A Hint of Poincaré Dodecahedral Topology in the WMAP First Year Sky Map

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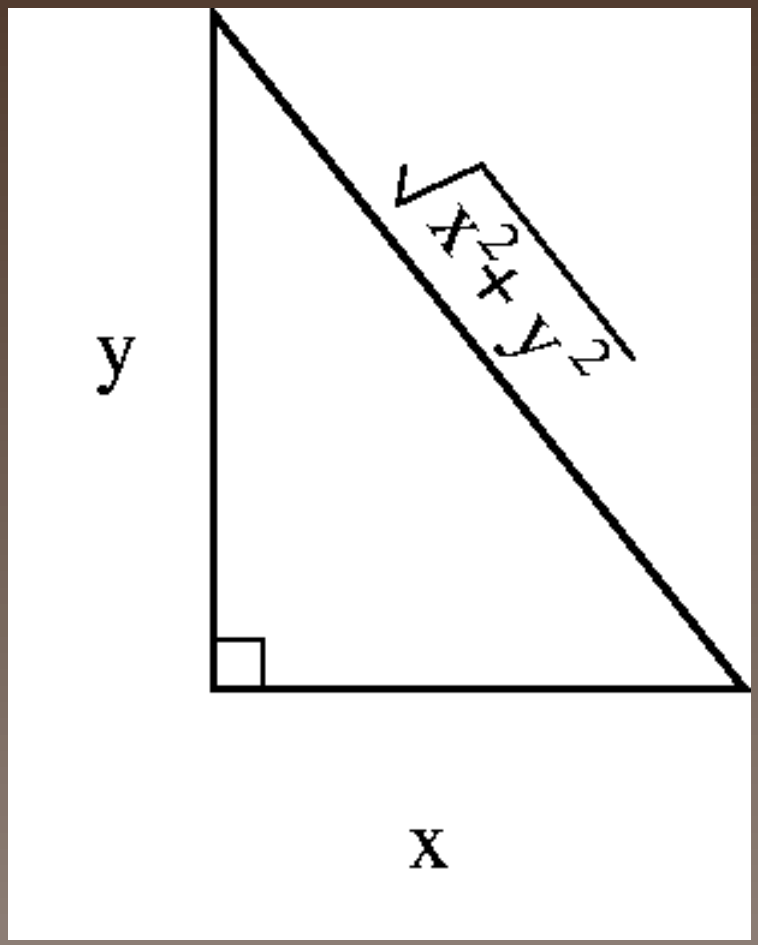
Geometry: Curvature + Topology



0 + - multi-c

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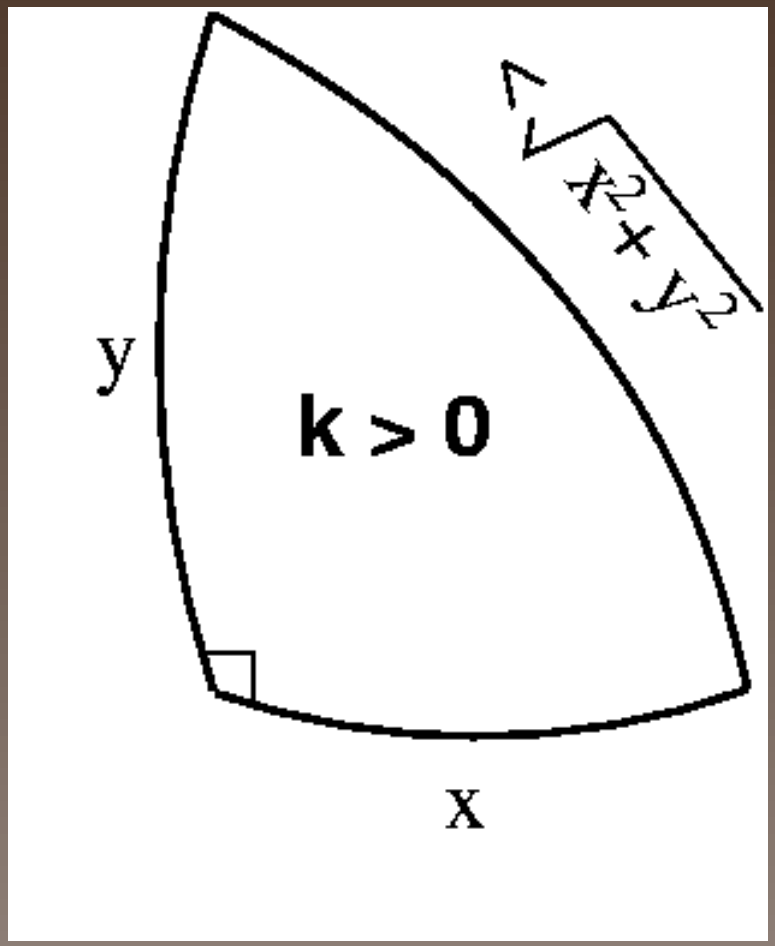

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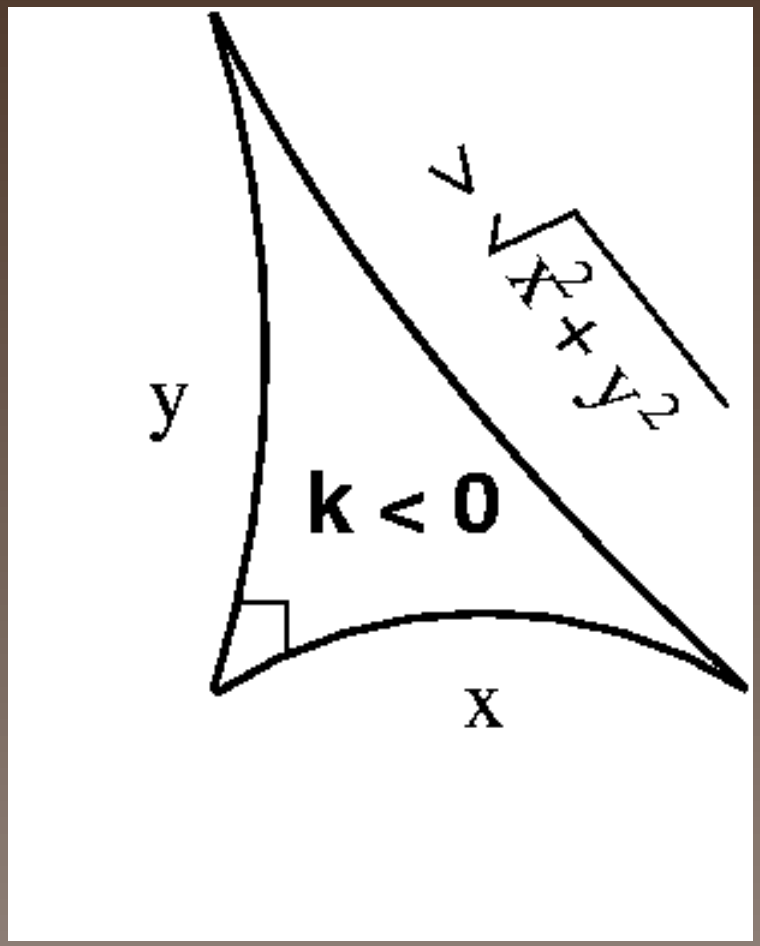

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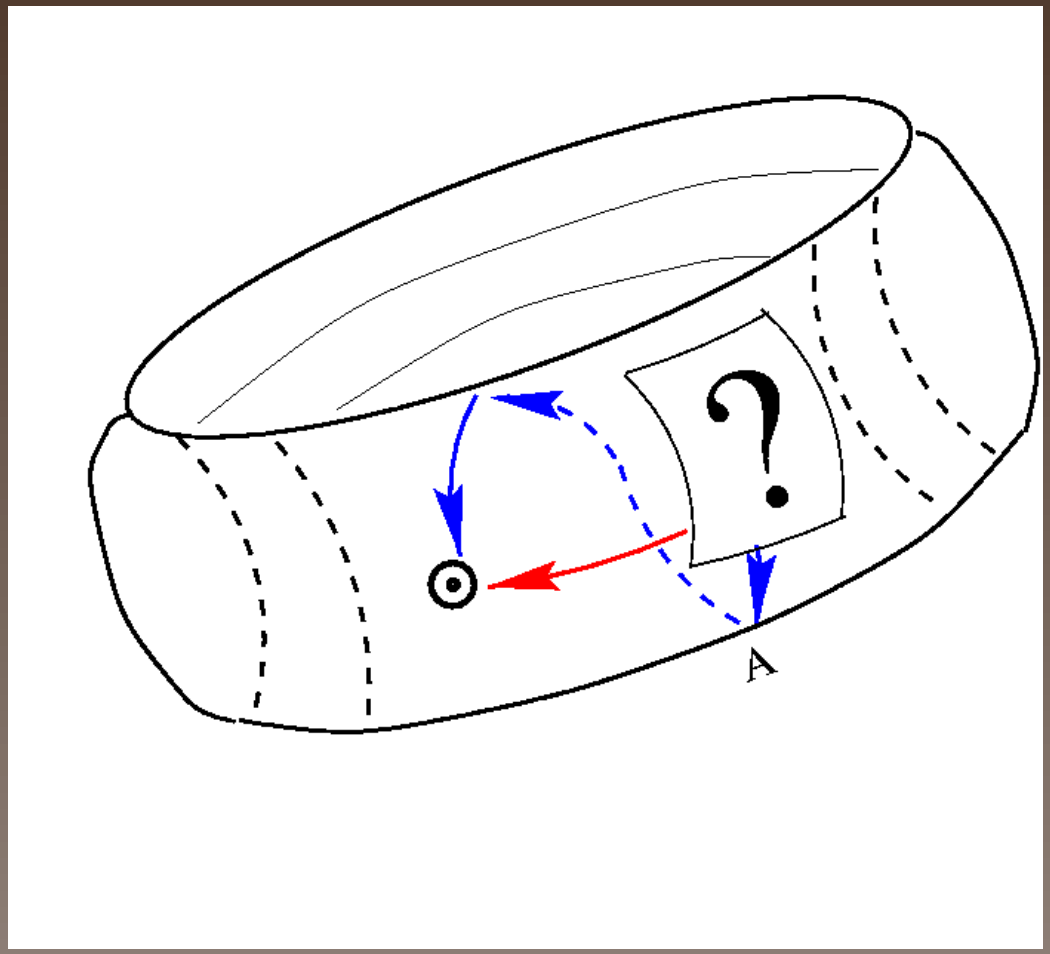

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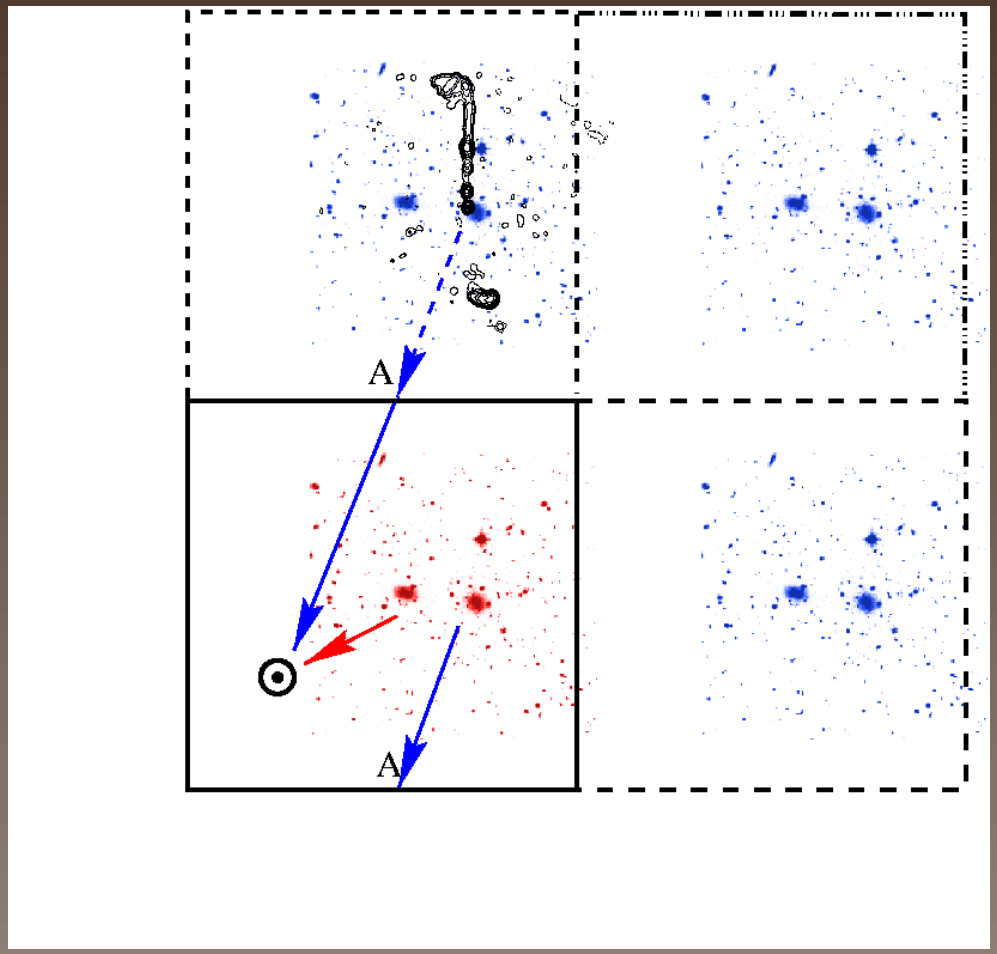
Geometry: Curvature + Topology



