Spitzer & Chandra Views of Massive HII Regions

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1. 30 Doradus
2. Comparison to NGC 3603 (MW), NGC 346 (SMC), NGC 604 (M33)
3. Outlook beyond the Local Group (NGC 5253, NGC 4038/39)

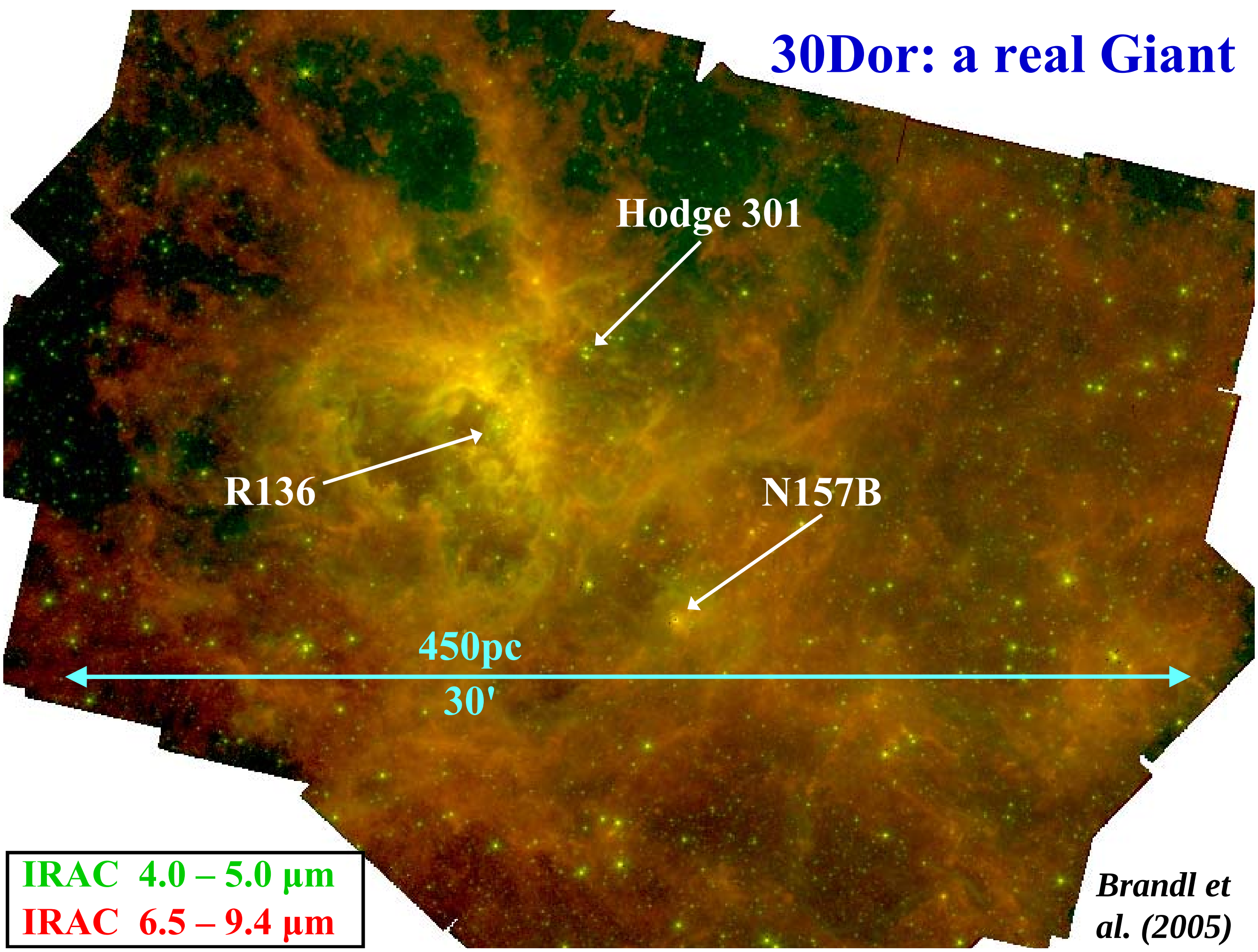
Note:

This PDF document has been edited from the version presented at the meeting. The most significant modifications concern the expansion of animated slides over multiple pages for better visibility and the omission of preliminary and unpublished IRS spectra. For any questions please contact brandl@strw.leidenuniv.nl

30 Dor

Hα luminosity	1.5×10^{40} erg/s	(Kennicutt 1984)
Ly-c flux (30 Dor)	1.1×10^{52} γ/s	(Kennicutt 1984)
Ly-c flux (NGC2070)	4.5×10^{51} γ/s	(Walborn 1991)
NGC 2070	2400 OB stars	(Parker 1993)
mass (H_2)	7×10^{7} M_o	(Westerlund 1993)
mass (HII)	8×10^{5} M_o	(Chu&Kennicutt 1994)
E_{kin} (gas clouds)	$\geq 10^{52}$ erg	(Chu&Kennicutt1994)
L_{FIR}	10^{8} L_o	(Werner et al. 1978)

30Dor: a real Giant




30 Dor: Spitzer + Chandra – "the perfect team"
Chandra 0.5 – 0.7 keV
IRAC 3.2 – 4.0 µm
IRAC 6.5 – 9.4 µm


First there was Chandra – and then there came Spitzer …
Chandra 1.1 – 2.3 keV
Chandra 0.5 – 0.7 keV
IRAC 6.5 – 9.4 µm

X-ray Super-bubbles

"Standard view" (Chu & Kennicutt (1986), Chu & Mac Low (1990), Chu & Kennicutt (1994)):

• Winds and outflows from O stars create cavities in the ISM

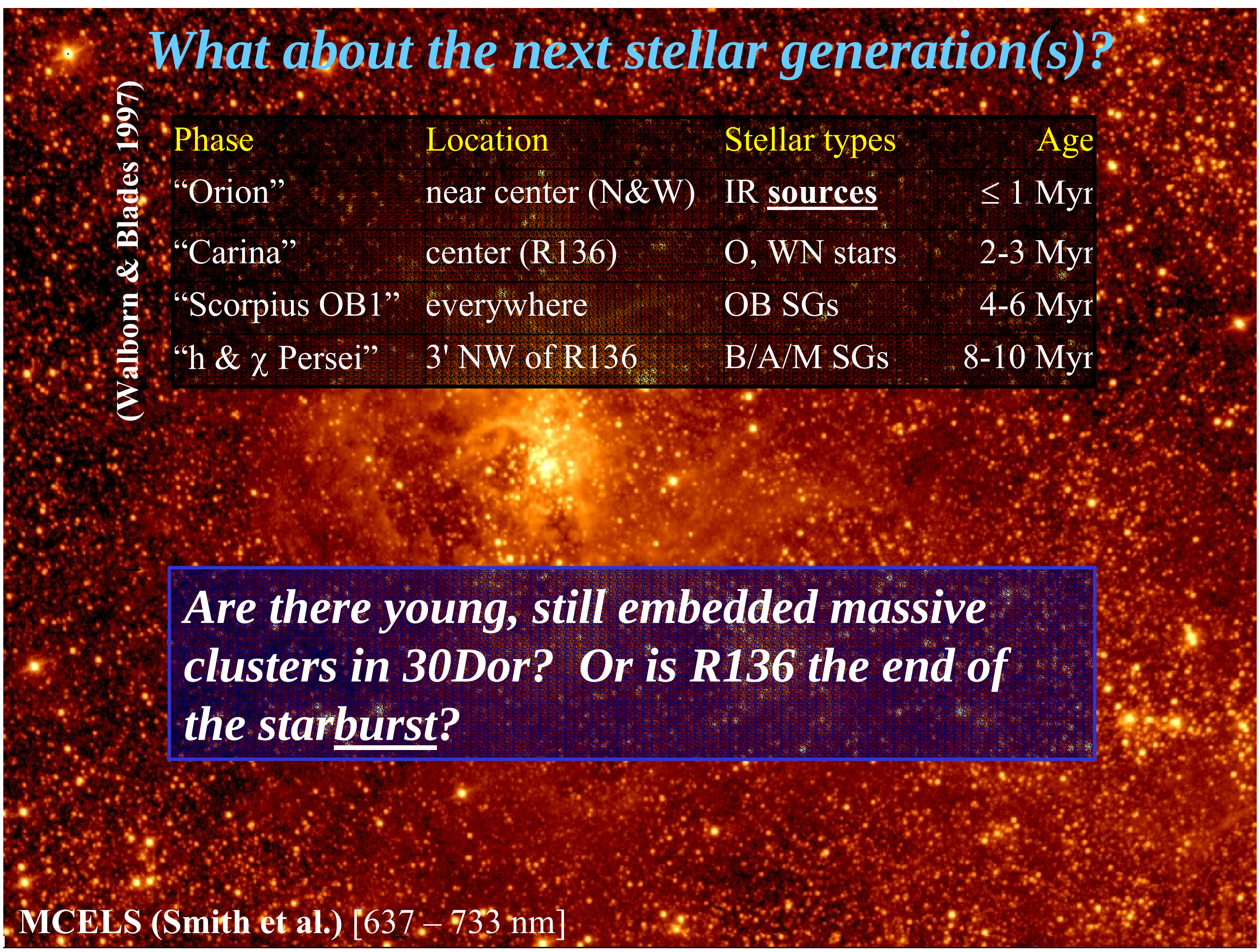
• O stars → SNe

• (off-center) SNe create high-velocity expanding sheels and fill the cavities with diffuse, hot X-ray gas

What this implies:

X-ray emission traces the *previous* generation of O-stars in 30 Dor

→What's their origin???



