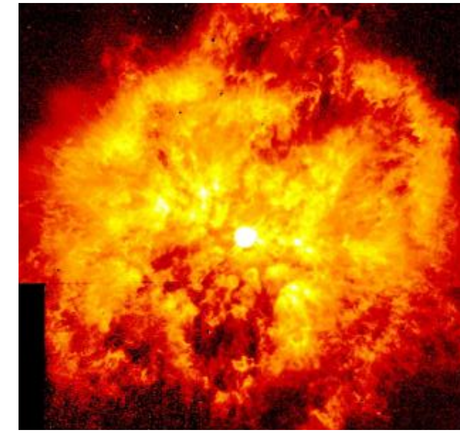
Evolution and Properties of massive stars



The Galaxy

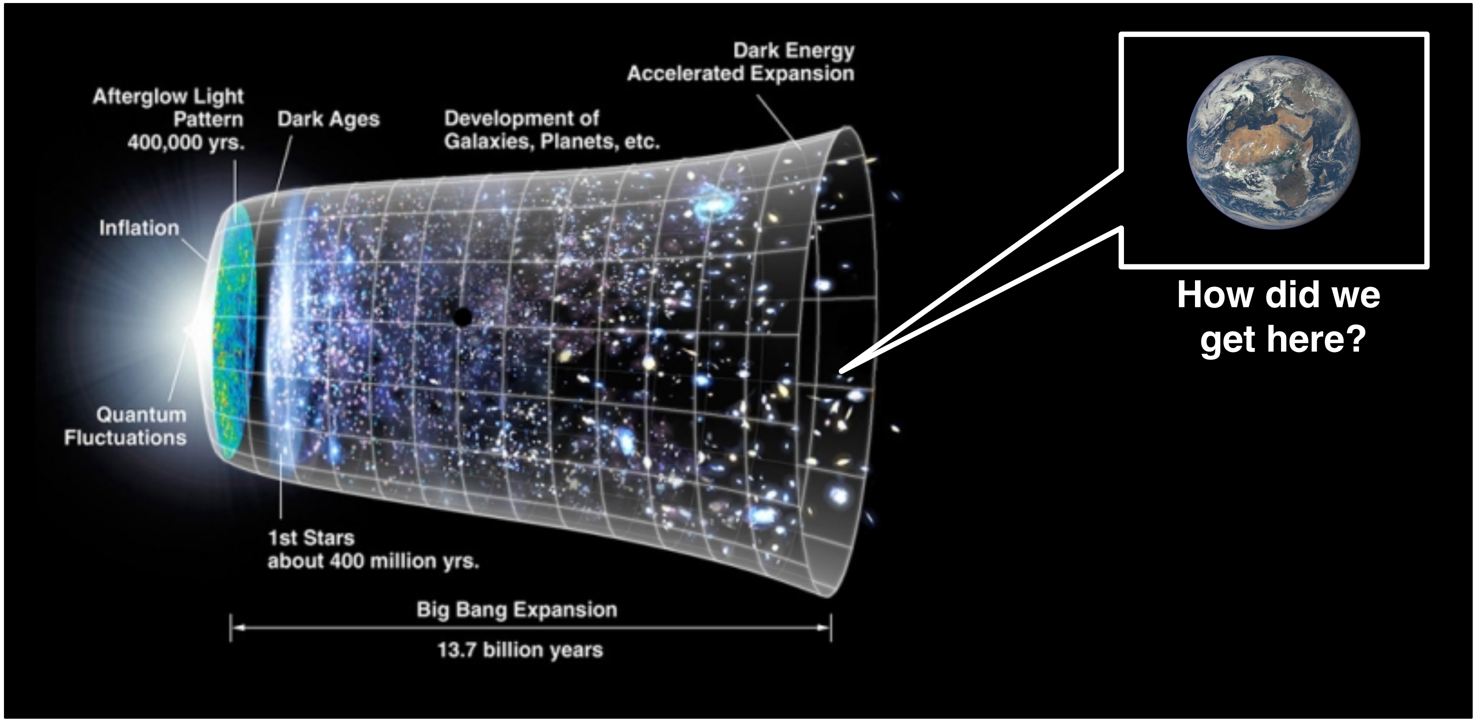
The Magellanic Clouds

and slightly beyond

With inputs from S. de Mink, A. Fullerton, D.J. Hillier, T. Lanz, M. Postman, H. Sana, N. Walborn

Cosmic Origin program + ESA Cosmic Vision + JWST

→ The origin and evolution of galaxies, stars and planets

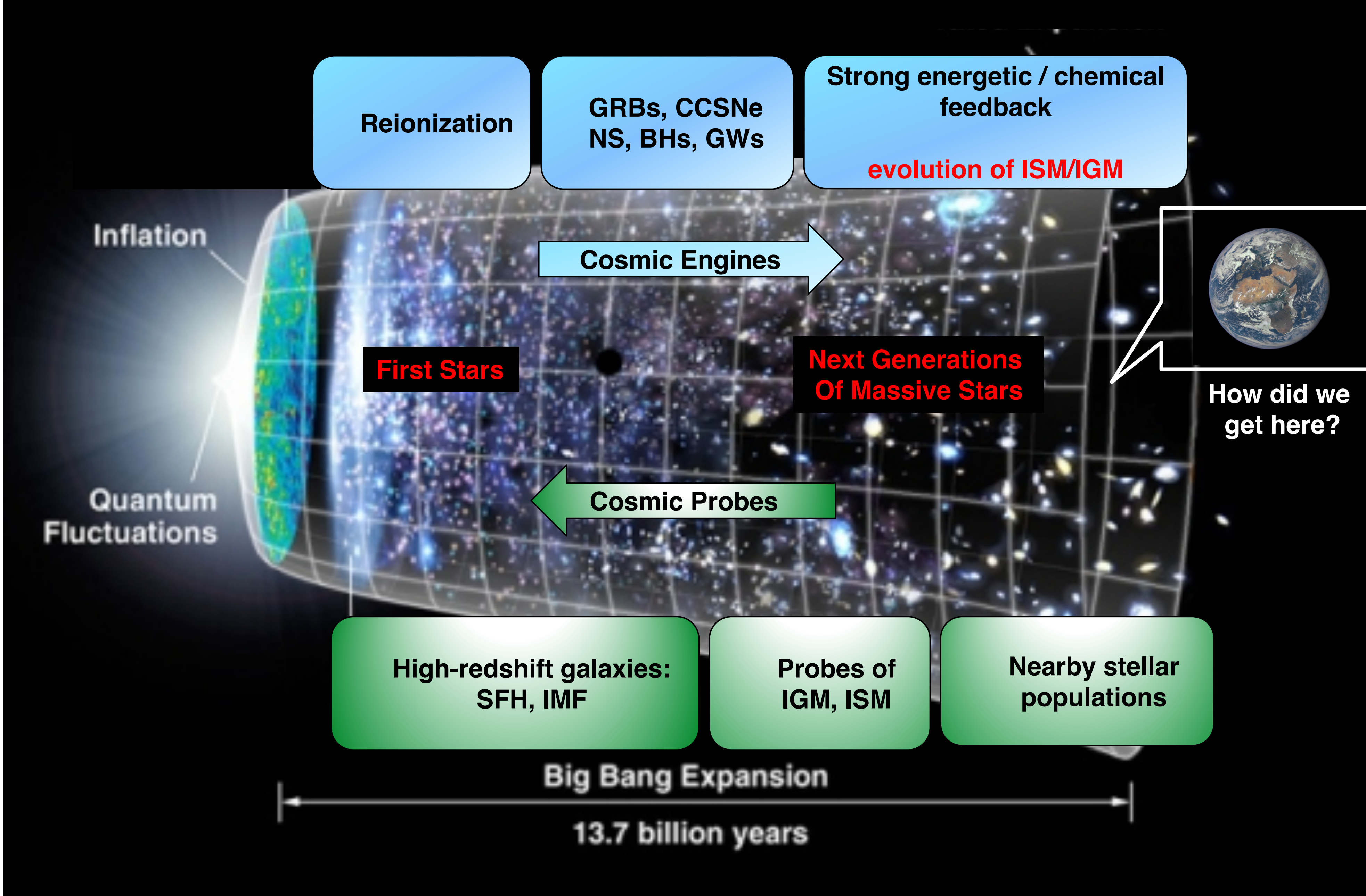


Fundamental questions :

- ✓ When did the first stars form and how did they shape their environments?
- ✓ What are the cosmic origins of chemical elements?
- ✓ How do exchange of mass and momentum between stars and the environment shape the origin and evolution of galaxies?

