Long-term observations of the Galilean moons with high spatial and spectral resolutions

（高空間・高分散分光によるガリレオ衛星の長期観測）

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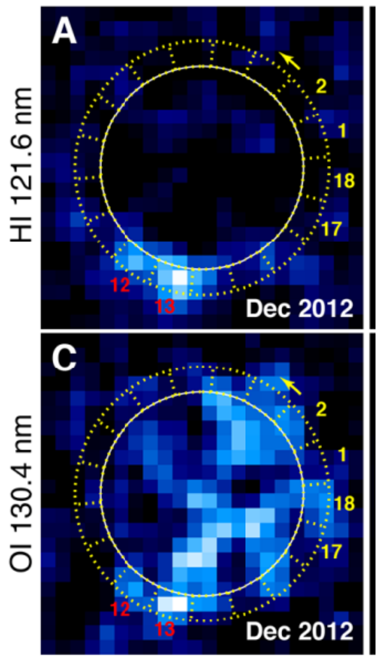
ABSTRACT

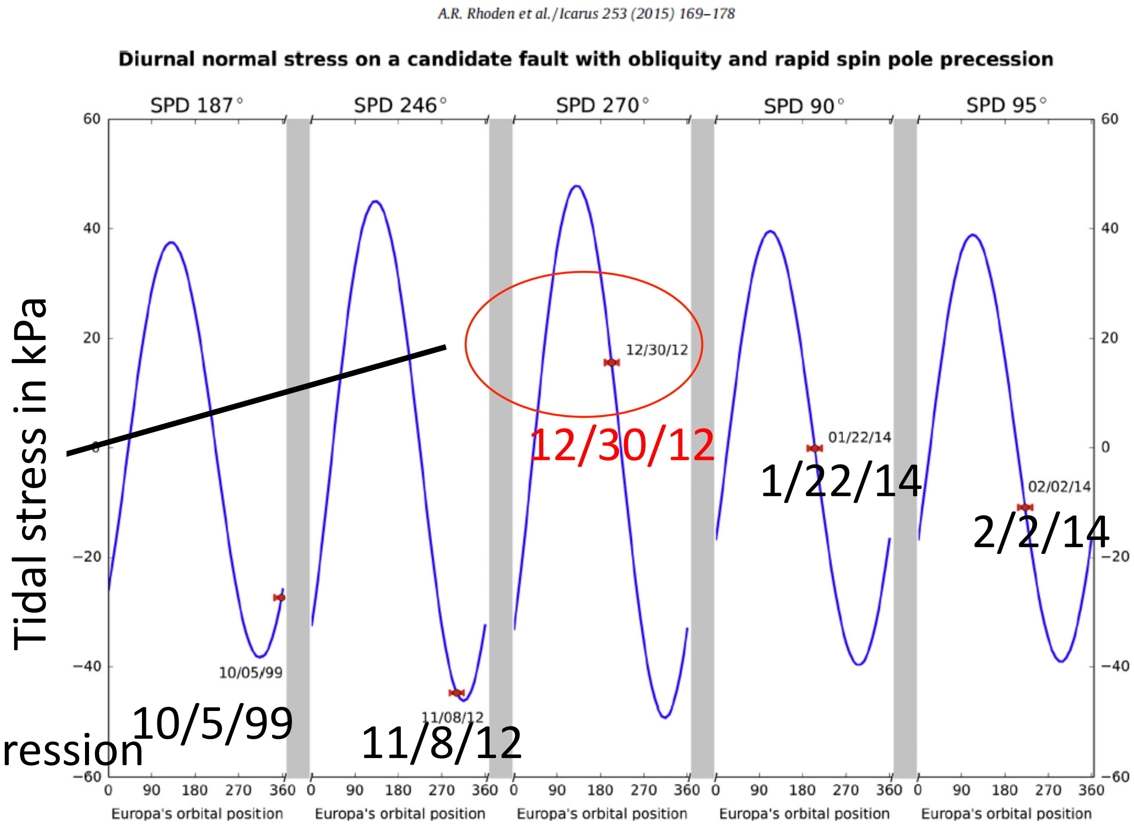
We plan a long-term monitoring of localized water vapor plume activities on the Galilean moons with a combination of an Extreme Adaptive Optics (ExAO) and a near-infrared high-dispersion spectrograph mounted on the Kyoto 3.8m telescope. The simple high-dispersion spectrograph with a spectral resolution of 220,000 puts just behind the ExAO. Since the ExAO on the 3.8m telescope provides a spatial resolution of 70 milli-arcsecond, corresponding to ~160km on the Galilean moons, such a unique instrument has a potential to detect localized water vapor absorptions on the Galilean moons. We start to observe from the beginning of 2017. In this report, we introduce our current status toward the long-term monitoring of the Galilean moons.

HST and Voyager observations of Europa

- Plume activity detected at only one time.
- Lyman α and OI emission lines detected.



