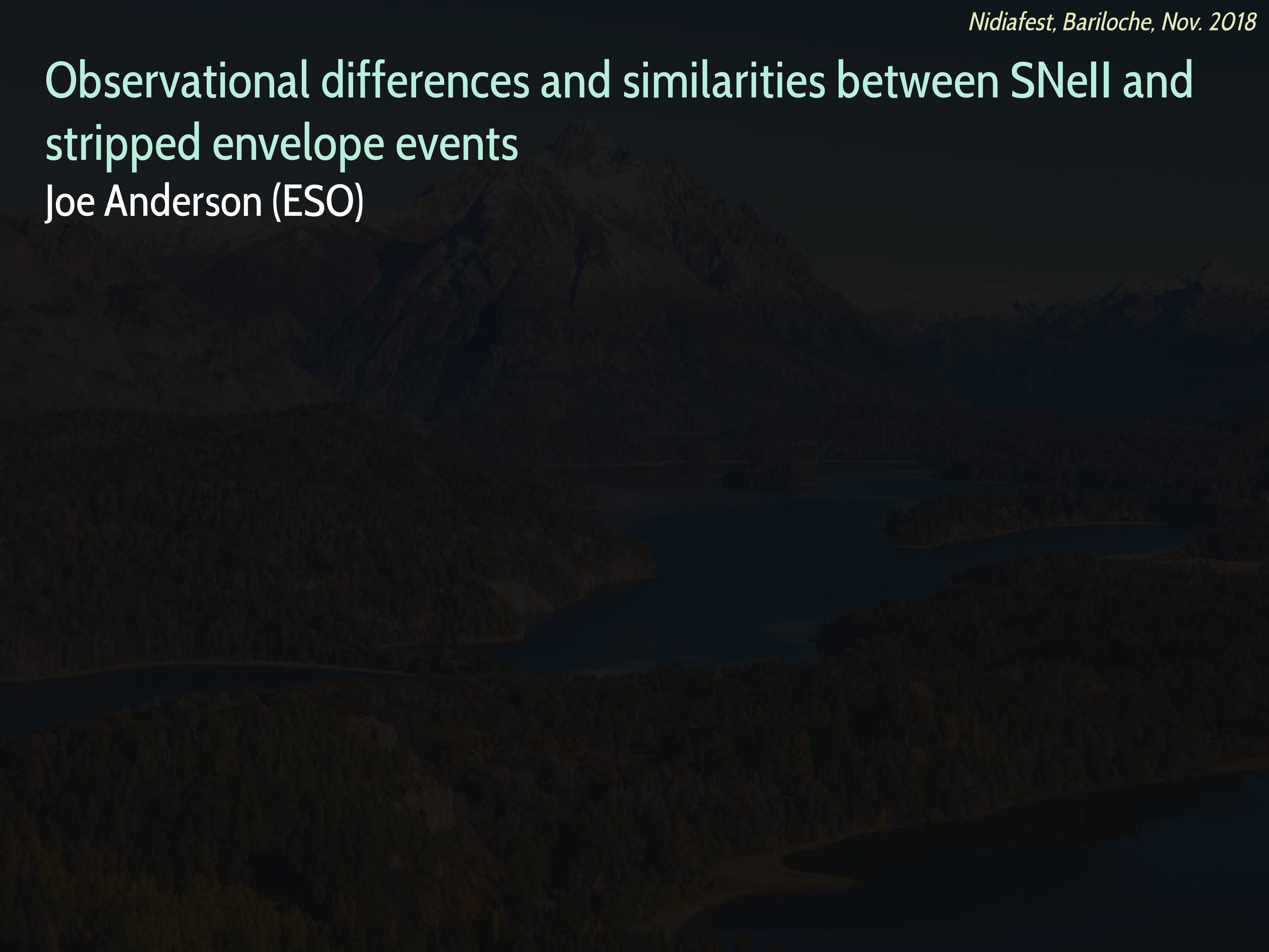
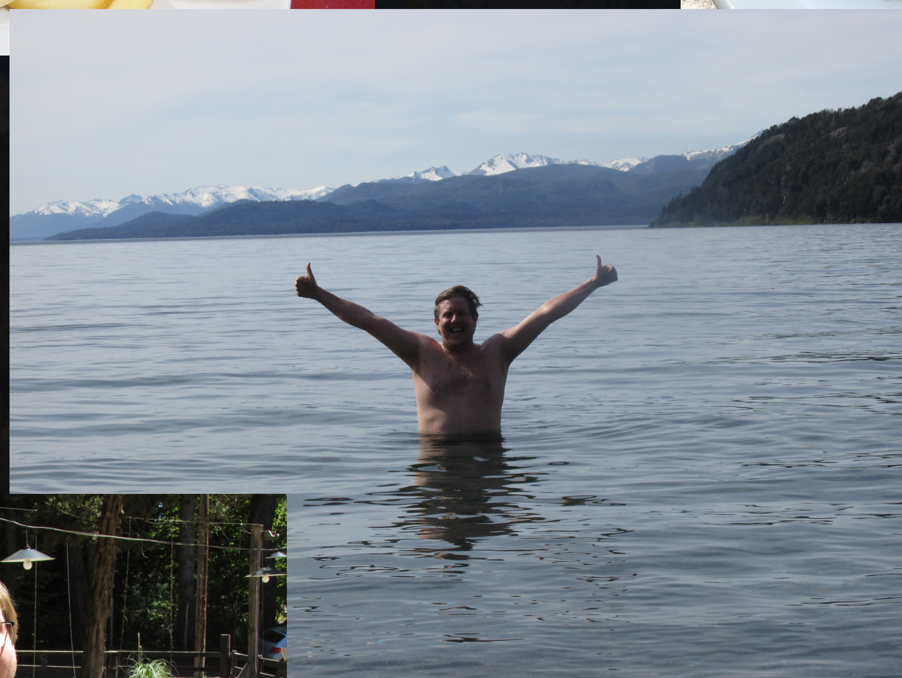
# Observational differences and similarities between SNeII and stripped envelope events

Joe Anderson (ESO)



# Nidiafest!

# Nidiafest... in Bariloche!




# Core-collapse supernova (CCSNe) progenitor constraints

## Contradictory conclusions…?

## *(SNII=IIP+IIL, SE-SNe=IIb+Ib+Ic)*

- SE-SN ejecta mass constraints suggest low-mass progenitors (consistent with SNII progenitors?) *(e.g. Drout+11; Lyman+16; Prentice+16; Taddia+18)*
- Environment studies (both resolved and unresolved) suggest higher mass progenitors for SNIc, then SNIb, then SNII *(e.g. Anderson+12; Galbany+16; Kangas+17; Maund17,18)*
- Direct detections (lack off) for SE-SNe suggest low-mass progenitors (?) *(e.g. Eldridge+13)*
- Nebular constraints suggest SNIc come from higher mass progenitors *(e.g. Fang+18)*

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*How do we put all this together to get a complete picture of the mass ranges for different CC SN progenitors? How can we estimate the relative contribution of e.g. single-star and binary system scenarios?*

