SMA: From Galaxies to Circumstellar Disks

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SMA Advisory Committee - July 18, 2018

Outline

- Harvard's Astronomy 191
  - How I first got involved with the SMA
- Molecular emission in interacting galaxy NGC 3627
  - How do excitation conditions of CO(2-1) vary across large-scales?
  - Law+18, ApJ, under review
- Continuum survey of circumstellar disks in Serpens
  - Does high stellar surface density impact dust mass?
  - Law+17, AJ, 154, 6

Ay191 – initial involvement with SMA

- Ay191 in junior year at Harvard College, run by John Kovac
    - One of the half-semester projects incorporated SMA data
- Continued working on Ay191 project after 2017 graduation
    - NGC 3627
- Collaboration with Luca Ricci began the summer after Ay191 on a different SMA project
    - Serpens
- Remote and on-site observing

NGC 3627 (M66)

- Barred spiral galaxy
- Distance ~ 11 Mpc
- Inclination = 61°
- Numerous multi-wavelength studies from X-ray to radio continuum
- Active star formation in nucleus and bar ends

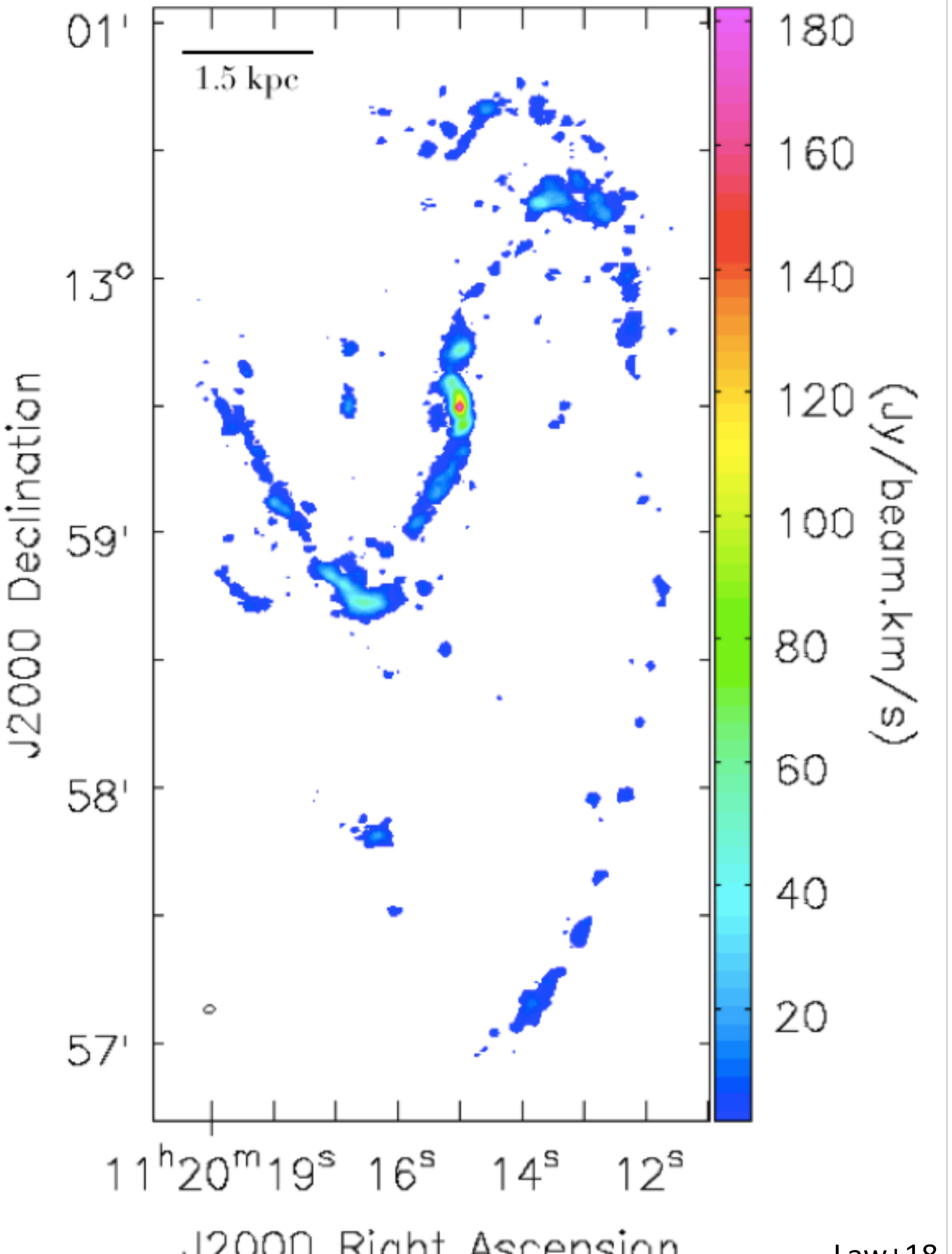
- Goal: To study excitation and mass (H_2) distribution by comparing the $^{12}CO(2-1)$ data from the SMA with the $^{12}CO(1-0)$ data from BIMA

Image Credit: NASA/JPL/ESA

de Vaucouleurs+91, Warren+10, Casasola+11, Lee & Jang 13, Beuther+17

Large-scale $^{12}CO(2\text{-}1)$ emission

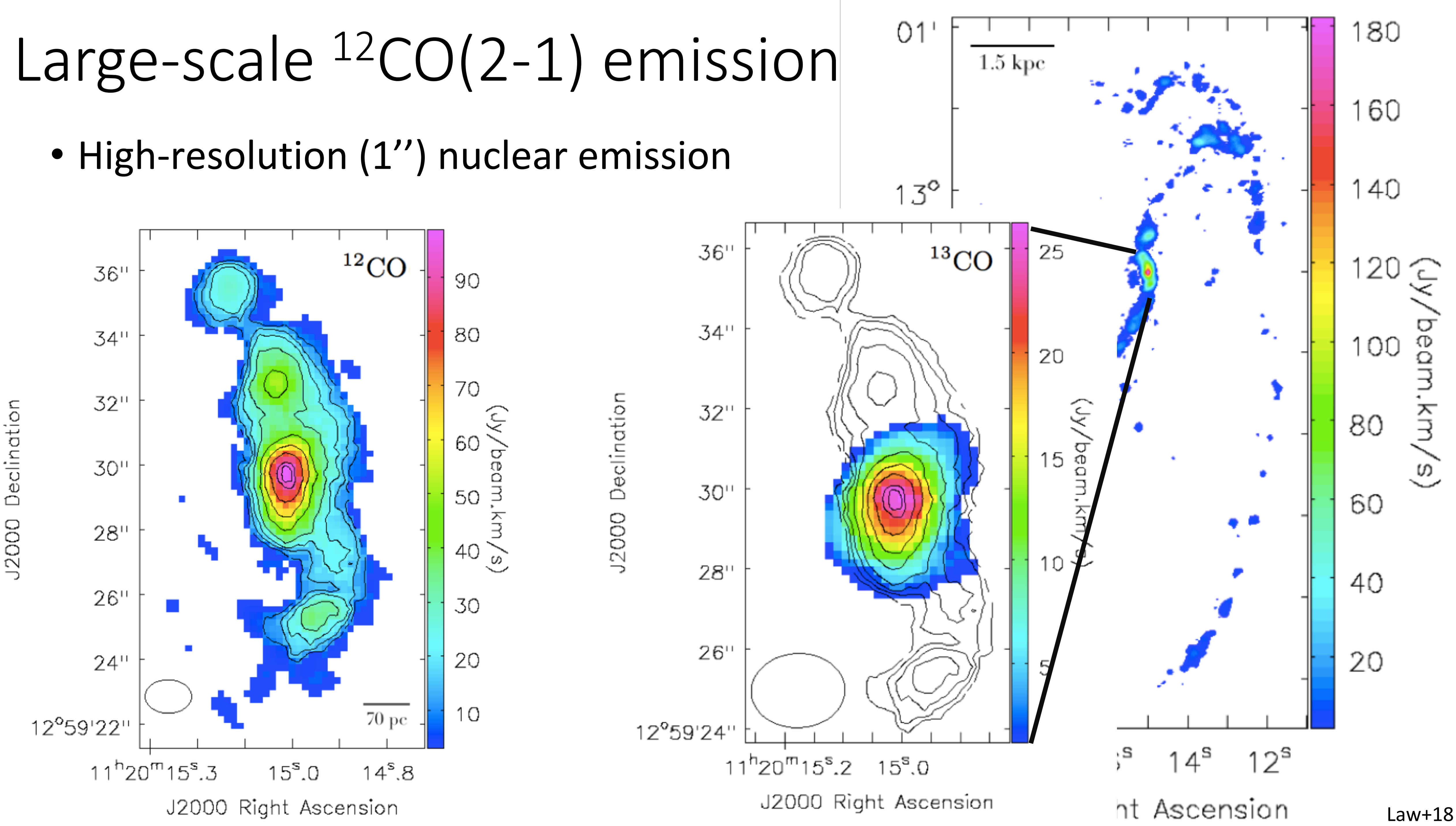
- Taken in sub-compact, compact, and extended configurations in 2016-2017
- Mosaic of 32 pointings
- Resolution of 2'' over the whole galaxy
  - Spatial scales of molecular clouds (100pc)
- Most complete, in terms of resolution and spatial coverage, $^{12}CO(2\text{-}1)$ map



