Progress report on the study of data acquisition and analysis method for precise radial velocity measurement using astro-comb II.

（公募研究）天文コムを利用した視線速度精密測定のためのデータ取得・解析法の研究

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outline of my talk

* some backgrounds nad motivations to start this Koubo-Kenkyu

* development of rv analysis code for astro-comb (and Th-Ar)
    potential precision to measure rv with HIDES

* preliminary examinations of astro-combs and Th-Ar spectra in FY2017

* summary and comments on Okayama Astrophysical Observatory (OAO)

some backgrounds and motivations …

* Mainly for exoplanet searches and asteroseismology, we have made radial-velocity measurements of stars with our 188 cm telescope, HIgh Dispersion Echelle Spectrograph, and an iodine cell (gas cell) at Okayama for these 18 years and its precision is about 2 m/s or so.

* The precision is apparently not photon noise limited.

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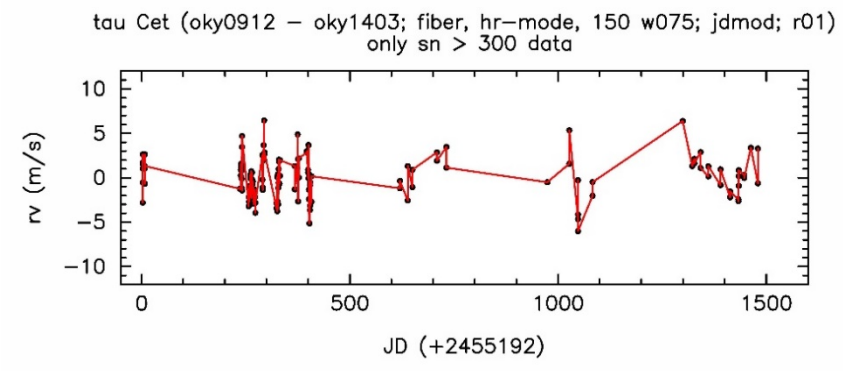
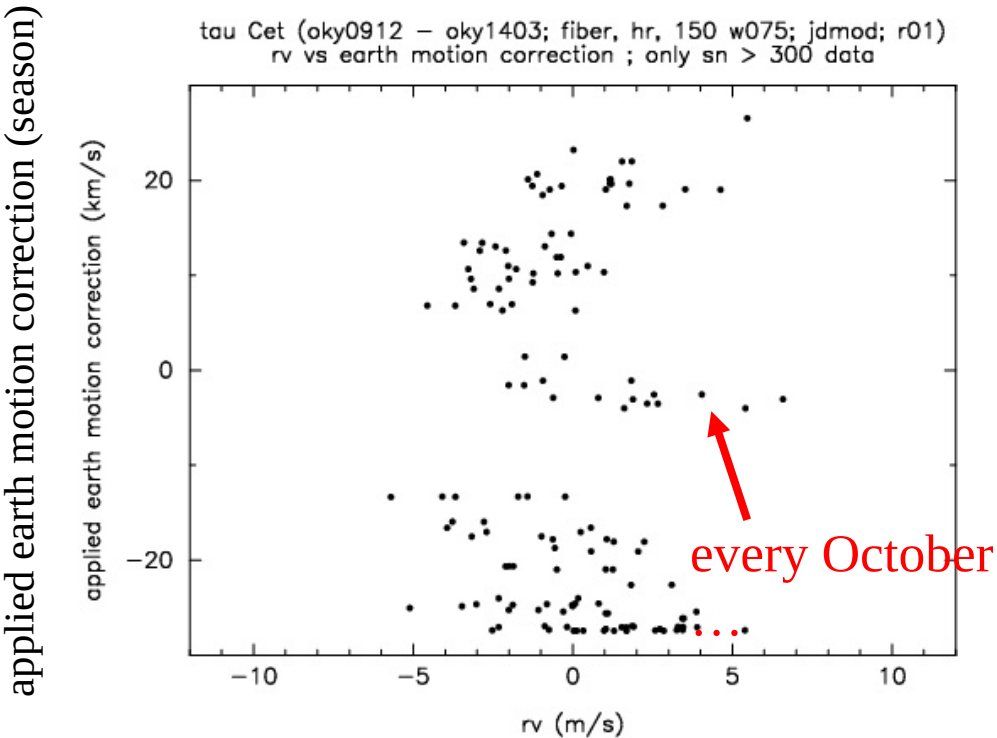


σ∼2 m/s



* In 2014, AIST(+YNU, UEC) was funded to build their astro-comb and suggested us to install it in HIDES. We took it a good opportunity to examine the problem in detail.

