The star formation history of embedded clusters

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Outline

- Introduction
- Cluster sample & analysis tools
- Star formation history
- Cluster formation
- Conclusions

Galactic star formation

- Stars do not form in isolation, but in embedded clusters
  - large, gravitationally unbound associations
  - compact, gravitationally bound starburst clusters

Galactic star formation

- Stars do not form in isolation, but in embedded clusters
  - large, gravitationally unbound associations
  - compact, gravitationally bound starburst clusters

Main questions

- What is their star formation history?
  - Single burst, Age spread, sequential star formation
- What is the role of feedback and filaments?
- Are there differences with cluster morphology?

How do we study them?

- Stellar content
  - Near-infrared imaging and spectroscopy: stellar properties
  - Mid-infrared imaging: Young Stellar Objects
- Dust:
  - Far- infrared (Herschel) and Sub-mm
- Gas:
  - Radio and mm observations

Spectral classification

- near-infrared spectroscopy with SINFONI (VLT) and LUCI(LBT)
  - Multi-object-spectroscopy
  - Integral field spectroscopy

Spectral cla

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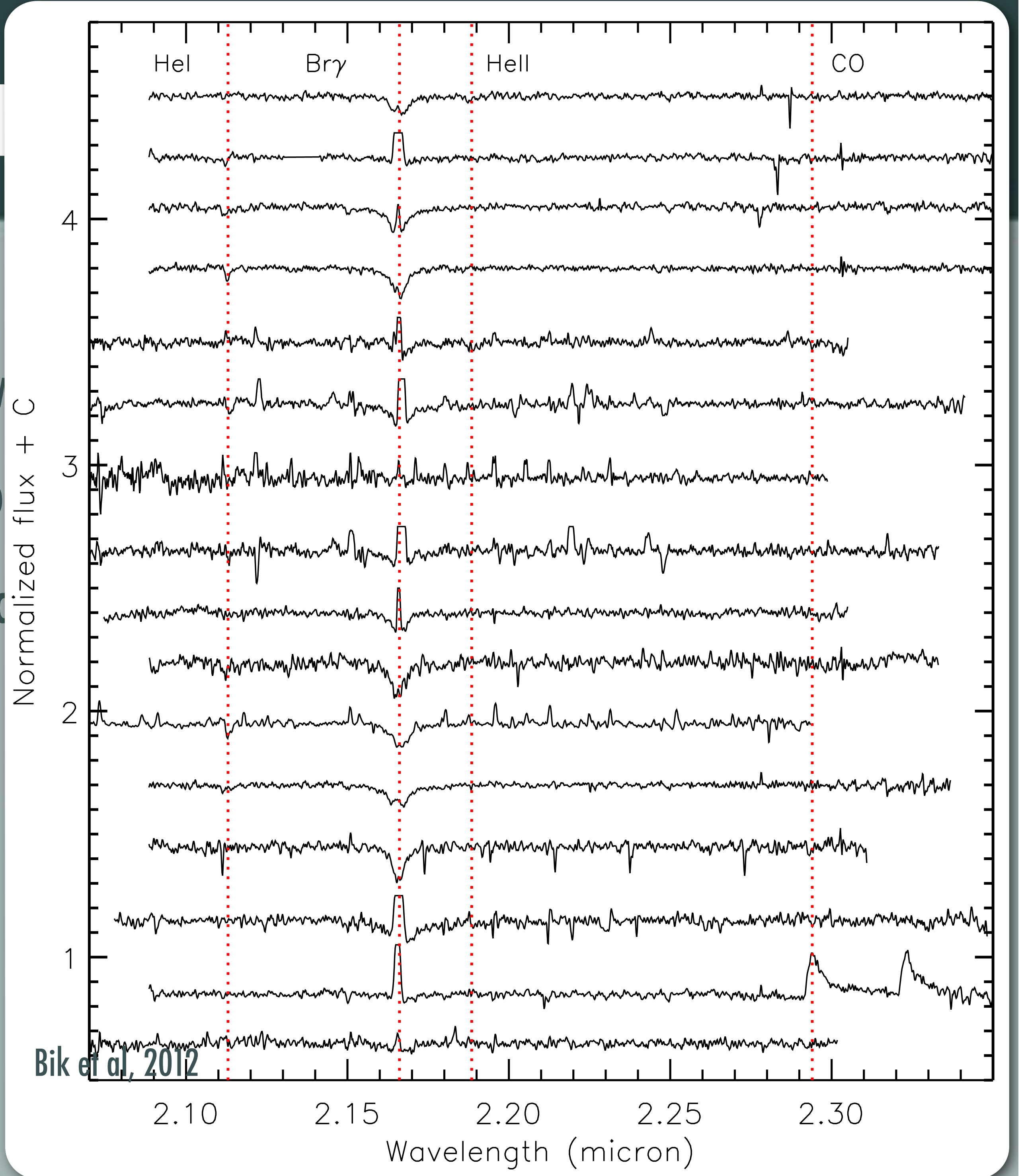
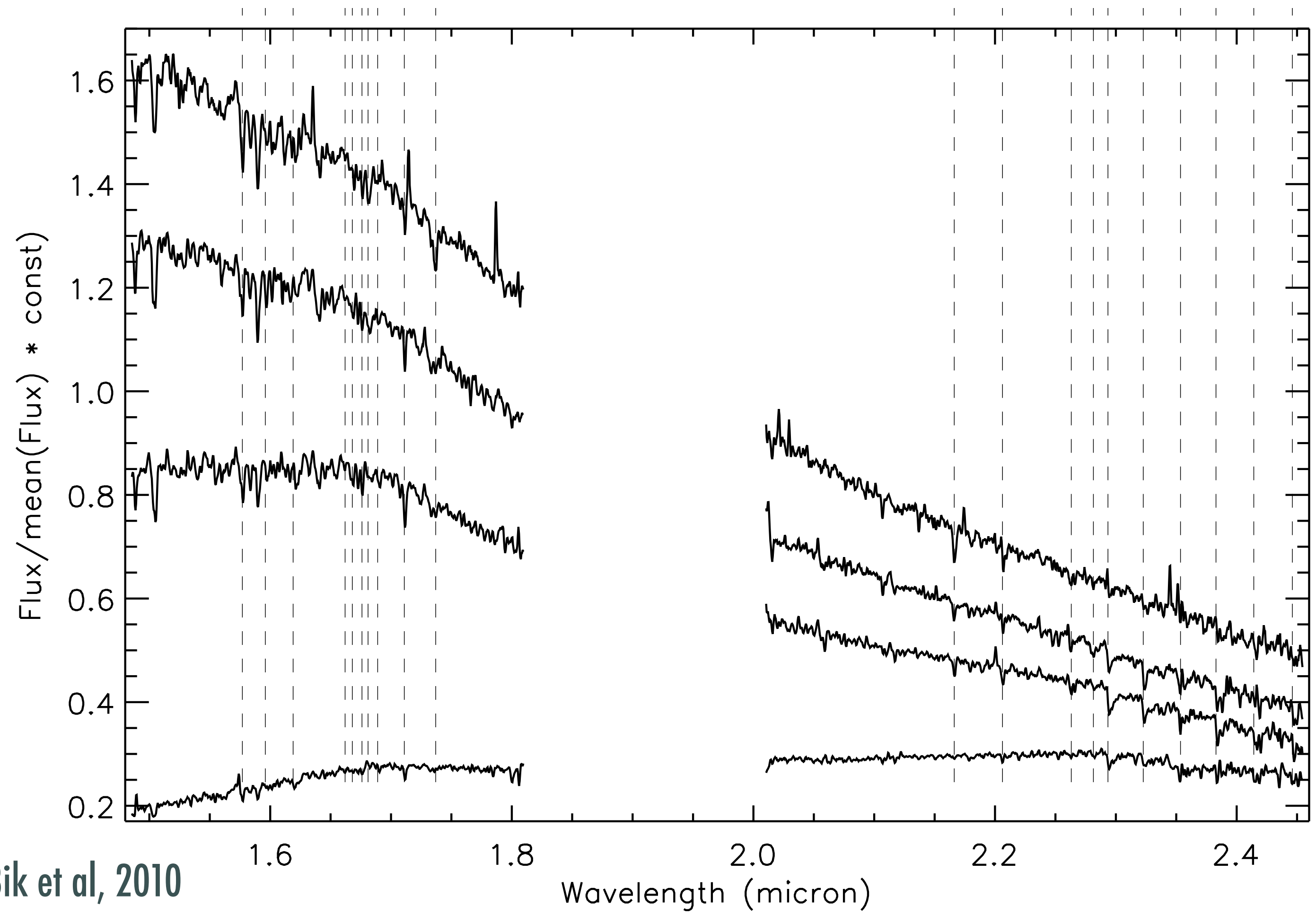
  - Multi-object-spectrosco
  - Integral field spectrosc



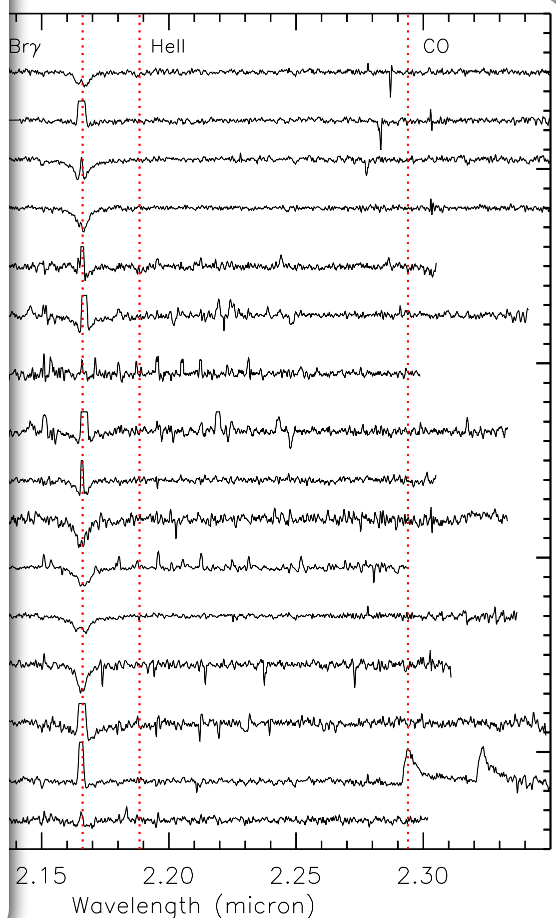
Bik et al, 2012

Spectral classification

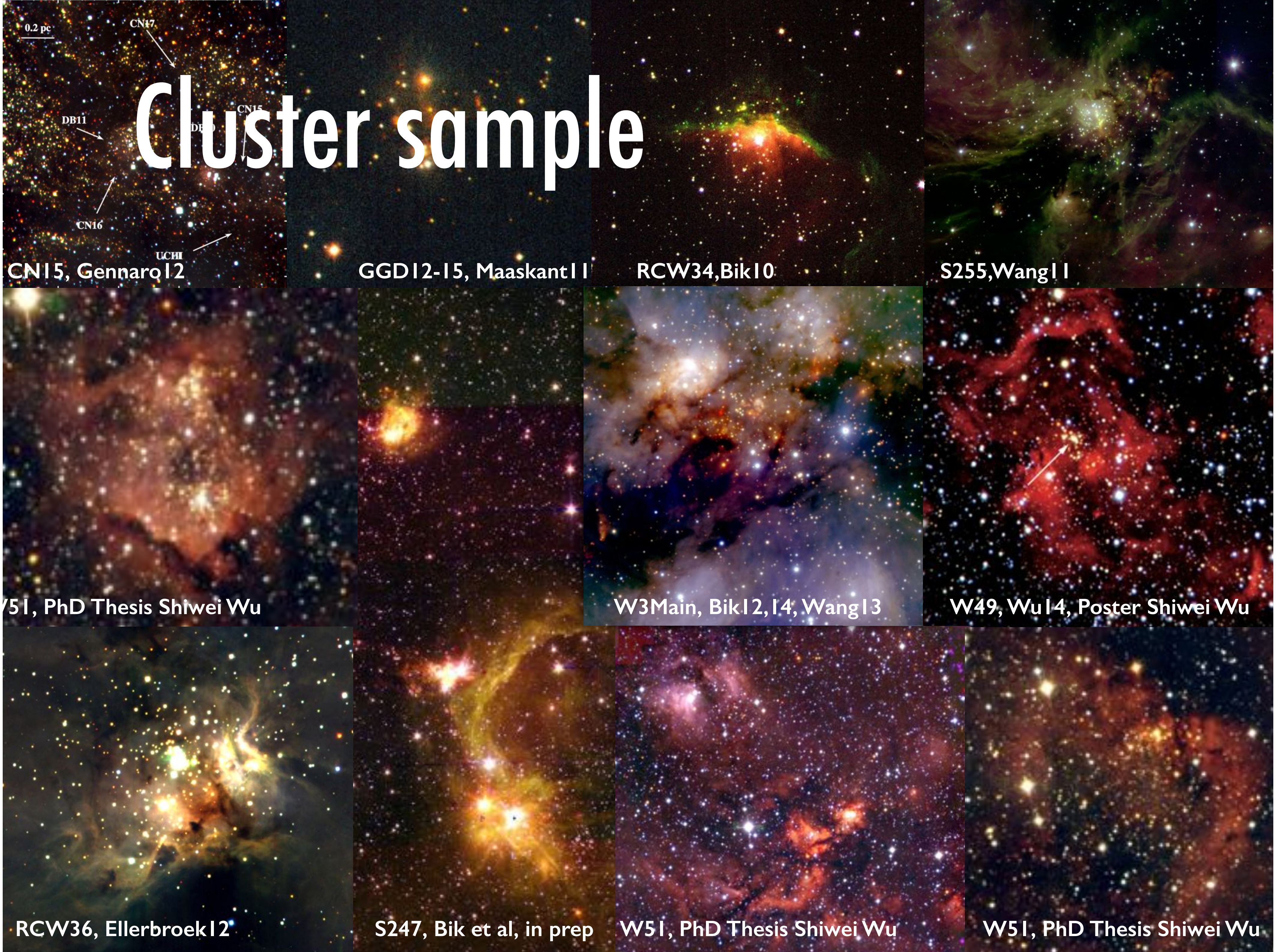
- near-infrared spectroscopy with SINFONI (VLT) and LUCI(LBT)



