Connecting galactic magnetic fields to the interstellar medium: Looking for statistical correlations

Cameron Van Eck and Jo-Anne Brown,
University of Calgary, Canada
in collaboration with
Andrew Fletcher and Anvar Shukurov,
Newcastle University, UK

July 9, 2012

clvaneck@ucalgary.ca

Image: NASA/JPL-Caltech (nasaimages.org)

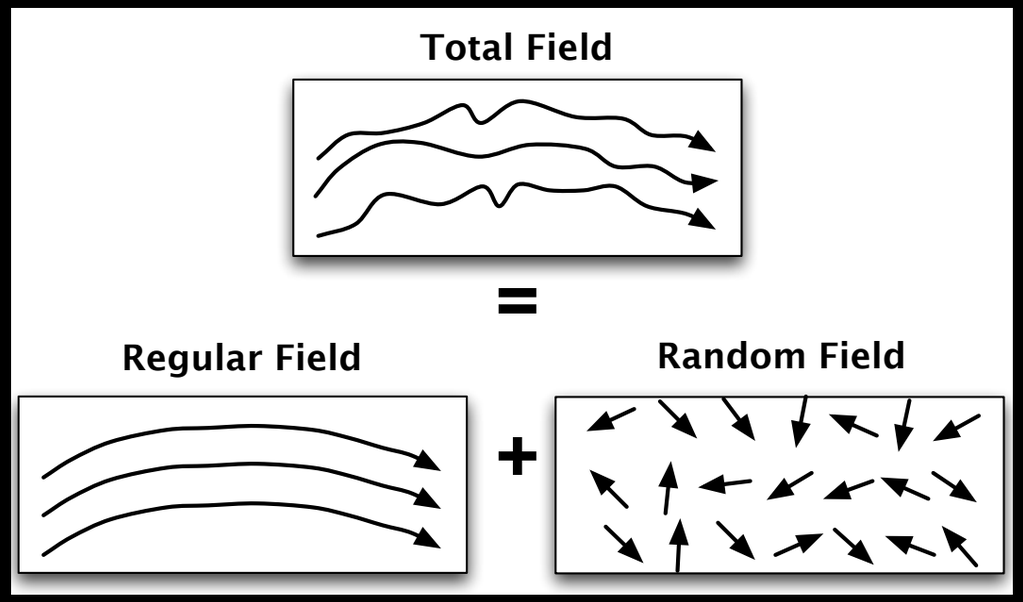
Outline

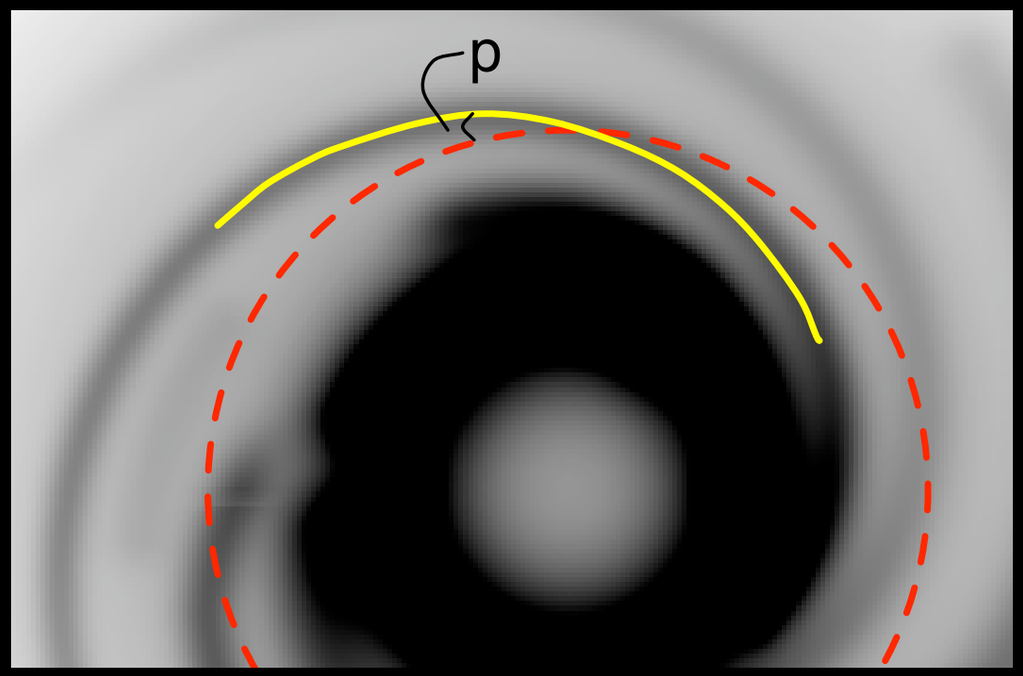
- Magnetic observations of spiral galaxies
- Results of statistical correlations with other galaxy parameters
- Tests of magnetic dynamo theories

Magnetic observations of galaxies

- Magnetic fields in galaxies are divided into two components, a large-scale regular field and small-scale unresolved turbulence.