two to three times wider wavelength region than that of I2 technique

30 % higher throughput without contamination of I2 lines in stellar spectra

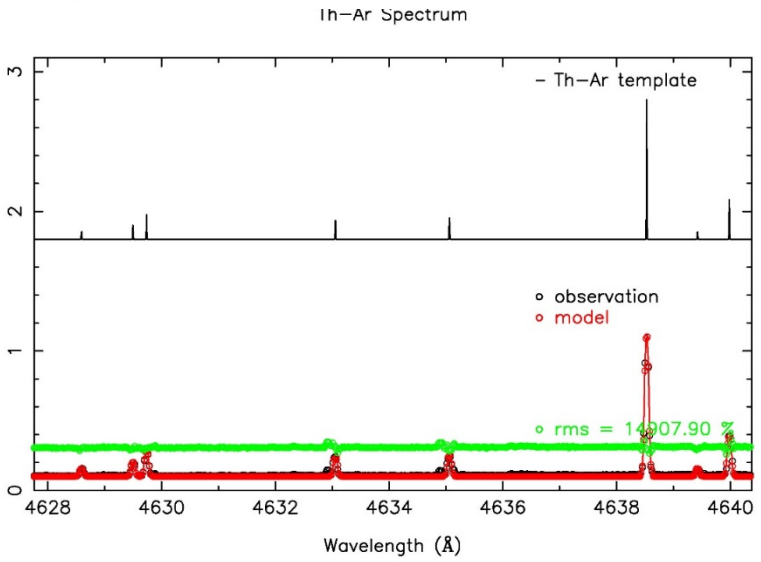
development of rv analysis code for astro-comb (and Th-Ar)

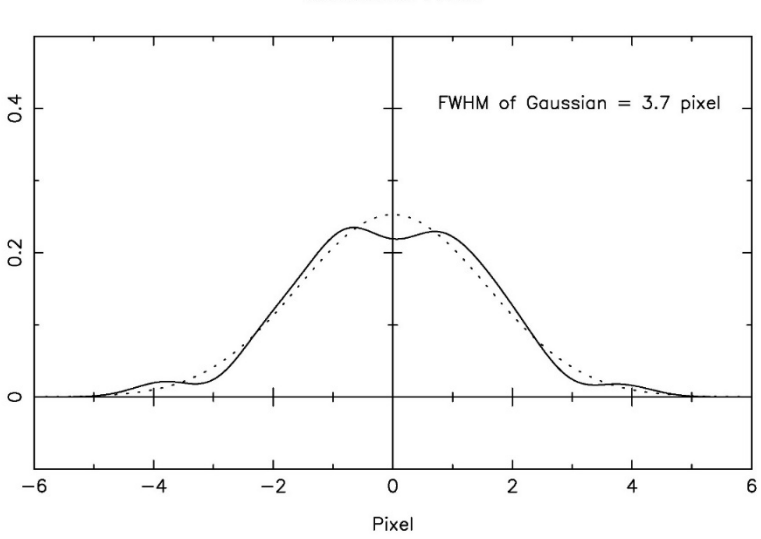
* the first step to measure rv's of astronomical objects is to determine the wavelength of astro-comb (or Th-Ar) spectrum on the CCD detector.

* to take into account variations of instrument profile (IP; or shape of emission lines) more properly, we use a multiple Gaussian (one central and several satellite Gaussians) profile model in the spectrum fitting.

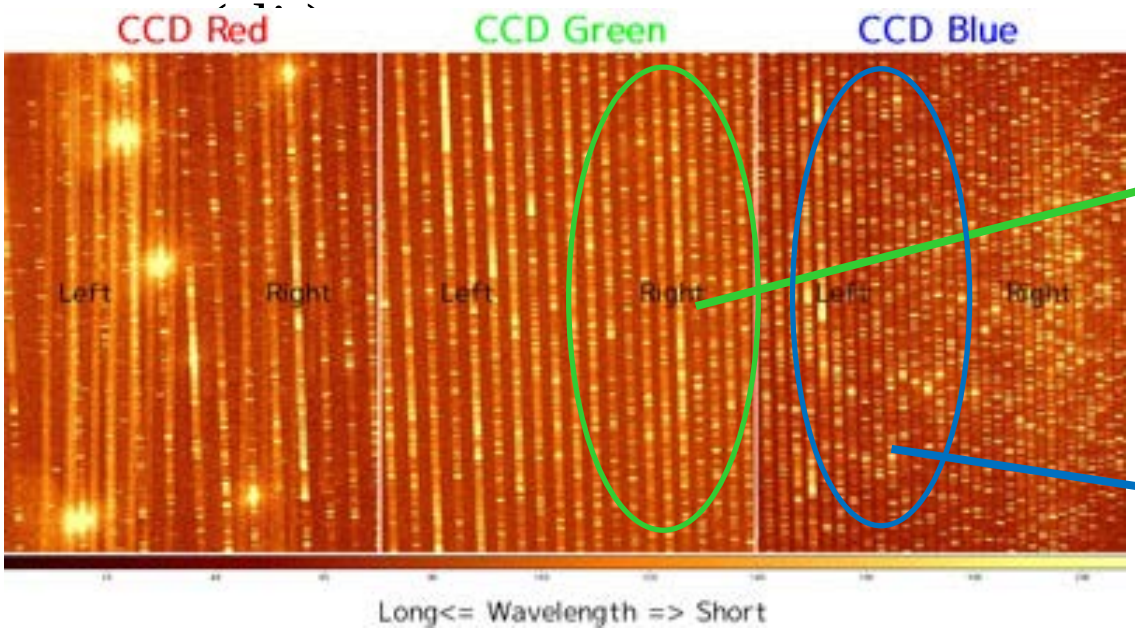
* wavelength at each detector position is determined so that the 1st moment of the monochromatic IP is zero.

