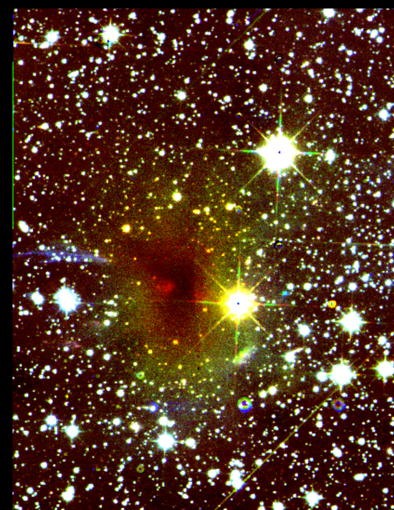
Ices in small dense molecular cores



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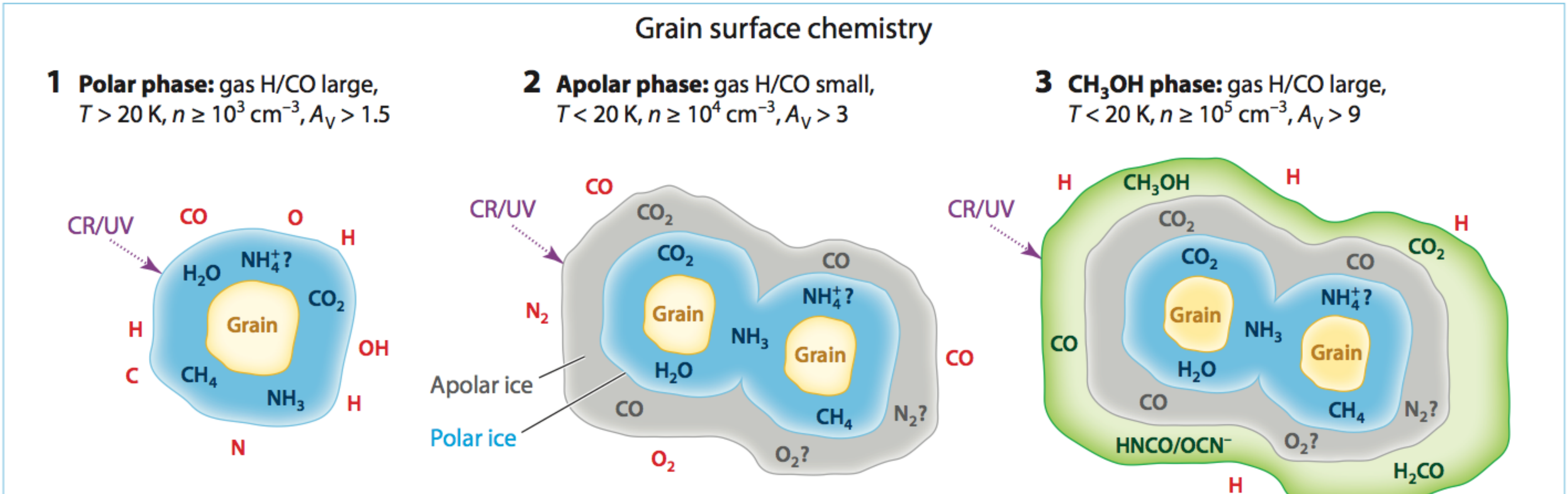
In collaboration with Klaus Hodapp, Adwin Boogert, Marcia Rieke, Michael Meyer, and Thomas Greene

The Physics and Chemistry of the Interstellar Medium 2019

Intro on Icy Grain Growth

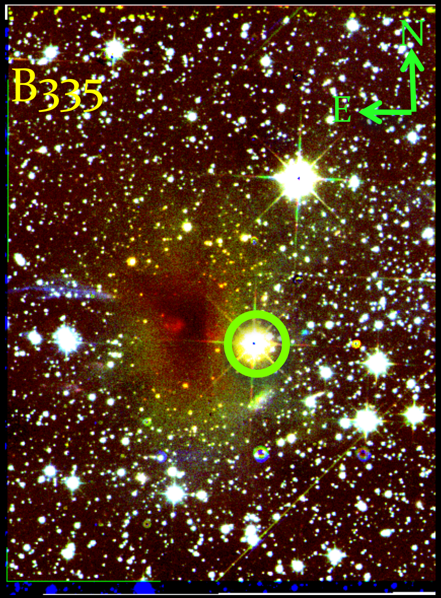
- Complex molecule formation occurs in cold dense molecular clouds on the surface of grains
- Icy mantles promote grain growth
- Unconstrained conditions for the formation of molecules
  - Timescales
  - Density

