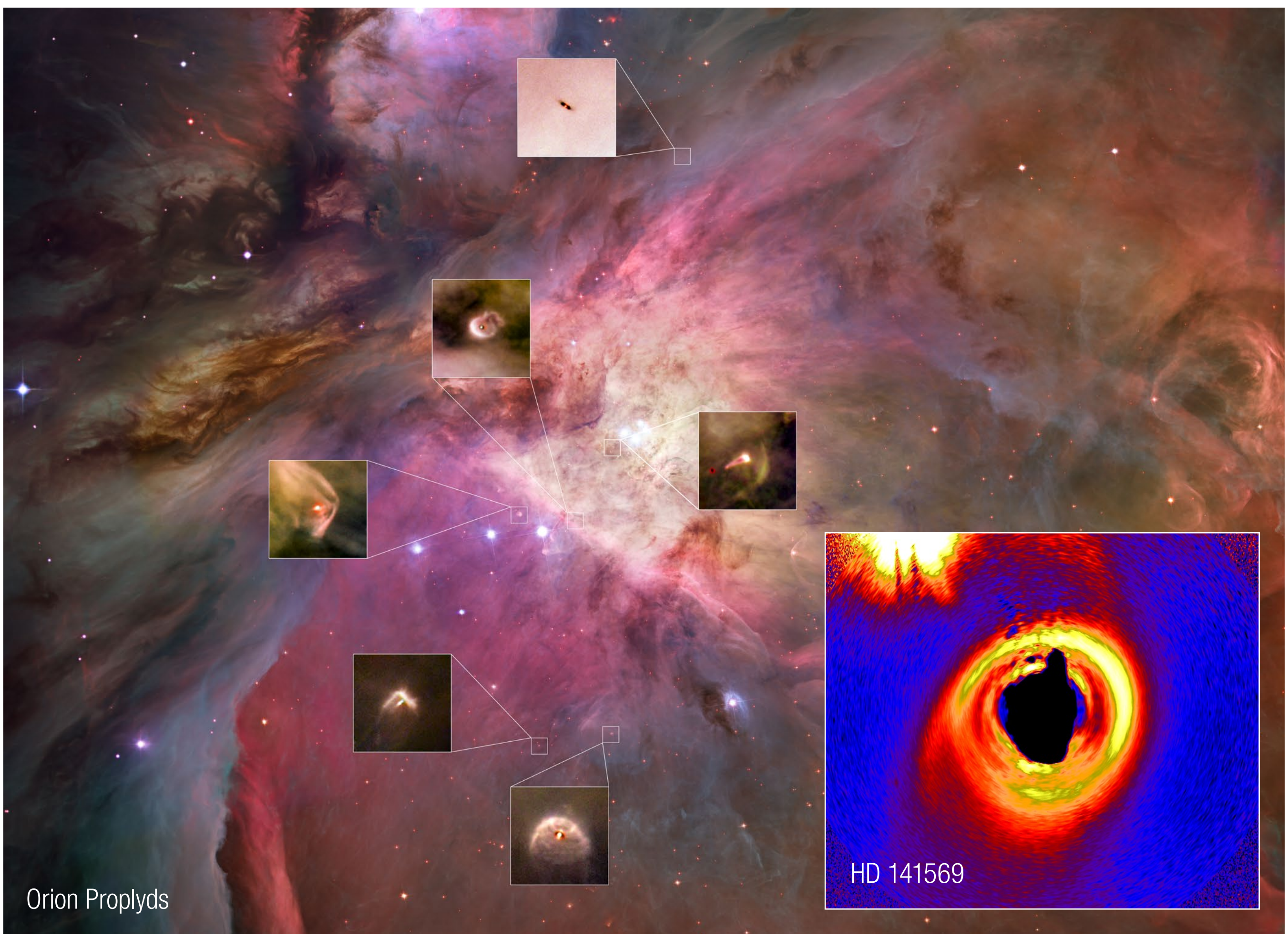
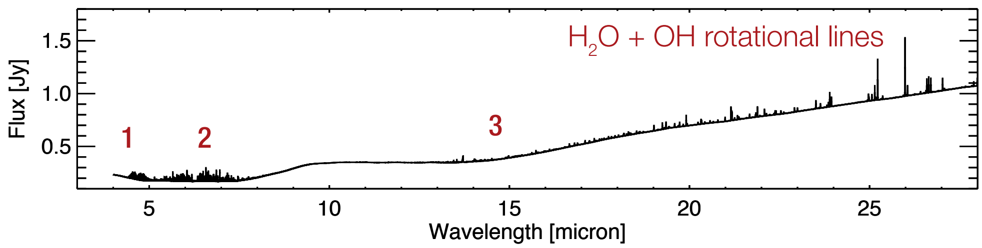
NASA's James Webb Space Telescope: Molecular Spectroscopy of Protoplanetary Disks

During the gas-rich phase of planet formation, protoplanetary disks act as "chemical factories." The high densities and high temperatures in the inner disk, coupled with strong UV and X-ray irradiation impinging on the disk surface, lead to a rich volatile chemistry that drives the composition of planetesimals, and ultimately the make-up of fully assembled planetary bodies and their atmospheres. The main spectroscopic tracer of molecular gas on scales of a few AU is infrared line emission by gaseous molecules such as H_2O, CO, CO_2, OH and a growing list of organics. The spectroscopic modes of JWST NIRSpec and MIRI cover the main molecular bands of gas in planet-forming regions, tracing gas at temperatures of 100-1000 K. The integral field units of JWST will resolve the molecular emission in nearby protoplanetary disks, while the high sensitivity will allow observations of disks as far away as the Magellanic Clouds, constraining the chemistry of planet formation in a wide range of environments.
The resolving power of $\lambda/\Delta\lambda$~2700 separate individual lines in complex molecular bands, and allow for accurate measurements of weak lines critical for constraining chemical models, including those of rare isotopologues.

