Mapping the Realm of Hot Jupiters

Bun'ei Sato（OAO/NAOJ）, Shigeru Ida（Titech）,
Eri Toyota（Kobe Univ.）, Masashi Omiya（Tokai Univ.）,
Debra Fischer（SFSU）,
Greg Laughlin（UC Santa Cruz）,
Paul Butler（Carnegie Inst. of Washington）,
Geoff Marcy（UC Berkeley）

Mapping the Realm of Hot Jupiters

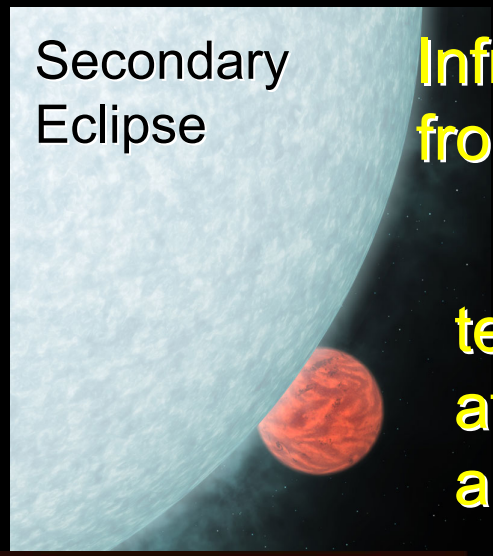
- Doppler search for Hot Jupiters with Subaru/HDS, Keck, Magellan（N2K consortium）
  - Hunting “transiting” planets
  - Since 2004, 7 planets were discovered from N2K
  - 1 transiting planet（HD149026b）from Subaru
  - ~45 more planet-candidates not yet confirmed
- Subaru intensive program
  - S06A（10 nights）, S06B（10 nights）
  - Determine orbital parameters of planet-candidates making use of long time-baseline
  - New planets confirmed

Hot Jupiters

- Giant planets in short-period orbits
  - P＜14d、$M_p \sin i$＞0.5M_J: ~20% of exoplanets
- High-probability transit candidates
  - information about planet itself（radius, internal structure, atmosphere, etc.）
- Tracers of multi-planet systems
  - resonant configuration
  - orbital evolution of planetary systems
- Test case of planet formation theory
  - migration, tidal circularization,,,

Transiting Planets

Provide information on planet itself which can't be obtained from Doppler observations



Infrared emission from planets

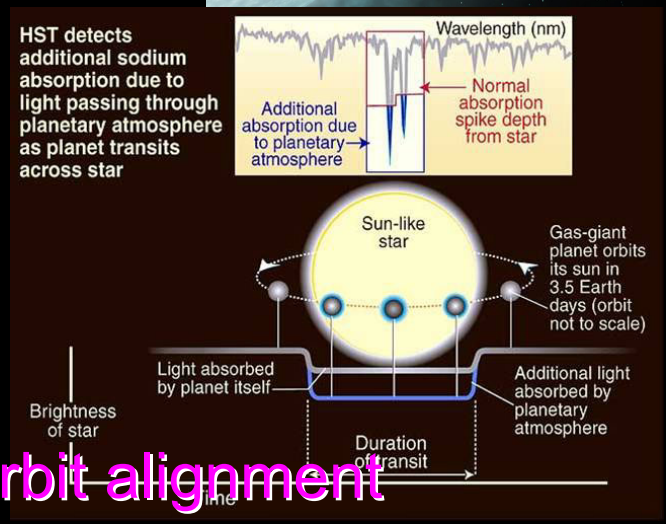
⇩

temperature, atmosphere, albedo,,,

Planetary radius

⇩

density, internal structure (w/ or w/o solid core)



Transmission spectroscopy

⇩

elements in atmosphere

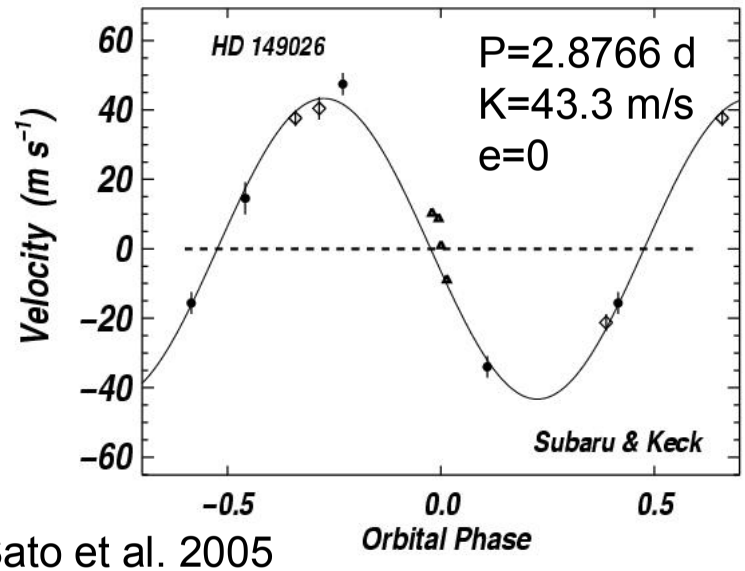
Rossiter effect ⇨ spin-orbit alignment

HD 149026

Transit planet from Subaru, Keck, Fairborn（V=8.2, G0IV）

- $M_p \sin i = 0.36 \pm 0.03\ M_{JUP}$ → 1.2 M_{SAT}
- $R_p = 0.725 \pm 0.05\ R_{JUP}$ → 0.86 R_{SAT}
  （$i = 85.3 \pm 1.0°$）