Answers to these questions require a qualitative jump in our understanding of massive stars

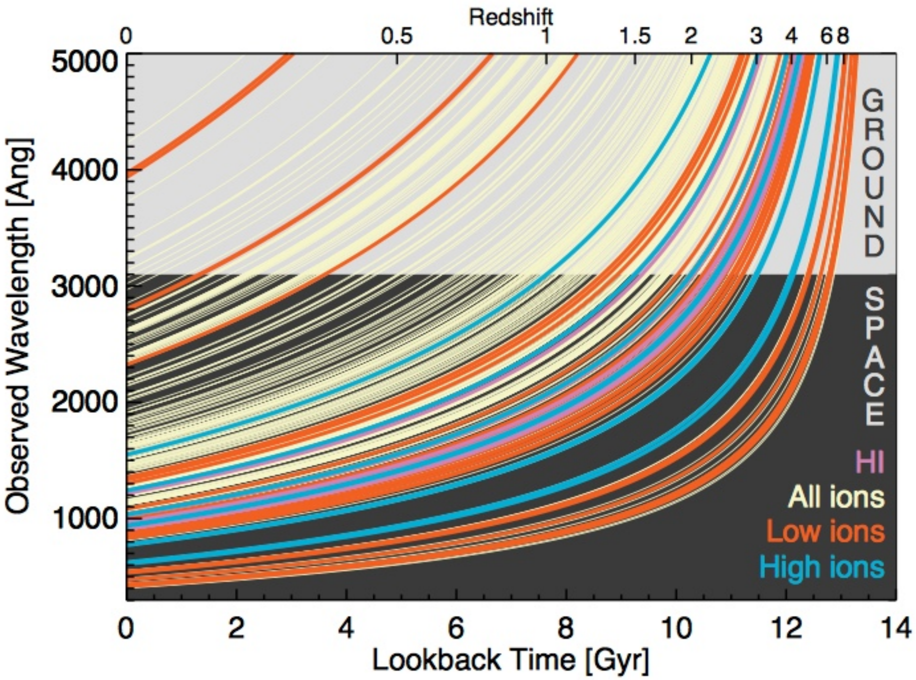
Massive Stars are major drivers of Cosmic Evolution



Why the UV?

UV → thousands of atomic/molecular transitions

→ direct, quantitative measures of the state of elements



From AURA reports

The future of UVOIR space astronomy

Why the UV?

UV → thousands of atomic/molecular transitions

→ direct, quantitative measures of the state of elements

→ emission peak of massive stars coincides with the λ-range

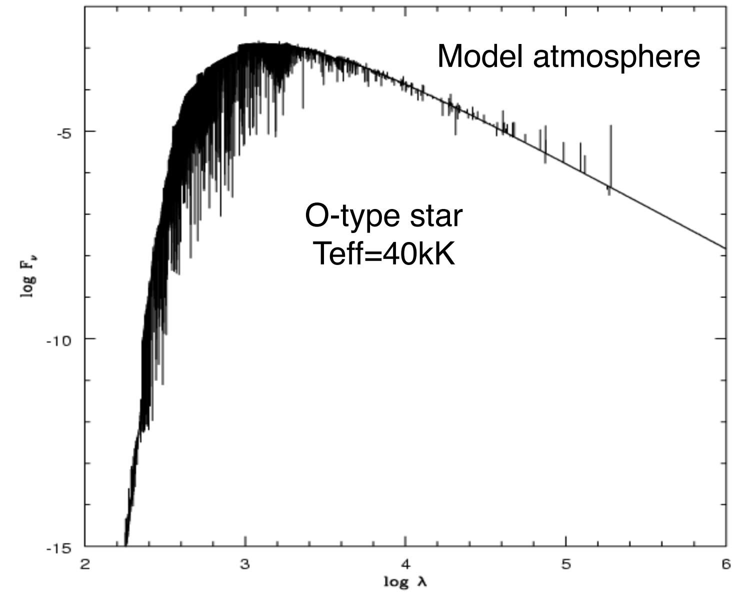
where line density is maximal → strong radiative acceleration

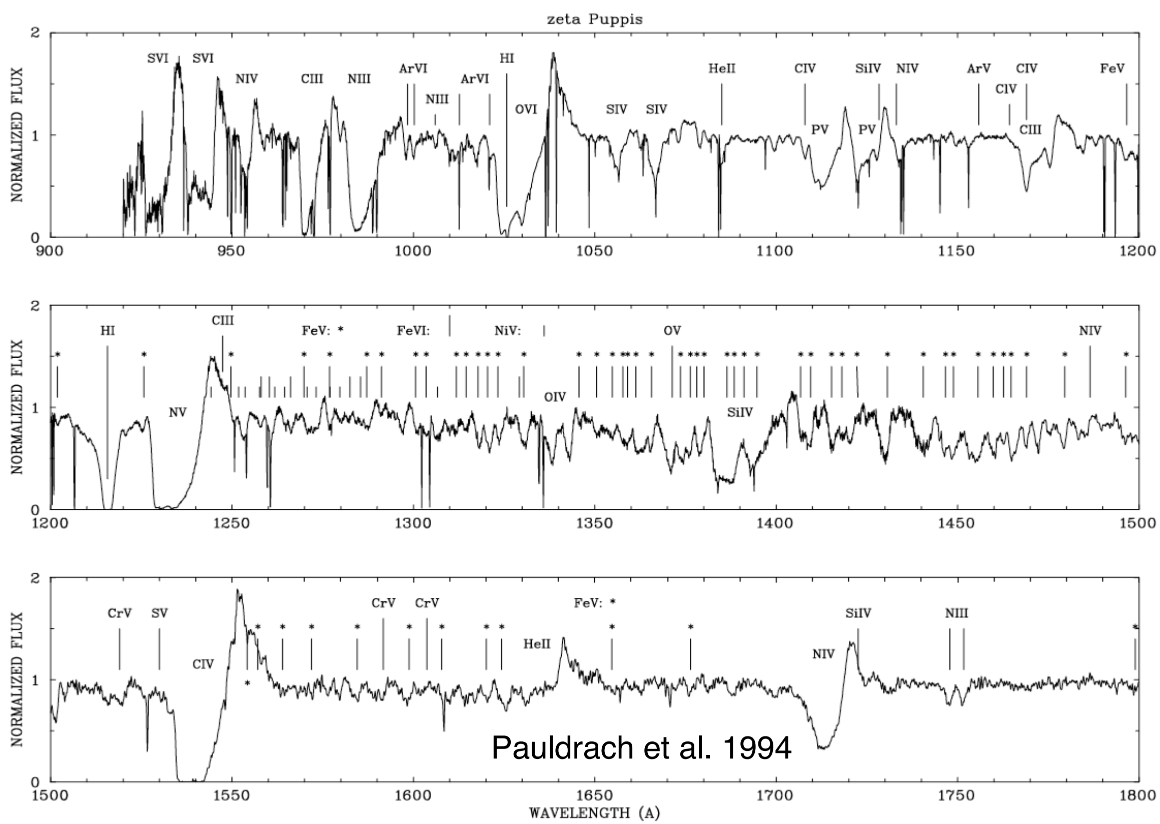
UV spectral window (900 – 2000 Å)

→ direct access to $\dot{M}$ and V_∞

→ wind inhomogeneities

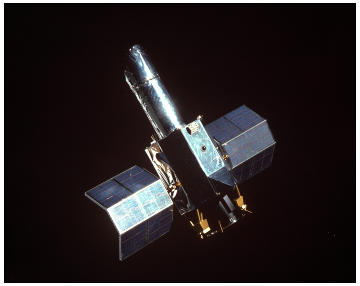
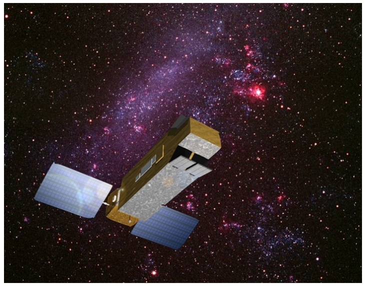
→ accurate CNO surface abundances