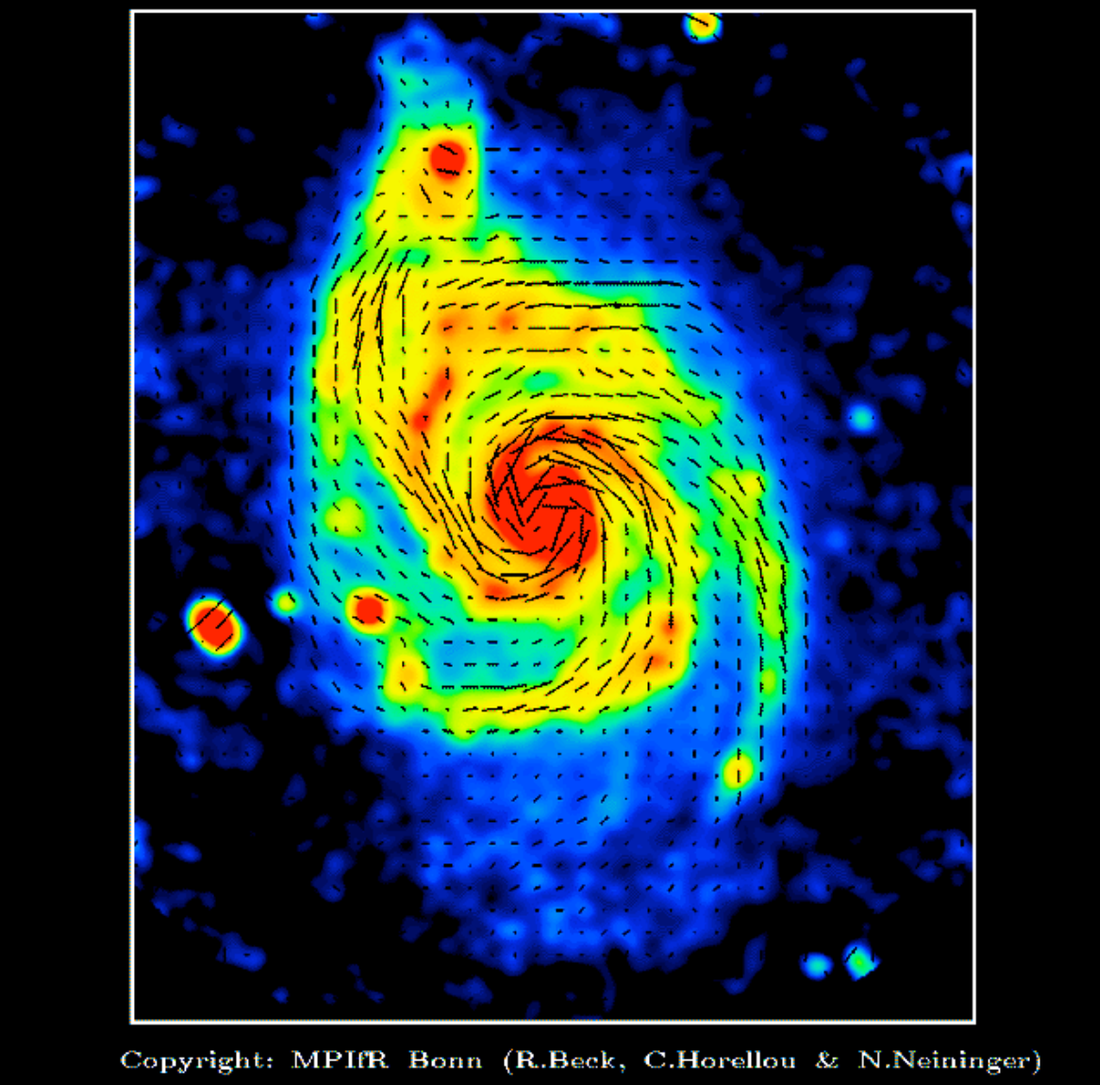
- The regular field geometry can be measured in term of spiral pitch angle.





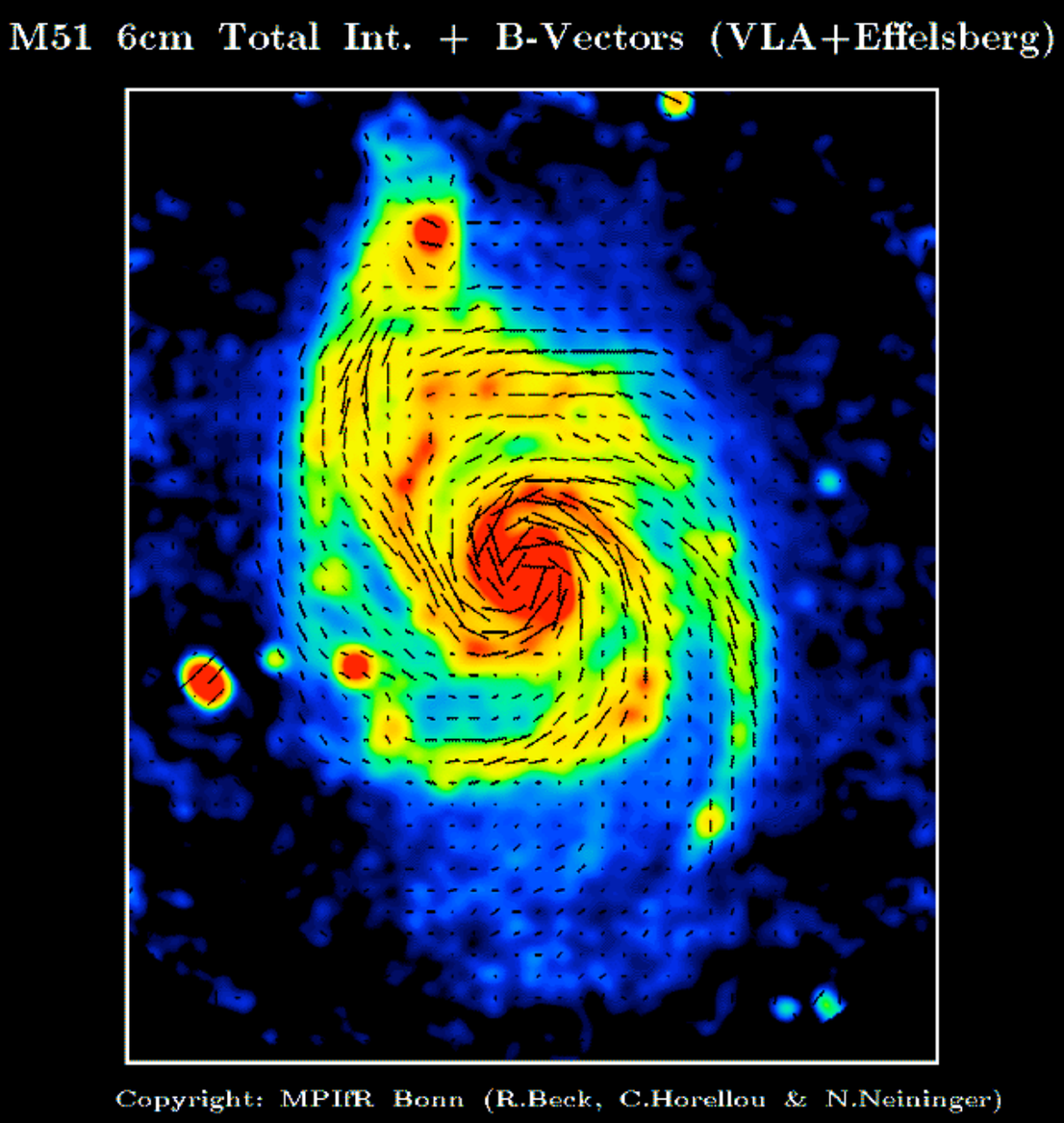
Magnetic observations of galaxies

- Magnetic fields in galaxies are inferred from synchrotron emission
- Total field strength is calculated from intensity of synchroton emission
- Strength of regular field calculated from intensity of polarized emission



