Distributed Massive Stars and Possible Implications for Star Formation and Clusters

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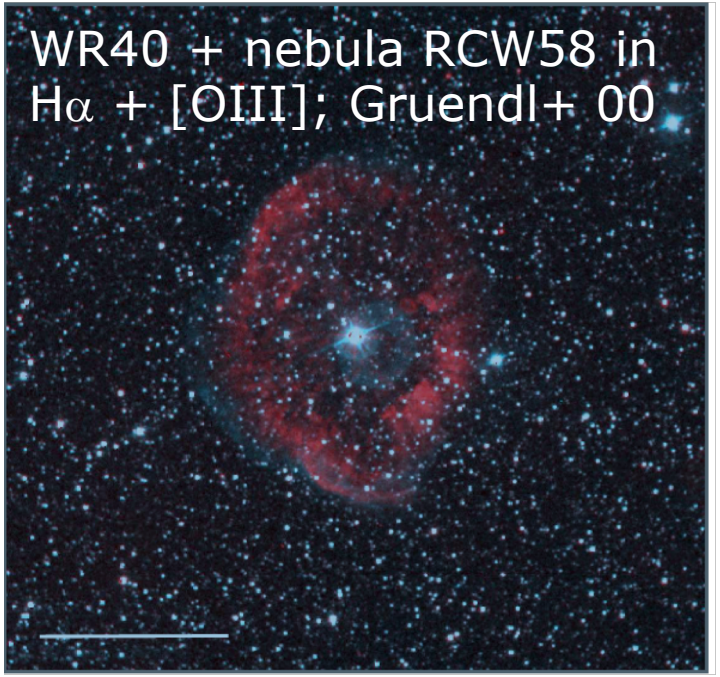
(S. Van Dyk, P. Morris, J. Mauerhan, J. Toàla and G. Morello)

Overview

- Introduction
  - Wolf-Rayet stars … in brief
  - Massive star distribution
  - Possible resolutions
- Runaways (walkaways?) and the bow shock phenomenon
- The nebula NGC3199 and the Wolf-Rayet star WR18
- GAIA DR2 results
- Possible solutions
- Summary conclusions

Wolf-Rayet Stars… v.short summary

- Evolved from O stars > 20$M_\odot$
- A few million years old
- High mass-loss rates and fast winds
- Past ejecta and WR ring nebulae
- WN/WC/WO subtypes, evolution
- Precursors of supernovae (likely type Ibc)



Massive Star 'Isolation'

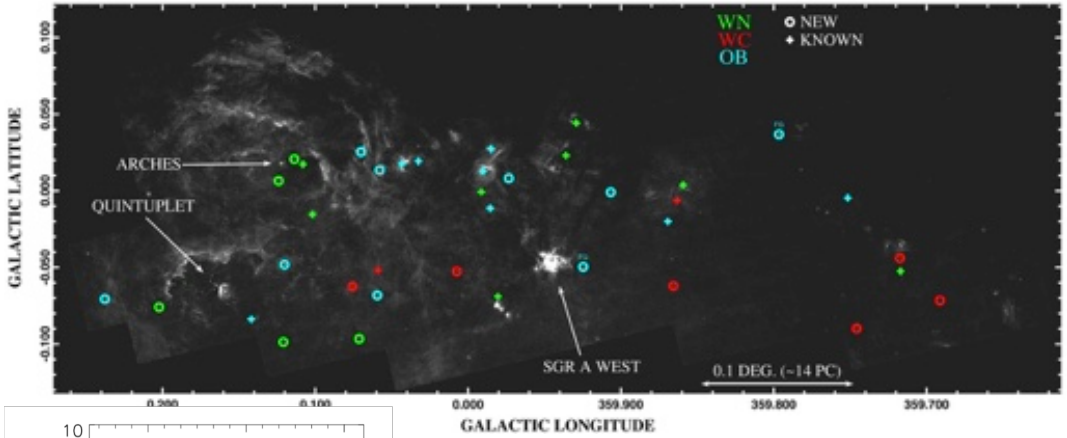
Galactic O stars:

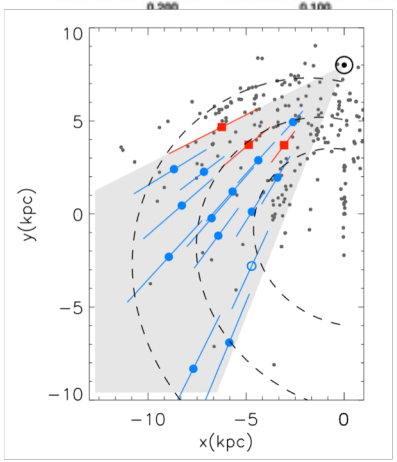
- < 20% O stars in isolation (Gies 87; Mason+ 98; Maíz-Apellániz+ 04)
- ~ 5-10% are true field stars (de Wit+ 04, 05)

Wolf-Rayet (WR) stars:

- ~ 7% WR stars in the LMC are truly isolated with another 10% in supergiant shells rather than clusters or OB associations (Gruendl & Chu 08).
    - Number of examples for 'isolated' massive stars in LMC e.g. work of Oey+, also in the region of 30 Dor (Bressert+ 12).

