Cosmic Flows: from Observations to Simulations

CLUES 2012 Meeting

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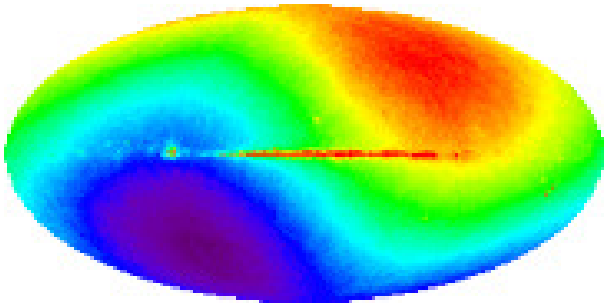
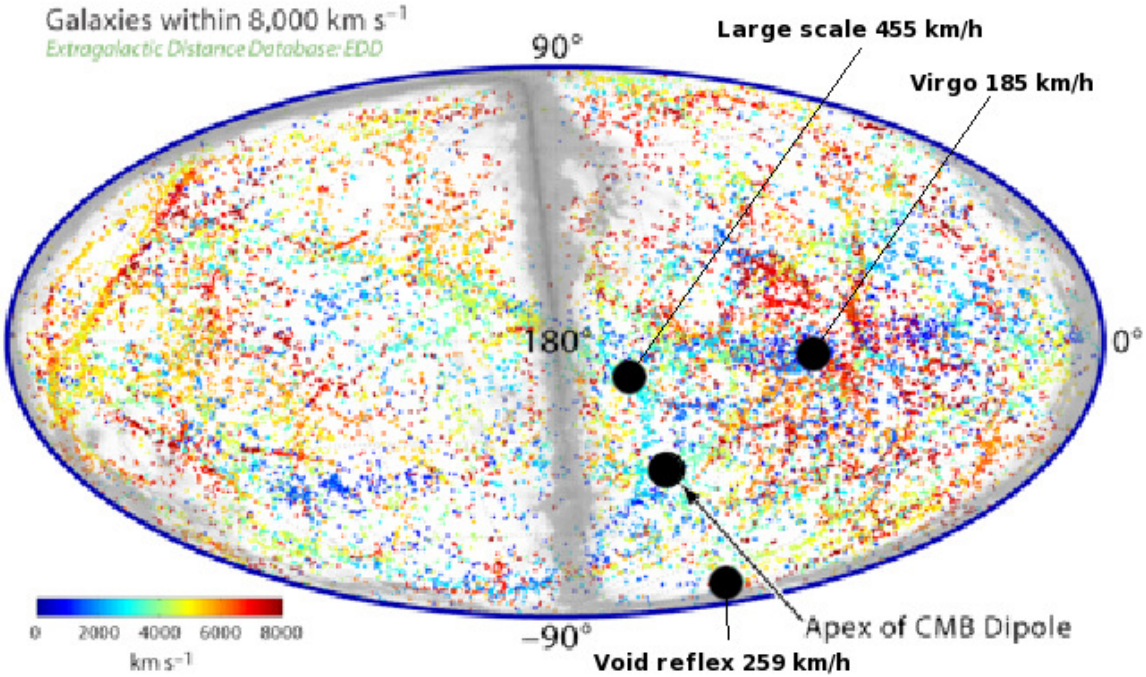
Cosmic Flows

CMB



Dipole $\rightarrow$ **deviant motions** from the Hubble expansion



Mostly due to **large scale** structures

Cosmic Flows

Goal: Reconstruct density-velocity fields → need of $v_{peculiar\ radial}$

Why: velocity = **high linearity**, **large-scale correlation** (> density)

$$\hookrightarrow \vec{\nabla}.\vec{v} = -H_0 f(\Omega_m, \Omega_\Lambda)\delta \quad (1)$$

