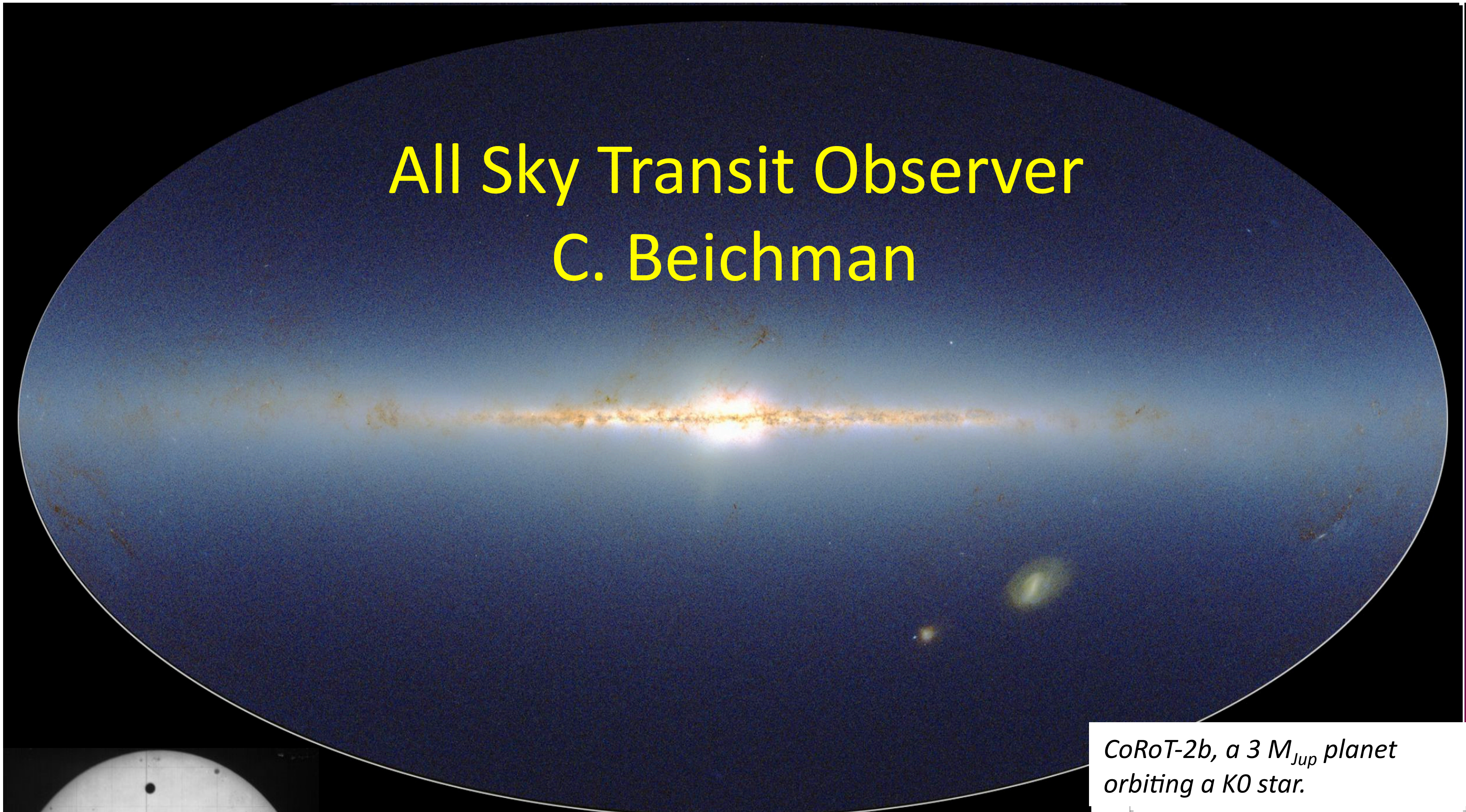
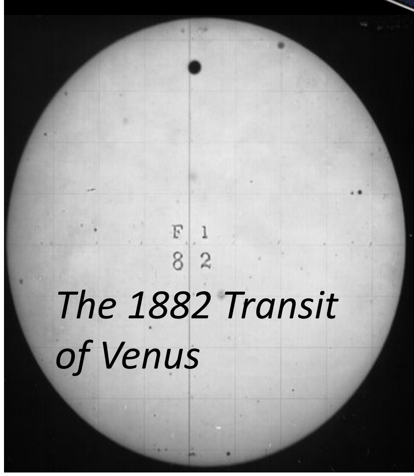
All Sky Transit Observer

