Astrophysics Advisory Committee

K2 End of Mission Science Planning

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July 20, 2017

K2 Mission Genesis

K2 is a follow-on to the original Kepler mission, driven by the loss of two reaction wheels.

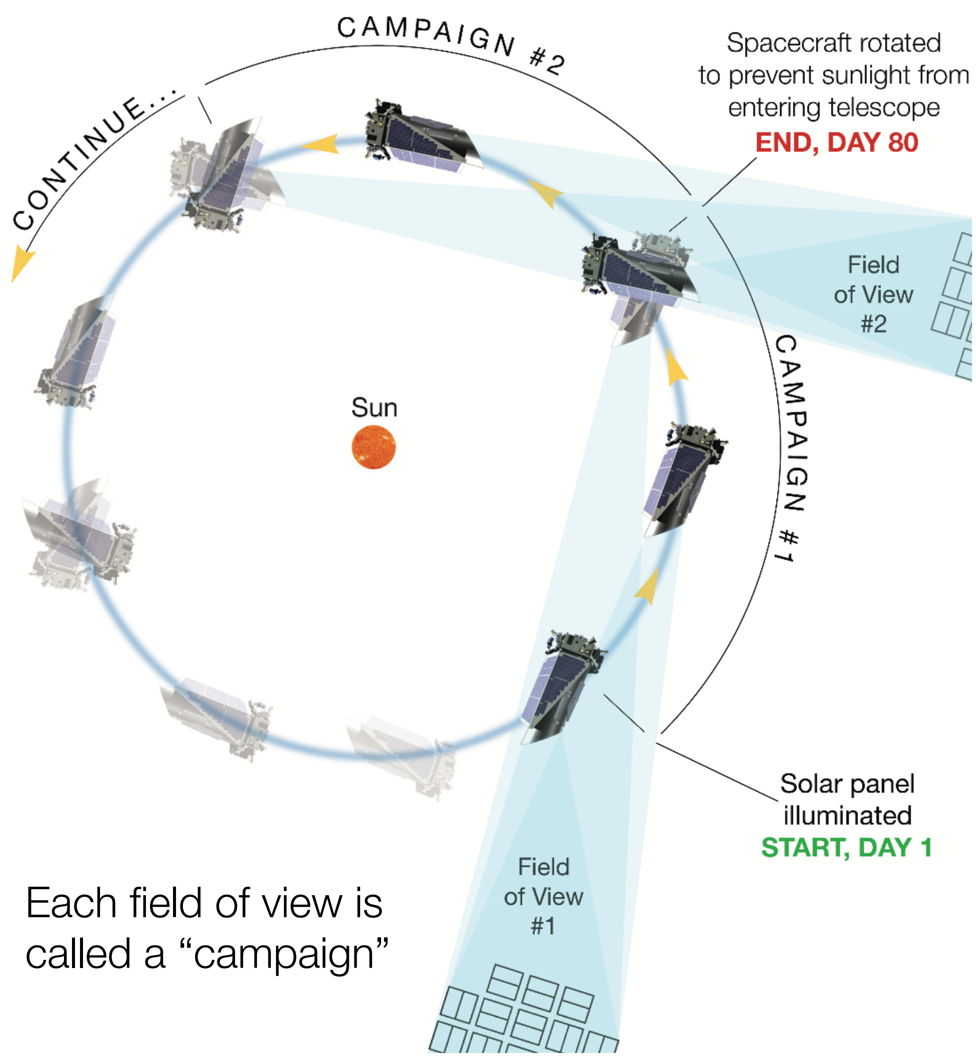
- Unable to control Roll, Pitch and Yaw against the solar pressure at the original Kepler Field of View as the sun incidence angle moves a degree/day
- The remaining reaction wheels could control two axes
- Solicited community input and received 42 white papers describing potential science
- Also solicited community input on attitude control options and hosted a 2-day workshop

The result was the K2 mission concept…

K2 Implementation

K2 points in the ecliptic, where the roll axis of symmetry is oriented towards the sun and the resulting roll disturbance is minimized.

- The remaining reaction wheels control Pitch and Yaw.
- Keeping the solar panels pointed at the sun limits the period the telescope can stare at a single field to ~80 days
- The mission observes a sequence of different fields along the ecliptic plane as the spacecraft orbits the sun