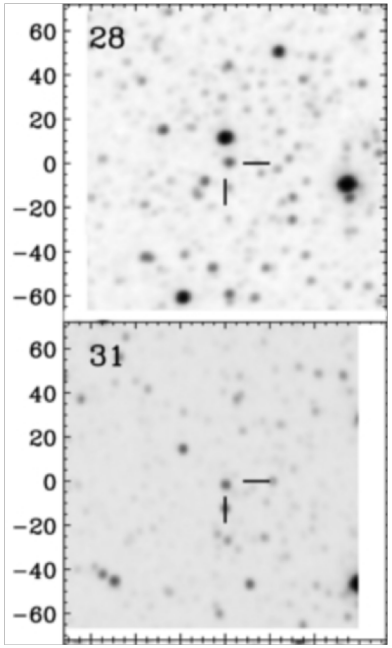
A Scattering of Massive Stars…





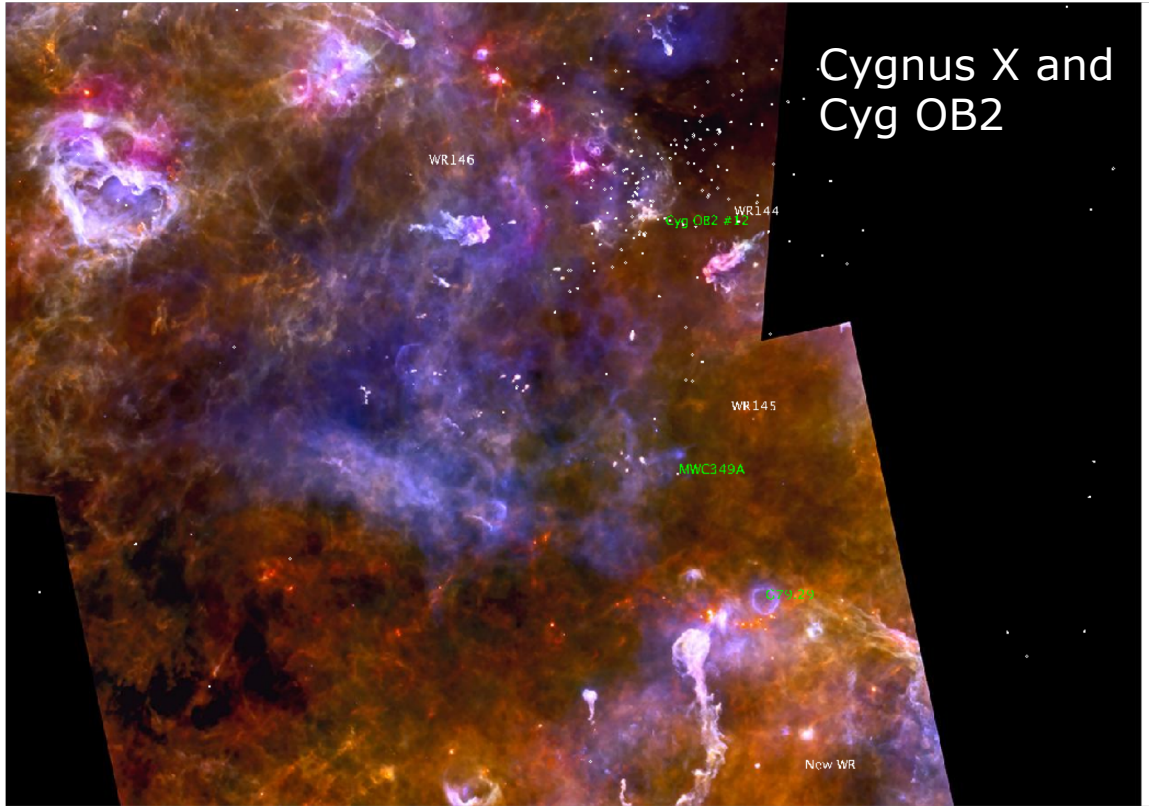
Massive stars scattered across inner galaxy; Mauerhan+ 11a

> 300 Wolf-Rayet stars distribution, only 25% in clusters or near HII regions; Rosslowe & Crowther 17



"Isolated" WR stars; Mauerhan+ 11b, Morello+ 17

Most massive stars not in main clusters



Cyg OB2 kinematics indicate no general expansion (Wright+ 16)

Stellar distributions (Wright+ 14)

- No evidence for mass segregation.
- No evidence massive stars are in regions of higher local density.
- Argue – **distribution always was like this..**

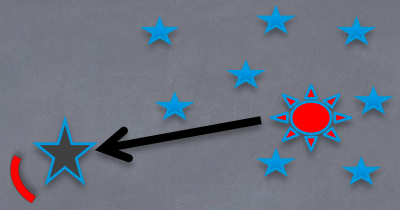
Background – Schneider et al (2016)

Herschel PACS/SPIRE

O Stars [Comeron+ 08 + Wright+ 15]

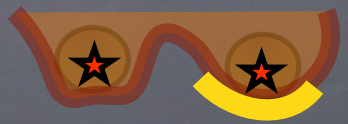
Possible causes of apparent isolation

Massive star expulsion from young clusters.
Binaries in SNe?



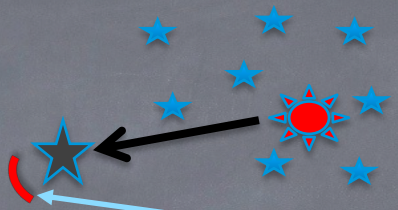
Low mass clusters
$\sim 10^2$-10^3 $M_\odot$.

Distributed/more isolated – e.g. via triggered SF.



Expulsion and bow shocks

Massive star expulsion from young clusters.
Binaries in SNe?