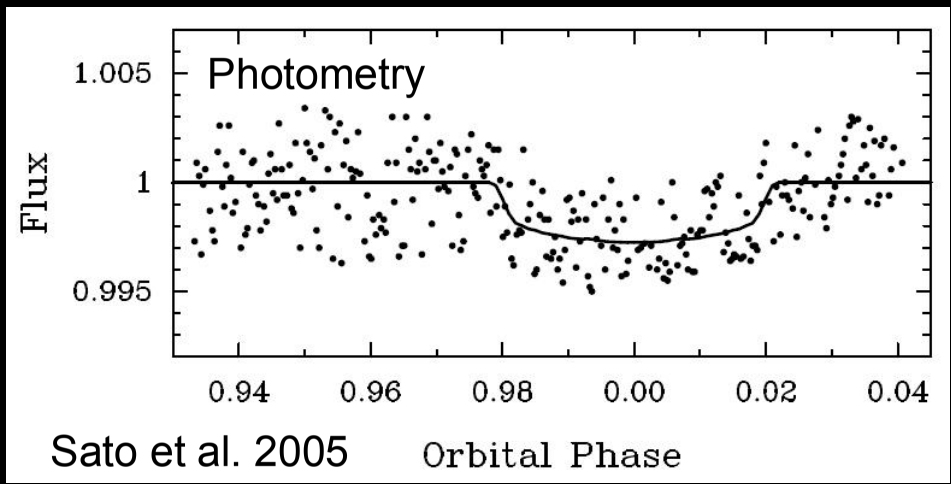
→ **$70 M_E$ solid core**



Sato et al. 2005

Support core-accretion scenario as planet formation mechanism

However, the origin of such a huge core is still unknown



Sato et al. 2005

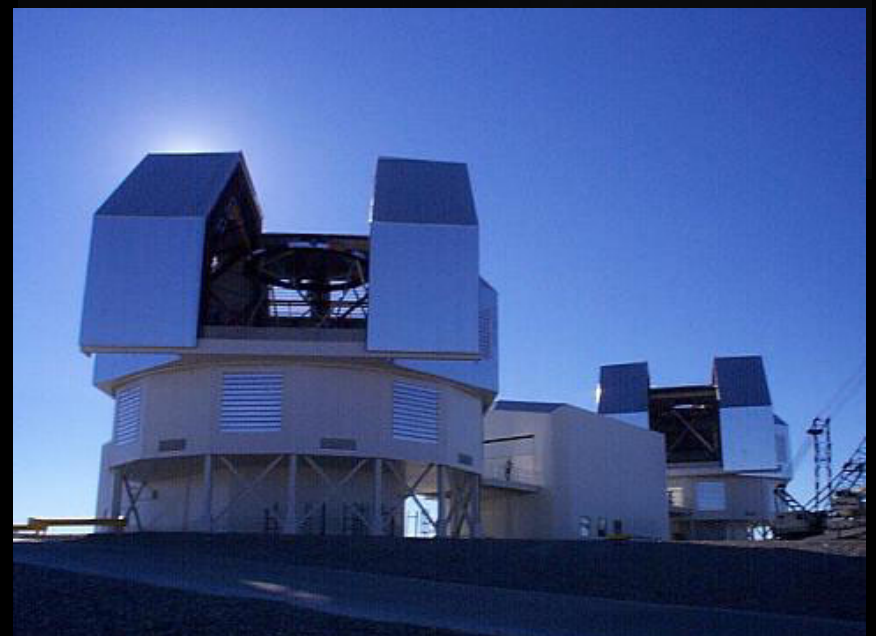
Key:
Detection of transiting planets in bright stars (V<10) for precise follow-up observations

- HD209458(V=7.7), HD149026(V=8.2), HD189733 (V=7.7), HAT-P-1(V=10)
- Transit systems from photometric survey (OGLE, TrES, WASP,,) are too faint (V=14-16) for Doppler follow-up
- Small transit depth of HD149026 would have been missed by current transit survey. Precise ephemeris is crucial to detect such a small variation.

