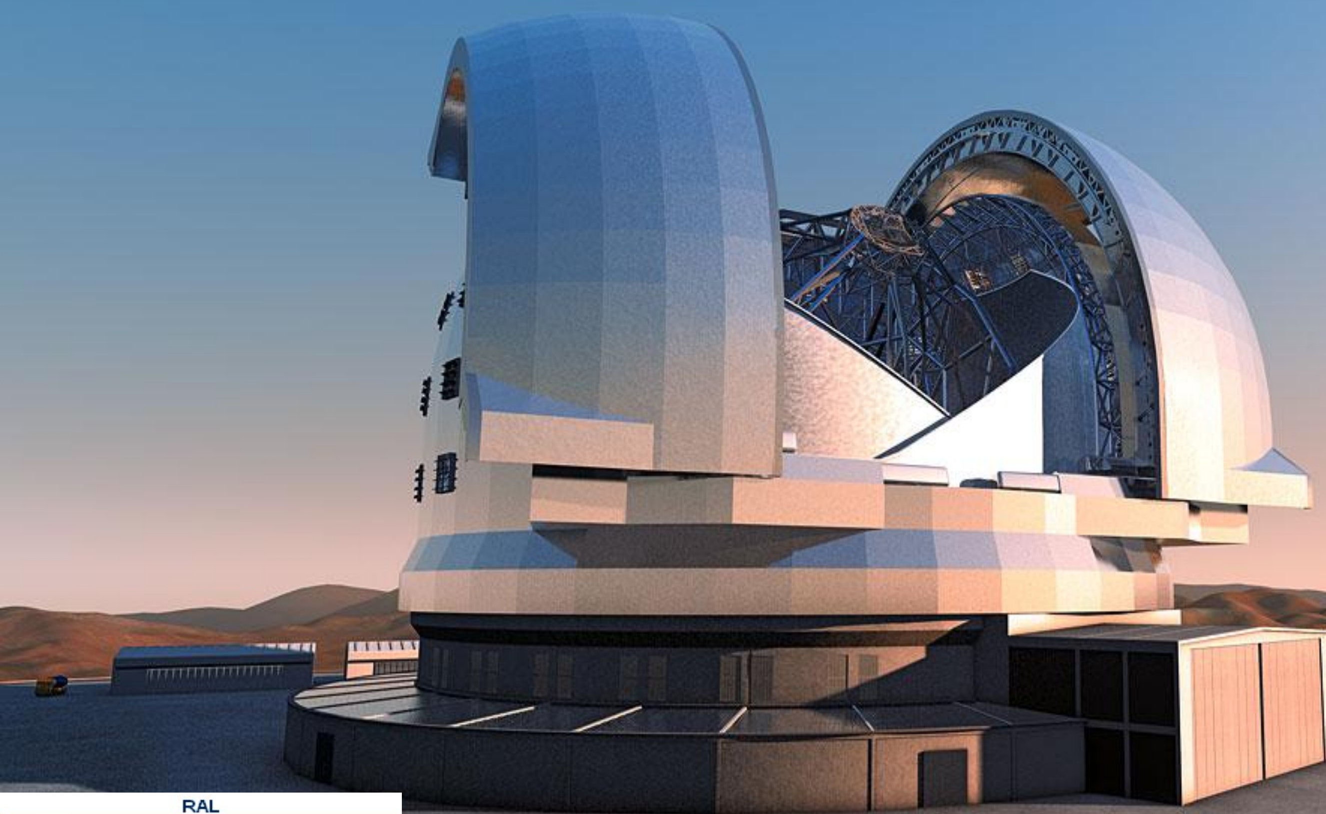
A high-multiplex (and high-definition) MOS for the E-ELT



MOSAIC

Lex Kaper, Univ.of Amsterdam

(on behalf of the MOSAIC team)

RAL Science & Technology Facilities Council

STFC UK Astronomy Technology Centre

LAM Laboratoire d'Astrophysique de Marseille

LNA Laboratório Nacional de Astrofísica

Observatório Nacional

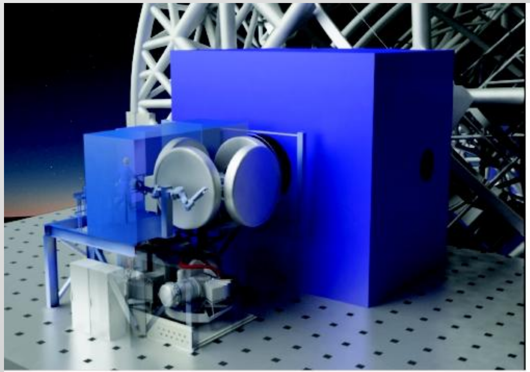
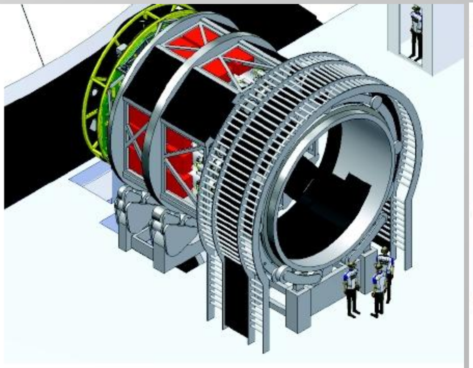
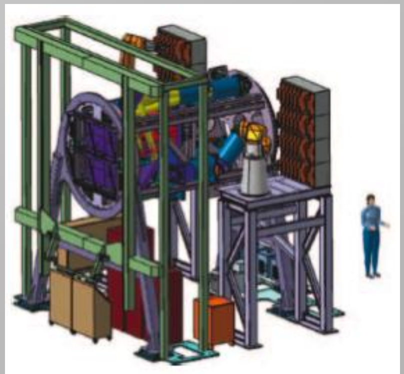
l'Observatoire de Paris

NOVA

MOS phase A studies (2010)

- EAGLE: AO assisted multi integral field NIR spectrometer (PI: J.G. Cuby)
- OPTIMOS-EVE: Optical-NIR fibre-fed MOS (PI: F. Hammer)
- OPTIMOS-DIORAMAS: Wide-field imager & low to medium resolution multi-slit spectrograph (PI: O. Le Fevre)

The E-ELT Science Working Group recognized "the very strong science case for an instrument which provides multi-object spectroscopy from the R to the H band, with a multiplex of at least 100, a field of view of 10 arcmin, and a spectral resolution of R~3000, or more, subject to a trade-off. A goal would be to extend the spectral range into the blue (and the red), and to include R = 5000 – 10000".
Should be able to work at natural (GLAO) seeing conditions.

MOS specifications

	Patrol field	Science field	Multiplex	Spaxel size	R	λ range
EAGLE	> 5′	1.5″x1.5″	> 20	MOAO 37.5 mas	4000 >10000	0.8-2.4 μm
OPTIMOS-EVE	7′ (unvig) 10′	0.9″ 1.8x2.9″ 7.8x13.5″	240 70 40	GLAO	6000 18000 30000	0.37-1.7 μm
OPTIMOS-DIORAMAS	6.8x6.8′	~0.1-0.5″	480 5″ slits 160 5″ slits	GLAO	~300 ~2000-3000	0.37-1.6 μm

TMT: WFOS, IRMS (talk Luc Simard)
GMT: GMACS, NIRMOS (talk George Jacoby)

Common focal plane → MOSAIC

MOSAIC

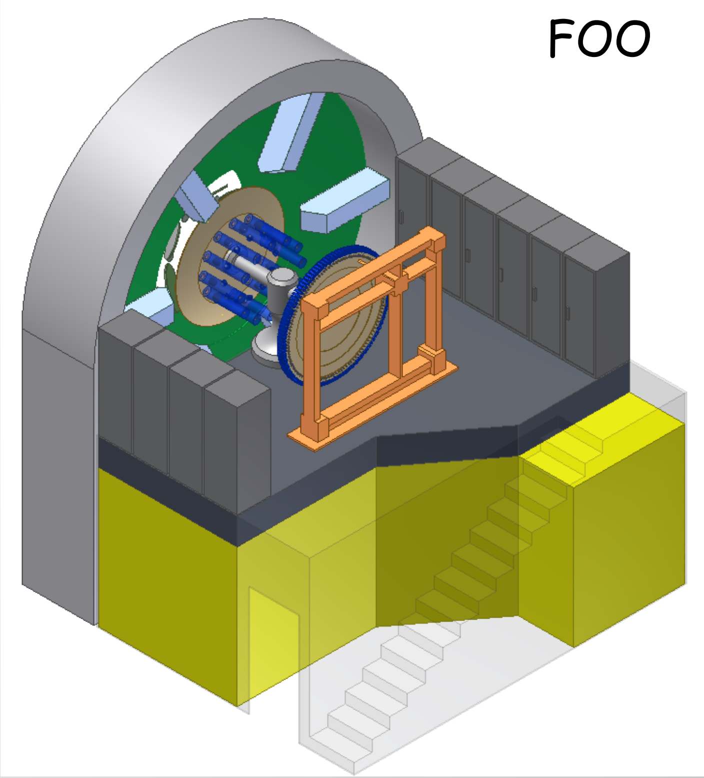
Table 3: Summary of top-level requirements from each Science Case

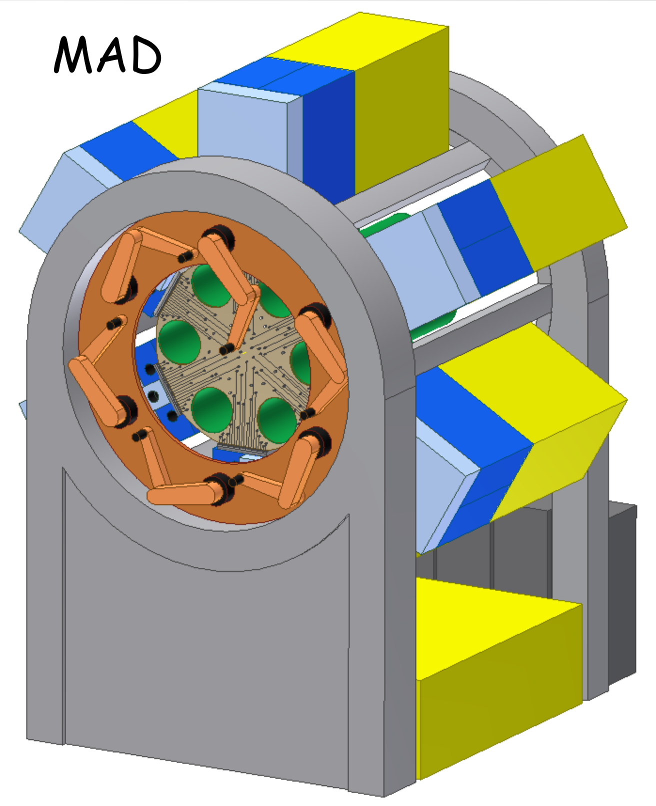
Case	Target densities	FoV/target	Spatial resolution	λ-coverage (μm)	*R*
SC1	1-2 arcmin^{-2}	2" × 2"[3]	40-90 mas	1.0-1.8 *1.0-2.45*	5,000
	10s arcmin^{-2}	–	(GLAO)	1.0-1.8 *1.0-2.45*	>3,000
SC2	1-2 arcmin^{-2}	2" × 2"	50-80 mas	1.0-1.8 *1.0-2.45*	5,000
	10s arcmin^{-2}	–	(GLAO)	1.0-1.8 *1.0-2.45*	> 3,000
SC3	≥ ~20 arcmin^{-2}	–	(GLAO)	0.8-1.7	≥5,000 *~10,000*
SC4	0.5-1 arcmin^{-2}	2" × 2"	(GLAO)	0.4-1.0 *0.37-1.0*	5,000 *10,000*
SC5	Dense	1" × 1" *1.5" × 1.5"*	≤75 mas *20-40 mas*	1.0-1.8 *0.8-1.8*	5,000
	10s arcmin^{-2}	–	(GLAO)	0.4-1.0	≥5,000 *≥10,000*
SC6	10s arcmin^{-2}	–	(GLAO)	0.41-0.46 & 0.60-0.68 *0.38-0.46 & 0.60-0.68*	≥15,000 *≥20,000*

Evans, Puech et al., ELT-MOS white paper

MOSAIC

- Fiber-only option
- Mixed Architecture Design

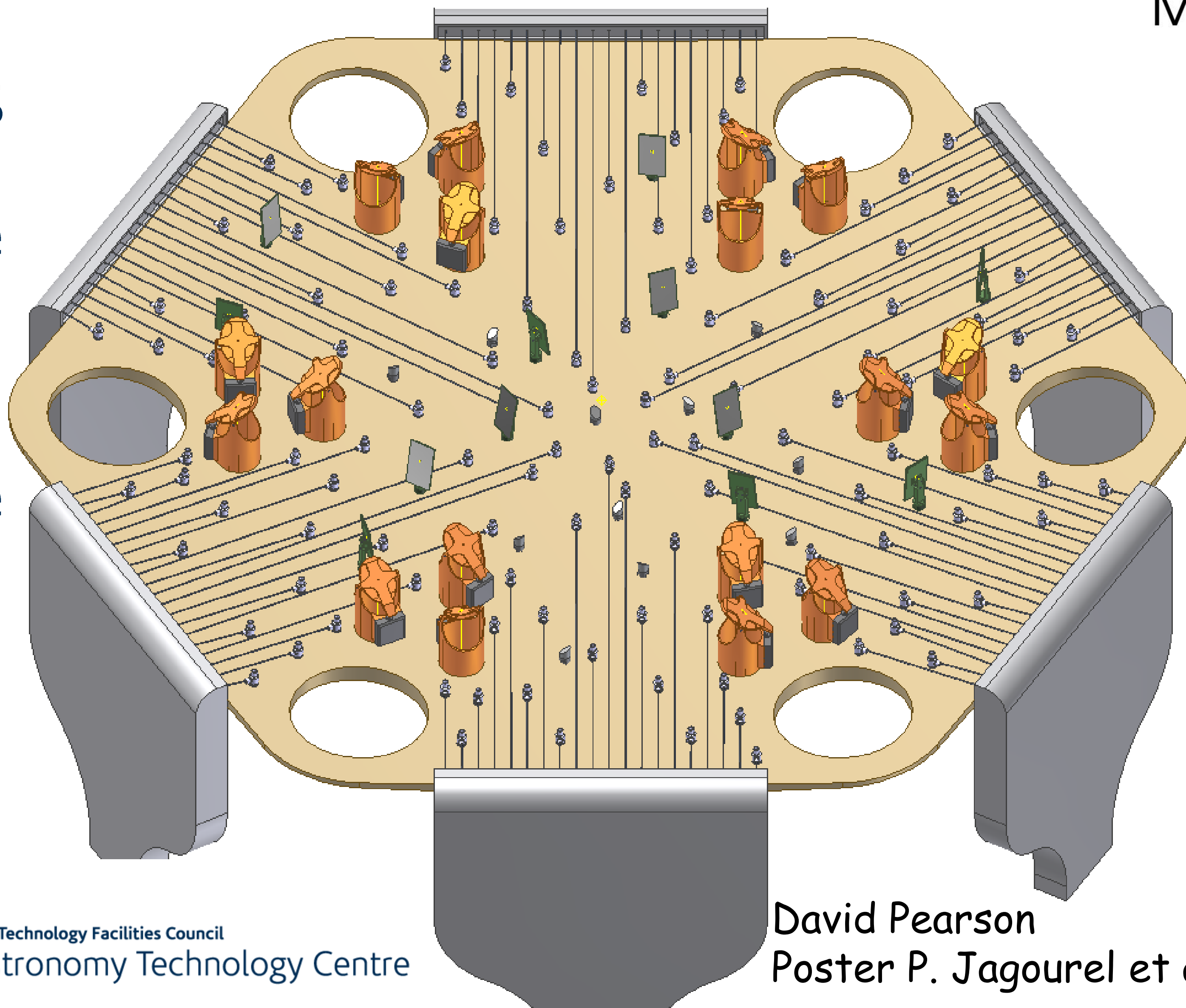




Fiber-fed spectrograph: sky background subtraction
➔ Poster Yang et al.; see also ESO Messenger March 2013

High multiplex science channels

6x LGS
6x NGS
12x science (high def.)
120x science (high mult.)



