

# *CoRoT* and *Kepler* time series

Focus session on time domain astronomy

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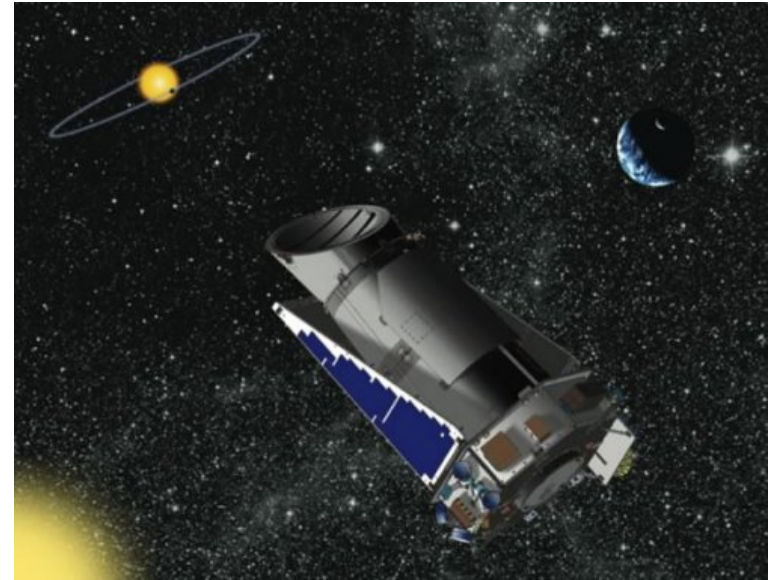
IVOA Interoperability meeting, Heidelberg, 12-17 May, 2013

## CoRoT



- Polar orbit
- 27 cm mirror telescope
- visual light
- 4 2k x 2k CCD imagers
- Several observed fields (each about 3 x 3 deg)

## *Kepler*



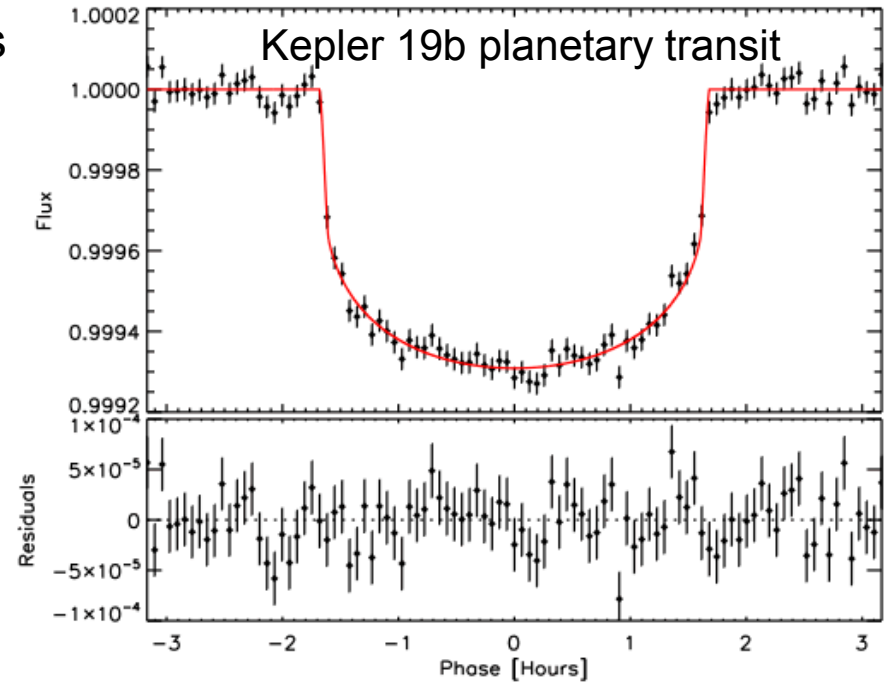
- Earth trailing orbit
- 0.95 m mirror telescope
- visual light
- 42 2k x 1k CCD imagers
- 1 observed field (105 deg<sup>2</sup>)

- **CoRoT**

- Launched Dec. 2006, no longer producing science data since Nov. 2012, recovery efforts ongoing
- **CO**nvection **RO**tation and planetary **T**ransits
- Asteroseismology, search for exoplanets
- ~160.000 stars
- 32 or 512 sec. sampling, max 150 days

