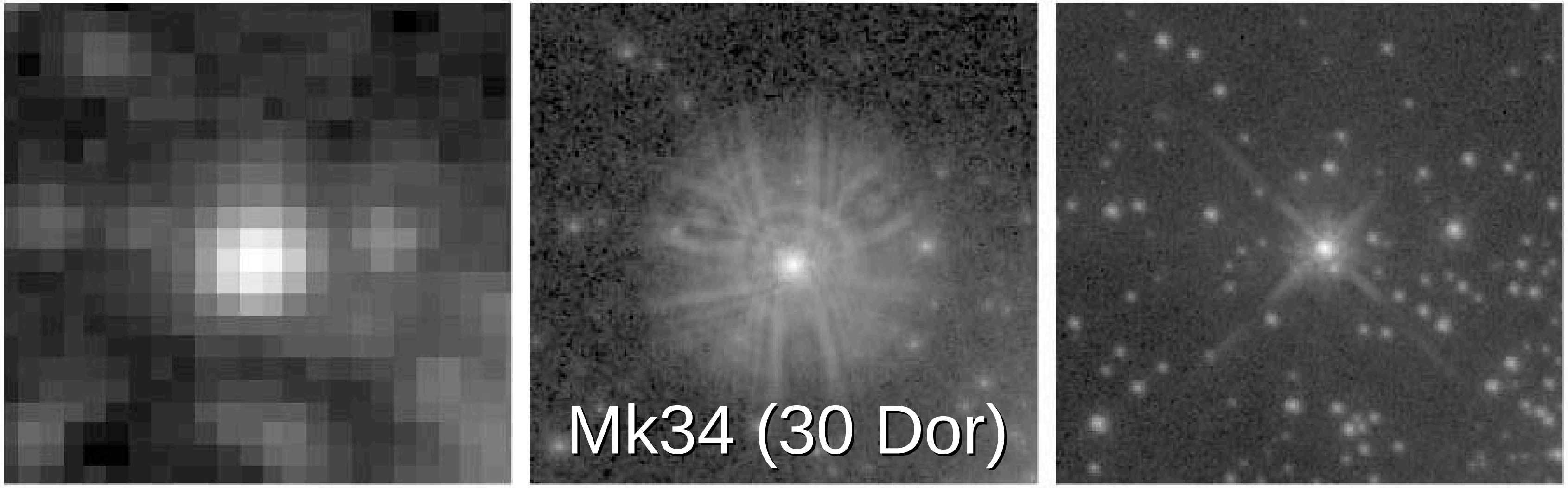
Hot Massive Stars: The Impact of HST



Ground image at 0.6 arcsec resolution | WFPC-1 image (before servicing) | WFPC-2 image (after servicing)

Paul Crowther

The University Of Sheffield.

Outline

- Massive stars - Introduction
- Stellar winds - Metallicity dependent winds
- Ejecta nebulae - Signatures of mass ejections
- Massive binaries - Colliding winds
- Young star clusters - A plethora of hot stars
- Starbursts knots - Templates for high-*z* galaxies

High Mass Stars

- High mass stars (M_{init}>8-9$M_{\odot}$), end their lives as core-collapse SN (Smartt talk)
- They possess high central pressures & temperatures & so burn much brighter than lower mass stars. For Solar-type stars $L \sim M^{4.7}$ while for high mass stars $L \sim M^{2.5}$
- A 25 $M_{\odot}$ star shines 50,000 times brighter than the Sun, so that it lives for only 1/2000 of the Solar lifetime (5Myr versus 11,000Myr for Sun)

Importance of massive stars

- Massive stars are intrinsically luminous, so may be detected individually to large distances (e.g. Blue supergiants seen at Mpc distances);
- O stars are the primary source of Lyman cont. photons in galaxies, & so enable the primary diagnostic of SFR (e.g. L(Hα), Kennicutt 1998);
- Stellar winds are up to 10^9 more powerful than the Solar case $\Rightarrow$ chemical enrichment, kinetic energy;
- In high-z star forming galaxies, signatures of massive stars are seen *directly* (UV continua, wind lines) & *indirectly* (ionized gas).

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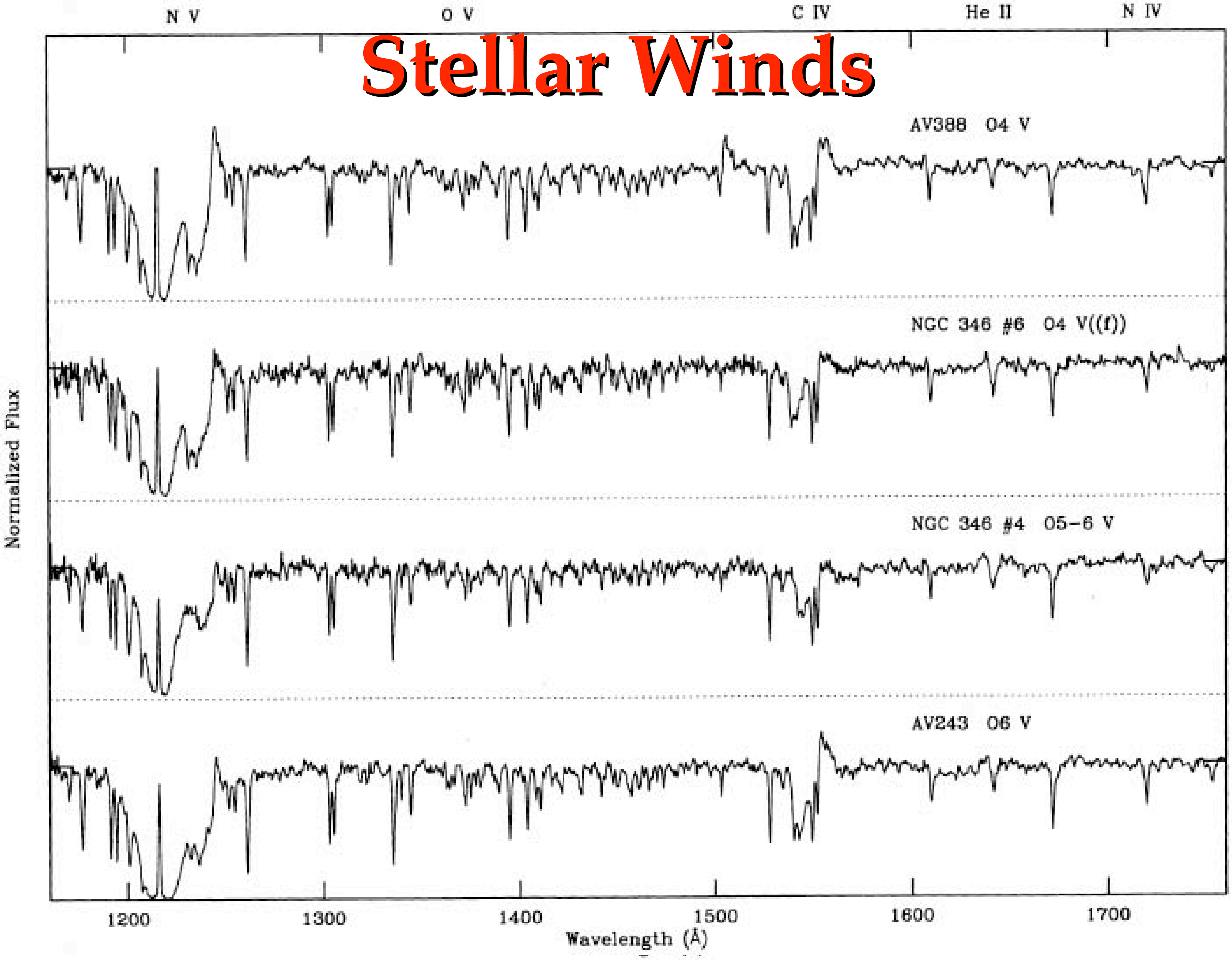
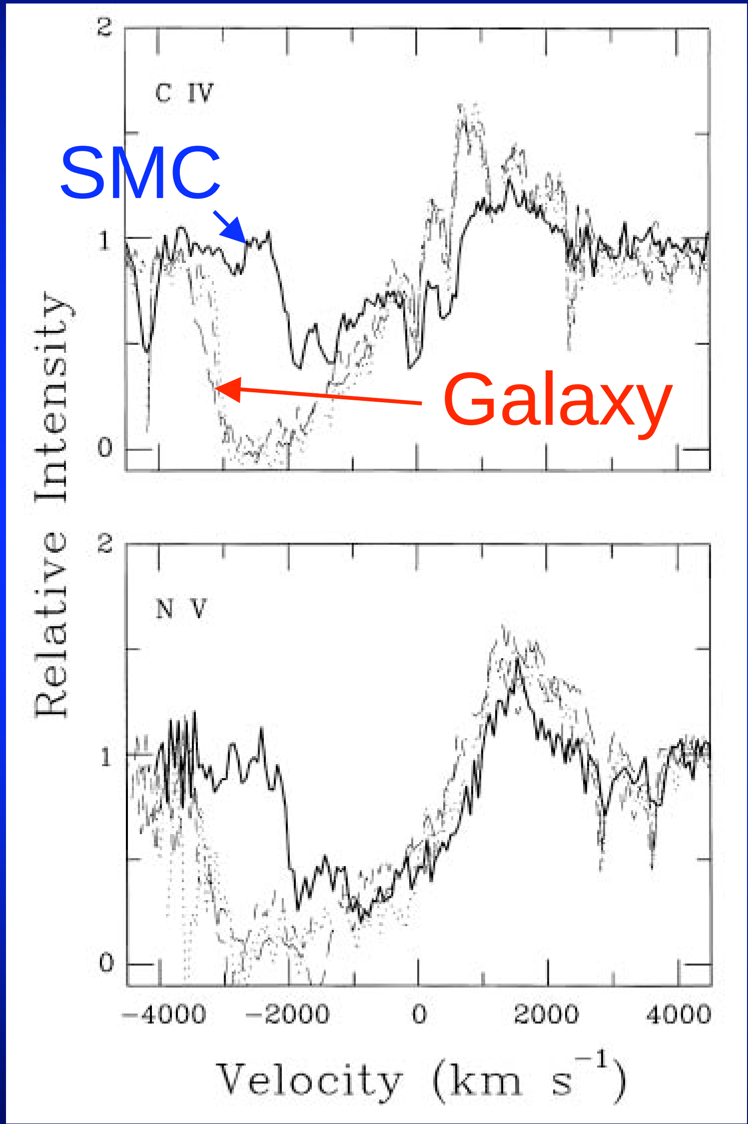
Stellar Winds



Metallicity dependent winds

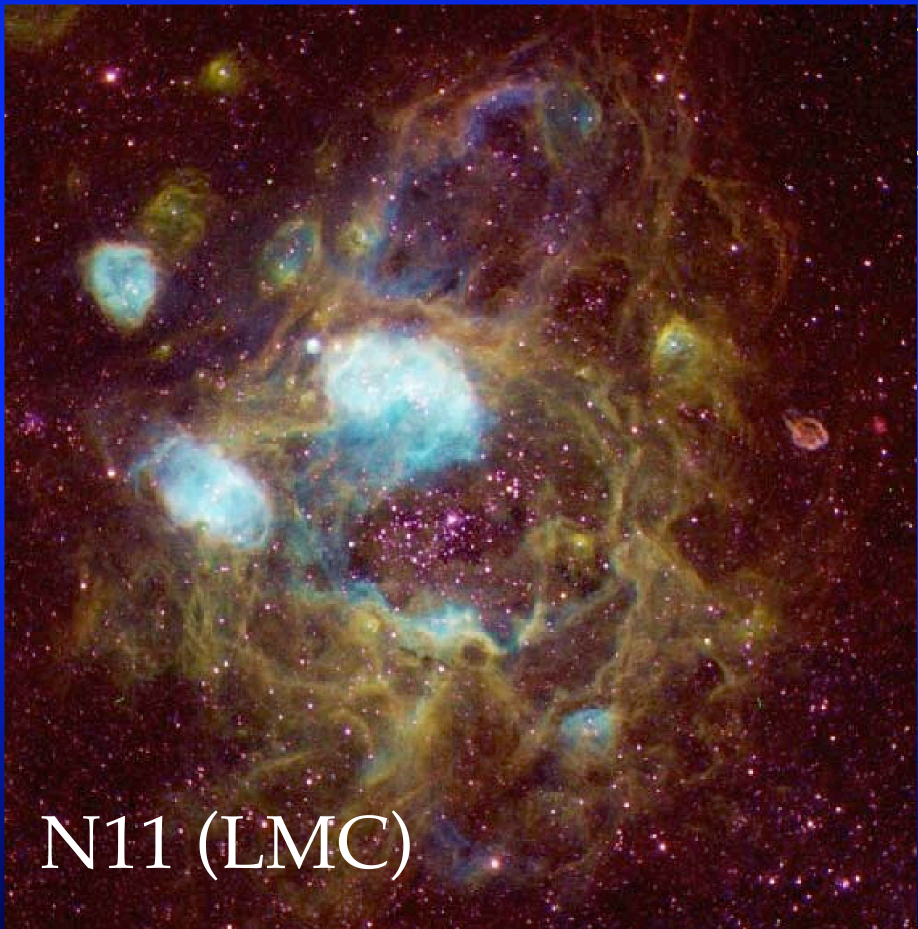
Winds predicted to be driven by radiation pressure through (CNO, Fe-peak) metal-lines (Puls et al. 2000; Vink et al. 2001).