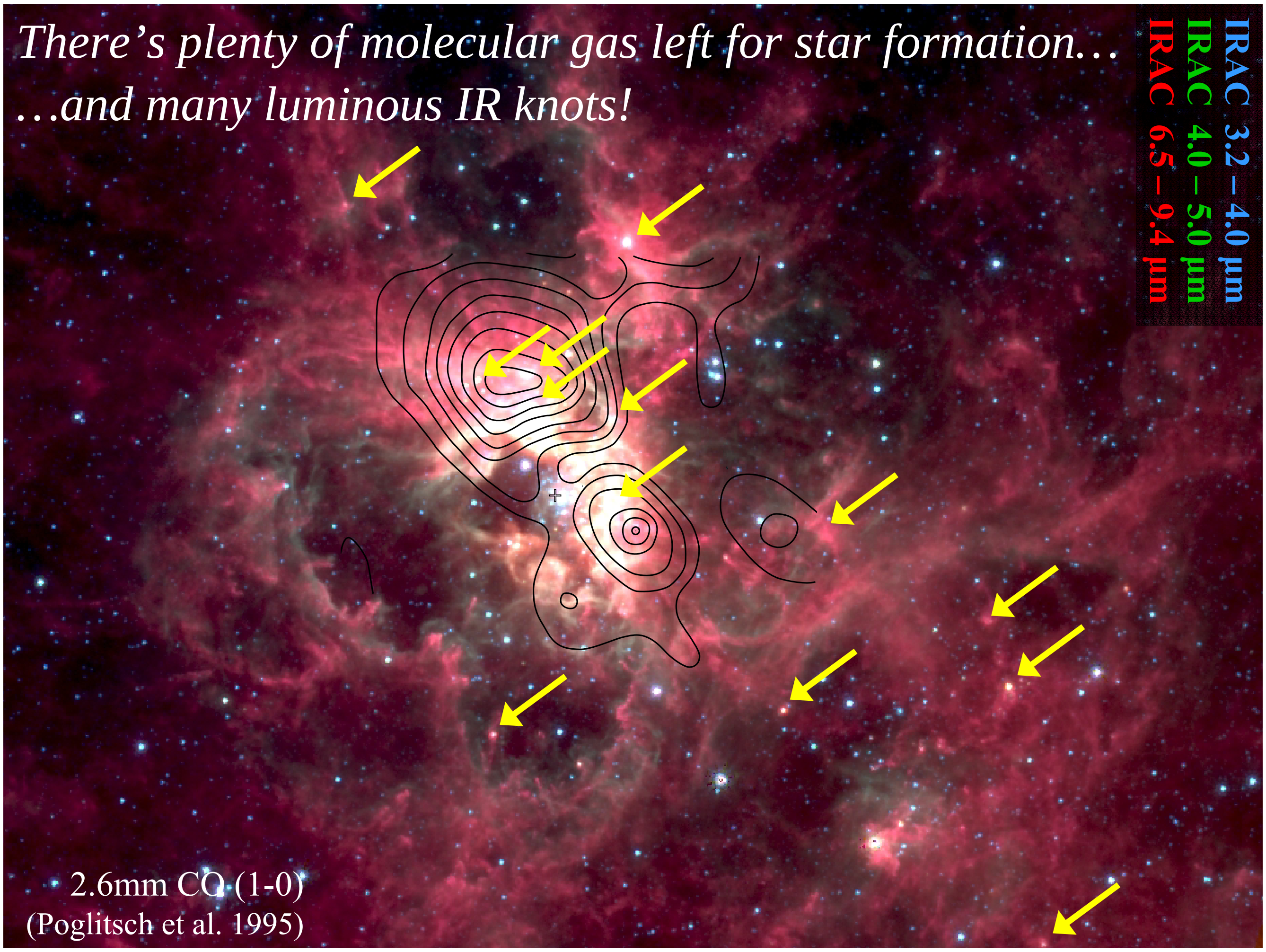
What about the next stellar generation(s)?

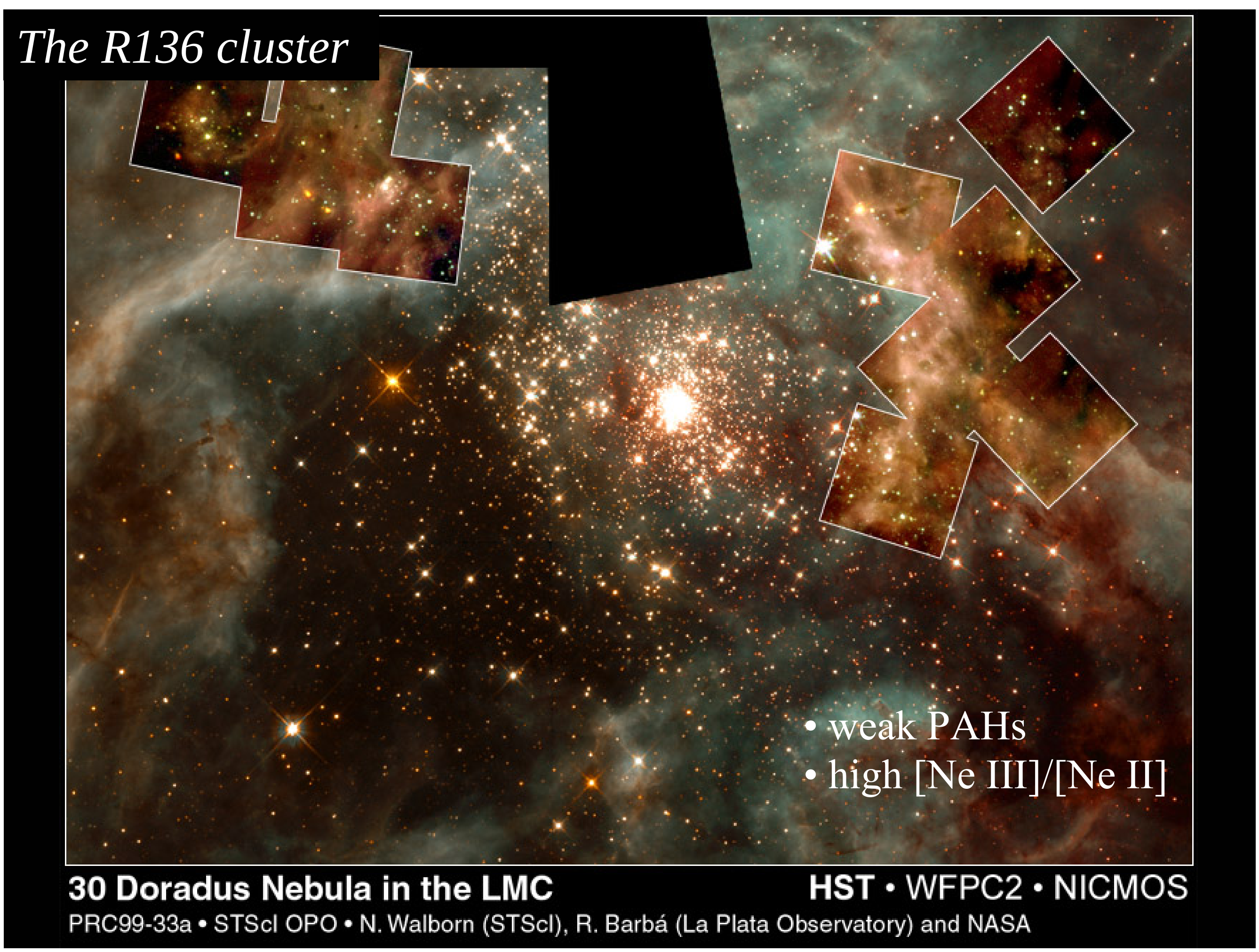
(Walborn & Blades 1997)

Phase	Location	Stellar types	Age
"Orion"	near center (N&W)	IR **sources**	≤ 1 Myr
"Carina"	center (R136)	O, WN stars	2-3 Myr
"Scorpius OB1"	everywhere	OB SGs	4-6 Myr
"h & χ Persei"	3' NW of R136	B/A/M SGs	8-10 Myr

Are there young, still embedded massive clusters in 30Dor? Or is R136 the end of the starburst?

MCELS (Smith et al.) [637 – 733 nm]


There's plenty of molecular gas left for star formation…
…and many luminous IR knots!
IRAC 3.2 – 4.0 μm
IRAC 4.0 – 5.0 μm
IRAC 6.5 – 9.4 μm
2.6mm CO (1-0)
(Poglitsch et al. 1995)


The R136 cluster
• weak PAHs
• high [Ne III]/[Ne II]
30 Doradus Nebula in the LMC
HST • WFPC2 • NICMOS
PRC99-33a • STScI OPO • N. Walborn (STScI), R. Barbá (La Plata Observatory) and NASA

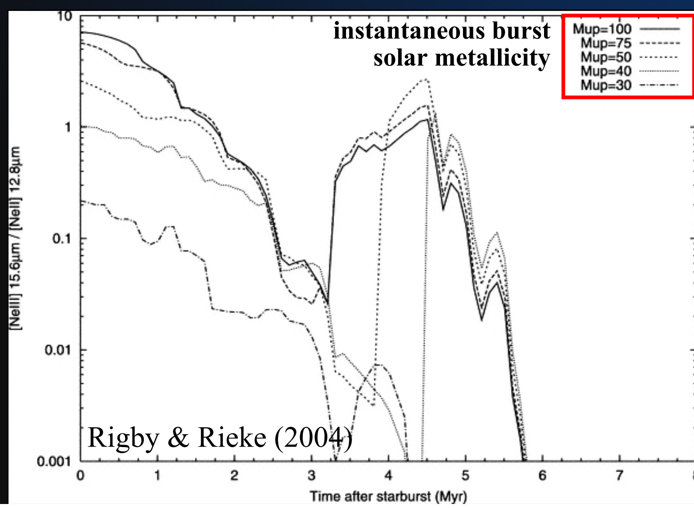
Side note: The [Ne III]/[Ne II] ratio

[Ne I] → [Ne II] (22 eV)
[Ne I] → [Ne III] (41 eV)

