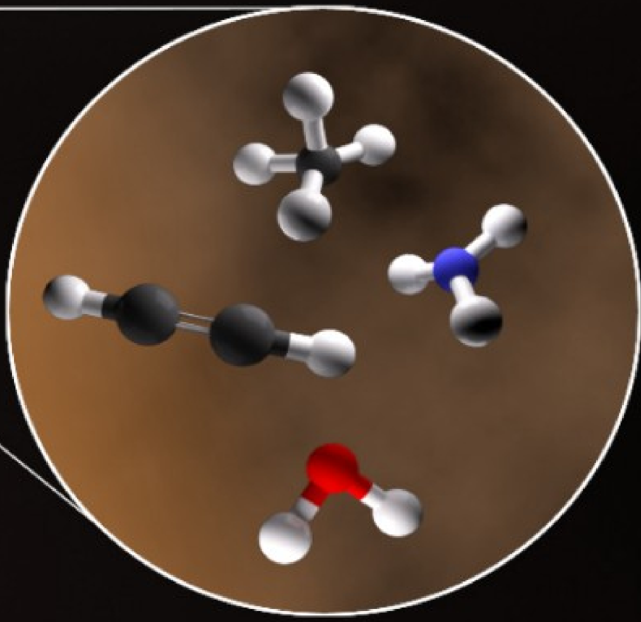
A High Resolution Infrared Spectroscopic Survey of Massive Young Stellar Objects



Andrew Barr
Leiden Observatory

Presented by:
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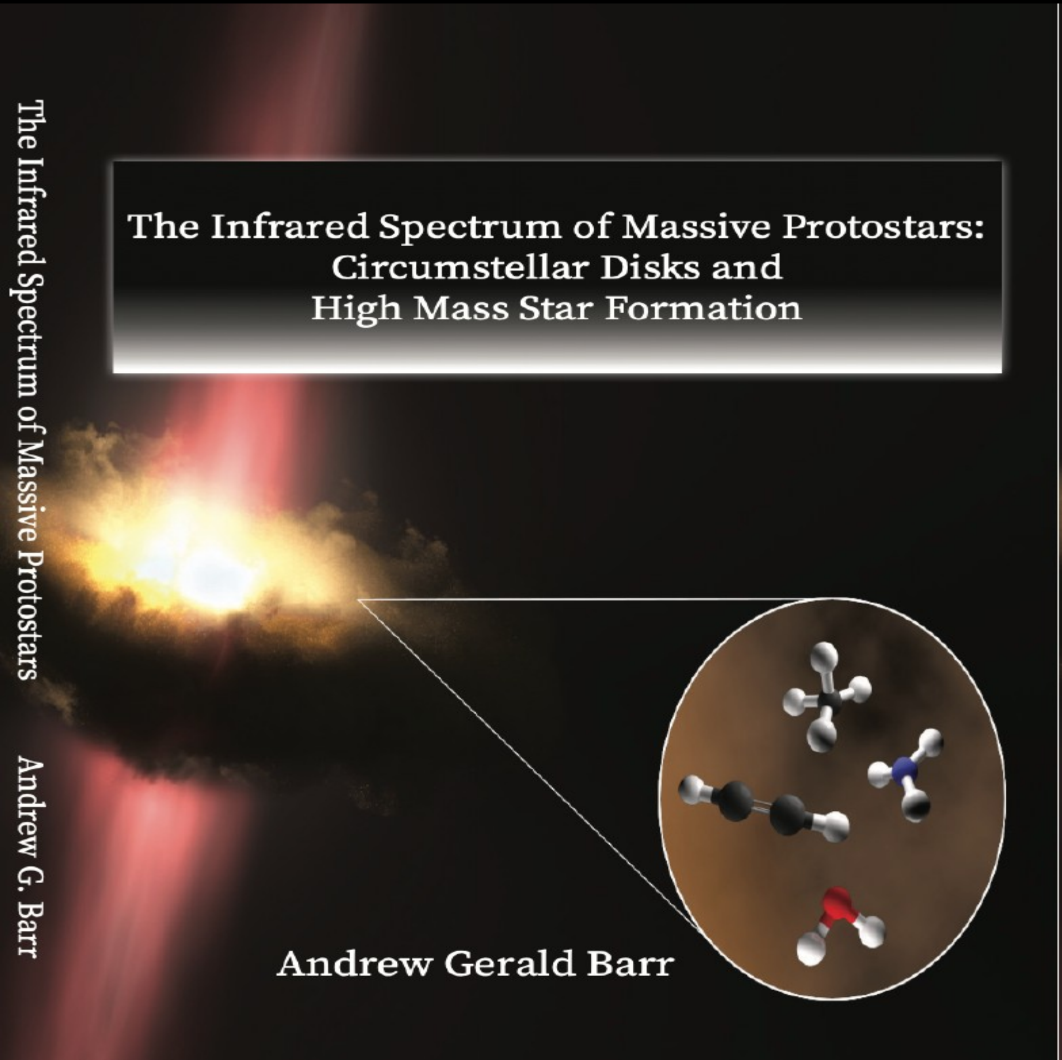
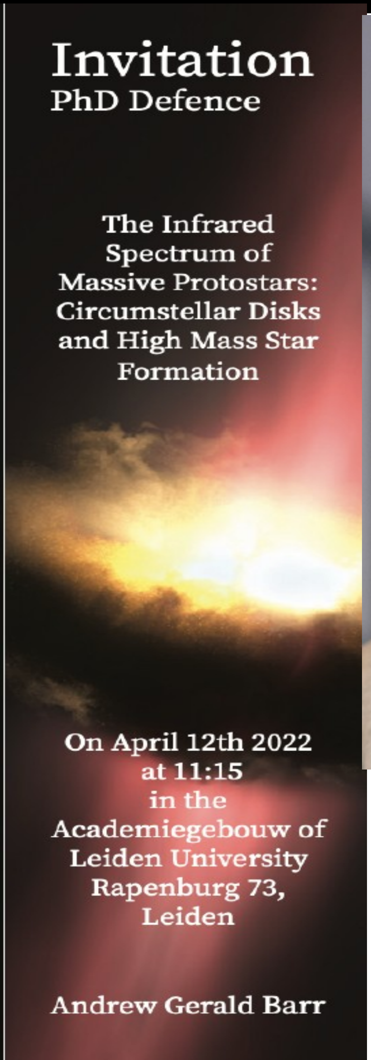
NASA IRTF/University of Hawaii

PhD Thesis Andrew Barr





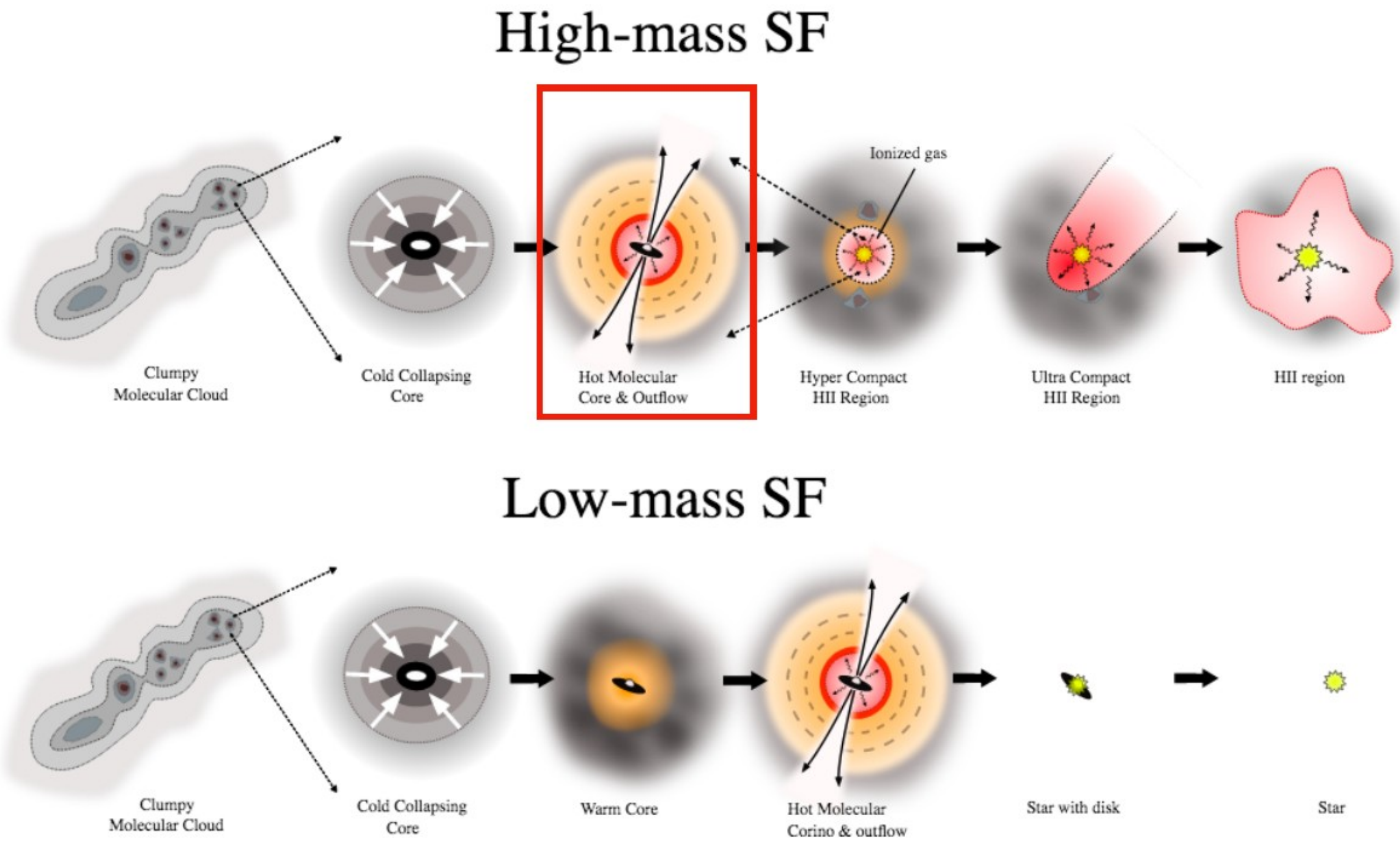
Advisors: Xander Tielens, Adwin Boogert

Andrew Barr Thesis Outline

- Chapter 1: Introduction Massive Star Formation
- Chapter 2: Abundant CS in AFGL 2591 *[ApJL 868, L2, 2018]*
- Chapter 3: Organics towards AFGL 2591 and 2136 *[ApJ 900, 104, 2020]*
- Chapter 4: H_2O towards AFGL 2591 and 2136 *[ApJ, Submitted]*
- Chapter 5: L-band Survey Massive YSOs *[A&A, Submitted]*

