# Fingerprints of Clearing Process - Spitzer Spectroscopy of Atomic Lines in Transitional Disks


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Transitional disks are protoplanetary disks characterized by an optically thin inner region of a few AU radius. The inner gap/hole might be caused by several mechanisms among which grain growth, photoevaporation, or a forming planet. Transitional disks could constitute the evolutionary link between the optically thick disks of young T Tauri and Herbig Ae stars and debris disks found around many main-sequence stars. In order to understand better the processes related to disk photoevaporation we initiated a program to analyze infrared spectra of a sample of transitional disks observed with the Spitzer Space Telescope. We present detections and upper limits of infrared lines from [Ar II] at 6.98 µm, [NeII] at 12.81 µm, and [Ne III] at 15.55 µm lines that trace the hot disk atmosphere and can be used to constrain disk photoevaporation rates. This rate determines the timescale of gas dissipation from the disk, thus sets an upper limit for planet formation timescale.


## Introduction:

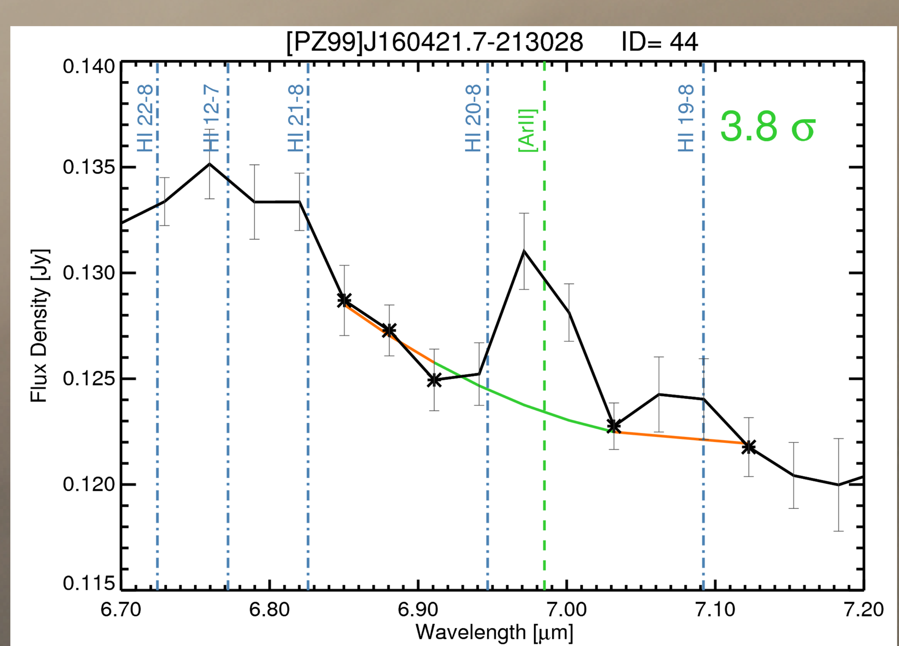
Young stars are often surrounded by circumstellar disks containing gas and dust. Most of the disk material is in the form of gas, while the dust component constitutes only a small fraction of the disk mass. These circumstellar disks are planet nurseries, they provide the raw material for planets to form. Thus, understanding their evolution, especially the evolution of the gas component, is key to the understanding of planet formation.

Mid-infrared atomic and ionic line ratios measured in spectra of pre-main sequence stars are sensitive indicators of the hardness of the radiation field impinging on the disk surface. Specifically, [Ar II]/[Ne II] and [Ne II]/[Ne III] line flux ratios could help discriminating between cases in which a hard/soft EUV, or hard/soft X-ray stellar spectrum provides the main source of ionization for the disk atmosphere (e.g. Hollenbach & Gorti 2009). To find out this question is necessary for properly estimating the photoevaporation rate and hence the disk lifetime.

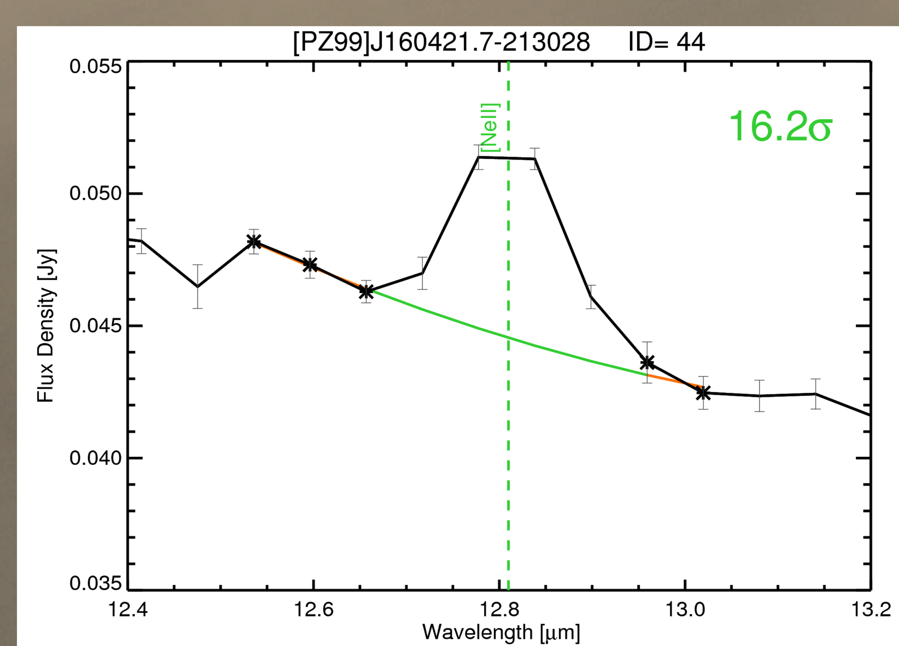
We present a low-resolution Spitzer IRS search for [Ar II] at 6.98 µm, [Ne II] at 12.81 µm, and [NeIII] 15.55 µm lines in 56 transitional disks. These objects, characterized by reduced near-infrared but strong far-infrared excess emission, are ideal targets to set constraint on the stellar radiation field because their lines are not contaminated by shock emission from jets/outflows. After demonstrating that we can detect atomic/ionic lines and recover their fluxes from the low-resolution spectra, here we report the first detections of [Ar II] lines towards protoplanetary disks. Finally, we also compare the [Ar II]/[Ne II] and [Ne II]/[Ne III] line flux ratios with model predictions in order to investigate the hardness of ionizing stellar spectrum.

