

The Dust to Ice Ratio Varies Among and Within Interstellar Clouds

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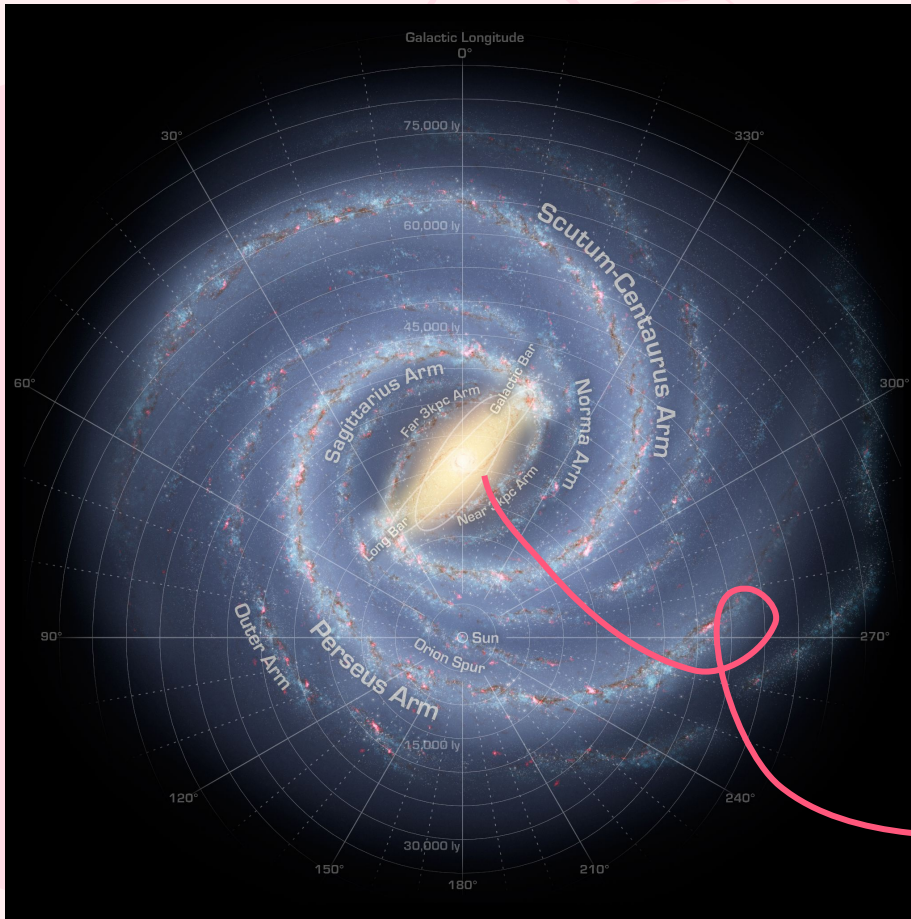
Background



JWST

- ★ Infrared Space Telescope
- ★ Why Infrared?
 - Redshift
 - Dust Extinction
- ★ Why Space?
 - Earth's atmosphere is opaque in the infrared. It glows.
 - The atmosphere limits angular resolution.





The Milky Way Galaxy

- ★ Barred spiral galaxy
- ★ The Galaxy has several spiral arms
- ★ At its center is the Central Molecular Zone (CMZ)

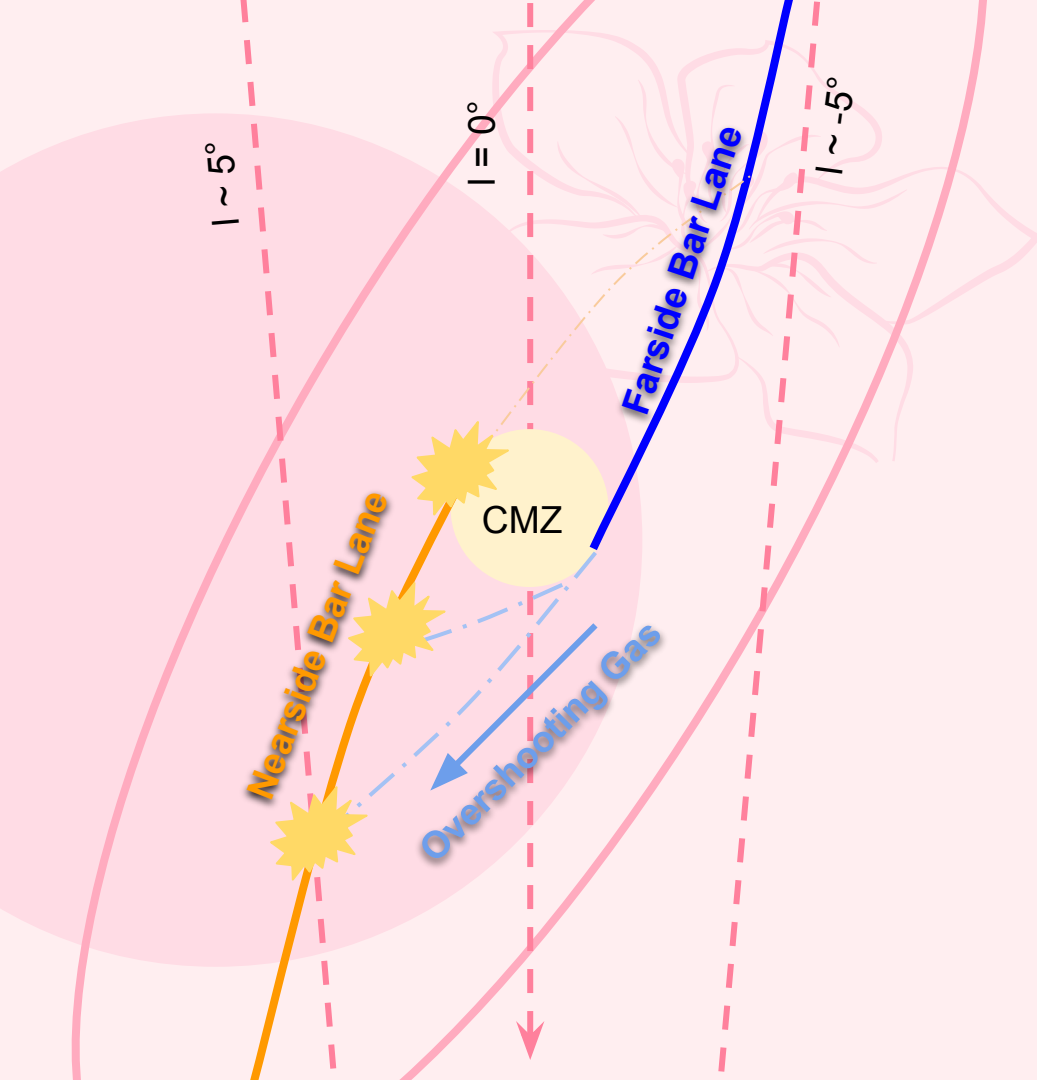
NASA - R. Hurt



NGC 4394

Barred Spiral Galaxies

- ★ Instead of a spherical gravitational potential (ie. the Sun), barred galaxies have a central bar-shaped potential.
- ★ This causes exotic, non-elliptical orbits along the length and perpendicular to the bar.

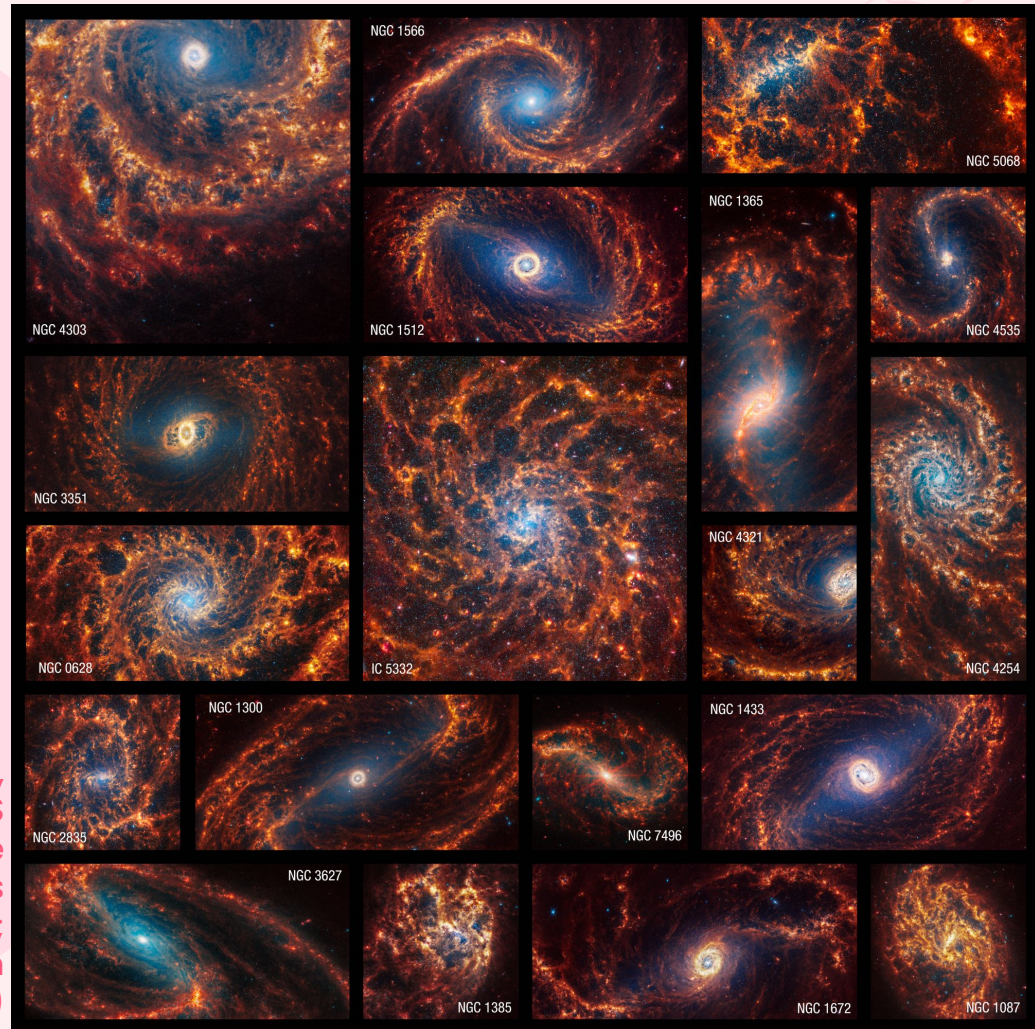


Dust Lanes

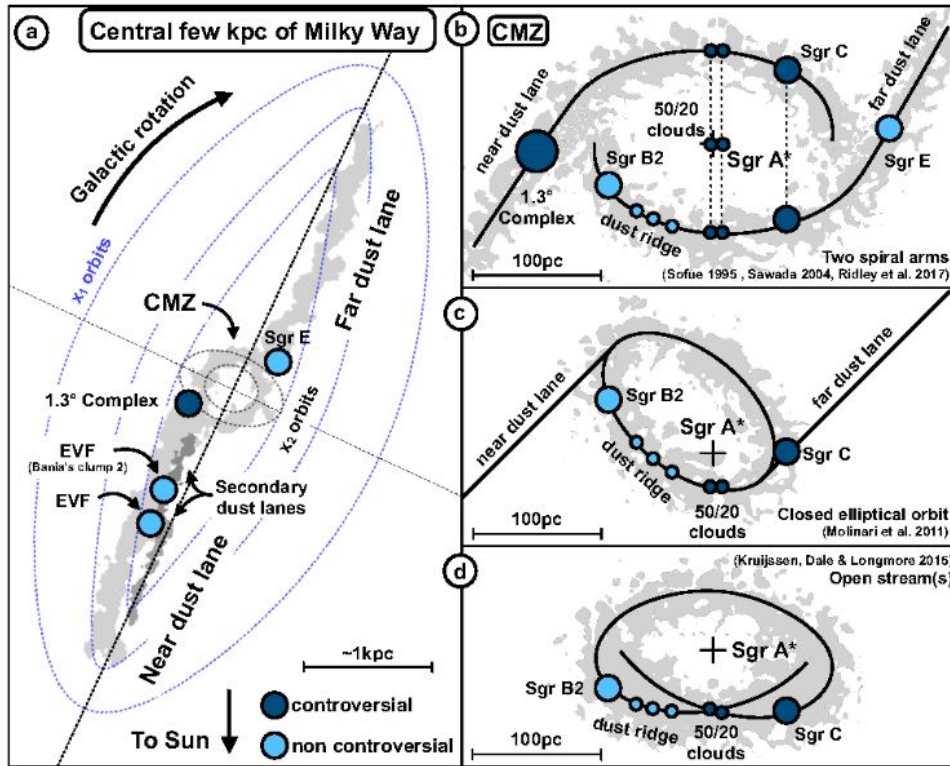
- ★ Dust/"Bar" lanes feed the CMZ material through huge streams of gas and dust.
- ★ As gas encounters the cusped ends of elongated bar orbits, it stalls and falls inward toward the Galactic Center.

The Centers of Other Galaxies

NASA, ESA, CSA,
STScI, PHANGS
Team, Janice Lee
(STScI), Thomas
Williams (Oxford);
Designer: Elizabeth
Wheatley (STScI)

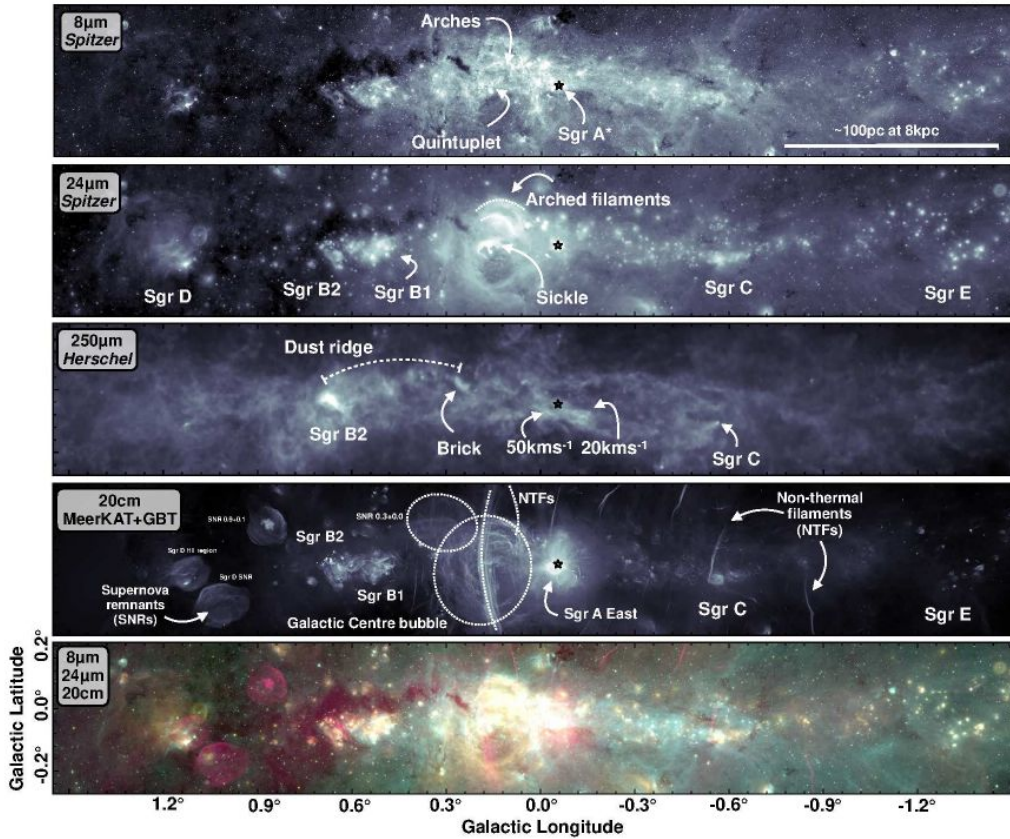


The Central Molecular Zone



- ★ Gas and dust orbiting the Galactic Center, Sgr A*
- ★ Gas is warm (~50 K) and turbulent
- ★ Extreme environment
- ★ Exact structure unknown

