# Subaru-TESS Synergy

Norio Narita (U. Tokyo/ABC/NAOJ)
on behalf of Japanese TESS consortium

# Outline

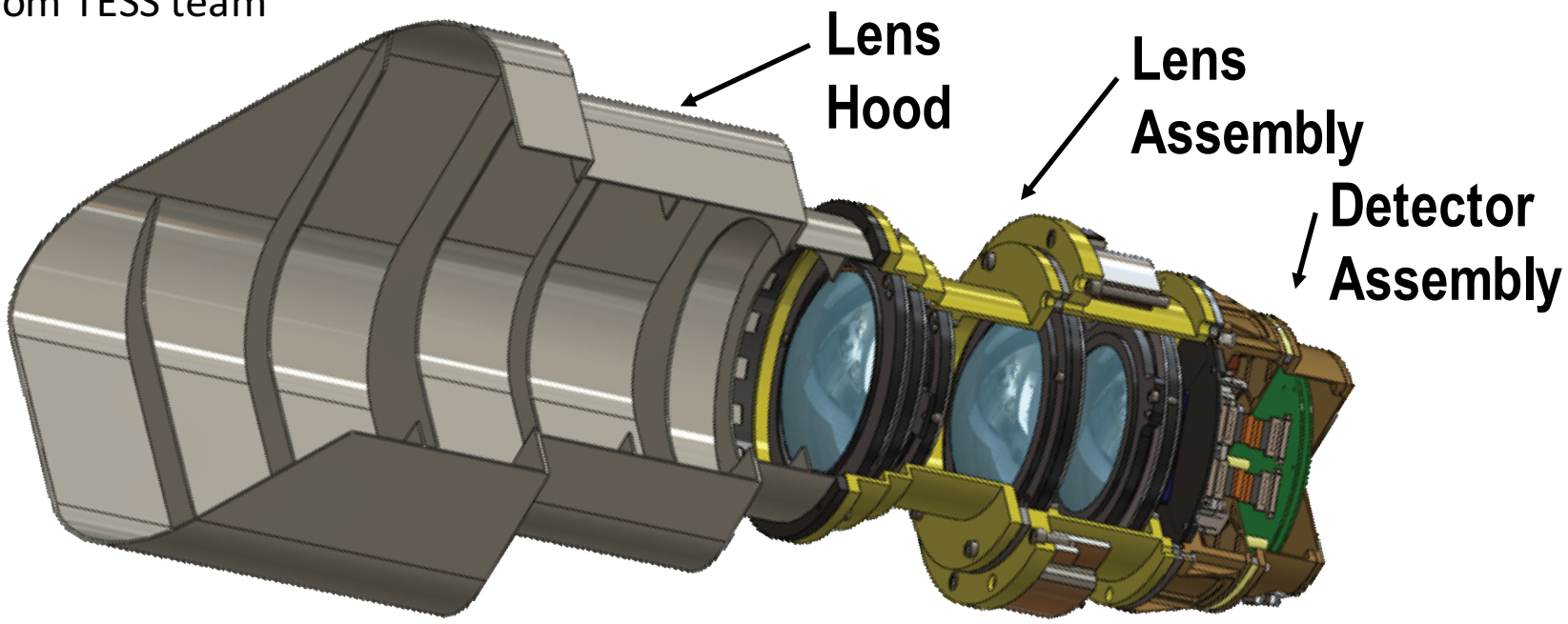
- Introduction of TESS
- Introduction of Japanese TESS Consortium
- Subaru-TESS Synergetic Science Cases
  - Exoplanets
  - Galactic Archaeology
  - Superflare stars
- Desired Instruments and Nights with Subaru
- Summary

# TESS Overview

- TESS is the next flagship space mission for exoplanet studies after Kepler mission, currently planned to launch in 2017 Dec
- Almost-all-sky survey of "transiting" planets around nearby 200,000 stars
- 2 year observation with 4 cameras (10cm diameter) each having 24$^{o}$ x 24$^{o}$ FoV


- Providing ~20 Earth-like transiting planets around HZ for further follow-up observations with ELTs and JWST

slide from TESS team

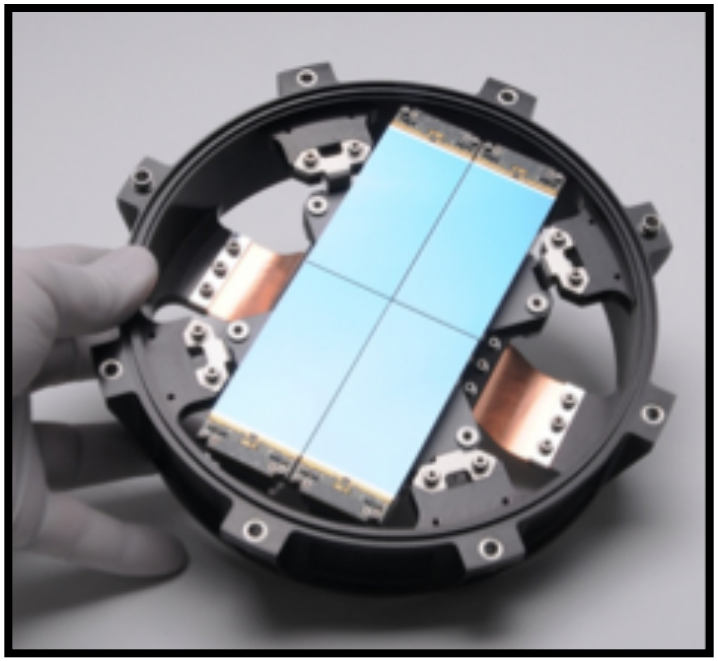



| | |
|---|---|
| Entrance pupil diameter | 10.5 cm |
| Bandpass | 600-1000 nm |
| Field of view | 24° x 24° |
| Cadence for target stars | 2 min |
| Cadence for full frame images | 30 min |

