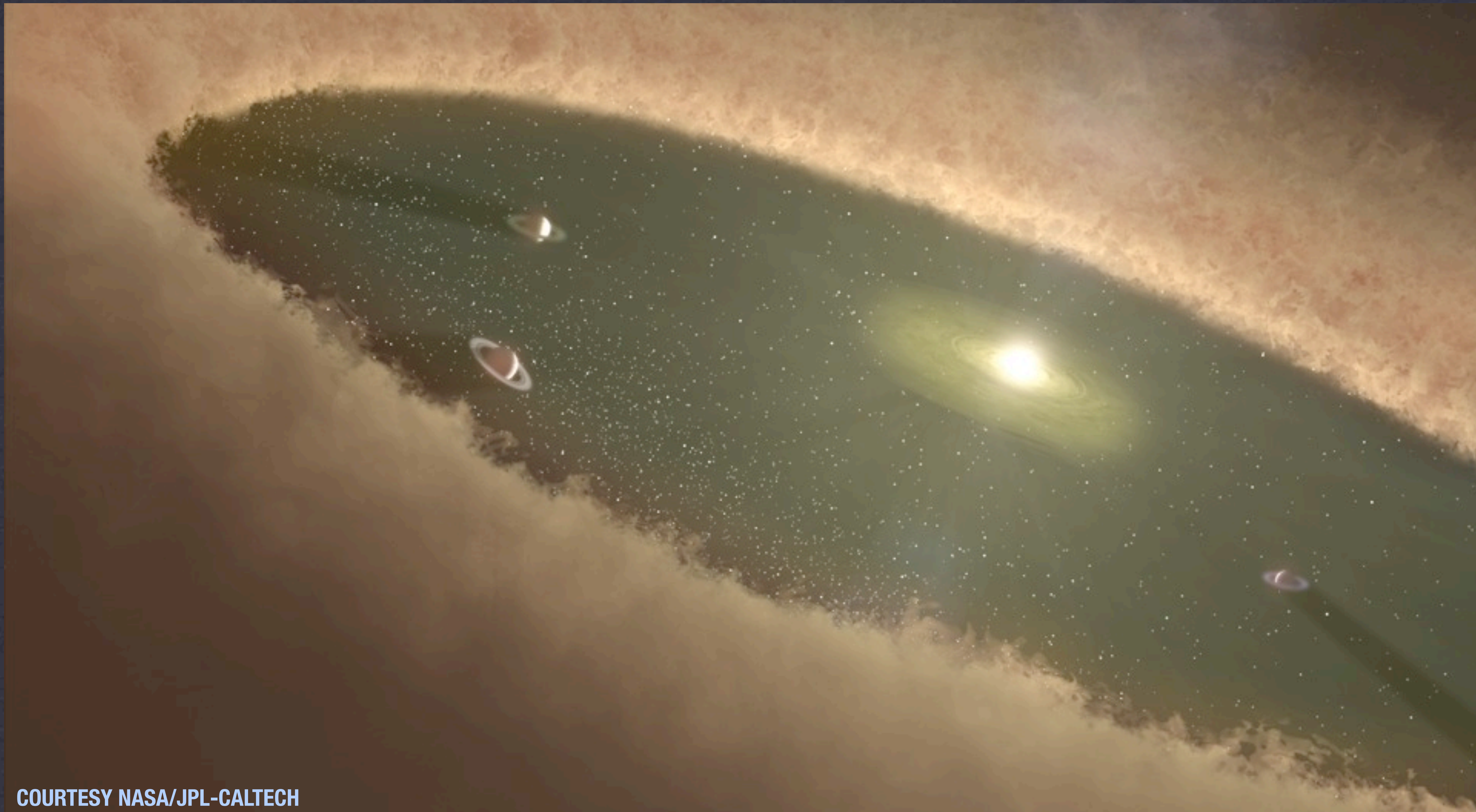

Transition Disk Chemistry in the Eye of ALMA

Spectroscopy2011

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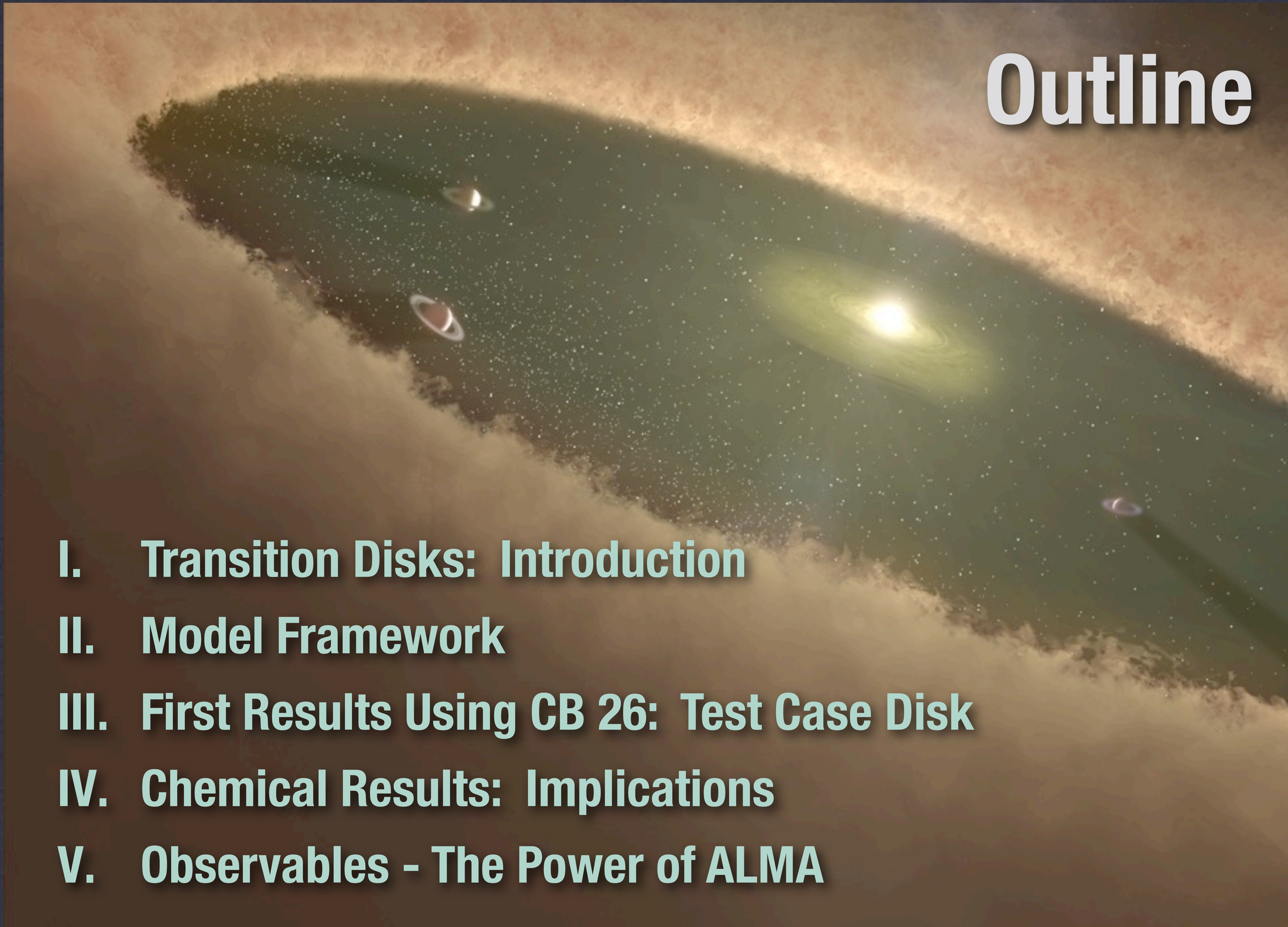
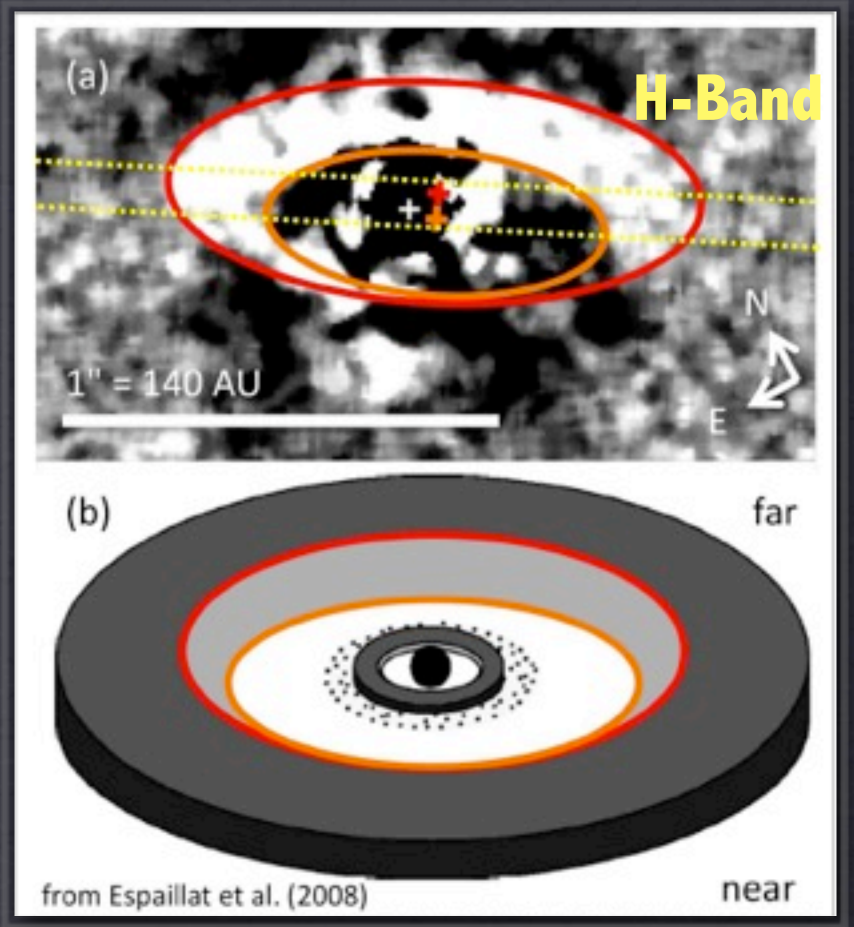
Outline



