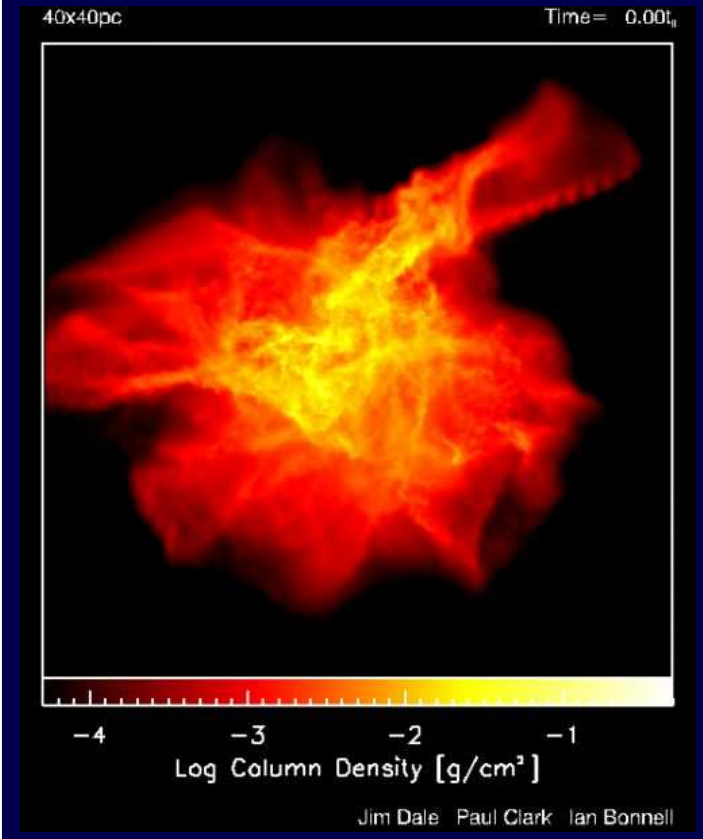
Lidia Oskinova & Yaël Nazé
Universität Potsdam & Université de Liège

XMM-Newton probes massive-star feedback in young massive star clusters

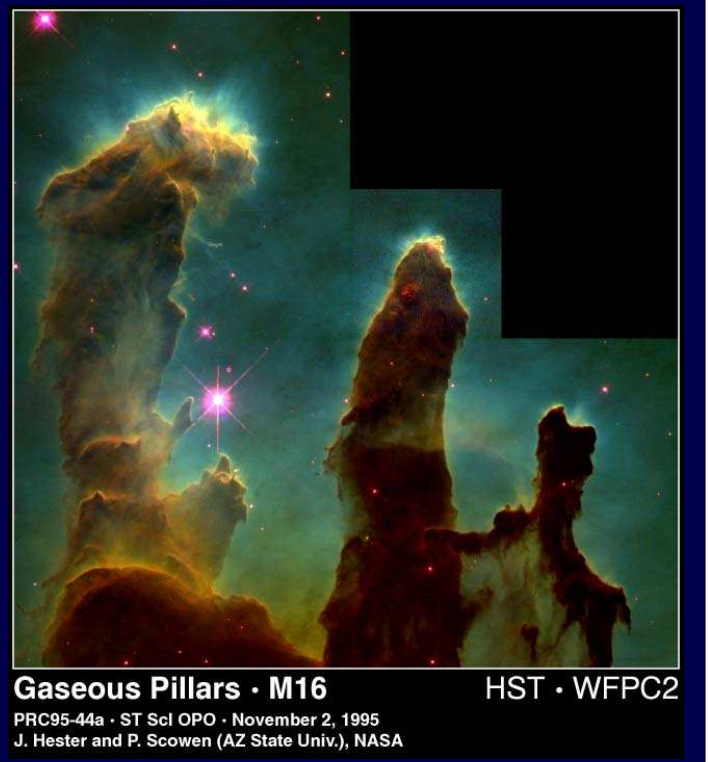
XMM-Newton: The Next Decade
European Space Astronomy Centre
4th - 6th June 2007, Madrid

Exact mechanism of massive-star formation is not known



- Giant Molecular Cloud (GMC)+ Turbulence
- Fragmentation → Star Cluster formation

- New-born massive stars
- Ionization, gas removal
- Stalled star formation



- Combined stellar outflows →
- Induce Turbulence →
- Shock the ambient GMC material →
- Trigger the next generation of star formation →

Feedback: the return of part of the output to its input

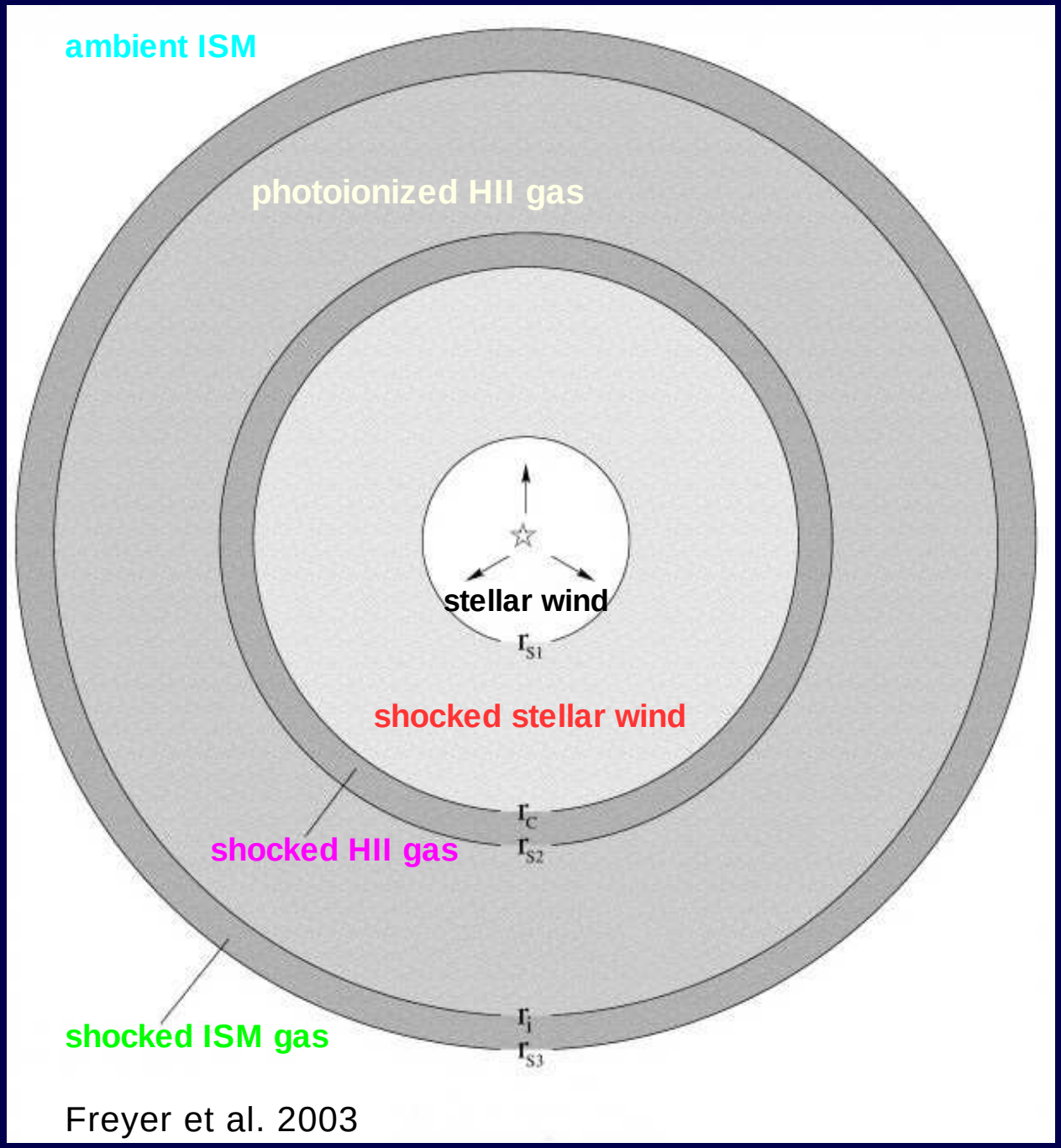
Negative Feedback

- Stalls star formation (low ε?!)
- Upper stellar mass?
- Cluster Infant Mortality

Positive Feedback

- Triggers new star formation
- Chemically enriches ISM
- **Sun** ← massive star forming region (SFR)
  (Hester+'04)

Structure of interstellar medium (ISM) around massive stars



Freyer et al. 2003

Without stellar wind:

Warm ISM

- HII region
- $T \approx 10$ kK
- **no X-ray emission**
- IR from HII PDR

With stellar wind:

