

**地球型惑星探査
のための
赤外線ドップラー
装置の開発(IRD)**

M. Tamura (NAOJ)

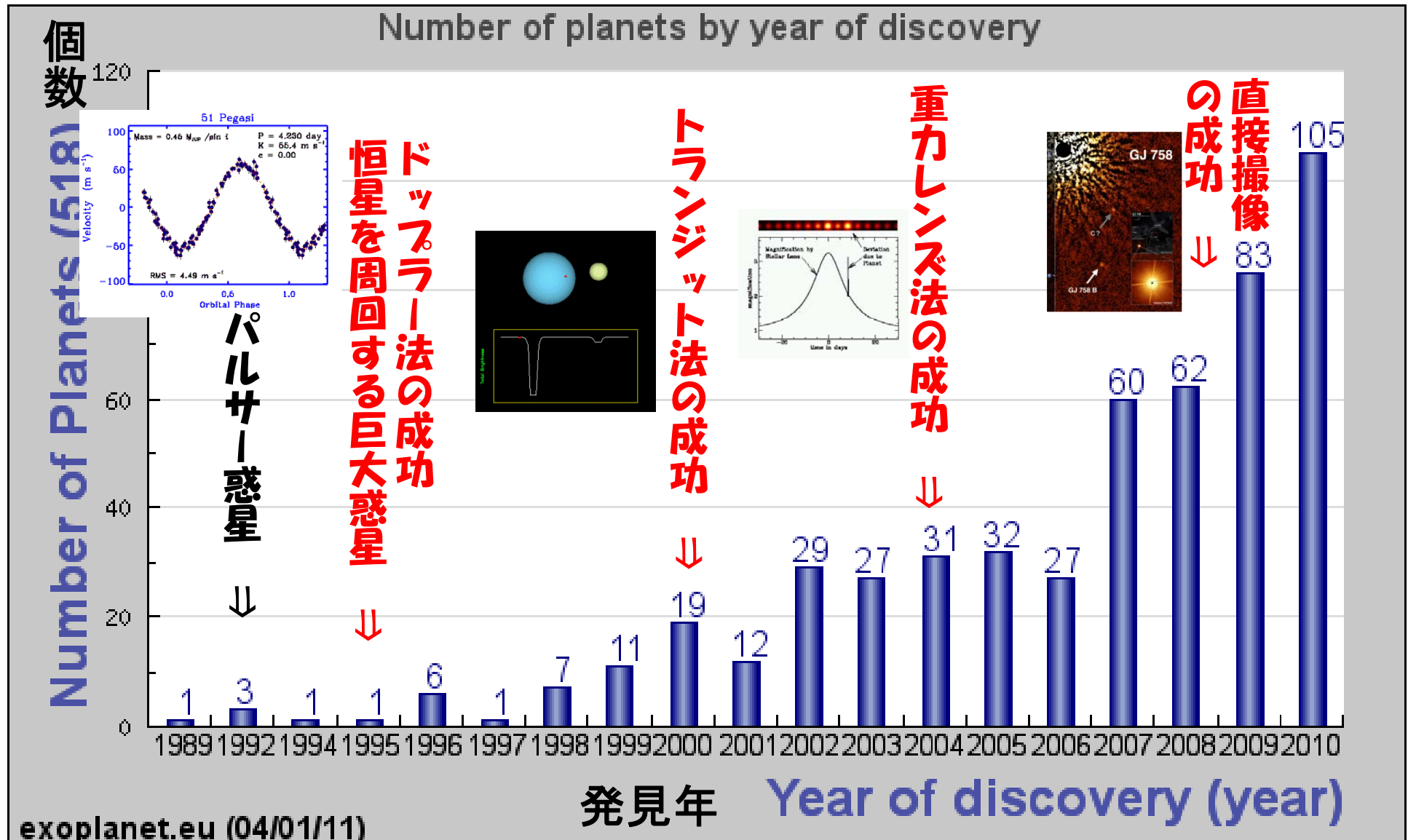
On behalf of IRD team

2011.1.18 10:45-11:05

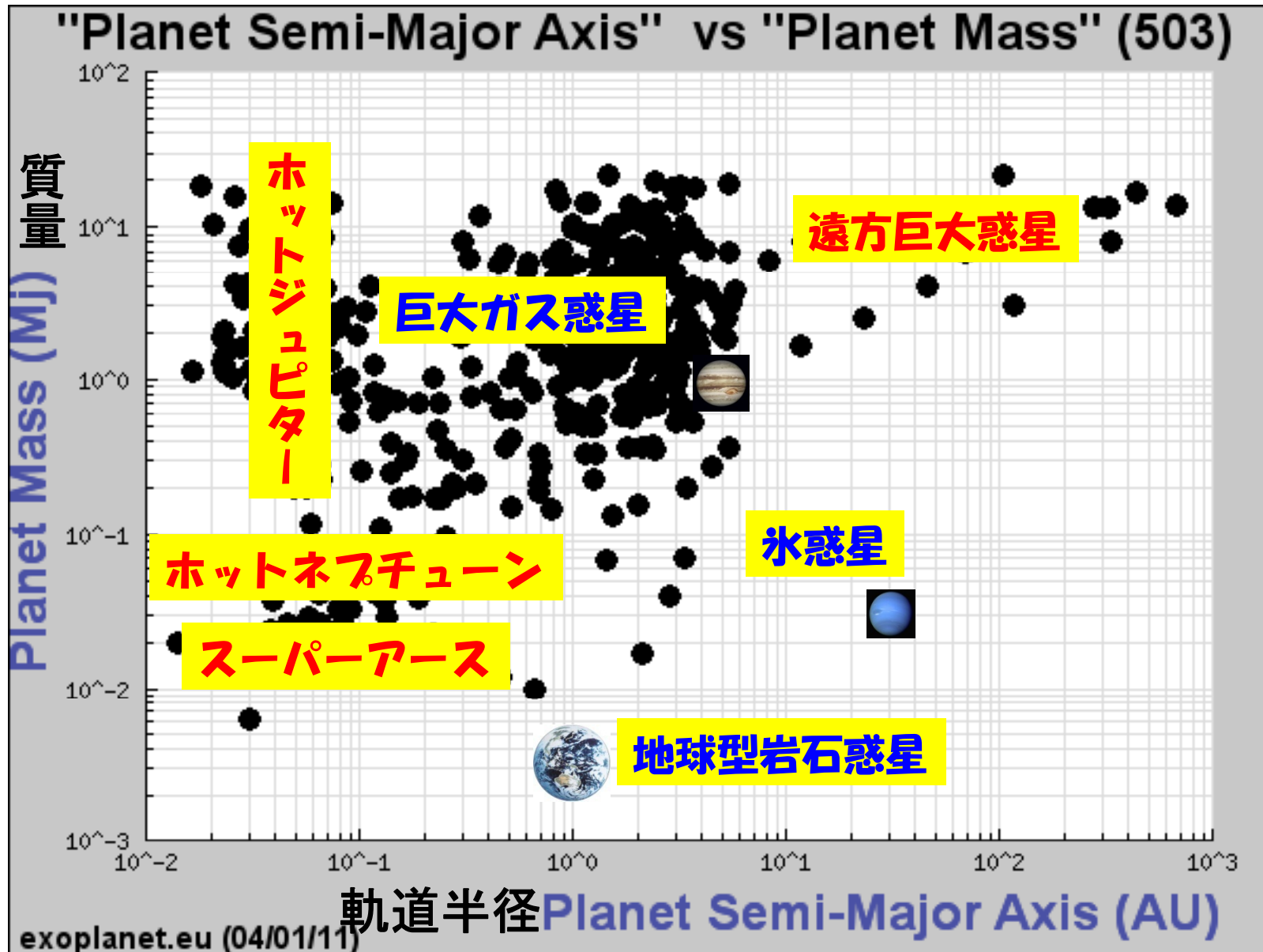
@すばる将来装置計画ワークショップ

>500 exoplanet candidates

パルサー法+ドップラー法+トランジット法（確認済のみ）+重力レンズ法+直接観測



Exoplanets by 2010: Strange New World



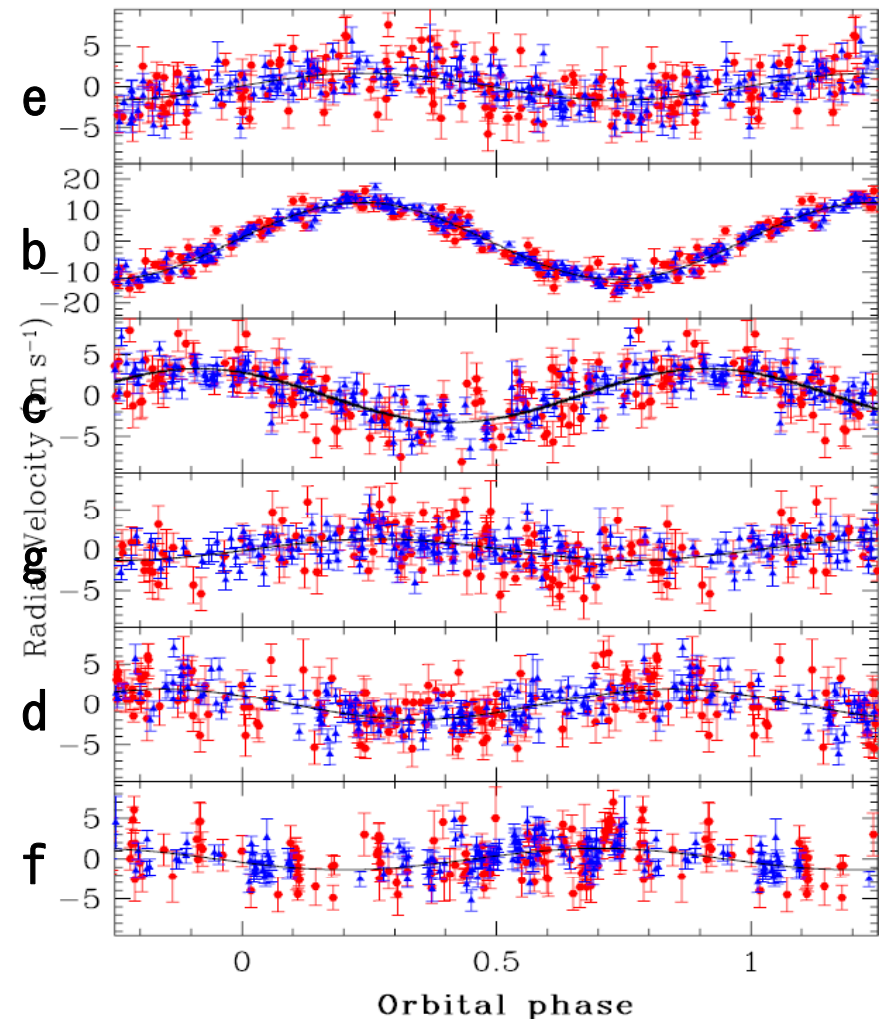
OPTICAL RVs are difficult for M stars

- Low mass planets are being discovered around M dwarfs but tough even with 8-m class telescopes

Gl581

- M3, 0.31 M_{\odot} $V=10.6$
- 6.3pc, 8Gyr
- Gl 581 b: 16 ME, 0.04 AU, 5.4 days, 12 m/s
- Gl 581 c: 6 ME, 0.07 AU, 12.9 days, 3 m/s
- Gl 581 d: 6 ME, 0.22 AU, 66.9 days, 1.9 m/s
- Gl 581 e: 2 ME, 0.03 AU, 3.1days, 1.7 m/s
- Gl 581 f: 7 ME, 0.76 AU, 433 days, 1.3 m/s
- Gl 581 g: 3 ME, 0.15 AU, 36.6 days, 1.3 m/s

