Towards a bar/bulge model for the Milky Way

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Why do we want to study the the bar/bulge region?

The bar is a main driver for the secular evolution of disc galaxies

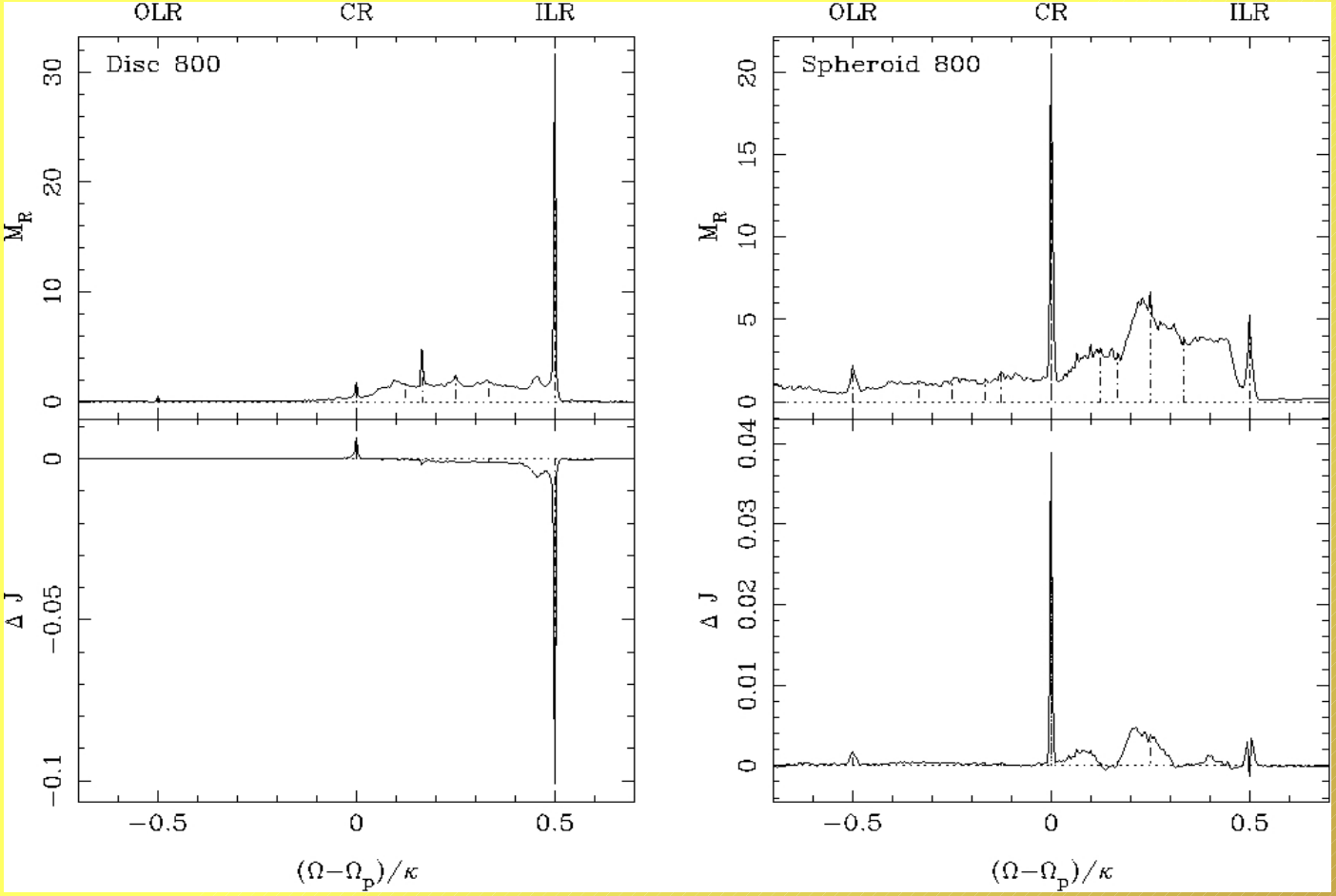
Pushes mass from the bar region to the center where it creates a CMC (central mass concentration)

Drives the angular momentum exchange with a disc galaxy: Angular momentum is emitted by near-resonant material in the bar region and is absorbed by near-resonant material mainly in the halo but also in the outer disc

The strength of the bar correlates well with the amount of angular momentum exchanged

(Athanassoula 2003)

Emitters and absorbers

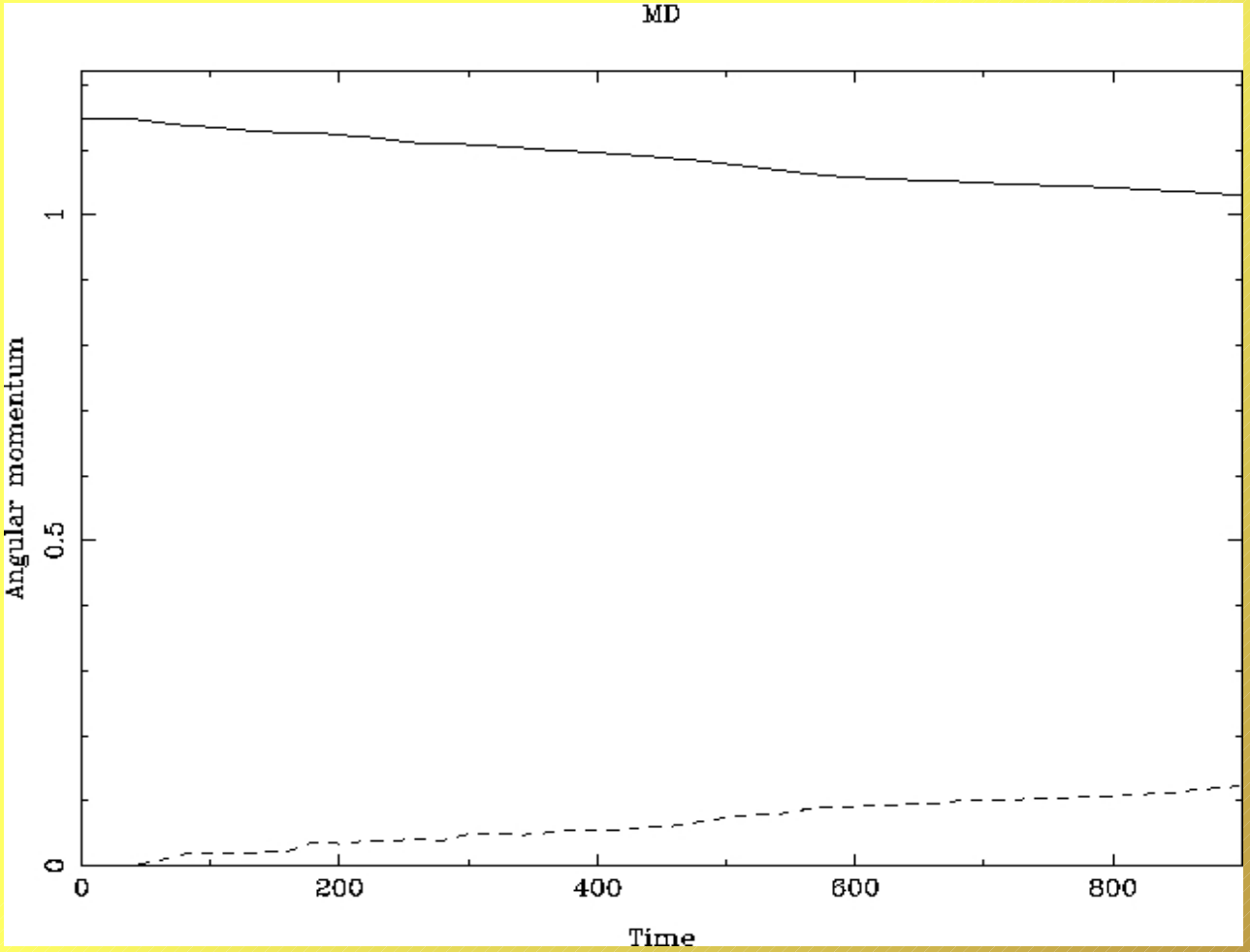


Example from a strong bar model Athanassoula 2003

Confirmed by Martinez-Valpuesta+ 2006, Ceverino+ 2007, Villa-Vargas+ 2009, Saha+ 2011 etc (different models, codes etc)

Angular momentum transfer

in disc



in spheroid

Sellwood 1980, Debattista and Sellwood 2000, Athanassoula 2003, 2005, Valenzuela and Klypin 2003, Martinez-Valpuesta et al 2006, Villa-Vargas and Shlosman 2009 etc

