AS3012:

Exoplanetary Science

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Room 226

Statistical properties of exoplanets

Global statistics (8th March 2005):

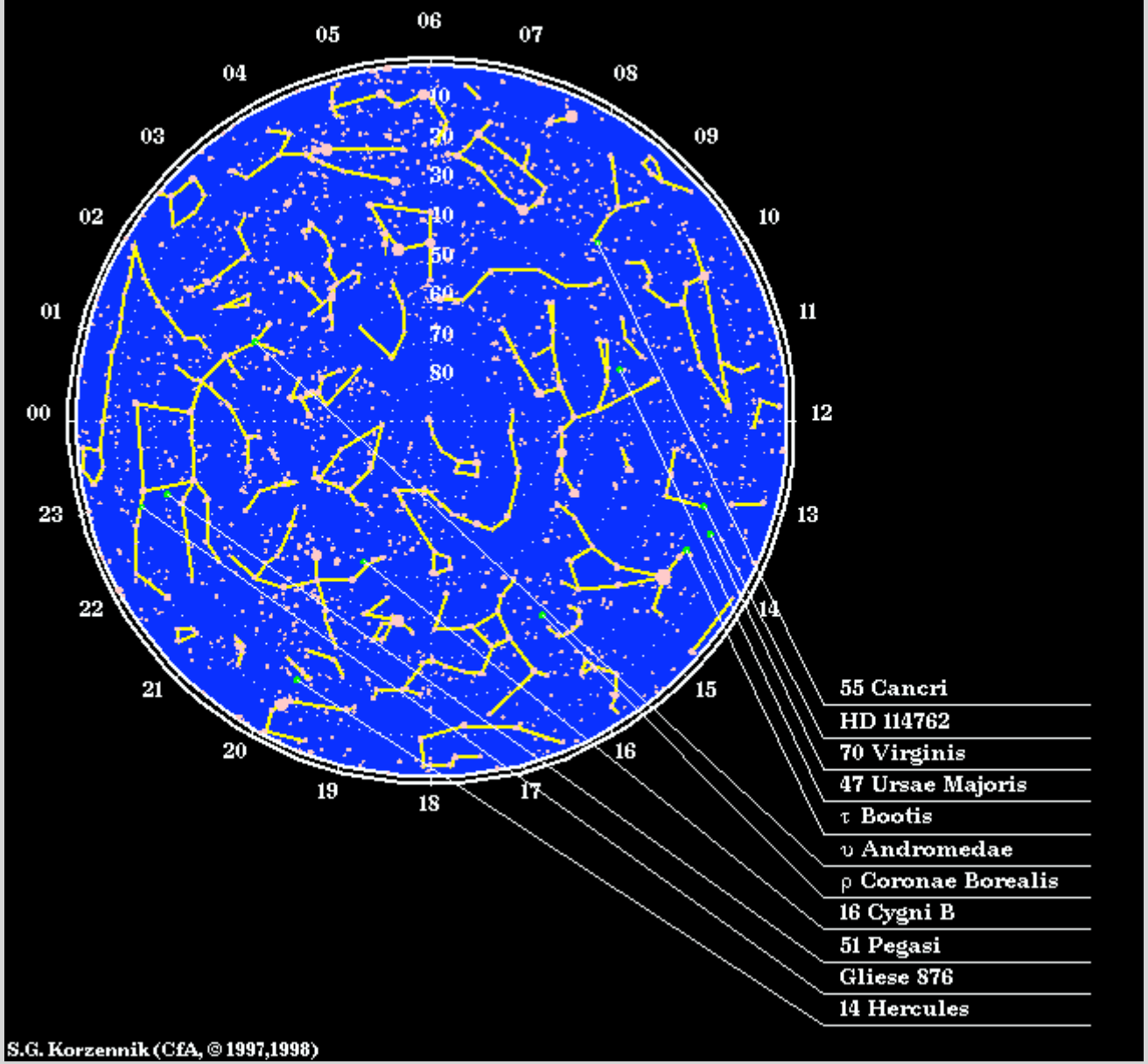
- 134 planetary systems
- 152 planets
- 14 multiple planetary systems

Analysis of the orbital parameters of the known planets allows us to understand the mechanisms of planetary formation

