



# Precision Radial Velocities for Giant Stars

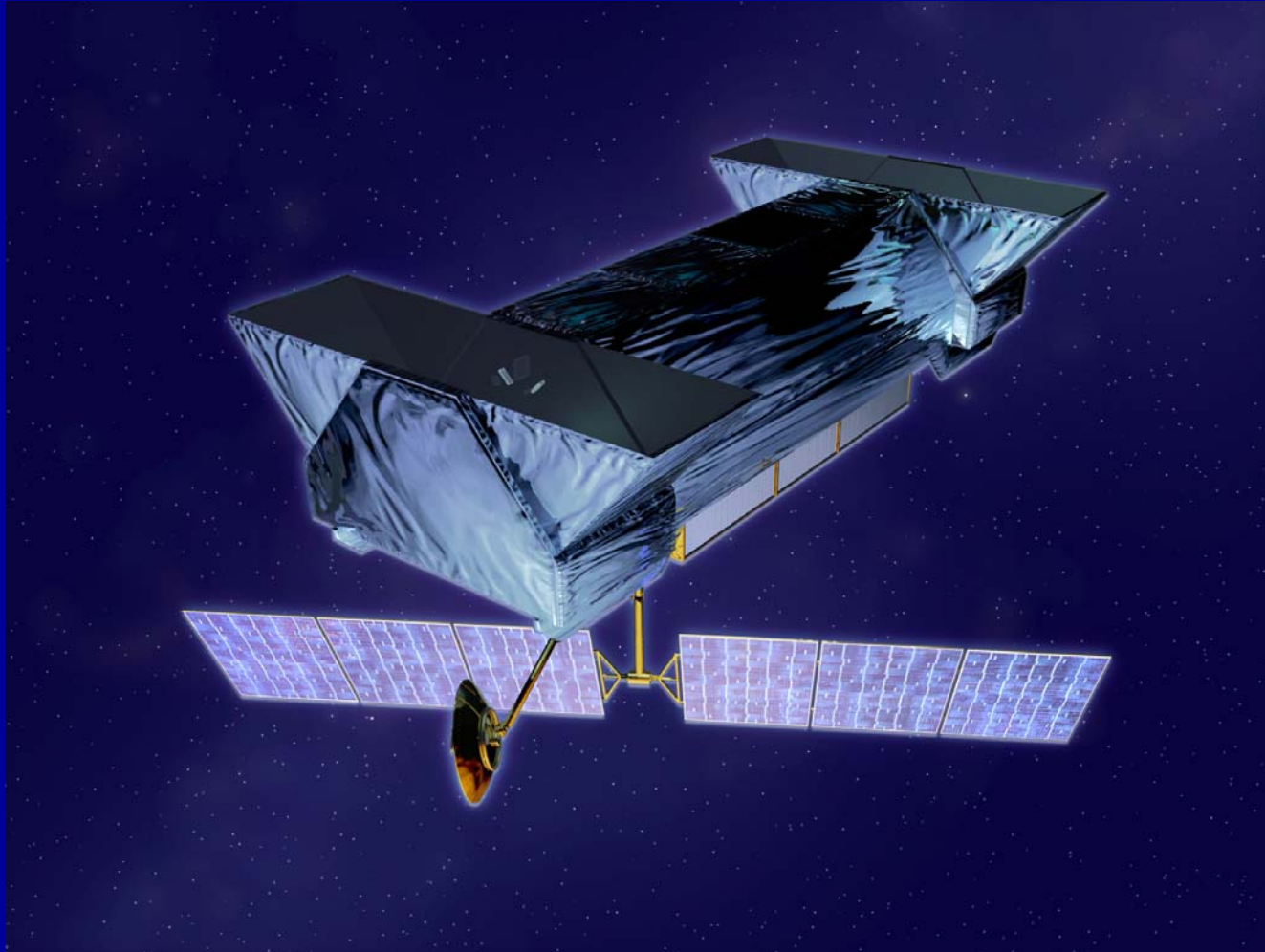
Andreas Quirrenbach  
(Sterrewacht Leiden)



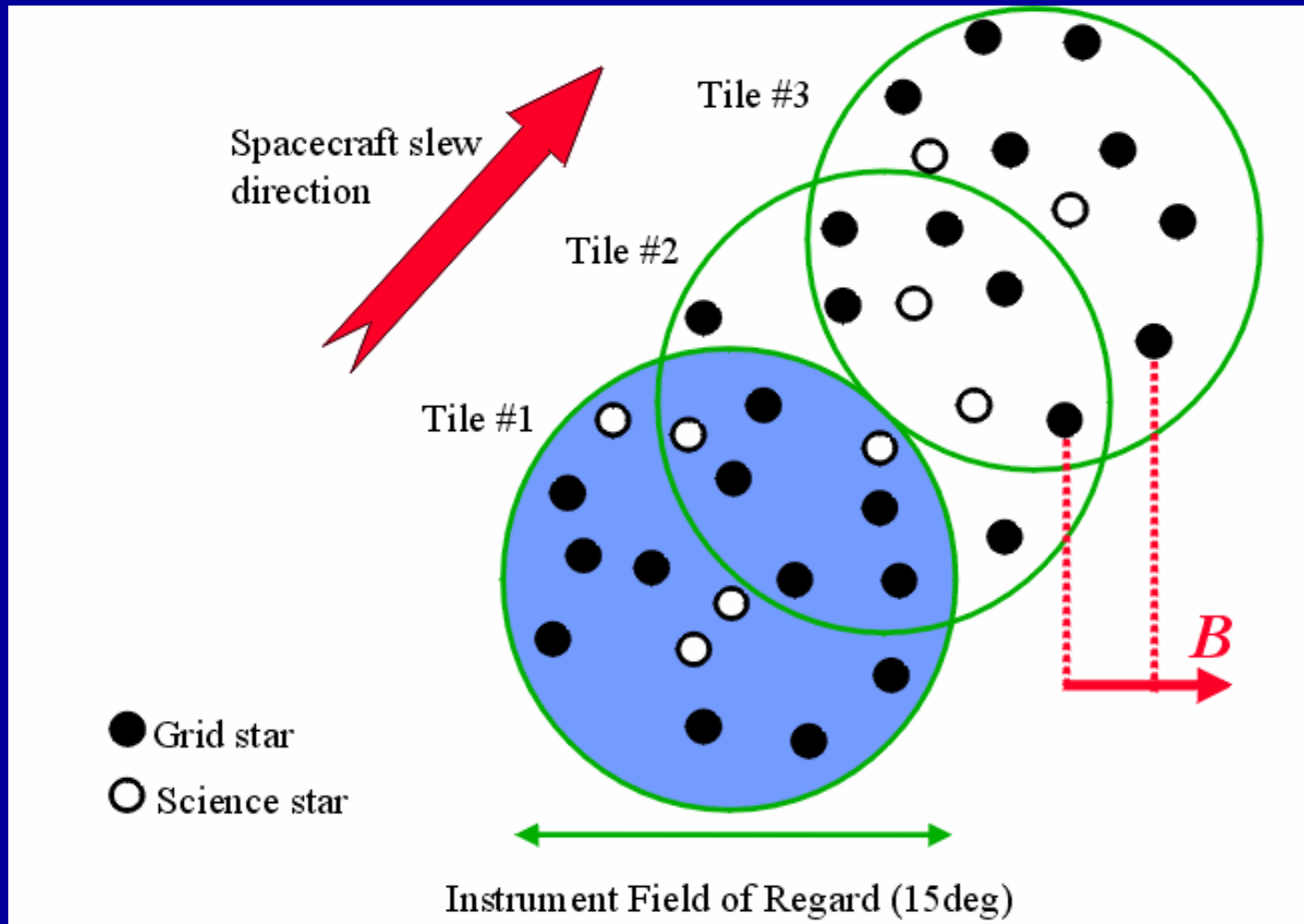
# Collaborators

- Sabine Reffert neé Frink (U Leiden)
- Saskia Hekker (U Leiden)
- David Mitchell (Cal Poly San Luis Obispo)
- Debra Fischer (SFSU)
- Geoff Marcy (U Berkeley)
- Paul Butler (Carnegie)

# The Space Interferometry Mission (SIM, NASA 2013)



# SIM Grid “Tiles”



# How to Find Reference Stars for SIM



- SIM needs thousands of grid and reference stars that are stable on the  $\mu\text{as}$  level.
- Proposed strategy:
  - Select stars that are so far away that planetary companions don't matter (K giants at 1 kpc or more).
  - Take advantage of the “brown dwarf desert”.
  - Weed out binaries with stellar companions through high-resolution spectroscopy.
- We have to demonstrate that K giants have sufficiently stable photospheres.



# Mt. Hamilton Observing Program

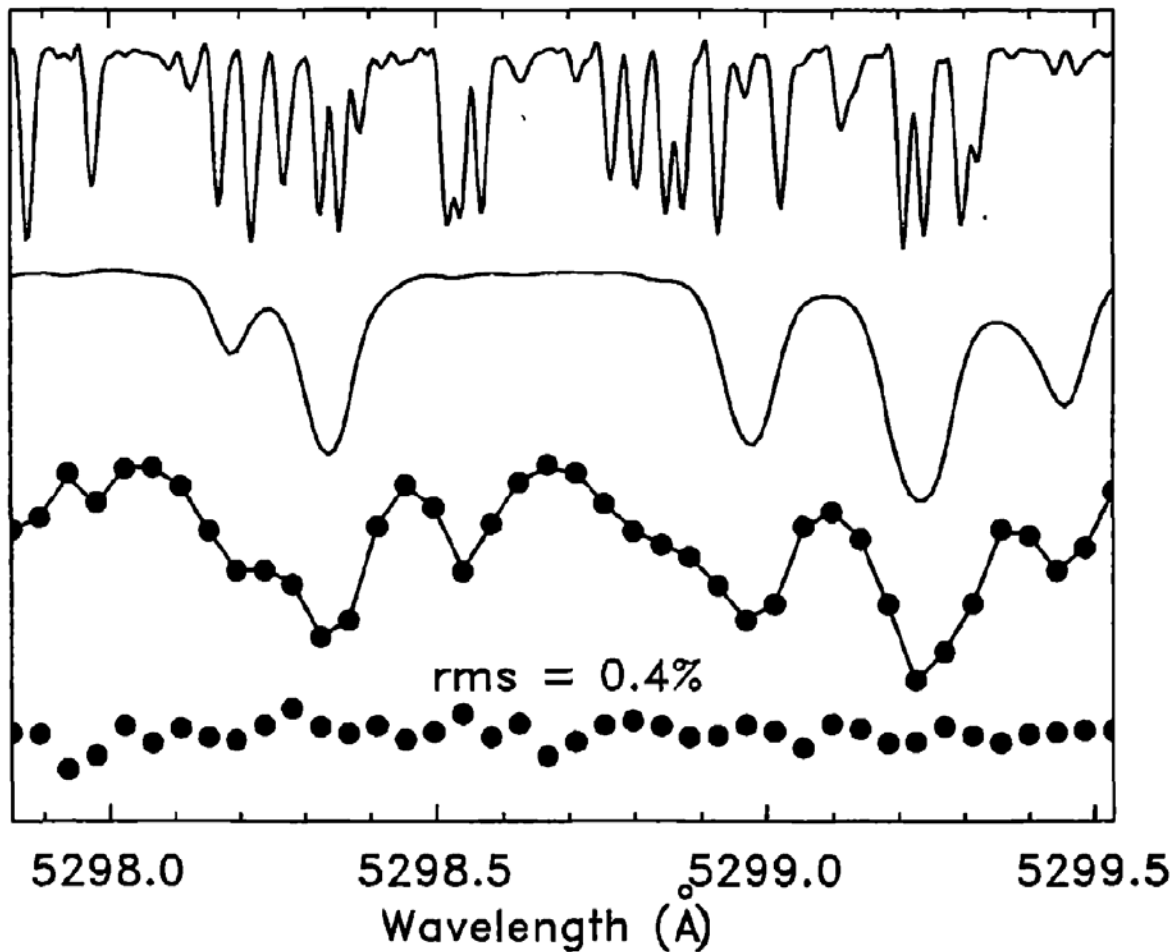
- 179 bright K giants ( $m_V < 6$ ) selected from HIPPARCOS catalog
- 0.6m CAT at Lick Observatory
- Hamilton Echelle Spectrograph ( $R = 60,000$ )
- Radial velocity precision 5...8 m/s
- Data reduction with Marcy / Butler pipeline
- Monitoring program started in 1999
- Typically 5 observing nights / month



