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Core-collapse SNe as tracers of massive star formation in nearby galaxies

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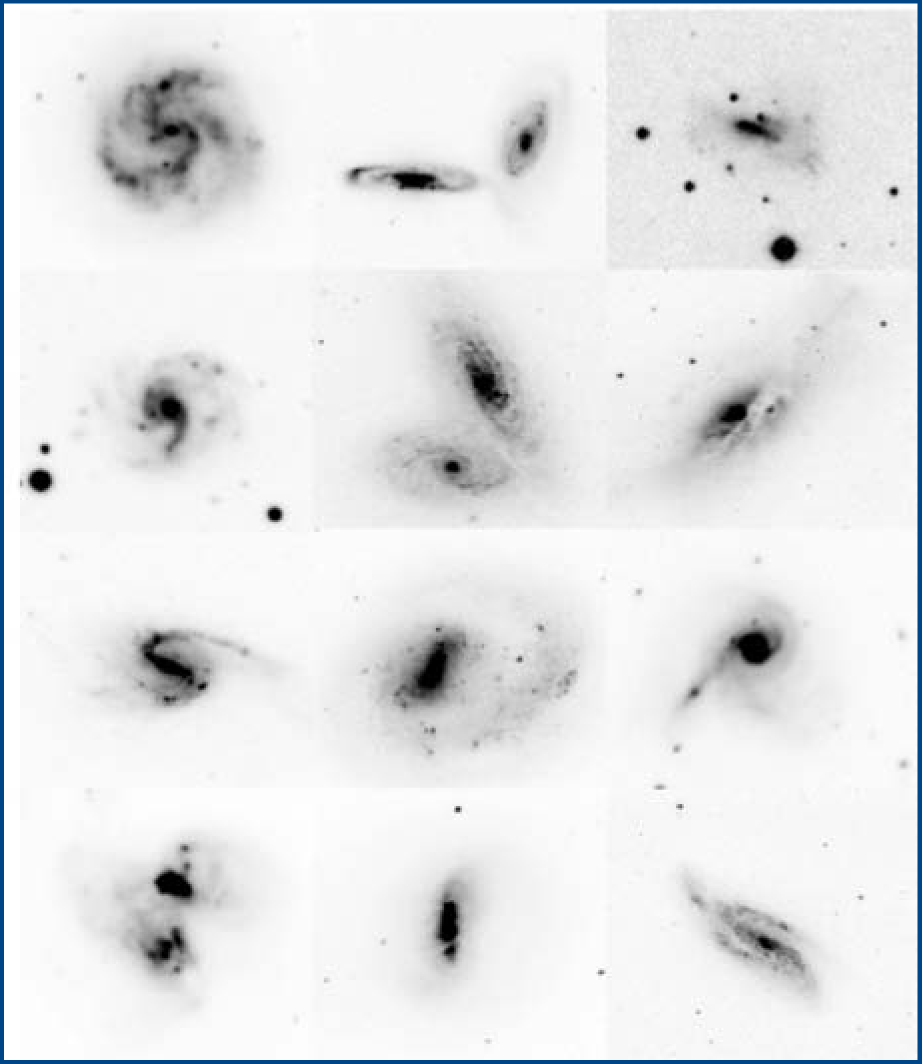
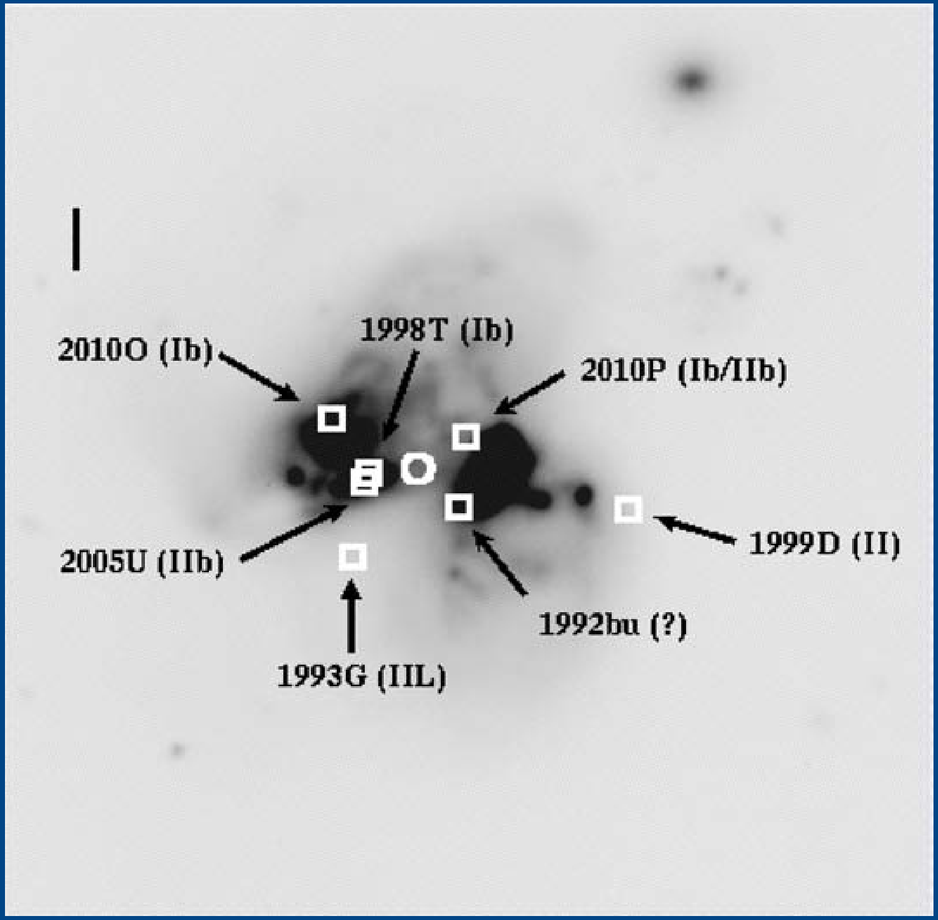
+Phil James, Stacey Habergham, Mario Hamuy, Ricardo Covarrubias

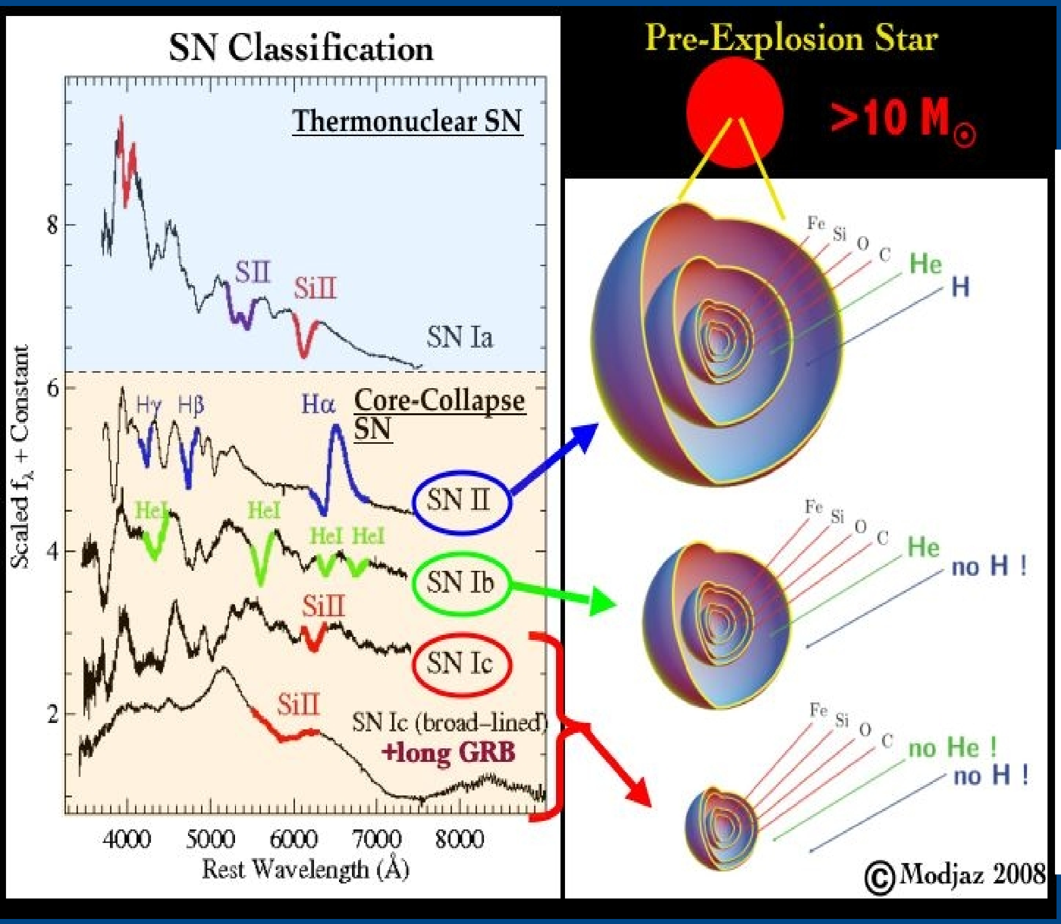


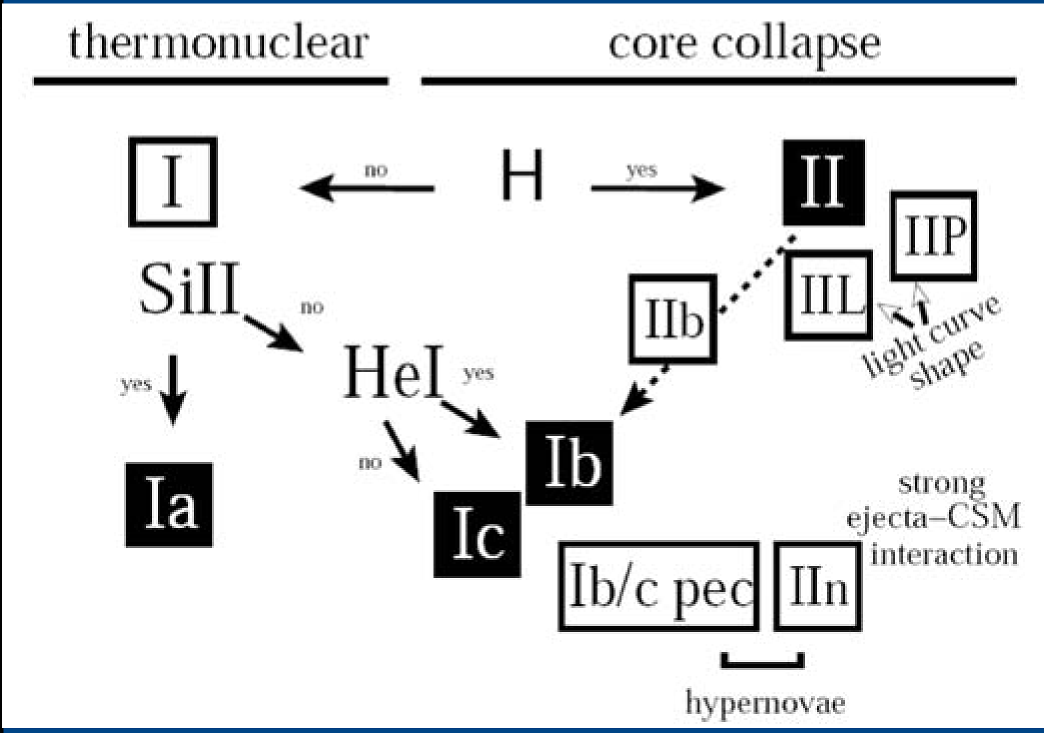


Outline

- **Introduction**
  - CC SN types
  - constraining progenitor systems
  - CC SNe as tracers of SF
- **Correlations of SN explosion sites with host galaxy SF**
  - constraints on progenitor lifetimes and masses
- **Host HII region spectroscopy**
  - constraints on progenitor metallicities
- **CC SNe as tracers of high mass SF**
  - radial distributions of CC SNe within galaxies
  - constraints on metallicity, ages or the IMF?
- **The multiple supernova population of Arp 299**
  - case study of 7 SNe within one host

SN classifications





Turatto (2003)

Diversity of CC SNe and their progenitors

- Stars above 8-10Msun explode as CC SNe
- What progenitor differences produce diversity of transient phenomena?

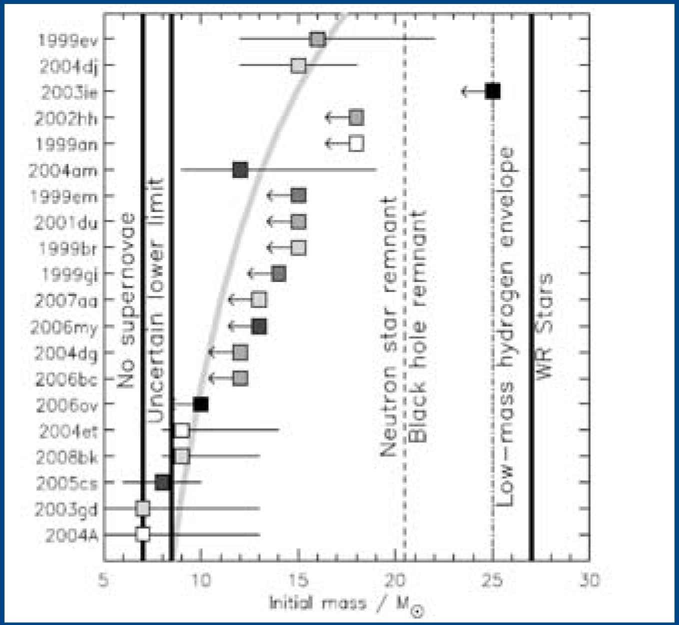
SNIIP → IIL → IIb → IIn → Ib → Ic

- Sequence of increasing pre-SN mass loss?
- Transient features determined by quantity of envelope retained, and nature of circum-stellar environment

- How does progenitor mass, metallicity, rotation, binarity, produce these differences?
- Which progenitor stars produce LGRBs, SN 'impostors'?

