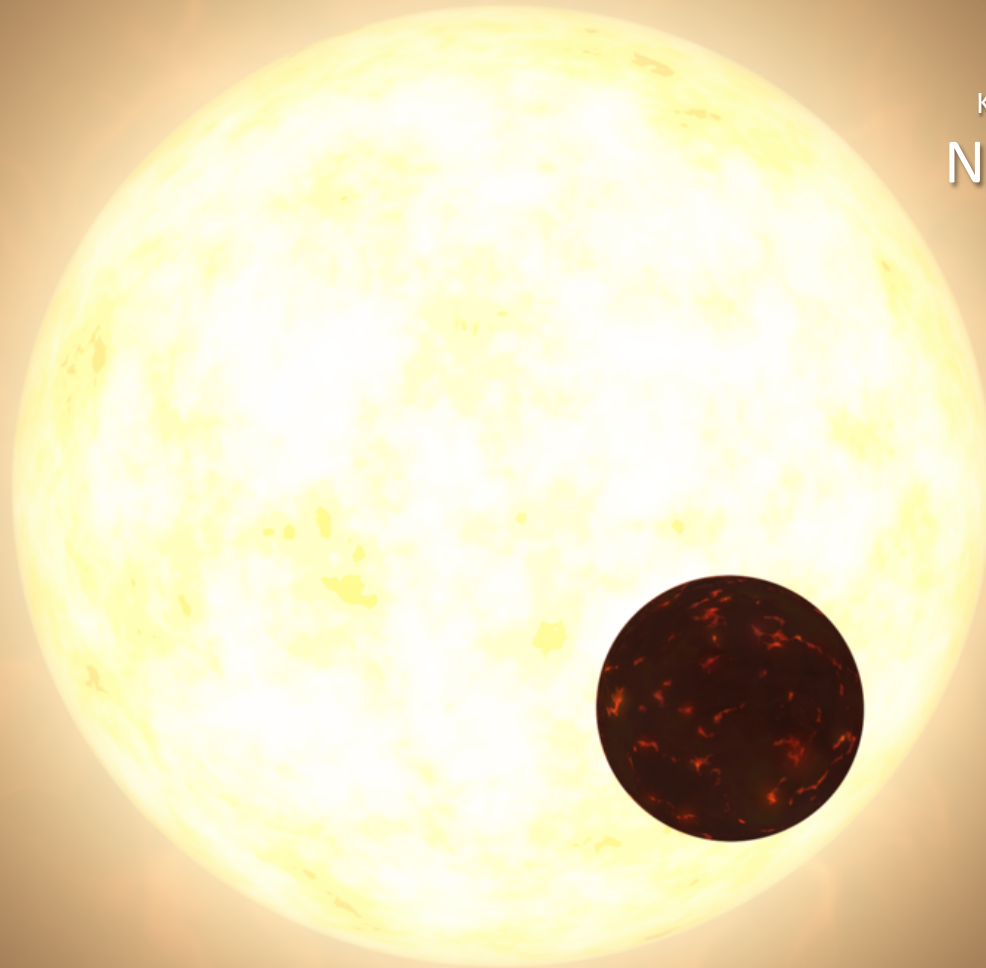


**Martin Still**

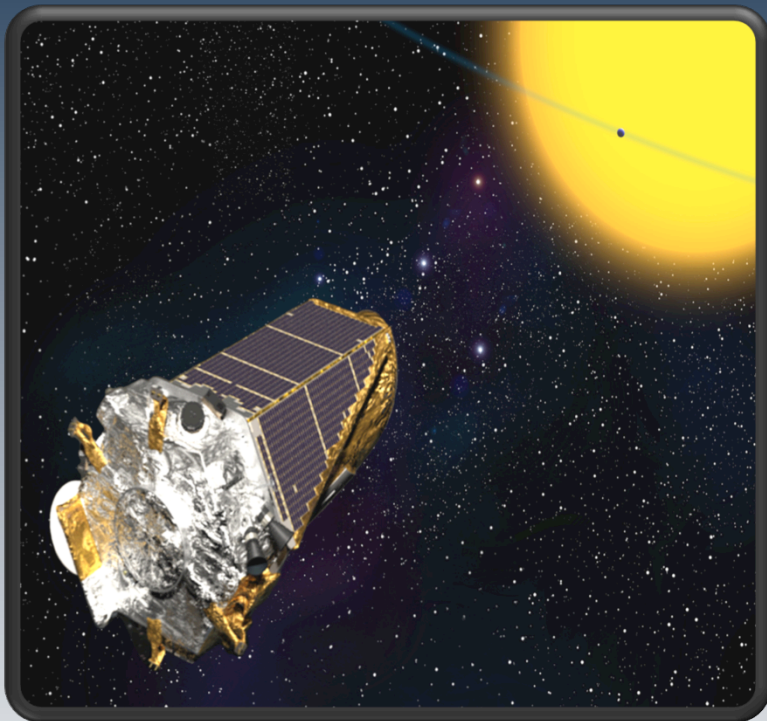
Kepler Guest Observer & Science Offices

NASA Ames Research

Center



# Working with Kepler Data: From Pixel Data to Light Curves

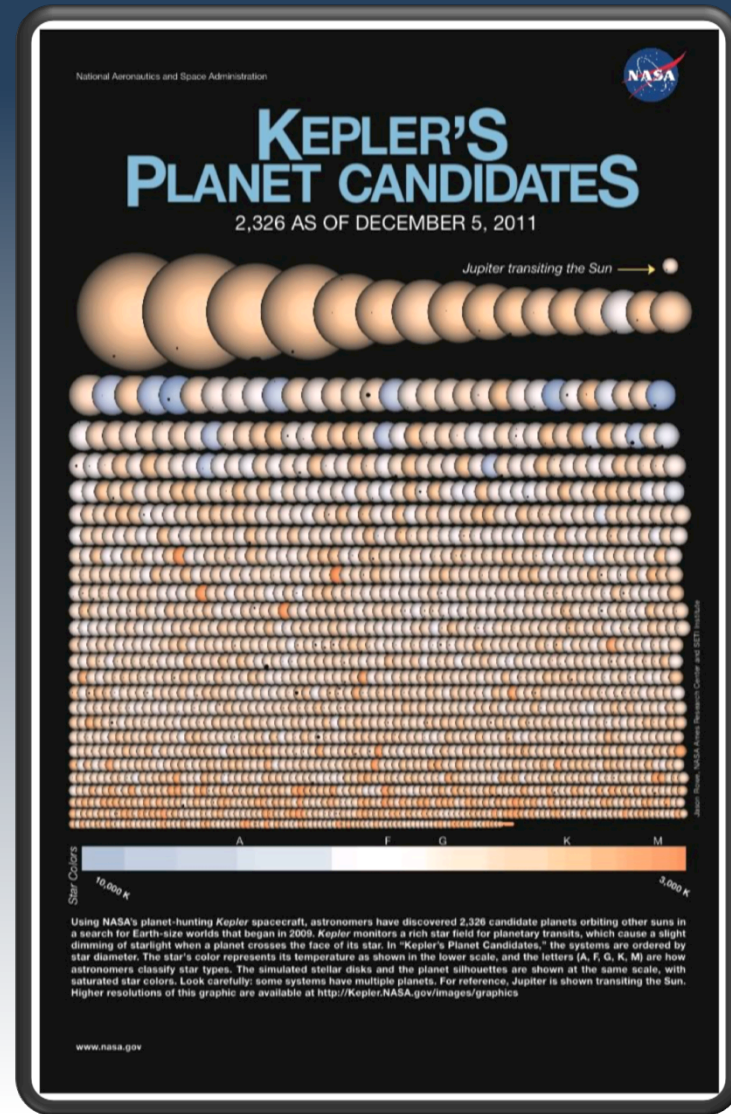
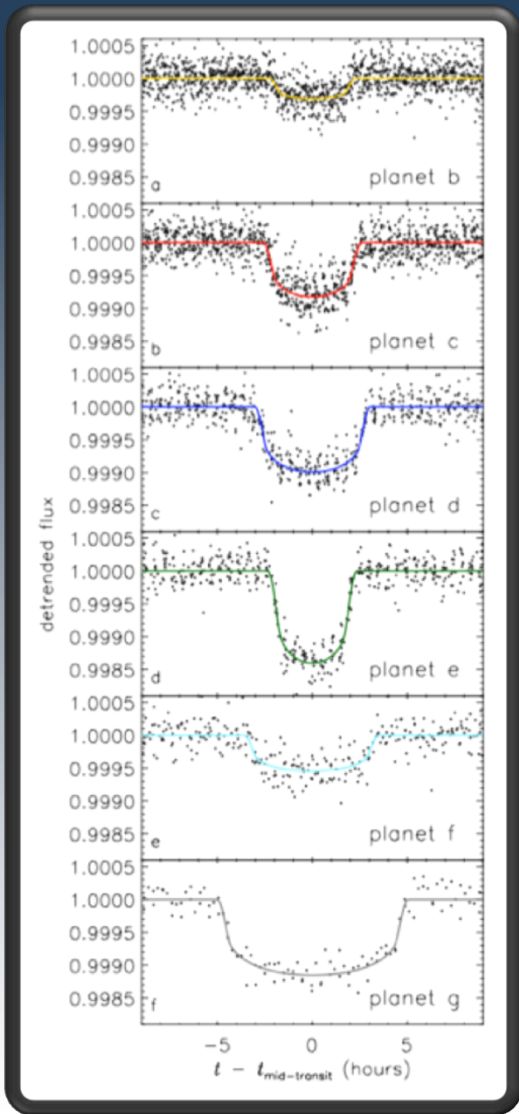