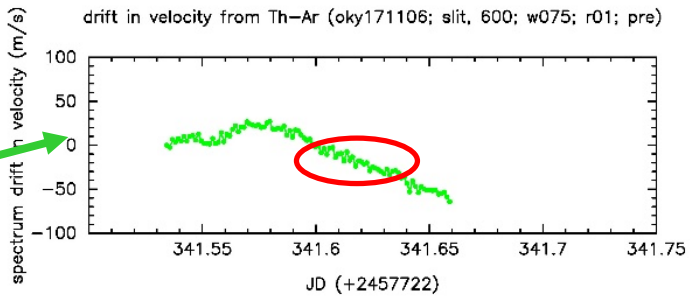
➔ so far, we use this code to examine drifts of emission spectra on the CCD detector

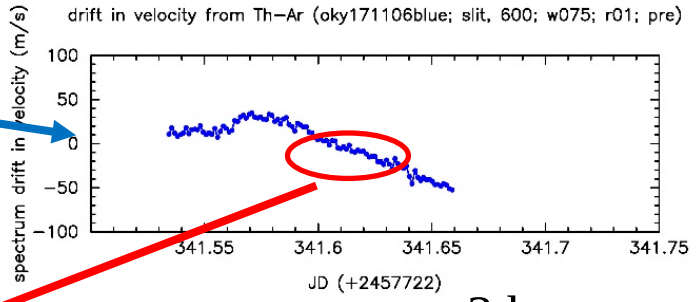




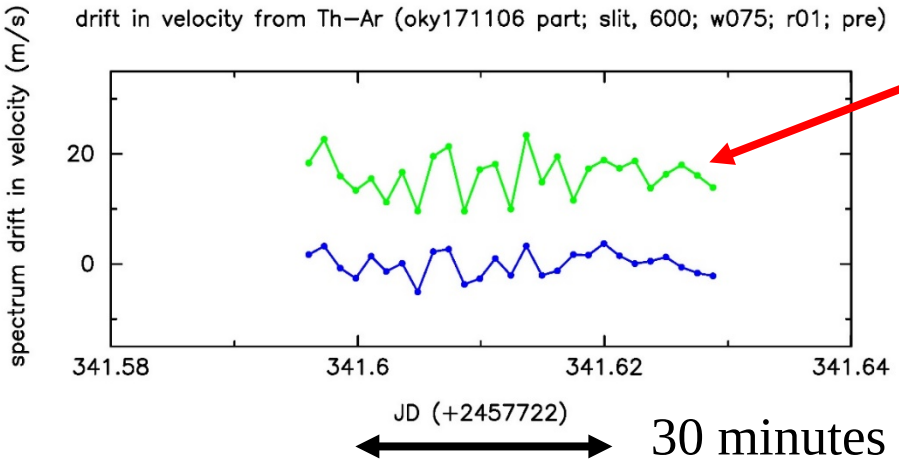
Potential precision to measure rv with HIDES by Th-Ar







3 hours



30 minutes

σg,apparent～2.7 m/s

σ(g-b)～2 m/s

➔ σg～ σb～1.4 m/s

➔ σall,random≦1 m/s

Once we can remove (compensate) the 2.7 m/s level short-term variations, HIDES may be able to measure rv with 1 m/s precision even with Th-Ar.

preliminary examinations of astro-combs and Th-Ar spectra in FY2017

the following results are all very preliminary

AIST comb

* the adjustment of the 1st version of AIST comb is finalized in May, 2017

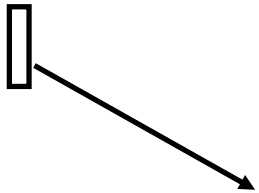
* although we planned to make test observations for several nights in December, 2017, the run was clouded out. So, we could only take experimental data..

