Hot Massive Stars: The Impact of HST

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Mk34 (30 Dor)

Ground image at 0.6 arcsec resolution
WFPC-1 image (before servicing)
WFPC-2 image (after servicing)
Outline

• Massive stars - Introduction
• Stellar winds - Metallicity dependent winds
• Ejecta nebulae - Signatures of mass ejections
• Massive binaries - Colliding winds
• Young star clusters - A plethora of hot stars
• Starbursts knots - Templates for high-z galaxies
High Mass Stars

- High mass stars \((M_{\text{init}} > 8-9M_\odot)\), end their lives as core-collapse SN (Smartt talk).
- They possess high central pressures & temperatures & so burn much brighter than lower mass stars. For Solar-type stars \(L \sim M^{4.7}\) while for high mass stars \(L \sim M^{2.5}\).
- A 25 \(M_\odot\) star shines 50,000 times brighter than the Sun, so that it lives for only 1/2000 of the Solar lifetime (5Myr versus 11,000Myr for Sun).
Importance of massive stars

- Massive stars are intrinsically luminous, so may be detected individually to large distances (e.g. Blue supergiants seen at Mpc distances);
- O stars are the primary source of Lyman cont. photons in galaxies, & so enable the primary diagnostic of SFR (e.g. L(H\(\alpha\)), Kennicutt 1998);
- Stellar winds are up to \(10^9\) more powerful than the Solar case \(\Rightarrow\) chemical enrichment, kinetic energy;
- In high-\(z\) star forming galaxies, signatures of massive stars are seen directly (UV continua, wind lines) & indirectly (ionized gas).
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UV P Cygni profiles provide diagnostics of mass-loss from hot star winds.

IUE provided comprehensive UV spectroscopy of Galactic OB stars (e.g. Howarth & Prinja 1989). Extension to Magellanic Clouds required HST/FOS for O stars (Walborn et al. 1995) & HST/STIS for B supergiants (Evans et al. 2004).

See Lennon talk

Stellar Winds

![Stellar Winds Diagram](image)
Metallicity dependent winds

Winds predicted to be driven by radiation pressure through (CNO, Fe-peak) metal-lines (Puls et al. 2000; Vink et al. 2001).

HST confirmed expected weaker, slower winds in low metallicity SMC (e.g. Prinja & Crowther 1998)
VLT/FLAMES survey

‘Young’ clusters
(<5 Myr)

‘Old’ clusters
(10-20 Myr)
Mass-loss rates

Theory: \( \frac{dM}{dt} \propto Z^{0.69 \pm 0.10} \)

Obs: \( \frac{dM}{dt} \propto Z^{0.78 \pm 0.17} \)

(Mokiem et al. submitted)

VLT/FLAMES survey provides \( \frac{dM}{dt} \)
(Mokiem et al. 2006, 2007). Z-dependent OB star winds needed for evolutionary models.
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Recent mass-loss history of Wolf-Rayet star WR124 revealed by ejecta nebula (Grosdidier et al. 1998). Radial density distribution of nebula provides wind structure & enables photo-ionization models of central star (Crowther et al. 1999).
In addition to continuous winds, some blue supergiants occasionally undergo violent eruptions.
Homunculus

η Car ‘erupted’ in 19th Century, becoming 2nd brightest star in sky, forming the Homunculus, a dusty reflection nebula (10 $M_\odot$?) illuminated by the star.
HST/WFPC2 image (50mas = 115AU res) shows the expansion from 4/94 - 9/95 (Morse et al. 1998).

A physical mechanism remains unclear (see e.g. Smith & Townsend 2007).
Recent effort has focused upon nature of central star, apparently a binary (5.5yr period). STIS 0.1x0.1” long-slit spectrum of central star reveals extreme parameters of $L=5 \times 10^6 \, L_\odot$, $\frac{dM}{dt}=10^{-3} \, M_\odot/yr$ (Hillier et al. 2001)
Mass ejections from other hot luminous stars have been discovered with HST such as Sher 25 (in NGC 3603), reminiscent of SN 1987A (Brandner et al. 1997).
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Radio surveys of massive binaries (e.g. Williams et al. 1997) reveal thermal (stellar wind) & non-thermal (colliding winds) components.

Positions of stars established by WFPC2 (Niemela et al. 1998) enabling their relative wind strengths.
New massive binaries

FGS enables searches for massive binaries in parameter space between spectroscopic (weeks) & astrometric (centuries) techniques.