## Kepler Characteristics

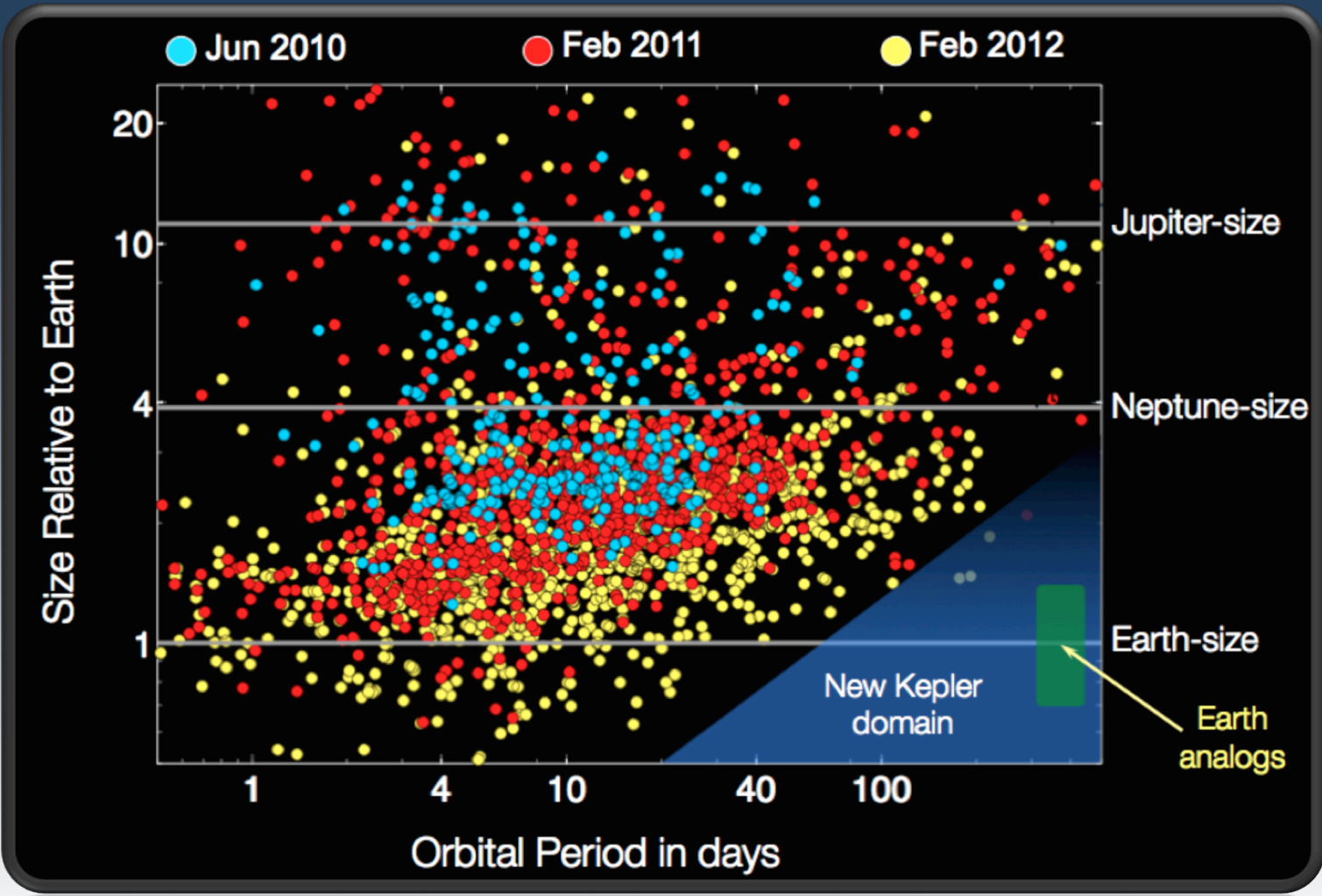
1. 1-m class space-borne telescope
  2. Single broad band photometer
  3. ~20 mas pointing stability
  4. 30- (and 1-) min data cadence
  5. multiple yrs of uniform data
  6. ~90% duty cycle
  7. 116 sq. deg field of view
- Individually, none of the above characteristics are unique
  - Collectively they are a unique and wonderful resource for exoplanet detection and characterization

detection and characterization











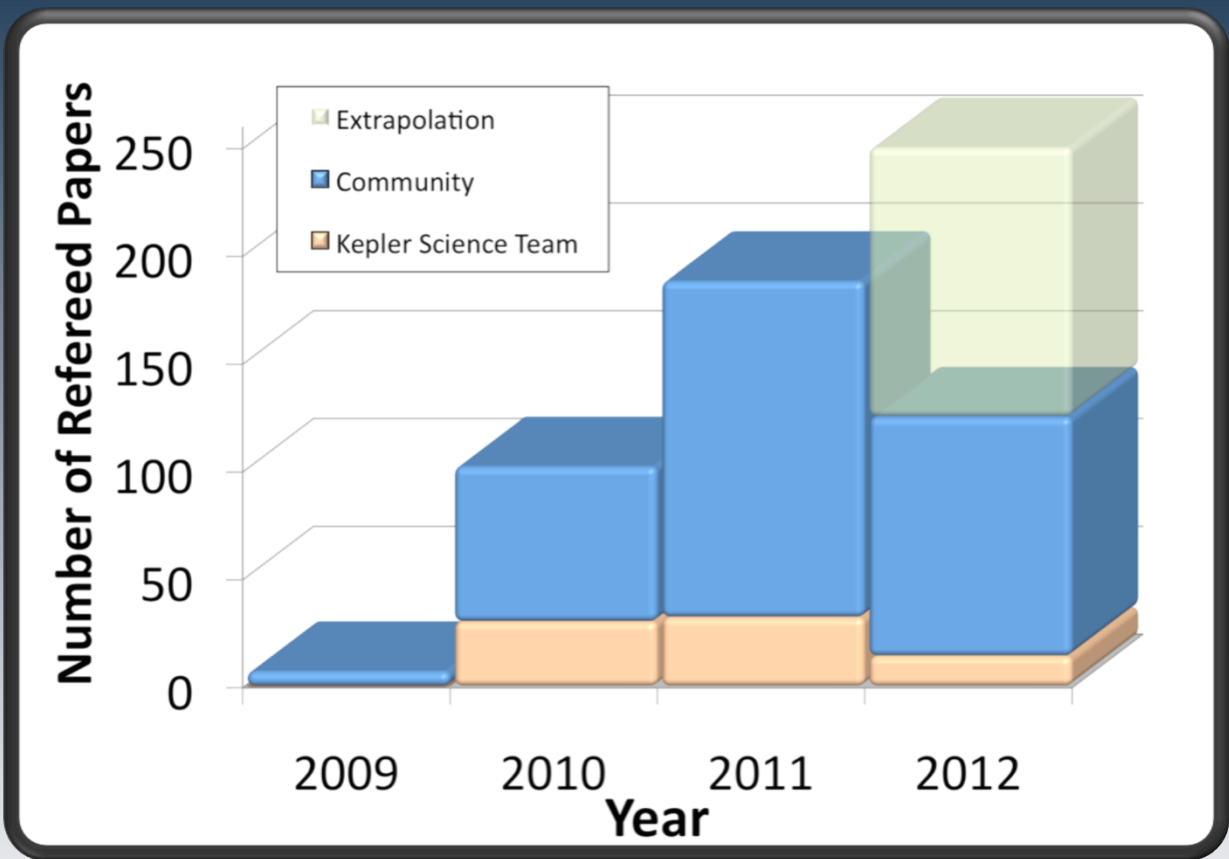
- » Continue exoplanet survey operation to produce an initial catalog of planet candidates
- » Execute a follow-up observing program that targets planet candidates with radius  $< 2.5 R_e$
- » Make a determination of  $\eta_e$
- » Facilitate community participation
- » Build and maintain a legacy archive and support community use of the Kepler data
- » Support community observations with Kepler





