

Understanding a Kepler 2- Wheel Mission

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Background

- By design Kepler stabilizes itself and maneuvers using reaction wheels.
 - Attitude control jets are normally used only to unload the reaction wheels of accumulated angular momentum and for emergency control.
- Kepler cannot point stably enough for high precision photometry with less than 3 reaction wheels.
- Two of the 4 reaction wheels on Kepler have failed leaving Kepler unable to continue its nominal exoplanet survey mission.

Current State of Kepler

- Kepler is currently in Point Rest State
 - A loosely-pointed, thruster-controlled state
 - Minimizes fuels usage and provides continuous X-band communications
 - Fuel should last for 3-4 years
- Tests to determine the revivability of the failed wheels are now complete
 - No more useful lifetime of the failed wheels appears available
- Investigating possibilities for a 2-wheel mission
 - Expect significant degradation over the 20 pmm photometric precision of the baseline mission
 - Lifetime of a 2-wheel mission should be several years.

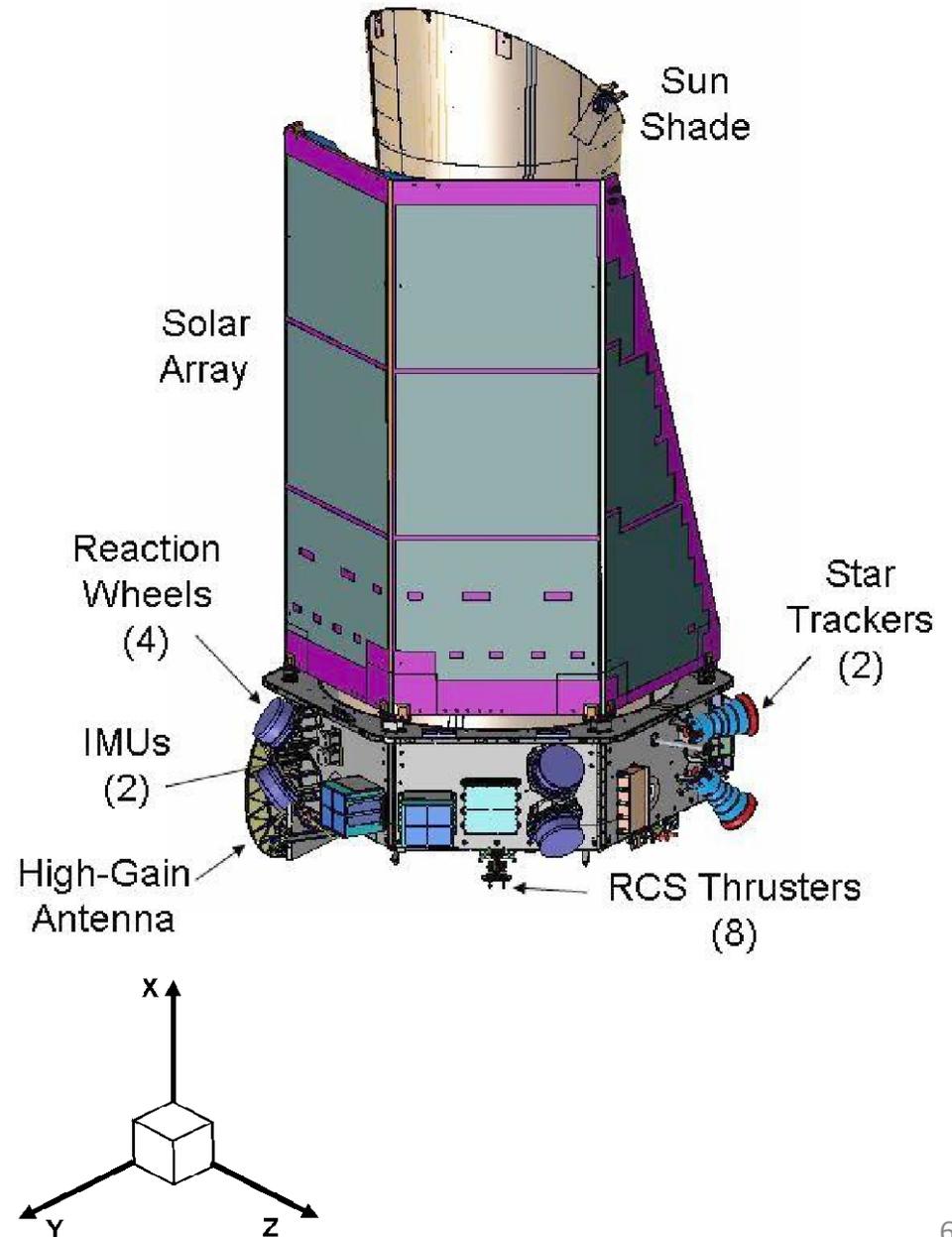
Mission Development Plan

- Concurrent development of science plan and pointing/operation plan
- Schedule
 - 2 Aug 2013 – Release of call for white papers