'Bow shock'

Low mass clusters
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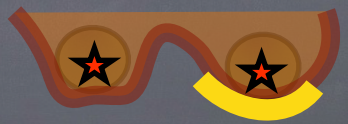
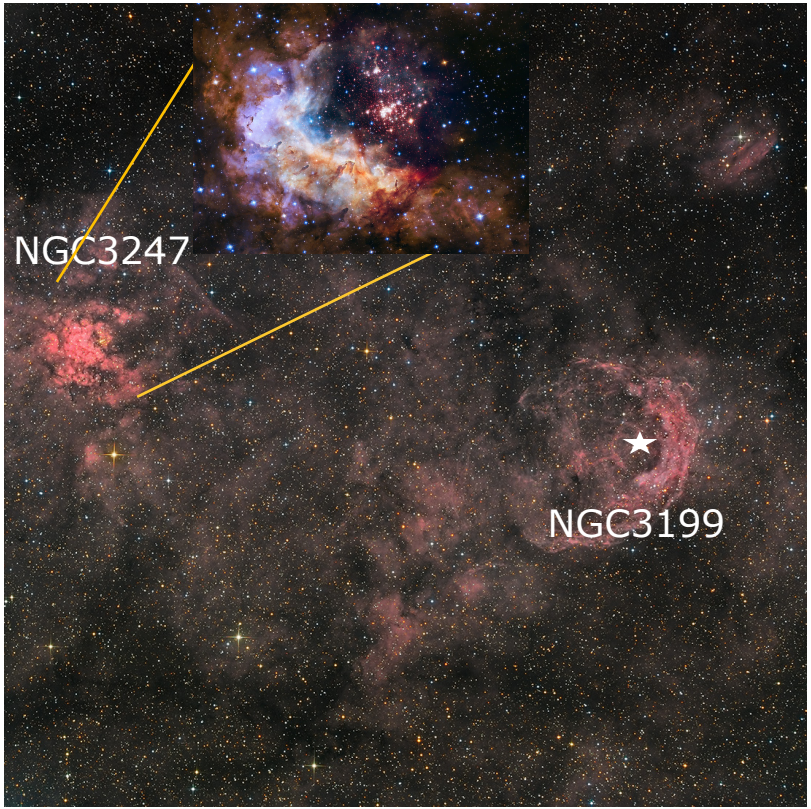
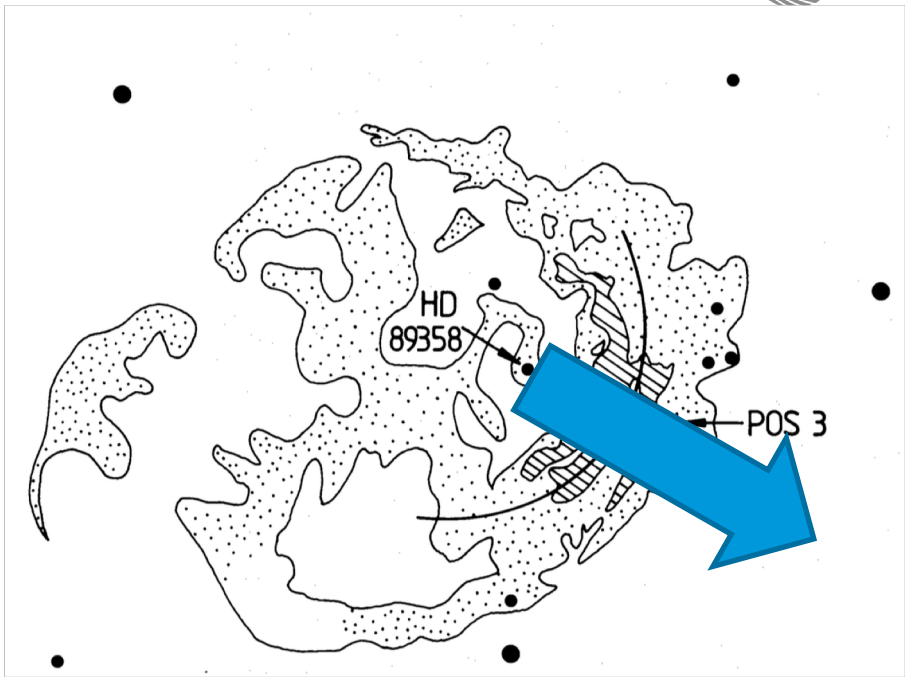


NGC3199 (nebula) and WR18 (star)

