Modeling Super-Earth Atmospheres
In Preparation for Upcoming Extremely Large Telescopes

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Image Credit: NASA Ames/JPL-Caltech/T. Pyle

Roadmap
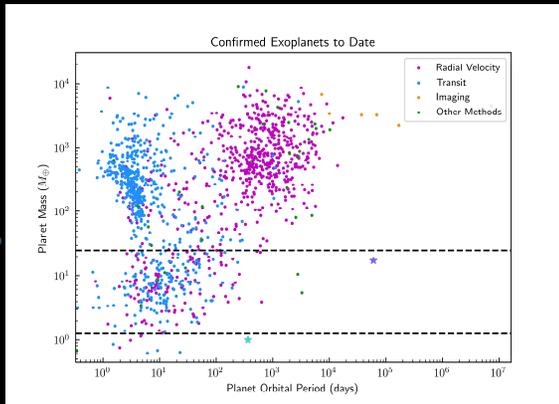
Research Goals & Current State of Super-Earth Detection
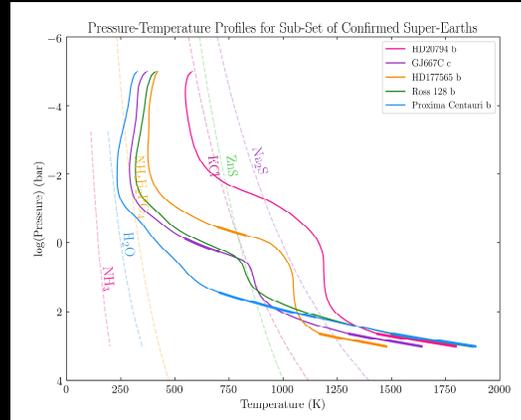
Atmosphere Modeling Tool (Past & Present)

Selecting Super-Earths for Follow-Up Observations
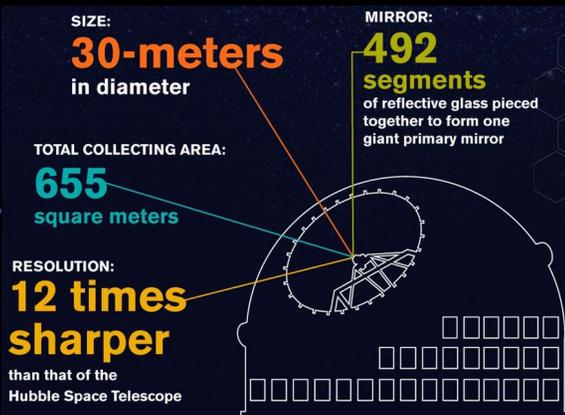
Future Observatories for Super-Earths
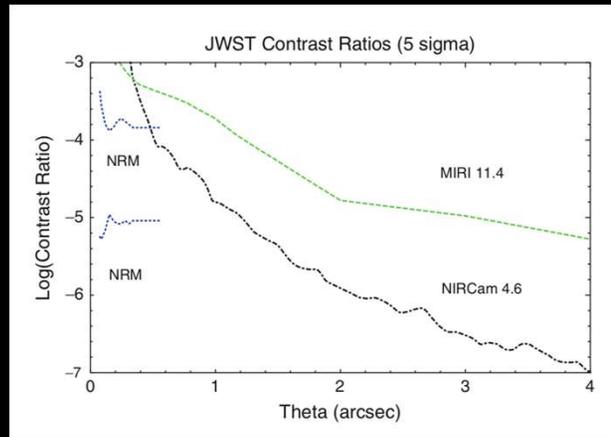
Preliminary Assessment of Upcoming Instruments' Capabilities for Super-Earths
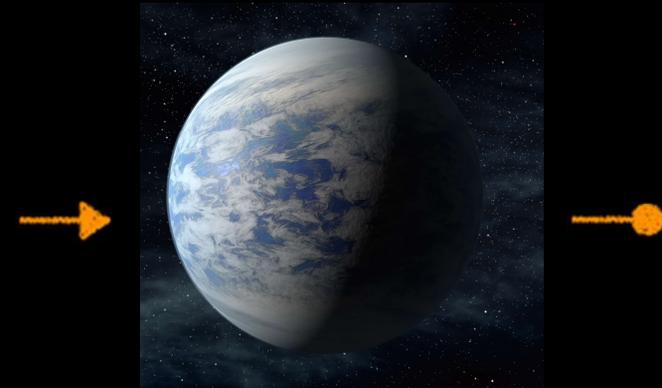
Conclusions & Future Work

Research Goals

- Extend previous modeling tool to simulate super-Earth planet atmospheres around M, K and G stars

- Apply modified code to explore the parameter space of actual and synthetic super-Earths to select most suitable set of confirmed exoplanets for follow-up observations with JWST and next-generation ground-based telescopes

- Inform the design of advanced instruments such as the Planetary Systems Imager (PSI), a proposed second-generation instrument for TMT/GMT

Current State of Super-Earth Detections (1)