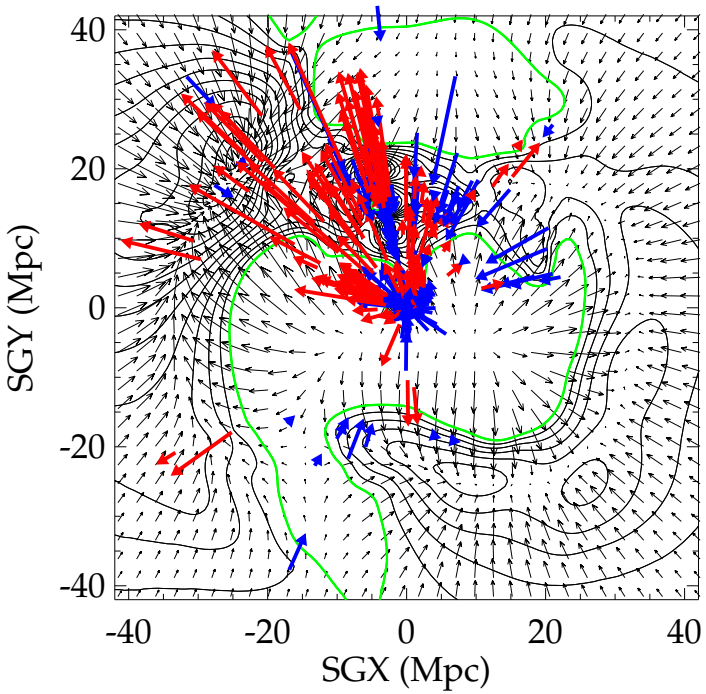


Figure: Courtois et al. 2012

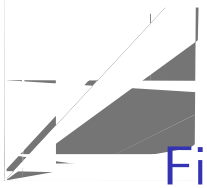


Figure: Courtois et al. 2012

1.a Cosmic Flows 1, 2, etc

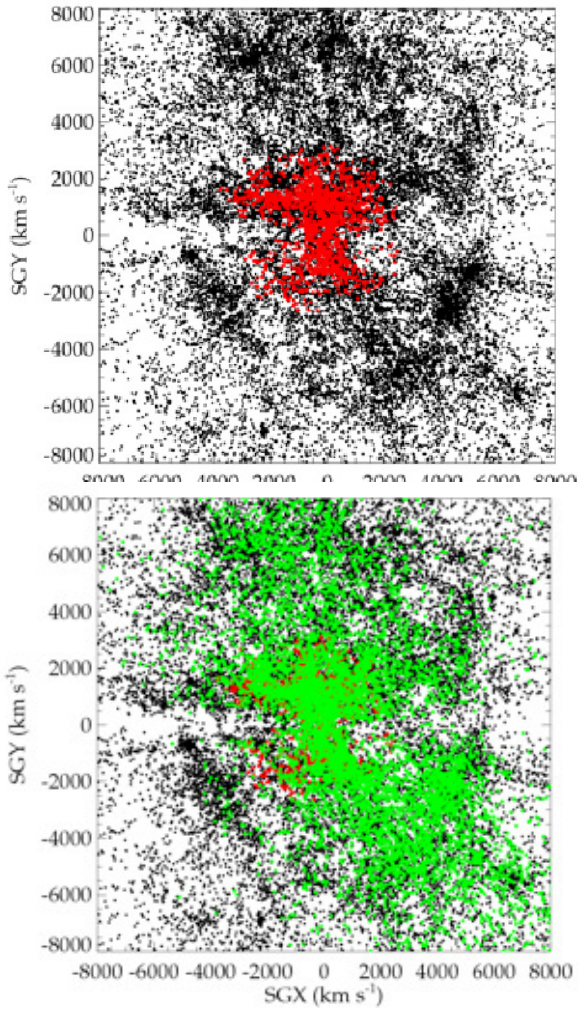


Figure: Courtesy of H. Courtois

Observed Galaxies

→ **Cosmic Flows - 1**

Tully et al. 2008, Courtois et al. 2012b, etc

→ **Cosmic Flows - 2**

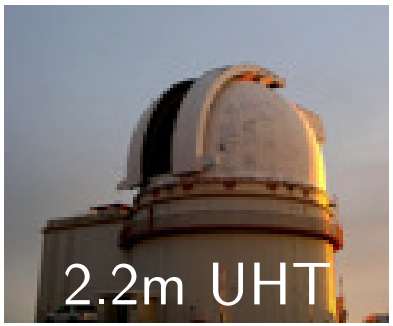
Courtois et al. 2011a, b, 2012a, Tully et al. 2012, etc

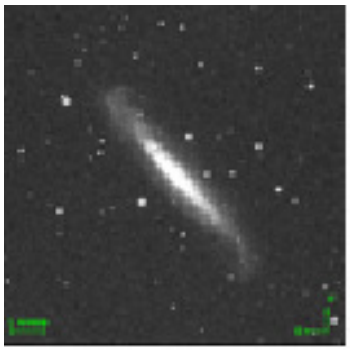
"Each CF" tends to improve:

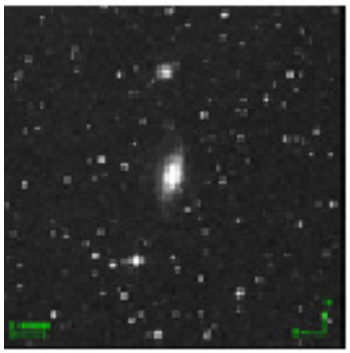
1. **quality** (*e.g. accuracy*)
2. **quantity** (*e.g. ZOA, farther*)

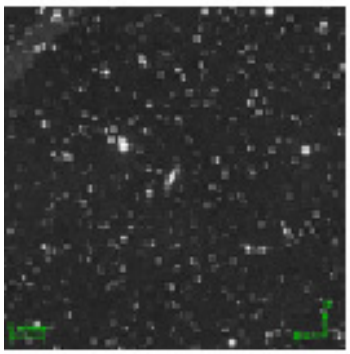
1.a Two very accurate observations

Photometry: Optical & Infrared

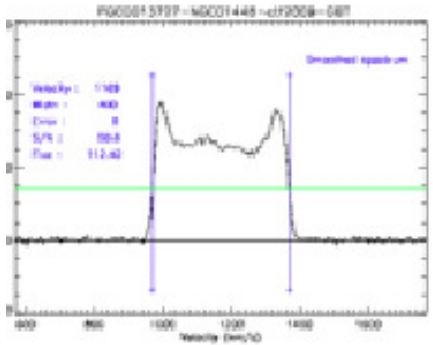


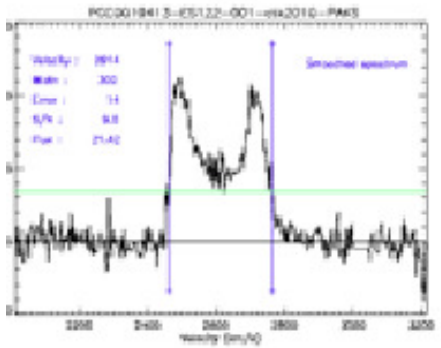


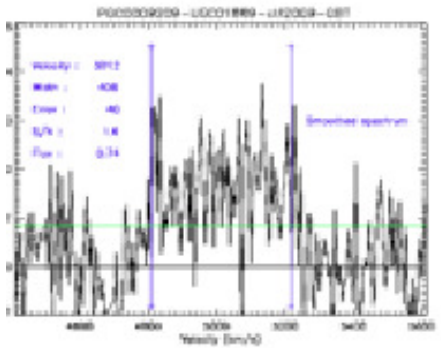




Radioastronomy: HI (21cm)