Roth et al. 2014

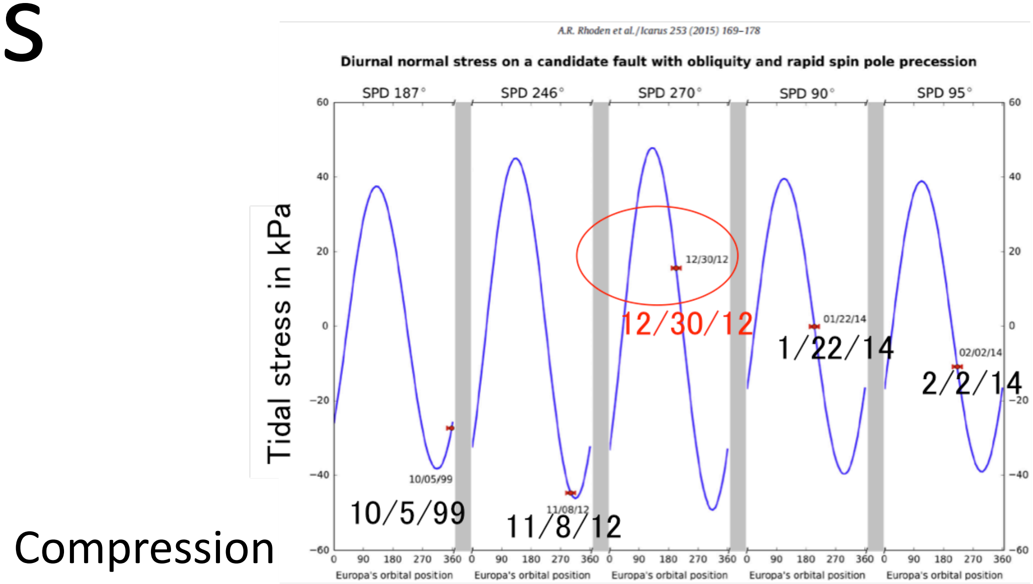


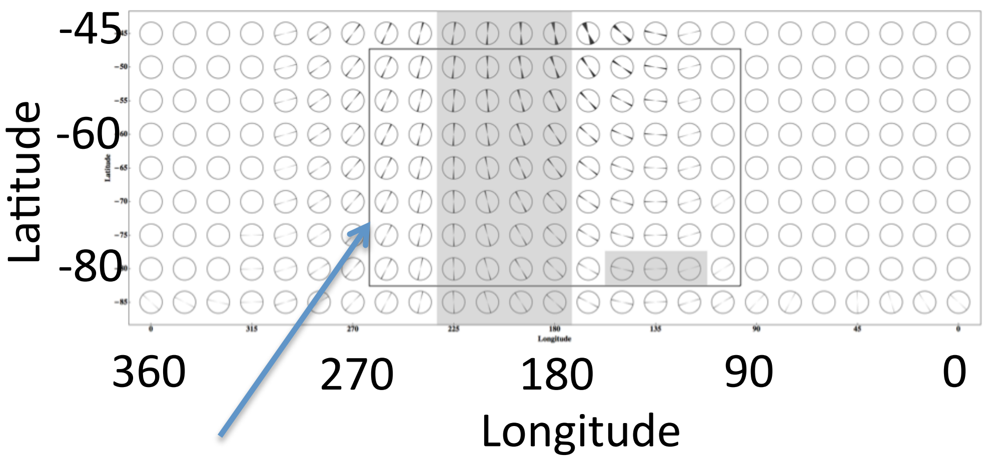
Rhoden et al. 2015

Motivations

- Confirm long-term temporal variation of plume activity due to tidal interaction.
- Identify the place where plume activity is high.
- Investigate composition of plume (internal sea)

  → thermal environment in the era of the Europa formation.

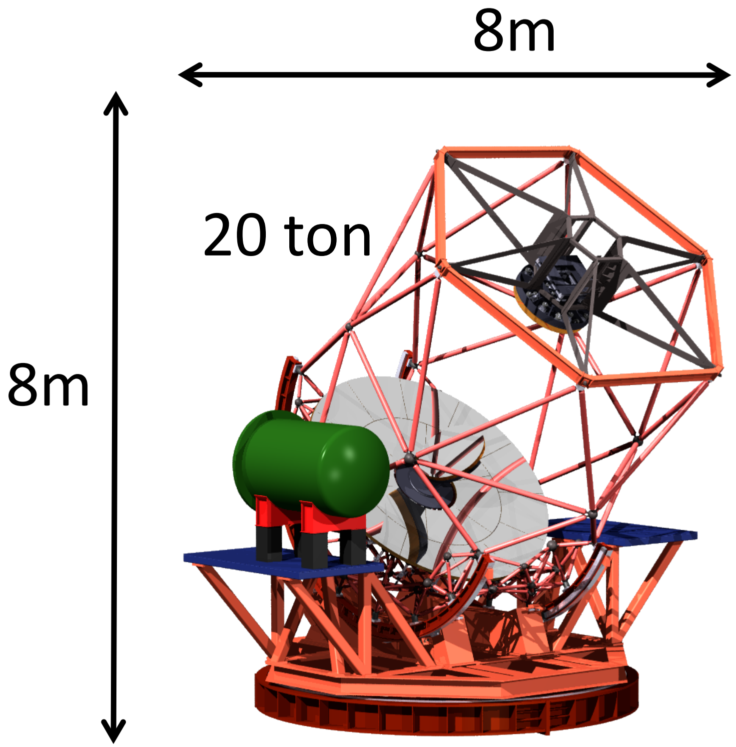


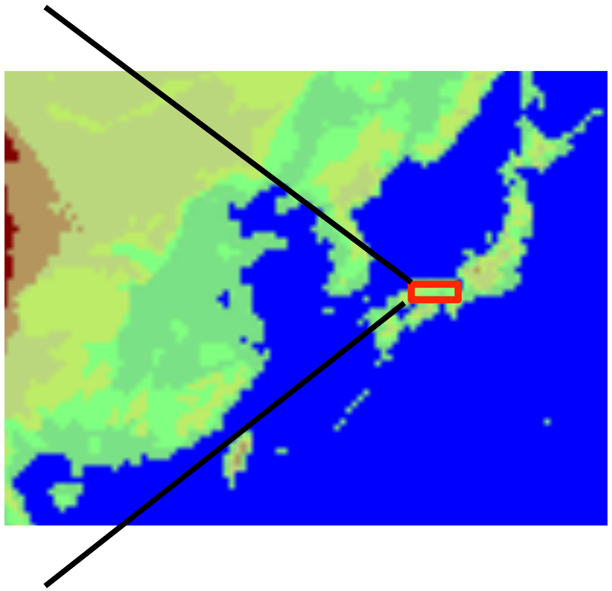


The plume activity is expected to be high in the southern hemisphere.

