The spectacular lives and deaths of Massive Stars
and future UVOIR Space Astronomy

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and future UVOIR Space Astronomy

Challenges

- Rare and short lived
  → Need for larger and larger distances

- Emit most of their light in the UV
  → Need for Space

- Form in crowded regions with companions
  → Need for superb spatial resolution
1. Introduction and motivation
Many roles of Massive Stars in Astrophysics

(1) Cosmic Engines
(2) Cosmic Probes
First Stars
Next Generations of Massive Stars
Cosmic Dark Ages

How did we get here?
Many roles of Massive Stars in Astrophysics

(I) Cosmic Engines
- Reionization
- Chemical enrichment
- Heating
- Seeding turbulence
- Galactic-scale outflows

(II) Cosmic Probes
- Cosmic Dark Ages
- First Stars
- Next Generations of Massive Stars

How did we get here?

Many fields rely (directly or indirectly) on massive star models

High redshift galaxies: Star formation history, IMF
Most energetic explosions
Extreme physics of NS & BHs
Nearby stellar populations
Probes of intervening gas (IGM, ISM)

Many roles of Massive Stars in Astrophysics

Reionization
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First Stars
Next Generations of Massive Stars

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High redshift galaxies: Star formation history, IMF
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What we tell our students ...
(the classic models that are widely used in astrophysics)
Hertzsprung-Russell diagram
... one century later ...

Log Effective Temperature (K)

Log Luminosity (Lsun)
How well do the classic widely used models do?
Data: VLT-FLAMES Survey of Massive Stars (Evans et al. 2006)
Data: Stars in the Large Magellanic Cloud (Fitzpatrick & Garmany, 1990)

Progenitor of SN 1987a
2. The complicated lives of massive stars

Four Questions triggered by Hubble (and VLT) observing 30 Dor
30 Dor (Tarantula Nebula) : the Massive Star “Deep Field”
30 Dor (Tarantula Nebula) : the Massive Star “Deep Field”

Stars > 200 solar masses? Crowther+00, +prep
Are they mergers? Schneider+15
Extension of model grids e.g. Koehler+15

1. Stars with masses well above the canonical upper mass limit
30 Dor (Tarantula Nebula) : the Massive Star “Deep Field”

2. Majority in very close Binaries. ~7 out of 10 will interact
   Sana+12+13, Dunstall+15

New records
- Most massive over contact system Almeida+15
- First X-ray binary in 30 Dor, Clark+15
- Most massive binary w/ O giants: Taylor+11
30 Dor (Tarantula Nebula) : the Massive Star “Deep Field”

3. Rotation, sometimes extreme
Dufton+12, 13, Ramirez-Agudelo+13, 15

New record: rotating $v_{\text{sin}i} > 500$ km/s
Dufton+11, Ramirez-Agudelo+13
30 Dor (Tarantula Nebula) : the Massive Star “Deep Field”

4. Many many Runaway Stars
   Evans+10,15, Sana+prep

80 Msun runaway star
   Evans et al. (2010)
Raising many new questions ...

1. Is there a Universal upper stellar mass limit?
2. High binary fraction Universal?
3. What are the origin and consequences of rotations?
4. Runaway stars.

(I) Cosmic Engines

(II) Cosmic Probes

Generations of Massive Stars

How did we get here?

Cosmic Time
2.1 Example
Finding the most massive stars
R136: ionizing star cluster

Weigelt & Baier (1985)

Hunter et al. (1995)

De Marchi et al. (2011)

ar-Forming Region 30 Doradus

HST • WFC3/UVIS

Slide w/ courtesy of Paul Crowther
### The 4 “super stars” in R136

**Crowther et al. 2010**

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<td>(220^{+55}_{-45})</td>
<td>(175^{+40}_{-35})</td>
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Separated by ~0.1 arcsec (about 5000 AU)

Based on *HST UV/Optical Spectra* (Ebbets, Heap, Massey) and near IR VLT spectra (Schnurr)
Can we do better ... dissecting R136 w/ Hubble

**HST/STIS**
39 HST orbits, 17 slits, 0.2” width
(PI: Crowther)

Crowther, Caballero-Nieves et al. in prep.

