Lidia Oskinova

Escape of Ly radiation from stochastic medium

Orion Nebula ESO/Hawk

We have a problem with $\langle f_{esc} \rangle$

Universe spent more ph than can be accounted for

Reducing opacity

Increasing output

Finding new sources

OB-type stars

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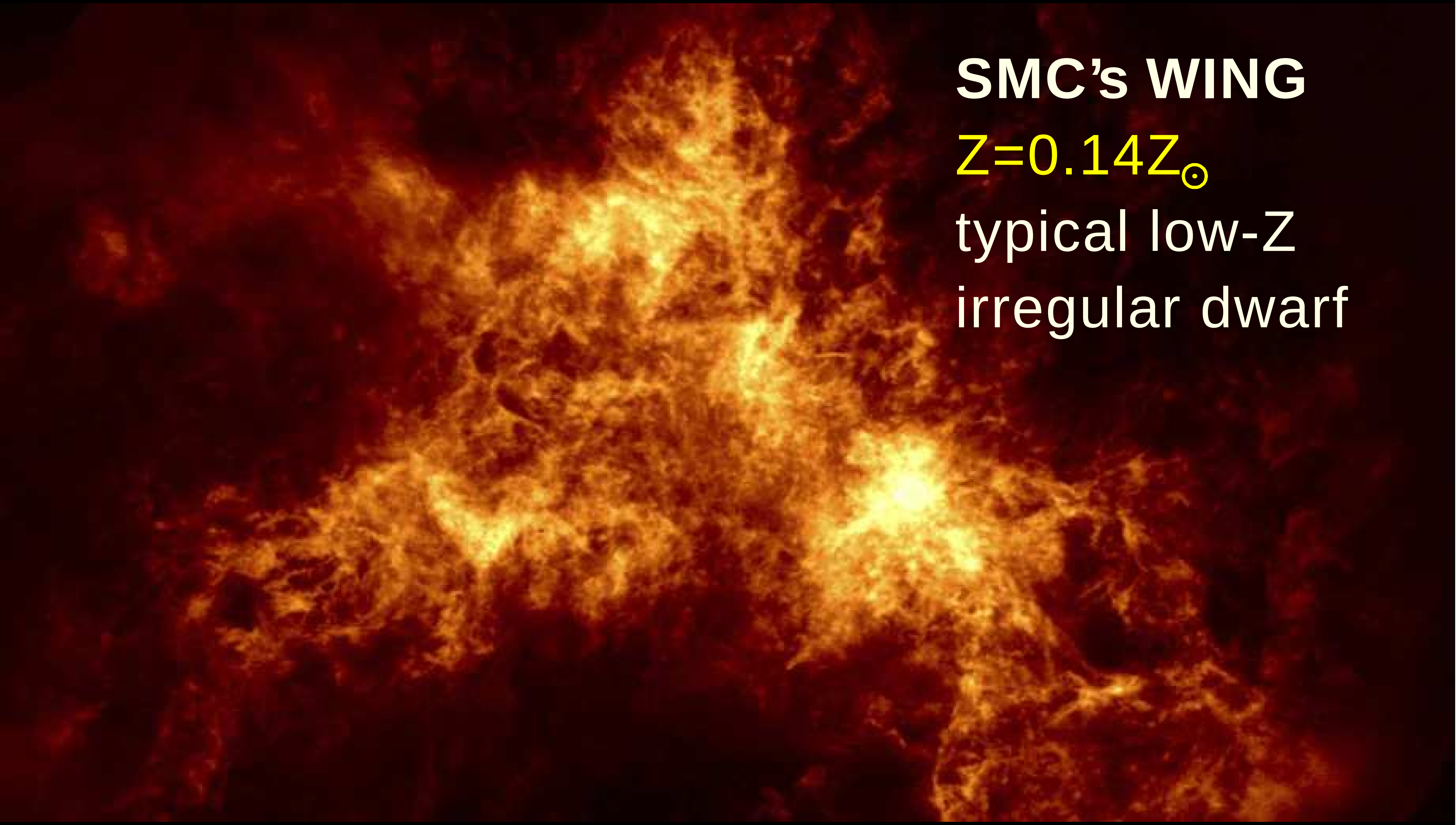
Double check: is there a problem?



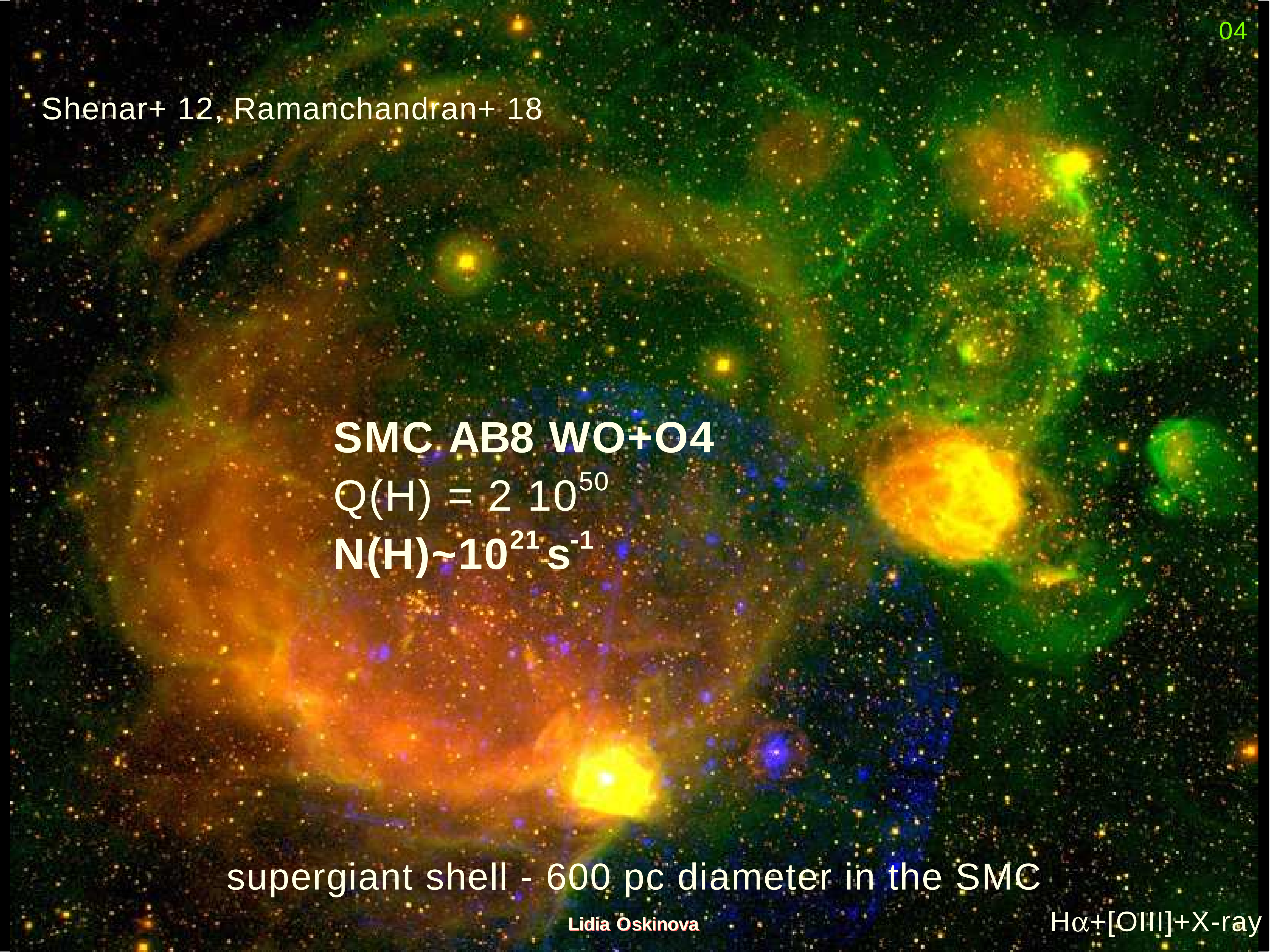
SMC's WING

$Z=0.14Z_{\odot}$

typical low-Z

irregular dwarf

Credit: The Australian Square Kilometre Array Pathfinder, Australian National University


Shenar+ 12, Ramanchandran+ 18
SMC AB8 WO+O4
Q(H) = 2 10^50
N(H)~10^21 s^-1
supergiant shell - 600 pc diameter in the SMC
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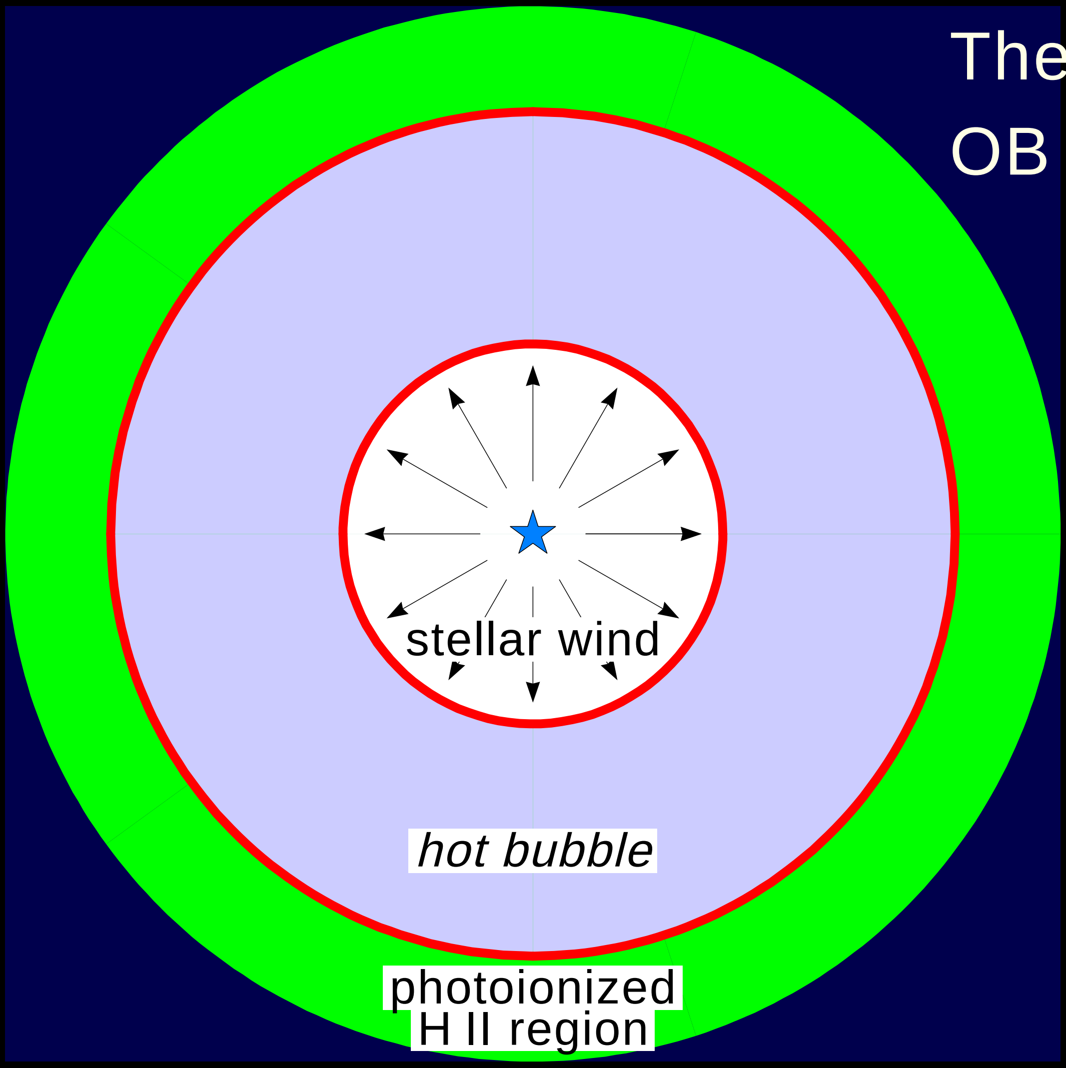
Hα+[OIII]+X-ray