The Central Molecular Zone



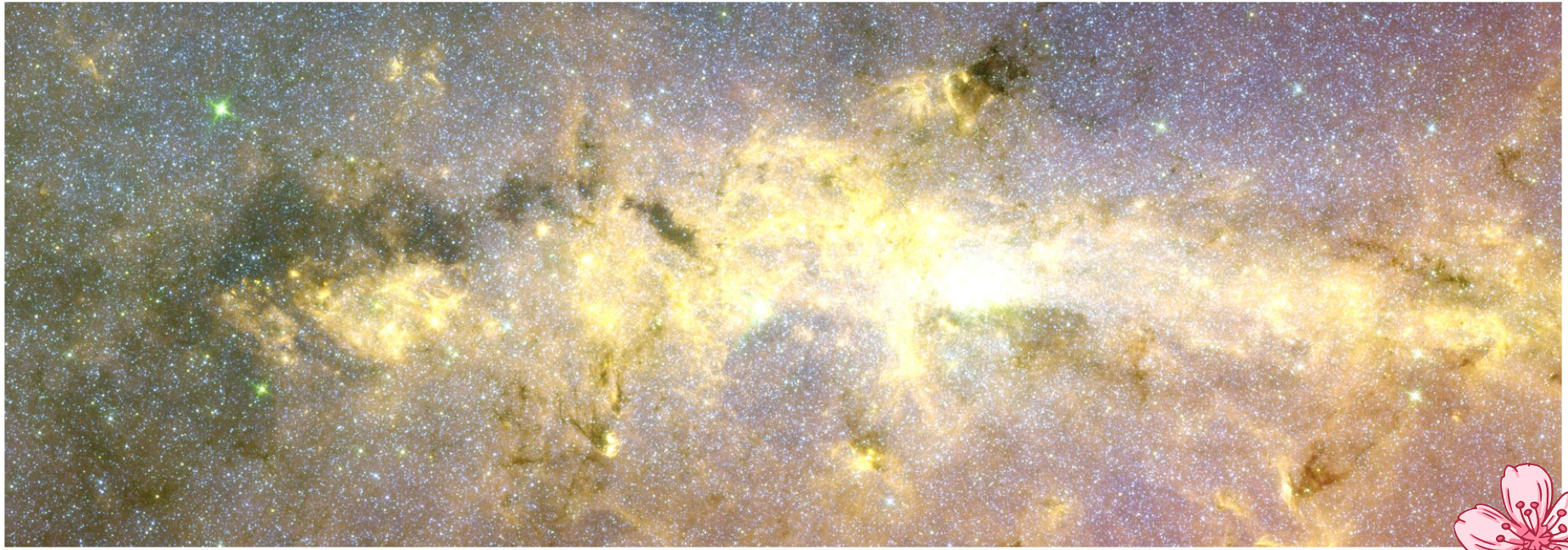
- ★ Gas and dust orbiting the Galactic Center, Sgr A*
- ★ Gas is warm (~50 K) and turbulent
- ★ Extreme environment
- ★ Exact structure unknown



