NGVLA Observations of Initial Conditions in High-Mass Star-Forming Clouds

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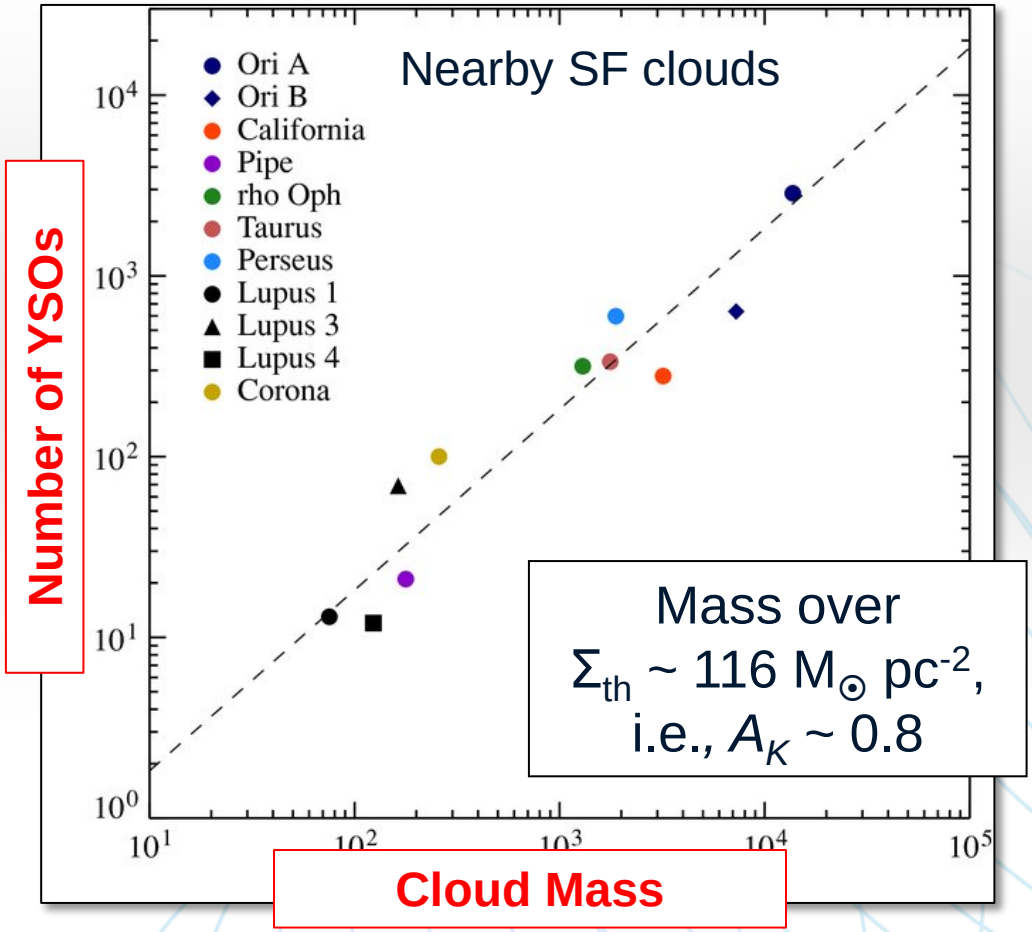
Stars form out of dense molecular gas

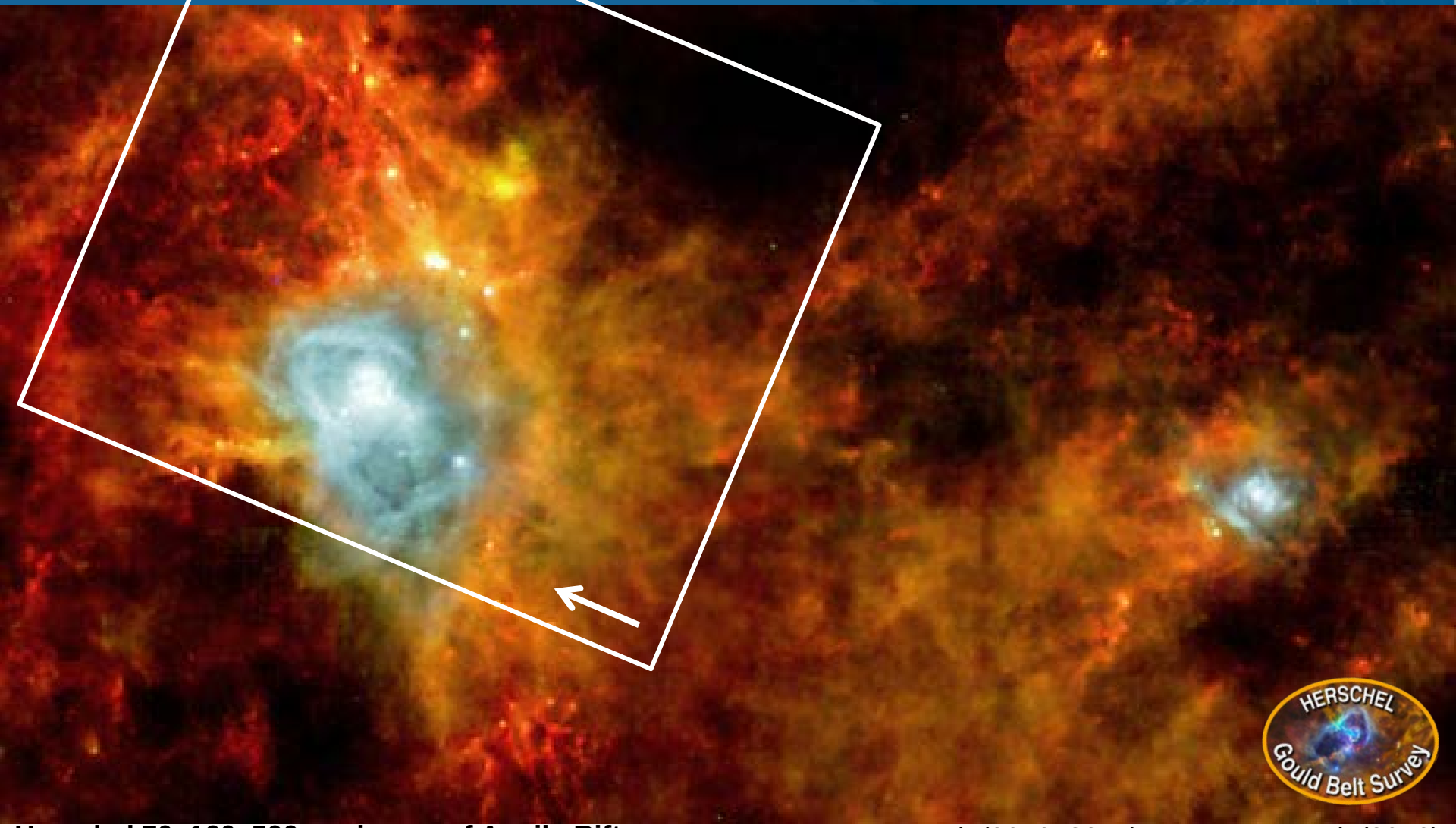
- Lada, Lombardi & Alves (2010) find a ***linear*** scaling between *N*(YSO) and the (H_2) mass of a cloud over a surface density threshold of ~116 $M_\odot$ pc^{-2}
- Interestingly, this threshold corresponds to a number density of ~10^4 cm^{-3}
- SFR ($M_\odot$ yr^{-1}) =

  $4.6 \pm 2.4 \times 10^{-8}\, M_{0.8}$ ($M_\odot$)



Lada, Lombardi & Alves (2010); see also Lada et al. (2012)

