# VERY MASSIVE STARS IN SUPER STAR CLUSTERS

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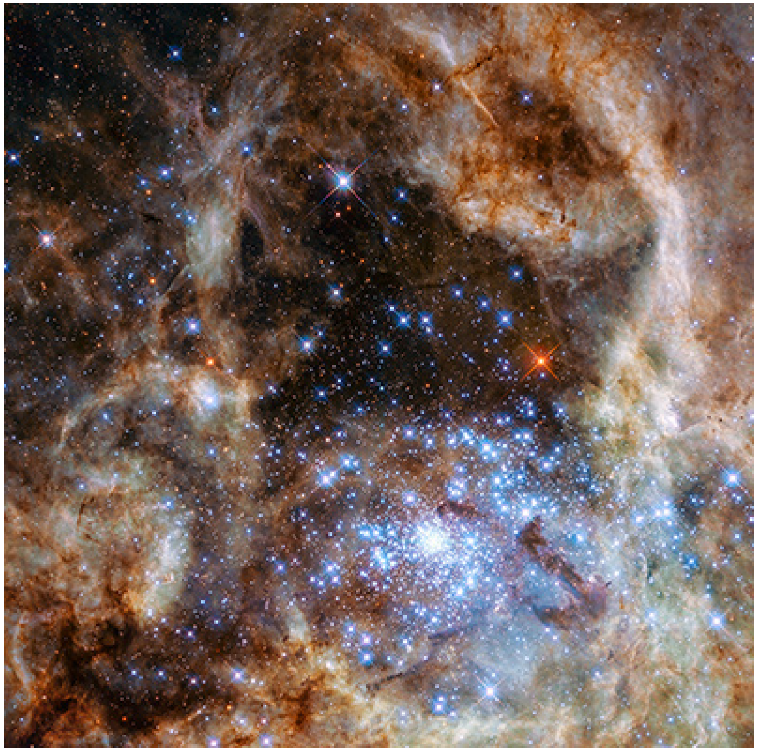
NGC 5253

30 Dor – R 136



# Preamble

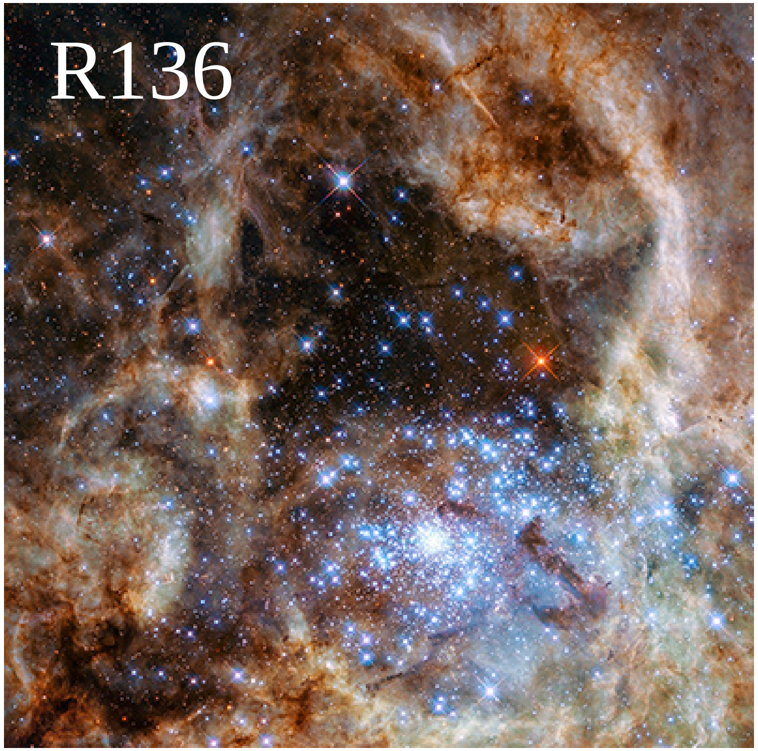
## What is the upper mass limit for stars?

- 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 $M_\odot$

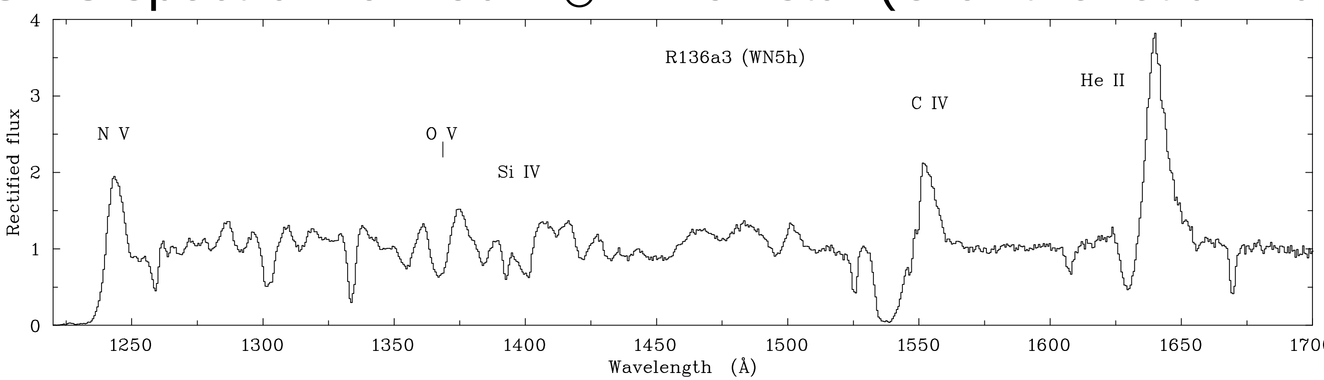



Crowther et al. (2010, 2016):