**HST/FGS:**
(PI: de Mink/Caballero-Nieves)
Caballero-Nieves, Nelan, de Mink et al. in prep.
... Yes, they are still extremely massive ...

35% detected close binaries already
with just two epochs, for 17/49 O stars

7 stars
>~ 100 Msun

w/ courtesy of P. Crowther & S. Caballero-Nieves
Yes, they are still extremely massive ...

Preliminary

7 stars

\[ \geq 100 \text{ M}_{\odot} \]

Implications: 100 + \( M_{\odot} \) stars and disproportionately contribute to ionizing radiation and strong spectral features (He II 1640 emission)

- Omitting these leads to (e.g. Starburst99, BPASS)
  - Under estimating **ionizing fluxes**
  - Over estimating the **age**
  - Over estimating the **metallicity**

Questions for ATLAST/HDST/LUVOIR ....

- Is there a (Universal) Upper mass limit?
- Resolving 100 pc everywhere in the Universe? \( \rightarrow \) What features do we see in the integrated (UV) spectra of “resolved” starbursts

w/ courtesy of P. Crowther & S. Caballero-Nieves
2.11 Example
The impact of extreme rotation rates
Predictions from theory
Predictions for very rapid rotators

Brott, SdM et al. (2011)

Slow rotators Expand

Z = 0.004
**Predictions for very rapid rotators**


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**Effective Temperature (kK)**

- **Rapid rotators**
- **Slow rotators Expand**

**Log [ Luminosity (L$_{\odot}$) ]**

- ES circulation
- Shear mixing

Brott, SdM et al. (2011)

Z = 0.004
Predictions for very rapid rotators

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Maeder89, Yoon+05/06
Maeder & Meyet 2000,
```

**Very** rapid rotators may shrink

Brott, SdM et al. (2011)

```
Z = 0.004
```

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**Chemically Homogeneous Evolution**
Stronger effects at low metallicity (in the early Universe)

Chemical yields?

Reionization?

Gamma-ray bursts?
(Yoon+Langer05, Woosley+Heger00)

Pop III impostors?
(e.g. Secszi+15)

ATLAST/HDST/LUVOIR ....

- Allow to test lower metallicities: e.g. the irregular galaxy I Zw 18 (~20 Mpc)
  Getting closer to the very first stars
- Imprints on the UV of more distant starbursts

Brott, SdM et al. 2011, Yoon+2006
Z = 0.004
(Small Magellanic Cloud)

Z = 0.008
(Large Magellanic Cloud)

Z = 0.012
(Solar Neighborhood)
2.111 Example
Massive Stars do not live alone

Is the binary fraction universal
7 out of 10 massive stars severely interact before they die
Questions for ATLAST/HDST/LUVOIR ....

- Is the binary fraction universal (e.g. in dense regions, low Z)
- Probing extreme low mass companions. (Like finding a planet)
- Imprints of binary products in UV spectra of distant populations
Questions in the context of a future UVOIR space telescope
1 AU everywhere in the solar neighborhood

100 AU everywhere in the Milky Way

0.1 pc everywhere in the Local Group

100 pc everywhere in the Universe!
100 AU everywhere in the Milky Way

0.1 pc everywhere in the Local Group

1 AU everywhere in the solar neighborhood

100 pc everywhere in the Universe!

10 pc in the Galactic Neighborhood

HDST: Breaking Resolution Barriers

Star forming region

Protoplanetary disk

Solar system

Slide credits: Dalcanton/Seager/?
Raising many new questions ...

1. Is there a Universal upper stellar mass limit?
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4. Runaway stars.

... ...

(I) Cosmic Engines

Generations of Massive Stars

(II) Cosmic Probes

Lower metallicity environments
Thank you