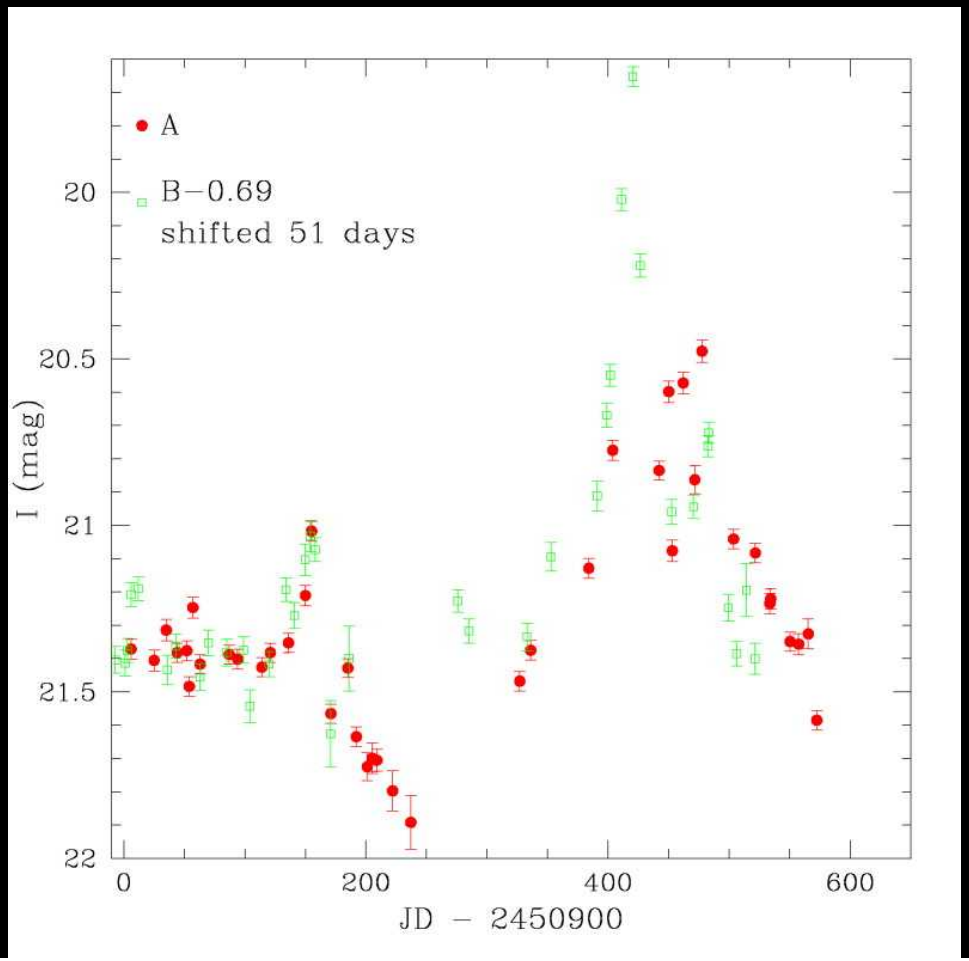


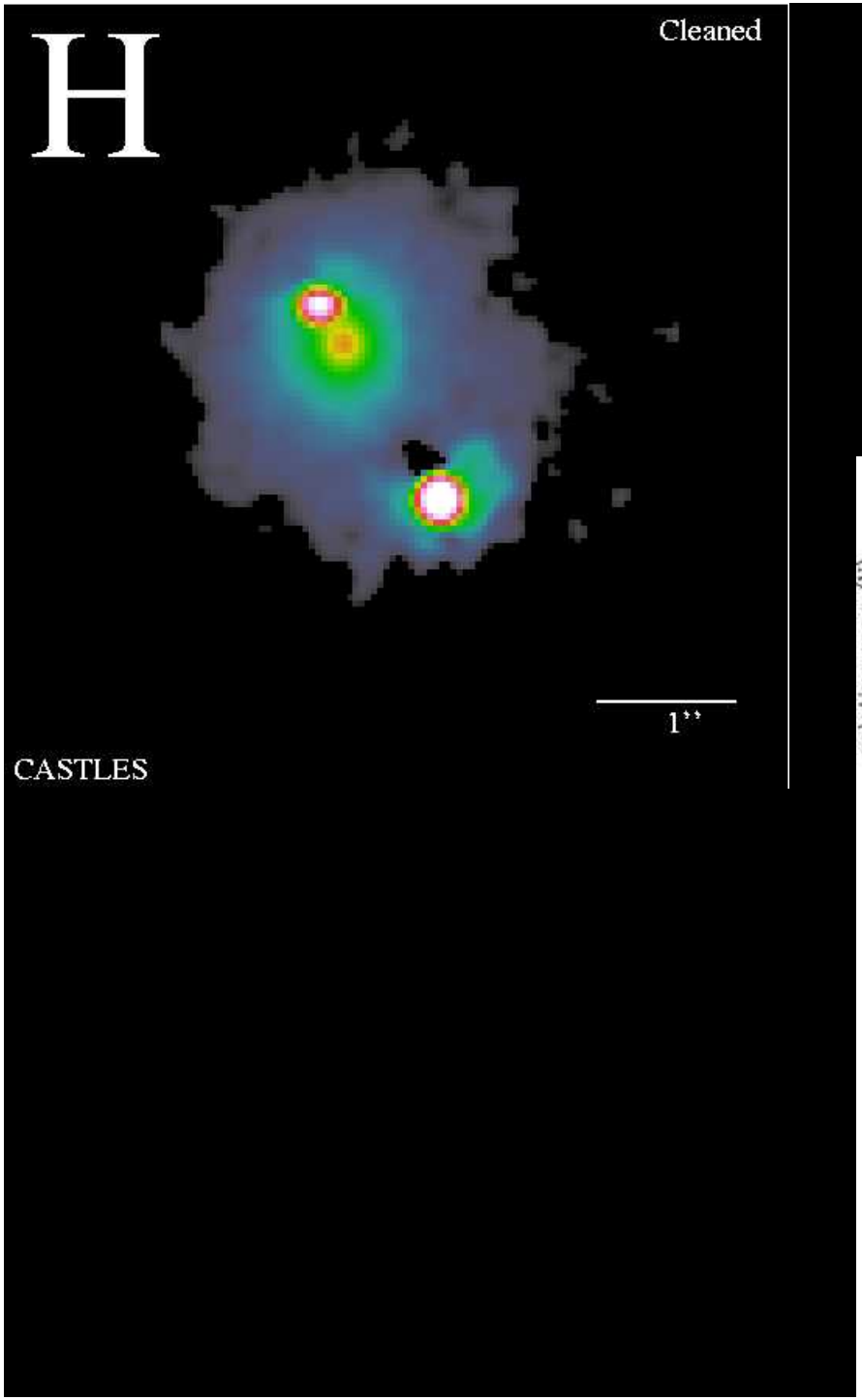




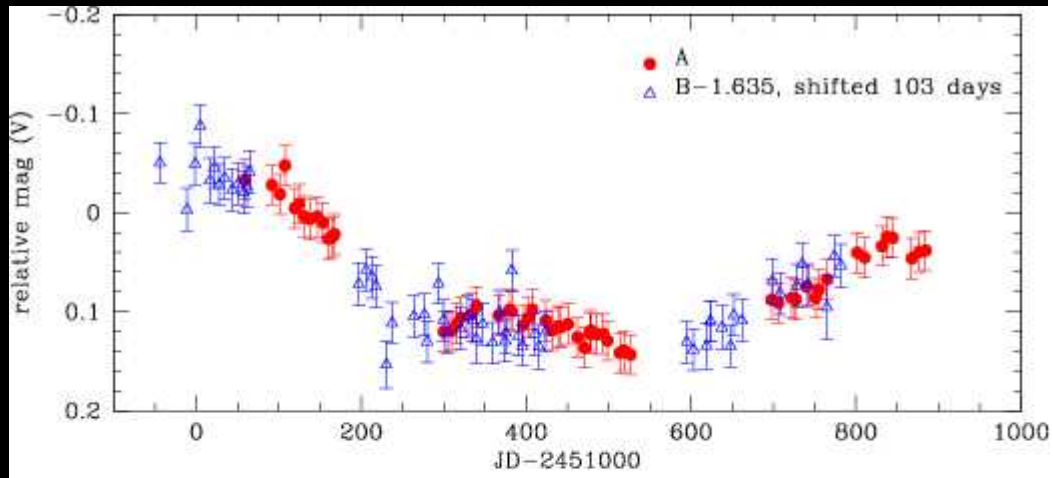
B1600+434 Burud et al. 2002

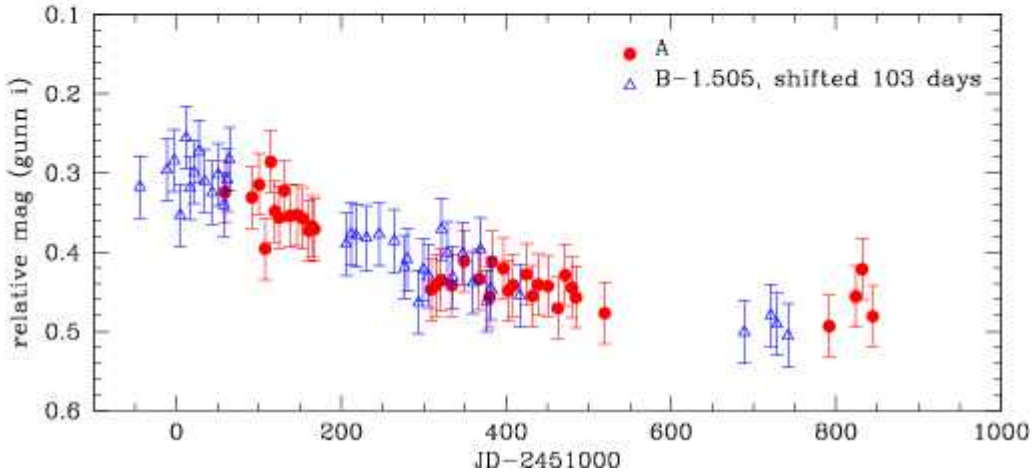
(Also Koopmans et al. 2000)