I. Transition Disks: Introduction
II. Model Framework
III. First Results Using CB 26: Test Case Disk
IV. Chemical Results: Implications
V. Observables - The Power of ALMA

COURTESY NASA/JPL-CALTECH

I. Circumstellar Disks in Transition

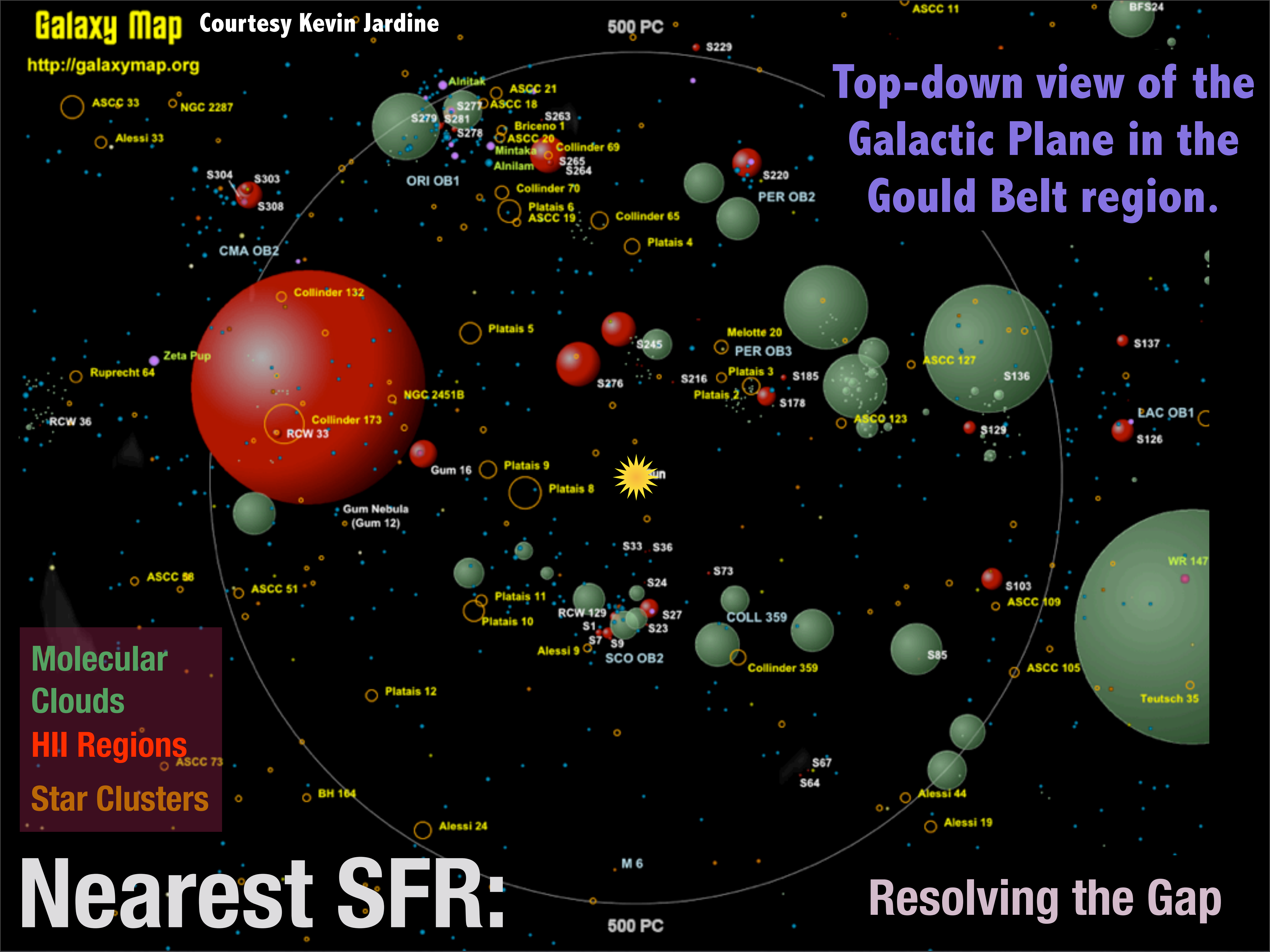


Thalmann et al. 2010: imaging the wall in LkCa 15; consistent with SED disk models ➡ the result of forming protoplanets?

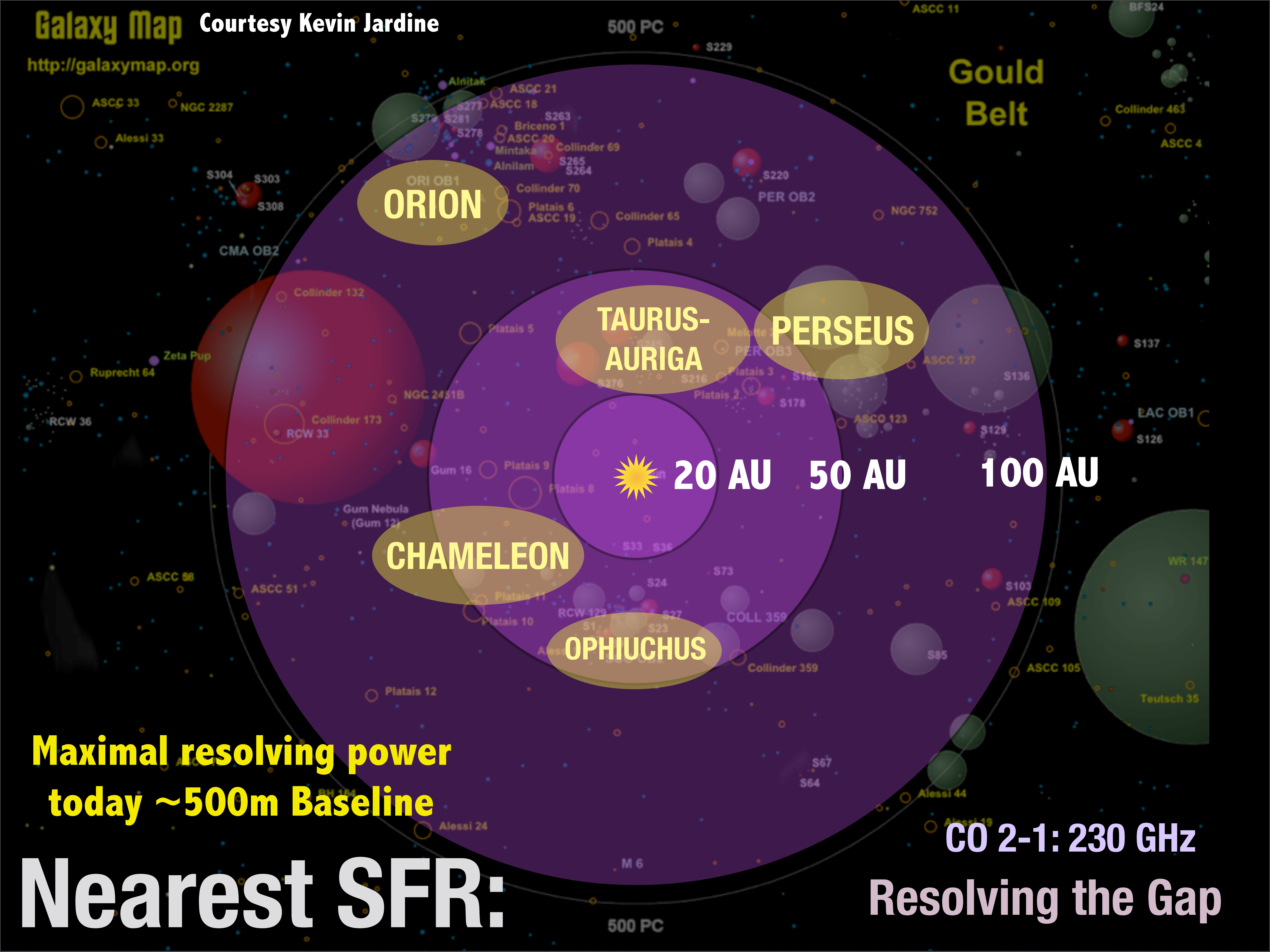
- Circumstellar disks observed ➡ sites of planet formation.
  - Once a protoplanet is massive enough it can dynamically alter the disk ➡ gaps, holes, etc.
  - The initial stages of planet formation involves grain growth and reduction of opacity
- Disks with gaps are called “Transition Disks.”
- Disk chemistry will respond to the change in physical conditions ➡ set initial chemical conditions at the point of planet formation.
- Prediction: The clearing of the inner-disk directly reveals the dense (and normally cold) gas rich midplane to the star.
  - Is this an observable effect? Must first be able to resolve this...
- ALMA has the power to resolve the gap → can directly probe evolving region.

