

Perspectives of Star Formation (Jun 22-26, 2026 @MPIA, Heidelberg)

JOYS+IPA: Systematic quantification of weak COM ice bands in protostars with JWST



Yuan Chen
Leiden Observatory/InterCat
→ MPE CAS



MAX-PLANCK-INSTITUT
FÜR EXTRATERRESTRICHE PHYSIK

PIs and collaborators: Ewine van Dishoeck, Henrik Beuther, Mike Ressler, **Thomas Henning**, Tom Megeath, Will Rocha, Martijn van Gelder, Łukasz Tychoniec, Katerina Slavicinska, Pooneh Nazari, Nashanty Brunken, Logan Francis, Caroline Gieser, Simon Reyes, and other members in the JOYS+ and IPA-HEFE teams

My “encounter” with MPIA & HD & Thomas

- **Jul-Aug 2018:** Summer Internship @MPIA

Visitors and new staff members at MPIA

Gäste / Visitors

Name	Heimatinstitut/ home institution	Betreuer / host	Raum/ room	von – bis / from – to
Weisz, Dan	UC Berkeley	Rix	E 110	27 Apr-23 Jul



Theodora	Emily Low	tbd	01 Aug-01 Dec
Flores, Lizxandra	Flock	tbd	13 Aug

Last update: 18 Jul 2018 (H. Seifert)

My “encounter” with MPIA & HD & Thomas

- **Jul-Aug 2018: Summer Internship @MPIA**
- **Nov 2018: Master program application**
application @U. of Heidelberg opens too late
took Leiden's offer in Mar 2019
- **Nov 2020: IMPRS PhD application**
interviewed in Jan/Feb 2021, no acceptance 💔
continued with Ewine in Oct 2021
Aug 2022: IMPRS Summer School on astrochemistry
May 2024: JOYS paper circulated to MIRI EC Consortium
- **Nov 2024: MPIA postdoc application**
no interview or acceptance 💔 joined MPE in Dec 2025
Jun 2026: PoPSF conference

Please take silicates
more seriously (and
properly cite our
experimental papers)



Be pragmatic and
don't bother too much
with silicates (you need
4 papers to graduate)

