Observational studies of gas in protoplanetary disks with high-resolution infrared spectroscopy at ESO-VLT

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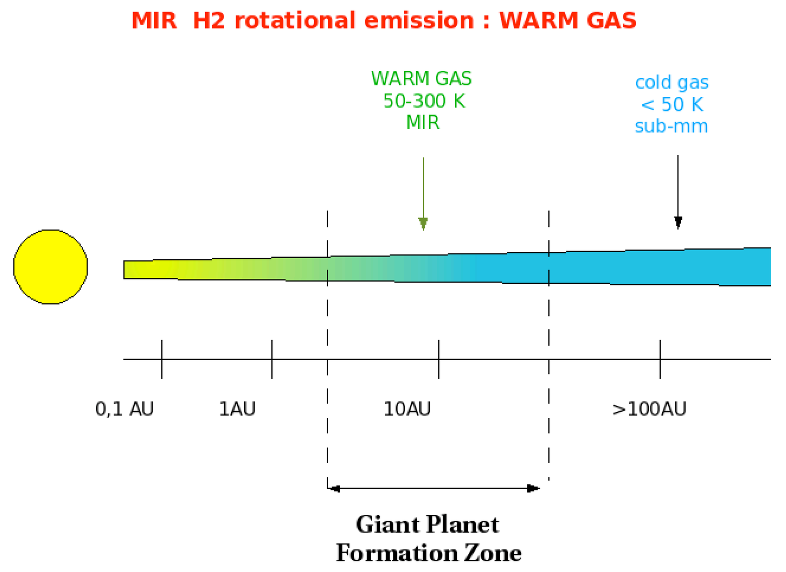
Searching for rotational H_2 emission at 12 and 17 μm in HAEBES with VISIR at ESO-VLT



Motivation:

- To probe the gas in the giant planet forming region of the disk.

Observations

- VISIR: ESO-VLT high resolution MIR spectrograph R~ 20000 (15 km/s).
- nearby Herbig Ae/Be stars with evidence for large gas reservoirs (e.g. with CO in the sub-mm).
- 44h (40% completed) P76 + 4h P78.

Table 3. Upper line flux limits derived

	0–0 S(2) (J=4–2) 12.278 μm		0–0 S(1) (J=3–1) 17.035 μm	
Star	Continuum F_ν [Jy]	Line Flux [$\times 10^{-14}$ ergs s^{-1} cm^{-2}] LW = 15 km s^{-1}	Continuum F_ν [Jy]	Line Flux [$\times 10^{-14}$ ergs s^{-1} cm^{-2}] LW = 15 km s^{-1}
UX Ori	1.9 (1.1)	<1.4	2.0 (1.5)	<1.3
HD 34282	0.3 (0.4)	<0.5	...	...
HD 100453	9.0 (0.7)	<0.9	14.8 (1.7)	<1.5
HD 101412	3.5 (1.0)	<1.2	1.6 (1.6)	<1.4
HD 104237	14.6 (1.8)	<2.2	4.4 (1.5)	<1.3
HD 142666	...	...	8.0 (1.2)	<1.1
HD 319139	...	...	2.5 (1.5)	<1.3

Table 4. Upper warm H_2 mass limits

	Upper mass limits in $M_J \sim 10^{-3} M_\odot$					
	12 μm			17 μm		
Star	150 K	300 K	1000 K	150 K	300 K	1000 K
UX Ori	27.9	1.9×10^{-1}	1.2×10^{-2}	1.0	6.8×10^{-2}	2.0×10^{-2}
HD 34282	13.8	9.7×10^{-2}	6.0×10^{-3}	...	...	...
HD 100453	1.9	1.4×10^{-2}	0.9×10^{-3}	0.1	0.9×10^{-2}	2.5×10^{-3}
HD 101412	5.3	3.7×10^{-2}	2.3×10^{-3}	0.2	1.6×10^{-2}	4.8×10^{-3}
HD 104237	5.0	3.6×10^{-2}	2.2×10^{-3}	0.1	0.8×10^{-2}	2.3×10^{-3}
HD 142666	...	...	...	0.2	1.0×10^{-2}	3.1×10^{-3}
HD 319139	...	...	...	0.2	1.2×10^{-2}	3.7×10^{-3}

Results

- None of the targets exhibit MIR H_2 emission .
- The disks contain :
  less than a few tenths of Jupiter Mass at 150K .
  less than a few Earth masses at 300 K and higher.

