The origin of thick discs

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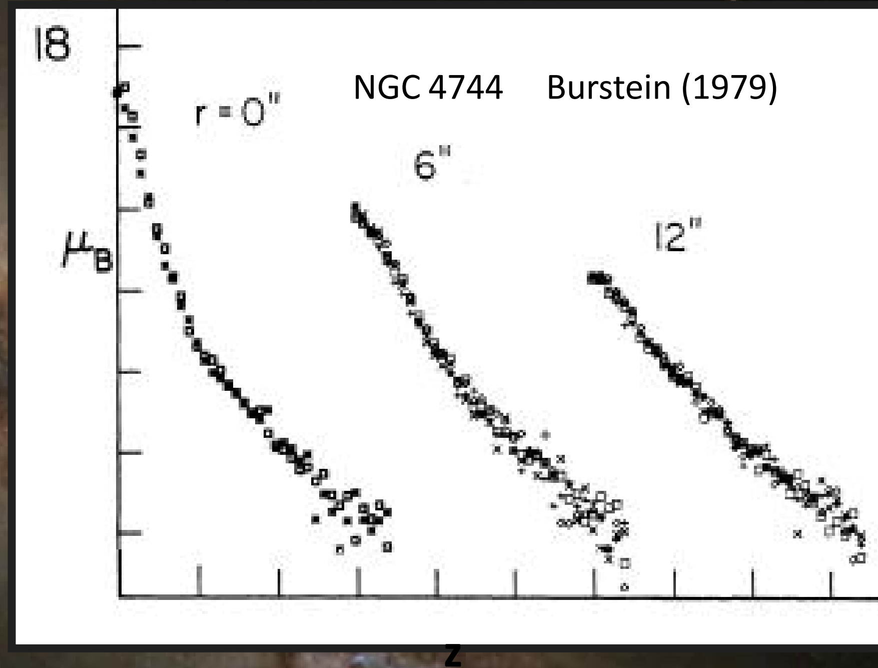
The thick disc discovery: ApJ 234 issue (1979)

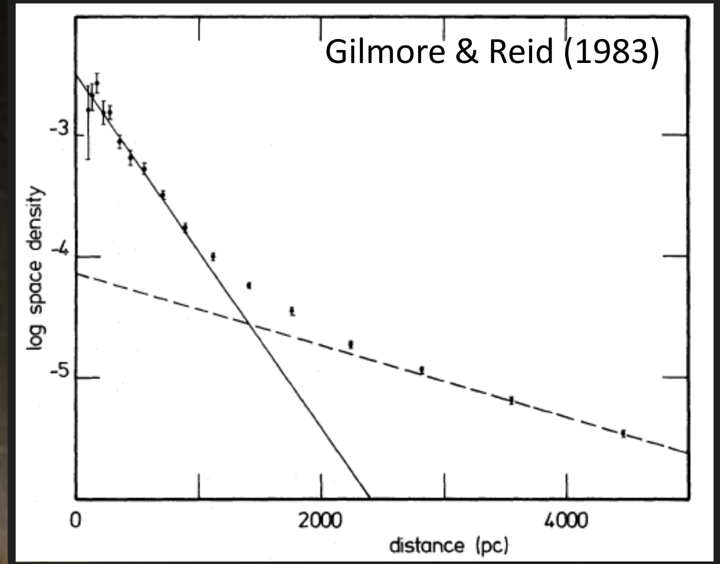
"The fainter parts of the perpendicular profile … require the presence of a third component, in addition to a thin and a bulge, termed here a ***<u>"thick" disk</u>***" -. Burstein (1979)

"… the luminosity distribution of the thin equatorial disk appears to be Gaussian out to ~300 pc, merging ***<u>into an exponential luminosity component</u>*** which extends out to large distances…" -. Tsikoudi (1979)



The Milky Way thick disc

"The density laws for stars with $M_v \geq 4$ follow a single exponential with a scale height ~300 pc for $100 \leq z \leq 1000$ pc, ***and a second exponential*** with scale height ~1450pc for z distances from ~1000 to at least 5000 pc"-. Gilmore & Reid (1983)