HST confirmed expected weaker, slower winds in low metallicity SMC (e.g. Prinja & Crowther 1998)

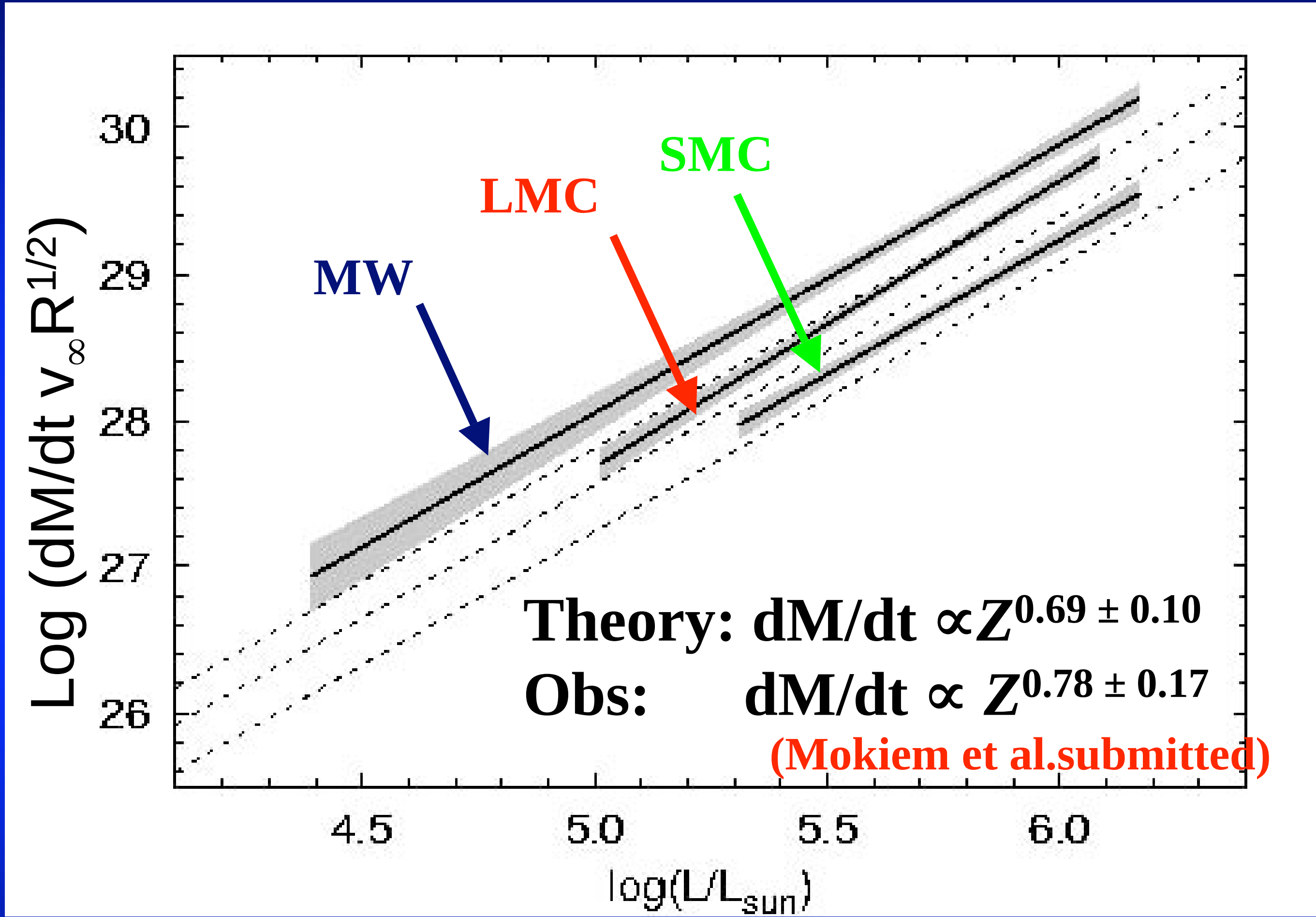


VLT/FLAMES survey

'Young' clusters	'Old' clusters
(<5 Myr)	(10-20 Myr)



Mass-loss rates



VLT/FLAMES survey provides dM/dt (Mokiem et al. 2006, 2007). Z-dependent OB star winds needed for evolutionary models.

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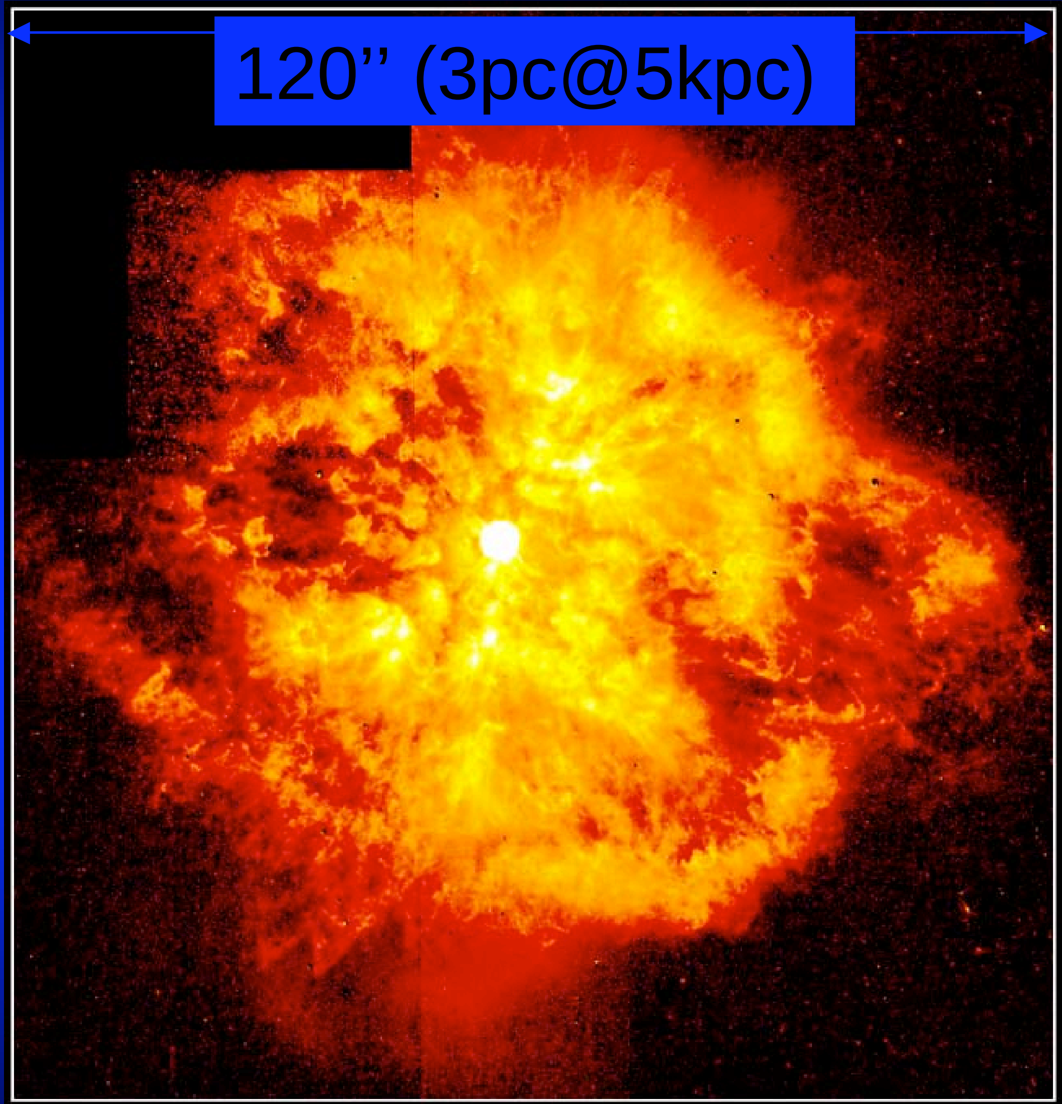
Nebulae

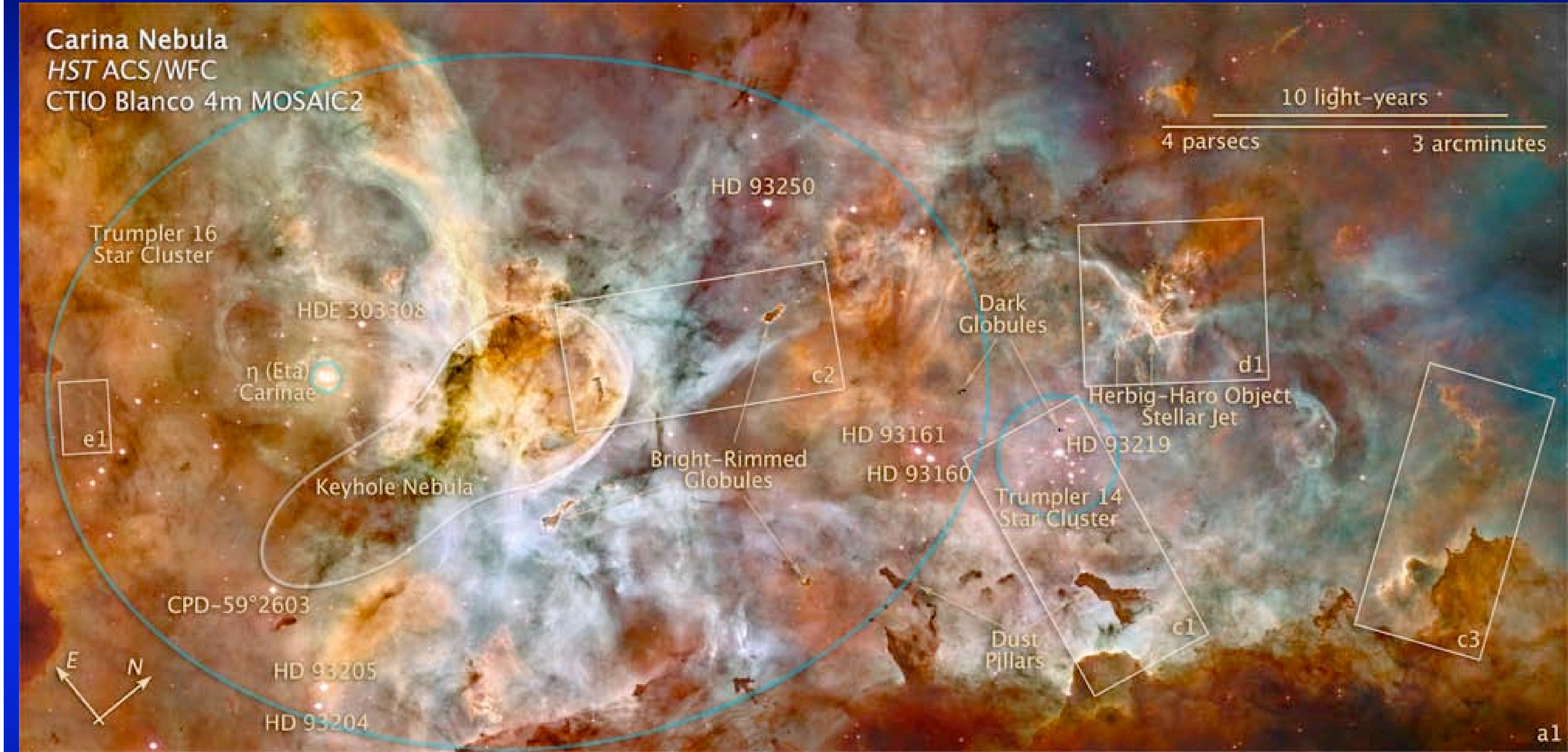
Recent mass-loss history of Wolf-Rayet star WR124 revealed by ejecta nebula (Grosdidier et al 1998).

Radial density distribution of nebula provides wind structure & enables photo-ionization models of central star (Crowther et al. 1999).



Nebula M1-67 around Star WR124 HST • WFPC2
PRC98-38 • STScI OPO • November 5, 1998
Y. Grosdidier and A. Moffat (University of Montreal) and NASA

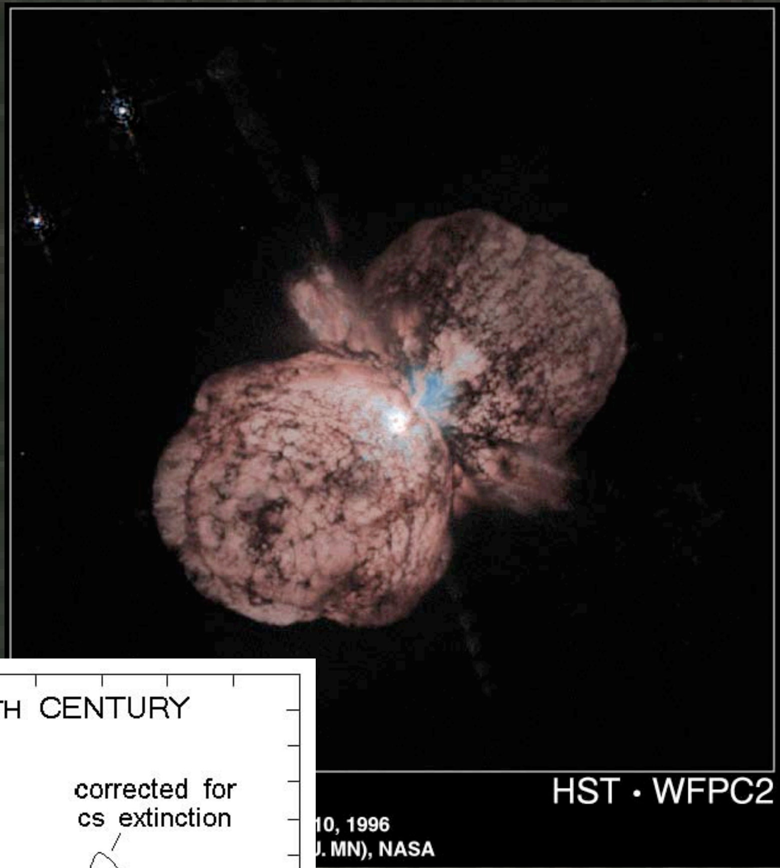
η Carinae



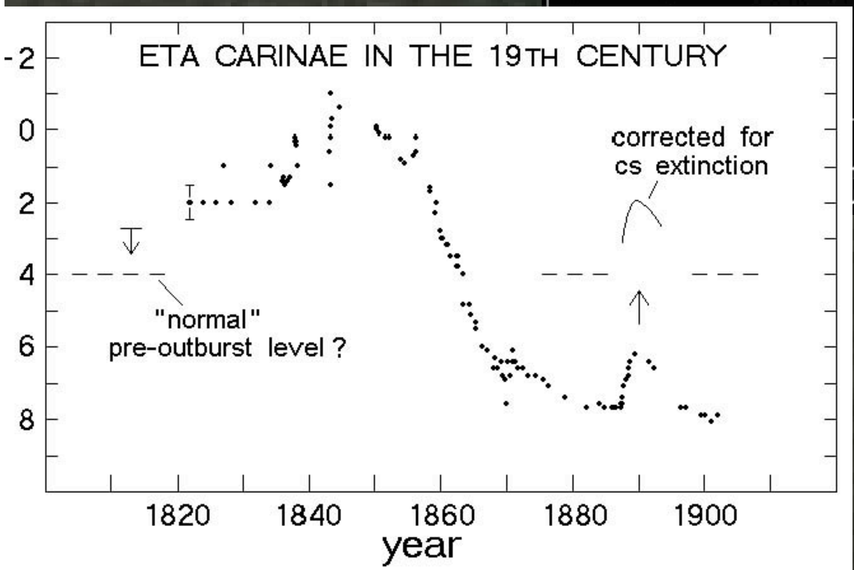
In addition to continuous winds, some blue supergiants occasionally undergo violent eruptions