AIST astro-comb as of May, 2017

30 min. exposure

42 GHz

temporally unavailable



550 nm

500 nm

intensity of comb lines varies considerably in short time

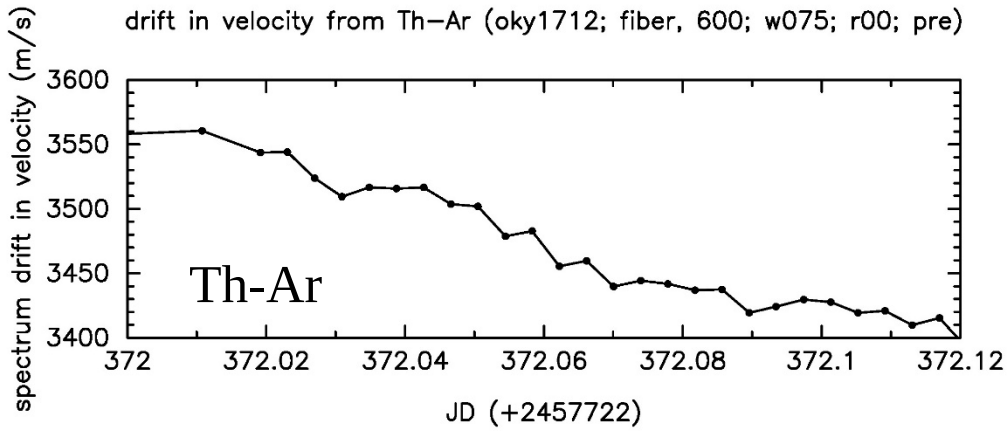
➔ so every time we fit the IP, we refer to the different portion of the spectrum.

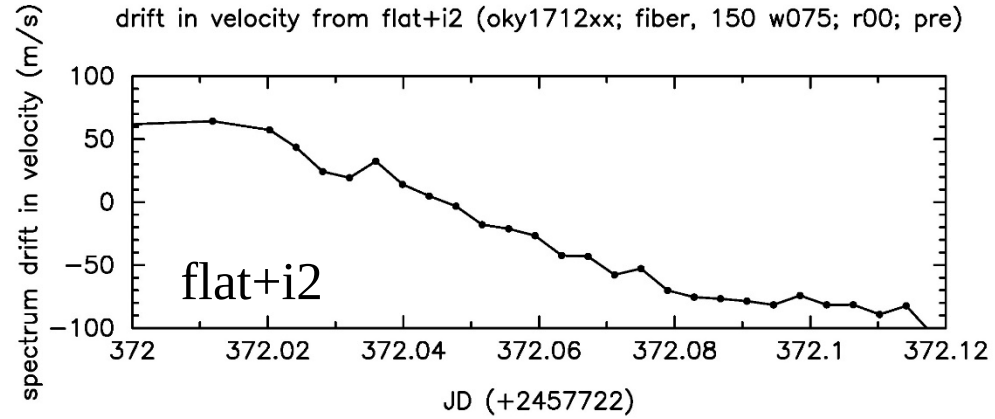
temporally unavailable

examples in December, 2017

temporally unavailable

AIST astro-comb





we took a sequence AIST astro-comb, Th-Ar, flat+i2 spectra with fiber-feeding mode and compared spectrum drift on the detector.

* all references can follow the gradual trend due to the distortion of the spectrograph

* the rv scatter of AIST astrocomb is the largest because of the limited wavelength coverage and its temporal variations

* the rv scatter of Th-Ar with the fiber-feed mode (10 m/s ~20 m/s) is larger than that with the slit mode. The rv scatter of flat+i2 is also large (more than a few m/s to 20 m/s)