Green Bank

Parkes

2.a Surface Photometry

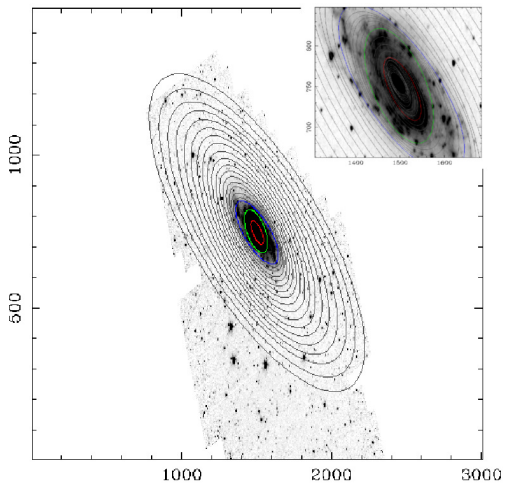


Figure: Isophotes

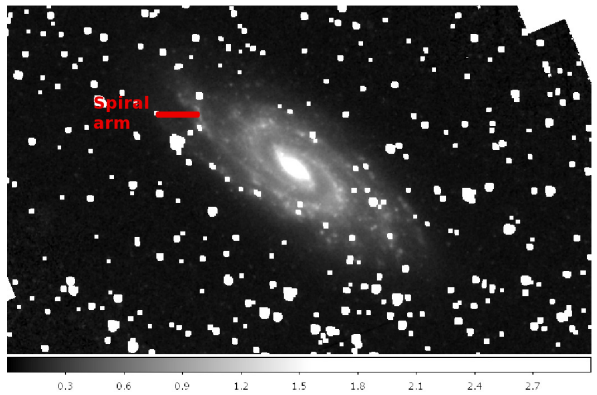


Figure: Masking

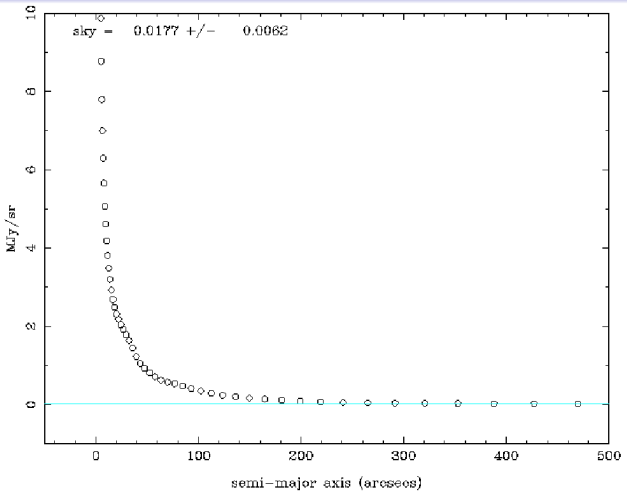


Figure: Sky

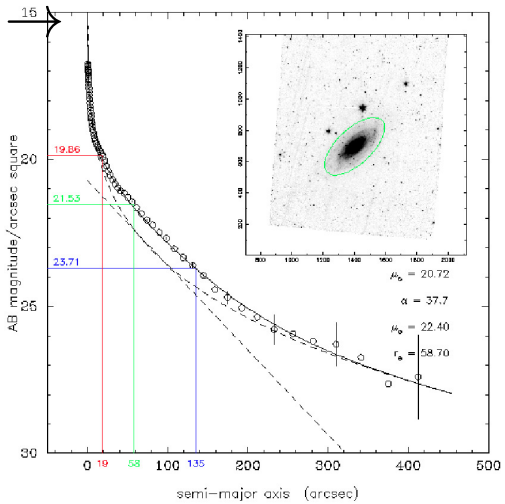


Figure: SB

Growthcurve

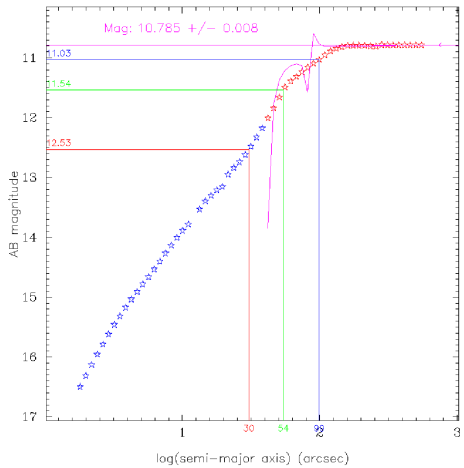


Figure: Asymp. & **Extr. mag**

2.b HI/Inclination

HI profile width at 50 % of the mean flux within the velocity range encompassing 90 % of the total HI flux.

