Sister Clusters: NGC 3293 and NGC 3324

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Star clusters as ideal stellar laboratories

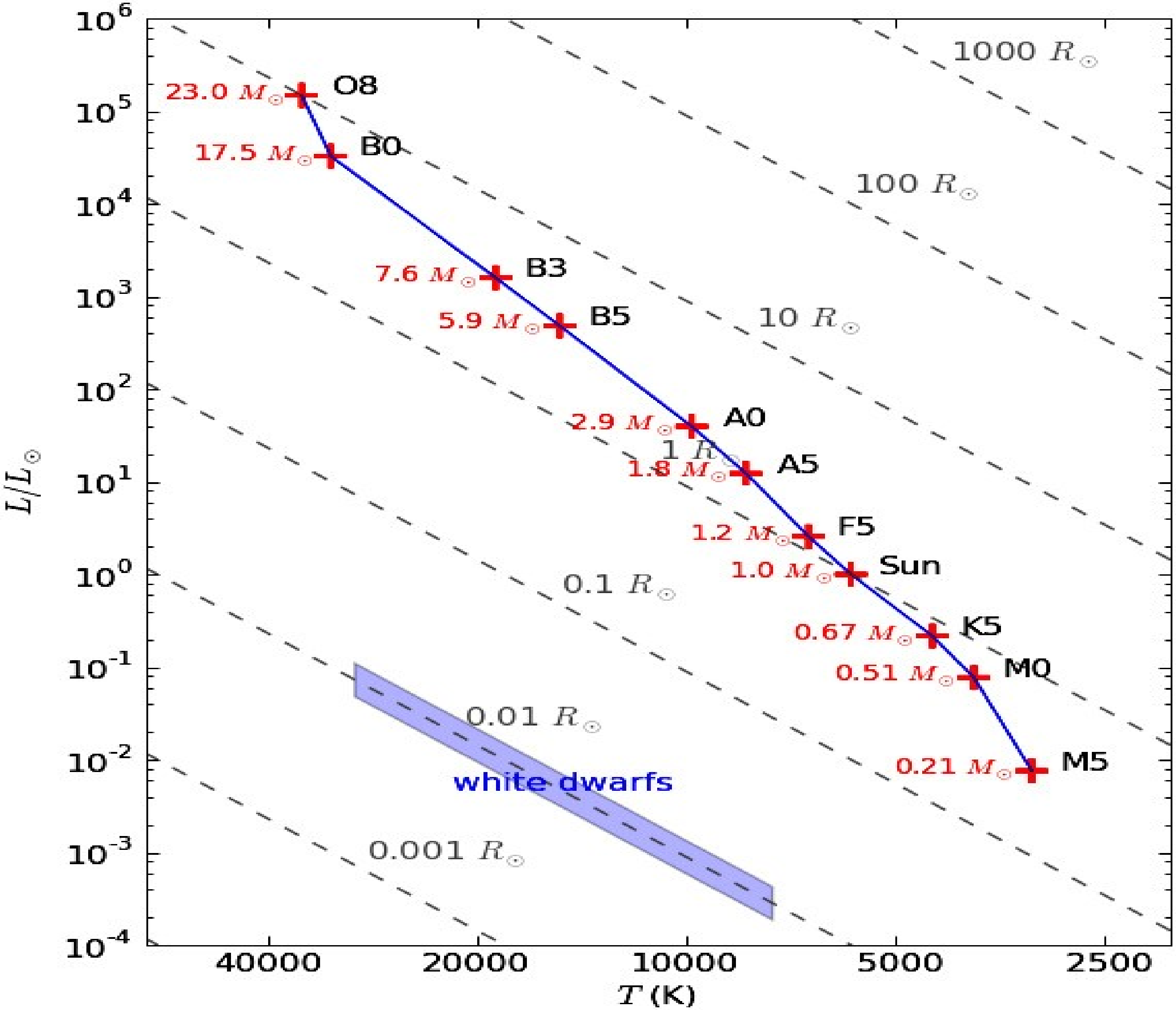
Star formation...still full of mysteries....

Evolving nbody systems...

"ecology of star clusters"

- IMF, stellar evolution, dynamics
- Initial conditions for star formation
- The larger picture....of galaxy formation!

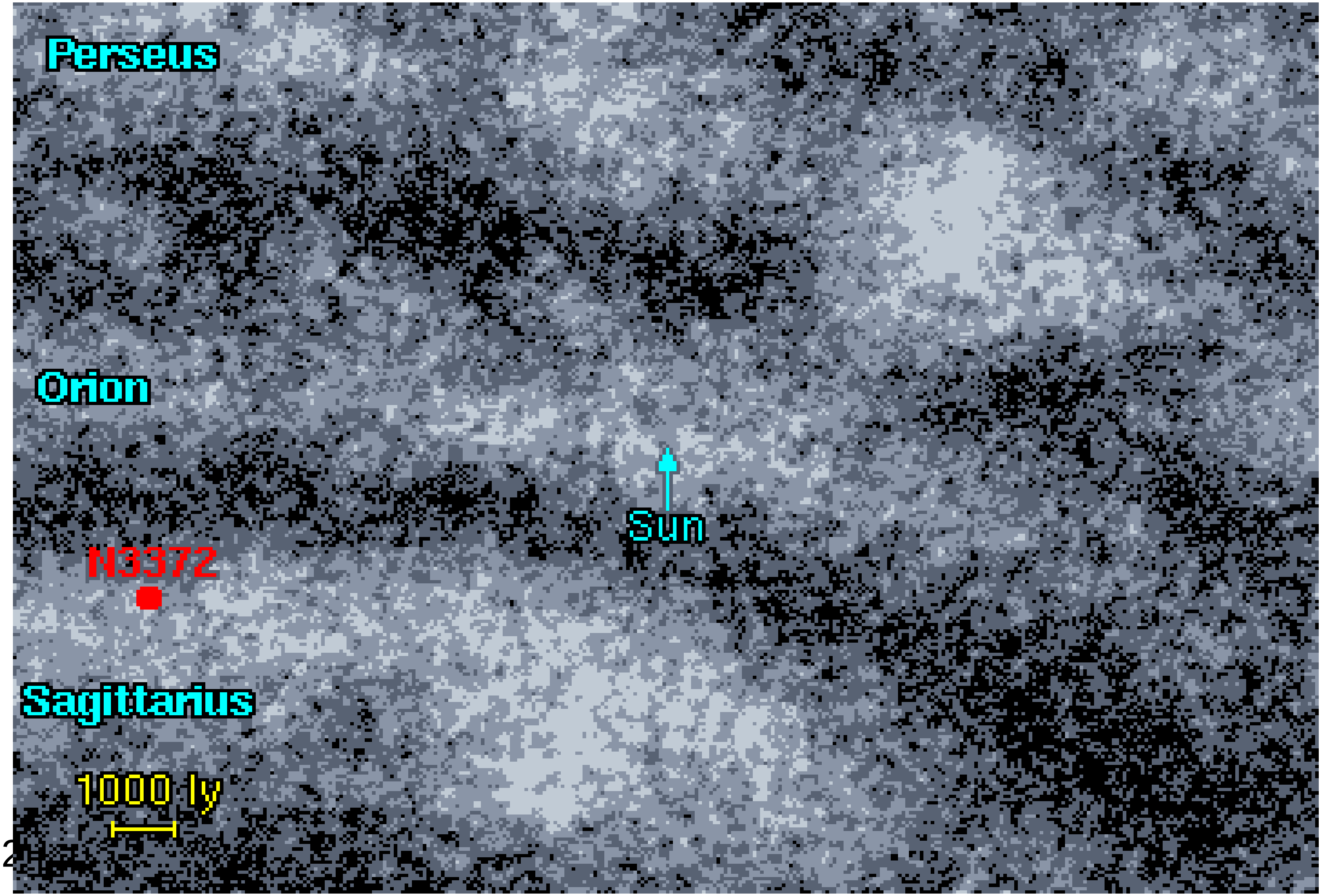
Star Clusters...the ideal samples...