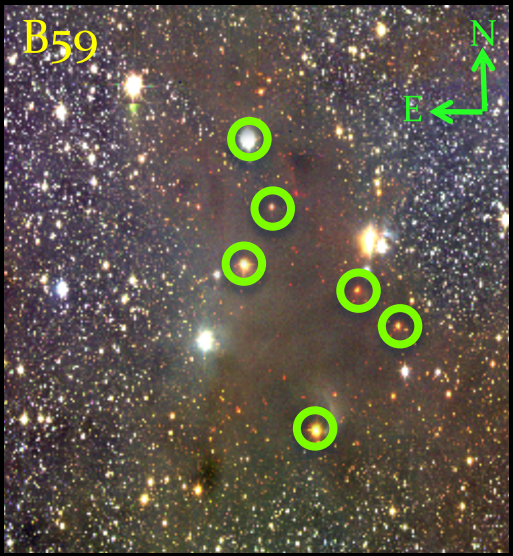


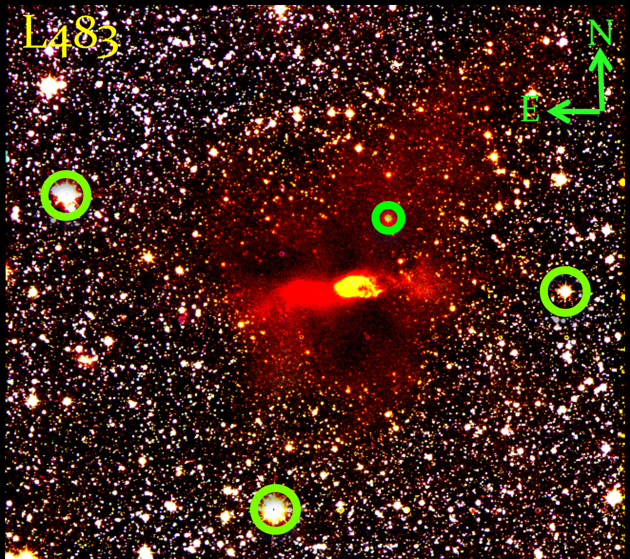
Boogert, Gerakines, & Whittet, 2015

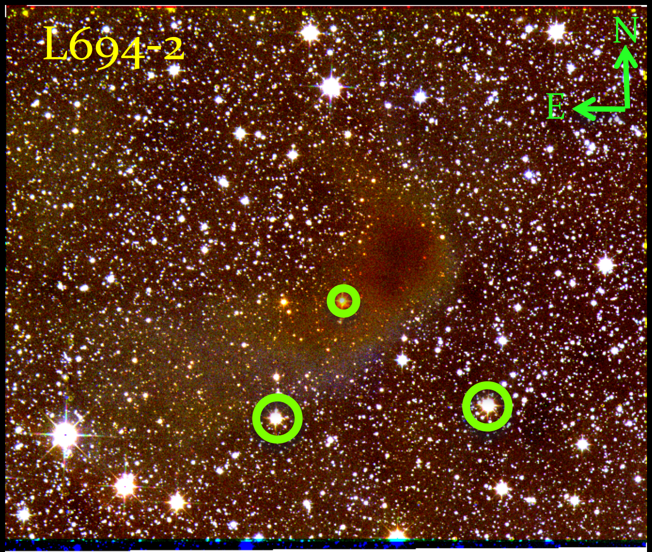
Background Star Sample

- 14 background stars of small dense molecular clouds
  - Clouds are at different evolutionary stages
  - Not looking at the protostar
  - ~7.3 – 12 mag (K band)
  - A_V from ~3-35 mag
- Observed using IRTF SpeX from ~2-5 μm
  - Simultaneously detect H_2O, CO, CH_3OH