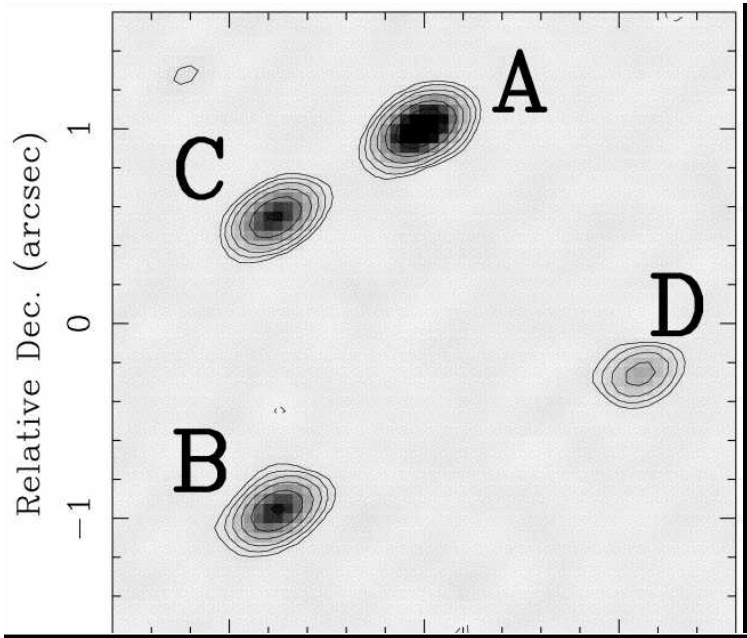




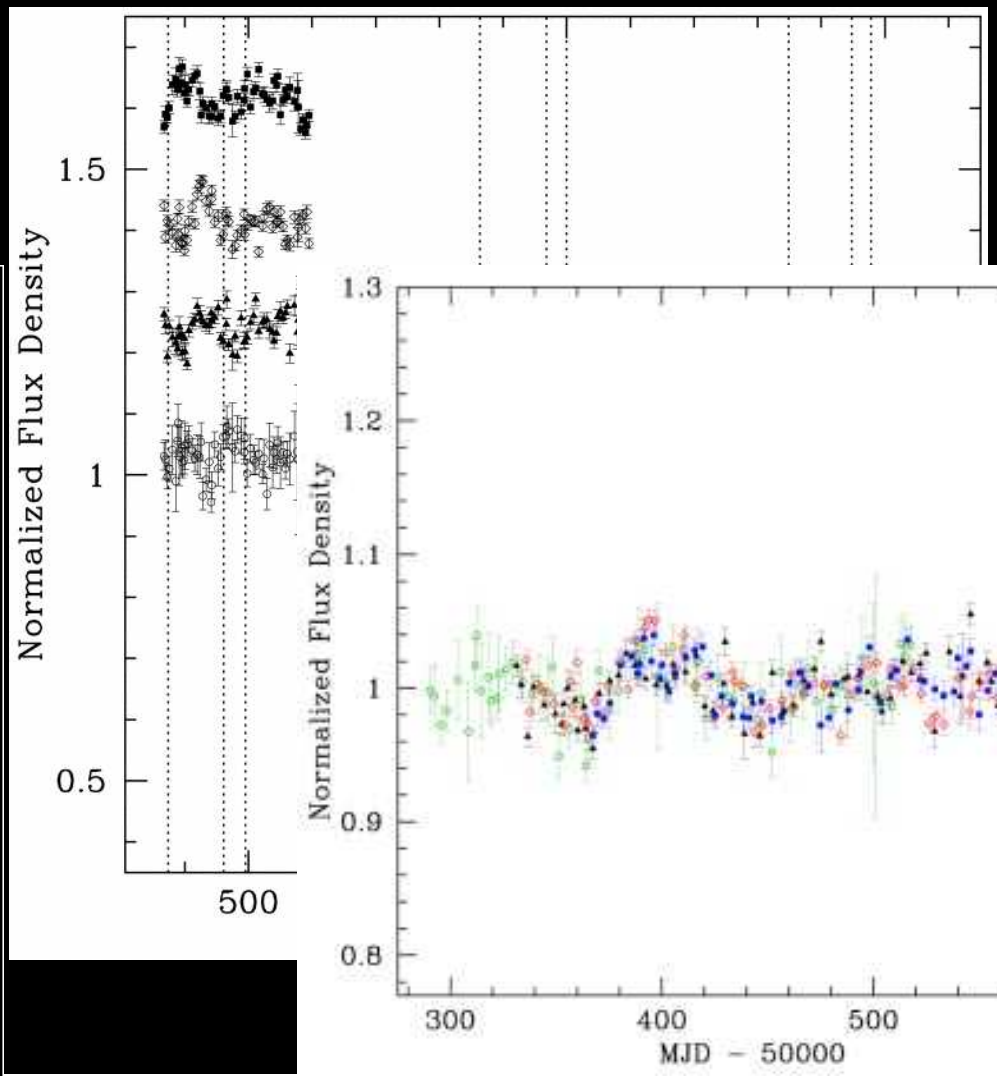
HE 2149-4735 Burud et al. 2000

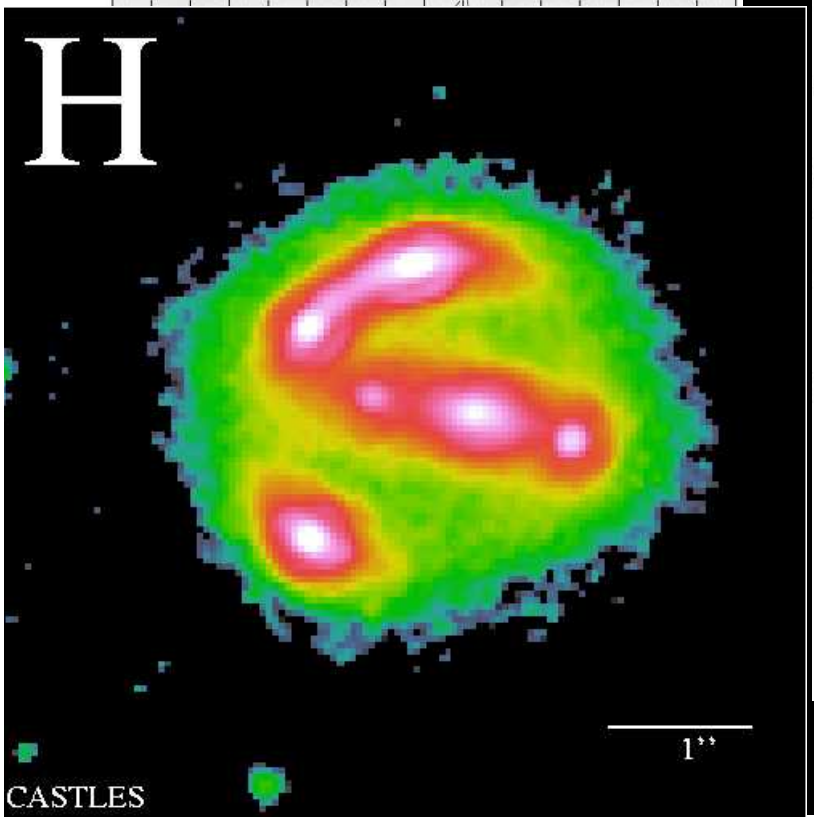


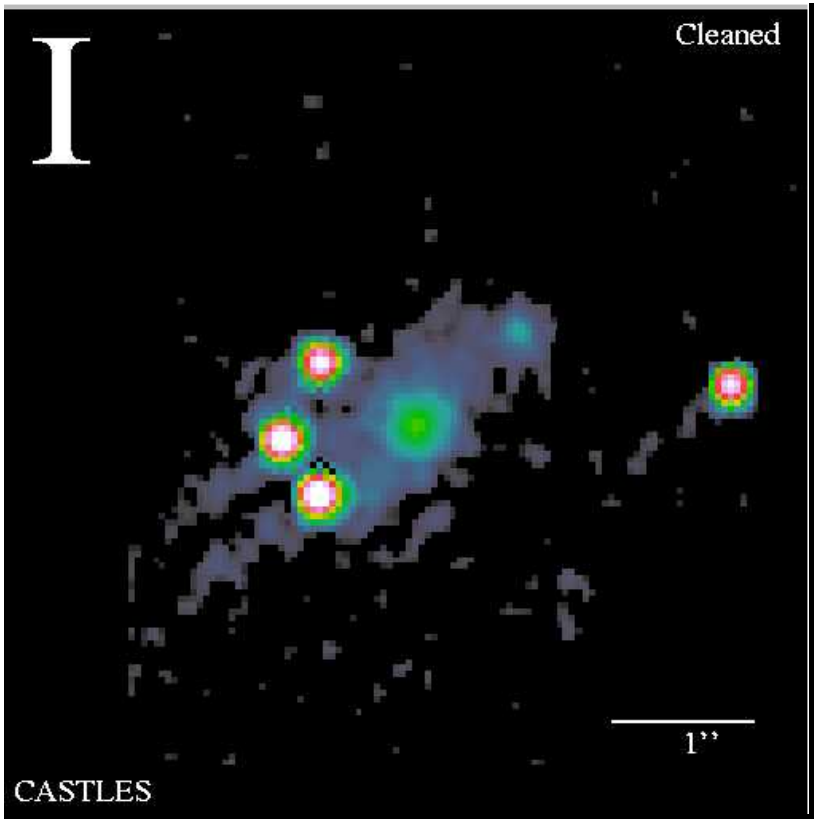




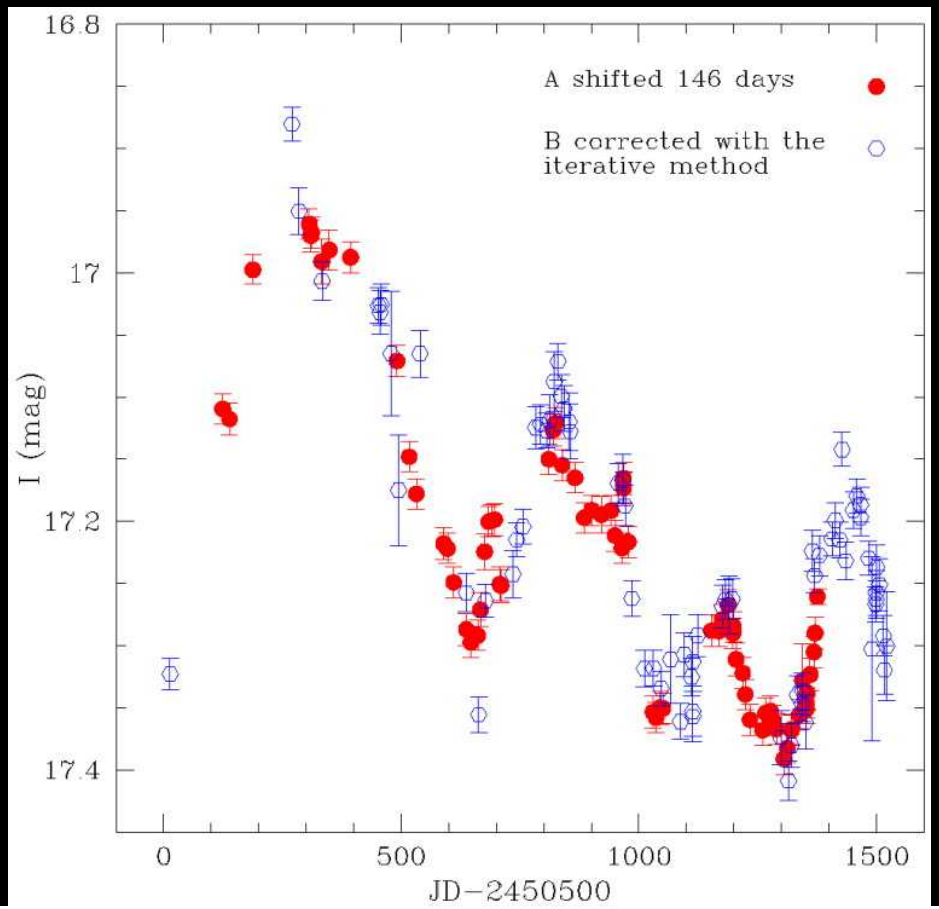
B1608+656 Fassnacht et al. 2002

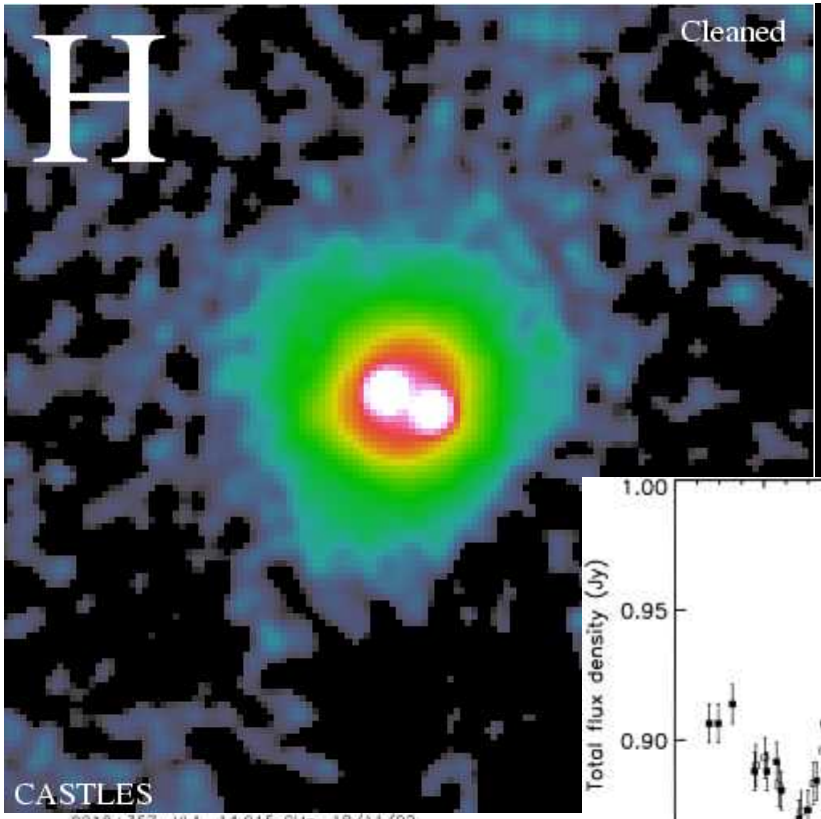