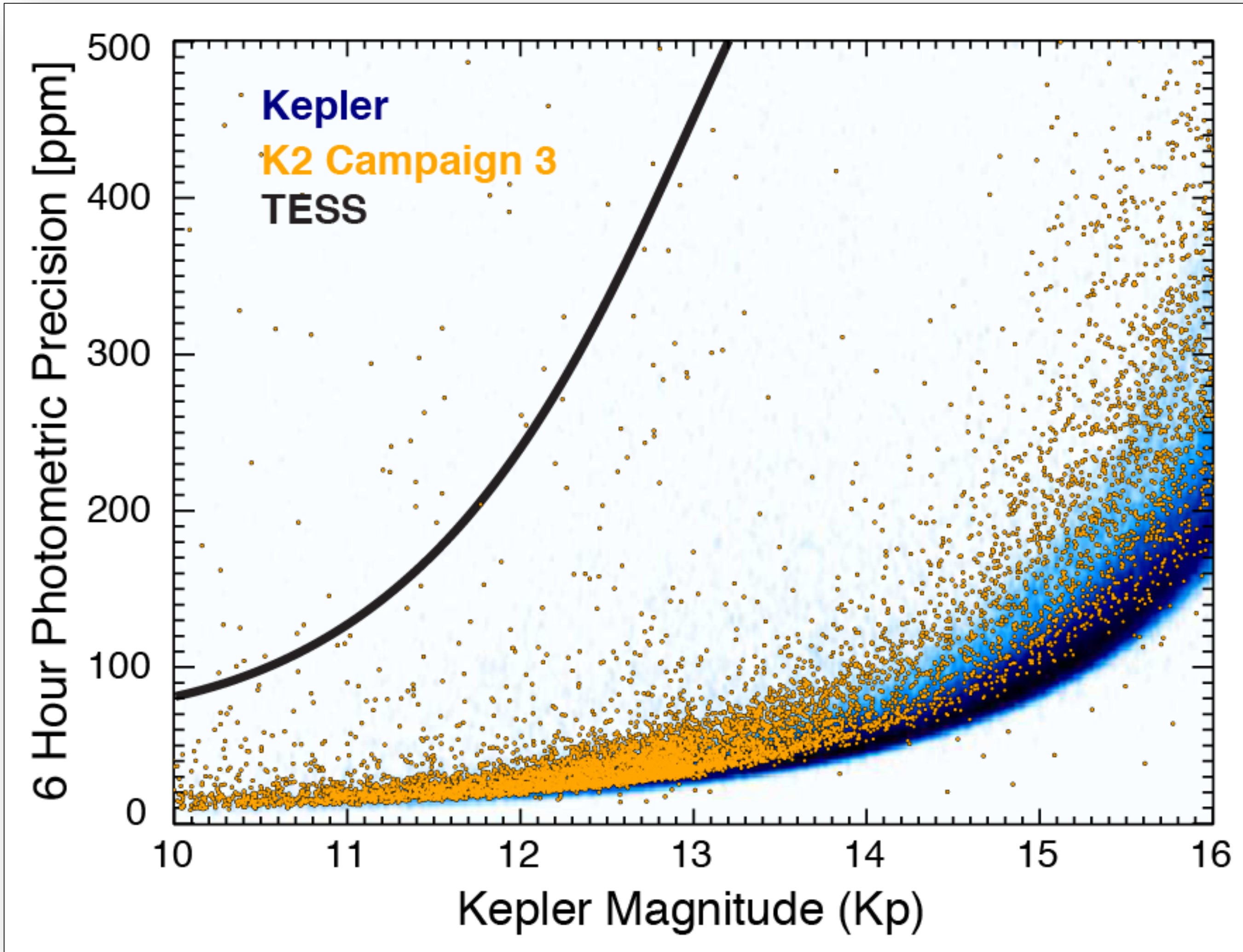
Each field of view is called a "campaign"

Kepler vs. K2

Kepler	K2
4-year observing period	80 days observing/campaign
Monthly science downlinks	Quarterly science downlinks
170,000 targets	≈30,000 targets/campaign (less frequent downlinks and larger apertures)
FOV selected for mature G-dwarfs, with few notable outliers	FOVs constrained to the ecliptic, with a wide range of available targets
Predominantly mission-directed research with a small competitive GO program	Community-directed research mission with science targets selected by peer review Data processing stops with photometry (no search done by the mission)

K2 Performance

K2's photometric precision is within 20% of that achieved by Kepler



Vanderburg et al. 2014

K2 Operational Challenges

Attitude Control

- The solar pressure balance ridge had to be determined on-orbit
- Dominated by the solar panels, but affected by other components
- No analytical model available

Communications

- At science attitude, low gain antennas pointed at ecliptic north/south
- Accurate high gain pointing (body-mounted antenna) was fuel inefficient
- Increasing range made both problems more difficult

Data Storage

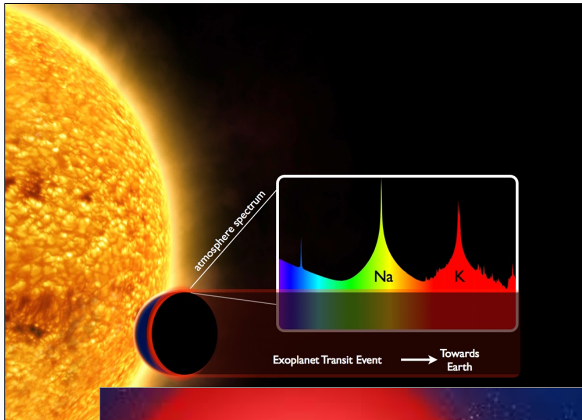
- Data compression affected by spacecraft motion and scene
- Under/over filling the recorder results in loss of science

Fuel Efficiency

- It all comes down to fuel!

K2 Science Promised:
Broad and Community-Driven

Discover high value exoplanets



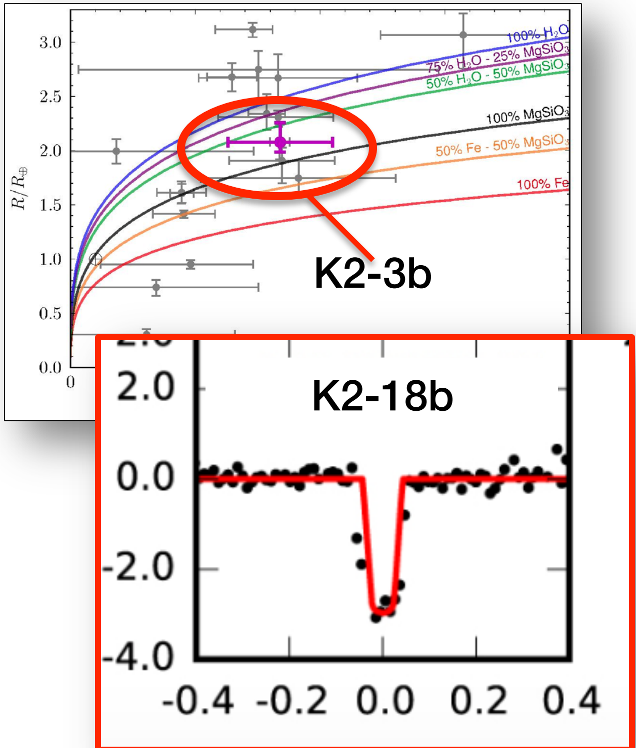
Study of protoplanetary disks & migration limits

Explore accretion physics and supernovae

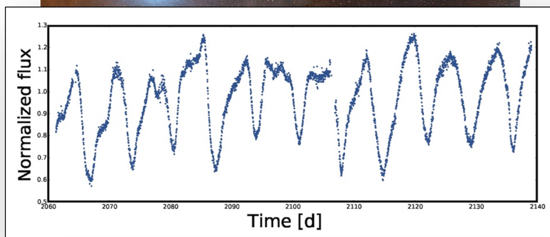
Examine astrophysics over a range of stellar properties