Herschel Observations: Aquila



Herschel 70, 160, 500 μm image of Aquila Rift Könyves et al. (2010, 2015); Bontemps et al. (2010)

Threshold originates from cylinder fragmentation

- Core formation occurs primarily due to ***fragmentation of parent filaments of ~0.1 pc width***

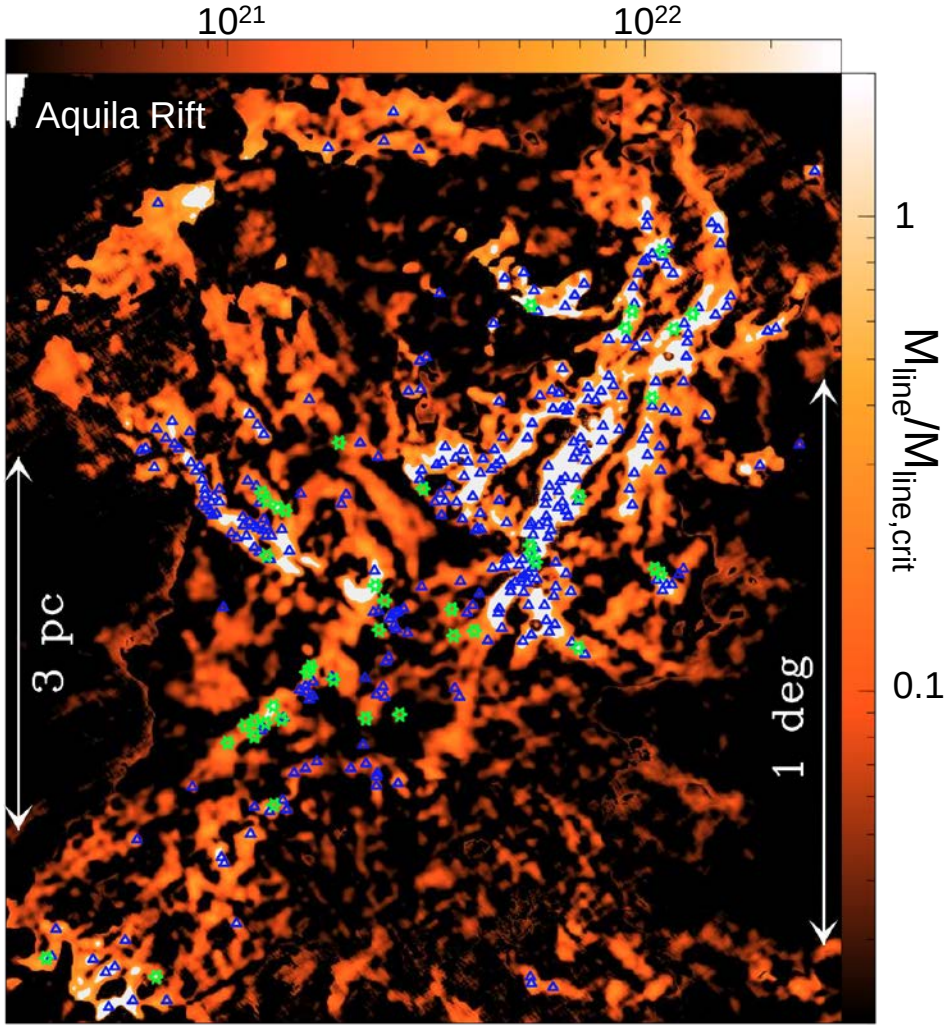
- **mass per unit length** M_{line} of an isothermal cylinder (see Ostriker 1964; Inutsuka & Miyama 1997)

- such cylinders *unstable* if:

$$\mathbf{M_{line} > M_{line,\,crit} = 2c_s^2/G}$$

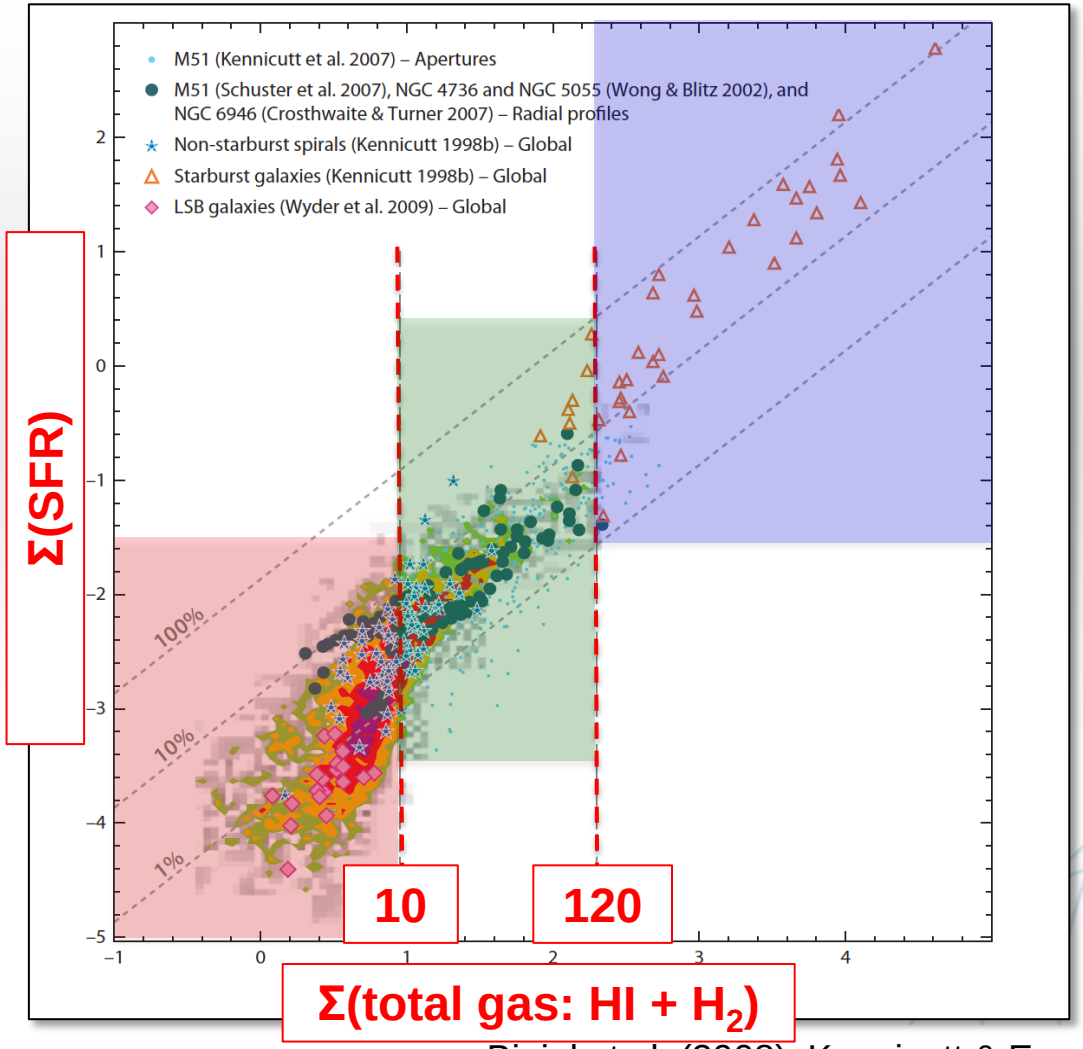
$$\sim 16\ M_\odot\ pc^{-1} \text{ at } 10\ K$$

- if $M_{line} \sim 16\ M_\odot\ pc^{-1}$, $W = 0.1$ pc, then $\boldsymbol{\Sigma_o = 160\ M_\odot\ pc^{-2}}$



André et al. (2010); Könyves et al. (2015)