Rhoden et al. 2015

Kyoto 4m telescope





- Telescope:
  - 18 petal-shape mirrors
  - high speed drive due to lightweight for follow-up of transient objects.
  - under construction phase
  - First light in 2016 and science operation in 2017

- Site (Okayama) condition:
  - Typical seeing: 1”
  - Wind speed: 10m/s

Extreme AO project on Kyoto 3.8m telescope

(Matsuo et al. 2014)

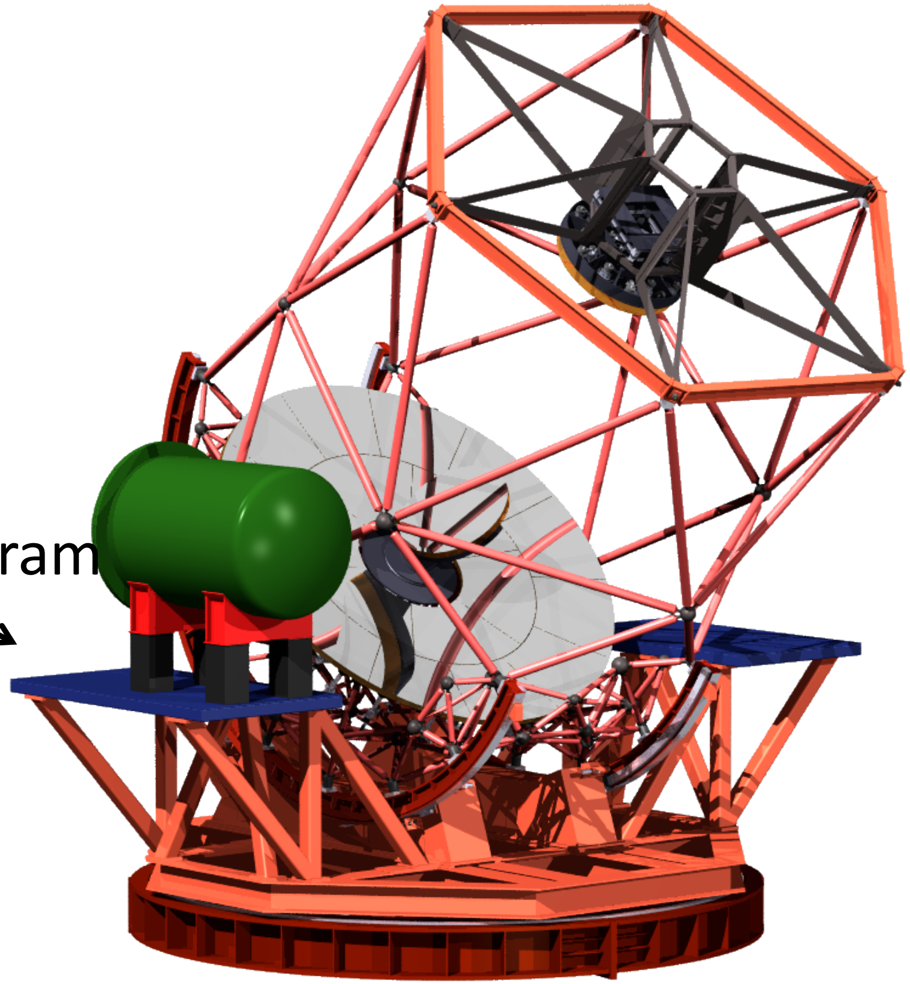
- Program
- 100 nights / year allocated for this project.
- Budget: ~$300k/yr for 3 years from MEXT, NAOJ, J-TMT.

- Purpose:

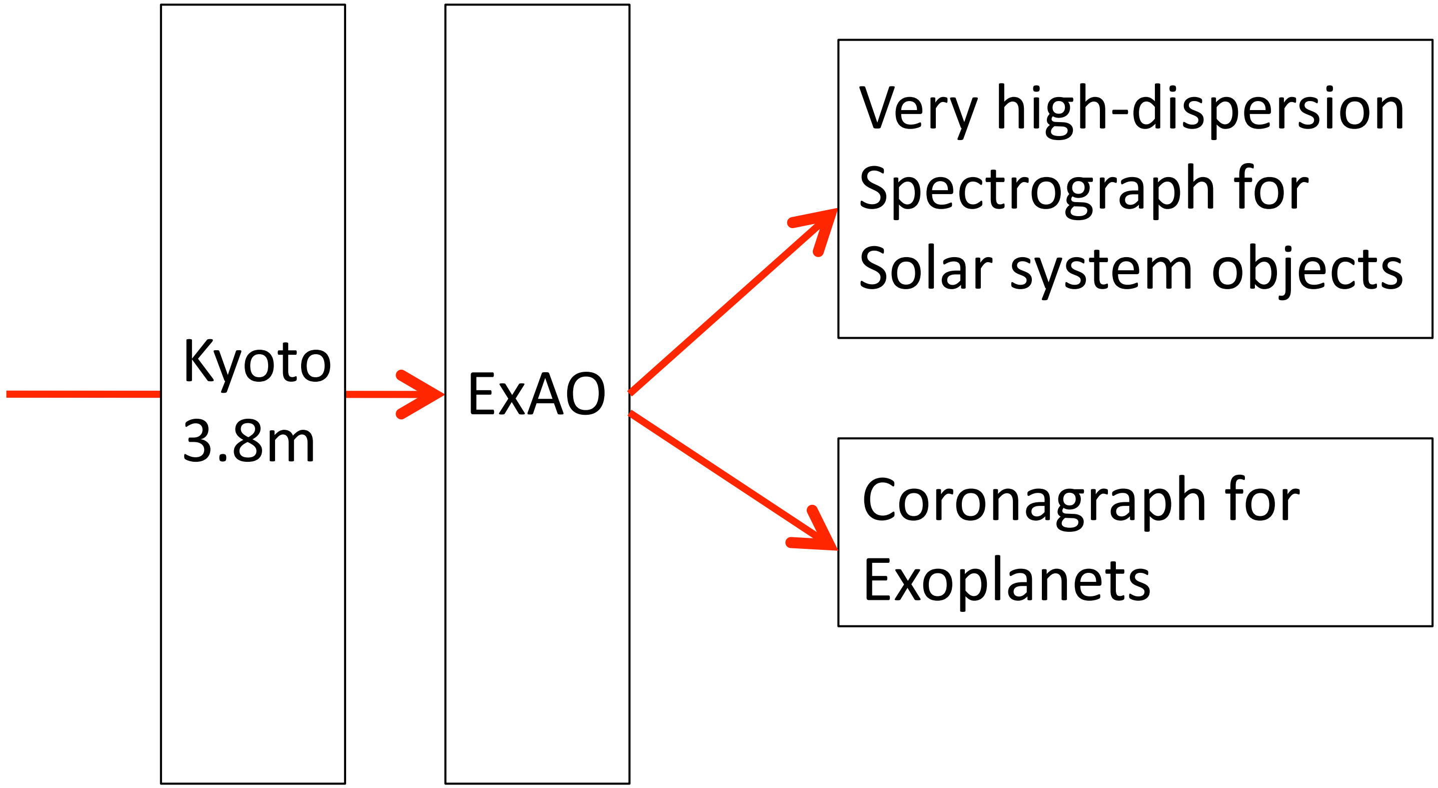
a) Establish ExAO techniques toward TMT in Japan

b) Characterize solar system objects, especially the Galilean moons.

c) Characterize self-luminous exoplanets.