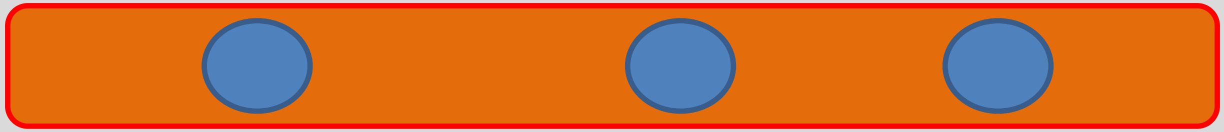


The stars in the thick disc of the Milky Way are old, metal poor, and α-enhanced (see, e.g., Fuhrmann 1998; Bensby et al. 2005). It has been inferred this is true for other thick discs.

"The thick disk abundance patterns are in excellent agreement with the chemical abundances observed in the metal-poor bulge stars" -. Prochaska et al. (2000)

Thick disc formation scenario 1

Dynamical heating of a cold disc by disc overdensities like giant molecular clouds or spiral arms (Villumsen 1985; Hänninen and Flynn 2002).



Thick disc formation scenario 1

“It is … necessary to postulate higher masses or larger numbers of Giant Molecular Clouds at earlier times in order to explain the velocity dispersions of the hottest disk populations”-. Villumsen (1985)

“… even a fourfold Giant Molecular Cloud number density compared with the present-day value in the solar neighbourhood … does not heat the disc up enough” -. Hänninen & Flynn (2002)

Thick disc formation scenario 2

Stars migrating outwards feel a decreased restoring force and reach larger heights above the mid-plane (Schönrich & Binney 2009a; Schönrich & Binney 2009b; Loebman et al. 2011; Solway et al. 2012; Minchev et al. 2012, Roškar et al. 2013).

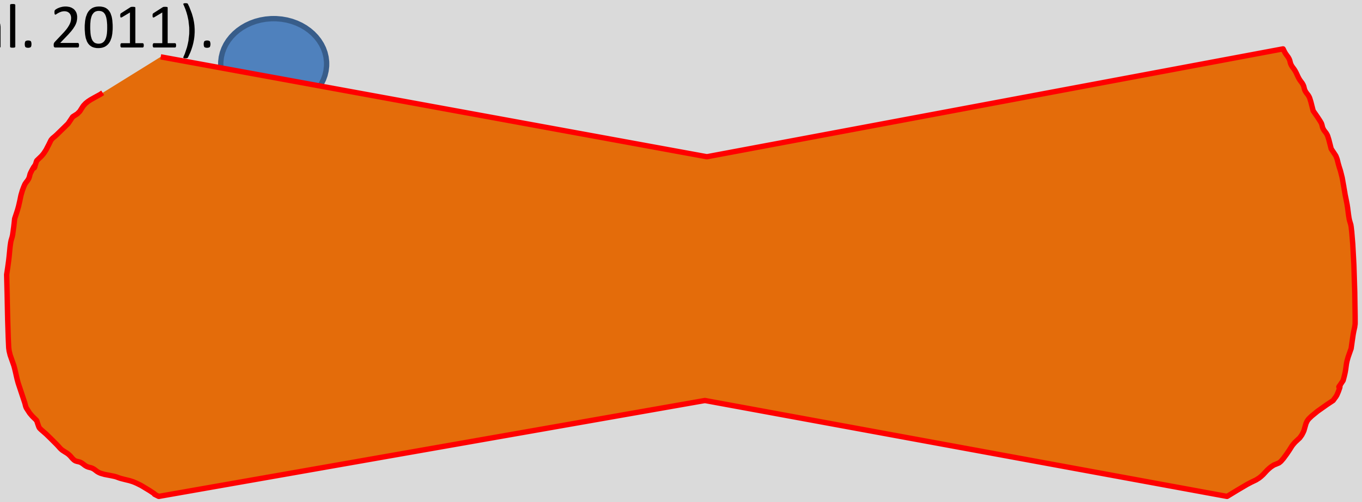
Thick disc formation scenario 2

"We compare the spatial, kinematic, and metallicity distributions of stars in the Milky Way disk … to predictions made by N-body simulations that naturally include radial migration … In these simulations, stars that migrate radially outward feel a decreased restoring force, consequentially they reach larger heights above the mid-plane. We find that this model is in qualitative agreement with observational data and can explain the disk's double-exponential vertical structure …" -. Loebman et al. (2011)