Bik et al, 2010



Cluster sample

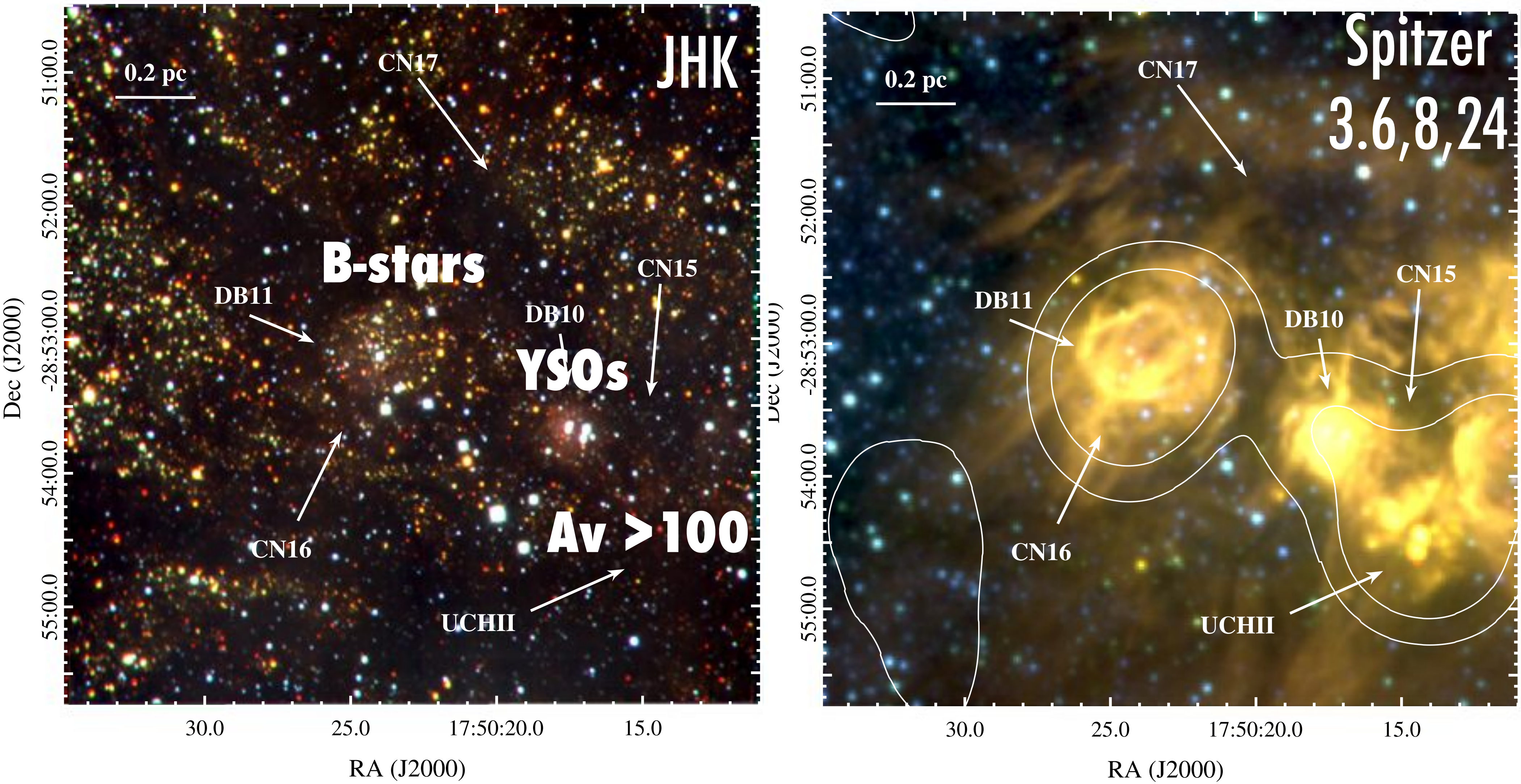



0.2 pc
CN17
CN15
DB11
DB10
CN16
UCHII
CN15, Gennaro12
GGD12-15, Maaskant11
RCW34,Bik10
S255,Wang11
'51, PhD Thesis Shiwei Wu
W3Main, Bik12,14, Wang13
W49, Wu14, Poster Shiwei Wu
RCW36, Ellerbroek12
S247, Bik et al, in prep
W51, PhD Thesis Shiwei Wu
W51, PhD Thesis Shiwei Wu

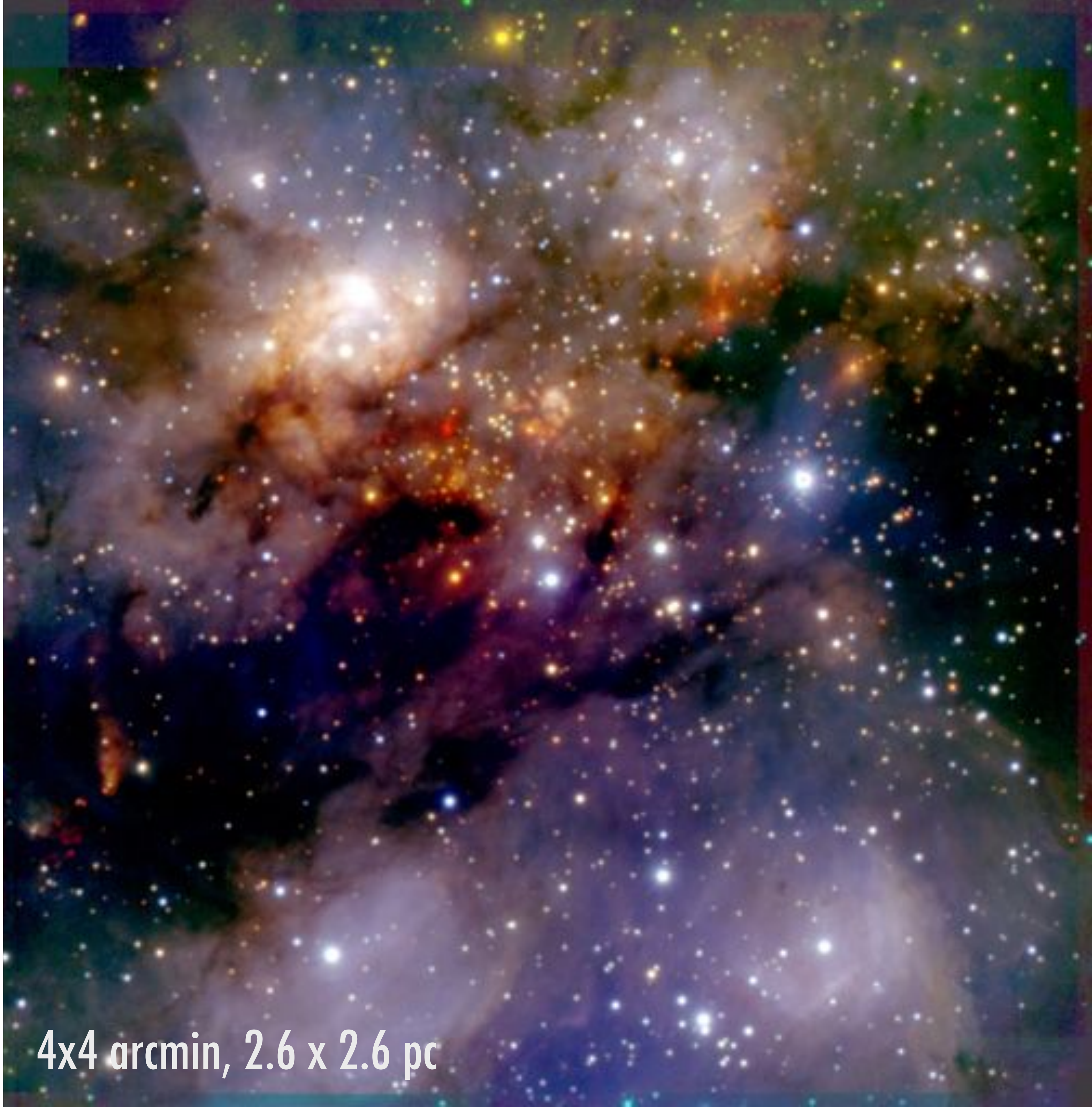
Star formation history

- Age dating clusters using:
  - absolute ages by placing stars in HRD
    - Caution: Accretion history, initial conditions is important(Preibisch et al, 2012, Soderblom et al, 2014)
  - relative ages
    - stars vs YSOs, class II vs class I sources
    - size of HII regions
    - deeply embedded vs not embedded

Star formation history CN15



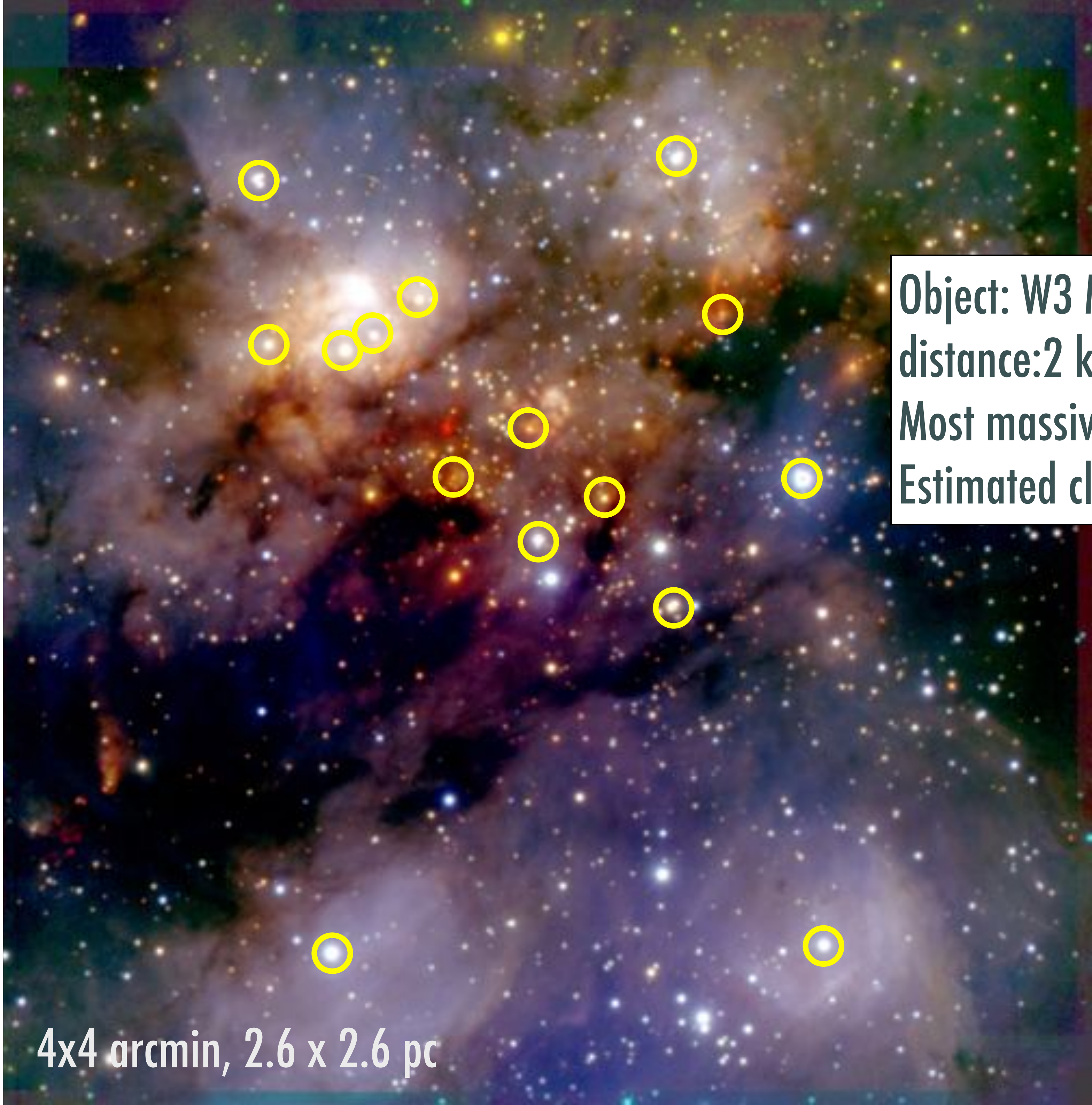
Gennaro, Bik et al, 2012



JHK, LUCI@LBT

Bik et al, 2012

Object: W3 Main
distance:2 kpc
Most massive star: 35 Msun (O7V)
Estimated cluster mass: ~4000 $M_\odot$