# Observing Procedure

- Use iodine cell for RV stabilization
- Aim for SNR = 80...100
  - Expose for up to 1800s
  - Sufficient for 5...8m/s precision
  - Not limited by systematic effects (3m/s precision demonstrated)
- Take one high-SNR template w/o iodine cell
- Determine RV by fitting each observation using template and iodine spectrum

# Data Analysis Principle (Butler et al.)



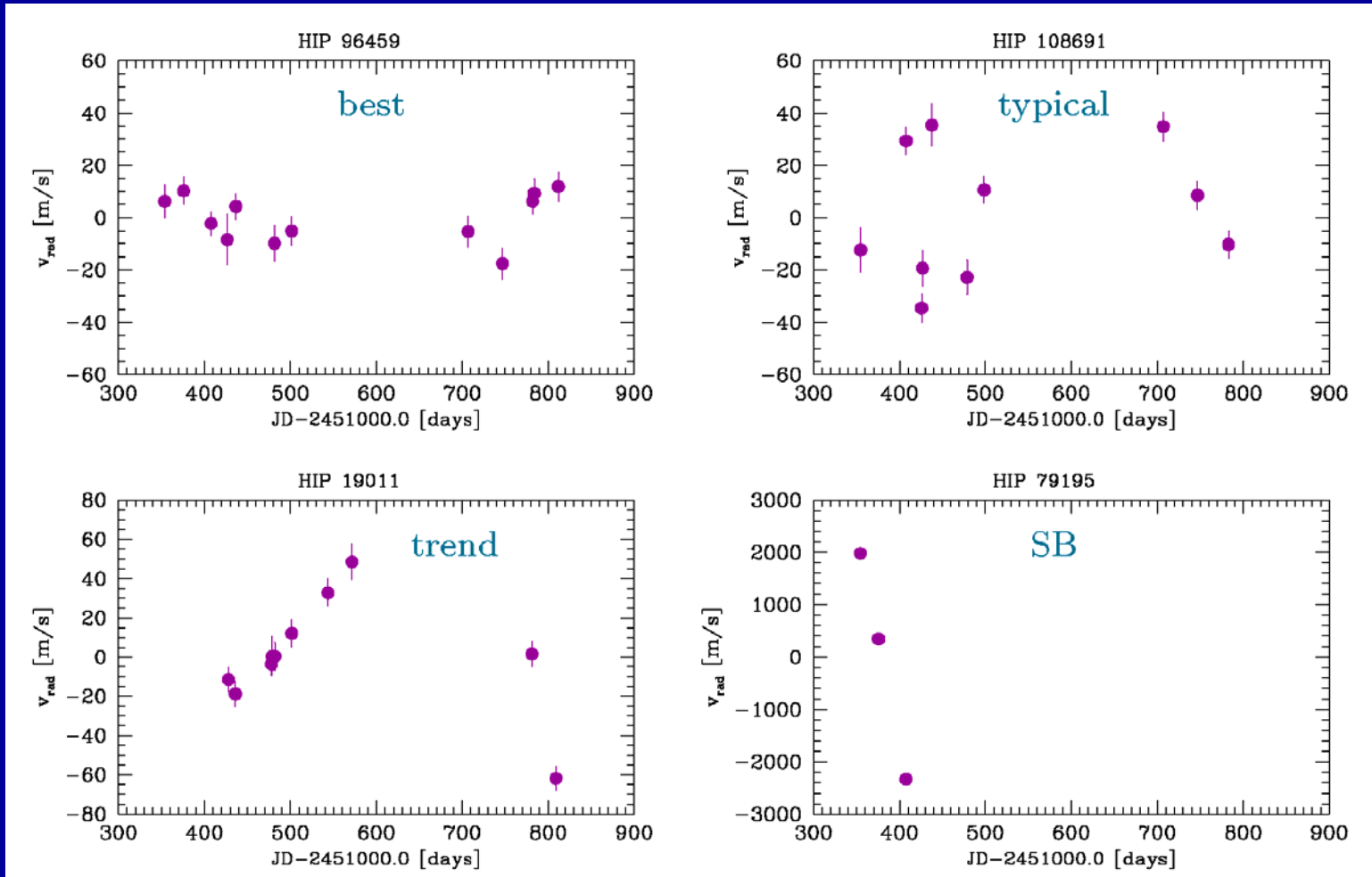
Iodine Template

Star Template

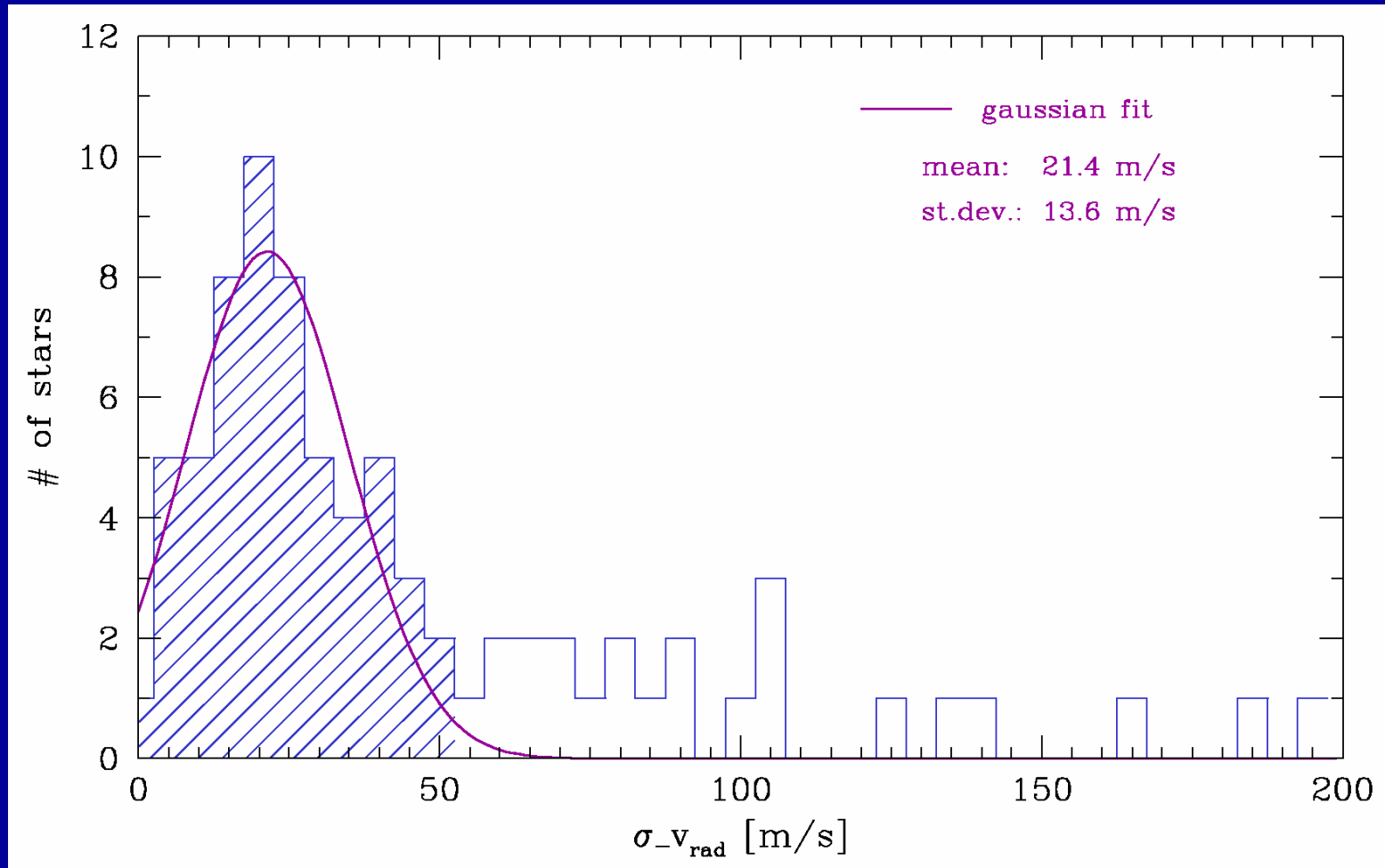
Data with Model

10× Residuals

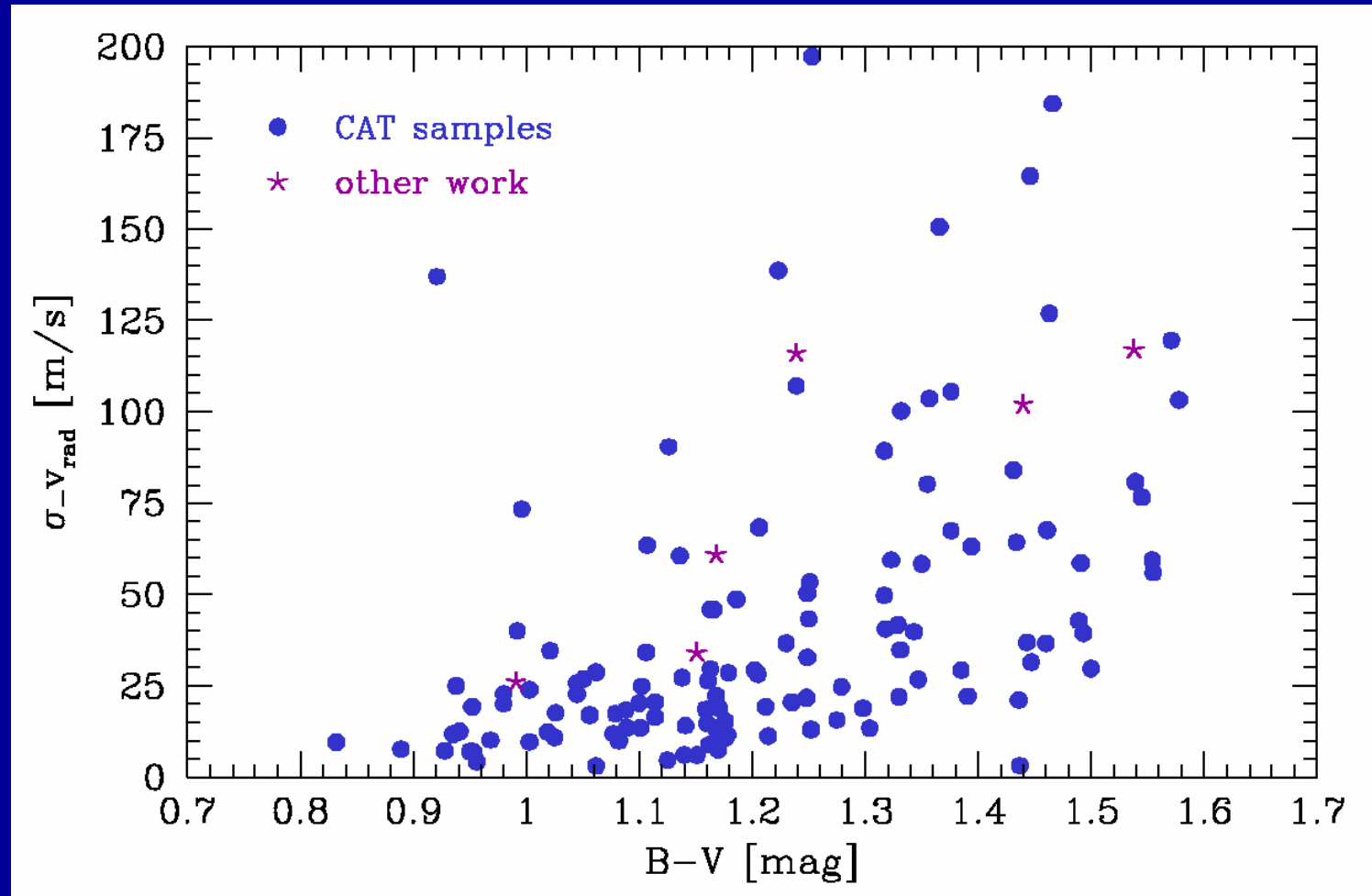
