K Giants as Grid Stars for SIM

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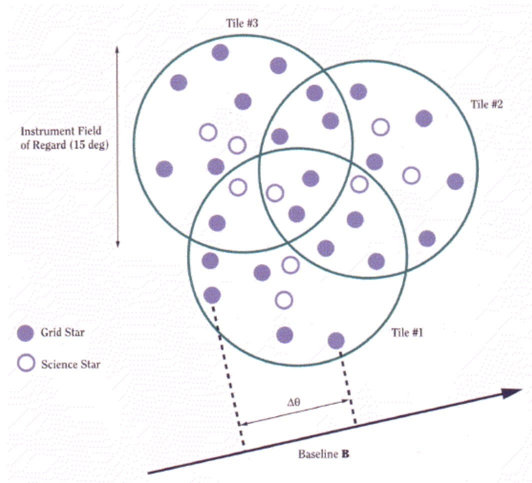


(*SIM*, NASA 1999, p. 71)

Requirements for the Grid

- number of stars:
  envisaged: ≈ 3000 stars ($\widehat{=}\,0.07$ stars/sq. deg., or 12 stars/15° FOR)
  minimum: ≈ 1000 stars ($\widehat{=}\,0.02$ stars/sq. deg., or 4 stars/15° FOR)
- distributed evenly over sky
- brighter than $\approx 12\,$mag
- astrometrically stable at a level of a few μas:
  $\rightarrow$ no double stars
  $\rightarrow$ astrometric signatures of planets $\lesssim$ a few μas

Effects of Double Stars in the Grid

- acceptable level of contamination of the grid from stars with planetary or stellar companions: $\lesssim$ 5–10%

	10%	20%	50%	← contamination level
4	66	41	6	
5	92	74	19	
6	98	90	34	
7	99.7	97	50	

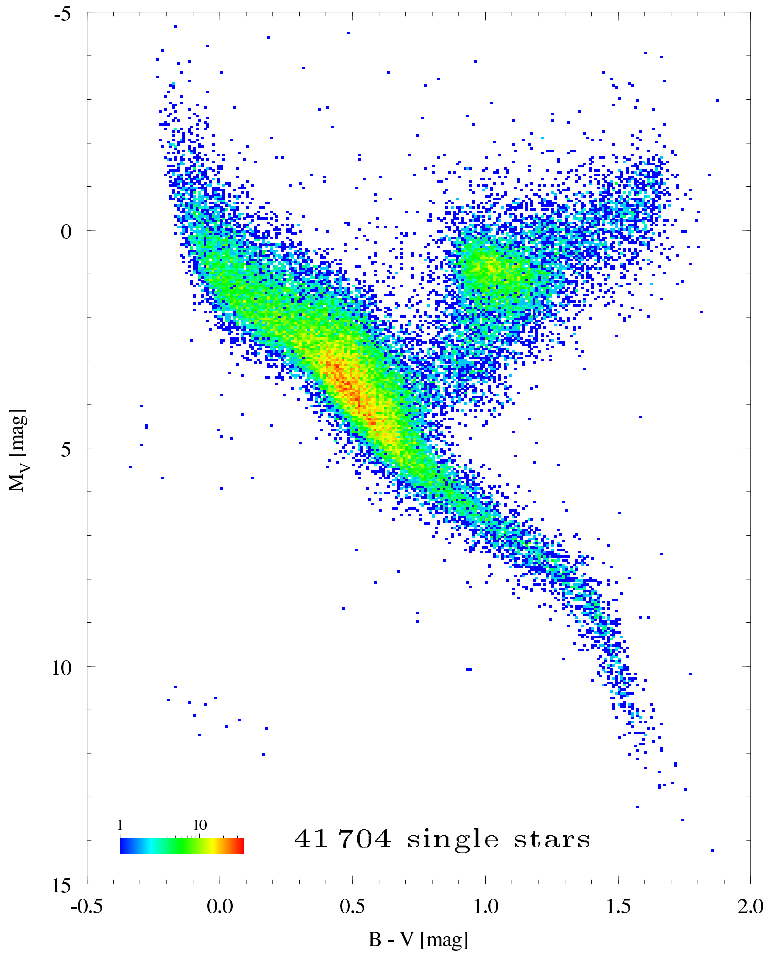
↑ no. of grid stars per observation

- some additional redundancy would be highly desirable

  → better do a good job from the ground!

