Starburst Activity on Small Scales

Sterrewacht Leiden

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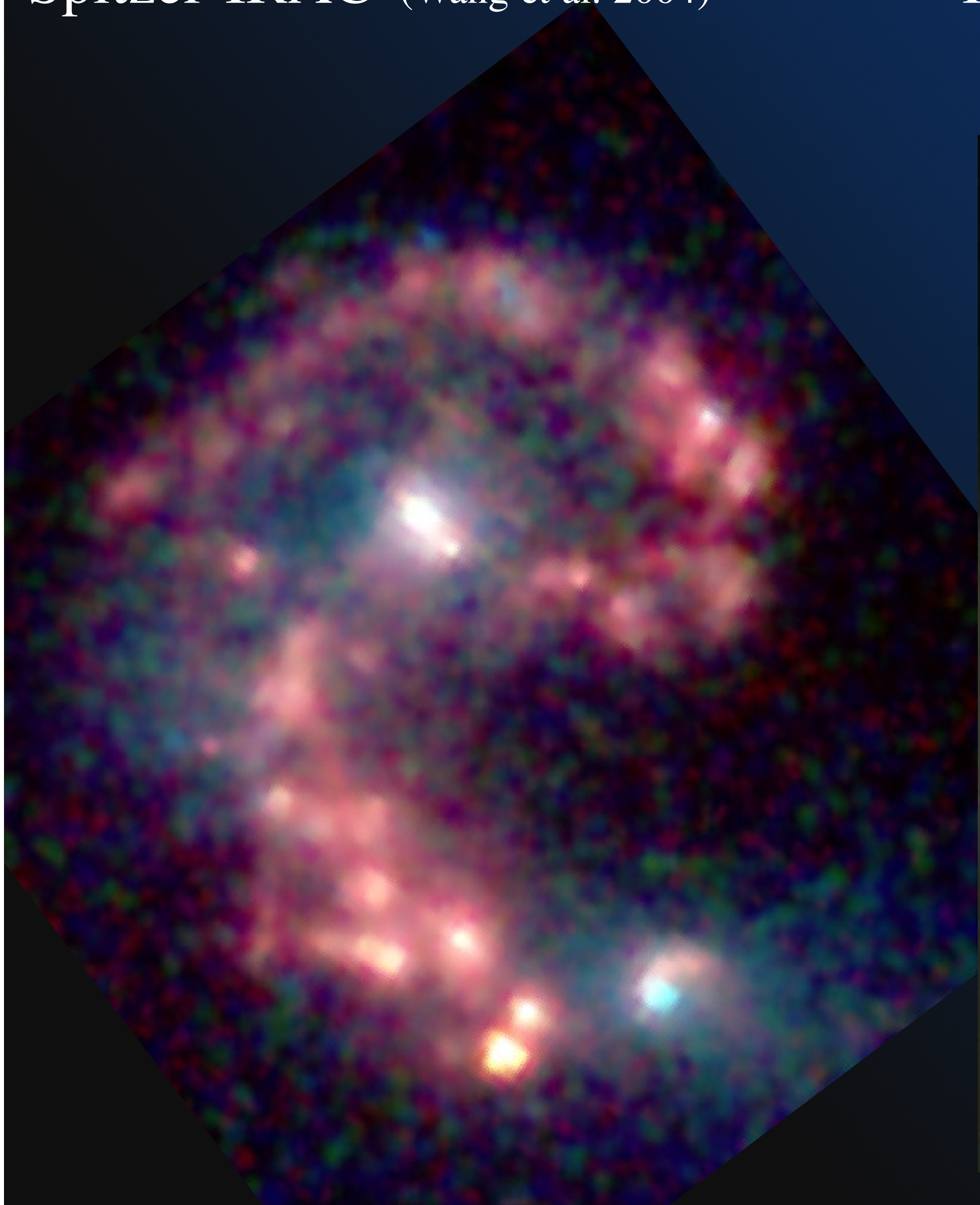
A. ***The Antennae Galaxies (NGC 4038/39)***
   – SSC ⇔ ISM ⇔ SFR

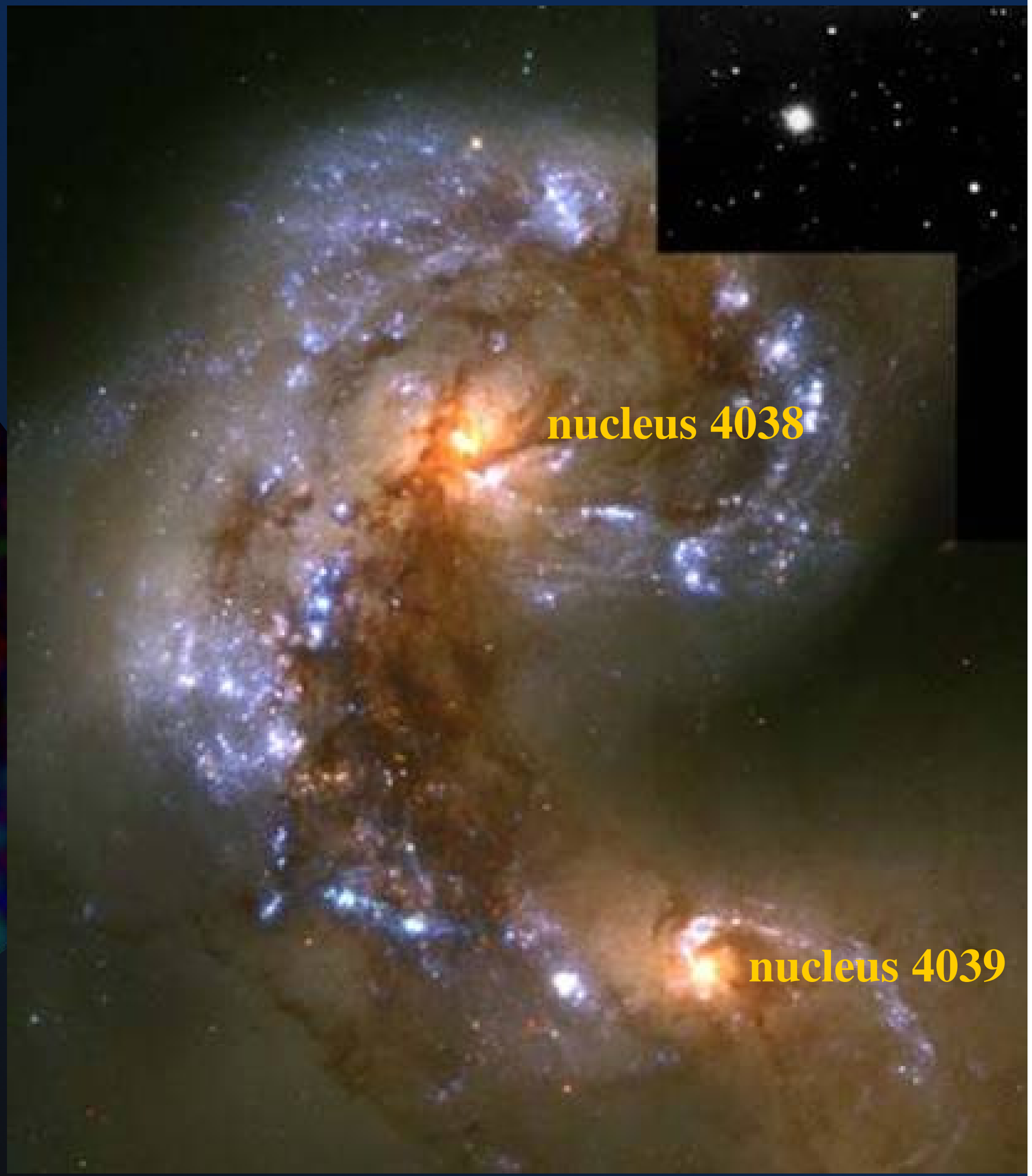
B. ***The Galactic HII region W49A***
   – zooming in on triggered MSF