four 2048 x 4096 CCDs

each CCD
= 2048 x 2048 imaging
+ 2048 x 2048 storing

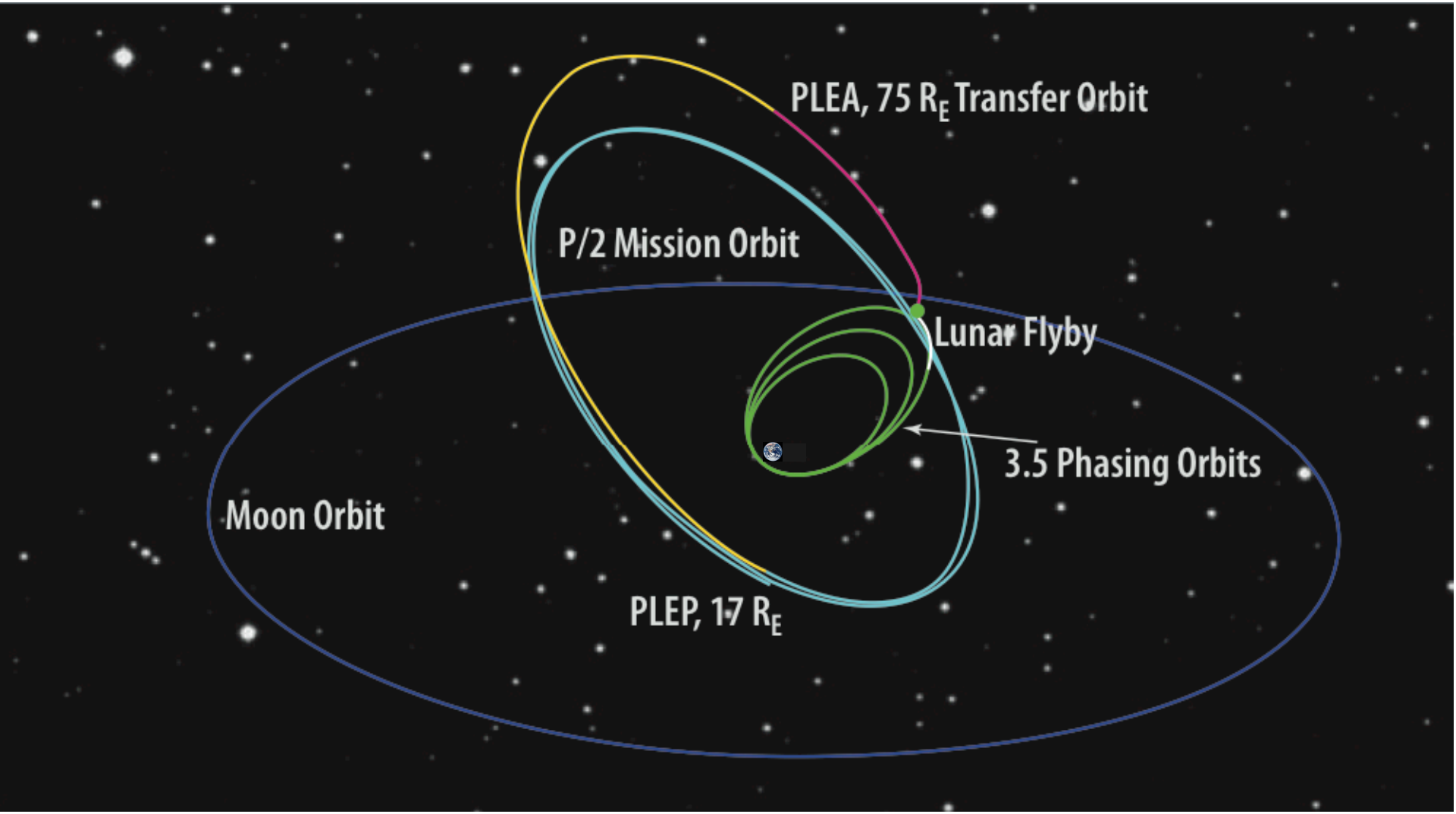
in total
4096 x 4096 imaging



# Upcoming TESS Timeline

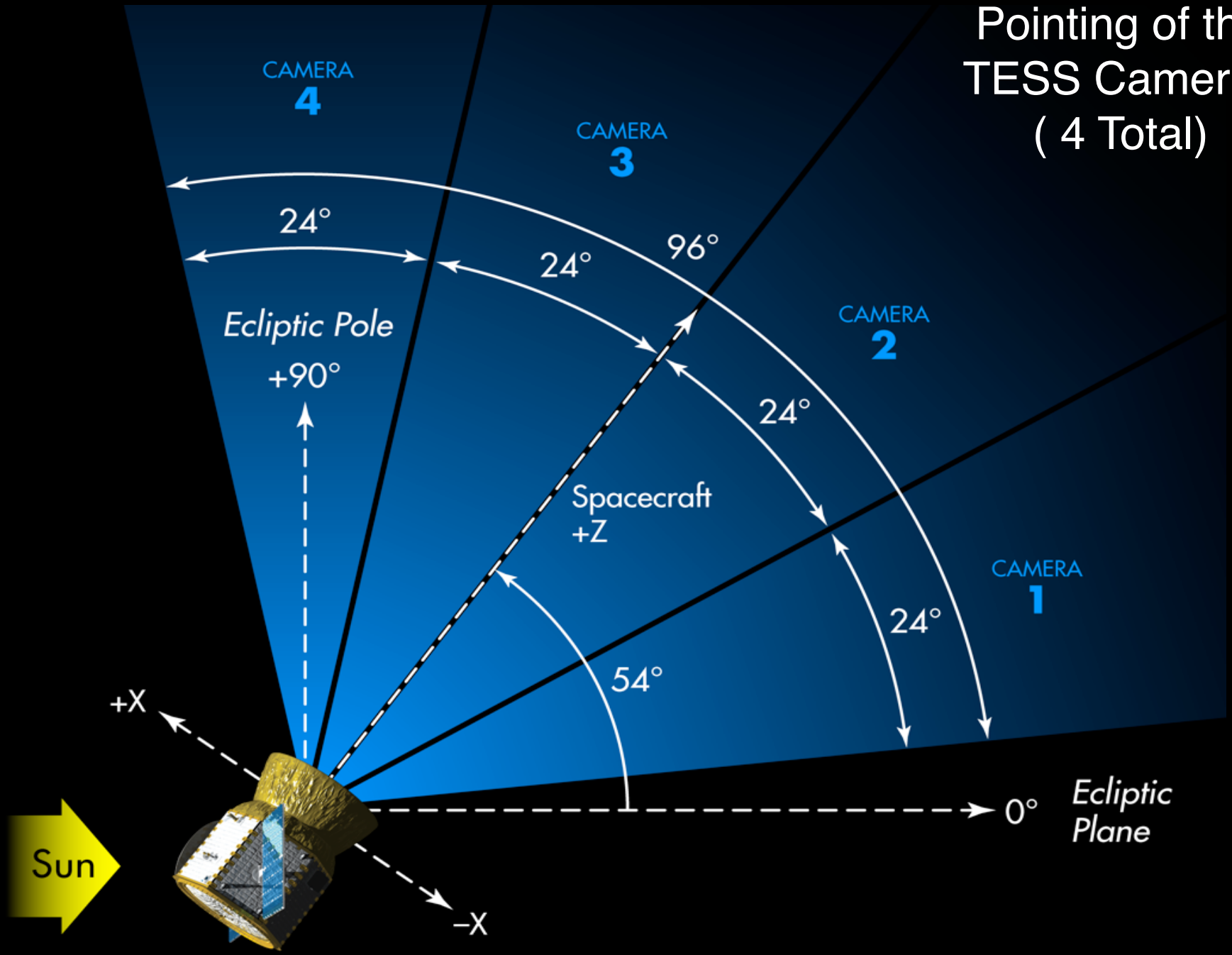
- Launch-9 month : Call for Guest Investigator Program (GIP)
- Launch-6 month : Proposal due for GIP
- Launch-1 month : Announcement of GIP results
- 2017 Dec 20: Launch date (currently scheduled, but may be postponed for a few months, no later than 2018 June)
  - Launch+2 month: Reach High Earth Orbit and engineering
  - Launch+3 month: Start observations from Southern hemisphere
- Start obs+6 month: Start data release (every 4 months)
  - Follow-up observations are possible from 19A semester