Law+18

Large-scale $^{12}CO(2\text{-}1)$ emission

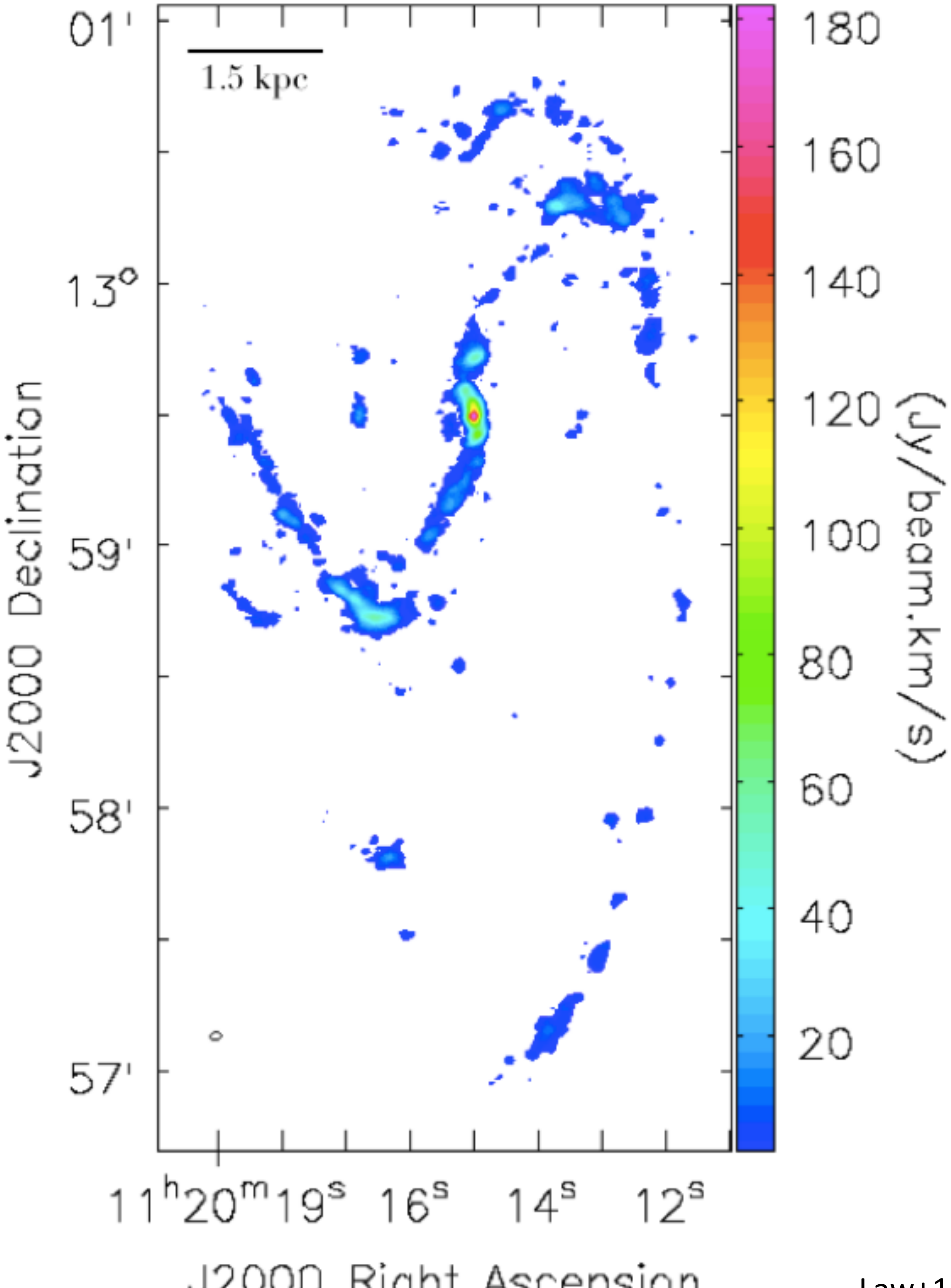
- High-resolution (1'') nuclear emission



Law+18

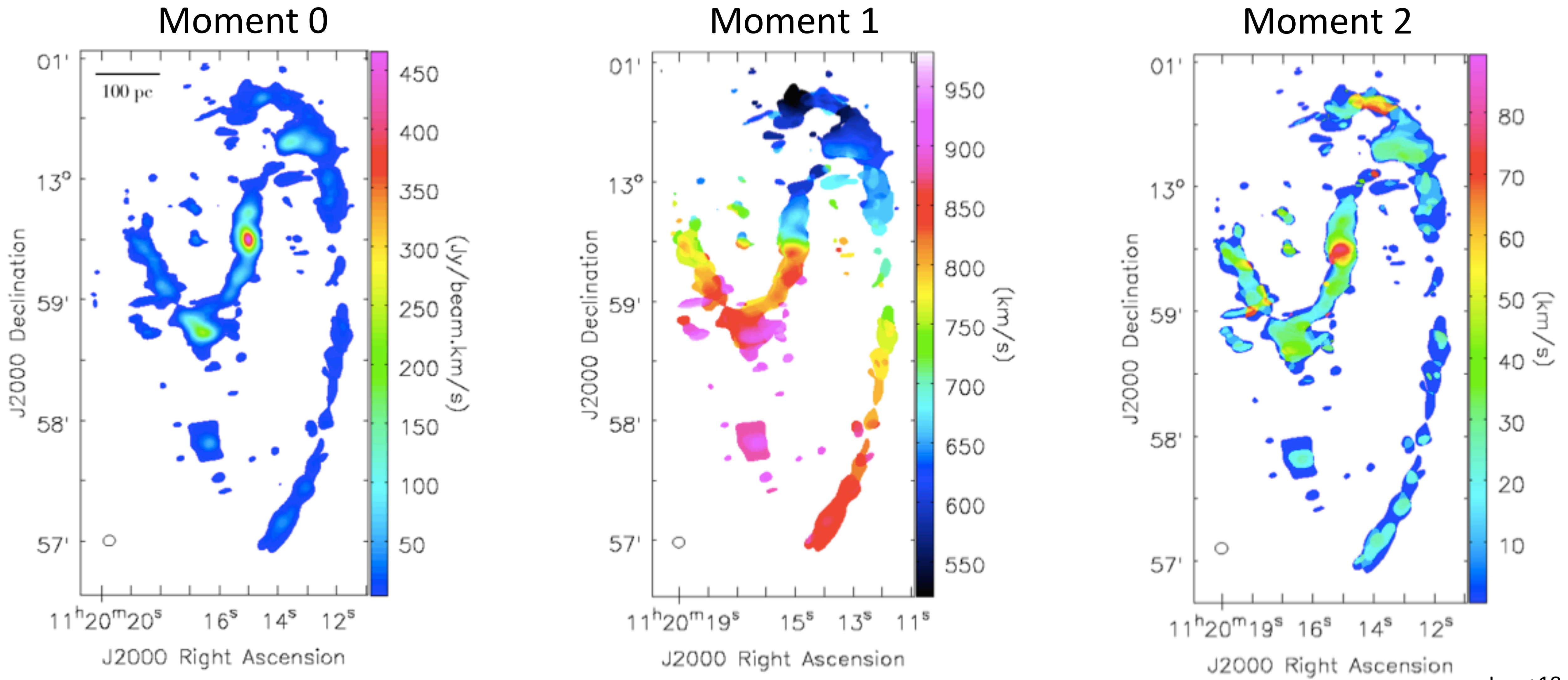
Large-scale $^{12}CO(2\text{-}1)$ emission

- High-resolution (1'') nuclear emission
- But we lose substantial large-scale emission in arms and inter-arm regions…