Why K Giants?

Hipparcos CMD diagram



(http://astro.estec.esa.nl/Hipparcos/vis_stat.html)

… because a typical K giant is $\approx 4\,\mathrm{mag}$ brighter than a G dwarf
($M_V \approx 0.5\,\mathrm{mag}$ vs. $4.7\,\mathrm{mag}$)

→ typically a K giant will be 7 times more distant than a G dwarf with the same apparent magnitude

Why is the distance so important?

... because the astrometric signature of a (planetary) companion scales with the inverse of the distance, e.g.:

astrometric signature of a planet of $1\,M_J$ orbiting a star of $1\,M_\odot$ at 5 AU (P=12 yrs):

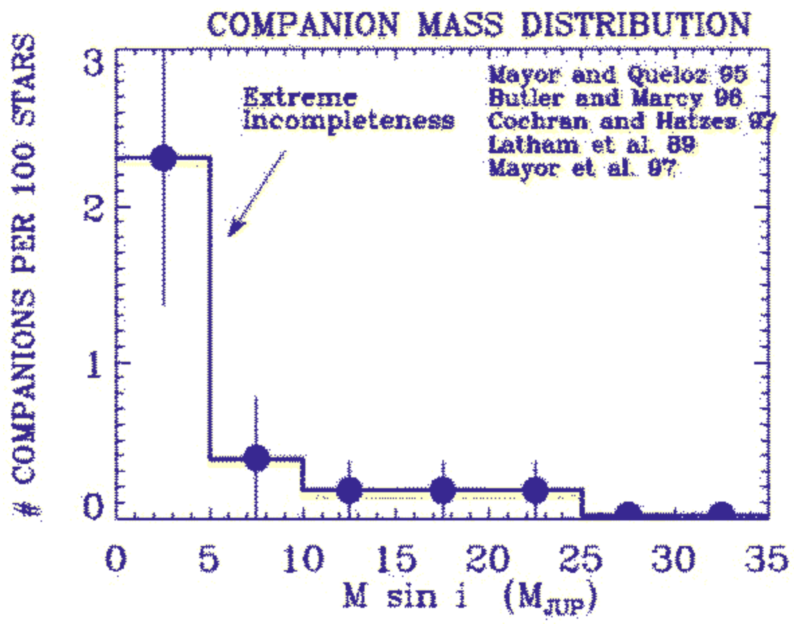
at a distance of 100 pc:	100 μas
at a distance of 1 kpc:	10 μas
at a distance of 2 kpc:	5 μas

→ grid stars with masses of the order of $1\,M_\odot$ would have to be located at distances of at least 1–2 kpc

→ we are left with

G dwarfs	fainter than	14.7 mag
K giants	fainter than	10.5 mag

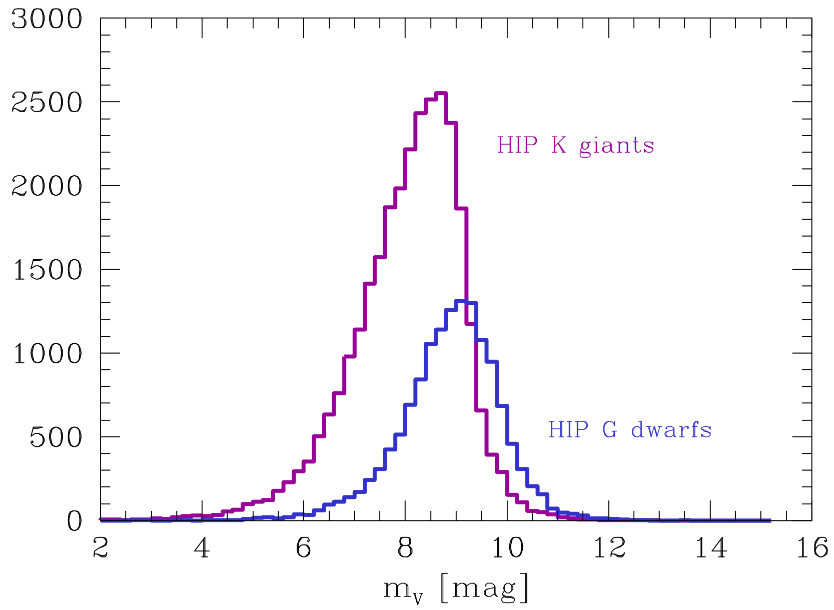
Strategy to select good Grid Candidates



(Marcy 1997, http://cannon.sfsu.edu/~gmarcy)