Hot-Warm ISM

- wind swept bubble
- $T \approx 1$ MK
- **X-ray emission**

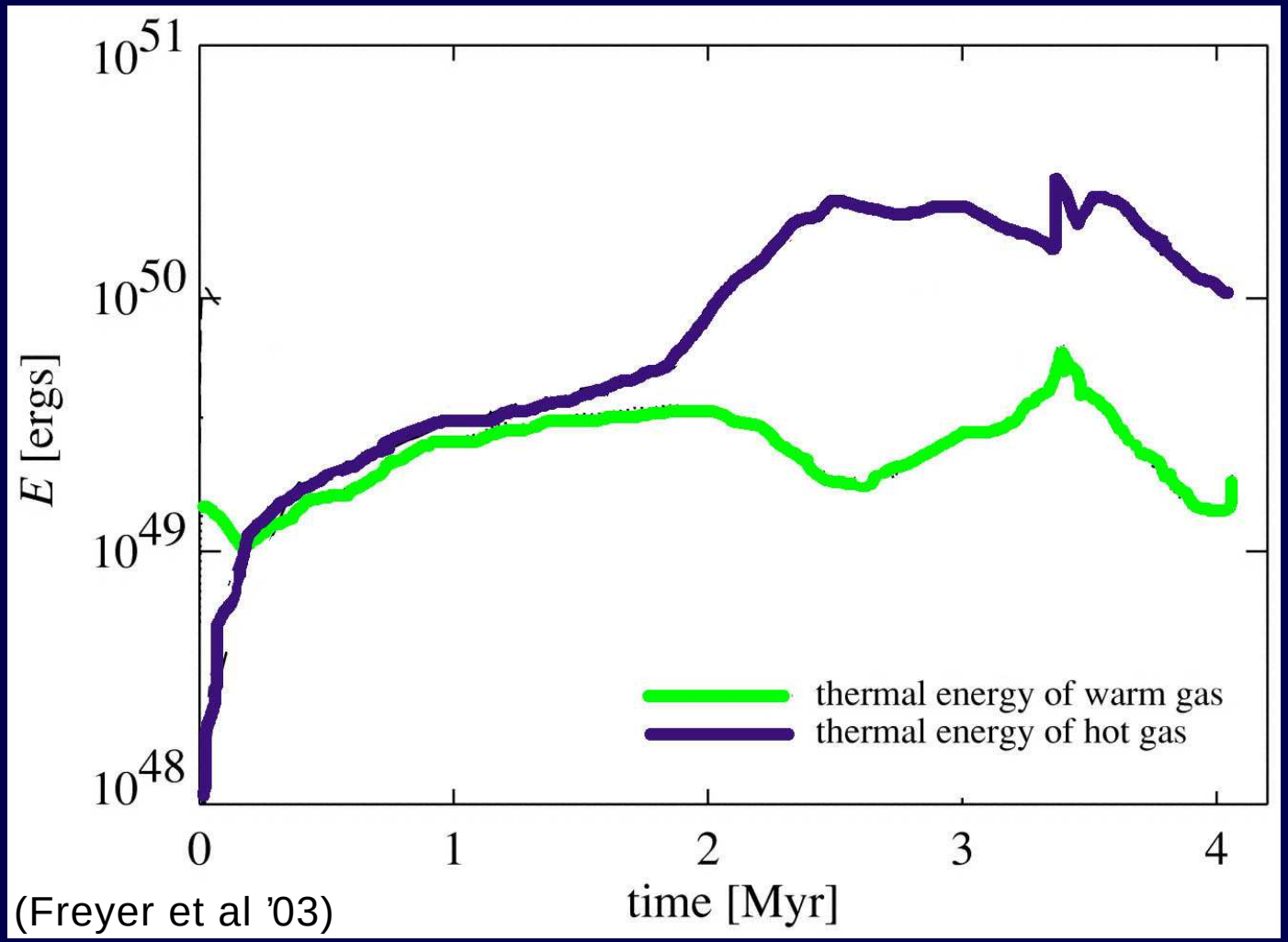
In massive star cluster:

Hot ISM

- cluster wind
- $T \approx 10$ MK
- superbubble
- $T \approx 1$ MK

Two feedback agents: radiative and mechanic energy

Evolution of thermal energy of ISM around $60_{\odot}$ star



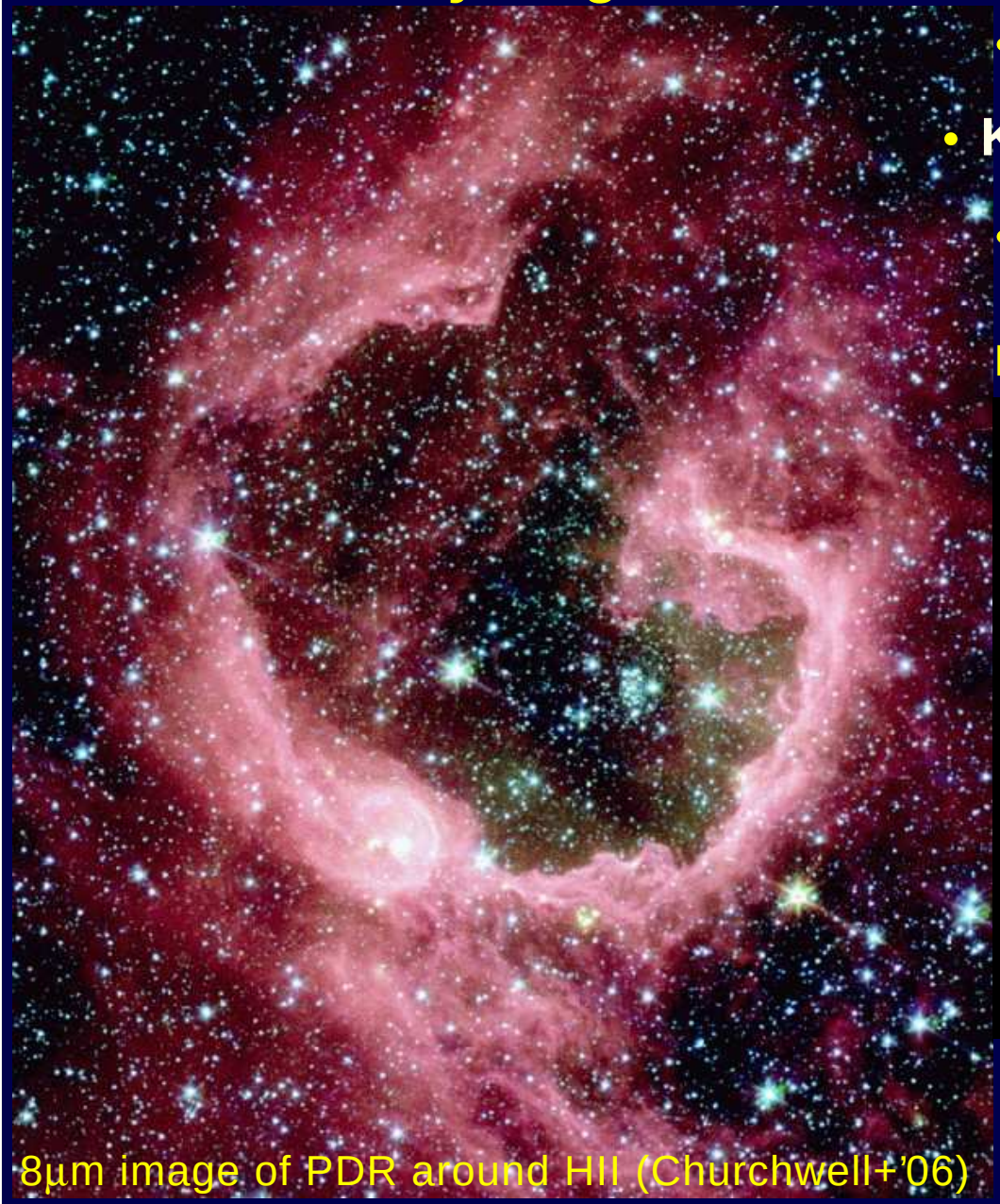
(Freyer et al '03)

What is the relative importance of feedback agents in inducing new star formation **?**

