Wolf-Rayet star Cluster and Association membership in Gaia DR2

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Wolf-Rayet (WR) stars

- Initial mass >25M⊙
  - Classical: He core burning
  - Main sequence.
- High mass loss rates
  - Reduced / negligible atmospheric H.
- Broad emission lines
  - He, N and C
- Tracer of massive star birth/evolution.

Image courtesy: ESA/Hubble & NASA

WR environments

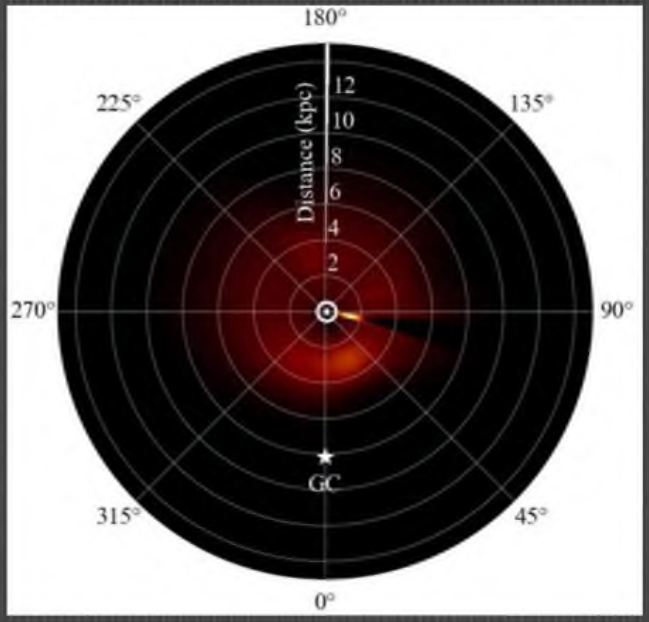
- Expected to form in clusters
  - Short lifetimes
- 10-30% of WR in clusters [1.]
- 35% in clusters and associations [2.]
  - Majority isolated?
  - Assignment has limitations
- Gaia DR2 archive contains 382 WR
  - Parallaxes and proper motions
  - 2/3 of known population

1. Lundstrom & Stenholm (1984), 2. van der Hucht (2001)

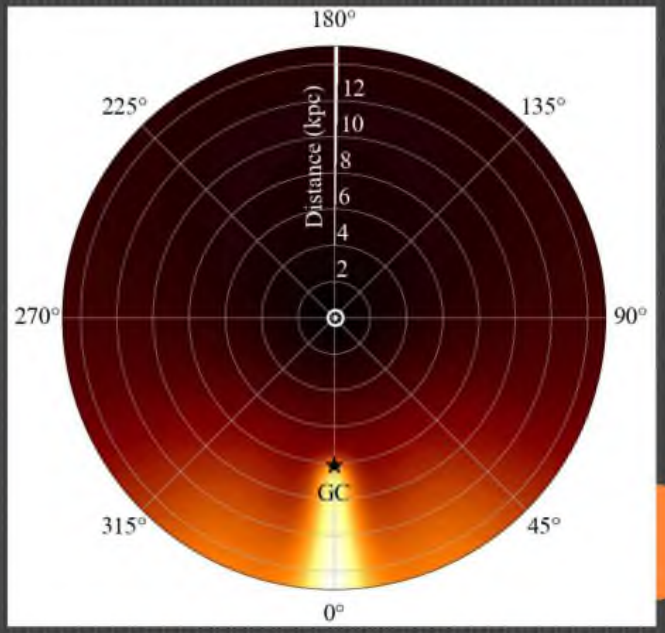
Methods

- Compare WR to other members
- Mainly OB stars
- 93 / 382 WR stars claimed members