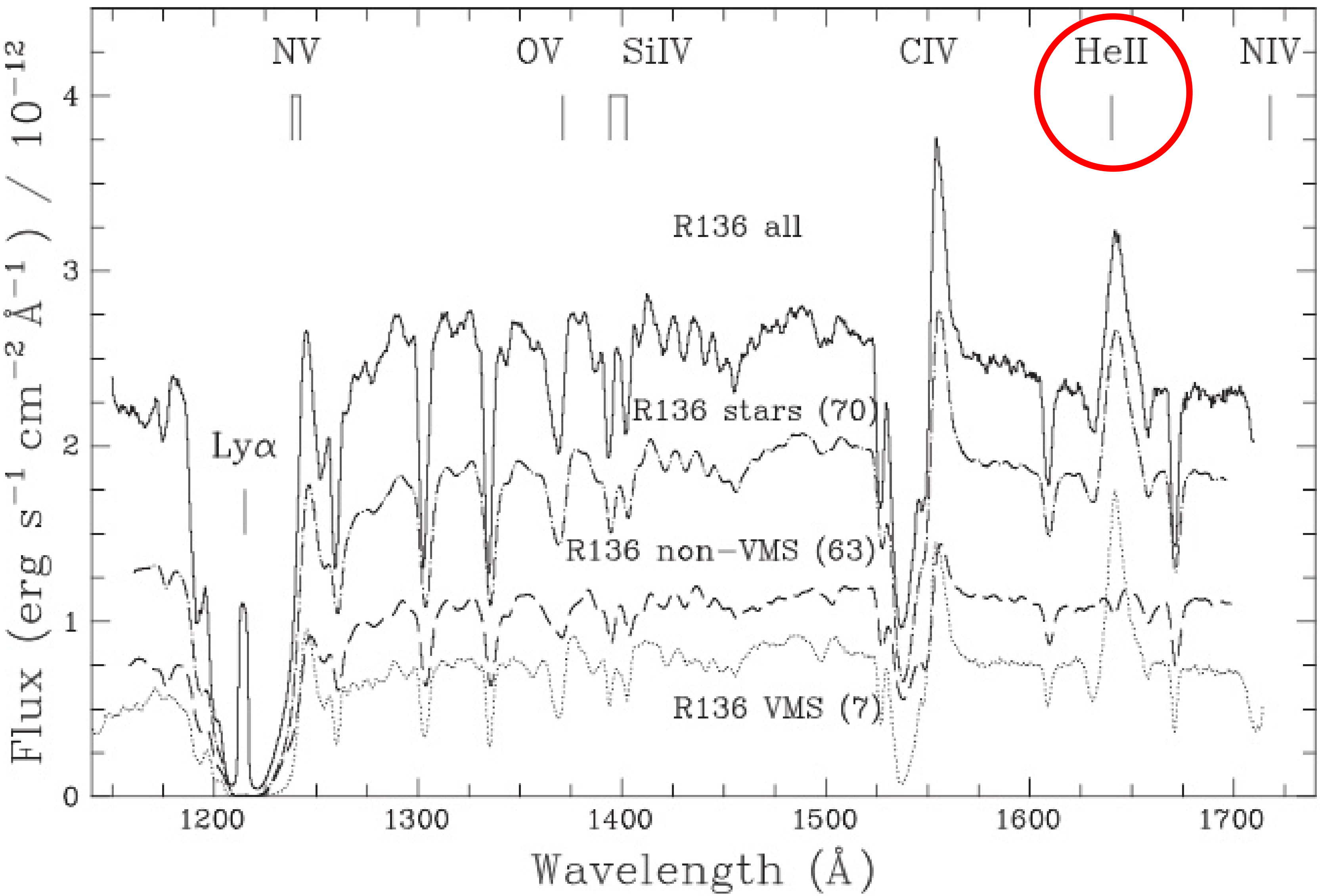
R136 in 30 Dor contains 8 VMS with
M > 100 $M_\odot$, cluster age = 1.5± 0.5 Myr

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

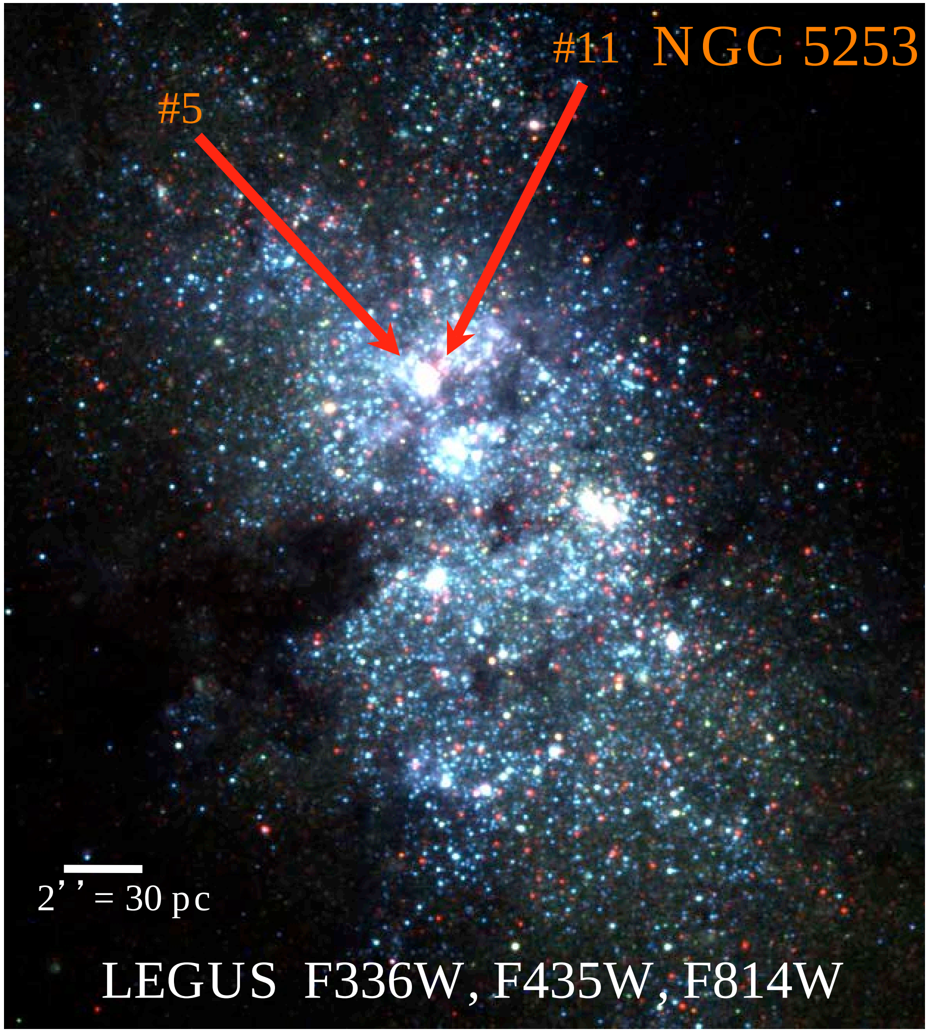
STIS spectrum of 180 $M_\odot$ WN5h star (Crowther et al. 2016)




