# THE ENVIRONMENTS OF SUPERNOVAE: IFU STUDY AND INTRODUCING THE AMUSING SURVEY

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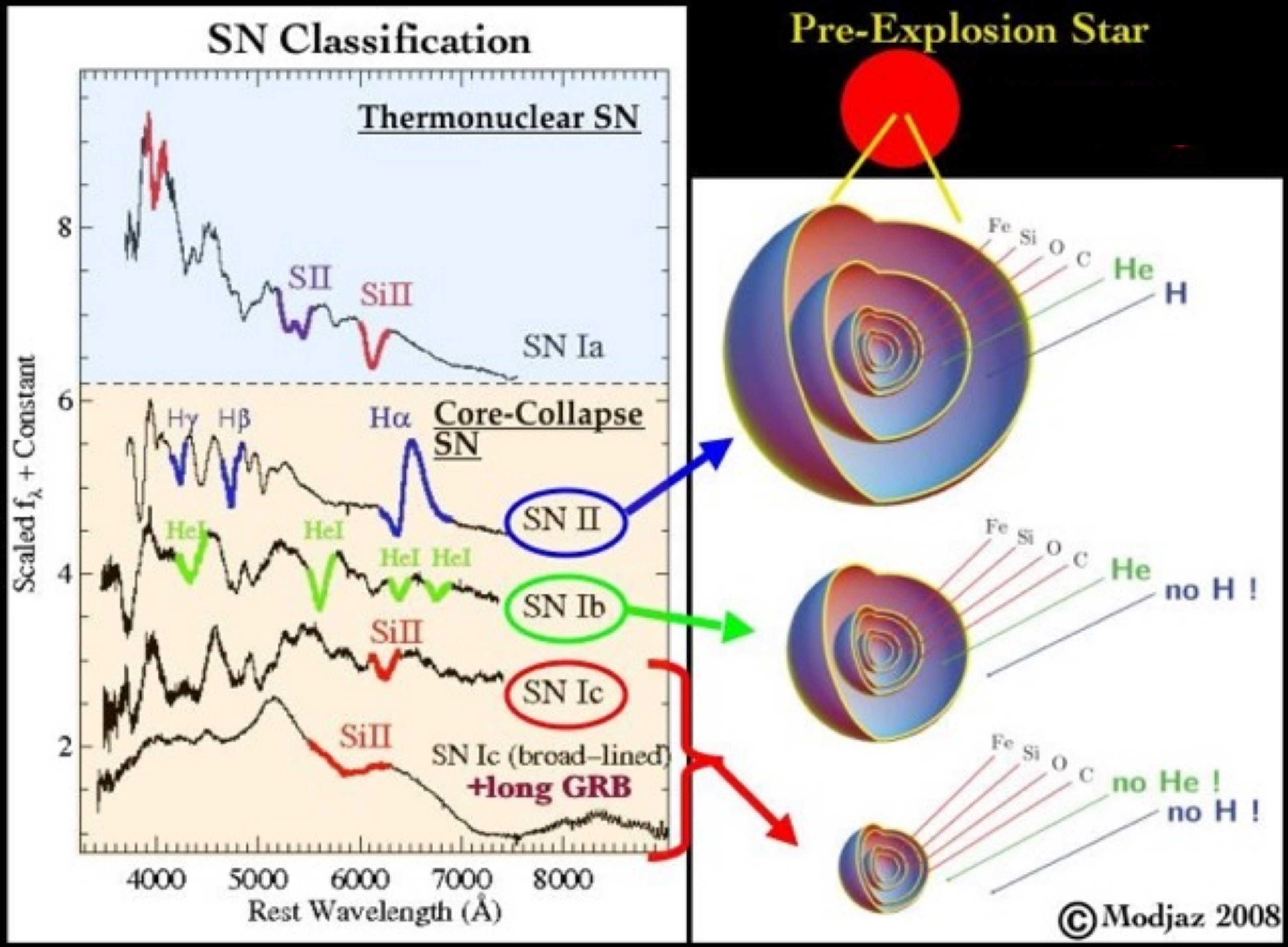
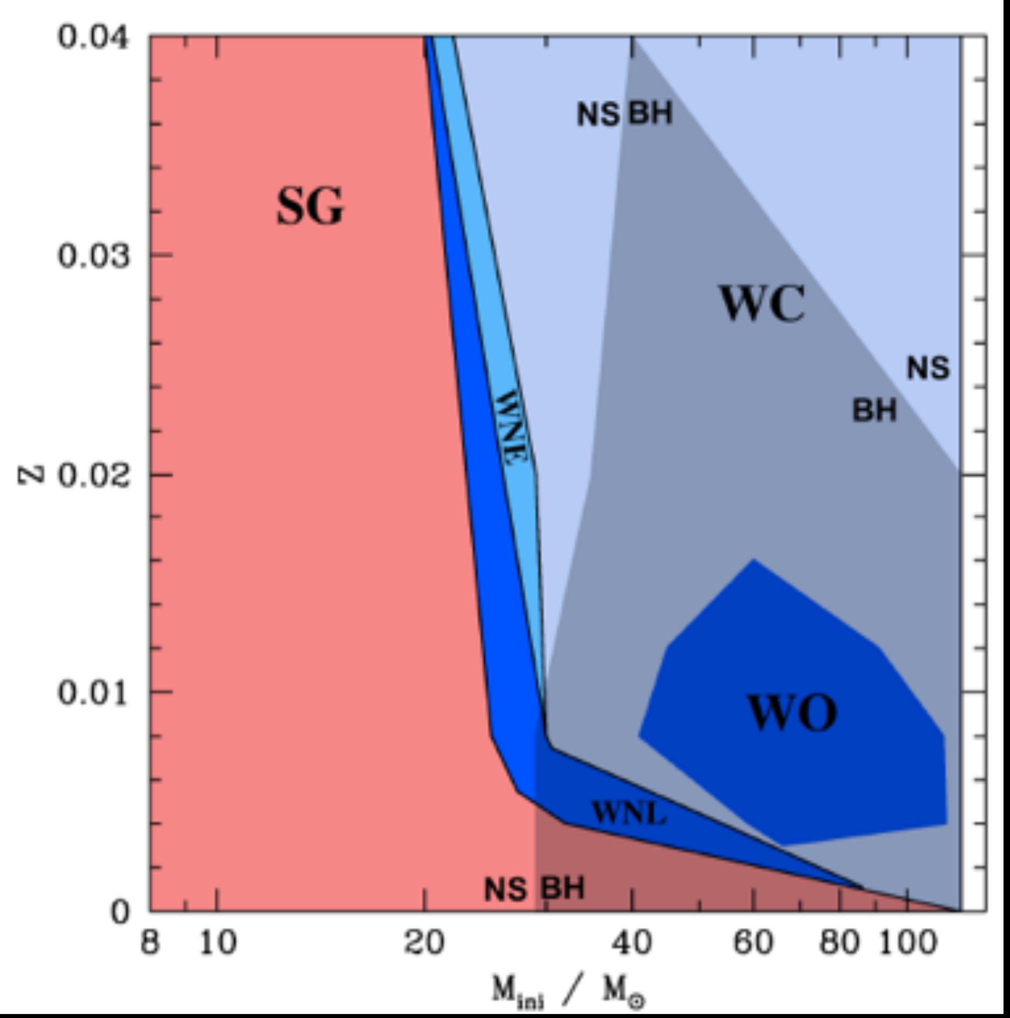
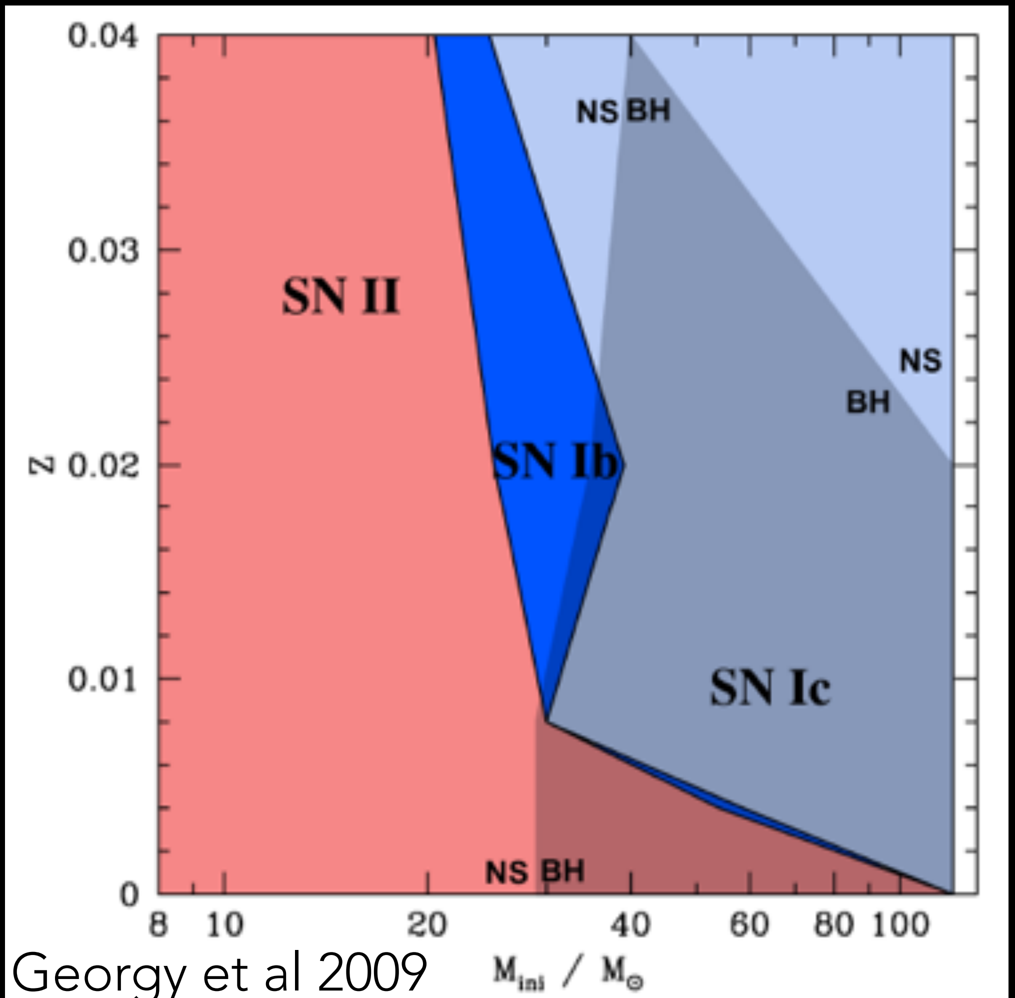
SAAO, 2017.11

# WHAT EXPLODED?

- Is there a one-to-one relation to the SN type?



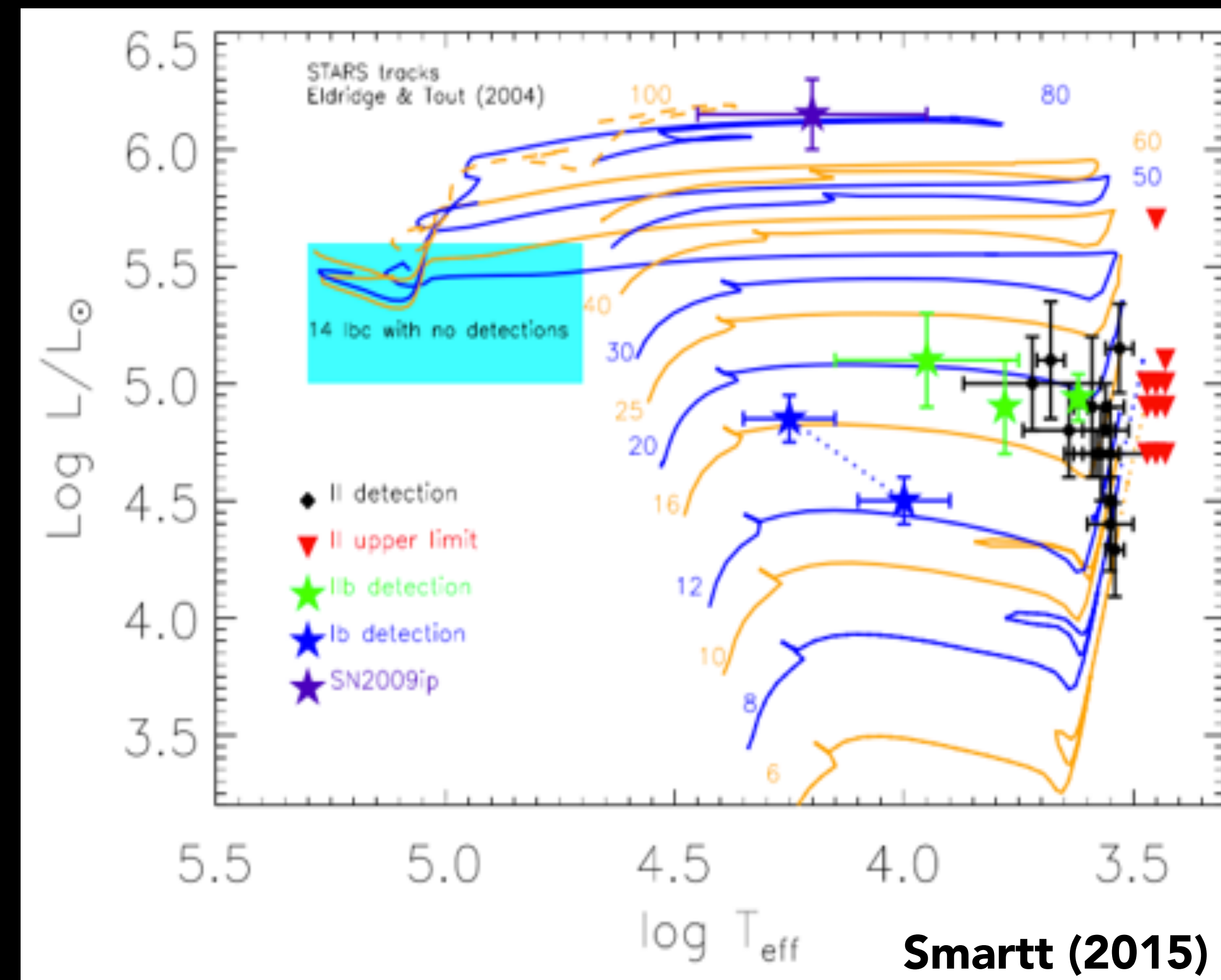



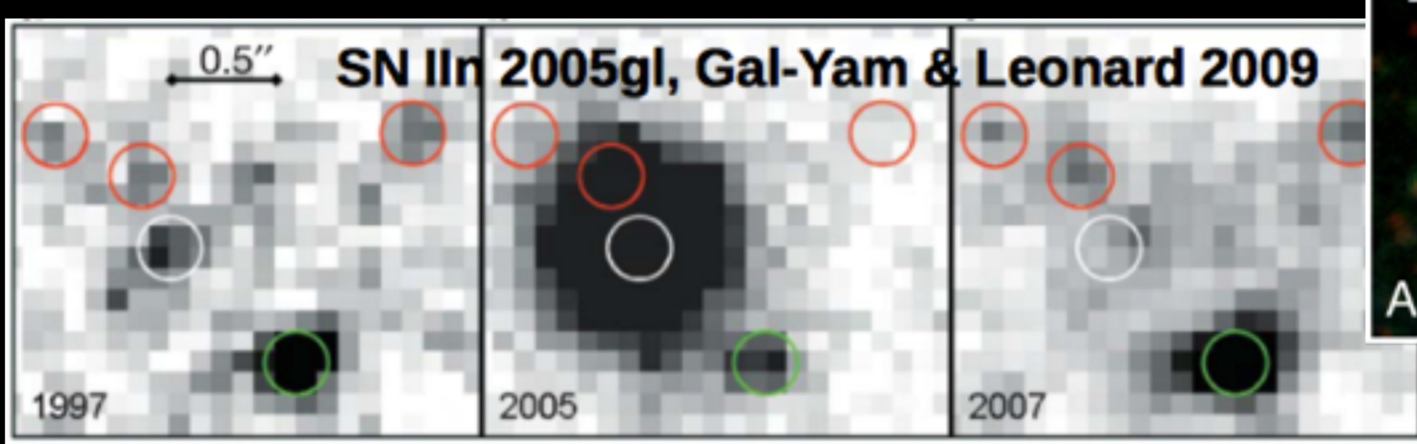

Georgy et al 2009

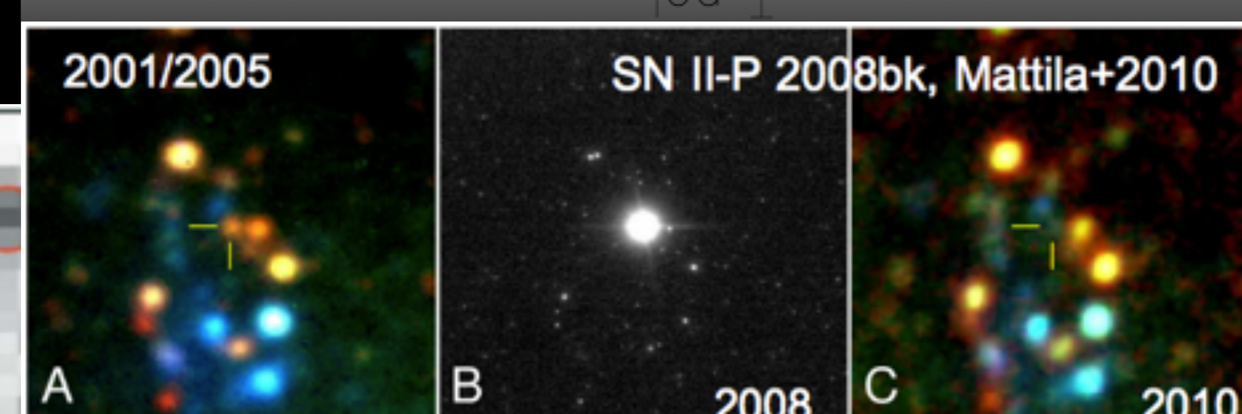
- Do the theoretical predictions match the observations?