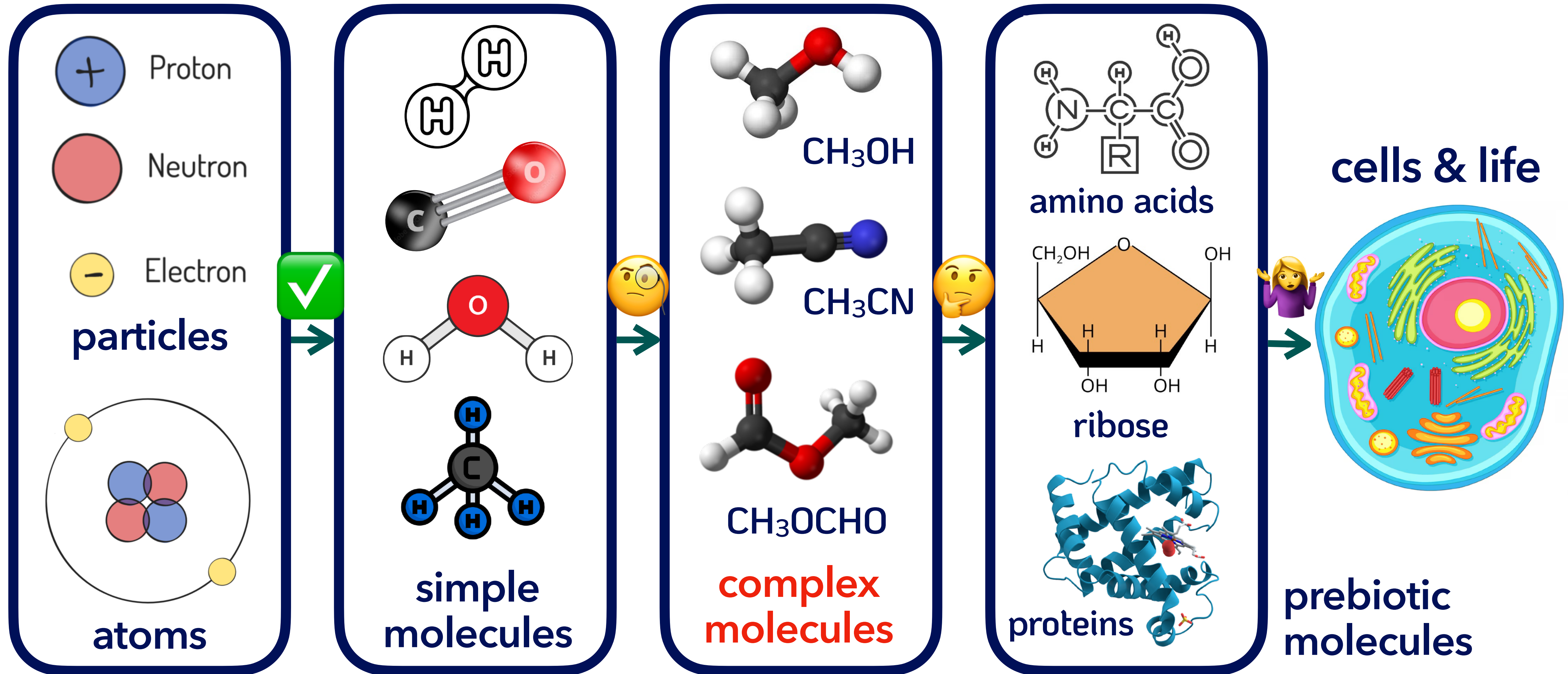


Me



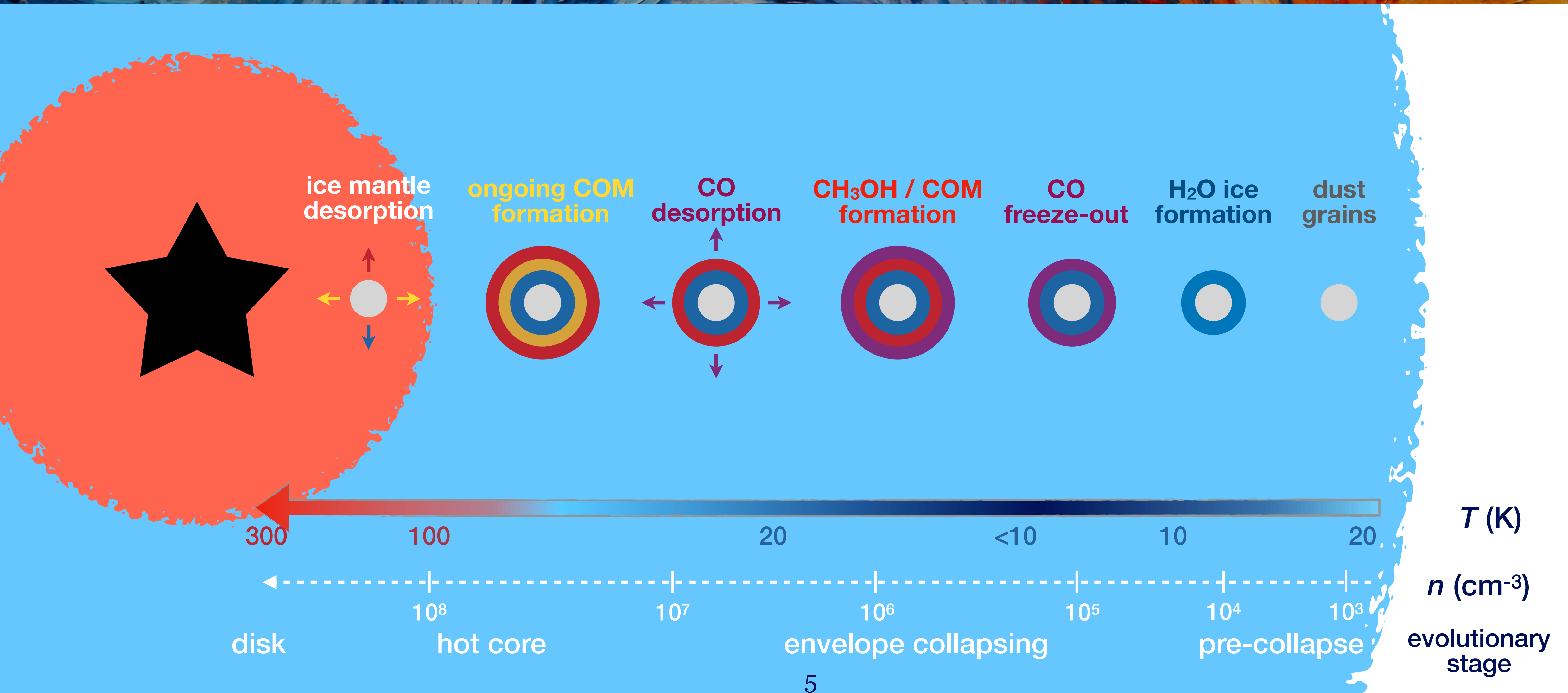
Why astronomers study COMs

complex organic molecules:
≥ 6 atoms & contain carbon



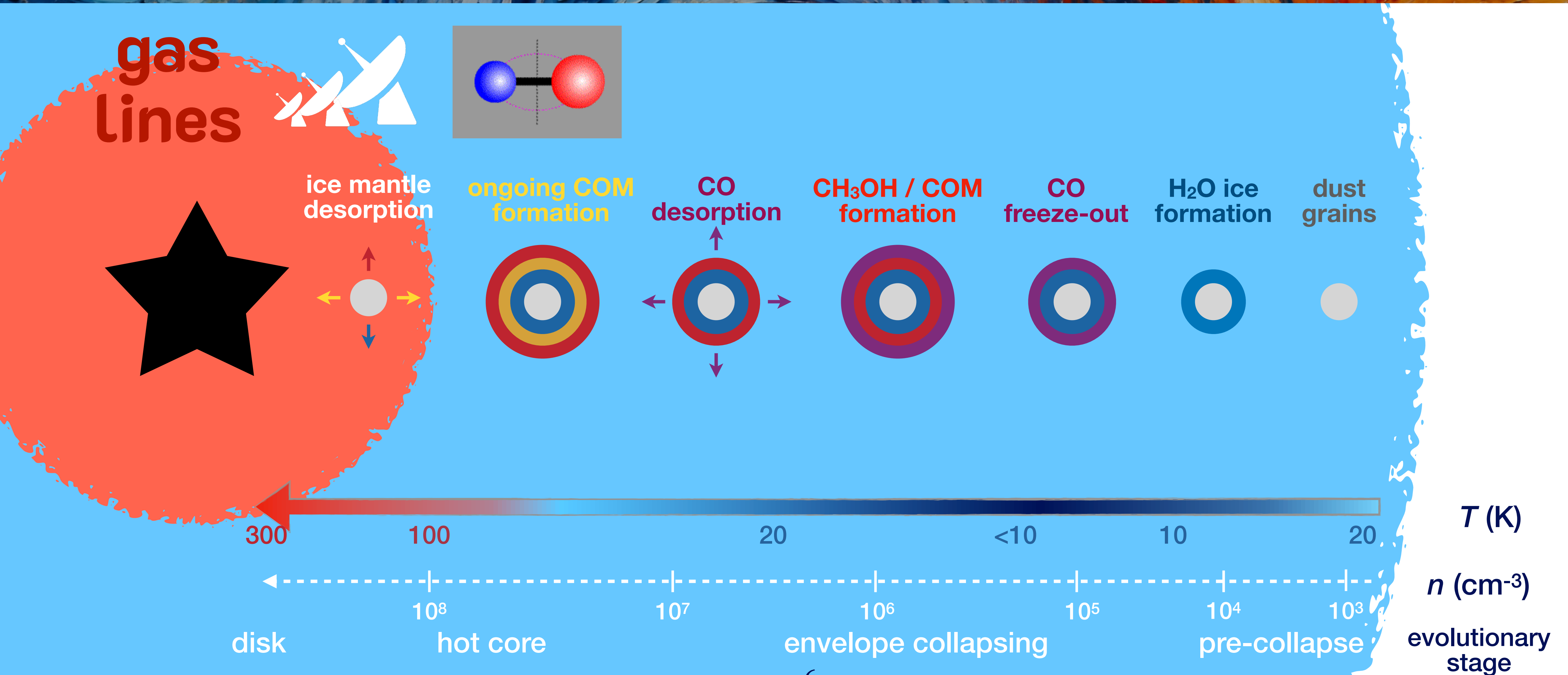
Our current understanding of COM formation in a protostellar system

After decades of studies by observers, theorists, and experimentalists...



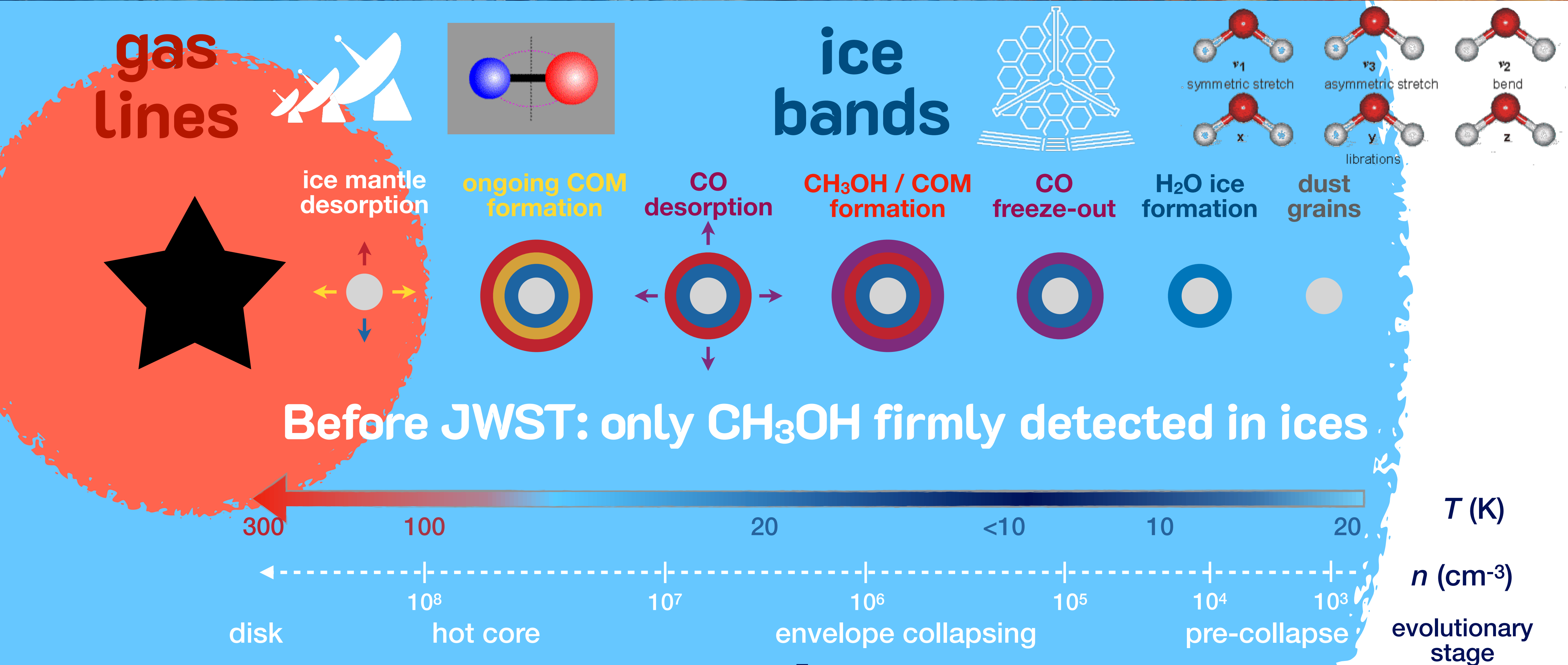
Our current understanding of COM formation in a protostellar system