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

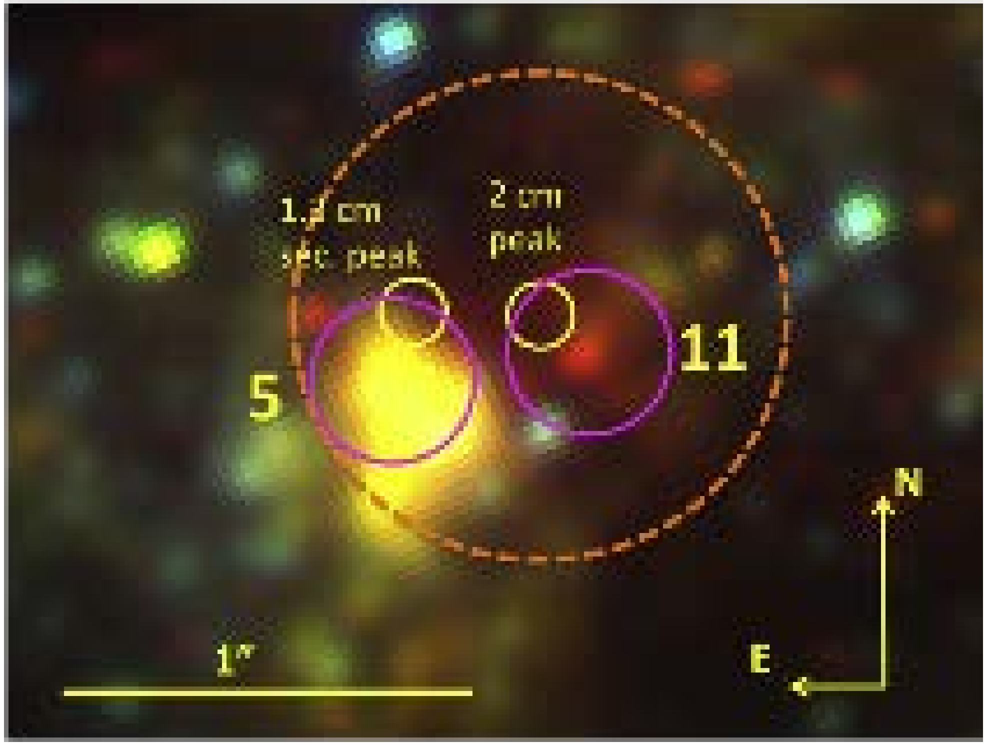



- Blue compact dwarf
- D=3.2 Mpc
- Young central starburst
- Z = 35% solar

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




F125LP, F336W, F814W

- 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:

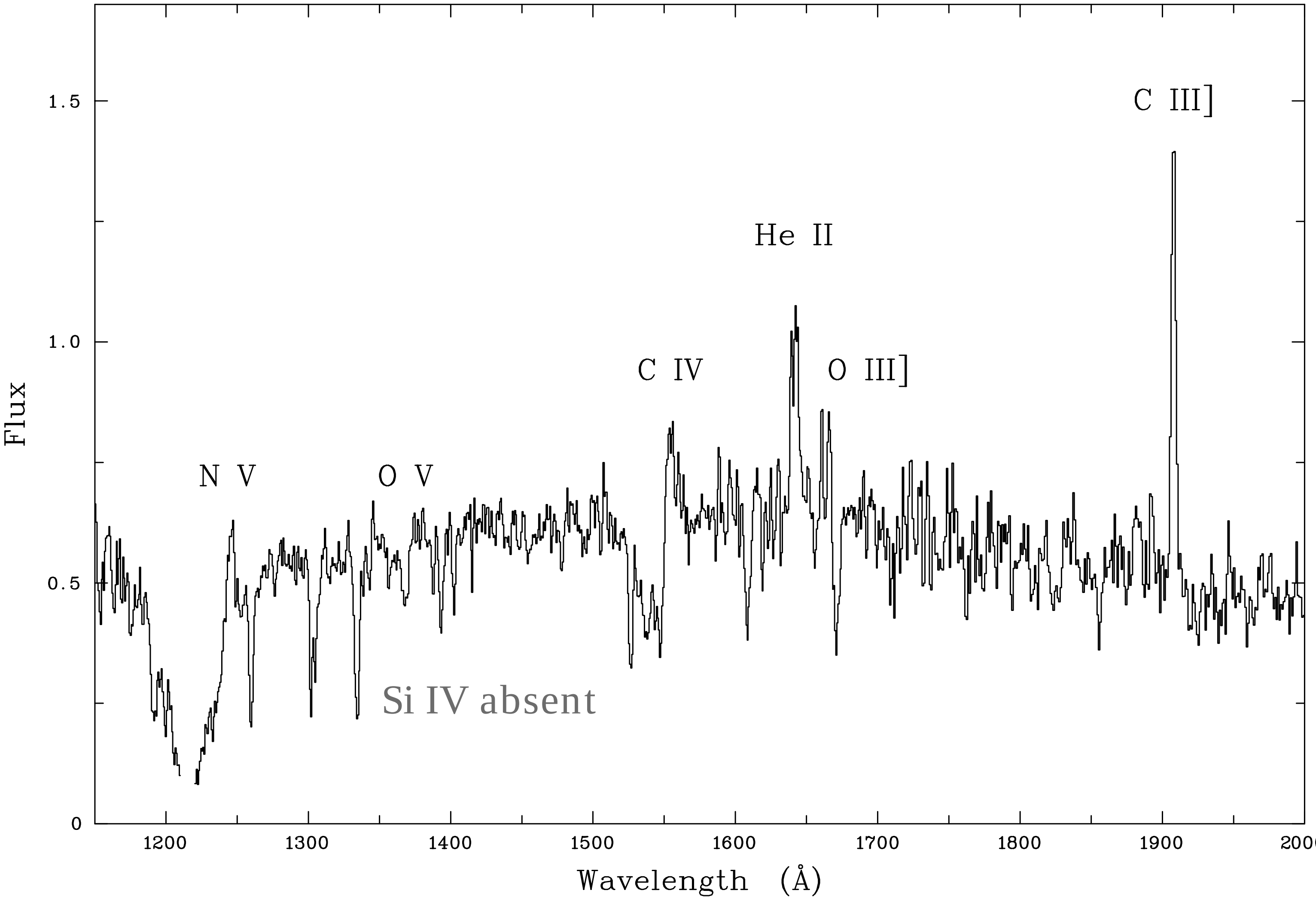
- Ages of #11 and #5 = 1 $\pm$ 1 Myr
- Masses = 2.5 x $10^5$ , 7.5 x $10^4$ $M_\odot$