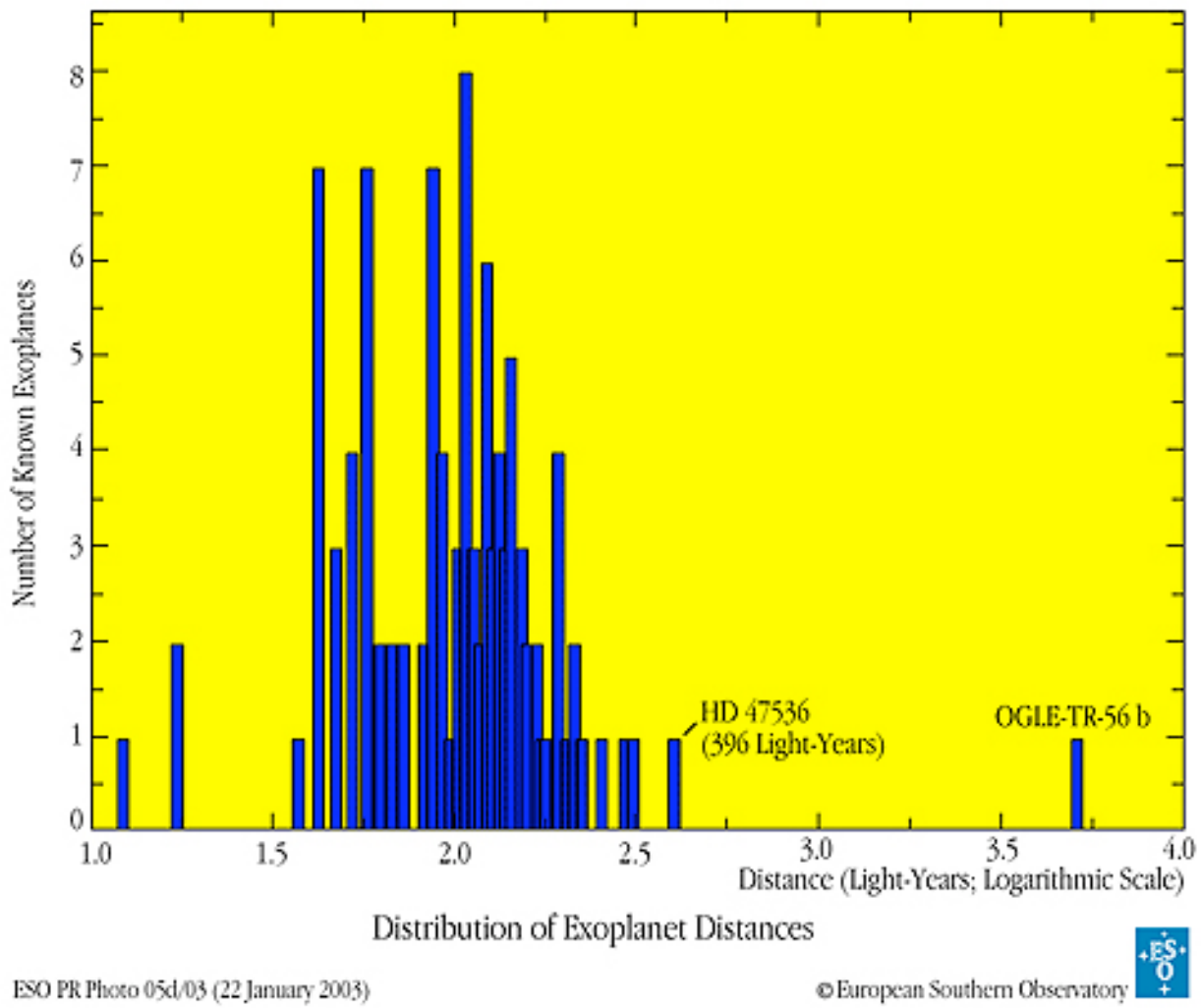
When examining statistical properties, the selection effects of the detection survey must be considered