# Early Results from Lick HES RV Measurements of K Giants



# Histogram of K Giant Radial Velocity Scatter



# Radial Velocity Scatter is Correlated with Color

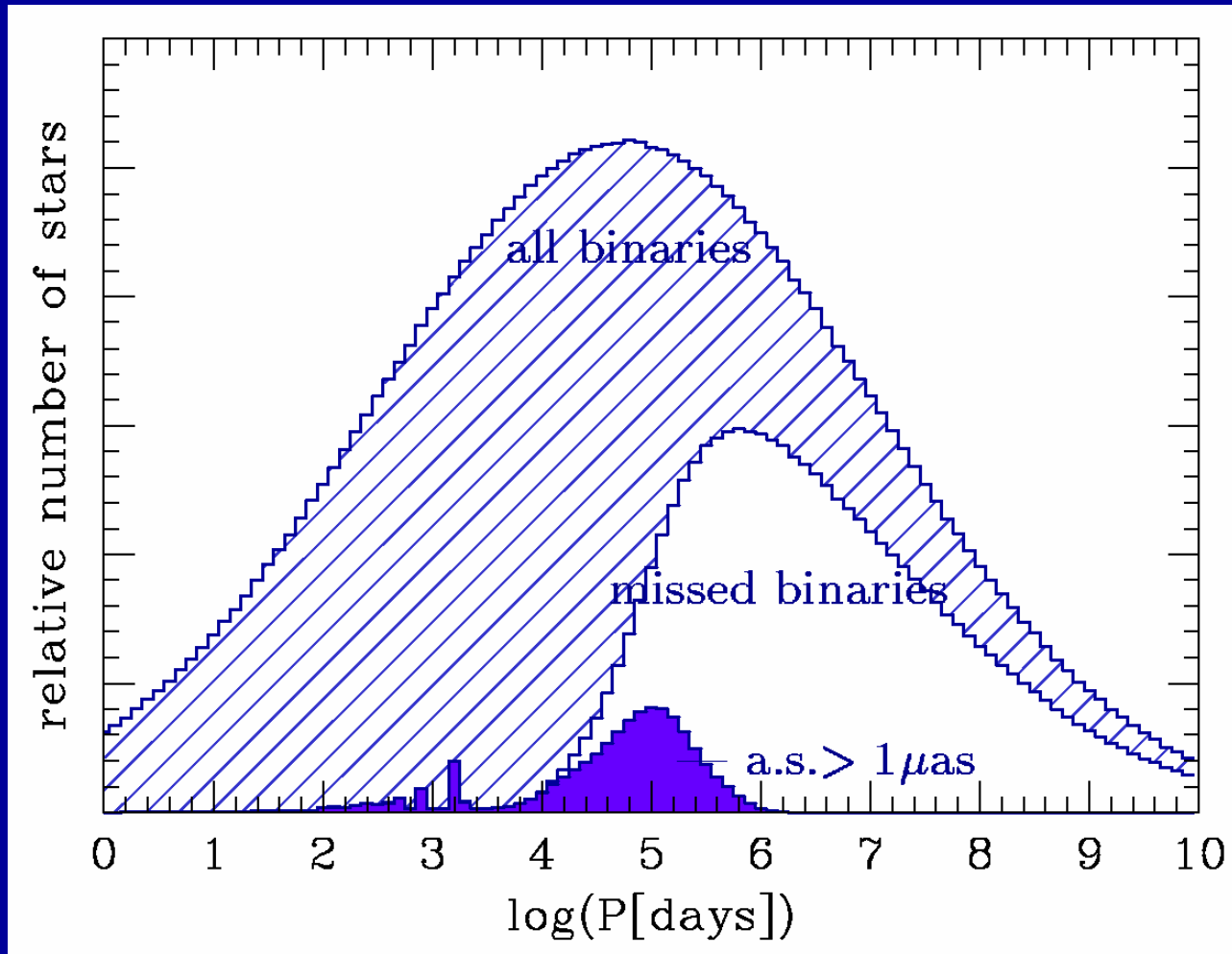




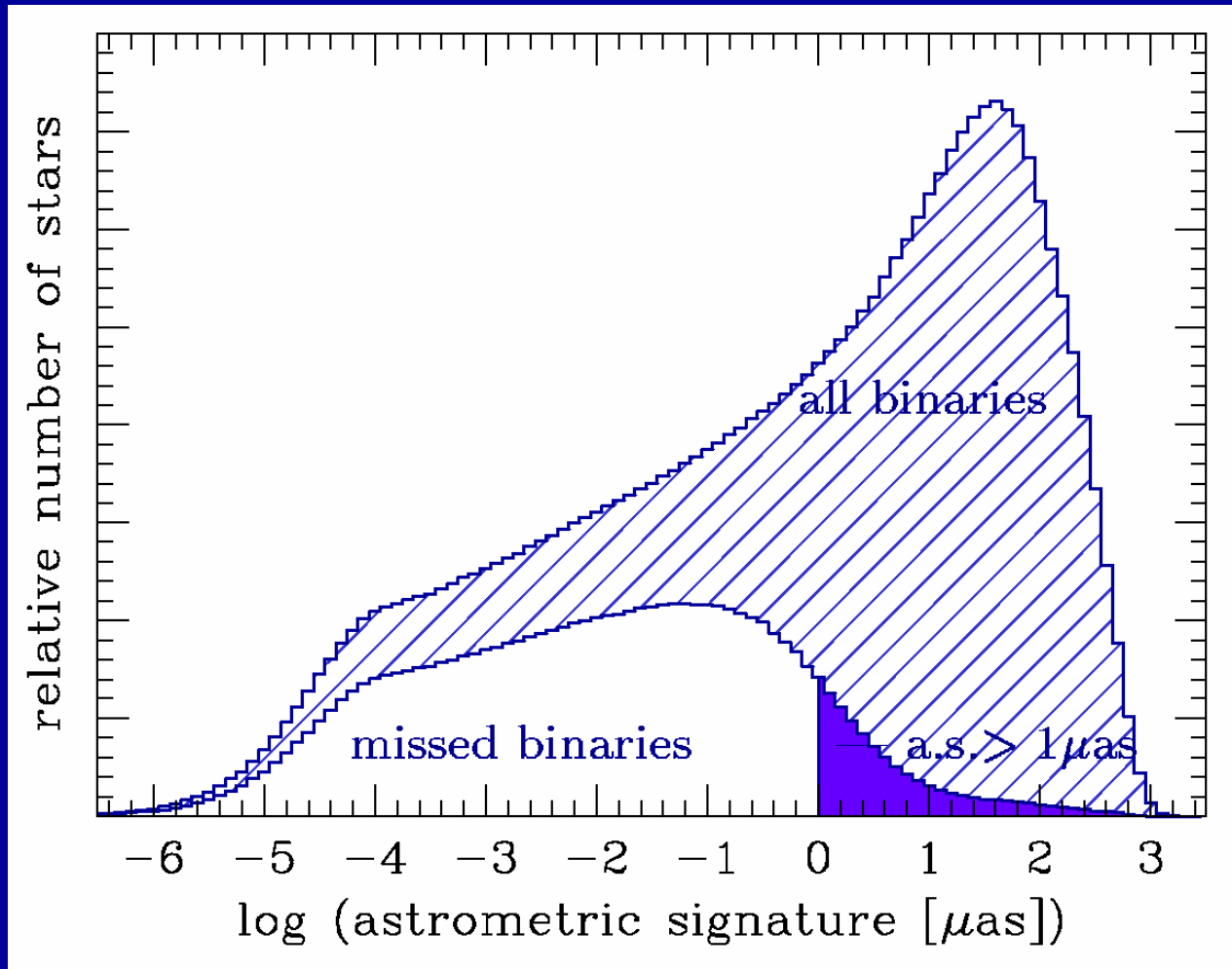
# SIM Grid Star Simulations

- Assume realistic binary population
  - Distribution of  $P$  and  $e$  from RV and AO work
- Assign random orientation of orbits and epochs
- Simulate RV survey with small number of observations per star
- Use  $\chi^2$  criterion to identify likely binaries
  - Lower threshold: reject some single stars
  - Higher threshold: let some binaries pass