"Doppler survey → Hot Jupiter → Transit"
is the most efficient at present

N2K Consortium

- Keck（USA）、Magellan（Chile）、Subaru（Japan）
- Search for Hot Jupiters around next 2000 solar-type stars
- Aiming to detect 60 Hot Jupiters and 5～6 transiting planets
- Precise Doppler measurement using Iodine absorption cell
- Current precision with HDS
  ~3 m/s（short-term）
  ~10 m/s（long-term）



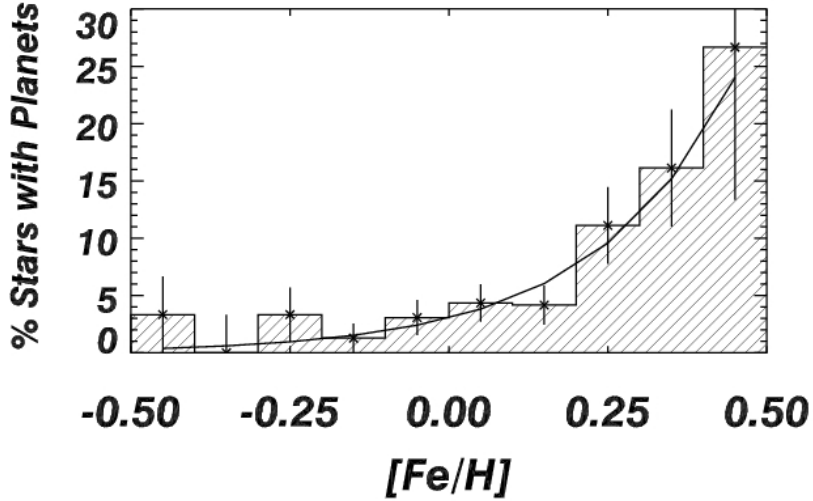
Group Members

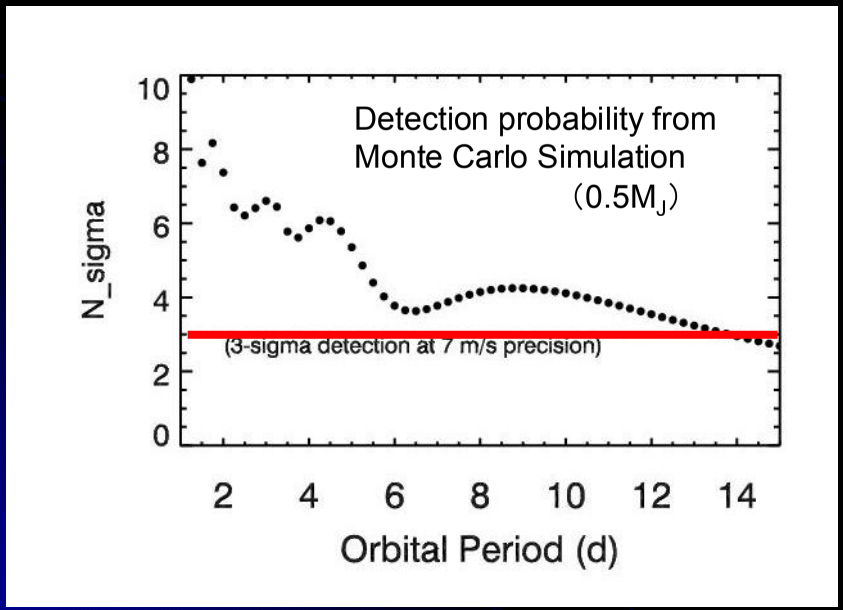
- Bun'ei Sato（PI）・・・Observation、Reduction、Analysis
- Shigeru Ida・・・Theory
- Eri Toyota, Masashi Omiya・・・Observation、Reduction、Analysis
- Debra Fischer（PI of N2K）・・・Observation、Analysis
- Greg Laughlin・・・Theory
- Paul Butler・・・Reduction、Analysis
- Geoff Marcy
- （Graduate students）

- Transit Network in Japan & USA
  - Greg Henry（USA）
  - Jun-ichi Watanabe（NAOJ）, Osamu Oshima（Kamogata High-School）, Shin-ichiro Ishiguma（Kobe Univ.）, et al.

Strategy

- Database of 14,000 stars
  - V＜10.5, d＜110 pc, FGK V,IV
  - metalliicty, activity, binary,,,
- High priority to metal-rich stars



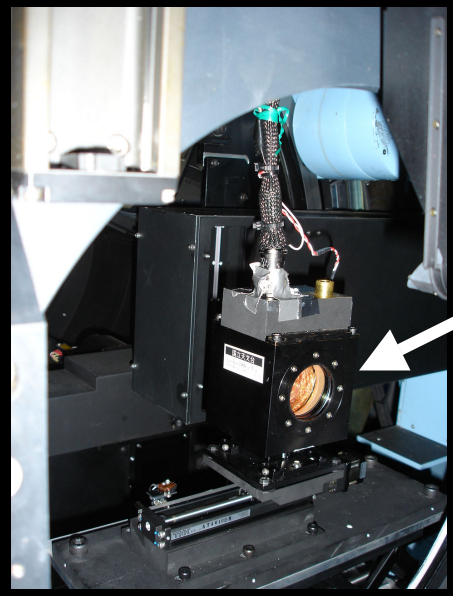


- 3＋1 nights observation
  - Identify candidates in 3 consecutive nights
    - RMS＞20 m/s → follow-up
    - RMS＜20 m/s → drop
  - Confirm candidates after 1 more night in 1 month later

