Quintuple Quasar in Leo Minor

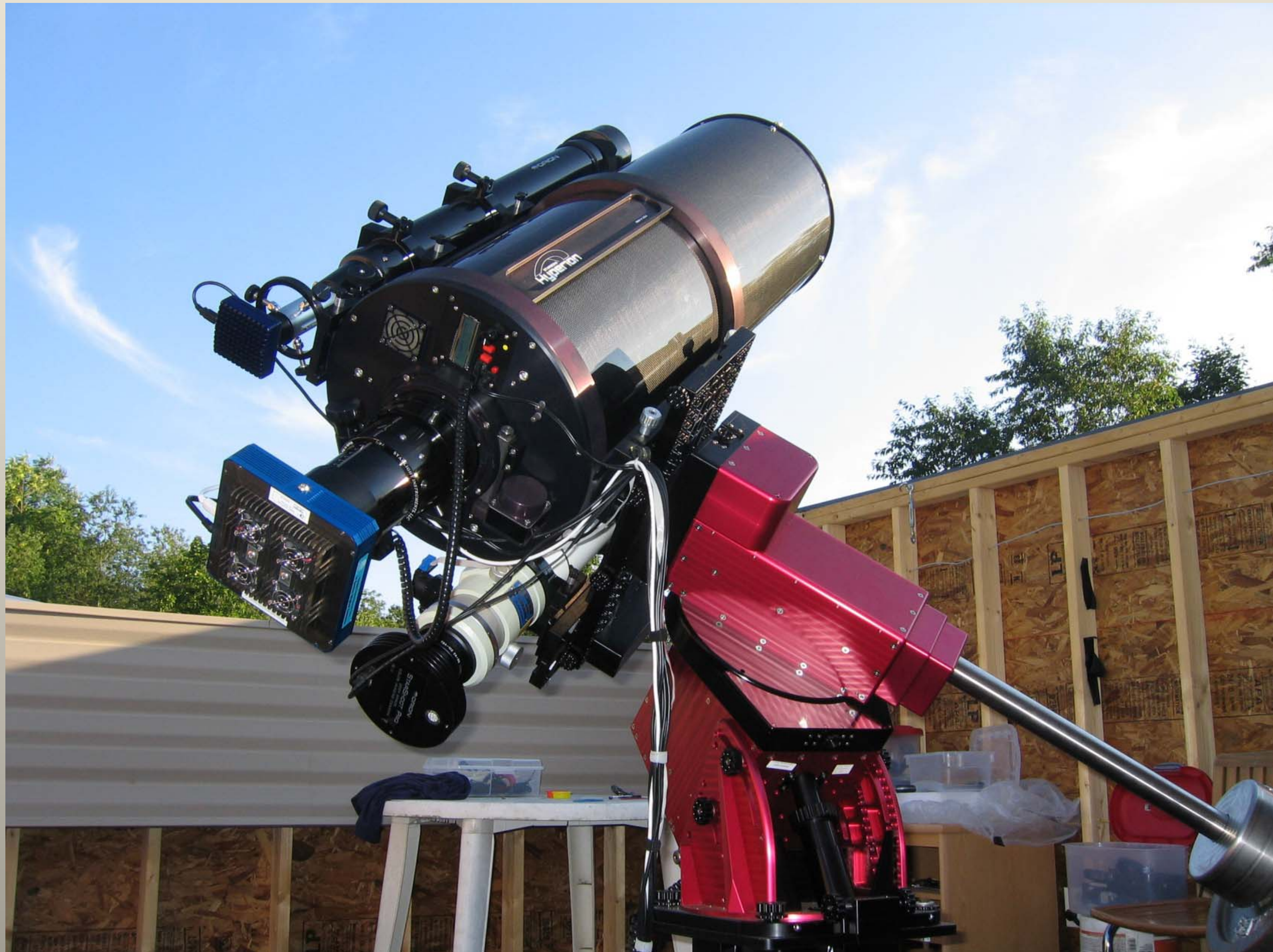
Dick Steinberg
DVAA Meeting
January 10, 2014

Astro-Imaging at Blue Mountain

- **Site, telescopes and cameras**
- **Wide-field color (106mm Takahashi FSQ + SSPro)**
  - The moon (~1 L s or 4×10^{-14} Mly)
  - Milky Way nebulae and clusters (~10^{-3} Mly)
  - Nearby galaxies (~10 Mly)
- **Deep monochrome (317mm Hyperion + U16M)**
  - Strongly-lensed galaxy ($z=0.38$ & 2.73 → 4.3 & 12 Gly)
  - Quadruply-imaged quasar ($z \sim 3$)