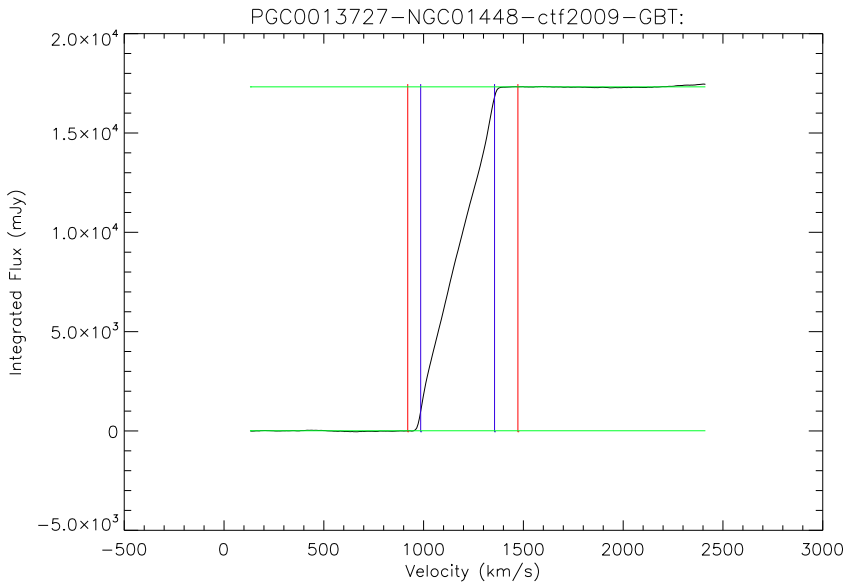


Figure: Courtois et al. 2011

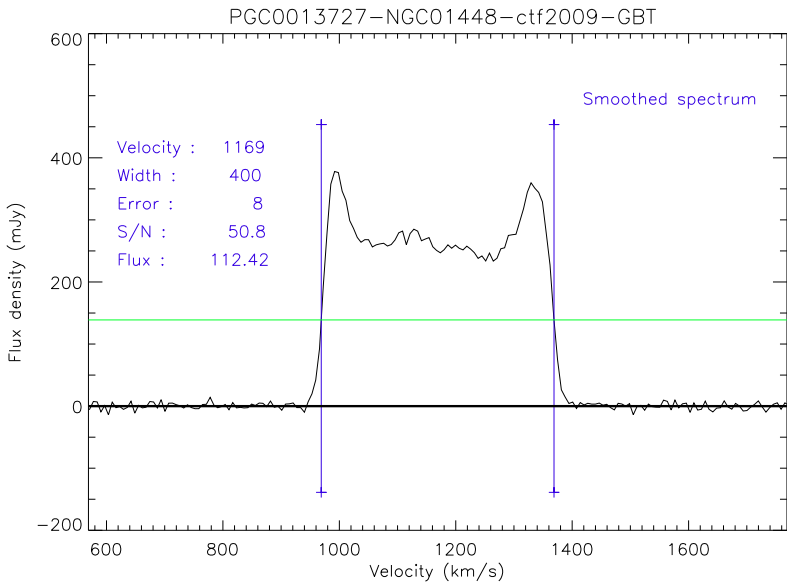


Figure: Courtois et al. 2011.

At **EDD**, *http://edd.ifa.hawaii.edu*, you can find all the material !

2.c Peculiar Velocities

$$v_{CMB} = H_0 \times d + v_{peculiar\ radial} \quad (2) \qquad m - M = 5log_{10}(d(Mpc)) + 25 \quad (3)$$

$$m\ (\text{Photometry}) + v_{HI}\ (\text{HI}) + d\ (\text{Cepheids, TRGB}) \rightarrow \textbf{TF: } L \propto v_{HI}^{\alpha},\ H_0$$

DATA

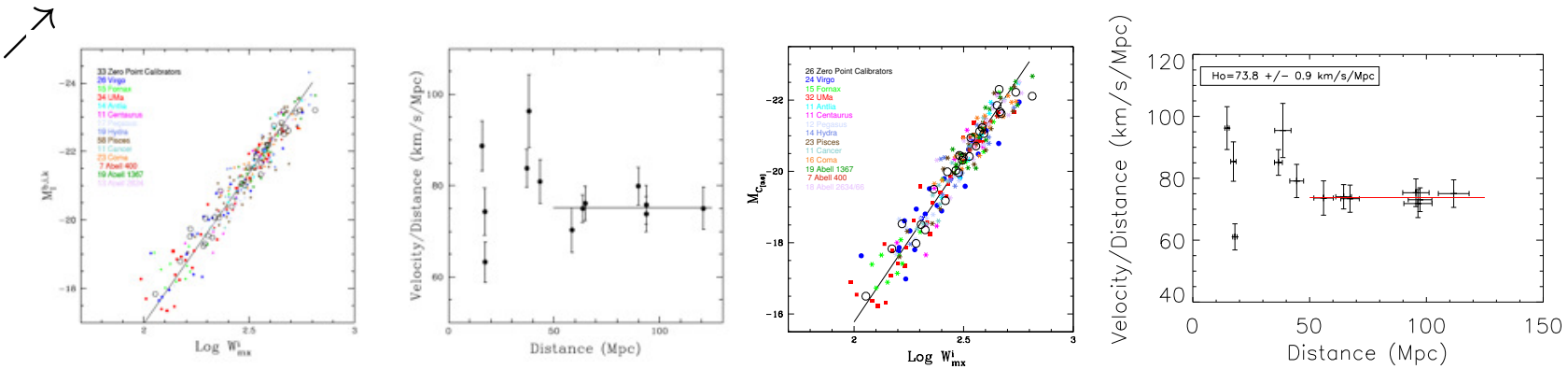


Figure: Tully et al. 2012, Sorce et al. in prep

$$\Downarrow \textbf{Luminosity} \ \&\ H_0 \Downarrow$$

$$m\ (\text{Photometry}) + v_{HI}\ (\text{HI}) + M\ (\textbf{Tully-Fisher}) \rightarrow d \rightarrow v_{pec}$$

Other methods: Not as far (Cepheids, TRGB, SBF), too sparse (SNIA), not in the field (Fundamental plane)