Confirmed Exoplanets to Date
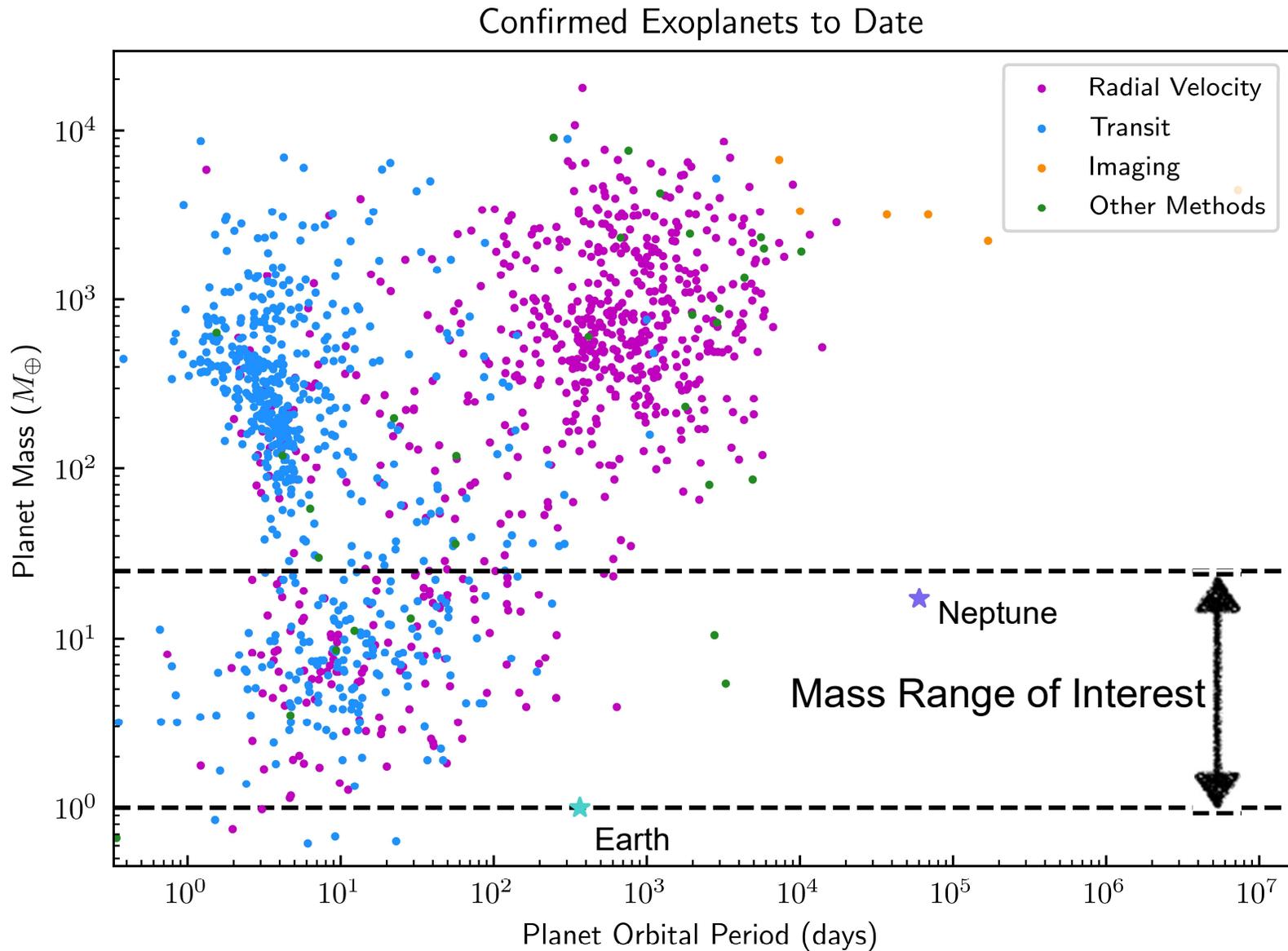
Data from NASA Exoplanet Archive

Current State of Super-Earth Detections (2)