# Binaries not Detected in Radial Velocity Survey



# Astrometric Signature of Missed Binaries

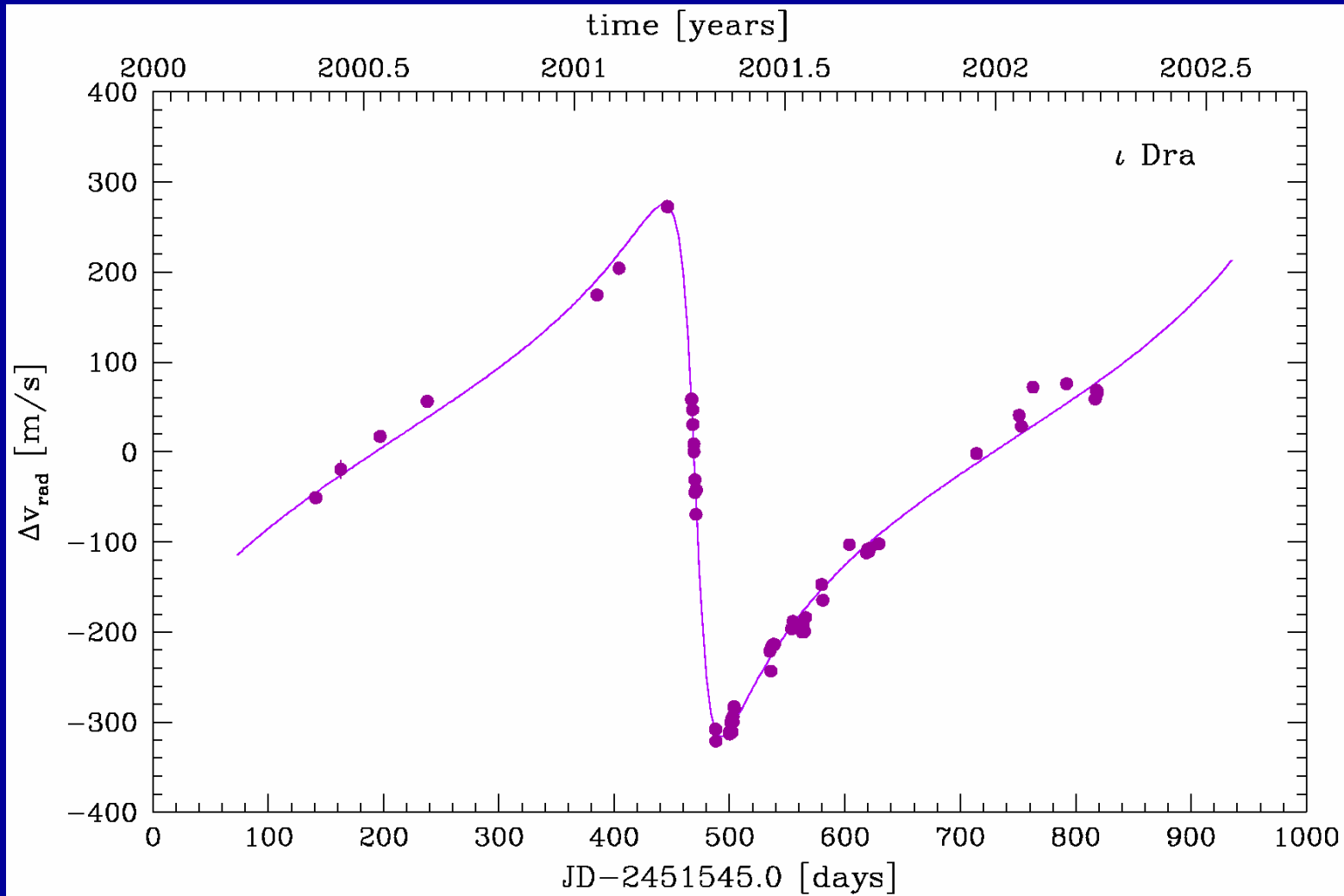




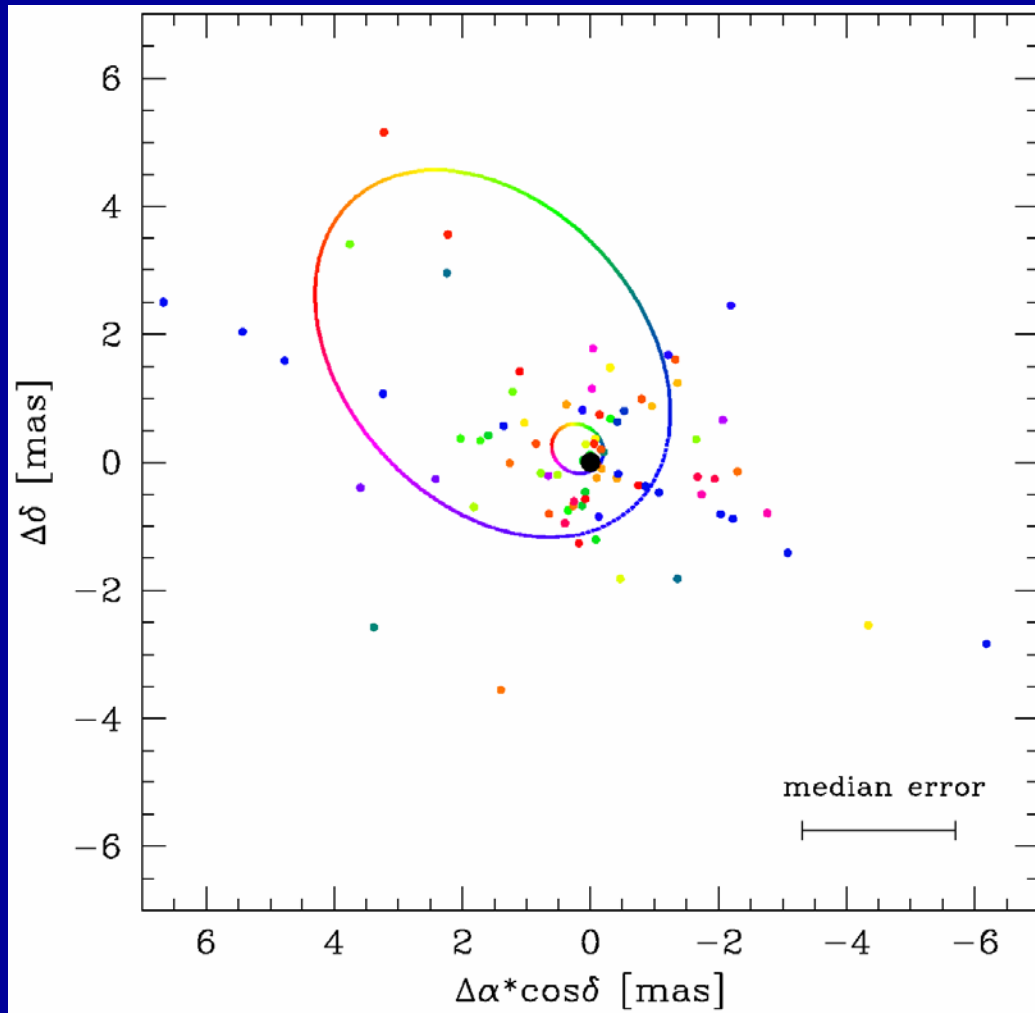
# Conclusions for SIM Grid

- Many K giant are sufficiently stable to allow efficient radial velocity vetting
- Survey precision should be  $\sim 20\text{m/s}$
- Most efficient survey strategy is two widely spaced observations per star
- $\chi^2$  criterion should be set to reject  $\sim 30\%$  of stars
- Remaining contamination by binaries with signatures  $> 1\mu\text{as}$  will be small ( $\sim 3\%$ )