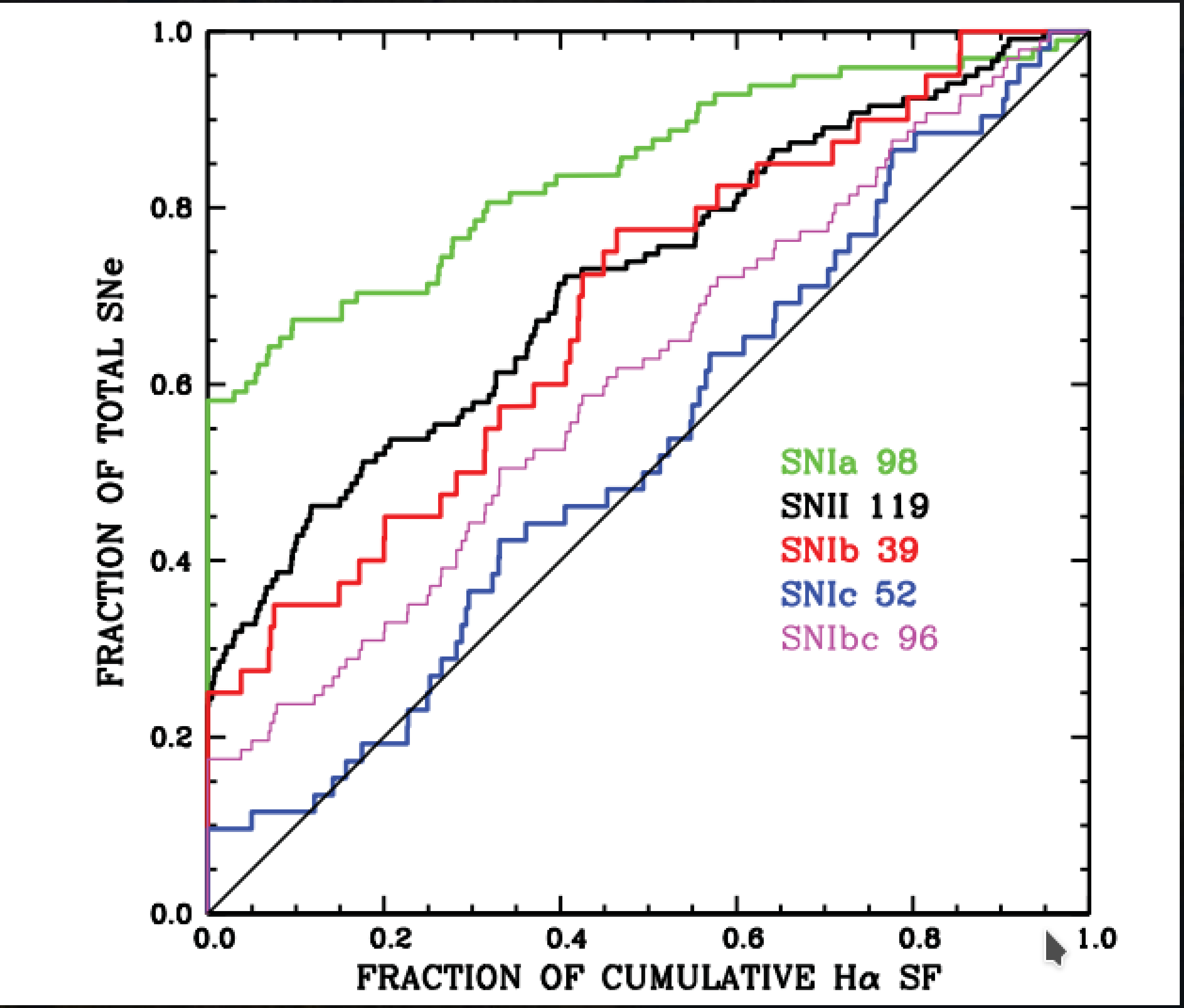
# This talk:

1) *"Core-collapse supernova progenitor constraints using the spatial distributions of massive stars in local galaxies"* (Kangas et al. 2017)

2) *"Significant differences in the estimated $^{56}$Ni masses of SNeII and stripped-envelope events (SE-SNe)"* (Anderson in prep.)

# A clear sequence of increasing association of SN types to host galaxy H-alpha emission (Anderson+12)

= a sequence of increasing progenitor mass…

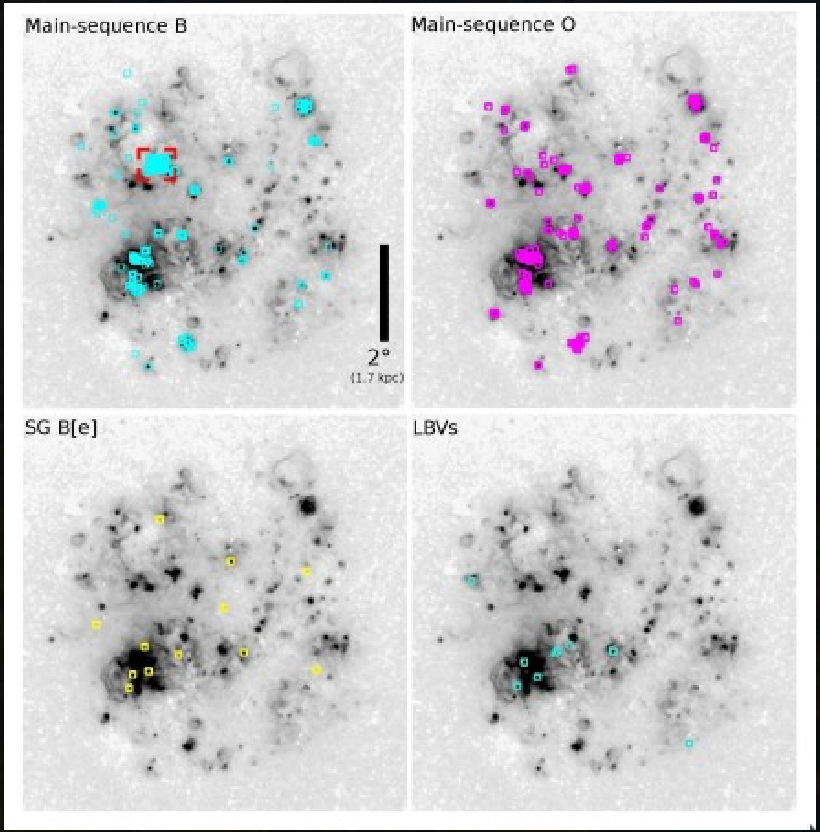


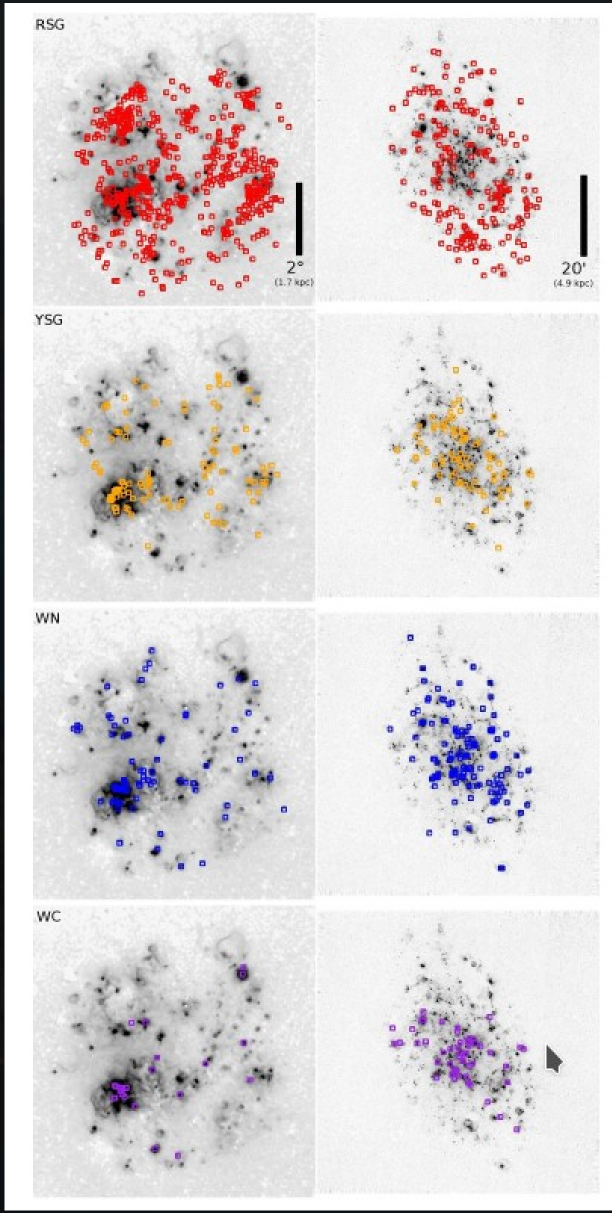
# “Core-collapse supernova progenitor constraints using the spatial distributions of massive stars in local galaxies” (Kangas et al. 2017)

## - spatial distribution of stars w.r.t. H-alpha emission

(**Stellar catalogues:** Bonanos+09; Neugent&Massey11; Drout+12; Neugent+12; Hainich+14; Humphreys+14; Smith&Tombleson15)