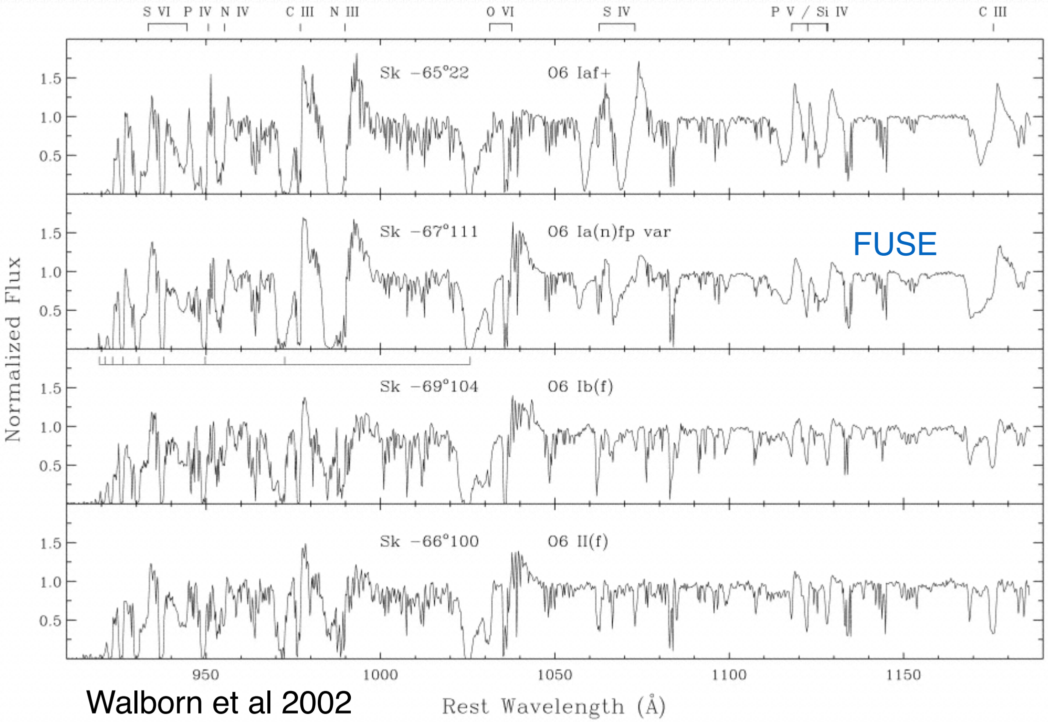




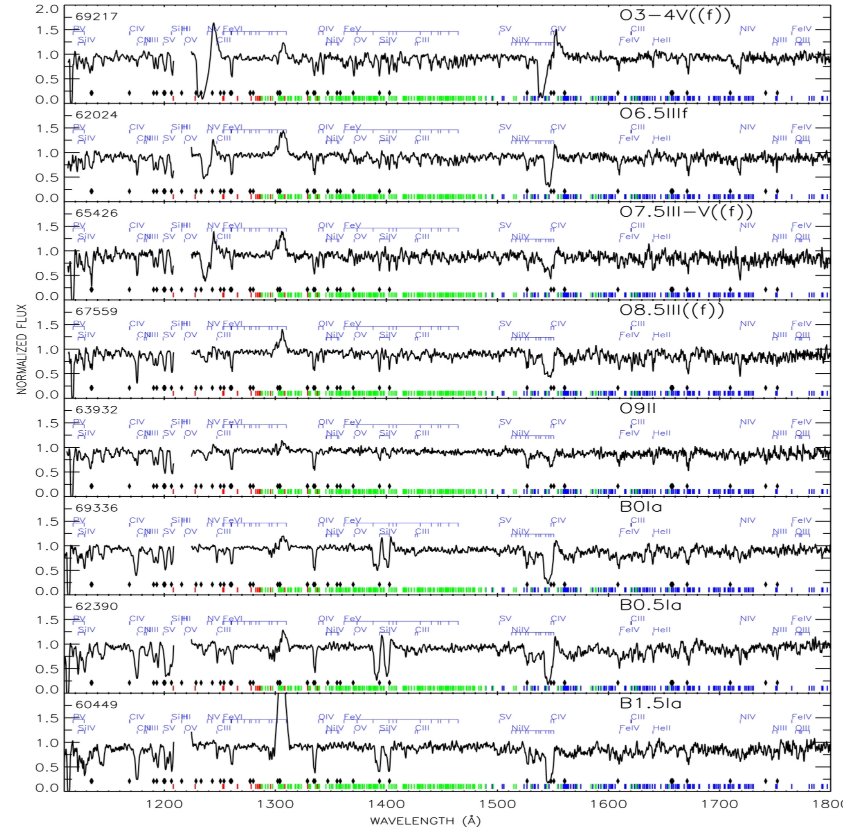
Present Status in the archives

Obs.	Instrument/Detector	Archives
IUE	**SWP**: 1150 – 1970 Å R ~ 10,000 – 20,000	~ 200 Galactic O and B stars (Walborn+ 1985, 1995)
FUSE	**Sic + Lif**: 905 – 1187 Å R ~ 15,000 – 20,000	~ 200 Galactic + 140 MCs OB stars (Pellerin+ 2002; Walborn+ 2002)
HST	**GHRS**: 1150 – 1900 Å (G140M) R ~ 15,000 – 35,000 (1st order) 70,000 – 90,000 (echelle)	~ 53 MCs + 11 LG OB stars (Walborn+ 1995; Bianchi+ 1996)
	STIS: 1150 – 1700 Å (MAMA E140M) R = 45,800 (echelle)	21 LMC + 36 SMC OB stars (Heap+ 2006; Bouret+ 2013; Crowther+ 2014)
	COS: 1150 – 1775 Å (G130M + G160M) R = 16,000 – 21,0000 1120 – 2250 Å (G140L) R ~ 2600	15 LMC + 32 SMC + 3 LG OB stars (Walborn+ 2017; Bouret+ 2015) 8 LG OB stars (Garcia+ 2014)

