Planets in different environments

"Is the formation and evolution of planets effected by the stellar environment?"

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Which factors are important for the formation of planets?

- Metal rich stars have a higher frequency of (massive) planets.

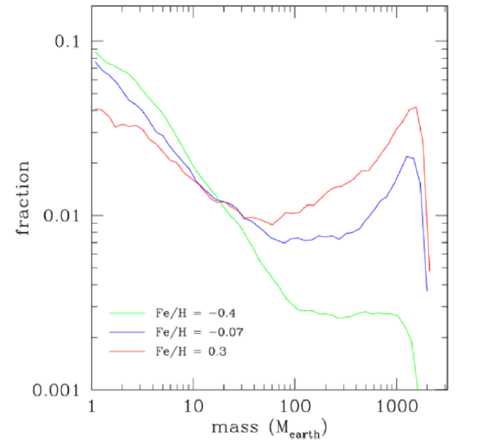
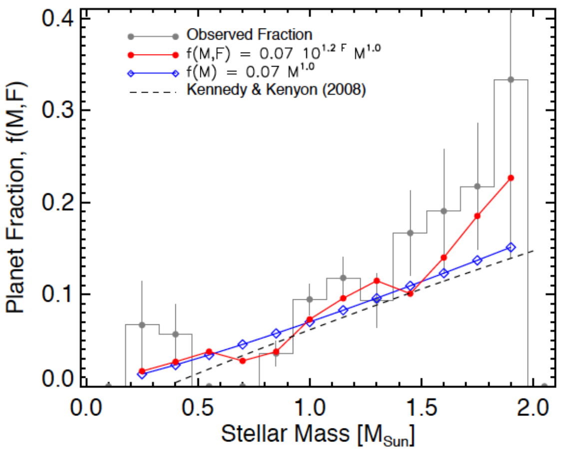


Fig. 2 Fraction of planets around a 1 $M_\odot$ star as a function of their mass (from simulations of Mordasini et al. 2006). Results are displayed for three different values of the metallicity of the star (and of the corresponding proto-planetary disk), as shown on the figure. It is seen that, high metallicities favour larger fractions of massive planets (in rough agreement with observations), while at low metallicities the presence of Earth-like planets is enhanced rather than suppressed. (Courtesy Y. Alibert).

Prantzos 2008, based on calculation from Mordasini et al. 2006

- More massive stars have more planets.



Johnson et al. 2010

Key questions:

---> Are the metallicity and the mass of the host star really the only factors that determine the outcome of planet formation?

---> Is planet formation different in a rich cluster compared to a region of low stellar density?

Formation of planets in clusters

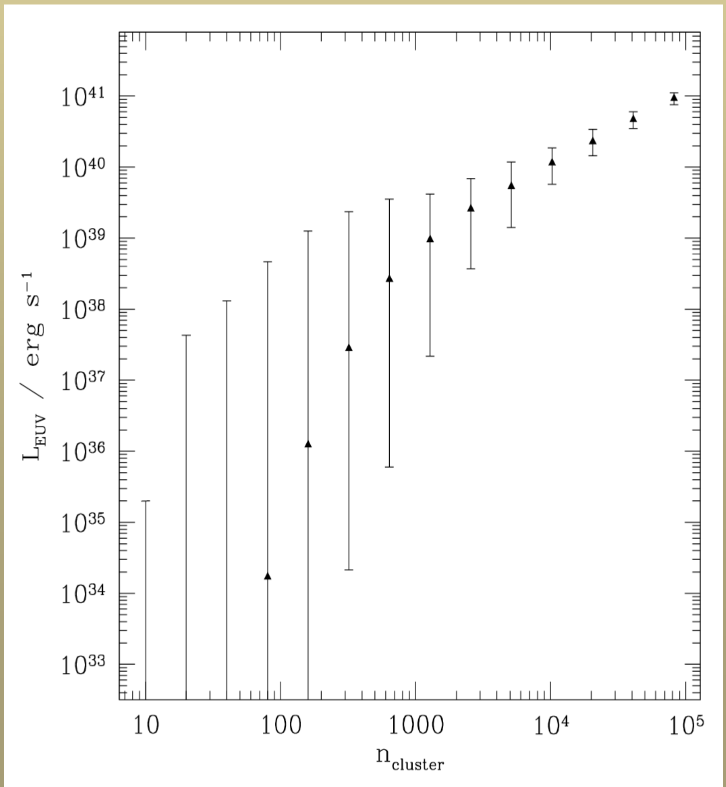
Most stars do not form in isolation but in stellar clusters.