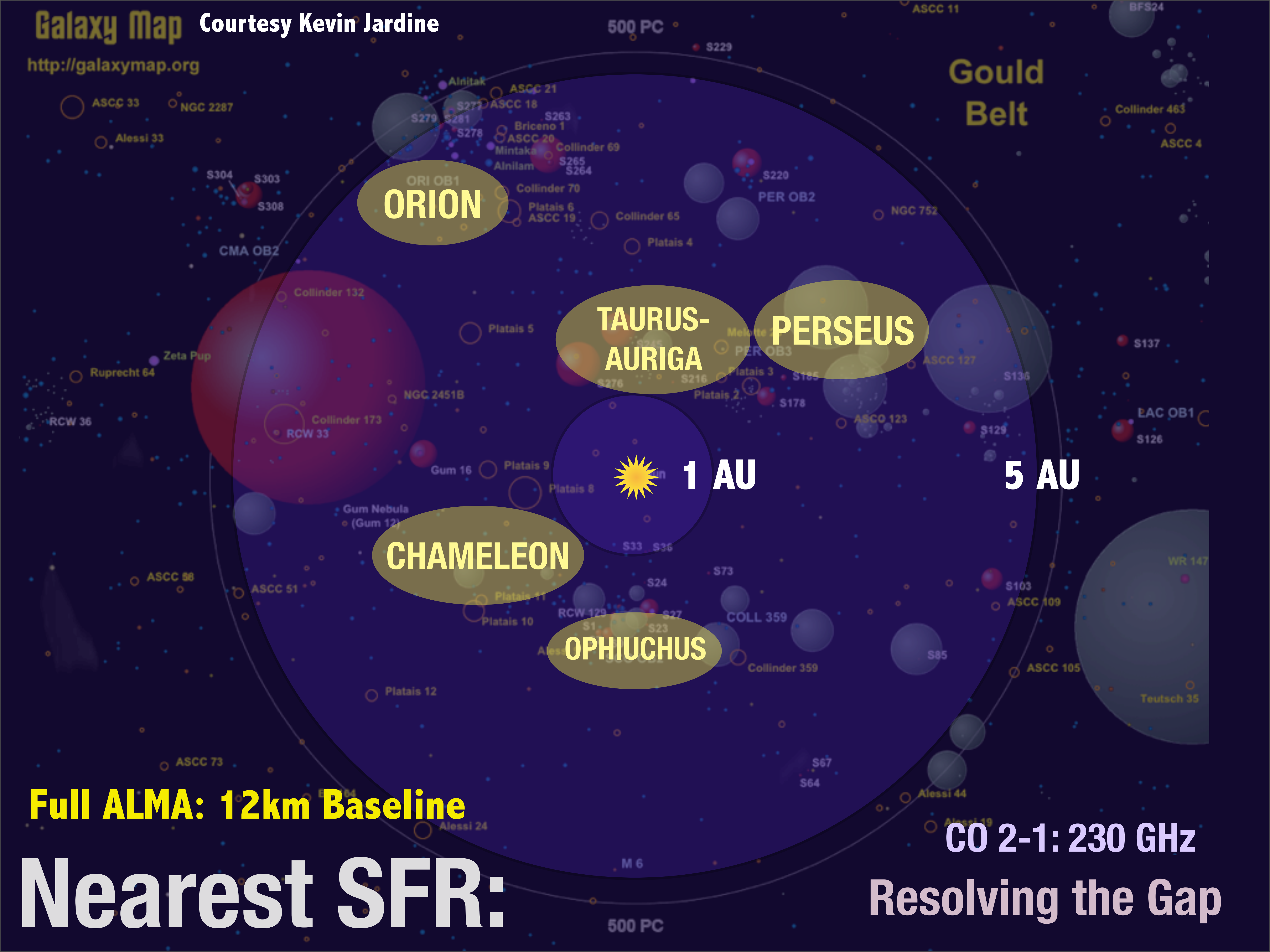
Nearest SFR:

Top-down view of the Galactic Plane in the Gould Belt region.

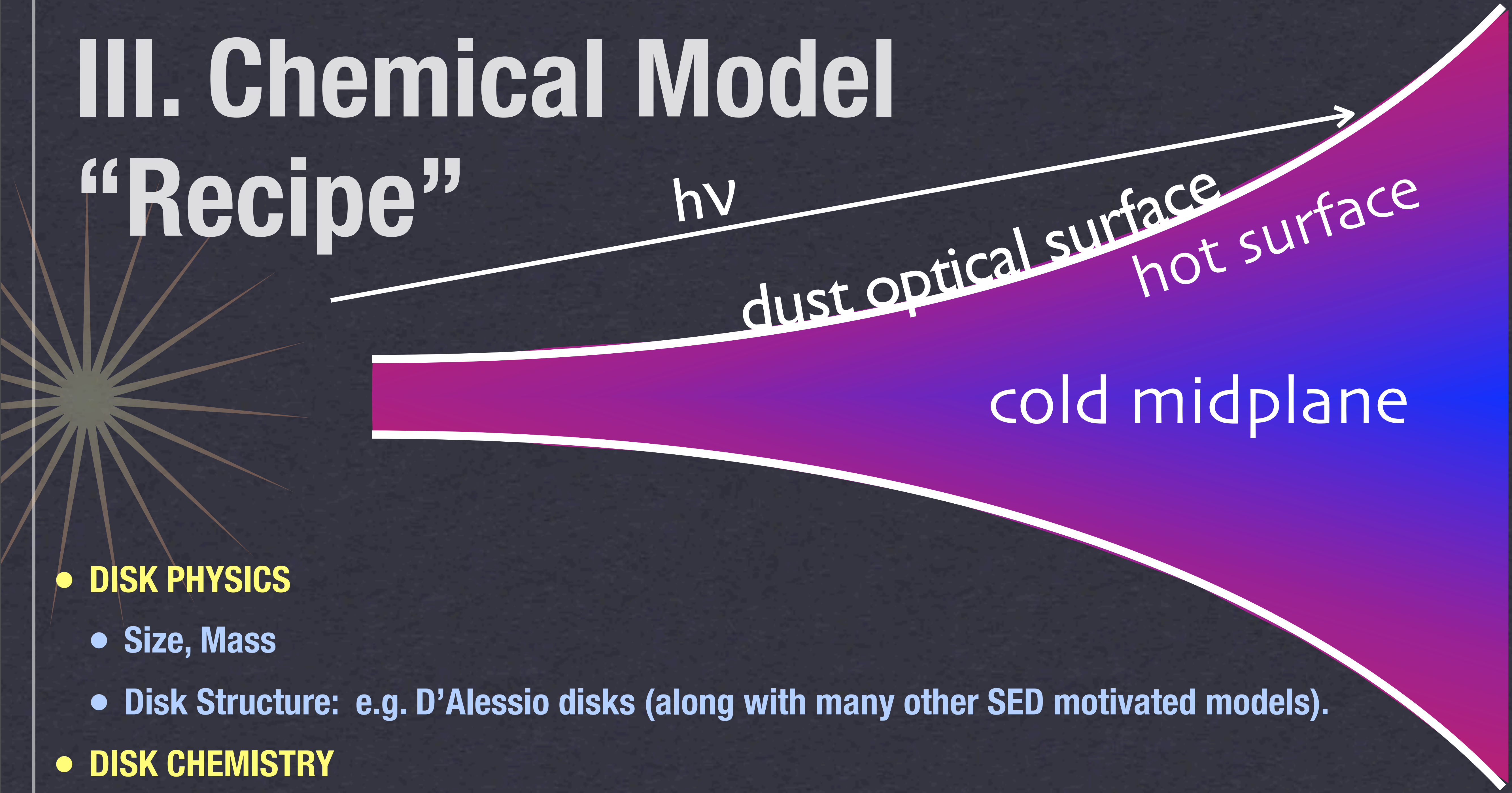


Resolving the Gap


Galaxy Map
Courtesy Kevin Jardine
http://galaxymap.org
Gould Belt
500 PC
ORION
TAURUS-AURIGA
PERSEUS
CHAMELEON
OPHIUCHUS
20 AU
50 AU
100 AU
Maximal resolving power today ~500m Baseline
CO 2-1: 230 GHz
Resolving the Gap
Nearest SFR:
500 PC
ASCC 33
NGC 2287
Alessi 33
S304
S303
S308
CMA OB2
Collinder 132
Zeta Pup
Ruprecht 64
RCW 36
Collinder 173
RCW 33
NGC 2451B
Gum 16
Platais 9
Platais 8
Gum Nebula (Gum 12)
ASCC 58
ASCC 51
Platais 11
Platais 10
RCW 129
Platais 12
Alessi 24
M 6
ORI OB1
Alnitak
ASCC 21
ASCC 18
S263
Briceno 1
ASCC 20
Mintaka
Alnilam
Collinder 69
S265
S264
Collinder 70
Platais 6
ASCC 19
Collinder 65
Platais 4
S229
S220
PER OB2
NGC 752
Platais 5
PER OB3
Platais 3
Platais 2
S178
ASCC 127
S136
ASCC 123
S129
ASCC 11
BFS24
Collinder 463
ASCC 4
S137
LAC OB1
S126
S33
S36
S73
S24
S27
S23
COLL 359
Collinder 359
S85
S103
ASCC 109
WR 147
ASCC 105
Teutsch 35
S67
S64
Alessi 44
Alessi 19