C. Beichman

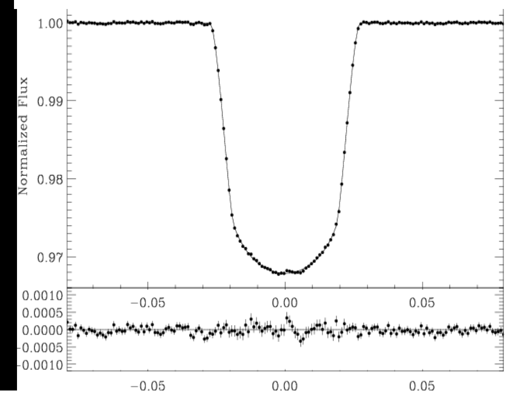




The 1882 Transit of Venus

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

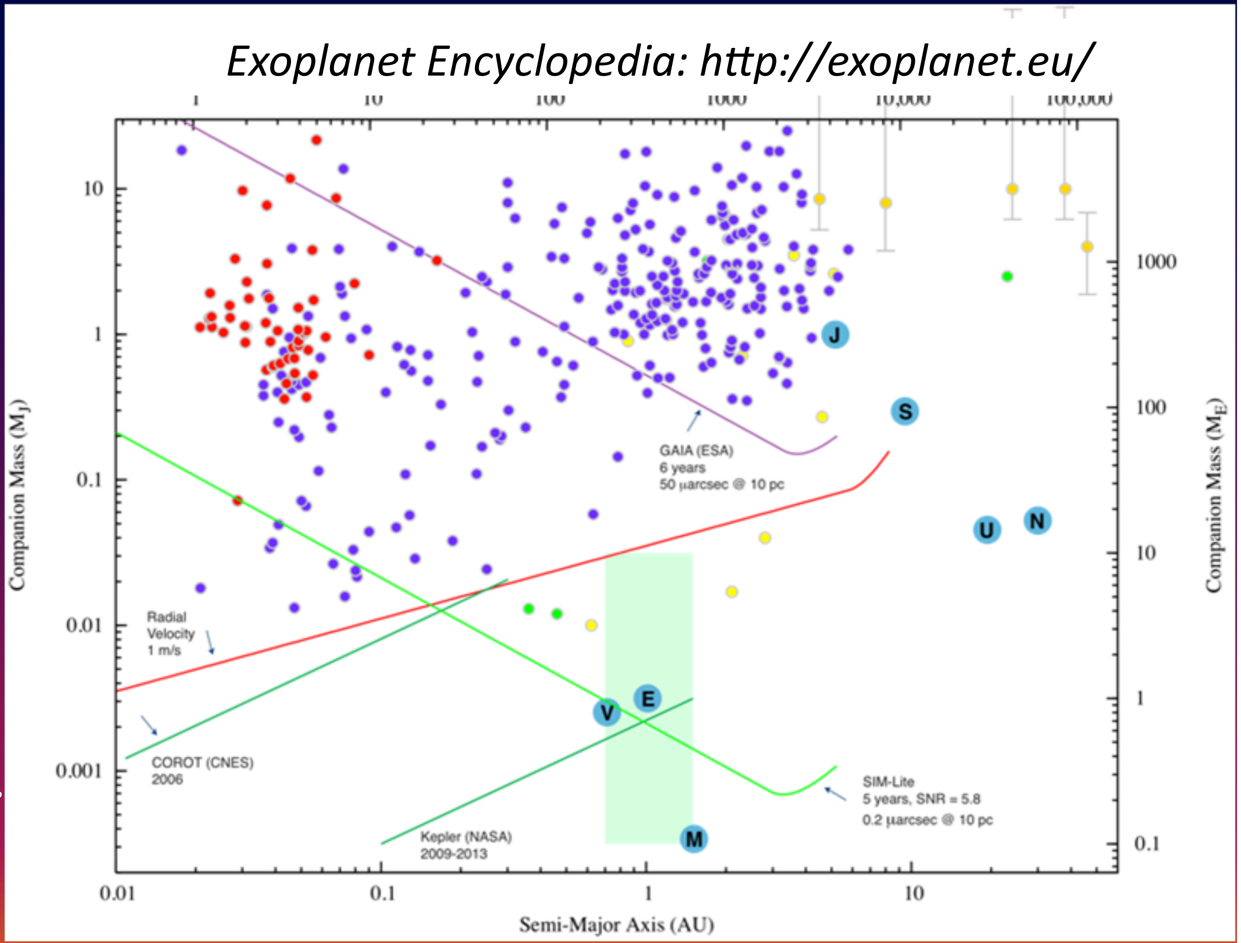
CoRoT-2b, a 3 M_{Jup} planet orbiting a K0 star.



Planet Census

349 Planets To Date

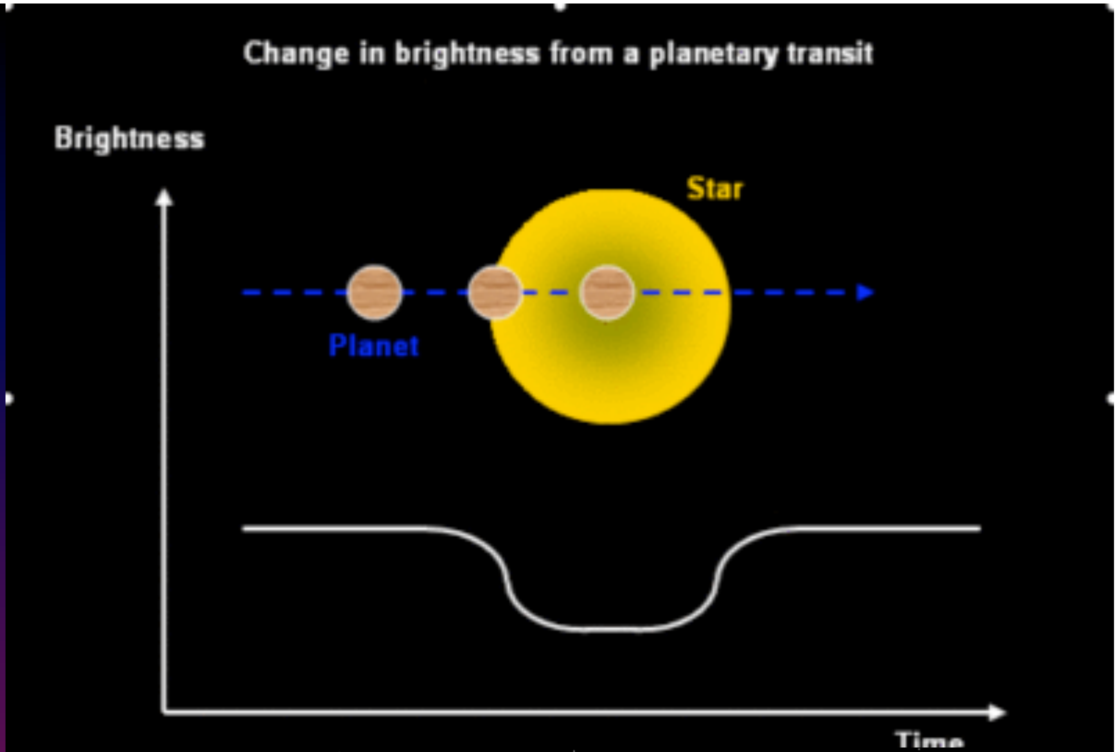
- Timing (1992)
  - 4 systems
  - 7planets
  - 2 multiple
- Radial Vel. (1995)
  - 275 systems
  - 323 planets
  - 33 multiple
- Transit (1999)
  - 59 planets
- Microlensing (2004
  - 8 planets
  - 1 multiple
- Imaging (2004)
  - 9 systems
  - 11 planets