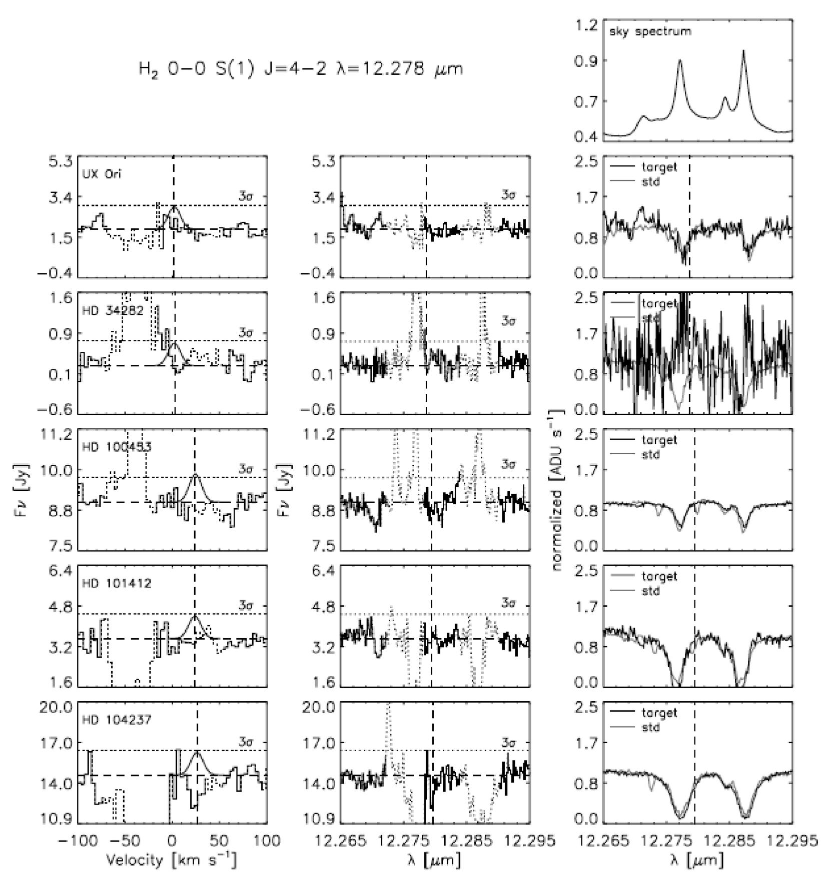


Fig. 1. Spectra obtained for the H_2 0-0 S(2) (J=4-2) line at 12.278 μm. The left panel shows a zoom to the -100 to 100 km s^{-1} interval of the atmospheric corrected spectra. A Gaussian of FWHM = 15 km s^{-1} and integrated line flux equal to the line-flux upper limits obtained is overplotted at the expected velocity shifted location (vertical dashed line, see Table 2). The central panel shows the full corrected spectra. Dotted lines show spectral regions strongly affected by telluric or standard star absorption features. The right panel shows the continuum normalized spectra of the standard star and the target before telluric correction. The uppermost right panel displays the sky spectrum from a half-chop cycle. The spectra are not corrected for the radial velocity of the targets.

