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OBSERVATIONS OF WARM WATER IN PROTOPLANETARY DISKS

- AND ITS CONNECTION TO DISK EVOLUTION AND PLANET FORMATION -

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Based on a PhD thesis by A. Banzatti, and on Banzatti et al. 2012 (ApJ, 745, 90), Banzatti et al. 2013a,b (submitted)

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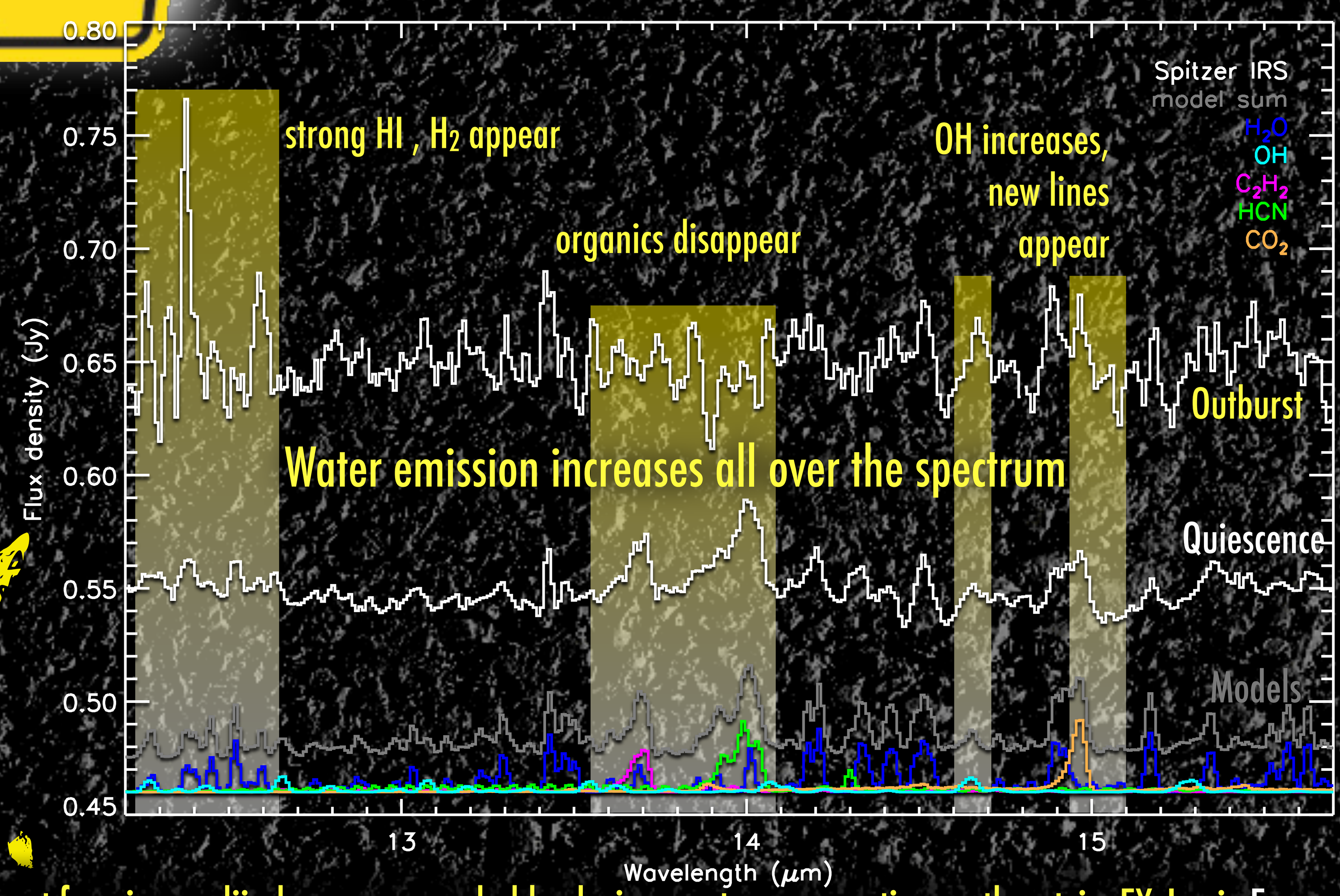
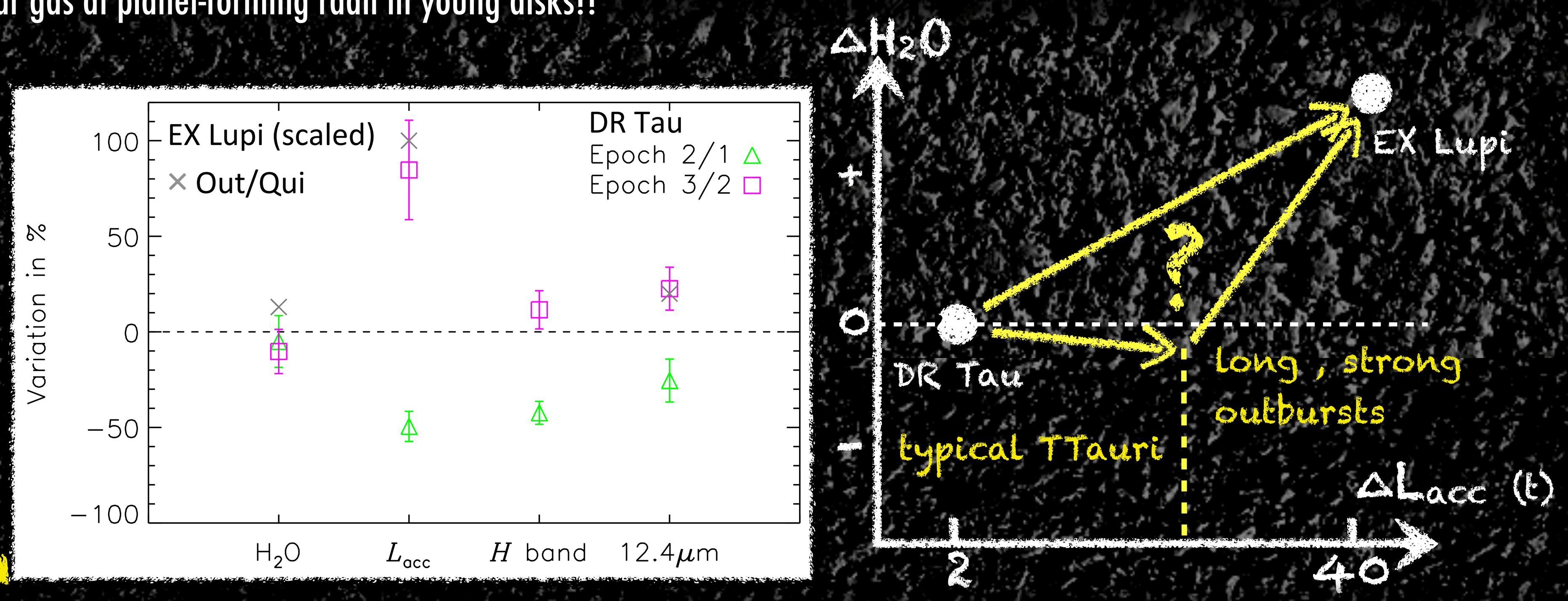
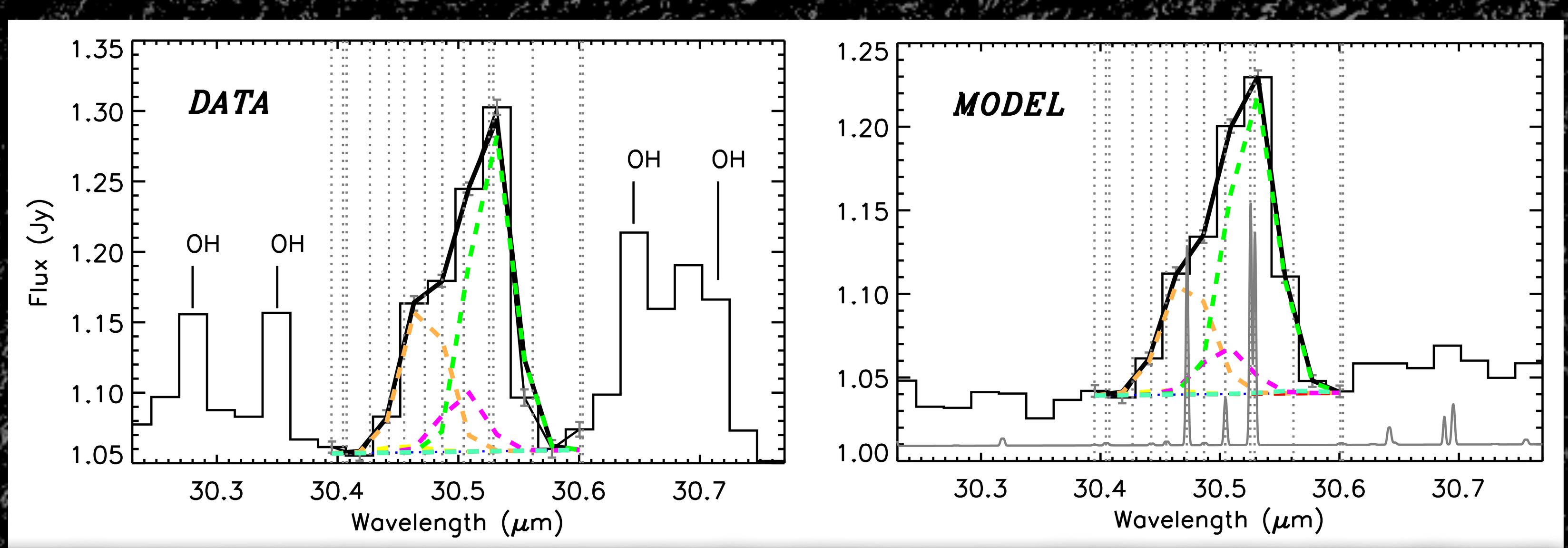


