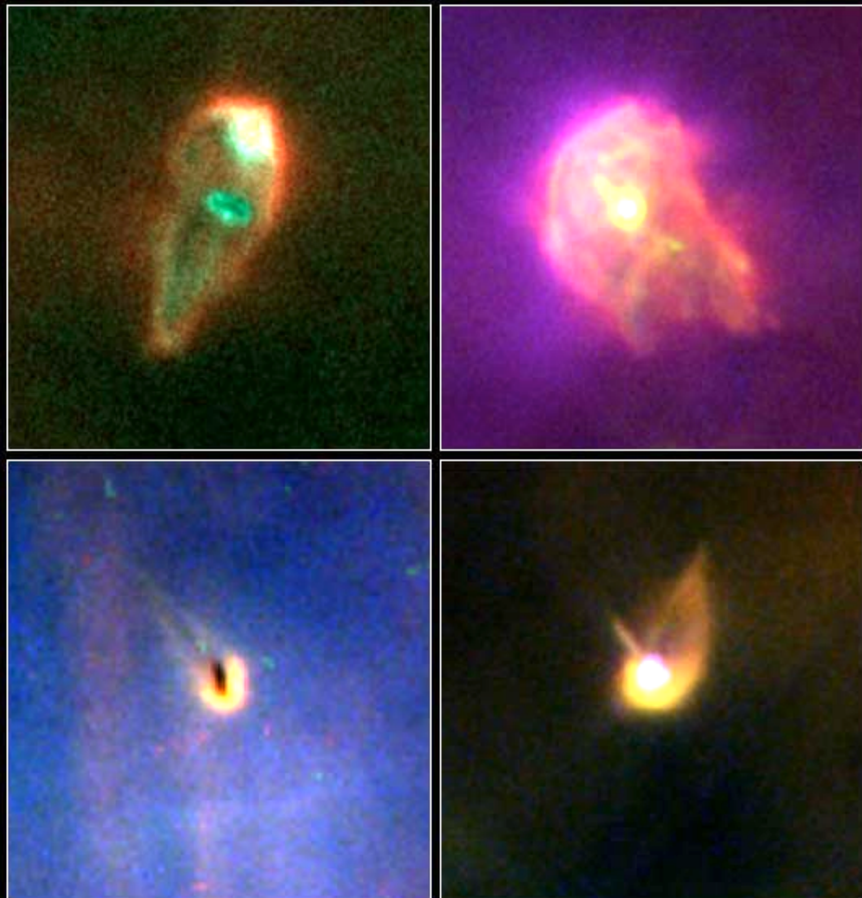

The Potential to Form Planets in the Orion Nebula

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NRC-Herzberg

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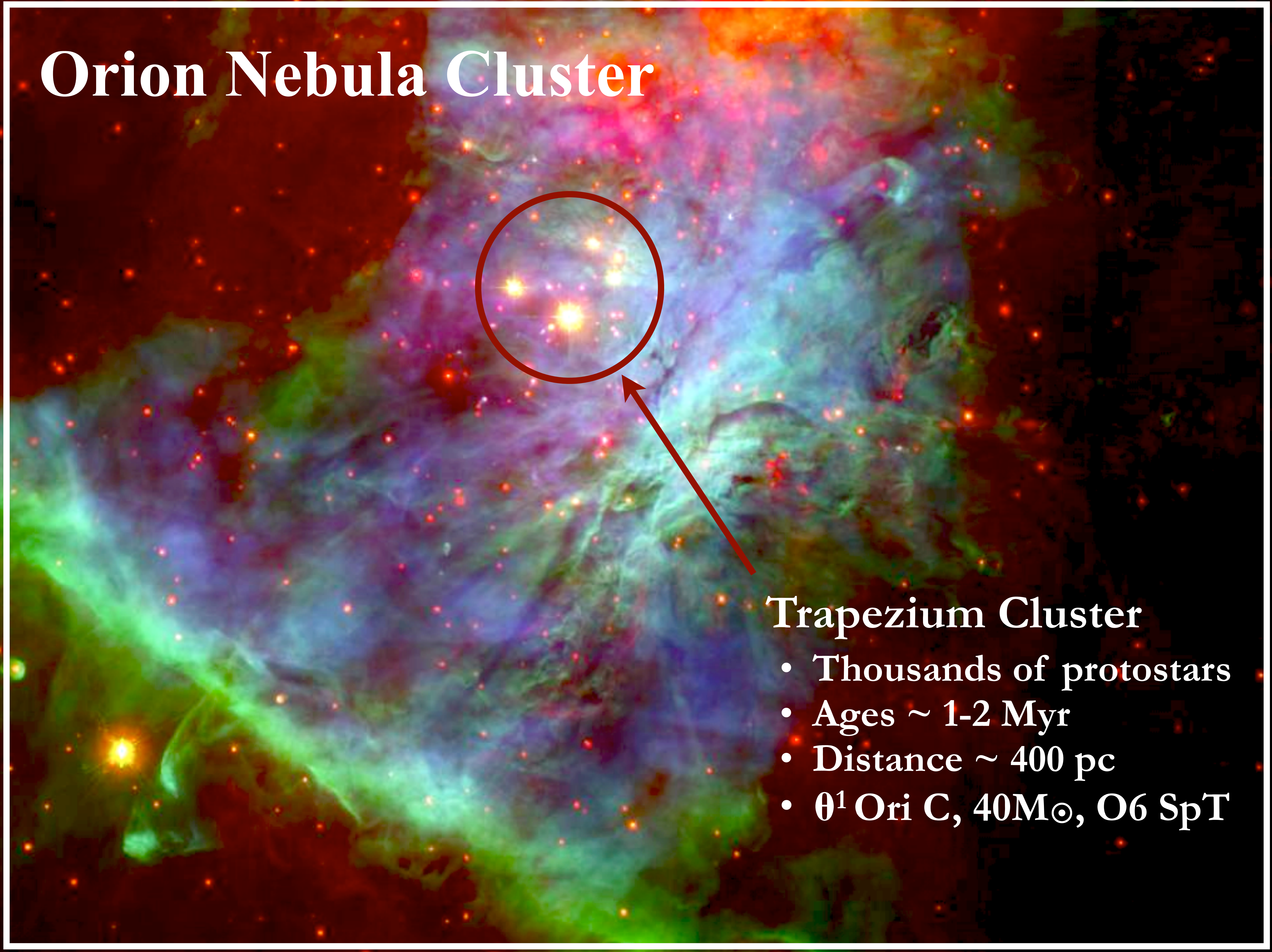
Jonathan Williams, Doug Johnstone,
John Bally, Meredith Hughes,
Luca Ricci, Brenda Matthews

Protoplanetary Disks in the Orion Nebula

Most stars form in rich clusters
Our Solar System formed in a
massive star forming environment.

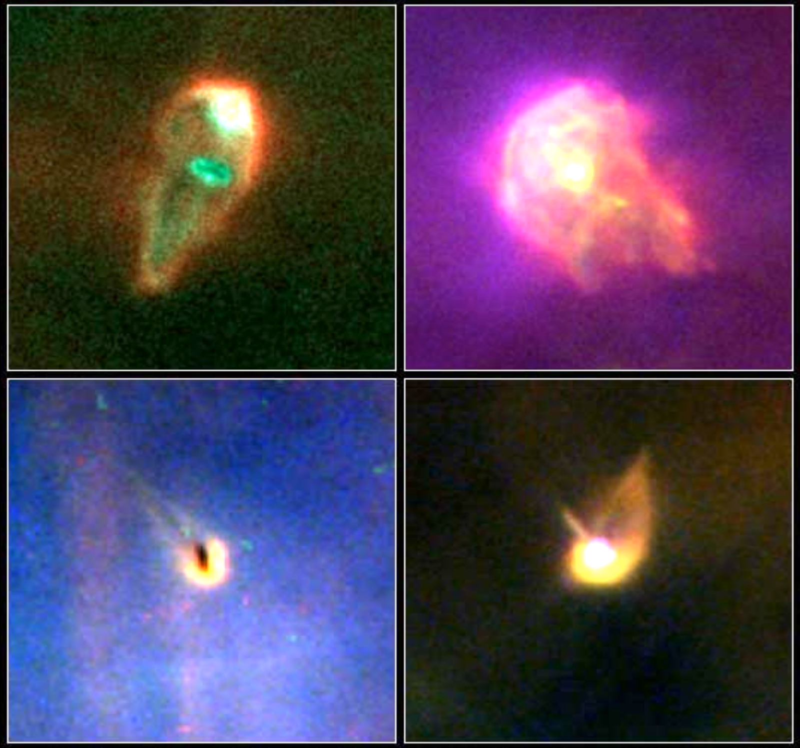
To understand planet formation, we need to study disk properties in massive star forming regions!

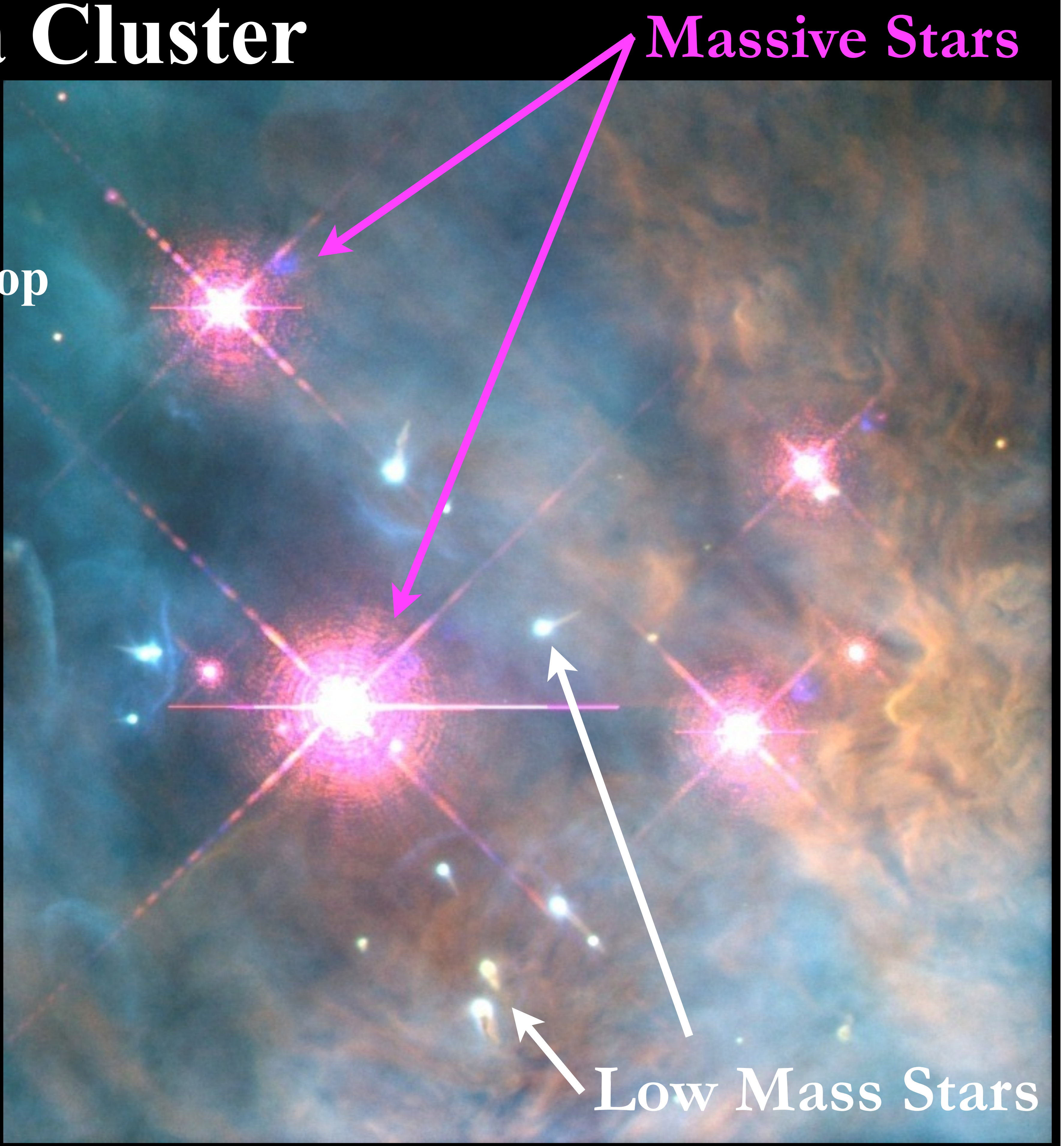
HST images of protostars in Orion


Orion Nebula Cluster
Trapezium Cluster
• Thousands of protostars
• Ages ~ 1-2 Myr
• Distance ~ 400 pc
• θ¹ Ori C, 40M☉, O6 SpT