In a cluster, the protoplanetary disks and the planets are effected by:

- the intensive X-ray and extreme UV-radiation (XUV) from the hottest stars in the cluster, and by
- close encounters of the disks and the planets with other stars in the cluster.

XUV-radiation in clusters

The XUV-radiation in clusters is dominated by the radiation from the most massive star of that cluster. In the outer parts of the disk, the XUV-radiation from the most massive star of the cluster is often larger than the XUV-radiation of the central star itself.



The integrated EUV luminosity for clusters with $n_{cluster}$ stars. The points show median values, the error bars show the range that encloses 90% of the distribution of luminosities (Armitage 2000).

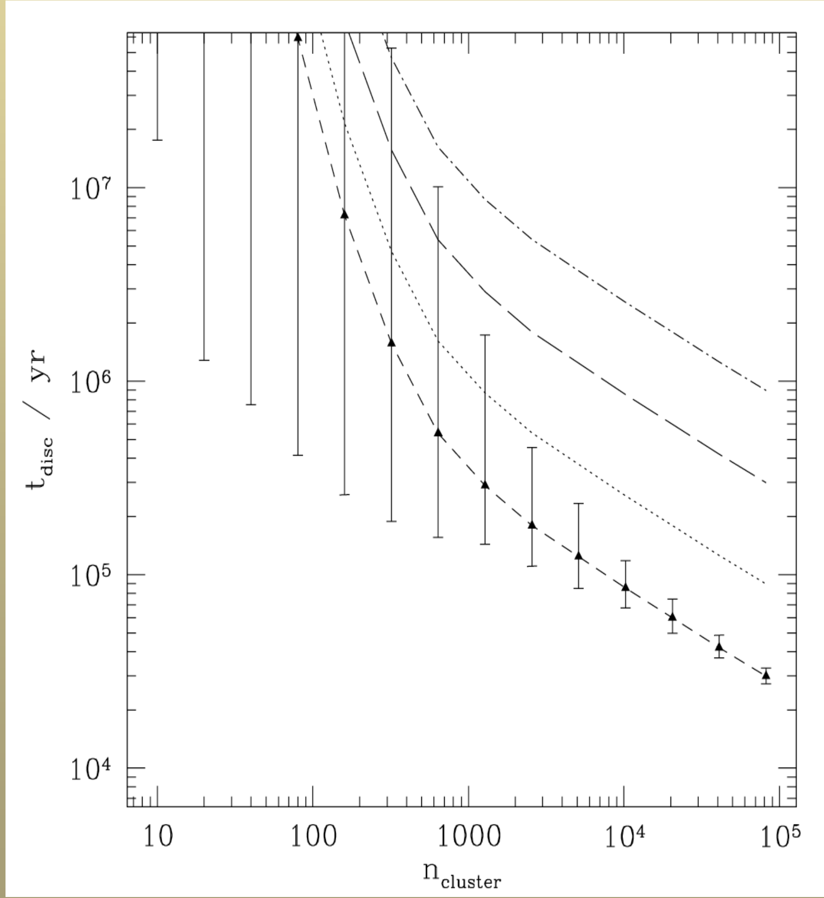
Did planet host stars form in clusters?

- Statistically 50% stars originate from OB associations which contain more than 1740 stars.
- Does this mean that also 50% of the planet-host stars were formed in clusters containg more than 1740 stars?
- The problem is that in a rich cluster, the lifetime of the disk can be as short as 10^5-10^6 yrs (Fatuzzo & Adams 2008).
- Is it possible that all planet-host stars formed in regions that contain only a few stars, or only in the outer regions of the clusters?
- We know that at least the sun has formed in a cluster that contained about 1200 stars (Gounelle & Meynet, 2012, Pfalzner et al. 2013).

---> Can planets form in rich clusters, or not?

Can planets form in rich star-clusters?

Armitage (2000) calculated that the lifetimes of the disk in clusters containing more than 300 stars is 10^6 years, or less.



Disks around stars in the Orion Nebula Cluster

Eisner et al. (2008): Only 4% of the stars have disks more massive than 0.02 M_{sun}, typically they have only 0.0015±0.0003 M_{sun}.