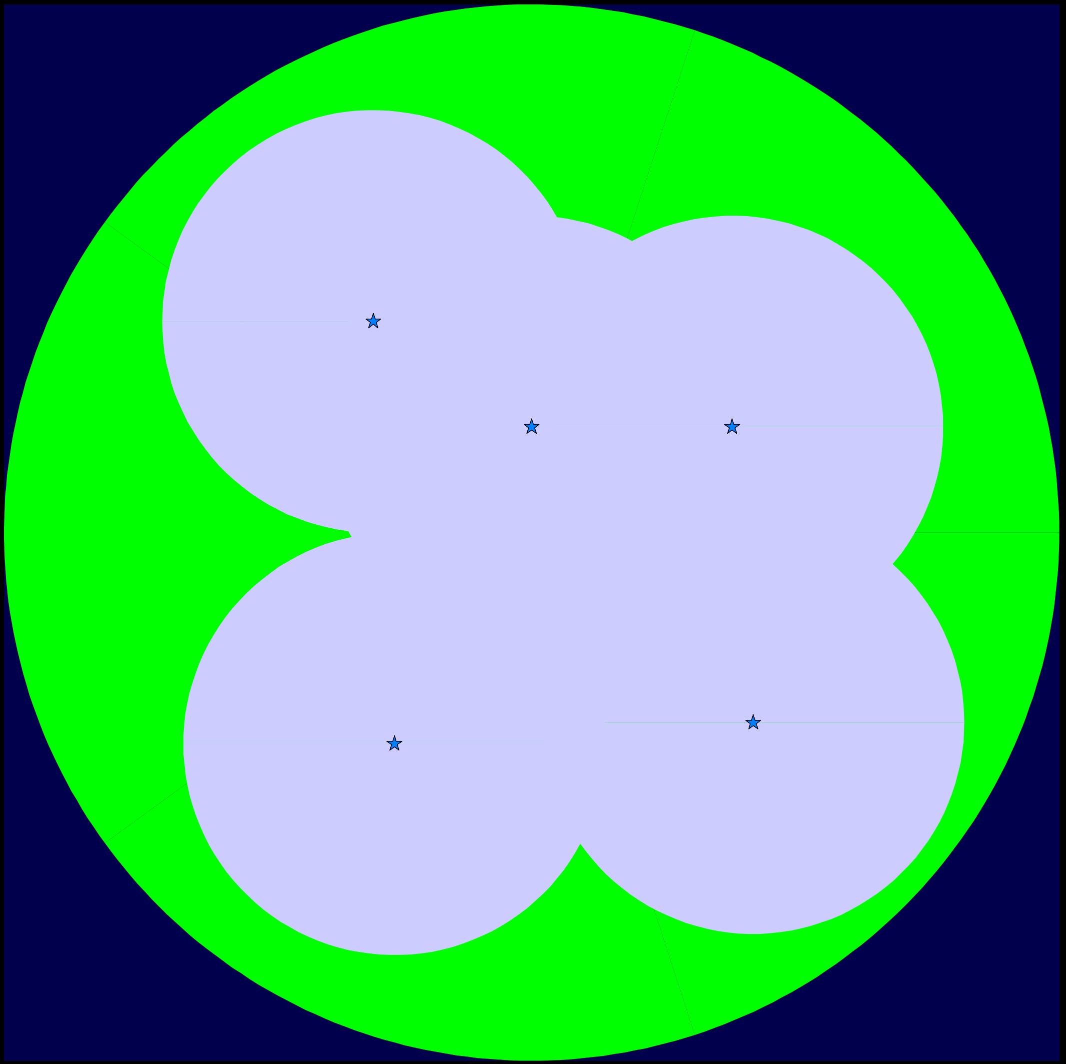

O3V star Q(H)=10^{49} s^{1}
N(HI)=2e21cm^{-1}
QSO z=2.43
N(HI)=2e21cm^{-1}
Credit: HST/ESA, A. Nota
Even SMC Wing: too high N(H)

Reducing opacity: bubbles → superbubble

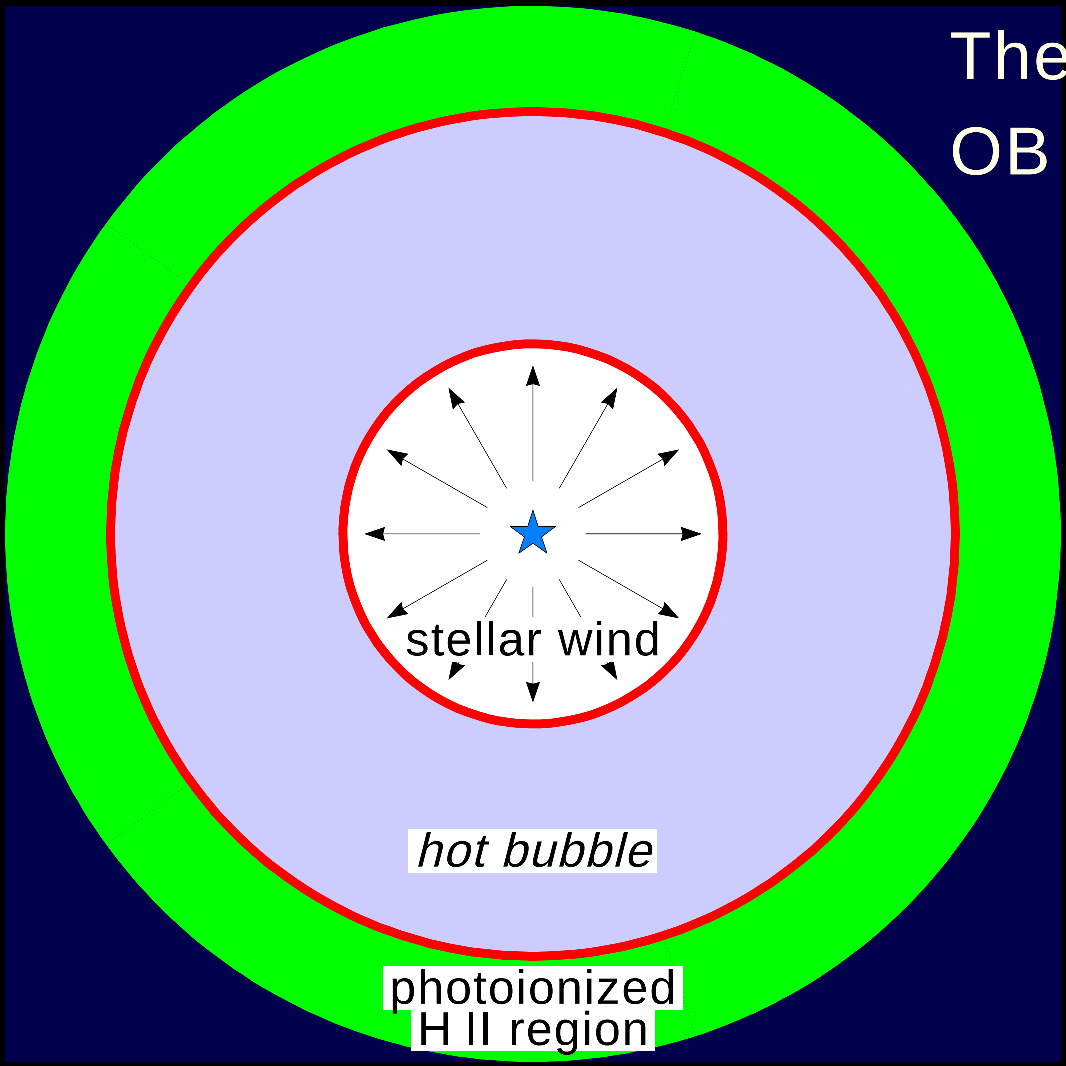
The escape of ionizing photons from OB associations (Dove+ 00)

Superbubble shells attenuate ionizing photons



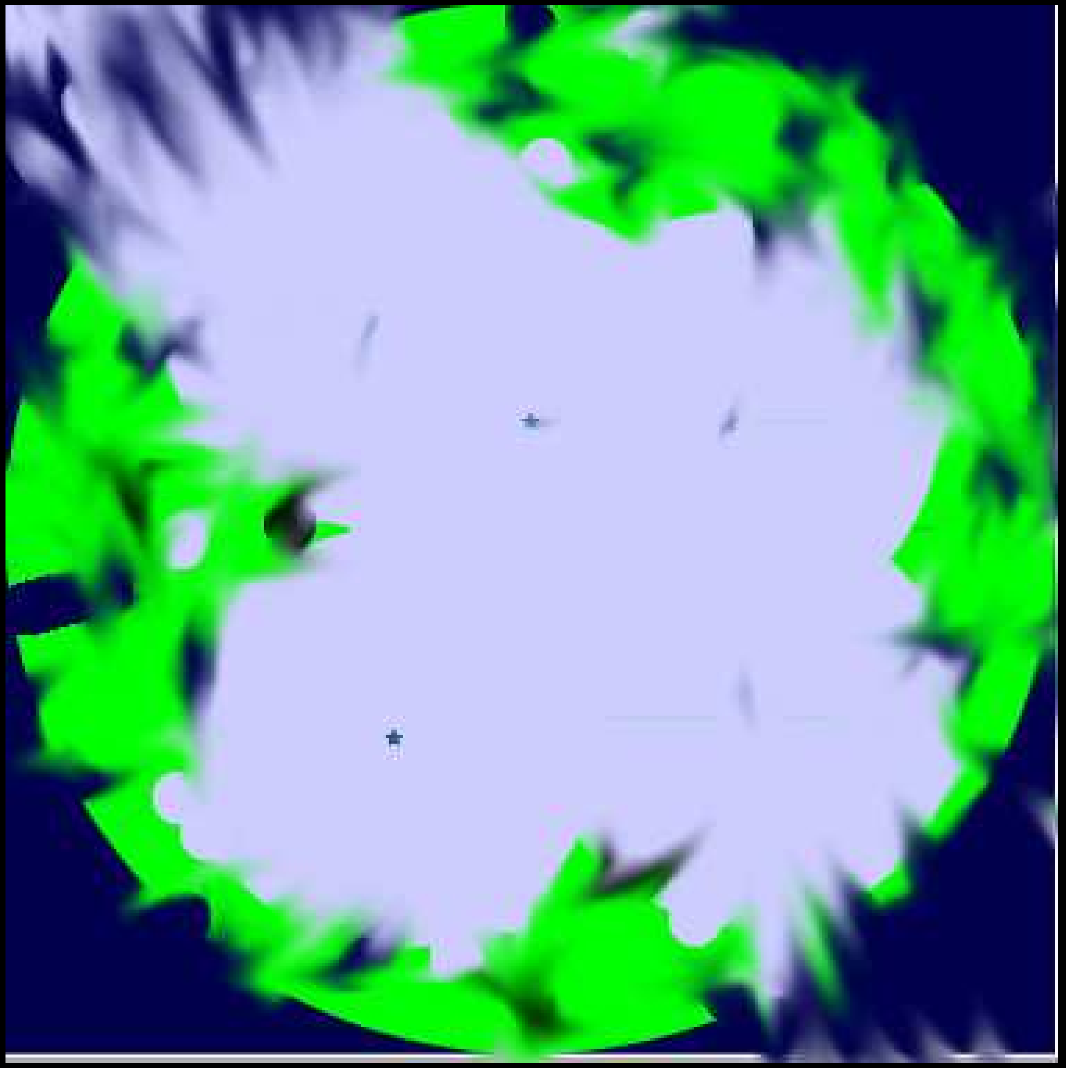


Reducing opacity: bubbles → superbubble



The escape of ionizing photons from OB associations (Dove+ 00)

Superbubble shells attenuate ionizing photons

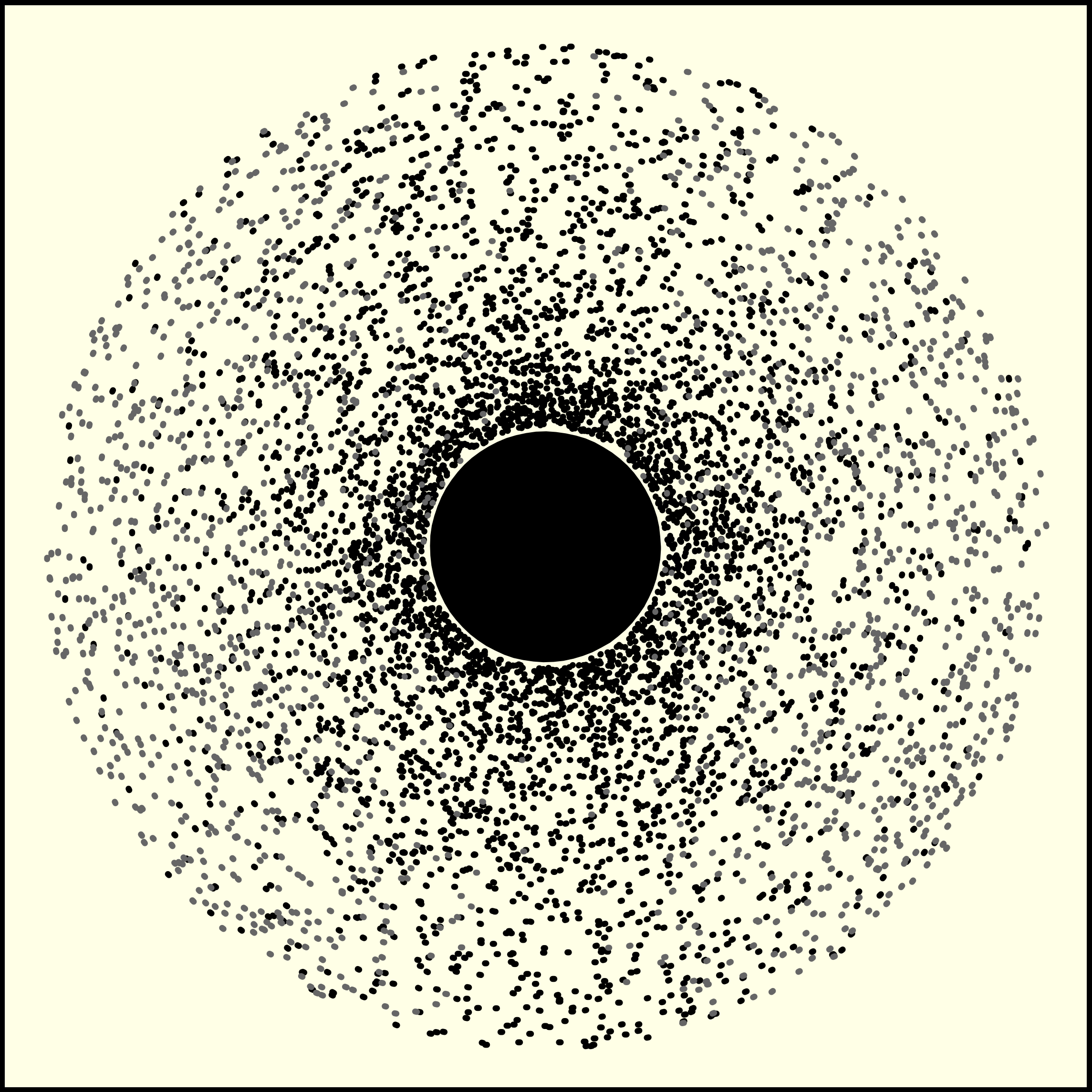


Clumpy shells

Blowouts

Reducing opacity: stochastic medium & porosity

3-D stochastic radiative transfer (Oskinova etal 2004, 2-D)