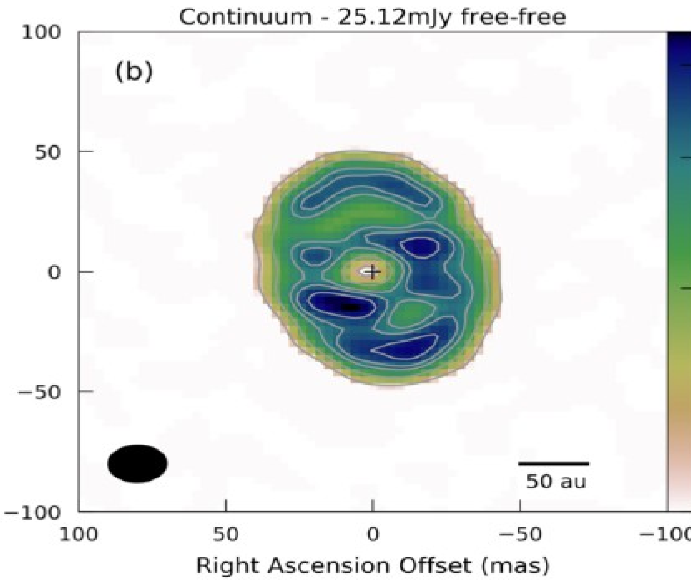
All based on R>=50,000 3-13 µm spectroscopy with EXES/SOFIA and TEXES/IRTF/Gemini

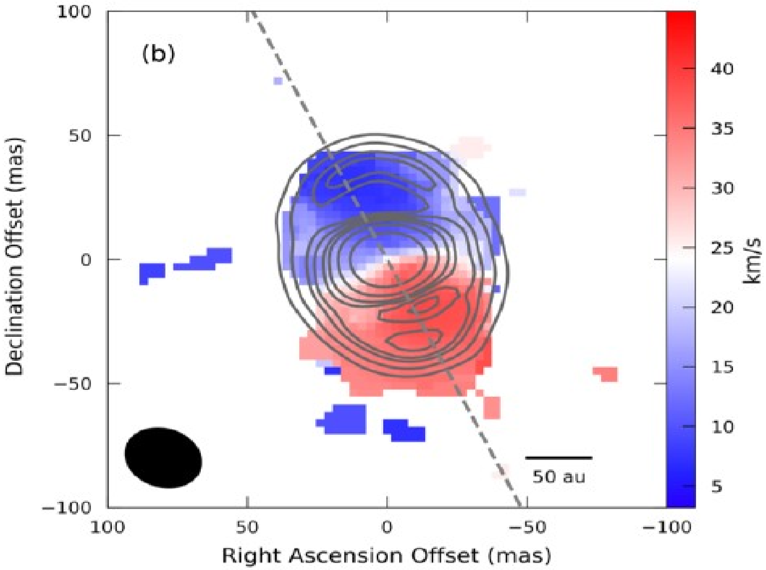
Introduction



High mass star formation happens much faster than low mass star formation, with critical phases taking place while still deeply embedded.

Introduction



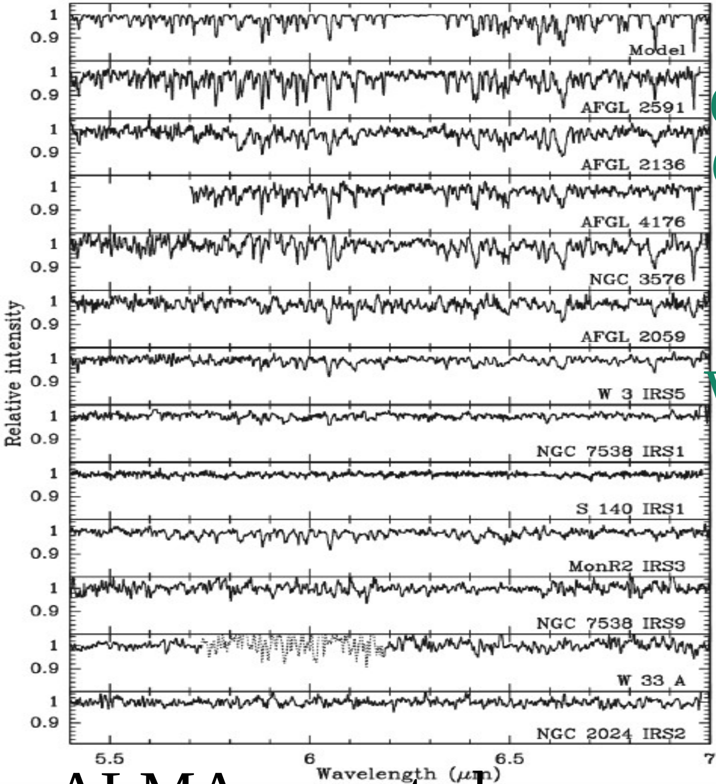


AFGL 2136: ALMA resolves dust disk in sub-mm continuum and rotation in H_2O v=2 line emission [Maud et al. 2019]

- Disks regulate accretion; their fragmentation may lead to binary formation
- Not all proposed modes of high mass star formation involve disks

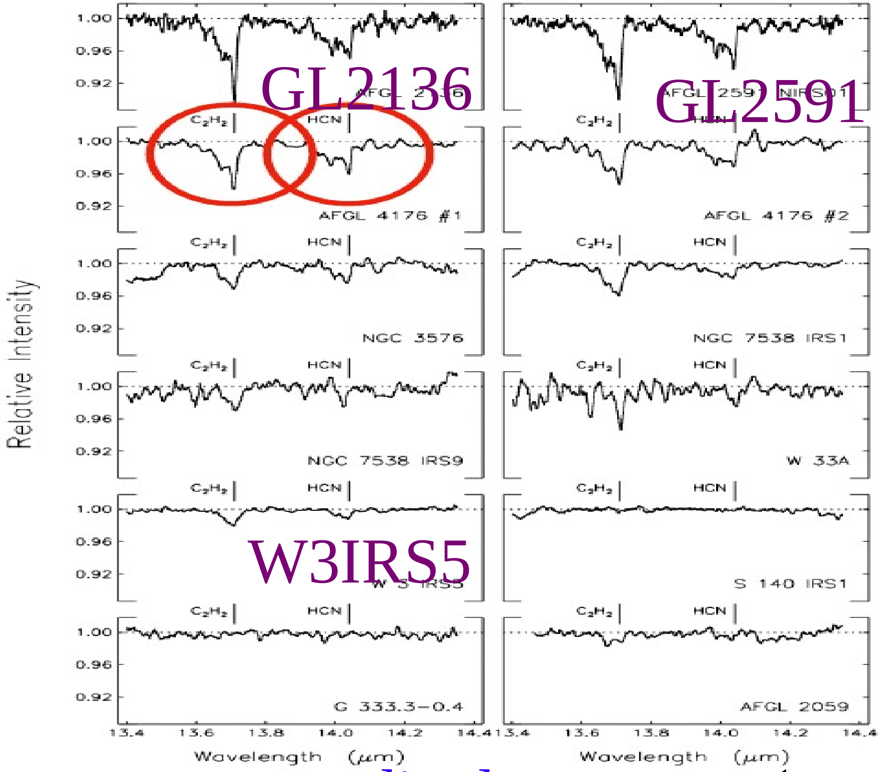
Introduction

H_2O [Boonman et al. 2003]



GL2591
GL2136
W3IRS5

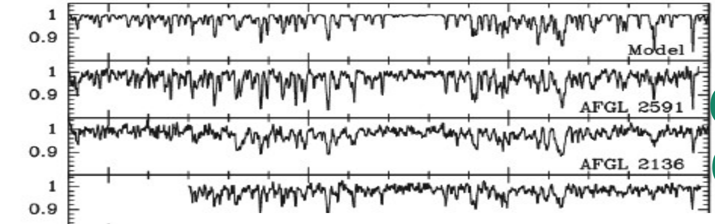
C_2H_2, HCN [Lahuis & Van Dishoeck 2000]



ALMA cannot observe species without permanent dipole moment (e.g., C_2H_2) and H_2O only in a limited way due to atmosphere.