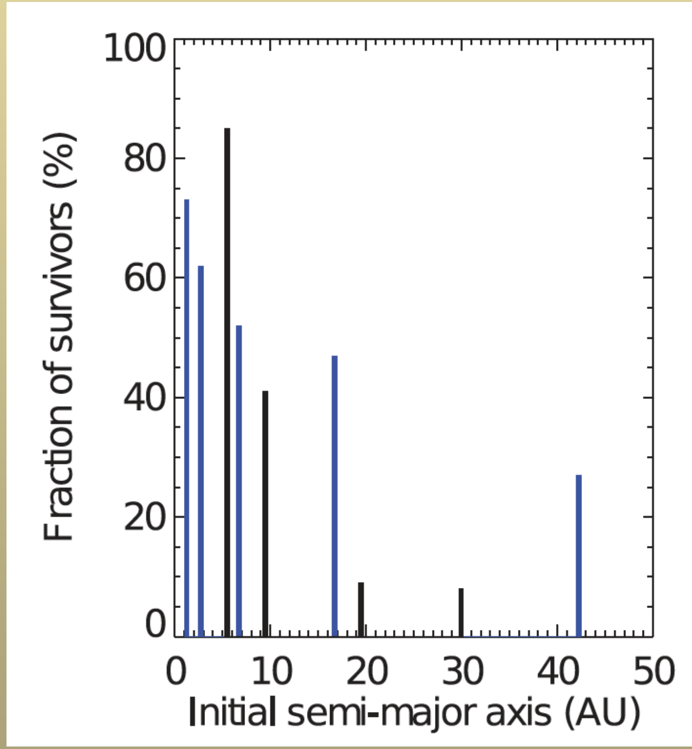
XUV radiation can also help planet formation

- Boss (2011): In order to explain the formation of planets like those in HR 8799 in the context of the GI model, he had to assume that the outer disk was removed within 10^5 years by the FUV and EUV radiation of a nearby OB-star.
- Throop & Bally (2005) and Mitchell & Stewart (2010): Photo-evaporation of the disk may accelerate the formation of planetesimals, because the gas-to-dust-ratio is increased.
- Alexander & Pascucci (2012): Disc clearing by EUV photo-evaporation can have a strong effects on the distribution of giant planet semimajor axes (pile up of Jupiter-mass planets at 1 AU).

Note that the formation of planets is a complicated process: There are local enhancement of the density in the proto-planetary disk (e.g. ALMA, van der Marel et al. 2013). Grain properties are different in different parts of the disk (e.g. VLTI, van Boekel et al. 2004).

Interaction between stars in clusters:

Fraction of survived planets as a function of their initial semimajor axis, for two different models (blue/black) for a cluster like the Orion Nebula Cluster (ONC). Inner planets have a higher probability of surviving after the stellar encounters, while outer planets can more easily escape from the system (Hao et al. 2013). See also Spurzem et al.2009 and Bonnell et al. 2001. Any planetary system with separation > 1 AU should be disrupted in a cluster with a density > 10^3 stars pc $^{-3}$.



Previous studies: open clusters

- Hyades (0.6 Gyrs, 400 M_{sun}): 98 stars surveyed for 5 years, no planet found (Cochran et al. 2002, Guenther 2005). Then a planet of eTau found (Sato et al. 2007), and a hot Jupiter (Quinn et al. 2013).
- M67 (3.2-5 Gyrs, 1400 M_{sun}): 3 planet found --> Frequency of hot Jupiters: $2^{+3.0}_{-1.5}$ %, consistent with solar neighbourhood (Brucalassi et al. 2014)
- NGC6791(3.5 Gyrs), NGC 6253: no planet found (Montalto et al. 2007; Montalto et al. 2011).
- NGC 2423 (0.75 Gyrs) + NGC 4349 (0.2 Gyrs): 10.6 and 19.8 M_{Jup} -objects found orbiting intermediate-mass stars (Lovis & Mayor 2007)
- Presaepe=M44 (0.7 Gyr, 600 M_{sun}) two planets among 53 stars found --> Frequency of hot Jupiters: $3.8^{+5.0}_{-2.4}$ %, consistent with solar neighbourhood (Quinn et al. 2012).
- NGC6811 (1 Gyr, 6000 stars): two Neptune-sized planets --> Frequency consistent with solar neighbourhood (Meibom et al. 2013).

--> The frequency of (close-in) planets host stars seems to be the same in clusters as in the solar neighbourhood.

