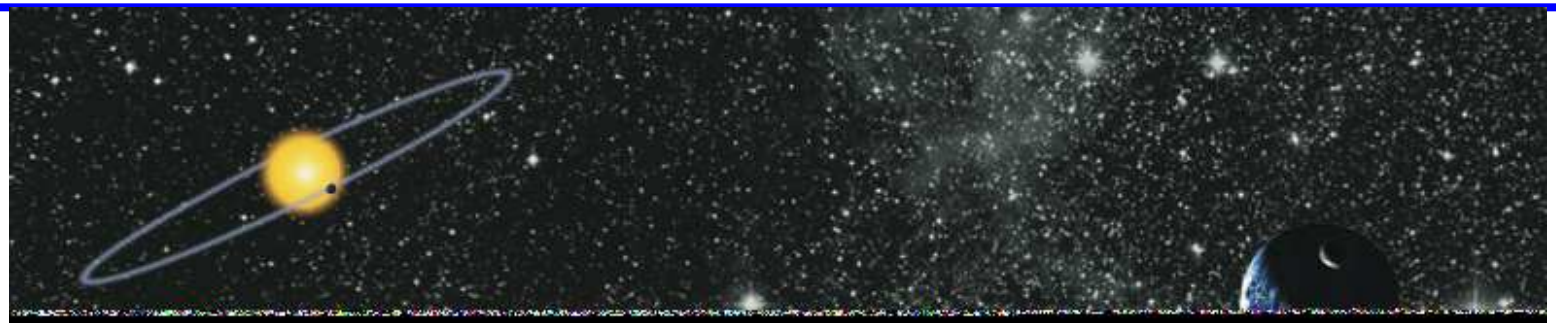
KEPLER; NASA'S FIRST MISSION CAPABLE OF FINDING EARTH-SIZE PLANETS IN THE HABITABLE ZONE

A Search for Earth-size Planets



W.J. Borucki & the Kepler Team

NASA Ames

IAU Mtg 11 October, 2010

SCIENCE QUESTIONS ADDRESSED

Kepler
A Search for Earth-size Planets

CRITICAL QUESTIONS

- **What is the frequency of Earth-size planets in or near the Habitable Zone (HZ) of solar-like stars?**
- **What are the distributions of sizes & semi-major axes?**
- **What are the frequency & orbital distributions of planets in multiple star systems?**
- **What are the distributions of semi-major axes, albedo, size, mass, and density of short-period giant planets?**
- **How are these properties associated with stellar characteristics?**

INSTRUMENT

Kepler
A Search for Earth-size Planets

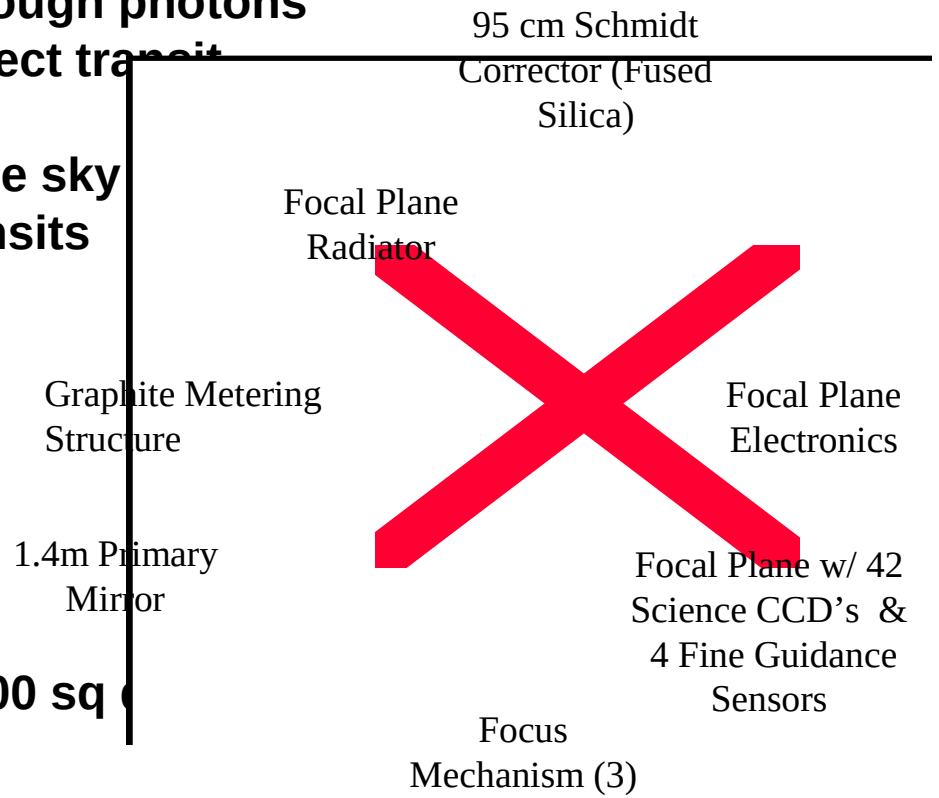
KEPLER: A Wide Field-of-View Photometer that Monitors ≥150,000 Stars for 3.5 yrs with Enough Precision to Find Earth-size Planets in the Habitable Zone

Use transit photometry to detect Earth-size planets

- **0.95 meter aperture provides enough photons**
- **Observe for several years to detect transit patterns**
- **Monitor a single large area on the sky continuously to avoid missing transits**
- **Use heliocentric orbit**
- **Up to 170,000 targets at 30 min cadence & 512 at 1 min**

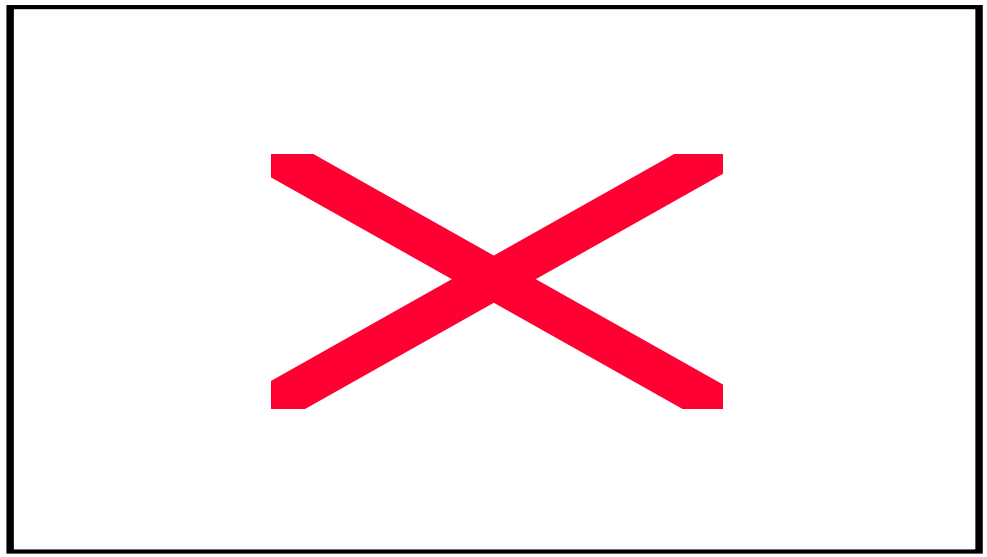
Get statistically valid results by monitoring; 100,000 stars