Phased reflex barycentric velocities of Gl581
Vogt et al. 2010

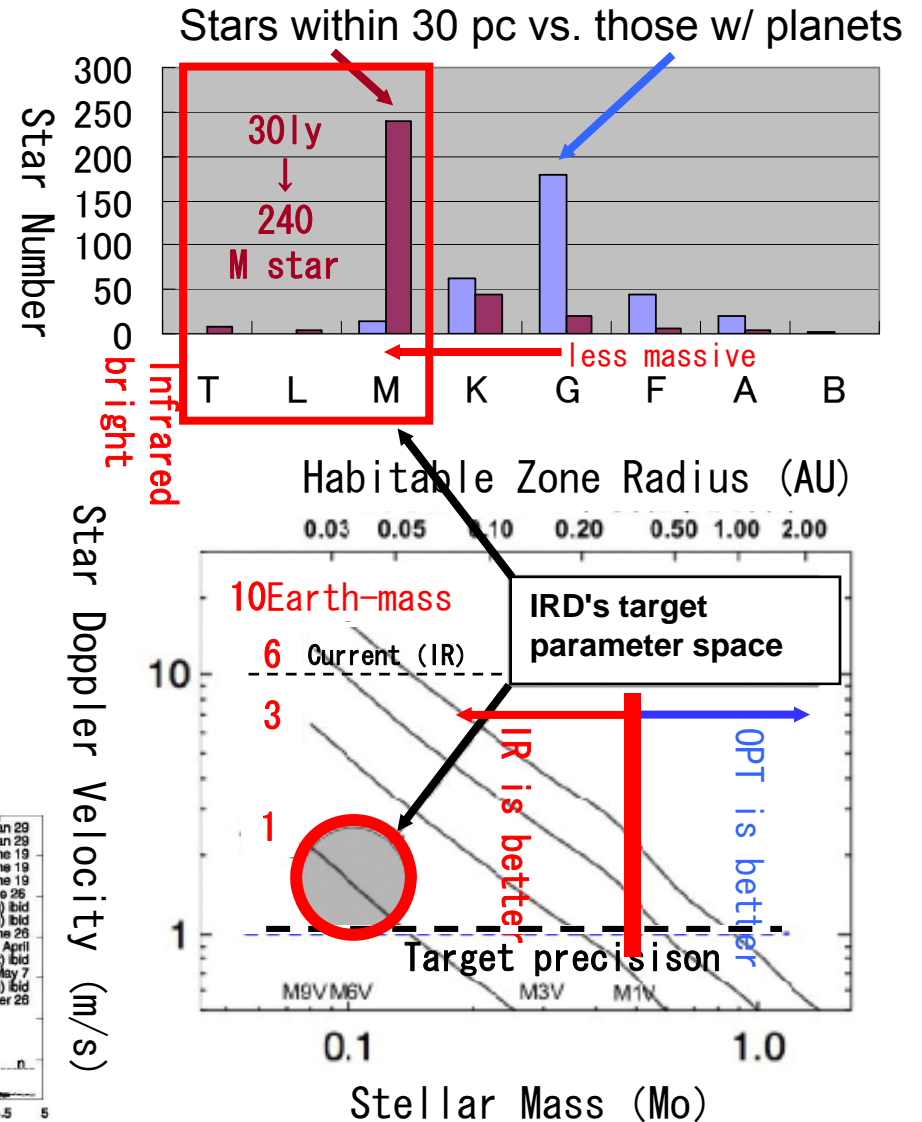
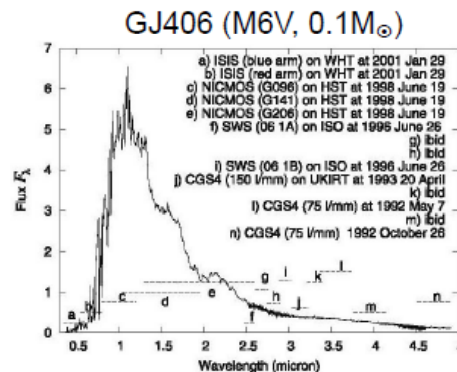


Subaru's next step: Earth-like planet hunting with IR Doppler Instrument

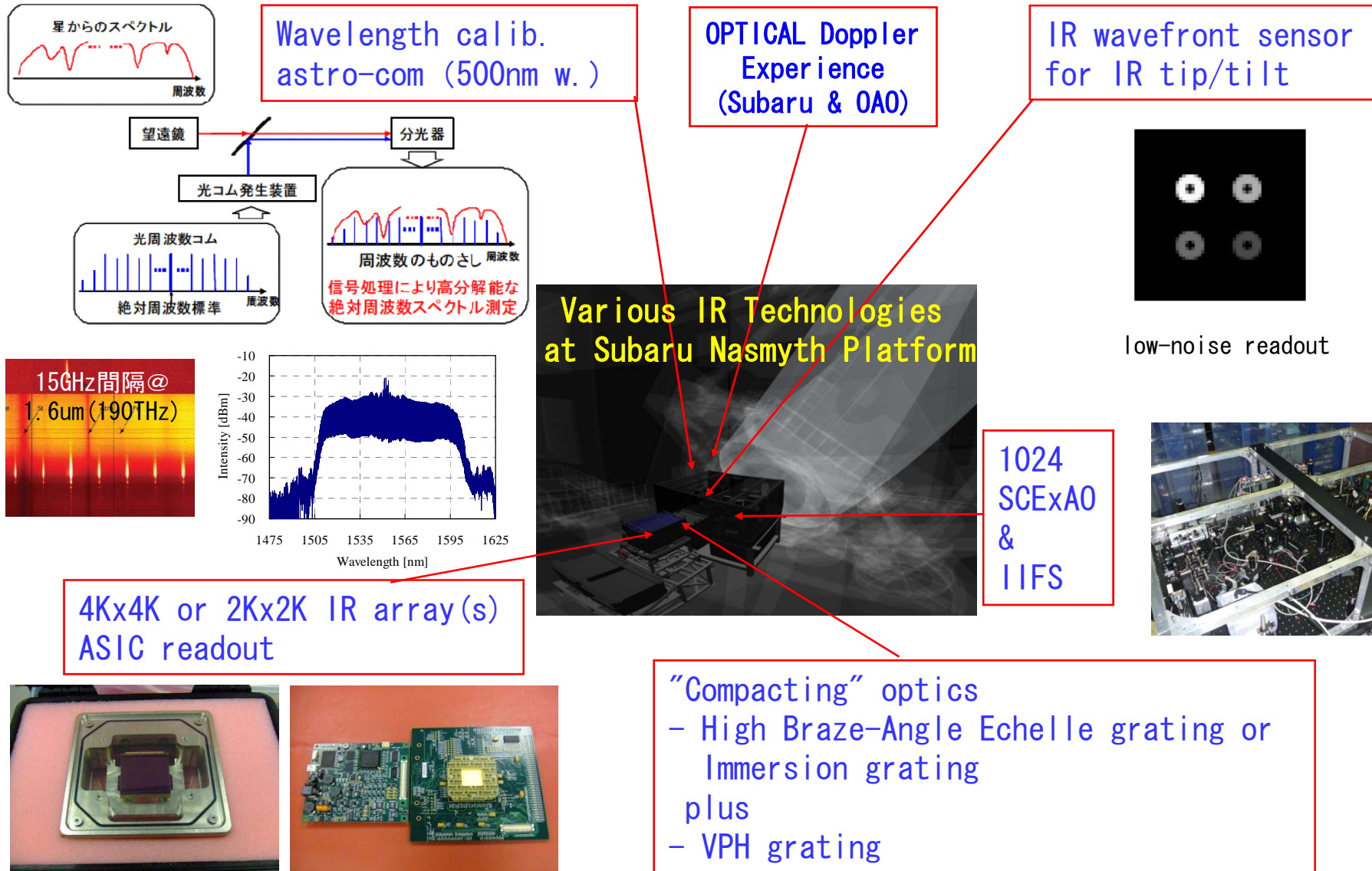
- ★ Infrared Doppler instrument (IRD) can be the first 1m/s precision IR **Earths finder** around low-mass stars on 8-m class telescopes.
- ★ The only approach for Japan to attack the Earth-like planets except for microlensing or TTV.
- ★ ~**1000 targets** can be observed for nearby M stars.
- ★ Providing targets for direct imaging w/ TMT-30m (**SEIT**).
- ★ Funded for five years (2010-2014).