these are probably due to fiber modal noise

University of Tokyo (UoT) astro-comb

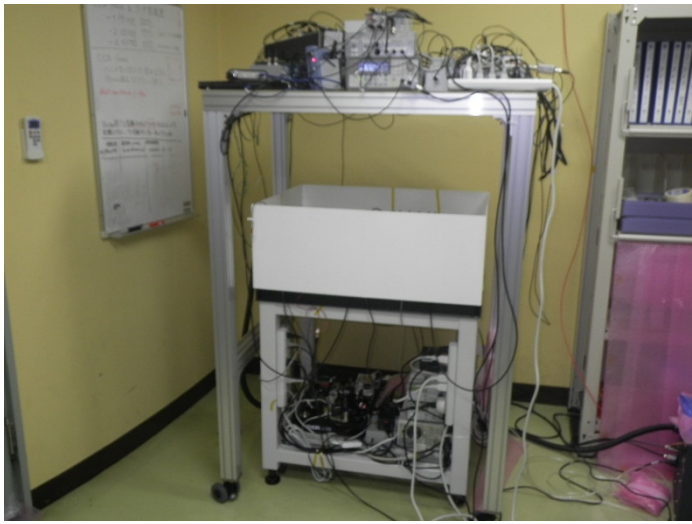
* Yoshioka-san's group at Photon Science Center, School of Engineering, University of Tokyo is developing an astro-comb for TAO 6.5m telescope. *http://www.fs.t.u-tokyo.ac.jp/index.html*

* HIDES is used for very preliminary test/observation in Dec., 2017
again clouded out …

