Pushing the limits of star formation relations in high-mass Galactic clouds

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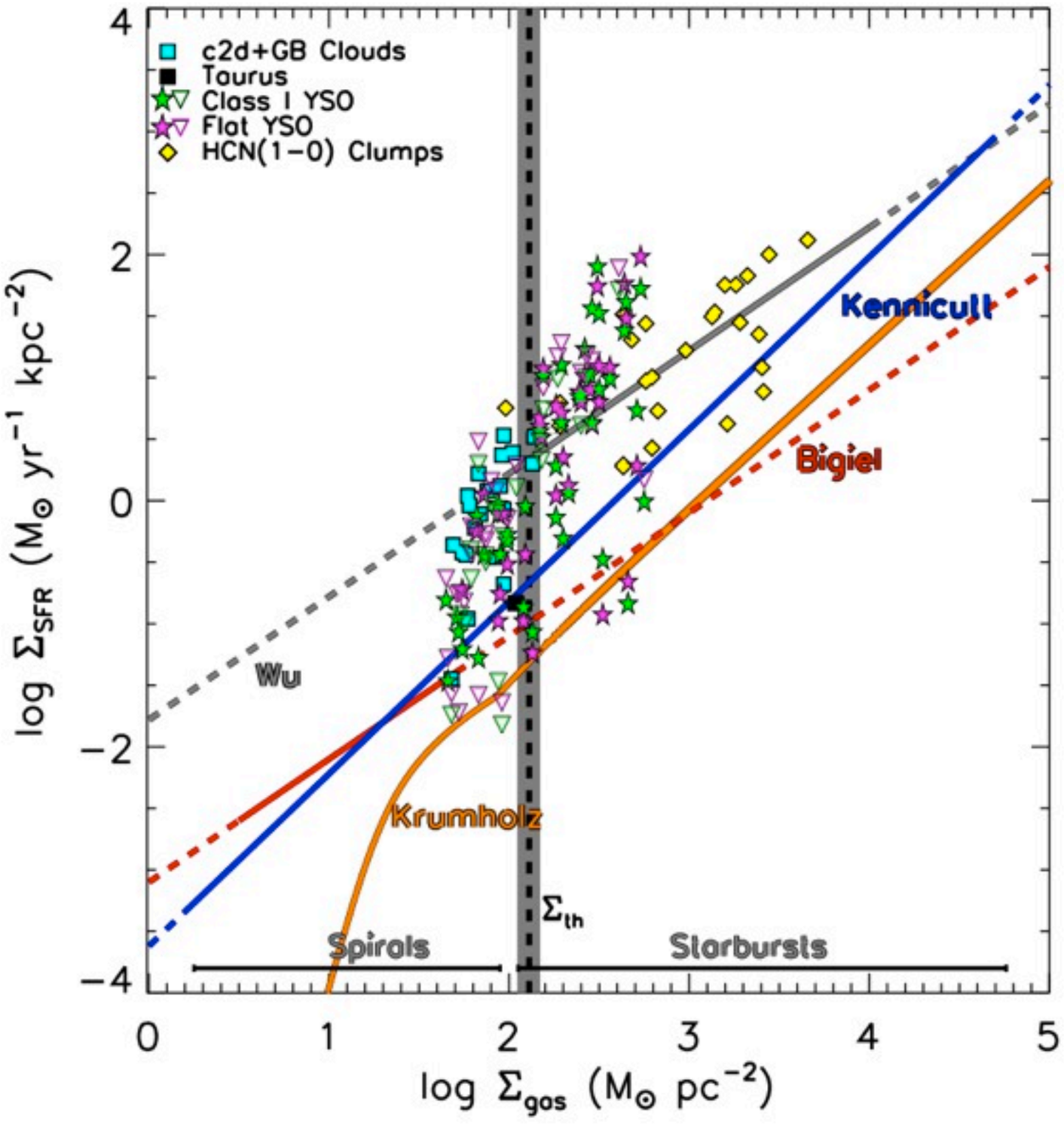
Why is there a relation between gas surface density and star formation rate?

Background and Motivation

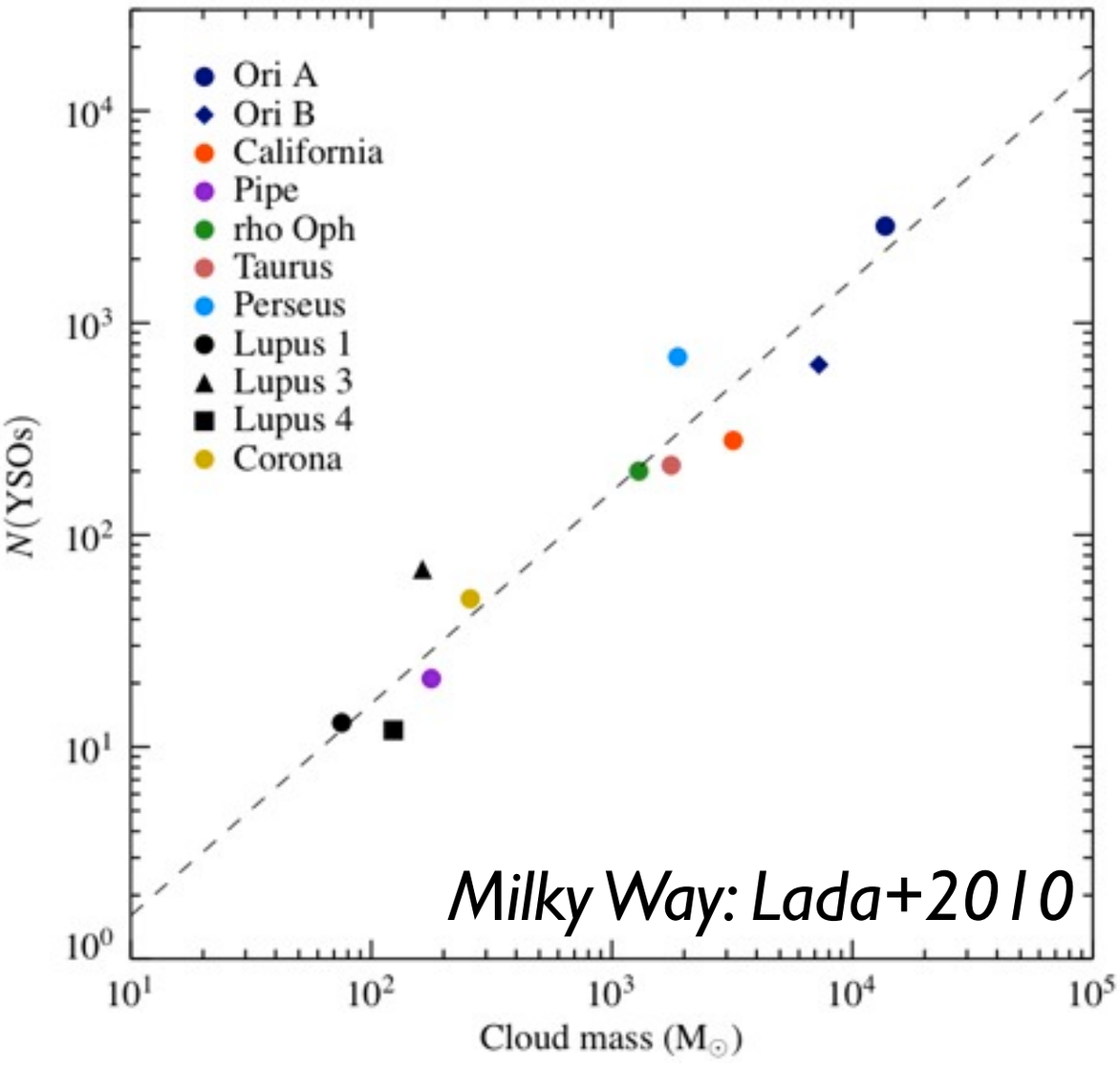


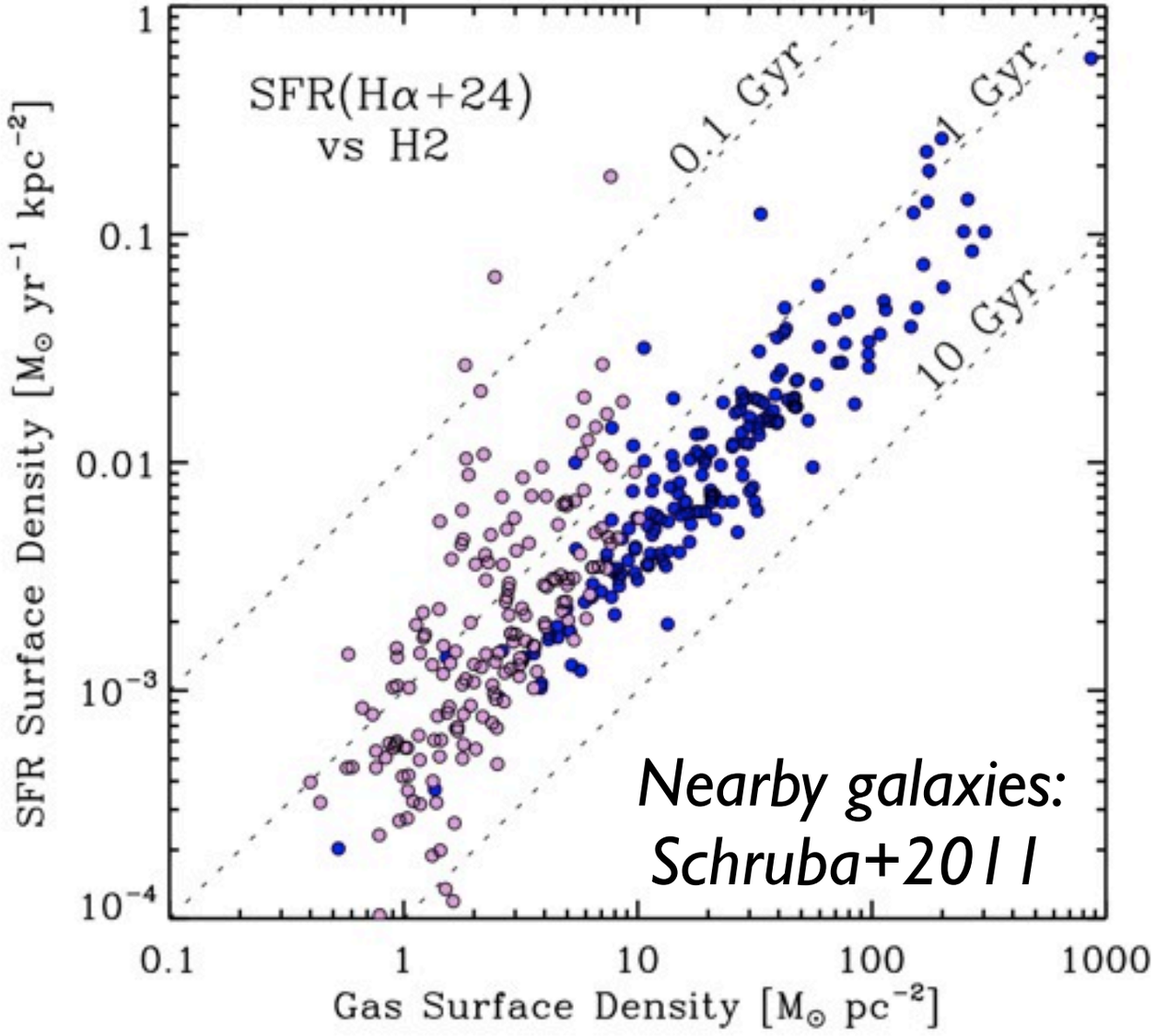
Heiderman et al. (2010)

- Local clouds do not follow extragalactic relations
- What about (more representative?) high-mass clouds (IRDCs)?

Background and Motivation

What is the connection between Milky Way star formation relations and extragalactic surface density relations?





