特別講演

HIDES：この15年とこれから

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岡山天体物理観測所
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（スライドには、神戸栄治さん、佐藤文衛さん、柳澤顕史からの貢献が多数あります）

懺悔

- HIDES装置論文を（まだ）出版できていません。
- 観測データを（まだ）出版できていません。

HIDESを作っていた頃の思い出

- ヘールボップ彗星
- あんなに明るい彗星だったのに188cm望遠鏡を向けて何か観測データを取ろうと言う意識が全く無かった。
- HIDESをあと1,2年早く稼働させることができていたら、と思うことがある。

個人的動機

- 赤色巨星からの質量放出現象を可視高分散分光で探る
- 分子吸収線の一本一本を狙う
- ミリ波分子輝線との関係を探る
  - ごく最近、遠赤外線で見える星周ダストシェルとの関係に気が付いた

昔を振り返ってみた

- 1996年7月1日着任、つまり来年7月でOAO勤続20年
- 最初の仕事：クーデ分光器スリット前光学系製作
- 1997年度当初　HIDES製作費予算措置
- 1999年4月　ファーストライト
- 2000年1月　共同利用開始
- その後、追加CCD措置

HIDES

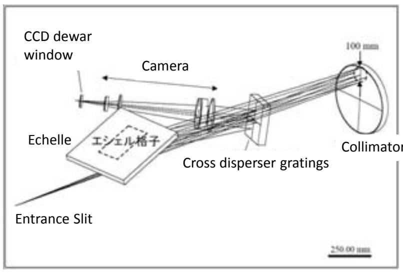
- High-Dispersion Echell Spectrograph
- Coude focus of the 188cm telescope
- 3 CCD (2k x 4k) mosaic camera
- Spectral resolusion (R=λ/Δλ)
  - R = 110,000 using 0.4" slit
  - R = 70,000 using 0.7" slit
- Instantaneous spectral coverage ~ 3,900 Å
- Limiting magnitude:
  - **12 mag.** (V-band, 1 hour exp., S/N=10@6000Å)
- I_2 cell mode
  - max. accuracy of radial velocity measurement ~ 2 m/s

いつも自分で思うこと

- 割に適当
- 深い詰め無し
- 概ね妥当（結果として）

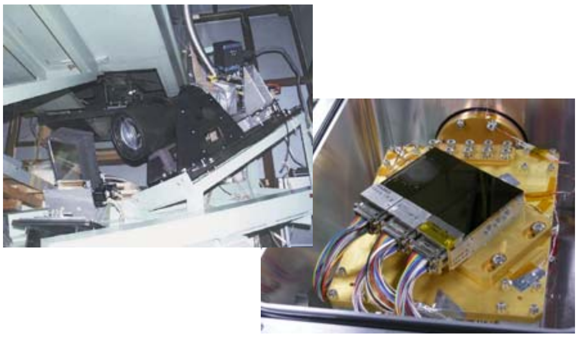
What is HIDES ?

- High dispersion echelle spectrograph placed at the Coude focus of the OAO188cm reflector. Operational since 2000.
- Most frequently used instrument at OAO
（~70% of the common user observation time is spent every year）



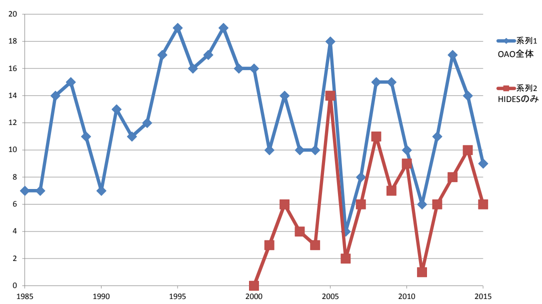
Izumiura (1999)

HIDES



HIDESによる成果

査読論文数



太陽系外惑星探索の始まる前

- 定金さん：初期の性能評価、成果出版
- 比田井さん：初期の継続的成果出版
- 竹田さん：当初より続くあまたの成果出版
- 平田さん：多方面での支援
- 青木和さん：データ解析の指針
- 増田さん：ソフトウェア製作
- 野口邦さん：多方面での支援

この場をお借りして改めて感謝いたします。
（記憶力の限界でここから漏れている方がいらしたら済みません）

太陽系外惑星の探索の始まり

- 偶然的要素
  - 星周ガス吸収線、5万では不足、きっちり分解能10万を出すことを強く意識して物事を進めた。
  - 分解能7万の時3ピクセルサンプリング、5万の時4ピクセルサンプリング
- 必然的要素
  - ヨードセルの装備
  - すばる時代の幕開け
    - ユーザーの移動
    - 望遠鏡時間の余裕
    - 何をやってもよい状態になったという自由な雰囲気、あるいは、何かを変えなければならないという切迫した気分