The Famous Antennae Galaxies

Spitzer-IRAC (Wang et al. 2004)

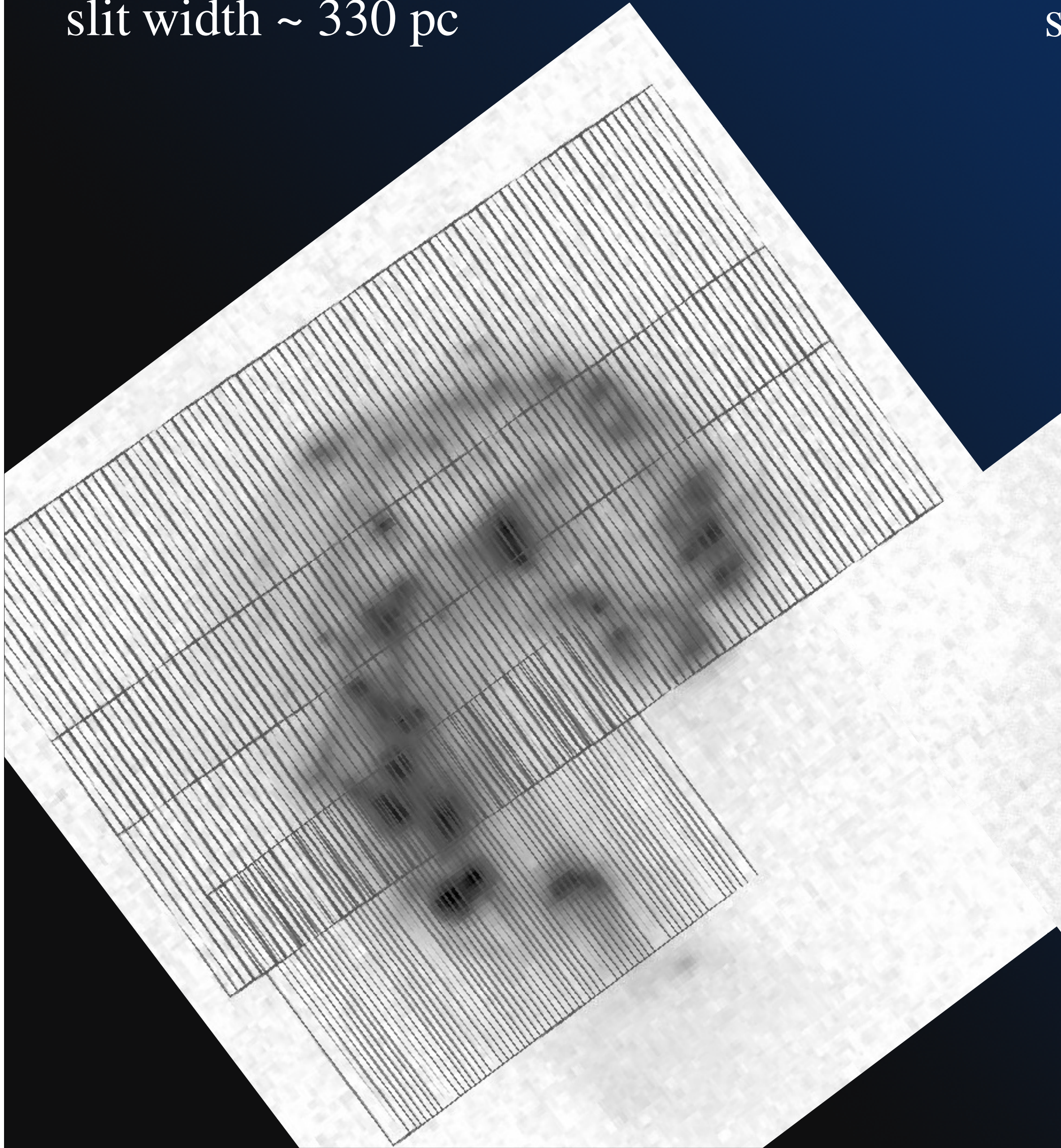


HST-WFPC2 (Whitmore & Schweizer (1995)