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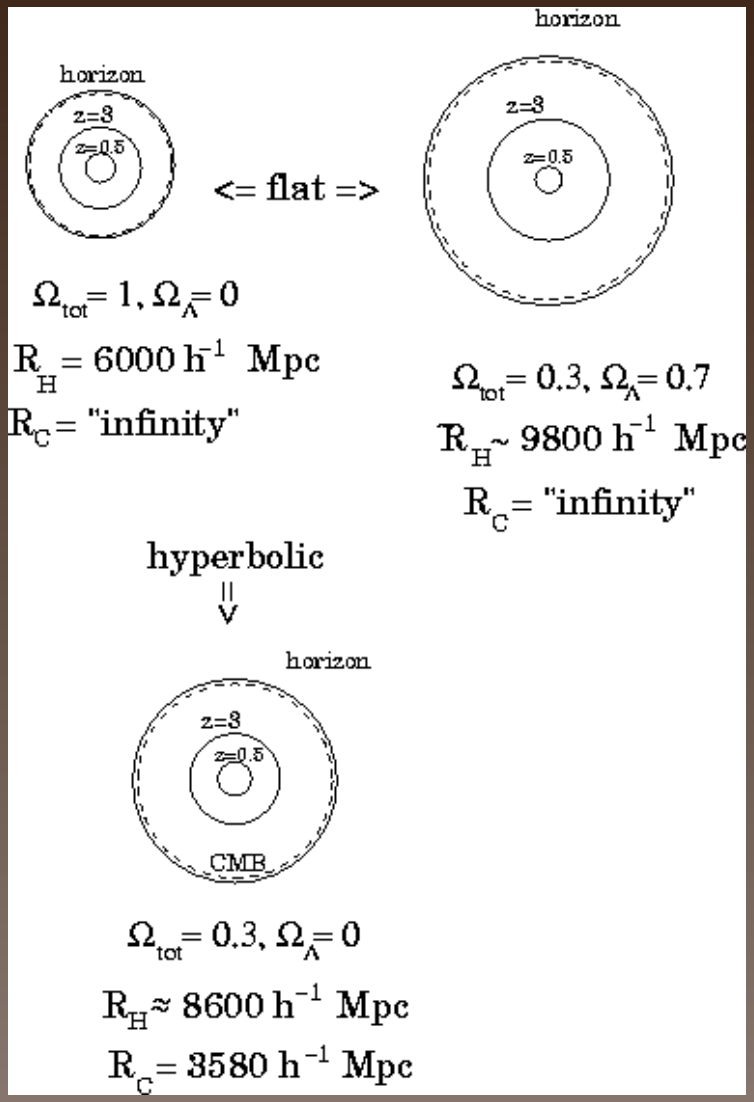
Geometry: Curvature + Topology


horizon
z=3
z=0.5
<= flat =>
horizon
z=3
z=0.5
$\Omega_{tot}= 1, \Omega_\Lambda= 0$
$R_H = 6000\ h^{-1}$ Mpc
R_C = "infinity"
$\Omega_{tot}= 0.3, \Omega_\Lambda= 0.7$
$R_H \sim 9800\ h^{-1}$ Mpc
R_C = "infinity"
hyperbolic
||
V
horizon
z=3
z=0.5
CMB
$\Omega_{tot}= 0.3, \Omega_\Lambda= 0$
$R_H \approx 8600\ h^{-1}$ Mpc
$R_C = 3580\ h^{-1}$ Mpc

0 + - multi-c

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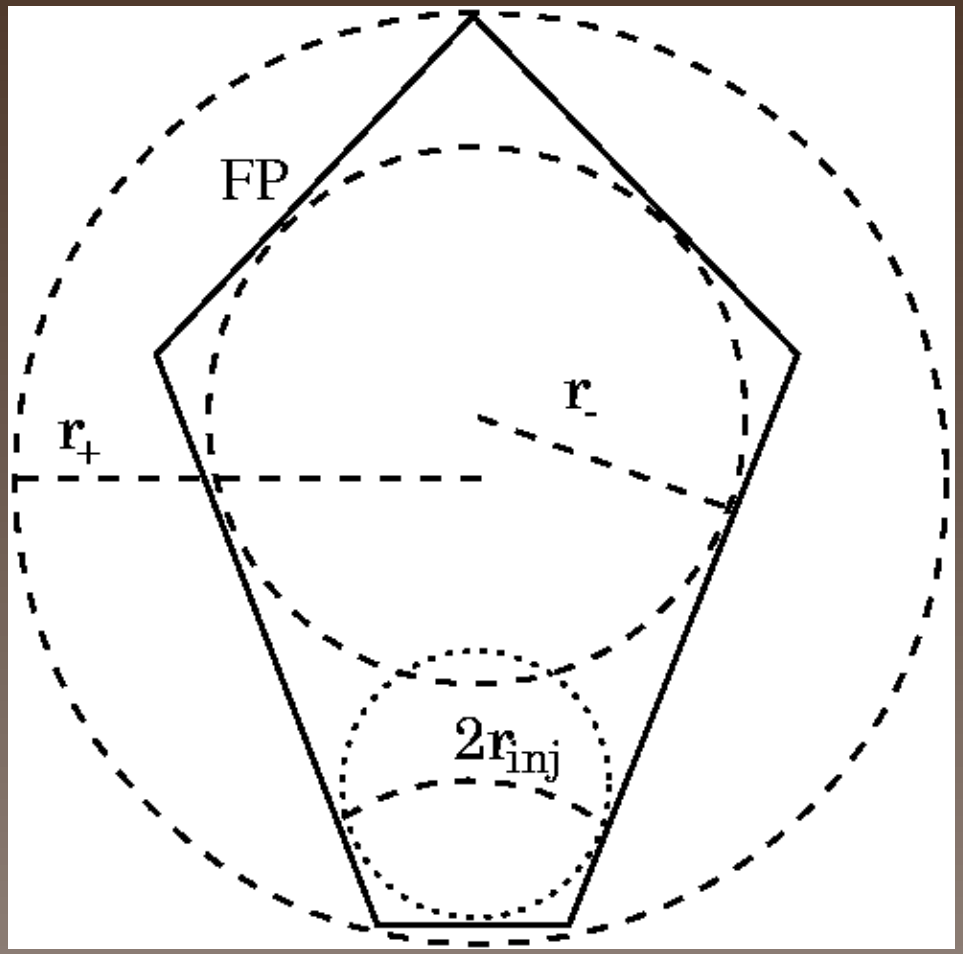
Geometry: Curvature + Topology



r_- : biggest sphere *inside* FD

r_+ : smallest sphere *containing* FD

$2r_{\mathrm{inj}}$: smallest closed spatial geodesic

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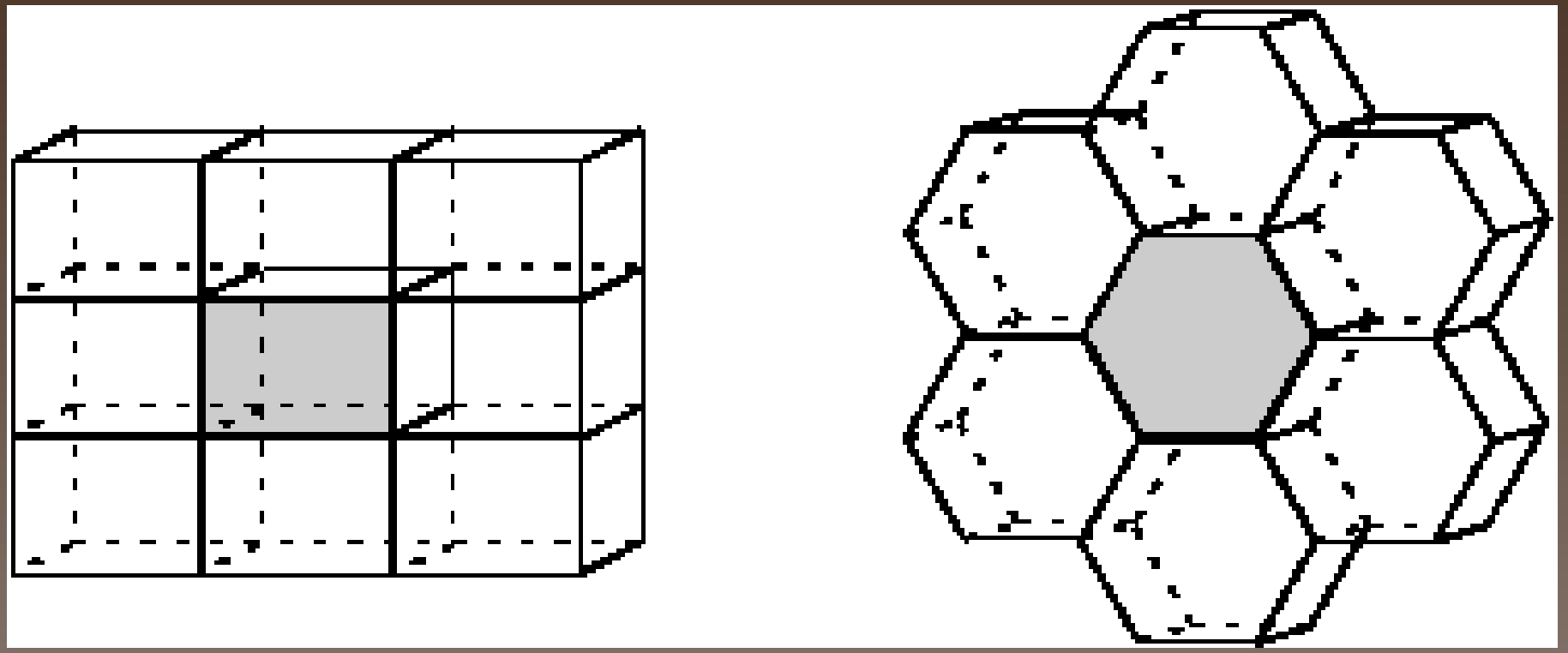
Geometry: Curvature + Topology



0

\+ - multi-c (Luminet & Roukema 1999: http://arXiv.org/abs/astro-ph/9901364)

Strategies - 3D

http://arXiv.org/abs/astro-ph/0010189

A. multiple topological images:
  A.i 3D (grav collapsed objects):
    A.i.1 local isometries - many "type I pairs" or "local pairs"
    A.i.2 cosmic crystallography - many "type II pairs" or "generator pairs",
    A.i.3 characteristics of individual objects

Strategies - 2D and non-multiple-imaging

A.ii 2D (microwave background, CMB):
- A.ii.1 identified circles principle:
- A.ii.2 patterns of spots
- A.ii.3 perturbation statistics assumptions

B. other:
- B.i cosmic strings
- B.ii nested crystallography

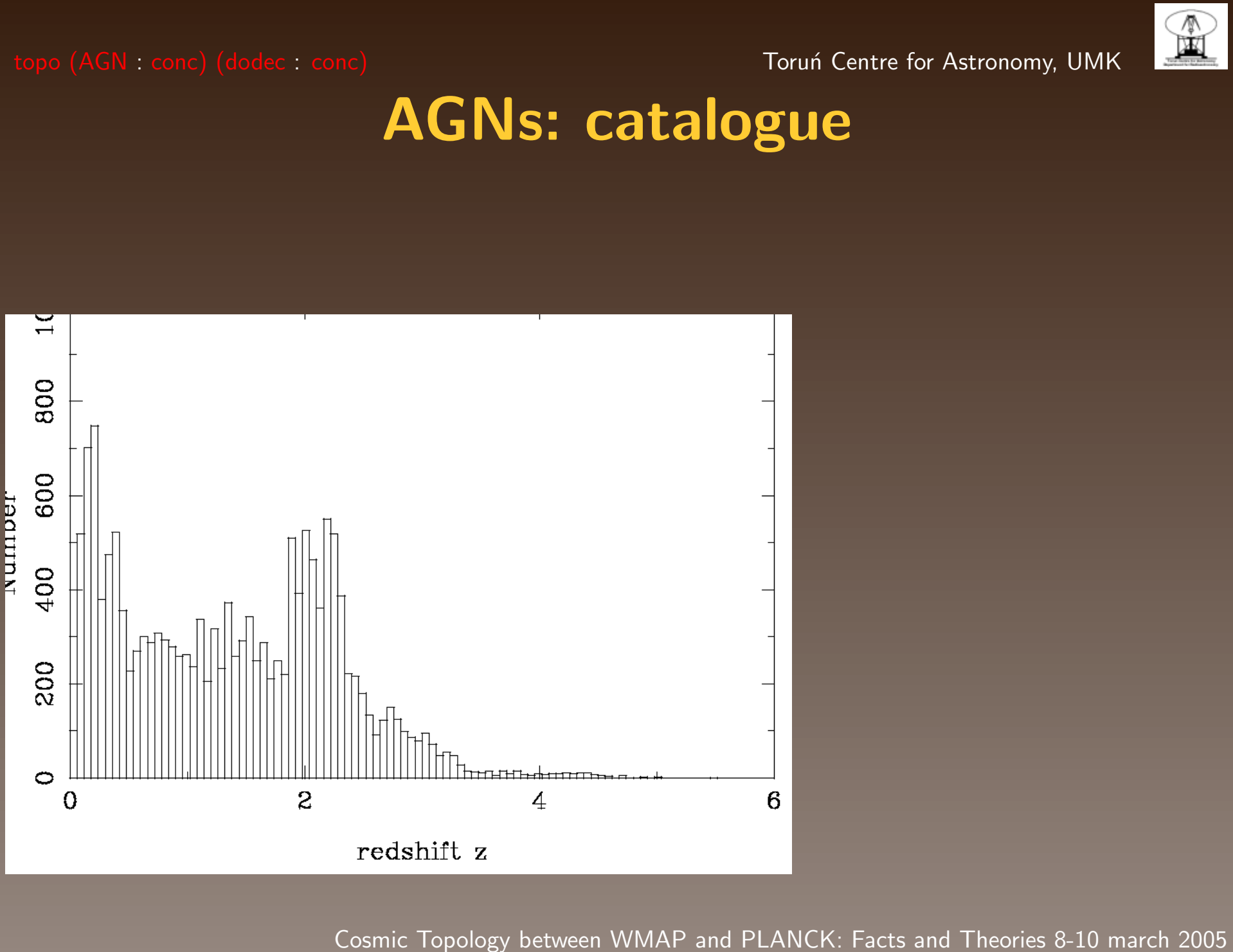
AGN Catalogues

Marecki, Roukema, Bajtlik

How can the S/N be increased? Remove N without removing S?