Introduction

H_2O [Boonman et al. 2003]



GL2591
GL2136

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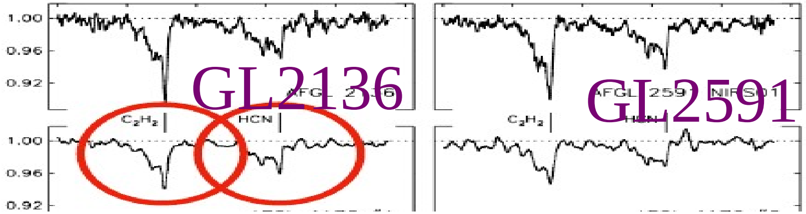
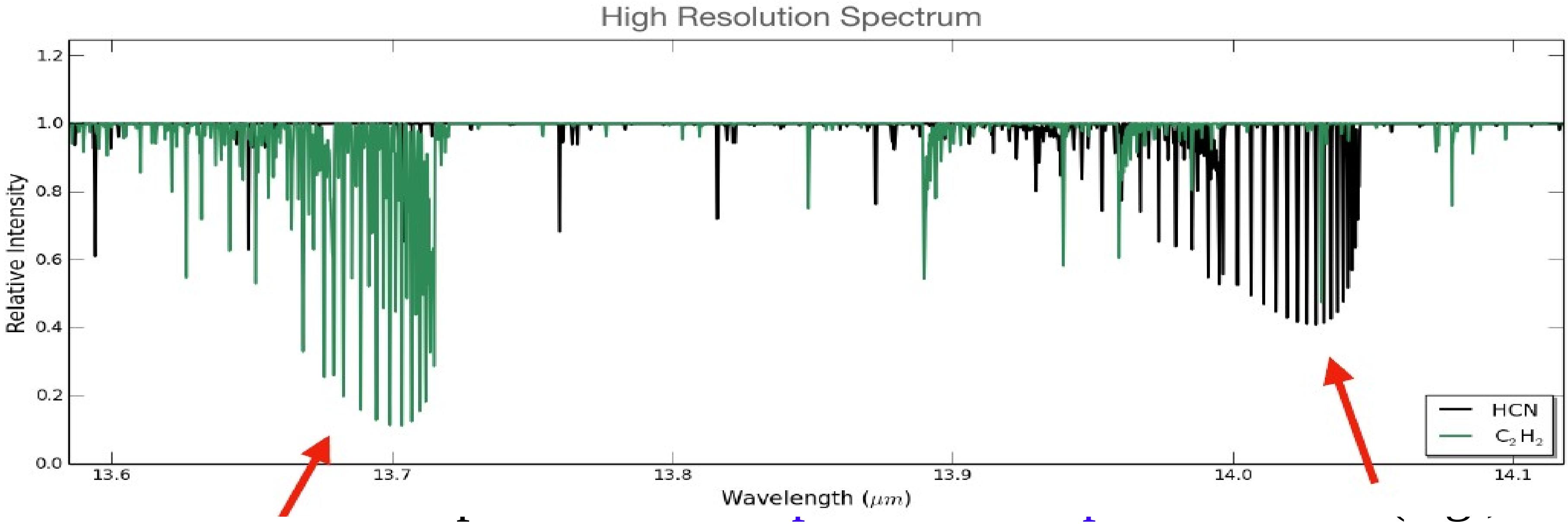
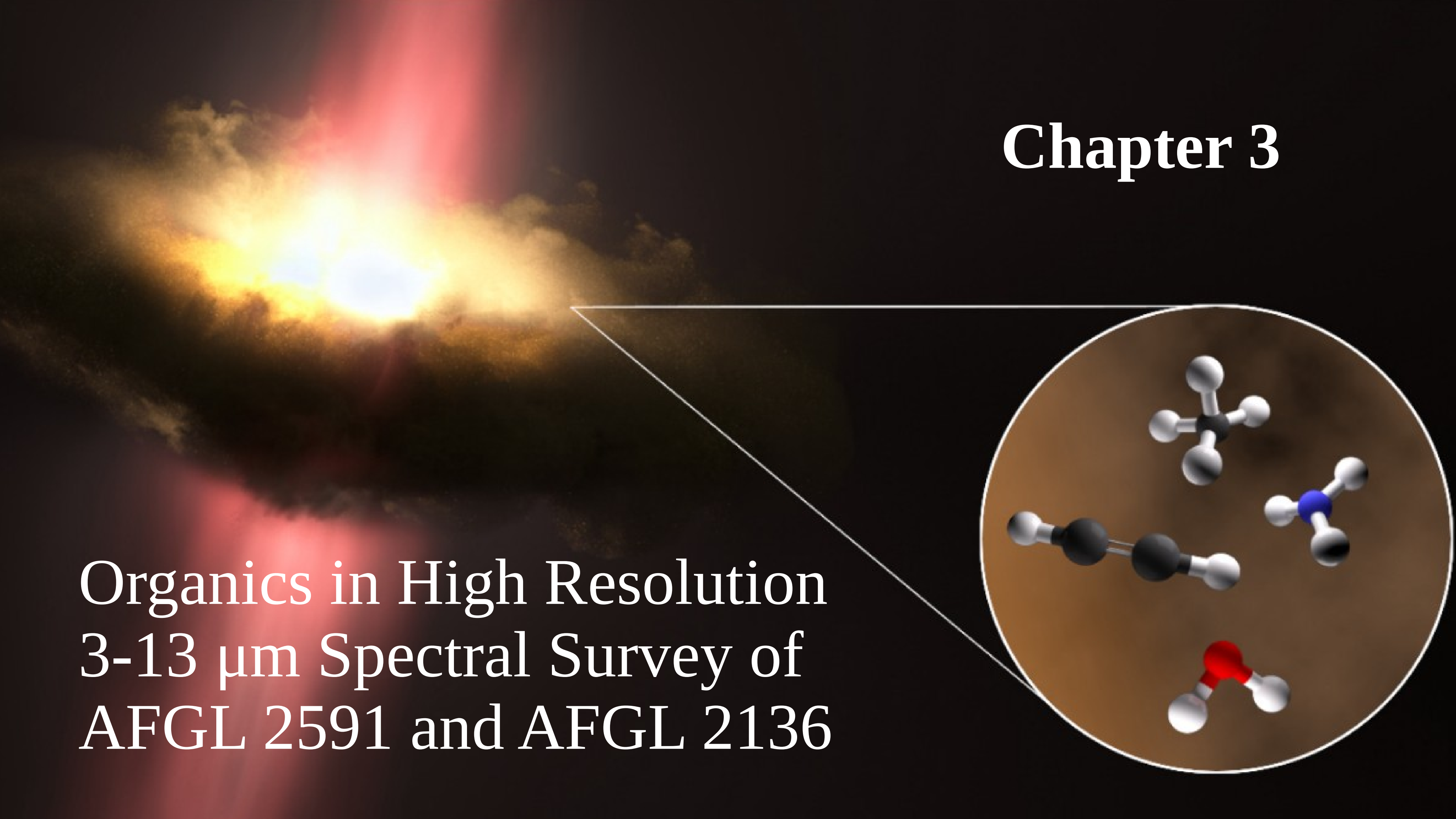


GL2136
GL2591



AL

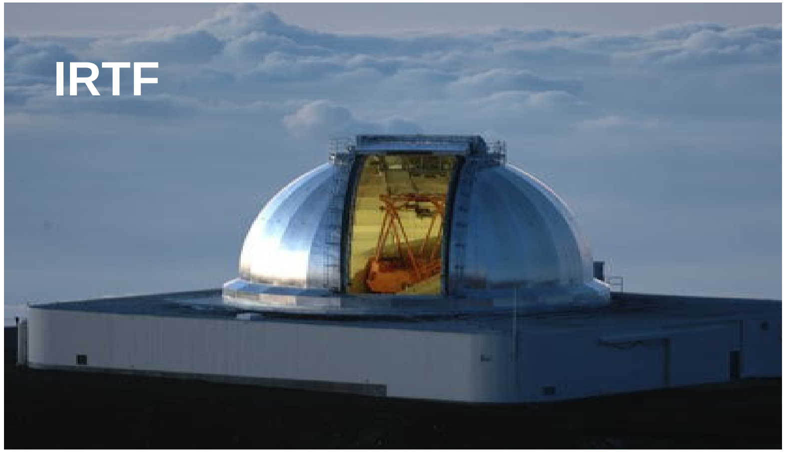
C_2H_2) and H_2O only in a limited way due to atmosphere.