Law+18

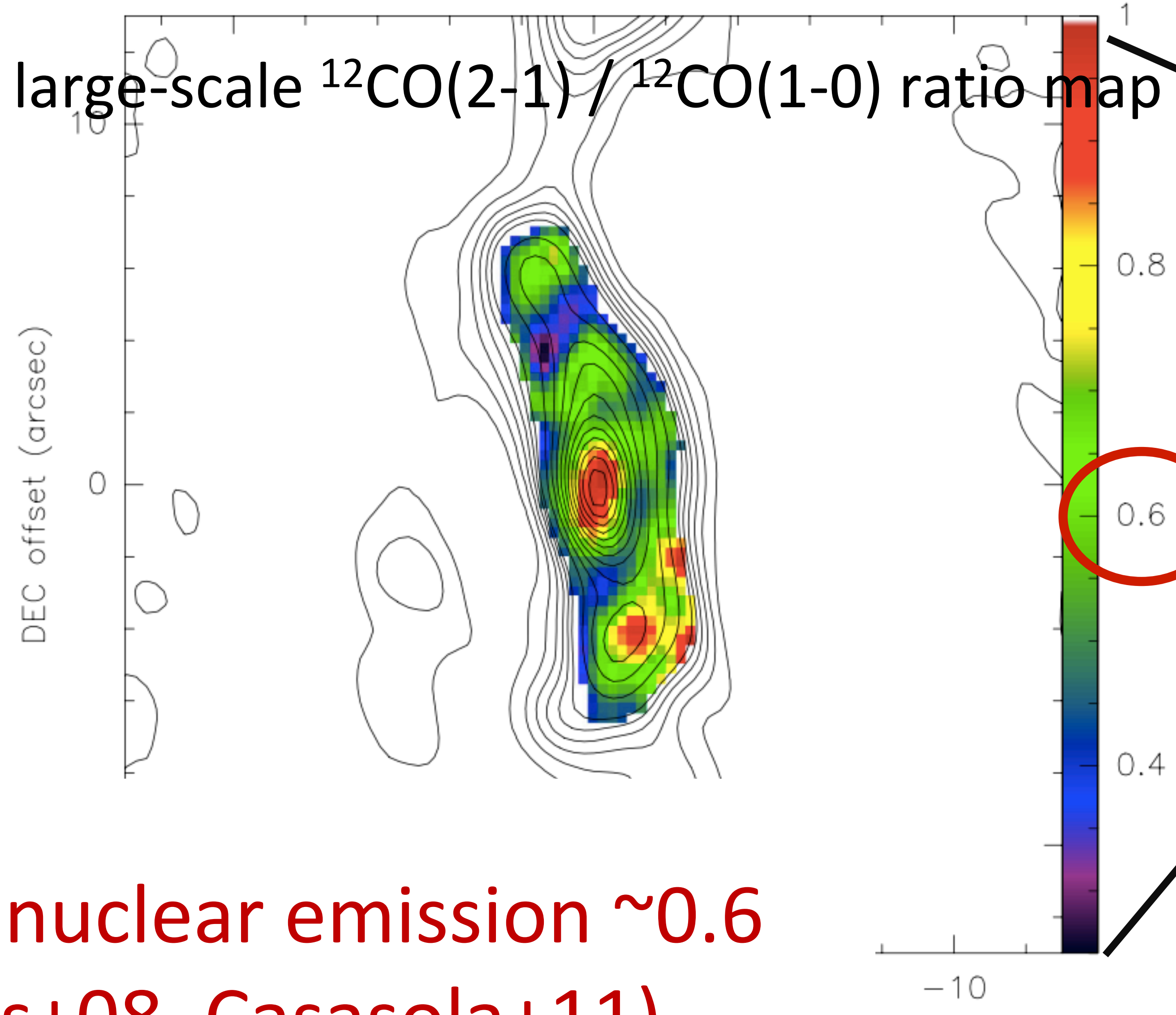
With 6'' *uv*-taper, spiral arms and inter-arm regions are clearly visible