# A Planet Orbiting the Giant Star $\iota$ Draconis



# HIPPARCOS Data of $\iota$ Dra with $80 M_{\text{Jup}}$ Signal

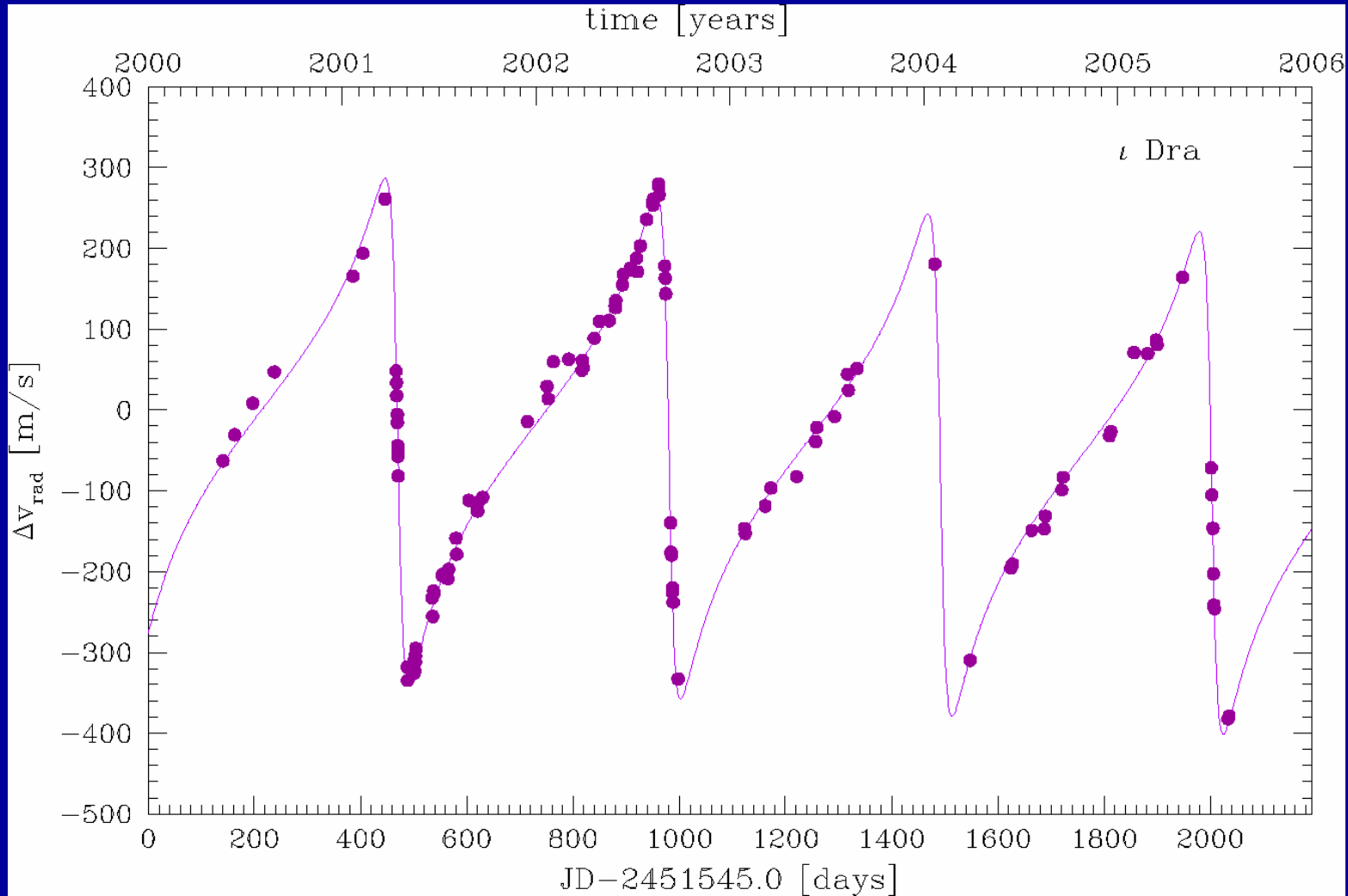




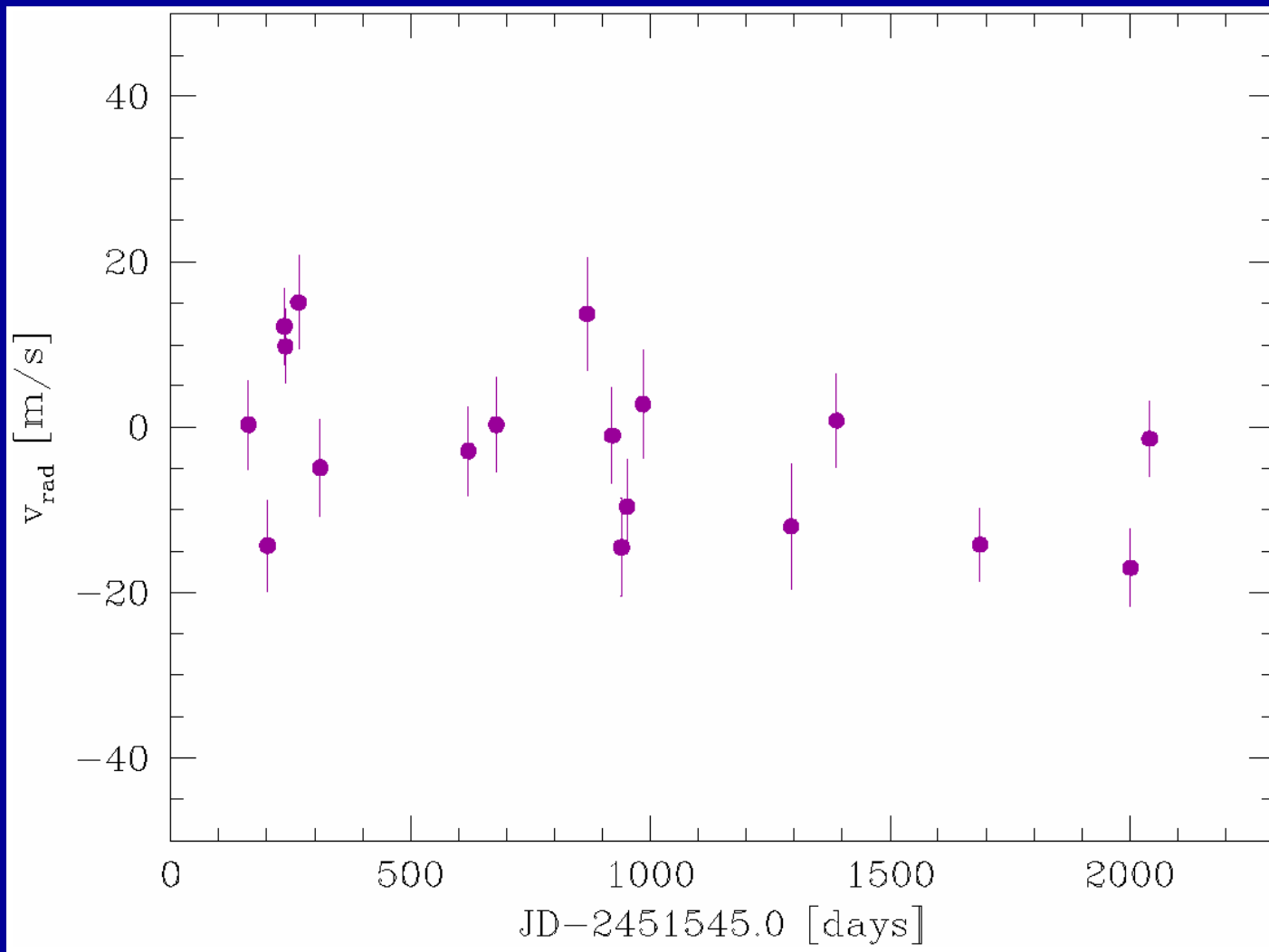
# Parameters of $\iota$ Dra

- $P = 536 \pm 5$  days
- $e = 0.70 \pm 0.01$
- $m \sin i = 8.9 M_{\text{Jup}}$
- $3\sigma$  upper mass limit  $45 M_{\text{Jup}}$  (from Hipparcos)