Magnetic observations of galaxies

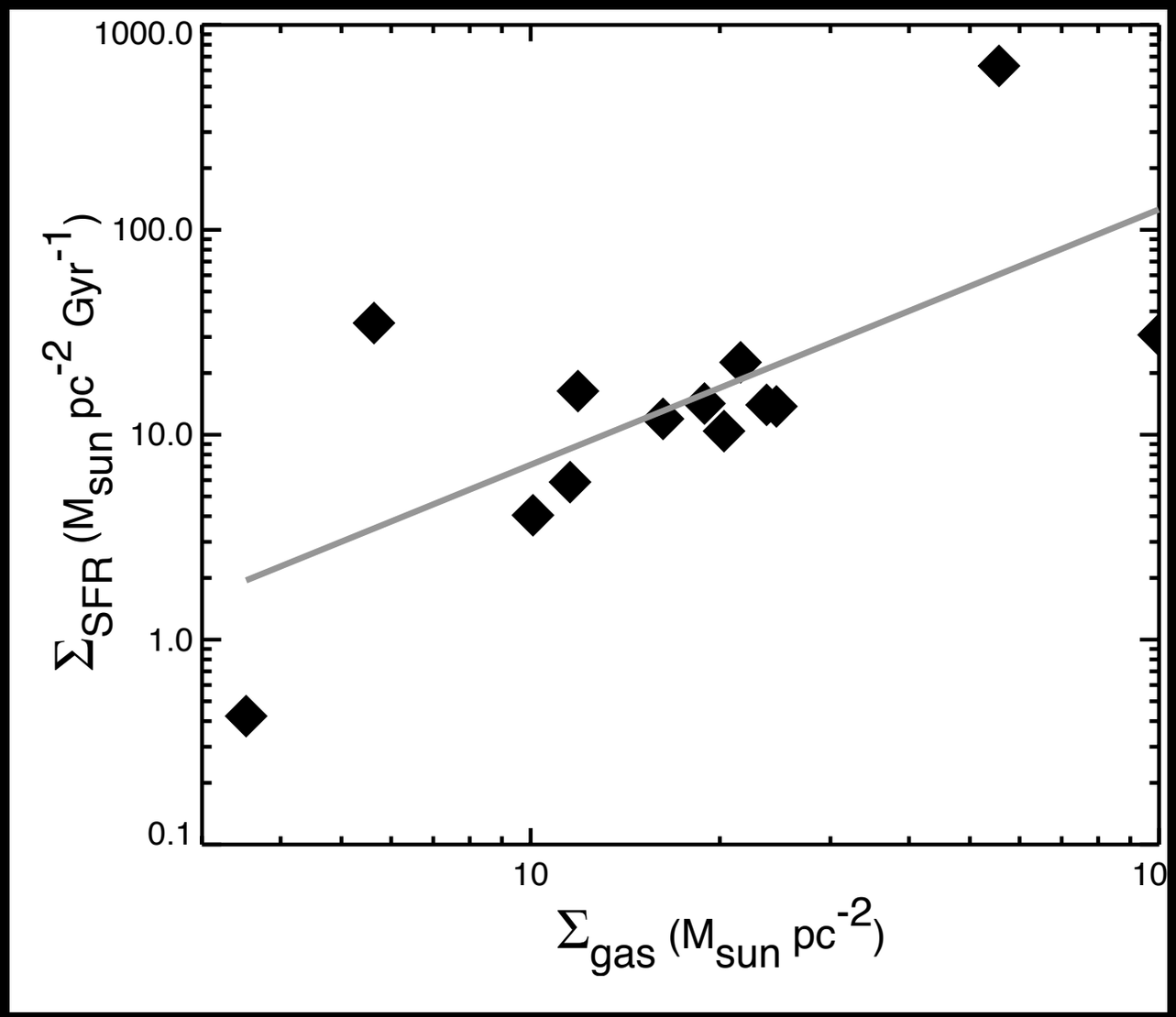
- Many galaxies have had magnetic field observations in recent years
- There are now more than 20 spiral galaxies with such observations, enough to begin statistical analysis
- Local values are not available, so global averages must be used