Confirmed Exoplanets to Date
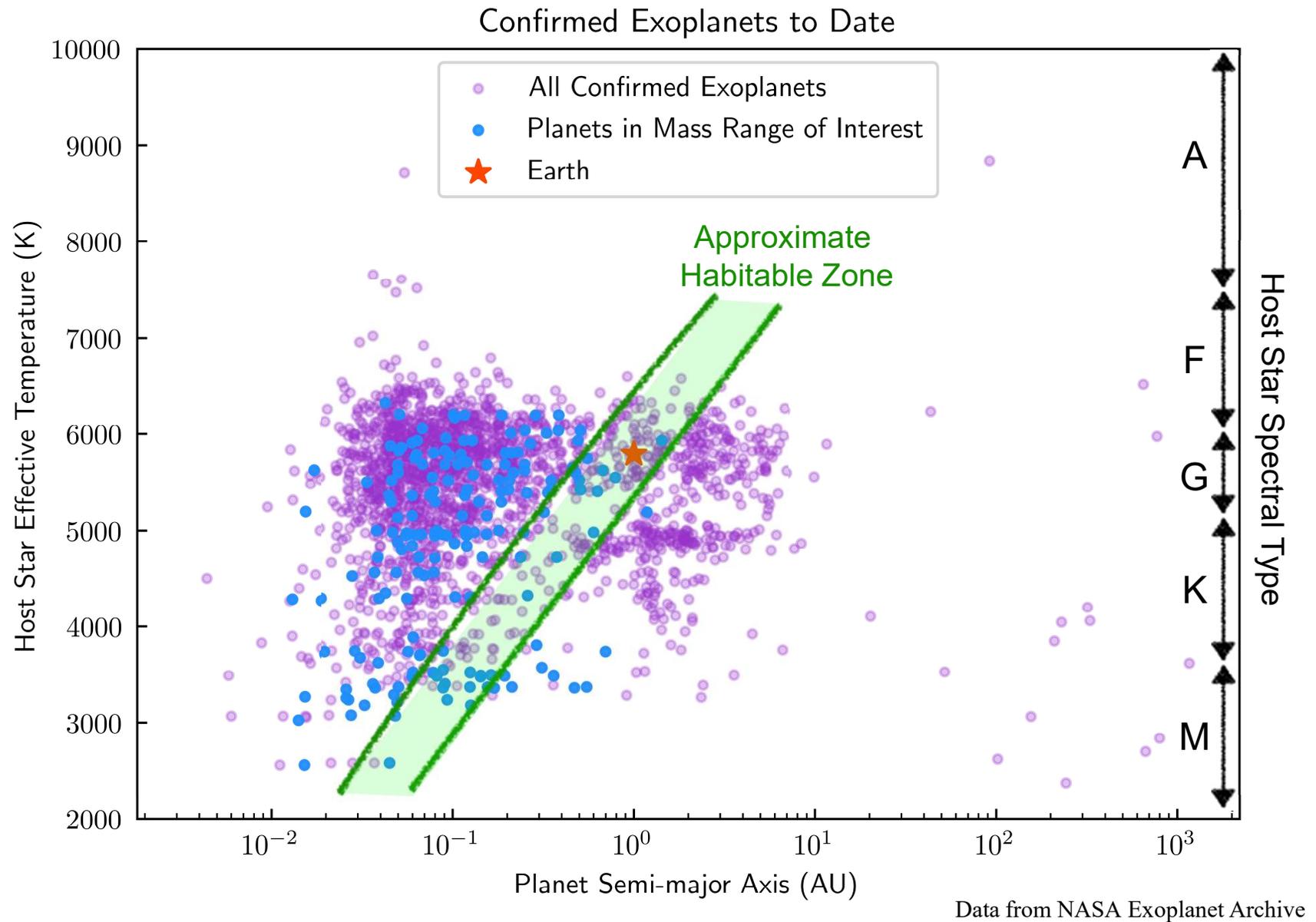
Atmosphere Modeling Tool

Evolution of Atmosphere Model

- Solar System Planets & Moons ~ 1980's
  (e.g., McKay et al. 1989)

- Brown Dwarfs ~ 2000's
  (e.g., Burrows et al. 2001)

- Hot Jupiters & Other Giant Exoplanets ~ 2000's
  (e.g., Fortney et al. 2005)

Limitations of the Model

- Pre-computed Atmospheric Abundances

- Limited Treatment of Clouds

- Lack of Surface Boundary Conditions

- Limited Combinations of High and Low Spectroscopic Resolutions
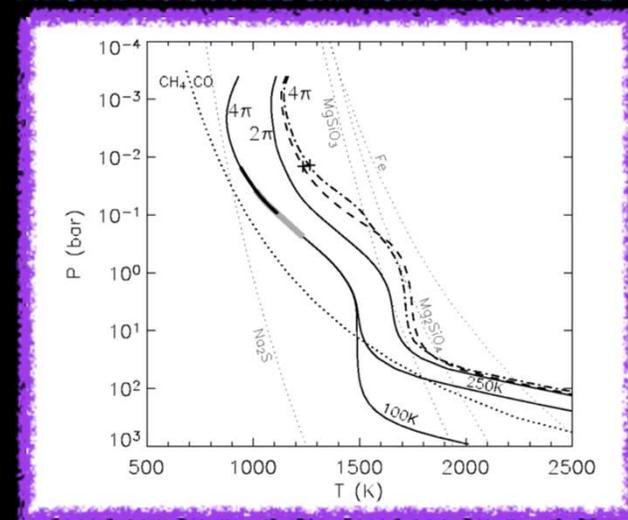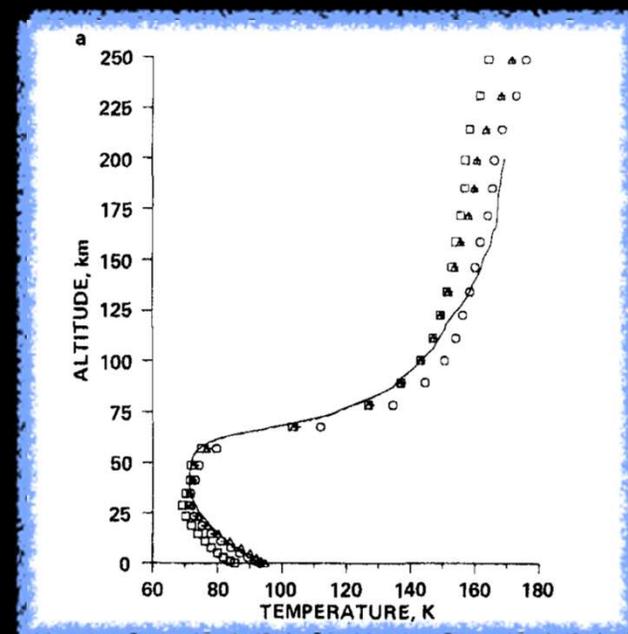
Super-Earth Atmosphere Modeling Code

