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Why are Venus, the Earth and Mars are so vastly different today, and what led towards these diverging evolutional pathways and ultimately such diverse atmospheric compositions? Extensive global, accurate monitoring of atmospheric composition with ground-based, high-resolution, infrared observations offers invaluable information to answer these questions, allowing for detection of trace gases of interest to compile the planets' atmospheric chemical inventory, as well as mapping of the isotopic composition of water vapor and other major constituents. Moreover, ground-based data are of the utmost importance to provide information complementary to more specialized observations performed in-situ by orbiters and landers.

The ground-based study and detection attempts of organics and trace gases in the atmosphere of has been particularly active in the past years (Krasnopolsky et al., 2004; Mumma et al., 2009; Villanueva et al., 2013), with overwhelming attention going to the search for markers of geological and biological activity (e.g. Knutsen et al., 2021; Montmessin et al., 2021; Webster et al., 2018; Korablev et al., 2021; Liuzzi et al., 2021). Similar considerations apply to Venus, which is now at the center of attention for the claims about the observation of PH_3 in its upper atmosphere (Greaves et al., 2021; Snellen et al., 2020; G. L. Villanueva et al., 2021a).

Isotopic ratios are reliable indicators of atmospheric loss as their relative abundances are tracers of the evolution from their bulk composition. The most prominent example is the measurement of D/H on Mars and Venus, which has been used as a tracer of atmospheric water loss over the course of their histories (e.g. Encrenaz et al., 2018; Hoffman et al., 1980; Vandaele et al., 2019; Villanueva et al., 2015; Villanueva et al., 2021b).

What critical instrumentation capabilities should Keck Observatory develop or maintain on 10 to 15-year timescales?

Following the needs of the planetary community, as summarized in the table here below, the primary instrument capabilities that Keck Observatory should maintain are:

	Requirement	Comments
Wavelength coverage:	**1 – 5 μm**	The 1-5 μm provides competitive sensitivities to space and broad molecular/ice capabilities.
Spectral Resolution:	**> 20,000 (minimum)** **> 50,000 (optimal)**	Separation between isotopic lines of O, C is usually narrow, it requires **high-resolution spectroscopy (R >20,000).** Optimal it would be R > 50,000.
Slit length:	**25″ optimal**	**Long-slit** spectroscopy, and/or IFU capabilities are essential for mapping. Slit length **> 15" is required** at least in LM, ~ 25" is optimal. Possibility to choose between different slit widths can be also important.
Guiding:	**Non-sidereal guiding**	**Non-sidereal active guiding** capabilities are essential, the selection of multiple wavelengths, independent of the operational wavelength of the spectrograph could be incredibly helpful.

Inclusion of **long-slits is essential** for this case study, as it is needed in order both to perform ABBA nodding on-slit and achieve optimum sky subtraction, and to complete **mapping** minimizing the required time when the disk of the planet is most extended (Figure 1). We recommend a minimum slit length of 15″, with optimal value of 25″. For both planets, having the capability to perform seasonal and diurnal mapping of water isotopic ratios from ground would be important to constrain escape processes, current reservoirs, and their evolution over time. The achievement of the above science objectives requires to have proper mapping capability, namely sufficient **slit length**, **guiding stability**, and sufficient spectral resolution.

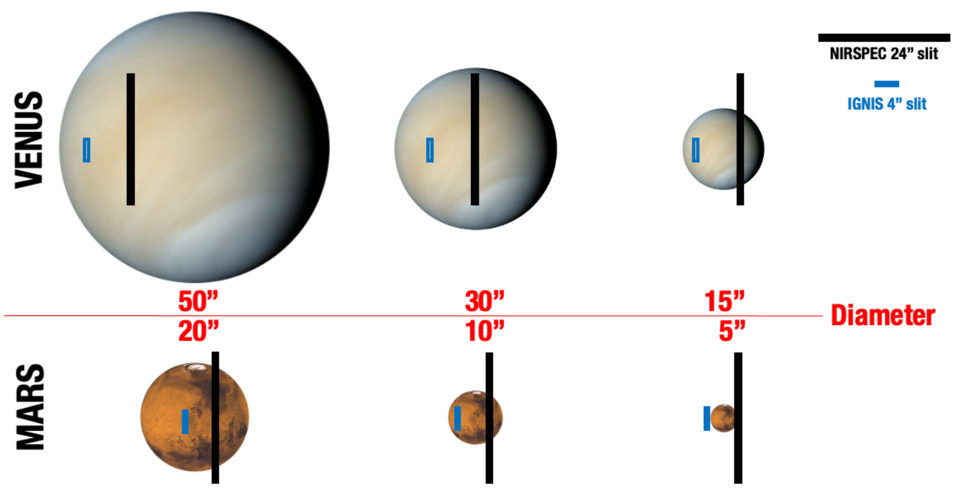

Figure 1. Comparison between the apparent size of Venus and Mars and slit length. Slit width is not on scale. Long slit spectroscopy is a critical instrumentation capability that Keck should maintain for the future.

NIRSPEC/Keck currently provides the wavelength coverage, wide spectral grasp per setting, high-resolution and it has a 24″ slit length, probably the longest slit available at IR wavelengths in the northern hemisphere. Compared to other ground-based facilities, Keck/NIRSPEC provides greater sensitivity. This results in shorter integration times and better background cancellation.

IGNIS has been proposed as new high-resolution spectrometer for Keck. IGNIS provides the necessary wavelength coverage and spectral resolution, but its current design lacks the slit length (currently designed to be 4″) which is essential to perform precise hemispheric mapping, especially considering the effects of seeing and planet rotation. Any new spectrometer being developed for Keck, should include a long-slit capability.

Why this critical instrumentation capabilities are competitive in 10 to 15-year timescales?

Ground-based long-slit high-resolution spectrometers in 2.8–5 μm range (as NIRSPEC/ Keck) **will remain competitive** in the next 10-15 years. The mapping capability provided is essential when performing complementary observations with both spacecraft and ground-based instrumentations of terrestrial planets. Orbital and rover measurements do not permit rapid hemispheric mapping, but this is achieved with ground-based observatories in a few hours. Importantly, with the recent upgrade, NIRSPEC is much more sensitive than before, enabling a significant contribution to understand the origin and the variability of organics on Mars/Venus. The much broader spectral grasp allows simultaneous mapping of H_2O, HDO (thus D/H), and isotopes of CO_2. Accurate measurements of the **global distribution** of O, H and C isotopic ratios in H_2O and CO_2 is fundamental to understand the distribution of present volatile reservoirs on Mars/Venus, and to quantify the past atmospheric loss. Joint observations of space-based and ground-based observations have provided and continue to promise an enriched level of science products.

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