SOFIA Spectroscopy of Hydrated Silicates in the Diffuse ISM and Ices in Dense Clouds

Jean Chiar, SETI Institute

Community Task Force Telecon

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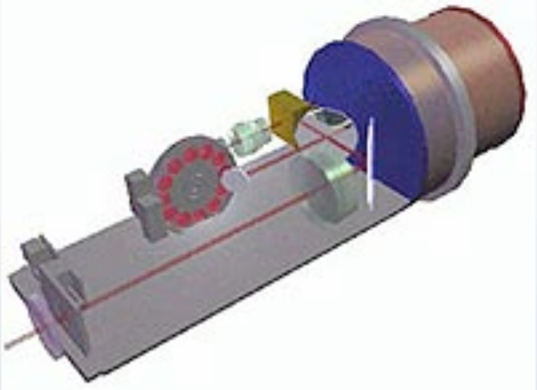
Collaborators

- Hydrated Silicates (*FLITECAM grisms*)
  - D. Whittet, RPI
  - K. Pitman, PSI
  - A. Hofmeister, Washington U, St. Louis, MO
  - I. McLean, UCLA
  - E. Smith, NASA Ames/SOFIA
- Ices in the 5-8 μm Region of Dense Clouds (*FORCAST grisms*)
  - D. Whittet (PI), C. Poteet, RPI
  - A. Boogert, Caltech
  - L. Keller, Ithaca College
  - S. Shenoy, USRA/SOFIA
  - C. Knez, JHU

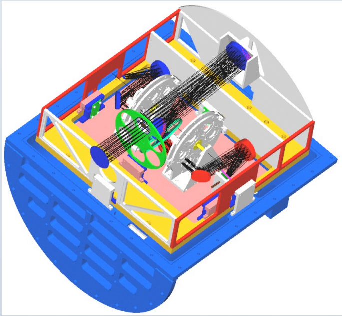
SOFIA Science Vision: dust processing in the Interstellar Medium (ISM)

- OH stretching mode of hydrated silicates in diffuse ISM
  - FLITECAM grisms
  - 2.22 – 3.47 μm R~900 observations will be used to quantify or limit the level of hydration in ISM silicate grains



Ian McLean, UCLA

- 5 – 8 μm region of low mass YSOs and one quiescent dense cloud line of sight
  - FORCAST grisms
  - Use high resolving power (R~1200) spectra to characterize the (organic) ice and dust components



T. Herter (Cornell U),
L. Keller (Ithaca College)

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What Can Hydrated Silicates Tell Us about Dust Processes?

- Dust evolution
  - Silicate dust created in outflows of evolved stars; **10-20% crystalline** (Molster et al. 2002; Kemper et al. 2004)
  - Silicates in diffuse ISM is **<2% crystalline** (Kemper et al. 2004,2005)
  - Silicates in protoplanetary disks (Olofsson et al. 2009) and comets (Crovisier et al. 1997; Sitko et al. 2011) is also crystalline

→ ISM dust must become amorphized by an efficient process in order to explain the observed low crystalline silicate abundance in the diffuse ISM

→ The same efficient process that can amorphize the grains will also form OH bonds within silicate particles

Amorphizing ISM silicates

- H+, He+ ions
  - Supplied by interstellar shocks in the warm ISM (Jones et al. 1996)
  - Low energy (10-50 keV) ions efficiently amorphize crystalline silicates (Demyk et al. 2004)
  - Implantation of the ions causes increase in porosity which allows H^+ to react within the silicates to form OH
  - Up to **3% hydration** can occur (Djouadi et al. 2011)

This can be tested by measuring the 2.7 μm OH absorption feature. Even a null detection is important as it will put a limit on the process.