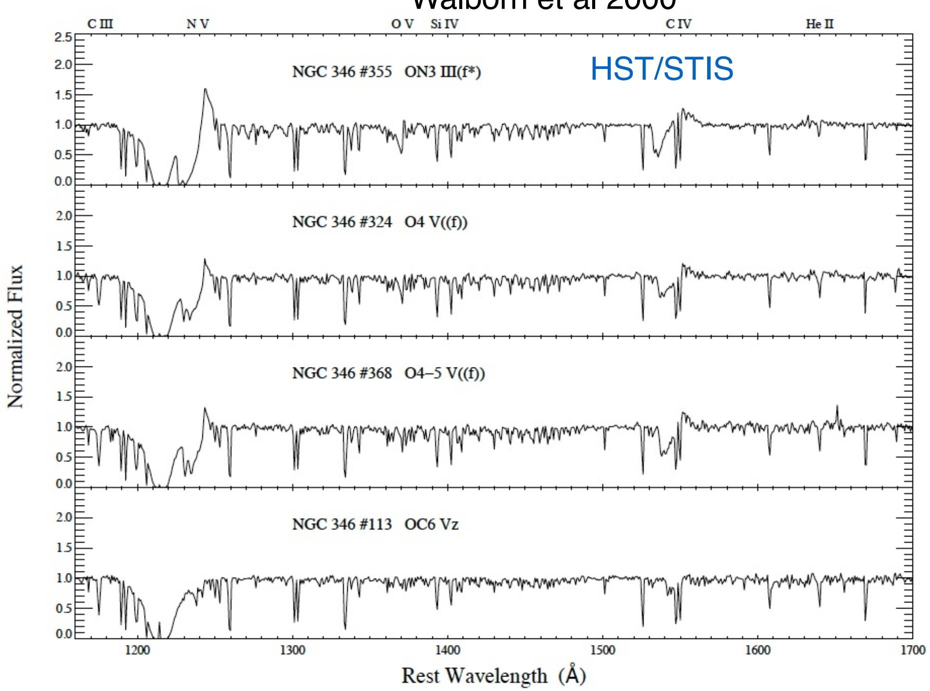
Walborn et al 2002

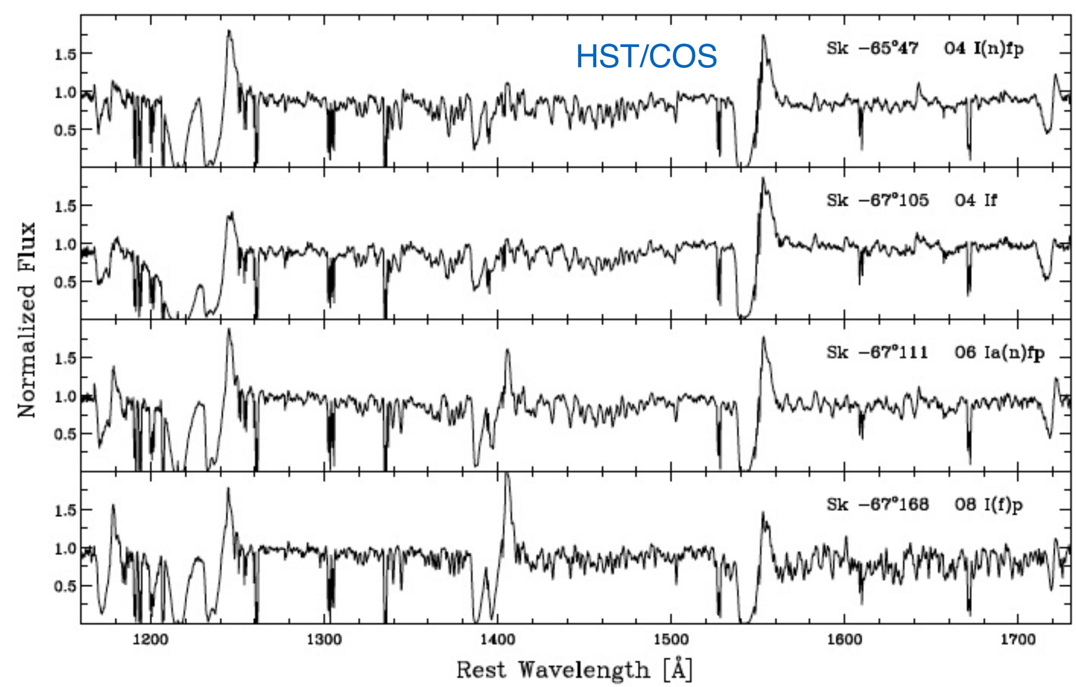


HST/COS

Garcia et al 2014

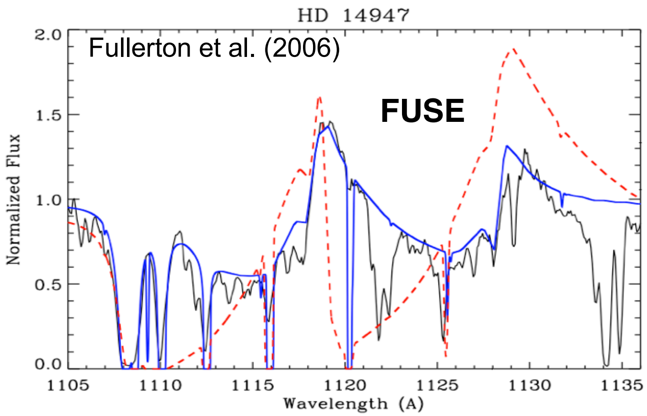
Walborn et al 2000

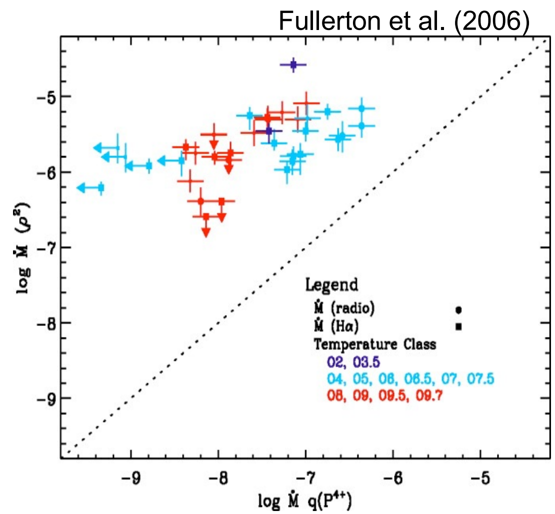




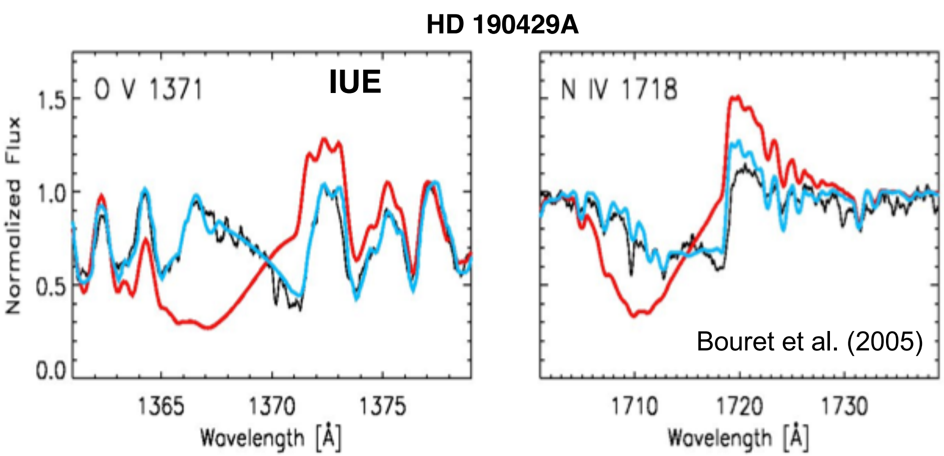
Walborn et al 2017

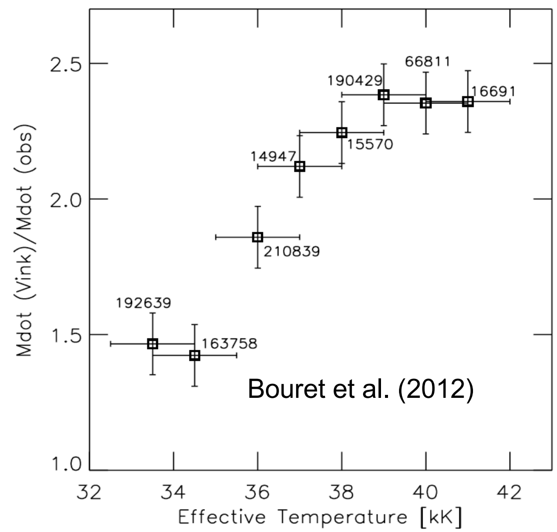
Some Results – 1: Clumping





$\dot{M}_{PV}$ up to a factor 100(!) discrepant with $\dot{M}_{H\alpha}$





FUV-UV (+optical):

- Ṁ reduced by factors 3 to 7 compared to theoretical predictions
- starts close to the base of the wind

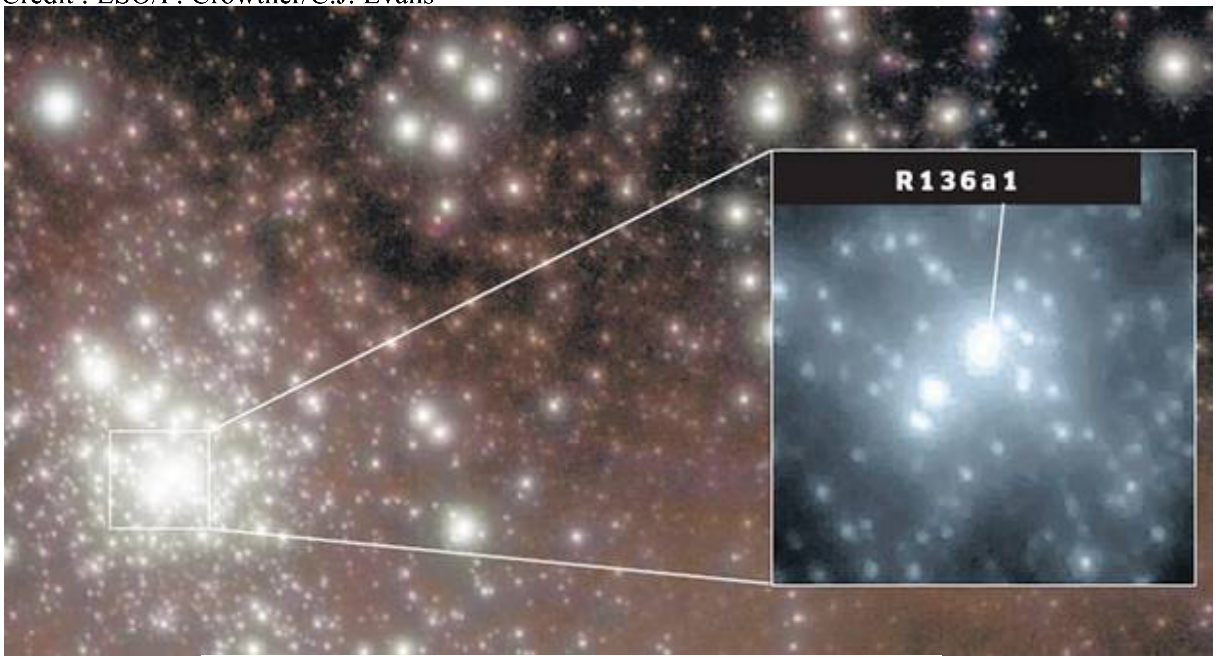
More realistic description of clumping → same reduction for Ṁ