- Applied Extrasolar Giant Planet (EGP) code to small, terrestrial-like exoplanets
- Solves radiative transfer equation via Toon et al. 1989 algorithm and iteratively determines radiative-convective equilibrium

Inputs

Distance from Star

Incoming Stellar Flux

Intrinsic Temperature

Chemical Abundances

Opacities

Surface Albedo

Surface Gravity

Cloud Properties

Outputs

Pressure-Temperature Profile

Effective Temperature

Visible Spectra

Thermal Infrared Spectra

Bond Albedo
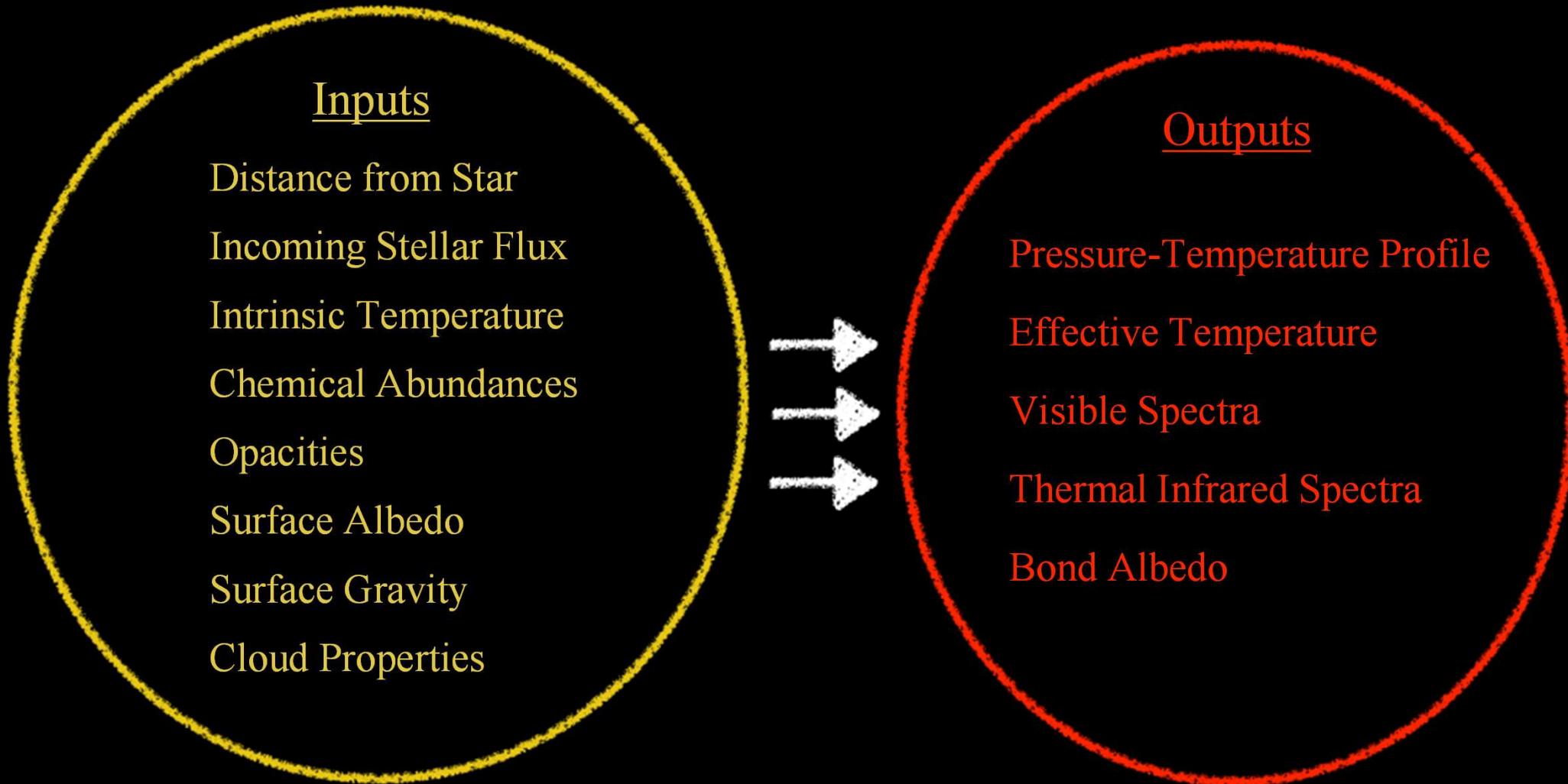
Sample of Atmosphere Modeling Results