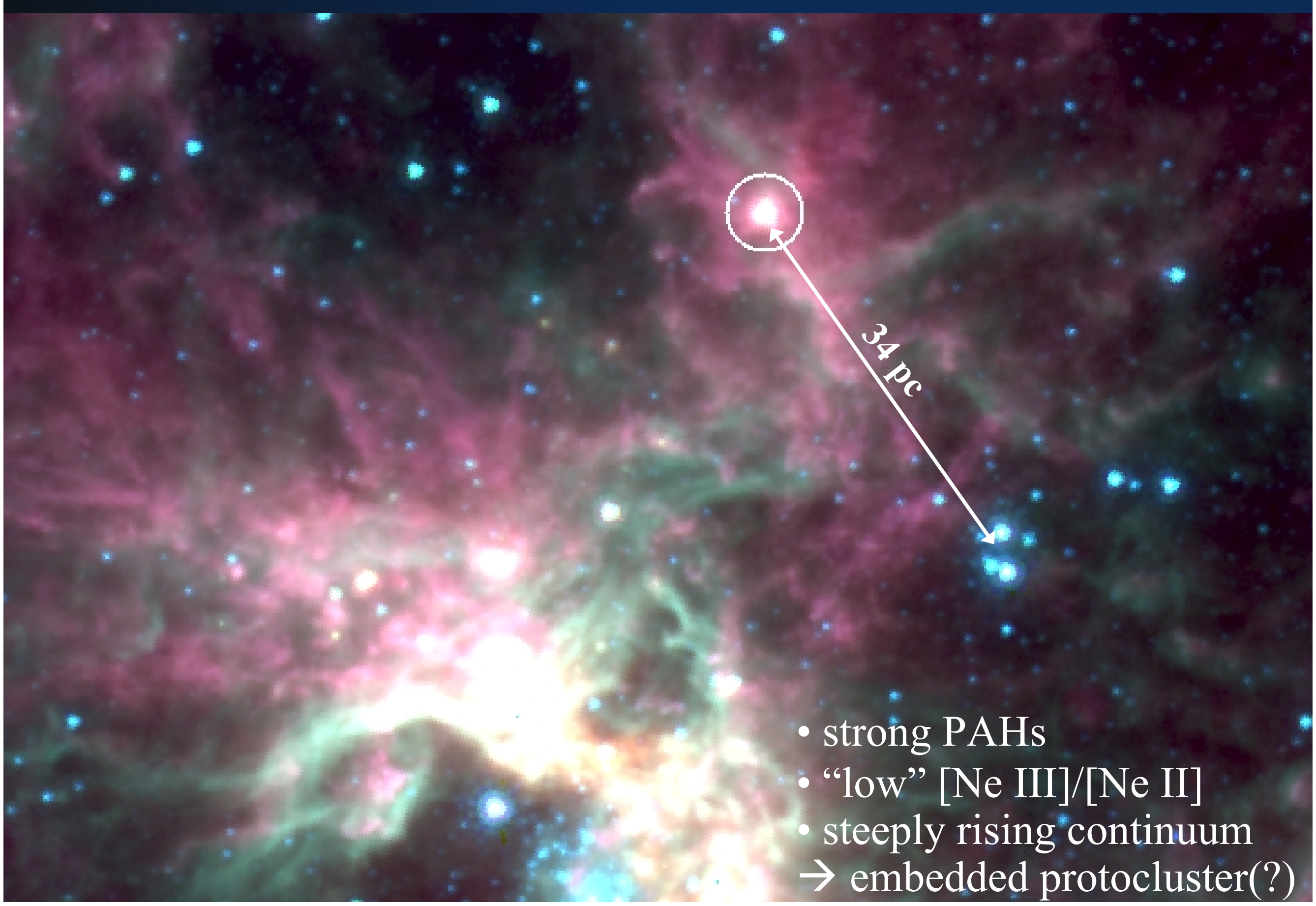
close in wavelength → excellent measure of the hardness of the radiation field

Starburst99 & CLOUDY	popul. IMF with M_{up} = 100M_o	single O star at T_{eff} = 50,000K	single WN star at T_{eff} = 100,000K
[Ne III] / [Ne II]	7	10	70

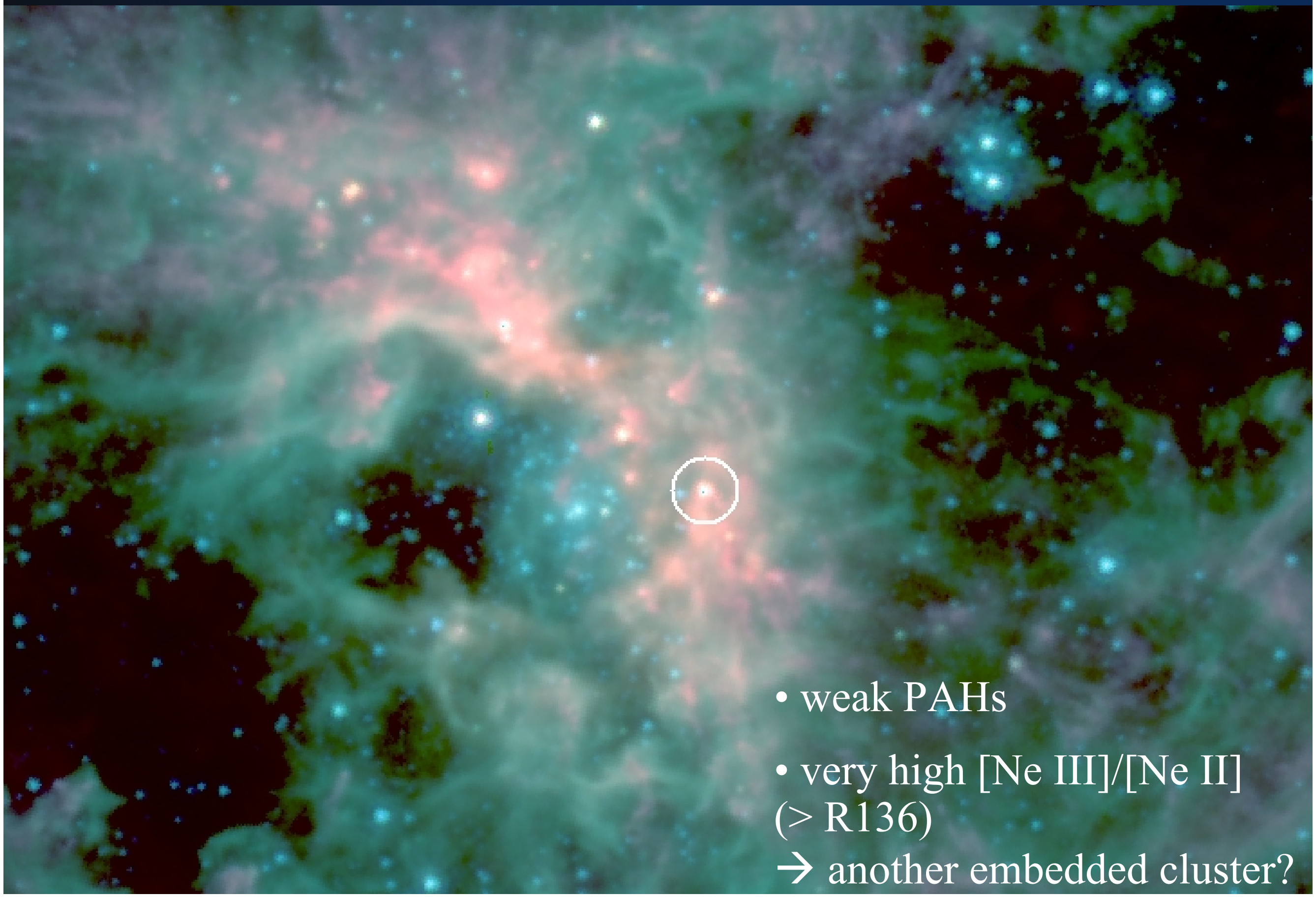
… a strong function of time and M_{up}:



Pos #10: a bright IR source in the North (near Hodge 301)