Magnetic field strengths and other physical parameters

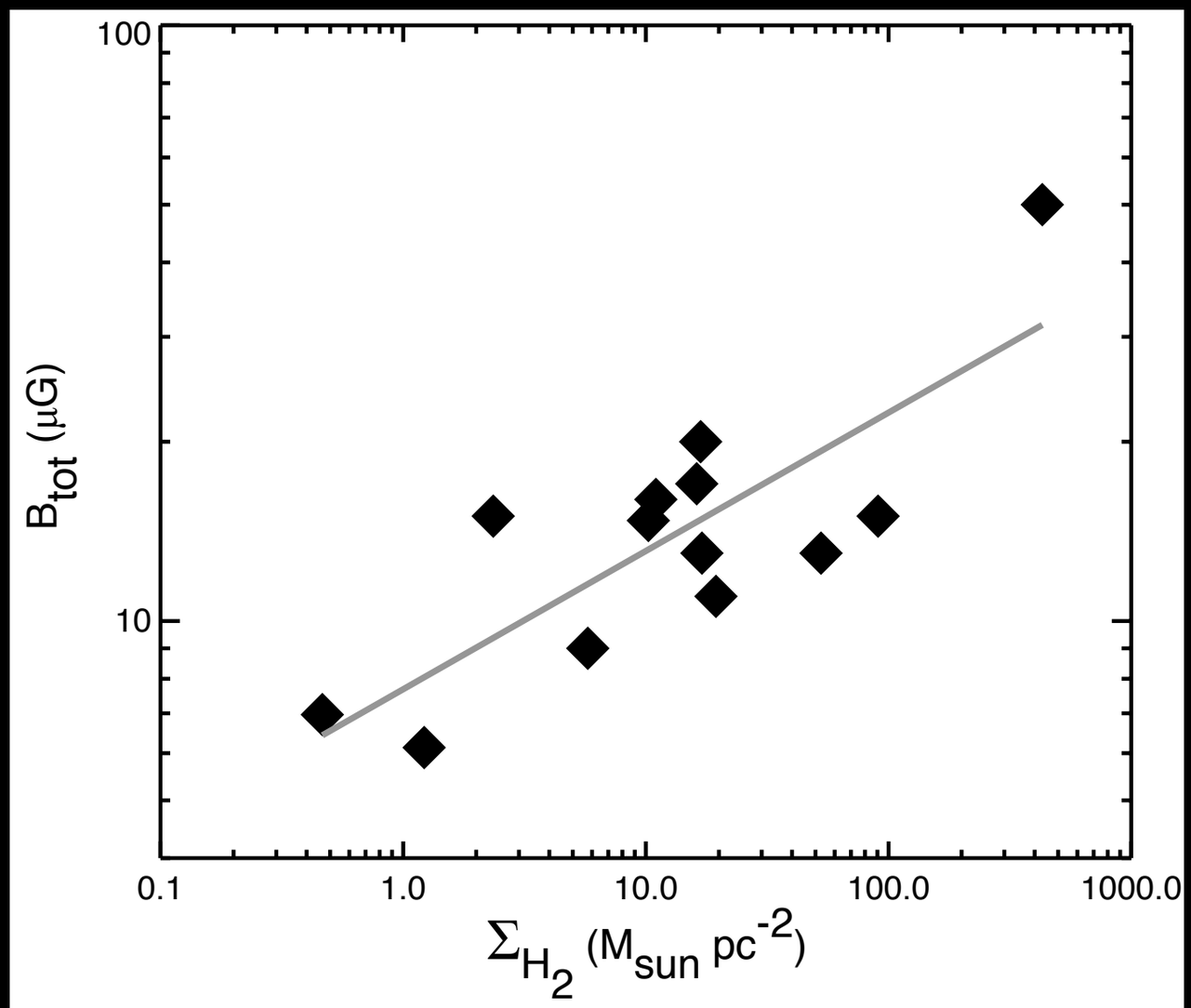
Galaxy	Magnetic Field	Rotation Curve	HI/H_2 Density	Star formation rate
M31 (NGC224)	Fletcher et al. (2004)	Sofue et al. (1999)	Boissier et al. (2007)	Tabatabaei & Berkhuijsen (2010)
M33 (NGC598)	Tabatabaei et al. (2008)	Sofue et al. (1999)	Boissier et al. (2007)	Verley et al. (2009)
M51 (NGC5194)	Fletcher et al. (2011)	Sofue et al. (1999)	Leroy et al. (2008)	Leroy et al. (2008)
M66 (NGC3627)	Soida et al. (2001)	de Blok et al. (2008)	Leroy et al. (2008)	Leroy et al. (2008)
M81 (NGC3031)	Krause et al. (1989)	Sofue et al. (1999)	Boissier et al. (2007)	Calzetti et al. (2010)
M82 (NGC3034)	Klein et al. (1988)	Sofue et al. (1999)	Lo et al. (1987)	Lo et al. (1987)
M94 (NGC4736)	Chyży & Buta (2008)	de Blok et al. (2008)	Crosthwaite (2001)	Leroy et al. (2008)
M99 (NGC4254)	Chyży (2008)	Dicaire et al. (2008)	Warmels (1988)	Rahman et al. (2011)
M104 (NGC4594)	Krause et al. (2006)	Tempel & Tenjes (2006)		
NGC253	Heesen et al. (2009)	Sofue et al. (1999)	Sorai et al. (2000)	Waller et al. (1988)
NGC891	Hummel et al. (1991)	Yim et al. (2011)	Yim et al. (2011)	Yim et al. (2011)
NGC1097	Beck et al. (2005)	Sofue et al. (1999)	Crosthwaite (2001)	Kennicutt (1998)
NGC1365	Beck et al. (2005)	Sofue et al. (1999)	Jałocha et al. (2010)	
NGC1566	Ehle et al. (1996)	Sofue et al. (1999)		
NGC4414	Soida et al. (2002)	Fridman et al. (2005)	Thornley & Mundy (1997)	Wong & Blitz (2002)
NGC4631	Hummel et al. (1991)	Sofue et al. (1999)		Irwin et al. (2011)
NGC4666	Dahlem et al. (1997)	Lehnert & Heckman (1996)		
NGC5775	Soida et al. (2011)	Heald et al. (2006)		
NGC6946	Beck (2007)	de Blok et al. (2008)	Leroy et al. (2008)	Leroy et al. (2008)
IC342	Graeve & Beck (1988)	Sofue et al. (1999)	Crosthwaite (2001)	Calzetti et al. (2010)