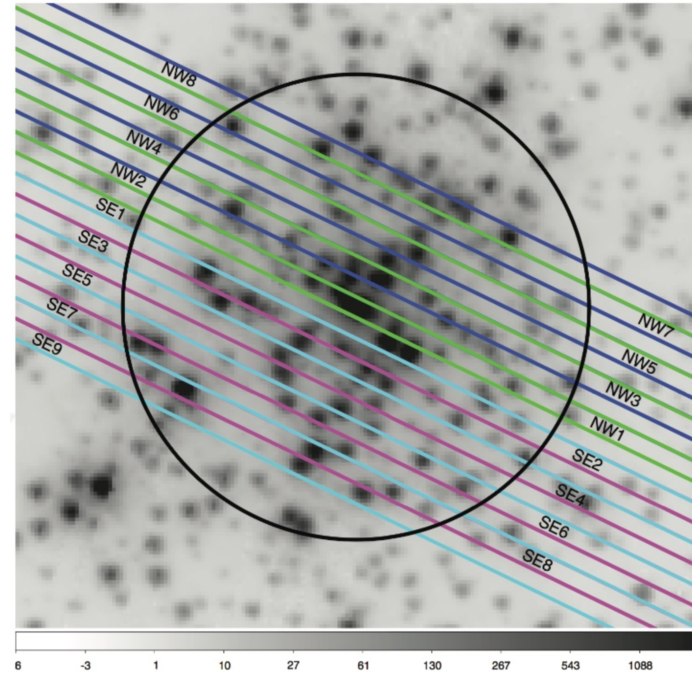
Properties seem identical at lower Z

Crowther et al. (2002); Hillier et al. (2003); Bouret et al. (2003, 2005, 2012, 2013, 2015); Fullerton et al. (2006); Martins et al. (2008)

Some results 2 - R136 : ionizing star cluster

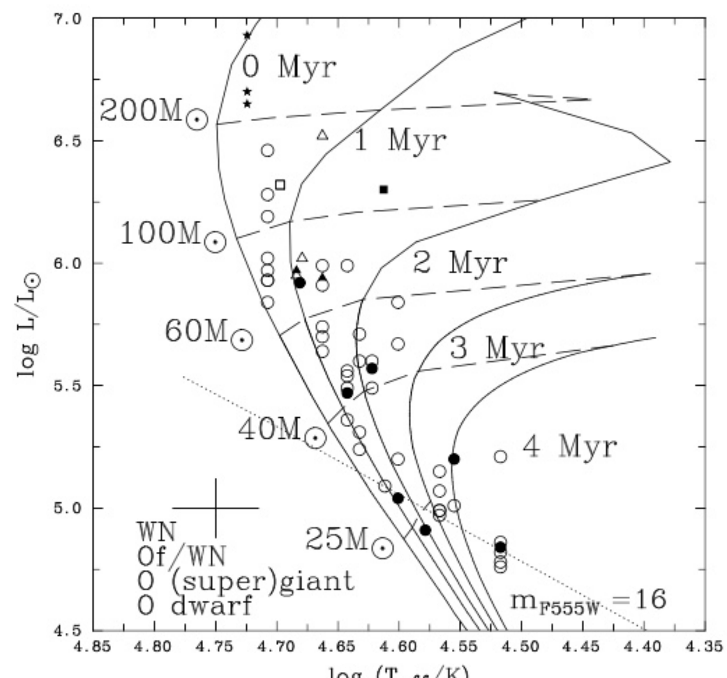
Crédit : ESO/P. Crowther/C.J. Evans





Crowther et al. 2016

HST/STIS (+ FGS) → 39 HST orbits, 17 slits, 0.2'' width



Several stars (>7) more massive than 100 $M_{\odot}$
(e.g. M(a1) ~ 315 $M_{\odot}$)

Some results 2 - R136 : ionizing star cluster

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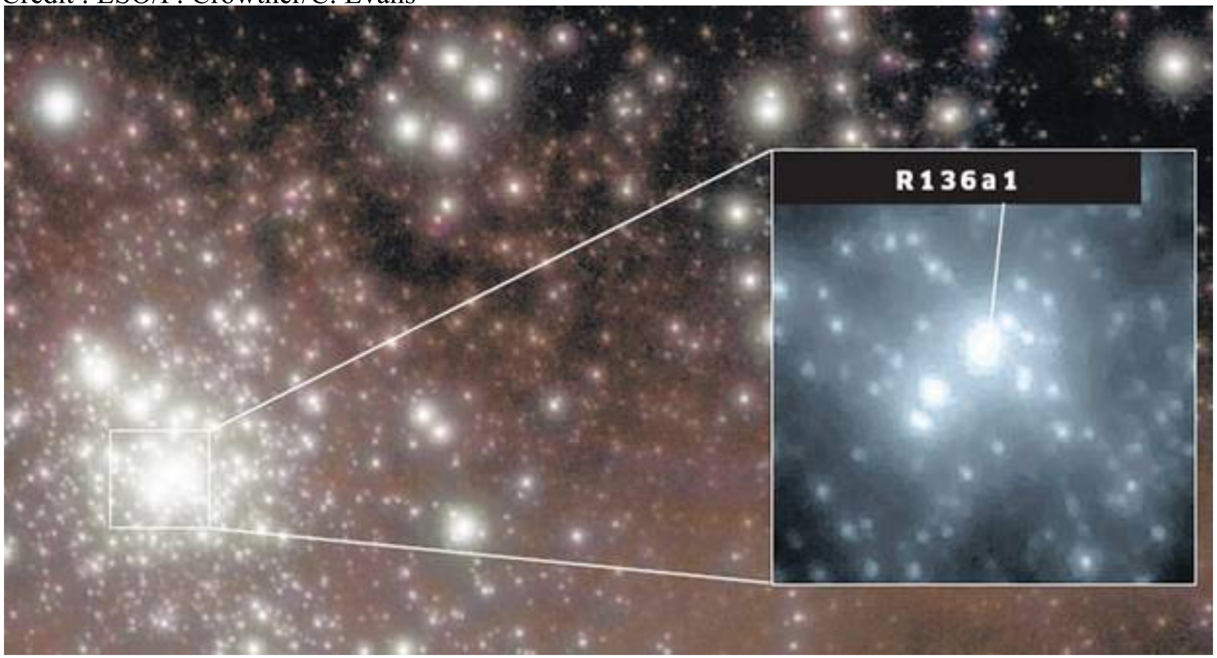