Distribution of planetary masses, eccentricities, and orbital periods

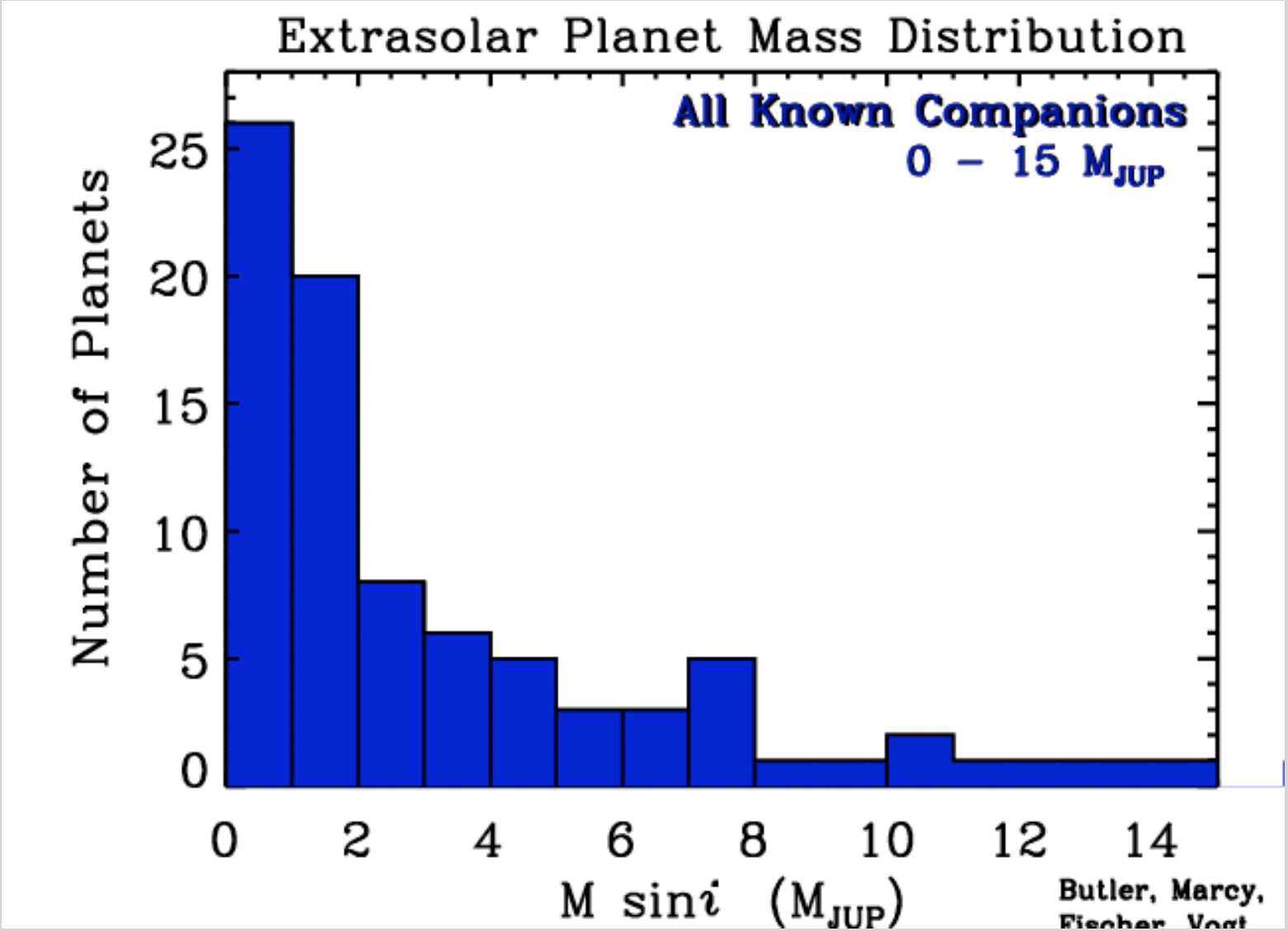
They are everywhere!