Previous studies: globular clusters

- 47 Tuc: Transit survey no planet found (Gilliland et al. 2000; Weldrake et al. (2005), ([Fe/H=-0.75])
- ω Centauri: Weldrake et al. (2008), ([Fe/H=-1.5...-1.8])
- M4: pulsar planet (Backer 1993; Thorsett et al. 1999), ([Fe/H=-1.11])

---> frequency of close-in planets at least factor 10 smaller

Thomson (2012):

Frequency of planets in NGC 6366 and 47 Tuc. Both are GCs have the same metallicity ([Fe/H]=-0.7..-0.9) but different stellar densities.

Study planet population in relatively metal rich GCs (NGC 6440, NGC 6441, NGC 6388 [Fe/H]=-0.5...-0.4).

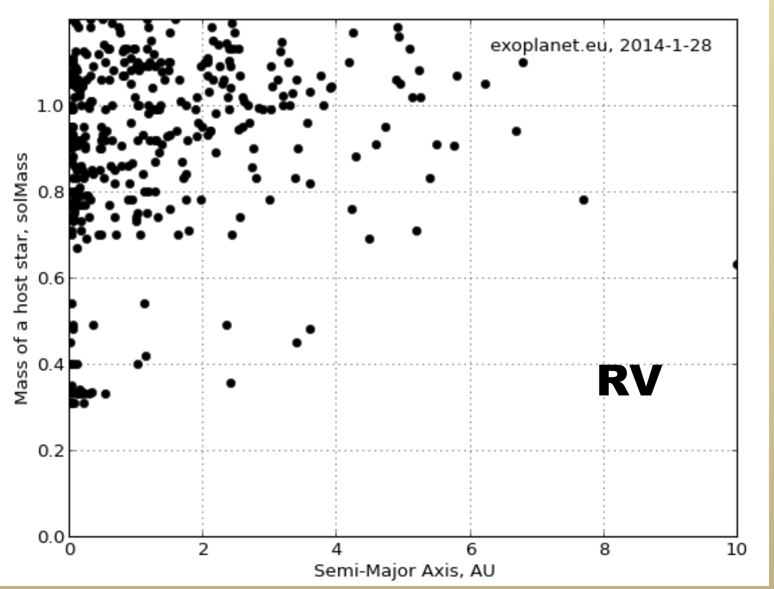
What is needed?

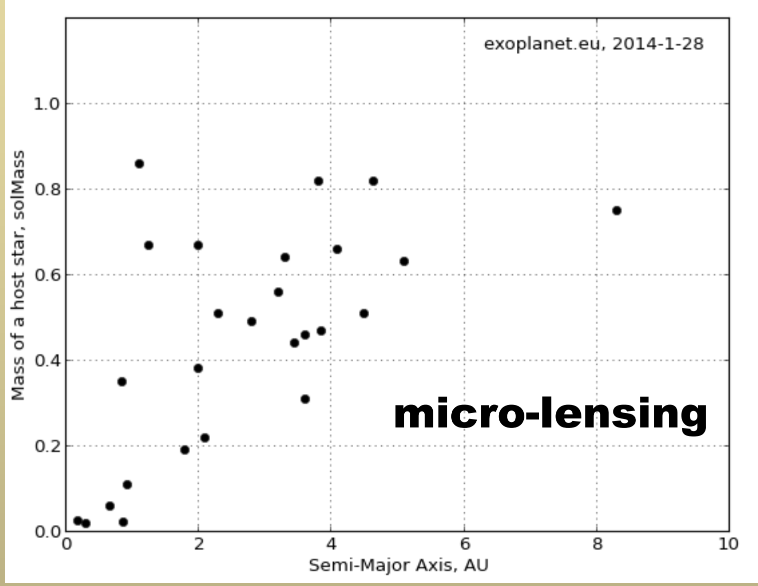
- Studies of the planet population in clusters containing a large number of stars, and in cluster containing only few stars.
- Studies of the planet population in regions of very high and very low stellar density.

How does the planet population change with the galactocentric distance?