- **Wide Field-of-view telescope (100 sq**
- **Large array of CCD detectors**



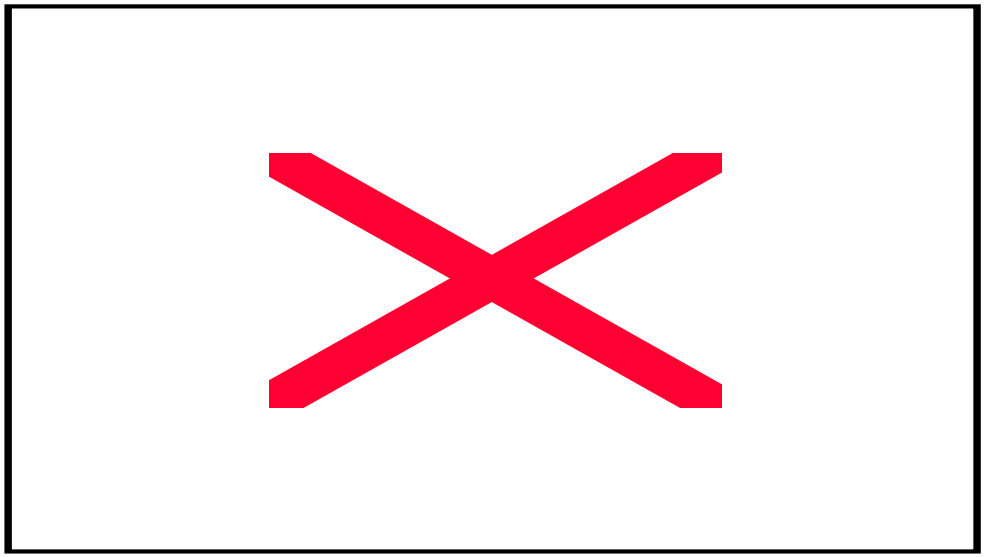
KEPLER DETECTS LIGHT FROM THE PLANET ITSELF

Kepler
A Search for Earth-size Planets



Scatter of the data points in the *Kepler* data is within the line thickness.

Kepler precision is 100 times better than that from ground-based observations.



Radiation from the planet itself is evident in the bottom panel.

The depth of the occultation is similar to that expected from an Earth-size planet orbiting a solar-like star.

OBSERVATIONS OF HAT-P7

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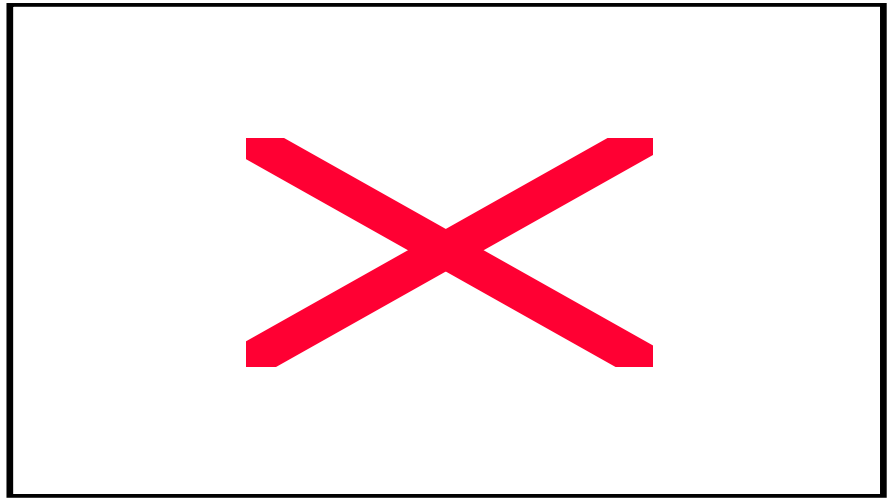
A Search for Earth-size Planets



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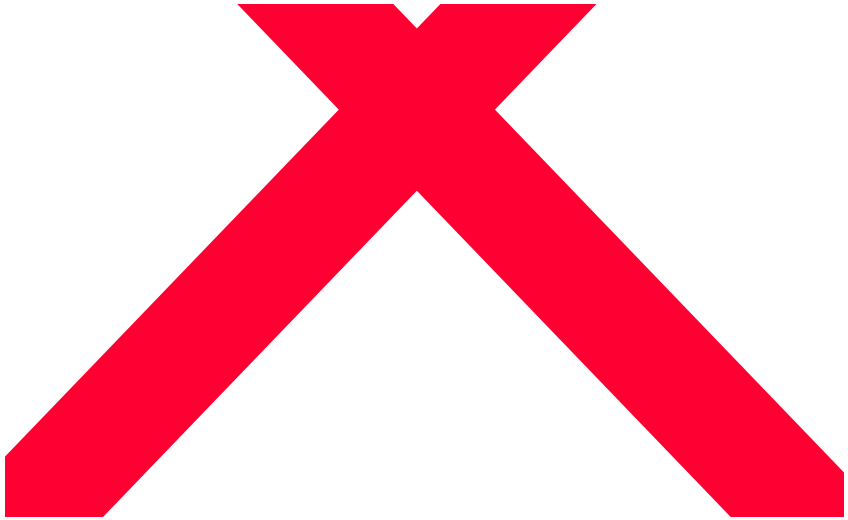
ELLIPSOIDAL VARIATIONS OF HAT-P7



The phase curve near the time of the occultation is best explained by a combination of the variation of the starlight due to the distortion of the star by the planet and light from the hot planet.