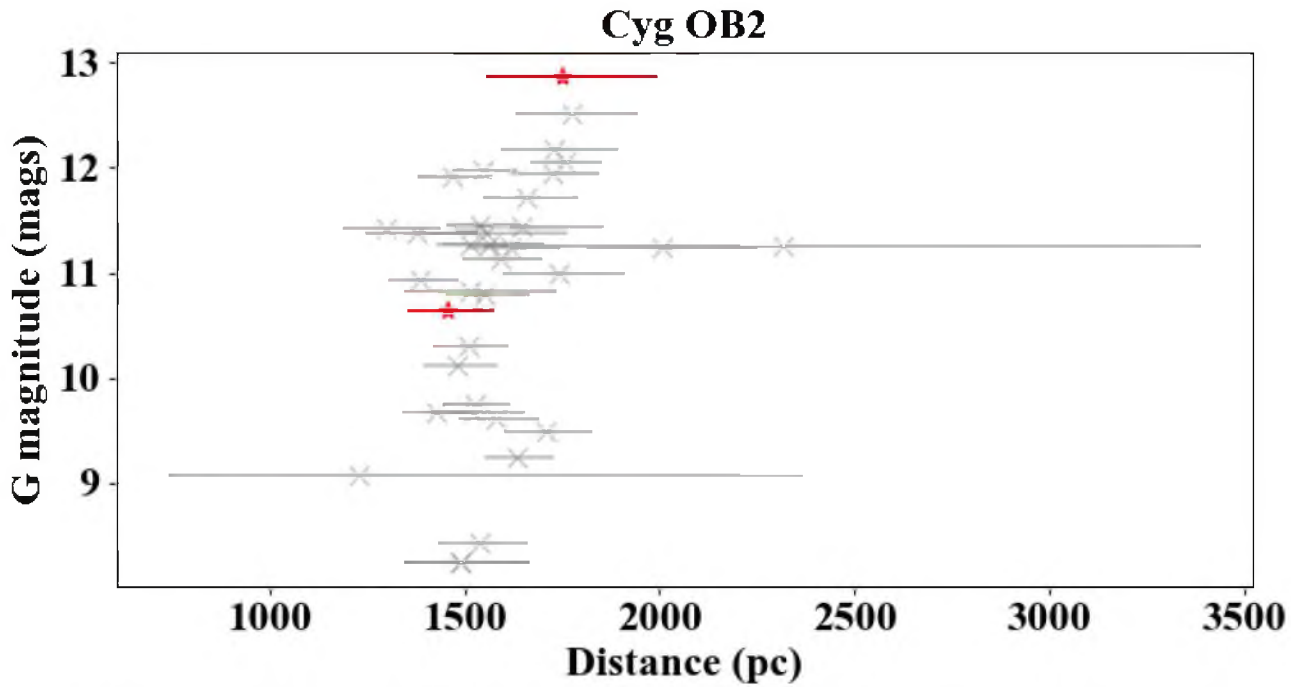
- Proper motion space
  - Bound groups
- Distance
  - From Bayesian methods
  - Prior: HII regions and extinction

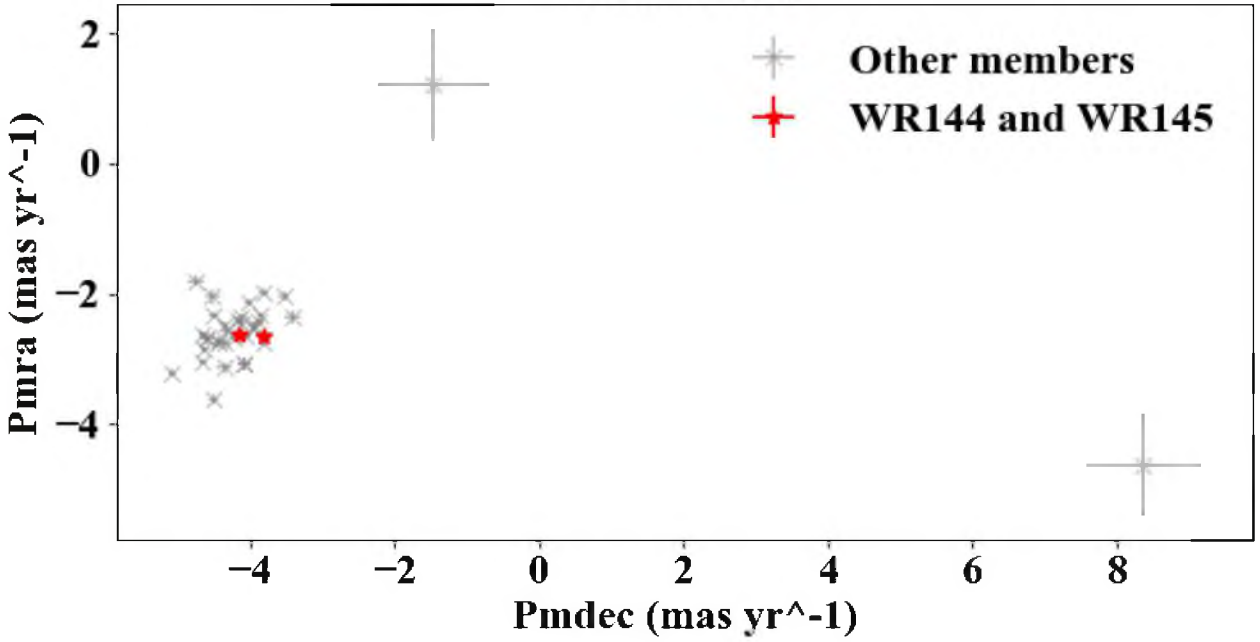


HII regions in radio



I band Extinction





O star members from Maíz Apellániz et al. (2013)

Results

- 39 / 58 claimed WR cluster members confirmed.
- 14 / 35 claimed WR association members confirmed.
- ~14% of 382 WR in clusters / associations.

