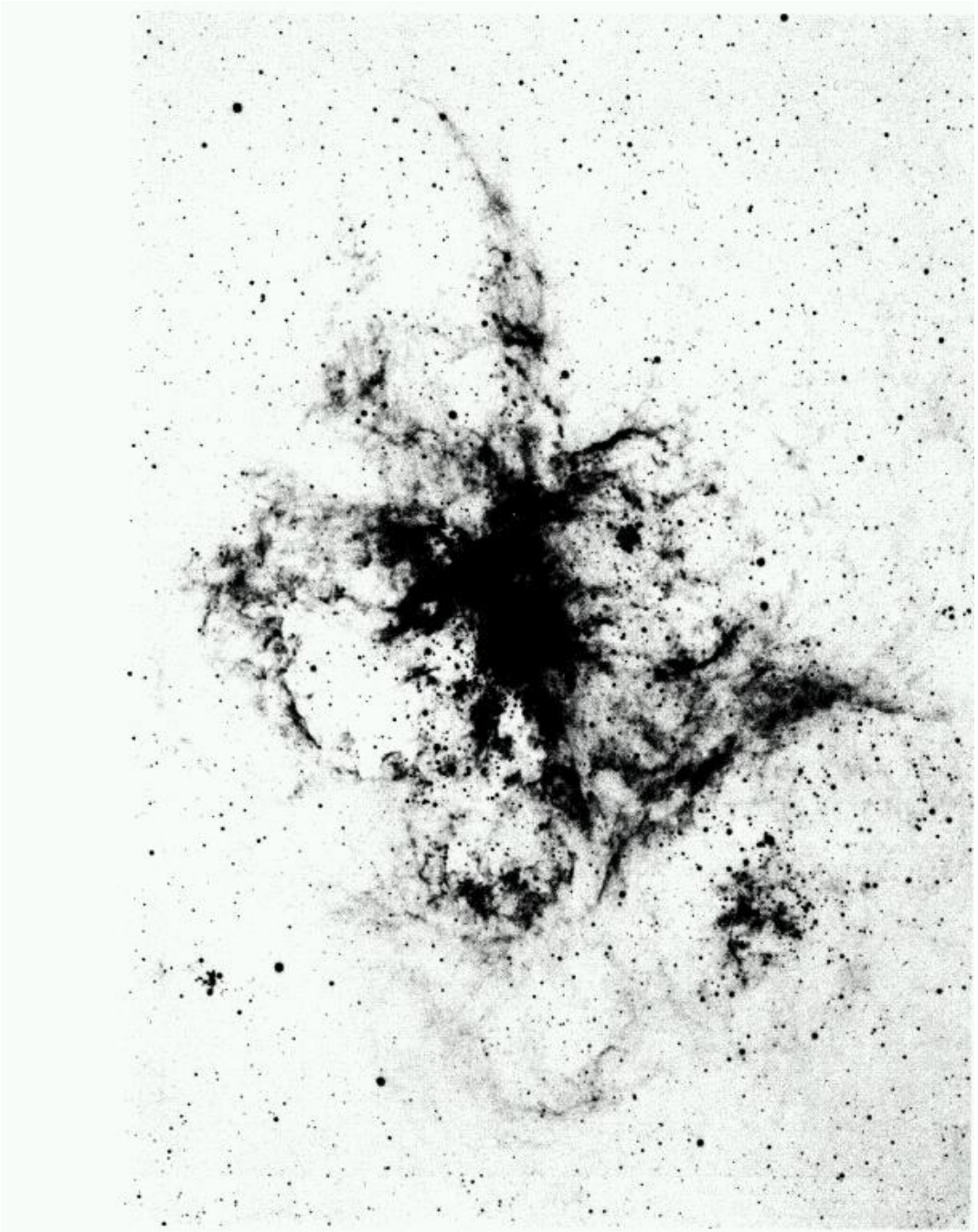
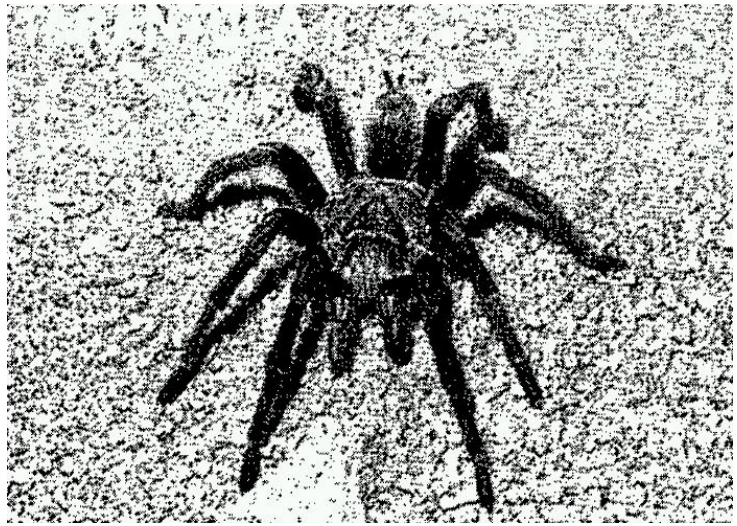
KITP talk, 21 November 2007

30 Doradus, NGC 2070, and R136: a brief overview of a resolved starburst

Hans Zinnecker (Astrophysikalisches Institut Potsdam)



Tarantula Nebula ([SII] image of the 30 Dor giant HII region taken by Walborn at CTIO/4m)



The Tarantula Nebula (VLT KUEYEN + FORS2)

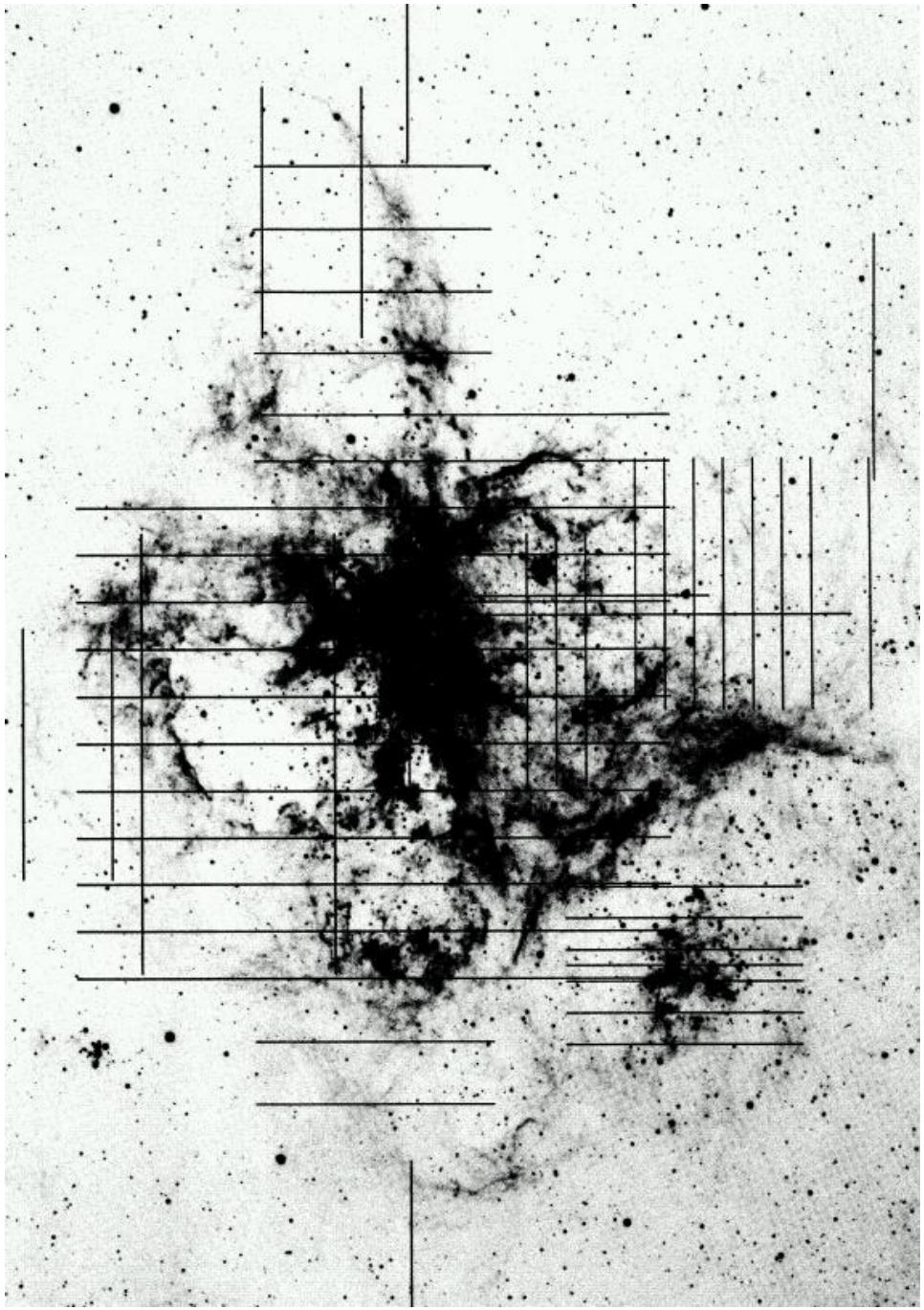
ESO PR Photo 05a/00 (8 February 2000)

R136
NGC 3603
Orion Nebula
(to scale)

Zinnecker & Yorke
(Annual Reviews 45)

Introductory summary and questions

- largest star forming HII region in the Local Group
- closest starburst 10^4 $M_\odot$/Myr/pc^3, "Rosetta Stone"
- nearby (LMC at 50 kpc) $\rightarrow$ details (e.g. IMF)
- stellar population:
  - high-masses: ~ 100 O-stars
  - bottom light IMF ? SFH ?
  - low-masses: < $3M_\odot$ pre-MS
- metallicity and age: $Z \sim Z_\odot/2.5$ and 3 ± 1.5 Myr
- origin: intersecting shells, gas infall from SMC ?
- evolution: proto-globular cluster? stay bound?

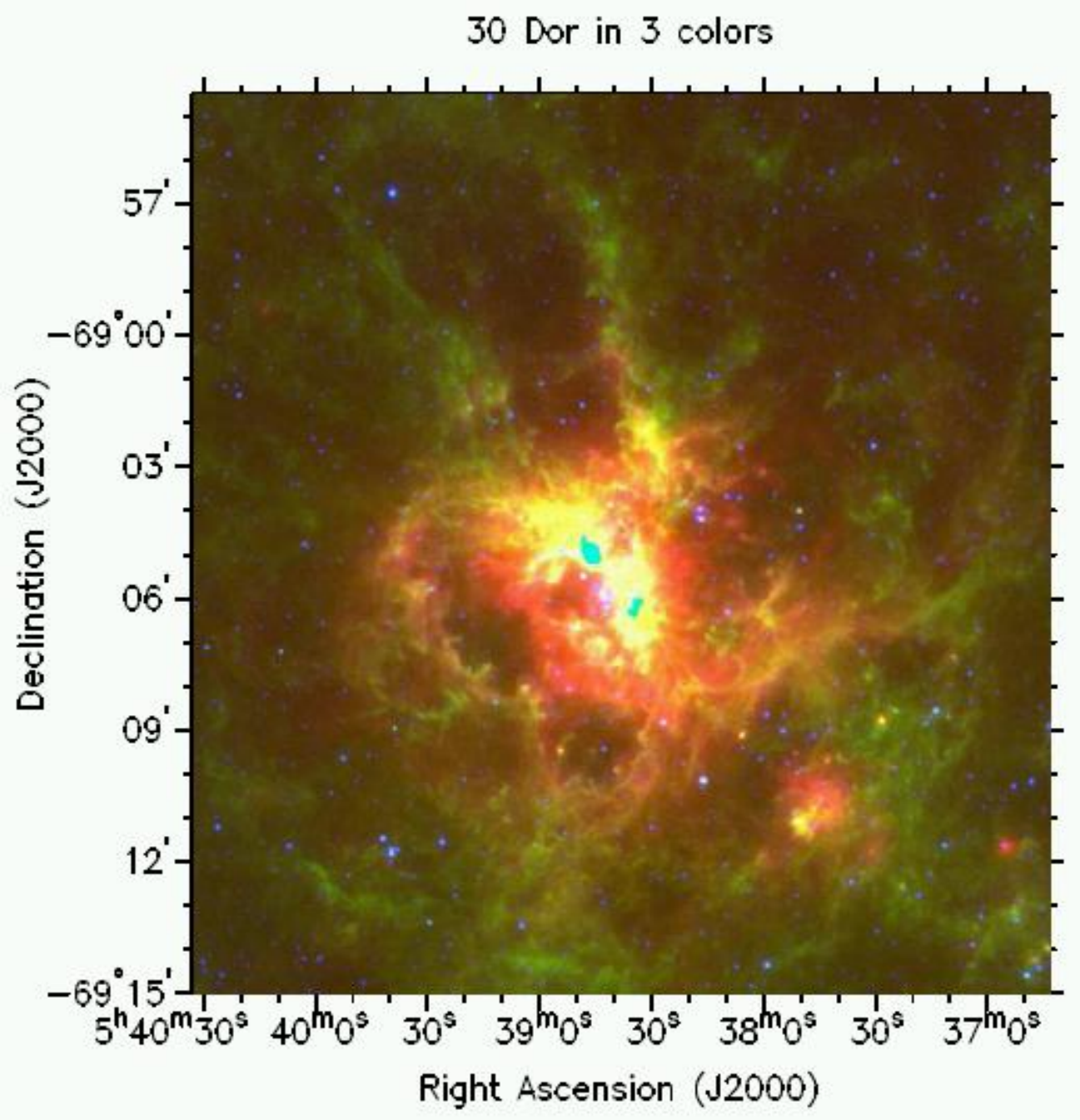


kinematic study
(slit positions)
HII velocity dispersion
~ 60km/s over 270pc

Chu & Kennicutt 1994

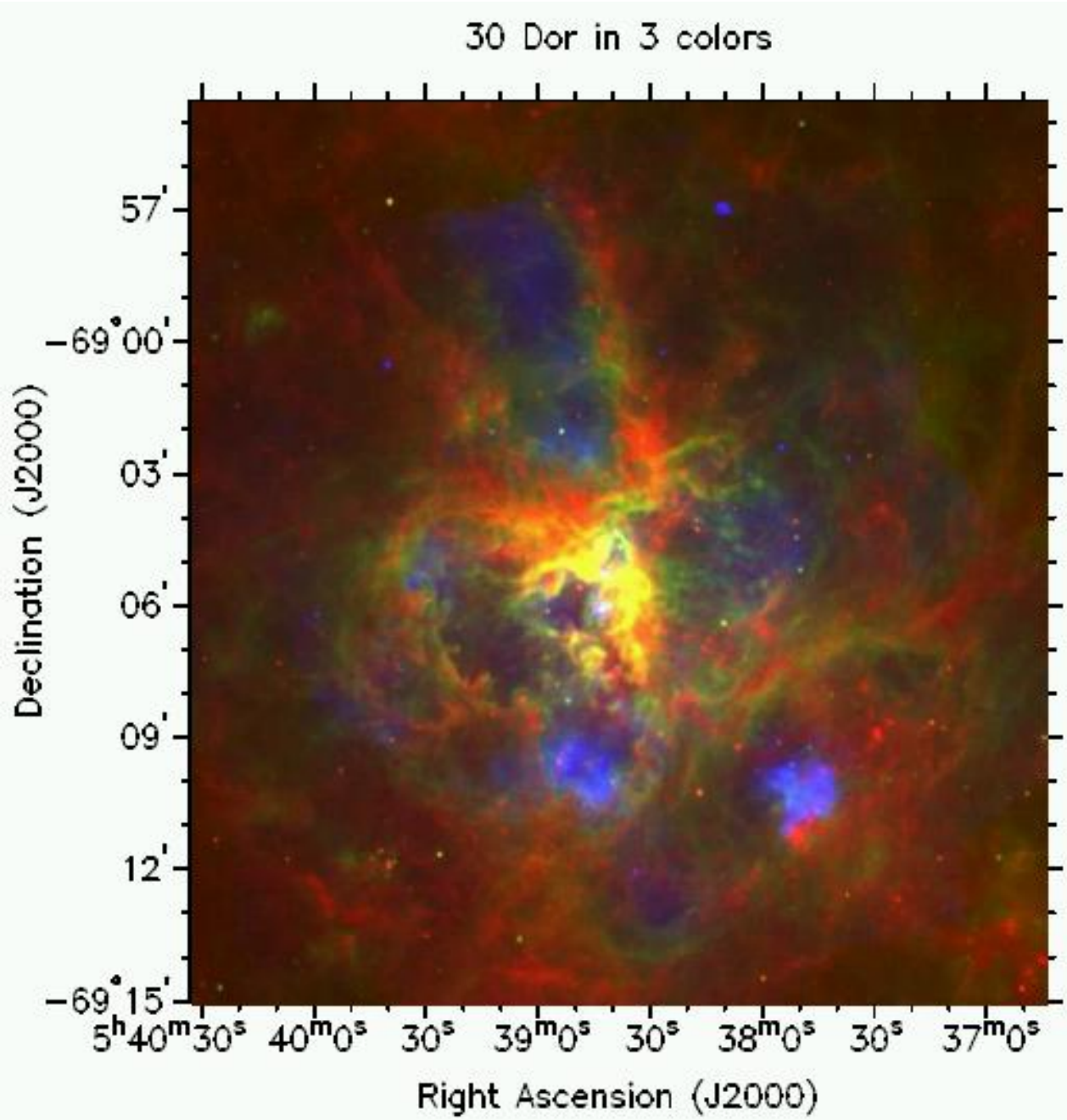
Introductory summary and questions (continued)

	stellar cluster	~ 10^5 $M_\odot$
•mass	total ionised gas	4.10^5 $M_\odot$
	mol. cloud (CO)	~ 10^5 $M_\odot$
•central mass density		~ 10^5 $M_\odot/pc^3$
•total luminosity		~ 10^8 $L_\odot$
•rate of ionising Lyc photons		~ 10^{52} s^{-1}
•equivalent number O3-stars		~ 100 (OK)
	E_{kin} (HII gas,tot)	~ 10^{52} ergs
•energetics	E_{kin} (R136 shell)	~ 10^{51} ergs
	E_{kin} provided by O-star winds, SNRs	