# KEPLER PUBLICATION STATISTICS

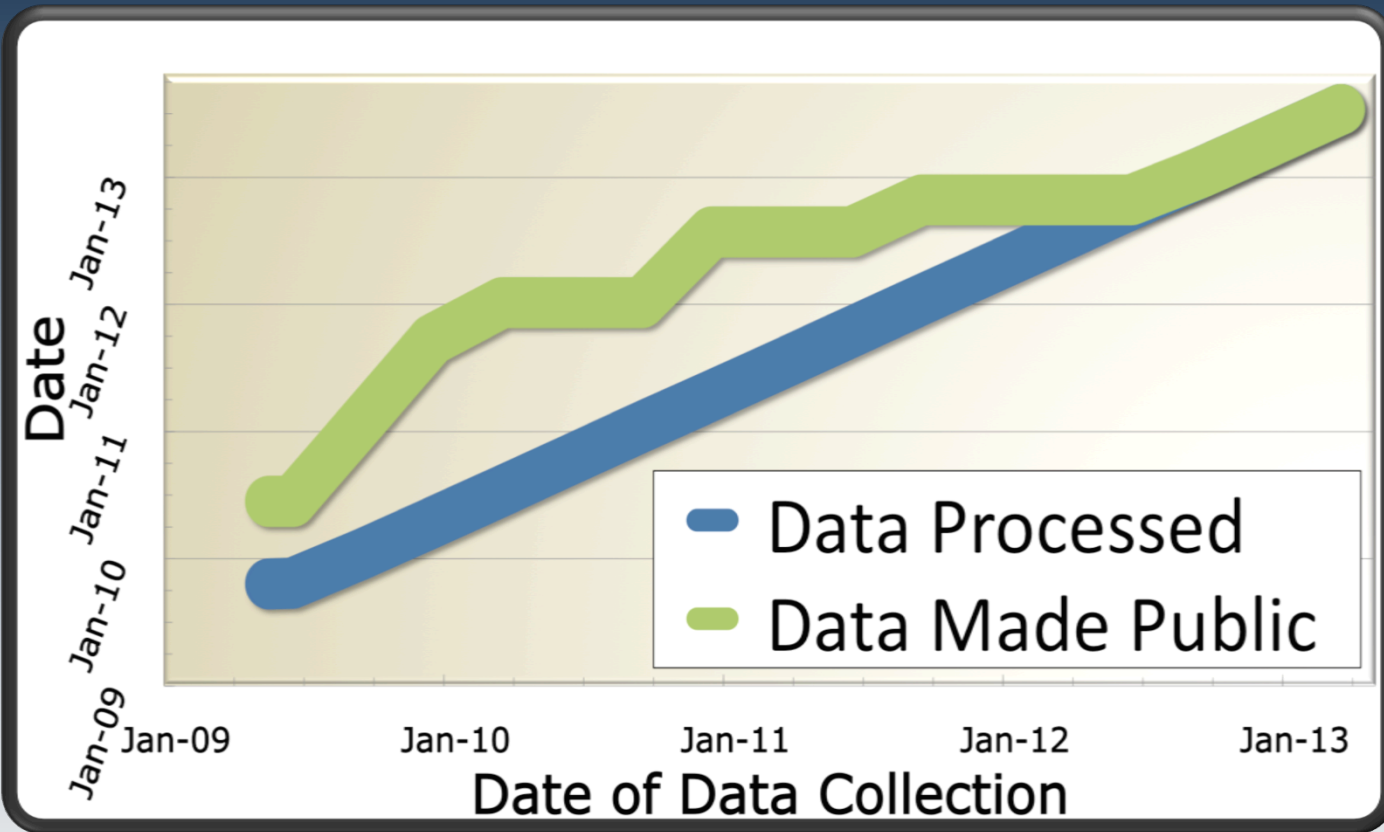
By number, Kepler publications are dominated by the independent community



archive.stsci.edu/kepler

No exclusive-use period for any Kepler data in the extended mission

Kepler is a community mission

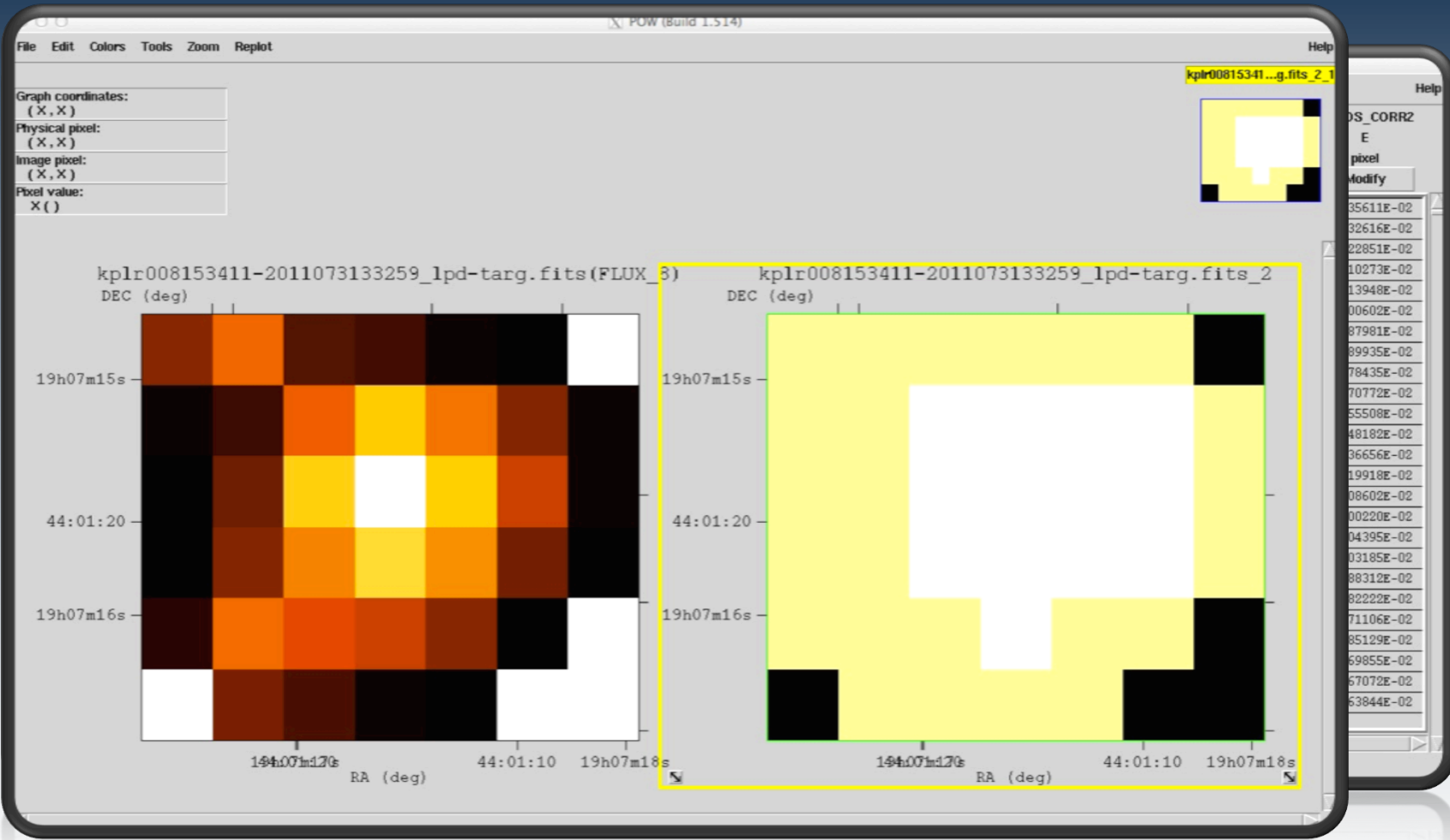




archive.stsci.edu/kepler

Full-Frame Images (FFIs) collected once per month





tv: Binary Table of kplr010666592-2010265121752\_lic.hits[1] in /Volumes/data/Kepler/KOI/HATP7/

File Edit Tools Help

TIME   
  TIMECORR   
  CADENCENO   
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  SAP\_BKG   
  SAP\_BKG\_ERR   
  PDCSAP\_FLUX   
  PDCSAP\_FLUX\_ERR   
  SAP\_QUALITY