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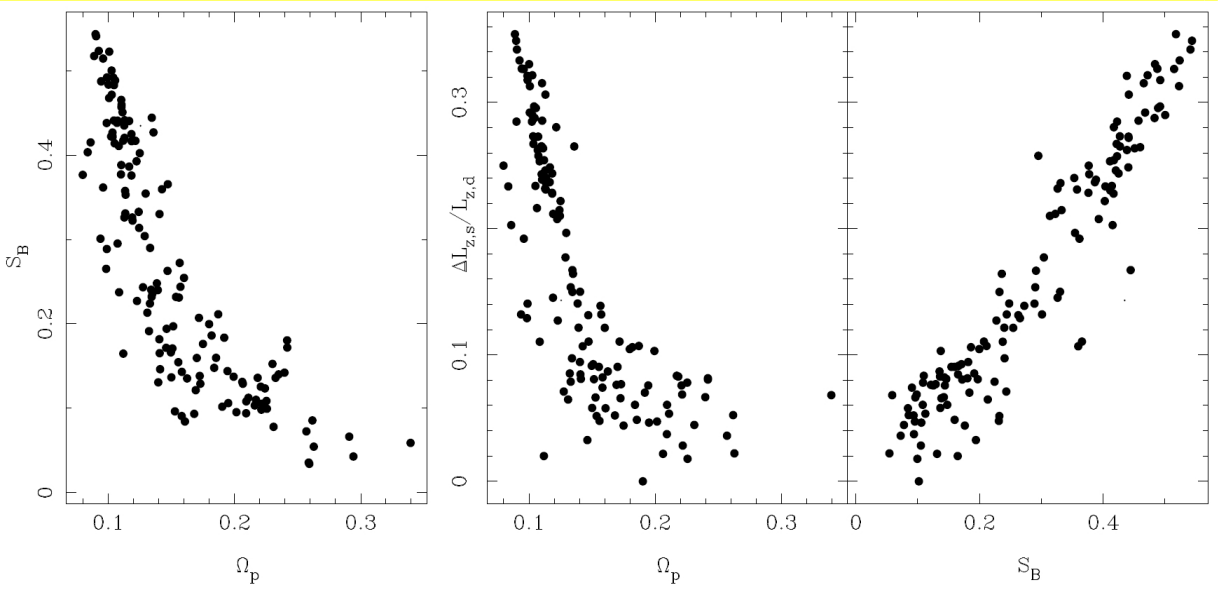
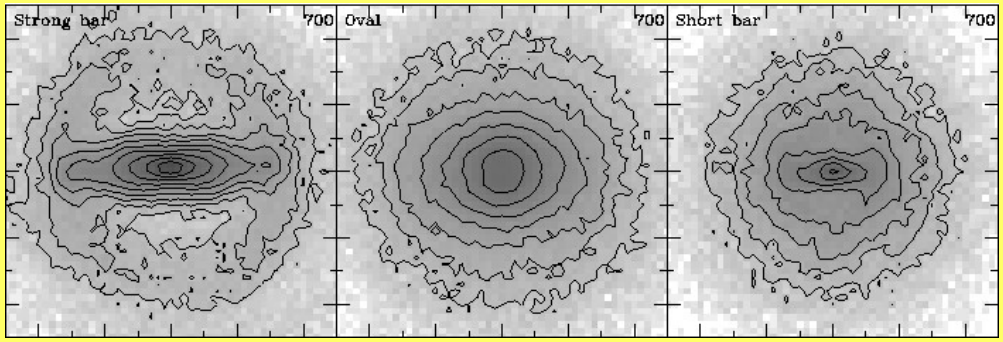
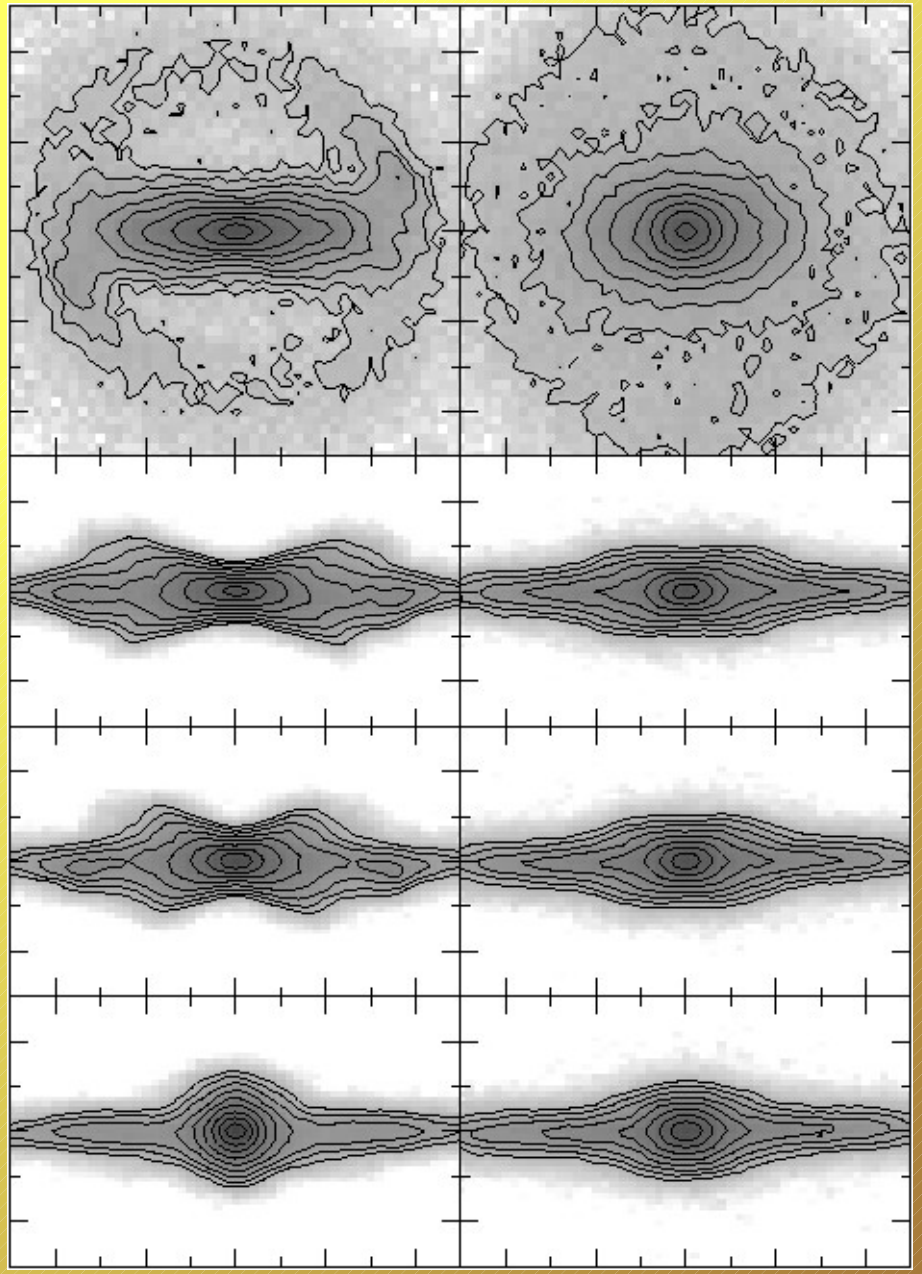
The strength of the bar correlates well with the amount of angular momentum exchanged



(Athanassoula 2003)

We could be witnessing the interaction between the three different types of bulges: classical, boxy/peanut and discy.


Strong bar
700
Oval
700
Short bar
700



Orbital structure in bars

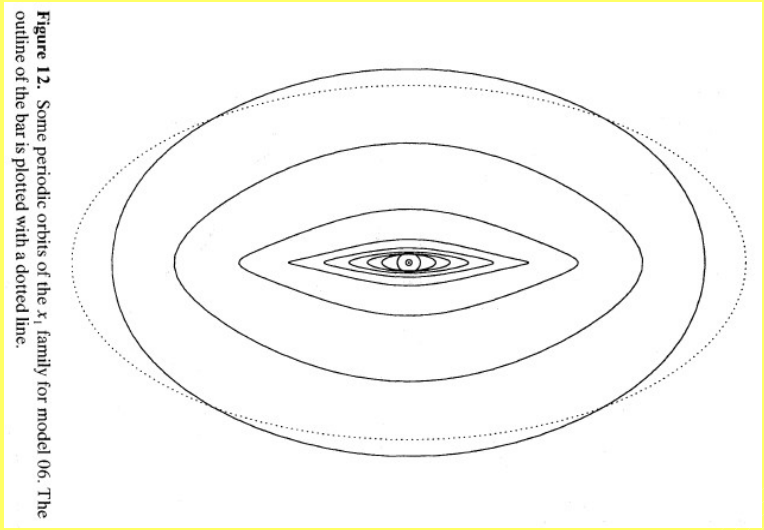
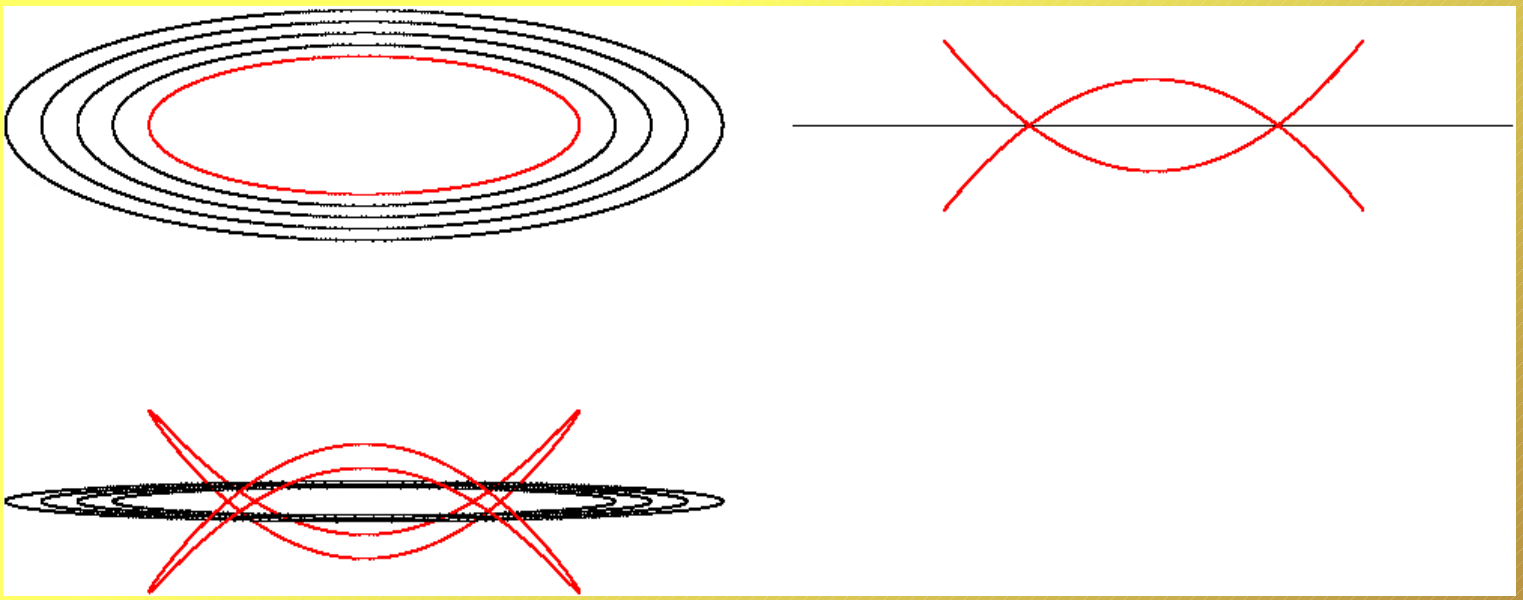
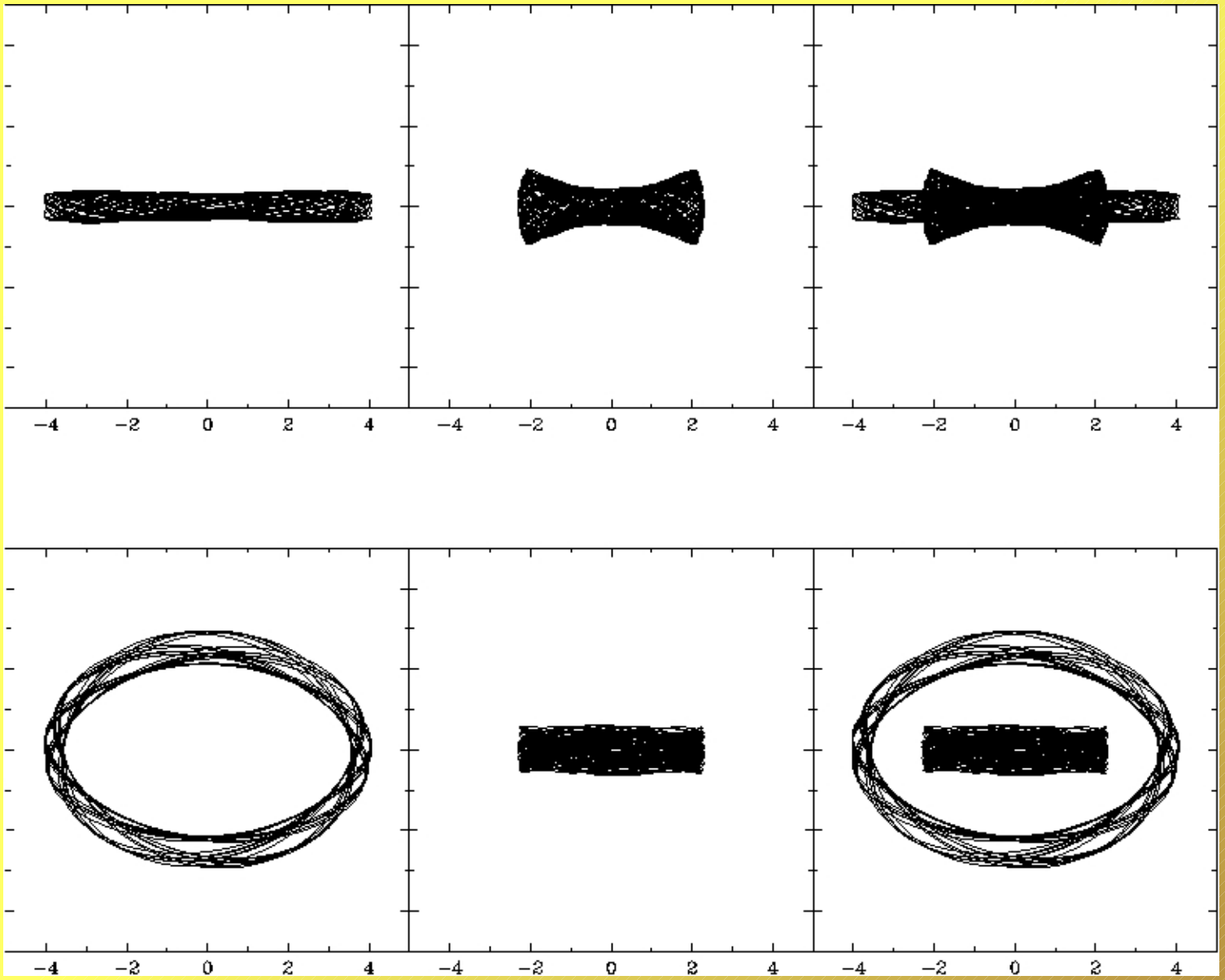