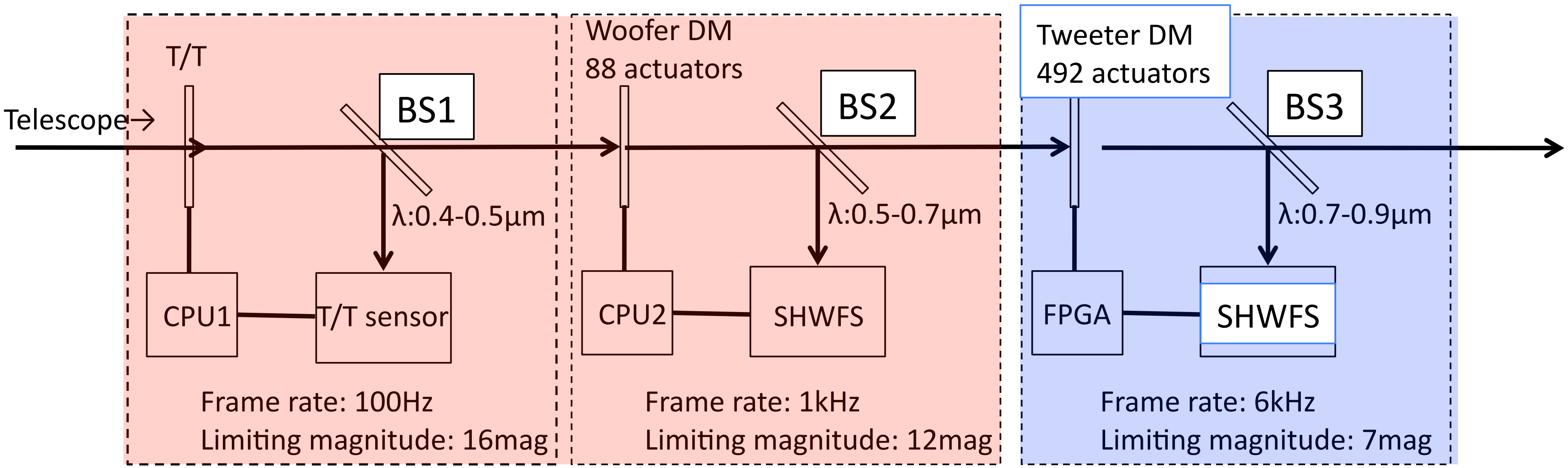


Block diagram

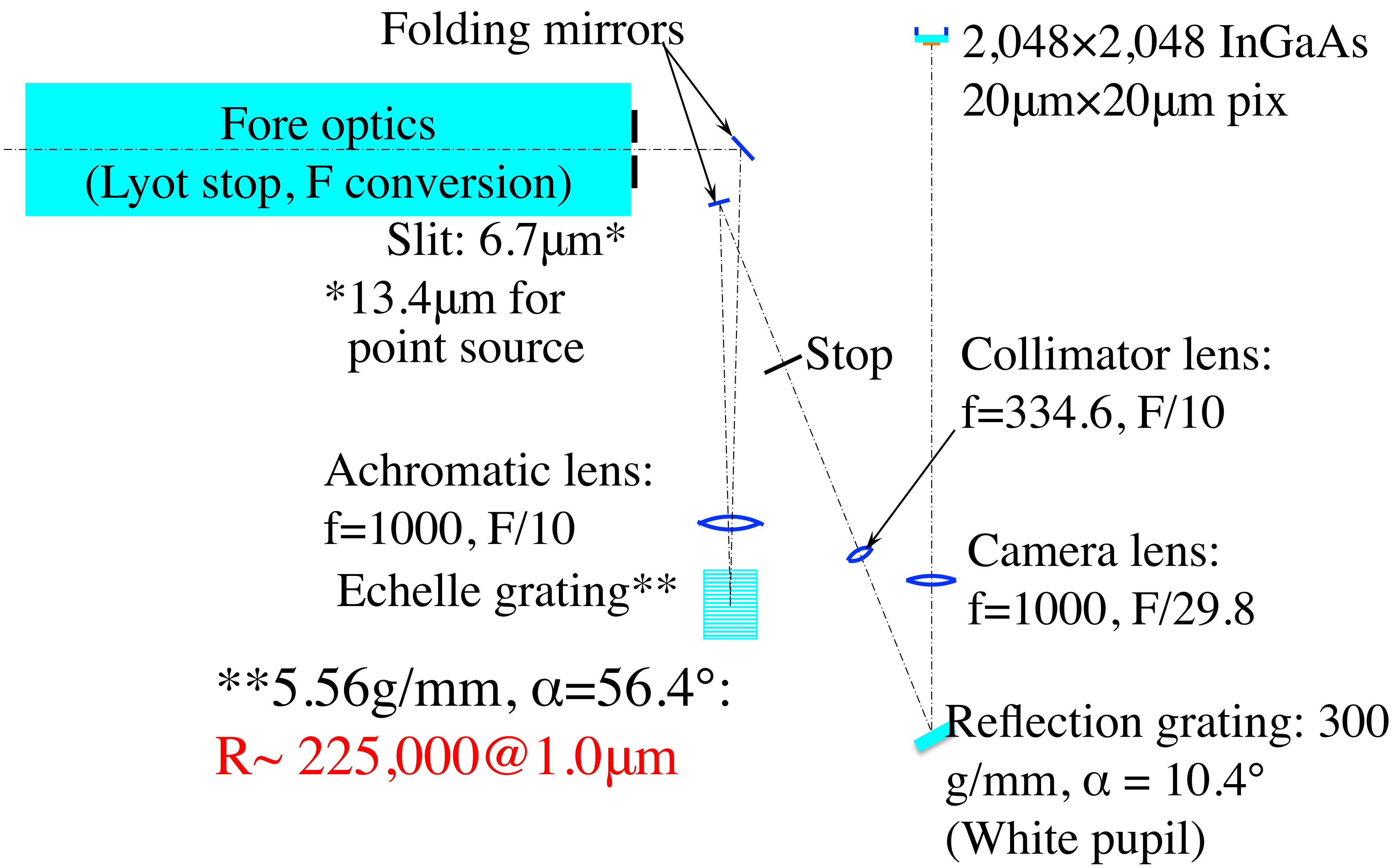


AO system diagram

- Compensate distorted wavefront due to atmospheric turbulence with three units
- Wavefront sensors optimized for the Galilean moons (their apparent diameters are lager than that of a point source).