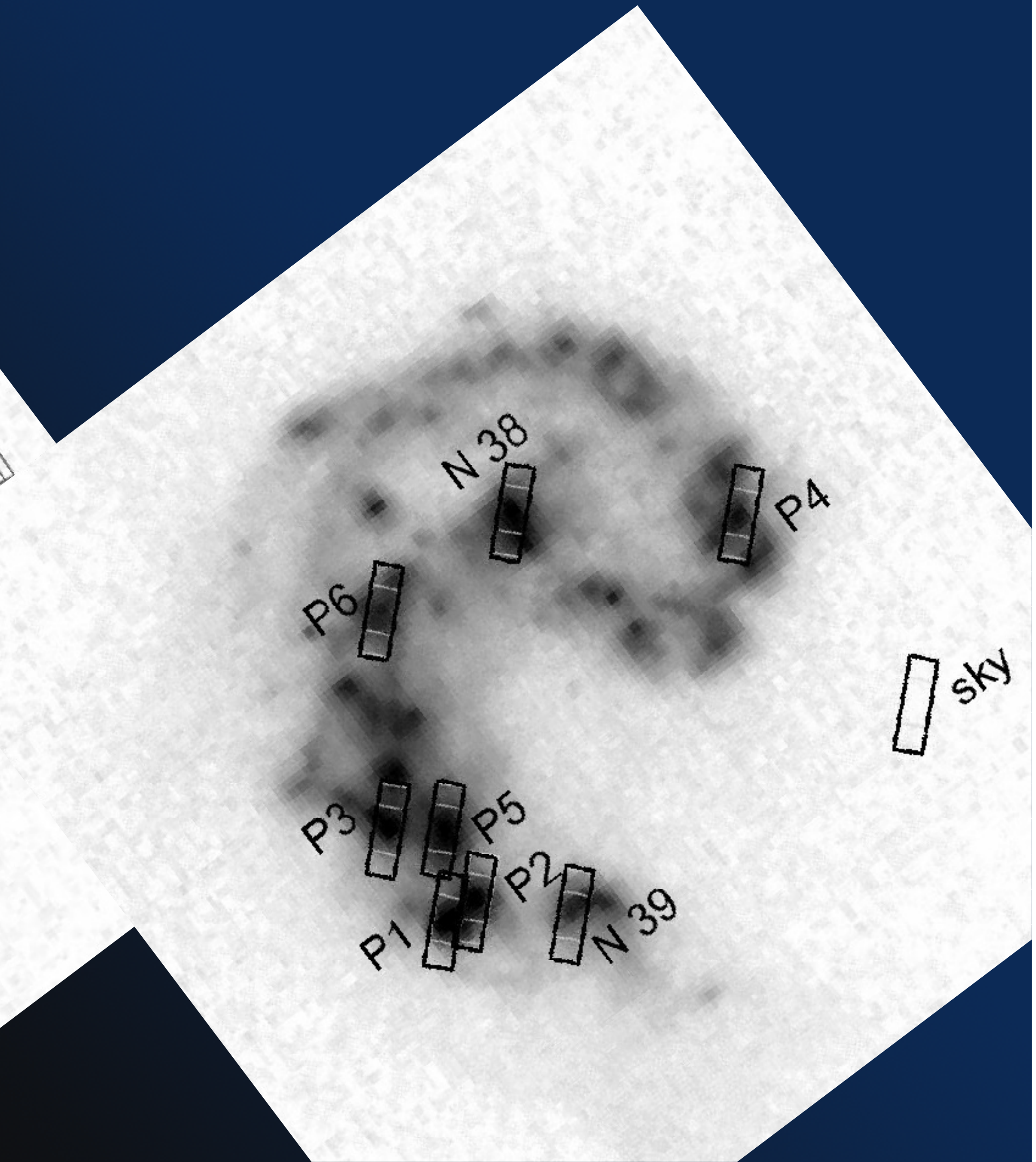


Our Spitzer Observations

Spectral map with IRS-SL:
R ~ 65 - 130, t_{int} = 0.5min,
slit width ~ 330 pc



Discrete pointings on IR peaks with
IRS-SH: R ~ 600, t_{int} = 12min,
slit size ~ 500×1200 pc^2



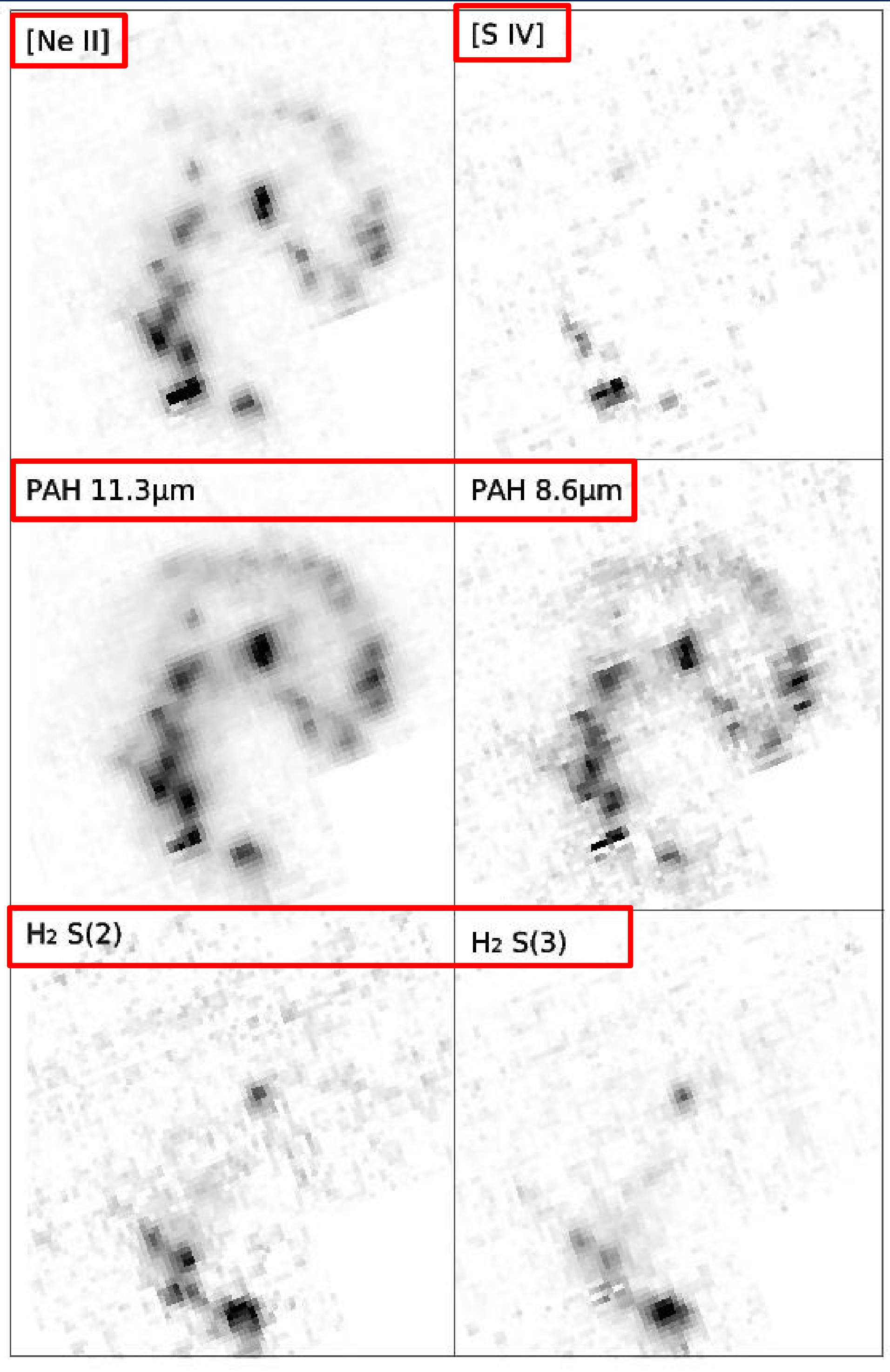
ISM Conditions across the Antennae

- [Ne II] – 21.6 eV: SF in the past 10 Myr: all peaks in the overlap region and both nuclei