Figure 12. Some periodic orbits of the x_1 family for model 06. The outline of the bar is plotted with a dotted line.



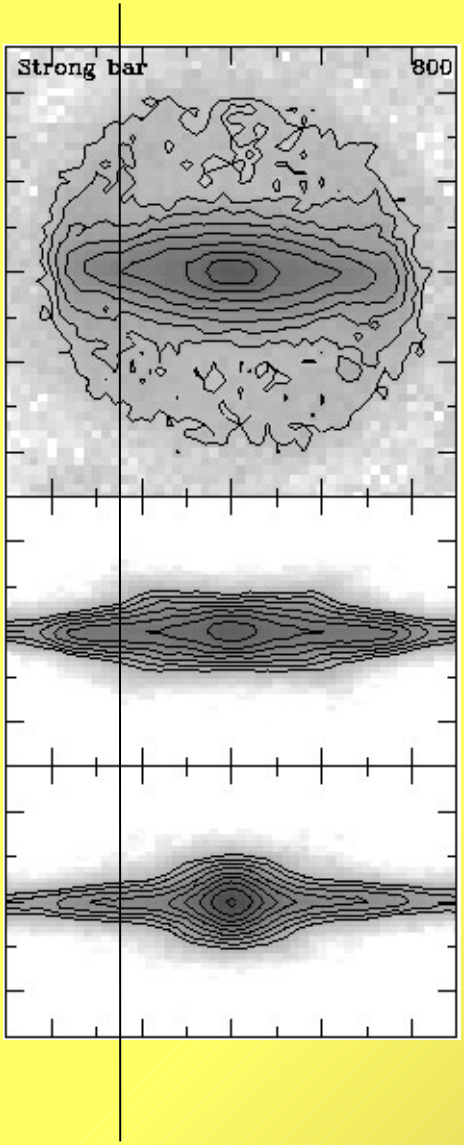
Peanuts should be SHORTER than bars



Athanassoula 05

Peanuts are shorter than bars in simulations

Qualitative :



Quantitative estimates :

Simulations :

Athanassoula and Misiriotis 2002

Athanassoula 05

Athanassoula and Beaton 2006

Orbital structure :

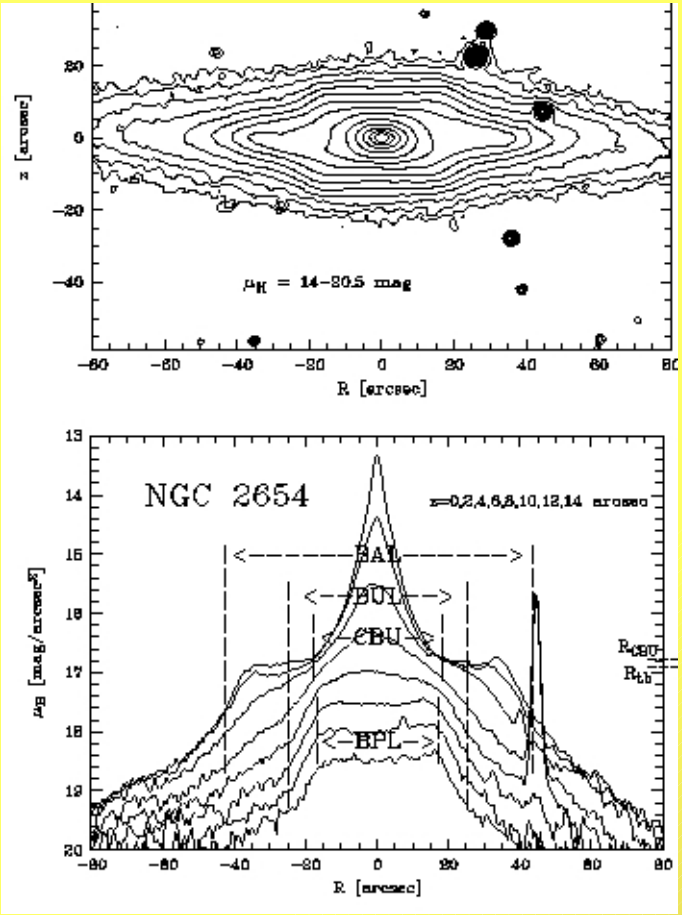
Pfenniger 1984

Patsis, Skokos and Athanassoula 2002

Thin and thick parts of bars

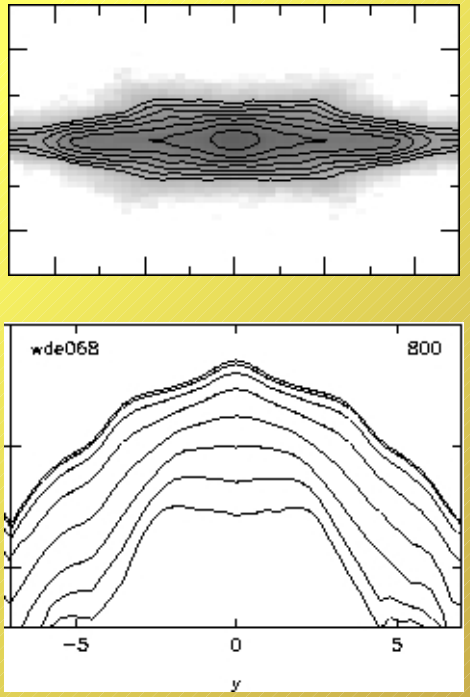
Observed peanuts are shorter than bars

A thin component in boxy/peanut bulges (observations)



Lutticke, Dettmar and Pohlen, 2000

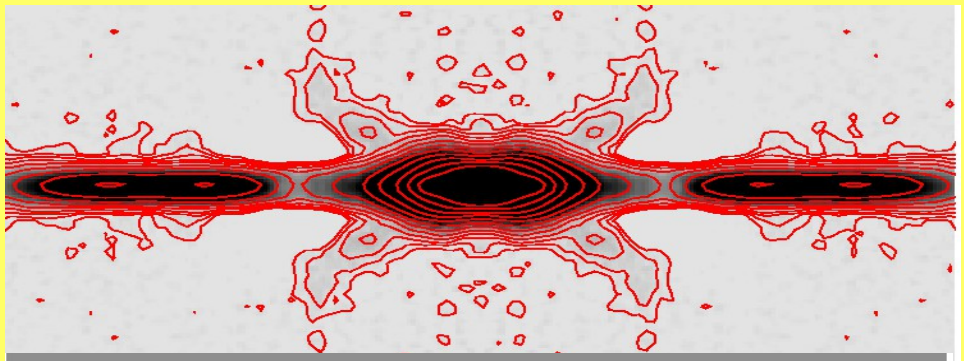
A thin component in edge-on bars (simulations)



Athanassoula 2005 (also Athanassoula and Misiriotis 2002)