# DIRECT PROGENITOR DETECTIONS

- Constrains initial progenitor mass (but not metallicity)
- Mostly SN II progenitors, so far
- Ib/c progenitor non-detections (but one): many/most are lower-mass binaries, or faint in pre-SN?
- Statistics increasing quite slowly; need progenitor disappearance confirmation

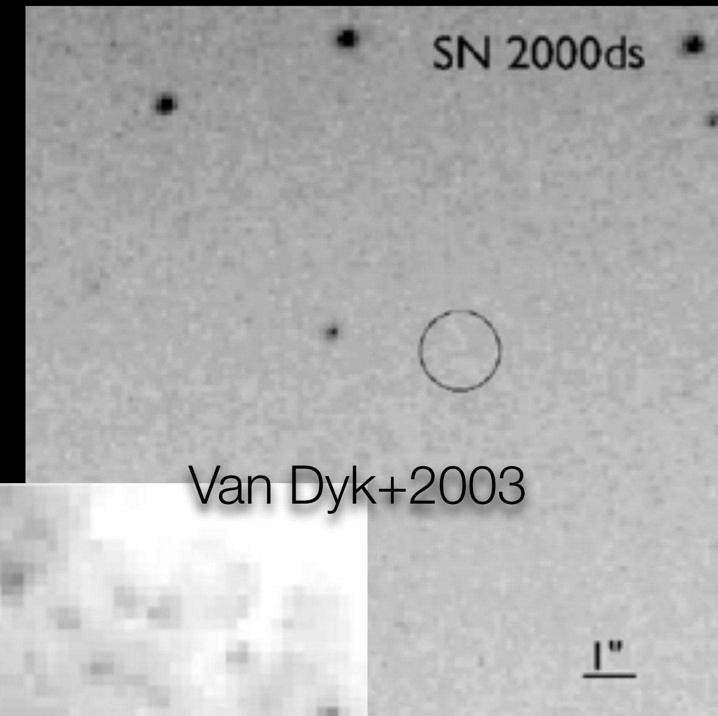


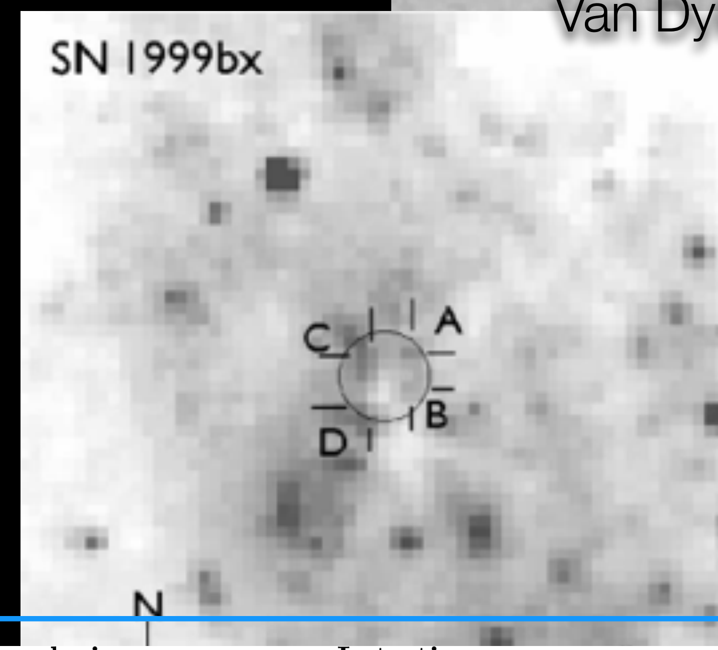



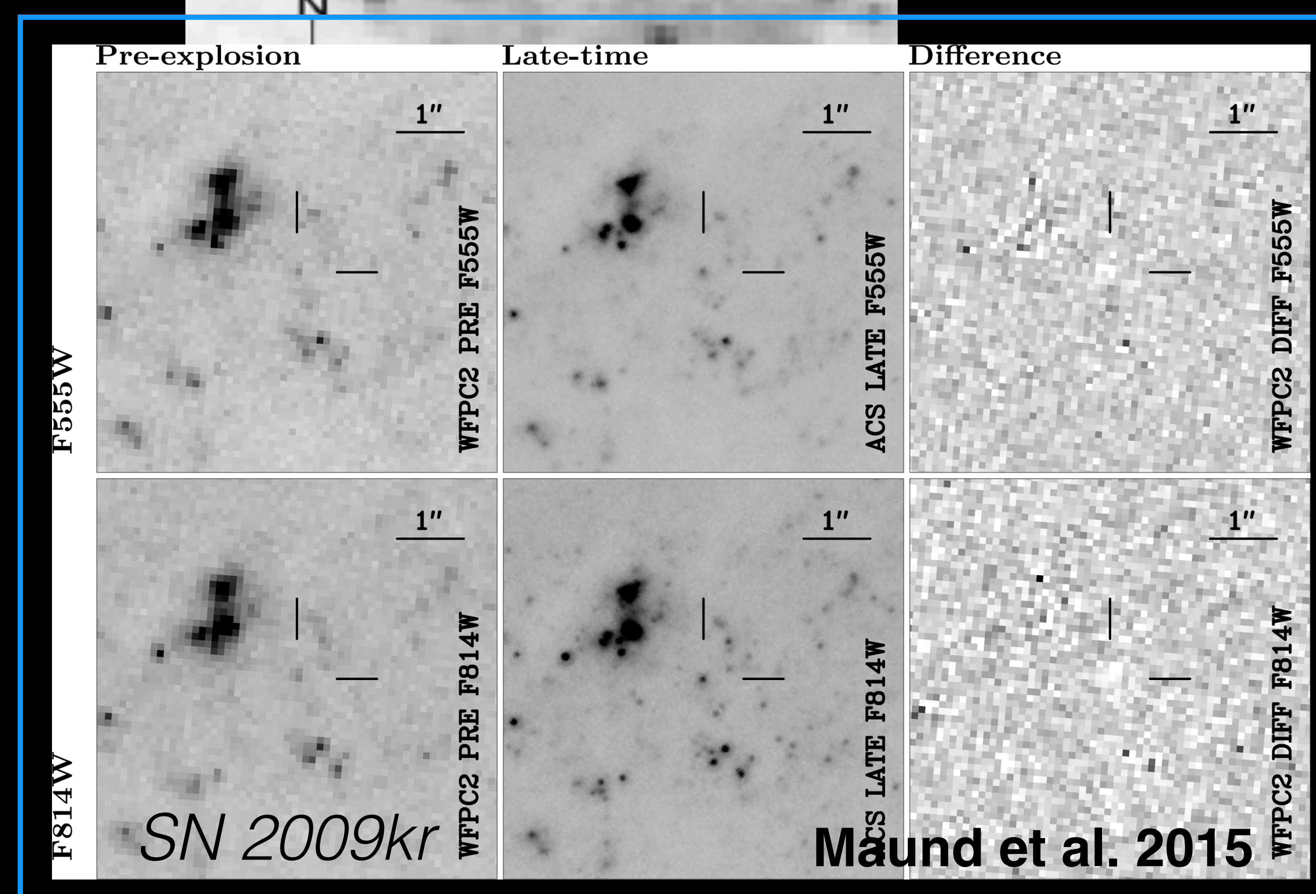



# LIMITATIONS IN DIRECT DETECTIONS

- Resolution (distance) limited!
- Not all SNe have pre-explosion data; difficult to increase statistics
- Existing data may not be good enough (only in 1-2 bands, crowding/ambiguity, shallow…)
- Ideally, should be accompanied with confirmation of progenitor disappearance (it may still be there or have been misidentified)
- Metallicity? Extinction?
- Relies heavily on star's luminosity and color (evolutionary status) very shortly before the explosion



# THE ENVIRONMENTS OF SUPERNOVAE

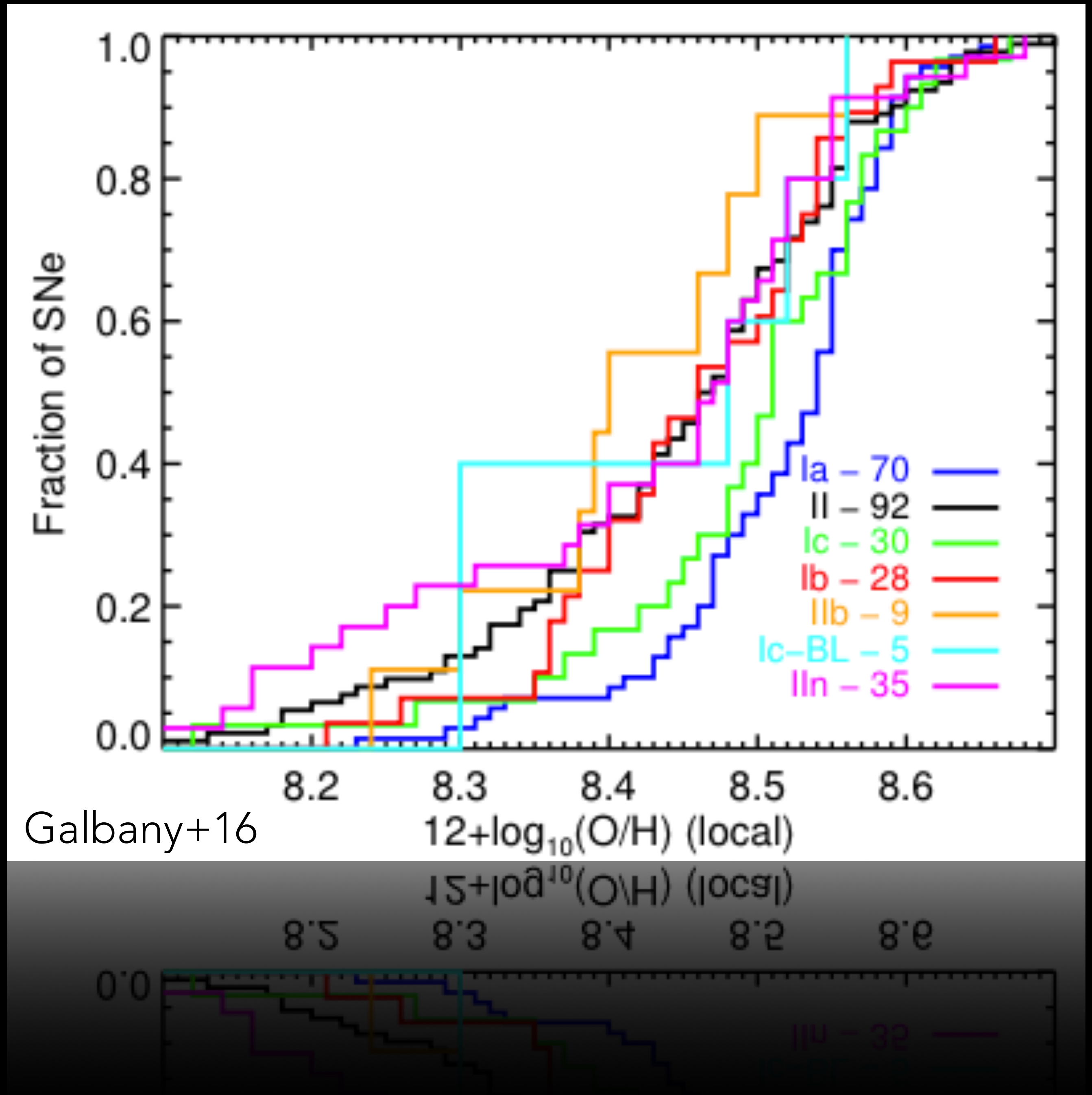
SDSS II: 139 SN Ia in 2005


SNe Ia: in all galaxy types
—> mix of young/old populations?

CCSNe: in star-forming galaxies
—> young populations?

# SN ENVIRONMENTS: METALLICITY

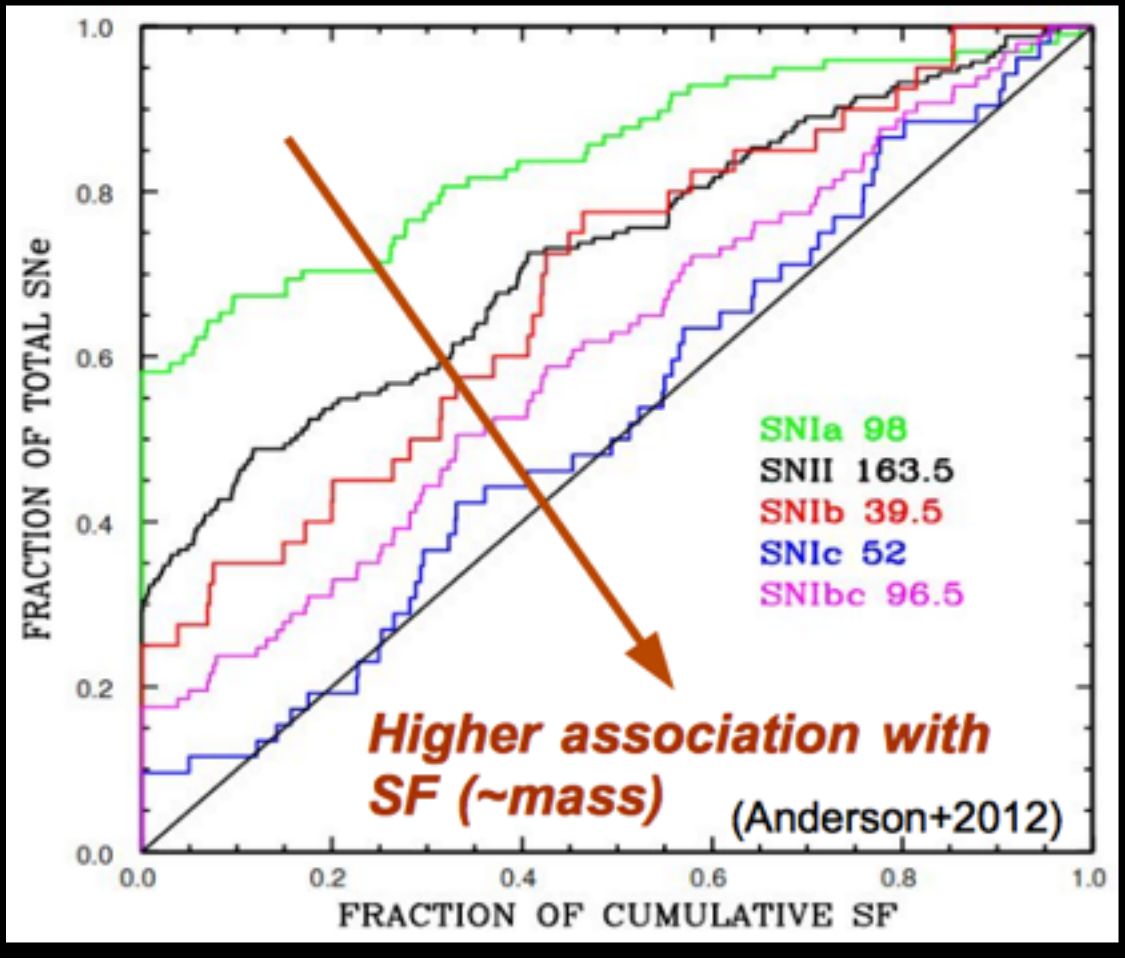
- In stripped (H-poor) SNe, outer envelope is removed —> WR stars
- Wind scales with metallicity
- Alternatively, binary interaction may also remove H/He
- Metallicity cannot be constrained from direct imaging alone
- Obs: metallicity does not seem to be significantly different among SN types (c.f. Anderson+, Galbany+)