- The age for #5 contradicts age of 3-5 Myr from presence of WR stars in optical spectrum

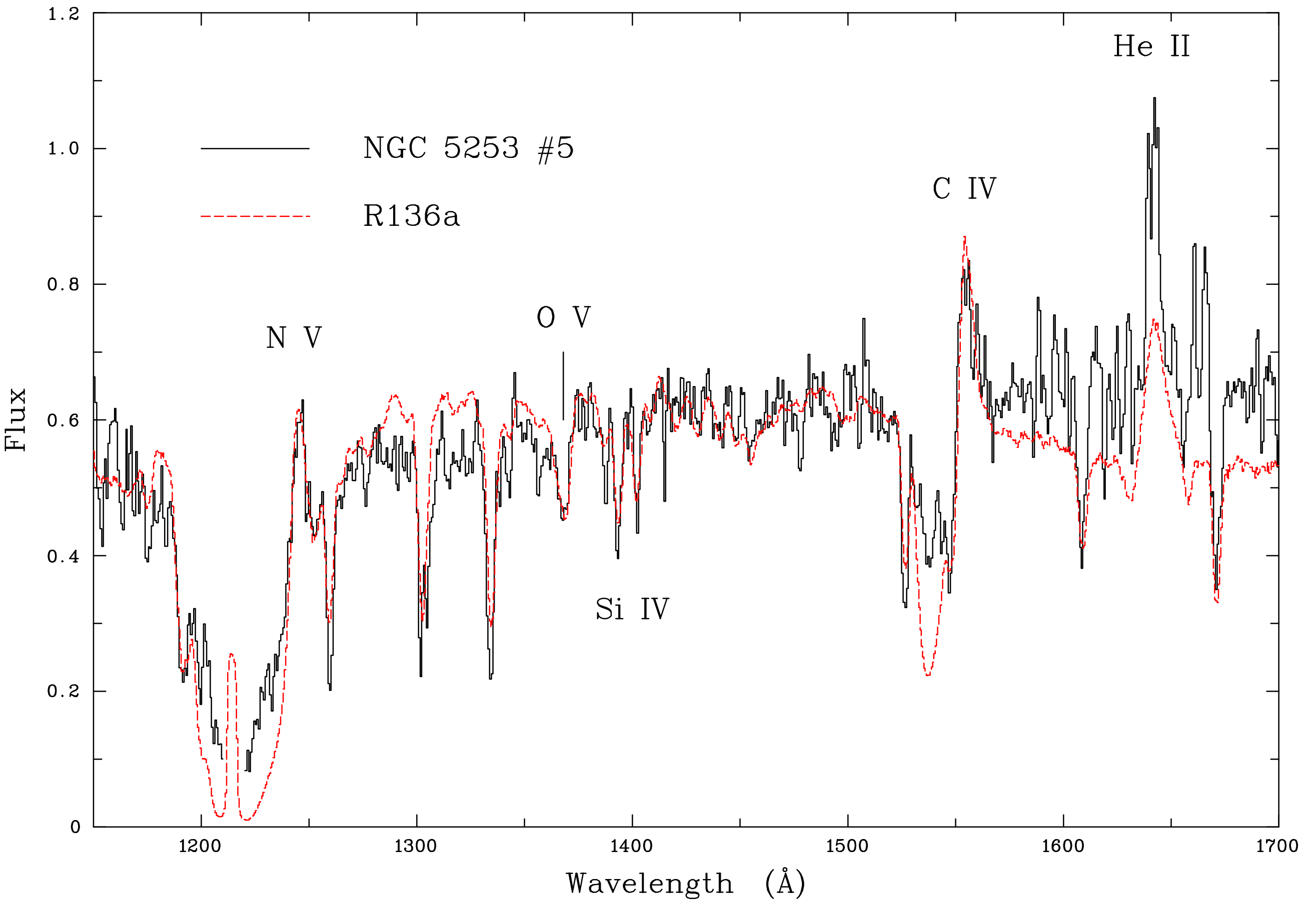
- Does cluster #5 contain very massive stars?