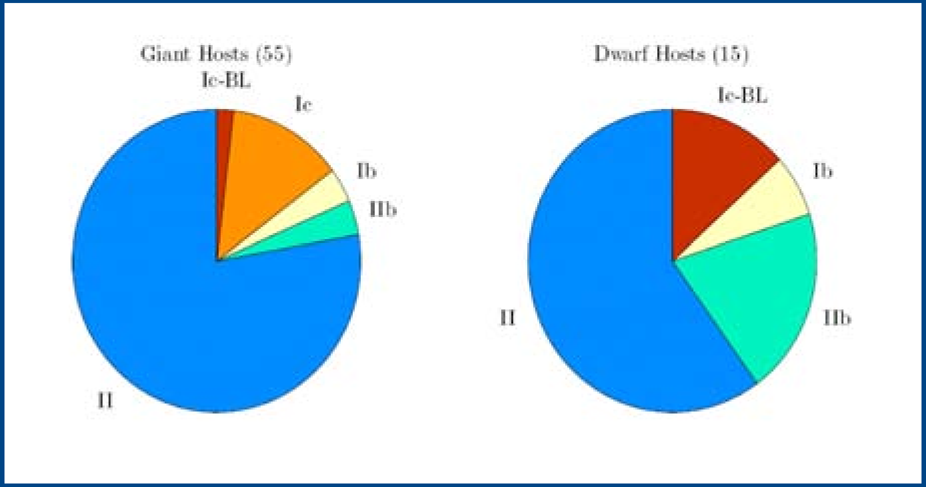
Constraining progenitor properties

- **Direct detections provide detailed info for individual nearby SNe**
  - low statistics, long-term answers
- **Host galaxy studies allow statistical samples to be studied**
  - multiple stellar populations



Smartt et al. (2009)

- **Constraining progenitor properties using environments *within* host galaxies**
  - allows statistical studies
  - differentiate between stellar populations



Arcavi et al. (2010)

CC SNe as tracers of SF within galaxies

- CC SNe give direct evidence of massive SF within galaxies
- With knowledge of progenitor systems and differences within CC SN groups, we can constrain properties of SF within different galaxies and environments

1) Make constraints on SN progenitors

2) Use constraints to infer properties of SF

Environments of SNe within host galaxies

a) Spatial correlations of SNe with host galaxy star formation

- **Search for differences in the association of explosion sites with SF regions by SN type**
  - use of Hα and near-UV host galaxy imaging
  - investigate differences in progenitor mass

b) Host HII region metallicity derivations

- **Evaluate differences between SNII and SNIbc environment metallicities**
  - host HII region spectroscopy
  - environment metallicities derived using emission lines
  - investigate differences in progenitor metallicity

Spatial correlations with host galaxy SF

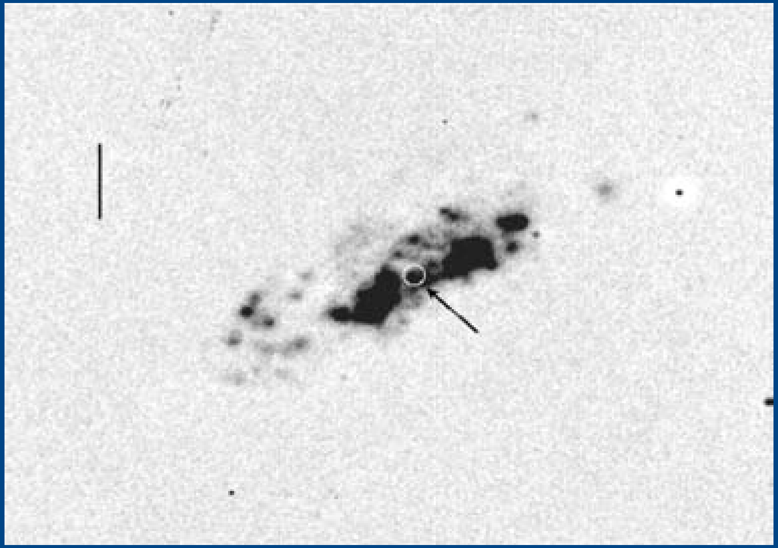
- **Host galaxy Hα imaging of large sample of CC SN**
  - 162.5 SNII (58 IIP, 13 IIL, 12.5 IIb, 19 IIn, 12 'impostors')
  - 97.5 SNIbc (40.5 Ib, 52 Ic)

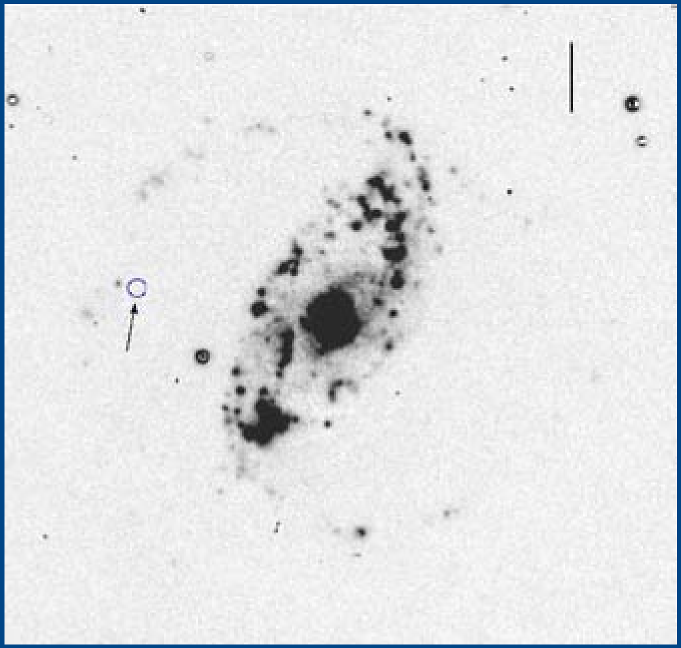


- ***GALEX* near-UV imaging also used**
- **Hα emission = 'on-going' SF: <10-15 Myr**
- **Near-UV emission = 'recent' SF: 16-100 Myr**

Host galaxy pixel statistics

- **'NCR' statistic to give the degree of association of an individual SN to the emission of its host galaxy**
  - James & Anderson (2006) (also Fruchter et al. 2006)
  - SNe studies; Anderson & James (2008), Kelly et al. (2008)
- **Statistic gives for each object a value between 0 and 1**
  - NCR value of 0 means zero flux or sky values
  - value of 1 means SN falls on highest count pixel





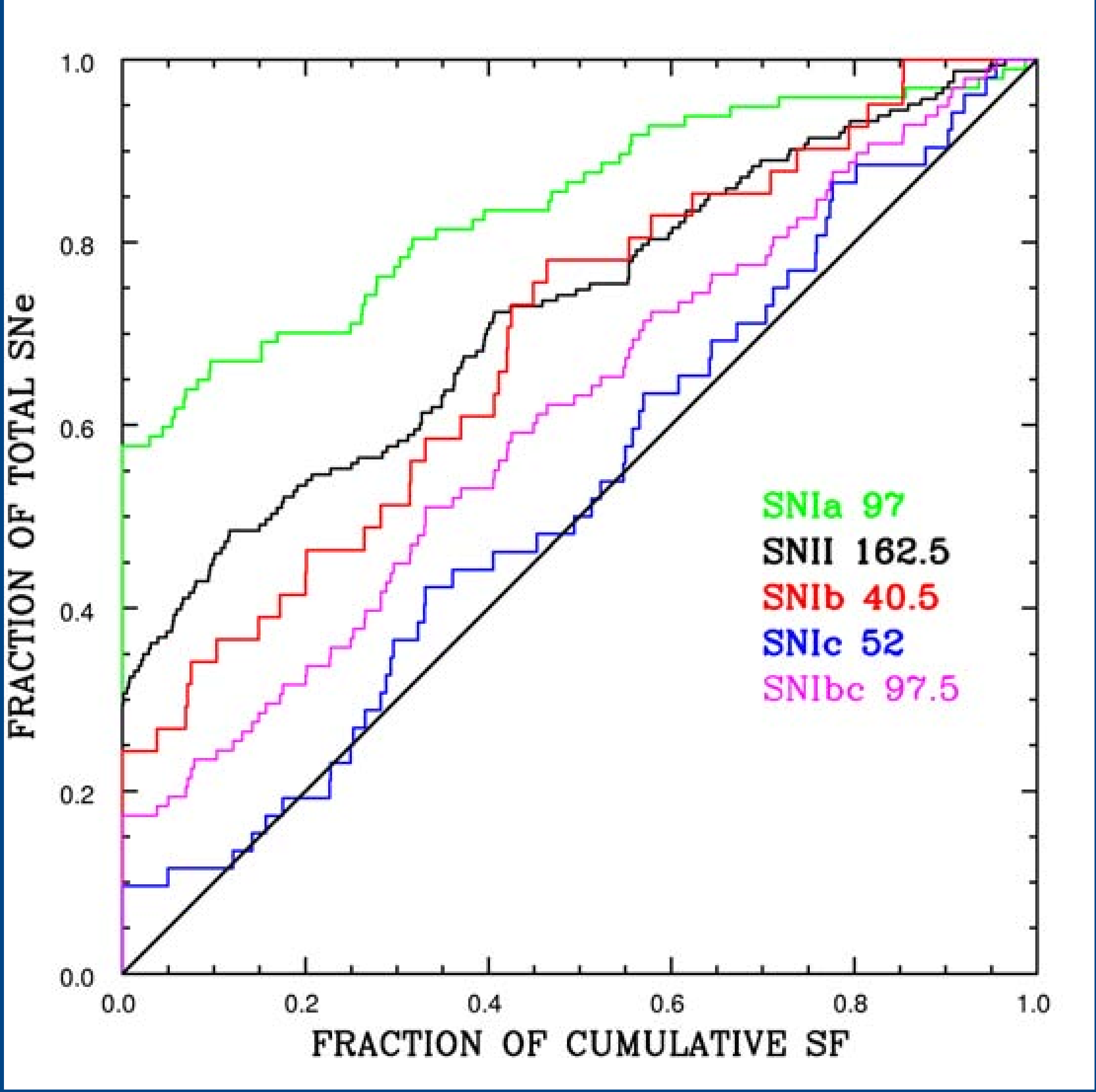
- **Build up distributions of all SN types**

Cumulative distributions

(Anderson et al. in prep)

- Increasing association to emission means shorter lived, higher mass progenitors

- Progenitor mass sequence observed: **Ia-II-Ib-Ic**
- SNIb do not trace 'on-going' SF: binaries?
- SNIc show highest degree of association: highest mass progenitors

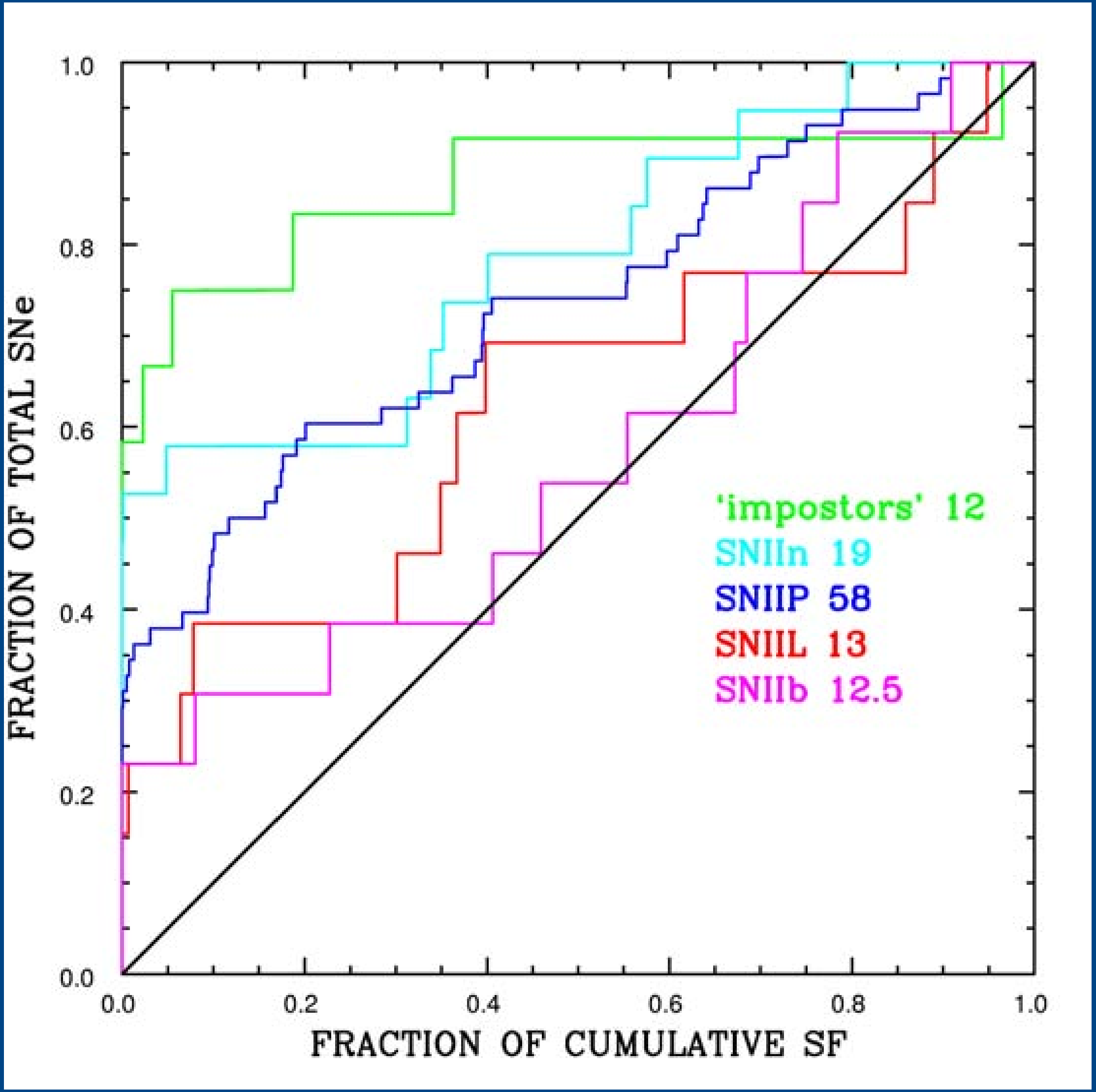


Cumulative distributions

(Anderson et al. in prep)

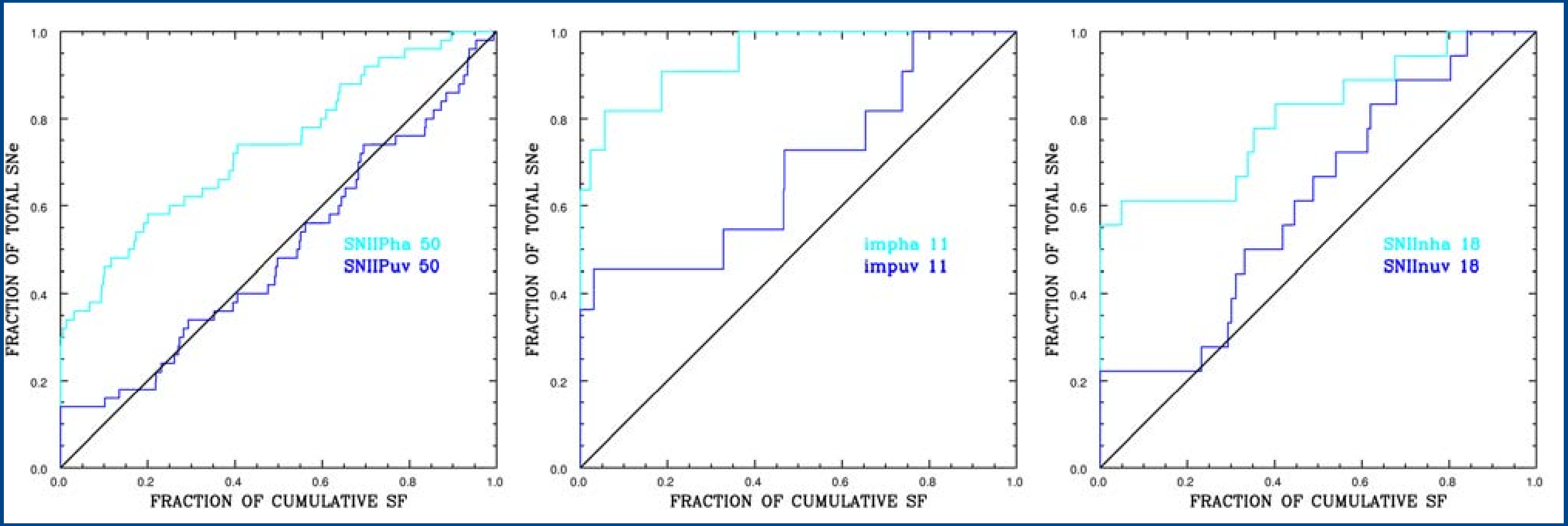
- SN 'impostors' – SNIIn – SNIIP – SNIIL – SNIIb

- SN 'impostors' and SNIIn show lowest correlation with emission; lower mass progenitors?
- SNIIL and SNIIb higher mass progenitors than IIP?



'On-going' and 'recent' SF

- SNIIP, IIn and 'impostors': correlation to 'recent' SF



- All show increased association to SF on longer timescales
- Additional evidence for low mass progenitors?