- Many stars unconfirmed:
- Scatter in proper motions
  - Cluster location unclear
- Conflicting distances
- Low membership numbers
  - Sparse clusters/associations

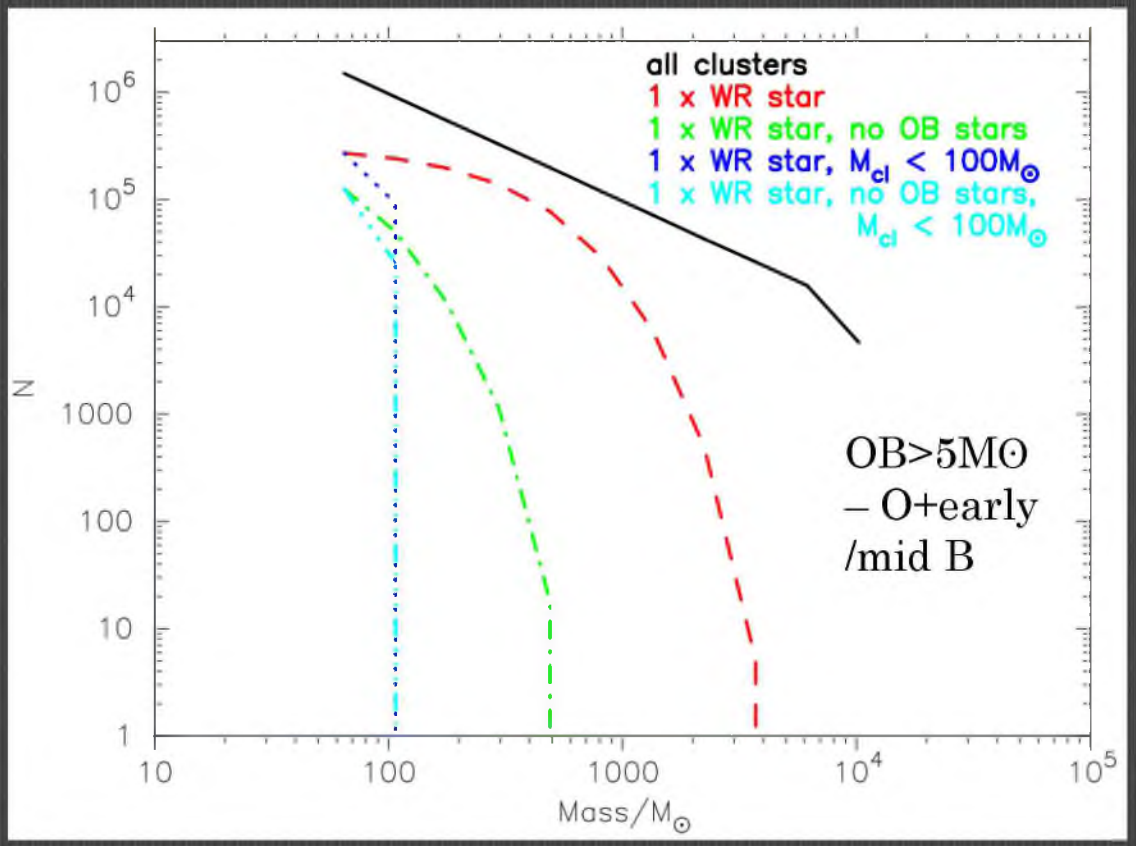
Possible causes of isolation

- Ejection from clusters and associations
  - Disruption of binary
  - Dynamical ejection
  - Produces runaways
- Born in faint / low mass regions
  - Only high mass star visible
  - Rest of region too faint
- Born in dissolving clusters / associations
  - Reach field densities over ~10Myr

Possible causes of isolation

- Ejection from clusters and associations
  - 8-16% of WR are runaways
    (Rate and Crowther, 2019, in prep).
- Low mass regions
  - Monte Carlo simulation
  - Cluster masses from power law
  - Populate using Maschberger (2013) IMF