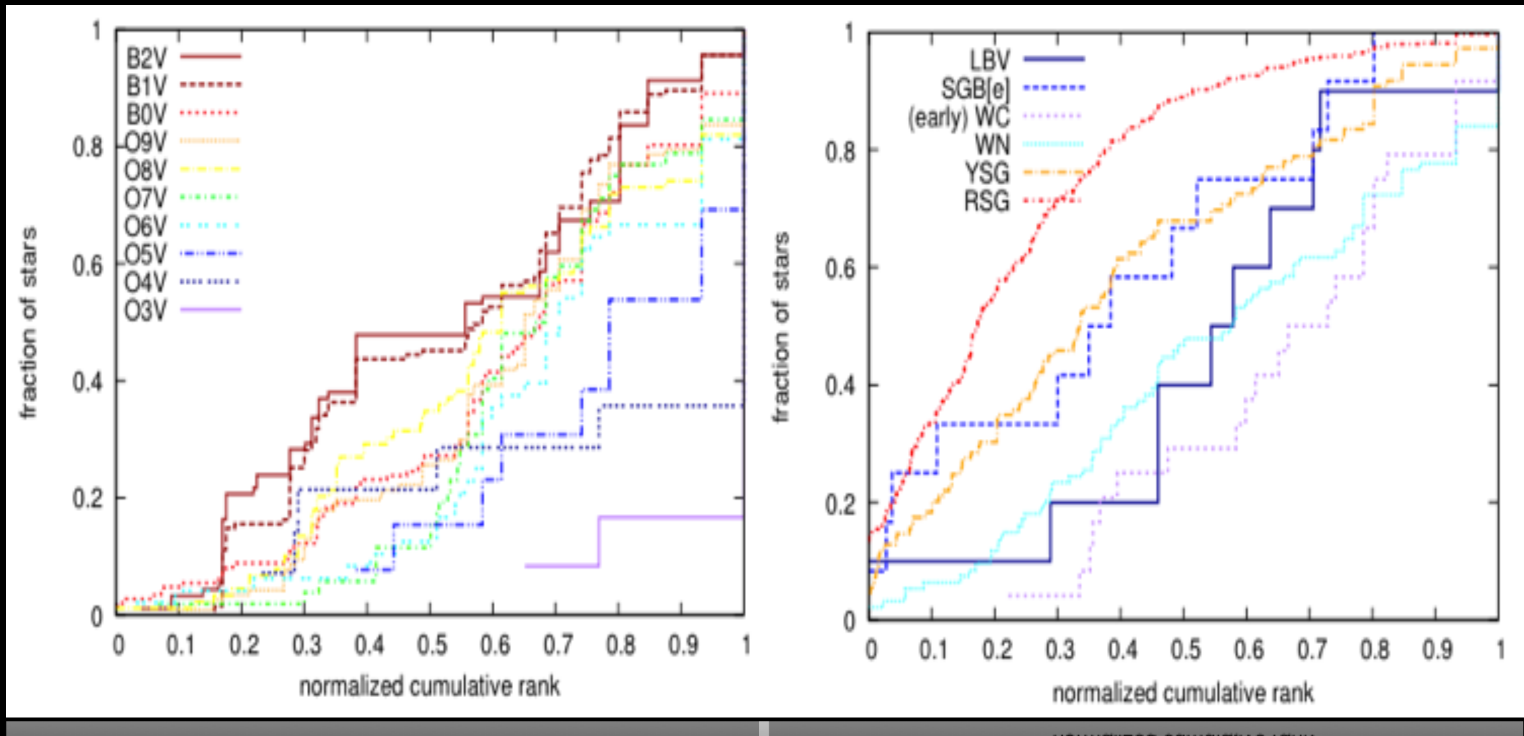


Galbany+16

# SN ENVIRONMENTS: AGE/MASS

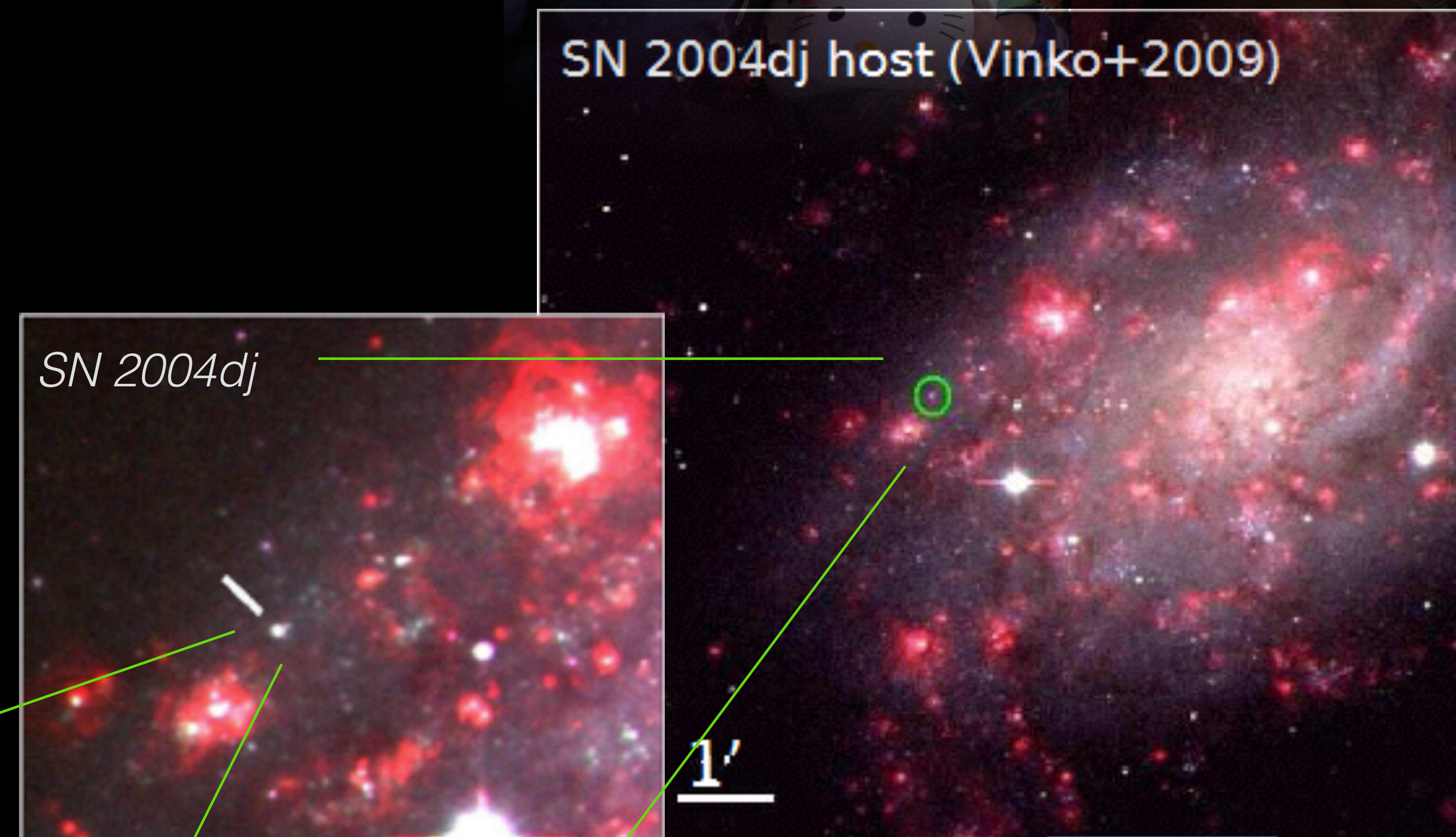
- HII regions: signposts of recent SF —> massive stars are still around
- H-alpha pixel statistics: Anderson et al. 2012: Ic > Ib > II > Ia progenitor mass
- SN-massive star connection: Kangas+17

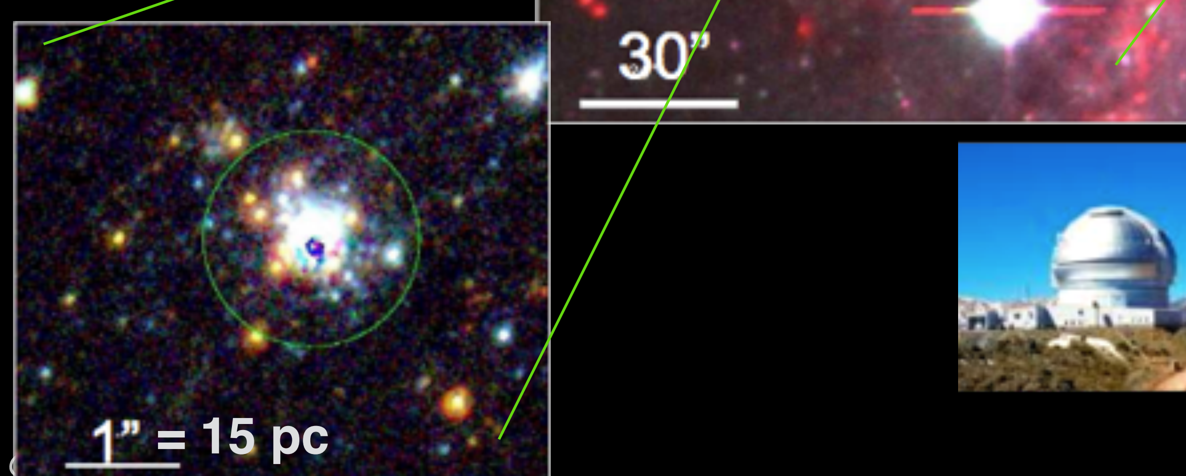


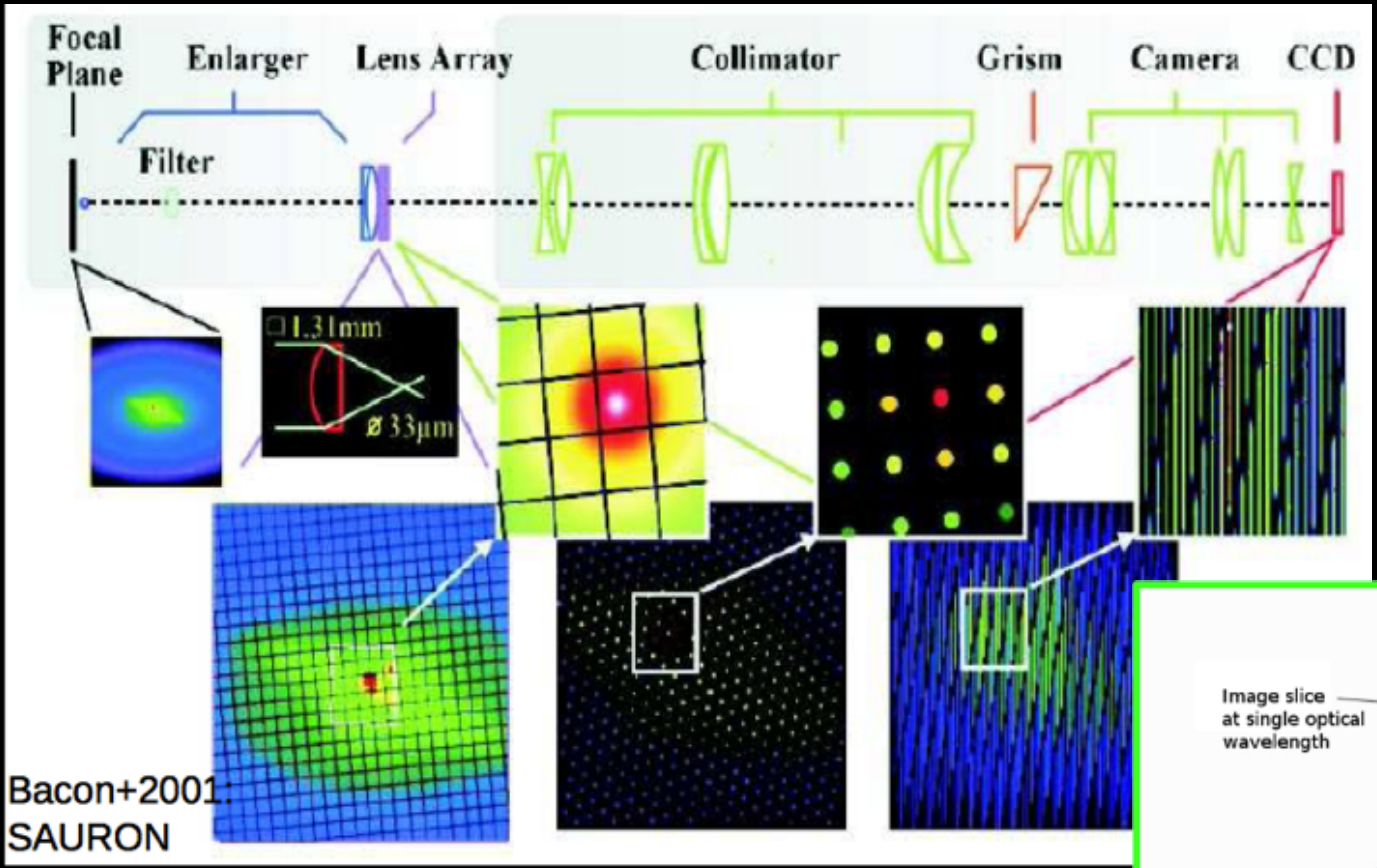
# CONSTRAINTS FROM THE SN PARENT STELLAR POPULATION

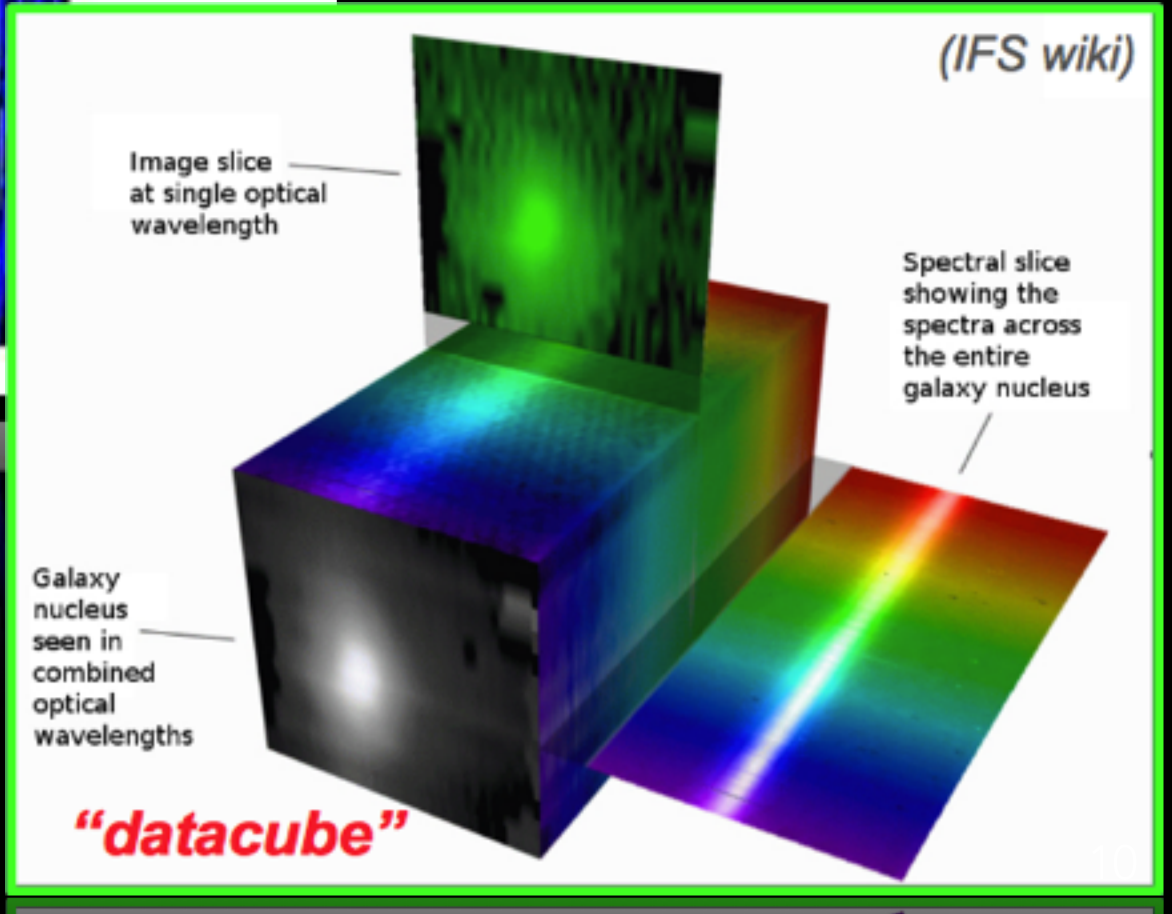
- The SN progenitor must have been born within a stellar population
- SN progenitor properties derived from the parent stellar population, assuming coevality
- Statistical study