Homunculus

AAT

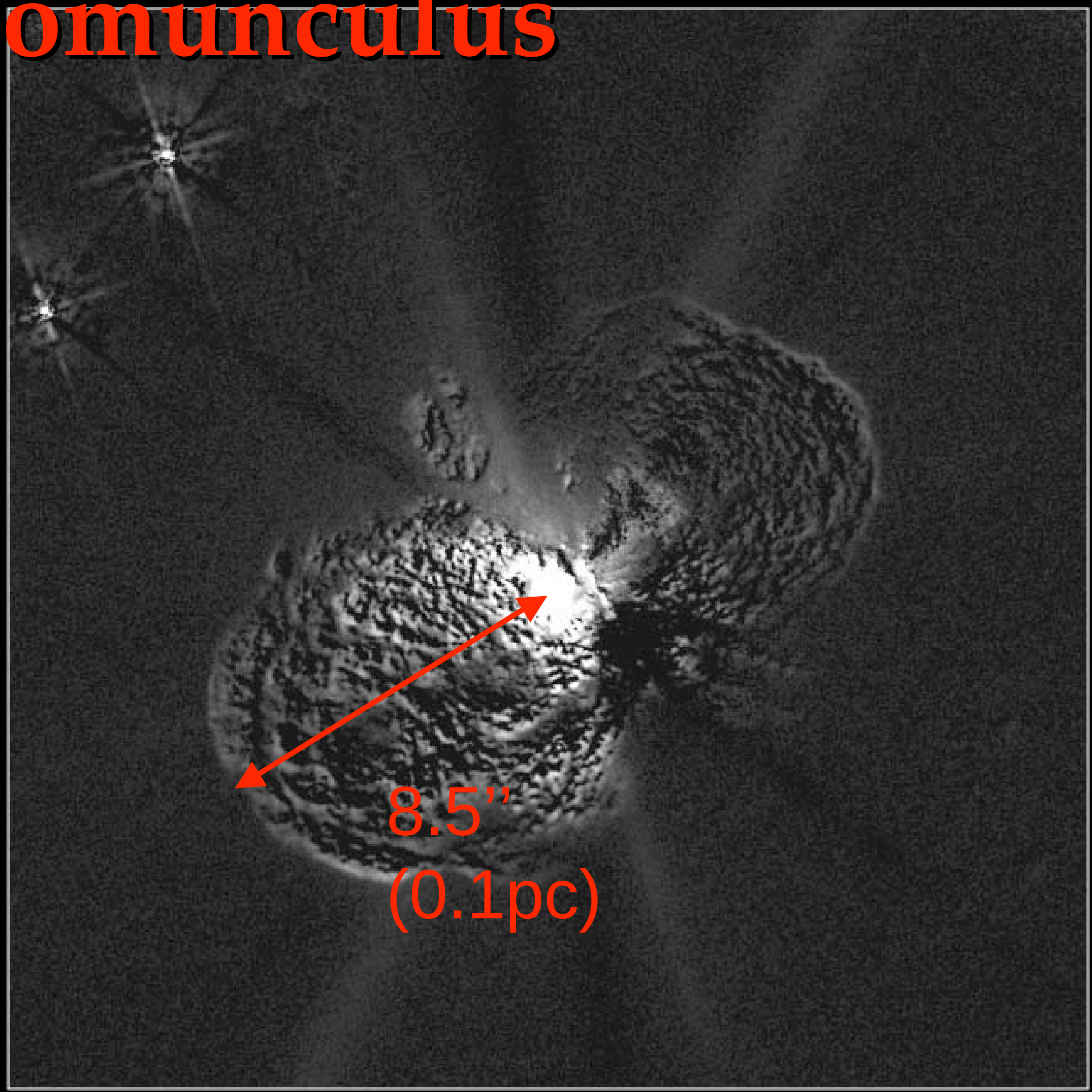


η Car `erupted' in 19th Century, becoming 2nd brightest star in sky, forming the Homunculus, a dusty reflection nebula (10 M_o?) illuminated by the star.



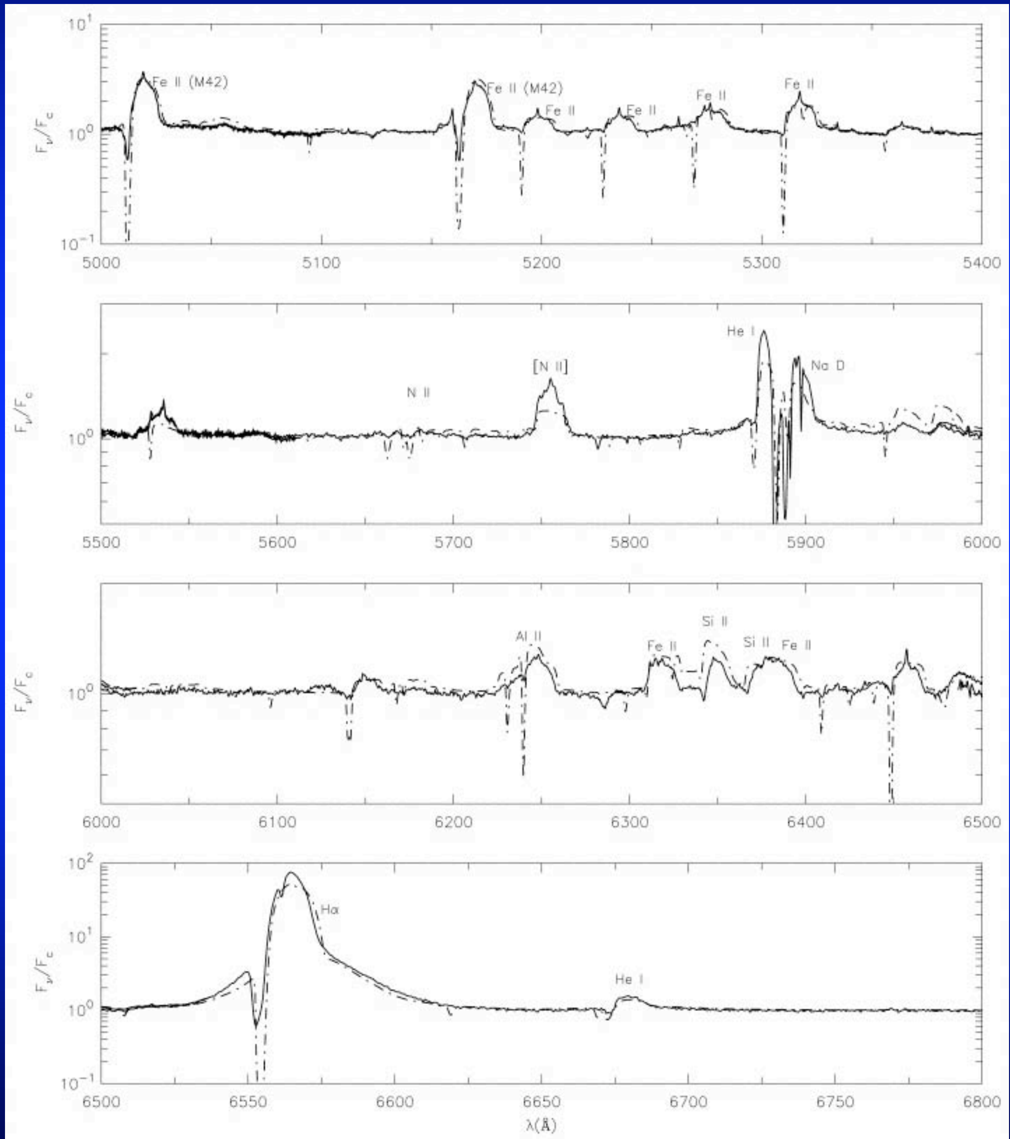
Homunculus

HST/WFPC2 image (50mas = 115AU res) shows the expansion from 4/94 - 9/95 (Morse et al. 1998).
A physical mechanism remains unclear (see e.g. Smith & Townsend 2007)



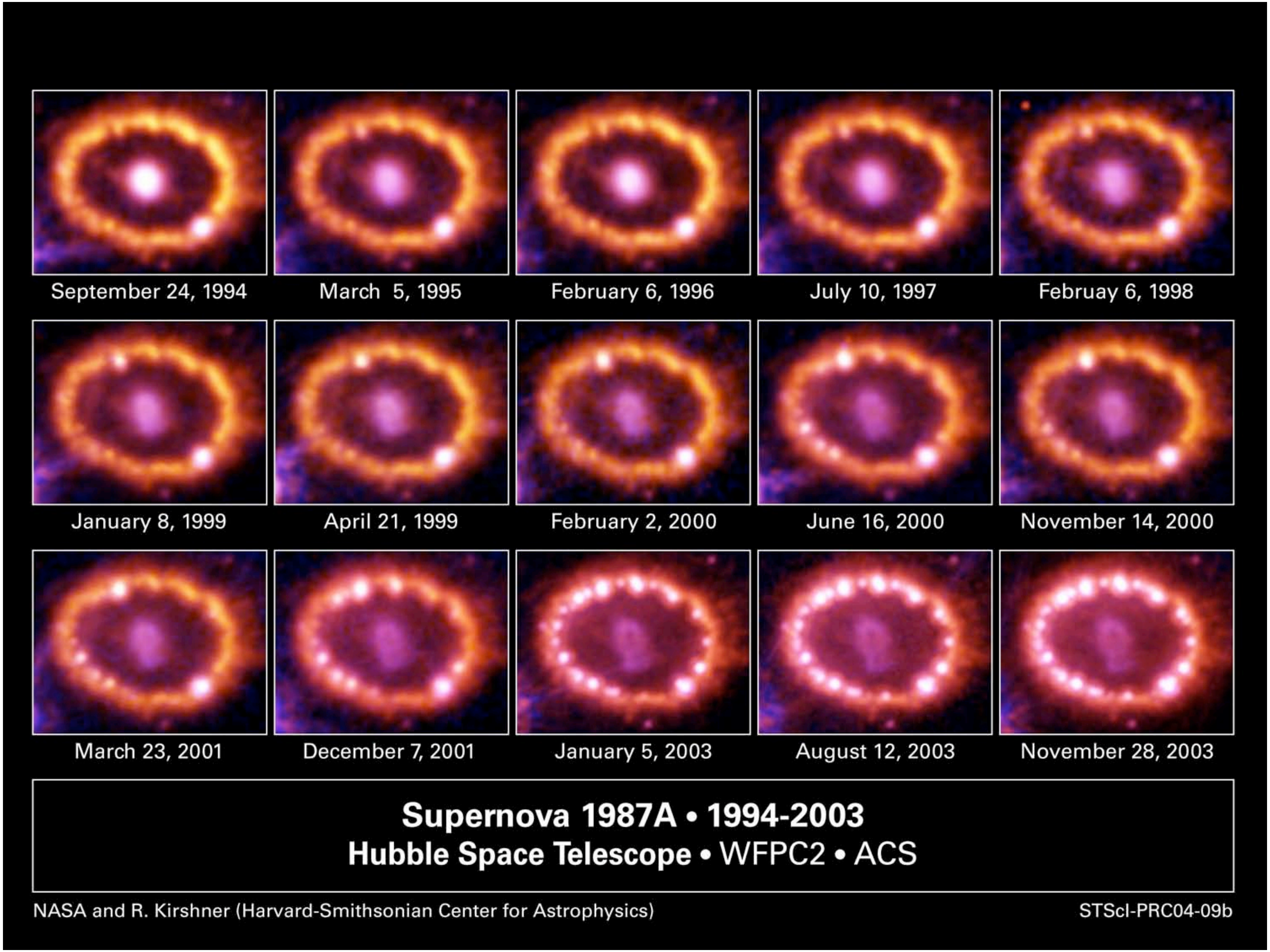
Changes in Eta Carinae HST • WFPC2
PRC96-23b • ST ScI OPO • June 10, 1996
J. Morse (U. CO), K. Davidson, (U. MN), NASA

Central star of η Carinae



Recent effort has focused upon nature of *central star*, apparently a binary (5.5yr period).