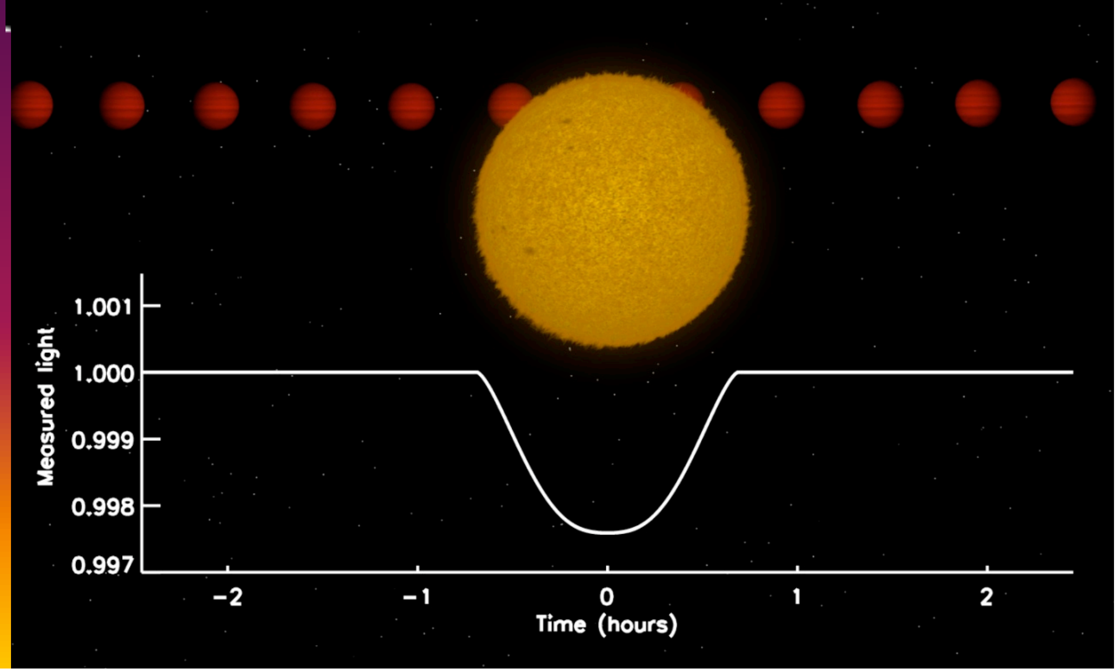


- Astrometry (2009)
  - 1 planet

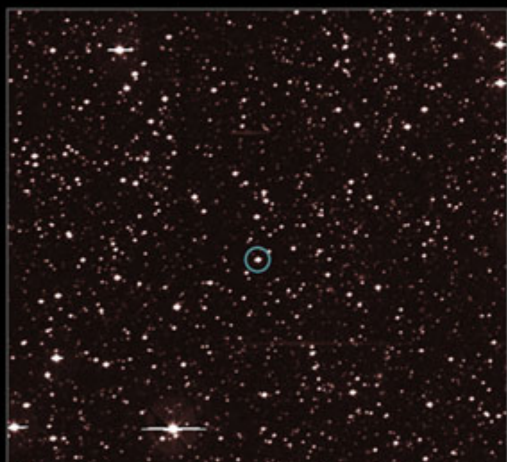
Transit Basics

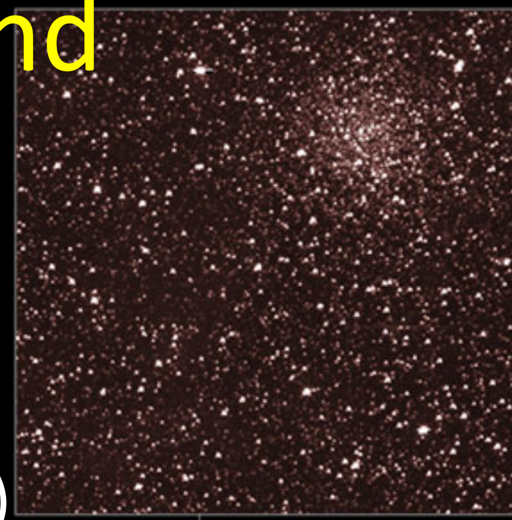
- Primary transit
  - Planet in front of star
  - $Fp/F^* = (Rp/R^*)^2 = 1\%$
    - Jupiter/G star
    - Earth/late M star
  - $Fp/F^* = 0.01\%$
    - Earth/G star
  - Transmission spectrum
- 0.5-10% prob. alignment
- Duration 2-10 hrs
- RV yields mass →density
- Secondary transit
  - Planet behind star
  - IR yields temperature
    - $Fp/F^* = (Rp/R^*)^2\ Bp(Tp)/B^*(T^*) \sim 0.1\%$
    - Emission spectrum
  - Visible yields albedo
    - $Fp/F^* = (Rp/R^*)^2\ Ap \sim 0.1\%$





How Do we Find Transits?