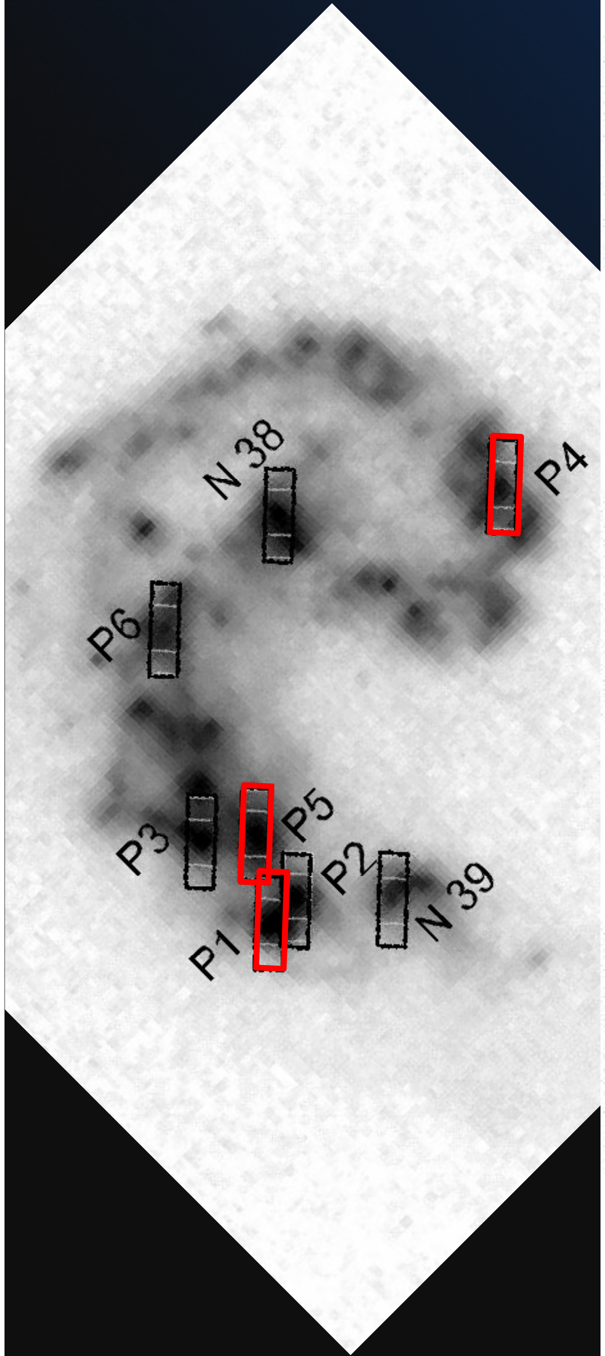
- [S IV] – 34.8 eV: SF in the past 4 – 6 Myr: peaks 1, 2 and nucleus of NGC 4039

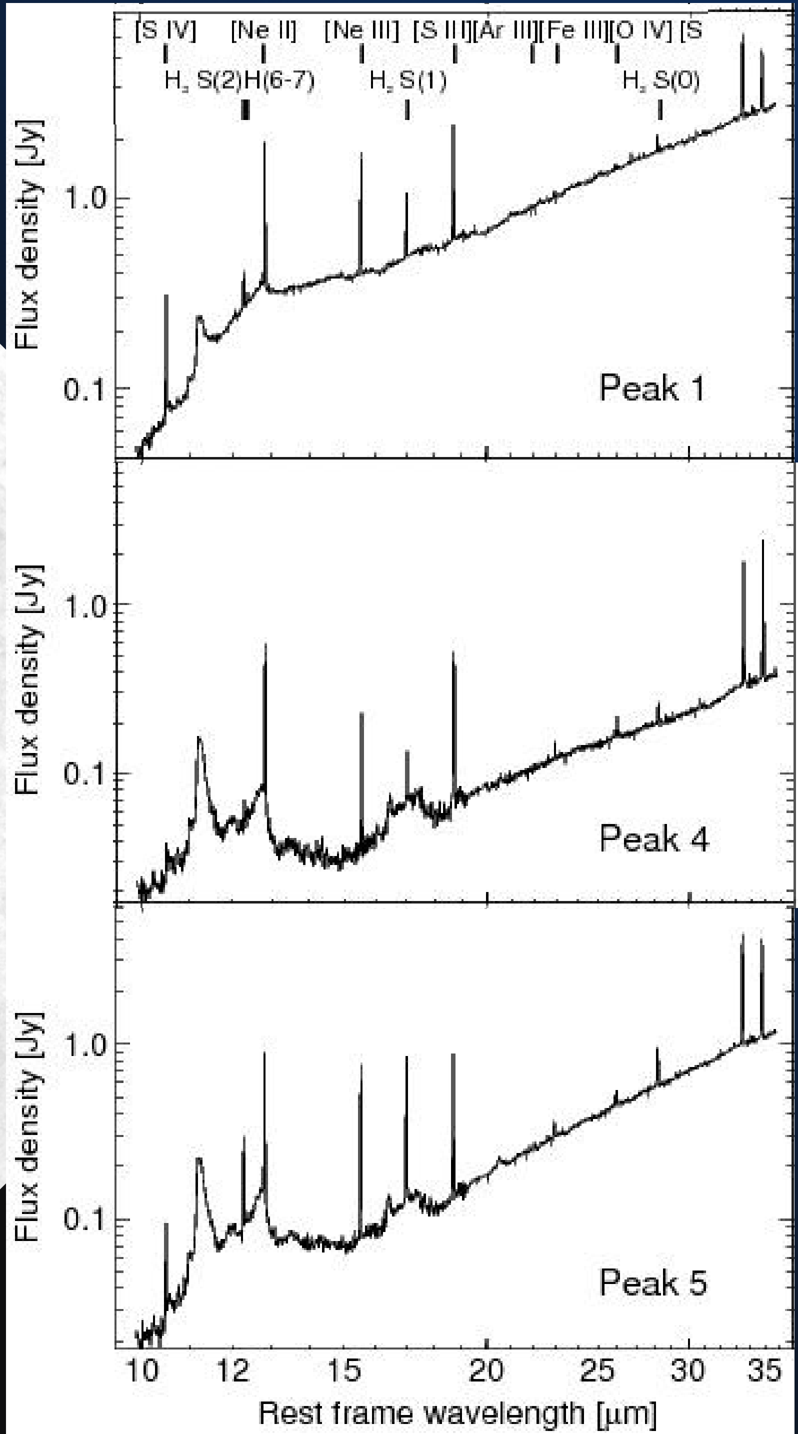
- PAH – traces PDRs: similar to [Ne II] but more diffuse; strong nucleus NGC 4038