- 1 - AGNs $\Rightarrow$ redshift filter: $\Delta z/z = 0.005$
- consider flat case
- 2 - maximum angle $\Delta\theta = 0.075$ rad, minimum $n_{\mathrm{pairs}} = 3$
- 3 - minimum sep. length $L_{\mathrm{selec}} = 150$ h^{-1} Mpc in BoP

(bunch of pairs)



AGNs: catalogue

- 15762 AGN with $z > 0.1$ (compilation dated 18.10.2001) ftp://ftp.quasars.org

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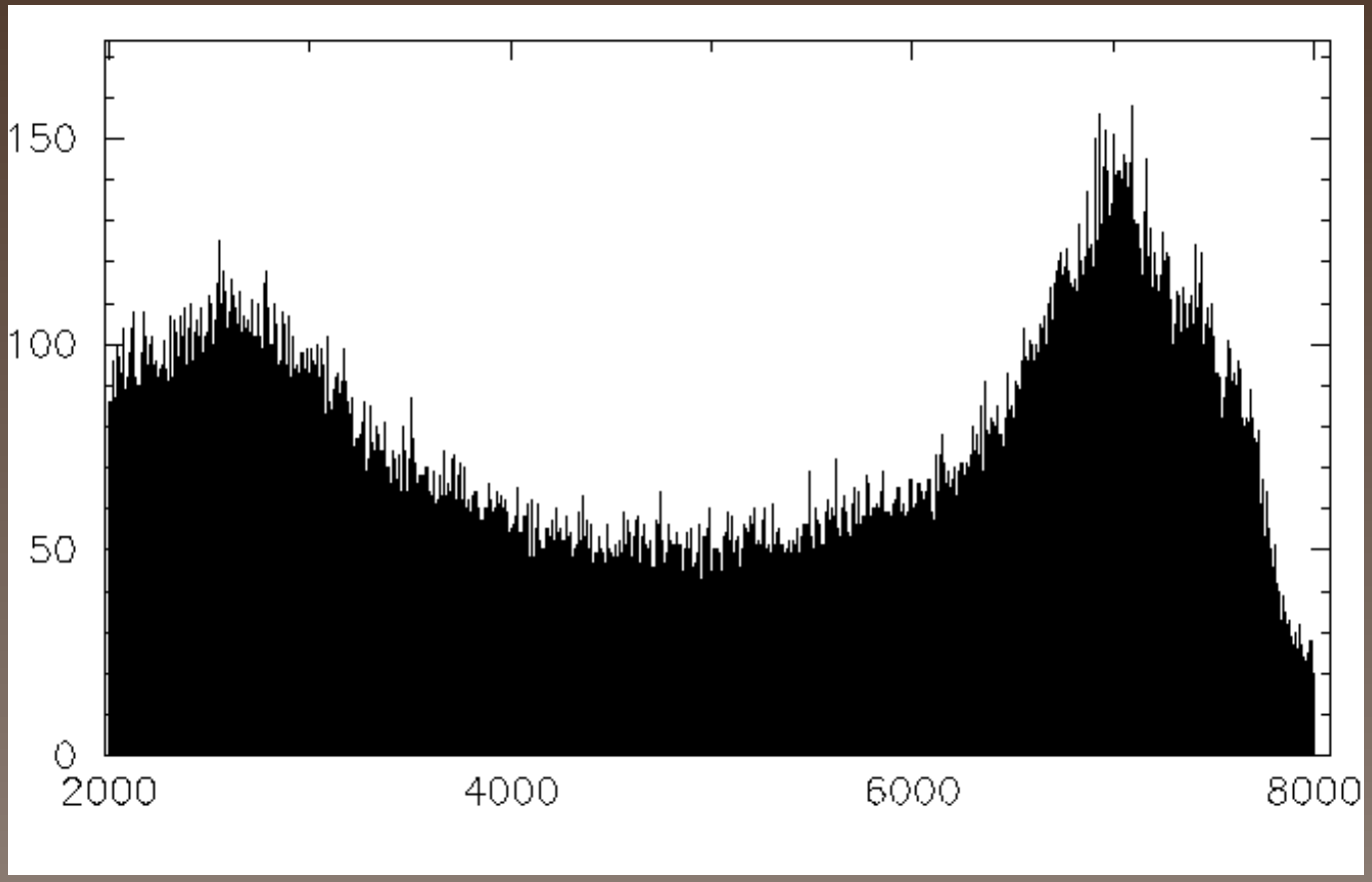
AGNs: redshift filter



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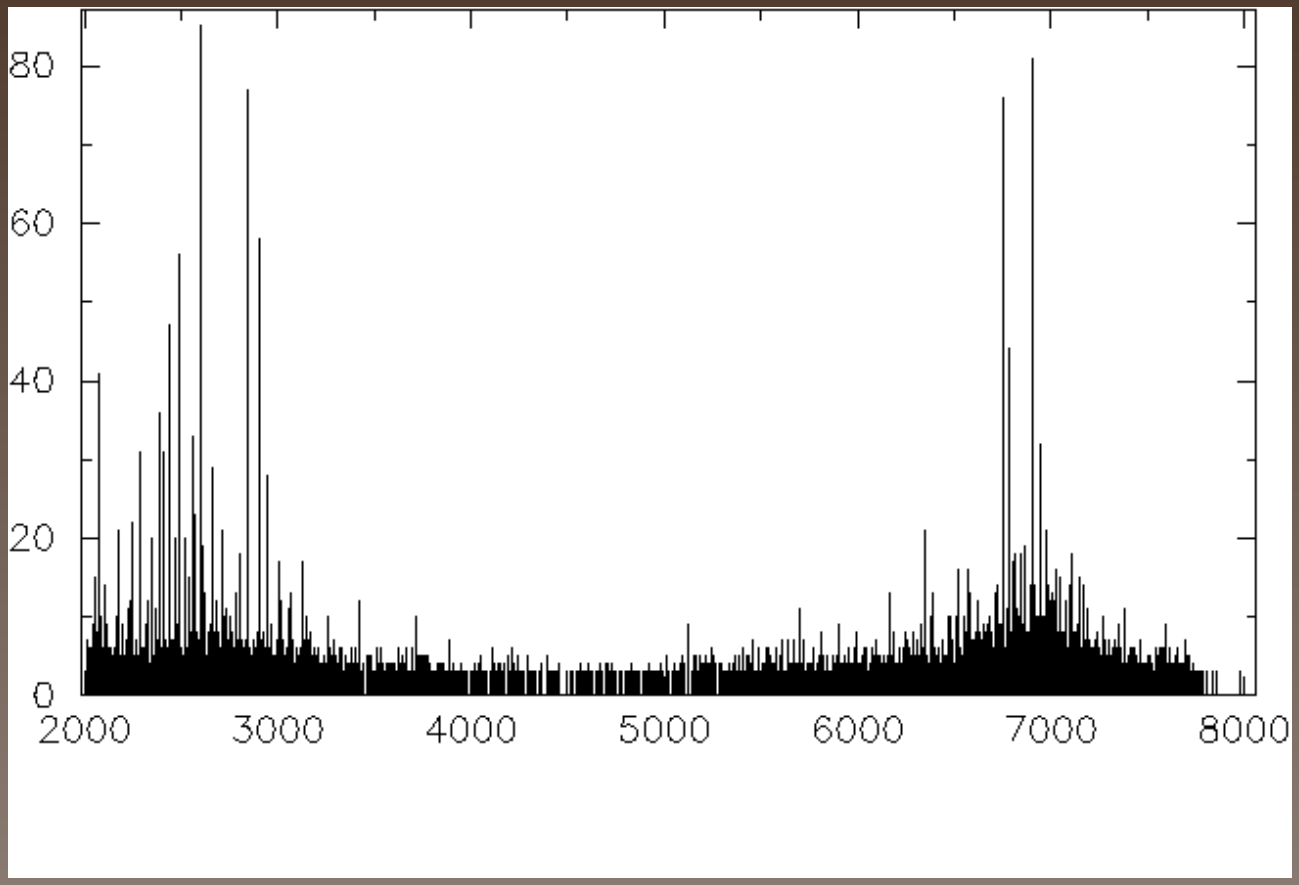
AGNs: BoP filter



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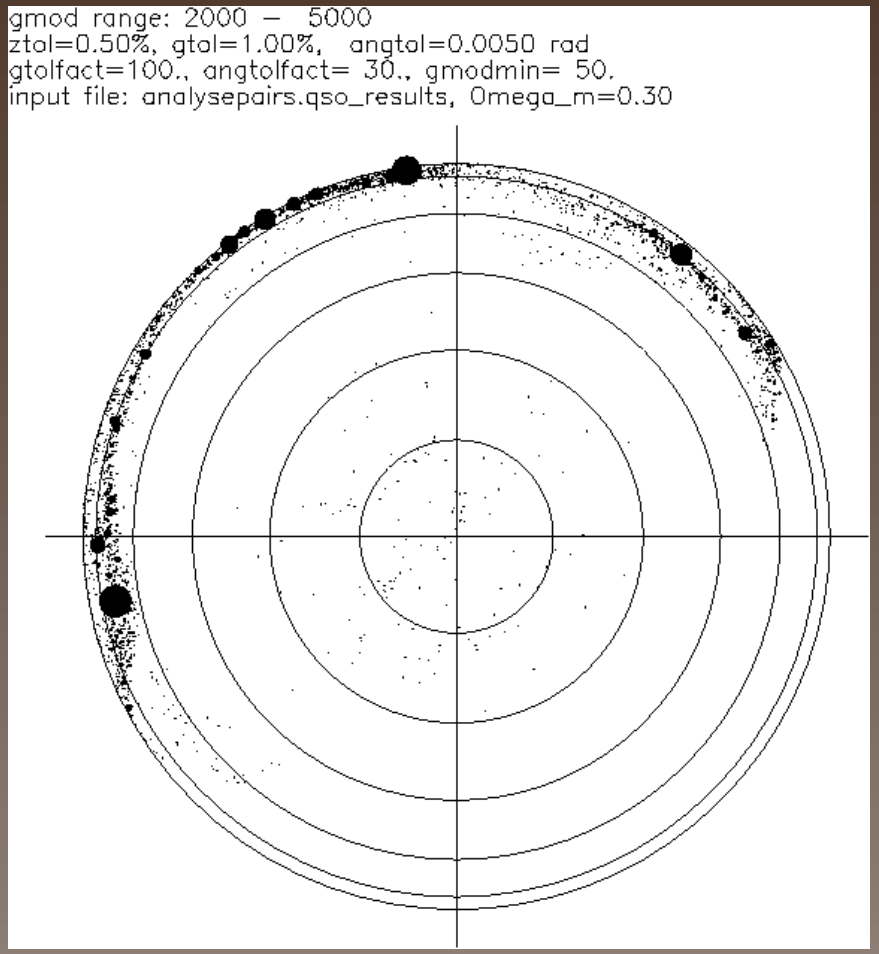
AGNs: where the BoPs point to



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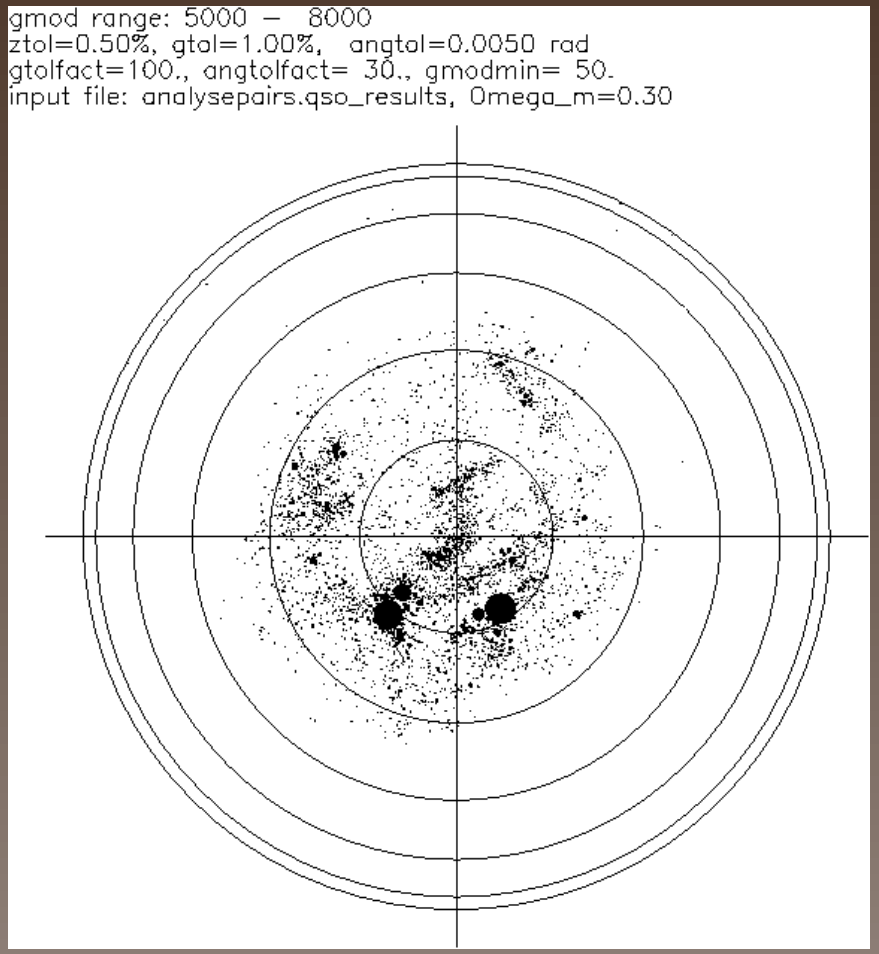
AGNs: where the BoPs point to



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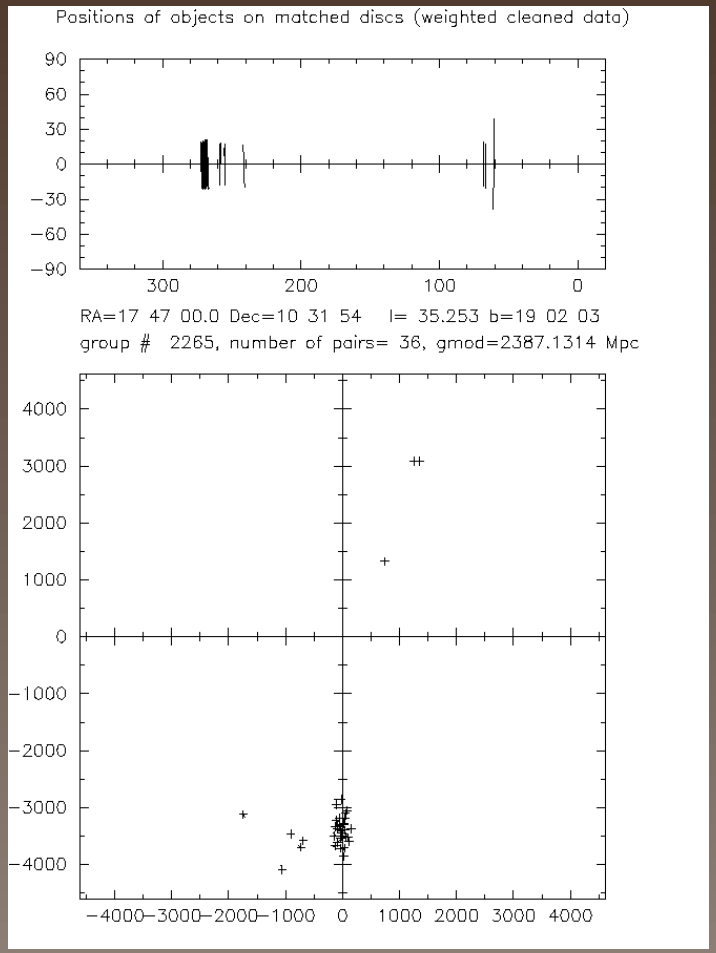
AGNs: highest peaks