VALIDATION OF DISCOVERIES

Kepler
A Search for Earth-size Planets

- **SNR > 7σ to rule out statistical fluctuations**
- **At least three transits to confirm orbital periodicity**
- **Light curve depth, shape, and duration**
- **Search for secondary eclipses**
- **Centroid analysis to identify signals from background stars**
- **High spatial resolution to identify extremely close bkgd stars.**
- **Radial velocity**
  - **Medium precision to rule out stellar companions**
  - **High precision to measure mass & confirm discoveries**

KEPLER OBJECT OF INTEREST

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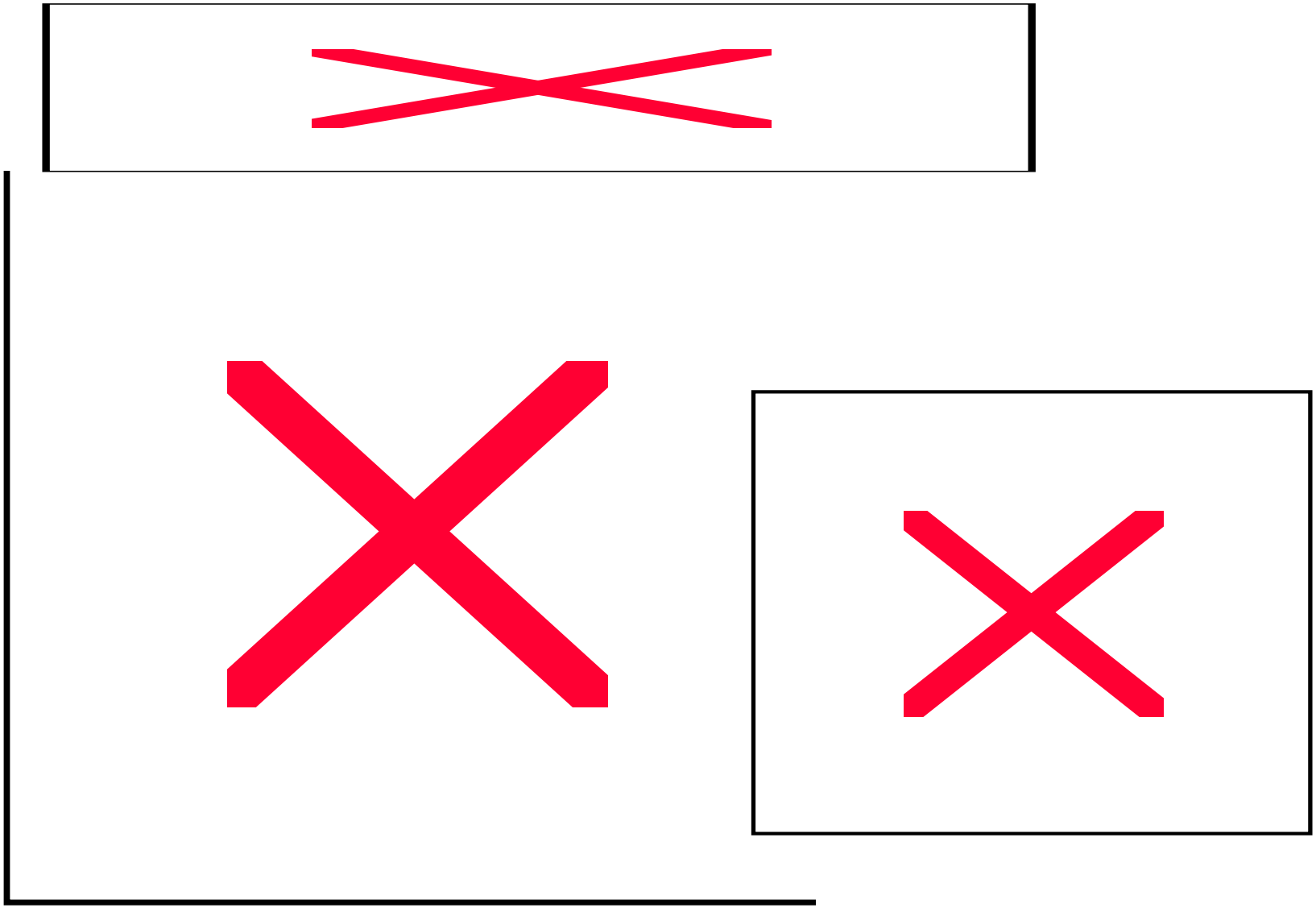
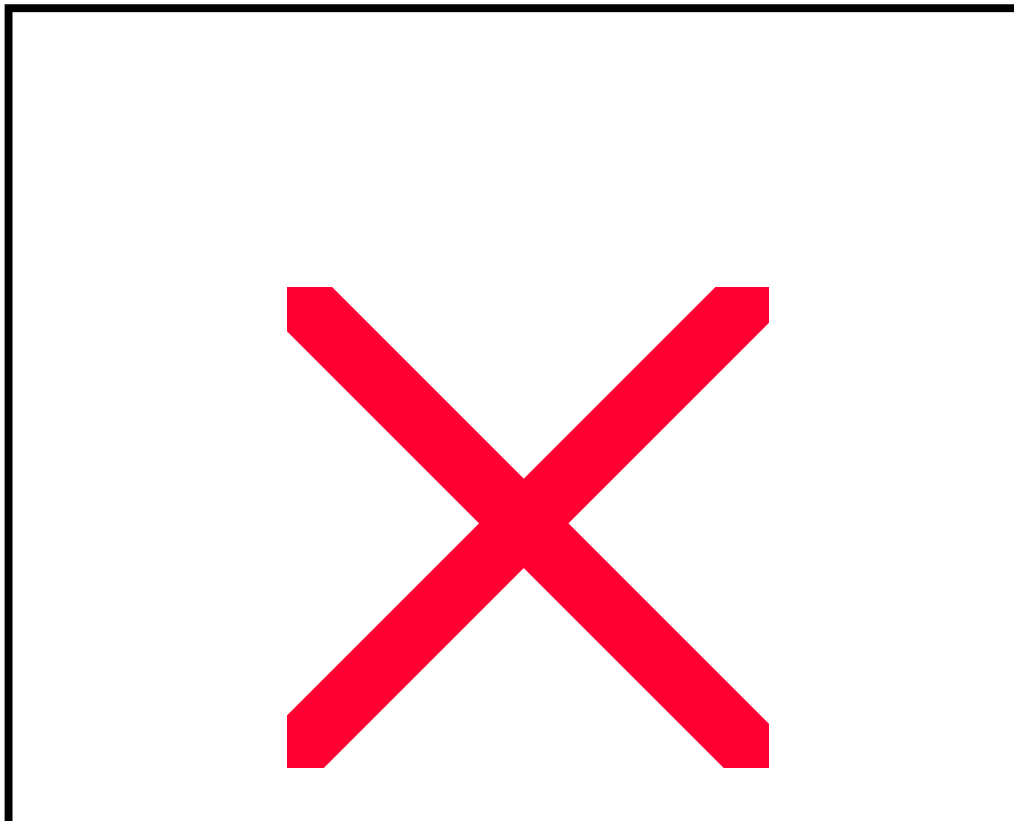


ACTIVE OPTICS IMAGE OF KOI#98 SHOW IT TO BE TWO STARS

Kepler
A Search for Earth-size Planets



TELESCOPES INVOLVED IN FOLLOW UP EFFORT

Kepler
A Search for Earth-size Planets

Texas:

2.7 Meter at the Mcdonald Observatory - (Harlan SmithTelescope) High resolution spectrograph

HET – (Hobby-Ebberly Telescope) with High resolution spectrograph. Can measure planet masses.