High mass stars – Low mass groups



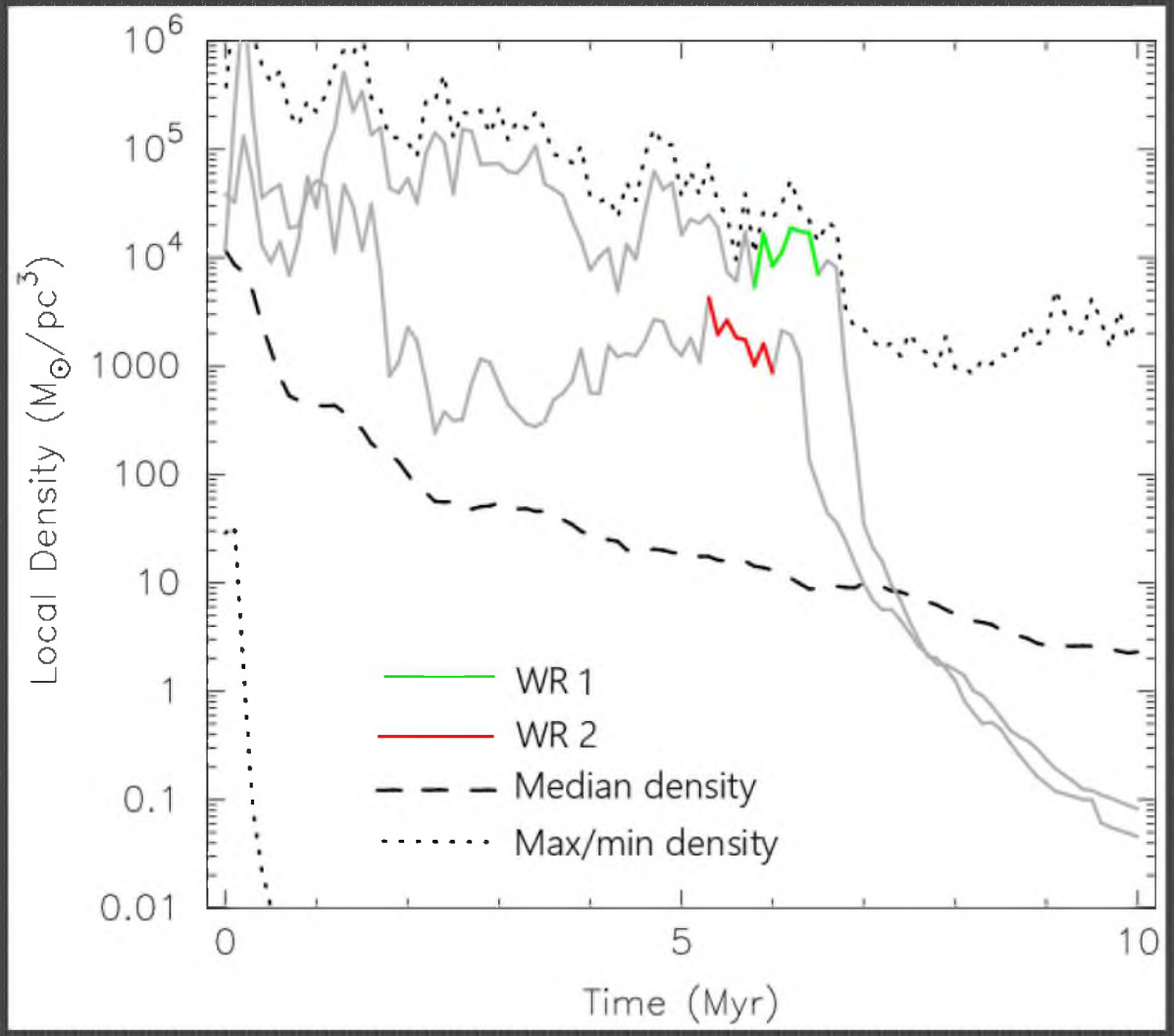
- 1 WR (>25Mo), no OB stars
  - No binaries
- 8%-15%

Cluster / Association Dissolution

- N-body simulations (based on Parker et al. 2014[1.2.]):
  - 1500 stars from IMF
  - Low / medium fractal substructure
  - Global density
  - Initial virial ratio
- Include stellar evolution
  - WR phase for >25M⊙
  - Excludes binaries

1. Parker R.J, Church R.P, Davies M.B, Meyer M.R, 2014, MNRAS, 437, 946
2. Parker R.J, Wright N.J, Goodwin S.P, Meyer M.R, 2014, MNRAS, 438, 620