3.a Reconstruction: Wiener-Filter

WF = *Linear Minimal Variance Estimator* *using noisy, sparse and incomplete data with the covariance matrix given by an assumed prior model.*

(CR (ΛCDM) ; IC) + WF = Constrained Simulations reproducing LSS

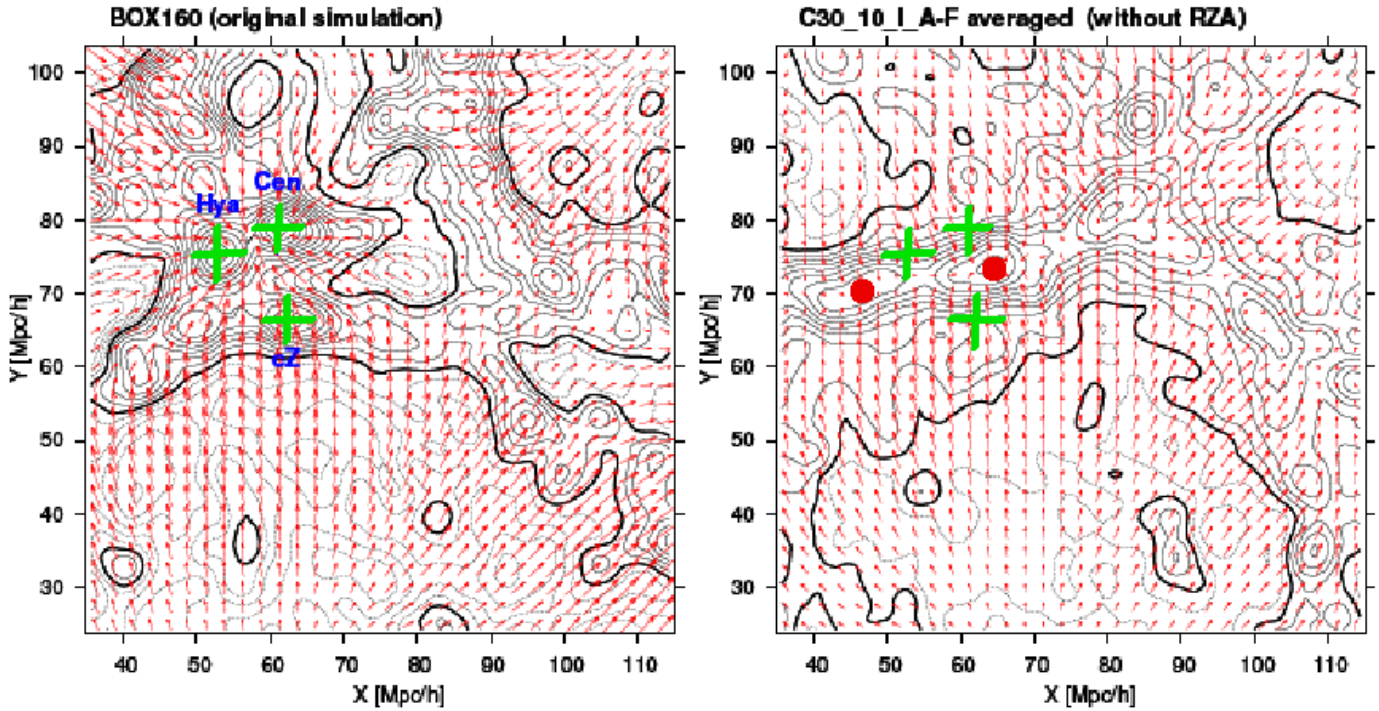


Figure: Adapted from Timur's Thesis

1. Structures are *not* at the proper **positions**.
2. The **quality** *decreases* quickly with the **scale**.

3.b Reconstruction: Reverse Zeldovich Approximation

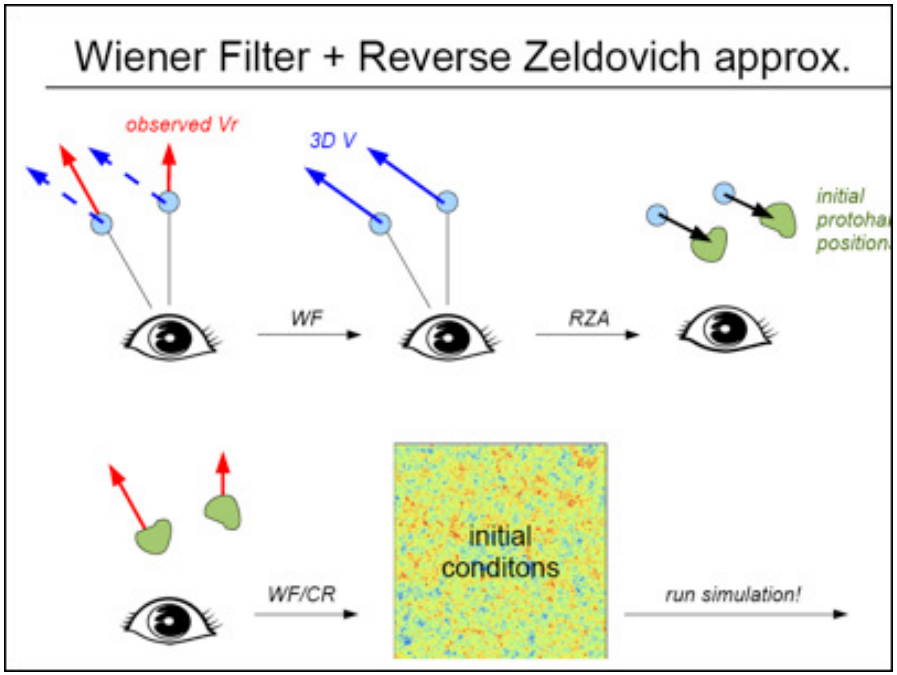