Orion Nebula Cluster

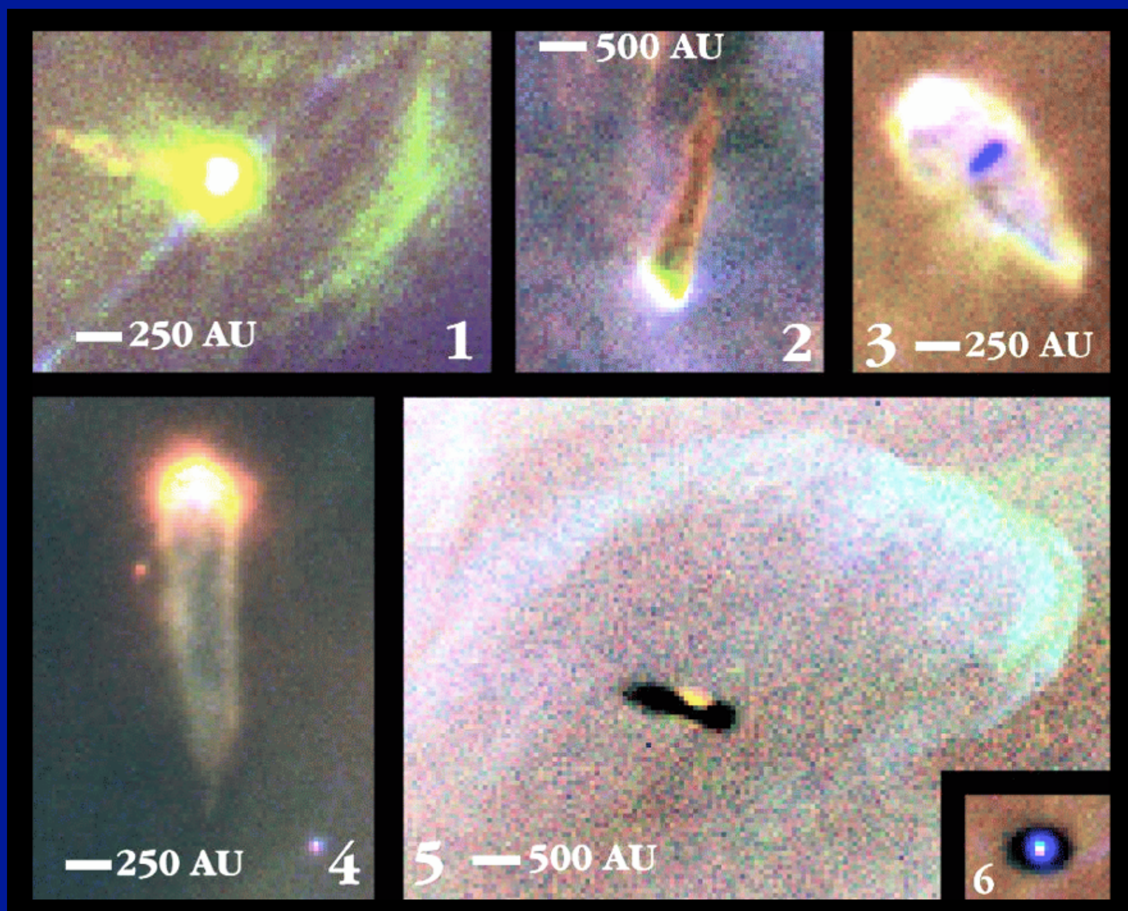
- Hostile environment
- Many low mass stars near ϑ^1C have teardrop shaped morphologies





PROPLYDS: PROtoPLanetarY DisksS

Photoevaporating Proplyds



C.R. O'Dell

VLA → mass-loss rate of 10^{-7} $M_\odot$/yr

Churchwell et al. (1987)

Mdisk < 0.1 $M_\odot$

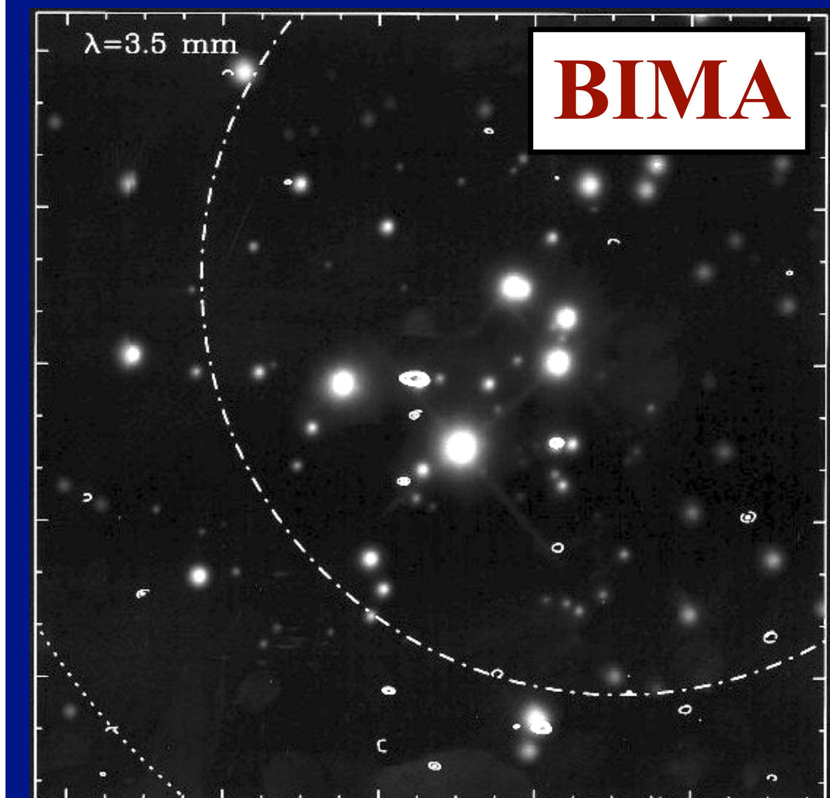
Evaporation Timescales < 1 Myr

Material removed too quickly!

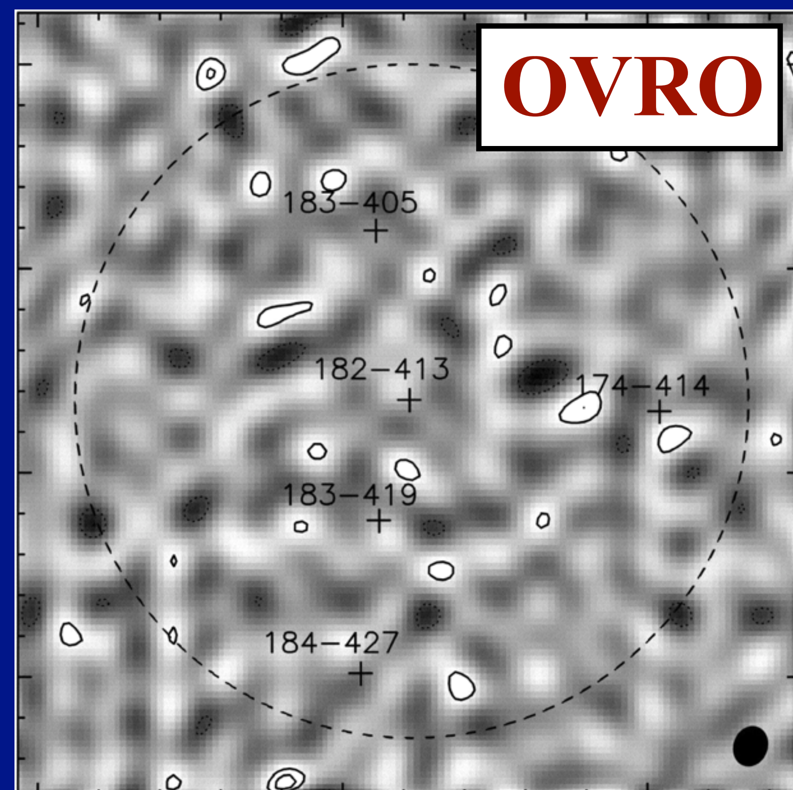
Is planet formation inhibited in rich clusters?

Disk Masses in Orion: Previous Attempts

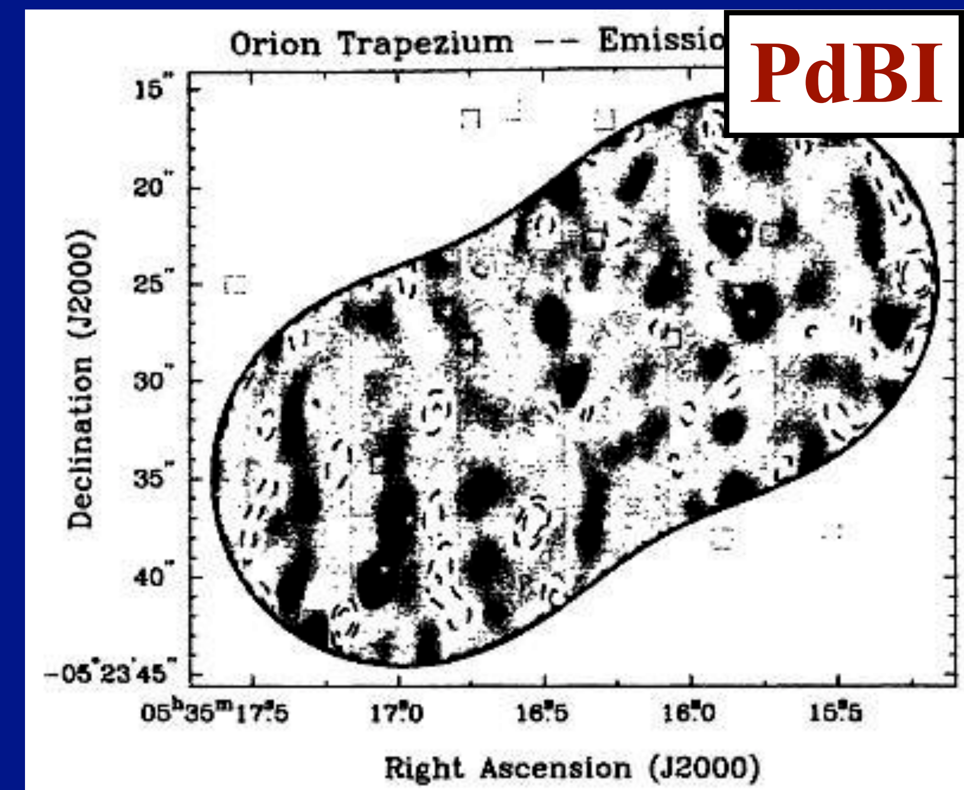
Millimeter Wavelength Interferometers (clustered disks)