After decades of studies by observers, theorists, and experimentalists...



Our current understanding of COM formation in a protostellar system

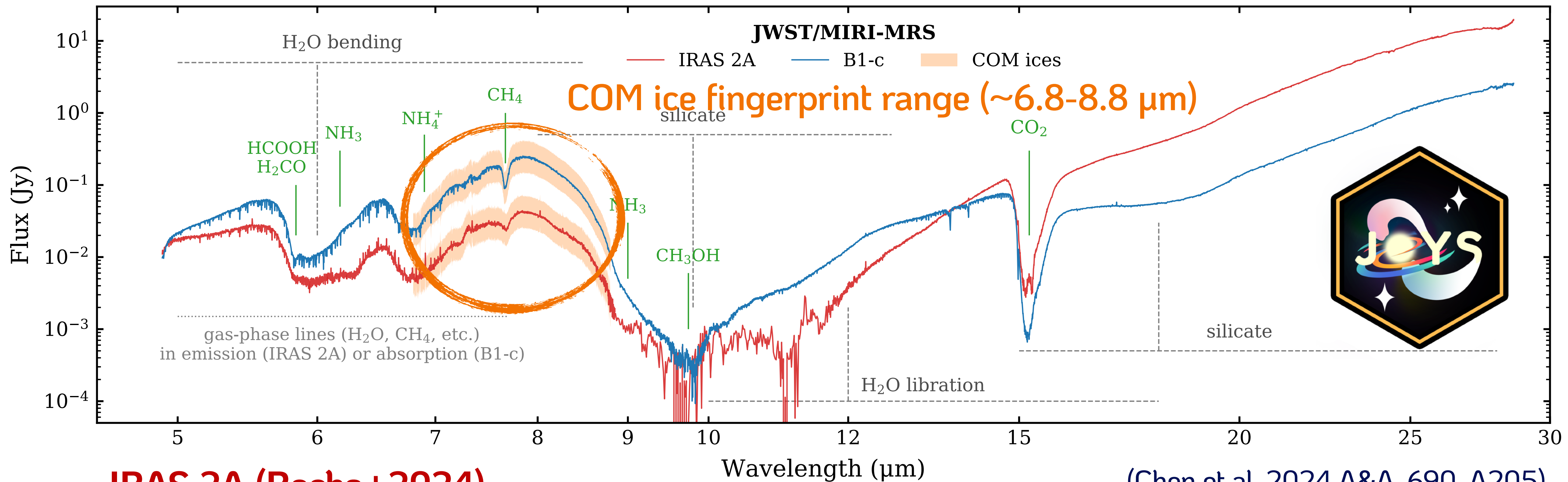
After decades of studies by observers, theorists, and experimentalists...



Observations of COM ices in protostars

Only became feasible after the advent of JWST!

JWST/MIRI-MRS observations of protostars (e.g., JOYS, IPA, CORINOS, HEFE, ...)