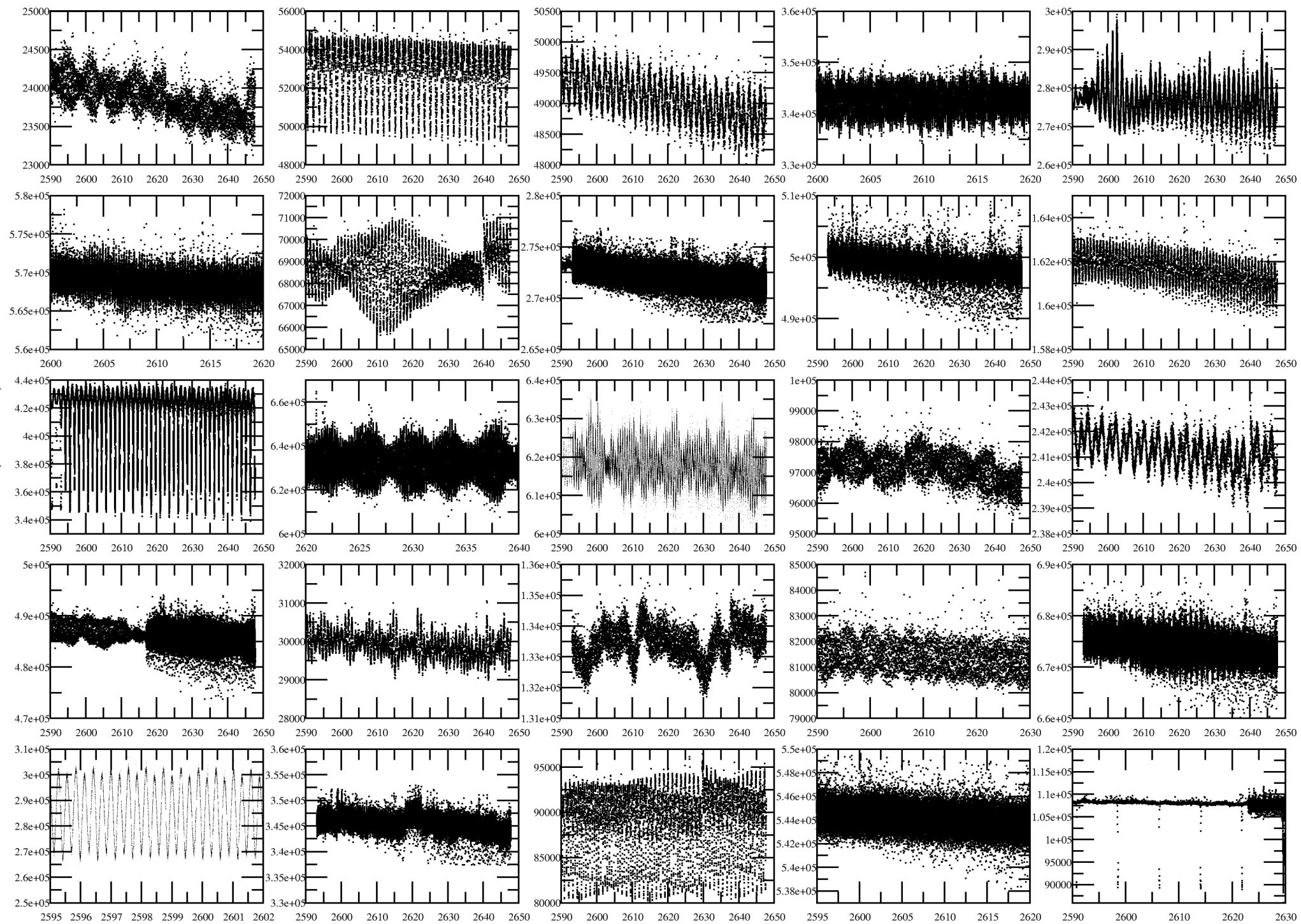
- **Kepler**

- Launched March 2009 (until 2016 at least)
- Exoplanet detection using transit method
- ~156.000 stars
- 1 or 30 min sampling, observing quarters of 90 days (up to 7 years total!)



- Both missions deliver densely sampled light curves with high photometric precision ---> unique data sets for stellar variability studies!

Flux (counts)



HJD (days)



# Time series (light curve) data

- Data volumes (minimum): ~1TB for CoRoT, ~ 10TB for Kepler (will be much more for e.g. LSST and Gaia!)
- Minimal data delivery for users: target ID, coordinates, stellar flux time series (ASCII or FITS format)
- Often more information is needed (usually present in FITS files headers)
  - Instrument parameters (e.g. to identify artifacts in the data)
  - Data reduction information, e.g. background flux, noise levels, quality flags...
  - Additional time columns, e.g. barycentric or heliocentric Julian dates
  - Additional flux columns (different data reduction or extraction)
  - Complementary data from other databases & higher level metadata

# CoRoT Data Center at IAS: <http://idoc-corot.ias.u-psud.fr/> Downloading CoRoT light curves per observed run

You can retrieve the N2 data by downloading a whole set for a given run (last version available) :

Runs	Light curves of the Astero channel (AN2_STAR)	Monochromatic light curves of the Exo channel (EN2_STAR_MON)	Chromatic light curves of the Exo channel (EN2_STAR_CHR)	EN2_WINDESCRIPTOR files of the Exo channel	Light curves from imagettes files of the Exo channel (EN2_STAR_IMAG and associated WINDESCRIPTOR)
IRa01	<a href="#">here</a> [MD5] [SHA-1] (94MB)	<a href="#">here</a> [MD5] [SHA-1] (1,5GB)	<a href="#">here</a> [MD5] [SHA-1] (5,9GB)	<a href="#">here</a> [MD5] [SHA-1] (40MB)	<a href="#">here</a> [MD5] [SHA-1] (289MB)
SRc01	<a href="#">here</a> [MD5] [SHA-1] (44MB)	<a href="#">here</a> [MD5]	<a href="#">here</a> [MD5]	<a href="#">here</a> [MD5]	<a href="#">here</a> [MD5]
LRc01	<a href="#">here</a> [MD5] [SHA-1] (251MB)				
LRa01	<a href="#">here</a> [MD5] [SHA-1] (217MB)				
SRa01					
LRc02					
SRc02					
SRa02					
LRa02					
LRc03					
LRc04					
LRa03					
SRa03					
LRc05					
LRc06					
LRa04					
LRa05					
LRc07					
SRc03	Not Available	Not Available			<a href="#">here</a> [MD5] [SHA-1] (4.6MB)
LRc08					<a href="#">here</a> [MD5] [SHA-1] (419MB)
SRc03					
SRa05		<a href="#">here</a> [MD5] [SHA-1] (1,3GB)	<a href="#">here</a> [MD5] [SHA-1] (3,3GB)	<a href="#">here</a> [MD5] [SHA-1] (17MB)	<a href="#">here</a> [MD5] [SHA-1] (180MB)

Tar archives with FITS files, format depends on type of light curves (some are multi-colour)