# TESS High Earth Orbit and Downlink



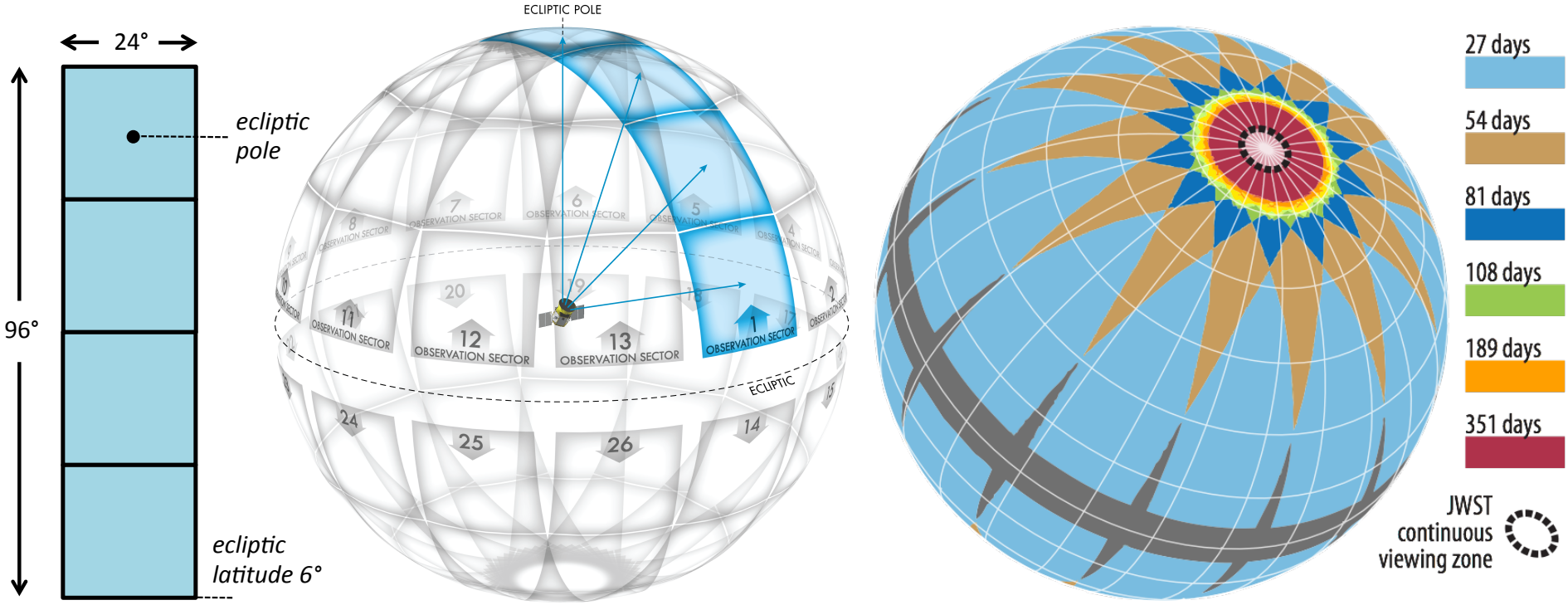

The orbit is stable over decades.