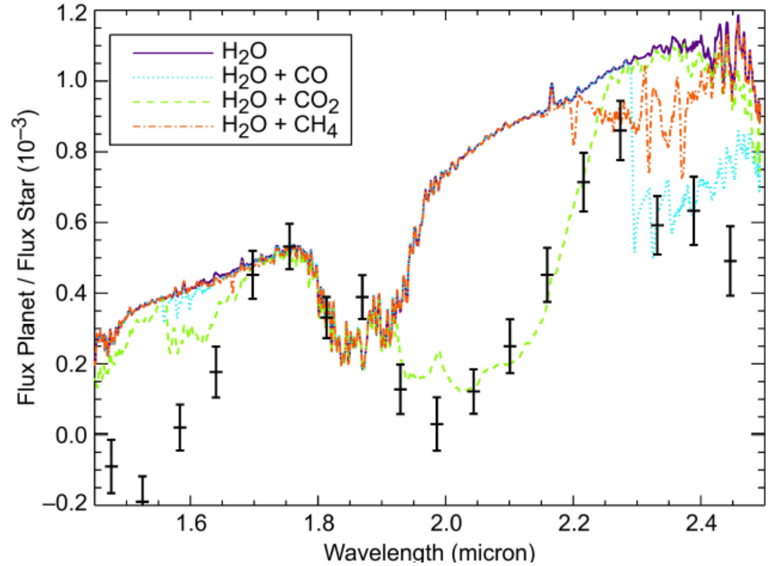
- Follow-up RV detections (1-10% alignment)
- Transit surveys
  - 10%-0.5% alignment (<0.1 to 1 AU)
  - 1%-10% incidence of gas giant planets (<0.1 to 3 AU)

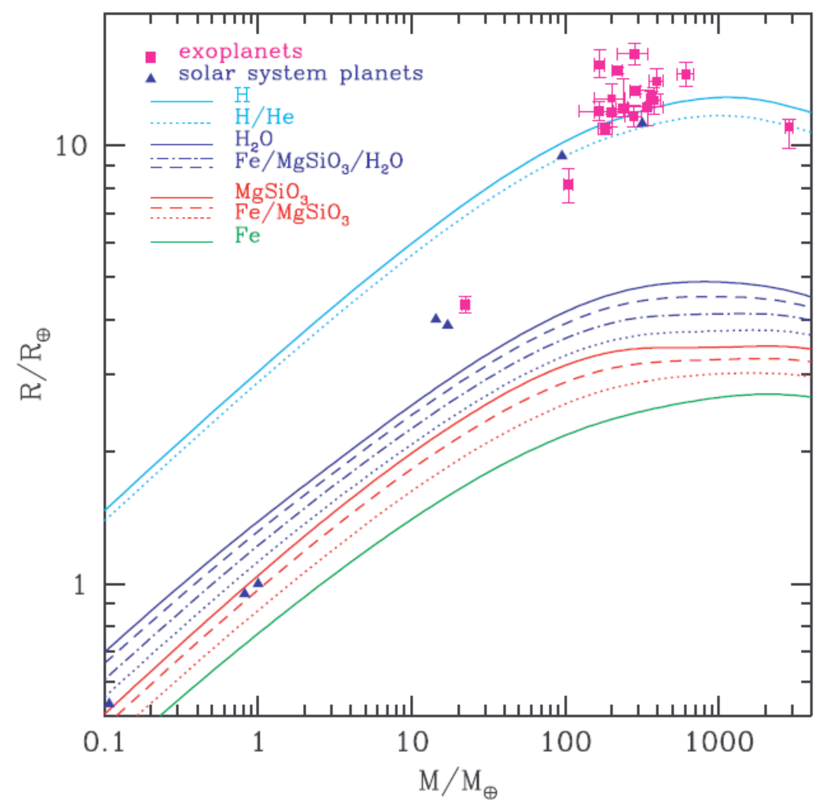
  →10^{-3} probability →at least 10^4 stars for 10 gas giants
- Ground-based surveys at 3,000-5,000 micro-mag over thousands of sq. deg.
- Space-based surveys at 20-50 micro-mag over 10s sq. deg (CoRoT) to 100 sq. deg (Kepler)
  - Kepler will monitor 150,000 stars for 4 years

Why Transits?