- H_2 S(2,3): both nuclei + SSCs; 45% of the S(3) from nucleus of NGC 4039



Properties of Super Star Clusters (SSCs)





brightest source at cm λ

radio: thermal ~ 5000 O5 stars (Neff & Ulvestad 2000)

faint optical counterpart

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bright, compact radio source

steep radio → evolved stellar population

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brightest sub-mm peak

4×10^8 M_o molecular gas

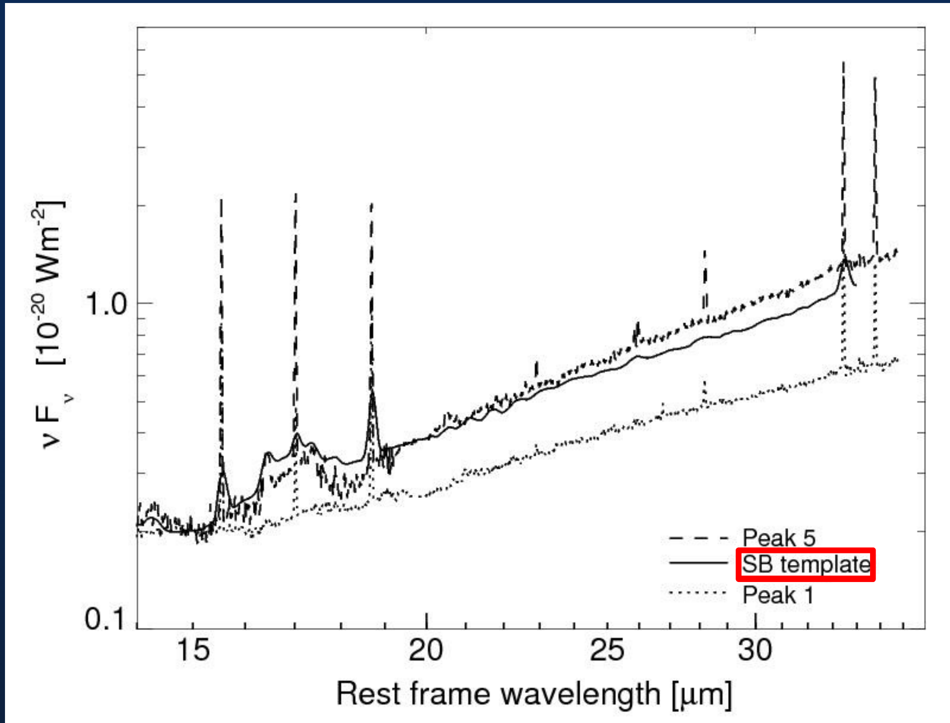
A_V ~ 12 mag

radio emission ← SNe

Toward KS Law – Step 1: Calculate SFRs

peak 5: sub-mm peak, non-thermal radio
peak 1: cm-source, thermal radio source

→ mid-IR cluster SEDs resemble SB galaxies



Now: F_{15} & F_{30} → L_{IR} → SFR

Note: the Kennicutt (1998) L_{IR} ⇔ SFR applies to dusty SBs in the continuous star formation approximation, with ages of order 10–100 Myr. → systematically overestimate the SFRs.

Position	L_{IR}[a] [10^9 $L_\odot$]	SFR [$M_\odot$/yr]
nuc 4038	3.67	0.63
nuc 4039	1.86	0.33
peak 1	11.41	1.97
peak 2	10.40	1.81
peak 3	4.35	0.74
peak 4	1.29	0.22
peak 5	3.86	0.66
peak 6	1.31	0.22

$L_{IR} = 3.8\times10^{10}$ L_o

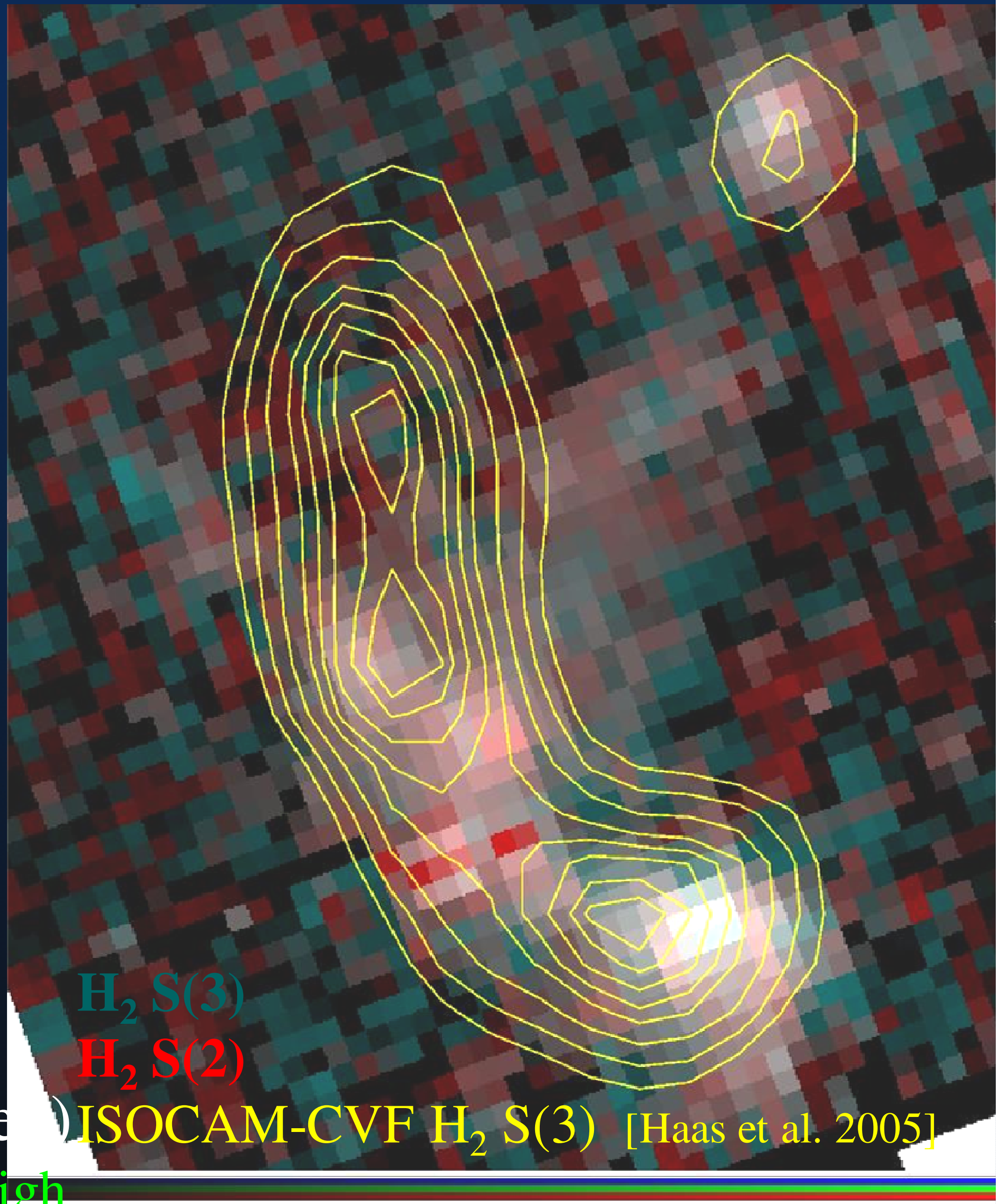
cp. 7.2×10^{10} L_o, for the whole galaxy (Sanders et al. 2003)