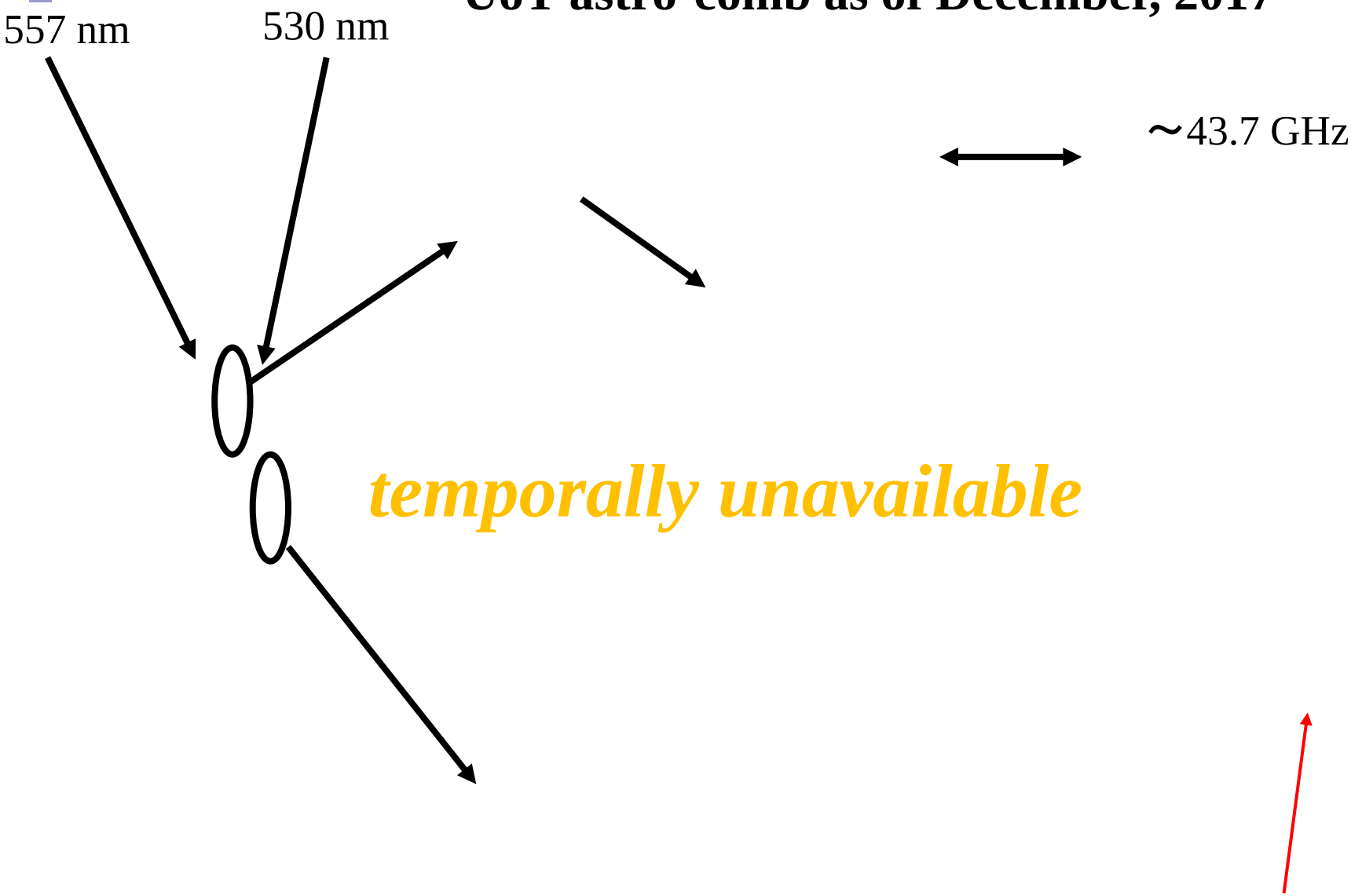
* compact in design

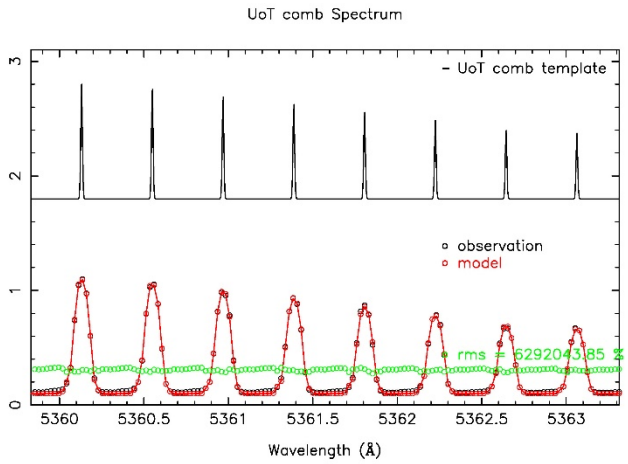
* (durable) Ti:sapphire laser comb with repetition rate of 1.5 GHz

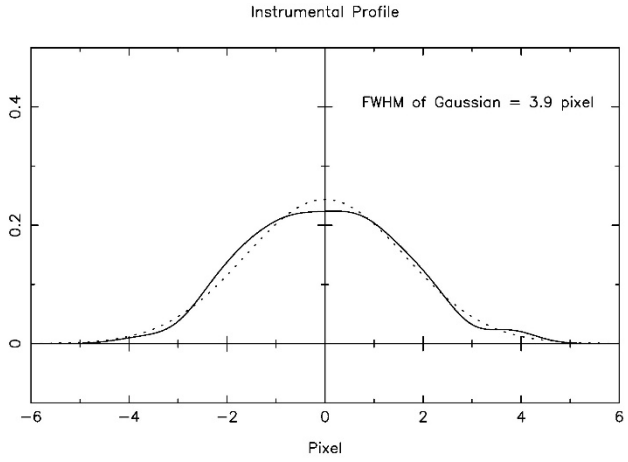
*only need one Fabry-Perot to pick up optimally separated comb lines
➔ fairly strong and temporally stable
➔ still limited to 20 nm〜30 nm width due to incomplete mode-filtering