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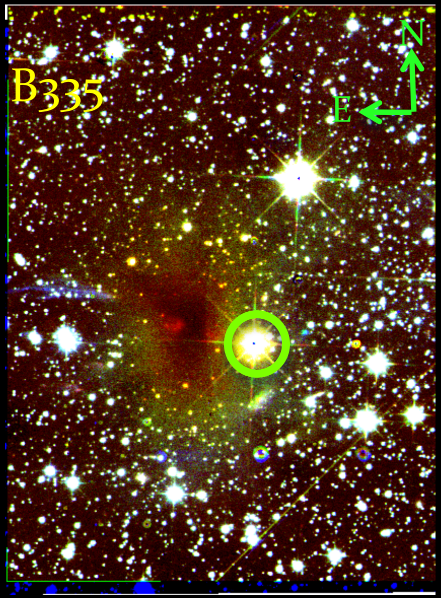
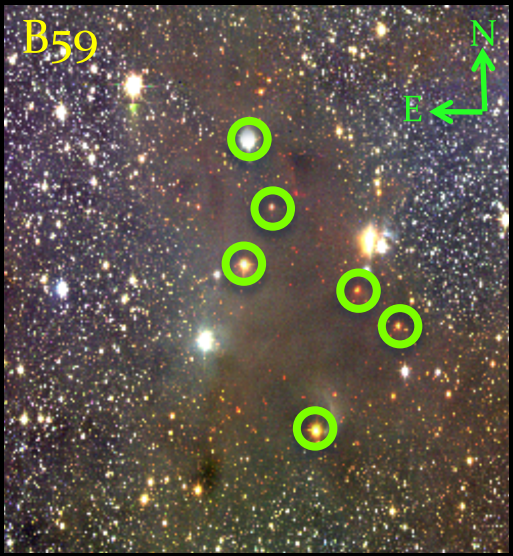
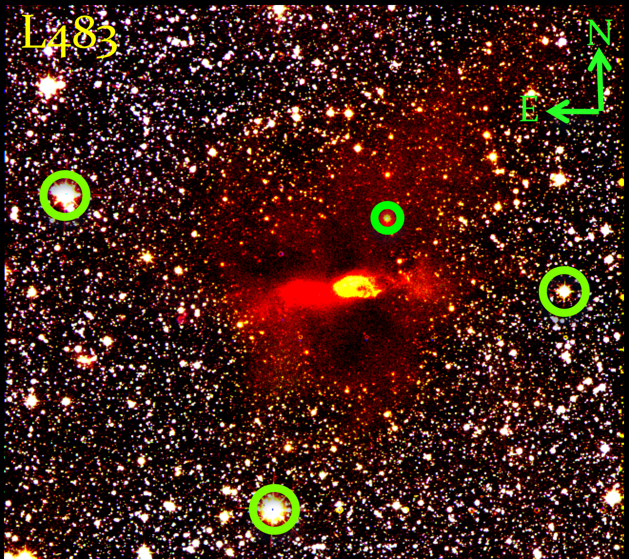
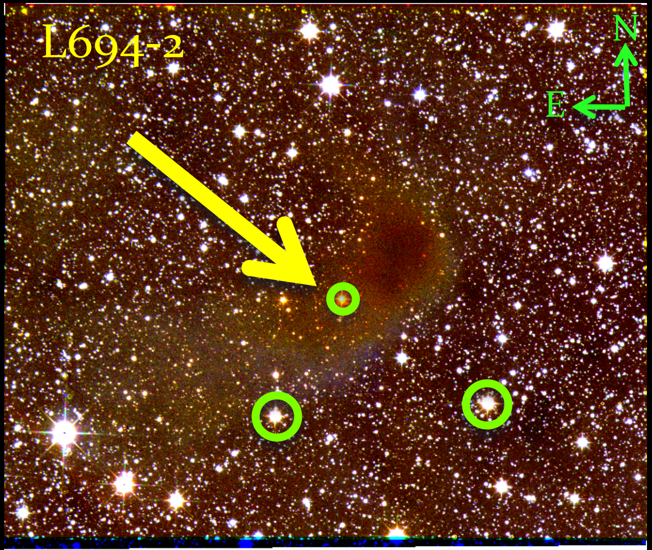
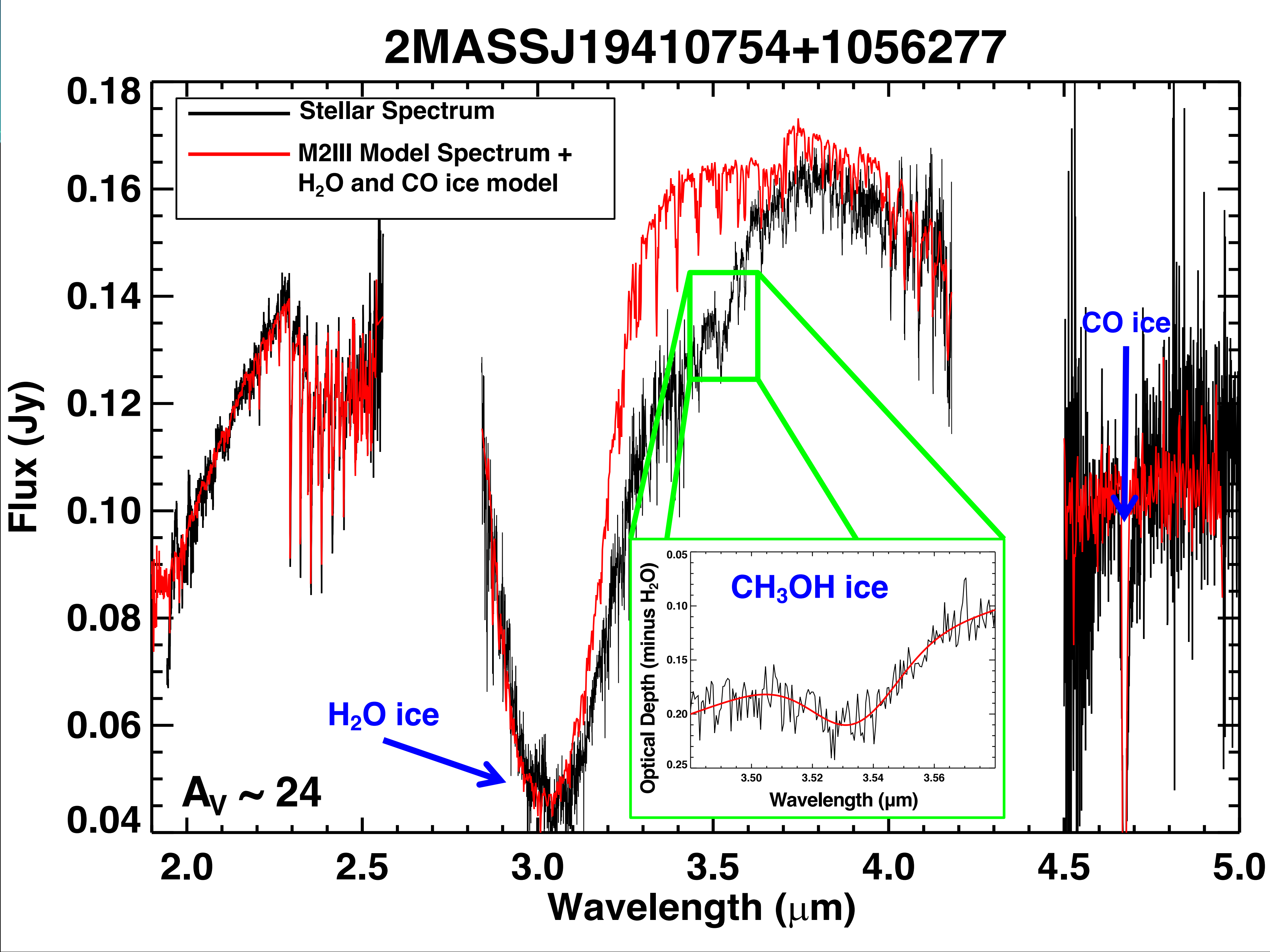