SFR ~ 6.6 M_o/yr

Toward KS Law – Step 2: Calculate Mass(H_2)

- H_2 among the strongest lines (but 5 × less H_2 than previously reported by Haas et al. 2005)

Position	$M(H_2)^e$ $[10^6\ M_\odot]$
nuc 4038	2.24
nuc 4039	3.56
peak 1	3.09
peak 2	3.20
peak 3	3.39
peak 4	0.22
peak 5	4.24
peak 6	0.30



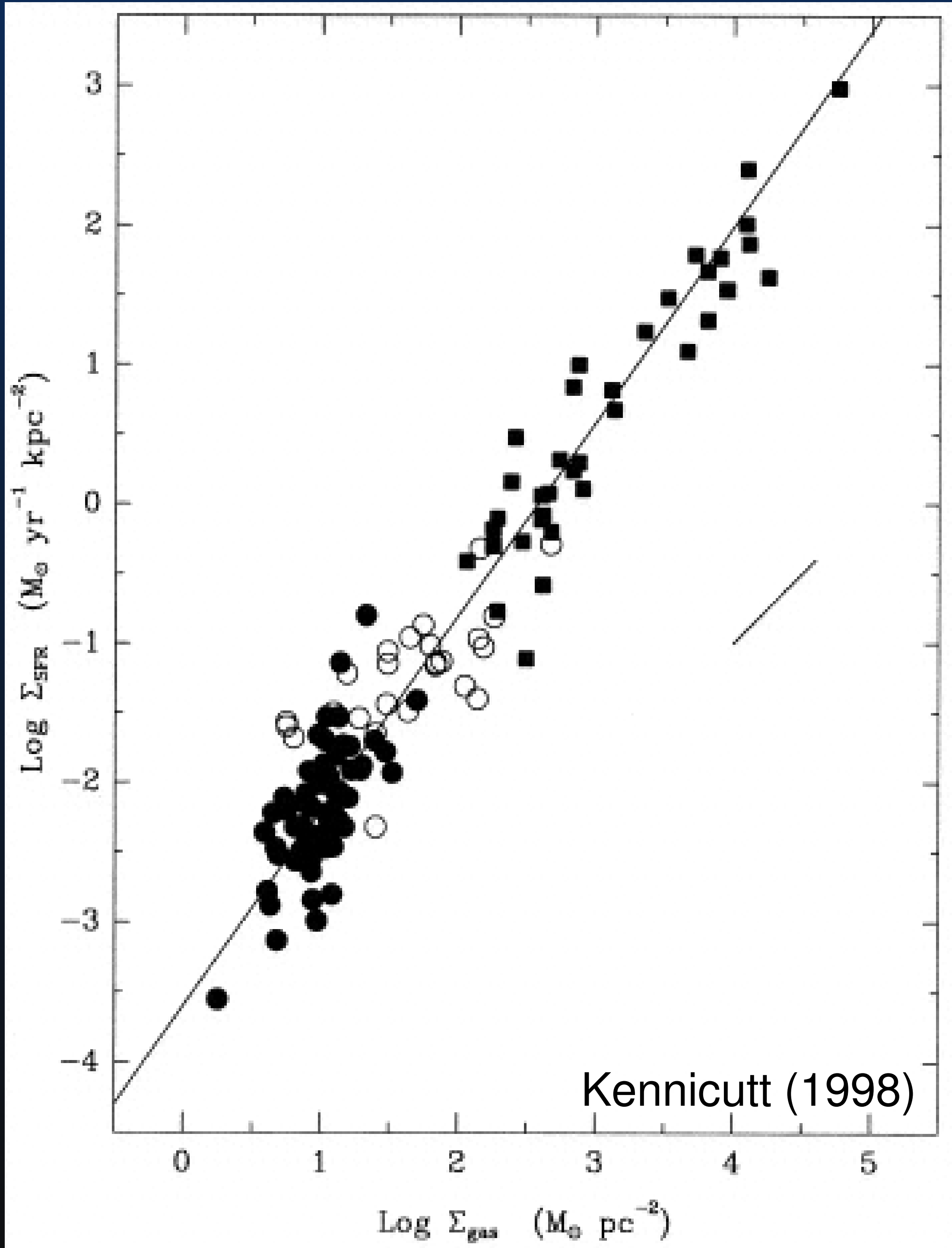
H_2 temperature ~ 300 K (thermalized)
~ULIRGS (Higdon et al. 2006) but twice as high as for SINGS galaxies (Roussel et al. 2007)

SSCs and the Schmidt-Kennicutt Law

Problems!?

- H_2^{warm} → H_2^{tot}
- CO → H_2^{tot}
- H_2 ⇔ HI ⇔ HII
- aperture effects (SSC ⇔ GMC)
- Averaged galaxies: $t_{MSF} << t_{SB}$; SSCs: $t_{MSF} \sim t_{SB}$

$$\Sigma_{gas} = \varepsilon / (1-\varepsilon) \cdot \Sigma_{gas\text{-}obs} \quad ?$$