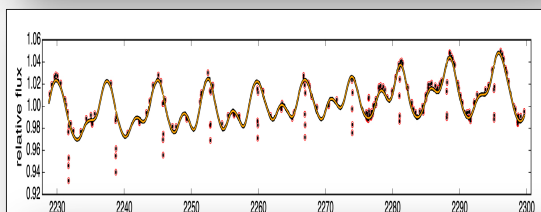
K2 Science Delivered:
Broad and Community-Driven

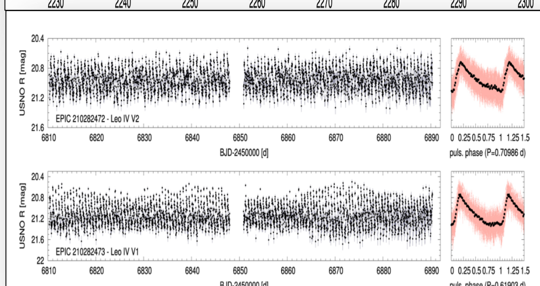
Discover high value exoplanets



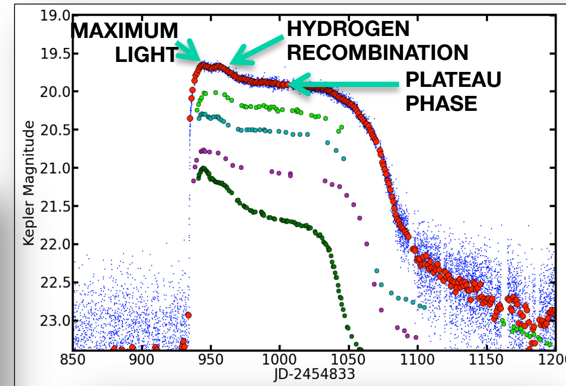
Study of protoplanetary disks & migration limits

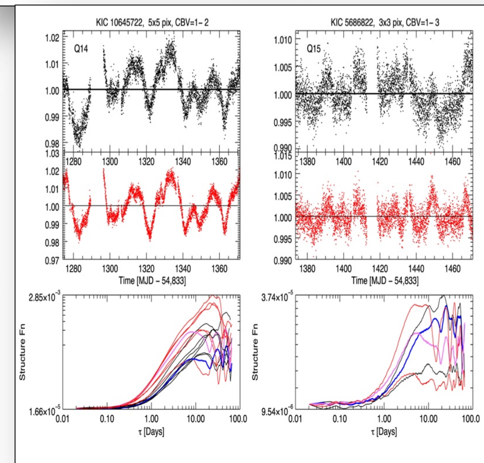






Explore accretion physics and supernovae

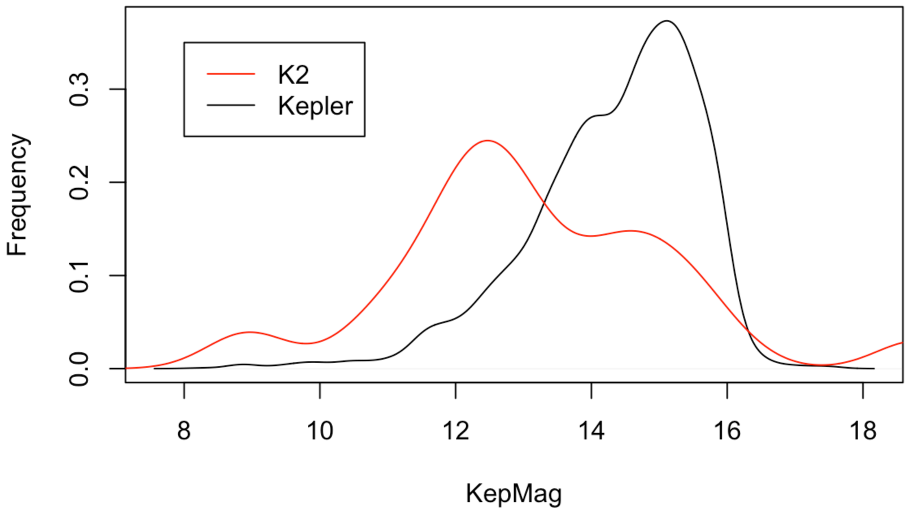




Examine astrophysics over a range of stellar properties

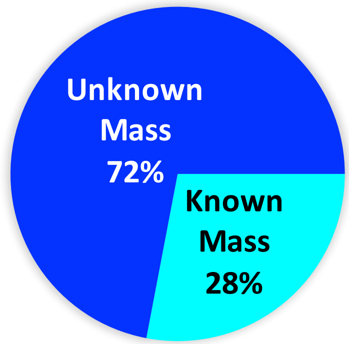
K2 Science Highlights:
High-value Exoplanets

K2 exoplanets are around bright stars and amenable to characterization.