High-dispersion spectrograph

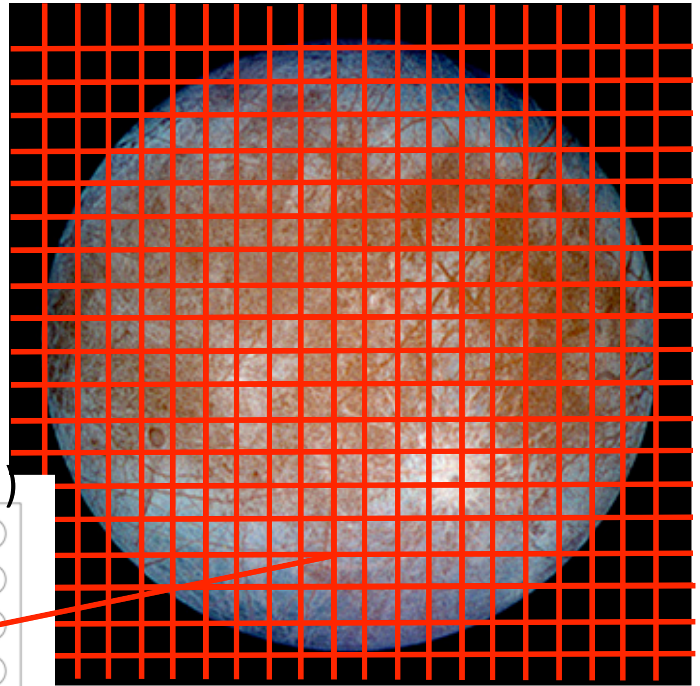


Europa Observation with SEICA

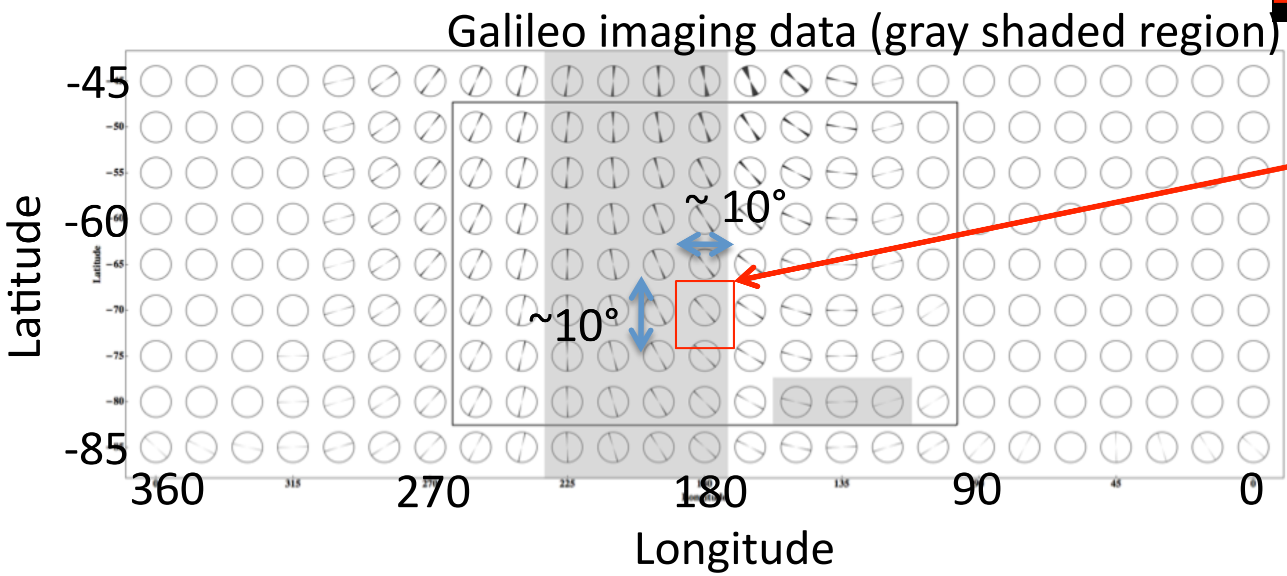
- ExAO provides a high spatial resolution.

  → 19 x 19 (~ 165km) for Europa

  (~ 1.4 times higher than HST)



Comparing of Europa with the spatial resolution at 1μm



Distribution of candidate faults (Rhoden et al. 2015)

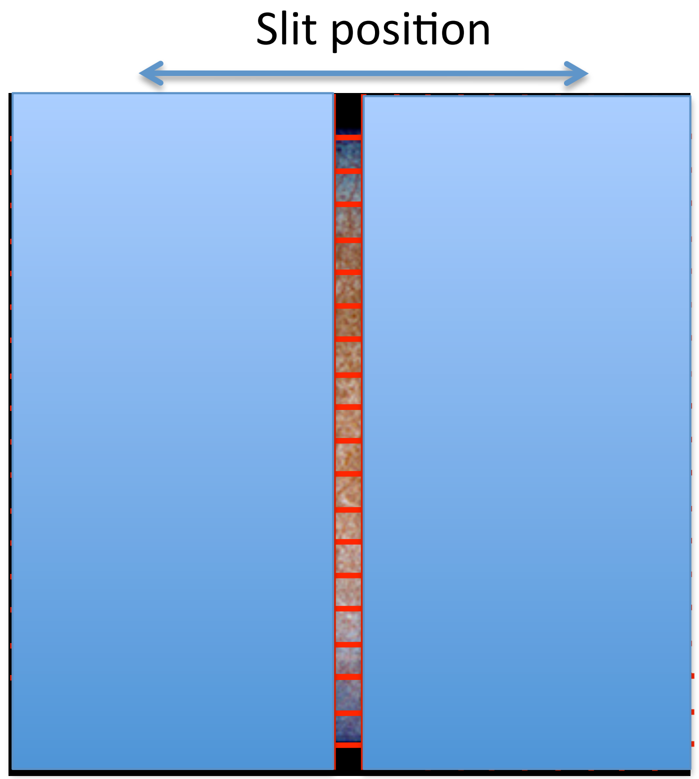
Observation Method

- Restrict one dimension due to the slit of spectrograph.