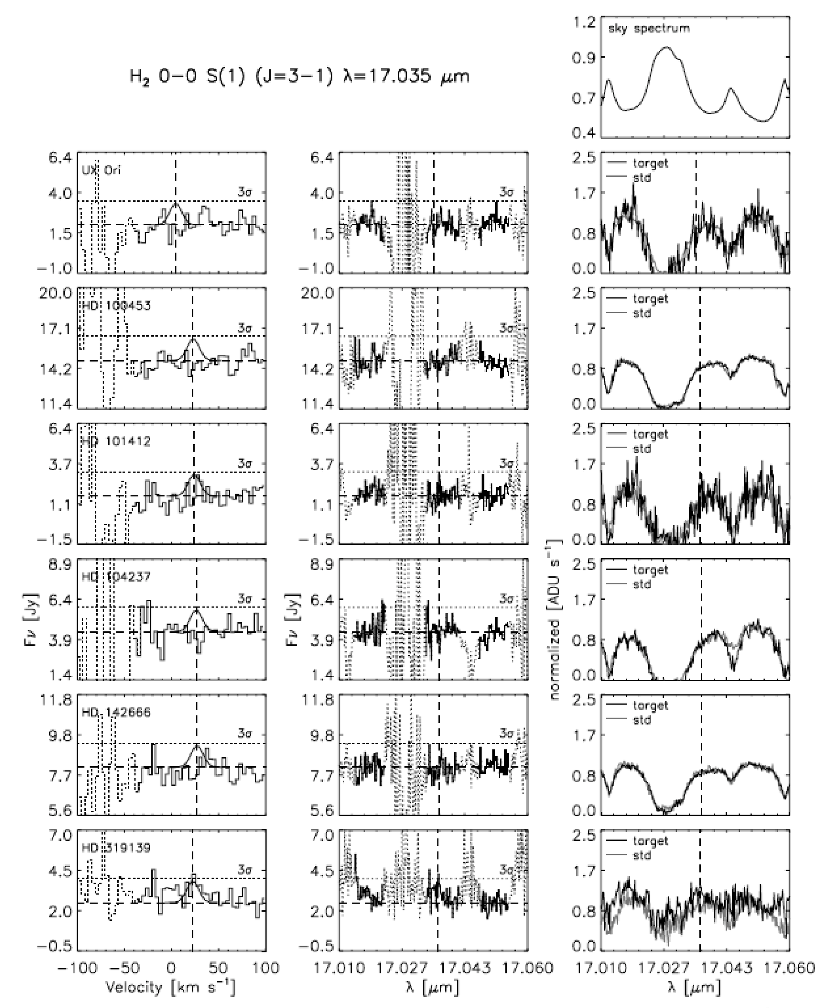
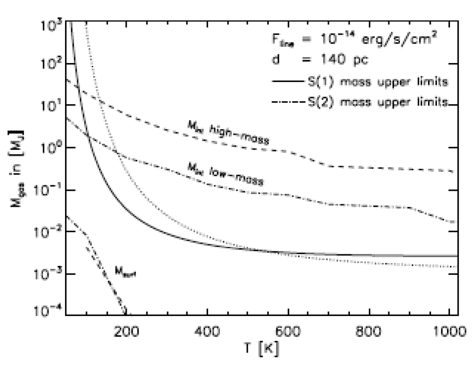
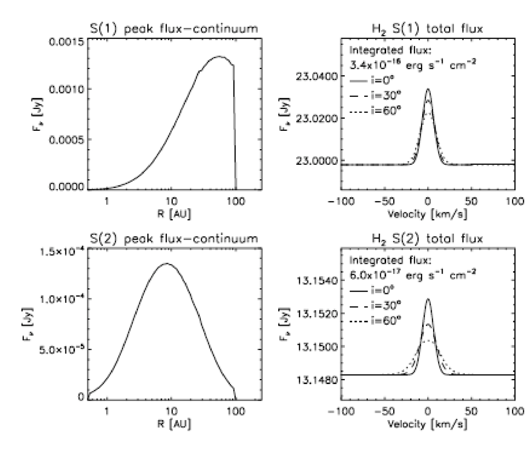


Fig. 2. Spectra obtained for the H_2 0-0 S(1) (J=3-1) line at 17.035 μm. The left panel shows a zoom to the -100 to 100 km s^{-1} interval of the atmospheric corrected spectra. A Gaussian of FWHM = 15 km s^{-1} and integrated line flux equal to the line-flux upper limits obtained is overplotted at the expected velocity shifted location (vertical dashed line, see Table 2). The central panel shows the full corrected spectra. Dotted lines show spectral regions strongly affected by telluric or standard star absorption features. The right panel shows the continuum normalized spectra of the standard star and the target before telluric correction. The uppermost right panel displays the sky spectrum from a half-chop cycle. The spectra are not corrected for the radial velocity of the targets.