Chapter 3

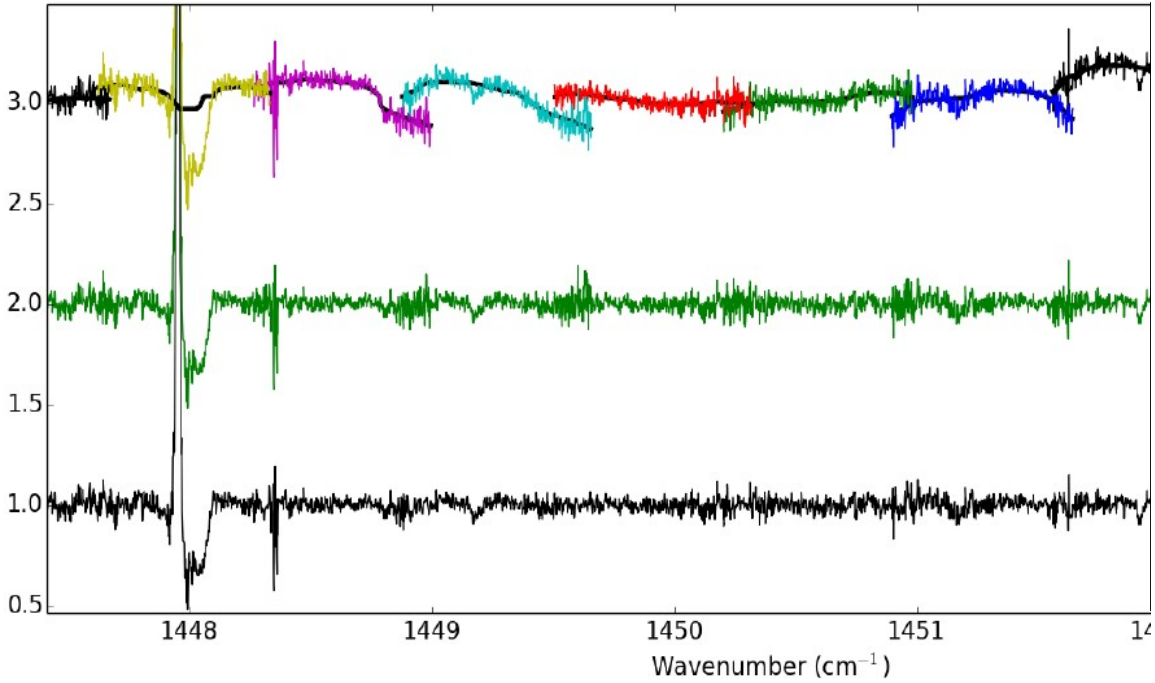
Organics in High Resolution 3-13 μm Spectral Survey of AFGL 2591 and AFGL 2136

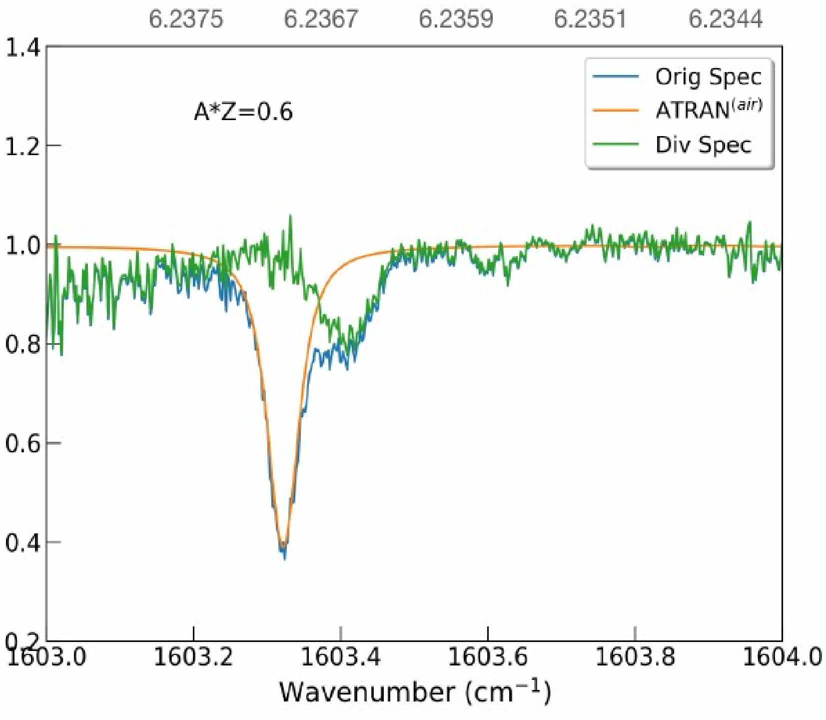
Chapter 3: Organics



First full spectral survey in mid-IR at high spectral resolution (R=50,000)

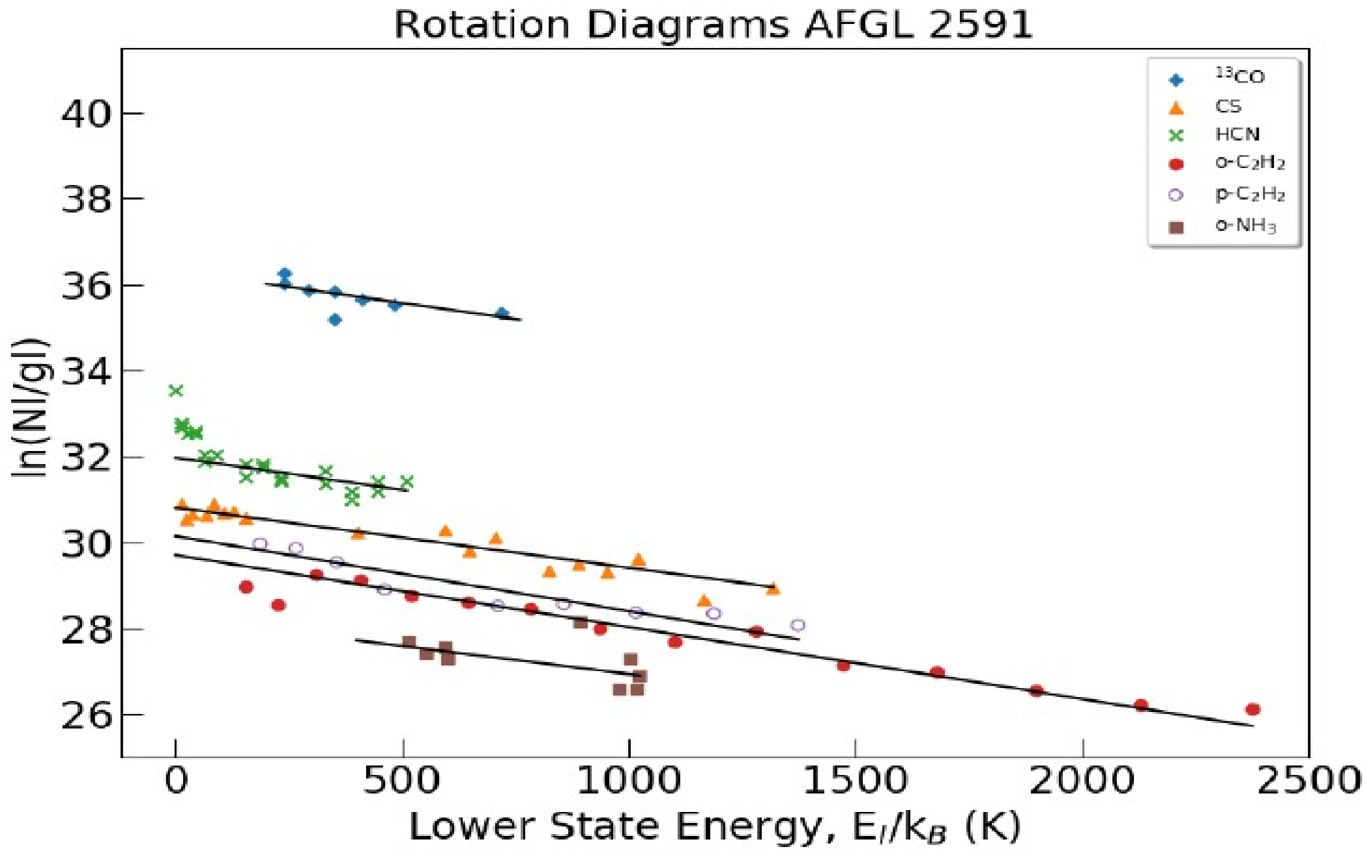
- 3 μm iSHELL/IRTF: HCN, C_2H_2
- 4.7 μm iSHELL/IRTF: CO
- 5.5-8.0 μm EXES/SOFIA: HCN, C_2H_2, CS, H_2O
- 8.0-13.3 μm TEXES/Gemini+IRTF: HCN, C_2H_2, NH_3





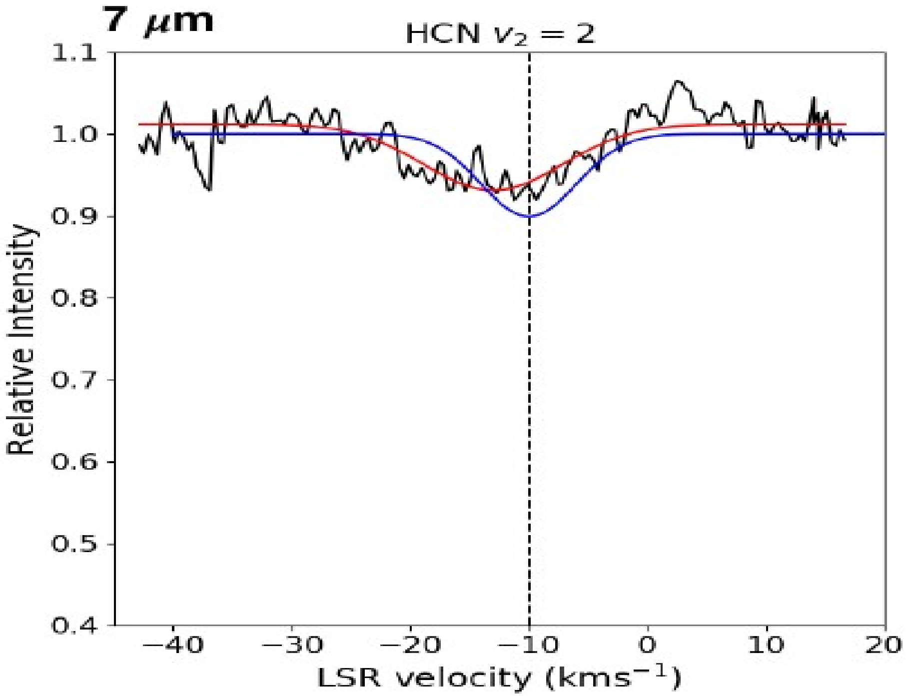
SOFIA/ EXES order curvatures and telluric correction