Pressure-Temperature Profiles for Sub-Set of Confirmed Super-Earths
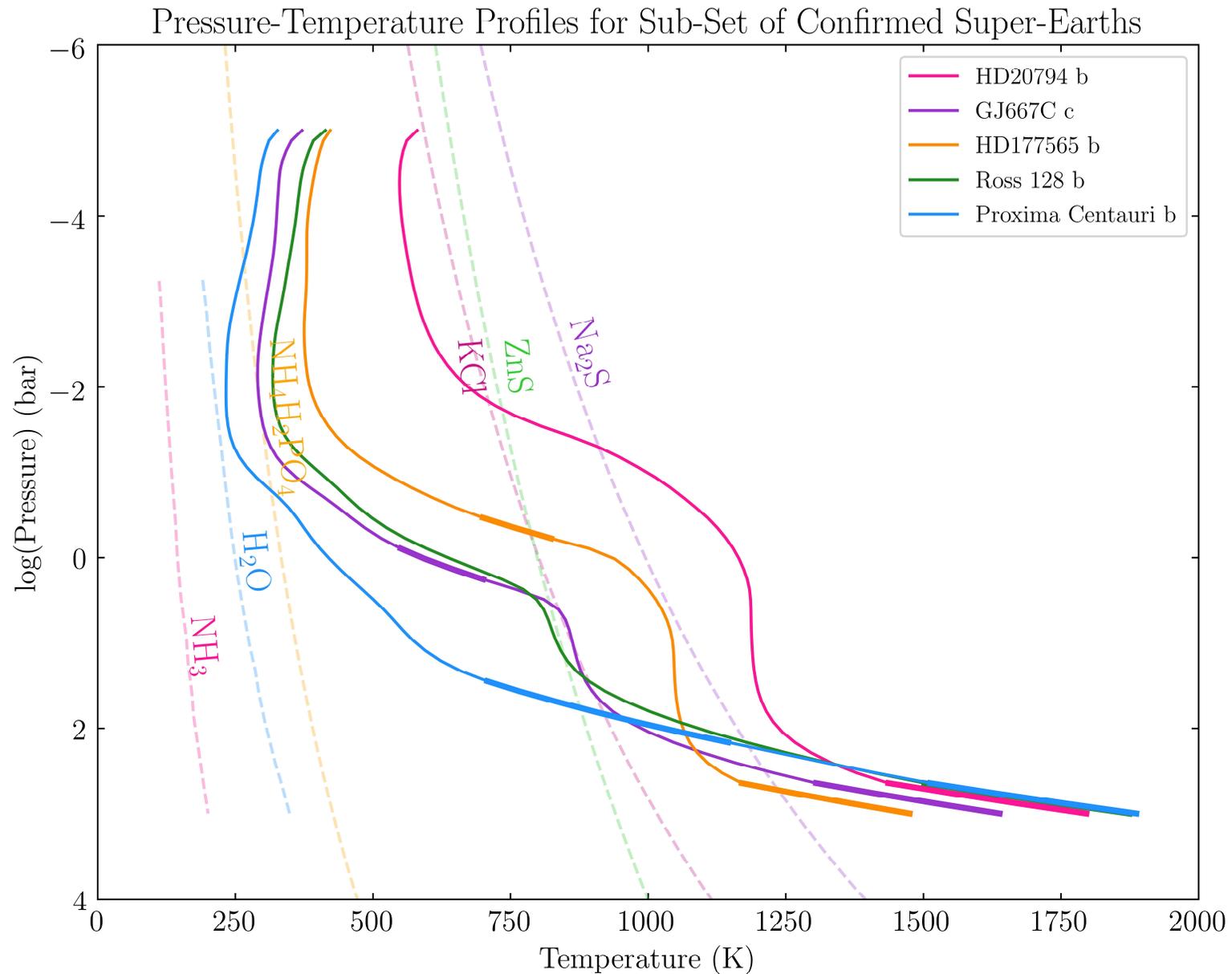
Planet Selection for Follow-Up Observations

Confirmed Exoplanets: ~3900

↓

Exoplanets with $M < 25 M_\oplus$: ~360

↓

Low-Mass Planets with Angular Separations > 0.01": ~50
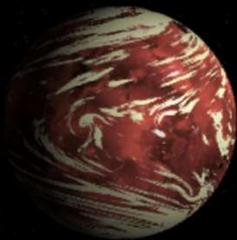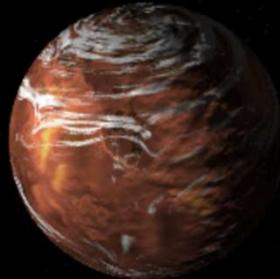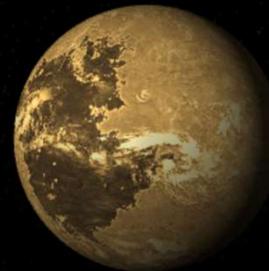
Ross 128 b   GJ667C f   Proxima Centauri b   61 Virginis c

# Future Ground-based Observatories for Super-Earths

- By mid-2020's, next-generation telescopes such as TMT, GMT, E-ELT expected to achieve first light
- Planetary Systems Imager (PSI) proposed second generation instrument for TMT
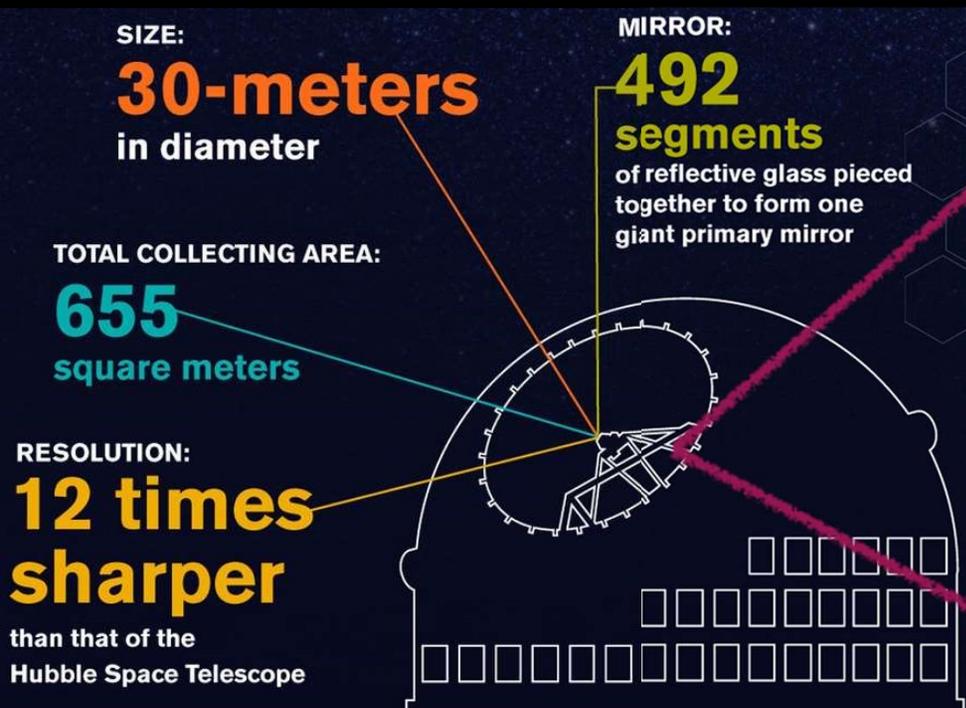