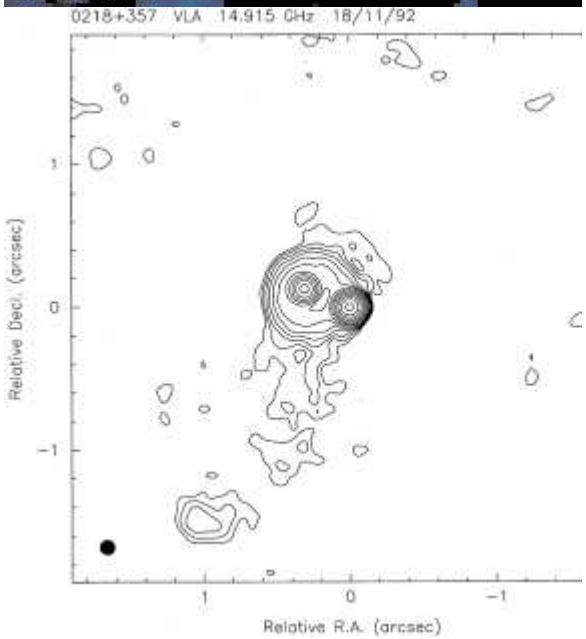
J0911.5+0551 Hjorth et al. 2002

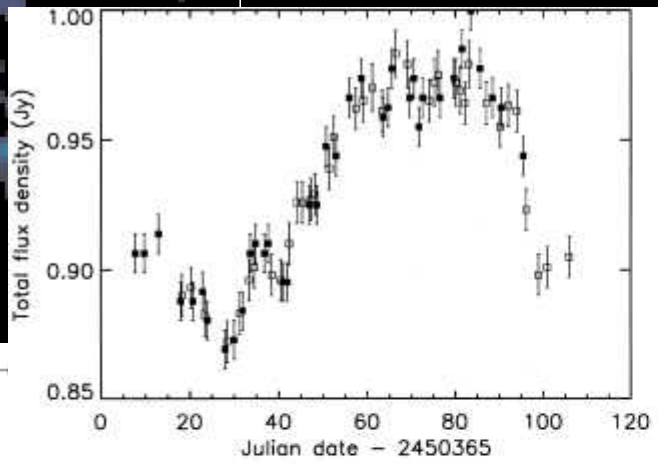


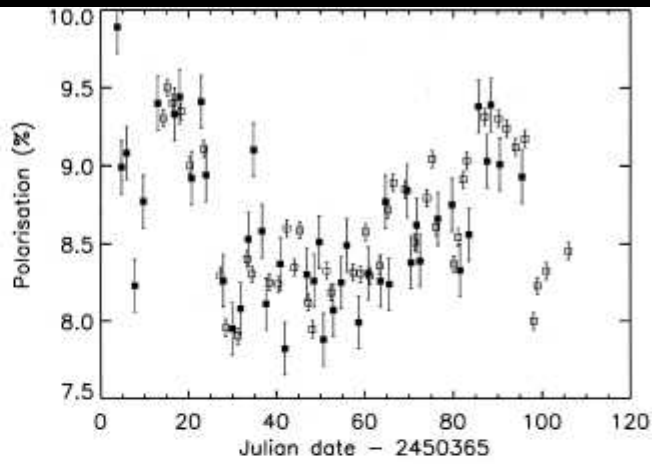


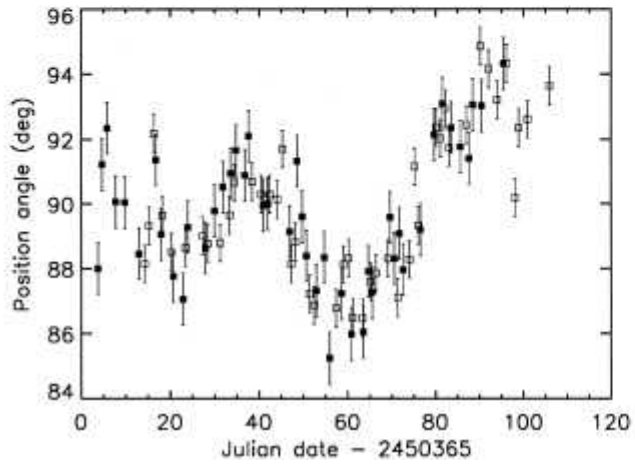
B0218+357 Biggs et al. 1999

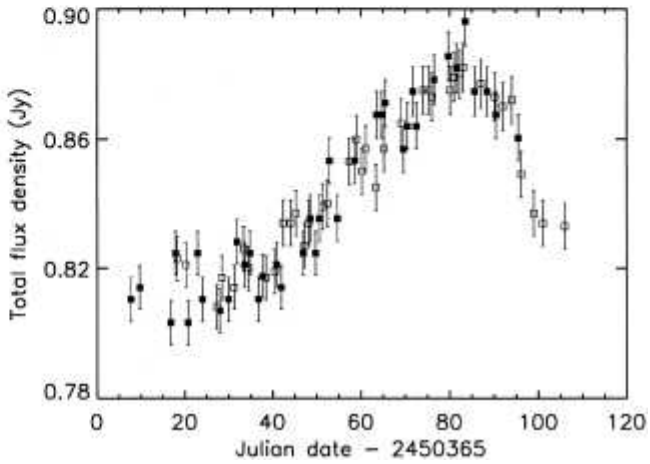
(also Cohen et al. 2000)