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<input type="checkbox"/> All	BJD - 2454833	d		e- <i>s</i>	e- <i>s</i>	e- <i>s</i>	e- <i>s</i>	e- <i>s</i>	e- <i>s</i>	
<input type="checkbox"/> Invert	<input type="checkbox"/> Modify	<input type="checkbox"/> Modify	<input type="checkbox"/> Modify	<input type="checkbox"/> Modify	<input type="checkbox"/> Modify	<input type="checkbox"/> Modify	<input type="checkbox"/> Modify	<input type="checkbox"/> Modify	<input type="checkbox"/> Modify	<input type="checkbox"/> Modify
1	539.4488246	1.496731E-03	21069	1.0201570E+06	2.5822620E+01	4.5529540E+03	2.8666860E+00	NULL	NULL	136
2	539.4692588	1.497270E-03	21070	1.0204900E+06	2.5823510E+01	4.5569100E+03	2.8667140E+00	1.0165790E+06	2.5823510E+01	0
3	539.4896929	1.497809E-03	21071	1.0204400E+06	2.5824420E+01	4.5377540E+03	2.8667430E+00	1.0165280E+06	2.5824420E+01	0
4	539.5101272	1.498348E-03	21072	1.0204000E+06	2.5825320E+01	4.5723490E+03	2.8667720E+00	1.0164890E+06	2.5825320E+01	0
5	539.5305612	1.498887E-03	21073	1.0207680E+06	2.5826220E+01	4.5634320E+03	2.8668000E+00	1.0168570E+06	2.5826220E+01	128
6	539.5509953	1.499425E-03	21074	1.0208730E+06	2.5827120E+01	4.5520730E+03	2.8668290E+00	1.0169620E+06	2.5827120E+01	0
7	539.5714296	1.499964E-03	21075	1.0210070E+06	2.5828020E+01	4.5587140E+03	2.8668570E+00	1.0170950E+06	2.5828020E+01	2048
8	539.5918636	1.500502E-03	21076	1.0211480E+06	2.5828920E+01	4.5508820E+03	2.8668850E+00	1.0172360E+06	2.5828920E+01	2048
9	539.6122978	1.501040E-03	21077	1.0210660E+06	2.5829820E+01	4.5462750E+03	2.8669140E+00	1.0171540E+06	2.5829820E+01	0
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12	539.6736002	1.502653E-03	21080	1.0212740E+06	2.5832520E+01	4.5559610E+03	2.8669990E+00	1.0173620E+06	2.5832520E+01	0
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14	539.7144685	1.503727E-03	21082	1.0215680E+06	2.5834320E+01	4.5408170E+03	2.8670550E+00	1.0176560E+06	2.5834320E+01	0
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21	539.8575075	1.507483E-03	21089	1.0221290E+06	2.5840620E+01	4.5383540E+03	2.8672520E+00	1.0182170E+06	2.5840620E+01	0
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24	539.9188099	1.509090E-03	21092	1.0219010E+06	2.5843320E+01	4.5343170E+03	2.8673360E+00	1.0179890E+06	2.5843320E+01	0
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27	539.9801123	1.510696E-03	21095	1.0221900E+06	2.5845450E+01	4.5500880E+03	2.8672130E+00	1.0182780E+06	2.5845450E+01	0

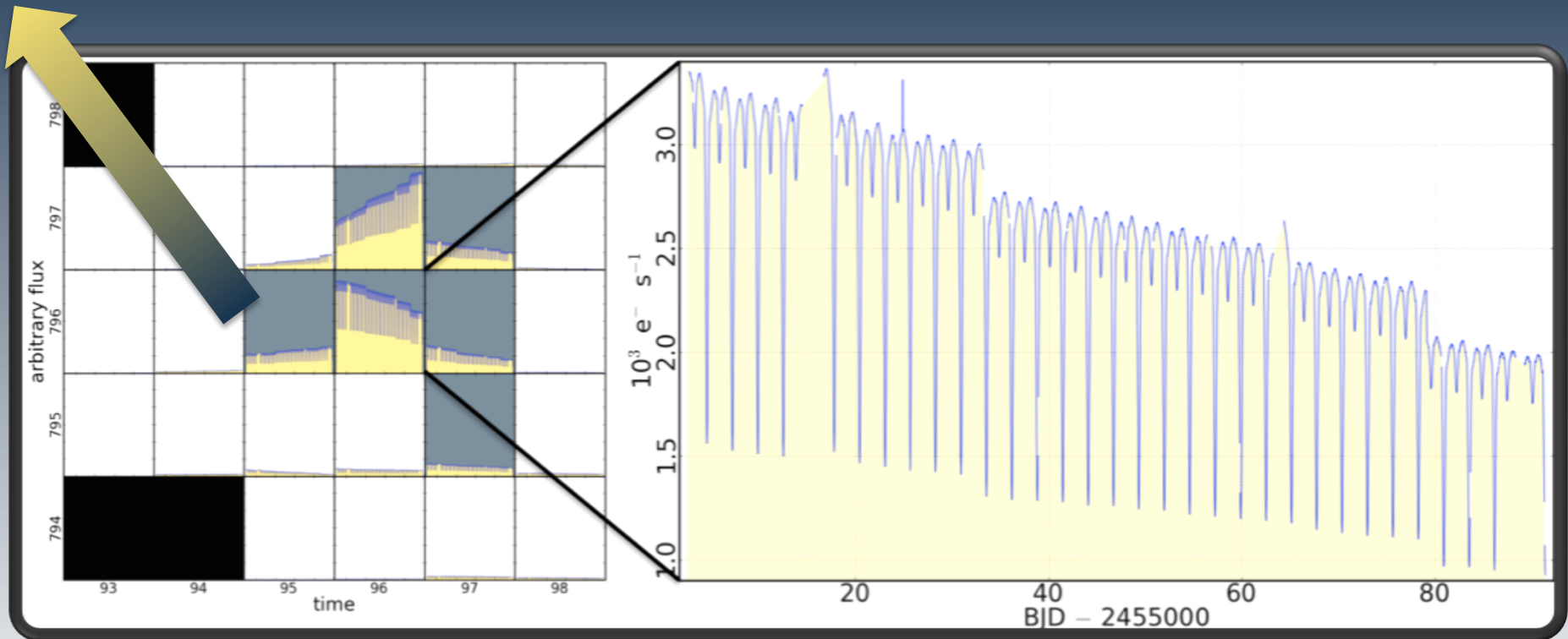
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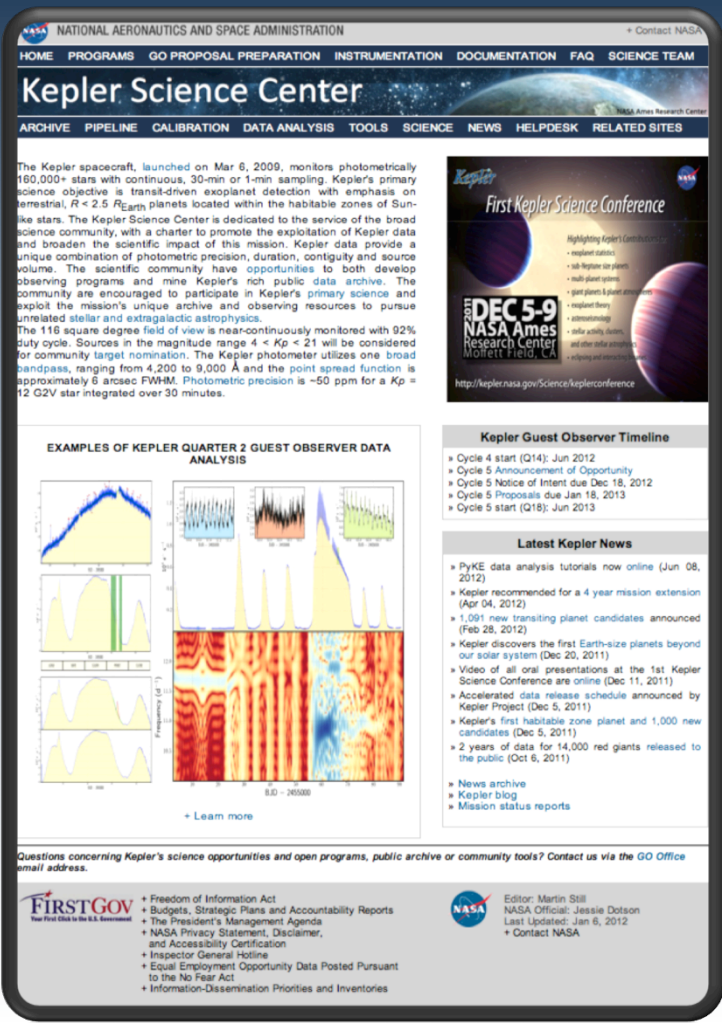


BJD - 5422000

Dominated by:

- Differential Velocity Aberration (DVA)
- thermal/focus drift
- spacecraft motion





NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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## Kepler Science Center

ARCHIVE PIPELINE CALIBRATION DATA ANALYSIS TOOLS SCIENCE NEWS HELPDESK RELATED SITES

The Kepler spacecraft, launched on Mar 6, 2009, monitors photometrically 160,000+ stars with continuous, 30-min or 1-min sampling. Kepler's primary science objective is transit-driven exoplanet detection with emphasis on terrestrial,  $R < 2.5 R_{Earth}$ , planets located within the habitable zones of Sun-like stars. The Kepler Science Center is dedicated to the service of the broad science community, with a charter to promote the exploitation of Kepler data and broaden the scientific impact of this mission. Kepler data provide a unique combination of photometric precision, duration, contiguity and source volume. The scientific community have opportunities to both develop observing programs and mine Kepler's rich public data archive. The community are encouraged to participate in Kepler's primary science and exploit the mission's unique archive and observing resources to pursue unrelated stellar and extragalactic astrophysics.