TMT Schematic
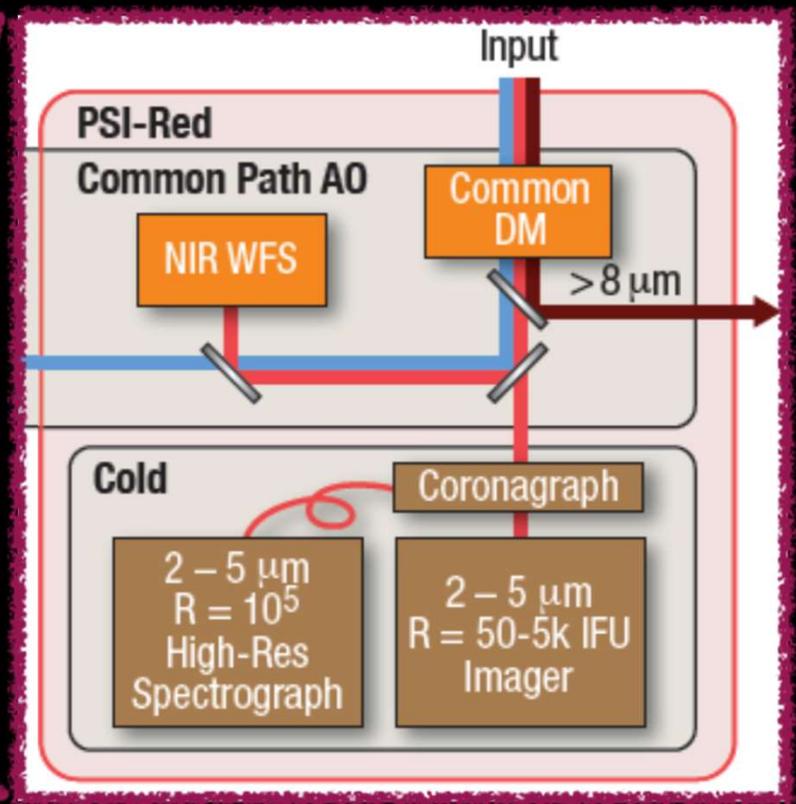
Skemer et al. 2018

PSI Red Channel (2-5 μm)