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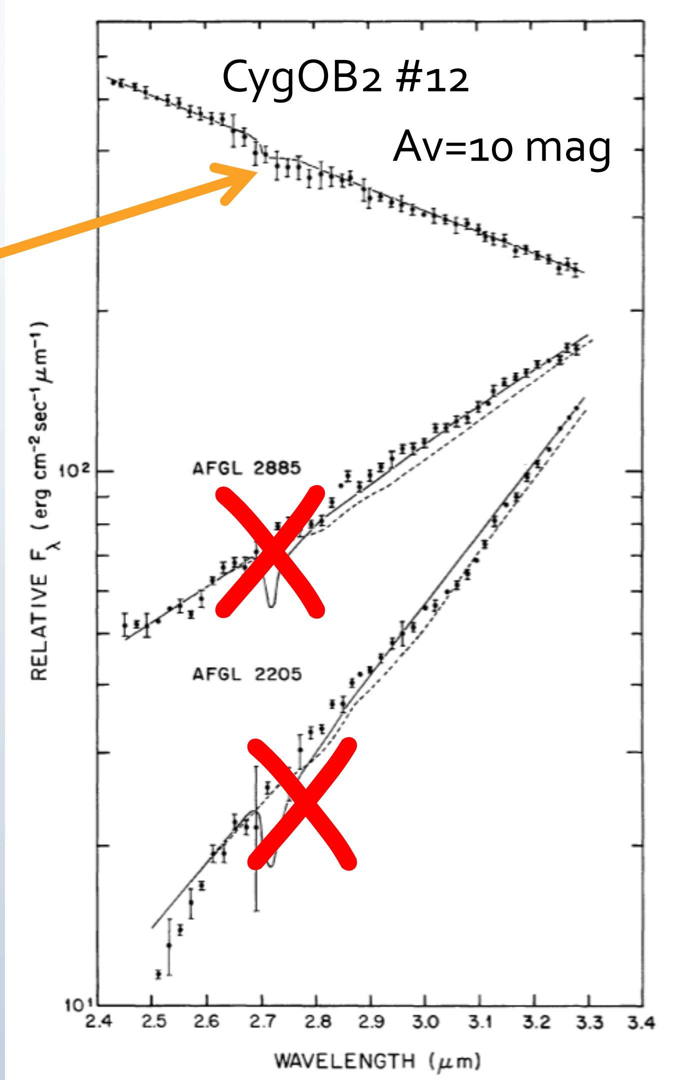
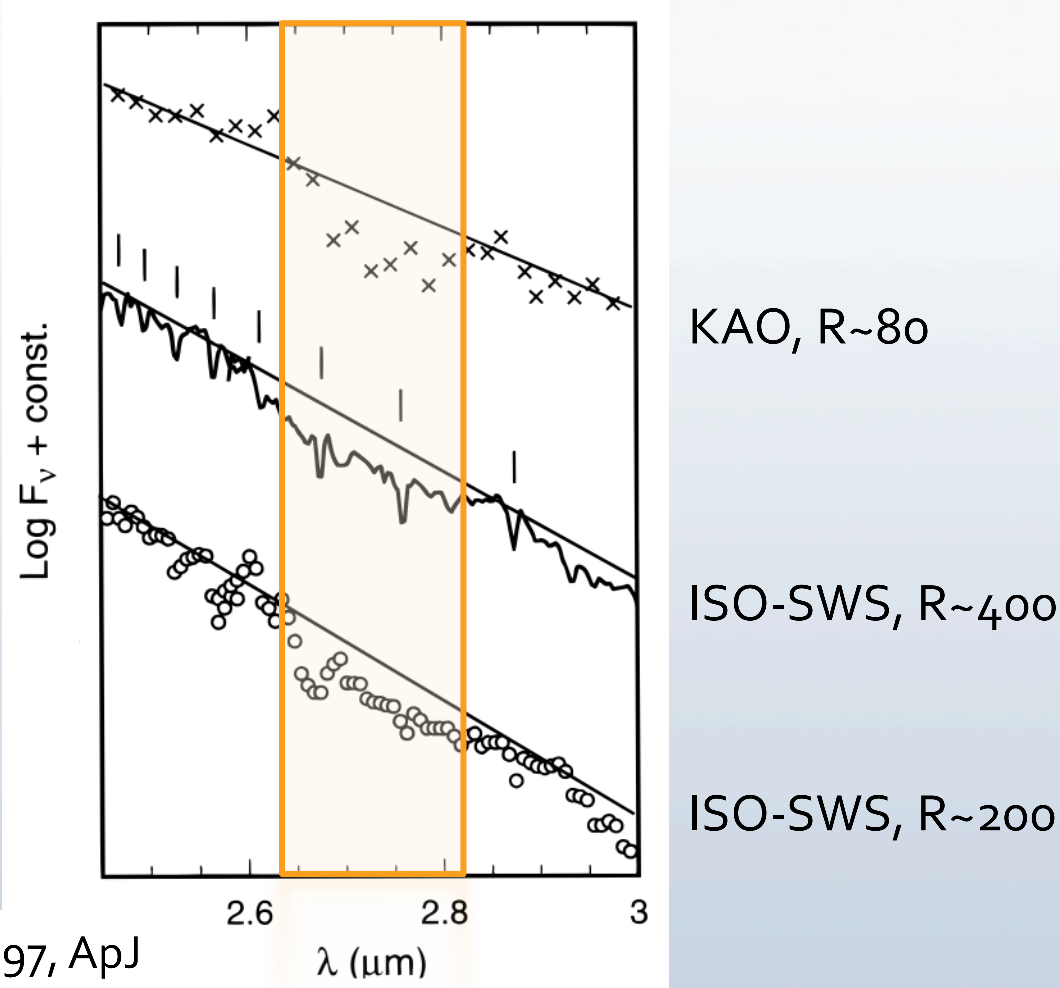
The History of Hydrated Silicate Observations

- 1985: Knacke et al.
  - KAO spectra
  - Marginal detection in **Cygnus OB2 #12**
    - Correction for telluric CO_2 was incomplete
  - X the extinction in these sources is mainly circumstellar (late-type stars)