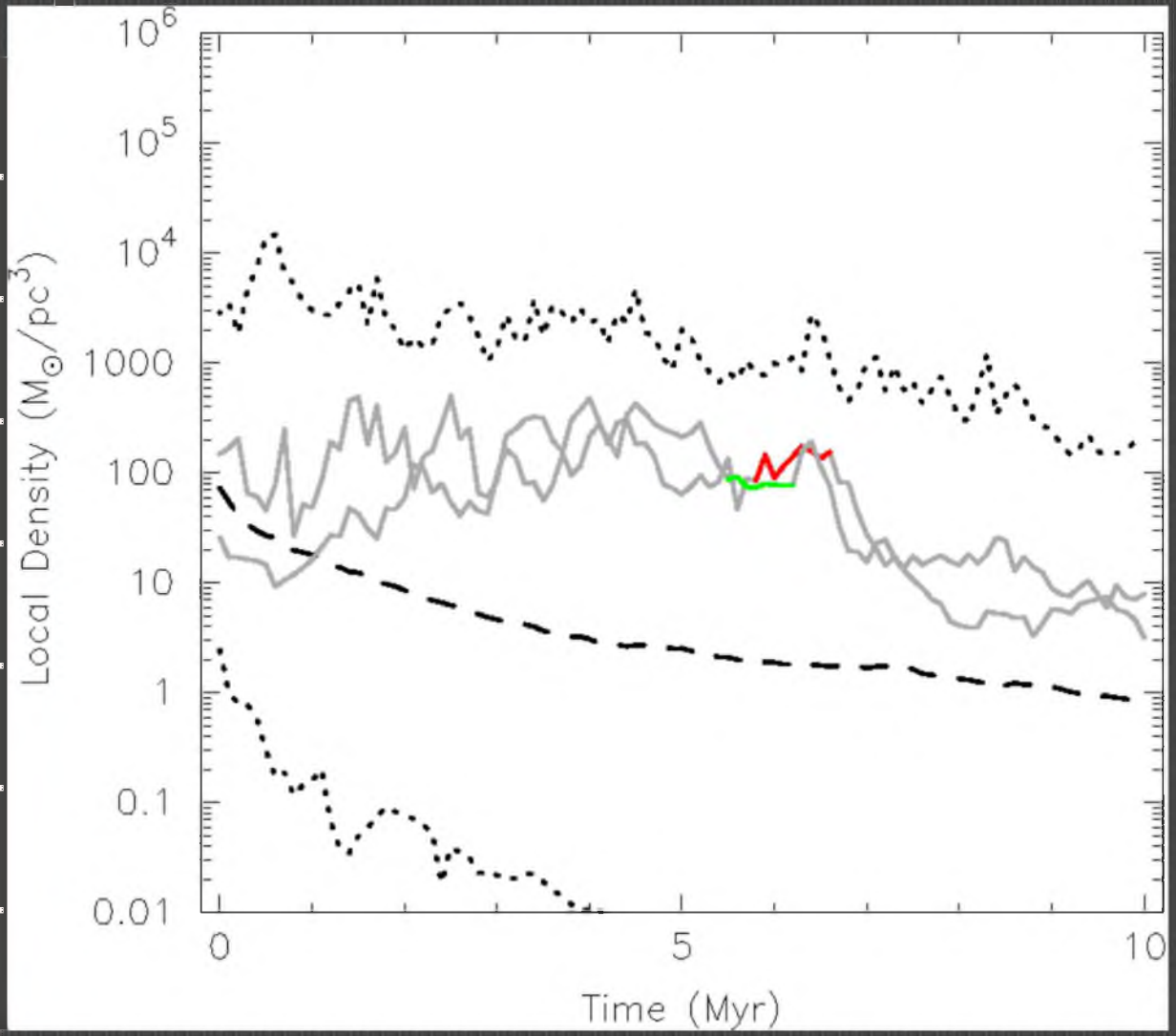
N-body simulations – Clusters



Initially dense, highly substructured

90 % in high density (1000M⊙/pc^3) regions

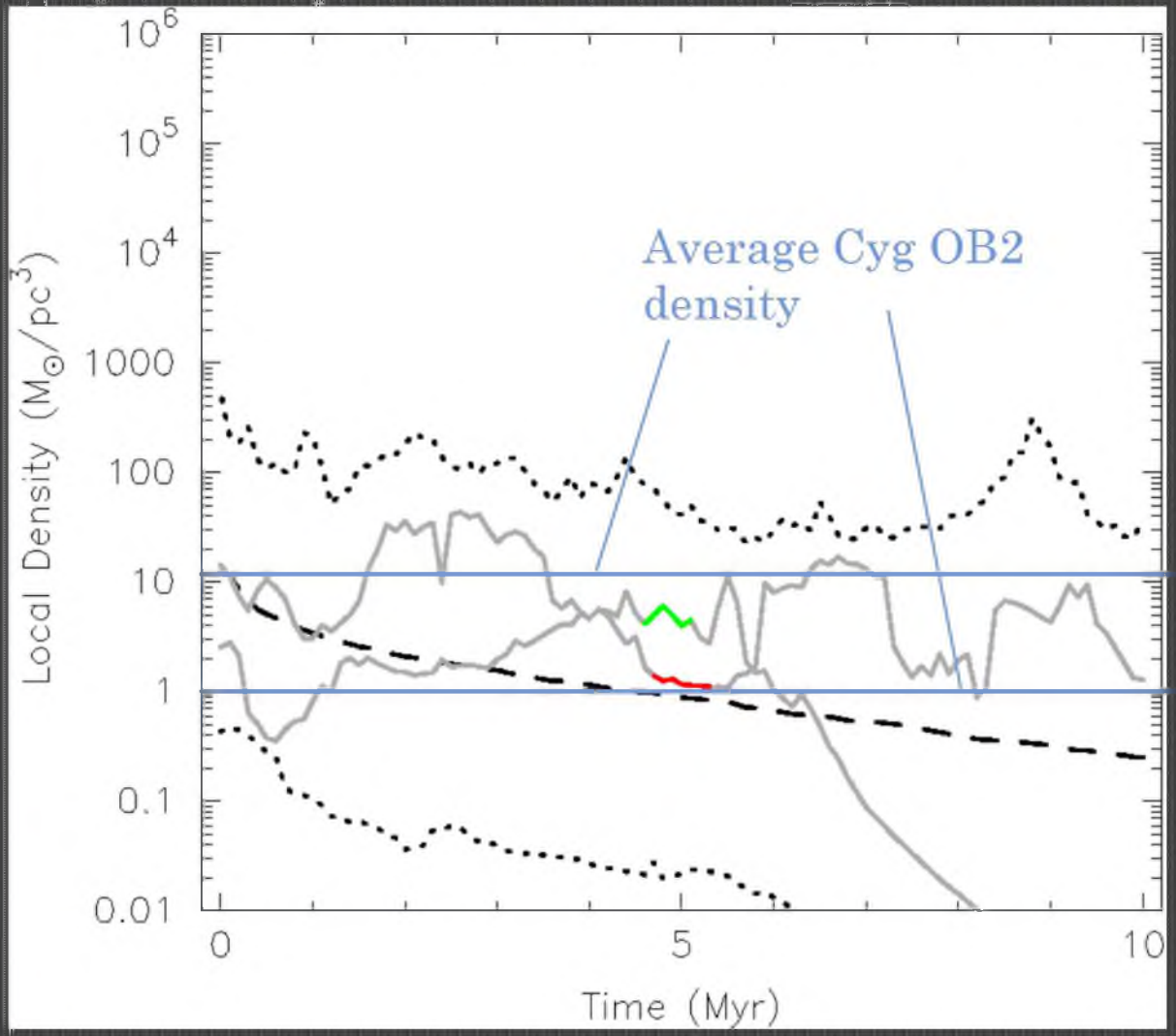
N-BODY SIMULATIONS - ASSOCIATIONS



77% of WR in ~100M⊙/pc^3 or 1000M⊙/pc^3 environments

Moderately dense, highly substructured

N-body simulations - Associations



Moderate density and substructure.

1-10M⊙/pc^3 typical.

Mass segregation avoided.

Cyg OB2 density: 1-10M⊙/pc^3 (Based on Wright et al., 2014)

Conclusions

- ~14% of 382 WR in clusters / associations.
  - 10% in clusters
  - Many stars unconfirmed.
- Causes of isolation:
  - 8-16% of WR are runaways.
  - 8-15% in low mass groups.
  - 59-74% in moderate density regions.
- Most WR formed in large, moderate density regions.
  - Dissolve over time.

Massive stars

- > 8M⊙
- Lifetime: <50Myr
- Temperature: >10,000K
- Luminosity: 10^3-10^6 L⊙
- <1% of all stars at birth

