Modelling the Milky Way

Using Milky Way observations with the M2M method

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Motivation

- Made-to-measure (M2M) method
  - Used with theoretical models and external galaxies
  - Milky Way = not really => fill the gap !
  - Good at modelling a variety of observables but needs a potential.
- Nbody models
  - Used extensively – disks, spirals, bars, bulges etc but difficult to tailor.
- Perhaps.....
  - Use Nbody + M2M together ?
  - Benefit Milky Way modelling ?

Nbody Model

- Shen et al (2010)
- Motivation
  - Disconnect between merger history of MW and currently understood bulge formation mechanisms
  - Could a pseudo-bulge match observed MW kinematics ?
- Nbody thin disc simulation ~10^6 particles
  - Bar forms, buckles and thickens, pseudo-bulge appears
- Key result for M2M purposes
  - With appropriate scaling, matches BRAVA data,
    pattern speed = ~40 km/s/kpc
    bar angle = ~20 degrees (weakly constrained),

M2M Exercise

- Utilise Shen et al Nbody model, and
- BRAVA (l,b) field observations

- Determine the bar angle and pattern speed using M2M modelling

- M2M results consistent with Shen et al ?

- Collaborators = RJL + Shude Mao, Juntai Shen, Yougang Wang. MNRAS Feb 2013 publication.

M2M Weight Evolution

$$F(\mathbf{w}) = \mathcal{L} + \frac{1}{\epsilon}\frac{dS}{dt} + \mu R + \sum_k \lambda_k C_k$$

$$\mathcal{L} = -\frac{1}{2}\chi^2 + \lambda_D \sum_j \ln(p_{D,j})$$

$$S = -\sum_i w_i \left[\ln(\frac{w_i}{m_i}) - 1\right]$$

$$\frac{\partial F}{\partial w_i} = 0 \quad \forall w_i \quad => \frac{dw_i}{dt} = -\epsilon w_i G(\mathbf{w})$$

Weights

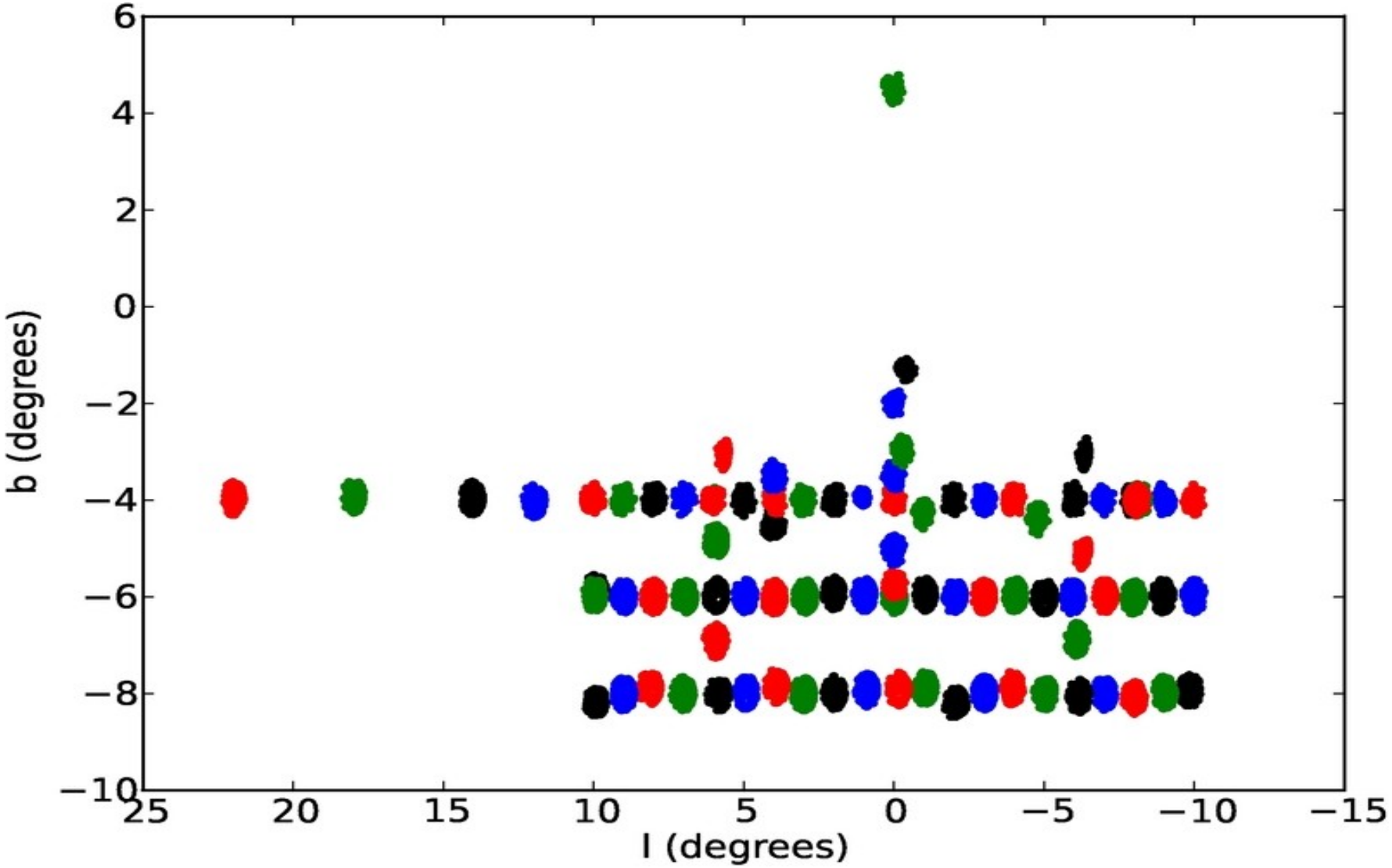
- Weights = fractional luminosity
- Constraint C_k to ensure $\sum_i w_i = 1$
- Weight convergence as important as observable reproduction
- Morganti & Gerhard entropy function (no moving prior)