The 116 square degree field of view is near-continuously monitored with 92% duty cycle. Sources in the magnitude range  $4 < Kp < 21$  will be considered for community target nomination. The Kepler photometer utilizes one broad bandpass, ranging from 4,200 to 9,000 Å and the point spread function is approximately 6 arcsec FWHM. Photometric precision is ~50 ppm for a  $Kp = 12$  G2V star integrated over 30 minutes.

### Kepler Science Conference

DEC 5-9  
NASA Ames Research Center  
Moffett Field, CA

Highlighting Kepler's Contributions:

- exoplanet statistics
- solar system planets
- multi-planet systems
- giant planets & planet atmospheres
- exoplanet theory
- exoplanet discovery
- exoplanet characterization
- exoplanet science
- exoplanet data analysis
- exoplanet data visualization
- exoplanet data access

<http://kepler.nasa.gov/science/keplerconference>

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- Cycle 4 start (Q14): Jun 2012
- Cycle 5 Announcement of Opportunity
- Cycle 5 Notice of Intent due Dec 18, 2012
- Cycle 5 Proposals due Jan 18, 2013
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### Latest Kepler News

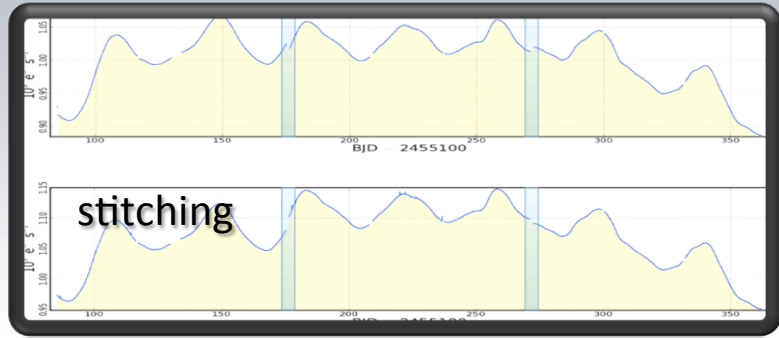
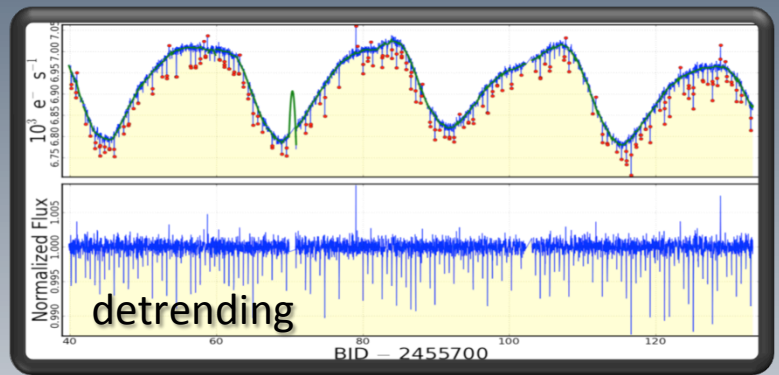
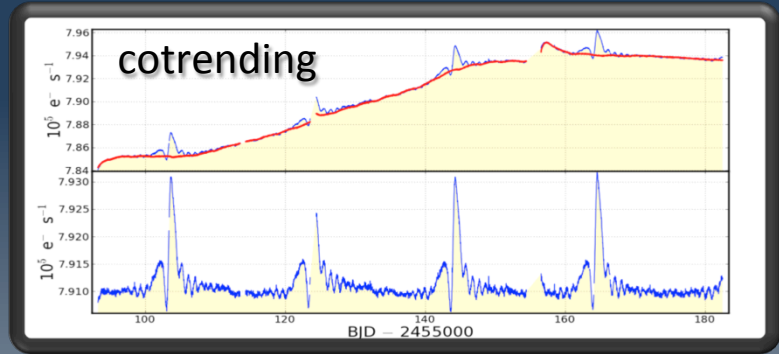
- PyKE data analysis tutorials now online (Jun 08, 2012)
- Kepler recommended for a 4 year mission extension (Apr 04, 2012)
- 1,001 new transiting planet candidates announced (Feb 28, 2012)
- Kepler discovers the first Earth-size planets beyond our solar system (Dec 20, 2011)
- Video of all oral presentations at the 1st Kepler Science Conference are online (Dec 11, 2011)
- Accelerated data release schedule announced by Kepler Project (Dec 5, 2011)
- Kepler's first habitable zone planet and 1,000 new candidates (Dec 5, 2011)
- 2 years of data for 14,000 red giants released to the public (Oct 6, 2011)
- News archive
- Kepler blog
- Mission status reports

Questions concerning Kepler's science opportunities and open programs, public archive or community tools? Contact us via the GO Office email address.

**FIRSTGOV**  
First Look into the U.S. Government

- Freedom of Information Act
- Budgets, Strategic Plans and Accountability Reports
- The President's Management Agenda
- NASA Privacy Statement, Disclaimer, and Accessibility Certification
- Inspector General Hotline
- Equal Employment Opportunity Data Posted Pursuant to the No Fear Act
- Information-Dissemination Priorities and Inventories

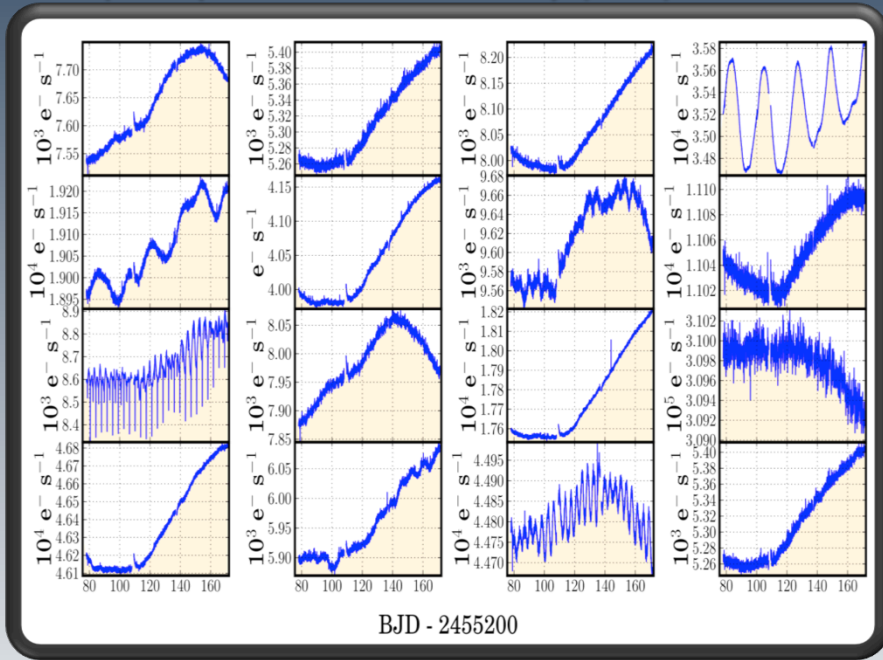
NASA Editor: Martin Still  
NASA Official: Jessie Dotson  
Last Updated: Jan 6, 2012  
• Contact NASA



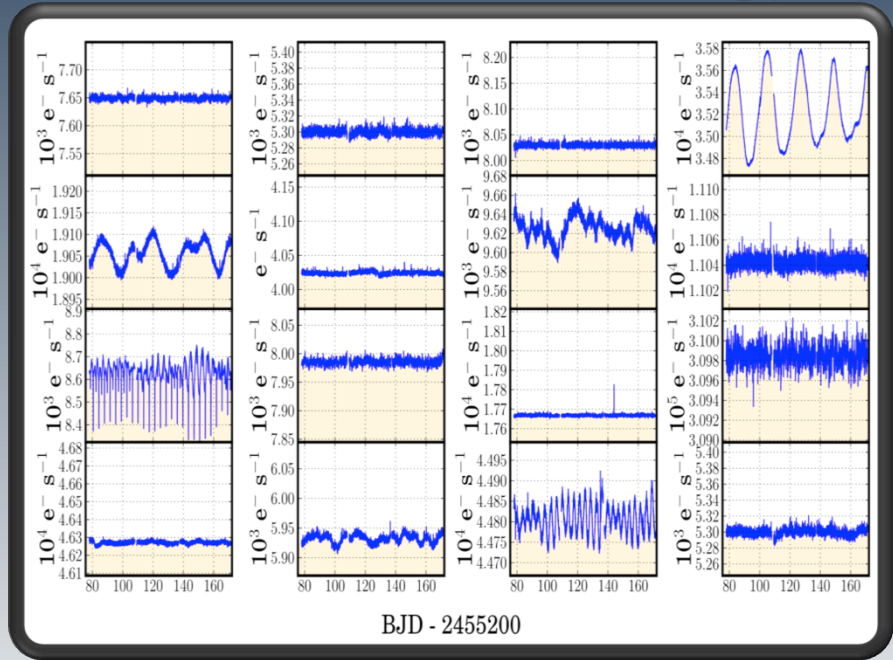
- » PyKE is *not* the Kepler pipeline
- » The Kepler pipeline is monolithic and optimized to perform upon  $10^5$  stars as an ensemble
- » PyKE is modular and designed to perform upon data of individual targets
- » PyKE tunes data to the specific requirements of the scientist, rather than the general requirements of the Kepler pipeline