Program


188cm reflector


HIDES


Iodine cell

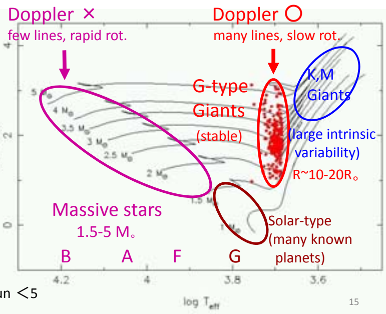
- Okayama planet search program since 2001
  - Doppler technique (precision ~5 m/s)
  - 188cm reflector at Okayama Astrophys. Observatory, NAOJ
  - High dispersion echelle spectrograph (HIDES, ~2000)
  - Iodine cell (~2001)
  - ~300 G-type giant stars from Hipparcos catalogue
    - 0.6＜B-V＜1.0, stable against pulsation, G6～K1III
    - －3＜M_v＜2, corresponding to 1.5＜M/M_sun＜5
    - δ＞－25°, observable from Okayama
    - V＜6, to achieve high S/N which warrants an accuracy better than 10 m/s
    - Known variables and spectroscopic binaries are excluded beforehand

Exoplanet search in G-giants

G-giants are descendant of intermediate-mass stars & are suitable targets for planet searches around massive stars

Massive stars on M.S.
(early-type O-A stars)
:only few broad lines

Massive evolved stars:
(late-G giants)
:many sharp absorption lines
:low surface activity



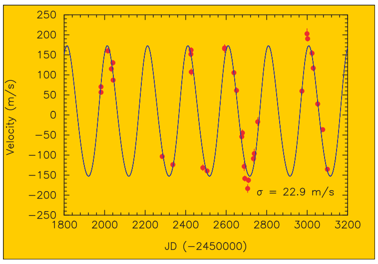
0.6＜B-V＜1.0 ⇔ G6～K1III
－3＜M_v＜2 ⇔ 1.5＜M/M_sun ＜5

What from G-giants

- How common are planetary systems in intermediate-mass stars?
  - Many young B, A stars have proto-planetary disks (HAEBE stars)
  - almost no planet searches targeting massive stars (O-A type stars, >1.5M_{sun})
- Dependence of properties of planets on host stars' mass
  - More massive stars have more planets and more massive planets?
  - Suppressed by strong radiation from early-type host stars?
- Constrain timescale of planet formation
  - Lifetime of proto-planetary disk around massive stars are shorter than those around lower mass stars
- Evolution of planetary systems
  - How do planetary systems react to the red giant phase?

This slide is modified after the submission of the material

First "Japanese Planet Candidate": HD 104985b
(The Extrasolar Planets Encyclopaedia, http://exoplanets.org/linkframe.html) (2003)

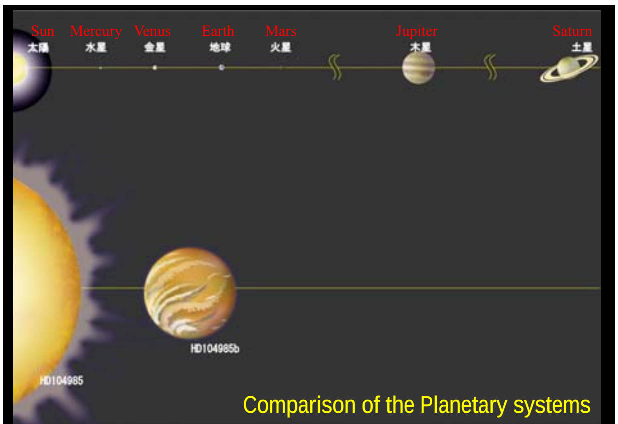


G9III (V=5.8, 100pc)

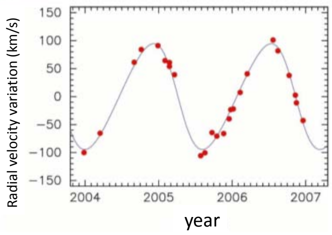
P = 198.5 d
K = 164 m/s
e = 0.06
[Fe/H] = −0.15
M1 = 2.3 M☉
m2sini = 8.3 MJ
a = 0.88 AU

Sato et al. 2003, Astrophys. J. Letters, 597, L157-L160, First planet candidate around G-type giant

This planet is in the list of 305 well-characterized exoplanets that are the targets of "NameExoWolrds: An IAU Worldwide Contest to Name Exoplanets and their Host Stars!"



The first discovery of a planet in
an open cluster member (ε Tau) in 2007
This is also the target of “NameExoWorlds”



Planet:
Mass: 8 M_jup
Orbital Period: 595 d

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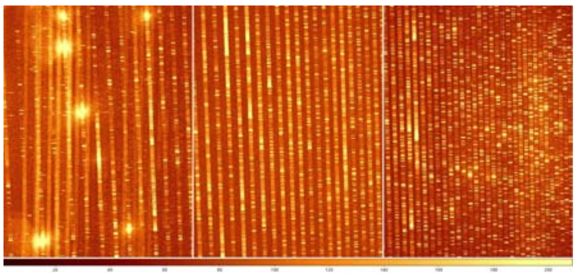
高性能化

- モザイクCCD化
  - 中屋さん
  - 大塚さん
- ファイバーフィード化
  - 神戸さん、吉田さん

Example of HIDES data

(Th-Ar arc line spectrum)

3800A



7700A

Spectral resolution (λ/Δλ) = 100,000

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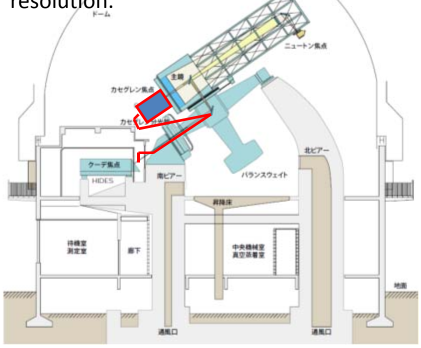
Linking the Cassegrain focus and the Coude focus by optical fibers of 1) high efficiency and 2) high resolution.