Image courtesy: ESA/Hubble & NASA

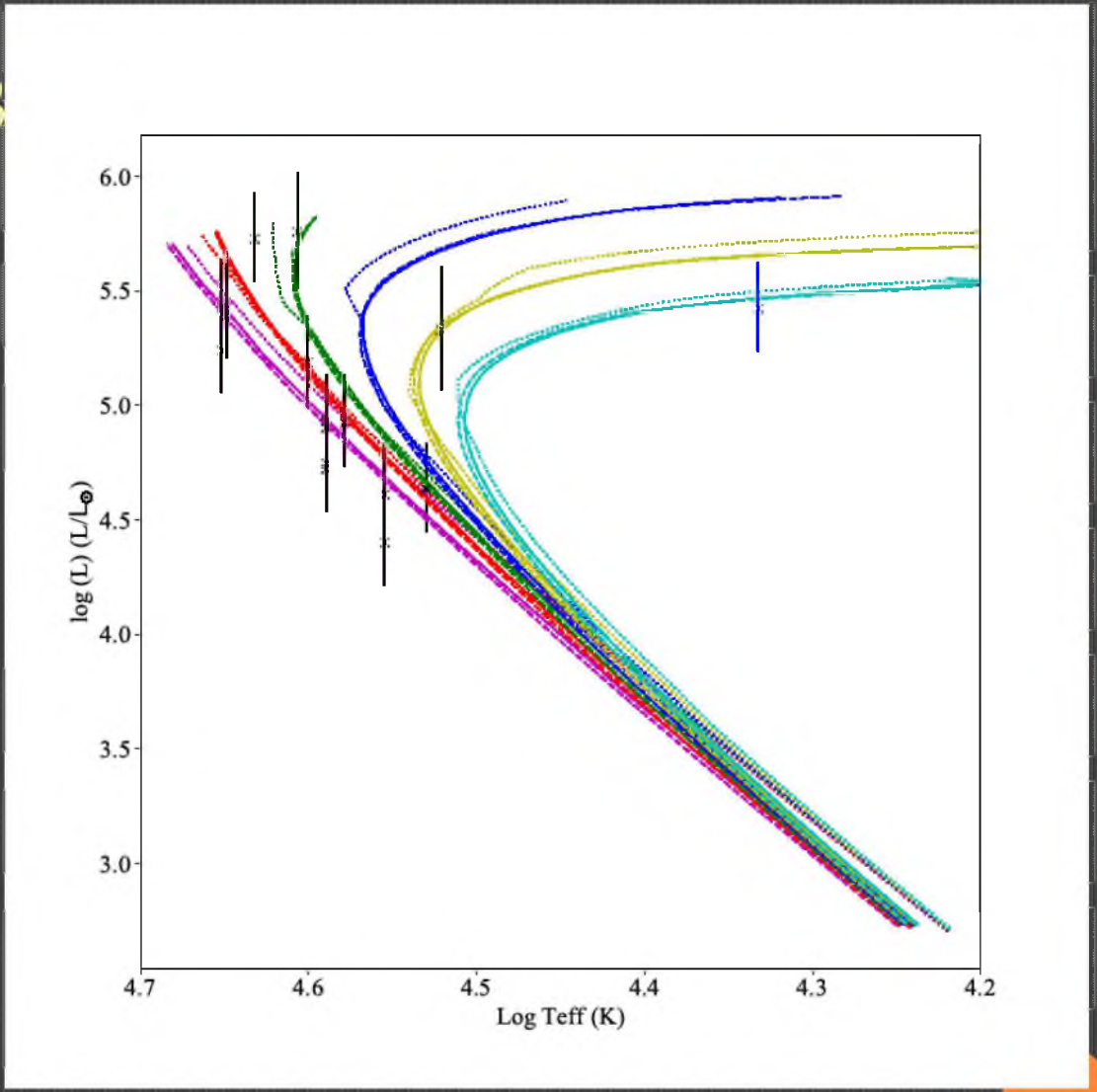
Why study massive stars?