Mundy et al. (1995)
λ = 3.5 mm
low sensitivity



Bally et al. (1998)
λ = 1.3 mm
no detections

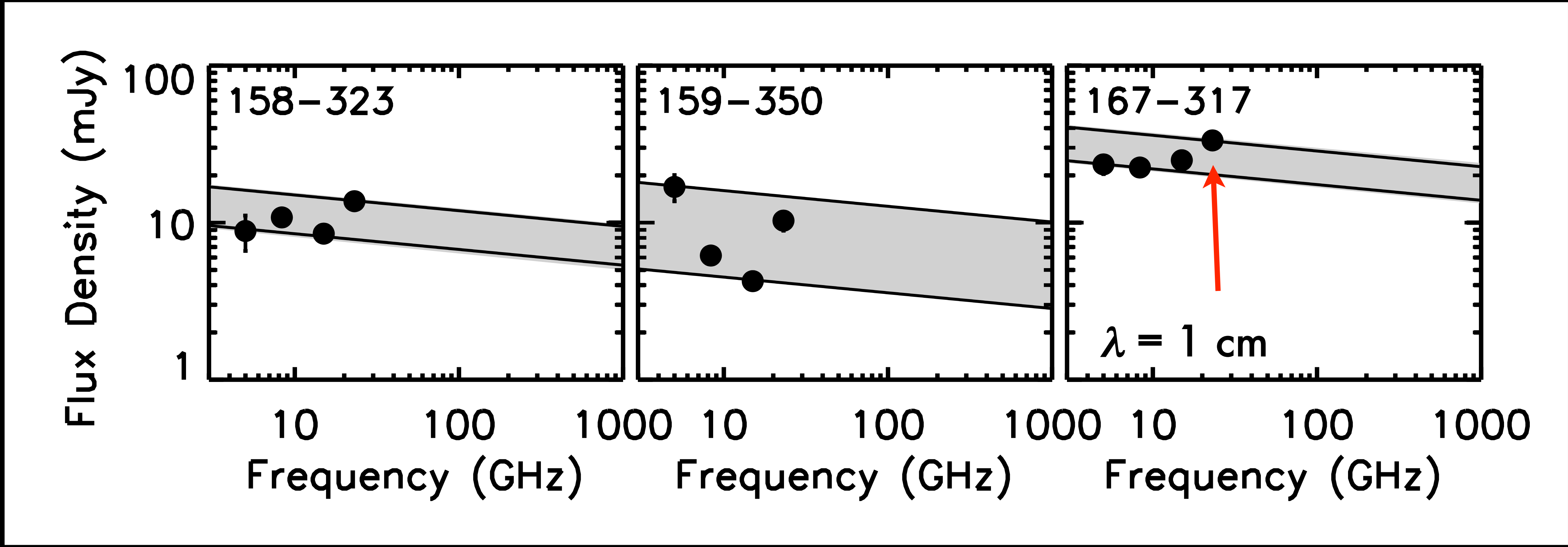


Lada (1999)
λ = 1.3 mm
never published

Mdisk ≲ 15 M_{JUP}

Radio-Submillimeter SED

$F_{free\text{-}free} \sim \nu^{-0.1} + F_{dust} \sim \nu^{2\text{-}4}$



Radio-Submillimeter SED

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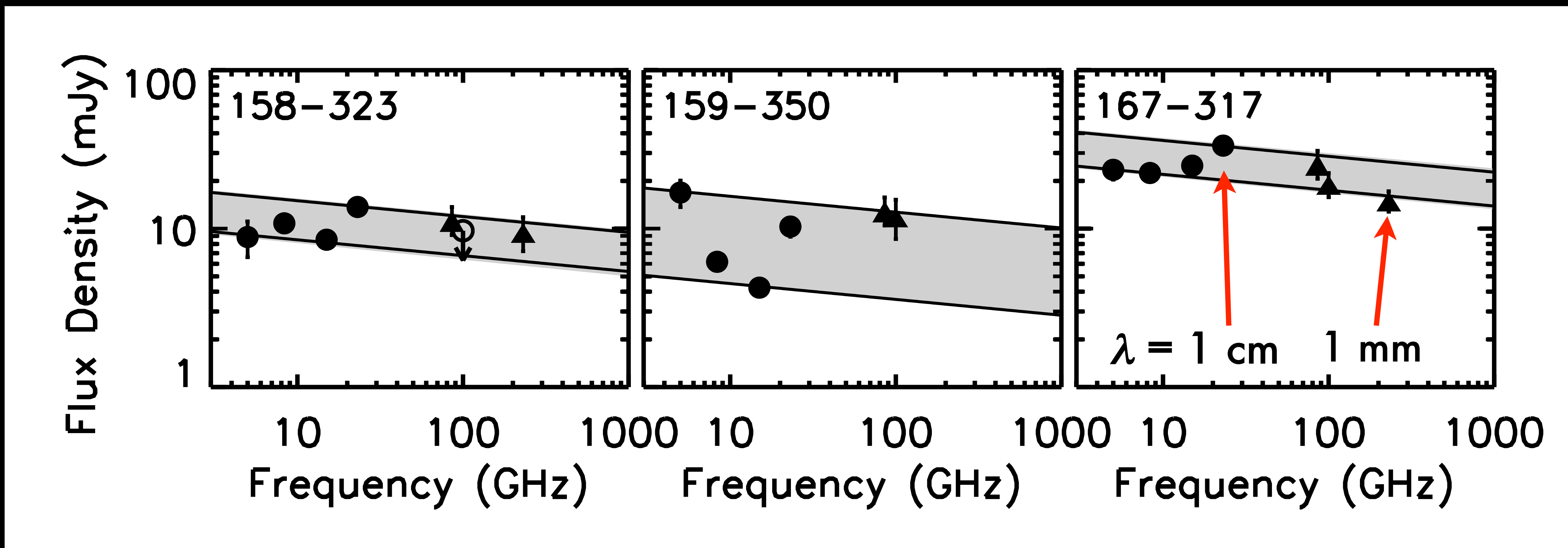

Radio-Submillimeter SED

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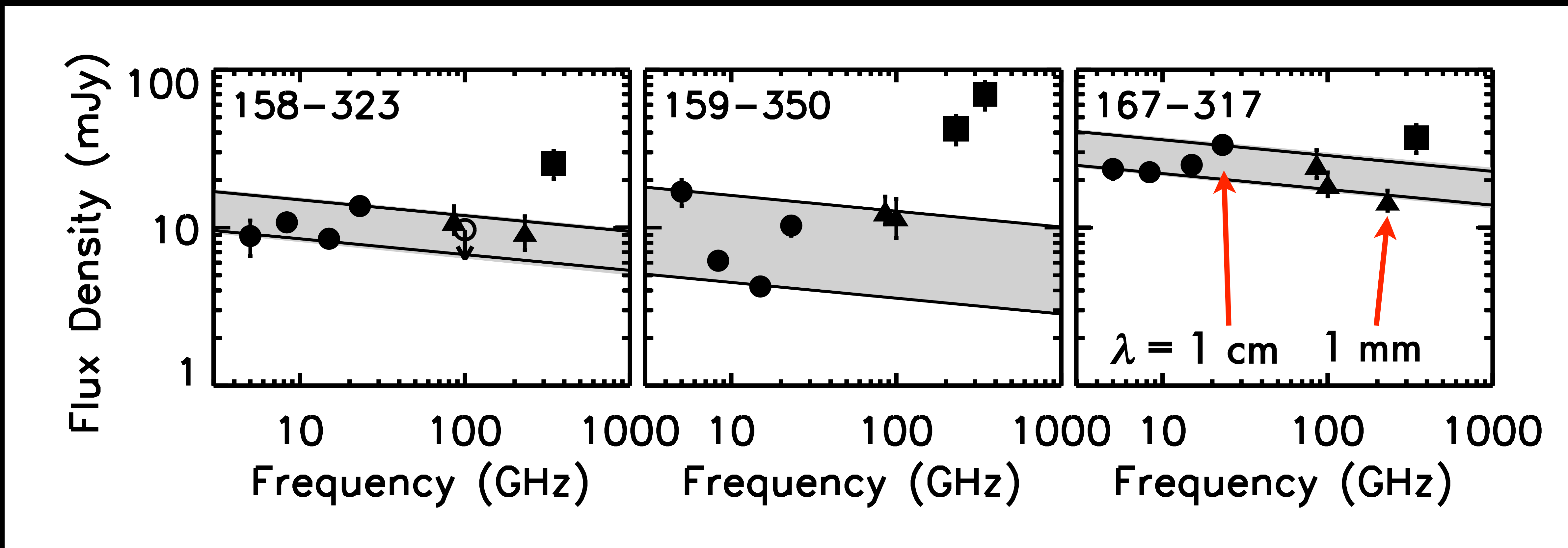
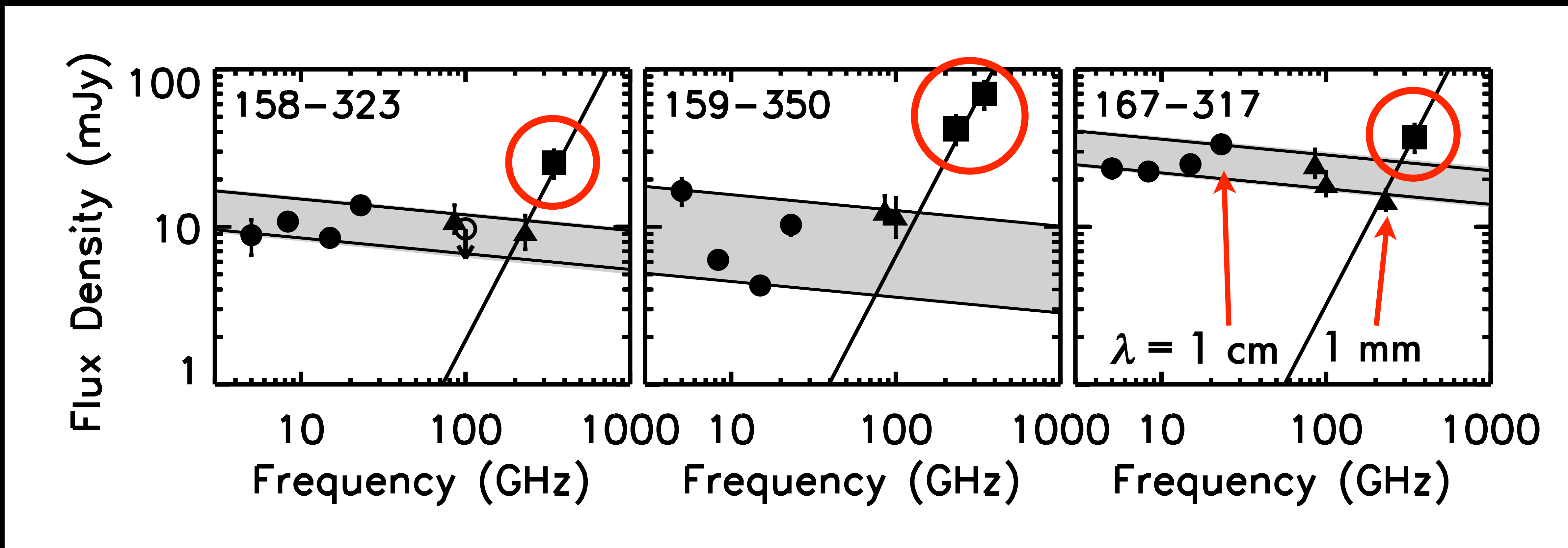


Higher frequency observations: more sensitive to dust emission!