Thin and thick parts of bars

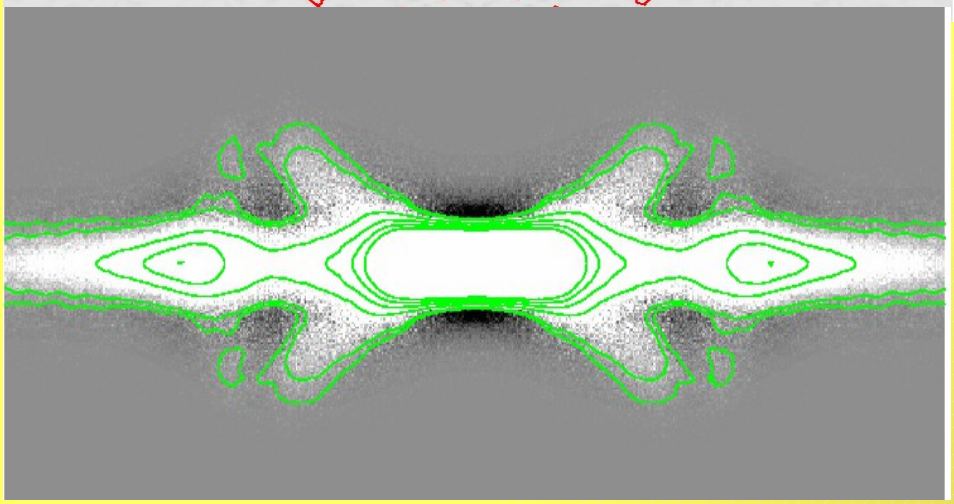
X shapes



NGC 4710 unsharp masked

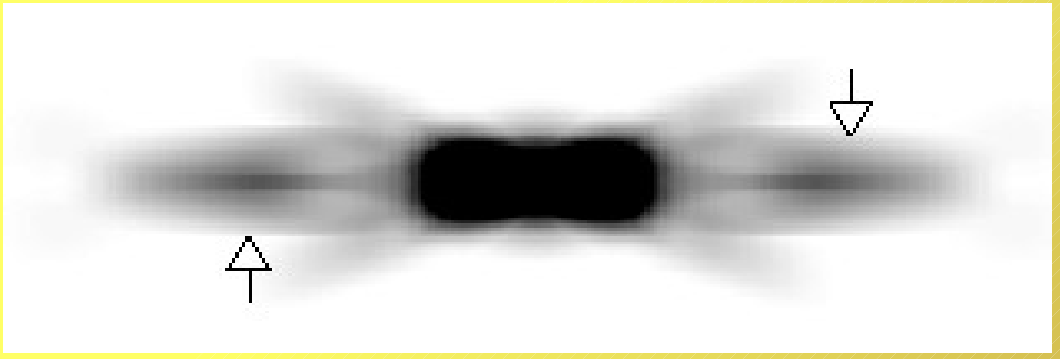
Aronica, Athanassoula, Bureau, Bosma et al (2003)

Bureau, Aronica, Athanassoula, Dettmar, Bosma, Freeman 2006



N-body simulation

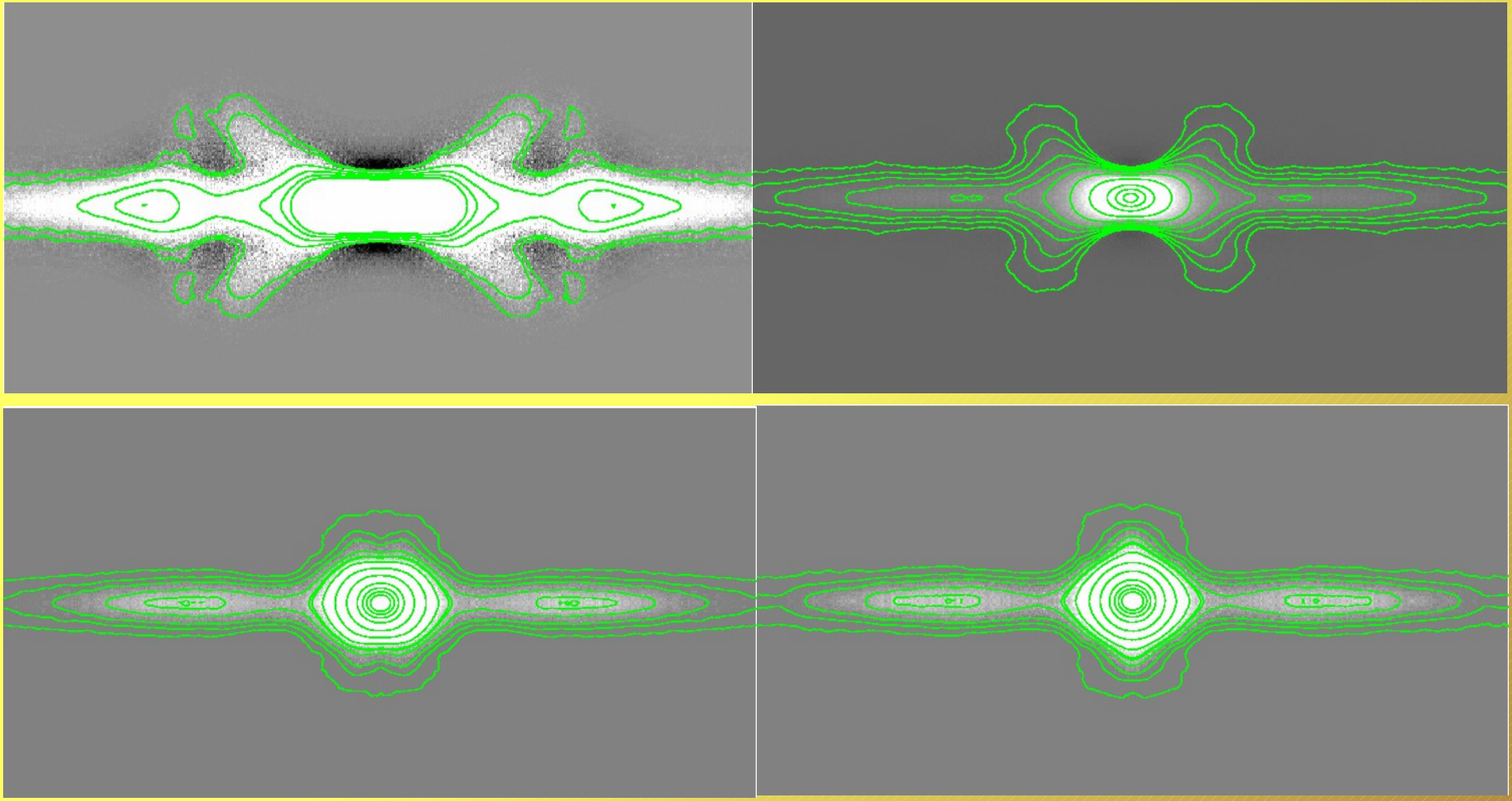
Athanassoula (2005)



3-D periodic orbit calculation

Patsis, Skokos and Athanassoula (2002)