STIS 0.1x0.1" long-slit spectrum of central star reveals extreme parameters of $L=5x10^6\ L_\odot$ $dM/dt=10^{-3}\ M_\odot/yr$ (Hillier et al. 2001)


September 24, 1994
March 5, 1995
February 6, 1996
July 10, 1997
Februay 6, 1998
January 8, 1999
April 21, 1999
February 2, 2000
June 16, 2000
November 14, 2000
March 23, 2001
December 7, 2001
January 5, 2003
August 12, 2003
November 28, 2003
Supernova 1987A • 1994-2003
Hubble Space Telescope • WFPC2 • ACS
NASA and R. Kirshner (Harvard-Smithsonian Center for Astrophysics)
STScI-PRC04-09b

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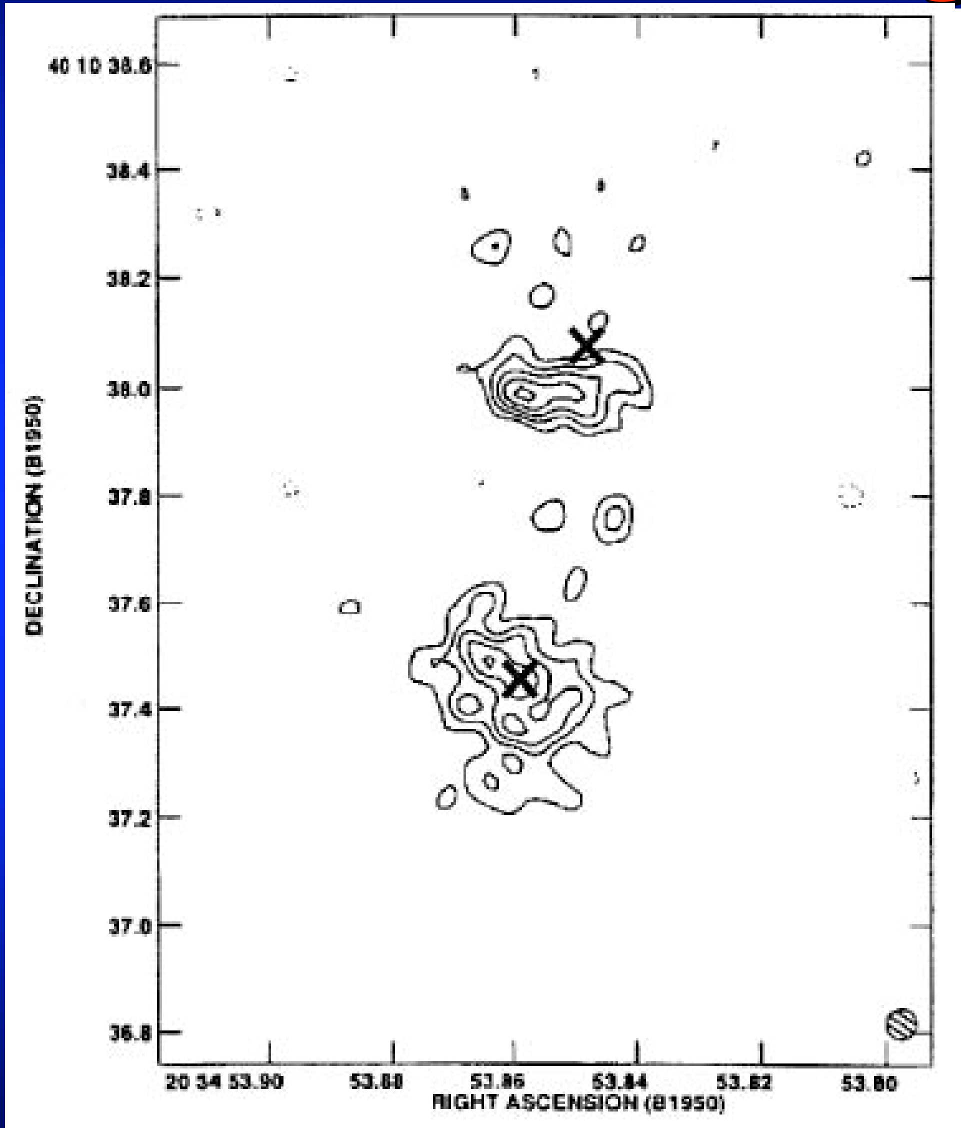
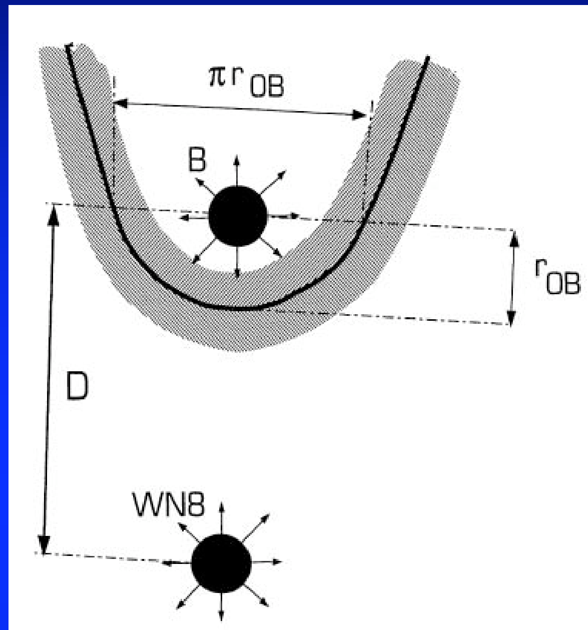
Colliding winds





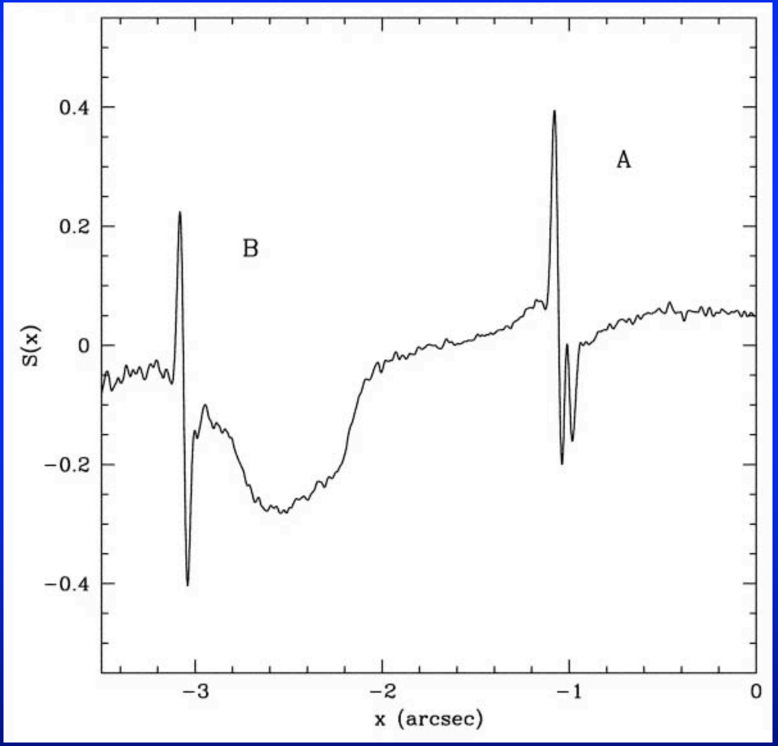
(e.g.
97)
ellar
mal

Positions of stars established by WFPC2 (Niemela et al. 1998) enabling their relative wind strengths.

New massive binaries

FGS enables searches for massive binaries in parameter space between spectroscopic (weeks) & astrometric (centuries) techniques.

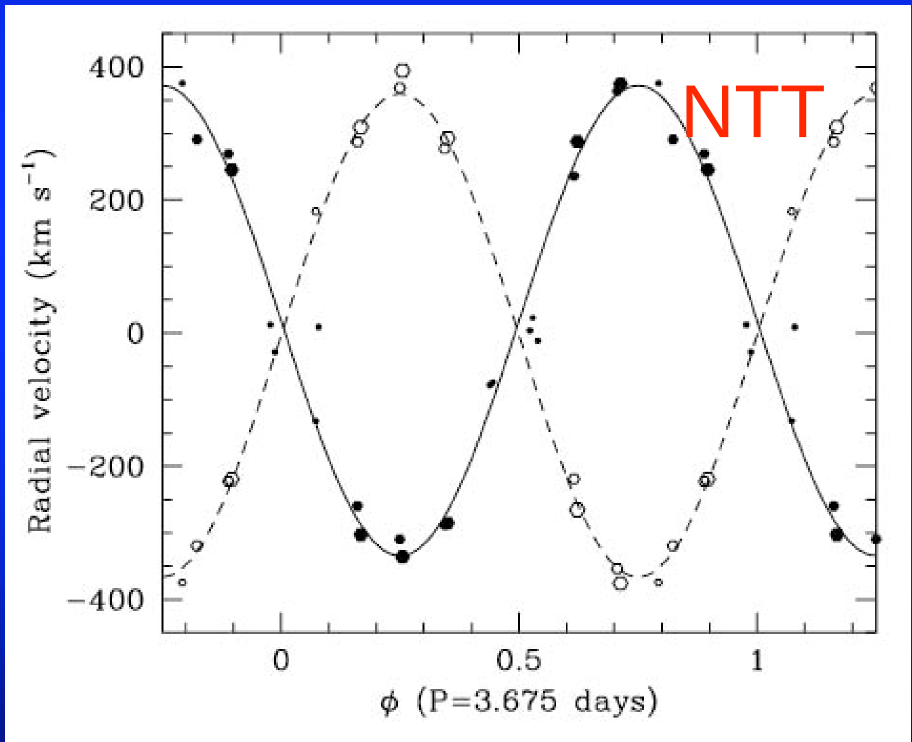
Survey of 23 OB stars in Carina revealed 5 new binaries, including an early O dwarf companion to HD93129A (prototype O2 supergiant), separated by only 55 mas (137AU). Later confirmed by detection of non-thermal radio emission.



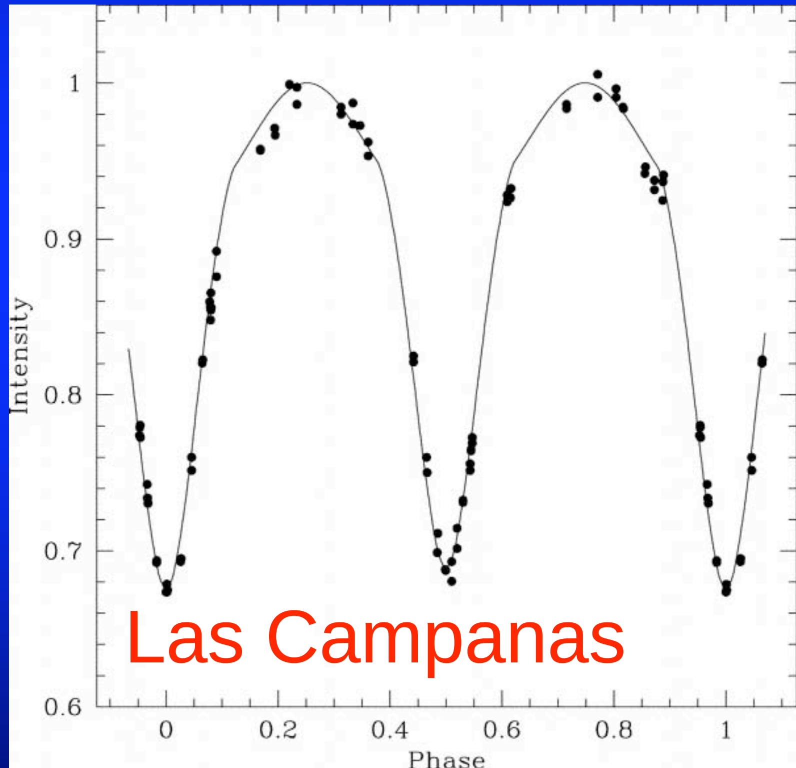
Nelan et al. (2004)

WR20a

To date, the 3.7day eclipsing binary system WR20a (2 x WN6) hosts the highest masses ($82M_\odot$, $83\ M_\odot$),