Figure: Timur's Thesis

$$\underline{\text{Zeldovich Approx.:}}$$

$$\vec{x}(t) = \vec{q} + D(t)\vec{\Psi}(\vec{q})$$

$$\vec{v}(t) = \dot{D}(t)\vec{\Psi}(\vec{q})$$

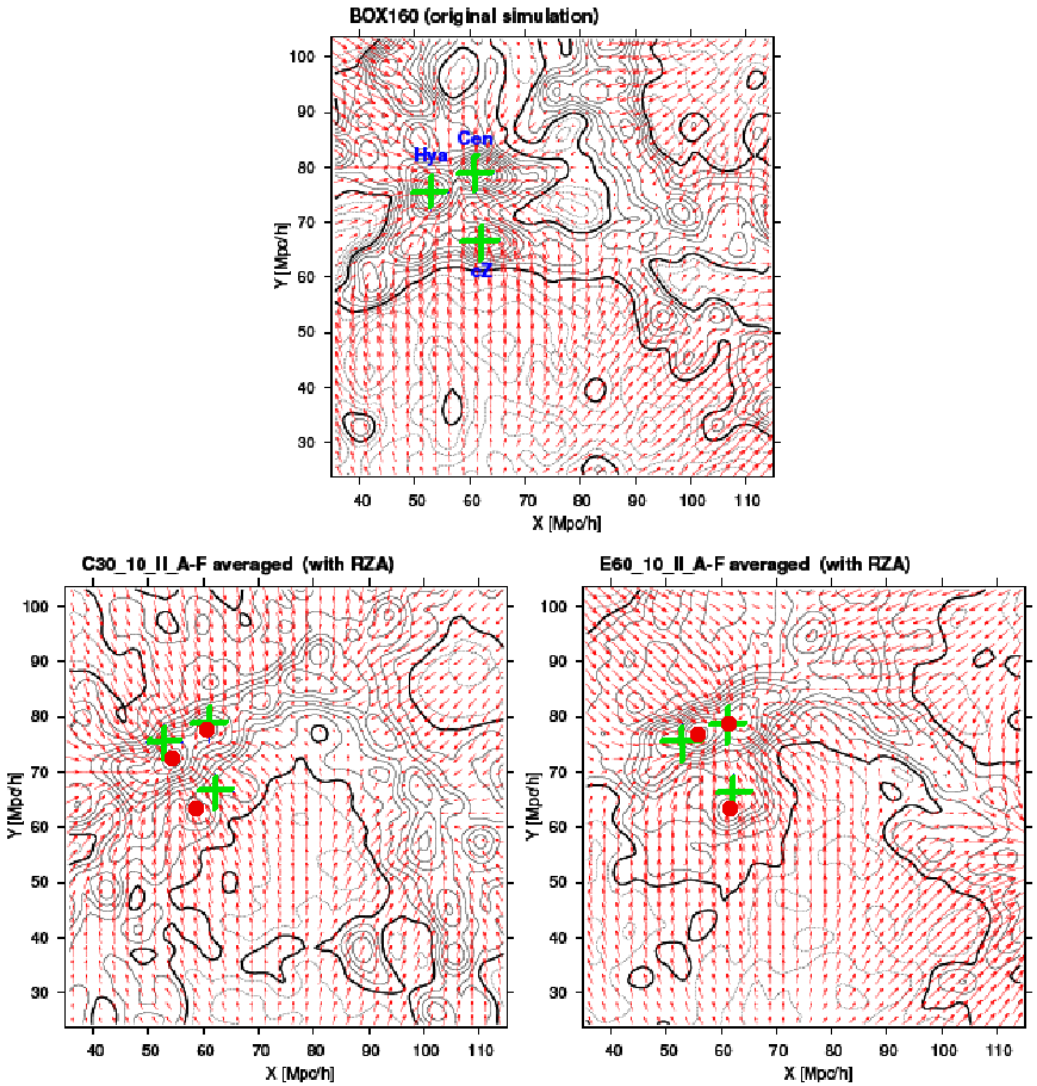


Figure: Adapted from Timur's Thesis

3.c Reconstruction: Summary

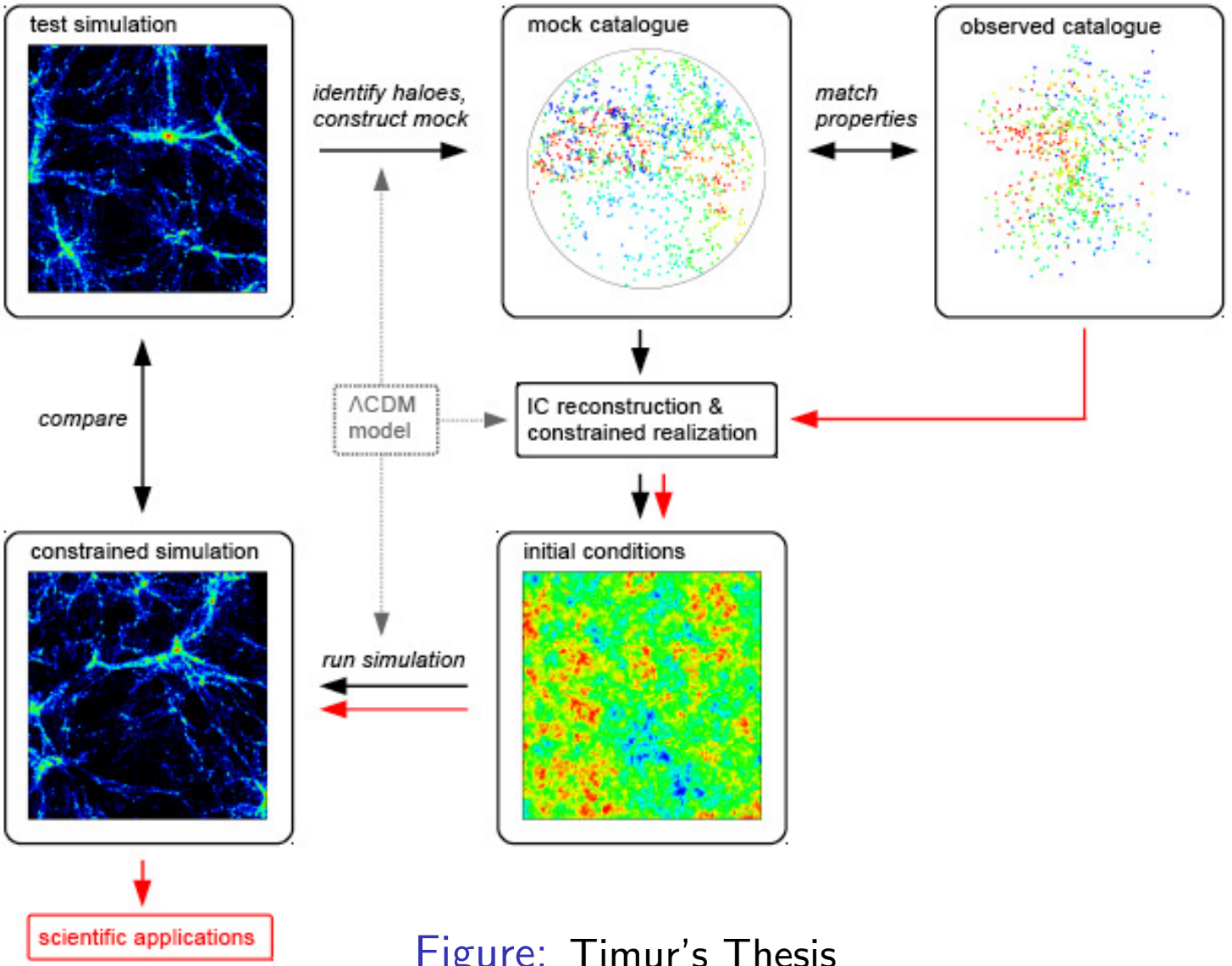


Figure: Timur's Thesis

4.a Cosmic-Flows 1: Inanimate

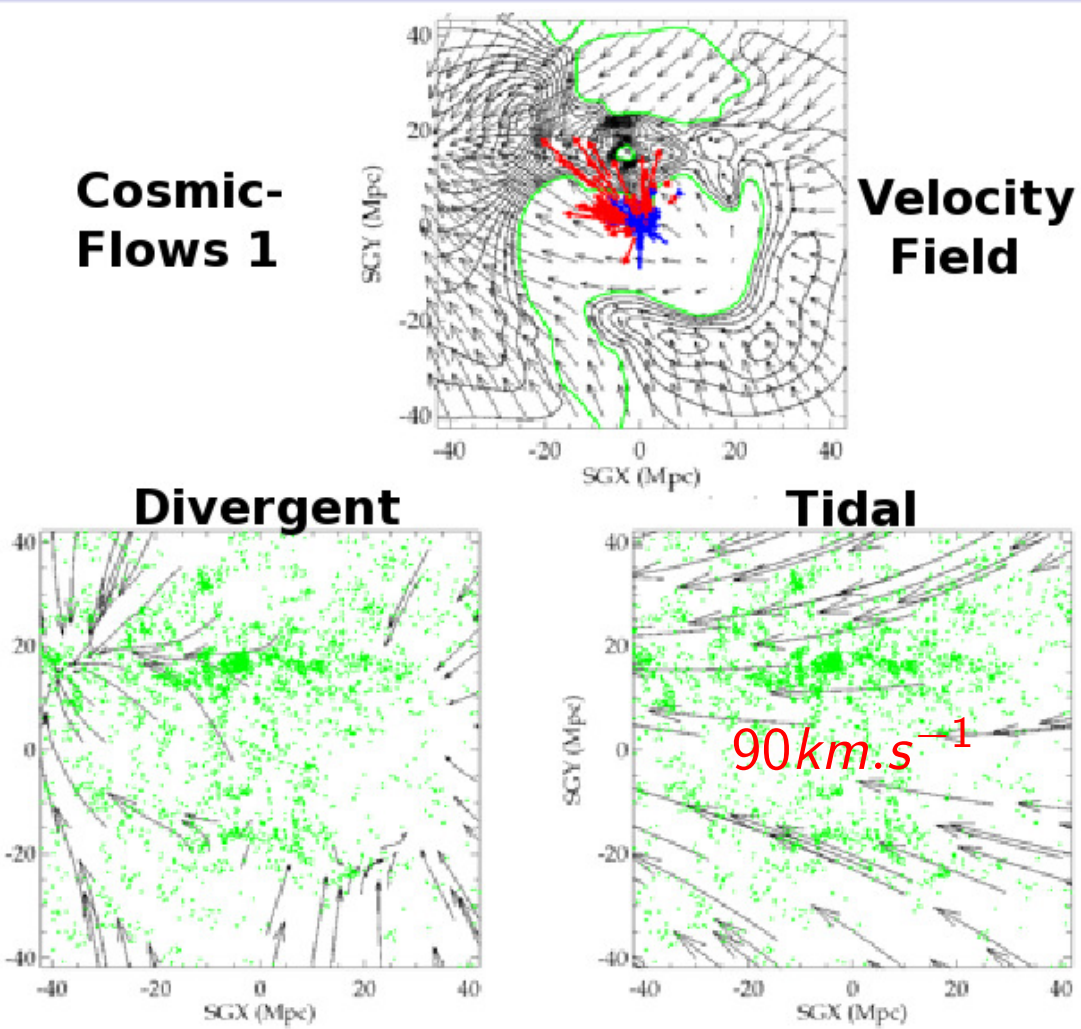


Figure: Adapted from Courtois et al. 2012

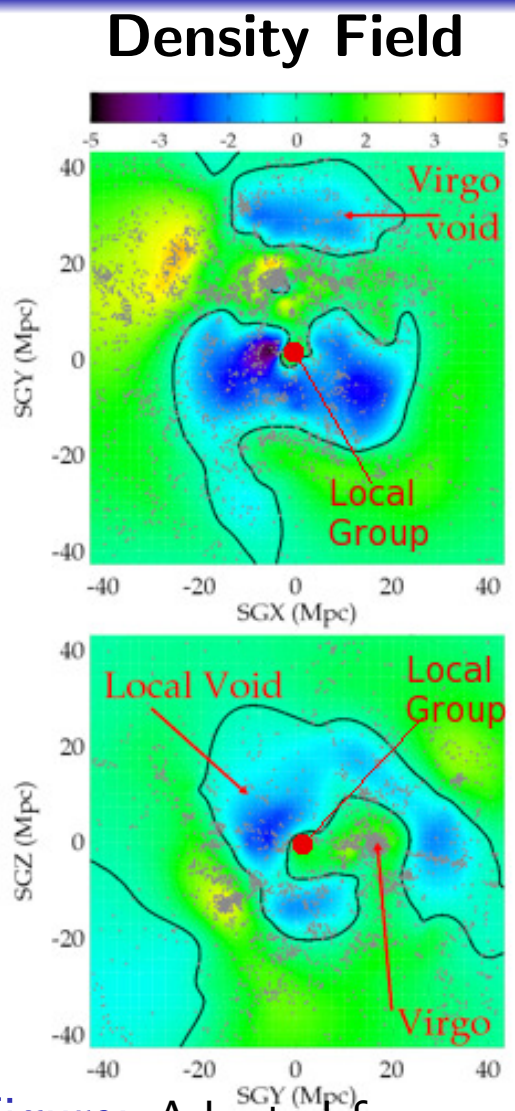