- To answer this, analysed archival HST/ FUV STIS + FOS spectra of #5 + optical VLT/UVES spectra

# NGC 5253 - #5: FOS+STIS spectra



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




Smith et al., 2016, ApJ, 832, 38

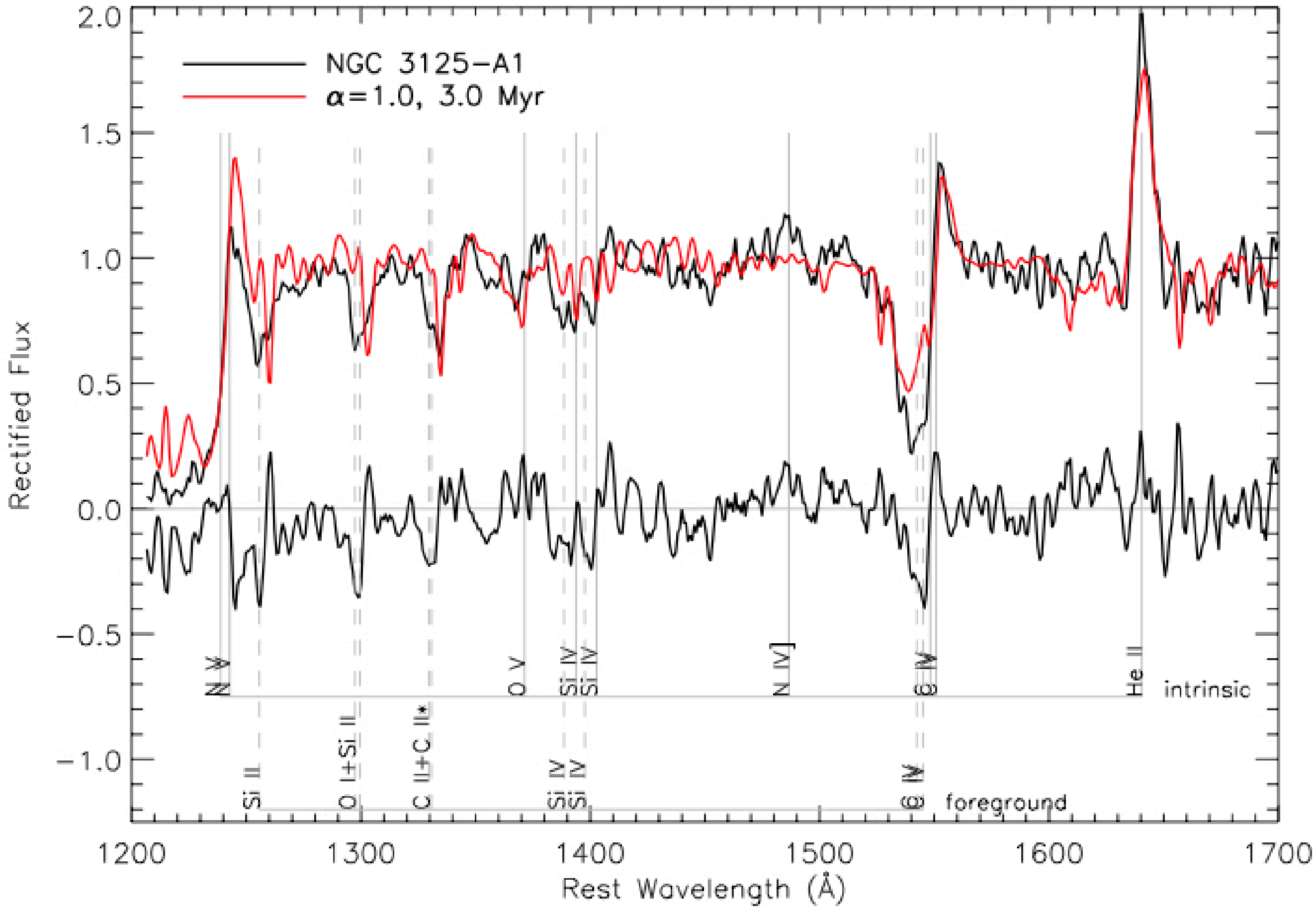
#5 is 1-2 Myr old and contains VMS

- 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

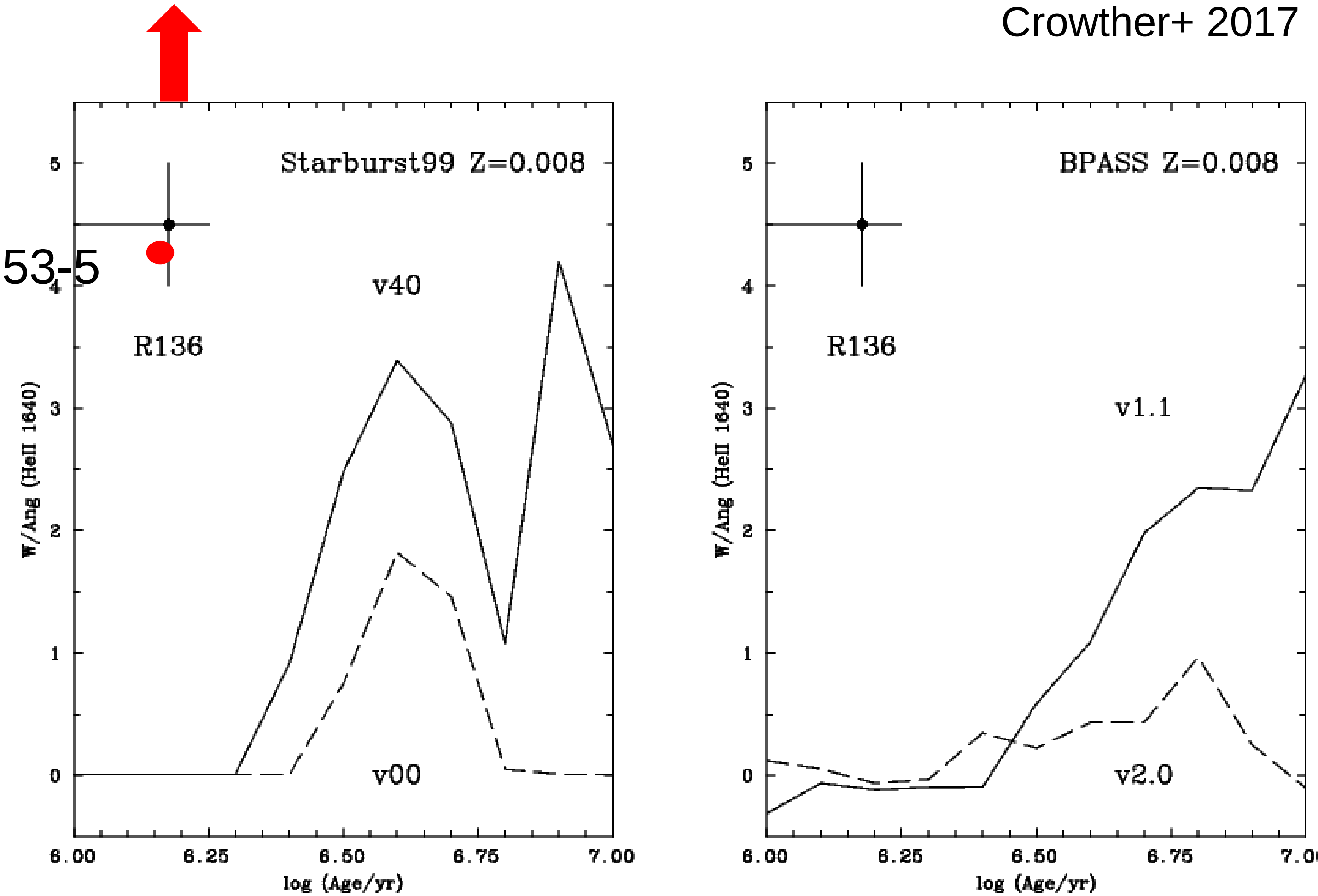
- Massive star-forming regions that contain Wolf-Rayet bump at λ4686 may be much younger than 3-5 Myr if VMS are causing bump