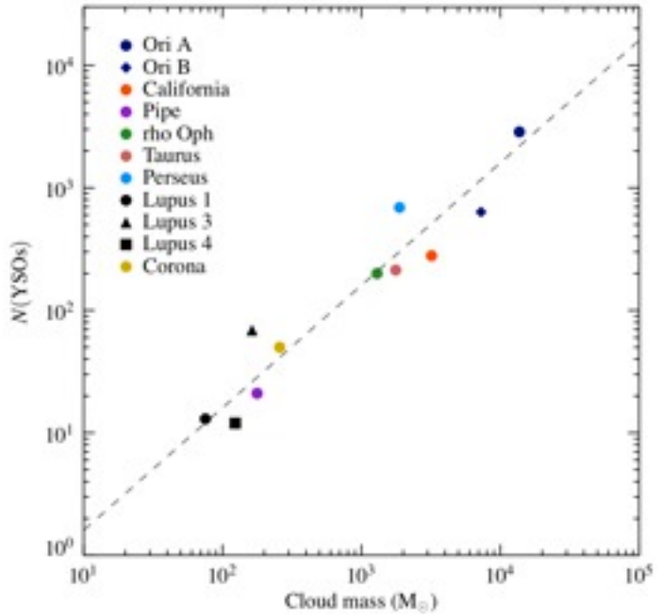
1° ≈ 50 pc (@ 2.8 kpc) *state of the art "beam"*

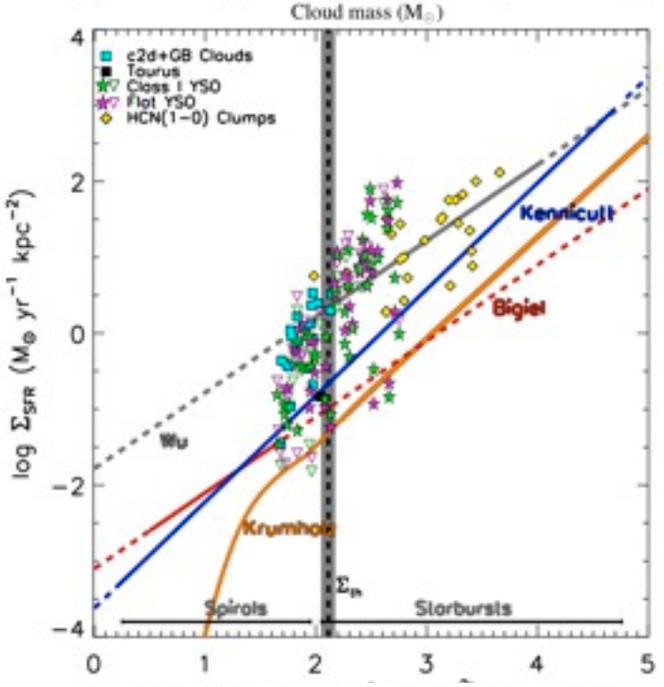
"Infrared-dark cloud"

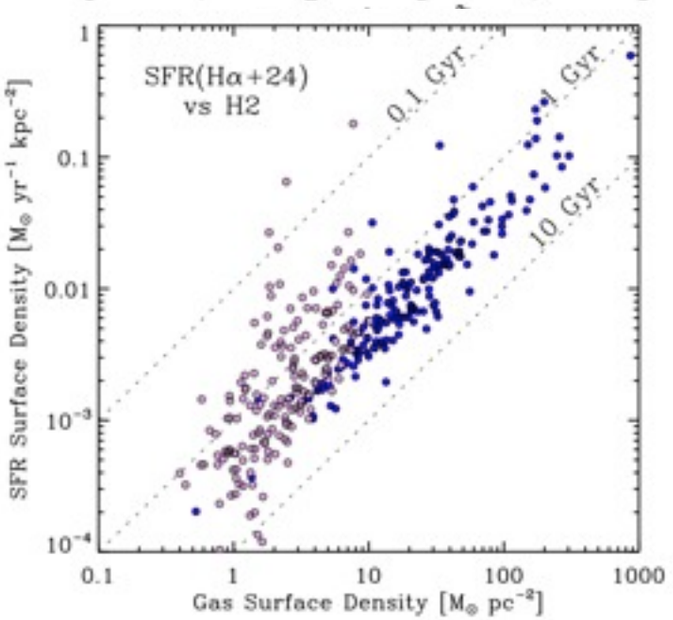
Image:
Herschel + *Spitzer*
Blue = MIPS 24um
Green = PACS 70um
Red = PACS 160um

Outline

- How do IRDCs fit into picture?
- Same observational techniques <u>cannot</u> be used for IRDCs
- *New approach!*
- This talk: <u>empirical</u> focus:
  - Sensitive to dense gas only
  - *x-axis*: Using dust emission
  - *y-axis:* probe SF with *Herschel*
- What are possible reasons for the large scatter in Galactic relations?

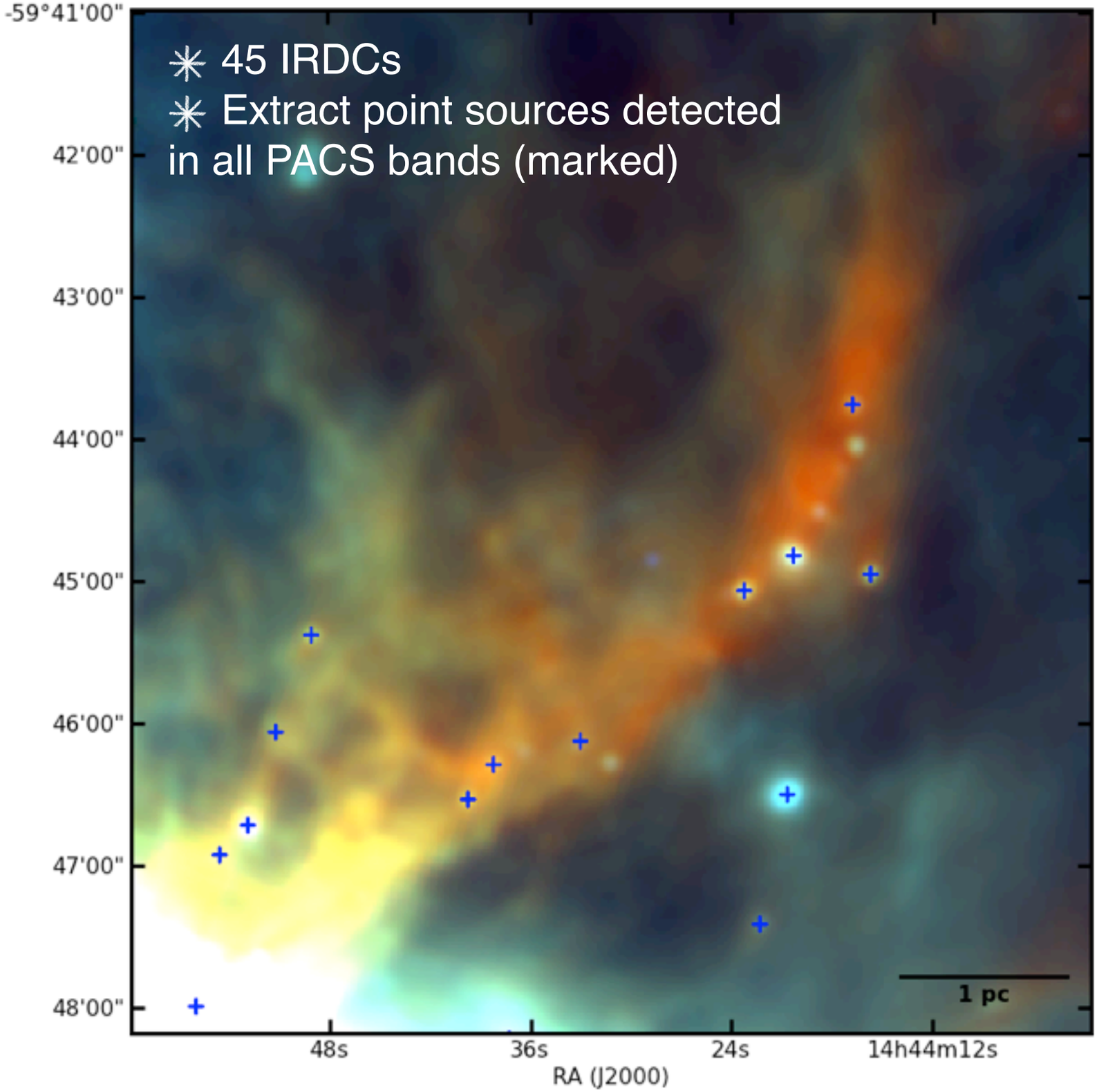






Observations: *Herschel*

EPoS Guaranteed time key program



Ragan+2012

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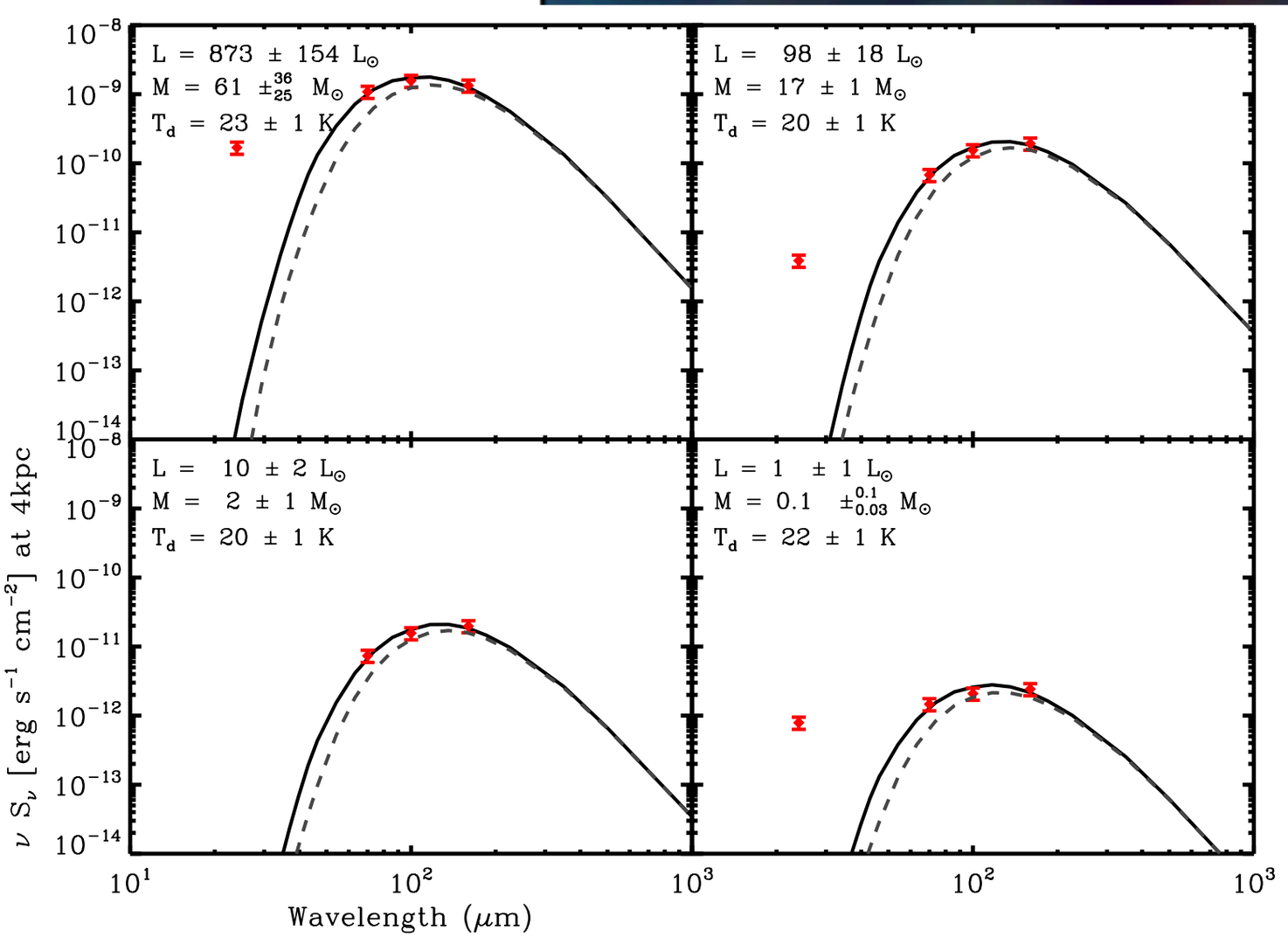
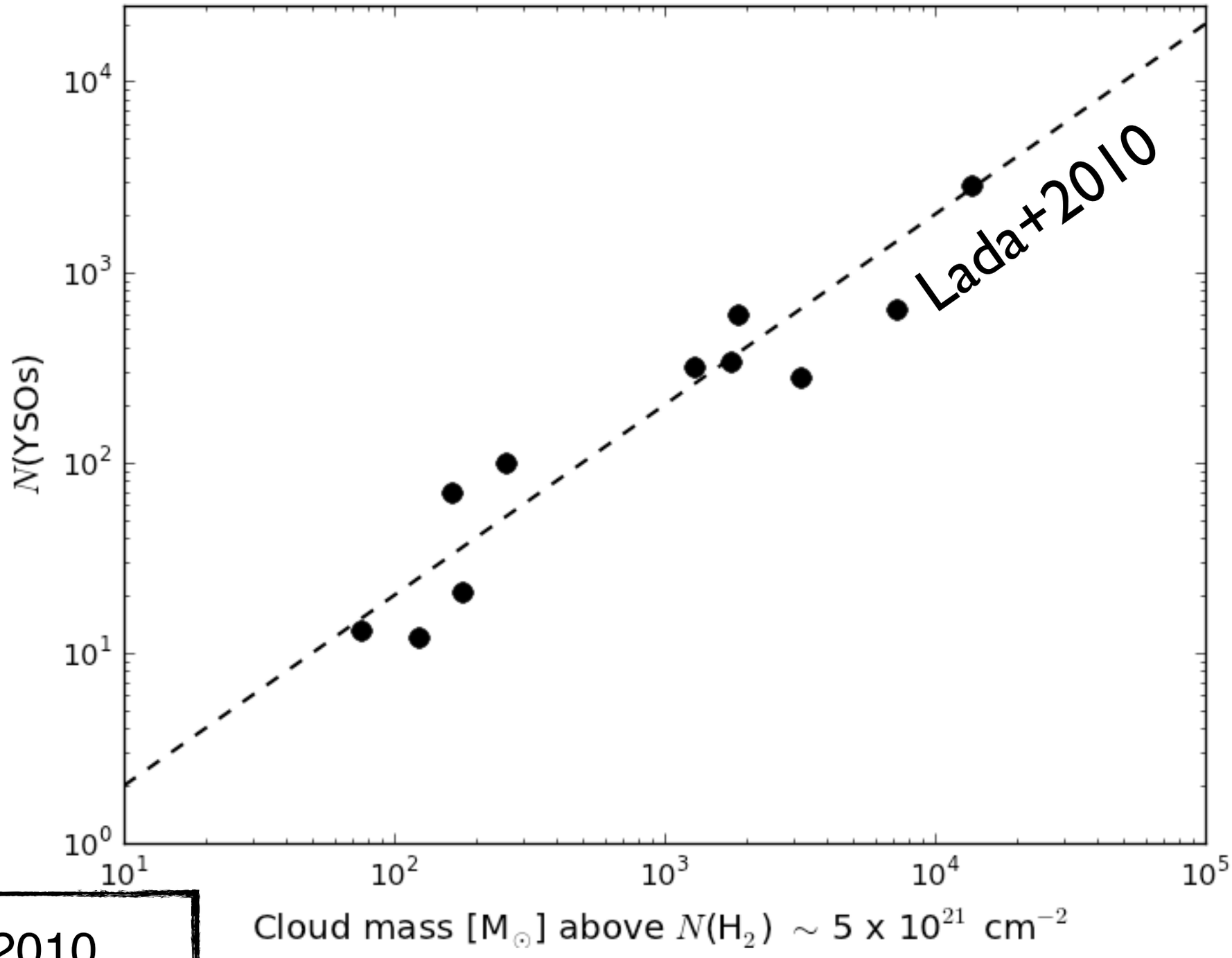