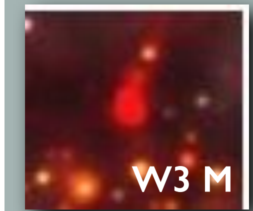
JHK, LUCI@LBT

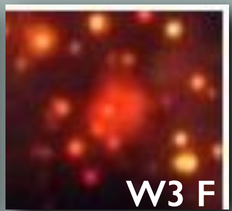
Bik et al, 2012

Age spread in W3 Main

Young
<~100,000 yr

0.2 pc 0.2 pc 0.5 pc 0.7 pc





Hyper Compact HII region

Ultra Compact HII regions

Compact HII region

Tieftrunk et al, 1997; Bik et al, 2012

Age spread

Young
<~100,000 yr

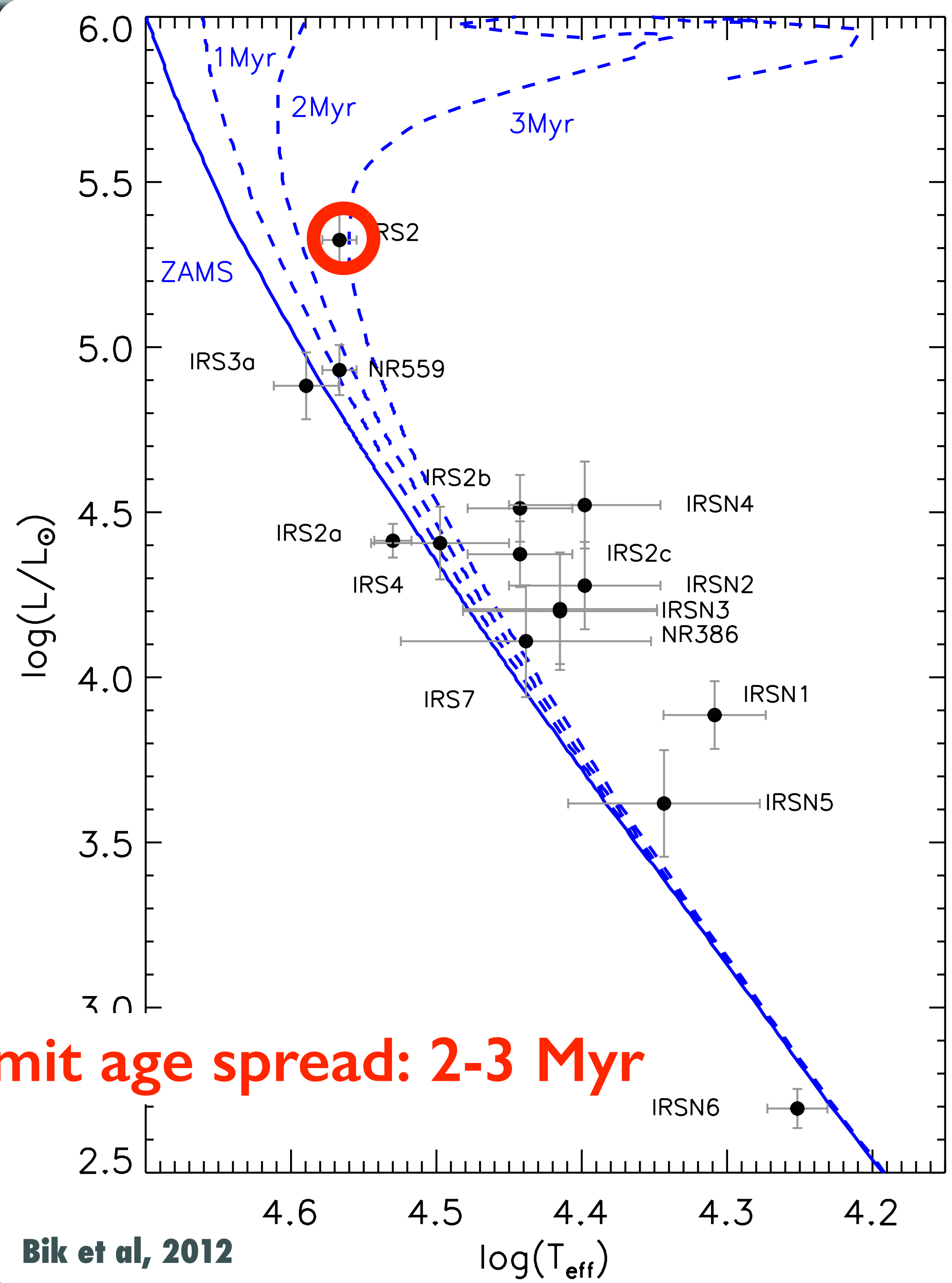
0.2 pc | 0.2 pc | 0.5 pc

Hyper Compact HII region

Ultra Compact HII regions

Compact HII region

Tieftrunk et



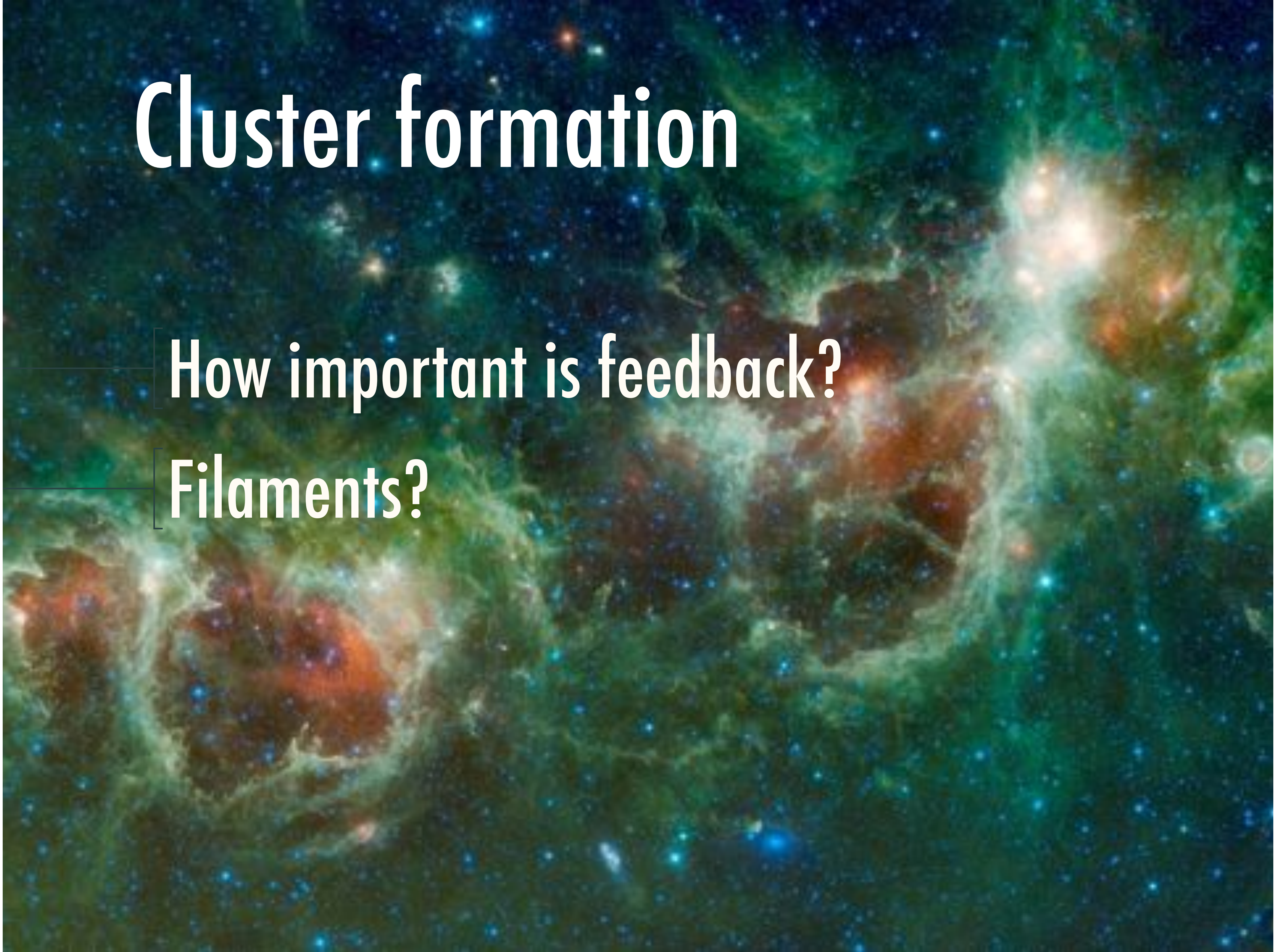
Upper limit age spread: 2-3 Myr

Bik et al, 2012

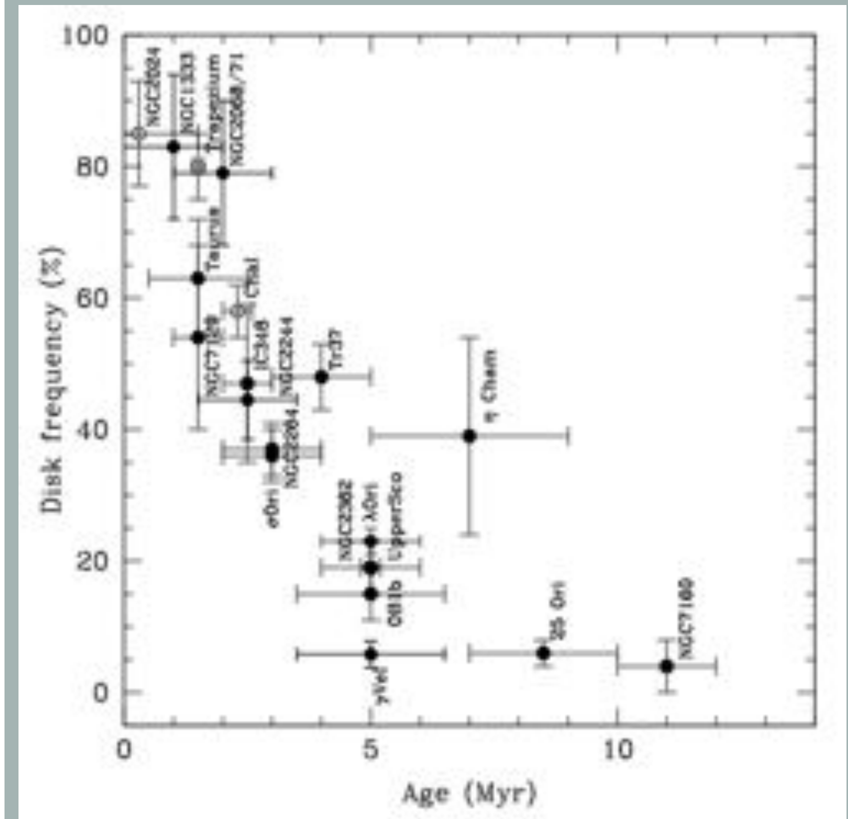
Star formation history

- Theoretical explanations for age spread: dynamical time, density of the core, SFR and core formation efficiency (Elmegreen 2000, Dib 2013, Parmentier 2013)

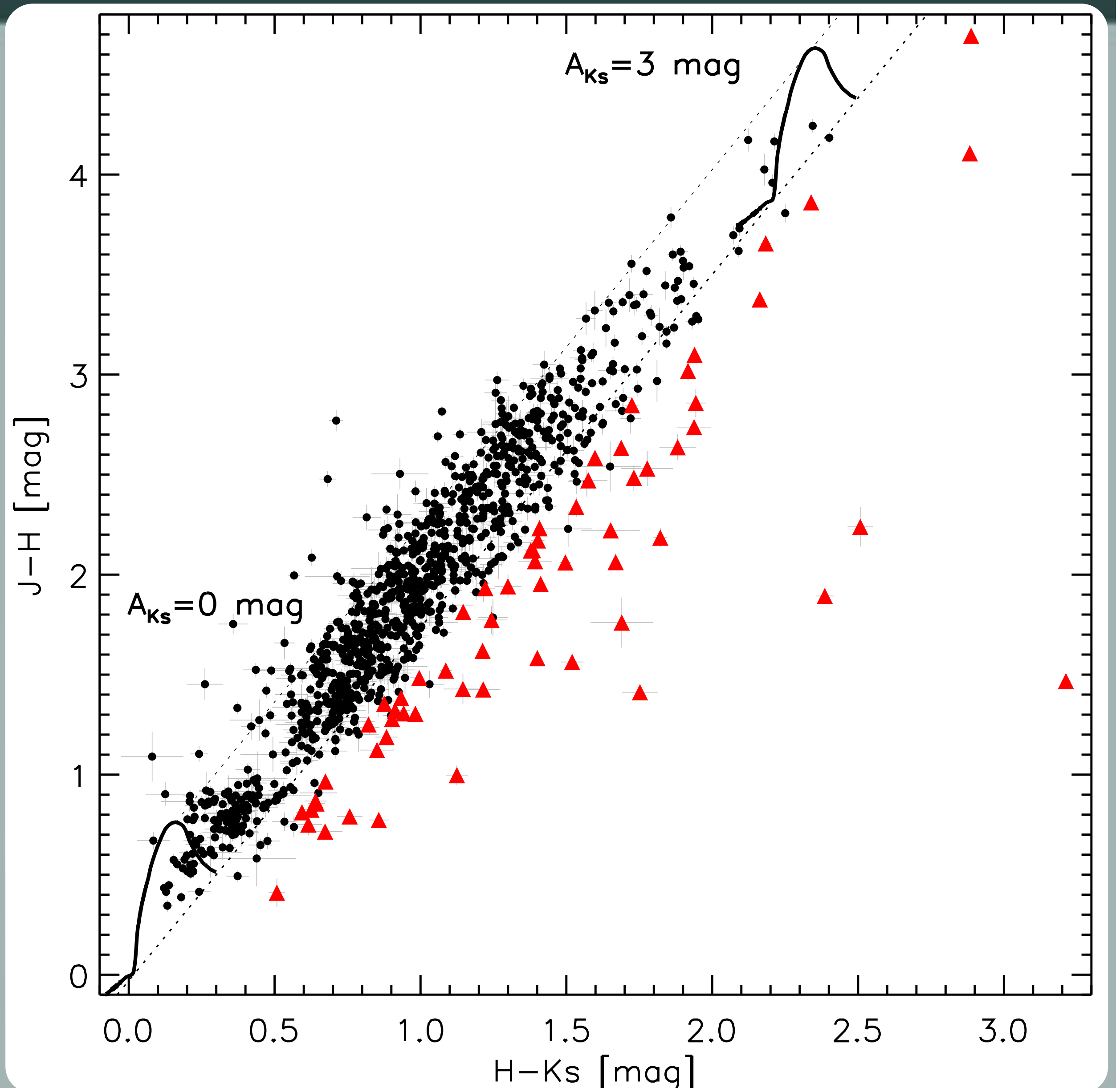
- Age spread inside a cluster hard to measure:
  - Starburst clusters: no age spread (Kudryavsteva 2012)
  - Extended cluster: age spread detected (Bik 2012, Da Rio 2014, Reggiani 2011)
  - OB associations with no age spread (Preibisch et al, 2012)


Cluster formation
How important is feedback?
Filaments?