→ Obtain 19 observing points simultaneously.

- Acquire spectra of all spatially-resolved points over the entire disk, adjusting the slit position with T/T mirror.

→ Total observing time is 19 times longer than that of usual observation.



Comparing of Europa with the spatial resolution at 1μm

Atmospheric compensation

- ExAO provides the two advantages.

  - acquire multiple observing points simultaneously.
  - stabilize point-spread function.

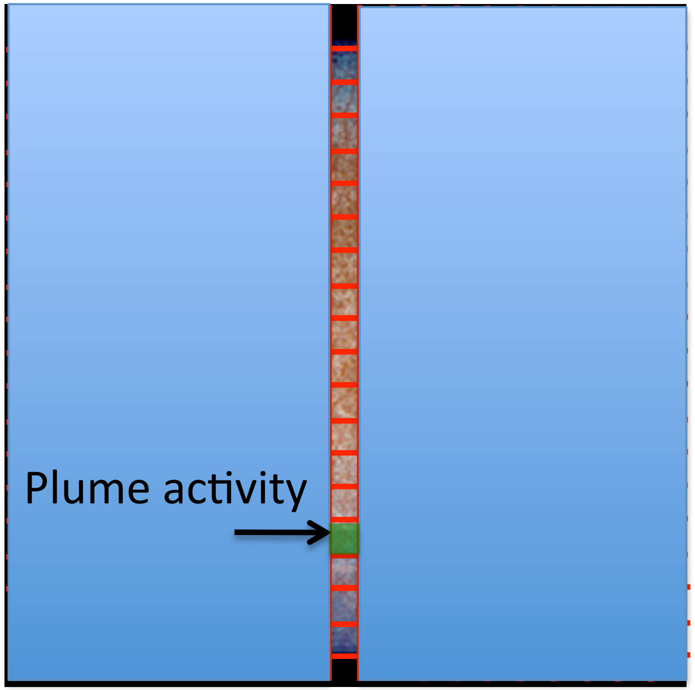
→ High precision spectro-photometry

- Accurate atmospheric compensation:

  Spectrum of plume =

  (spectrum included in plume activity)

  – (spectrum w/o plume).



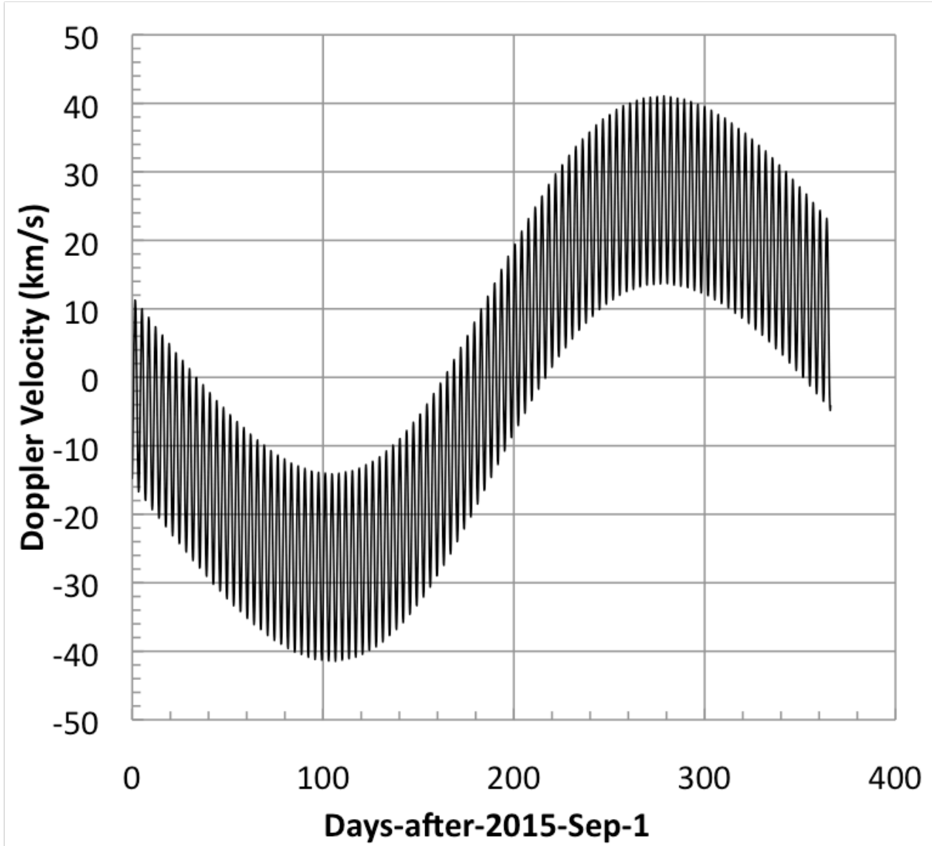
Comparing of Europa with the spatial resolution at 1μm

Doppler-shift measurement

- The water vapor absorption can be separated from the telluric one, thanks to the large doppler velocity.