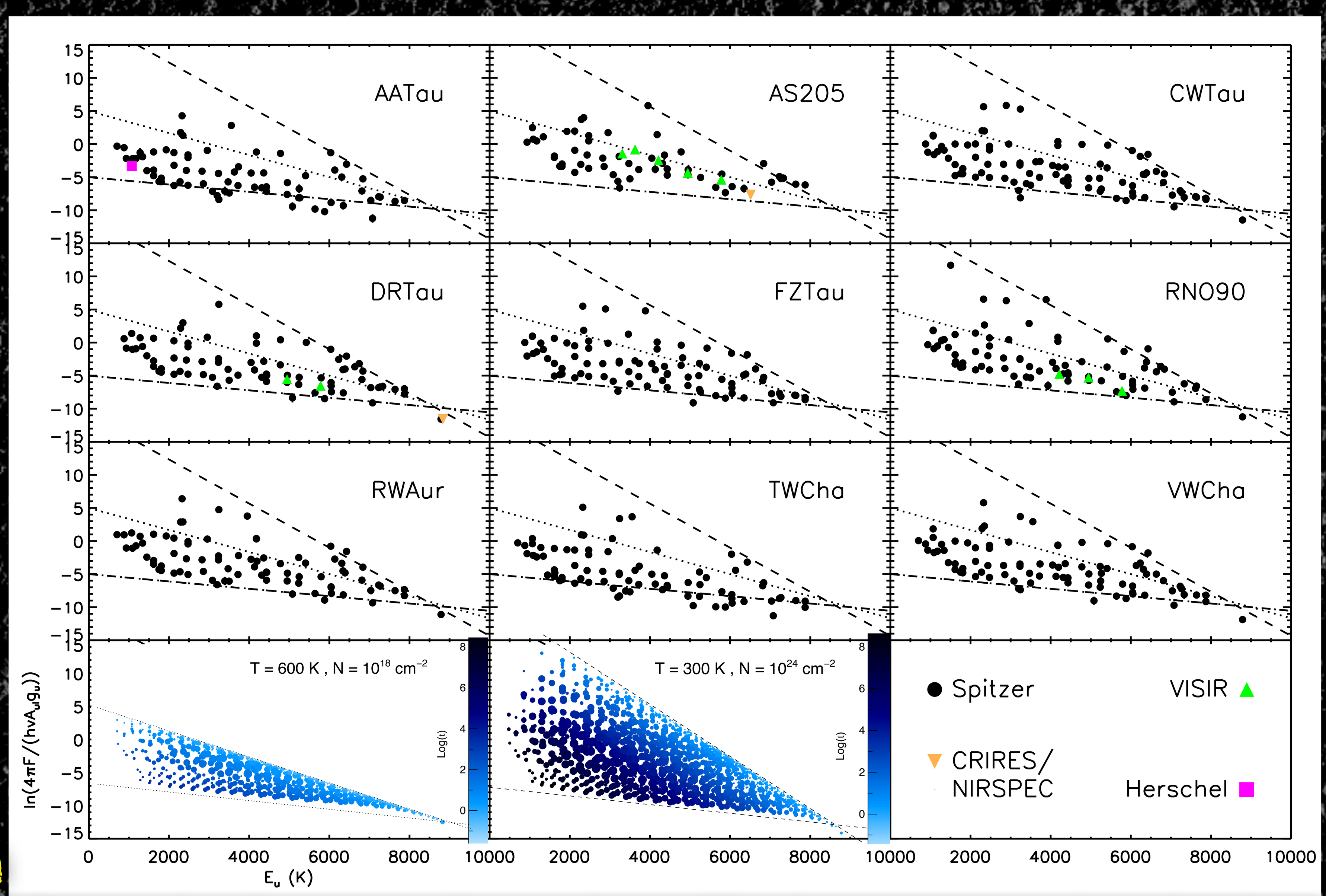
1. Molecular gas emission at planet-forming radii changes remarkably during a strong accretion outburst in EX Lupi. From comparison of Spitzer spectra: in outburst the gas emits from a larger extent of the disk, water increases and is photodissociated into OH, organics disappear... Accretion outbursts during the T Tauri phase may shape the conditions of the molecular gas at planet-forming radii in young disks!!