Figure: Adapted from Courtois et al. 2012

4.a Cosmic-Flows 1: Animate

1. Towards the Great Attractor (Plane: (SGX,SGY))

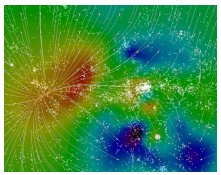


Figure: Courtesy of D. Pomarède

2. Away from the Local Void (Plane: (SGY, SGZ))

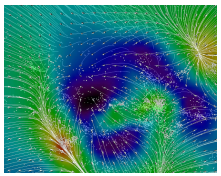


Figure: Courtesy of D. Pomarède

3. Voyage to the Great Attractor (4 dimensions)

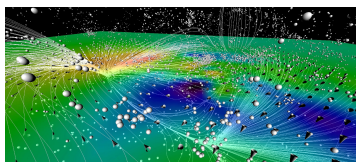
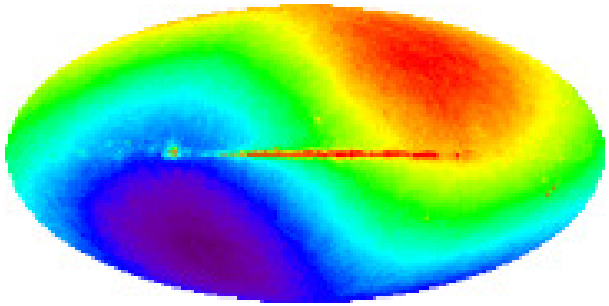


Figure: Courtesy of D. Pomarède

Conclusion

Observations → Reductions → **Constrained Simulations (RZA)** → Analysis