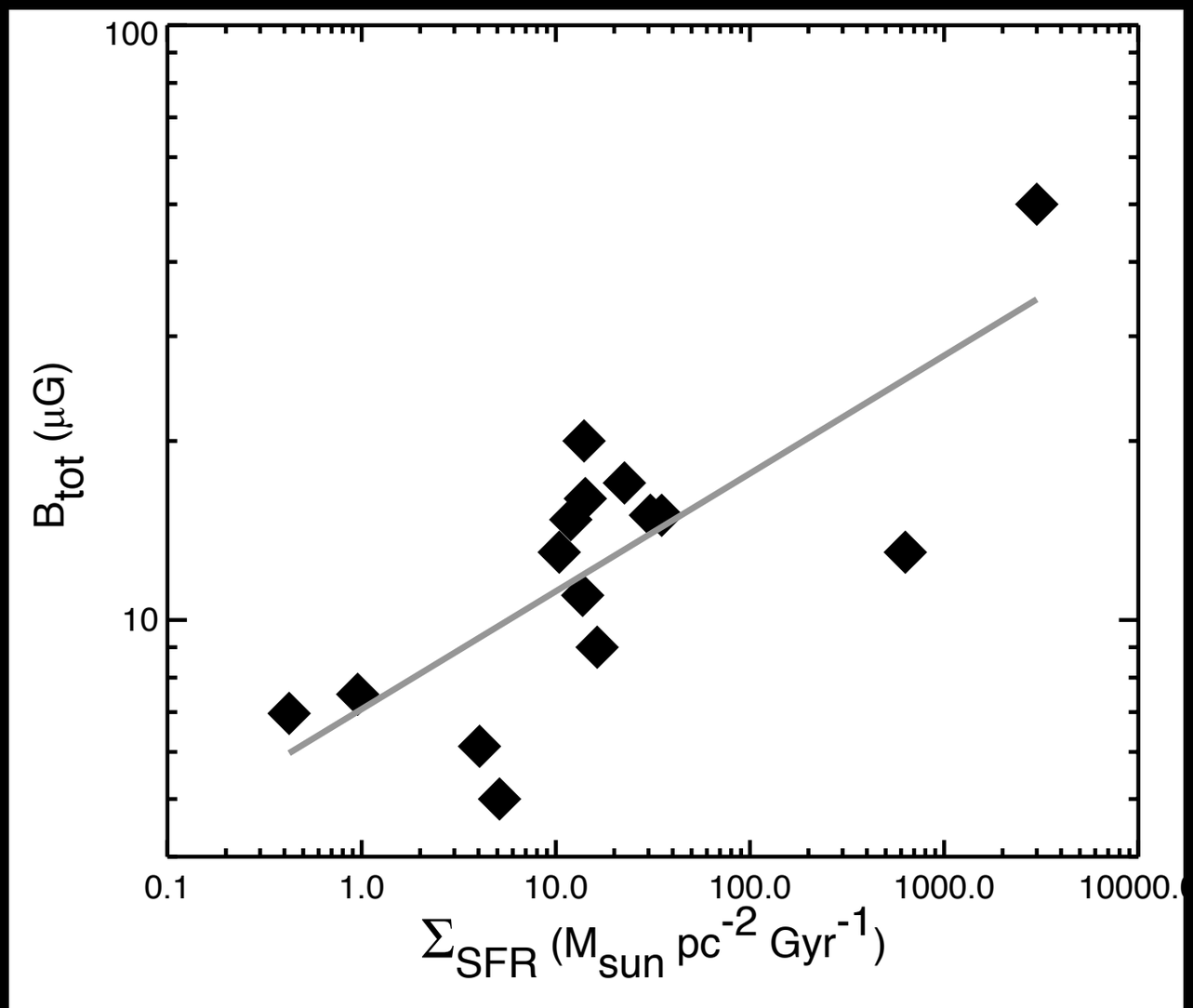
Confirming known correlations



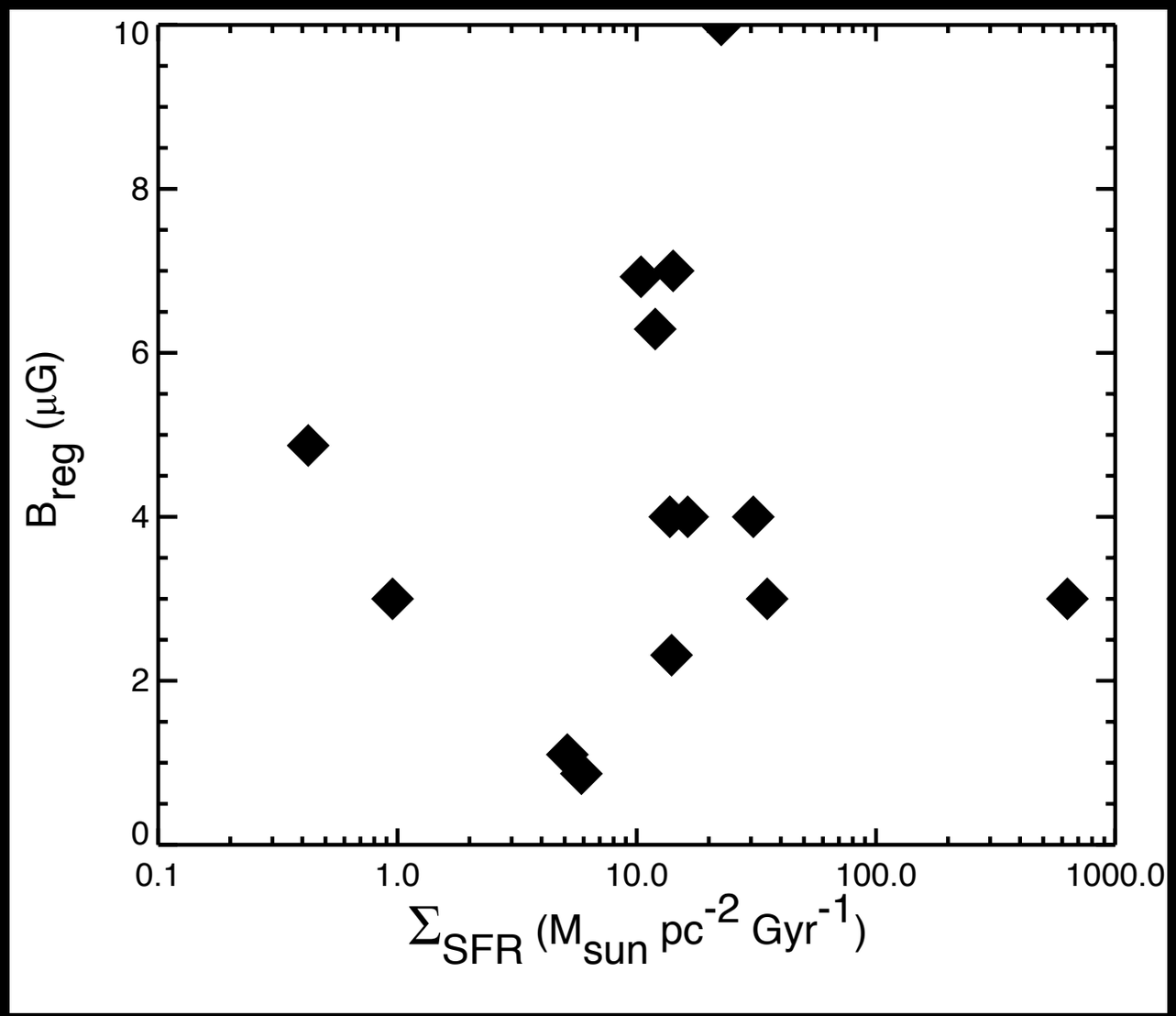
- Schmidt-Kennicutt law: a known correlation between gas density and SFR.
- Our slope: 1.2 ± 0.4
  Their slope: 1.3 ± 0.3

