VERY MASSIVE STARS IN SUPER STAR CLUSTERS

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NGC 5253

30 Dor – R 136
What is the upper mass limit for stars?

• Figer (2005) – upper mass limit is 150 M\(_{\odot}\) but this was based on Arches cluster – too old at 4 Myr to sample true IMF

• Most massive eclipsing binary: NGC 3603-A1 (116±31, 89±16 M\(_{\odot}\); Schnurr+ 2009)

• To measure upper mass limit, we need a very young (< 2 Myr), massive (> 10^4 M\(_{\odot}\)), resolved cluster = R136 in 30 Dor in LMC

• VMS are defined as stars with M > 100 M\(_{\odot}\)

• Upper mass limit in many population synthesis codes = 100 M\(_{\odot}\)
Crowther et al. (2010, 2016):

R136 in 30 Dor contains 8 VMS with $M > 100 \ M_\odot$, cluster age = $1.5 \pm 0.5$ Myr

Parameters of most massive star:
R136a1 $M=265 \pm 50 \ M_\odot$, 
$log L/L_\odot = 6.94 \pm 0.09$, $T_{\text{eff}}=53 \pm 3 \ \text{kK}$

VMS have optically thick winds – spectra are similar to W-R stars but H-rich
Crowther et al. 2016: composite spectra of R136
– He II originates from VMS
• Blue compact dwarf
• D=3.2 Mpc
• Young central starburst
• Z = 35% solar

NGC 5253 contains many young star clusters with W-R features

LEGUS: Legacy Extragalactic UV Survey – HST program aimed at studying the stellar and cluster content of 50 nearby galaxies (PI: D. Calzetti)
Two clusters at centre of NGC 5253: #5, #11

- Cluster #11: massive ultracompact H II region (Turner & Beck 2004)
- Cluster #5: peak of Hα emission in galaxy – contains optical WR features
- #5 and #11 are separated by projected distance of 5 pc
Calzetti et al. (2015):

13 band photometric study of brightest and youngest star clusters in NGC 5253

Detailed SED fits:
• Ages of #11 and #5 = 1 ± 1 Myr
• Masses = 2.5 x 10^5, 7.5 x 10^4 M☉

• The age for #5 contradicts age of 3-5 Myr from presence of WR stars in optical spectrum
• Does cluster #5 contain very massive stars?
• To answer this, analysed archival HST/ FUV STIS + FOS spectra of #5 + optical VLT/UVES spectra
NGC 5253 - #5: FOS+STIS spectra

Si IV absent
STIS FUV spectrum of #5 compared with co-added R136a STIS spectrum

#5 is 1-2 Myr old and contains VMS

- blue-shifted O V wind absorption
- broad He II emission
- Si IV P Cygni is absent


95% of He II 1640 in R136a originates in VMS (Crowther et al. 2016)
Evidence for VMS in other SSCs

- Massive star-forming regions that contain Wolf-Rayet bump at $\lambda_{4686}$ may be much younger than 3-5 Myr if VMS are causing bump

Wofford et al. (2015)
Current SSP models cannot reproduce strength of He II 1640 Å

NGC3125-A1 EW=7.1 Å

NGC 5253-5
**Ionizing Fluxes**

**R136**
- \( Q(\text{H I}) = 7.5 \times 10^{51} \text{ s}^{-1} \)
- 4 most massive VMS produce 25% of ionizing flux (Doran et al. 2013)

**NGC 5253 – clusters #5 and #11**
- \( Q(\text{H I}) = 2.2 \times 10^{52} \text{ s}^{-1} \) for central 5 pc region (Turner & Beck 2004)
- Only 50% of this flux is accounted for from SED modelling (Calzetti et al. 2015) – extends to \( M_{\text{upper}} = 100 \, M_{\odot} \)
- For clusters #5, #11, we need just 12 VMS to supply extra ionizing flux
Choi, Conroy & Byler (2017) – model NGC 5253 clusters using $M_{\text{upper}} = 300 \, M_\odot$ and find they can match observed $Q(H)$ if VMS are included.
• NGC 5253 is a young, low Z, nuclear starburst

• The nuclear cluster #5 is < 2 Myr old and contains very massive stars

• Cannot assume massive star-forming regions displaying W-R features are 3-5 Myr old – could be VMS present

• Need to find more local examples of young, massive clusters containing VMS by obtaining UV spectra with HST – will do this in Cycle 25

• JWST will obtain UV rest frame spectra of high-z galaxies - will their spectra show VMS?

• Population synthesis models need to be extended to include VMS, which will dominate the mechanical, chemical and ionizing feedback in the first 2 Myr for young massive clusters
High Redshift Galaxies

- JWST will obtain UV rest frame spectra of high-z galaxies - will their spectra show VMS?

- Clear signature will be presence of broad He II emission, O V wind absorption and the absence of Si IV P Cygni emission

- Population synthesis models need to be extended to include VMS, which will dominate the mechanical, chemical and ionizing feedback in the first 2 Myr for young massive clusters
Optical bump characteristics

Cluster #5 and R136a: broad He II 4686 only
Chemical enrichment

- Giant H II region (50 pc) ionized by central clusters is enriched in N by x 2-3 (Walsh & Roy 1987, Kobulnicky et al. 1997, Monreal-Ibero et al. 2010, 2012)

- Source of N enrichment is a puzzle
  - WR stars?
  - But no He enrichment (Monreal-Ibero et al. 2013)
  - Kobulnicky et al (1997) suggested late O stars as source of N enrichment

- Can fast rotating massive stars produce N enrichment?

Ionized outflow centred on nuclear clusters with $v_{\text{exp}} \sim 70 \text{ km s}^{-1}$ (Westmoquette et al. 2013)
Nitrogen Enrichment

Köhler et al (2015): LMC evolutionary model grids from 70-500 $M_\odot$ with rotation - N enrichment is ubiquitous

Surface N abundance

- $V_{\text{rot}} = 20\%$ critical
- $V_{\text{rot}} = 10\%$ critical

20\% critical case – observed N enrichment of N=7.45 is reached after 0.26 Myr

He abundance increases after 2.2 Myr

Dynamical time scale for enrichment = 0.5 Myr

Mass of excess N from observations = 1-10 $M_\odot$ depending on filling factor (0.01-0.1)

This mass can be produced by rotating stars with $M > 50 M_\odot$ given cluster mass