Survey of 23 OB stars in Carina revealed 5 new binaries, including an early O dwarf companion to HD93129A (prototype O2 supergiant), separated by only 55 mas (137AU). Later confirmed by detection of non-thermal radio emission.

Nelan et al. (2004)
To date, the 3.7 day eclipsing binary system WR20a (2 x WN6) hosts the highest masses (82$M_\odot$, 83 $M_\odot$),

Rauw et al. 2004

Bonanos et al. 2004
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Historically R136a, the ionizing cluster of 30 Doradus in the LMC, was considered as a potential supermassive star. Weigelt & Baier (1985) first resolved R136a into multiple components using speckle imaging.
A plethora of early O stars

HST/FOS (Massey & Hunter 1998) spectroscopy revealed a multitude of early O stars in R136, indicating youth (1-2 Myr) & high individual stellar masses (>120 M☉). Total stellar mass of R136 probably exceeds 5x10⁴ M☉.
Starbirth in 30 Doradus

Heydari-Malayeri talk

30 Doradus Nebula Details

HST • WFPC2 • NICMOS

PRC99-33b • STScI OPO • N. Walborn (STScI), R. Barbá (La Plata Observatory) and NASA
HST also spatially resolved the Milky Way cluster NGC 3603 (Brandner et al. 1997), again revealing many early O stars (Drissen et al. 1993).

Central cluster comparable to R136a in 30 Doradus within ~1pc (Crowther & Dessart 1998).
The Arches young massive cluster in the Galactic Centre has been spatially resolved with NICMOS, permitting its present-day Mass Function to approximate the IMF, suggesting an upper stellar mass limit of \( \sim 150 \, M_\odot \).
Westerlund 1 (Wd1) is a highly reddened ($A_v \sim 10$ mag) young, compact Galactic cluster.

Discovery of Wolf-Rayet stars, Luminous Blue Variables, yellow hypergiants, red supergiants at ESO suggest Wd1 represents a very high mass cluster.
NTT imaging of low mass stars suggests a mass of $6 \times 10^4 \, M_\odot$ (Brandner et al. 2007) in agreement with $M_{\text{dyn}} \sim 4 \times 10^4 \, M_\odot$ from VLT spectroscopy (Mengel & Tacconi-Garman 2007).

NTT/SOFI survey reveals 24 WR stars, from which $\tau \sim 5 \, \text{Myr}$ obtained (Crowther et al. 2006).
WR population of giant HII regions in NGC 1313 (4Mpc), is within reach of VLT/FORS (Hadfield & Crowther 2007). HST/ACS invaluable in disentangling stellar content, reminiscent of NGC 604 in M33 (Drissen et al. 1993).
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Far-UV spectroscopy of starburst clusters

STIS UV spectroscopy of individual clusters (Chandar et al 2004) enables ages, from comparison with spectral synthesis predictions.
For NGC3125-A1 cluster (0.4Z☉), UV spectral synthesis models imply 4Myr (2×10^5 M☉), based on Magellanic Cloud template OB stars from HST (Hadfield & Crowther 2006).
IZw18

STIS spectroscopy of clusters within HII galaxy IZw18 (~1/30 $Z_\odot$, Aloisi talk) reveals WR signatures (Brown et al. 2002; Crowther & Hadfield 2006).

Brown et al. 2002
Lyman Break galaxies

Composite Keck rest-frame UV spectrum of 811 $z \sim 3$ Lyman Break galaxies (Shapley et al 2003) includes spectral O & WR signatures. Wiklind talk
Lensed Lyman break galaxy MS1512-cB58 (z\sim 2.7)

Pettini et al. (2003) were only able to reproduce its rest-frame UV spectrum with Magellanic Cloud templates rather than Galactic OB stars.

Low metallicity of MS1512-cB58 from wind lines is in agreement with ISM techniques (Pettini et al. 2002)
Summary

• **UV sensitivity:**
  • UV stellar signatures of Magellanic Cloud OB stars critical to Z-dependent winds;
  • Metal-poor hot star templates of application to high-z star forming galaxies

• **High spatial resolution:**
  • Stellar ejecta associated with hot massive stars;
  • Resolved stellar populations in Local Group massive clusters;
  • Young star clusters in more distant galaxies
IAU Symposium 250

MASSIVE STARS AS COSMIC ENGINES

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– Atmospheres of massive stars;
– Physics & evolution of massive stars;
– Massive stellar populations in the nearby Universe;
– Hydrodynamics & feedback from massive stars in galaxy evolution;
– Massive stars as probes of the early Universe

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