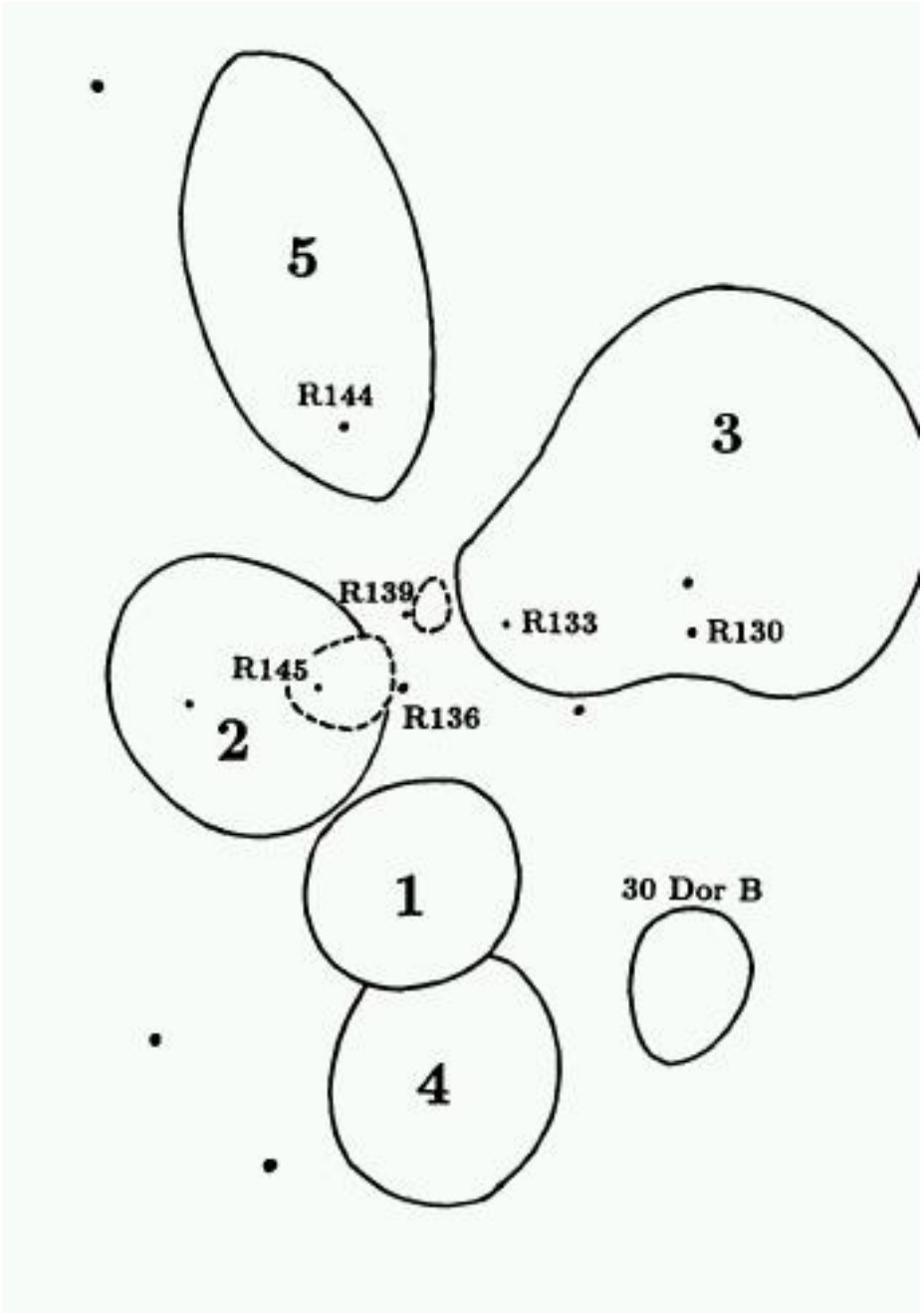
24μm green
8μm red
2 MASS K-band blue

Brandl, Chu, & Townsley
(priv. comm.)



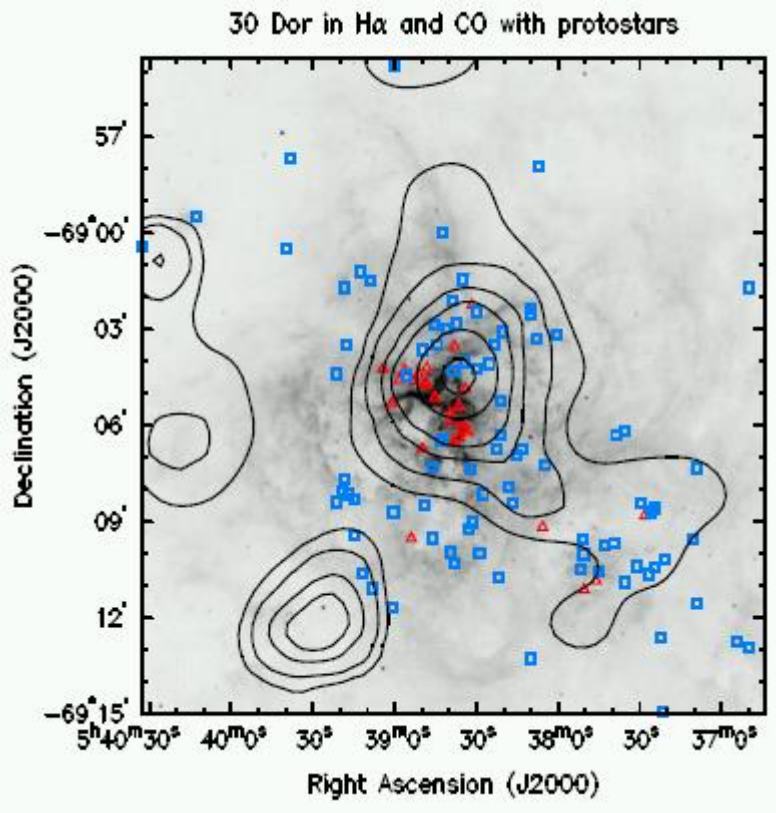
Hα green
8μm red
Chandra 0.5-2 keV blue

Brandl, Chu, & Townsley
(priv. comm.)

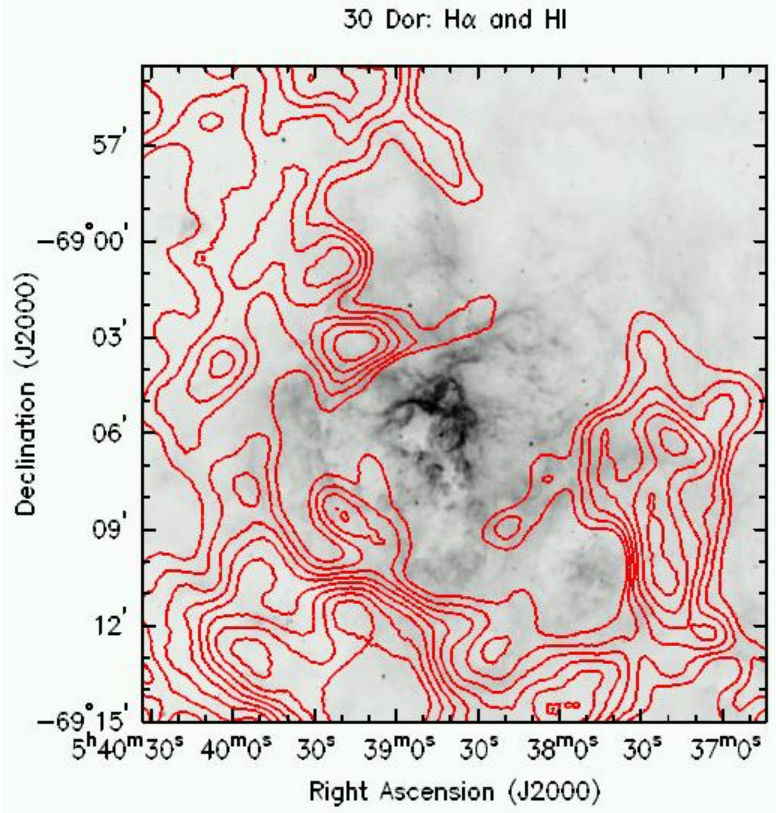


30 Dor expanding shells and kinematic features

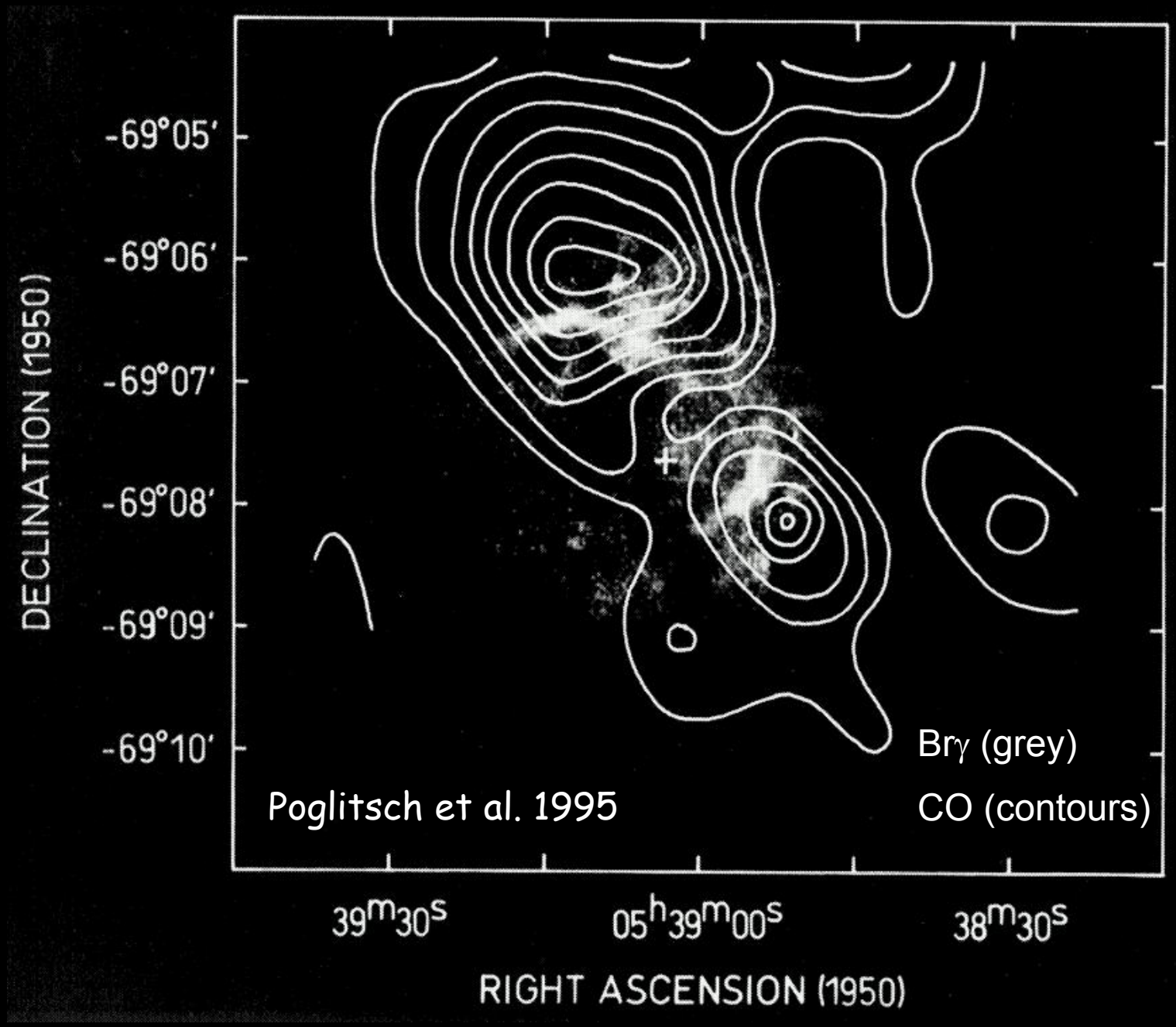
Chu & Kennicutt 1994

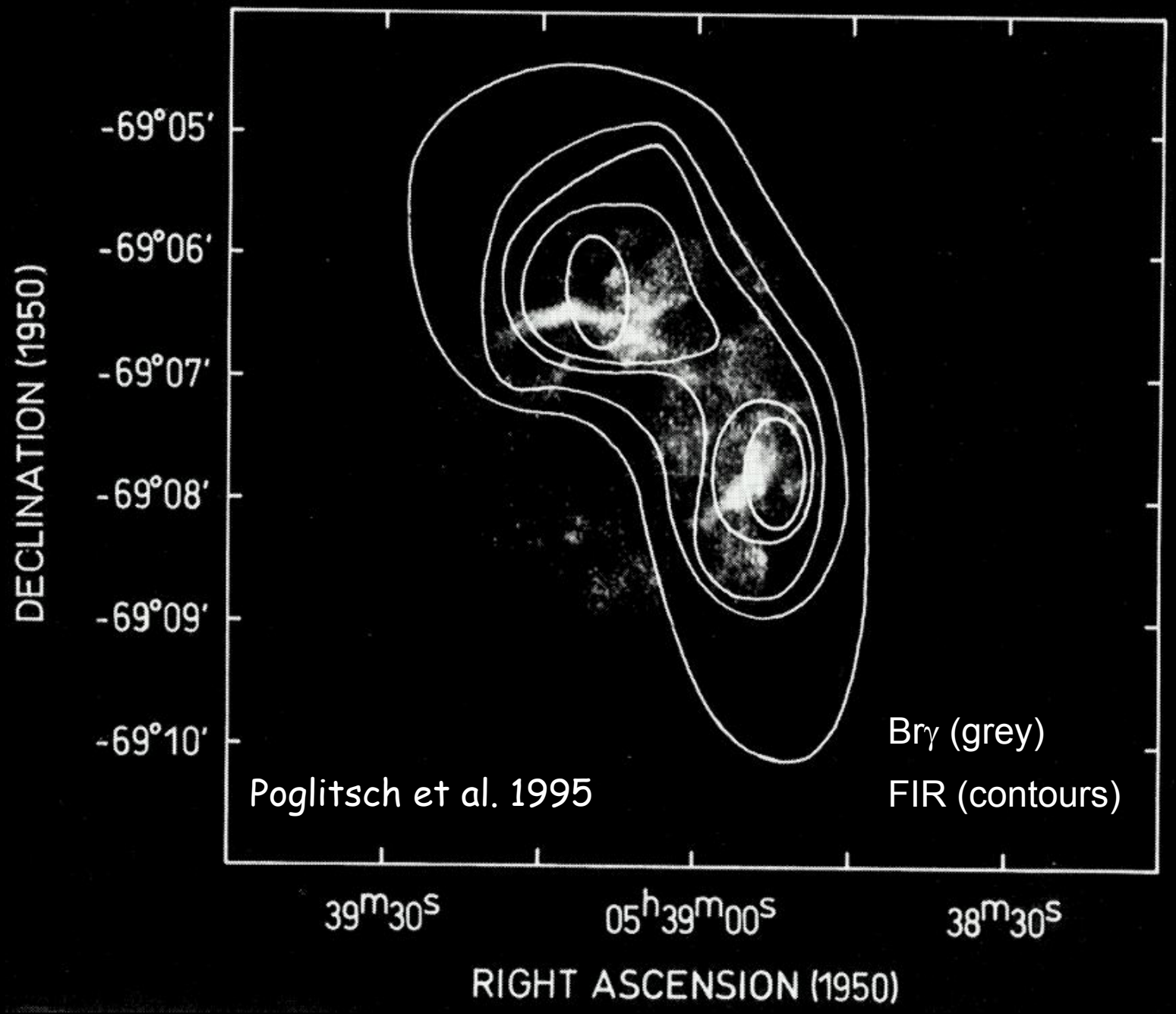


Fukui et al. 1999



Kim et al. 2003


-69°05′
-69°06′
-69°07′
-69°08′
-69°09′
-69°10′
DECLINATION (1950)
39m30s
05h39m00s
38m30s
RIGHT ASCENSION (1950)
Brγ (grey)
CO (contours)
Poglitsch et al. 1995


