Constraining supernova progenitors and star-formation properties through the AMUSING survey

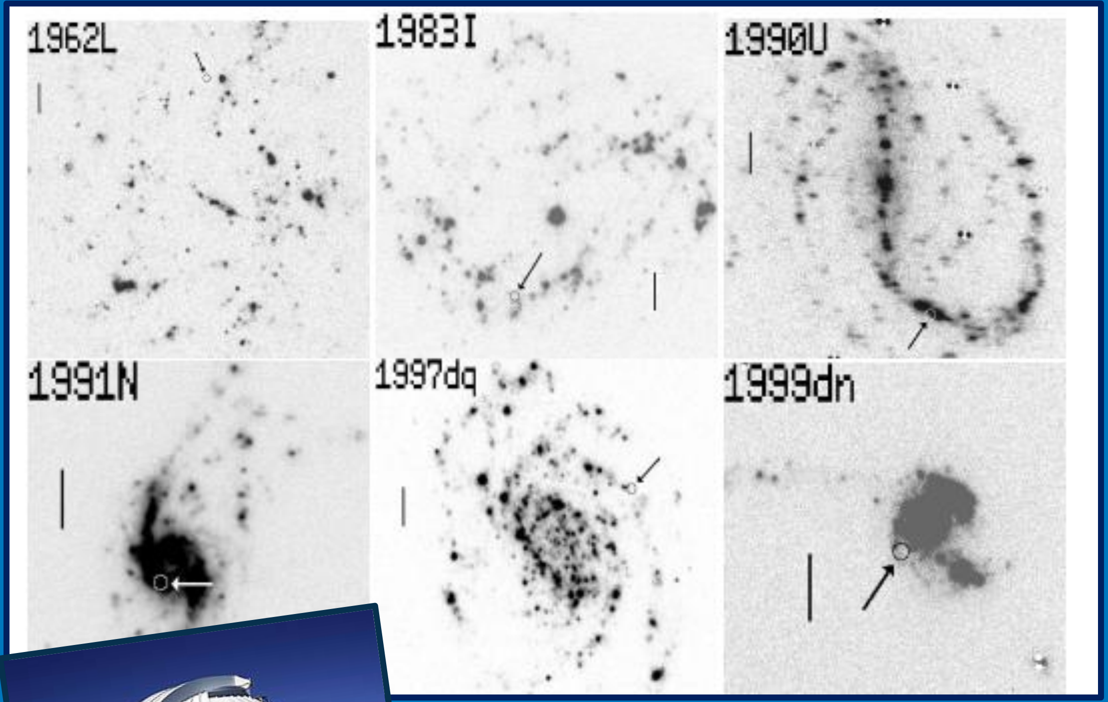
Joe Anderson, ESO Chile

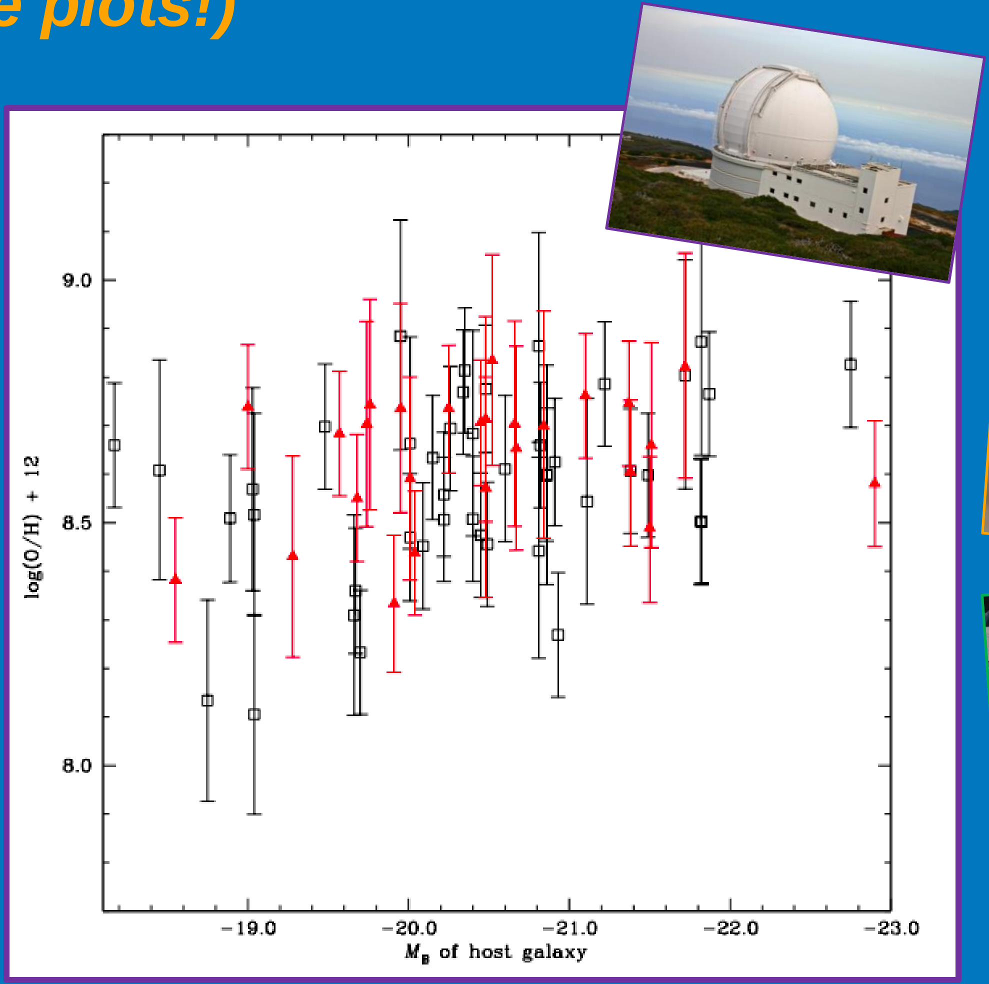
A decade of discoveries with MUSE and beyond, 18-22 November 2024

...back where it all (for me) began...

...the HaGS survey (JKT), long-slit spectroscopy at the WHT... (and horrible plots!)

James&Anderson06



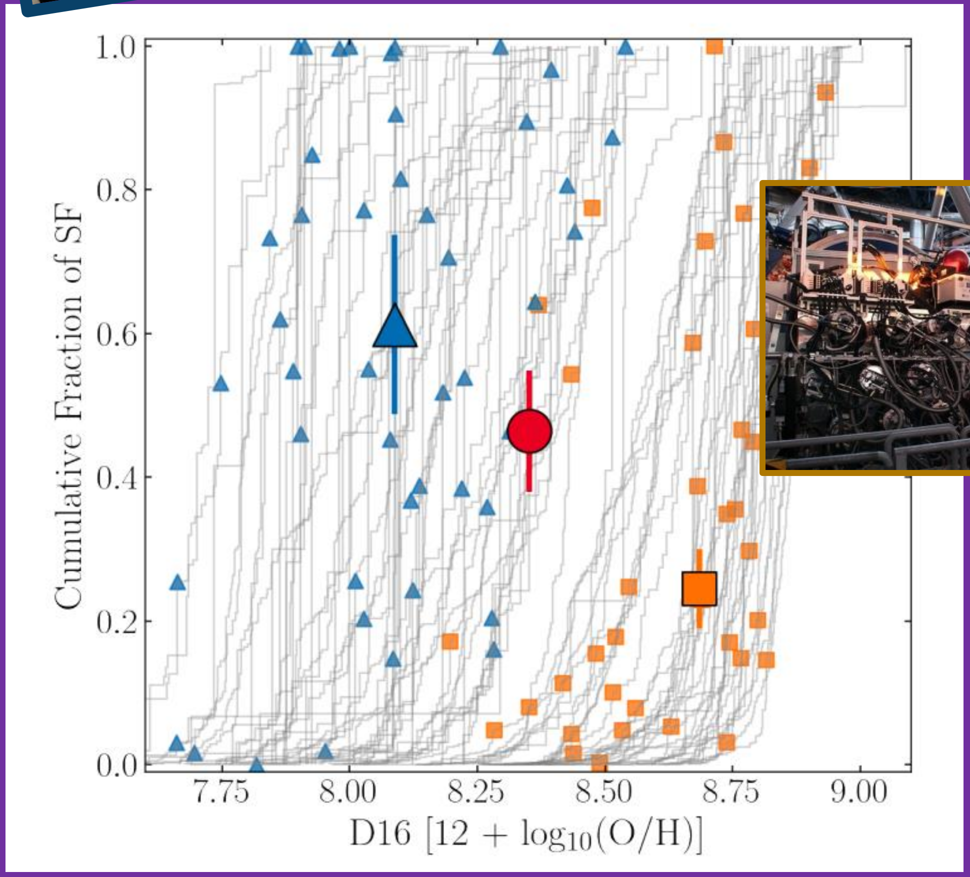


Anderson+10

...To ~1000 supernova host galaxies (10,000s HII regions) observed through AMUSING(+) with MUSE!

...we don't even need to request telescope time!

Pessi+23b



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Challenge: how do we plot this?
How do we understand this?

Core-collapse supernovae (CCSNe)

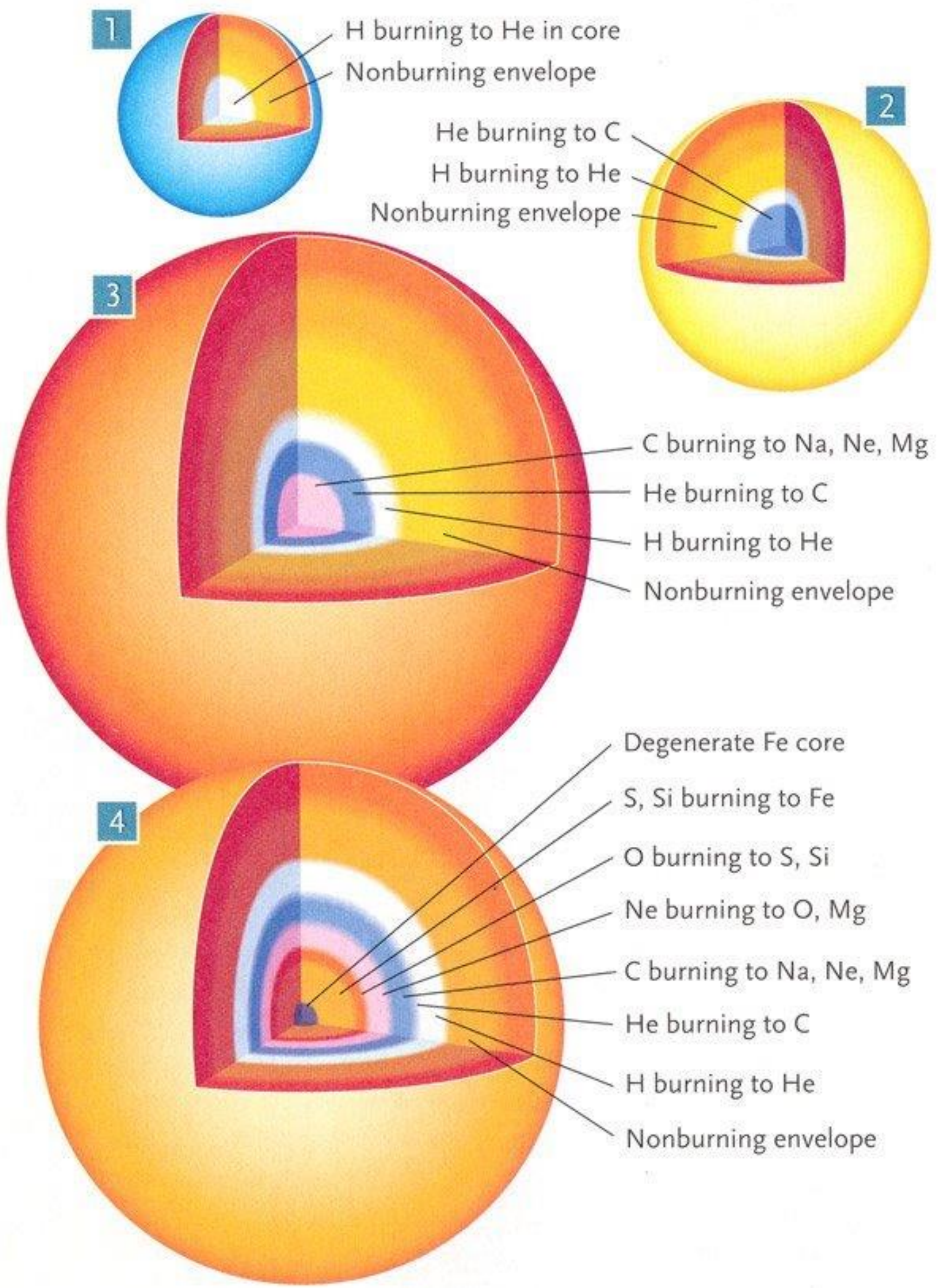
The explosive deaths of massive stars (>8-10Msun)