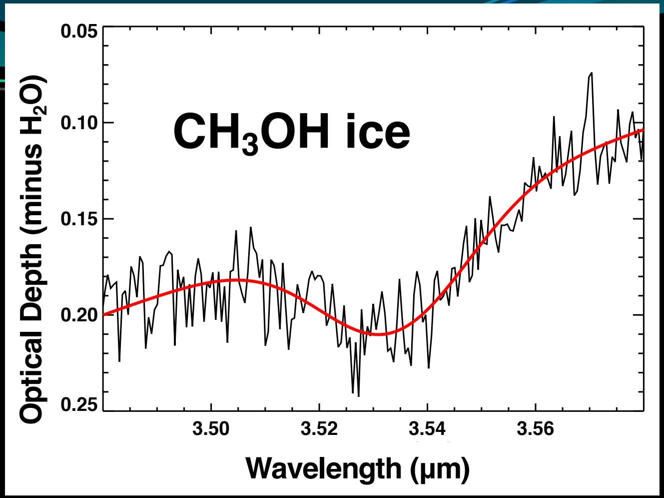


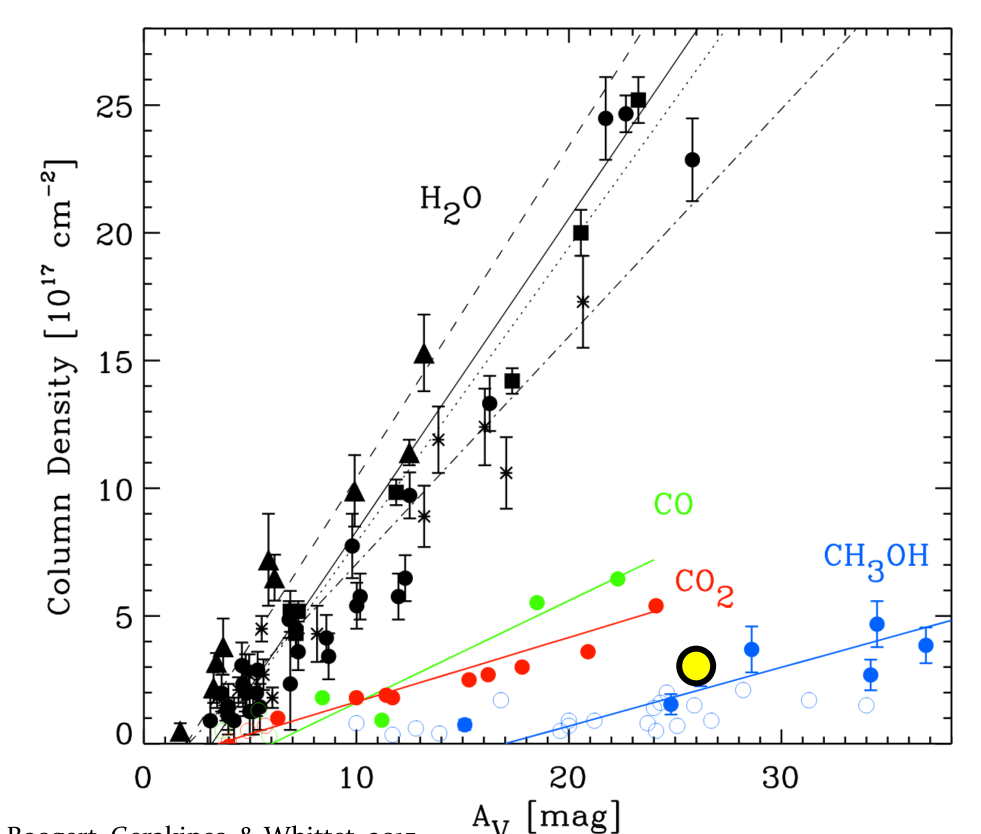



2MASSJ19410754+1056277
Stellar Spectrum
M2III Model Spectrum +
H2O and CO ice model
CH3OH ice
Optical Depth (minus H2O)
Wavelength (µm)
H2O ice
CO ice
AV ~ 24
Flux (Jy)
Wavelength (µm)
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
2.0
2.5
3.0
3.5
4.0
4.5
5.0
0.05
0.10
0.15
0.20
0.25
3.50
3.52
3.54
3.56

Close up of CH_3OH

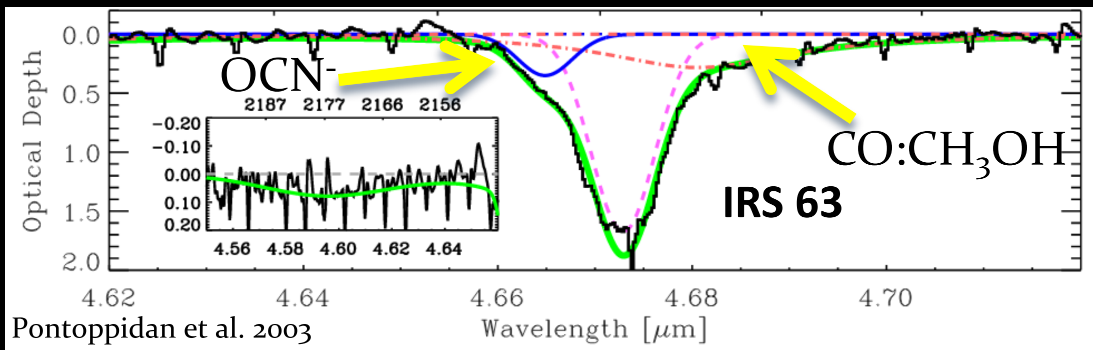
- CO ice hydrogenation to H_2CO and CH_3OH ice are key initial steps in the formation of more complex molecules
- CH_3OH at 3.53 µm C-H stretching mode
- Column Density
  - 3.1×10^{17} cm^{-2}
- CH_3OH:CO:H_2O
  - 1:3:7