2. A simultaneous X-shooter + VISIR monitoring of DR Tau. A deeper insight on the accretion – water chemistry connection is provided by comparison of DR Tau and EX Lupi. Long and strong outbursts change the thermal structure of the inner disk and increase water emission, while UV photochemistry may dominate the short-term accretion variability typical of the T Tauri phase.



3. A new de-blending procedure to extract individual water transitions from Spitzer spectra of disks, which to date still provide the largest survey of water vapor in planet formation regions. A large coverage of rotational lines is needed for better insights into the origin of water (see right below) and to complement data from higher-resolution instruments (e.g. from Herschel).



4. First rotation diagram analysis of water emission from protoplanetary disks: a large scatter suggests a large column density. Optically thin water lines de-blended from Spitzer spectra support evidence for large abundances that are expected from inward migration and evaporation of icy solids.. a new connection between observations, disk evolution and planet formation?

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SLOW

ABSTRACT

My research is devoted to study the conditions and evolution of the terrestrial planet formation region in young circumstellar disks (1-10 AU disk radii), by means of spectroscopic observations of gas emission. My main focus is the infrared spectrum of water vapor (H_2O), which provides thousands of emission lines tracing the warm and dense regions inward of the snowline in disks and helps characterize the chemical environments of planet formation. My research considers also the emission from OH (hydroxyl) that is tightly connected to the formation and destruction of the water molecule, as well as the emission from some organic molecules that trace the carbon chemistry (C_2H_2, HCN, and CO_2). Particular consideration is given to the non-steady accretion phenomena that happen during the T Tauri phase of young stellar objects, which are used as a tool to better understand the origin and evolution of molecules in inner disks.