Imaging setup at Blue Mountain

12.5” Hyperion on Paramount ME - July 2010



The Cameras

- Color – Orion StarShoot Pro v1

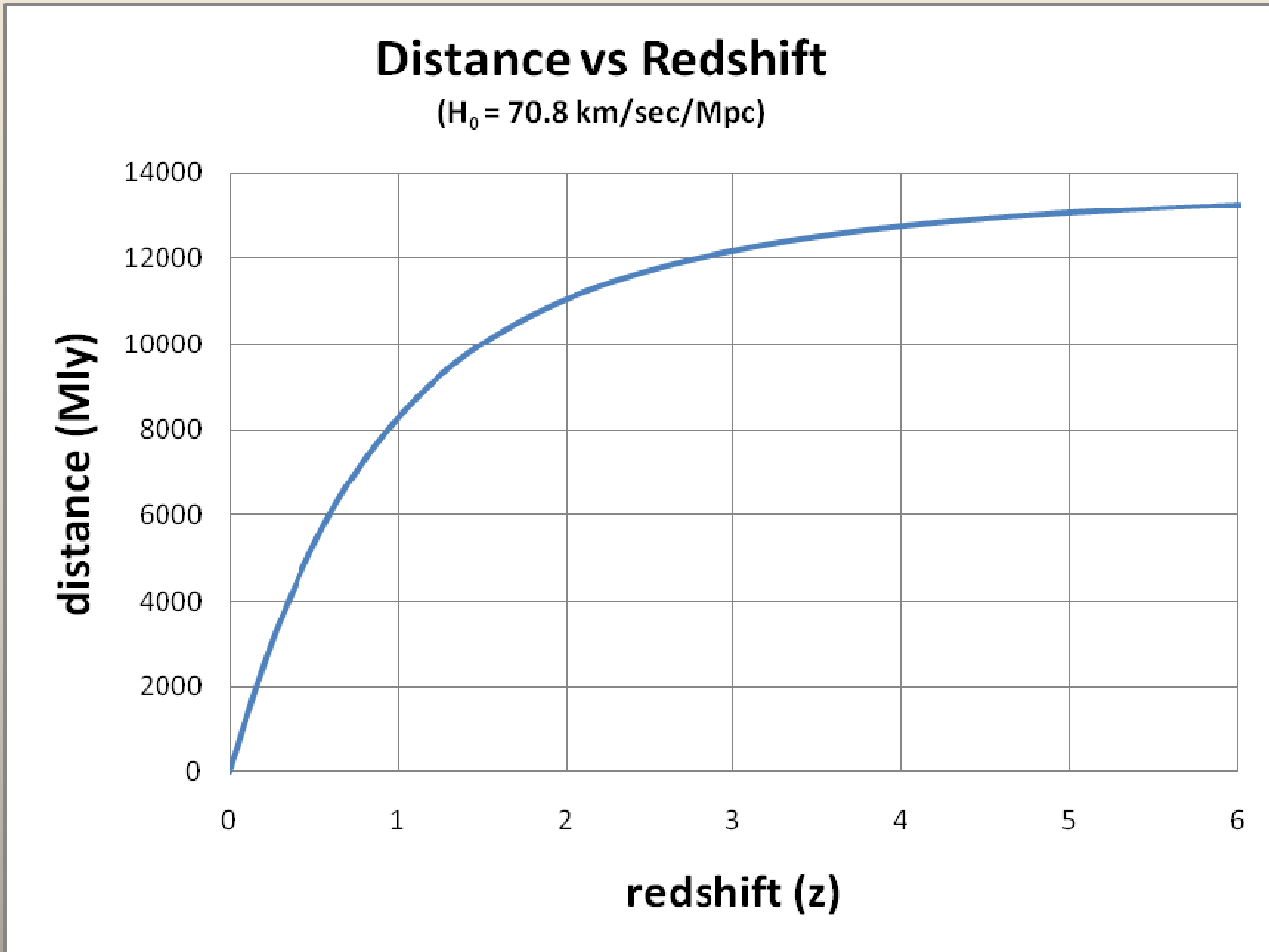
(used with NP101 and TAK FSQ106)

- Monochrome – Apogee U16M

(used with 12.5" Hyperion)

Apogee U16M

- Large chip monochrome camera
- Kodak KAF-16801E full frame CCD
- 4096x4096 pixels (16MP total), each 9 x 9 microns
- Chip size 37x37 mm (52mm diagonal)
- FOV with 12.5" Hyperion – 50x50 arc min
- Plate scale – 0.73 arc sec/pixel
- Microlenses and anti-blooming gates
- Peak QE (550nm) 69%
- Thermoelectric cooling (max 45 C below ambient)
- Limiting magnitude ~21 (w 12.5" Hyperion at BMVO)



(distance = c * look-back time)