Preliminary Assessment of PSI's Super-Earth Capabilities

PSI Contrast Curves with 50 Selected Super-Earth Candidates
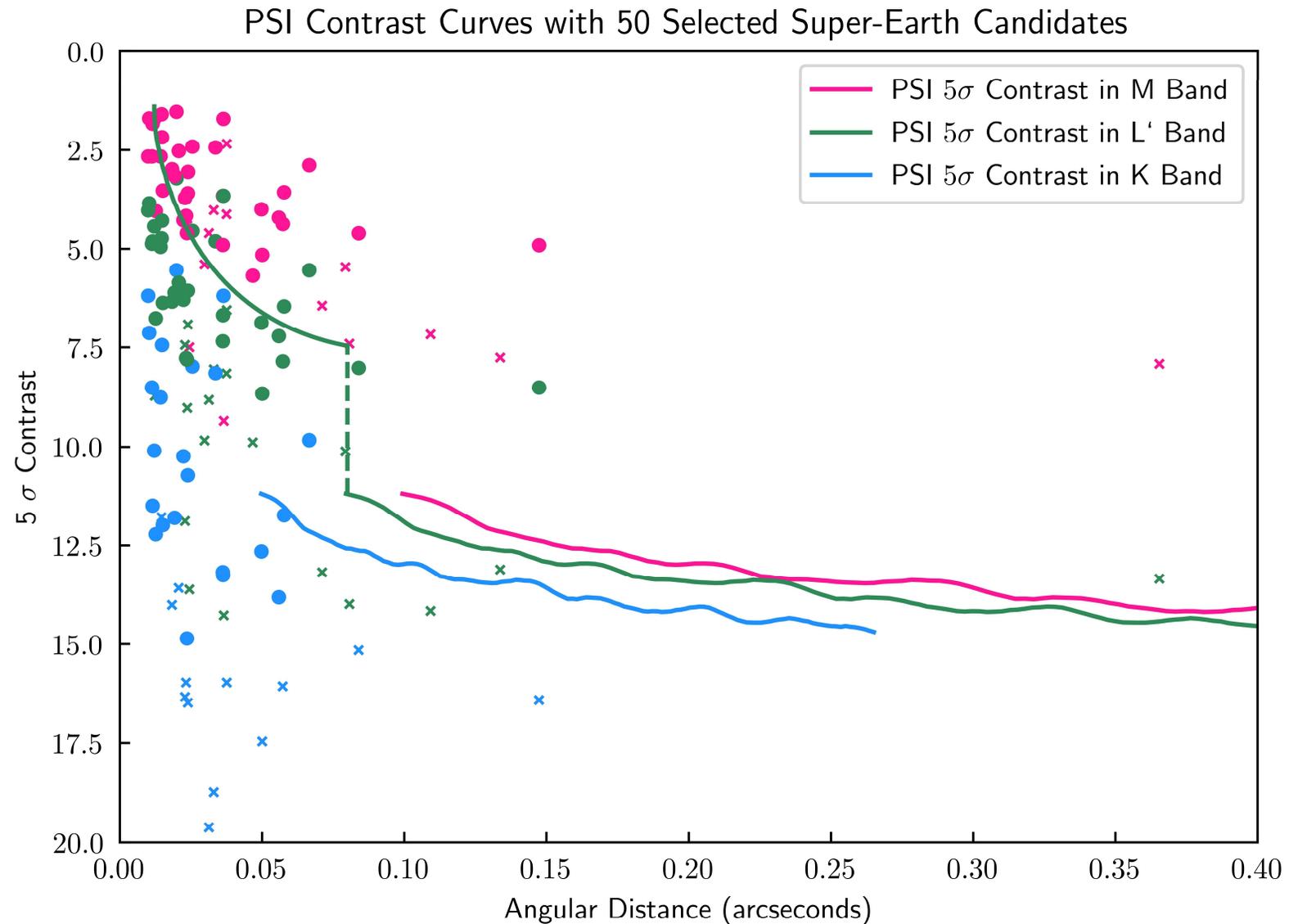
Examples of Simulated Spectra for 3 Planets

Spectra for Sub-Set of Confirmed Planets

JWST's Super-Earth Capabilities

JWST Contrast Ratios (5 sigma)

MIRI 11.4

NIRCam 4.6

NRM

NRM

Log(Contrast Ratio)