Effective opacity: the product of

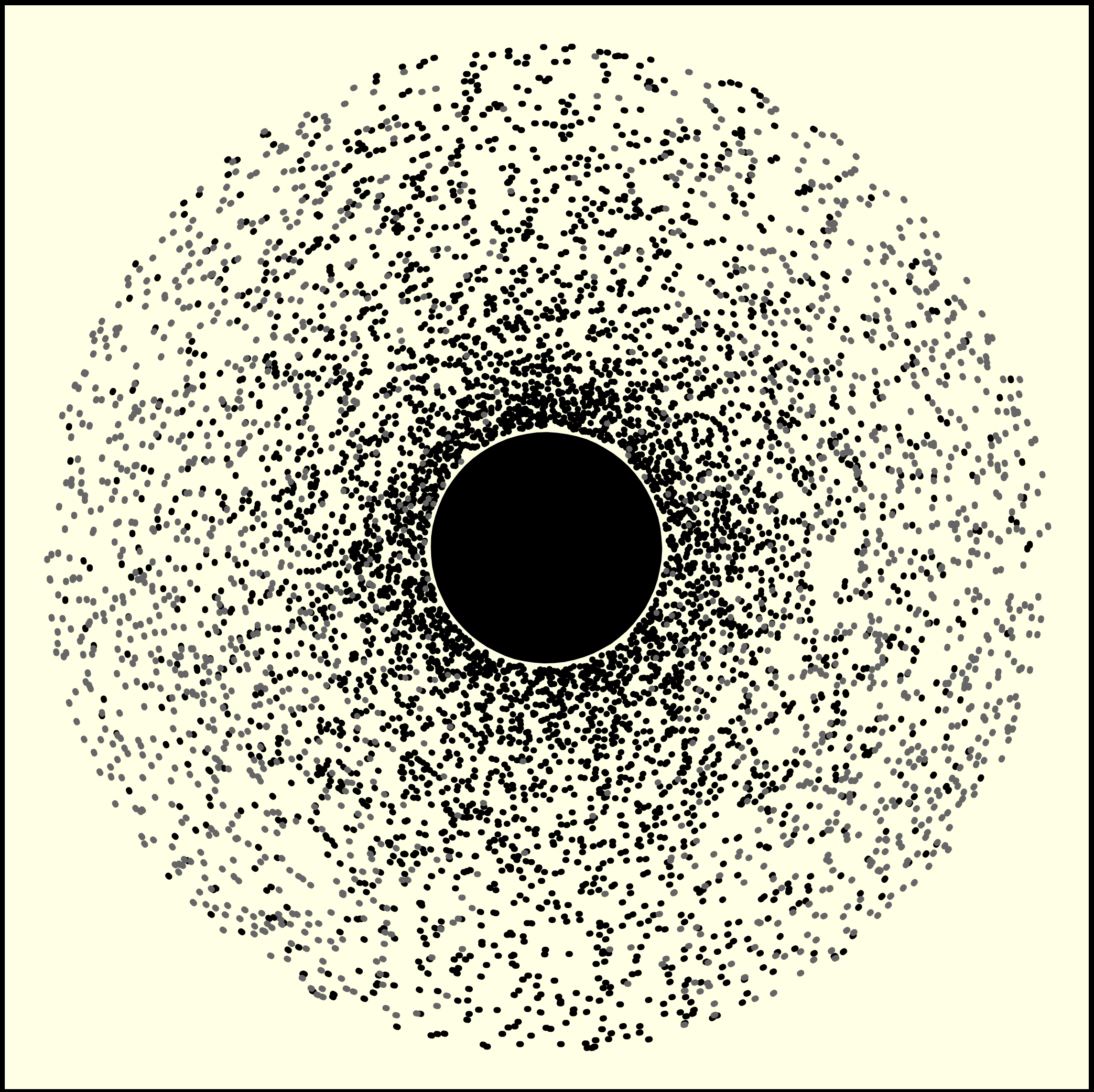
- number of clumps per V

  $n(r)/r^2$ [cm^{-3}]

$$\kappa_{\rm eff} = n(r)r^{-2}.$$

Reducing opacity: stochastic medium & porosity

3-D stochastic radiative transfer (Oskinova etal 2004, 2-D)



Effective opacity: the product of

- number of clumps per V

  $n(r)/r^2$ [cm^{-3}]

- cross section of clumps

  σ [cm^2]

$$\kappa_{\text{eff}} = n(r)r^{-2} \cdot \sigma \cdot$$

Reducing opacity: stochastic medium & porosity

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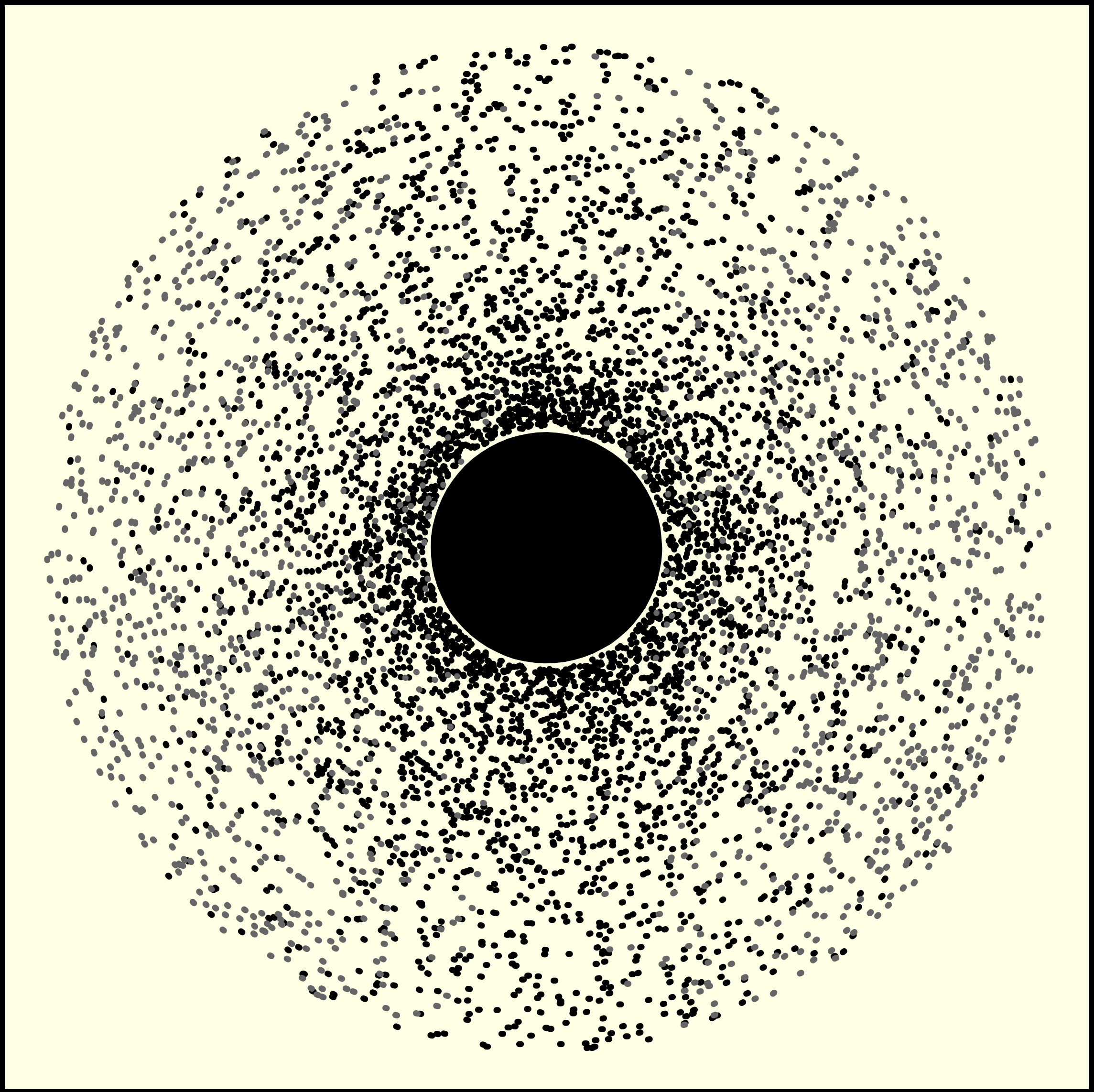


Effective opacity: the product of

- number of clumps per V

  $n(r)/r^2$ [cm^{-3}]

- cross section of clumps

  σ [cm^2]

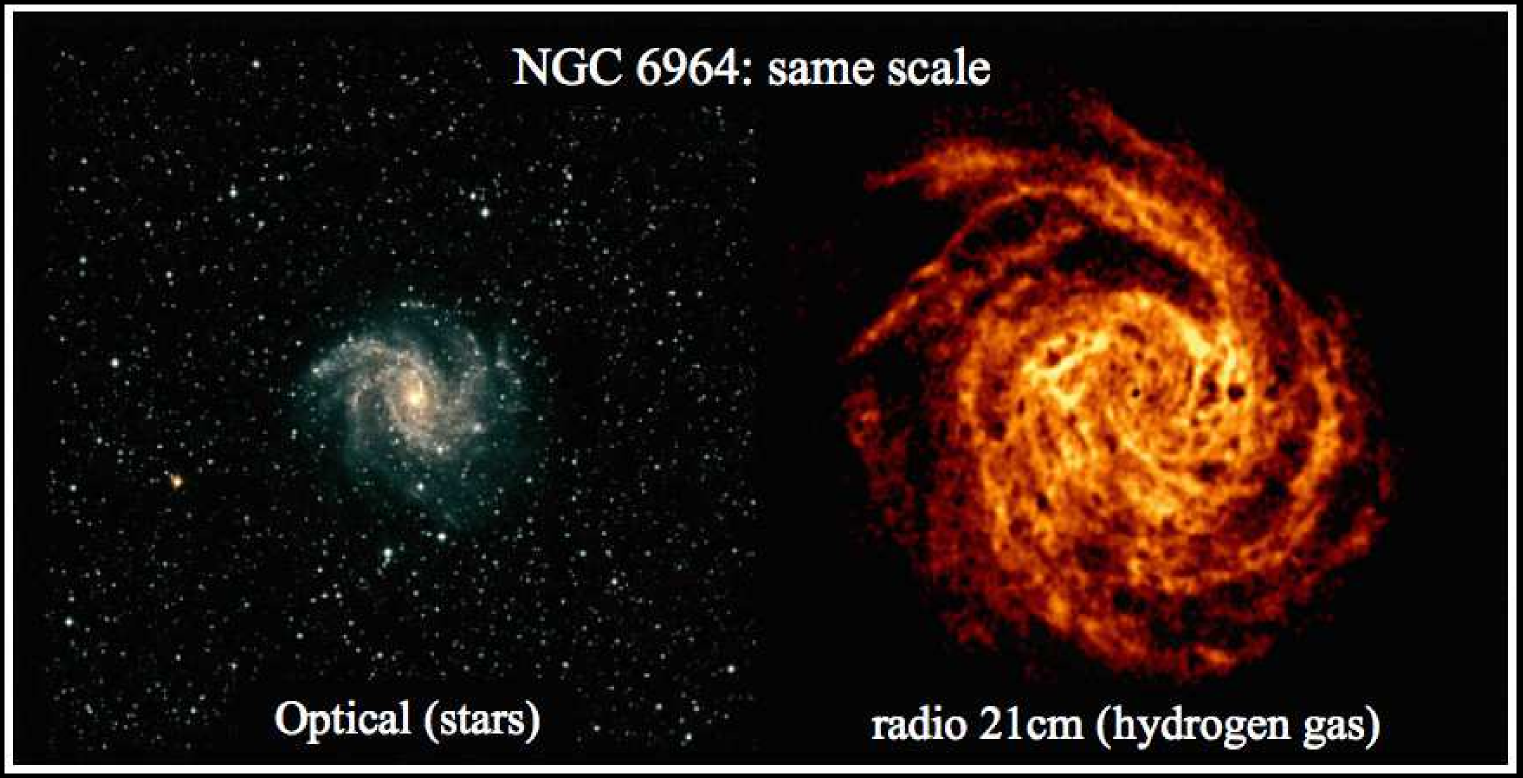
- probability that a photon which hits a clump is absorbed