Hawaii:

Keck 1 Telescope – with HIRES. Can measure masses to a precision of ±1m/s.

Arizona:

Mayall 4 Meter

2 Meter with a spectrograph, medium resolution, reconnaissance observations

WIYN 3.5 Meter with a High resolution spectrograph, search for faint companions next to the KOI.

MMT (Multiple Mirror Telescope) - infrared with adaptive optics

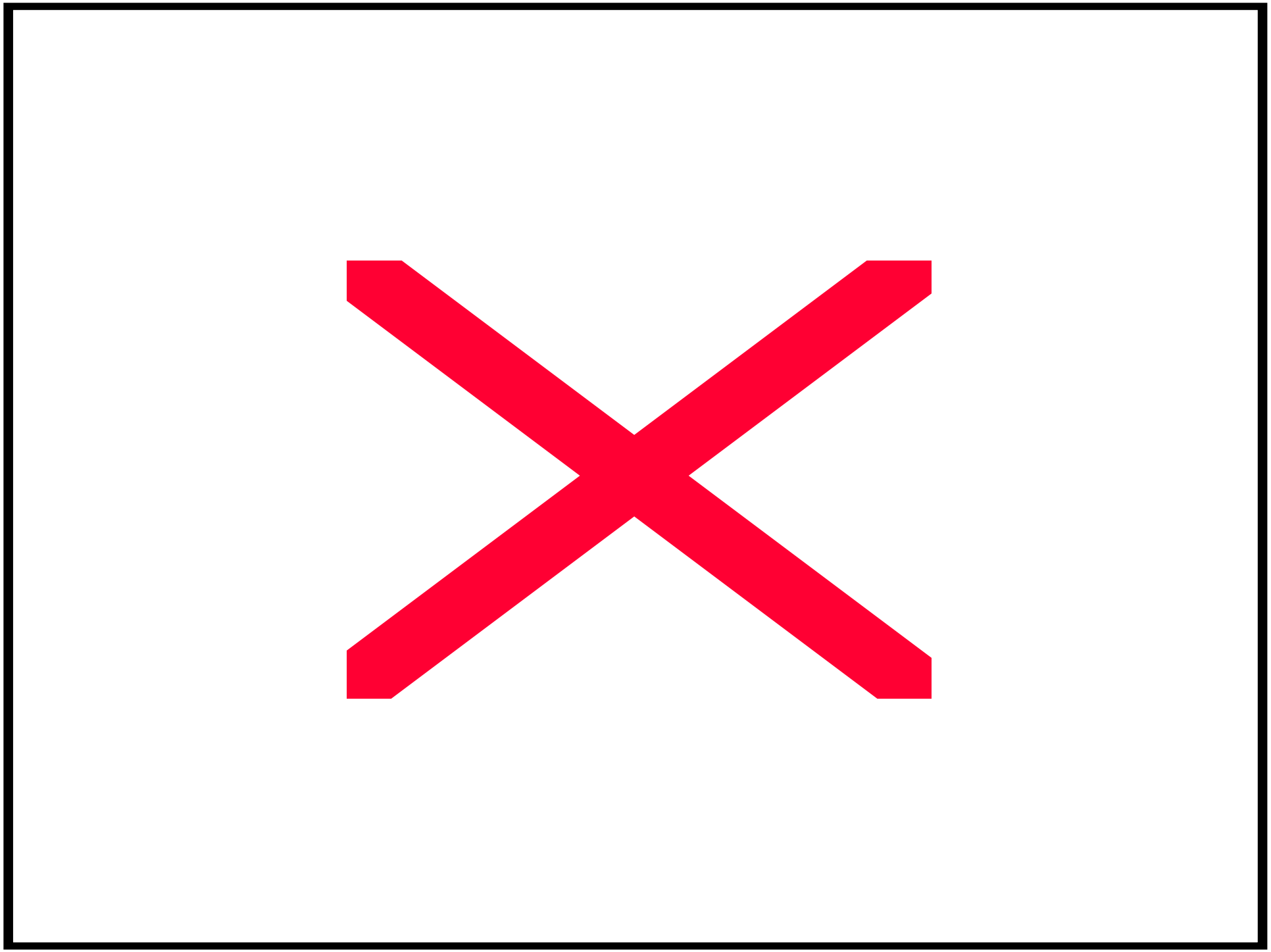
Tillinghast Reflector with TRES (Tillinghast Reflector Echelle Spectrograph) - 1.5 Meter - High resolution spectrograph

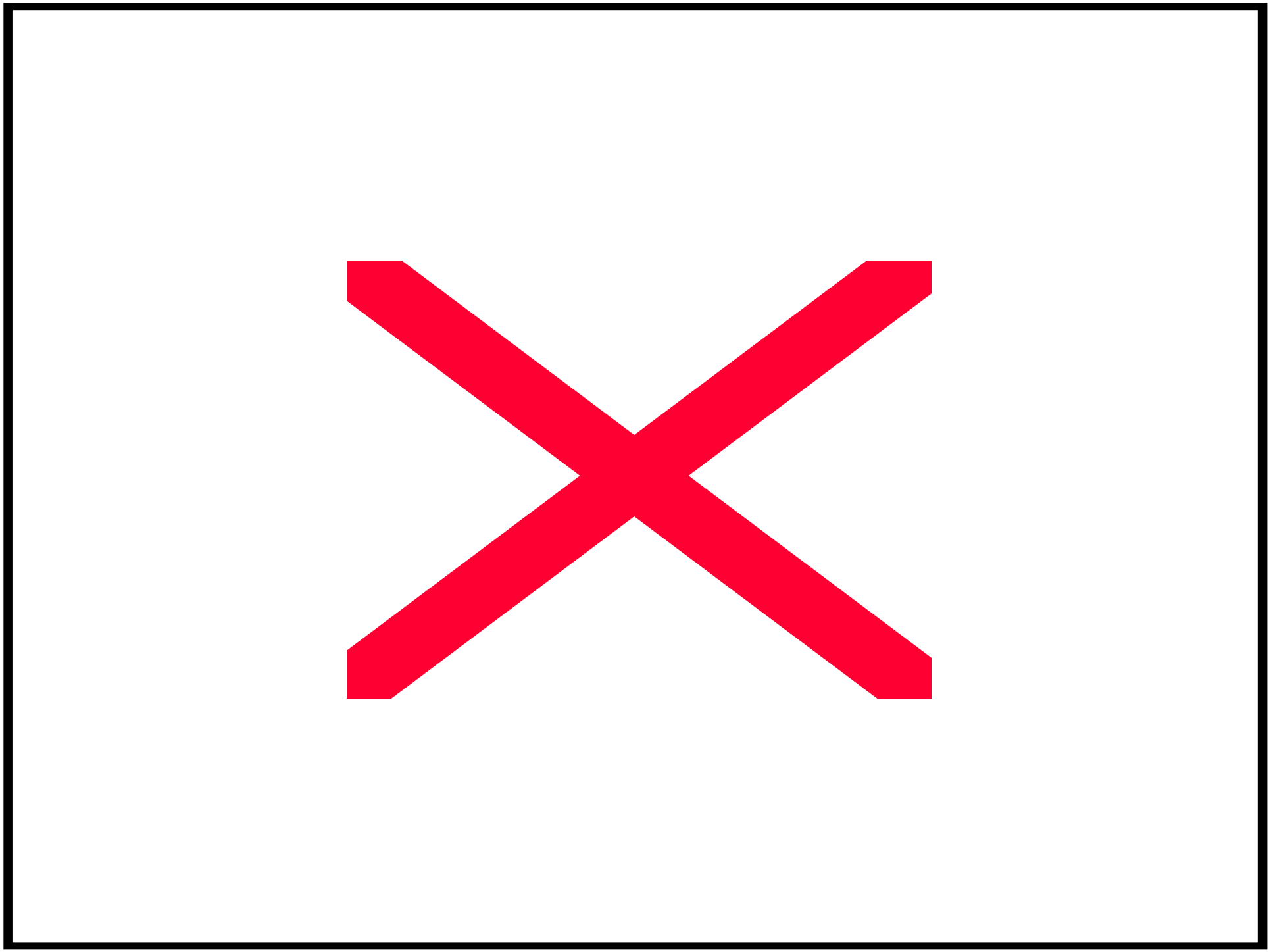
California:

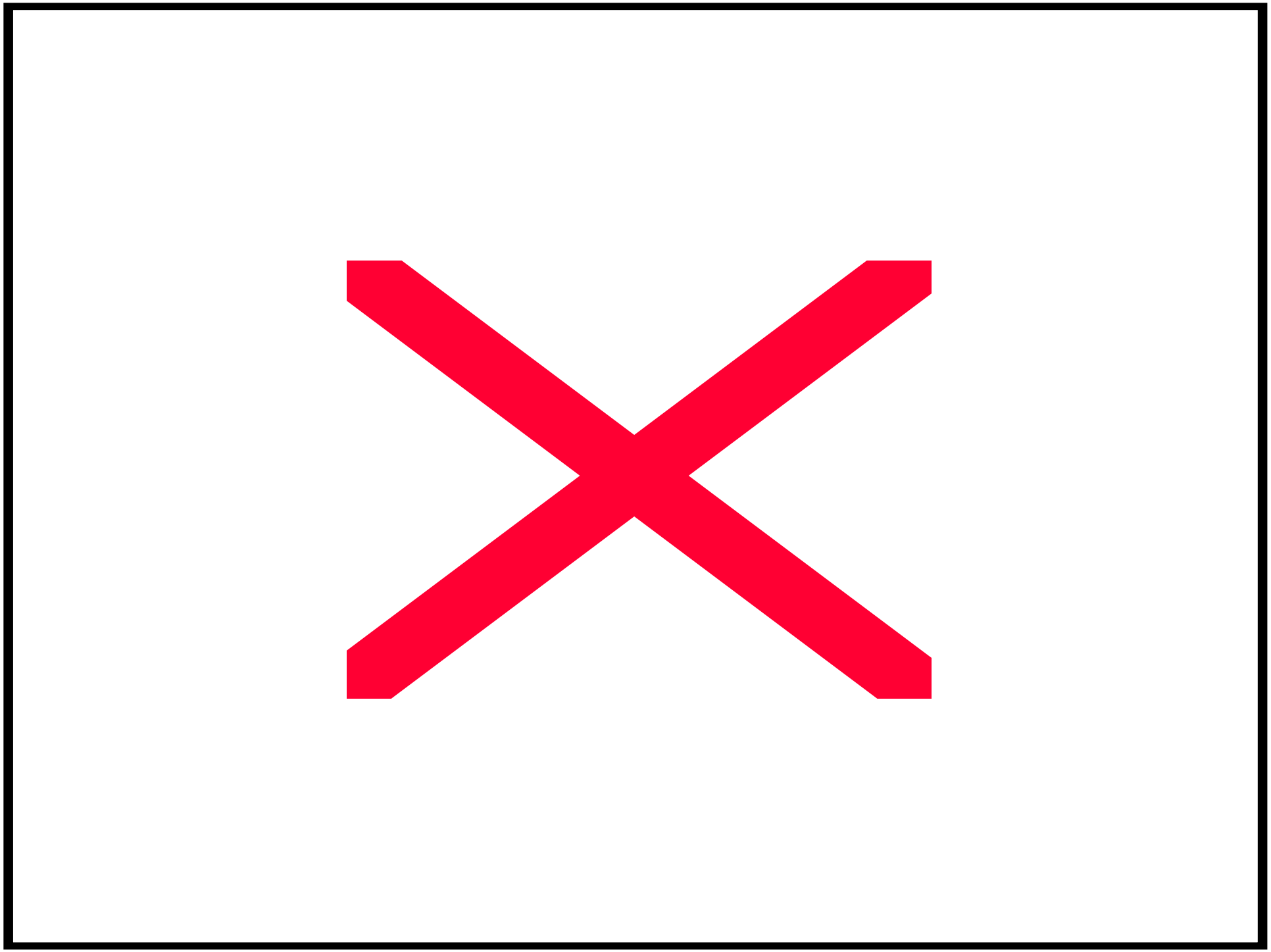
Hale - 200 inch at Palomer Mt. Infrared with adaptive optics.
Shane - 3 Meter - High resolution spectrograph