Science & Technology Facilities Council
UK Astronomy Technology Centre

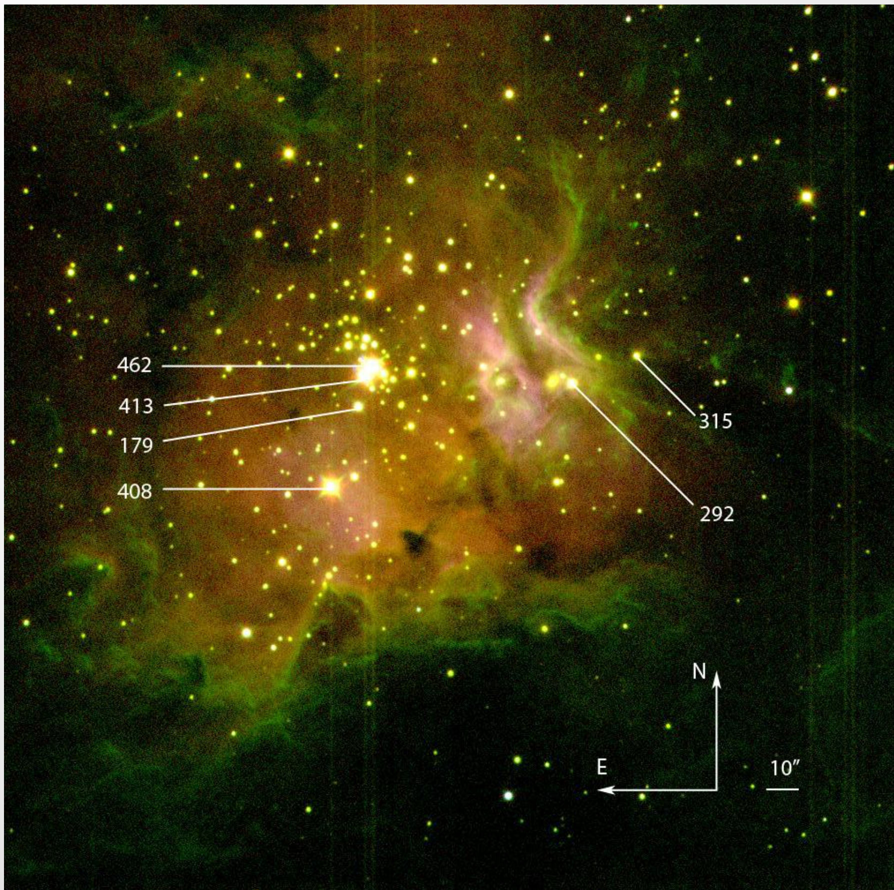
David Pearson
Poster P. Jagourel et al.

Why do I care about the E-ELT and its instrumentation?

- I want to use the E-ELT to study *massive stars: their formation, evolution and fate* (Lennon, Evans, Przybilla, Davies).
- The E-ELT will provide the opportunity to move out of our Galaxy, in the Local Group and beyond and to study massive star evolution as a function of environmental conditions.
- Being involved in the instrumentation studies provides the opportunity to steer the concept(s) and to facilitate scientific progress.
- It is actually fun to collaborate with your European (and Brazilian) colleagues on such a challenging project.

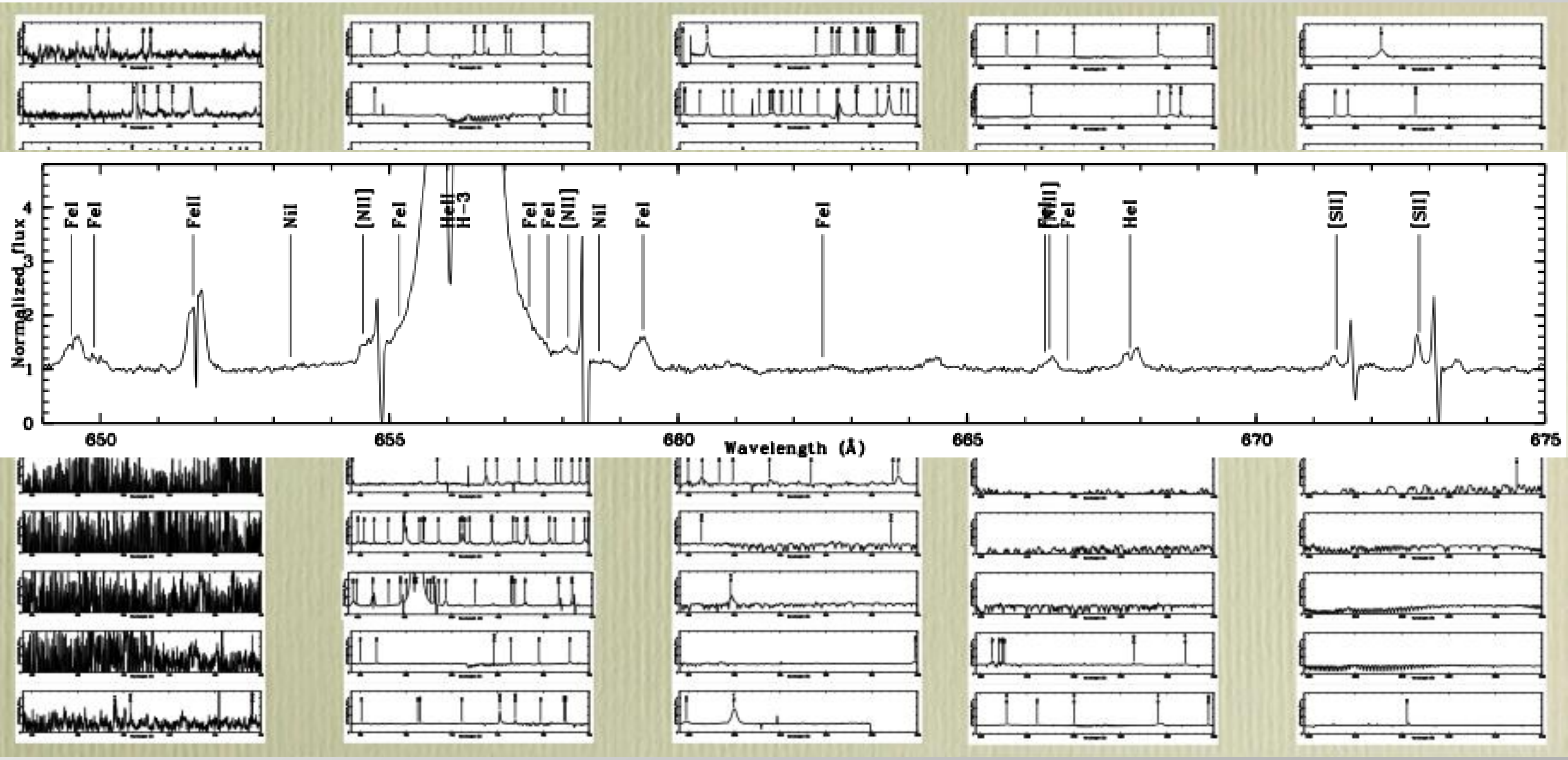
Importance of this ESO workshop: inform your colleagues (and ESO) about your scientific wishes and demands.

VLT/X-shooter spectra of a massive YSO deeply embedded in a massive star forming region



IRAS 08576-4334 (NTT/SOFI)

X-shooter spectrum 300 – 2500 nm



The formation of massive stars

Sample & Follow-on observations

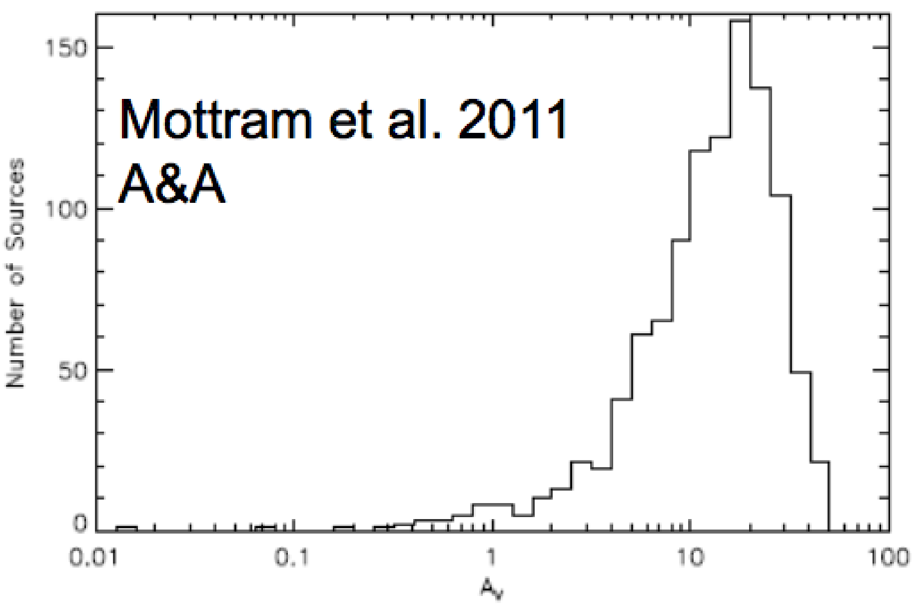
UNIVERSITY OF LEEDS

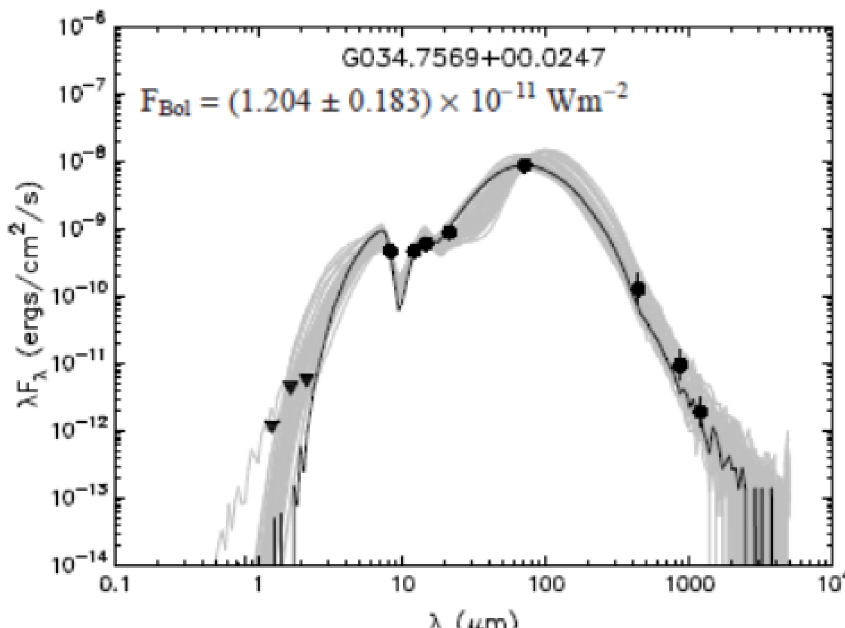
Properties relevant for this talk:

Optically in visible, NIR faint (for hi-res), MIR bright

Distance typically few kpc

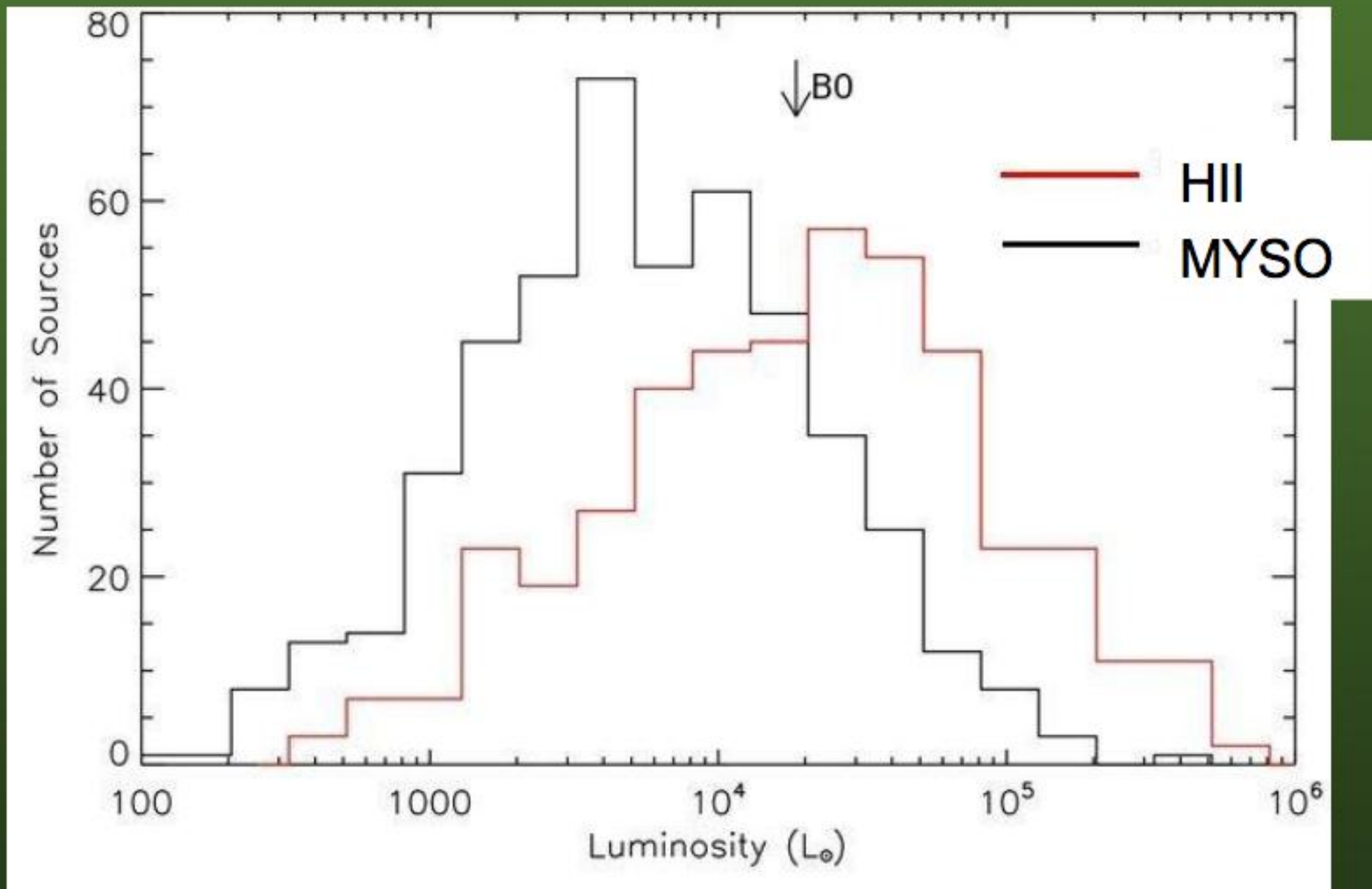
Talk Rene Oudmaijer





Luminosity Function

UNIVERSITY OF LEEDS



See also Mottram et al. 2011 ApJL

Massive stars are born as giants: B275 in M17

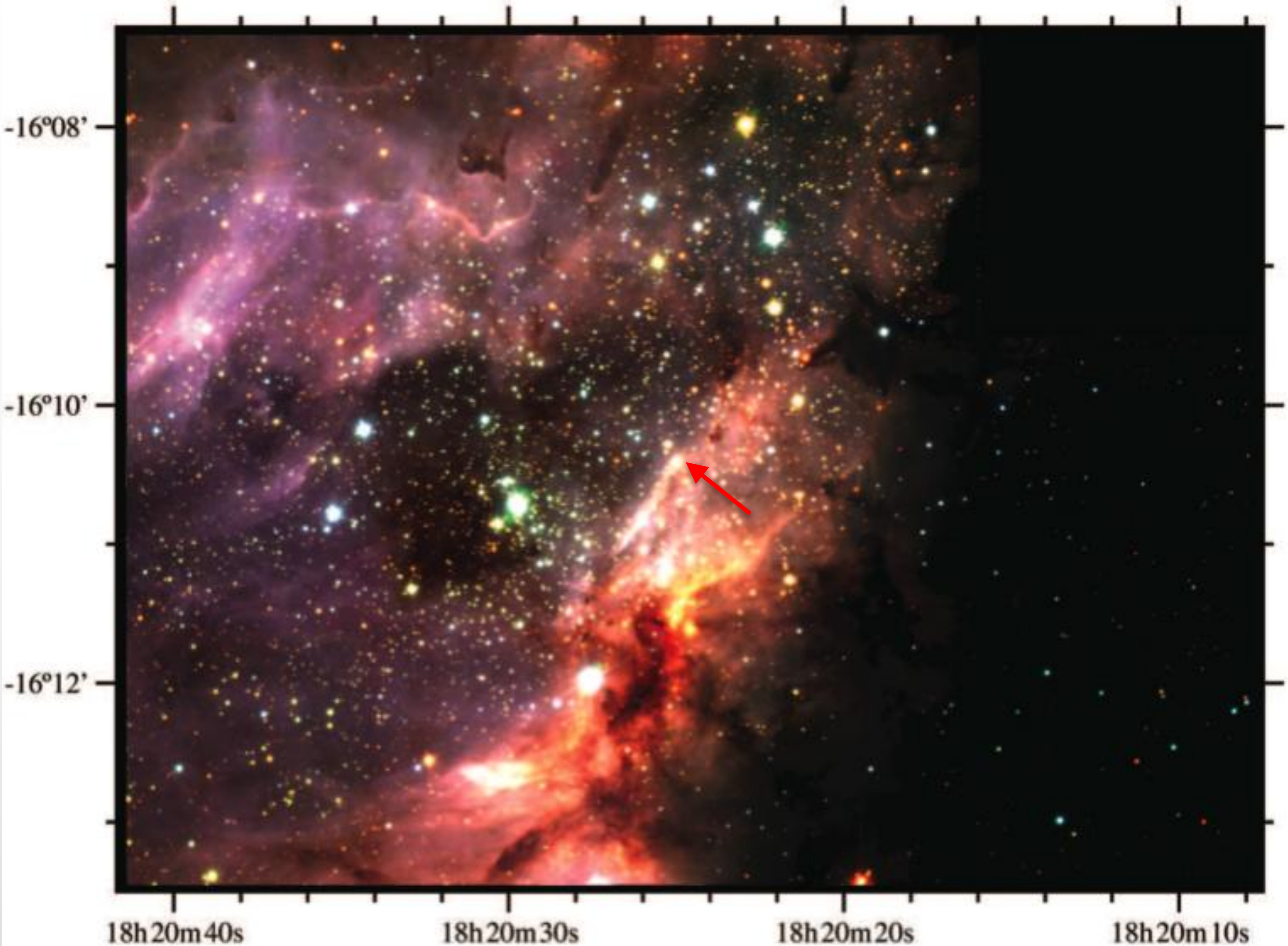


FIG. 1.—*J* (*blue*), *H* (*green*), and *K* (*red*) mosaic of the M17 cluster obtained with ISAAC at the VLT.

Hoffmeister et al. (2008)

B275: massive YSO in M17

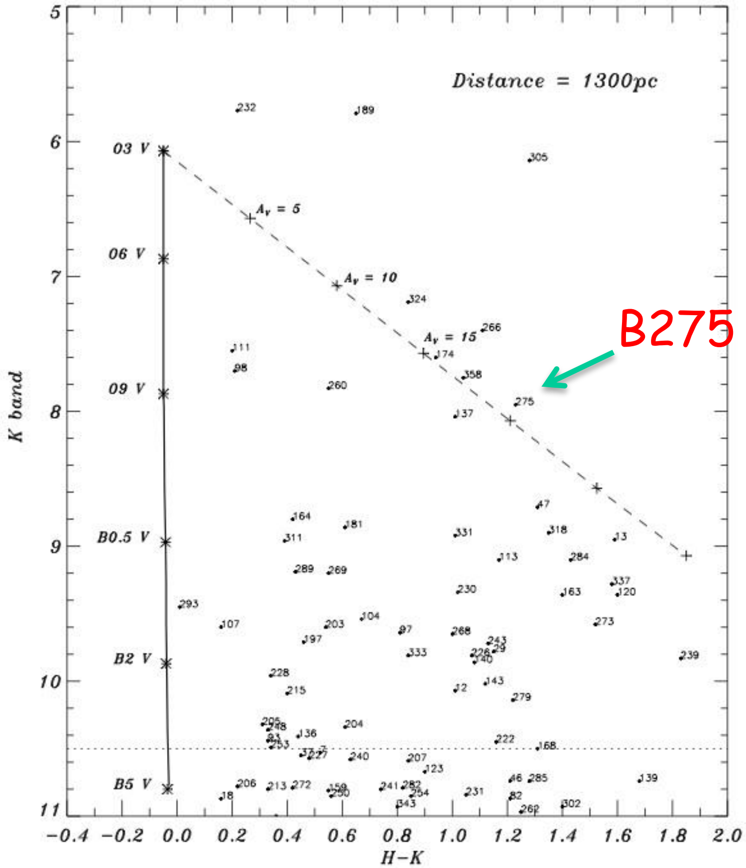


FIG. 3.—The *HK* color-magnitude diagram for M17. Stars shown here are the same set of stars that were plotted in Fig. 2 and are displayed in the same manner. The location of the main sequence is shown using a distance of 1300 pc. The reddening slope for an O3 V is shown with a dashed line. The *K*-band completeness limit, *K* = 10.5, is displayed as a horizontal dotted line.

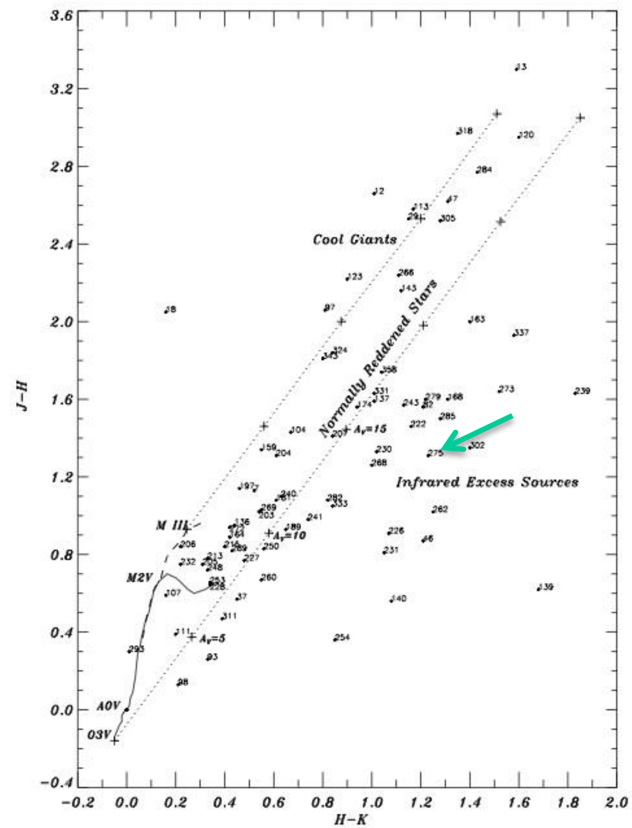


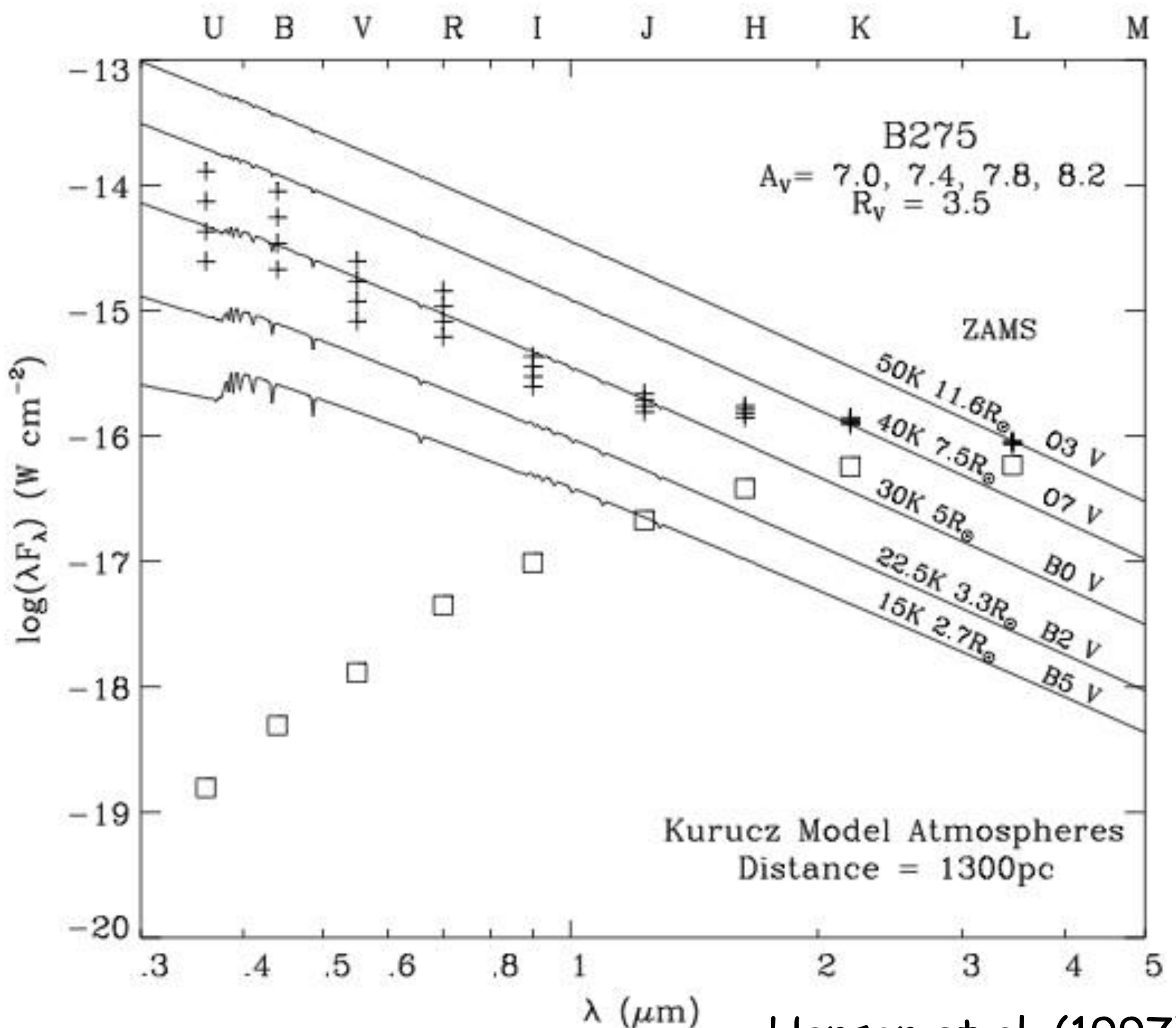
FIG. 2.—The *JHK* color-color diagram for M17. This includes all stars found in the Bumgardner (1992) 6′ × 6.′2 field where the stars had magnitudes of *J* < 14.25, *H* < 13.43, and *K* < 11.0. The numbers refer to the star numbers identified by Bumgardner, which are used in the text and tables with a B prefix. The exact position of the star on the diagram is marked with a circle to the left of the number. We suspect B18, and have confirmed that B139 and B239 have been misidentified in the three bands. Their colors as shown here from the Bumgardner survey are incorrect. The reddening slopes for an O3 V and a cool (G or K type) giant are shown as short-dashed lines.

Hanson et al. (1997)

SED B275:

SpType B0 V
L ~ 20,000 Lo

d = 1.98 ± 0.14 pc
(radio parallax;
Xu et al. 2011)



Hanson et al. (1997)

FIG. 15.—The spectral energy distribution of the YSO B275. This source shows Balmer lines in the optical, and interstellar DIB features, but no uniquely stellar absorption features (Fig. 8) Procedure and symbols are as in Fig. 10. The SED implies the spectral type would be early-B. This sources shows very strong CO emission in the near-infrared.