Questions

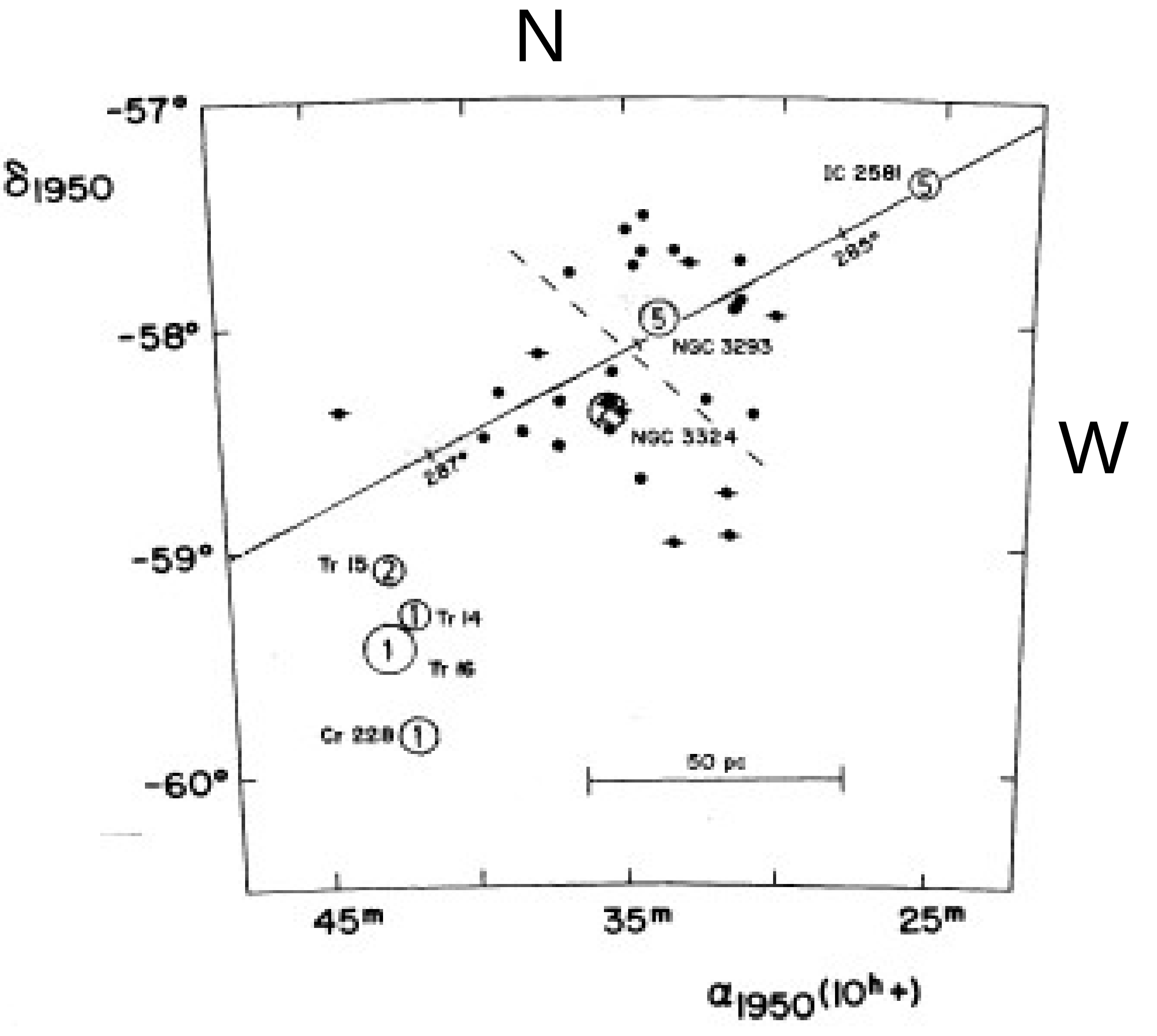
- What is the star formation mechanism and for how long is it active ....age spread of stars (Sung et al. 1998)? Is it coeval or sequential (Iben &Talbot 1966; Herbst & Miller 1982; Adams et al. 1983)?
- What forms first, massive or low mass stars?
- Is the IMF slope universal? Is it bimodal? Why do some open clusters show an apparent deficit of low mass stars (van den Bergh & Sher 1960; Adams et al. 1983; Lada et al. 1993; Phelps & Janes 1993; Sung et al. 1998; Prisinzano et al. 2001), even though they are young enough to exclude stellar loss by dynamical evolution?
- Does the IMF vary from cluster to cluster even within the same star formation region, probably by changes in the initial conditions of the star formation process (Scalo 1986, Lada & Lada 1995)?