What are the observational X-ray hints on the triggering mechanism **?**

Two feedback agents: radiative and mechanic energy

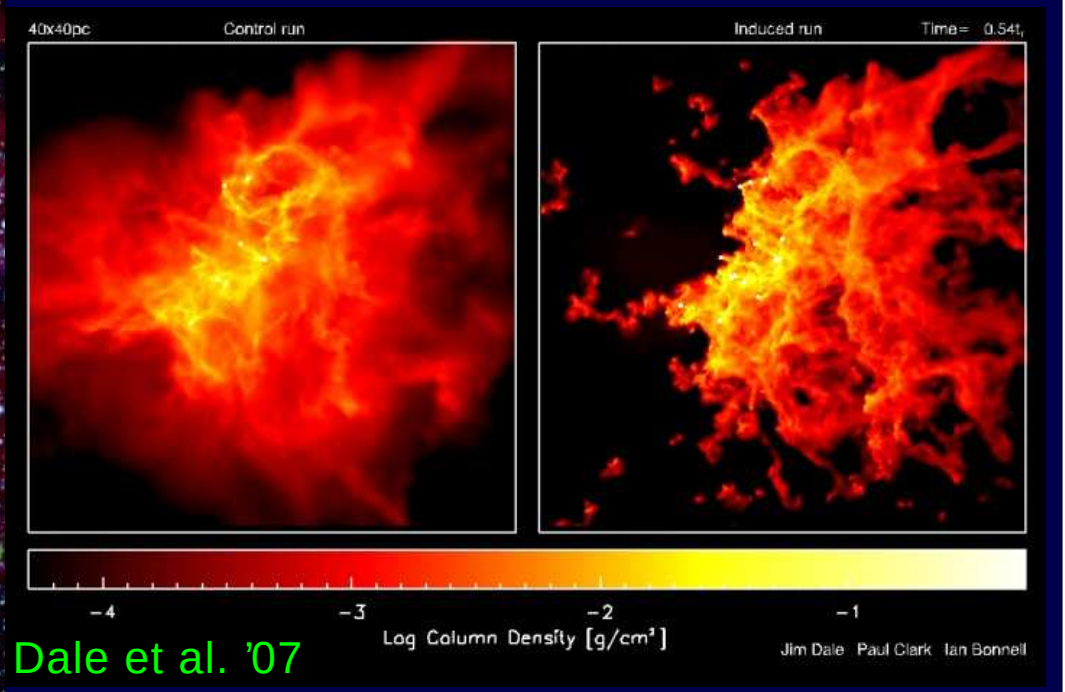
Low mass young clusters



8μm image of PDR around HII (Churchwell+'06)

- Small number of intermediate-mass stars
- Weak stellar winds
- **Key feedback agent: ionizing radiation**
- Triggered star formation in the PDR (Elmegreen '98)

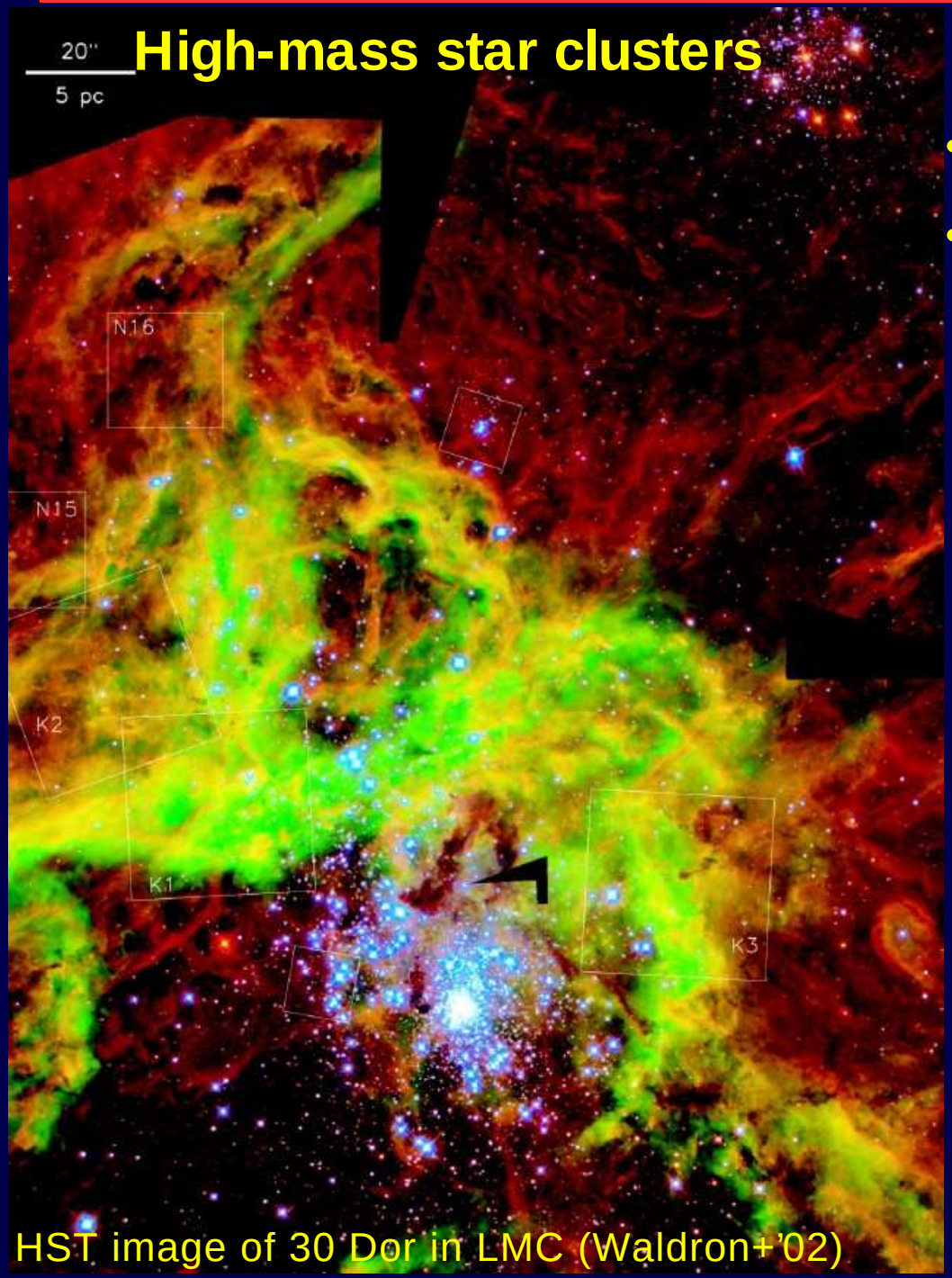
Included in state-of-the-art star formation code



Dale et al. '07

- **Dramatic effect on the morphology**
- **Minor effect on star formation**

Two feedback agents: radiative and mechanic energy



HST image of 30 Dor in LMC (Waldron+'02)

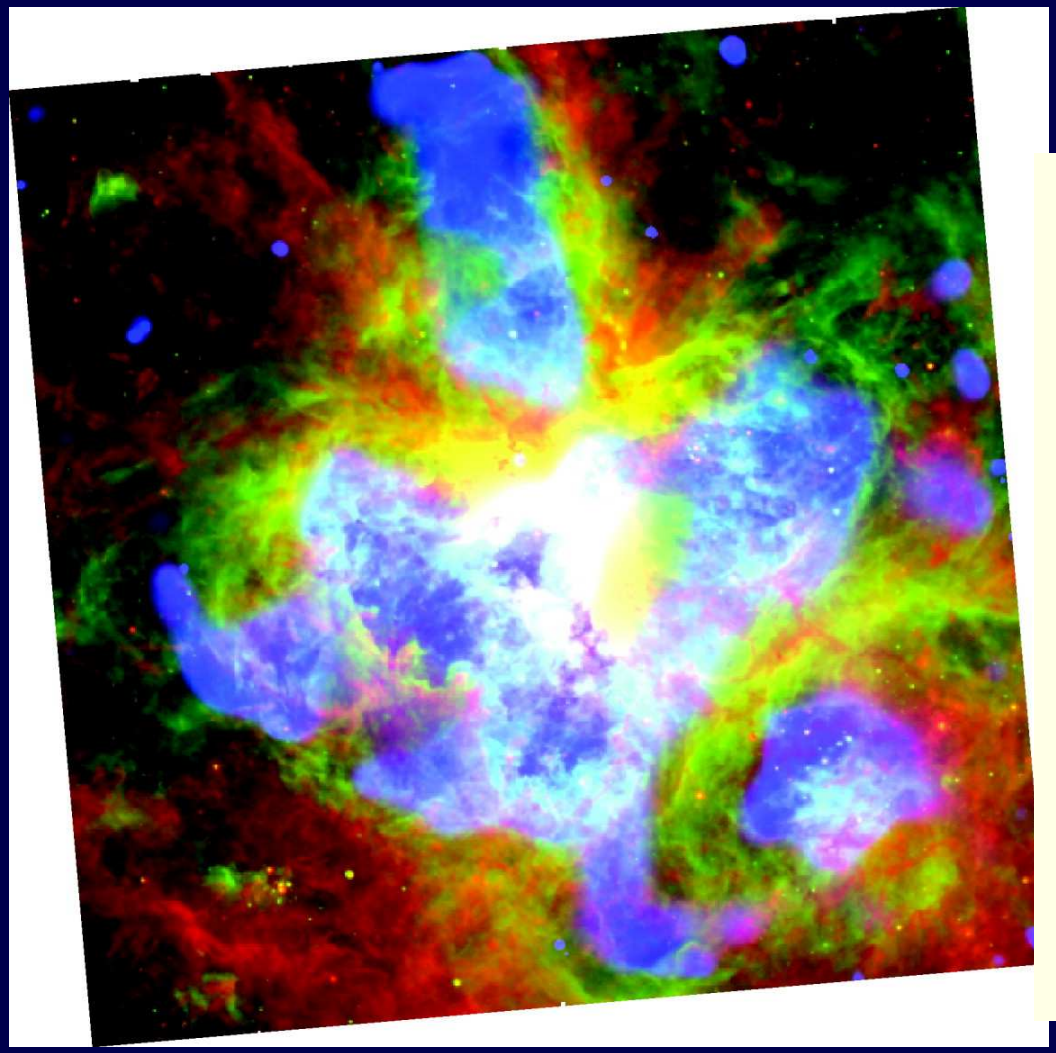
- Sample full IMF: most massive stars
- Strong stellar winds and SNe

Stellar winds: key feedback agent ?