Analysis & Interpretation

- The upper limits to the disk's warm gas mass are smaller than the amount of warm gas in the interior layer of the disk, but they are much larger than the amount of mass expected to be in the surface layer.
- We calculated the H_2 emission at 12 and 17 μm from a Chiang & Goldreich (1997) two-layer optically thick disk model of HAEBES disk.
- The predicted line fluxes of the two-layer disk model are of the order of $10^{-16} - 10^{-17}$ erg s^{-1} cm^{-2}, *much smaller than the detection limits of our observations* (0.4×10^{-14} erg s^{-1} cm^{-2}).
- If the two-layer approximation to the structure of the disk is correct, we are essentially *blind to most of the warm H_2 in the disk* because it is located in the optically thick interior layer of the disk.
- Our non-detections are explained because of the intrinsically low thermal H_2 emission flux levels from the surface layer.
- Additional heating sources have a major impact on the expected H_2 emission. A simultaneous increase in the gas-to-dust ratio and gas temperature can boost the H_2 emission to detectable levels. In our sources, *the molecular gas and dust in the surface layer have NOT significantly departed from thermal coupling* ($T_{gas}/T_{dust} < 2$) and that the gas-to-dust ratio in the surface layer is very likely lower than 1000.





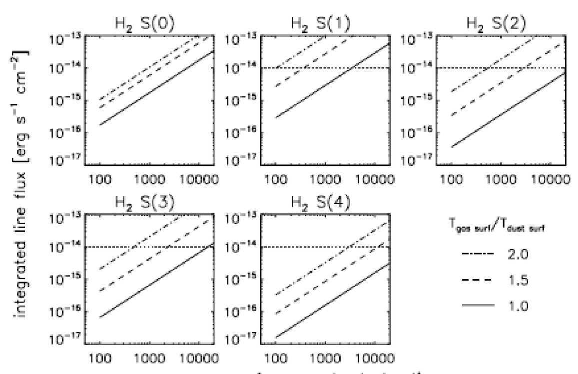
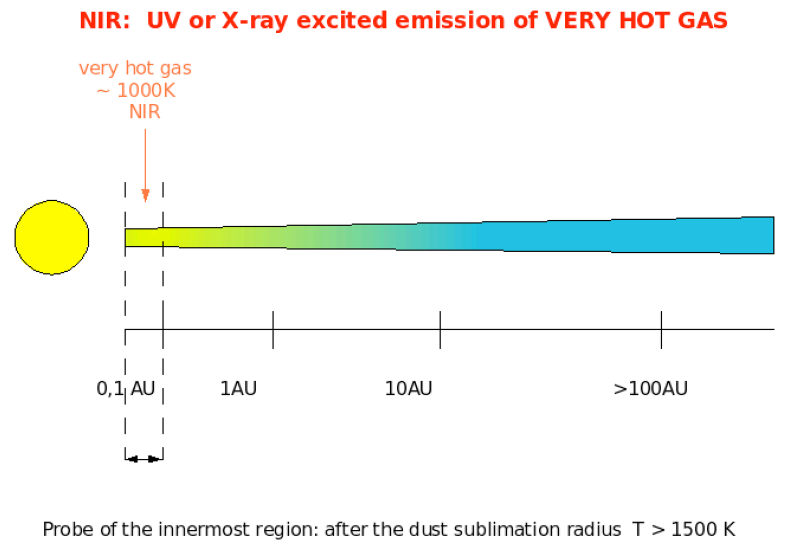


Fig. 9. H_2 S(0), S(1), S(2), S(3), S(4) line fluxes for the two-layer low-mass disk model as a function of the gas-to-dust ratio in the surface layer for T_{gas}/T_{dust} in the surface ranging from 1.0 to 2.0. The dotted horizontal line present typical ground detection limits. The S(0) line is only observable from space.