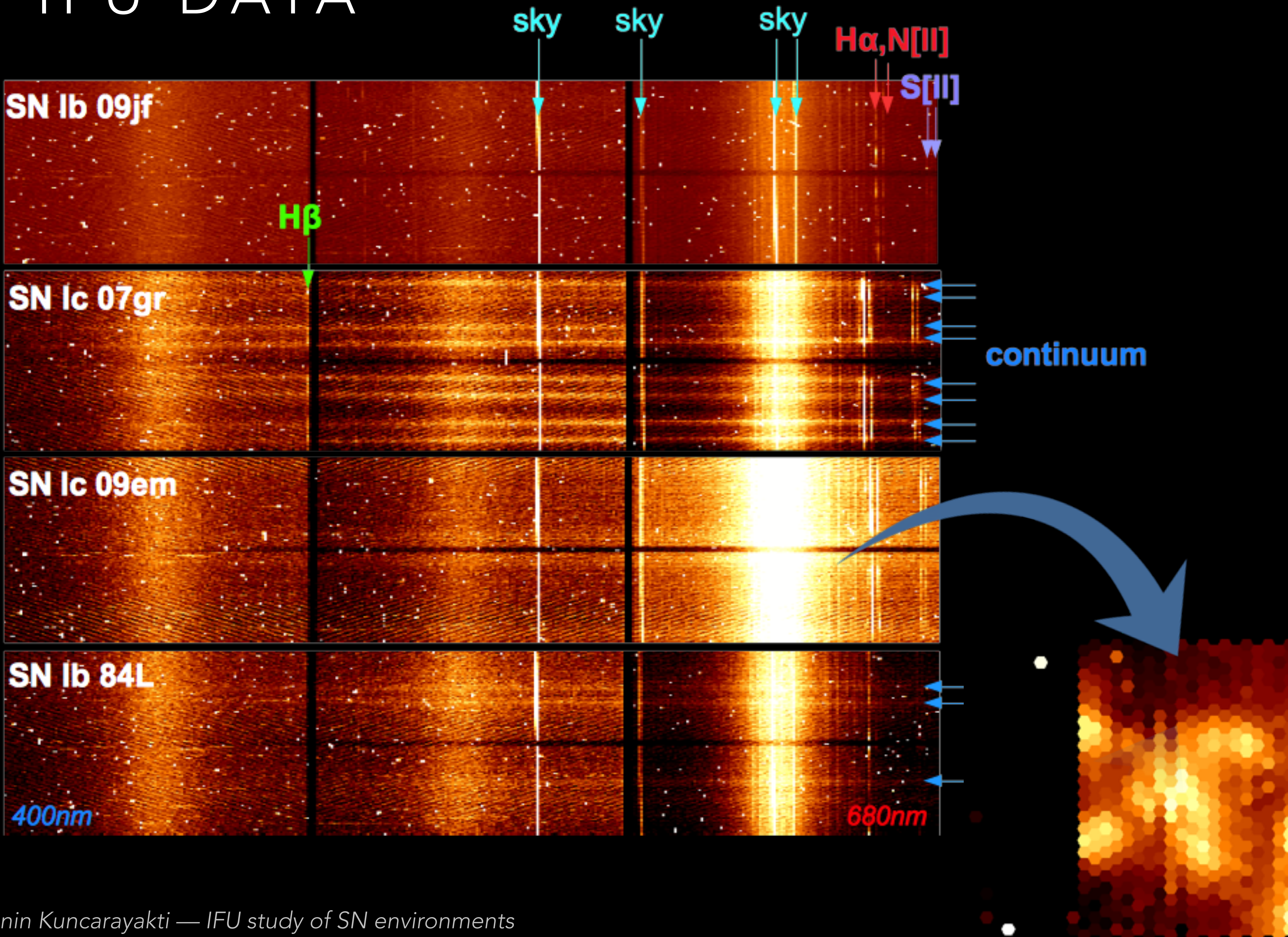



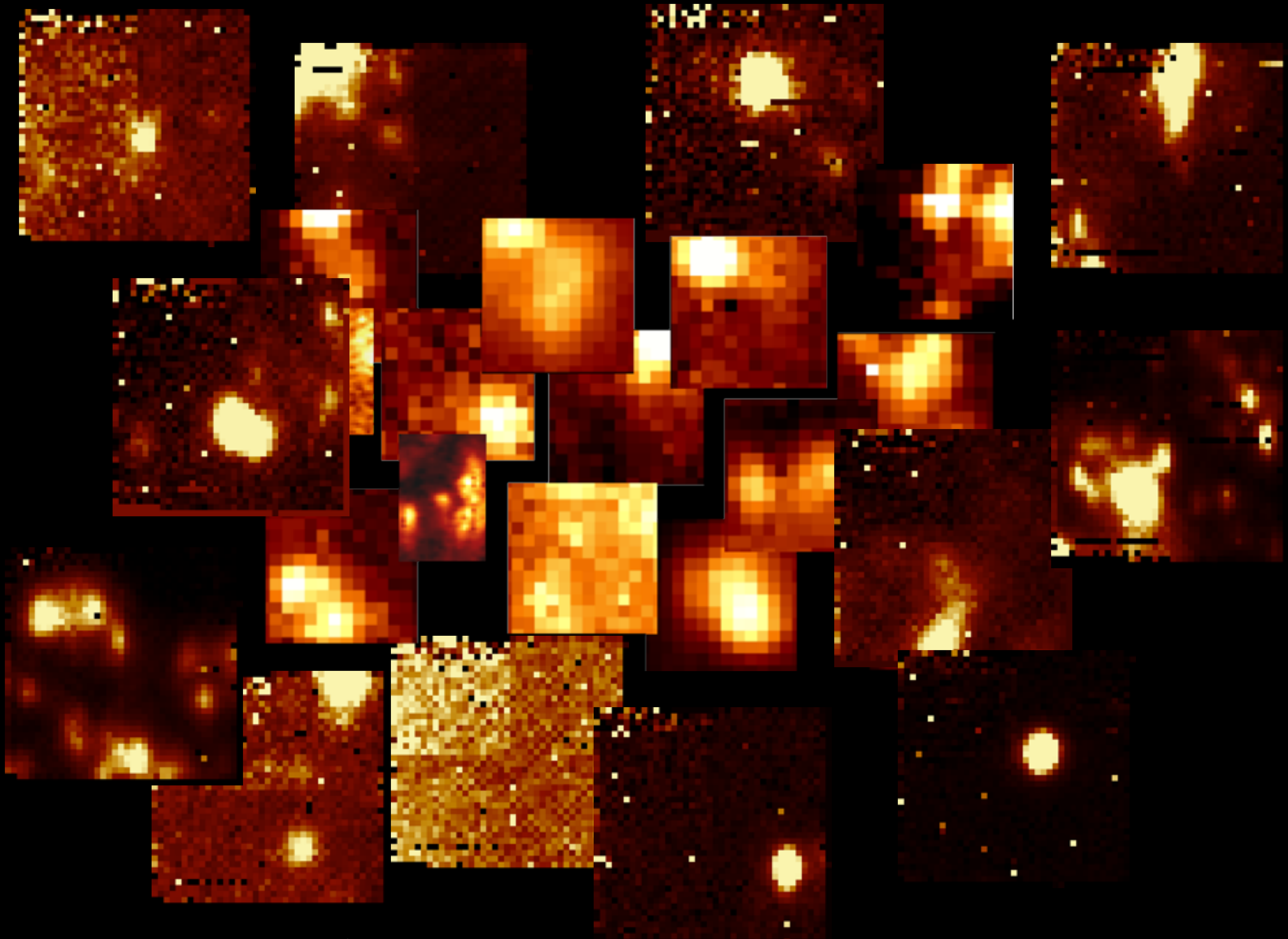

# INTEGRAL FIELD (IFU) SPECTROSCOPY



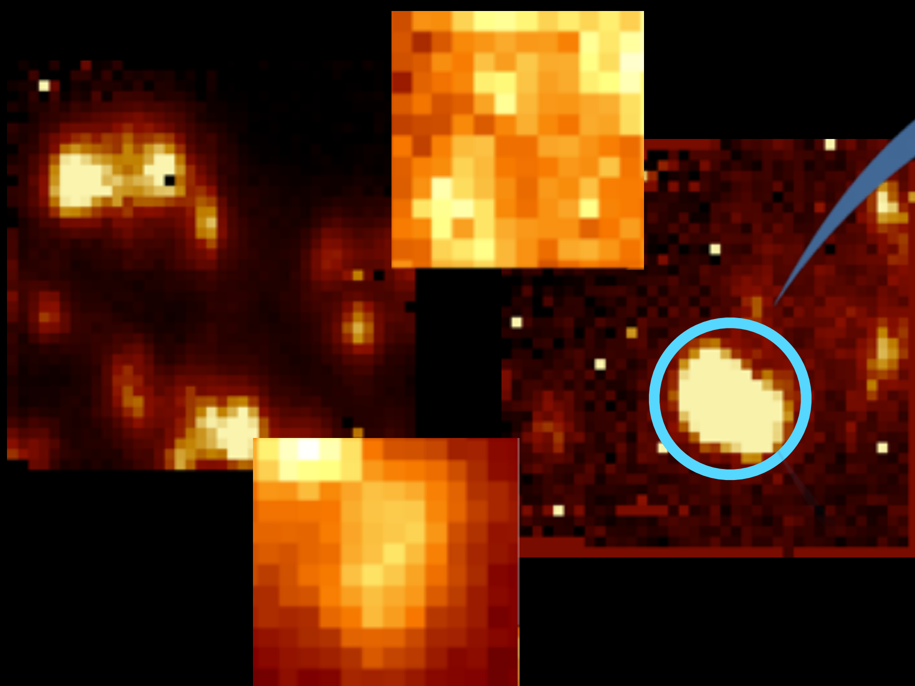



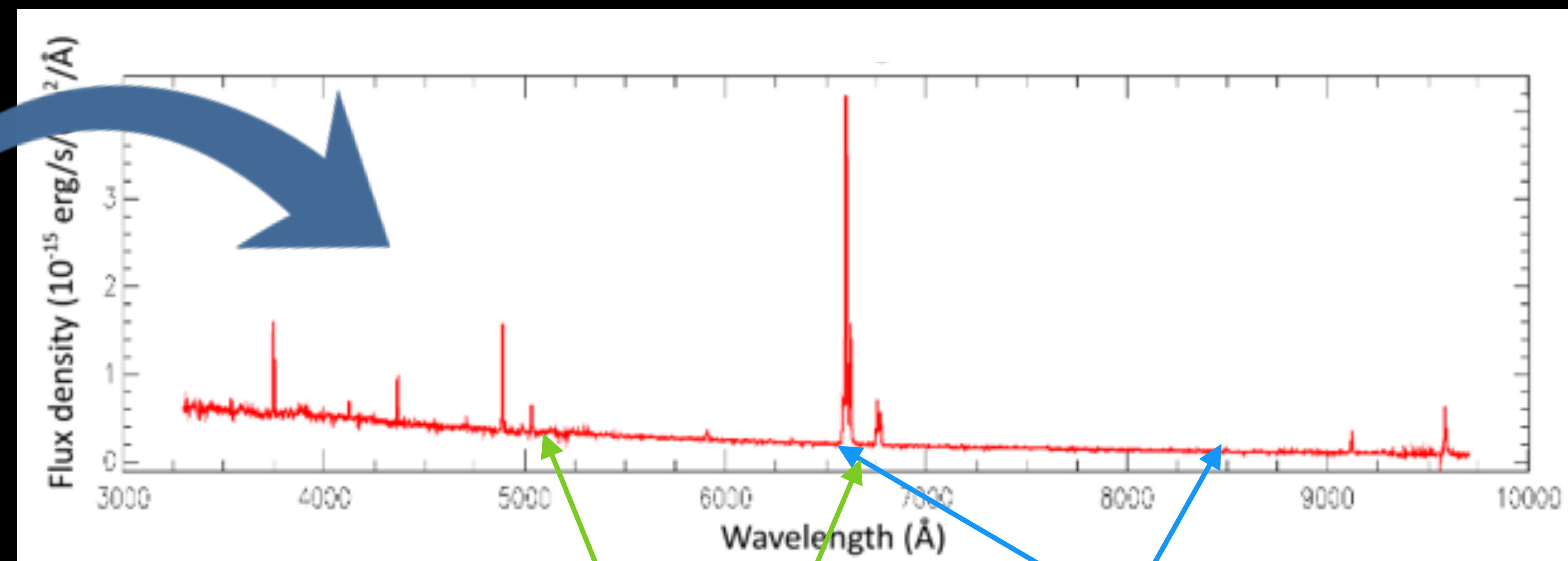
# IFU DATA


sky
sky
sky
Hα,N[II]
S[II]
SN Ib 09jf
Hβ
SN Ic 07gr
continuum
SN Ic 09em
SN Ib 84L
400nm
680nm