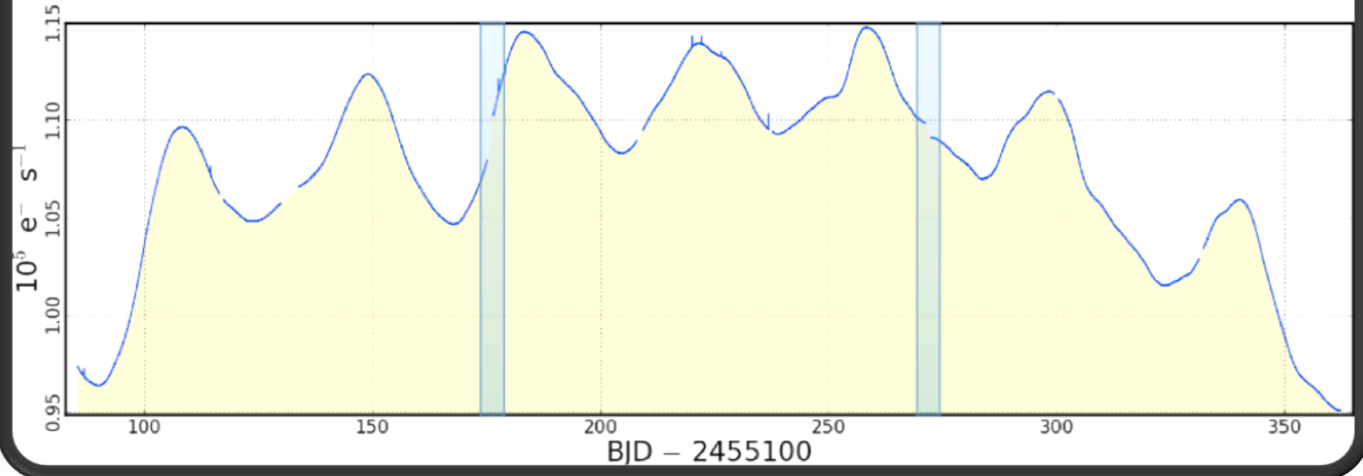
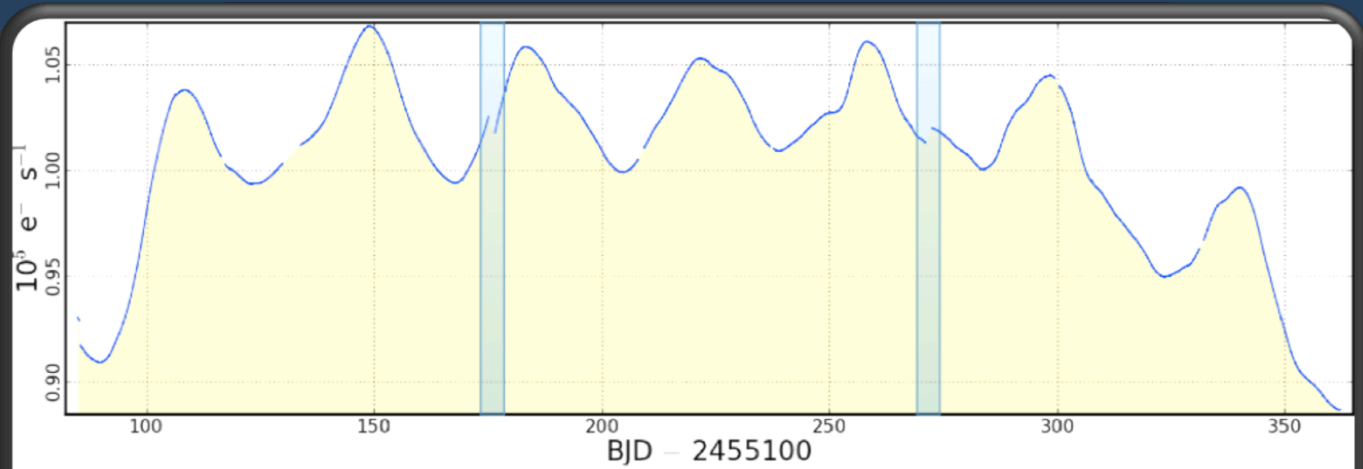
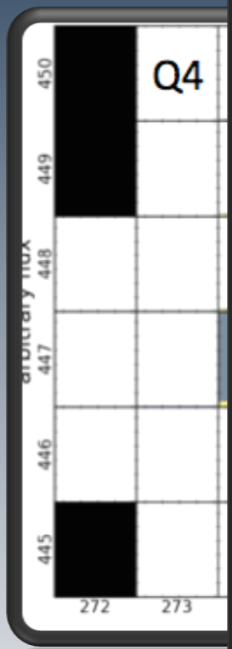
## Simple Aperture Photometry (SAP)