 - 3 Sept 2013 – Due date for submission of white papers
 - 1 Nov 2013 – End of review period for white papers, report submitted to NASA HQ
 - 1 Feb 2014 – Senior Review proposal for repurposed Kepler submitted to NASA HQ
 - Spring 2014 – Decision for funding for repurposed Kepler spacecraft
 - Summer 2014 – Begin new science program(s)

Current Understanding of 2-wheel Operation Capabilities

- Kepler will probably operate in a drifting mode instead of a pointed mode
 - In principle Kepler could point with a stability of a few arc seconds for extended periods but fuel usage would be high: a few months lifetime
 - Known parameters of the drift mode discussed later
- Retain only the current instrument capabilities unless flight software rewrites are deemed cost effective
- Suitable data downlink attitudes and operations are expected to be possible

Kepler Spacecraft Attitude Components. The sun is in the y direction and the boresight (viewing direction) is in the x direction



Kepler Photometer

21 modules:

Two ~2k x 1k CCDs

~4 asec pixels

~2.25 deg square

One dead module

Total FOV ~100 deg²

~13 deg diameter

Current Photometry mode:

<170,000 targets

Records postage stamp ~20 pixels
for each target

Coadd 6 sec exposures up to 30
minute samples

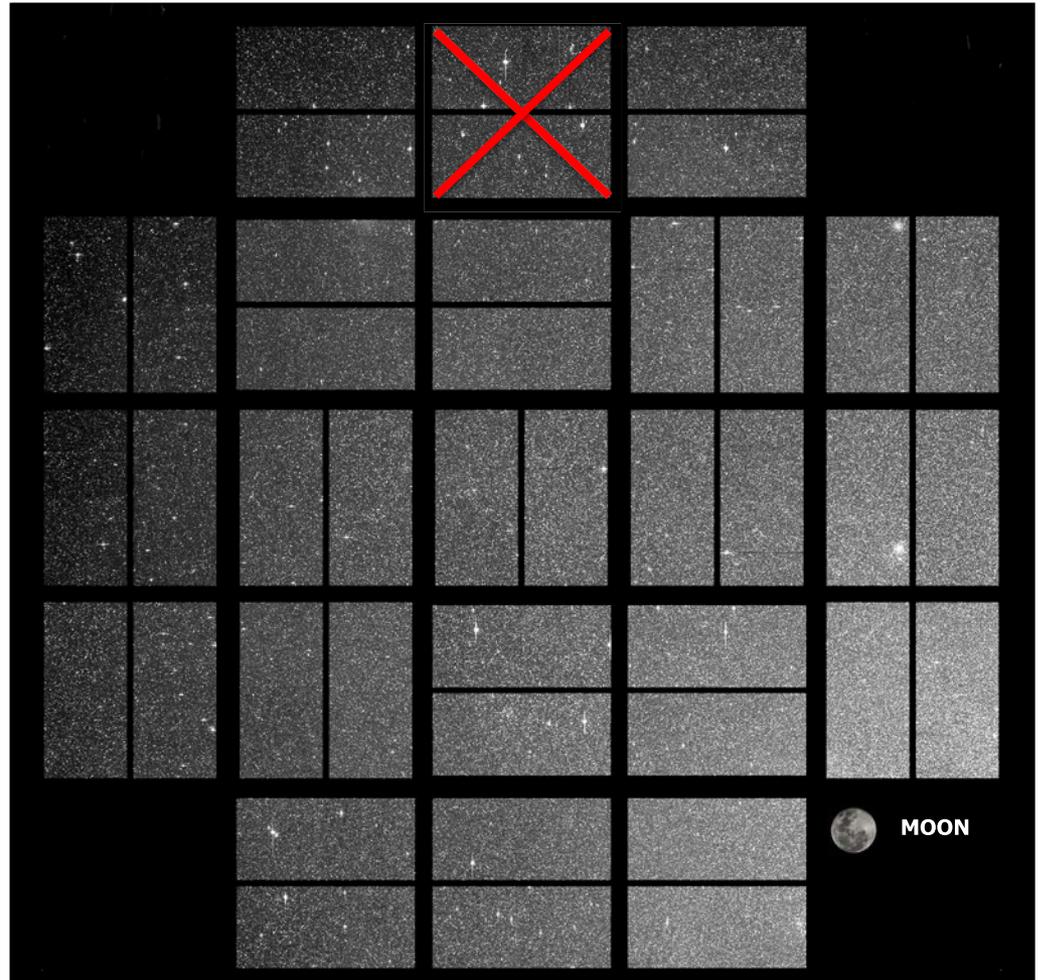
1 minute coadd available for up to
512 targets