Interpretation of the K-S scaling relation

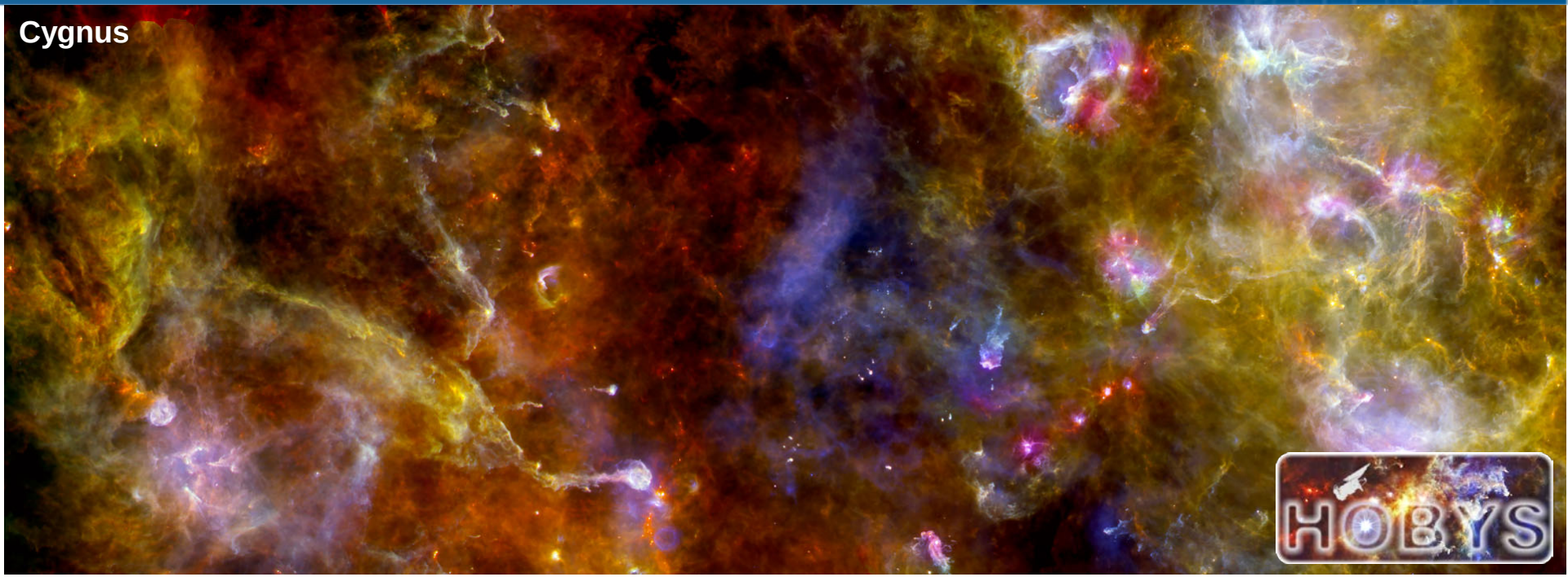


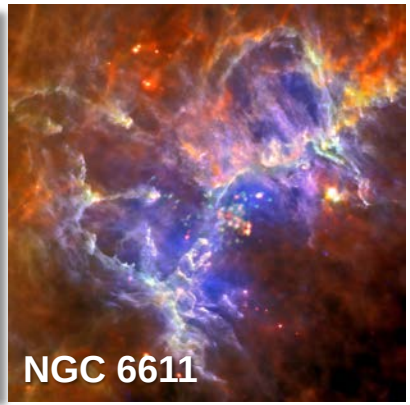
- **Σ(gas) < 10 $M_\odot$ pc^{-2}** : gas is **atomic**, little but some H_2 / dense gas
- **Σ(gas) ≈ 10-120 $M_\odot$ pc^{-2}** : gas is **atomic + molecular**, latter are discrete clouds of constant column density
- **Σ(gas) > 120 $M_\odot$ pc^{-2}** : gas is **molecular**, little atomic gas

- is ***dense filament fragmentation*** the universal process defining the onset of star formation in galaxies?

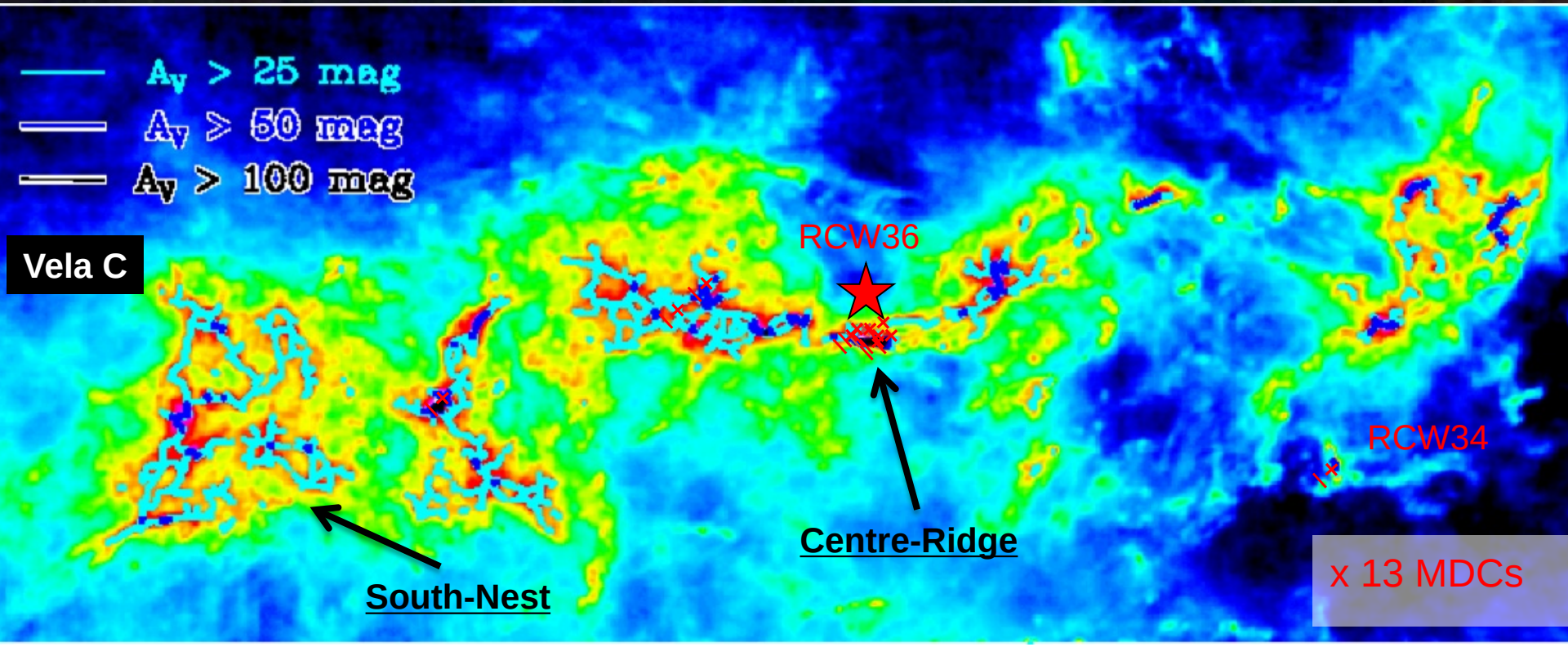
Bigiel et al. (2008); Kennicutt & Evans (ARAA; 2012); see also Schruba et al. (2011)