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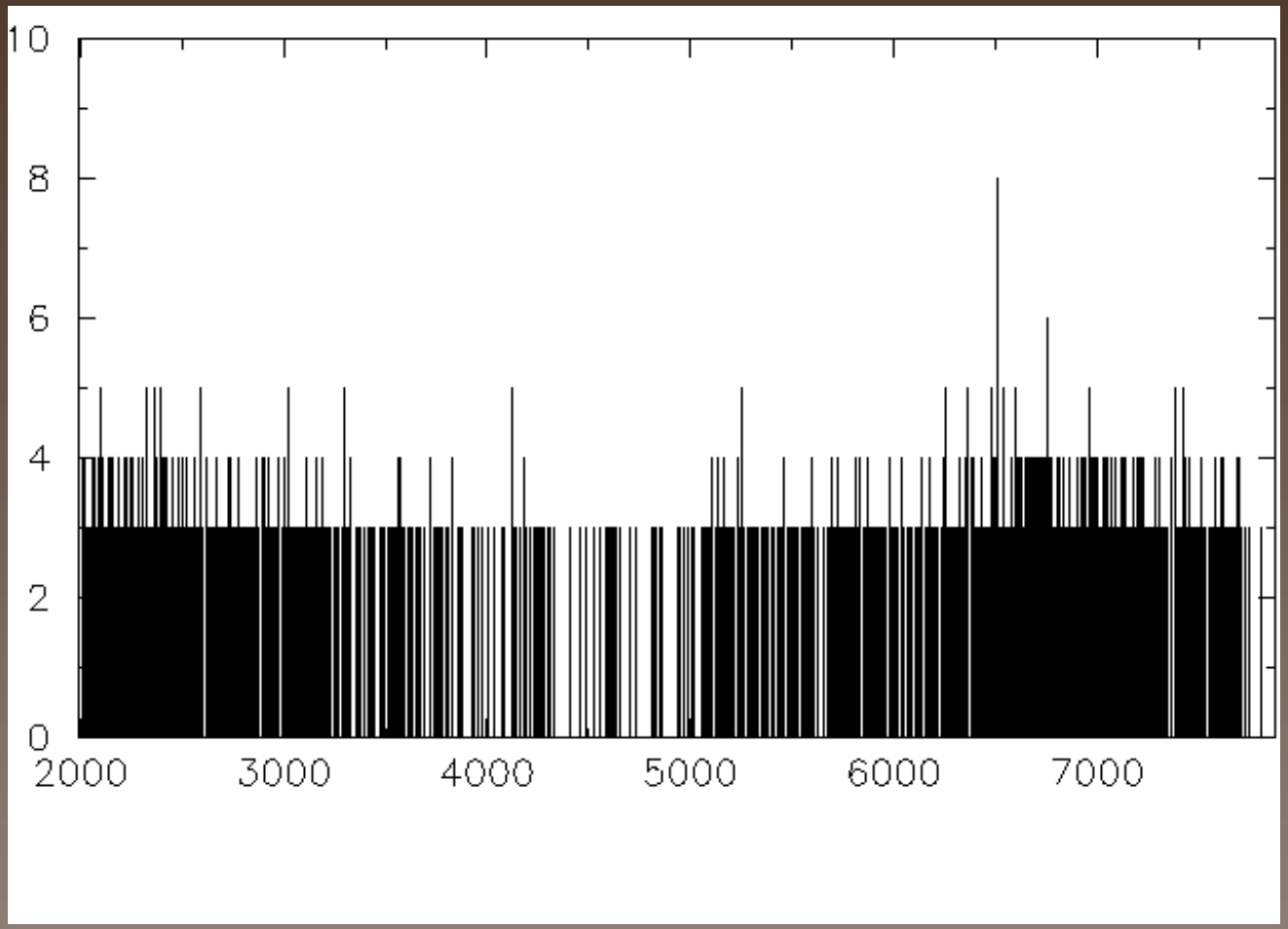
AGNs: L_{selec} criterion



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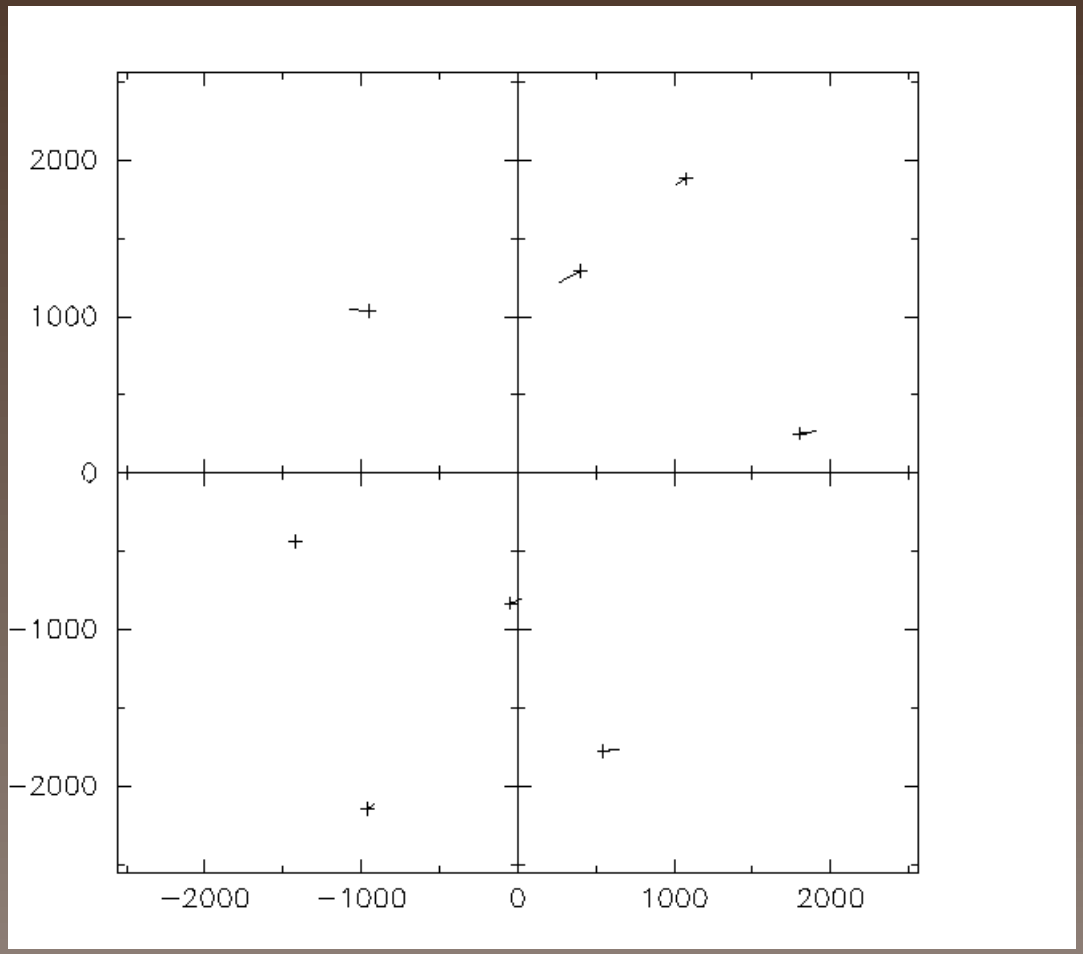
AGNs: BoPs after L_{selec} criterion



0 + - multi-c

AGN: Conclusion

- AGN short lifetimes implies redshift filter to improve S/N
- application to large AGN catalogue compilation reveals apparent signals
- closer analysis $\Rightarrow$ these are selection effects
- no signal found in compilation of radio-loud AGNs (RLAGNs)

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Marecki, Roukema, Bajtlik, astro-ph/0412181, A&A in press

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The Identified Circles Principle

Discovery of principle: Cornish, Spergel & Starkman (1996)

http://arXiv.org/abs/gr-qc/9602039

CQG, 15, 2657 (1998)

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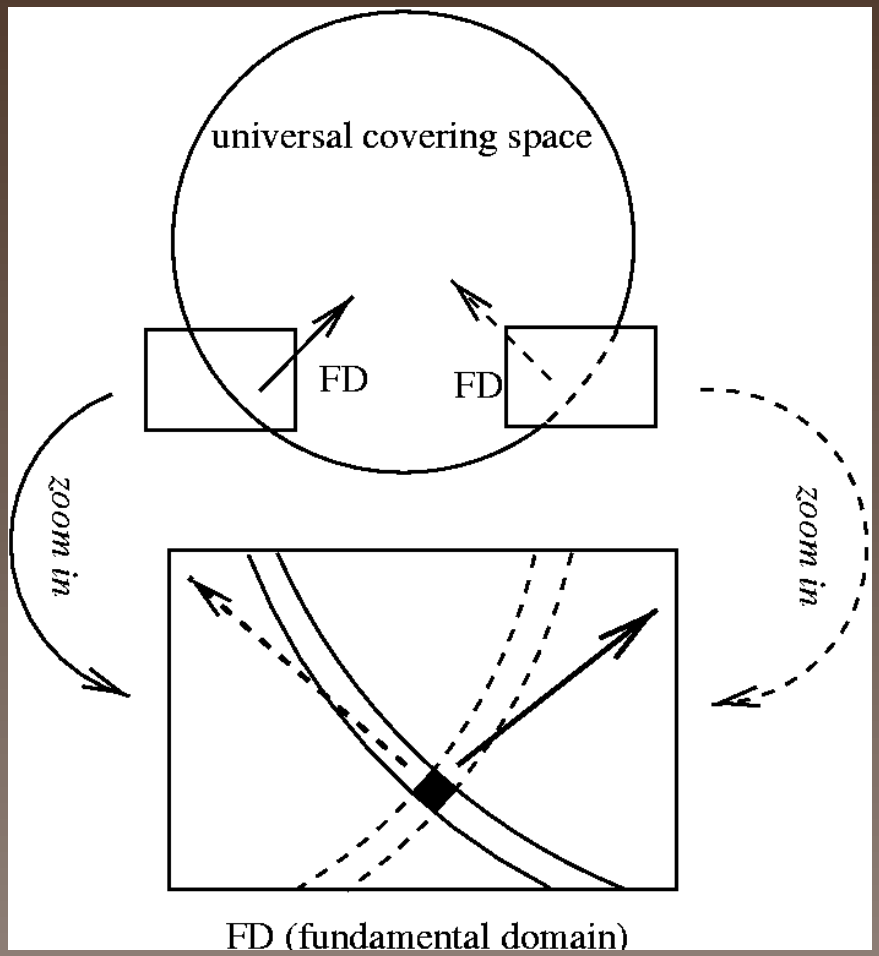
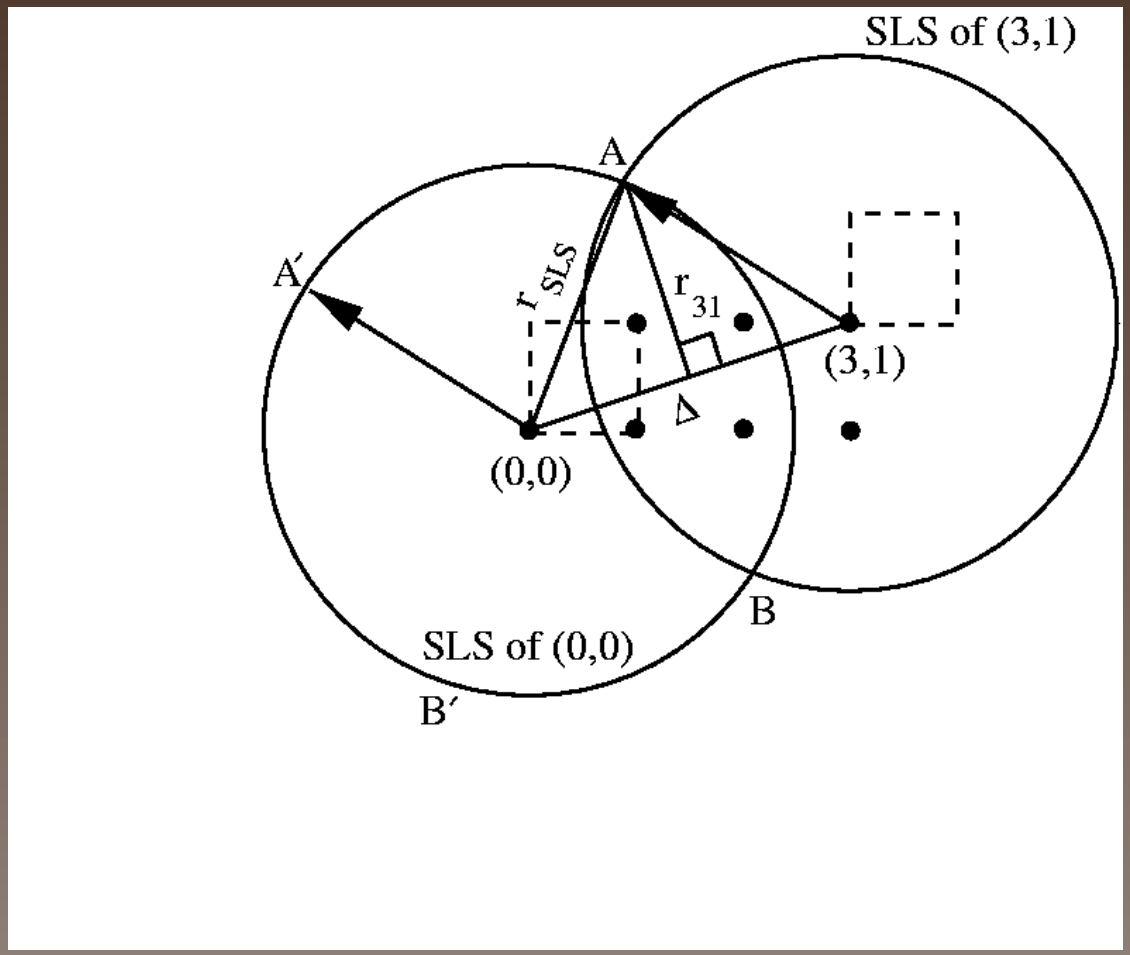
The Identified Circles Principle