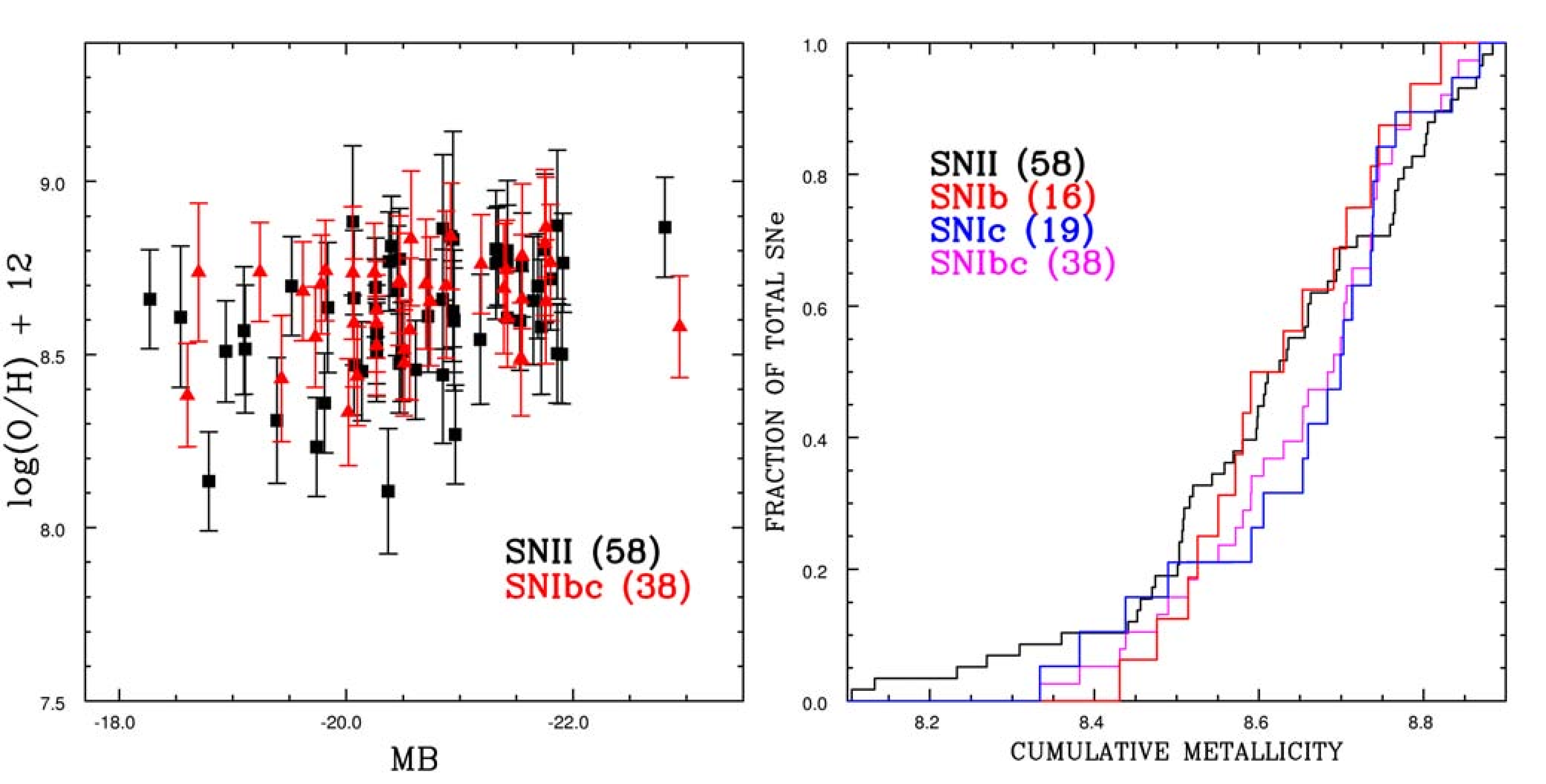
Progenitor mass constraints

- **SNIbc show higher association to 'on-going' SF than SNII**
  - higher mass progenitor stars
  - *NOTE*, this does not *necessarily* mean single stars
- **SNIb do not trace SF on timescales <15Myr (?)**
  - therefore majority of progenitors from lower mass stars
  - hence, binary progenitors?
- **SNIc arise from the highest mass stars that explode in CC**
- **SNIIP trace SF on timescales 16-100Myr**
  - majority of progenitors from less than 12msun
  - consistent with direct detection constraints
- **SNIIn *do not* trace SF on the shortest timescales**
  - majority of progenitors *do not arise from very massive progenitor stars*
- **SNIIL and IIb possibly more massive prog. than IIP**

Host HII region metallicities

- **Host HII region optical spectroscopy obtained for 96 CC SNe**
  - initial sample published in Anderson et al. (2010)
  - 58 SNII, 38 SNIbc
- **Main aim to evaluate differences in progenitor metallicties between hydrogen rich and hydrogen poor SNe**
  - other studies on SNIb-Ic-BLIc-GRBs; Modjaz et al. (2011), Leloudas et al. (2011)
- **Environment metallicities derived from ratio of strong emission lines**
  - Pettini & Pagel O3N2 or N2 used

Host HII region metallicities



- Only 0.04 dex difference between Ibc and II
- Tentative metallicity sequence: II-Ib-Ic

Progenitor metallicity constraints

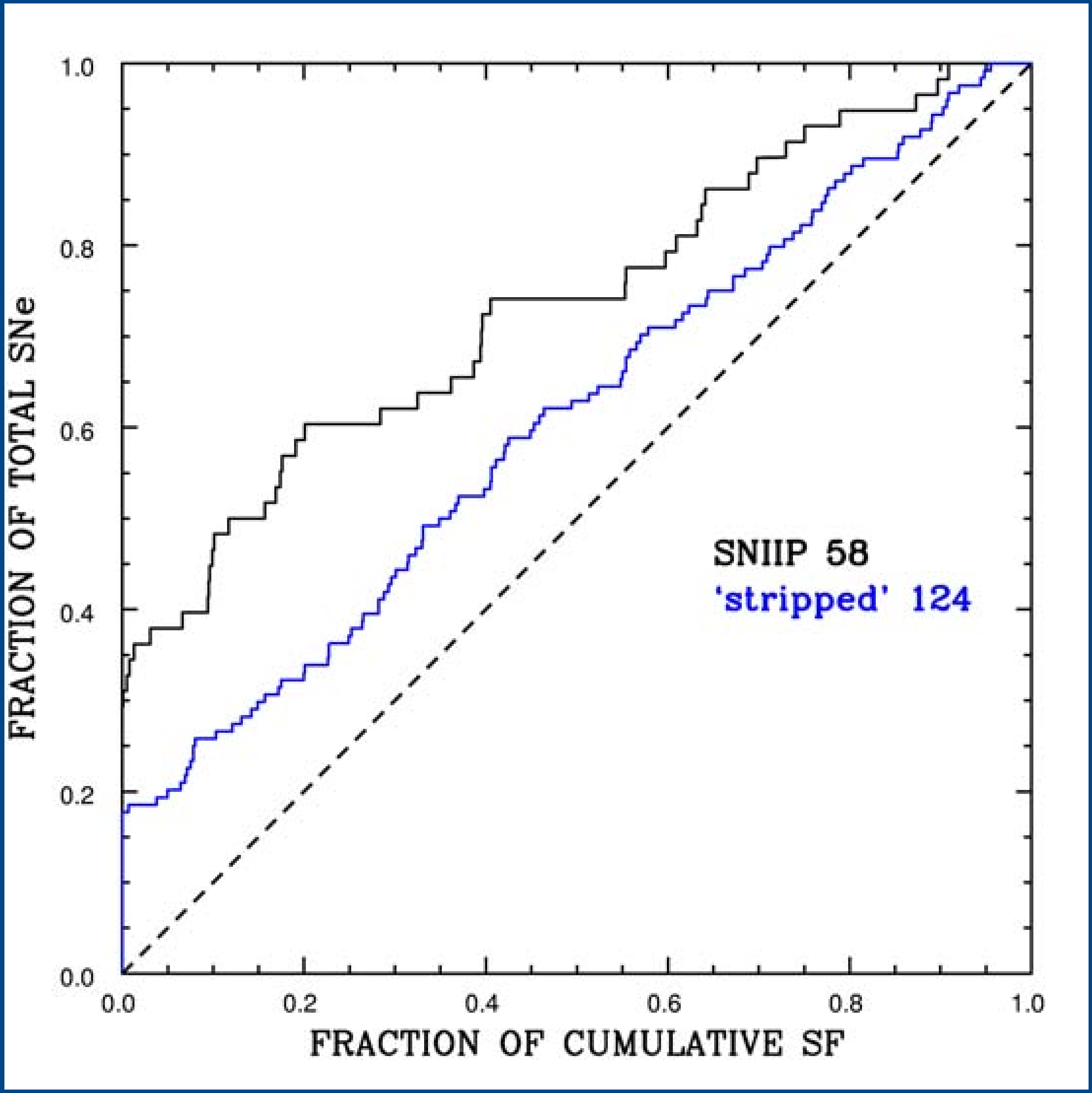
- **SNIbc have higher metallicity progenitors than SNII, *but* difference is not statistically significant**
  - metallicity does not significantly effect type produced?
- **SNII-Ib-Ic metallicity sequence is as expected, *but*, again not significant**
  - significant differences claimed elsewhere
- **Caveat in this work is the lack of SNe in low luminosity host galaxies**
  - sample taken from Asiago and is hence dominated by massive galaxies
  - *however*, still expect to see trend *within* these galaxies
- ***Representative* sample needed from un-targeted survey**
  - but, hard to get SNII *at* exact explosion sites

Progenitor properties, CC SNe as tracers if massive SF

- SNIbc arise from more massive stars than SNII
- All 'stripped envelope' SNe (excluding IIn) show a higher association to SF than SNIIP: higher mass progenitors
- No large metallicity difference between SNII and SNIbc

- Assumption of higher mass progenitors for 'stripped envelope' than hydrogen rich SNe (IIP)
- Use relative distributions of CC SNe within galaxies to investigate SF properties of galaxies

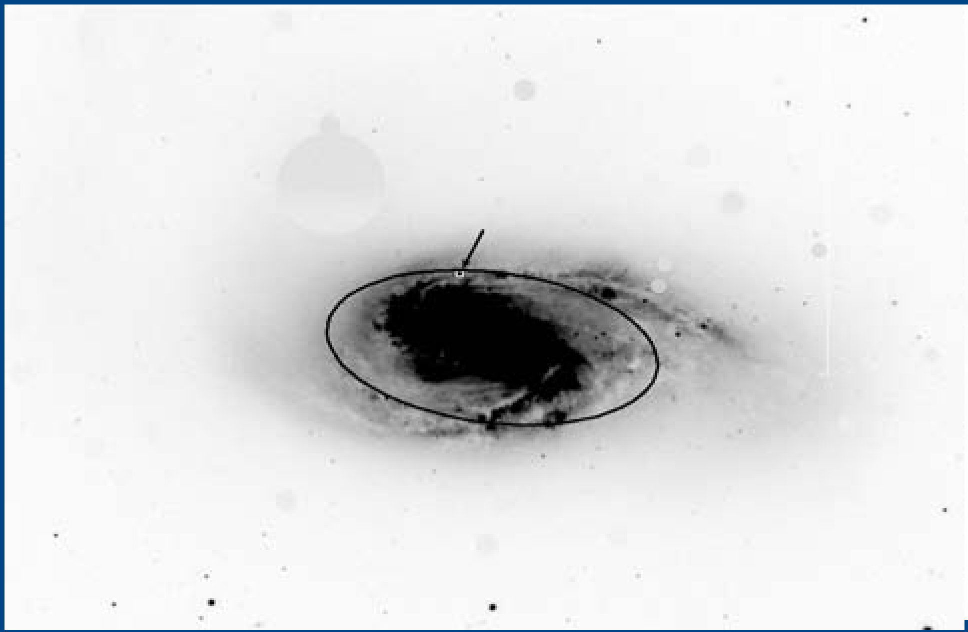
'Stripped envelope' (SE) > SNIIP (mass)

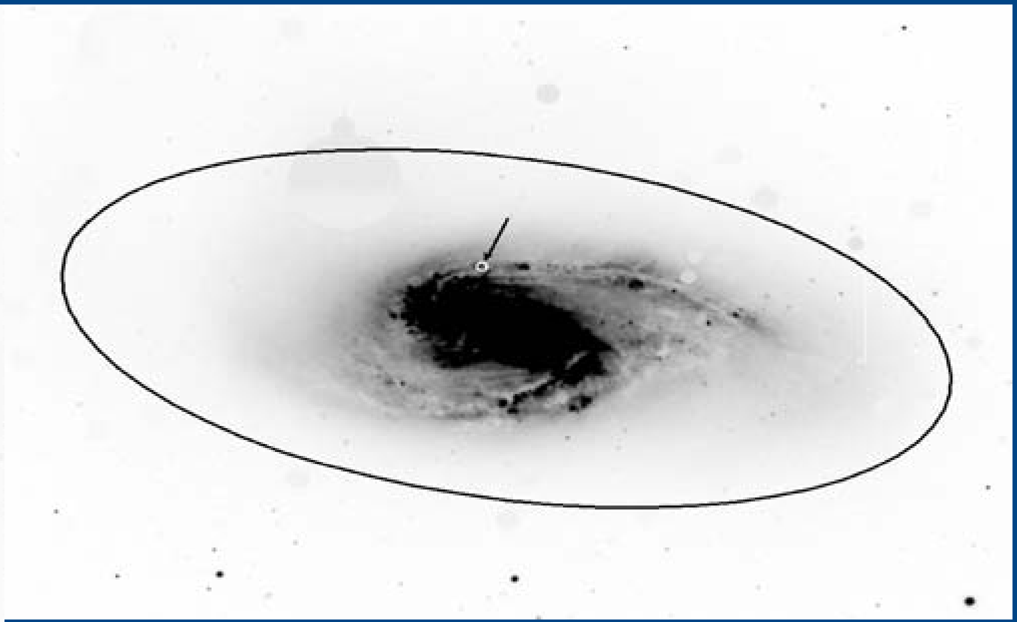


- 'Stripped envelope' events = SNIIL + IIb + Ib + Ic
- *ALL* have higher associations to SF than SNIIP

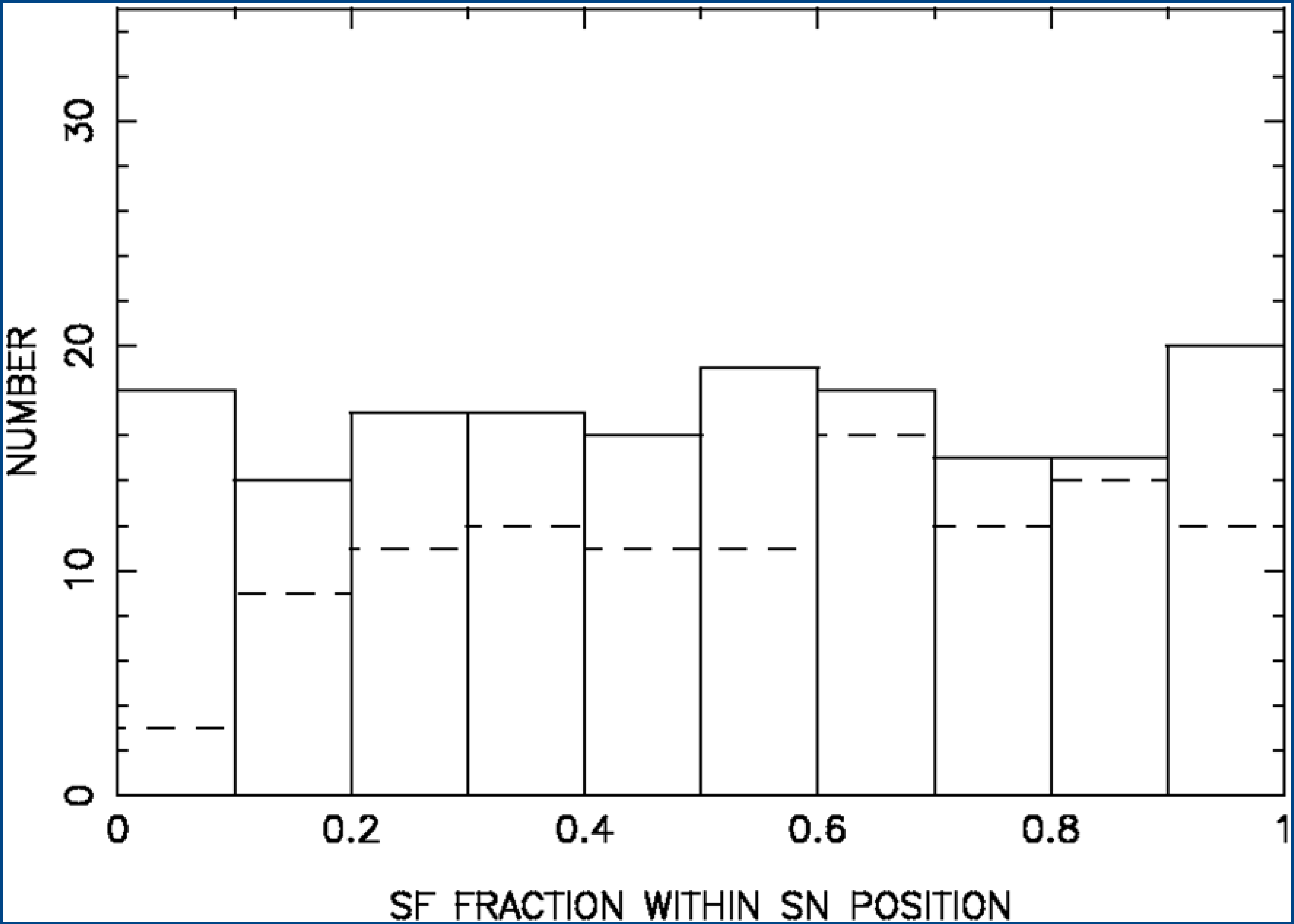
Radial distribution of CC SNe

- **Analysis of radial distribution of CC SNe with respect to young (Hα) and old (*R*-band) stellar populations**
  - same sample as previous pixel analysis
- **Radial analysis gives value between 0 and 1 for each SN**
  - radial Fr of 0 SN falls on central pixel of emission
  - value of 1 means SN falls outside any galaxy emission
- **Build distributions for all CC SN types**