High-mass Star Formation with HOBYS





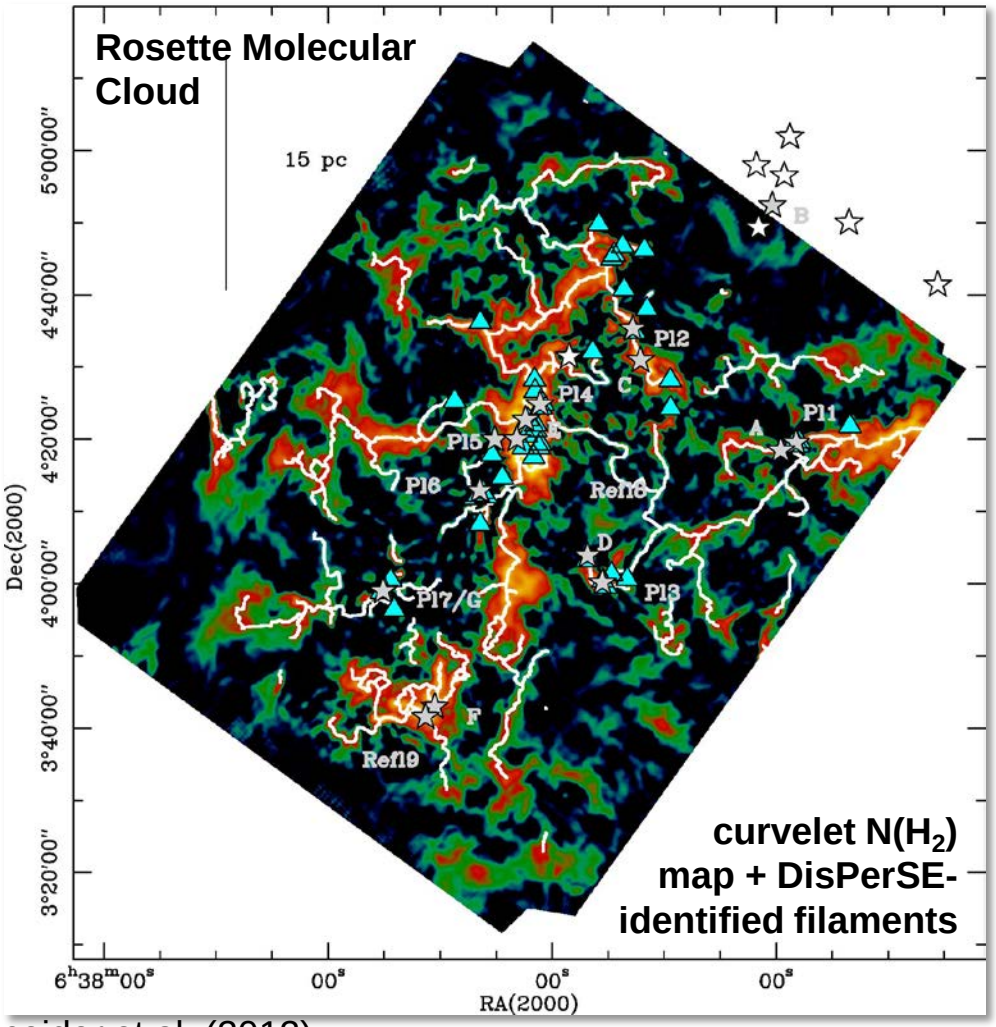
High-mass Star Formation and Ridges



- disorganized networks ('nests') and dominating 'ridges' show relative importance of turbulence vs. gravity
- high-mass stars only found in '**ridges**' ; filaments of A_V > 100

Hill et al. (2011); Minier et al. (2012)

Ridges and Filament Intersections



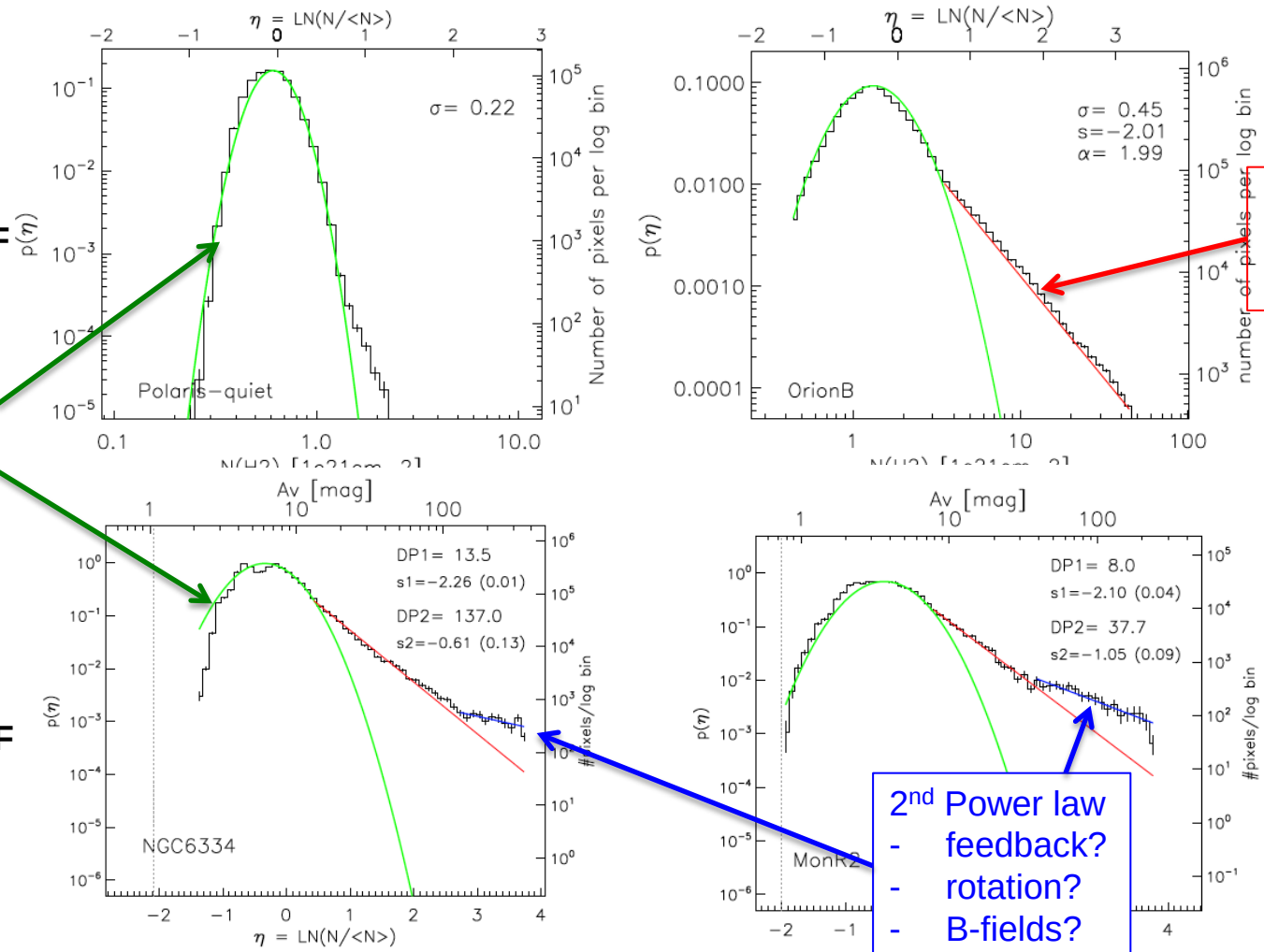
Schneider et al. (2012)

- massive clumps and IR clusters found at **filament intersections**
- more clustered star formation: mass flow along filaments into intersections? “secular” evolution? feedback?