  $(1 - e^{-\tau_{\rm clump}})$

- optical depth = integral over effective opacity

$$\kappa_{\rm eff} = n(r) r^{-2} \cdot \sigma \cdot (1 - e^{-\tau_{\rm clump}})$$

Reducing opacity: stochastic medium



Assuming: 1) average opacity at Ly edge $\chi = 10$ pc^{-1}

2) a clump is on average 100 times denser

clumps with size > 0.01 pc are opitcally thick

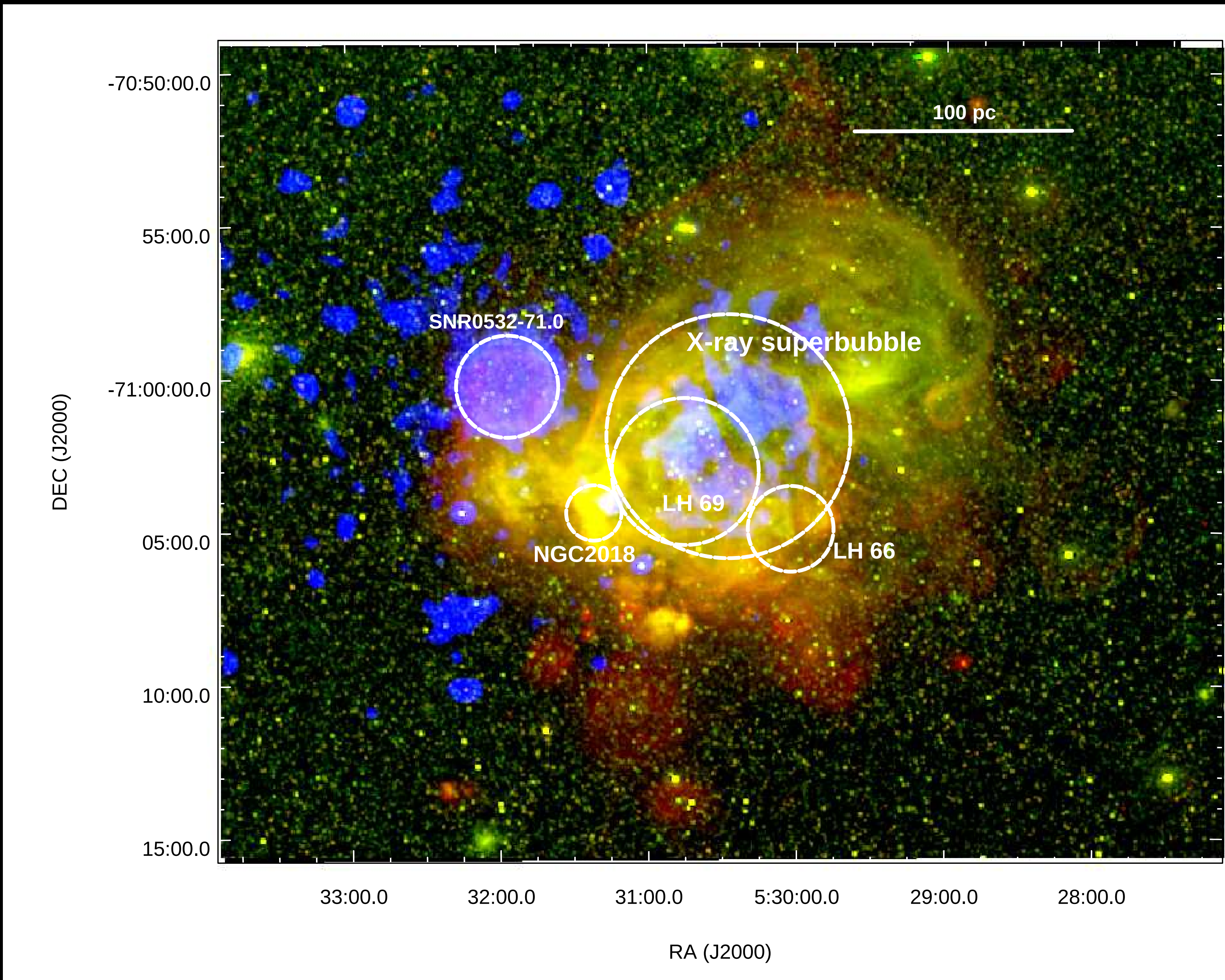
Effective opacity depends only on geometrical distribution of clumps

It becames small if the clump filling factor is small (how realistic?)

Blowouts!

Reducing opacity: feedback from massive stars

The complex LMC-N206 Ramachandran et al. (2017, 2018)

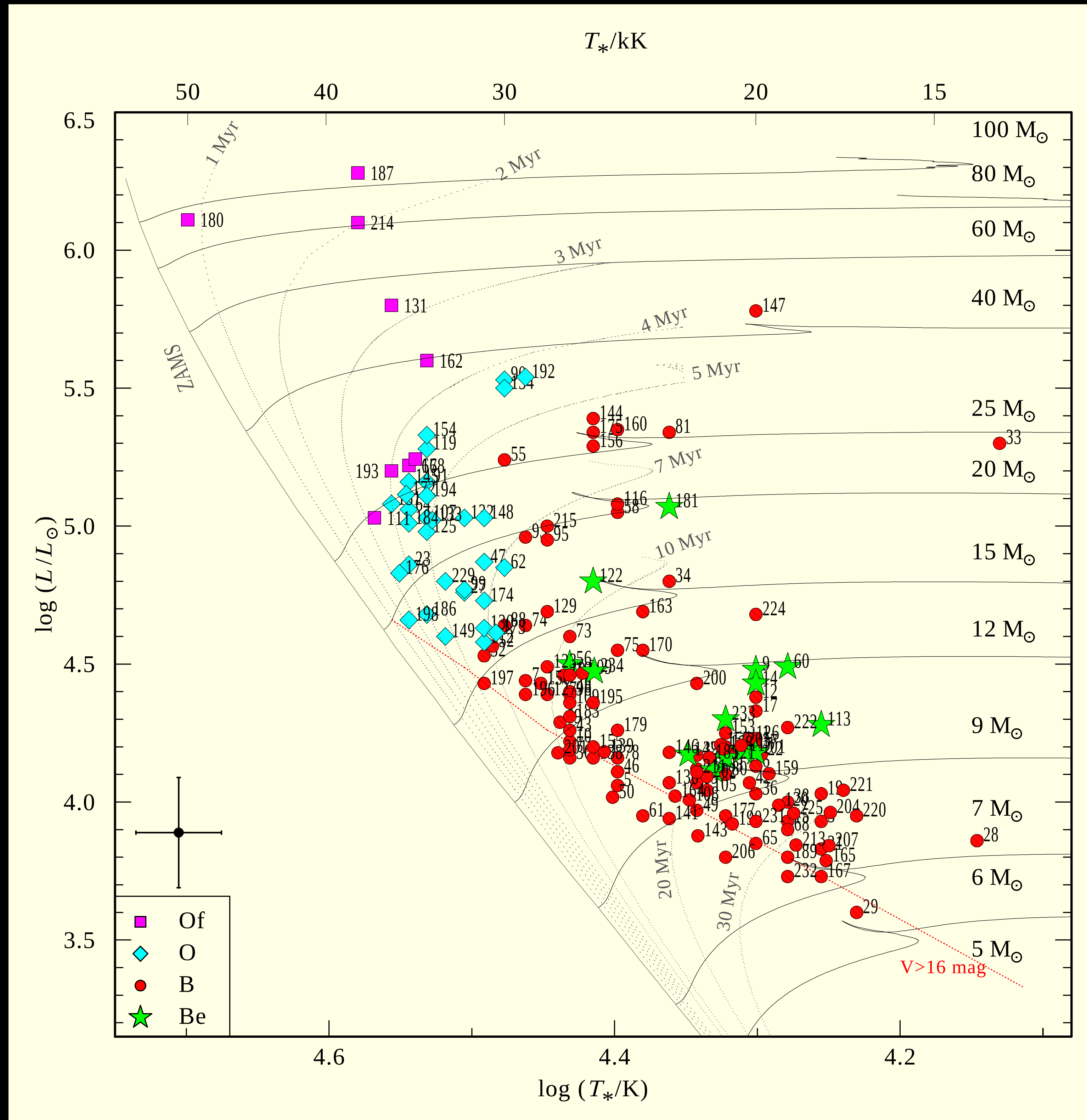


- SFR = 0.002 $M_\odot$/yr
- Cavity filled with X-rays (blue)
- H II region: Hα (red), [O III] (green)
- Young clusters / associations

LMC-N206 complex: HRD of the massive-star population (V < 16 mag)

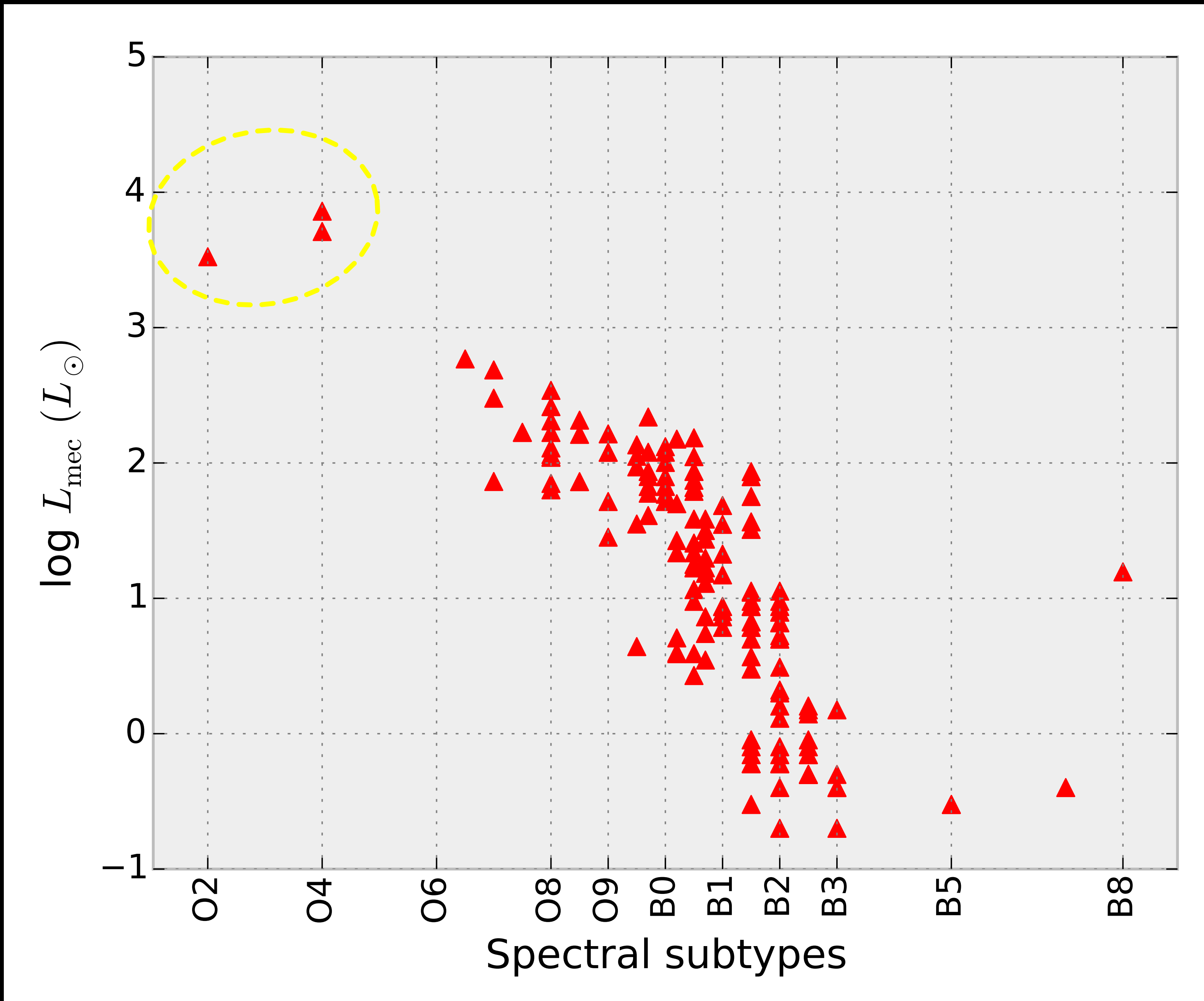
Tracks and isochrones from (Brott et al. 2011, Köhler et al. 2015)