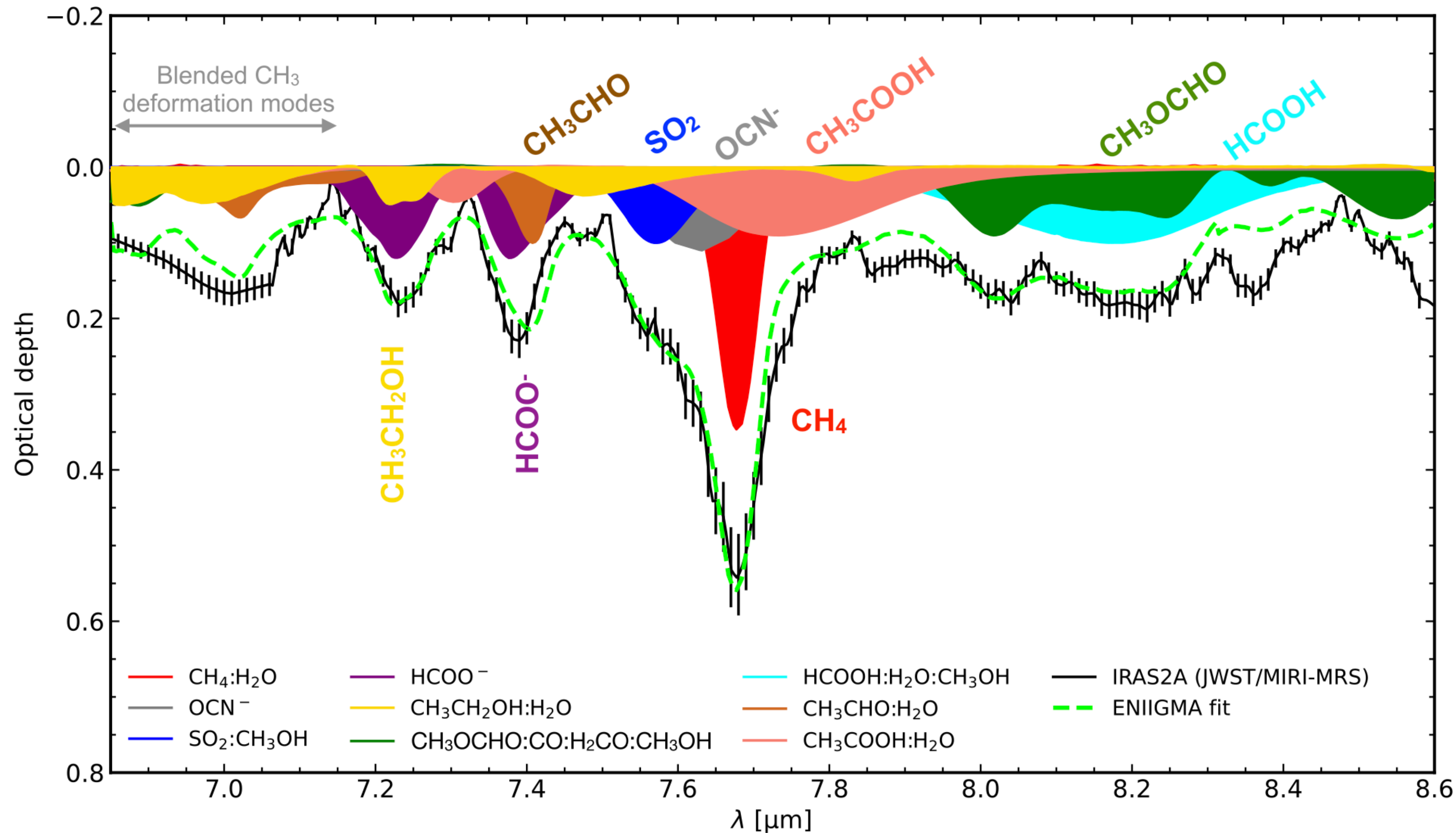


IRAS 2A (Rocha+2024)

B1-c (Chen+2024)

(Chen et al. 2024 A&A, 690, A205)

Fitting COM ice fingerprints in JWST spectra (IRAS2A)



lab spectra
(in color)

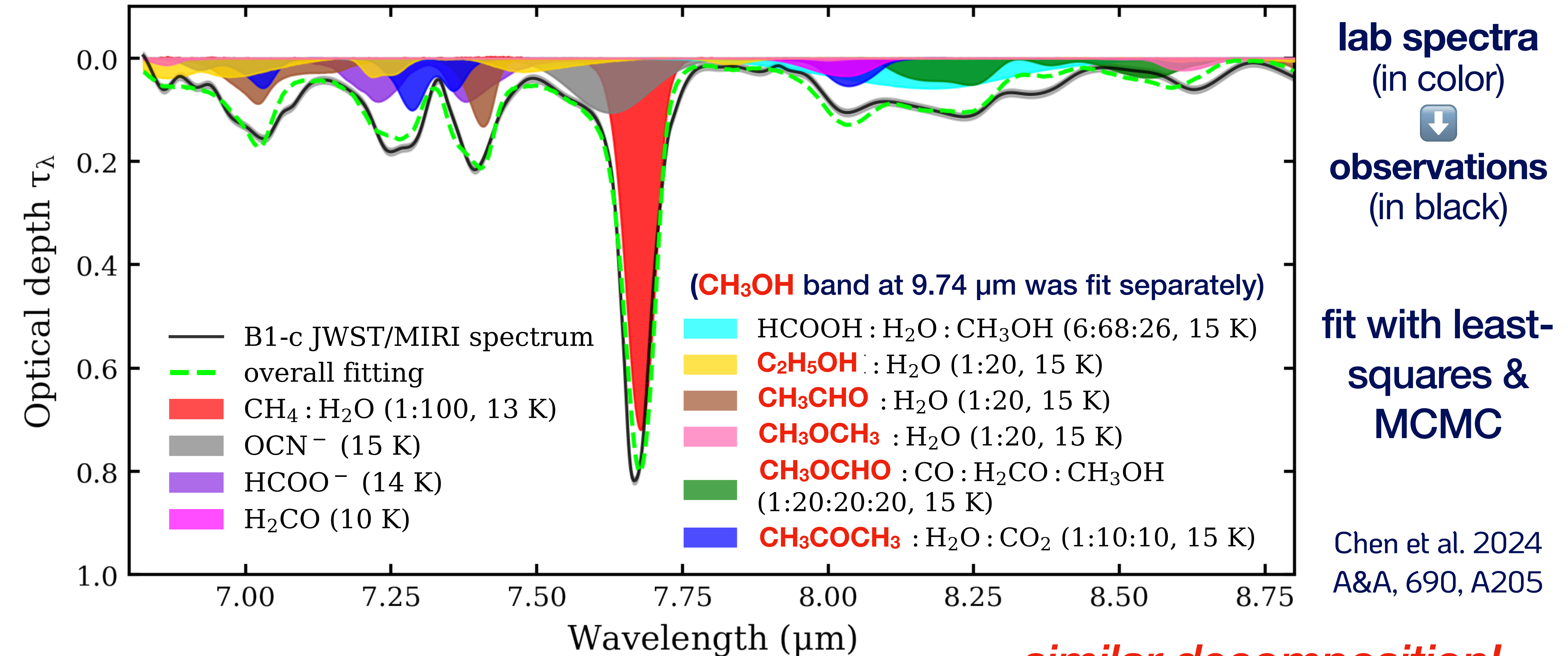


observations
(in black)

fit with ENIIGMA
(genetic algorithm)

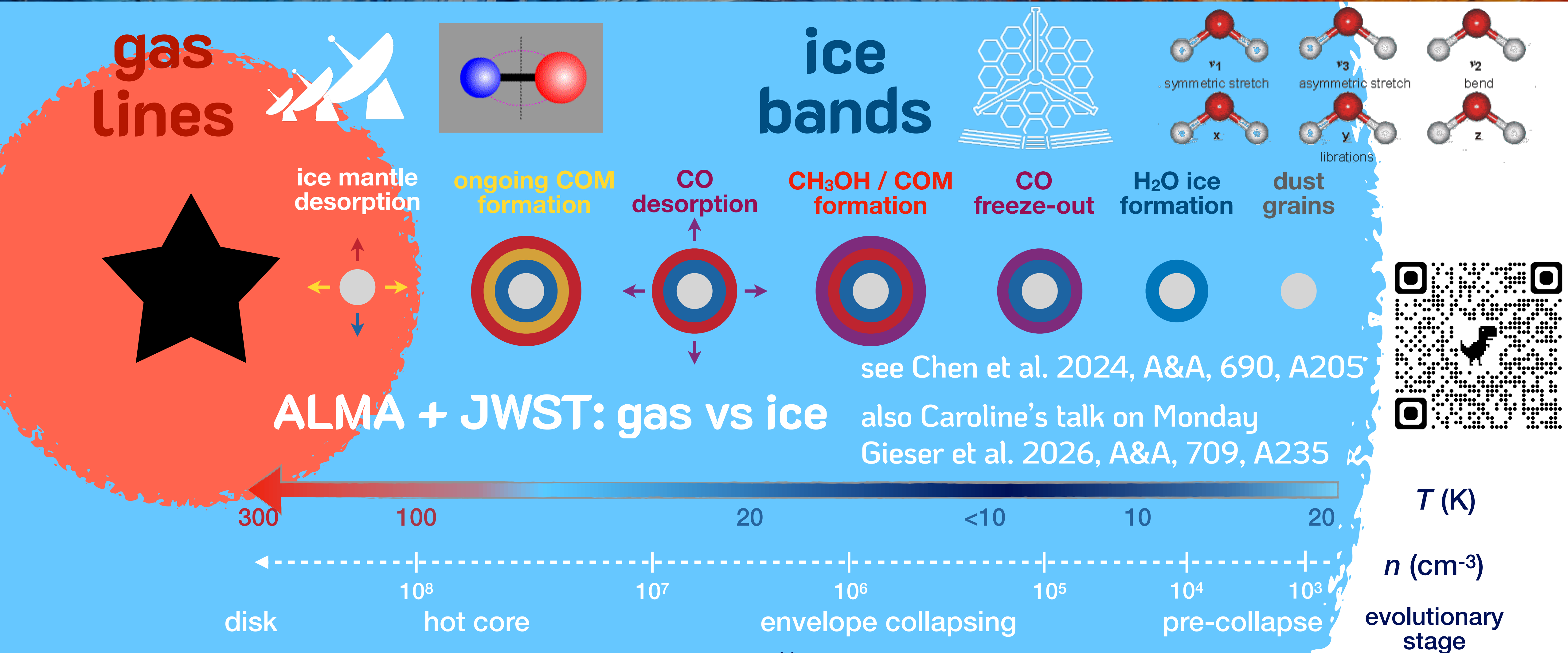
Rocha et al. 2024
A&A, 683, A124

Fitting COM ice fingerprints in JWST spectra (B1-c)



Our current understanding of COM formation in a protostellar system

After decades of studies by observers, theorists, and experimentalists...