V=13.5
R=12.1
J=7.1
H=6.5
K=6.0



Subaru IRD: Key Technical Components



IRD General Specification

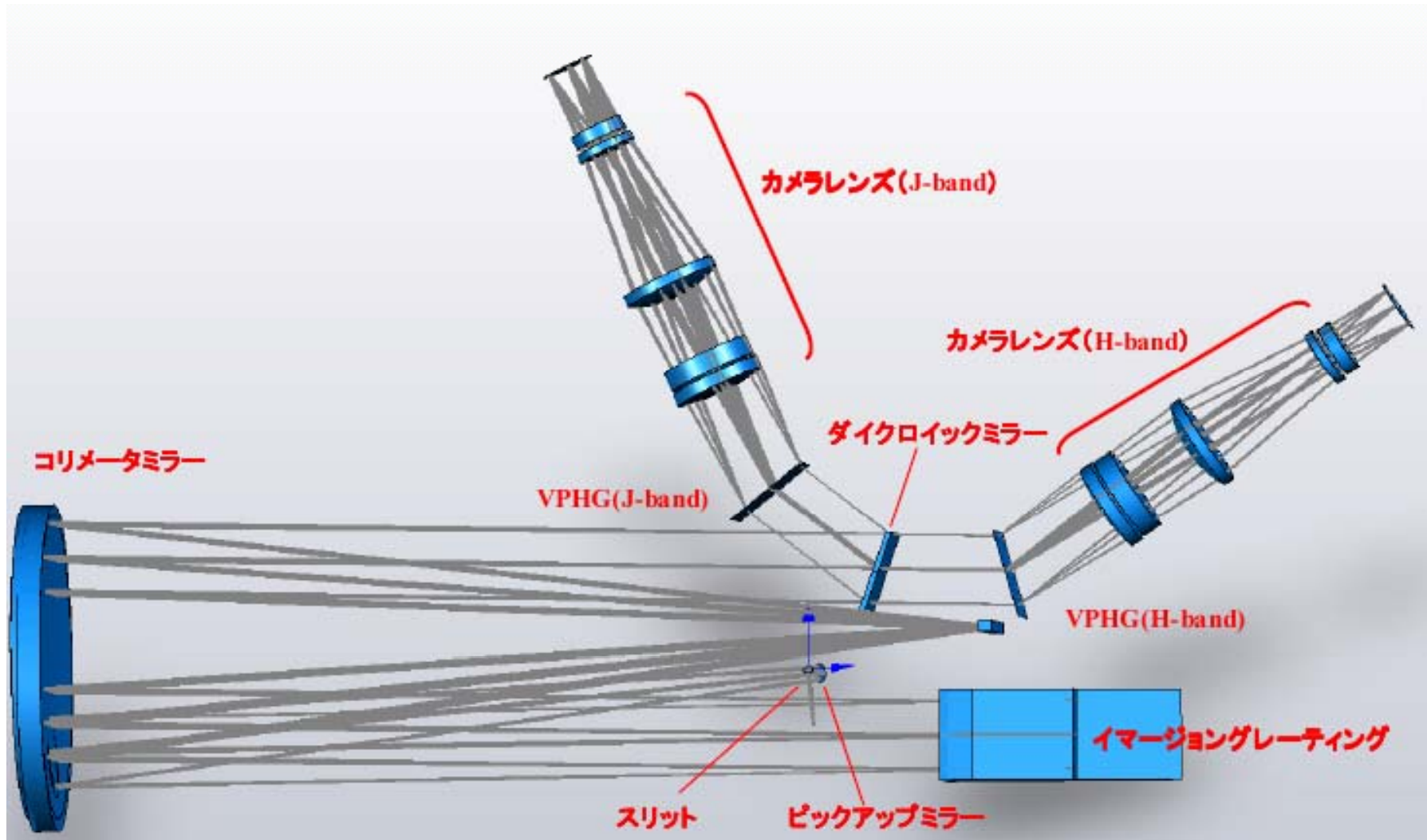
- Wavelength: 1.2-1.8 (goal 1.1-1.9) μm
- Spectral resolution: 70,000 (3 pixel sampling)
- Pixel scale: 0.1 arcsec/pixel
- Slit: 0.3x 3 (goal 0.3x5) arcsec²
- Dispersive optics: ZnSe Immersion or traditional echelle (high Blaze angle) & VPHGx2
- Optics temperature: -50°C
- Detector: HgCdTe 2048² or 4096²
- Velocity precision: 1 m/s w/astro-comb
- Fiber-fed: object+reference+sky+comb

IR array selection

- H2RG x 2 arrays or
- H4RG-15 x 1 array
- Collaboration w/ UH-IFA

Name	Format (# of pixels)	Pitch (μm)	Number of Outputs	Institutions, Observatories and Programs using HxRG arrays
H1RG	1024×1024	18	1, 2, or 16	<ul style="list-style-type: none"> • Wide-field Infrared Survey Explorer (WISE) • Orbiting Carbon Observatory (OCO) • Development programs in Astronomy & Earth Science
H2RG	2048×2048	18	1, 4, or 32	<ul style="list-style-type: none"> • James Webb Space Telescope (JWST) NIRCcam, NIRSpec, FGS • Joint Dark Energy Mission (JDEM) • Astronomy institutions and observatories: Calar Alto, Caltech, CFHT, ESO, ESTEC, Gemini, GSFC, IRTF, ISRO, IUCAA, JHU-APL, Keck, LBNL, LMU, MIT, MPLA, MPS, OCIW, Penn State, RIT, SALT, SAO, Subaru, TATA, U. Arizona, UCLA, UC Berkeley, U. Hawaii, U. Rochester, U. Toronto, U. Wisconsin, Wendelstein Observatory • Space surveillance applications
H4RG-10	4096×4096	10	1, 4, 16, 32, or 64	<ul style="list-style-type: none"> • Joint Milli-Arcsec Pathfinder Survey (J-MAPS) • Development programs in Astronomy
H4RG-15	4096×4096	15	1, 4, 16, 32, or 64	<ul style="list-style-type: none"> • In development, first on sky telescope test in 2011