Observation

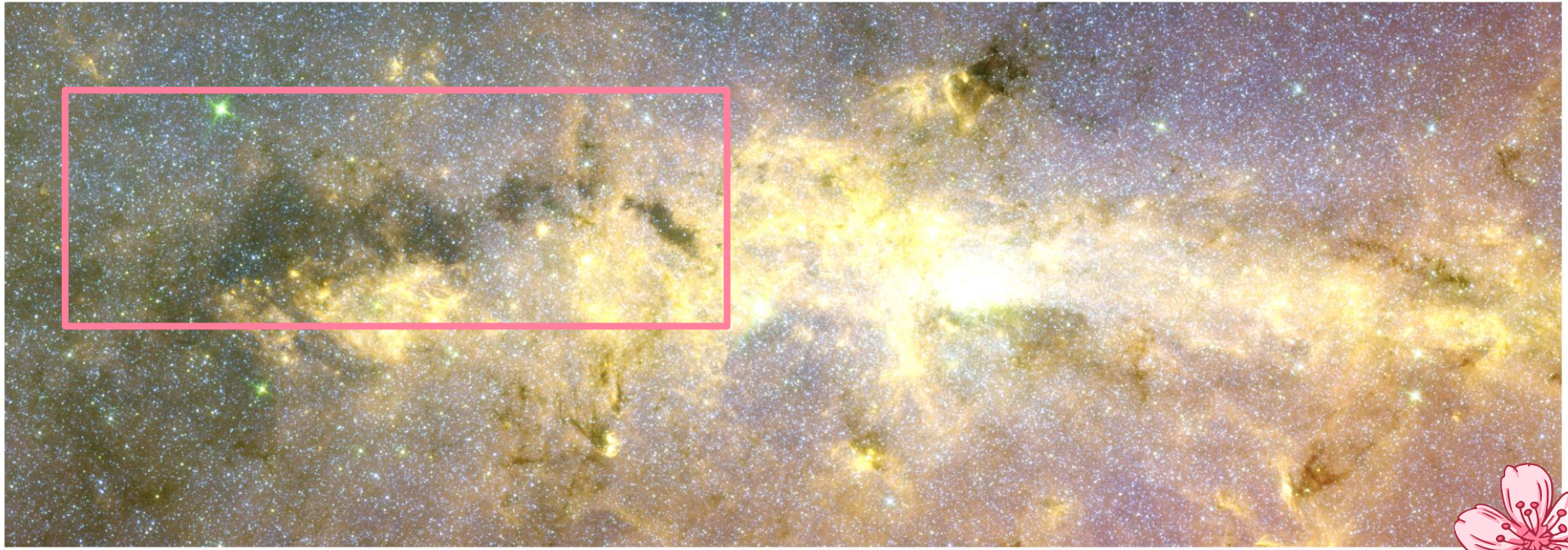
s





Spitzer

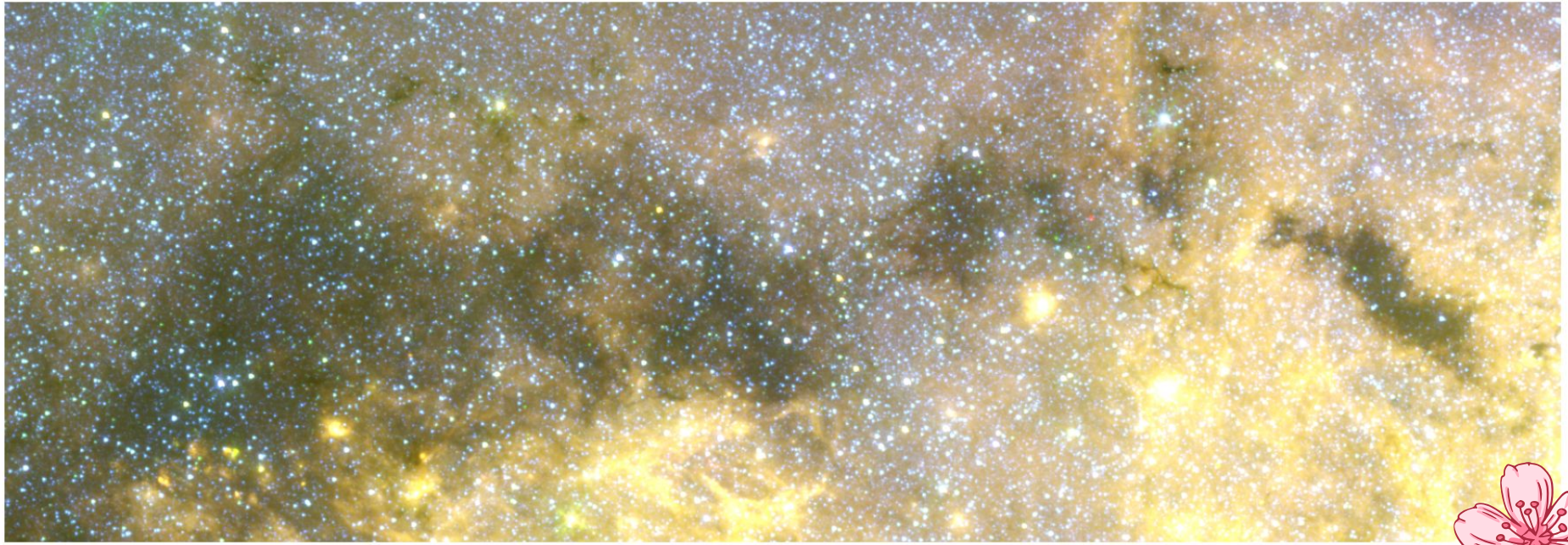
The Milky Way's Central Molecular Zone



The Milky Way's Central Molecular Zone

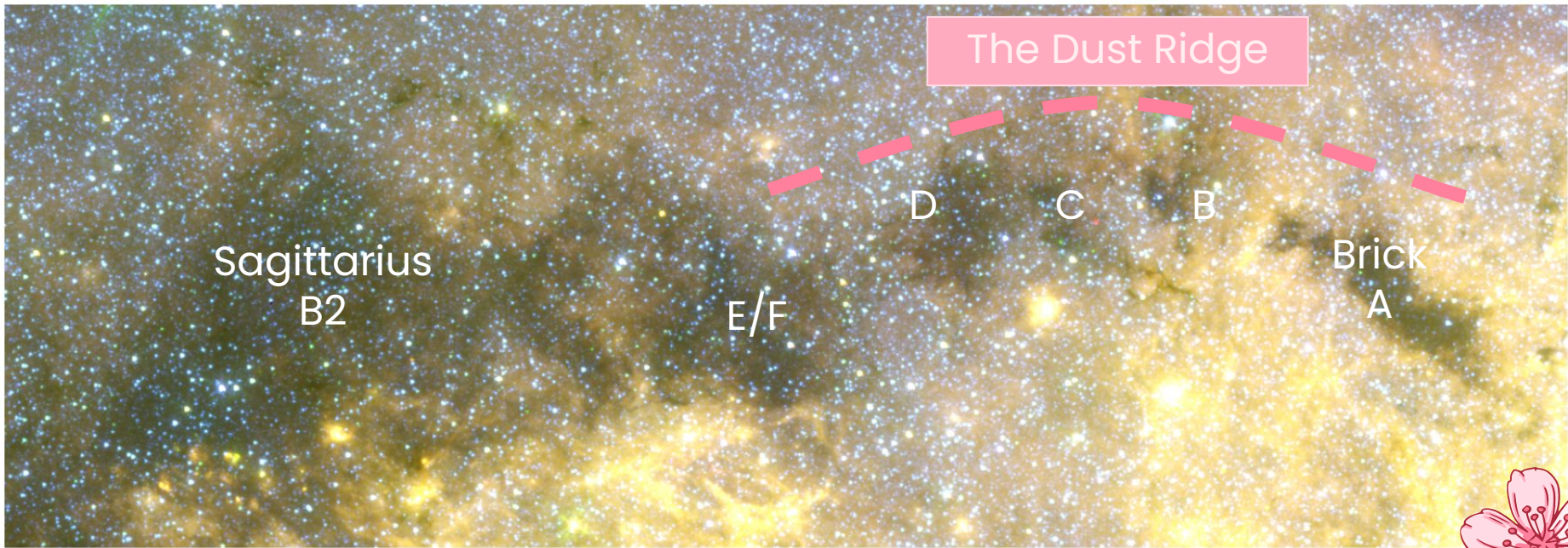
Spitzer





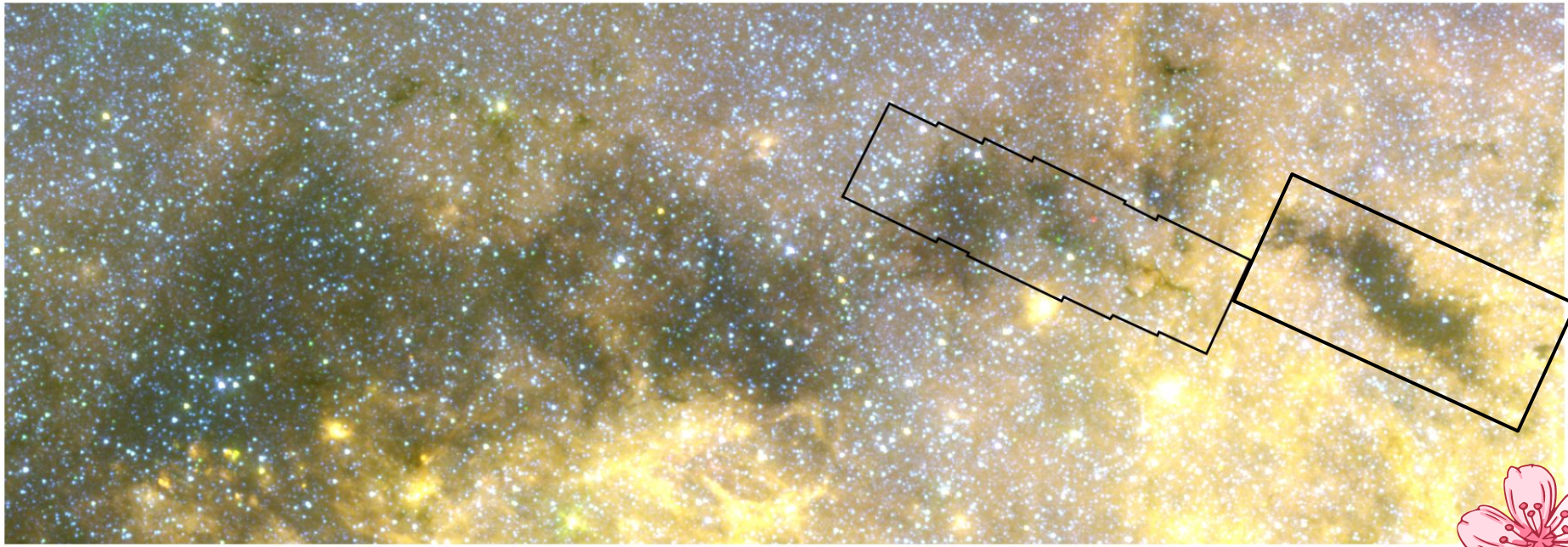
Spitzer

CMZ: Dust Ridge



Spitzer 

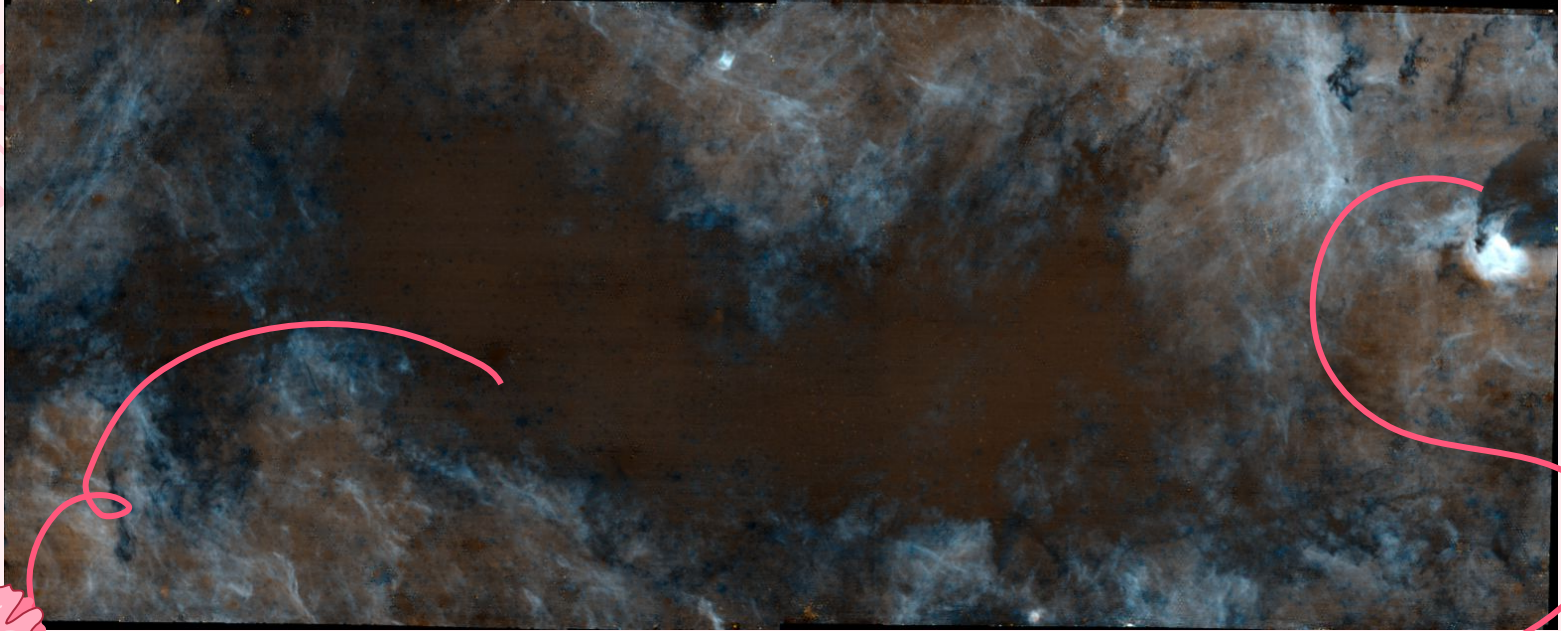
CMZ: Dust Ridge



Spitzer

CMZ: Dust Ridge - JWST Observations

Ginsburg et al 2023

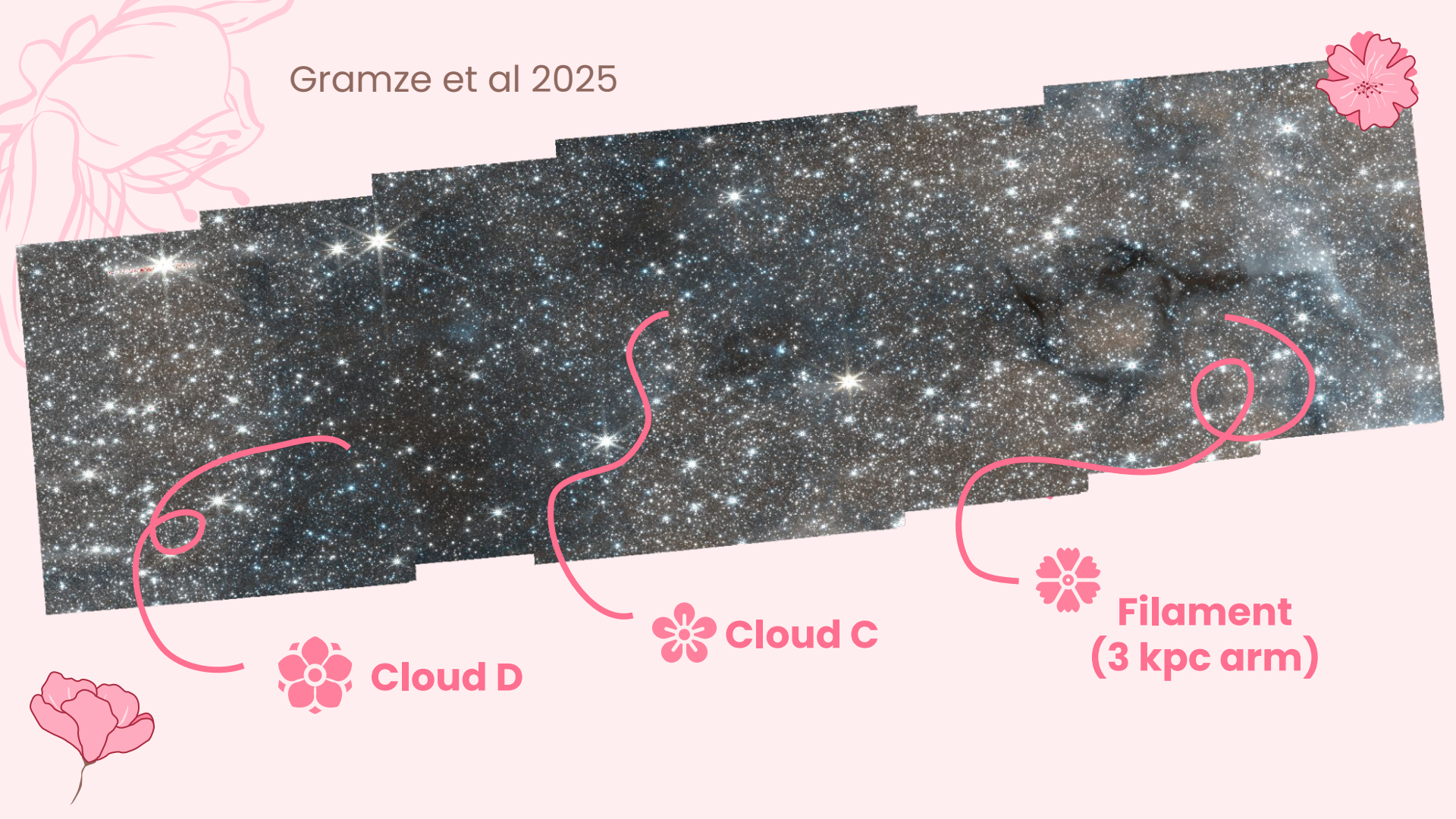


 **Brick**



**Star
Formation
Region**

Gramze et al 2025



Cloud D



Cloud C



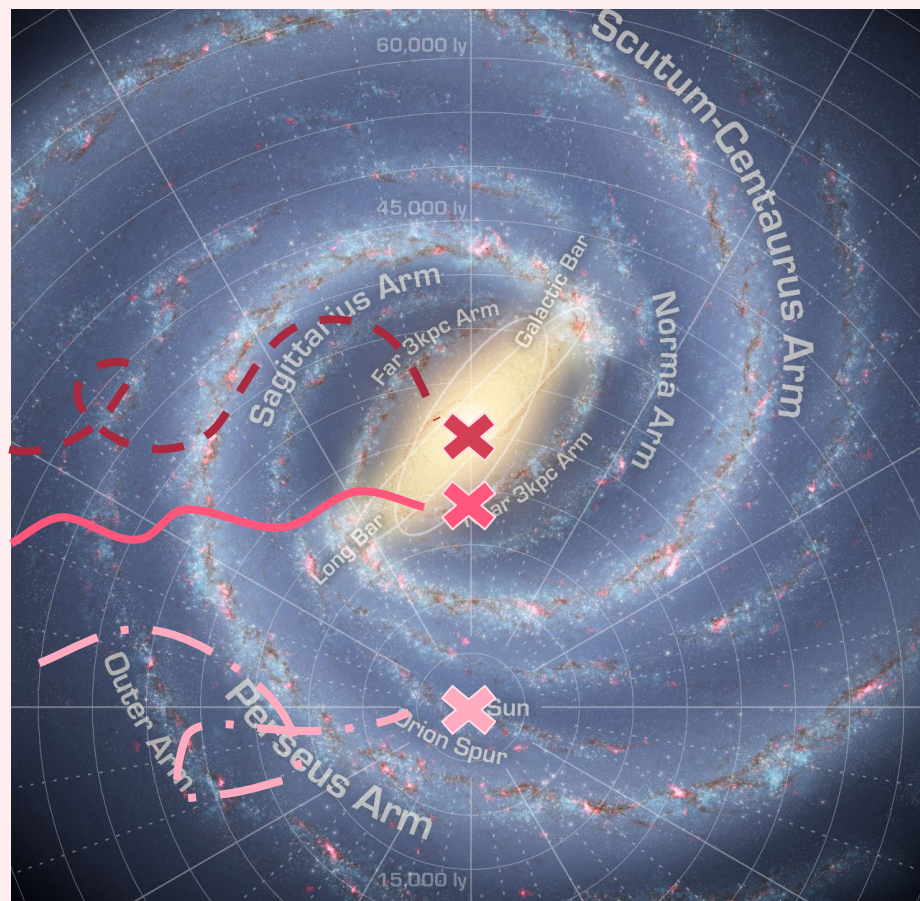
Filament
(3 kpc arm)

Where in the Galaxy are we Looking?

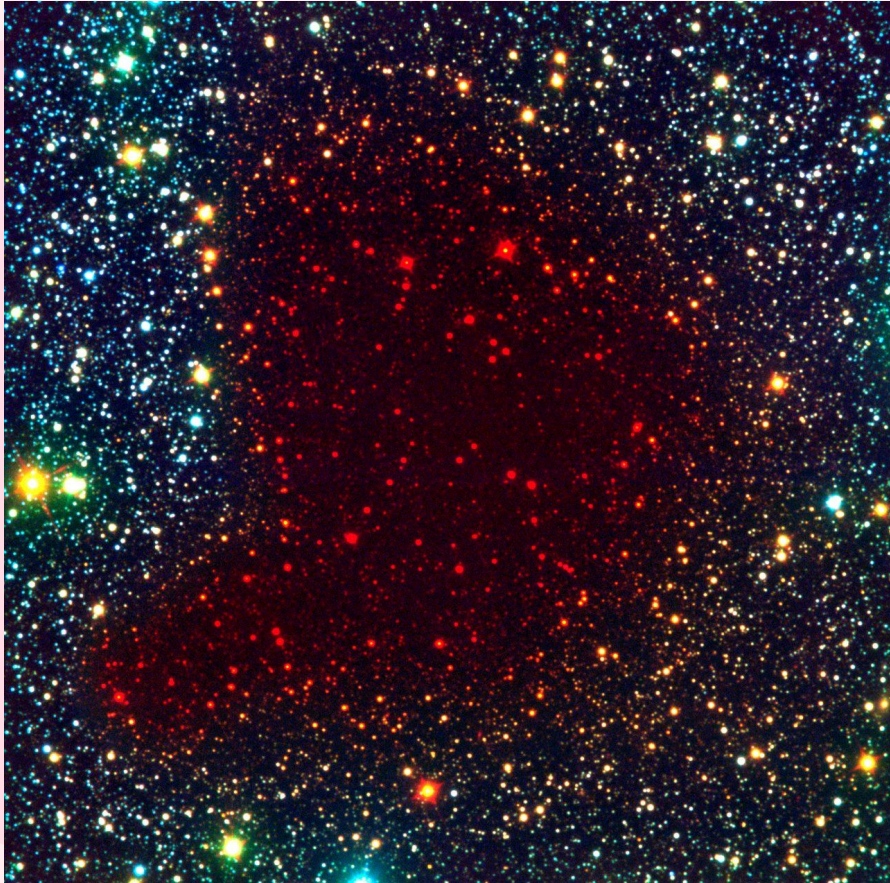
CMZ / Dust Ridge

Filament

The Sun



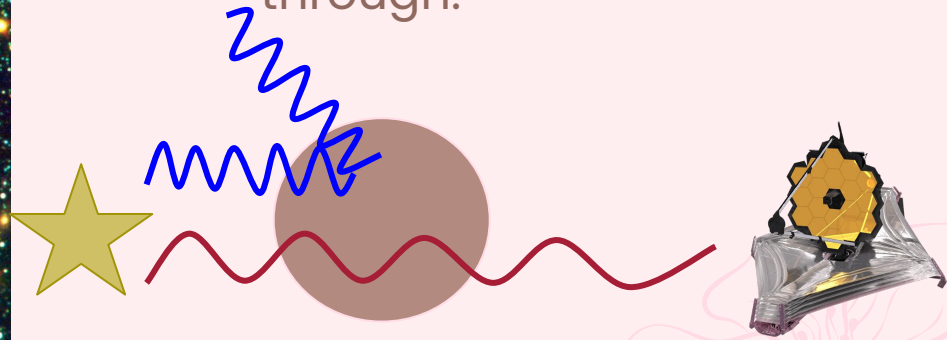
NASA - R. Hurt



ESO

Dust Reddens Stars

- ★ Dust blocks shorter wavelengths of light.
- ★ Only redder light gets through.



Why are the stars behind the clouds blue, not red?





Dust Grain

CO

H₂O

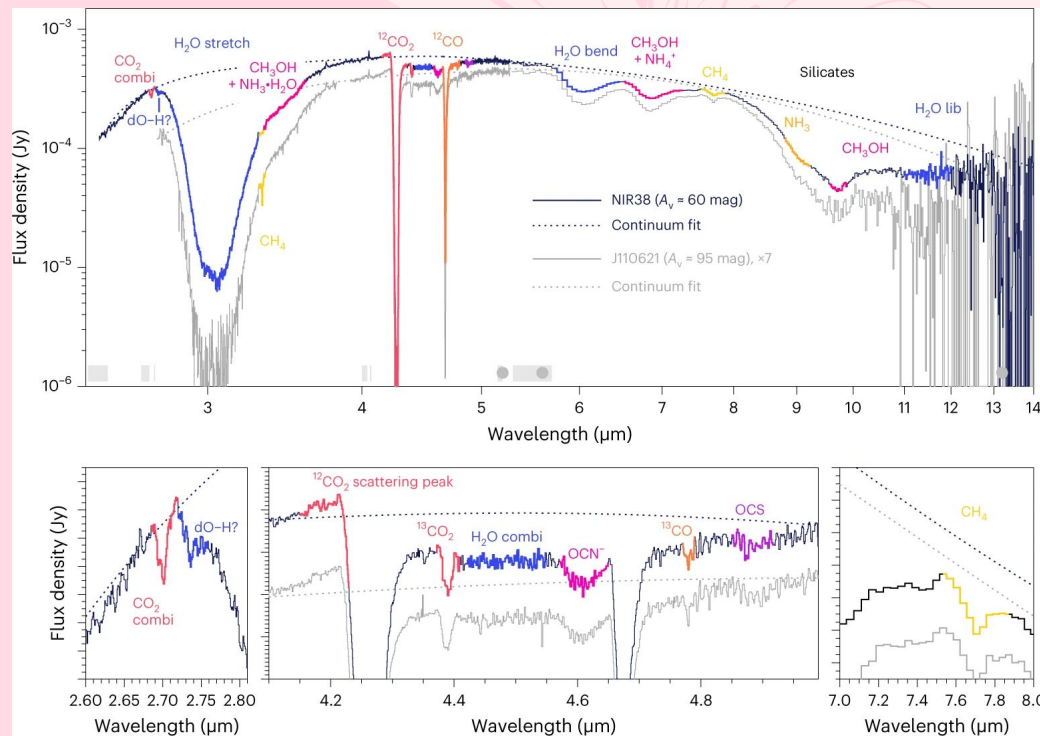
CO₂

Icy Mantle

Interstellar Ices

- ★ When gas gets cold and dense, molecules such as CO freeze onto dust grains
 - Infrared dark clouds
- ★ This ice has an effect on near-infrared light

Interstellar Ices

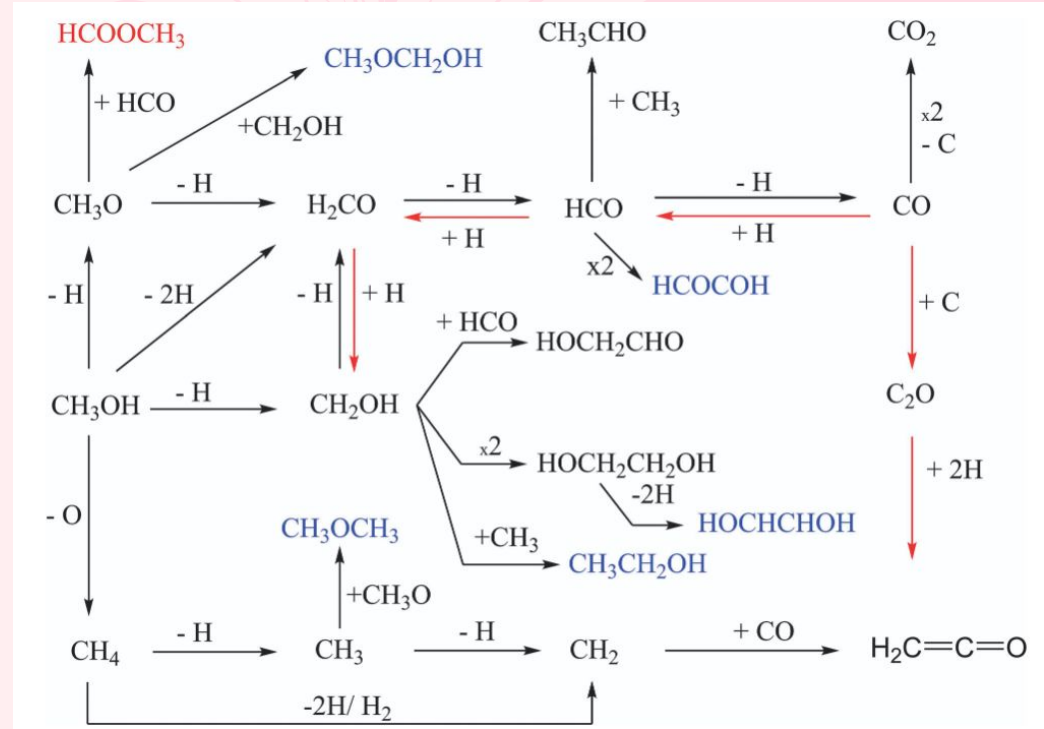


- ★ Absorption features for these ices appear in the near-infrared.
- ★ JWST is sensitive to the wavelengths where these features appear.