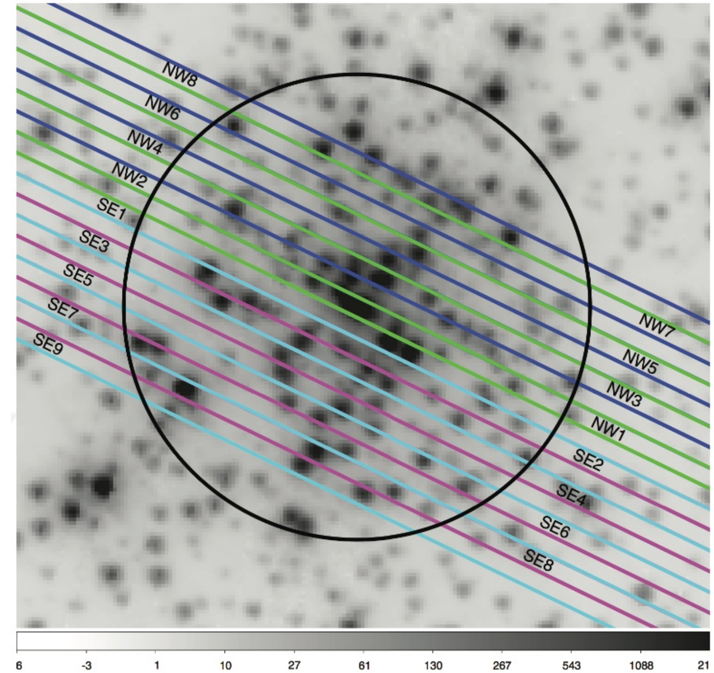

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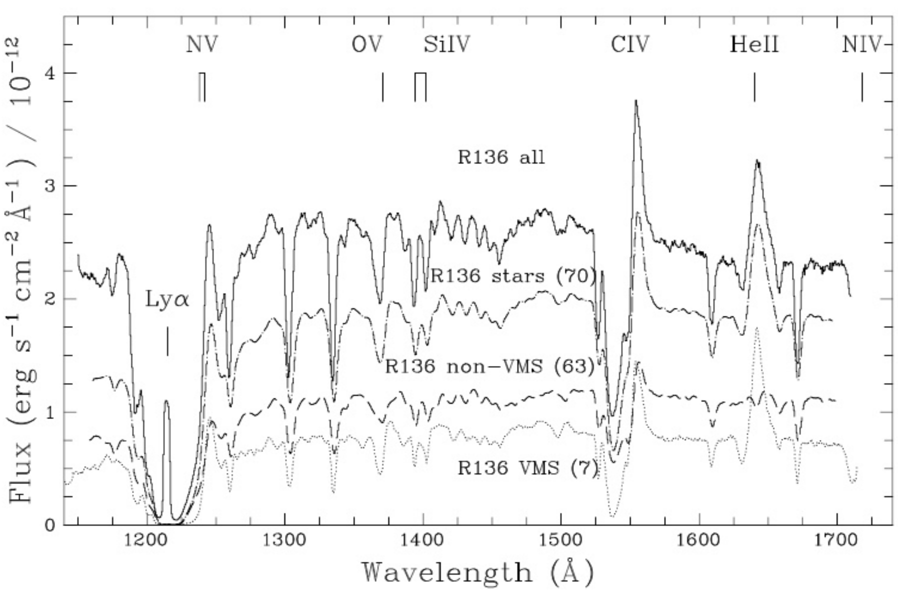


Several stars (>7) more massive than 100 $M_\odot$ (e.g. M(a1) ~ 315 $M_\odot$)

100 + $M_\odot$ stars disproportionally contribute to ionizing radiation and strong spectral features (He II 1640 emission)

Omitting these leads to (e.g. Starburst99, BPASS)

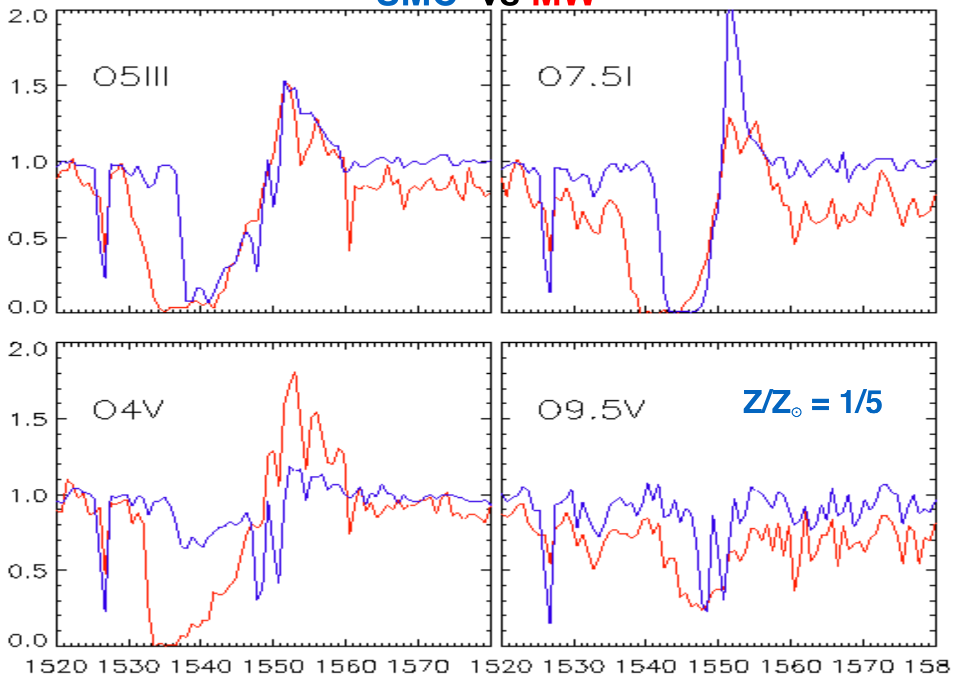
- Under estimating **ionizing fluxes**
- Over estimating the **age**
- Over estimating the **metallicity**

Some results 3 - Ṁ(Z) beyond the MCs

Theory → Mass loss rates (and V_∞) scale down with metallicity: $\dot{M} \propto Z^{0.69}$ (Vink et al. 2001)

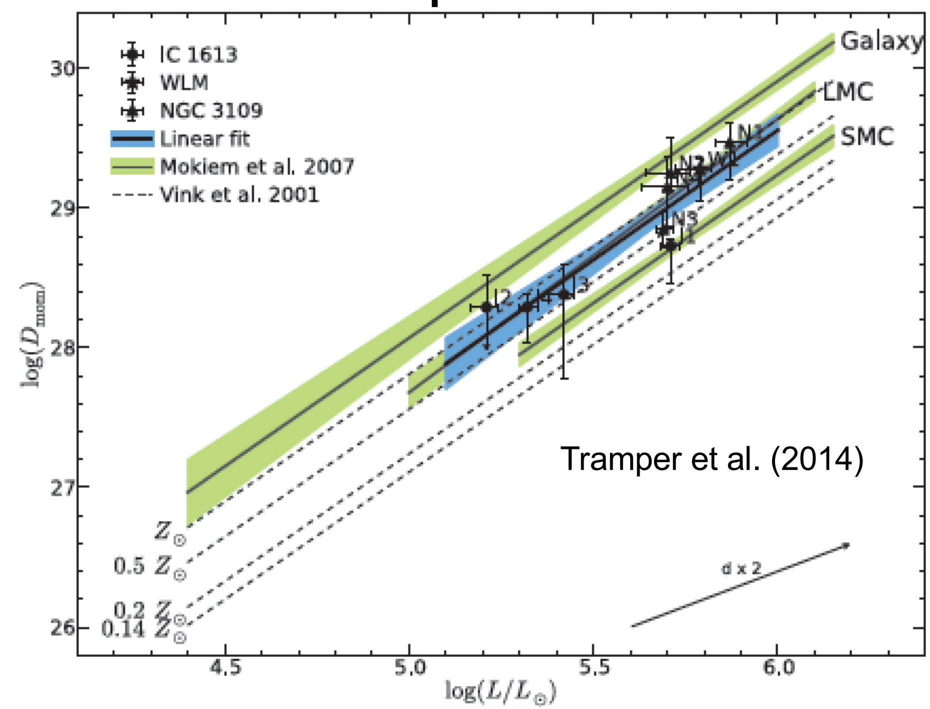
→ lower mass-loss rates in the MCs compared to the Galactic case

SMC vs MW



Ṁ of O stars in WLM/IC1613/NGC3109 (Z/Z⊙ ~1/7)