Latest value of Ho = 67.8(km/s)/Mpc with 1/Ho = 13.8 Gyr

Date published	Hubble constant (km/s)/Mpc	Observer	Citation	Remarks / methodology
2013-03-21	67.80 ± 0.77	Planck Mission	[13][14][15][16][17]	The ESA Planck Surveyor was launched in May 2009. Over a four-year period, it performed a significantly more detailed investigation of cosmic microwave radiation than earlier investigations using HEMT radiometers and bolometer technology to measure the CMB at a smaller scale than WMAP. On 21 March 2013, the European-led research team behind the Planck cosmology probe released the mission's data including a new CMB all-sky map and their determination of the Hubble constant.
2012-12-20	69.32 ± 0.80	WMAP (9-years)	[18]	
2010	$70.4^{+1.3}_{-1.4}$	WMAP (7-years), combined with other measurements.	[19]	These values arise from fitting a combination of WMAP and other cosmological data to the simplest version of the ΛCDM model. If the data are fit with more general versions, H_0 tends to be smaller and more uncertain: typically around 67 ± 4 (km/s)/Mpc although some models allow values near 63 (km/s)/Mpc.[20]
2010	71.0 ± 2.5	WMAP only (7-years).	[19]	
2009-02	70.1 ± 1.3	WMAP (5-years). combined with other measurements.	[21]	
2009-02	$71.9^{+2.6}_{-2.7}$	WMAP only (5-years)	[21]	
2006-08	$77.6^{+14.9}_{-12.5}$	Chandra X-ray Observatory	[22]	
2007	$70.4^{+1.5}_{-1.6}$	WMAP (3-years)	[23]	
2001-05	72 ± 8	Hubble Space Telescope	[24]	This project established the most precise optical determination, consistent with a measurement of H_0 based upon Sunyaev-Zel'dovich effect observations of many galaxy clusters having a similar accuracy.
prior to 1996	50–90 (est.)		[25]	
1958	75 (est.)	Allan Sandage	[26]	This was the first good estimate of H_0, but it would be decades before a consensus was achieved.

The Relativistic Doppler Shift

We learned before about the Doppler shift, that is the change in the wavelength of a spectral line due to the motion of its source. When the source is moving with a very high velocity, the exact expression for the Doppler shift becomes more complicated. We call this the **relativistic Doppler formula**.

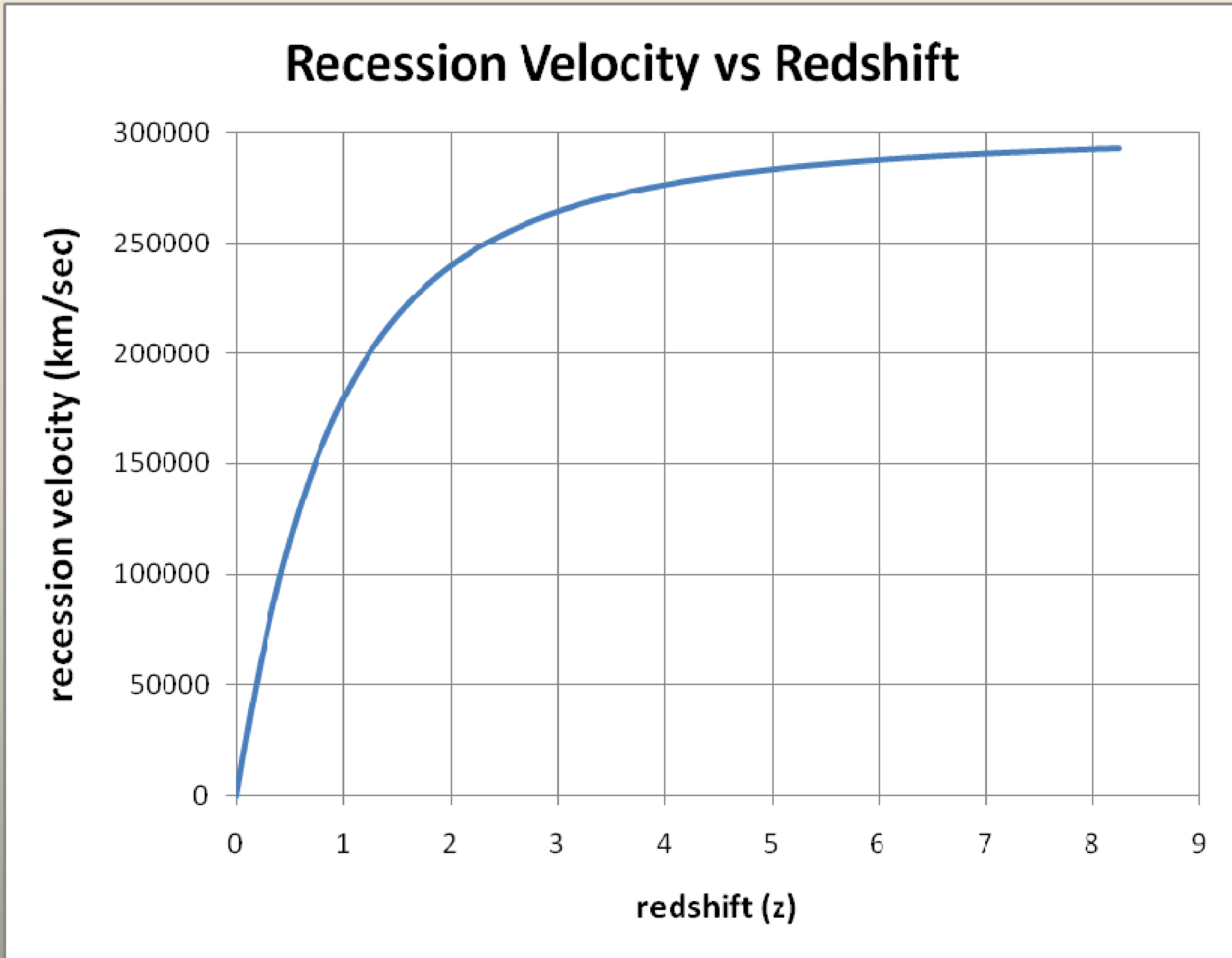
$$\frac{\text{shift in wavelength}}{\text{wavelength}} = \frac{\Delta\lambda}{\lambda} = z \qquad \textbf{REDSHIFT}$$