- *Fit SEDs with modified blackbody*
- *Estimate mass, temperature, luminosity*
- *500 protostellar cores extracted in sample of 45 clouds*

Ragan+2012

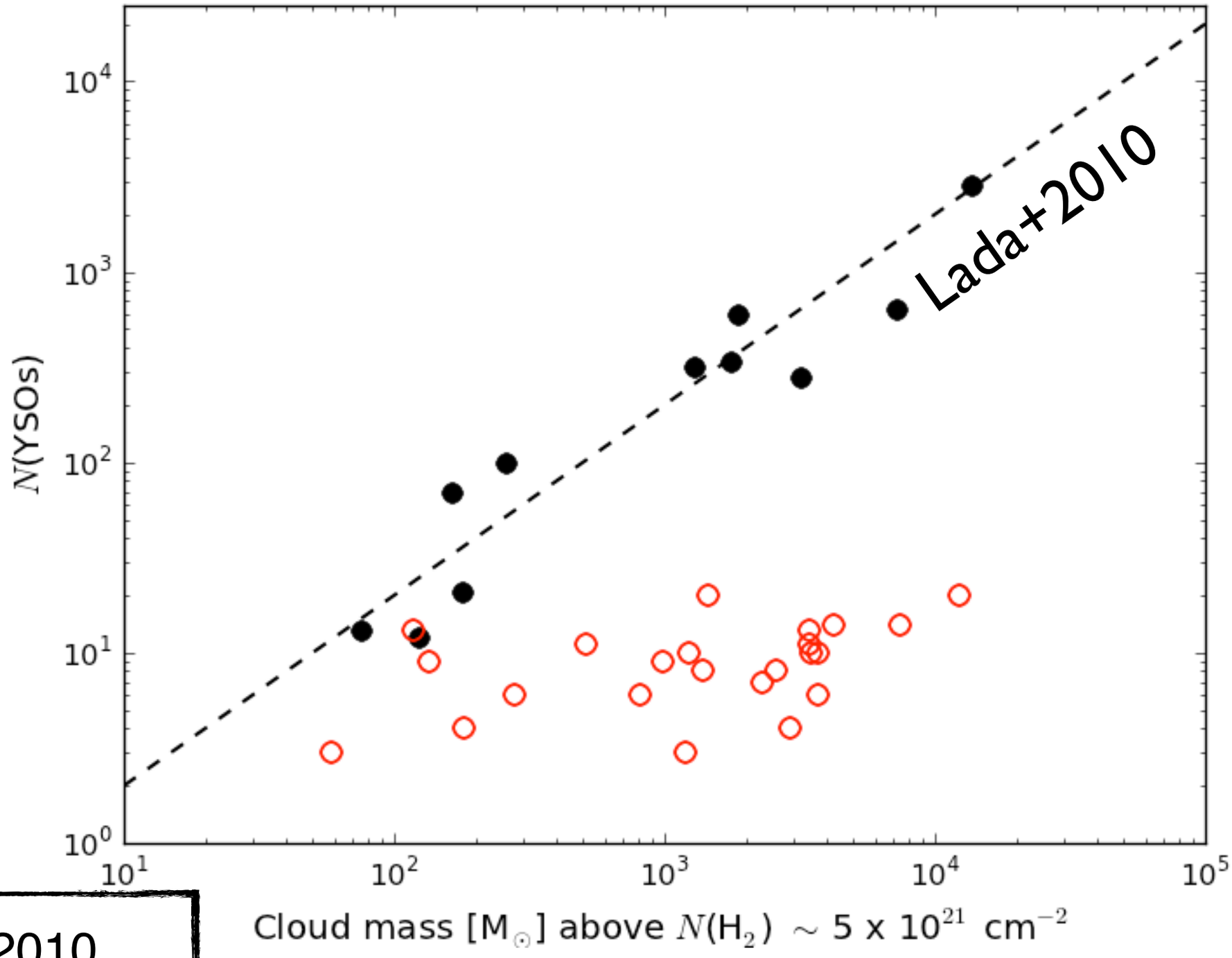
Cloud-level relations



- Lada+2010
- Ragan+2012

Ragan+2012

Cloud-level relations



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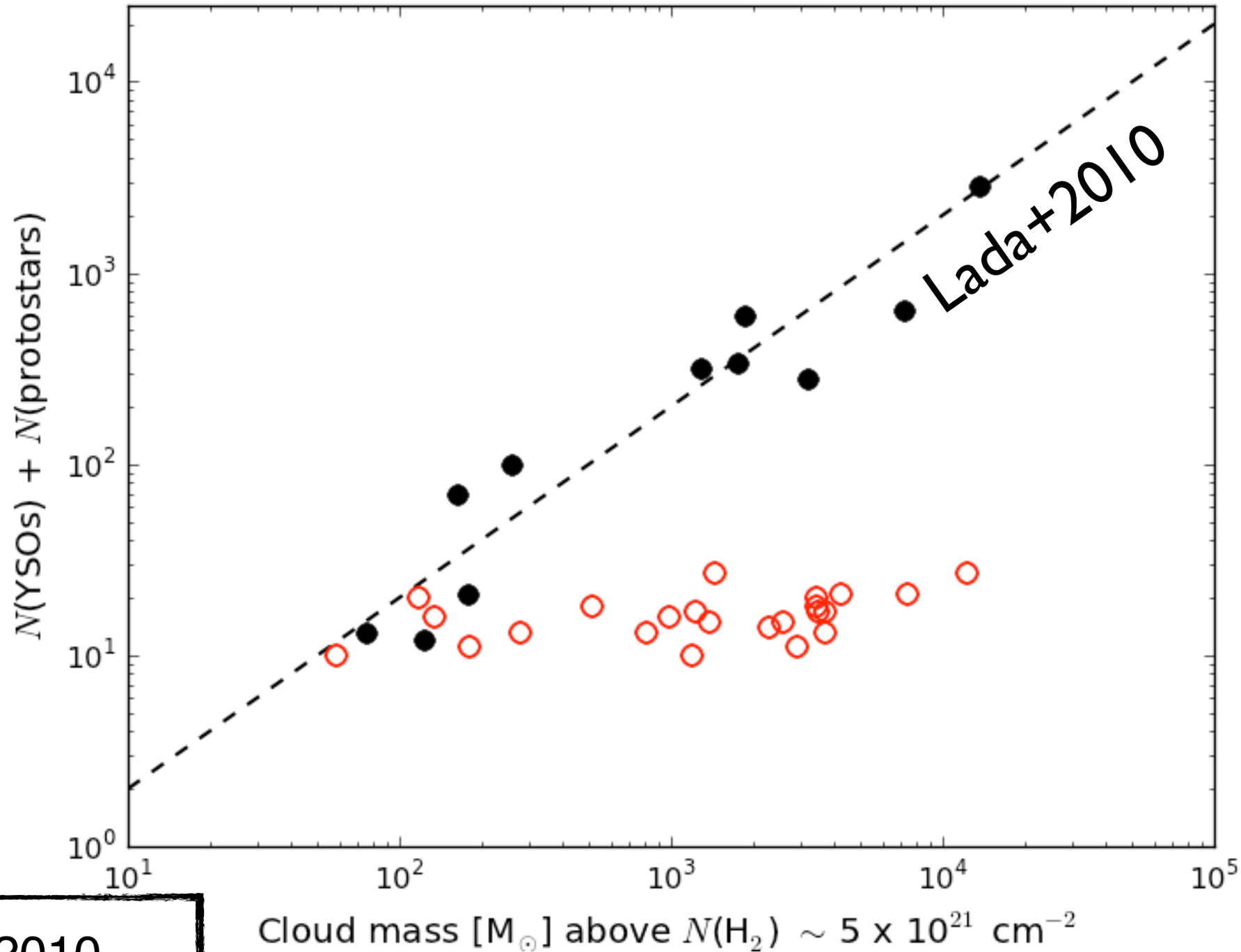

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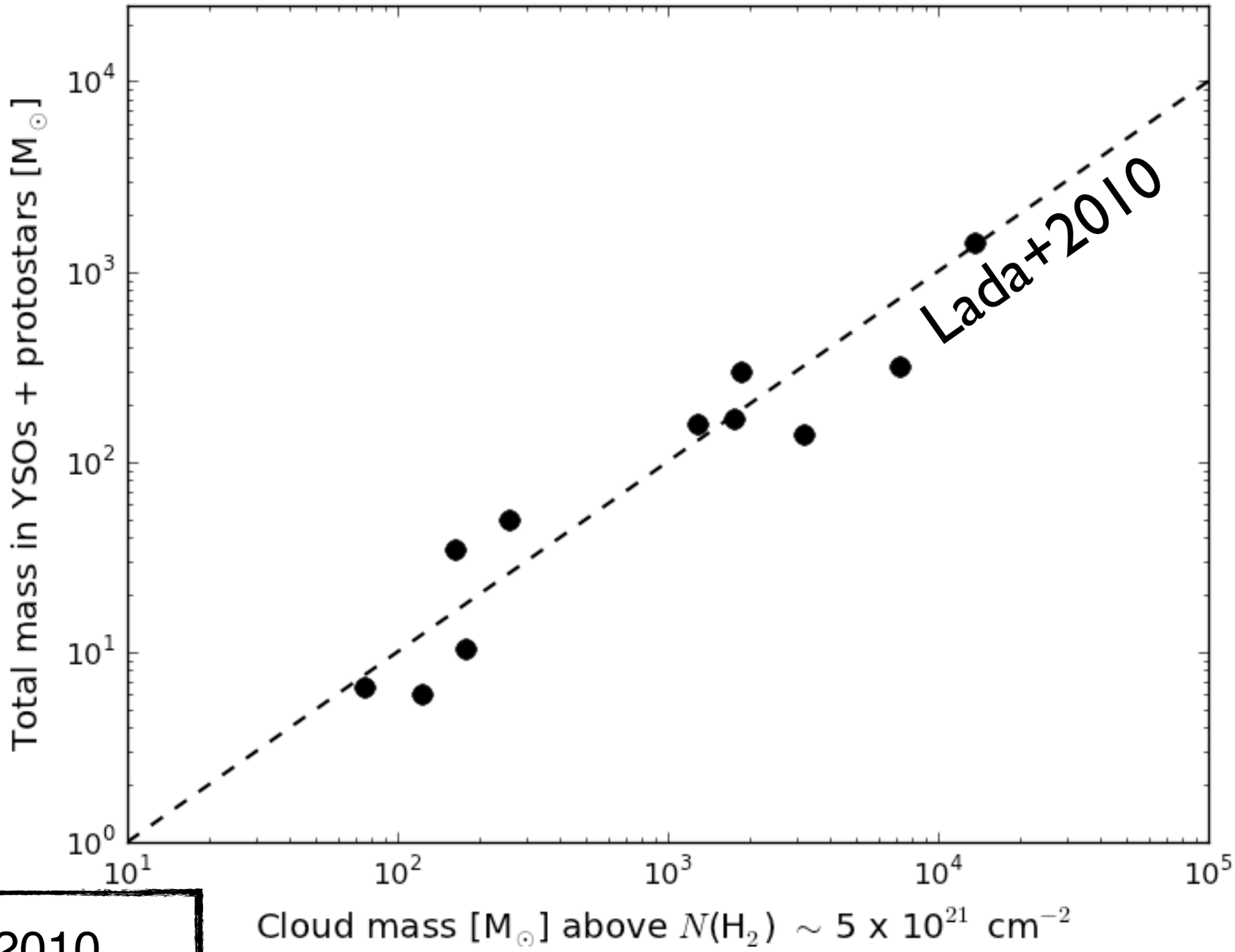