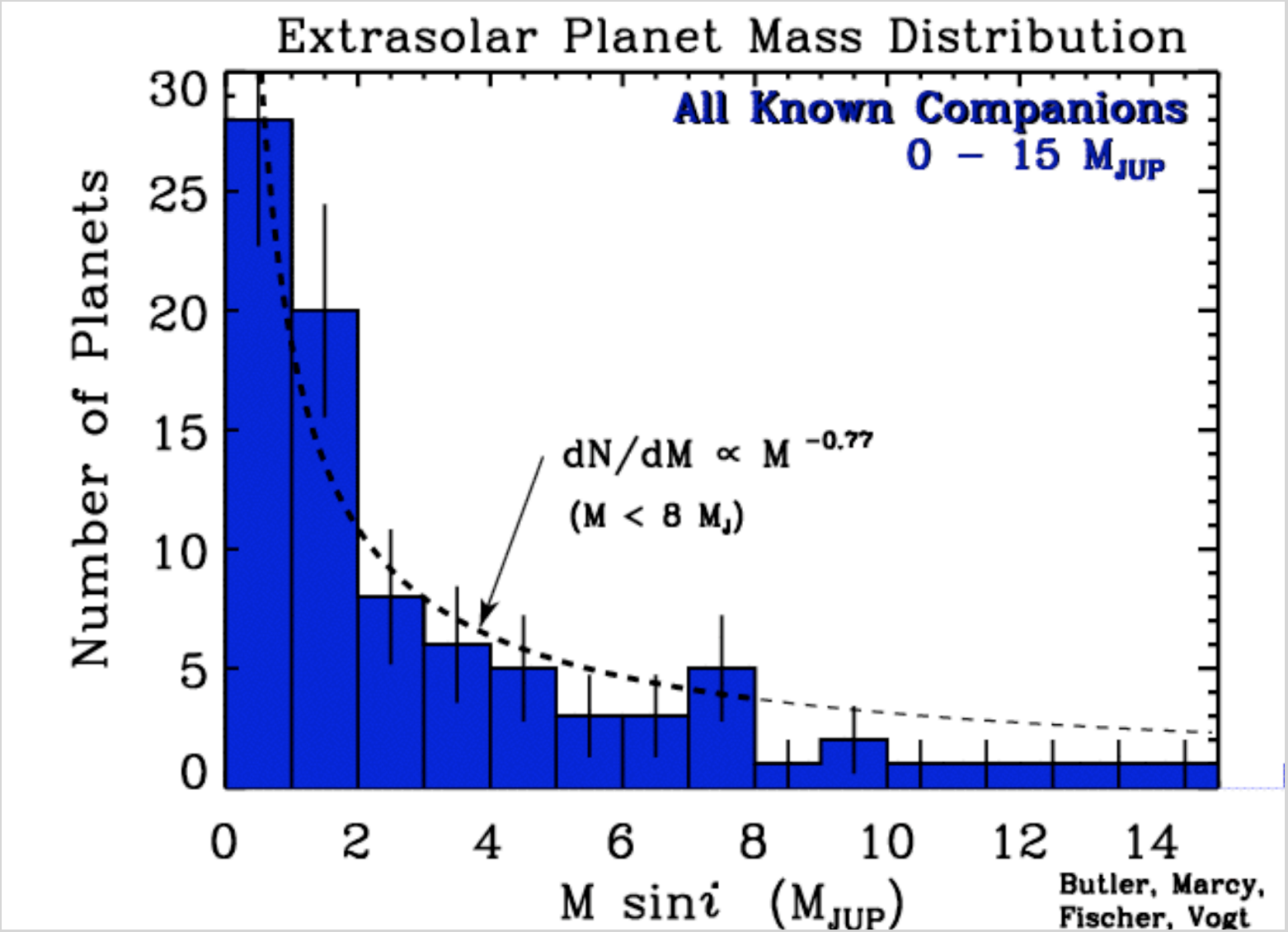


S.G. Korzennik (CfA, © 1997,1998)



Over 1000 stars have been surveyed using the radial velocities technique giving a nearly complete sample of solar-type stars within 30 pc

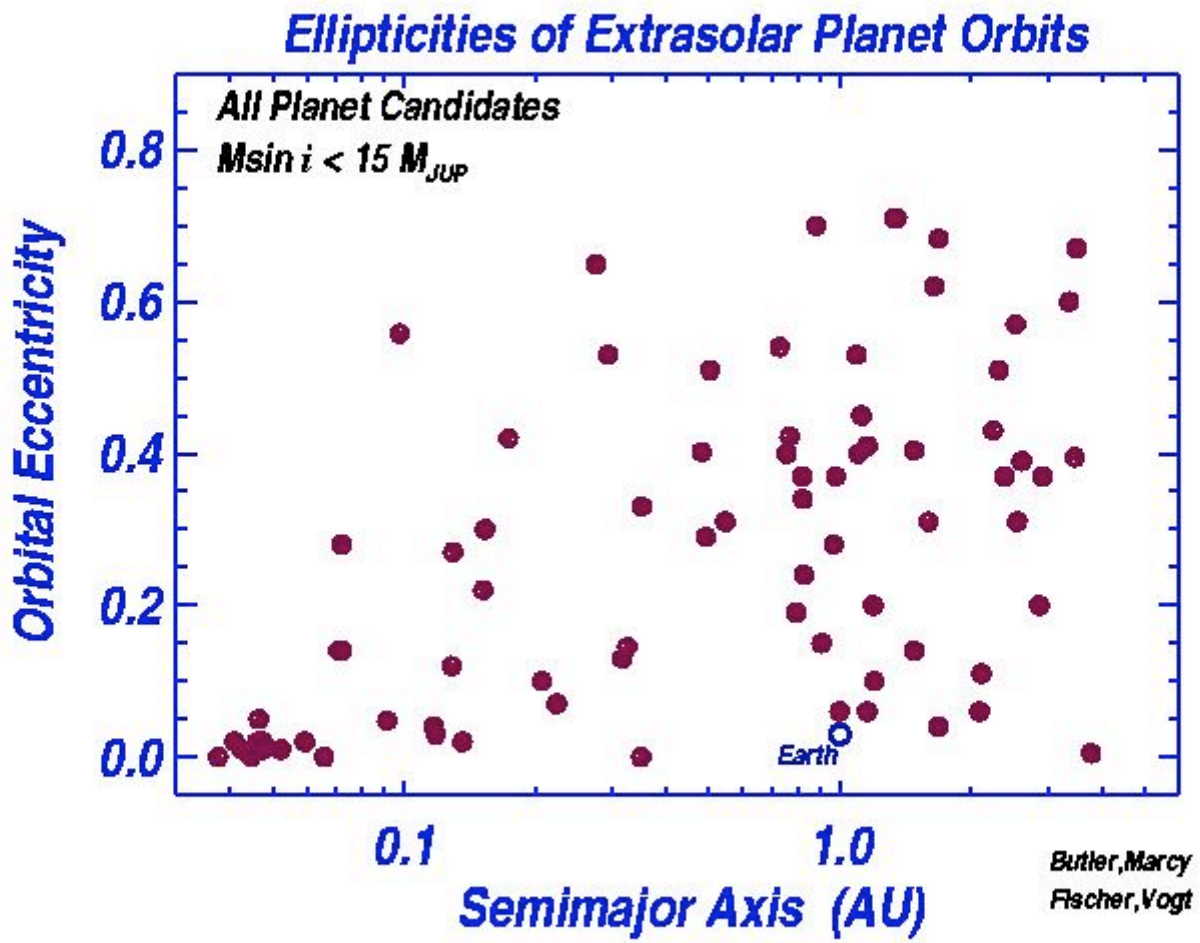

Extrasolar Planet Mass Distribution
All Known Companions
0 – 15 M_{JUP}
Number of Planets
25
20
15
10
5
0
0
2
4
6
8
10
12
14
M sin$i$ (M_{JUP})
Butler, Marcy,
Fischer, Vogt