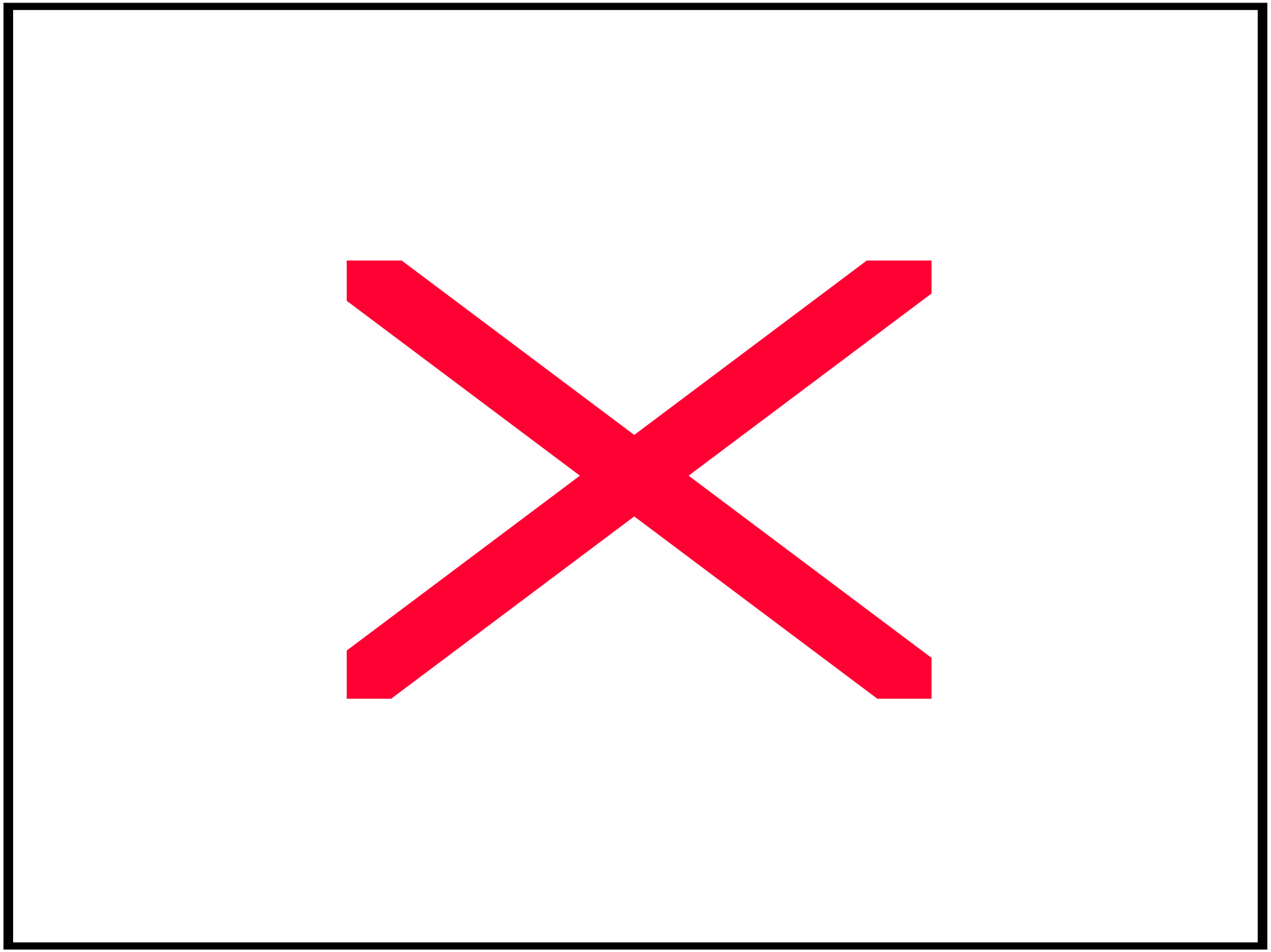
Spain (Canary Islands):

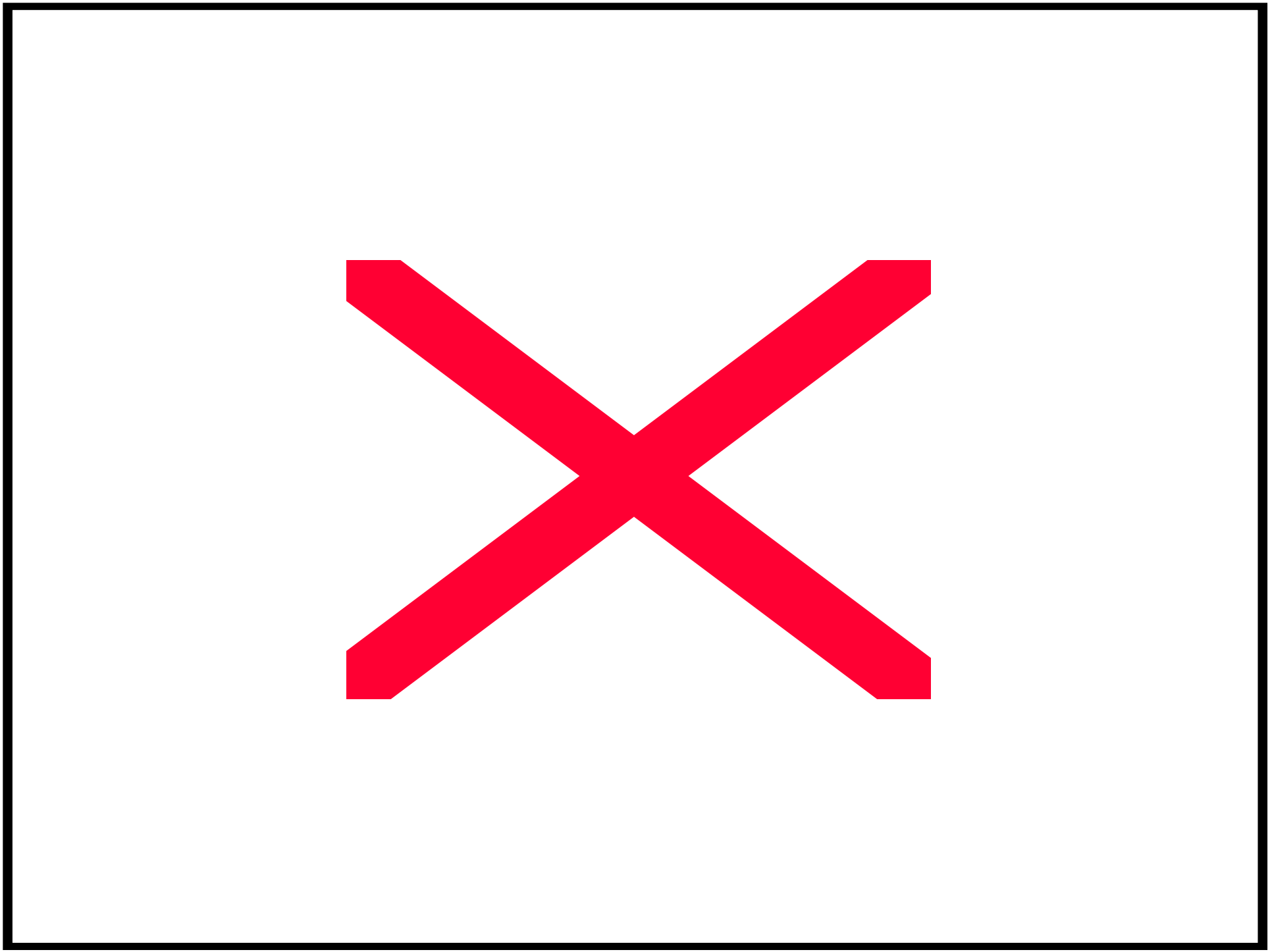
Nordic Optical Telescope with the FIber-fed Echelle Spectrograph spectrograph