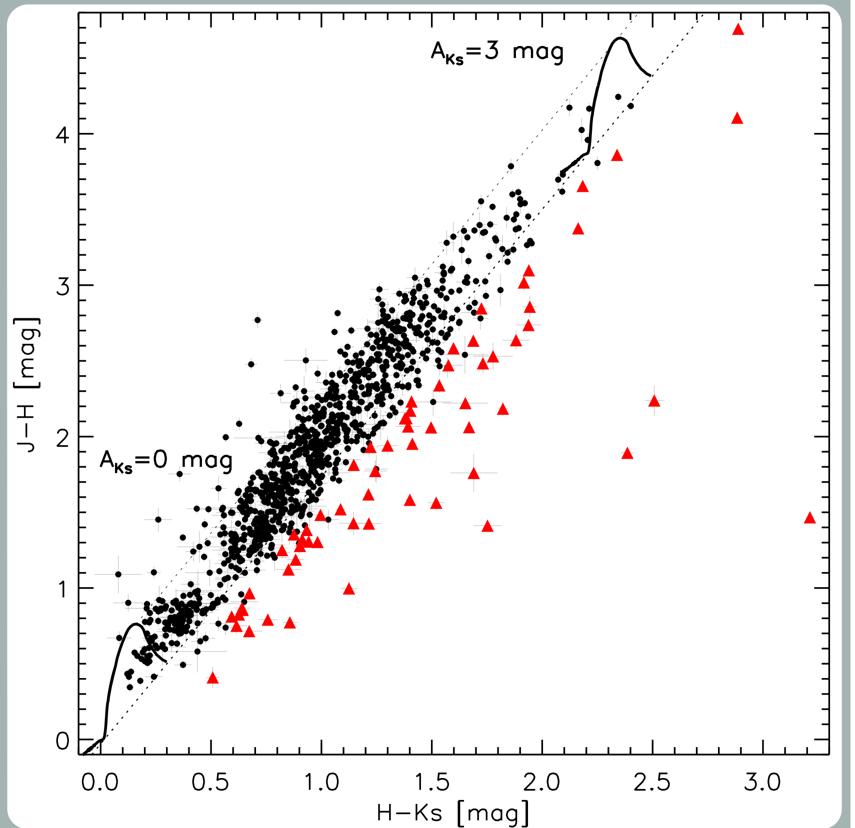
Feedback in W3 Main



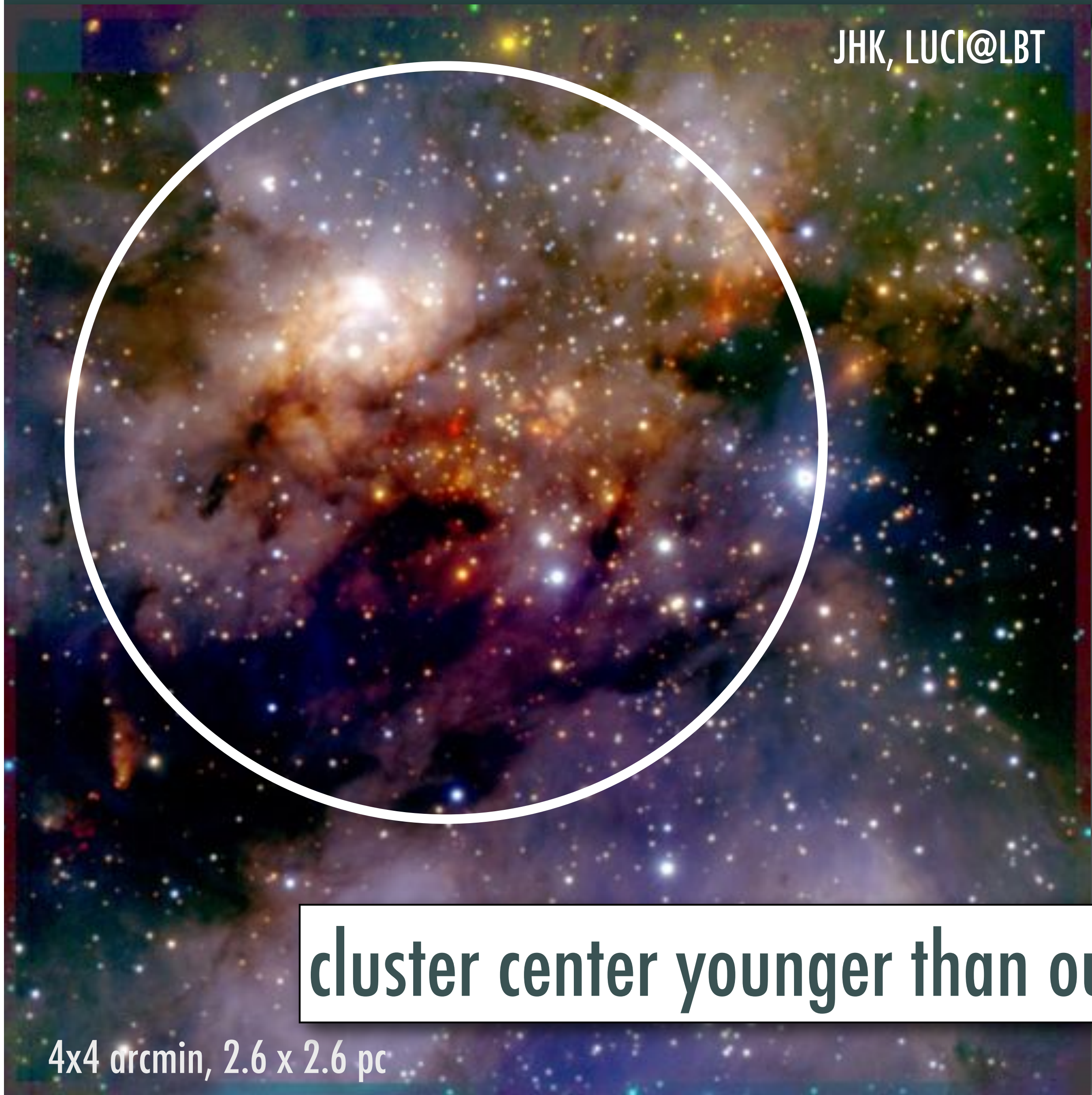
Hernandez et al, 2008



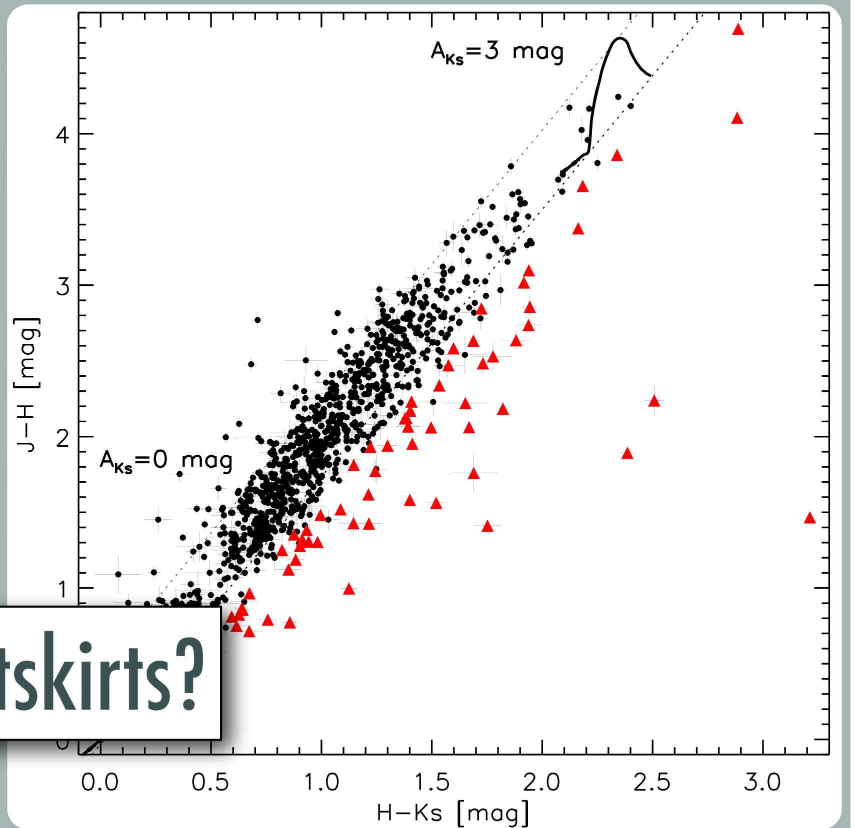
Feedback in W3 Main



Feedback in W3 Main

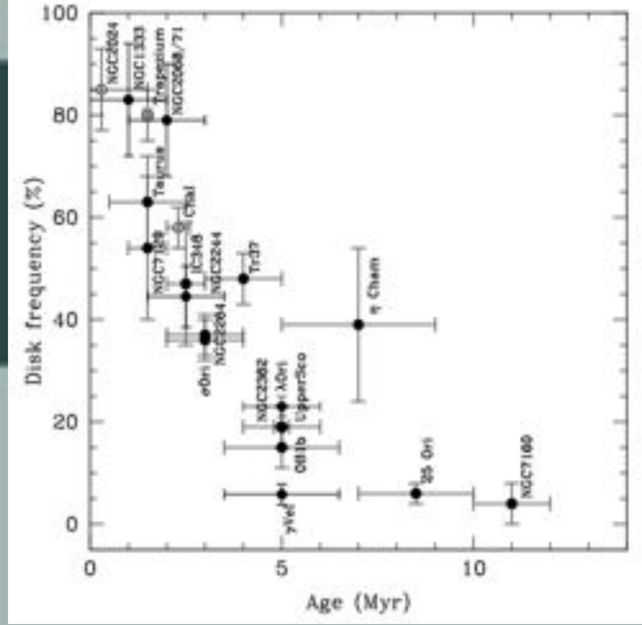


Average: 7.7 ± 2.3 %
< 1pc: 9.4 ± 3.0 %
> 1pc: 5.6 ± 2.2 %



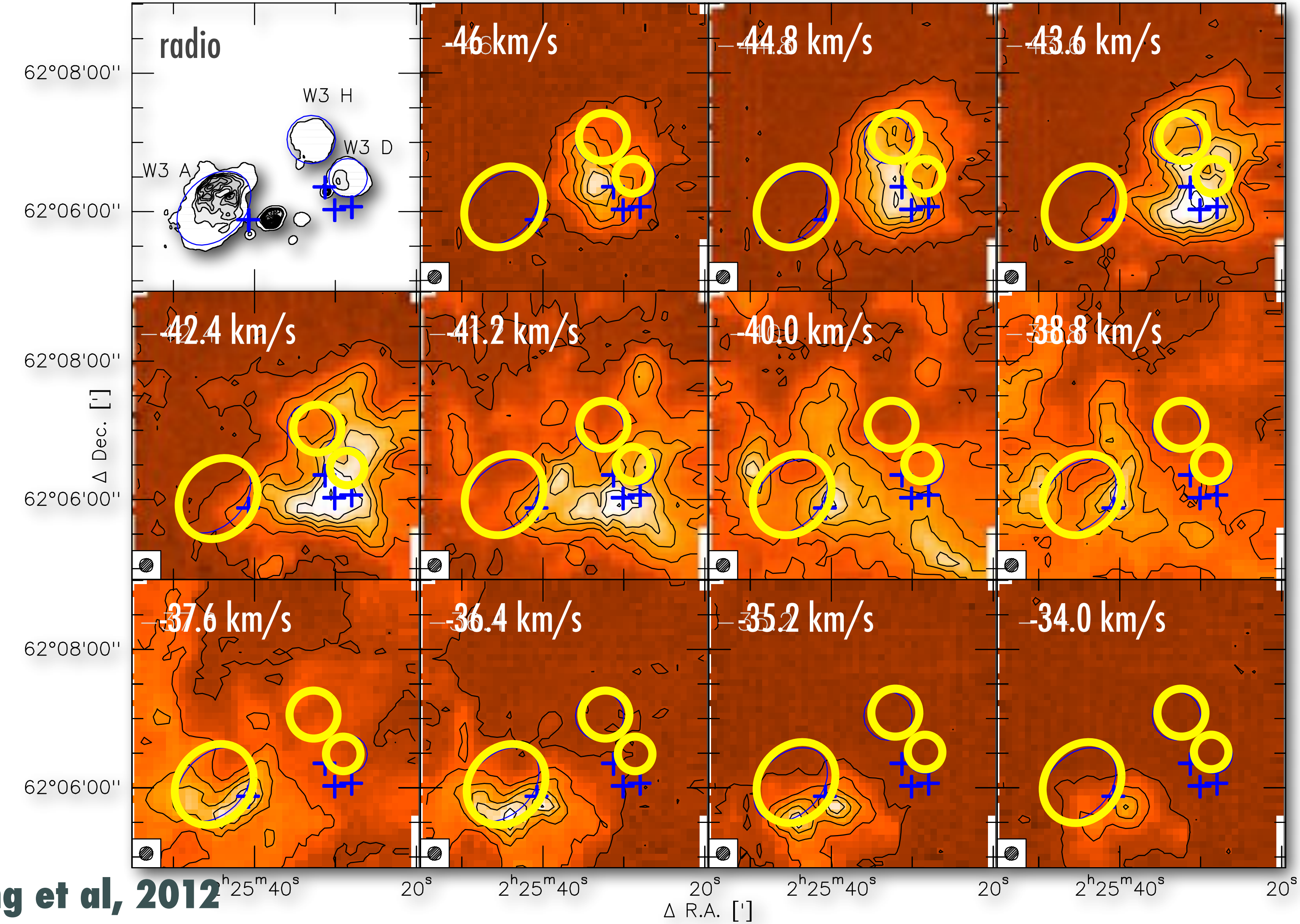
cluster center younger than outskirts?

Disk fraction



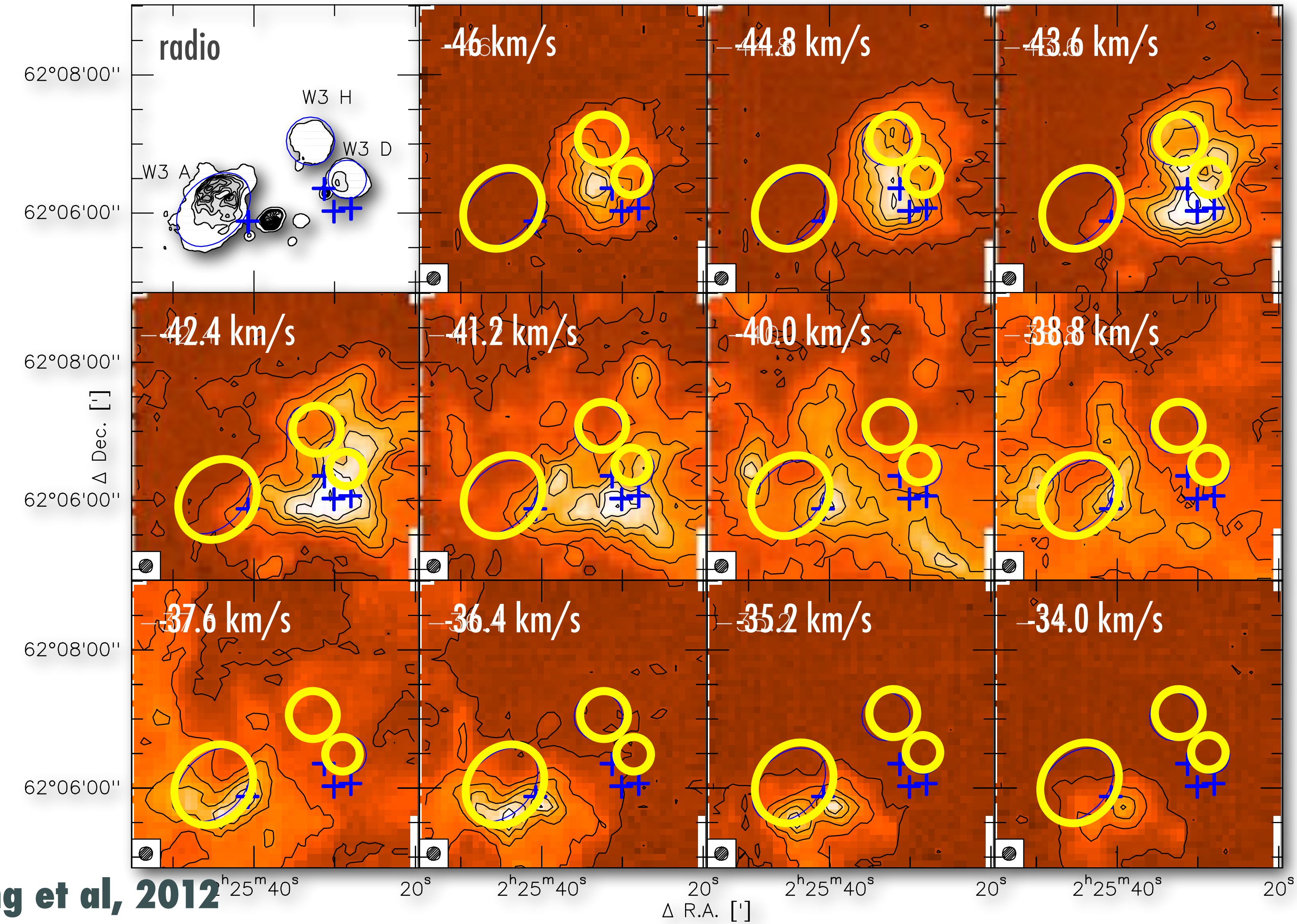
- Low average disk fraction in W3 Main:
  - EUV (λ < 1200 Å) radiation confined in HII regions and does not reach the entire cluster.
  - Stellar densities to low to affect disks via dynamical interaction (Megeath et al, 1996, Olczak et al, 2010, Juan de Ovelar et al, 2013)
  - FUV (λ > 1200 Å) heats the disks and enhances accretion and shortens disk lifetimes (Fang et al, 2012)

Triggered star formation?