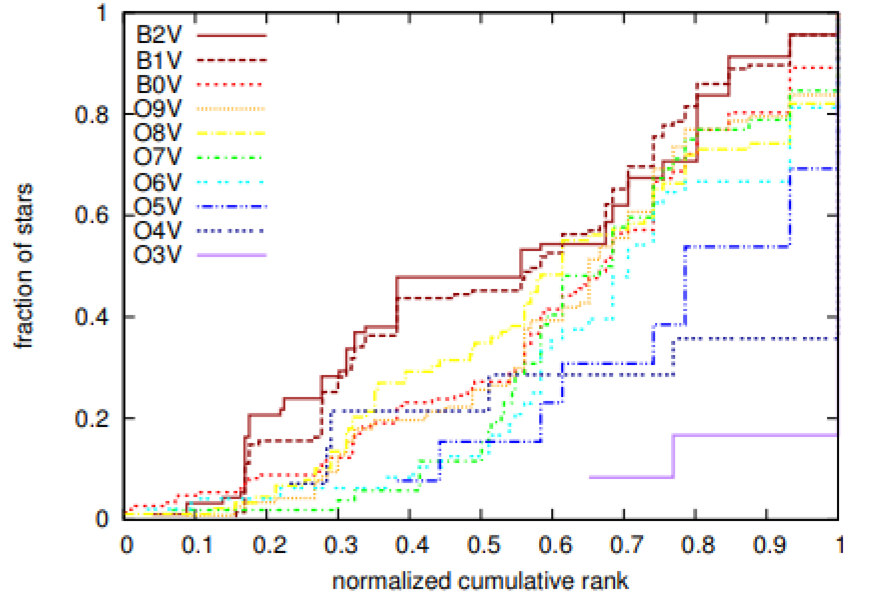
## LMC+M33

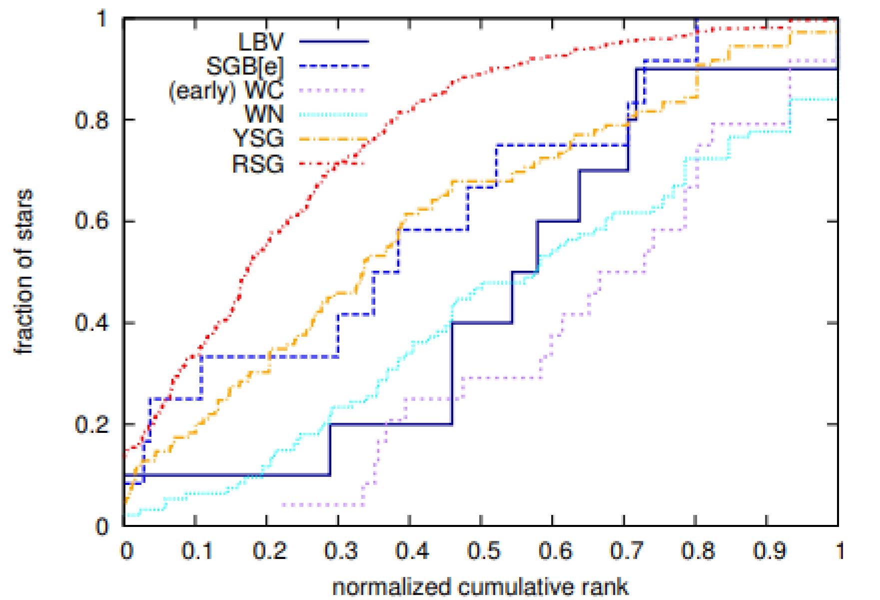


# Spatial distributions of massive stars w.r.t. H-alpha (Kangas+17)

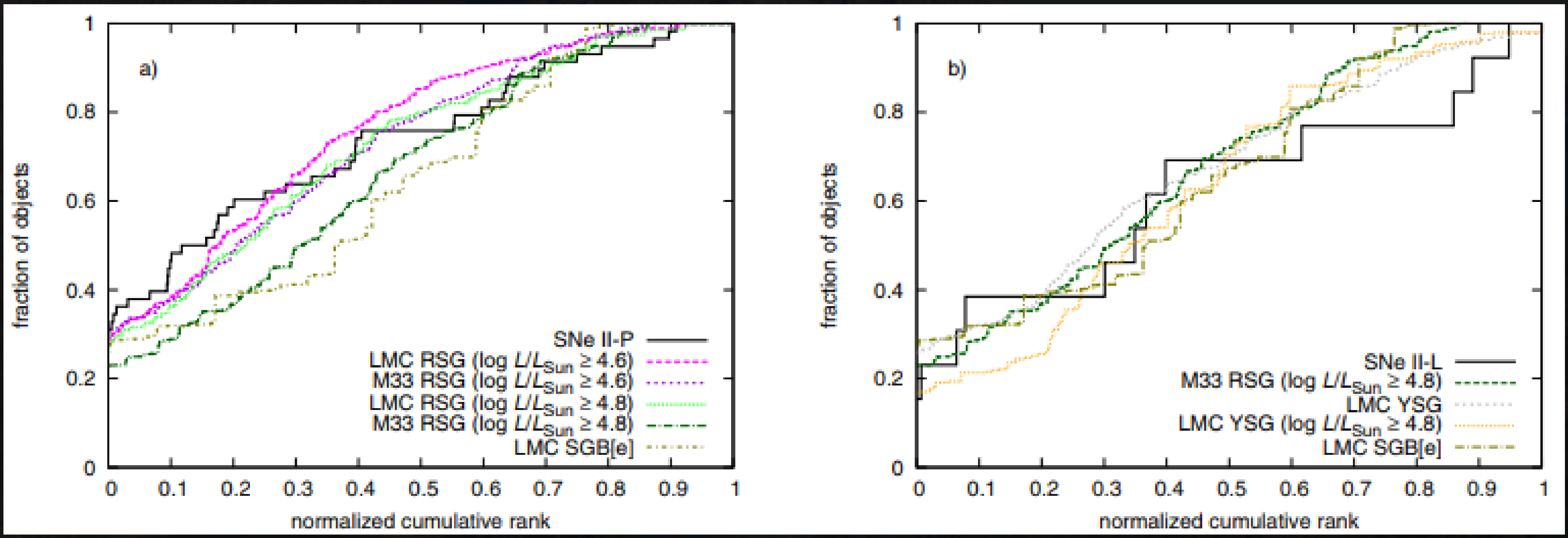
| | | 20 Mpc | | 35 Mpc | |
|---|---|---|---|---|---|
| Stellar type | $N$ | ⟨NCR⟩(acc) | ⟨NCR⟩(err) | ⟨NCR⟩(acc) | ⟨NCR⟩(err) |
| Random | 250 | 0.095 ± 0.007 | – | 0.101 ± 0.006 | – |
| B2V (8 $M_\odot$) | 92 | 0.486 ± 0.030 | 0.472 ± 0.030 | 0.524 ± 0.030 | 0.513 ± 0.029 |
| B1V (13 $M_\odot$) | 135 | 0.530 ± 0.024 | 0.509 ± 0.025 | 0.537 ± 0.023 | 0.529 ± 0.023 |
| B0V (17.5 $M_\odot$) | 147 | 0.627 ± 0.022 | 0.610 ± 0.023 | 0.631 ± 0.022 | 0.603 ± 0.022 |
| O9V (20 $M_\odot$) | 117 | 0.692 ± 0.022 | 0.658 ± 0.023 | 0.646 ± 0.023 | 0.615 ± 0.023 |
| O8V (25 $M_\odot$) | 89 | 0.667 ± 0.028 | 0.637 ± 0.029 | 0.623 ± 0.030 | 0.594 ± 0.030 |
| O7V (31 $M_\odot$) | 52 | 0.719 ± 0.027 | 0.685 ± 0.029 | 0.678 ± 0.030 | 0.645 ± 0.031 |
| O6V (37 $M_\odot$) | 48 | 0.742 ± 0.031 | 0.711 ± 0.034 | 0.706 ± 0.035 | 0.673 ± 0.036 |
| O5V (44 $M_\odot$) | 13 | 0.805 ± 0.065 | 0.776 ± 0.060 | 0.785 ± 0.061 | 0.755 ± 0.063 |
| O4V (53 $M_\odot$) | 14 | 0.820 ± 0.073 | 0.784 ± 0.075 | 0.792 ± 0.085 | 0.745 ± 0.083 |
| O3V (64 $M_\odot$) | 12 | 0.961 ± 0.027 | 0.931 ± 0.030 | 0.952 ± 0.034 | 0.911 ± 0.037 |
| RSG | 543 | 0.182 ± 0.010 | 0.180 ± 0.010 | 0.229 ± 0.010 | 0.228 ± 0.010 |
| RSG ($\log L/L_\odot < 4.6$) | 361 | 0.155 ± 0.011 | 0.152 ± 0.011 | 0.196 ± 0.011 | 0.196 ± 0.011 |
| RSG ($\log L/L_\odot \geq 4.6$) | 182 | 0.236 ± 0.018 | 0.239 ± 0.018 | 0.295 ± 0.017 | 0.290 ± 0.017 |
| RSG ($\log L/L_\odot \geq 4.8$) | 76 | 0.267 ± 0.031 | 0.268 ± 0.031 | 0.321 ± 0.029 | 0.321 ± 0.029 |
| YSG | 109 | 0.331 ± 0.029 | 0.328 ± 0.029 | 0.387 ± 0.028 | 0.375 ± 0.028 |
| YSG ($\log L/L_\odot \geq 4.8$) | 37 | 0.373 ± 0.044 | 0.362 ± 0.044 | 0.417 ± 0.047 | 0.412 ± 0.044 |
| SG B[e] | 12 | 0.340 ± 0.086 | 0.342 ± 0.079 | 0.371 ± 0.083 | 0.375 ± 0.082 |
| LBV | 10 | 0.523 ± 0.082 | 0.511 ± 0.075 | 0.539 ± 0.085 | 0.527 ± 0.080 |
| Classical LBV | 3 | 0.774 ± 0.115 | 0.750 ± 0.086 | 0.785 ± 0.110 | 0.761 ± 0.096 |
| Low-luminosity LBV | 7 | 0.416 ± 0.077 | 0.409 ± 0.072 | 0.434 ± 0.087 | 0.427 ± 0.081 |
| WN | 94 | 0.561 ± 0.031 | 0.544 ± 0.032 | 0.575 ± 0.032 | 0.553 ± 0.032 |
| Early WN | 67 | 0.508 ± 0.035 | 0.490 ± 0.036 | 0.525 ± 0.036 | 0.503 ± 0.036 |
| Late WN | 27 | 0.676 ± 0.058 | 0.663 ± 0.057 | 0.684 ± 0.059 | 0.665 ± 0.057 |
| WN (no H) | 45 | 0.515 ± 0.043 | 0.492 ± 0.044 | 0.517 ± 0.043 | 0.502 ± 0.043 |
| Early WN (no H) | 38 | 0.442 ± 0.039 | 0.419 ± 0.041 | 0.442 ± 0.039 | 0.430 ± 0.040 |
| Late WN (no H) | 7 | 0.847 ± 0.081 | 0.832 ± 0.073 | 0.866 ± 0.070 | 0.821 ± 0.076 |
| (Early) WC | 24 | 0.656 ± 0.045 | 0.641 ± 0.045 | 0.662 ± 0.048 | 0.632 ± 0.050 |