Nearest SFR:
Resolving the Gap
Full ALMA: 12km Baseline
CO 2-1: 230 GHz
Galaxy Map
Courtesy Kevin Jardine
http://galaxymap.org
Gould Belt
ORION
TAURUS-AURIGA
PERSEUS
CHAMELEON
OPHIUCHUS
1 AU
5 AU
500 PC
500 PC

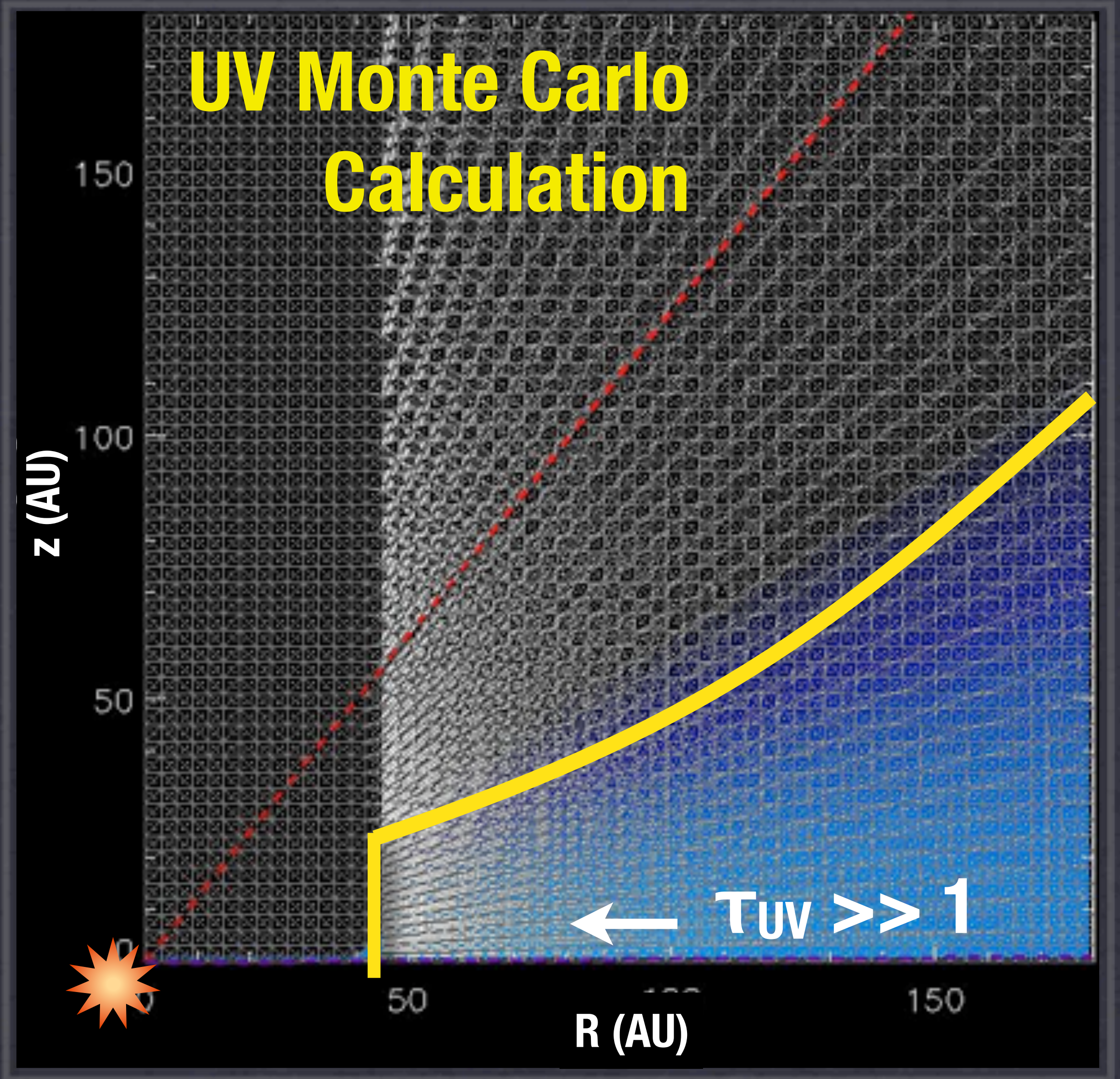
III. Chemical Model "Recipe"

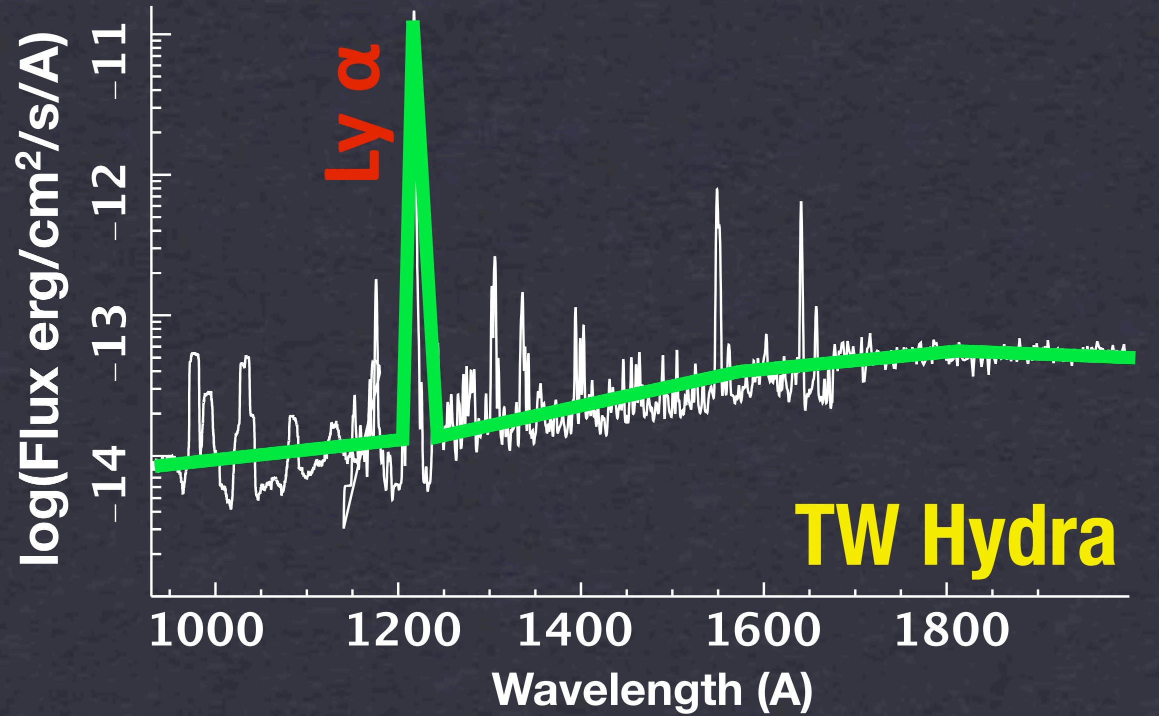


- **DISK PHYSICS**
  - Size, Mass
  - Disk Structure: e.g. D'Alessio disks (along with many other SED motivated models).
- **DISK CHEMISTRY**
  - Dust (e.g. Weingartner & Draine), composition and settling.
  - Shape of the UV field, continuum and line (Bethell), stellar and ISRF.
  - Relevant chemical network (Fogel et al. 2011): ~6000 Reactions, ~600 Species.
- **END PRODUCTS:** Observables? Can calculate resulting line emission: LIME (Brinch et al. 2010).

III. UV-Field: Continuum

- UV drives the chemistry through processes such as photodissociation and photo-desorption.
- Dependent on dust composition (opacity) and dust settling ➡ many young disks highly settled.
- Transition disks structurally evolved ➡ require full M.C. radiative transfer treatment.
- Include a separate treatment for Ly α photons which behave differently (Bethell & Bergin 2011; Fogel et al. 2011).