References

- Carmona, A., van den Ancker,M. E., Henning, T., Ya. Pavlyuchenkov, C.P. Dullemond, M.Goto, W.F.-Thi, J.Bouwman, & L.B.F.M. Waters. 2008, A&A , 477, 839
- Chiang, E. I., & Goldreich, P. 1997, ApJ, 490, 368

Searching for H_2 2.12, 2.22 and 2.24 μm emission in the CTTS LkHα 264 and the debris disk 49 Cet with CRIRES at ESO-VLT



Motivation:

- To probe the gas in the terrestrial planets region of the disk.

Observations

- CRIRES: ESO's new VLT high resolution NIR spectrograph R~ 45000 (6.6 km/s).
- LkHa 264 : a classical T Tauri star.
- 49 Cet : debris disk with CO detections in the sub-mm.

Table 2. Summary of the observations.

Star	λ [μm]	Date	UT [hh:mm]	t_{exp} [s]	Airmass	seeing [arcsec]	Calibrator[a]	t_{exp} [s]	Airmass	seeing [arcsec]
LkHα 264	2.1218	8 Nov 2006	06:25	720	1.4	1.2	HIP 13327	160	1.3	0.9
	2.2233, 2.2477	8 Nov 2006	06:52	720	1.4	1.0	HIP 13327	160	1.3	0.9
49 Cet	2.1218	9 Nov 2006	02:38	240	1.1	0.8	HIP 8497	40	1.0	1.2
	2.2233, 2.2477	9 Nov 2006	03:07	240	1.2	0.7	HIP 8497	40	1.0	1.2

[a] Spectrophotometric standard stars were observed immediately following the science observations.

Results

- 1-0 H_2 S(1) emission at 2.1218 micron confirmed in LkHα 264.
- *first detection of the 1-0 H_2 S(0) line from a protoplanetary disk.*
- upper limits on the 2-1 H_2 S(1) line flux at 2.2477 micron in LkHα 264.
- Any of the three lines is detected in 49 Cet.

Table 3. H_2 line fluxes and upper limits measured

		LkHα 264			49 Cet		
		1-0 S(1) 2.1218 μm	1-0 S(0) 2.2233 μm	2-1 S(1) 2.2477 μm	1-0 S(1) 2.1218 μm	1-0 S(0) 2.2233 μm	2-1 S(1) 2.2477 μm
Continuum	[ergs s^{-1} cm^{-2} μm^{-1}]	9.2×10^{-11}	1.5×10^{-10}	1.6×10^{-10}	3.5×10^{-9}	1.7×10^{-9}	1.5×10^{-9}
3σ	[ergs s^{-1} cm^{-2} μm^{-1}]	4.2×10^{-12}	8.2×10^{-12}	1.0×10^{-11}	1.0×10^{-10}	1.8×10^{-10}	3.1×10^{-10}
Flux[a]	[ergs s^{-1} cm^{-2}]	3.0×10^{-15}	1.0×10^{-15}	$< 5.3\times10^{-16}$	$< 5.4\times10^{-15}$	$< 8.9\times10^{-15}$	$< 1.6\times10^{-14}$
Mass H_2 at 1500 K[b]	[$M_\odot$]	5.6×10^{-9}	...	...	$< 4.2\times10^{-9}$	...	...

[a] For the calculation of upper limits, we assumed that the FWHM of the line is of 6-8 km s^{-1}.
[b] Mass calculated using Eq. 1, T=1500 K and LTE conditions.