Herschel N(H_2) Probability Density Functions

Low-mass SF

High-mass SF



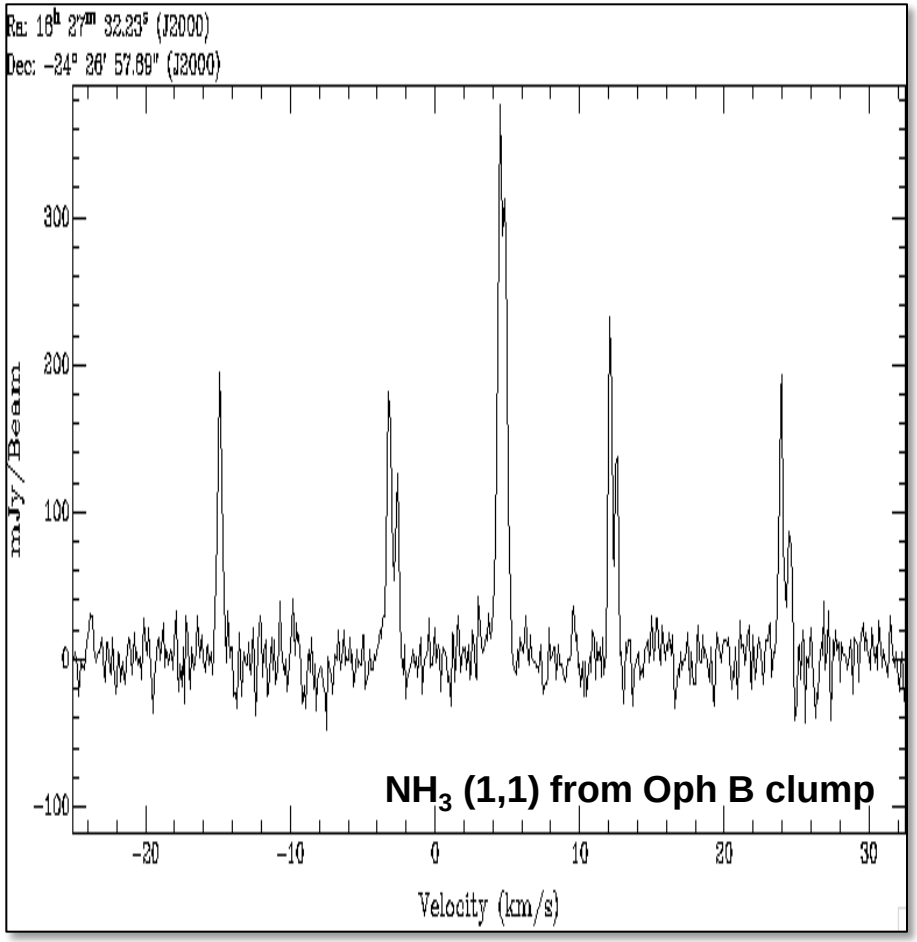
lognormal (turbulence)

Power law (gravitational infall)

2nd Power law
- feedback?
- rotation?
- B-fields?

Schneider et al. (2013; 2015); also Russeil et al. (2013), Rivera-Ingraham et al. (2015)

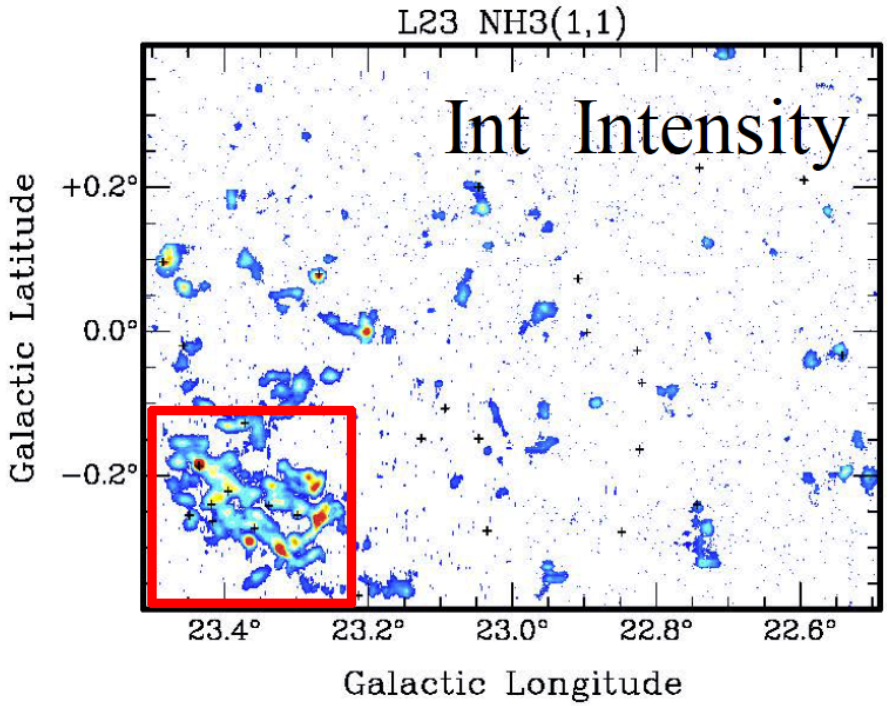
Ammonia observations of nearby SF regions

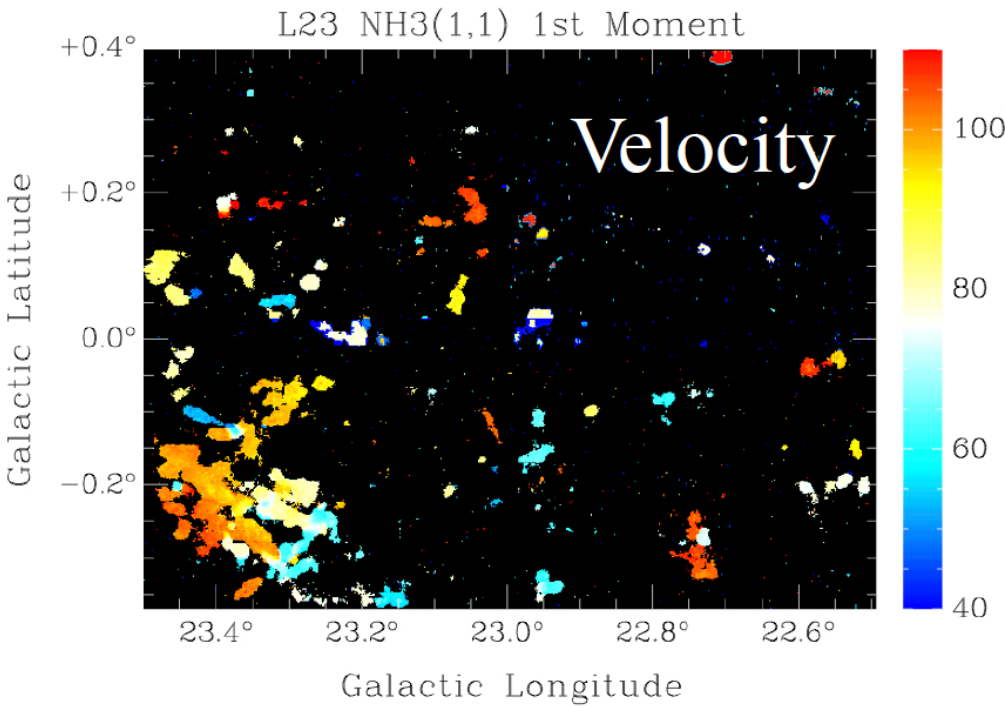


Friesen et al. (2008)

- **NH_3** rotational-vibrational emission traces dense gas, n_{crit} [NH_3(1,1)] ~ $10^{3\text{-}4}$ cm^{-3}
- Can probe:
  - **ridge dynamics**, role of turbulence in formation
  - **gas kinematics**, flows from ridges to clusters, explore filament intersections
  - **LOS gas temperatures**, explore external heating
  - **abundances**, cf. accurate column densities