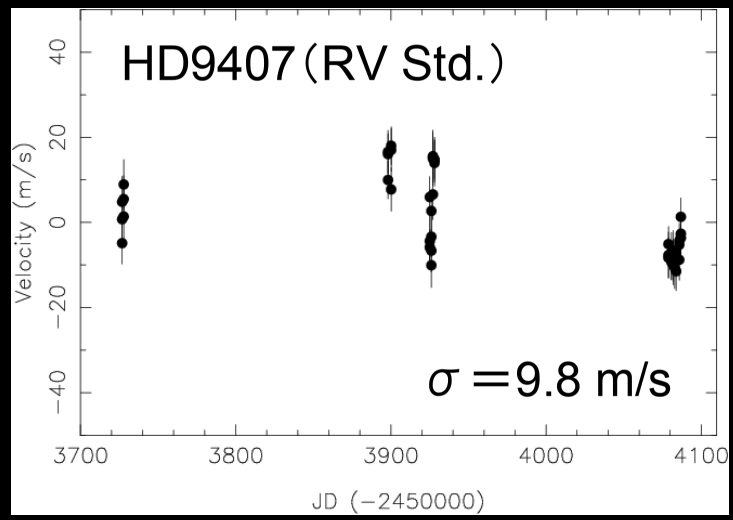
HDS Observation

- λ =3500-6100 Å
- R~45,000
- SN~150 for V~8 with 80s exp.
- RV precision using Iodine Cell
  - ~3 m/s（within the same run）
  - ~10 m/s（long-term）
  - systematic error between pre- and post-I_2 cell replacement (and pre- and post-earthquake)
- >100 stars/night

- Observations are now almost fully automated
  - observers only need change exposure time
  - great effort by Tajitsu-san