Select	DATE	DATEJD	DATEHEL	STATUS	REDFLUX	REDFLUXDEV	GREENFLUX	GREENFLUXDEV	BLUEFLUX
23A	D	D	J	E	E	E	E	E	E
yyyy-mm-jjThh:mi:ss	COROT JULIAN DAY	COROT JULIAN DAY		ELECTRONS	ELECTRONS	ELECTRONS	ELECTRONS	ELECTRONS	ELECTRONS
<input type="checkbox"/> All									
<input type="checkbox"/> Invert									
1	2007-02-03T13:05:53.000	2.590045509073E+03	2.590049982487E+03	9	4.163629E+05	9.711546E+03	1.025038E+05	3.642345E+03	1.581949E+05
2	2007-02-03T13:14:25.000	2.590051435029E+03	2.590055908168E+03	0	4.180468E+05	7.956298E+03	1.022476E+05	3.063443E+03	1.570602E+05
3	2007-02-03T13:22:57.000	2.590057360986E+03	2.590061833848E+03	16	4.183796E+05	9.009035E+03	1.020234E+05	3.545518E+03	1.569270E+05
4	2007-02-03T13:31:29.000	2.590063286942E+03	2.590067759528E+03	0	4.180485E+05	1.485986E+04	1.022411E+05	5.587126E+03	1.569962E+05
5	2007-02-03T13:40:01.000	2.590069212898E+03	2.590073685208E+03	0	4.177449E+05	9.390163E+03	1.022943E+05	3.574360E+03	1.571913E+05
6	2007-02-03T13:48:33.000	2.590075138855E+03	2.590079610888E+03	0	4.183437E+05	1.019362E+04	1.024649E+05	3.994630E+03	1.571392E+05
7	2007-02-03T13:57:05.000	2.590081064812E+03	2.590085536568E+03	0	4.177274E+05	9.981426E+03	1.024448E+05	3.798916E+03	1.572613E+05
8	2007-02-03T14:05:37.000	2.590086990768E+03	2.590091462249E+03	0	4.174542E+05	6.345261E+03	1.024935E+05	2.634932E+03	1.573250E+05
9	2007-02-03T14:14:09.000	2.590092916725E+03	2.590097387929E+03	36	4.191141E+05	9.293336E+03	1.022291E+05	3.844240E+03	1.569177E+05
10	2007-02-03T14:22:41.000	2.590098842682E+03	2.590103313609E+03	0	4.175901E+05	9.614719E+03	1.022442E+05	3.821578E+03	1.573274E+05
11	2007-02-03T14:31:13.000	2.590104768639E+03	2.590109239290E+03	0	4.174960E+05	7.878013E+03	1.023414E+05	3.187052E+03	1.574162E+05
12	2007-02-03T14:39:45.000	2.590110694595E+03	2.590115164969E+03	0	4.175974E+05	8.726795E+03	1.023315E+05	3.298300E+03	1.573521E+05
13	2007-02-03T14:48:17.000	2.590116620552E+03	2.590121090649E+03	8	4.180145E+05	1.577869E+04	1.023986E+05	5.469698E+03	1.571704E+05
14	2007-02-03T14:56:49.000	2.590122546508E+03	2.590127016329E+03	0	4.179165E+05	7.198164E+03	1.023130E+05	3.044901E+03	1.570422E+05
15	2007-02-03T15:05:21.000	2.590128472464E+03	2.590132942008E+03	16	4.179568E+05	7.461863E+03	1.021604E+05	2.989277E+03	1.568566E+05
16	2007-02-03T15:13:53.000	2.590134398421E+03	2.590138867688E+03	0	4.183412E+05	9.245952E+03	1.022179E+05	3.232375E+03	1.572059E+05
17	2007-02-03T15:22:25.000	2.590140324377E+03	2.590144793368E+03	0	4.176759E+05	8.840103E+03	1.022329E+05	3.370405E+03	1.572425E+05
18	2007-02-03T15:30:57.000	2.590146250334E+03	2.590150719047E+03	0	4.178376E+05	7.733802E+03	1.022215E+05	3.011939E+03	1.570797E+05
19	2007-02-03T15:39:29.000	2.590152176291E+03	2.590156644727E+03	0	4.181150E+05	1.069012E+04	1.023017E+05	3.961668E+03	1.571807E+05
20	2007-02-03T15:48:01.000	2.590158102247E+03	2.590162570407E+03	0	4.181277E+05	5.486179E+03	1.022811E+05	2.051909E+03	1.573224E+05

# Selecting light curves based on their properties and/or target properties obtained from external observations

## Corot Exoplanet Public N2 data

### Available products

- Chromatic light curves  AND/OR
- Oversampled light curves (32s)  AND/OR
- Light curves from imagerettes (32s)
- N2 context

### Observational informations

Start date  (DD-MM-YYYY)

Corot ID  Use semi-colon, comma or blank character as separator. All

Magnitude from ( $\geq$ )

Right ascension from

Declination from

Magnitude difference (B-V) from

Spectral type from  The spectral type contained in the headers is based on a SED or isochrone analysis of multi-colour concerning luminosity classes.

Spectral type to  For more information, please read [Deleuil et al.](#) and if needed please contact [Claire Moutou](#).

Luminosity class

Long Run (and initial Run)

Short run

Run

Selection based on target properties such as spectral type, from other than CoRoT data

Selection based on classification results obtained from the light curves

### Selection based on the class of variability of the star

Variability class

Type of variability

Probability of variability

The COROT Variable Classification is based on an analysis coherent but should be used with care, in particular when used for scientific purposes. A description of the N3 product is given [here](#). If necessary, please contact [Claire Moutou](#).