The History of Hydrated Silicate Observations

- 1997: Whittet et al.
  - ISO-SWS spectrum of Cyg OB2 #12



Whittet et al. 1997, ApJ

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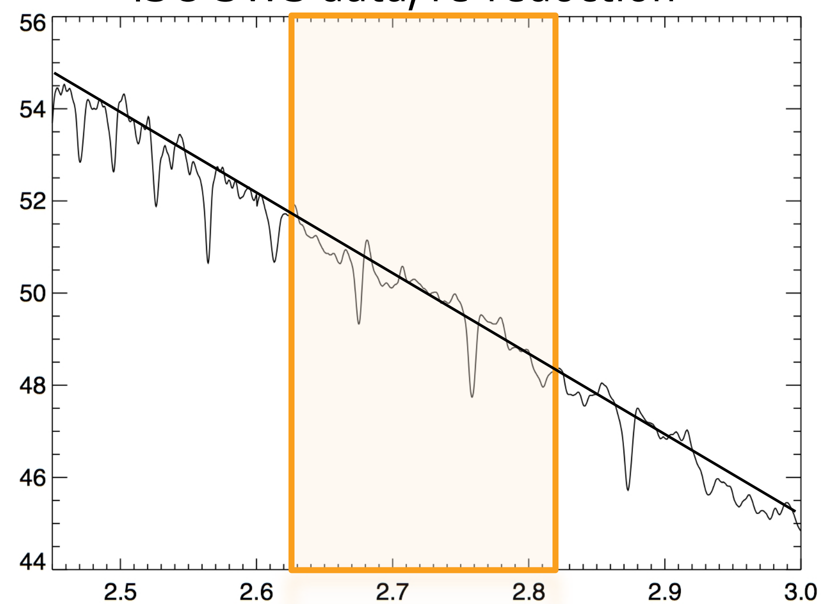
The History of Hydrated Silicate Observations

- 1997: Whittet et al.
  - ISO-SWS (AOT01) spectrum
  - Re-reduction of data resulted in disappearance of the feature (Whittet et al. 2001)

ISO SWS data, re-reduction



Data reduction courtesy of A. Boogert

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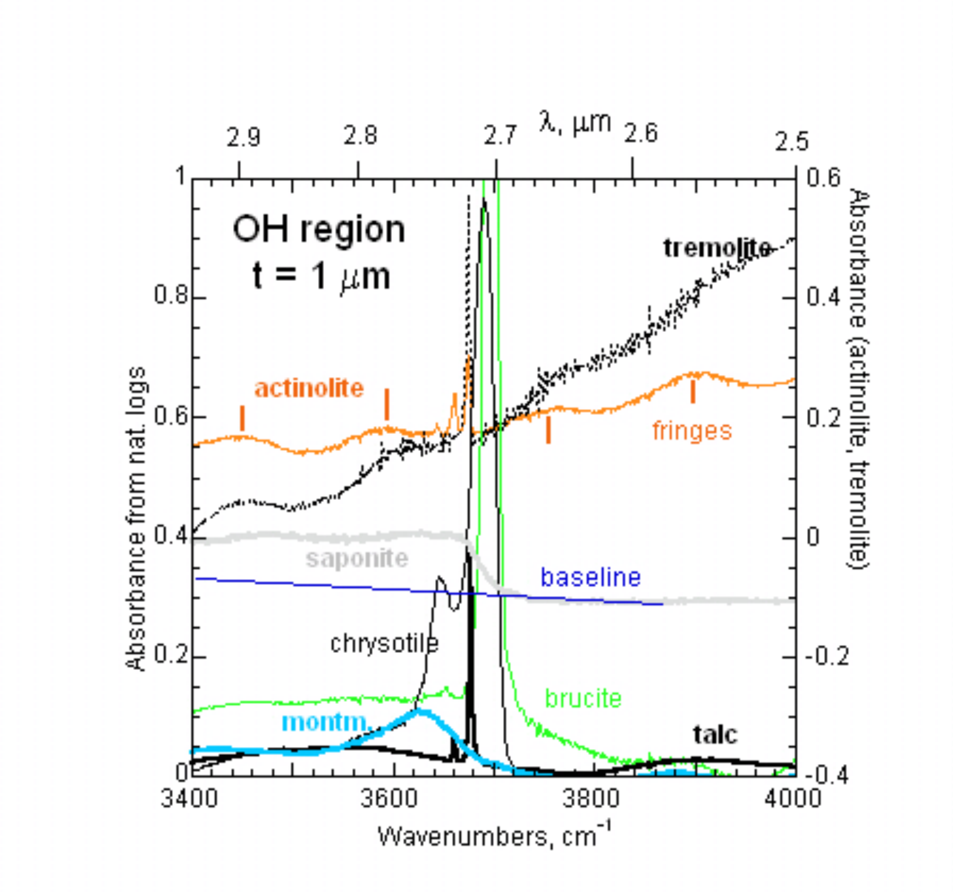
Lab-produced Hydrated Silicates



Hofmeister & Bowey 2006

- These OH bands are the strongest astronomically accessible bands of hydrous silicates
- Experimentally produced hydrated silicate minerals
- (Wiggles are fringes due to scattering in the sample. New experiments using mineral chips by cols Hofmeister and Pitman are underway, and will eliminate the fringing problem.)