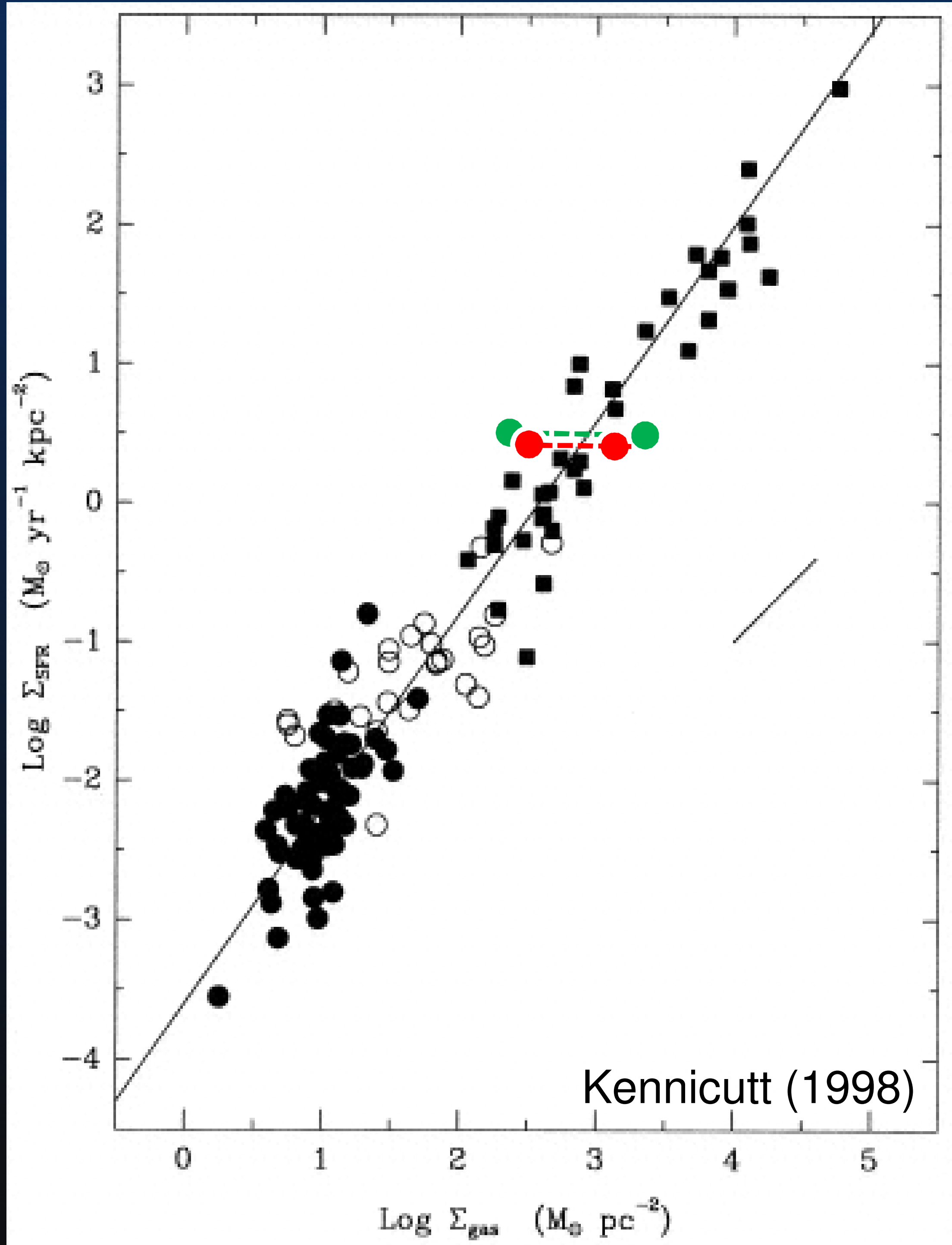
SSCs and the Schmidt-Kennicutt Law

Results *(on 2 dusty SSCs):*

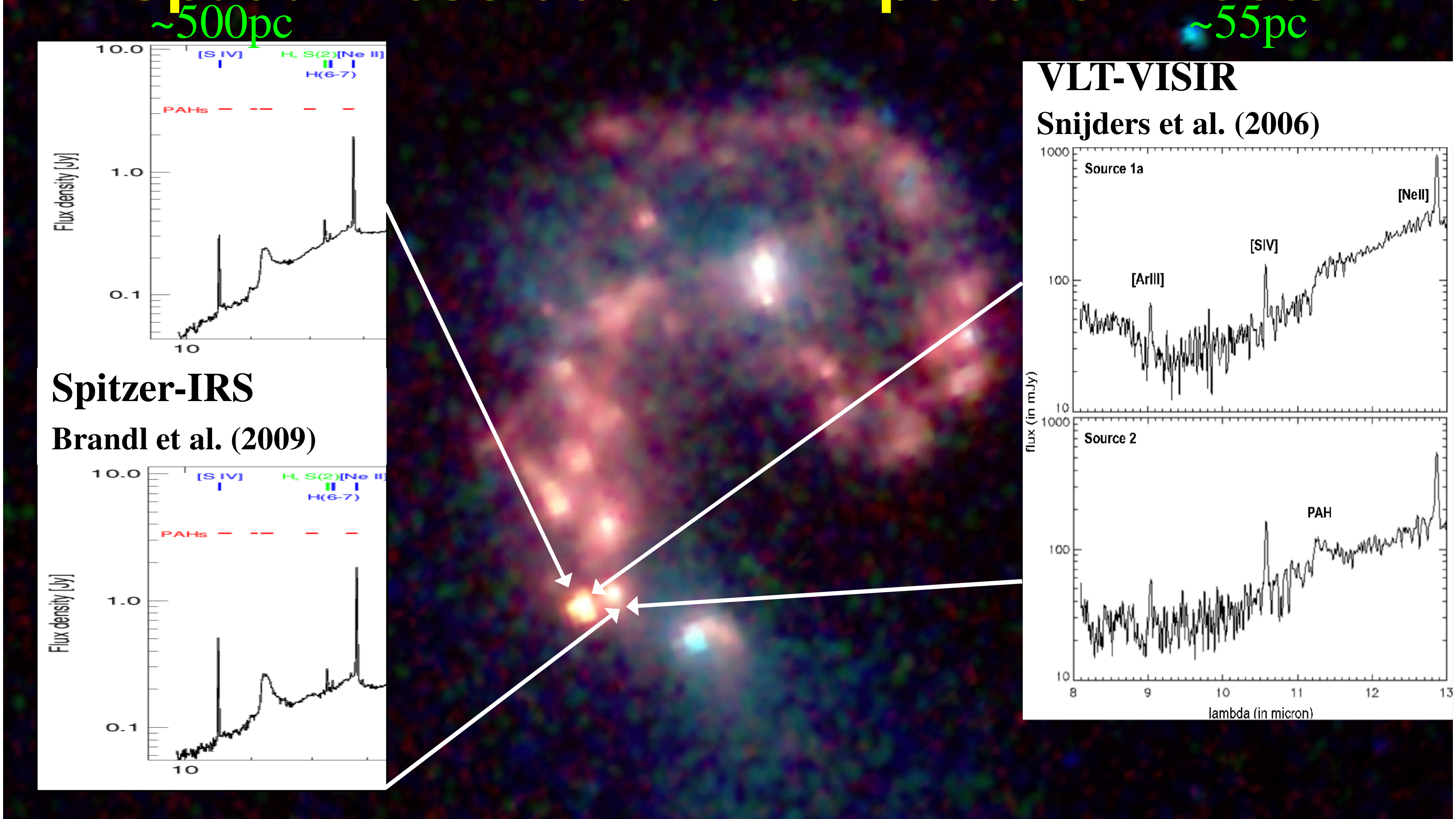
- "left" points: H_2^{warm} → H_2^{tot}
  (Brandl et al. 2009)

- "right" points: CO → H_2
  (Wilson et al. 2000)