## Cotrended Aperture Photometry aka Pre-search Data Conditioning (PDC)

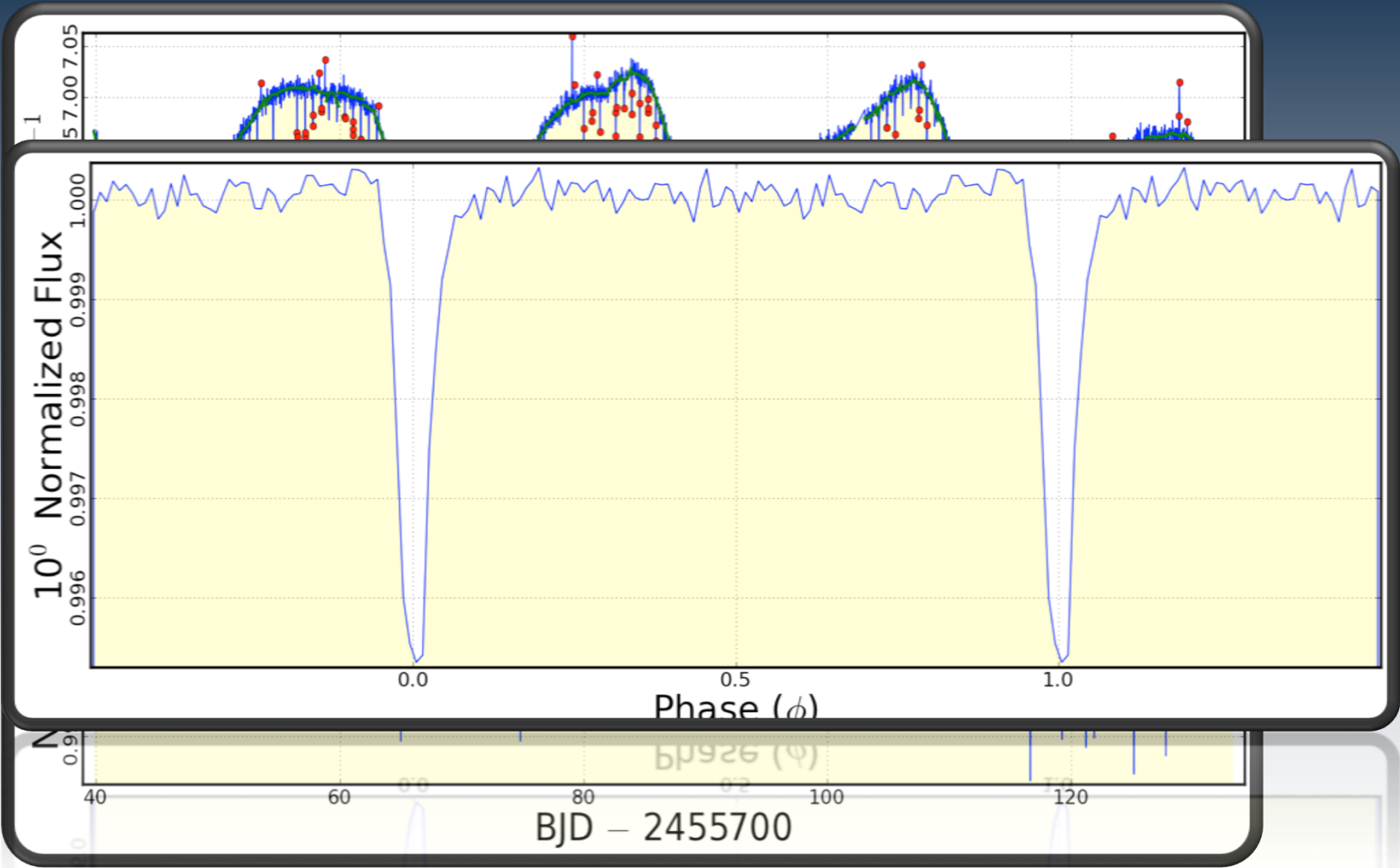


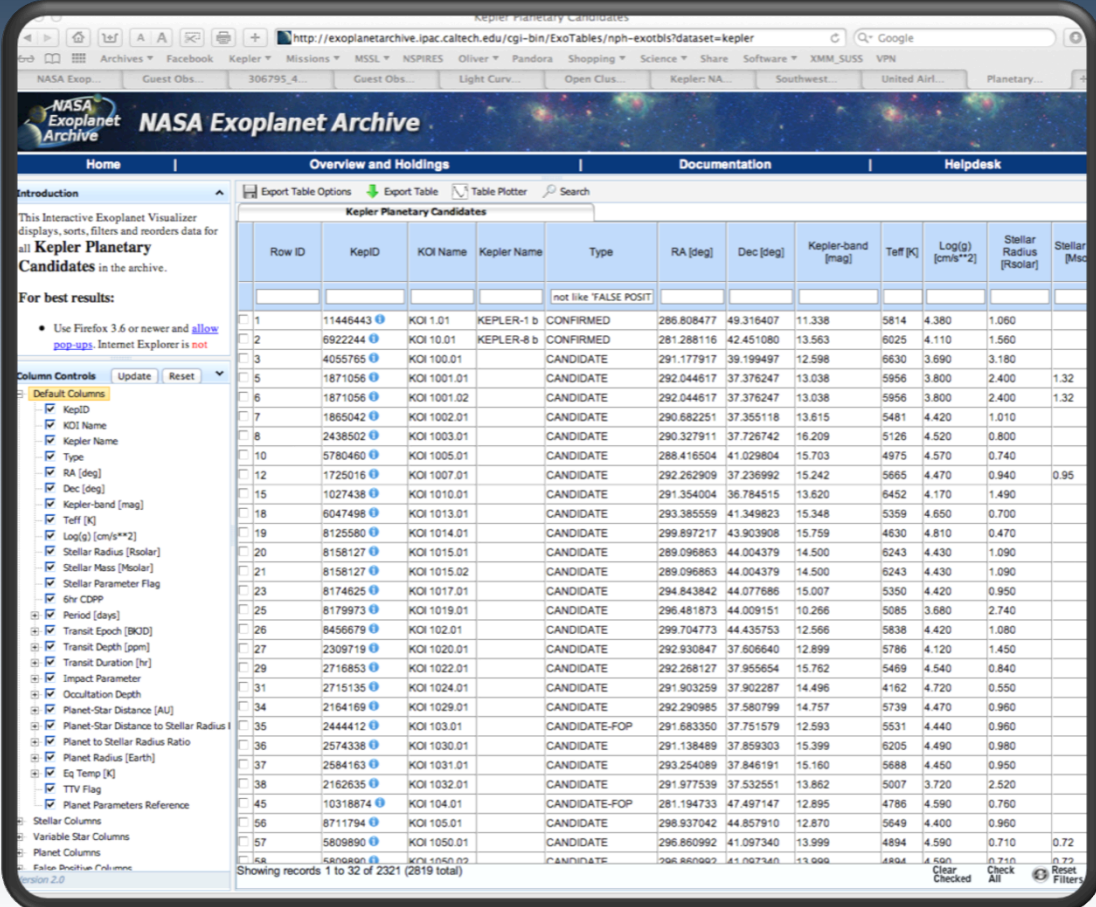
spacecraft rolls 90 deg once every 93 days for efficient solar panel operation  
 targets generally fall on 4 different CCDs every 372-d orbit





depth of transits depends upon source confusion within the photometric aperture  
CROWDSAP and FLXFRSAP keywords are included in light curve files i.e. approximations to fraction of light from other sources and fraction of target light falling within the aperture





The screenshot shows the NASA Exoplanet Archive interface. The main table displays Kepler Planetary Candidates with columns for Row ID, KepID, KOI Name, Kepler Name, Type, RA [deg], Dec [deg], Kepler-band [mag], T<sub>eff</sub> [K], Log(g) [cm/s<sup>2</sup>], Stellar Radius [R<sub>solar</sub>], and Stellar Mass [M<sub>solar</sub>]. The table lists various candidates, including confirmed planets like Kepler-1 b and Kepler-8 b, and numerous candidates (KOIs).

Row ID	KepID	KOI Name	Kepler Name	Type	RA [deg]	Dec [deg]	Kepler-band [mag]	T <sub>eff</sub> [K]	Log(g) [cm/s <sup>2</sup> ]	Stellar Radius [R <sub>solar</sub> ]	Stellar Mass [M <sub>solar</sub> ]
1	11446443	KOI 1.01	KEPLER-1 b	CONFIRMED	286.808477	49.316407	11.338	5814	4.380	1.060	
2	6922244	KOI 10.01	KEPLER-8 b	CONFIRMED	281.288116	42.451080	13.563	6025	4.110	1.560	
3	4055765	KOI 100.01		CANDIDATE	291.177917	39.199497	12.598	6630	3.690	3.180	
5	1871056	KOI 1001.01		CANDIDATE	292.044617	37.376247	13.038	5956	3.800	2.400	1.32
6	1871056	KOI 1001.02		CANDIDATE	292.044617	37.376247	13.038	5956	3.800	2.400	1.32
7	1865042	KOI 1002.01		CANDIDATE	290.682251	37.355118	13.615	5481	4.420	1.010	
8	2438502	KOI 1003.01		CANDIDATE	290.327911	37.726742	16.209	5126	4.520	0.800	
10	5780460	KOI 1005.01		CANDIDATE	288.416504	41.029894	15.703	4975	4.570	0.740	
12	1725016	KOI 1007.01		CANDIDATE	292.262909	37.236992	15.242	5665	4.470	0.940	0.95
15	1027438	KOI 1010.01		CANDIDATE	291.354004	36.784515	13.620	6452	4.170	1.490	
18	6047498	KOI 1013.01		CANDIDATE	293.385559	41.349823	15.348	5359	4.650	0.700	
19	8125580	KOI 1014.01		CANDIDATE	299.897217	43.903908	15.759	4630	4.810	0.470	
20	8158127	KOI 1015.01		CANDIDATE	289.096863	44.004379	14.500	6243	4.430	1.090	
21	8158127	KOI 1015.02		CANDIDATE	289.096863	44.004379	14.500	6243	4.430	1.090	
23	8174625	KOI 1017.01		CANDIDATE	294.843842	44.077686	15.007	5350	4.420	0.950	
25	8179973	KOI 1019.01		CANDIDATE	296.481873	44.009151	10.266	5085	3.680	2.740	
26	8456679	KOI 1020.01		CANDIDATE	299.704773	44.435753	12.566	5838	4.420	1.080	
27	2309719	KOI 1020.01		CANDIDATE	292.930847	37.606640	12.899	5786	4.120	1.450	
29	2716853	KOI 1022.01		CANDIDATE	292.268127	37.955654	15.762	5469	4.540	0.840	
31	2715135	KOI 1024.01		CANDIDATE	291.903259	37.902287	14.496	4162	4.720	0.550	
34	2164169	KOI 1029.01		CANDIDATE	292.290985	37.580799	14.757	5739	4.470	0.960	
35	2444412	KOI 1030.01		CANDIDATE-FOP	291.683350	37.751579	12.593	5531	4.440	0.960	
36	2574338	KOI 1030.01		CANDIDATE	291.138489	37.859303	15.399	6205	4.490	0.980	
37	2584163	KOI 1031.01		CANDIDATE	293.254089	37.846191	15.160	5688	4.450	0.950	
38	2162635	KOI 1032.01		CANDIDATE	291.977539	37.532551	13.862	5007	3.720	2.520	
45	10318874	KOI 104.01		CANDIDATE-FOP	281.194733	47.497147	12.895	4786	4.590	0.780	
56	8711794	KOI 1050.01		CANDIDATE	298.937042	44.857910	12.870	5649	4.400	0.960	
57	5809890	KOI 1050.01		CANDIDATE	296.860992	41.097340	13.999	4894	4.590	0.710	0.72
58	5809890	KOI 1050.02		CANDIDATE	296.860992	41.097340	13.999	4894	4.590	0.710	0.72