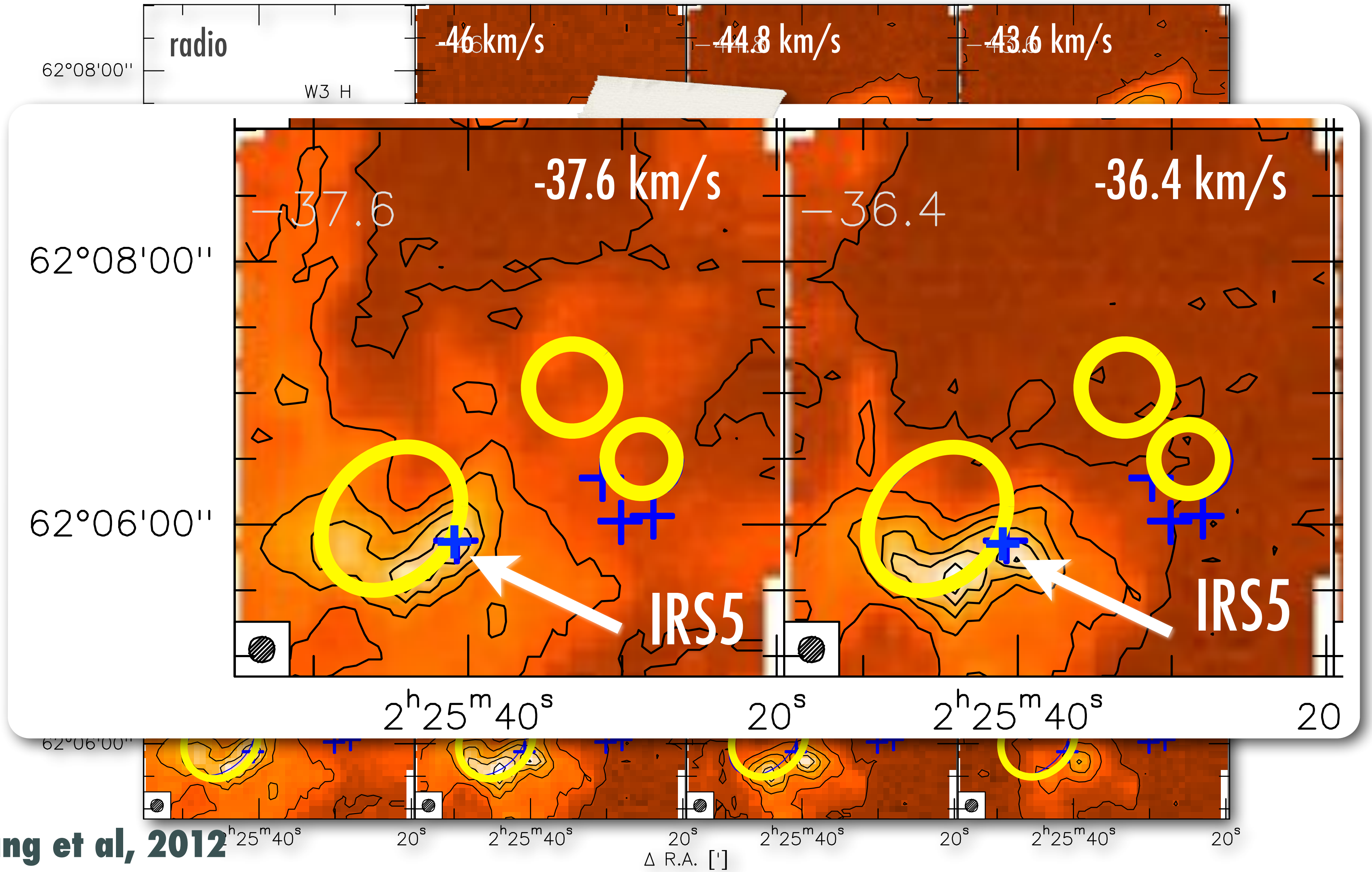
Wang et al, 2012

Triggered star formation?



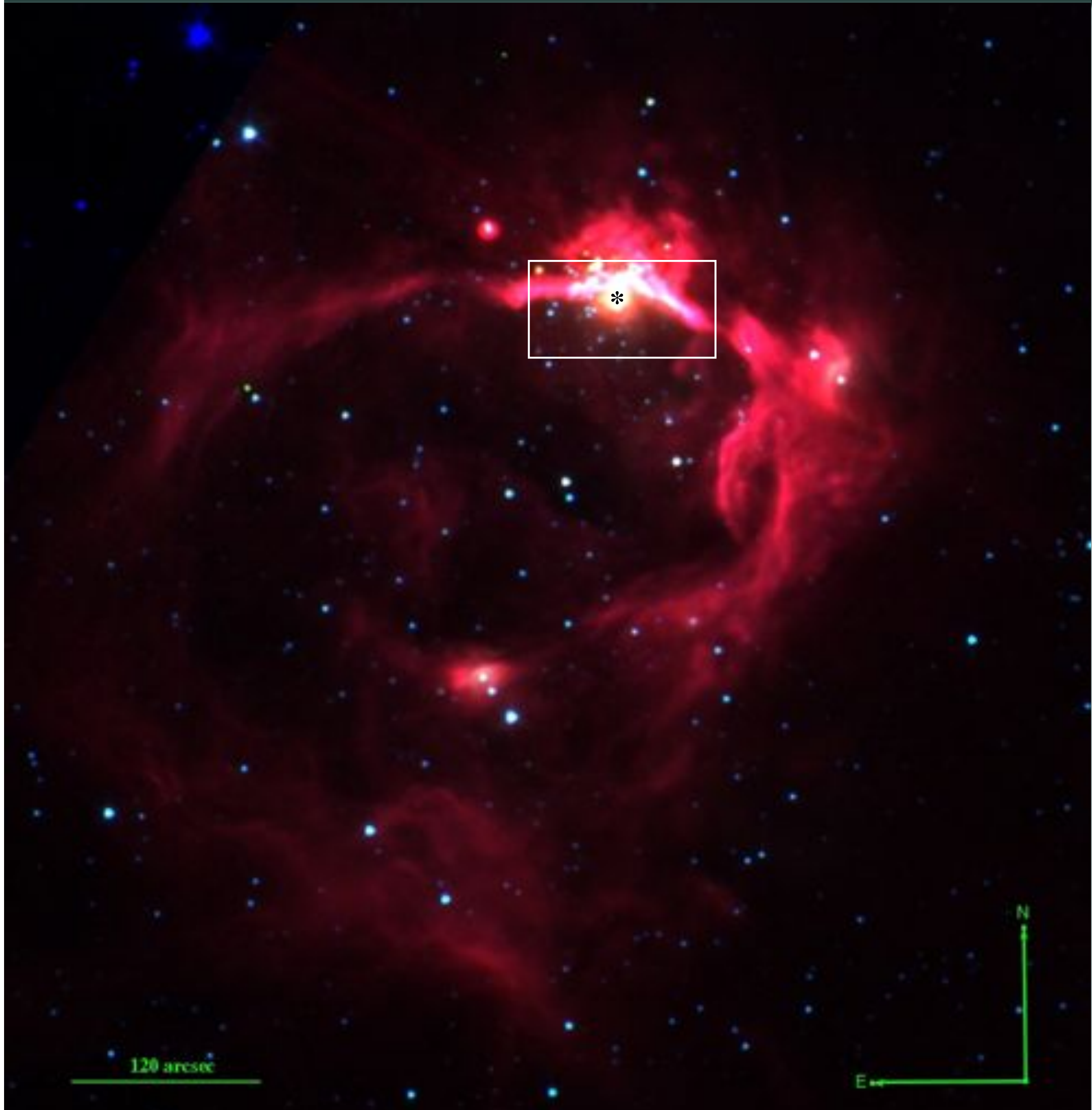
Wang et al, 2012

Triggered star formation?