- make sure the grid candidates have no stellar companions (astrometry, radial velocities)
- take advantage of the Brown Dwarf Desert
- place the grid candidates in such a distance that giant planets won't affect the grid accuracy

Composition of the Hipparcos Catalogue



279	O stars
10 534	B stars
18 803	A stars
25 807	F stars
23 107	G stars
	(9 212 giants + 13 895 dwarfs)
32 973	K stars
	(29 466 giants + 3 507 dwarfs)
5 042	M stars
	(4 076 giants + 966 dwarfs)

→ although K giants are very common in the Hipparcos Catalogue (≈28% of all stars), there are only 173 K giants fainter than 10.5 mag, i.e. more distant than 1 kpc

→ need for fainter star catalog as source of grid candidates

Tycho Catalogue

- faintest all-sky catalog with color information
- ≈1 million stars down to ≈11.5 mag (complete to ≈10.5 mag)
- more than 100 000 bona-fide late-type giants (out of around 250 000 stars with $B - V > 1$ mag);
  ≈25% of these are fainter than 10.5 mag
- some duplicity and variability information available to sort out problematic stars in the first place
- additional radial velocity observations needed to clean up the grid from double stars

→ good source for grid candidates, even better with Tycho2!

Hipparcos Catalogue

- still very useful to examine the properties of K giants in more detail
- get an estimate on statistics:
  - How many K giants are in multiple systems?
  - How many K giants are variable?
  - How many grid candidate stars do we have to observe to get a certain amount of good ones?
- proxy sample of K giants brighter than 6 mag:
  already some radial velocity observations!