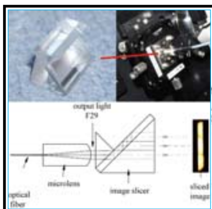


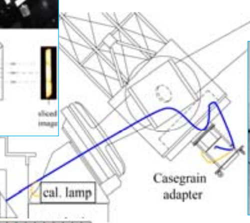
HIDES(高分散エシェル分光器) 2009B～2010A

- ファイバーフィード化計画
  - カセグレン焦点から光ファイバーでHIDESまで光を導く
    - 望遠鏡効率向上＋高速ガイド＋イメージスライサで限界等級の1等級向上を目指す。
  - クーデ焦点スリット前光学系の新規設計・製作
  - 高効率光ファイバーフィード系(φ2.7”)の設計・製作
  - 平成21年10月に188cm望遠鏡に装着してエンジニアリングファーストライトに成功
  - **平成21年12月にサイエンティフィックファーストライトに成功**
  - **2010A期(平成22年1～6月)に性能評価の推進**
    - **1等級の限界等級の向上**
    - **シーイングやガイドへの依存性の低減**
    - **IP(機械輪郭)の安定化**
    - **短期的視線速度測定精度の向上 → ～1 m/s へ(分解能5万で)**
    - **光ファイバー(端面研磨から)、イメージスライサーの経験の蓄積**

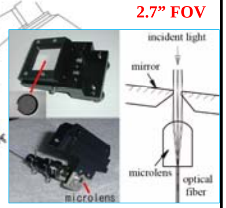
  (ファイバーフィード＋イメージスライサーは、奇しくも世界的な
  新しいトレンドらしい)

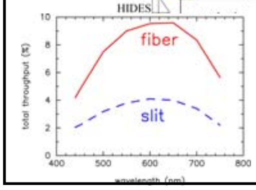
HIDES Fiber System



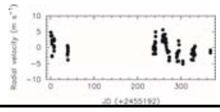


2.7” FOV





left: higher (10 %) total throughput
below: < 2m/s rv measurement precision



tau Cet

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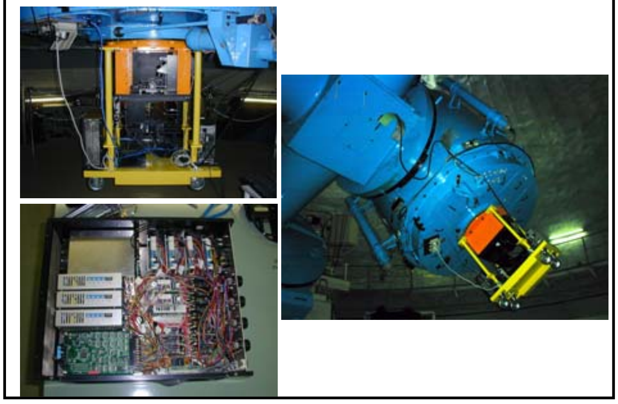
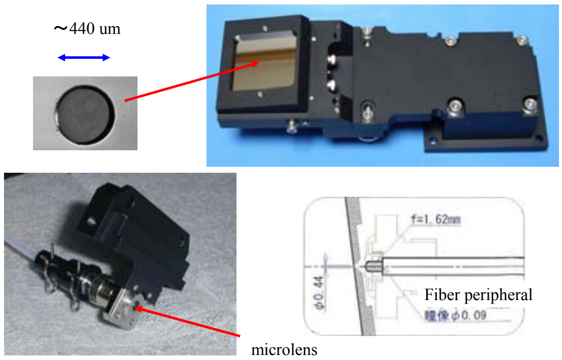
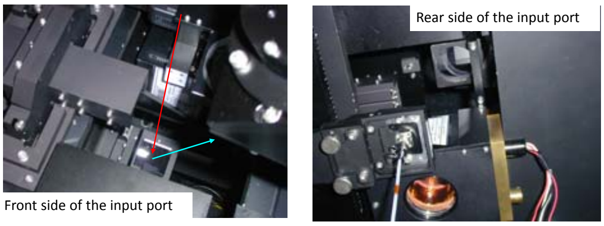
Cassegrain fiber input unit

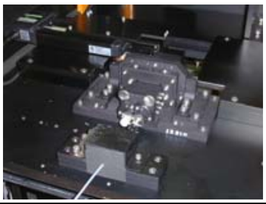


HE input port (at Cassegrain focus)