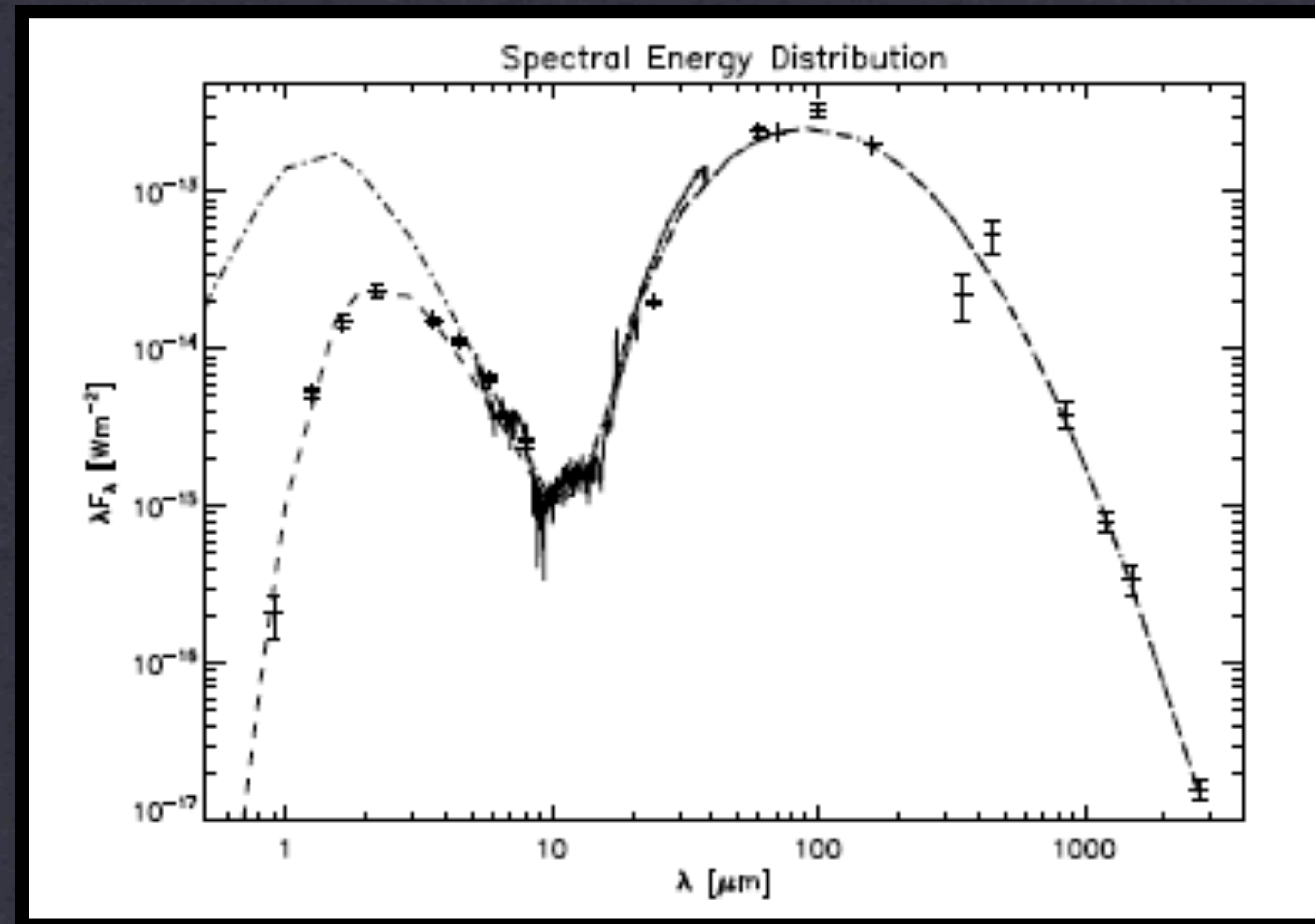
IV. CB 26: An Overview

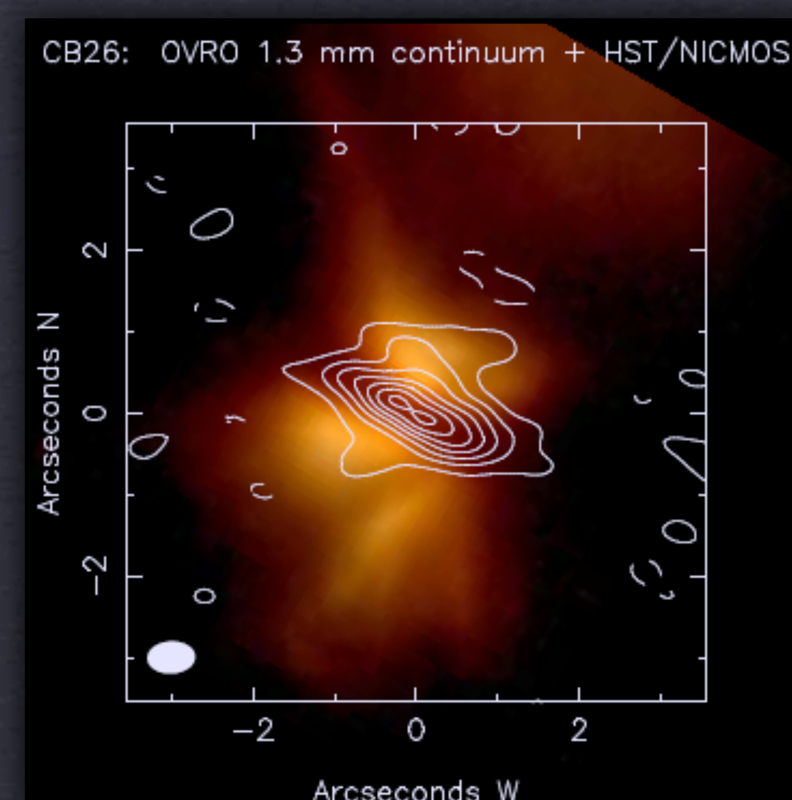
- Disk at the edge of a Bok Globule CB 26, 10° North of Taurus/Auriga dark cloud, D ≈ 140 pc.

  Circumstellar disk - edge on.

  - $R \approx 200AU$ [2]
  - $R_{gap} \approx 45AU$ [2]
  - $M_{disk} \approx 0.1\ M_{sol}$ [1]
  - $L_* > 0.5\ L_{sol}$ [3]
  - $M_* \approx 0.5 \pm 0.1\ M_{sol}$ [1]
  - $M_{dust} \approx 3e\text{-}3\ M_{sol}$ [2]

- Specific model but typical T Tauri parameters used for model calculation → can generalize results.