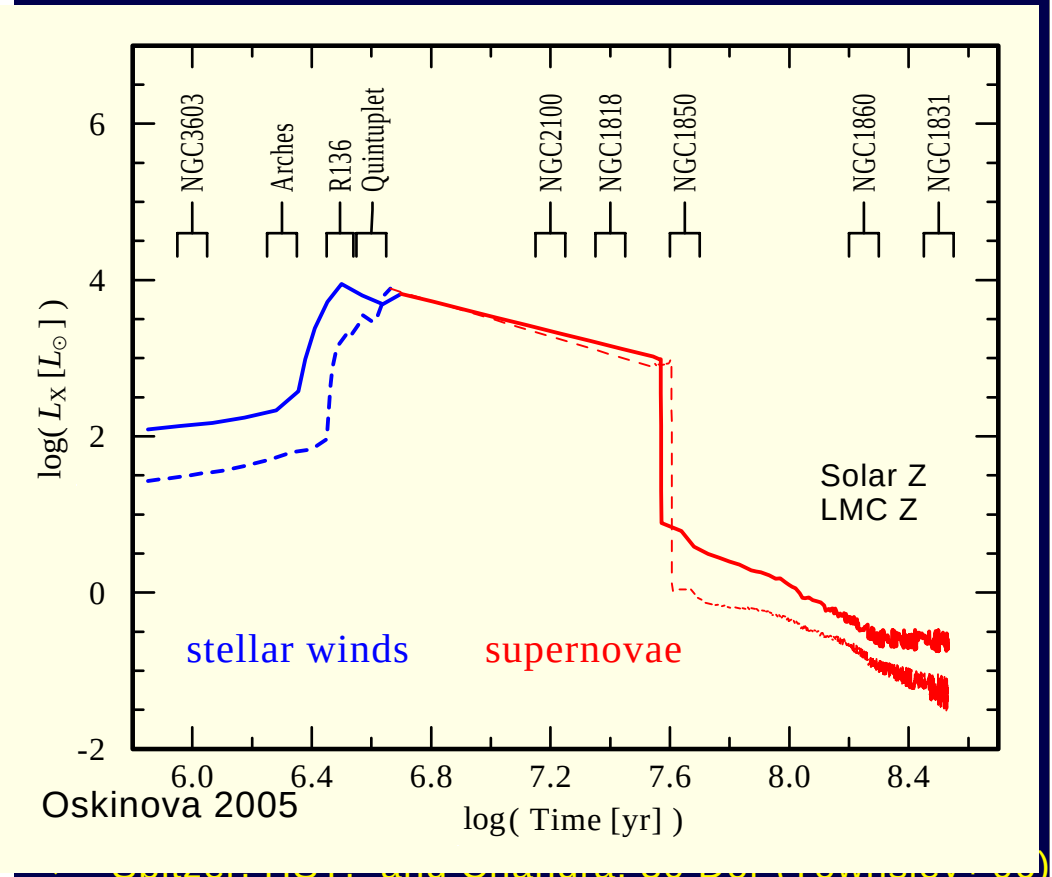
- induce matter clumping
- increase cooling
- trigger star formation

(e.g. Freyer et al. '03, Tenorio-Tagle et al. '05)

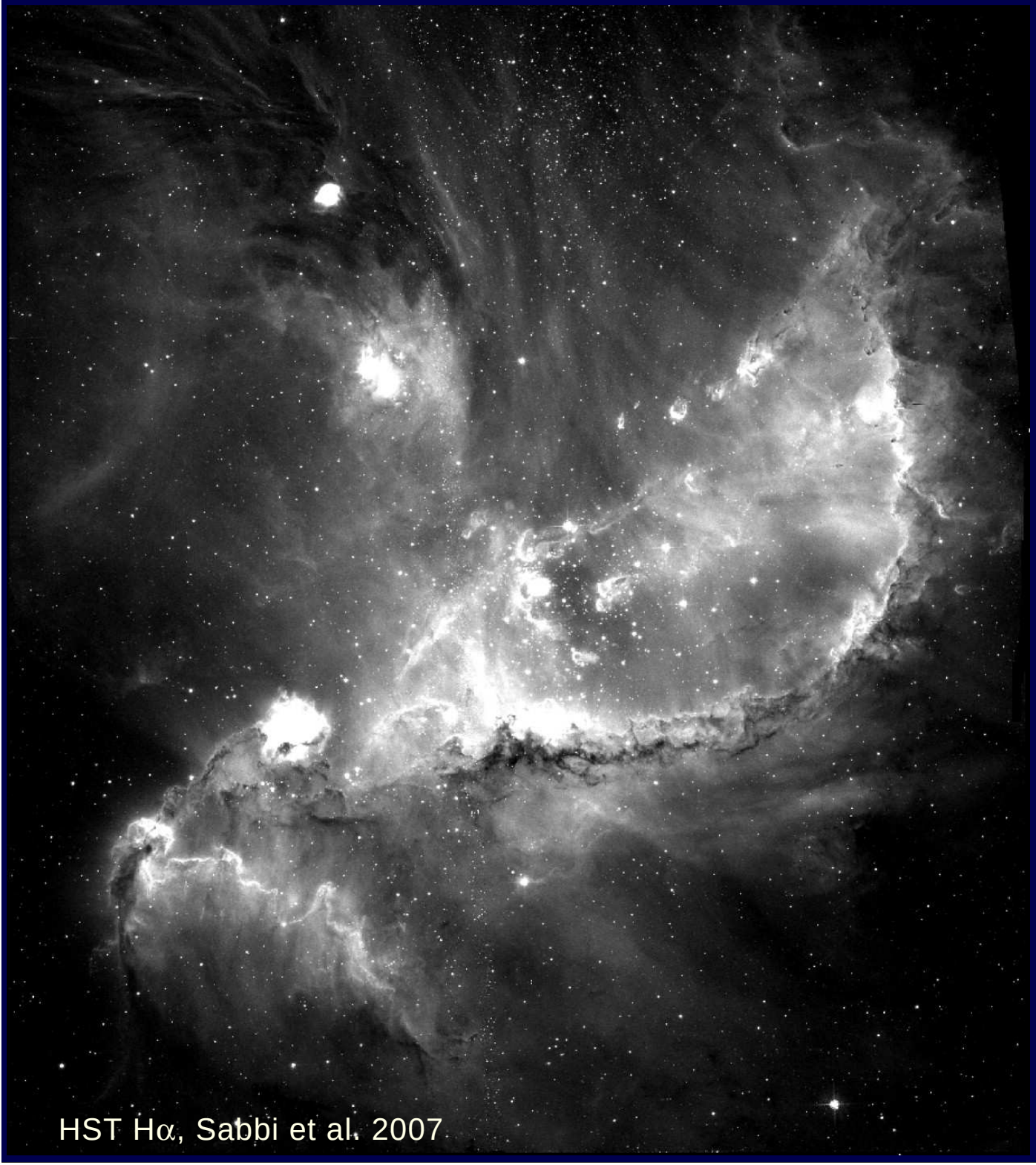
X-ray observations can be used to discriminate feedback agents