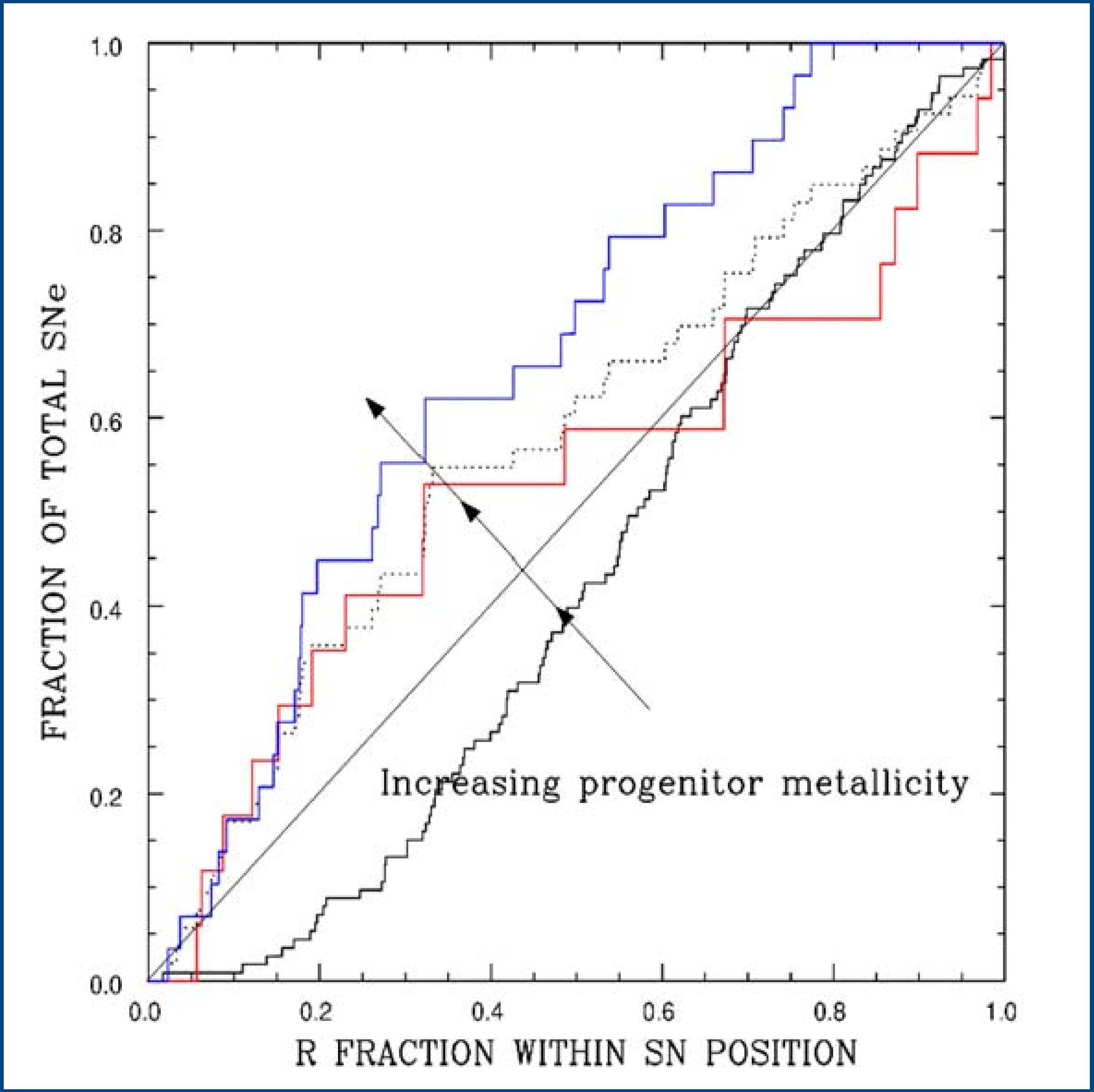
Anderson & James (2009): CC SNe follow the radial distribution of SF



Anderson & James (2009); progenitor metallicity?

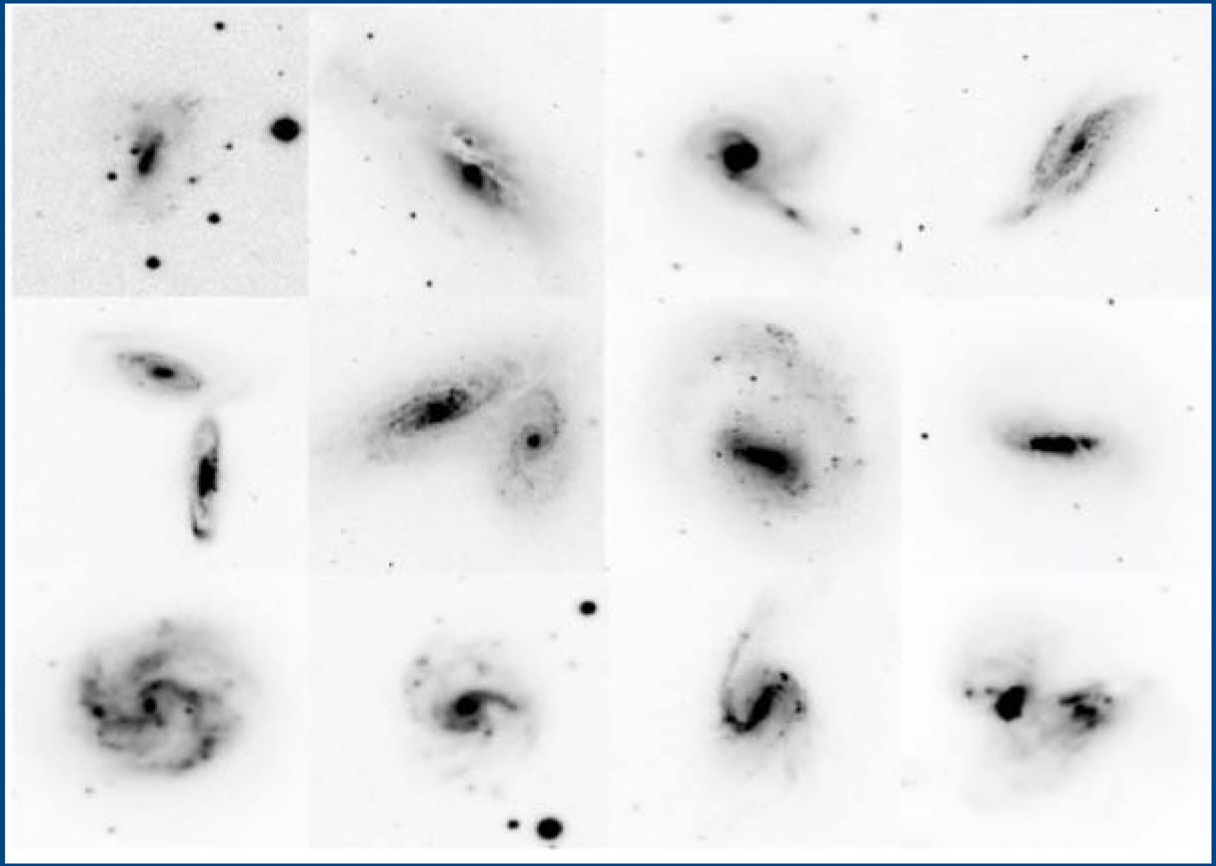
- SNIbc more centrally concentrated in host galaxies
- A metallicity trend?

NO!!! trend is only seen in disturbed galaxies!



Habergham, Anderson & James (2010); separating sample by disturbance

- **Eye-ball classifications done of galaxy sample**
  - obvious merger, tidal tails, asymmetries etc…
- **Sample separated into disturbed and undisturbed samples**



Radial distributions in disturbed and undisturbed samples

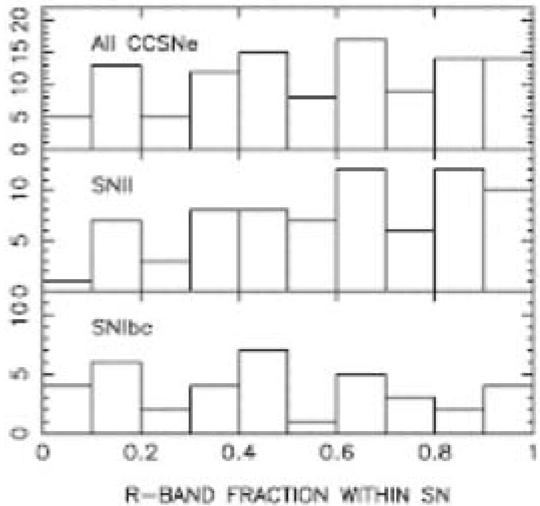


Figure 1. Histogram showing the distribution of fractions of host galaxy *R*-band light lying within the locations of each CCSN in our undisturbed host galaxies. The top plot represents the distribution of all CCSNe, the middle SNII, and the lower SNIbc.

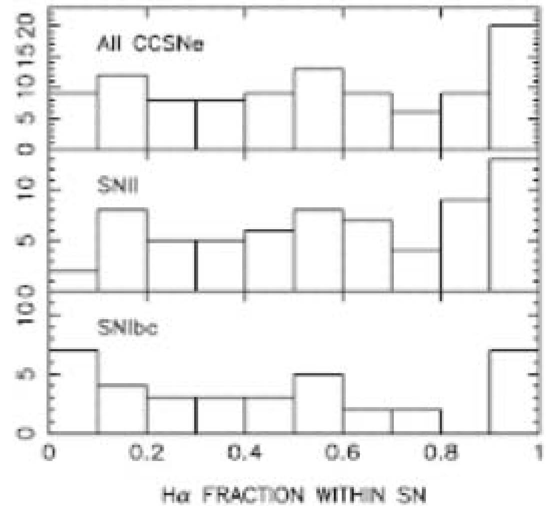


Figure 3. Histogram showing the distribution of fractions of host galaxy Hα light lying within the locations of each CCSN in our sample, for the undisturbed host galaxies. Again, the upper plot shows the overall CCSNe distribution, the middle SNII, and the lower SNIbc.

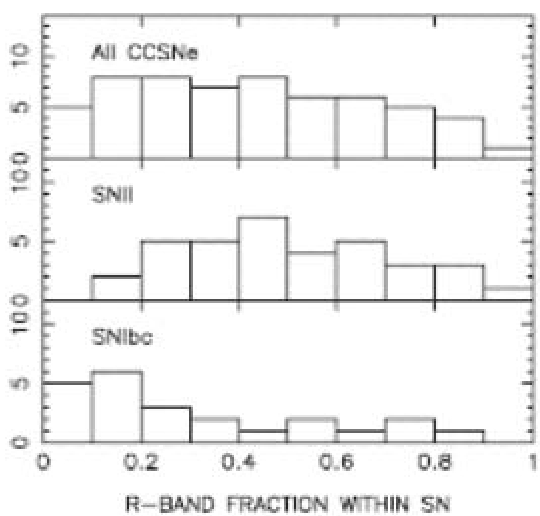


Figure 2. Same as Figure 1, but for the disturbed host galaxies.

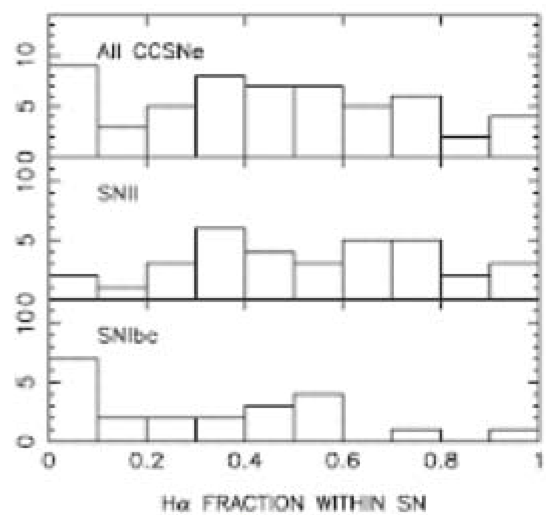


Figure 4. Same as Figure 3, for the disturbed host galaxies.

An updated sample

(Habergham, James & Anderson, in prep)

[htb]

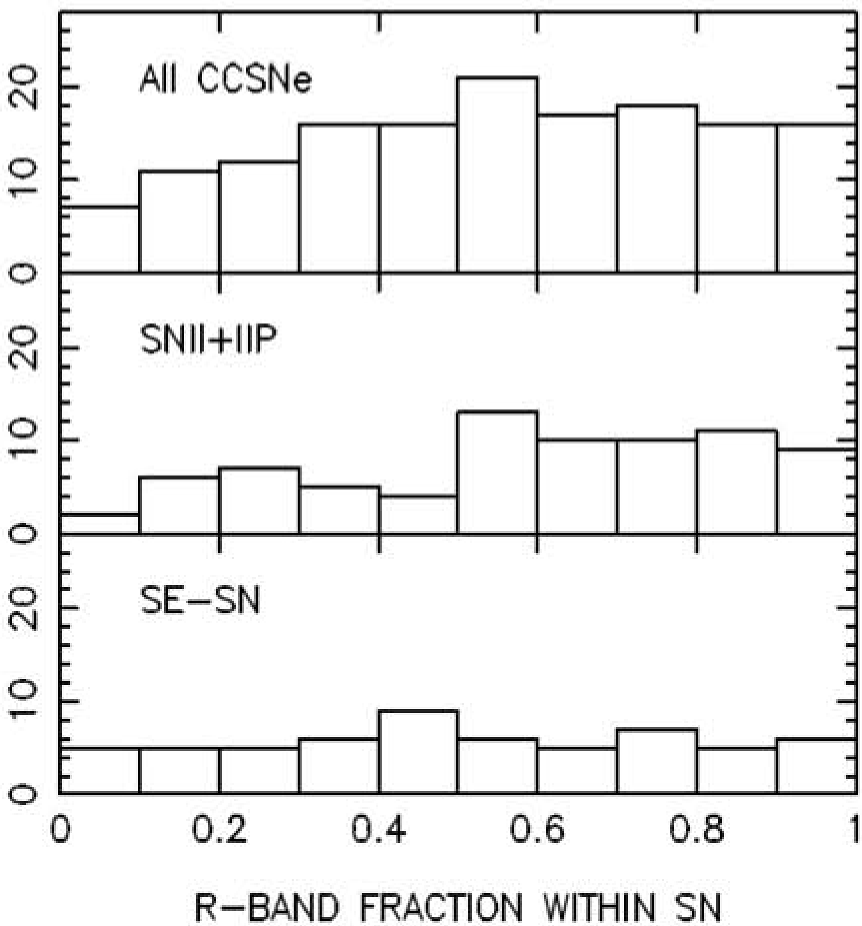


Figure 2. Fractional *R*-band light distribution of CCSNe in undisturbed host galaxies.