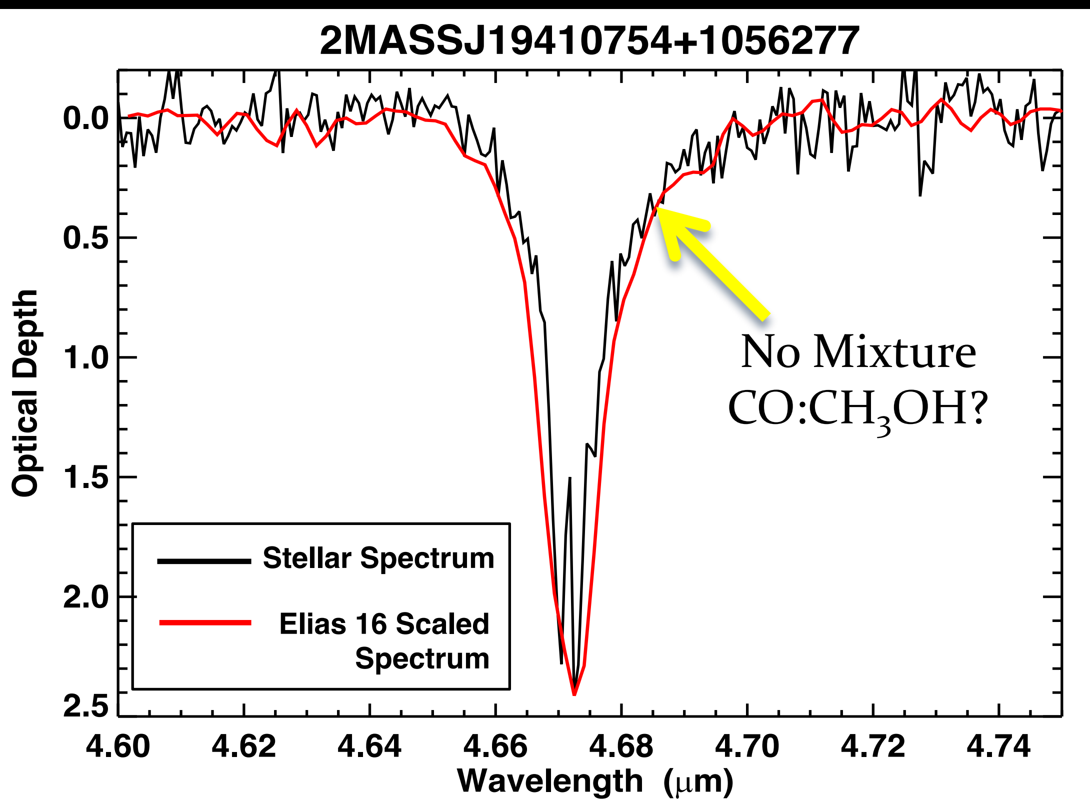




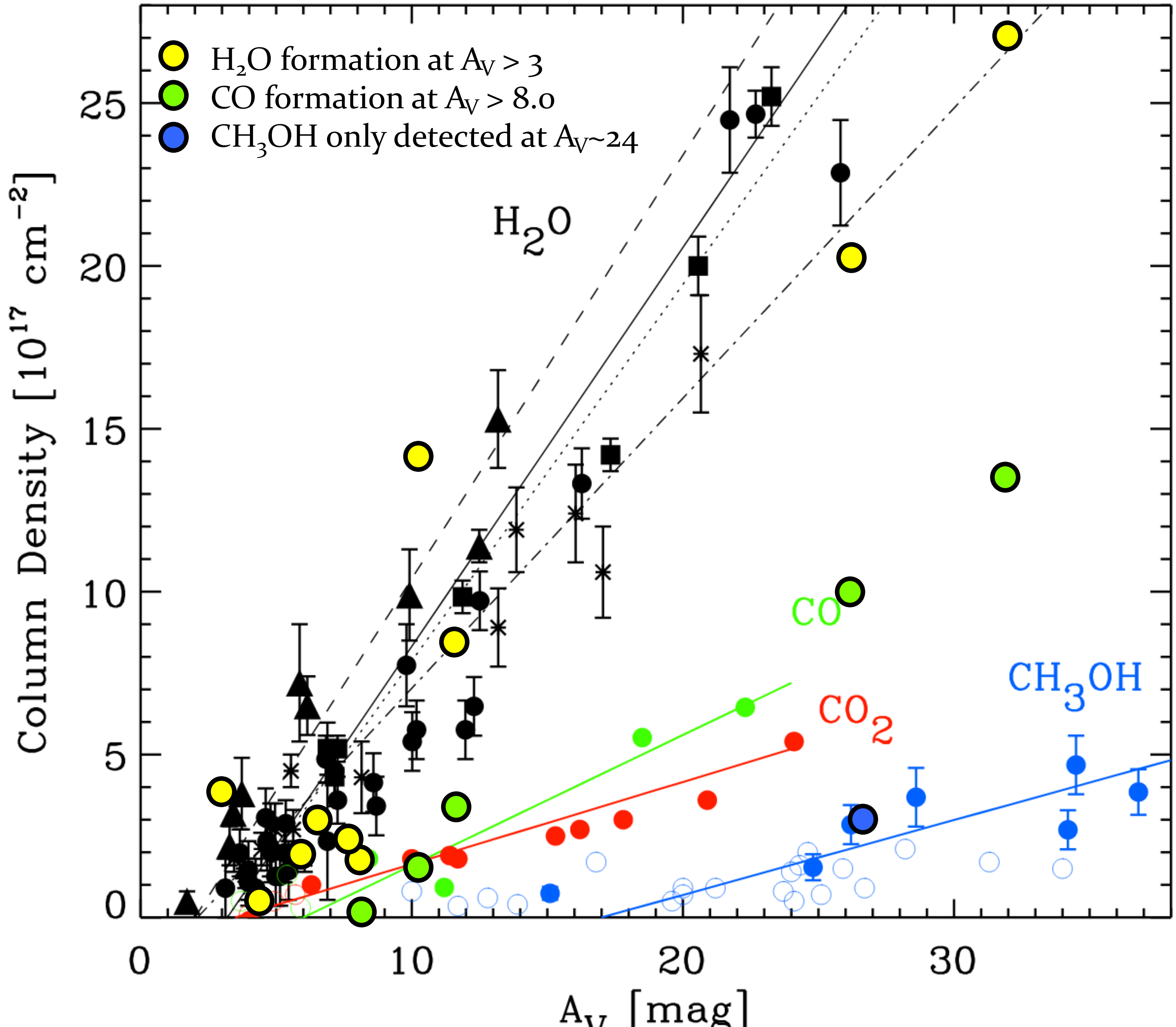
Boogert, Gerakines, & Whittet, 2015

Close up of CO





- Since CH_3OH is detected at 3.53 μm, would expect to see red wing in CO feature
- Compare to Spectrum of Elias 16 – No CH_3OH, less than 1% w.r.t H_2O
- Pure CO and pure CH_3OH detected, but no mixture?