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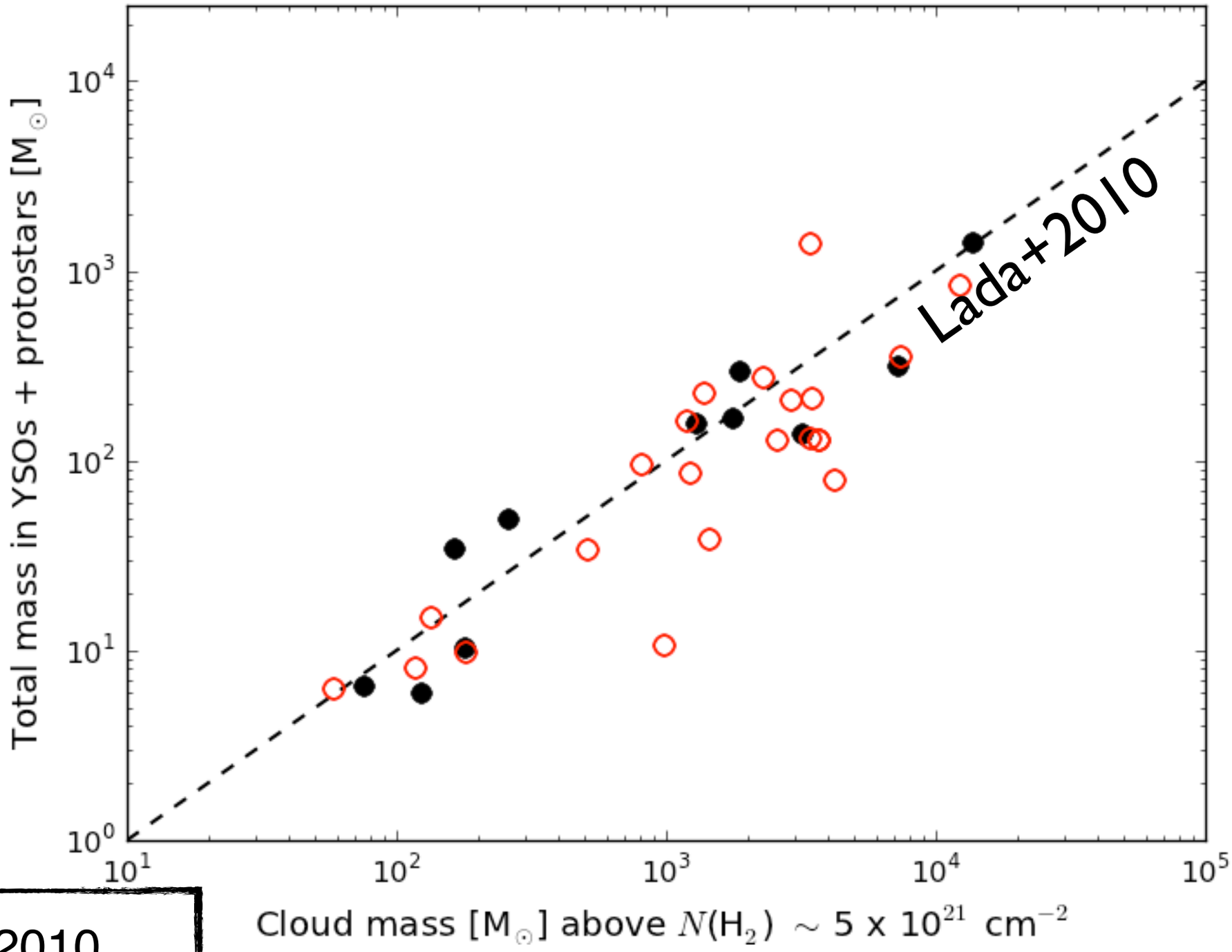

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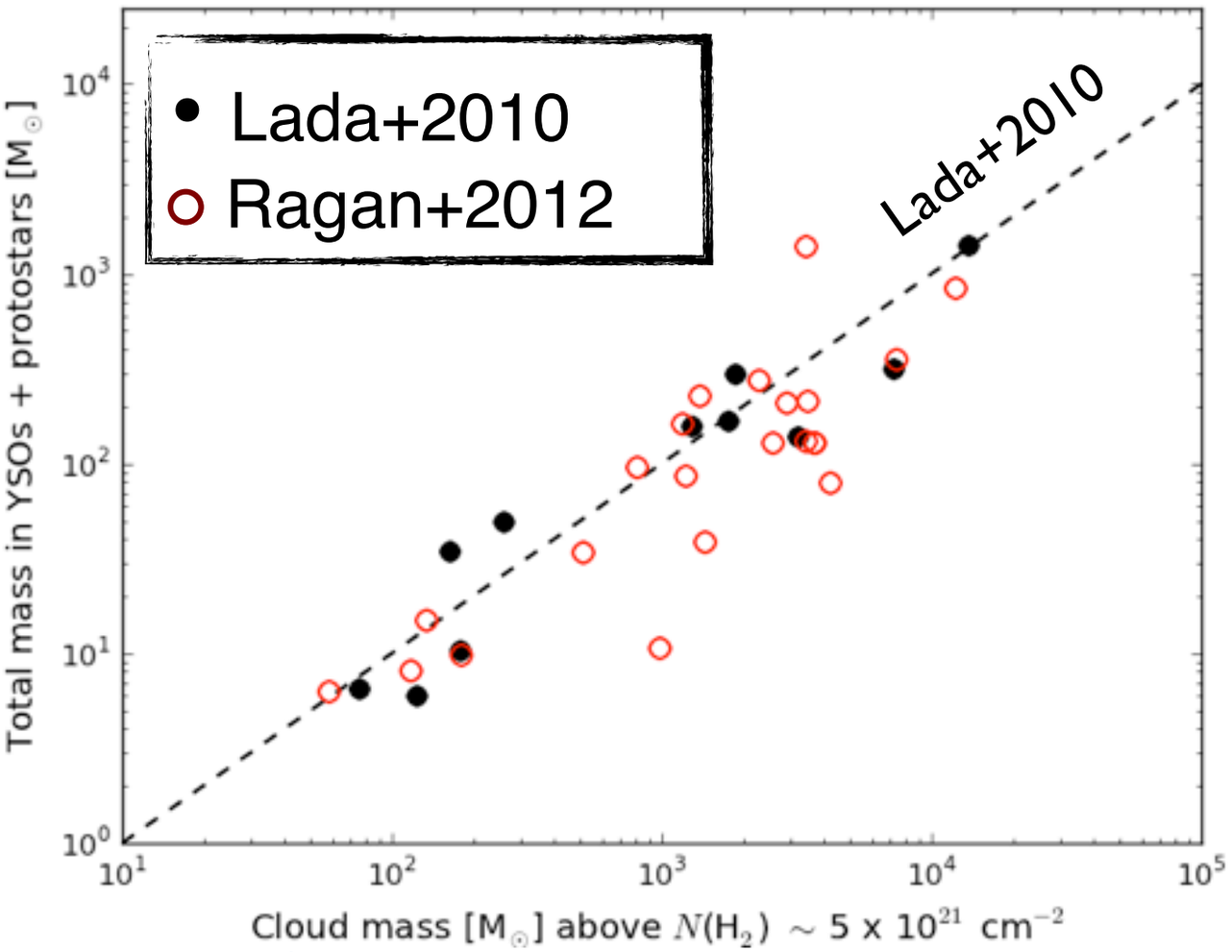
Ragan+2012

Summary: Cloud-level relations

Mass in YSOs & embedded cores



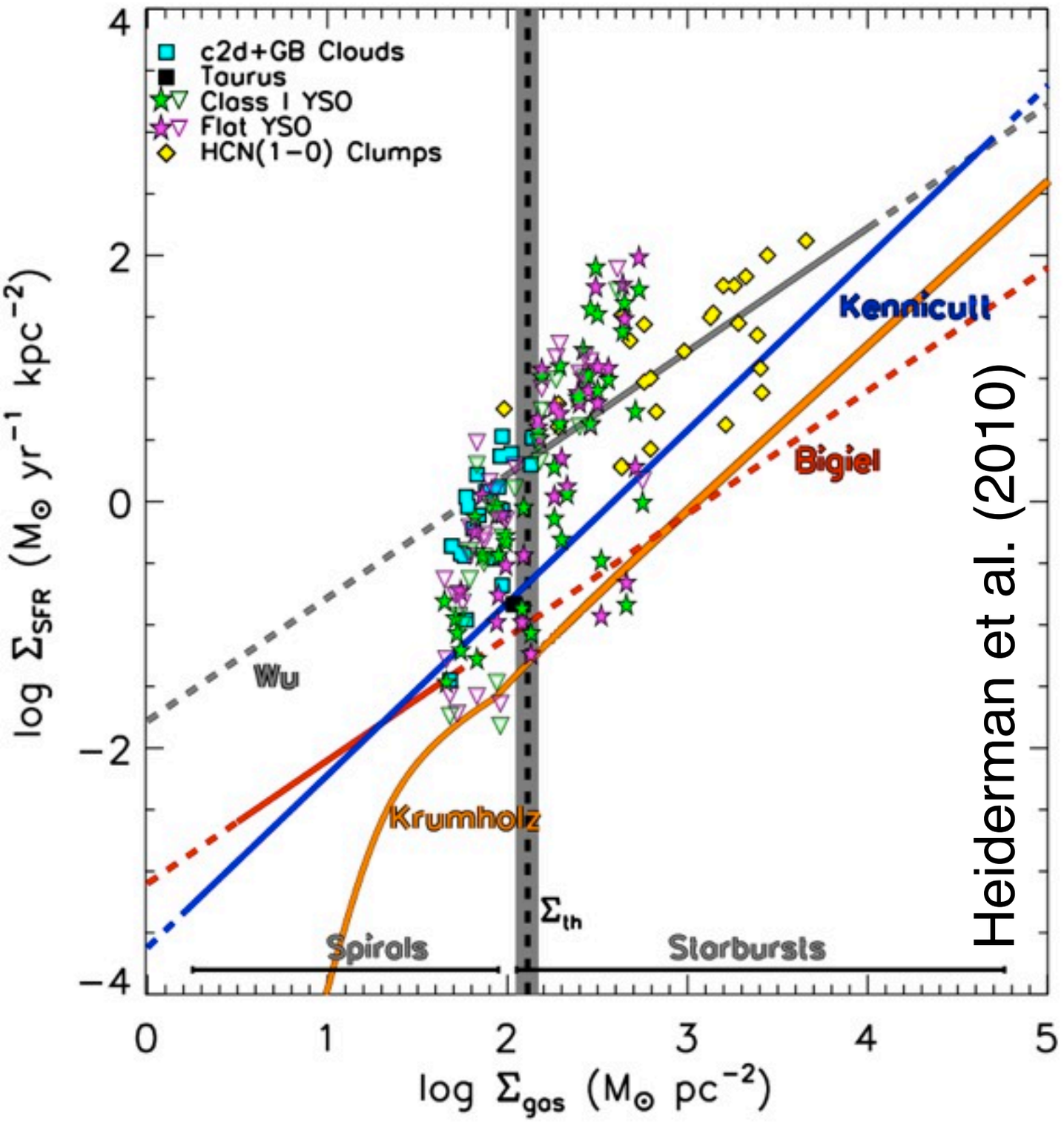
Mass in dense gas

- Pure star counts do not account for all star formation in IRDCs
- *Herschel* reveals (unresolved) embedded population
- Total mass in protostellar cores (maybe containing cluster) better match to expected “Lada-relation”

Ragan+2012

Surface density relations

How do we transition between individual cloud accounting to surface density relations?



The x-axis:

Because of observational limitations for distant clouds, we probe just the dense gas using dust emission from the ***ATLASGAL*** *875 micron survey (Schuller+2009)*

We select a threshold

$N_{H2} \sim 5 \times 10^{21}$ *cm*$^{-2}$

New extinction mapping techniques (see Kainulainen +2013) will access lower-density gas

The y-axis: Estimating Σ_{SFR} for IRDCs

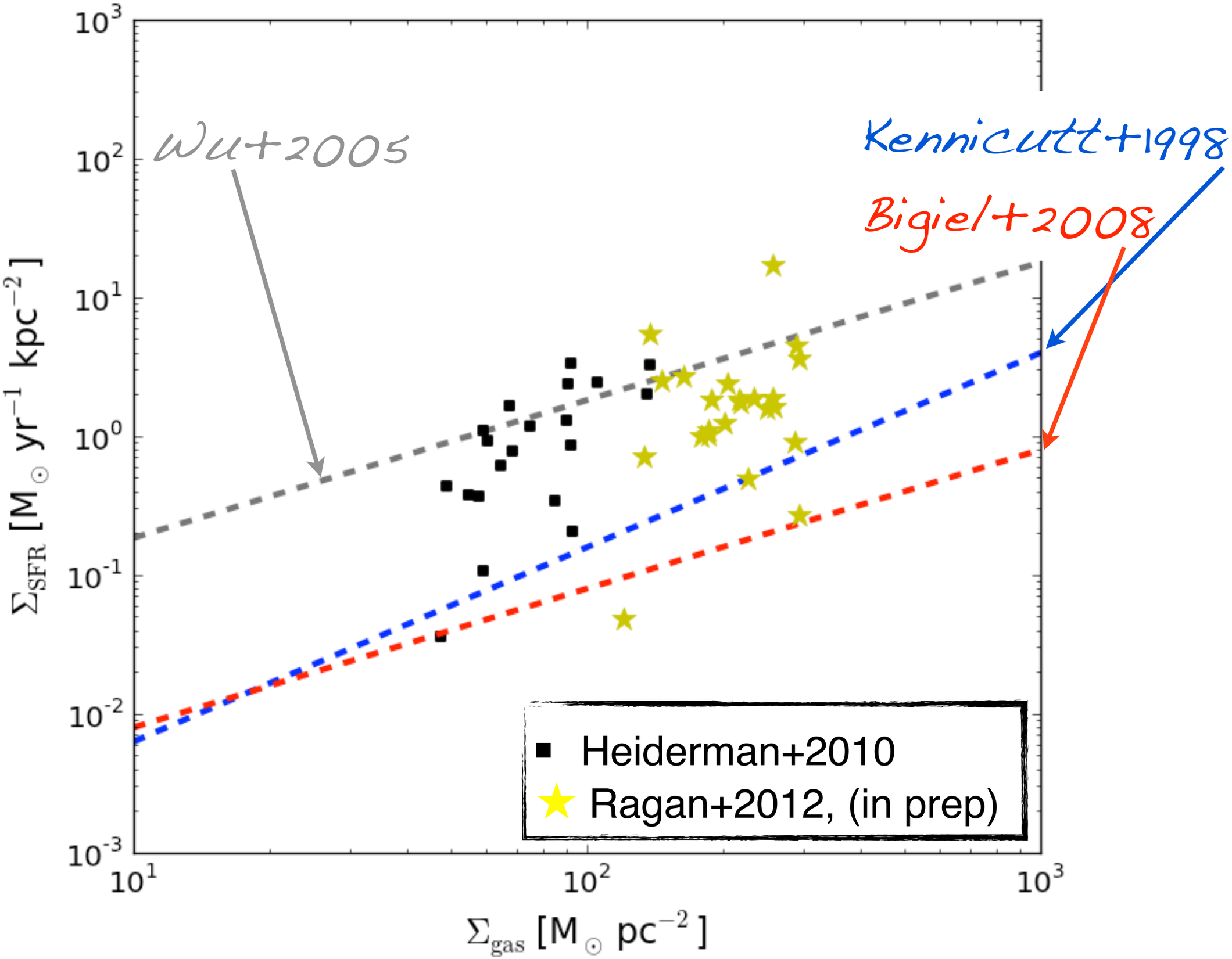
- Star counts (Heiderman et al. 2010)
- *We need some tweaks for distant IRDCs!*

$$\Sigma_{SFR} = N_{YSO,tot} \times \left(\frac{< M_{YSO} >}{M_\odot}\right) \times \left(\frac{t_{ClassII}}{yr}\right)^{-1} \times \left(\frac{A_{cloud}}{kpc^2}\right)^{-1} (M_\odot yr^{-1} kpc^{-2})$$