Iodine Cell in front of the slit of HDS（since Jun. 2006）



Status

- S04A（4 nights）
- S04B（4 nights）
- S05B（5 nights）

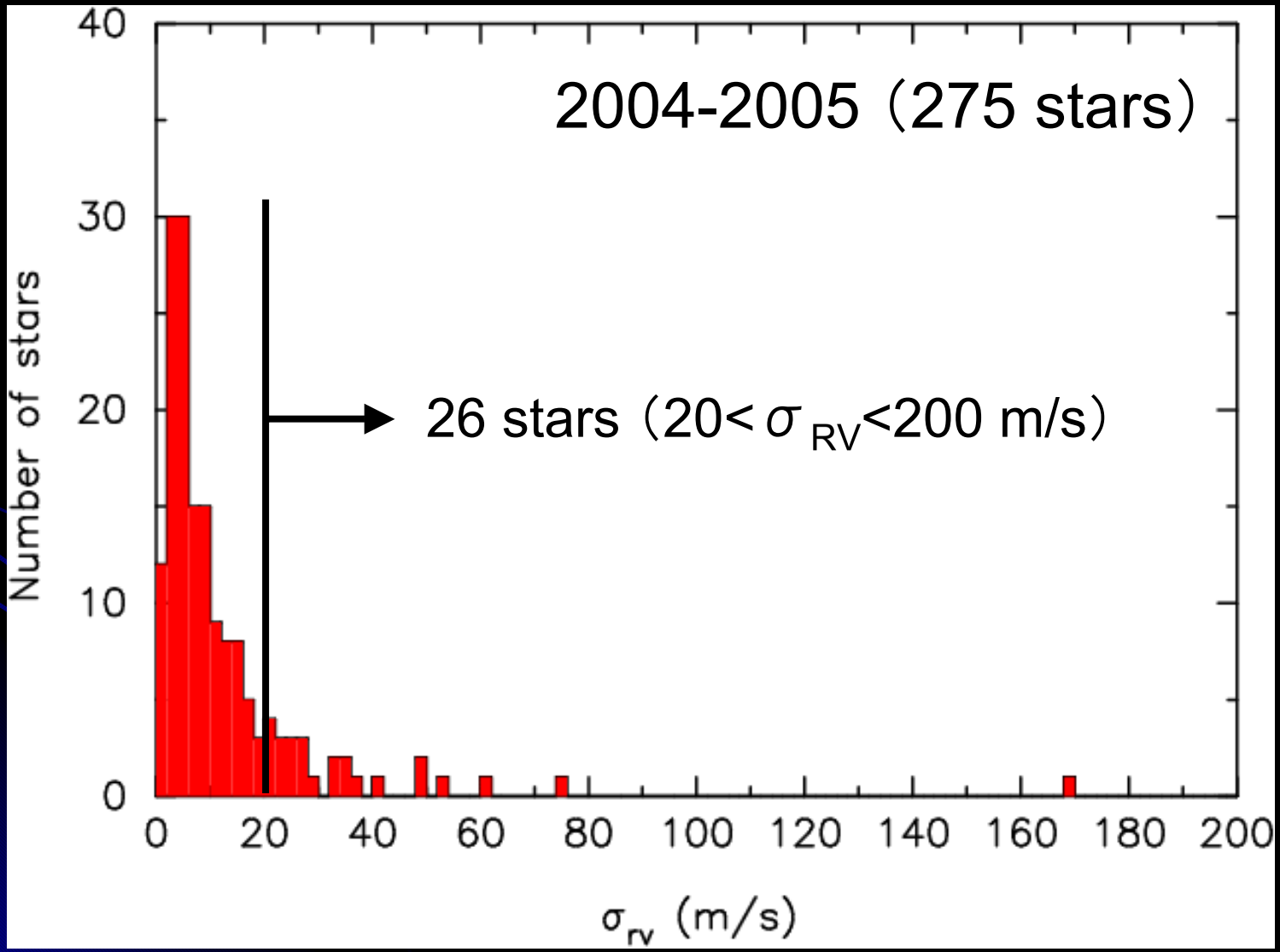
} find planet candidates

- S06A（10 nights）
  6（Jun.）+4（Jul.）
- S06B（10 nights）
  10（Dec.）

} confirm orbital parameters
（and find new planet candidates）

635 stars
>3 times: 512 stars