[htb]

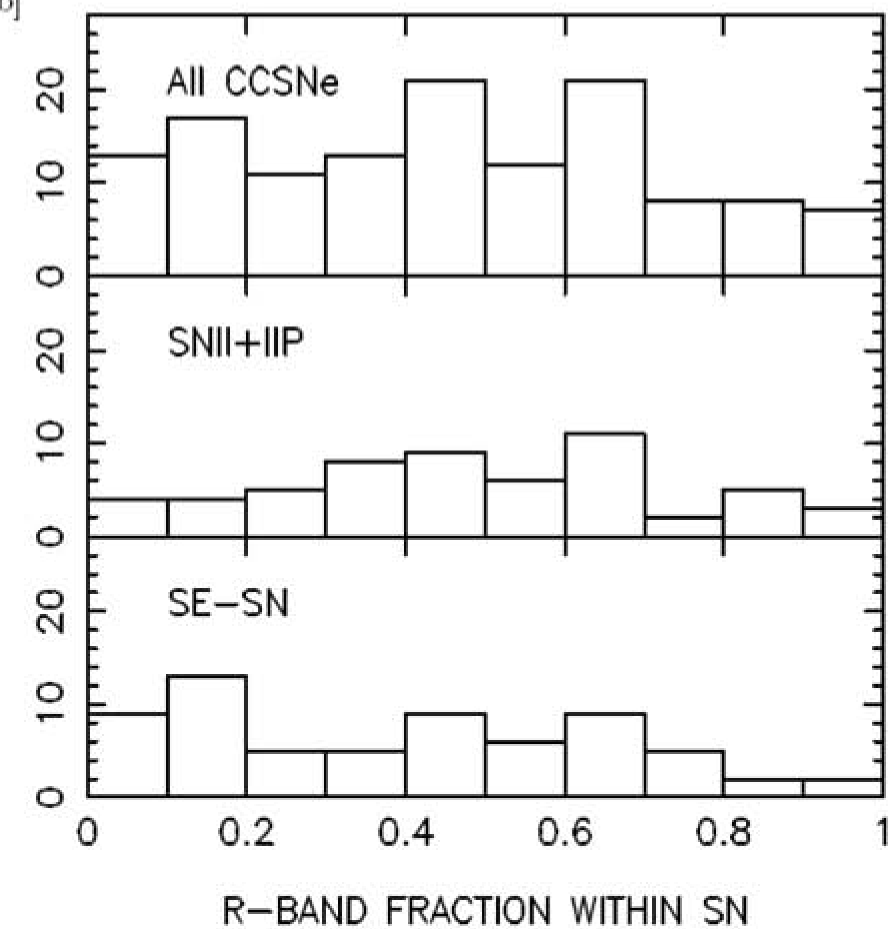


Figure 3. Fractional *R*-band light distribution of CCSNe in disturbed host galaxies

Central excess of SE in disturbed galaxies

- **Central excess is dominated by those SNe occurring in disturbed host galaxies**
- **This is the *opposite* to what one would expect if this were a metallicity effect**

  - metallicity gradients are much shallower or non-existent in disturbed/interacting galaxies (Kewley et al. 2011)
- **Starburst age effect?**

  - stars producing CC SNe occur on very short timescales
  - all disturbed galaxies have SF on longer timescales
- **IMF effect?**

  - dominance of 'stripped envelope' events in central regions naturally explained by changes in IMF

Changes to the peak of the IMF

- Changes to IMF in Universe?
- Appears most likely to happen in very dense environments

IMF in the Galactic centre and starburst regions L31

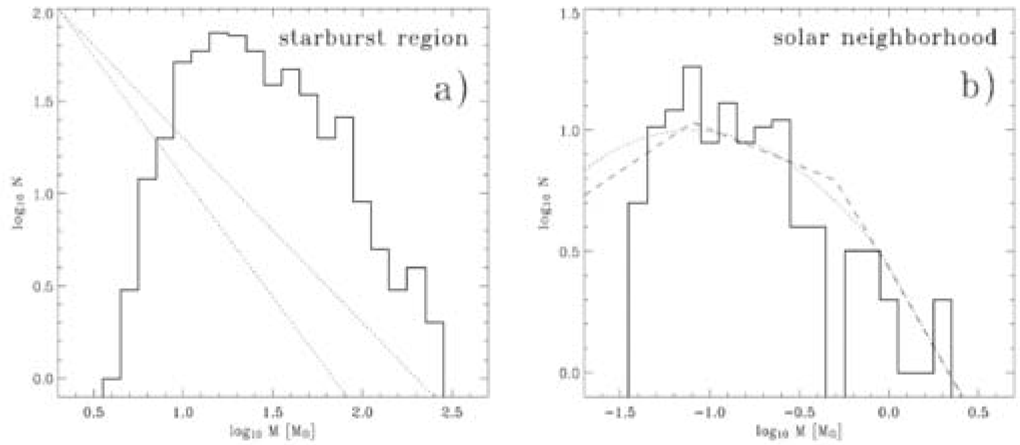


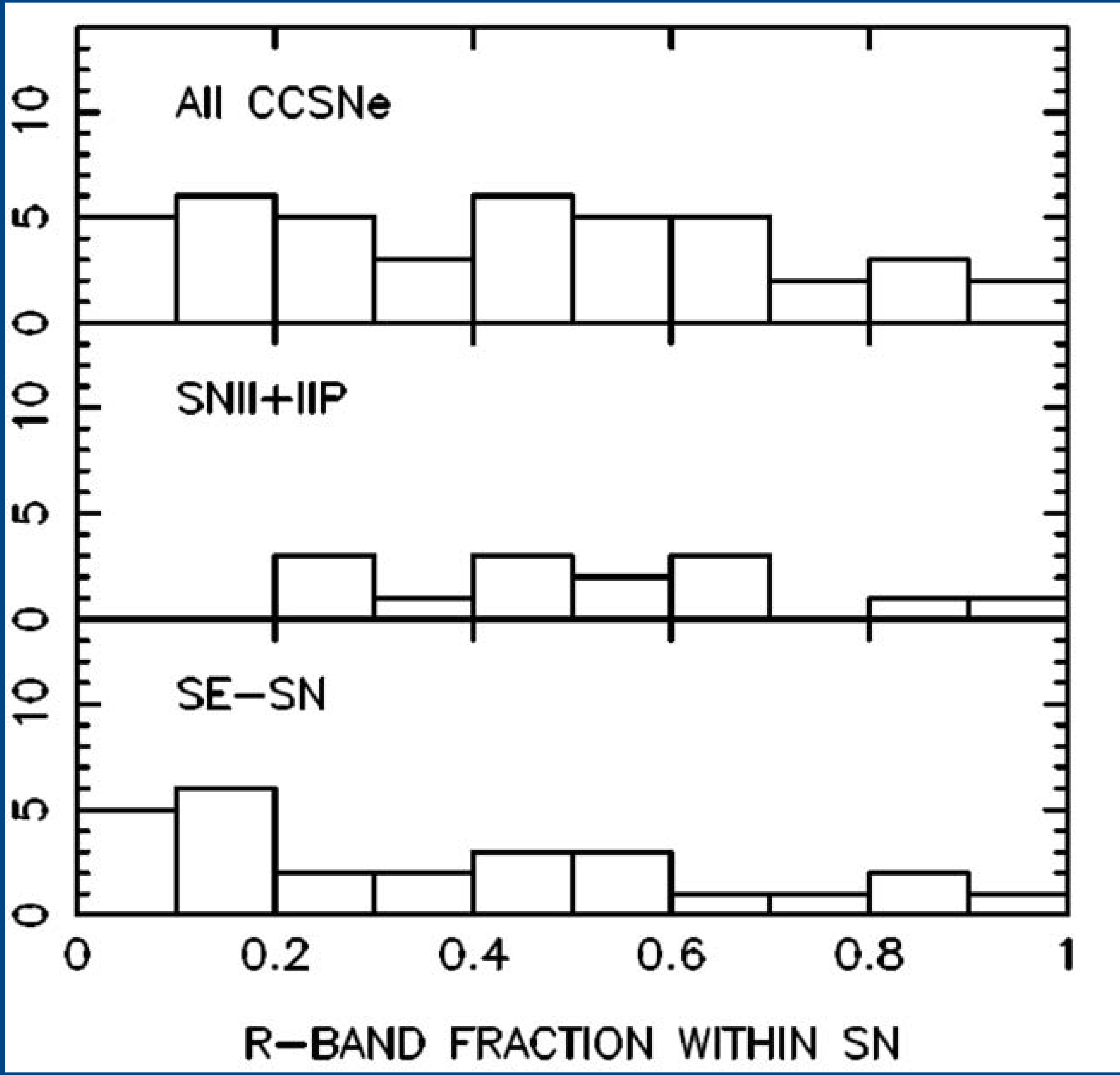
Figure 3. (a) Mass spectrum of gravitational condensations in the starburst calculation at a time when 15 per cent of the gas is converted into collapsed objects (which we identify as direct progenitors of individual stars). To guide the eye, we indicate a slope −1.0 and the Salpeter slope −1.3 with dotted lines. The mass function in our simulated starburst environment shows a broad peak in the range 10–25 $M_\odot$ and falls off for larger masses. It is thus top-heavy compared to the IMF in the solar neighbourhood (Salpeter 1955; Kroupa 2002; Chabrier 2003). (b) Mass spectrum of collapsed objects in a calculation focusing on nearby molecular clouds (see Jappsen et al. 2005). It agrees well with the IMF in the solar vicinity. For comparison we overplot the functional forms proposed by Kroupa (2002) with dashed lines and by Chabrier (2003) with dotted lines. Our two calculations differ mainly in the adopted EOS, i.e. in the chemical and thermodynamic state of the star forming gas, other parameters are comparable.

Klessen et al. (2007)

- IMF peak changes to higher masses in starburst regions
- *Prediction:* effect pronounced in extreme environments…

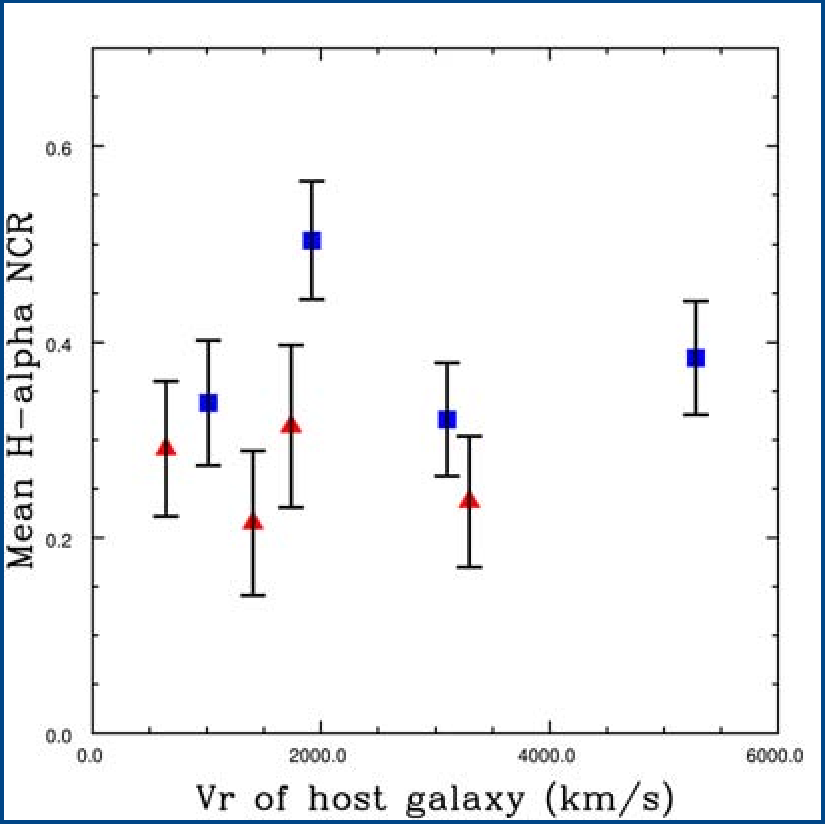
The most disturbed galaxies

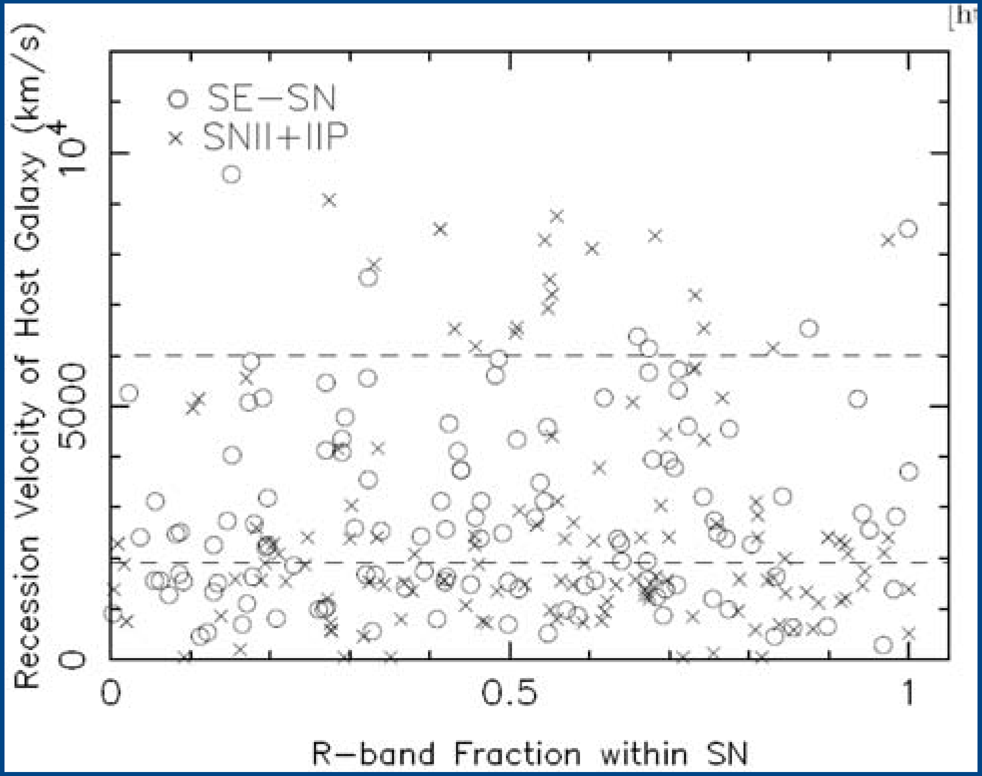
- Galaxies further separated to make 'extreme' sample
- Central 20% of light completely dominated by SE events!
- ZERO SNIIP in central regions!