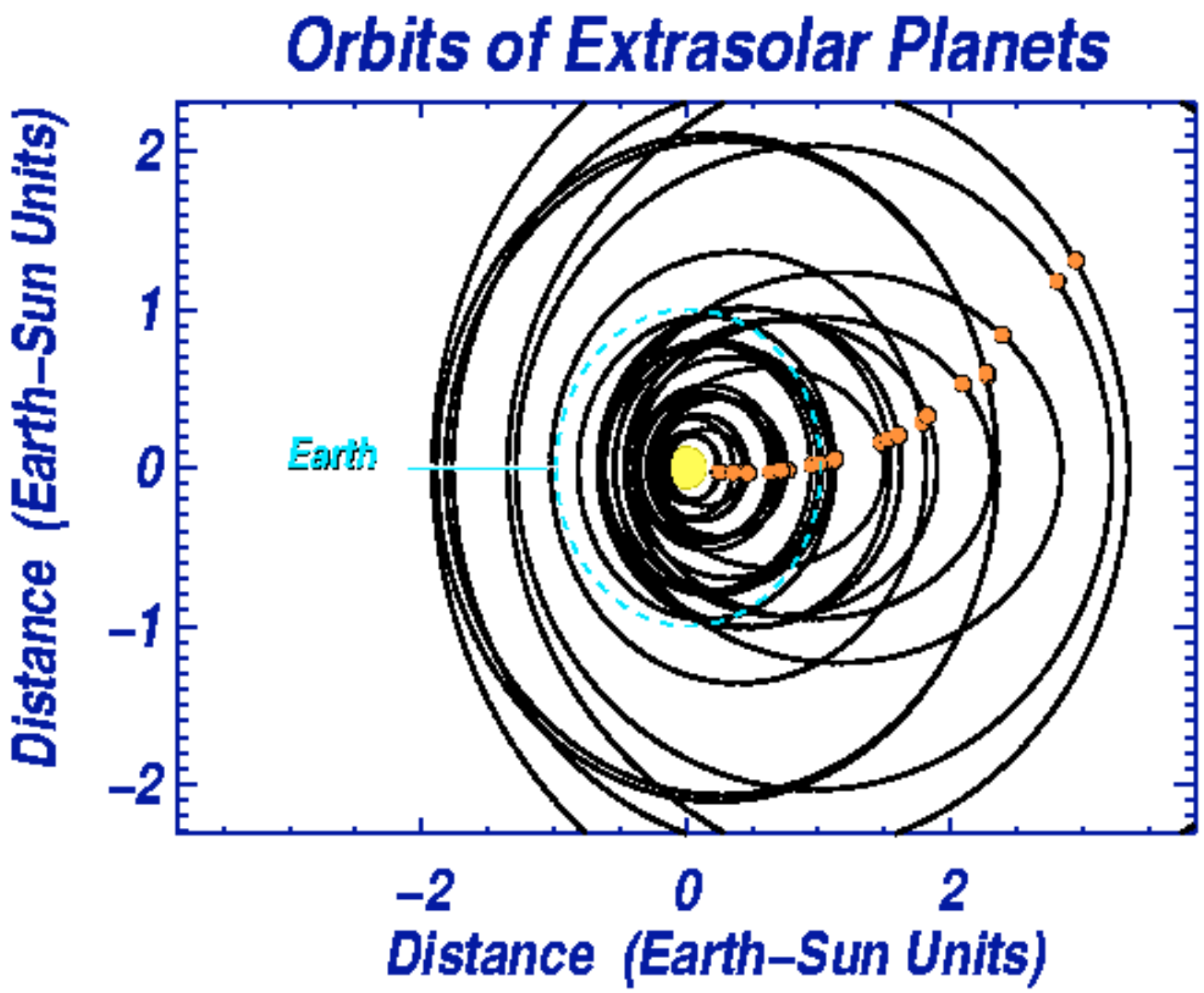


Occurrence varies inversely with mass

The exoplanet mass function

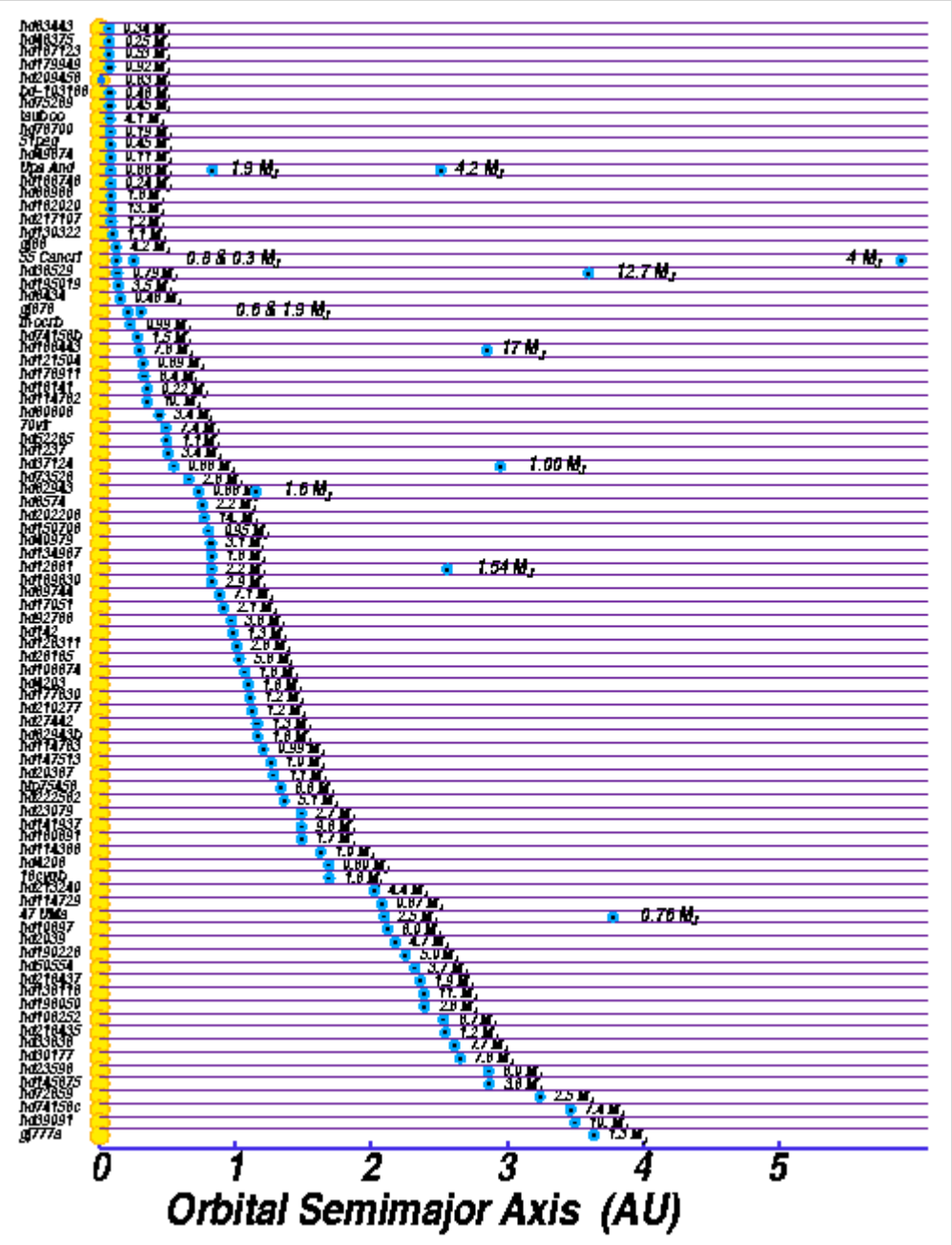
- Mass distribution of known companions rises towards low mass
- A precision of 3 m/s reveals Saturn-mass planets within 1 AU and Neptune-mass planets with 0.1 AU, implying that the true mass function probably rises even more steeply toward lower masses than the observed mass function
- In other words, this may suggest that there are many more terrestrial planets than giants
- Lack of companions have $M \sin i > 10\ M_J$ (the brown dwarf desert)


Ellipticities of Extrasolar Planet Orbits
All Planet Candidates
Msin i < 15 M_JUP
Orbital Eccentricity
0.8
0.6
0.4
0.2
0.0
Earth
0.1
1.0
Semimajor Axis (AU)
Butler,Marcy
Fischer,Vogt


Orbits of Extrasolar Planets
Earth
2
1
0
−1
−2
Distance (Earth–Sun Units)
−2
0
2
Distance (Earth–Sun Units)