Chapter 3: Organics



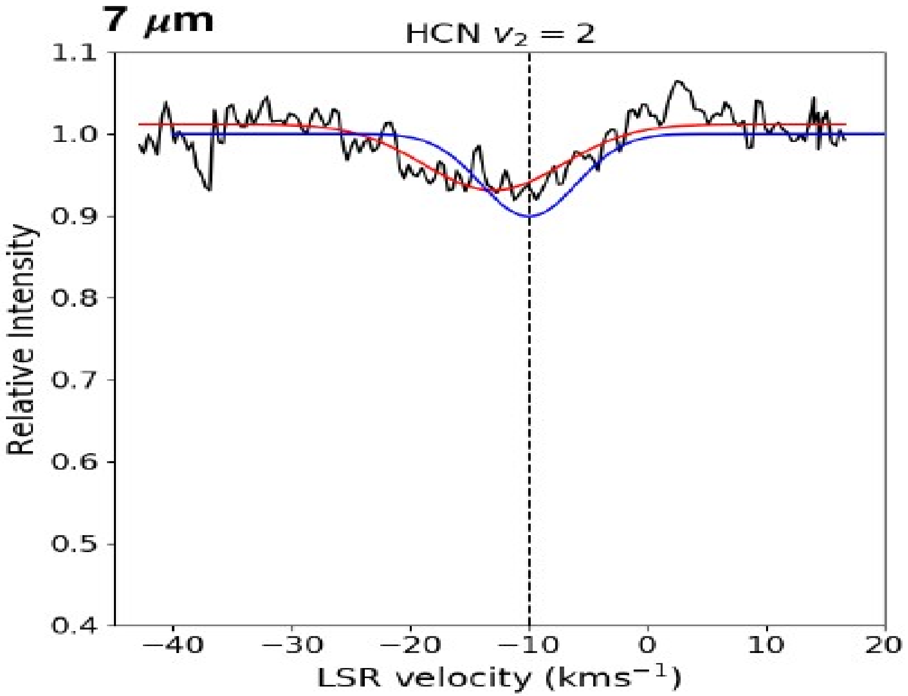
- Many absorption lines detected: CS, HCN, C_2H_2, NH_3, CO
- Rotational excitation temperatures are high, ~600 K

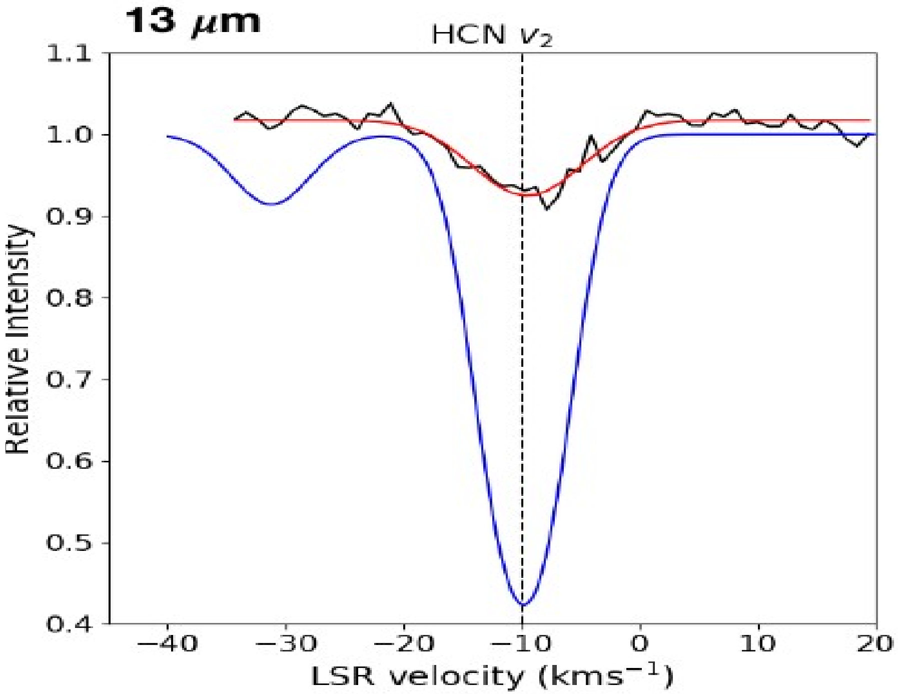
Chapter 3: Organics



7 μm HCN line with ~600 K LTE model

Chapter 3: Organics





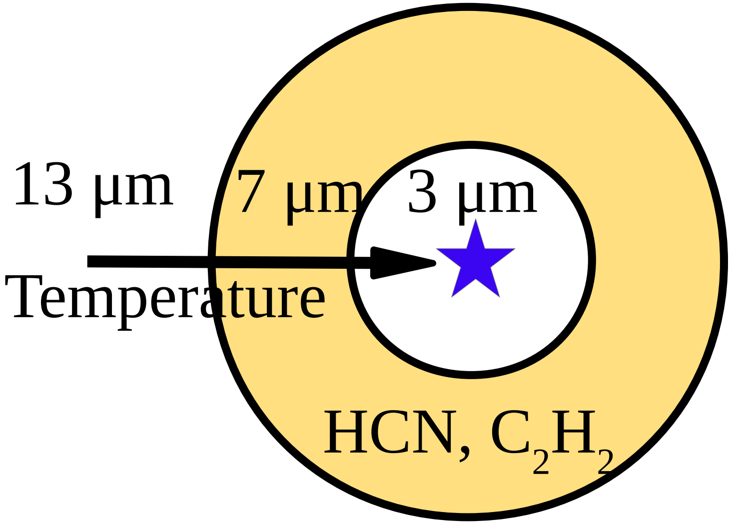
7 μm HCN line with ~600 K LTE model

Same LTE model overpredicts 13 μm line by factor of ~7.

Chapter 3: Organics

Model 1: HCN and C_2H_2 created by hot gas chemistry, present in ring with right conditions (T~600 K).

- 7 µm, *deepest absorption lines:* hot gas covering most of continuum
- 13 µm, *weaker absorption lines:* partial coverage by cooler dust larger R



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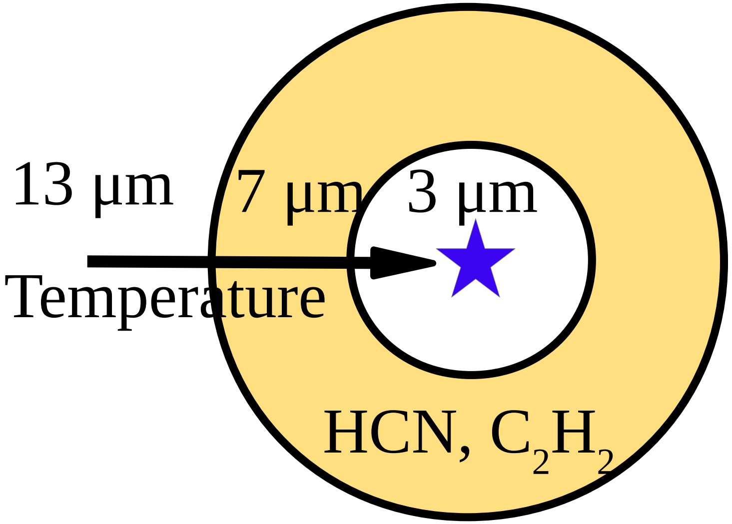