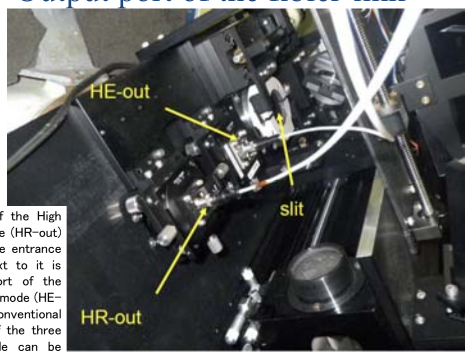




Fiber input port
@Cassegrain focus



Output port of the fibler-link



Output port of the High resolution mode (HR-out) attached to the entrance of HIDES. Next to it is the output port of the high efficiency mode (HE-out) and the conventional slit. Anyone of the three observing mode can be selected from remote.

（Kambe et al. 2012, in “Okayama User’s Meeting 2012”）

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HE output（coude focus; FFP[star] slice mode）

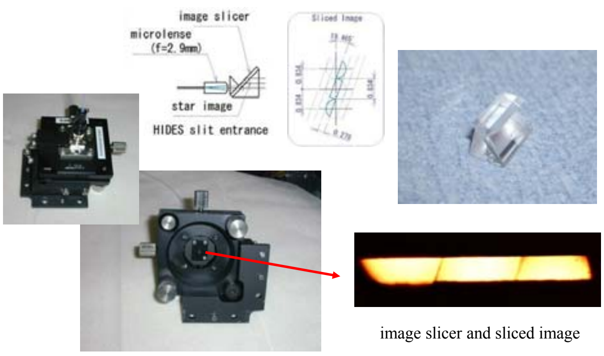
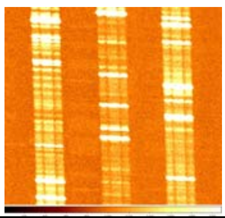


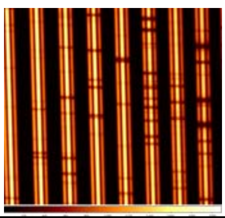
image slicer and sliced image

HIDES fiber-link first light &
Early performance verification results
from commissioning observations

- Engineering first light: 11-12 Oct, 2009
  - First trial of the whole HE mode system attached to the telescope
  - Resolution (R～52,000) & Usable waveband (λ > 440 nm for red cross disperser) confirmed to be as designed
  - No significant improvement in the throughput due to insufficient optics alignment



Th-Ar

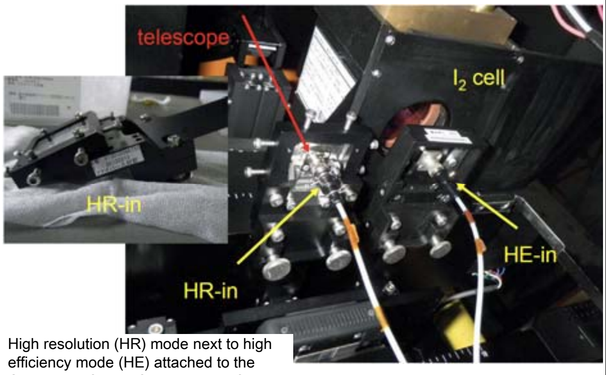


αCMi

Features of High Efficiency (HE) mode optics

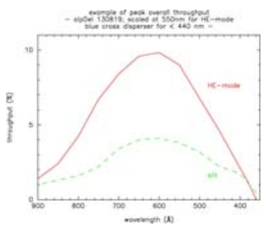
- Linking the Cassegrain focus of the 188cm reflector to its Coude focus with an optical fiber (commercially available)
  (3rd mirror (0.8) x 4th mirro (0.8) x Coude room window (0.9) =0.58 ➔ 0.9X or 0.87x 0.87x 0.93= 0.70 ➔ 0.90)
- Introducing light falling into ϕ2.7” area at the Cassegrain focus into the fiber with a 100um core
  (F-transformation by microlens F18➔ F3.7)
- Slicing the star (or pupil) image into 3 pieces by an image slicer at the entrance slit of HIDES
  (F-transformation by microlens F3.7➔ F29)
  Far Field Pattern (pupil) Slice、Near Field Patter (image) Slice changeable
  slit efficiency 0.4 (0.75”, R～70,000) ➔ 0.8X (FOV 2.7” /3 slices ; R～52,000)
- Iodine cell insertion/extraction available
  Investigate the precision in RV measurements achievable with this system

High resolution mode of the fiber-link for HIDES

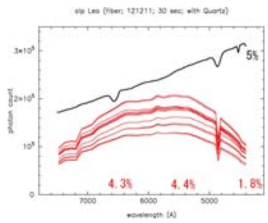


High resolution (HR) mode next to high efficiency mode (HE) attached to the Cassegrain focus of the 188cm reflector at OAO. (Kambe et al. 2012)

High efficiency and high resolution modes of the fiber-link for the high dispersion echelle spectrograph (HIDES) (Kambe et al. 2013)



High efficiency mode provides a peak efficiency reaching 10% including atmospheric extinction and telescope reflectance (red line). It is very high for a high dispersion spectrograph. Green line shows the case for usual observations using a conventional slit.