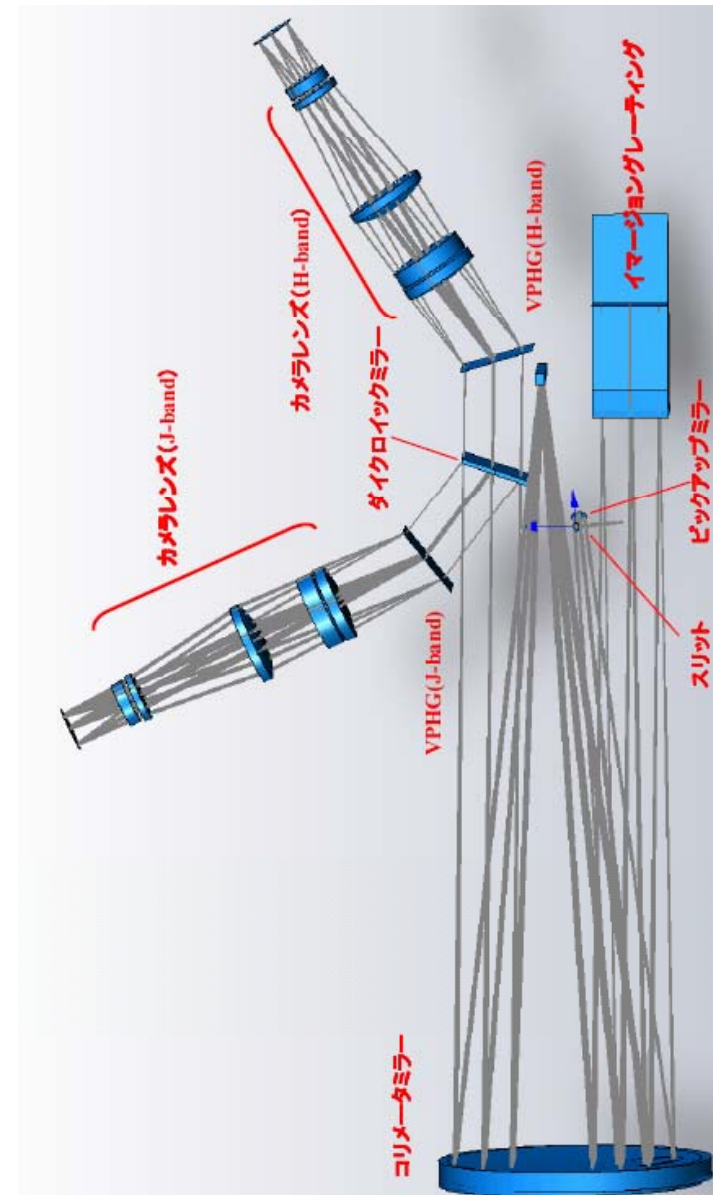
Optics Design 1



Design by Ikeda

IRD: Layout 1

- Light from slit is reflected by pickup mirror, then collimated by reflective collimator mirror.
- Collimated light is dispersed by ZnSe immersion grating and again collimated by collimator mirror (making pupil again).
- Then light is split by dichroic mirror; J band in reflective side while H band in transitive side.
- Then cross-dispersed by VPH gratings.
- VPH grating has a higher throughput than traditional grating, making camera lens compact.
- Then Echelle format images are produced by camera lenses on IR arrays (HAWAII2-RG).

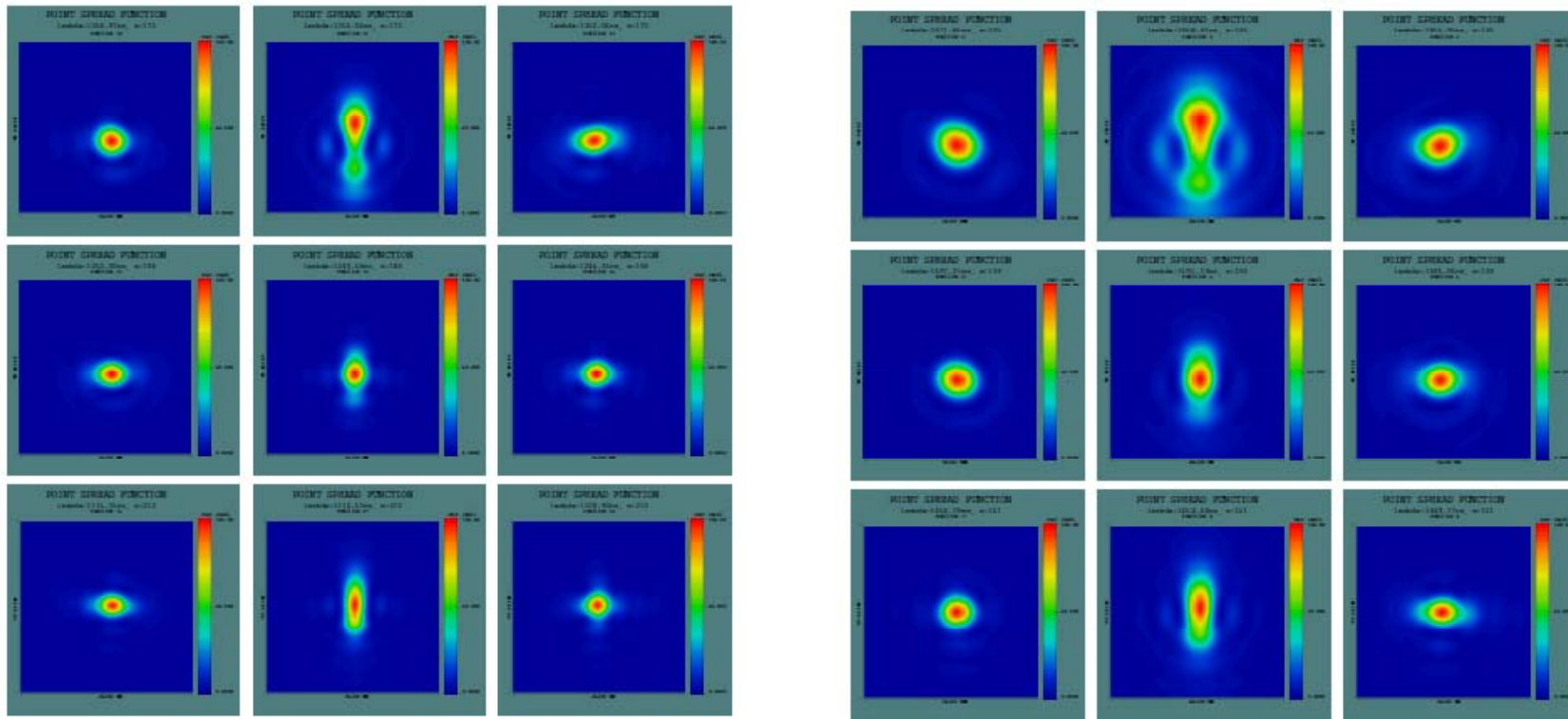


IRD Optics Spec Summary (Design 1)

Telescope	F number Aperture	13.9 (Subaru Nas) 8000mm
Slit	Slit length Slit width	1.62mm (3.0arcsec) 0.16mm (0.3arcsec)
Collimator	Focal length Type	840.6mm Reflective-type
Immersion Echelle	Material Blaze angle Groove pitch Effective aperture	ZnSe 70° 50.65μm 60mm
Cross-Disperser (J band)	Light incident angle Groove density Size	17.6° 200 lines/mm 80mmx80mm
Cross-Disperser (H band)	Light incident angle Groove density Size	13.5° 277 lines/mm 80mmx80mm
Camera (J/H com.)	Focal length Material	281.1mm 5-pieces glass
Detector	Format Pixel size	HgCdTe 2048x2048 pixels 18μm (HAWAII2-RG)

Optical Performance (Design 1)

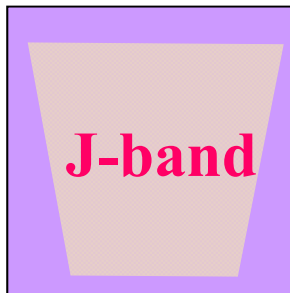
- All PSFs are within 3 pixels and have enough imaging performance to keep the spectral resolution, although some Strehl ratios are smaller (0.2–0.9).