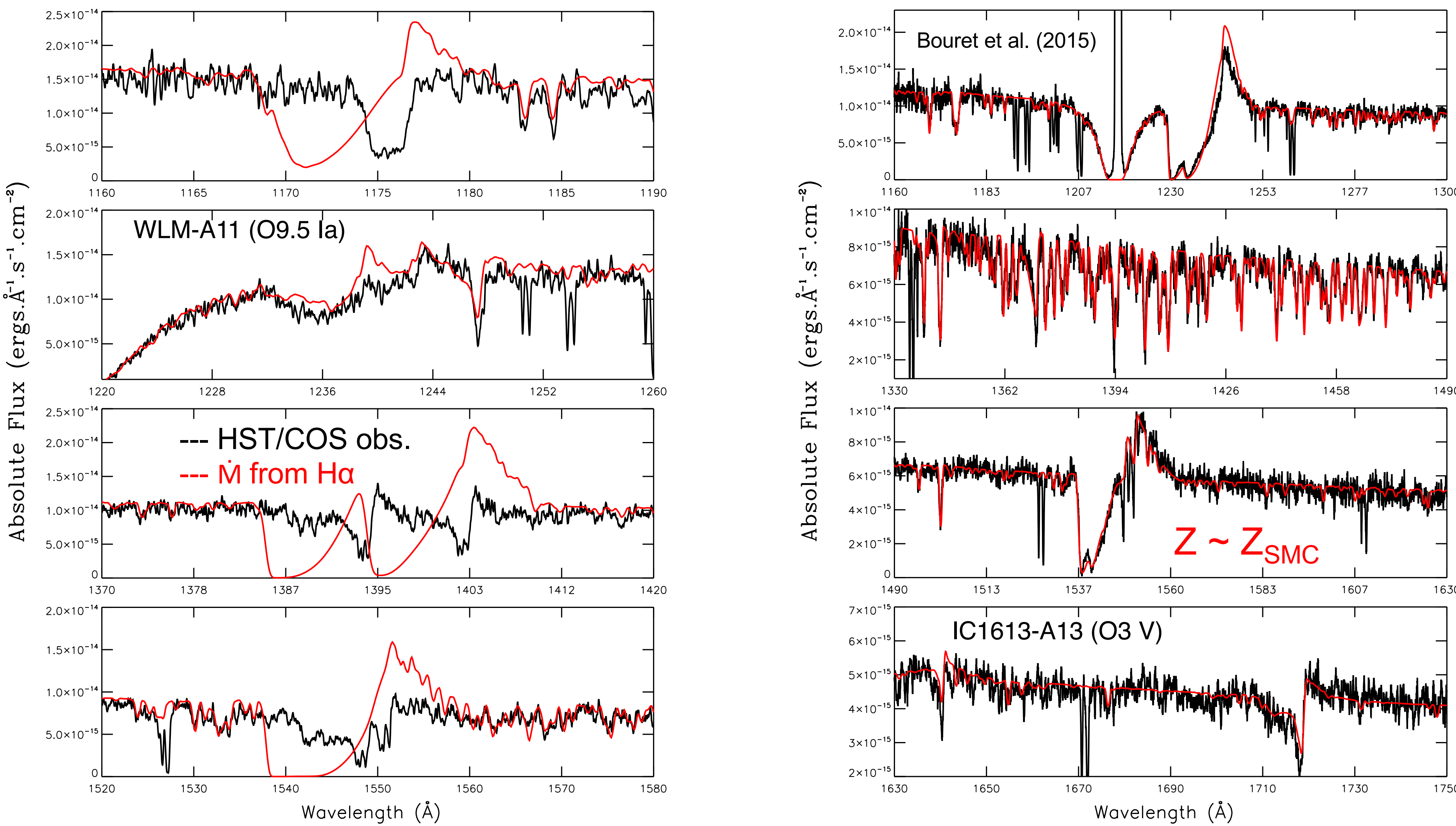
→ stellar winds at low-metallicity may be stronger than predicted



But Hα poorly sensitive for low Ṁ

Observe these stars in the UV with HST/COS

Some results 3 - $\dot{M}(Z)$ beyond the MCs



UV + optical $\dot{M}$

→ smaller than those by Tramper et al. (2011)

→ Does not support a breakdown in the $\dot{M}$ – Z relation

→ but only 3 stars

What is needed to go beyond?