Measured total efficiency of the high resolution mode (R~100,000) including the telescope reflectance and atmospheric extinction by observing the star, alpha Leo in December 2012. One red line corresponds to one measurement from one exposure. Differences between the lines are due to guiding errors and sky fluctuation. The black line indicates an expected spectrum of alpha Leo when the total efficiency is 5% at every wavelength. The figure shows that the actual efficiency is higher than 4% in the range from 550nm to 650nm, which is 4 times better than usual observations with a conventional slit.

Noteworthy performances and features of HIDES fiber system

- a reciprocal wavelength resolution (R) of 50,000 for a wide field of view (FOV) of 2.7”
  - ✓ owing to development of high-throughput image slicer
  - ✓ much wider FOV compared to the typical seeing size at OAO (1.5”)
- as high as 10% total throughput including everything
  - ✓ very stable performance since its first-light in December , 2009
- less than 2 m/s long-term precision in radial velocity measurement precision
  - ✓ adopt an iodine cell for our non super-stabilized spectrograph
  - ✓ verified by multiple groups (Kambe+, 2013; Beck+ 2015)
- a high wavelength resolution fiber-feeding route is under development
  - ✓ R of 110,000 for a FOV of 1.6”, thus much higher FOV compared to slit configuration (0.38”)
  - ✓ more than 4 % peak total throughput is already reached
  - ✓ will open to community in a year
- astro-comb project is ongoing
  - ✓ the target wavelength is 380 nm to 540 nm
  - ✓ first test may come in early 2016

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This slide was added after the submission of the material

Precision of radial velocity measurement

Table 5. Accuracy per measurement of the radial velocity observations.

γ Psc	N	original uncertainties σ_{noise} [m s^{-1}]	$\sigma_{meas.}$ [m s^{-1}]	normalised uncert. σ_{noise} [m s^{-1}]	$\sigma_{meas.}$ [m s^{-1}]
Hermes	1316	0.3	7.3	0.3	7.4
Coralie	1946	0.2	7.2	0.2	6.6
Hides	1306	0.1	4.2	0.1	3.6
Sophie	485	0.6	10.8	0.5	8.7
All	5053	0.1	7.0	0.1	5.4
θ^1 Tau	N	σ_{noise} [m s^{-1}]	$\sigma_{meas.}$ [m s^{-1}]	σ_{noise} [m s^{-1}]	$\sigma_{meas.}$ [m s^{-1}]
Hermes	1286	0.1	3.5	0.1	4.1
Coralie	790	0.2	4.4	0.2	4.5
Hides	1283	0.1	2.3	0.1	2.1
Sophie	360	0.6	9.7	0.4	6.1
All	3719	0.1	4.3	0.1	3.0

Notes. N gives the number of data points finally used in the single-site data-set. σ_{noise} reports the average noise amplitude in the frequency range between 1000 and 1200 μHz. $\sigma_{meas.}$ is the average measurement uncertainty in a data-set.

Beck et al. 2015 “Detection of solar-like oscillations in the bright red giant stars γ Psc and 1 Tau from a 190-day high-precision spectroscopic multisite campaign” , AA, 573, id 138,

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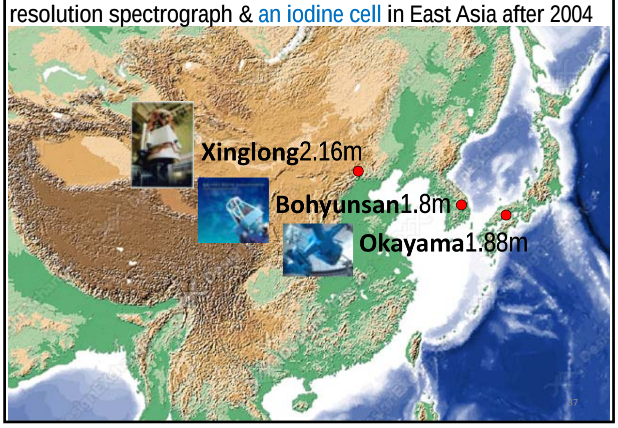
国際協力

- 可及的速やかにニッチを埋める
- はりぼてでも良いから大きく見せる
  – 実は後からついてくる(だろう)
- パートナーの発掘
- 周囲の人の支援
- 偶然の幸運

Distribution of 2m-class telescopes equipped with a high resolution spectrograph & an iodine cell in East Asia after 2004

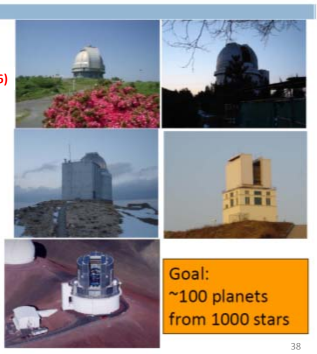


This slide is modified after the submission of the material

East-Asian Planet Search Network (EAPSNET)