"… we find that as stellar samples migrate, on the average, their velocity dispersion change in such a way to approximately match the non-migrating population at the radius at which they arrive" -. Minchev et al. (2012)

Thick disc formation scenario 3

Dynamical heating of the thin disc due to satellites crossing it (Quinn et al. 1993; Robin et al. 1996; Walker et al. 1996; Velázquez & White 1999; Chen et al. 2001; Hayashi & Chiba 2006; Kazantzidis et al. 2008; Read et al. 2008; Villalobos & Helmi 2008; Moster et al. 2010; Qu et al. 2011).



Thickening + flare!

Thick disc formation scenario 3

“[Because] thin disc do not survive mergers, any galaxies which have suffered a merger but possess thin disks today must have reformed their thin disc by a secondary process” -. Quinn et al. (1993)

“... disc galaxies may accrete quite massive satellites without destroying the disc, particularly, if the orbits are retrograde” -. Velázquez & White (1999)

“When the presence of gas in the disc is taken into account, this thickening is reduced by 25 per cent (50 per cent) for an initial disc gas fraction of 20 per cent (40 per cent) ...” -. Moster et al. (2010)

Thick disc formation scenario 4

Stars accreted from satellite galaxies form the thick disc (Statler 1988; Gilmore et al. 2002; Abadi et al. 2003; Navarro et al. 2004; Martin et al. 2004; Read et al. 2008).

Kinematical signatures!

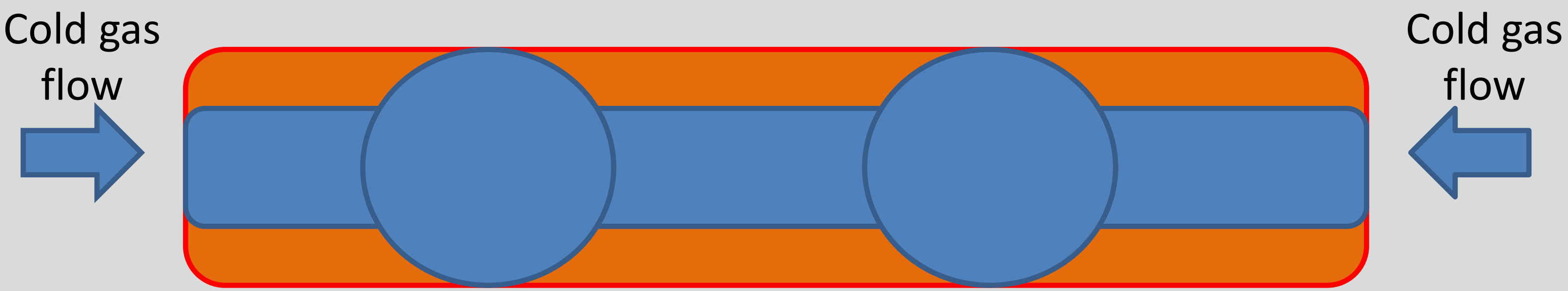
Thick disc formation scenario 4

“The bulk (60%) of the thick disk consists of the tidal debris of satellites whose orbital plane was roughly coincident with the disk and whose orbits were circularized by dynamical friction prior to full disruption” -. Abadi et al. (2003)

“[Galaxies merging with an] impact angle $\theta < 20^\circ$ … are dragged into the disc plane by dynamical friction. Their accreted stars … settle into a thick disc” -. Read et al. (2008)

Thick disc formation scenario 5

Thick disc formed from the dissolution of high-mass star-forming clumps with high velocity dispersion (Kroupa 2002) or in a disc with giant star-forming clumps in a gravitationally unstable disc at high redshift (Elmegreen & Elmegreen 2006; Bournaud et al. 2009).



Thin disc forms from gas accreted through cold flows or which has not been spent in the first star formation burst.