Theta (arcsec)
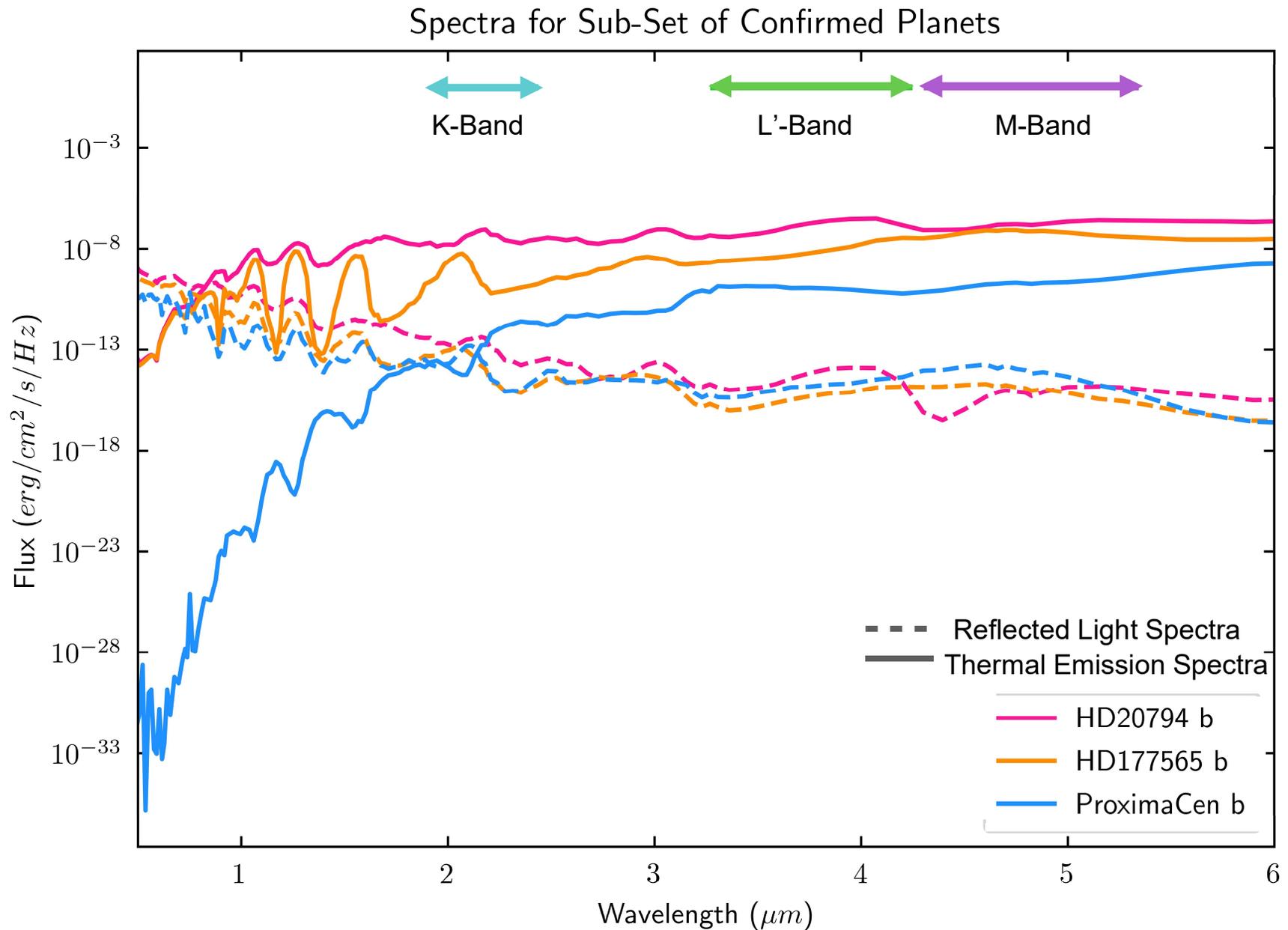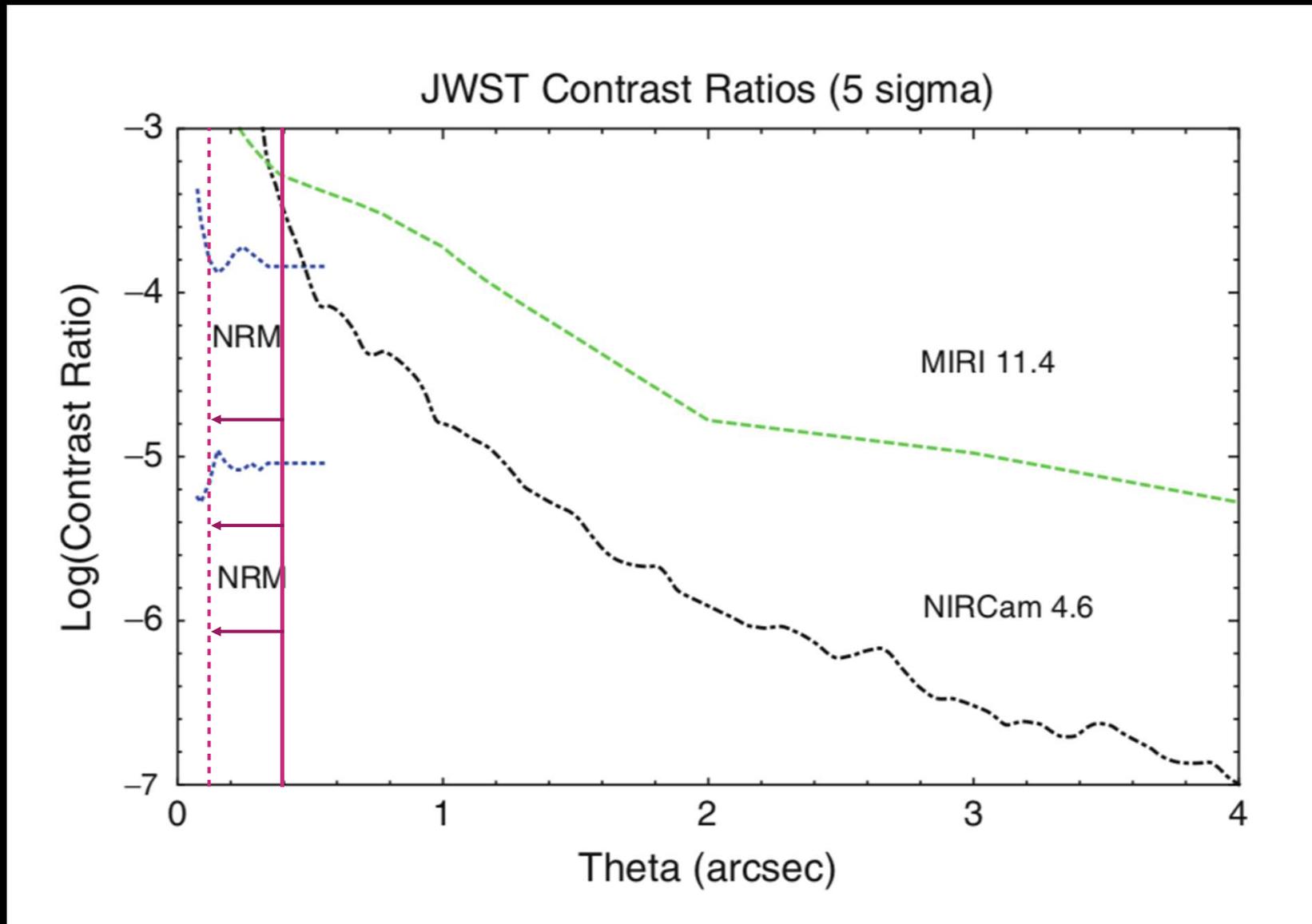
Conclusions

- EGP code can be applied to model known super-Earth atmospheres

- Instruments such as PSI on next-generation ground-based telescopes are likely to be able to image some super-Earths

- At present, the scarcity of super-Earth candidates at large star-planet separations limit the imaging capabilities of JWST

Future Work

- Incorporate TESS super-Earth detections to expand the set of candidates for follow-up observations

- Modify the EGP code to account for optically thin atmospheres (e.g., proper surface boundary condition)