NGC 3372, Carina Nebula



NGC 3293

- Moderately young cluster
- 2.6 kpc
- Belongs to the rich Carina complex...Tr14, Tr15, Tr16, Cr 228, NGC 3324, IC 2581




DSS colored
N
30'
Powered by Aladin


AllWISE color
30'
Powered by Aladin
2.596° x 1.937°
N
E


2MASS colored
30'
Powered by Aladin
2.596° x 1.937°
N
E

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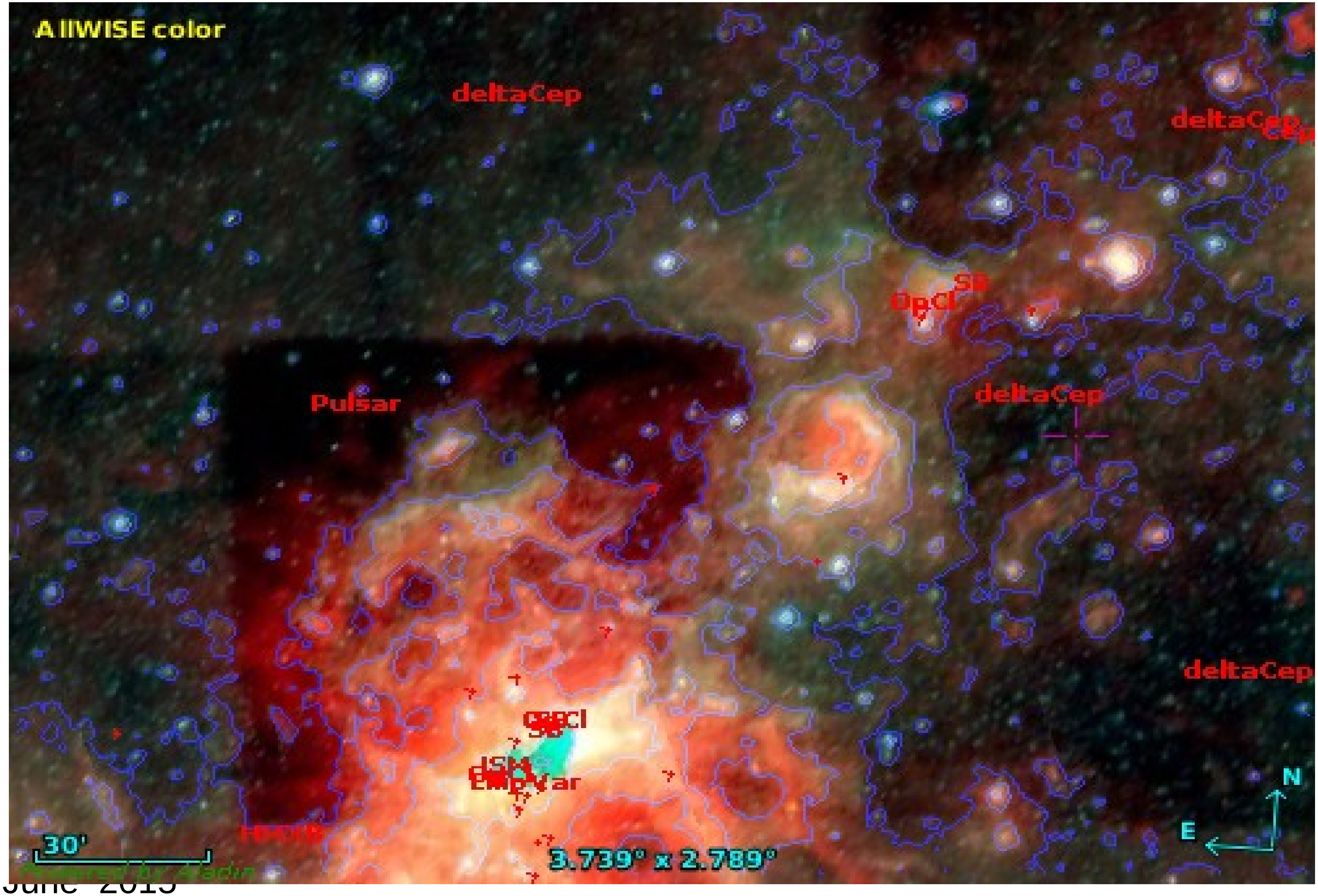
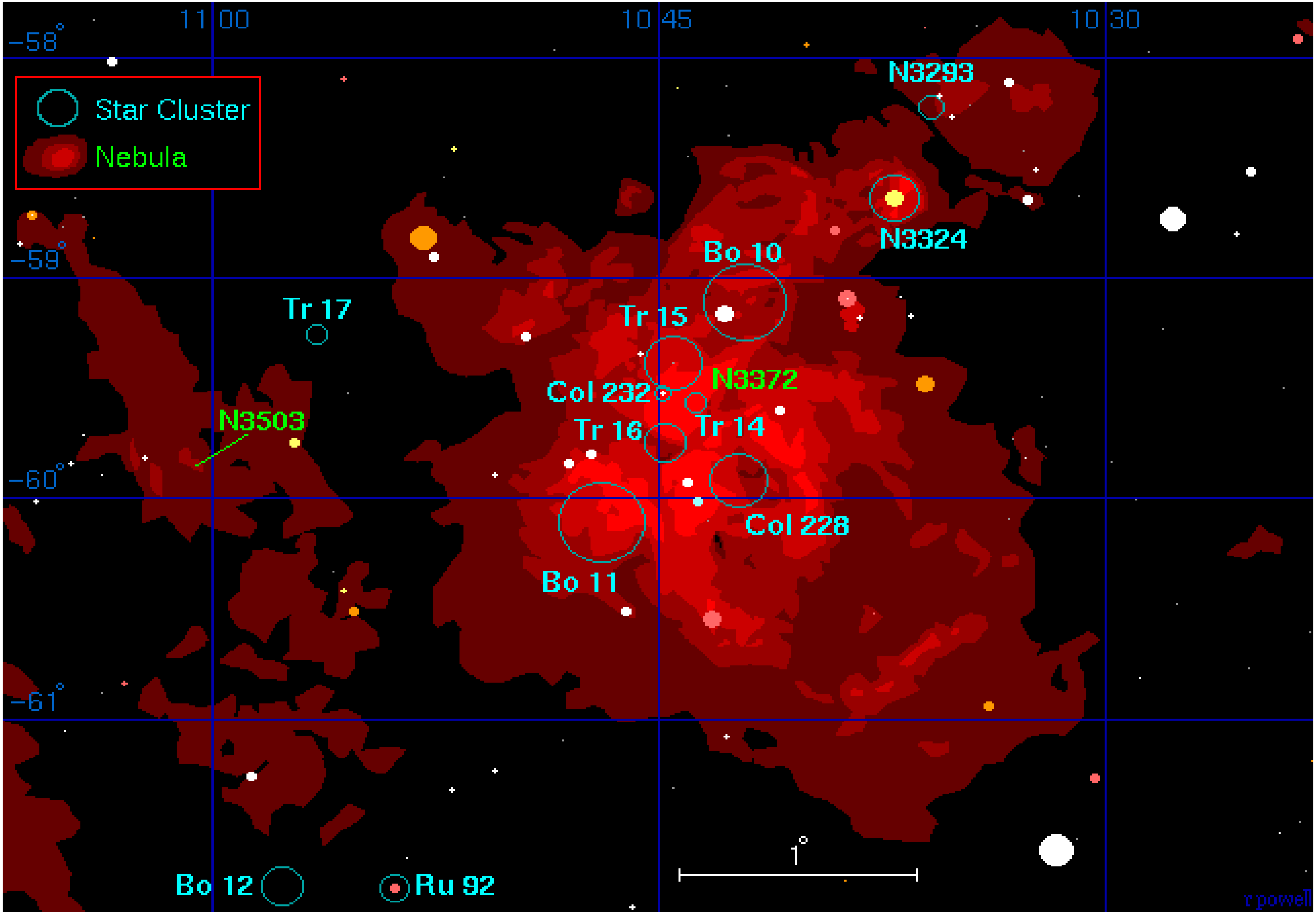