VLT/X-shooter spectrum M17-B275

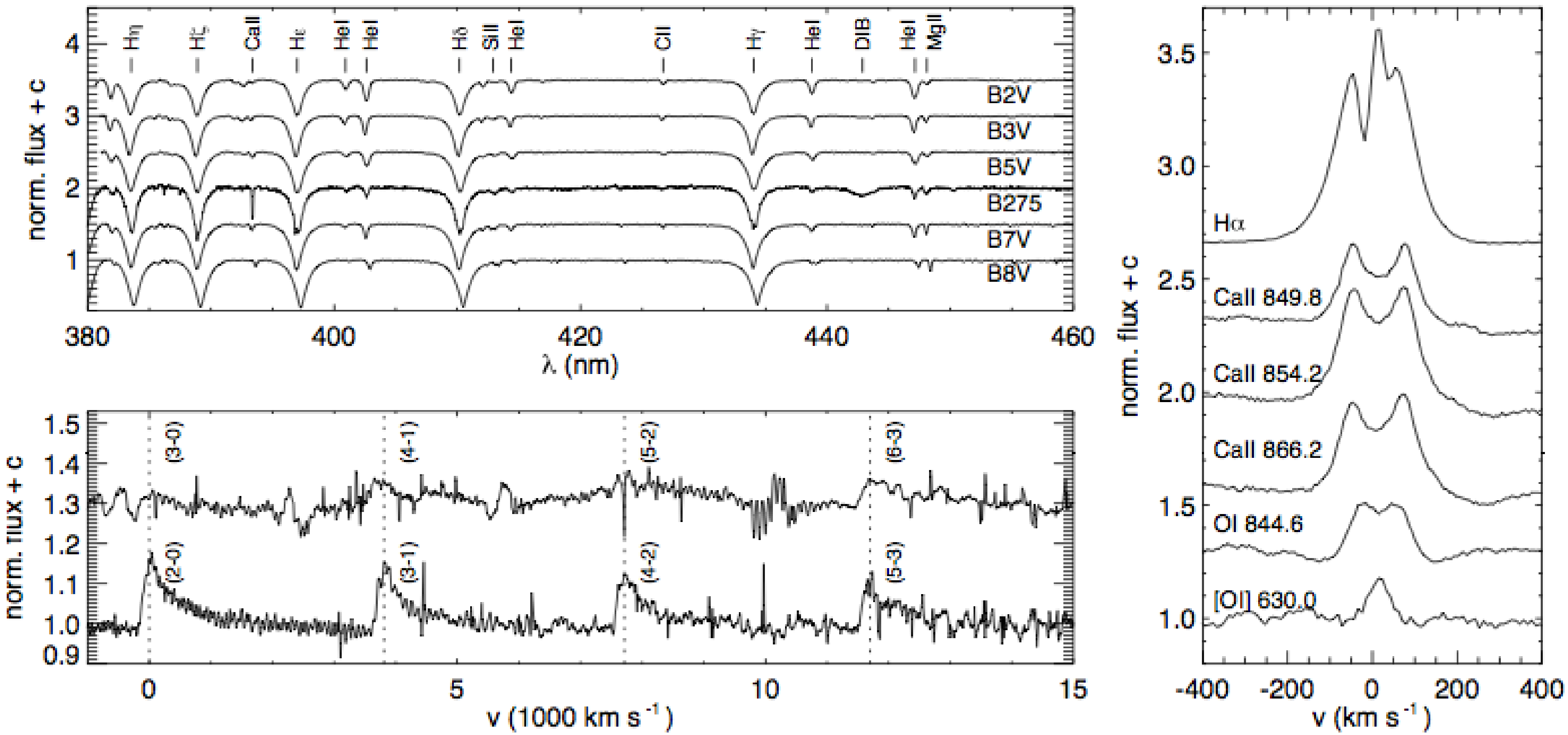


Fig. 1. *Top left:* The blue spectrum of B275 in M17 shown next to B main-sequence-star spectra (Gray & Corbally 2009). *Bottom left:* The 1st and 2nd overtone CO emission bands. Zero velocity corresponds to the first component in the series (at 2294 and 1558 nm, respectively). *Right:* A sample of the emission line profiles in the spectrum of B275. The Ca II triplet lines and O I 845 nm are superposed on hydrogen Paschen series absorption lines. The flux of the Hα line is scaled down by a factor 5; the structure near the peak is a remnant of the nebular-line subtraction.

Ochsendorf, Ellerbroek et al. 2011, A&A 536, L1

FASTWIND models → B7 III

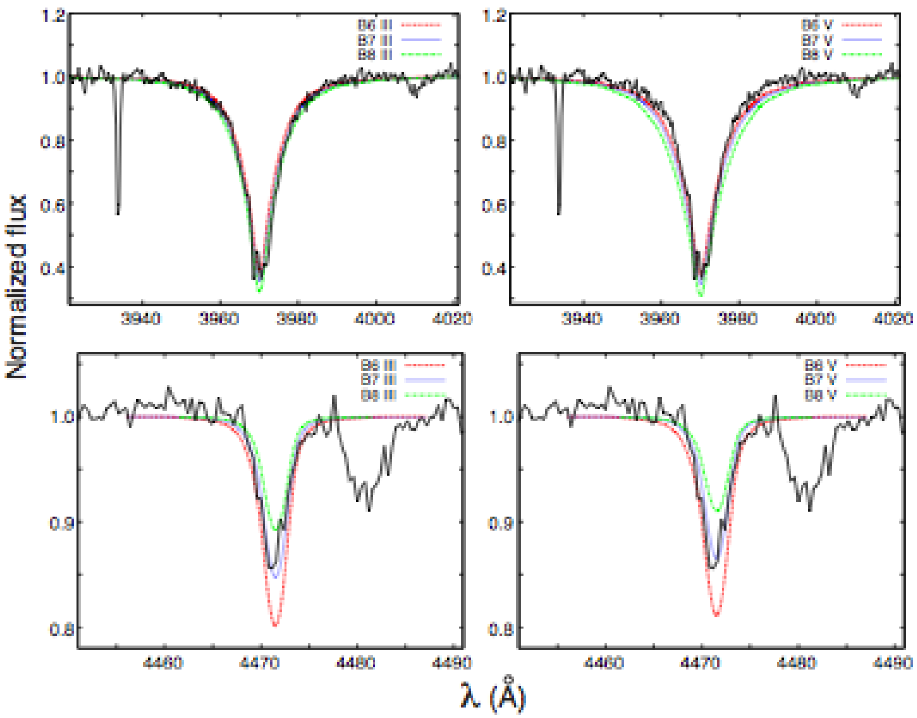


Fig. 2. FASTWIND model profiles of He*ϵ* (*top*) and He I 447.1 nm (*bottom*) lines for B6–B8 giants (*left*) and main-sequence stars (*right*). The B7 III model provides the best fit with the observed profiles.

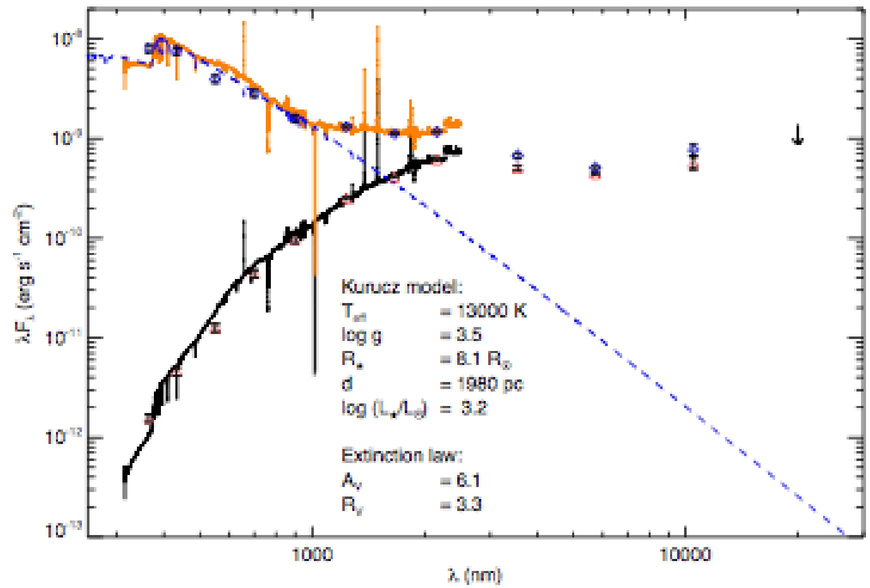


Fig. 3. The flux-calibrated X-shooter spectrum of B275 from 300–2500 nm (black) along with the photometric data (red triangles, black error bars) from Chini et al. (1980) (UVBRI), 2MASS (Skrutskie et al. 2006, JHK), *Spitzer* GLIMPSE (Benjamin et al. 2003, 3.6, and 5.8 μm), and Nielbock et al. (2001) (N, Q). When dereddened (A_V = 6.1 mag, orange line, blue diamonds), the SED is described well by a B7 III Kurucz model (blue, dashed line). The excess flux at 500 – 800 nm is an instrumental feature.

B275: "bloated" PMS star contracting to MS

B275 is on its way to become a 6 – 8 Mo star

Still surrounded by disk

Ochsendorf et al. 2011

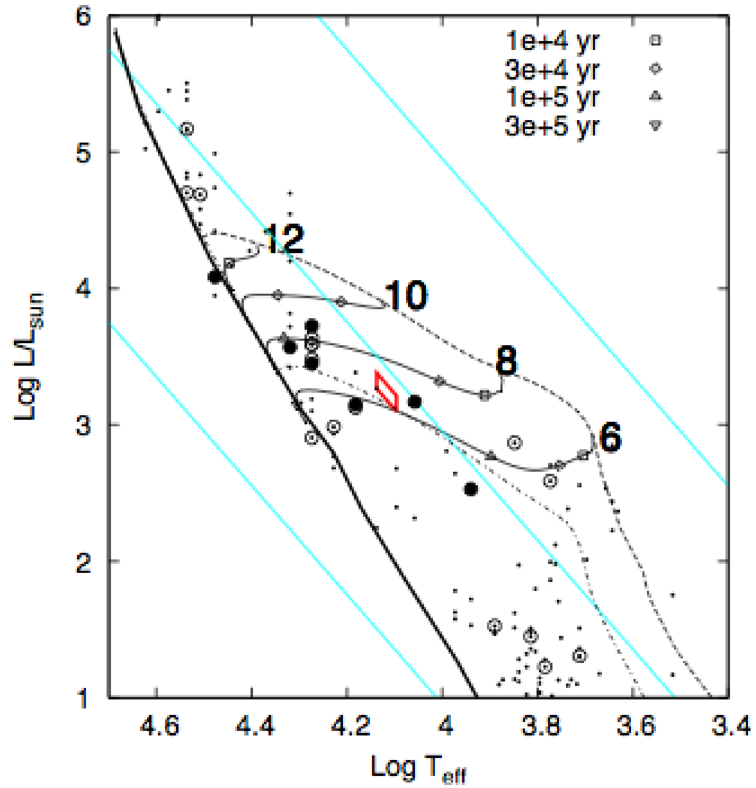


Fig. 4. The location of B275 (red parallellogram) in the HRD next to PMS tracks from Hosokawa & Omukai (2009) with the ZAMS mass labeled and open symbols indicating lifetimes. The thin dashed and thin dot-dashed lines are the birth lines for accretion rates of 10^{-4} $M_{\odot}$ yr^{-1} and 10^{-5} $M_{\odot}$ yr^{-1}, respectively; the thick solid line is the ZAMS (Schaller et al. 1992). The filled and open circles represent stars in M17 for which a spectral type has been determined (Hoffmeister et al. 2008), within a radius of 0.′5 and 1.′0, respectively; dots are other stars in M17. B275 is on its way to becoming a 6–8 $M_{\odot}$ ZAMS star.

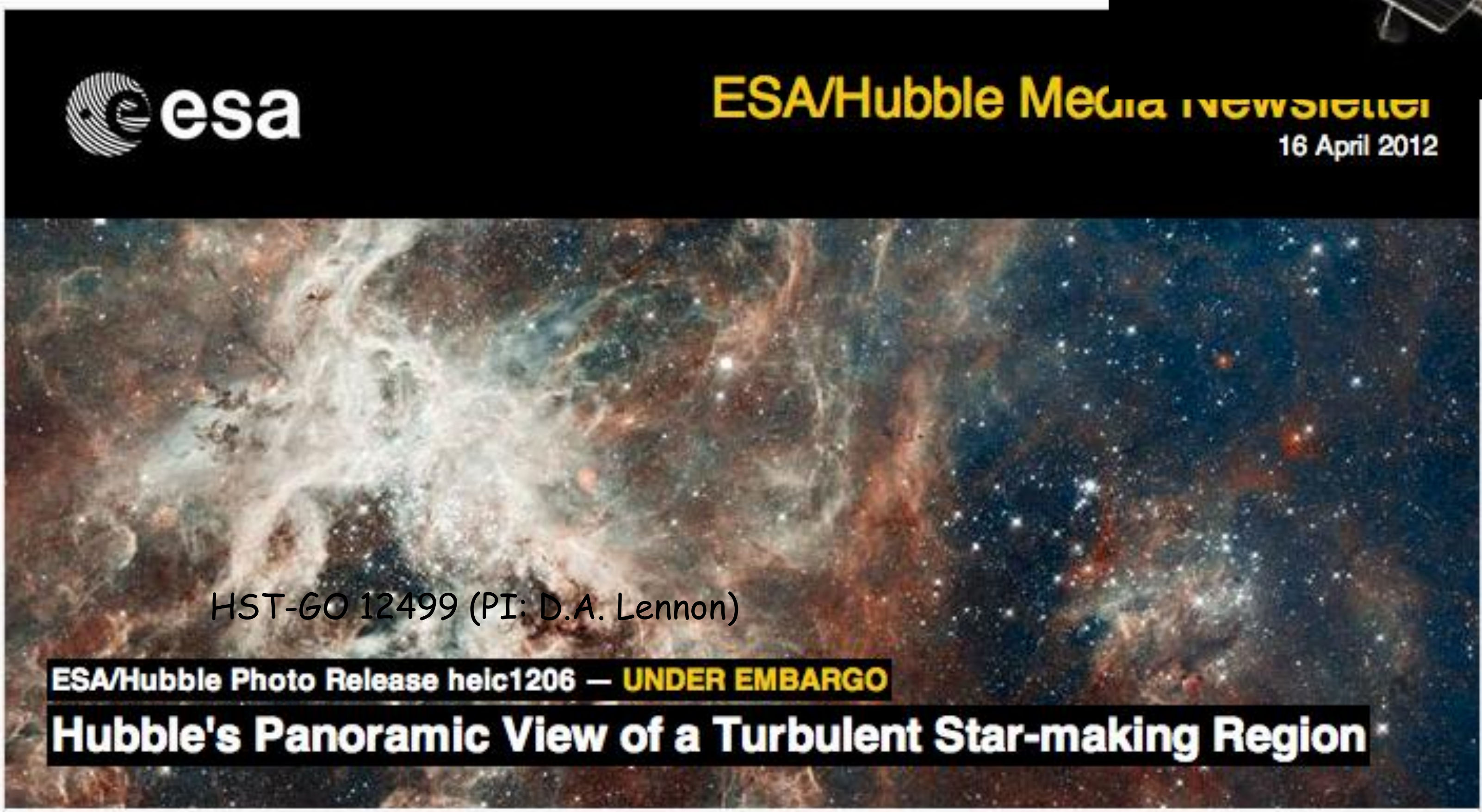
Massive stars in external galaxies

NGC 602 in SMC (HST)