Unsharp masking simulations from different viewing angles

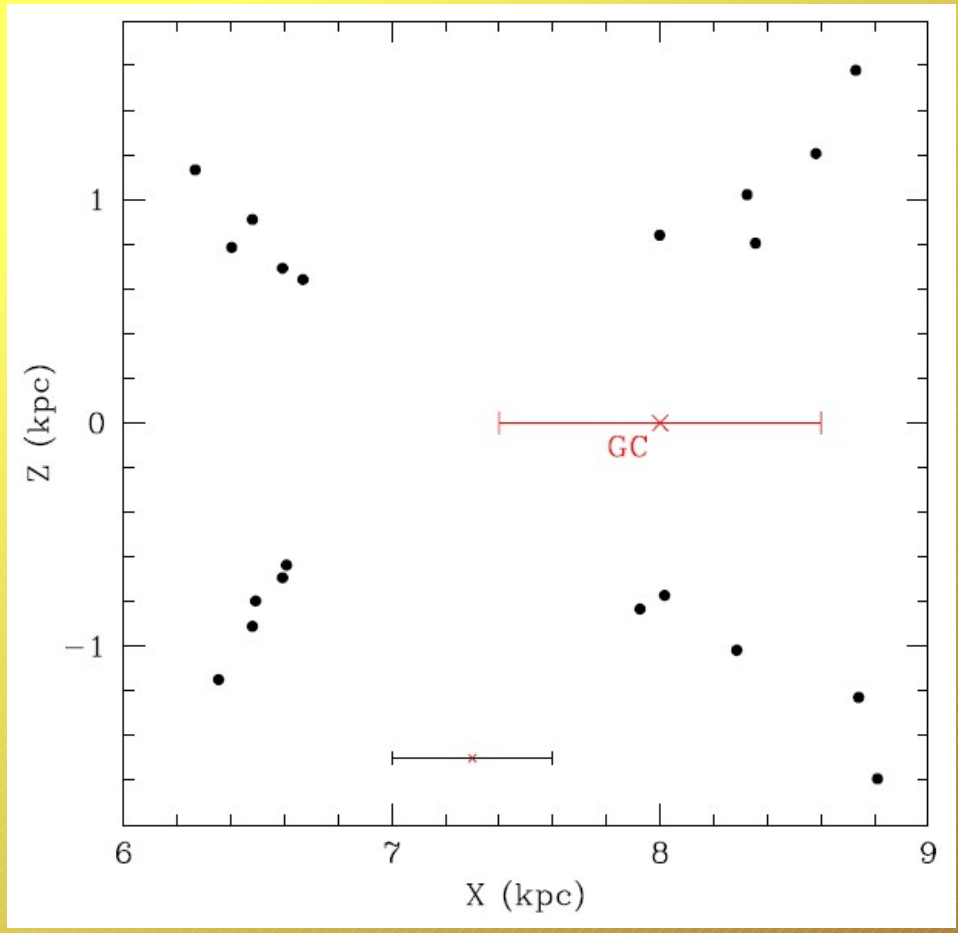


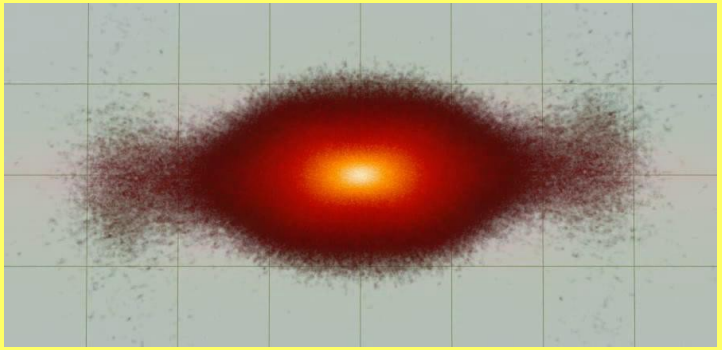
Athanassoula 2005

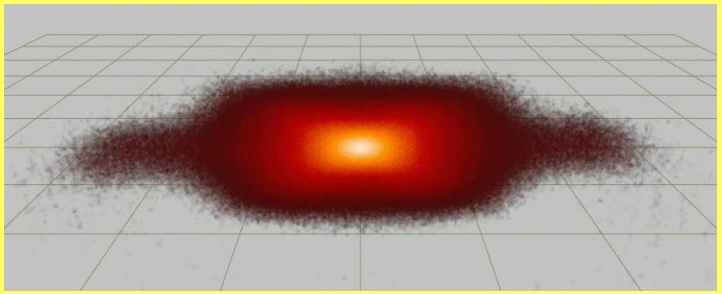
McWilliam & Zoccali 2010

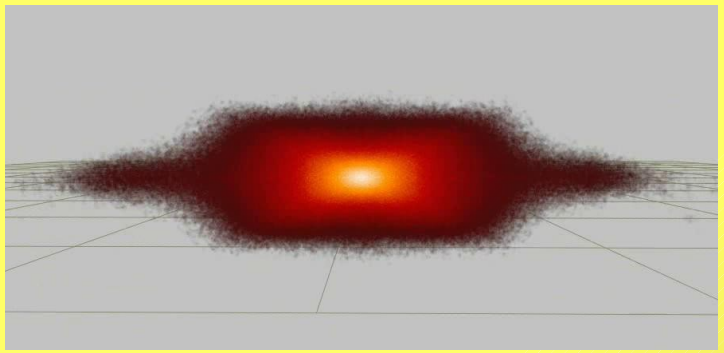
Nataf et al 2010

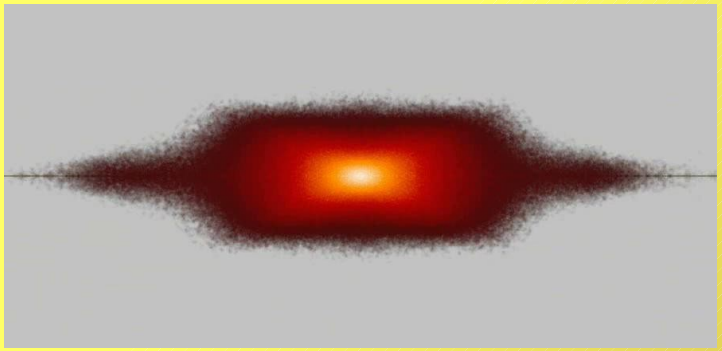
etc



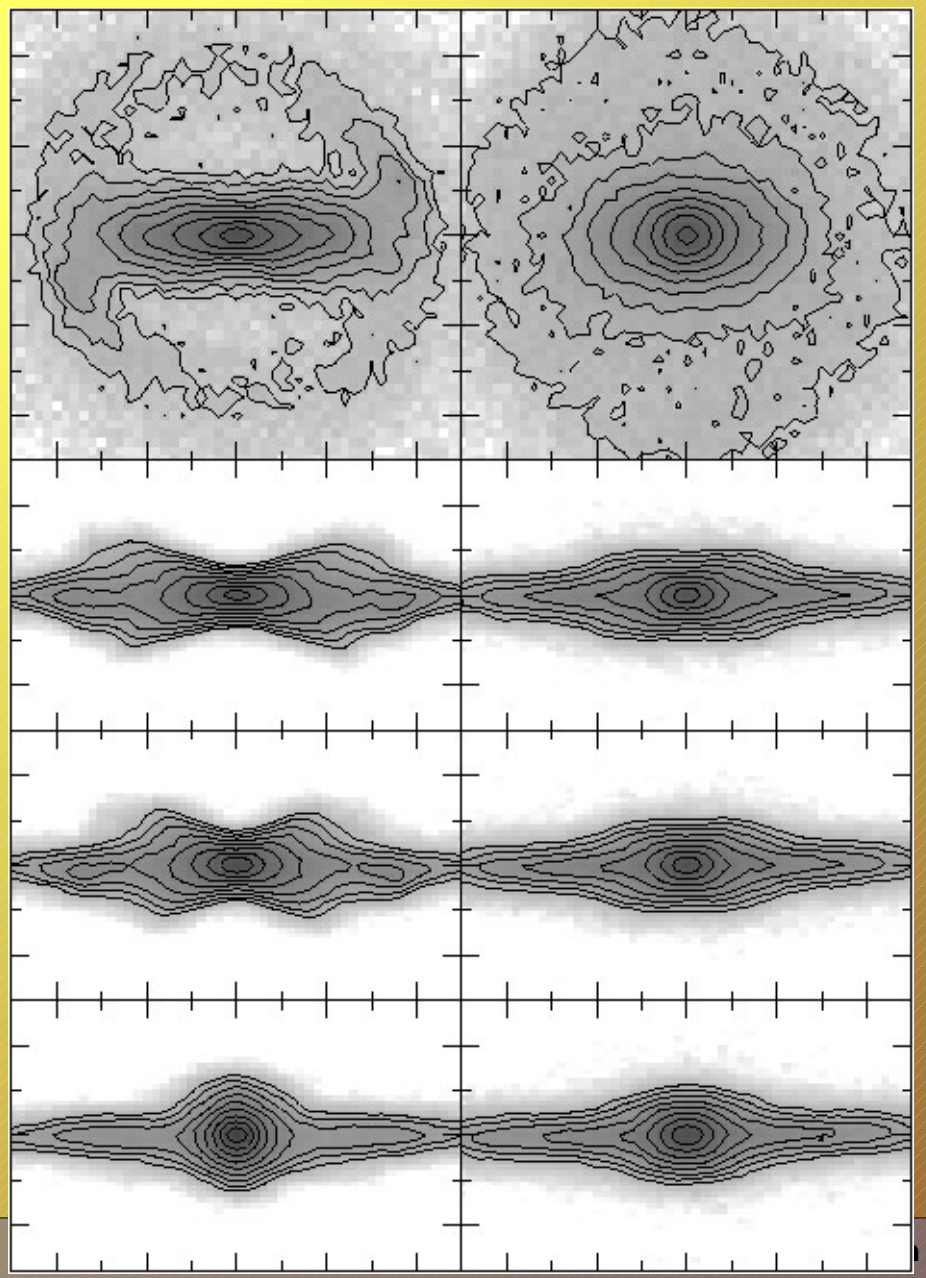








For a full movie see
http://lam.oamp.fr/research/dynamique-des-galaxies/
scientific-results/milky-way/bar-bulge/how-many-bars-in-mw



What can we do with such simulations?

– Extend the Besançon model. Inner parts. Self-consistently calculated velocities

- Compare simulations with GAIA data

How do we do the comparisons?

--F(6D phase space, age, chemical compositions, time,....)

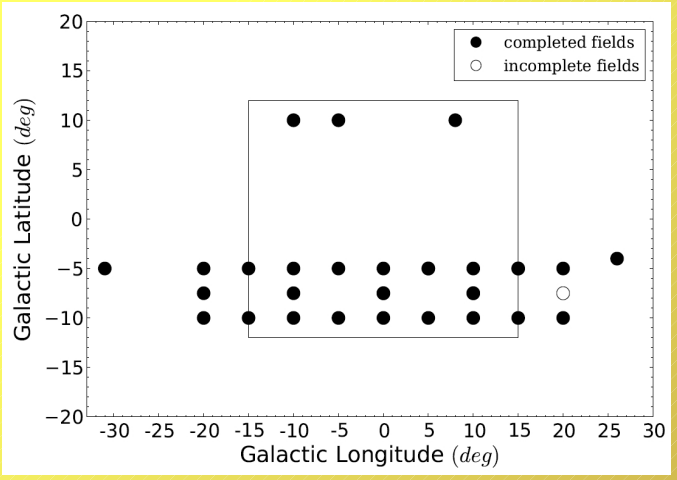
Talks of James Binney and Paul McMillan

time

- Ask a specific question (e.g. is it a box or a peanut ? What is the ratio of the lengths of the thin and the thick parts of the bar? Can I bracket the bar strength? etc.), or model a specific feature (e.g. relate kinematics and chemistry)
Even better: ask several specific questions

Example from ARGOS collaboration

ARGOS spectroscopic survey



AAOmega fibre spectrograph on the AAT

Spectral region 8400 – 8800

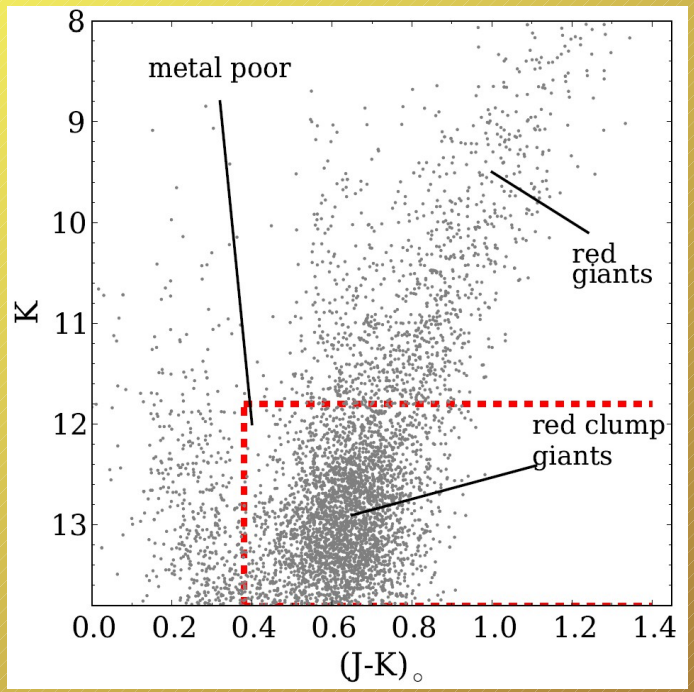
Resolution about 11 000

28 fields, about 1000 stars per field

Stars selected from the 2MASS Survey
11.5 < K < 14
Errors in J, K < 0.06

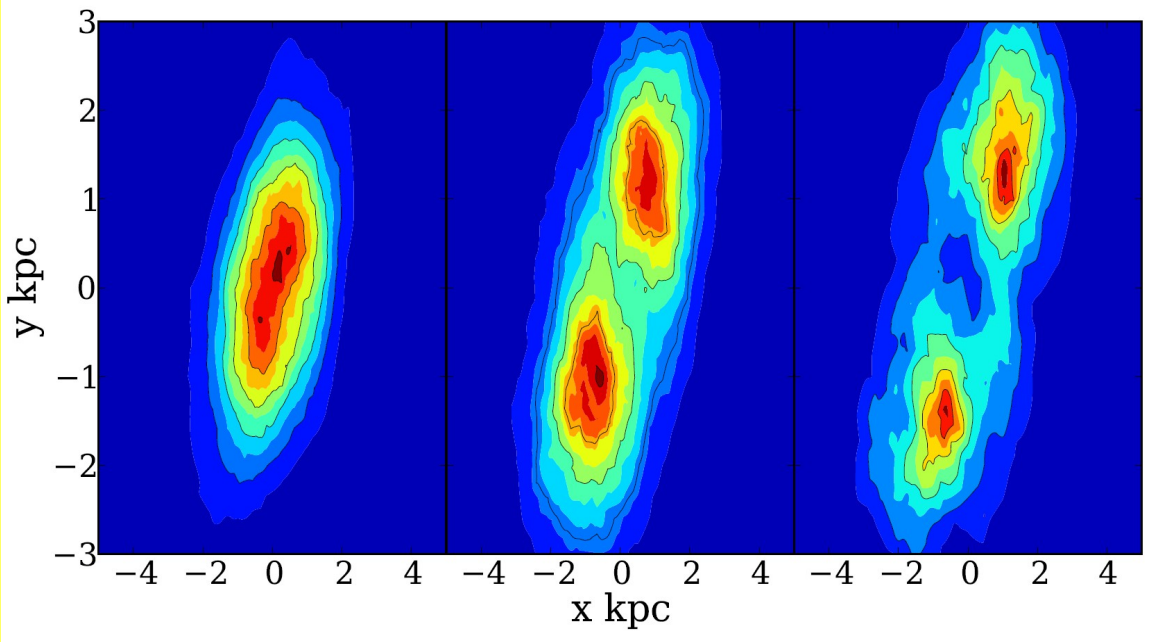
Include stars in red rectangle
Includes bulge giants + excludes foreground disc dwarfs