Stars with initial masses >8-10Msun

- **Hyrodgen-rich** Type II supernovae (**SNeII**)
- **Hydrogen-poor** 'Stripped envelope' SNe (**SE-SNe** – types IIb, Ib, Ic...)

CCSNe should be accurate tracers of massive star formation (SF)

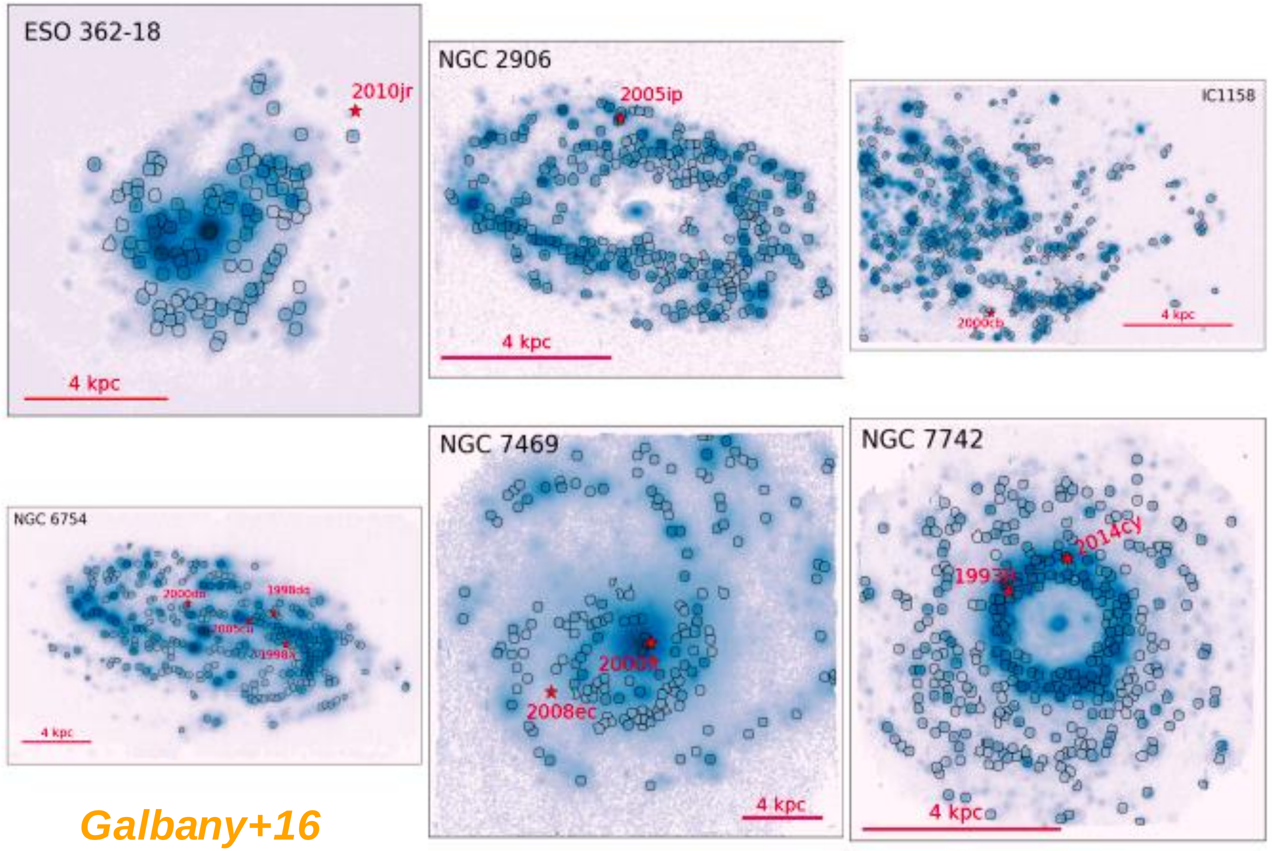
Synergy: using SF to understand SNe, and SNe to understand SF!



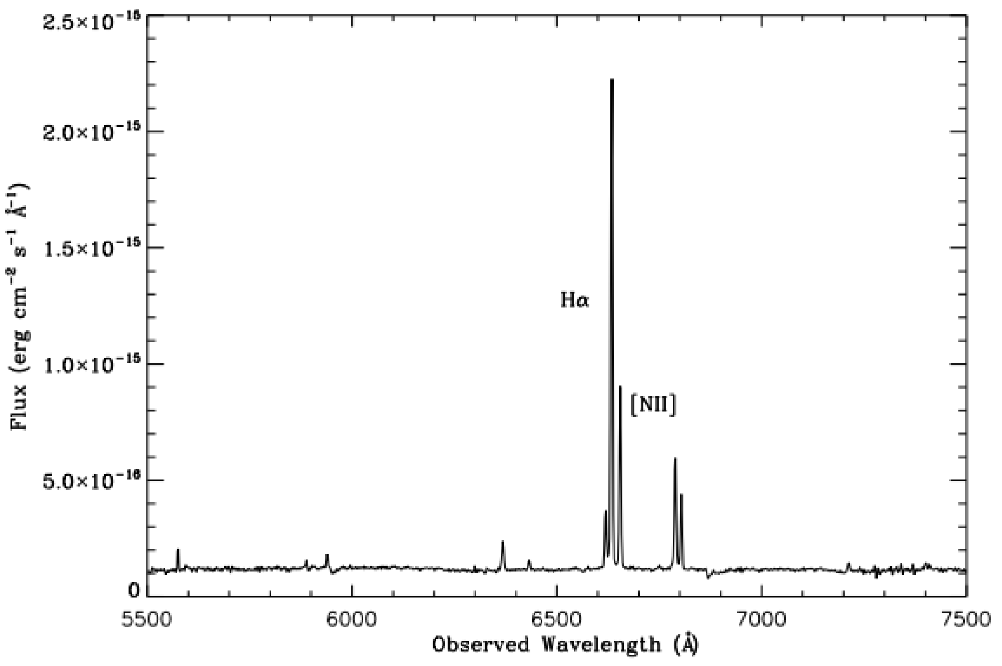
H-alpha emission and HII regions

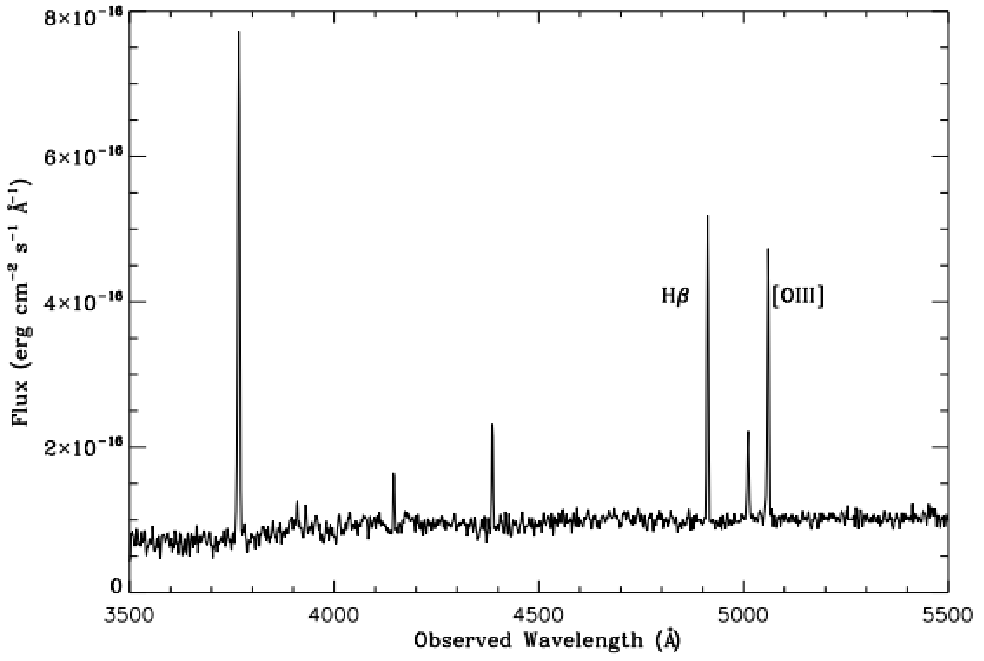
Interstellar medium ionised by massive stars

HII regions studied to understand star formation in nearby galaxies... Or, properties can be assumed and used to infer supernova progentior properties – studying the 'environments' where different SNe explode:

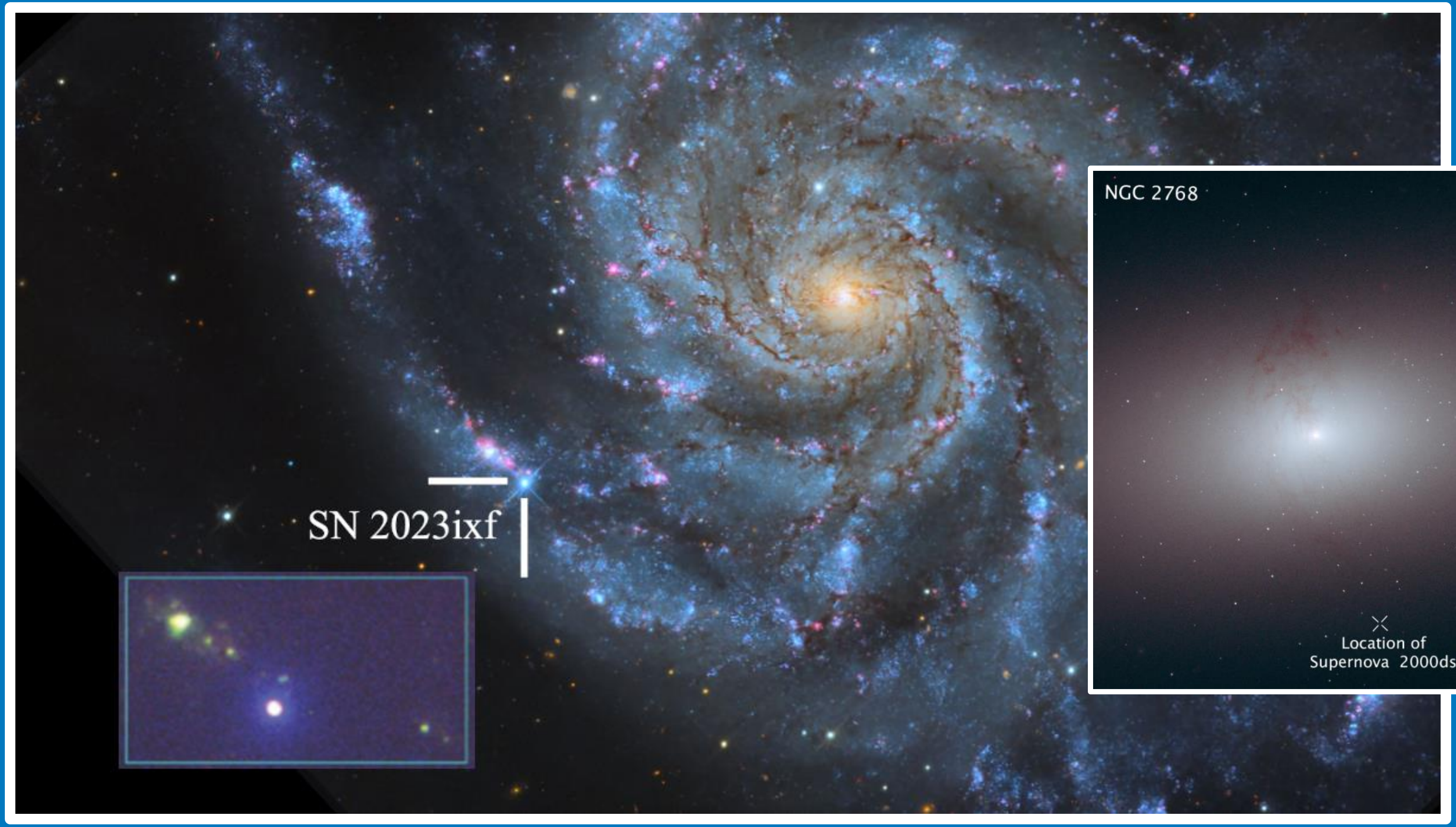


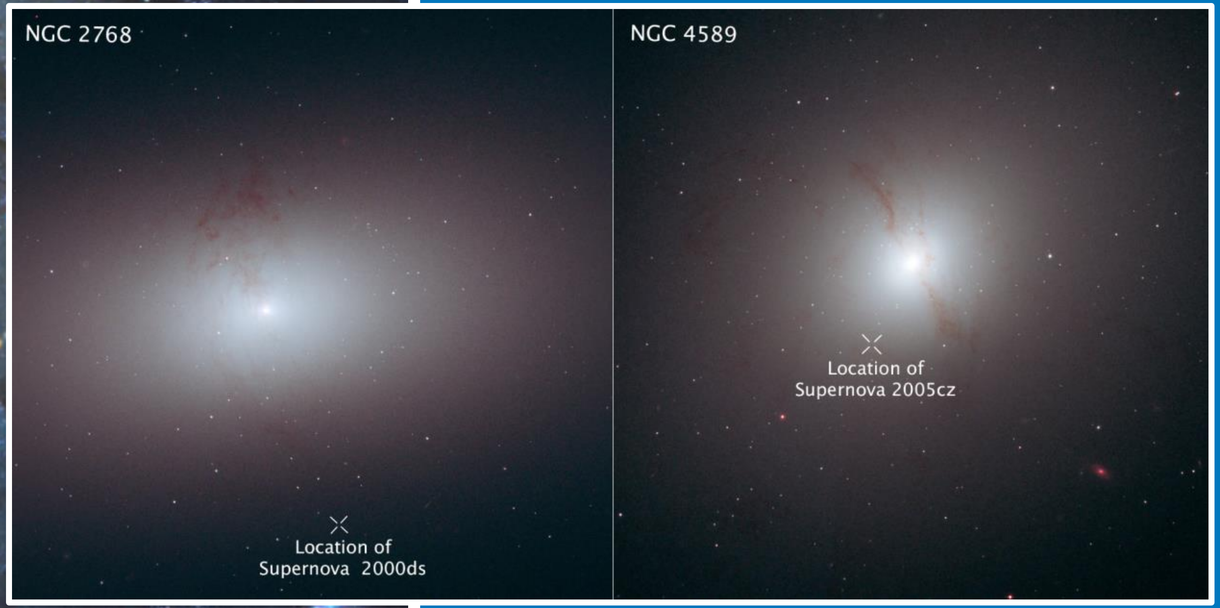
Galbany+16





Core-collapse supernovae are exclusively found in star-forming galaxies – strong evidence that they are linked to massive stars! *(most basic 'environment' study)*





The All-weather MUse Supernova Integral field Nearby Galaxies – AMUSING, survey

A 'bad weather', 'filler' program

Starting in P95, we have requested for many/most semesters 99hrs of 'filler' time for different supernova host galaxy proposals, requesting FLI>0.5; THN; >1.2'' observing conditions:

- **Type Ia SNe (SNeIa) from the Carnegie Supernova Program** – cosmology, progenitors,...
- **Tidal Disruption Events (TDEs)** – understanding host galaxy preference, …
- **Low-luminosity hosts of SNeII** – the use of SNeII as metallicity indicators, ...
- **ASASSN CCSNe (see next slides)** – constraining progenitors and explosions, …
- **Nearby SNe with high-resolution spectroscopy** – extinction, CSM, …

>40 publications thus far...

Data also been used heavily for galaxy evolution/dynamics/chemical enrichment studies (led by Sebastian Sanchez+)

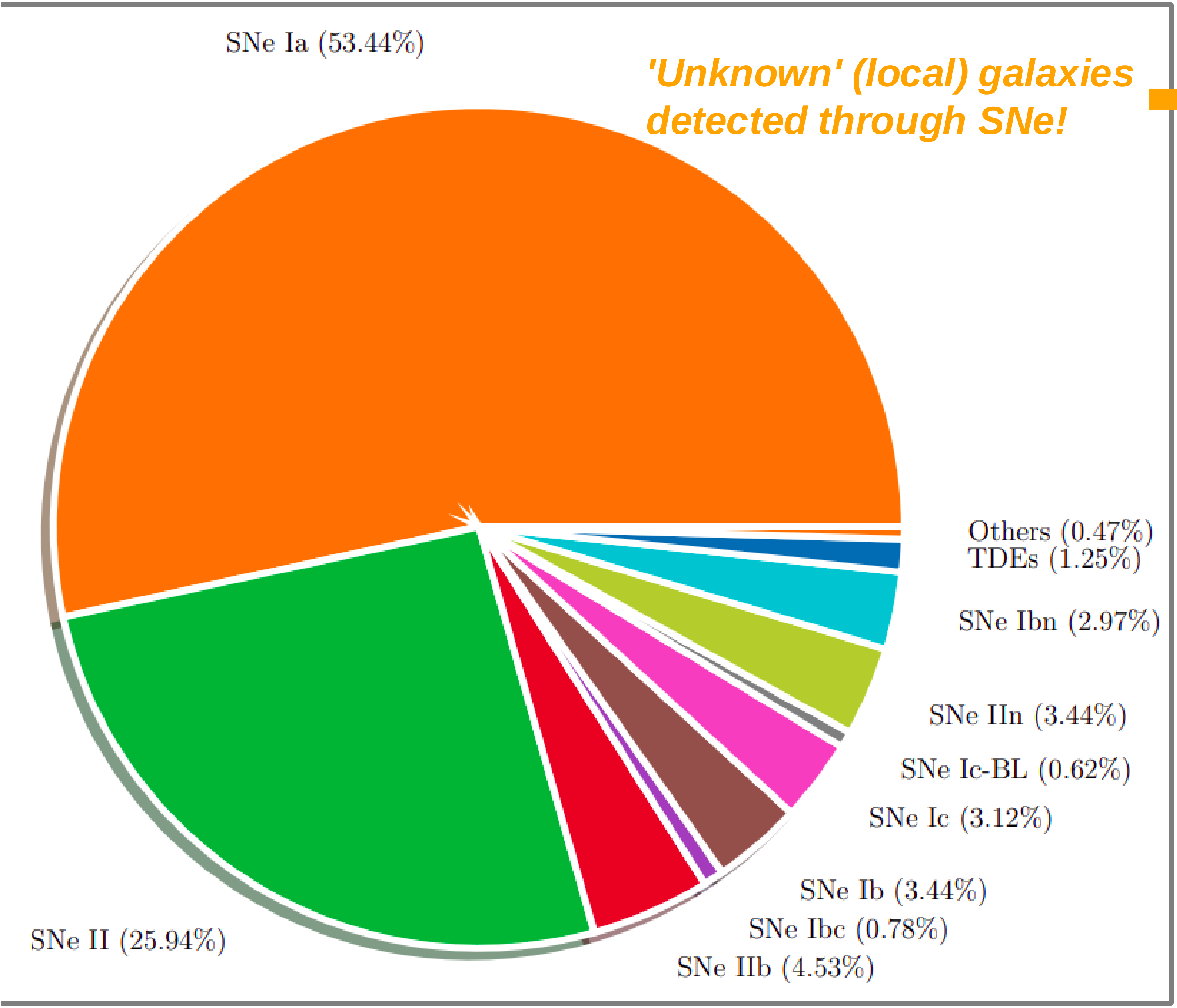
The All-weather MUse Supernova Integral field Nearby Galaxies – **AMUSING**, survey