VLT/FLAMES Tarantula Survey
(Evans et al. 2011) ~1000 O stars

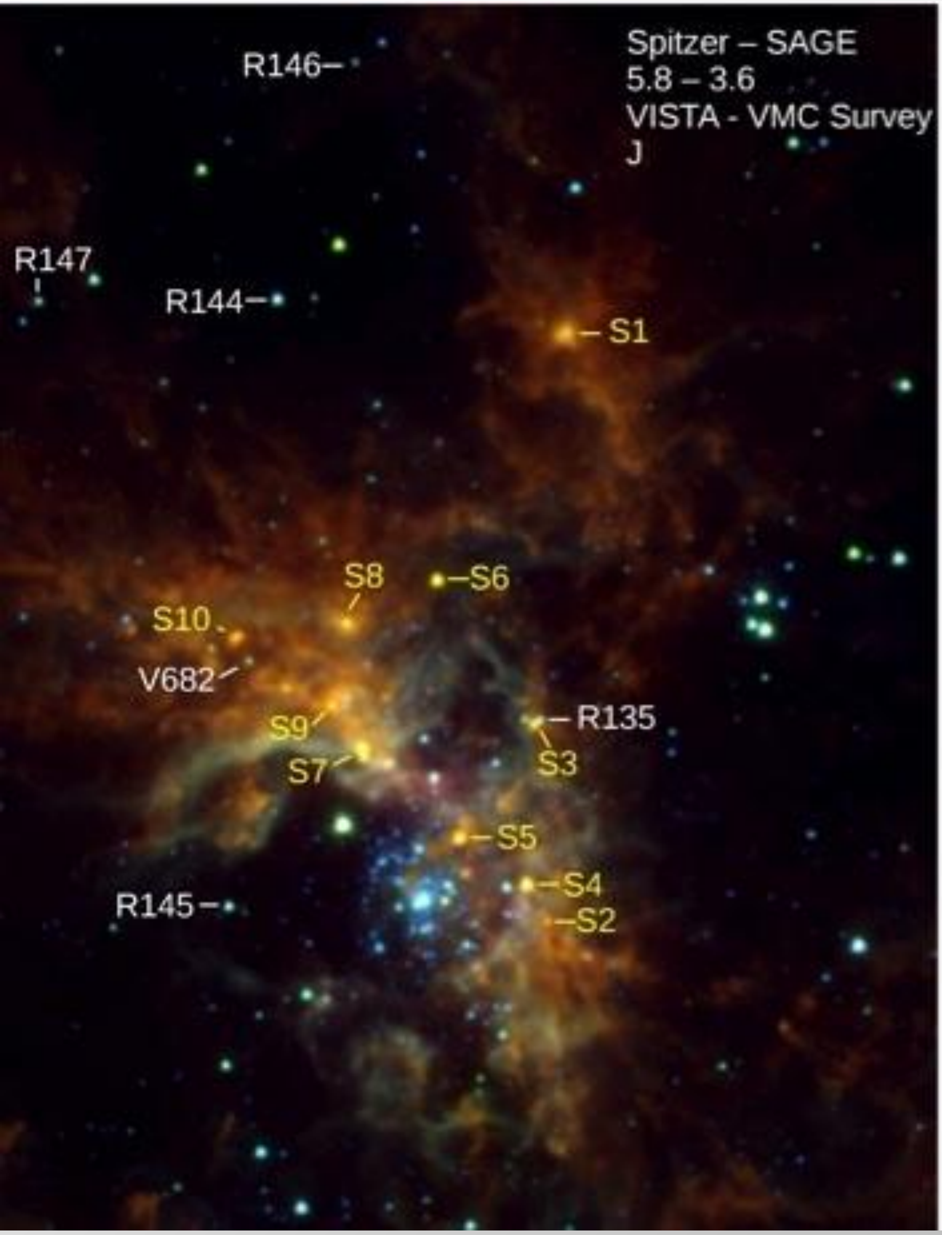
22nd Anniversary of
Hubble Space Telescope

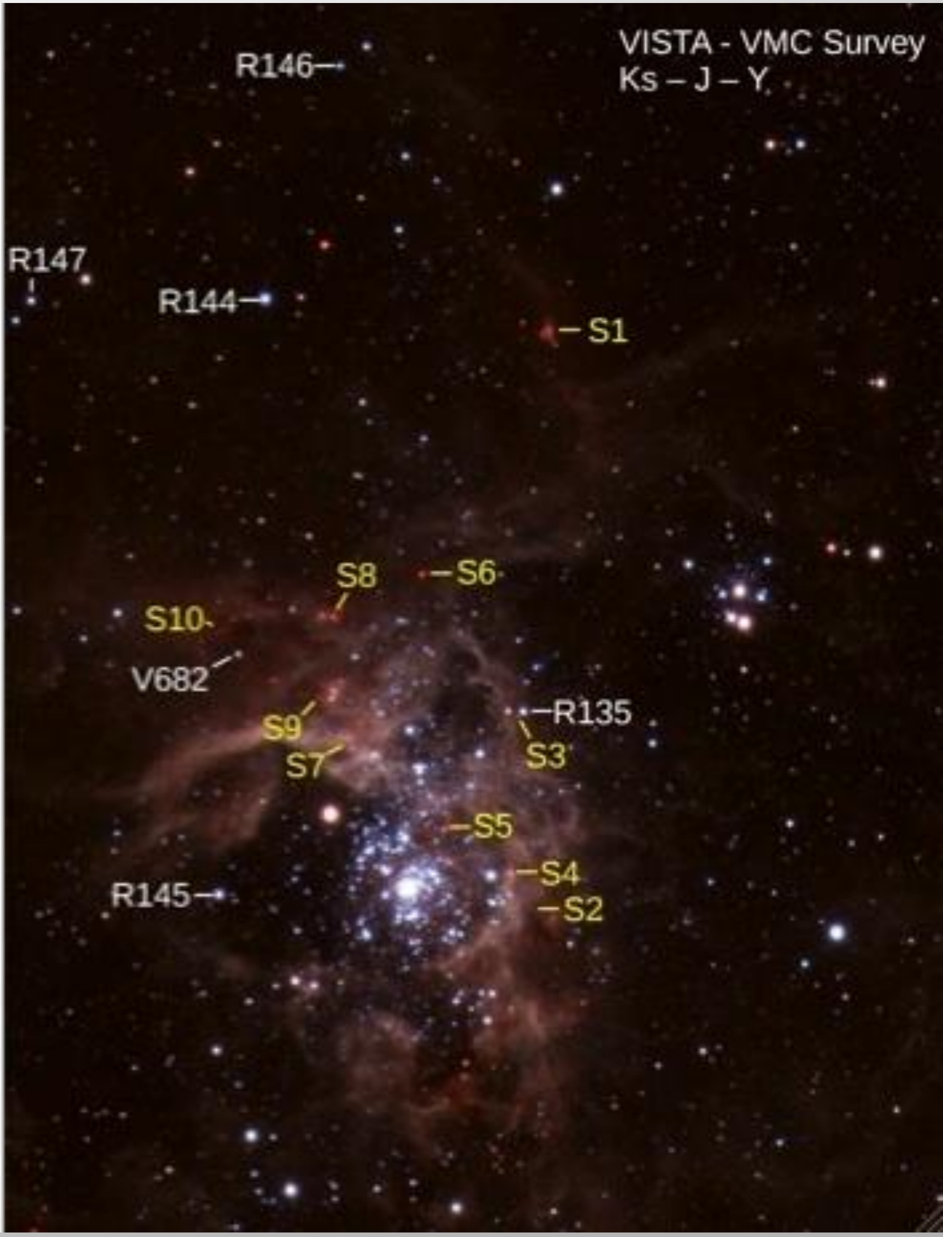
May 2012



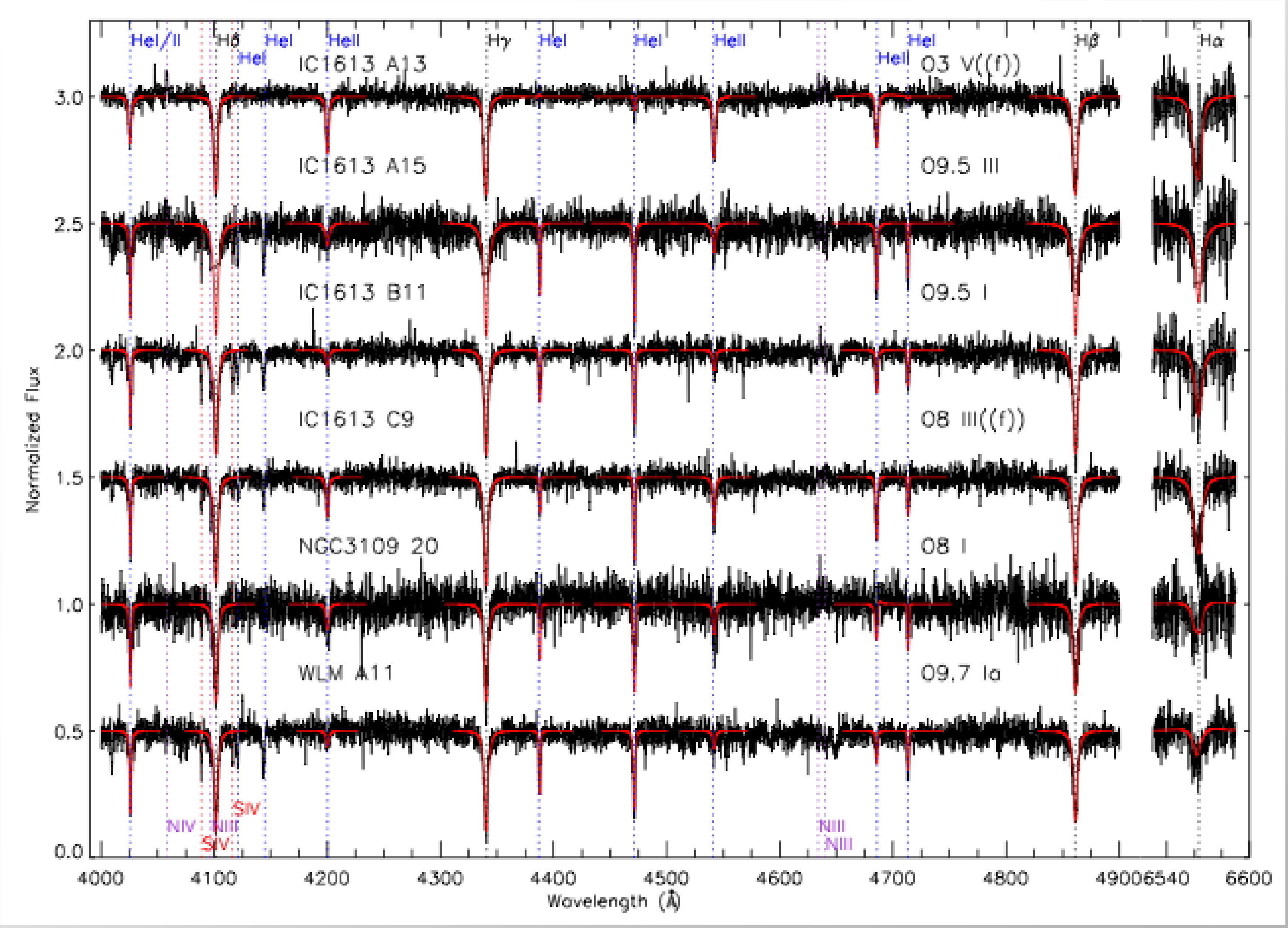
HST-GO 12499 (PI: D.A. Lennon)