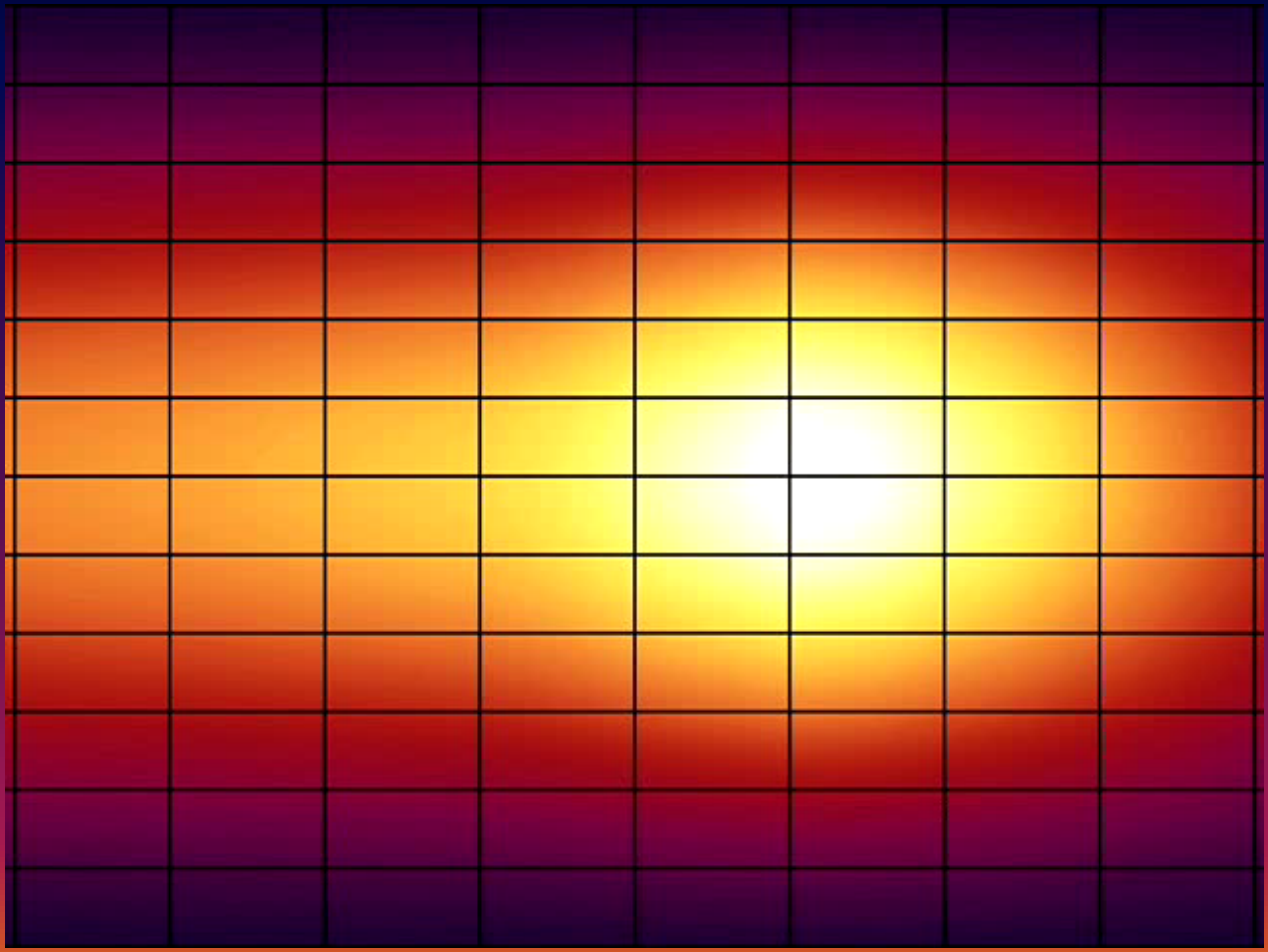
- Orbit inclination
- Orbital separation
- Star/Planet spin-orbit
- Stellar limb darkening
- Stellar mass/density
- Planetary radius
- Timing for other planets
- Rings/moons
- Reflected light (albedo)
- Composition (Vis & IR)
- Vertical structure
- Global Circulation

