Supercomputing in the Age of Discovering Superearths, Earths and Exoplanet Systems

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Ad Hoc Big Data Task Force of the NASA Advisory Council Science Committee
All the Known Planets In 1994
A More Recent Pictures of Planets

All 786 Known Planets

*3,338 planets as of 9/28/16
ALL 786 KNOWN PLANETS

(TO SCALE)

(SOME PLANET SIZES ESTIMATED BASED ON MEAS.)

THIS IS OUR SOLAR SYSTEM.

THE REST OF THESE ORBIT OTHER STARS AND WERE ONLY DISCOVERED RECENTLY. MOST OF THEM ARE HUGE. BECAUSE THOSE ARE THE KIND WE LEARNED TO DETECT FIRST, BUT NOW WE'RE FINDING THAT SMALL ONES ARE ACTUALLY MORE COMMON. WE KNOW NOTHING ABOUT WHAT'S ON ANY OF THEM.
A Search for Earth-size Planets

Exoplanet Discoveries Over Time

Radii estimated for non-transiting exoplanets
Discovery data dithered randomly within discovery year
Enabling Kepler

- Back illuminated CCDs (20 ppm photometric precision)
- Sophisticated algorithms
- Computational infrastructure
How Does Kepler Work?
How Hard is it to Find Good Planets?

**Jupiter (~1%)**

**Earth (~0.01%)**

**Kepler Candidate KOI-351**
- $R_p = 9.7R_e$
- $P = 331.6d$

**Kepler Planet — Kepler-20e**
- $R_p = 0.87R_e$
- $P = 19.58d$
• Launched March 7 2009
The Search Problem
Keeping Up with the Data
64 hosts, 712 CPUs,
3.7 TB of RAM,
~300 TB of raw disk storage
Hardware Architecture: NAS Pleiades Supercomputer

- 7.25 Pflop/s peak cluster
- 246,048 cores
- 938 TB of memory
- 29 PB of storage

Transiting Planet Search Running on Pleiades
A Search for Earth-size Planets

Processing Kepler Data on the NAS Pleiades

Processing scales from 100s of cores on local cluster to 10s of 1000s of cores on the NAS
Kepler-452b
Light Curve

A Search for Earth-size Planets
Transit-like signals can be produced by a number of astrophysical phenomena:

- Background Eclipsing Binaries
- Triple star systems with an EB/planet
- Background/Foreground planet

BLENDER can assess statistical confidence in planetary nature of a candidate

Computationally intensive: Supercomputer essential
BEB odds: $1.21 \times 10^{-12}$  
BP odds: $2.56 \times 10^{-10}$  
HTP odds: $2.35 \times 10^{-6}$

Vs: (Expected) Planet odds: $9.97 \times 10^{-4}$

Therefore, odds ratio is $\sim 424:1$
A Search for Earth-size Planets
Kepler Small Habitable Zone Planets Now Include One Orbiting a Sun-Like Star
David Kipping and team have been searching for exomoons in ~400 light curves from Kepler on the NAS Pleiades supercomputer.

Each search consumes 50,000 CPU hours.

~40 light curves were searched as of 2014.

~300 were searched in 2015.

Exomoons remain elusive: None have been conclusively discovered.
TESS Elation!
• All sky transit survey to find Earth’s closest cousins

• 2 year primary mission

• Launch in December 2017 (tentative)

• TESS will identify best planets for follow up and characterization with James Webb and very large telescopes
• Processing TESS data on the NAS

- SPOC Pleiades Front End
- Worker Machine
- Storage Array
- Storage Area Network (link layer = Fibre Channel)
- SPOC Network (link layer = 10GiB Ethernet)
- ADB Server
- MOM
- PostgreSQL
- Worker
- object: PI::Worker Name [waiting for message]

- Pleiades Compute Node
- "Compiled" MATLAB Science Algorithm
- PI::RemoteSubTaskExecutor
- Pleiades Node
- RMOM
- Gateway Machine

- Infiniband Network
- NFS
Supercomputing has played an increasingly important role in exoplanet searches, validation and characterization.

The Kepler and TESS missions were and are not achievable without supercomputing.

The role of supercomputers in exoplanet science is sure to grow in the future as the amount of data and sophistication of the software continue to increase with future missions.