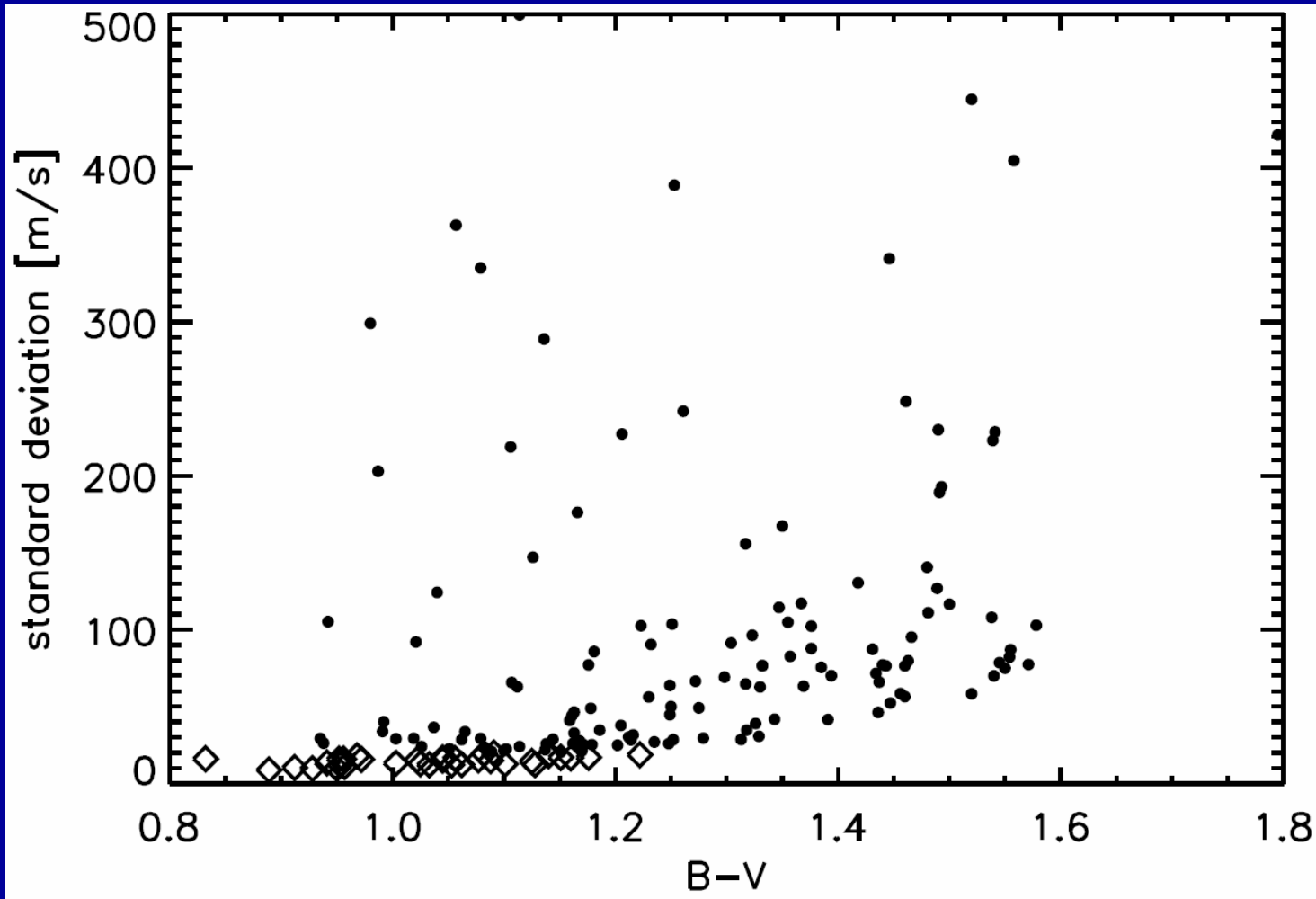
# $\iota$ Dra Four Years Later



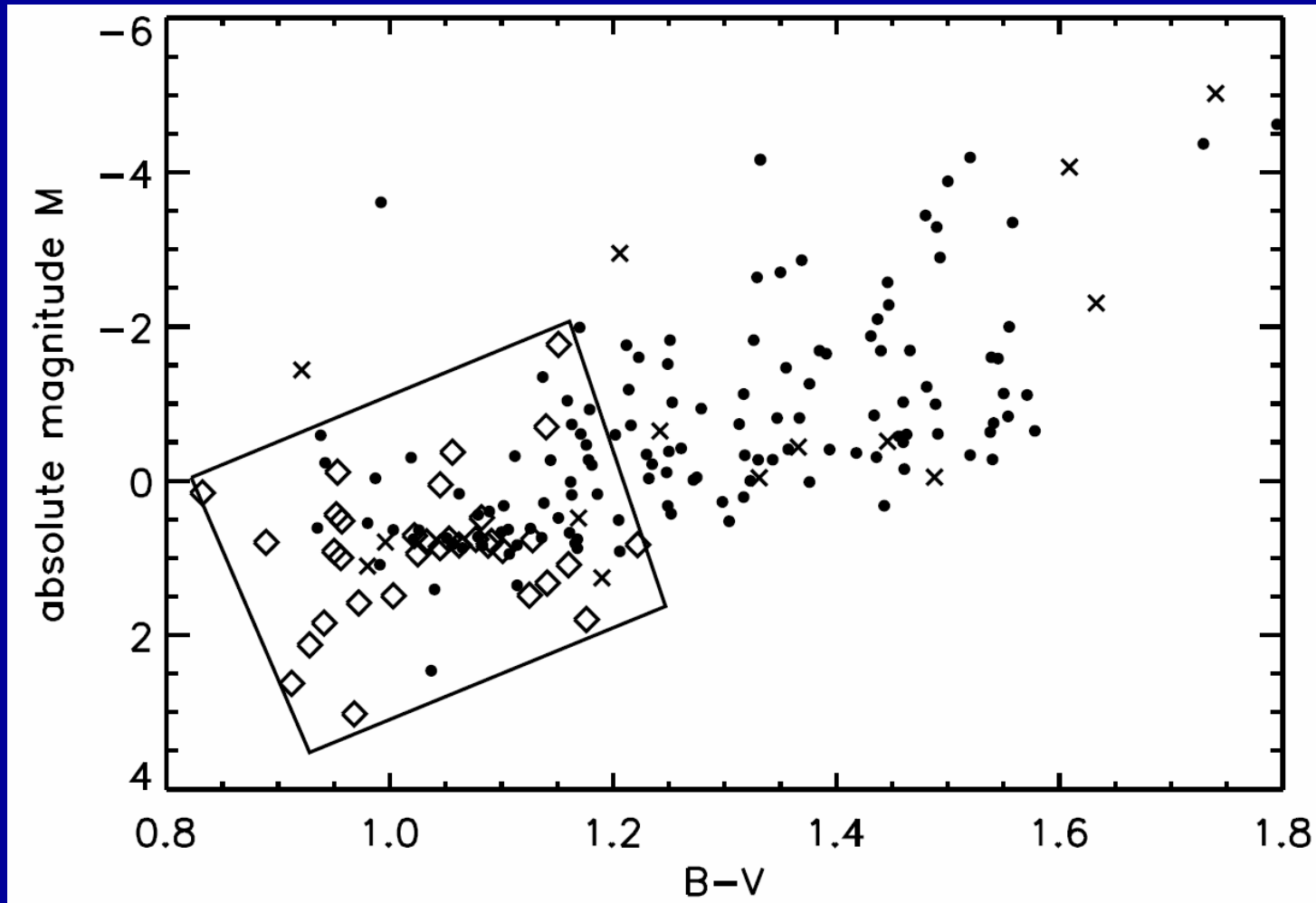
# A Star with Nearly Stable Radial Velocity



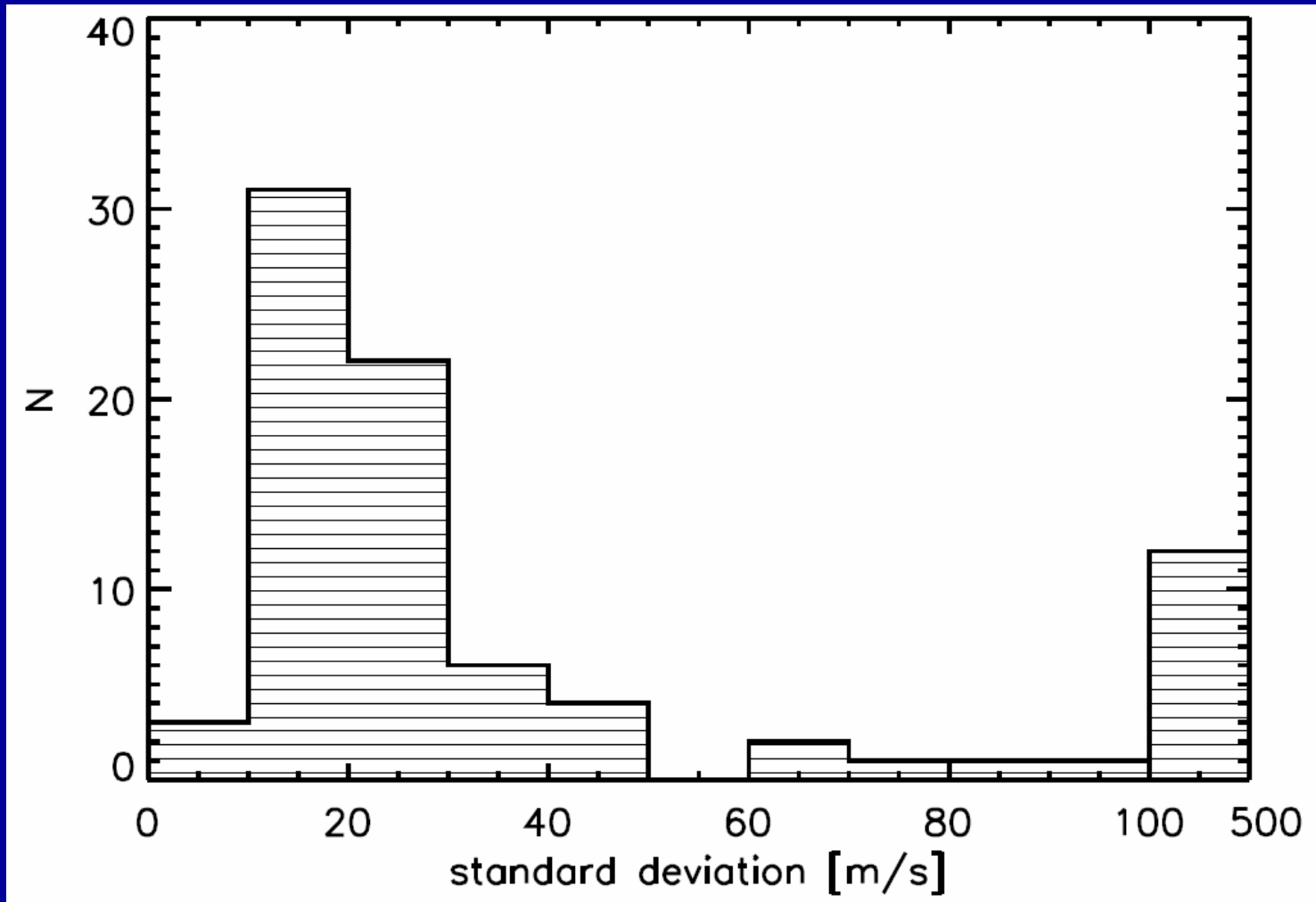
# Radial Velocity RMS versus Stellar Color



# Color-Magnitude Diagram of Sample K Giants



# Radial Velocity RMS Histogram for “Blue” K Giants

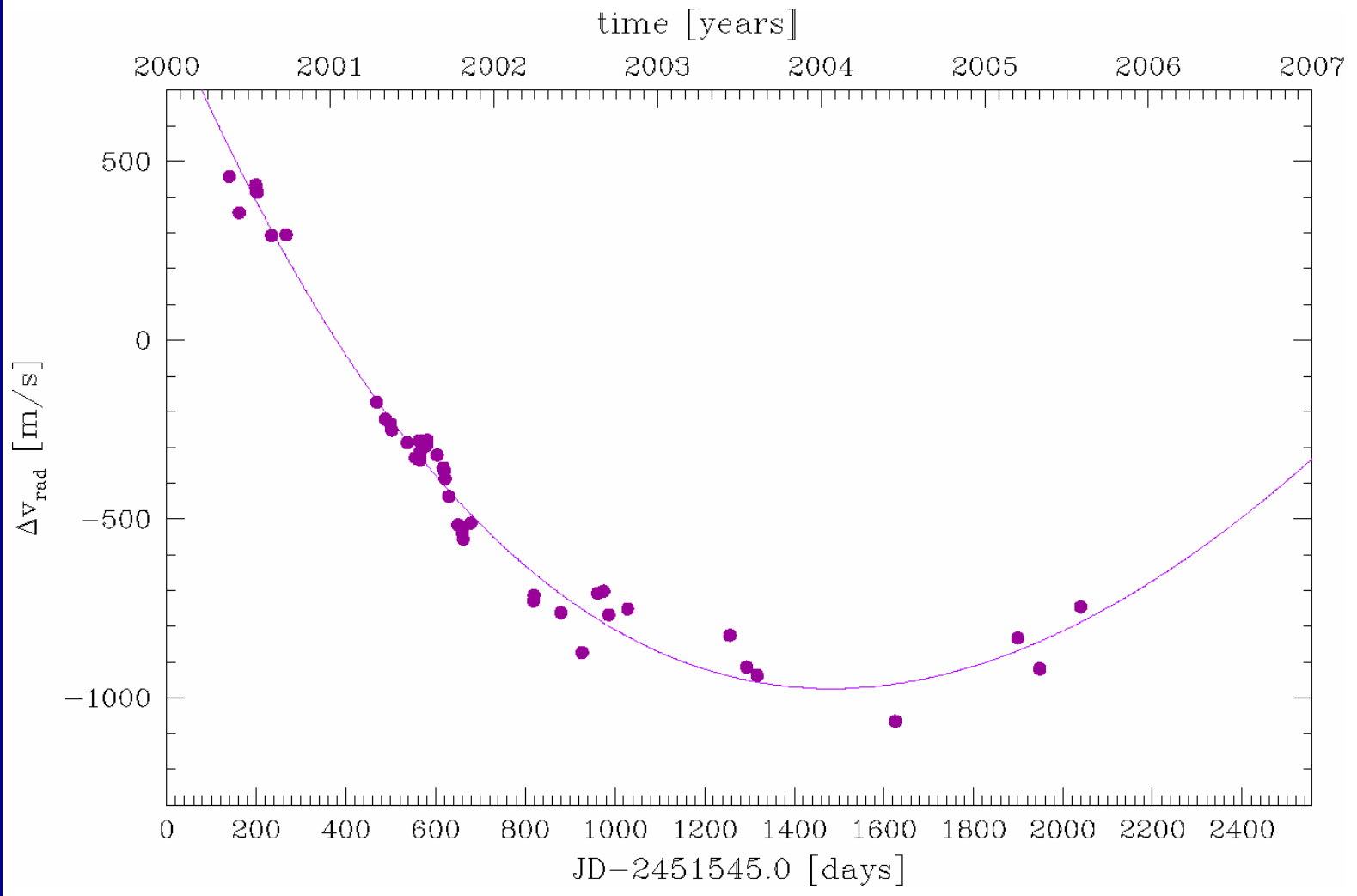


# Results on Stars with RV Variations Less Than 20m/s



- Essentially all observed stars are variable on the few m/s level
  - Likely due to undersampled p-mode oscillations
  - Consistent with detection of solar-type oscillations in two K giants (Barban et al. 2004)
- All “stable” stars to left of coronal dividing line
  - Separation of hot coronae from cool winds
  - Consistent with photometric stability