AllWISE color
deltaCep
deltaCep
SB
OpCl
Pulsar
deltaCep
deltaCep
SB
ISM
EmObj
30'
3.739° x 2.789°
N
E

Clusters in Carina

Catalogue Name	Equatorial Coordinates RA (2000)	Dec	Galactic Coordinates l°	b°	Size (arcmins)	Distance (ly)	Age (million years)	Other Names
BH 90	10 11.9	-58 04	283.1	-1.5	4'	8400	88	
IC 2581	10 27.5	-57 37	284.6	+0.0	5'	8000	14	
NGC 3293	10 35.8	-58 14	285.9	+0.1	6'	7600	10	Gem Cluster
NGC 3324	10 37.4	-58 39	286.2	-0.2	12'	7550	6	
Collinder 228	10 42.1	-59 55	287.4	-1.0	14'	7200	7	
Bochum 10	10 42.3	-59 08	287.0	-0.3	20'	6600	7	
Trumpler 14	10 44.0	-59 33	287.4	-0.6	5'	8900	7	
Trumpler 15	10 44.8	-59 22	287.4	-0.4	14'	6050	8	
Trumpler 16	10 45.0	-59 43	287.6	-0.7	10'	8700	6	Eta Carinae Cluster
Collinder 232	10 45.0	-59 33	287.5	-0.5	4'	7850	5	
Bochum 11	10 47.3	-60 05	288.0	-0.9	21'	7850	6	
Ruprecht 92	10 53.8	-61 45	289.5	-2.0	7'	7700	63	
Trumpler 17	10 56.5	-59 12	288.7	+0.4	5'	7150	51	
Bochum 12	10 57.5	-61 43	289.9	-1.8	10'	7250	41	

- IC 2581 +NGC 3293....h and χ Persei?
- Differences in their most luminous stars, identical MS, same age
- NGC 3324+Tr 15, $2X10^6$
- Tr 14, Tr16, Cr 228...very young...million years
- SF initiated $5X10^6$ yrs ago...NGC 3293, IC 2581
- Wave of SF 25-35 kms^{-1} in direction of increasing longitude, sequential SF

Turner et al, 1980, AJ, 85, 9


11 00
10 45
10 30
−58°
−59°
−60°
−61°
Star Cluster
Nebula
N3293
N3324
Bo 10
Tr 17
Tr 15
N3372
Col 232
N3503
Tr 16
Tr 14
Col 228
Bo 11
1°
Bo 12
Ru 92
r powell

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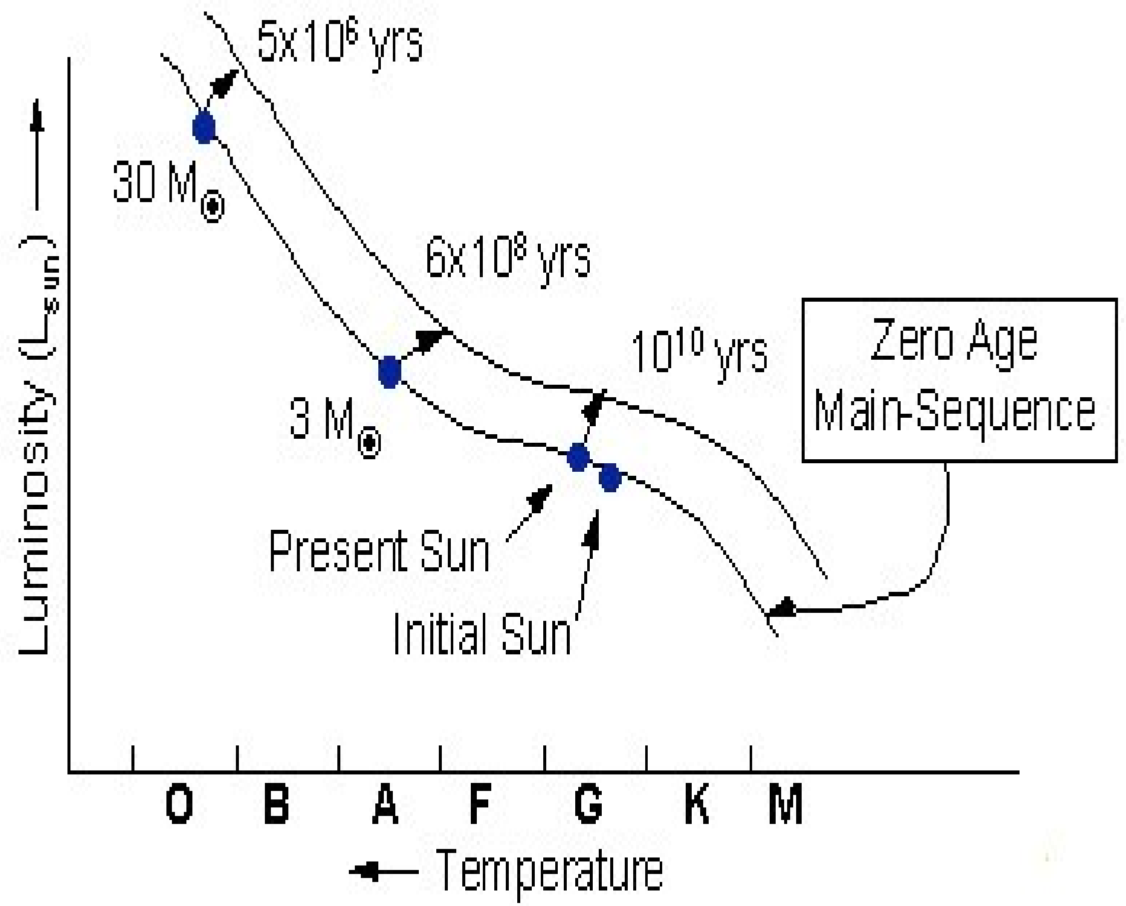
Too simplistic a picture....what about O stars in NW?

Sequential star formation...