Selection effects

- In both pixel stats work and radial distributions, analysis of numerous possible selection effects done





- No significant selection effects to explain our results

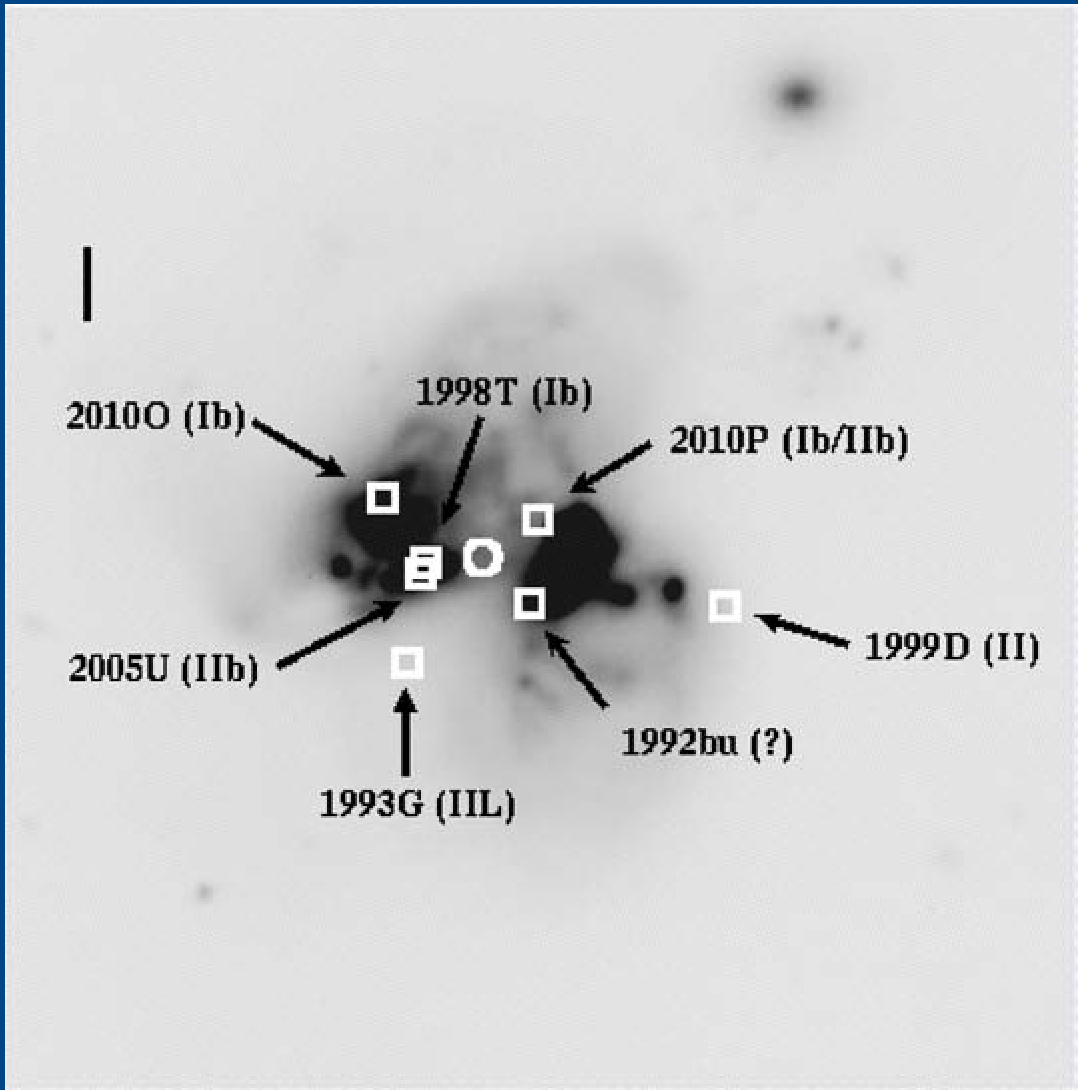
Conclusions from radial analysis

- **Central excess of SE SNe compared to SNIIP**
  - previously attributed to metallicity
  - excess *dominated* by those SNe in disturbed galaxies
  - metallicity effect should go in opposite direction
- **Central excess is most easily explained by a change in the peak of the IMF in dense highly star SF regions**
- **Numerous selection effects investigated and none can explain our results**
- **Observational evidence for changes to IMF**

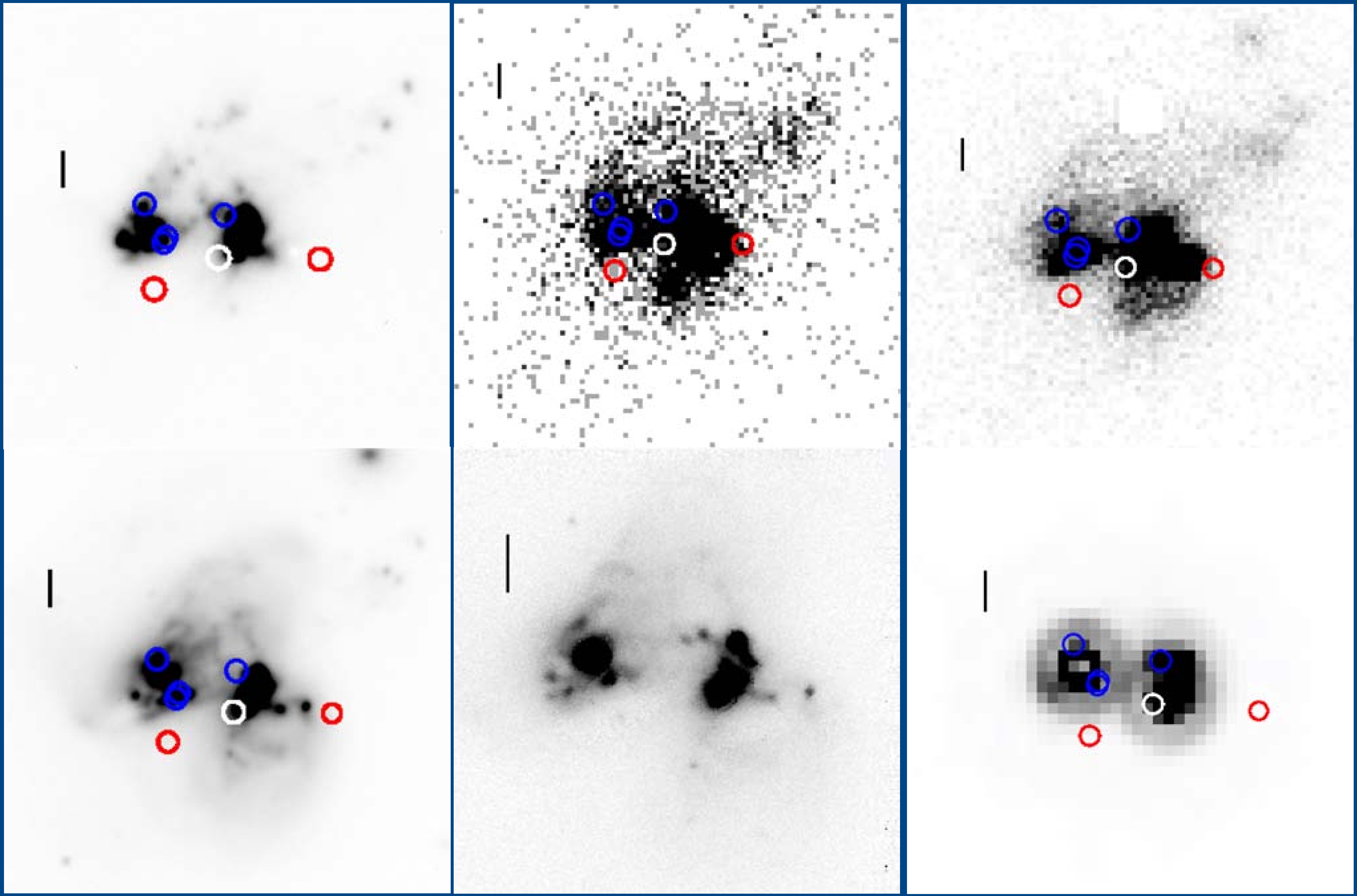
A case study: the 7 SNe of Arp 299

(Anderson, Habergham & James 2011)

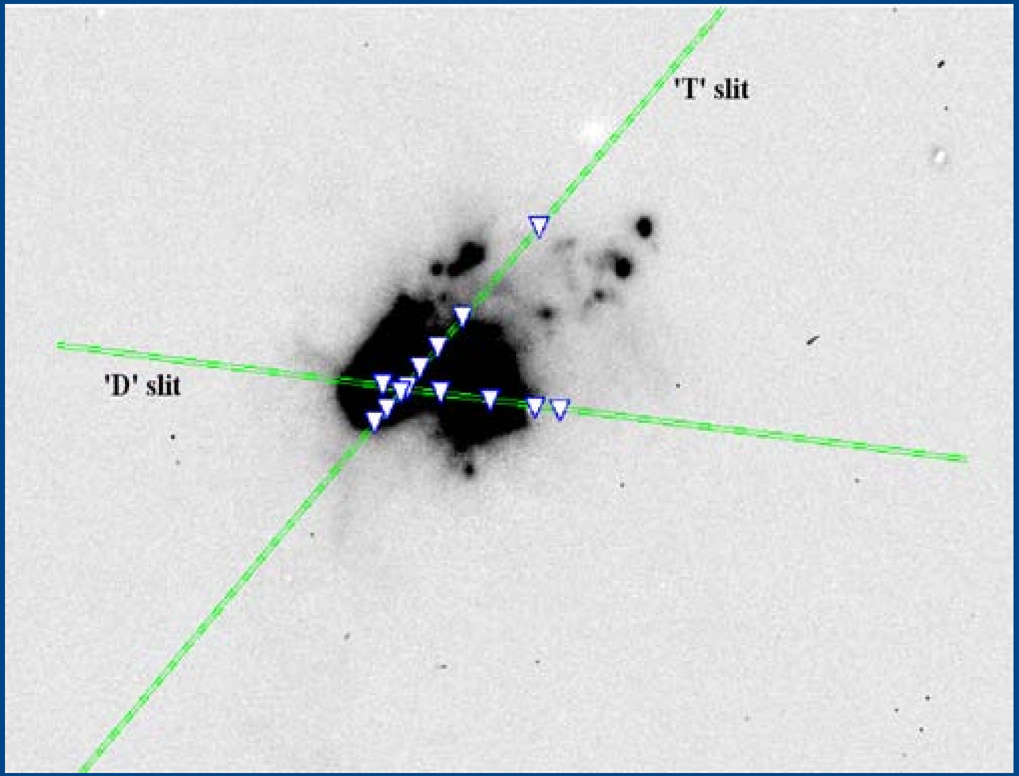
- Interacting starburst; NGC 3690, IC 694
- 7 SNe discovered over last 20 years
  - 6 CC, 1 unknown
- Investigate large number of SE events, together with environments where SNe are found

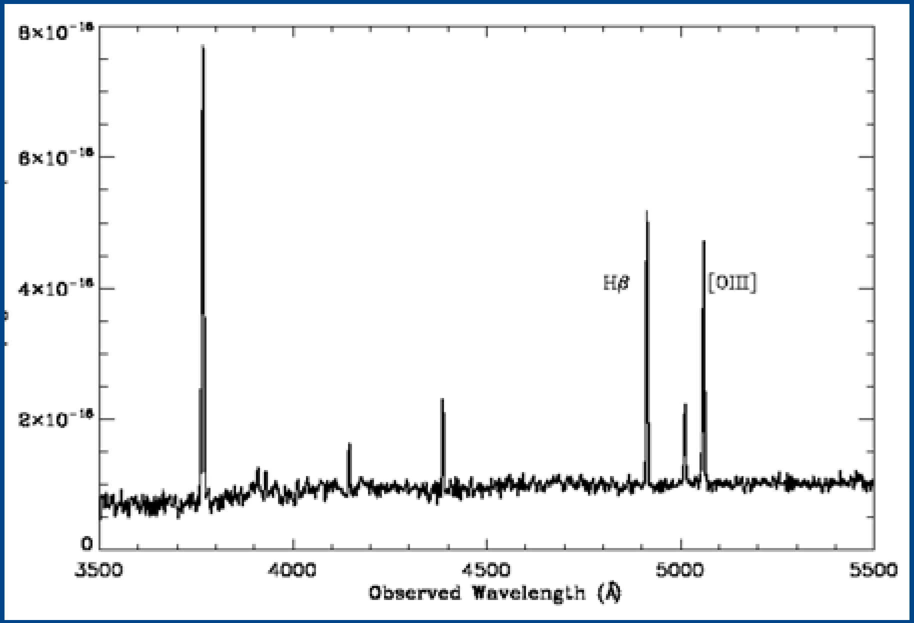


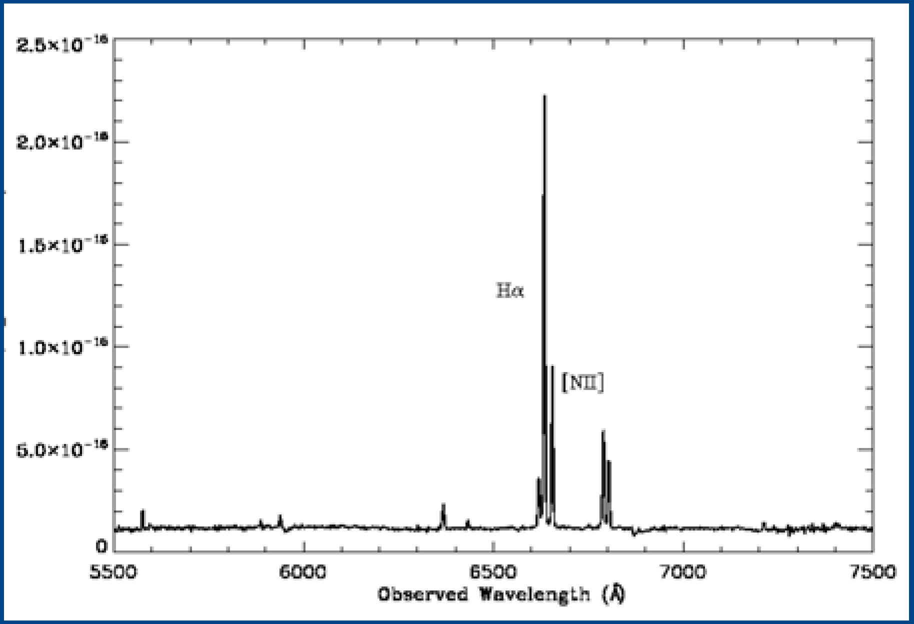
A case study: the 7 SNe of Arp 299



A case study: the 7 SNe of Arp 299







A case study: the 7 SNe of Arp 299

- **Ratio of SE to 'normal' SNII is high**
  - ~10% chance probability (5% if include IIL)
- **All SE events are more centrally concentrated than SNII**
  - ~7% probability
- **All SN environment metallicities are similar and no gradient found across galaxy**
- **All SE events are found to occur nearer to bright HII regions (in all tracers of SF) than 'normal' events**
  - ~7% probability

A case study: the 7 SNe of Arp 299

Two different -but non-mutually exclusive- interpretations on the system and its SNe:

1) Distribution and relative rates of SNe can be explained by age of system; insufficient time has expired for observed rates to match 'true'. This would then give additional *independent* evidence for higher mass progenitors for SNIb and IIb over SNIIP

2) Given the *assumption* of higher mass progenitor stars (from pixel statistics), results imply that the centrally peaked and enhanced SF is biased towards the production of high mass stars.

