ASTrO will monitor over 2 million of the brightest stars in the 2MASS Survey

CoRoT-2b, a 3 $M_{\text{Jup}}$ planet orbiting a K0 star.

The 1882 Transit of Venus
349 Planets To Date

- **Timing** (1992)
  - 4 systems
  - 7 planets
  - 2 multiple
- **Radial Vel.** (1995)
  - 275 systems
  - 323 planets
  - 33 multiple
- **Transit** (1999)
  - 59 planets
- **Microlensing** (2004)
  - 8 planets
  - 1 multiple
- **Imaging** (2004)
  - 9 systems
  - 11 planets

- **Astrometry** (2009)
  - 1 planet

Exoplanet Encyclopedia: [http://exoplanet.eu/](http://exoplanet.eu/)
Transit Basics

• Primary transit
  – Planet in front of star
  – \( \frac{F_p}{F^*} = \left( \frac{R_p}{R^*} \right)^2 = 1\% \)
    • Jupiter/G star
    • Earth/late M star
  – \( \frac{F_p}{F^*} = 0.01\% \)
    • Earth/G star
  – Transmission spectrum

• 0.5-10\% prob. alignment
• Duration 2-10 hrs
• RV yields mass \( \rightarrow \) density

• Secondary transit
  – Planet behind star
  – IR yields temperature
    • \( \frac{F_p}{F^*} = \left( \frac{R_p}{R^*} \right)^2 \frac{B_p(T_p)}{B^*(T^*)} \sim 0.1\% \)
    • Emission spectrum
  – Visible yields albedo
    • \( \frac{F_p}{F^*} = \left( \frac{R_p}{R^*} \right)^2 A_p \sim 0.1\% \)
How Do we Find Transits?

- Follow-up RV detections (1-10% alignment)
- Transit surveys
  - 10%-0.5% alignment (<0.1 to 1 AU)
  - 1%-10% incidence of gas giant planets (<0.1 to 3 AU)
    \[ \Rightarrow 10^{-3} \text{ probability} \Rightarrow \text{at least } 10^4 \text{ stars for 10 gas giants} \]
- Ground-based surveys at 3,000-5,000 micro-mag over thousands of sq. deg.
- Space-based surveys at 20-50 micro-mag over 10s sq. deg (CoRoT) to 100 sq. deg (Kepler)
  - Kepler will monitor 150,000 stars for 4 years
Why Transits?

- Orbit inclination
- Orbital separation
- Star/Planet spin-orbit
- Stellar limb darkening
- Stellar mass/density
- Planetary radius
- Timing for other planets
- Rings/moons
- Reflected light (albedo)
- Composition (Vis & IR)
- Vertical structure
- Global Circulation

- Transit + RV
  - Planet mass/radius → bulk density & composition
  → theory of formation and evolution
Mapping Weather on HD189733

- 920 K on the dark side to 1200 K on the sunlit side.
- Temperature variation is mild → Winds spread heat
JWST Observations of Transits

\[ \text{CO, H}_2\text{O} \]
From Deming et al (2009):
- JWST/NIRSpec observations of water absorption in a habitable super-Earth (T = 302K and R = 1.8R⊕) orbiting an M star at 20 pc
- JWST/MIRI secondary eclipse photometry at 15 μm for a warm (T = 500K) exo-Neptune (R = 4R⊕) orbiting at 0.2 AU from a K2V star.
What Is In The Future for Transits

• Kepler and CoRoT discoveries of hundreds of planets, from hot Jupiters to cool Earths
  – Detailed follow-up difficult since stars faint (V= 13 mag)
• Follow-up observations of bright planets
  – HST spectroscopy (on-going)
  – JWST spectroscopy (on-going)
• Surveys of brighter stars
  – PLATO (few 1000 sq. deg at V=10-12 mag) --- ESA study
  – TESS (few million stars, whole sky, visible) --- NASA study
  – AStRo (few million stars, whole sky, near-IR) --- NASA study
### Planets Detected In Monte Carlo Simulation

<table>
<thead>
<tr>
<th>Single Transit SNR</th>
<th>Gas/Icy</th>
<th>Rocky</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (10&gt;SNR&gt;3)</td>
<td>178</td>
<td>520</td>
</tr>
<tr>
<td>Medium (50&gt;SNR&gt;10)</td>
<td>695</td>
<td>22</td>
</tr>
<tr>
<td>High (SNR&gt;50)</td>
<td>577</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>1450</td>
<td>542</td>
</tr>
</tbody>
</table>

*2×10^6 stars in unconfused 60% of sky; Final SNR≥7; # Transits/star≥3
Yield By Spectral Type

![Graph showing yield by spectral type. The x-axis represents spectral types from A3 to M6, and the y-axis represents a unitless value labeled as $\tilde{u}$ Planet. The graph displays step-like distributions for different spectral types, with peaks at different intervals.](image-url)
Distance To Closest Transits

Distance

Distance (pc)

Cumulative Number

Jw (mag)

Distance

Jw mag
Planets Around M stars in Near IR

- Ratio of # of stars detectable in a near IR (0.65-1.65 μm) vs. deep red (0.55-1.0 μm) as a function of effective stellar temperature. Near-IR survey finds 3-5 times more M star planets than visible light survey.
- M star planet in few day orbits are in Habitable Zone
**Concept Overview**

*All Sky Transit Observer (ASTrO)* is a near-infrared sky survey designed to monitor the brightest, closest stars for transiting planets with a focus on late type stars, with a goal of improving our understanding of the formation and evolution of planets and planetary systems

**Key Measurements**

- Monitor the entire sky with continuous viewing periods of at least 60 days three times over a 3-year mission
- Observe in the near-IR \([J_W = 0.65-1.65 \mu m]\) where late type stars are brightest
- Observe with a precision of <100 \(\mu\)mag in 1 hr for a star with \(J_W = 9\) mag

**Mission Description**

- Twenty four individual cameras with 0.1 m apertures, 0.65-1.65 \(\mu\)m
- HgCdTe 2k×2k arrays, 4 arrays per camera (4k×4k arrays possible alternative)
- Flight system inserted into L2 Orbit, injected mass is suitable for shared Delta IV launch vehicle or smaller LV
- 3-yr lifetime with 5 year goal (consumables sized for 5 years)
- Mission OPS implements Kepler-like concept
Questions for Investigation

• What orbit is favorable
  – Stable all-sky viewing vs. cost of getting there

• What instrumentation is required
  – SNR over relevant integration time → aperture
  – Continuous obs vs. rpt’d snapshots → # cameras
  – Sky coverage → # cameras, FOV
  – Stellar type → near-IR vs. visible

• What spacecraft parameters
  – Data rates
  – Pointing