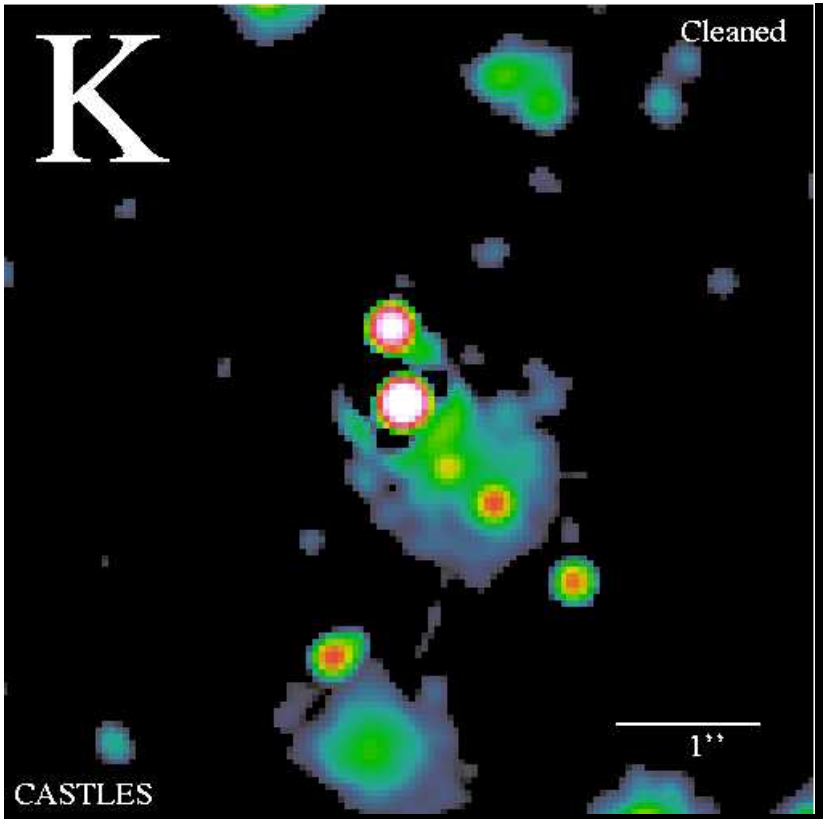




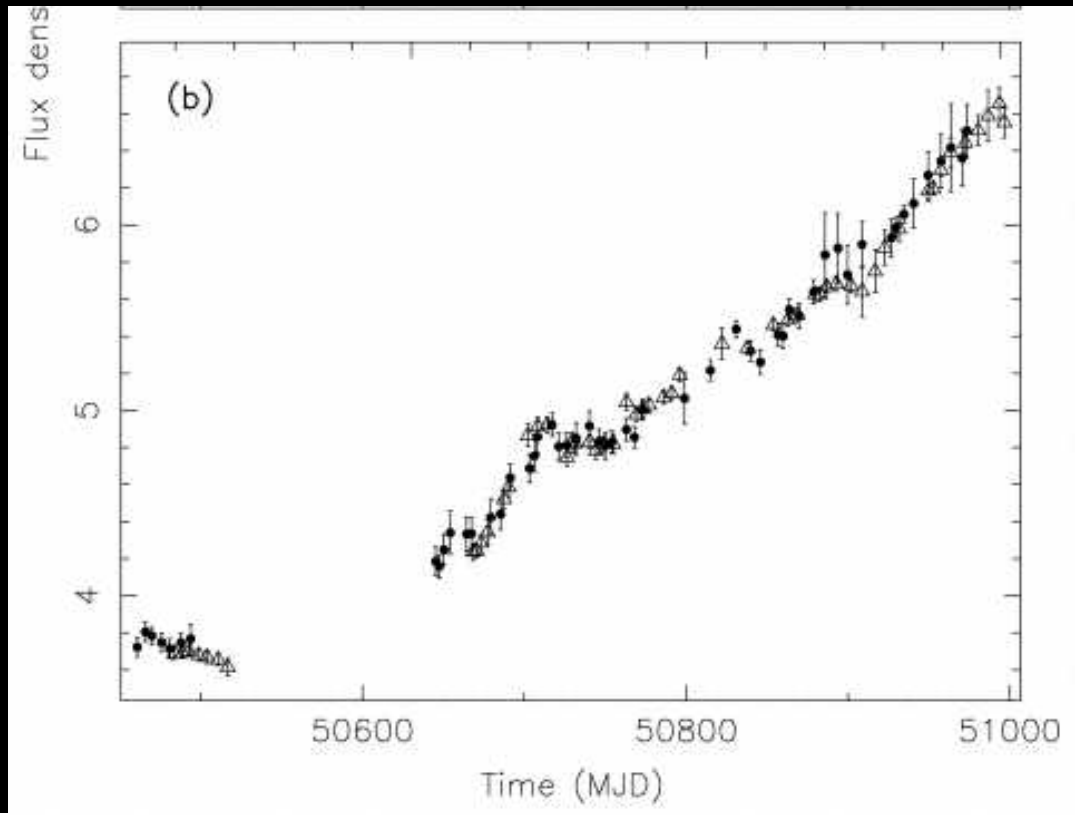


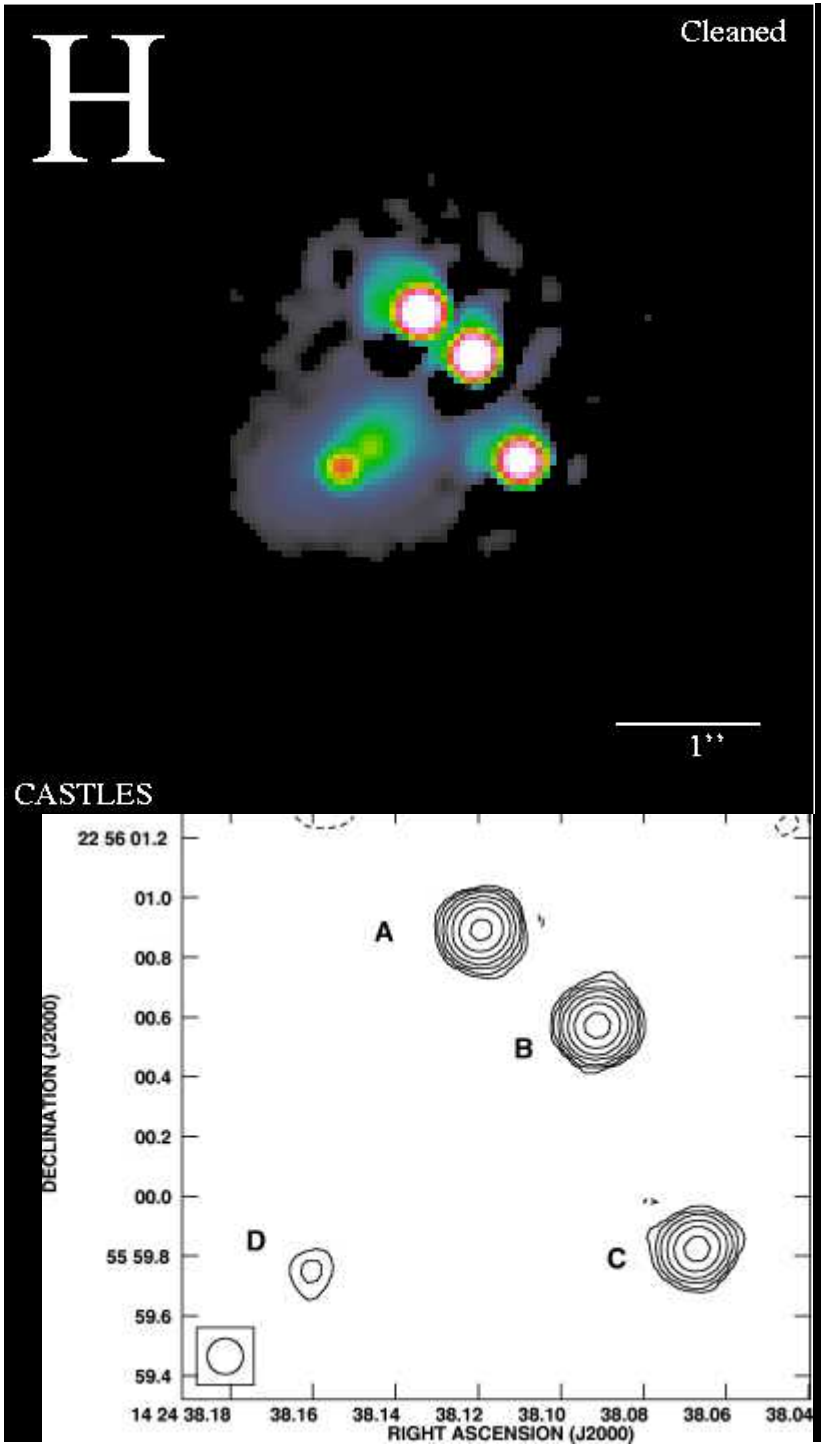




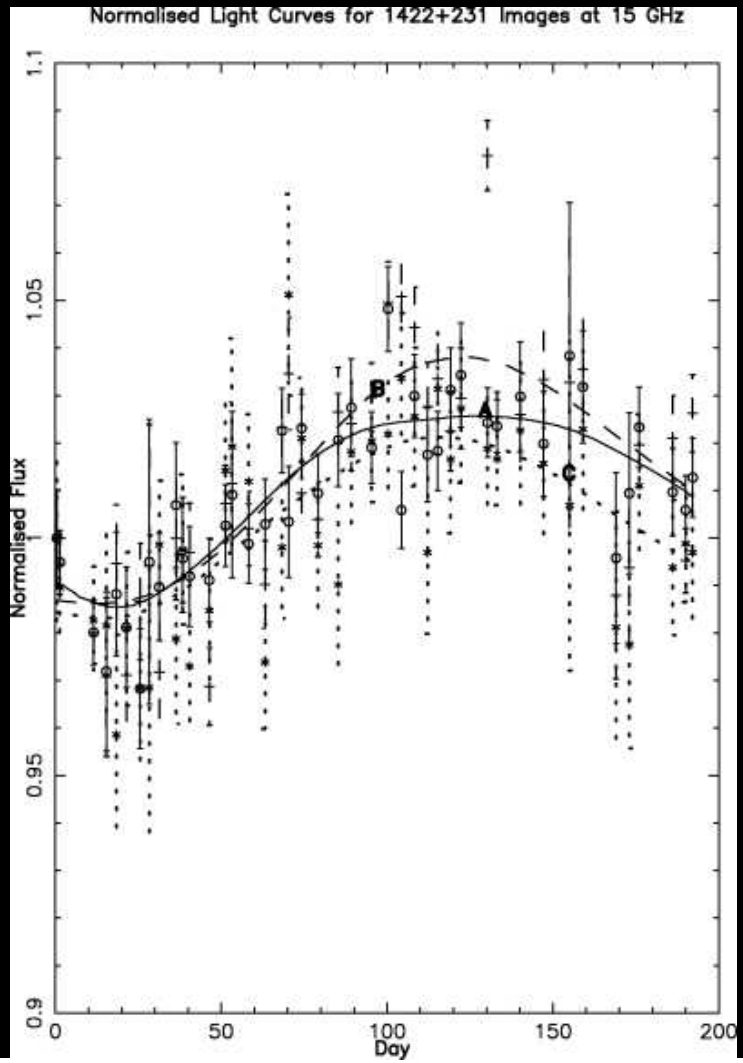


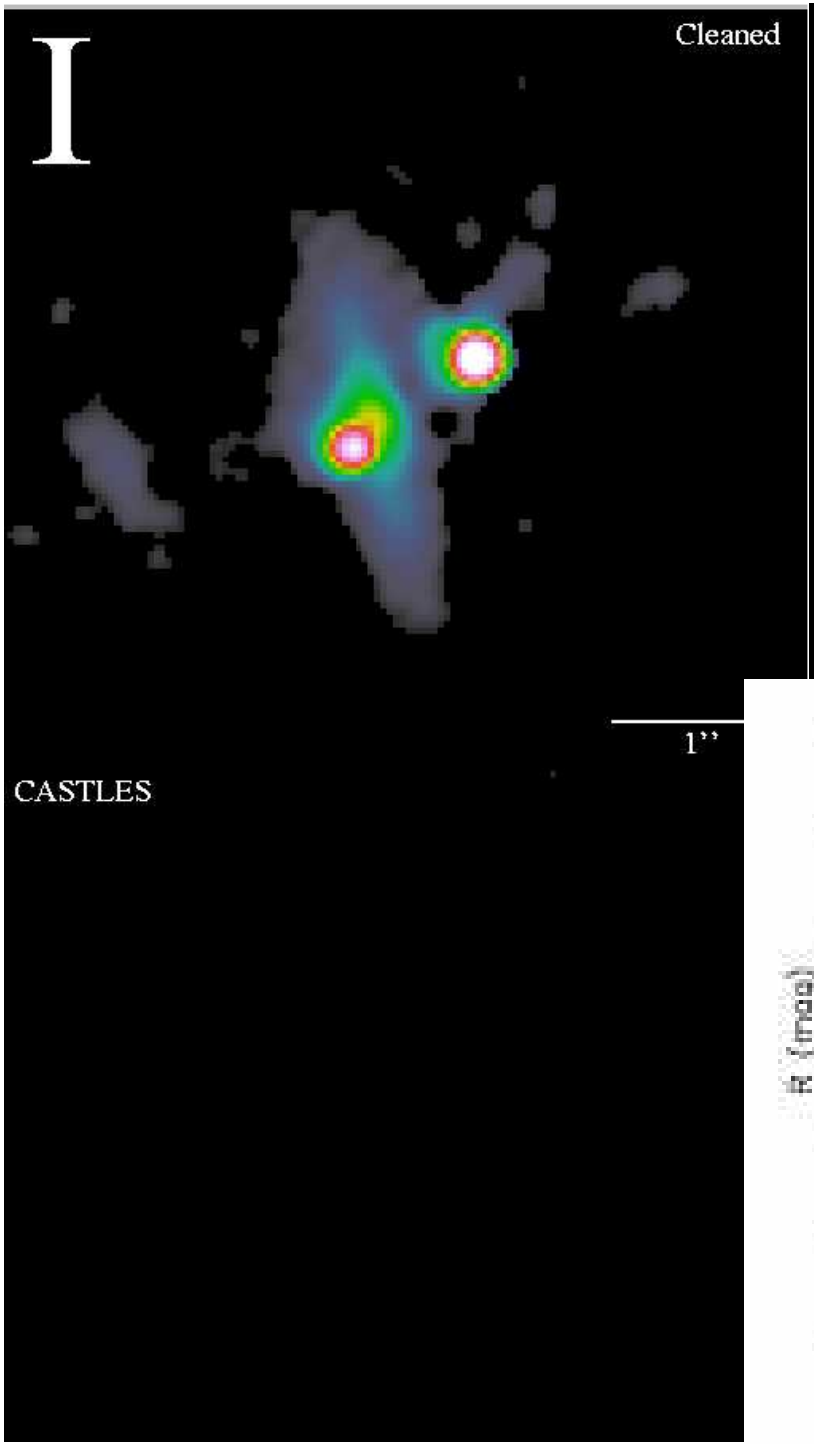
PKS1830-211 Lovell et al. 1998



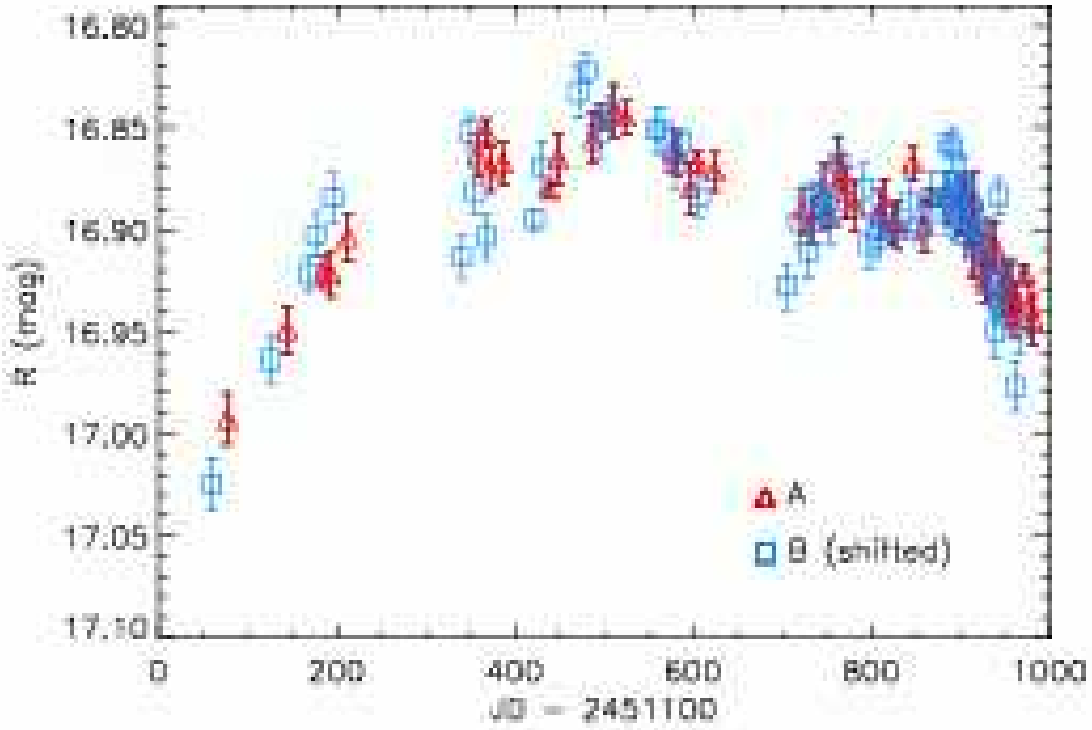


B1422+231 Patnaik & Narasimha 2001





0951+2635 Jakobsson et al. 2004



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5. Method for determining delay, errors
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Lensed-quasar time-delays:

Lots of progress in past few years;

Massive Ongoing Programs:

VLA, Wise, NOT, MDM, Maidanak, Calar Alto

Increasing fraction of systems will have delay measurements.

but

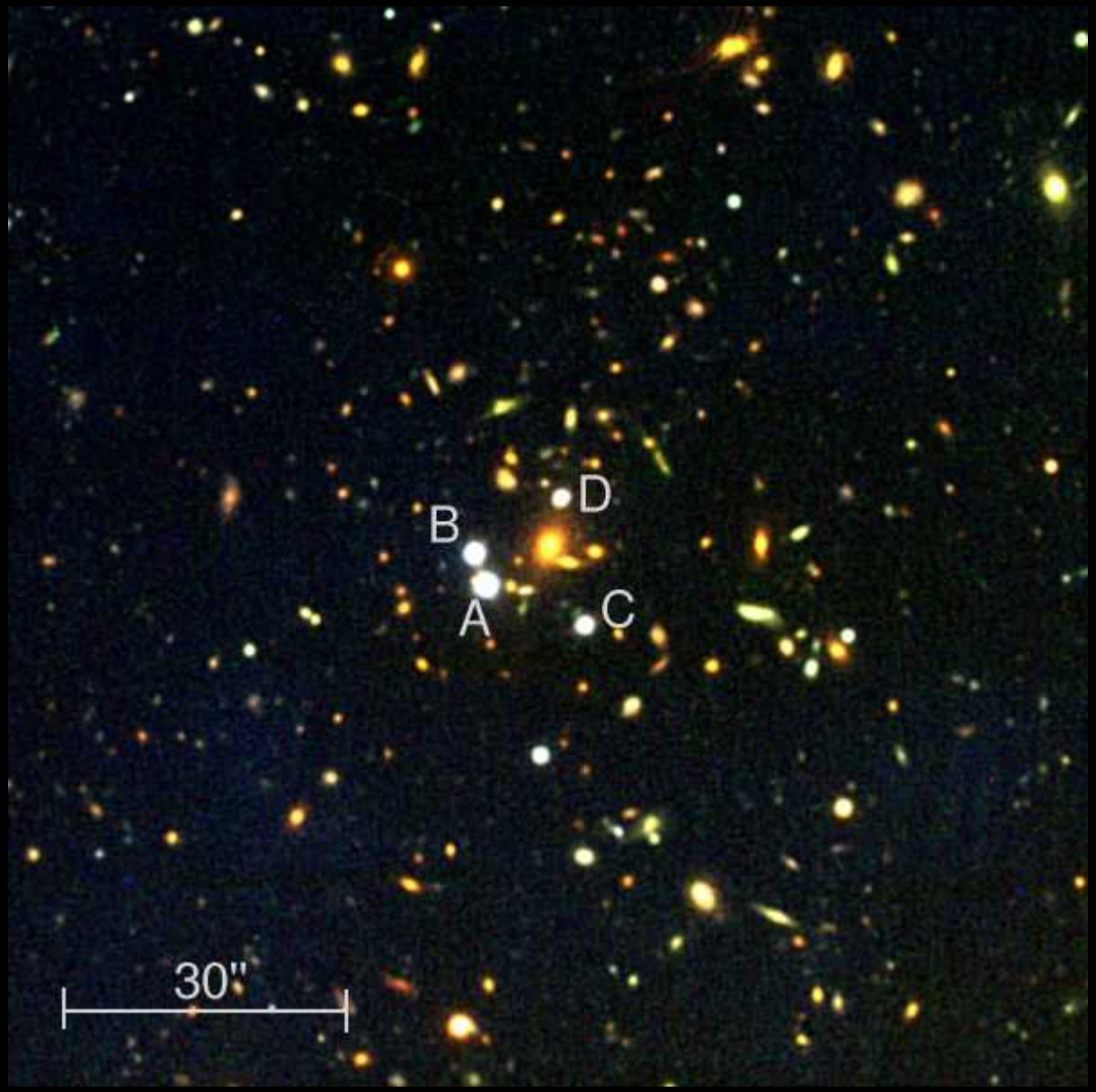
How can some of the fundamental problems be overcome?

Large-separation, cluster-lensed, quasars

Statistics valuable for probing large-scale structure formation history

Oguri et al. 2004 SDSS 1004+4112

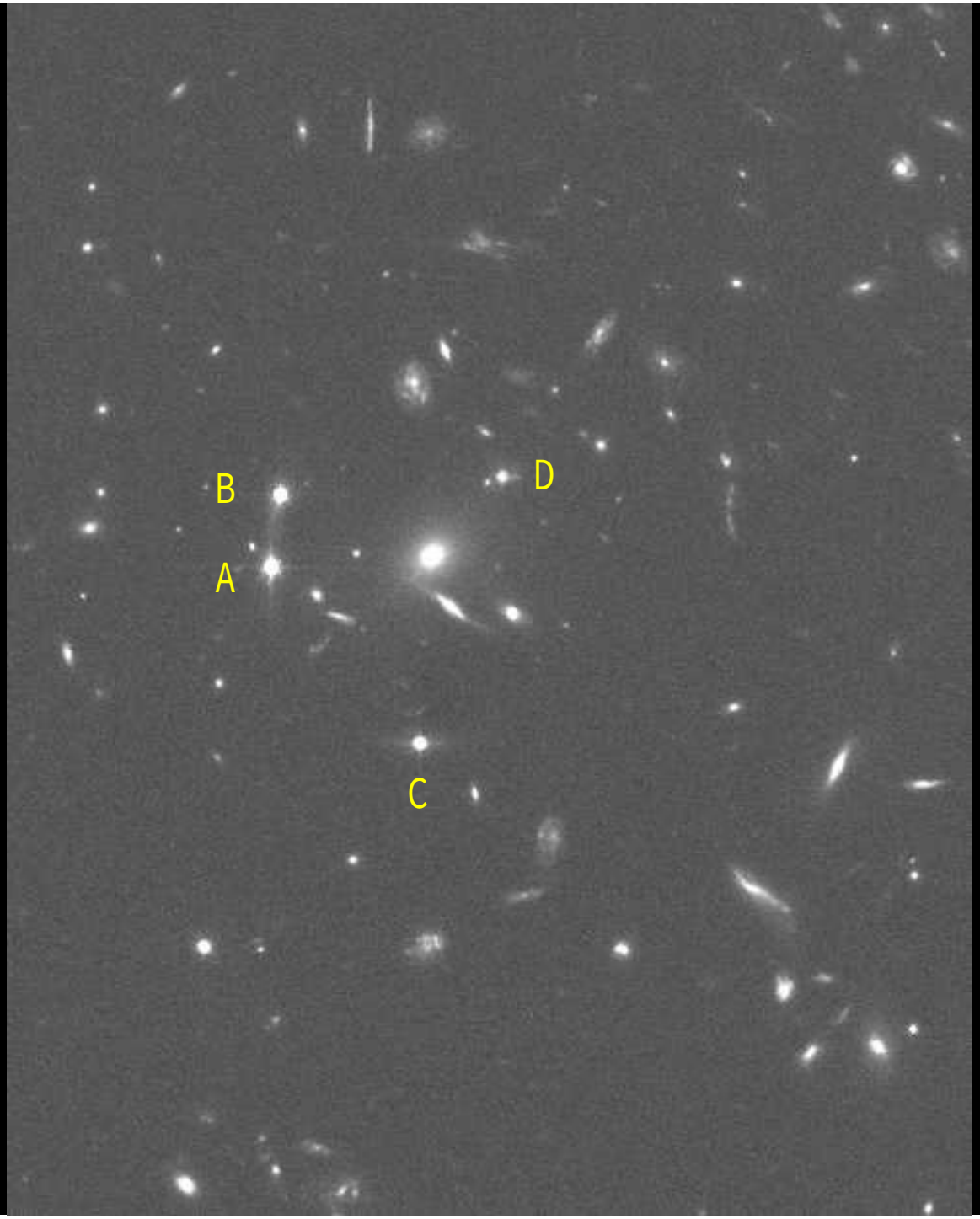
the first (truly) large-separation lensed quasar