-69°05'
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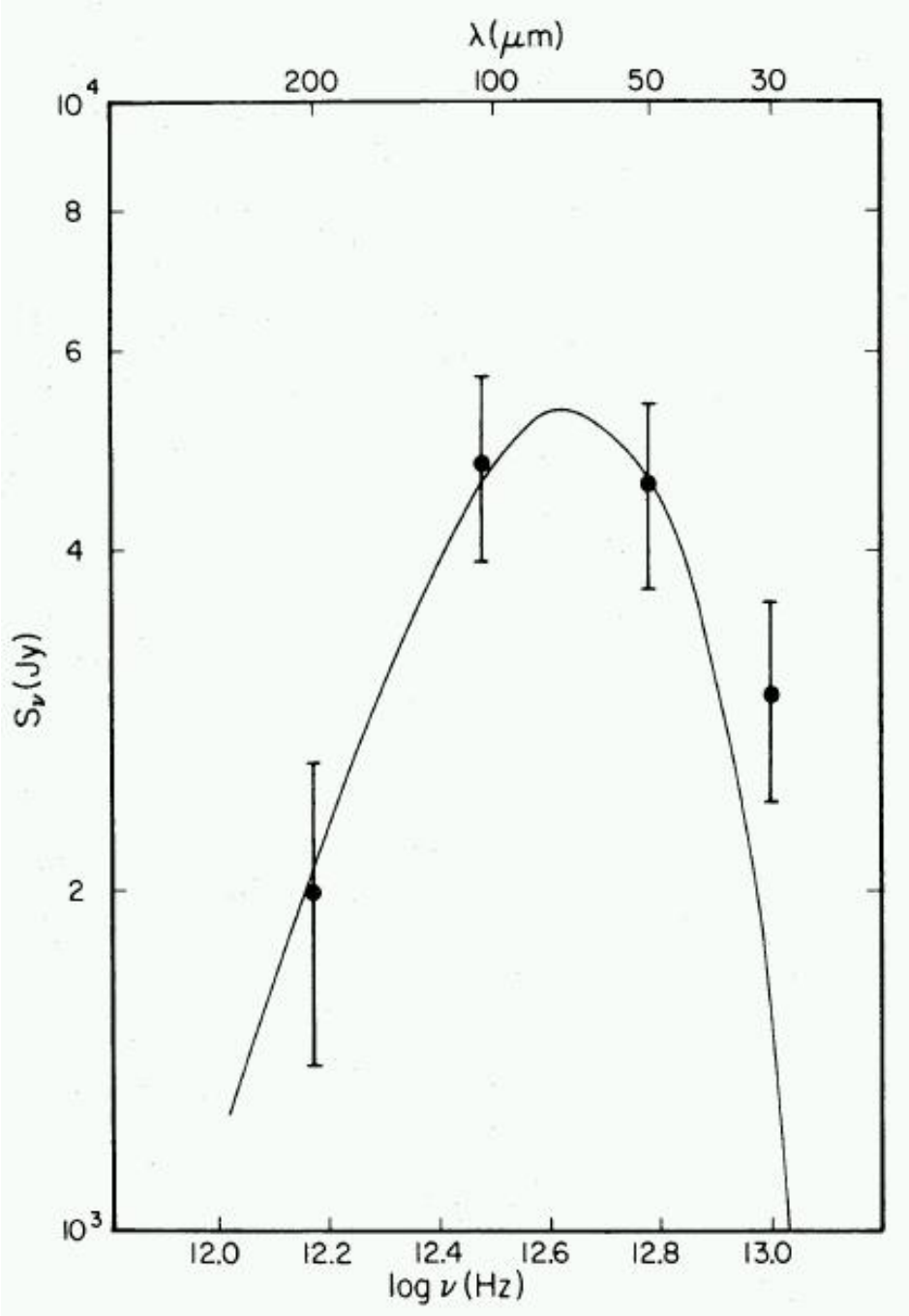
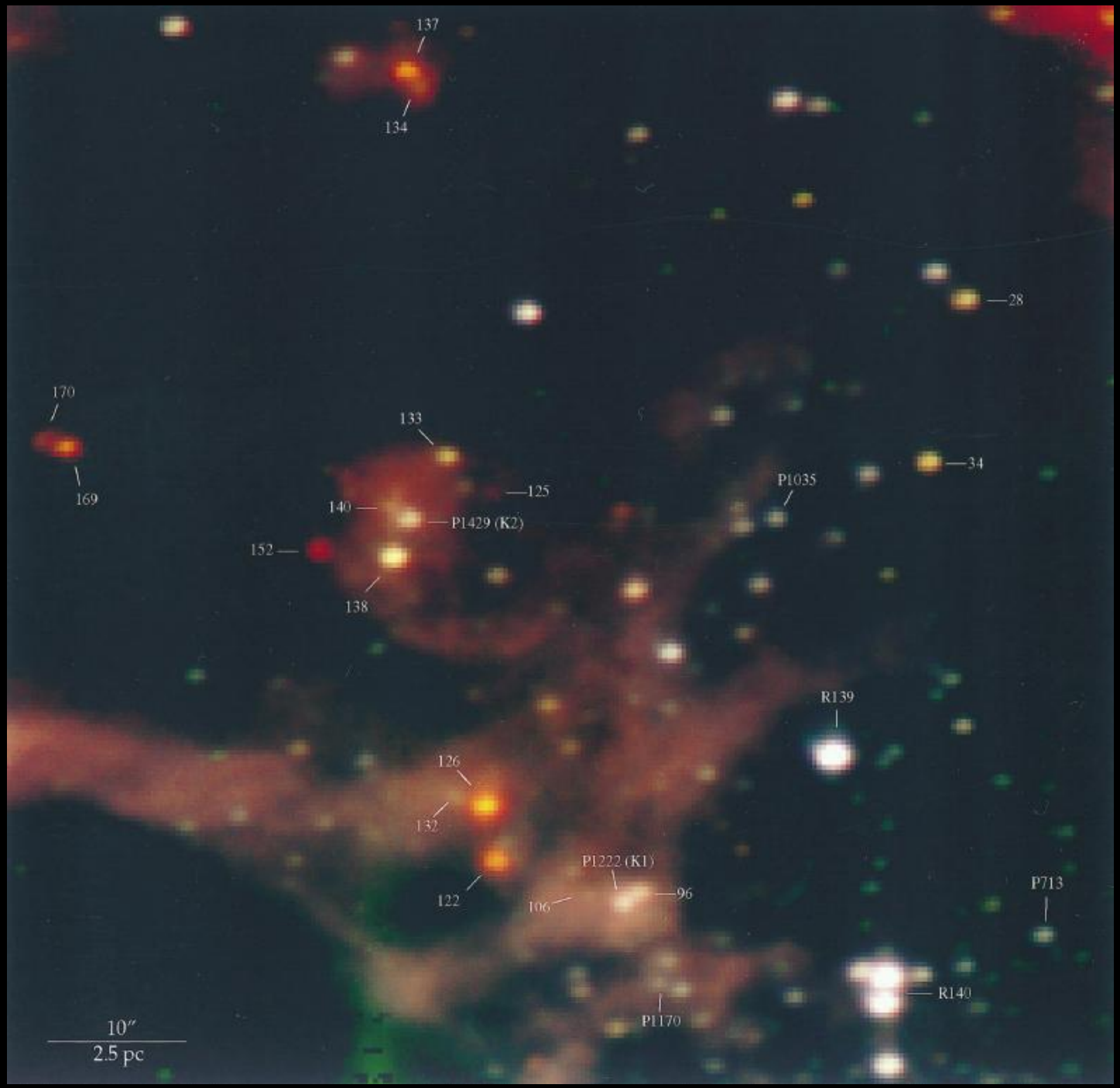
-69°10'
DECLINATION (1950)
39m30s
05h39m00s
38m30s
RIGHT ASCENSION (1950)
Brγ (grey)
FIR (contours)
Poglitsch et al. 1995



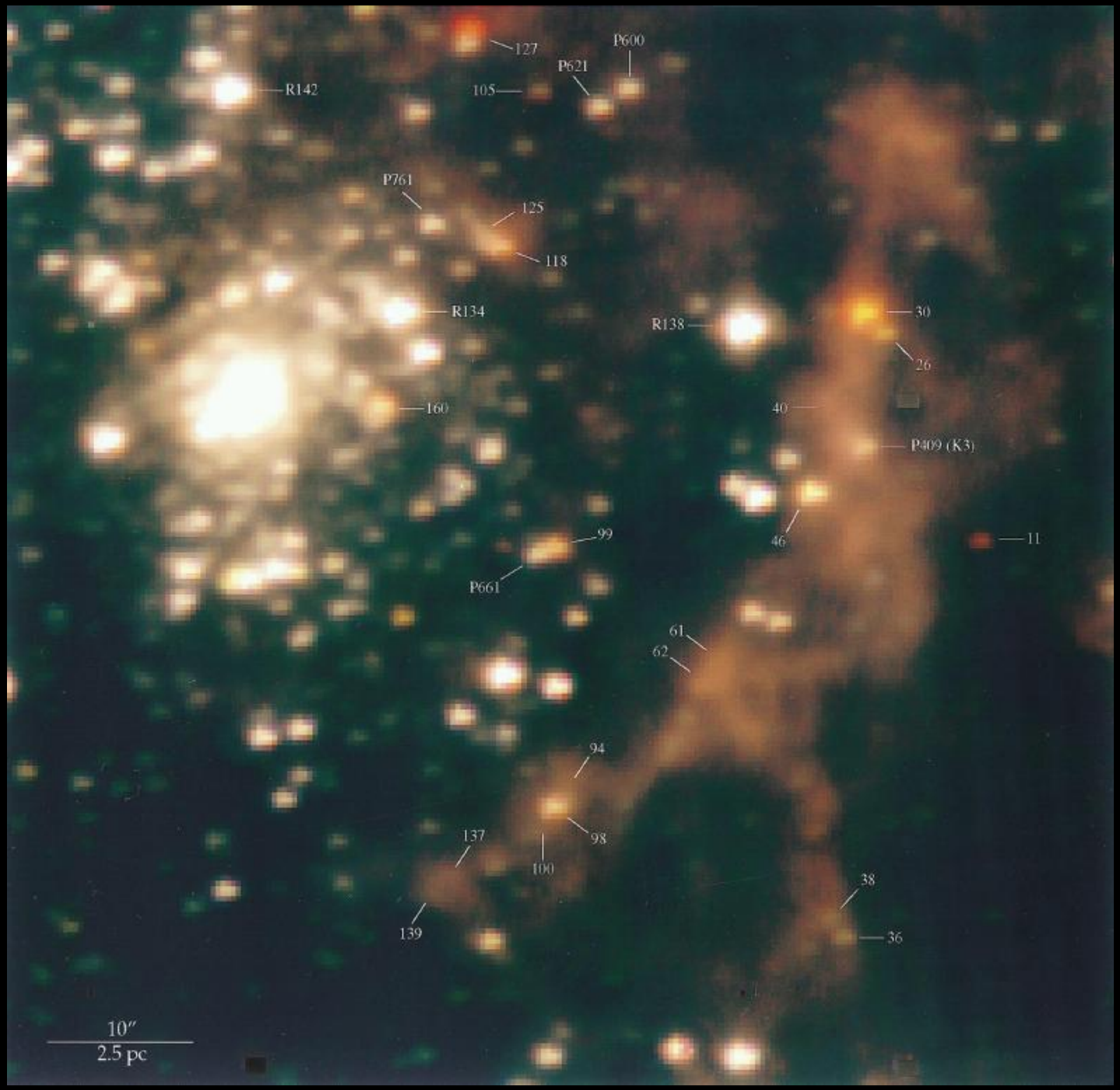
The far-infrared
spectral energy distribution
of the 30 Dor nebula;
the curve is a 75 K blackbody fit.

Werner et al. 1978



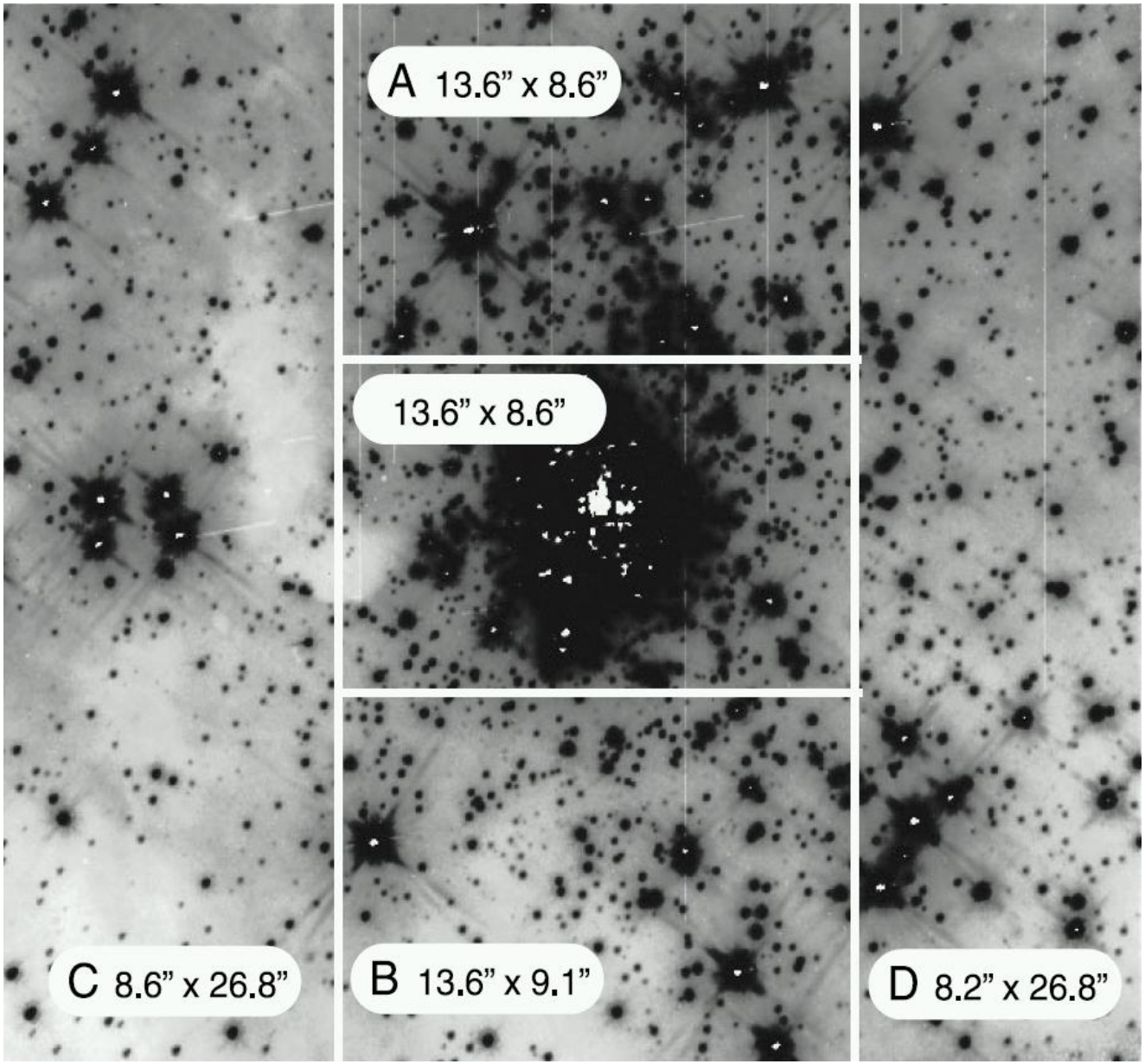
NIR images (JHK)
red sources:
protostars?

Rubio et al. 1998



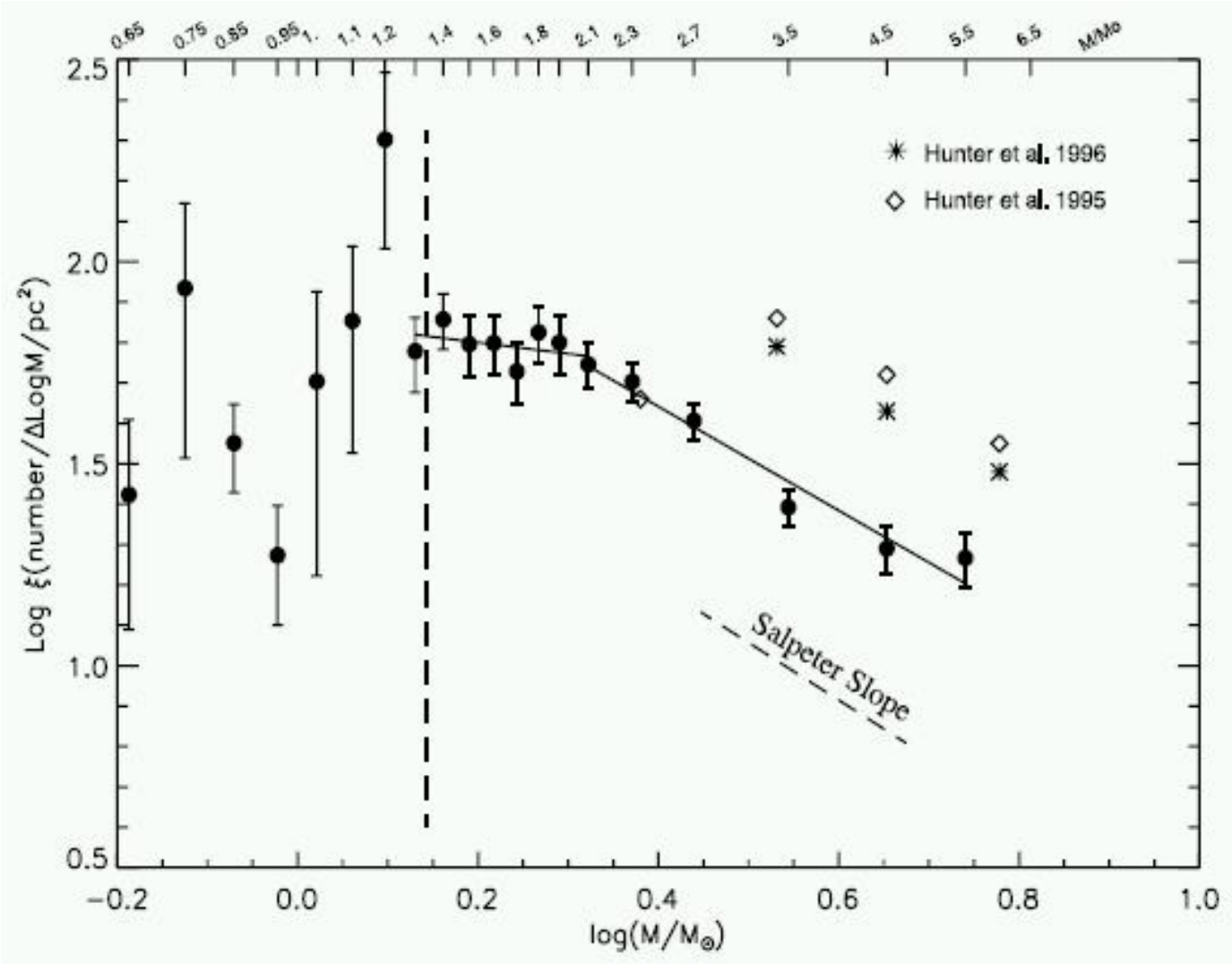
NIR images (JHK)