Thick disc formation scenario 5

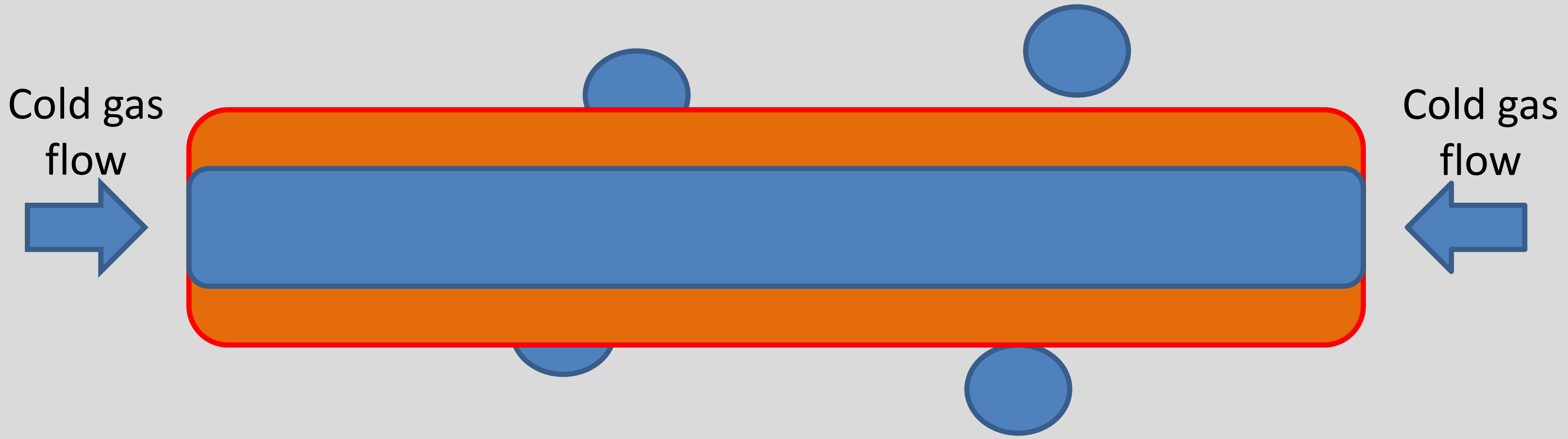
"[The Milky Way thick disc] large velocity dispersion may have been produced through a high star formation rate and thus an Initial Cluster Mass Function extending to massive embedded clusters ($\sim 10^{5-6} M_{\odot}$)" -. Kroupa (2002)

"The results indicate that HST ultra deep field disks are thick, with an average z_0=1.0±0.4 kpc. … The UDF disks look like young versions of modern thick disks" -. Elmegreen & Elmegreen (2006)

"Simulations of gas-rich young galaxies show formation of internal clumps by gravitational instabilities, clump coalescence into a bulge, and disk thickening by strong stellar scattering" -. Bournaud et al. (2009)

Thick disc formation scenario 6

Thick disc from stars formed during gas-rich mergers of protogalactic fragments and stars contained in those fragments (Brook et al. 2004; Robertson et al. 2006; Brook et al. 2007; Richard et al. 2010).



Thin disc forms from gas accreted through cold flows or which has not been spent in the first star formation burst.