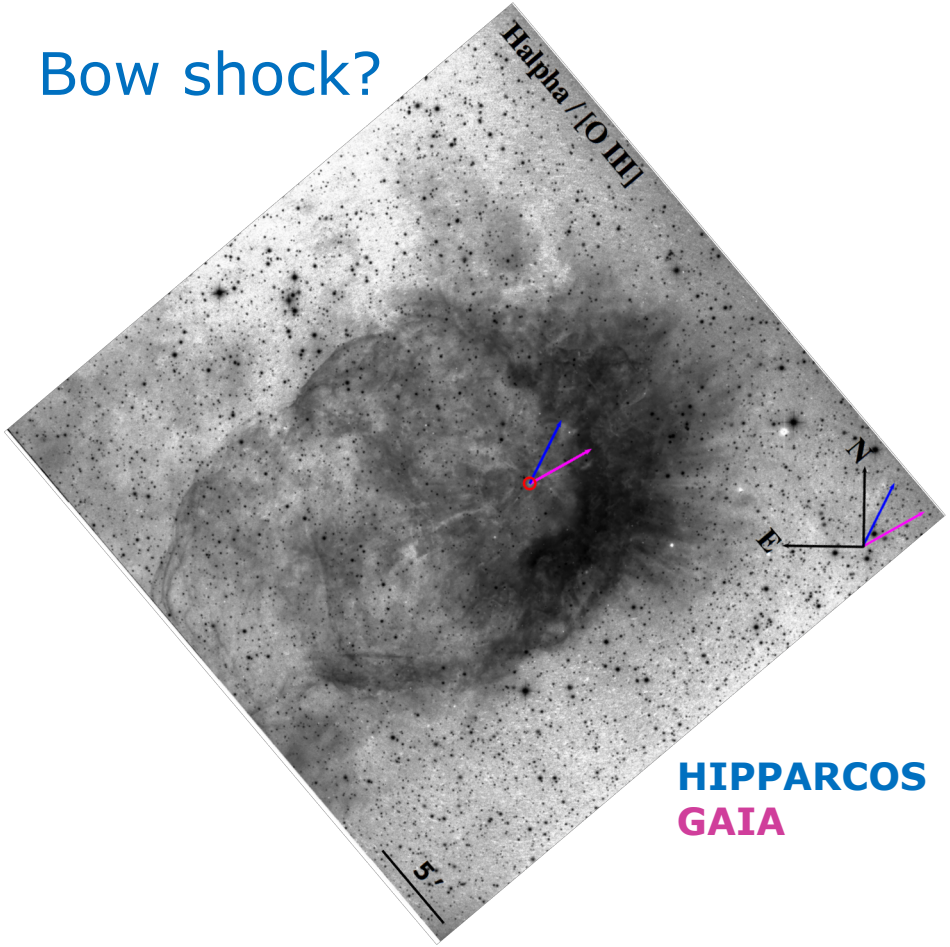


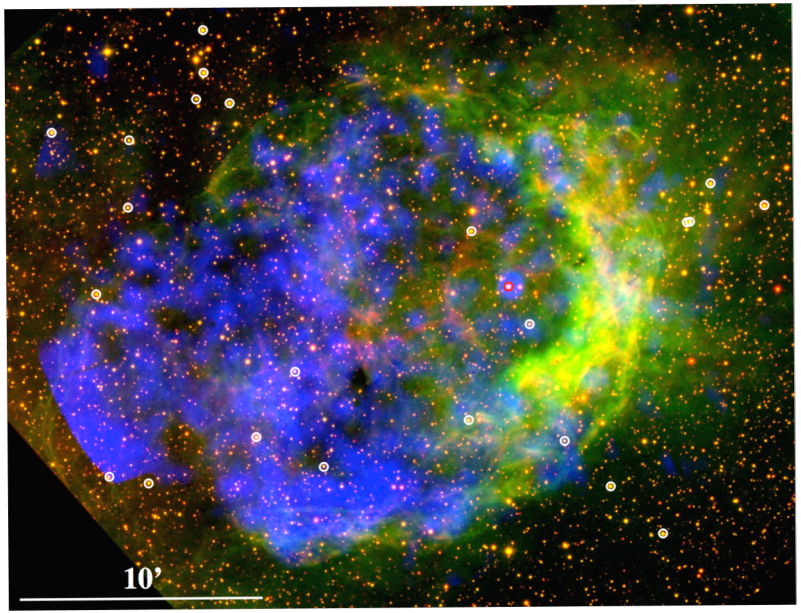
NGC3247 -- Westerlund 2



WR18=HD89358. Modelled nebula as a bow-shock created by the star as it travelled at 60km/s to south-west (***Dyson & Ghanbari 89***).

Bow shock?





HIPPARCOS
GAIA

Stars with similar proper motions (GAIA DR1) shown as circles.
(Toala, Marston+ 17)

GAIA DR2 proper motions of WR stars

- Purpose: Look for anomalous proper motions of Galactic WR stars.

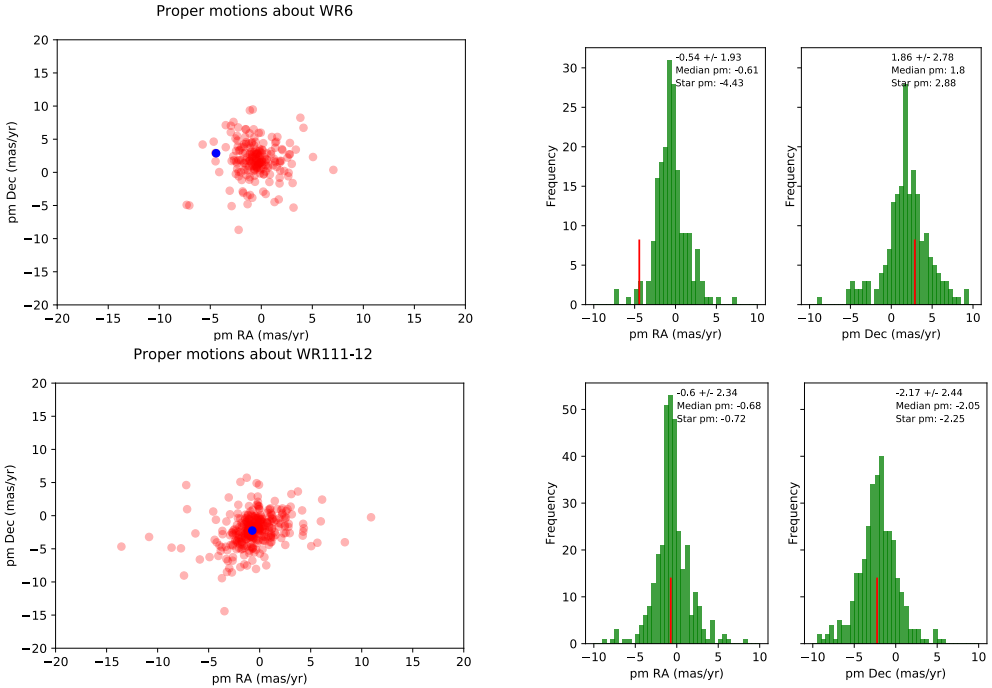
- Use GAIA DR2 release data.
  - Enables proper motions of hundreds of WR stars in the Galaxy.
  - Obtained most accurate coordinates from 2MASS correlation.
  - Sample of 372 of 638 Galactic WR stars have quantifiable proper motions.
  - Test for outlier proper motion relative to the local field – area of sky, approx 8pc apparent radius and incorporating stars with 1.645*std_dev(field proper motions) → 90% outlier confidence.