# Higher level data products: light curve classification



## CoRoT Public N3 Products

→ [BACK TO HOME](#)

### THE COROT VARIABLE CLASSIFIER

The COROT Variable Classification is based on an analysis of the COROT light curves described in [Debosscher et al.](#) The resulting classification is

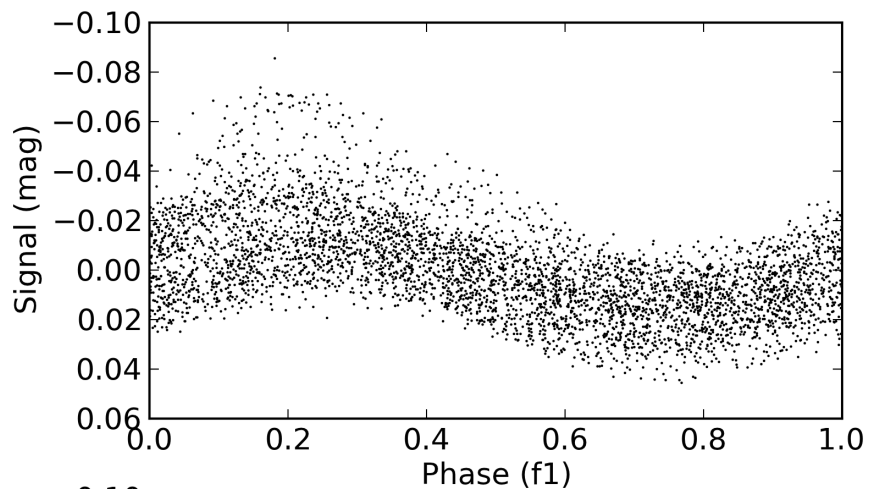
Type	Run IRa01 (Updated : 19/02/2013)	Run SRc01 (Updated : 19/02/2013)	Run LRC01 (Updated : 19/02/2013)	Run LRA01 (Updated : 19/02/2013)	Run SRA01 (Updated : 19/02/2013)	Run LRC02 (Updated : 19/02/2013)	Run SRc02 (Updated : 19/02/2013)
N3 CVC	<a href="#">here</a> (9,3MB)	<a href="#">here</a> (6,6MB)	<a href="#">here</a> (11MB)	<a href="#">here</a> (11MB)	<a href="#">here</a> (7,7MB)	<a href="#">here</a> (11MB)	<a href="#">here</a> (11MB)

Column description:  
-----

- 1) objectname=CoRoT ID
- 2) normalized Mahalanobis distance to the centre of the most probable class (class 1)
- 3) normalized Mahalanobis distance to the centre of the second most probable class (class 2)
- 4) normalized Mahalanobis distance to the centre of the third most probable class (class 3)
- 5) classprob1=relative probability for class 1
- 6) classprob2=relative probability for class 2
- 7) classprob3=relative probability for class 3
- 8) classcode1=variability class 1
- 9) classcode2=variability class 2
- 10) classcode3=variability class 3
- 11) Pf1=significance parameter frequency 1 (probability)
- 12) Pf2=significance parameter frequency 2 (probability)
- 13) Pf3=significance parameter frequency 3 (probability)

**Results from an automated supervised light curve classifier, very useful for selecting science targets!**

# Light curve classification example



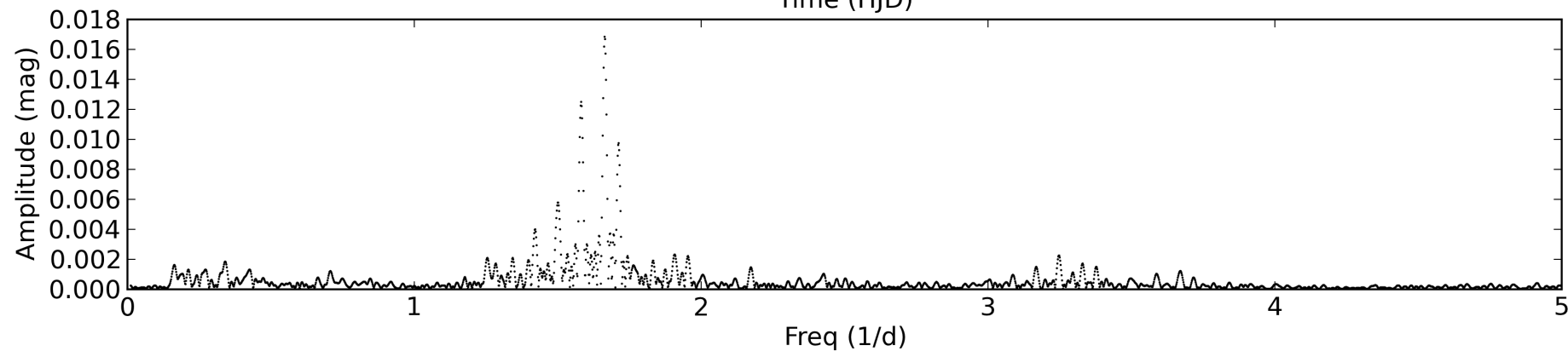
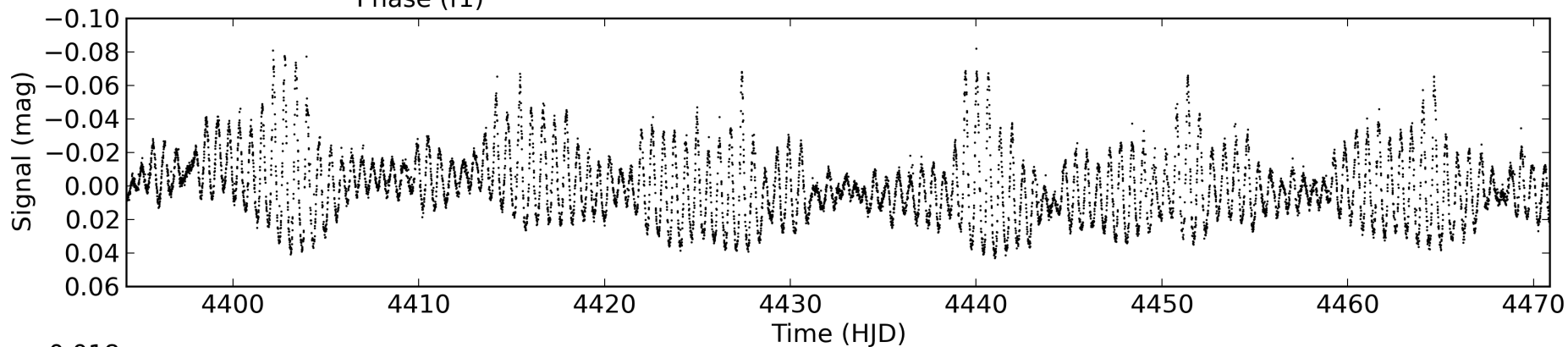
102678037

f1=1.665 c/d

f2=1.582 c/d

SPB /  $\gamma$  Dor

MD=1.09 prob=0.99



# CoRoT data tools at the Spanish VO

<http://sdc.cab.inta-csic.es/corotfa/>

THE COROT PUBLIC ARCHIVE AT CAB

Run:

## Data Type

Asteroseismology  
 Light curves

Exoplanet  
 Monochromatic light Curves  
 Chromatic Light Curves  
Variability Type:  
 Low Frequency  
(If not checked, by default: 'All Frequency')

## Search

Corot ID:

'Object Id' is used only for asteroseismology data.