The Identified Circles Principle



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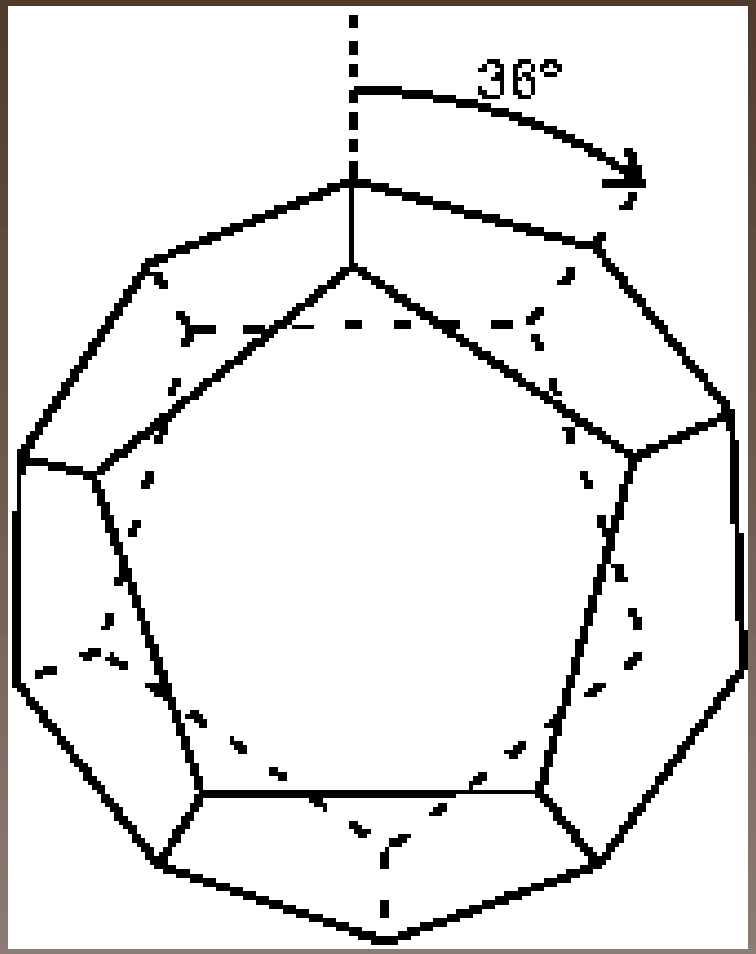
The Poincaré Dodecahedral 3-Manifold



- FD = positively curved dodecahedron
- covering space is S^3 (hypersphere)
- 120 copies of FD tile S^3
- Luminet et al. (2003) find this favoured by WMAP statistics

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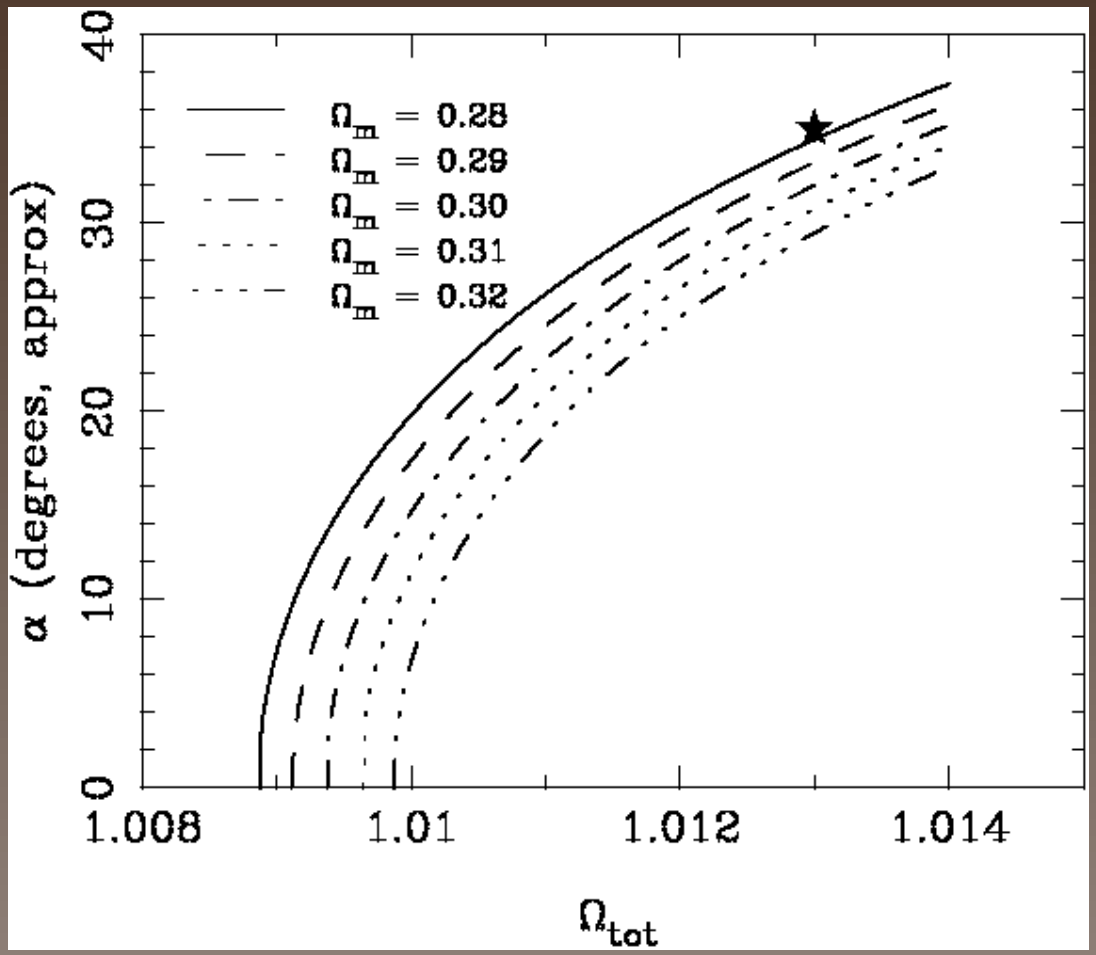
circle size vs Ω_{tot}



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SDSS galaxies — standard ruler in corrn function

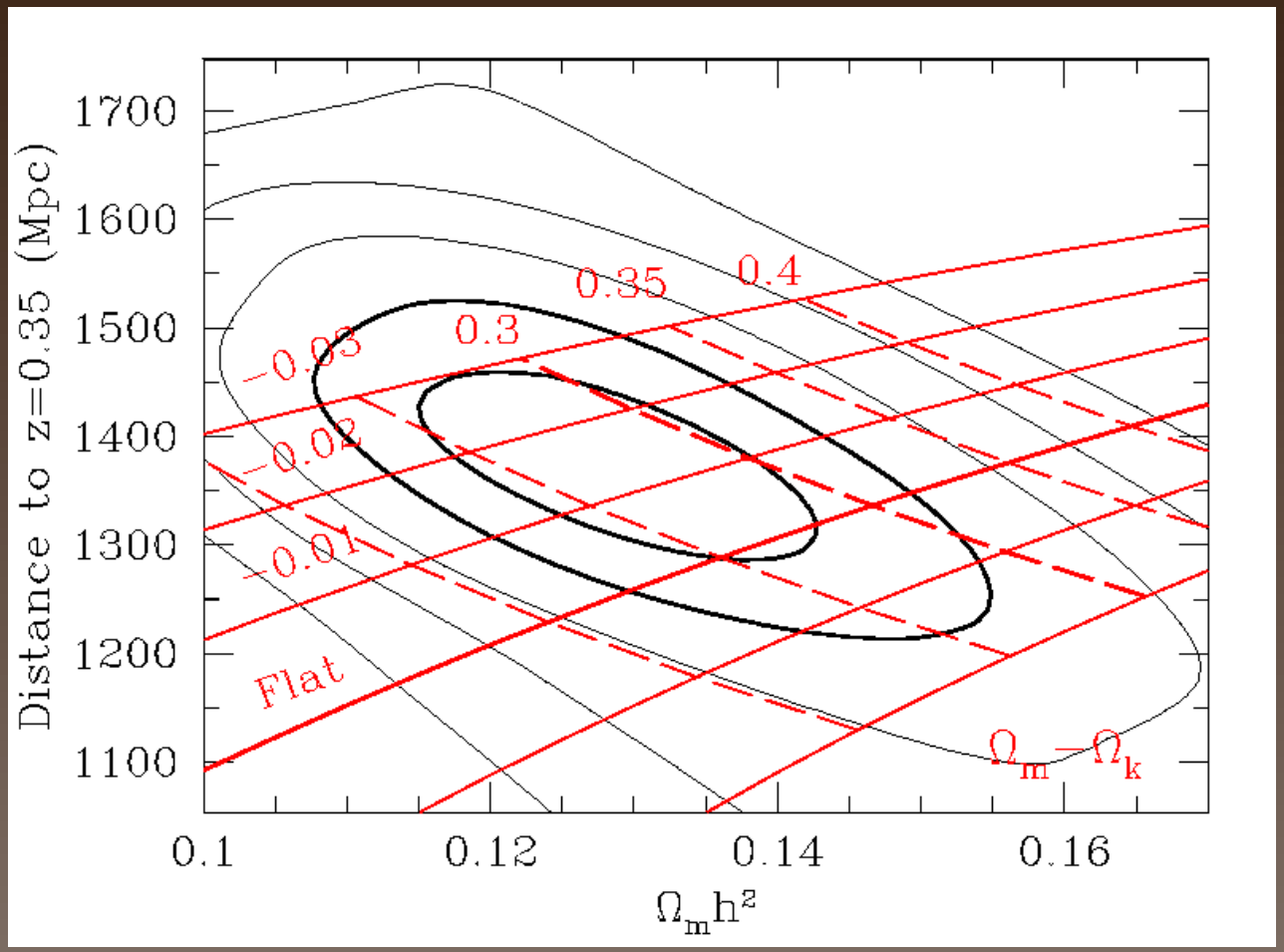

Fig. 12a, Eisenstein et al. astro-ph/0501171

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The Poincaré Dodecahedral 3-Manifold

Correlation statistic to detect best circle matches:

$$S \equiv \frac{\left\langle 2 \left(\frac{\delta T}{T}\right)_i \left(\frac{\delta T}{T}\right)_j \right\rangle}{\left\langle \left(\frac{\delta T}{T}\right)_i^2 + \left(\frac{\delta T}{T}\right)_j^2 \right\rangle} \qquad (1)$$

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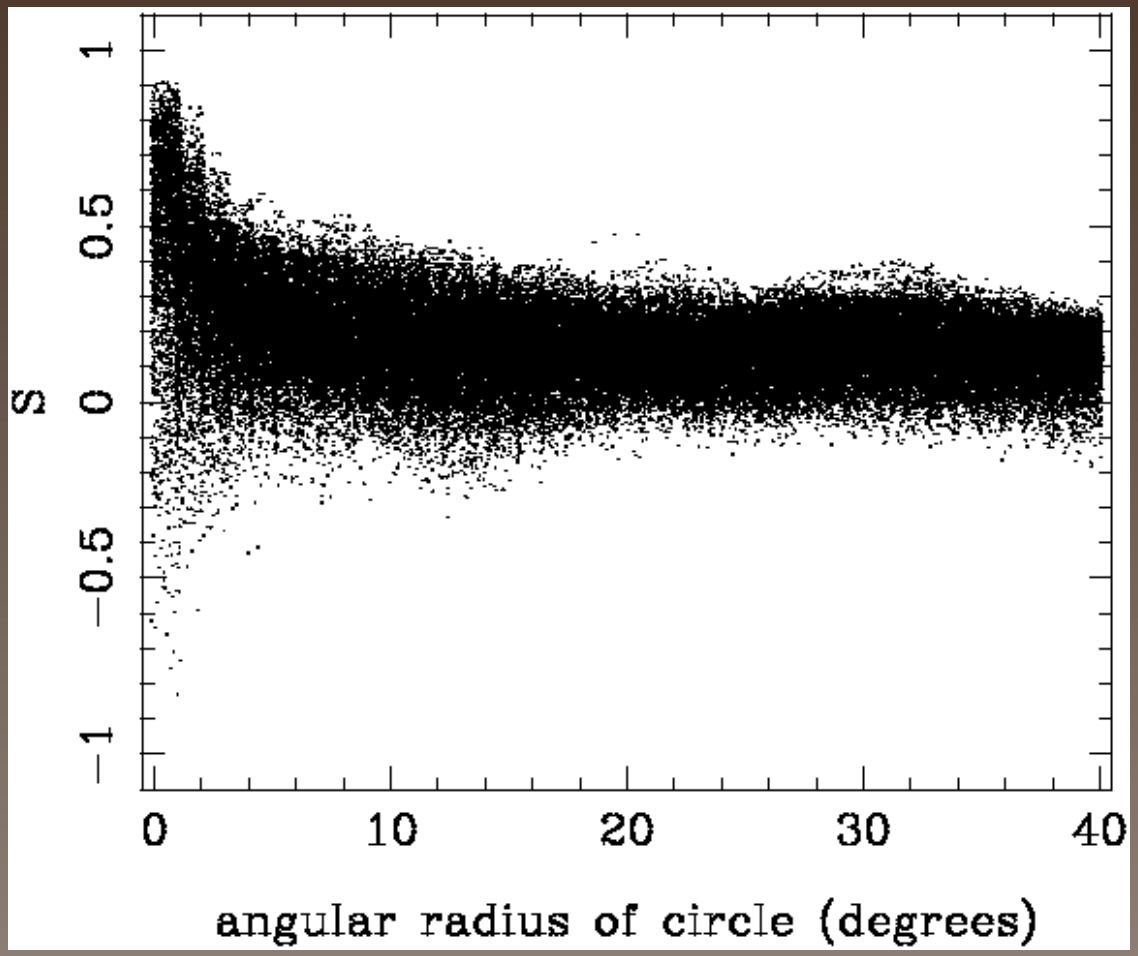