Evolution of L_X from cluster wind



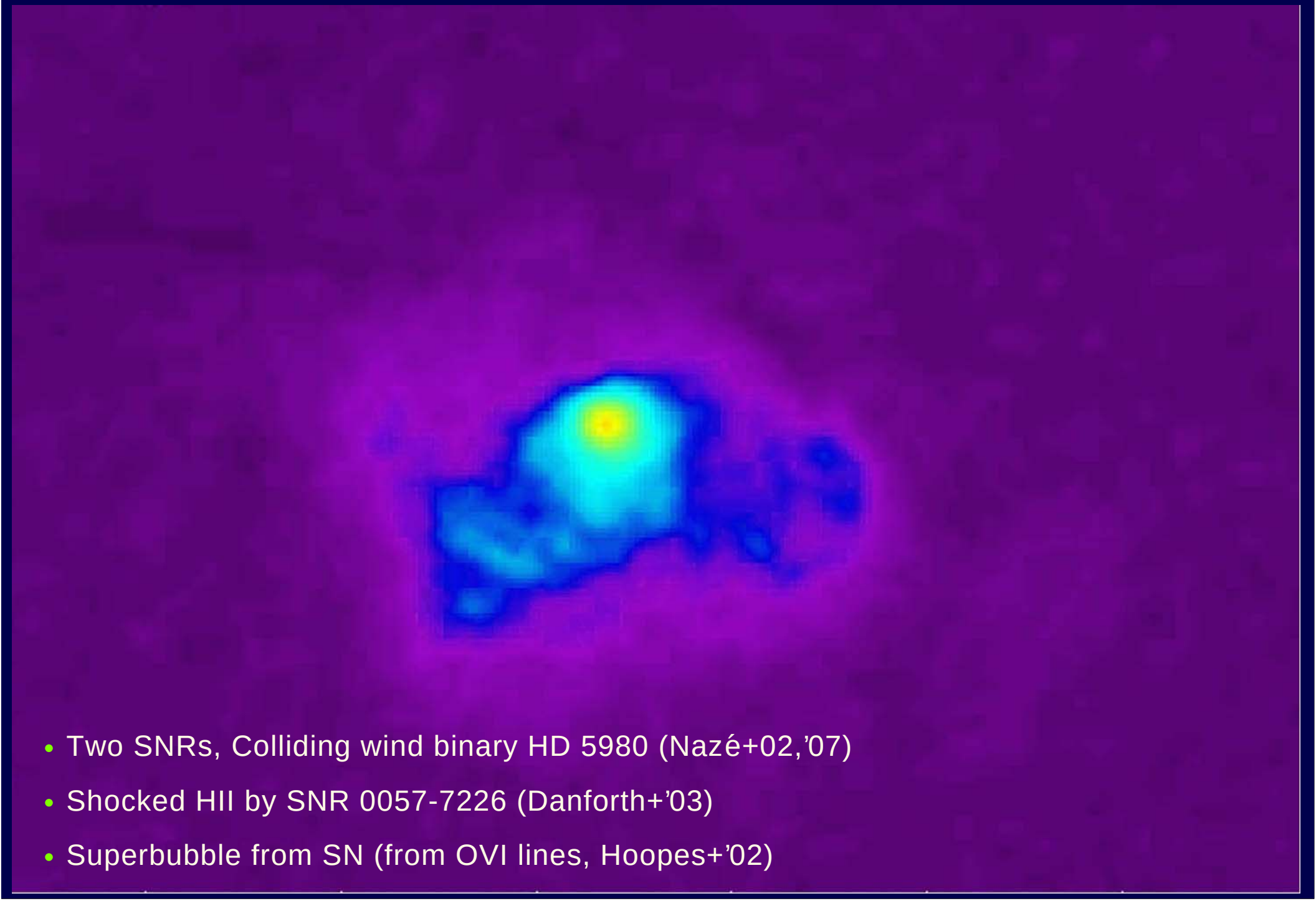
- spatial correlation of YSO and diffuse X-ray emission
- chemical gradients
- discriminate "true" diffuse X-rays from unresolved low-mass stars
- X-ray dating of low-mass stars (perhaps high-mass, too?)



NGC 346 in SMC

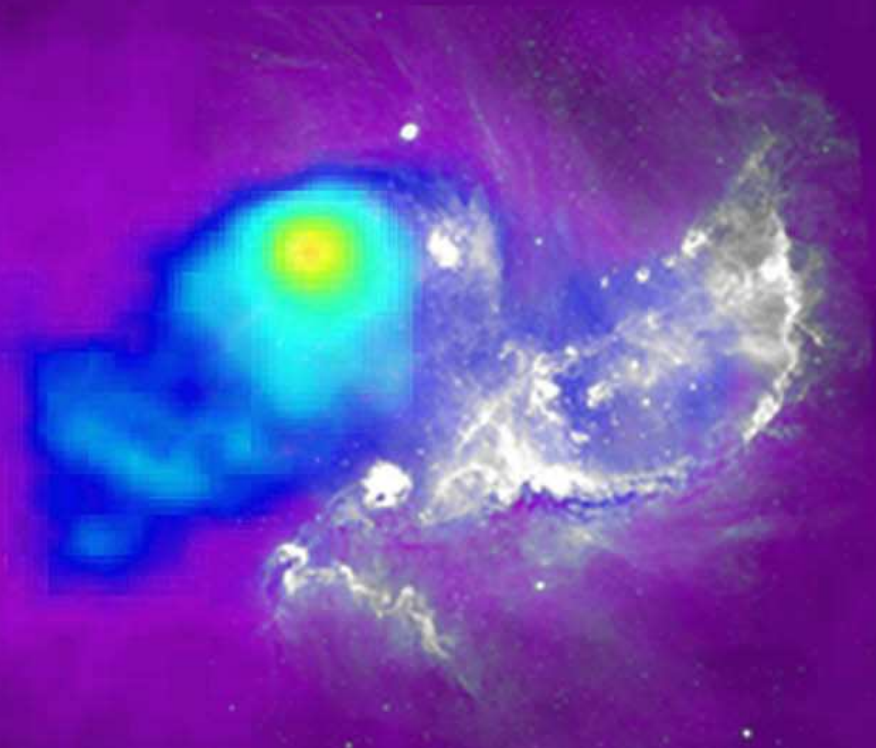
- ≈ 3 Myr old
- Largest HII region in the SMC
- Major fraction of O-stars in the SMC, LBV HD5980
- Sequential star formation (Massey+'89)
- dust and compact embedded clusters (Rubio+'00)
- triggered by the outflows of the central cluster (Walborn+'02)

XMM-Newton image of the area around NGC 346



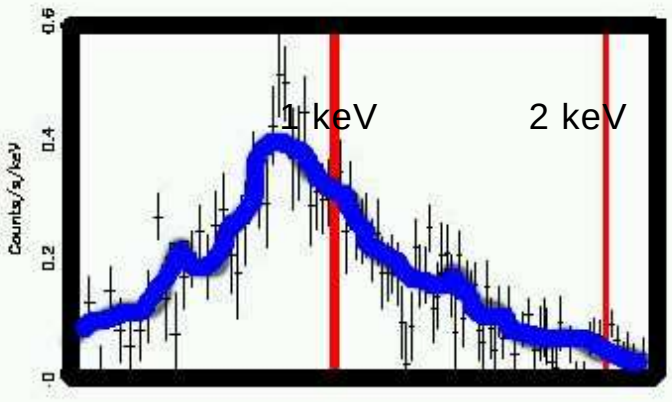
- Two SNRs, Colliding wind binary HD 5980 (Nazé+02,’07)
- Shocked HII by SNR 0057-7226 (Danforth+’03)
- Superbubble from SN (from OVI lines, Hoopes+’02)

XMM-Newton and HST images of the area around NGC 346



- Two SNRs, Colliding wind binary HD 5980 (Nazé+02,’07)
- Shocked HII by SNR 0057-7226 (Danforth+’03)
- Superbubble from SN (from OVI lines, Hoopes+’02)

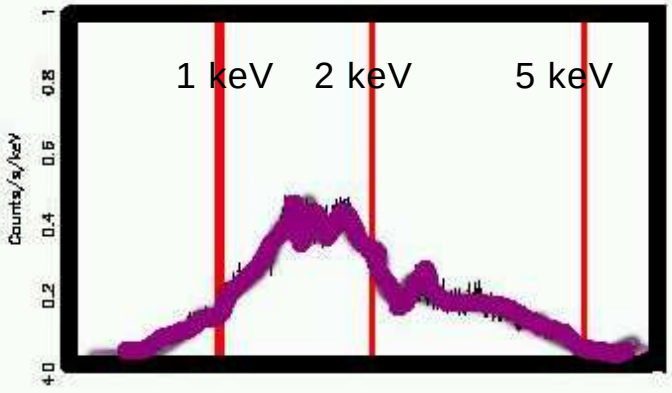
Diffuse emission vs. unresolved sources. Role of XMM-Newton



M17 (Townsley et al. '06)