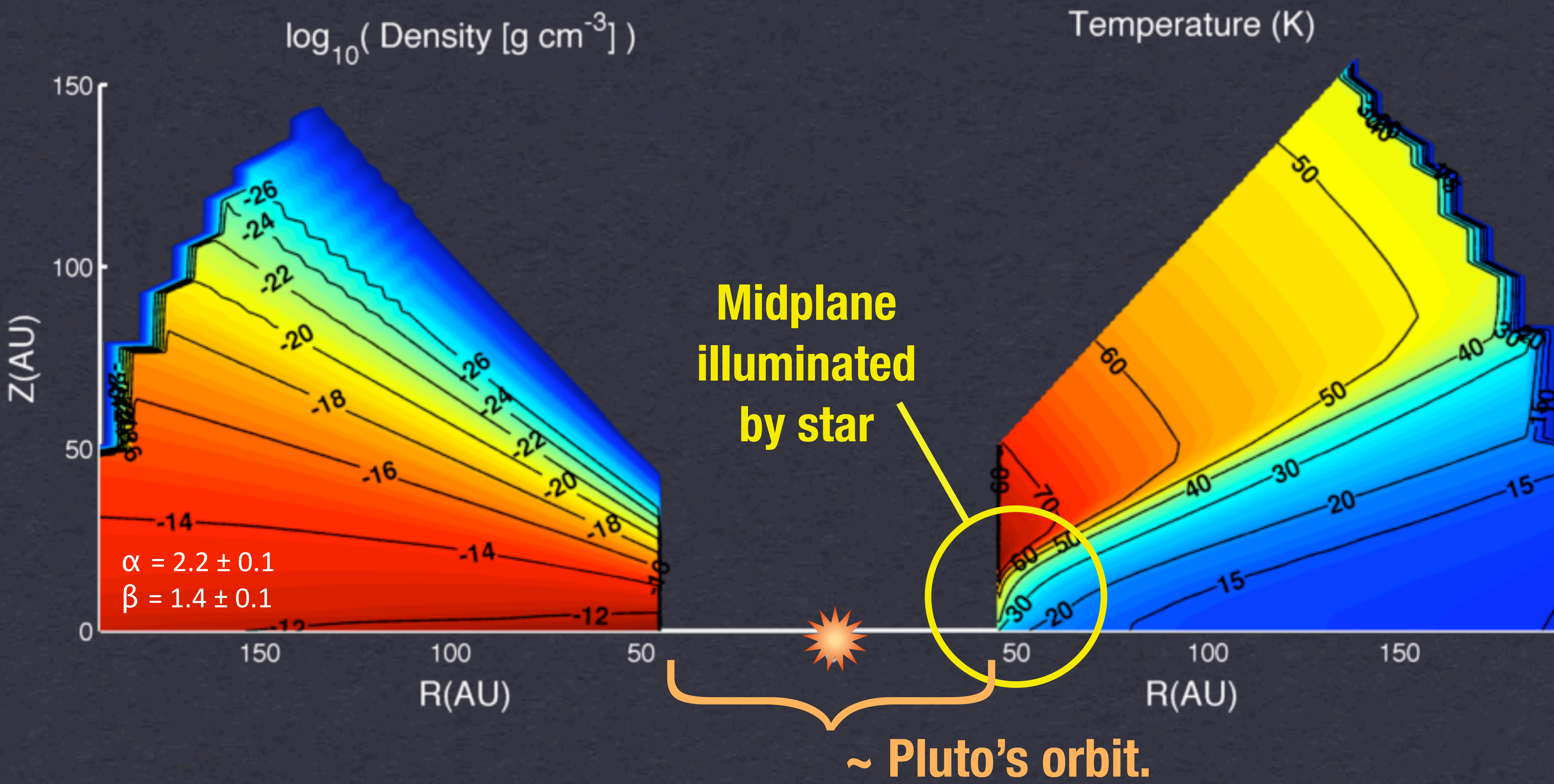


Sauter et al. 2009

[1] Launhardt & Sargent 2001; [2] Sauter et al. 2009; [3] Stecklum et al. 2004

IV. CB 26 Model

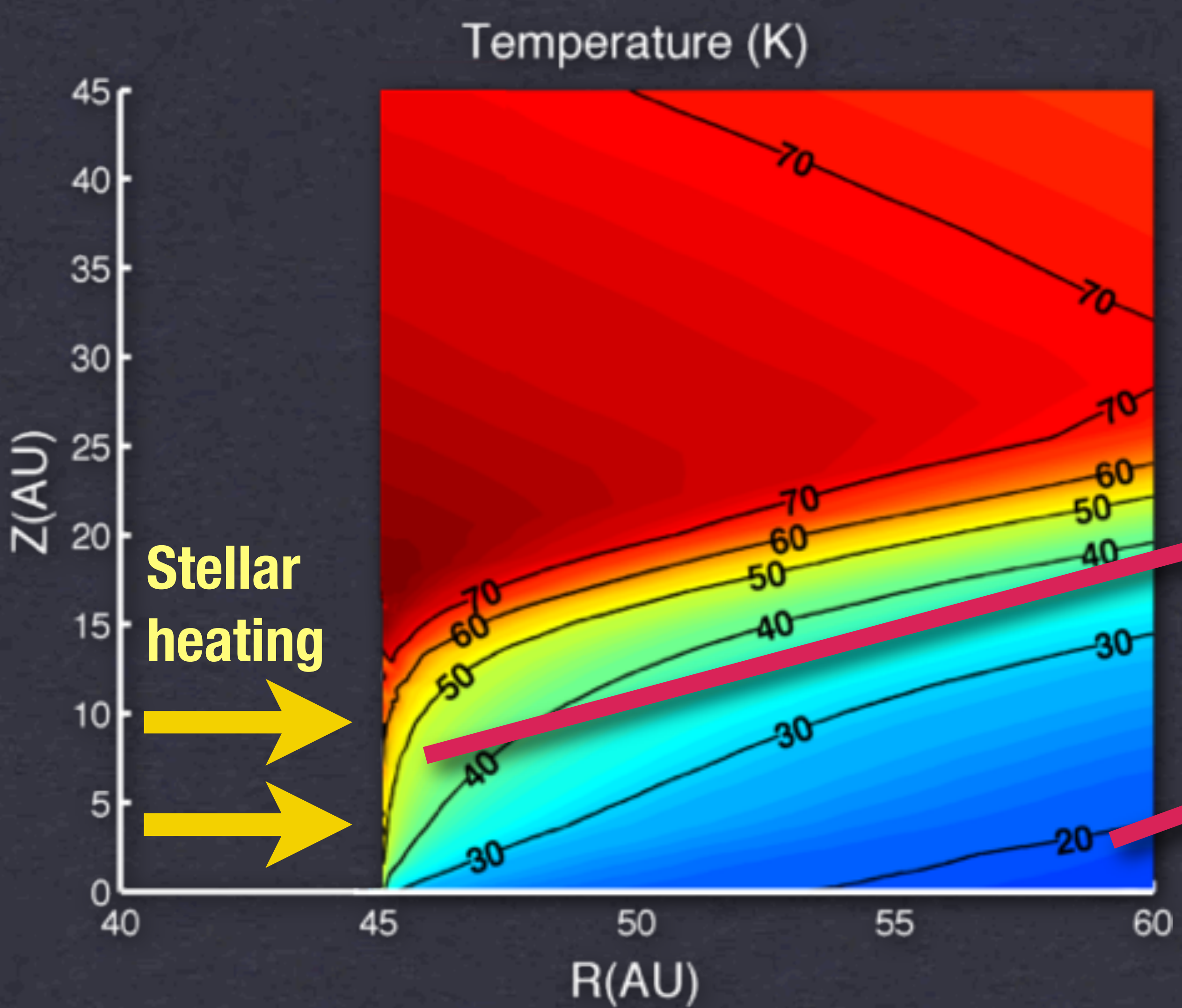
Sauter et al. 2009 used spatially resolved maps in the NIR and mm along with the object's SED to create a consistent physical model for the system.