zero rotation

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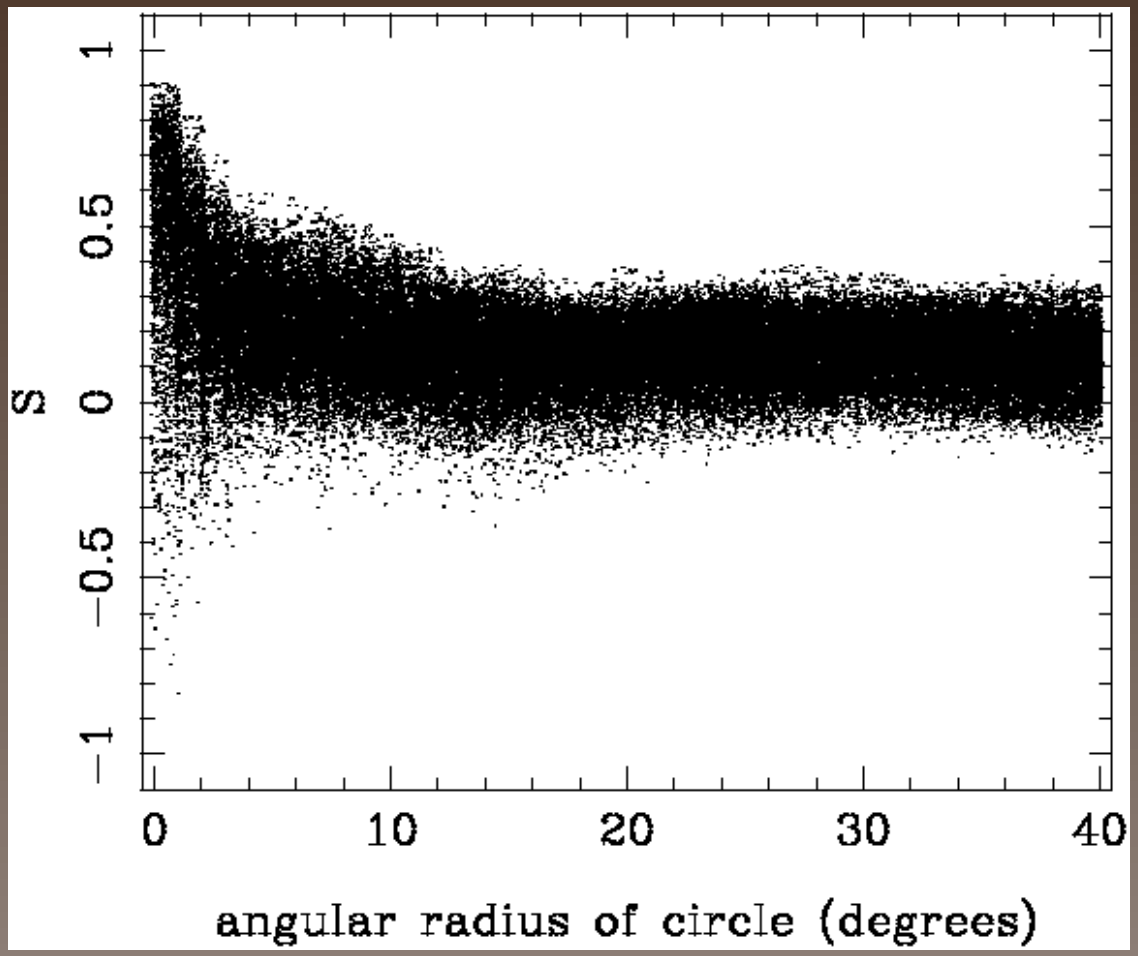
The Poincaré Dodecahedral 3-Manifold



$+36^\circ$ rotation

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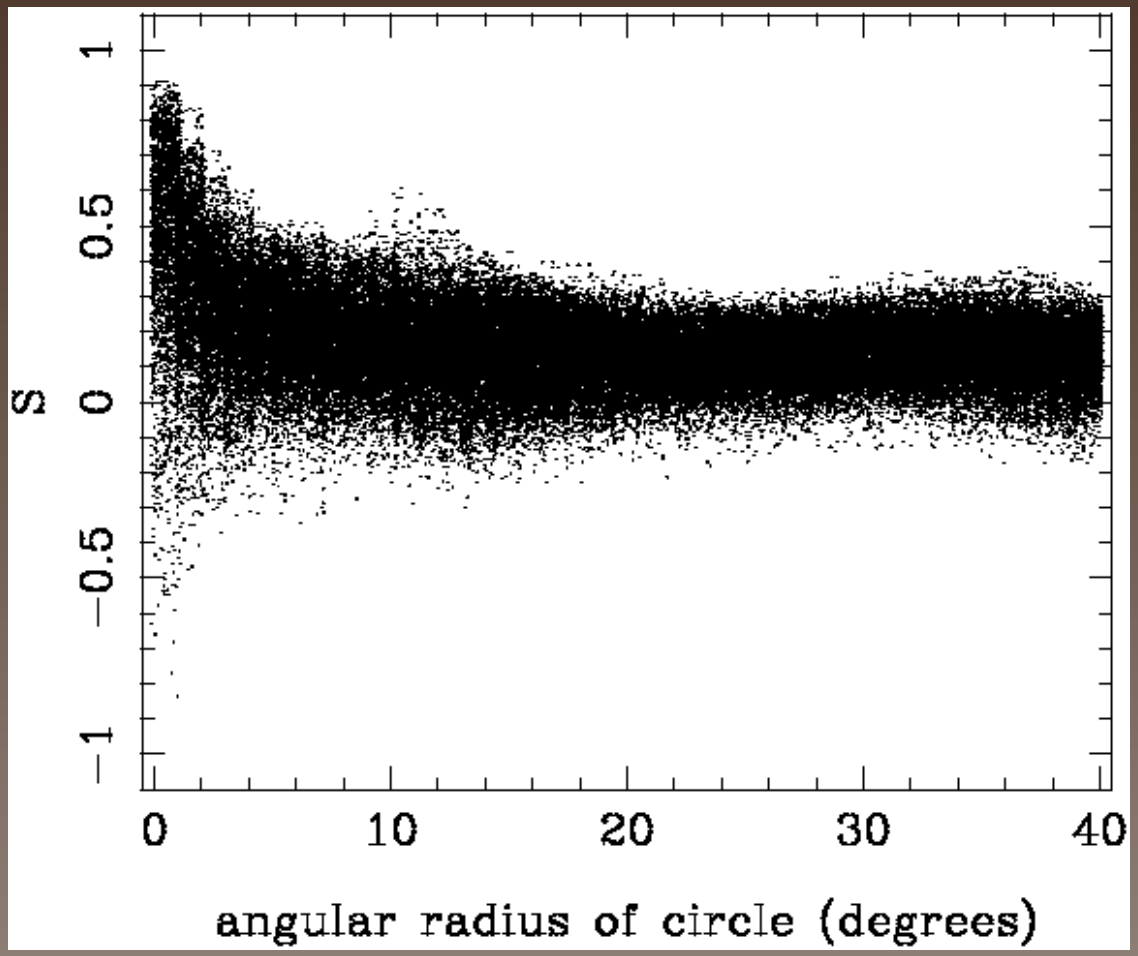
The Poincaré Dodecahedral 3-Manifold



-36° rotation

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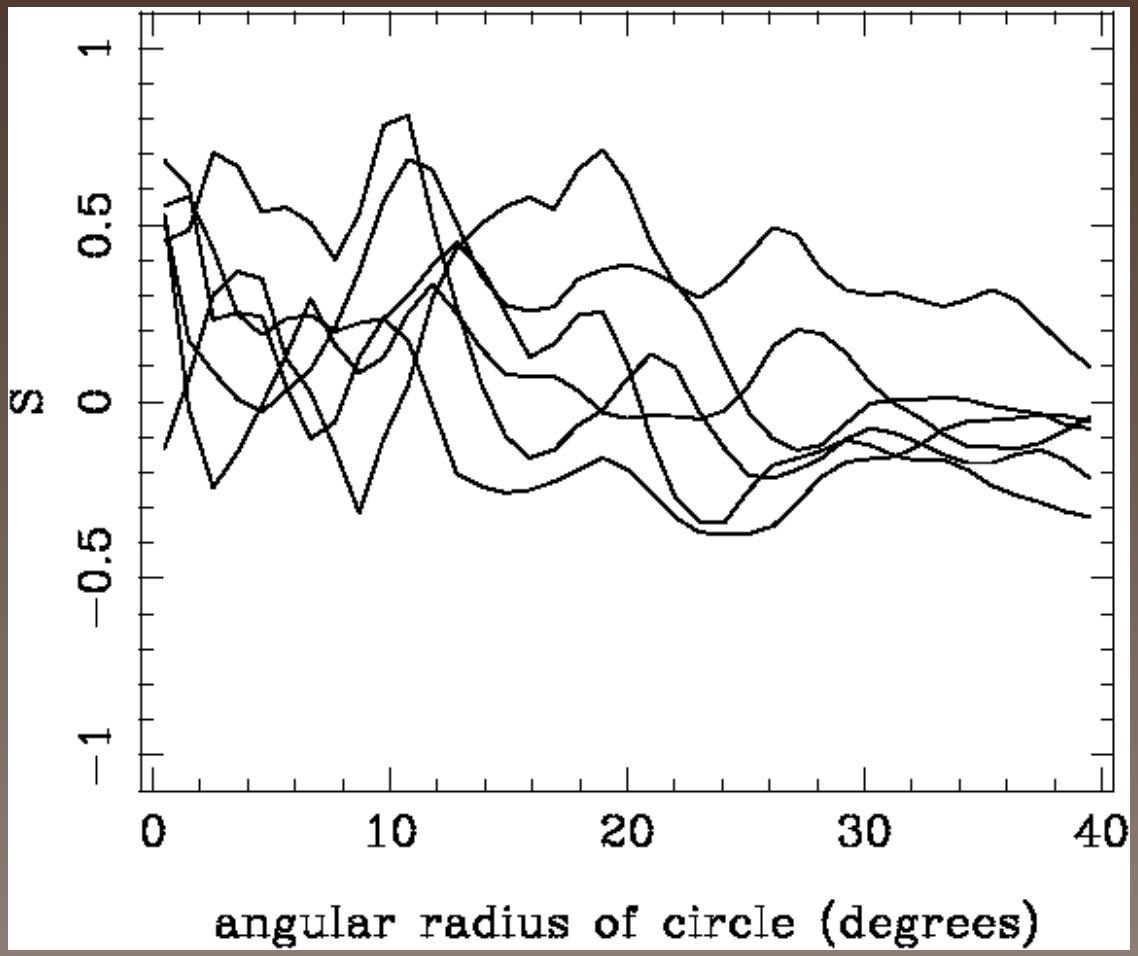
The Poincaré Dodecahedral 3-Manifold



zero rotation

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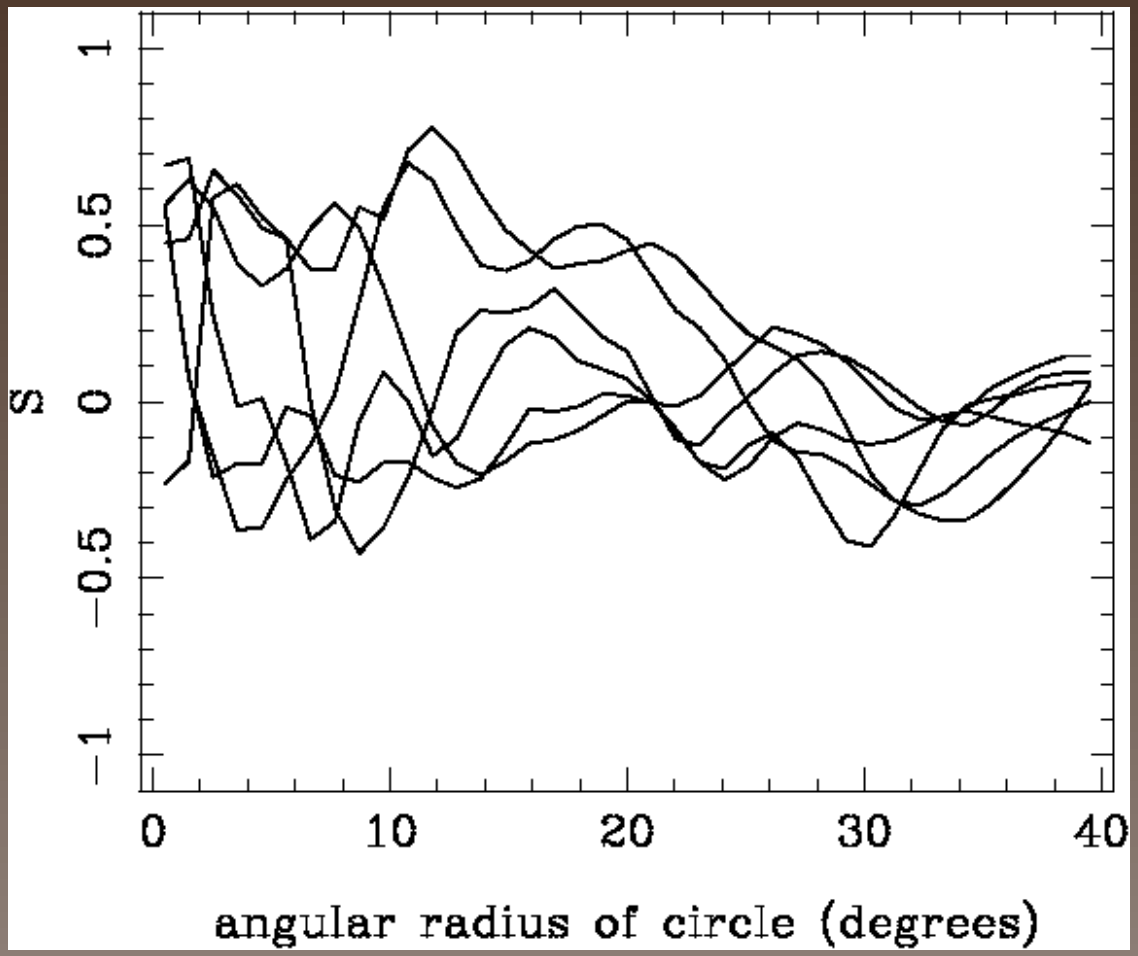