# Pointing of the TESS Cameras ( 4 Total)



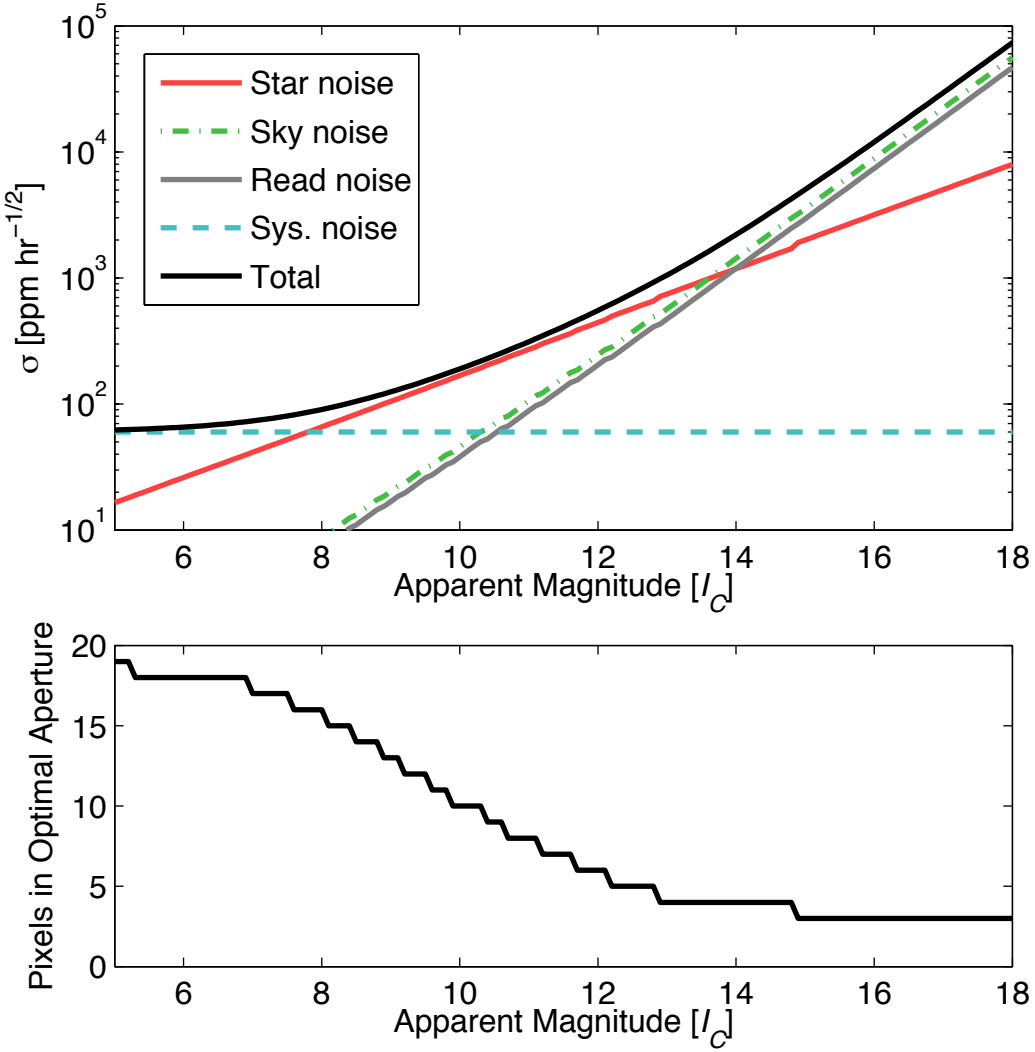

slide from TESS team

# TESS Field of View and Strategy




- TESS observes 27 days for each rectangle sector (24$^o$ x 96$^o$)
- Start with southern hemisphere (1 year) and then monitor northern hemisphere (1 year), and possible extension.

# TESS Expected Sensitivity




- Better than 0.1% (per hr) photometric precision for I mag < 12
- Sufficient to detect (sub)Earth-size planets around M dwarfs
- 1% precision for I~16
- It may be also useful for other science cases

# Guest Investigator Program

**Guest Investigator Proposals:**
**$2.5M funding per year**

| 2-minute cadence | Working with FFIs | Targets of Opportunity | Discretionary Targets |
|---|---|---|---|
| ~10,000 targets/year | Science that doesn't need 2-min cadence | Known science, unknown targets (e.g. supernovae) | Unknown science |
| "Survey" proposals encouraged | Development of new software tools (high bar!) | ToO Science Leads identify targets for inclusion | Responding to new discoveries |
| Data processed with core data | Funding only | Targets and funding are decoupled | Targets only |
| Targets and funding are decoupled | | | Ad hoc peer review |

TESS is also considering to make GCN alerts for transient events.

slide from TESS team

# Introduction of Japanese TESS Consortium

<Aims>

1. Detailed considerations of Subaru-TESS synergetic campaign
   - What kinds of science?
   - How many nights are desired?
   - Which instruments are desired?
2. Providing latest information of TESS to Japanese community
   - preparing Guest Investigator Program proposals
   - 4 Japanese researchers are joining the TESS team as collaborators and can access to latest information

# Activities of Japanese TESS Consortium

<Previous activities>

- 2015 Nov. 26-27: Japanese TESS Science Workshop
  - about 60 attendees
  - 19 talks for not only exoplanets, but also asteroseismology, galactic archeology, super-flare stars, supernovae, transient, variable stars, Wolf-Rayet stars
- 2016 Jan: call for consortium members
- 2016 August: start monthly regular meeting
  - Discussions of various science cases
  - Discussions of various available telescopes/instruments