<2 times: 123 stars

RV Variations



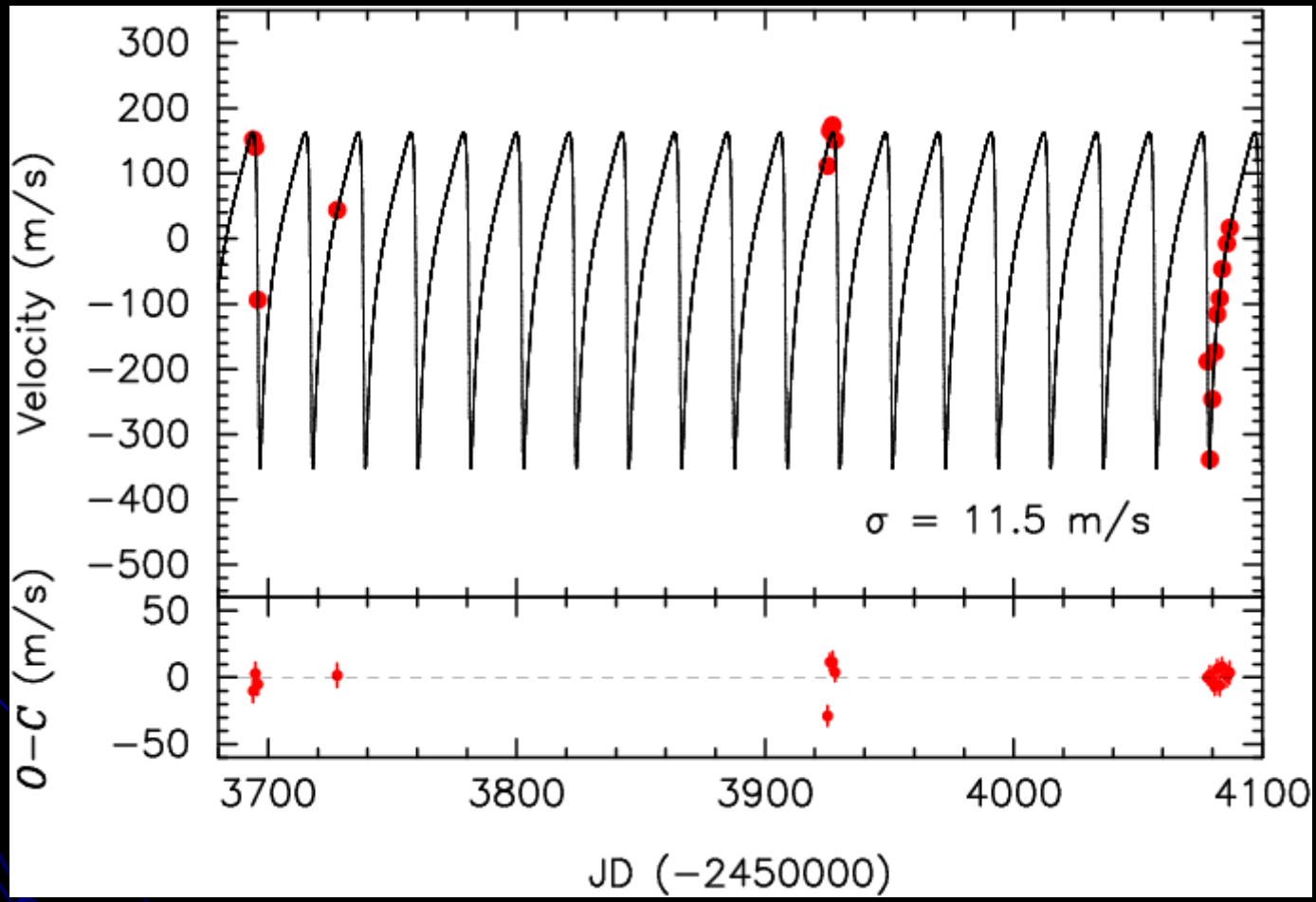
New Planet from Subaru

G5IV

P=21 d
K_1=259 m/s
e=0.68

$M_p \sin i$=2.9 M_J
a=0.16 AU

M_1=1.2$M_\odot$
[Fe/H]=0.22

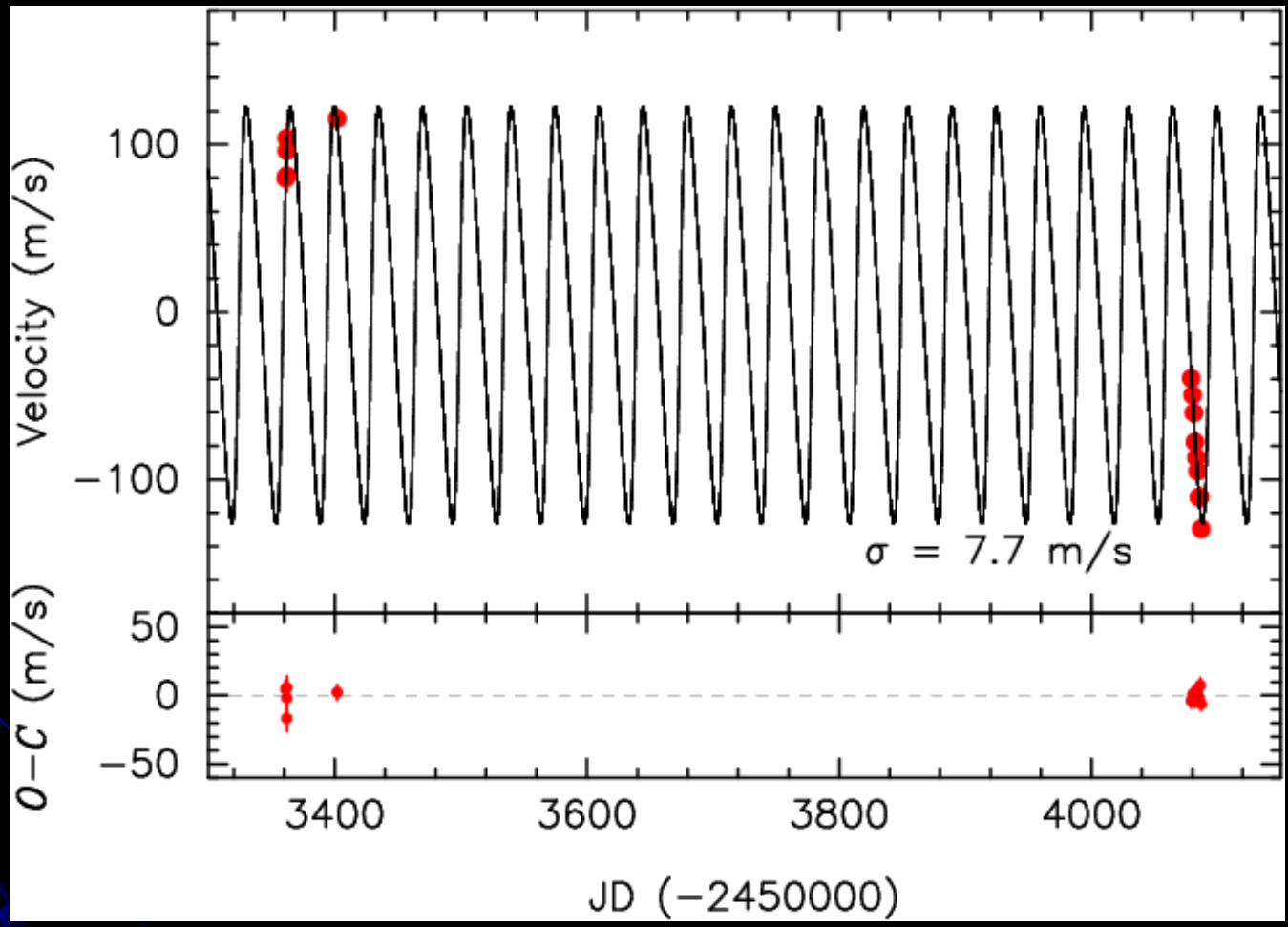


New Planet from Subaru

G5

P=35 d
K_1=125 m/s
e=0.3

$M_p$sini=1.9 M_J
a=0.2 AU
(M_1=1$M_\odot$)