# A Typical Binary Star

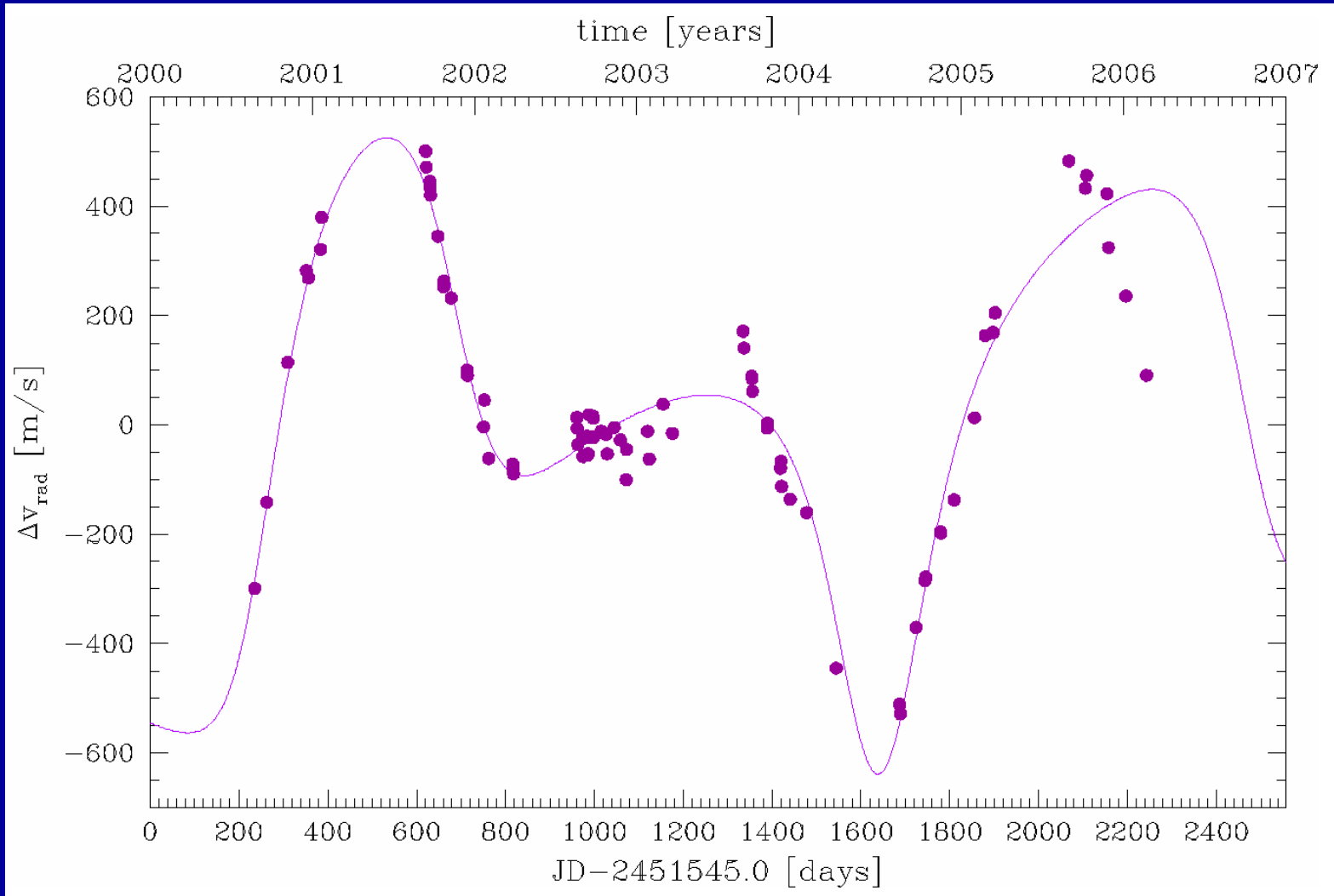




# Results on Binaries

- Sample selected against known binaries
  - A few slipped in nonetheless
- Several previously unknown binaries found
- Good orbital solutions frequently take many years

# A Possible Non-Hierarchical Triple System

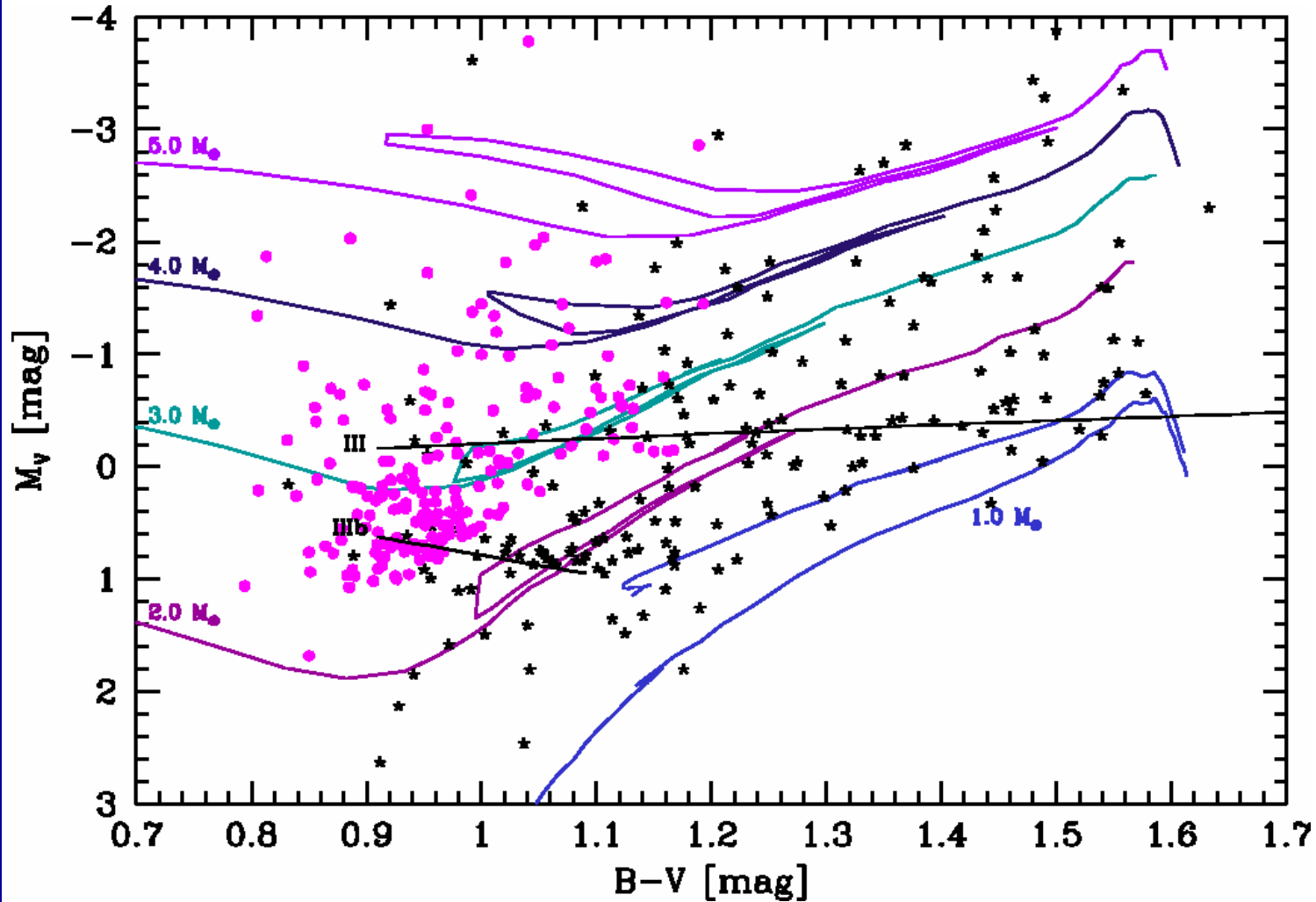


# An Opportunity to Look for Planets around Intermediate-Mass Stars



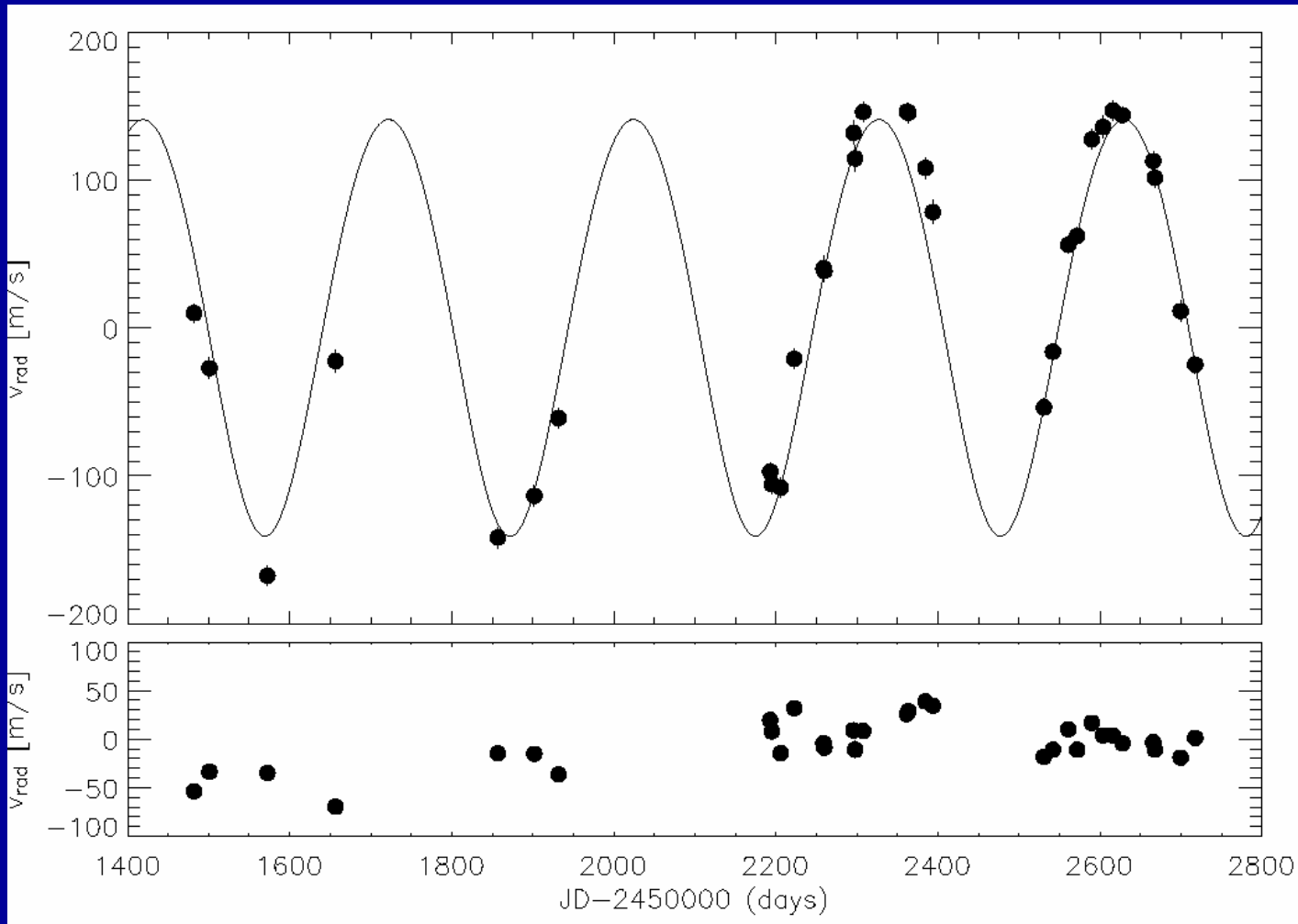
- Typical target star masses higher than in G star surveys
- Sample enlarged to cover range  $2...5 M_{\odot}$
- But more difficult than G star surveys
  - Stellar masses not known well
  - More noise from p-mode oscillations
  - Discrimination against photospheric effects
  - Sorry, no “Hot Jupiters”