Rubio et al. 1998



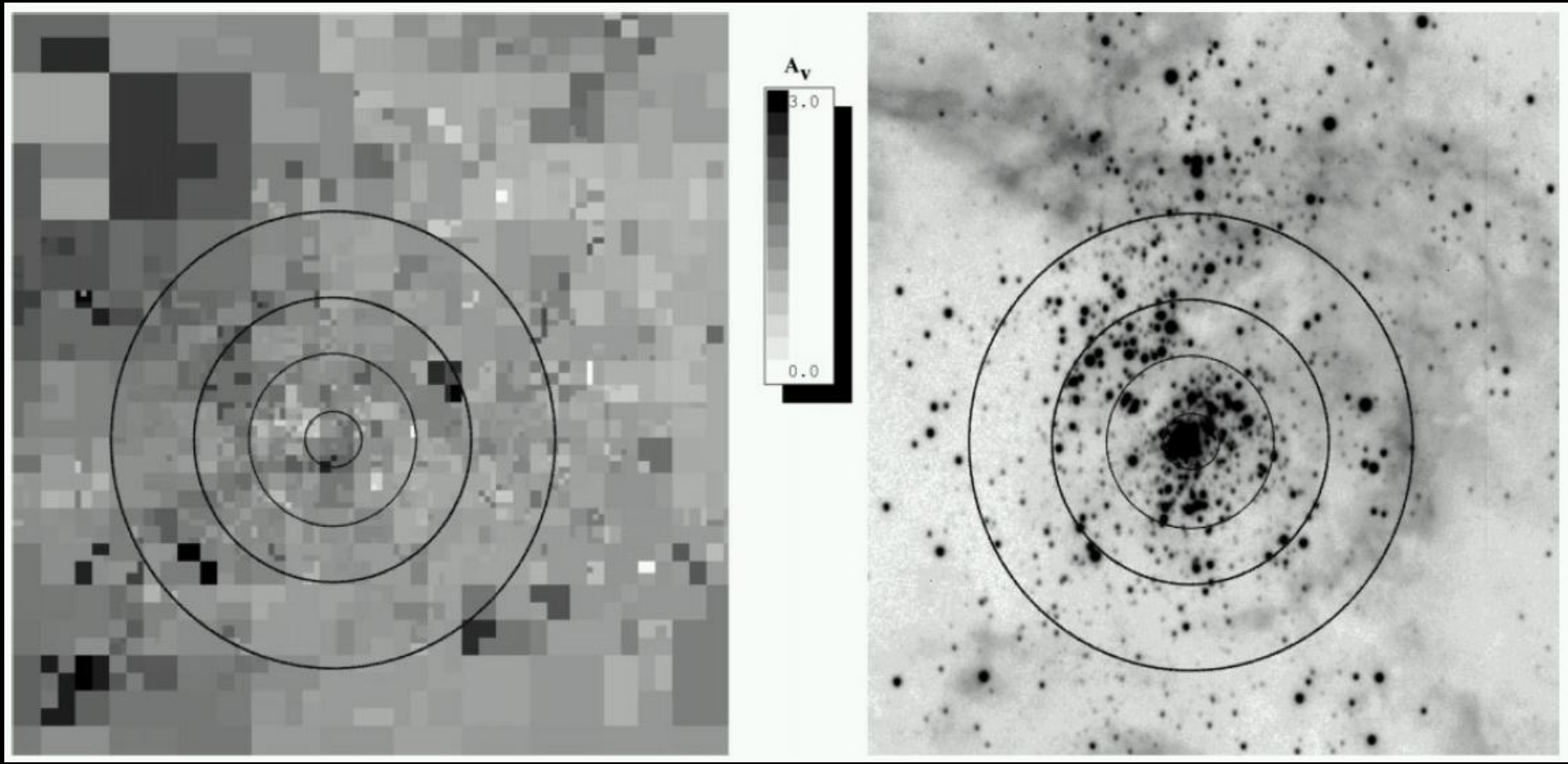
HST/WFPC2 F814W image of R136 (A, B, C, D → IMF)

Sirianni et al. 2000



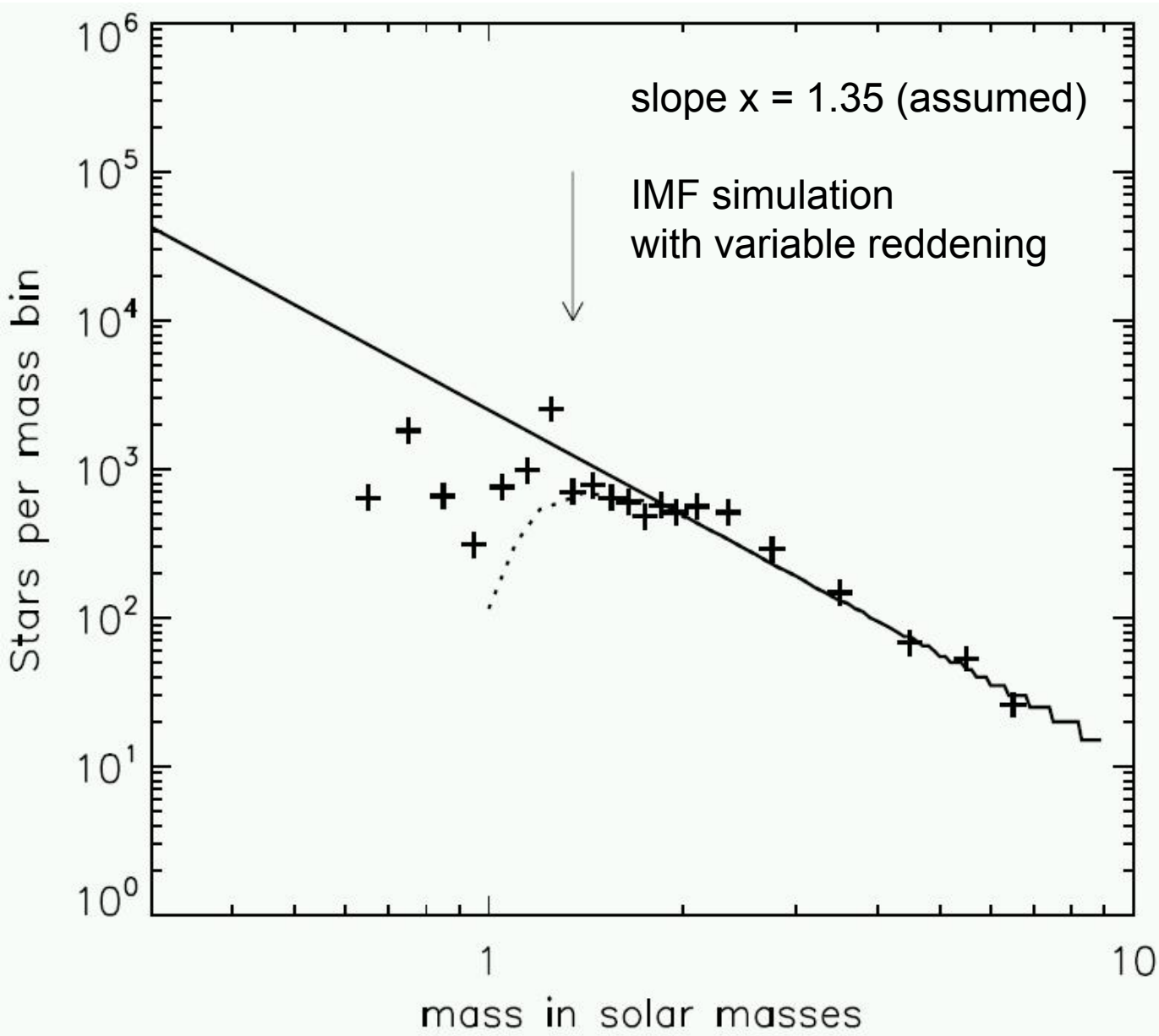
IMF in 2-3 pc annulus in R136

Sirianni et al. 2000



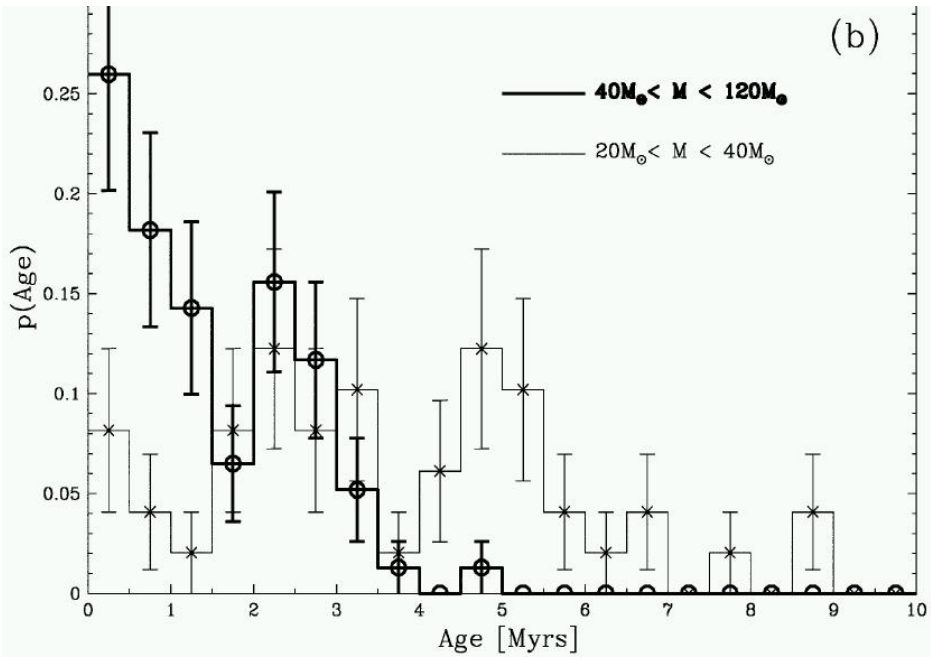
Reddening map of 30 Doradus calculated with an adaptive algorithm.
The circles are centered in R136 with radii of 5", 15", 25", and 40".
The reddening scale goes from A_V=0 to A_V=3.0, calculated assuming R_V=3.05.
North is up and east to the left; size is 133" or ~30 pc.

Selman et al. 1999

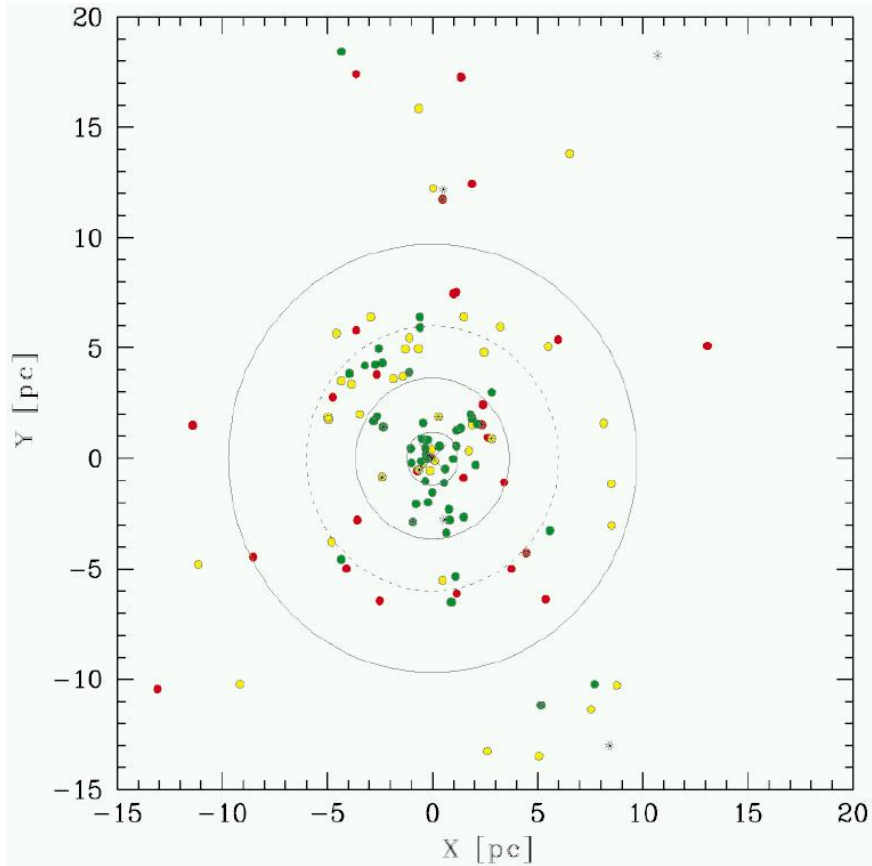


Andersen et al.
2007, Ap.J. subm.

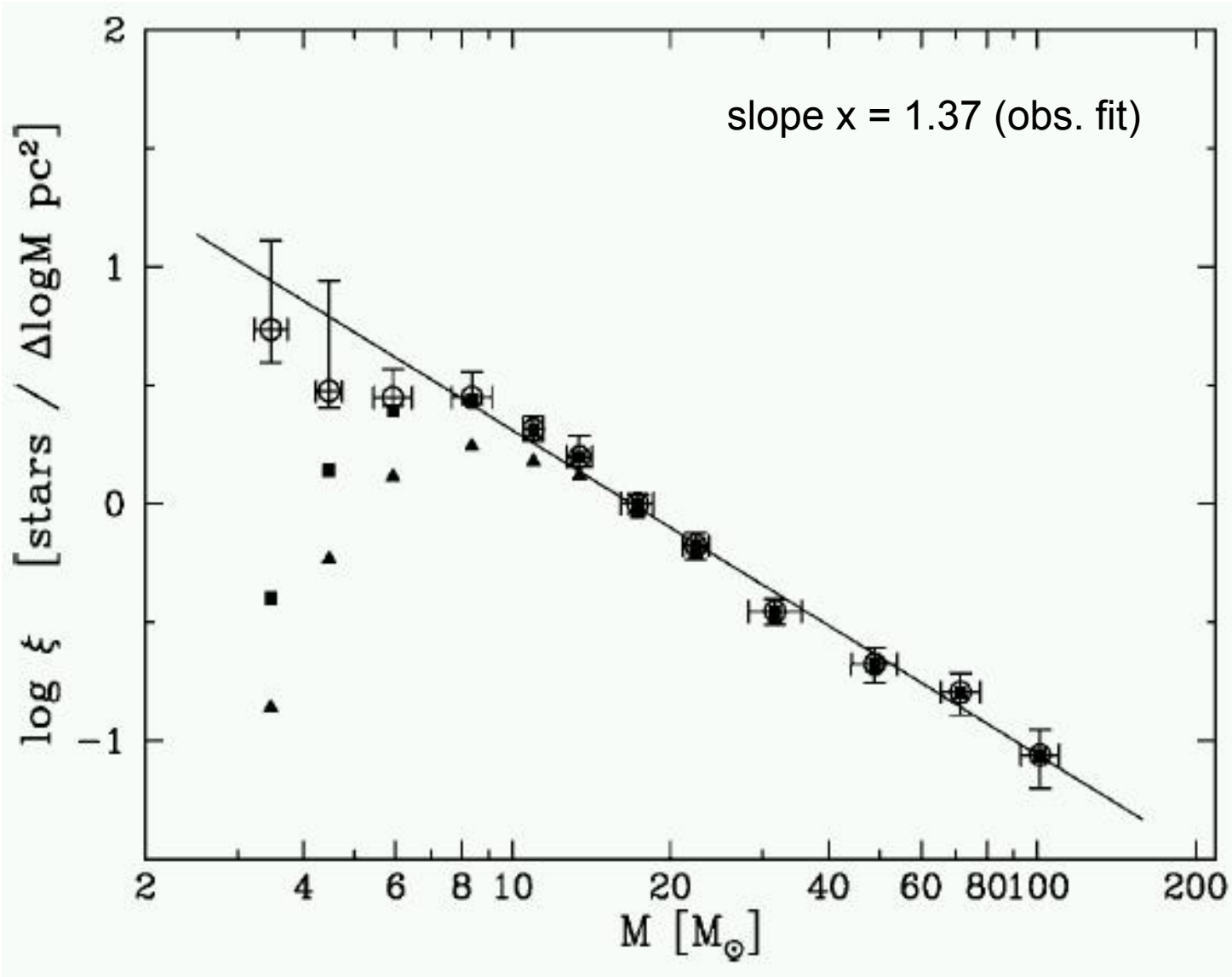
Selman et al. 1999



SFH of the cluster (3 bursts)