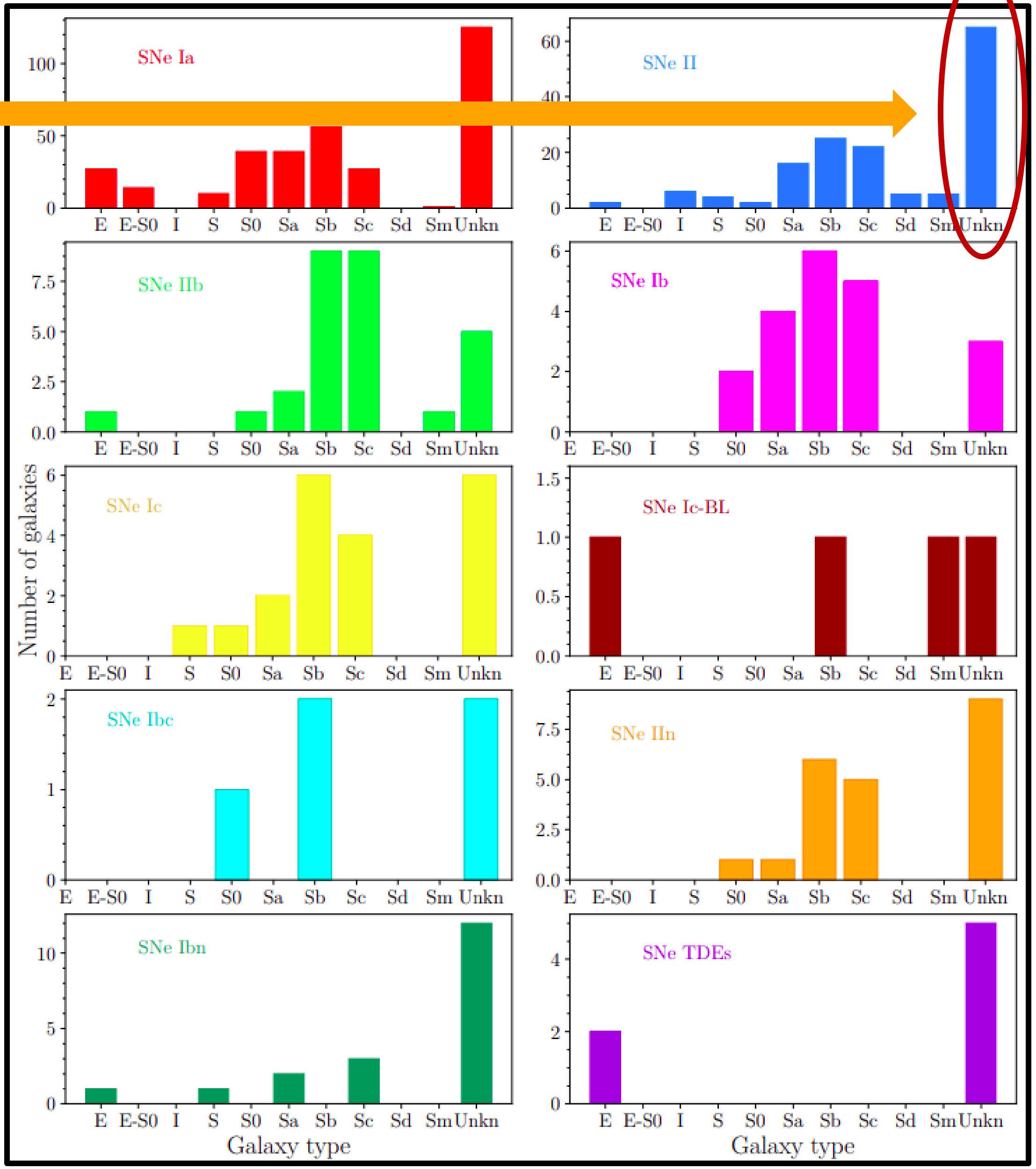
Many years requesting 'bad weather' proposals with MUSE..

Proposal ID	Ia	II	IIn	Ib	Ic	IIb	Ibc	I	SLSN	TDE	LBV	FB(
095.D-0091	89 (3 91bg, 9 91T, 1 03fg, 1 02cx, 1 CSM)	1	1	-	-	-	-	-	-	-	-	-
096.D-0296	39 (2 91T, 1 02cx)	9	3	2 (1 bn)	-	1	-	-	-	1	-	-
097.D-0408	51 (2 91T, 1 CSM)	10	3	3	7	6	-	-	-	-	-	-
098.D-0115	29 (1 91T)	-	-	-	-	-	-	-	-	-	-	-
099.D-0022	36 (2 91bg, 6 91T, 2 03fg, 3 02cx)	2	-	3	1	-	-	-	-	-	-	-
100.D-0341	1	12	3	1	3	4	-	-	-	-	1	-
101.D-0748	22 (1 91bg, 1 91T)	38	9	3 (1 bn)	9 (1 bl)	4	1	-	1	-	-	-
102.D-0095	41 (7 91bg, 7 91T, 1 03fg)	2	-	-	-	-	1	-	-	-	-	-
103.D-0440	4 (1 02cx)	60	7	5	4 (2 bl)	7	-	-	-	7	-	1
104.D-0503	-	34	-	1	-	1	-	-	-	-	-	-
106.2104	53 (6 91bg, 9 91T, 3 03fg)	1	1	-	-	-	-	-	-	-	-	-
111.24UM	1	7	-	12	9	10	5 (2 bl)	-	-	-	-	-
111.24VQ	1	4	1	18 (17 bn)	-	1	1	-	-	-	-	-
112.25XB	-	11 (9 87A)	-	-	-	1	-	-	-	-	-	-
113.26FT	2	49	-	7	10 (1 bl)	5	2	1	-	-	-	-
AMUSING	369 (19 91bg, 37 91T, 7 03fg, 6 02cx, 2 CSM)	240	28	55 (19 bn)	43 (4 bl)	40	10 (2 bl)	1	1	8	1	1
AMUSING+	92 (1 91bg, 1 91T, 16 02cx)	91	14	8	24 (3 bl)	3	5	3	2	6	2	-
TOTAL MUSE	461 (20 91bg, 38 91T, 7 03fg, 22 02cx, 2 CSM)	331	42	63 (19 bn)	67 (7 bl)	43	15 (2 bl)	4	3	14	3	1

Galbany+ in prep.

'Unknown' (local) galaxies detected through SNe!

