The Space Interferometer for Cosmic Evolution (SPICE):
The Far-Infrared Universe at High Spatial Resolution

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***Abstract*— The Space Interferometer for Cosmic Evolution (SPICE) is a Far-Infrared probe mission concept. SPICE's unprecedented sub-arcsecond resolution and superlative sensitivity in the wavelength range 25 - 400 microns will enable the mission's scientific objectives including observations of large statistical samples of distant galaxies, protoplanetary disks, and debris disks. SPICE will greatly improve understanding the physical processes that drive the evolution of galaxies and their central massive black holes throughout cosmic time, planet formation and water delivery to nascent planets, and planetary system architectures and their evolution.**

Keywords*— *Far-infrared, interferometry, high spatial resolution, Fourier Spectroscopy, Astrophysics, Cosmology

I. SPICE Mission Concept

The SPICE concept design employs a two-input variable baseline interferometer that achieves u-v plane coverage through scanning of the baseline and rotation of the instrument (see figure 1). The two interferometric inputs are directed towards a central instrument employing a Fourier Transform Spectrometer (FTS). The SPICE Far-infrared Interferometry Probe mission offers:

- Wavelength range 25 - 400 μm (approximate),
- Angular resolution 0.3 (λ/100 μm) arcseconds for high quality imaging,
- Dense u-v plane coverage,
- Integral field spectroscopy over a 1 x 1 arcmin Field of View (FoV),
- Spectral resolution λ/Δλ > 3000 in each spatial resolution element, through using a single "double Fourier" beam combiner.

SPICE has the ~same angular resolution as the Webb Telescope (i.e., JWST), at ten times longer wavelengths - more than an order of magnitude better spatial resolution than any other far-infrared observatory (see Fig. 2). Fig. 3 illustrates this enhanced resolution using three examples: an extragalactic deep field (left), a protoplanetary disk (center), and a debris disk (right).

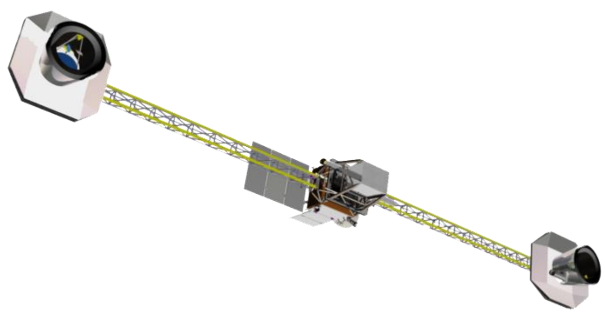

Fig. 1. Illustration of SPICE Probe design concept. Two receivers separated by a variable baseline direct light to the central instrument.

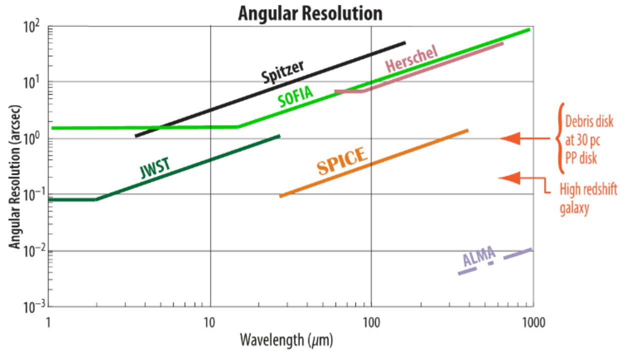

Fig. 2. Angular Resolution of SPICE mission, in context.

II. SPICE Science

The SPICE Science team is comprised of an instrument simulation and modelling working group (WG) and several science working groups. Science WG topics include galaxy evolution, star and planetary formation, and debris disks.

A. Galaxy Evolution

The key goal of galaxy formation studies is to understand the physical processes that drive the evolution of galaxies and their central massive blackholes throughout cosmic time. A crucial component of the baryonic content of galaxies is the gas and dust in between stars, i.e., the interstellar medium (ISM). Indeed, the infrared emission of galaxies makes up about half of the cosmic radiation background from galaxy formation and evolution processes, and the star formation rate density of the Universe is dominated by dust-obscured star formation emitting in infrared, at least out to z~4. Dust attenuation severely biases UV and optical observations.

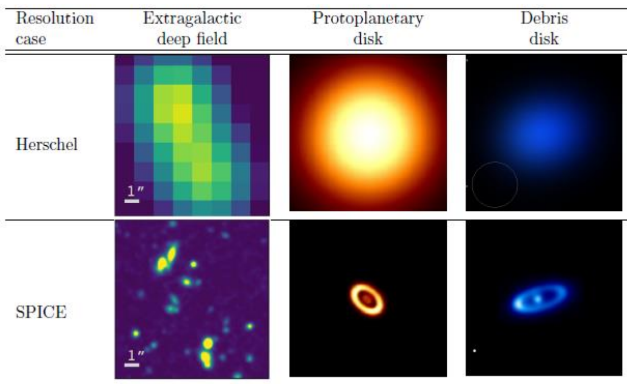

Fig. 3. Comparison of Herschel and SPICE spatial resolution for a variety of observation targets.