McClure et al 2023

Icy Dust Grain Chemistry

- ★ The formation of large, organic molecules occurs on the surfaces of icy dust grains.
- ★ These molecules are the building blocks of life.

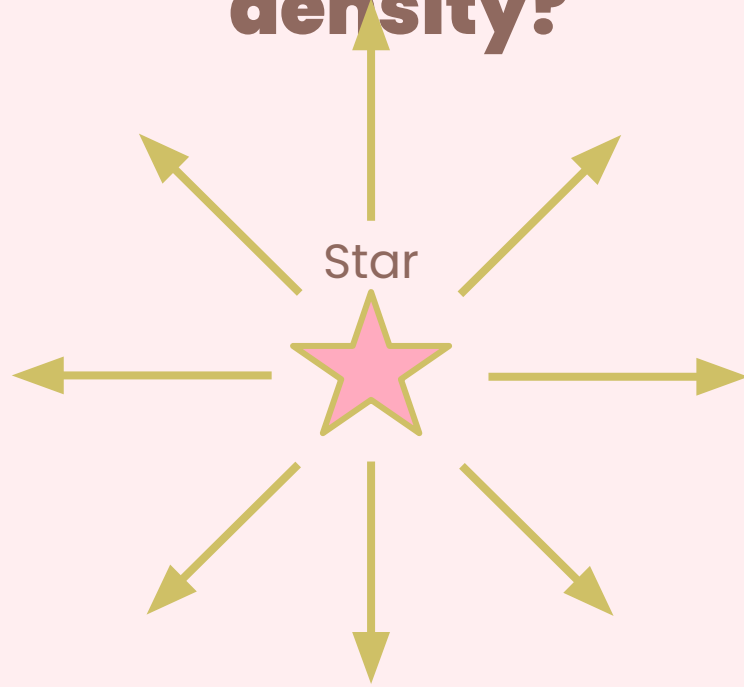


Surajit et al 2015

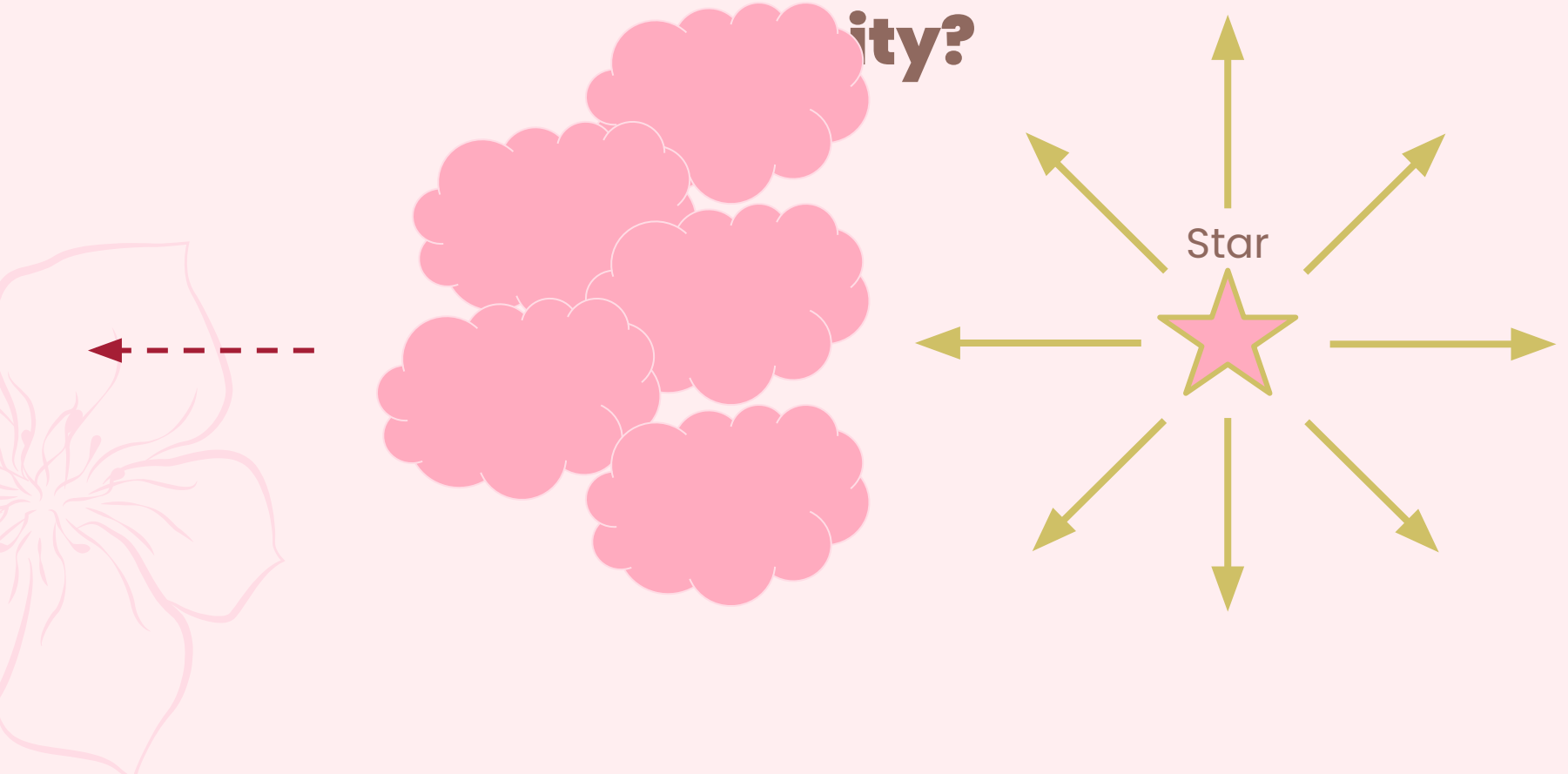
**How do we measure how much
ice is in a cloud?
Its column density?**



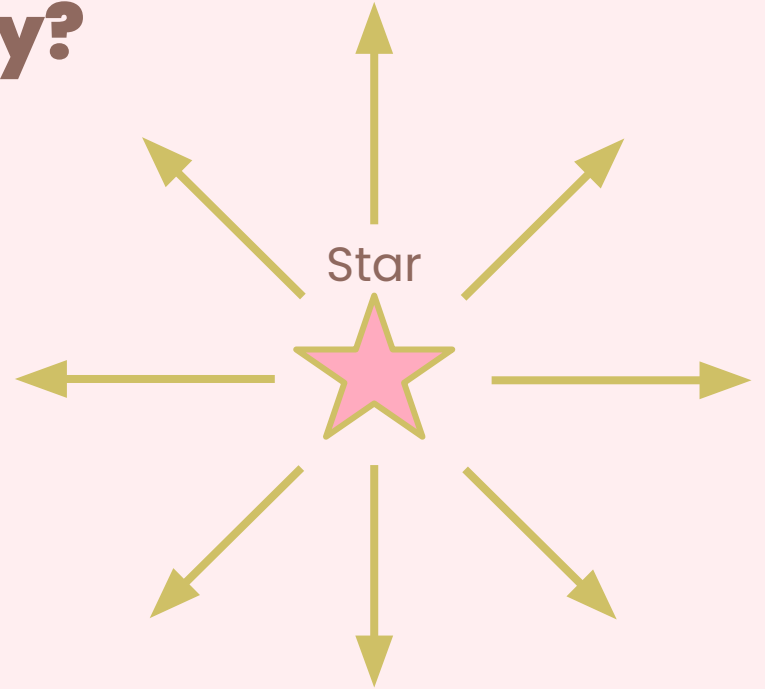
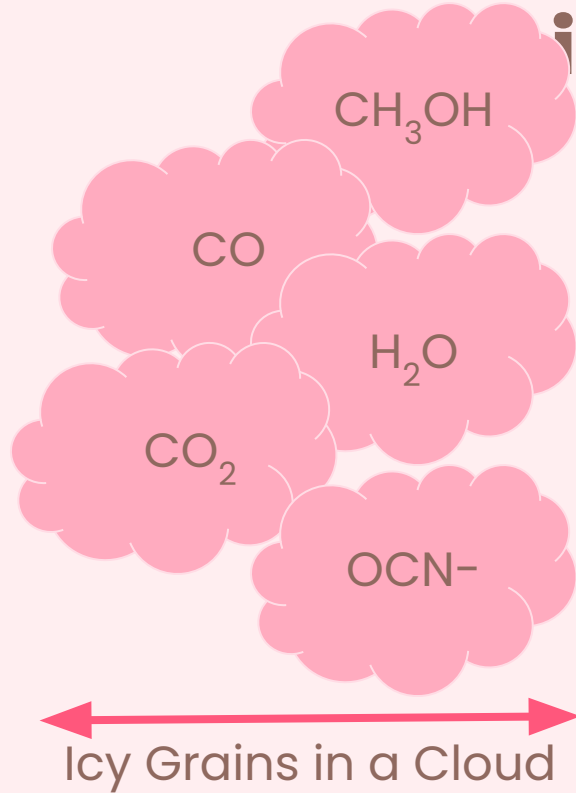
How do we measure ice column density?



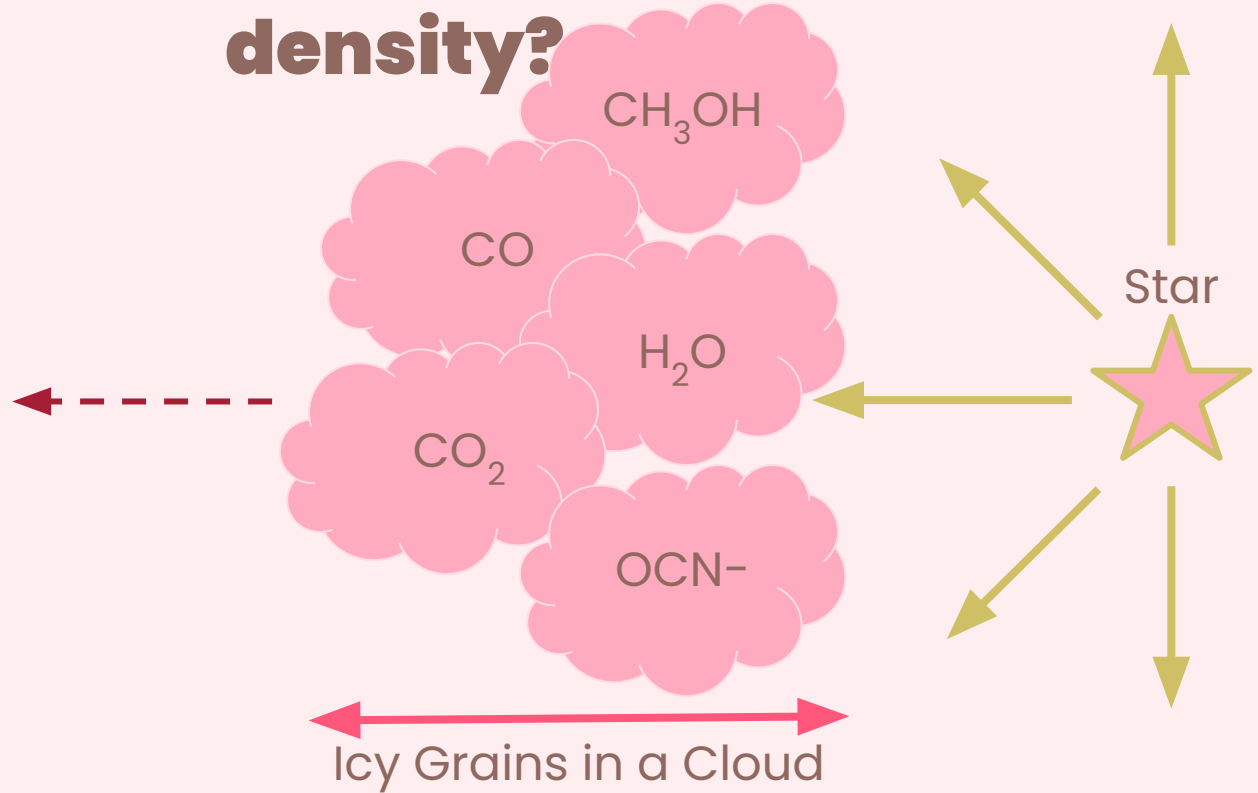
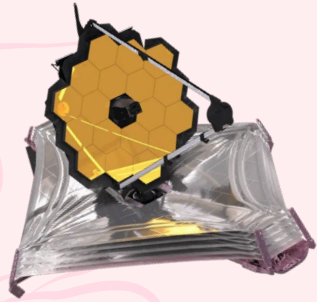
How do we measure ice column density?



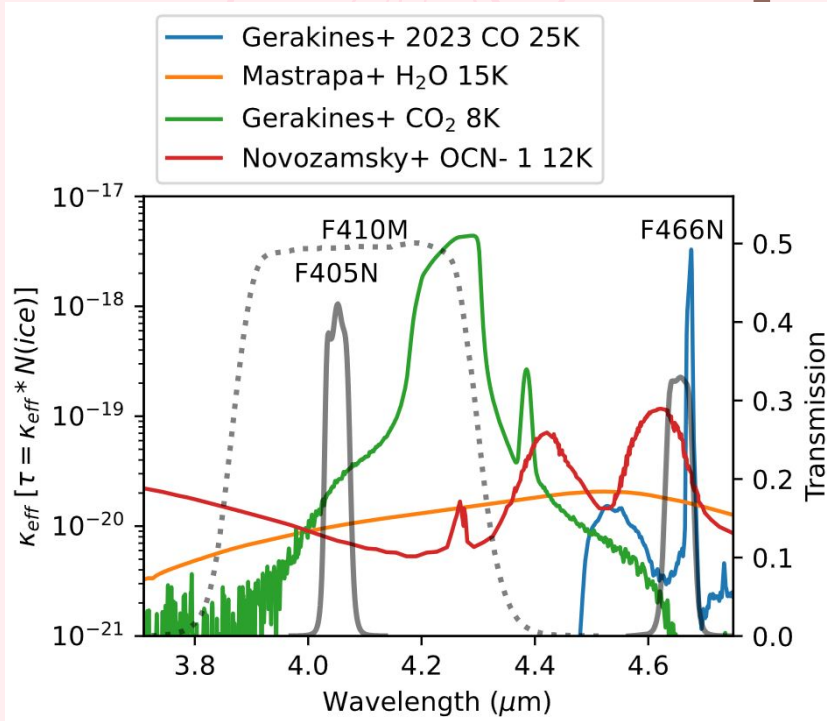
How do we measure ice column density?



How do we measure ice column density?



How do we measure ice column density?