→ ***Interferometry with the Submillimeter Array at 850 μm***

Radio-Submillimeter SED

$F_{free\text{-}free} \sim \nu^{-0.1} + F_{dust} \sim \nu^{2\text{-}4}$

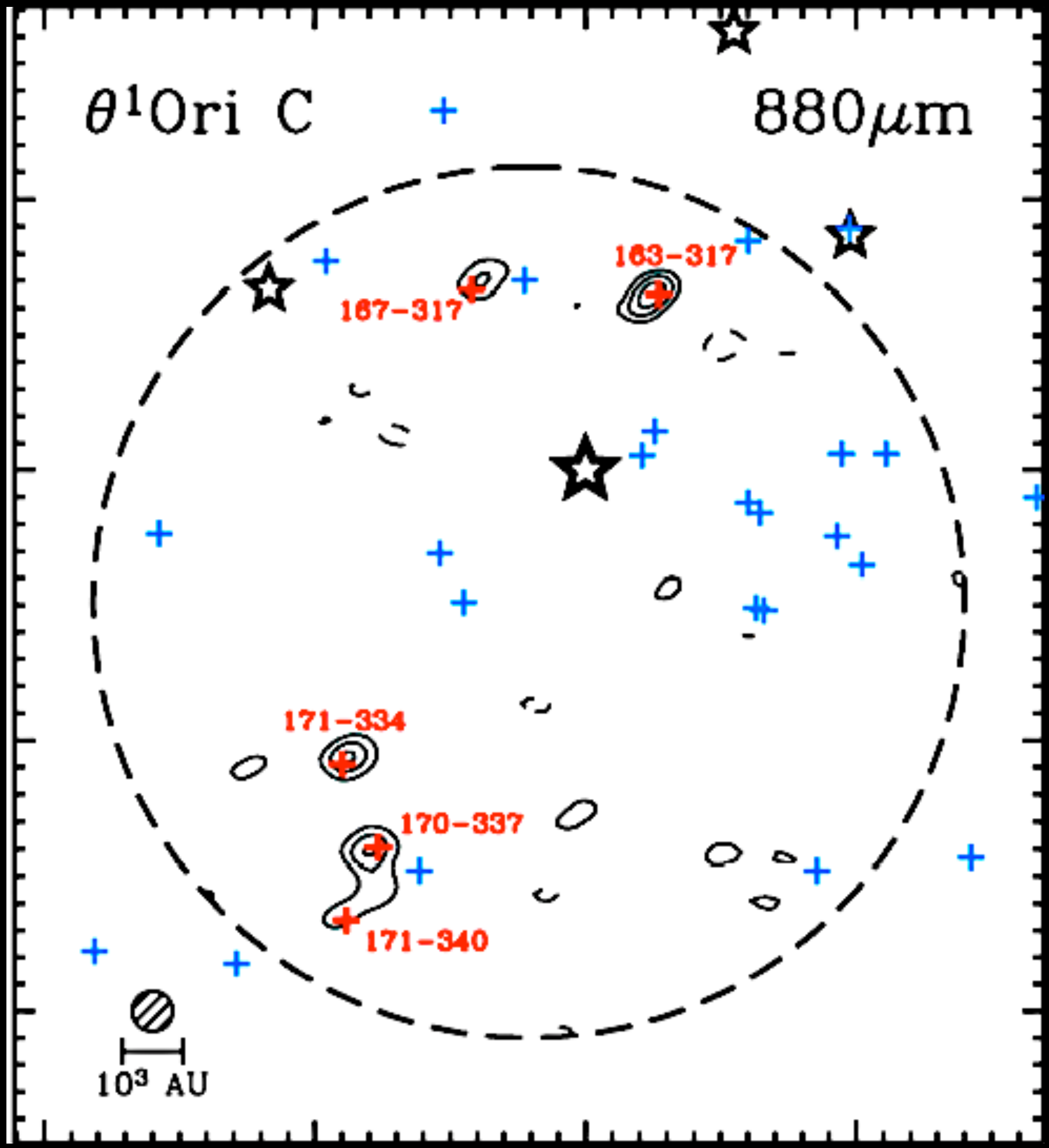


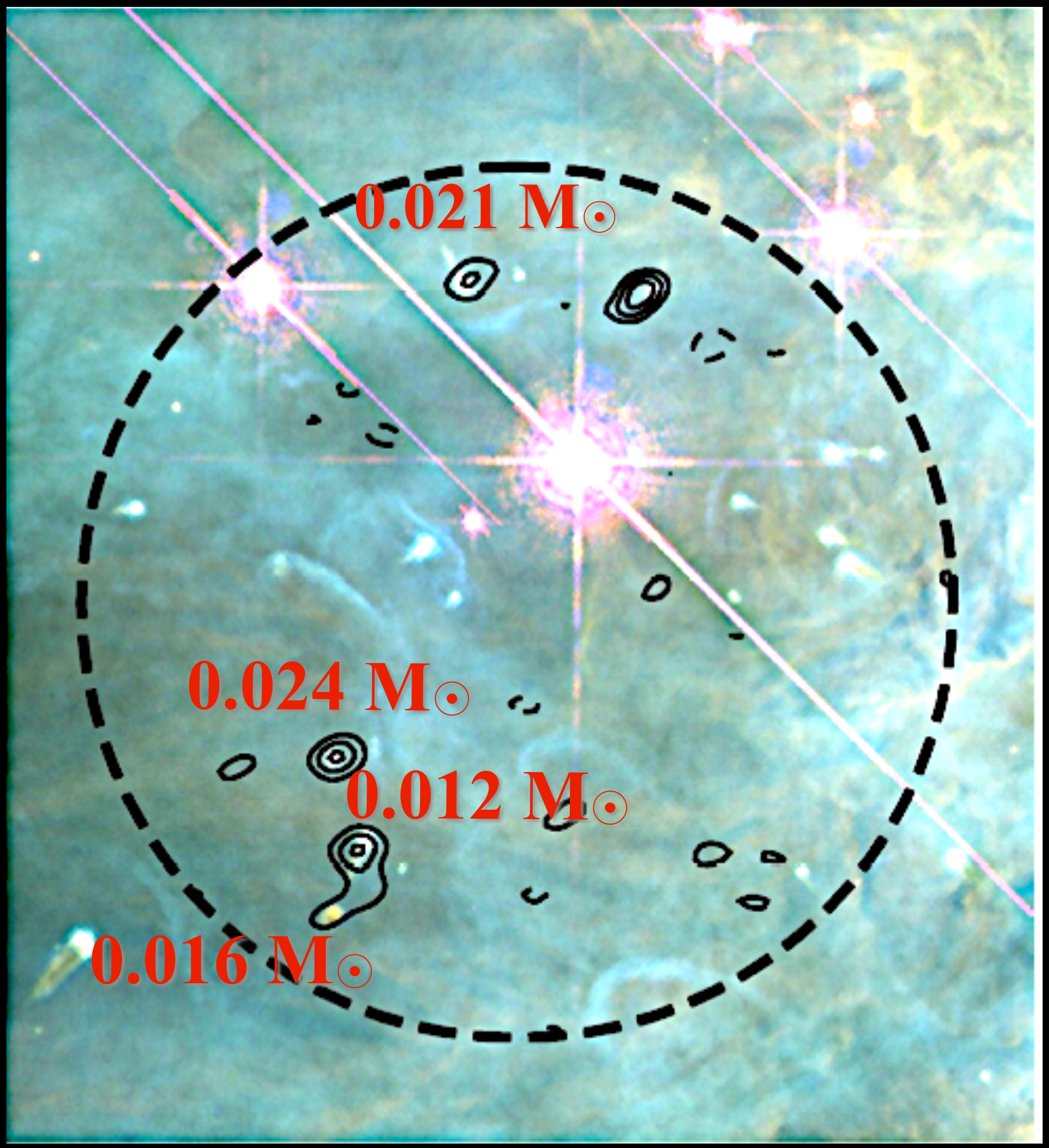
Higher frequency observations: more sensitive to dust emission!

→ ***Interferometry with the Submillimeter Array at 850 μm***

Submillimeter Array Pilot Study: First Masses of the Orion Proplyds

(Williams, Andrews & Wilner 2005)





4/23 disks detected: $M_{disk} \sim 0.01 M_\odot$ (MMSN)

At least some proplyds have the potential to form planets like our own!

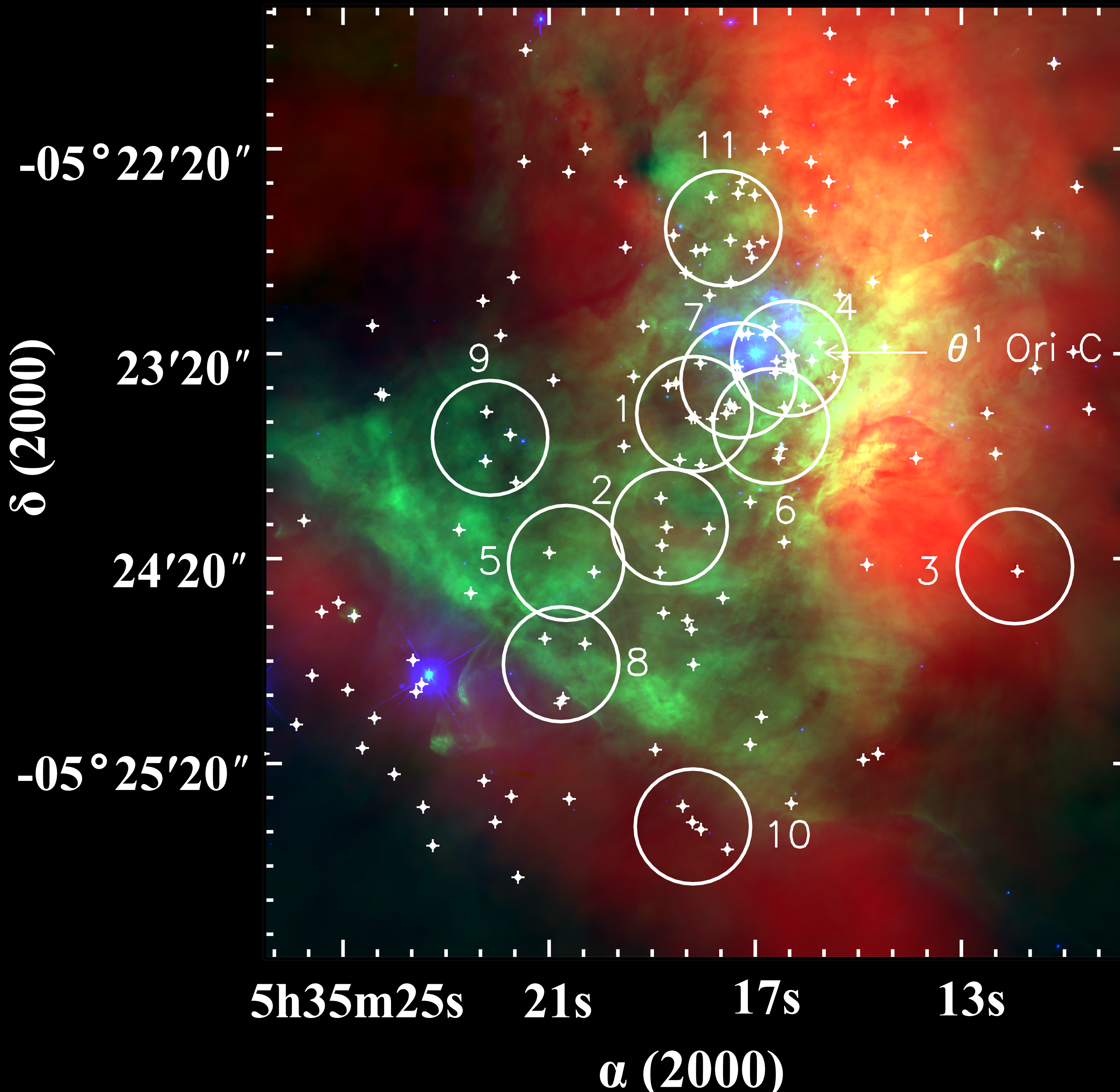
SMA survey of protoplanetary disks in Orion

11 SMA fields at 850 μm
~ 2" resolution
~ 1-2 mJy rms

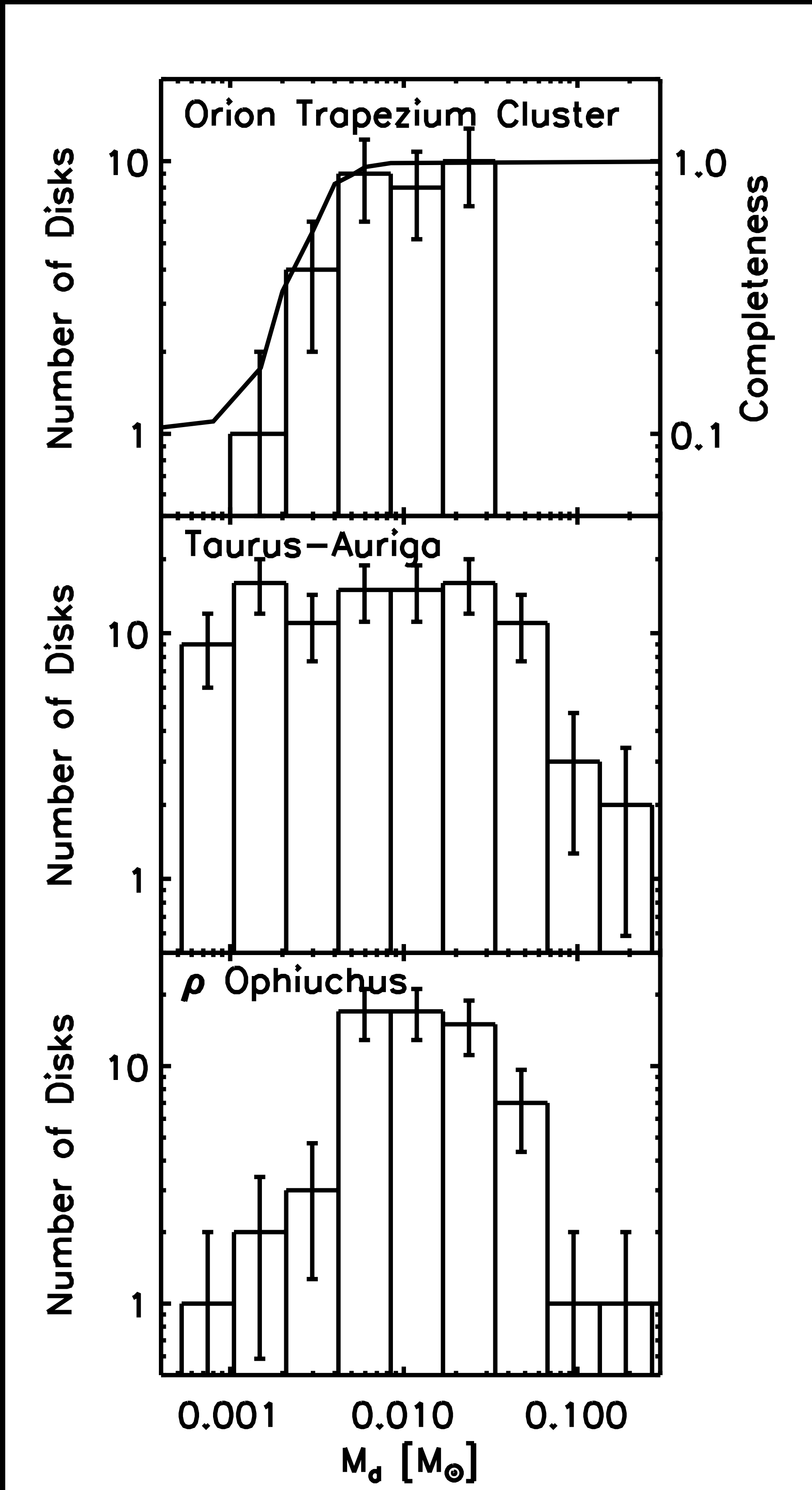
55 Orion disks surveyed within 0.3-pc of O-star, θ^1C

28 disks detected at ≥ 3σ

Image: Red = SCUBA 450 μm (Johnstone & Bally 1999) Green = HST Hα; Blue = HST V (Bally 2000)