Molecular spectroscopy with JWST is not restricted to protoplanetary disks. NIRSpec and MIRI will enable detailed observations of the chemistry of protostars, molecular outflows, and the atmospheres of cool and evolved stars throughout the Galaxy. The same molecular bands will be observable in exoplanetary atmospheres. Beyond the Milky Way, JWST can constrain the chemistry of the interstellar medium of both nearby and distant galaxies. The improvements in sensitivity and spectral resolving power in the 3-28 μm waveband, compared to previous facilities, opens a vast new discovery space in the molecular universe.



Molecular spectroscopy of protoplanetary disks with JWST



Model parameters

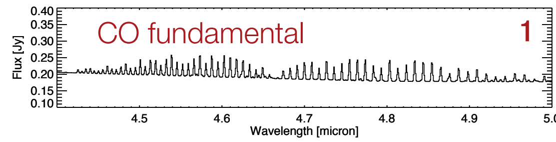
Protoplanetary disk around a young solar-type star: Teff=4250 K; $L_\star$=1 L_{sol}; 0.01 M_{disk}=M_{sol} disk, distance=125 pc.
Abundances based on Spitzer and ground-based IR spectroscopy

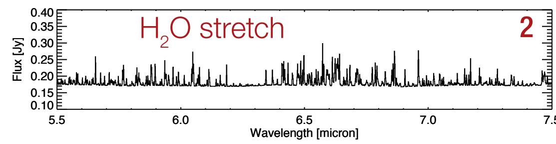
What does it mean?

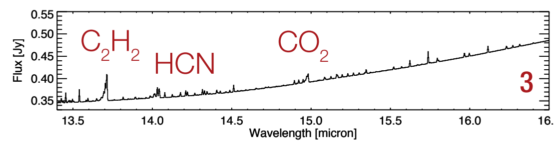
The mid-IR molecular lines from protoplanetary disks are formed in the disk surfaces at 1-10 AU.

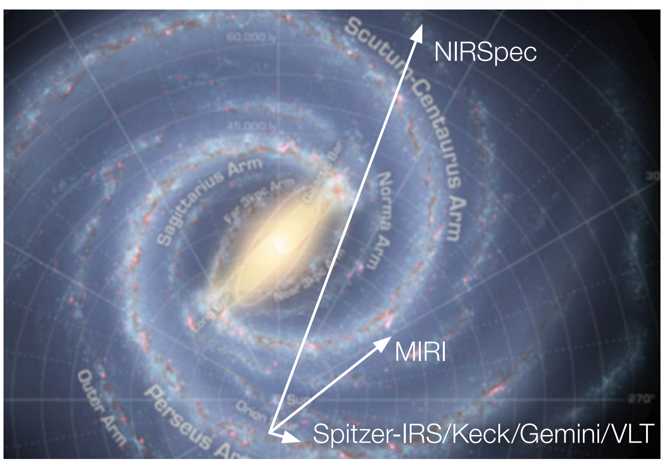
JWST observing modes

NIRSpec: 1-5 µm @ R~2700
MIRI: 5-28 µm @ R~2700









Spectroscopy of disks throughout the Milky Way Galaxy

- NIRSpec (R~2700/1-5 µm) can reach protoplanetary disks around Solar mass stars out to 40 kpc (Herbig Ae disks out to 100 kpc, including the Magellanic Clouds).
- MIRI can obtain 5-28 µm R~2700 spectra of protoplanetary disks out to 7 kpc.
- Several orders of magnitude improvement over current capabilities for mid-IR spectroscopy of molecular gas.

Near-Infrared Spectrograph (NIRSpec)

Micro-Shutter Assembly (MSA)
- 4 separate quadrants over 3.4' by 3.4' FOV
- 365 x 171 user configurable shutters per quadrant

Fixed slits (FS)
- Always open, no overlap with MSA on detectors
- Four narrow slits and one 1.6'' square for high throughput

Integral Field Unit (IFU)
- 3'' x 3'' FOV in 30 slices, each 0.1'' (dispersion) x 3'' (spatial)

Mid-Infrared Instrument (MIRI)

Direct Imaging
- nine photometric bands from 5 to 28 µm

Coronagraphic Imaging
- three four-quadrant phase masks (4QPMs) at 10.65, 11.4, & 15.5 µm, Lyot coronagraph at 23 µm

Low-Resolution Spectroscopy (LRS)
- 5-14 µm, $\lambda/\Delta\lambda$ ~ 100 at 7.5 µm, 0.6'' x 5.5'' slit

LRS Slitless Spectroscopy for exoplanet studies

Medium Resolution Spectrometer (MRS)
- $\lambda/\Delta\lambda$ ~ 2200 – 3500
- 4.9 to 28.8 µm, enabled by four IFUs
- 3.7'' to 7.7'' field-of-views (wavelength-dependent)

See more at jwst.stsci.edu and jwst.nasa.gov
and do your own ETC calculations at jwst.etc.stsci.edu