Definition of a Nearby Proxy Sample

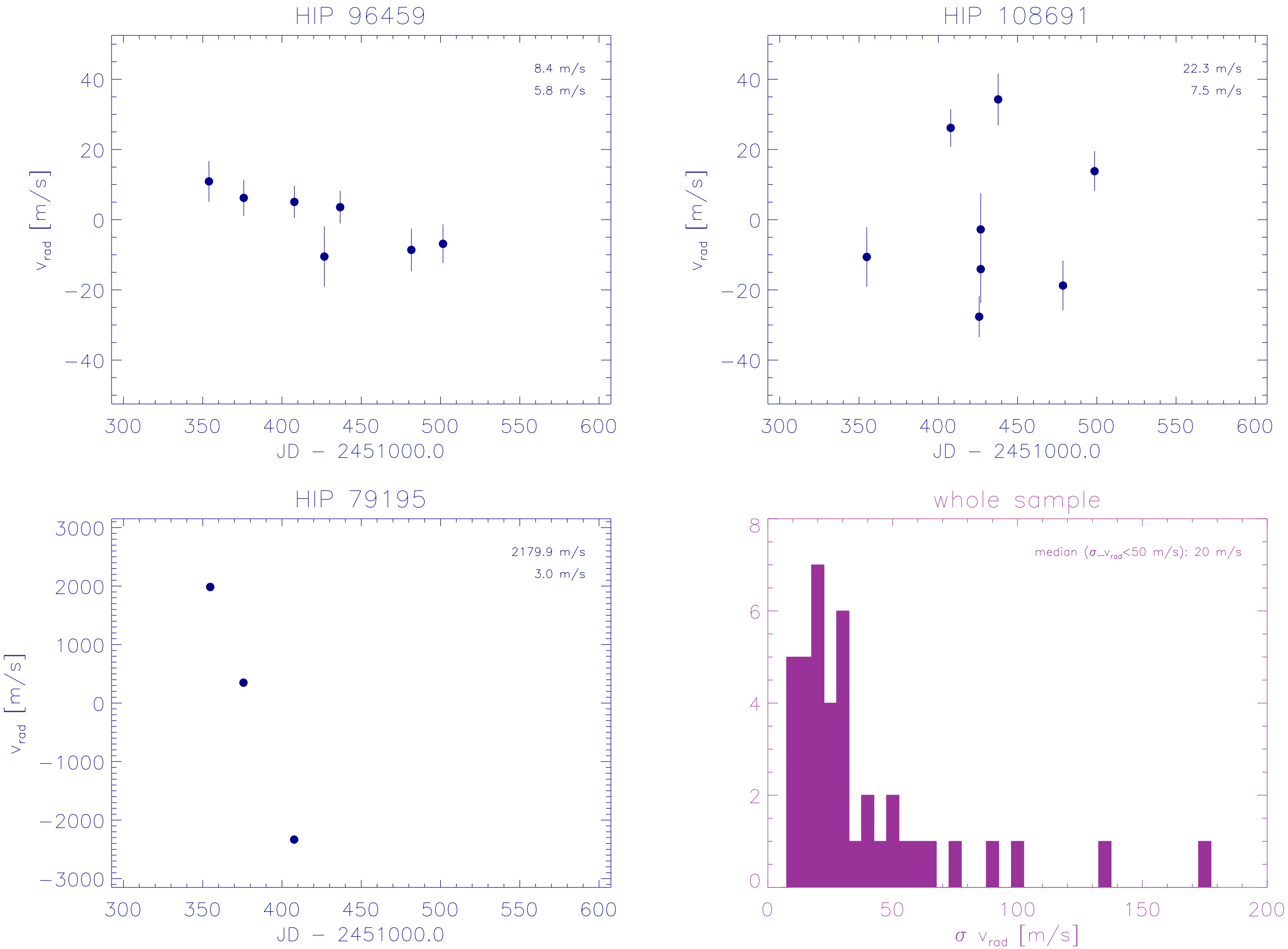
- Hipparcos K giants brighter than 6 mag
- good astrometric quality
- no indication for duplicity or variability from Hipparcos, ACT and TRC
  (but no additional information from literature taken into account)
- accessible from Mount Hamilton (Lick Observatory)

→ there are 145 such stars!

Radial Velocity Observations of the Proxy Sample

- started to monitor the radial velocity variations in this sample, using the Coude Auxiliary Telescope (CAT) at Lick Observatory with the Hamilton Spectrograph and the Iodine Cell with a precision of 5–7 m/s
- so far there are 45 for which we have at least 3 observations, typically 5–7 observations
- of these, only 14 show variations larger than 50 m/s, and 3 of them are known spectroscopic binaries
- these known spectroscopic binaries could be recovered very easily, with only 2 or 3 observations
- the median variation of the velocities for the rest of the sample is 20 m/s on timescales of a few months

Proxy Sample Results



Present Status of Observations

No.	n_{obs}	Δ $v$rad [m/s]	σ $v$rad [m/s]
HIP 379	4	6.8	39.9
HIP 2497	5	6.7	28.9
HIP 6732	5	5.2	21.4
HIP 9110	4	4.9	137.2
HIP 11432	6	7.6	21.4
HIP 13905	6	5.3	24.1
HIP 15861	5	5.1	370.9
HIP 19011	6	6.5	10.6
HIP 19388	6	5.7	13.2
HIP 22860	5	6.8	22.6
HIP 30457	4	4.6	28.0
HIP 79195	3	3.0	2179.9
HIP 79540	5	4.8	29.3
HIP 80693	5	4.4	25.6
HIP 81660	5	3.9	15.2
HIP 83254	5	5.1	51.9
HIP 84671	5	4.6	51.9
HIP 84950	4	4.2	100.1
HIP 85139	5	6.4	60.6
HIP 85888	4	4.6	15.2
HIP 88636	5	5.2	28.7
HIP 88684	5	4.8	9.9
HIP 88839	5	5.1	8.1