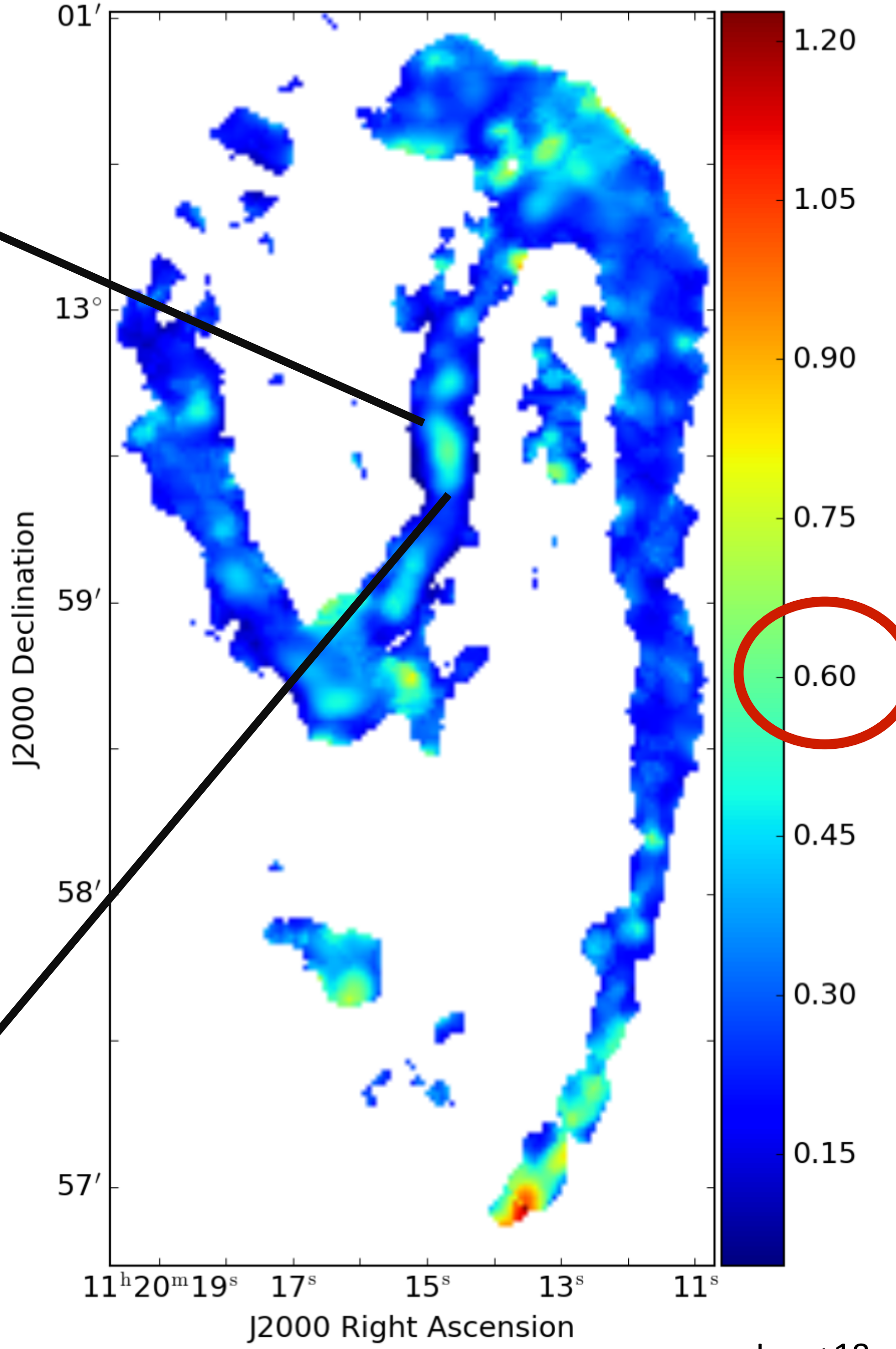
Law+18

Line ratio map

- First large-scale $^{12}CO(2\text{-}1)$ / $^{12}CO(1\text{-}0)$ ratio map



Casasola+11

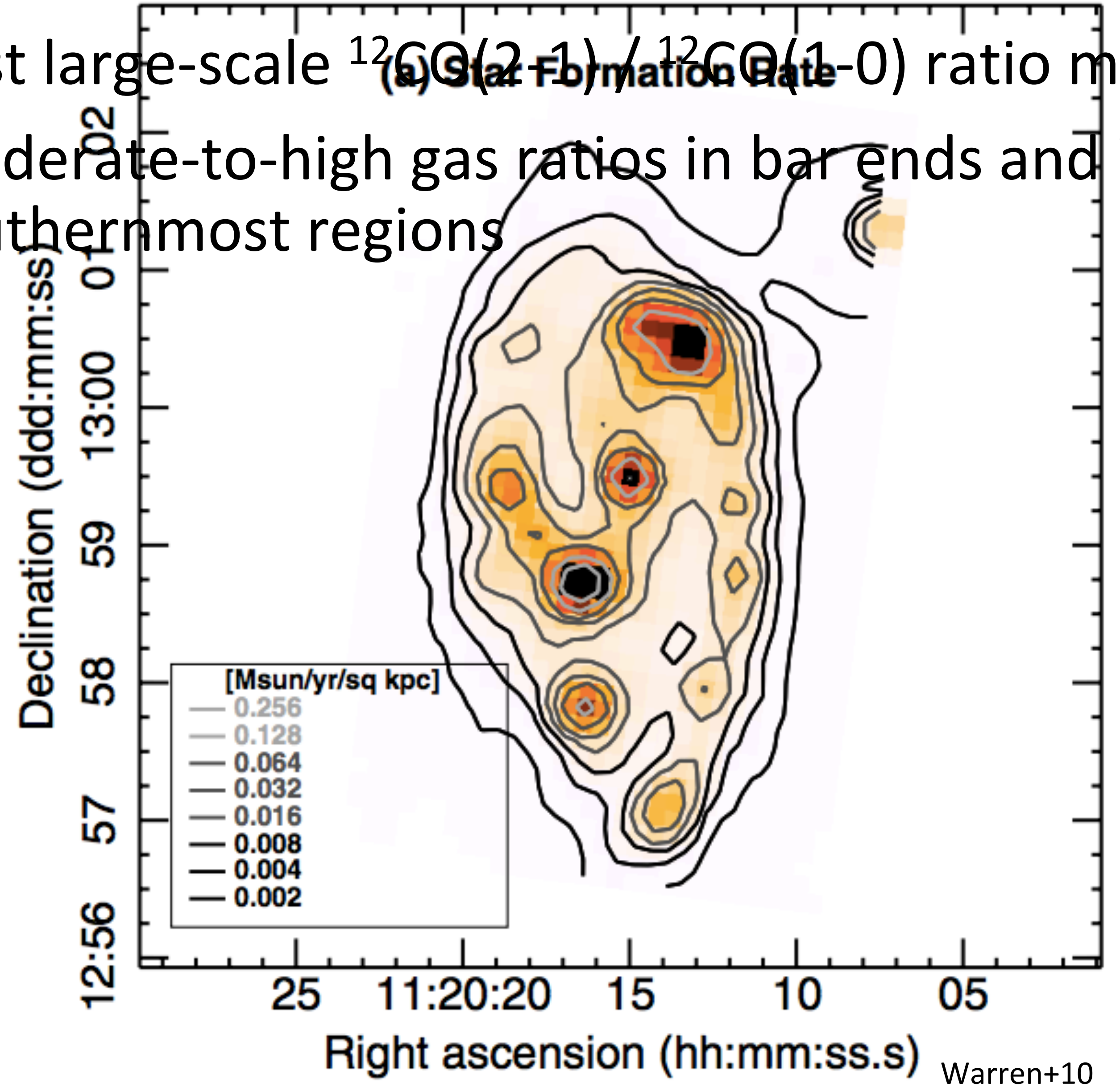


Law+18

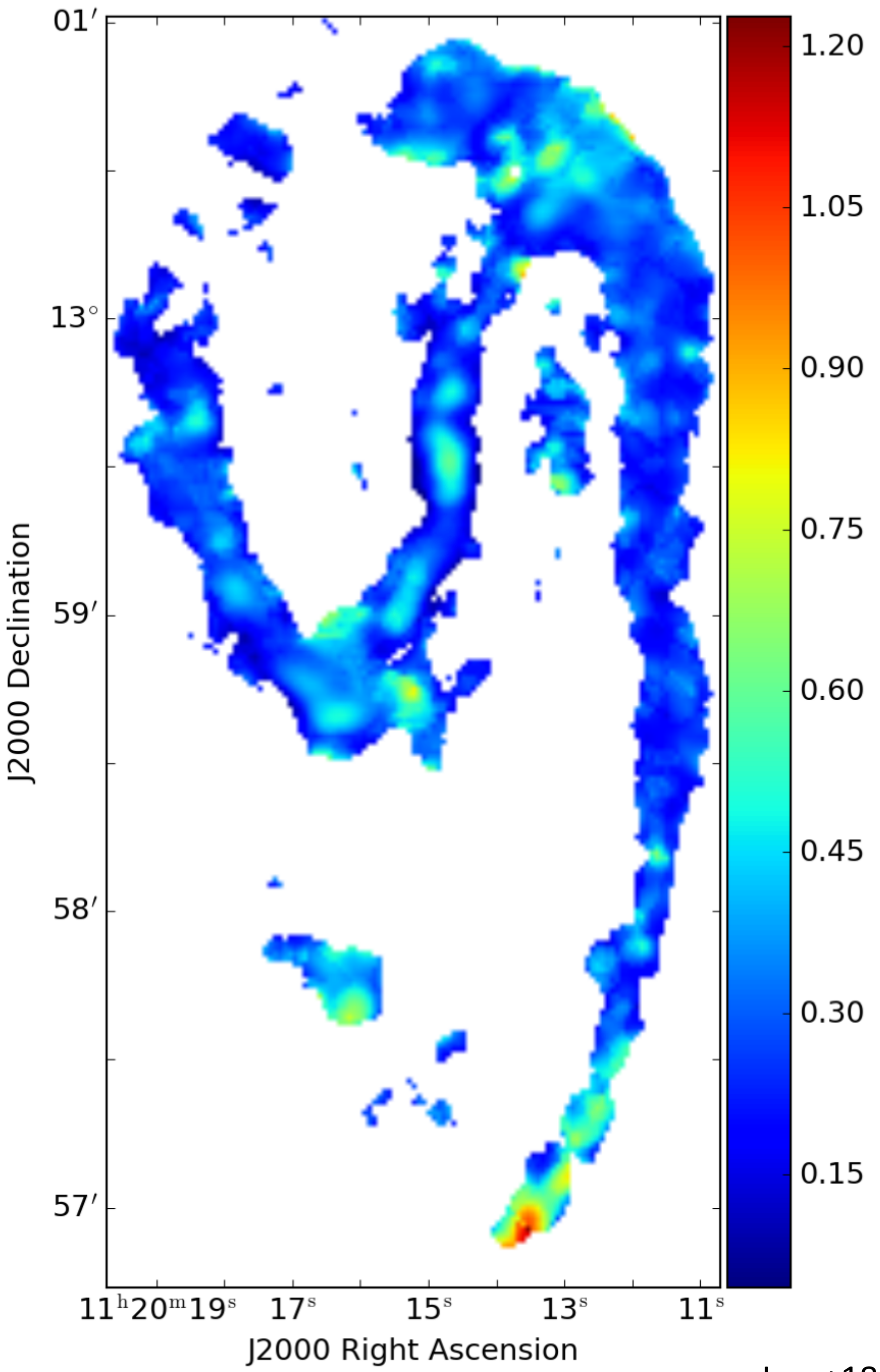
Bulk nuclear emission ~0.6 (Krips+08, Casasola+11)

Line ratio map & SFR

- First large-scale ^{12}CO(2-1) / ^{12}CO(1-0) ratio map
- Moderate-to-high gas ratios in bar ends and in southernmost regions