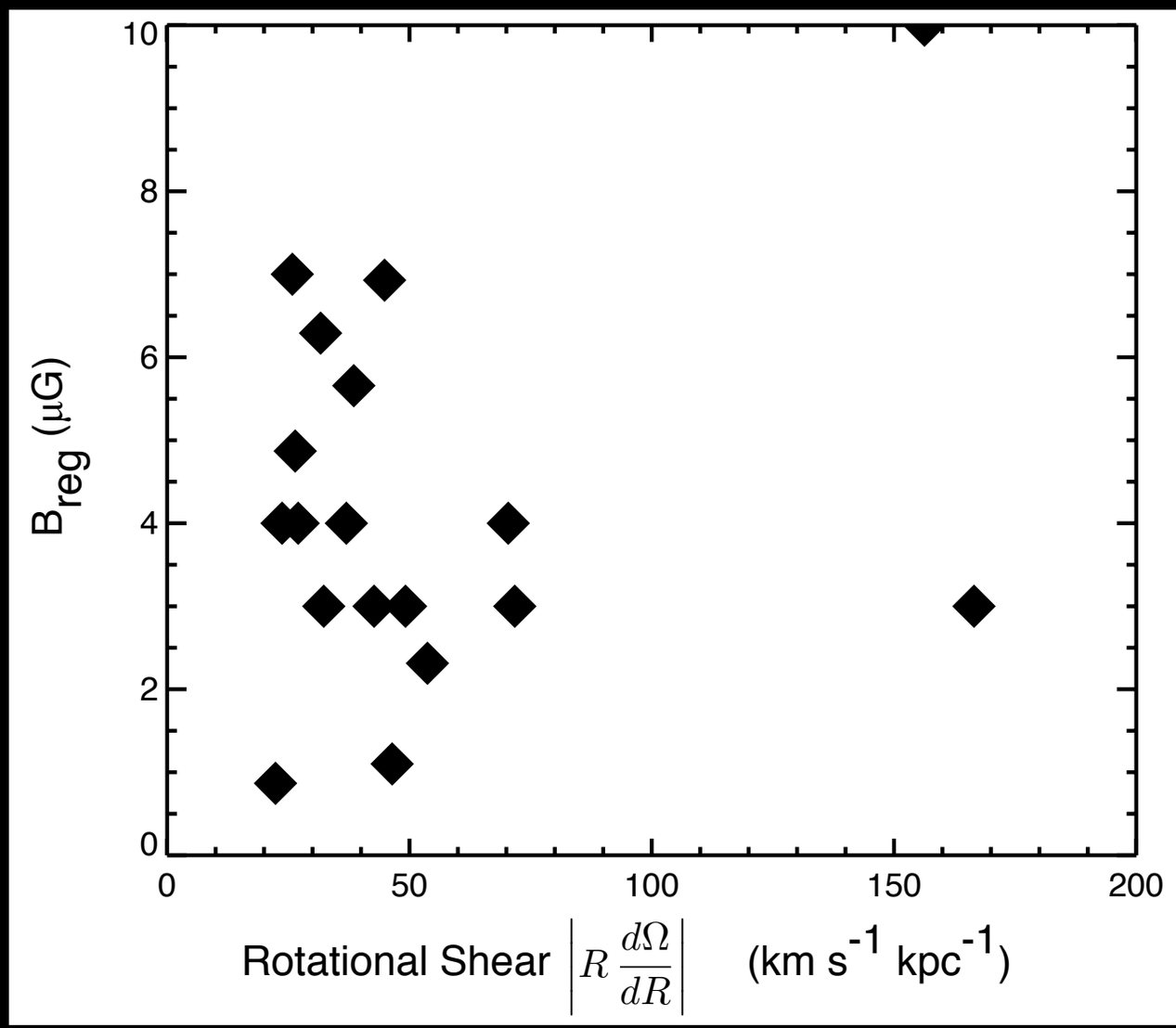
Correlations between ISM and total magnetic field