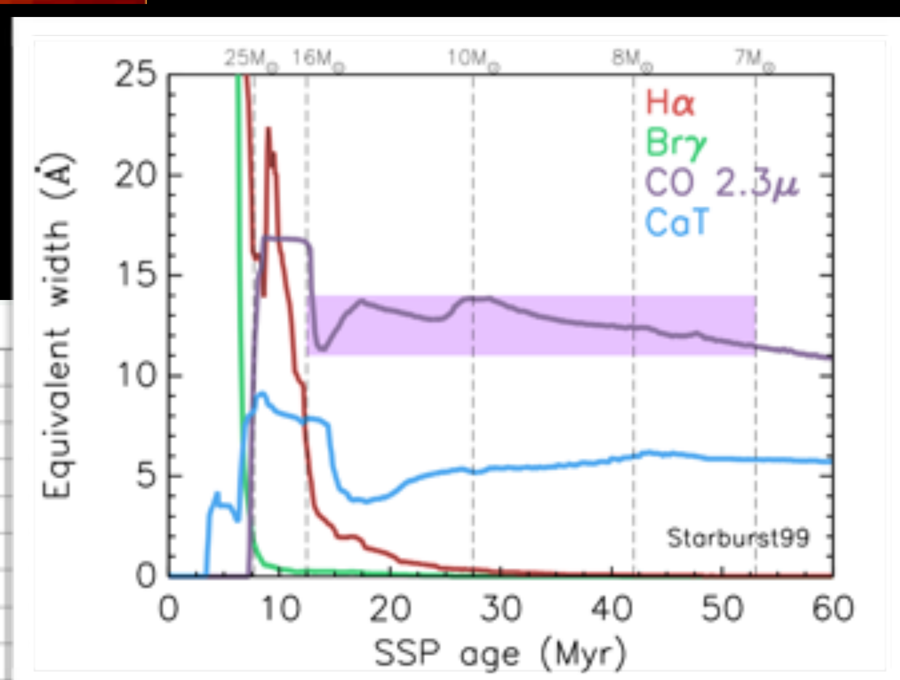
# SN PARENT STELLAR POPULATION — AGE & METALLICITY DETERMINATION

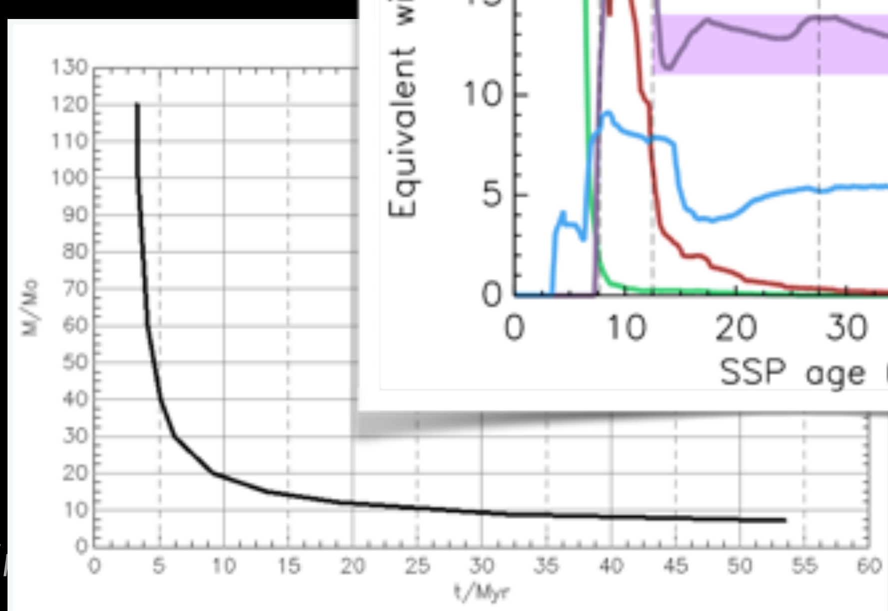





Age indicators

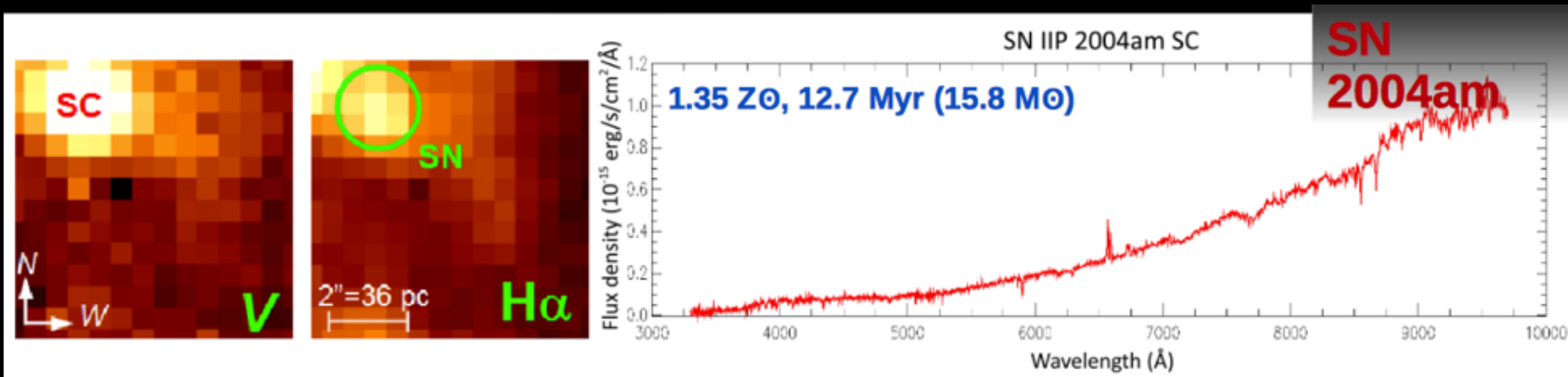
Metallicity via strong lines



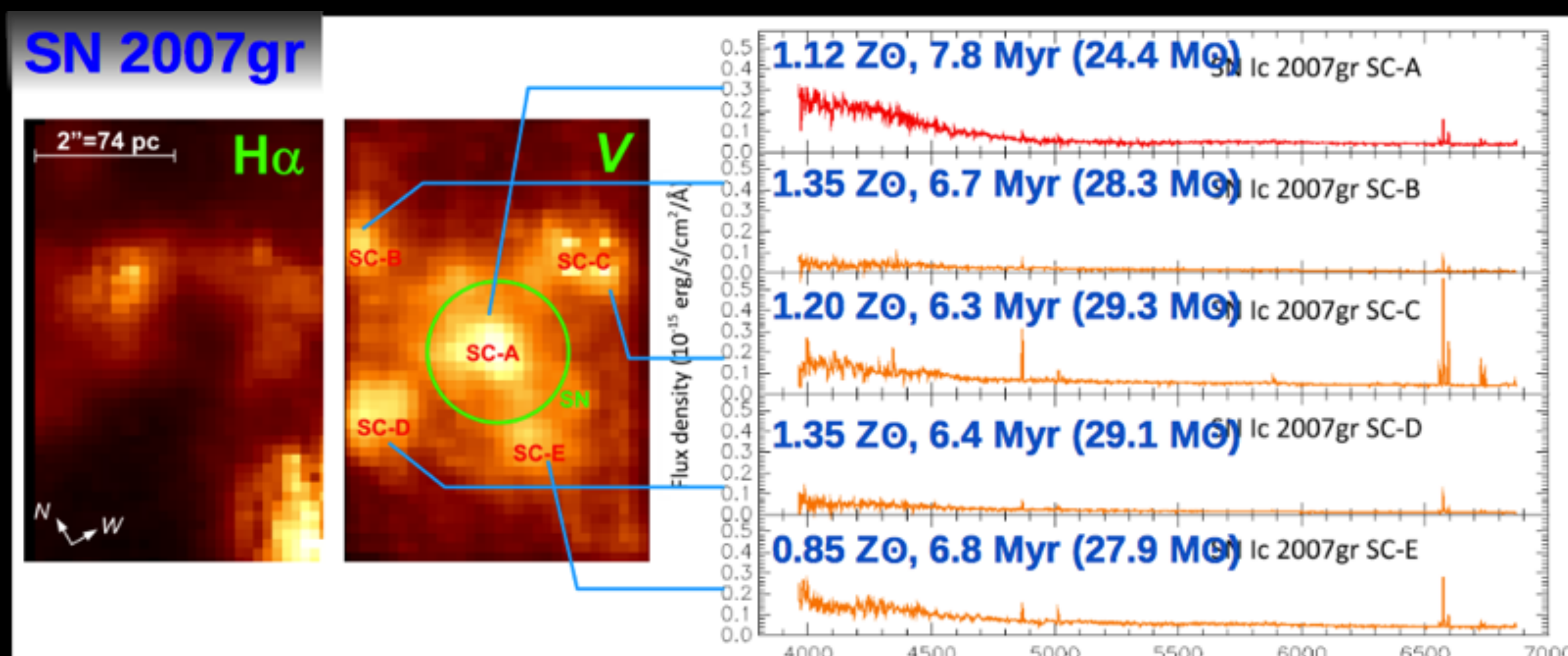




Age (i.e. lifetime) of a star is governed by its initial mass & metallicity

# SOME INDIVIDUAL RESULTS (HK+13ab)

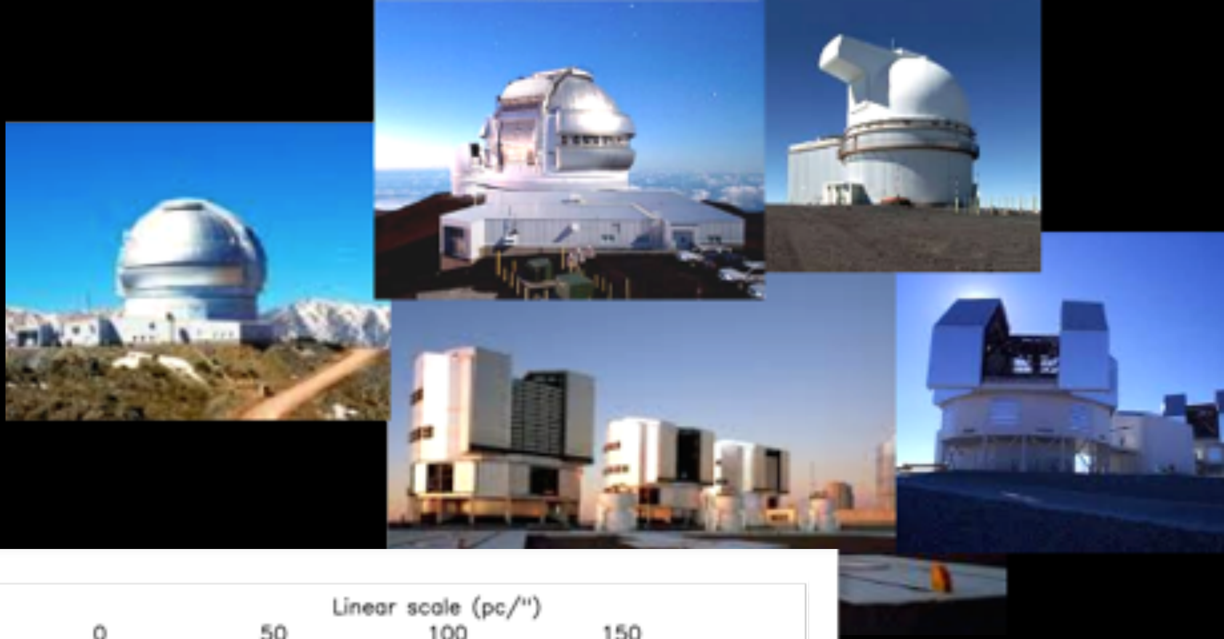



30—135 Myr (Smith+06, cluster SED); 10—35 Myr (Lancon+08, cluster SED)

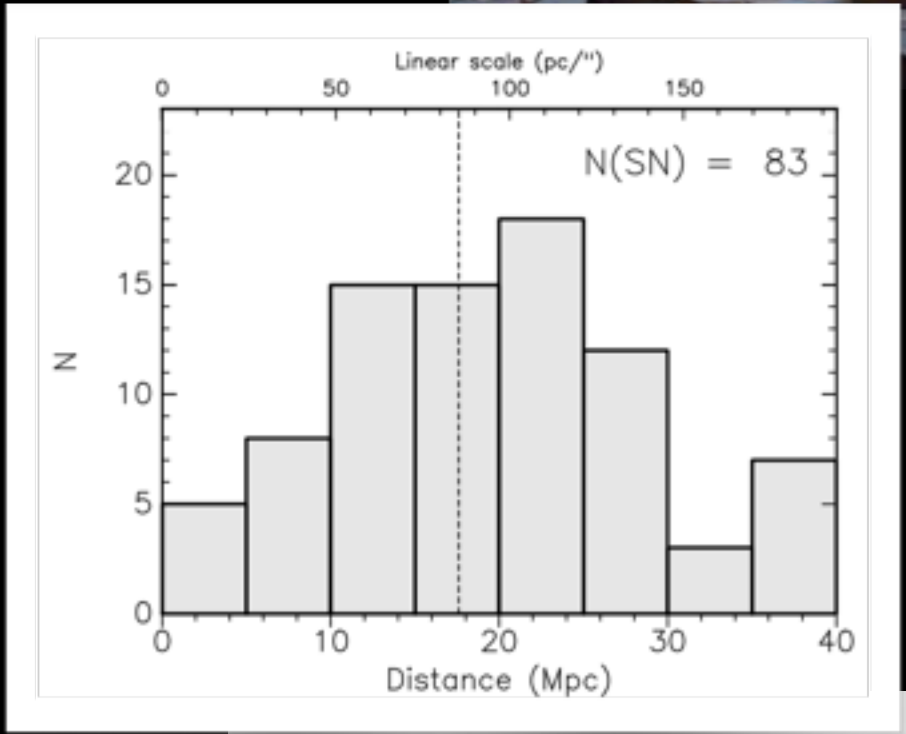


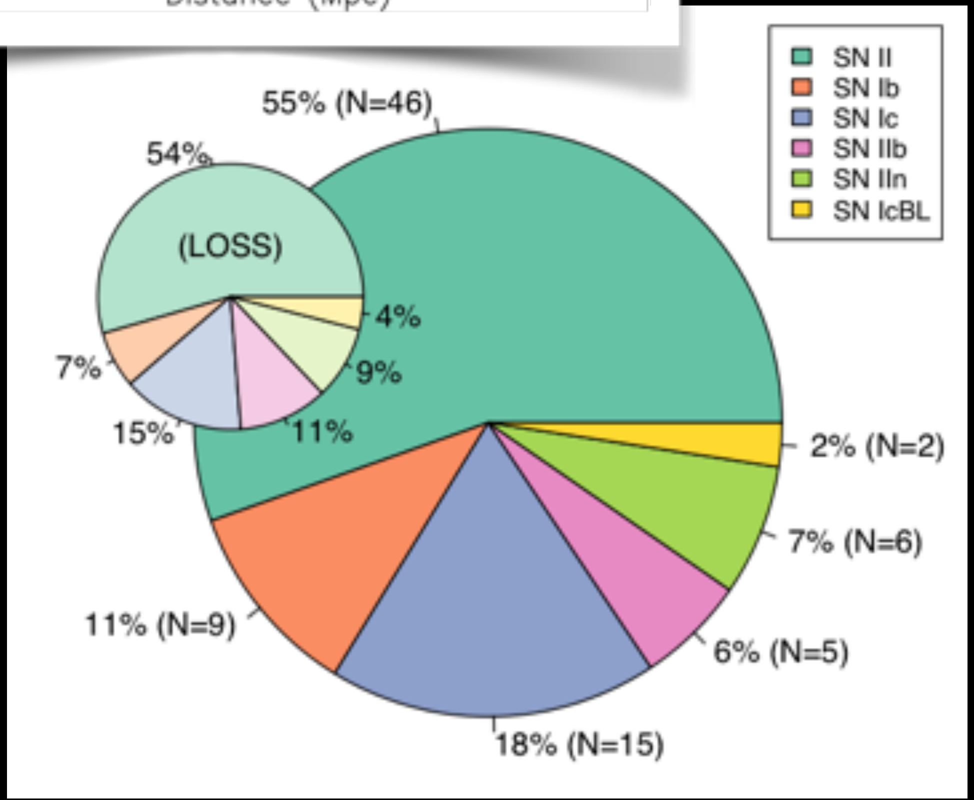

Ref → Crockett+2008: 7 or 20-30 Myr (SC-A central, SED)

# IFU SURVEY OF NEARBY SN SITES



- Extension of Kuncarayakti et al. 13ab (UH2.2/SNIFS, Gemini/GMOS-N)
- Identify the parent stellar population of the SN, minimize contamination & determine SN progenitor properties
- Add southern CCSN sites within 40 Mpc (VLT/VIMOS, MUSE, SINFONI, Gemini/GMOS-S, Magellan/IMACS)
- 83 SN sites in total (combined with HK +13ab), includes all main CCSN subtypes
- Aims to better constrain progenitor mass & metallicity