Pos #16: IR peak near R136

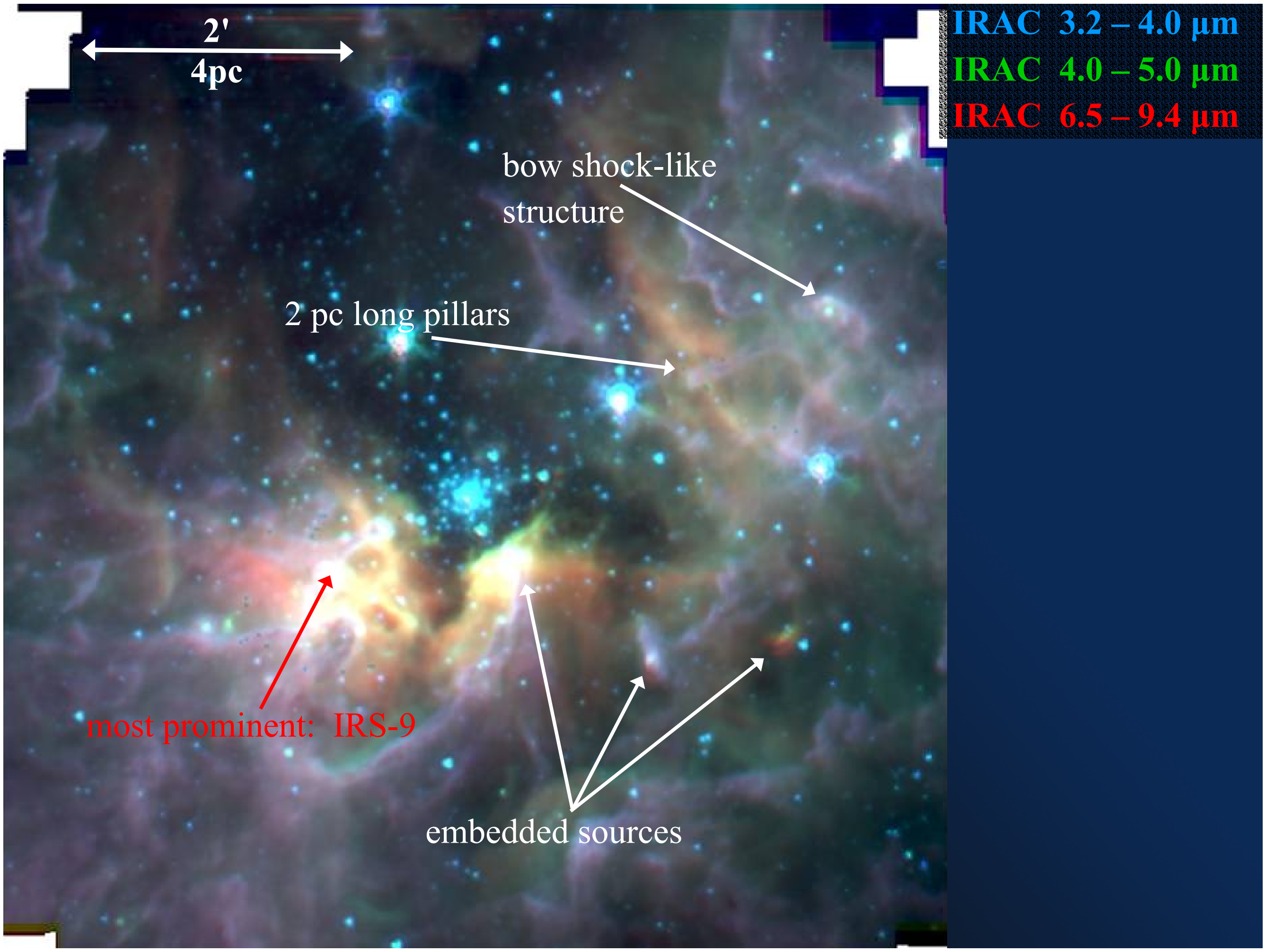


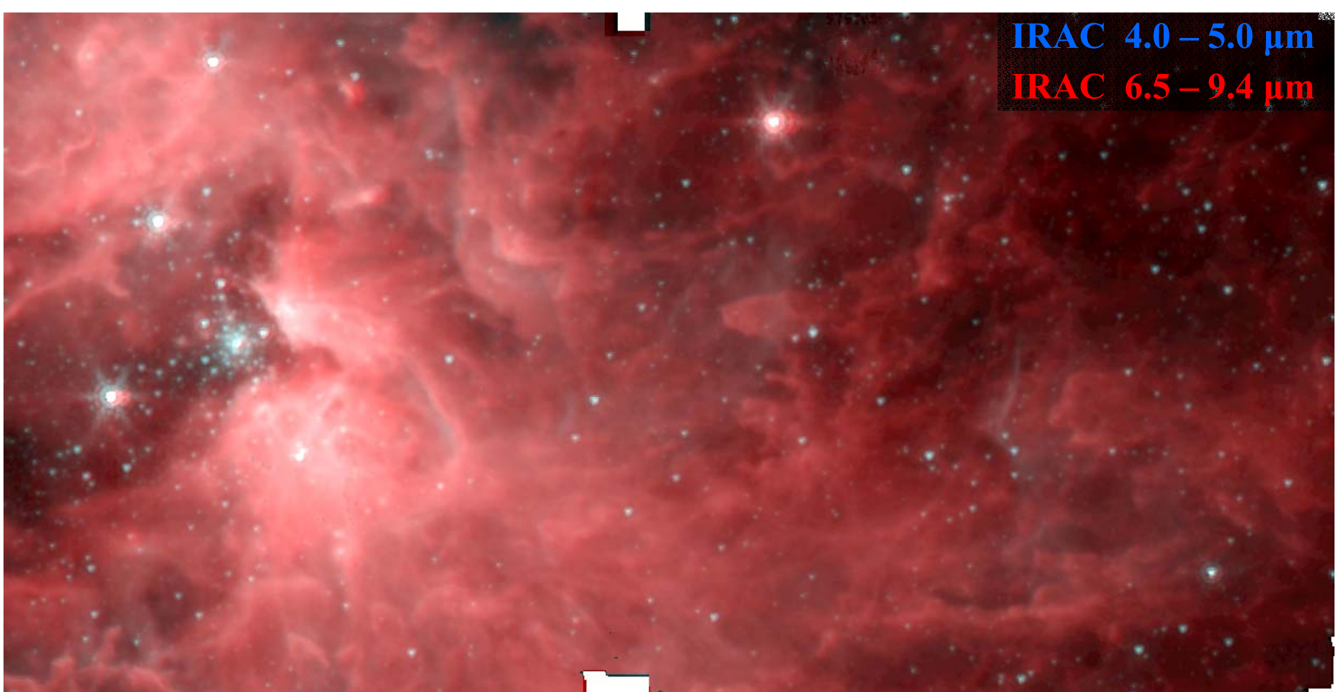
II. Comparison to

A. NGC 3603

"The most massive optically visible HII region in our Galaxy"

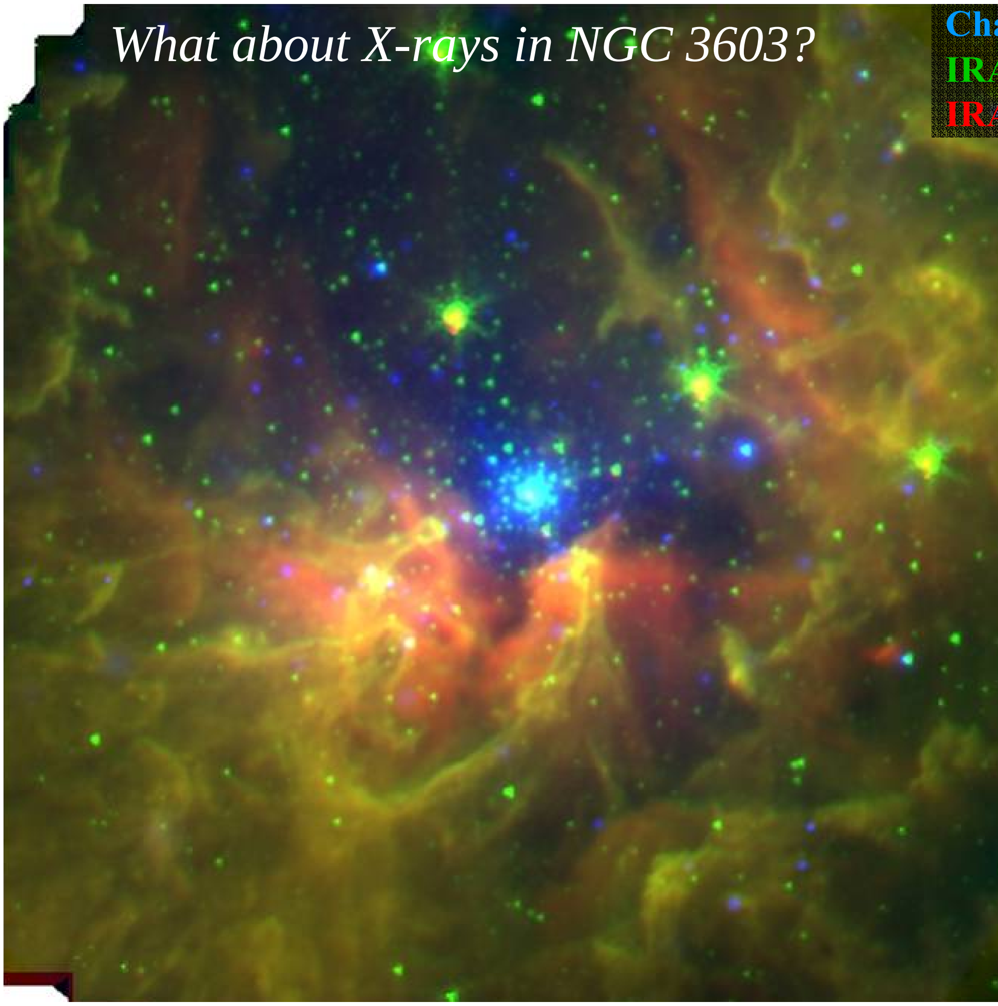
- $L_{bol} \sim 10^7 L_o$ (Orion: $\sim 10^5 L_o$)
- > 50 O stars
- > 10^{51} Lyman continuum photons / s
- Hα luminosity 2×10^{39} erg/s
- central stellar density > R136





- asymmetric GMC: NGC3603 sits near the edge – just like Orion, R136, …
- molecular cloud extends much further (~20pc) southwest
- pillar-like structures visible all the way out

What about X-rays in NGC 3603?