# Spatial distributions of massive stars AND spatial distribution of SN types w.r.t. H-alpha

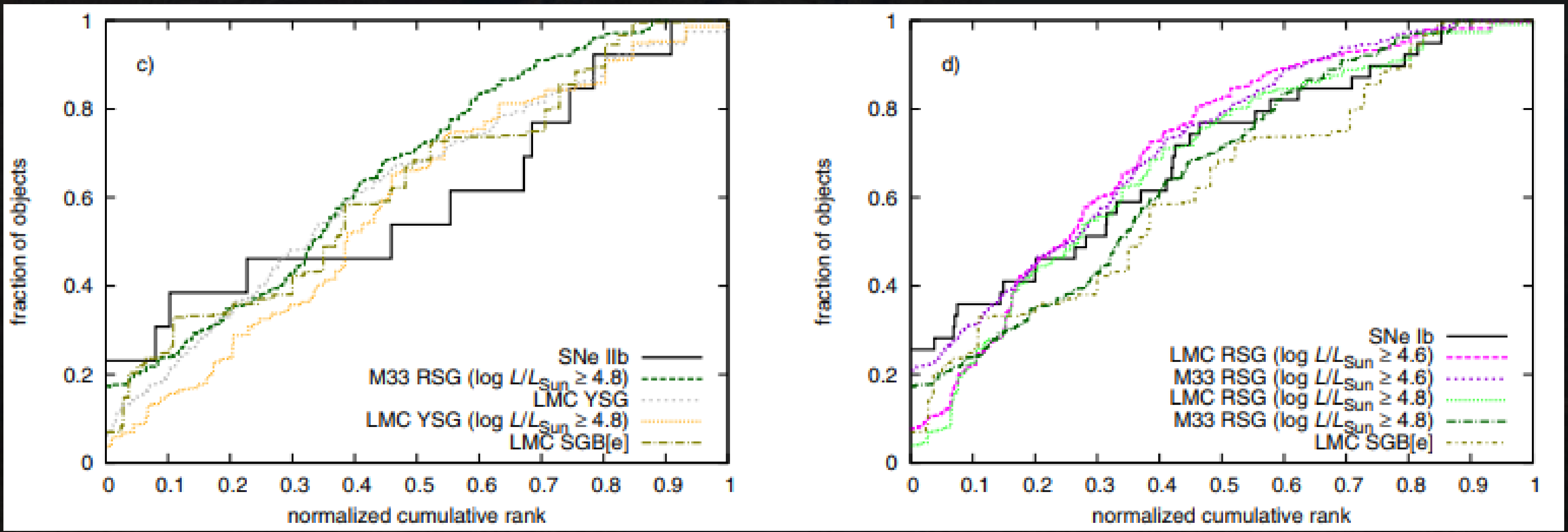
(Kangas+17)




- SNII explosion sites best matched with RSG/YSG and SG Be stars
- Some possibility that faster decliners more closely follow YSGs…

# Spatial distributions of massive stars AND spatial distribution of SN types w.r.t. H-alpha

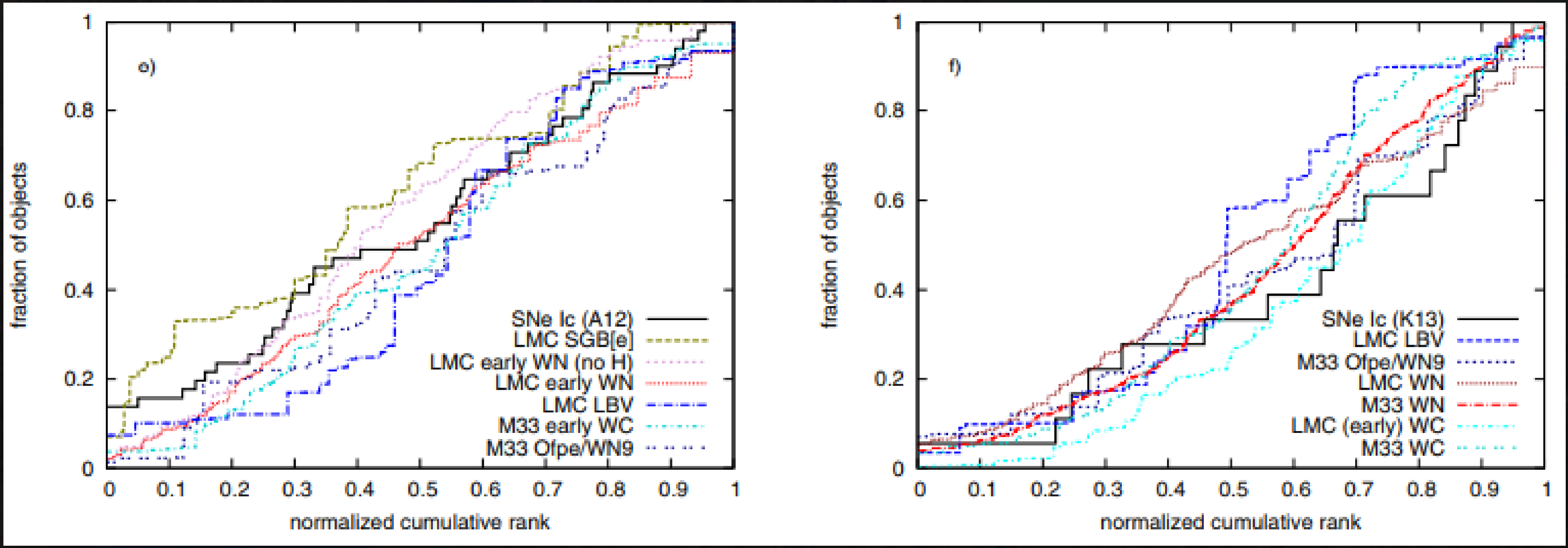
(Kangas+17)