COMice fingerprints: toward a larger sample

Systematic analysis of weak bands in 6.8–7.9 μm

Case studies:

IRAS 23385 & IRAS 2A
(Rocha+2024; JOYS+)

B1-c (Chen+2024; JOYS)

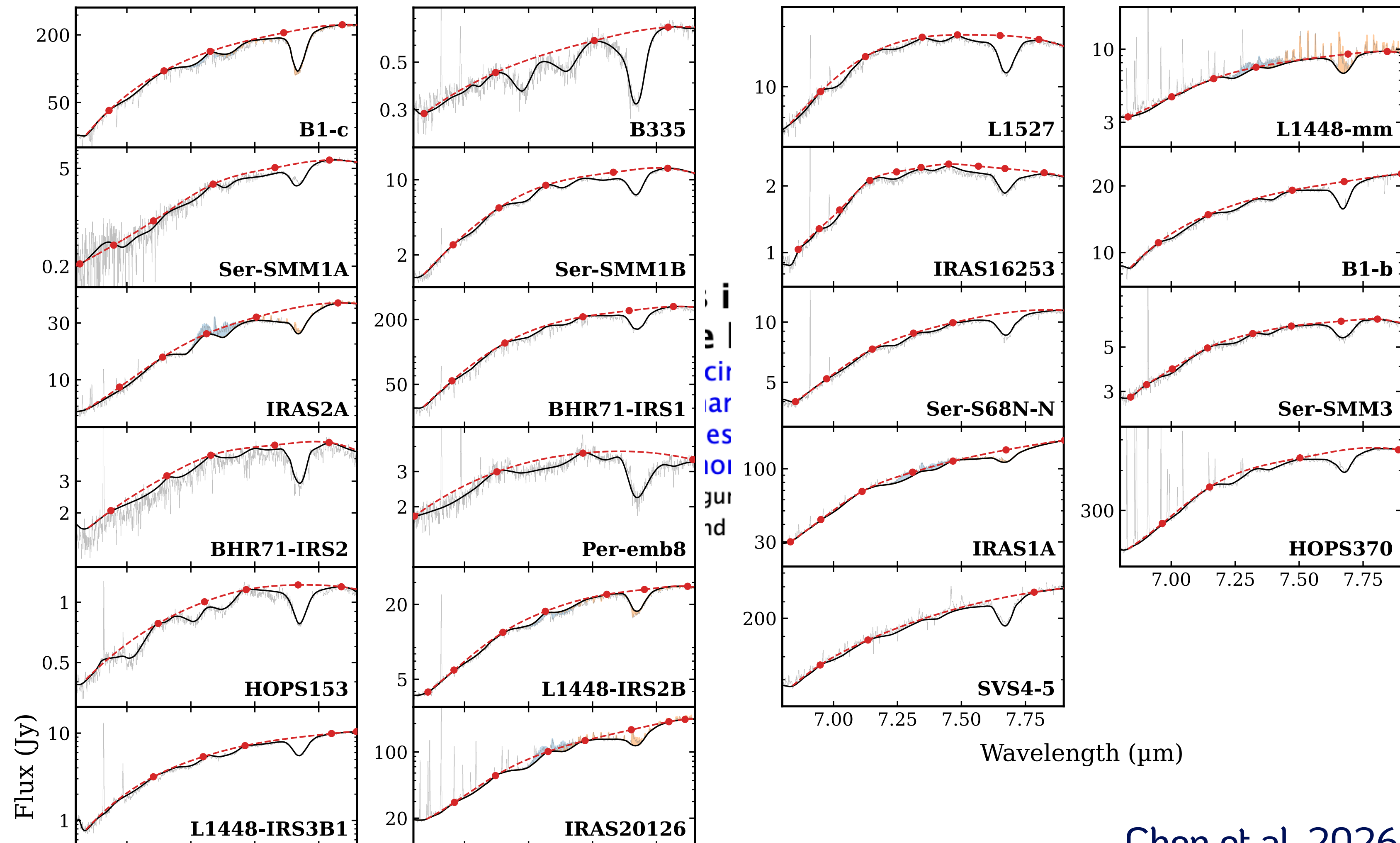
L483 & Ser-emb7
(Turner+2026; CORINOS)

IRAS 18089
(Gieser+2026; JOYS)



The full **JOYS+IPA** sample:
21 Class 0/I protostars
(mostly low-mass) selected

Step 1: local continuum subtraction

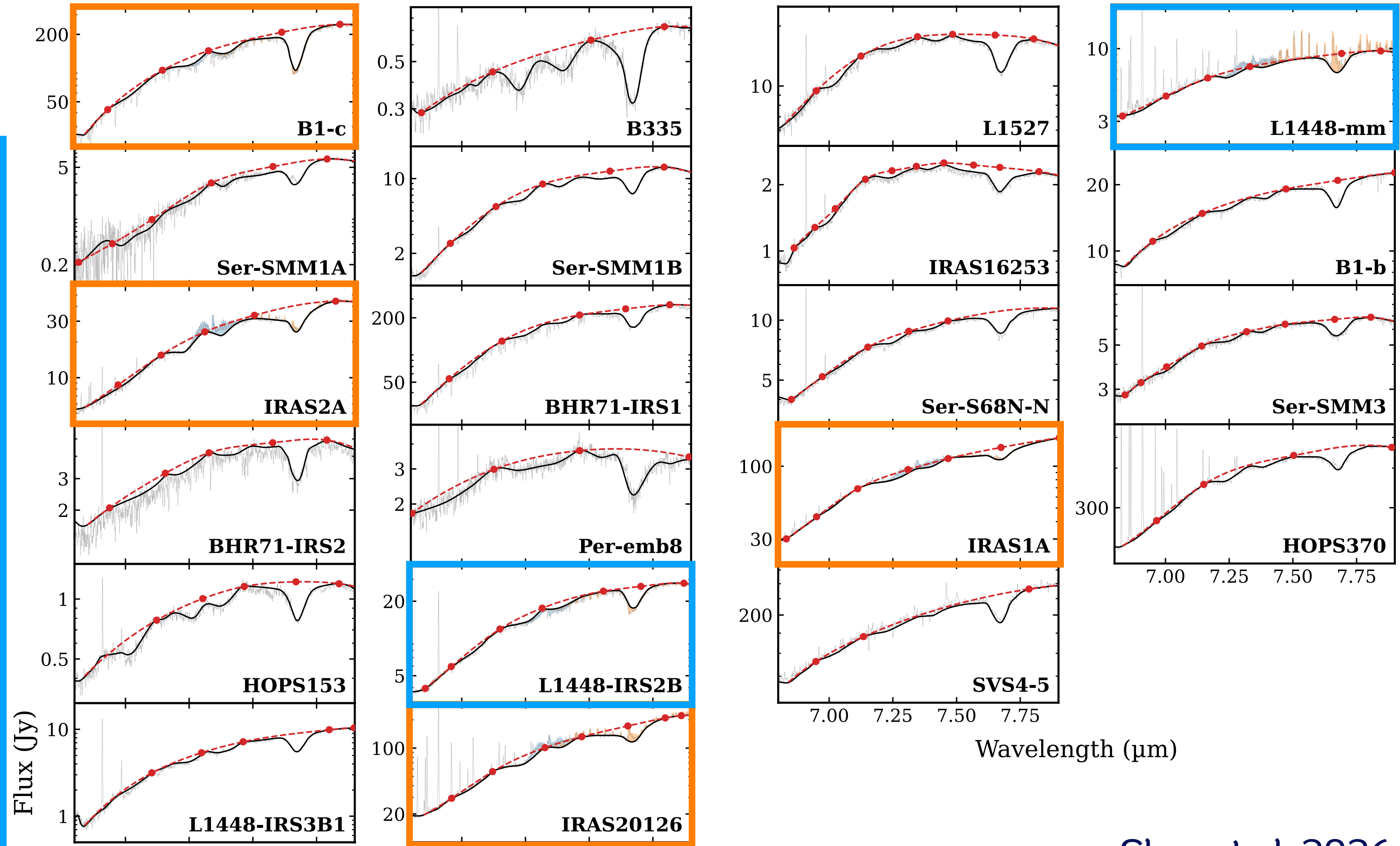
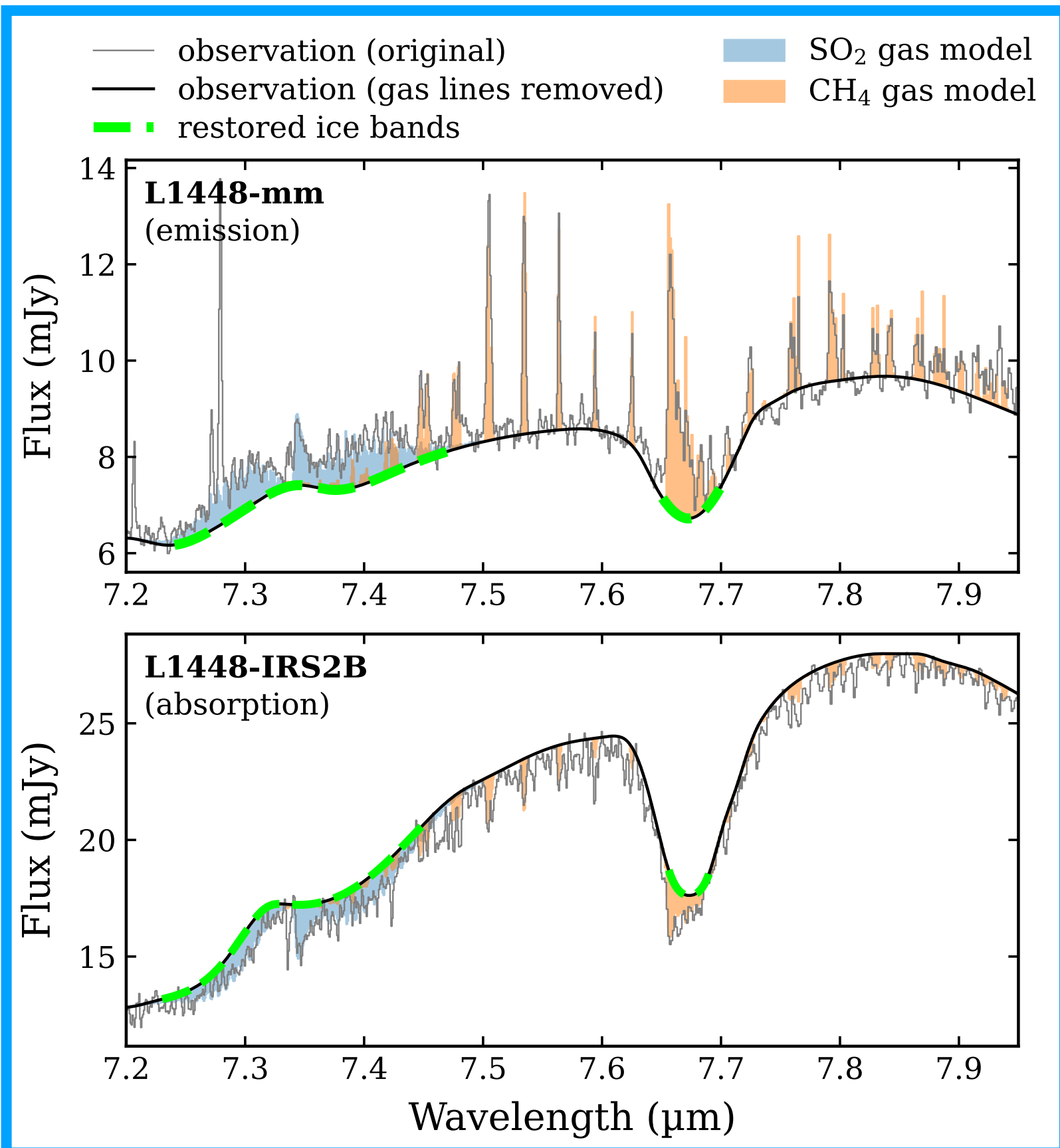