- Telluric pressure broadening : ~ 0.05-0.10 cm^{-1} atm^{-1}

→ High-dispersion spectroscopy of R > 100,000



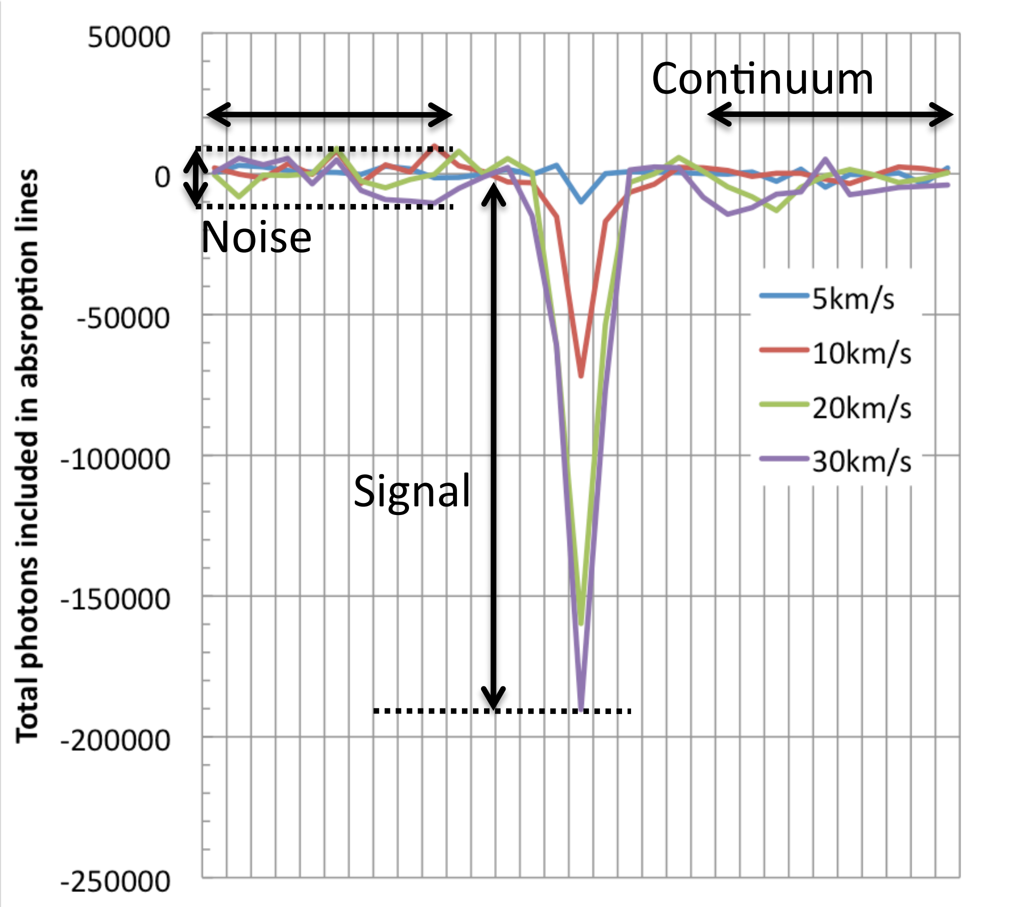
Doppler velocity between Europa and Earth.

Column density of water vapor on Europa

- Based on the previous observation (Roth et al. 2013), the characteristics of the plume occurred at the south pole are
- Estimated eruption rate: 7000 [kg/sec] → 2.3 x 10^29 [/sec]
- Height of the water column: 200 [km]
- Velocity of the water column: 400 [m/sec]

- Since the life time of water vapor is ~ 500 sec, the number of water vapor molecules included in the water column is 1.4x10^32.
- Assuming that the water vapor molecule is none except for the plume, the column density for this observation with a spatial resolution of 160km^2 is 5 x 10^17 [/cm^2].

Detectability of water vapor absorptions on Eurpoa



Sum of the water vapor absorptions
In 1 hour integration

Definition:

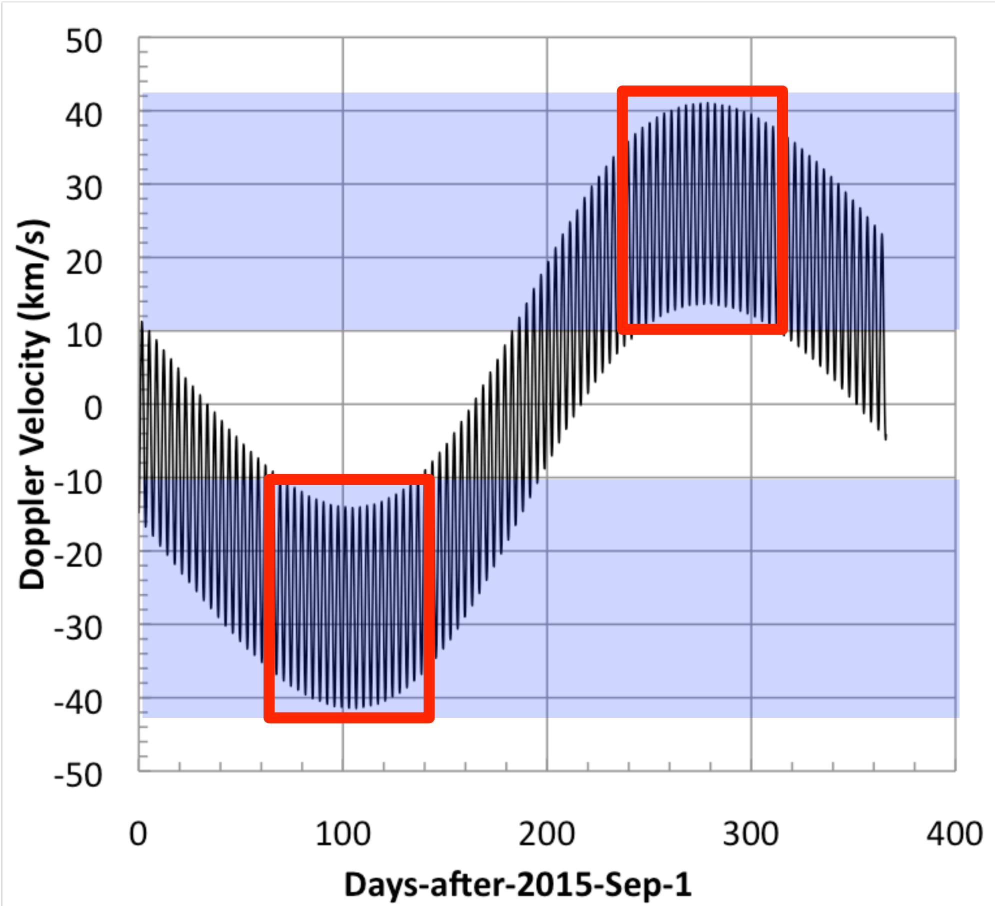
$$S/N \equiv \frac{\text{Peak of absorption line}}{\text{RMS in continuum}}$$

Doppler velocity	S/N
5km/s	0.86
10km/s	4.80
20km/s	7.17
30km/s	6.68

Long-term observations of Europa

- This program potentially cover one orbital period of the Europa (red frame).

