Unveiling young exoplanet atmospheres with high dispersion spectroscopy

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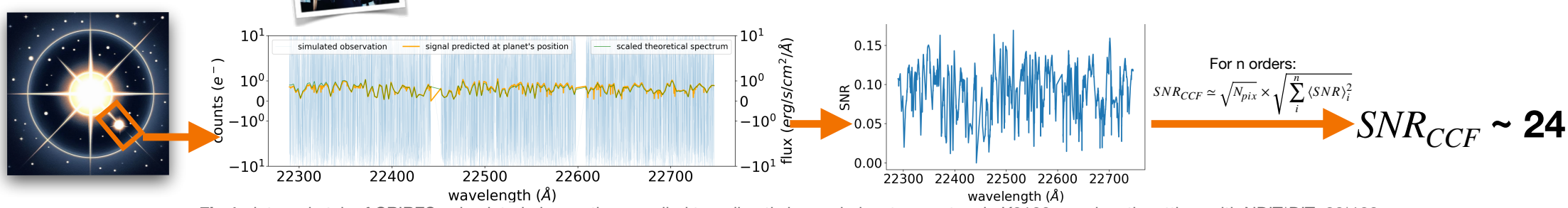

Fig 1 plots a sketch of CRIRES+ simulated observations applied to a directly imaged planetary system in K2166 wavelength setting, with NDIT*DIT=30*120, projected separation=0.295 arcsec (5 pixel), stellar signal removed by subtraction. The plot shows spectral order 25 of a input spectrum (T=1400K, log (g)=4.0) generated from BT-Settl models (*Allard et al., 2013*).

- **We want to target:** the young planets embedded in circumstellar disks are expected to be young and probably still in formation processes. This poster focuses on the candidate planetary system HD 169142 (*Hammond et al., 2023*).
- **We want to understand:** the feasibility of atmospheric characterization of directly imaged embedded protoplanets via high dispersion spectroscopy (HDS) in the era of CRIRES+ and ELT.
- **We are working on:** developing a pipeline to generate synthetic observations by CRIRES+, and assess the effect of extinction from the disk, the ability to extract the spectra with flux contrast analysis and Bayesian inference on cross-correlation mapping.

The flowchart of EXOCRIRES synthetic observation pipeline

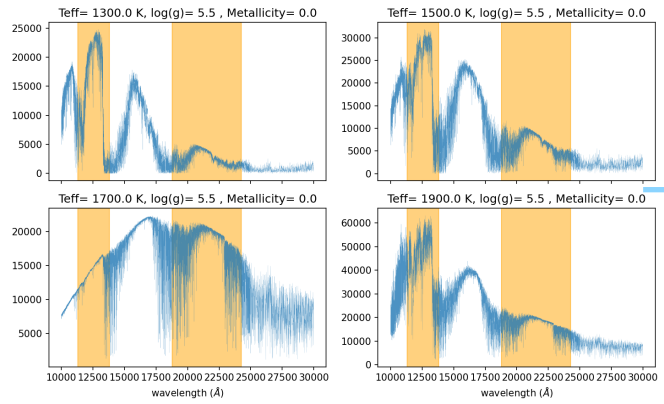

Fig 2.1 shows some examples of theoretical spectra from BT-Settl library. The range of parameters T_{eff}, $log(g)$ and Z are constrained from previous observations on other objects (e.g. PDS 70b).

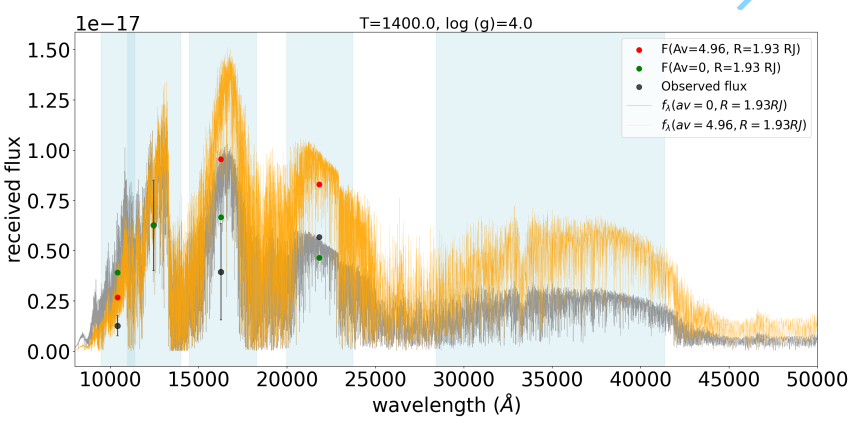

Fig 2.3 The plot shows the degeneracy of essential parameters of HDS detectability, radius (R) and the extinction (Av). We applied the ISM extinction law from *Chen et al., 2019* into MCMC. Then both the best-fit extincted spectrum from MCMC (the orange one), and the intrinsic spectrum with Av=0 (the grey one) are scaled to be consistent with J-band measurement of SPHERE in Hammond et al., 2023, which K-band measurement is regarded as a non-detection limit. The best-fit extincted spectrum is then inputted into the ETC simulator.