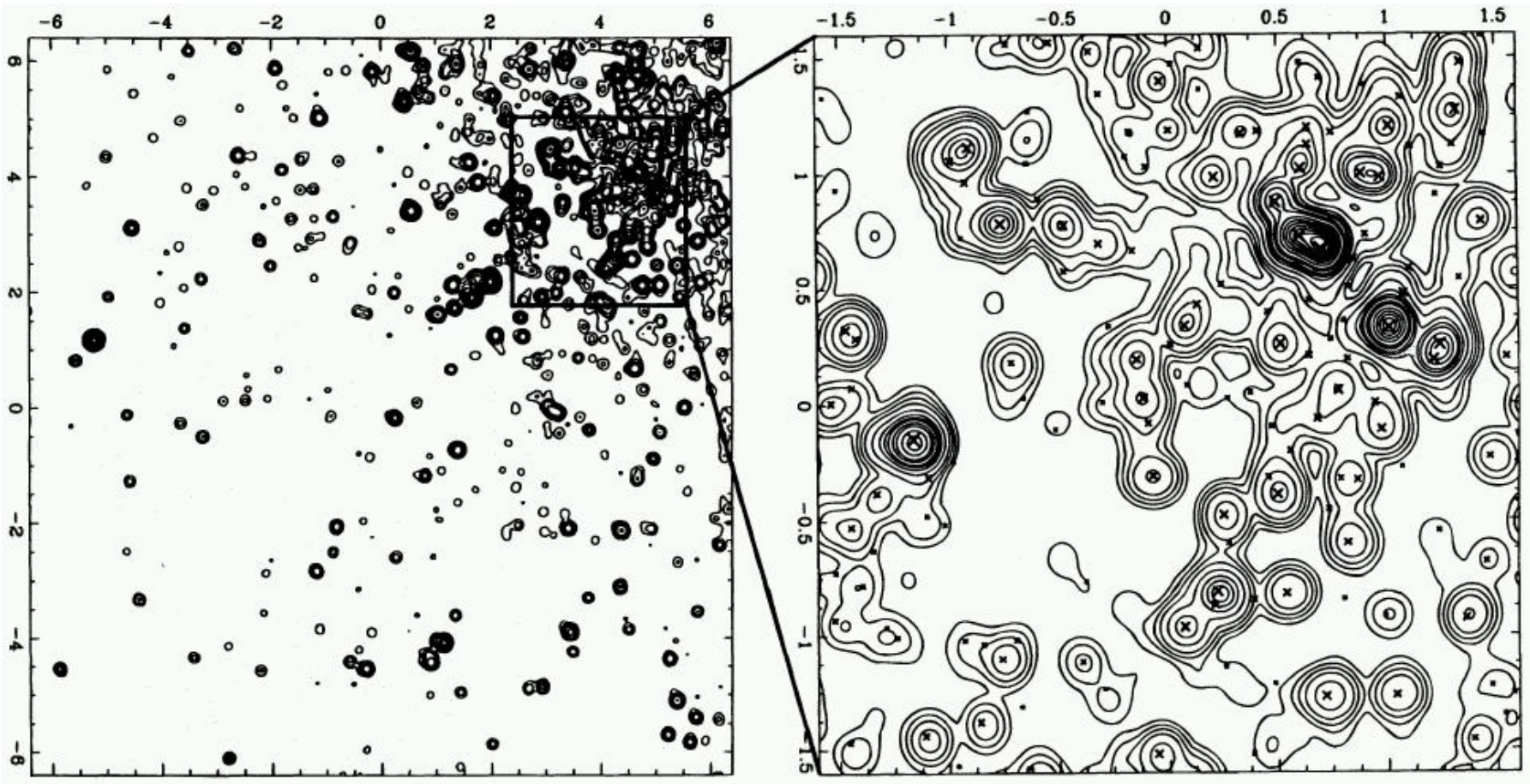


Spatial distribution of stars with M> 20 $M_\odot$ as a function of age: green for youngest, yellow for middle-aged, and red for oldest stars (approx. 1.5, 2.5, 5 Myr).
WR stars are plotted using an asterisk.



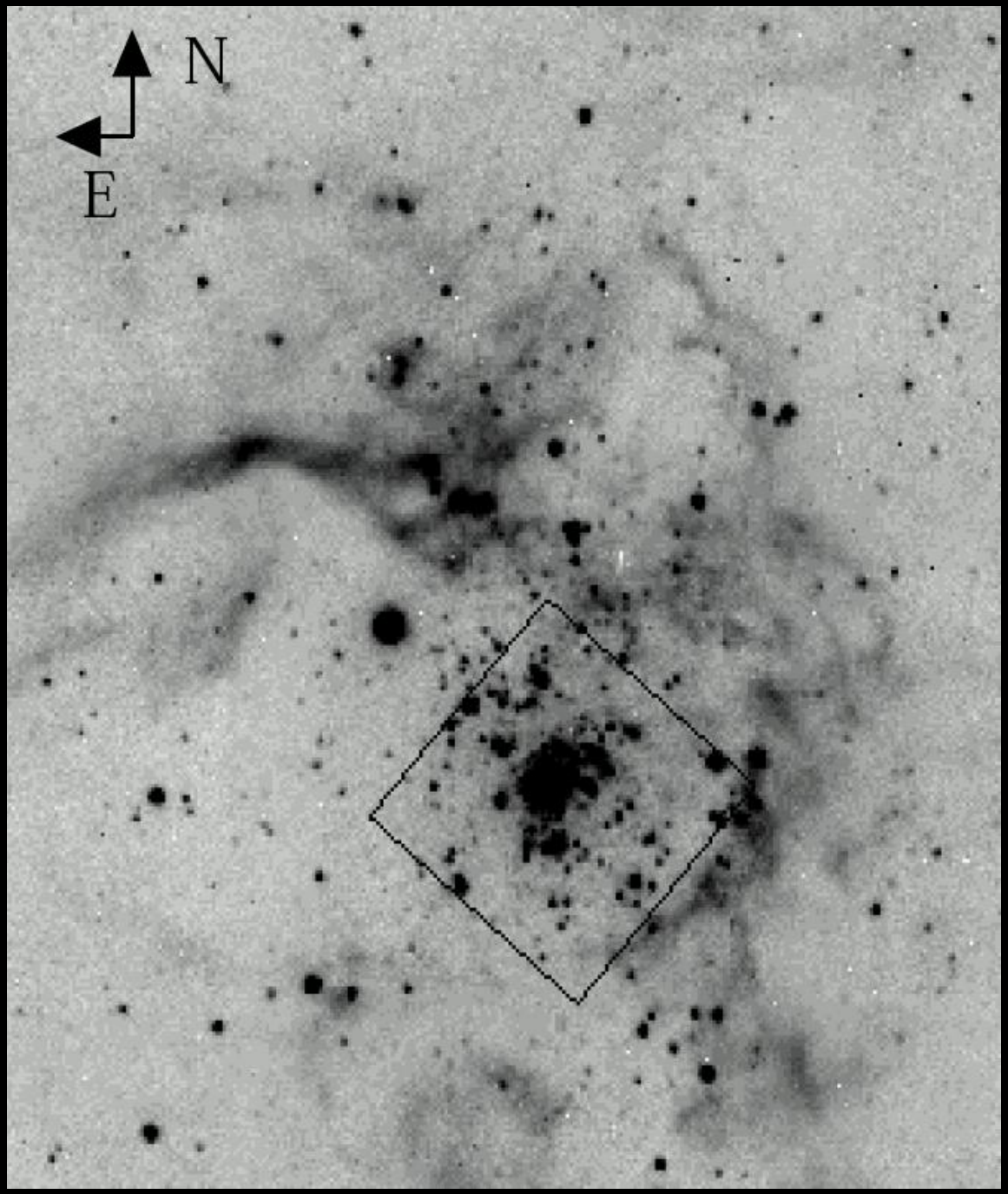
The IMF of 30 Doradus for the sample of stars with $r > 15''$

Selman et al. 1999



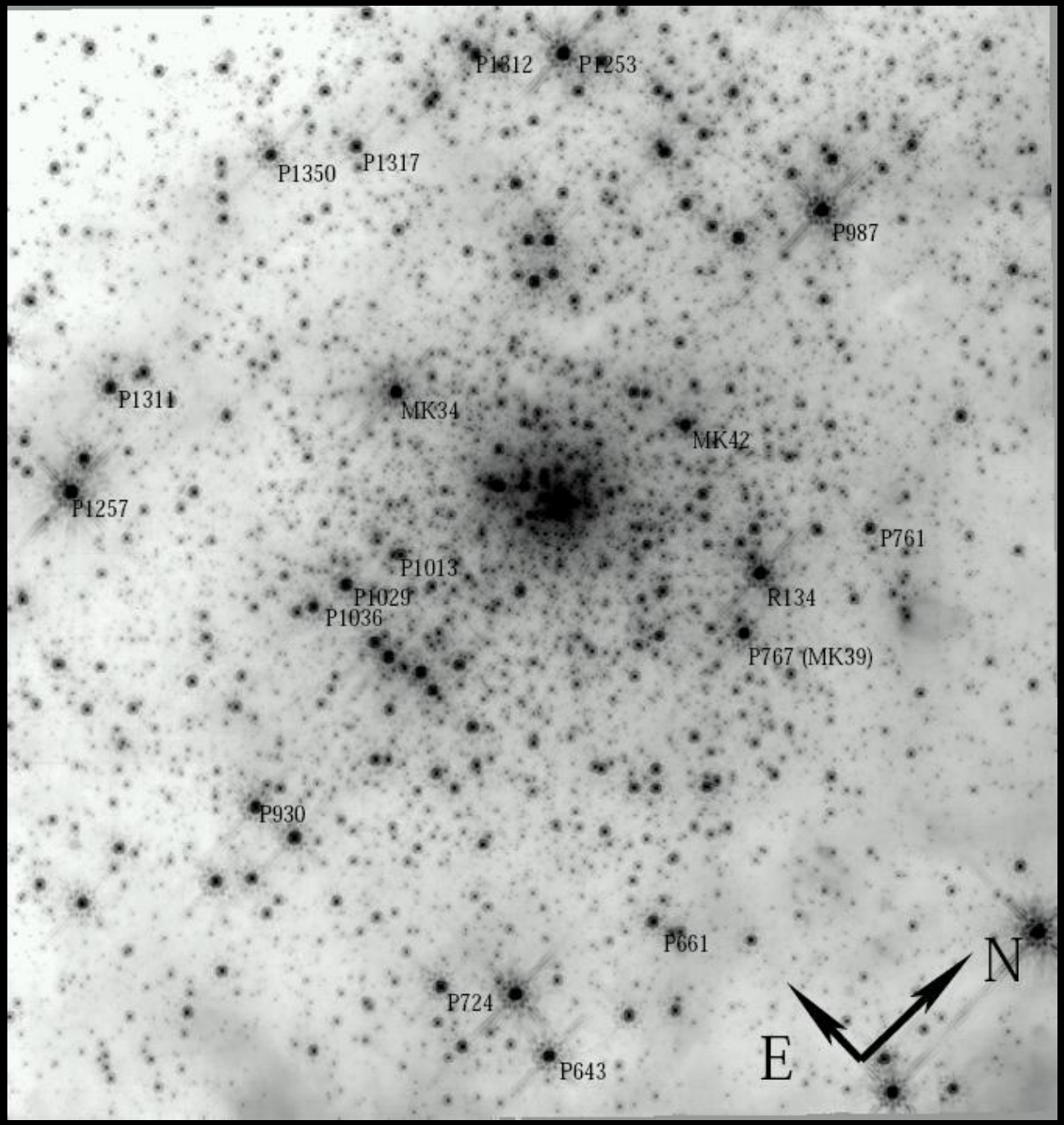
R136 – SE quadrant (K-band adaptive optics at ESO/3.6m)

Brandl et al. 1996



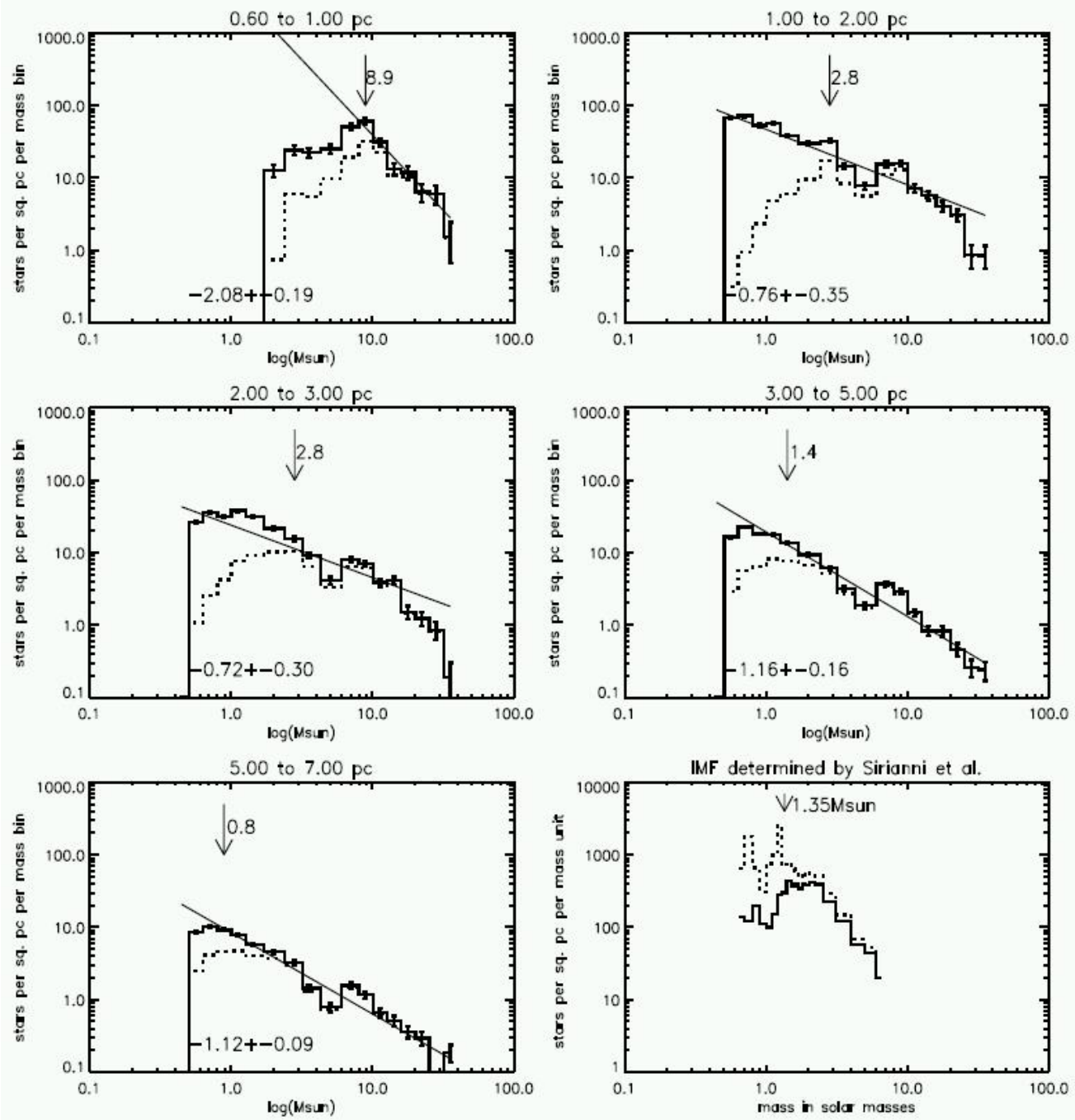
ESO 2.2m NIR image
(NICMOS finding chart)

Andersen et al. 2007,
Ap.J. subm.

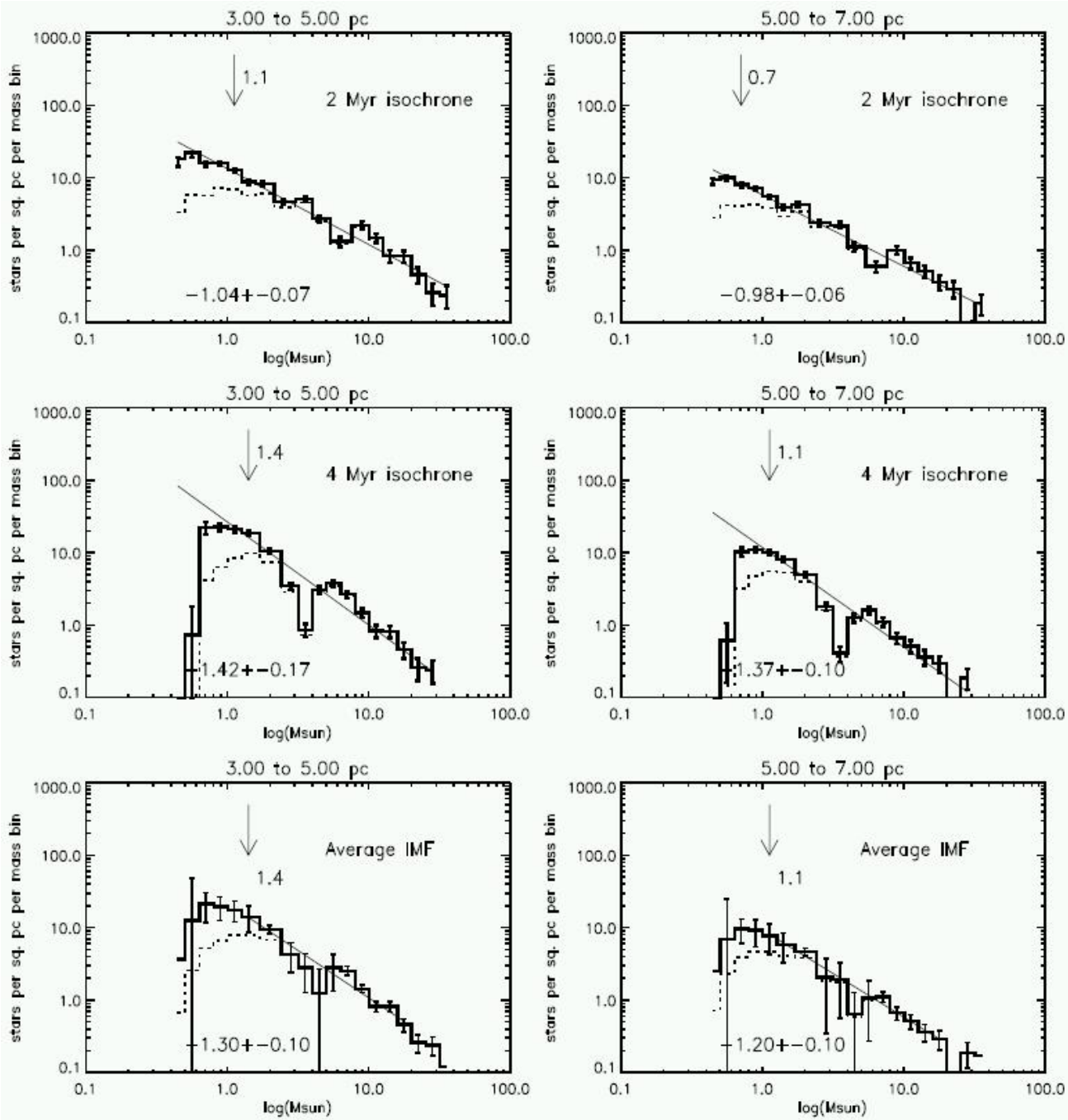


F160W (H-band) NICMOS image centred on R136 (1‘ x 1‘ = 15pc x 15pc)

Andersen et al. 2007, Ap.J. subm.