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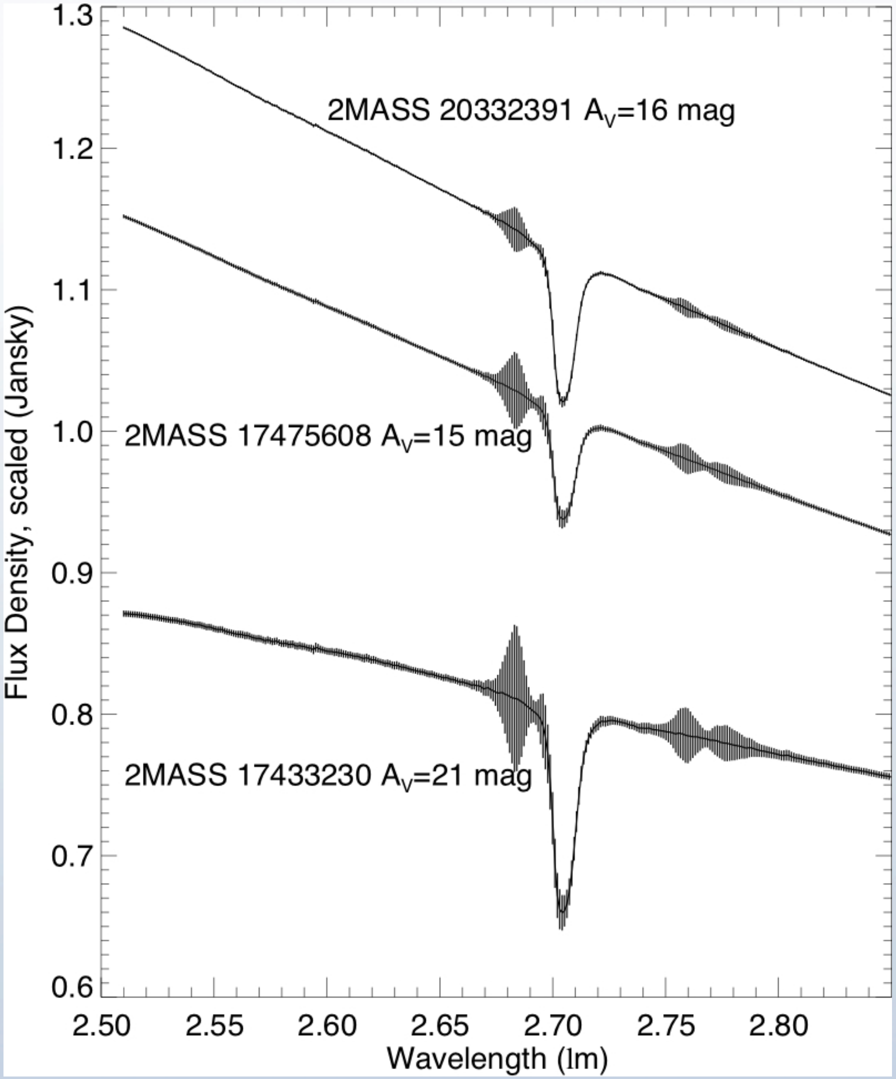
What we expect from SOFIA-FLITECAM

- Lines of Sight
  - Diffuse ISM (no H_2O ice or circumstellar material!)
  - Higher extinction than previous DISM line of sight
- Data quality from SOFIA-FLITECAM
  - R ($\lambda/\Delta\lambda$) ~ 900 compared to 200-400 for ISO-SWS data
  - S/N > 50 in the lowest transmission parts of the spectrum
- Proof of concept
  - Assuming 3% hydration
  - Absorption due to brucite (just as an example)
- Stay tuned for actual observations!