But

- No of stars per subgroup much larger....is it due to each subgroup made of one or more clusters?
- Age gradient not as steep

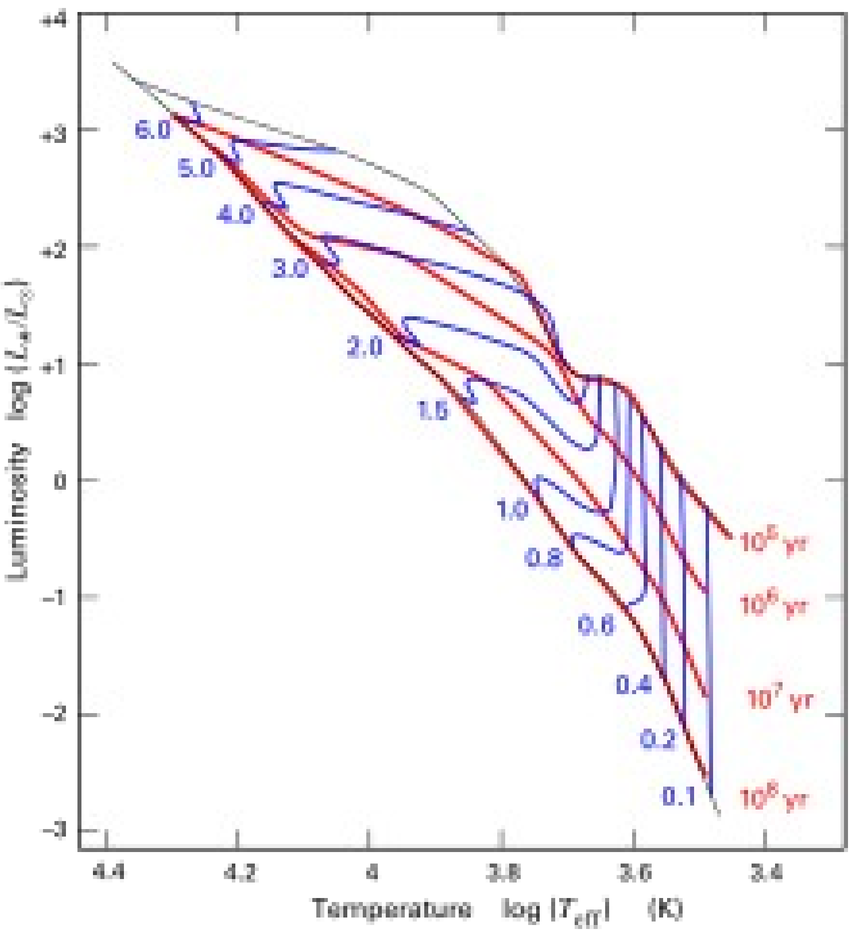
Nuclear age....turn off



$$\frac{t_{MS}}{t_{sun}} \approx \left(\frac{M}{M_{sun}}\right)^{-2.5}$$

Lower bound of cluster age

Contraction age .....turn-on



Free-fall timescale, which is roughly 100,000 years for solar-mass protostars

Stellar evolution tracks (blue lines) for the pre-main-sequence.

Hayashi tracks (nearly vertical), low mass, fully convective <0.5 Mo

Henyey track (more massive)

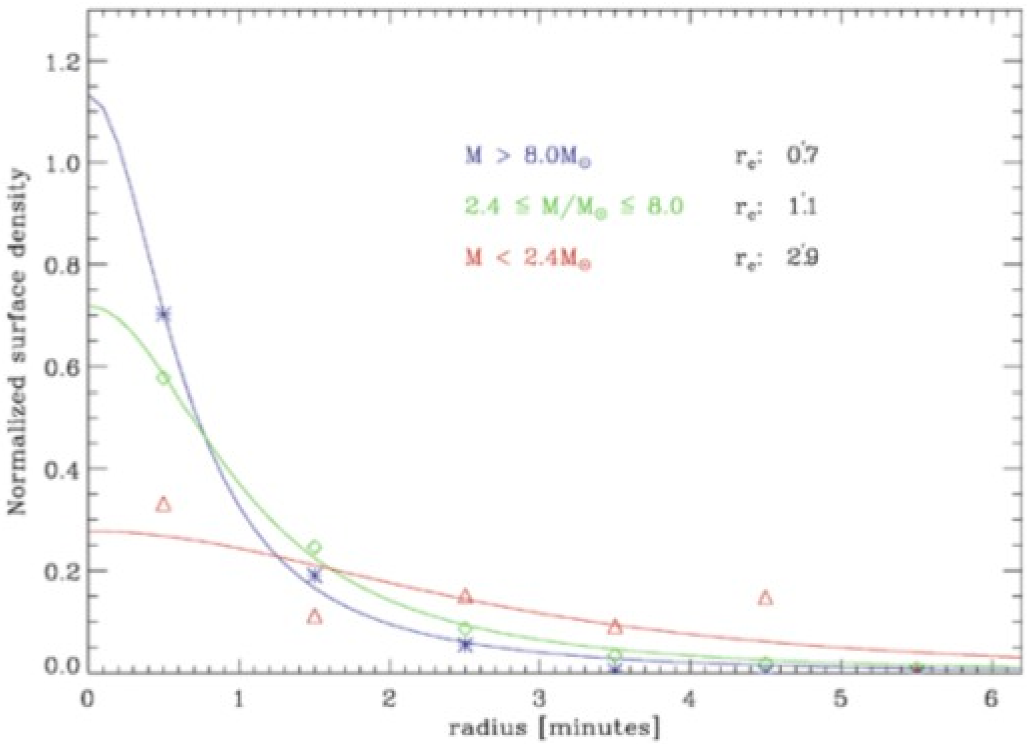
The red curves labeled in years are isochrones at the given ages.

- Nuclear age t_N $6X10^6$ yr contraction age t_c $25X10^6$ yr...age spread?
- Variation of IMF with time? Which forms first (low or high mass)?
- Lack of low mass stars...preference to high mass?
- Herbst & Miller, 1982, AJ 87, 11

prob: selection effects close to the detection limit of the photographic plates (Deeg & Ninkov 1996).

- Completeness....? Observational artifact?
- Models....Baume, 2003..