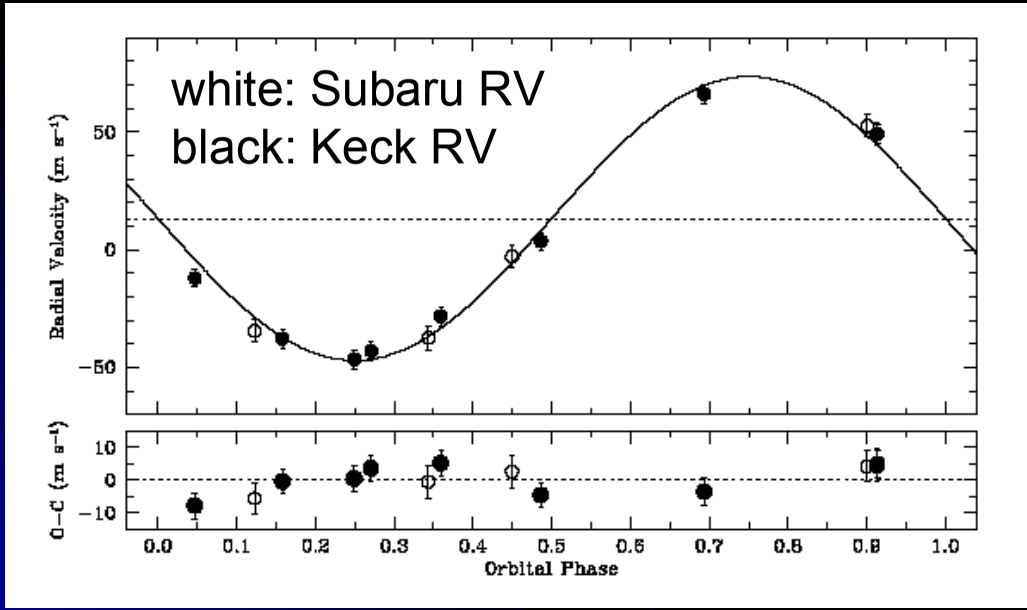


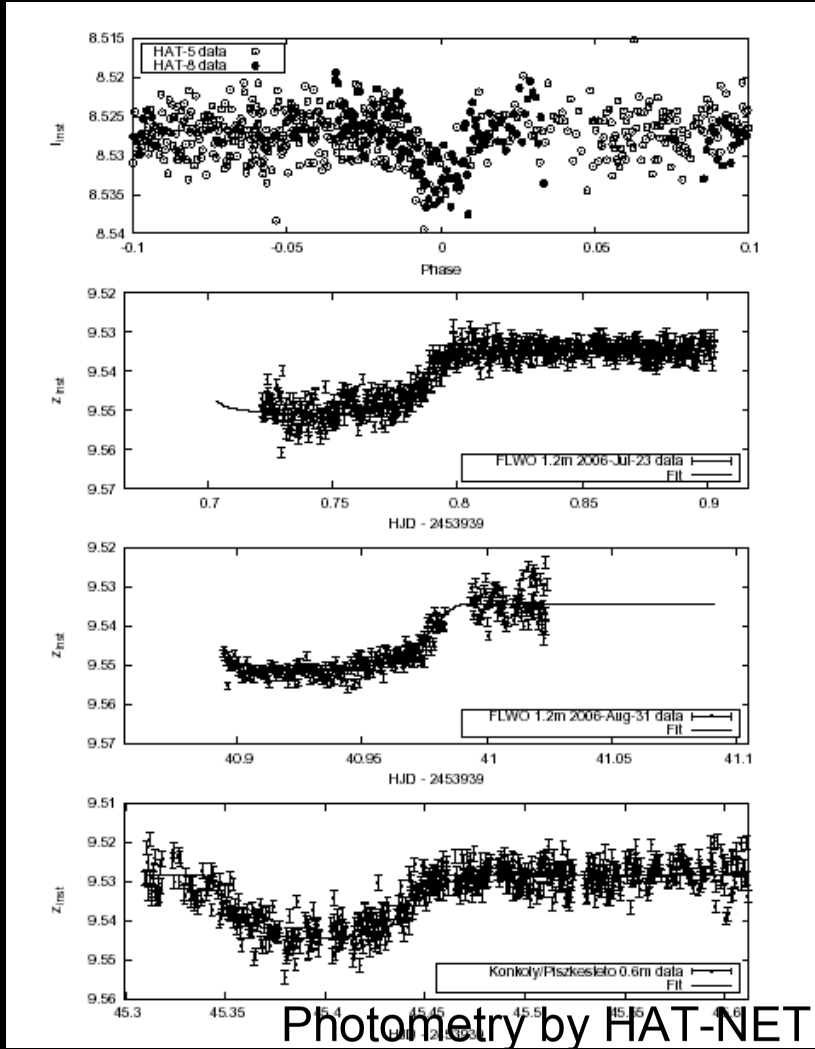
Confirm Transiting Planet

HAT-P-1 (Bakos et al. 2006)