# Color-Magnitude Diagram of Enlarged Sample



# Example of Planet Fit

( $m \sin i = 6.5 M_J$ )





# Difficulties with Interpretation

- A couple dozen stars with nearly sinusoidal RV variations
- Additional scatter could be due to intrinsic variability
- Need to identify mechanism for variability
  - Companions
  - Oscillations
  - Starspots



# The Starspot Hypothesis

- + Periods of several hundred days similar to rotation period
- No photometric variations seen by HIPPARCOS
- Coherence over a fair number of rotations
- Single spot or spot group cannot produce sinusoidal variation
  - RV curve is flat when spot is on back side



# The Oscillation Hypothesis

- + g-modes could give plausible periods
- + Could produce relatively large RV variations without photometric variability
- Excitation mechanism unclear
- Sinusoidal variations would have to be due to one single mode



# The Companion Hypothesis

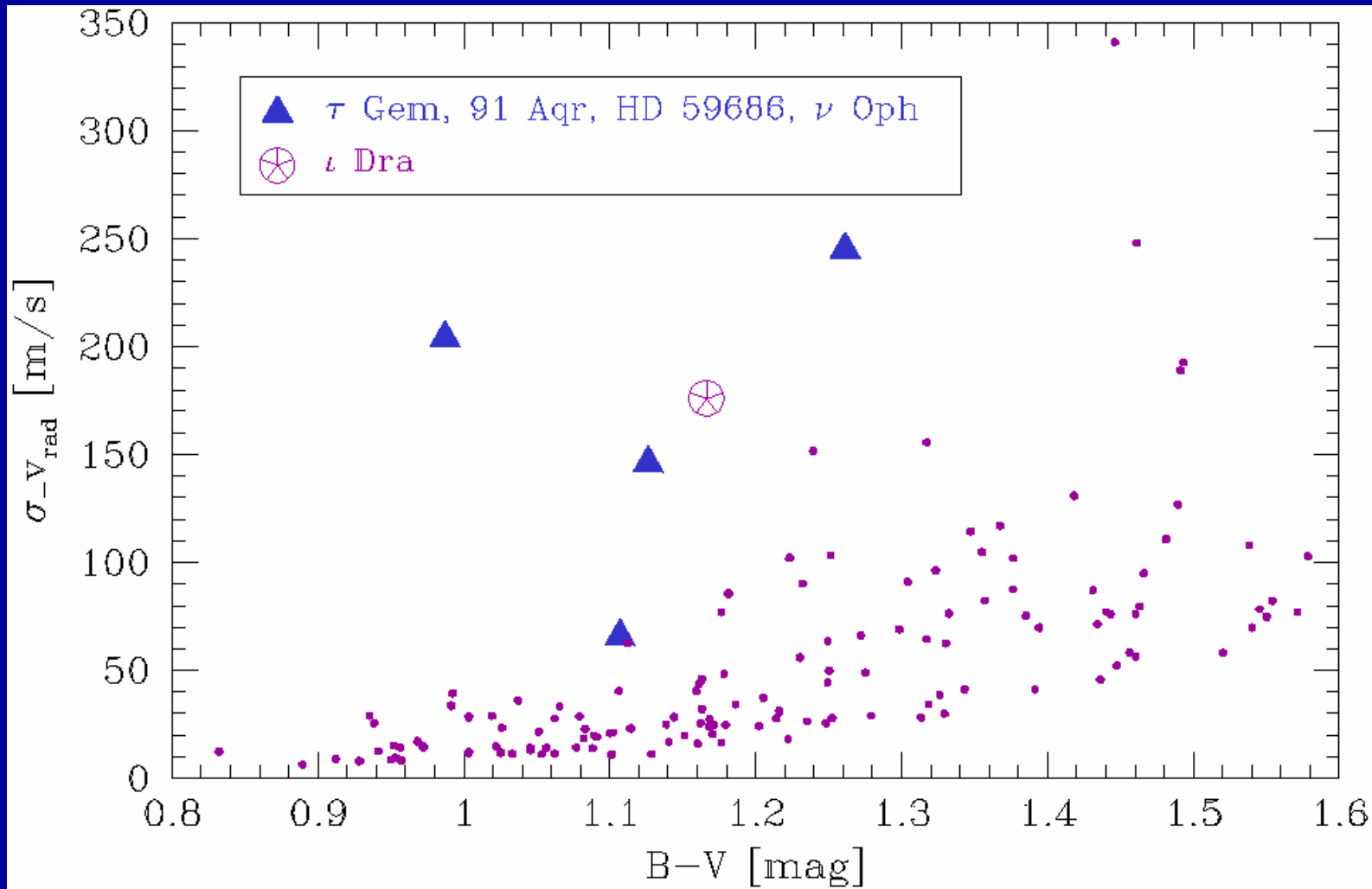
- + Circular orbits give sinusoidal variations naturally
- + Coherence over long time explained naturally
- + Multiple systems can explain additional trends
- ± Implies population of massive planets on circular orbits not found around G dwarfs

# Ways to Distinguish between Hypotheses

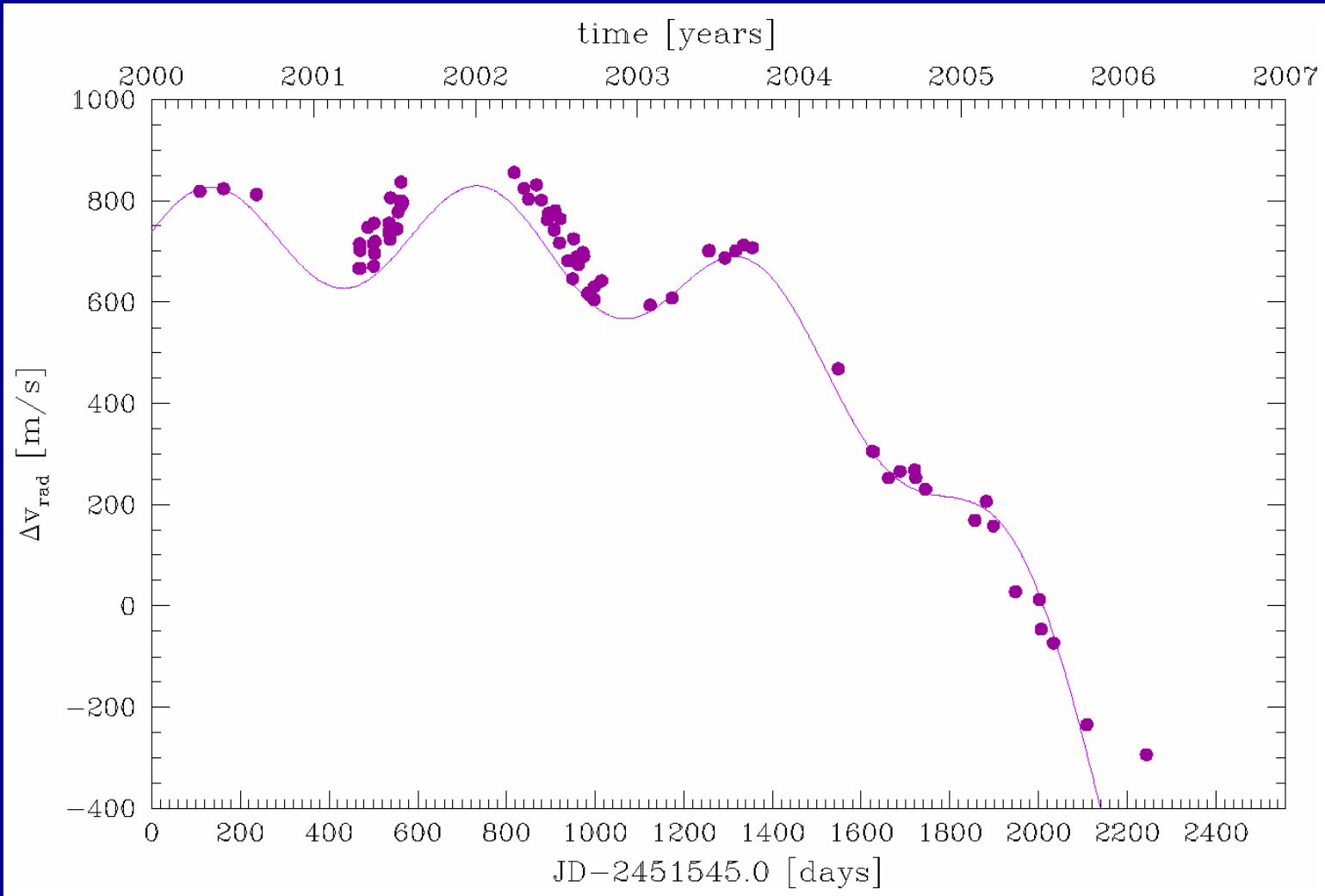


- Correlations with stellar parameters
  - Companions could be identified as outliers
- Analysis of line profiles
  - Companions → stable
  - Oscillations, spots → variable
  - Need quantitative predictions of variability
  - Data analysis and theory underway
- Keep observing ...

# Likely Planets have Unusually High Radial Velocity RMS



# The more Complicated Cases Need more Data





# Future Instrumentation Needs

- A small telescope ( $\sim 1\text{m}$ ) is sufficient (but larger telescopes are better)
- Need RV precision of a few m/s, perhaps 1m/s
- Long-term RV stability is crucial
- Weekly to monthly sampling for long-term variations
  - Single site is ok
- Hourly sampling or continuous observing for Solar-type oscillations
  - Multi-site is highly desirable

# Position Available!

- Professorial Position at Heidelberg University
- W3 = full professor
- Located at Landessternwarte Königstuhl
- Observational astronomy strongly preferred
- See me for details if interested