RDP for mass regines



Mass segregation
Not Dynamical

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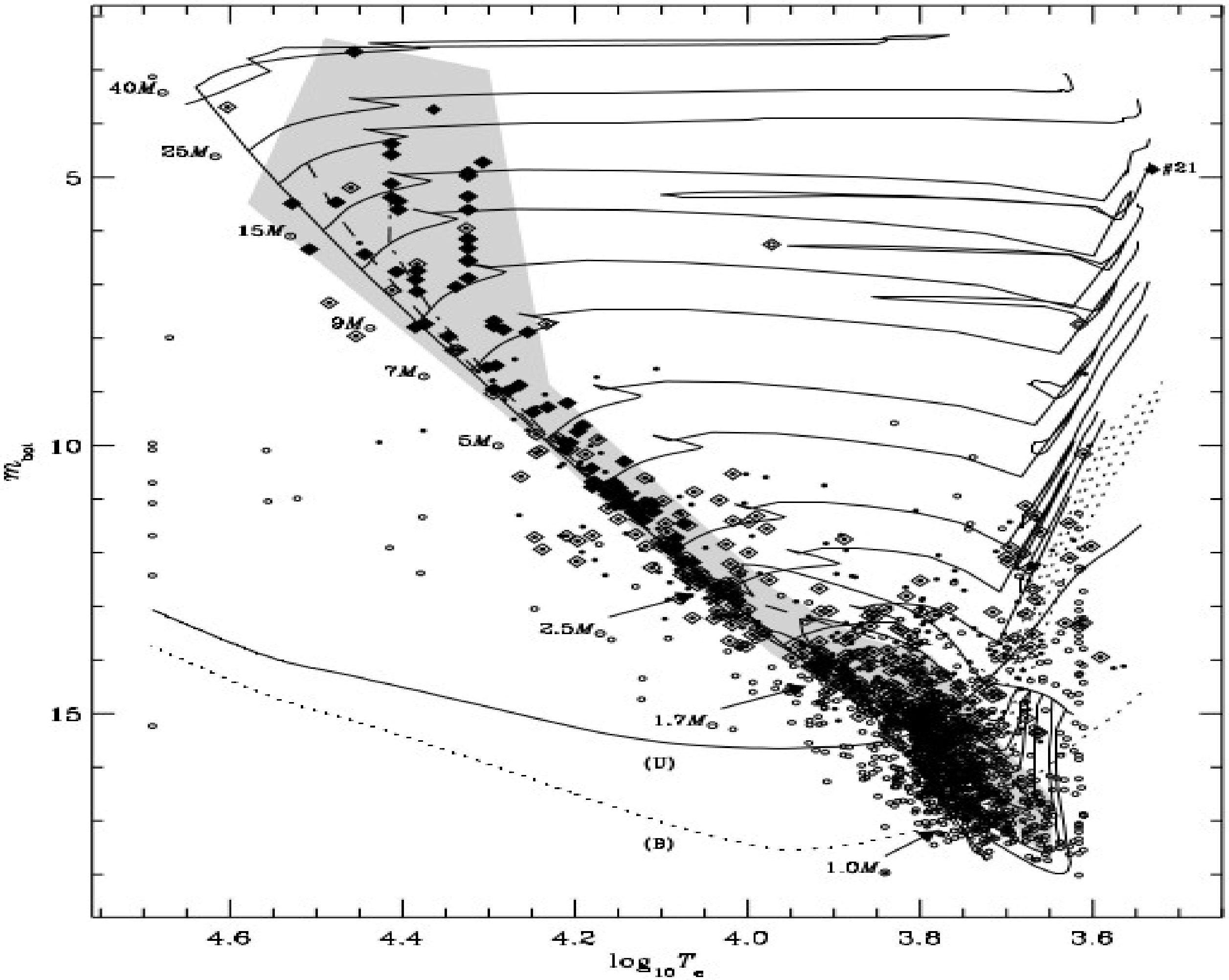
NGC 3293



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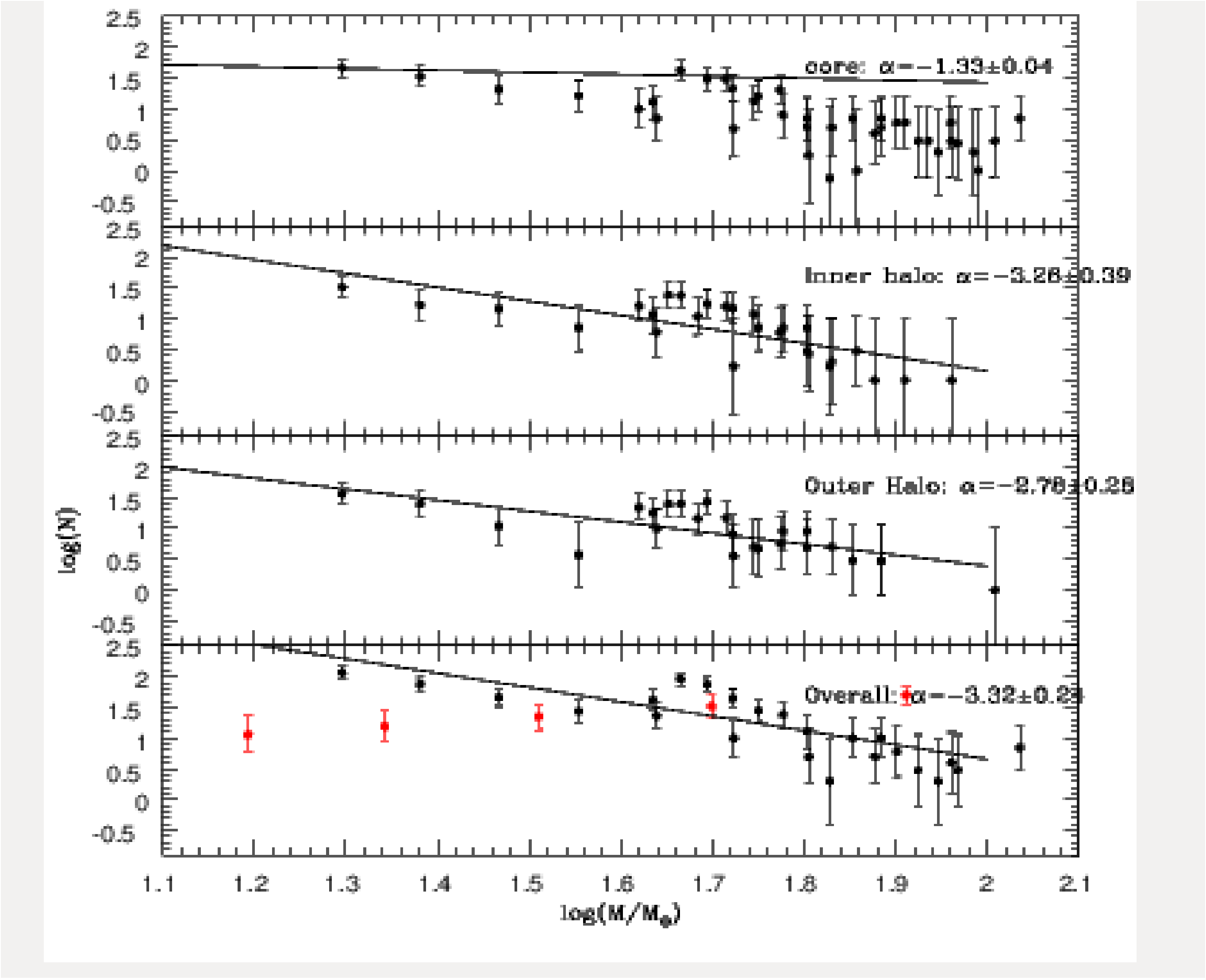
Slawson, 2007, Astrophys Space Sci (2007) 312: 171–187

Mass function



- Good representative of IMF
- Relaxation time 30×10^6 yr
- $t_N < t_c$ implies that low mass stars formed first
- High mass stars only one crossing time old
- Low mass stars too young to evaporate

Is something missing?