- Massive stars are *not* co-eval
- Ages spread from 0 - 30 Myr
- 3 stars with log L > 6 are the youngest (<5 Myr) and most massive (60 - 80 $M_\odot$)



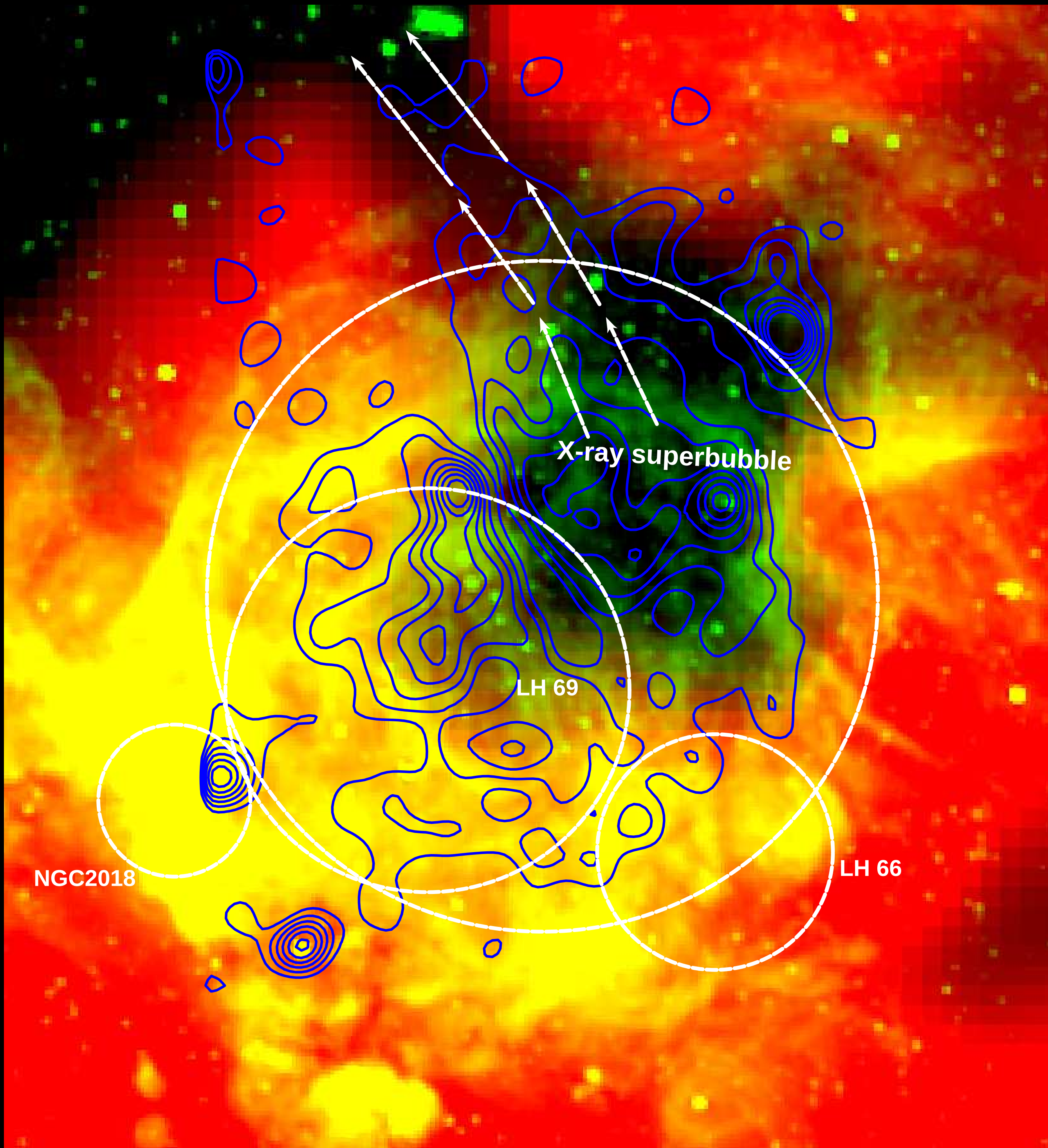
Stellar-winds feedback: mechanic energy and momentum

Mechanical energy input by the winds: $L_{\rm mec} = \frac{1}{2}\Sigma_i \dot{M}_i v_i^2$



- **50%** from the **two WR stars**
- **30%** from **three earliest O stars**
- Long-time average: **comparable feedback from SNe (rate 2.2 Myr^{-1})**

Reducing opacity: OB associations creating chimneys



Energy stored in
- X-ray gas (E.M. and T_X)
- E_{kin} of Hα shells and H I

~5 10^{51} erg

(Kavanagh et al. 2012)

Mechanical energy from stellar winds and SNe, accumulated over 30 Myr: **higher by factor ~15 !**

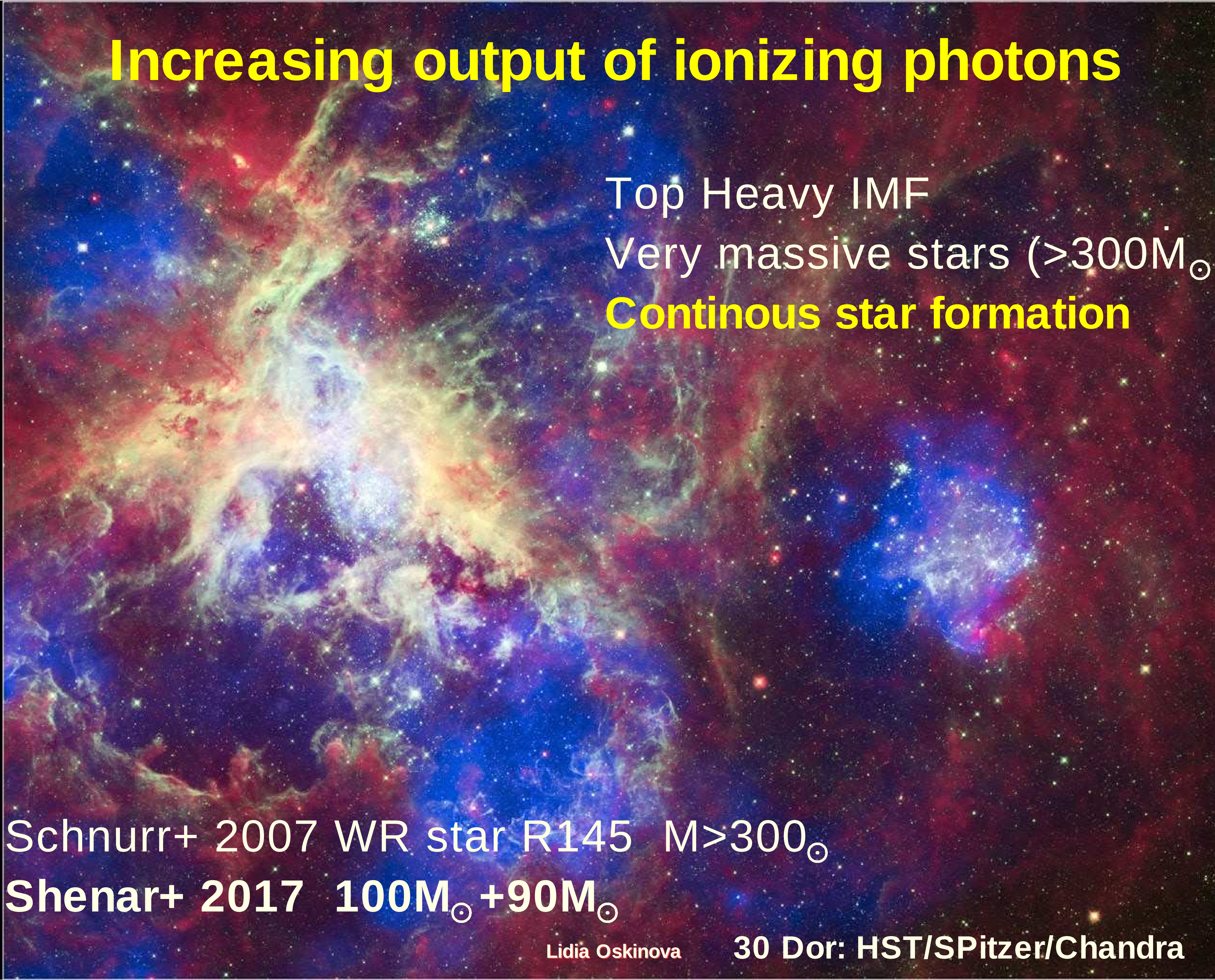
Energy sinks:
- radiative cooling: negligible
- Mass loading and turbulent mixing
- **Leakage of hot gas and UV photons**

Increasing output of ionizing photons

Top Heavy IMF

Very massive stars (>300$M_\odot$)

Continous star formation



Schnurr+ 2007 WR star R145 M>300$_\odot$

Shenar+ 2017 100$M_\odot$+90$M_\odot$

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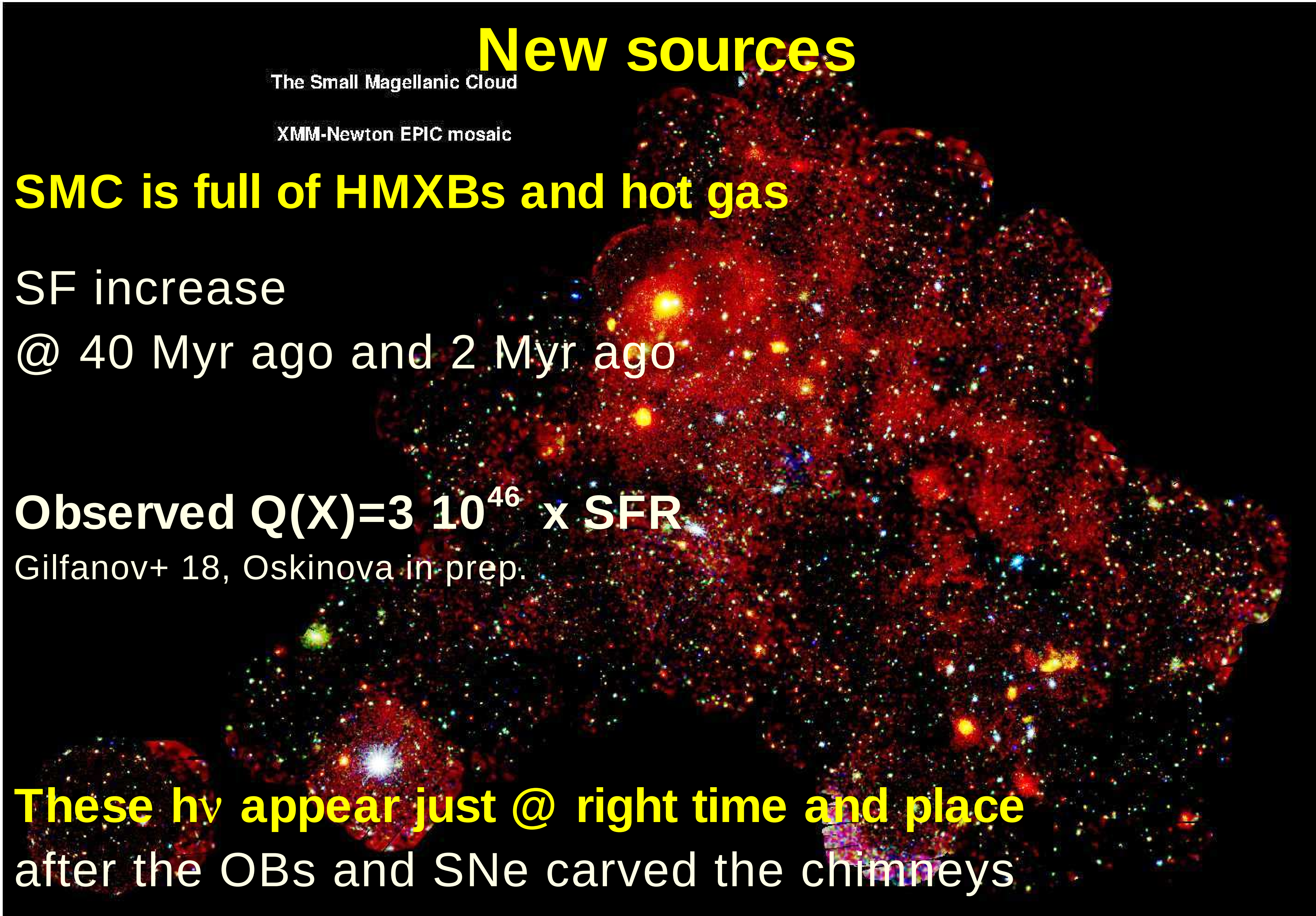
30 Dor: HST/SPitzer/Chandra