Orion Disk Mass Distribution

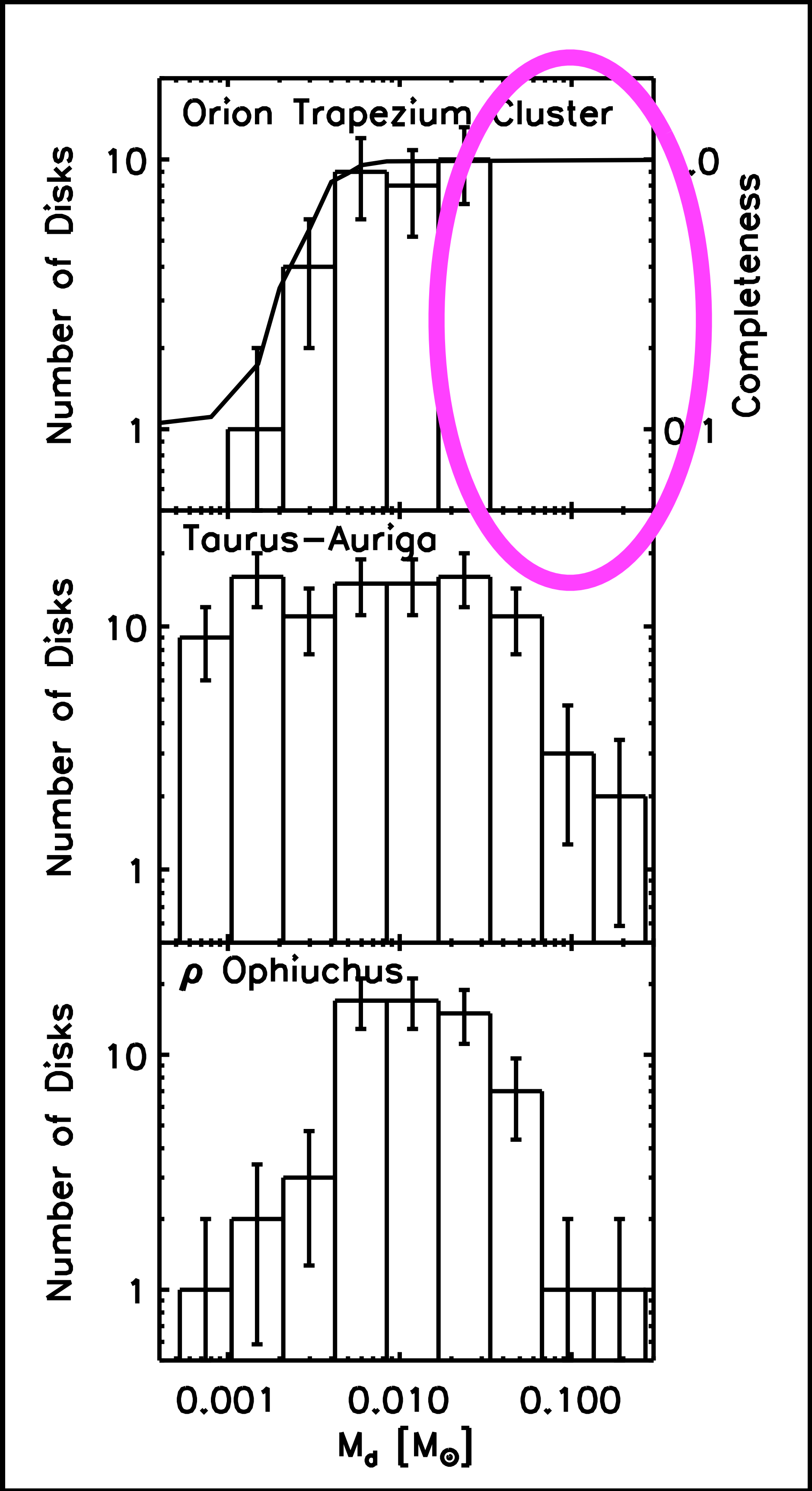


Comparison with regions that lack high mass stars, Taurus, ρ Ophiuchus (results from SCUBA surveys by Andrews & Williams, 2005, 2007)

Orion distribution truncated $M_d > 0.04\ M_\odot$

Mann & Williams 2009a

Orion Disk Mass Distribution



Comparison with regions that lack high mass stars, Taurus, ρ Ophiuchus (results from SCUBA surveys by Andrews & Williams, 2005, 2007)

Orion distribution truncated $M_d > 0.04\ M_\odot$

Orion lacks massive disks found in low mass star forming regions!

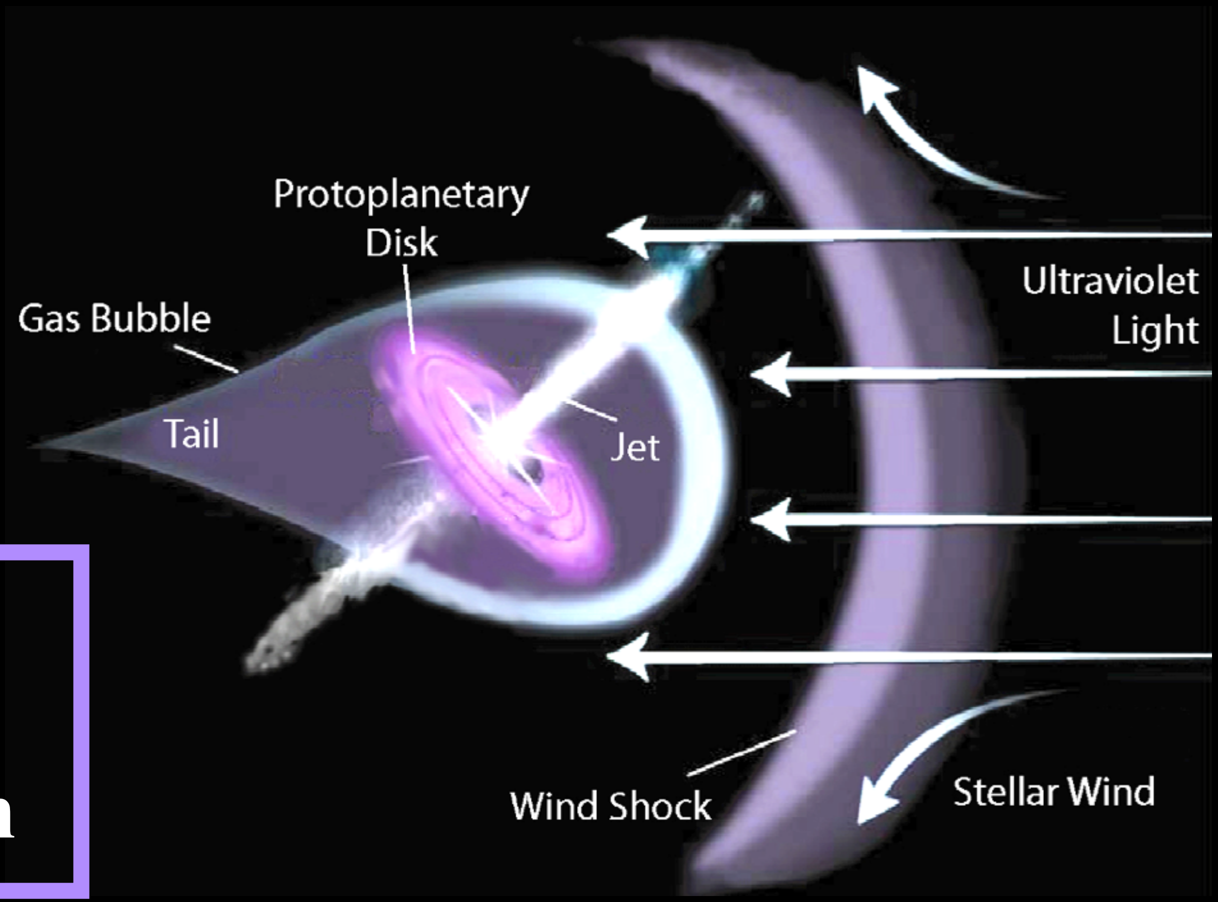
Mann & Williams 2009a

Comparison with Theoretical Models of Photoevaporation

Johnstone et al. 1998; Störzer & Hollenbach 1999; Adams et al. 2004; Clarke 2007

Proplyd observations:

- **Most proplyds are unresolved by HST; r < 60AU**
- **The disk mass distribution is truncated: M < 0.04 M$_\odot$**
- **trend of disk mass and radius**



Most reasonable interpretation of the disk mass truncation is a loss of the outer disks by photoevaporation

Mann & Williams 2009a

Planet Formation Potential

~ 11% of Orion disks have similar masses, sizes to the inferred initial conditions of our SS (Mdisk ≥ 0.01 $M_\odot$ within 60AU)

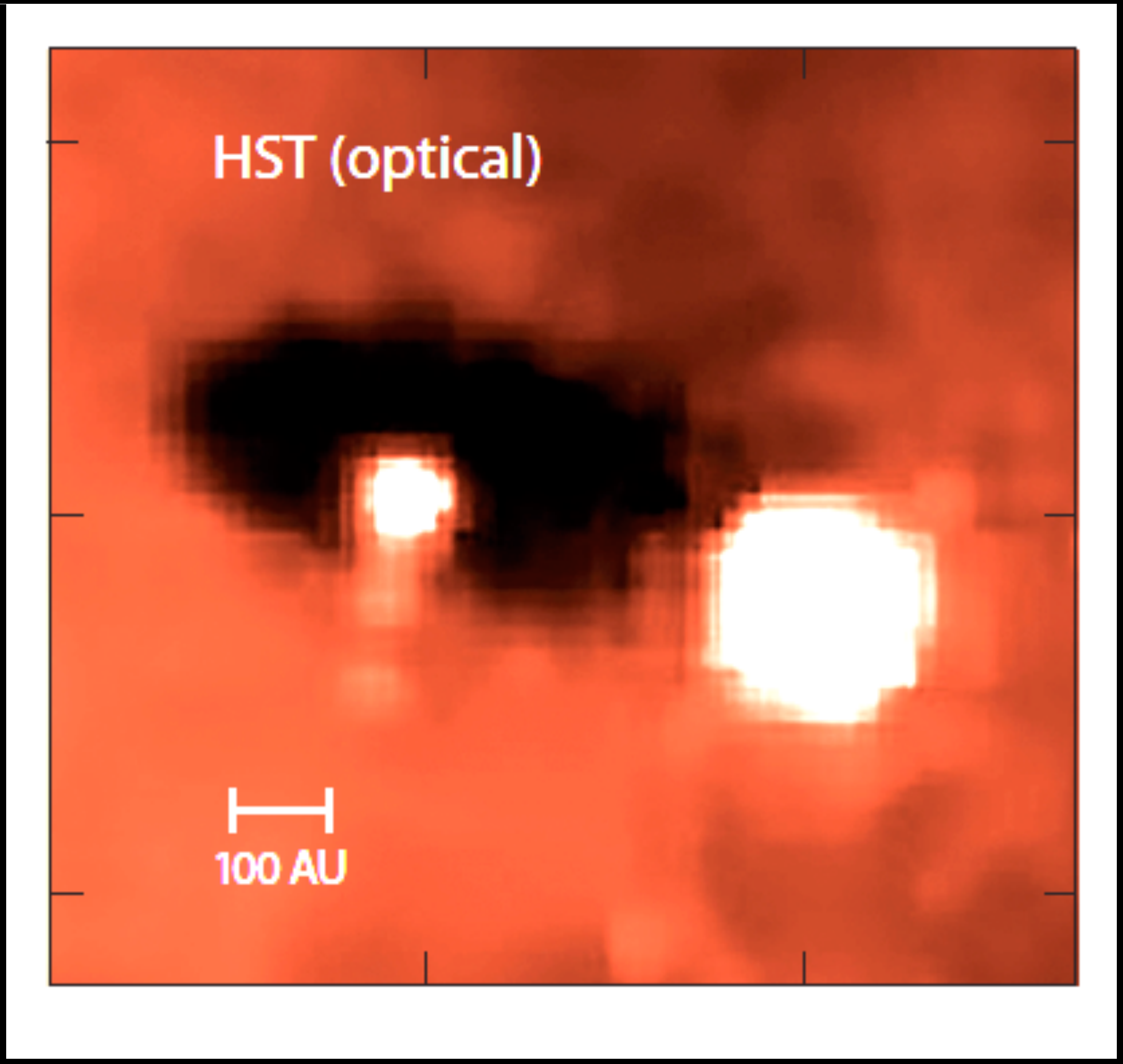
~ 13% of disks in Taurus, ρ Ophiuchus have Mdisk ≥ 0.01 $M_\odot$ within 60 AU

Planet formation is not less likely in rich clusters containing massive O-stars.

Mann & Williams 2009a

Binary System 253-1536 in Orion

Separation: 1.1″ (440 AU)
Distance: 1 pc from θ^1C
Radii: 300AU, < 60AU



HST discovery image
Smith et al. (2005)