Multiplicity of star clusters: Time-space correlations

- At the Solar Circle, at least 12% of all open clusters appear to be experiencing some type of interaction with another cluster
- Correlated star formation
- Simulatenous formation
- Sequential formation
- Tidal capture
- Optical doubles

For two clusters separated by a distance larger than three times the outer radius of each cluster, the amount of mutual disruption is negligible. Innanen et al. (1972)

If primordial binary star clusters do form, they appear not to be able to survive as such for long

No long term binary stability

Or, general open cluster samples are biased against older clusters because they contain less luminous stars.

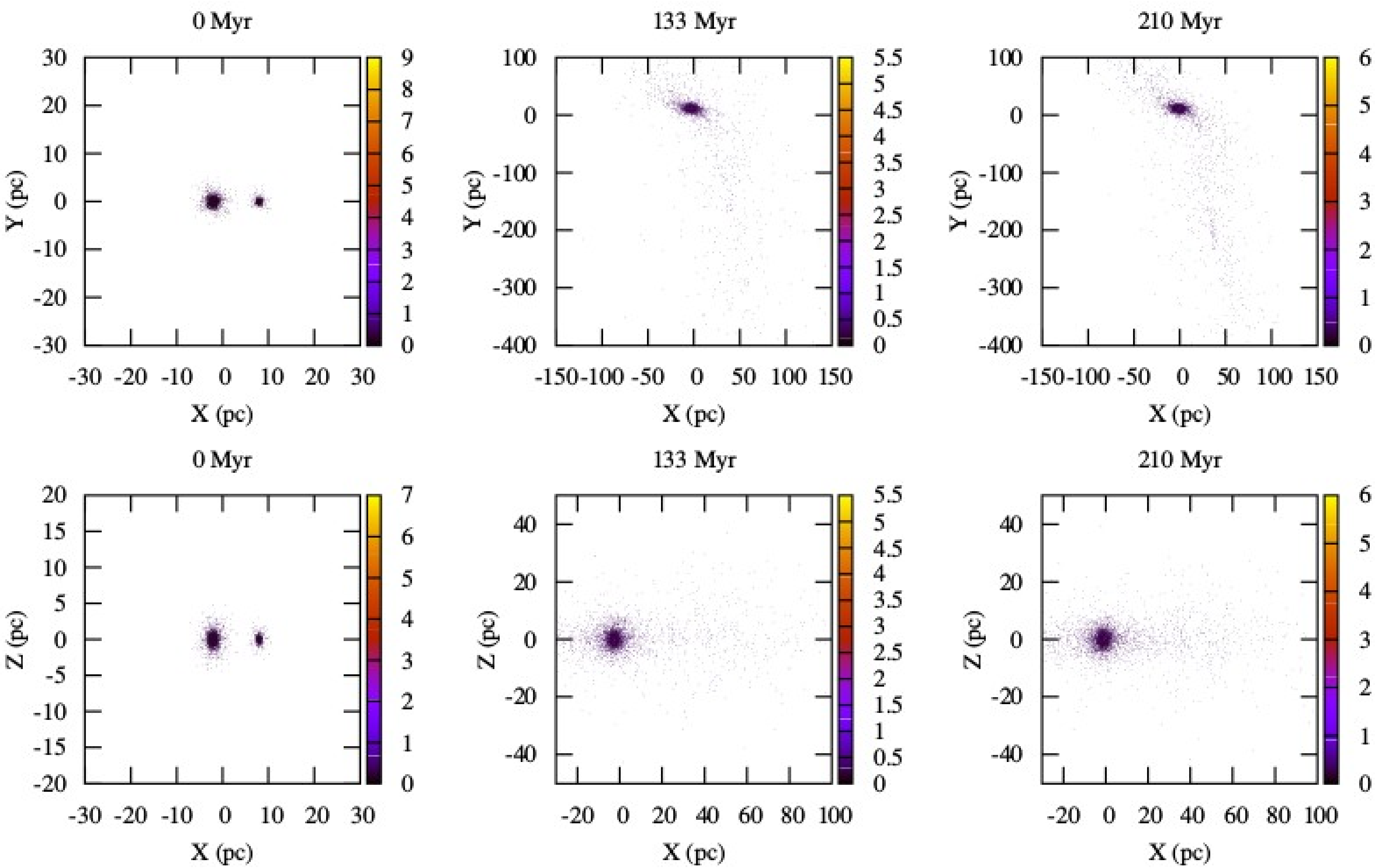
- Fraction of candidate binary clusters in the Milky Way disk is comparable to that in the Magellanic Clouds, $\sim$10%
- Out of this population, nearly 40% of them can be classified
- as genuine primordial binary open clusters, only $\sim$17% appear to be able to survive as conspicuous pairs for more than 25 Myr.
- The distribution of open cluster separations exhibits an apparent peak at 10–15 pc

Classification scheme

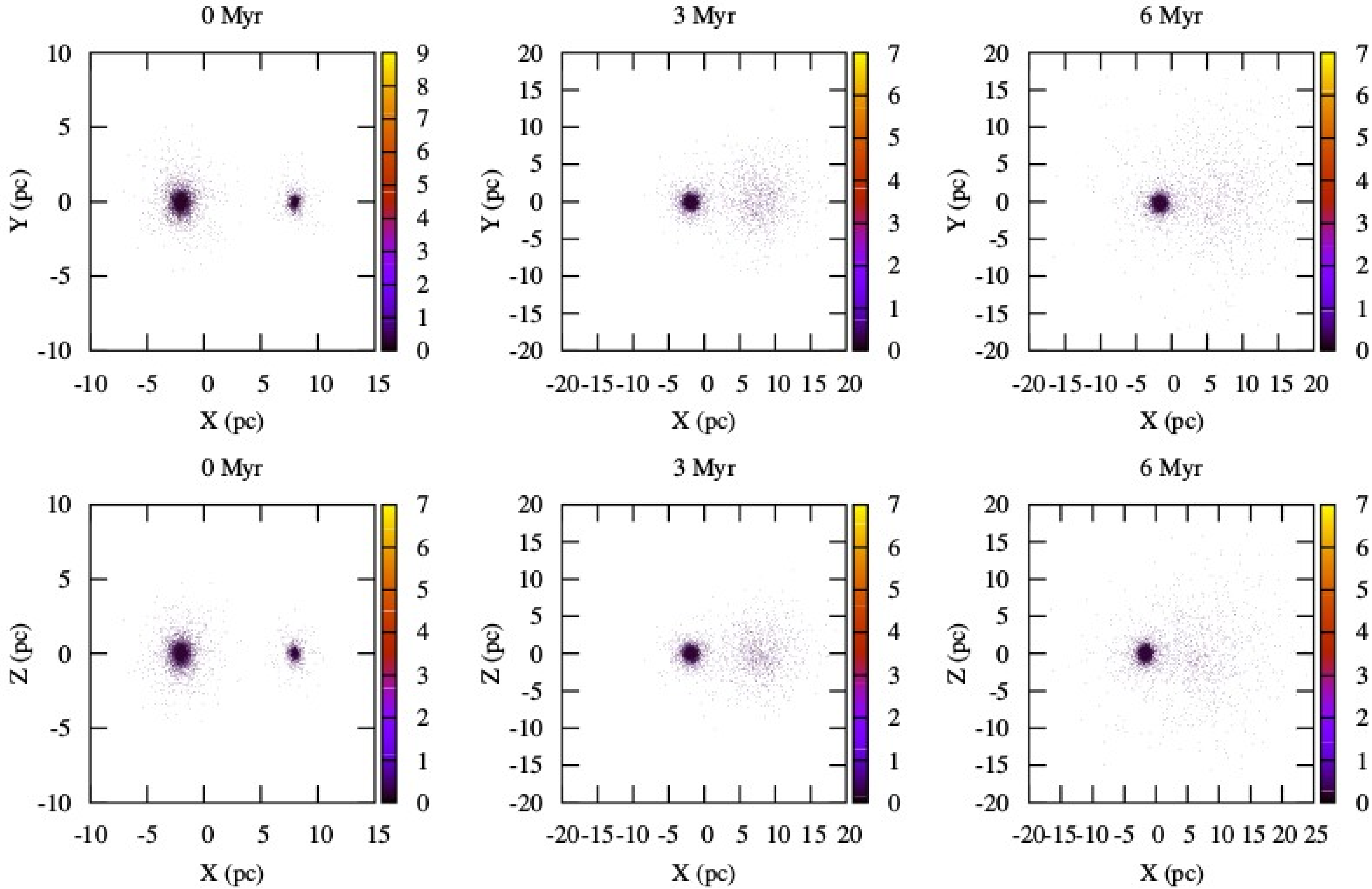
The strength of the cluster–cluster interaction is maximum when the intercluster separation becomes smaller than the tidal radii. This interpretation was proposed in de la Fuente Marcos & de la Fuente Marcos (2009c)