Object ID:

Coordinates List:

## Light Curve Filter Criteria

Obs Date:

From:  -  -

To:  -  -

Vmag:  -

B-V:  -

Spectype:

Lumclass:

Variability class ([Important note](#)):  
(Only for exoplanet data)

Relative probabilities for the three most likely classes.

First  Second  Third

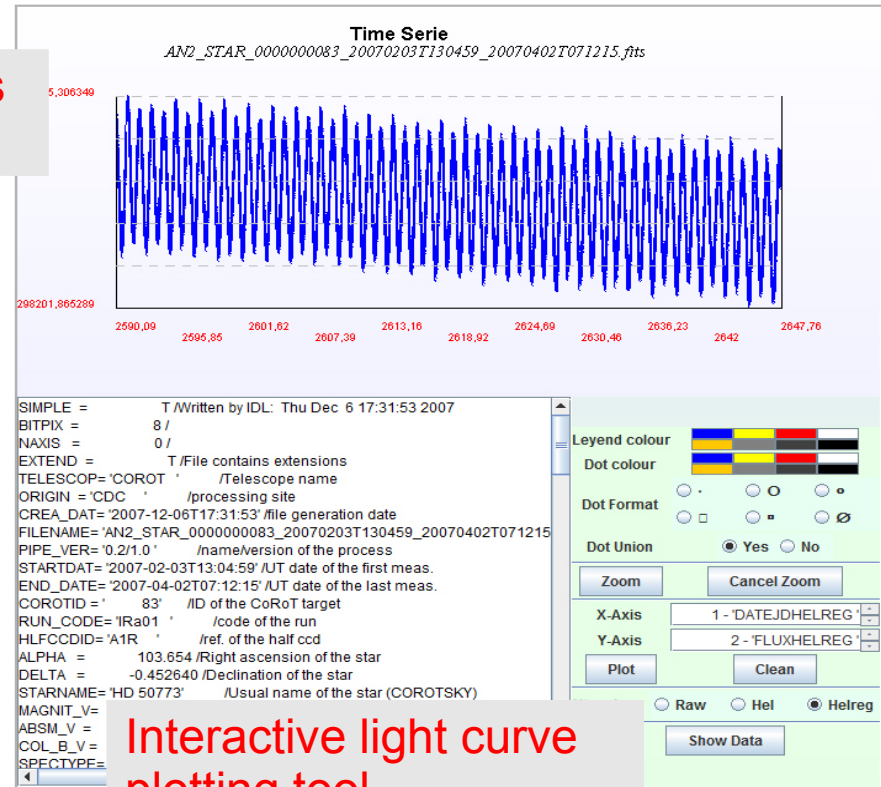


Retrieval Format:  Mark Fits:  Mark ASCII:  RAW:  HEL:  HELREG:

ASTEROSEISMOLOGY

Choice of different data formats for download

RUN	COROT ID	OBJECT ID	RA(J2000)	DEC(J2000)	START DATE	END DATE	TYPE	STATUS
IRa01	20	HD 49933	102.708	-0.54088	2007-01-31 11:06:34.0	2007-04-02 07:12:15.0	F	V
IRa01	83	HD 50773	103.654	-0.45264	2007-02-03 13:04:59.0	2007-04-02 07:12:15.0	A	
IRa01	116	HD 50747	103.603	-1.12698	2007-01-31 11:06:34.0	2007-04-02 07:12:15.0	A	IV
IRa01	123	HD 50844	103.709	-1.07078	2007-02-03 13:04:59.0	2007-04-02 07:12:15.0	A	
IRa01	156	HD 50846	103.728	-1.37579	2007-02-03 13:04:59.0	2007-04-02 07:12:15.0	B	
IRa01	187	HD 50405	103.262	-1.88363	2007-02-06 13:34:53.0	2007-04-02 07:12:15.0	A	
IRa01	214	HD 51106	103.976	-1.58537	2007-01-31 11:06:34.0	2007-04-02 07:12:15.0	A	
IRa01	223	HD 50170	102.966	-2.17604	2007-01-31 11:06:34.0	2007-04-02 07:12:15.0	F	
IRa01	263	HD 292790	103.686	-2.12311	2007-02-06 13:34:53.0	2007-04-02 07:12:15.0	F	
IRa01	400	HD 50890	103.745	-2.80359	2007-02-06 13:34:53.0	2007-04-02 07:12:15.0	G	III