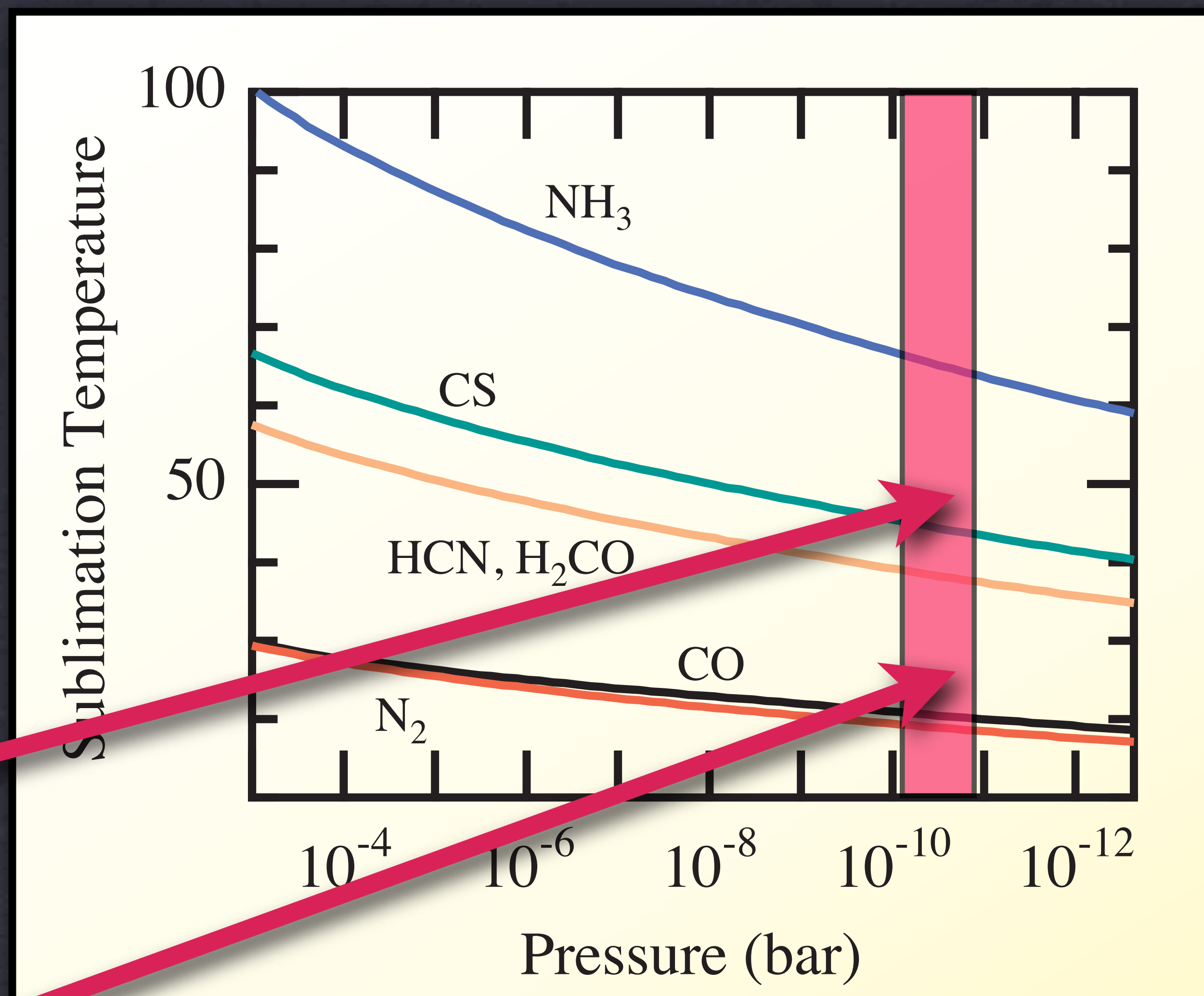


IV. CB 26 Model

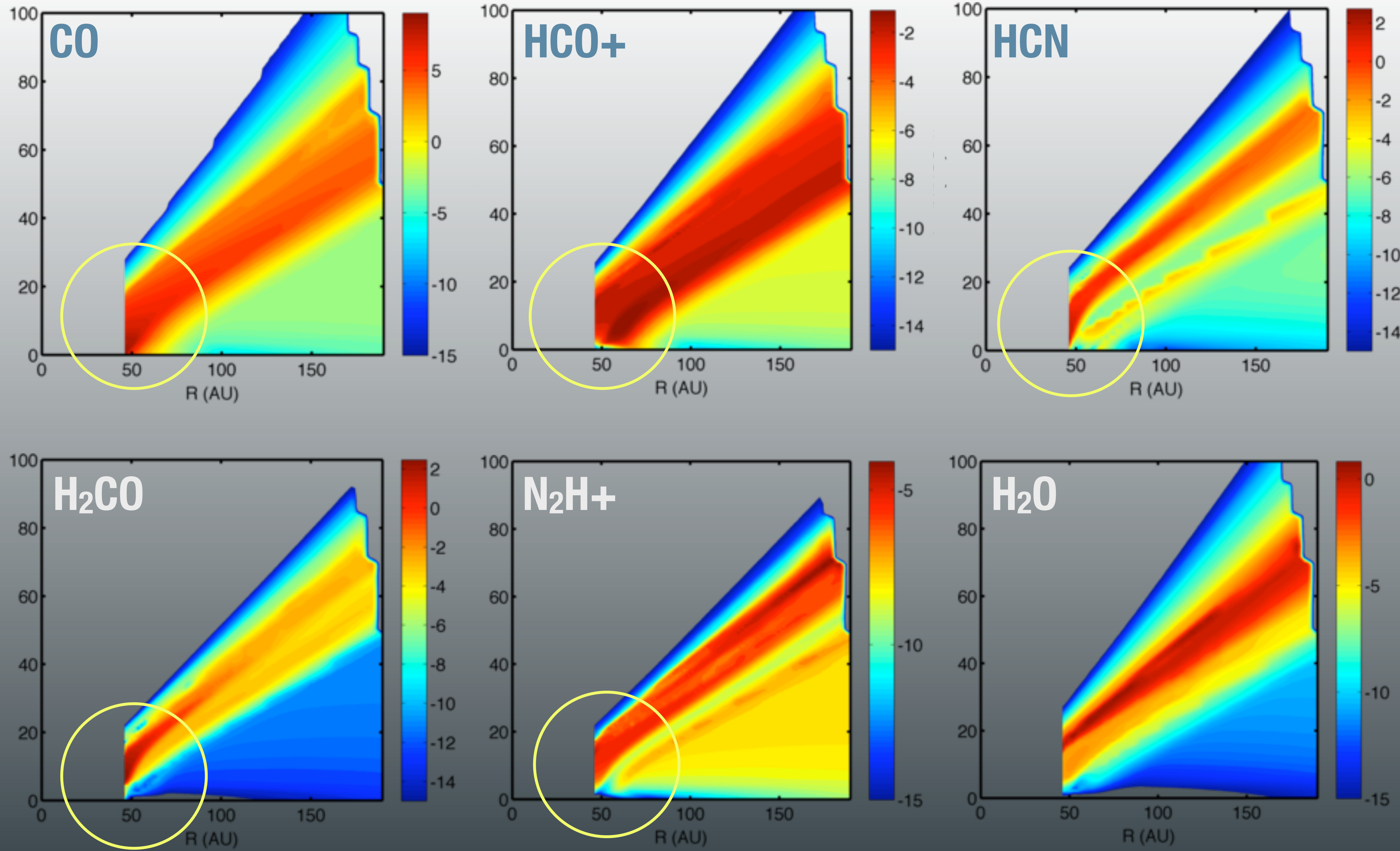
Sauter et al. 2009 used spatially resolved maps in the NIR and mm along with the object's SED to create a consistent physical model for the system.

Dense midplane normally cold (~15K) at large distances from star.





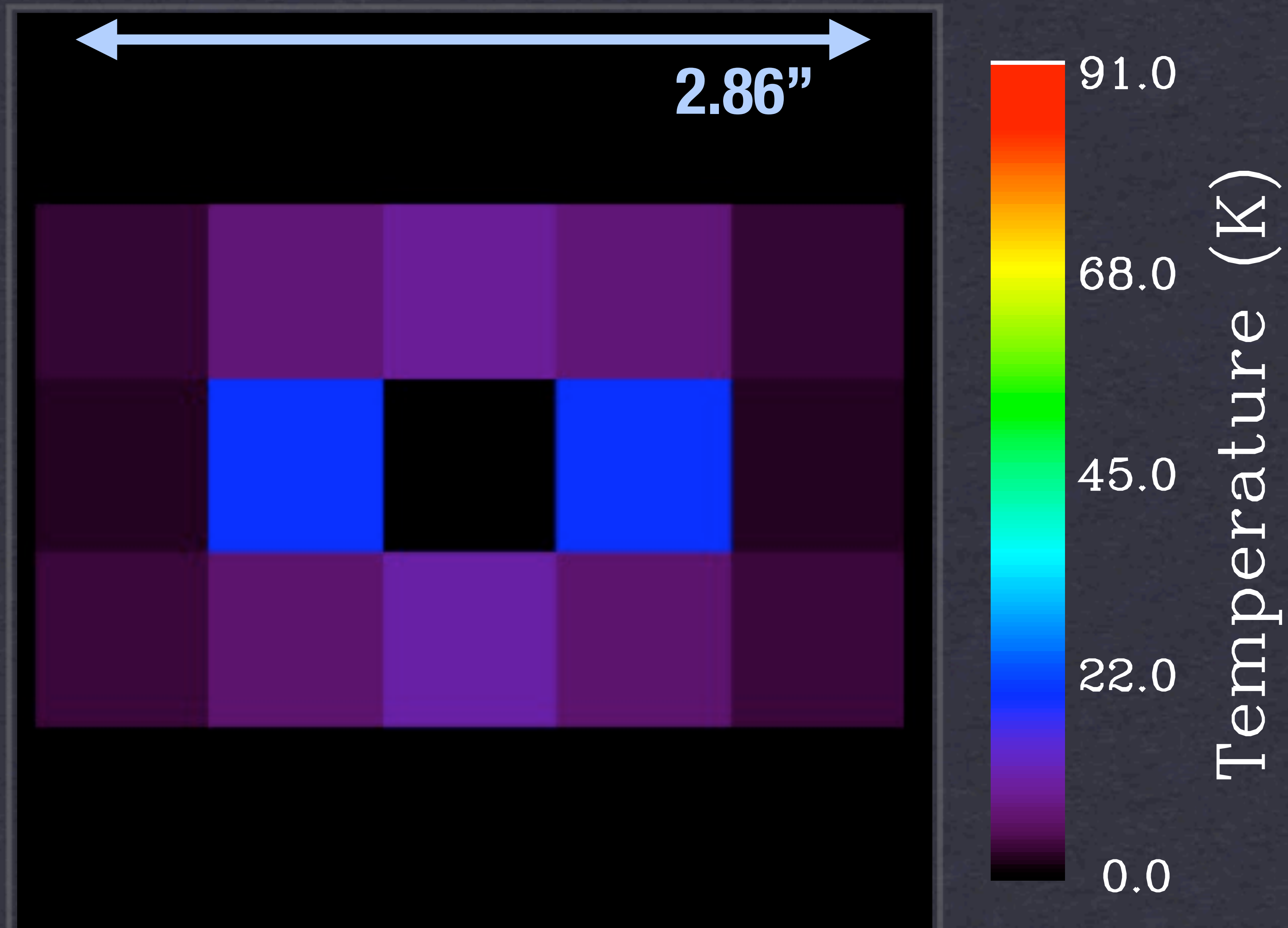
Wall heated to T = 30-50K, species that would typically be frozen out at the midplane can be sufficiently heated → desorb from grains



Chemical model results: gas phase molecules at the wall!