Wofford et al. (2015)

NGC3125-A1 EW=7.1 Å

Crowther+ 2017




Current SSP models cannot reproduce strength of He II 1640

# Ionizing Fluxes

## R136

- $Q(H\ I) = 7.5 \times 10^{51}\ s^{-1}$
- 4 most massive VMS produce 25% of ionizing flux

(Doran et al. 2013)

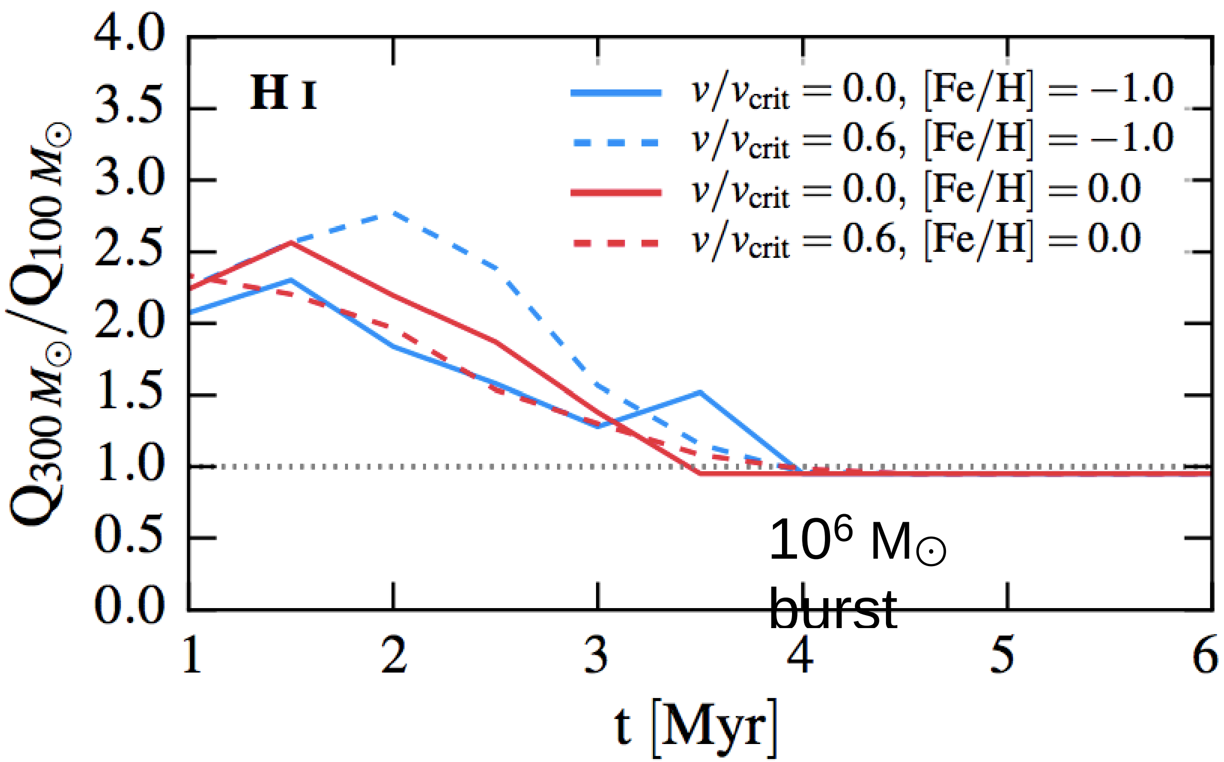
## NGC 5253 – clusters #5 and #11

- $Q(H\ I) = 2.2 \times 10^{52}\ s^{-1}$ 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 $M_{upper} = 100\ M_{\odot}$