No.	n_{obs}	Δ $v$rad [m/s]	σ $v$rad [m/s]
HIP 90067	6	5.4	43.4
HIP 91004	5	6.7	175.3
HIP 92747	5	6.8	75.5
HIP 93026	6	...	...
HIP 96459	7	5.8	8.4
HIP 101986	7	6.4	53.2
HIP 105497	7	5.8	10.0
HIP 108691	7	6.7	23.6
HIP 109023	7	5.8	21.0
HIP 109068	8	4.4	29.6
HIP 109602	7	6.1	31.0
HIP 110986	5	5.7	88.0
HIP 111944	6	3.9	38.4
HIP 112067	6	8.5	20.5
HIP 113084	6	6.2	21.9
HIP 113562	6	8.0	218.8
HIP 113622	5	5.8	18.1
HIP 113686	6	7.7	36.5
HIP 113864	7	5.3	21.7
HIP 114449	6	5.9	15.9
HIP 117567	5	6.4	63.7
HIP 117756	4	5.0	17.2

Questions we intend to answer

- Are K giants really good types of stars for use with the SIM grid?
- How many of the K giants are photospherically active, and at what levels and timescales?
  Does this activity eventually prevent the identification of low-mass companions?
- How many stars would have to be observed in order to find 3000 qualifying stars?
  I.e., what is the overall fraction of binary stars missed by our selection criteria?
- What would be an efficient observing strategy for the whole grid star sample?
- Which precision is needed for the radial velocity observations?
  How many stars can we observe in one night, and what accuracy can we achieve?

Tycho Sample

- $\approx$ 30 000 K giants with $10.5\,\mathrm{mag} \lesssim m_\mathrm{V} \lesssim 11.0\,\mathrm{mag}$
  (probably twice as many and fainter in Tycho2!)
- proper motions from ACT, TRC and STARNET
  helpful to identify giants and dwarfs and
  already a few astrometrically unstable stars
- taking 4 high resolution spectra for $\approx$ 6000 such stars requires:
  750 nights at a 3 m telescope (Lick 3m, ESO 3.6m)
  or
  125 nights at a 10 m telescope (Keck I, VLT, Gemini South)

$\rightarrow$ huge amount of observing time, but ...

...probably well worth the effort!

Majewski Sample

- metal-poor giants and supergiants below $\delta=+20°$
- distances of several kpc, very well suited for the grid
- largely anonymous stars, no information at all concerning astrometric stability (variability, duplicity)
- effort to clean this sample from binary stars with a radial velocity survey therefore probably a little bit larger than for the Tycho sample, but if feasible one could end up with very good grid stars

next step:

get several radial velocities for a small number of stars from both the Tycho sample and the sample from Majewski and compare...

→ already submitted a proposal for Lick 3 m time

FAME Sample

- there are $\approx$ 7000 K giants with $7.5\,\mathrm{mag} \lesssim m_{\mathrm{V}} \lesssim 9.0\,\mathrm{mag}$ in the Hipparcos Catalogue with no signs of variability or duplicity
- at the corresponding distances of 250–500 pc the effects of giant planets cannot be neglected
- astrometric accuracy of FAME better than 50μas for stars brighter than 9^{th} magnitude
  → not precise enough to sort out all problematic planetary companions
- combination of Hipparcos and FAME data probably yields astrometric accuracies precise enough to clean the grid from giant planets
  (combined errors divide by the epoch difference of $\approx$14 years)

→ detailed simulations will be necessary to assess the feasibility of this approach!

Questions to be addressed by Simulations

- What overall fraction of multiple systems will be missed with a radial velocity survey (e.g. face-on systems)?
  (assuming realistic distributions of binary masses, periods, inclinations and eccentricities)
- What type of systems would not affect the grid accuracy (e.g. systems with periods much larger than the mission duration)?
- Which individual stars have the highest chances for any unseen companions and should be avoided?
  (taking every piece of information available for each indiviudal star into account, including the actual radial velocity observations)
- How large are the effects of possible starspots?

Summary

- luminous stars such as K giants are the best type of stars for the grid
- irrespective of whether the grid candidate stars will be drawn from a Tycho sample, the sample of halo giants by Majewski or from combined Hipparcos and FAME data -
  a radial velocity survey of all grid candidates seems to be necessary to ensure the astrometric stability of the final grid
- the first results for a proxy sample of nearby Hipparcos K giants look rather encouraging