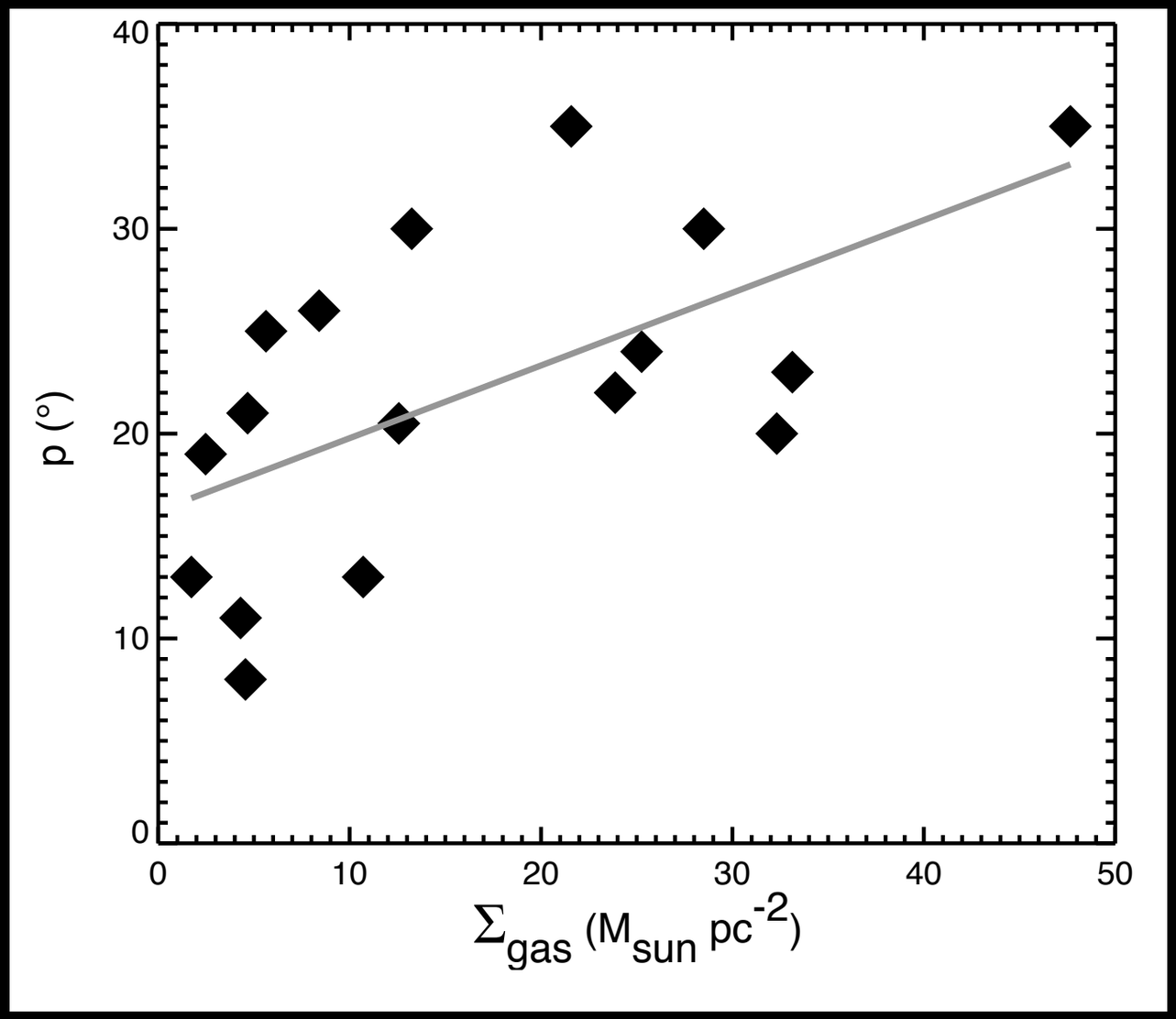


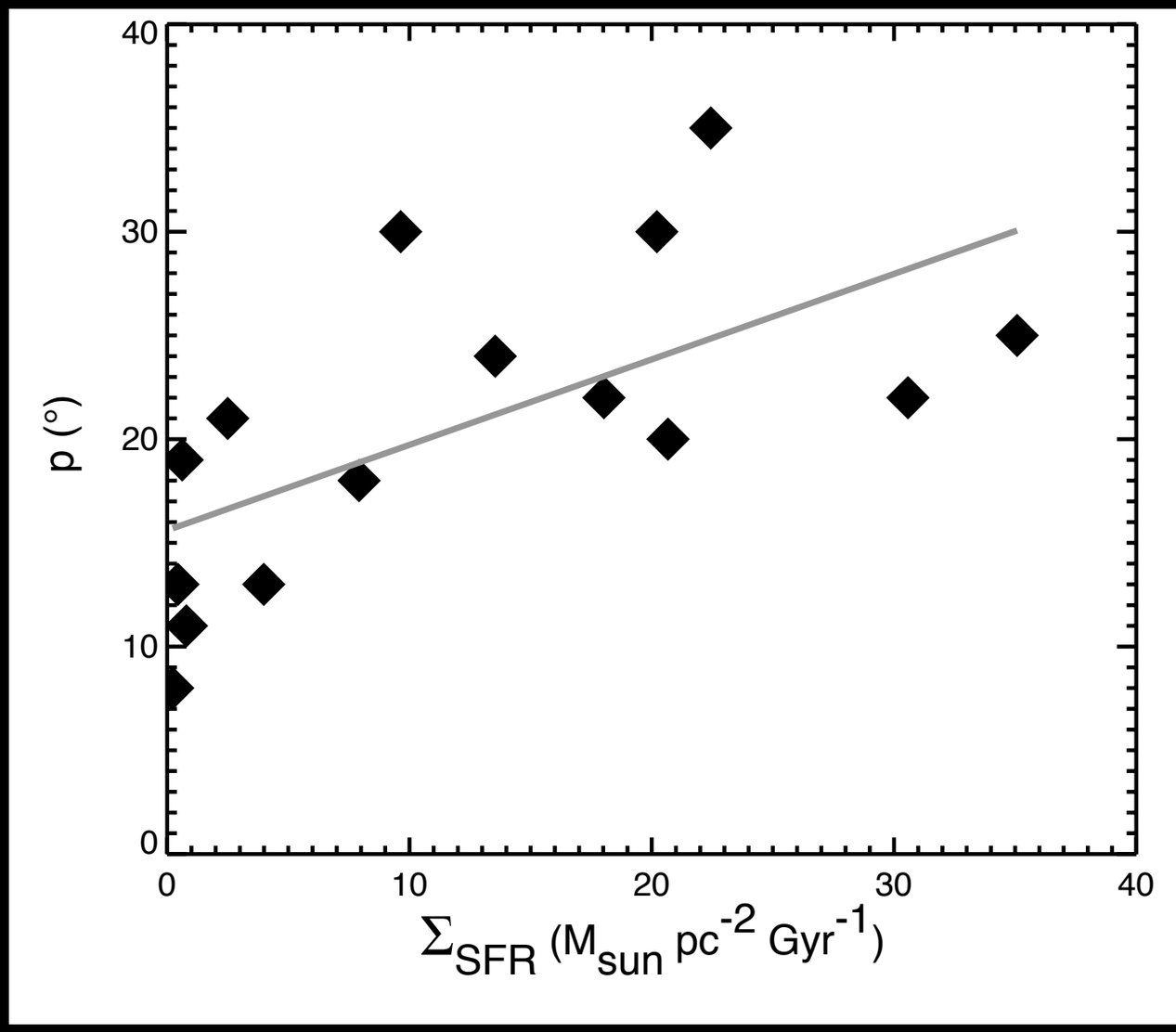
Correlations between ISM and regular magnetic field





Correlations between ISM and magnetic pitch angle





Correlations between ISM and magnetic field

	B_{total}	$B_{regular}$	Magnetic pitch
$B_{regular}$ (μG)	0.325 (5.9%, 18)		
HI density ($M_\odot\, pc^{-2}$)	0.213 (25%, 16)	0.009 (96%, 16)	0.142 (28%, 29)
H_2 density ($M_\odot\, pc^{-2}$)	**0.415 (4.8%,13)**	0.093 (67%, 12)	**0.404 (1.9%,18)**
Gas (HI + H_2) density ($M_\odot\, pc^{-2}$)	0.339 (13%, 12)	0.063 (78%, 12)	**0.457 (0.80%,18)**
Star formation rate density ($M_\odot\, pc^{-2}\, Gyr^{-1}$)	**0.490 (1.1%, 15)**	0.056 (78%, 14)	**0.580 (0.26%, 15)**
Angular velocity (Ω) ($km\, s^{-1}\, kpc^{-1}$)	0.180 (30%, 18)	-0.104 (55%, 18)	0.200 (12%, 30)
Rotational Shear ($R\,\frac{d\Omega}{dR}$) ($km\, s^{-1}\, kpc^{-1}$)	-0.090 (61%,18)	0.043 (80%, 19)	0.232 (7.1%, 30)
Dynamo Number ($R\,\Omega\,\frac{d\Omega}{dR}$) ($km^2\, s^{-2}\, kpc^{-2}$)	0.193 (26%, 18)	0.021 (90%, 18)	0.228 (7.7%, 30)

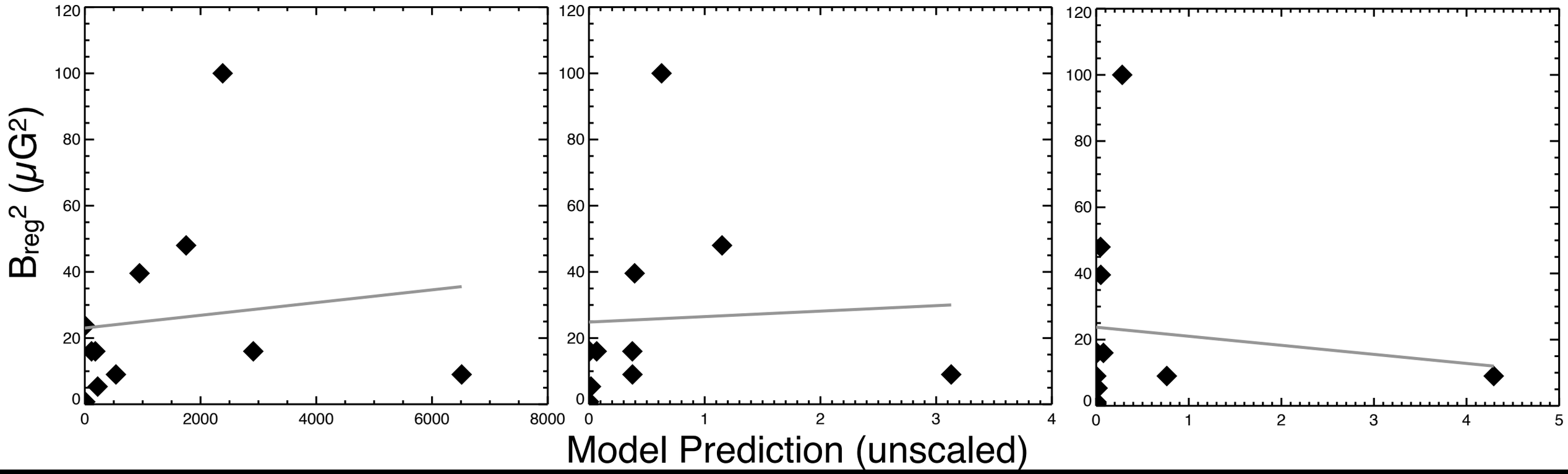
Kendall's τ (significance, # of galaxies)

Tests of dynamo models

- Large-scale field in disk galaxies is believed to be caused by αΩ-dynamo, but saturation mechanism not known.