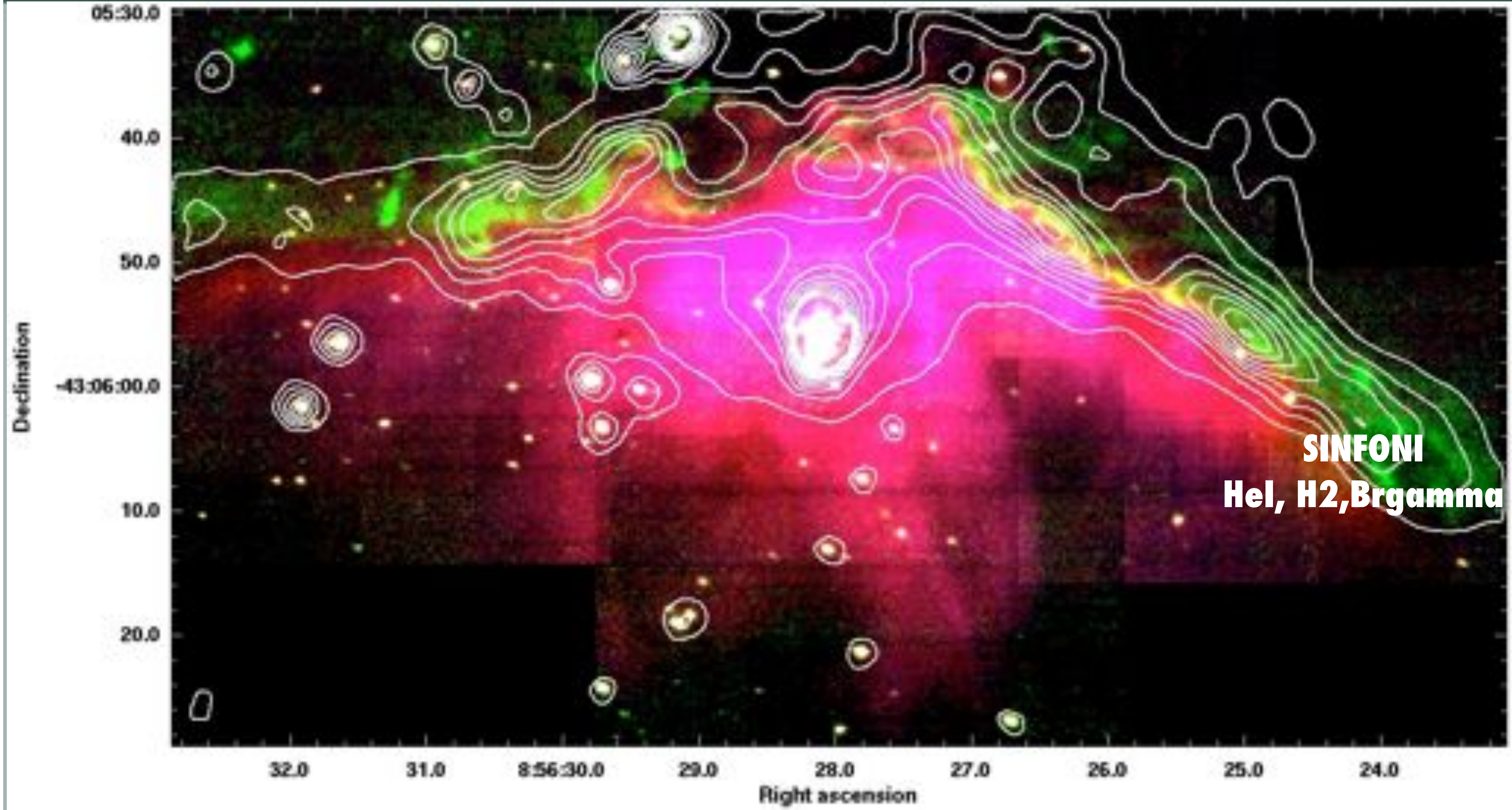


Wang et al, 2012

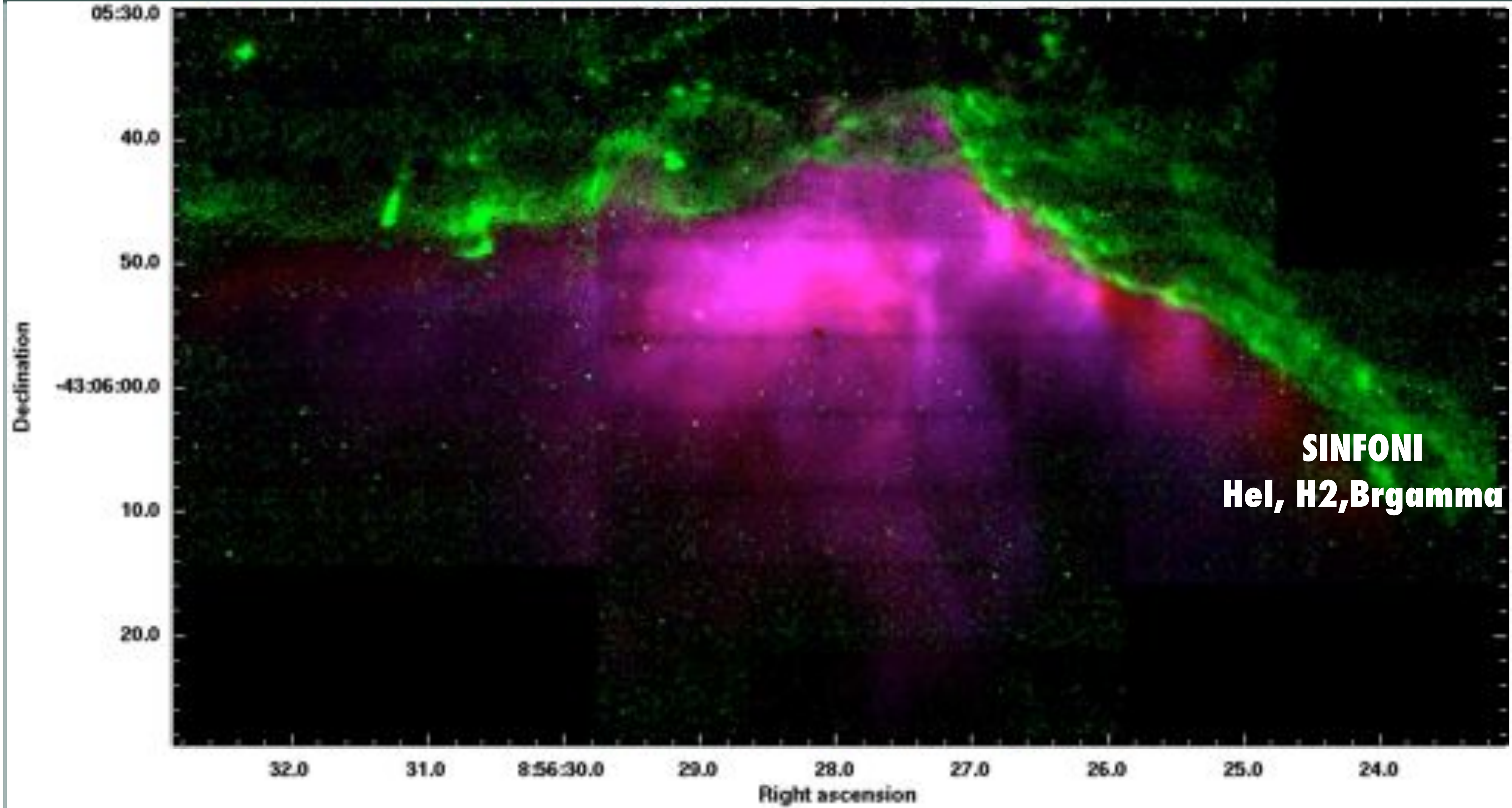
Feedback in RCW 34



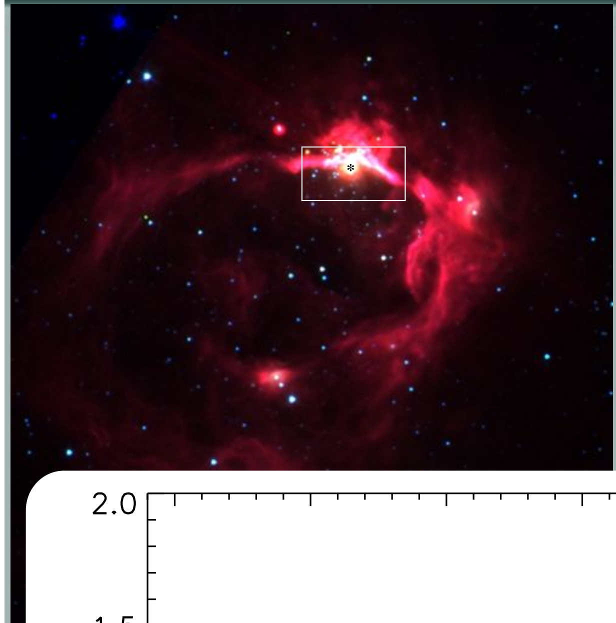
Feedback in RCW 34

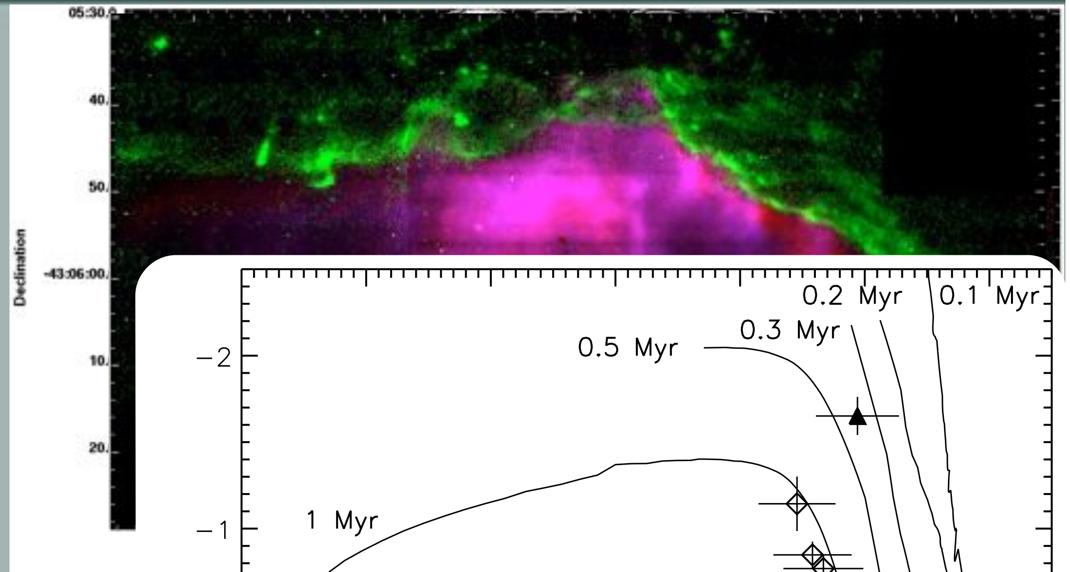


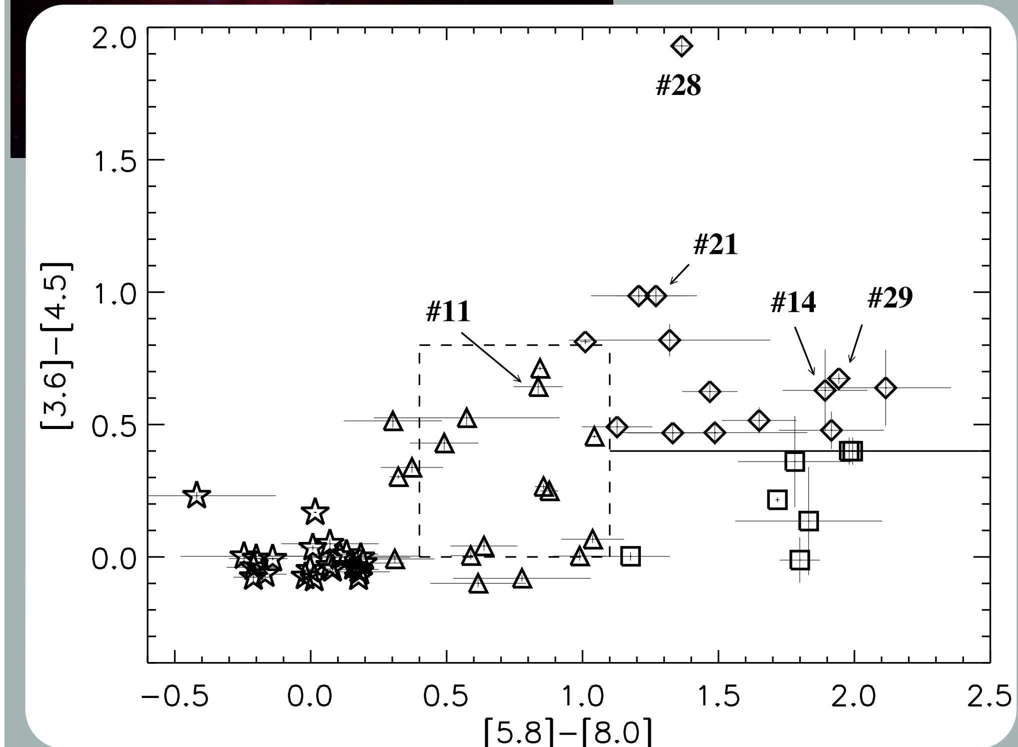
Feedback in RCW 34

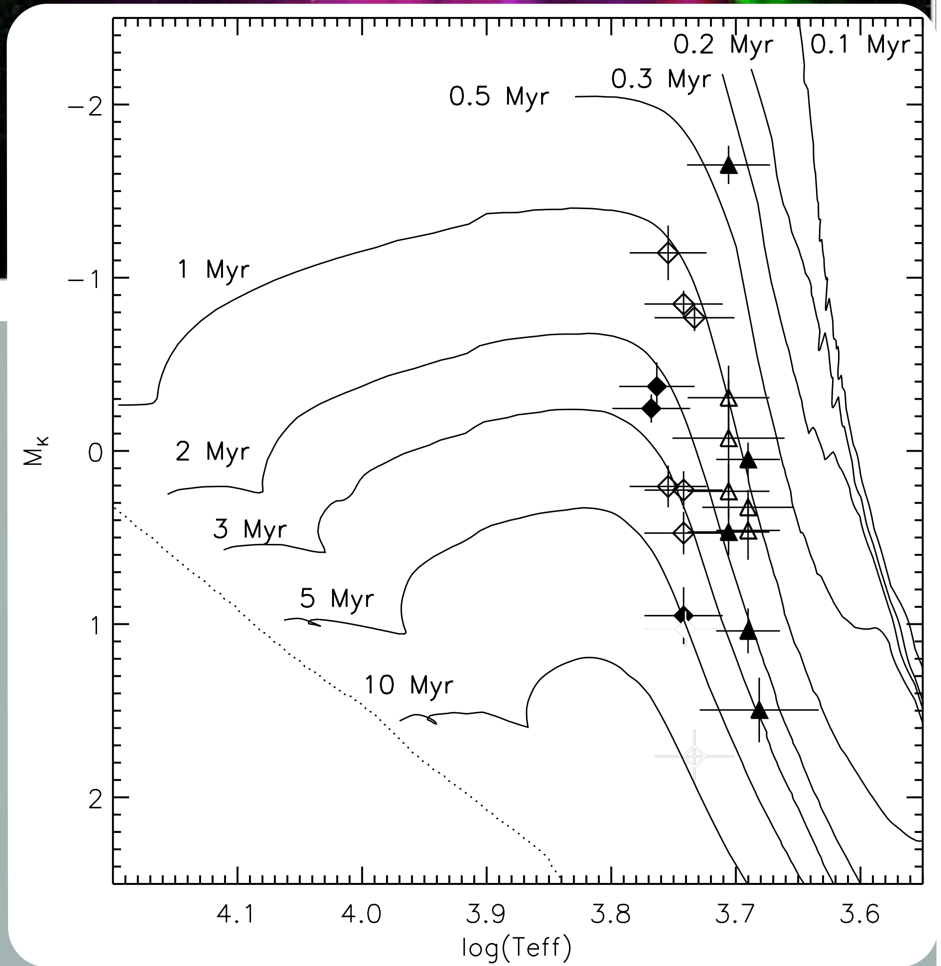


Feedback in RCW 34



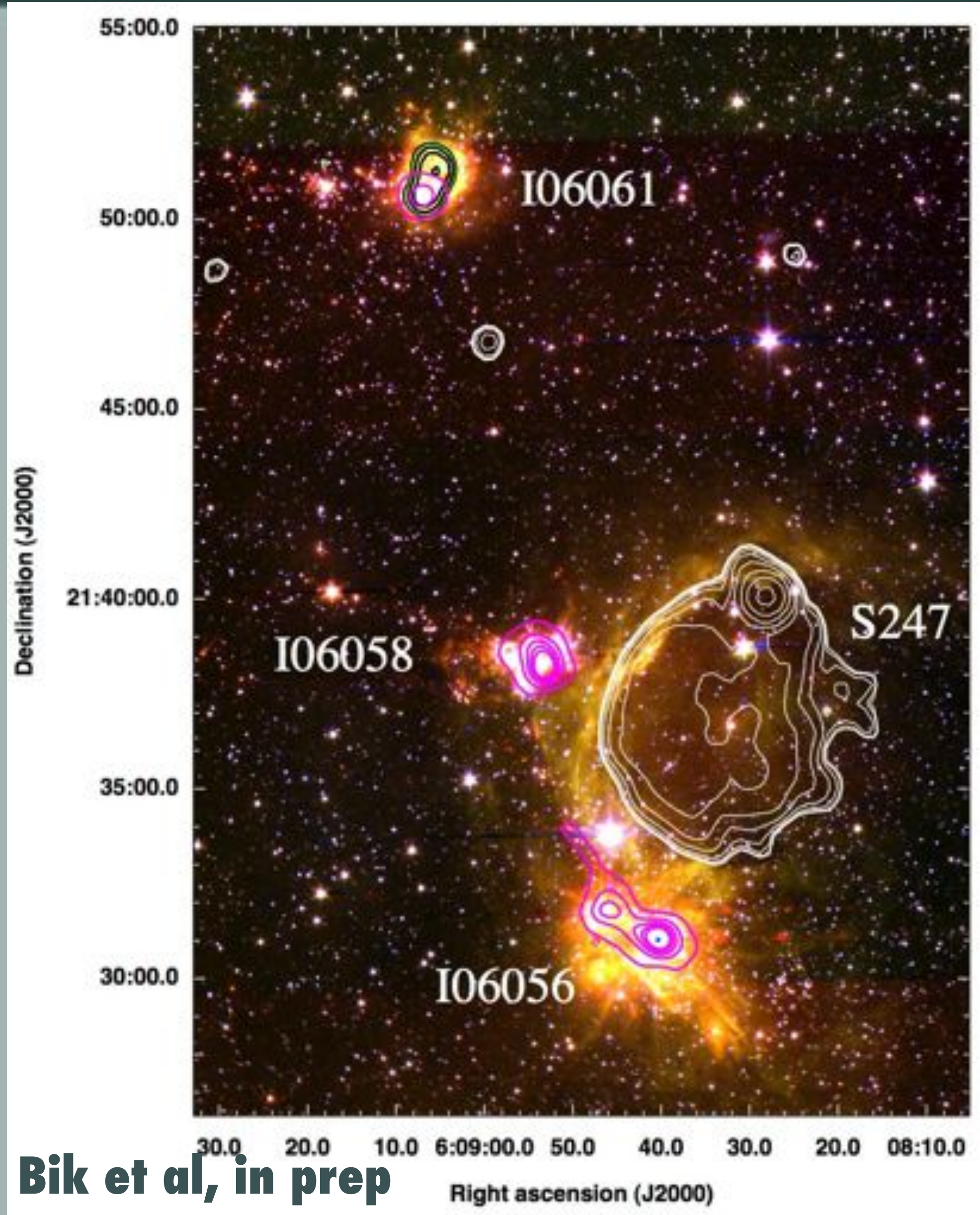






More triggered SF?

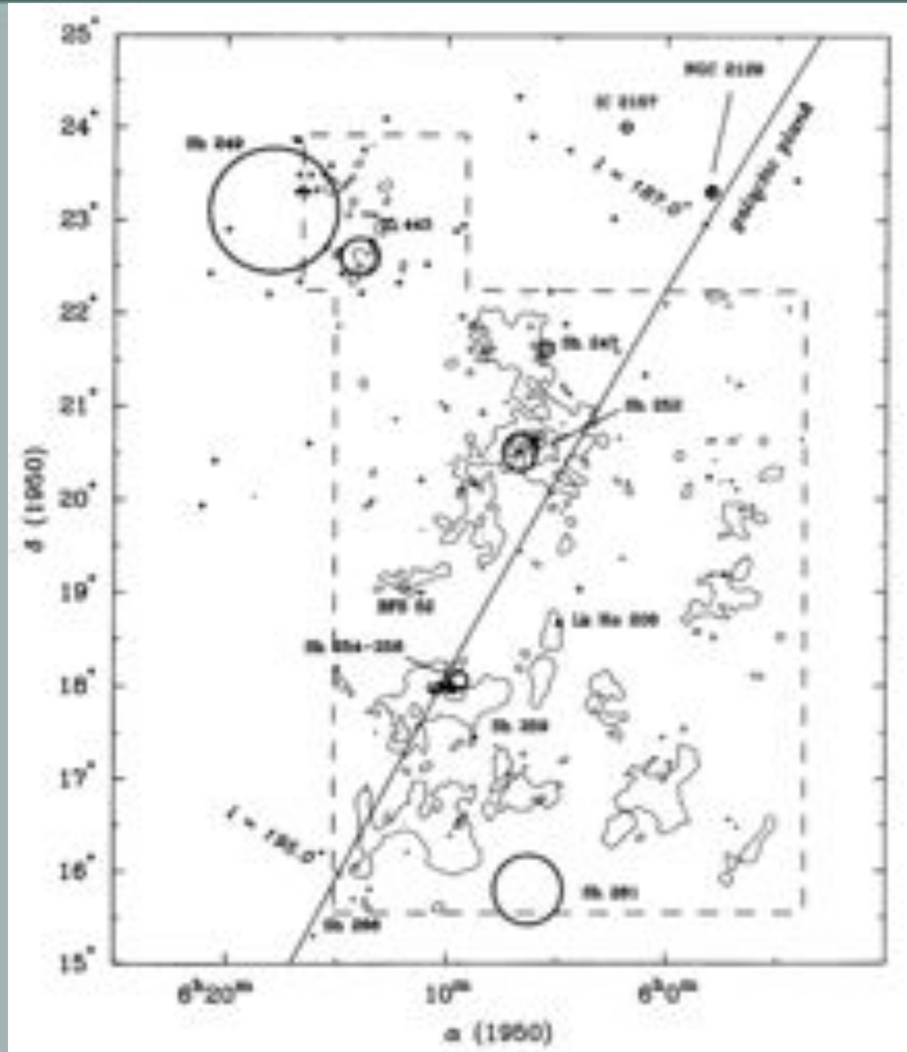
- Large association: Gem OB1
- harbors many HII regions and small embedded clusters
- focus on S247 and its environment.