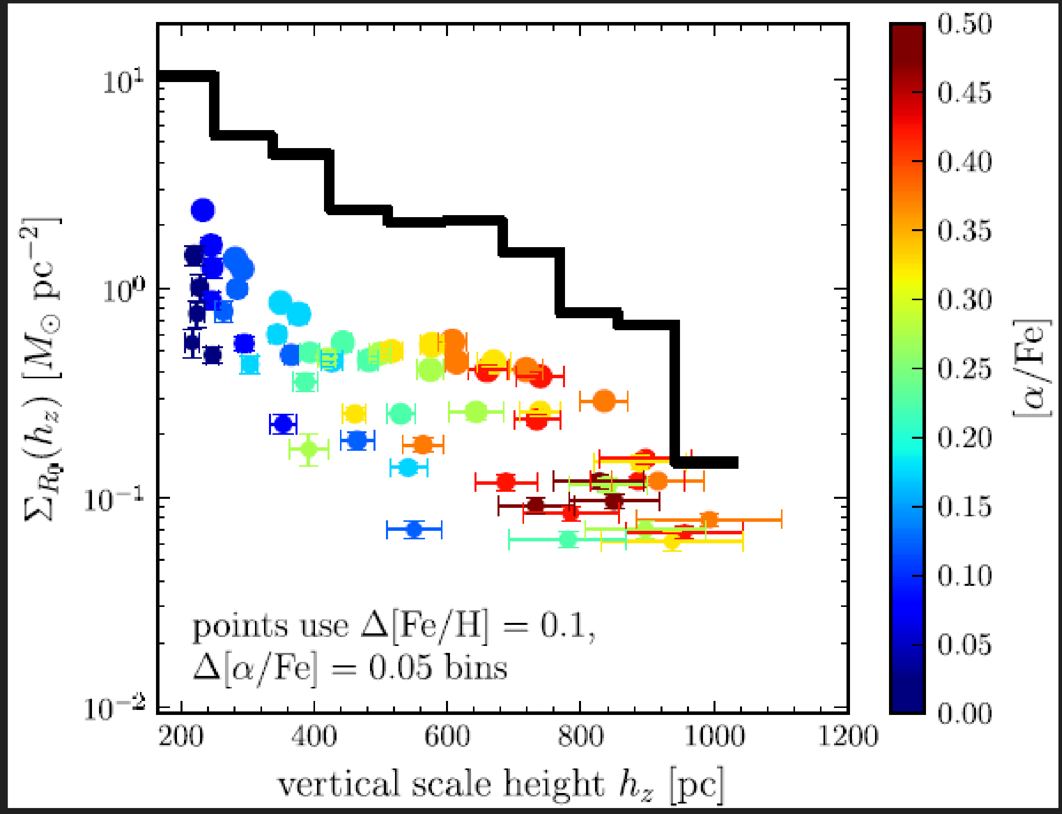
Thick disc formation scenario 6

"Our results indicate that the thick disk is created in an epoch of multiple mergers of gas-rich building blocks, during which a central galaxy is formed. The stars that form during this merging period, when a high SFR is triggered, are the dominant source of thick-disk stars" -. Brooks et al. (2004)

"We show that stars formed during the merger … and those formed after the merger have different kinematical and chemical properties. The first ones are located in the thick disc or the halo. …The difference in the rotational support of both components results in the rotation of the thick disc lagging that of the thin disc by as much as a factor of 2 …" -. Richard et al. (2010)

Are thin and thick discs distinct components?

"[We show] that the Milky Way has a continuous and monotonic distribution of disk thicknesses: there is no "thick disk" sensibly characterized as a distinct component" -. Bovy et al. (2012)



A semantic comment

THE MILKY WAY HAS NO THICK DISK

Jo Bovy[1,2,3], Hans-Walter Rix[4], & David W. Hogg[4,5]

Astrophys. J., in press

ABSTRACT

Different stellar sub-populations of the Milky Way's stellar disk are known to have different vertical scale heights, their thickness increasing with age. Using *SEGUE* spectroscopic survey data, we have recently shown that mono-abundance sub-populations, defined in the [α/Fe]-[Fe/H] space, are well described by single exponential spatial-density profiles in both the radial and the vertical direction; therefore any star of a given abundance is clearly associated with a sub-population of scale height h_z.