Radial velocities (1.2 km/sec)
[Fe/H], [alpha/Fe]



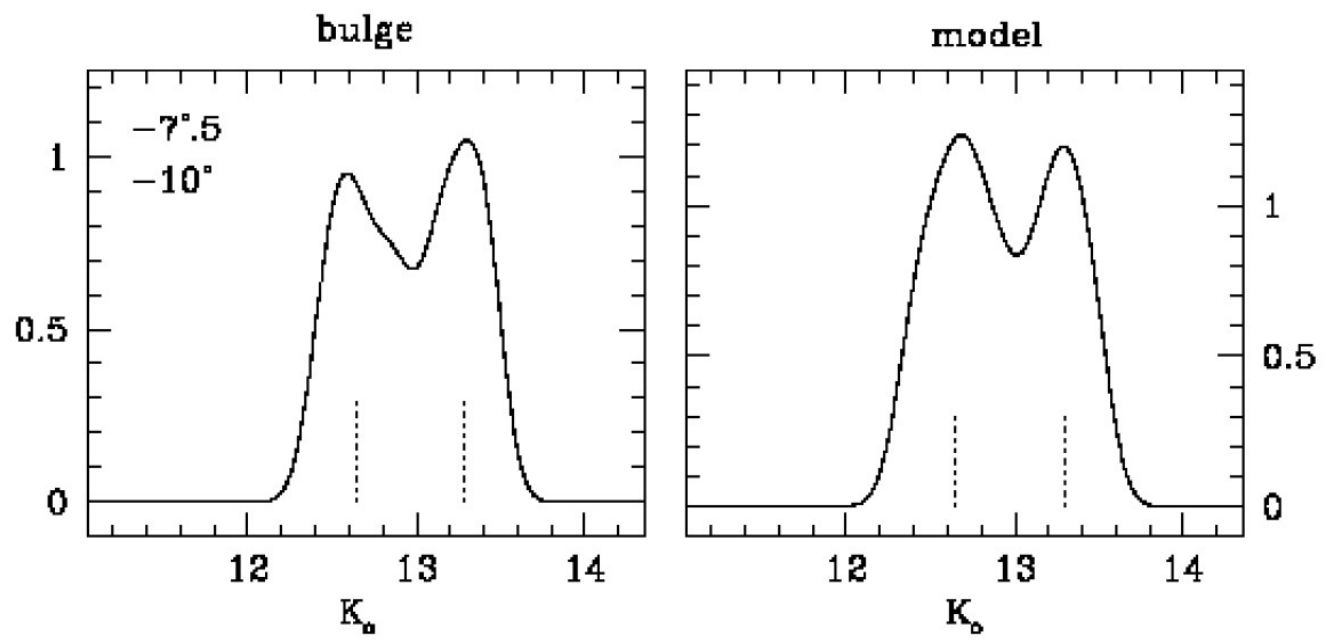
Ness et al 2012a,b,c,d

ARGOS spectroscopical survey (Ness et al 2012a)

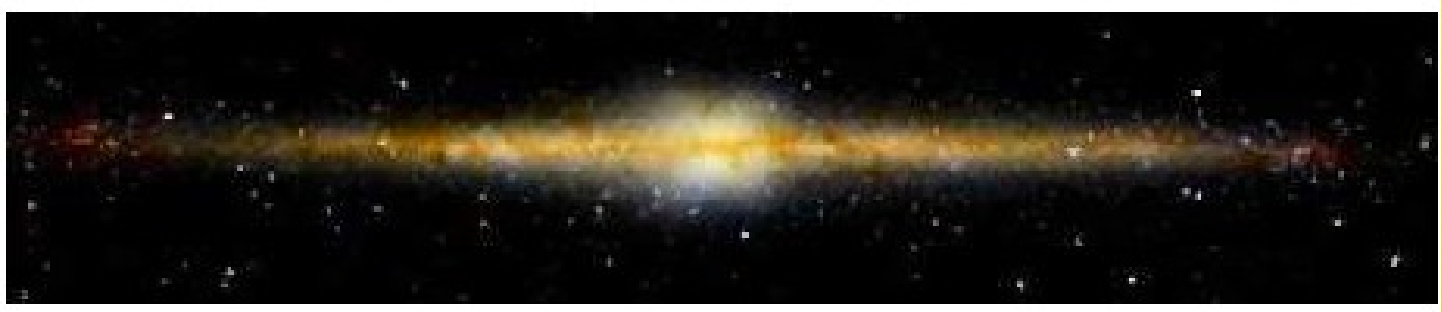


Simulations:

3 slices in z



A tale of two bars



Our Galaxy is barred

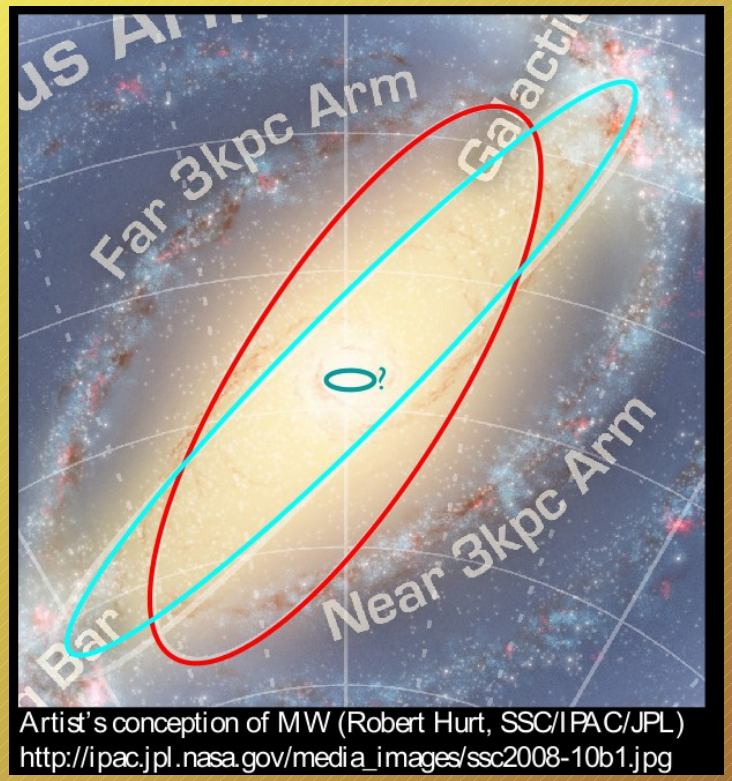
COBE/DIRBE bar (Binney et al 97)

Signal for a second bar:

The Long bar

Hamersley et al 2001
Benjamin et al 2005
Lopez-Corredoira et al 2005, 2007

Benjamin

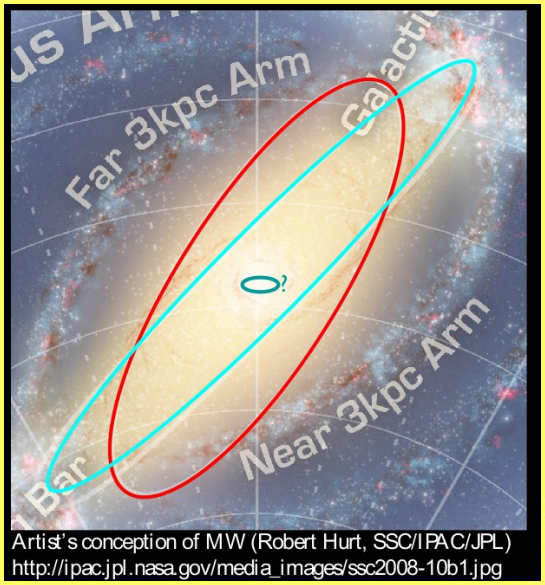


Artist's conception of MW (Robert Hurt, SSC/IPAC/JPL)
http://ipac.jpl.nasa.gov/media_images/ssc2008-10b1.jpg

A single bar in the Galaxy

So how are the COBE/DIRBE bar and the Long bar related?
Clue: Long bar is vertically very thin, COBE/DIRBE bar is very thick.

Athanassoula (2006): There is a single bar of which the COBE/DIRBE bar is the boxy/peanut part and the Long bar is the thin outer parts. Tested by Cabrera-Lavers et al (2007).