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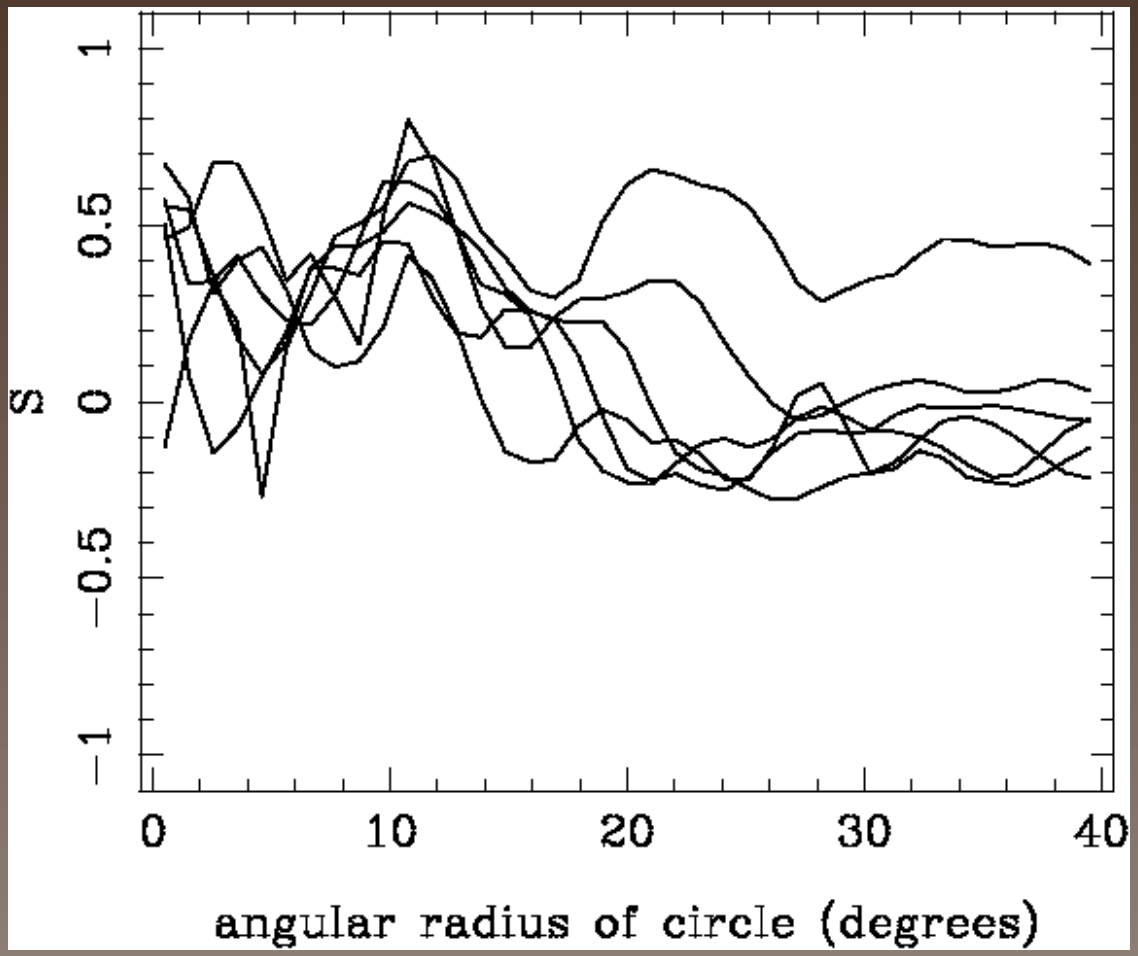

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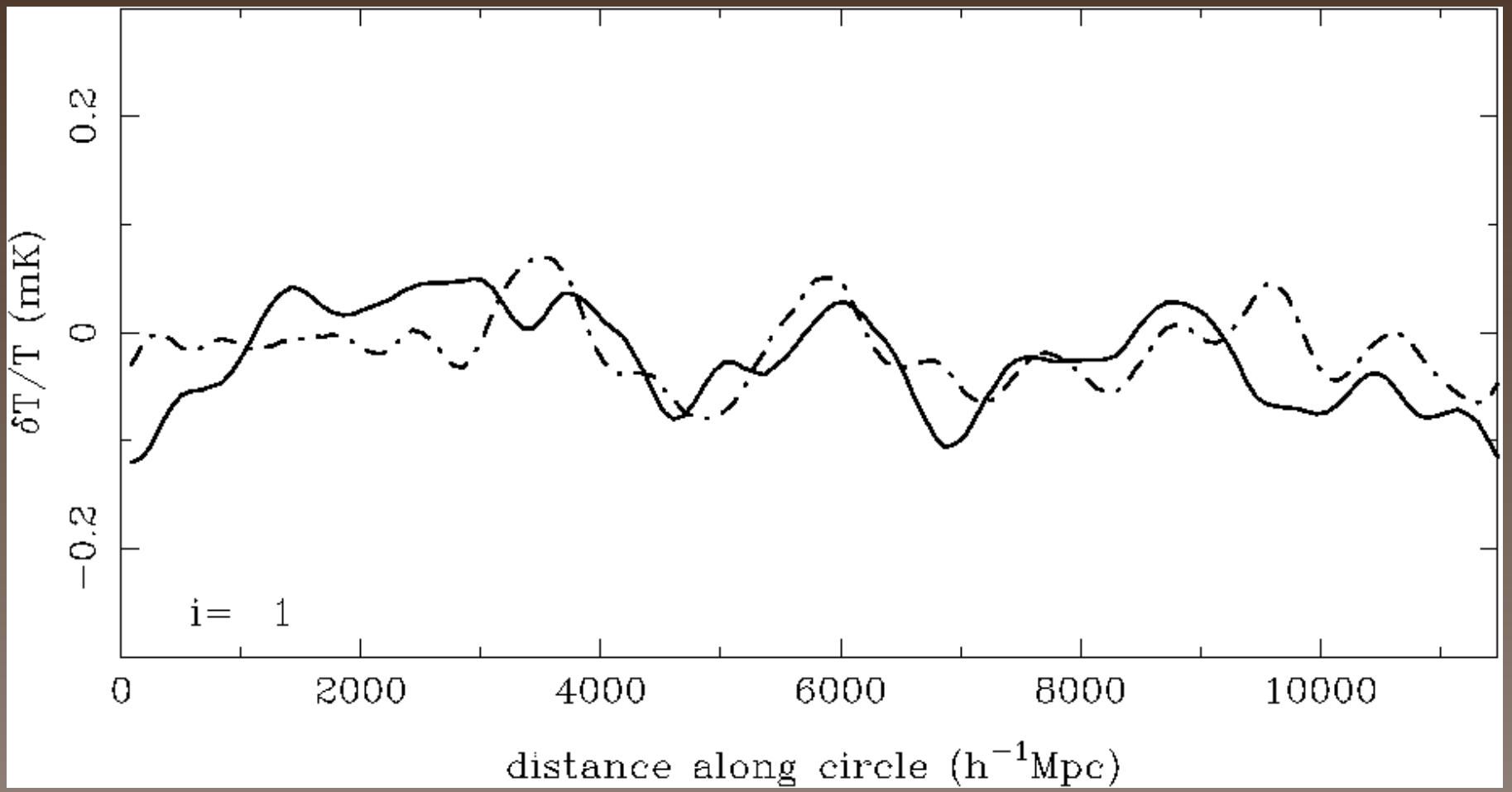

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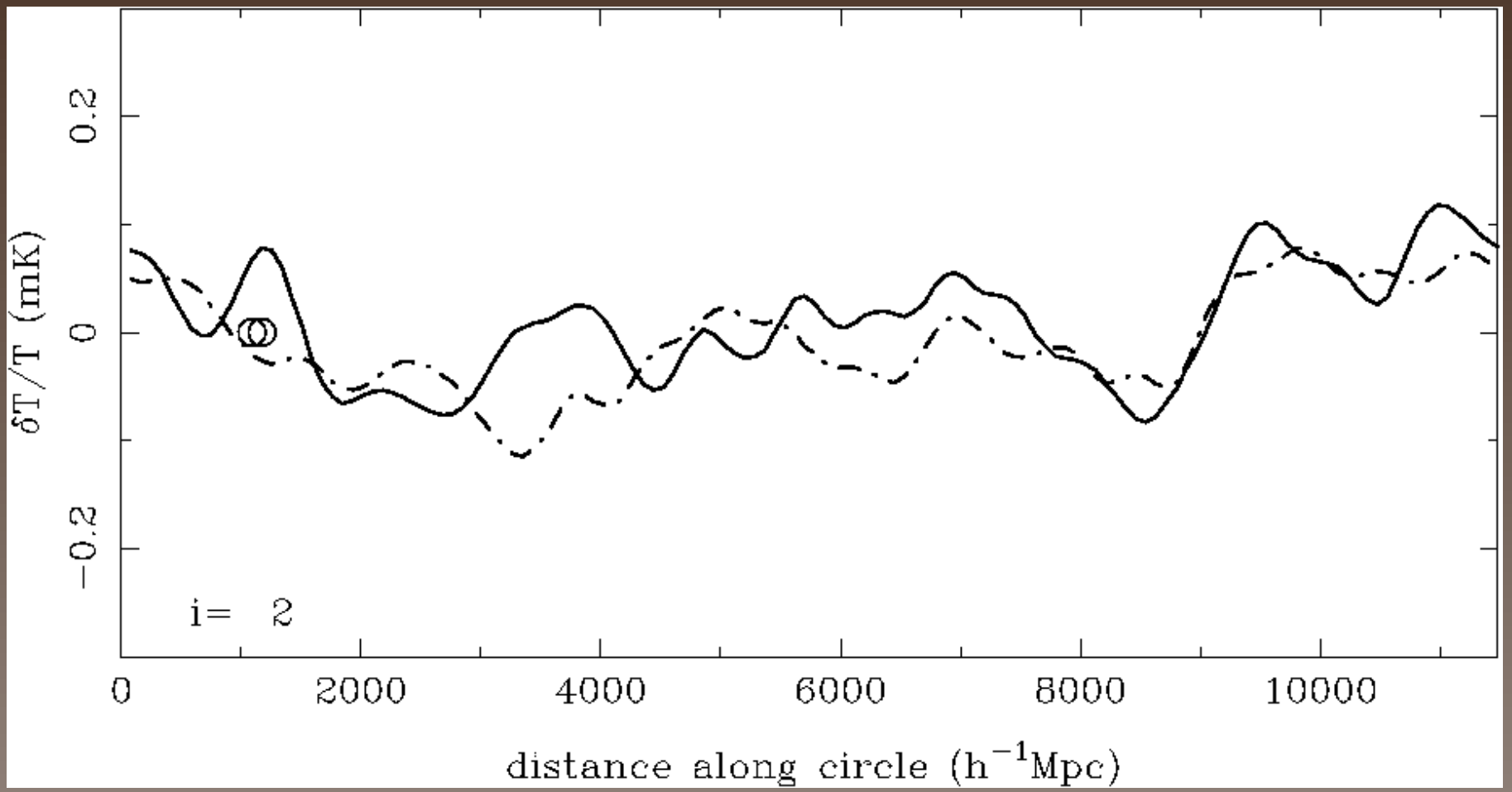

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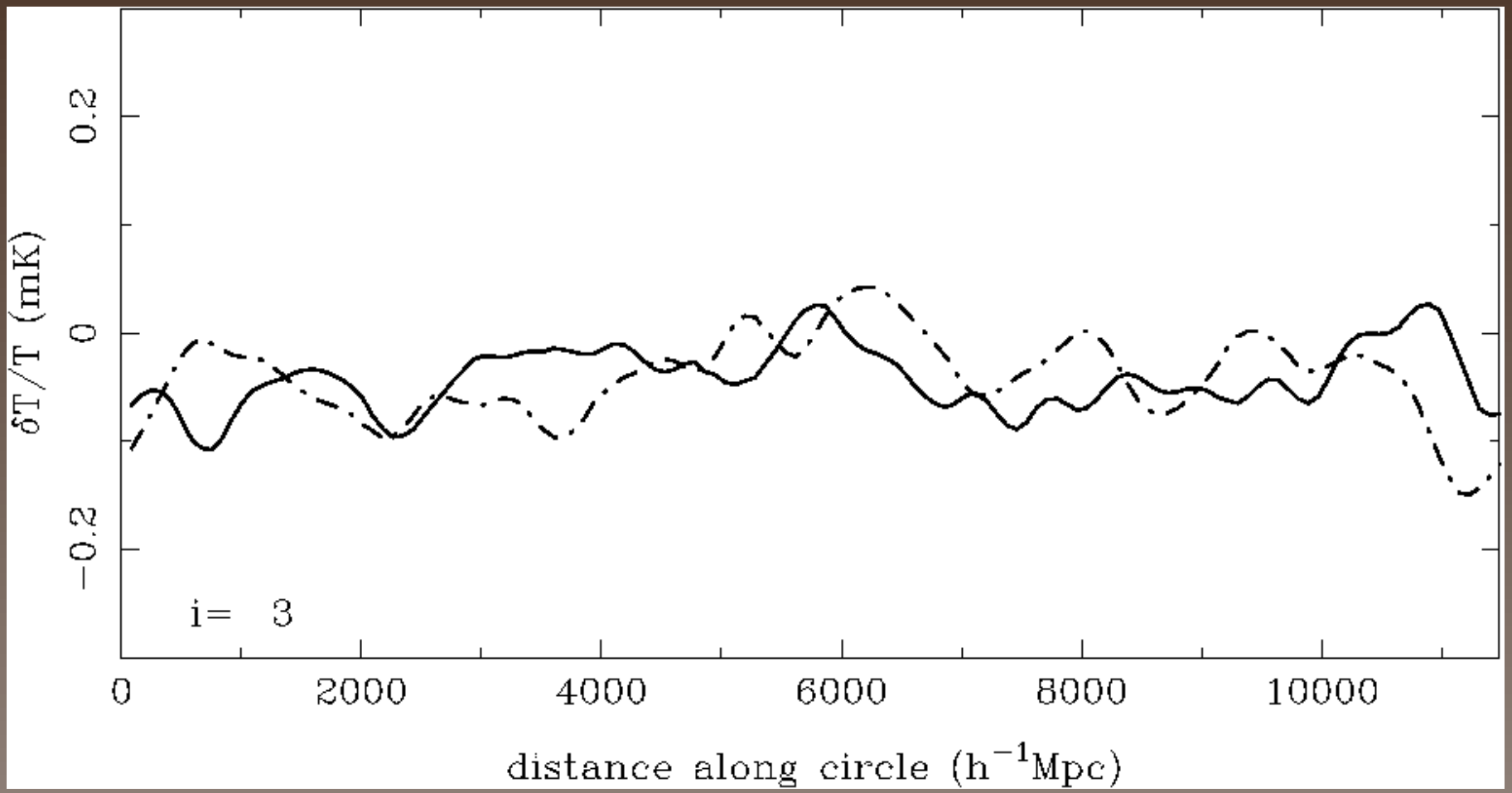