Rauw et al. 2004



Bonanos et al. 2004

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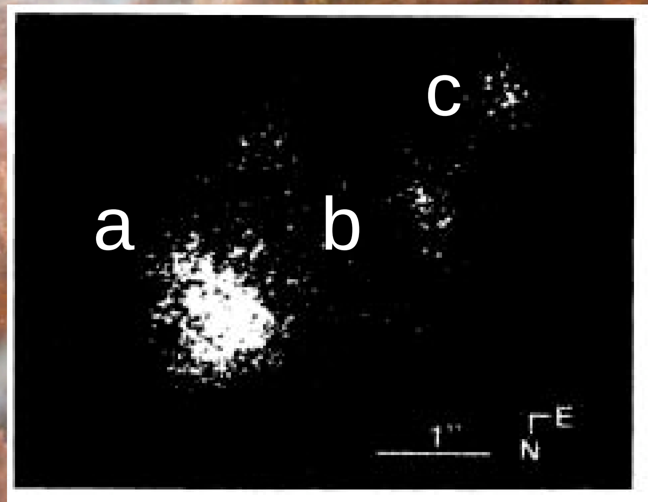
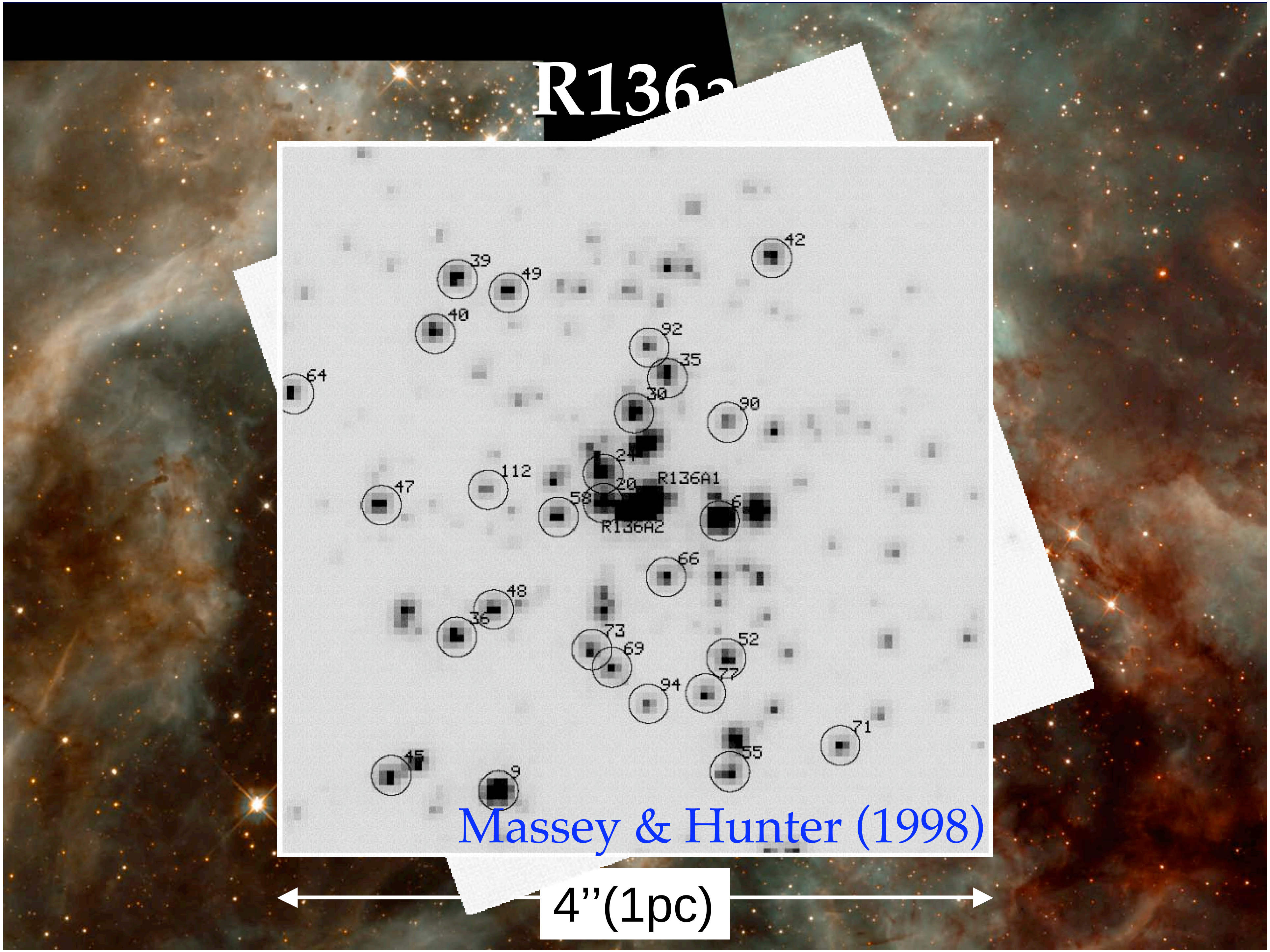
Spatially resolved clusters

Historically R136a, the ionizing cluster of 30 Doradus in the LMC, was considered as a potential supermassive star.

Weigelt & Baier(1985) first resolved R136a into multiple components using speckle imaging.

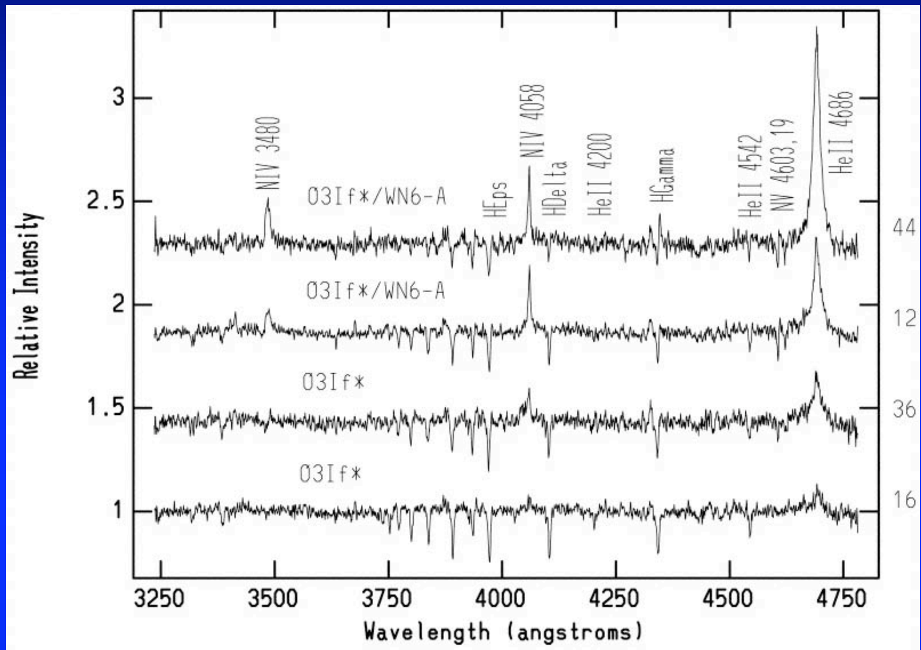


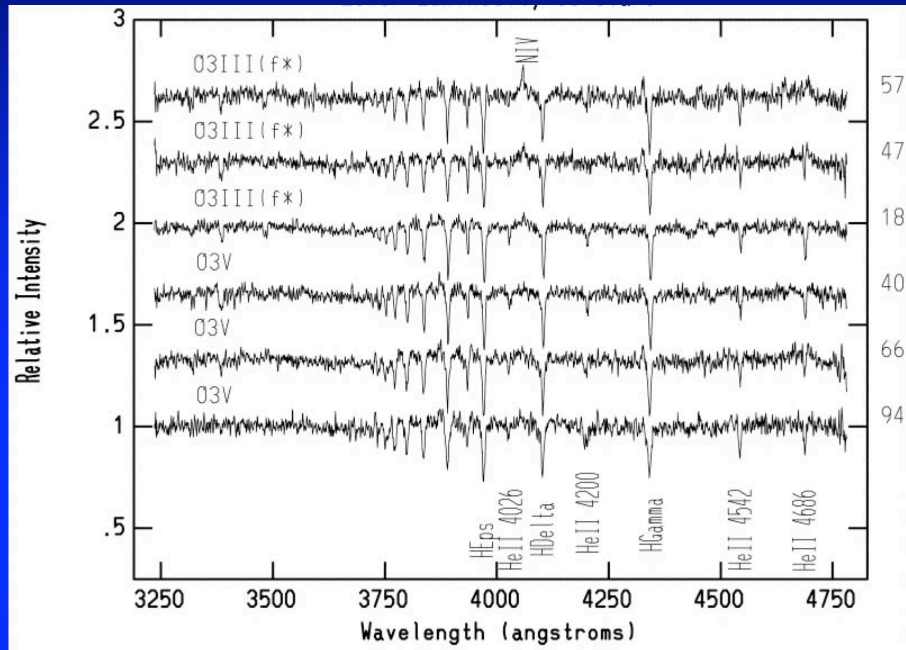
R136a



39
49
42
40
92
35
64
30
90
24
112
R136A1
47
20
58
6
R136A2
66
48
36
73
69
52
77
94
71
45
55
9
Massey & Hunter (1998)
4''(1pc)

A plethora of early O stars

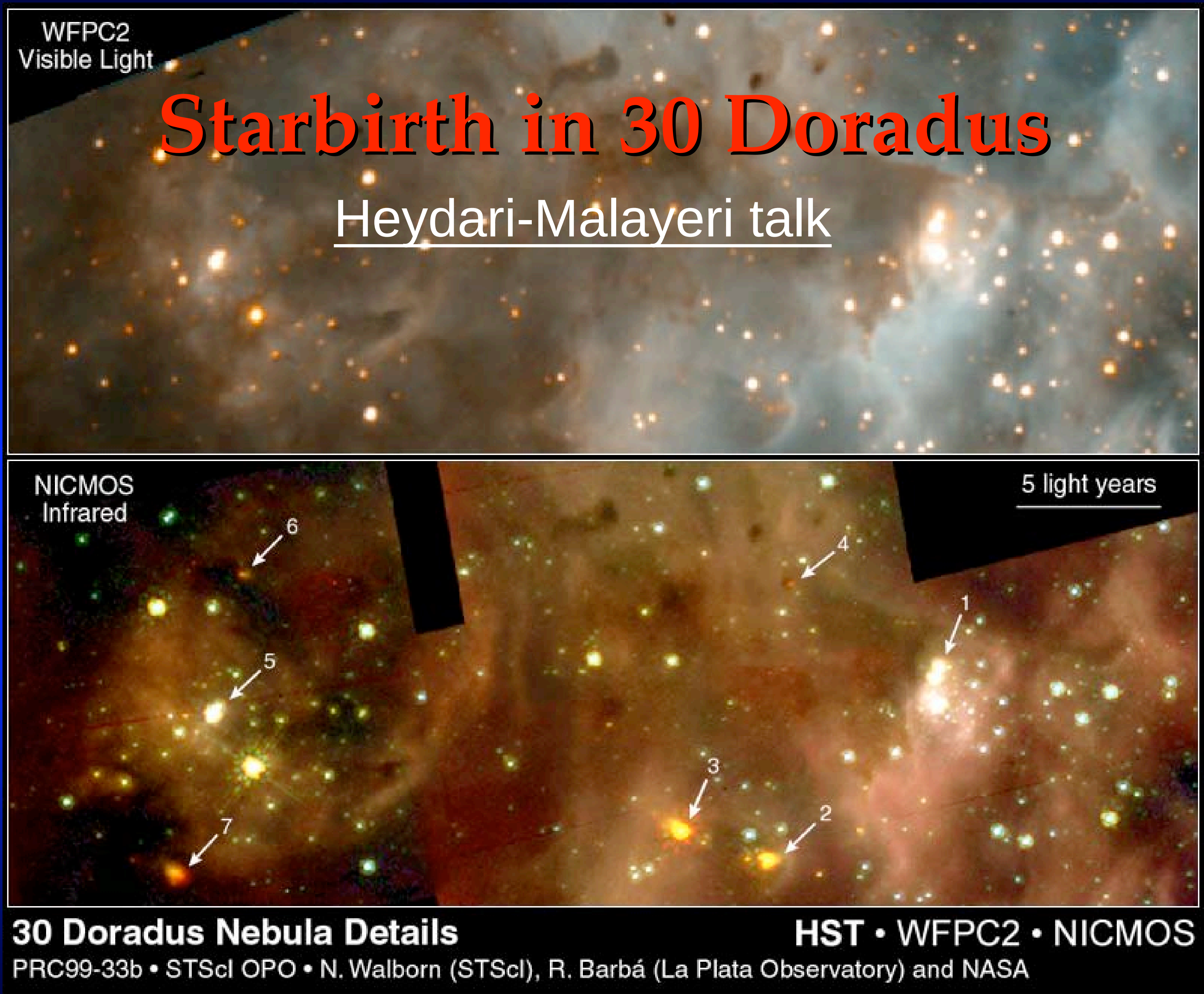




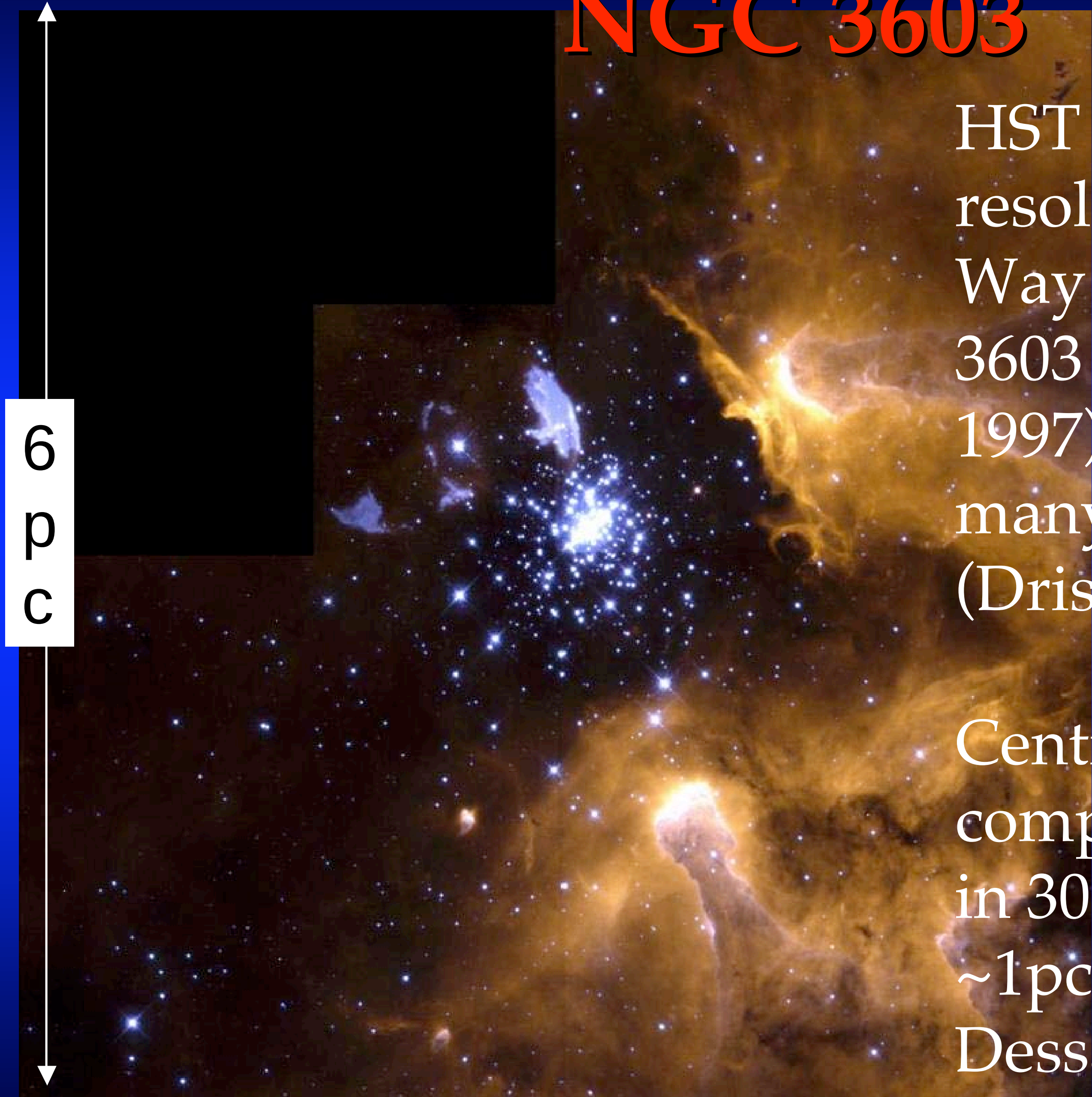
HST/FOS (Massey & Hunter 1998) spectroscopy revealed a multitude of early O stars in R136, indicating youth (1-2 Myr) & high individual stellar masses (>120 $M_\odot$). Total stellar mass of R136 probably exceeds 5×10^4 $M_\odot$

Starbirth in 30 Doradus

Heydari-Malayeri talk



NGC 3603



HST also spatially resolved the Milky Way cluster NGC 3603 (Brandner et al. 1997), again revealing many early O stars (Drissen et al. 1993).