EX LUPI: ACCRETION AFFECTS DISK GAS MOLECULES (fig. 1)

A pioneering contribution of my research is the study of the molecular gas emission observed toward the strongly variable T Tauri star EX Lupi (Banzatti et al. 2012). Mid-infrared Spitzer spectra obtained previous to and during a recent strong accretion outburst were compared, and found that the gas changes remarkably between the two phases. The emission in quiescence is composed of the typical molecular lines that dominate mid-infrared spectra of T Tauri systems (e.g. Pontoppidan et al. 2010): a dense forest of water, OH, C_2H_2, HCN, and CO_2 lines. These lines are observed in emission and attributed to warm gas layers in the disk at a few AU from the central star. During outburst, water emission increases in strength, new and stronger OH lines are detected, and emission from organics disappears. These changes are interpreted as due to a larger emitting area of the warm gas in outburst, when the disk is increasingly heated up by the increase in mass accretion rate onto the star. In addition, enhanced UV radiation is found to play a key role in producing OH from photodissociation of water. The behavior of organics remains unclear... All molecular emissions are difficult to analyze and interpret, because of strong blending between lines. This is particularly true for water, which has thousands of lines scattered all over the infrared. Yet, it is vital to study in detail the infrared emission from warm molecules to be able to understand the planet-forming inner disk region. The remarkable findings of this work motivated follow-up investigations in two directions.

DR TAU: EXPLORING THE ACCRETION - WATER LINK (fig. 2)

One direction was taken to better understand the role of accretion variability in shaping the conditions of water vapor in inner disks during the T Tauri phase. A new-concept monitoring program was performed observing the T Tauri system DR Tau with two high spectral resolution spectrographs at the ESO Very Large Telescope (VLT). VLT/VISIR (resolving power R=20000) was used to resolve individual mid-infrared (12.4 μm) water lines from the disk, while VLT/X-shooter (R=9000-17000) was used to simultaneously monitor the UV-NIR (0.3-2.5 μm) and measure changes in accretion luminosity. Three epochs of simultaneous observations were successfully taken, during which the accretion luminosity changed by a factor of 2, while water emission did not change significantly. The behavior observed in EX Lupi and in DR Tau is consistent with a scenario where non-steady accretion phenomena have two effects: one is to heat the inner disk, but considerable variations are perhaps produced only when accretion increases enough and over long enough timescales for the thermal structure of the disk to change (≈months, as in EX Lupi). Another effect is to photodissociate water by means of UV radiation. This latter process is very fast and probably shapes the evolution of water and other molecules during the short-term accretion variability typical of the T Tauri phase.

ON THE WATER ABUNDANCE IN YOUNG DISKS (fig. 3,4)

A second direction was taken to tackle another fundamental problem: the origin of water vapor in inner disks and its connection to disk evolution and planet formation. The water molecule in the gas phase is thought to be linked to fundamental processes happening in disks. Competing theories provide two different perspectives, where water is produced by evaporation of icy solids migrating inward of the snowline (Ciesla & Cuzzi 2006), or formed in situ via gas-phase reactions (Glassgold et al. 2009). While migration and evaporation of icy solids would make water emission a good tracer of disk evolution and planet formation conditions, in-situ formation in a static disk may or may not be connected to what happens deeper in the disk midplane. It is therefore essential to distinguish which process dominates in order to understand what we learn from observing (or not observing) water vapor in inner disks. One way to do that is by measuring the abundance of warm water vapor in young disks, which is expected to be enriched by evaporation of icy migrators crossing the snowline. In my PhD, for the first time, a systematic rotation diagram analysis has been applied to water emission over a considerable sample of young circumstellar disks. A de-blending procedure was developed to extract a large number of emission lines from Spitzer spectra, so to allow a more comprehensive interpretation of the observed emission. This rotational analysis promises to be very important to reliably constrain water abundances, which may be larger than previously thought and possibly favor the migration scenario. Measurement of resolved optically thin lines within the forest of optically thick lines is proposed to be a key tool to address the (still open) question. We may be one step closer in finding important answers on the conditions of water vapor in disks and on its connections to disk evolution and to the formation of (wet/dry) terrestrial planets...