$M_{protostars,tot} \times f_{YSO-to-core}$

from part I

Surface density relations



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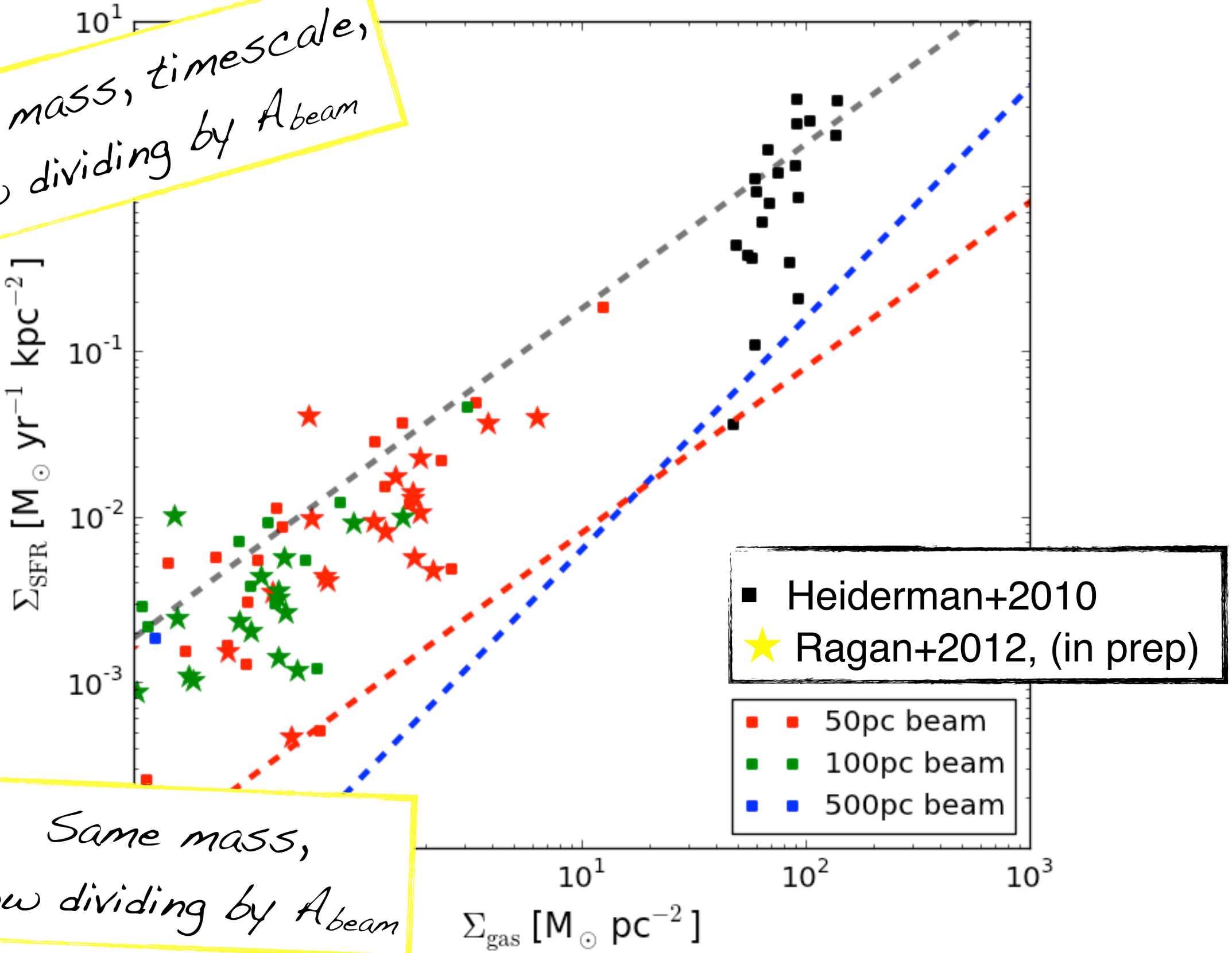
from part I

Use uniform beam instead

Surface density relations

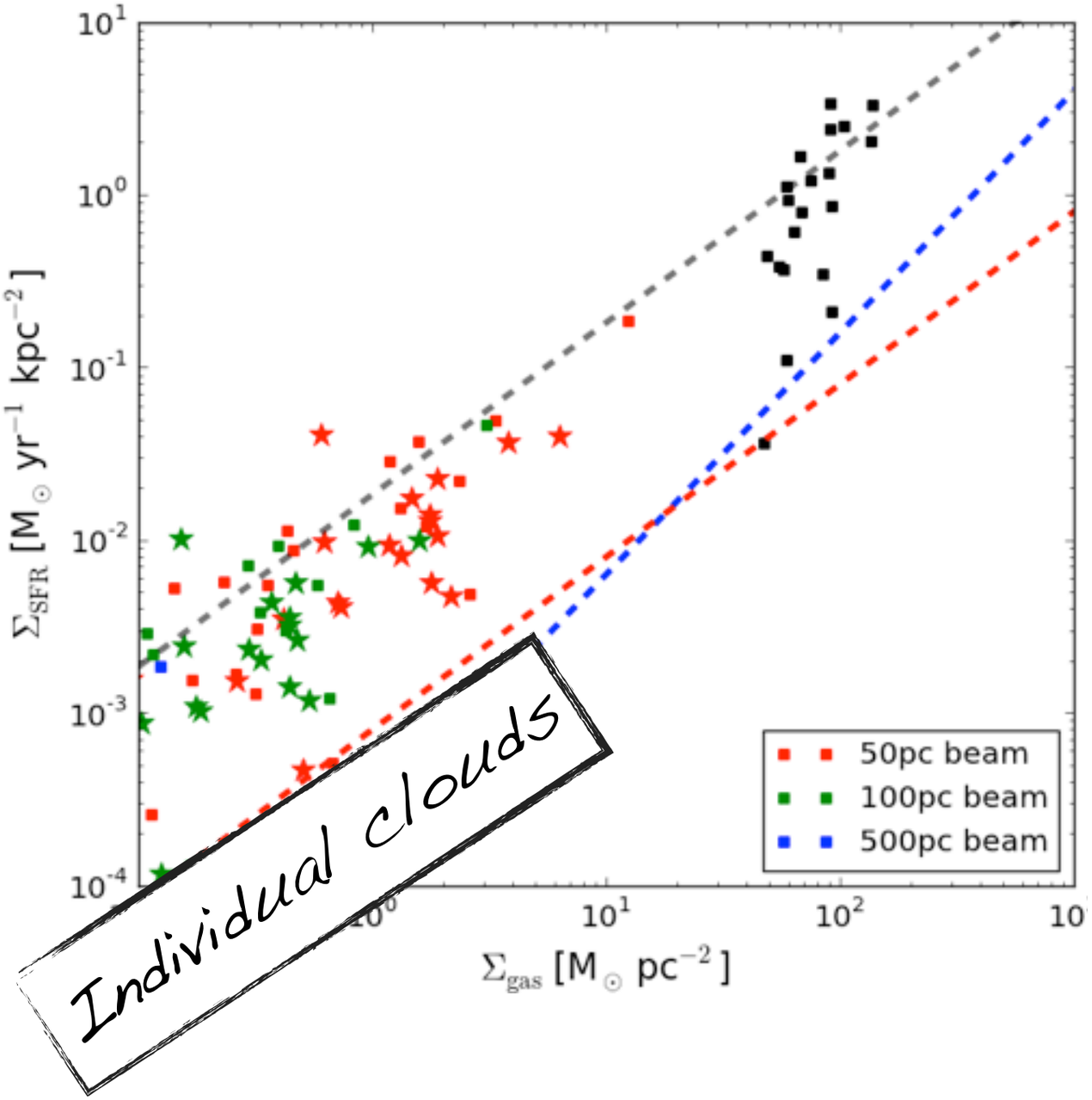
Same mass, timescale, now dividing by A_{beam}