# Current Consortium Members: 49

## Members' Affiliations

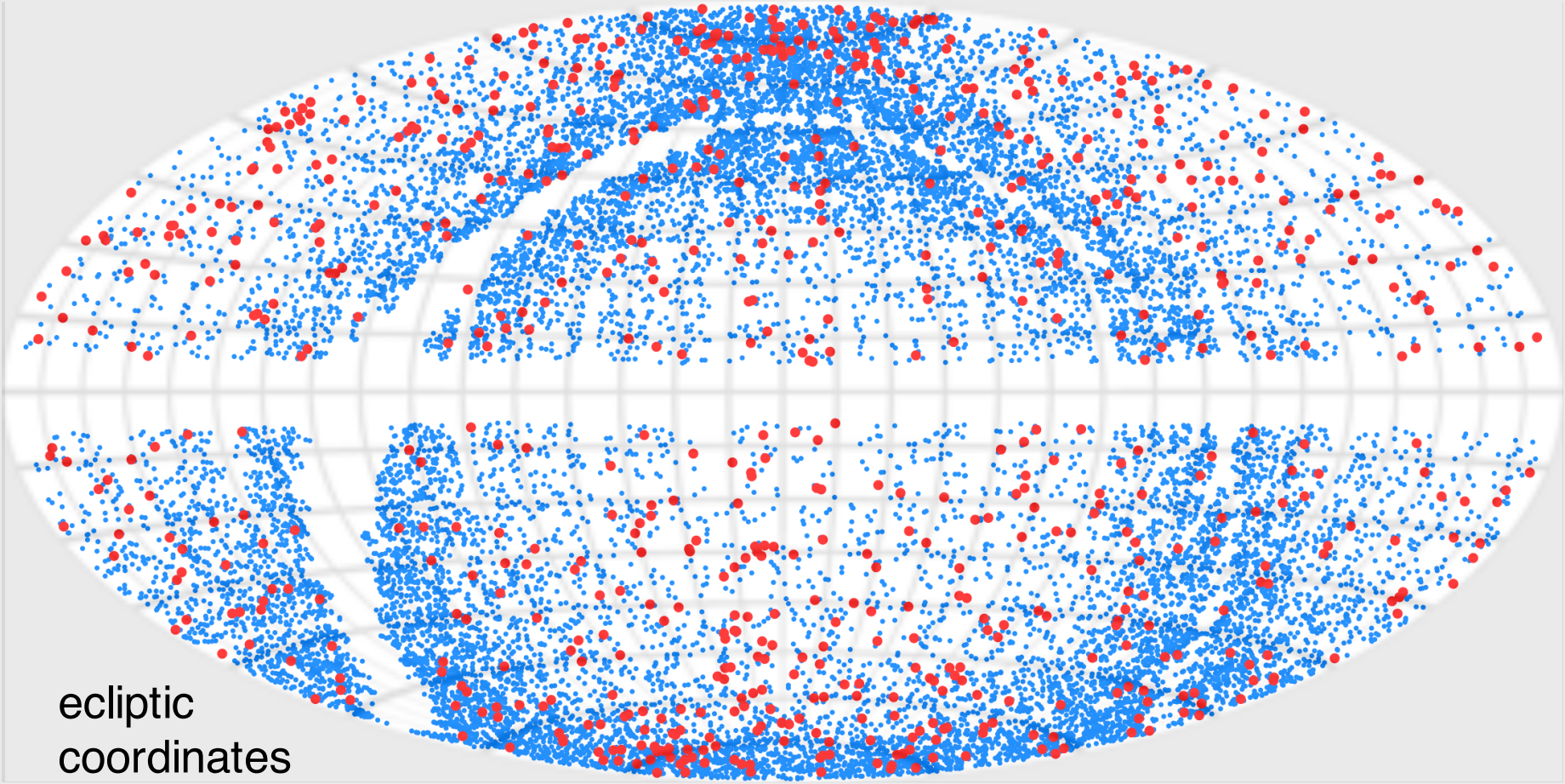
- University of Tokyo
- Tokyo Institute of Technology
- Astrobiology Center
- NAOJ
- Kyoto Univ.
- Nagoya Univ.
- Osaka Univ.
- Japan Spaceguard Association
- Tokyo University of Science
- Univ. of Aizu
- Saitama Univ.
- Tokai Univ.
- Chiba Institute of Technology

- Professors : 13
- Assoc. Professors : 10
- Assist. Professors : 10
- Postdoc/researchers : 9
- Graduate students : 7

# Subaru-TESS Synergetic Science Cases Under Consideration

- Exoplanets
- Galactic Archaeology
- Superflare Stars

# Simulated TESS Planet Detections




Sullivan et al. (2015)

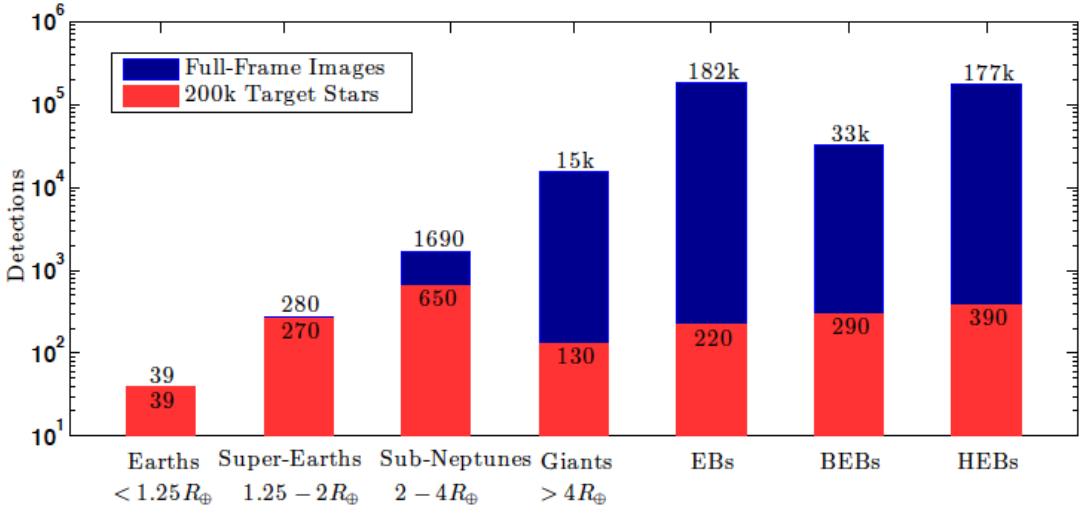
detectable planets around pre-selected target stars