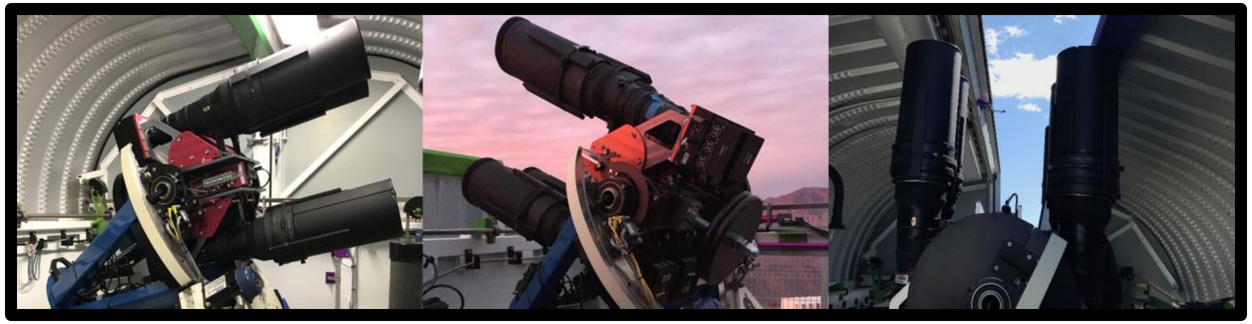




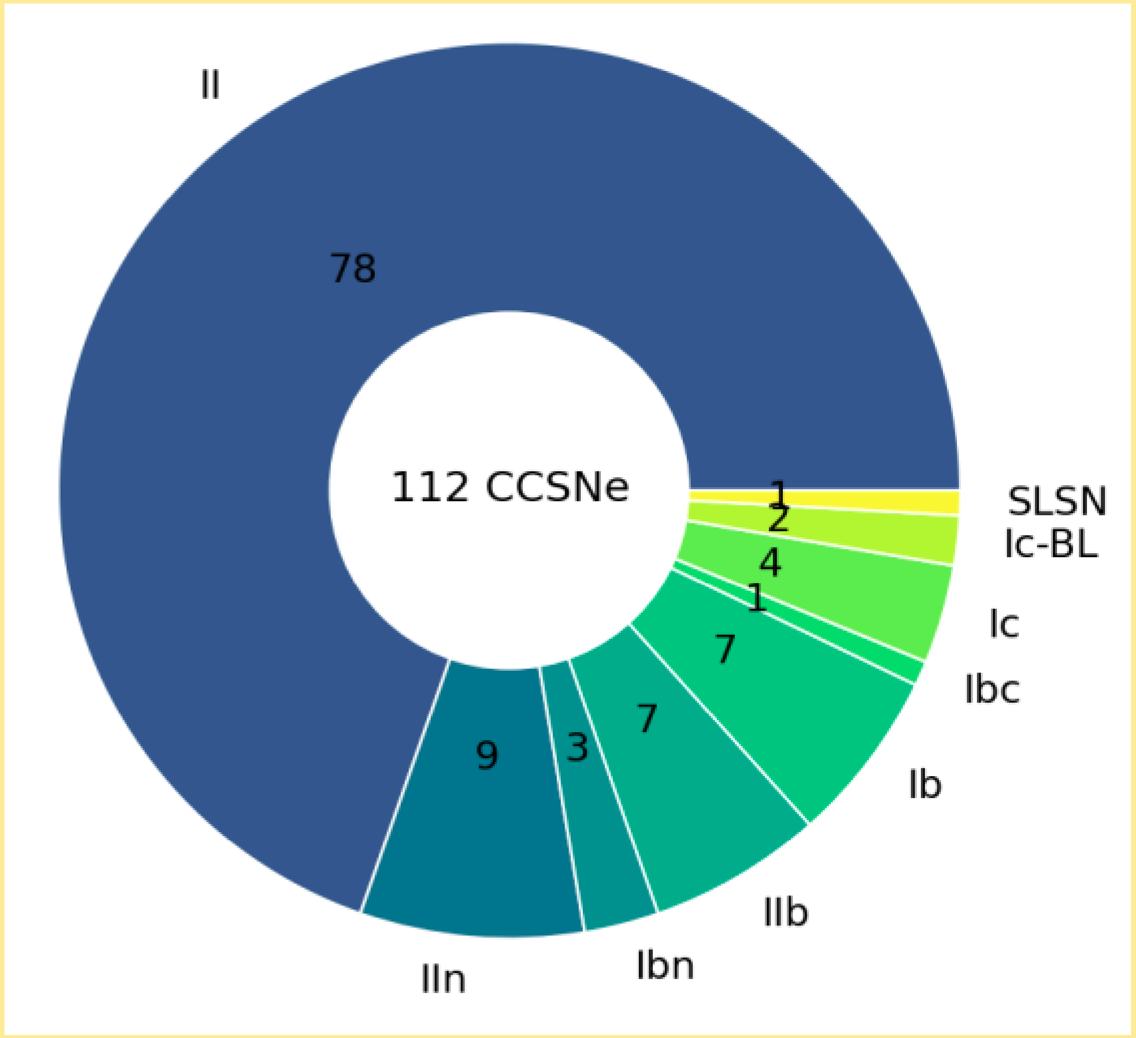
ASAS-SN-AMUSING

Synergy of matching an untargeted supernova sample with the power of MUSE

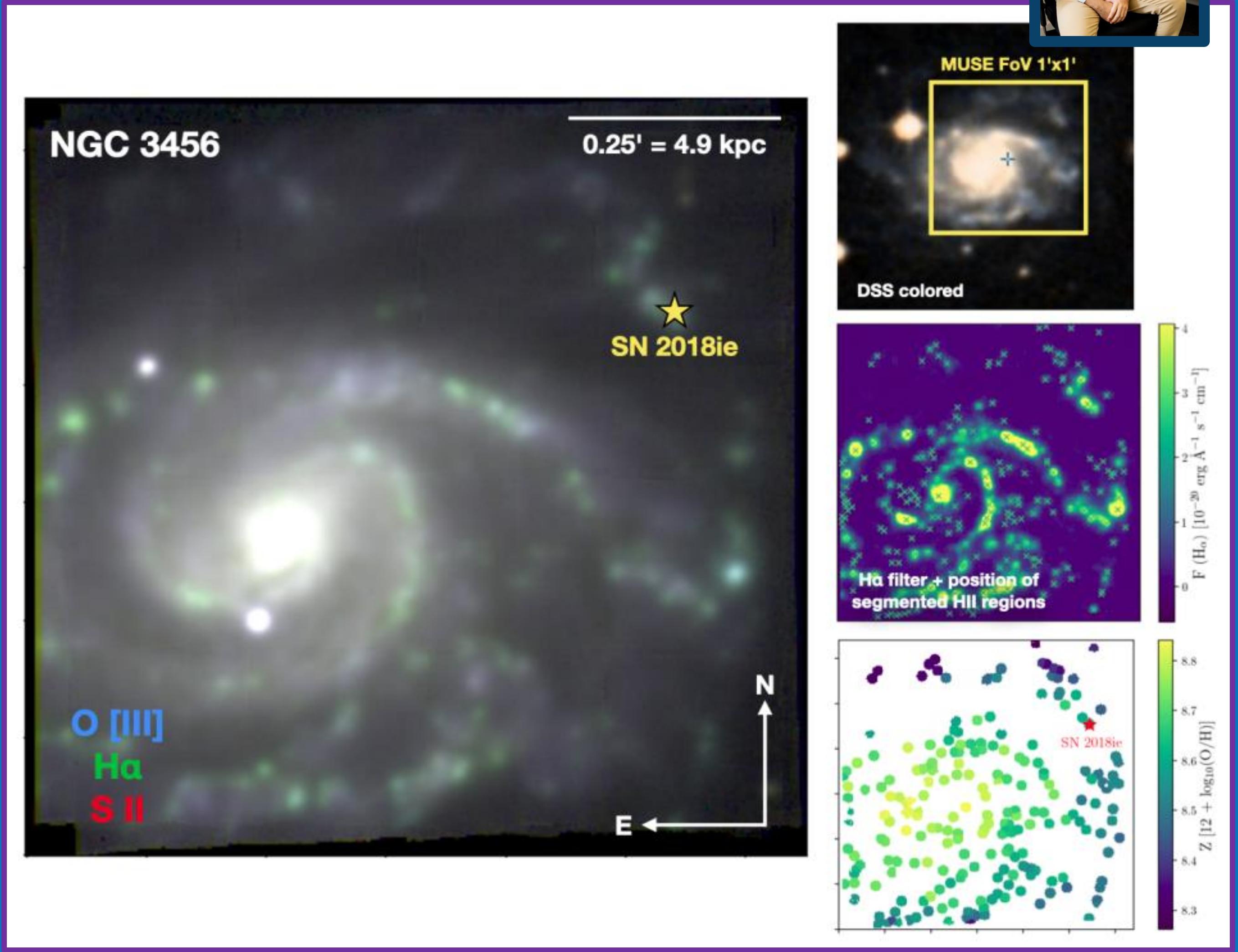
- **ASAS-SN: The All-Sky Automated Survey for Supernovae**
  - Scanning the entire sky down to 18th mag (optical) every night
  - **Untargeted – no bias towards bright galaxies**
  - Supernovae, and many other 'transients'
- **~100 ASAS-SN CCSN hosts analysed with MUSE (thus far...)**
  - Randomly selected from ASAS-SN sample
- ASAS-SN+MUSE:
  - Compare SN environments between types
  - **Compare environments with all other HII regions**



~100 ASAS-SN SN environments observed with MUSE



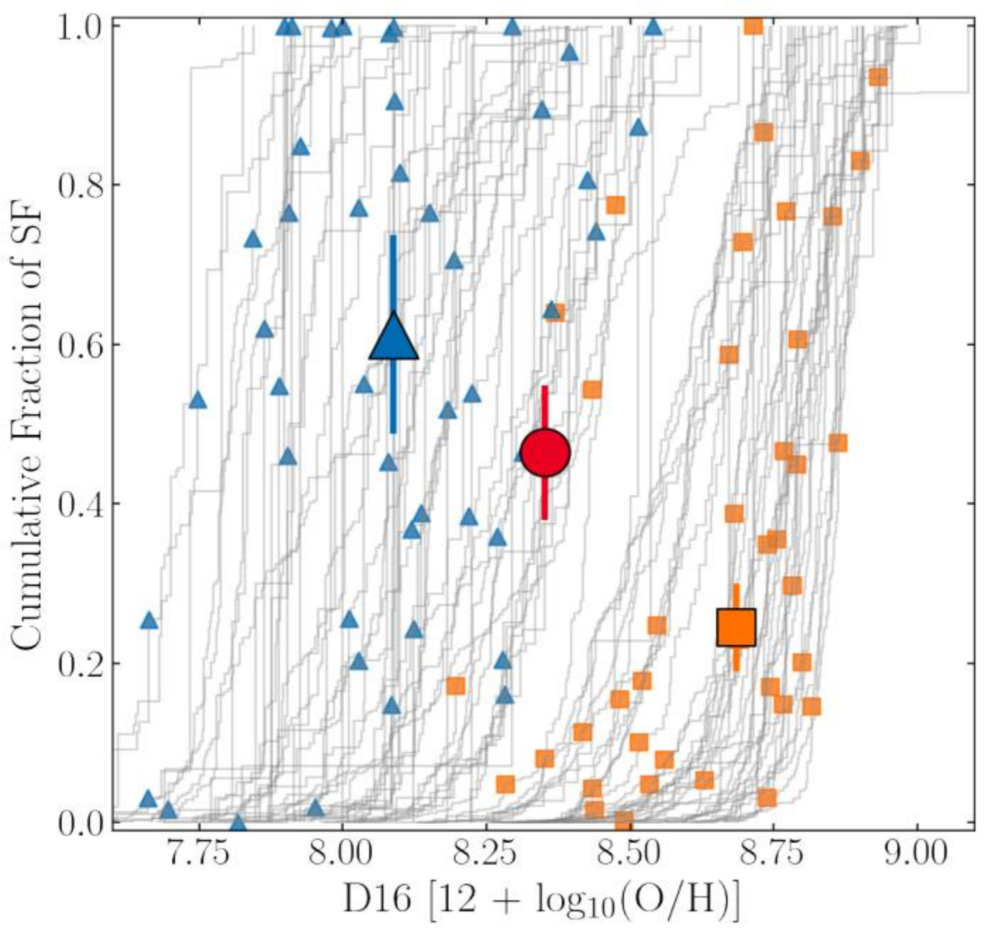
Pessi+23a



The oxygen abundance of CCSN environments... *and* all other HII regions (Pessi+23b)