For G, K-gaints

- ■Okayama 1.88m tel., Japan
  - □300 GK giants (V<6), since 2001
  - □ 20 planets and 2 brown dwarfs
  - □New 3 yr-project started in 2013(--2016)
- ■Xinglong 2.16m tel., China & Okayama
  - □100 GK giants (V~6), since 2005
  - □ 1 planets and 2 brown dwarfs
  - □Liu, Wang, Zhao et al.
- ■Bohyunsan 1.8m tel., Korea & Okayama
  - □140 GK giants (V<6.5), since 2005
  - □ 1 planets and 1 brown dwarf
  - □Omiya, Han, Lee et al.
- ■Subaru 8.2m tel., Japan & EAPSNET
  - □>200 GK giants (6.5<V<7), since 2006
  - □ 1 planets and 1 brown dwarf
  - □Japan-China-Korea collaboration
- ■TUBITAK 1.5m tel., Turkey
  - □50 GK giants (V~6.5), since 2008
  - □ Selam, Yilmaz, Bikmaev et al.
  - □? planets and ? brown dwarfs



Goal:
~100 planets
from 1000 stars

Astronomy with precise radial velocity measurements
- Extra-solar planet search and Asteroseismology -
(since 2006)

List of detected sub-stellar companions

Green: Korea-Japan collaboration

Yellow: China-Japan collaboration

Grey: Project observation at OAO

↓

EAPSNET collaborations

23 planets and 6 brown dwarfs

~half of known planets in giant stars

Planet Name	Stellar Sp. Type	Stellar Mass ($M_\odot$)	Stellar Radius ($R_\odot$)	Planetary Mass (M_{JUP})	Semi-major Axis (AU)	Eccentricity	([Fe/H] (dex)	Observatory
HD 119445 b	G6 III	3.9	20.5	37.6	1.71	0.08	+0.04	OAO, BOAO, 2009
o Uma b	G4 II-III	3.1	14.1	4.1	3.9	0.13	−0.09	OAO
ν Oph b	K0 III	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ν Oph c	K0 III	3.0	15.1	27	6.1	0.17	+0.13	OAO
HD 175679 b	G8 III	2.7	11.6	37	3.4	0.38	−0.14	OAO, Xinglong, 2012
ε Tau b	K0 III	2.7	13.7	7.6	1.93	0.15	+0.13	OAO, 2007
11 Com b	G8 III	2.7	19	19.4	1.29	0.23	−0.28	OAO, Xinglong, 2008
HD 180314 b	K0 III	2.6	9.2	22	1.4	0.26	[illegible]	Subaru, OAO, 2010
HD 2952 b	K0 III	2.5	[illegible]	[illegible]	1.2	0.13	[illegible]	OAO
75 Cet b	G3 III:	2.5	10.5	3.0	2.1	0.12	+0.00	OAO
HD 120084 b	G7 III:	2.4	[illegible]	4.5	4.3	[illegible]	[illegible]	OAO
HD 100655 b	G9 III	2.4	9.3	1.7	0.76	0.085	+0.15	OAO, BOAO, 2012
81 Cet b	G5 III	2.4	11	5.3	2.5	0.21	[illegible]	OAO, 2008
18 Del b	G6 III	2.3	8.5	[illegible]	2.6	0.08	[illegible]	OAO, 2008
HD 104985 b	G9 III	2.3	11	8.3	0.95	0.09	−0.35	OAO, 2003
ω Ser b	G8 III	2.2	12.3	1.7	1.1	0.11	−0.24	OAO
ξ Aql b	K0 III	2.2	12	2.8	0.68	0	−0.18	OAO, 2008
14 And b	K0 III	2.2	11	4.8	0.83	0	−0.24	OAO, 2008
o CrB b	K0 III	2.1	10.5	1.5	0.83	0.19	−0.29	OAO
HD 81688 b	K0 III-IV	2.1	13	2.7	0.81	0	−0.34	OAO, 2008
HD 173416 b	G8 III	[illegible]	13	[illegible]	[illegible]	0.21	[illegible]	OAO, Xinglong, 2009
HD 145457 b	K0 III	1.9	9.9	2.9	0.76	0.11	−0.14	Subaru, OAO, 2010
6 Lyn b	K0 IV	1.7	5.2	2.4	2.2	0.13	−0.13	OAO, 2008
HD 4732 b	K0 IV	[illegible]	[illegible]	2.4	[illegible]	[illegible]	+0.00	OAO, AAT
HD 4732 c	K0 IV	1.7	5.4	2.4	4.6	0.23	+0.00	OAO, AAT
HD 210702 b	K1 IV	1.7	5.1	1.9	1.2	0.17	+0.01	OAO
HD 5608 b	K0 IV	1.6	5.5	1.4	1.9	0.19	+0.06	OAO
κ CrB b	K0 IV	1.5	5.0	1.6	2.6	0.09	+0.10	OAO
HD 167042 b	K1 IV	1.5	4.5	1.6	1.3	0.10	+0.00	OAO, 2008

This slide is modified after the submission of the material

Exoplanet in G-giants (Sato et al. in prep.)