- SNeIIb and SNeIb explosion sites best matched with RSG/YSGs

# Spatial distributions of massive stars AND spatial distribution of SN types w.r.t. H-alpha

(Kangas+17)

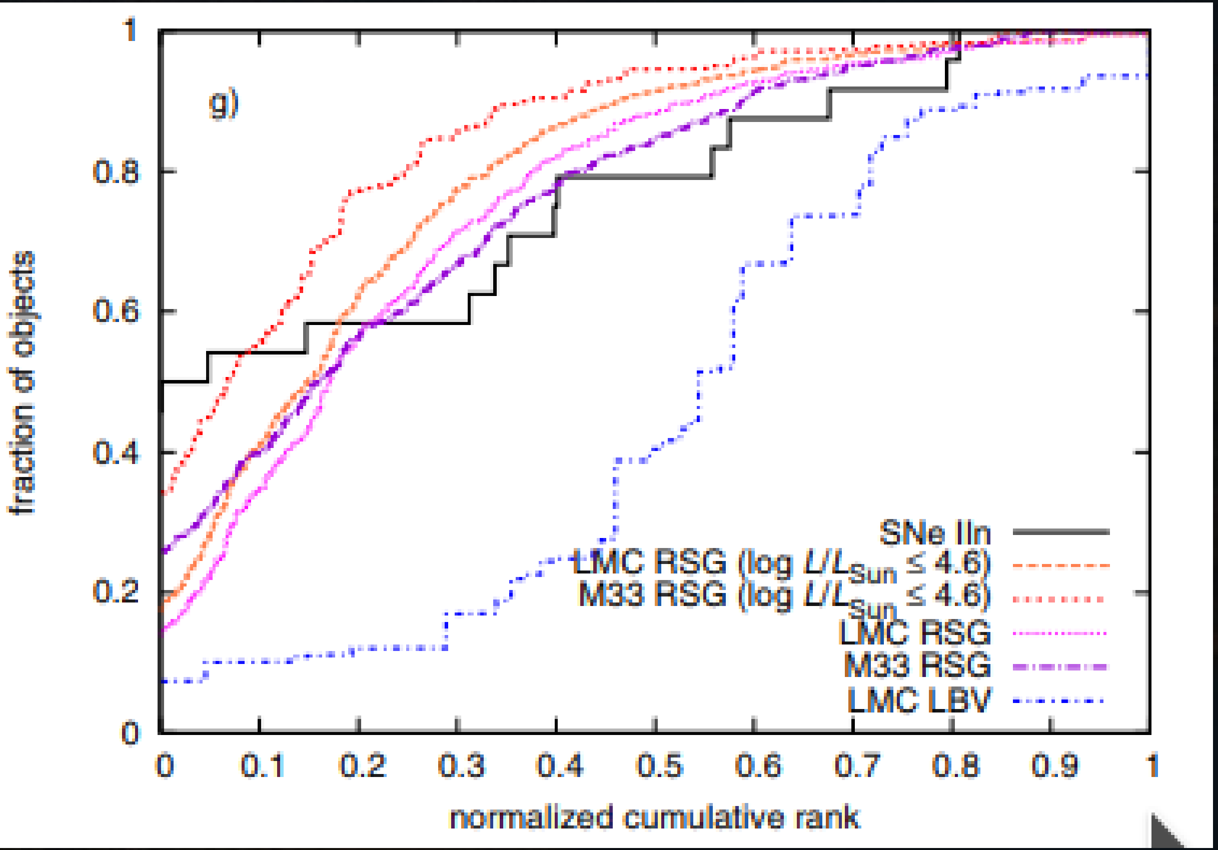



- SNeIc explosion sites best matched with WR (WN) stars

# Spatial distributions of massive stars AND spatial distribution of SN types w.r.t. H-alpha

(Kangas+17)

- SNeIIn explosion sites *inconsistent* with LBV population
- Best matched with RSGs



# Environment constraints on CC SN progenitor stellar types:

1) Consistently through different studies SNIc appear to be more associated with star formation than other types

- SNIc best matched with WR stars w.r.t. H-alpha emission
- SNIc arise from more massive progenitors than other CC types

2) SNII+SNIIb+Ib show similar association to star formation

- all have explosion sites best matched with RSG/YSG stars
- suggests similar (low) mass progenitors for SNII/IIb/Ib
- suggests most IIb and Ib come from binary systems

3) SNIIn show ~low association to star formation

- explosion sites best matched with RSG progenitors
- explosion sites ***inconsistent with LBV progenitors***

# “Significant differences in the estimated $^{56}$Ni masses of SNeII and stripped-envelope events (SE-SNe)” (Anderson in prep.)

Two basic methods for calculating $^{56}$Ni masses for CCSNe:

1) tail luminosity (SNeII)

2) Arnett’s rule (SE-SNe)

# A meta-analysis of literature $^{56}$Ni masses

An ADS search for 'supernova'+'type II'/'type IIb'/'type Ib'/'type Ic'...

- all $^{56}$Ni masses: models, observations
- multiple values for the same SN averaged (no preference for method)
  - different bolometric corrections
  - different Av corrections
  - different assumed distances