Chen et al. 2026

COM ice fingerprints: toward a larger sample

Systematic analysis of weak bands in 6.8–7.9 μm

Watch out the rovibrational lines of **SO₂** and **CH₄** gas!

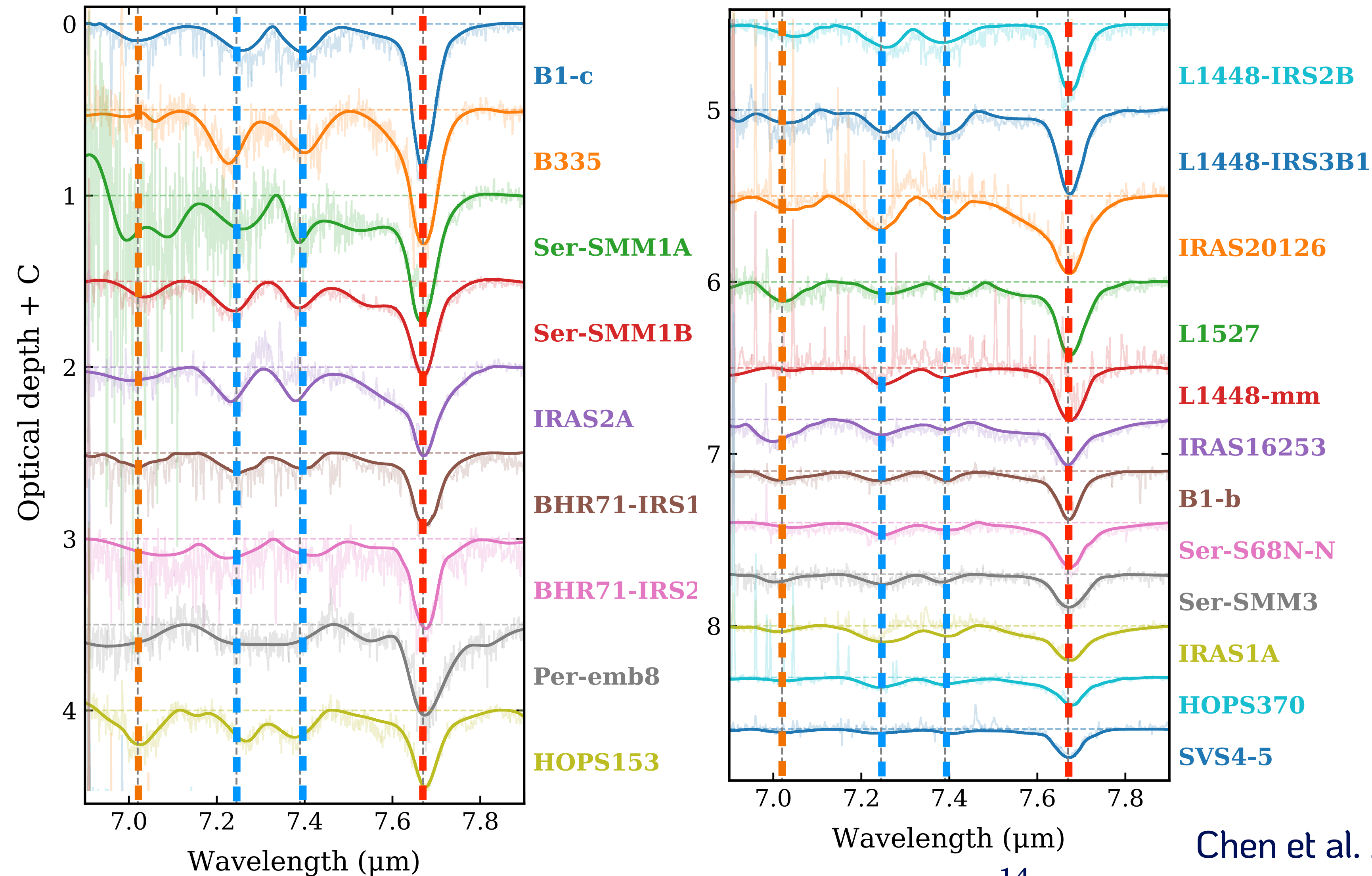


Chen et al. 2026

Step 0 (optional): gas line removal

COM ice fingerprints: toward a larger sample

Systematic analysis of weak bands in 6.8–7.9 μm



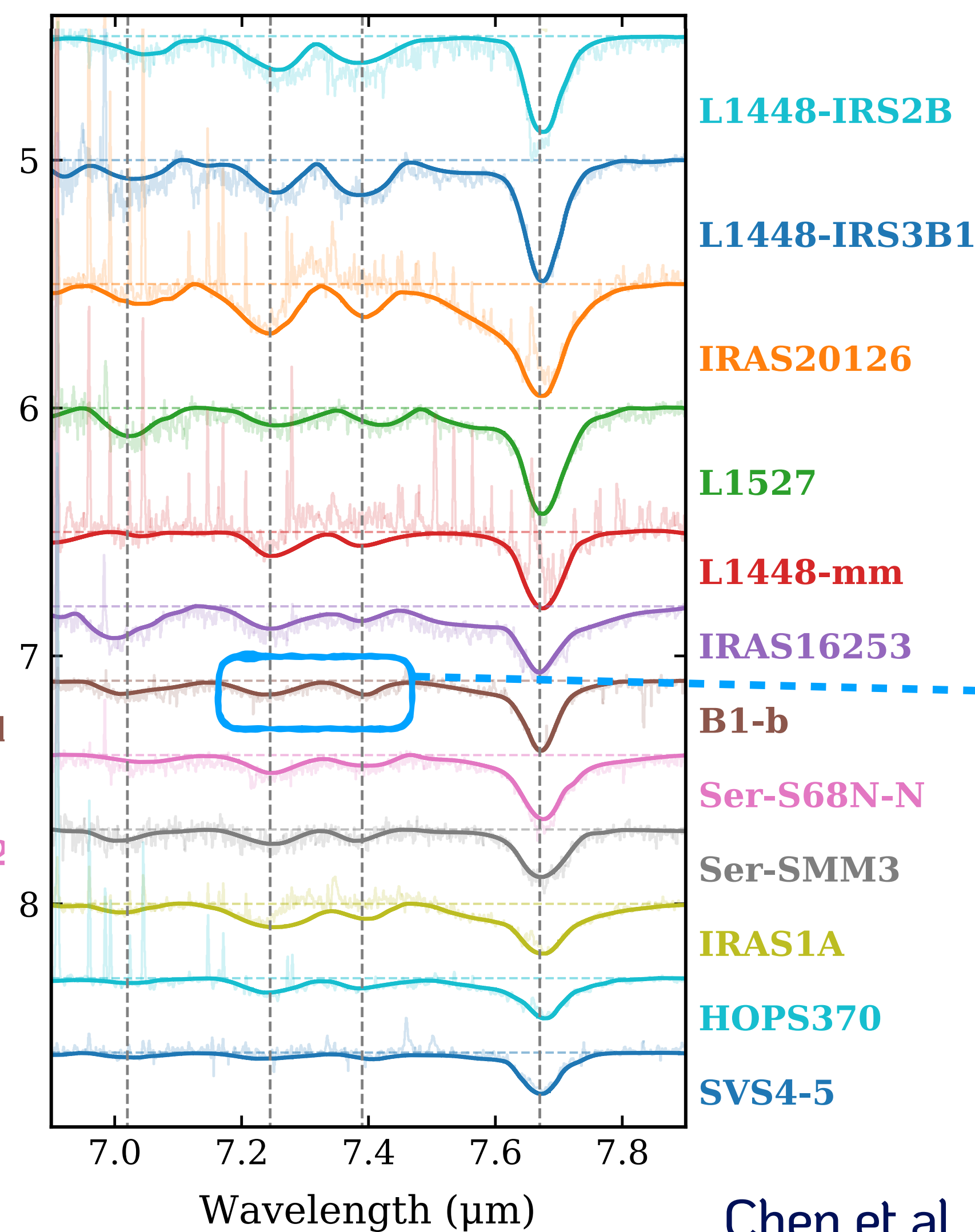
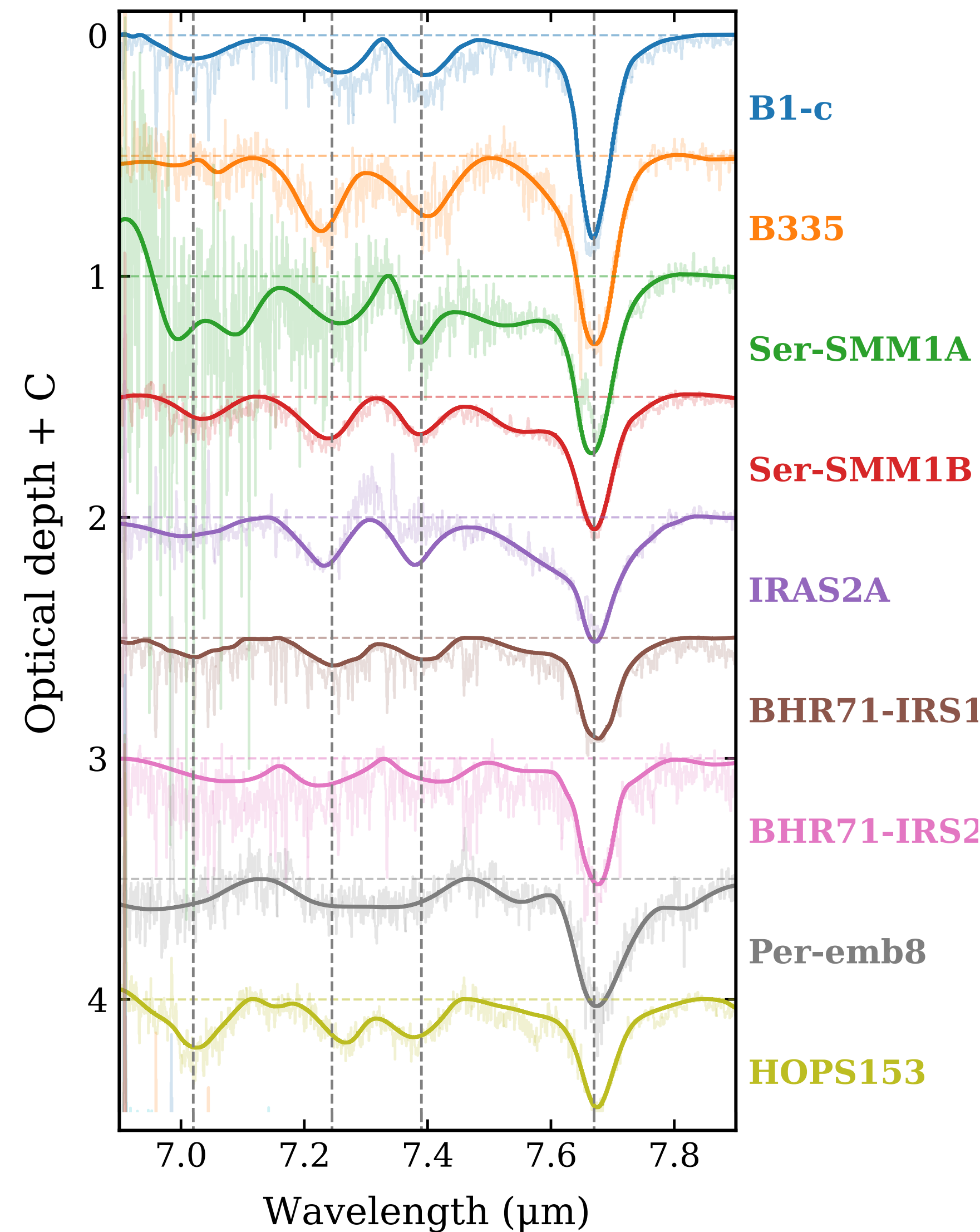
Focus on 4 bands with regular appearance:

- **7.67 μm**
CH₄, strongest
- **7.24 & 7.40 μm**
HCOO⁻, COMs?
(Schutte+1999)
- **7.02 μm**
COMs? weakest & less constrained

Chen et al. 2026

COMice fingerprints: toward a larger sample

Systematic analysis of weak bands in 6.8–7.9 μm



Chen et al. 2026

Step 2: band property measurements

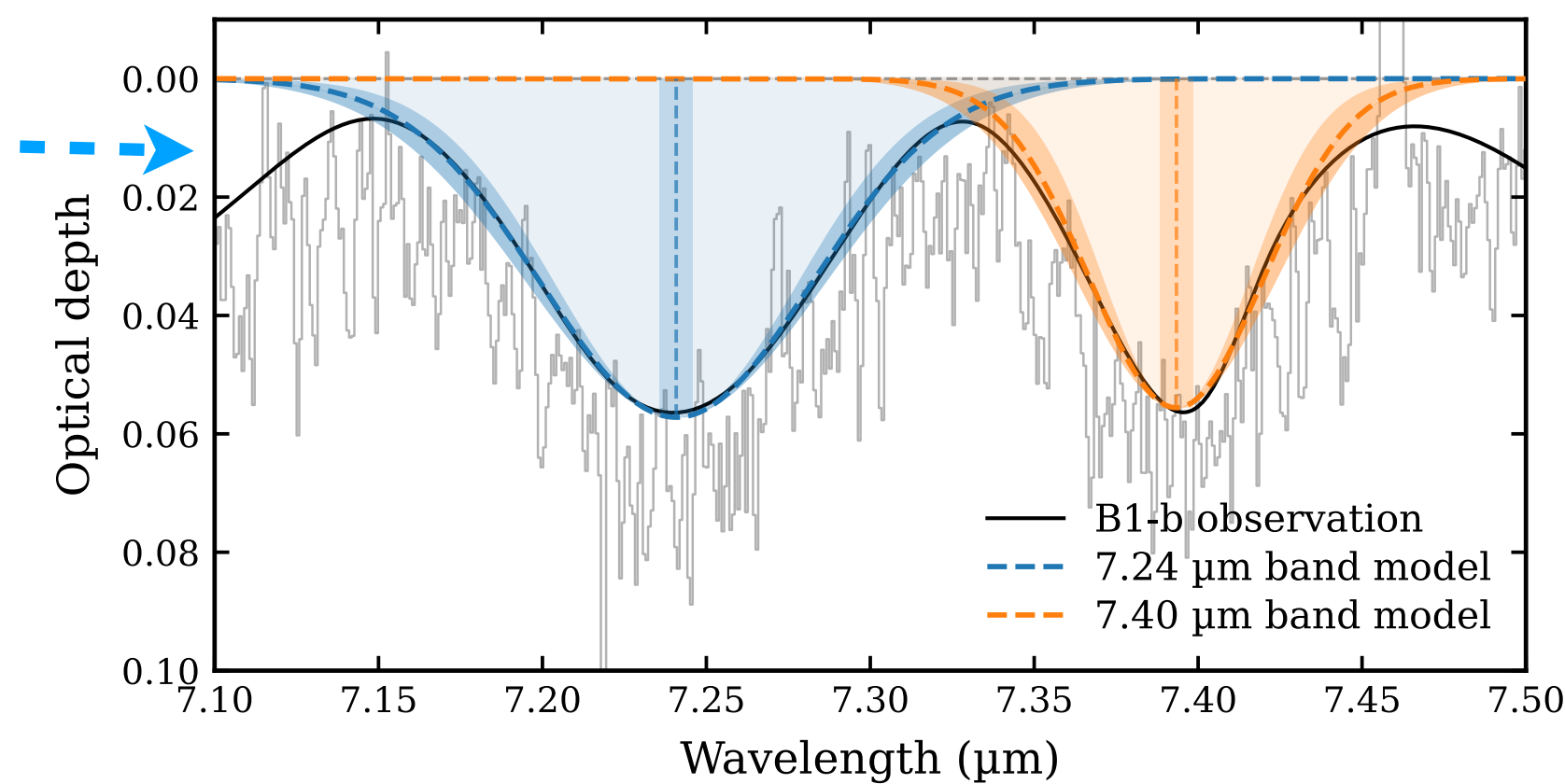
(by Gaussian fitting / by definition)