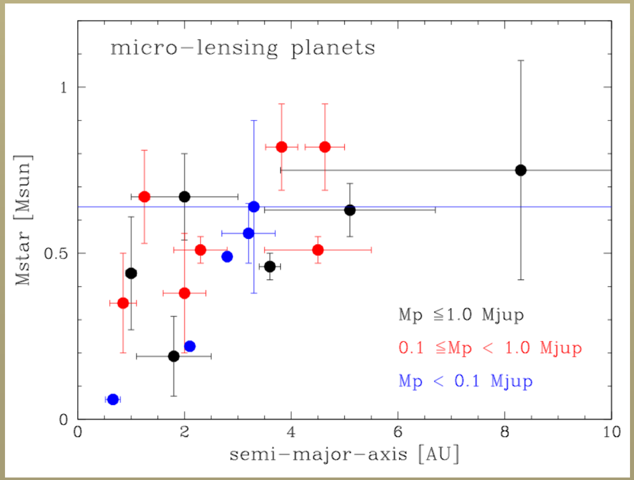
Is the planet population different in the galactic bulge, in globular clusters, or in nearby dwarf galaxies?

How about using micro-lensing to study the planet population in the galactic bulge and in nearby galaxies?



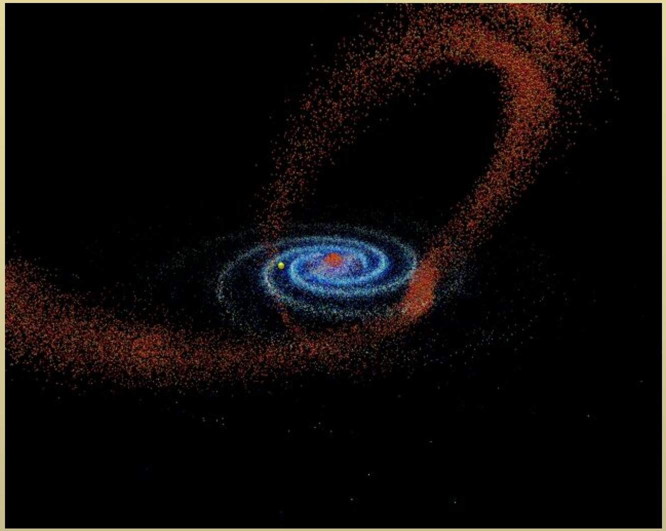


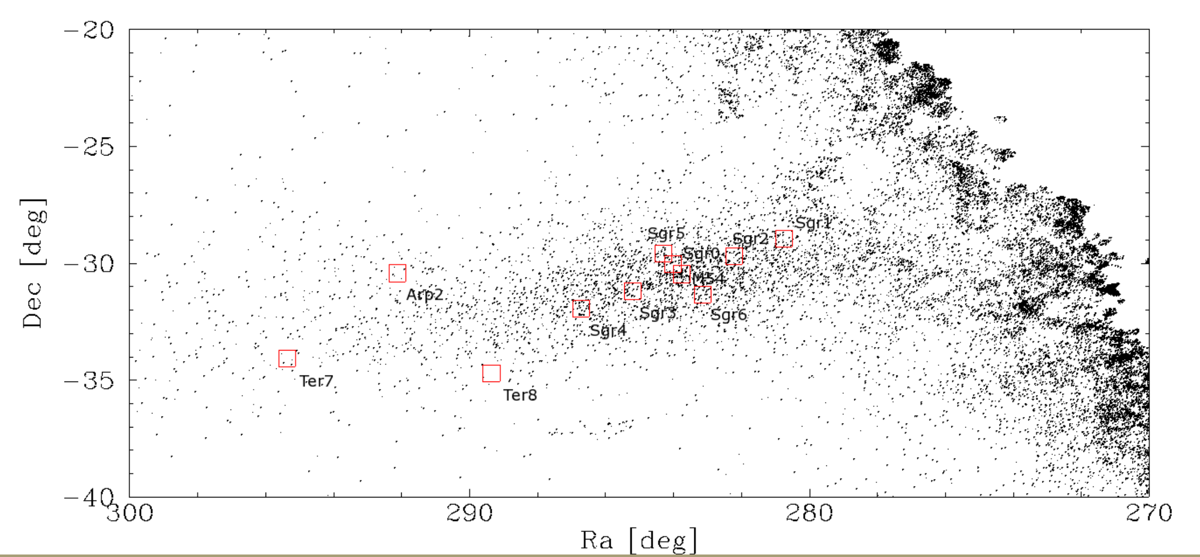
Results of RV-searches and micro-lensing searches are difficult to compare.