Current Full Field mode

Records all pixels

Takes 20 min

No data compression



The *Kepler* Science Pipeline:

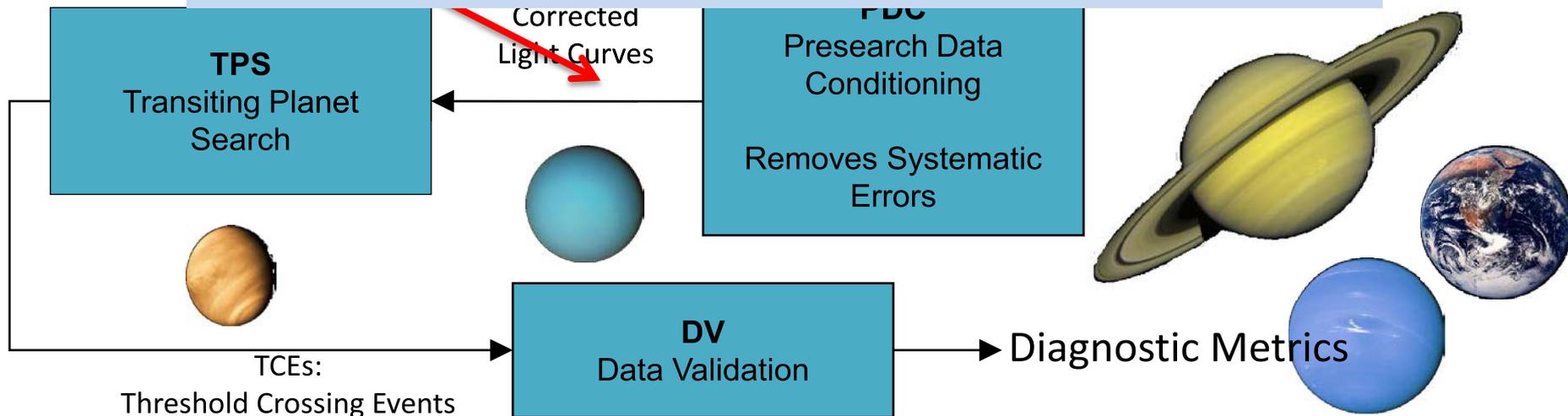
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Associated

There is currently no “best” method for recovery of long time scale photometry.

Kepler has some ideas only.

This is a potential topic for Senior Review funding.

Currently no ideas on how to modify the pipeline for to accommodate scanned observations



Pointing with 2 Wheels

- JPL and Ball Aerospace have both suggested 2-wheel control modes that stabilize Kepler in 2 axes while allow drifts in the 3rd axis largely driven by torque from sunlight.
 - Drift tracks are expected to last from several hours to 4 day with lengths of 1 or 2 degrees
 - Periods of relatively stationary pointing may exist as solar torque accelerates the boresight away from an initial position or slows down and reverses the scan direction.
- Details of possible 2-wheel control modes are still being worked out
 - Requirements of suggested science investigations may be able to influence details of performance

Ball Pointing Concept

Schematic view of two possible point-drift mode observations on a CCD.

~4 day period

jitter of ~0.5-1.0 arcsec along a ~1.4 degree long drift line.

Reset of the pointing brings boresight back to near the start point.