**SNII = 115 values**

**SNIIb = 27**

**SNIb = 33**

**SNIc = 48**

**SNIc-BL = 32**

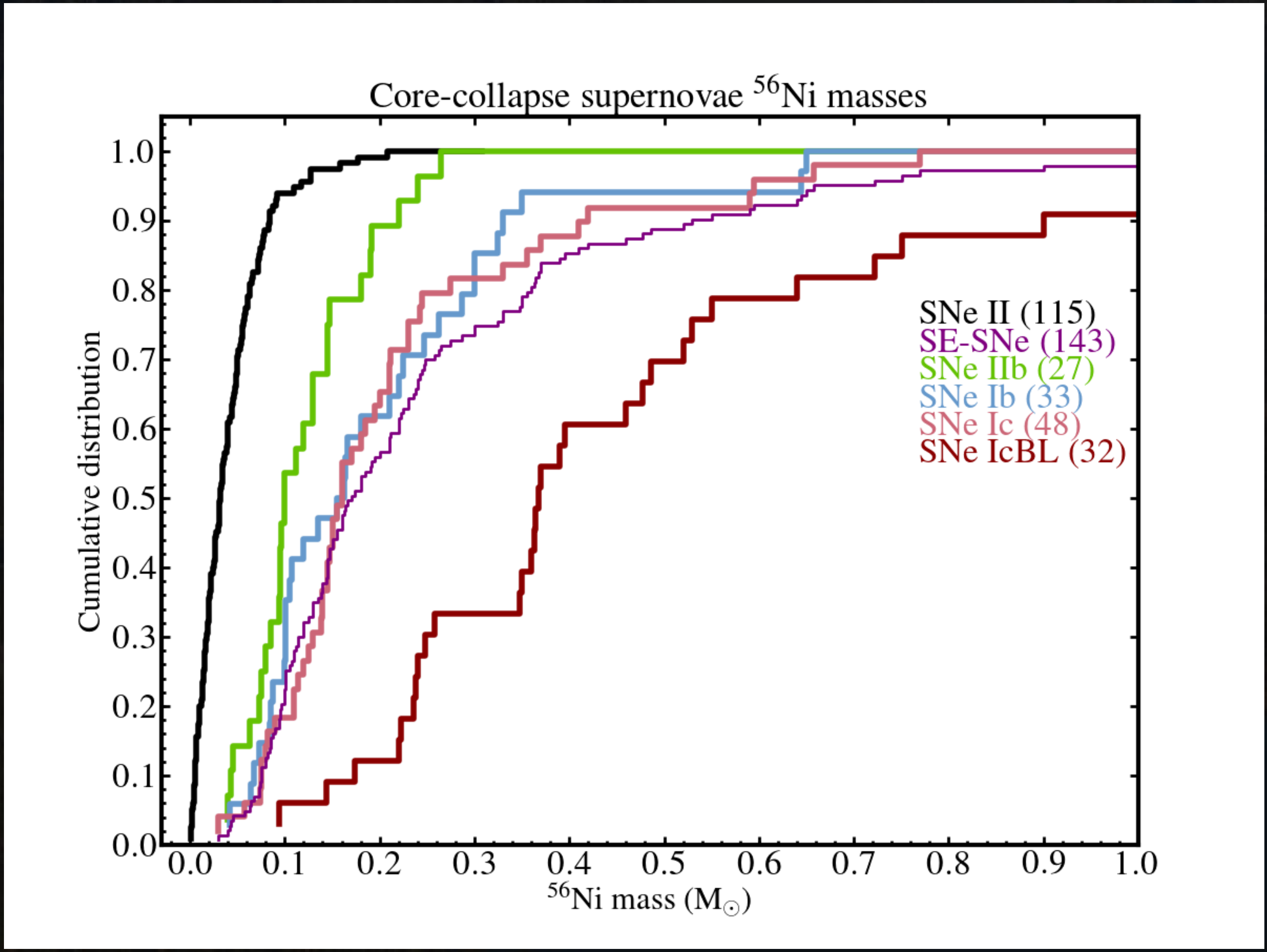
**(SE-SNe = 143)**

# CC SN observed/estimated $^{56}$Ni distributions

**SNII median = 0.032**

**SNIIb = 0.100**
**SNIb = 0.163**
**SNIc = 0.160**
**SNIcBL = 0.369**

**SE-SNe = 0.174**



# SE-SNe clearly have higher estimated $^{56}$Ni masses than SNII

- Highly significant statistical $^{56}$Ni mass differences between SNII and all other CC (SE-SN) types
- Zero SE-SN values lower than 0.03Msun, while 52 (~50%) SNII lower than such values
- SE-SNe have some very high estimated values! Highest SNII = 0.36Msun, SNIIb = 0.28Msun; **SNIb = 0.92Msun(!); SNIc = 0.84Msun; SNIcBL = 2.4Msun!!!**

  **(SNIa estimates are ~0.6Msun)**

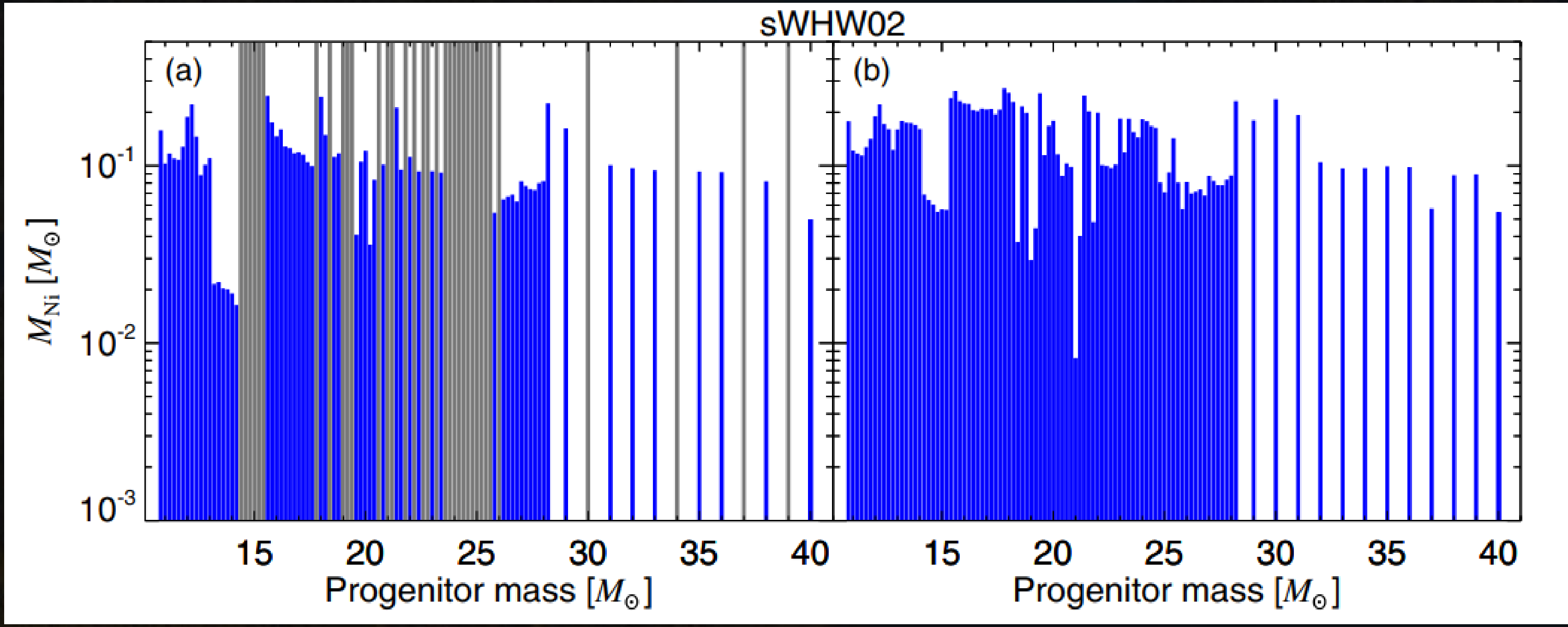
# Possible implications and caveats

- Significantly higher $^{56}$Ni masses for SE-SNe than SNII would appear inconsistent with even roughly similar progenitor masses
  - higher $^{56}$Ni mass requires higher core → higher ZAMS mass (?)
- Would we find SE-SNe that explode with <0.01 Msun $^{56}$Ni???
  → (very) faint
- The largest $^{56}$Ni masses seem too high to be realistic
- There are a number of SE-SN values that do overlap with the SNII distribution
- Are extinction corrections correct?