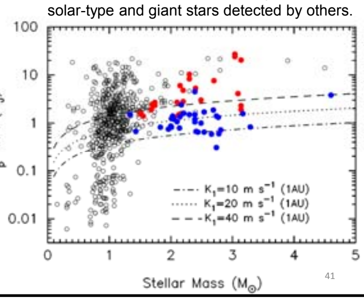
(Project program at OAO＋EAPSNET Collaborations)

- Low mass planets(< 1 M_Jup)
- Short period planets
- Distant(>5AU) planets
- High eccentricity planets
- Multiple planet systems

- 3 planets newly added
- In total 23 planets and 6 brown dwarfs detected
- Amounting to about half of known planets in giant stars
- Leading the world

(as of 2014-08-22)

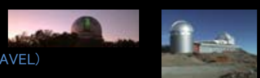
Red dots: sub-stellar objects discovered at OAO, blue dots: low-mass planet candidates identified at OAO, blank circles: planets in solar-type and giant stars detected by others.



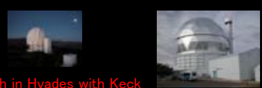
This slide was added after the submission of the material

Major planet searching groups with Doppler technique (in solar-like stars)

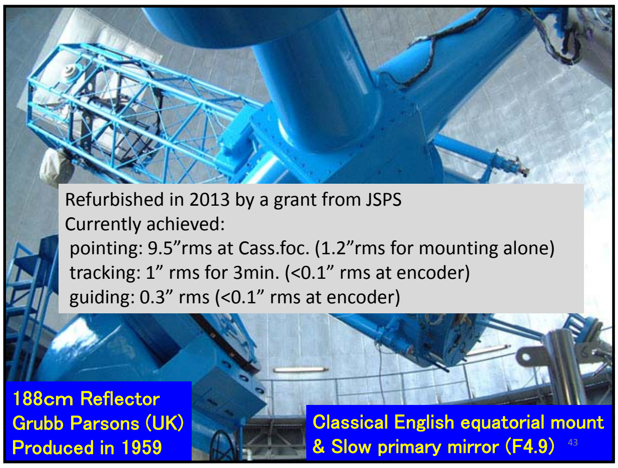
- ✓Marcy, Butler, Fischer et al
- ✓Lick, Keck, AAT, Magellan
- ✓since 1987
- ✓1330 FGKM dwarfs (1200 stars older than 2Gyr ＋100 stars at 50-500Myr)
- ✓Also N2K for hot Jupiters since 2004 (Subaru joined)

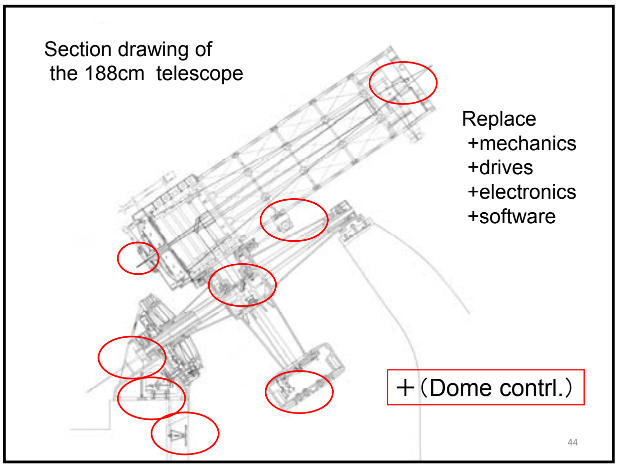


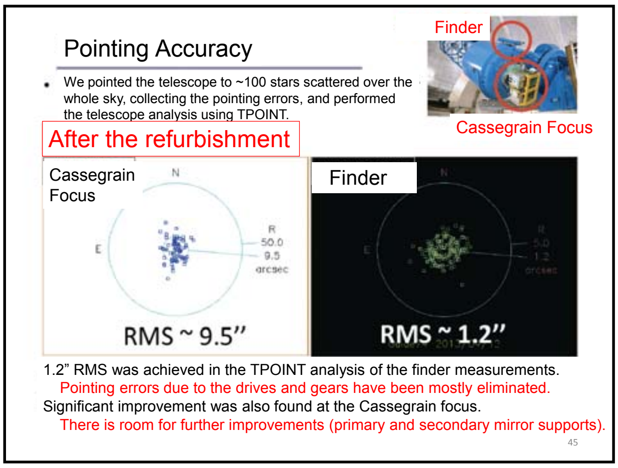
- □Mayor, Udry, Naef et al.
- □ELODIE(OHP),COLARIE(La Silla)
- □since 1994 (after a long history of CORAVEL)
- □>1900 FGKM dwarfs
- □HARPS(ESO 3.6m) -> sub-Saturn mass planet. Also targeted at Metal-poor stars