New sources



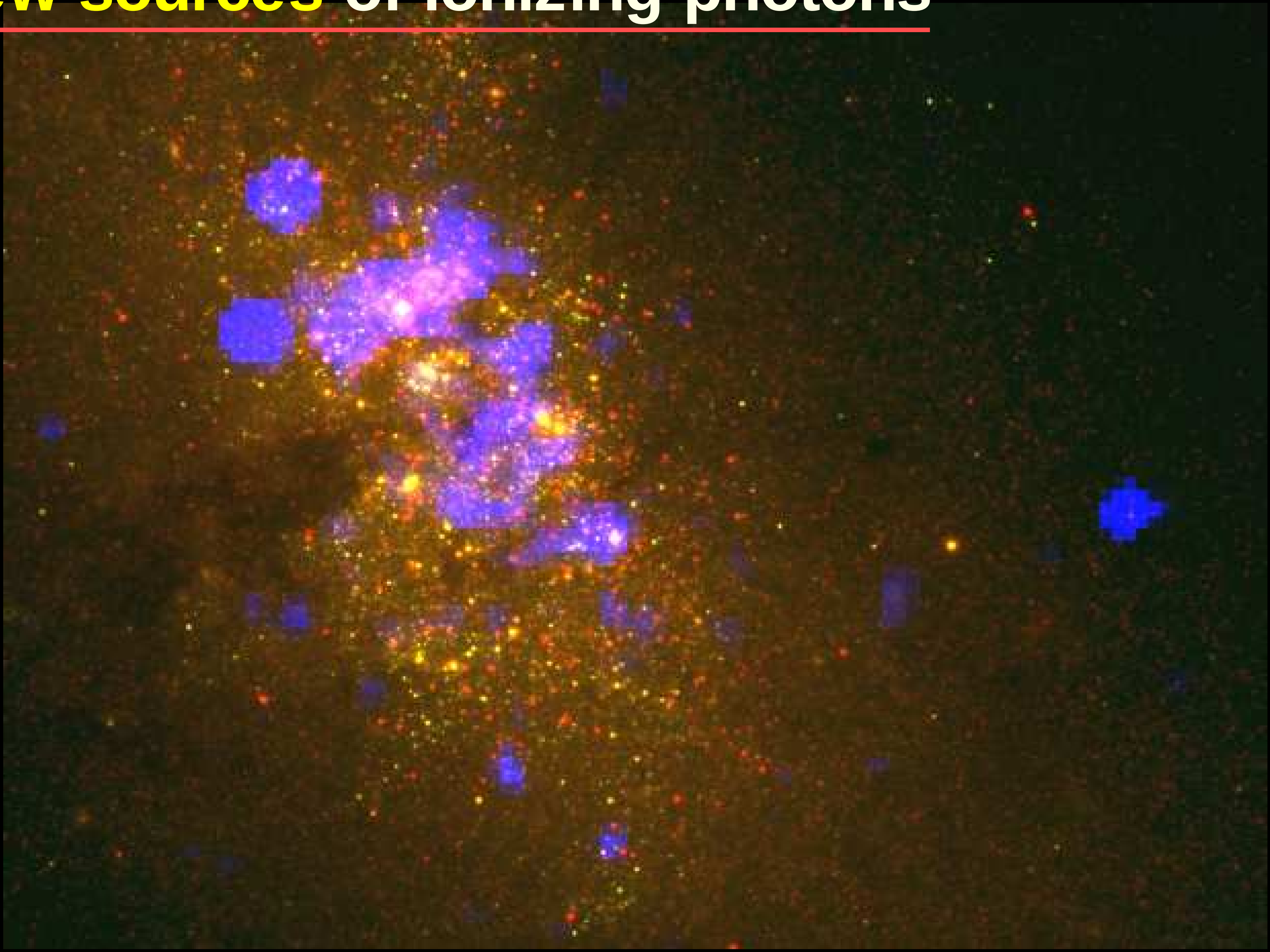
SMC is full of HMXBs and hot gas

SF increase
@ 40 Myr ago and 2 Myr ago

Observed Q(X)=3 10^{46} x SFR
Gilfanov+ 18, Oskinova in prep.

These hν appear just @ right time and place
after the OBs and SNe carved the chimneys

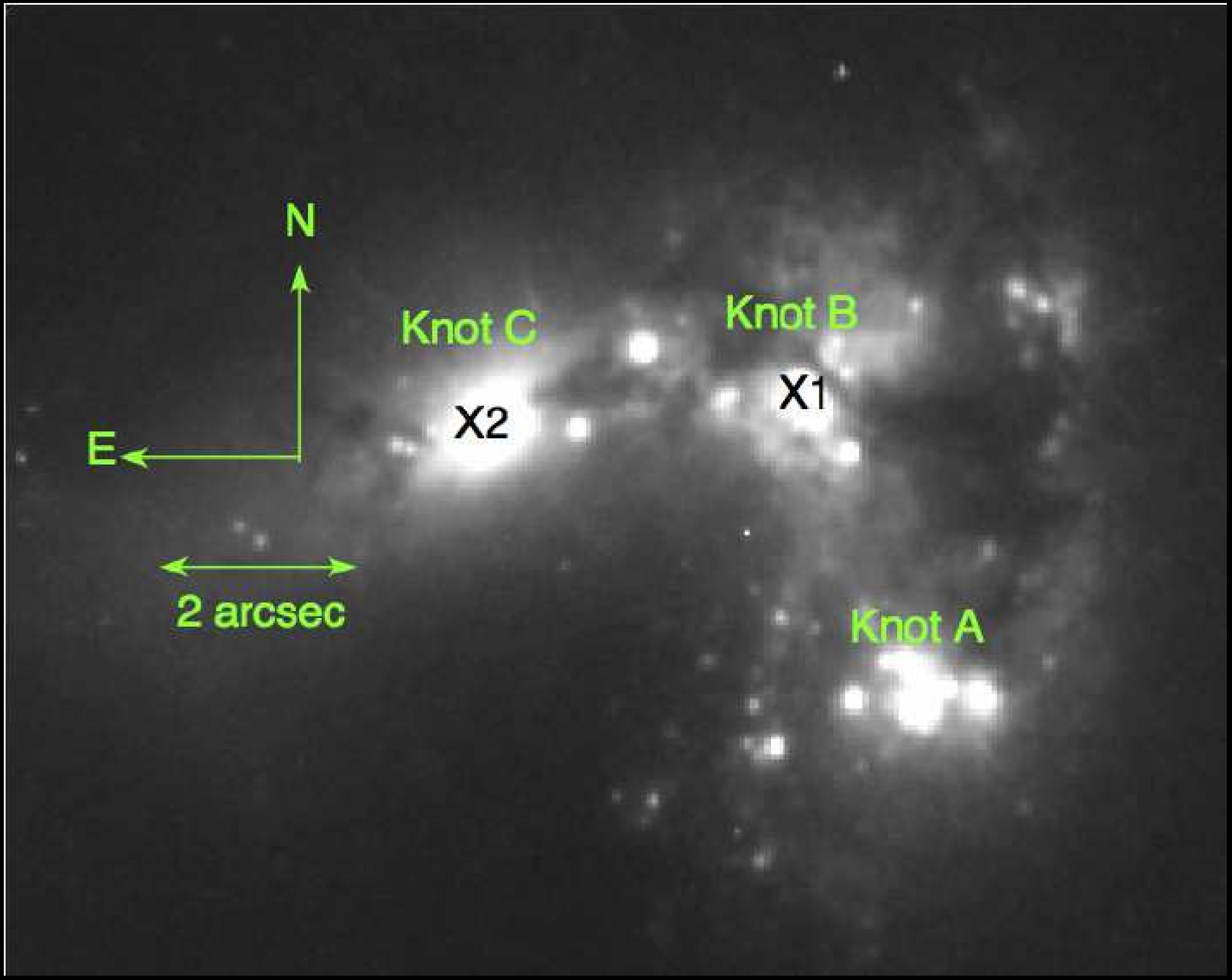
New sources of ionizing photons



HST/Chandra NGC 5253 - **large number of HMXBs** (Oskinova in prep.)

New sources: ULXs in Haro 11

2 ULXs with lg(Q(X)) ~50



HST/Chandra Haro 11 (**Prestwich+ 15)**

New sources: ULXs in Haro 11

2 ULXs - could be low mass stars!

Outflows v=0.1c. Relativistic jets.

Pinto+ 15, Nature

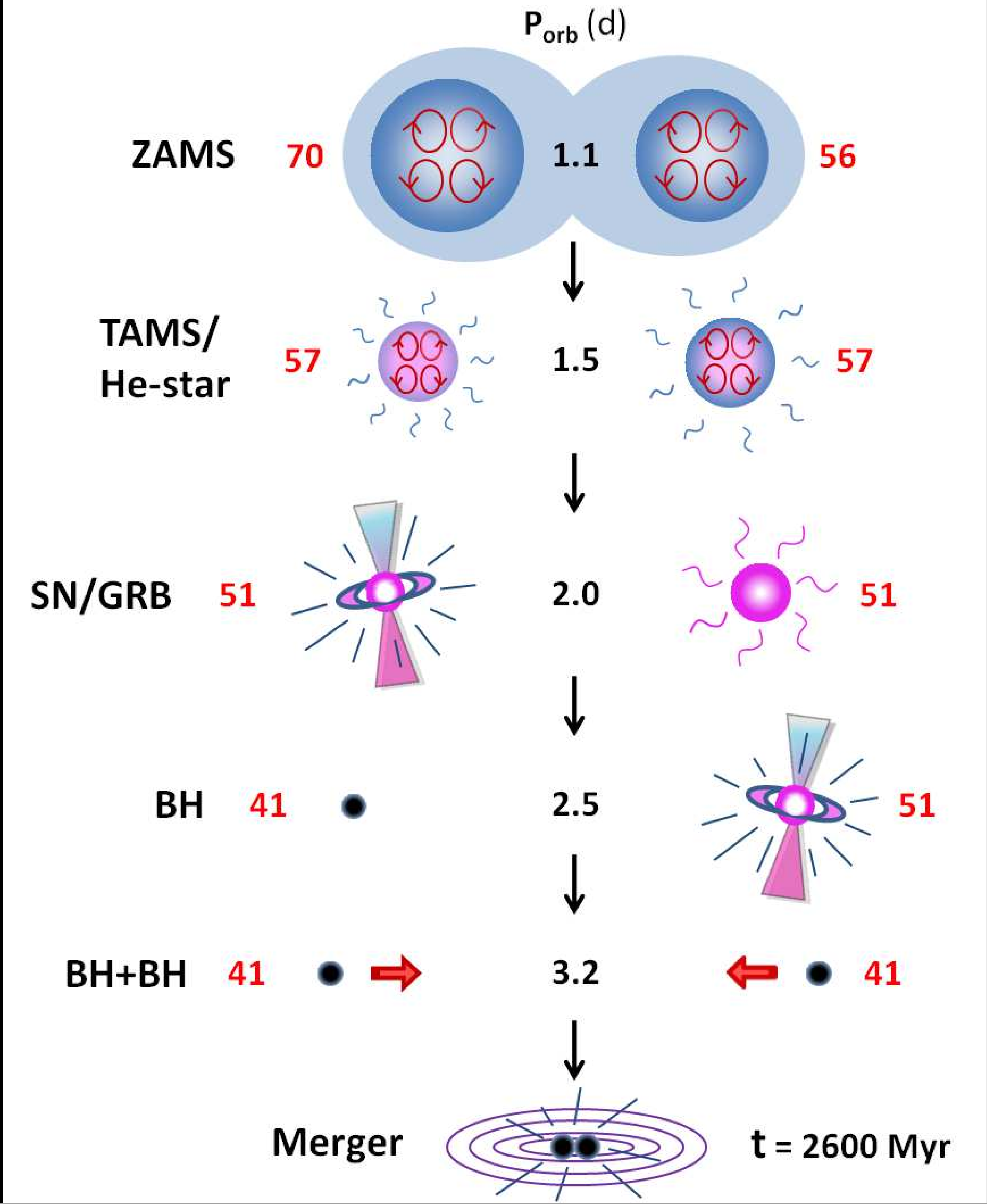
On mice and men

OR on local galaxies and first galaxies

Higher masses stars and black holes?