Interactive light curve plotting tool



# Kepler data at KASOC (Kepler Asteroseismic Science Operations Center)

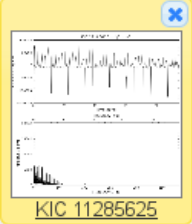
<http://kasoc.phys.au.dk/>

✓ Deselect all

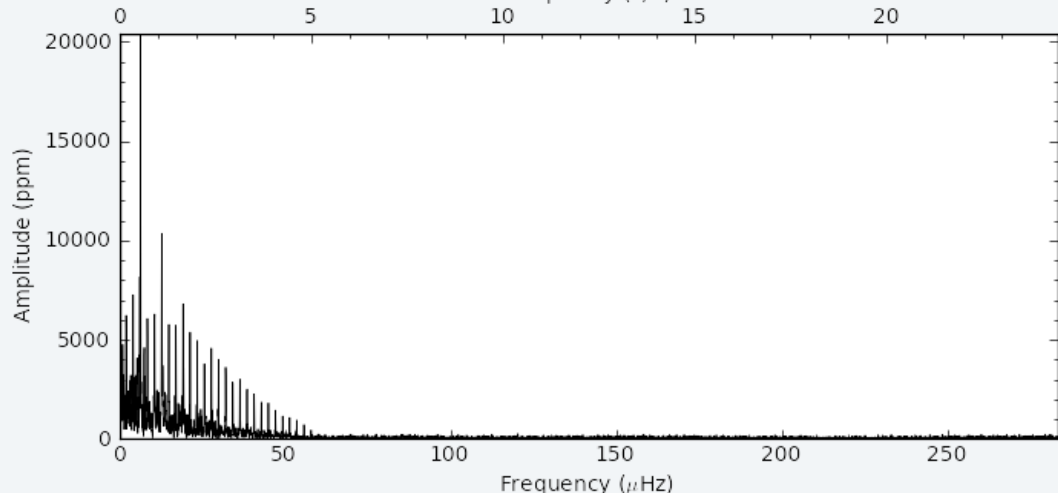
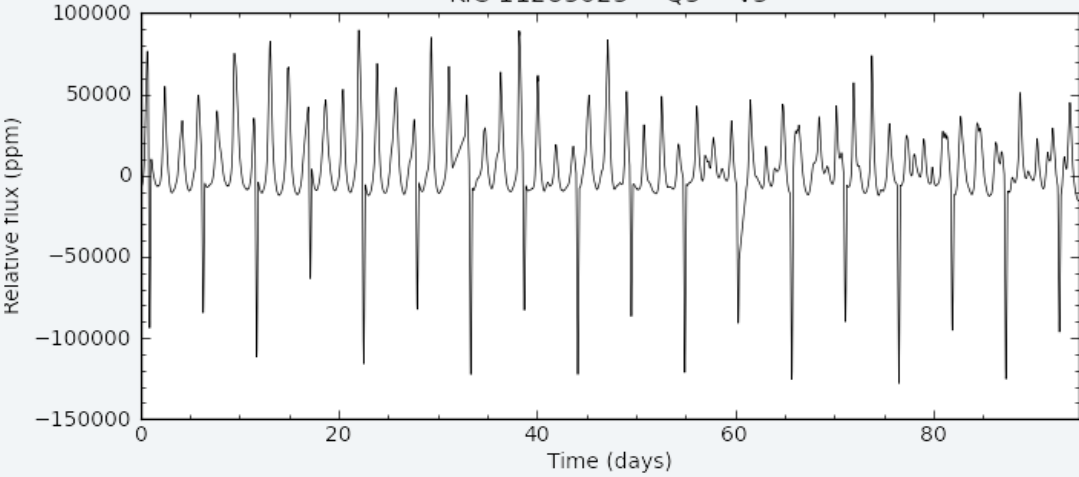
	Filename	File size	KIC-10 number	Cadence	Season	TRF	Points	Magnitude	RA	Dec	Radius	Teff	log G	[Fe/H]	Contamination
<input checked="" type="checkbox"/>	 kplr011285625-2009131105131_llc	37.0 kB	11285625	Long	Q0	No	476	10.143	19:00:51.89	49:05:22.1	2.61	6882	3.753	-0.127	0.009
<input checked="" type="checkbox"/>	 kplr011285625-2009166043257_llc														0.009
<input checked="" type="checkbox"/>	 kplr011285625-2009259160929_llc														0.009
<input checked="" type="checkbox"/>	 kplr011285625-20092011121230_slc														0.009
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<input checked="" type="checkbox"/>	 kplr011285625-2010203174610_slc														0.009
<input checked="" type="checkbox"/>	 kplr011285625-2010234115140_slc														0.009
<input checked="" type="checkbox"/>	 kplr011285625-2010265121752_slc														0.009

Plot

Settings




KIC 11285625



-Target query (using identifiers or based on observed properties)  
-Light curve and Fourier amplitude spectrum visualization tools

Download format:

- ASCII lightcurve
- FITS lightcurve
- Target Pixel data
- Above table with KIC parameters
- Plots of timeseries and amp. spectr
- wget script (ASCII)
- wget script (FITS)
- wget script (TPD)

 Download Selected

# Kepler data at the MAST archive

[http://archive.stsci.edu/kepler/data\\_search/search.php](http://archive.stsci.edu/kepler/data_search/search.php)

[Archive Status](#)

## Kepler Data Search & Retrieval

[Help](#)  
[Field Descriptions](#)

**Standard Form**

[File Upload Form](#)

<input type="button" value="Search"/>			<input type="button" value="Reset"/>			<input type="button" value="Clear Form"/>		
<b>Target Name</b> <input type="text"/>		<b>Resolver</b> NED		<b>Radius (arcmin)</b> 0.02				
<b>Right Ascension</b> <input type="text"/>		<b>Declination</b> <input type="text"/>		<b>Equinox</b> J2000				
<b>Kepler ID</b> <input type="text"/>		<b>Investigation ID</b> <input type="text"/>		<b>2Mass ID</b> <input type="text"/>				
<b>KEP Mag</b> <input type="text"/>		<b>Target Type</b> <input checked="" type="checkbox"/> Long Cadence <input checked="" type="checkbox"/> Short Cadence		<b>Release Date</b> <input type="text"/>				
<b>Teff</b> <input type="text"/>		<b>Log_G</b> <input type="text"/>		<b>Quarter</b> <input type="text"/>				
<b>Condition Flag</b> All Targets								
<b>User-specified field 1</b> Kepler ID		<b>Field Descriptions</b> <input type="text"/>		<b>User-specified field 2</b> Kepler ID		<b>Field Descriptions</b> <input type="text"/>		
<b>User-specified field 3</b> Kepler ID		<b>Field Descriptions</b> <input type="text"/>		<b>User-specified field 4</b> Kepler ID		<b>Field Descriptions</b> <input type="text"/>		
<b>Output Columns</b> twoMass conflict flag Teff Log G Metallicity E(B-V) Radius Total PM G-R color Module Output			<b>Sort By:</b> ang_sep (') Kepler ID null			<input type="checkbox"/> Reverse <input type="checkbox"/> Reverse <input type="checkbox"/> Reverse		
<input type="button" value="up"/> <input type="button" value="down"/> <input type="button" value="remove"/> <input type="button" value="reset"/>			<b>Output Coords:</b> <input checked="" type="radio"/> Sexagesimal <input type="radio"/> Degrees <input type="radio"/> Hours			<b>Output Format</b> HTML_Table		