PSFs in J band (left) & H band (right). Each box is 3 pixels of the array.

Optics Design 2 For 4k x 4k

Old design



H2RG

J-band

+ VPH (for J band)

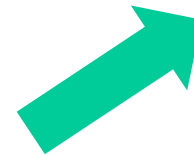


H2RG

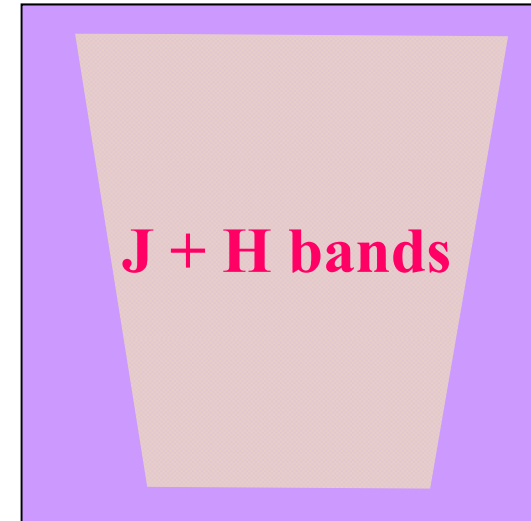
H-band

+ VPH (for H band)

H4RG15



New design



+ single VPH

- wide FOVs for collimator & camera
- fast camera optics
(pix size... H2RG:18um, H4RG:15um)
- low efficiency due to wide wavelength coverage of VPH

⇒ offaxis aberrations by collimator
(=offset parabola) are very large
Not acceptable !

Optics Design 2 For 4k x 4k

Old design



H2RG

J-band

+ VPH (for J band)



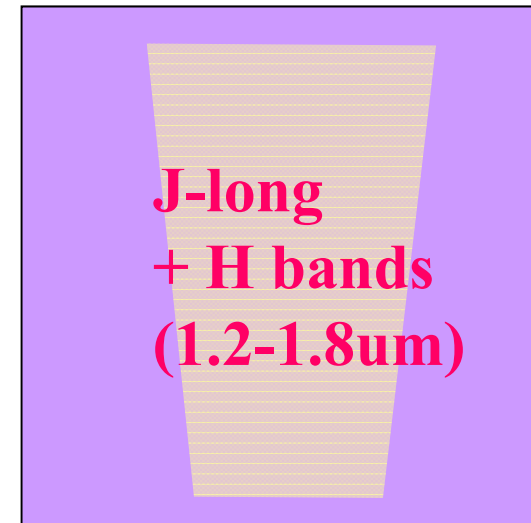
H2RG

H-band

+ VPH (for H band)

H4RG15

New design



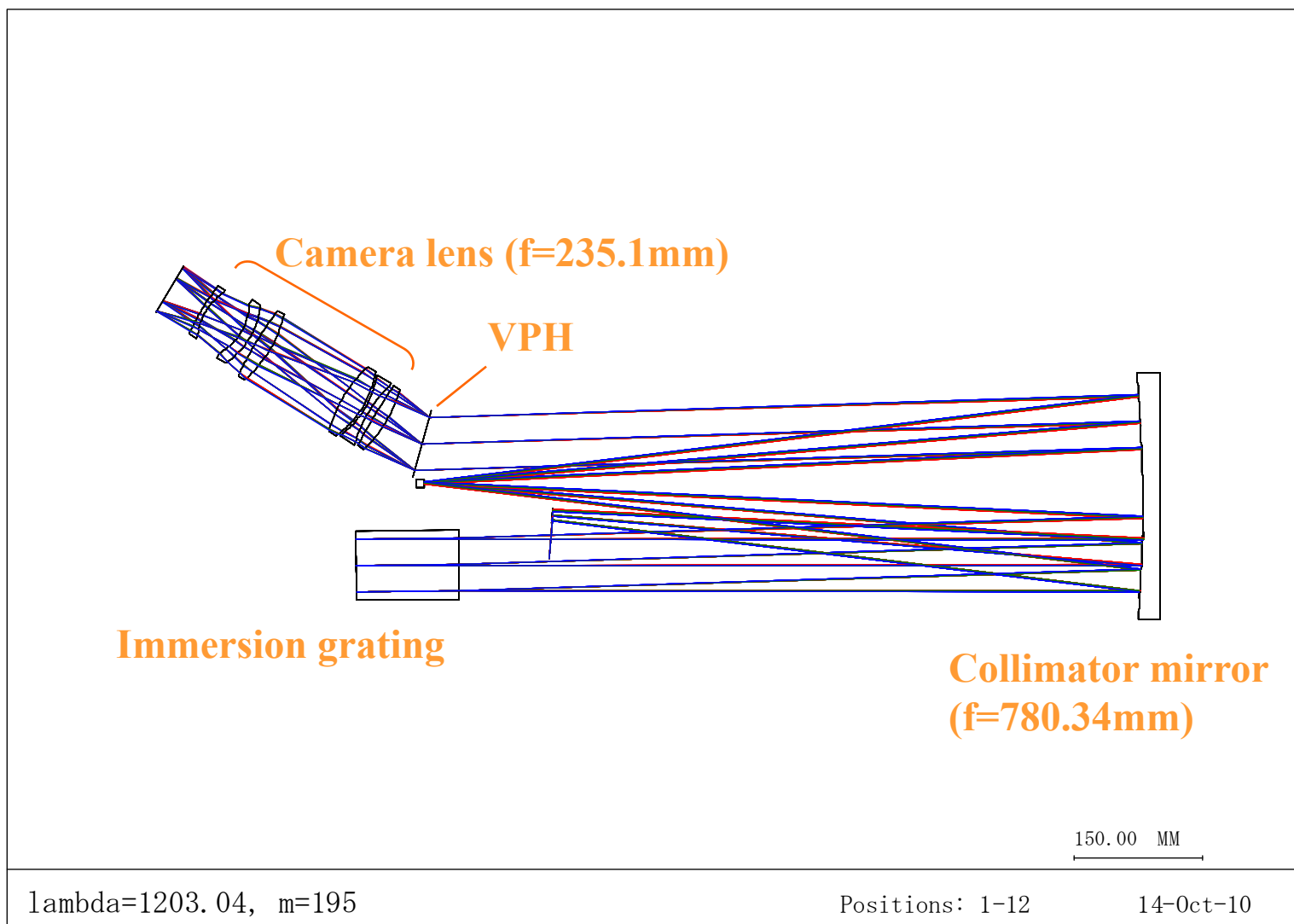
J-long
+ H bands
(1.2-1.8um)

+ single VPH

- same collimator and IG to the current design
 - new VPH grating
 - new camera design
- $f=280\text{mm} \Rightarrow f=230\text{mm}$
 $4 \text{ lenses} \Rightarrow 6 \text{ lenses}$