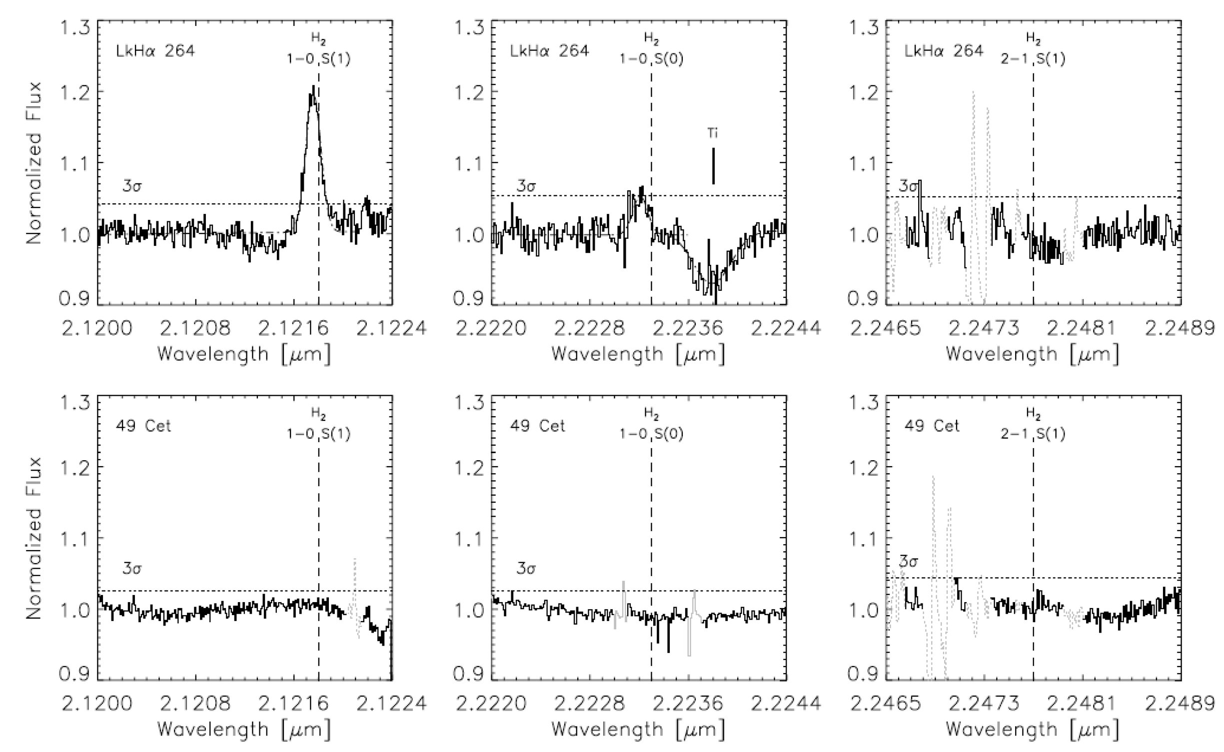


Fig. 1. CRIRES spectra of LkHα 264 (upper panels) and 49 Cet (lower panels) in the regions of the H_2 ν=1-0 S(1), H_2 ν=1-0 S(0) and H_2 ν=2-1 S(1) emission lines. The H_2 ν=1-0 S(1) and the H_2 ν=1-0 S(0) lines are detected in LkHα 264. A photospheric Ti feature at 2.2238 μm is observed in LkHα 264. In dash-dot lines are illustrated the gaussian fits to the detected lines. The H_2 ν=2-1 S(1) line is not present in LkHα 264. In the case of 49 Cet none of the three H_2 features are present in emission. Horizontal dotted lines show the 3σ continuum flux limits. The spectra is not corrected for v_{LSR} of the star. Regions of poor telluric correction are in gray-dotted lines in the spectra.