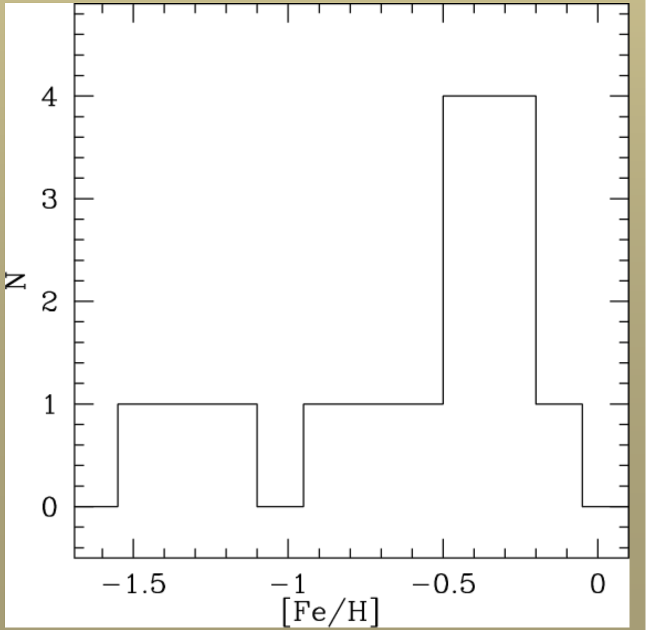


Sagittarius Dwarf Elliptical Galaxy

The Sagittarius dwarf elliptical galaxy is orbiting our galaxy at almost a right angle to the disk. It is currently passing through the disk; stars are being stripped off of it with each pass and joining the halo of our galaxy. Stars in this galaxy are metal poor.