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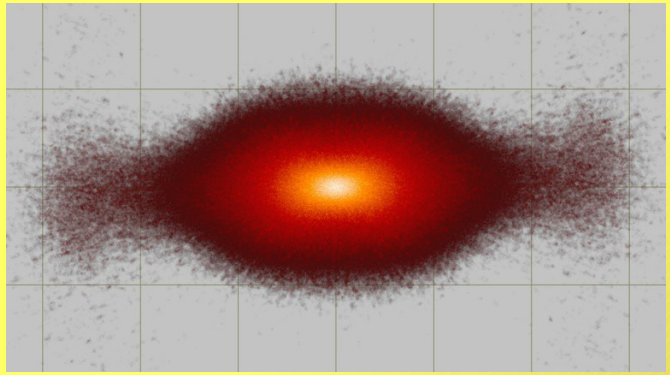
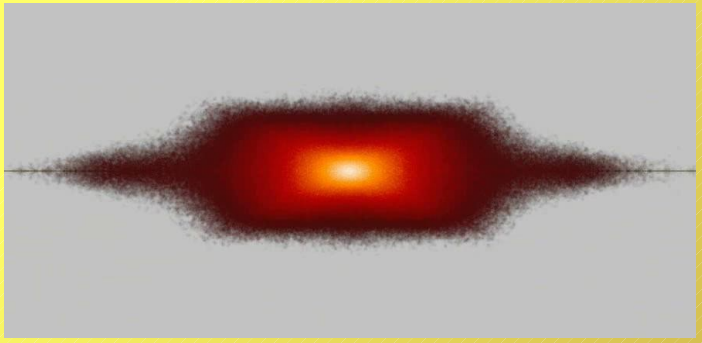
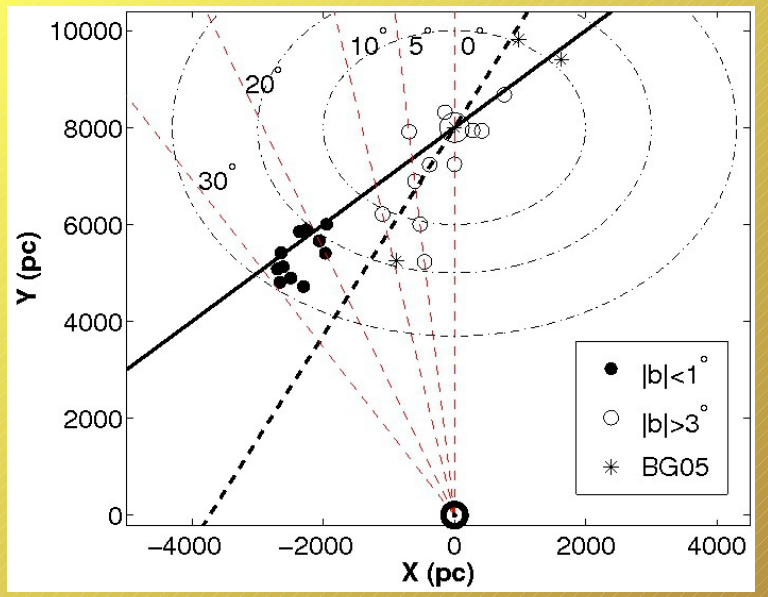




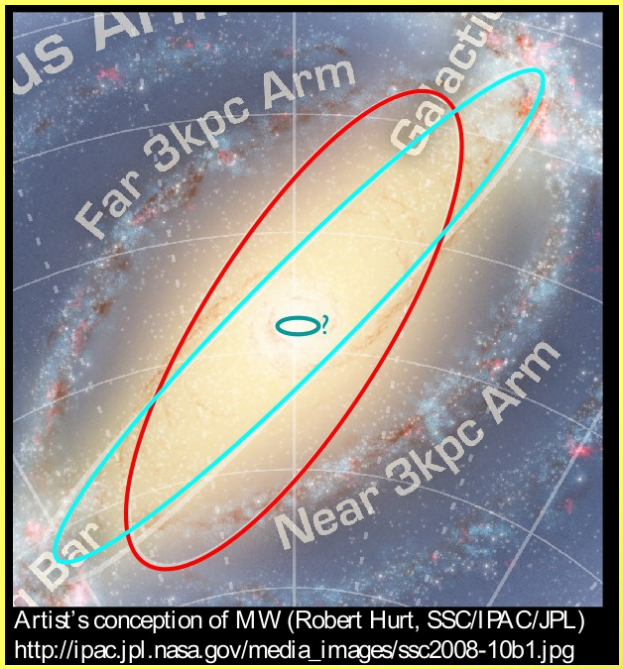


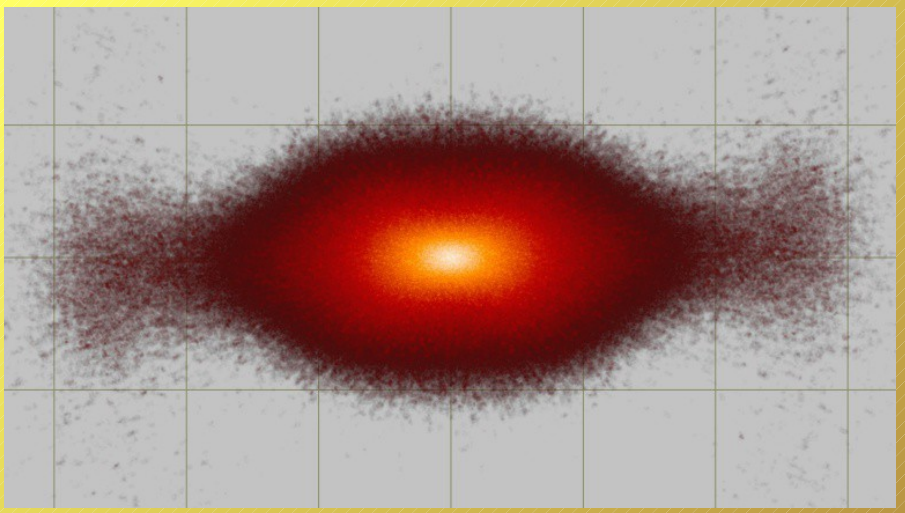
Cabrera-Lavers 2007

But:

The difference in position angles? (20 and 40 degrees)

Arguments summarised in Romero-Gomez et al (2011).
See also Martinez-Valpuesta and Gerhard (2011). Good agreement

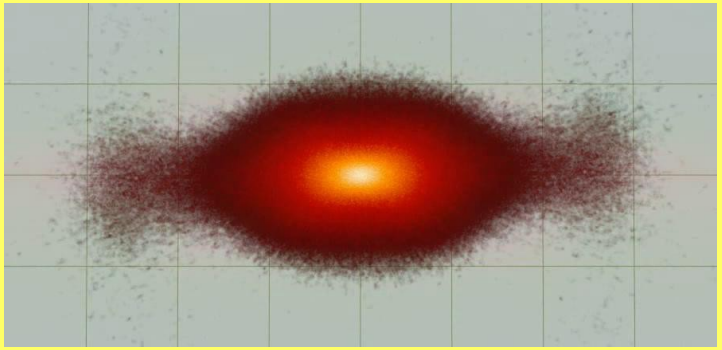


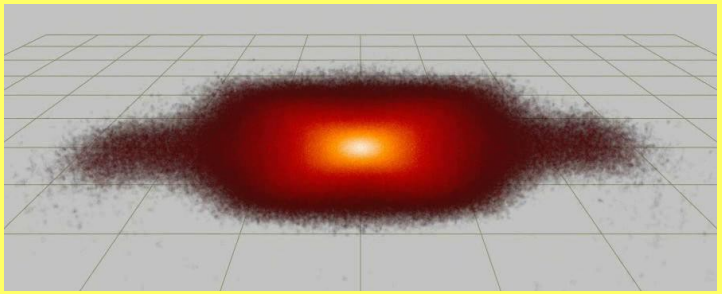


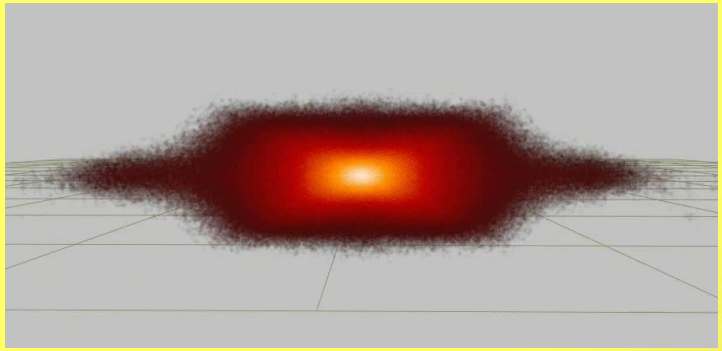
Zasowski, Benjamin and Majewski (2011)

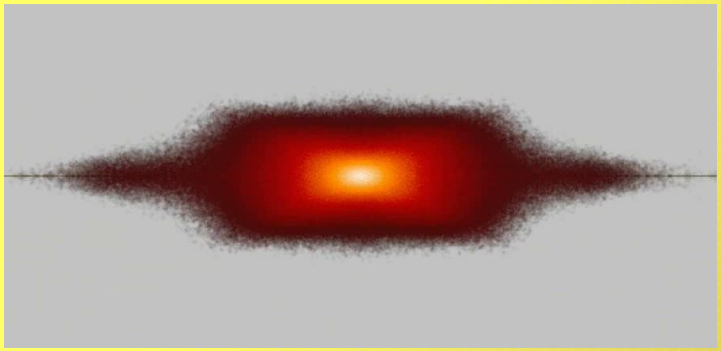
The long bar is at 25 – 35 degrees

Face-on view of the bar: The B/P part is thicker than the outer part. This can contribute to the angle difference between the Long 'bar' and the COBE/DIRBE 'bar'