detectable planets around other stars in full-frame images

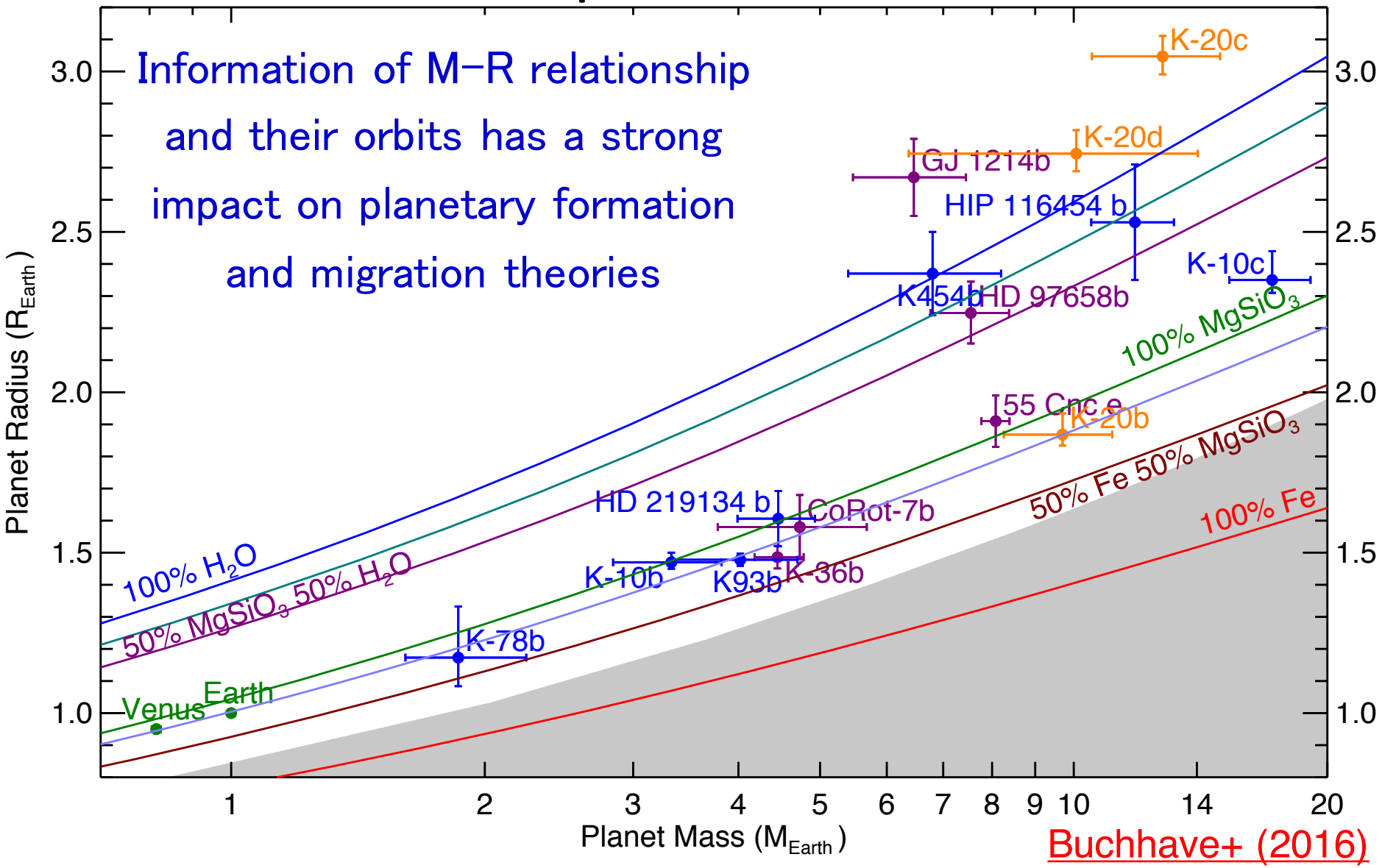
slide from TESS team

# TESS Planet Yield Simulation (Sullivan+2015)

- about 300 planets: smaller than 2 $R_{earth}$
  - among those, ~165 planets are orbiting M dwarfs
  - ~100 planets are orbiting I<10 host stars
  - about 20 planets are orbiting within or near habitable zone
- about 650 planets: between 2 $R_{earth}$ and 4 $R_{earth}$
  - boundary of "super-Earth" and "mini-Neptune"
  - also important targets for planetary science



# Subaru/IRD can reveal mass-radius relationship of small planets in detail



# How many planets are observable from Hawaii?

Mid-late M dwarfs with J<11 and max. elevation > 45 deg, from Hawaii

| | Number | $<2R_E$ | $2\text{-}4R_E$ | $<2R_E$ $0.2<S/S_E<1.5$ | $<2R_E$ $0.2<S/S_E<0.8$ |
|---|---|---|---|---|---|
| ≦3000K | 4 | 2 | 2 | 2 | 1 |
| ≦3100K | 3 | 2 | 1 | 2 | 2 |
| ≦3200K | 1 | 1 | 0 | 1 | 1 |
| ≦3300K | 9 | 7 | 2 | 7 | 5 |
| ≦3400K | 30 | 20 | 10 | 4 | 0 |
| Total | 47 | 32 | 15 | 16 | 9 |

# Desired Subaru Instruments/Nights

- Concentrate on 30 favorable & interesting planets
  - Less than 3400K, J<11, not rapidly rotating or active
  - (mostly J>10 for which 8m class telescope are needed)
  - 15 planets each for 1-2 $R_{Earth}$ and 2-4 $R_{Earth}$ planets
  - Including ~10 planets in the habitable zone with <2 $R_{Earth}$
  - ~360 hours with Subaru/IRD are desired to determine the mass and eccentricity of the planets

➢ About 60 nights including weather success rate

# Other Exoplanet Science Cases

- Characterizations of planetary atmospheres/orbits
  - Transmission spectroscopy to probe planetary atmospheres
  - Doppler tomography to measure spin-orbit misalignments

- Detecting Niche Exoplanets
  - giant planets around giant (III) stars
  - giant planets around early-type (BA) stars
  - planets around young stars
  - planets around stars in stellar clusters