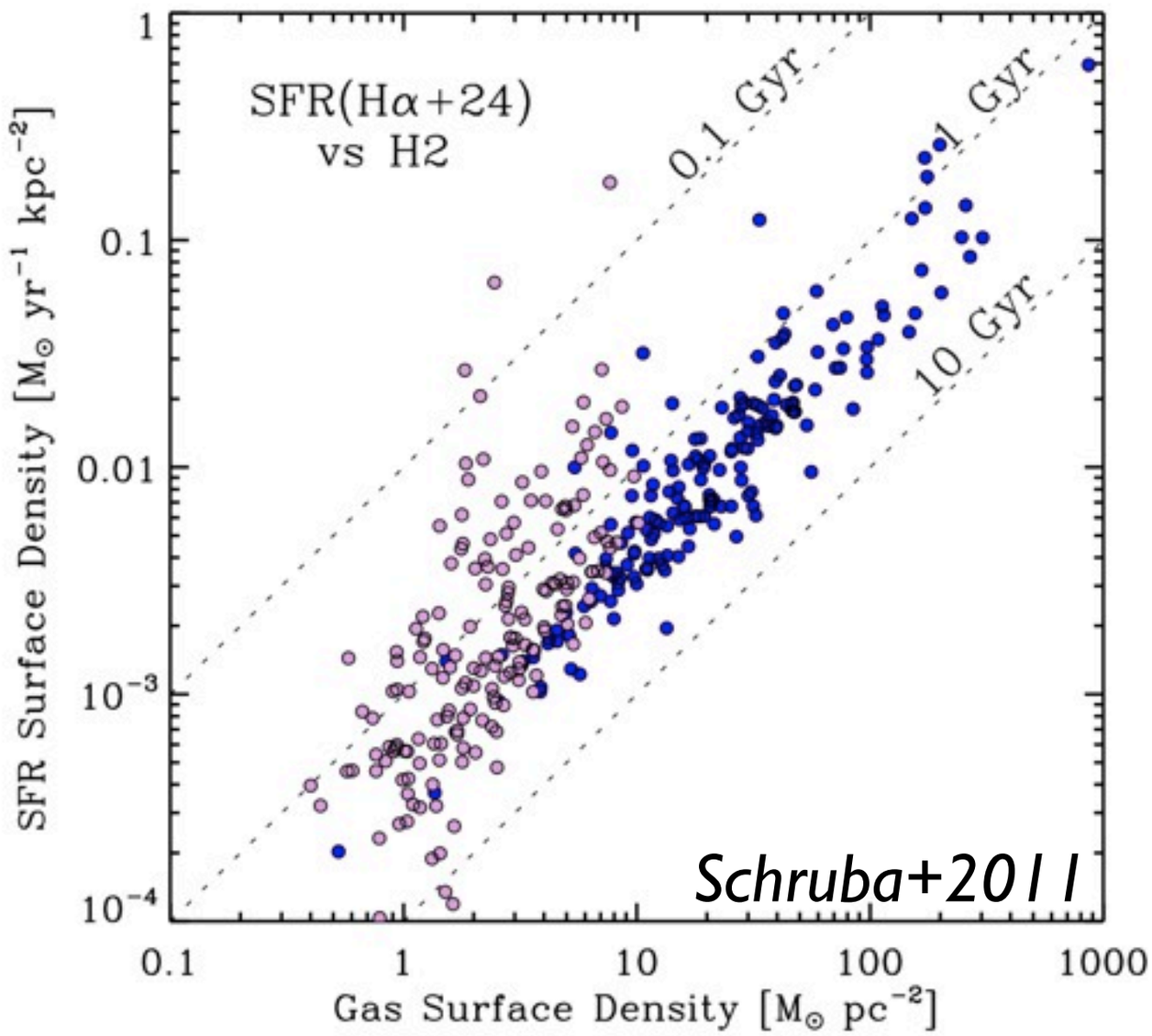


Same mass, now dividing by A_{beam}

Surface density relations

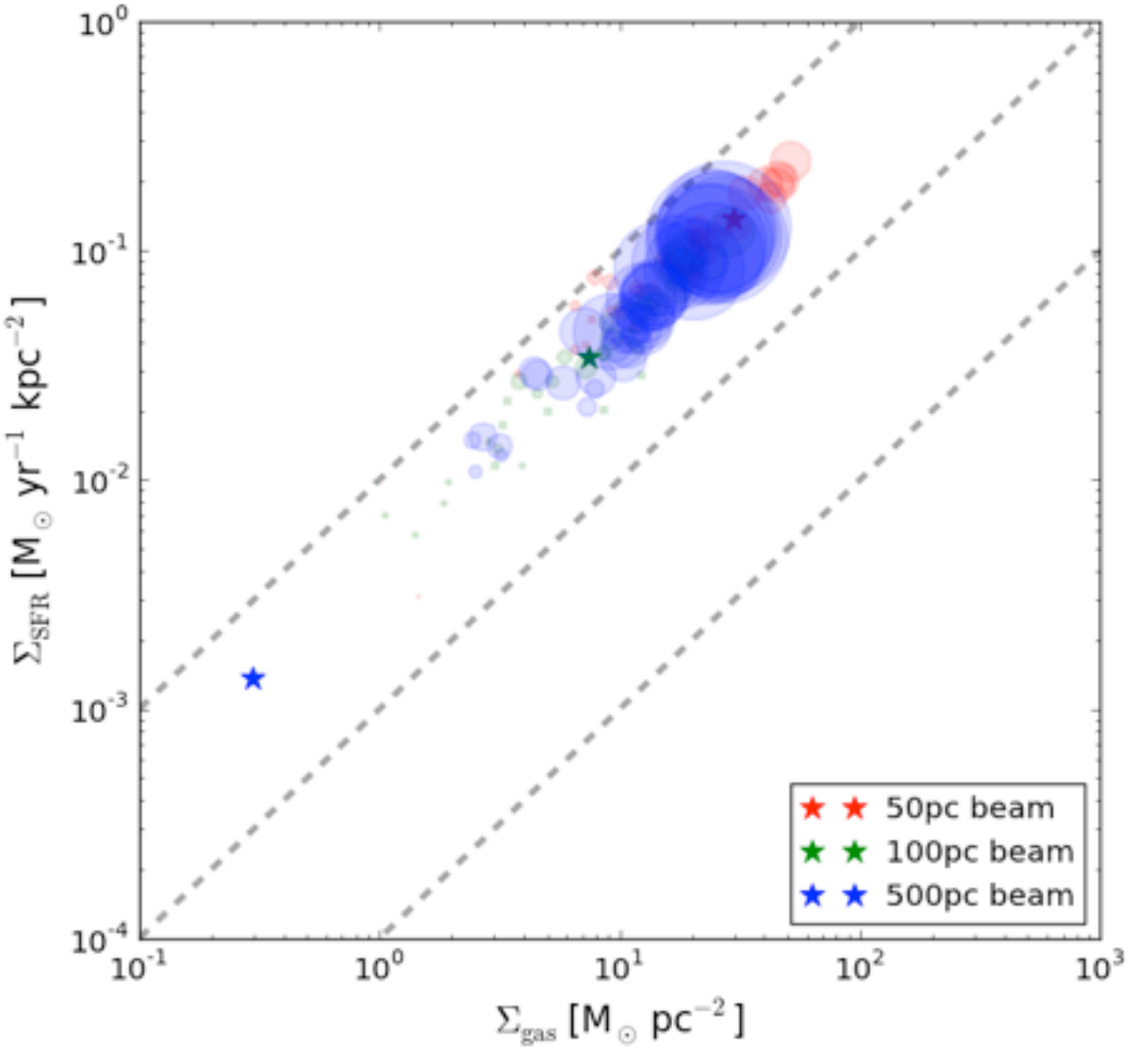
A fair comparison?

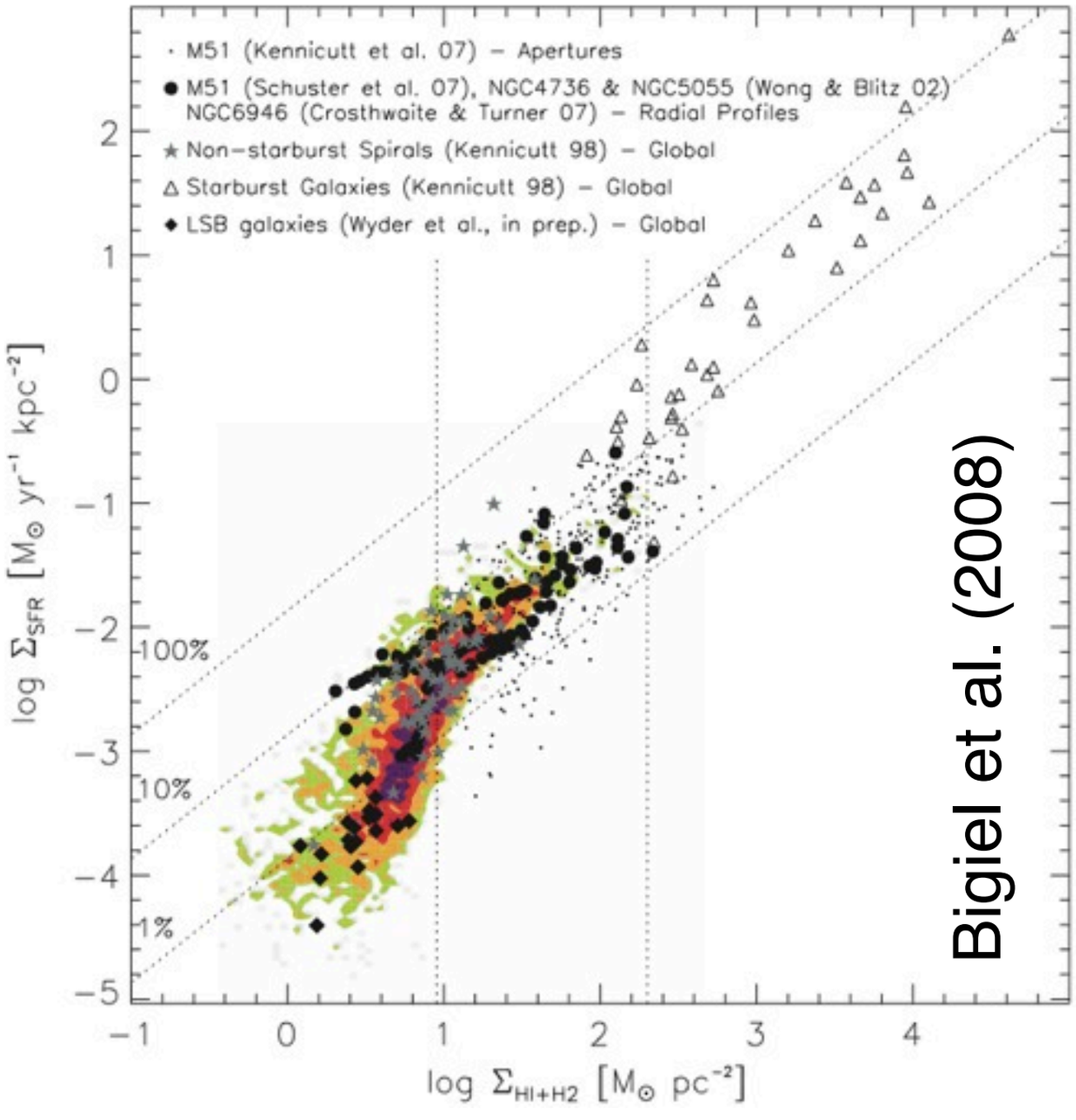




Surface density relations

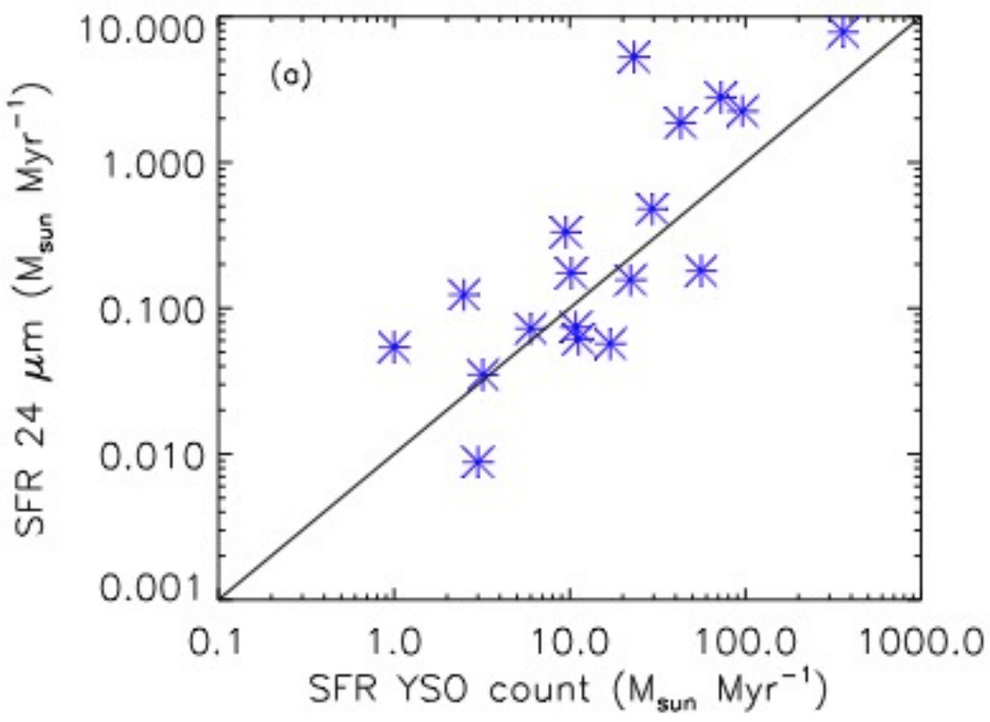
Random linear combinations of IRDCs in varying beams

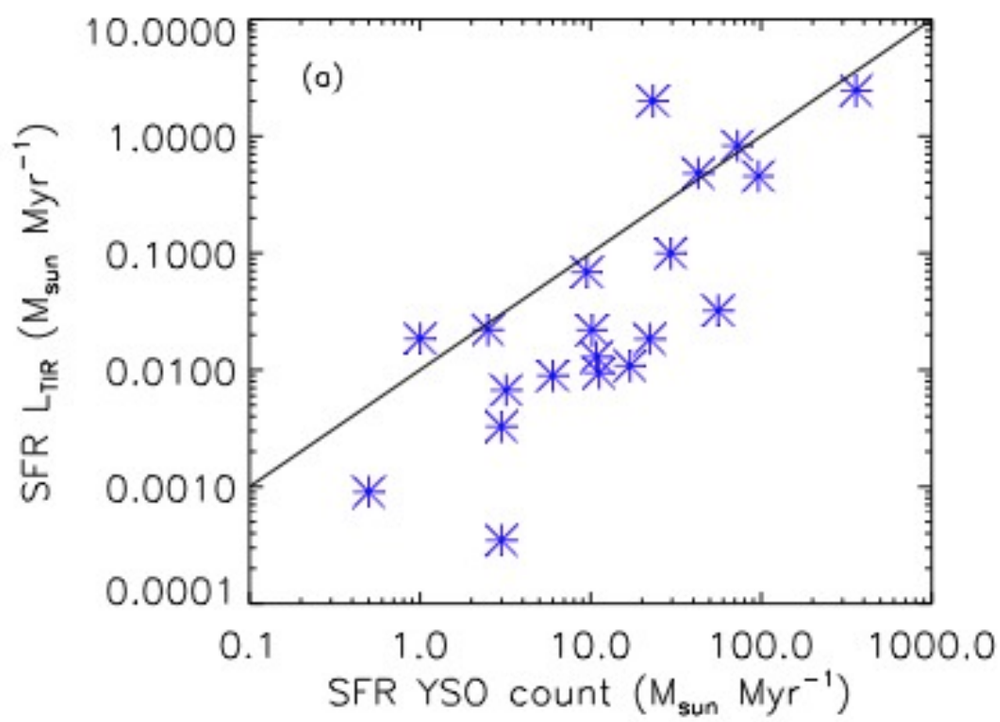




Caveats: SFR measures are poorly calibrated!

- *Chomiuk & Povich 2011*
  - MW SFR probes subject to systematic underestimates due to IMF under-sampling
- *Vutisalchavakul & Evans 2013*
  - L_{24um} , L_{TIR}, underestimate SFR compared to star counts