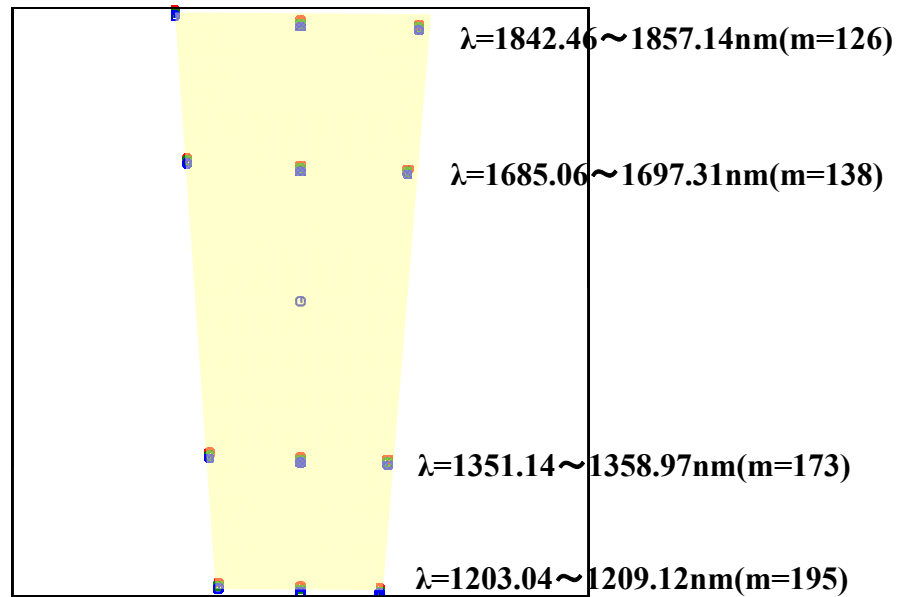
This change does not degrade the velocity accuracy !

Optical layout (2D)

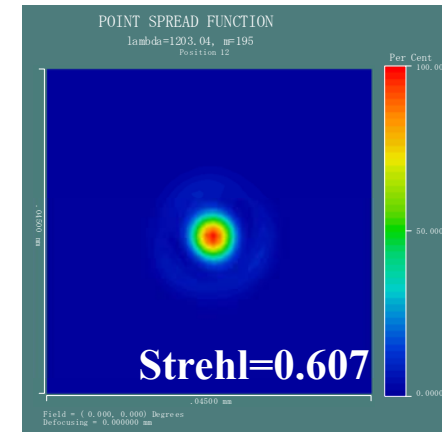
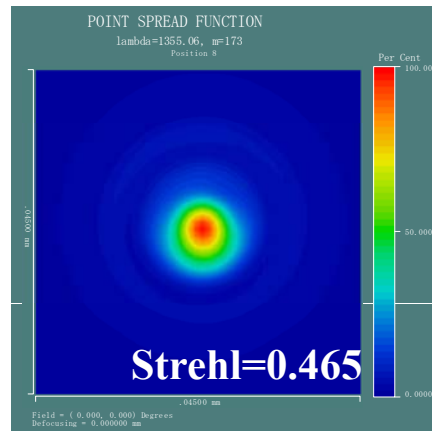
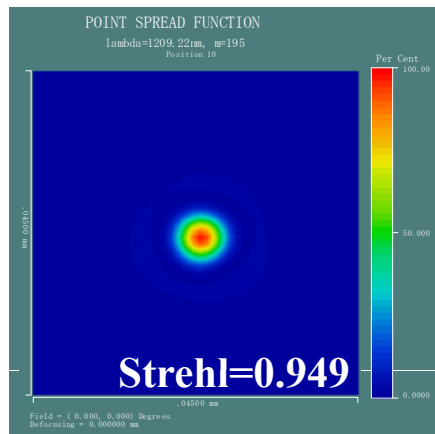
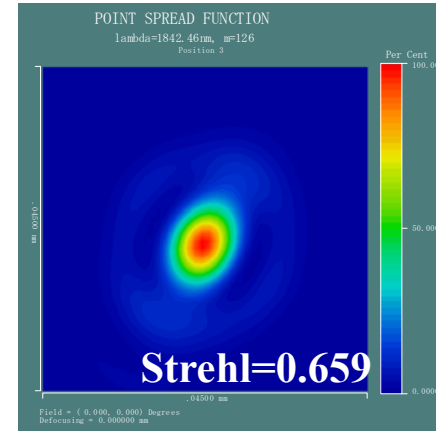
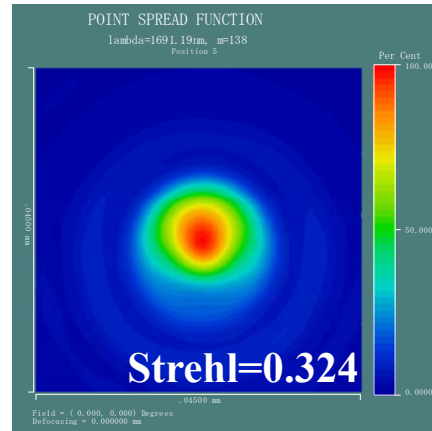
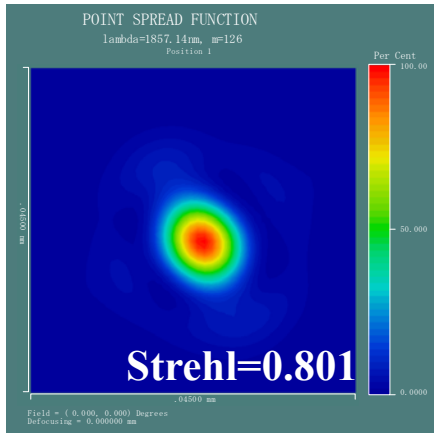


Optical performances: Echellogram

H4RG15



Optical performances: PSF (box size = 3pix²)



Our Astro-comb design

- Under development at Kurokawa-lab (TAUT)
- Prototype comb already exists
- Spec summary