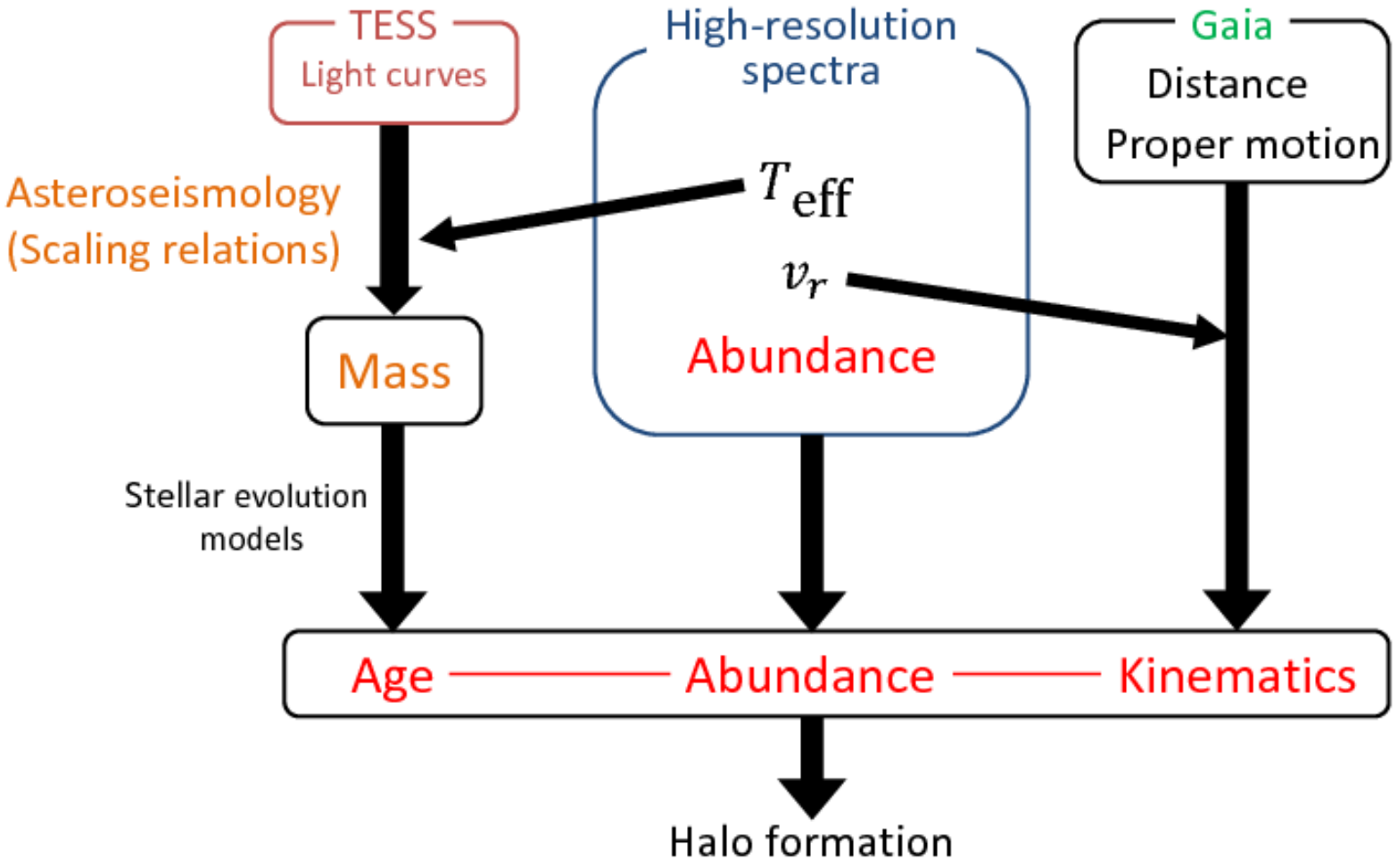
# TESS and Galactic Archaeology

- TESS is also useful for asteroseismology
  - 60 targets with 20 sec sampling
  - 750 targets with 2 min sampling
  - mainly red giants in the Milky Way galaxy
  - One can propose more 2 min sampling targets in GIP

- This is the first opportunity to investigate stars in the galactic halo by space-photometric asteroseismology
  - CoRoT, Kepler, K2 observed only limited volume

# Galactic Archaeology with TESS+Subaru+GAIA

## Courtesy of T. Matsuno (Sokendai/NAOJ)



# Desired Subaru Instruments/Nights

- Subaru HDS offers high-spectral resolution and high-SNR with the new image slicers (Tajitsu et al. 2012)

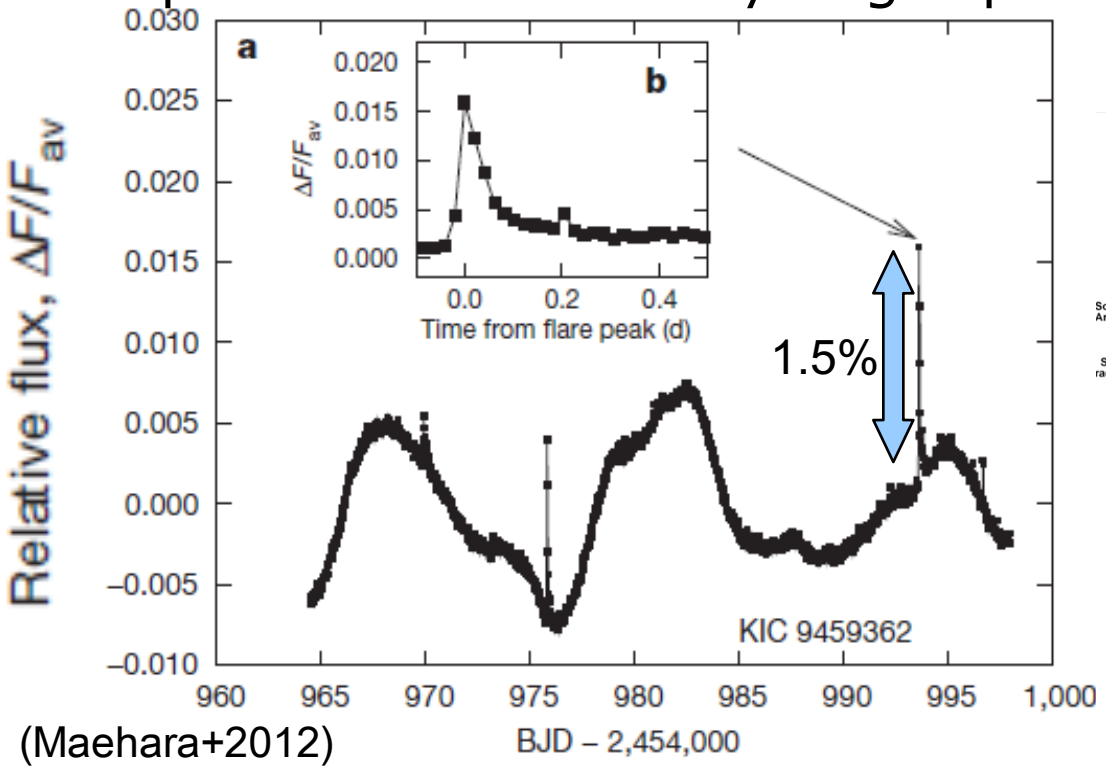
- Can determine $T_{eff}$, $v_r$, and abundance of 100 or more red giants in the galactic halo

➢ About 15 nights (for 100 stars) are desired (including weather success rate)

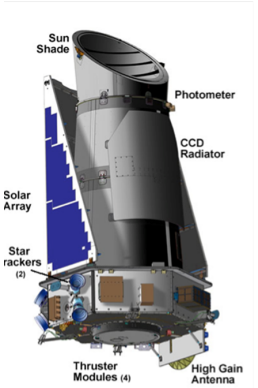
# Superflare Stars

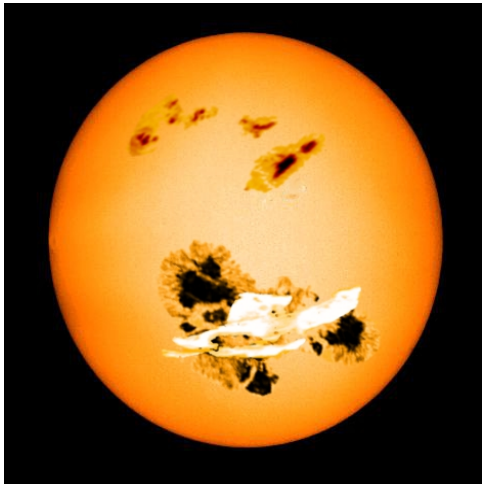
- Previous studies with Kepler data (Maehara+2012 Nature, etc)
  ⇒ Discoveries of about 300 superflare stars (10-10,000 times energetic than maximum Solar flares)