Top → diffuse

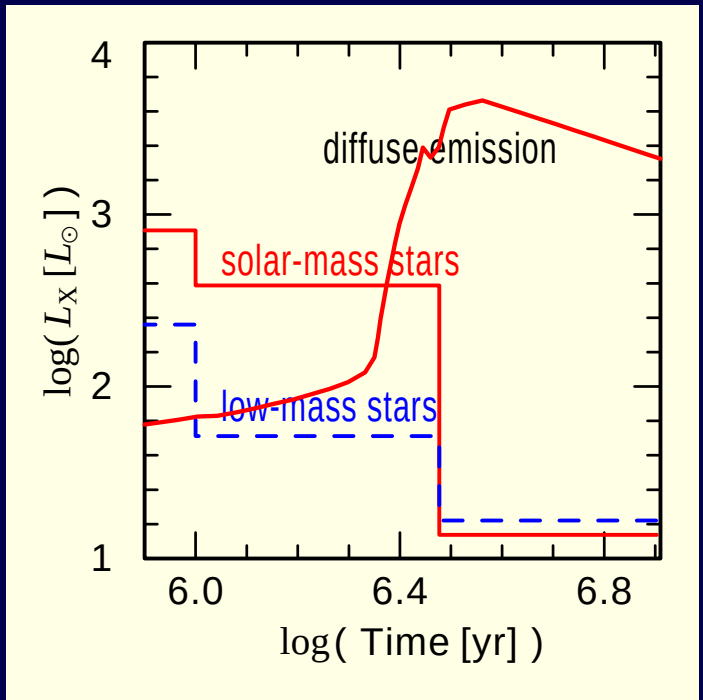
Bottom →point sources



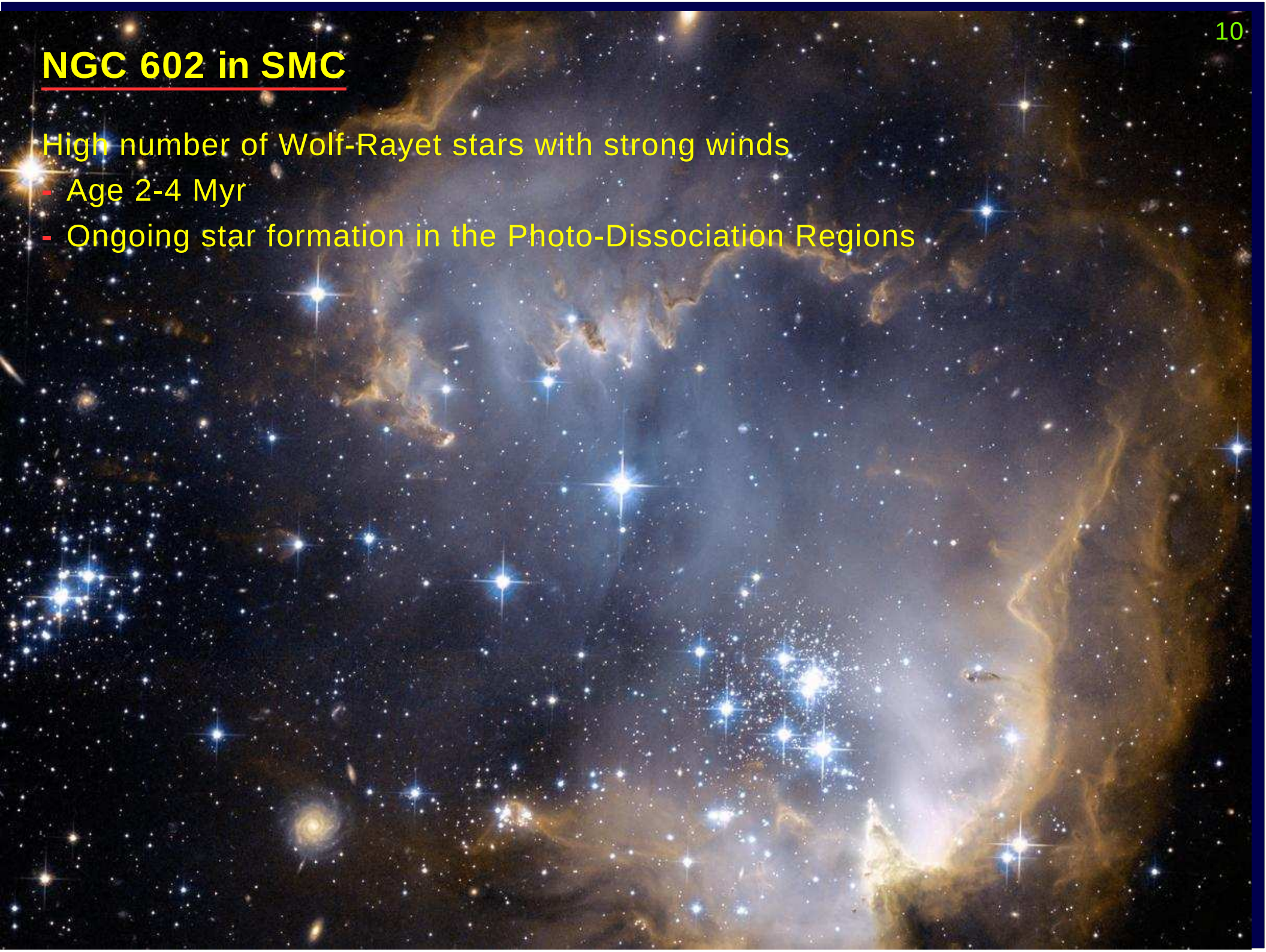
Never 100 per cent sure

- Chandra: SFRs in the Galaxy
- Resolved diffuse emission
- YSO: harder spectrum
- Flaring
- Activity declines with age
- Spatial distribution
- Large work done (see Townsley+'06)

- Individual sources in SFR cannot be resolved in other galaxies
- XMM-Newton: soft response; high sensitivity
- large field of view; Imaging spectroscopy



NGC 602 in SMC



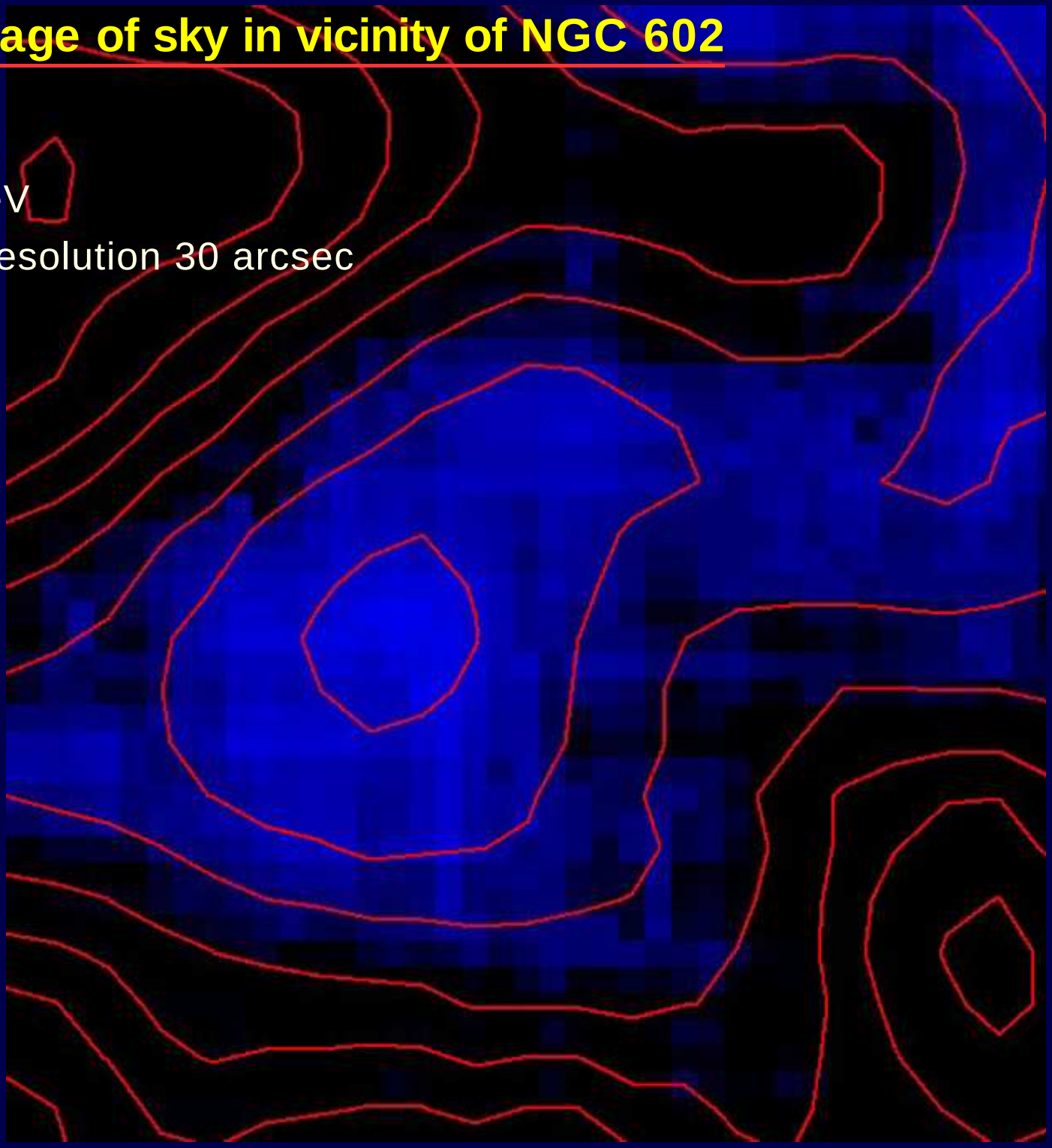
High number of Wolf-Rayet stars with strong winds