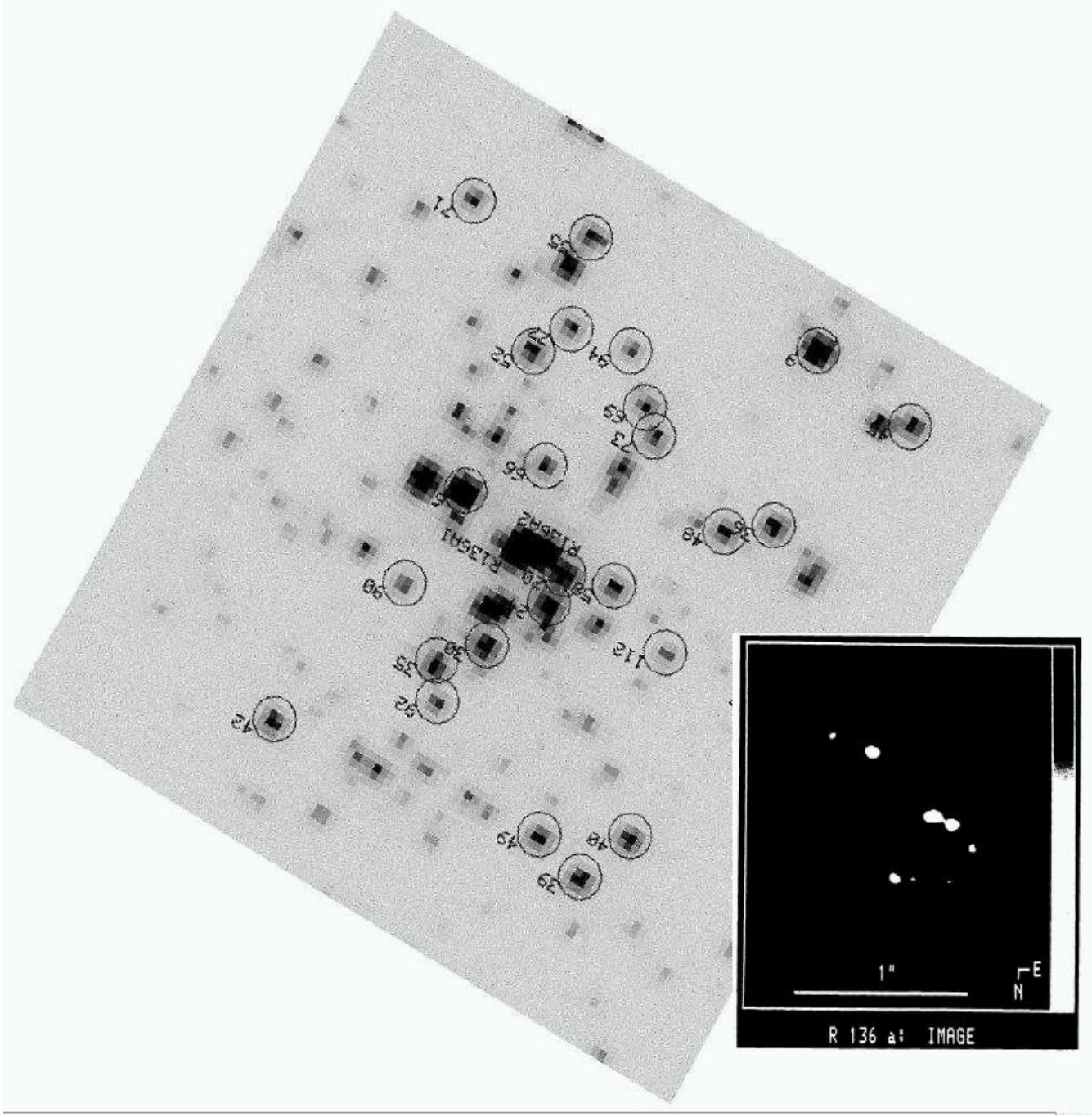


Andersen et al. 2007, Ap.J. subm.

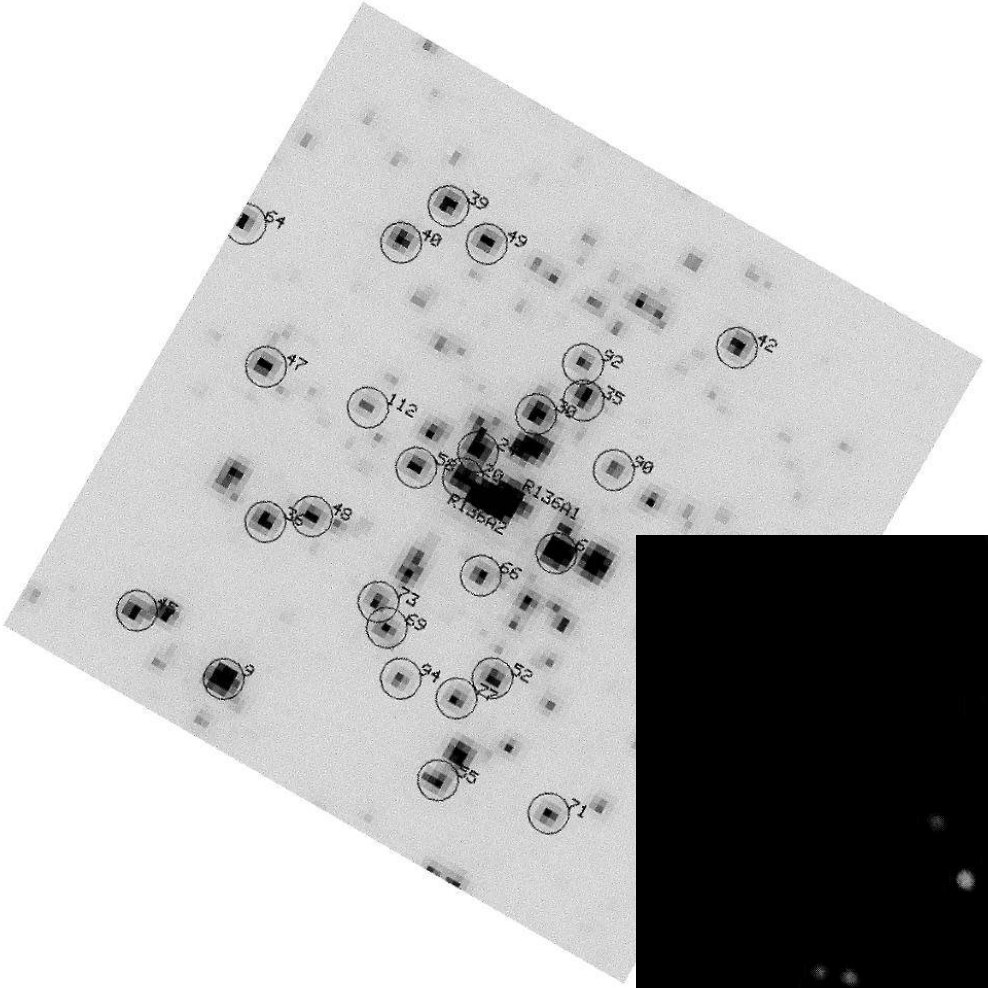


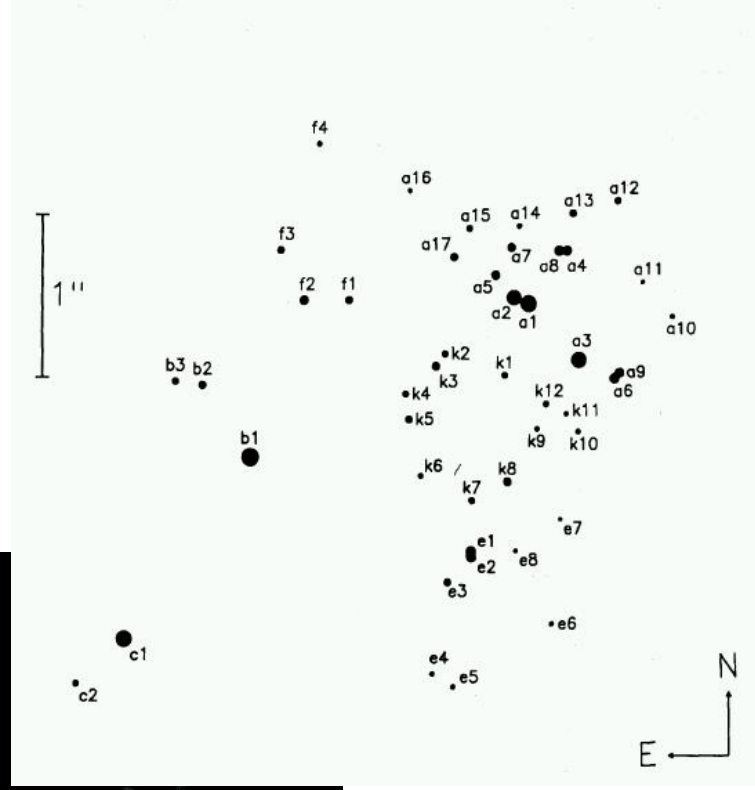
annular IMFs (vertical arrow = completeness limit)

Andersen et al. 2007, Ap.J. subm.



Massey & Hunter 1998
Weigelt & Baier 1985

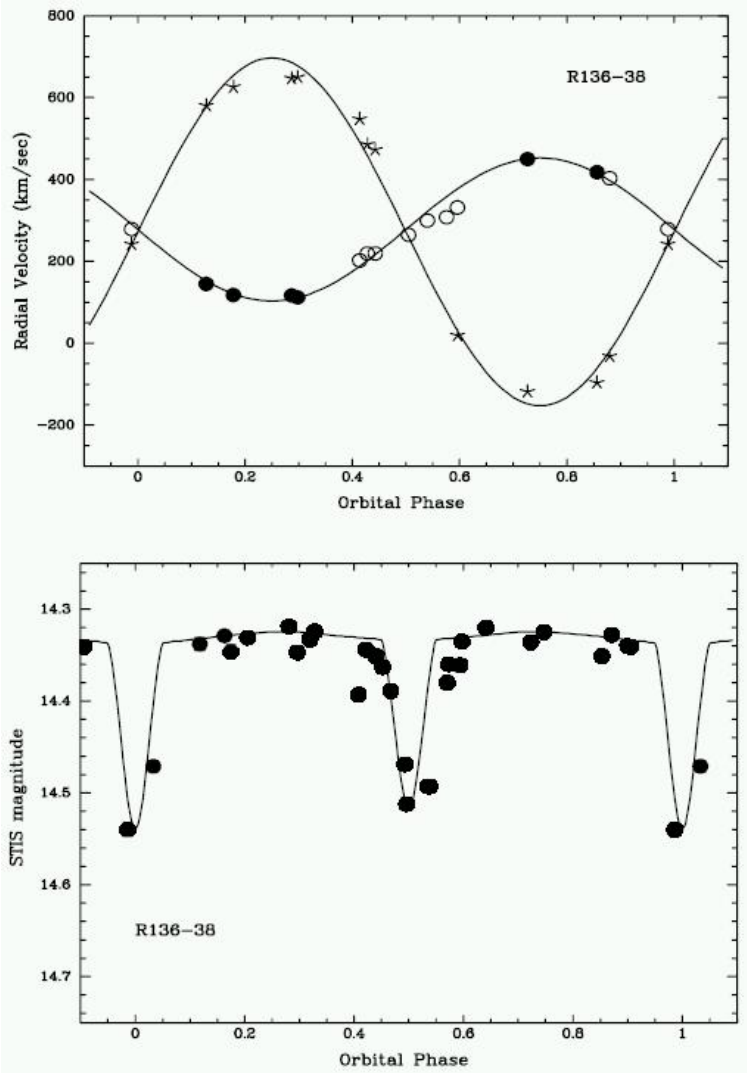


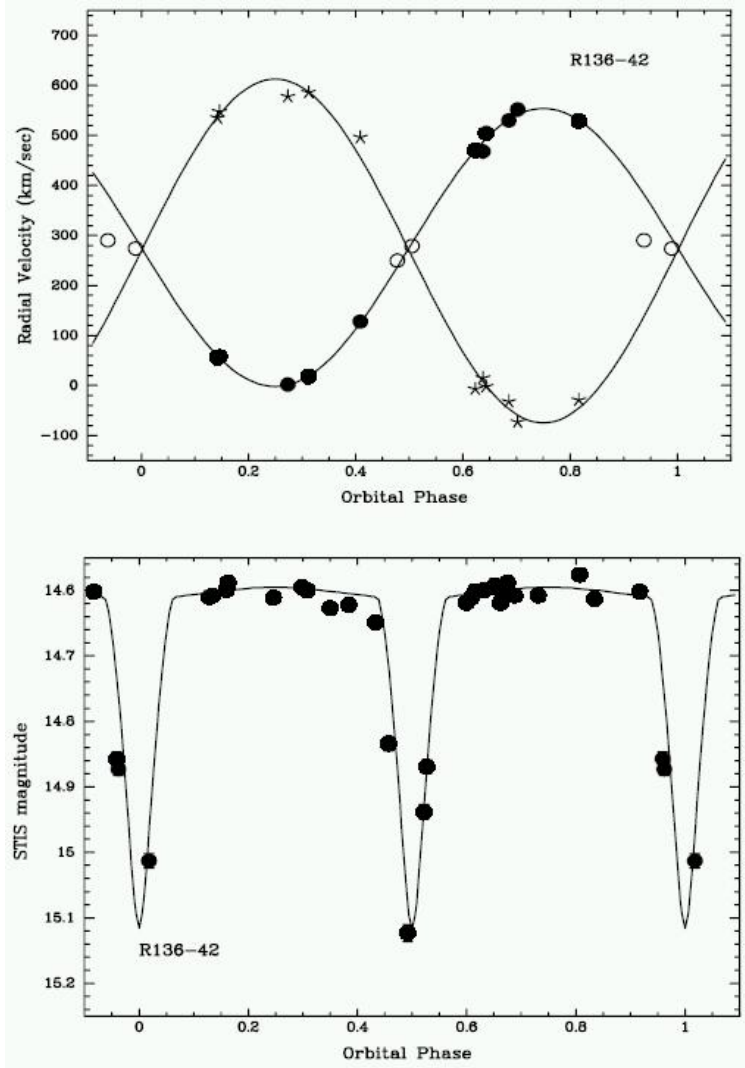


Massey & Hunter 1998
Pehlemann et al. 1992

massive eclipsing binaries in R136

Massey et al. 2002





SB2E: 57 $M_\odot$ + 23 $M_\odot$

SB2E: 40 $M_\odot$ + 32 $M_\odot$

Massive Stars in Interacting Binaries
ASP Conference Series, Vol. 367, 2007
N. St-Louis & A.F.J. Moffat

High-Mass Stars in the Centers of Young Dense Clusters: Mass Segregation, Binary Mergers and Gamma-Ray Bursts

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Abstract. We start by discussing dense, young star-clusters, particularly the 30 Doradus cluster with its core R136. The question of mass segregation and core collapse of the massive stars is addressed. Analytical estimates of relaxation times and collision times predict that the central N=10 subsystem of massive stars in the R136 core will evolve dynamically in such a way and fast enough (i.e. within their main-sequence lifetime of a few Myr) that a dominant massive binary system is formed whose orbit will shrink to a point where merging of the components appears inevitable. The merger product will be spinning rapidly, and we put forward the idea that this rare and very massive object might be the perfect precursor of a gamma-ray burst (collapsar).