Bik et al, in prep

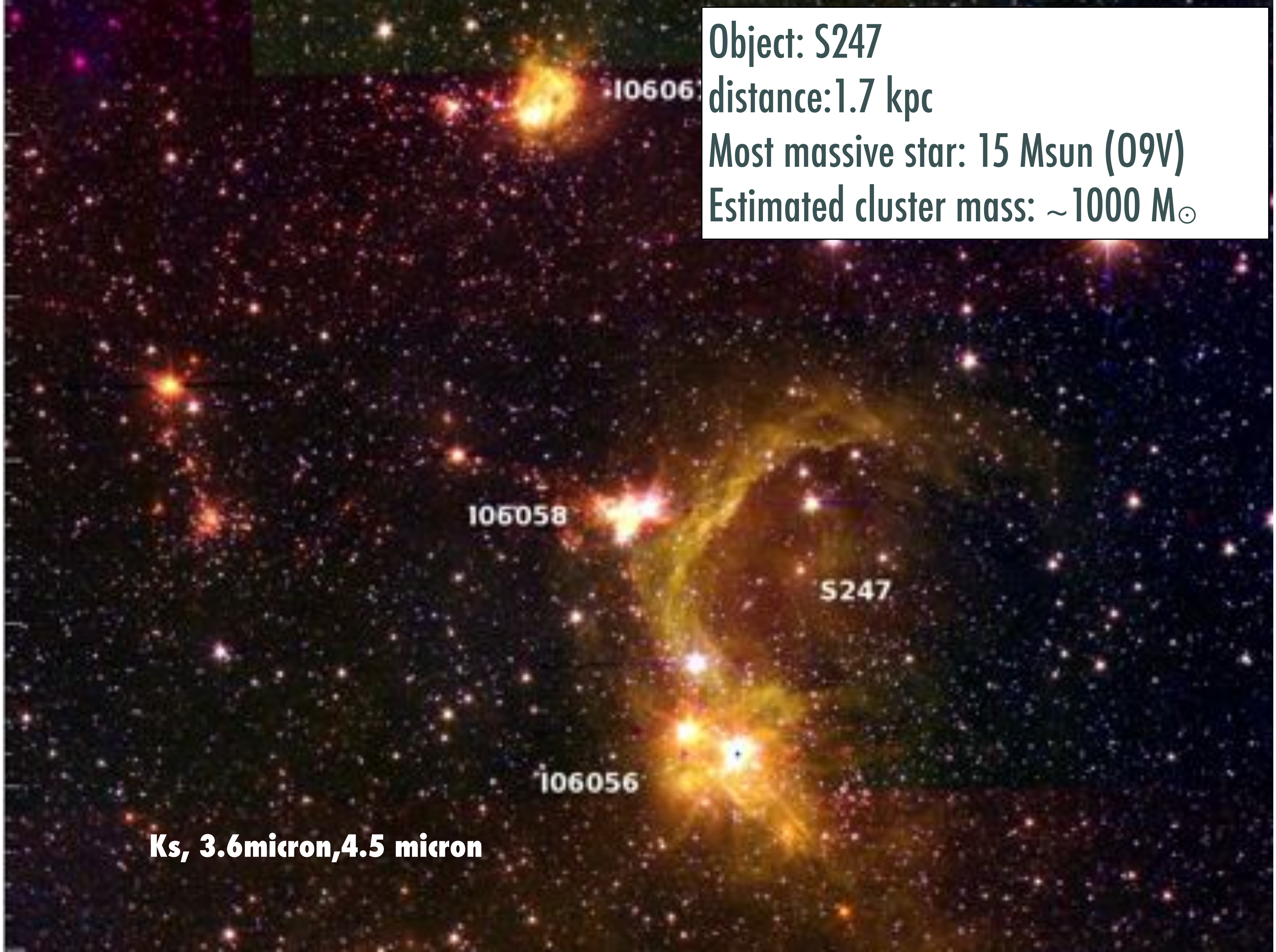
...or filaments?

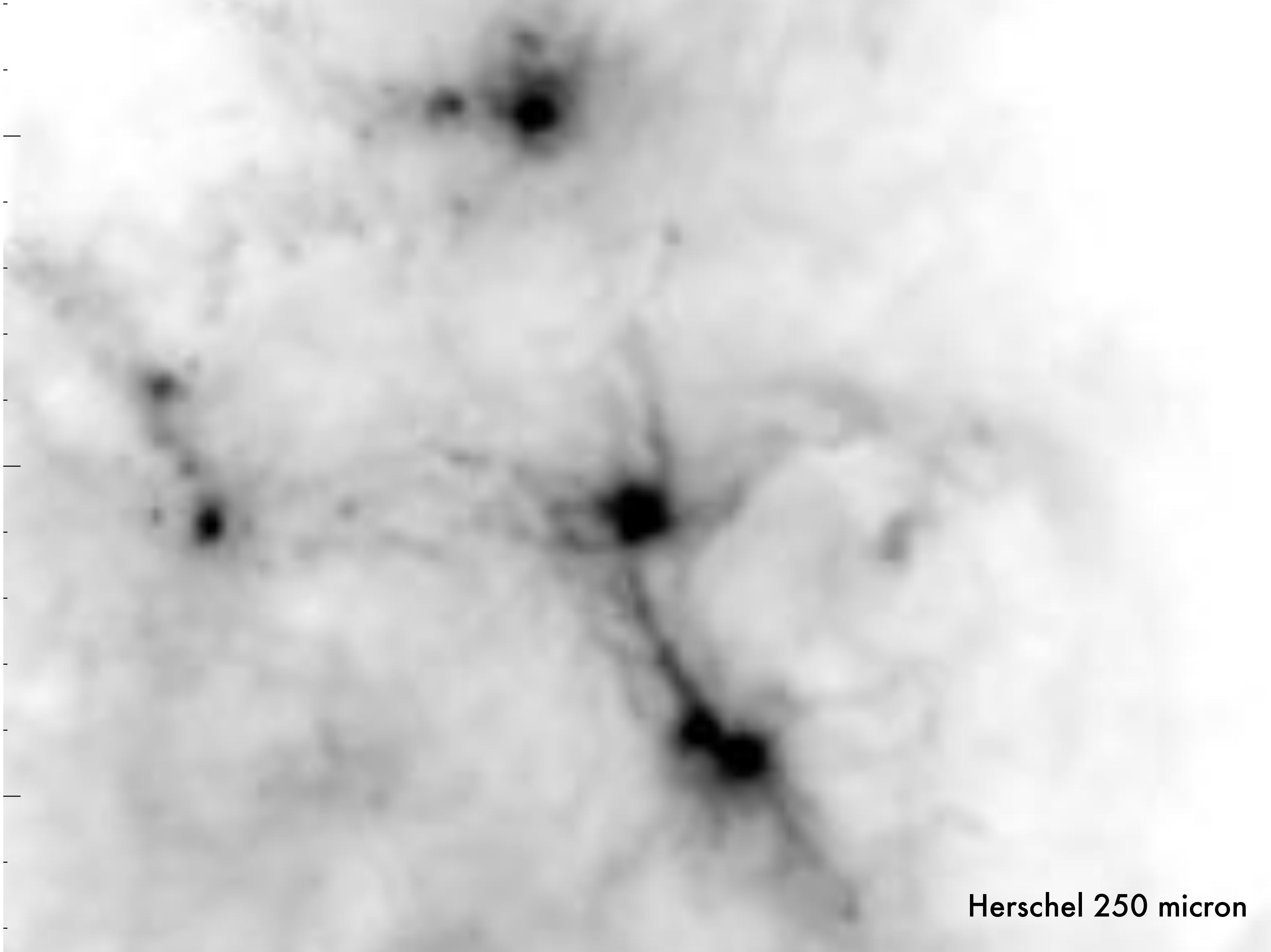
- Large association: Gem OB1
- Outer galaxy
- harbors many HII regions and embedded clusters
- focus on S247 and its environment.



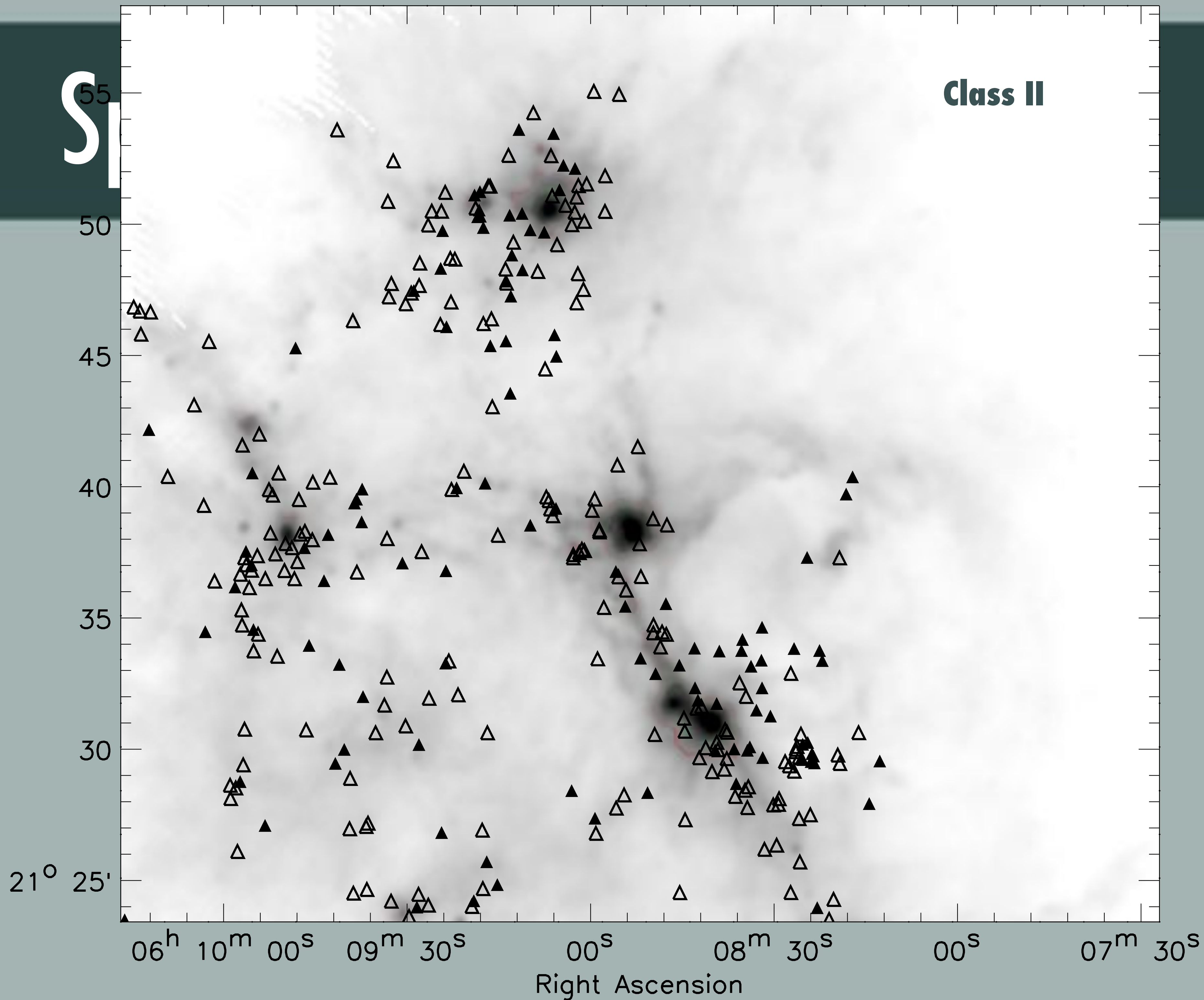
Bik et al, in prep

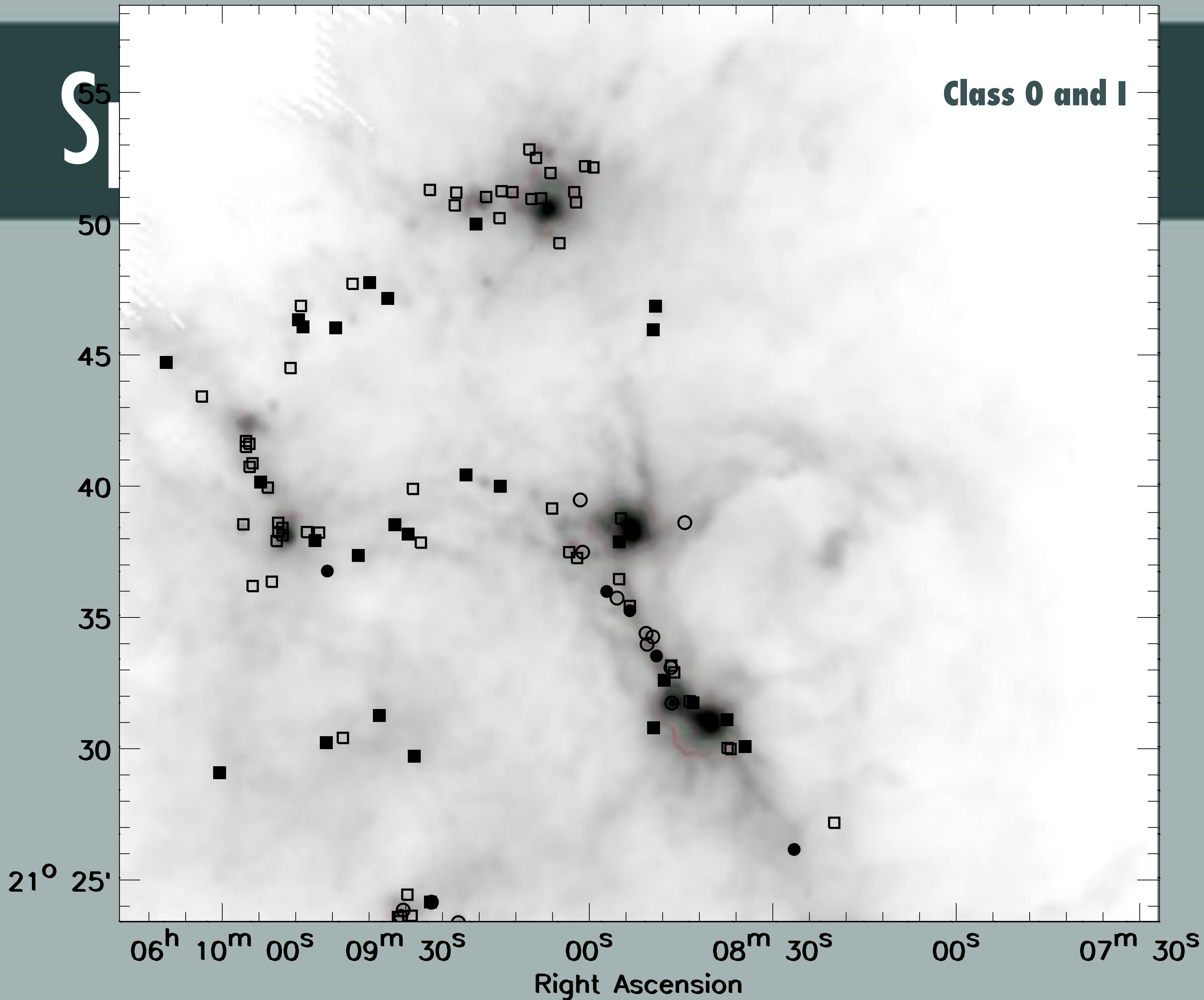
Object: S247
distance:1.7 kpc
Most massive star: 15 Msun (O9V)
Estimated cluster mass: ~1000 $M_\odot$