UoT astro-comb as of December, 2017





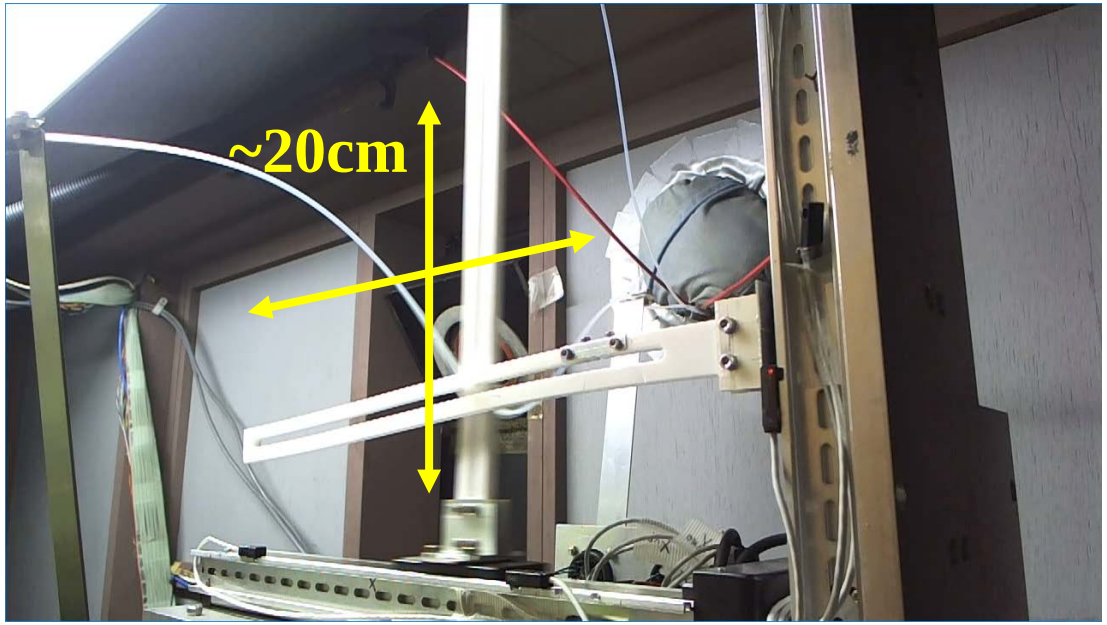


temporally unavailable

σ(3 orders) ~8 m/s

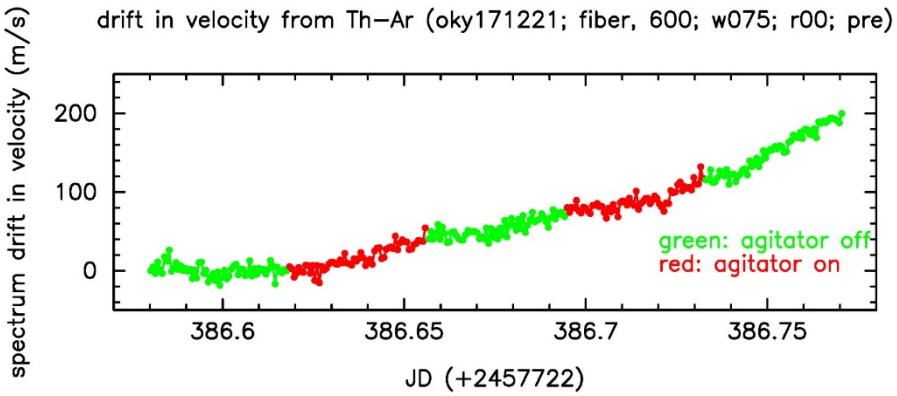
test of fiber agitator

* The open-use of our telescope is finished on Dec. 21, 2017, we had a chance to test the first version of the fiber agitator to reduce the fiber noise.
* it shakes the fiber randomly in 2D at every sub-seconds.