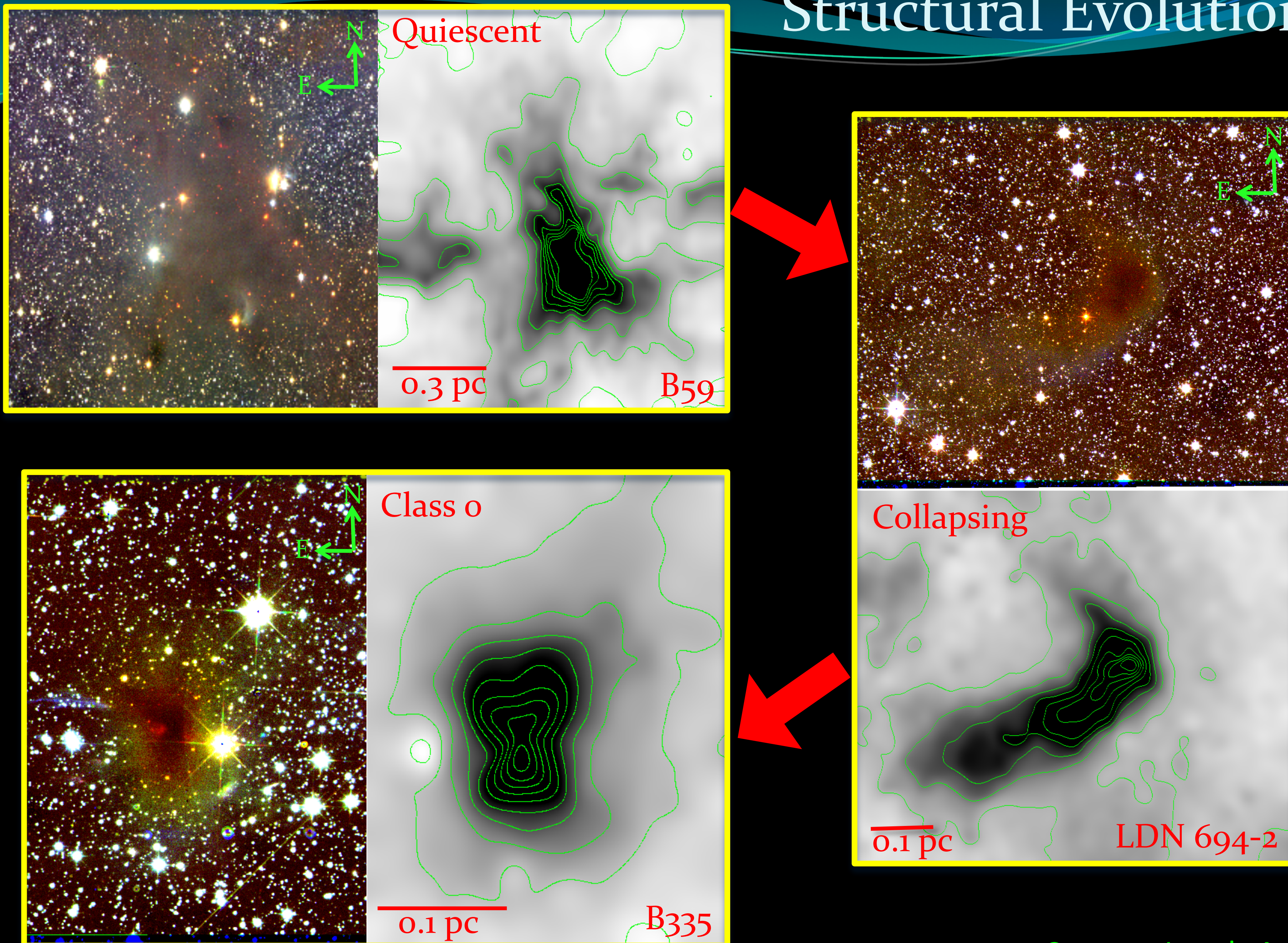


Boogert, Gerakines, & Whittet, 2015

Extinction Maps

- Created 5 maps using NICER technique with combination of JHK (UKIRT), Ch1, and Ch2 (*Spitzer*)
  - Will be improved using XNICER (Lombardi, 2018)
- Map smoothing using a Gaussian Smoothing Function (preliminary)
- Typical spatial resolution of previous extinction maps using 2MASS ~3 arcminutes
  - ~ 20" spatial resolution for 3 clouds
  - ~35-50" spatial resolution for 2 clouds