Proper Motions (PMs) from GAIA DR2

Plots of PM in RA versus PM in Dec

Above:
WR6 – clear outlier (v_{trans}~60km/s)

Below:
Very typical PM distribution as illustrated for WR111-12



- ~ 6% show clear outlier status.
- ...not near the 75% outside of clusters/HII regions indicated by Rosslowe & Crowther 17.

Formation in 'isolation'

- Recent work on W3 and related high mass star forming regions -- Rivera Ingraham+ 18 -- suggests that ***the main factor for high mass star formation is likely $\dot{M}$ rather than total mass, M, in a region***.

- If **containment**, that minimizes disruption, is available for a period of significant $\dot{M}$
  → massive star.

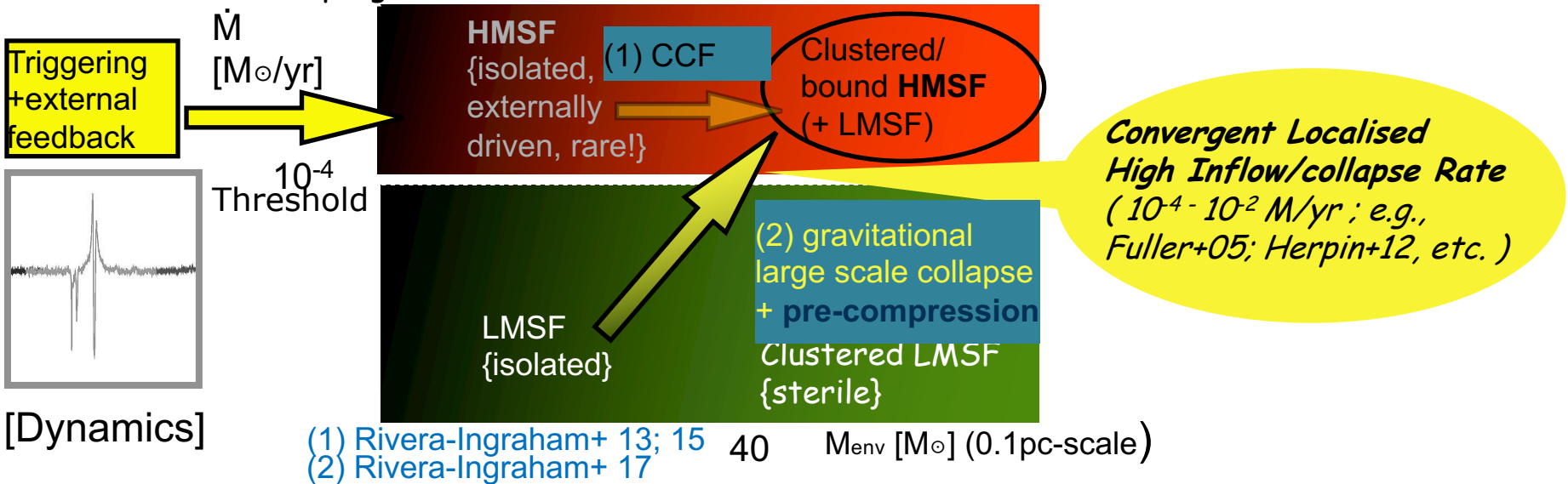
- Herschel studies suggest this is likely to be rarer than for more purely gravitational collapse, …but could particularly occur in regions of **high external pressures – triggered star formation. *Convergent Constructive Feedback (CCF; Rivera-Ingraham+ 13)***

High Mass Star Formation

- Isolated HMSF, no/few companions, formed in peripheries of triggered regions
- > loose associations
- > subclusters neighbourhoods of associations, out-in progression

Evolutionary Model F(t)

- Compact bound massive clusters
- formed @ center of potential wells from large scale collapse or active compression of dense region:
- prolonged SF

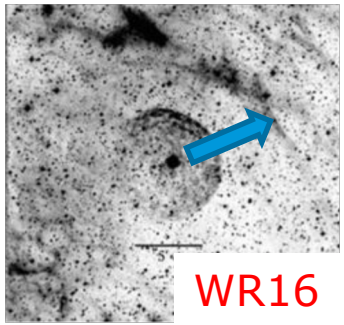


(1) Rivera-Ingraham+ 13; 15
(2) Rivera-Ingraham+ 17

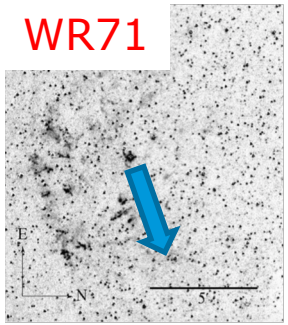
Brief Summary

WR stars have not moved far from their original birthplaces (generally).

- Supernova progenitors (type Ibc[-BL]) – **not exploding in clusters** (much of the time).
- Limited dynamical ejection from clusters (e.g. around NGC6357; Gvaramadze+ 11).
- Oddly – many of the fast-moving WR stars have well-known **ejecta shells** (seen about 15% of the time, Stock+ 12).