P=4.46529 d
K_1=60.3 m/s
e=0.09
$M_p \sin i = 0.53 M_J$
$R_p = 1.36 R_J$

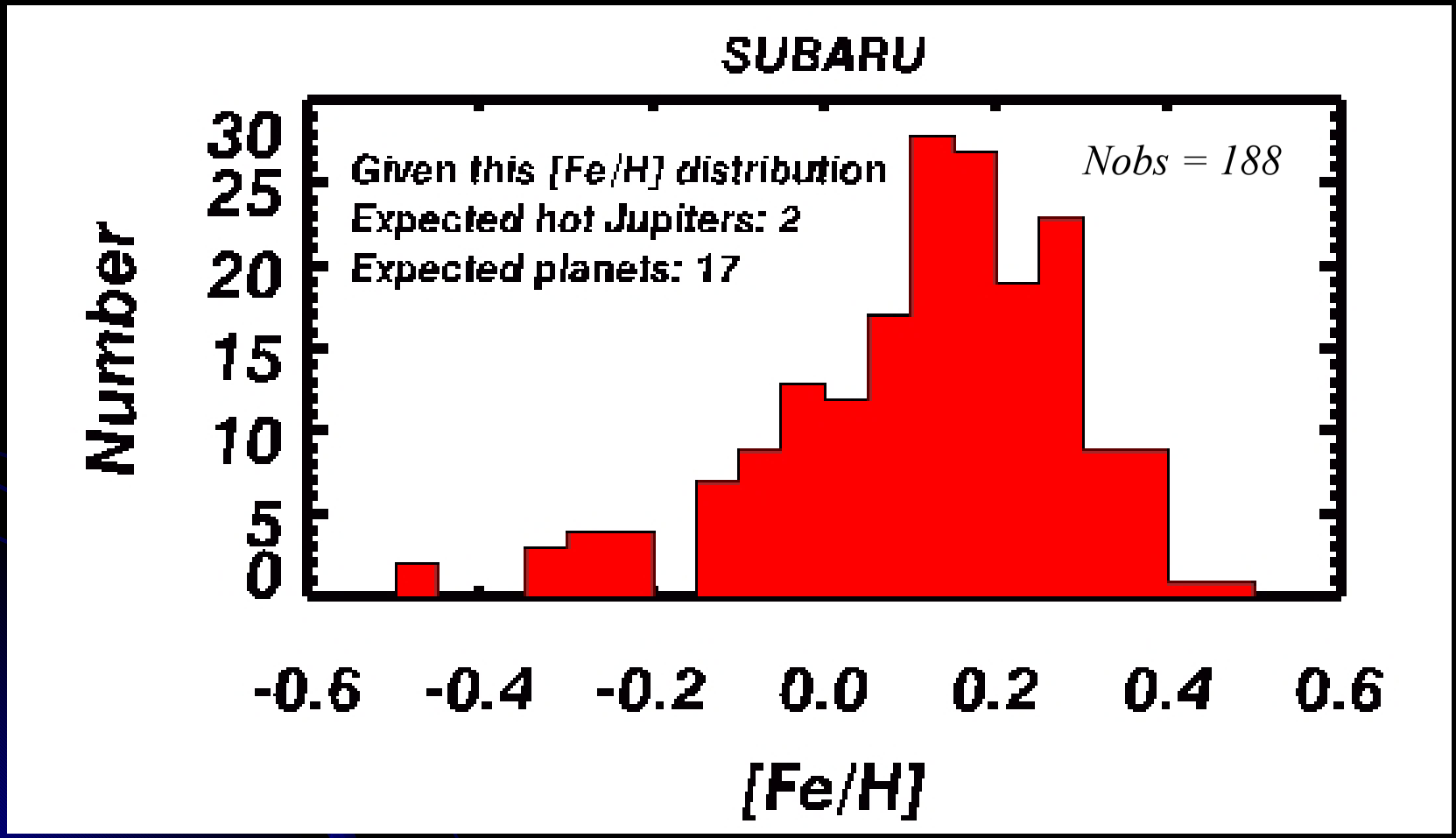
Secondary star in a binary system has a trasiting hot jupiter





Photometry by HAT-NET

Metallicity



Fischer et al.（in preparation）

Future Prospects

- Improve measurement precision
  - ~10 m/s systematic error between pre- and post-I_2 cell replacement (and pre- and post-earthquake)
  - improvement of software is required
- ~10 new planets will be discovered from the current data
- 10-20 planet candidates need additional follow-up observations
  - planet candidates with longer（and multiple）periods
  - new candidates found from intensive runs

Contribution to Community

- Large database of solar-type stars
  - 635 stars from Subaru（2000 stars from N2K）
  - metallicity, activity, binary, radial velocity,,,
- Targets of future mission
  - direct detection of outer planets
  - HJ with large eccentricity have outer planets ?（“sling-shot” scenario）

Merit of Queue-Observation

- Quick determination of short-period orbit
  - ex.) 10 consecutive nights
- Regular monitoring of long-period orbit
  - ex.) every 1~2 month

- A few tens of planet-candidates need such extensive monitoring
  - not necessary need “full” consecutive nights
  - ex.) 1~3 hours × 10 consecutive nights
  - ex.) 1 hour at every HDS night