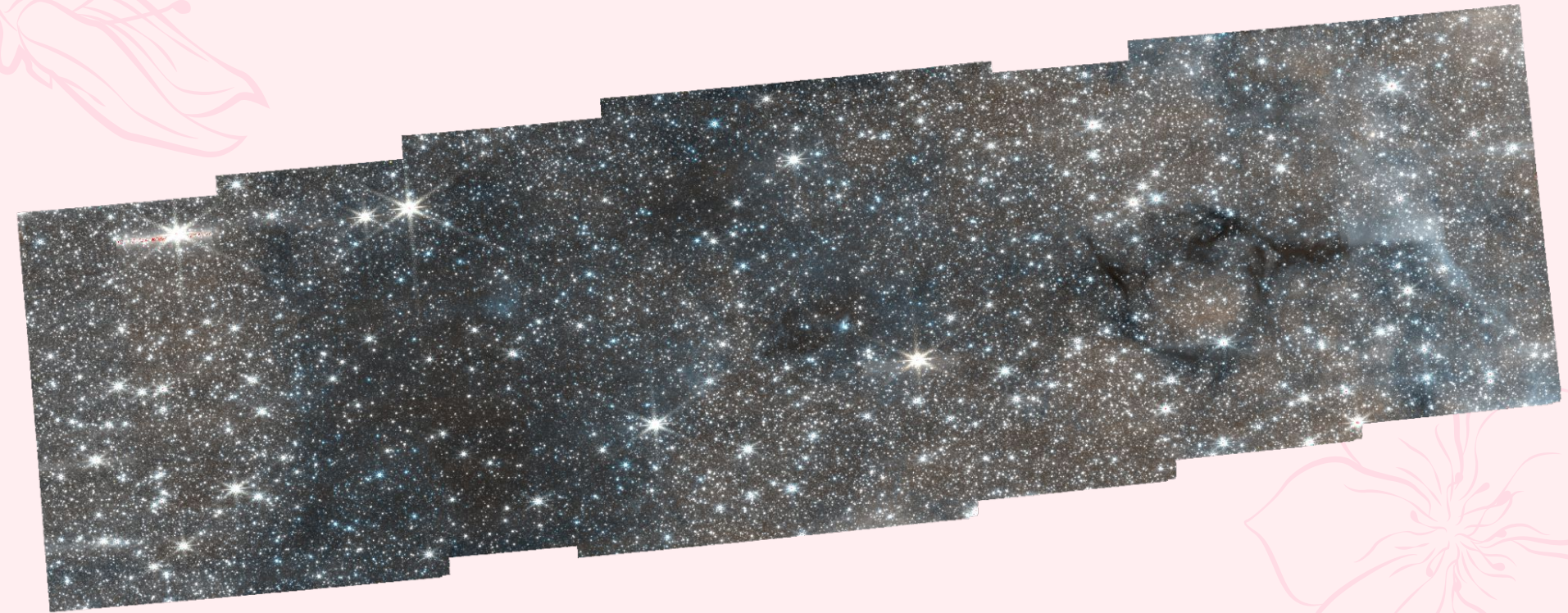
Ginsburg et al 2025

- ★ F466N is heavily impacted by ice absorption by CO ice
 - H₂O and OCN- ice contribute
- ★ Laboratory measurements of ice opacities in infrared wavelengths
 - How much ice is required to extinguish starlight to what we observe?

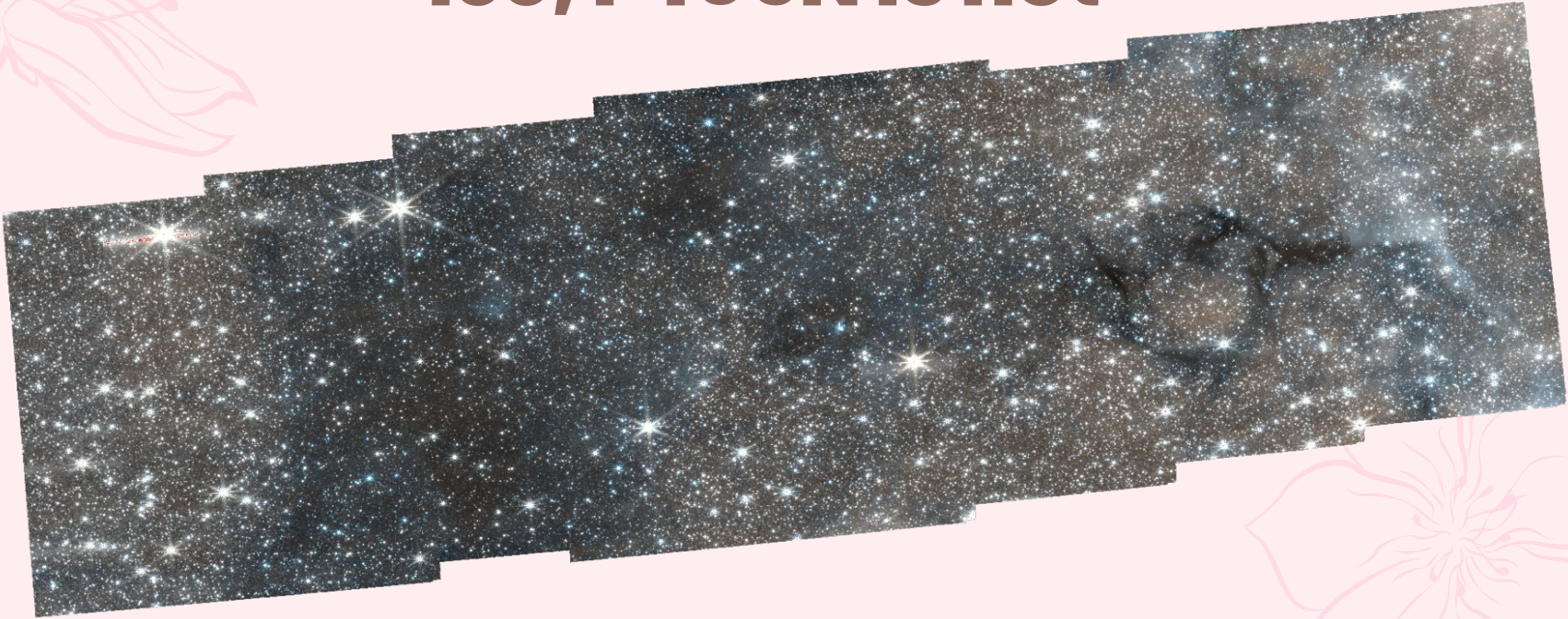
Why are the stars behind the clouds blue, not red?



Blue = F405N, Red = F466N



F466N is heavily impacted by ice, F405N is not

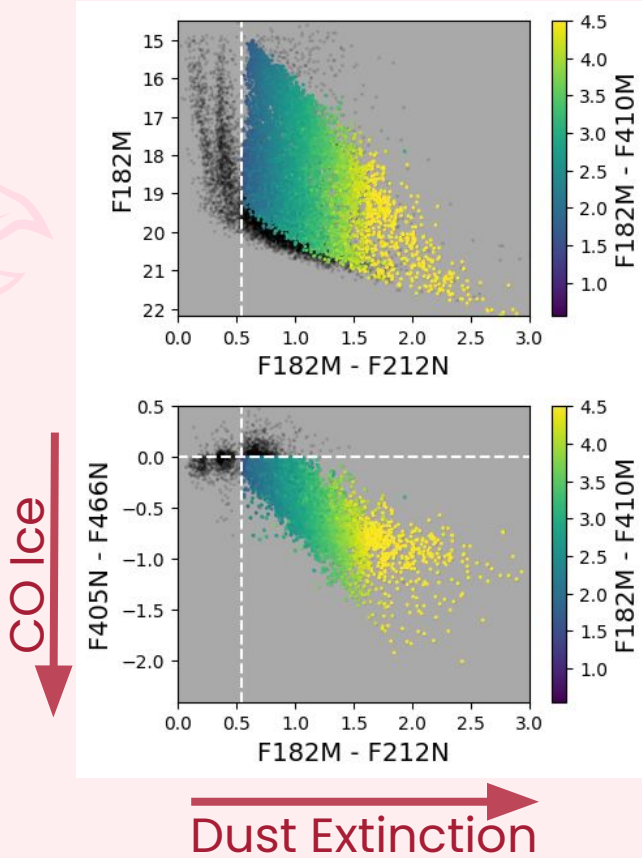


How do we measure ice column

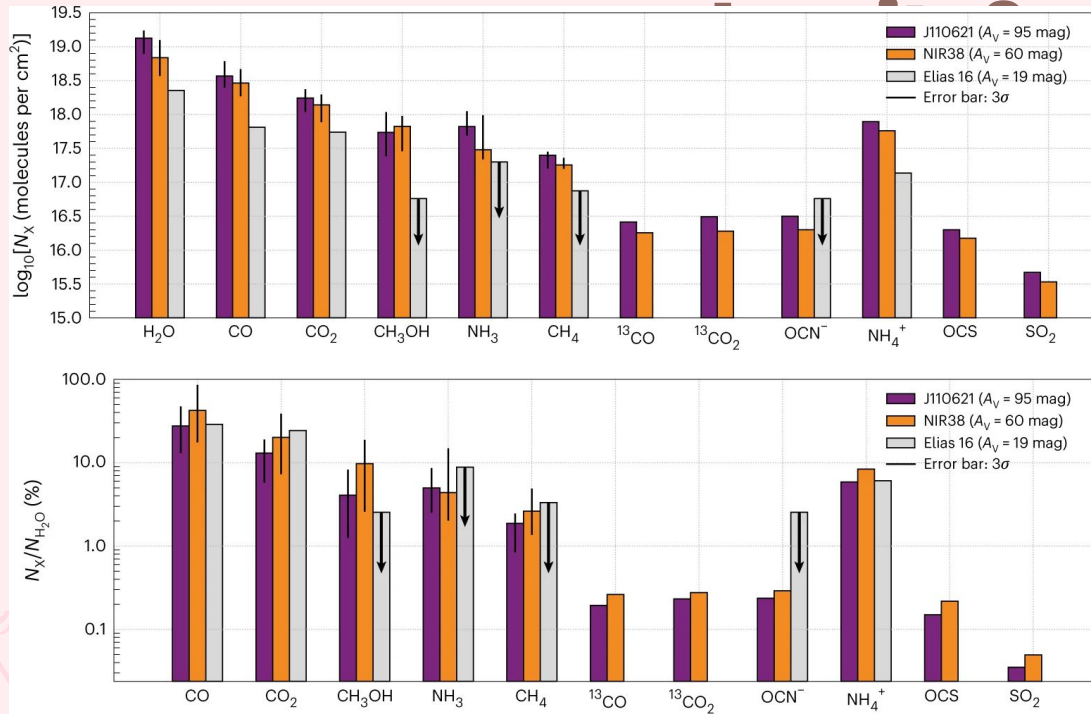
sity?

Select for stars behind the ice-rich cloud impacted by ice

- ★ Correct for dust extinction using bands with no ice absorption.
 - Dust reddens starlight.
- ★ Measure impact of ice absorption with photometric colors
 - F405N-F466N

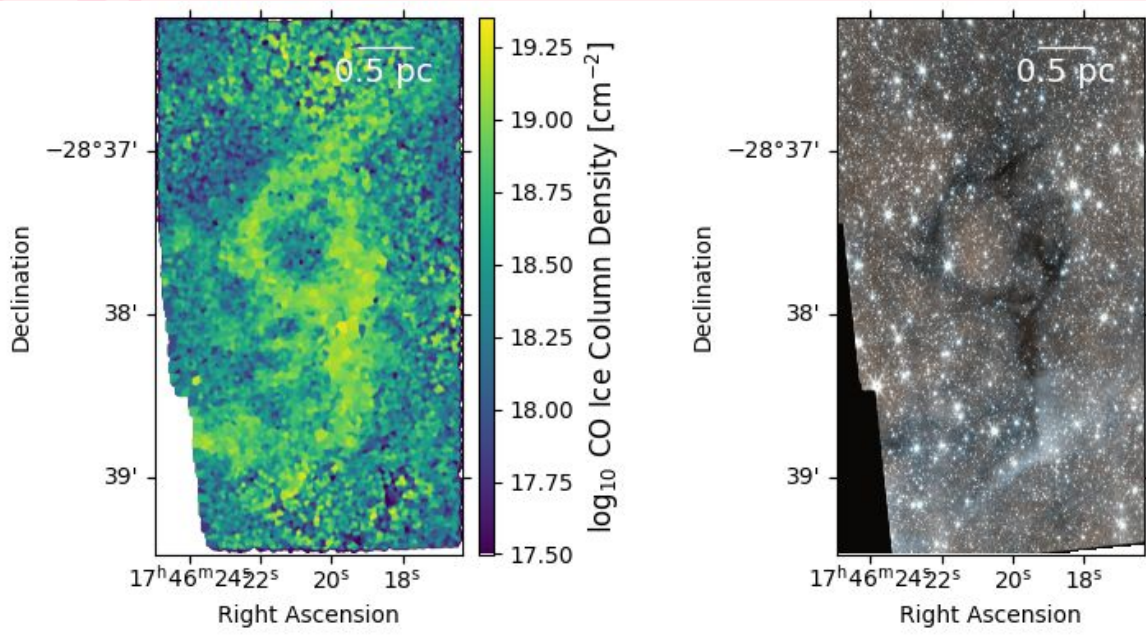


How do we measure ice column



- ★ Multiple ice species affect F466N
- ★ Assume that the ice composition is consistent across environments
- ★ Use standard ice composition to measure column for each species

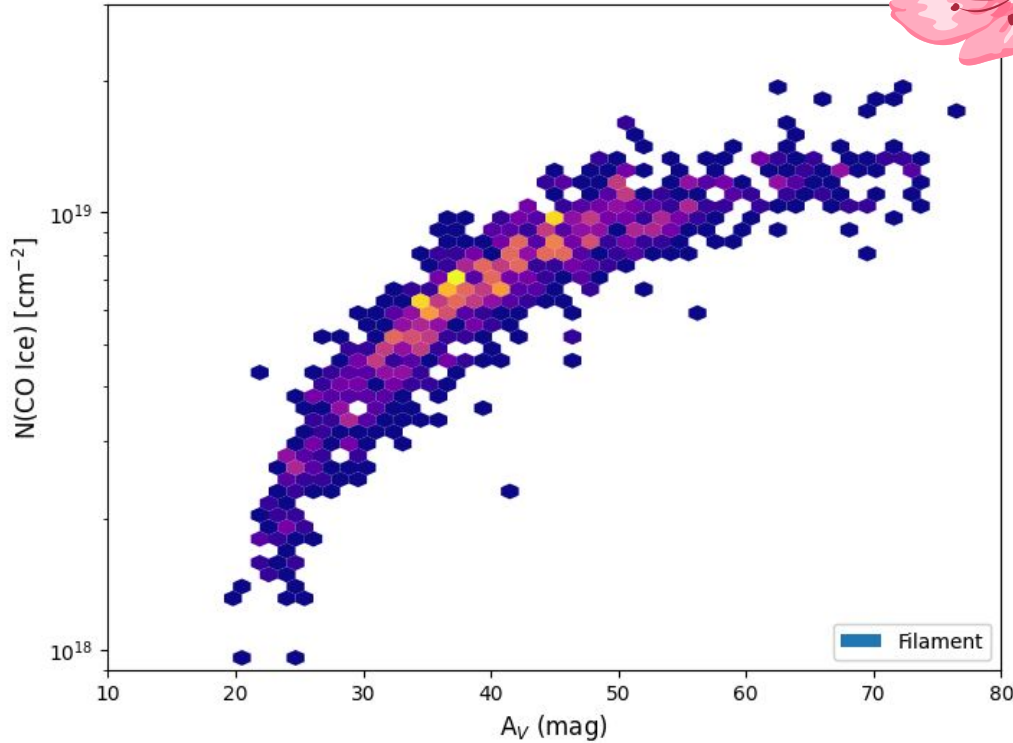
How do we measure ice column density?