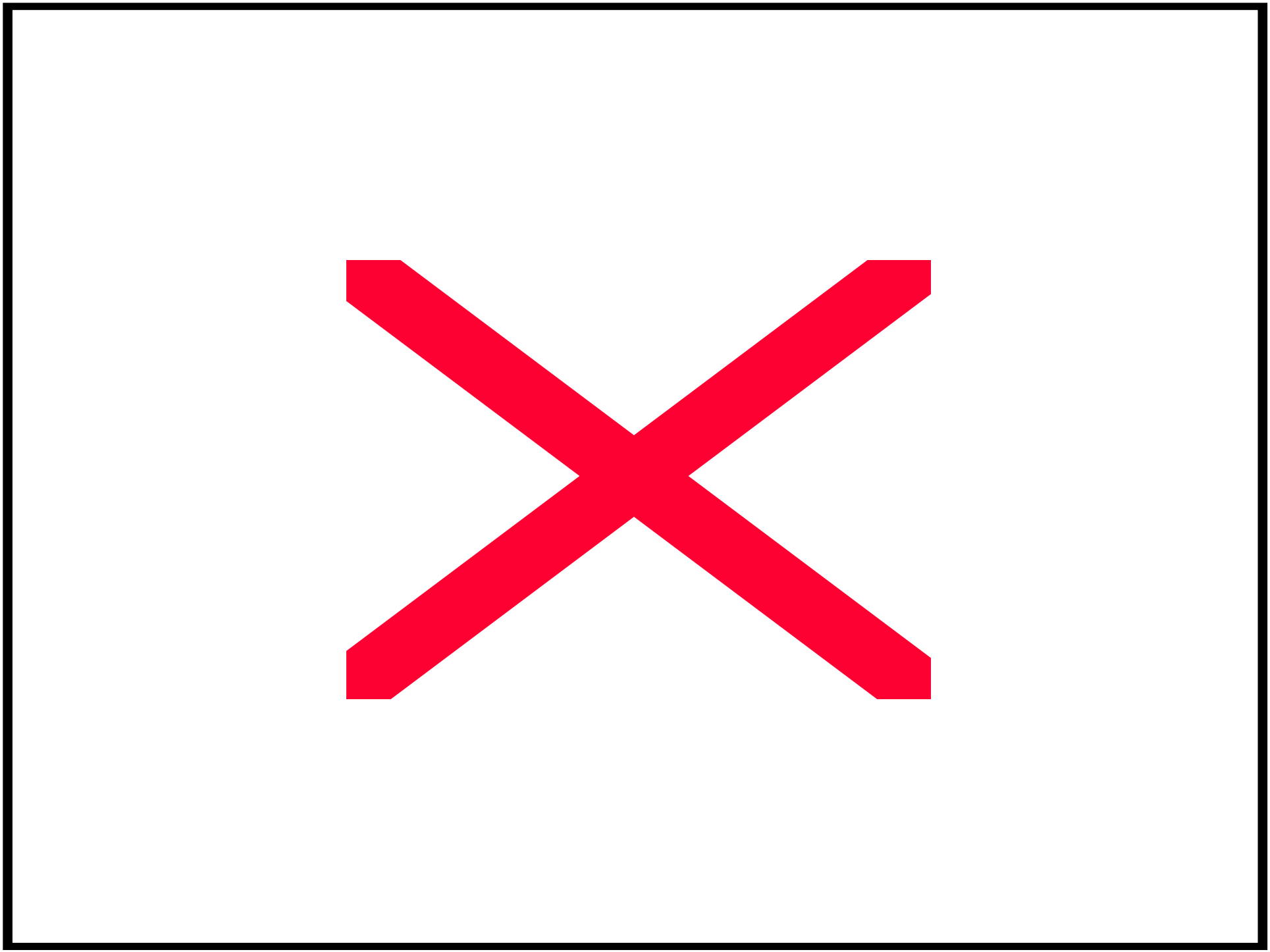


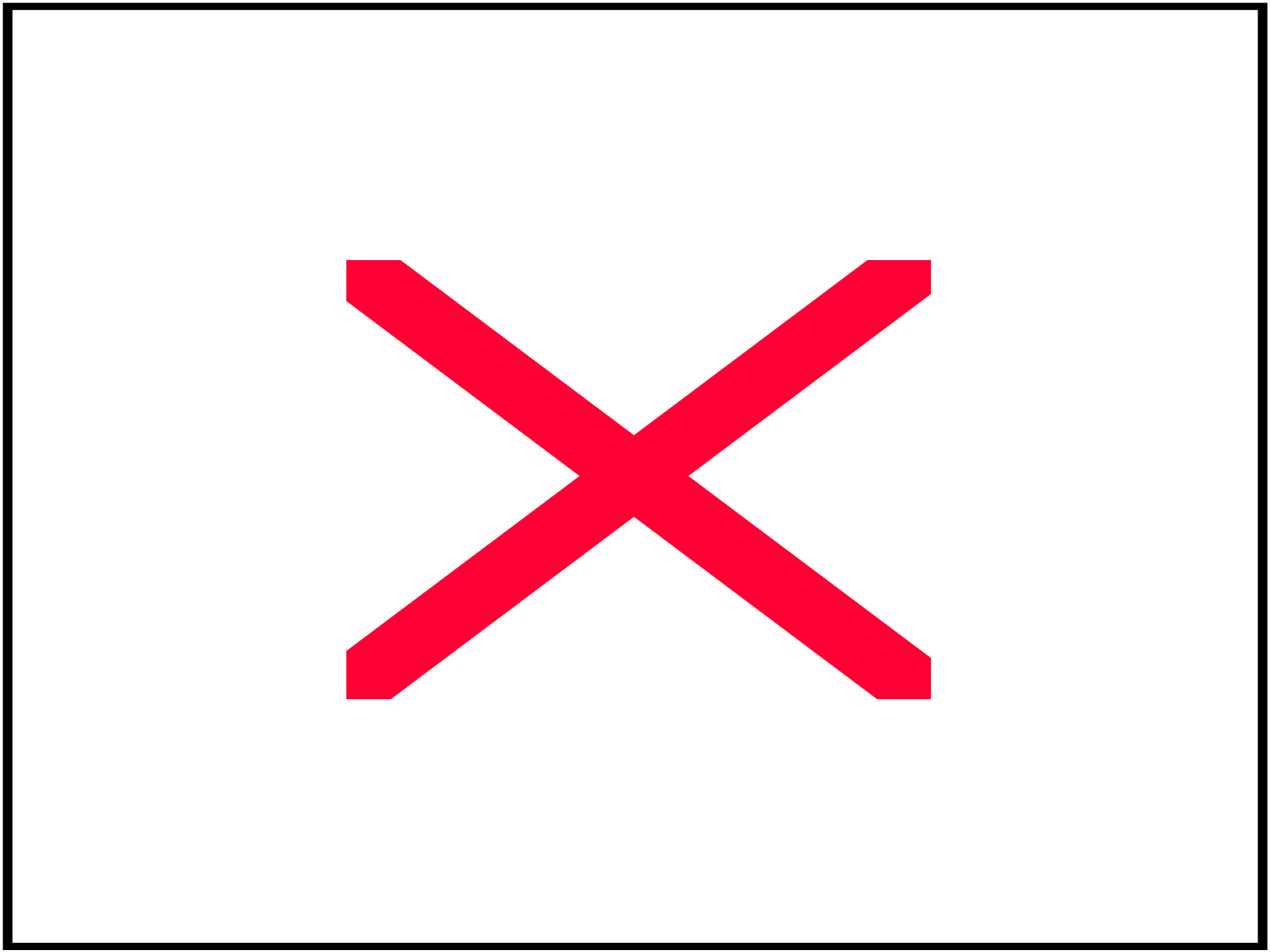






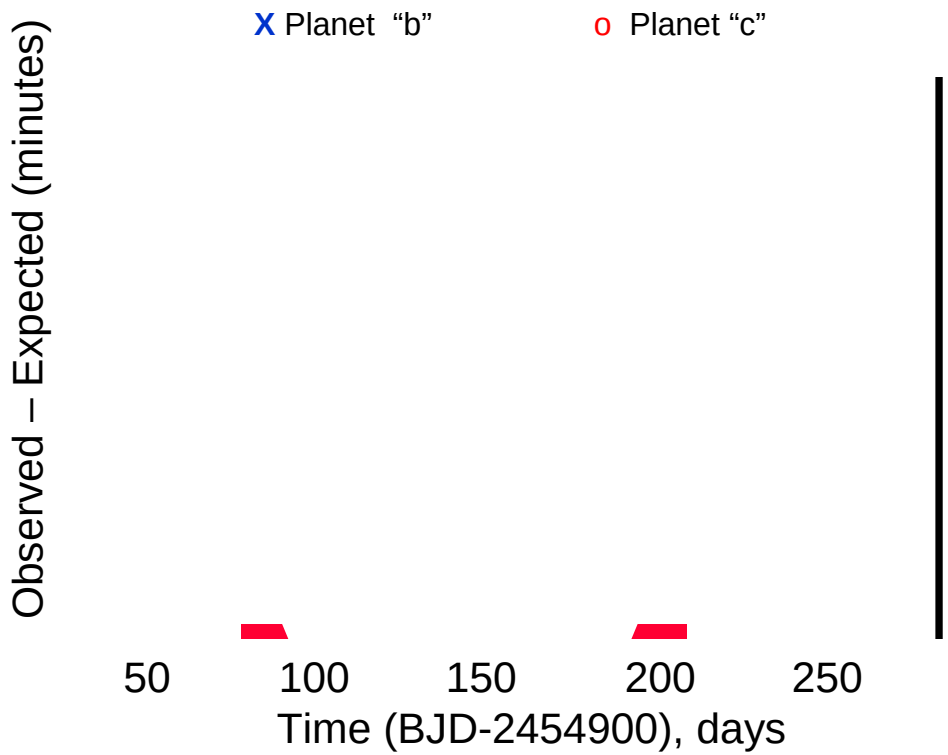






KEPLER 9; A STAR WITH AT LEAST TWO TRANSITING PLANETS

Kepler
A Search for Earth-size Planets



	Kepler 9b	Kepler 9c
Orbital Period (d)	19.24	38.91
Semi-major axis (AU)	0.14	0.225
Radius (Rearth)	9.4	9.2
Mass (Mearth)	80.1	54.7
Density (gr/cc)	0.52	0.38

The gravitational interaction between the two planets cause the transit times of each planet to vary. These variations allow the masses of the planets to be derived. The photometric and transit timing results allow the density to be estimated and provide information on the composition of the planets.

HIGHLIGHTS

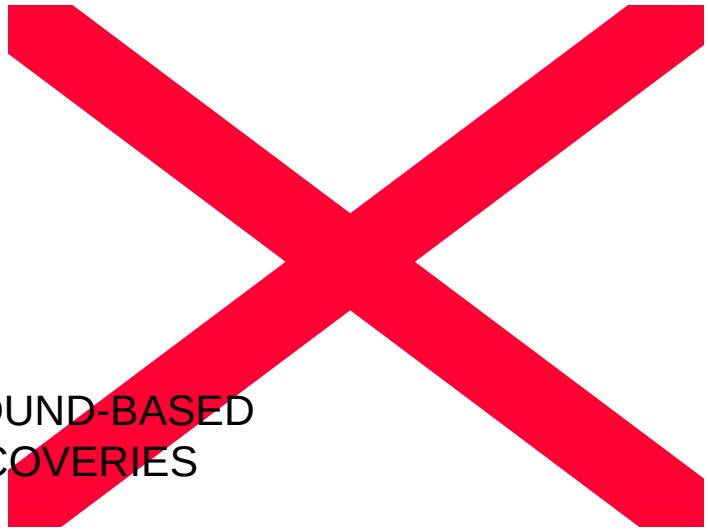
Kepler
A Search for Earth-size Planets

- 800 planetary candidates have been detected