RAMPS results





Jackson et al. (2016, in prep)

- **RAMPS**: **R**adio **A**mmonia **M**id-**P**lane **S**urvey (PI: J. Jackson)
- numerous locations of extended NH_3 emission seen, many of which are high-mass star formation regions (at 33” FWHM)

High-mass SF regions need high resolution: NGVLA

- Targeting a maximum linear resolution of 0.1 pc
- **At 15 kpc, 1.3” res. = 0.1 pc**
- Can probe filaments and cores down to this critical length scale across most of the stellar disk of the Galaxy
- 1.3” at 23.7 GHz can be done with JVLA in C-configuration…

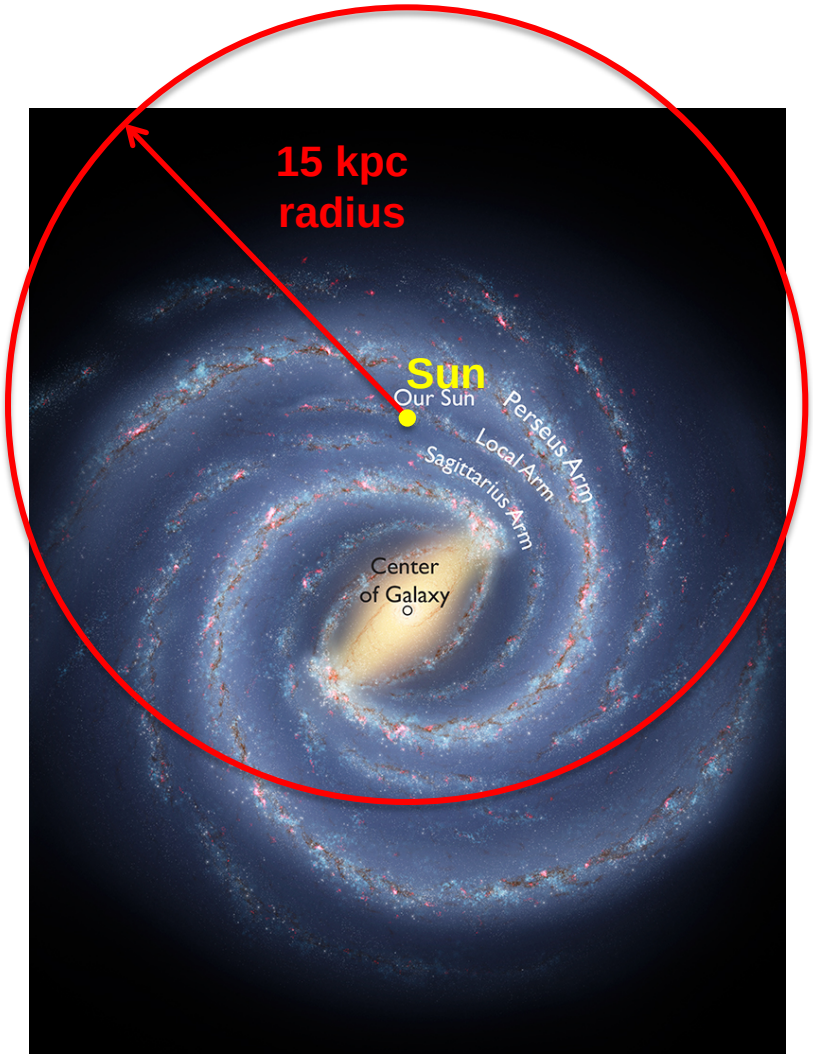
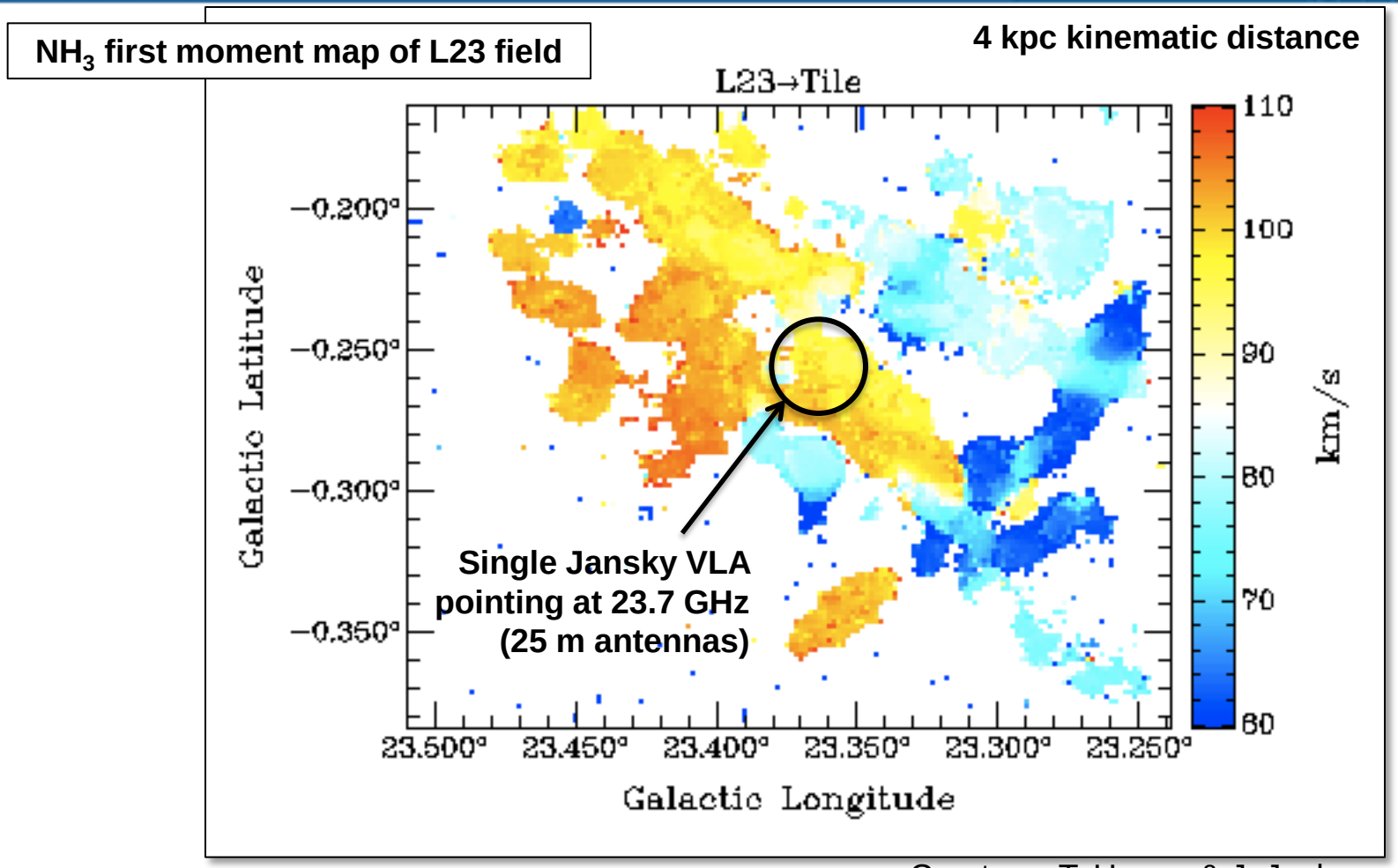