$$z = \sqrt{\frac{\left(1 + \frac{v}{c}\right)}{\left(1 - \frac{v}{c}\right)}} - 1$$

Since galaxies are moving away from us, their doppler shifts are always positive, that is, the wavelengths of the spectral lines are **redshifted**. Astronomers use the expression redshift, denoted usually by **z**, to indicate the magnitude of the doppler shift.

v/c vs z

v/c	z	vel (km/s)
0.500000	0.732051	150000
0.250000	0.290994	75000
0.125000	0.133893	37500
0.062500	0.064581	18750
0.031250	0.031754	9375
0.015625	0.015749	4688
0.007813	0.007843	2344
0.003906	0.003914	1172
0.001953	0.001955	586
0.000977	0.000977	293
0.000488	0.000488	146
0.000244	0.000244	73
0.000122	0.000122	37
6.10E-05	6.10E-05	18
3.05E-05	3.05E-05	9


Recession Velocity vs Redshift
300000
250000
200000
150000
100000
50000
0
recession velocity (km/sec)
0
1
2
3
4
5
6
7
8
9
redshift (z)

Reference wavelengths (at rest):

Lyman α 1216 Å

Ca II H,K lines 3969Å and 3934Å

Doppler shift: $\lambda / \lambda_o = 1+z$

SDSS J1004+4112, a Quadruply-Imaged QSO

- Discovered in 2003 (SDSS) by Inada et al. (including Gordon Richards)
- Spectroscopy at Keck I measures z=1.73
- Lensed by galaxy cluster at z=0.68
- Note that A is about 1 magnitude brighter than C

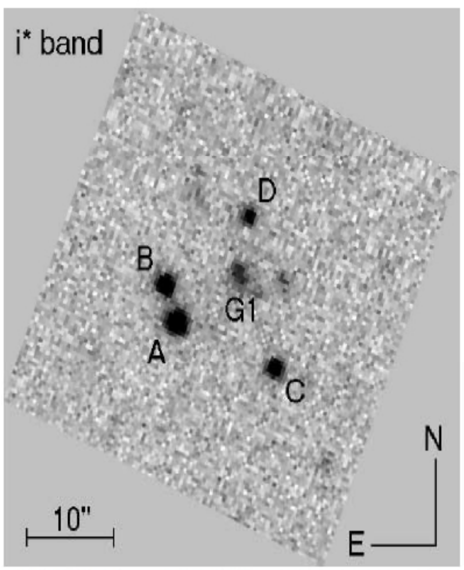


FIG. 2.— SDSS i^*-band image of SDSS J1004+4112. Components A, B, C, and D are lensed images while component G1 is the brightest galaxy in the lensing cluster.