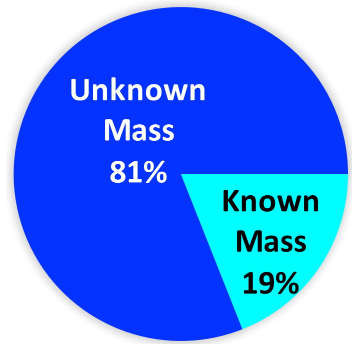


K2 Planets

All

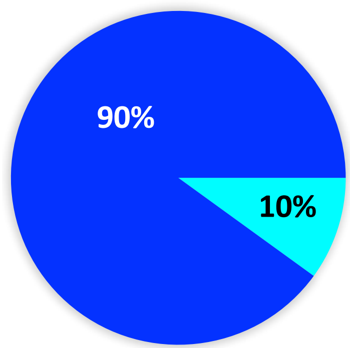


R < Neptune



Kepler Planets

All



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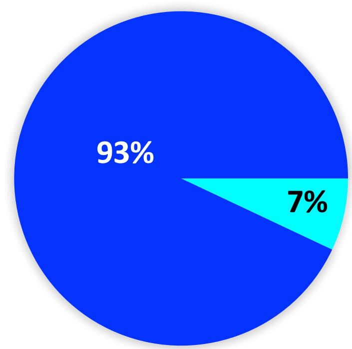
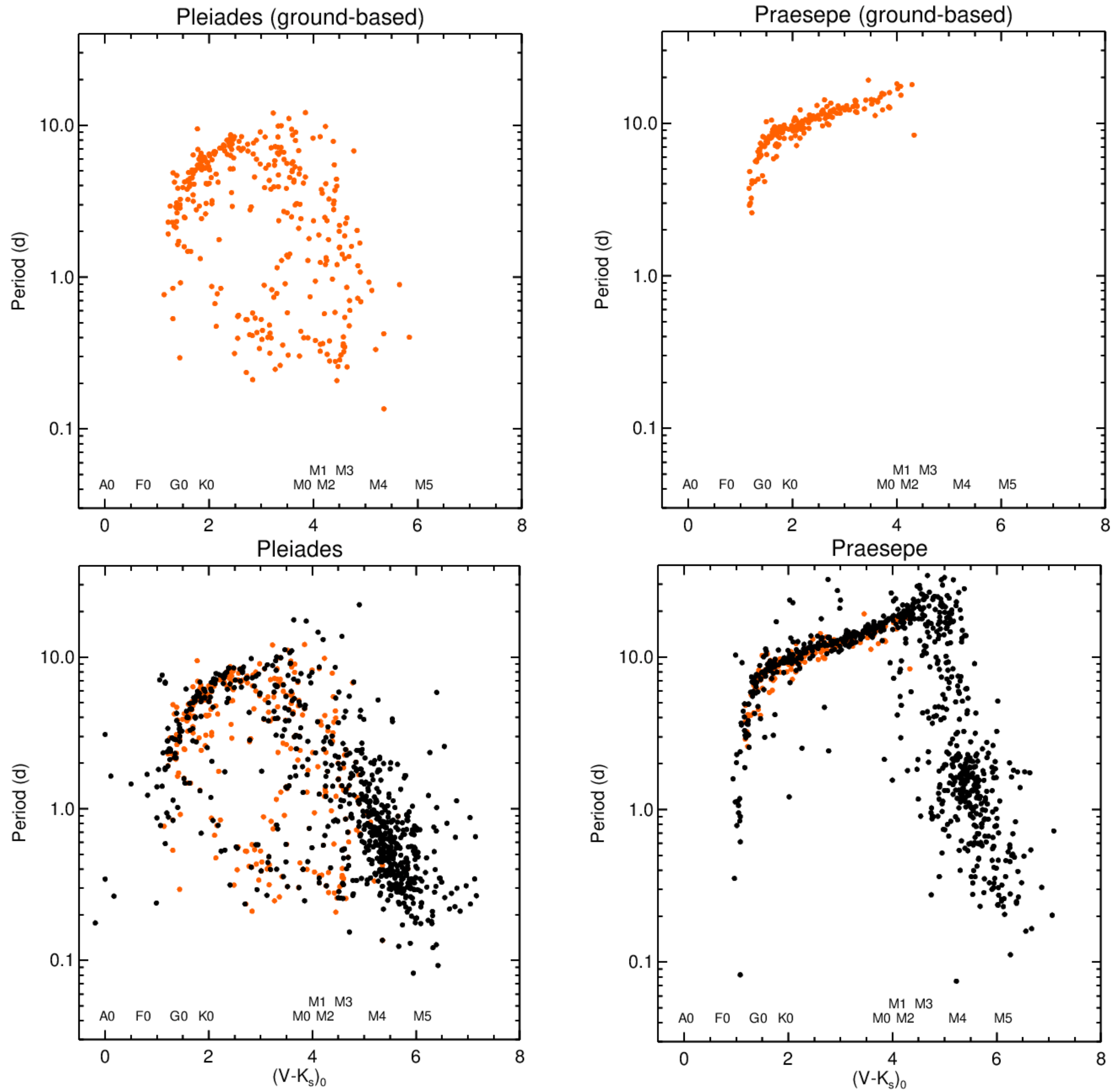


K2 Science Highlights:
Stellar Rotation as a Probe of Evolution

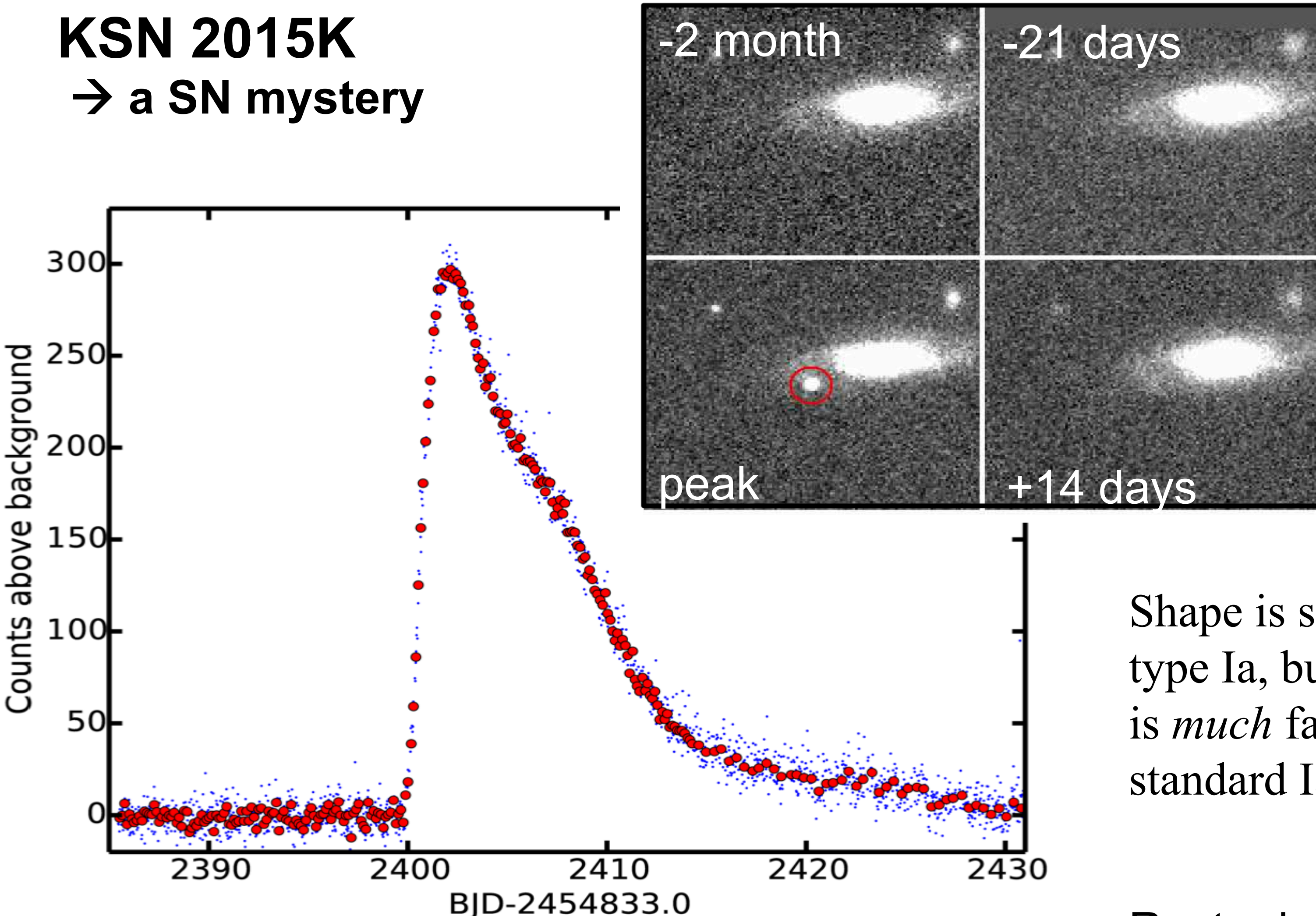
- K2 is exploring rotation rates *to lower masses and higher precisions* than ever before
- The mission is among the first to show well-defined period vs. color (mass) relation at very low masses (<0.4 Msun).
- For the youngest stars, the data is also shedding light on the angular momentum budget and its dependence on mass and circumstellar disk properties.
- Detailed analysis of the K2 light curves is revealing starspot evolution and stellar differential rotation