LIME Results: $C^{18}O$: J=2-1

Pre-ALMA

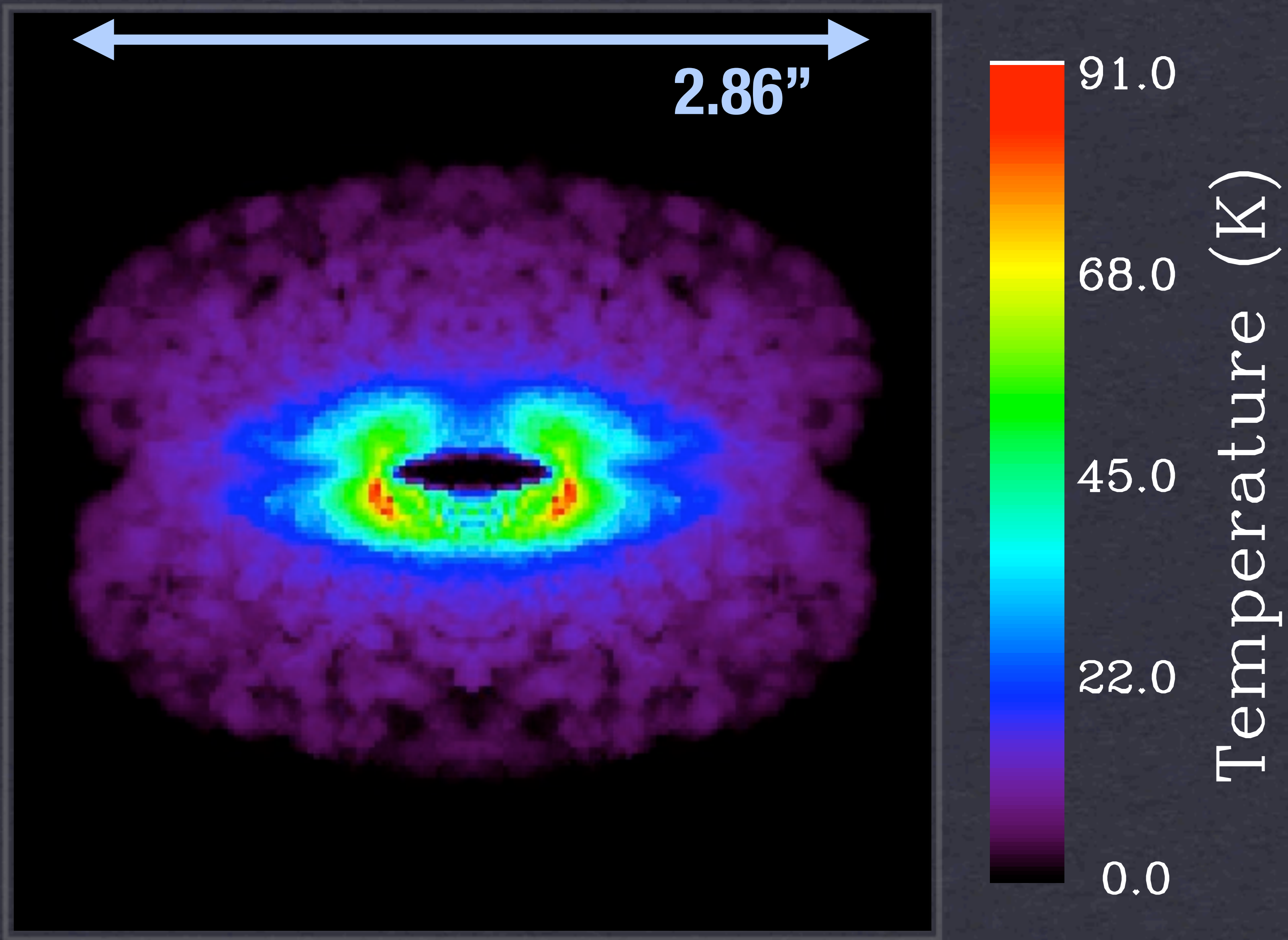


0.57” Res - 140pc
with a 500m baseline

$$i = \frac{\pi}{2\sqrt{2}} \approx 60^\circ$$

LIME Results: $C^{18}O$: J=2-1

ALMA-Era

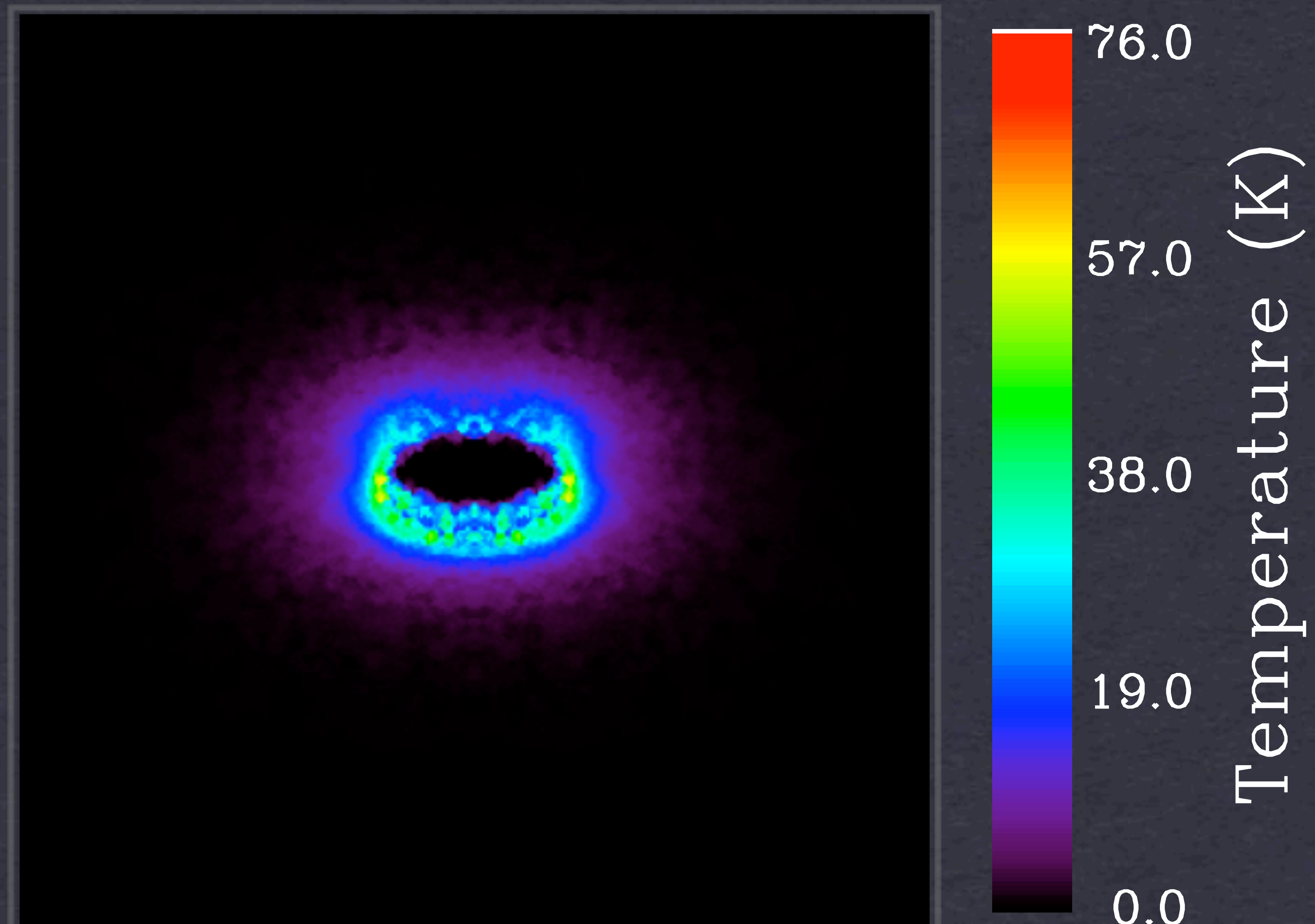


0.02” Res - 140pc
with a 12km baseline

$$i = \frac{\pi}{2\sqrt{2}} \approx 60^\circ$$

$C^{18}O$: J = 6-5

a=0.01" ν = 658.6GHz
D = 140pc



"Ideal" (τ_{dust} << 1) observation.

Actual observations will be dependent on inclination angle. Dust optically thick near the midplane.

Edge on disk obs. at 0.5 mm with column R = 200AU, density ~ 1e14 g/cm^{-3}: $\tau_{dust, 0.5mm} > 1$ for $z < 15AU$.

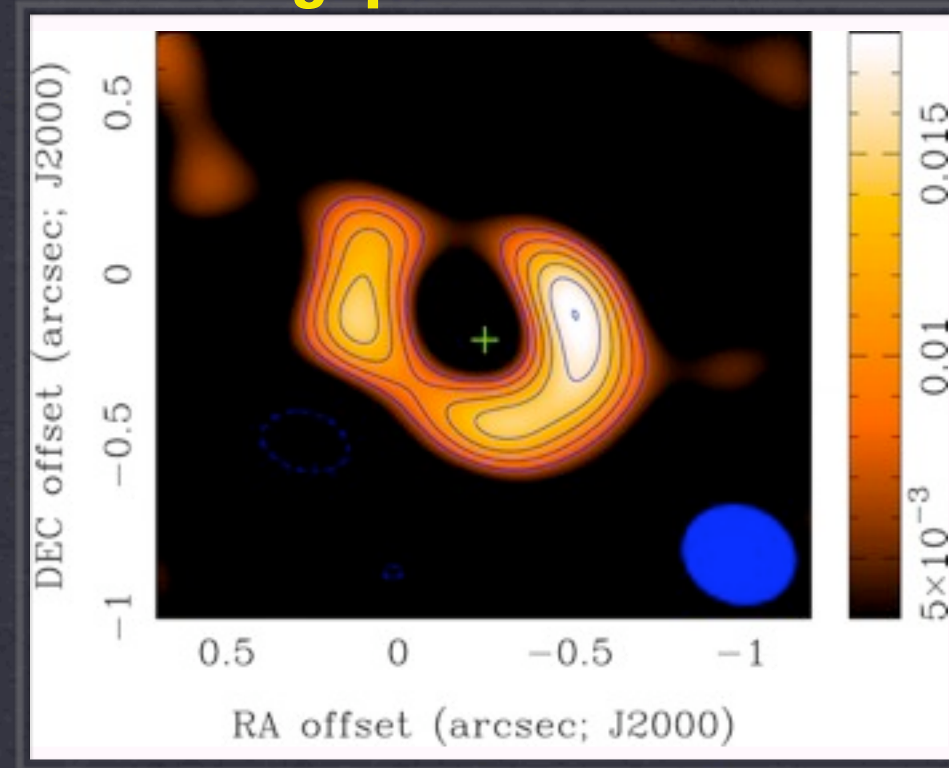
However, only the case for nearly edge on systems. →

No significant dust obstruction for midplane emission for i ~ 0-75°.
This corresponds to ~93% of disks observed on the sky.

Summary

- ALMA provides us with the ability to significantly increase the resolved sample size of planet-forming disks.
    - Will allow us to gain a full picture of the evolutionary process of disk dispersal and planet formation.
- High sensitivity allows us to go both deeper, and to use new tracers not previously employed due to sensitivity limitations.
    - Wall will distinctly light-up at high J states - can selectively probe the transition region.
- The interface between the inner gap and outer disk (the wall) in transition disks should be a chemically active and interesting region that sets the initial conditions for protoplanet chemistry.

Observe gaps in dust...



The future: warm molecular rings!