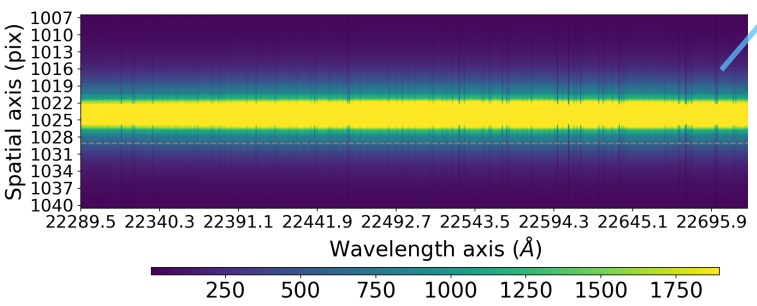

Fig 2.4 is an example of a 2-D "raw" spectra generated from the simulator, with spatial axis reconstructed from ETC simulator,. The planetary spectrum is spatially resolved from the host star (grey dashed line) at pixel 5, but still completely embedded in the PSF wing of the stellar light. The telluric absorption shown in this figure can significantly affect SNR in some spectral orders (i.e. order 29 to order 26 in K2166), as illustrated in Fig 3.2.

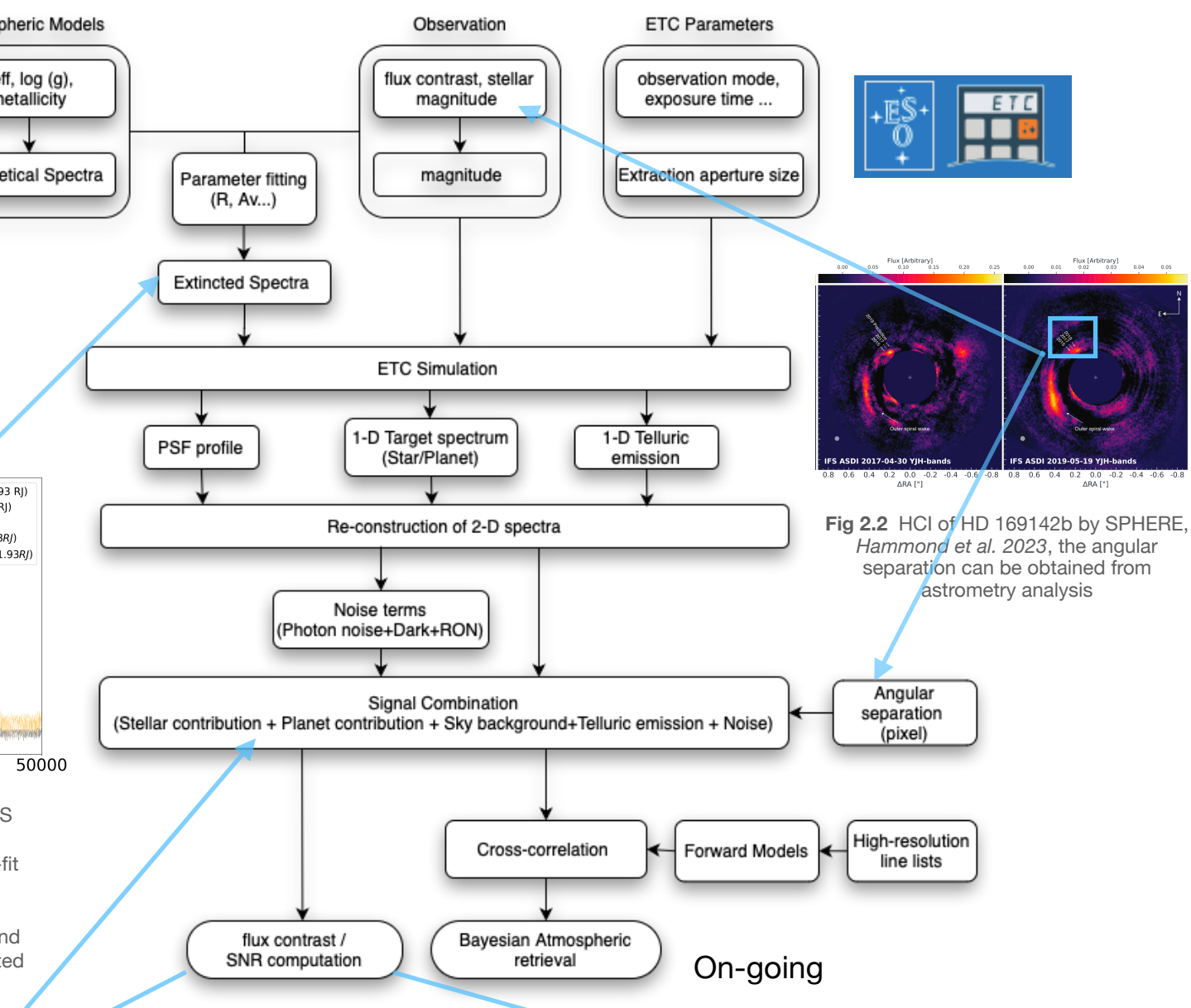

Fig 2.2 HCI of HD 169142b by SPHERE, *Hammond et al. 2023*, the angular separation can be obtained from astrometry analysis

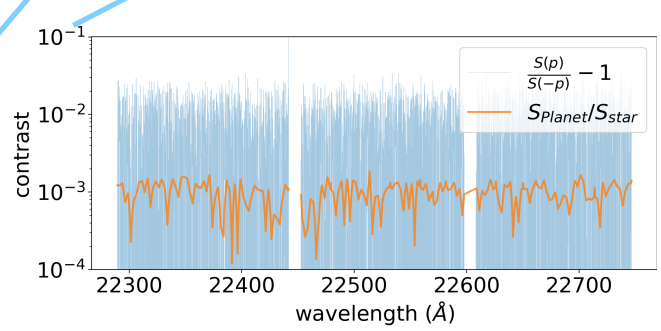

Fig 3.1 illustrates the contrast spectrum between the planetary signal subtracted from Fig 2.4 and diffracted signal from its host star. The stellar flux is dampened by AO at the position of planet, leading the noise-free flux contrast (the orange curve) up to 10^{-3}, indicating an optimistic detection of atmospheric emission with cross-correlation and Bayesian retrieval afterwards.

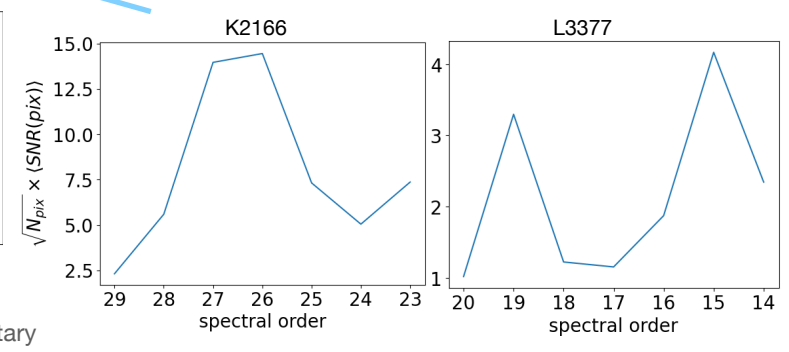

Fig 3.2 The pixel-summed SNR of spectral orders in K2166 and L3377 setting varies from 1 to 15, leading the sum-up SNR of all orders to ~ 23.95 in K2166, and ~6.4 in L3377.

- **Current Results:**
  - With a preliminary assessment of planet-to-star flux contrast (~10^{-3} at order-25) and S/N ~23.95 of the cross-correlation of all orders in K2166 wavelength setting, K-band observations have the clear potential to achieve a CRIRES+ detection in the presence of extinction values compatible with SPHERE observations in *Hammond et al., 2023*.
  - Assuming the detection in SPHERE is on the photosphere of the protoplanet and the planet still embedded in the protoplanetary disk, the dust extinction can thus affect the detectability of young planets. Observing in longer wavelengths (L/M band) may help to avoid strong extinction effects. Although stronger telluric emissions and absorptions decrease S/N to ~6.4 on the cross-correlation of orders in L3377, there is still a potential for detection.
- **Next Step:** The high-resolution forward models will be applied for cross-correlation and a Bayesian retrieval framework based on *Brogi et. al., 2019* will be implemented for the retrieval atmospherical composition. The comprehensive pipeline will also explore a wider range of orbital architectures consistent with current and future candidate protoplanets.