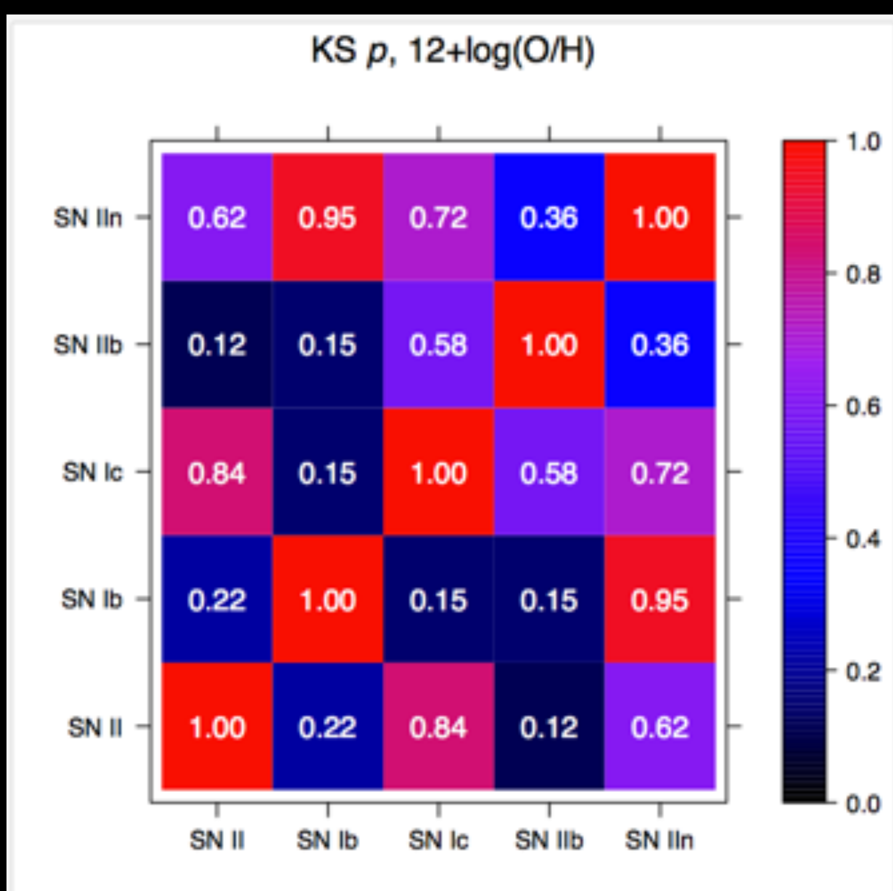


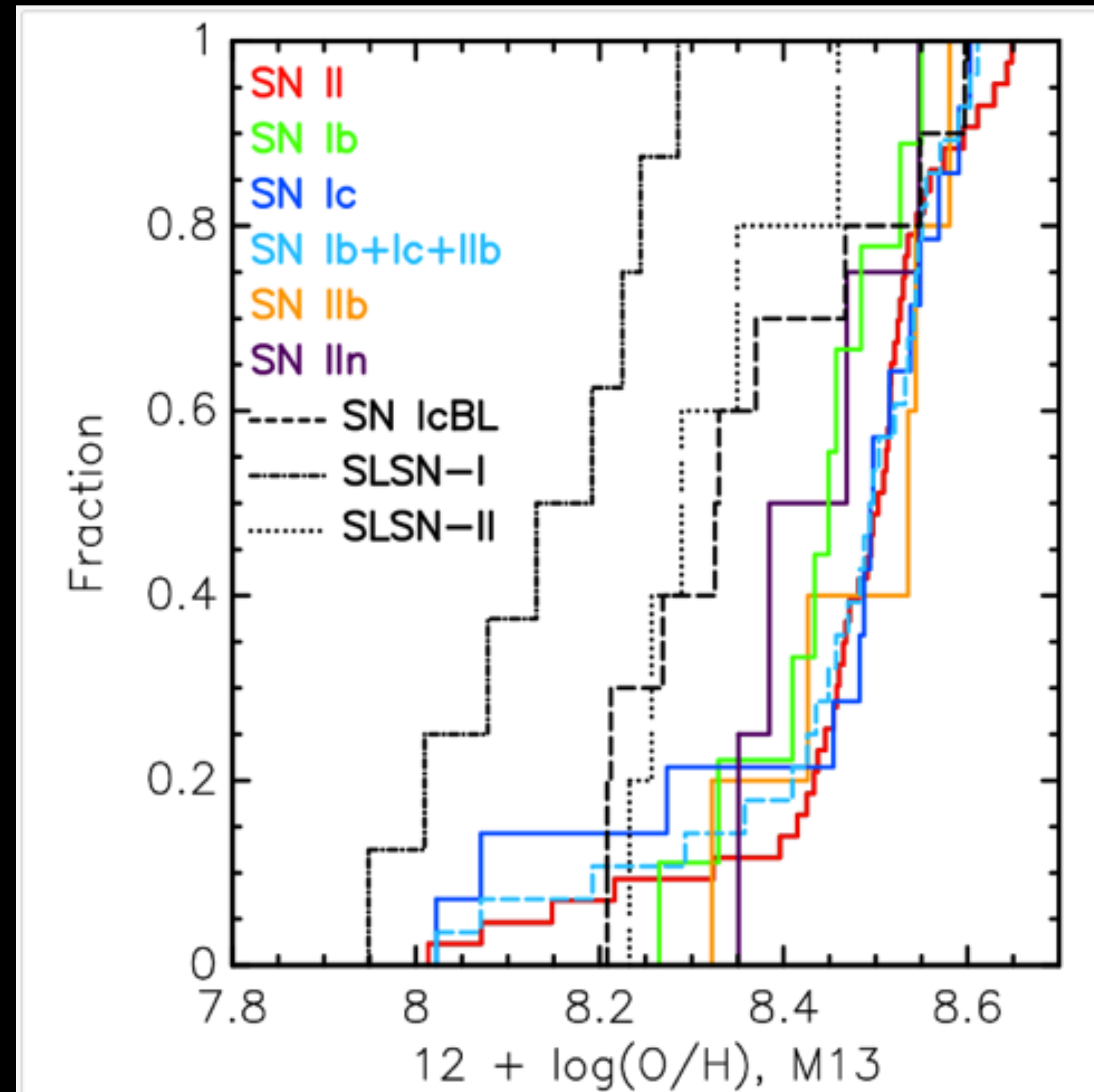




*HK et al. 2017, arxiv/1711.05765*

# METALLICITY

- Metallicity differences are not statistically significant



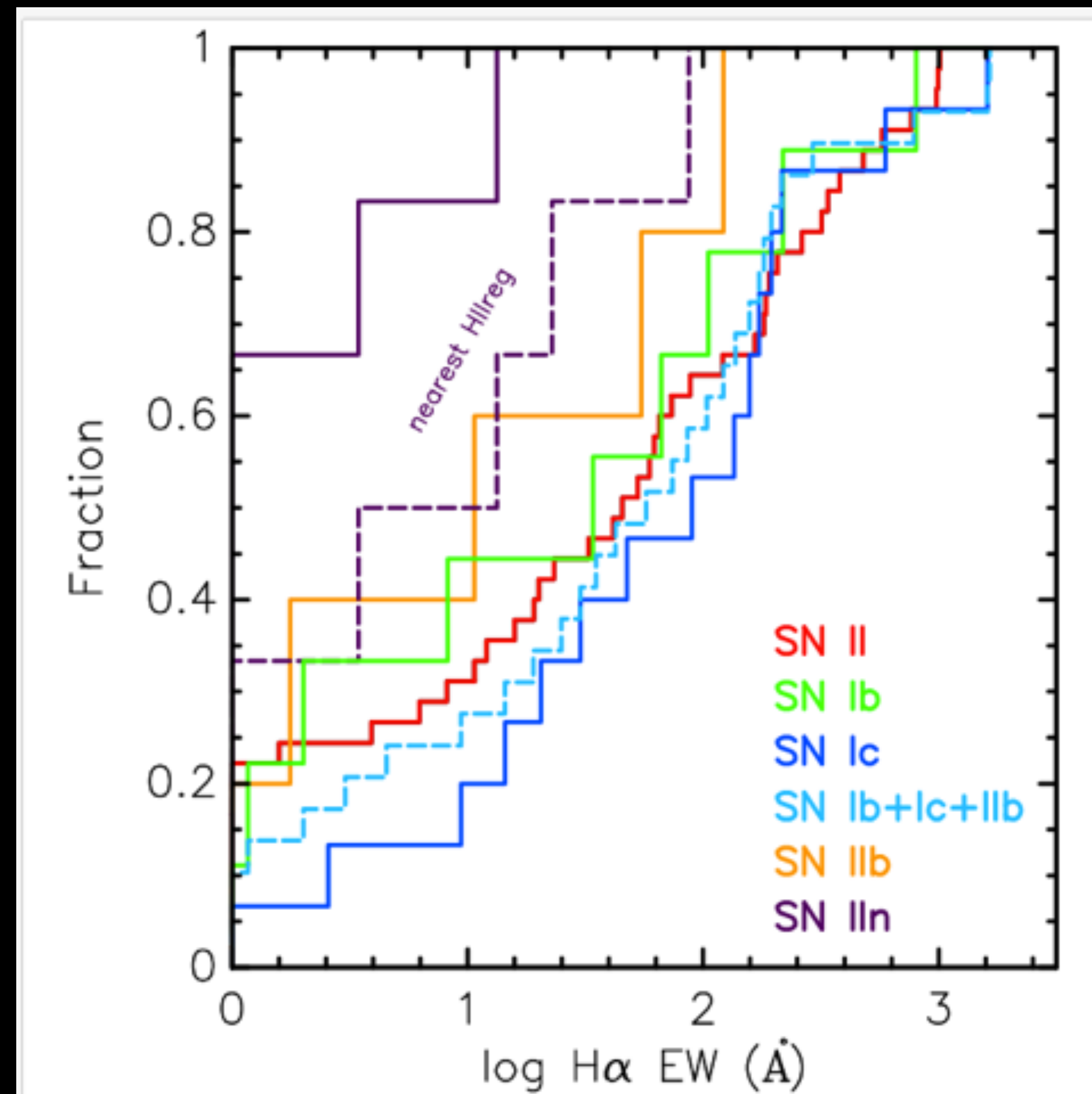



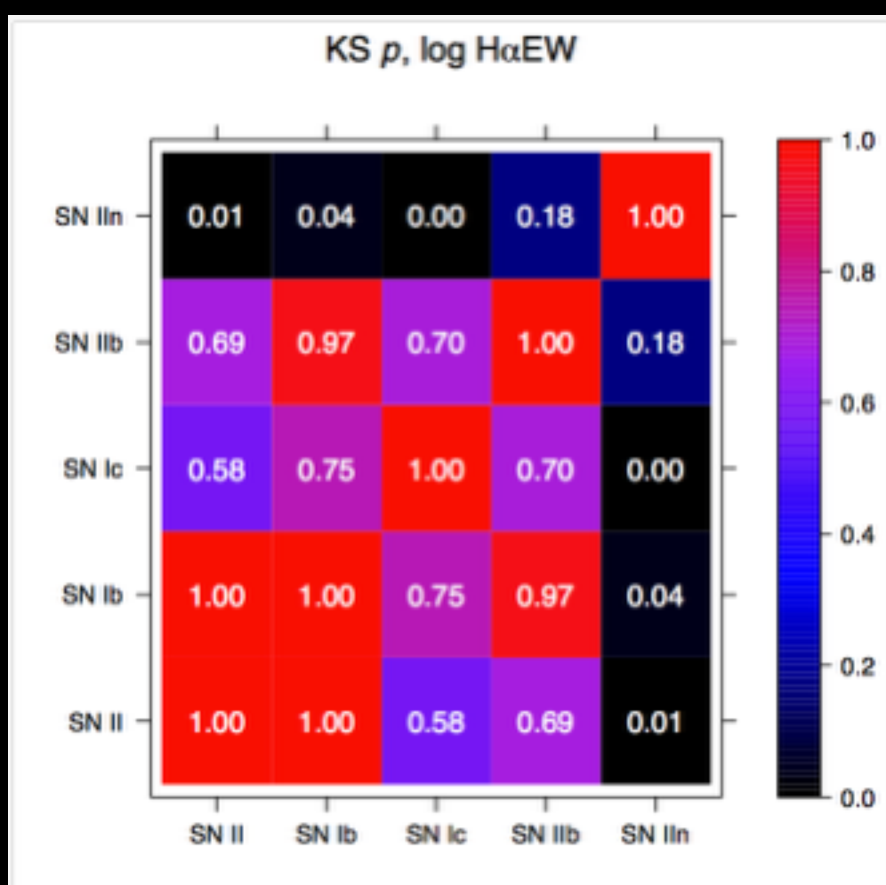

IcBL: Modjaz+11, SLSN: Leloudas+15

*arxiv/1711.05765*

# PROGENITOR AGE/MASS

- Instantaneous burst assumed, HαEW
- No significant difference between subtypes, except IIn
- Ic at the high-mass end, IIn at low mass

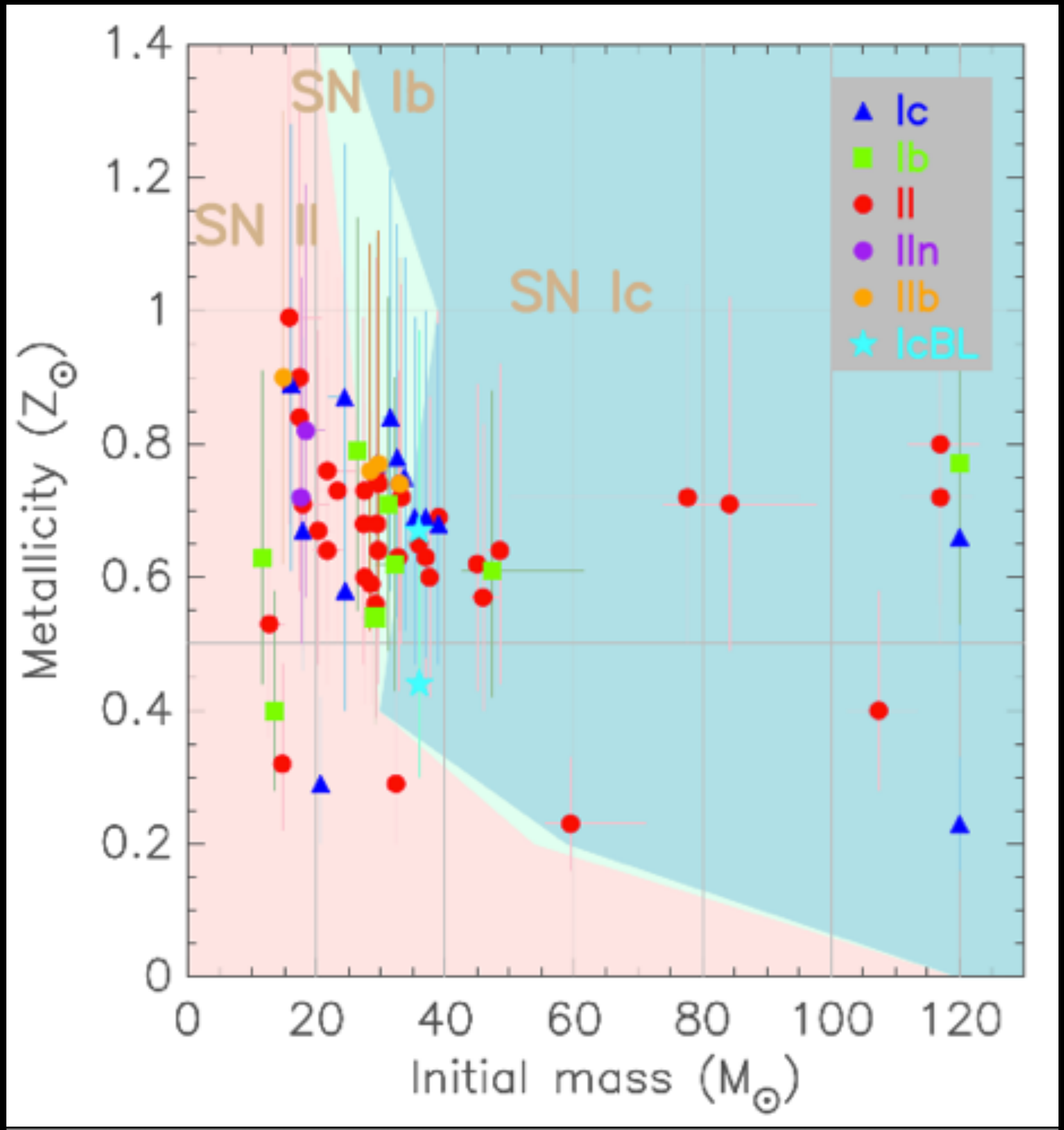



*arxiv/1711.05765*

# MASS-METALLICITY DIAGRAM

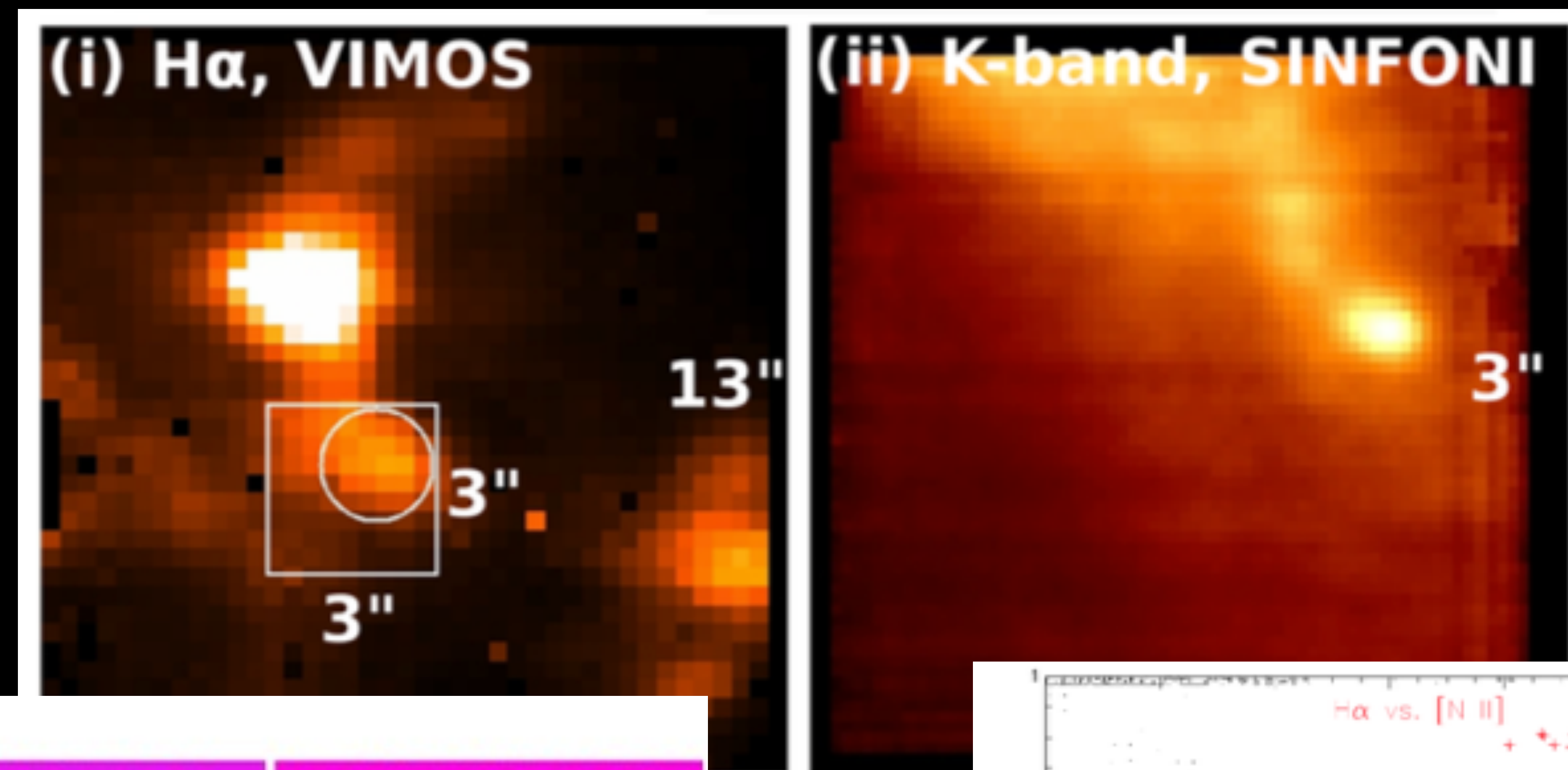
- Compared to Georgy et al. 09 single stellar evolution model
- Considerable spread of data points on the M-Z plane, no groupings according to SN subtype observed (i.e. they overlap)
- Some Ib/c correspond to binary progenitors
- Note: caveats on the detection of and association with the "real" SN parent population (50% chance superposition, HK+13b), uncertainty in star formation history and SSP models