SDSS 1004+4112

HST/ACS F814W

Kochanek et al., in prep.



Large-separation, cluster-lensed, quasars

Statistics valuable for probing large-scale structure formation history

but

Also good for time delays/Ho:

No microlensing

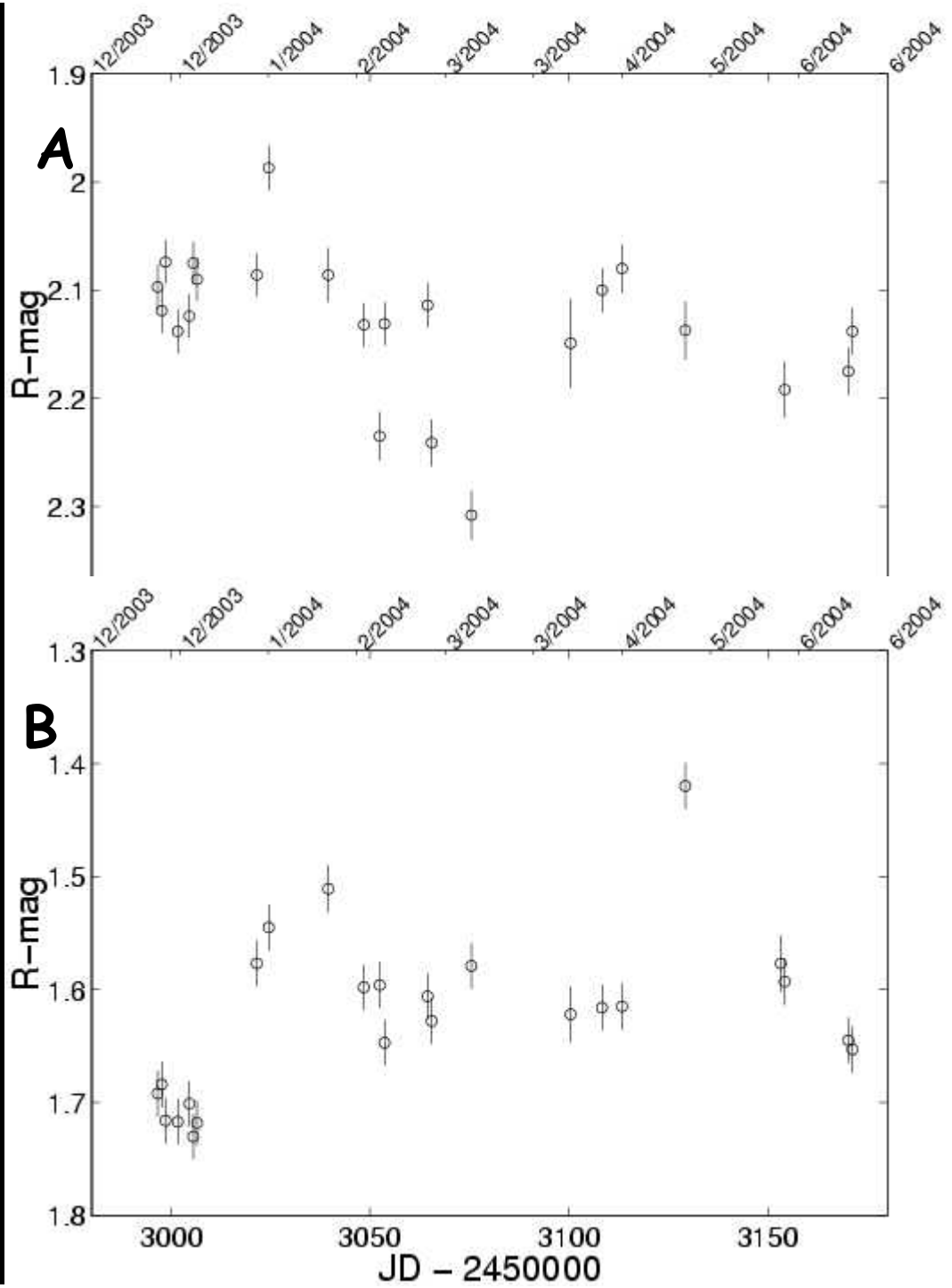
No dust (flux ratios reliable)