The frequency of long-duration gamma-ray bursts (GRB)

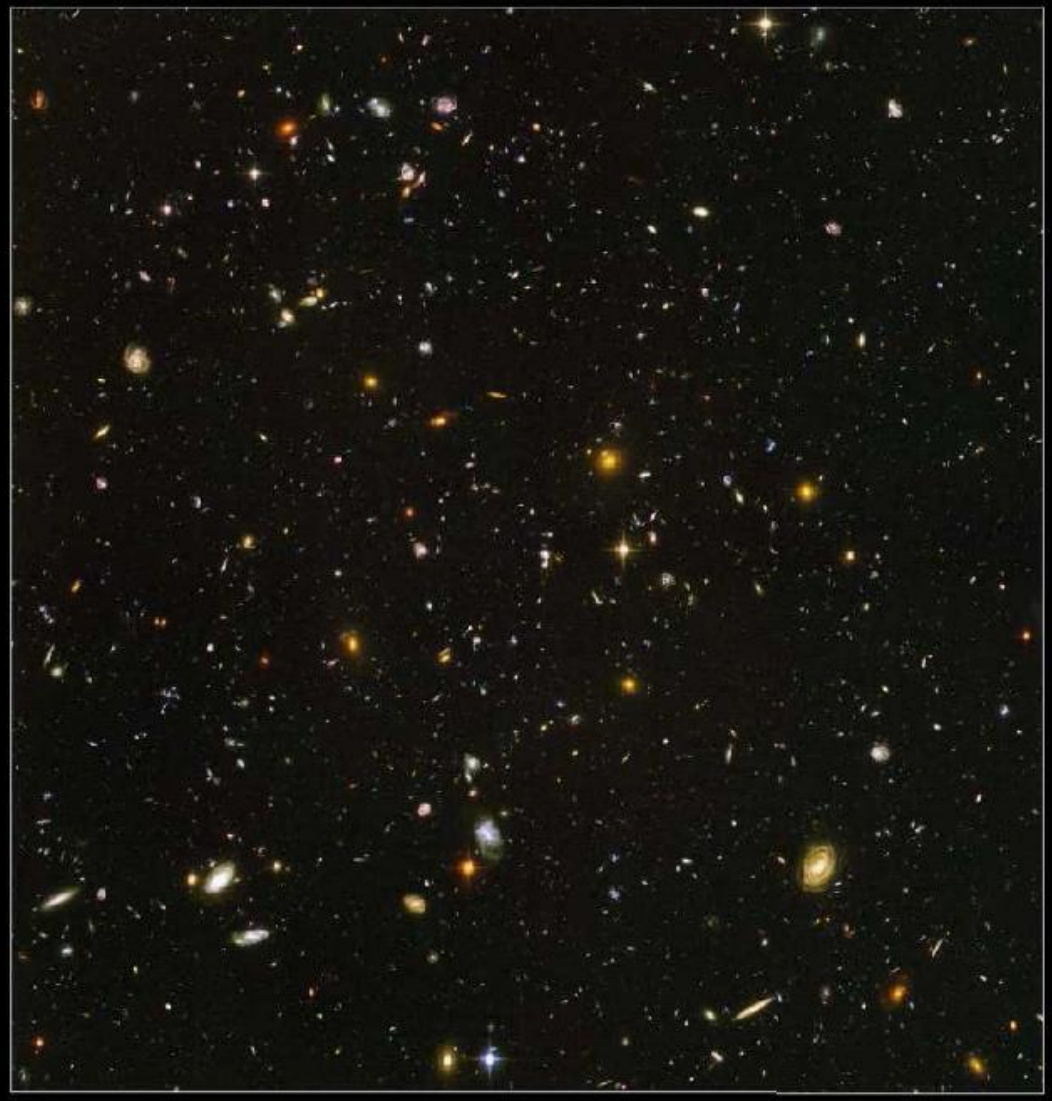
collapsar model of GRBs, requiring
rapidly rotating massive star progenitor,
perhaps due to merger of two massive stars
in the centers of dense young clusters
(this scenario can explain the rarity of GRBs)

GRB frequency depends on (cf. Zinnecker 2006)

- cluster formation rate (1 per Myr per galaxy)
- number of relevant high-z galaxies in the HUDF (9000 fuzzy galaxies in 3'x3' HST/ACS field, implying 10^{11} such galaxies over the full 4π sky)

- beaming factor of relativistic jet (10^{-3} sr)

$\Rightarrow$ GRB rate at earth = 1 Myr^{-1} 10^{11} 10^{-3}
= 1 day^{-1}, as observed!

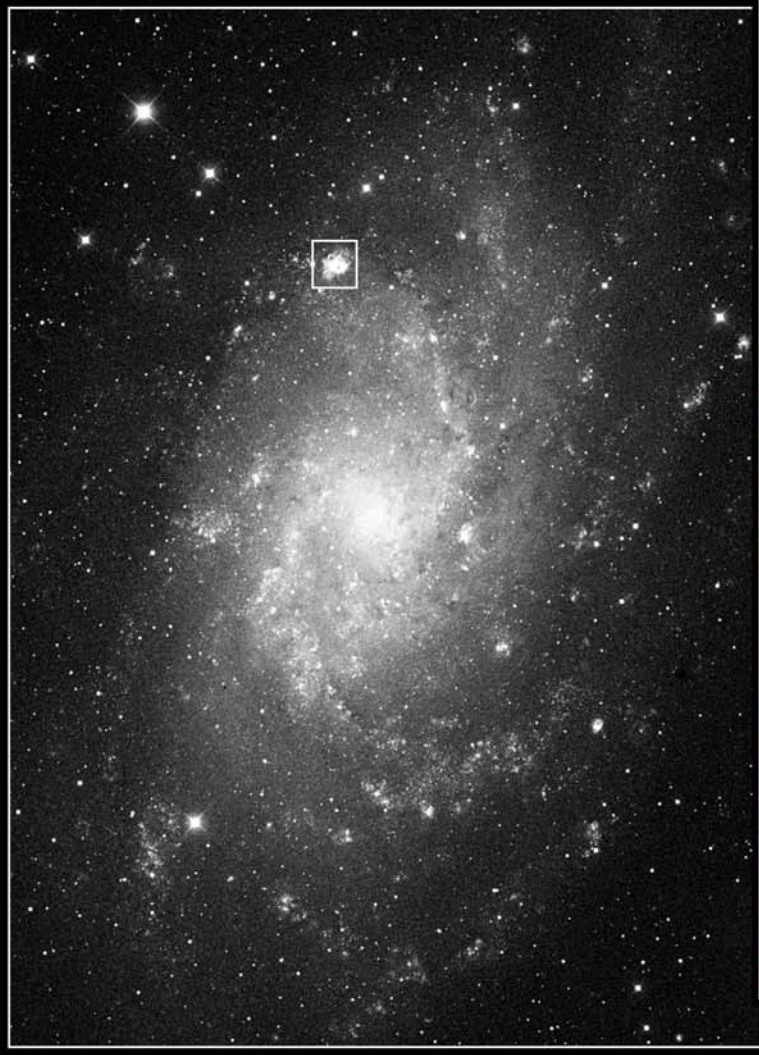


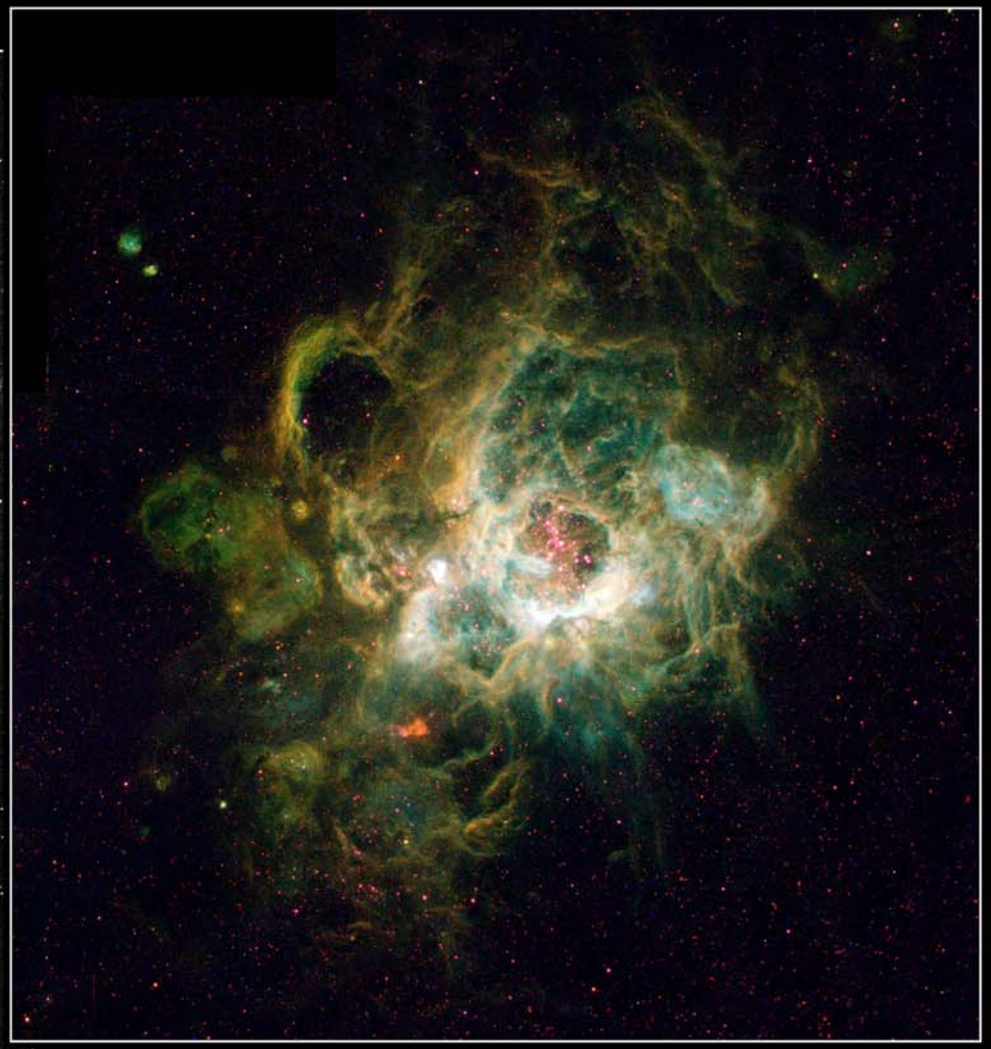
Hubble Ultra Deep Field

Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, S. Beckwith (STScI) and the HUDF Team

STScI-PRC04-07a



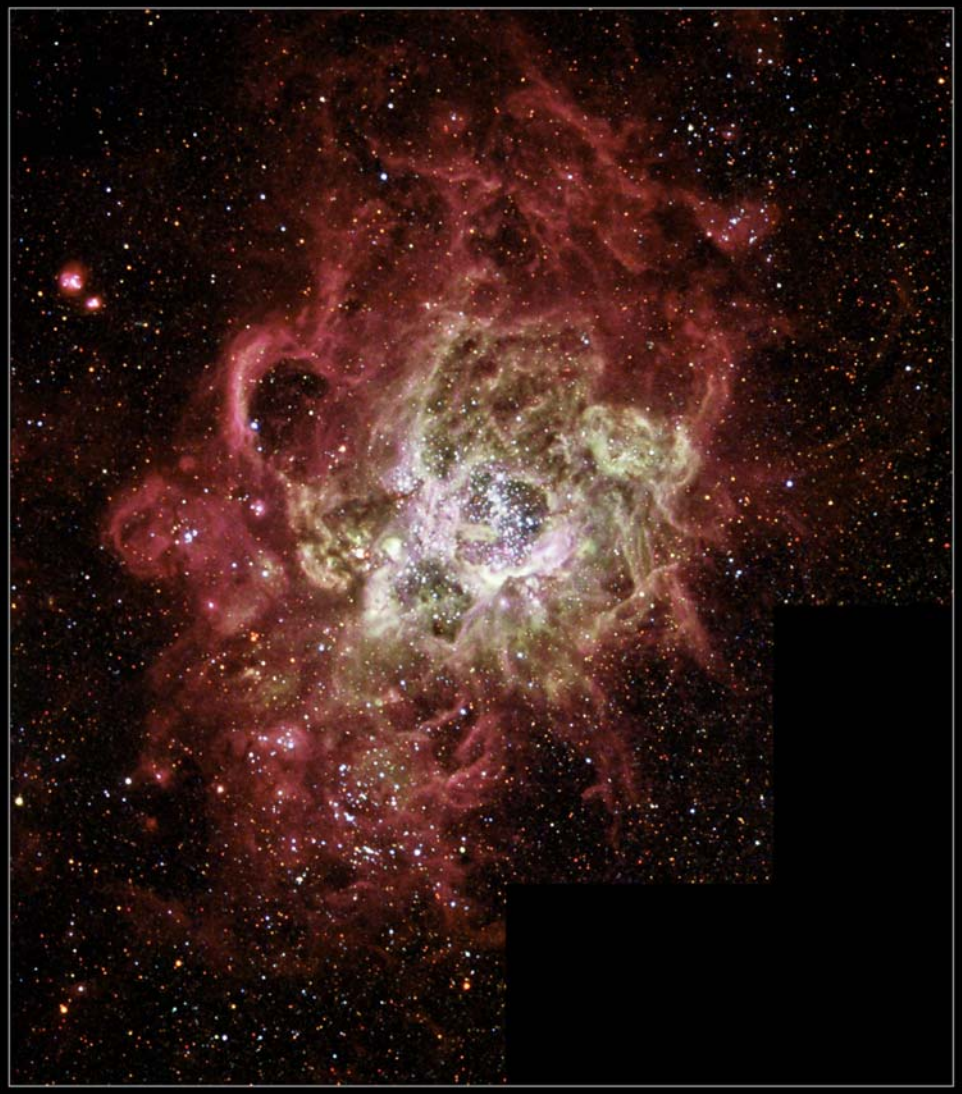


NGC 604 in Galaxy M33

Hubble Space Telescope • Wide Field Planetary Camera 2

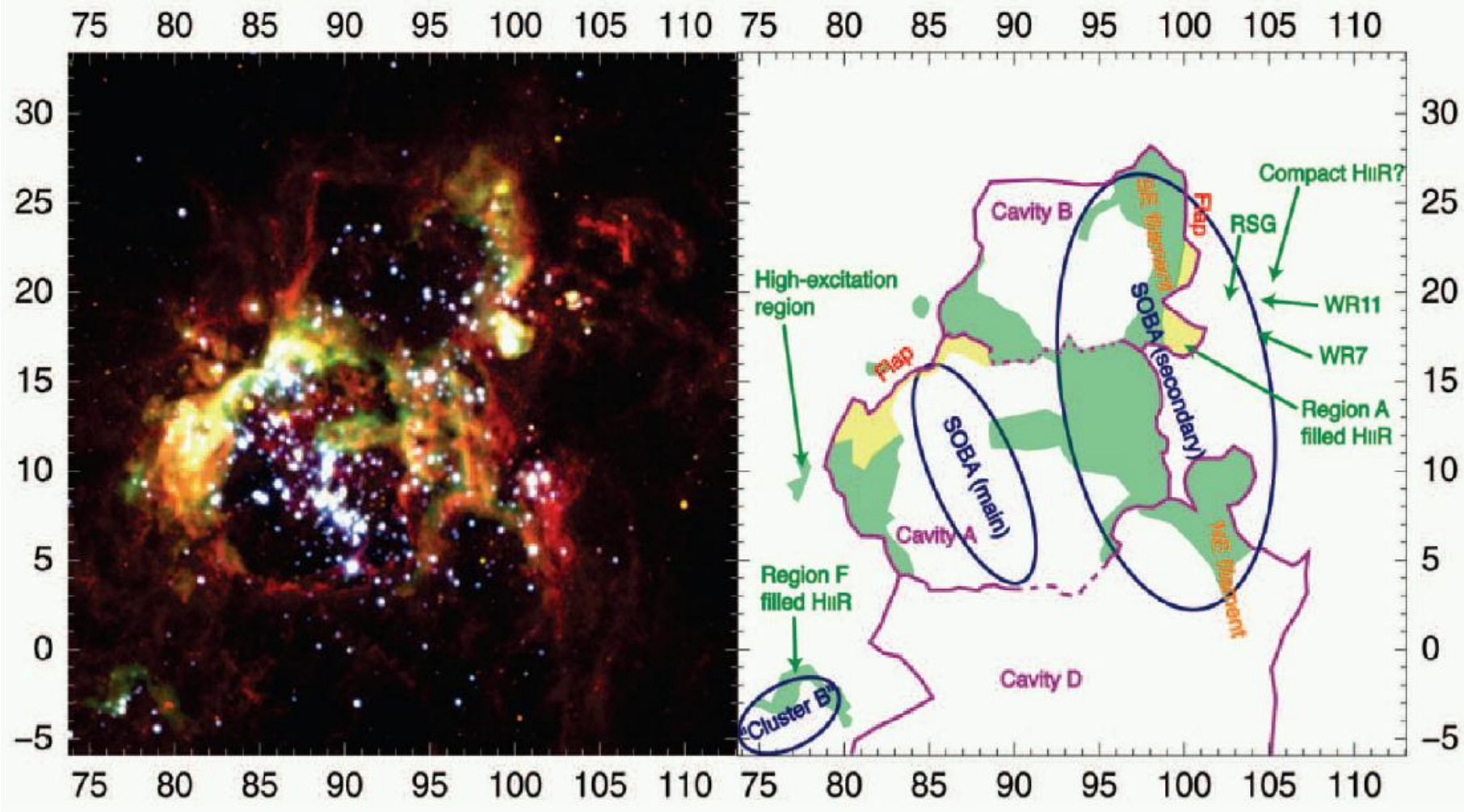
PRC96-27 • ST ScI OPO • August 7, 1996 • Hui Yang (U.IL) and NASA