WR16



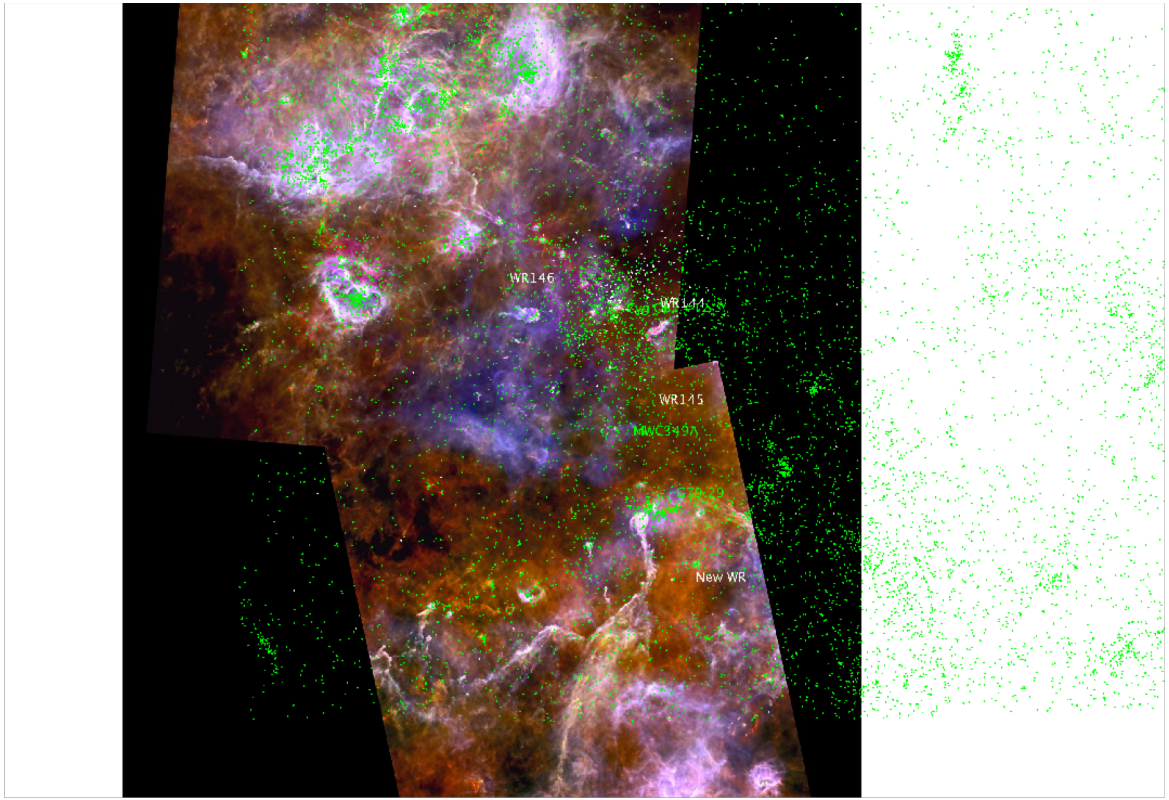
WR71

So we are left with the conclusion that the majority of WR (high mass) stars are

- found scattered within associations or in **relative isolation** (a few in 'total' isolation)
- …and may be in **(very) low-mass clusters**.

Additional slides

YSO distribution and massive stars in Cygnus X



List of WR stars with outlier PMs from GAIA DR2

WR4, WR6**, WR7, WR13, WR16**, WR40**, WR44-1, WR54, WR57, WR71**, WR88, WR92, WR111d, WR115, WR136**, WR148**, WR150, WR102-21, WR118-6, WR119-2, WR46-15, WR122-15, WR102-25 (23 out of 372, or 6%).

'Missing' WR21 and WR22 from Moffat+ 98 list (marked **) – no evidence of 'runaway' motion based on DR2 data. Those in red have known ejecta nebulae.

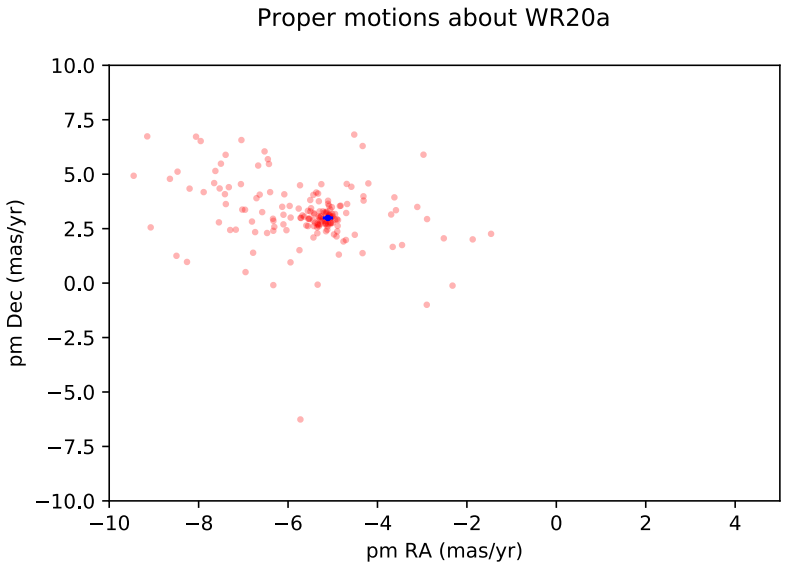
Remarkably similar to O star rate of field stars (de Wit+ 05) and for apparently isolated LMC WR stars (Gruendl & Chu 08).