K2 Science Highlights: *Supernovae*

KSN 2015K

→ a SN mystery



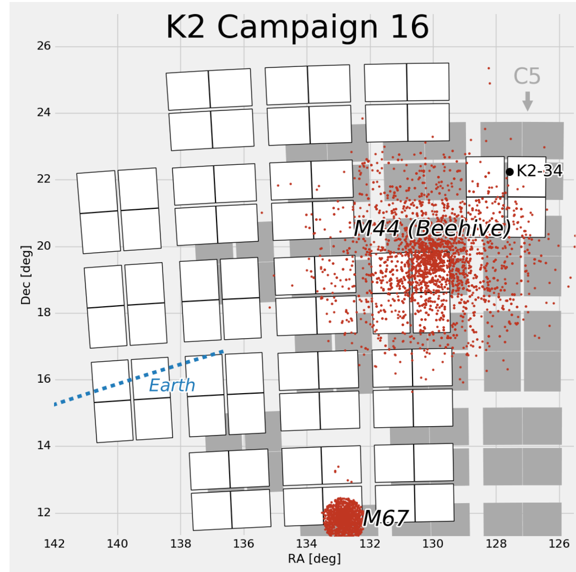
Shape is similar to type Ia, but rise time is *much* faster than standard Ia!

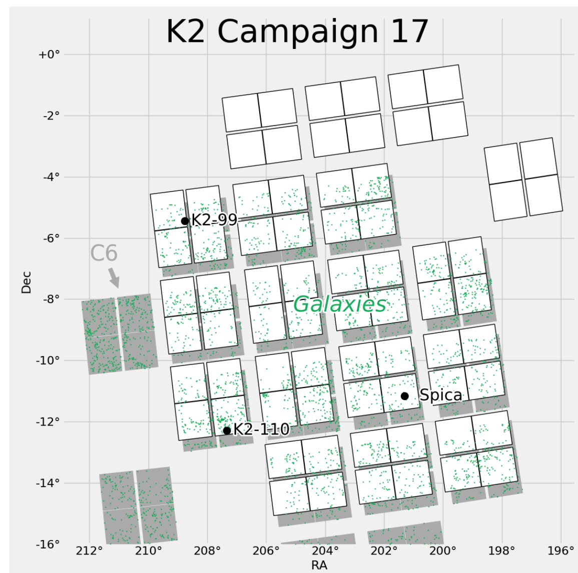
Rest+, in prep.

C16 & C17: Focus on Supernova
(with bonus star clusters!)

- C16 & C17 are "forward facing" to facilitate simultaneous ground observations.
- Observing ~ 10,000 galaxies in each campaign. Expected to yield 10 – 15 SN per campaign
- Star clusters M44 & M67

- C16 DDT deadline is 8/31
- C17 target deadline is 10/12





K2 Science Breadth

Enabled by:

Long-baseline,

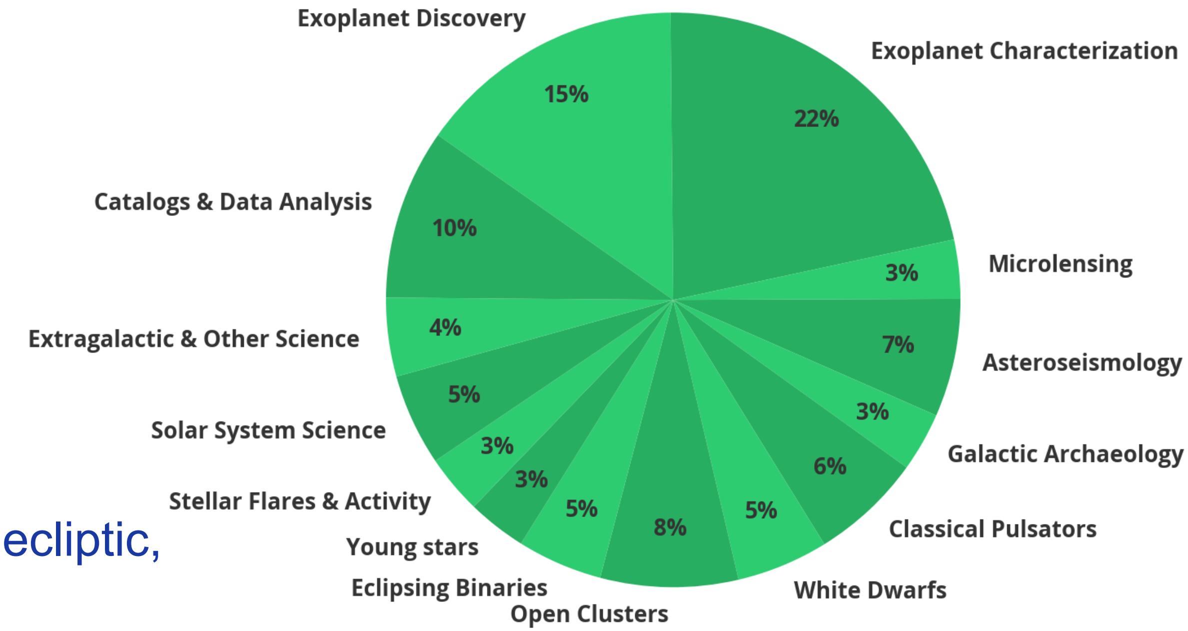
High-cadence,

High-precision photometry,

In diverse fields around the ecliptic,

Simultaneously monitoring thousands of targets,

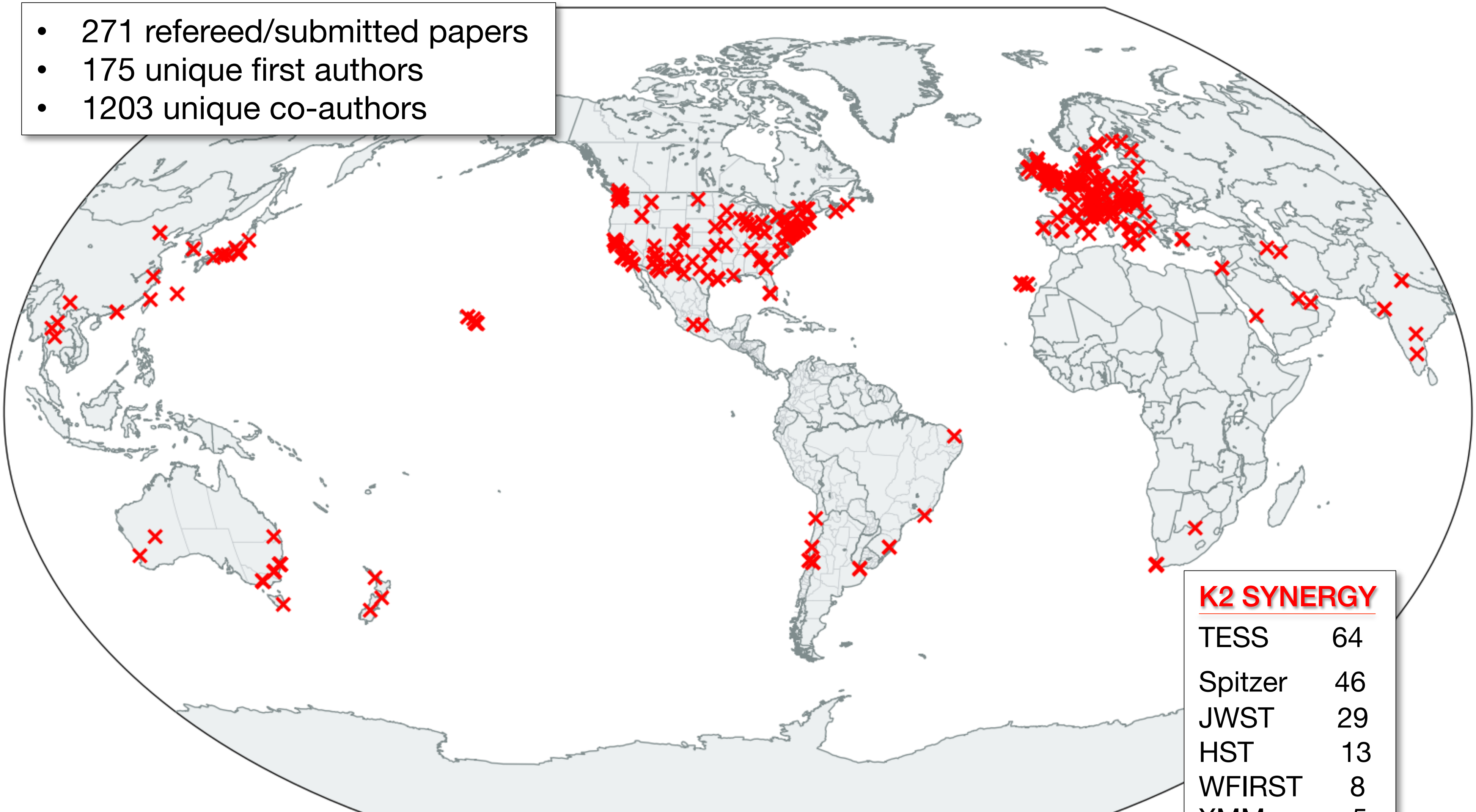
Community-driven science and no exclusive use period.



… the K2 mission has enabled a diverse array of scientific investigation!

Community Engagement

- 271 refereed/submitted papers
- 175 unique first authors
- 1203 unique co-authors



K2 SYNERGY

TESS	64
Spitzer	46
JWST	29
HST	13
WFIRST	8
XMM	5

Community Engagement

A dynamic community is incentivized by:

- Consensus selection of Fields-of-view
- Competitive, peer-reviewed selection of targets and funding
- Increased funding for investigators that deliver value-added products to the community
- Open data access – no exclusive data rights

Community Response – 1 Example

MAST K2 - Trappist-1

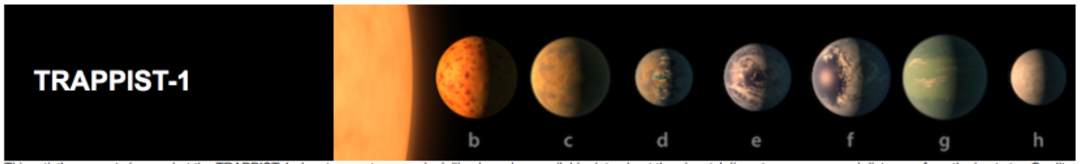
Secure https://archive.stsci.edu/k2/trappist1/

Apps | Bookmarks | art resources | R resources | python resources | NEO | stats learning | Other Bookmarks

Barbara A. MIKULSKI ARCHIVE FOR SPACE TELESCOPES

MAST | STScI | Tools | Mission Search | Search Website | Follow Us | Register | Forum

About MAST | Getting Started



This artist's concept shows what the TRAPPIST-1 planetary system may look like, based on available data about the planets' diameters, masses and distances from the host star. Credit: NASA-JPL/Caltech

The raw cadence data for the K2 observations of the TRAPPIST-1 system are now available.