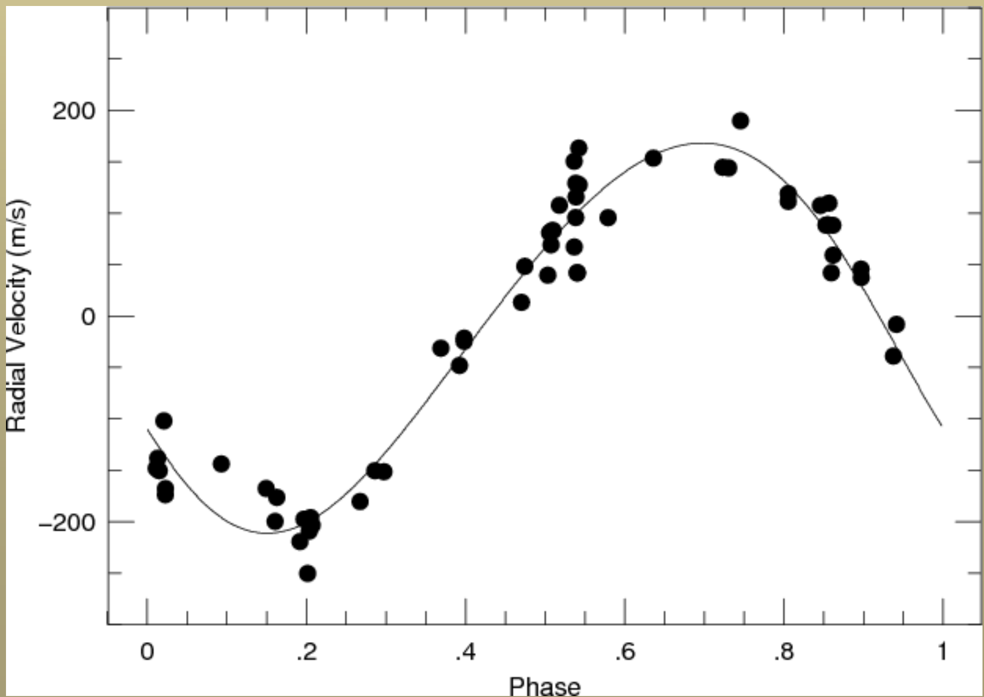




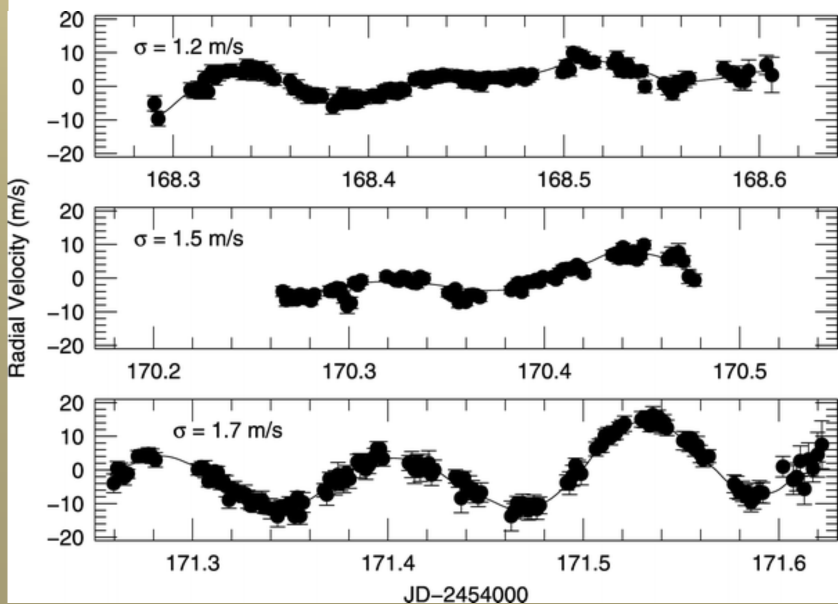


Is it possible to detect the planets of giant stars in SDEG by using the RV-method?

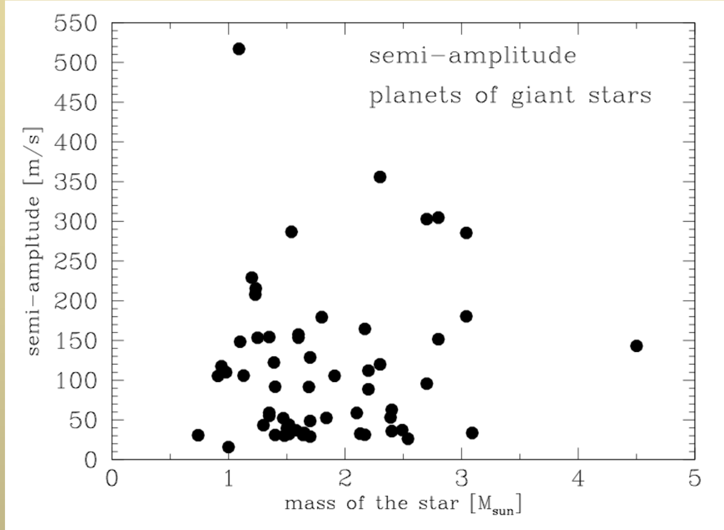
Example: planet with 10.50+/-2.57 M_{Jup}, and an orbital period of 516 days of a K4III star with 1.80+/-0.25 M_{sun}.