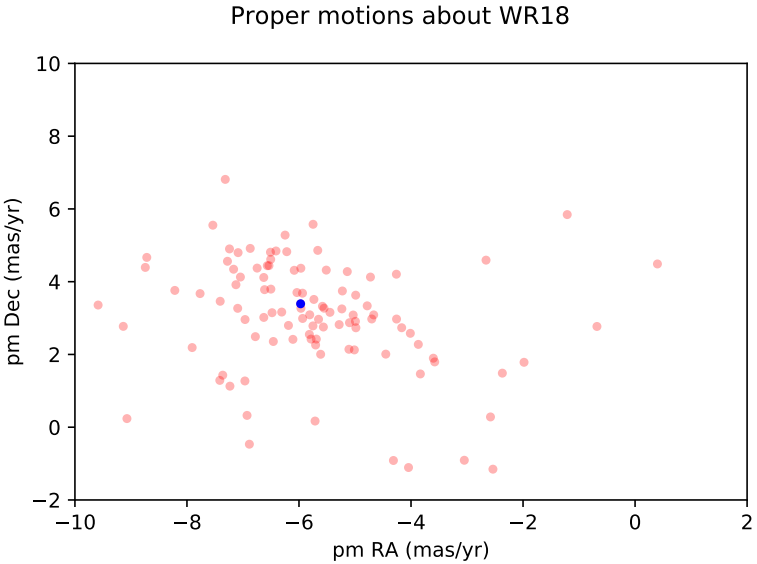
WR6 – EZ CMa

De Zeeuw+ 99. From HIPPARCOS parallax and motions → Collinder 121. But GAIA DR2 puts distance nearly twice as far and proper motions then inconsistent. It is seen as an outlier.

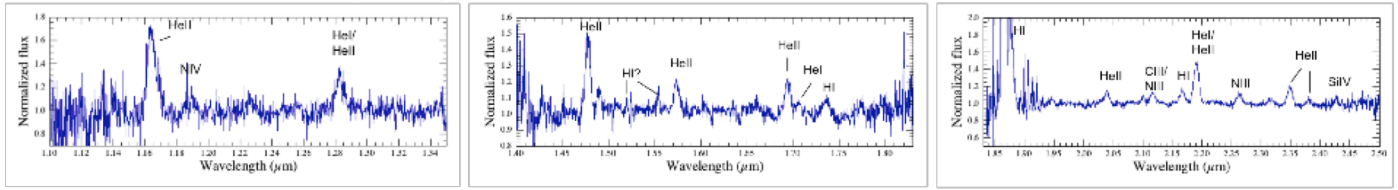
Note this work also suggests most high mass star formation tends to be spread out over associations.

WR20a/Westerlund 2 and WR18

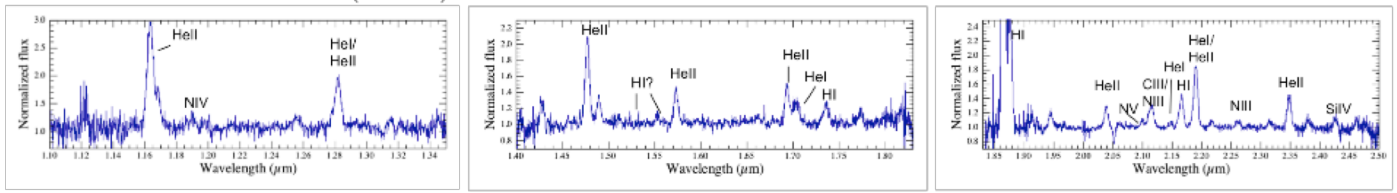




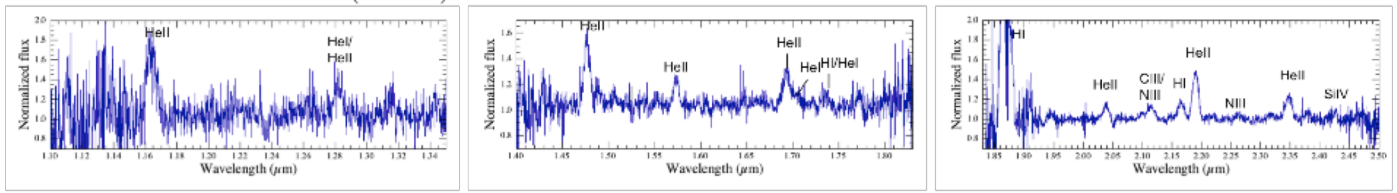
2MASSJ18225904-1312311 (WN4-5)



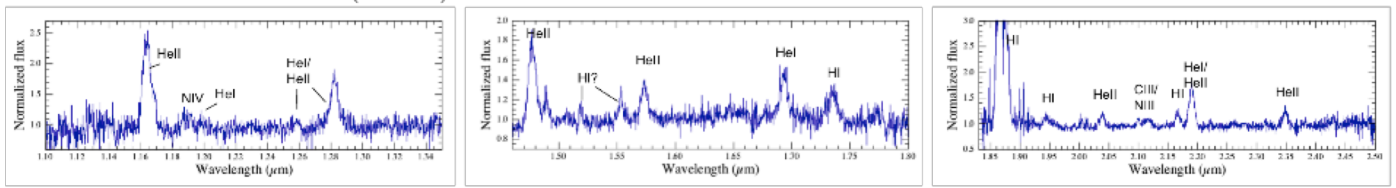
2MASSJ18244626-1154270 (WN4-5)