Utlising the full power of MUSE with an untargeted, bias-limited sample of CCSNe

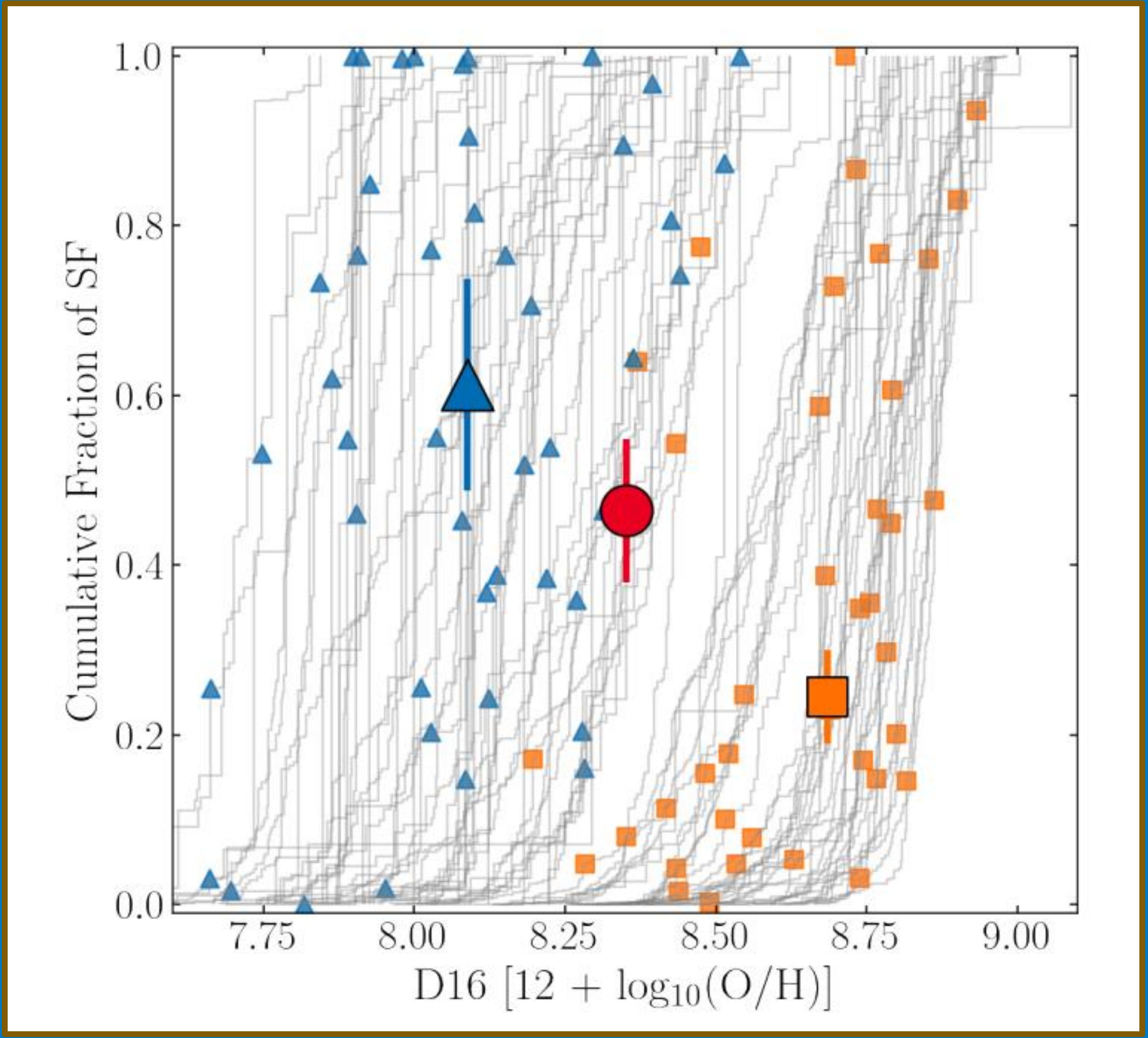
Pessi+23b

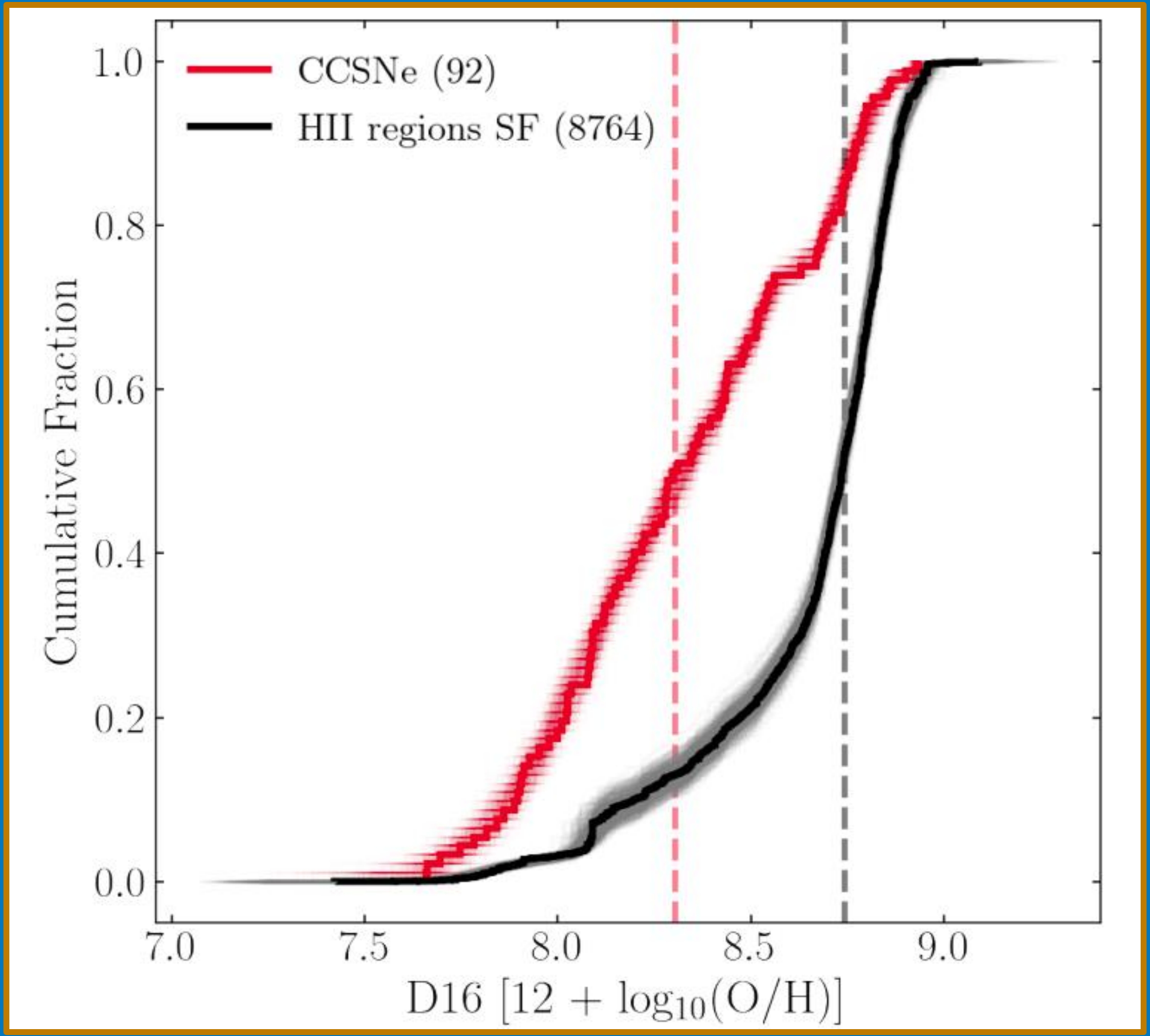


Compare the explosion sites of CCSNe with all other star forming regions (HII regions) within host galaxies:

- **Do CCSNe follow the star formation – as traced by HII regions – within their host galaxies?**
  - Constraints on progenitors...
  - Or... constraints on massive star formation...
- **Do different SN types explode at lower/high Z?**
- **~100 CCSNe, ~8700 HII regions...**

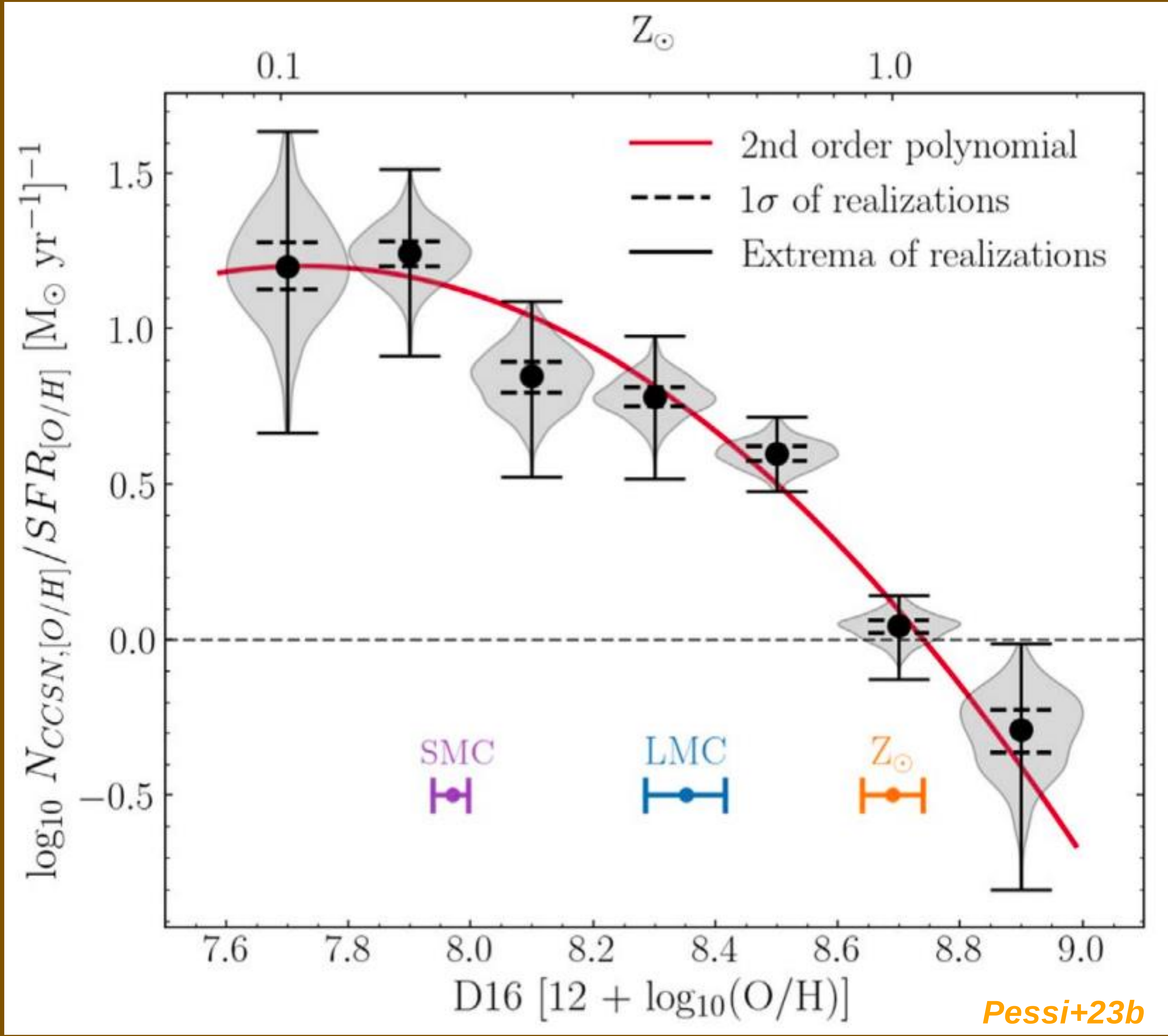
A metallicity dependence on the occurrence of CCSNe





Pessi+23b

A (strong) metallicity dependence on the occurrence of CCSNe



Pessi+23b

A high occurrence of CCSNe in low-metallicity HII regions, per unit star formation

Per unit star formation (H-alpha), CCSNe are much more frequent at lower oxygen abundance (metallicity, Z)

- Within higher Z galaxies CCSNe 'prefer' to explode in lower abundance HII regions
- CCSNe are more frequent (per unit star formation) within lower-Z galaxies

(Some previous hints in this direction from other works, e.g. Graur+17.)

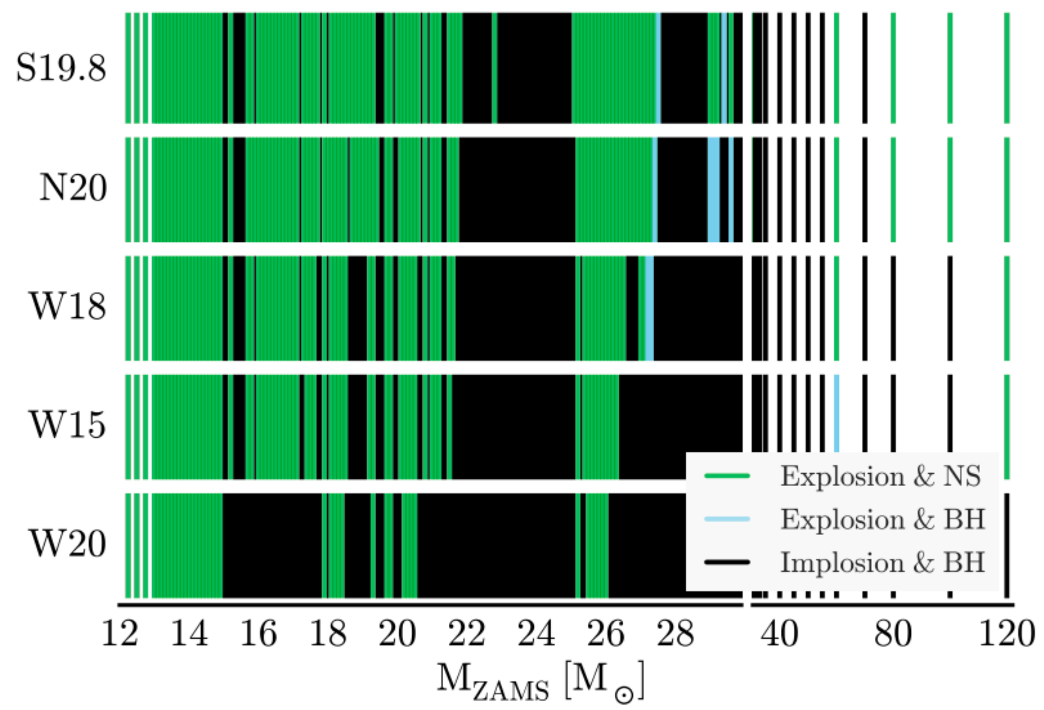
"The occurrence of CCSNe per unit SF in abundances close to the SMC and LMC values are higher by factors of ~15 and ~5 than at abundances close to solar." (Pessi+23b)

A high occurrence of CCSNe in low-metallicity HII regions, per unit star formation

How can we explain this?