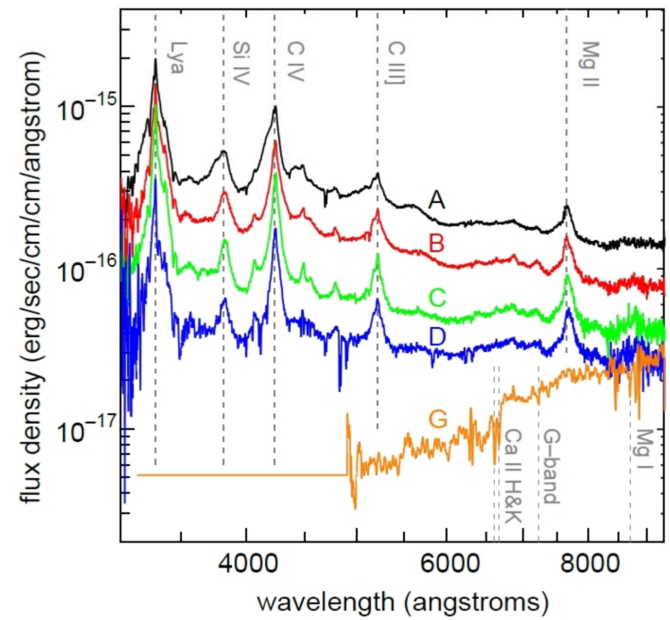
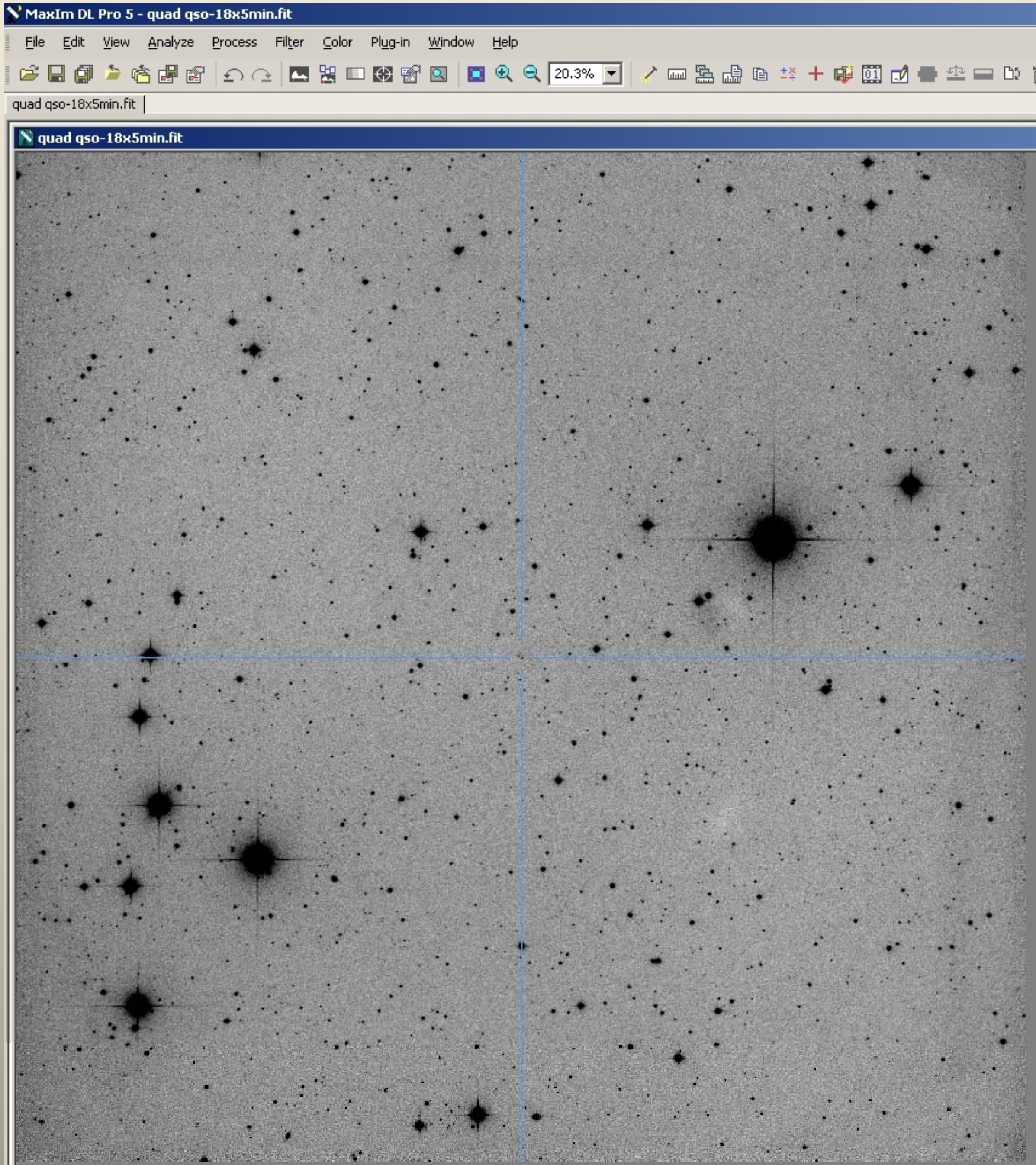