Illustration: R. Hurt and B. Saxton

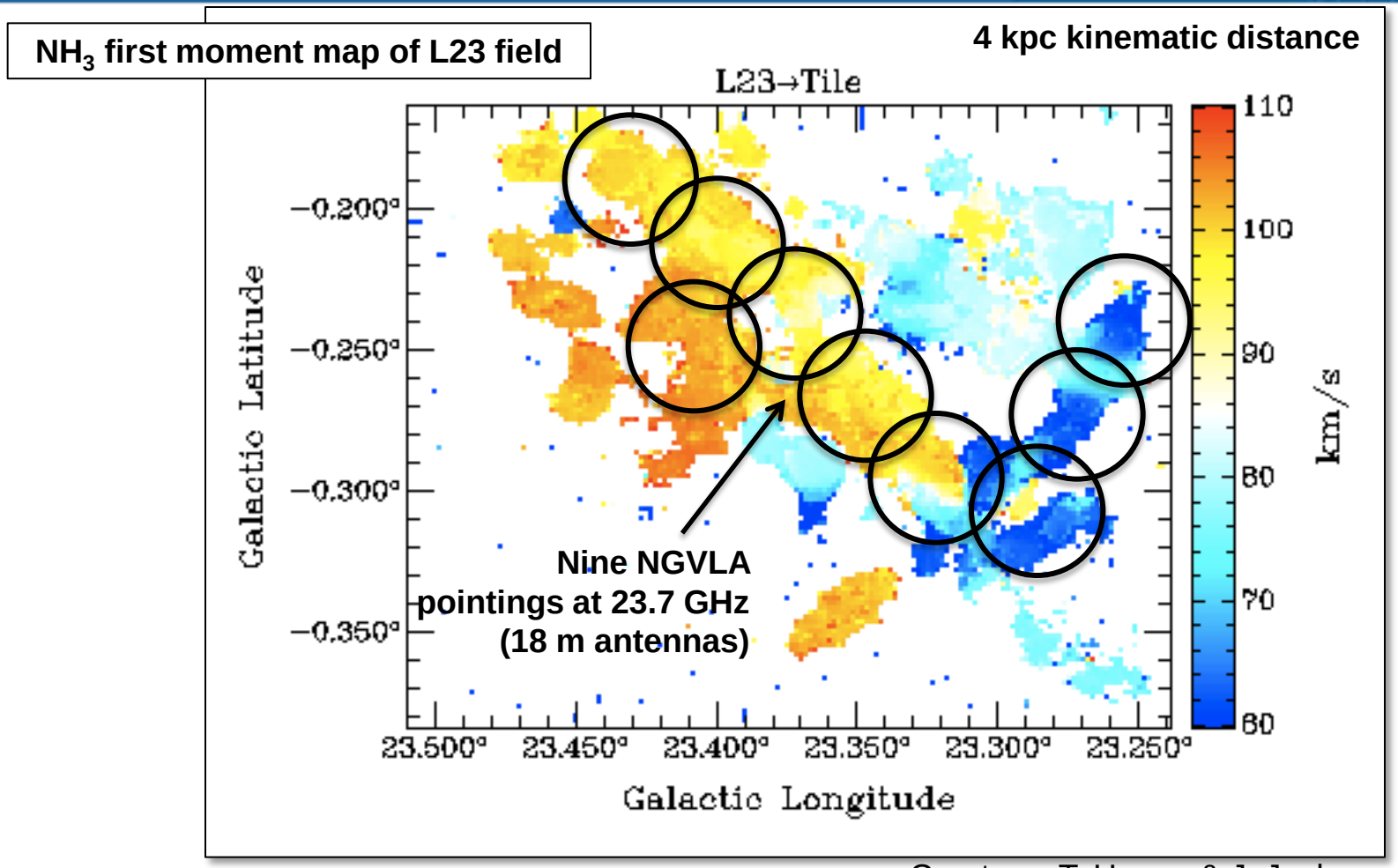
High-mass regions need high sensitivity: NGVLA



Courtesy: T. Hogge & J. Jackson

ΔT(rms) ~ 3 K in 3.3 hr integration (0.1 km s^{-1} channels, 27 antennas)

High-mass regions need high sensitivity: NGVLA



Courtesy: T. Hogge & J. Jackson

ΔT(rms) ~ 3 K in 3.3 hr integration (0.1 km s^{-1} channels, 150 antennas)

Summary

- High-resolution (0.1 pc) molecular line observations of filaments in high-mass star-forming regions are a critical NGVLA target

- 150 antennas of 18-m diameter within 3 km can yield 1.3” beam sizes over a 2.66 arcmin FOV at 23.7 GHz (NH_3 lines), resolve filaments out to 15 kpc

- sample ~10× more fields to the same sensitivity as JVLA (“mapping speed”) or 1 field to much greater sensitivity

- NGVLA wide-band could also sample *other* lines besides those of NH_3, e.g., **CCS 2_1-1_0**, **HC_5N 11-10**, **H_2O 6_{16}-5_{23}**

Thanks to:

Philippe André, Vera Könyves, Arabindo Roy, Doris Arzoumanian, Derek Ward-Thompson and the Herschel Gould Belt Survey Team;

Frederique Motte and the Herschel OB Young Star Survey Team; and

Taylor Hogge, Jim Jackson, and the RAMPS team

Thank you

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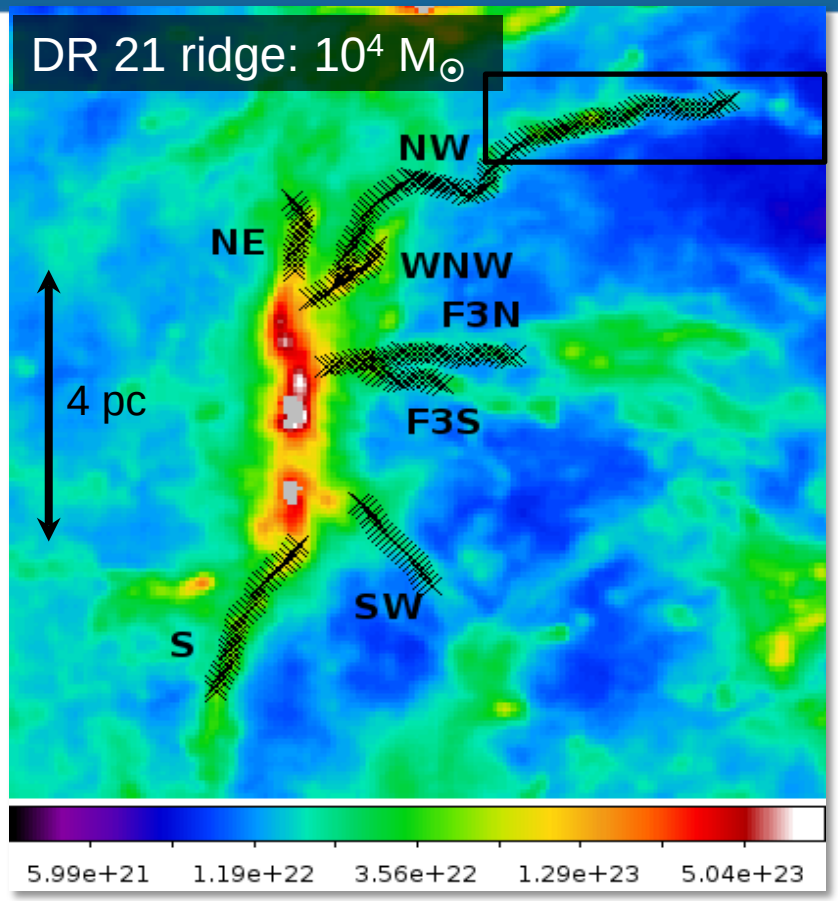
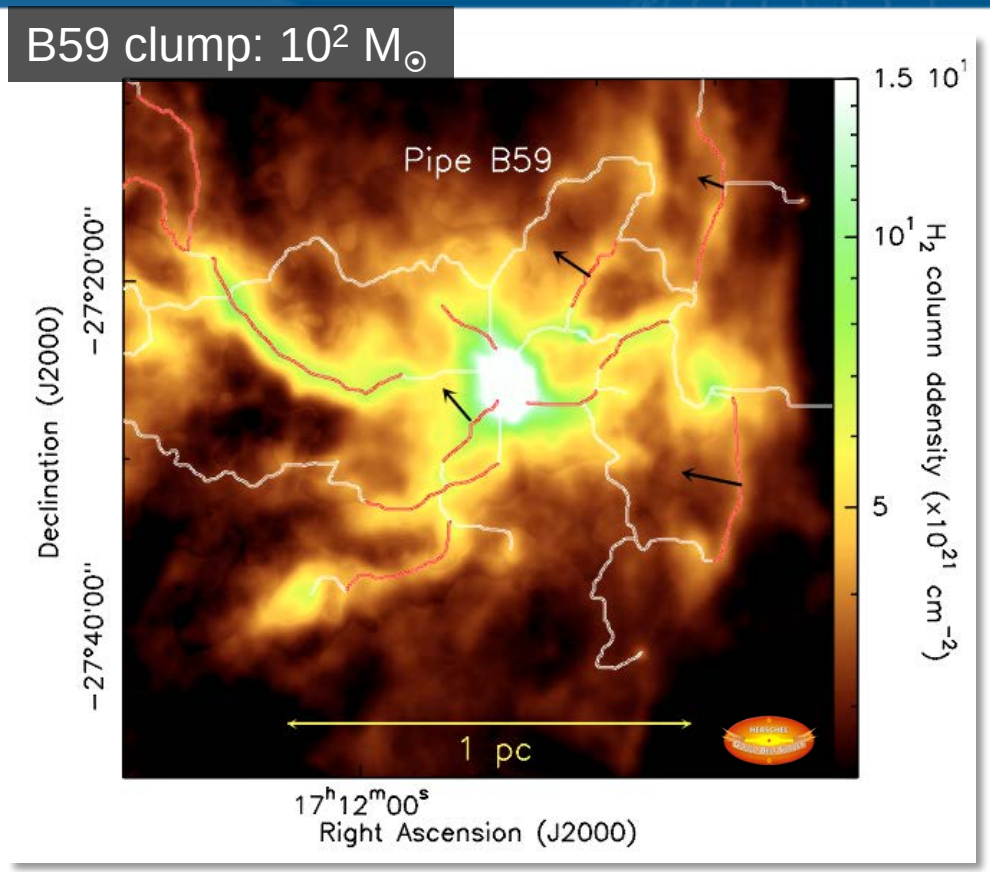
High-mass Star Formation and Ridges