$$\text{Cluster Pairs} \begin{cases} \text{Detached}, \ R_{T1} + R_{T2} < S \\ \begin{array}{c} \text{Interacting} \\ R_{T1} + R_{T2} > S \end{array} \begin{cases} \text{Weak}, \ R_{T1} \text{ AND } R_{T2} < S \\ \text{Semi}-\text{Detached}, \ R_{T1} \text{ OR } R_{T2} < S \\ \text{In}-\text{Contact}, \ R_{T1} \text{ AND } R_{T2} > S \end{cases} \end{cases}$$

Nbody 6:Shredding/Tidal distortion (Unequal mass rations)



Early Evolution
Fast expansion/Mass loss



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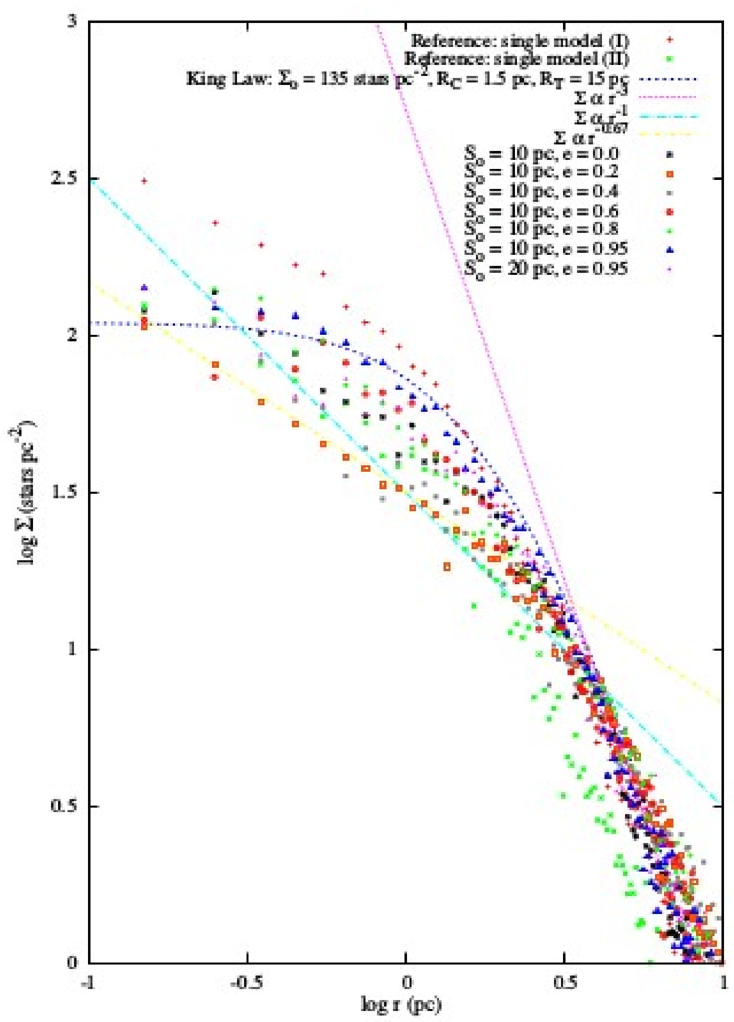
NGC 3293+NGC 3324

- The outer regions of merger remnants are similar to those of an equivalent single cluster having twice the population of the individual clusters but the number density of the inner regions is rather different.
- Merger models characterized by higher central concentration are preferentially associated with pairs with high initial eccentricity and, therefore, shorter merger timescale.
- Pairs in which the mutual tidal disruption has been the weakest

as they have been interacting for a shorter period of time. This explains why their cores are nearly 25%–50% denser than that of an equivalent King model.

Merger Signatures



Merging of two stellar systems is expected to give surface density profiles Σ(r) ∝ r^ {−3} (Sugimoto & Makino 1989; Makino et al. 1990; Okumura et al. 1991).

Velocity distributions

IRIS/IRMS

The figure on the left illustrates three clusters with varying masses (30Dor: 10^5 $M_\odot$, NGC3603: 10^4 $M_\odot$, Orion: $10^3 M_\odot$) which will be resolved with IRIS at distances up to 20 Mpc away.

- Impact of merging on the evolution of close and therefore young open cluster pairs is all but negligible. The same can likely be said about young star cluster pairs in other galaxies.
- On the other hand, the rapid decrease in star cluster numbers for ages older than 20 Myr can also be the result of merging or tidal disruption in close primordial pairs.Merging and tidal disruption of the less massive companion may easily halve (at least) the initial population of relatively close open cluster pairs.
- Merging, disruption, and infant mortality, concurrently, can efficiently reduce the number of observed young star clusters and accelerate dramatically the transition of stars born in clusters to the field populations
- Needs to be considered in IMF studies

Angular resolution (~10AU at 140 pc at 10 μm) and high dispersion spectroscopy R~ 100,000

A comprehensive picture of spatial, temporal & velocity distribution of YSOs

Thank You

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