peak wavelength λ_{peak}

band width **FWHM**

peak opacity τ_{peak}

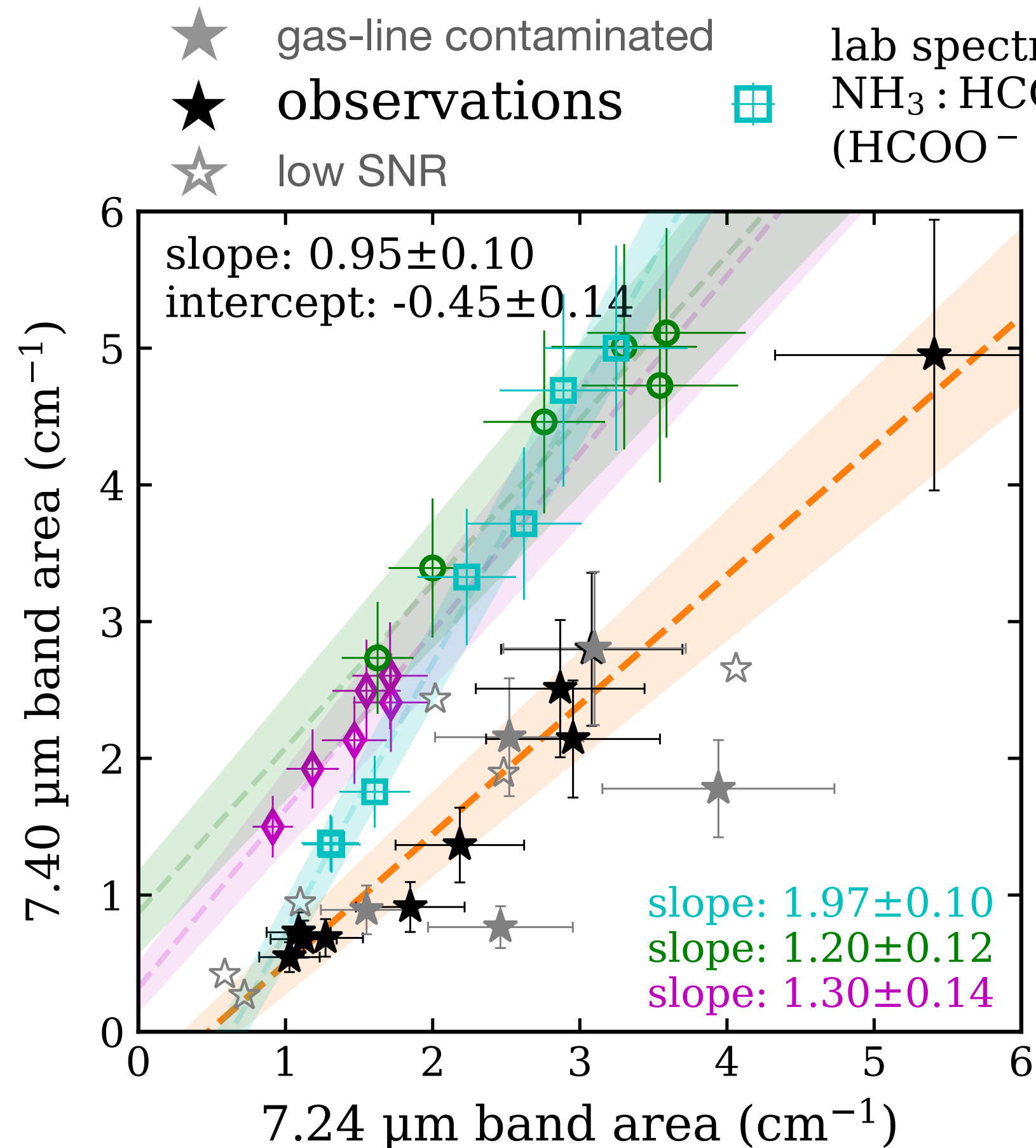
integrated area I_{band}



$$\Delta\lambda_{\text{peak}} = 0.005 \mu\text{m}$$

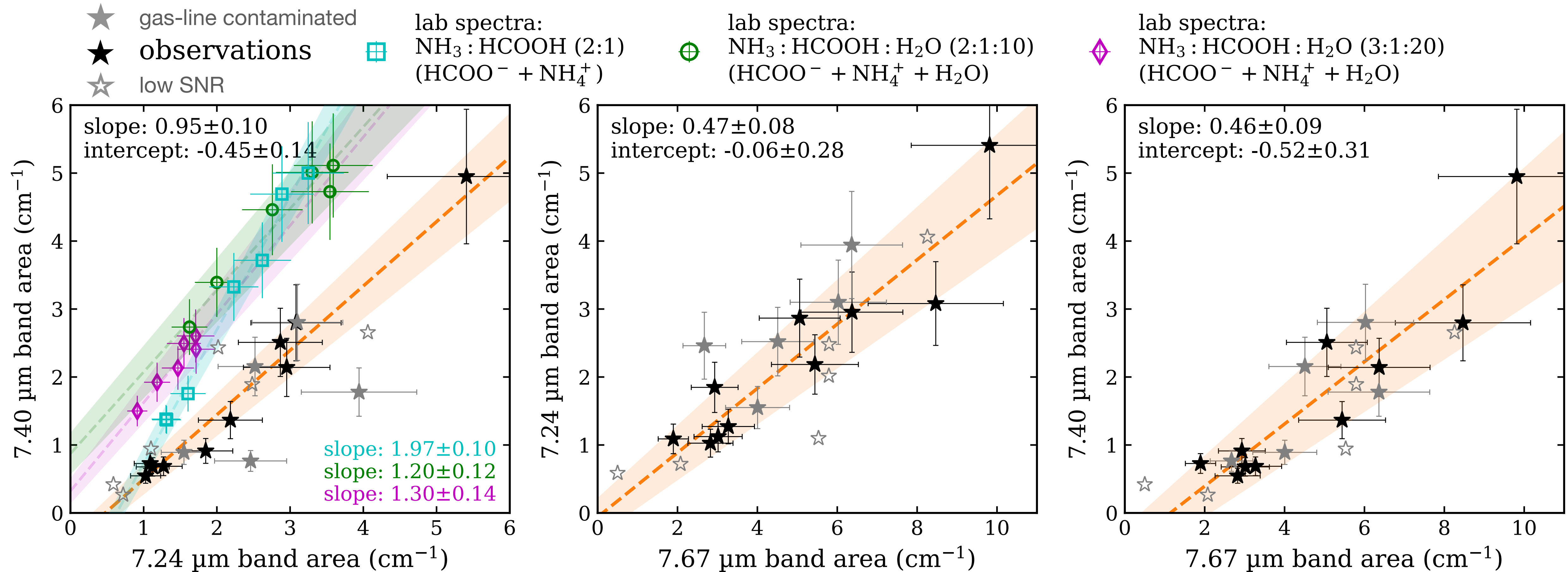
$$\Delta\text{FWHM} = 0.01 \mu\text{m}$$

Results I: band area correlations at 7.24, 7.40, 7.67 μm



- 7.24 vs 7.40 obs only:
bands at 7.24 and 7.40 μm are strongly correlated
➔ **co-occurrence favors attribution to HCOO^- ice**
- 7.24 vs 7.40 obs vs lab:
lab spectra of HCOO^- ices show stronger band at 7.40 μm ,
while in observations the 7.24 μm band is stronger
➔ **other contributors to the 7.24 μm band than HCOO^- ice**

Results I: band area correlations at 7.24, 7.40, 7.67 μm



- Strong correlations among three bands!
- ➔ **Non-detection of ice bands is more likely due to low ice abundances and sensitivity limits, doesn't necessarily mean no ice in a source**