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



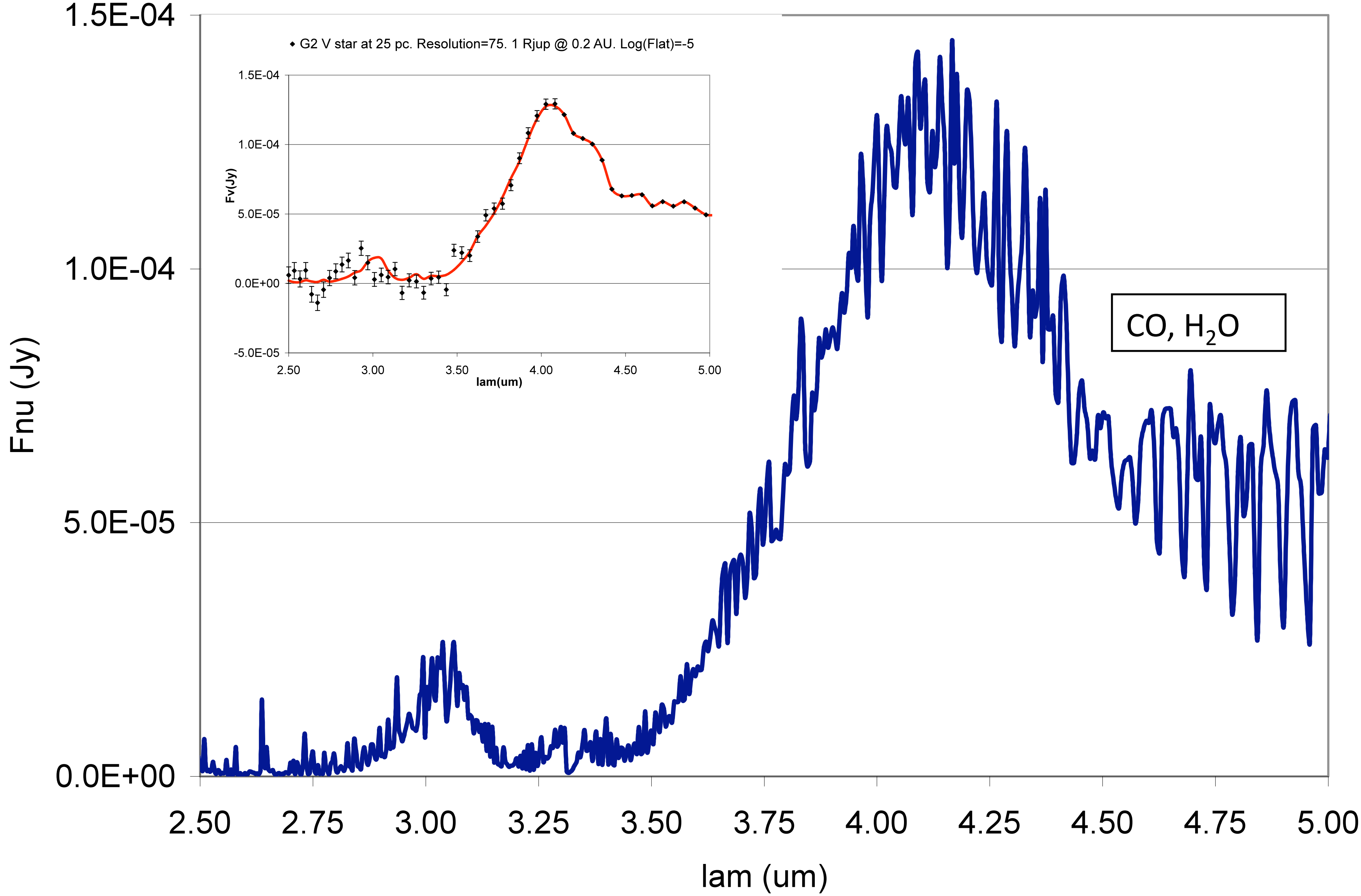


Mapping Weather on HD189733

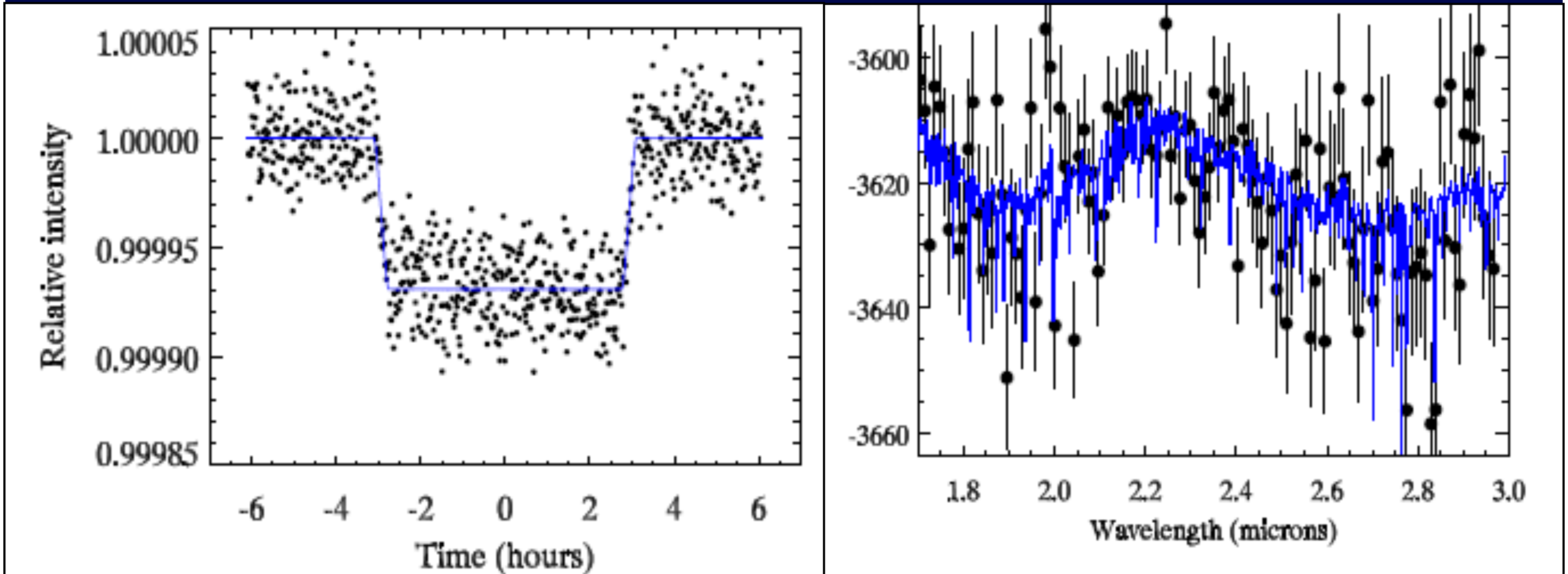


- 920 K on the dark side to 1200 K on the sunlit side.
- Temperature variation is mild → Winds spread heat

JWST Observations of Transits



JWST Follow-up Observations of Super Earth Transits



From Deming et al (2009):

- JWST/NIRSpec observations of water absorption in a habitable super-Earth ($T = 302K$ and $R = 1.8R_\oplus$) orbiting an M star at 20 pc
- JWST/MIRI secondary eclipse photometry at 15 µm for a warm ($T = 500K$) exo-Neptune ($R = 4R_\oplus$) orbiting at 0.2 AU from a K2V star.