- Quasi-periodic variations suggest the presence of spots
- Variations enable to estimate rotation period and size of spots
  ⇒ suggest Solar-like slowly rotating stars may also show superflares if extremely large spots exist




(Maehara+2012)



artist's illustration of a superflare star

Courtesy of Y Notsu (Kyoto)

# TESS and Superflare Stars

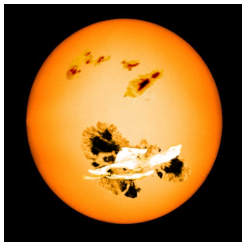
TESS will reveal

- occurrence rate, stellar rotation period, and size of spots
- (demerit) only photometric & only ≳30 days observation
  ⇒ Follow-up observations are necessary
- (merit) nearby & all-sky superflare stars can be detected

⇒ For especially interesting targets

- Long-term photometric monitoring for spot monitoring
- Direct time-resolved spectroscopy of flares
- Direct measurements of magnetic field using Zeeman effect

More detailed studies are possible than faint Kepler stars



Can uncover a dynamo mechanism which generates extremely large spots

# Follow-up Study with Subaru/HDS

・Subaru/HDS can provide high spectral resolution (R~160,000) and high SNR (SNR ~ 200-300)

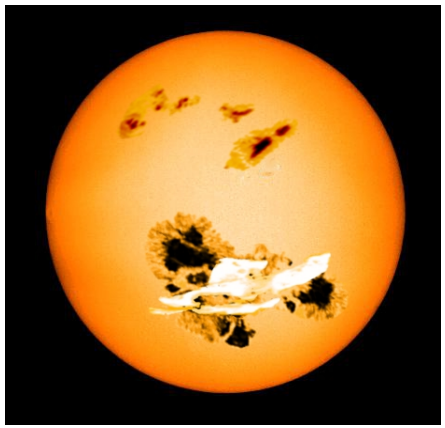
・It is not capable with 3-4m telescopes (including Kyoto 3.8m)

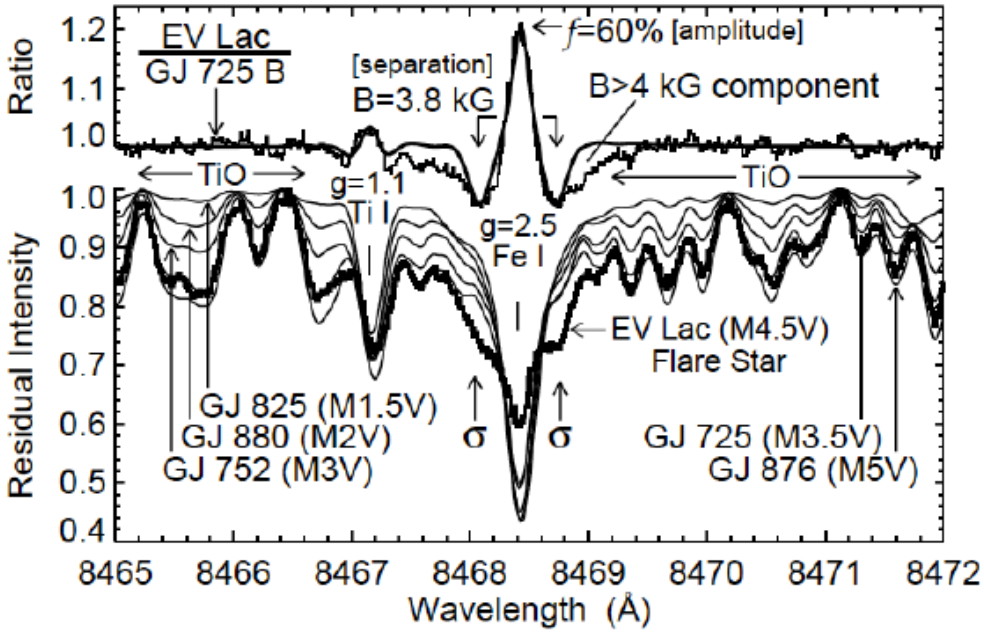
・High spectral resolution and high SNR spectroscopy for 20 MK superflare stars (V<10) to measure the line splitting caused by the Zeeman effect

・Enables direct measurements of the strength of the magnetic field of photospheres for the superflare stars

・Make comparisons with the strength of the magnetic field of corona, which can be derived from flare energy and duration (Namekata+2017 in prep)

→ About 10 nights are desired





# Summary of Desired Instruments/Nights

- Exoplanets
  - Detecting small planets around M dwarfs : IRD, 60 nights
  - Atmospheres of small planets : MOIRCS, 10 nights
  - Spin-orbit mislaignments of small planets : IRD, 10 nights
  - Detecting giant planets around giants : HDS, 15 nights
  - Detecting giant planets around BA stars : HDS, 10 nights
  - Detecting planets around young/cluster stars : IRD/HDS, 10 nights
- Superflare stars
  - Measurements of the Zeeman effect : HDS, 10 nights
- Galactic Archaeology
  - Studying galactic halo with TESS/Subaru/GAIA : HDS, 15 nights
- Science cases are still growing

# What Subaru can do with TESS?

- Subaru can follow-up new transiting planets and other interesting objects (red giants for asteroseismology, superflare stars, etc) soon after the data releases in a timely and efficient manner

- High scientific productivity is expected

We hope a chance of call for a medium size program similar to WFIRST

# Summary

- TESS is the next flagship exoplanet mission to search for interesting exoplanets in the solar neighborhood

- Not only exoplanets, but also other fields (such as galactic archeology, superflare stars, transients, etc) can receive benefits from TESS data

- Subaru-TESS synergetic campaign would benefit Subaru and Japanese astronomical community