Shen et al & BRAVA Data

- Shen et al end of run particle data
  - Luminous matter potential from particles (+ dark matter halo = logarithmic potential)
  - Initial positions and velocities for M2M particles
  - 3D density, fractional luminosity in BRAVA fields

- BRAVA field kinematic data
  - Mean radial velocity
  - Radial velocity dispersion
  - NB discrete velocity measurements not used directly

BRAVA Fields



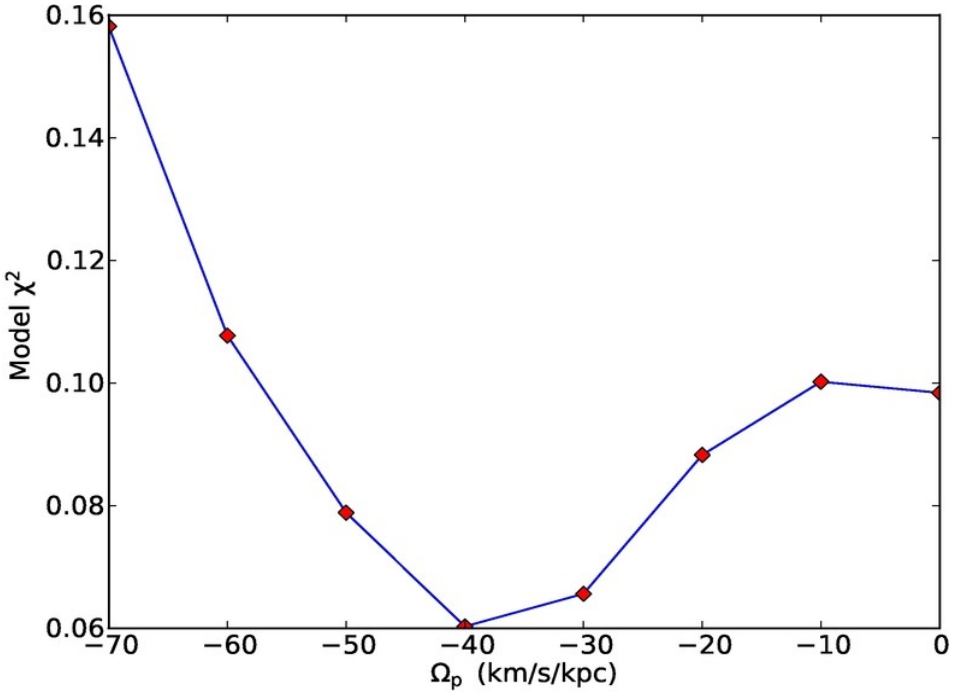
Enhanced M2M Implementation

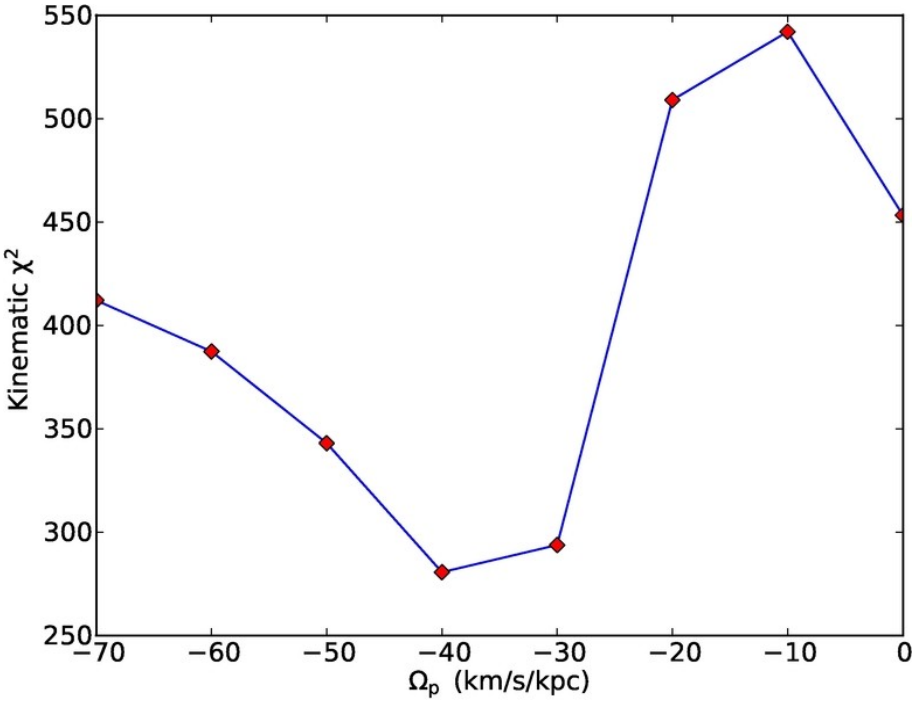
- Rotating frame kinematics
- Non-parallel projection los observables
- (l,b) field based observables
  (which particles are in which fields ?)
- First M2M + MW kinematic model