Table 1. **ASTROMETRY AND PHOTOMETRY FOR SDSS J1004+4112**

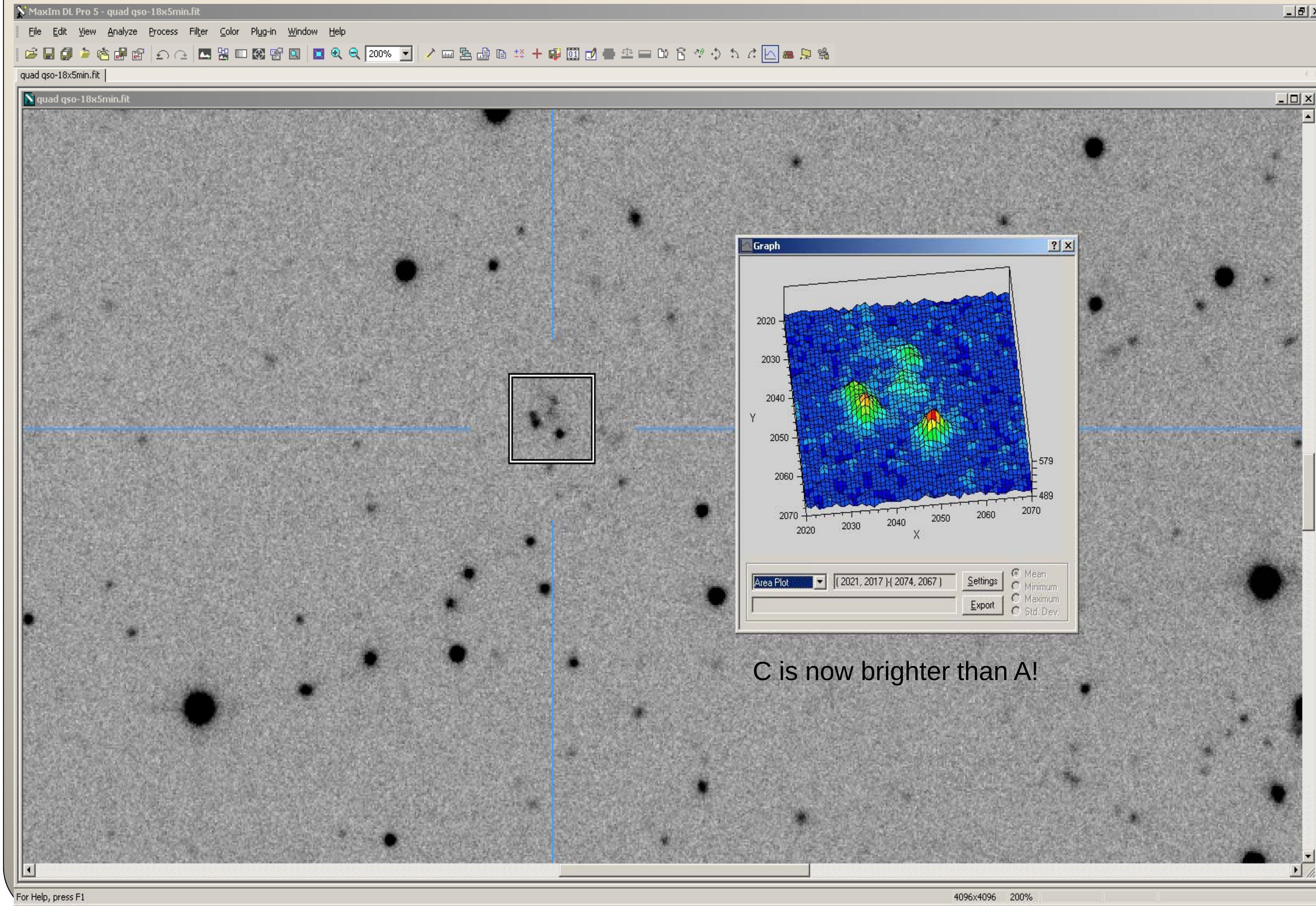
Object	R.A.(J2000)[a]	Dec.(J2000)[a]	g^{b}	r^{b}	i^{b}	z^{b}	$\Delta\theta^{c}$
A	10 04 34.794	+41 12 39.29	18.67±0.03	18.70±0.02	18.46±0.02	18.43±0.05	3."73
B	10 04 34.910	+41 12 42.79	19.05±0.06	19.10±0.06	18.86±0.06	18.92±0.06	0."00
C	10 04 33.823	+41 12 34.82	19.71±0.03	19.73±0.02	19.36±0.03	19.31±0.07	14."62
D	10 04 34.056	+41 12 48.95	20.67±0.04	20.51±0.04	20.05±0.04	20.00±0.13	11."44
G	10 04 34.170	+41 12 43.66	22.11±0.40	20.51±0.13	19.54±0.09	19.04±0.21	8."44



90-minute Hyperion image centered on the quadruple quasar (50 x 50 arcmin)

The brightest star is TW LMi, mag ~7.4

Hyperion image detail

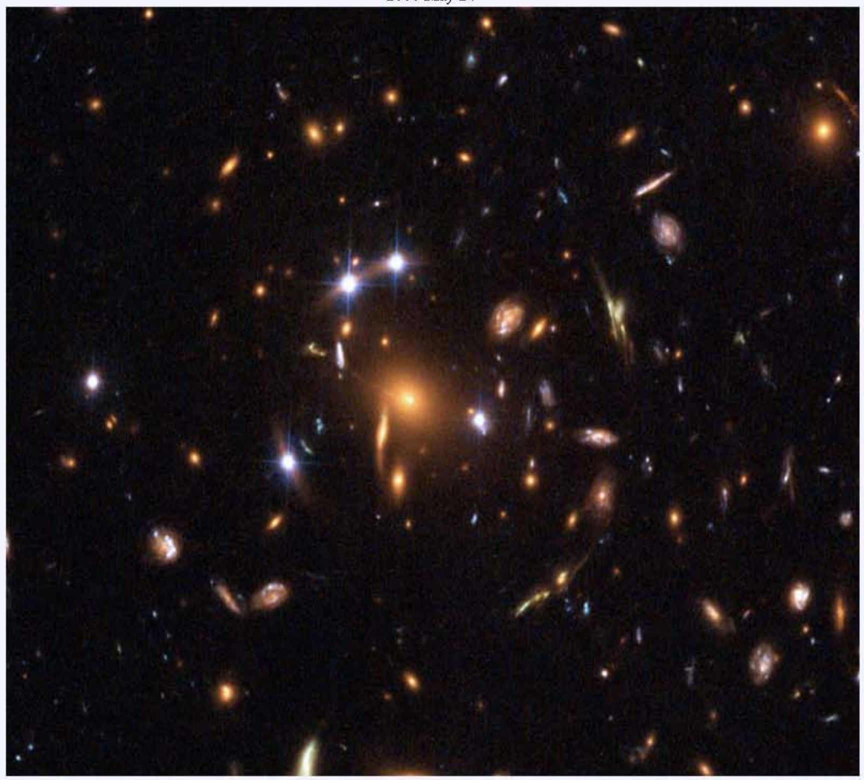


C is now brighter than A!

Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

2006 May 24



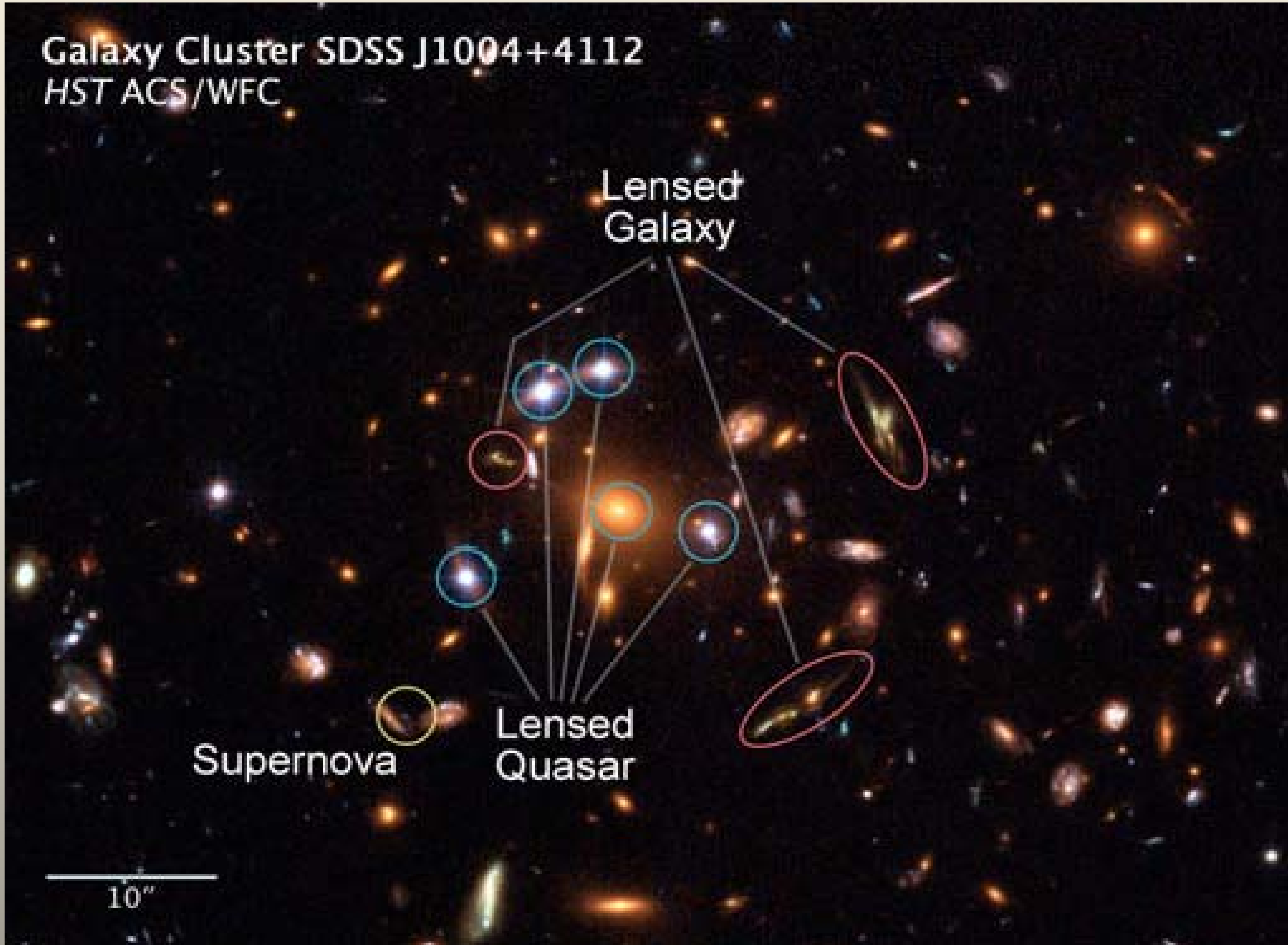
A Five Quasar Gravitational Lens
Credit: K. Sharon (Tel Aviv U.) and E. Ofek (Caltech), ESA, NASA

Explanation: What's happening near the center of this cluster of galaxies? At first glance, it appears that several strangely elongated galaxies and fully five bright quasars exist there. In reality, an entire cluster of galaxies is acting as a gigantic gravitational lens that distorts and multiply-images bright objects that occur far in the distance. The five bright white points near the cluster center are actually images of a single distant quasar. This Hubble Space Telescope image is so detailed that even the host galaxy surrounding the quasar is visible. Close inspection of the above image will reveal that the arced galaxies at 2 and 4 o'clock are actually gravitationally lensed images of the same galaxy. A third image of that galaxy can be found at about 10 o'clock from the cluster center. Serendipitously, numerous strange and distant galaxies dot the above image like colorful jewels. The cluster of galaxy that acts as the huge gravitational lens is cataloged as SDSS J1004+4112 and lies about 7 billion light years distant toward the constellation of Leo Minor.