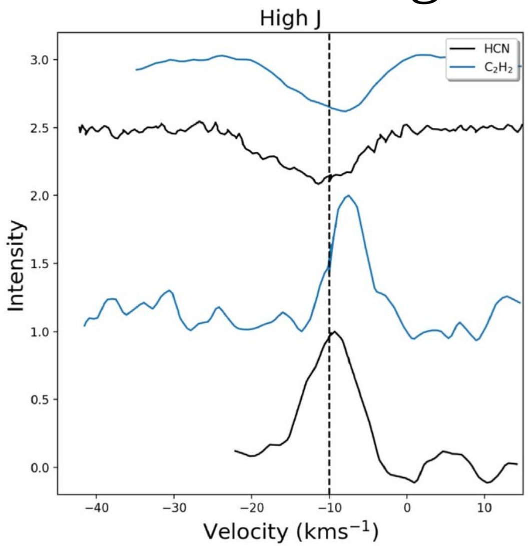

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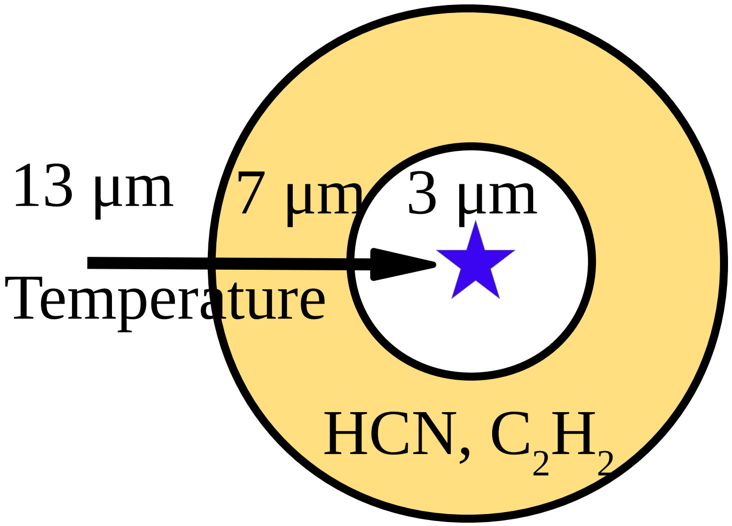
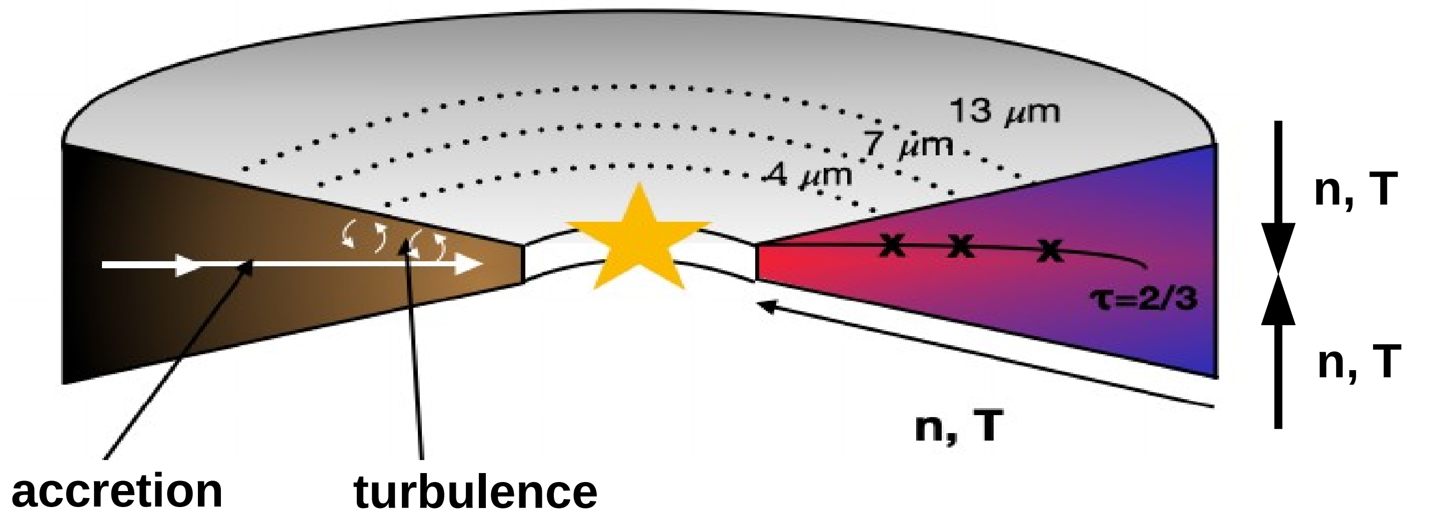


Both gas and dust same high temperature (~600 K), and gas distribution like a ring….. could be a disk.

Chapter 3: Organics

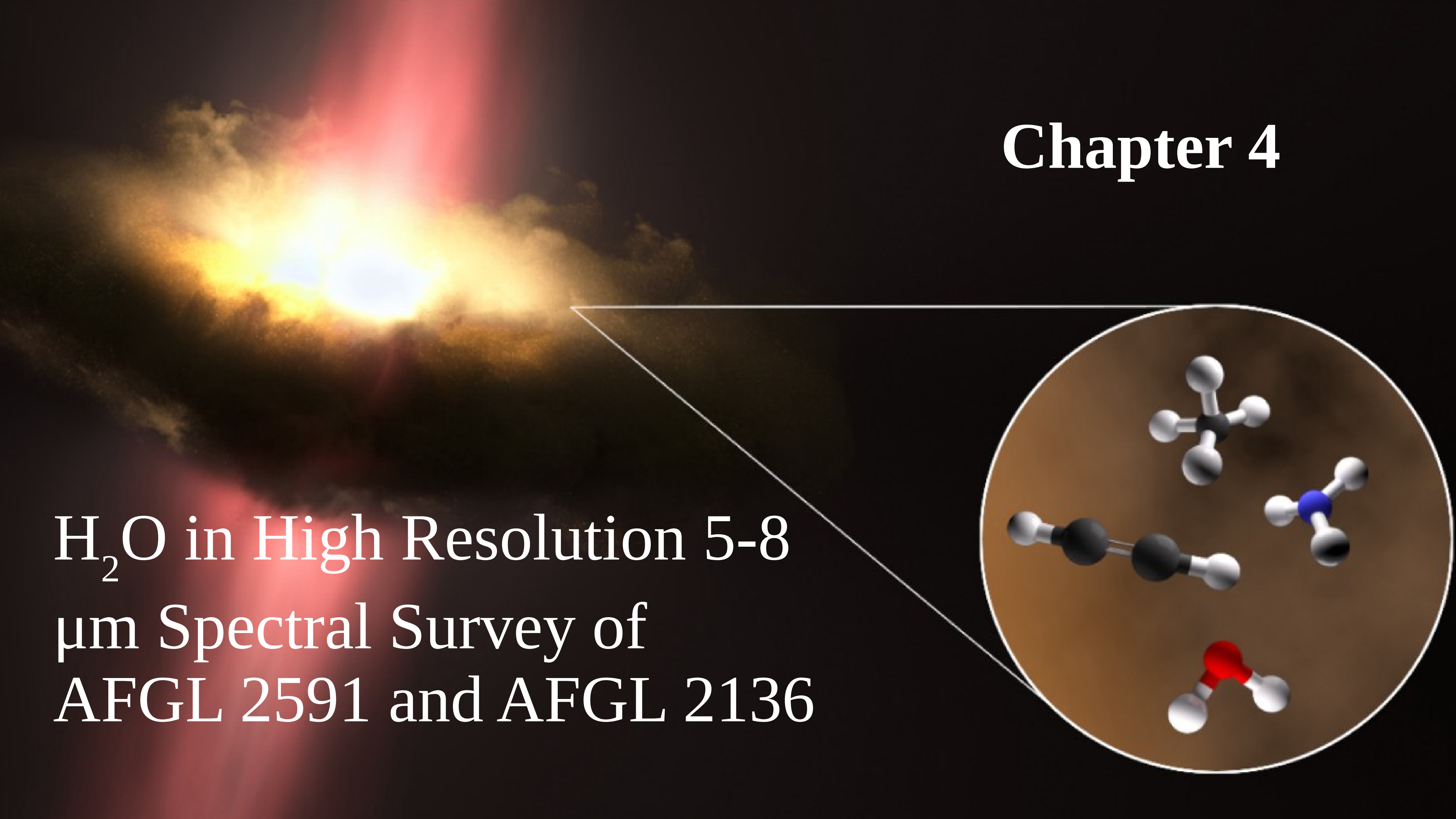
Model 2: Absorption lines do not probe foreground material but rather trace a circumstellar disk atmosphere

- Absorption lines require internally heated disk (externally heated disks would give emission lines, see T Tauri stars)
- Viscous heating in mid-plane?



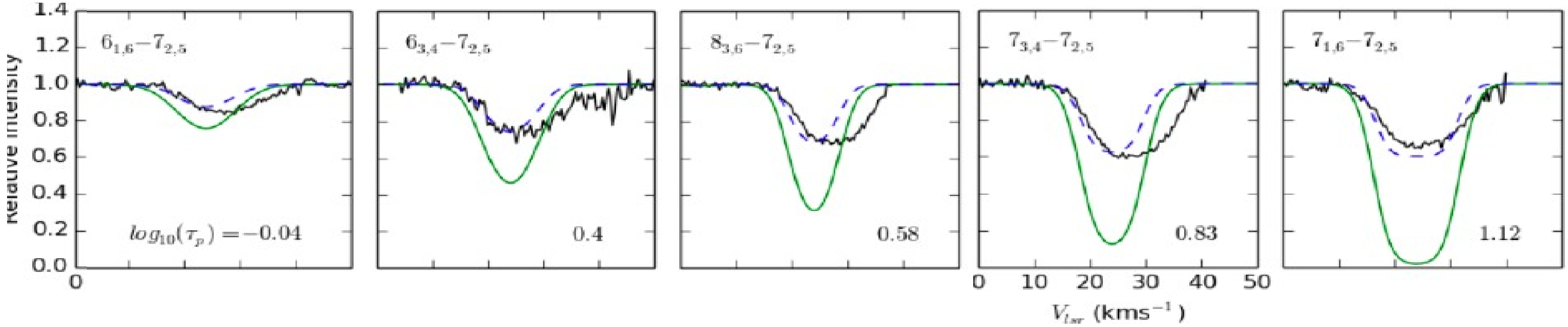
Chapter 4

H_2O in High Resolution 5-8 µm Spectral Survey of AFGL 2591 and AFGL 2136



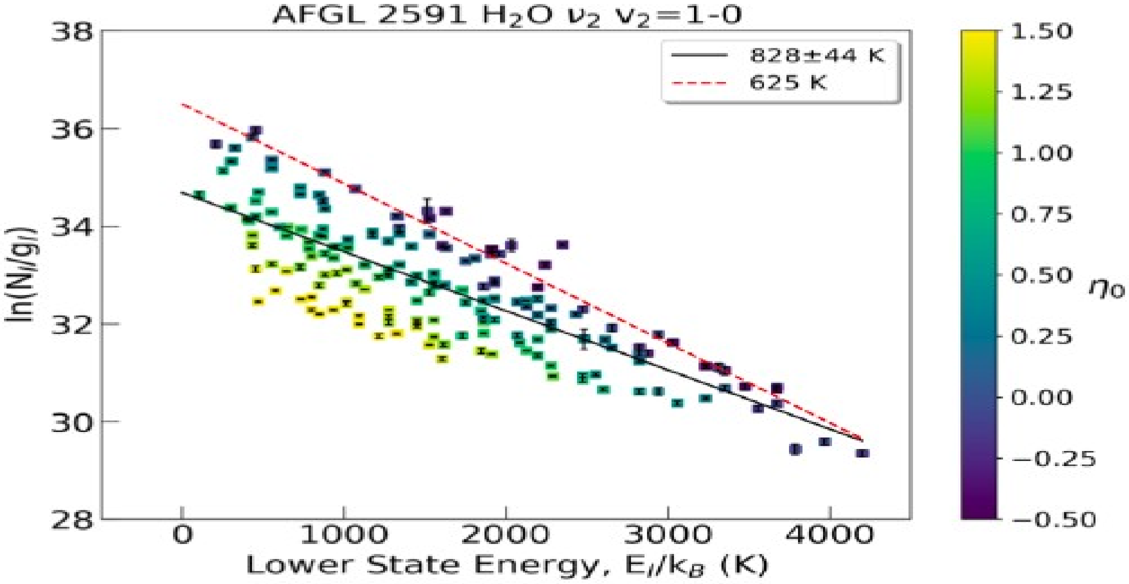
Chapter 4: H_2O

- SOFIA/ EXES detects hundreds of H_2O absorption lines toward MYSOs AFGL2136 and 2591
- Lines with same lower level appear to have different column density



- Due to different covering factor for lines at different wavelengths?