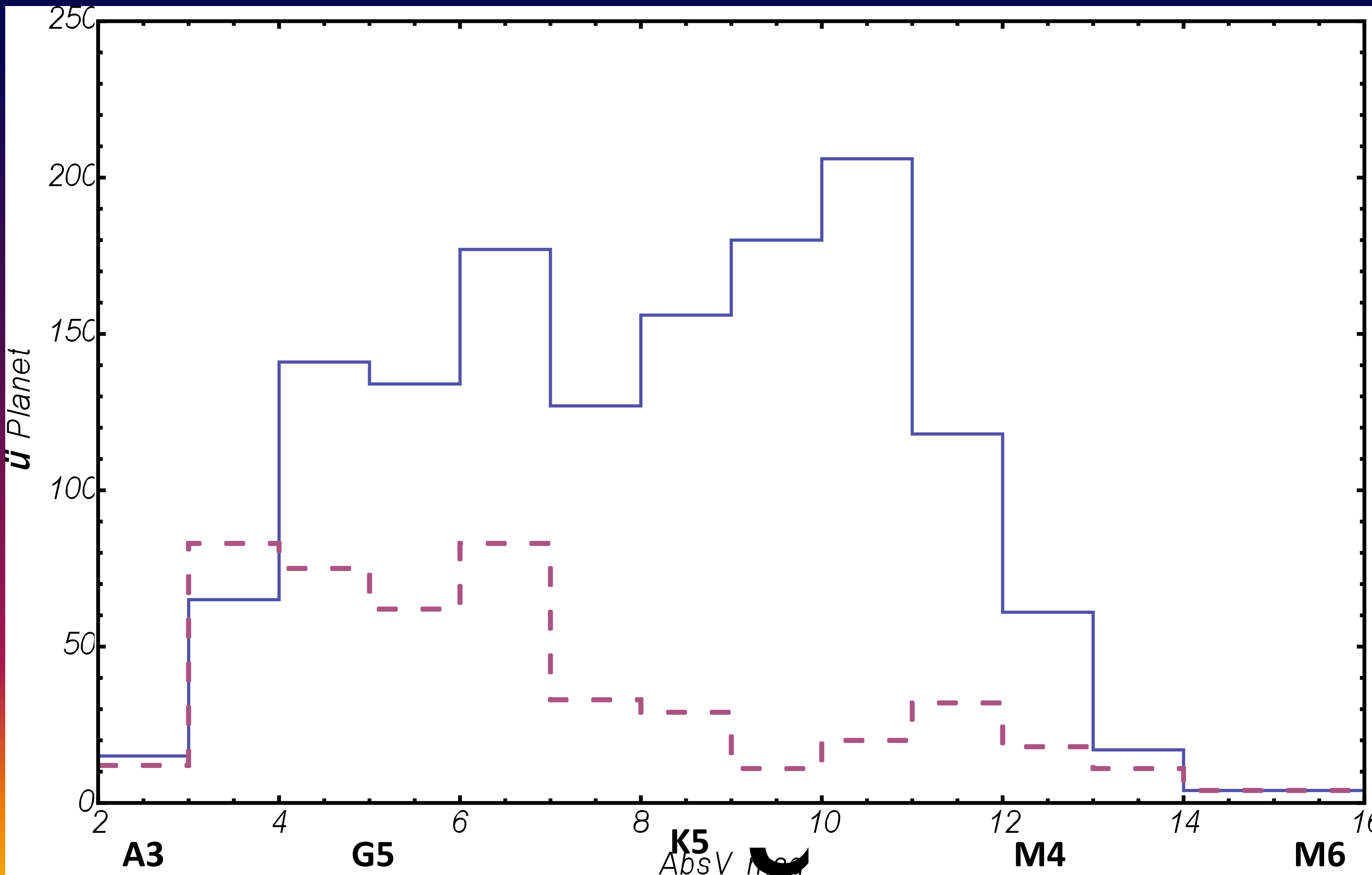
What Is In The Future for Transits

- 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

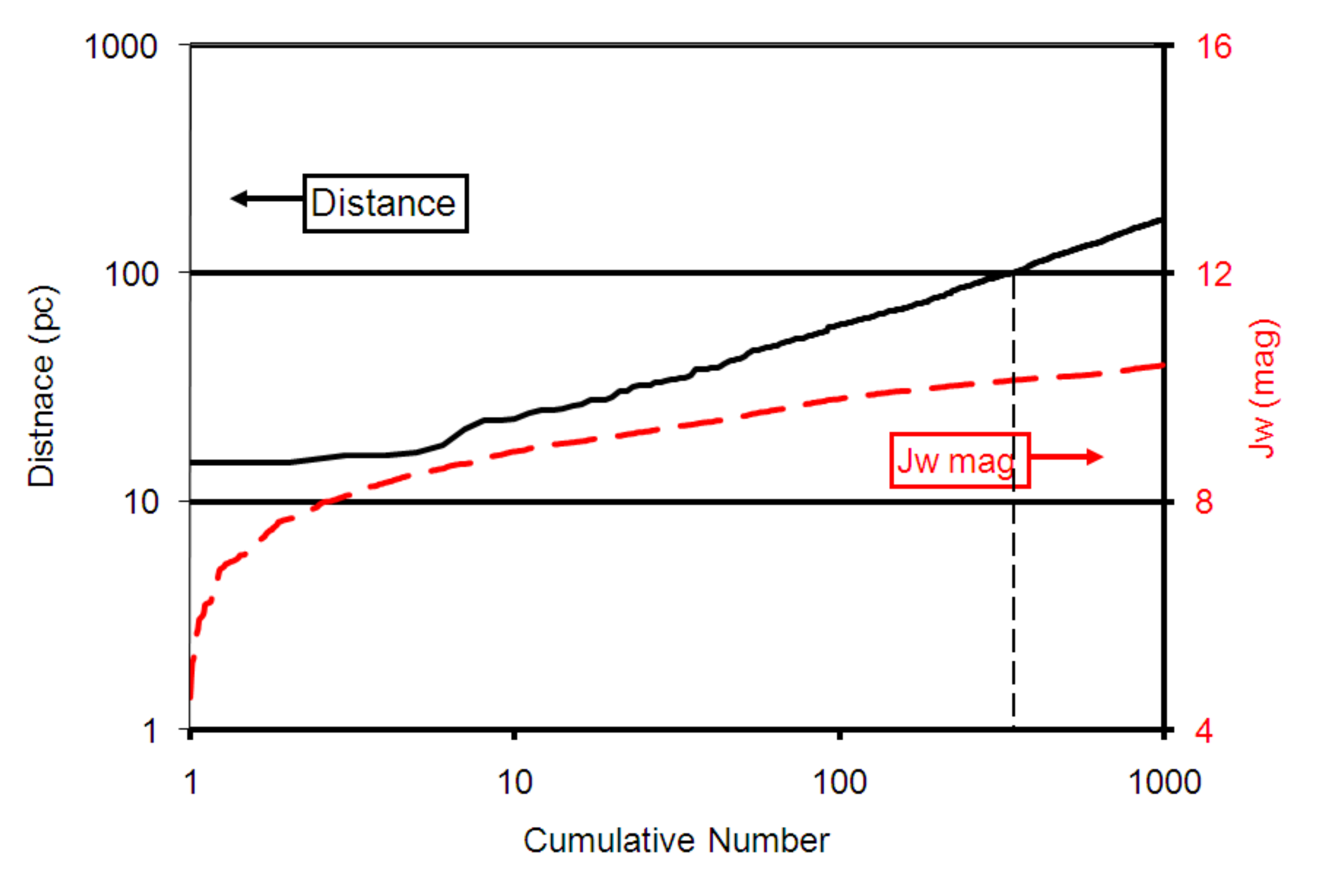
Yield From All Sky Surveys From Space: TESS or ASTrO

Planets Detected In Monte Carlo Simulation		
Single Transit SNR	Gas/Icy	Rocky
Low (10>SNR>3)	178	520
Medium (50>SNR>10)	695	22
High (SNR>50)	577	0
Total	1450	542