- We tested the regular field strengths and pitch angles predicted for three different ways the dynamo could saturate.

Tests of dynamo models



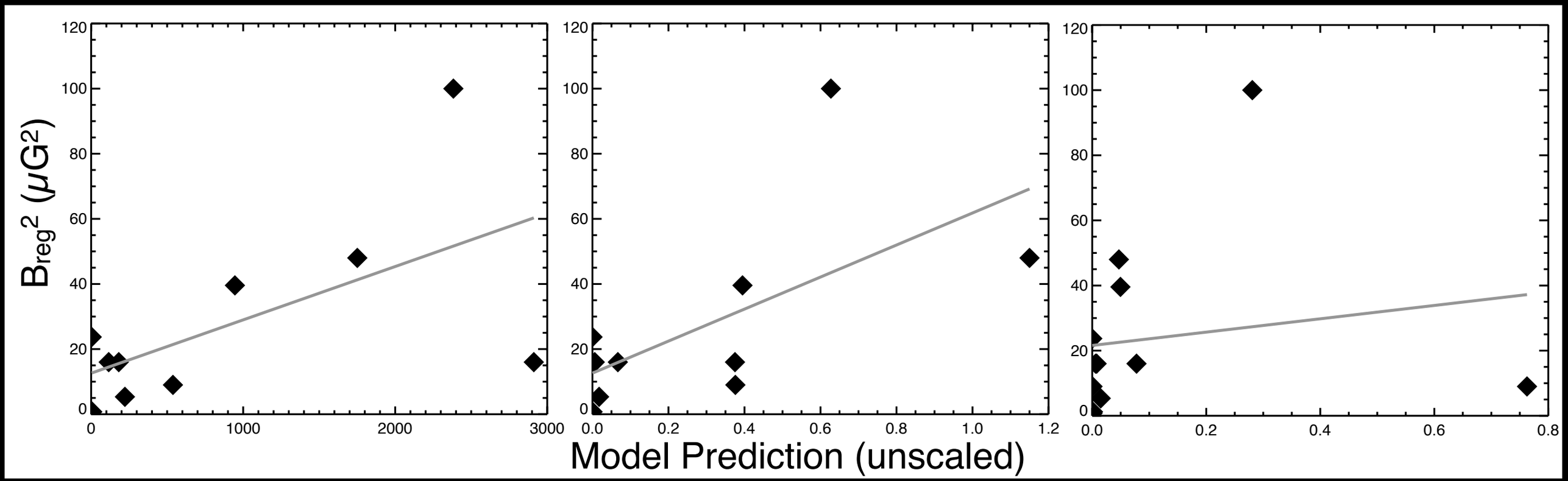
Energy balance
0.133 (70%, 11)

Magnetostrophic balance
0.054 (88%, 11)

Helicity balance
-0.119 (70%, 13)

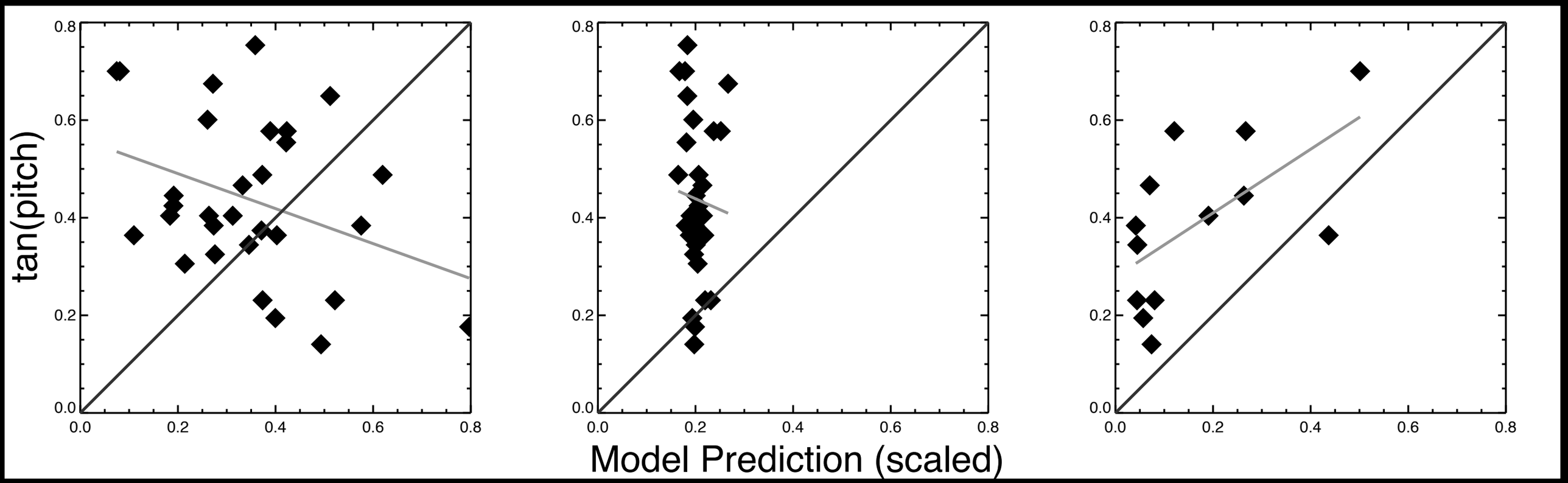
Tests of dynamo models*

*after removing one point:



Energy balance	Magnetostrophic balance	Helicity balance
0.595 (6.9%, 10)	0.624 (5.4%, 10)	0.162 (61%, 12)

Tests of dynamo models: pitch angles



Unsaturated
-0.351 (5.7%, 30)

Magnetostrophic balance
-0.062 (75%, 30)

Helicity balance
0.613 (2.6%, 13)

Summary

- We performed a statistical analysis of 20 spiral galaxies, found some interesting correlations/non-correlations.
- We have reproduced previously found correlations (Star formation vs H_2, B_{tot}).
- Testing dynamo theories with field strength is inconclusive, pitch angle looks promising. Helicity balance looks interesting, but more data is needed.