Triggered star formation by 30 Dor

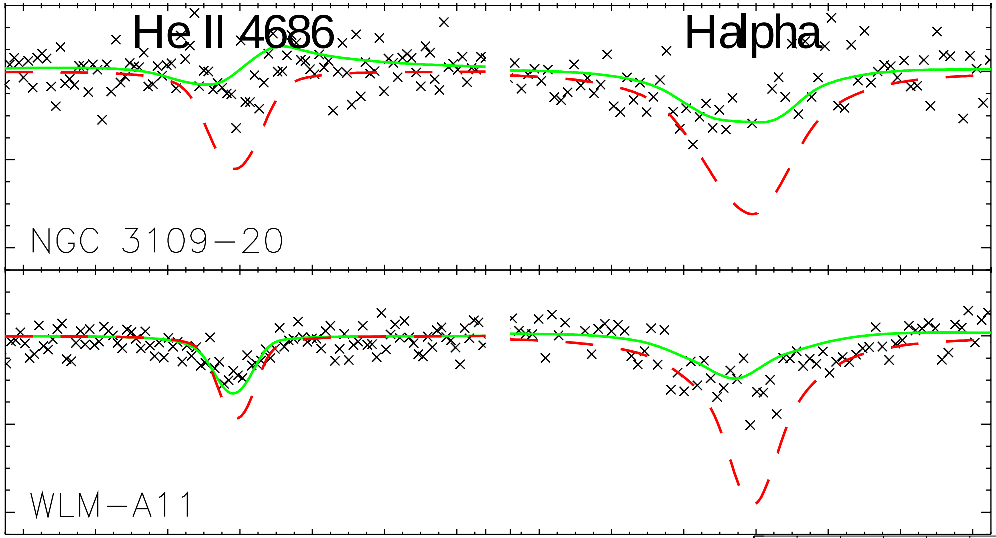


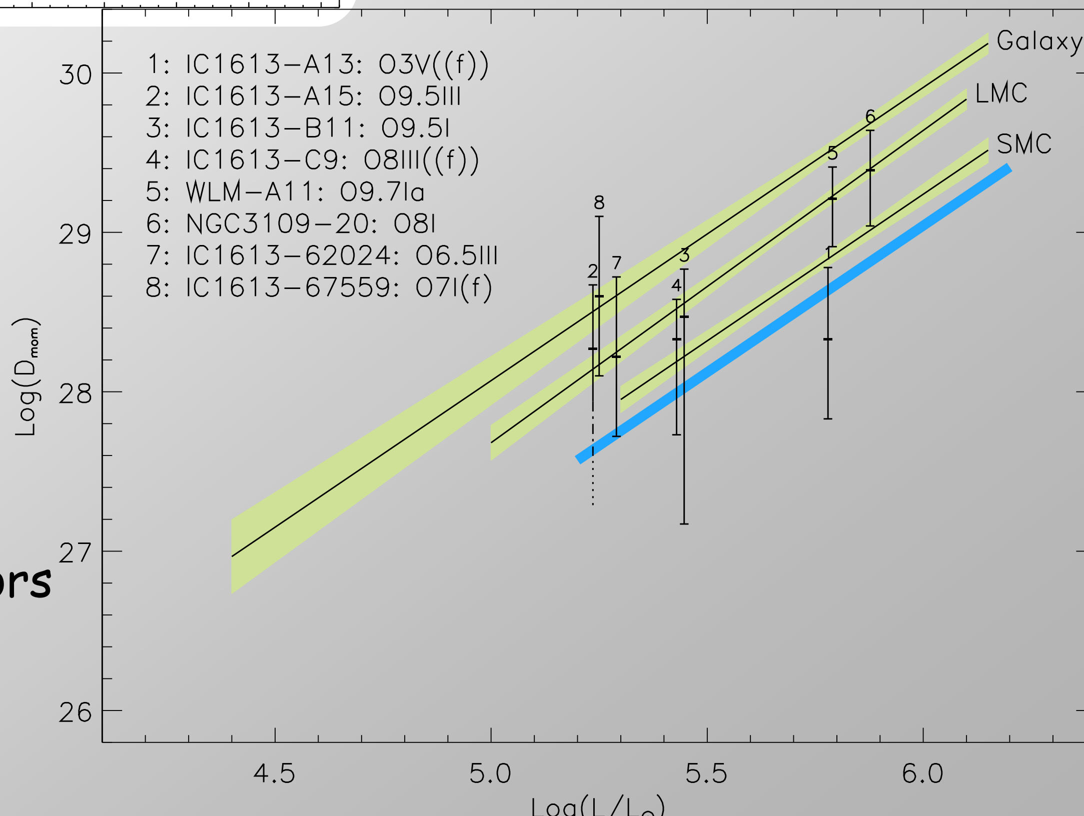



IC1613



Tramper et al. 2011, ApJ 741, L8

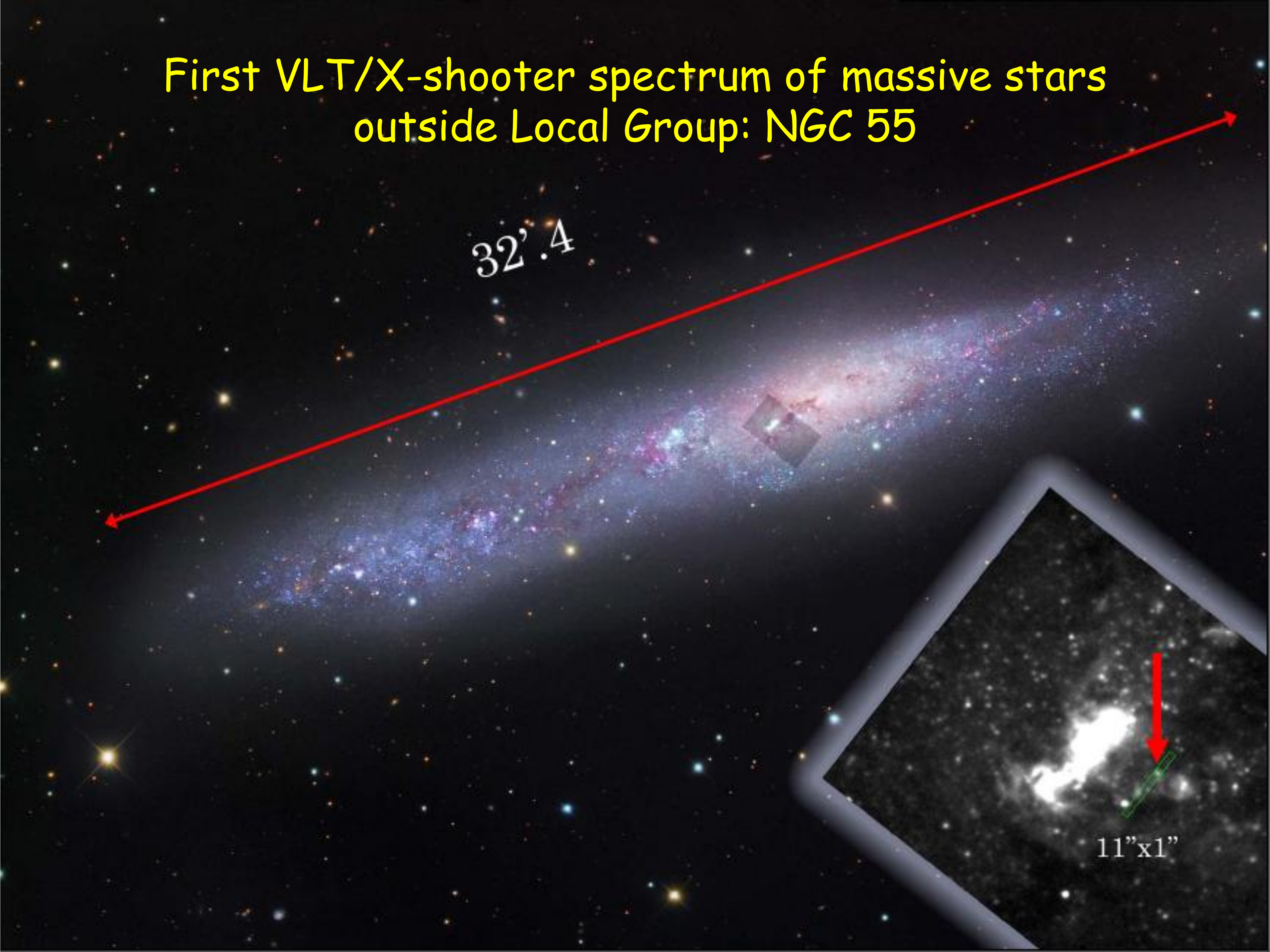




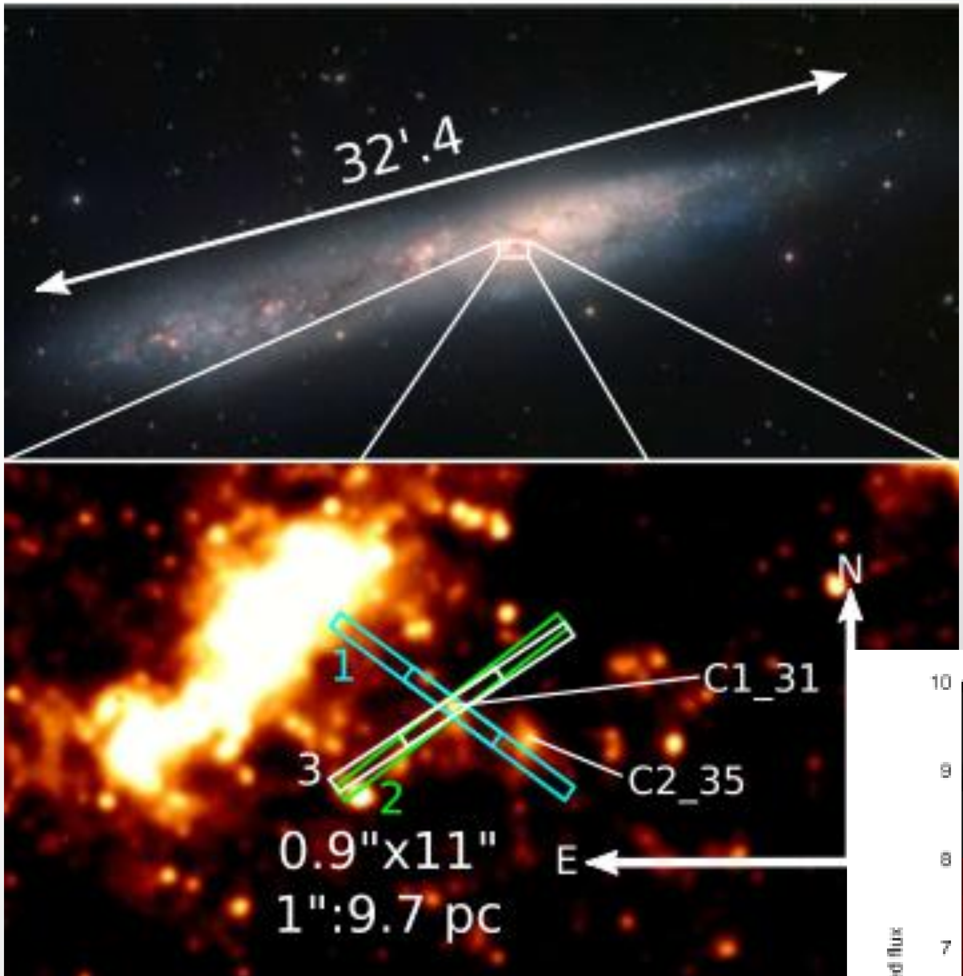
Predicted mass-loss rates as a function of decreasing metallicity are too low

If true, this would have a serious impact on our understanding of e.g. the first stars and GRB progenitors

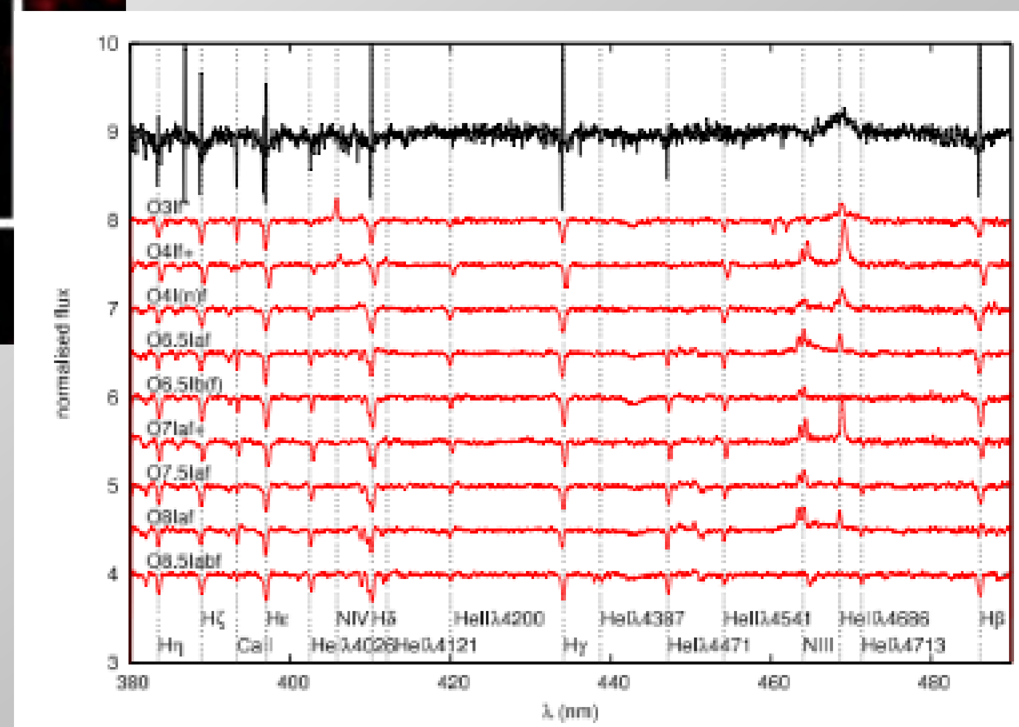
Tramper et al. (2011)

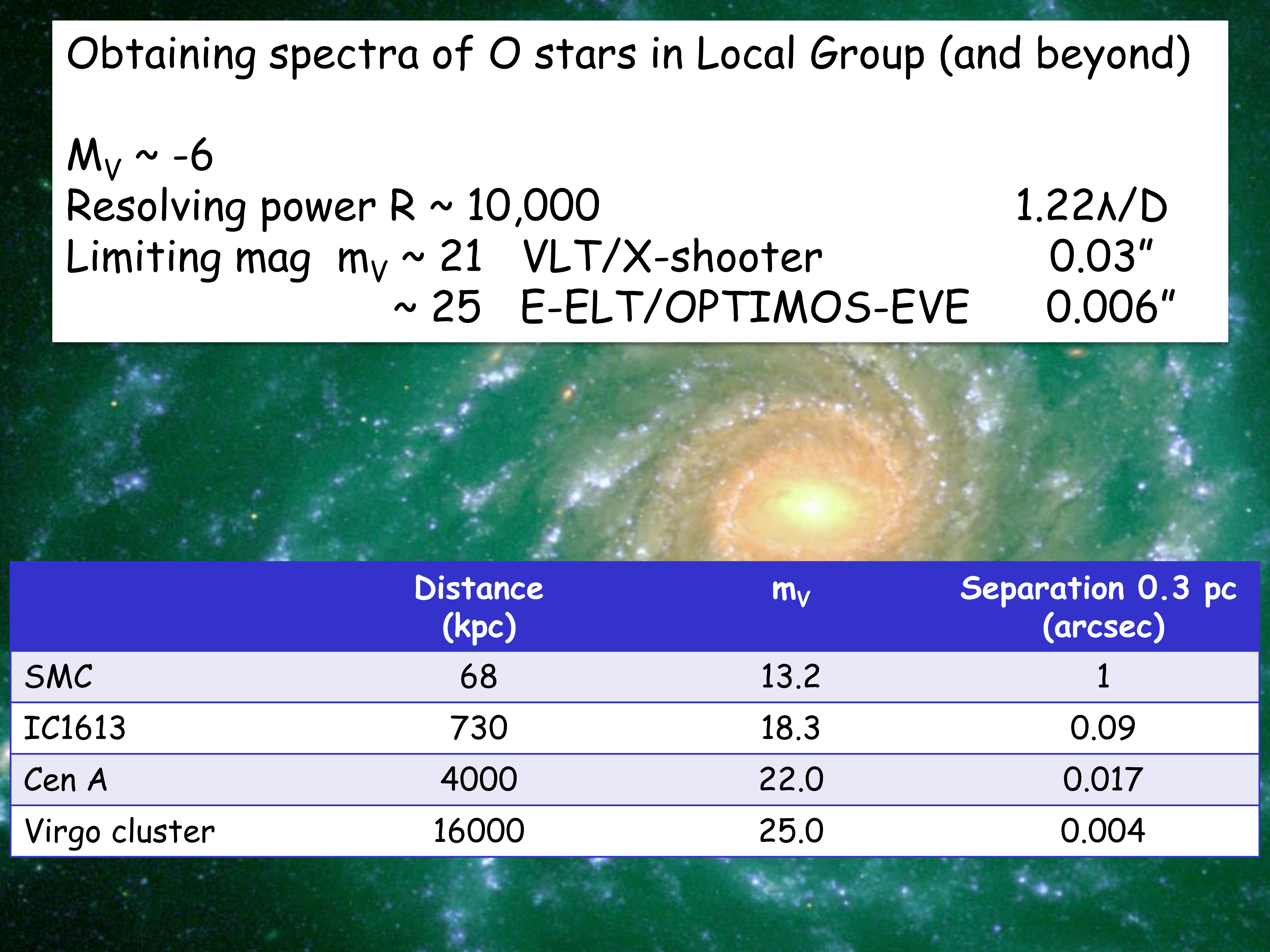

First VLT/X-shooter spectrum of massive stars outside Local Group: NGC 55
32'.4
11"x1"

Hartoog et al. 2012,
MNRAS 422, 367



Composite spectrum of handful of O stars and at least one WR star





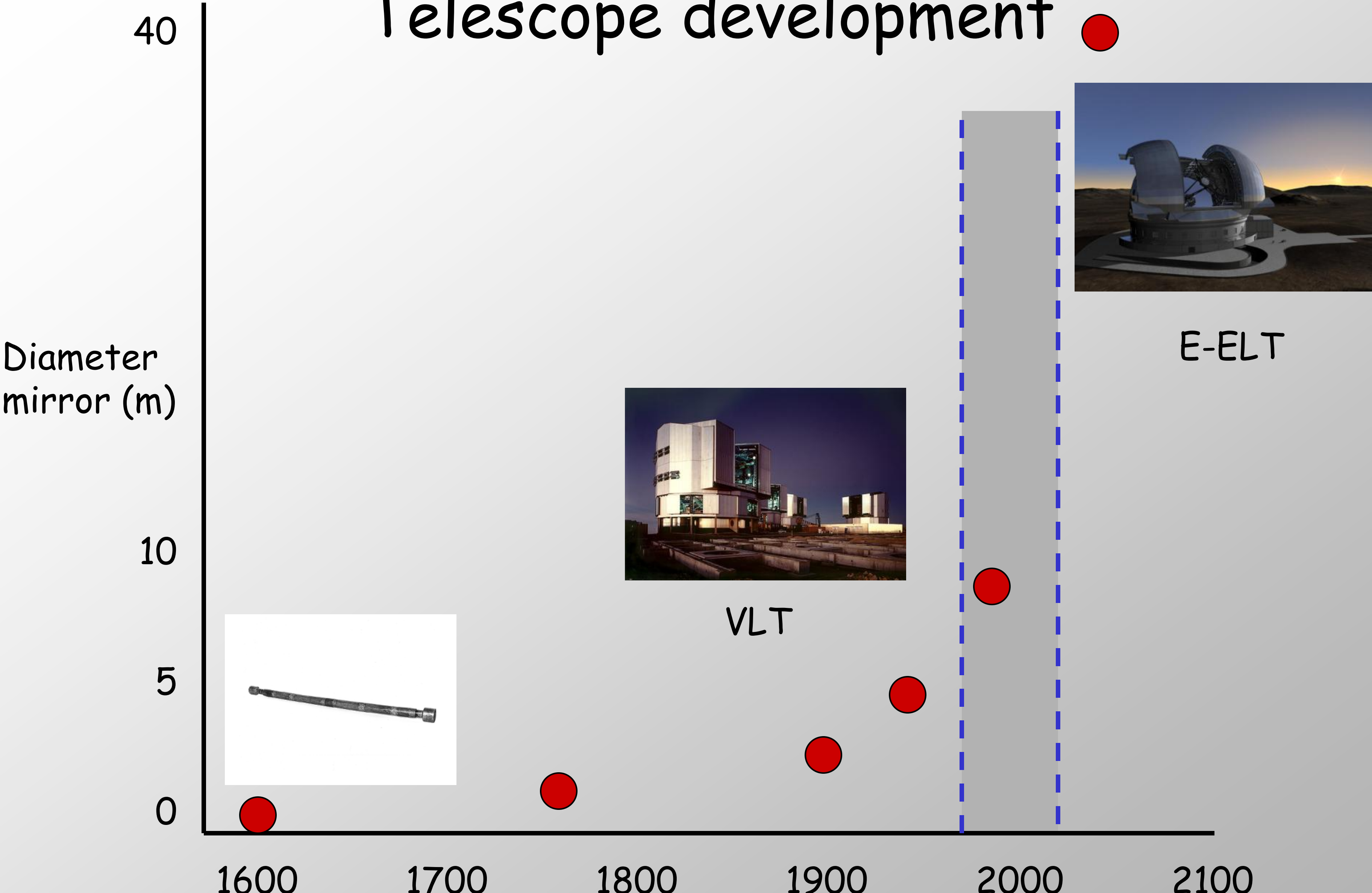
Obtaining spectra of O stars in Local Group (and beyond)