mostly discrete sources

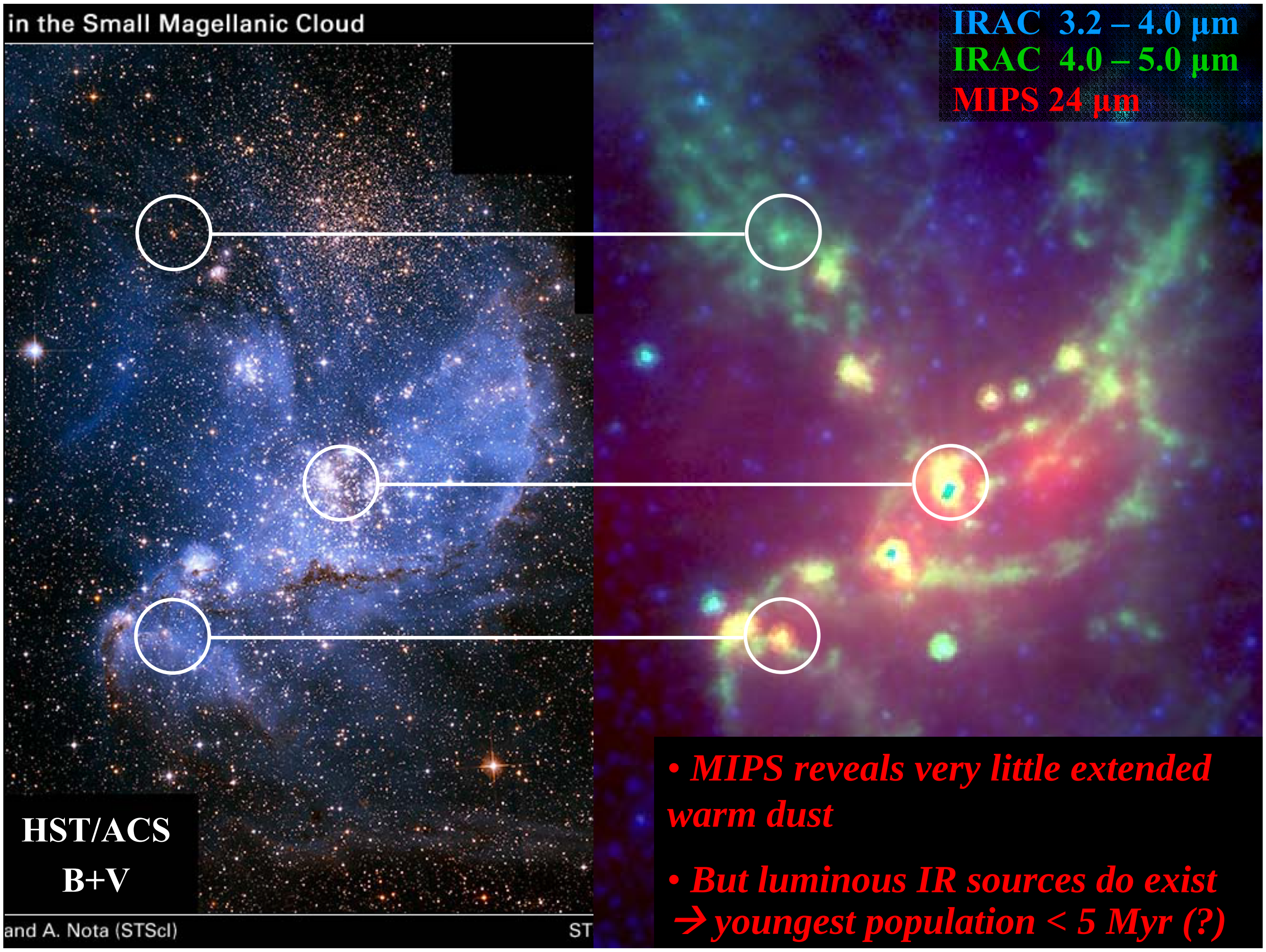
little diffuse emission

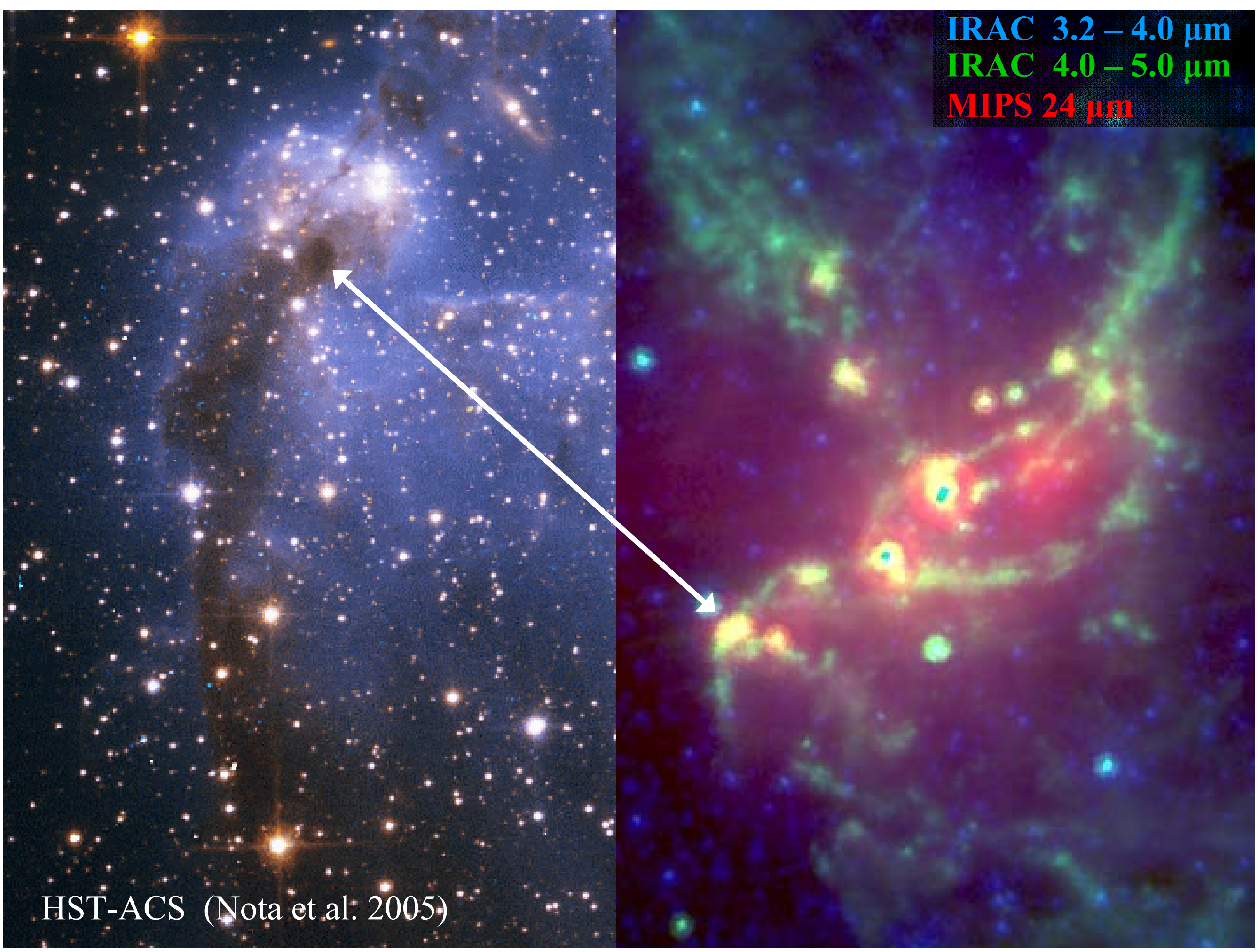
no “superbubble” (yet)

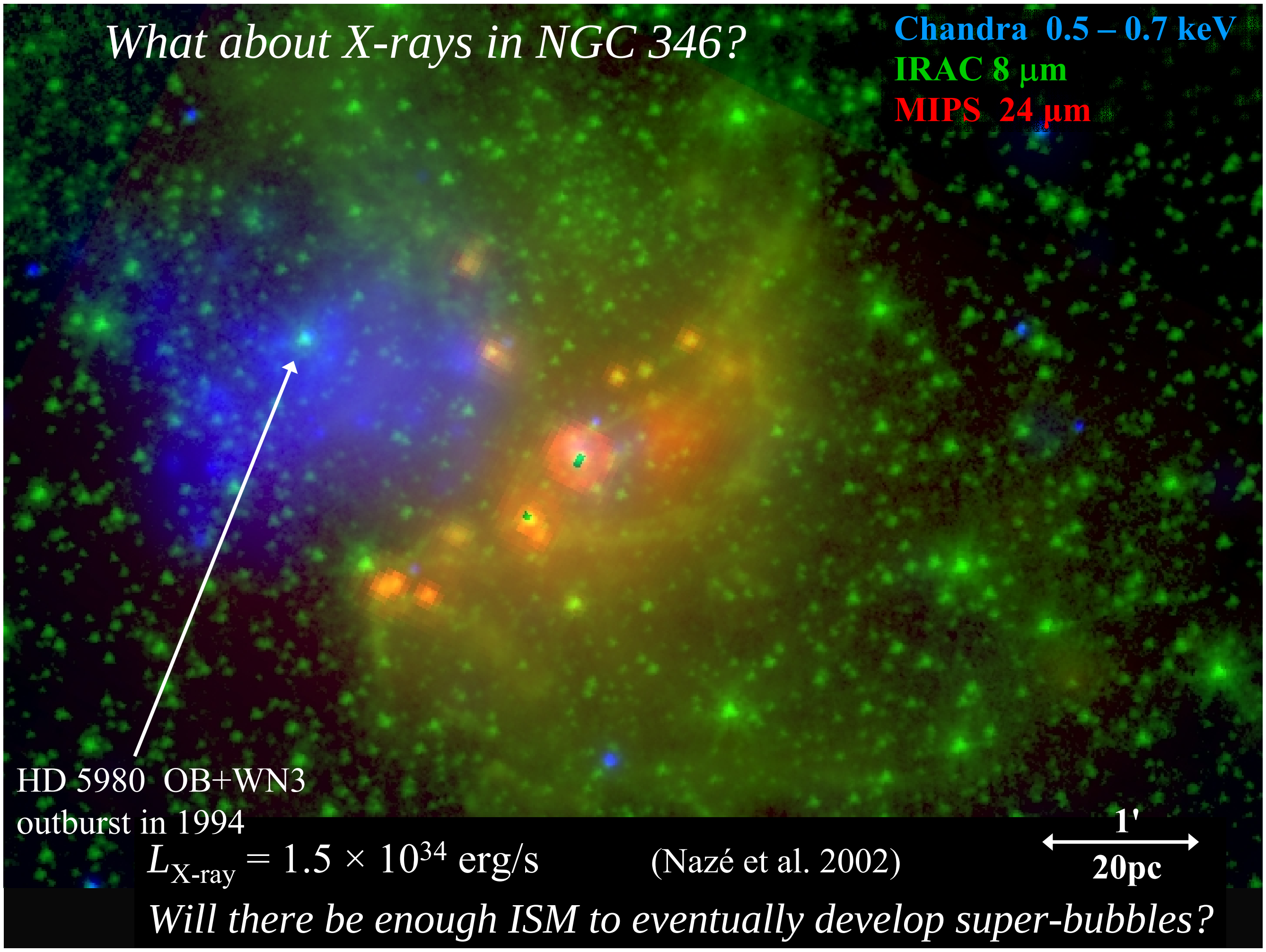
B. NGC 346

Largest SMC cluster	(NGC 346 ⇔ N66)
Hα luminosity	60 × Orion
O-stars	33 [22 in center] (Massey et al. 1989)
Metallicity	~1/10 Z_o (lowest in the sample)

HST-ACS revealed 2500 PMS stars → age ~ 5 Myr


in the Small Magellanic Cloud
IRAC 3.2 – 4.0 µm
IRAC 4.0 – 5.0 µm
MIPS 24 µm
HST/ACS
B+V
and A. Nota (STScI)
• MIPS reveals very little extended warm dust
• But luminous IR sources do exist
→ youngest population < 5 Myr (?)