- SOFIA/ EXES detects hundreds of H_2O absorption lines toward MYSOs AFGL 2136 and 2591



Lines with larger Einstein A values are suppressed...

Chapter 4: H_2O

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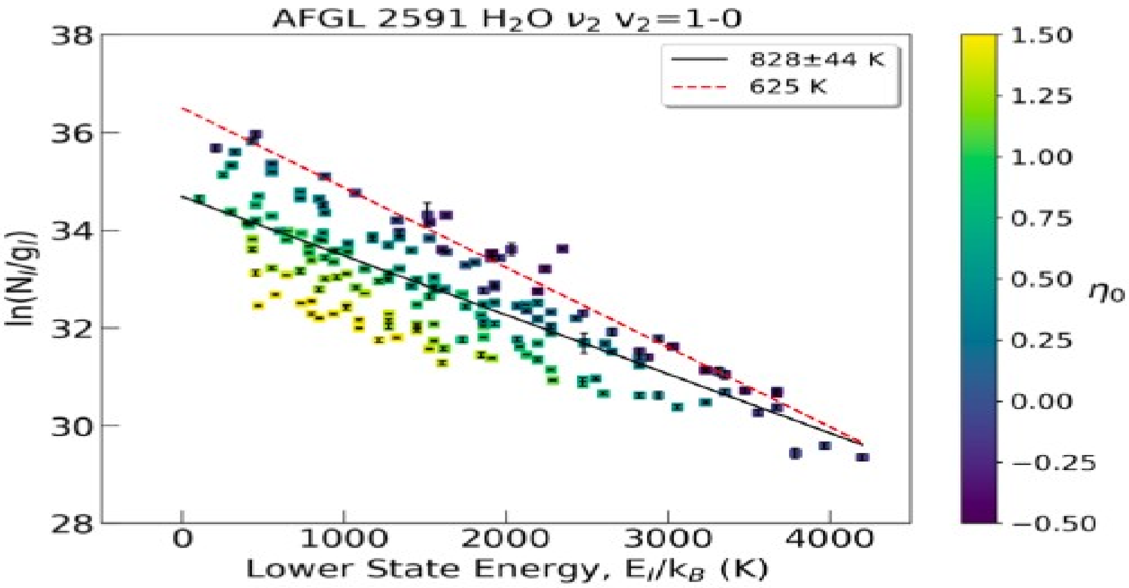
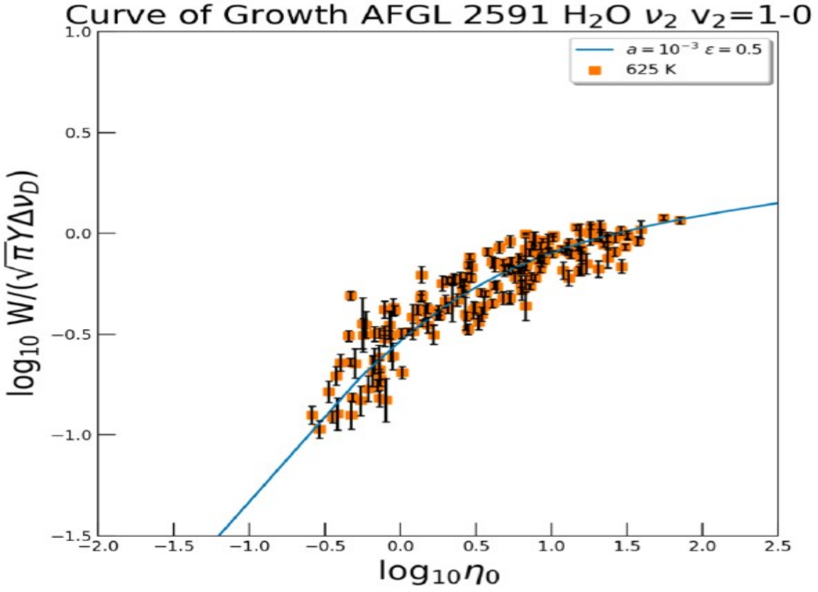
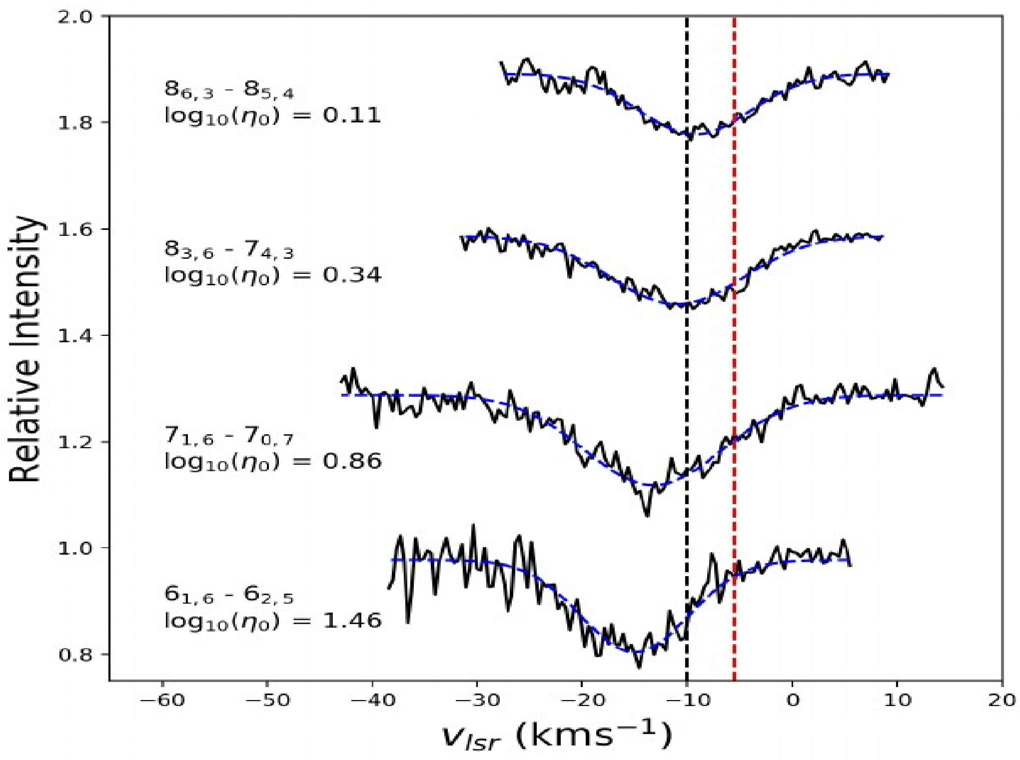




Lines with larger Einstein A values are suppressed….