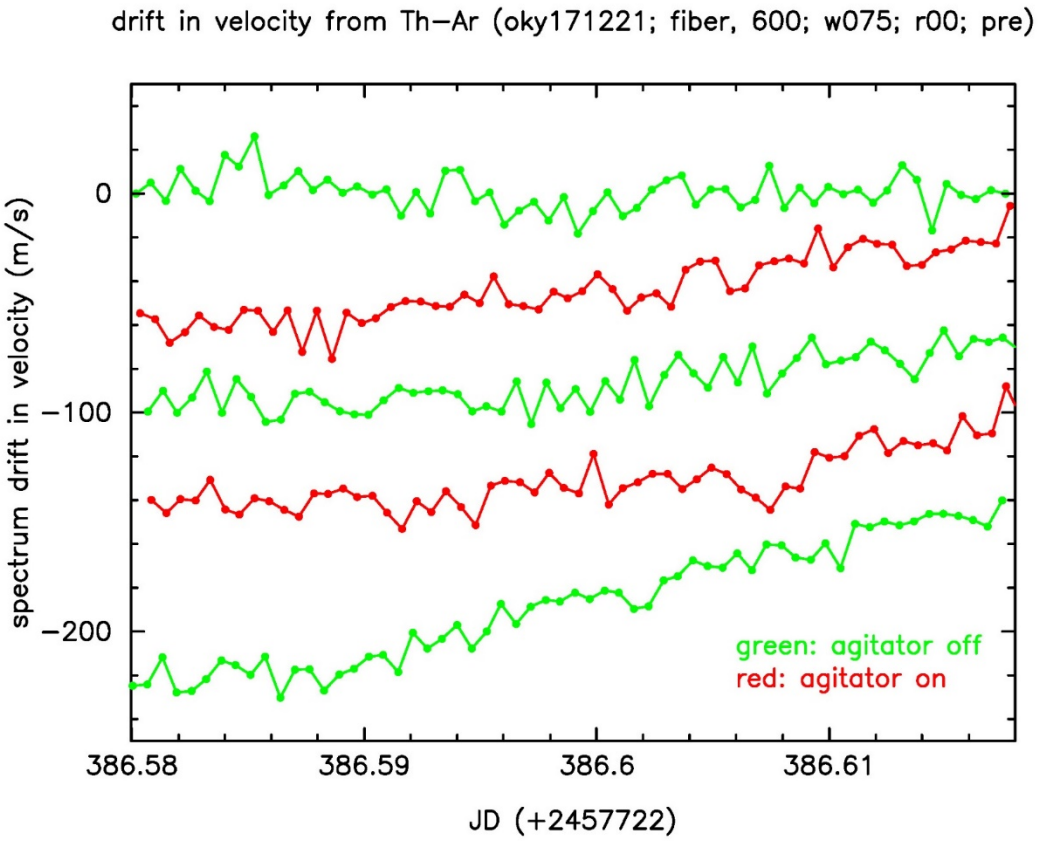
typical slit illumination

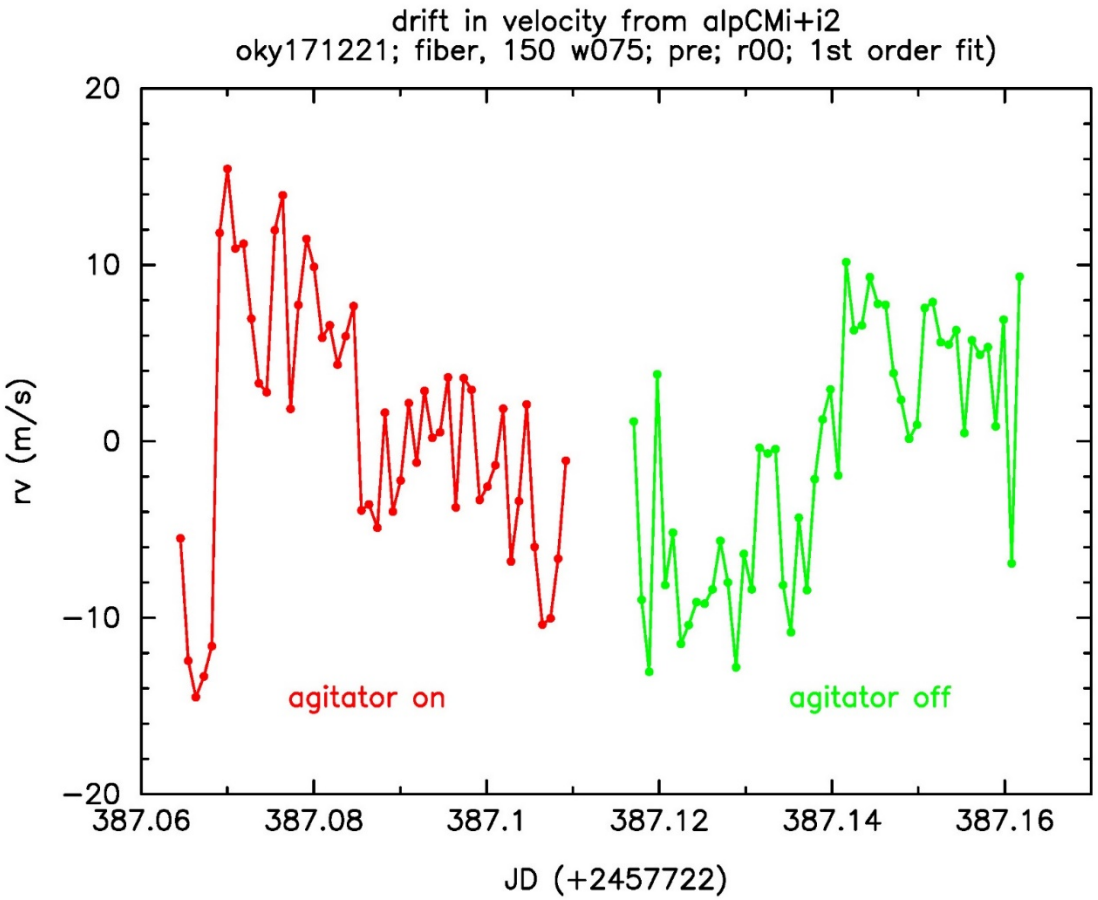
~6,000m/s



in the case of Th-Ar

5 second exposures





in the case of α CMi (+i2)

30 second exposures

➔ effects of this fiber agitator is not significant. Further study is necessary.

summary and comments on OAO

* we have provided test-bed of astro-combs and started experiments

* we have developed a code to determine astro-comb (and Th-Ar) spectrum on the CCD detector and examine the stability of HIDES.
potential ability to measure rv can be as good as 1 m/s

* based on the experiments at OAO, astro-combs developing groups are now revising their astro-combs.

* from April, the 188 cm telescope and HIDES will be operated by user groups led by the Exoplanet Observation Research Center at Tokyo Institute of Technology.
OAO will become Okayama Branch of the Subaru Telescope to promote open-use of Kyoto University 3.8m telescope

* HIDES is now under renovation to significantly increase its stability (Izumiura-san's [JSPS KAKENHI Grant Number JP16H02169)」)

➔ will be able to provide better testbed for astrocombs.

* we will continue our activity under collaborations with TiTech, AIST (ERATO and 新学術領域)[, UoT, and etc.]