Binary System 253-1536 in Orion

Separation: 1.1″ (440 AU)
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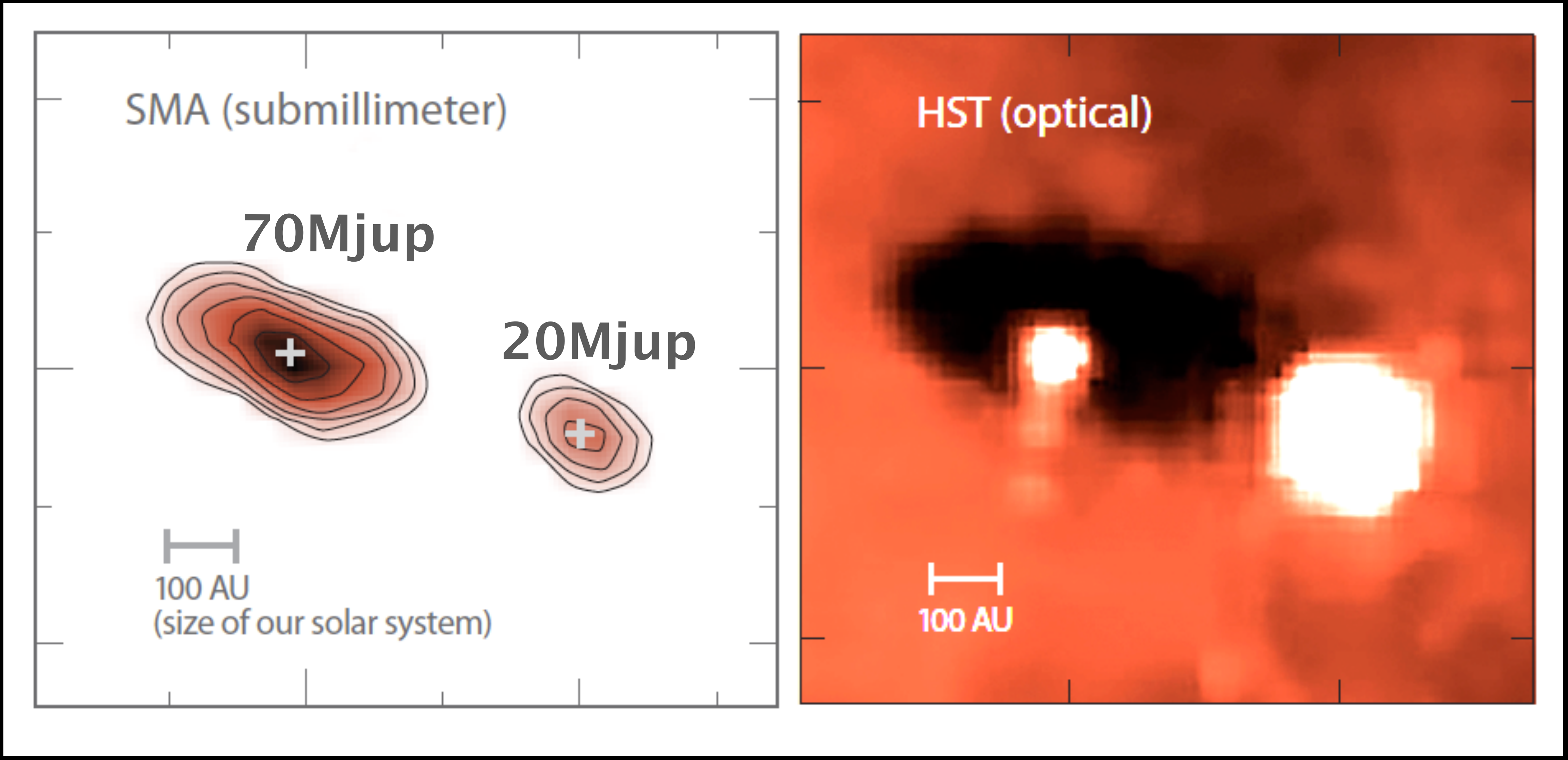
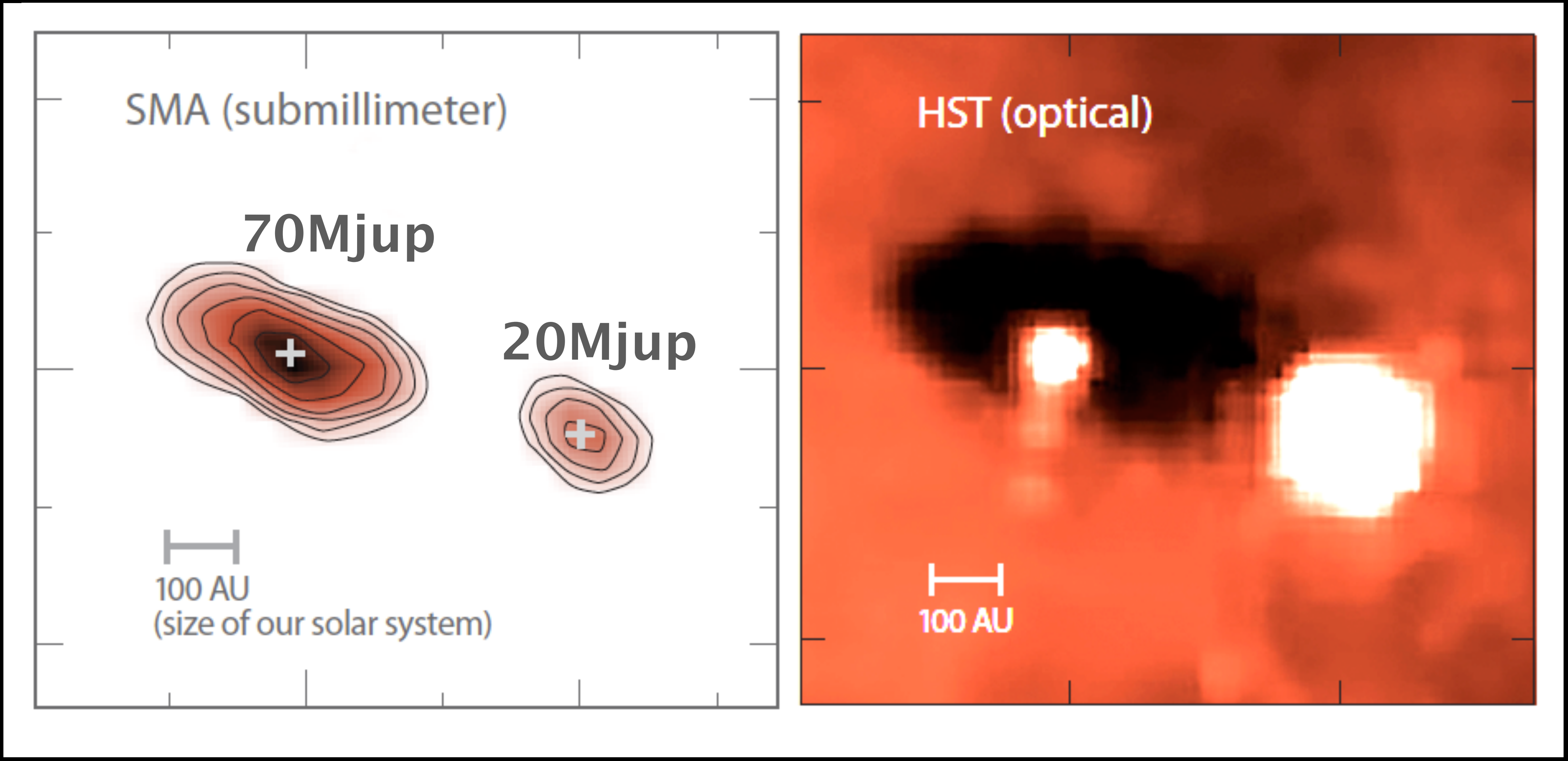


SMA 880μm emission,
contours begin at 3σ
Mann & Williams (2009b)

HST discovery image
Smith et al. (2005)

A Double Solar System in the Making?

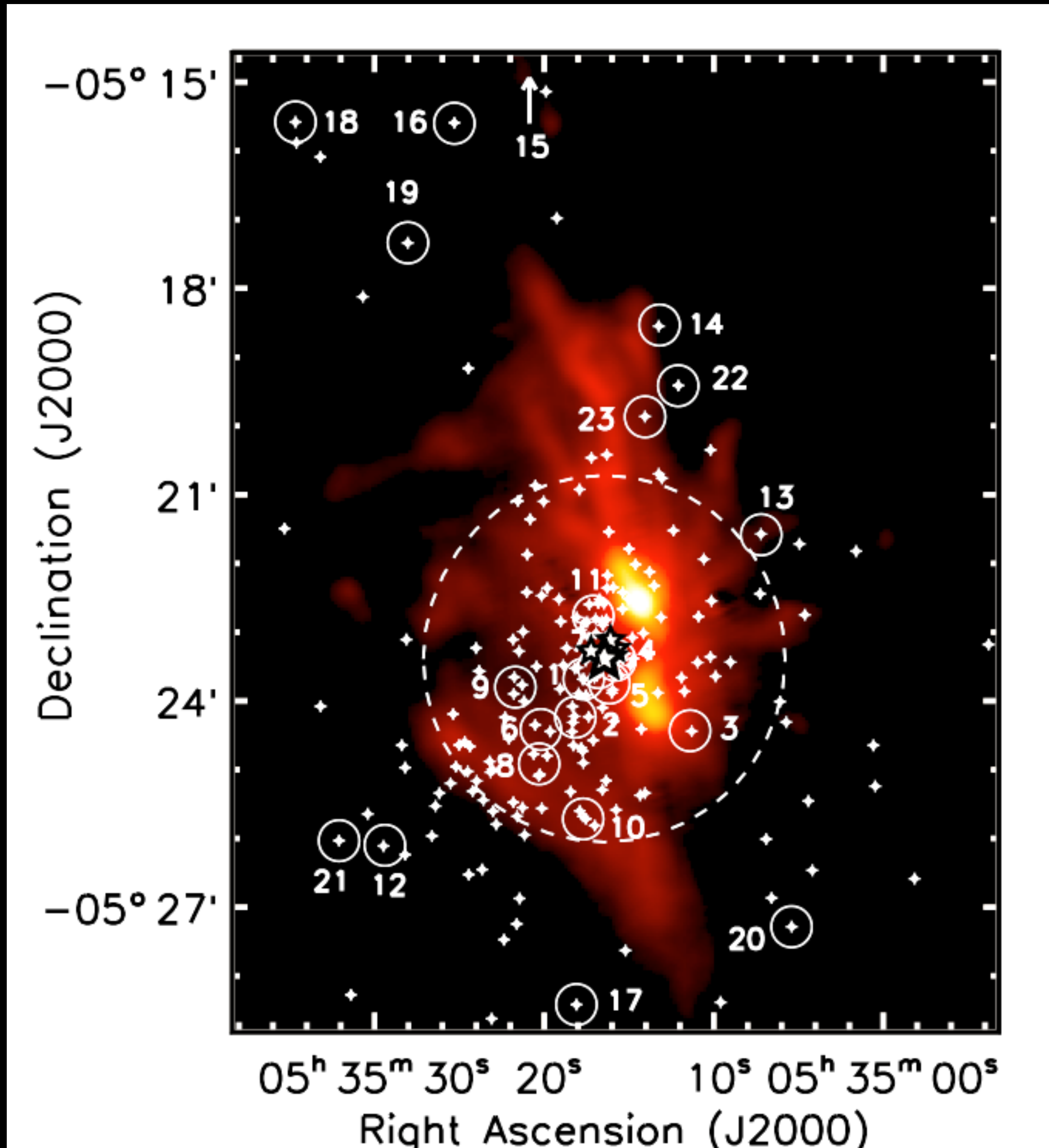
Separation: 1.1″ (440 AU)
Distance: 1 pc from θ^1C
Radii: 300AU, < 60AU



SMA 880μm emission, contours begin at 3σ
Mann & Williams (2009b)

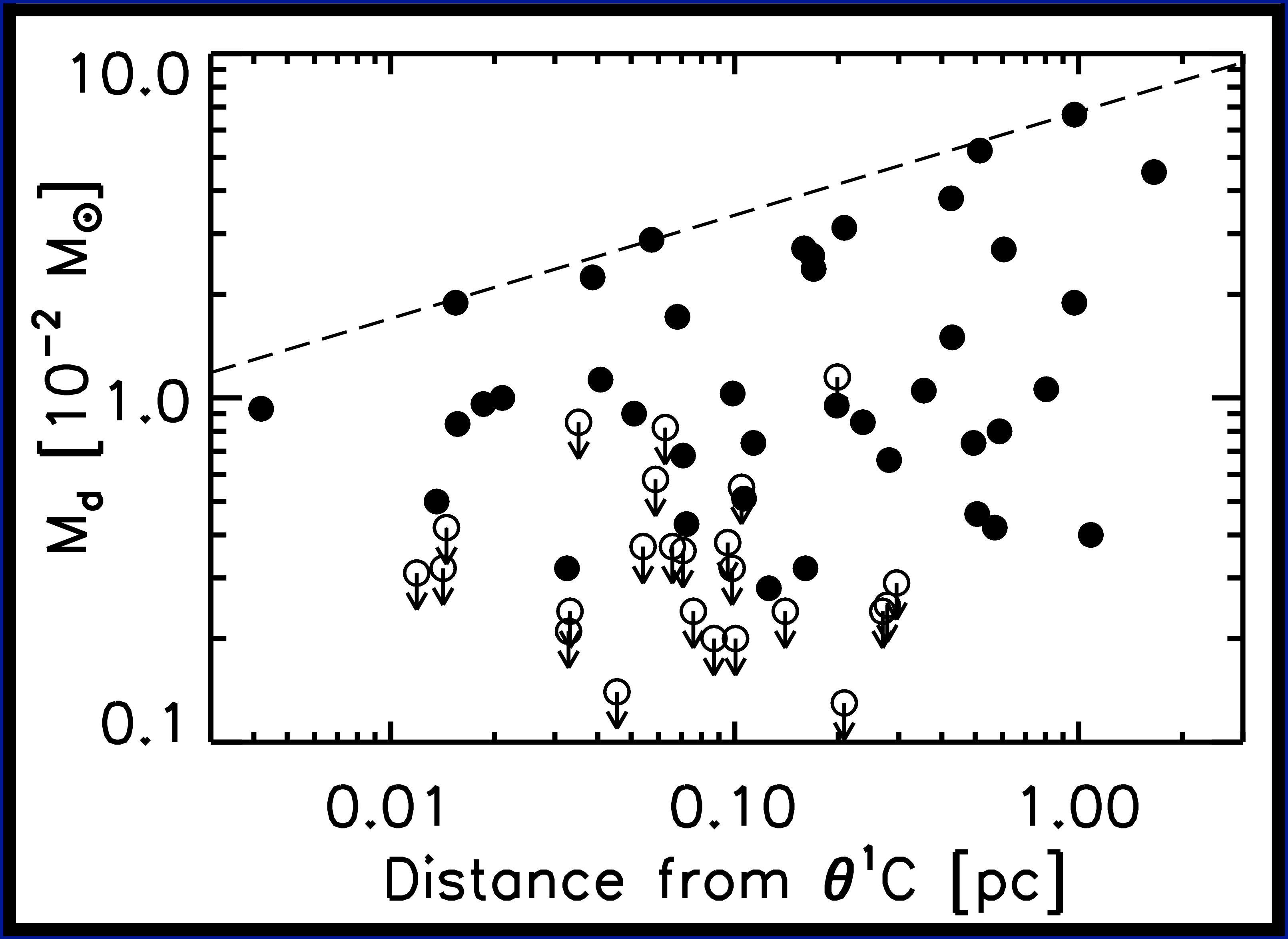
HST discovery image
Smith et al. (2005)