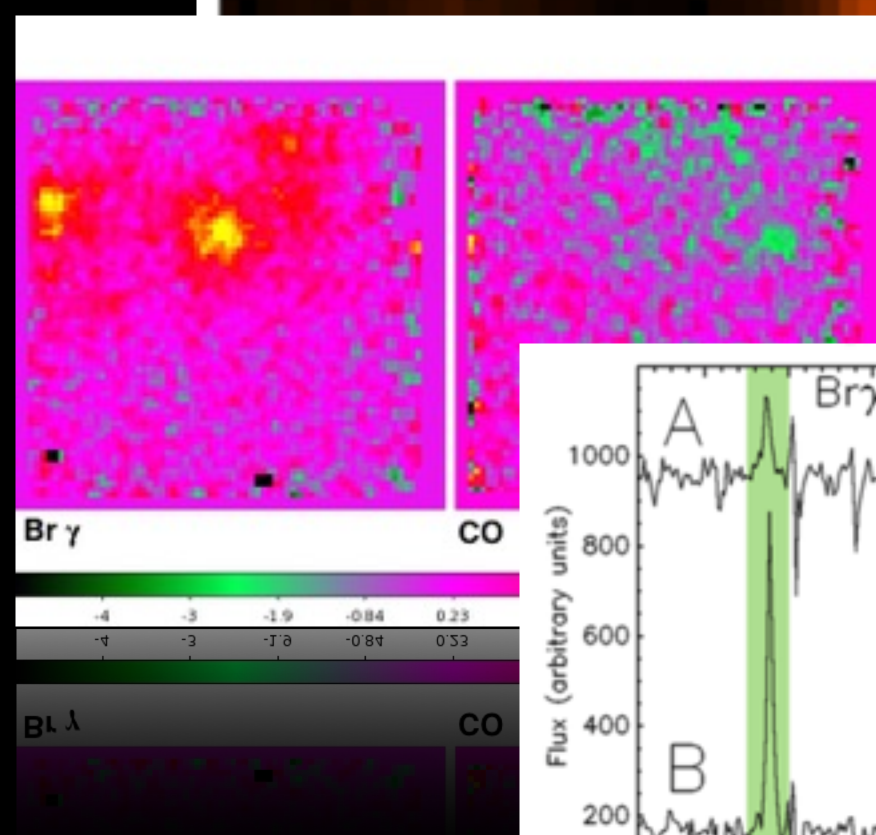


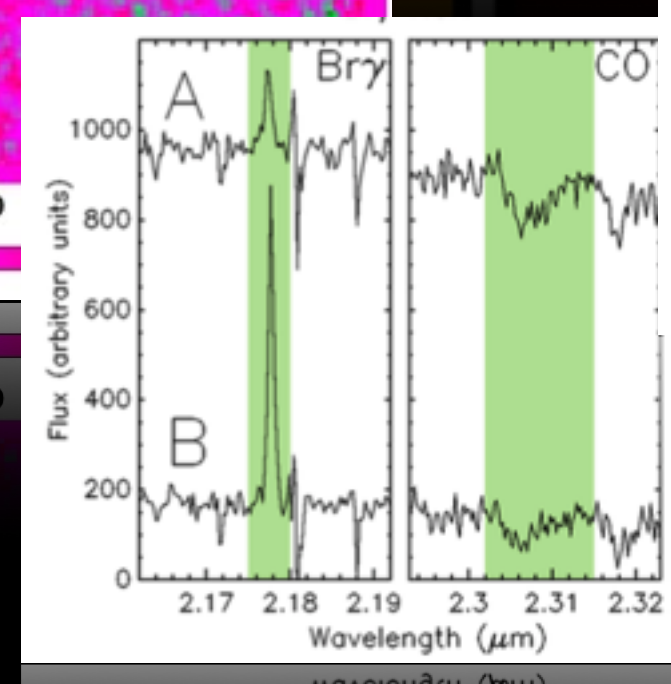

*arxiv/1711.05765*

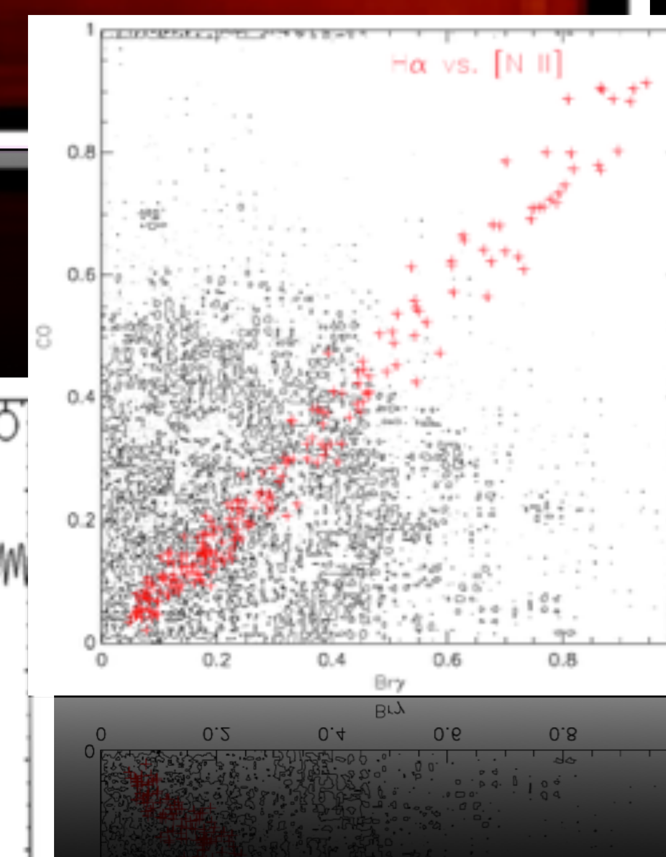
# IMPROVEMENT: AO-ASSISTED INFRARED IFU

- See previous caveat: what if the star formation history was not instantaneous?
- AO helps resolve the SN sites, better constraints on SFH
- SSP models: 2.3μ CO absorption & Brγ emission trace stellar populations of different ages



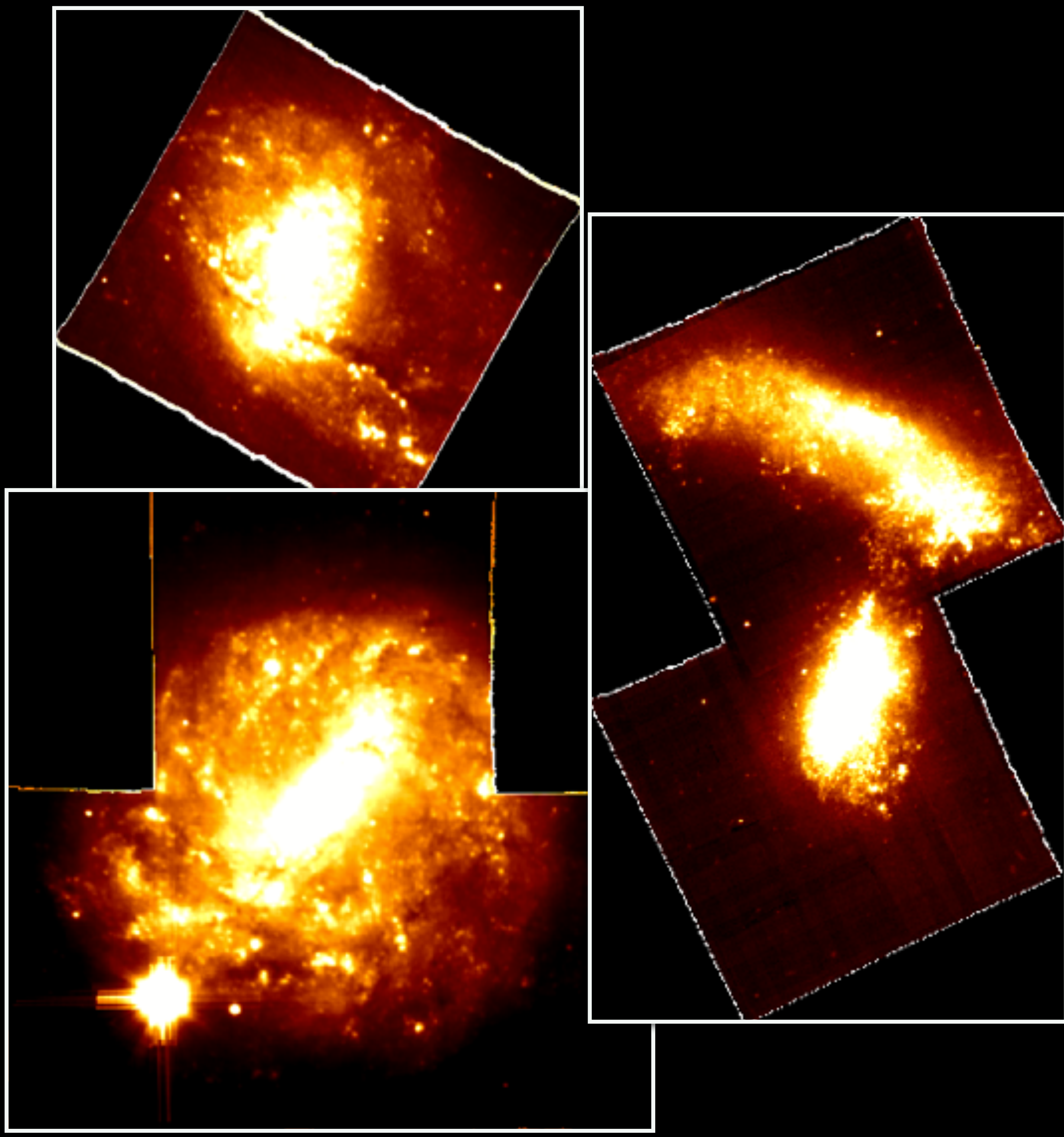



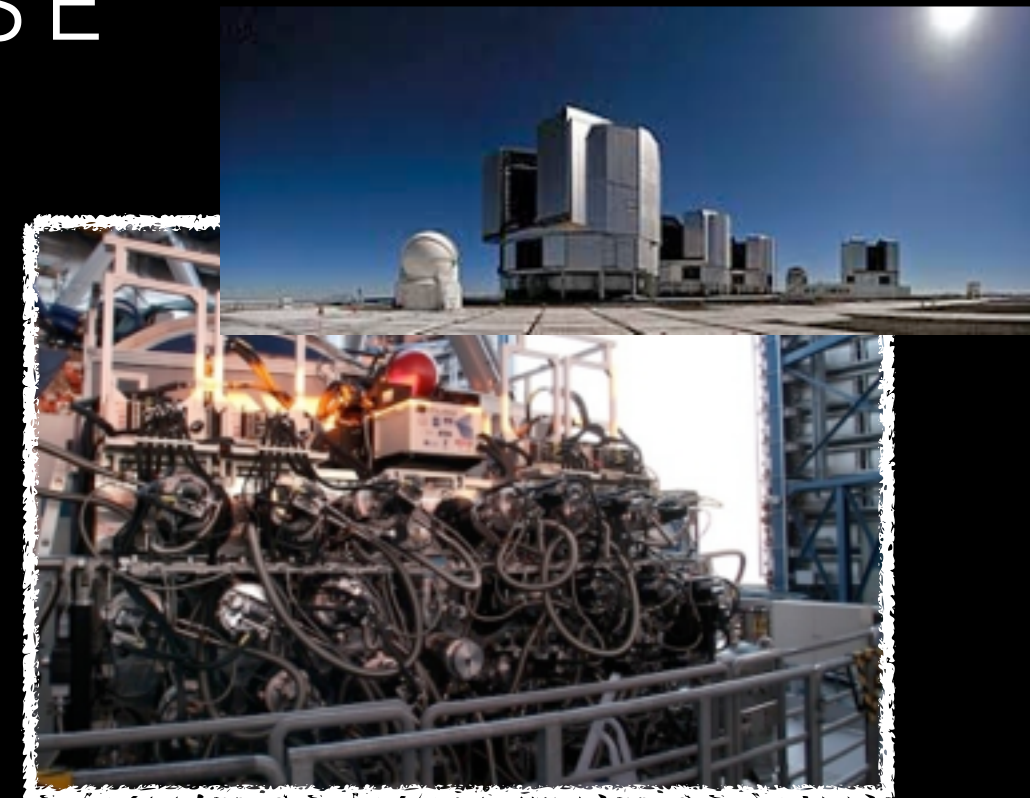

*arxiv/1711.05765*

# IMPLICATIONS

- Mass & metallicity are not the only main drivers of massive star evolution, mass loss (binary interaction, eruptions etc.) seems to be important
- This work adds more support for binary H-poor SN progenitors; c.f.:
    - Detections of SN binary companions (e.g. Folatelli+14, Maund+16)
    - 70% of massive stars are affected by binarity (Sana+12)
    - SN nebular spectroscopy (HK+15)
    - IMF calculations (Smith+11)
    - SN compact remnants (Davies+09)
    - …
- SN IIn progenitors are not that massive? (Anderson+12,15, Smith+15)

# UPCOMING: NEARBY SN HOST GALAXY ANALYSIS WITH VLT/MUSE





- VLT/Multi-Unit Spectroscopic Explorer: 1′ IFU, 0.2″/spaxel
- One or multiple pointings for each galaxy (90 000 spectra per pointing)
- May compare direct SN site (HaEW etc.) vs. galaxy-normalized (px-stat)

# AMUSING

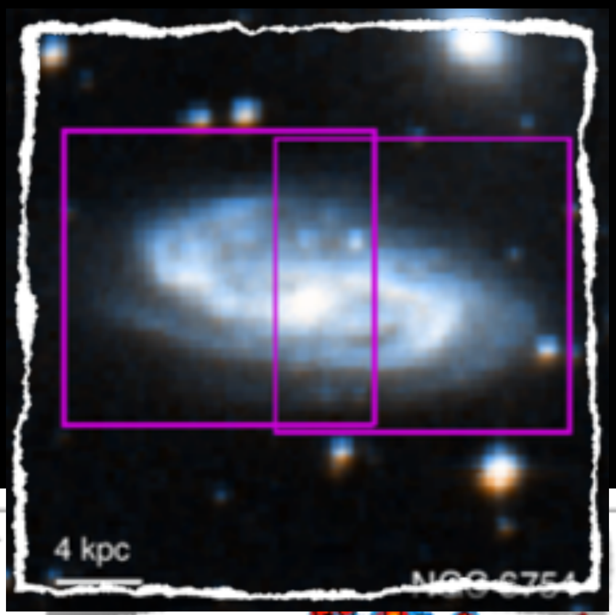
*ALL-WEATHER MUSE SUPERNOVA INTEGRAL FIELD NEARBY GALAXY SURVEY*

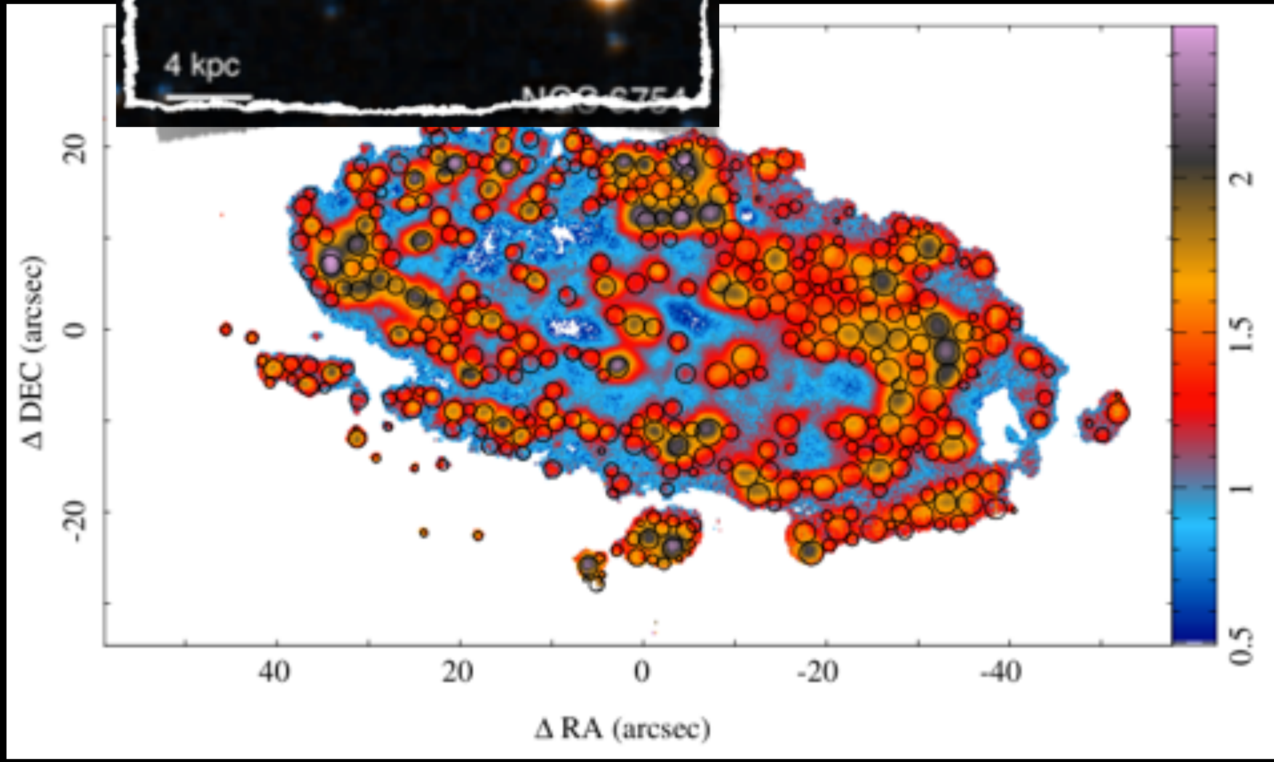
- MUSE survey of nearby SN hosts
- PI's: Joe Anderson (P95-97), Lluís Galbany (P98-99), HK (P100-101); 45-99h per period