Tomorrow's picture: Trifid of the north

< | Archive | Index | Search | Calendar | Glossary | Education | About APOD | Discuss | >

Authors & editors: Robert Nemiroff (MTU) & Jerry Bonnell (USRA)


Galaxy Cluster SDSS J1004+4112
HST ACS/WFC
Lensed Galaxy
Lensed Quasar
Supernova
10″

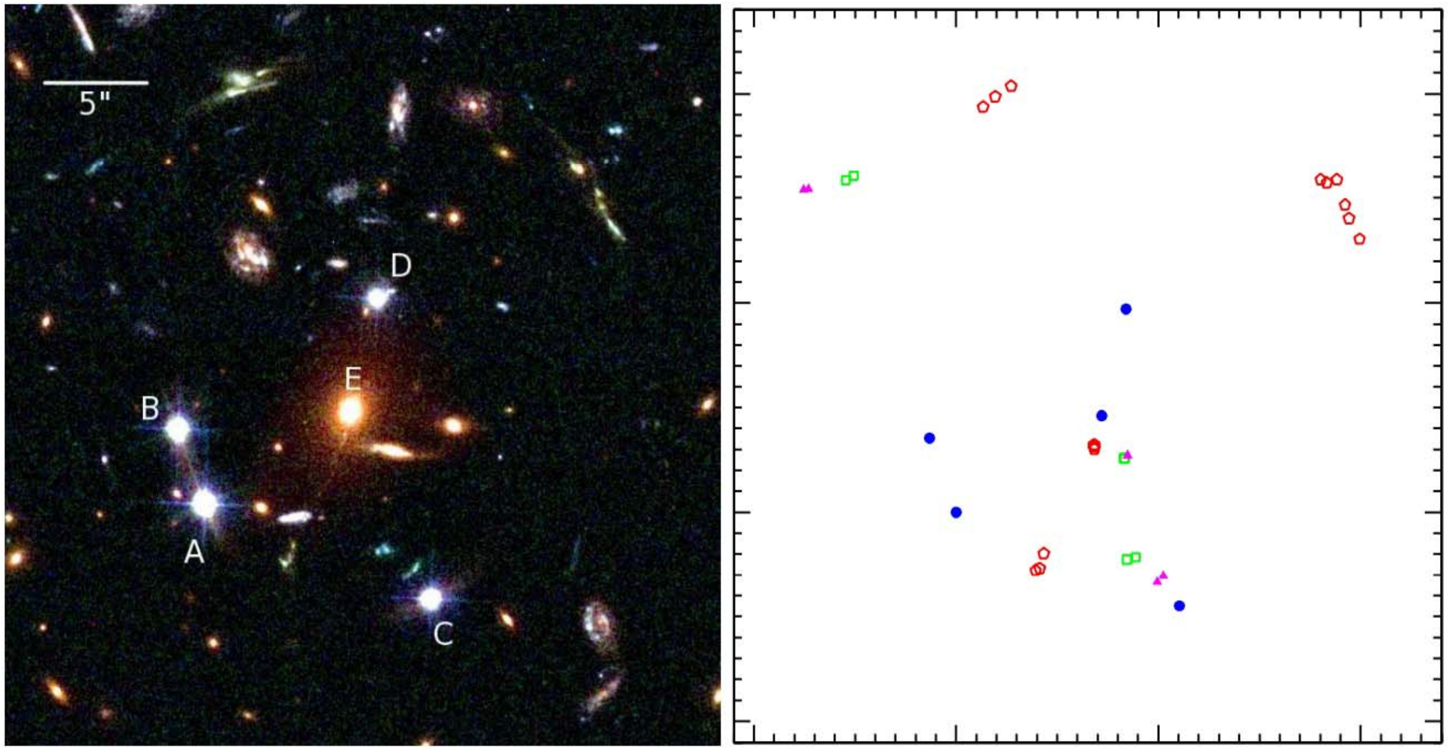


Fig. 1. *Left:* The HST/ACS image of SDSS J1004+4112. North is up and West is right. Stellar objects labeled by A–E are the 5 lensed quasar images. A large galaxy superposed on image E is the brightest cluster galaxy G1. *Right:* Positions of the 5 lensed quasar images (*filled circles*) and lensed galaxies images (*other symbols*). The size and orientation of the panel is same as the left panel. Different symbols have different redshifts. See Tables 2 and 3 for the relative coordinate values.