Analysis & Interpretation

- The detected lines are coincident with the rest velocity LkHα 264. They have a FWHM of 20 km s^{-1}. This is strongly suggestive of a disk origin for the lines.
- The measured 1-0 S(0)/1-0 S(1) (0.33 ± 0.1) and the 2-1 S(1)/1-0 S(1) (<0.2) line ratios indicate that the *emitting H_2 is at a T < 1500 K and that the H_2 is most likely thermally excited by UV photons.*
- Modeling of the shape of the line suggest that the disk of LkHα 264 should be *close to face-on (i < 35°).*
- The emission is spatially unresolved. The H_2 emitting region to is located in the inner 50 AU of the disk.
- There is a *few lunar masses of emitting H_2* in the inner 1 AU of LkHα 264, and less than a tenth of a lunar mass in the inner disk of 49 Cet.
- The lack of H_2 emission in the NIR spectra of 49 Cet and the absence of Hα emission suggest that the gas in the inner disk of 49 Cet has dissipated. These results combined with previous detections of ^{12}CO emission at sub-mm wavelengths indicate that *the disk surrounding 49 Cet should have an inner hole.*
- A comparative analysis of the physical properties of CTTS in which the H_2 1 − 0 S(1) line has been detected and non-detected indicates that the presence of H_2 emission is correlated with the magnitude of the UV excess and the strength of the Hα line.

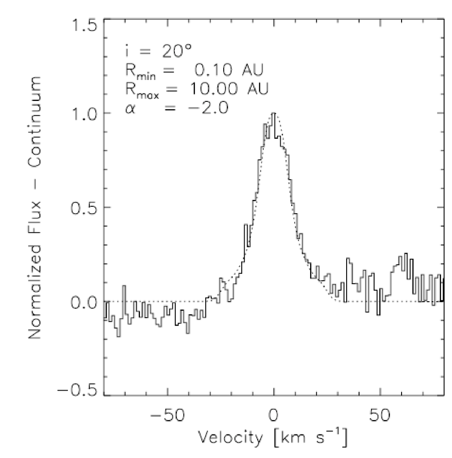


Fig. 2. Best model fit for the H_2 ν = 1 − 0 S(1) line detected in LkHα 264 assuming that the emission originates in a circumstellar disk. R_{min} and R_{max} are the inner and outer radius of the emitting region. α is the power law exponent of the intensity $I(R) \propto R^{\alpha}$.

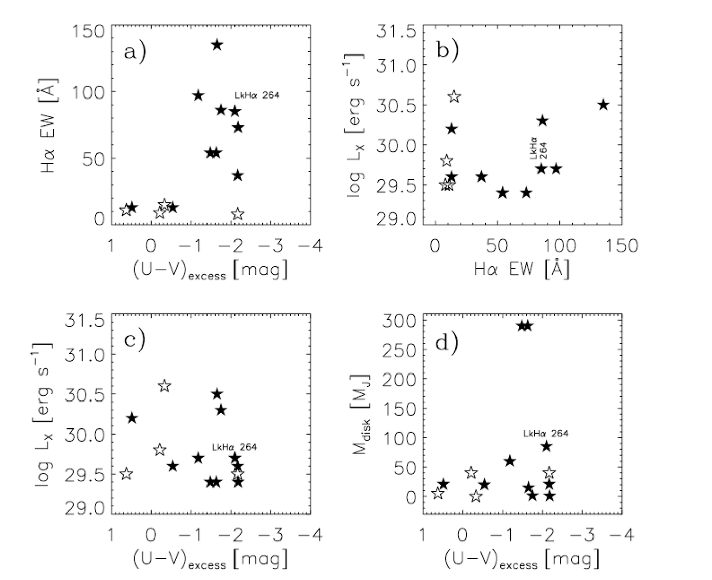


Fig. 3. Physical properties of classical T Tauri stars in which a search for the H_2 ν = 1 − 0 S(1) line was performed. Filled stars represent detections, non-filled stars represent non-detections. **a)** Hα *EW* versus $(U-V)_{excess}$. **b)** log L_X [erg s^{-1}] versus Hα *EW*. **c)** log L_X [erg s^{-1}] versus $(U-V)_{excess}$. **d)** M_{disk} versus $(U-V)_{excess}$.

References

- Carmona, A., van den Ancker, M.E., Henning, T., Goto, M., Fedele, D., & Stecklum. B. 2007, A&A, 476, 853 & 2008, A&A, 478, 795