Multiple sources, lots of constraints

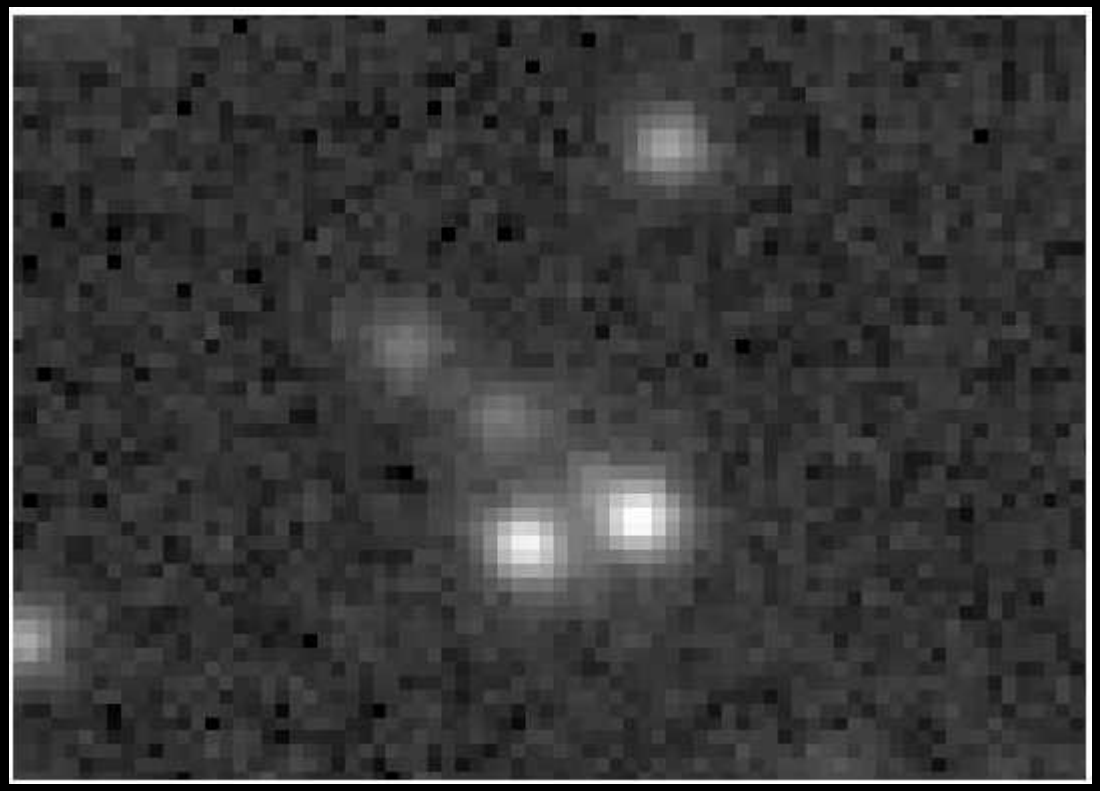
SDSS 1004+4112

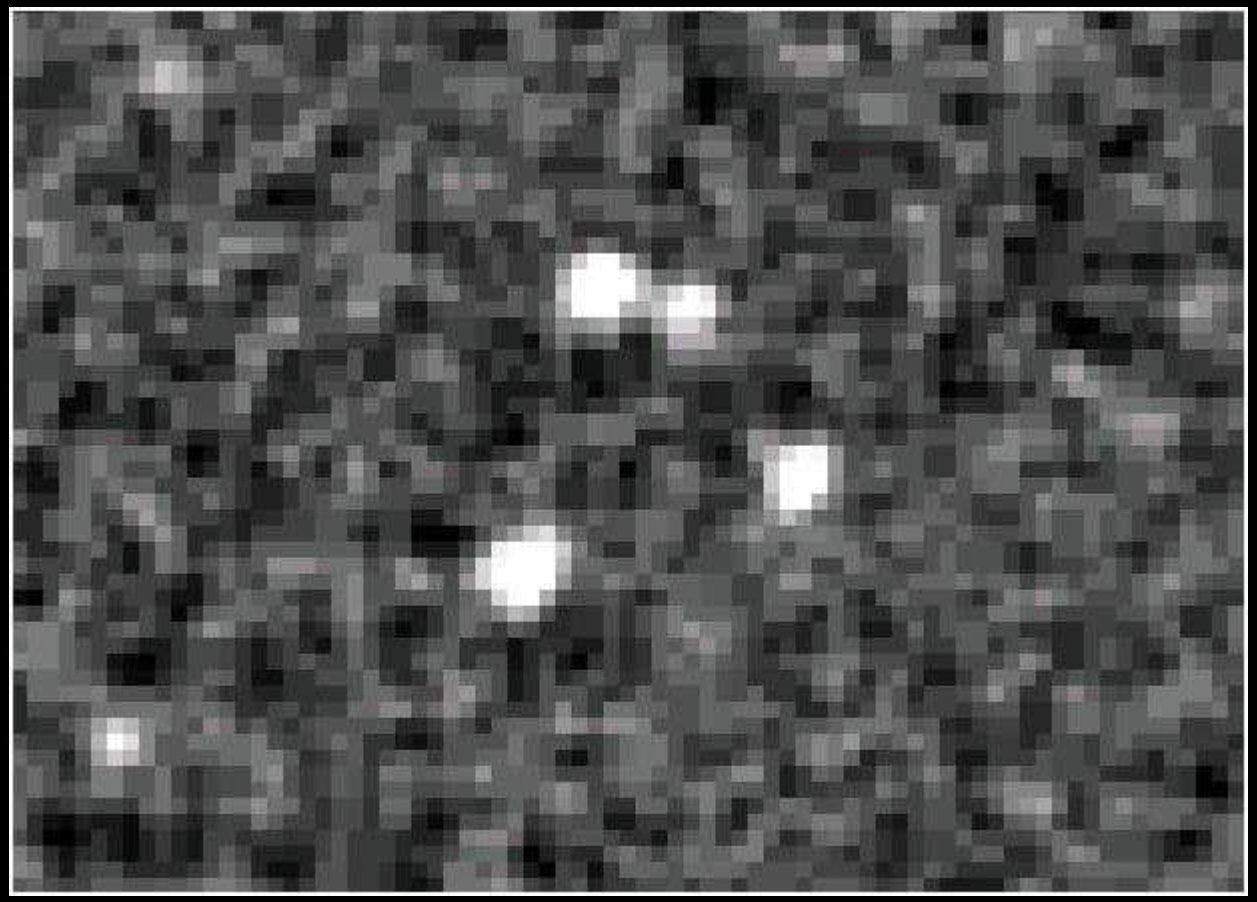
Wise Obs. monitoring program

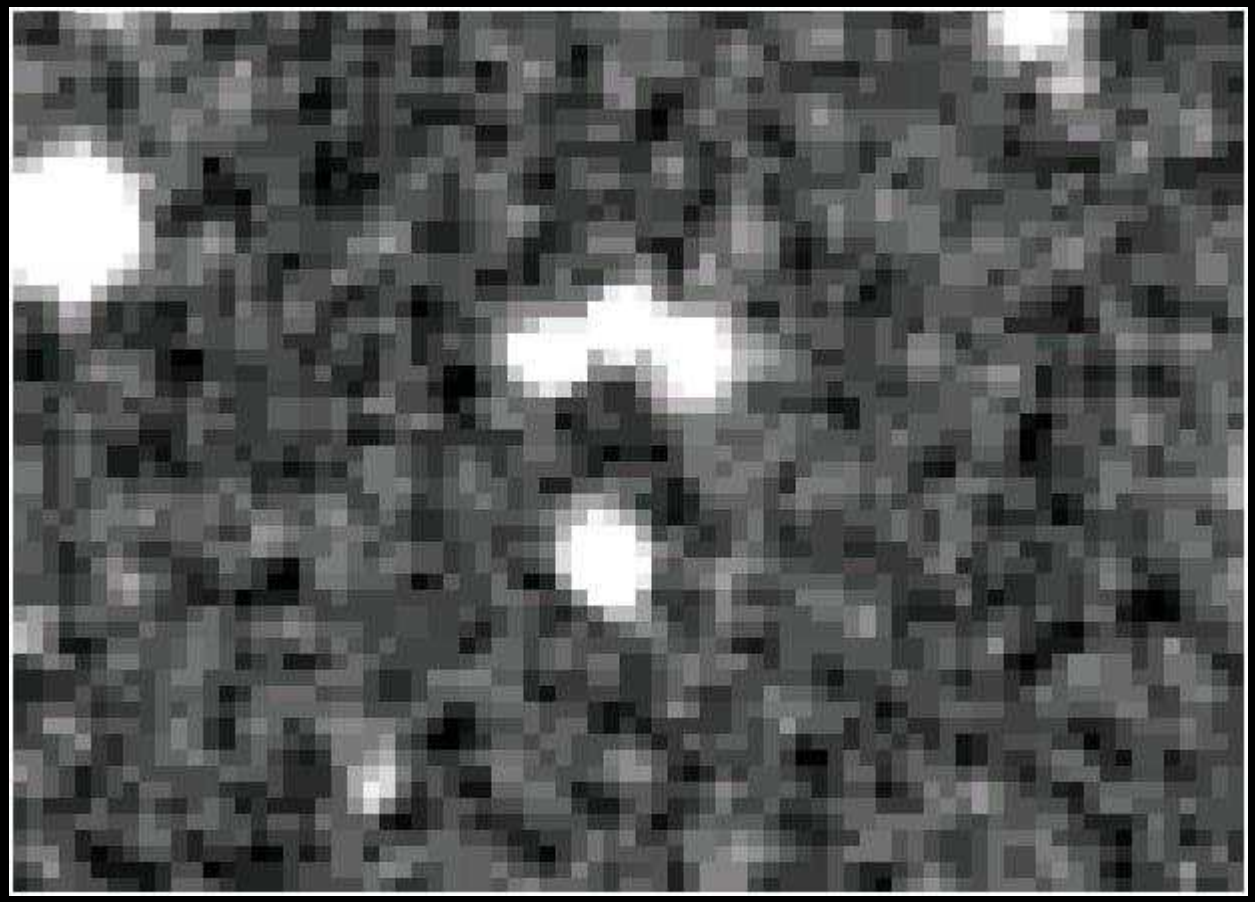
Delay (A-B) > 2 weeks

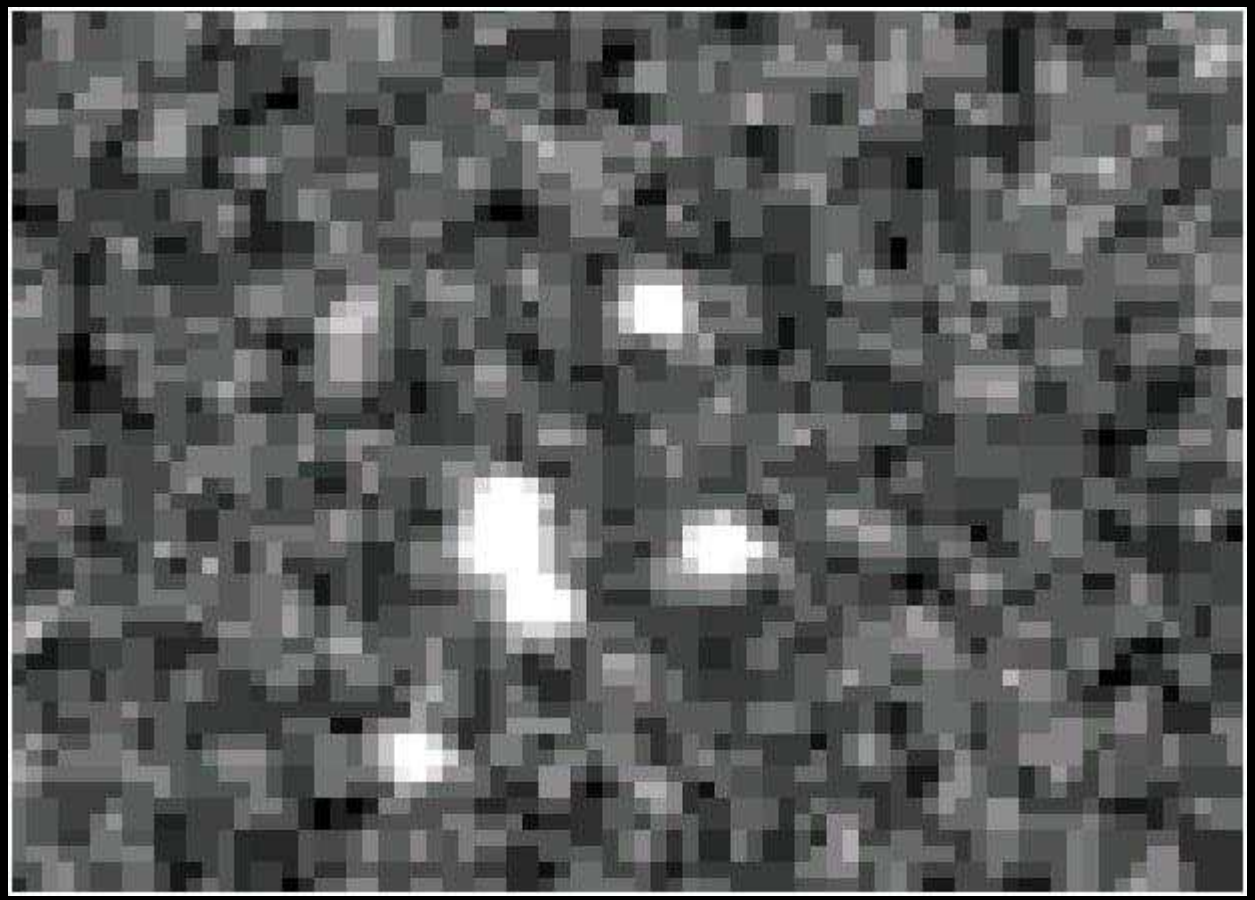


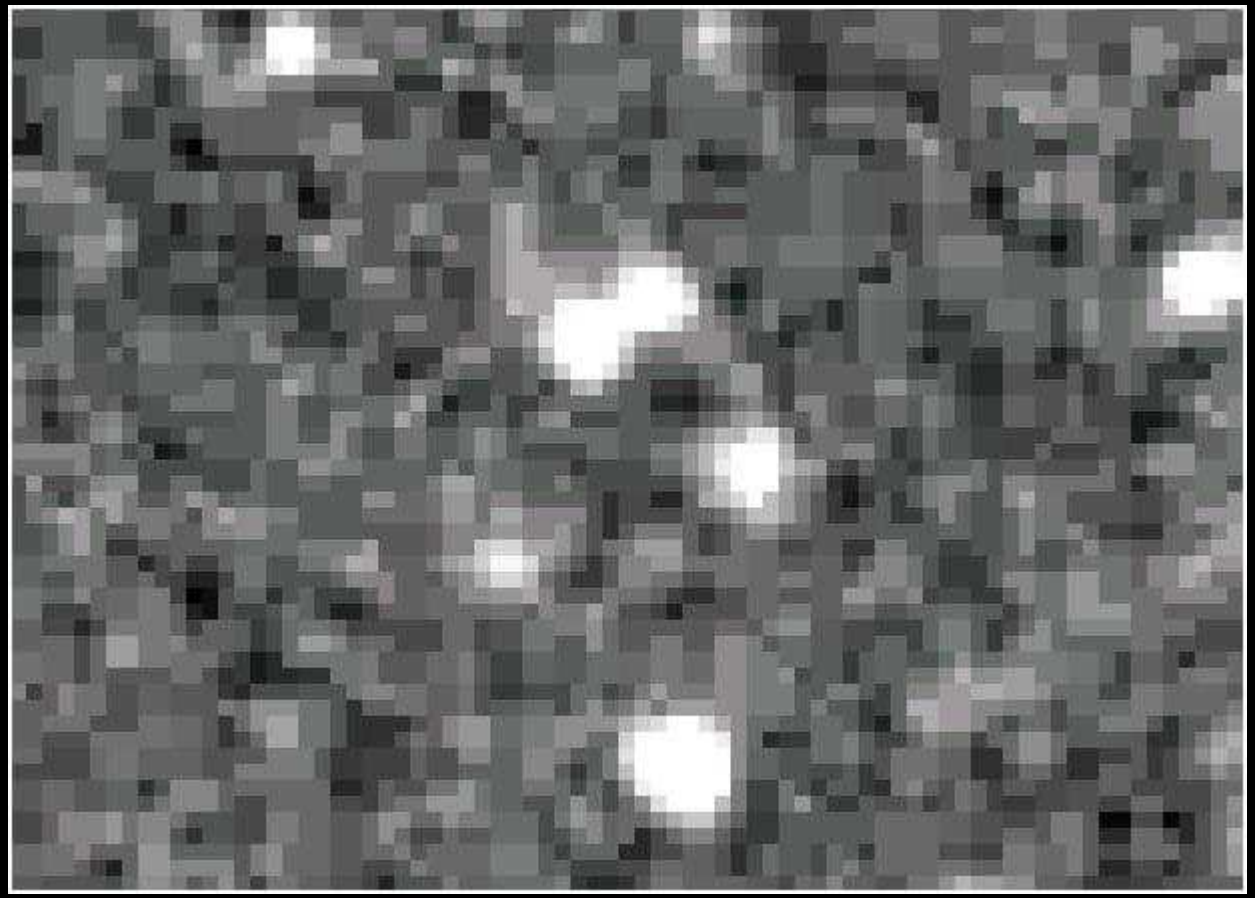
Searching for more QSOs lensed by rich clusters