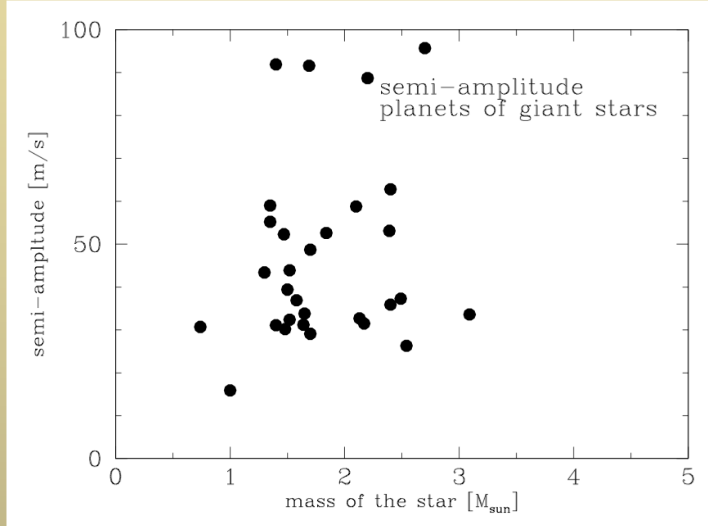


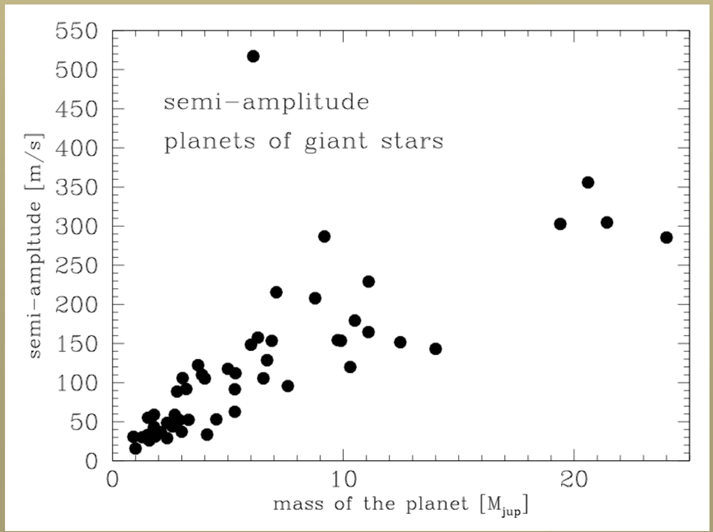
$$\nu_{max} = \frac{M/M_\odot}{(R/R_\odot)^2\sqrt{T_{eff}/5777\ \mathrm{K}}}\ 3.05\ \mathrm{mHz}.$$



61 planets of giant stars have been detected in the solar neighbourhood. These stars have massive planets, causing large RV-variations.







RV-accuracy required: ~10 m/s

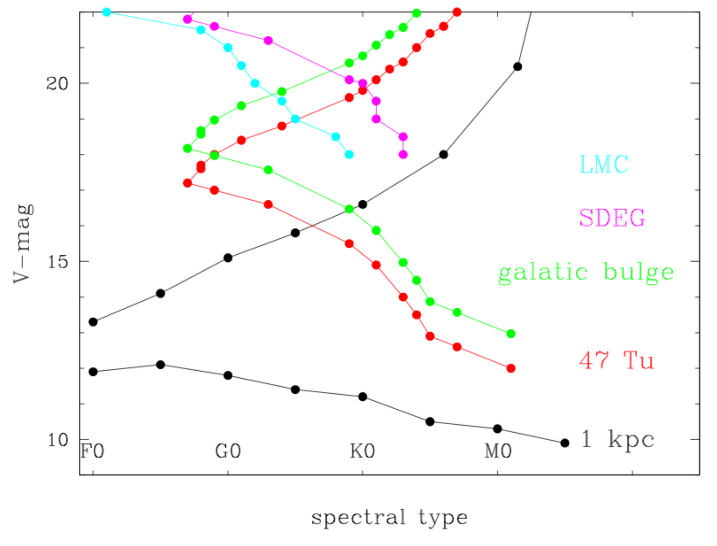
For example:

R=30000, S/N=100, $\Delta\lambda$=80nm --> 10 m/s

R=20000, S/N=150, $\Delta\lambda$=120nm --> 10 m/s

$$\sigma_{RV} \propto S^{-0.5} \cdot \Delta\lambda^{-0.5} \cdot R^{-1.5}$$

Limiting magnitude and exposure times required:



Bulge:

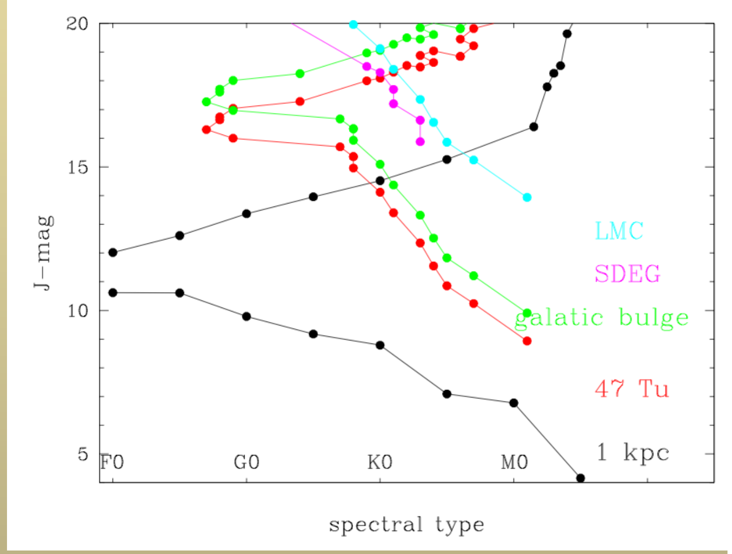
mV ≈ 17, mJ ≈ 15

47 Tuc:

mV=16, mJ ≈14

LMC:

mV≈18.5, mJ≈ 16.4



MOS observation of giant stars in SDEG:

V=19 mag, 10 m/s

R=20000 S/N=150 --> 1620s

R=30000 S/N=100 --> 1080s

“20-40 planets in 6 hours observing time”