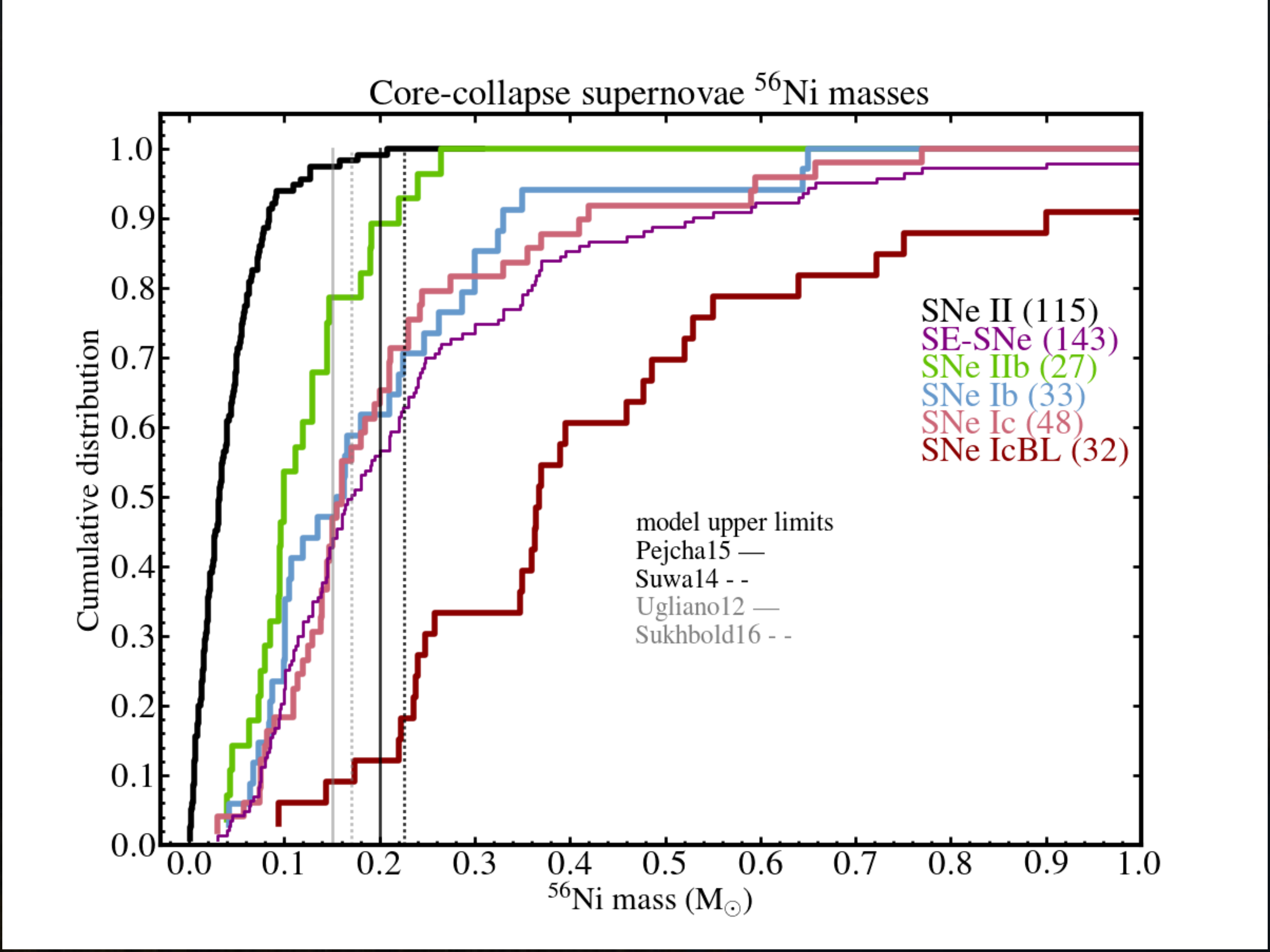
# From models the highest $^{56}$Ni mass is only 0.226Msun!

- Only so much material available at sufficiently high densities to produce $^{56}$Ni, even in high-mass progenitors
- A number of studies have investigated 'explodability' of massive stars, and their subsequent nucleosynthesis → $^{56}$Ni masses
  - different progenitor structures
  - different explosion energies, etc…

Pejcha&Thomson15



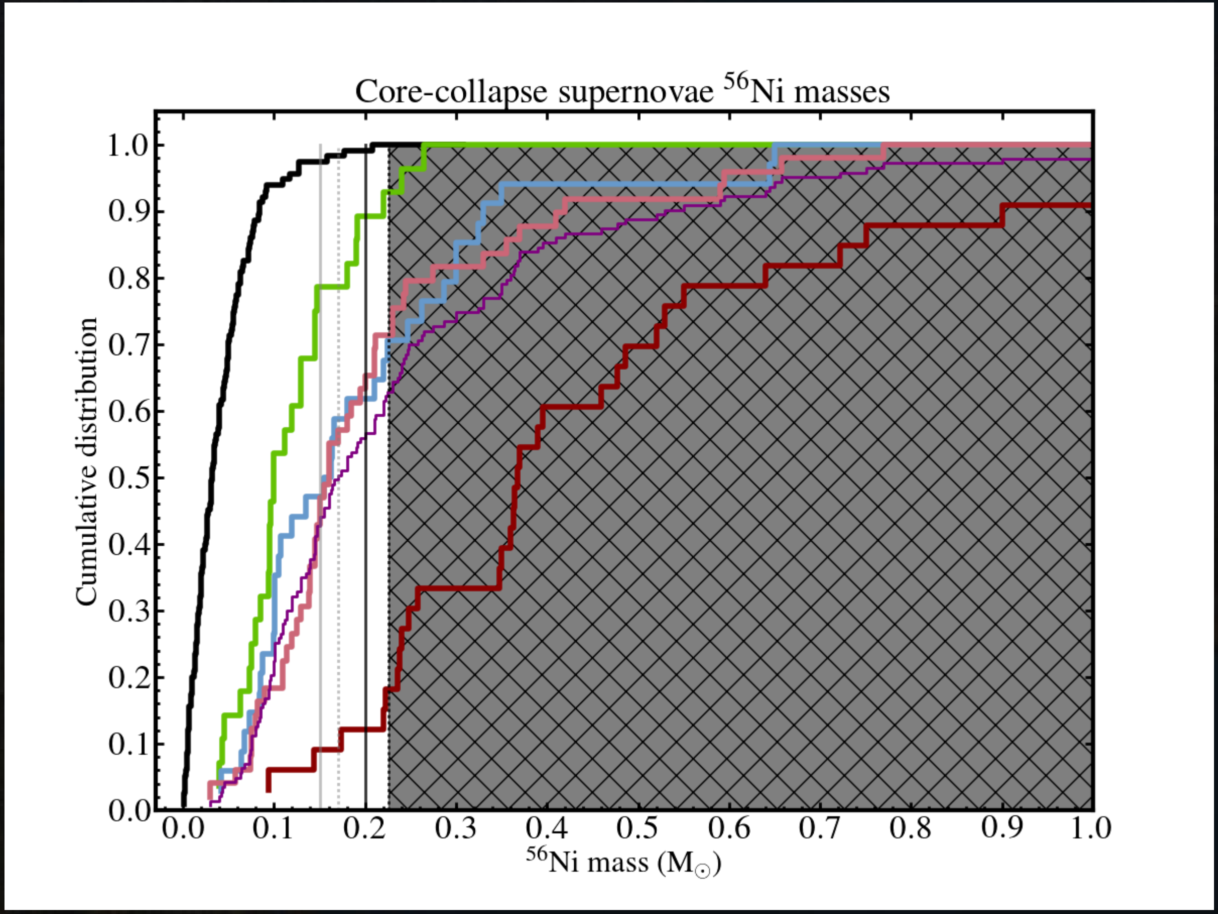
# ~35 % of SE-SNe have estimated $^{56}$Ni masses above explosion-model limit! *(…or >50% w.r.t. Ugliano+…)*



# 35 % of SE-SNe have estimated $^{56}$Ni masses that are not within range of explosion models

- 90% SNIIb within allowed range
- ~70% of SNIb and SNIc within allowed range
- SNIcBL: >80% NOT within allowed range

- ~100% of SNII within allowed range



# Implications/explanations

- IF real, results imply significant differences in progenitor structures for SE-SNe as compared to SNeII
  - (*much*) more massive progenitors maybe needed
  - inconsistent with most other work (even that which suggests some level of progenitor mass difference)
- A significant fraction of SE-SN derived $^{56}$Ni masses are higher than those predicted by explosion models
  - progenitor structures are wrong?
  - many/most SE-SNe NOT powered by $^{56}$Ni?
- Explosion models wrong?(?)
- Arnett's rule is too simplified?