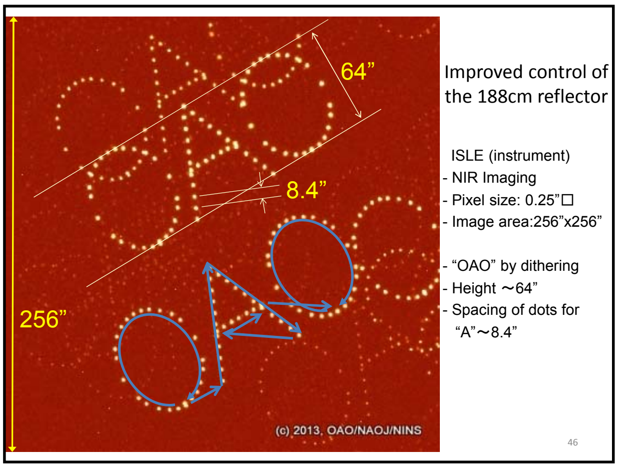


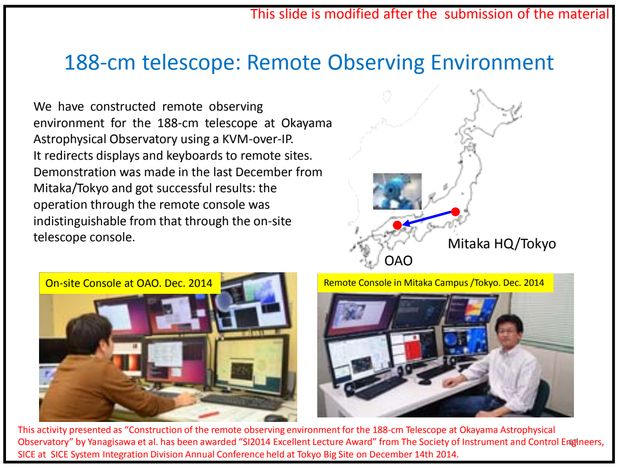
- ➢Cochran, Hatzes, Endl et al.
- ➢McDonald, HET
- ➢since 1987
- ➢~100(?)FGK dwarfs, also made a search in Hyades with Keck
- ➢M-dwarfs with HET, also various stars including young stars and K-giants.


Refurbished in 2013 by a grant from JSPS
Currently achieved:
pointing: 9.5”rms at Cass.foc. (1.2”rms for mounting alone)
tracking: 1” rms for 3min. (<0.1” rms at encoder)
guiding: 0.3” rms (<0.1” rms at encoder)
188cm Reflector
Grubb Parsons (UK)
Produced in 1959
Classical English equatorial mount
& Slow primary mirror (F4.9)
43


Section drawing of
the 188cm telescope
Replace
+mechanics
+drives
+electronics
+software
+(Dome contrl.)
44


Pointing Accuracy
We pointed the telescope to ~100 stars scattered over the whole sky, collecting the pointing errors, and performed the telescope analysis using TPOINT.
Finder
Cassegrain Focus
After the refurbishment
Cassegrain
Focus
Finder
RMS ~ 9.5”
RMS ~ 1.2”
1.2” RMS was achieved in the TPOINT analysis of the finder measurements.
Pointing errors due to the drives and gears have been mostly eliminated.
Significant improvement was also found at the Cassegrain focus.
There is room for further improvements (primary and secondary mirror supports).
45


64”
8.4”
256”
(c) 2013, OAO/NAOJ/NINS
Improved control of
the 188cm reflector
ISLE (instrument)
- NIR Imaging
- Pixel size: 0.25”
- Image area:256”x256”
- “OAO” by dithering
- Height ~64”
- Spacing of dots for
“A”~8.4”
46


This slide is modified after the submission of the material
188-cm telescope: Remote Observing Environment
We have constructed remote observing environment for the 188-cm telescope at Okayama Astrophysical Observatory using a KVM-over-IP.
It redirects displays and keyboards to remote sites.
Demonstration was made in the last December from Mitaka/Tokyo and got successful results: the operation through the remote console was indistinguishable from that through the on-site telescope console.
Mitaka HQ/Tokyo
OAO
On-site Console at OAO. Dec. 2014
Remote Console in Mitaka Campus /Tokyo. Dec. 2014
This activity presented as “Construction of the remote observing environment for the 188-cm Telescope at Okayama Astrophysical Observatory” by Yanagisawa et al. has been awarded “SI2014 Excellent Lecture Award” from The Society of Instrument and Control Engineers, SICE at SICE System Integration Division Annual Conference held at Tokyo Big Site on December 14th 2014.
47

これから

- 天文学的要求

さらなる高精度・高機能化の時代

- 高い精度
- 広い波長域
- 高い効率

- 光周波数コム
  - 産総研の稲場氏らとの共同研究
  - Hilger-Watts分光器のカメラ光学系C4&C10を外して、その機能を一旦撤去しても良いでしょうか？

3.8m望遠鏡

- 新高分散分光器？

まとめ

- 1997年4月の予算措置から3年に満たない2000年1月に共同利用観測を開始
  - 今から見ると時期尚早ともいえる未完の段階での公開踏切
  - 妥協した点は数多くあった
- 客観的に見るなら、古典的な、あるいはやや時代に遅れつつあった、オーバースペック気味の光学系を持つエシェル分光器
- それが救われ、多くの成果が挙げられたのは、多くの人の協力
- とりわけ、神戸さんによるヨードセルの装備と増田さん、佐藤さんら大学院生の若い力
- さらに高精度化へ
- 3.8m望遠鏡時代へ