The calibrated Light Curves and Target Pixel Files should arrive some time in June, and will have K2 IDs 200164267 and 246199087, both observed in short cadence. The K2 ID 200164267 is an 11x11 pixel custom mask, while K2 ID 246199087 is a smaller, standard-sized mask, for which the project will produce calibrated products. The smaller 246199087 mask is a subset of the 200164267 11x11 mask. As such, users who want to create their own light curves for TRAPPIST-1 using custom apertures are advised to download the data for the larger 200164267 mask.

Users may use the Python-based Kadenza software tool to extract the raw data. The README file at github is also a good source for understanding the content of these files. The Format Information for Cadence Pixel Files document describes both the raw cadence data and the associated pixel mapping reference files.

An "unofficial" set of TRAPPIST-1 Target Pixel Files (TPF) have been provided by Geert Barensten, which will compress all the raw cadence data into one file. The TPF is a time series of images in a binary FITS table, where each image (roughly 11x11 pixels) represents a single cadence.

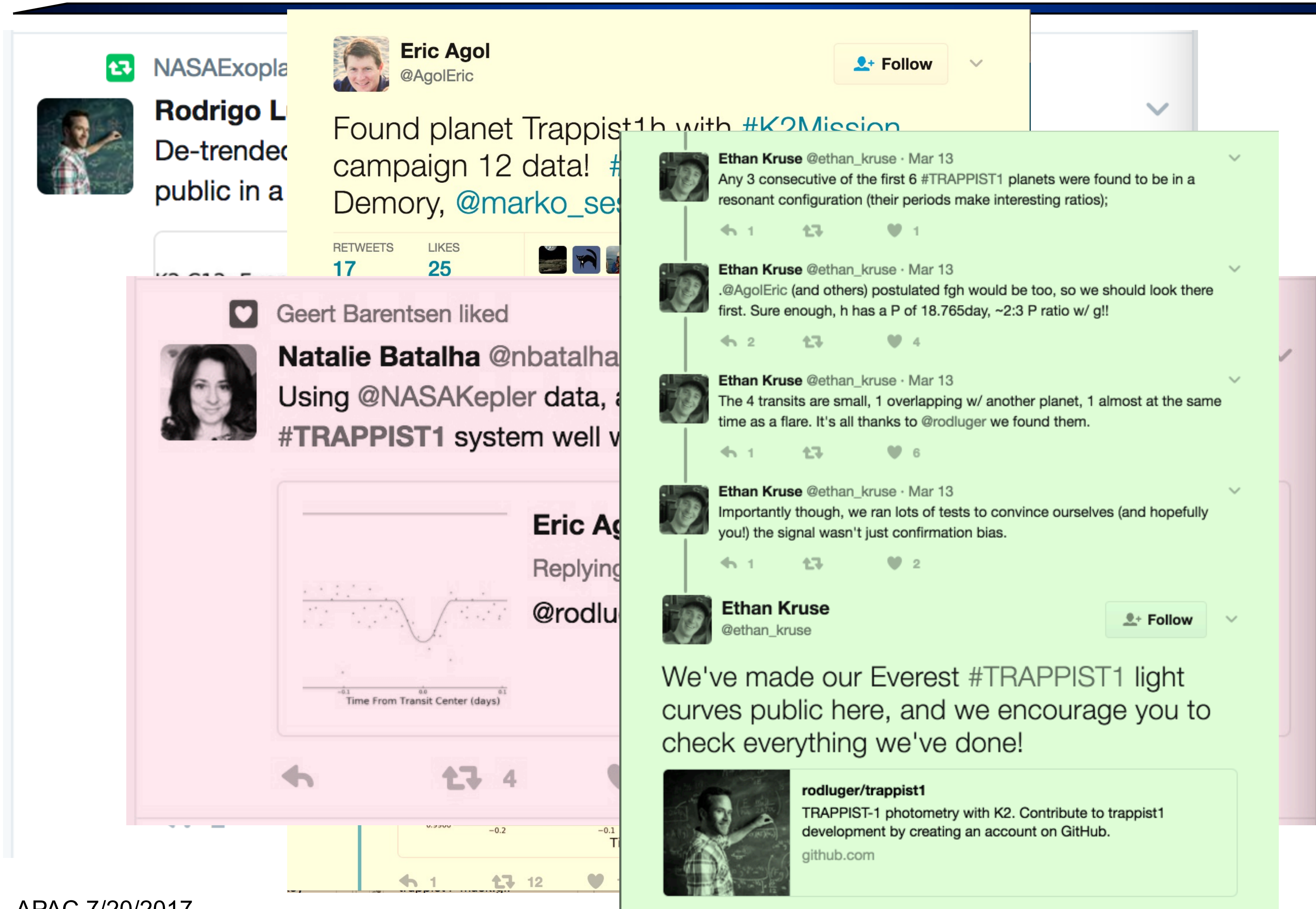
- **Download the unofficial, "pseudo-TPF" file, created by Geert Barensten:**
  Long Cadence | Short Cadence
  Important warnings and caveats can be found at this K2 Mission Office blog post.
- **Download all the raw K2 Campaign 12 data here:**
  https://archive.stsci.edu/missions/k2/c12_raw_cadence_data/
- **Download the corresponding Pixel Mapping Reference Files (PMRFs) at:**
  https://archive.stsci.edu/missions/k2/pmrfs/c12
- **Search the Portal for all available MAST data of** TRAPPIST-1.
- **The community has made iPython notebooks available that show how to analyze the TRAPPIST1 raw data release.**
  - Tom Barclay has created an iPython notebook that demonstrates how to create a quicklook light curve using the pseudo-TPF file.