Exoplanet eccentricities

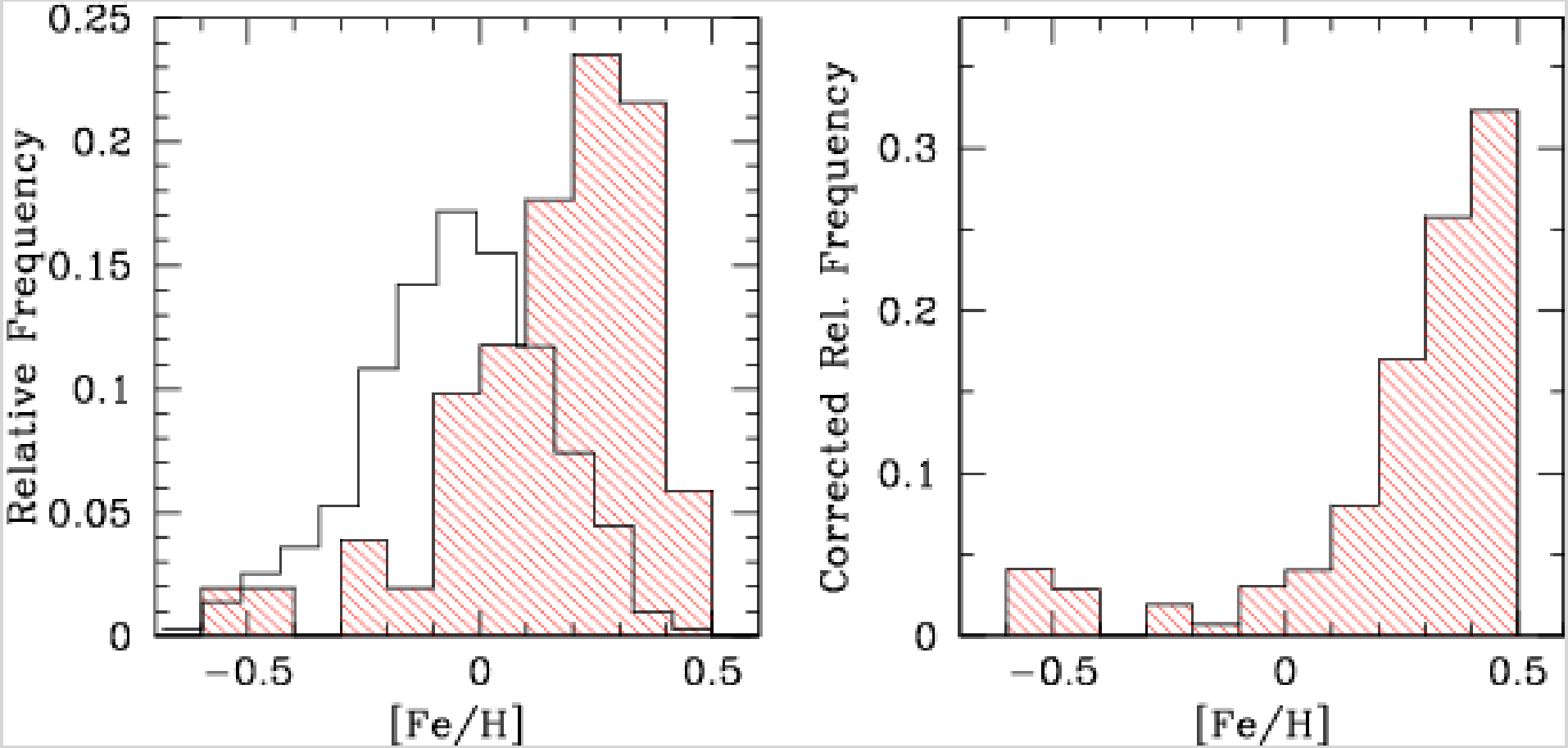
- Massive planets exist at small orbital radii. Closest in planet is at a = 0.035 AU, cf Mercury at ~ 0.4 AU. Less than 10 Solar radii.
- Orbital eccentricities are correlated with semi-major axis
- Hot Jupiters have close to circular orbits. All detected planets with semi-major axis < 0.07 AU have low e. This is similar to binary stars, and is likely due to **tidal circularization**
- Remaining planets have a wide scatter in e, including some planets with large e
- This eccentricity trend seems to be a unique characteristic of extra-solar planets and presumably stems from the formation or subsequent dynamics of the planets


1.9 M⊕
4.2 M⊕
0.8 & 0.3 M⊕
4 M⊕
12.7 M⊕
0.6 & 1.9 M⊕
17 M⊕
1.00 M⊕
1.6 M⊕
1.54 M⊕
0.76 M⊕
0
1
2
3
4
5
Orbital Semimajor Axis (AU)

