# RESOLVED STELLAR POPULATIONS AS PROBES OF THE PROGENITORS OF SUPERNOVAE







# THE PROBLEM WITH PROGENITOR DETECTIONS



2. Data not deep enough to detect progenitor

1. No pre-explosion data



Crockett et al., 2008, ApJ, 672, L99

3. Pre-explosion candidate revealed to not be progenitor



#### "STELLAR ASTROPHYSICS" PROGENITOR PROXIES

Spectroscopic diagnostics of age and metallicity (Kuncarayakti et al. 2013)







#### **Pixel statistics**

Anderson et al., 2012

### AGE → PROGENITOR MASS



Girardi et al., 2004

# SUPERNOVA PROGENITORS USING RESOLVED STELLAR POPULATIONS



#### PROGENITOR MASS ESTIMATES FOR SUPERNOVA REMNANTS



# Bayesian Isochrone fitting

Brightness and colours of the ensemble of stars can be used to determine the star formation history



When did the stars form?

How many episodes of star formation were there?

Which stars belong to which episode?

Which stars are single and which stars are binaries?

Which stars are "in the background"?

#### Colour magnitude diagram

Can answer most of these questions with: who cares? Use a mixture model and nested sampling

$$p(\mathbf{D}_{i}|...) = \sum_{j}^{N} (P_{BIN}p(\mathbf{D}_{i}|\tau_{j},\sigma_{j},w_{j}) + (1 - P_{BIN})p(\mathbf{D}_{i}|\tau_{j},\sigma_{j},w_{j}))$$
  
BINARY  
Don't have to decide which is the best solution for an

individual star, instead use the properties of the ensemble of stars to sort classifications (note: not determining star formation history)

Use the Bayesian Evidence to determine the best N

Also consider differential extinction:  $p(A'_V) \sim N(A_V, dA_V^2)$ 

## TYPE IC SN 2007GR

No detection of progenitor in pre-explosion WFPC2 F450W and F814W observations - but at the centre of a massive star association



#### STELLAR POPULATION AROUND SN 2007GR

#### Progenitor was likely a WR star

$N_m$	$n_{par}$	WFC3/UVIS	WFPC2
1	3	$0.00 \pm 0.15$	$0.00 \pm 0.13$
2	7	$42.34 \pm 0.18$	$16.70\pm0.18$
3	10	$42.70\pm0.18$	$15.92\pm0.18$
4	13	$42.20\pm0.18$	$14.19\pm0.19$

			Young			Old		
	$A_V$	$ au_1$	$\sigma_1$	$w_1$	$ au_2$	$\sigma_2$	$w_2$	
WFC3/UVIS WFPC2	$0.53 \pm 0.00 \\ 0.44 \pm 0.01$	$6.87 \pm 0.02$ $6.71 \pm 0.03$	$\begin{array}{c} 0.25 \pm 0.02 \\ 0.14 \pm 0.03 \end{array}$	$\begin{array}{c} 0.78 \pm 0.03 \\ 0.85 \pm 0.03 \end{array}$	$7.88 \pm 0.02$ $7.60 \pm 0.03$	$\begin{array}{c} 0.11 \pm 0.01 \\ 0.09 \pm 0.03 \end{array}$	$\begin{array}{c} 0.22 \pm 0.02 \\ 0.15 \pm 0.02 \end{array}$	





See that the SN position itself is in proximity but not directly associated with significant  $H\alpha$  emission

#### HOW CAN SUCH A LARGE STRUCTURE HAVE A SINGLE AGE?

Upper Scorpius OB association - 50 - 70pc diameter, single age of 5Myr

Can reproduce structures of ~150pc in radius from a single spatial location with velocity dispersions of ~20 - 40kms<sup>-1</sup>

#### STELLAR POPULATIONS AROUND TYPE IIP SUPERNOVAE



Consider stellar populations within 100pc of the positions of 12 Type IIP She with an identified progenitor (with a range of distances from 3.5 - 26 Mpc)

Maund, 2017, MNRAS, 469, 2202

### 2008BK



Youngest age component t ~ 26Myr or lifetime of 11 -  $12M_{\odot}$  star (agrees with previous direct studies of the progenitor)

# SMALL NUMBERS

In using ensembles of stars: the more stars you have, the more robust the solution. For small numbers, individual stars can have a large impact (e.g. SN 2012aw)



#### SN 1993J -IDENTIFYING THE RIGHT AGE COMPONENT



Invert the question: which age component does each star belong to?

Most of the bright stars in close proximity to 1993J are OB stars belonging to the 12.6Myr component

#### COMPARISON WITH DIRECT DETECTION



M(stellar population) ~ M(prog)  $\pm 3M\odot$ 

 $A_V$ (stellar population) ~  $A_V$ (prog) + 0.3

# CONCLUSIONS

- Stellar populations analysis can provide useful constraints (with limits) on the progenitors of SNe.
- Strong evidence, independently of pre-explosion images, for large extinction associated with Type Ibc SNe
- In general, assumptions of host extinction are likely underestimated for progenitors of all types of SNe
- Age of population around SN 2007gr suggest massive WR stars are producing some Type Ibc SNe