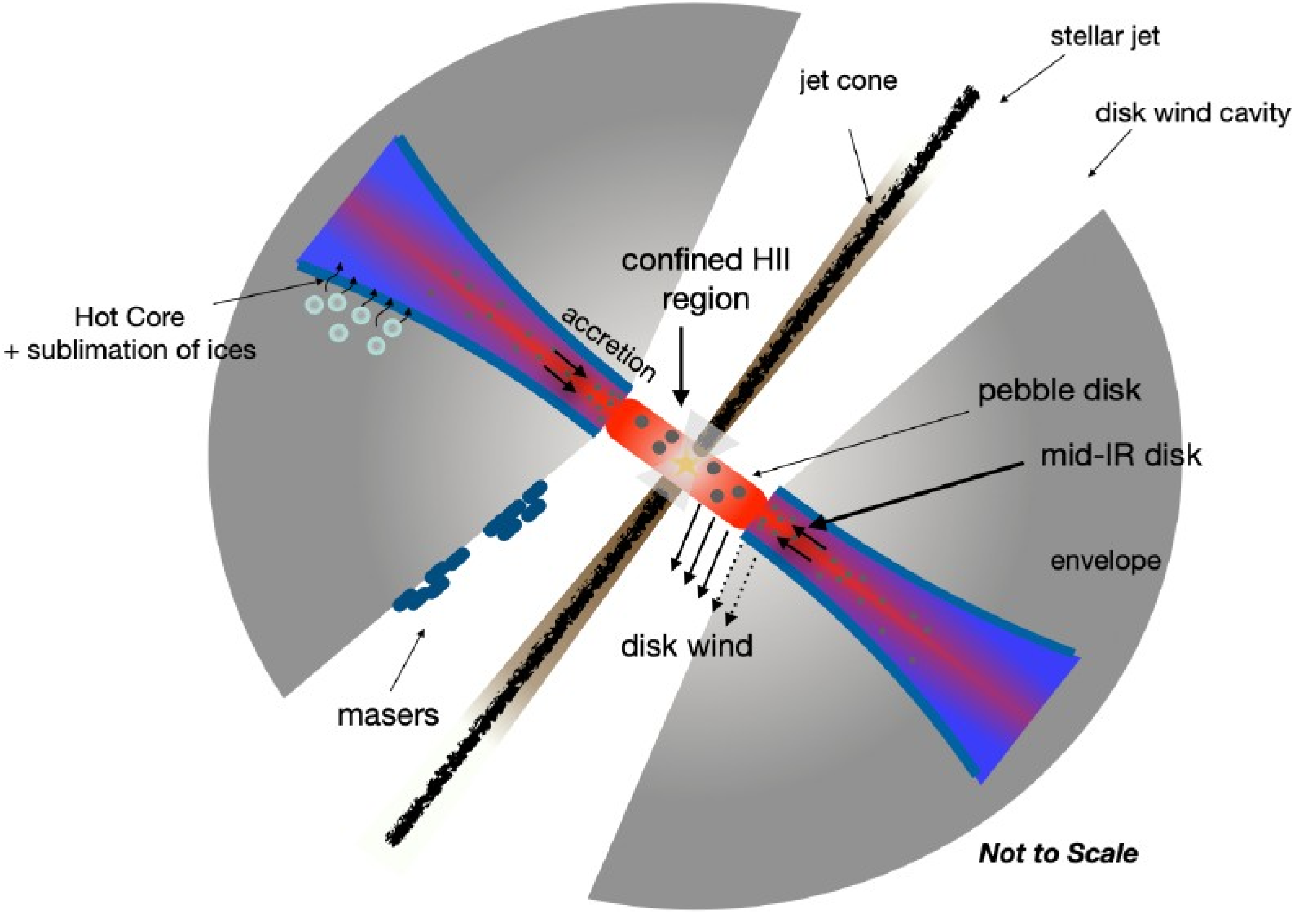
…and this is due to them becoming optically thick.

Chapter 4: H_2O



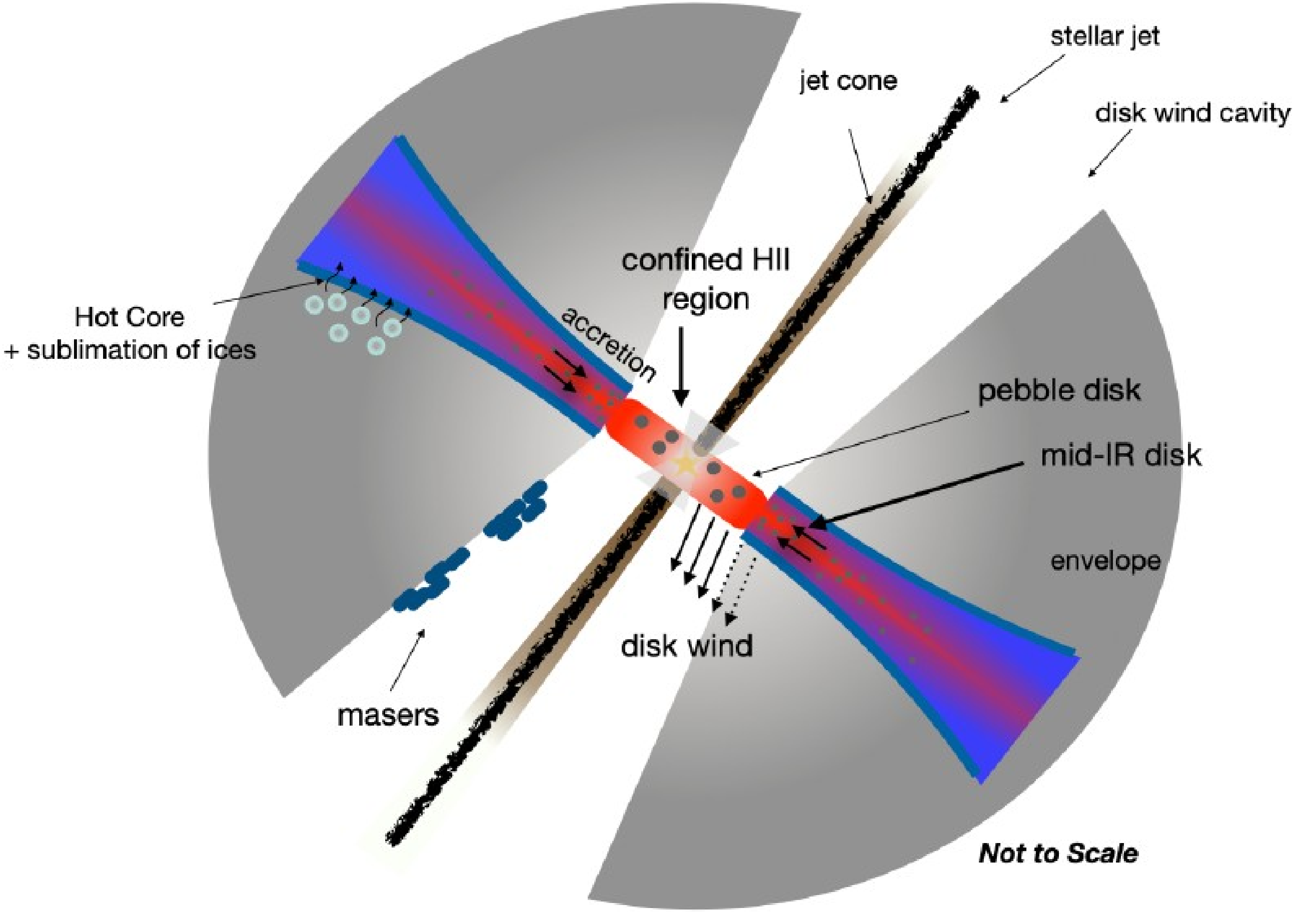
- Absorption line depths can be explained by a disk atmosphere model without a covering factor
- Consistent with high temperature and density (10^{10} cm^{-3}; T_{vib}~T_{rot})
- Line profiles reveal accelerating wind: lines originating from higher in disk move faster
- no Keplerian rotation: gas originates from blob in disk

Chapter 4: H_2O



- Inner 125 AU is pebble disk seen by ALMA and creates H_2O emission lines
- IR absorption lines (H_2O, C_2H_2, HCN…) formed in internally heated disk at larger radii
- IR disk shielded from UV light, which escapes through outflow cavity.

Chapter 4: H_2O



Problem:

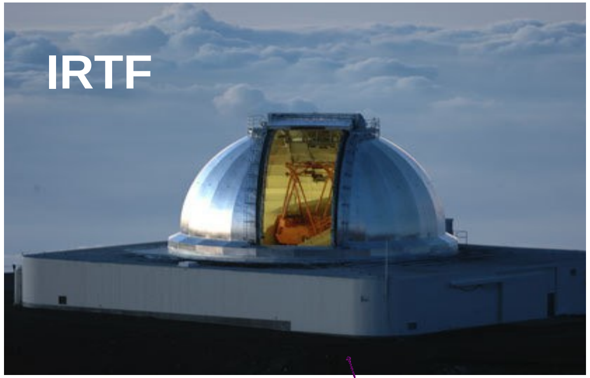
- accretion rate needed for 40 Msun star to heat disk to 600 K at 125 AU is 1.2 Msun/yr.
- Orders of magnitude more than reasonable (10^{-3} at most).
- Additional heating sources?

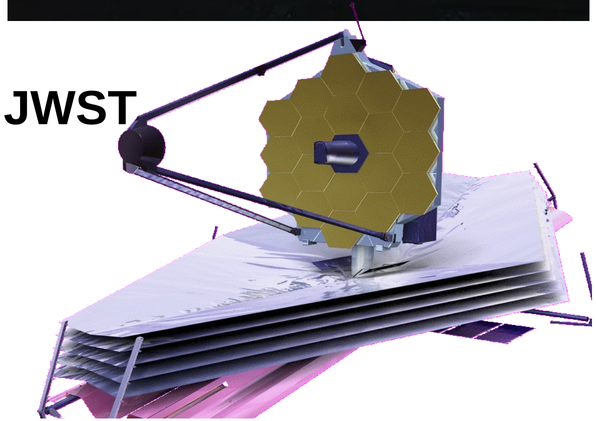
Summary and Conclusions

- First 3-13 µm spectral survey at high resolution of two massive YSOs
- Hundreds of lines of CO, CS, HCN, C_2H_2, NH_3 and H_2O (+many unidentified features)
- All species observed in absorption, except HCN and C_2H_2 at 3 µm
- High temperatures, densities, and abundances for all species
- Absorption lines may trace internally heated circumstellar disks
    - *But: accretion rates needed for this too high*
- Alternatively the lines probe gas in the foreground.
    - *But: inconsistencies covering factors [Chapter 5; subm to A&A]*

Future Work

- Theoretical connection between MYSO disk properties and SOFIA/IRTF observations





- High spectral resolution SOFIA/IRTF observations critical in interpretation of JWST observations of MYSOs at low resolution
- Continued exploration MYSOs with ALMA [see talk by Nick Indriolo]

Acknowledgements

- Jialu Li (University of Maryland)
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