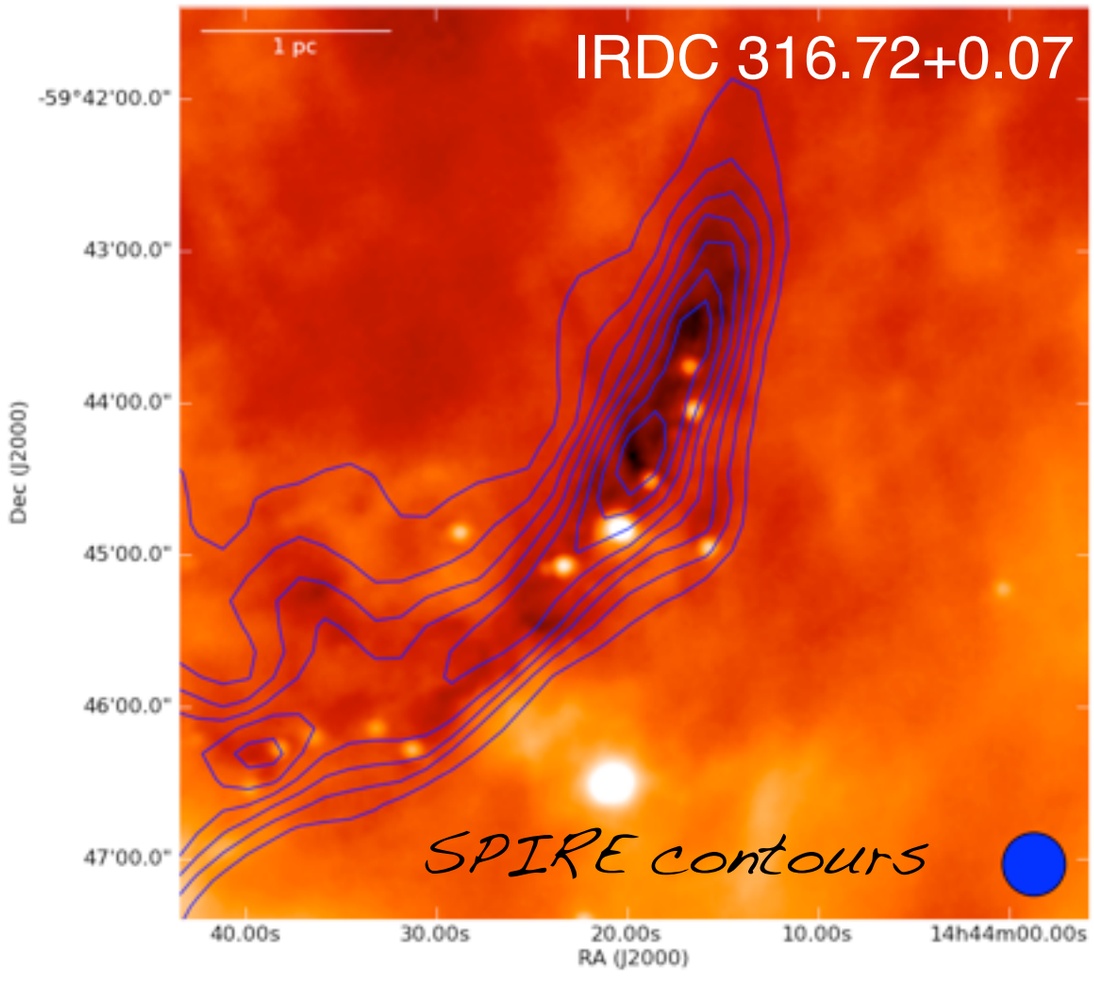


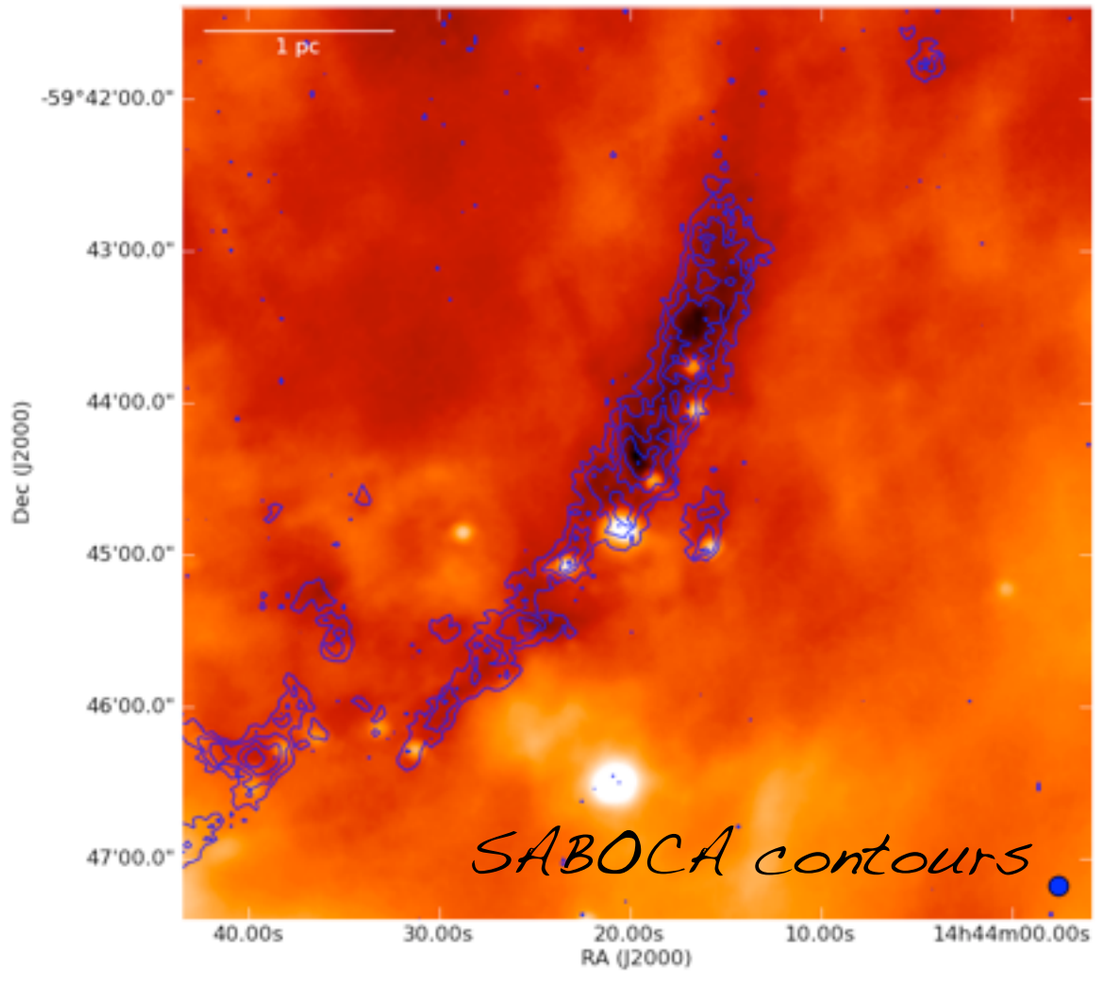


What drives the scatter?

Observations: *APEX/SABOCA*

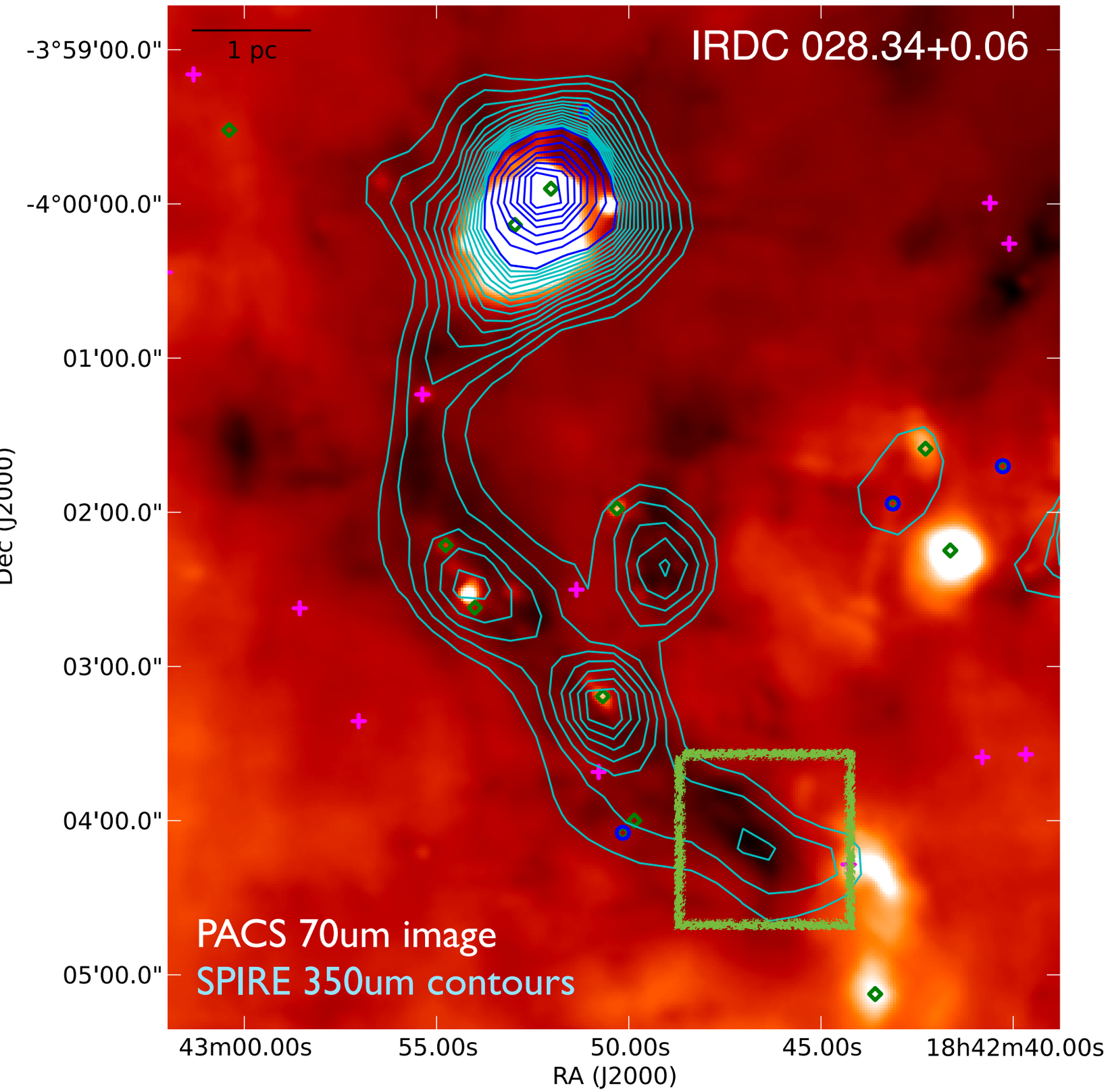
350 micron continuum observations,
resolving individual "clump" structures