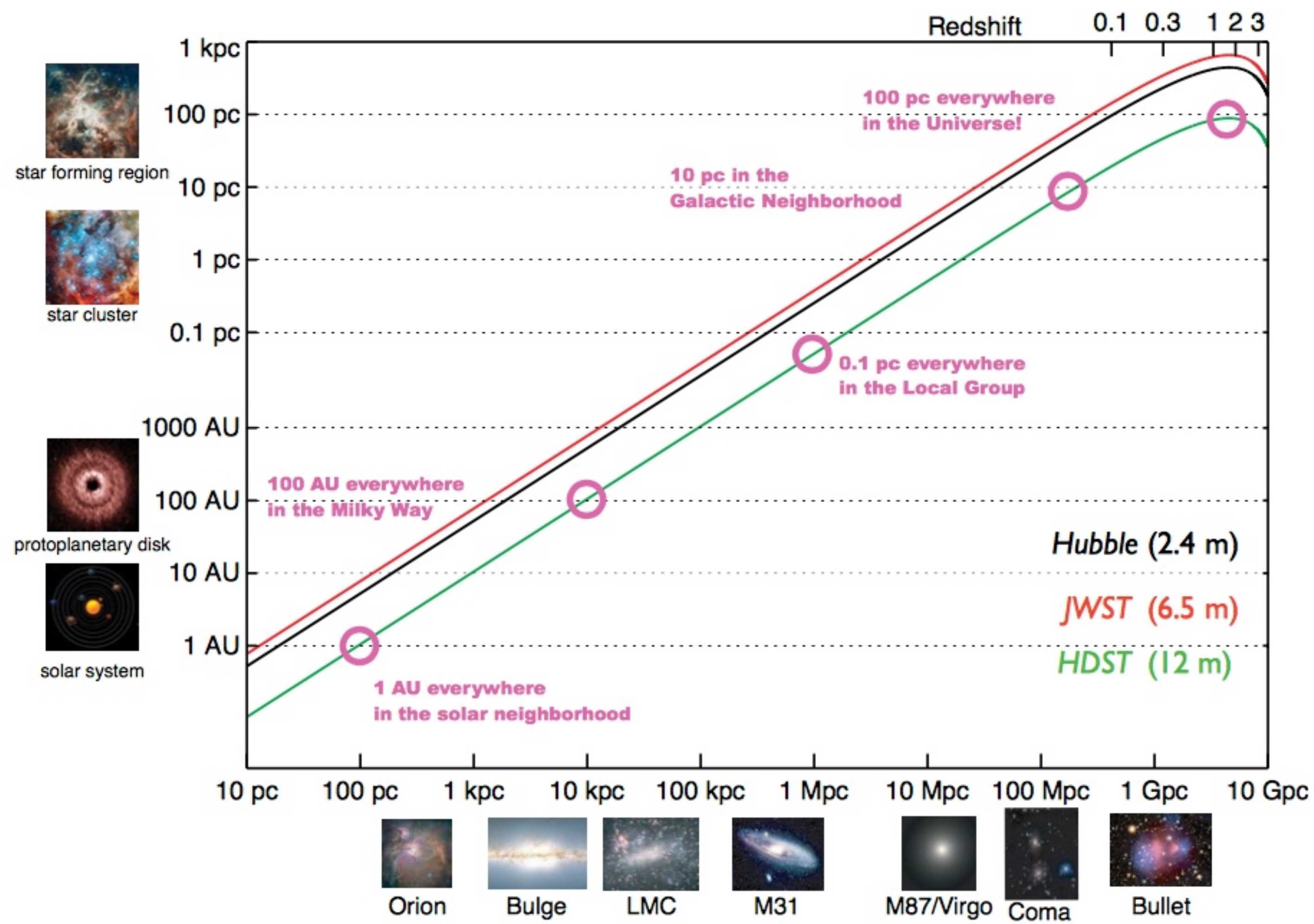
Challenges

Rare and short lived
→ Need for larger and larger distances

Emit most of their light in the UV
→ Need for Space

Form in crowded regions with companions
→ Need for high spatial resolution

→ Need for IFU / MOS



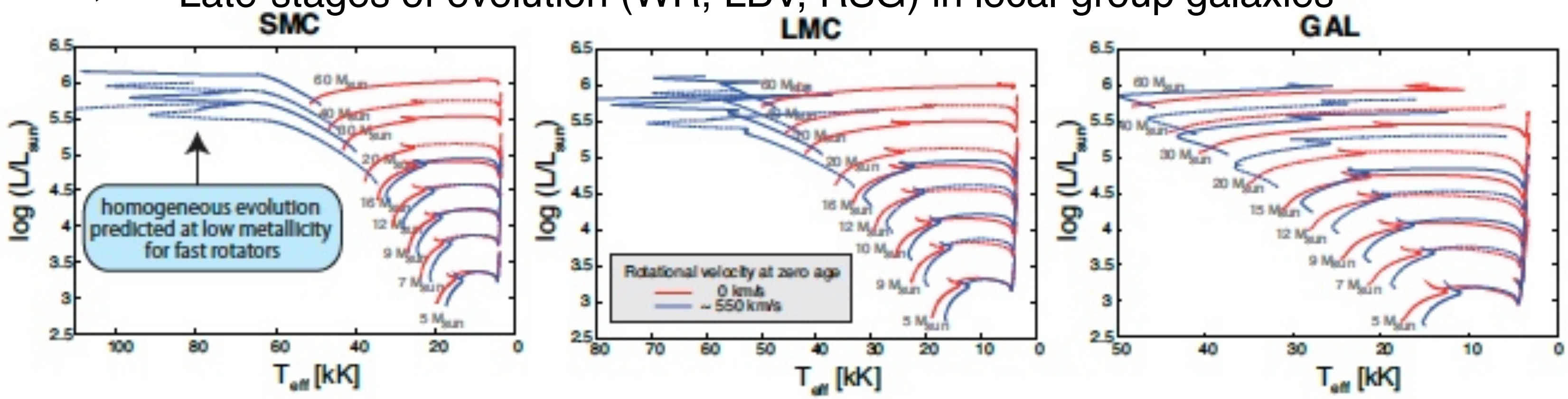
From AURA reports
The future of UVOIR space astronomy

Big questions

- ✓ How does the IMF vary with environment?
  - ✓ Is there a Universal upper stellar mass limit?
  - ✓ Is the stellar IMF the same in galaxies with much more intense star formation than the Milky Way?
  - ✓ What features in the integrated UV spectra of "resolved" starbursts (100 pc)?

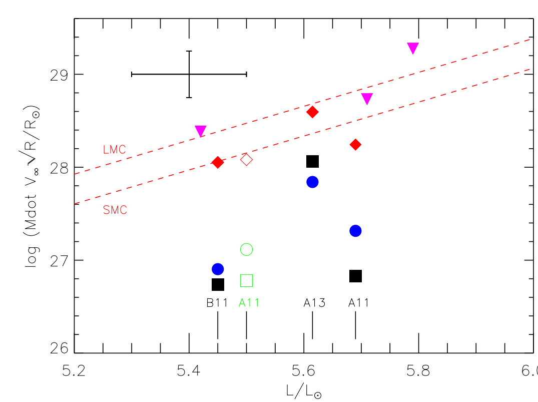
- ✓ How do massive star properties and evolution vary with metallicity
  - ✓ Hotter, more compact, fast(er) rotation?
  - ✓ CHE ? (more likely from Z_{LMC} and below)
  - ✓ Late-stages of evolution (WR, LBV, RSG) in local-group galaxies

Chemical Yields, Pop III impostors, GRBs, Reionization



Brott et al. (2011)

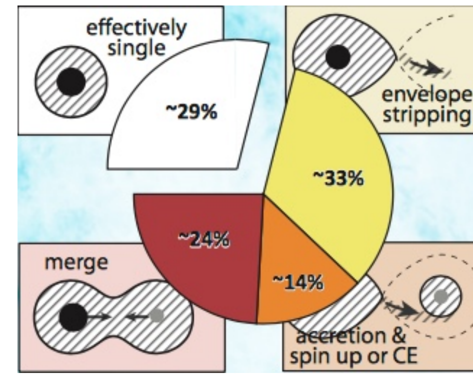
- ✓ Physics of radiatively-driven winds for various Z
  - ✓ What are the mass-loss rates, v_∞ ?
  - ✓ What is the effect of rotation?
  - ✓ Variability, clumping properties?
  - ✓ What consequences on evolution, feedback, spectral synthesis



Bouret et al. (2015)

Big questions

- ✓ Binary (high) fraction Universal ?
  - ✓ dense regions, low Z
  - ✓ Probing extreme low mass companions
  - ✓ Imprints of binary products in UV spectra of distant populations
  - ✓ What are the impact on rotational velocity distributions?
  - ✓ Link with the production of runaway stars



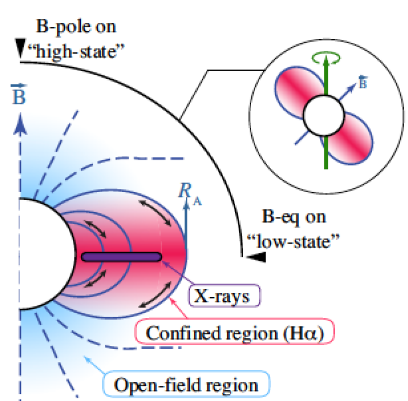
Court. H. Sana

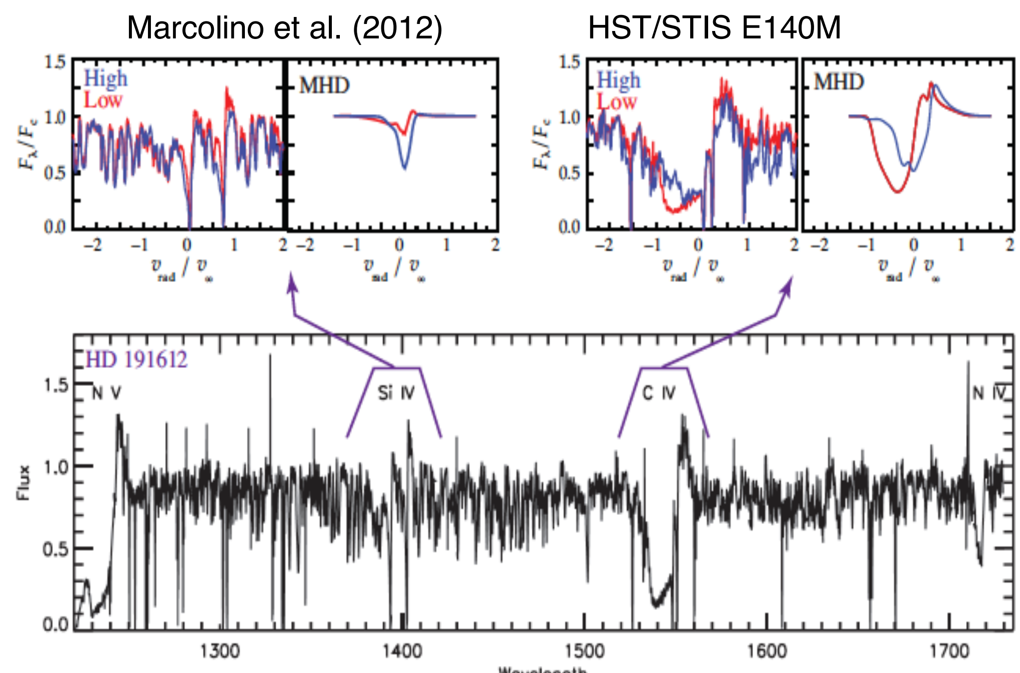
70% massive stars strongly interact before they die

- ✓ New kind of transients may need UV observations
  - ✓ CCSNe, Compact binaries… but TOO capability

- ✓ Spectropolarimetric capability :
  - ✓ search for magnetic fields as a function of Z
  - ✓ Study shapes of circumstellar environments

Absorption component probes regions with different velocity/density





Summary

FUV — UV — Optical / NIR — mid-IR

FUV
- Highly ionized wind
- Wind clumping
- Rotation

UV
- Stellar parameters
- Abundances
- Rotation
- Wind clumping
- Properties of inner wind
- Weak winds

Optical / NIR
- Stellar parameters
- Abundances
- Rotation
- Wind clumping

mid-IR
- IR excess
- Disks

Evolution and final fate of hot massive stars

ISM and extinction
Chemical enrichment and mixing
Dynamics and distribution of the ISM

Empirical and theoretical spectral library
Spectral population Synthesis
Feedback on Local and Global environment