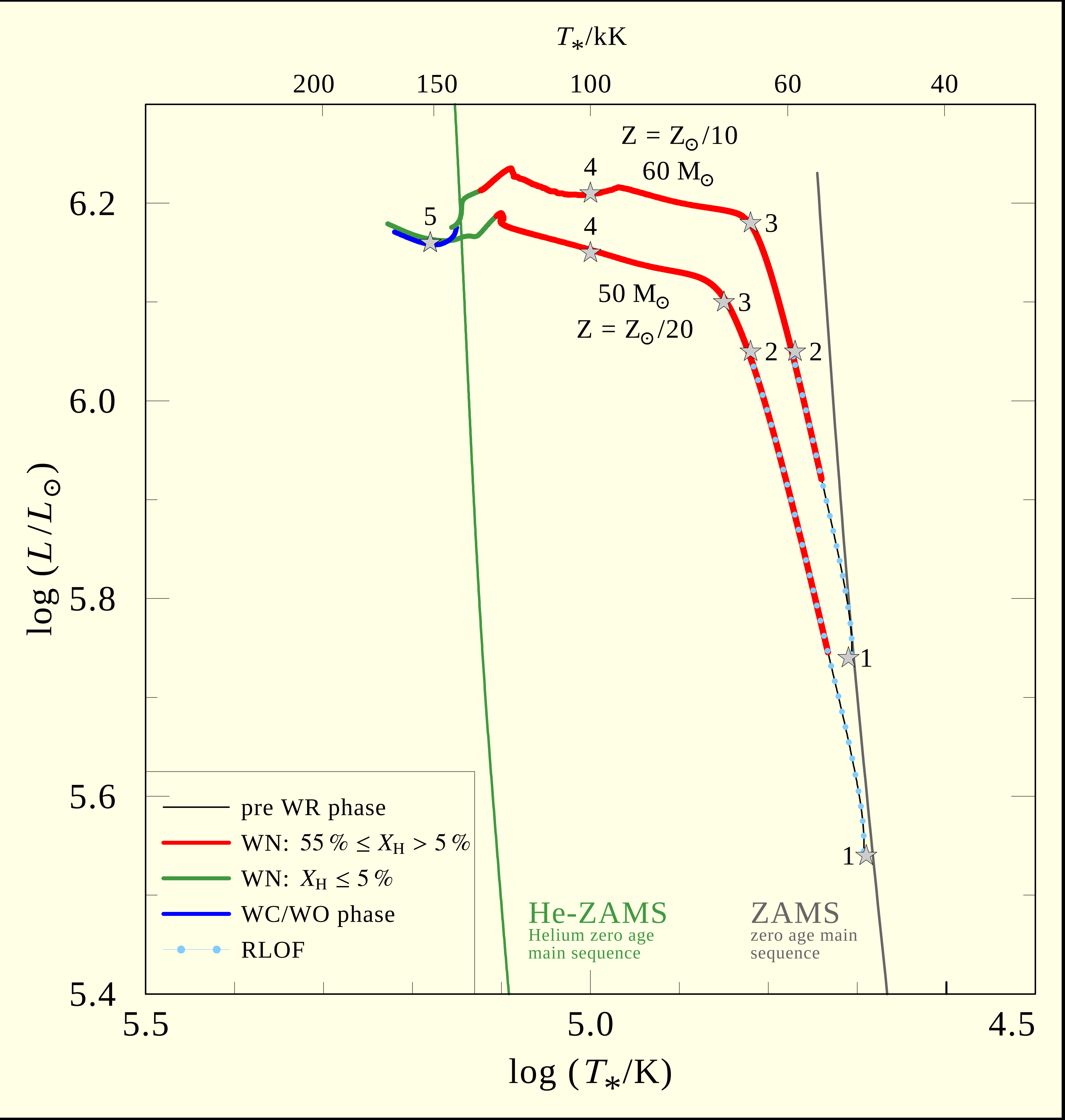
Mirabel+, Sazonov+

Marchant+ 16


P_orb (d)
ZAMS 70 1.1 56
TAMS/
He-star 57 1.5 57
SN/GRB 51 2.0 51
BH 41 2.5 51
BH+BH 41 3.2 41
Merger
t = 2600 Myr

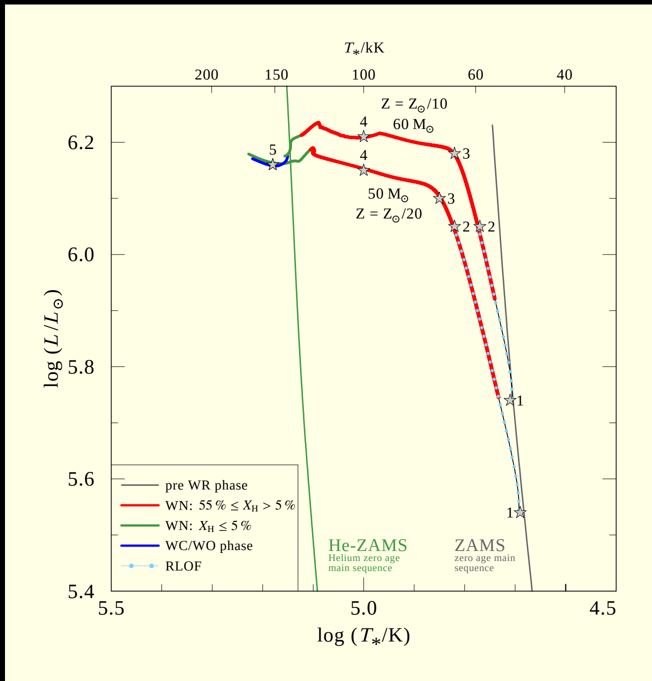
Do GW CHE progenitors exist in the observable Universe?

- **PoWR** synthetic spectra at key evolutionary stages
- Spectral Types and X-ray luminosities
- **Feedback**