Structural Evolution

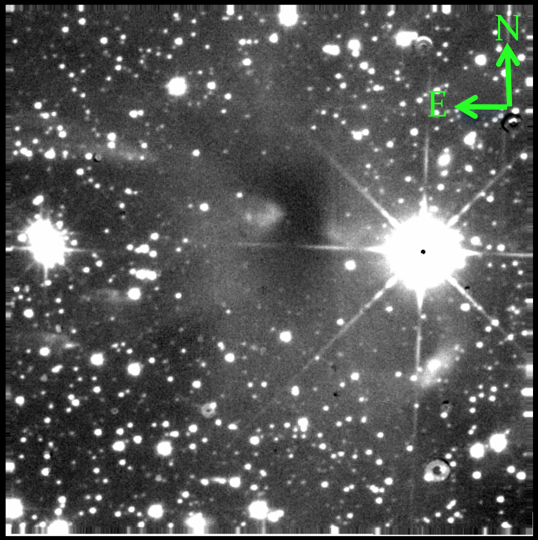


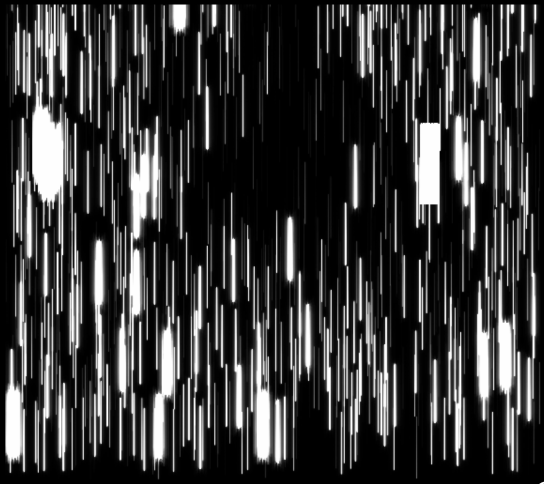
Contour Levels $A_V = 4$

NIRCAM Slitless Spectroscopy

- Need JWST to observe ice features for many background sources
  - Use Slitless Spectroscopy GTO time
  - B68 (Quiescent), L694-2 (Collapsing), and B335 (Star forming)
- aXeSIM Simulation of slitless spectroscopy
  - 0.45 hr, F430M filter

Will we be able to isolate individual stars well enough without significant overlap in order to measure the ice features?





Greene et al. 2017

NIRCAM Expected Results

- We expect several hundred spectra of sufficient quality to study H_2O, CO_2, and CO ice per cloud
- About one hundred spectra will be good enough to study the SHAPES of the ice features per cloud
- On the order of dozens of spectra per target will be suitable for CH_3OH and XCN (OCN^-) features and mapping the onset of complex grain surface chemistry per cloud
- A few spectra may be suitable for pioneering studies of $^{12}CO/^{13}CO$ ratio

Summary

- We observe the H_2O, CO, and CH_3OH ice features of background stars of small dense molecular cores
  - One detection of CH_3OH but the CO feature does not show any CH_3OH ice mixture
- Difficult to measure these ices from the ground
  - Need JWST to measure the ices
  - Can make a map of ices in dense cores
- High spatial resolution extinction maps will provide a clear picture of where ices form over evolutionary stages

The summit of Maunakea has always held a very significant cultural role for the indigenous Hawaiian community. We are thankful to have the opportunity to observe from this mountain.

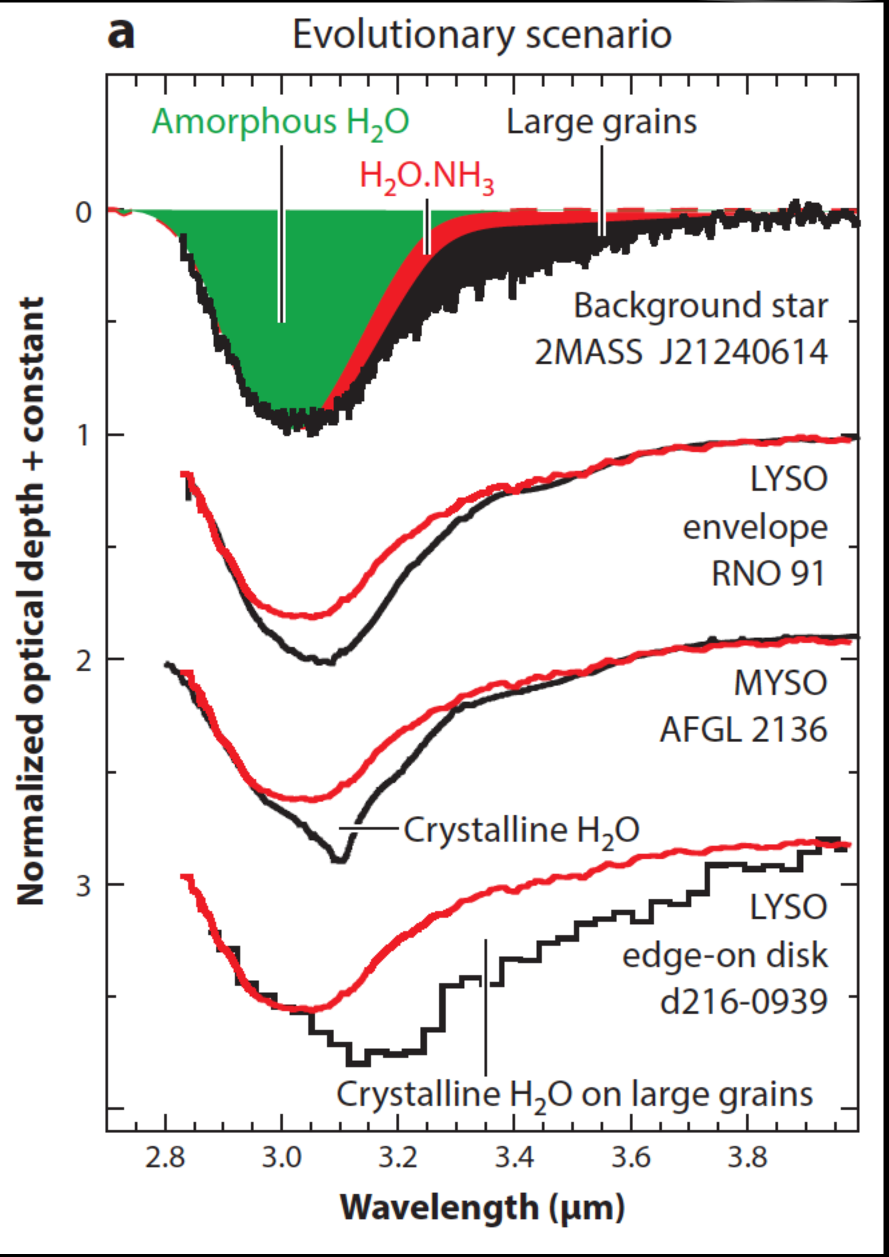
Additional Information

Sample

- Five clouds at different evolutionary stages
  - 1 quiescent/stable (B59), 2 collapsing (LDN 694-2, LDN 63), 2 Class 0 star-forming (LDN 483, B335)
- Against the galactic bulge
  - High background star density
    - Good spatial resolution, many lines of sight
- Nearby (≤ 250 pc)→ fewer foreground stars
- Sizes ~ 0.2 to 1 pc in diameter