- For clusters #5, #11, we need just 12 VMS to supply extra ionizing flux

# Ionizing Fluxes – Stellar Population Synthesis Modelling




Choi, Conroy & Byler ( 2017) – model NGC 5253 clusters using $M_{upper}$ = 300 M⊙ and find they can match observed Q(H) if VMS are included

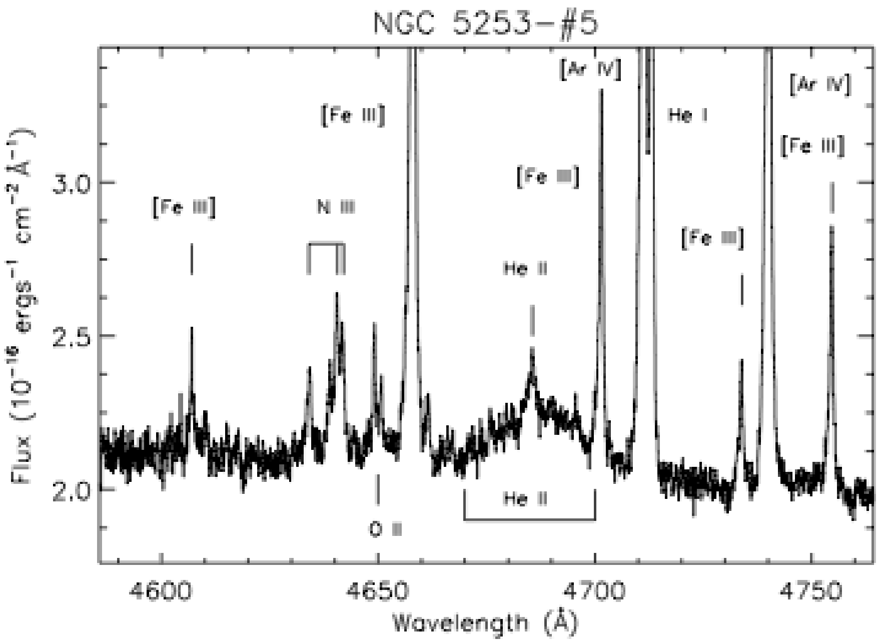
# Summary

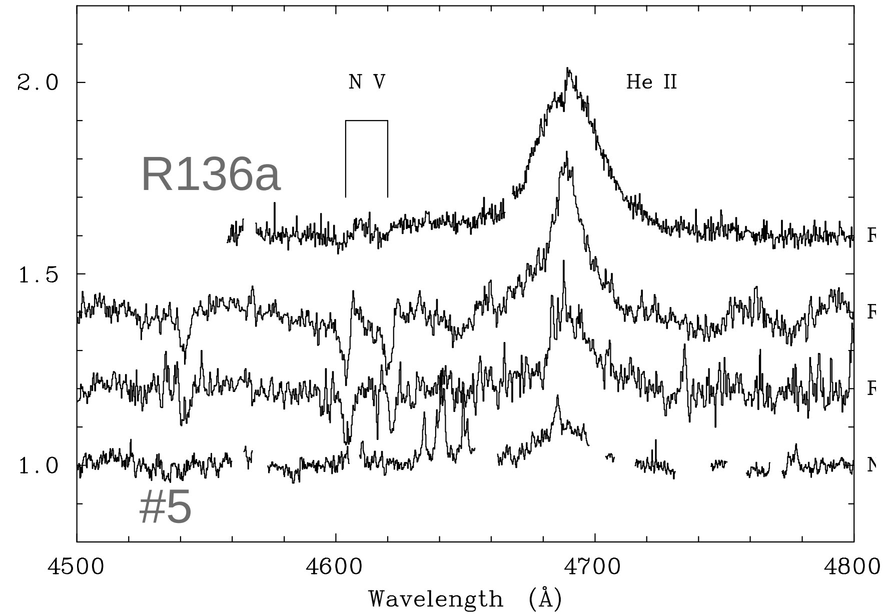
- NGC 5253 is a young, low Z, nuclear starburst
- The nuclear cluster #5 is < 2 Myr old and contains very massive stars
- Cannot assume massive star-forming regions displaying W-R features are 3-5 Myr old – could be VMS present
- Need to find more local examples of young, massive clusters containing 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