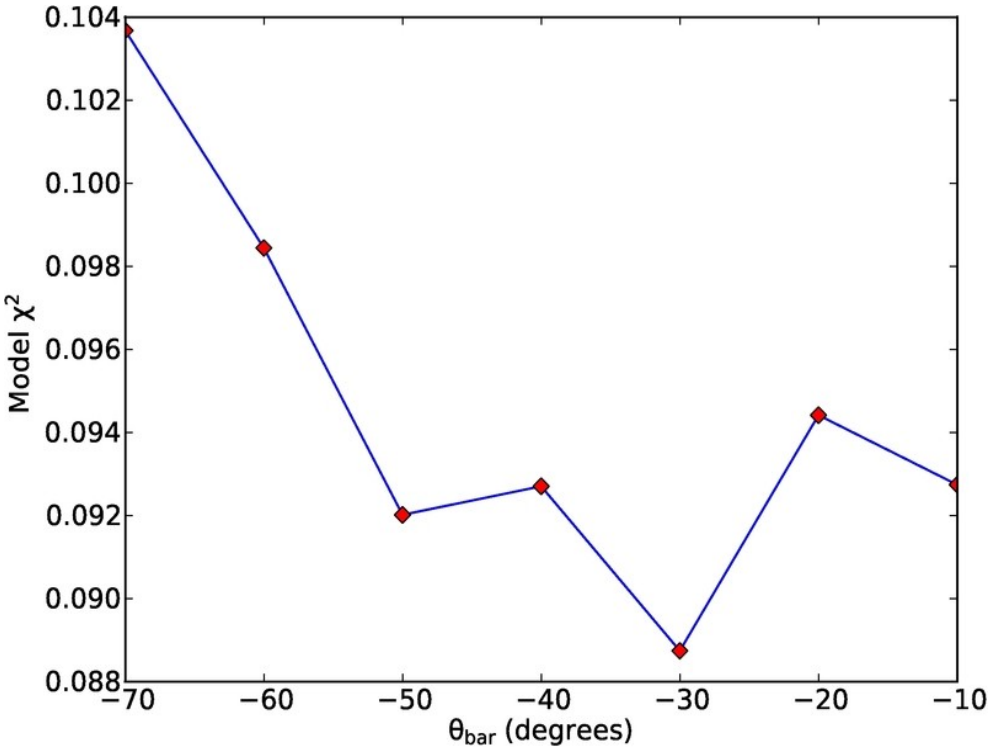
M2M Results

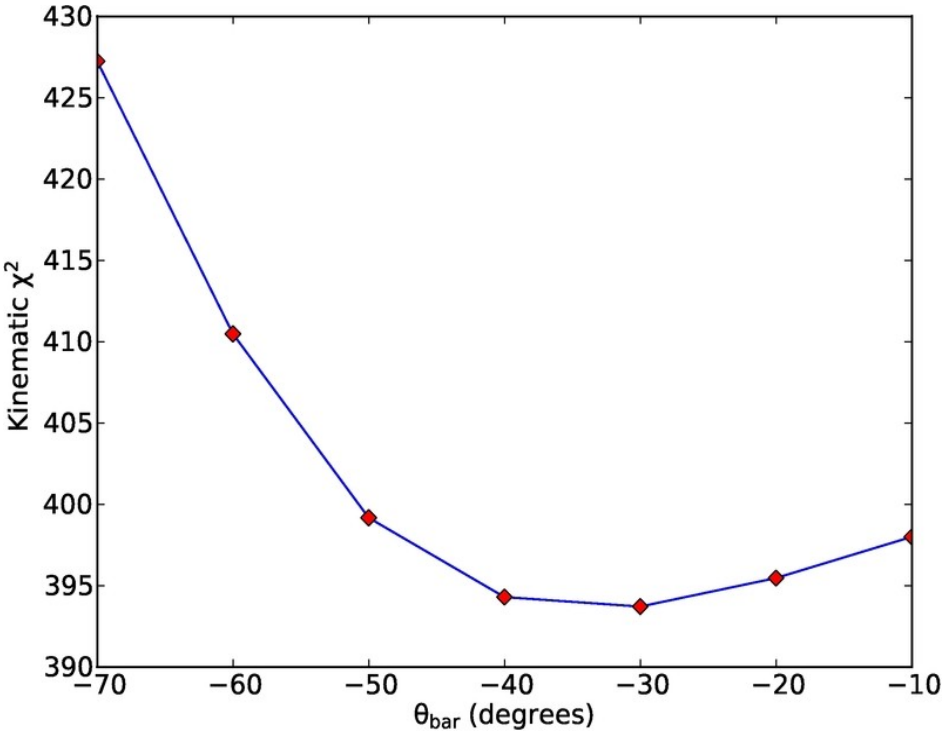
From 56 M2M models (no regularisation) varying pattern speed and bar angle,