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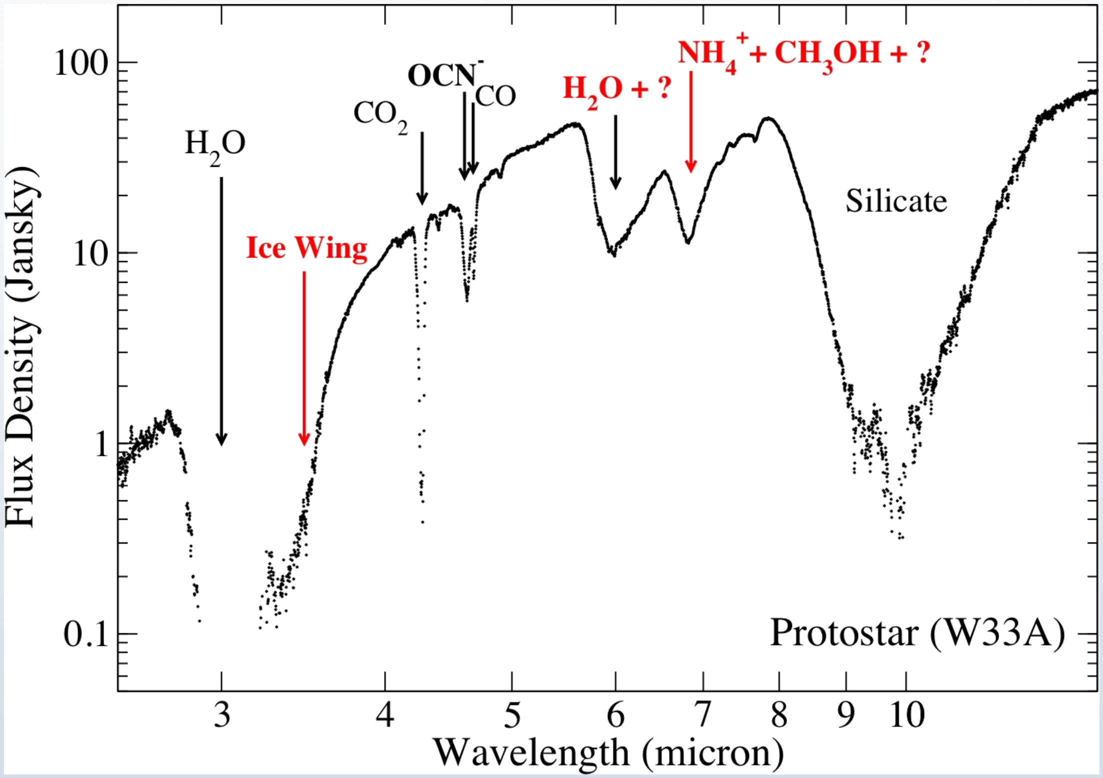
(Recent) History of the Study of Ice Absorption Features



ISO-SWS spectrum, Gibb et al. 2004

- Ice and dust absorption in the mid-IR
  - Absorption features labeled in **black** are well-studied and attributed to known species
  - Absorption features labeled in **red** are incompletely identified

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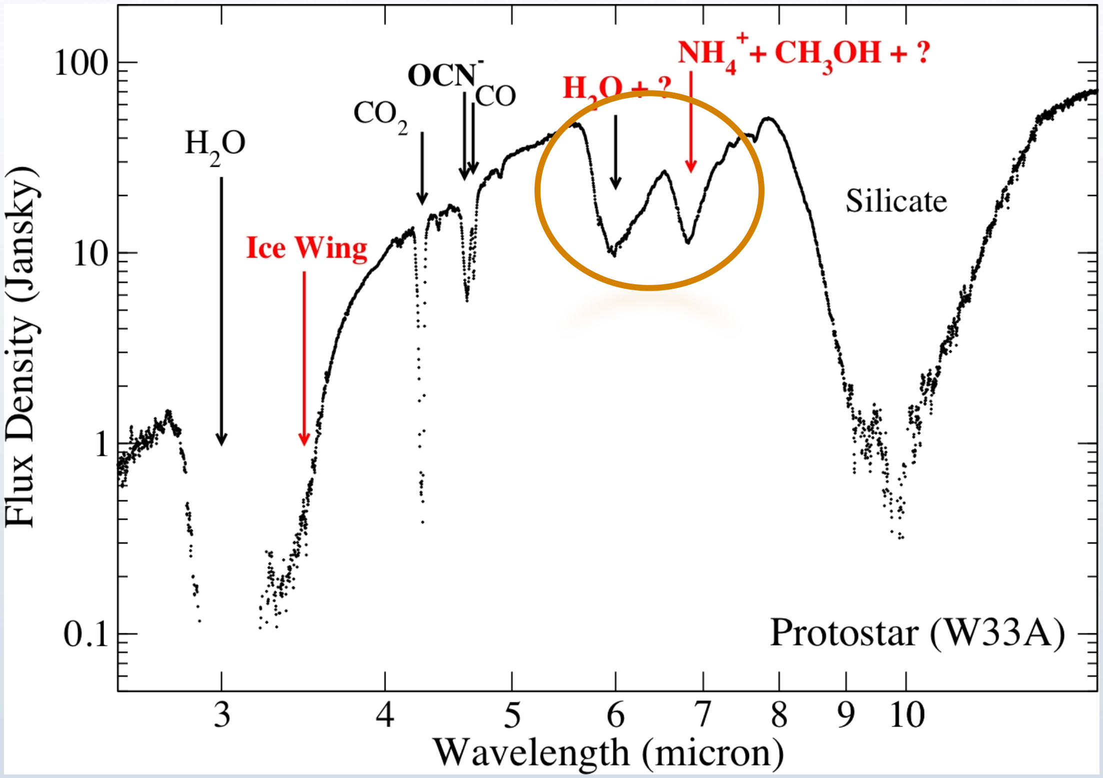
(Recent) History of the Study of Ice Absorption Features