$M_V \sim -6$

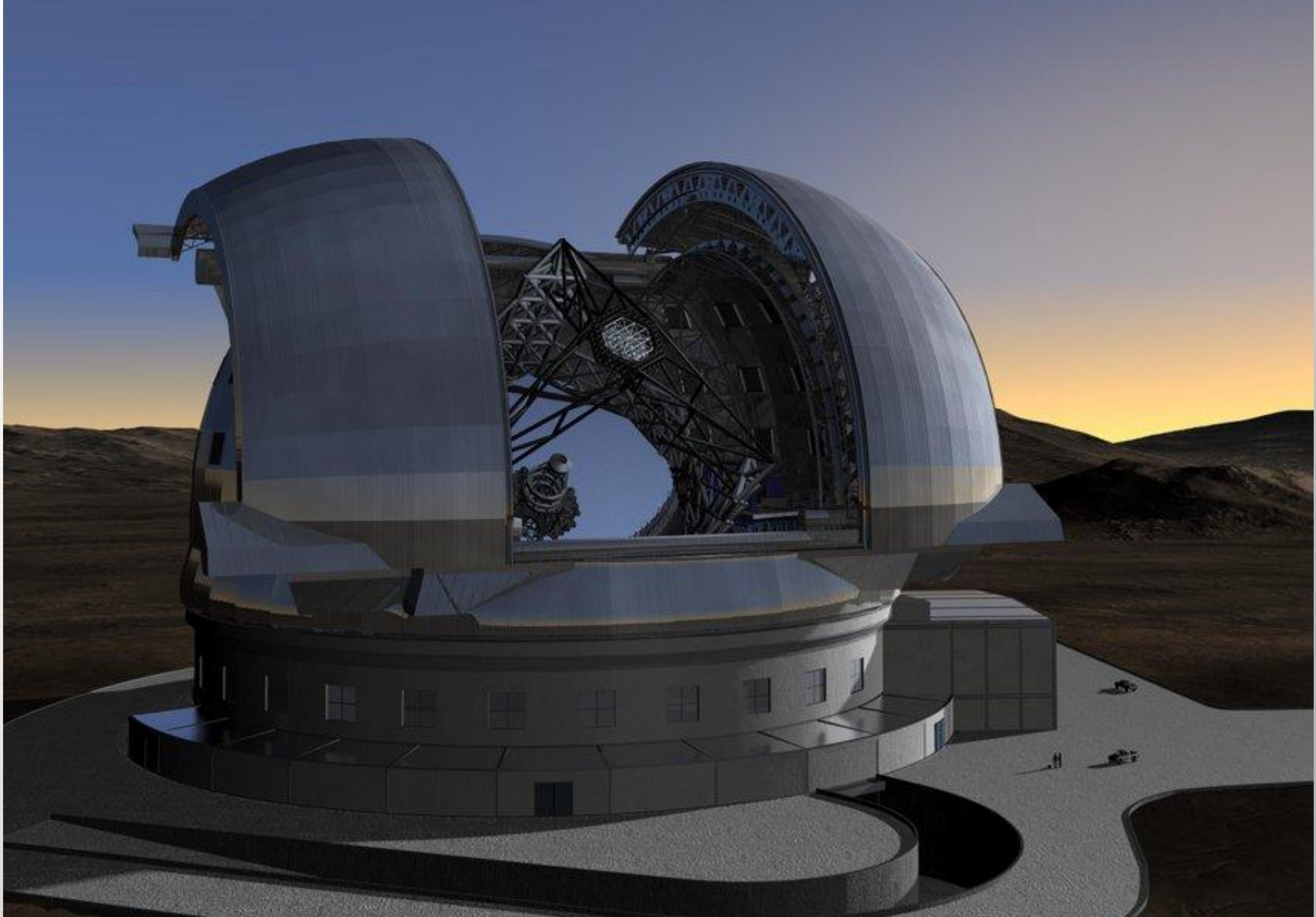
Resolving power R ~ 10,000			$1.22\lambda/D$
Limiting mag $m_V \sim 21$		VLT/X-shooter	0.03″
	~ 25	E-ELT/OPTIMOS-EVE	0.006″

	Distance (kpc)	m_V	Separation 0.3 pc (arcsec)
SMC	68	13.2	1
IC1613	730	18.3	0.09
Cen A	4000	22.0	0.017
Virgo cluster	16000	25.0	0.004