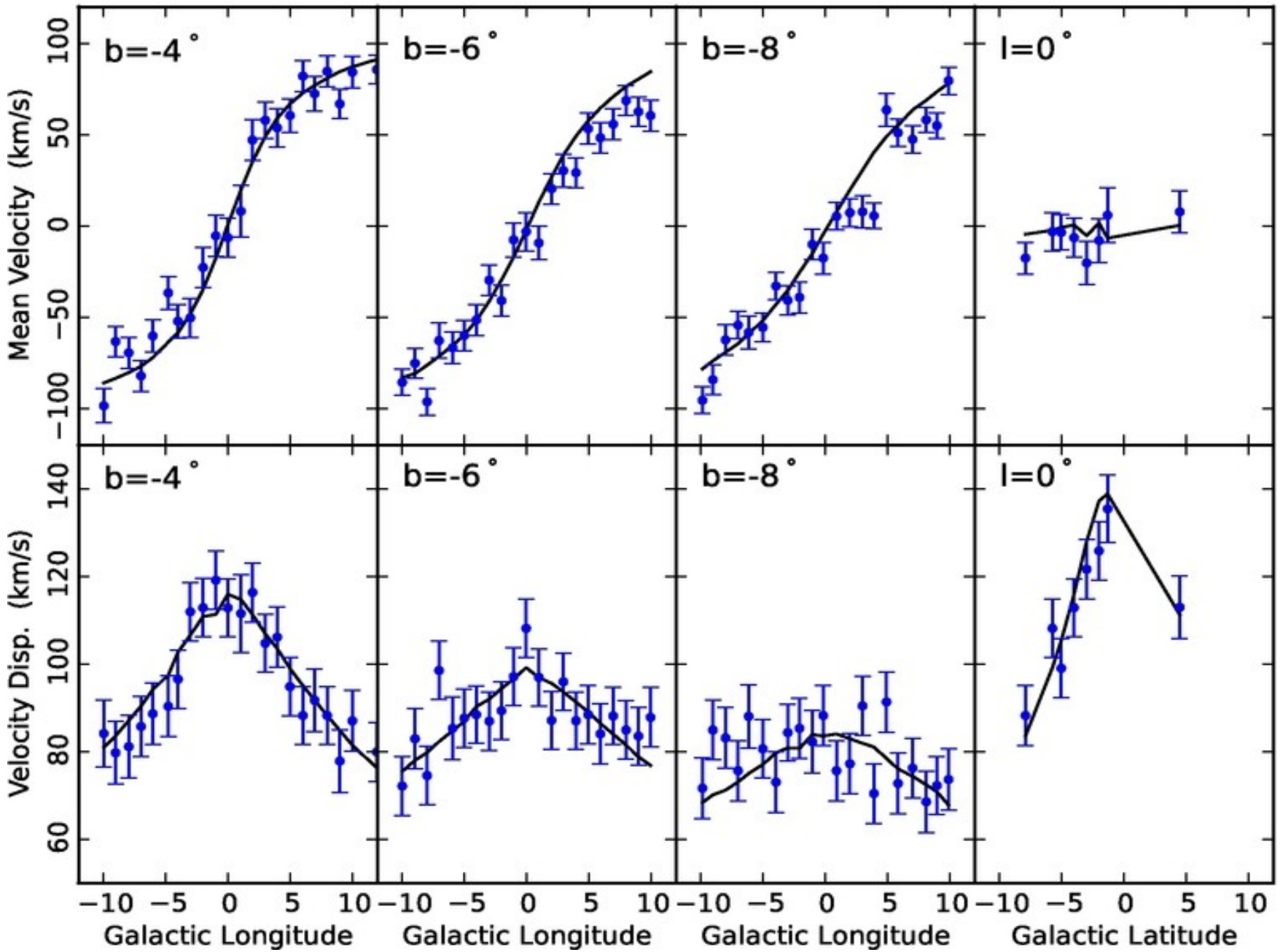
- Pattern speed = ~40 km/s/kpc
- Bar angle = ~30 degrees
- Good news = Not inconsistent with Shen et al !!


Model χ^2
Ω_p (km/s/kpc)


Kinematic χ^2
Ω_p (km/s/kpc)


Model χ^2
θ_{bar} (degrees)


Kinematic χ^2
θ_{bar} (degrees)


b=-4°
b=-6°
b=-8°
l=0°
Mean Velocity (km/s)
100
50
0
−50
−100
b=-4°
b=-6°
b=-8°
l=0°
Velocity Disp. (km/s)
140
120
100
80
60
−10 −5 0 5 10
Galactic Longitude
Galactic Longitude
Galactic Longitude
Galactic Latitude

Nbody + M2M + MW - What next ?

- Single MW component models – probably OK
  - Jason Hunt - PRIMAL - next talk
- Multi-component MW models ?
  - Eg Halo + streams + disc with bar & spirals + gas + dwarf galaxies etc
  - Do such multi-component Nbody models exist already ? If not, why not ?
- Stand back and re-assess ……

MW Models using GAIA Data

- Should there be a shared vision for MW modelling ?
  - What should it encompass ?
  - What can not be answered with GAIA ?

- What sort of modelling solution is envisaged ?
  - All MW components, full / partial galaxy ?
  - Total data, not just mass modelling ?
  - Single or multiple modelling techniques ?
    - Do they exist today ?
  - Iterative, Bayesian approach?
  - Which approaches will just not work ?
    - Too much GAIA data !

Science - General

- Start position = Current knowledge baseline
  - Things known to some confidence level
    - Existence, quantification, empirical relationships etc
  - Things not known
  - May include alternatives
- Investigation
- Afterwards = An improved knowledge baseline
  - New things added
  - Updated some existing things
  - Discard some existing things

Science – Milky Way

- What represents the current baseline ?
  - Is it a population synthesis model ?
  - Is it a Wikipedia page ?
  - It isn't ADS or astro-ph !!
- What can we carry forward to GAIA ?
  - eg barred spiral galaxy with central black hole
- What must/should we re-establish using GAIA data ?
  - eg central black hole mass, centre of Galaxy
- New ? Up to you !
  - eg the gravitational potential is a favourite !

Summary

- Nbody + M2M + single MW component – worth investigating further

- MW + GAIA – basics missing !

  No vision / no clear solution / baseline unclear.

  Is 2 - 4 years long enough ?

  Action the basics asap !!