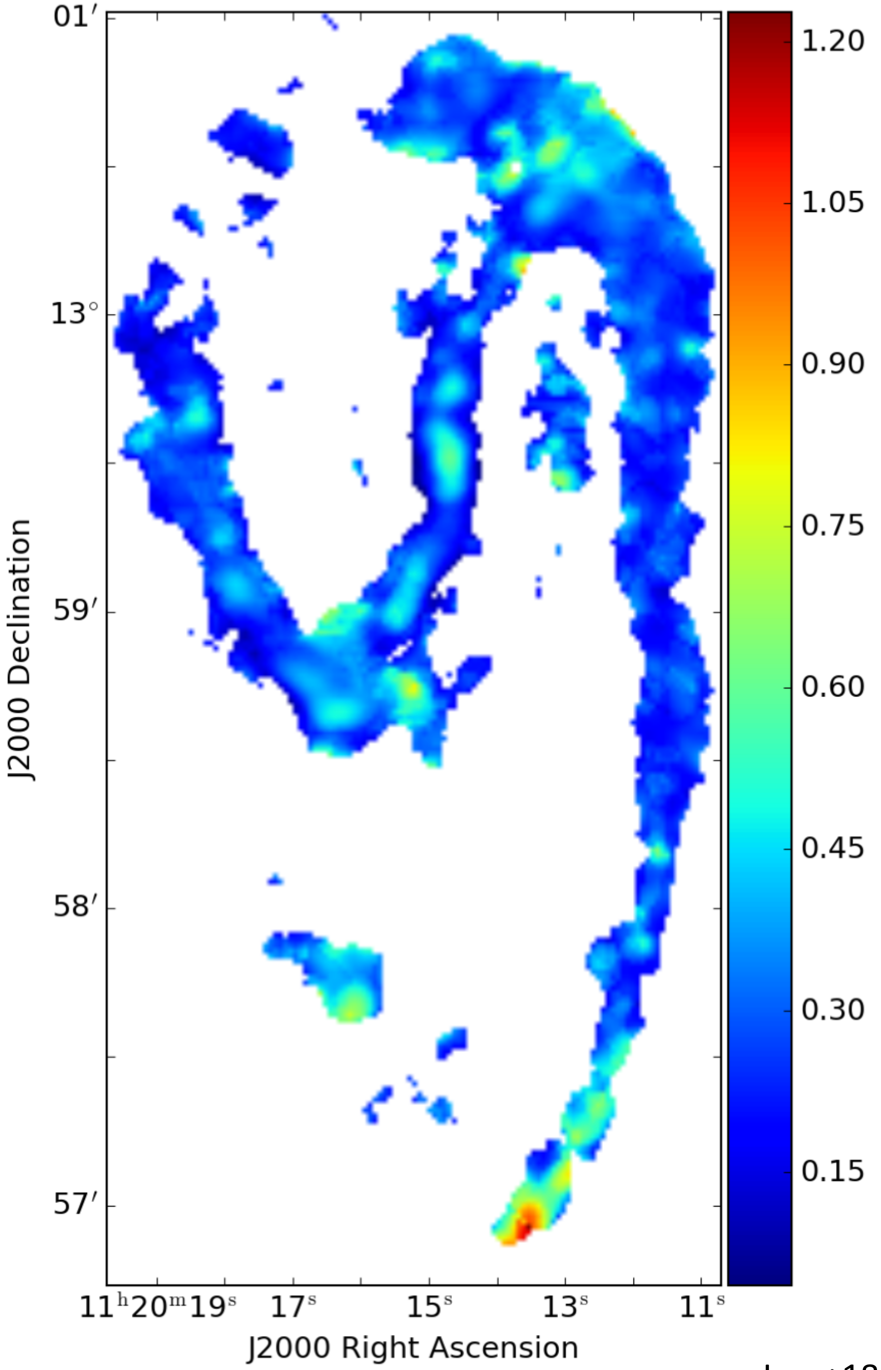
Warren+10



Law+18

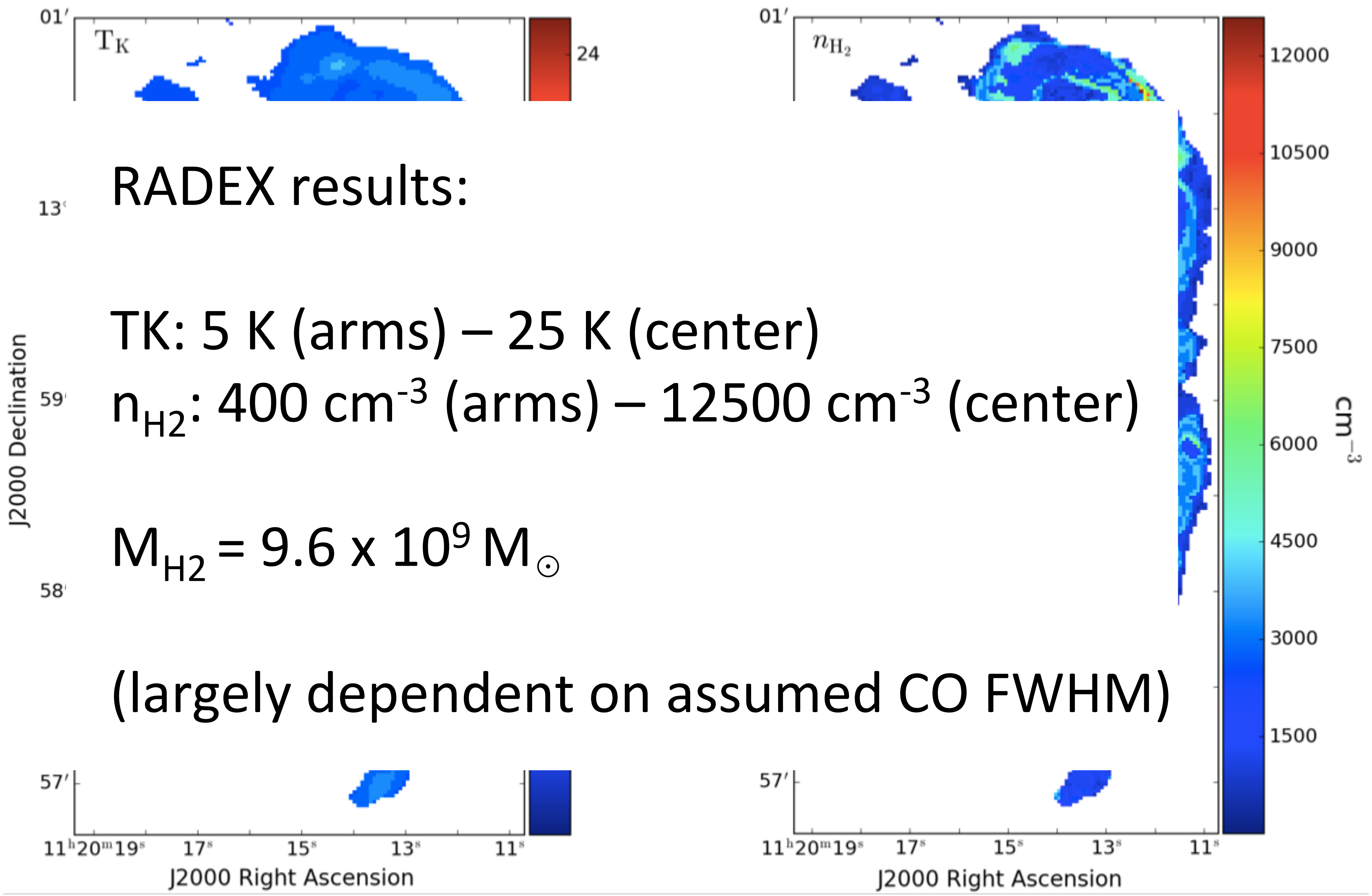
Line ratio map & SFR

- First large-scale $^{12}CO(2\text{-}1)$ / $^{12}CO(1\text{-}0)$ ratio map
- Moderate-to-high gas ratios in bar ends and in the southernmost regions
- Use RADEX code to estimate n_{H2} and T_K



van der Tak+07, Zhang+14; Lu+17

Law+18



RADEX results:

TK: 5 K (arms) – 25 K (center)

n_{H2}: 400 cm^{-3} (arms) – 12500 cm^{-3} (center)

$M_{H2} = 9.6 \times 10^9 M_\odot$

(largely dependent on assumed CO FWHM)

Law+18

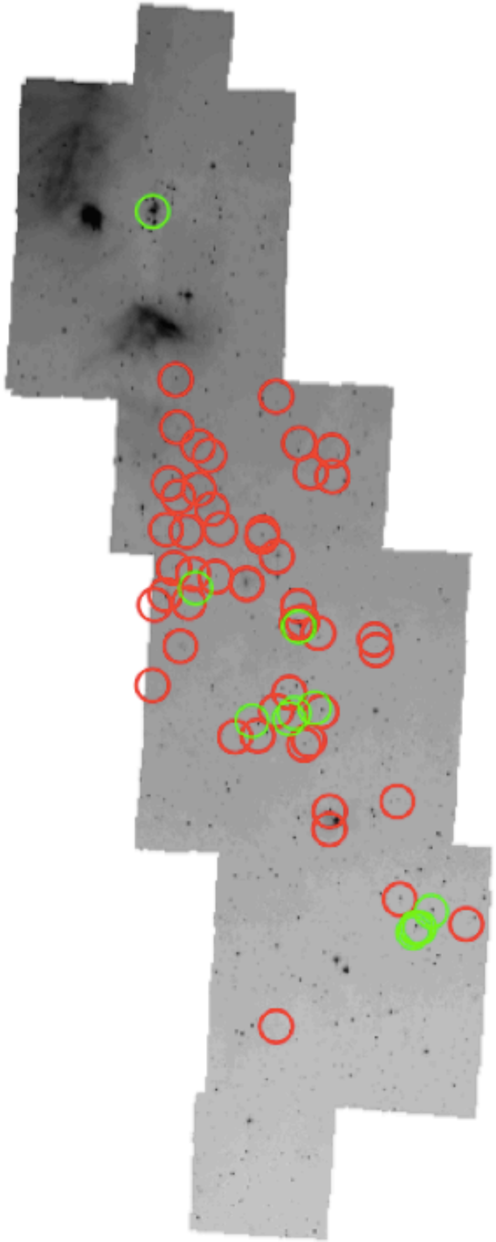
Quick summary

- Large ^{12}CO(2-1) survey of NGC 3627
  - Conspicuous emission in spiral arms and inter-arm regions
- Quantitative understanding of variations in ^{12}CO(2-1) / ^{12}CO(1-0) line ratio
- Spatial maps of kinetic temperature and H_2 number density
  - Refine H_2 mass estimates
  - Correlations between SFE and physical parameters
- Large-scale ^{12}CO(2-1) rotation curve