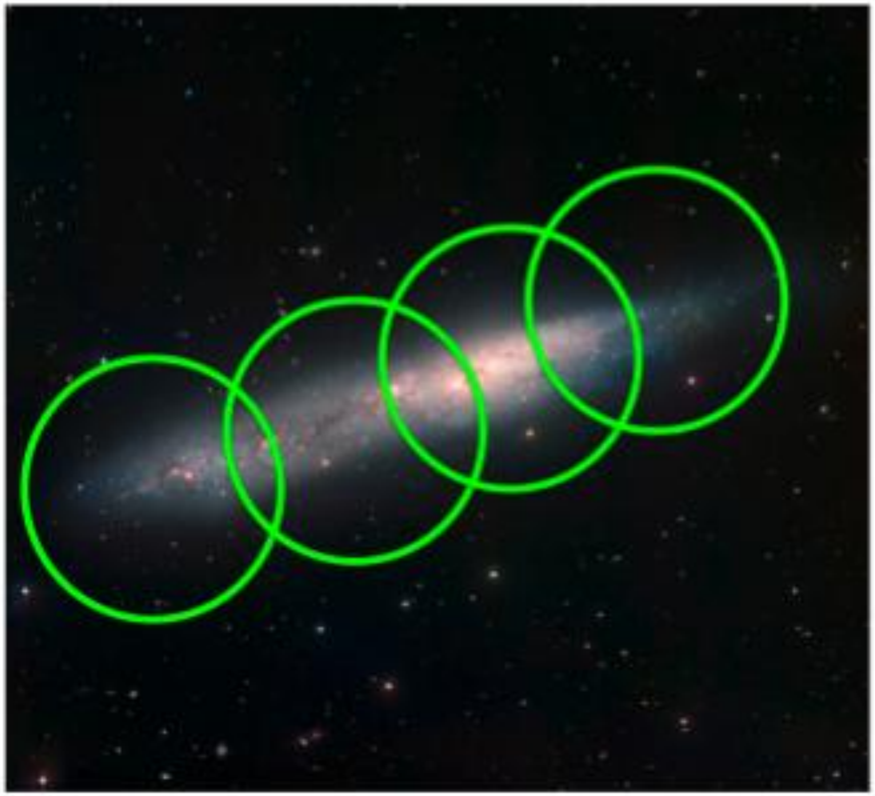
Telescope development

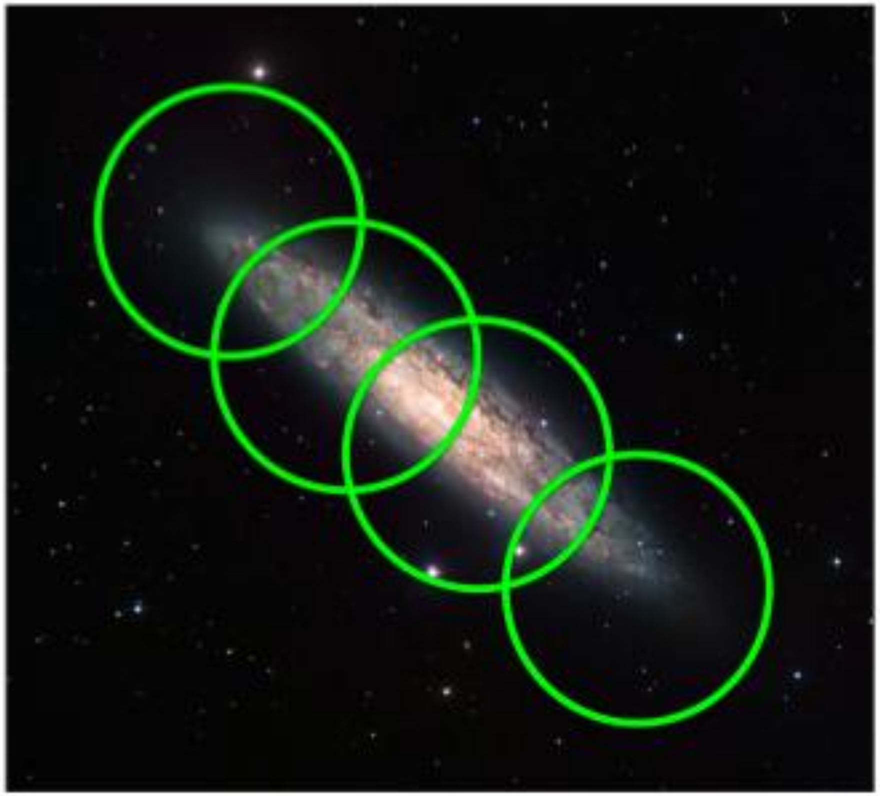


Extremely Large Telescope



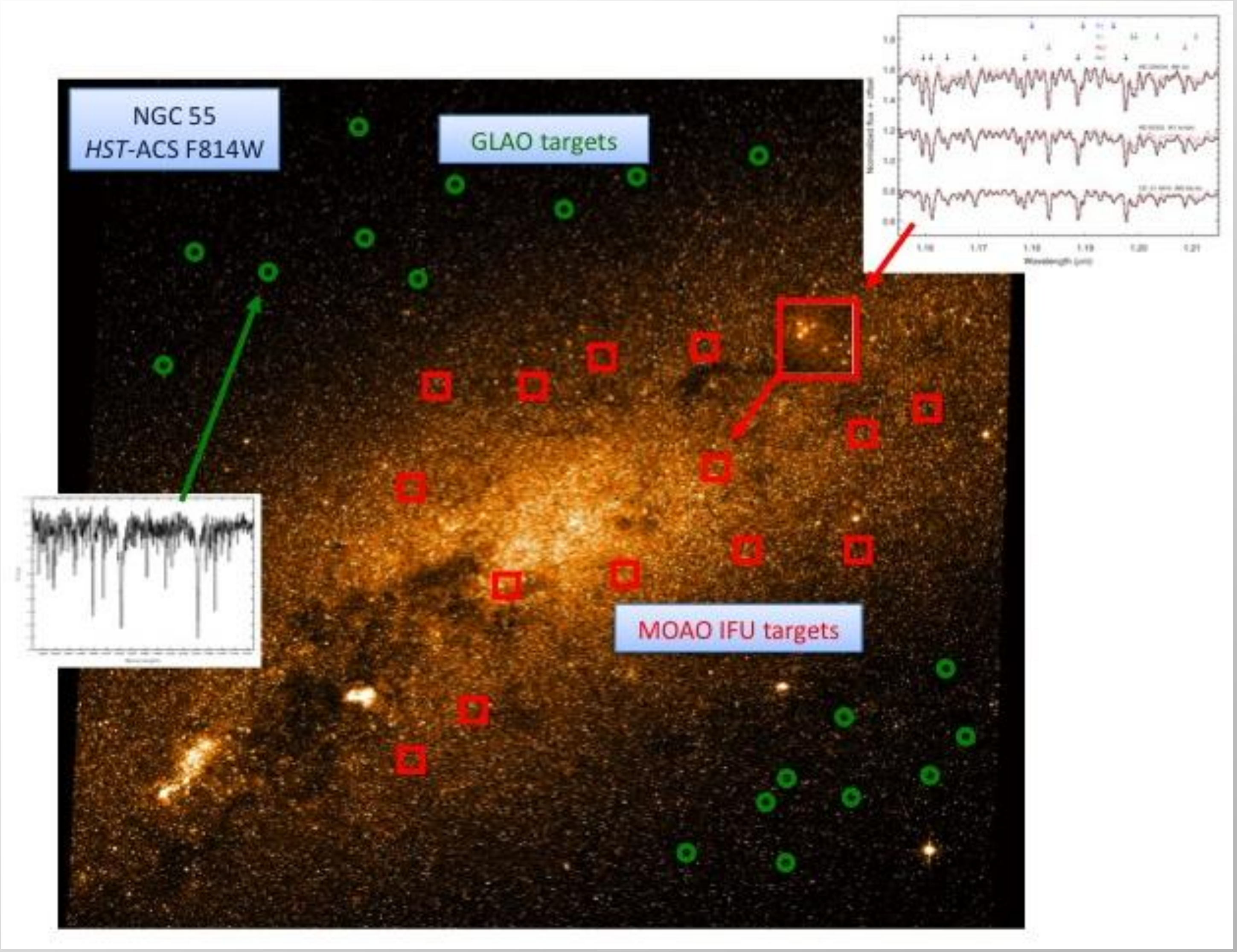
ELT-MOS pointings in NGC 55





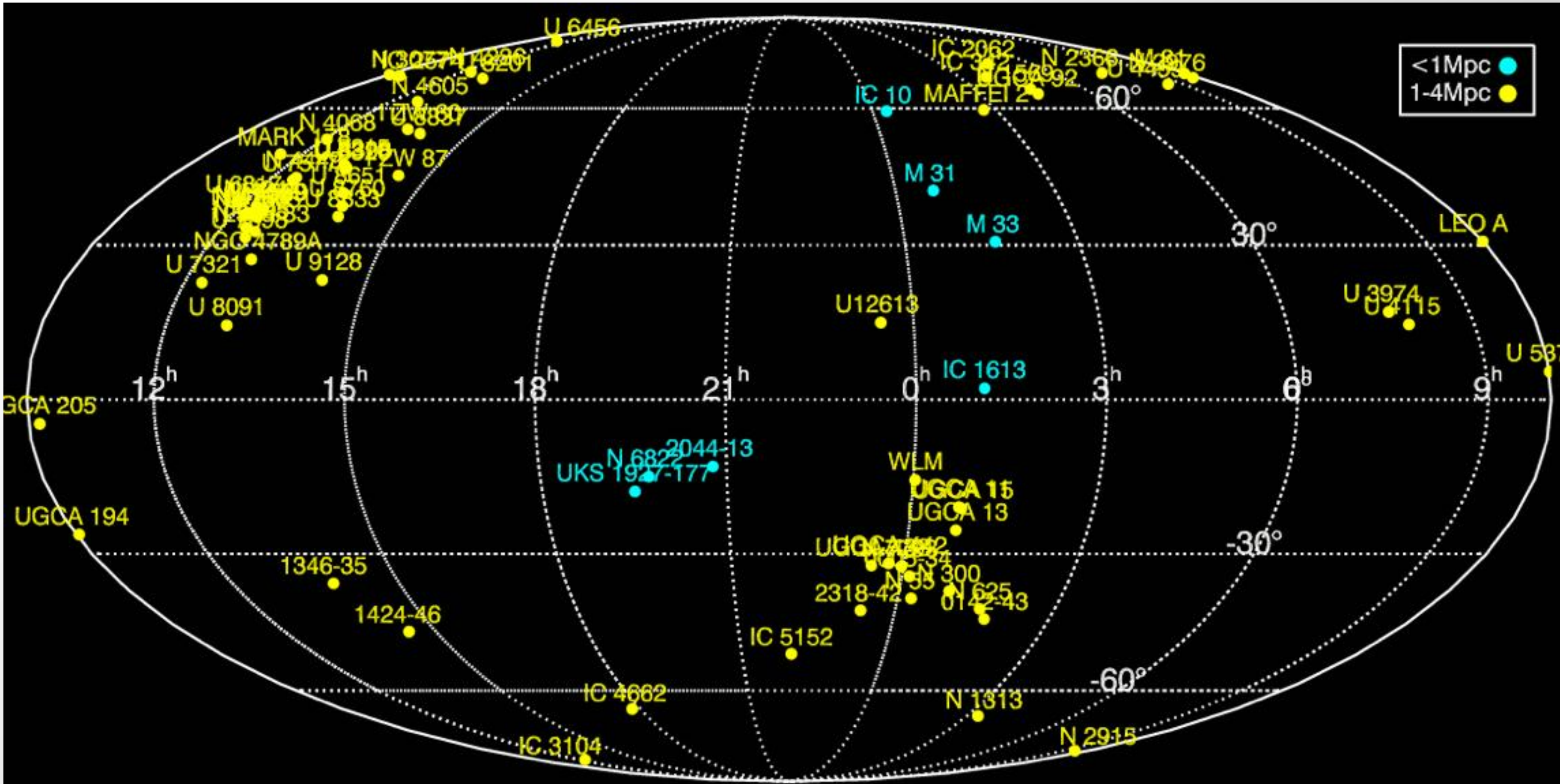
E-ELT/MOS example: NGC 55

Evans et al. Proc. SPIE
arXiv:1207.0768




RSG J-band spectra in Virgo
with S/N ~ 200
in 1 night E-ELT

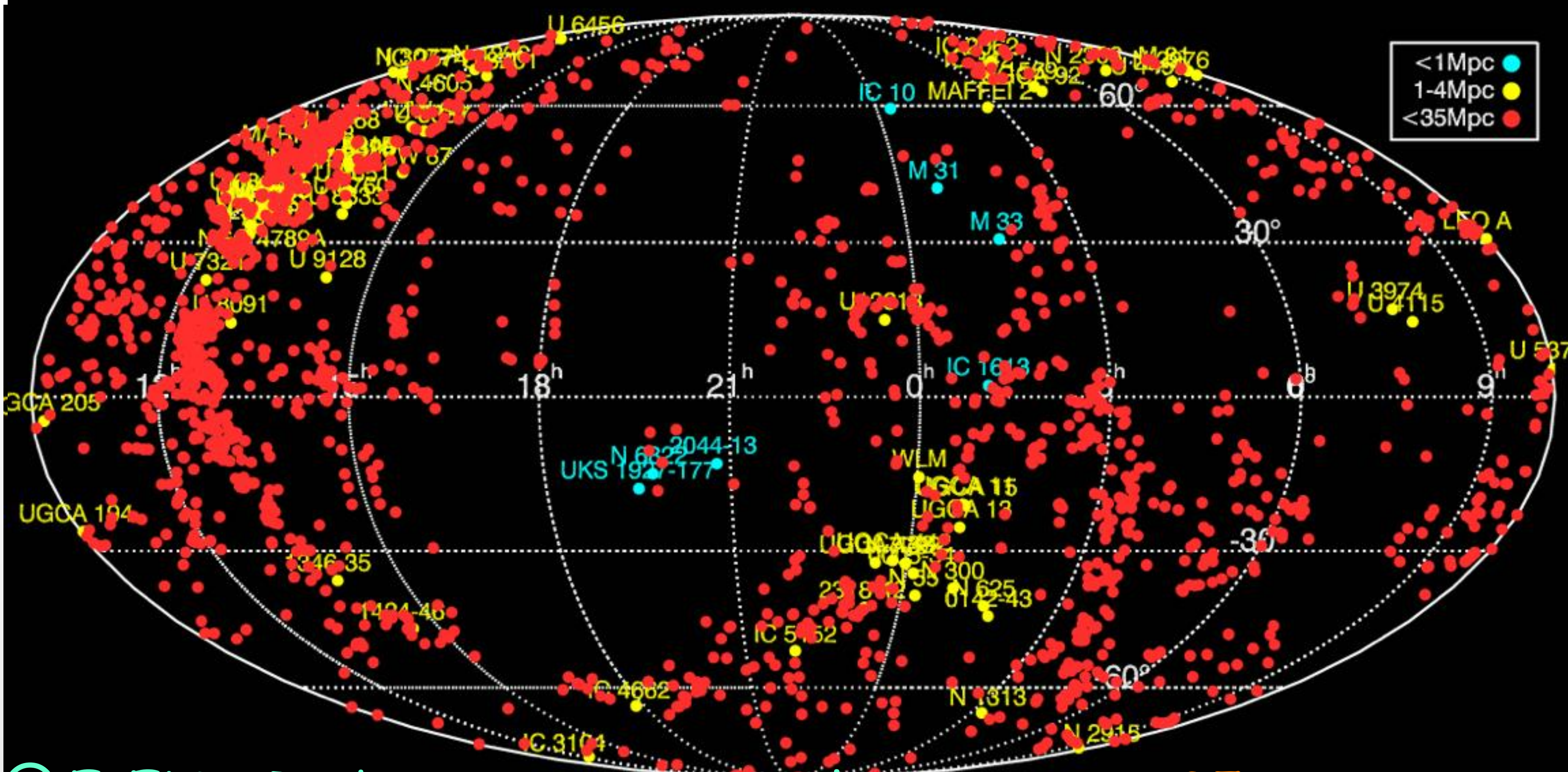
© Ben Davies



Evolved red giants in galaxies out to 4Mpc

- number of observable targets ~100

© Ben Davies



- E-ELT: Red supergiants in galaxies out to 35 Mpc
- number of observable targets increased to ~1500!!

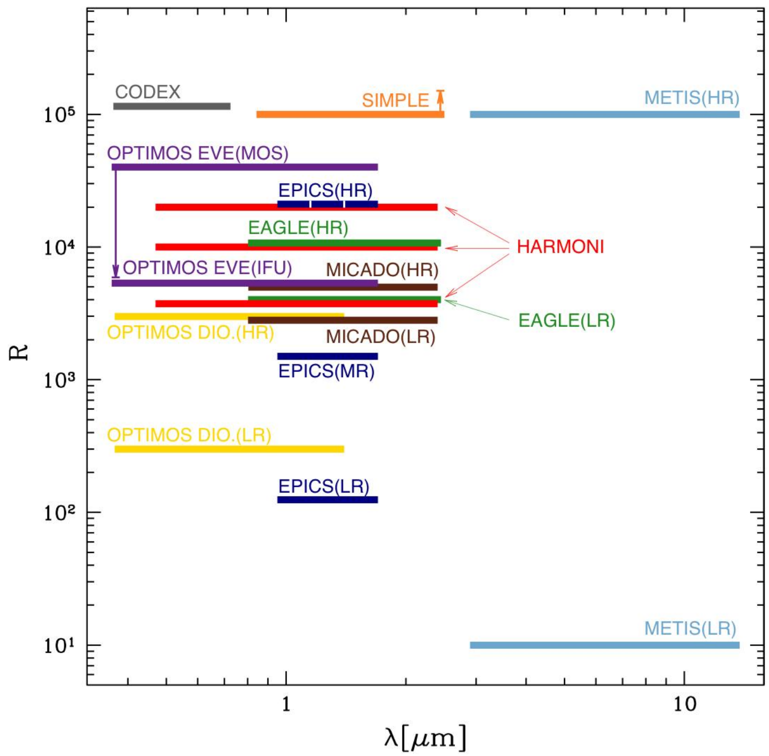
Conclusions

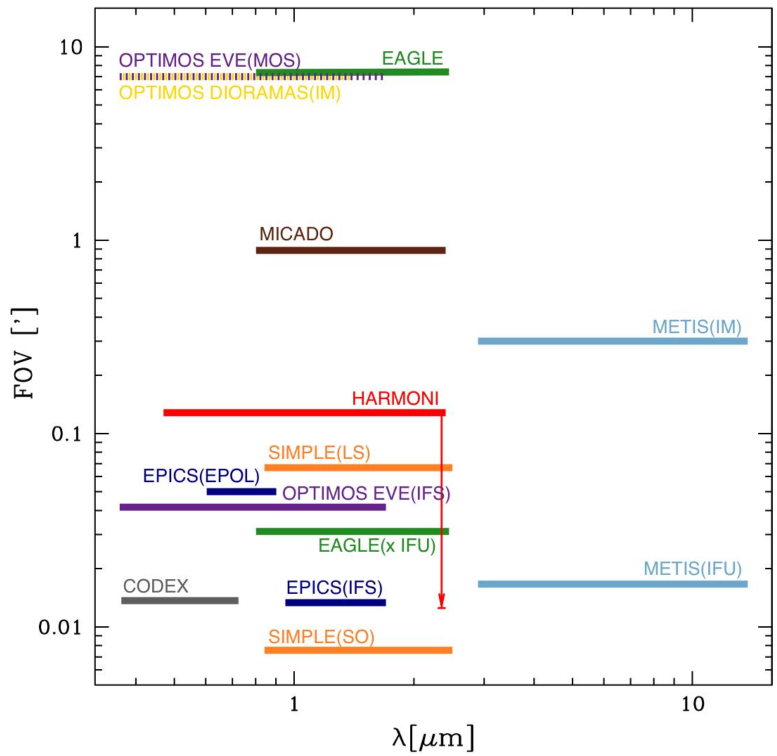
- A common focal plane has been a very fruitful approach to investigate the synergies and complementarities between different MOS concepts ➔ MOSAIC
- A fibre-link to HIRES seems to be a logical next step in this appraoch.
- Do not assume that it is impossible, just make the engineers think harder.
- With the E-ELT it will become possible to study massive star populations in a representative sample of galaxies (up to the Virgo cluster). *Extra-galactic astronomy and astrophysics will merge.*
- It is obvious that at distances in and beyond the Local Group multi-object spectroscopy is the way forward (certainly if the amount of telescope time is limited).

Conclusions

- With the E-ELT it will become possible to study massive star populations in a representative sample of galaxies (up to the Virgo cluster) in a way similar to current Galactic (and MC) studies.
  Extra-galactic astronomy and astrophysics will merge.
- Current observations with e.g. X-shooter and FLAMES/GIRAFFE show the potential of such studies (and deliver already very important results).
- It is obvious that at distances in and beyond the Local Group multi-object spectroscopy is the way forward (certainly if the amount of telescope time is limited).

E-ELT instrumentation





Year	ELT-IFU	ELT-CAM	ELT-MIR	ELT-4 (MOS or HIRES)	ELT-5 (MOS or HIRES	ELT-6	ELT-PCS
2012	Decide science requirements, AO architecture.		VISIR start on-sky	Develop science requirements for MOS/HIRES			Call for proposals for ETD
2013			TRL Review	Call for proposals for MOS/HIRES			
2014							
2015				Selection ELT-MOS/HIRES		Call for proposals	
2016							
2017							TRL check
2018							TRL check
2019						Selection	TRL check
2020							TRL check
2021							TRL check
2022 Tel technical first light							

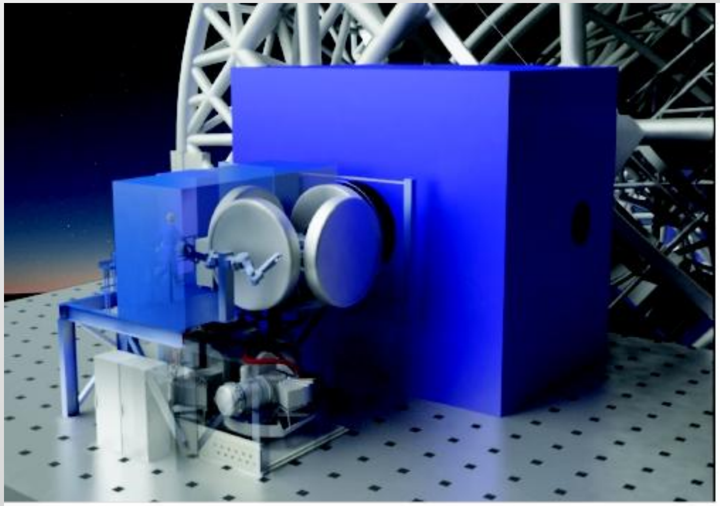
	Pre-studies taking the form of phase A or delta-phase A work and/or ESO-funded Enabling Technology Development (ETD)
	Decision point
	Development of Technical Specifications, Statement of Work, Agreement, **Instrument Start.**

Table 1.2. The E-ELT instrumentation roadmap.

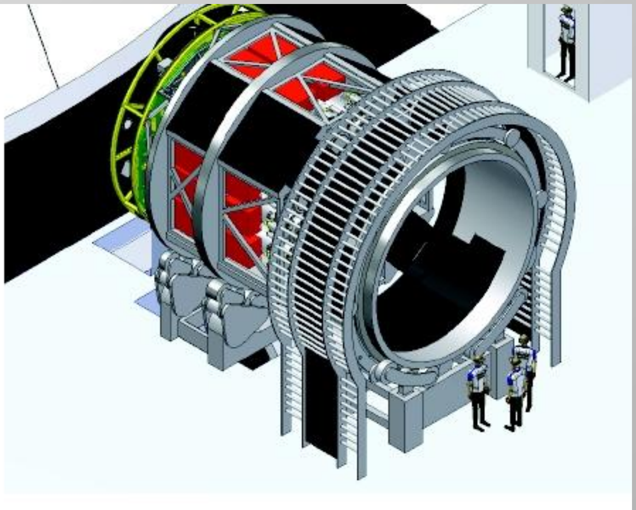
E-ELT MOS

- Explore E-ELT's large field of view: 10′ x 10′
- Obtain optical-NIR spectra of several hundred targets in one shot
- At low-level AO (OPTIMOS-EVE, *high multiplex*) or high-level AO (EAGLE, *high definition*)

➔ MOSAIC



OPTIMOS-EVE



EAGLE