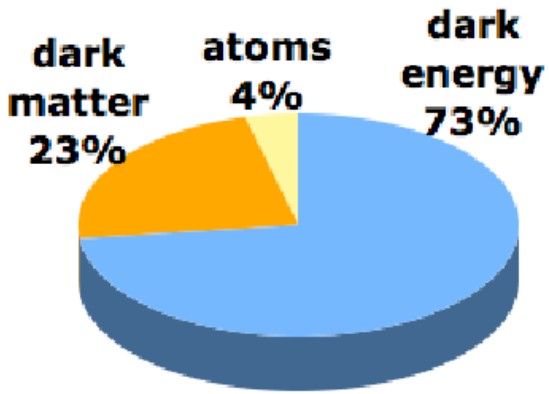
CMB



↪ **Great Attractor** *in CF2 data: nature and position?*

↪ $90 km.s^{-1}$ = **Shapley?** *Farther? (Kashlinsky et al.)*
(not in CF2 data → in CF2 Simulations)

Universe Content



↪ *Dark Matter & Energy*

Aknowledgments

Thank you

References

1. R.B. Tully & J.R. Fisher, *A&A*, 54:661-673, 1977.
2. R.B. Tully et al., *ApJ*, 184:676, 2008.
3. S. Gottlöber et al., *CLUES*, 309, 2010.
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