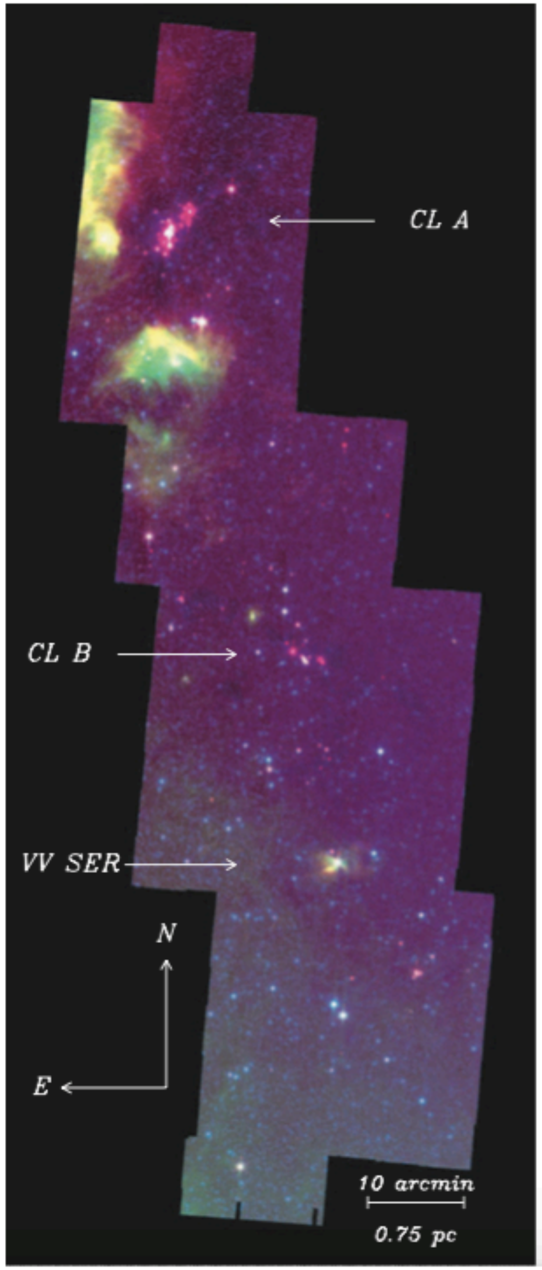
Serpens star-forming region

- Distance = 415 pc
- Age = 1 – 3 Myr
- Contains several hundreds of YSOs
- Relatively high stellar surface density
  - Does this lead to tidally-disrupted disks?
  - If so, comparisons with lower stellar density regions of comparable age should reveal lower Serpens masses

- Goal: To obtain an inventory of disk masses in a dense stellar cluster and compare with other well-studied star-forming regions



Spitzer, 8 μm

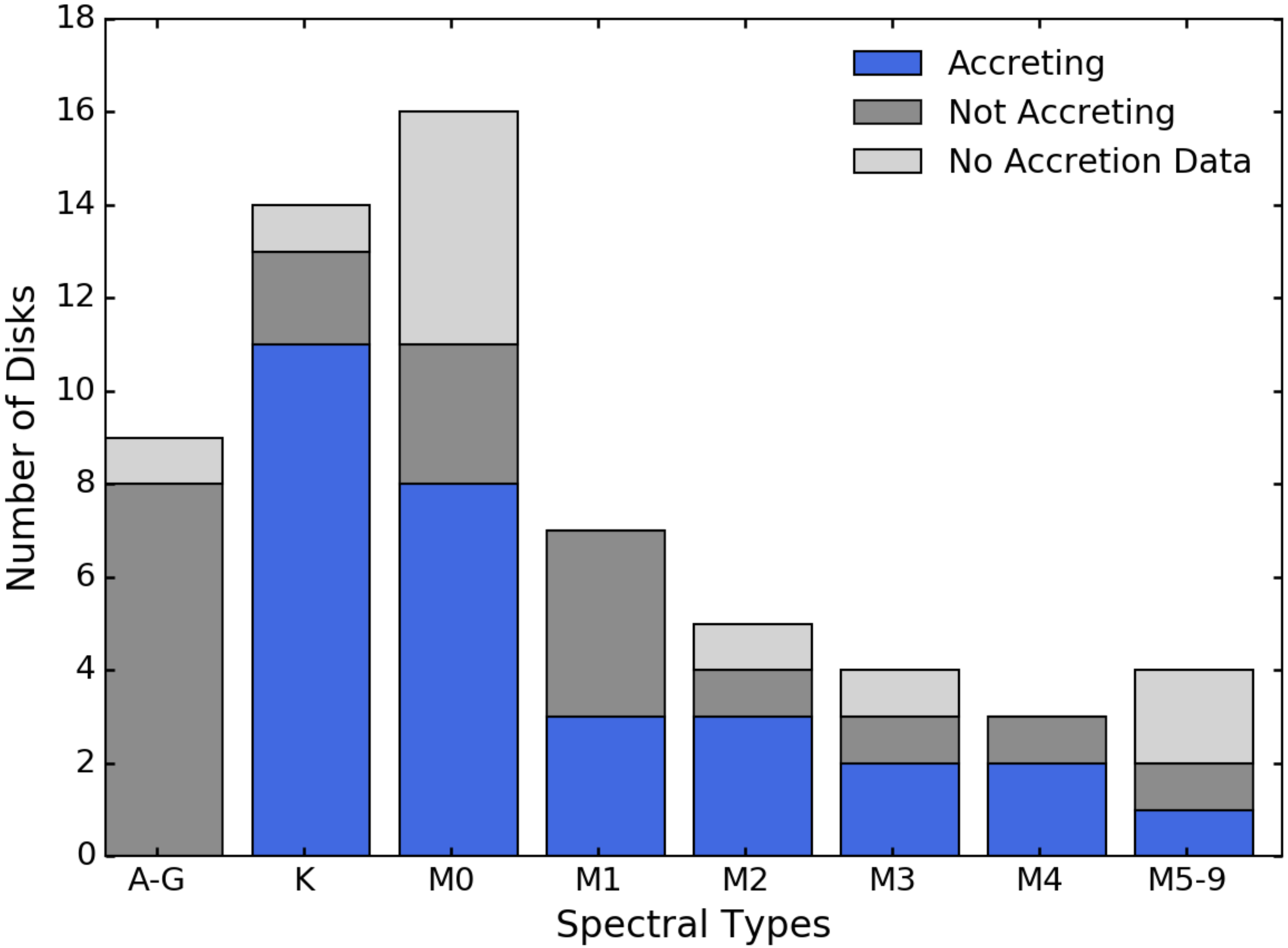


Harvey+2007

Dzib+2007, Eiroa+08, Oliveira+13, Megeath+16

SMA observations: sample selection

- 1.3 mm continuum survey
- 50% of known Class II YSOs
- Known stellar masses and luminosities
- Observations in compact configuration during March – June, 2016
- Sensitive to disks with $M_{dust} \geq 10\ M_\oplus$