# Extended light curve data products: *Kepler* pixel data

Summary of kplr011285625-2009131105131\_lpd-targ.fits in /STER/jonas/kplr011285625/data/pixel-data-fits/

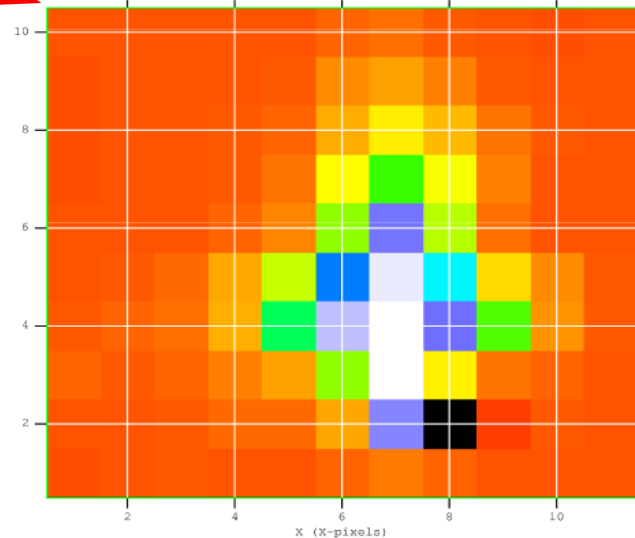
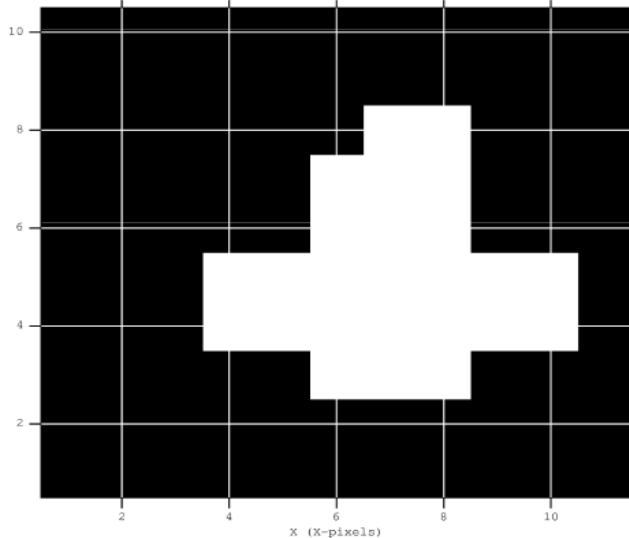
Index	Extension	Type	Dimension	View
<input type="checkbox"/> 0	Primary	Image	0	Header Image Table
<input type="checkbox"/> 1	TARGETTABLES	Binary	10 cols X 476 rows	Header Hist Plot All Select
<input type="checkbox"/> 2	APERTURE	Image	12 X 12	Header Image Table

Binary Table of kplr011285625-2009131105131\_lpd-targ.fits[1] in /STER/jonas/kplr011285625/data/pixel-d...

Select	TIME	TIMECORR	CADENCENO	RAW_CNTS	FLUX	FLUX_ERR	FLUX_BKG
D	E	J	count	144E	144E	144E	144E
BJD - 2454833	d		e-/s	e-/s	e-/s	e-/s	
Inv			expand	expand	expand	expand	
<input type="checkbox"/> All			Image	Image	Image	Image	Image
			Image	Image	Image	Image	Image
			Image	Image	Image	Image	Image
			Image	Image	Image	Image	Image
			Image	Image	Image	Image	Image
5	120.6201979	3.111109E-04	574				
6	120.6406320	3.117					
7	120.6610663	3.124					
8	120.6815006	3.130					
9	120.7019348	3.137					
10	120.7223690	3.143					
11	120.7428034	3.150					
12	120.7632375	3.156					
13	120.7836718	3.163					
14	120.8041060	3.169					
15	120.8245403	3.176					
16	120.8449745	3.182					
17	120.8654088	3.188					
18	120.8858431	3.195					
19	120.9062773	3.201					
20	120.9267115	3.208					
21	120.9471459	3.214					
22	120.9675800	3.221					
23	120.9880143	3.227					
24	121.0084484	3.234					