Gibb et al. 2004

- Absorption in 5-8 μm region
  - Strong source-to-source variation
  - Blend of absorptions due to several dust & ice species
- Existing Astronomical Data
  - KAO → high mass YSOs, low resolution (R~50)
  - ISO-SWS → high mass YSOs, high resolution (R~1000)
  - Spitzer-IRS → low mass YSOs, quiescent dense cloud material, low resolution (R~60-100)

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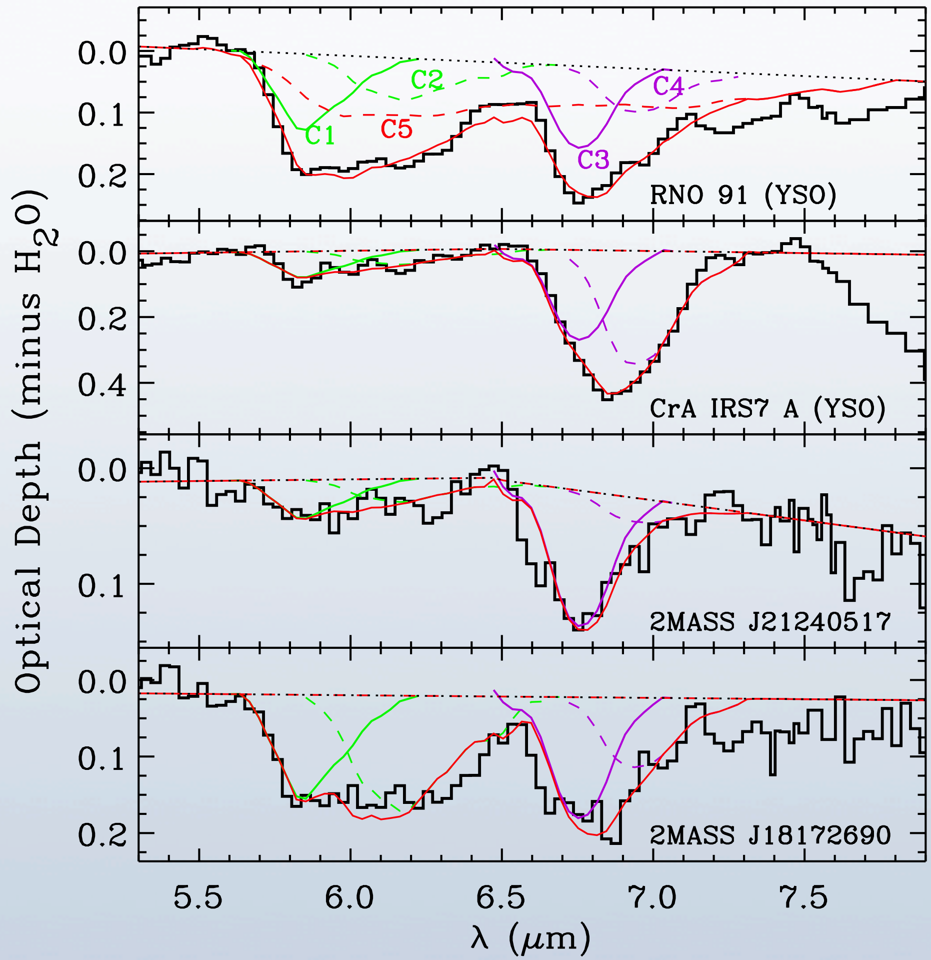
Absorption Features in the 5 to 8 μm Region

- Detected toward low-mass YSOs (upper two spectra)
- Detected in quiescent dense cloud sightlines (bottom two spectra)
- Decomposed into 5 components
- Large source-to-source variations

Spitzer IRS, R~60-100



Boogert et al. 2008, 2011

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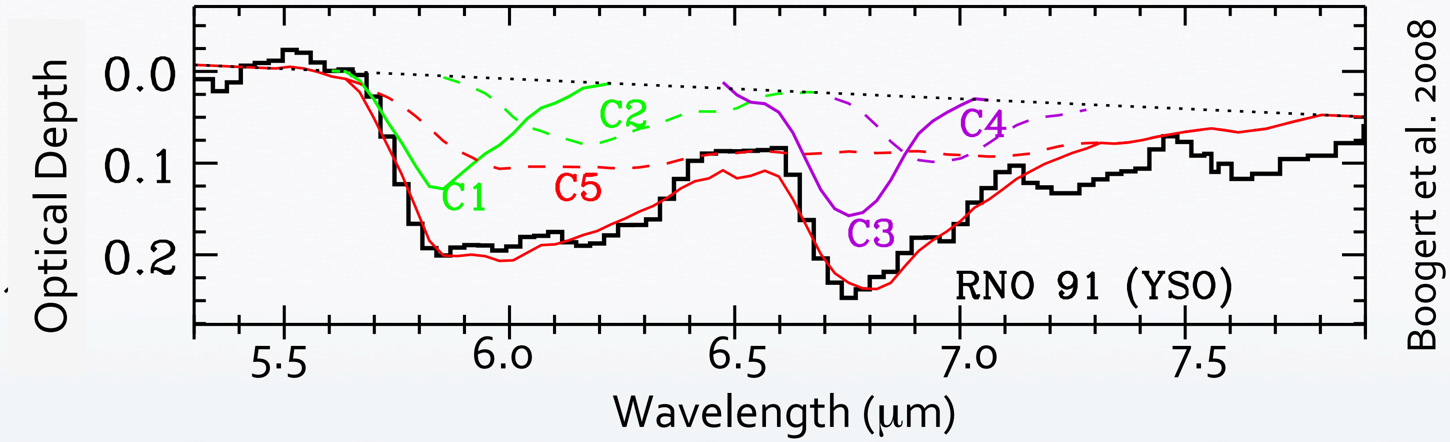
Absorption Features in the 5 to 8 μm Region