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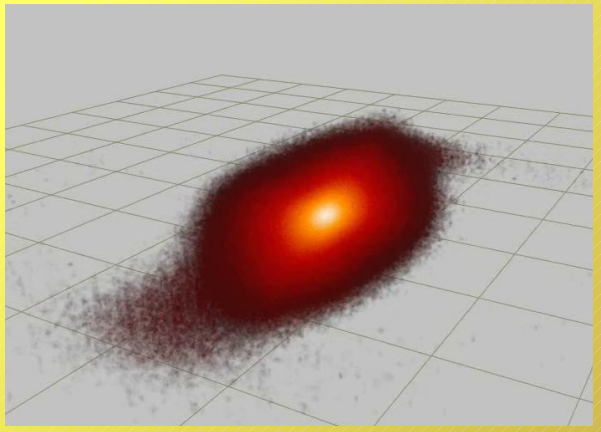
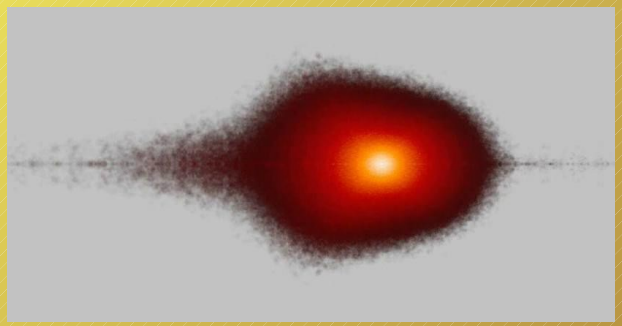
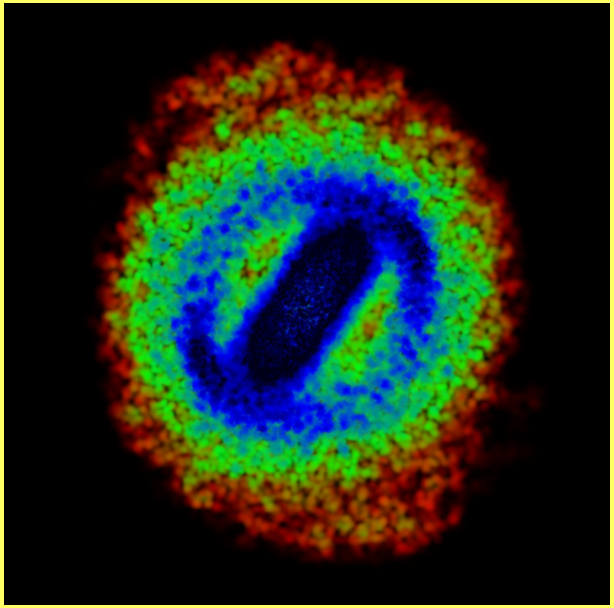
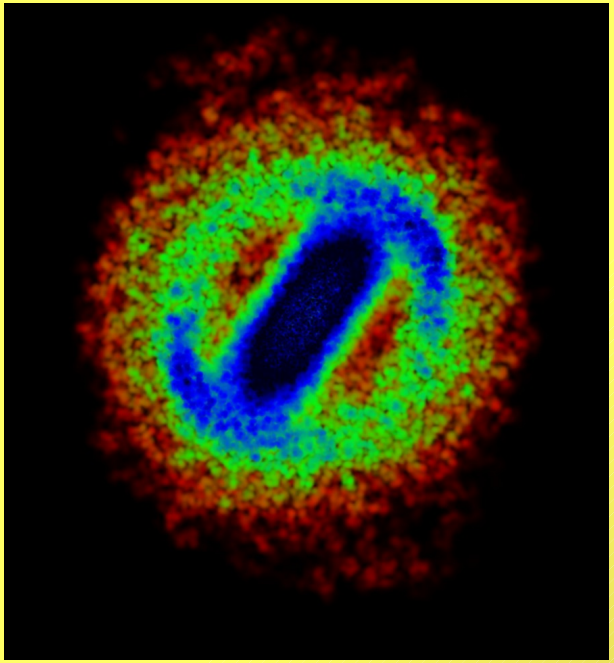
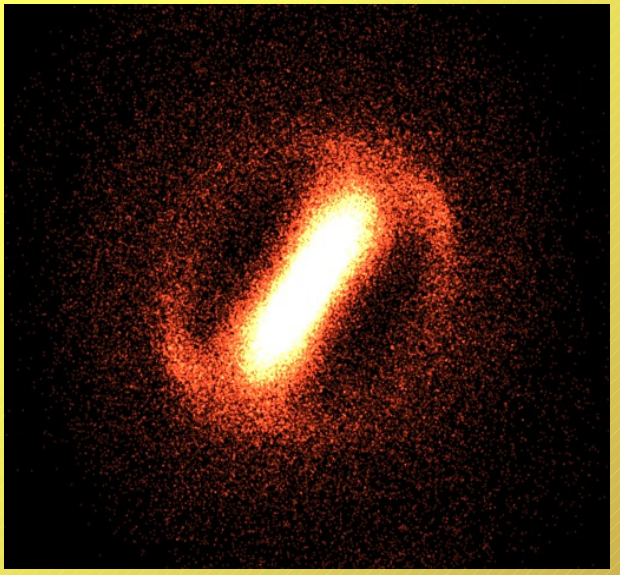
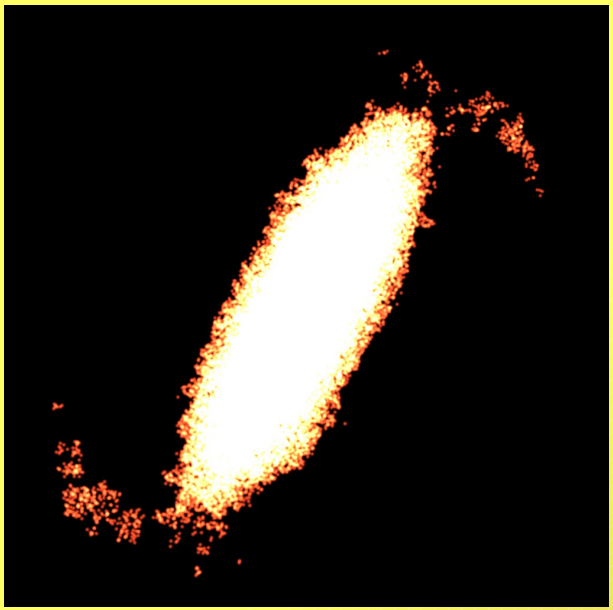


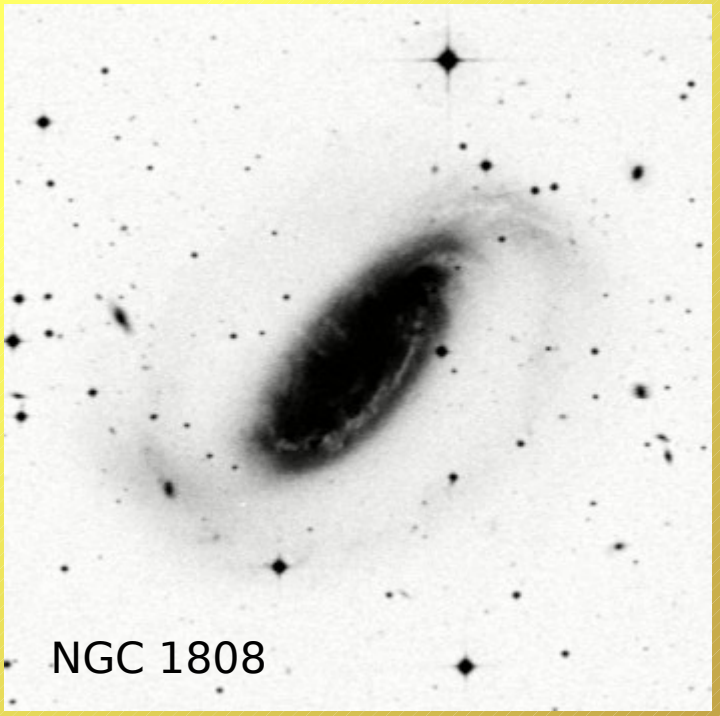








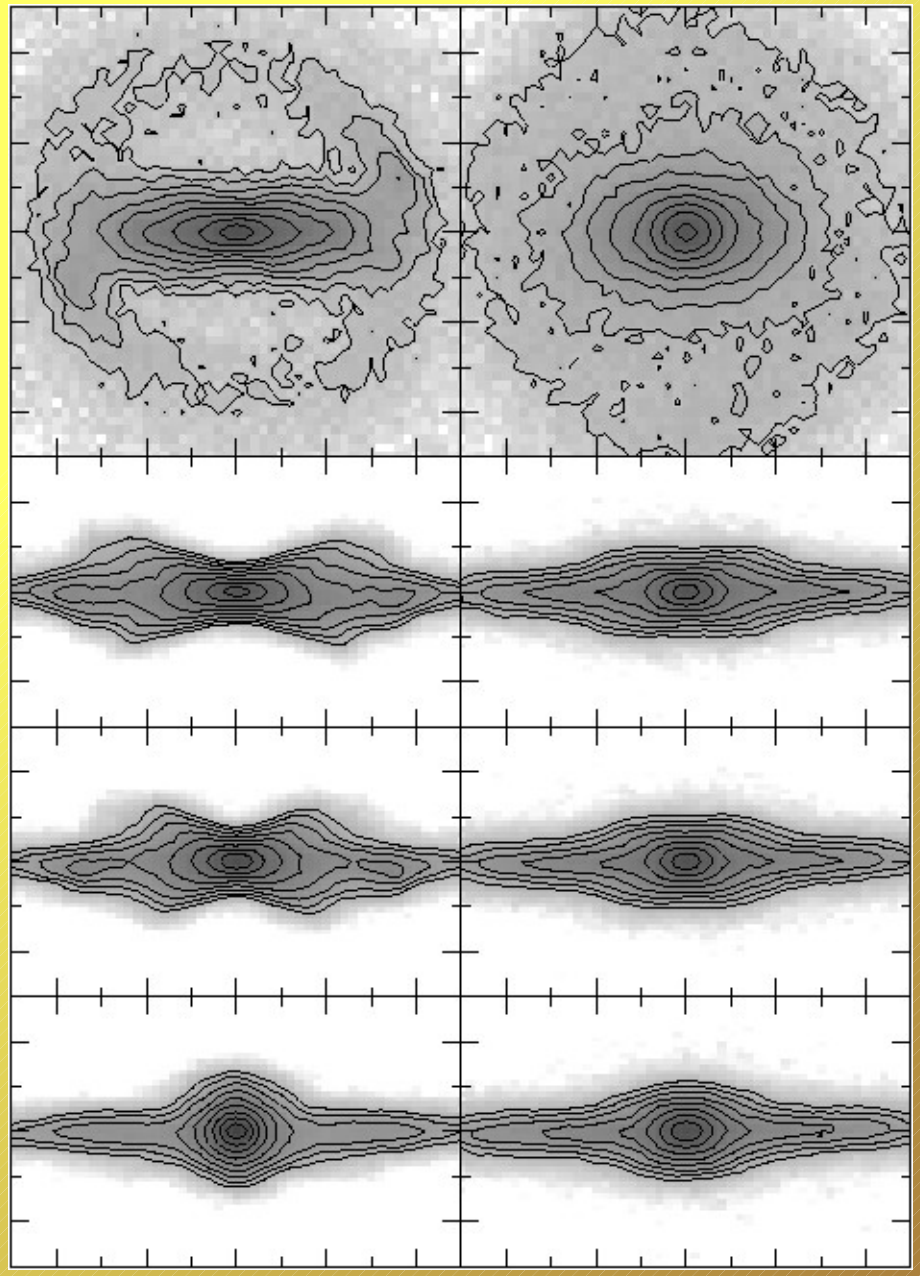




A leading extension in the ring: This may be the reason that we see the long bar at a larger angle than the COBE/ DIRBE bar (or may contribute substantially to it). It is sufficient, but Not necessary

Feature found in: Athanassoula and Misiriotis 02

Use for the MW: Romero-Gomez et al 2011



Errors are different in observations and in numerical Simulations

GAIA measurement errors, also extinction etc

Simulations can also have biases, particularly related to SF and feedback

A simulation particle is NOT a star

10^7 particles

A cluster of stars born at the same time

10^9 particles. VERY few simulations

The end