Central cluster comparable to R136a in 30 Doradus within ~1pc (Crowther & Dessart 1998).

Arches cluster

The Ar
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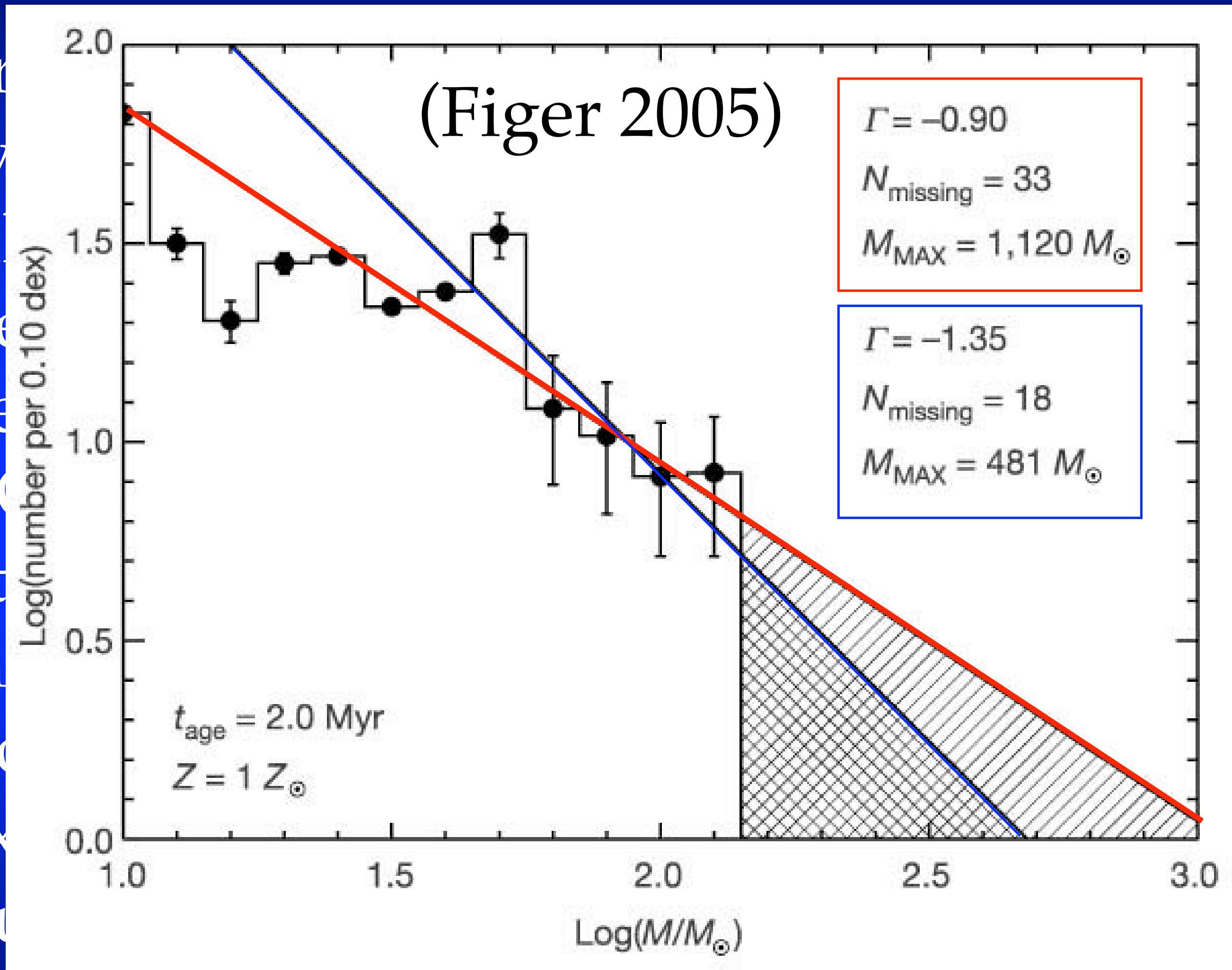
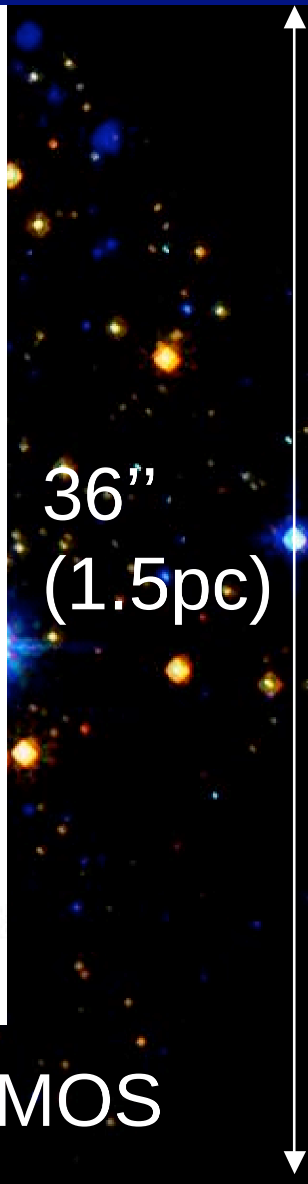
has bee
resolve
NICM
permit
presen
Functi
approx
IMF, su
upper stellar mass
limit of ~150 $M_\odot$

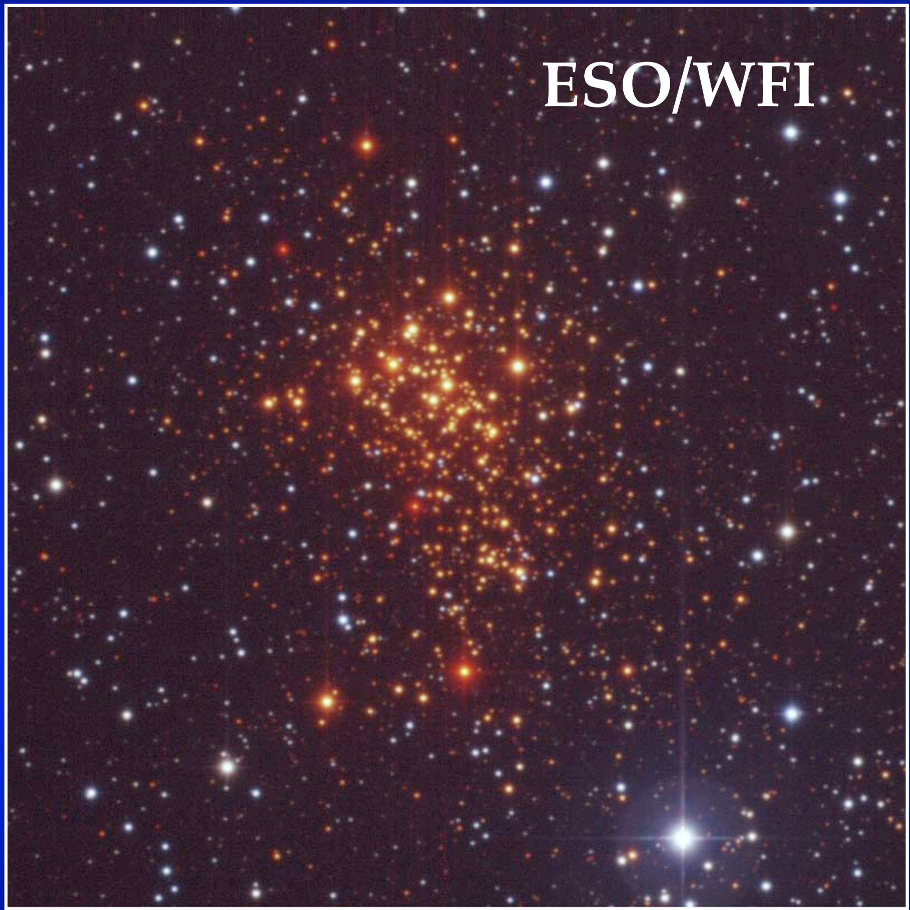




Westerlund 1

Westerlund 1 (Wd1) is a highly reddened (A_v~10 mag) young, compact Galactic cluster.

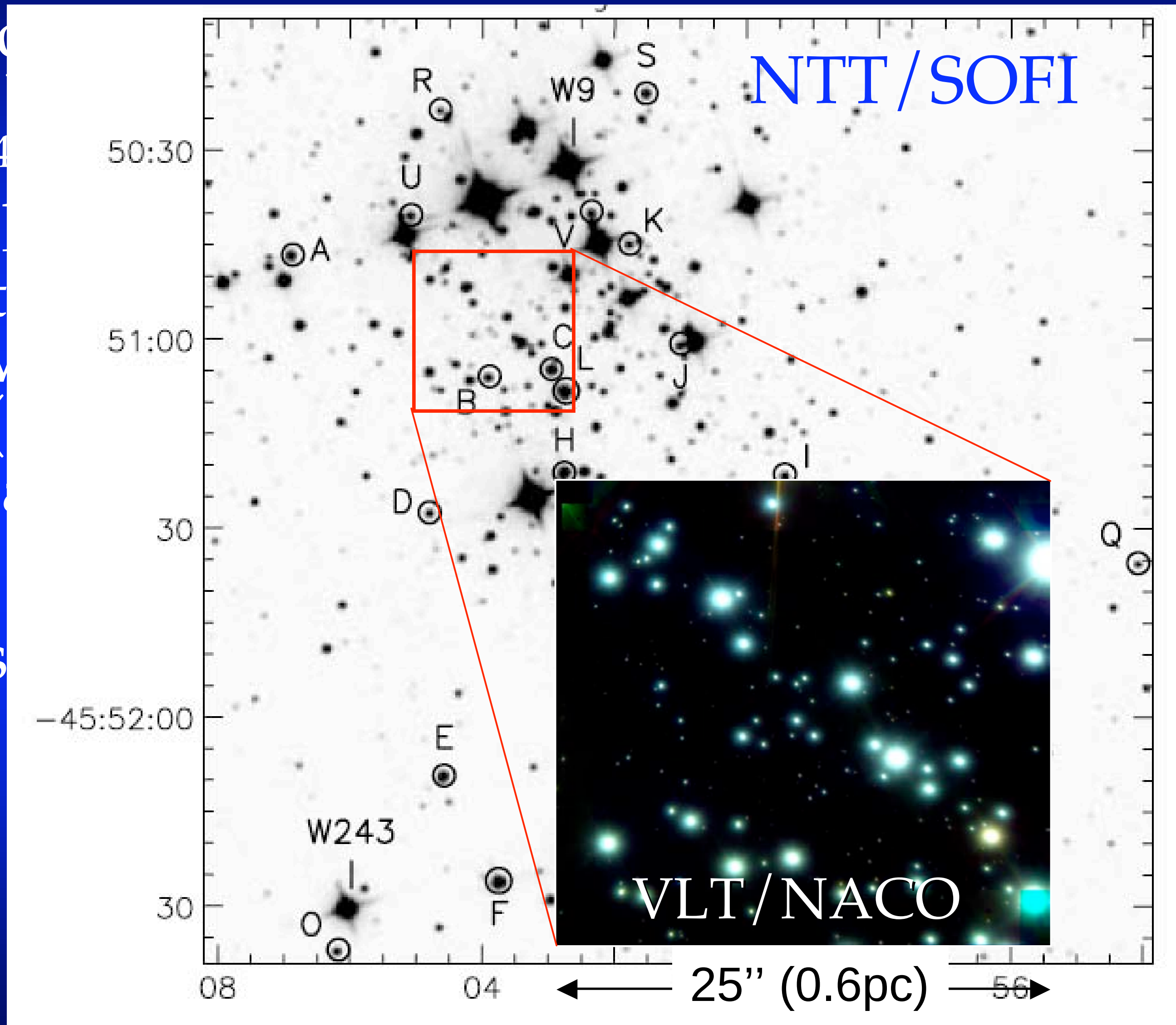
Discovery of Wolf-Rayet stars, Luminous Blue Variables, yellow hypergiants, red supergiants at ESO suggest Wd1 represents a very high mass cluster.