Disks in Orion Beyond the Trapezium Cluster



Large scale view of the Orion Nebula Cluster at 850 μm taken with SCUBA-JCMT (Johnstone & Bally 1999)

Disk Mass Dependence on Cluster Location



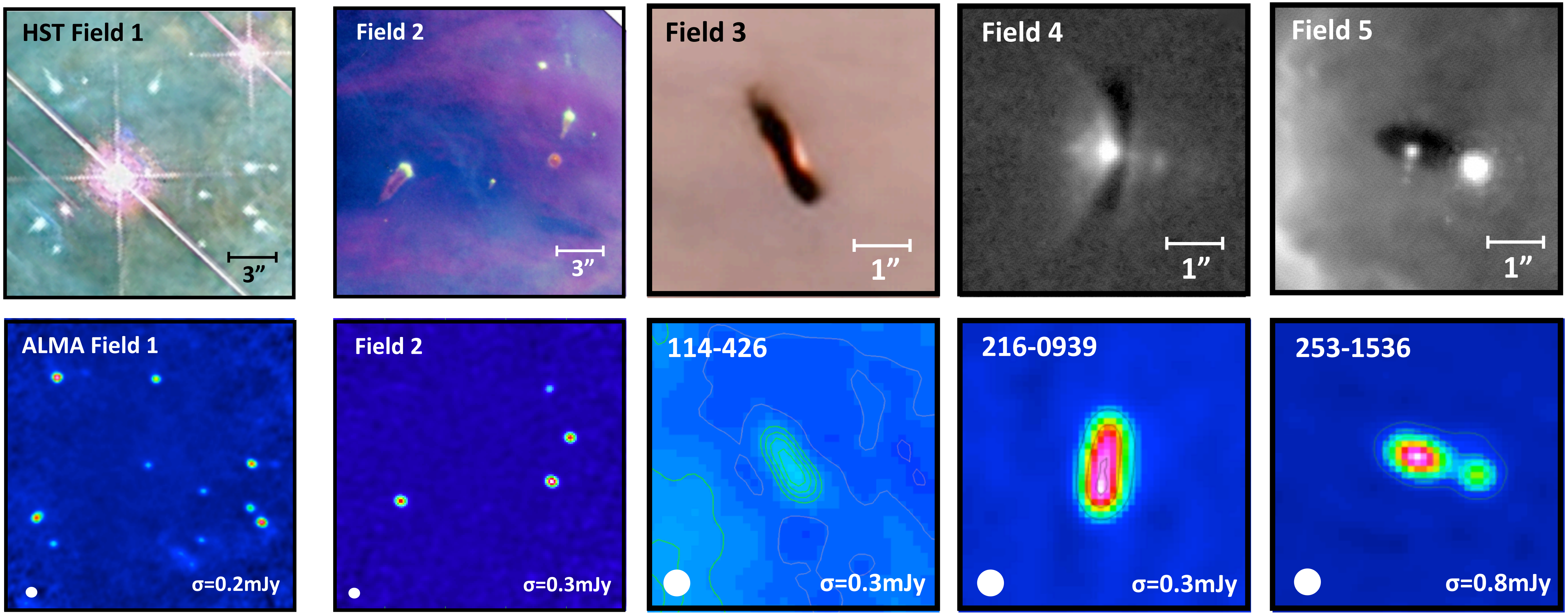
The formation of massive disks is not precluded in rich clusters

Consistent with their formation 1 Myr ago and subsequent photoevaporation by θ^1C

mass-loss negligible beyond 0.3 pc from θ^1C

Mann & Williams (2010)

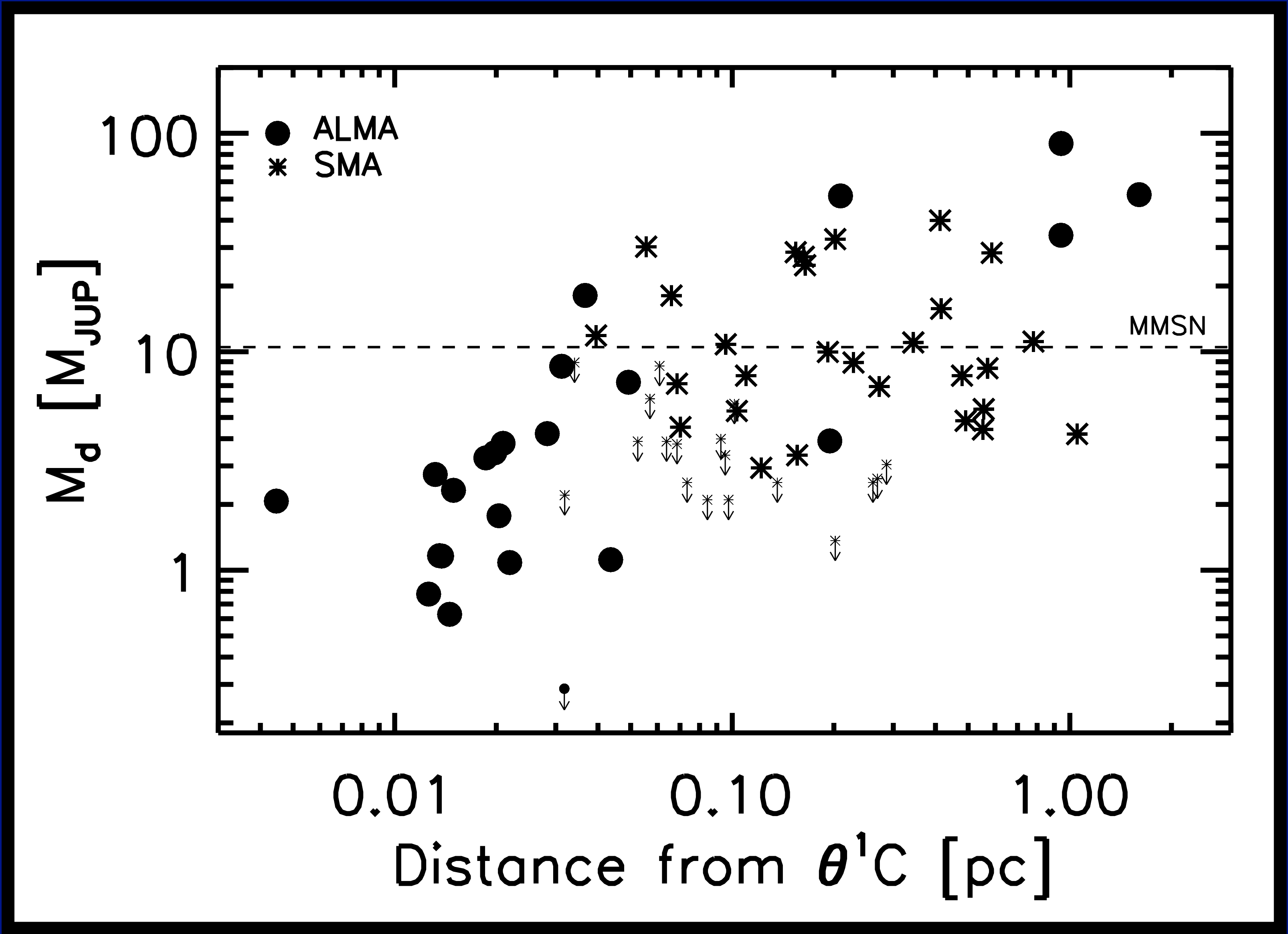
ALMA Early Science in Cycle 0: PI (R. Mann)



Mann et al. (2014)

James Di Francesco, Sean Andrews, Jonathan Williams, Doug Johnstone, John Bally, Meredith Hughes, Luca Ricci, Brenda Matthews

ALMA and SMA observations



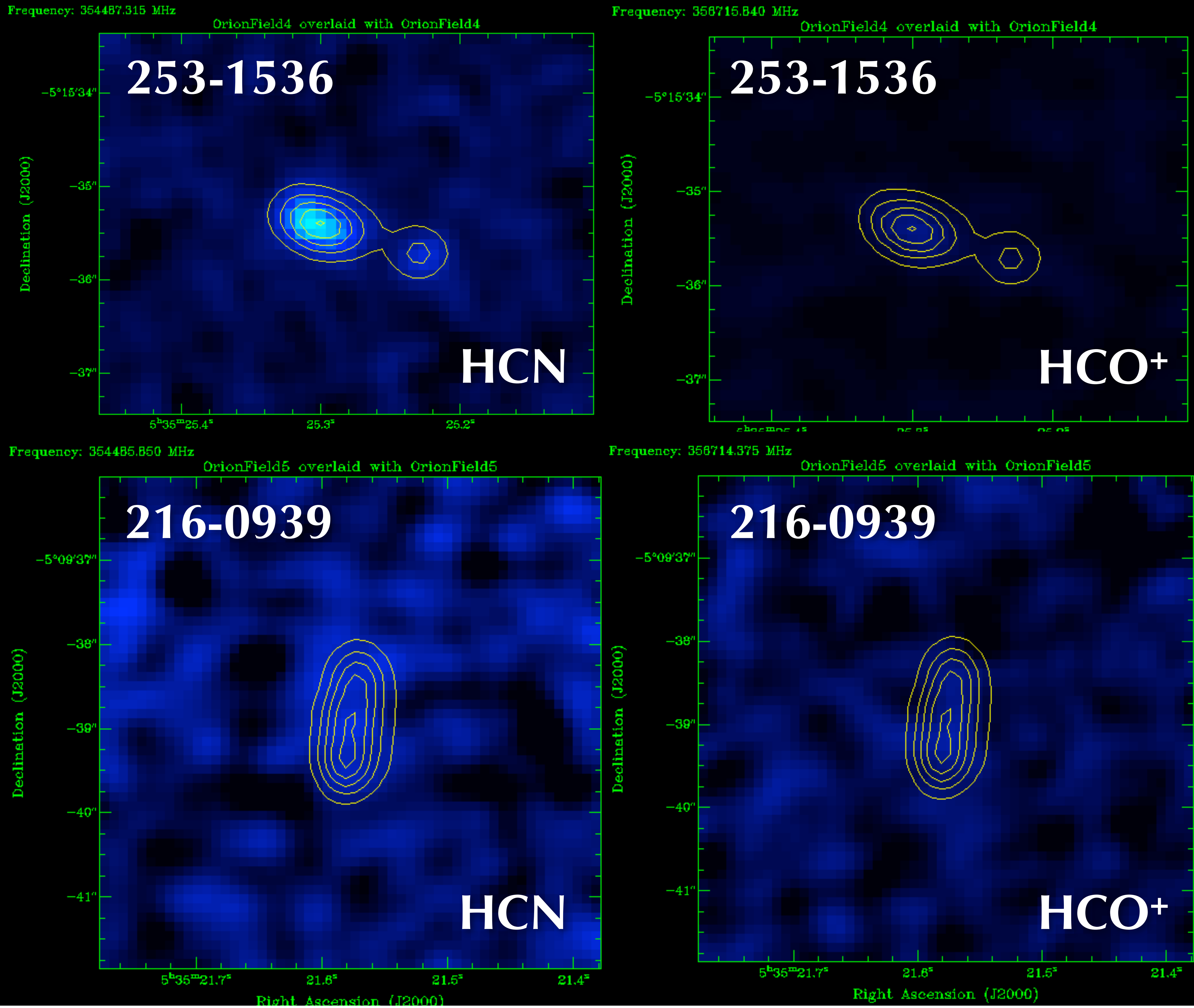
Probe sub-Jupiter mass disks near θ^1C with ALMA