## Results:

First [Ar II] detections in protoplanetary disks (30% of the sample). An example:




Several [Ne II] detections (57% of the sample). One example:




Upper limits for [Ne III] line flux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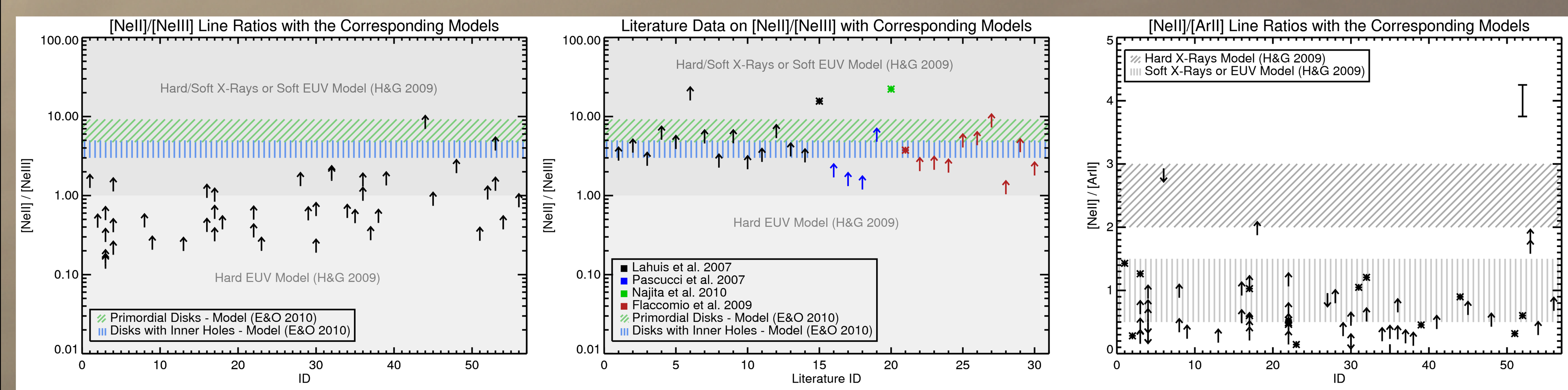
## Sample Selection and Data Reduction:

- 56 transitional disks -- collected all available Spitzer IRS low-resolution spectra
- Data reduction: FEPS (Formation and Evolution of Planetary Systems Legacy Science program) Spitzer pipeline (Bouwman et al. 2008)
- Flux measurement with IDL: five-point Newton-Cotes integration and Monte Carlo: $10^4$ spectra generated → flux uncertainties
- Upper limit calculation, in the case of line non-detection
- Determination of the [NeII]/[NeIII] and [ArII/NeII] line flux ratios

## Line Flux Ratios:




## Conclusion & Discussion:

Our results can be summarized as follows:

1. We report the first detections of [Ar II] lines in protoplanetary disks. We detected this line in 4 sources at ≧ 3σ and in 13 sources at 1.3–2.9σ level in our sample. In conclusion, altogether 30% of the sample show possible [Ar II] emission.
2. We also detect [Ne II] lines for the first time in LR IRS spectra. 57% of the objects present [Ne II] emissions (29 detections with ≧ 3σ and 3 possible detections with 1.5–2.9σ) in our sample.
3. Our [Ne II]/[Ne III] line flux ratio when combined with literature data suggest that the layer emitting [Ne II] and [Ne III] is mostly ionized by a soft EUV or soft/hard X-ray stellar spectrum.
4. The mean of [Ar II]/[Ne II] line flux ratio is close to 1, which points to a soft X-rays/EUV stellar spectrum rather than a hard X-ray spectrum reaching the [Ar II] and [Ne II] emitting layer of the disk.

A dominance of the soft X-ray component would point to larger photoevaporation rates than when photoevaporation is solely driven by EUV photons, which influences the lifetime and extension of dust gaps in transitional disks (Owen et al. 2011), thus planet formation timescale.

- It will be possible to detect [Ar II] line with the spectrometer *MIRI at James Webb Space Telescope* with a very high signal-to-noise ratio, but not resolve the line.
- *EXES on SOFIA* is less sensitive than MIRI, but in high resolution mode will provide up to R~120,000 or 2.5 km/s around 7µm enabling to spectrally resolve [Ar II] lines if they trace photoevaporating gas at tens of AU from the central star as predicted.

*Image Credit: NASA*