- Absorption in 5.5 – 7 μm region (minus H_2O)
  - **C1:** mostly explained by HCOOH, H_2CO (1-5%, ~6% w.r.t. H_2O)
  - **C2**: at least 3 carriers: NH_3 (10-50% of absorption), H_2O:CO_2 mixtures (Oberg et al. 2007; Knez et al. 2005), ions
  - **C3**: correlates tightly with H_2O
  - **C4:** increases with lower H_2O-ice abundance, so may already be present before ice mantle forms
  - **C5:** Organic residue?

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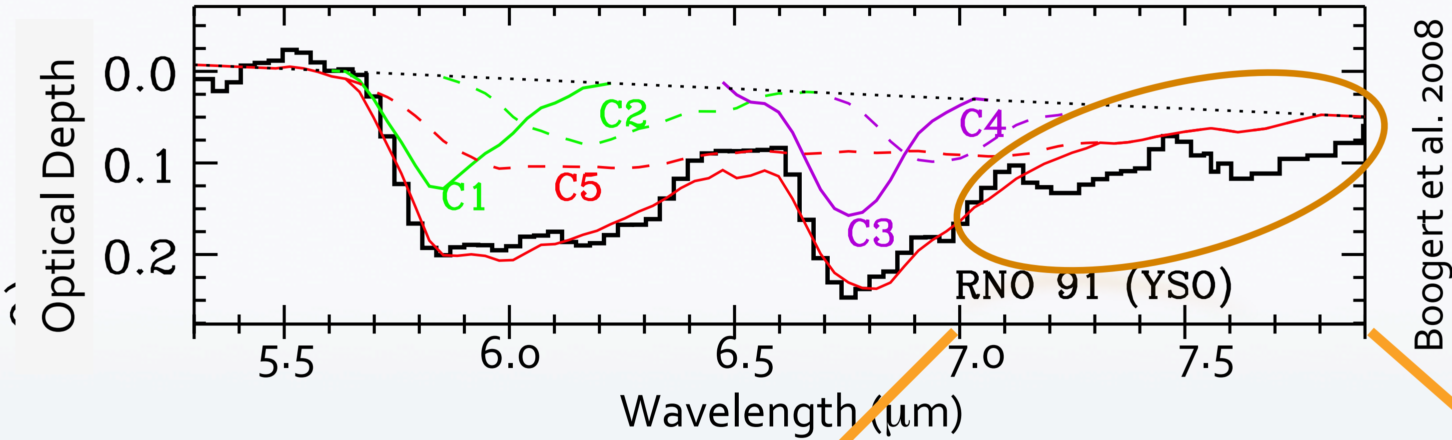
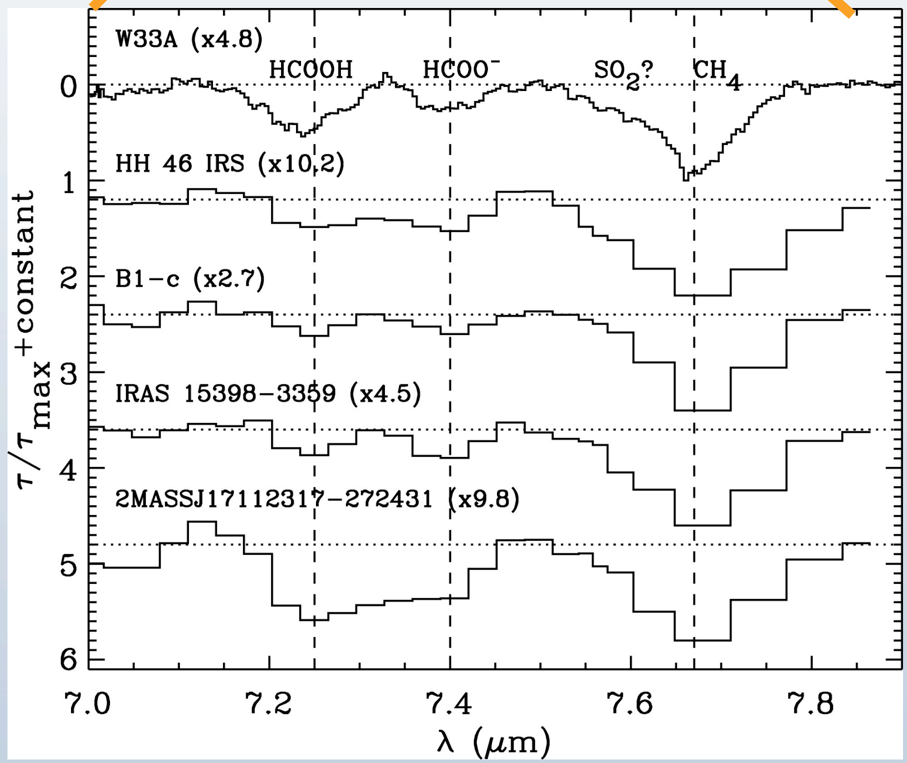
Absorption Features in the 5 to 8 μm Region