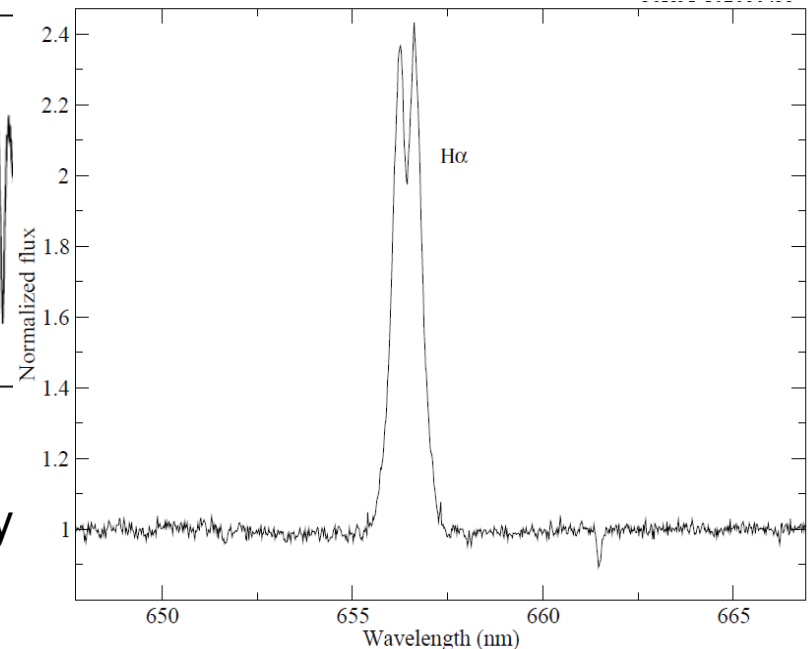
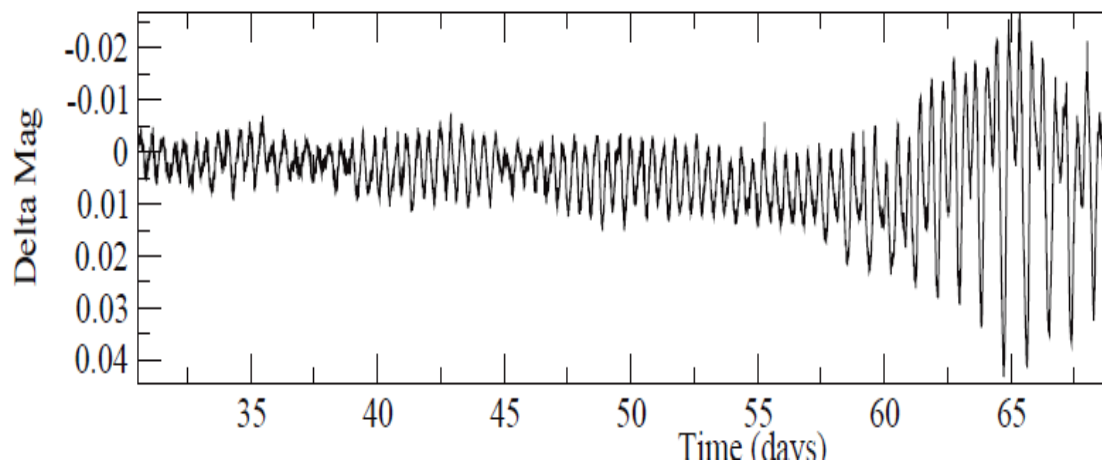
Aperture mask, determines which pixels are summed to produce the light curve

Small image of CCD pixels covering the target, for each measurement (instead of just one summed flux value)



# How can VO help for stellar variability studies?

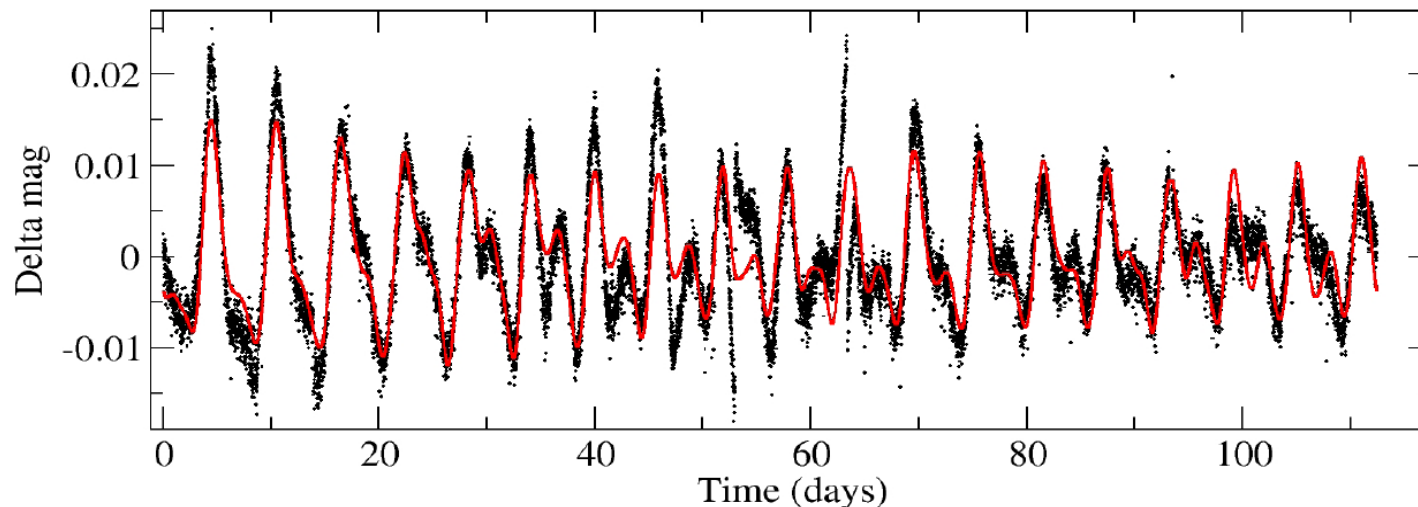
- Time series data (single bandpass) are not sufficient to fully characterize and study stars!
  - Use VO to complement time series with other observational and higher level data, such as high-resolution spectroscopy, photometry in other bands, temperatures, gravities, parallaxes...



Combining CoRoT light curves and spectroscopy  
(Sarro et al., 2013)

# Light curve analysis tools in the VO?

- Some commonly used light curve analysis tools:
  - Period determination by means of Fourier amplitude spectrum (e.g. for pulsating stars) or box-least-squares periodogram (e.g. for planetary transits)
  - Filtering and detrending methods to reduce instrumental artifacts or disentangle variability at different time scales
  - Linear and non-linear least-squares fitting (e.g. of sine functions)



# Stellar variability data mining and the VO

- Combining large observational data sets for data mining purposes, constructing training sets for light curve classifiers
- Data mining tools such as dimensionality reduction and clustering techniques in the VO?
  - scalability of methods with future data amounts in mind