Statistically significant correlation between disk mass and distance to θ^1C

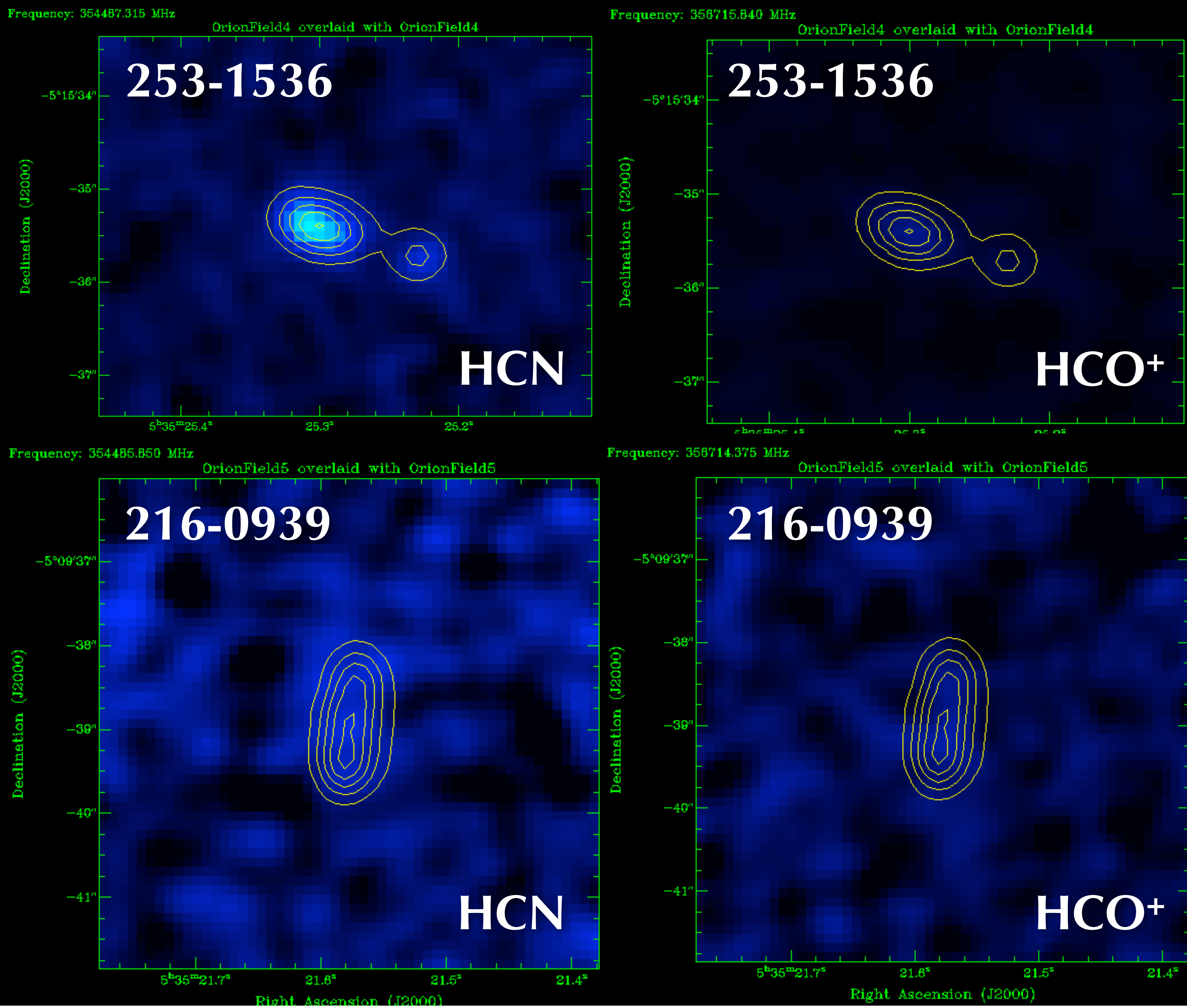
Lack of disks with masses appropriate to reproduce our Solar System within *0.03 pc* from θ^1C

Mann et al. (2014)

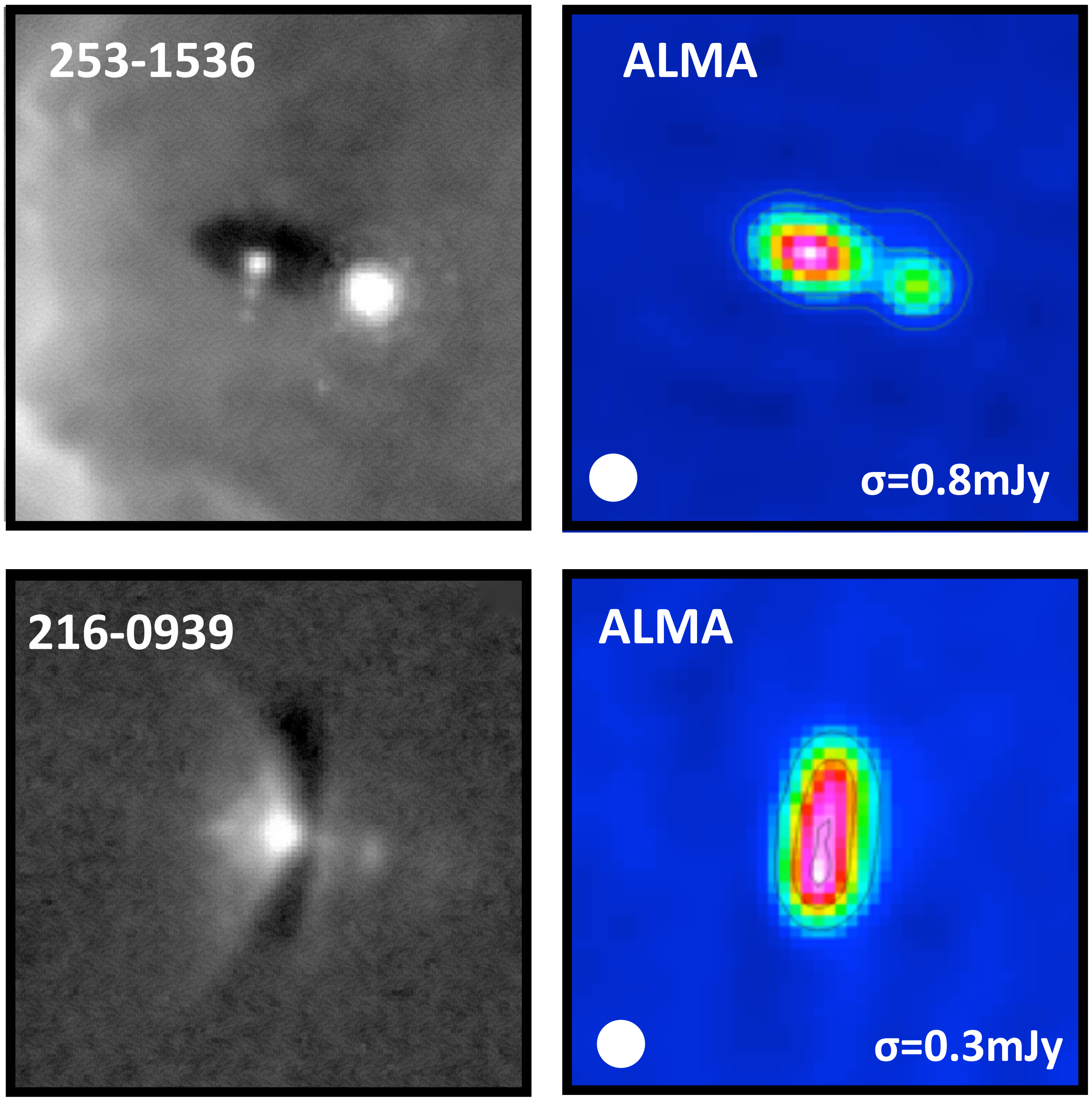
Gas in the Orion Disks



Gas in the Orion Disks



Gas in the Orion Disks



Dynamical masses of the stellar host through Keplerian rotation in the disk gas emission.

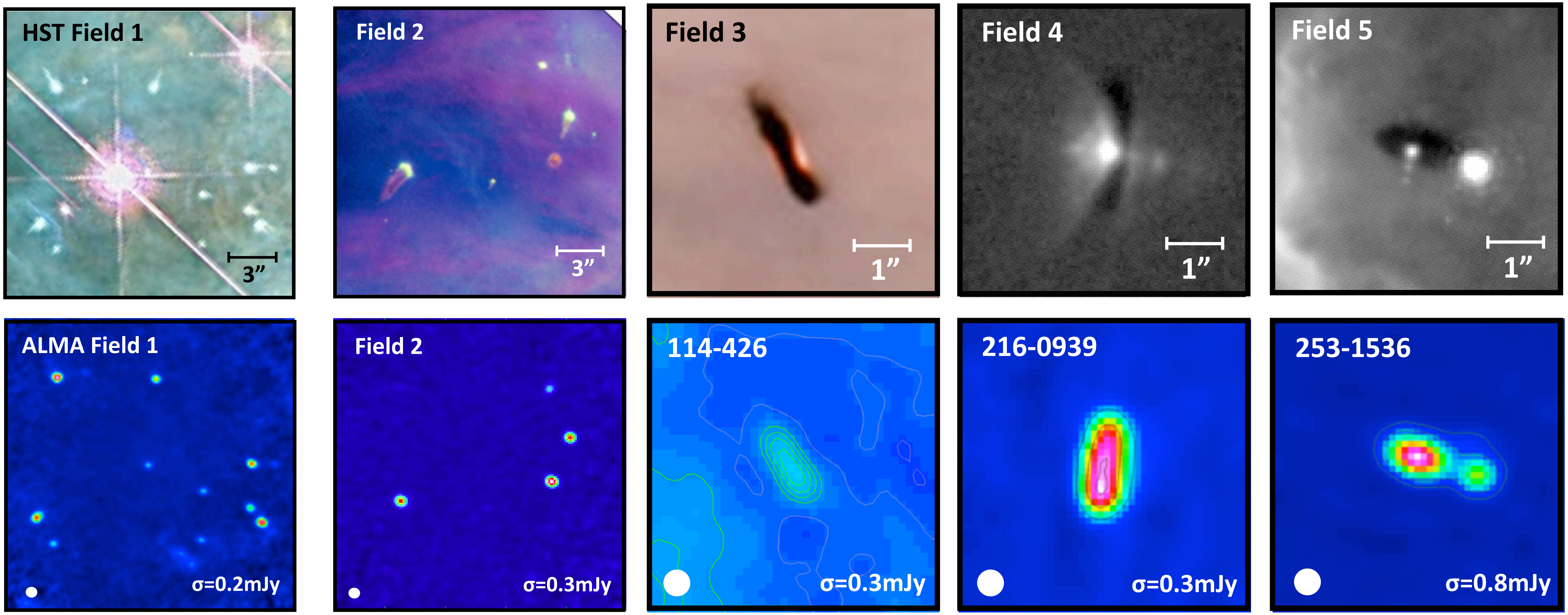
Compare Stellar and Disk Masses

$M_{primary} = 3\ M_{\odot} \pm 1\ M_{\odot}$

$M_{secondary} > 0.2\ M_{\odot}$

Williams et al. in prep

ALMA Cycle 1 observations: 300 protoplanetary disks in Orion



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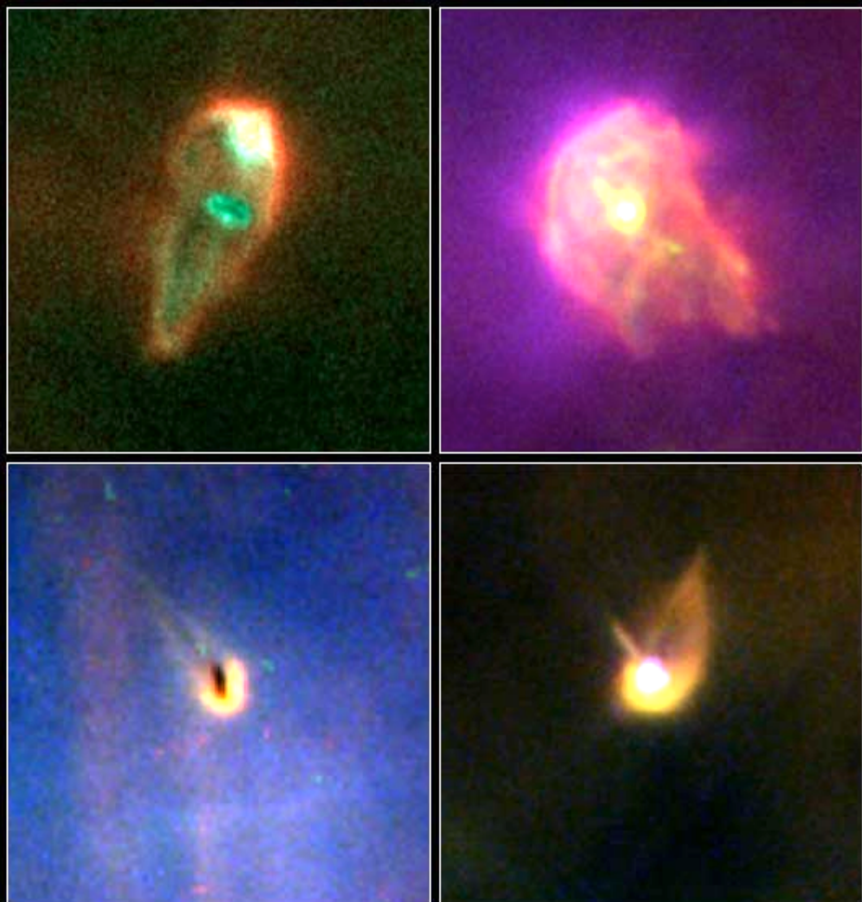

Summary

- Reduced disk masses in Orion near O-star due to loss of outer disks by UV photoevaporation

- Despite photoevaporation, the potential for planet formation is not lower than in regions that lack massive stars.

- Massive disks around binary stars discovered with the SMA

- Disk mass dependence on distance from O-star in Orion revealing the erosion of the disk mass distribution

- First clear detections of gas in Orion disks with ALMA


2015 ALMA Summer School
DRAO, Penticton, BC
4 - 8 May, 2015
in advance of the expected ALMA Cycle 3 proposal deadline
a place of mind
UBC
NRC·CNRC
Pre-registration and more information:
contact Brenda.Matthews@nrc-cnrc.gc.ca