Observations

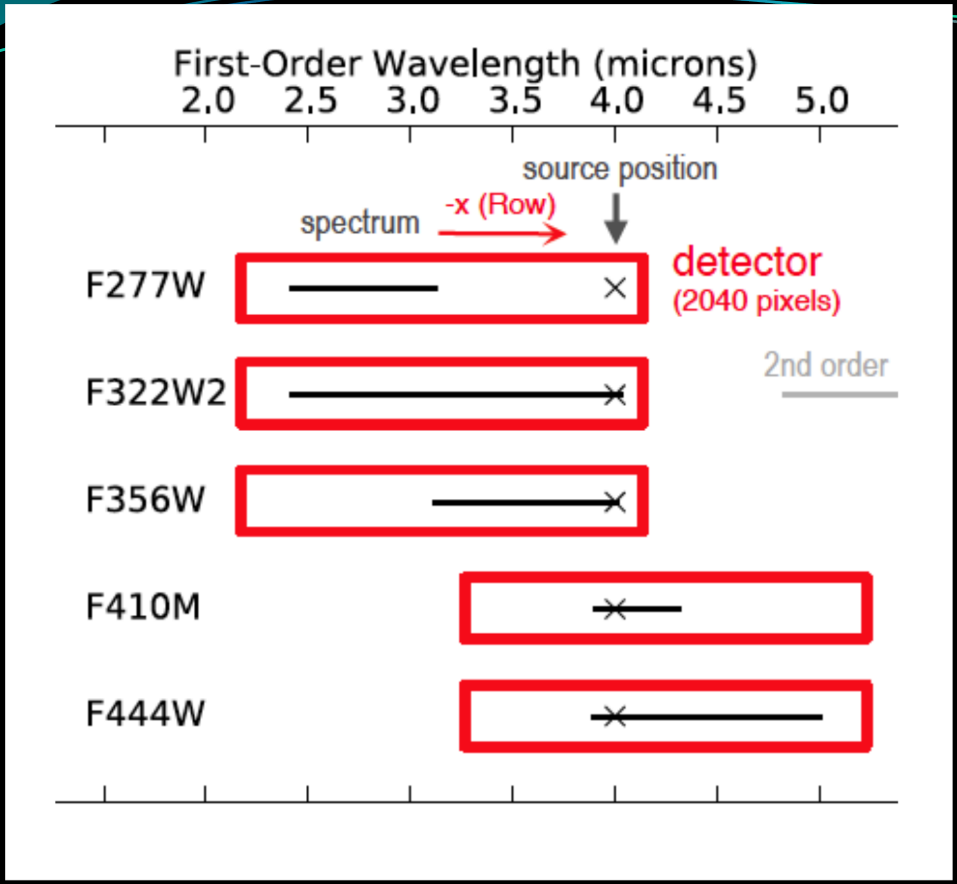
- Molecular Cloud Extinction Maps
  - UKIRT Photometry
    - WFCAM Instrument – JHK bands
    - K Mag Limit ~21 Mag with SNR 10
  - Warm Spitzer Photometry
    - IRAC Ch 1 and 2
    - Ch 1 Mag Limit ~19 with SNR 20
- Ice Features H_2O and CO
  - IRTF Spectra
    - SpeX Instrument – L and M bands



a
Evolutionary scenario
Amorphous H2O
H2O.NH3
Large grains
Background star
2MASS J21240614
LYSO
envelope
RNO 91
MYSO
AFGL 2136
Crystalline H2O
LYSO
edge-on disk
d216-0939
Crystalline H2O on large grains
Normalized optical depth + constant
0
1
2
3
2.8
3.0
3.2
3.4
3.6
3.8
Wavelength (μm)

Filter/Grism	Spectral Features	Integration Time
F277W grism1 F277W grism2	H_2O continuum	204s SHALLOW2 204s SHALLOW2
F356W grism1 F356W grism2	H_2O, H_2O:NH_3 CH_3OH	204s SHALLOW2 204s SHALLOW2
F410M grism1 F410M grism2	CO_2, continuum CO-gas contin.	204s SHALLOW2 204s SHALLOW2
F430M grism1 F430M grism2	CO_2 $^{13}CO_2$	204s SHALLOW2 204s SHALLOW2
F460M grism1 F460M grism2	OCN^- CO	204s SHALLOW2 204s SHALLOW2
F480M grism1 F480M grism2	CO, ^{13}CO continuum	204s SHALLOW2 204s SHALLOW2
		TOTAL TIME: 10.2 h per object

Six observations for the six different filters are planned (each filter is listed in the table to the right). At each of the targets we will take one deep F444W direct image. We will do a 1x3 mosaic pattern, counted by APT as 3 visits, to cover the intra-module gaps and will do a 4-point sub-pixel dither pattern for oversampling.



Bin AB mag	expected clean spectra
11-12	1
12-13	2
13-14	2
14-15	4
15-16	8
16-17	13
17-18	22
18-19	22
19-20	43
20-21	60

- Does not suffer any overlap with neighboring spectra
  - If only one star spectrum is found in a 5 x 1024 pixel box
  - If the star more than 5 mag (factor 100) fainter
    - Or overlapping star spectrum is itself less than 1-sigma significant