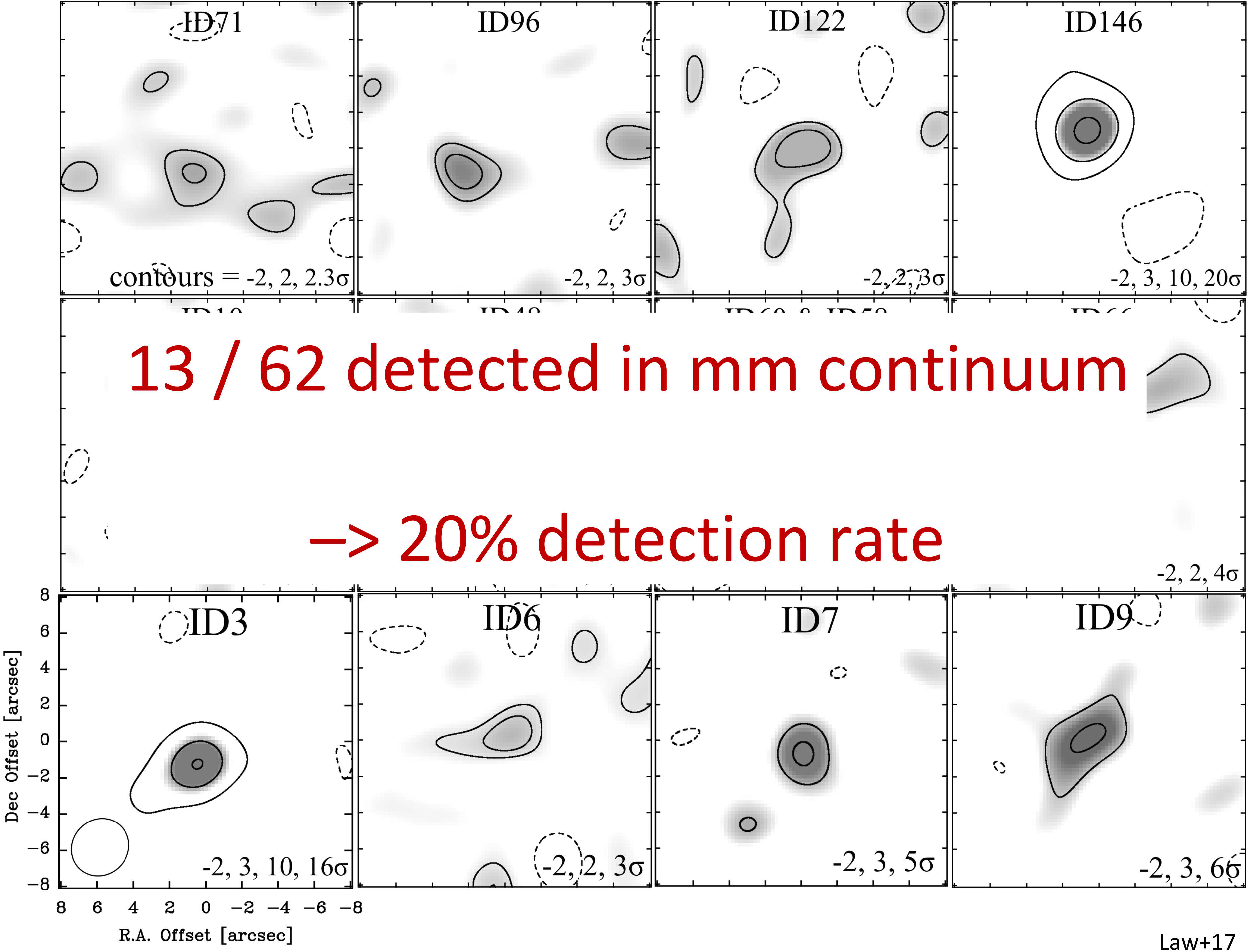


Oliveira+13

Law+17

13 / 62 detected in mm continuum

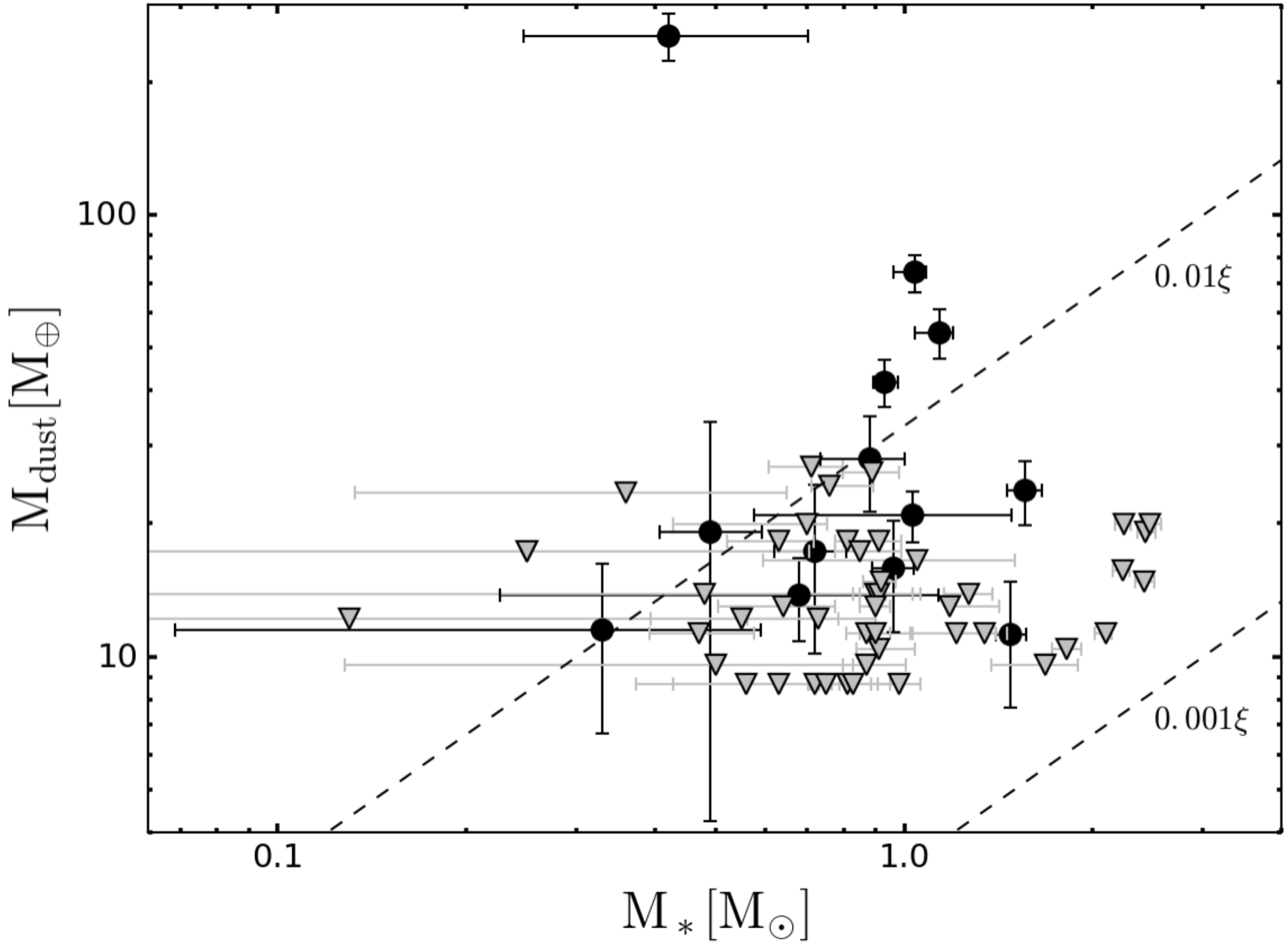
–> 20% detection rate



Law+17

Calculating dust masses

- Dust masses from:
  - 10 – 260 $M_\oplus$
- Median:
  - $5.1_{-4.3}^{+6.1}\ M_\oplus$
- No trend between stellar mass and dust mass
  - Likely because of high fraction of non-detections

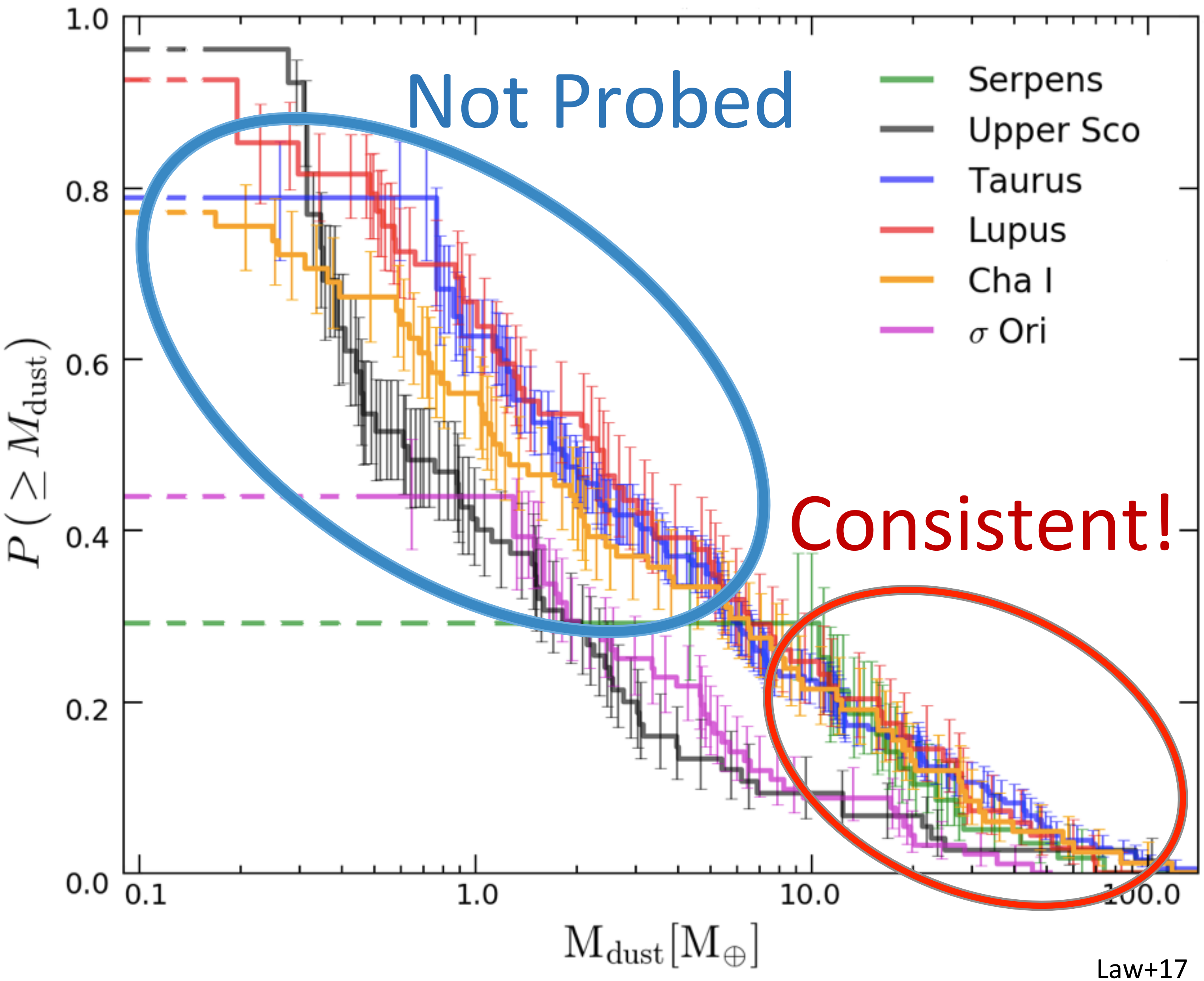


Ansdell+17

Law+17

Serpens has dust masses consistent with age

- CDF of Serpens is consistent with other young (1 – 3 Myr) regions
  - Caveat:
    - SMA survey only probed down to 10 $M_\oplus$
- Likely need higher stellar surface density for disk truncation