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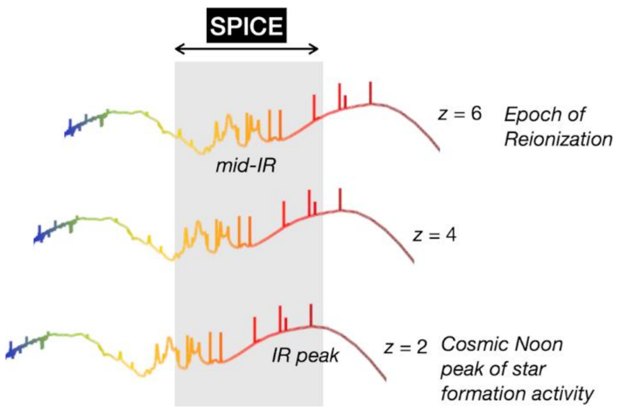

Fig. 4. SPICE spectral coverage demonstrated with redshifted galactic spectra.

Probing the stellar, gaseous, metal and blackhole content of galaxies in infrared wavelengths will provide a complete and unbiased view of the physical and chemical processes inside galaxies.

The high spatial resolution of SPICE (~0.3 arcsec) compared to its predecessors, Spitzer (~6-18 arcsec) and Herschel (~5-40 arcsec), and its >10x larger field of view compared to that of ALMA, will enable us, for the first time, to disambiguate the infrared emission of *individual* (unlensed) galaxies beyond the local Universe in statistically large samples. In addition, the high spatial resolution of SPICE will allow for studies of far-IR cooling lines in *individual* star forming regions and the diffuse ISM of galaxies other than the Milky Way, providing context for the ALMA detections of these lines at high redshifts and connecting the local Universe to the epoch of reionization and first galaxies.

B. Protostar and Planetary Formation

Planetary disks, which give rise to planets, comets, and asteroids, are the gas-rich disks that surround young stars. Protostar observations at far-infrared wavelengths, dominated by the emission from gas-rich protoplanetary disks surrounding these young stars, remain spatially unresolved. Detecting and resolving the location of gas species at high-resolution in protoplanetary disks is the essential next step to constrain models of planet formation. Of those species, water is perhaps the most important molecule driving the origins of life, and much of the water is thought to be frozen. With sub-arcsecond spatial resolution, and spectral resolving powers $R>10^3$ from space, SPICE will be the first instrument to detect and resolve the location of water-ice in protoplanetary disks in nearby star forming regions and define how this is delivered to young planets. Moreover, probing for the carbon and oxygen bearing species only accessible at far-infrared wavelengths that are necessary for the complex chemical interactions that occurred in our Solar System, SPICE will constrain the chemical evolution with which planets, comets, and asteroids form.

C. Debris Disks

Debris disks are analogues of the Solar system's small-body populations seen to orbit other stars. The origin of a debris disk's radial profile, whether it be structured or not, remains unclear. Current sensitivity can detect disks about ten times dustier than Solar system levels, with disks detected around approximately 20% of stars. We know that the Solar system's debris disk lies somewhere among the faintest 80%, but do not know whether this is unusually faint or not.

Although dust is only present in trace amounts compared to the other components of our universe, it plays important roles in many astrophysical processes. Fig. 5 illustrates the proportional dust composition of the universe.

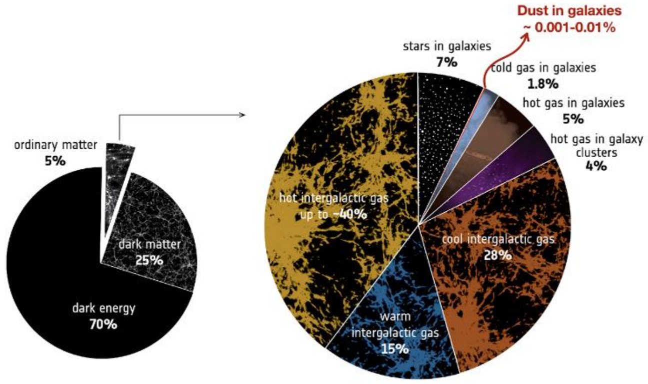

Fig. 5. Proportion of dust in the composition of the Universe.

D. SPICE Instrument Simulation and Modelling

The Instrument Performance Modelling working group has developed and continues to refine a Python-based Far-Infrared Interferometer Simulator (PyFIInS) [5]. This tool is used in parallel with other instrument modelling and design activities with a goal to understand and predict the abilities and limitations of a SPICE-like system more accurately. This will allow exploration of limits on the scientific questions that can be answered with the high spatial resolution far-infrared observations of SPICE and translate these results into technical specification definitions for a far-infrared space-based interferometer mission such as SPICE. Publicly available versions of these tools, and associated documentation, are in preparation.

III. Conclusions and Future Work

We must now consider the next big leap in far-infrared astronomical observations. Although both Herschel and Spitzer operated successful missions with high spectral resolution, they were both limited in spatial resolution due to the fundamental diffraction limit of their 3.5 m and 0.85 m primary mirrors, respectively. Clearly, high spatial resolution (sub-arcsecond) should be our next step in observing in the Far-Infrared.

References

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