NGC 604 in Spiral Galaxy M33



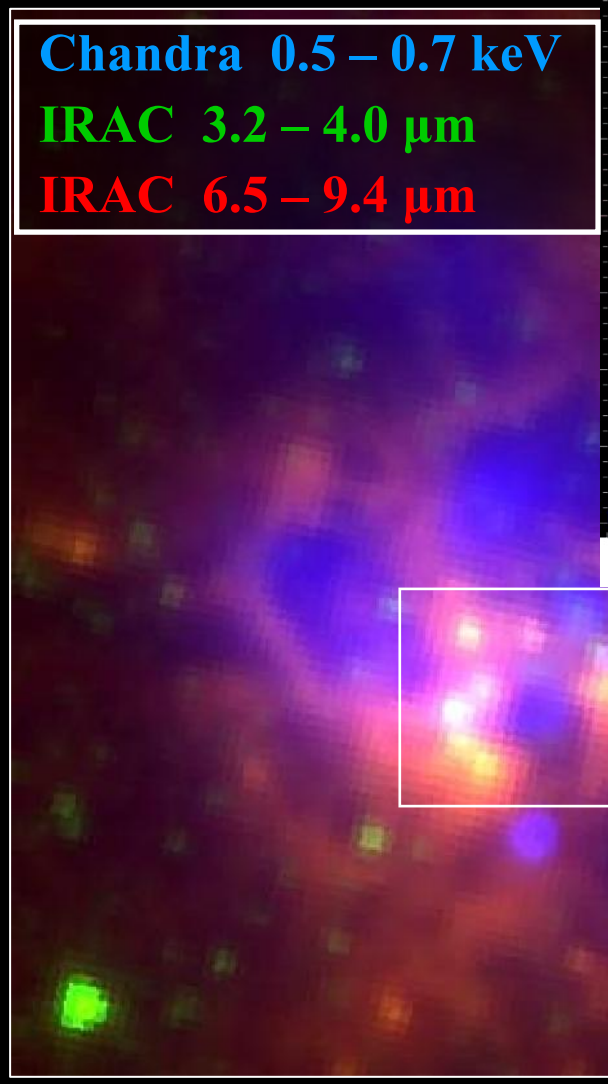
Hubble Heritage

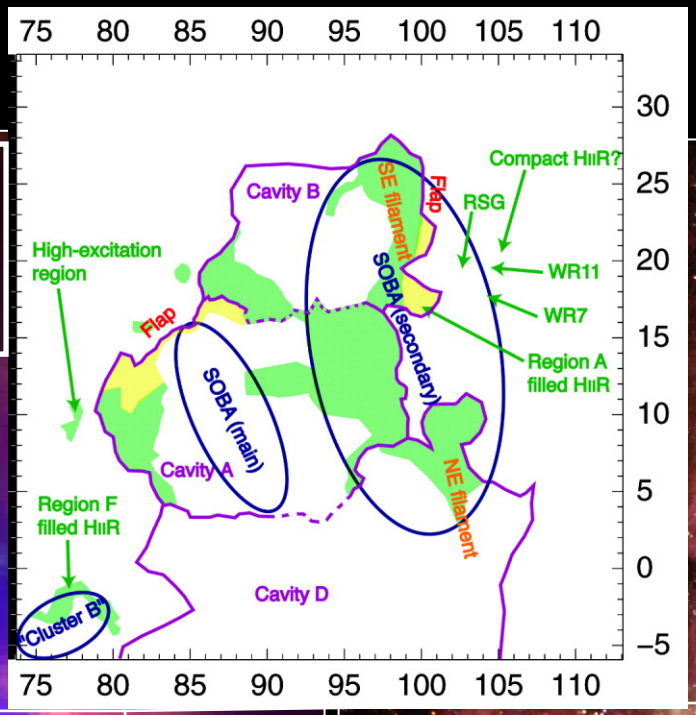
NASA and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC03-30

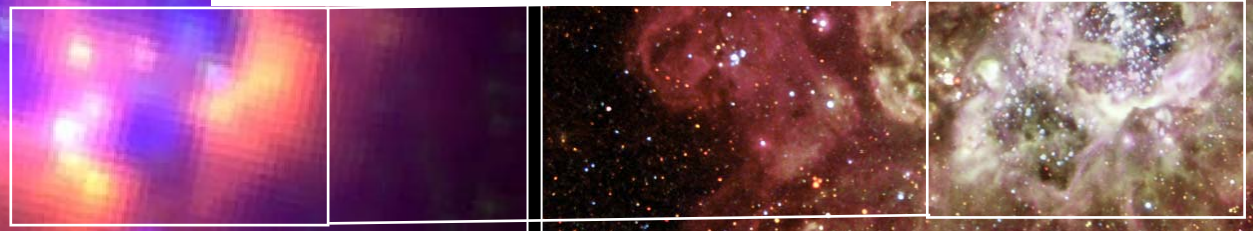


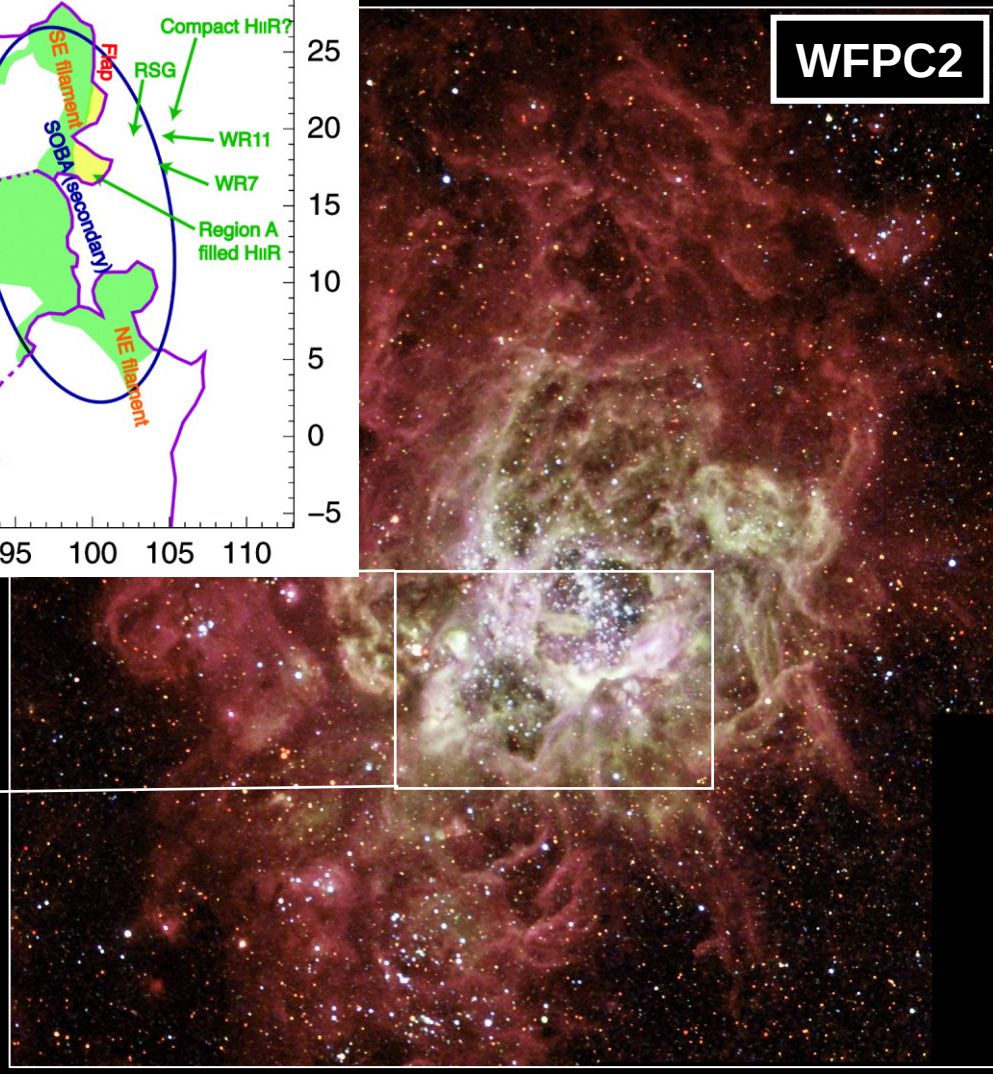
Maíz-Apellániz et al. 2004

The structure of NGC 604



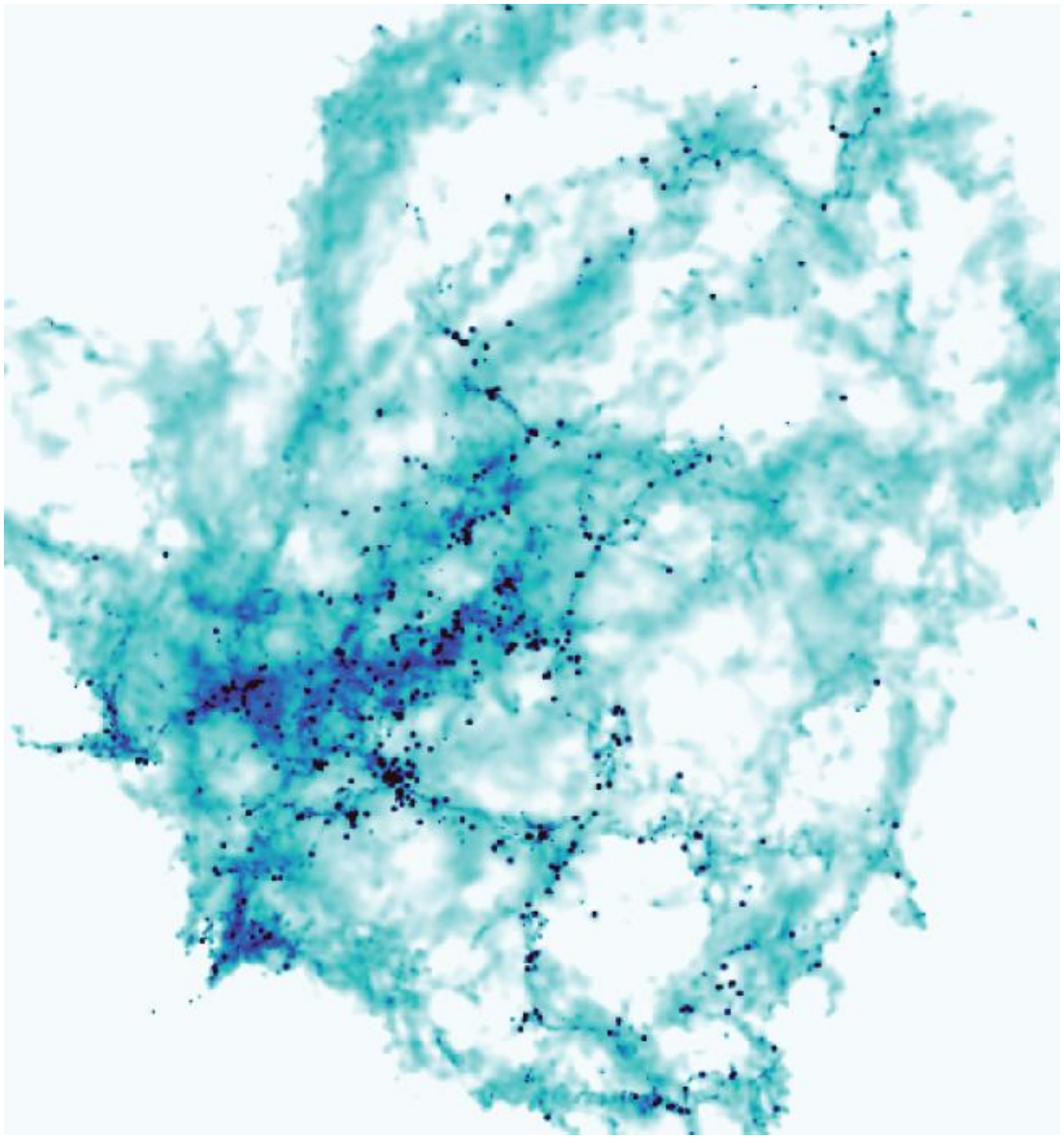






Brandl, priv. comm.

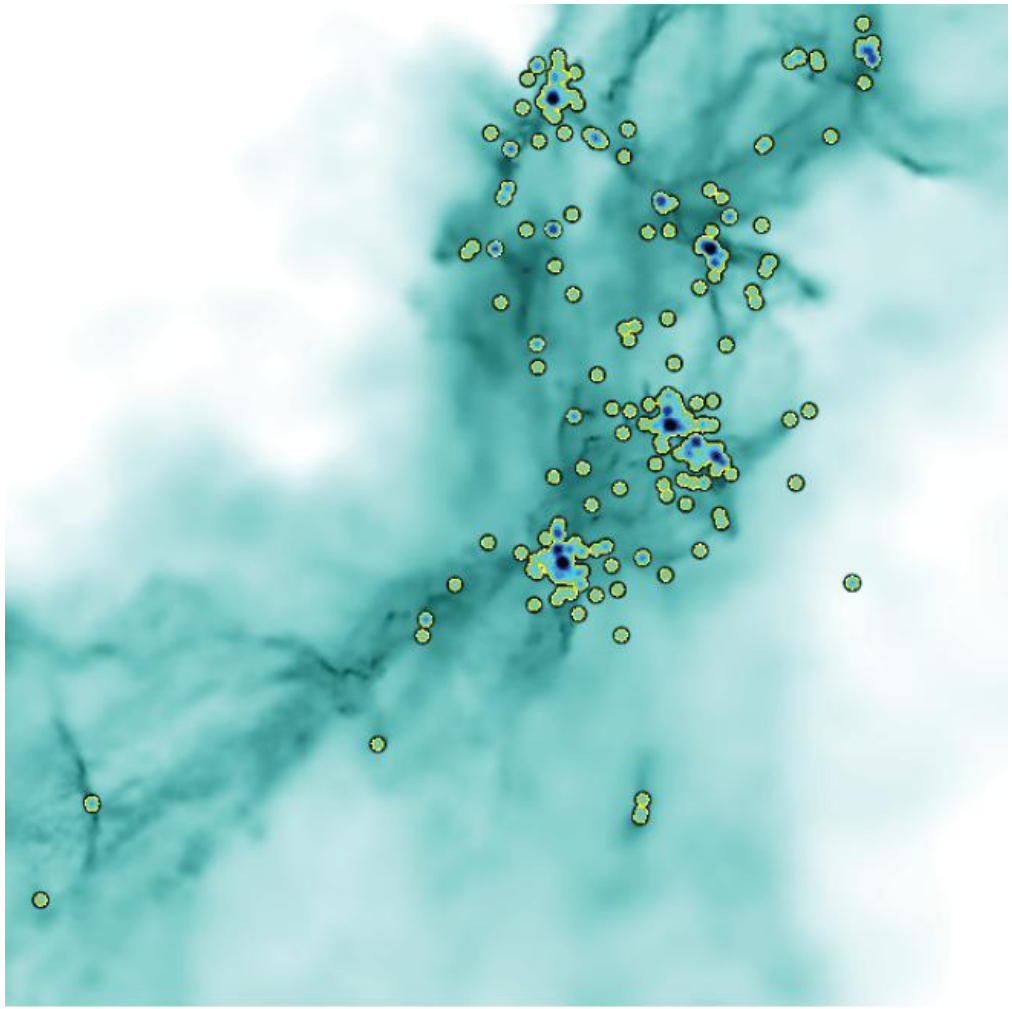
Hunter et al. 1996



from Zinnecker & Yorke 2007
(Annual Reviews, Vol. 45)

SPH simulation of a 10^6 $M_\odot$
100 pc turb. molecular cloud
collapse with $E_{turb} \cong E_{grav}$
(Bonnell, Clark, & HZ, in prep.)

simulation frozen at t = 10^7 yr
= half a crossing/free-fall time



from Zinnecker & Yorke 2007
(Annual Reviews, Vol. 45, 481)

SPH simulation of hierarchical cluster formation (sub-clusters in the process of „wet" merging)
(Bonnell, Bate, & Vine 2003)

References

Werner et al. 1978
Kennicutt 1984
Melnick 1985
Weigelt and Baier 1985
Walborn and Blades 1987
Kennicutt and Chu 1988
Hyland et al. 1992
Pehlemann et al. 1992
de Marchi et al. 1993
Parker 1993
Parker and Germany 1993
Chu and Kennicutt 1994
Malumuth and Heap 1994
Moffat et al. 1994
Hunter et al. 1995
Poglitsch et al. 1995
Brandl etal. 1996
Hunter et al. 1996
Massey and Hunter 1998
Rubio et al. 1998
Bosch et al. 1999
Fukui et al. 1999
Portegies Zwart et al. 1999
Selman et al. 1999
Zinnecker et al. 1999
Grebel and Chu 2000
Sirianni et al. 2000
Bosch et al. 2001
Massey et al. 2002
P. Zwart & McMillan 2002
Zinnecker et al. 2002
Kim et al. 2003
Maíz-Apellániz et al. 2004
Maercker and Burton 2005
Selman and Melnick 2005
Koen 2006
Townsley et al. 2006
Zinnecker 2006
Andersen et al. 2007
Zinnecker and Yorke 2007

QUESTIONS for discussion:

1) definition "starburst" (SFR density or lum. density)

2) 30 Dor: initial conditions? (irrecognizable after MSF)

3) how to form 100 massive stars in such a small volume?

4) R136: truncated IMF? one-shot or multi-episode burst?

5) R136: initial mass segregation and stellar collisions?
(likely conditions for progenitor of GRB or even IMBH?)

6) 30 Dor: a model for the origin of globular clusters?

Happy Thanksgiving Day