**2×10^6 stars in unconfused 60% of sky; Final SNR$\geq$7; # Transits/star$\geq$ 3*		

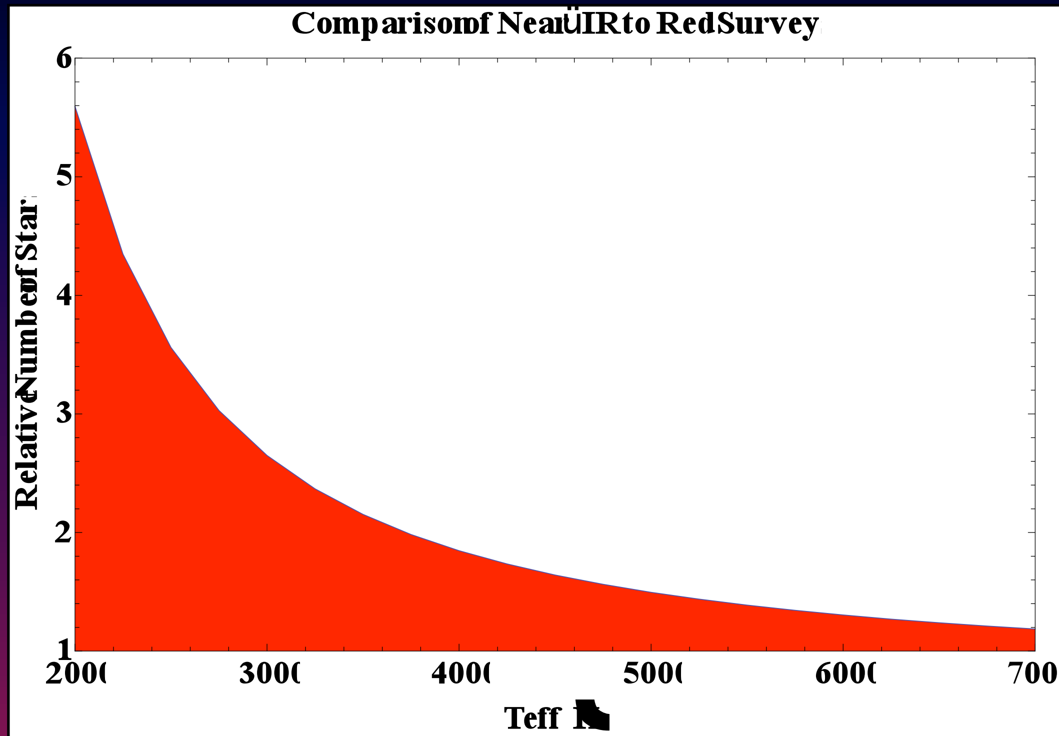
Yield By Spectral Type



Distance To Closest Transits



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 µm] where late type stars are brightest
- Observe with a precision of <100 µmag 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 µm
- 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