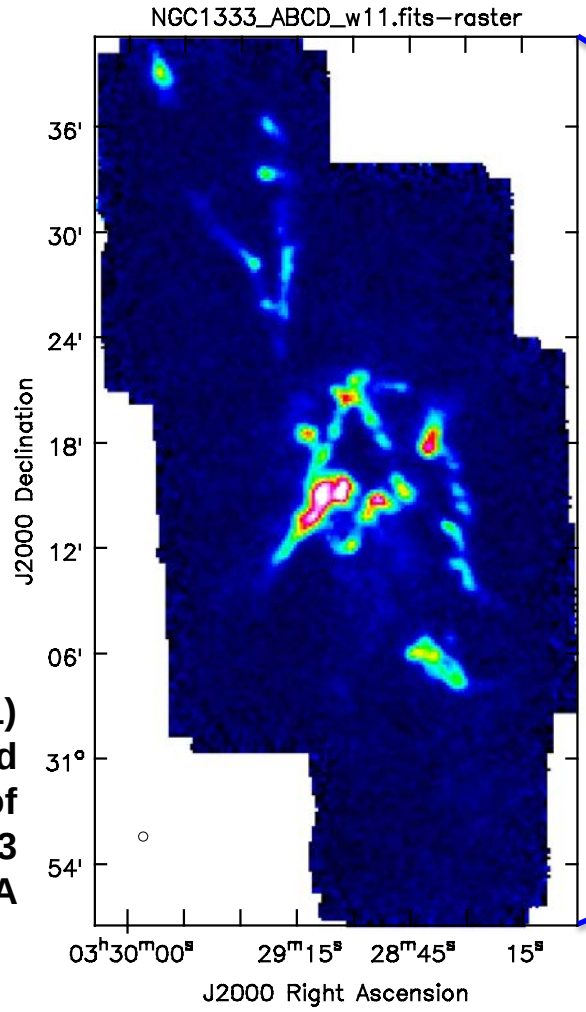




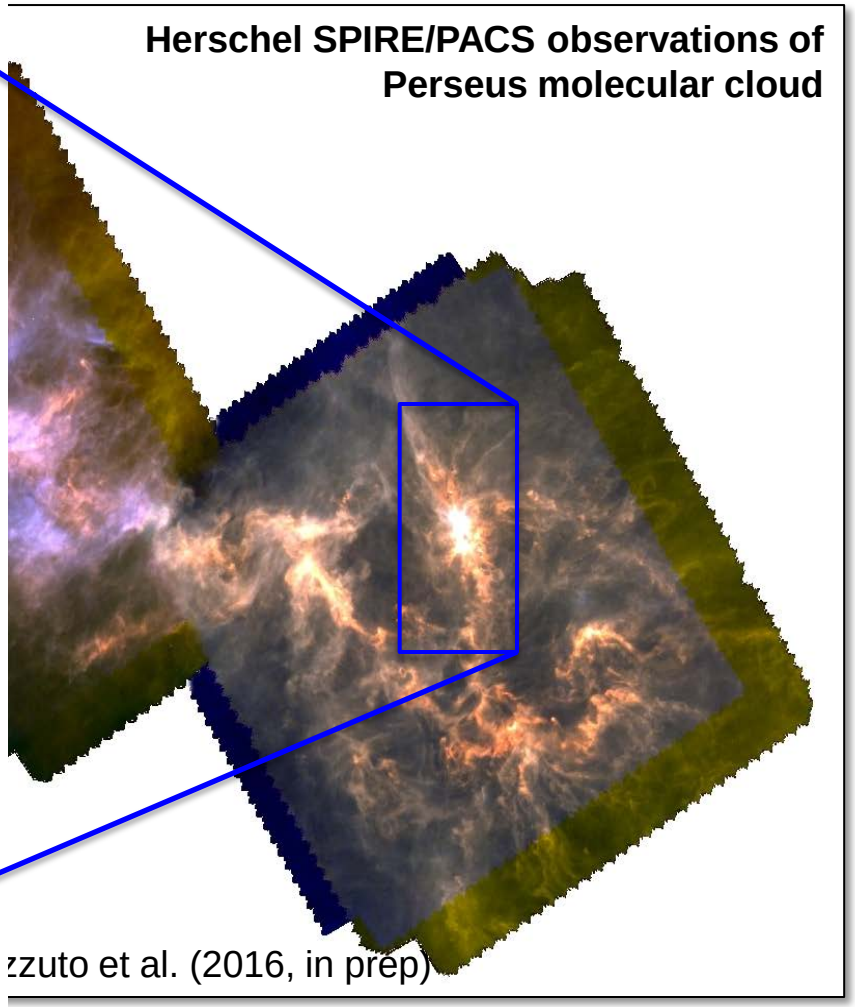
- ridges formed and fed by filament merging
- sub-filaments also surround (feed?) dominant clump in Pipe Nebula

Hennemann et al. (2012), Schneider et al. (2010), Peretto et al. (2012)

Ammonia observations of nearby SF regions



NH_3 (1,1) integrated intensity of NGC 1333 with KFPA



zzuto et al. (2016, in prep)

Green Bank **A**mmonia **S**urvey (2016), in prep