5 arcmin (7pc @ 4.5kpc)

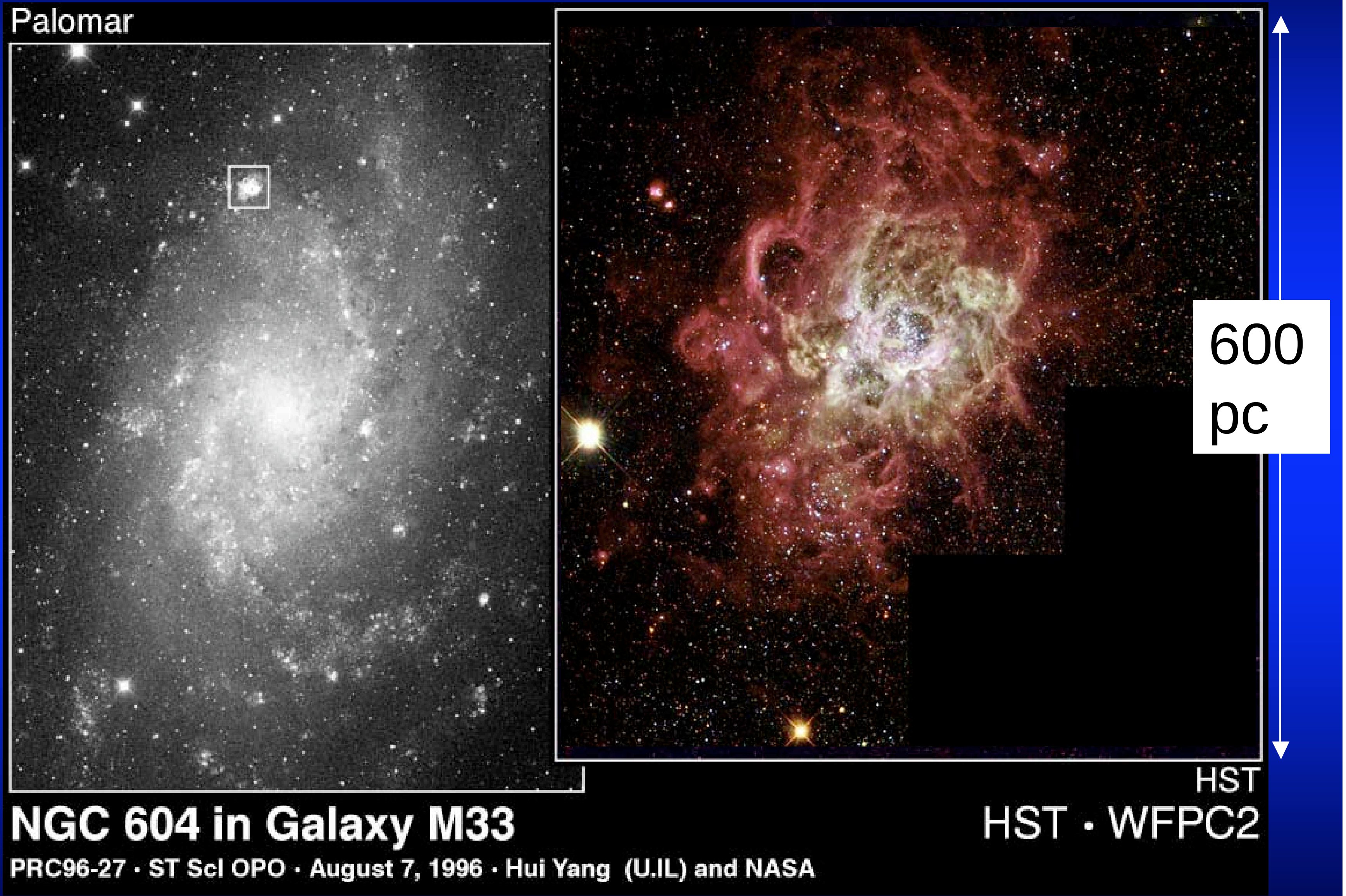
Wd1

NTT imaging o
stars suggests
mass of 6 x 10^4
(Brandner et al
agreement wit
10^4 $M_\odot$ from V
spectroscopy (
Tacconi-Garma



NTT/SOFI survey reveals 24 WR stars, from which τ~5Myr obtained (Crowther et al. 2006).

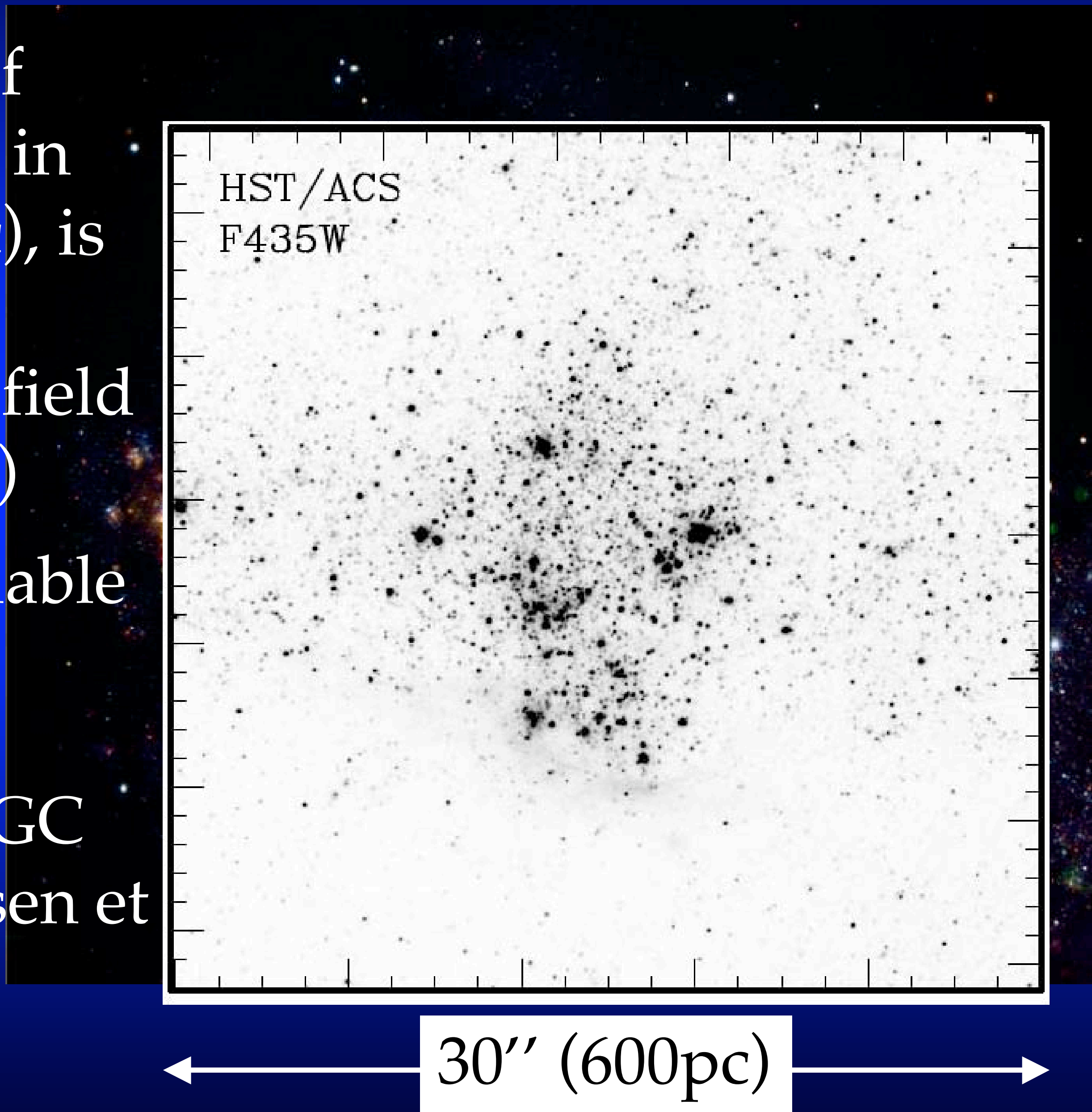
NGC 604 in M33



NGC 1313

WR population of giant HII regions in NGC 1313 (4Mpc), is within reach of VLT/FORS (Hadfield & Crowther 2007)

HST/ACS invaluable in disentangling stellar content, reminiscent of NGC 604 in M33 (Drissen et al. 1993).



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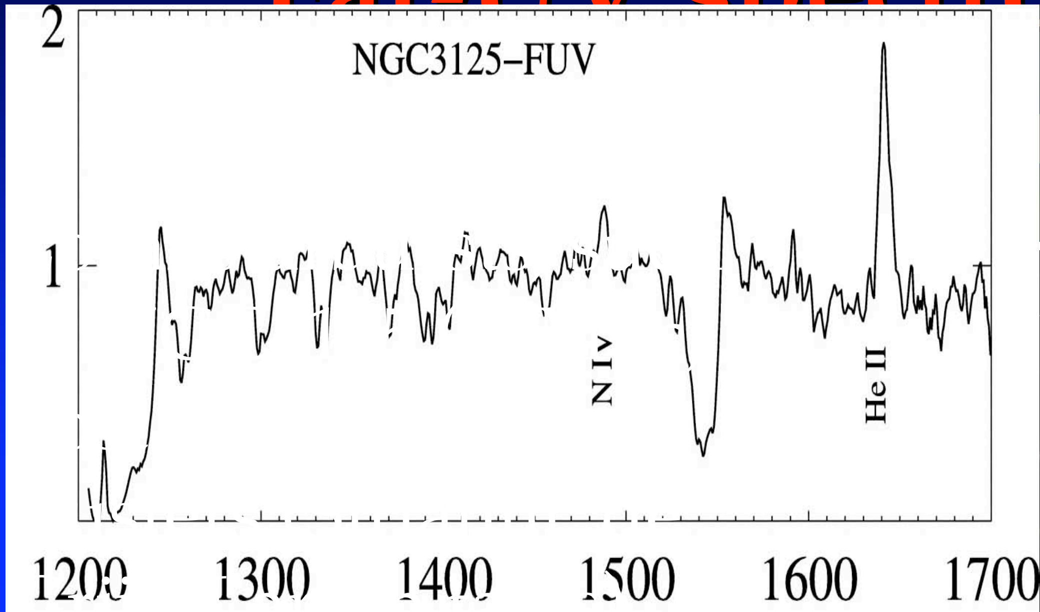
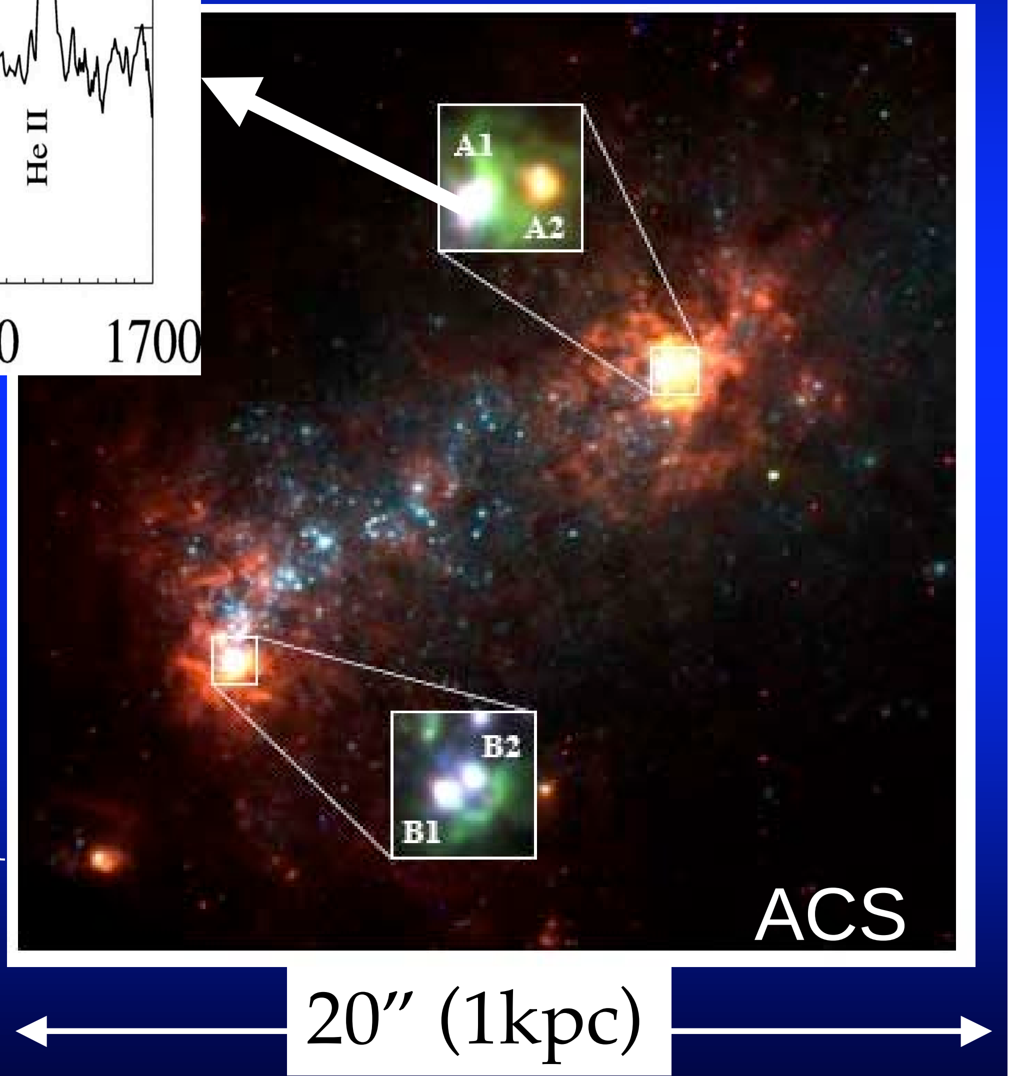
Far-UV spectroscopy of
usters