Spectrometer Resolution

分光器の分解能 3 [GHz]@1500 nm

About 7000 lines of comb

約7000本のコム

Frequency stability

周波数安定性

0.5 MHz/week

Comb interval

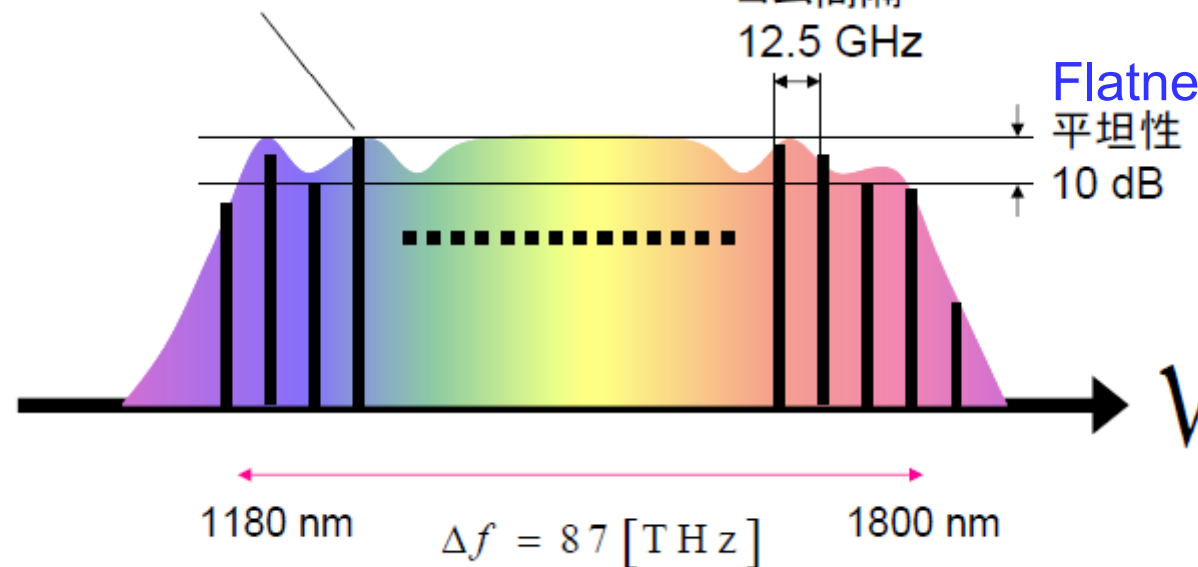
コム間隔

12.5 GHz

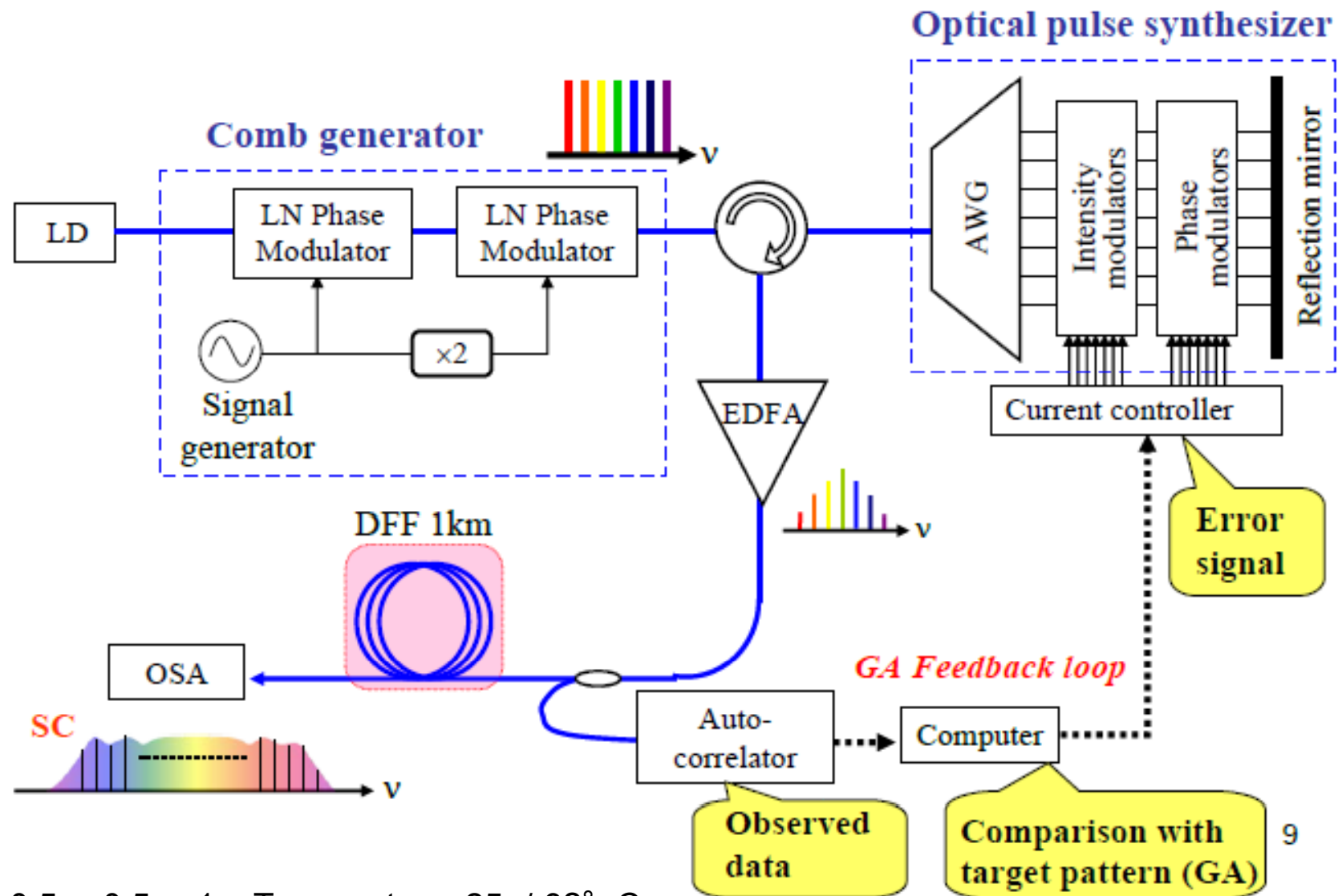
Flatness

平坦性

10 dB



Our Astro-comb design (Kurokawa-lab)



Size: 0.5m x 0.5m x 1m; Temperature: 25 +/- 3 °C

Current IRD team and contributors (FY 2011)

★ Aoki, Guyon, Hall, Harakawa,
Hashimoto, Hayano, Hayashi,
Hirano, Hodapp, Ikeda,
Izumiura, Kambe, Kashiwagi,
Kokubo, Kudo, Kurokawa,
Kusakabe, Kuzuhara, Kwon,
Matsuo, Morino, Nagata,
Narita, Nishikawa, Nishiyama,
Sato, Suenaga, Suto, Suzuki,
Takahashi, Takami, Takato,
Tamura, Terada, Usuda, Washimi

blue=students

Working teams

- ★ Optics team
- ★ Camera team
- ★ Astro-comb and new gas-cell team (incl. fibers)
- ★ Lab experiments (optics, fibers)
- ★ IR wave-front sensing team
- ★ Science (Target and Data reduction) team
- ★ HDS new CCD and non-exoplanet science applications
- ★ Subaru interface & collaboration with IRCS-upgrade
- ★ Observation software (plan)
- ★ Project management
- ★ JSPS fund direct CoIs

Summary

- We have started the construction of a high-precision (1 m/s) near-infrared spectrometer (IRD) dedicated for the Earth-like planet detection around ~1000 low-mass stars.
- This is one of the important steps on the roadmap to TMT/SEIT for Earth-like planet detections, imaging, and characterization.
- Optical designs for 2 kinds of detector options exist.
- An original type of frequency comb systems covering 1.2-1.8 μm will be used for the extreme accurate wavelength calibration.
- Fiber-fed optics both from the telescope and the comb will be used.
- We plan to have a CDR in FY2011 and first light in FY2014.