- Age 2-4 Myr
- Ongoing star formation in the Photo-Dissociation Regions

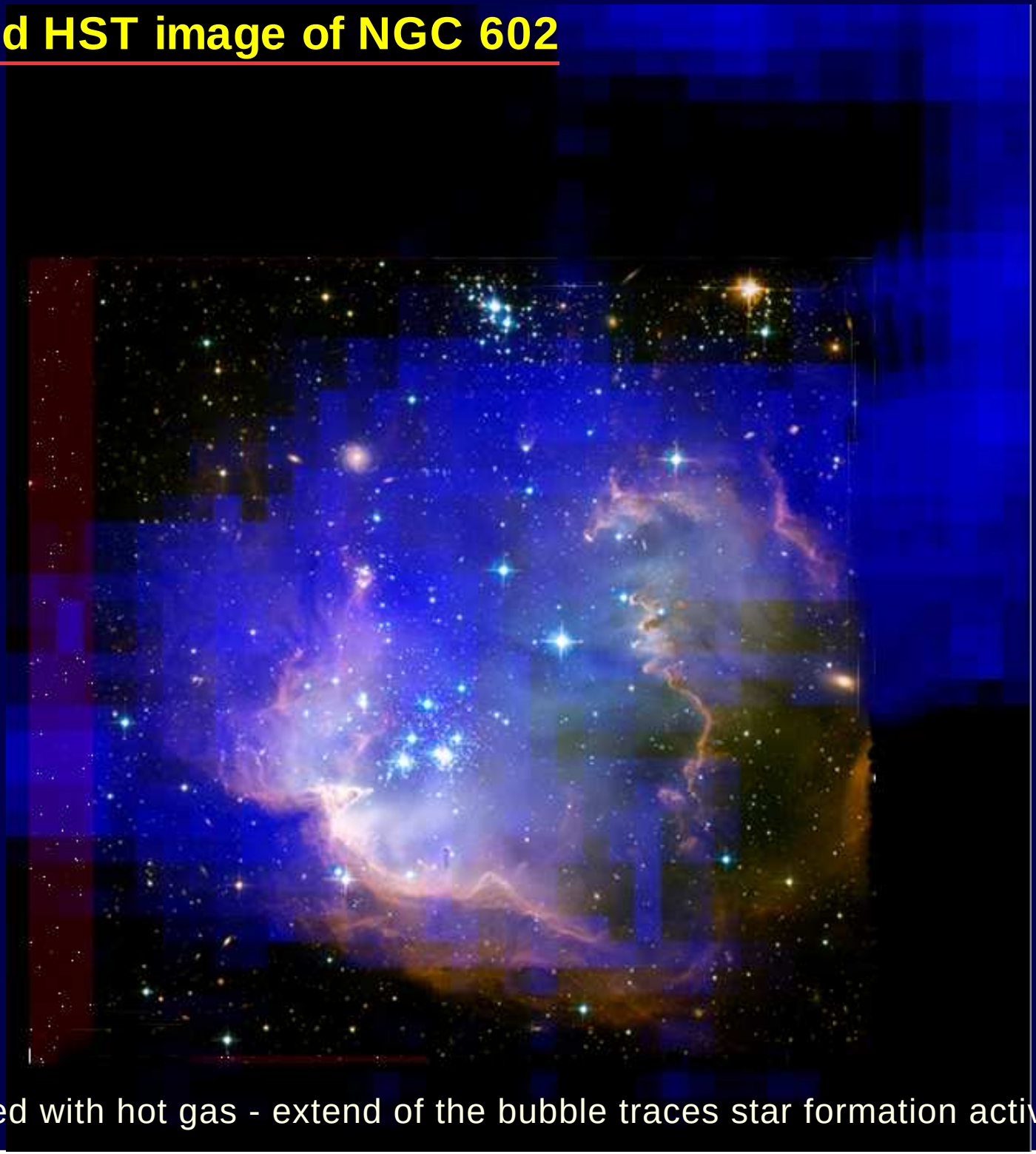
ASCA image of sky in vicinity of NGC 602

ASCA SIS:

- 0.4-12 keV
- angular resolution 30 arcsec



ASCA and HST image of NGC 602



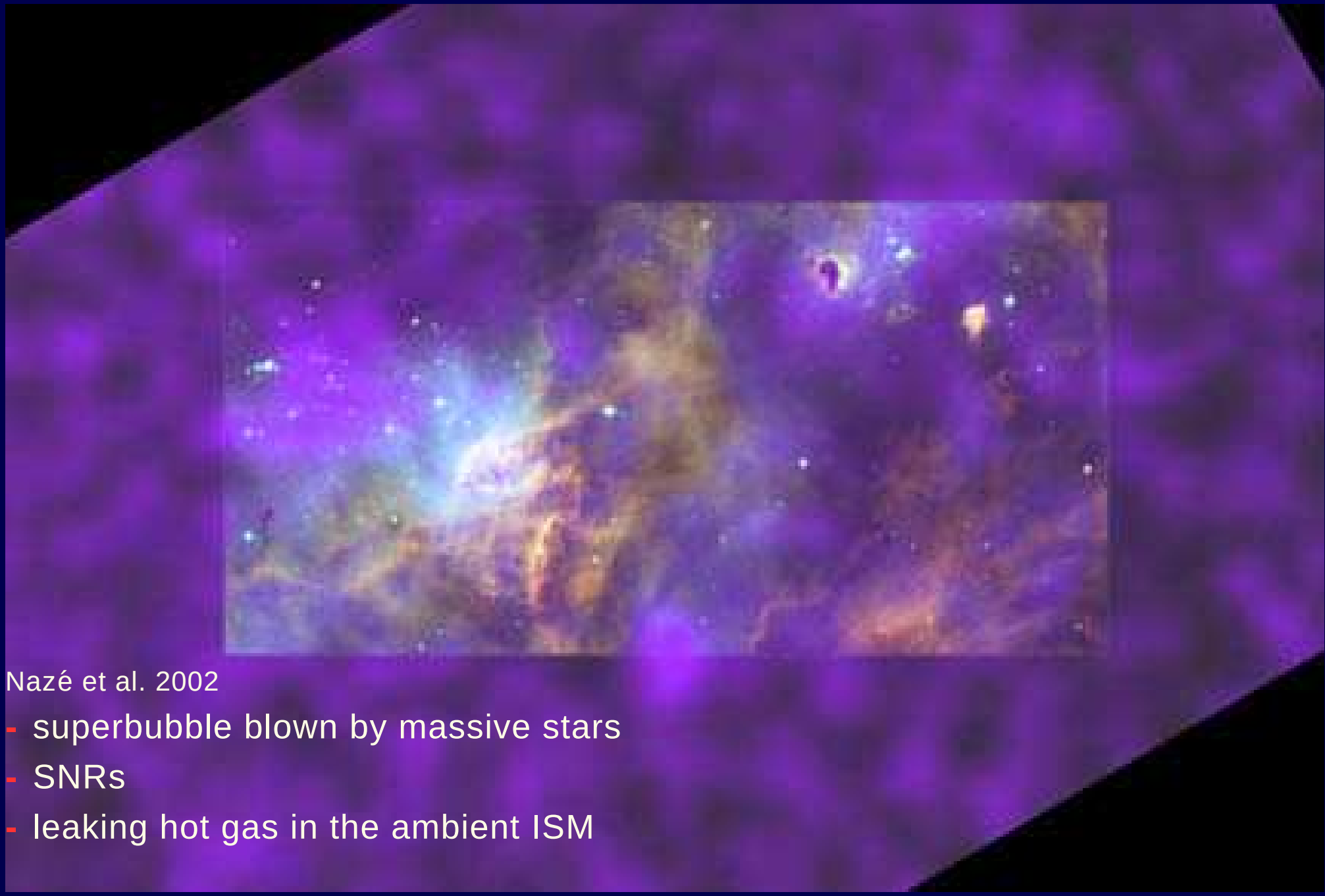
NGC 602: filled with hot gas - extend of the bubble traces star formation activity **Oskinova+ '07**