- Characteristics and identification of 312 planetary candidates were released to the public in June. Q1 data will be released for all the remaining candidates in February 2011.
- Hundreds of the remaining candidates were observed during the summer.
  - Active optics; 83 stars
  - Speckle; 72
  - Reconnaissance spectra; 193
  - Centroid plots; 129
- After analysis of these data, announcements of many new and smaller exoplanets are expected in February 2011.

KEPLER CANDIDATE DISTRIBUTION IMPLIES MOST ARE SMALLER THAN NEPTUNE

Kepler
A Search for Earth-size Planets

KEPLER CANDIDATES



GROUND-BASED
DISCOVERIES

SUMMARY

A Search for Earth-size Planets

KEPLER IS FUNCTIONING WELL.

DATA NECESSARY TO OBSERVE > 300 CANDIDATES HAS BEEN RELEASED SO THAT THE COMMUNITY CAN HELP DISCOVER EXOPLANETS.

DATA FOR AN ADDITIONAL 500 CANDIDATES WILL BE RELEASED IN FEB.

ANNOUNCEMENT OF MANY NEW EXOPLANETS IS EXPECTED EARLY IN 2011 WHEN THE ANALYSIS OF THIS SUMMER'S FOLLOW UP OBSERVATIONS HAVE BEEN COMPLETED.