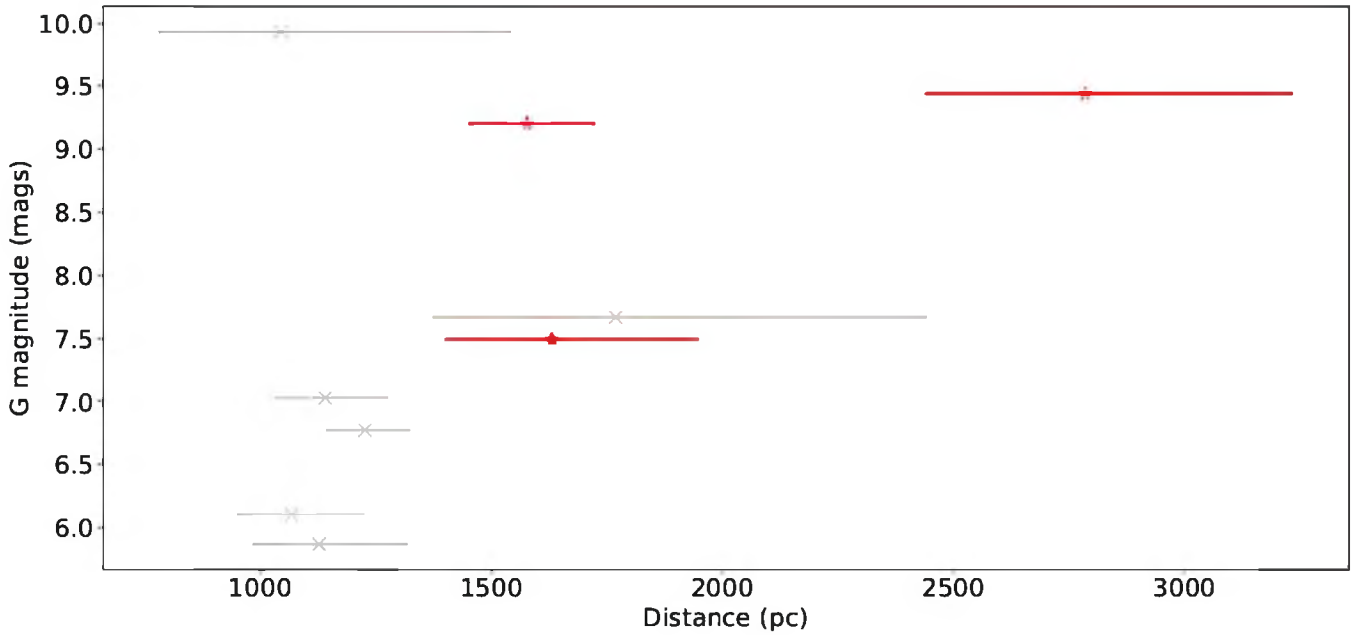
- Produce ionizing photons
  - HII regions
- Progenitors
  - GW phenomena
  - LGRBs
- Mechanical feedback
  - Stellar winds
  - Quench star formation
- Generate α process elements
  - Oxygen, carbon, etc
  - Core fusion
  - Deaths as supernovae

Image courtesy: ESA/Hubble & NASA

Isochrone fits

- Check WR subtypes match cluster ages
  - All should be < ~5Myr.
- Use other group members
- Generally good agreement.

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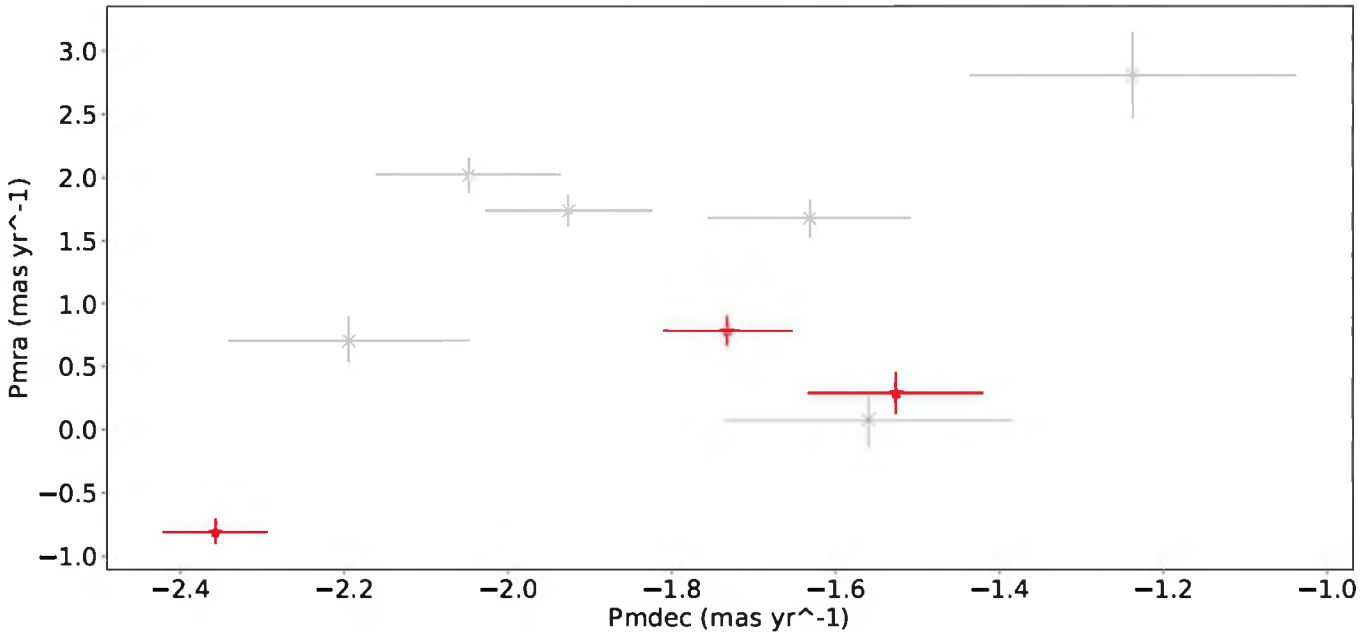
Distance (pc)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Pmdec (mas yr^-1)