Summary/conclusions

1) SN progenitors:

- Progenitor mass sequence observed: SNIa-II-Ib-Ic
- SNIbc arise from higher mass progenitor stars than SNII
- *All* 'stripped envelope' SNe show higher degree of association to SF than SNIIP; hence higher mass progenitors
- SNIIn appear to arise from the low mass end of the CC SN mass range

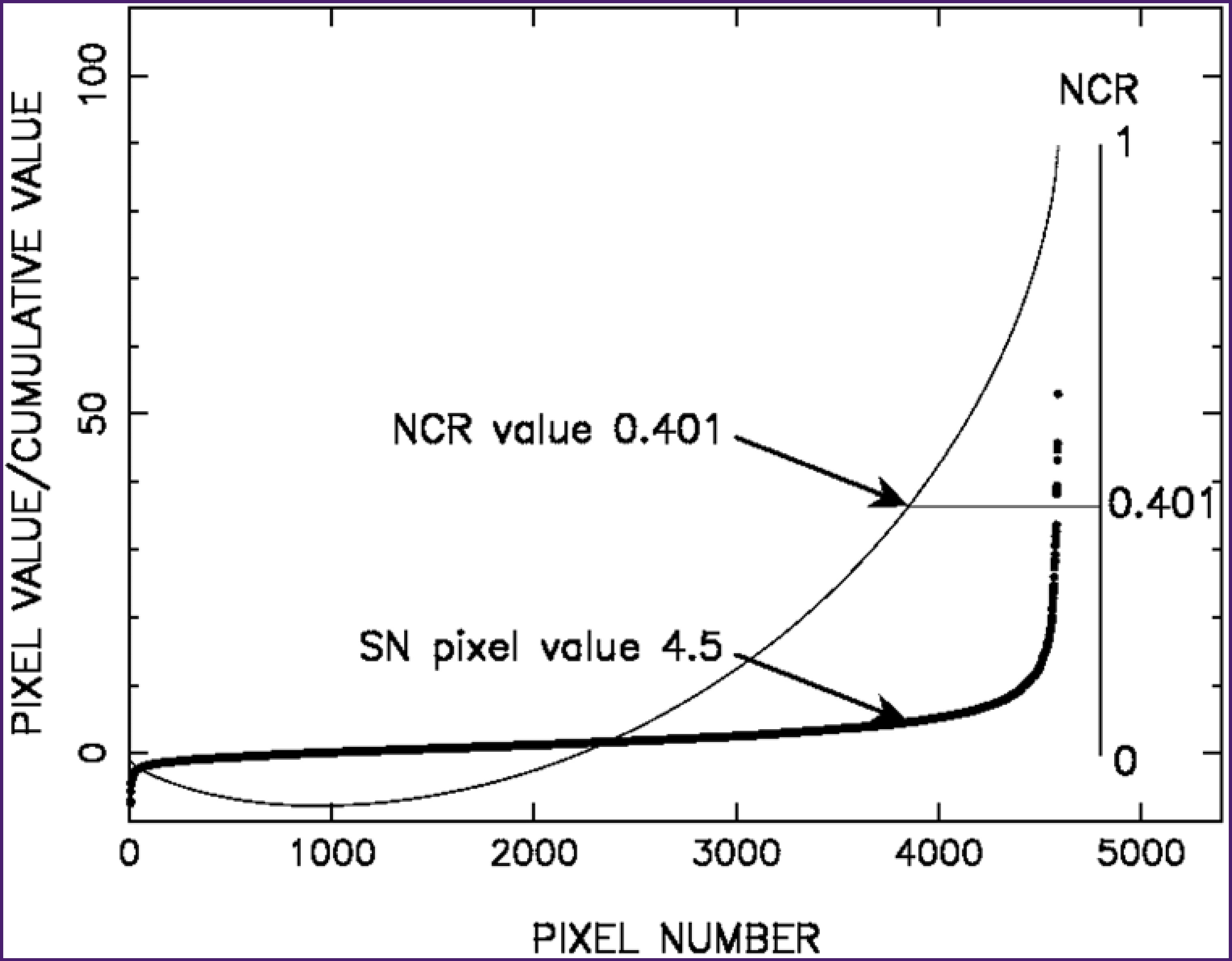
- SNIbc progenitors have only slightly higher metallicities than SNII
- Tentative metallicity sequence: SNII-Ib-Ic

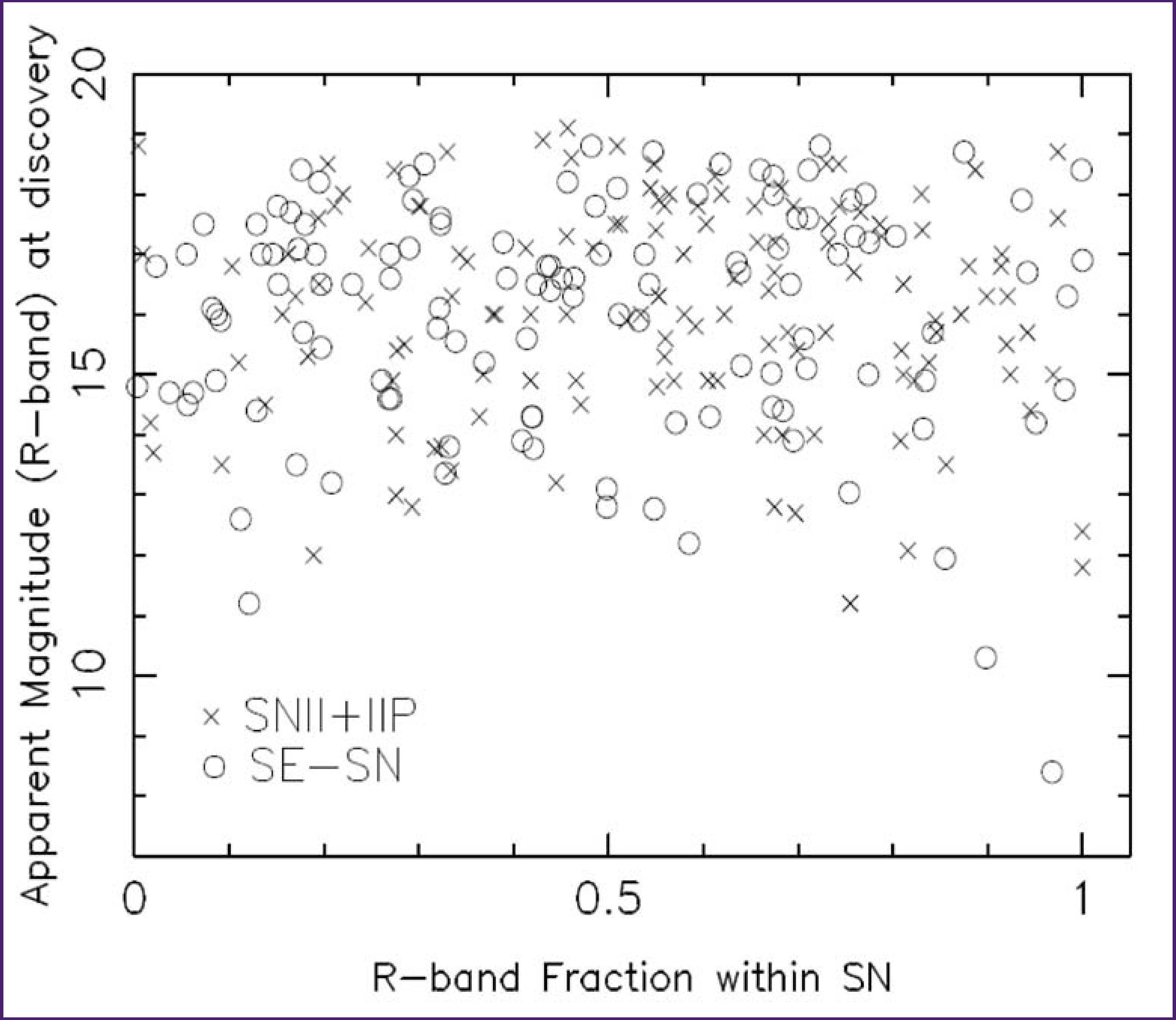
Summary/conclusions

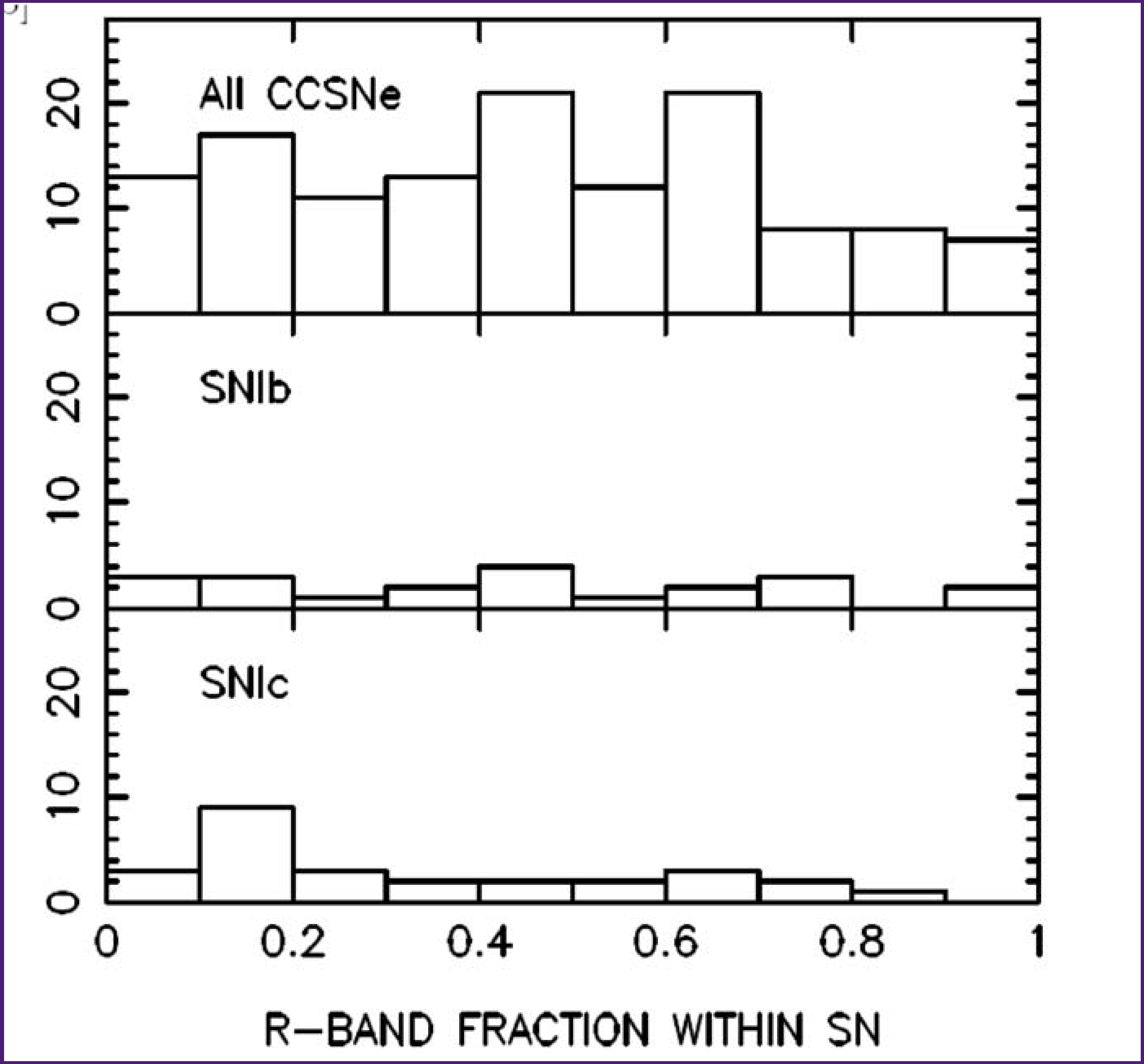
2) SF properties of nearby SN host galaxies

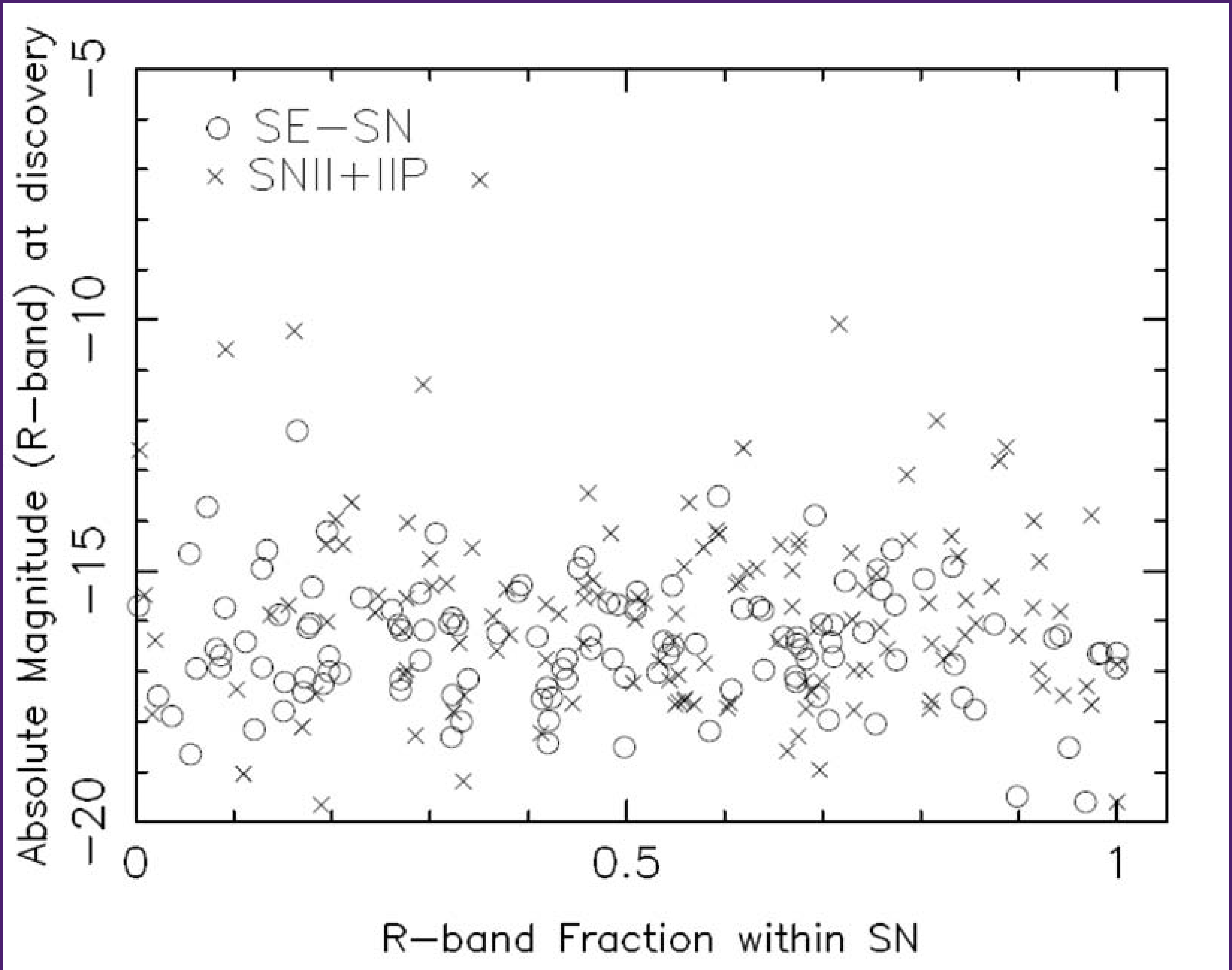
- 'Stripped envelope' events are found to occur more centrally within host galaxies than SNIIP
- Centralisation is dominated by those in disturbed hosts
- Results cannot be explained by metallicity or age effects