- ★ Measure the ice column density for each star behind the cloud
- ★ Interpolate between the positions of each star
- ★ Make a column density map

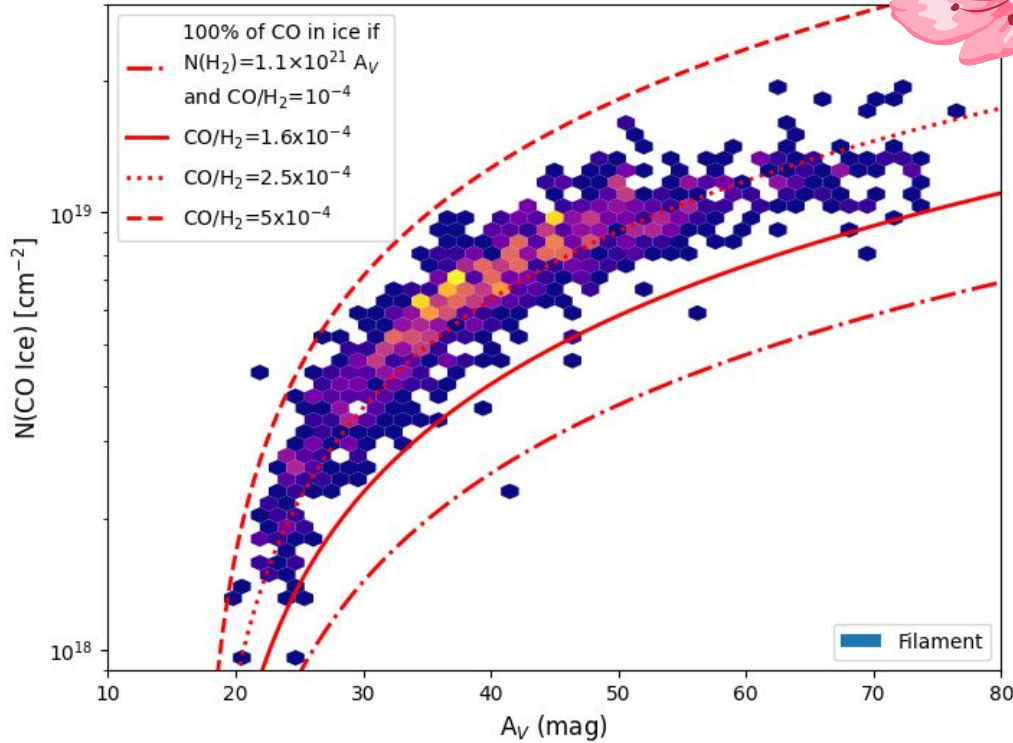


**Galactic
Variation in
Solid CO to
Dust**



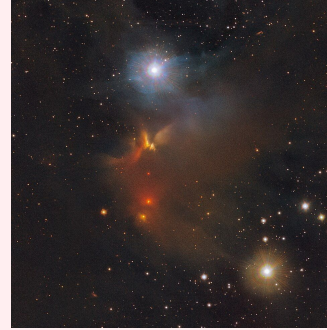
The Filament

- ★ We measure the CO ice column density toward each red clump star
- ★ Assuming $\text{H}_2\text{O}:\text{CO}_2:\text{CO} = 10:1:1$

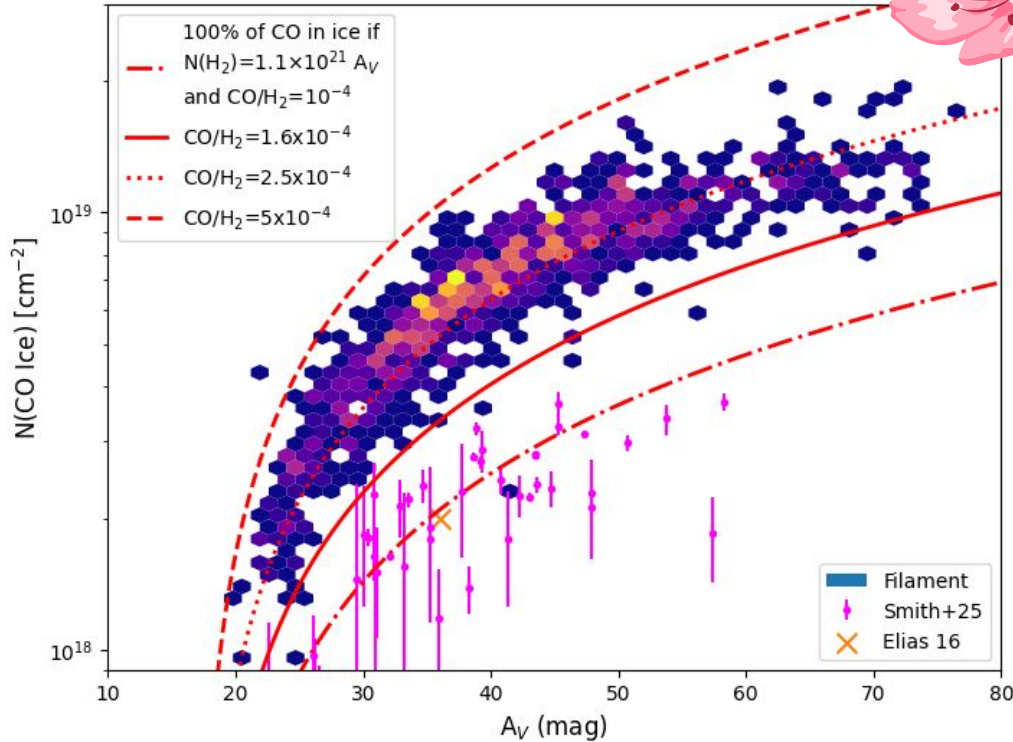


CO Abundance

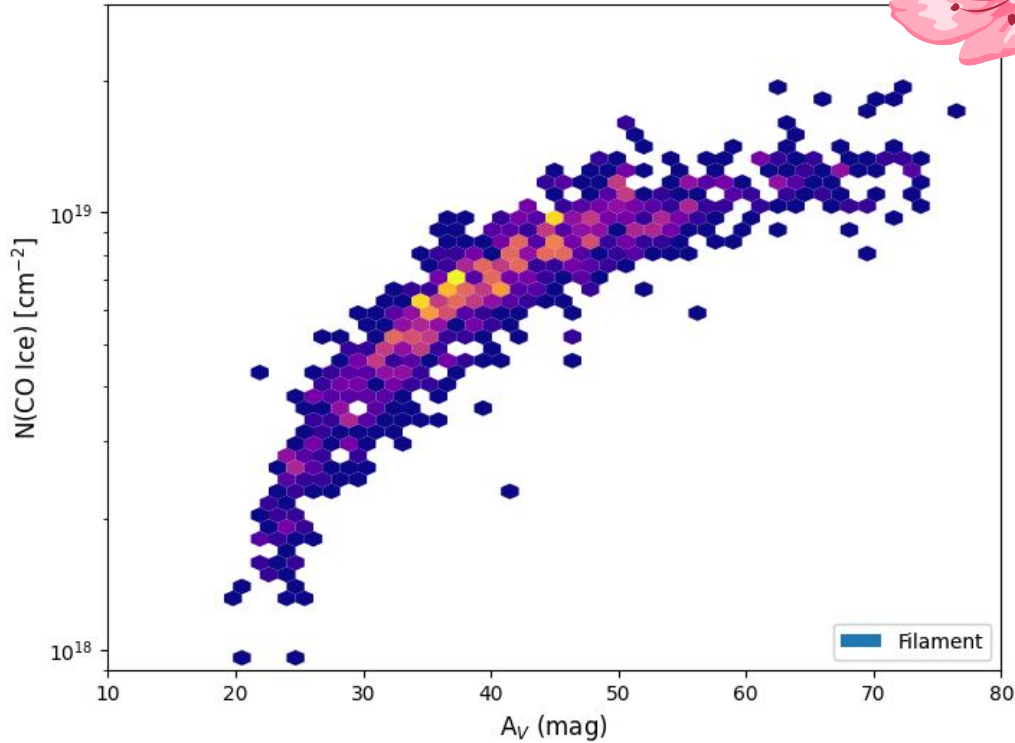
- ★ Each red line is a different CO abundance
- ★ Higher abundance = more CO in ice



The Filament Chameleon

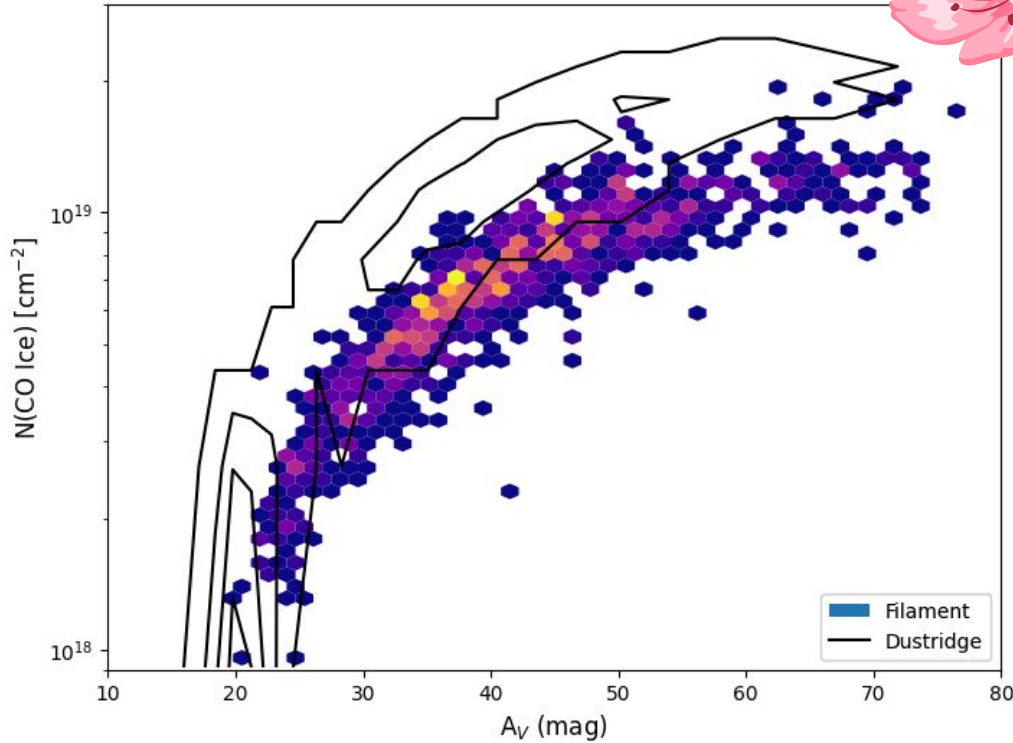


- ★ Chameleon I = solar neighborhood low mass star forming region
- ★ Lower CO abundance than the filament



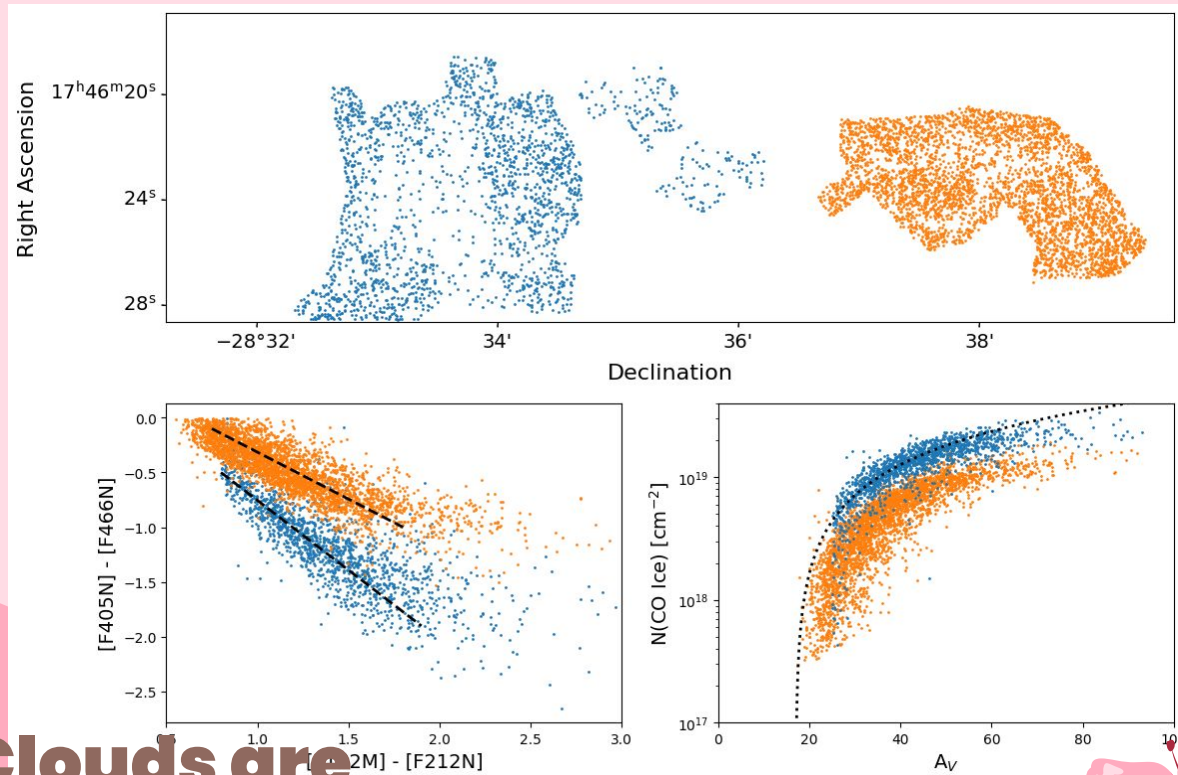
The Filament

- ★ Removed extra points for clarity

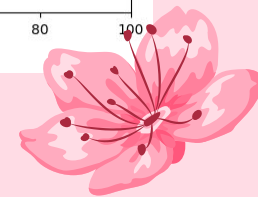


Filament vs dust ridge

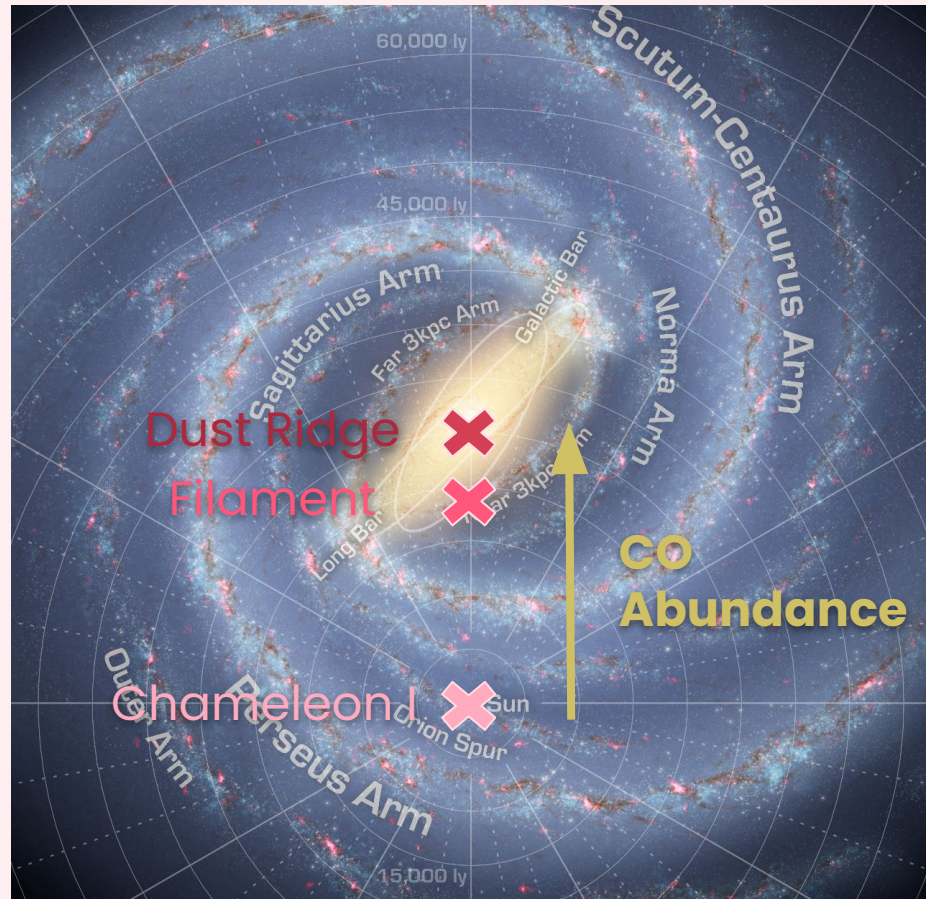
- ★ The dust ridge is in the CMZ
- ★ It has an even higher CO abundance than the filament!