Law+17

Quick summary

- Detect thermal emission in 13 / 62 Serpens disks
- No statistical difference between Serpens and Taurus, Cha I, or Lupus
  - No observed $M_{dust} – M_*$ trend in Serpens
  - Require higher stellar density for disk tidal truncation (e.g., Rosotti+14)
- Fraction of Serpens disks with $M_{dust} \geq 10\ M_\oplus$ is less than 20%
  - Giant planet formation rare or substantially progressed after few Myrs
- ALMA proposal to detect lower mass disks

NGC 3627

- $^{12}CO(2\text{-}1)$ survey of NGC 3627
- Quantitative understanding of variations in $^{12}CO(2\text{-}1)$ / $^{12}CO(1\text{-}0)$ line ratio
- Spatial maps of T_K and n_{H2}
  - Refined H_2 mass estimates
  - Correlations between SFE and physical parameters
- Large-scale $^{12}CO(2\text{-}1)$ rotation curve

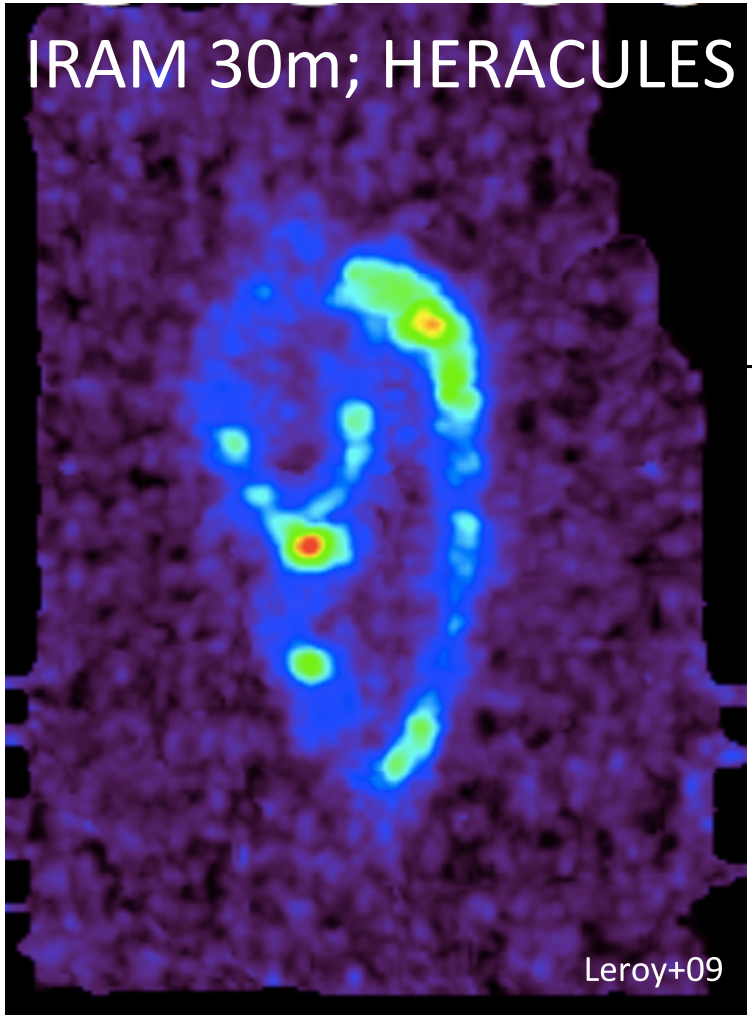
Law+18, ApJ, under review

Serpens

- Detected thermal emission in 13 / 62 Serpens disks
- No statistical difference between Serpens and Taurus Cha I, or Lupus
- Fraction of Serpens disks with $\geq 10\ M{\downarrow}\oplus$ is less than 20%
  - Giant planet formation rare or substantially progressed after few Myrs

Law+17, AJ, 154, 6

Appendix Slide 1: Calculating $R_{21,10}$



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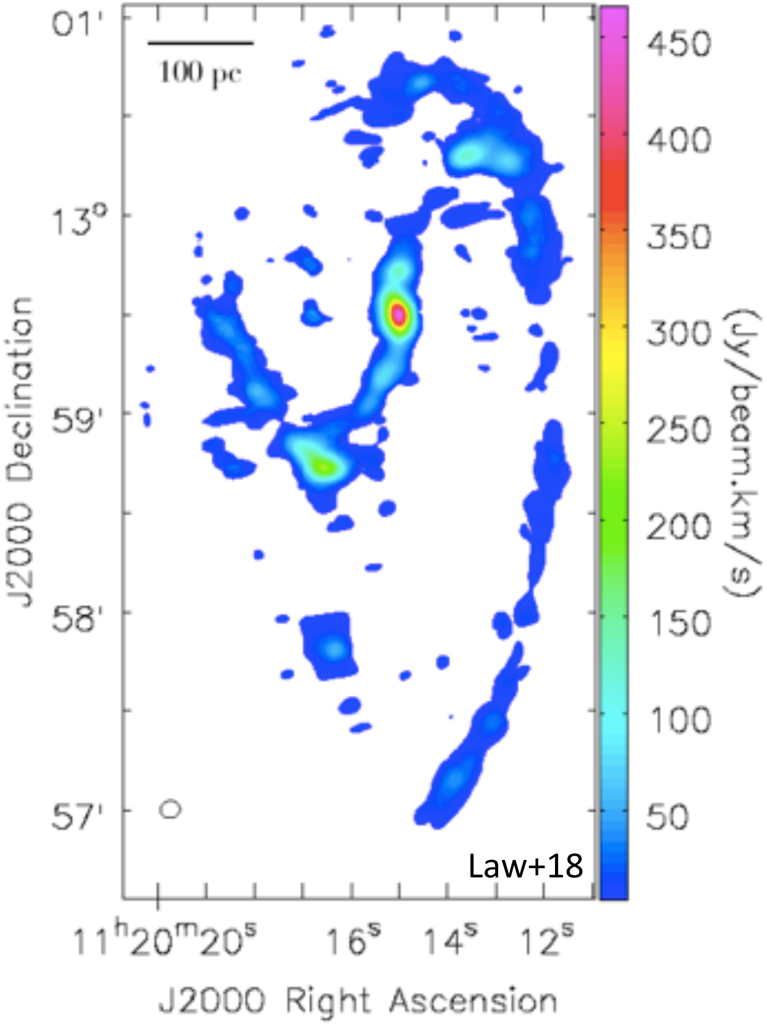
SMA



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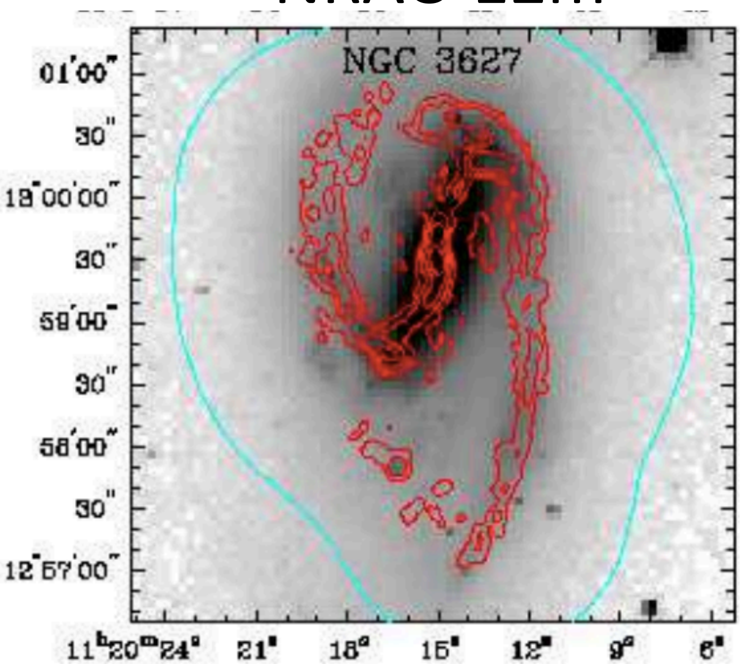
BIMA SONG +
NRAO 12m



Regan+01, Helfer+03

^{12}CO(2-1)

^{12}CO(1-0)

Appendix Slide 2: Calculating dust masses

- Adopt the standard continuum flux to dust mass prescription:

$$M_{\mathrm{dust}} = \frac{F_\nu d^2}{\kappa_\nu B_\nu(T_{\mathrm{dust}})}$$

Hildebrand 1983, Beckwith+90

- Scale dust temperature with stellar temperature:

$$T_{\mathrm{dust}} = 25\,\mathrm{K} \times (\mathrm{L}_*/\mathrm{L}_\odot)^{0.25}$$

Andrew+13