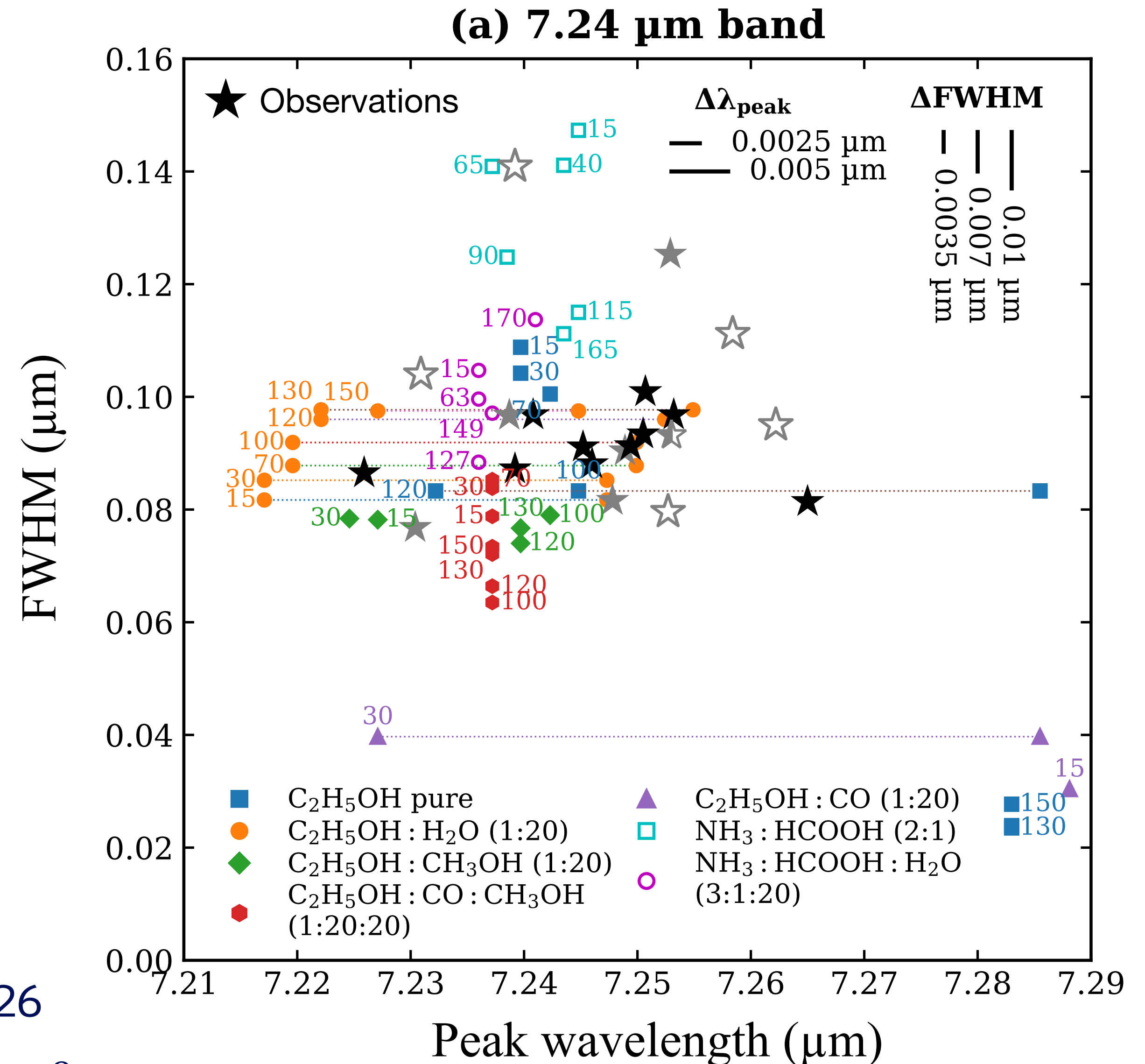
Chen et al. 2026

Results II: identification w/ peak wavelength & FWHM

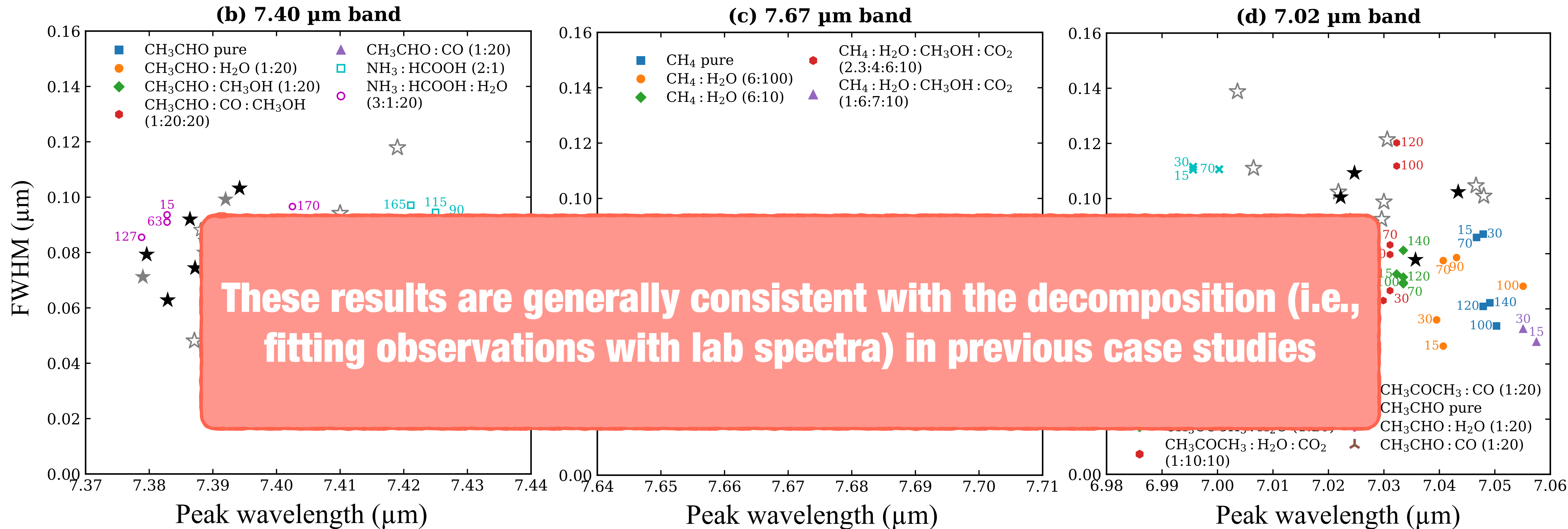
“Boogert plot”:

- band properties (peak & width)
laboratory vs observation
- used to find potential contributing species of observed ice bands
- **C₂H₅OH** is a plausible carrier of the 7.24 μm band, but there is degeneracy in its mixing condition
- **HCOO-** mixed with **H₂O** is favored than **HCOO-** pure (FWHM too large)

Chen et al. 2026



Results II: identification w/ peak wavelength & FWHM



- The **7.40 μm** band also favors **HCOO-** mixed with **H₂O** than its pure form
- CH_3CHO band is too redshifted

- The **7.67 μm** band has very constant band properties in observations
- **CH₄** should be present in a **mixed** environment than a **pure** one

- Both **CH₃CHO** and **CH₃COCH₃** mixed with **H₂O** are possible contributors

Note: this band is weak with less constrained properties

Take-away messages from this large-sample study

- Weak ice bands in $\sim 7\text{--}8\ \mu\text{m}$ can now be routinely detected by JWST
- The long-suggested carrier of the 7.24 and 7.40 μm bands, **HCOO- ice**, can be confirmed, with two notes:
 - HCOO- is likely to be present in a **H₂O-rich** environment than in a pure form
 - HCOO- seems **not** the only carrier of these two bands, given the difference in band area ratios
- The 7.67 μm band has very constant peak positions and widths
 - CH₄ should be the dominant (if not only) carrier of this band
 - CH₄ is also present in a mixed environment, not in pure form
- Comparing band properties between observations and lab spectra is a powerful tool for ice identification, not only on **speices**, but also on **environments**, while only robust with large samples

Outlook: toward a different mass regime

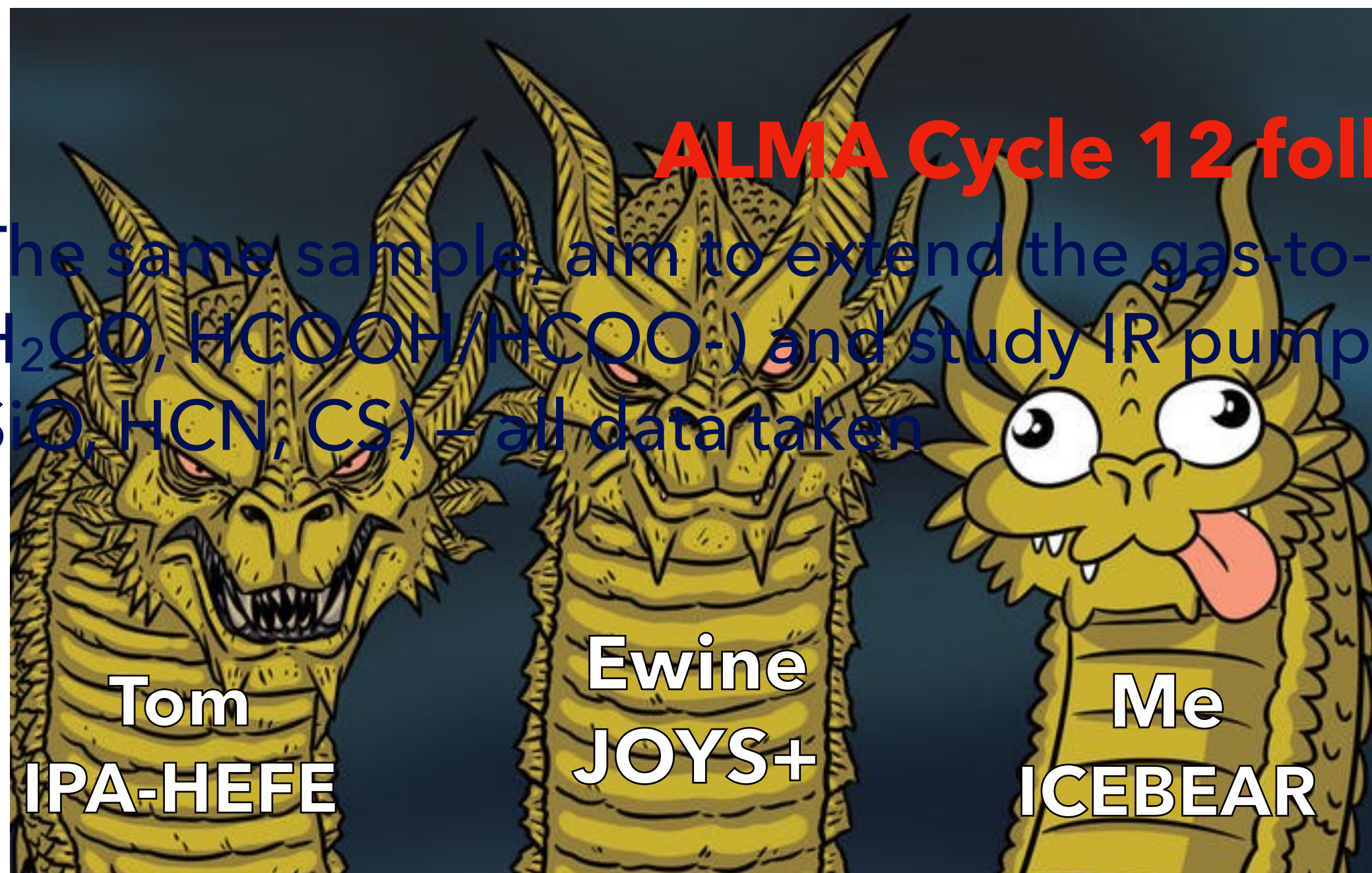
JWST Cycle 4 GO – ICEBEAR (44 hr)

Investigating **C**hemical **E**volution **B**etween ic**E** and g**A**s in massive protosta**R**s

- Proposed main science goal: gas-to-ice comparisons of COMs in high-mass protostars
- High S/N **MIRI-MRS** + simultaneous **MIRI imaging** + dedicated bkg obs of **15 high-mass hot cores** (selected from ALMA programs) across the galactic plane
- 90% data taken, data reduction ongoing, preliminary spectra & images available

ALMA Cycle 12 follow-up program for ICEBEAR

The same sample, aim to extend the gas-to-ice comparisons to simple species (e.g., HNCO/OCN-, H₂CO, HCOOH/HCOO-) and study IR pumping effects via vibrationally excited gases (e.g., SO₂, SiO, HCN, CS) – all data taken



If you are interested, please contact me
via yuanchen@mpe.mpg.de