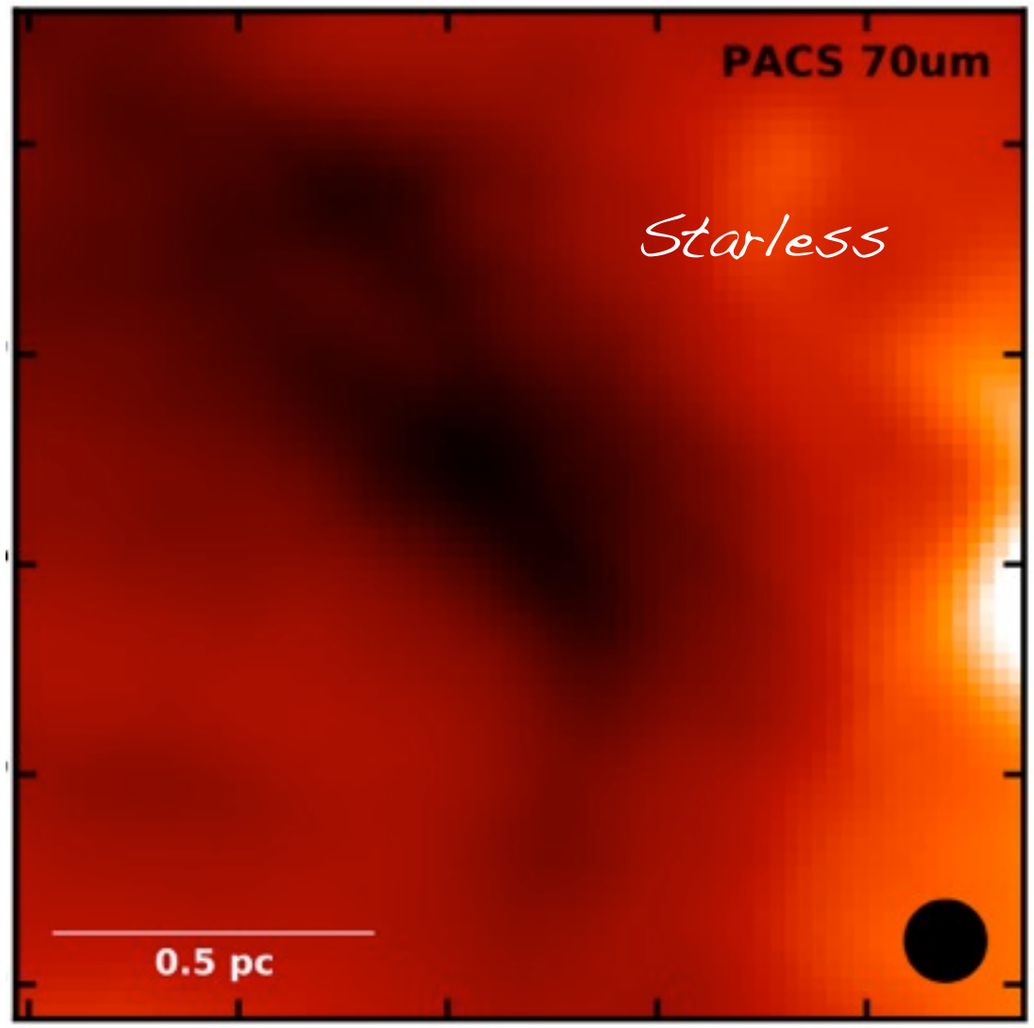
Ragan+submitted

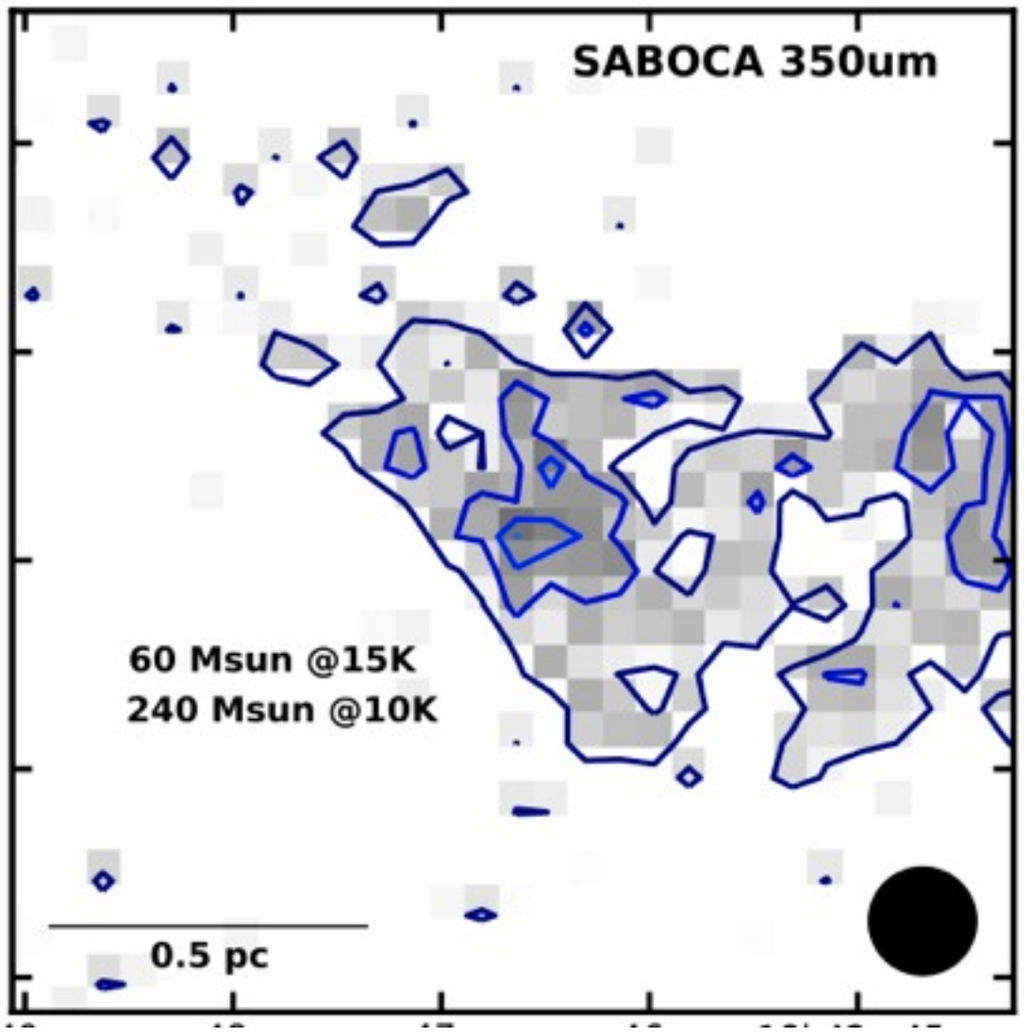
Observations: *APEX/SABOCA*



Observations: *APEX/SABOCA*

G028.34+0.06

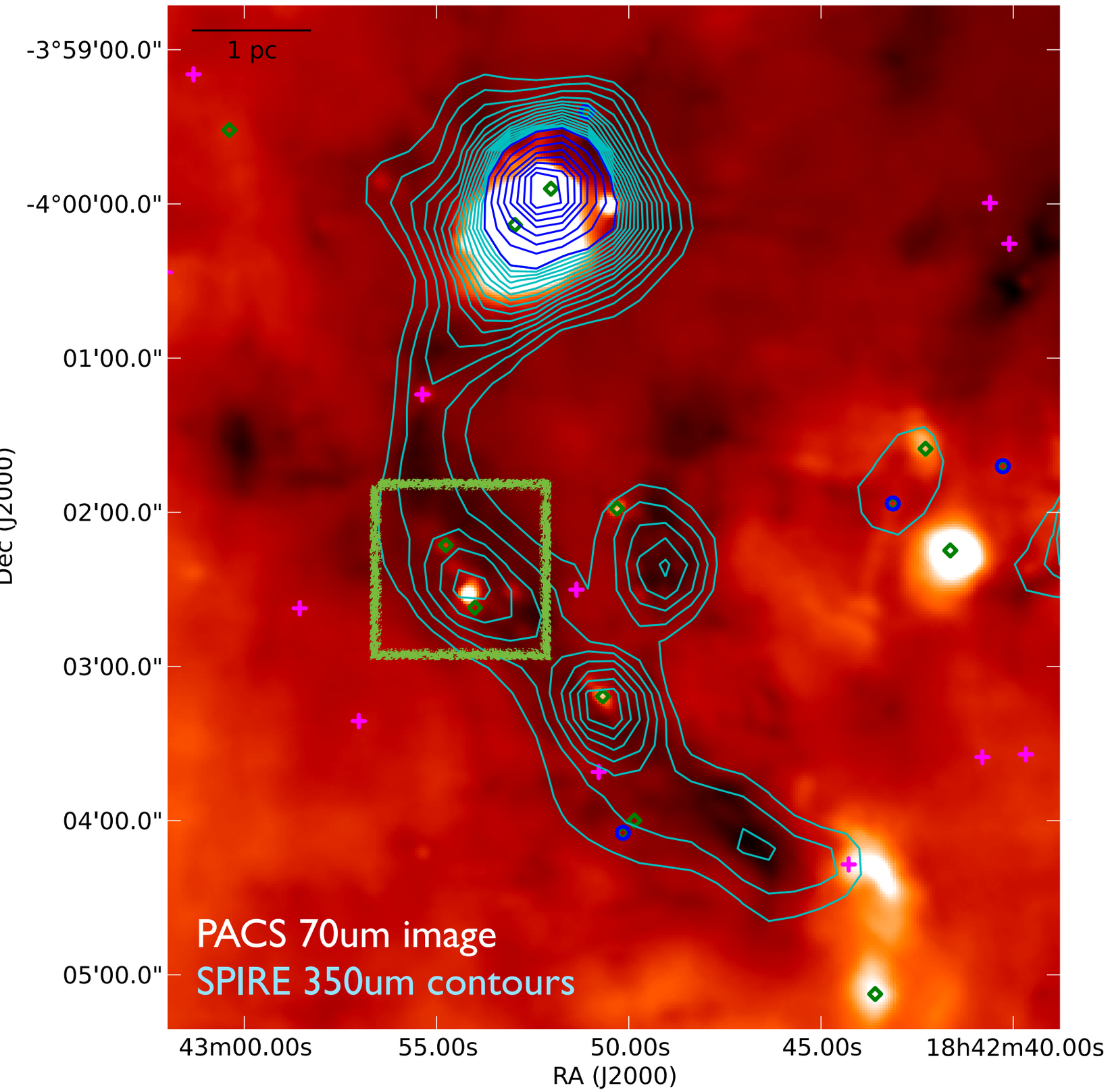




$N(H_2) \approx 2.7 \times 10^{22}$ cm^{-2}

$\Sigma(H_2) \approx 500$ M$_\odot$ pc^{-2}

Observations: *APEX/SABOCA*



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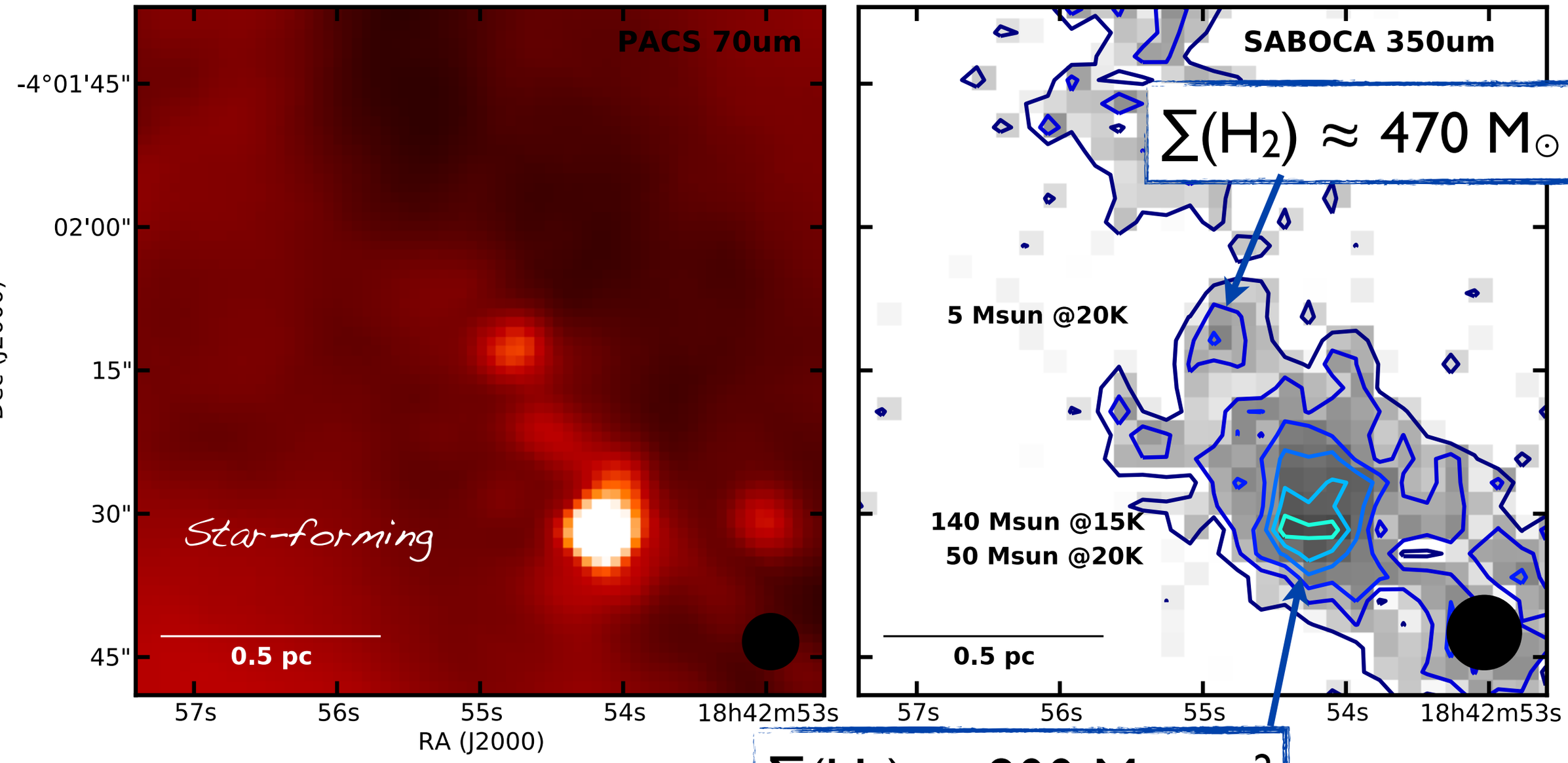


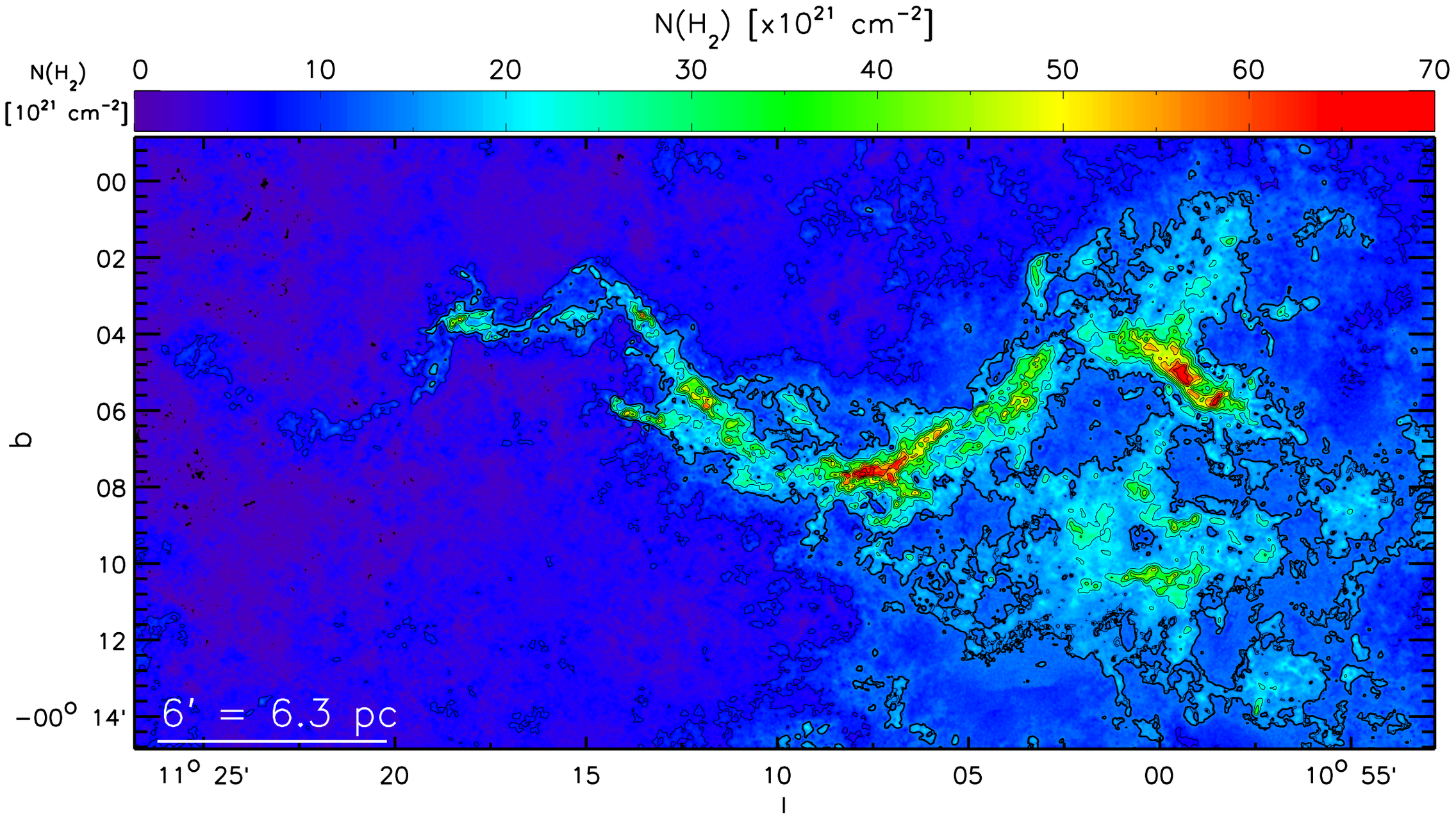
"Column density is a necessary (but not a sufficient) condition for star formation."

Why is there a relation between gas surface density and star formation rate?

- Recover linear relation between mass in protostars vs. cloud mass
- Recover surface density relations if uniform beam area applied
- Column density “necessary but not sufficient” condition for star formation

Future work: probing low column dnesities in IRDCs

G11.11 high-fidelity extinction map



Kainulainen, Ragan, Henning, Stutz 2013 (astro-ph/1305.6383)