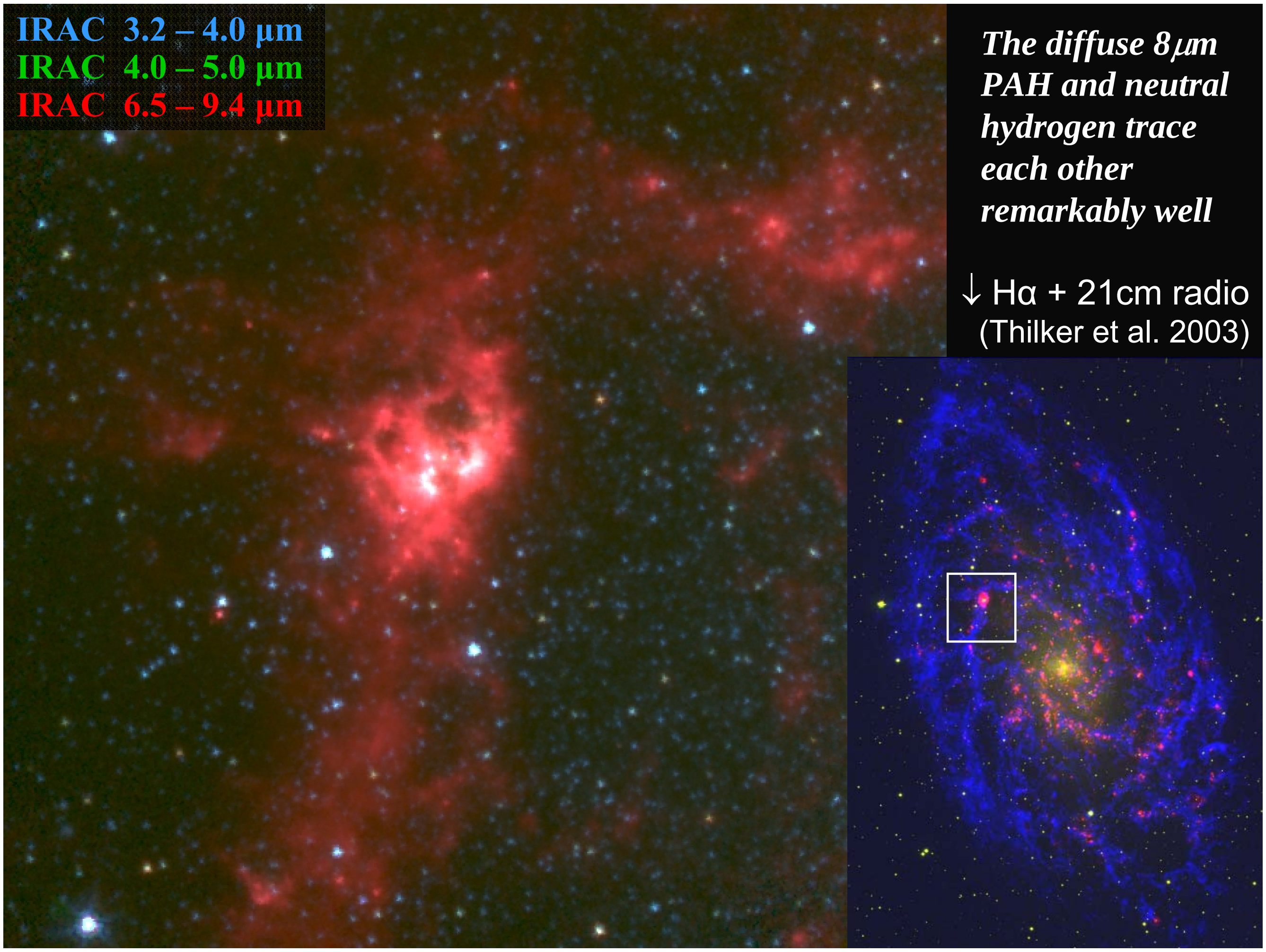

IRAC 3.2 – 4.0 µm
IRAC 4.0 – 5.0 µm
MIPS 24 µm
HST-ACS (Nota et al. 2005)