**CMZ Clouds are
Icier than disk
clouds**



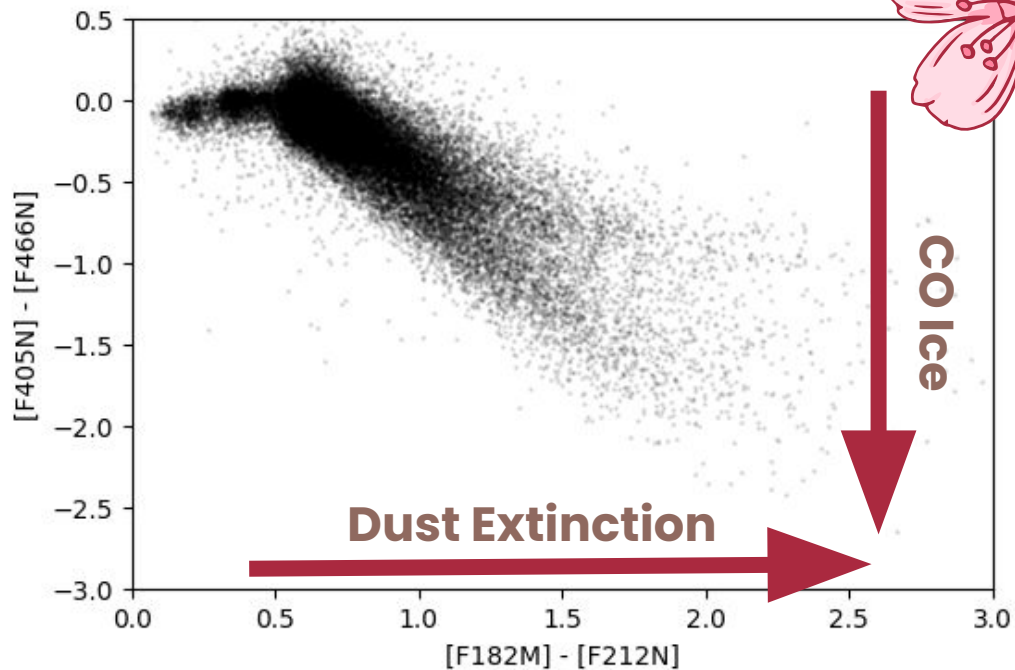
**CO
Abundance
Increases as
Galactic
Radius
Decreases**



NASA - R. Hurt

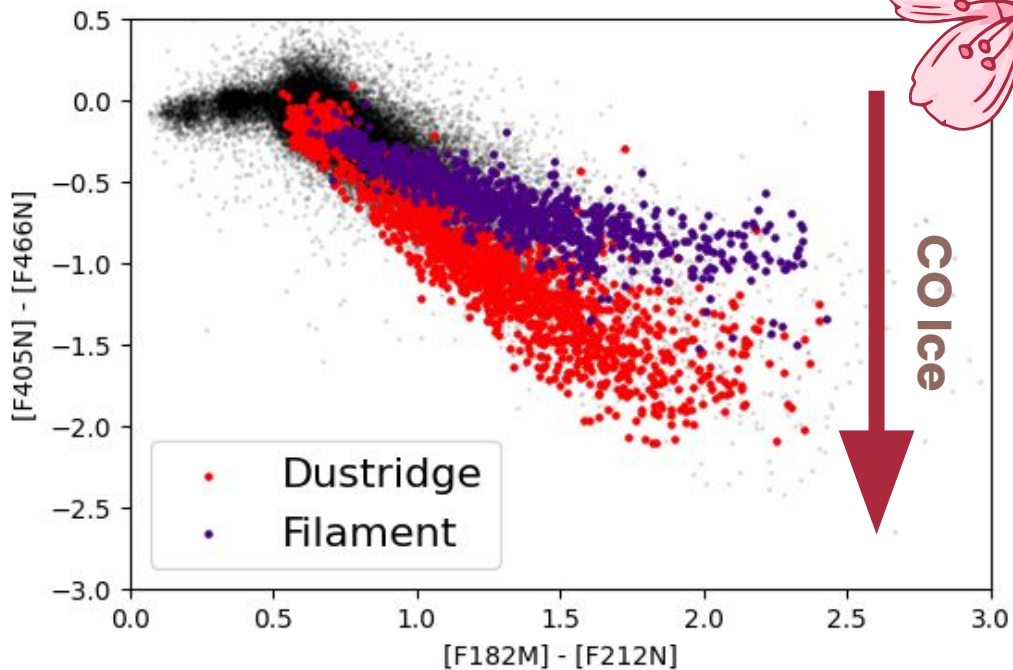


CMZ Cloud Variation

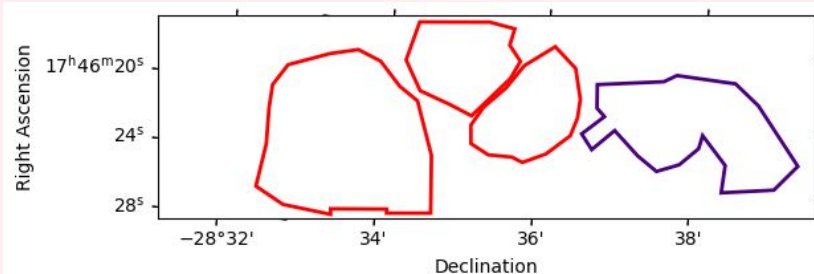


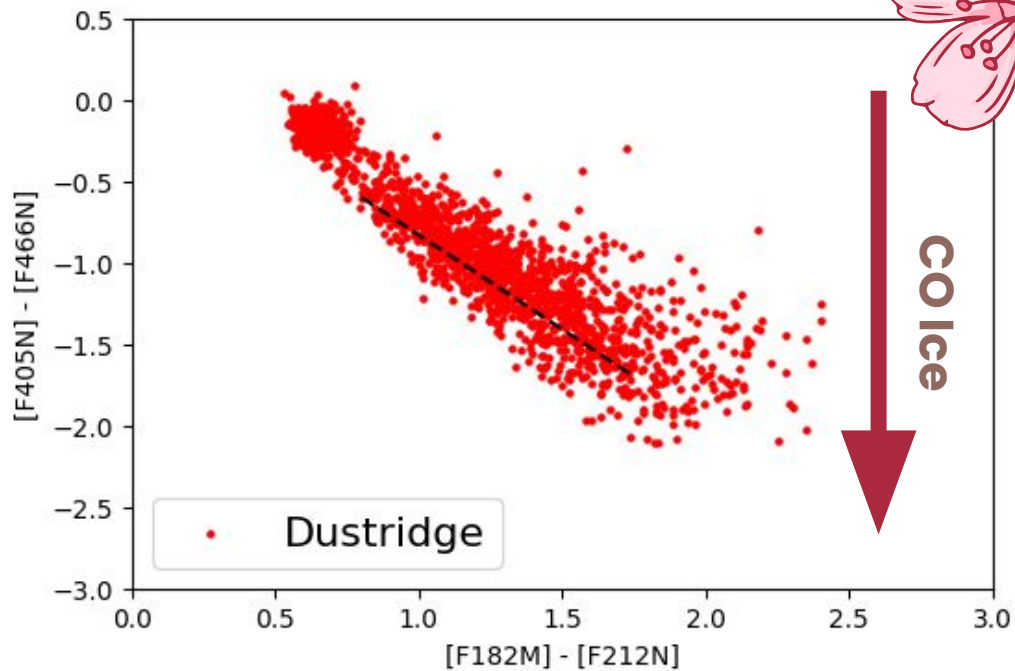
Color-Color Diagram

- ★ Shorthand for dust extinction and CO ice ratio
- ★ $[F466N]$ becomes fainter as $N(\text{CO ice})$ increases

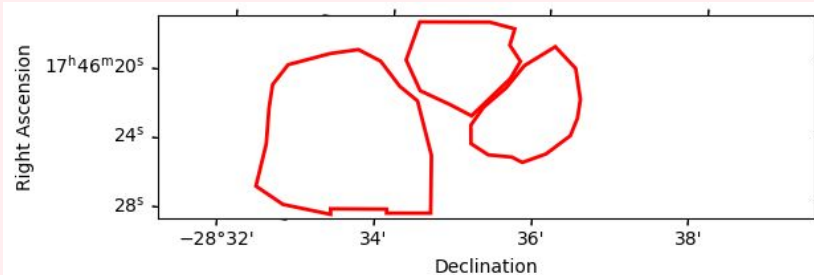


**Different
Slopes =
Differences
in Ice**

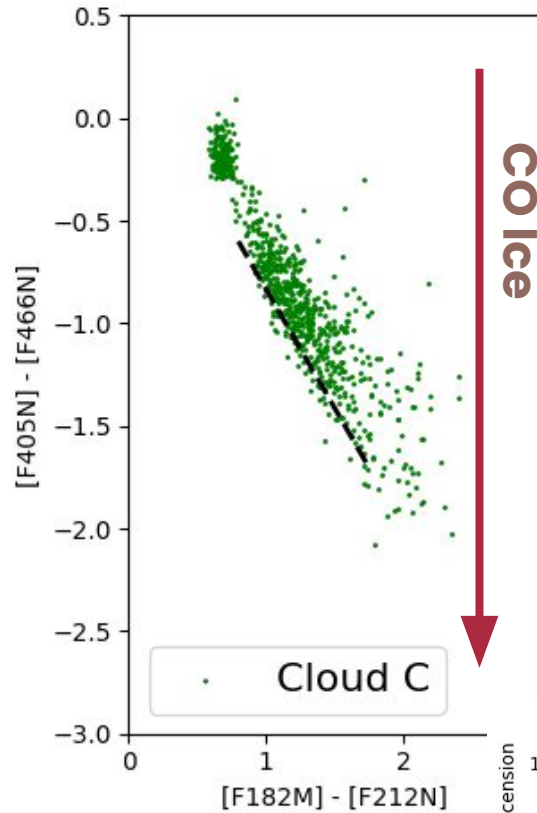
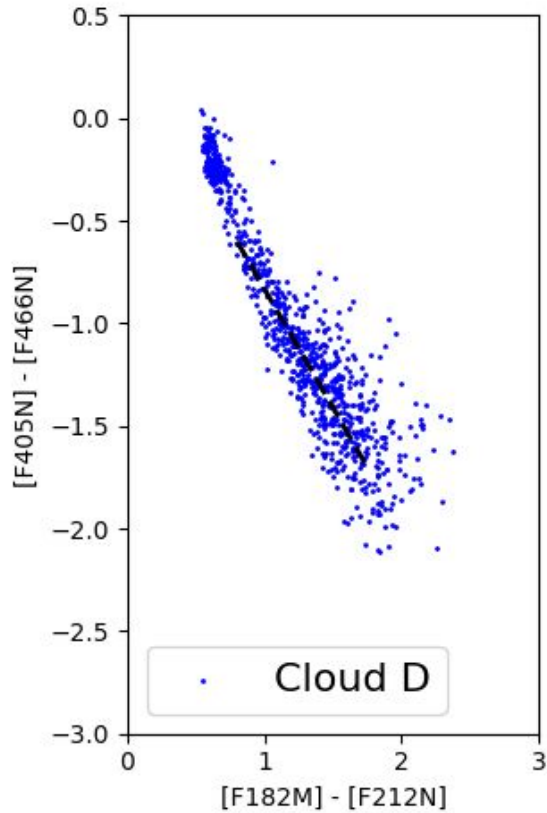




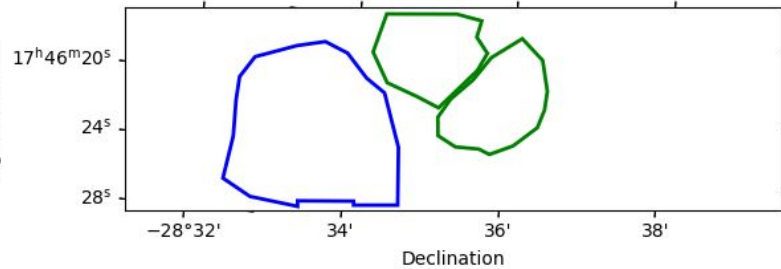
Dust Ridge

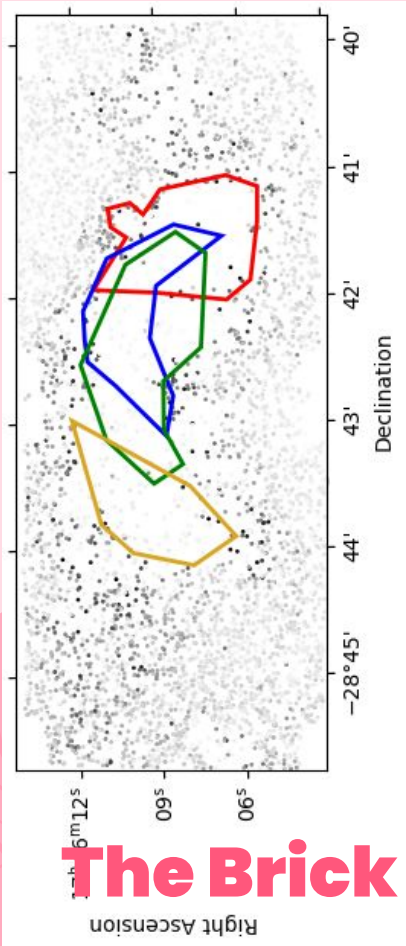


Comparing Dust Ridge Clouds

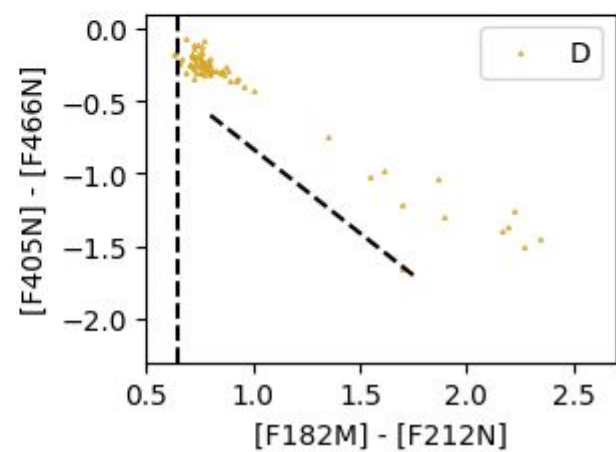
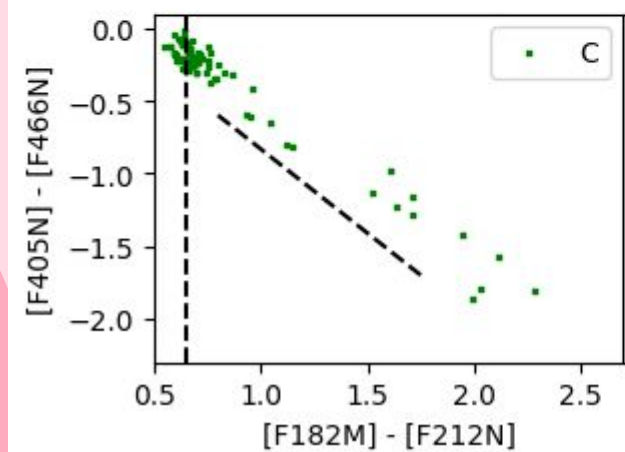
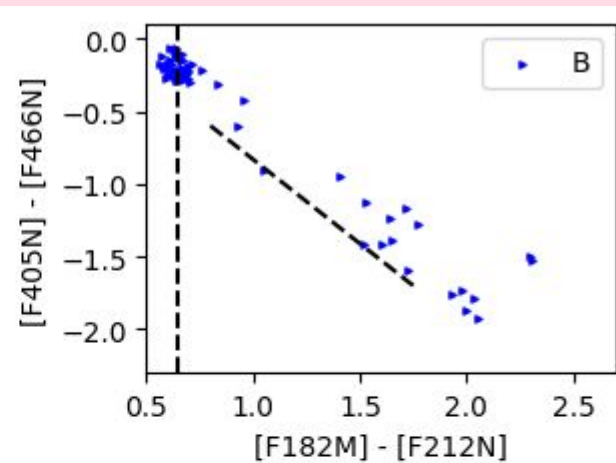
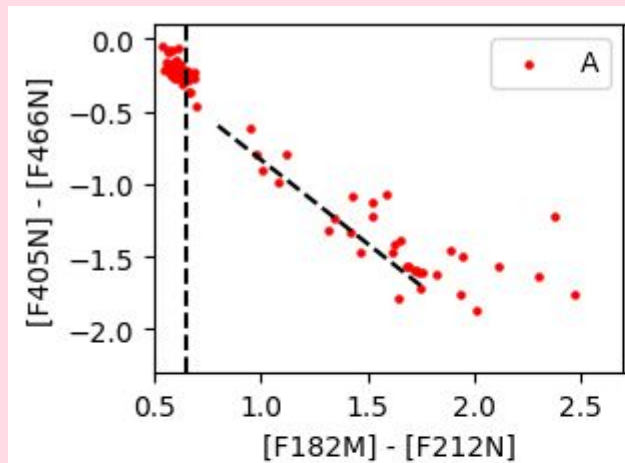