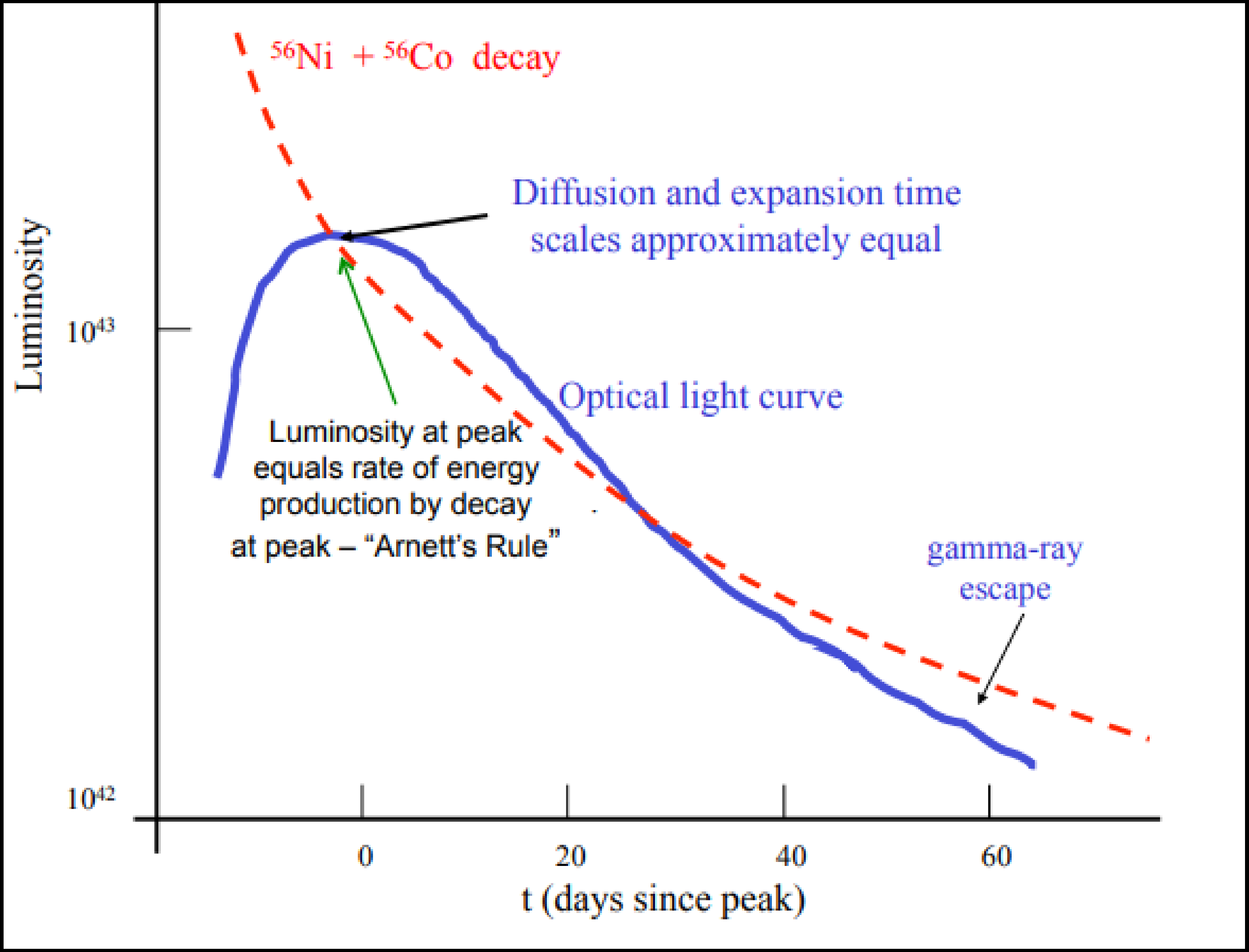
# Summary

Now many independent methods for constraining CC SN progenitor masses. Some inconsistencies... But:

1) SNIc on average arise from higher masses than rest of CC SN
2) SNIIb, Ib appear to come from similar masses to SNII, suggesting that the majority arise from binary systems
3) The majority of SNIIn appear to come from similar masses to SNII, BUT a number of obvious counterexamples

Clear differences between SNII and SE-SN $^{56}$Ni masses that are rarely discussed in the literature. Either:

1) Significant differences in progenitor structures... or
2) Estimates of $^{56}$Ni masses are wrong... or
3) Many SE-SNe have a different/additional power source?



$^{56}$Ni + $^{56}$Co decay
Diffusion and expansion time scales approximately equal
Luminosity
$10^{43}$
$10^{42}$
Optical light curve
Luminosity at peak equals rate of energy production by decay at peak – "Arnett's Rule"
gamma-ray escape
0
20
40
60
t (days since peak)

# Specific $^{56}$Ni values

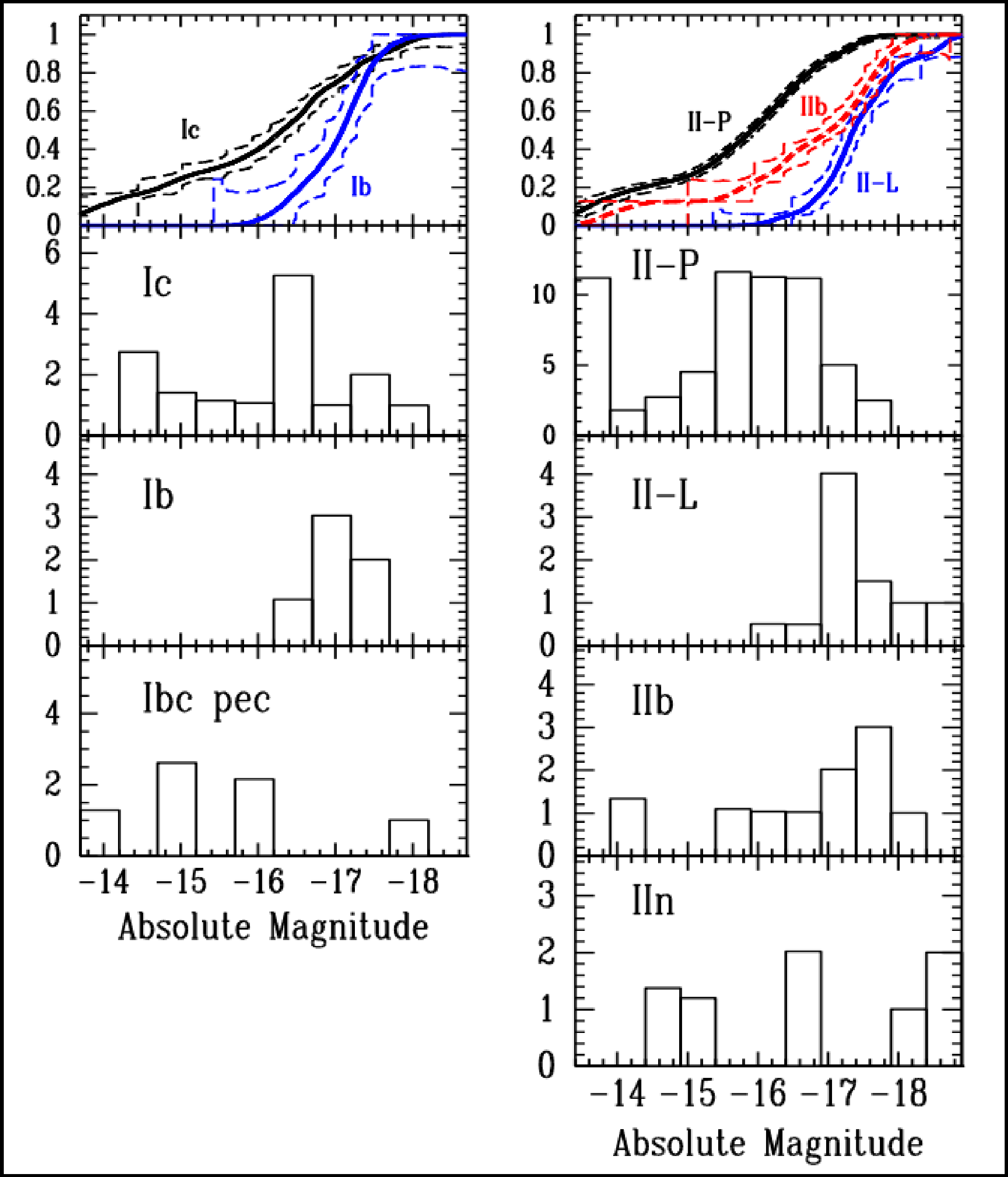
SN1987A = 0.072Msun
SN1999em = 0.044
SN2005cs = 0.004
SN2013ej = 0.018

SN1993J = 0.112
SN2016gkg = 0.085

SN1984L = 0.645
SN2008D = 0.088
iPTF13bvn = 0.073

SN1994I = 0.075
SN2011bm = 0.657

SN1998bw = 0.583


Ic
Ib
II-P
IIb
II-L
Ic
Ib
Ibc pec
II-P
II-L
IIb
IIn
−14 −15 −16 −17 −18
Absolute Magnitude
−14 −15 −16 −17 −18
Absolute Magnitude