→ SSCs fit the KS law



Spatial Resolution and Aperture Effects



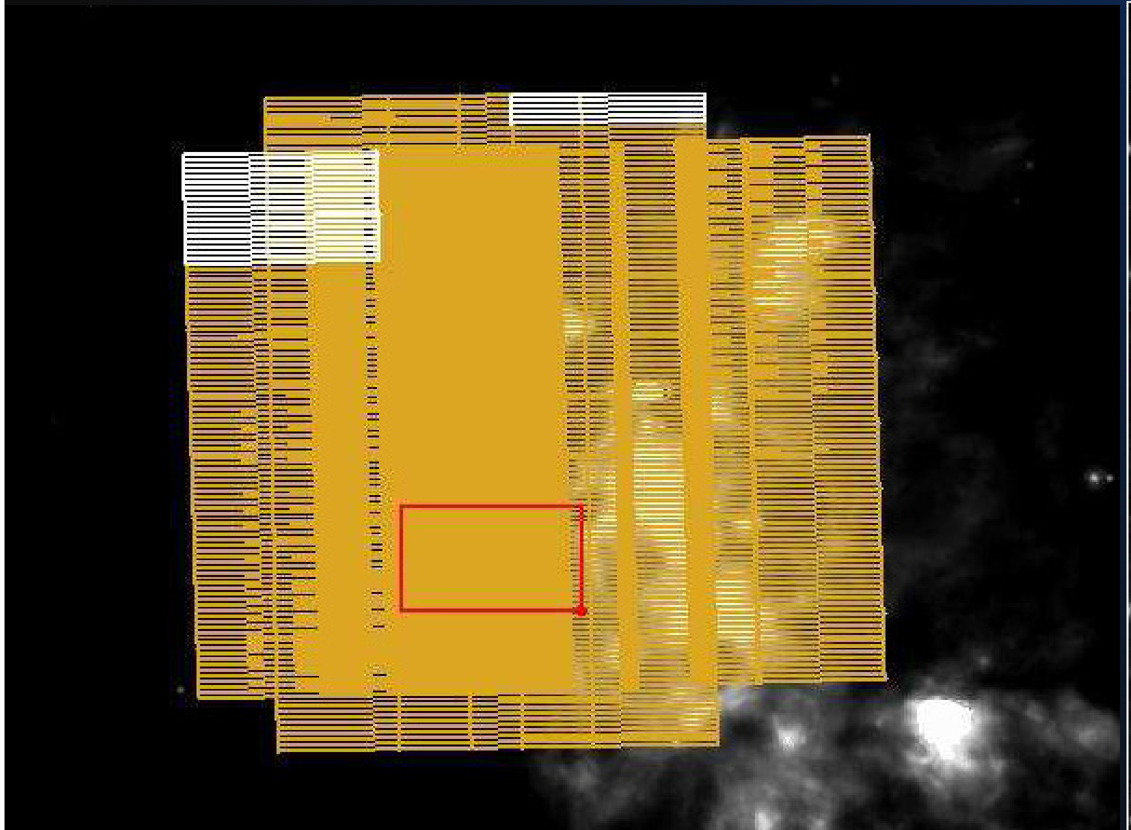
Same continuum fluxes (L24μm), but very different strength of molecular tracers (PAHs, H_2) ➔ Result = f {*resolution*}

Solutions: (*i*) build bigger telescopes and/or (*ii*) observe regions nearby

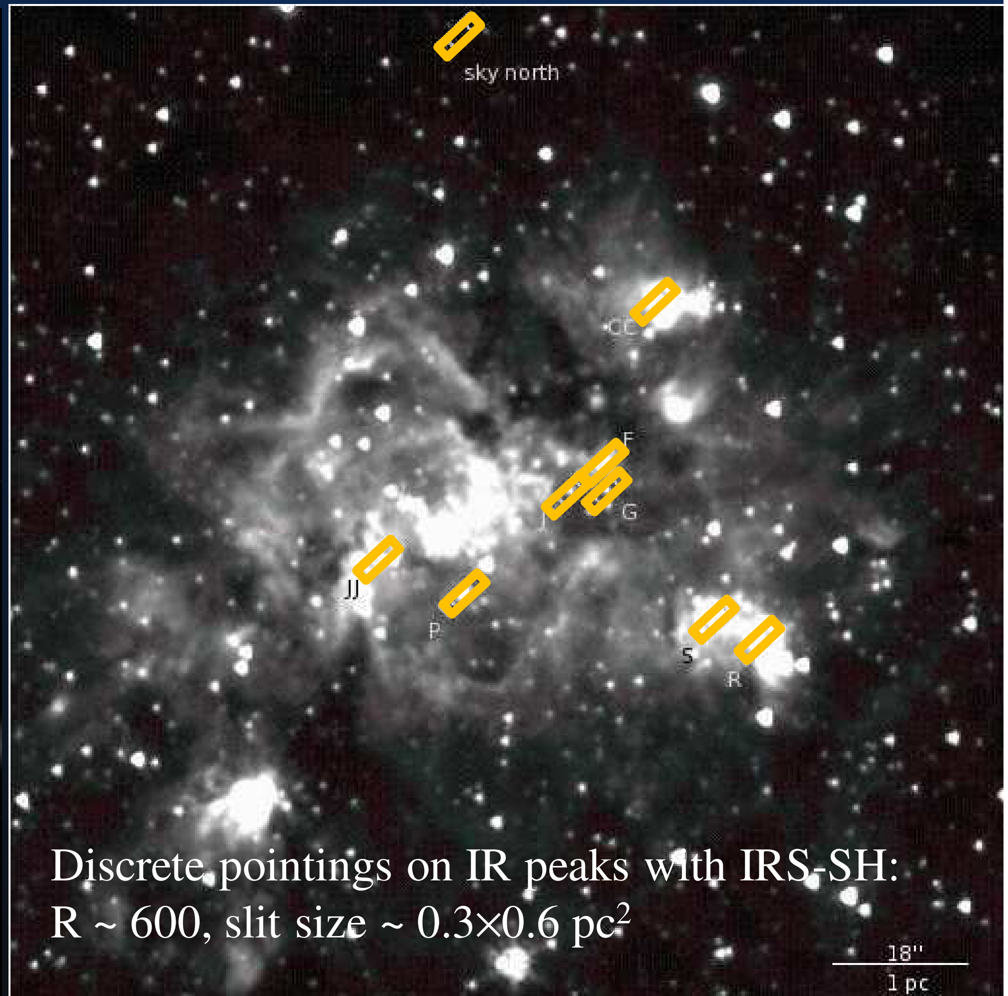
Part B: W49A

W49A

- discovered by Westerhout (1958)
- distance ~ 11.4 kpc, size > 55pc
- largest concentration of heavily embedded stars in the MW
- 316 water masers, 40 separate UCHIIRs (de Pree et al. 1997)
- $L_{IR} \geq 10^7 L_o$ (Becklin et al. 1973)



Spectral map with IRS-SL:
R ~ 65-130, "sky" positions in white



Discrete pointings on IR peaks with IRS-SH:
R ~ 600, slit size ~ 0.3×0.6 pc^2

Since this part of my talk on W49A contains unpublished results it has been dropped from these slides – my apologies

Summary

- SSCs fit on KS law – but large uncertainties

- $L_{SSC} \sim 400 \times L_{W49A} \rightarrow$ scaling?

- Relevant scales: few 100 pc to few parsecs

- Higher angular resolution essential to study complex SSC environments/formation

- *What are clouds, clumps,* ε_{SF}, t_{ff}, ρ_{gas} *in reality?*