Right Ascension

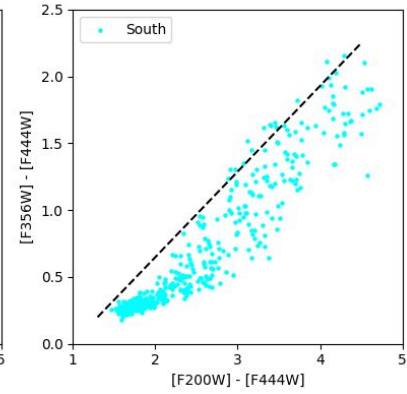
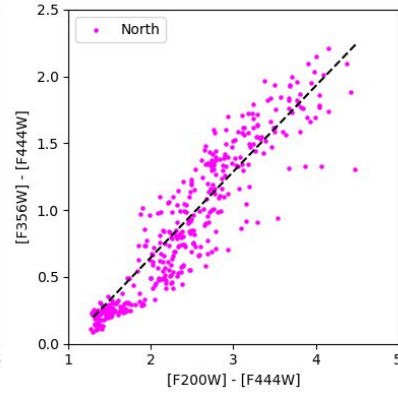
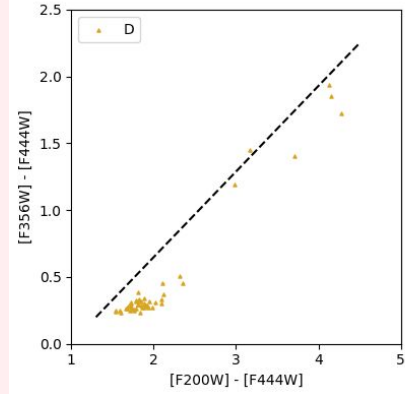
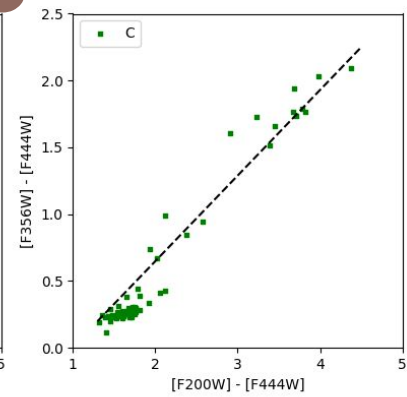
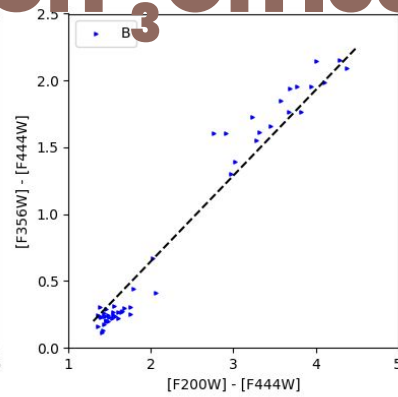
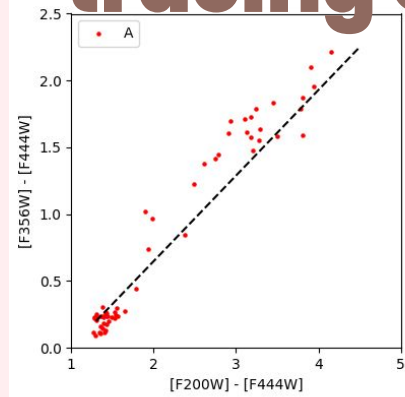
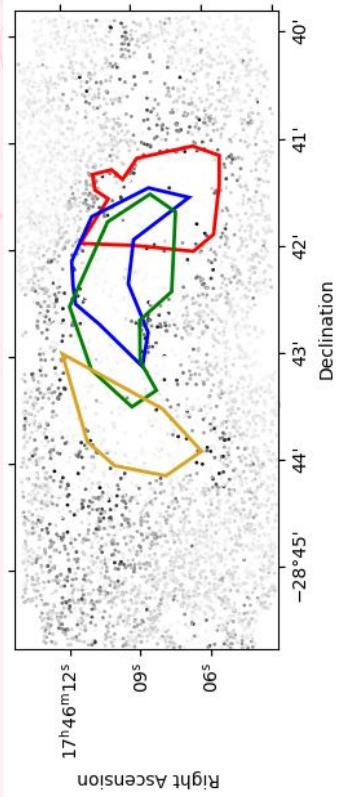




The Brick



Variation in Independent Data tracing CH₃OH Ice





**What Causes
These
Differences?**





Gas Metallicity?

But clouds in the same region of the
Galaxy should have the same
metallicity, right?

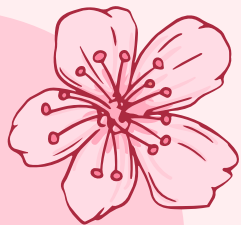


Ice



Composition?

But why would the ice composition change
from cloud to cloud?



Chemical History?

Could some clouds be chemically altered or “older” relative to other CMZ clouds?

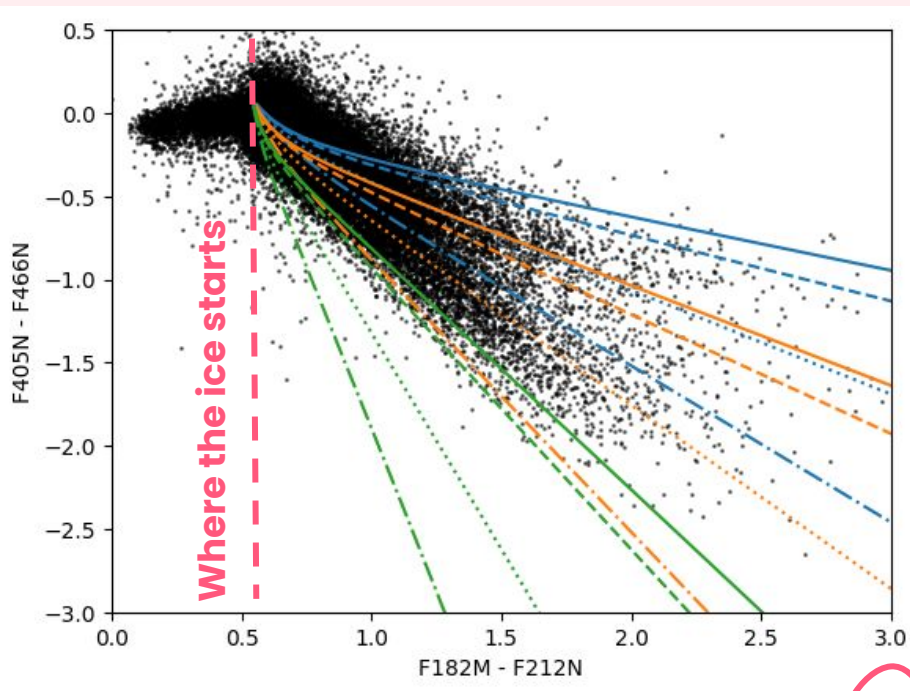


$\text{H}_2\text{O}:\text{CO}:\text{CO}_2 = 10:1:1$

10:1:0.5

15:1:1

20:1:1



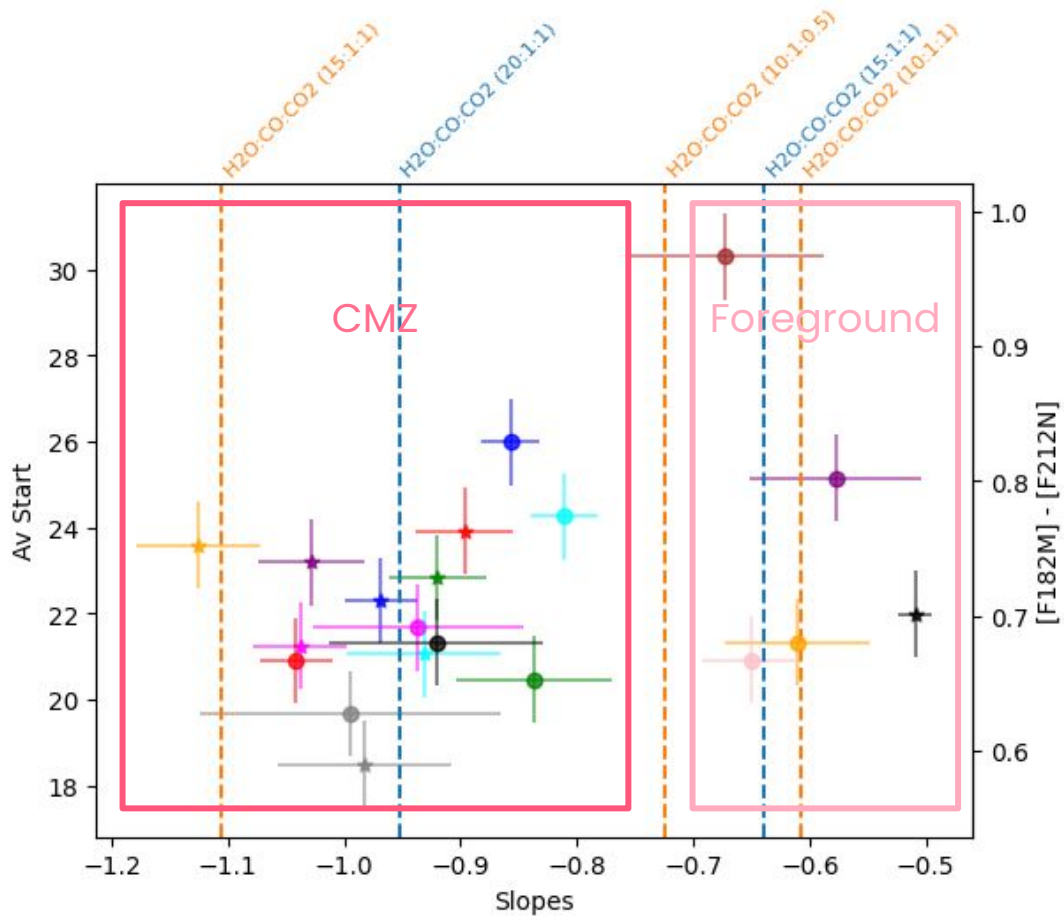
$\text{CO}/\text{H}_2 = 5 \times 10^{-4}$

2.5×10^{-4}

1×10^{-4}

Modeling Ice

- ★ We can model the influence of ice column on the observed colors.
- ★ Two properties matter:
 - CO abundance
 - Ice composition
- ★ These properties are degenerate in this space, overlapping models
- ★ Spectroscopy is needed



- ★ Filament
- ★ Cloud C1
- ★ Cloud C2
- ★ Cloud D
- ★ Cloud B
- ★ Filament Right
- ★ Left Cloud D
- ★ Cloud C North
- ★ Cloud C South
- ★ Brick North
- ★ Brick South
- ★ Brick Head
- ★ Brick South Fluff
- ★ Brick North Fluff
- ★ Brick SFR
- ★ Brick SFR Wide
- ★ Brick Punch
- ★ Brick S Fore
- ★ Brick N Clear
- ★ Brick Top C
- $CO/H_2 = 1.6e-4$
- $CO/H_2 = 2.5e-4$

What dominates variation in the ice to dust ratio?

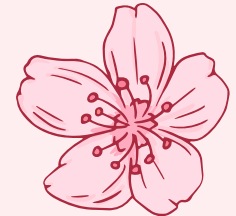
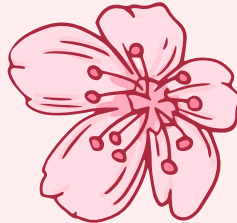
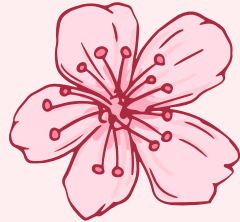
- ★ Gas metallicity or ice composition.
- ★ Future spectroscopic surveys are needed toward the Galactic Center.

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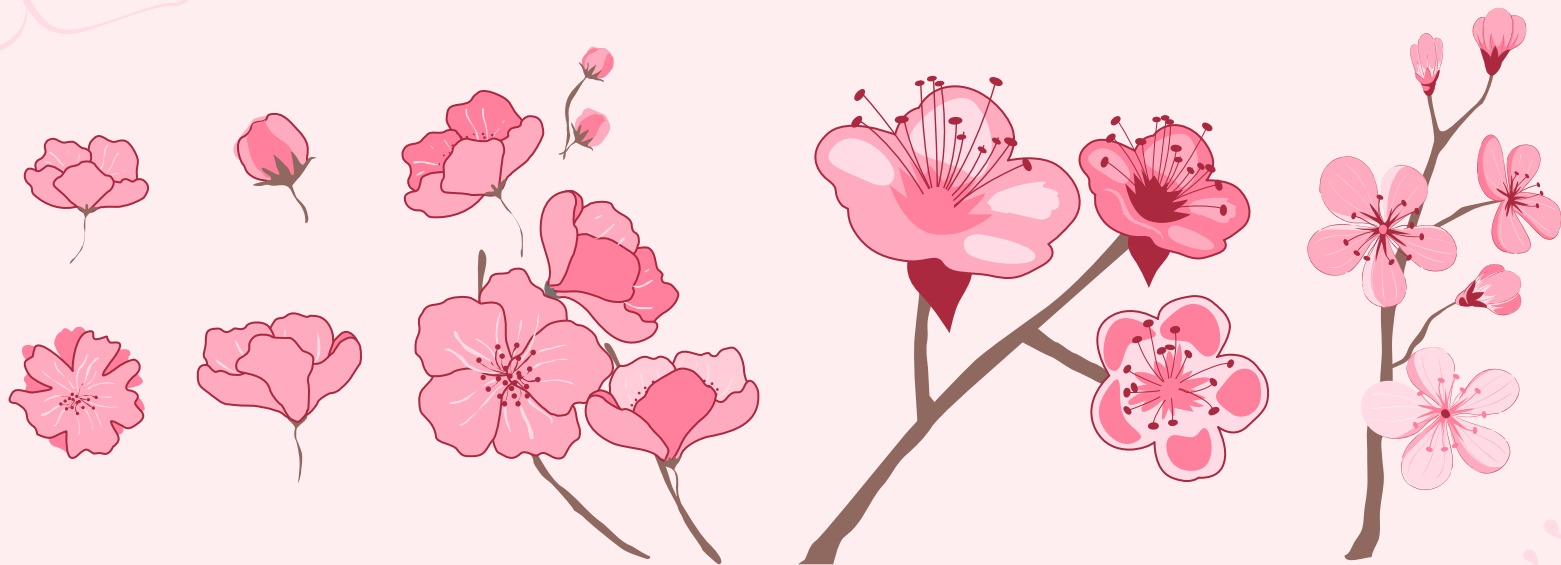




ALTERNATIVE RESOURCES



ALTERNATIVE PREMIUM RESOURCES



ALTERNATIVE PREMIUM ICONS