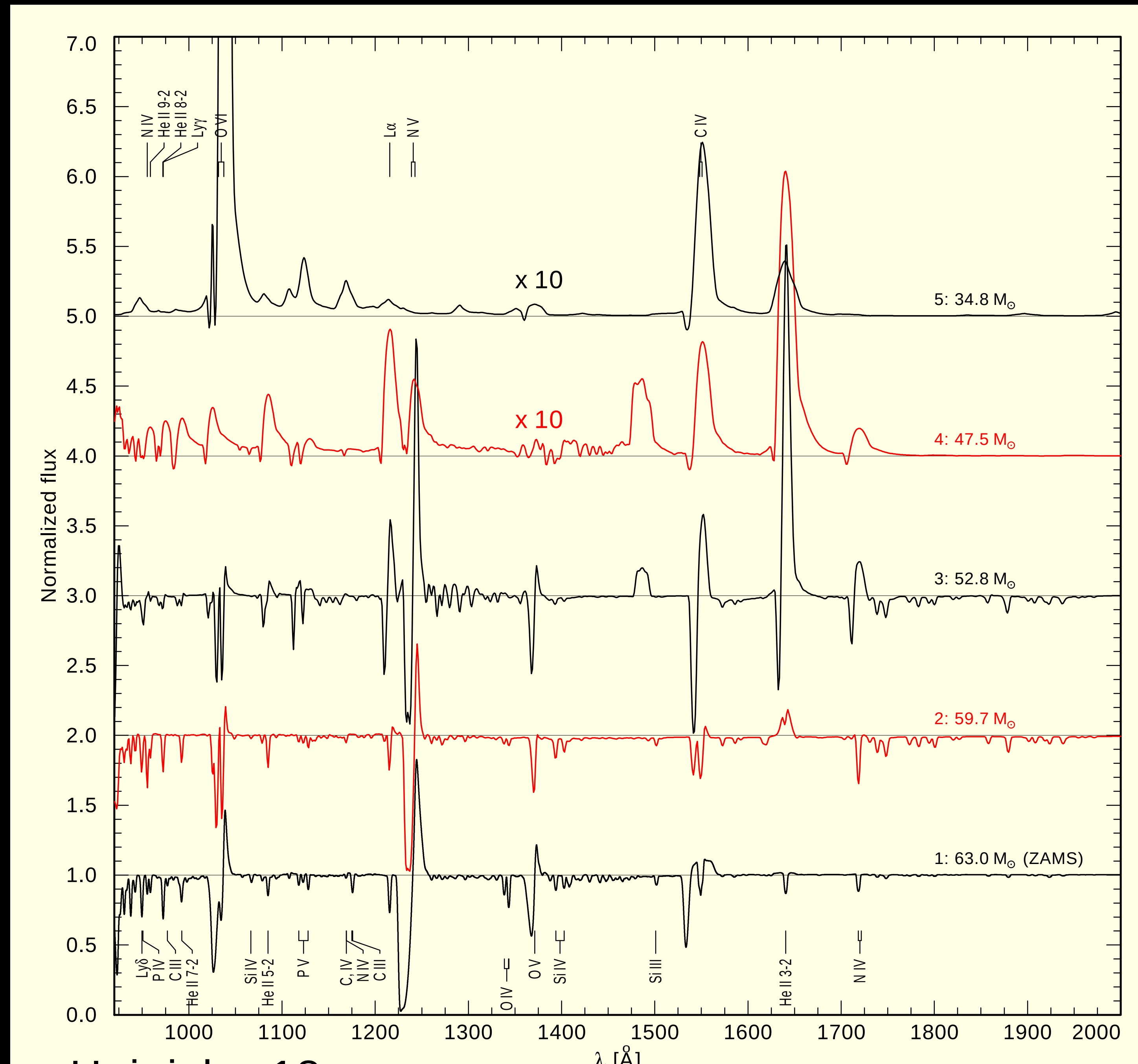
Hainich+ 2018

WN+BH Q(X)=10^{49} s^{-1}

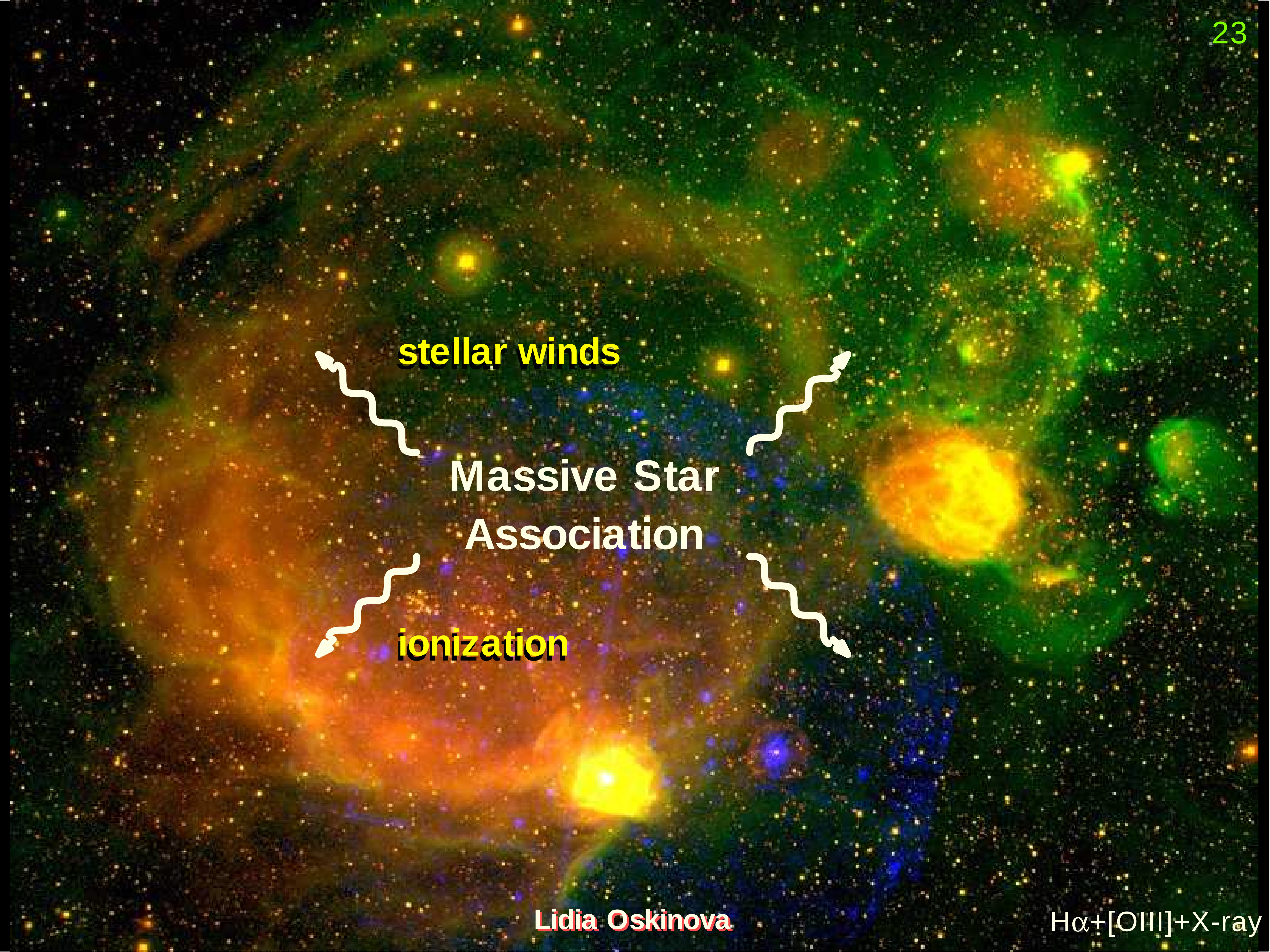


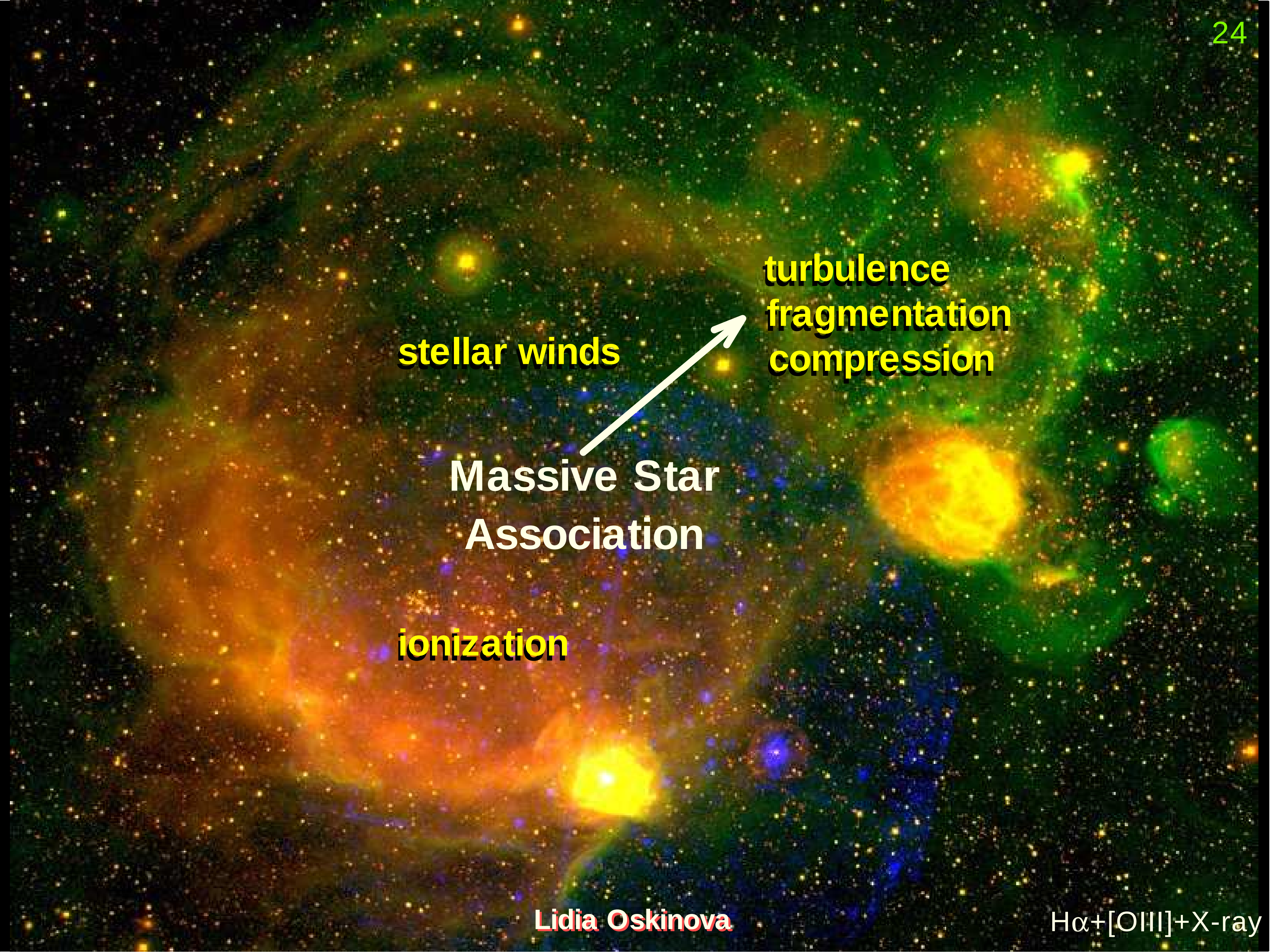
Time increases from bottom to top : UV - strong metal lines

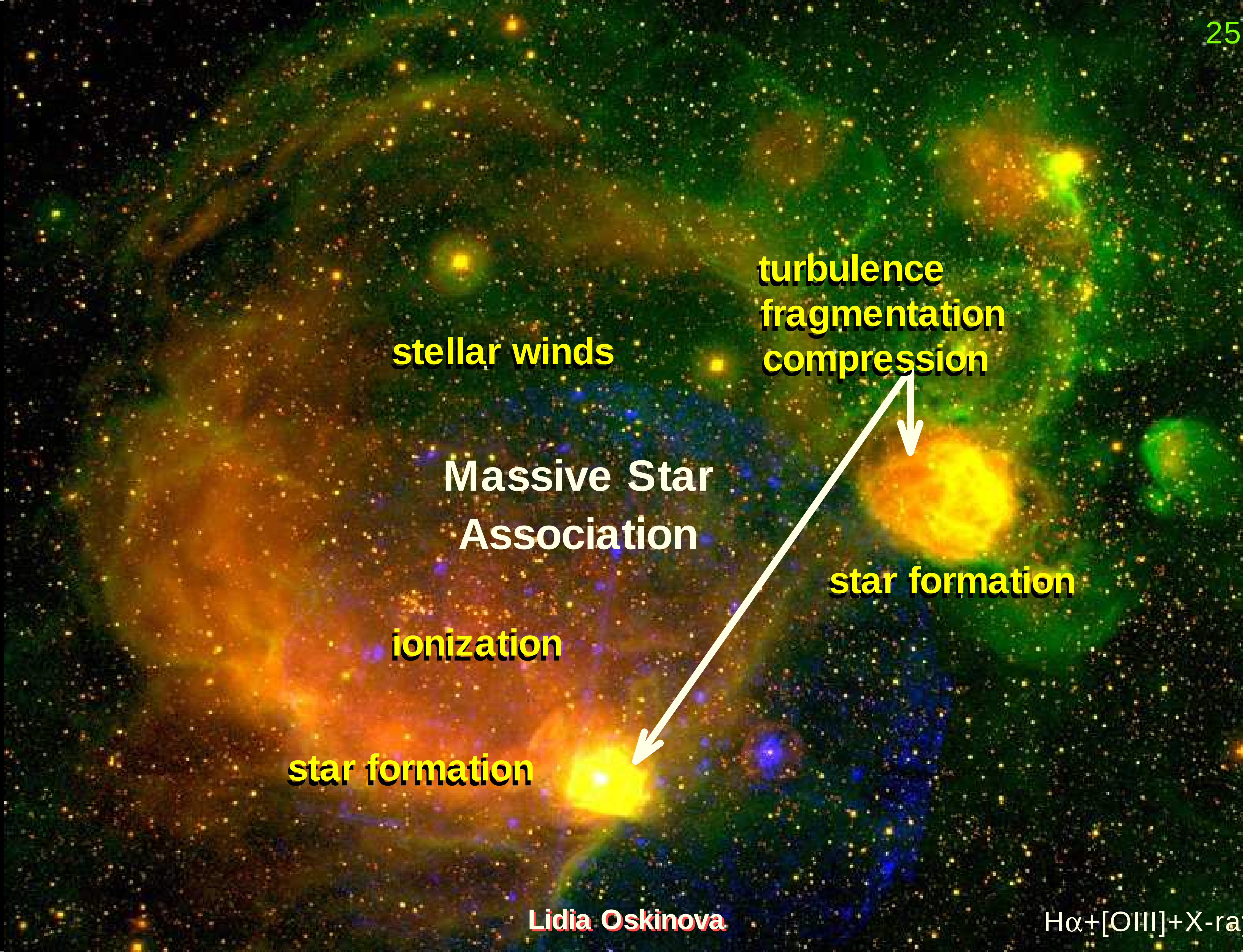
- O3V $\log\dot{M} = 10^{-6}$
- O3I $\log\dot{M} = 10^{-5.6}$
- WN2 $\log\dot{M} = 10^{-5}$
- WN2 $\log\dot{M} = 10^{-3.5}$
- WO1 $\log\dot{M} = 10^{-5}$

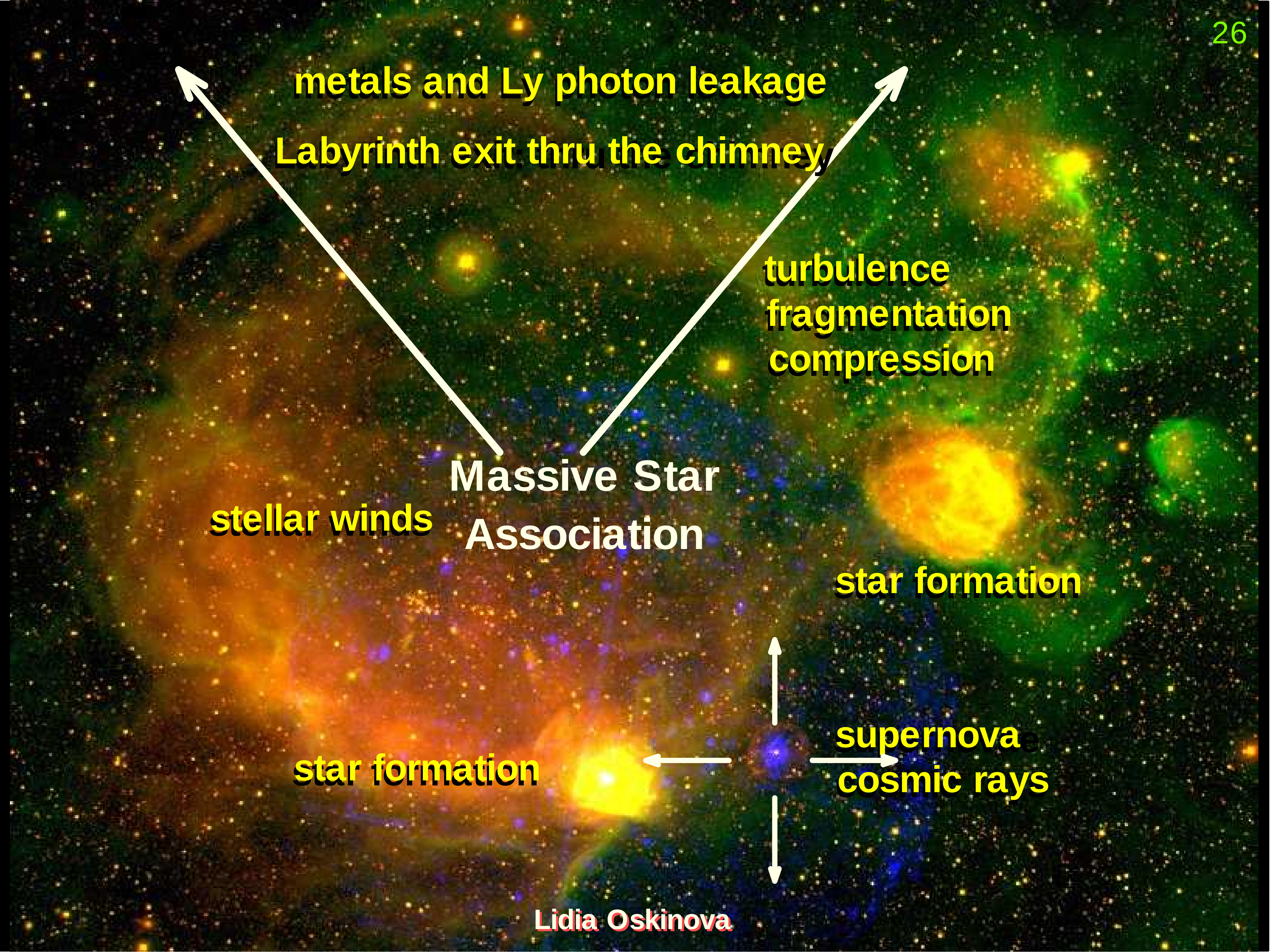


Hainich+ 18


stellar winds
Massive Star Association
ionization
Lidia Oskinova
Hα+[OIII]+X-ray


24
turbulence
fragmentation
compression
stellar winds
Massive Star
Association
ionization
Lidia Oskinova
Hα+[OIII]+X-ray


turbulence
fragmentation
compression
stellar winds
Massive Star
Association
star formation
ionization
star formation
Lidia Oskinova
Hα+[OIII]+X-ray


metals and Ly photon leakage
Labyrinth exit thru the chimney
turbulence
fragmentation
compression
Massive Star
Association
stellar winds
star formation
supernova
cosmic rays
star formation
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Summary

- **Reducing opacity**
  - Clumping: may not be sufficient
  - Blow-outs and chimneys: effective after first SNe
- **Increasing Output**
  - Continous star formation
  - Heating and ionization by HMXBs
- **Finding new sources in First galaxies**
  - Heavier BHs
  - ULXs and HLXses: higher X-ray fluxes per SFR
  - Heating of the IGM