We discuss four possible explanations... Any of which (if true) would have profound impact of our understanding of massive star explosions (CCSNe) and/or massive star formation:

- **<u>Massive star 'explodability':</u>**
  - The explodability of massive stars has a strong dependence on progenitor metallicity
  - It is much harder to successfully explode stars at solar Z than lower Z



Sukhbold+16

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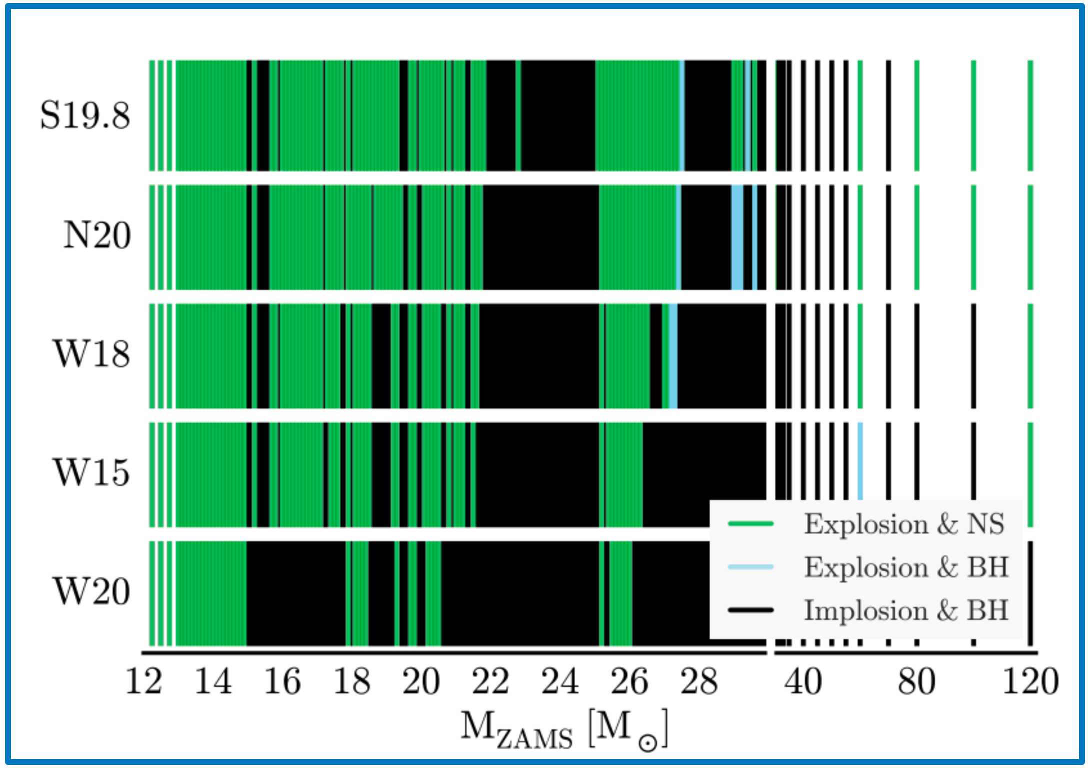
Problem: explosion models go in the opposite direction – black hole formation (and failed SNe) are predicted to be more common at lower Z...



Sukhbold+16

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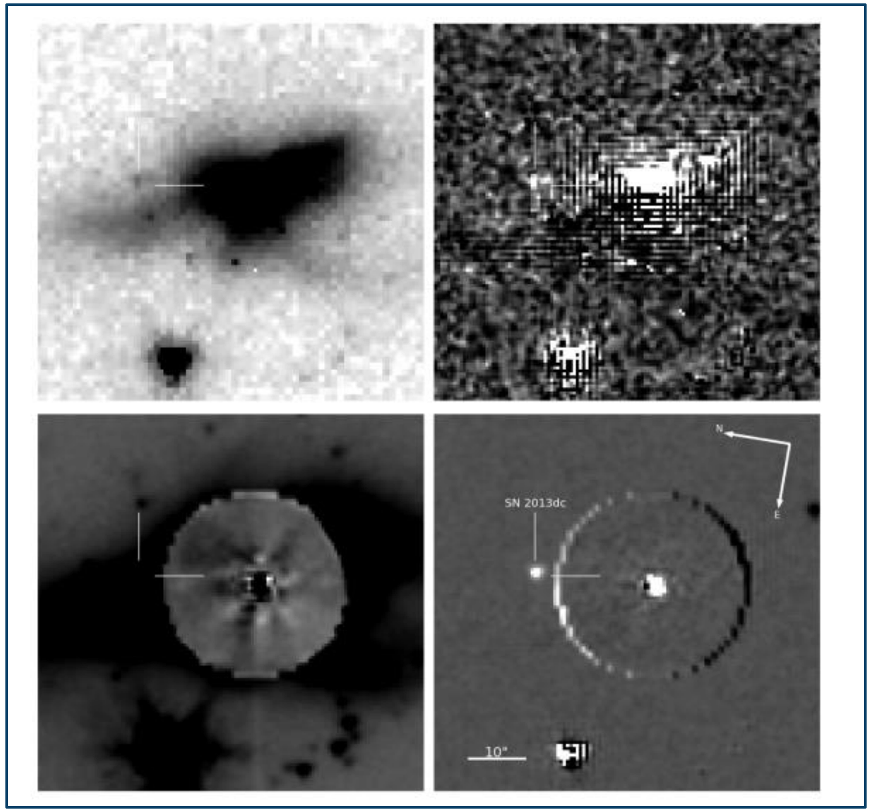
- **<u>Selection effects:</u>**
  - We are missing many more CCSNe within high Z HII regions/galaxies (than at low Z)



Fox+21

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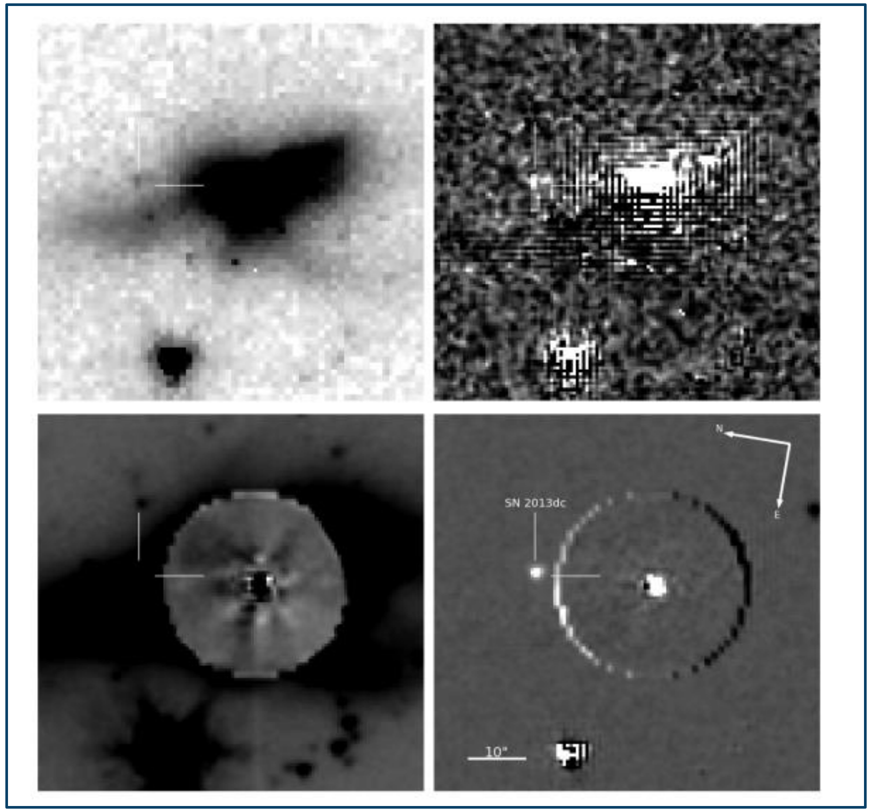
Problem: the factor between solar and SMC is 15(!!!), this means we would need to miss a huge number of SNe, and intrinsic CCSN rates are currently wildly underestimated!!!



Fox+21

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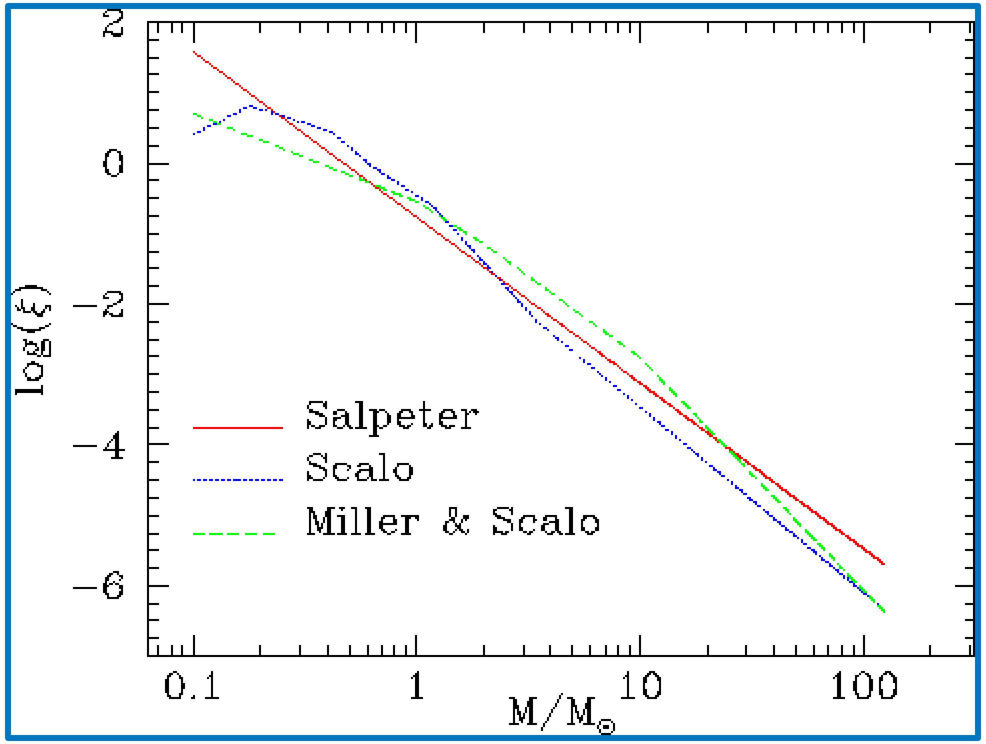
We discuss four possible explanations... Any of which (if true) would have profound impact of our understanding of massive star explosions (CCSNe) and/or massive star formation:

- **Changes in the Initial Mass Function (IMF):**
  - The IMF in low Z (low mass) galaxies and HII regions is biased towards producing (many) more massive star per unit star formation than HII regions at solar Z
  - *Some claims that at high-z (low Z) the IMF is indeed top heavy...*