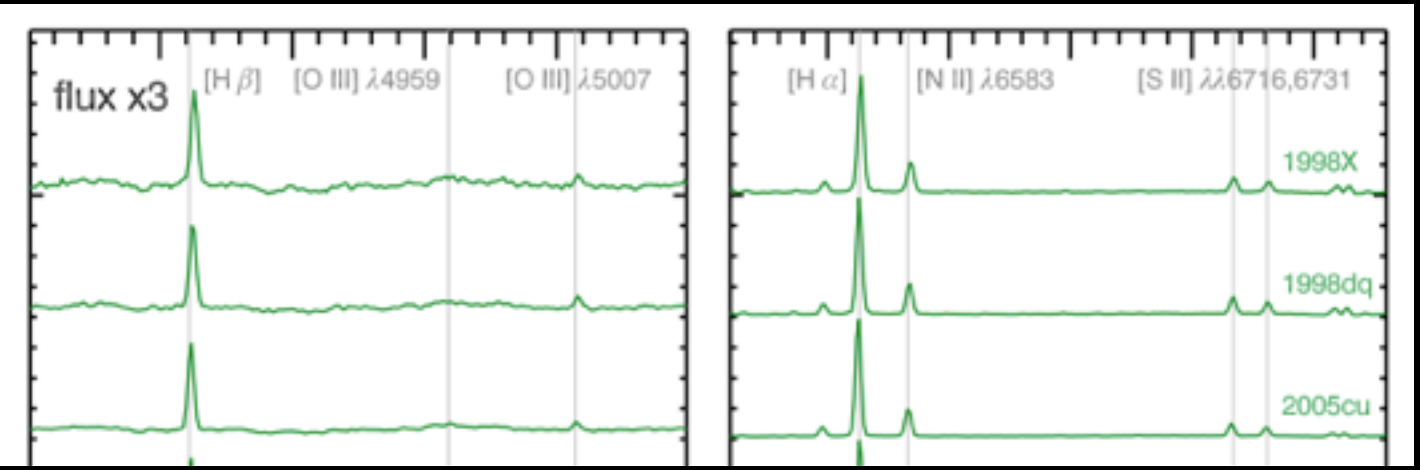
- Sub-optimal weather
    - Still better image quality than e.g. MaNGA or CALIFA
- Various science topics (SN-related)
- Galaxy science: collaboration with CALIFA (S. Sánchez++)
- We welcome collaboration!

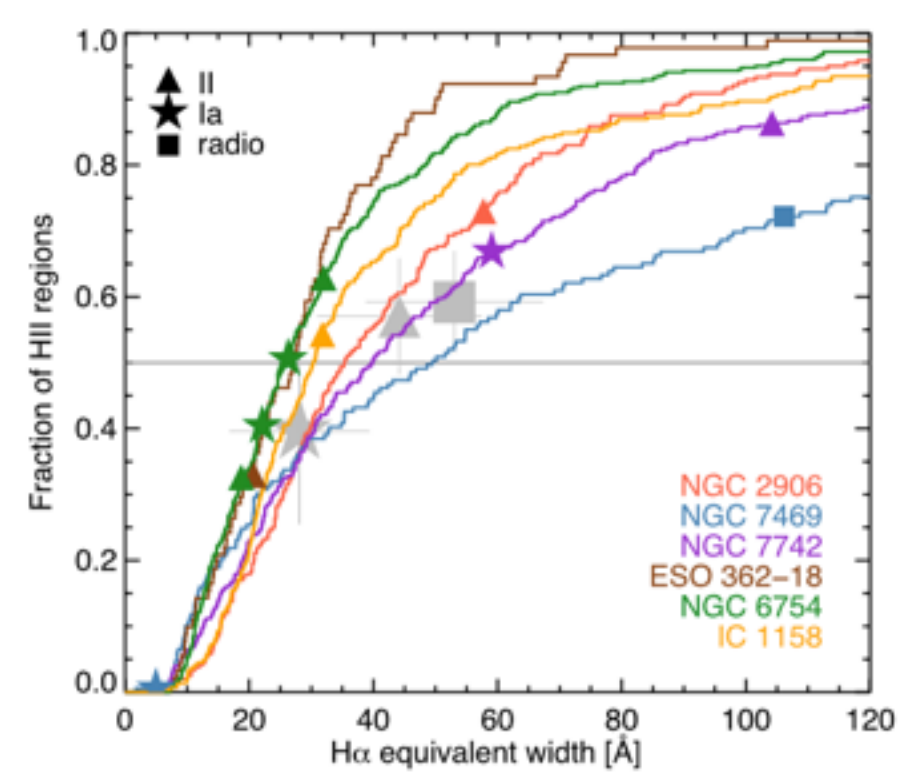
# AMUSING

- Pilot papers (MUSE SV): Sánchez+15, A&A 573; Galbany+16, MNRAS 455



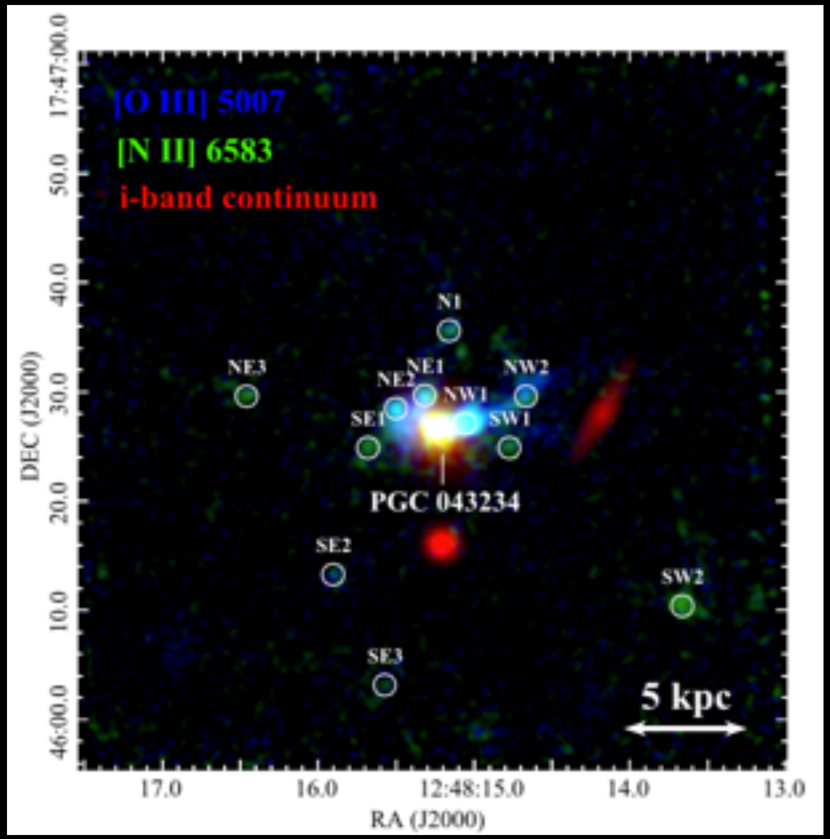



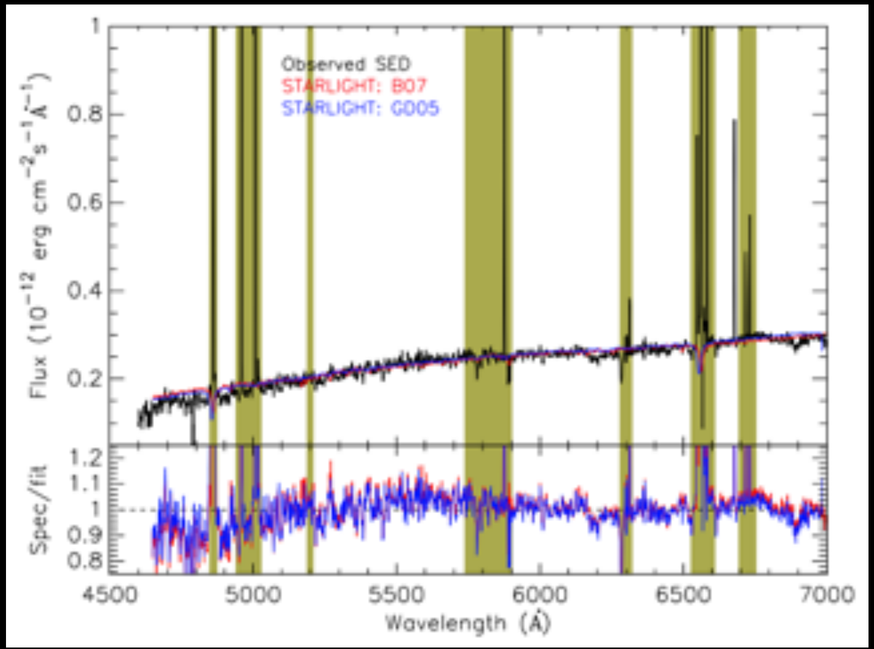



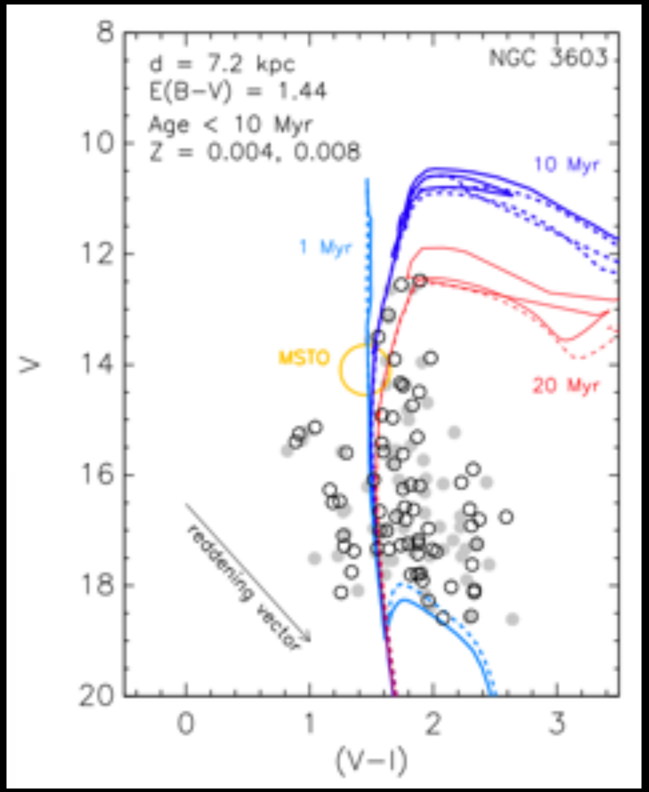
# OTHER RESULTS & RELATED WORKS

- *Prieto+16, ApJL 830:* recent merger in post-starburst TDE host



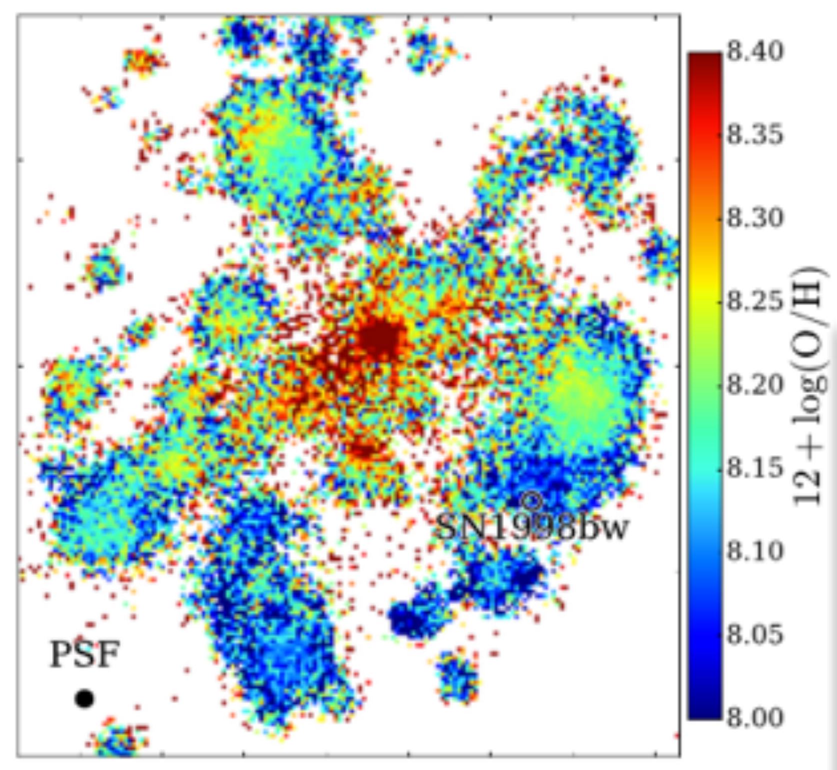

- *HK+16, A&A 593 (MUSE SV):* testing the validity of SSP models

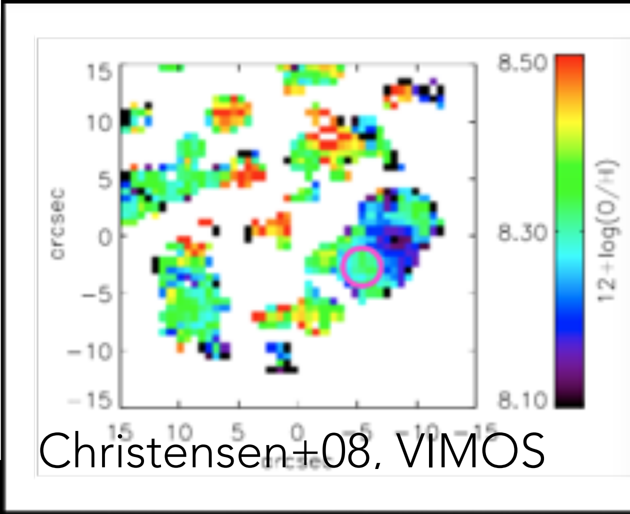


# OTHER RESULTS & RELATED WORKS

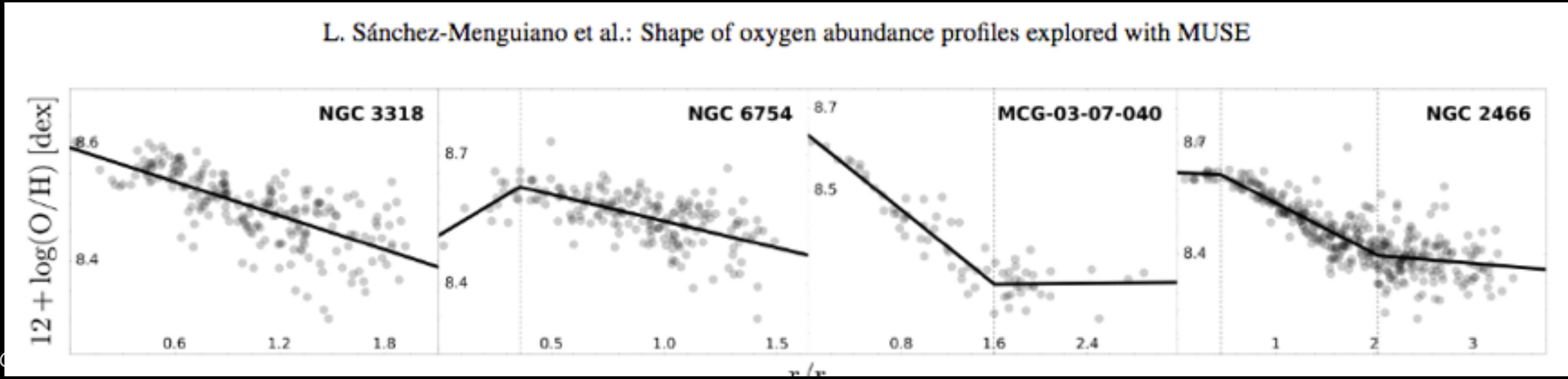
- *Krühler+17, A&A 602:* SN1998bw/GRB980425 host




Christensen+08, VIMOS

- *Sánchez-Mengiano+17, A&A accepted (1710.01188):* galaxy oxygen abundance profiles



# SUMMARY

- IFU survey of nearby CC SN sites (< 40 Mpc), 80+ objects, type-II, IIb, Ib, Ic, IcBL, IIn
- Resolve explosion sites, identify SN parent stellar population, infer SN progenitor properties
- Results:
    - No significant mass/metallicity difference between SN subtypes, although there are trends
    - Different SN types overlap on M-Z diagram (no clear division)
    - Other aspects such as mass loss & binarity are important in stellar evolution
- Future: study with MUSE, larger statistical survey (e.g. AMUSING)

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**Thank you!**