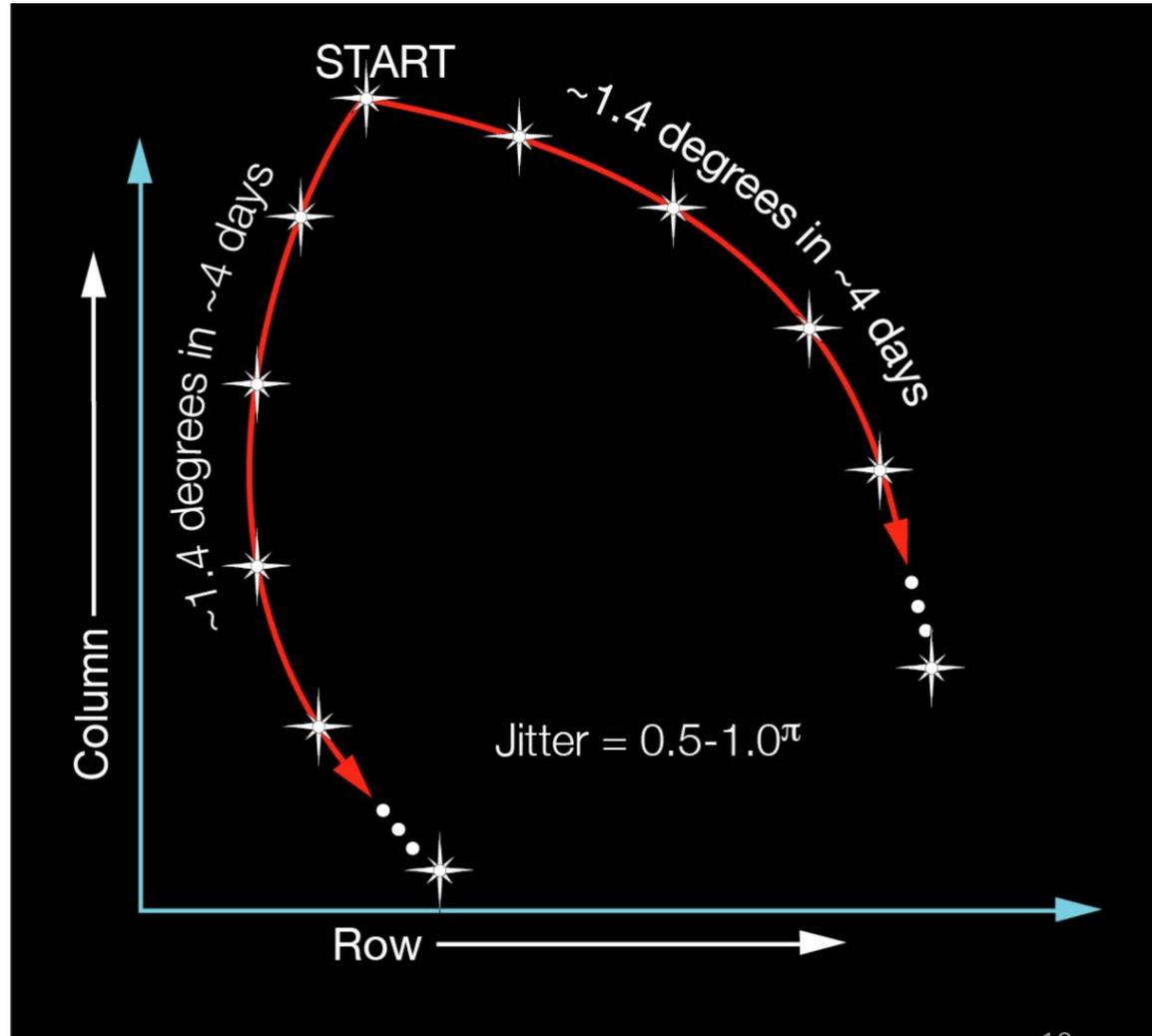
Drift rate estimated ~0.9 arcsec/minute (~1 pixel in ~5 minutes), possibly less.

Path of a target during the drift will inscribe an arc shape on the focal plane.

During pointing, no thruster activity is required.

After some days the reaction wheels must be unloaded.

Would interrupt observations for perhaps 30 min to 1 hour.