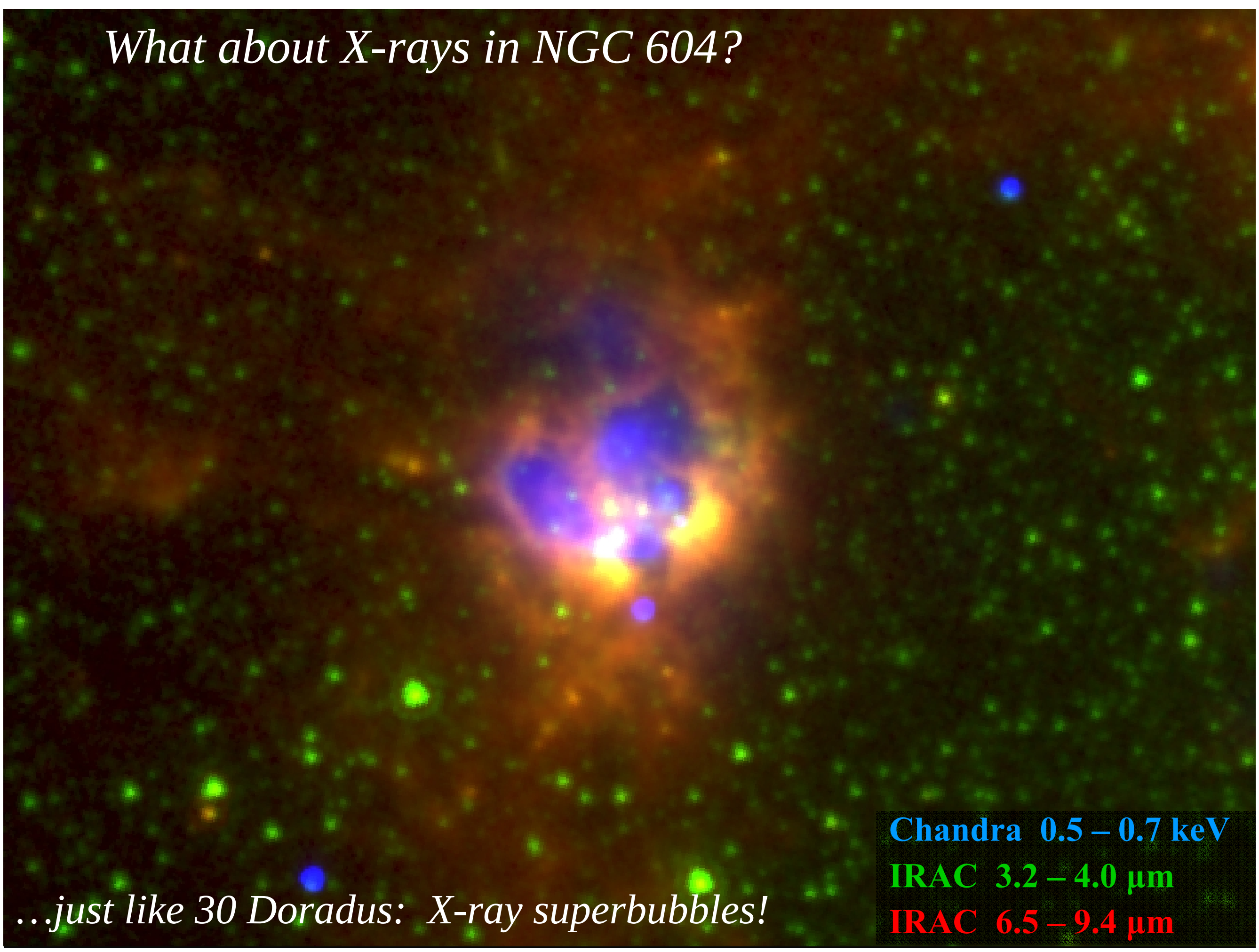


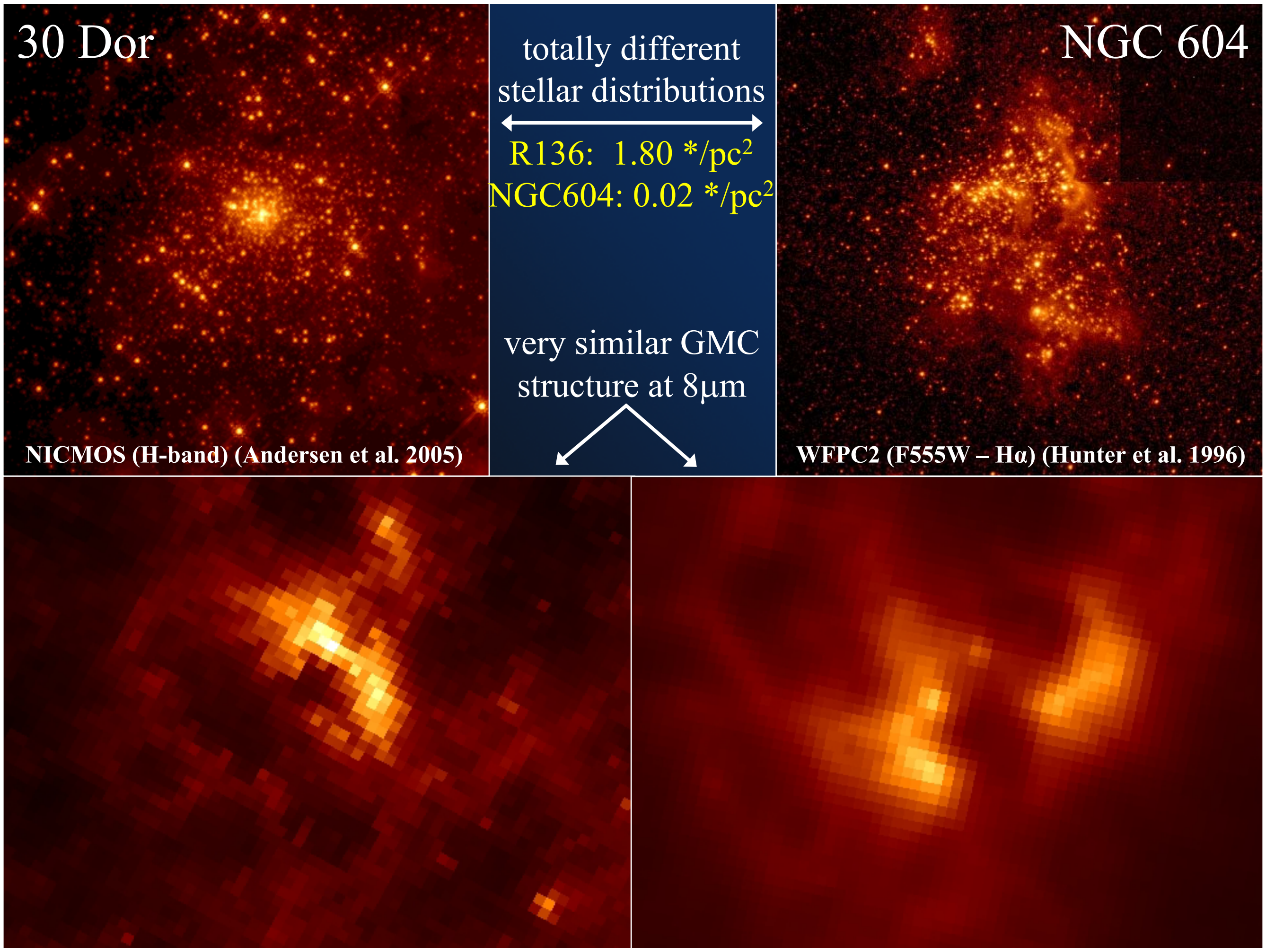
C. NGC 604

"2nd most massive HII region in the Local Group"

Distance	840 kpc
Hα luminosity	~ ¼ of 30 Dor but 450×Orion


IRAC 3.2 – 4.0 µm
IRAC 4.0 – 5.0 µm
IRAC 6.5 – 9.4 µm
The diffuse 8µm PAH and neutral hydrogen trace each other remarkably well
↓ Hα + 21cm radio
(Thilker et al. 2003)


What about X-rays in NGC 604?
…just like 30 Doradus: X-ray superbubbles!
Chandra 0.5 – 0.7 keV
IRAC 3.2 – 4.0 µm
IRAC 6.5 – 9.4 µm