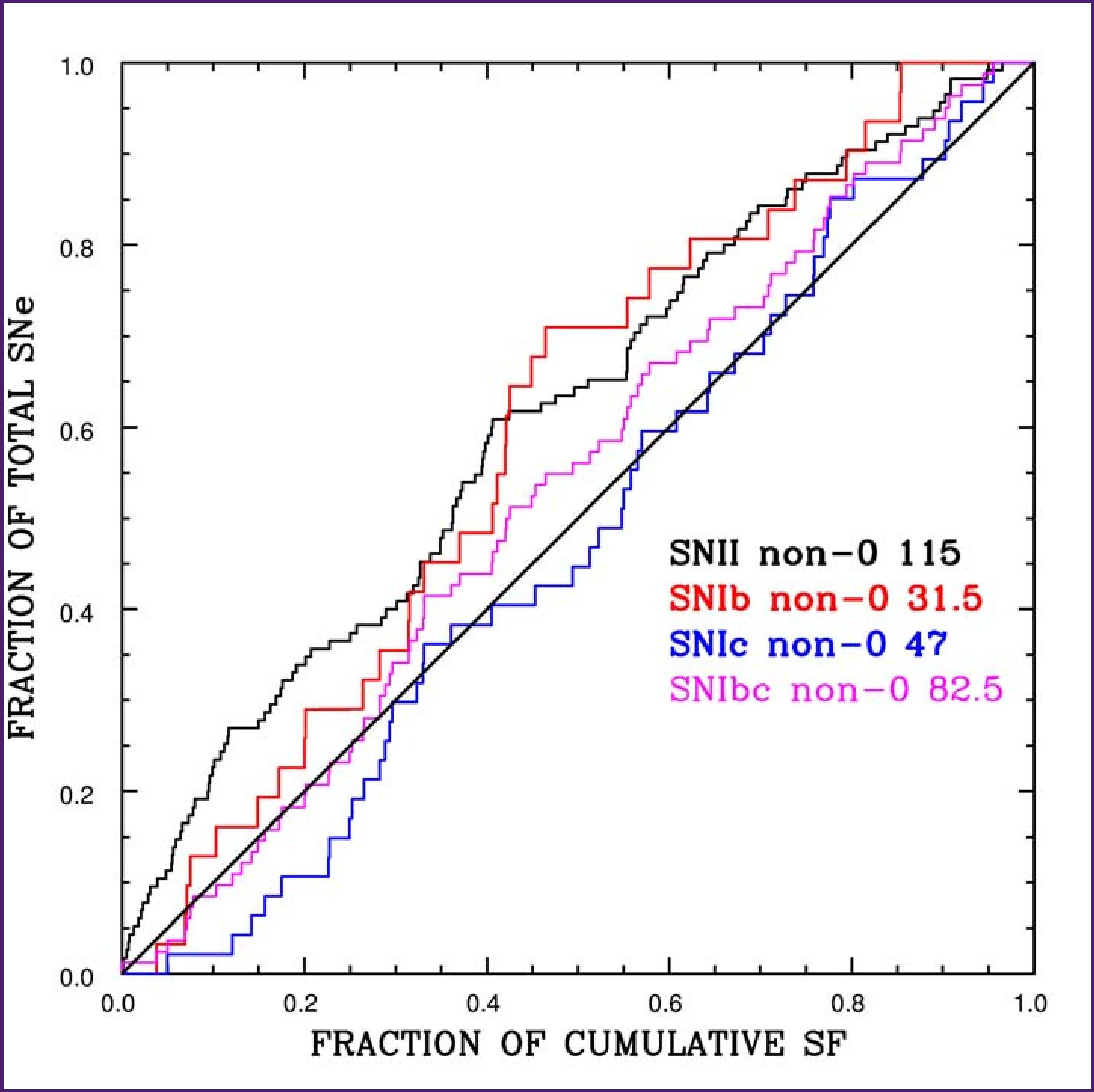
- Results most easily explained by a **change in peak of the IMF in denser highly SF regions**

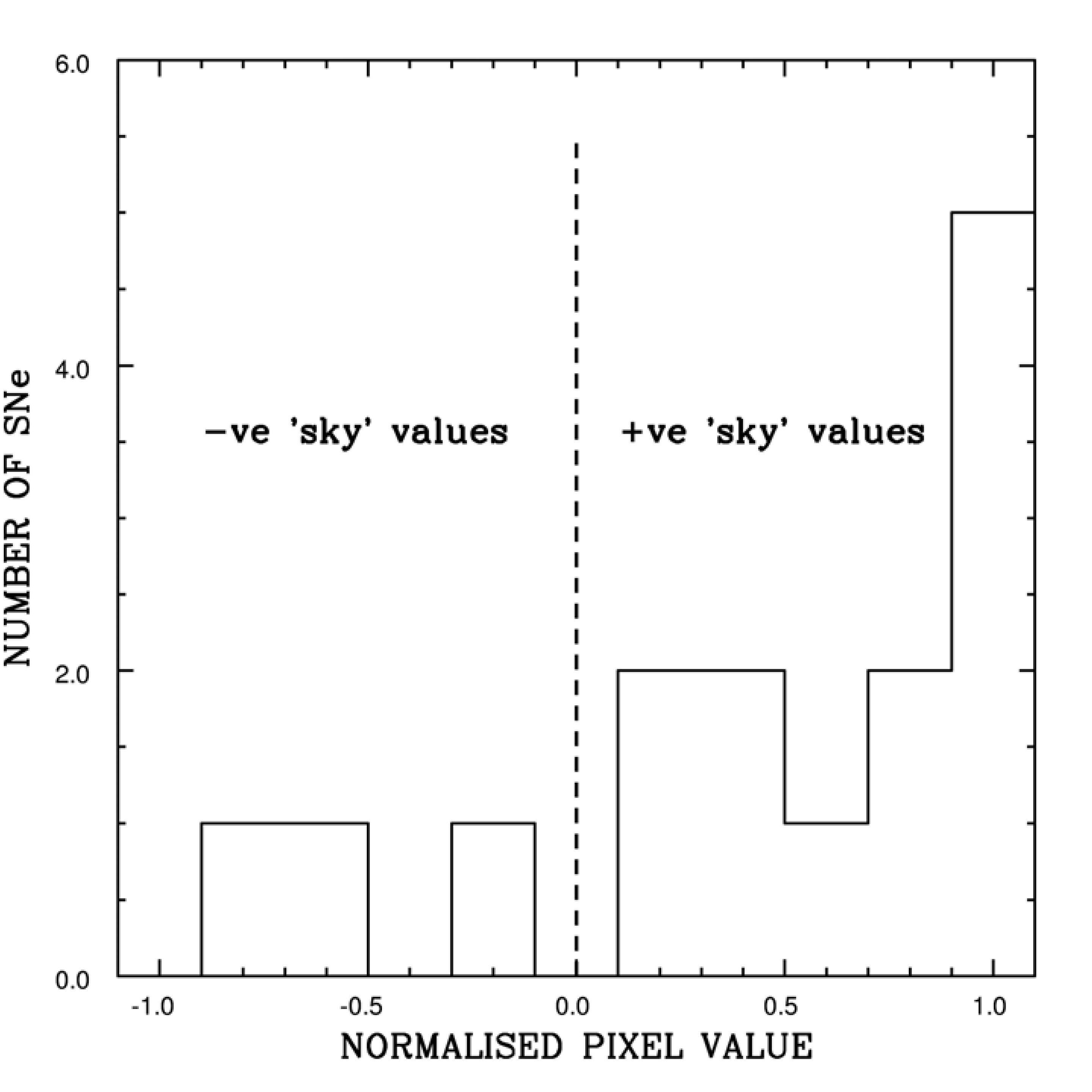

NCR
1
0.401
0
NCR value 0.401
SN pixel value 4.5
PIXEL VALUE/CUMULATIVE VALUE
100
50
0
0
1000
2000
3000
4000
5000
PIXEL NUMBER

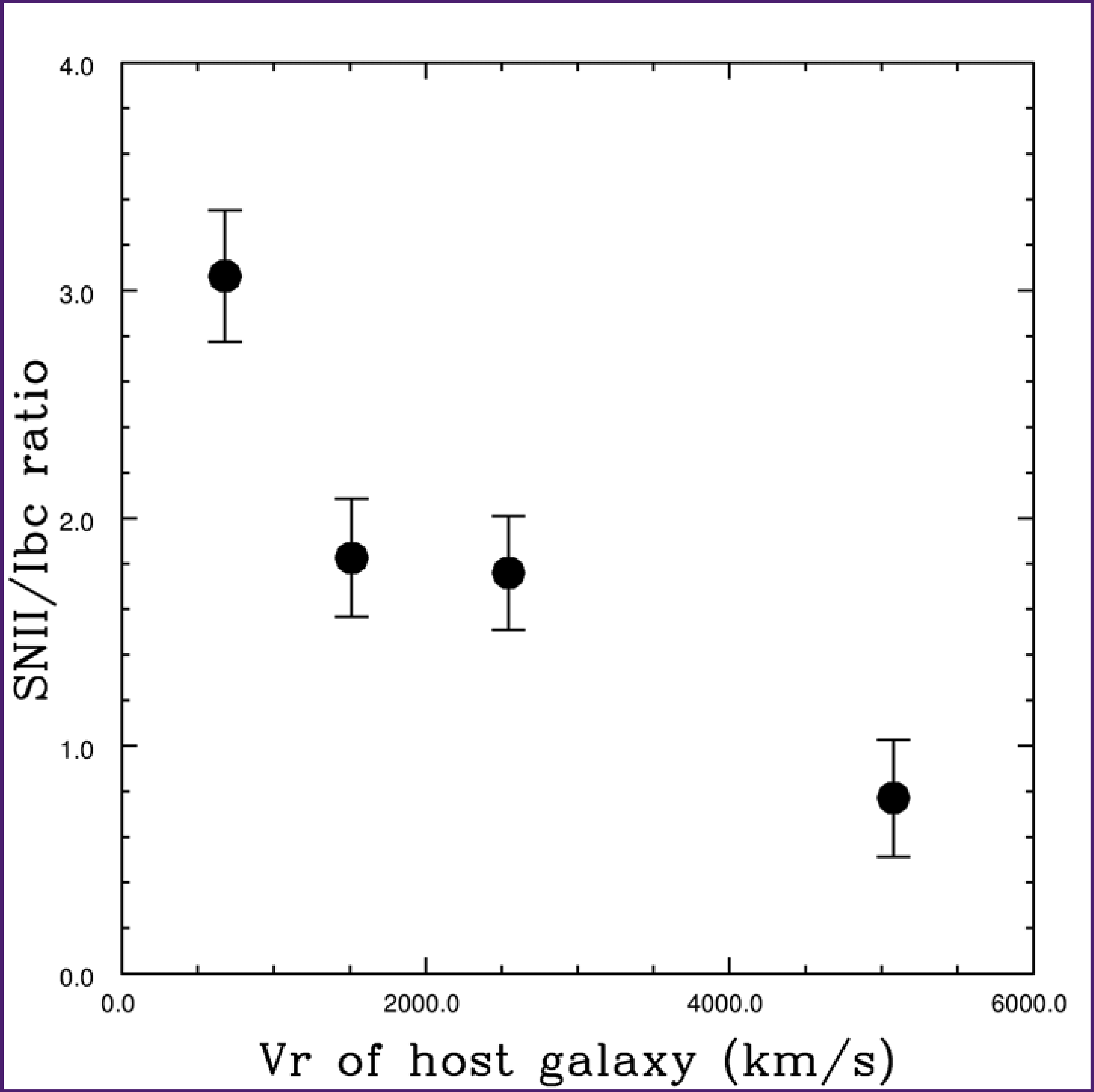

Apparent Magnitude (R−band) at discovery
20
15
10
0
0.5
1
R−band Fraction within SN
SNII+IIP
SE−SN

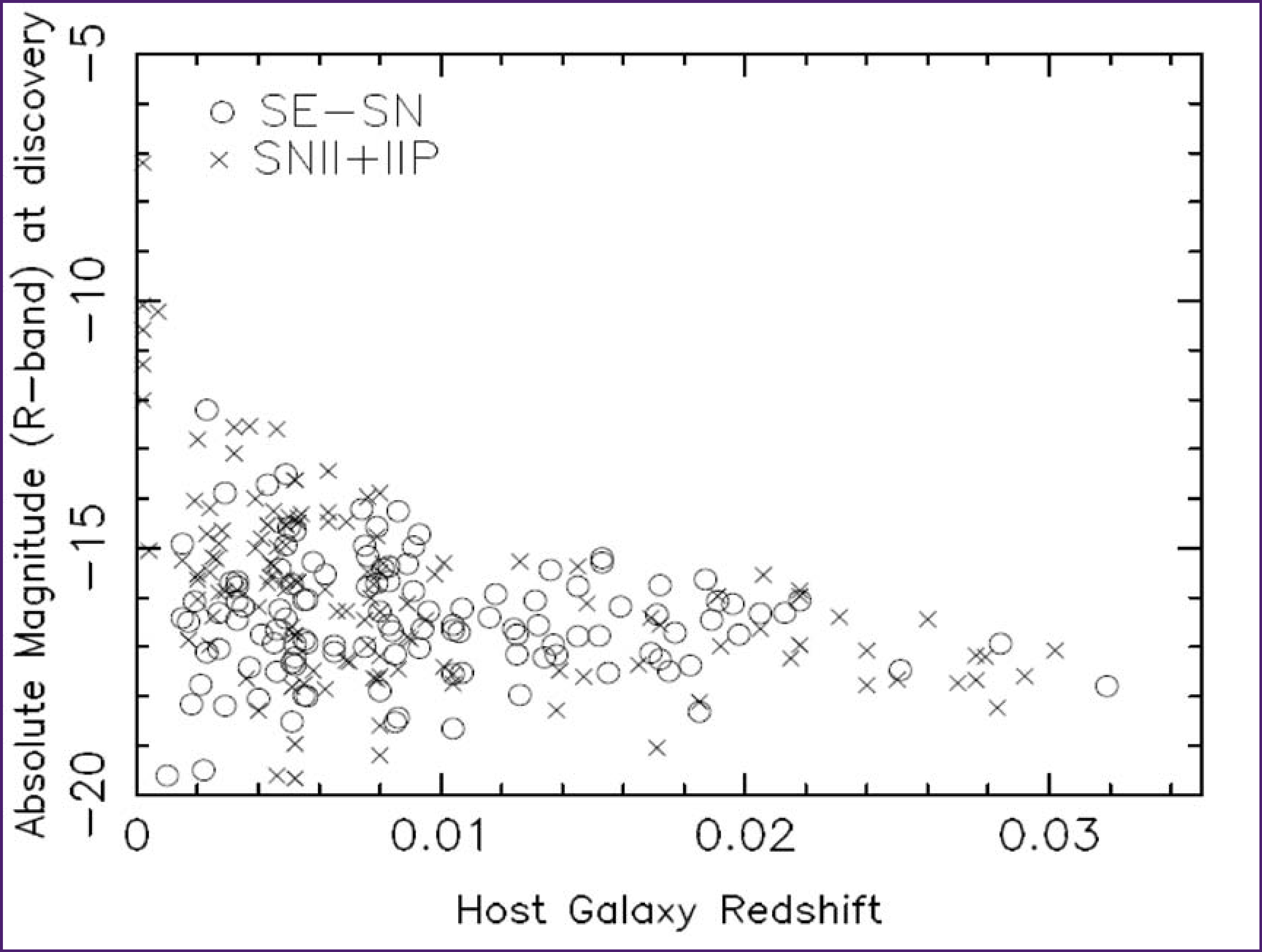

All CCSNe
SNIb
SNIc
0
10
20
0
0.2
0.4
0.6
0.8
1
R–BAND FRACTION WITHIN SN


SE−SN
SNII+IIP
Absolute Magnitude (R−band) at discovery
−5
−10
−15
−20
0
0.5
1
R−band Fraction within SN


FRACTION OF TOTAL SNe
FRACTION OF CUMULATIVE SF
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
SNII non-0 115
SNIb non-0 31.5
SNIc non-0 47
SNIbc non-0 82.5


6.0
4.0
2.0
0.0
NUMBER OF SNe
−ve 'sky' values
+ve 'sky' values
-1.0
-0.5
0.0
0.5
1.0
NORMALISED PIXEL VALUE


4.0
3.0
2.0
1.0
0.0
SNII/Ibc ratio
0.0
2000.0
4000.0
6000.0
Vr of host galaxy (km/s)



SE−SN
SNII+IIP
Absolute Magnitude (R−band) at discovery
−5
−10
−15
−20
0
0.01
0.02
0.03
Host Galaxy Redshift

Frequency of the types of supernova

One supernova
Total data:1522

Multiple supernovae
Total data:471