Photometric performance

- Measurements during coarse pointing periods in the nominal mission indicate:
 - 1 minute integration with +/-0.5 arcsec pointing yields ~300-600 ppm rms (0.3 - 0.6 mmas) rms for 12th magnitude star
 - Perhaps 1 mmag for +/-1 arcsec pointing
 - Drifting over many pixels may limit the overall relative photometry to ~0.3-1%
- However:
 - Mike Shao believes that calibration of pixel variations using spare CCDs from the flight batch can beat down this problem
 - Drift over many pixels may be an advantage
 - Might achieve ~100 ppm rms precision
 - But, don't know yet if flight spares are available
- Image motion will complicate removal of smear due to shutterless operation. Effect on photometry currently unknown.

Sky accessibility and Sun constraints

- 45 -135 deg from sun
 - Power positive and telescope aperture properly shaded
 - No first order constraints in this section of the celestial sphere
 - Accessible sky changes with season but have constant viewing zones at ecliptic poles
 - May be issues with available scan lengths or guide star availability
- Initial pointing must be established
 - Fine guidance sensor usage and constraints
 - Need to define where the guide stars are to be found on the FGS sensors so need to find suitable guide stars for each starting point
 - Star trackers have TBD (5 asec) accuracy

Normal Photometry Operation

- All pixels read out for each exposure
 - Target and Aperture definitions determine which pixels are compressed, recorded and downlinked.
- Individual Kepler targets are selected and stored as, most often postage stamp type, pixel groups called target apertures.
- Target apertures do not need to be rectangular, or even contiguous.
 - The apertures can contain up to 32767 pixels each
 - An aperture must be one of 1024 configurable on-board aperture definitions.
- Maximum of 170,000 targets
 - Independently the maximum number of pixels that can be used is 5.44 million.
 - Using all 5.44 million pixels takes about 12 minutes of time to readout and store on board. Less pixels used, require less time to store
- Several large apertures can be used to read out a single entire CCD or perhaps a module (2.6 or perhaps 5.2 deg²).
- Changes from this operation require flight software modification

Integration times

- Available integration times are 2.5, 2.6, ... 8 sec with a 0.51895 sec readout time for each integration.
 - Allowed times are formed from the sequence “25, 26, 27... 77” times a base of 0.10379 sec.
 - Not all possible times have been tested, but any can be selected without flight software modification.
- Not all combinations of these parameters are allowable
 - Limited in part by the time needed to transfer the coadded image to the data recorder, ~12 minutes for the full 5.44 million pixels.
- Altering this mode of specifying the observations requires flight software changes.
- In the nominal mission, a V=12 star provided 1.4×10^6 electrons in a single 6 sec integration.
 - Stars brighter than ~11.5 saturate the pixels in 6 sec.
 - The same count rate for a V=12 star is expected in a 2-wheel mission, but saturation may be reduced if the image is spread out over more pixels in one integration.

Cadences

- During the nominal Kepler mission, 6 sec integrations were coadded to 30 min samples
- 1 min coadds were available for up to 512 targets
 - 1 min targets had to be 30 min targets as well
- Increasing the number of 1 min cadence targets requires changes to the flight software and would place constraints on the focal plane readout and data downlink which might be hard to accommodate.

FFI operation

- Kepler can also return the entire CCD pixel array in a full-frame image (FFI).
 - FFI pixels may be coadded in a manner similar to the target pixels
 - Not compressed by the current flight software.
- An FFI can be taken with any of the allowed integration times.
- Requires about 20 minutes to store in on-board memory
- The on-board recorder can hold 42 such images.

Possibilities for Modification of Flight Software

- Compression of FFIs, modification of FFI readout for less than all modules
- Other ways of collecting pixels optimized for scanning operation, etc.
 - Currently we cannot make apertures that follow the targets.
 - Either a long narrow aperture or multiple apertures must be defined to cover the entire scan track of a target or a rewrite of flight software to allow other collection modes must be done
- Other ideas?
- Note: Flight software modification will cost money and time and therefore may not be thought cost effective for any but the most compelling science.

References

- White paper call:
<http://keplerscience.arc.nasa.gov/docs/Kepler-2wheels-call-1.pdf>
- Call FAQ:
<http://keplerscience.arc.nasa.gov/FAQ.shtml>
- Instrument handbook & other documentation:
<http://keplergo.arc.nasa.gov/Documentation.shtml>