- Absorption in 7 - 8 μm region
  - HCOOH, $HCOO^-$, SO_2, CH_4
  - ISO-SWS, upper spectrum, high mass YSO
  - Spitzer-IRS, low mass YSOs



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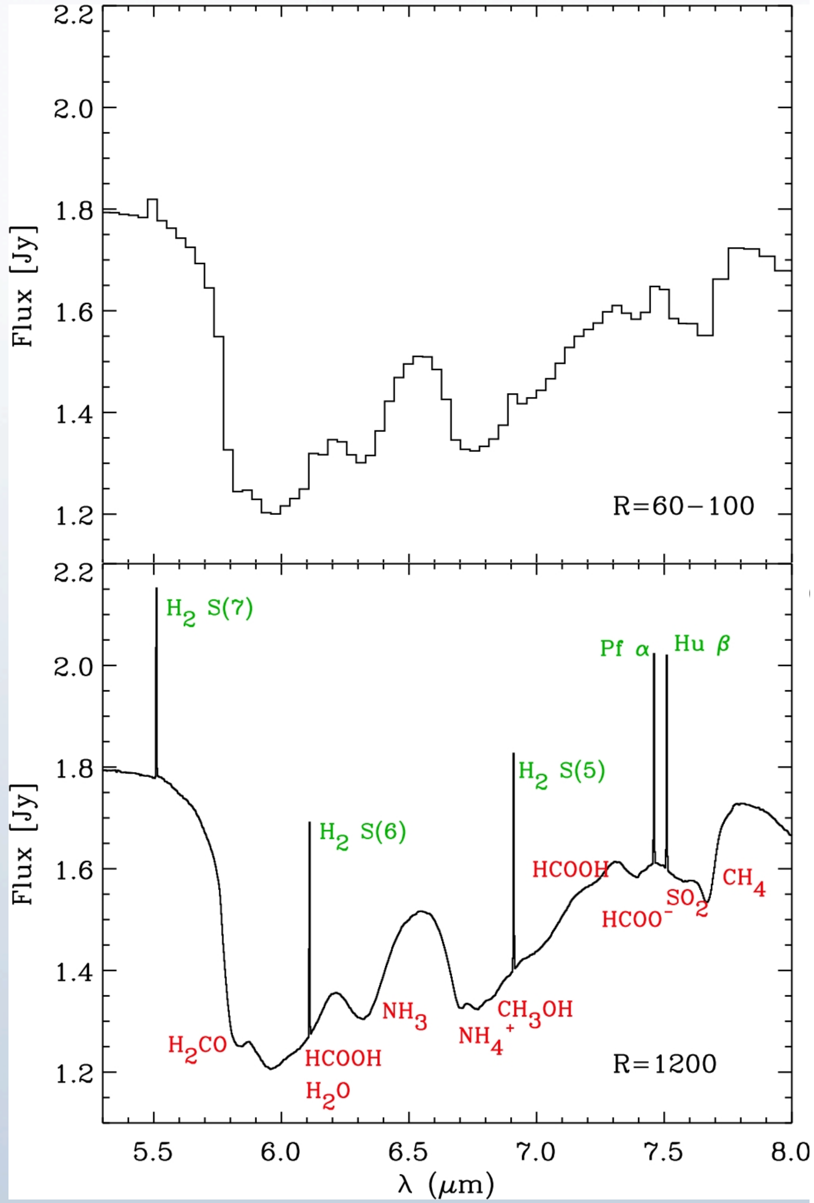
What we expect from SOFIA-FORCAST

- Our target list includes four low-mass YSOs and one field star
  - The low-mass YSOs were chosen to sample a range of environments
- We will use the cross-dispersed mode which will yield R~1200
- Gas phase lines will be well-separated from the ice/dust features
- Stay tuned for the real SOFIA-FORCAST spectra!



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Summary

- SOFIA-FLITECAM will be employed to…
  - Observe **hydrated silicates** in the diffuse ISM
  - Enlighten us about the process that turns crystalline silicates into the amorphous silicates we see in the ISM
- SOFIA-FORCAST will be employed to…
  - Observe the first high-resolution 5 to 8 μm spectra of quiescent cloud material and of low-mass YSOs that sample different environmental conditions (thermal/ energetic processing)
  - Better identify (and quantify) the contributors to the absorption, and thus the conditions that lead to their formation

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