Orbital semi-major axes

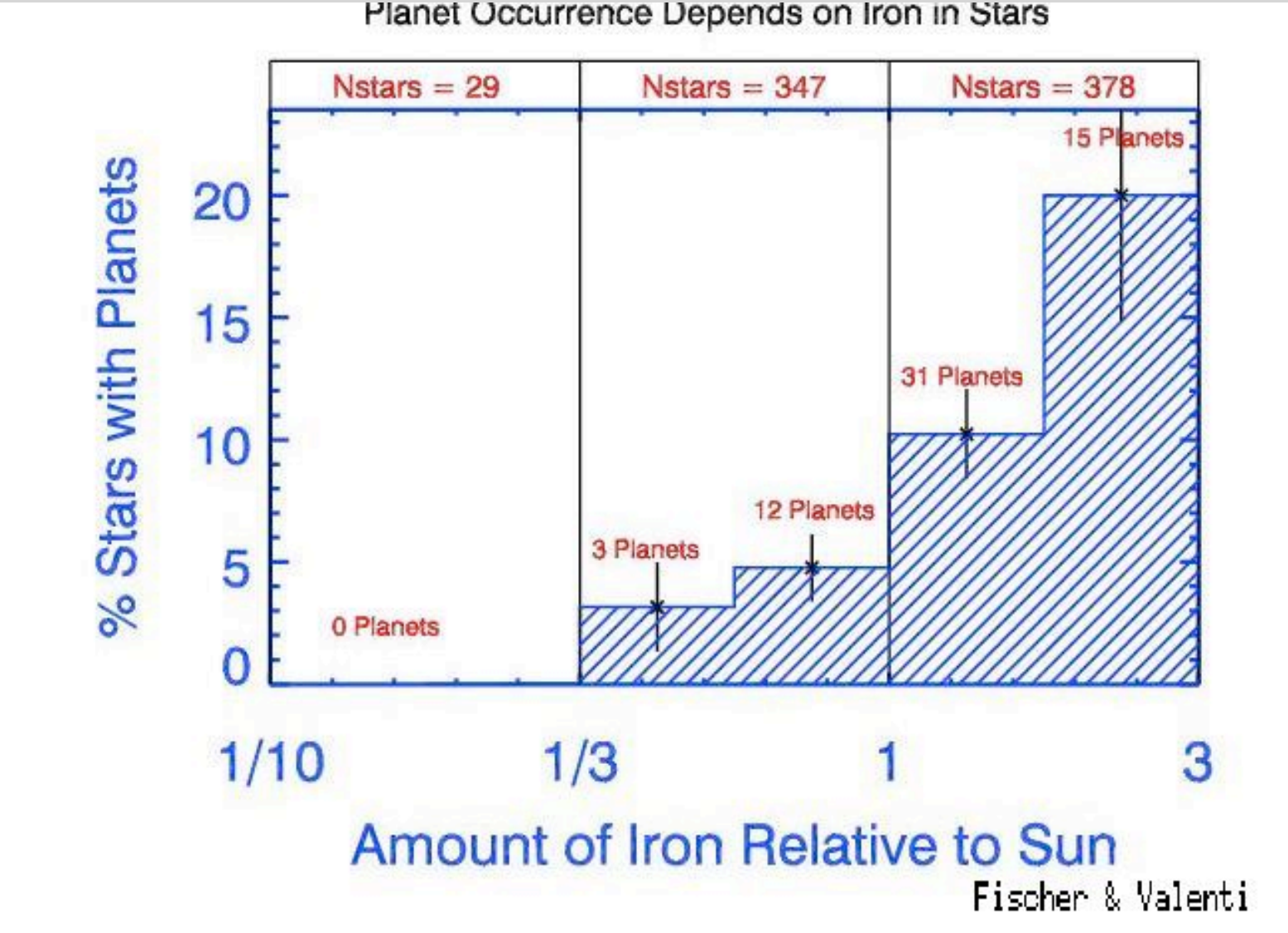
- Strong selection effect in favour of detecting planets at small orbital radii, arising from:
  - lower mass planets can be detected there
  - mass function rises to smaller masses
- Selection effect explains excess of planets within 0.2 AU relative to those orbiting beyond 2 AU, but doesn't explain why orbits within 0.2 AU are preferred to those between 0.2 AU and 0.6 AU
- The large number of planets found at 0.05 AU may be due to a halting mechanism that occurs during *planetary migration*

Metallicity distribution of stars with and without planets



Left plot: metallicity of stars with planets (shaded histogram) compared to a sample of stars with no evidence for planets (open histogram)

(data from Santos, Israelian & Mayor, 2001)


Planet Occurrence Depends on Iron in Stars
Nstars = 29
Nstars = 347
Nstars = 378
15 Planets
31 Planets
12 Planets
3 Planets
0 Planets
% Stars with Planets
20
15
10
5
0
1/10
1/3
1
3
Amount of Iron Relative to Sun
Fischer & Valenti

Host star metallicities

Planets are preferentially found around stars with enhanced metal abundance.

Cause or effect? High metal abundance could:

(a) Reflect a higher abundance in the material which formed the star + protoplanetary disc, making planet formation more likely.

(b) Result from the star swallowing planets or planetesimals subsequent to planets forming. If the convection zone is fairly shallow, this can apparently enrich the star with metals even if the primordial material had Solar abundance.

Detailed pattern of abundances can distinguish these possibilities, but results currently still controversial.

Summary of statistics

- Around 7% of stars have Jupiter-mass companions orbiting in eccentric orbits within 4 AU
- Around 1% of solar-type stars have Jupiter in 0.05 (3-5 day) orbits (Hot Jupiters)
- The mass distribution of substellar companions rises abruptly near 5 M_J and continues increasing down to the detection limit near 1 M_J
- Orbital eccentricities correlate positively with semi-major axes, distinguishing planets from binary stars
- The planet bearing stars are metal-rich relative to both nearby stars and the Sun