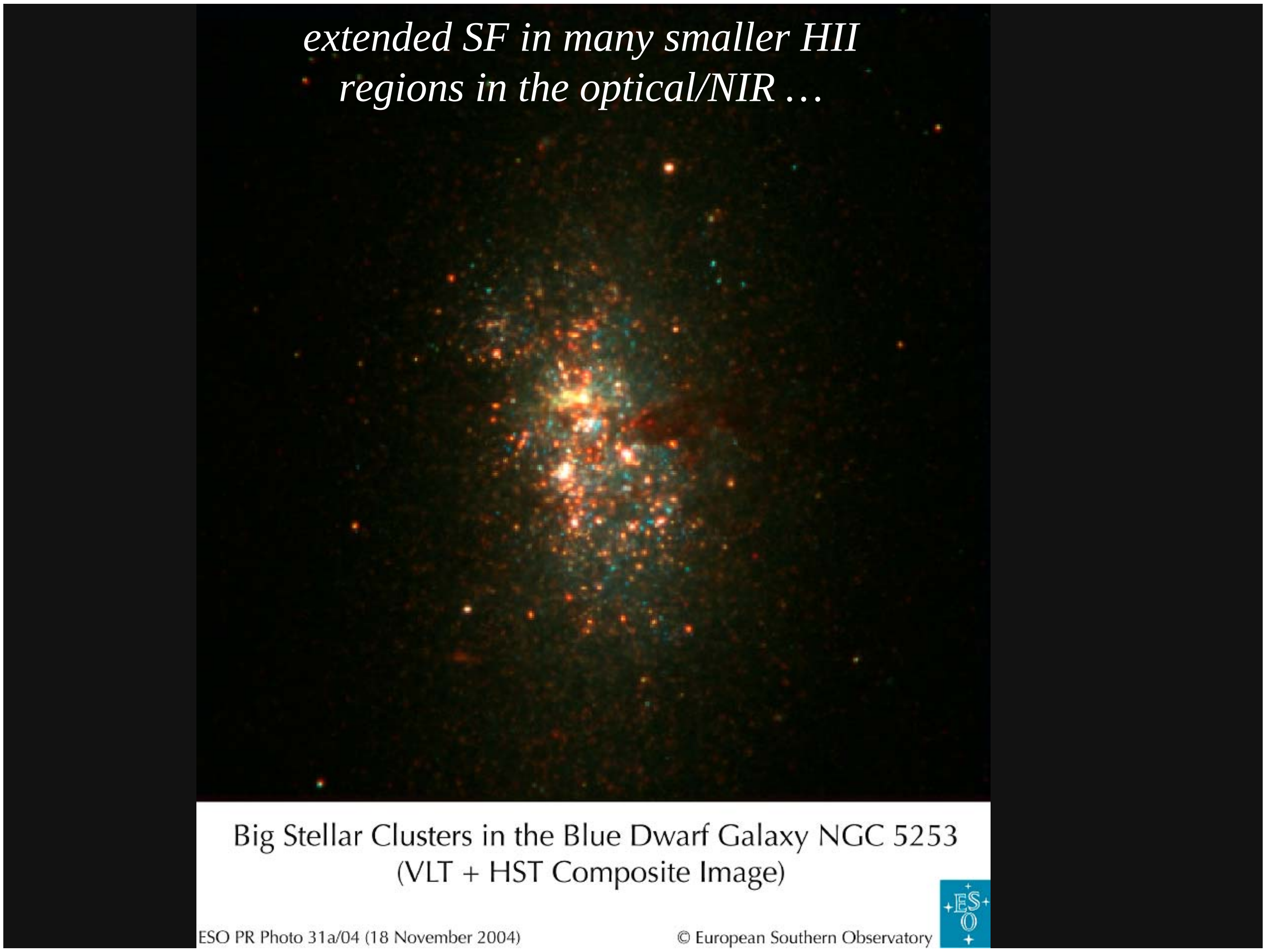


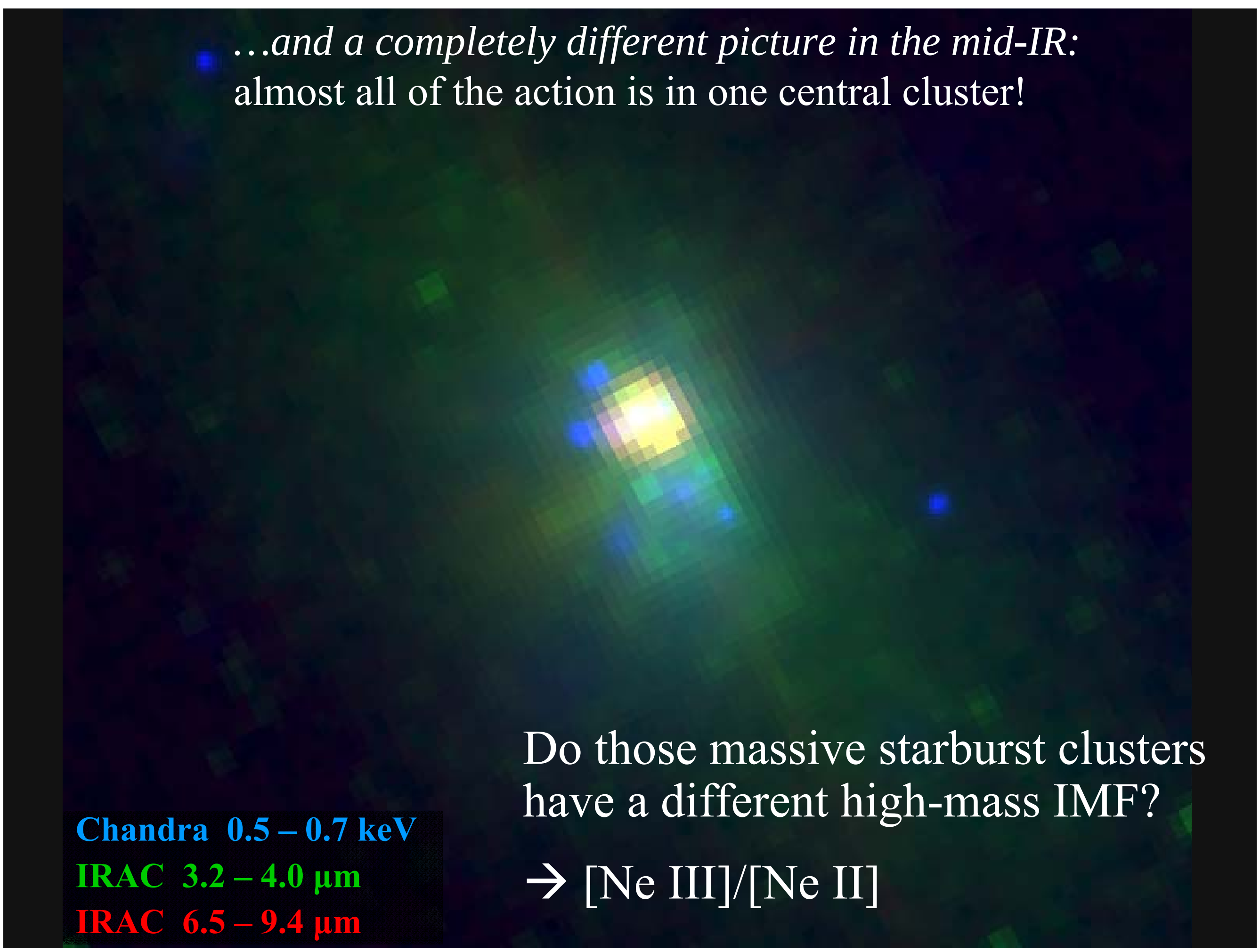
III. Outlook

A. NGC 5253

One of the closest Wolf-Rayet galaxies

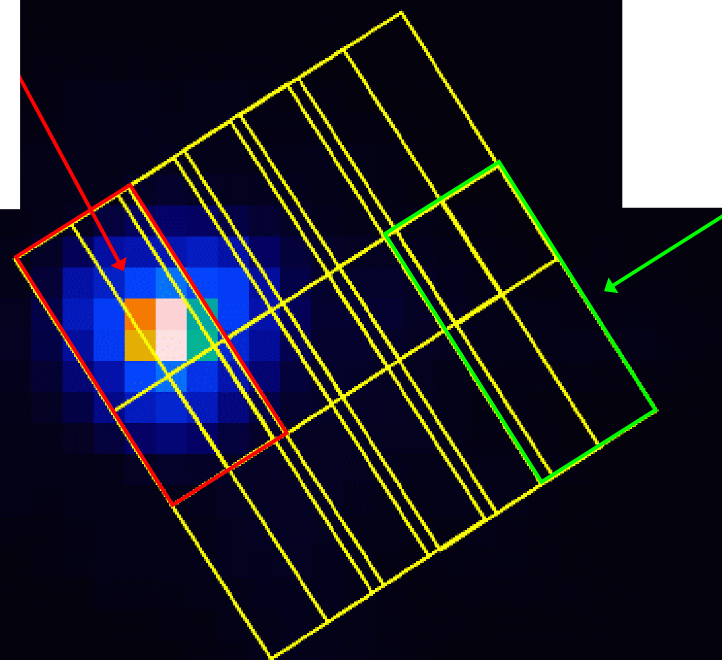
Distance	3.2 kpc	(Freedman et al. 2001)
Metallicity	¼ Z_o	
Br-α flux (2")	1000 O7-star equivalents	(Crowther et al. 1999)


extended SF in many smaller HII regions in the optical/NIR …
Big Stellar Clusters in the Blue Dwarf Galaxy NGC 5253
(VLT + HST Composite Image)
ESO PR Photo 31a/04 (18 November 2004)
© European Southern Observatory
ESO


…and a completely different picture in the mid-IR:
almost all of the action is in one central cluster!
Do those massive starburst clusters have a different high-mass IMF?
→ [Ne III]/[Ne II]
Chandra 0.5 – 0.7 keV
IRAC 3.2 – 4.0 μm
IRAC 6.5 – 9.4 μm

The [Ne III]/[Ne II] ratio in NGC 5253…

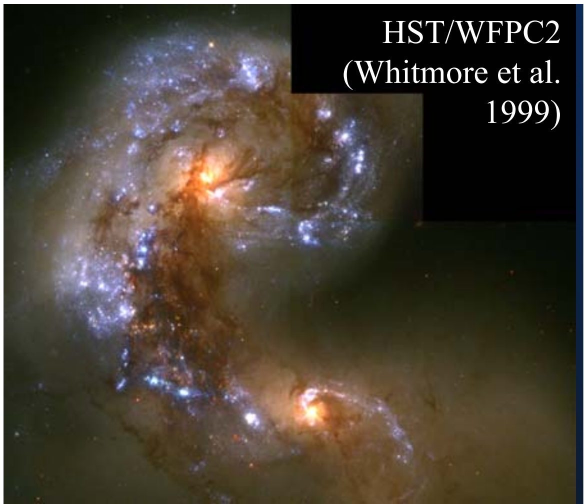
probed with an IRS spectral map

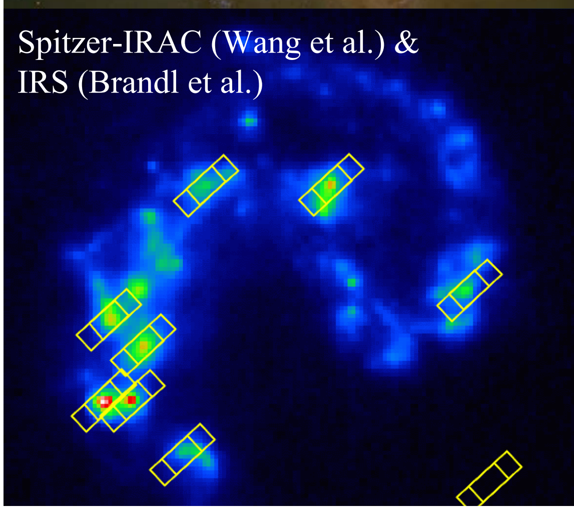


…is a function of distance from the mid-IR peak

B. NGC 4038/39

See next talk by Brad Whitmore…!





NGC 4038: [Ne III]/[Ne II] ~ weak

NGC 4039: [Ne III]/[Ne II] ~ strong

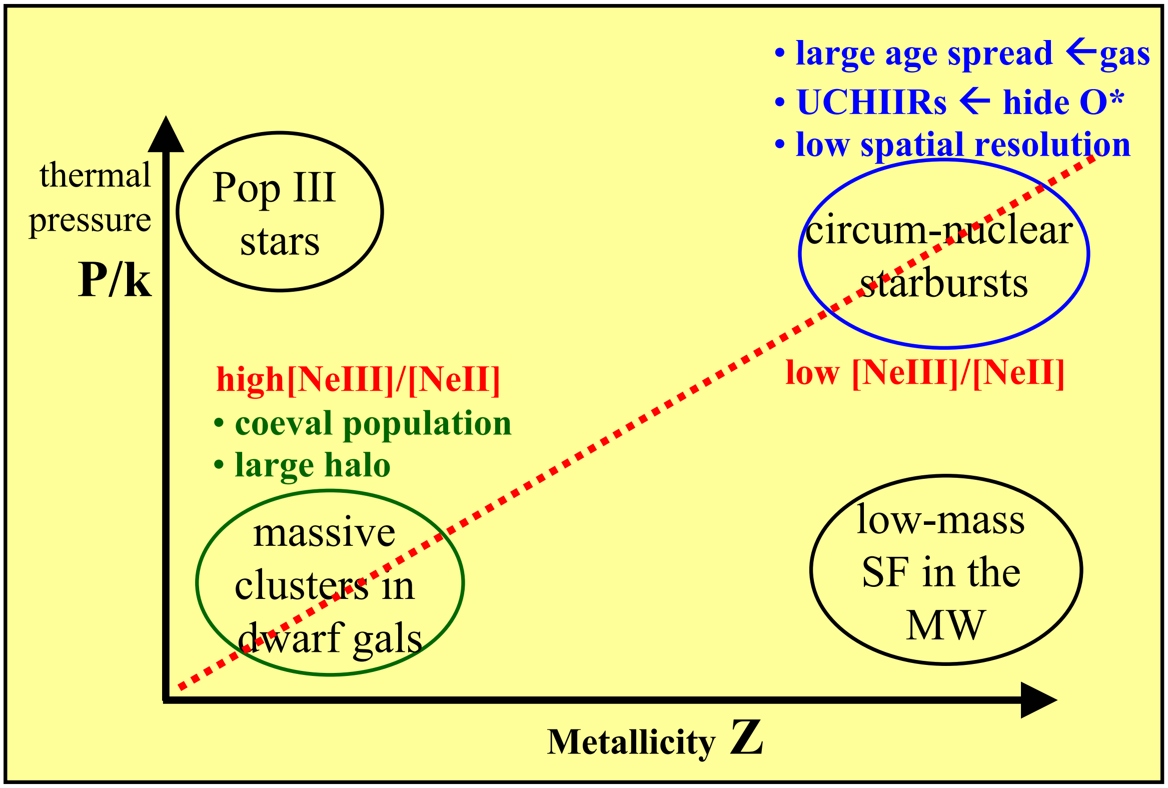
→ nucleus of NGC4039 more active!

BUT: young clusters in overlap region more active than either nucleus!

~~SUMMARY~~ → White Paper Questions

- *Where do the SNe that produce the X-ray superbubbles come from?*
- *Why are massive clusters sitting at the edges of dense clouds?*
- *Why do most massive star-forming GMCs look so similar?*
- *What is the sub-structure and content of extragalactic IR SSCs?*

- *Is the simplistic view on the next slide correct?*
- *These questions need JWST (MIRI) – how can we support JWST?*


• large age spread ←gas
• UCHIIRs ← hide O*
• low spatial resolution
thermal
pressure
P/k
Pop III
stars
circum-nuclear
starbursts
high[NeIII]/[NeII]
• coeval population
• large halo
low [NeIII]/[NeII]
massive
clusters in
dwarf gals
low-mass
SF in the
MW
Metallicity Z