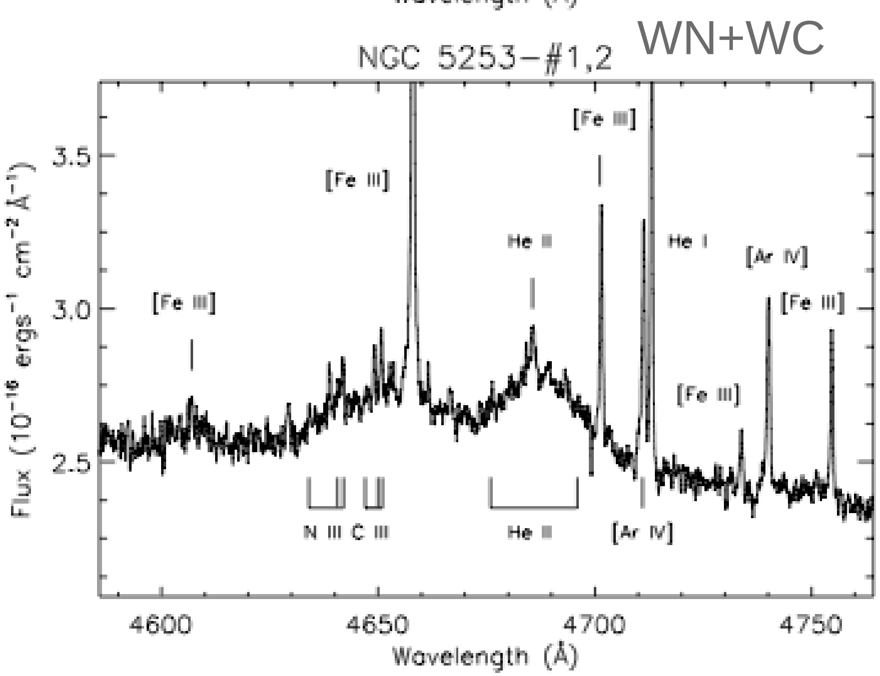
# High Redshift Galaxies

- 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

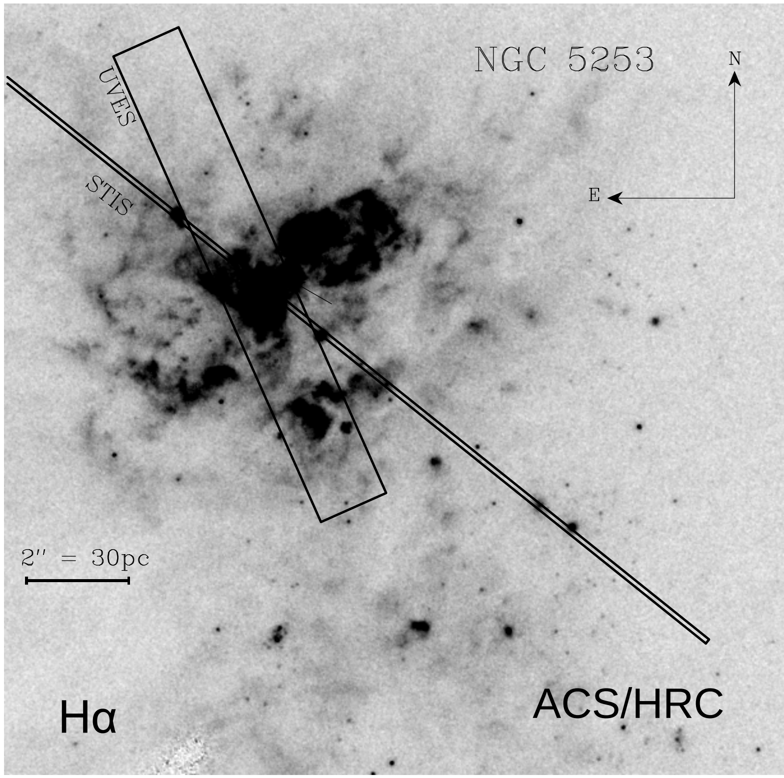



Cluster #5 and R136a: broad He II 4686 only

# Chemical enrichment

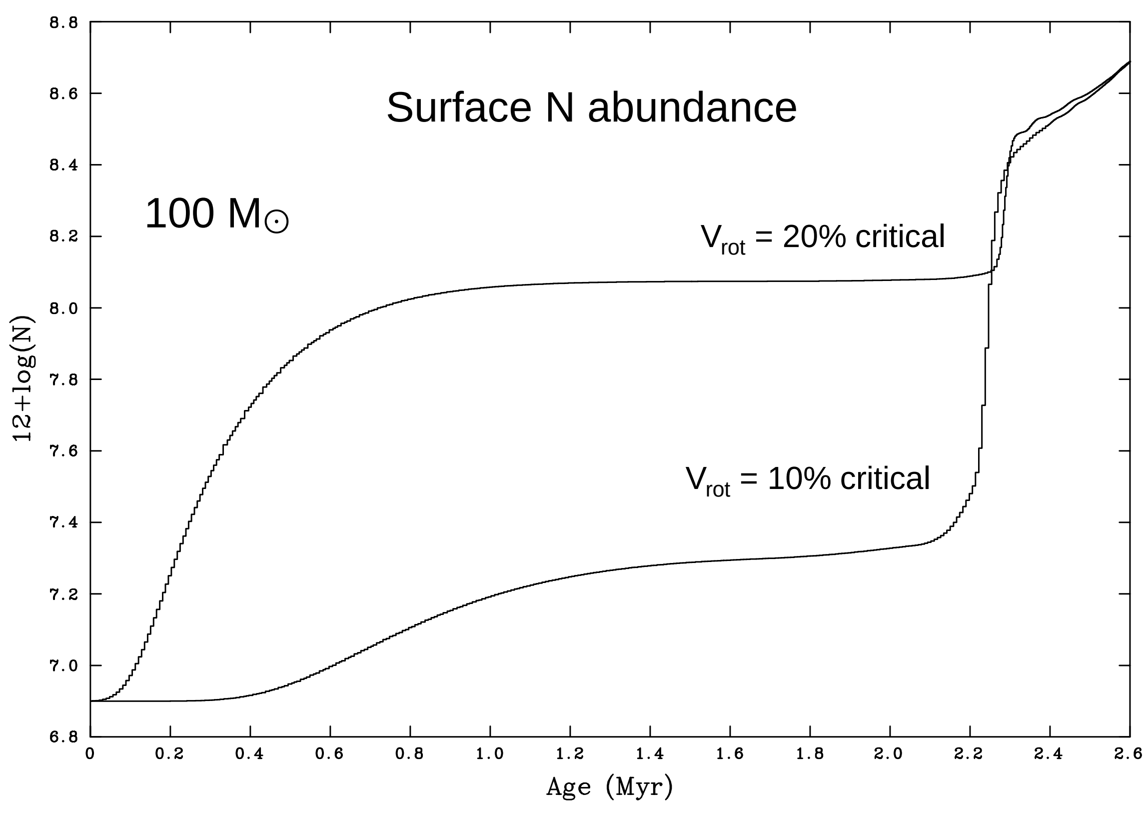



Ionized outflow centred on nuclear clusters with $v_{exp} \sim 70$ km $s^{-1}$ (Westmoquette et al. 2013)

- 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?

# Nitrogen Enrichment

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




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