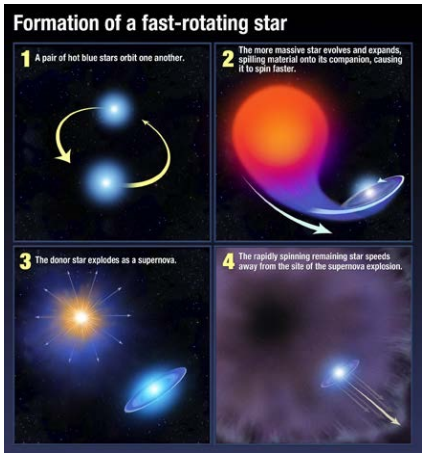
2MASSJ18282046-1216364 (WN4-5)



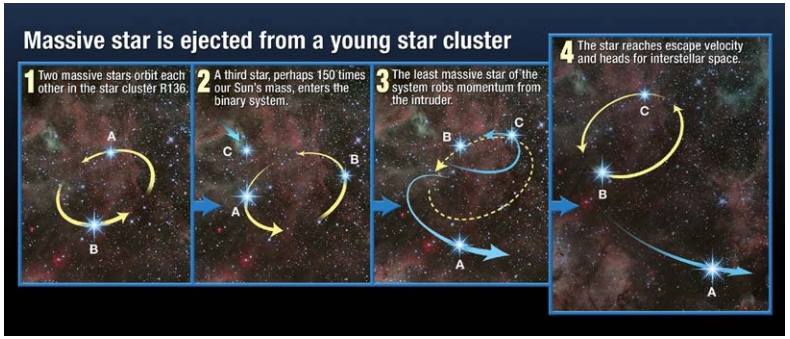
2MASSJ18442065-0236510 (WN4-5)



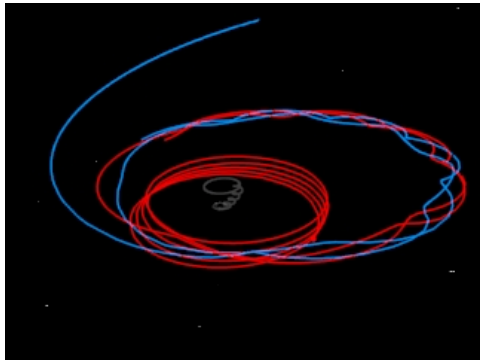
Potential Explanations for Isolated Massive Stars: Walkaways, Runaways, Hyper-runaways, Hypervelocity stars



Ejection from binary system when star explodes as SN

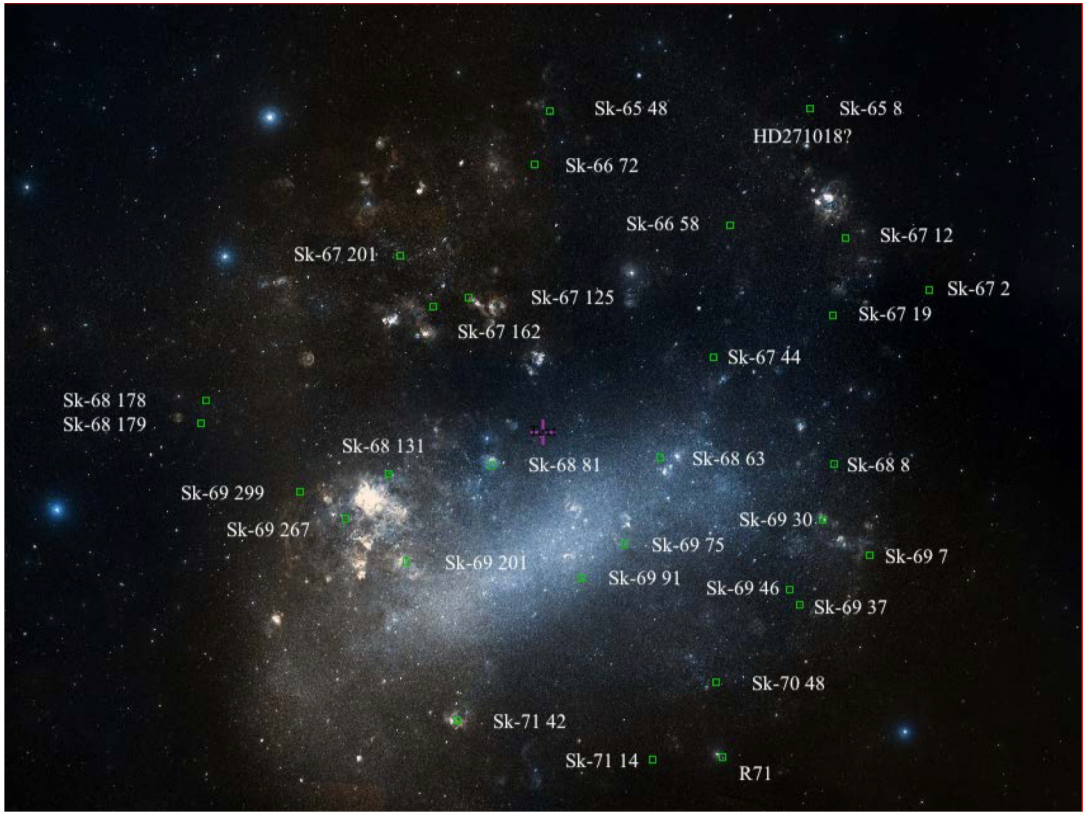


Dynamical ejection from massive dense cluster



Via dynamical interaction with a massive black hole

LMC Massive stars in GAIA DR1 – Lennon+18



Despite isolation – little evidence they are all/mostly runaways.

2 of 31 possible high velocity objects (R71, Sk 67-2)