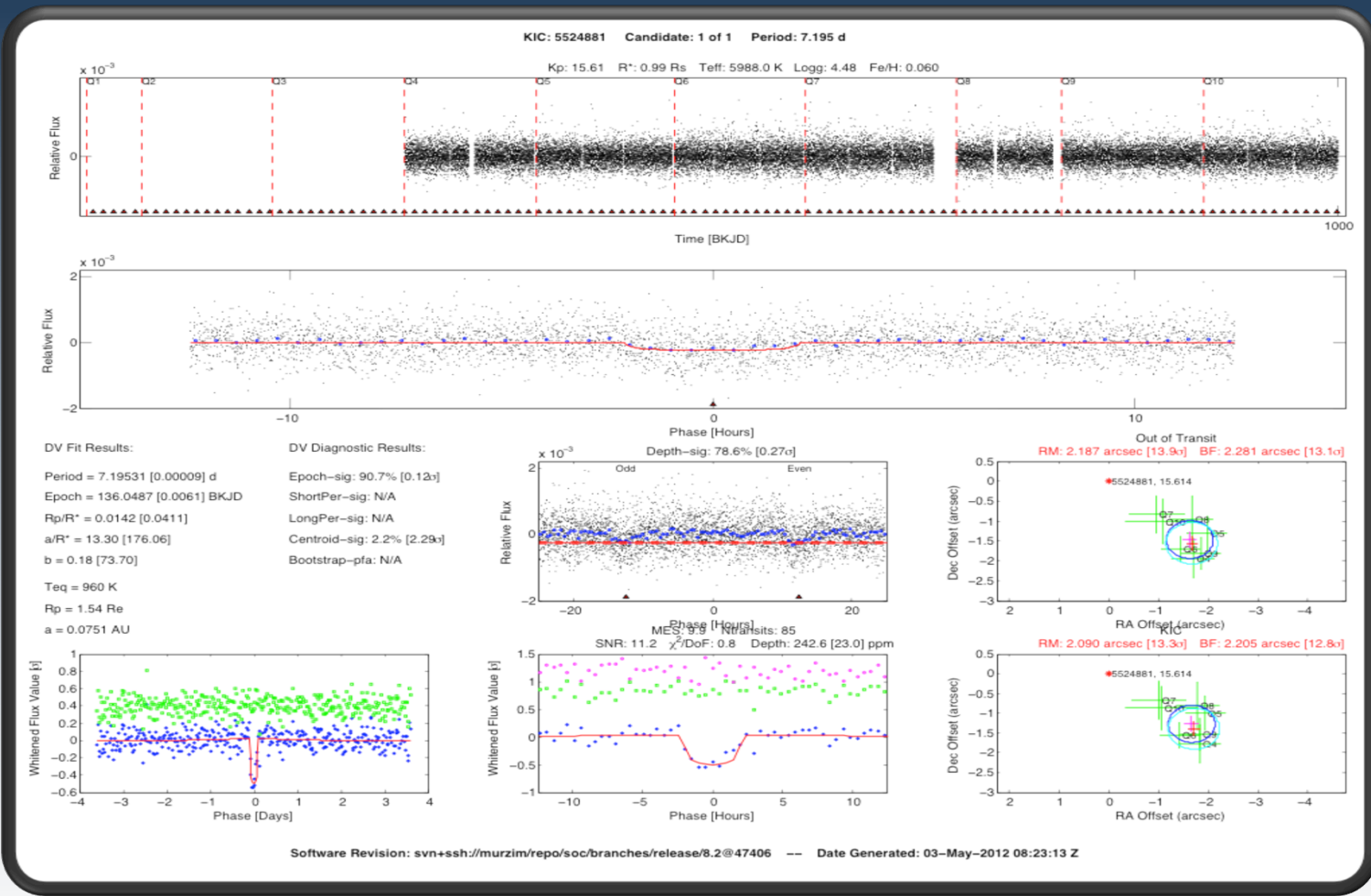
Showing records 1 to 32 of 2321 (2819 total)

## Archived Product (~10/2012)

1. Threshold Crossing Events (TCEs)
2. Kepler Objects of Interest (KOIs)
3. Vetting diagnostics

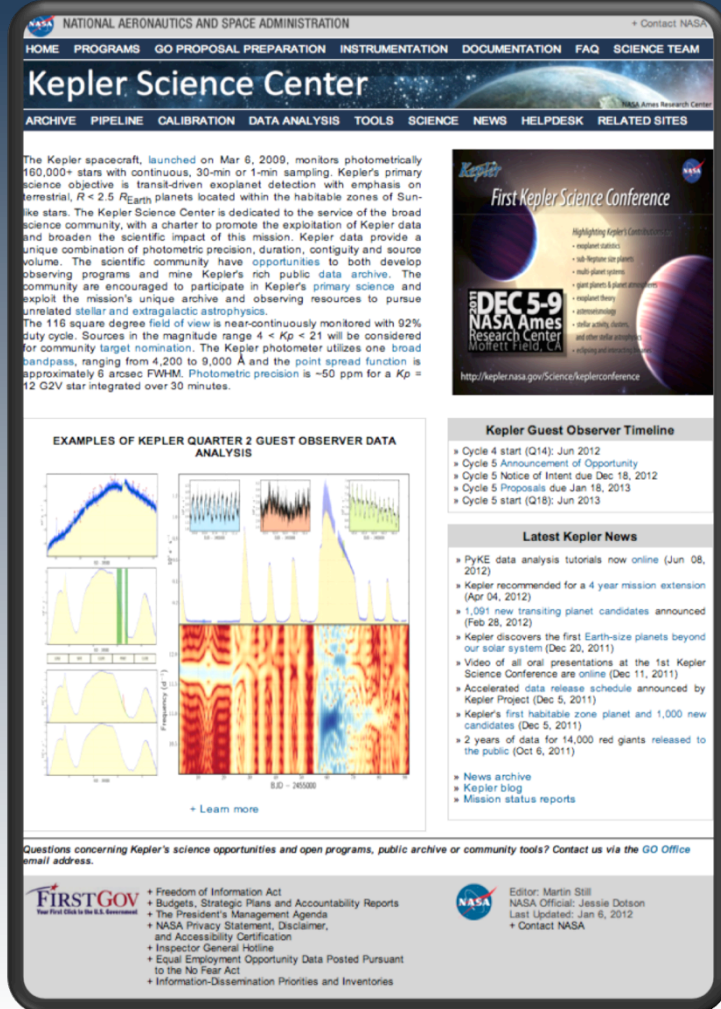


PDF documents and electronic tables containing vetting diagnostics for every TCE e.g. planet candidate, eclipsing binary, contaminating background binary or data artifact?



## » Kepler Science Center website

- » Data Processing Handbook
- » Archive Users Manual
- » Data Characteristics Handbook
- » Data Release Notes
- » PyKE download and installation
- » Data and PyKE primer
- » Walkthrough examples with PyKE



**NASA NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

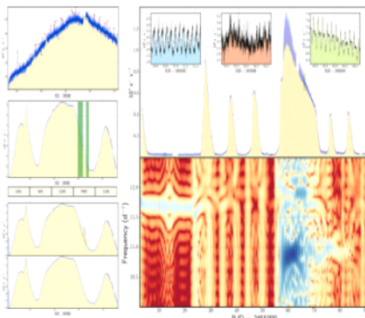
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### EXAMPLES OF KEPLER QUARTER 2 GUEST OBSERVER DATA ANALYSIS



Learn more

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- » PyKE data analysis tutorials now online (Jun 08, 2012)
- » Kepler recommended for a 4 year mission extension (Apr 04, 2012)
- » 1,091 new transiting planet candidates announced (Feb 28, 2012)
- » Kepler discovers the first Earth-size planets beyond our solar system (Dec 20, 2011)
- » Video of all oral presentations at the 1st Kepler Science Conference are online (Dec 11, 2011)
- » Accelerated data release schedule announced by Kepler Project (Dec 5, 2011)
- » Kepler's first habitable zone planet and 1,000 new candidates (Dec 5, 2011)
- » 2 years of data for 14,000 red giants released to the public (Oct 6, 2011)

- » News archive
- » Kepler blog
- » Mission status reports

Questions concerning Kepler's science opportunities and open programs, public archive or community tools? Contact us via the GO Office email address.

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MARTIN STILL

- » The Kepler extended mission plan relies critically on the participation of a broad exoplanet community
- » From Oct 2012, Kepler will be operated as an open mission to that purpose
- » Product and resources are coming online *now* and over the coming months at Kepler, NExSci and MAST to support community driven planet candidate
  - » identification
  - » disposition
  - » characterization
  - » completeness
- » PyKE tools provide means to customize & optimize Kepler data
- » PyKE is open-source, free to use, but also designed for community contribution – send more/better tools!

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