THE MILKY WAY HAS NO DISTINCT THICK DISK

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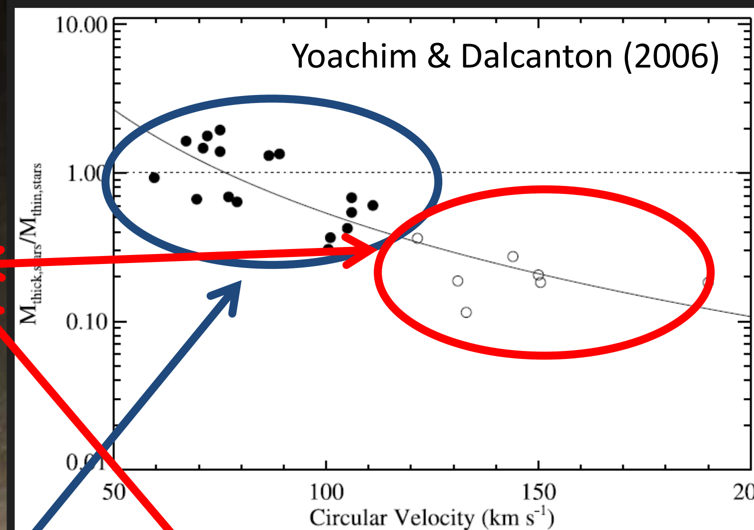
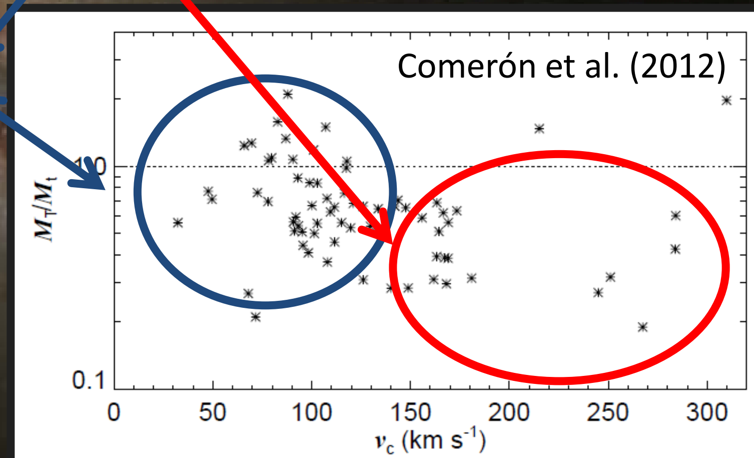
Different stellar sub-populations of the Milky Way's stellar disk are known to have different vertical scale heights, their thickness increasing with age. Using *SEGUE* spectroscopic survey data, we have recently shown that mono-

Comparison of the scenarios

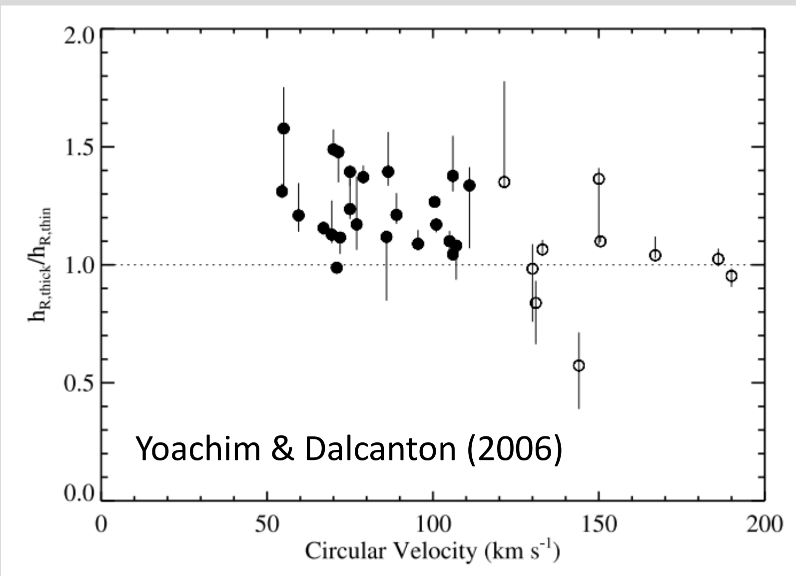
Formation scenario	Secular process/ Fast process
Heating by disc overdensities	Secular
Radial Migration	Secular
Heating by satellites	Both?
Star accretion	Both?
Clumpy discs	Fast
Merger of fragments	Fast





Thin and thick disc scalelengths

"The resulting best fit values are: (2120±200) pc for the radial scale length … of the thin disc; (3050±500) pc for … the thick disc" -. Polido et al. (2013)



"We make a first estimate of the thick disk scale length of L_{thick} = 2.0 kpc, assuming L_{thin} = 3.8 kpc for the thin disk." -. Bensby et al. (2011)