NIIB in the Large Magellanic Cloud

Hubble Heritage

...a perfect case of sequential star formation

XMM-Newton and HST image of LMC N11B



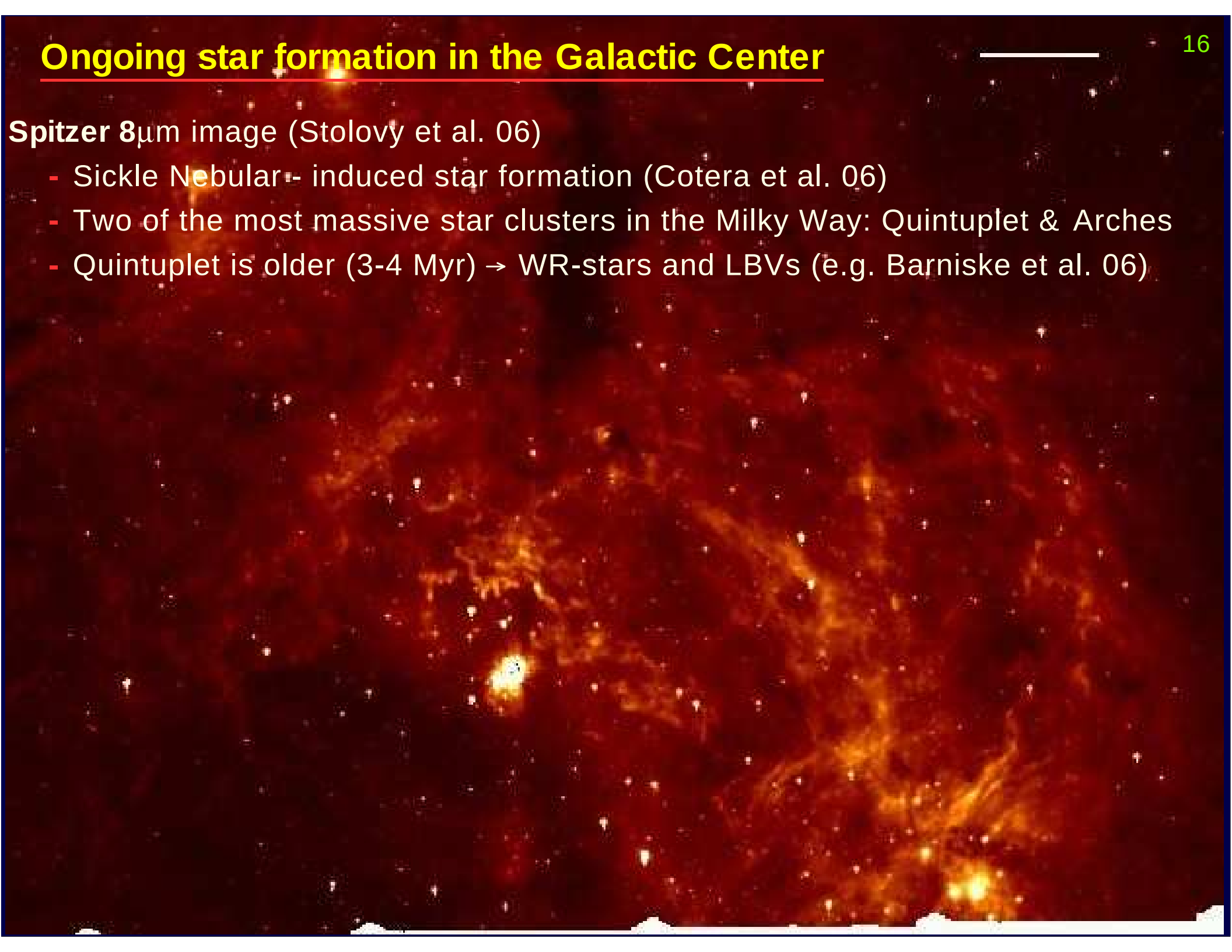
Nazé et al. 2002

- superbubble blown by massive stars
- SNRs
- leaking hot gas in the ambient ISM

Ongoing star formation in the Galactic Center

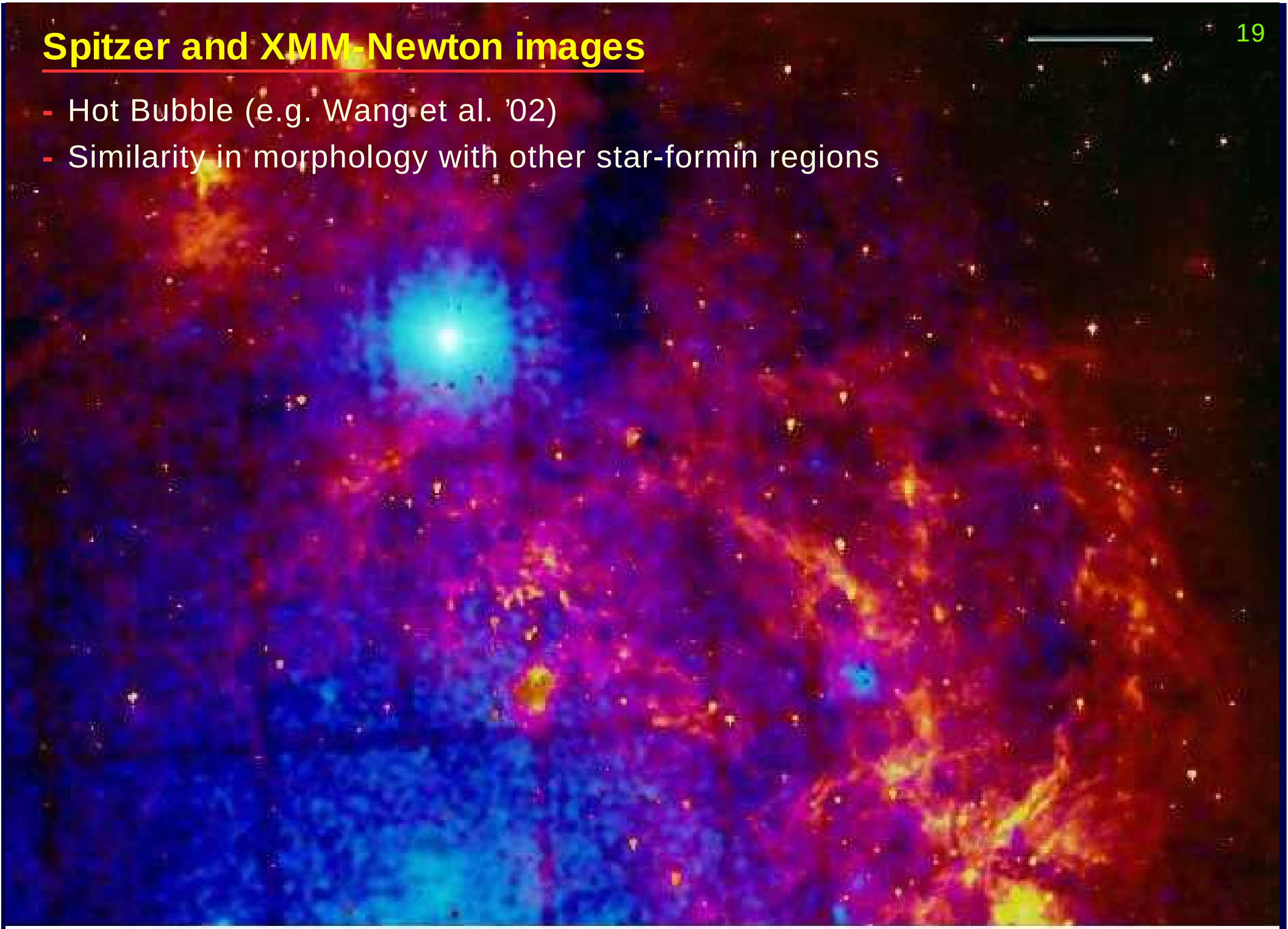
Spitzer 8μm image (Stolovy et al. 06)

- Sickle Nebular - induced star formation (Cotera et al. 06)
- Two of the most massive star clusters in the Milky Way: Quintuplet & Arches
- Quintuplet is older (3-4 Myr) → WR-stars and LBVs (e.g. Barniske et al. 06)



Spitzer and XMM-Newton images

- Hot Bubble (e.g. Wang et al. '02)
- Similarity in morphology with other star-formin regions



Conclusions & Future with XMM-Newton

- X-ray emission provides tool
  to distinguish between different feedback agents
- XMM-Newton is especially apt to observe faint diffuse emission
- Unresolved low-mass stars population
  can be distinguished spectroscopically
- Mechanic energy and mass input
  cannot be neglected in star-formation models