-> Investigate between plume activity and tidal fluctuation.

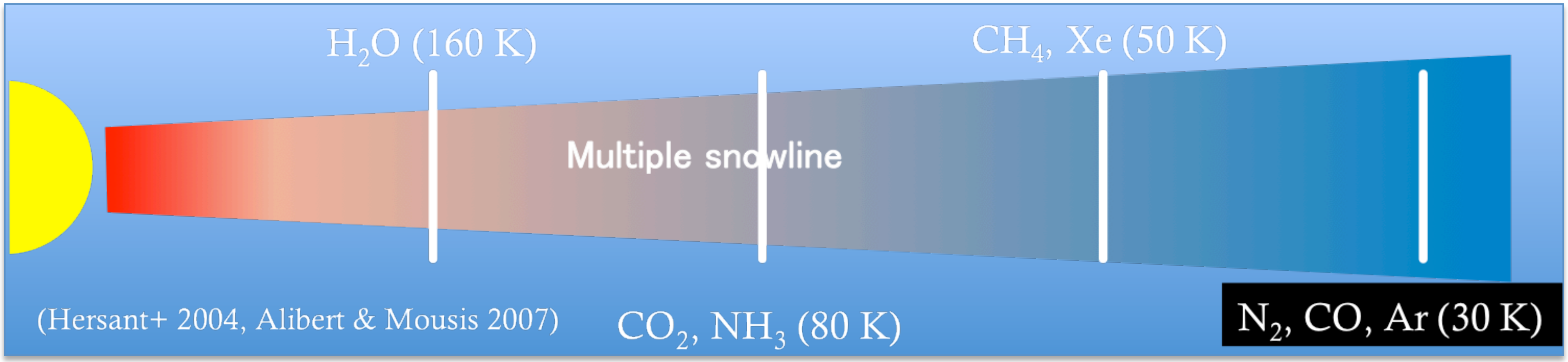


Doppler velocity between Earth and Europa

High-dispersion spectroscopy

- Various volatiles as well as water vapor molecules may be acquired→ CH_4,CO_2, CO, etc…

→ Thermal history in the era of the Europa formation.



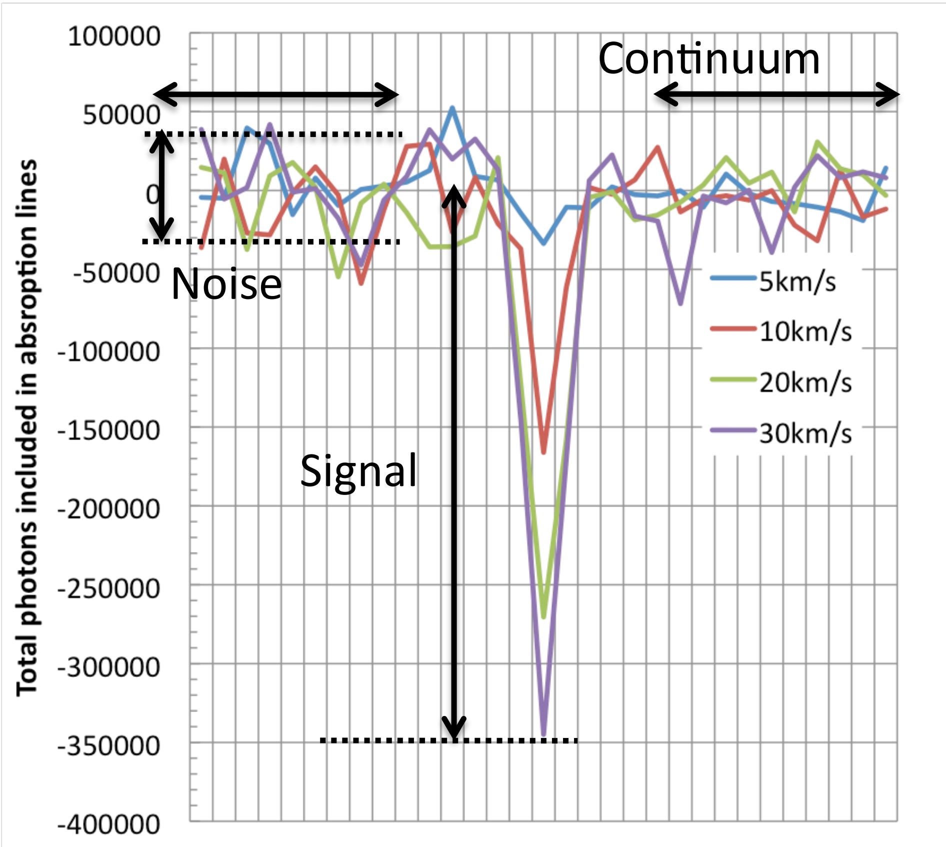
A Step toward Europa observations

- Enceladus is a suitable target for establishment of this method because the plume activity on Europa is observed only one time.

Note that:

- estimated column density of the water vapor on Enceladus is 1 x 10^17 [/cm^2] ← 1/10 of Europa
- Enceladus is 5 mag fainter than Europa.

Detectability of water vapor absorptions on Enceladus



Sum of the water vapor absorptions in 10 days (240 hrs) integration

Doppler velocity	S/N
5km/s	0.59
10km/s	1.66
20km/s	2.43
30km/s	2.91

→ Longer time integration is needed compared to the case of Europa.

How to contribute to the future space missions?

- This program potentially identifies where and when the plume activity is high.

→The information will enhance the scientific values of future space missions such as the JUICE and the Europa clipper.

(The number of the JUICE flyby to Europa is only two during the mission)

Summary

- We propose a large-scale observation of Europa with a combination of ExAO and high-dispersion spectrograph:
- First detection of H_2O molecules (including several other molecules).
- Relation between fault activity and tidal fluctuations.
- Investigation of the thermal history in Europa.

→ Possible contribution to the JUICE and the Europa Clipper programs.