Bolzonella

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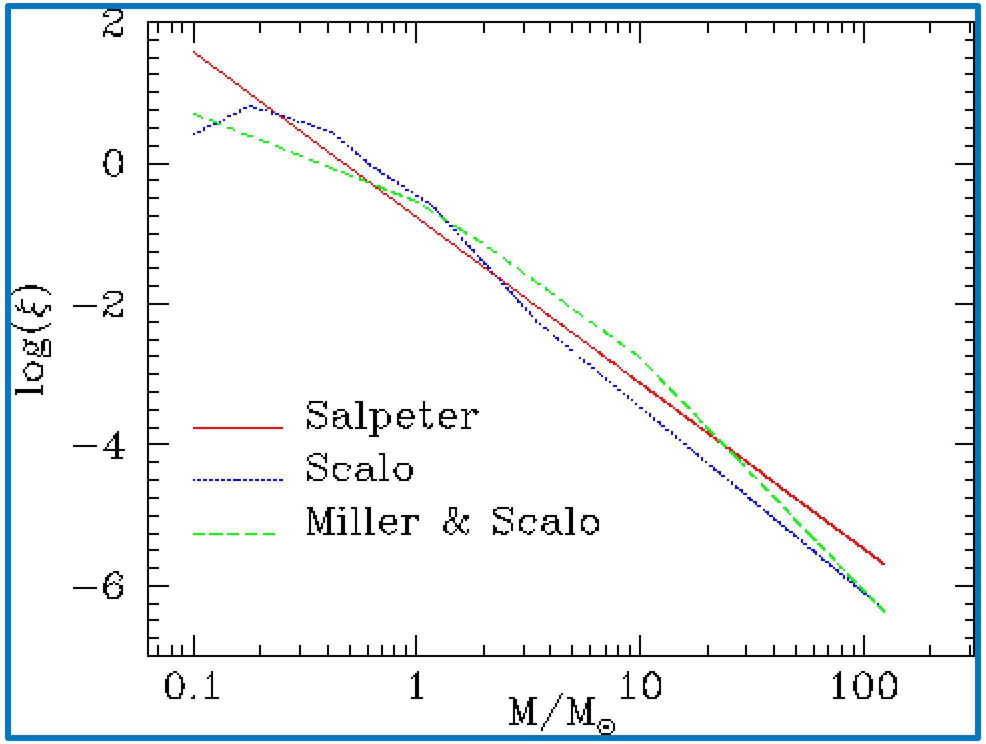
Problem: again, the effect would need to be huge!



Bolzonella

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- **<u>Changes in H-alpha -> SFR conversion:</u>**
  - Star formation is different at low Z, meaning that the conversion from H-alpha flux to SFR is significantly off at low Z
  - There is some Z dependence on H-alpha -> SFR (which we already consider), but this would need to be much higher...

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  - There is some Z dependence on H-alpha -> SFR (which we already consider), but this would need to be much higher...

Problem: no physical basis for such a strong H-alpha -> SFR Z dependence. H-alpha SFR at high z (low Z) could be significantly overestimated...

A high occurrence of CCSNe in low-metallicity HII regions, per unit star formation

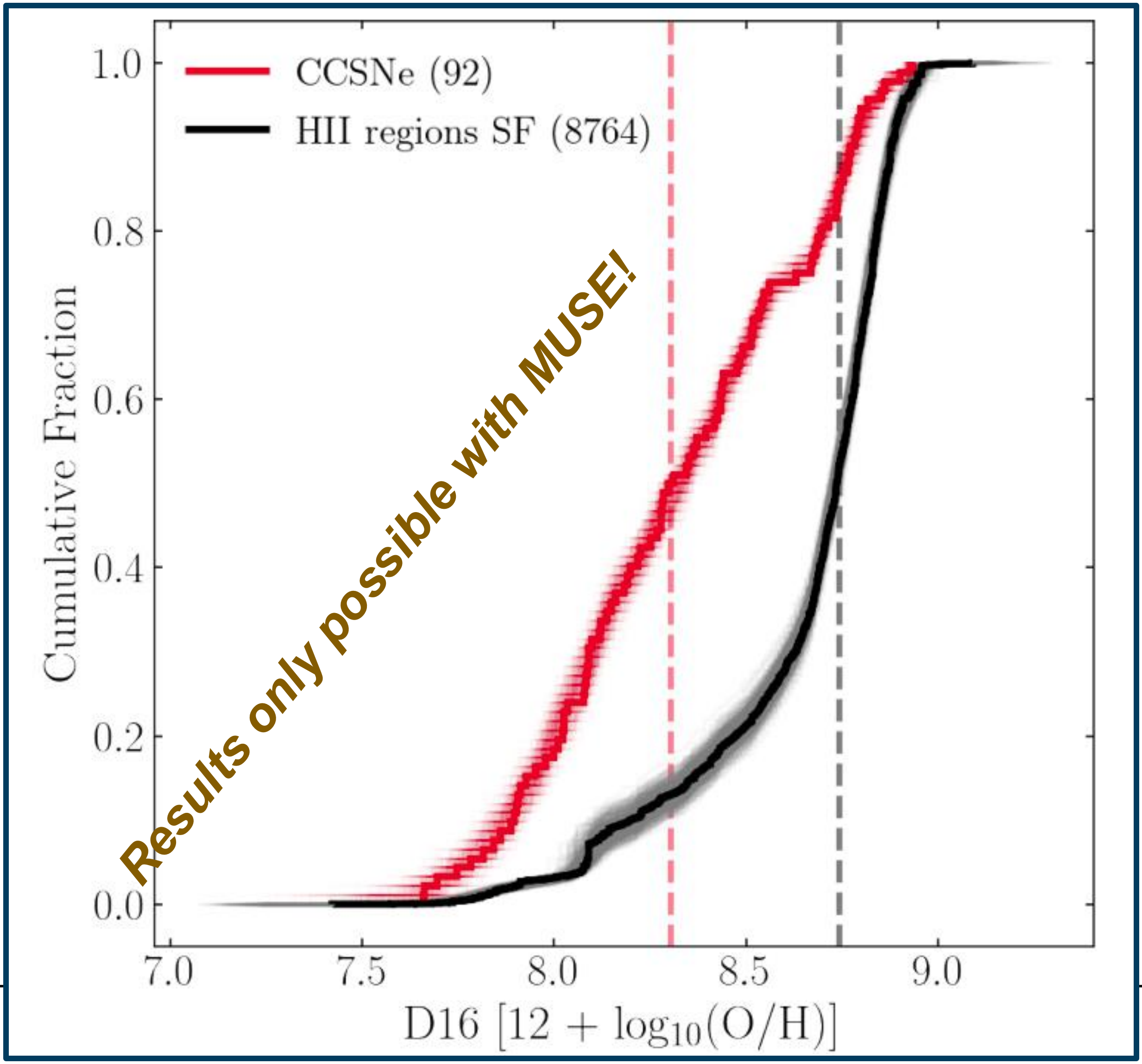
How can we explain this?

We discuss four possible explanations... Any of which (if true) would have profound impact of our understanding of massive star explosions (CCSNe) and/or massive star formation:

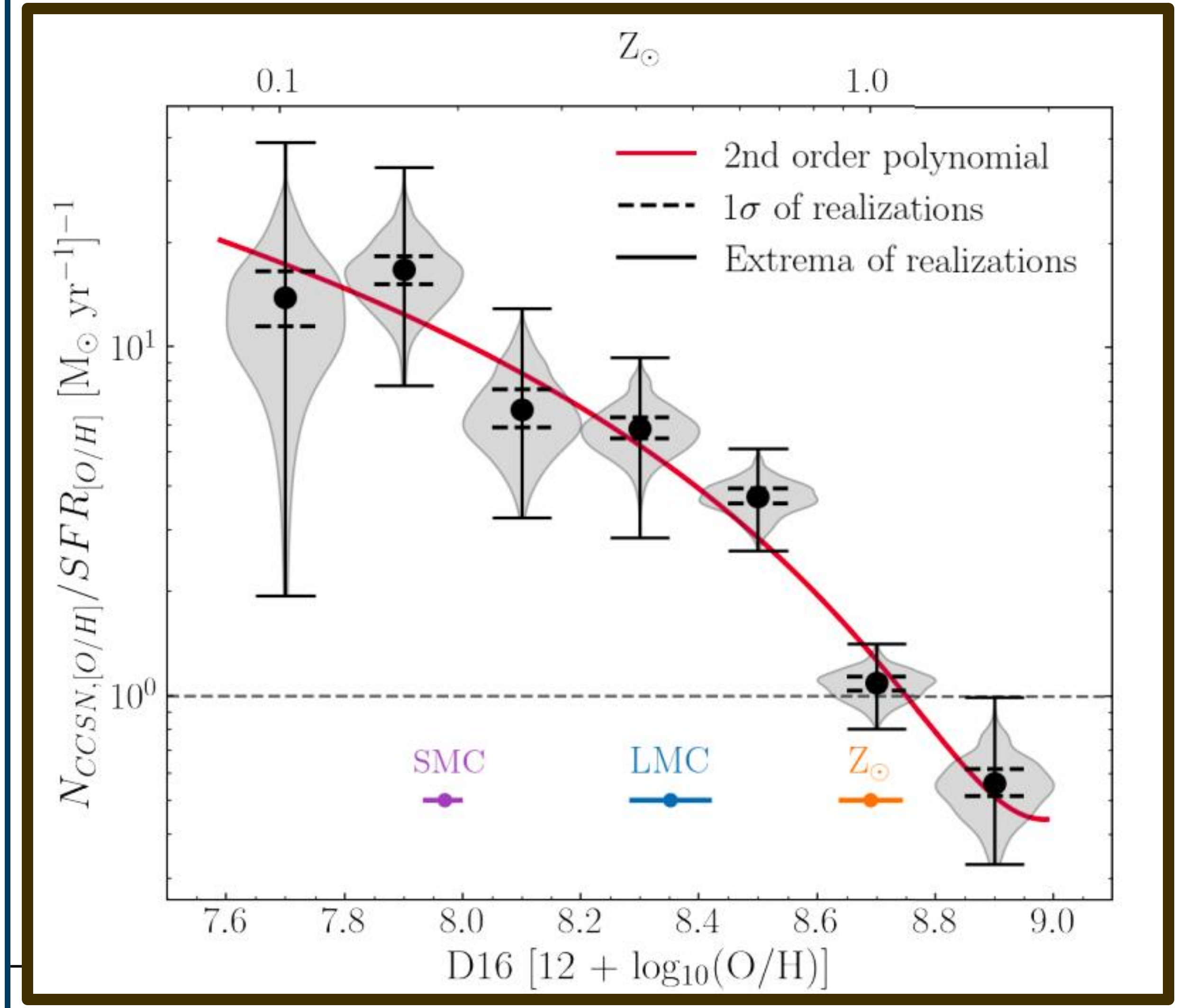
Have we have simply done something wrong in our analysis???

A high occurrence of CCSNe in low-metallicity HII regions, per unit star formation

Per unit star formation (H-alpha), CCSNe are much more frequent at lower oxygen abundance (metallicity, Z)



Pessi+23b



The future (SNe ⟷ SF)?

- **Pre-explosion progenitor spectra(!) [MUSE/BlueMUSE]:**
  - **Large database of nearby galaxies observed by MUSE *before* supernovae explode, 'direct detections' in spectral space :)**
- **BlueMUSE:**
  - **To enable robust stellar population fits for progenitor constraints, more accurate oxygen abundances...**
- **WST:**
  - **Large mosaics of nearby galaxies, resolving individual HII regions properly...**
- **HARMONI:**
  - **Using and comparing CCSNe and H-alpha as SF tracers as a function of z**

Thanks: Lluis Galbany, Hanin Kuncarayakti, Claudia Gutierrez, Joe Lyman, Sebastian Sanchez, Jose Luis Prieto, **Thallis Pessi** (and many more!)