3/8 @ 9am
C12 raw data released

March downloads:

1,469 GB
537 users
57 countries

Community Response – 1 Example



Community Response – 1 Example

A terrestrial-sized exoplanet at the snow line of TRAPPIST-1

Rodrigo Luger, Marko Sestovic, Ethan Kruse, Simon L. Grimm, Brice-Olivier Demory, Eric Agol, Emeline Bolmont, Daniel Fabrycky, Catarina S. Fernandes, Valérie Van Grootel, Adam Burgasser, Michaël Gillon, James G. Ingalls, Emmanuël Jehin, Sean N. Raymond, Franck Selsis, Amaury H.M.J. Triaud, Thomas Barclay, Geert Barentsen, Laetitia Delrez, Julien de Wit, Daniel Foreman-Mackey, Daniel L. Holdsworth, Jérémy Leconte, Susan Lederer, Martin Turbet, Yaseen Almleaky, Zouhair Benkhaldoun, Pierre Magain, Brett Morris, Kevin Heng, Didier Queloz

(Submitted on 12 Mar 2017)

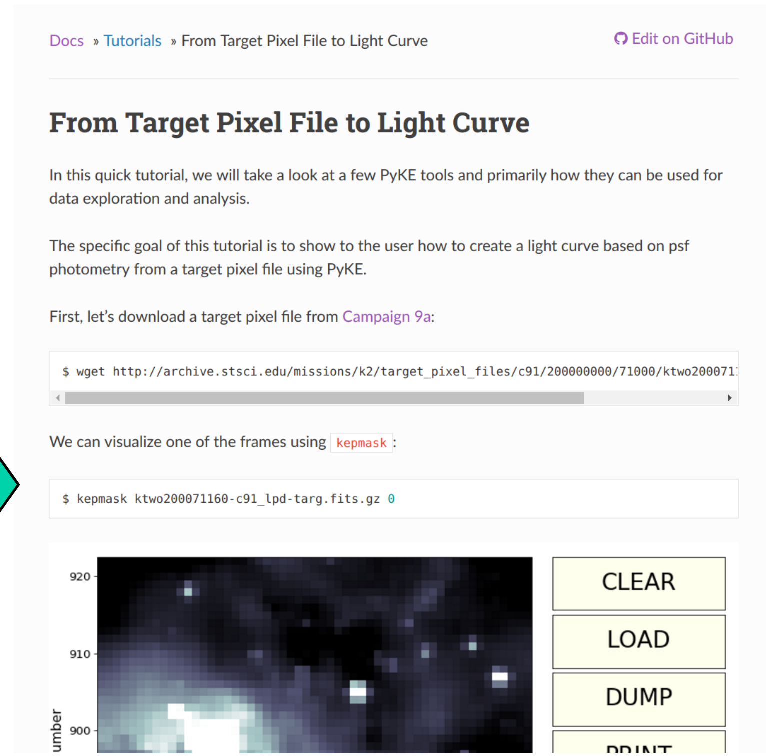
The TRAPPIST-1 system is the first transiting planet system found orbiting an ultra-cool dwarf star. At least seven planets similar to Earth in radius and in mass were previously found to transit this host star. Subsequently, TRAPPIST-1 was observed as part of the K2 mission and, with these new data, we report the measurement of an 18.764 d orbital period for the outermost planet, TRAPPIST-1h, which was unconstrained until now. This value matches our theoretical expectations based on Laplace relations and places TRAPPIST-1h as the seventh member of a complex chain, with three-body resonances linking every member. We find that TRAPPIST-1h has a radius of 0.715 Earth radii and an equilibrium temperature of 169 K, placing it at the snow line. We have also measured the rotational period of the star at 3.3 d and detected a number of flares consistent with an active, middle-aged, late M dwarf.

Comments: 36 pages, 8 figure, 2 tables Submitted to Nat. Astron. on 3/10/2017

60 hours after raw data release!

Preparing for Mission End…

- Revised process for Cycle 6 proposals (Campaigns 17, 18, & 19) in order to avoid (possibly) unnecessary review overhead
  - Target proposals due in fall (Step 1)
    - Streamlined submission (outside of NSPIRES) and remote peer review
  - Funding proposals (Step 2) due after start of C17 (April 2018)
    - Standard NSPIRES proposal
    - Must use targets chosen from earlier step, but anyone can submit a proposal.
- GO office focusing on developing and updating legacy user tools and developing tutorials.
- Increased monitoring of critical spacecraft systems to facilitate early identification of performance degradation



Mission Operations End

Probably some time next Spring, when the fuel finally runs out – *inherently unpredictable*

- Spacecraft operations has become more fuel efficient over time
  - Science observing is the main consumer of fuel, followed by anomalies
- As fuel and pressure diminishes (mono-propellant hydrazine), thruster performance becomes less predictable
  - Will lead to degraded pointing control and more image motion
- When thrusters can no longer support good science pointing, a final downlink of the on-board recorder will be performed
  - Will communicate closely with the science community as the end of mission approaches
- Transmitters will be turned off and the spacecraft will be abandoned in place

Mission Science End

Current funding runs into FY20, assuming fuel will last through Campaign 19

- In all cases, funding will provide for final campaign delivery to the archives and extended community support through the GO Office (as much as an additional year)
- If fuel is consumed earlier, we will consider using some of the funding to reprocess campaigns with the latest pipeline

Lessons Learned

Recipe for a Successful Open Mission (v 0.1)

<u>Ingredients</u>

- Data
  - Release early as possible
  - Multiple products with different levels of processing
  - Documentation
  - Software tools
  - Multiple repositories
- Science Funding
  - In-project scientists using data
  - Funding for broad community participation
- Outreach & more outreach

<u>Special Sauces</u>

- Data opens new phase space
  - Photometric sensitivity
  - Uninterrupted time sampling
- Data applicable to new & growing fields
  - Exoplanets
- Data applicable to fields that are short on data
  - Asteroseismology
  - Galactic archaeology
- Supportive Community