Herschel 250 micron

Spatial distribution


Class II
55
50
45
40
35
30
21° 25'
06h 10m 00s
09m 30s
00s
08m 30s
00s
07m 30s
Right Ascension


Class 0 and I
55
50
45
40
35
30
21° 25'
06h 10m 00s
09m 30s
00s
08m 30s
00s
07m 30s
Right Ascension

Towards extreme environments


Wu et al, 2014

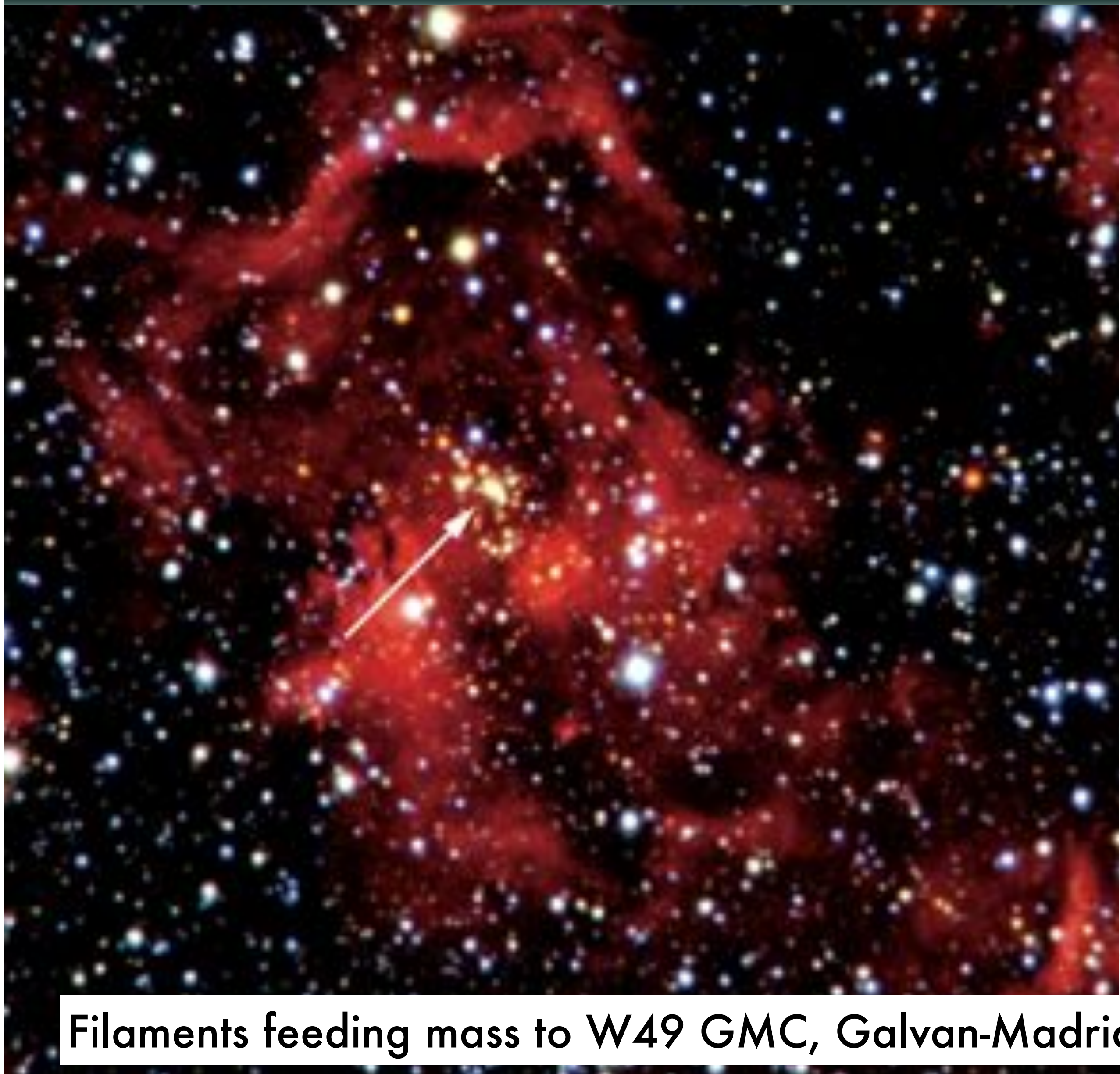
Poster Shiwei WU

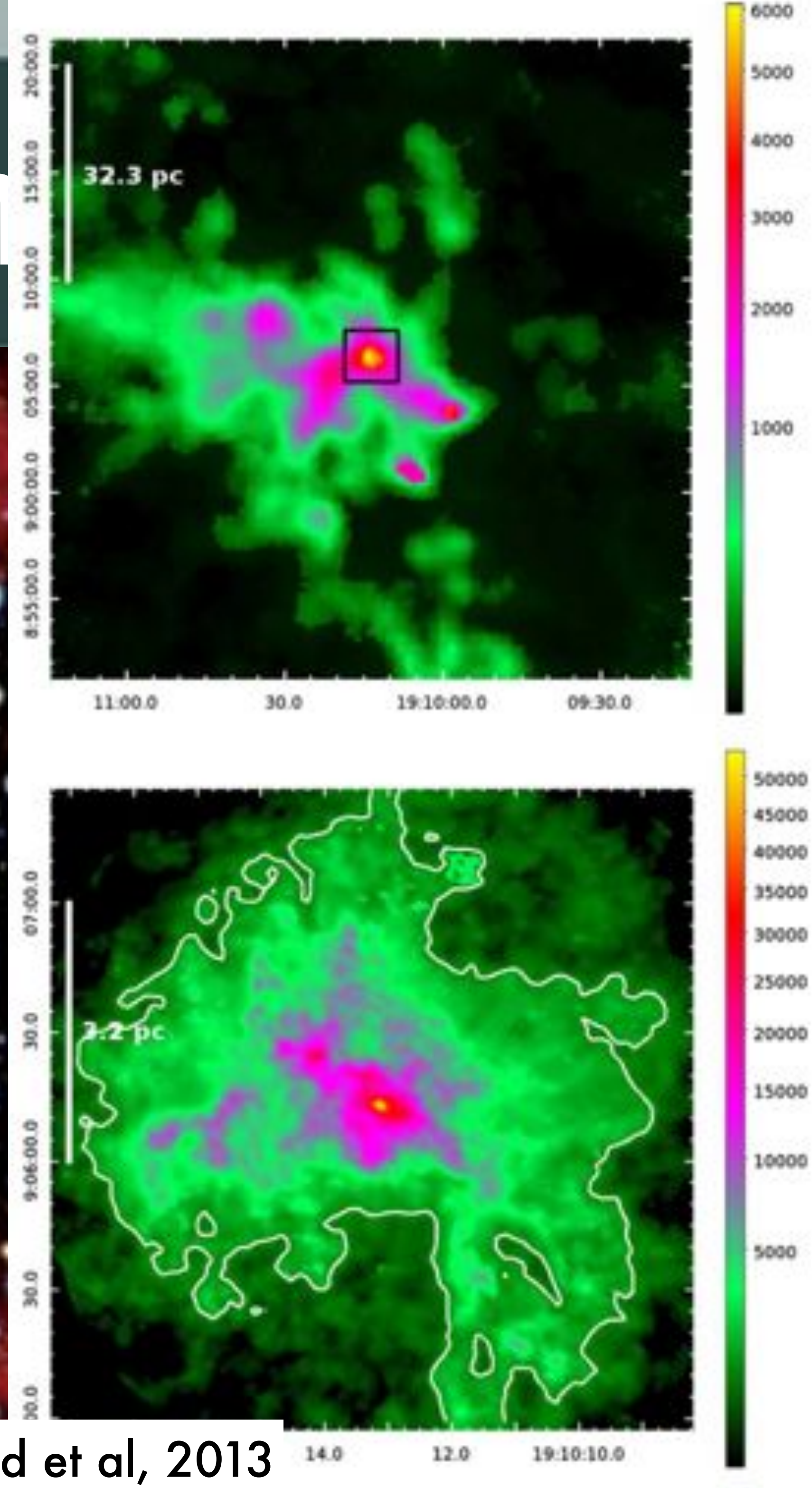
Towards extreme environments

Object: W49
distance:11.4 kpc
Most massive star: 100-180 Msun
Estimated cluster mass: >10^4 $M_\odot$

Poster Shiwei WU

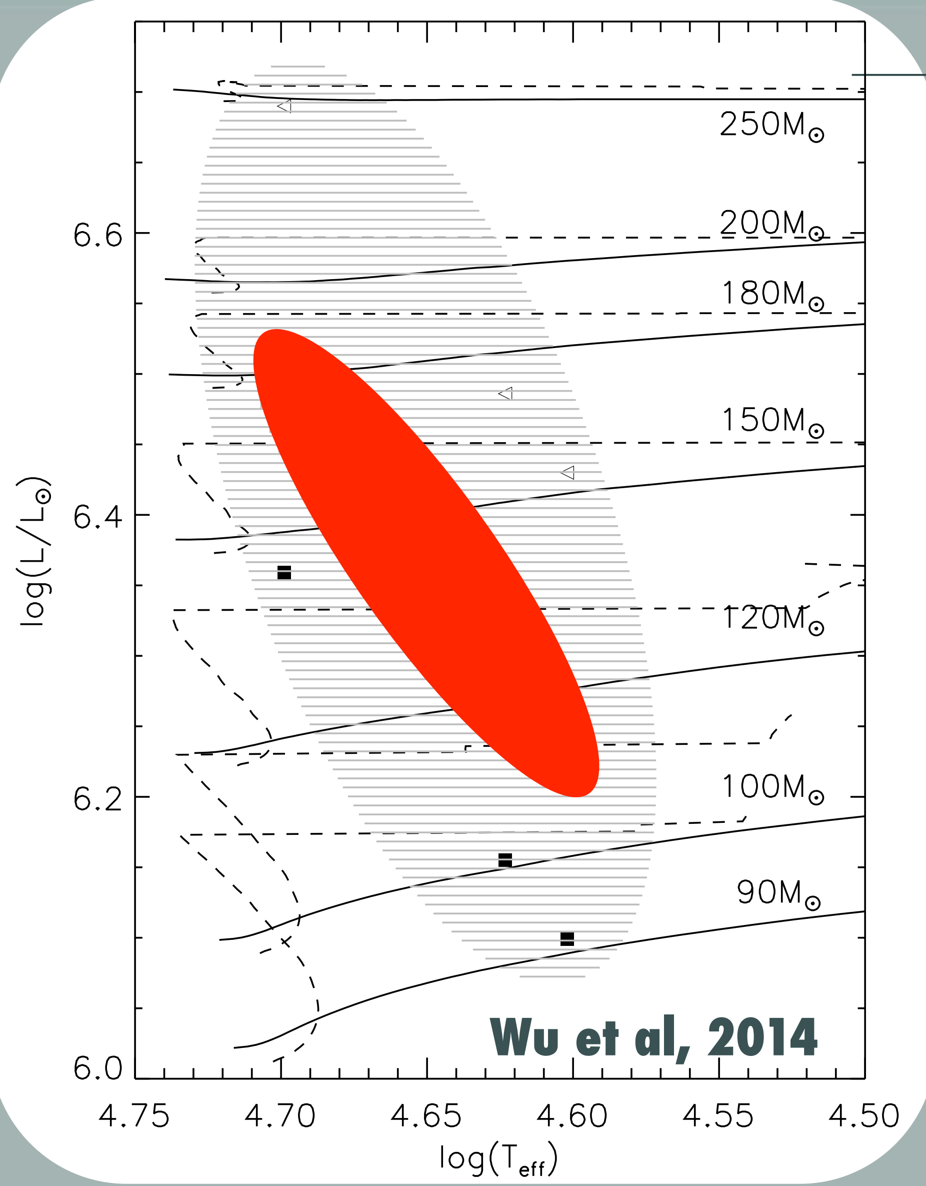
Towards extreme en



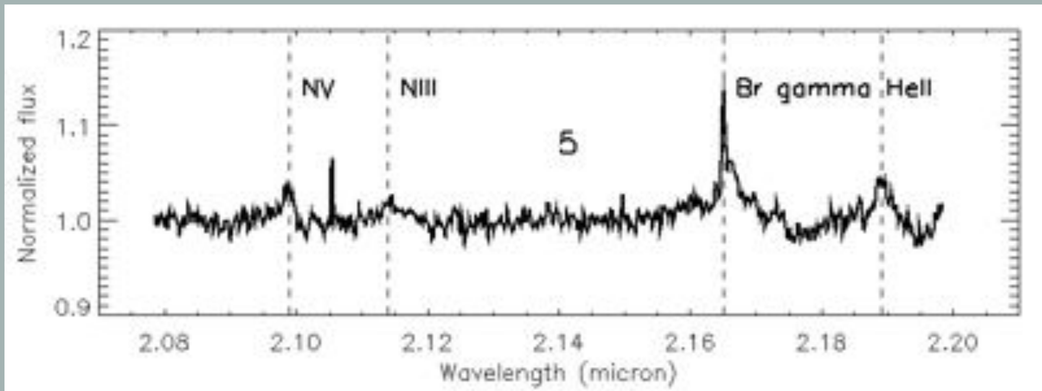


Filaments feeding mass to W49 GMC, Galvan-Madrid et al, 2013

Spectroscopic survey W49



- O2-O3.5If* (supergiant):
  - M=80-180 Msun
  - Strong stellar wind
  - Many more early O stars (Poster Shiwei Wu)



Filaments vs triggering

- Feedback has little effect in forming the bulk of stars. (see also Kendrew 2012)
- Embedded clusters form at crossing points of filaments
- Filaments transfer mass to the forming high-mass cluster
- HII region heats up the dust and affects the filament (some triggering).
  - Densest filament in region
  - most recent star formation

Conclusions

- Star formation history is complex:
  - Sequential star formation (different sub clusters with different ages)
  - Age spread sometimes observed, sometimes not, related to dynamical time?
- Cluster formation:
  - feedback does not cause the bulk of the star formation
  - star formation at the crossing points of filaments