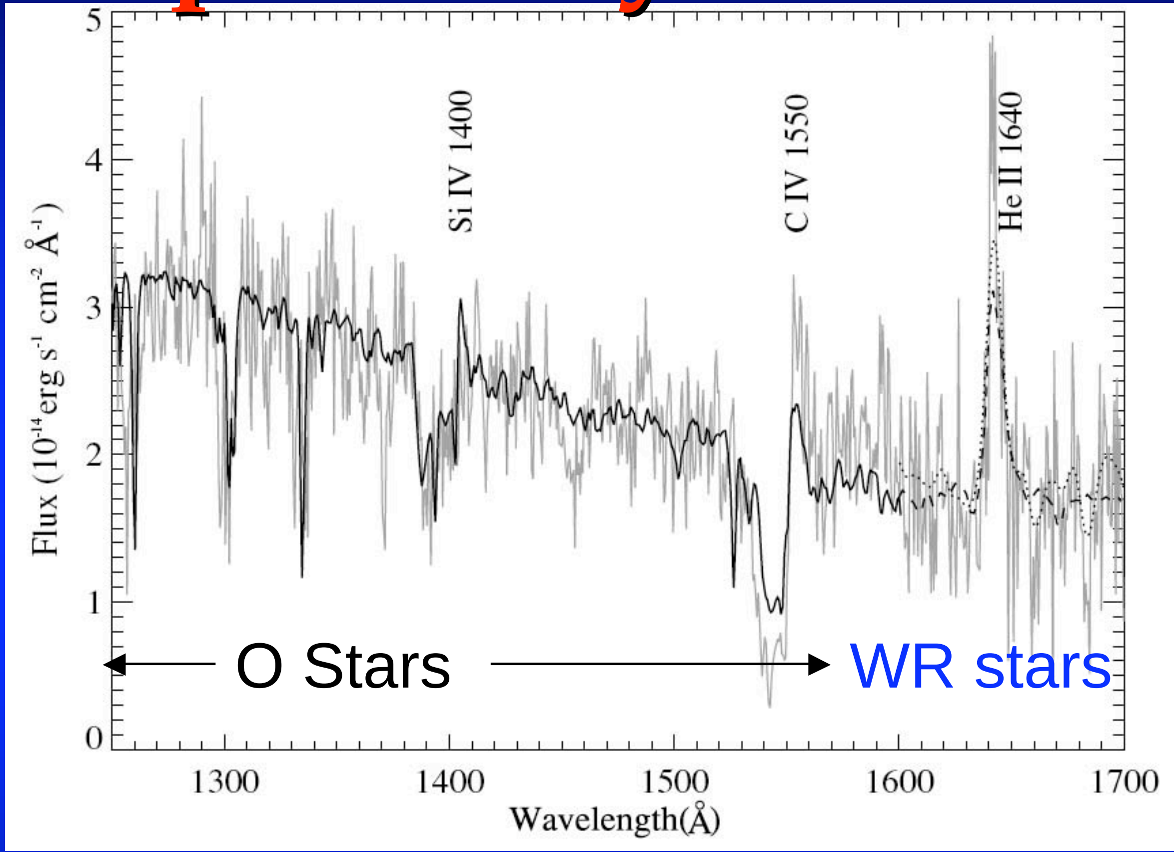


Grijs, Larsen talks)

STIS UV spectroscopy of individual clusters (Chandar et al 2004) enables ages, from comparison with spectral synthesis predictions.



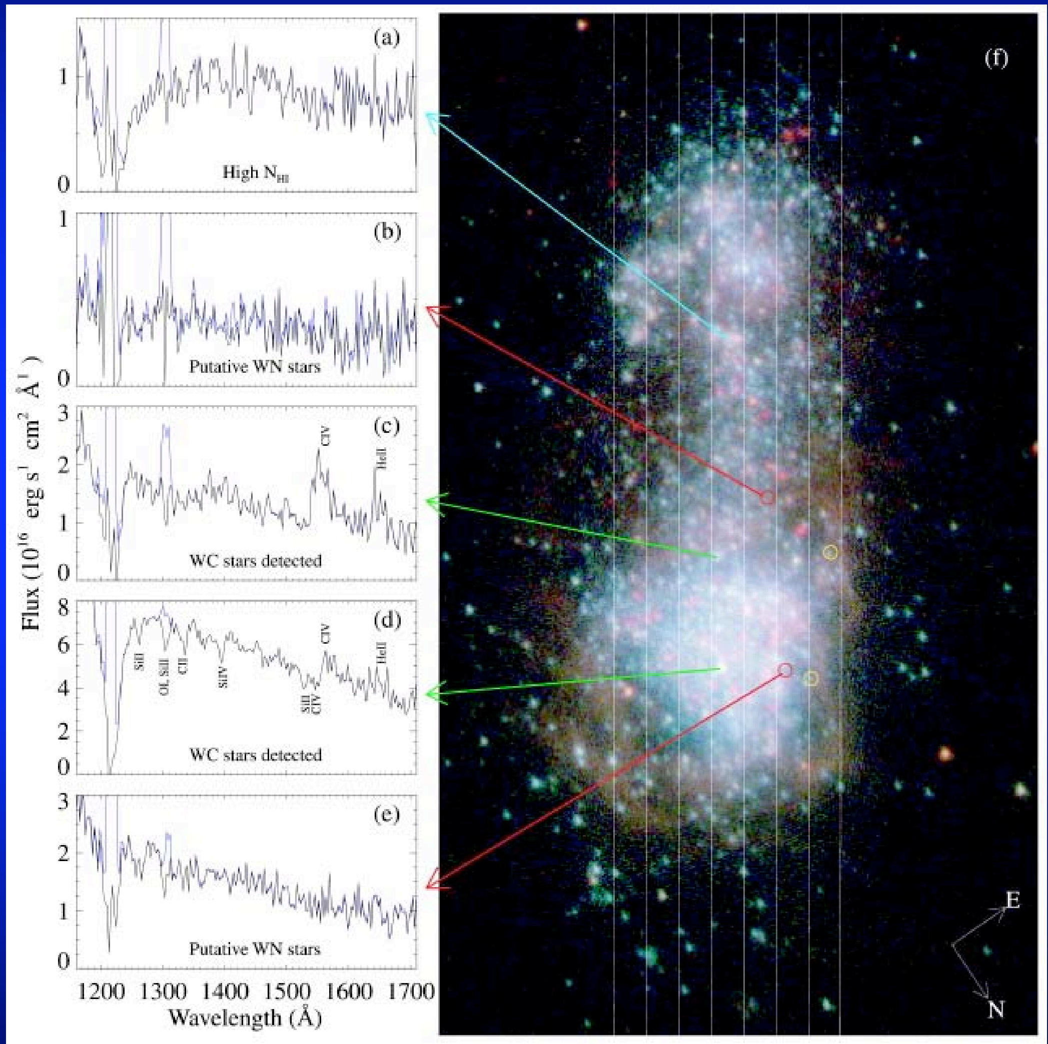
Spectral synthesis



For NGC3125-A1 cluster ($0.4Z_{\odot}$), UV spectral synthesis models imply 4Myr ($2x10^5$ $M_{\odot}$), based on Magellanic Cloud template OB stars from HST (Hadfield & Crowther 2006).

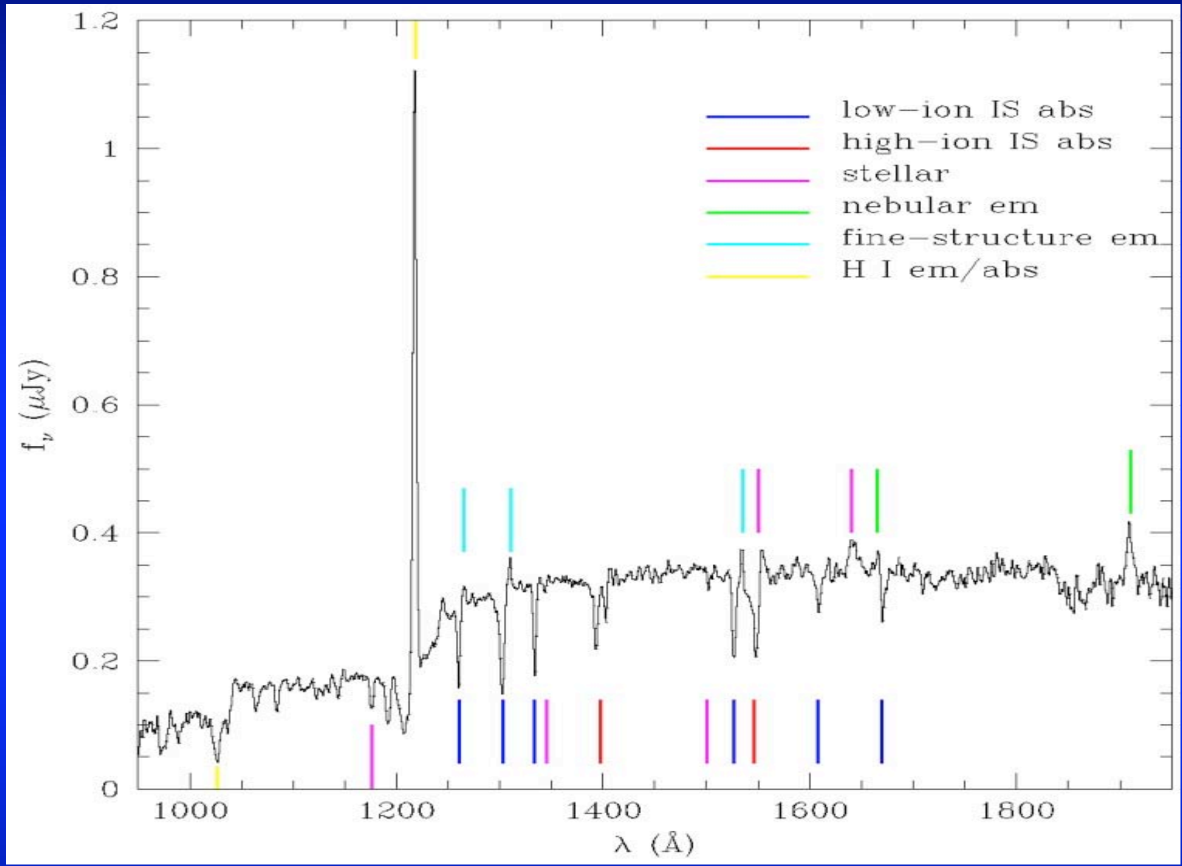
IZw18

STIS spectroscopy of clusters within HII galaxy IZw18 (~1/30 $Z_{\odot}$, Aloisi talk) reveals WR signatures (Brown et al. 2002; Crowther & Hadfield 2006).



Brown et al. 2002

Lyman Break galaxies

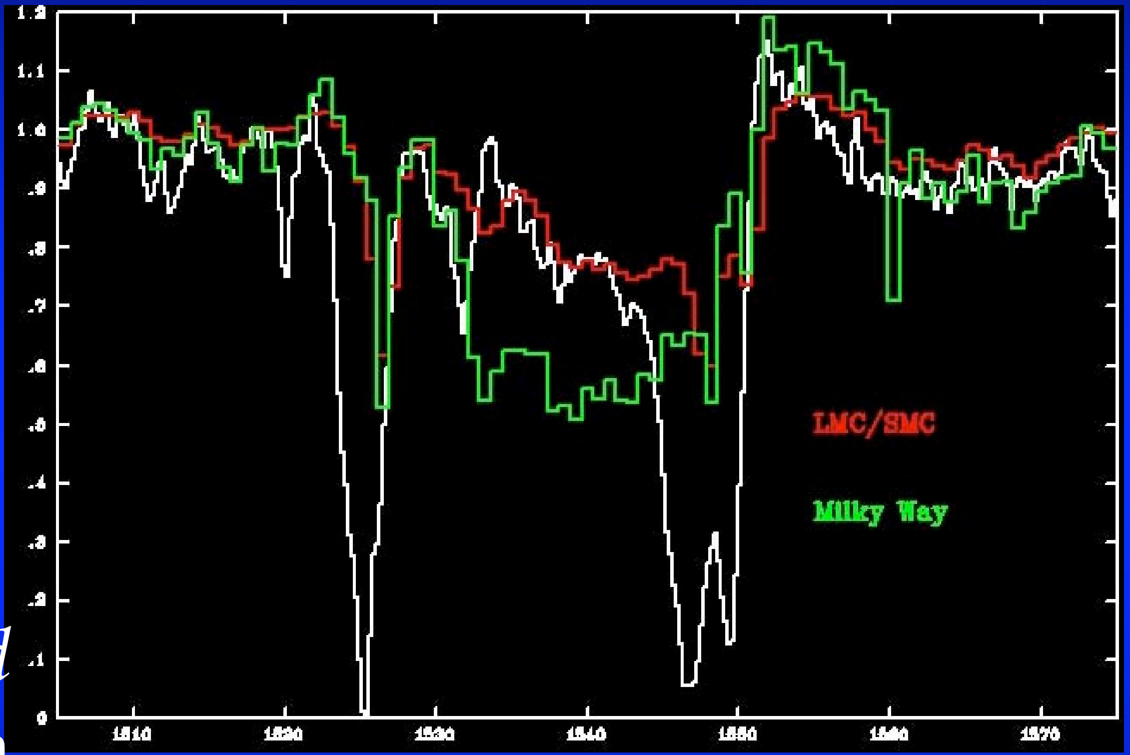


Composite Keck rest-frame UV spectrum of 811 *z*~3 Lyman Break galaxies (Shapley et al 2003) includes spectral O & WR signatures. Wiklind talk

MS1512-cB58

Lensed Lyman break galaxy MS1512-cB58 (z~2.7)

Pettini et al. (2003) were only able to reproduce its rest-frame UV spectrum with *Magellanic Cloud* templates rather than *Galactic* OB stars.



Low metallicity of MS1512-cB58 from wind lines is in agreement with ISM techniques (Pettini et al. 2002)

Summary

- UV sensitivity:
  - UV stellar signatures of Magellanic Cloud OB stars critical to Z-dependent winds;
  - Metal-poor hot star templates of application to high-z star forming galaxies
- High spatial resolution:
  - Stellar ejecta associated with hot massive stars;
  - Resolved stellar populations in Local Group massive clusters;
  - Young star clusters in more distant galaxies

IAU Symposium 250

- Atmospheres of massive stars;
- Physics & evolution of massive stars;
- Massive stellar populations in the nearby Universe;
- Hydrodynamics & feedback from massive stars in galaxy evolution;
- Massive stars as probes of the early Universe

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