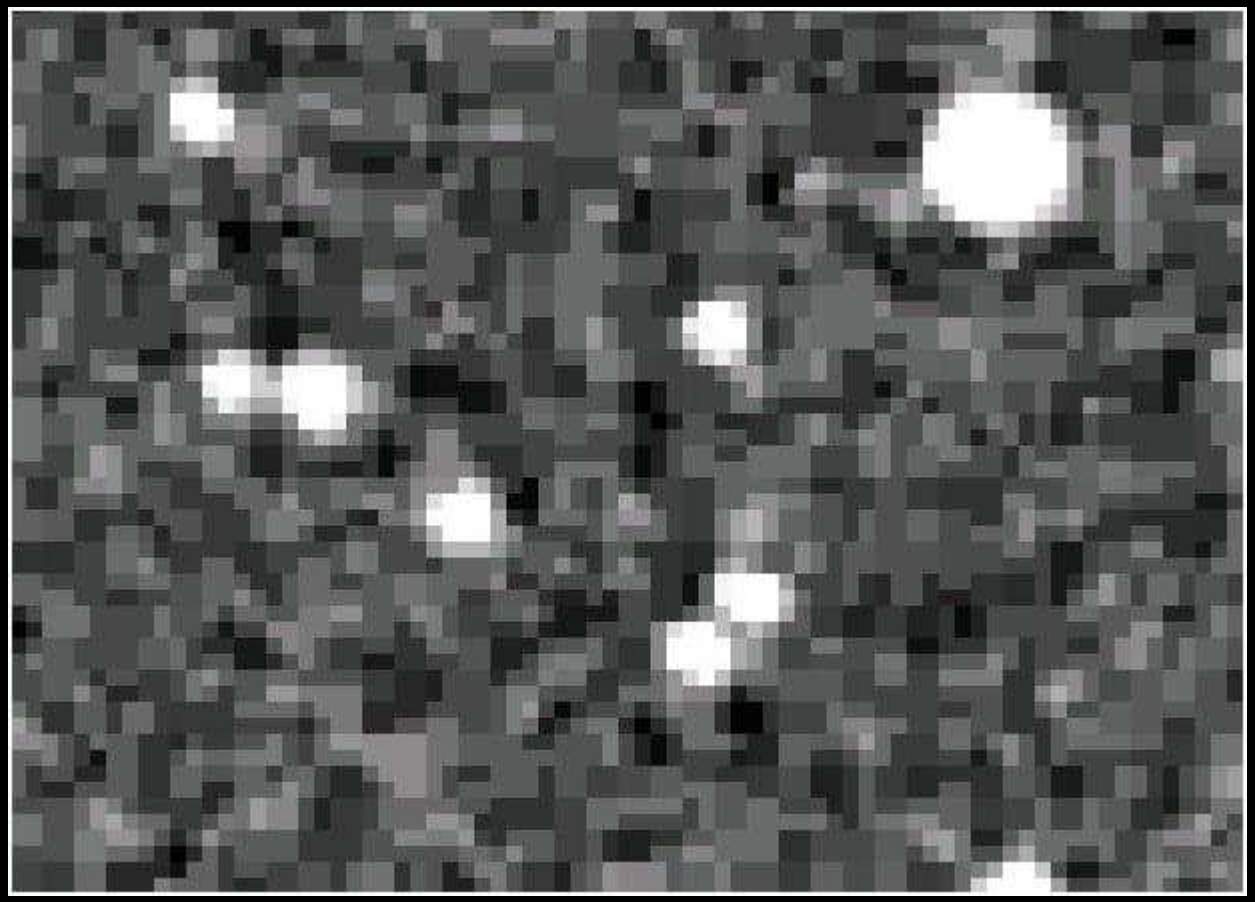


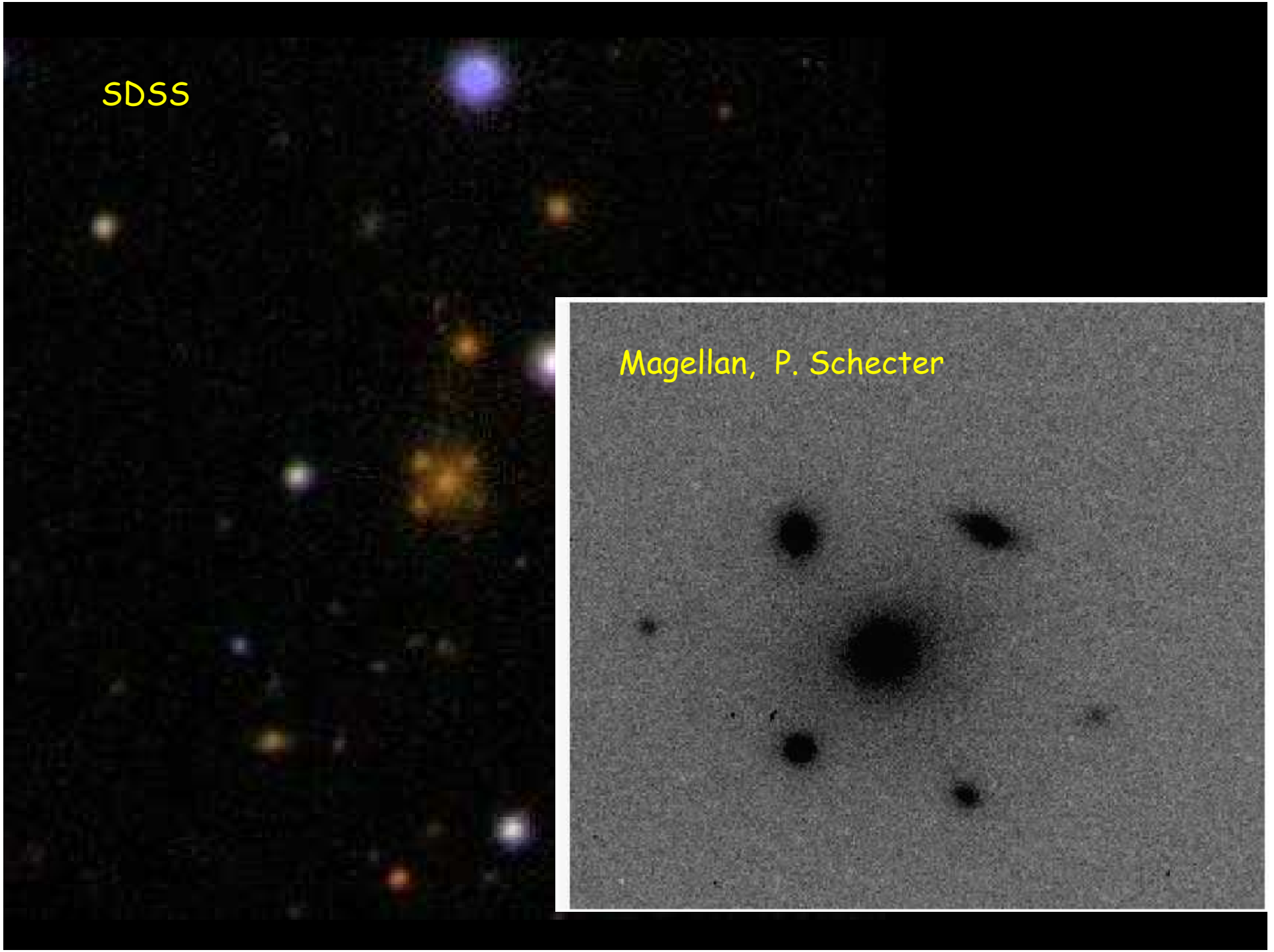








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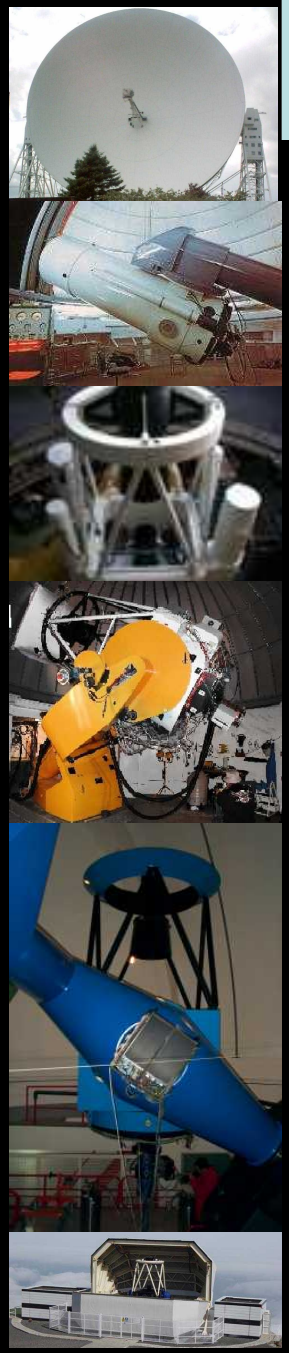
Magellan, P. Schecter



Two predictions/speculations

1. Measured time delays will become available for most systems, will play role in understanding galaxy structure and perhaps H0, after all.
2. Additional quasars lensed by clusters will be discovered / will have time delays, and may prove particularly useful.