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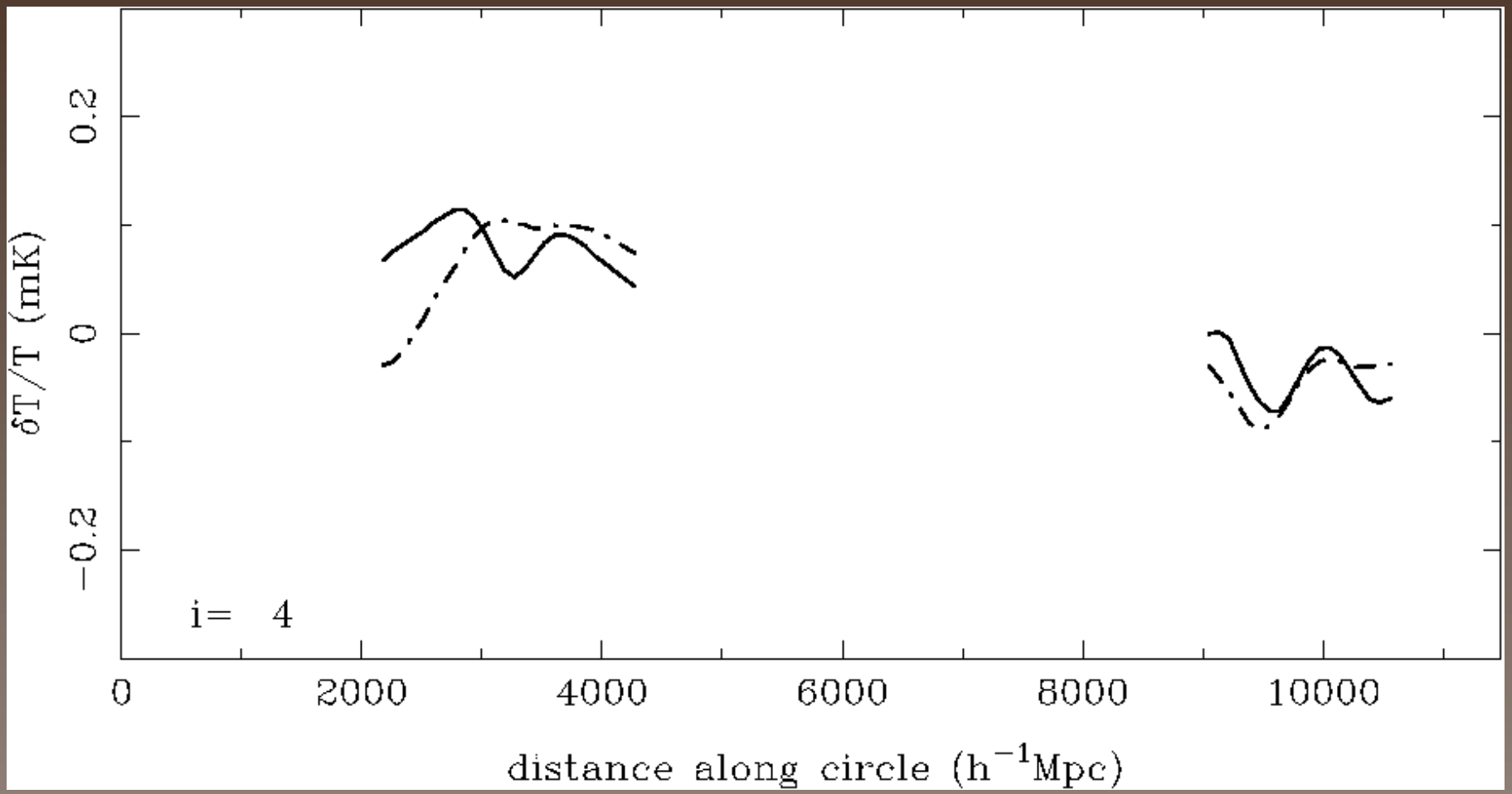

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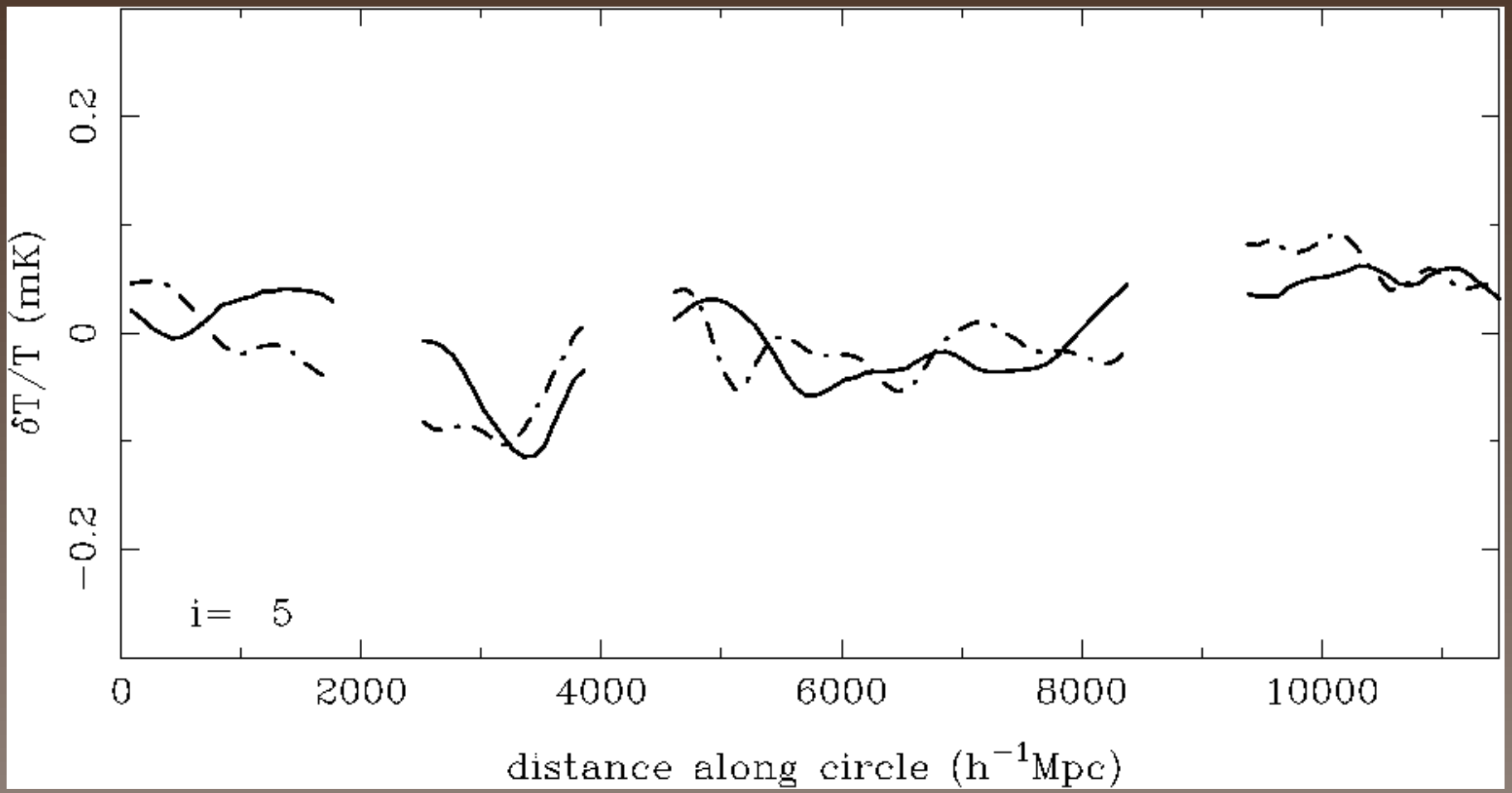

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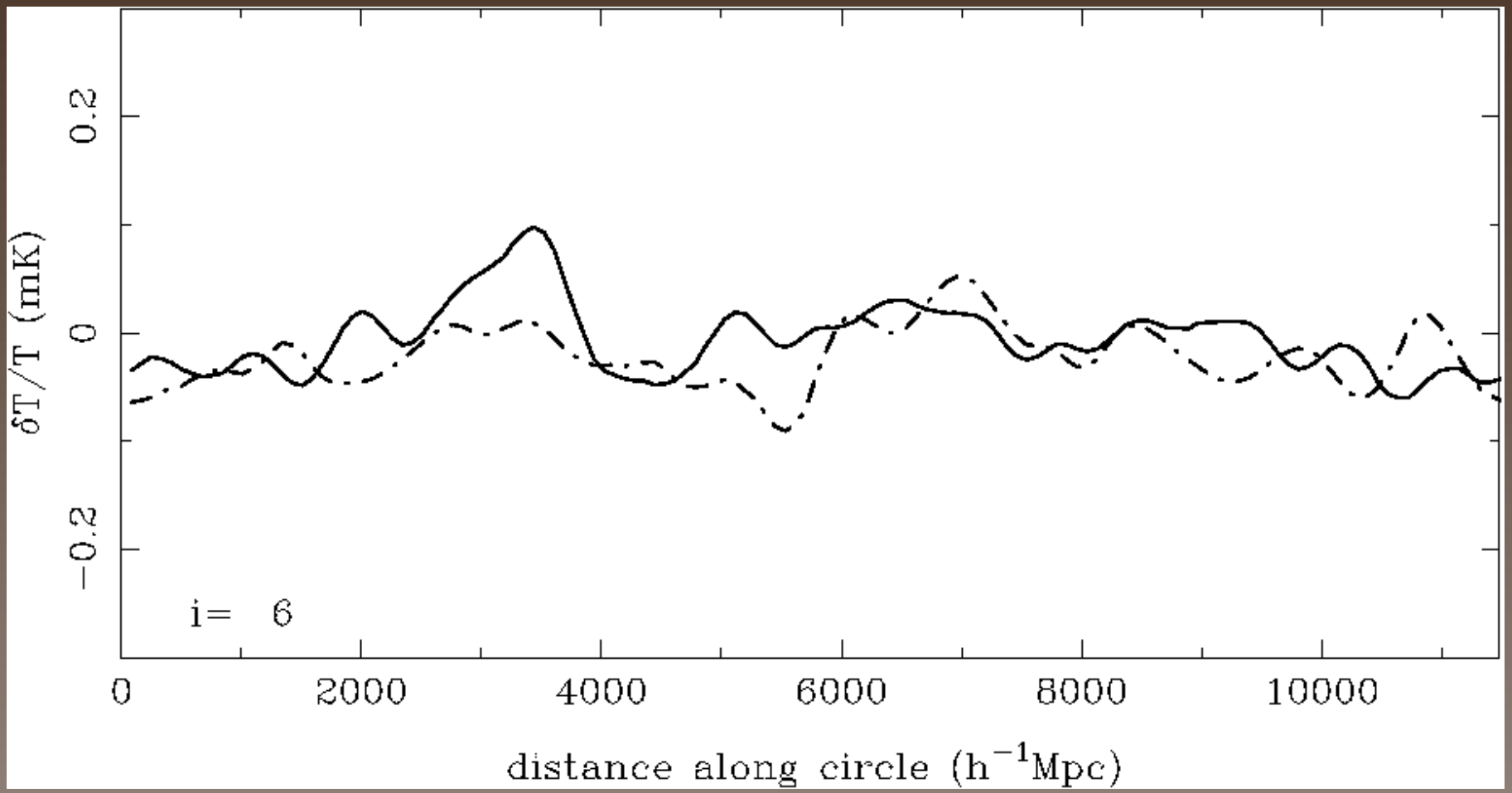


Dodecahedral Hypothesis: Conclusions

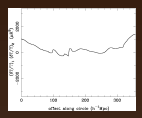
- best Poincaré dodecahedral solution has matched circles of radius $11 \pm 1^\circ$
- the six circle pairs independently have high correlations

Dodecahedral Hypothesis: Conclusions

i	l^{II} in $^\circ$	b^{II} in $^\circ$	α in $^\circ$
1	252.4	64.7	9.8
2	50.6	50.8	10.7
3	143.8	37.8	10.7
4	207.5	9.5	10.7
5	271.0	2.7	11.8
6	332.8	25.0	10.7

Roukema, Lew, Cechowska, Marecki, Bajtlik, A&A, 423, 821 (2004)

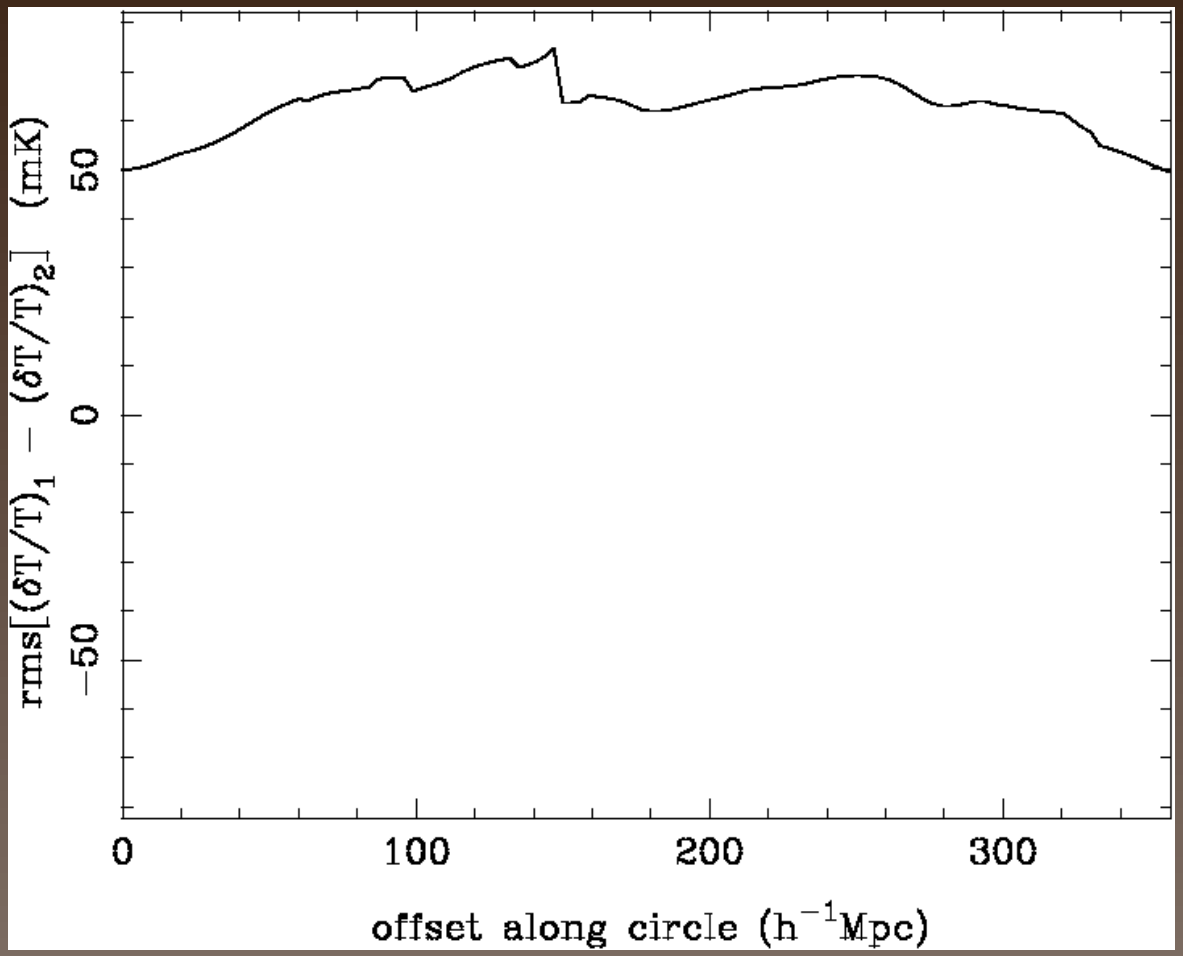
http://arXiv.org/abs/astro-ph/0402608

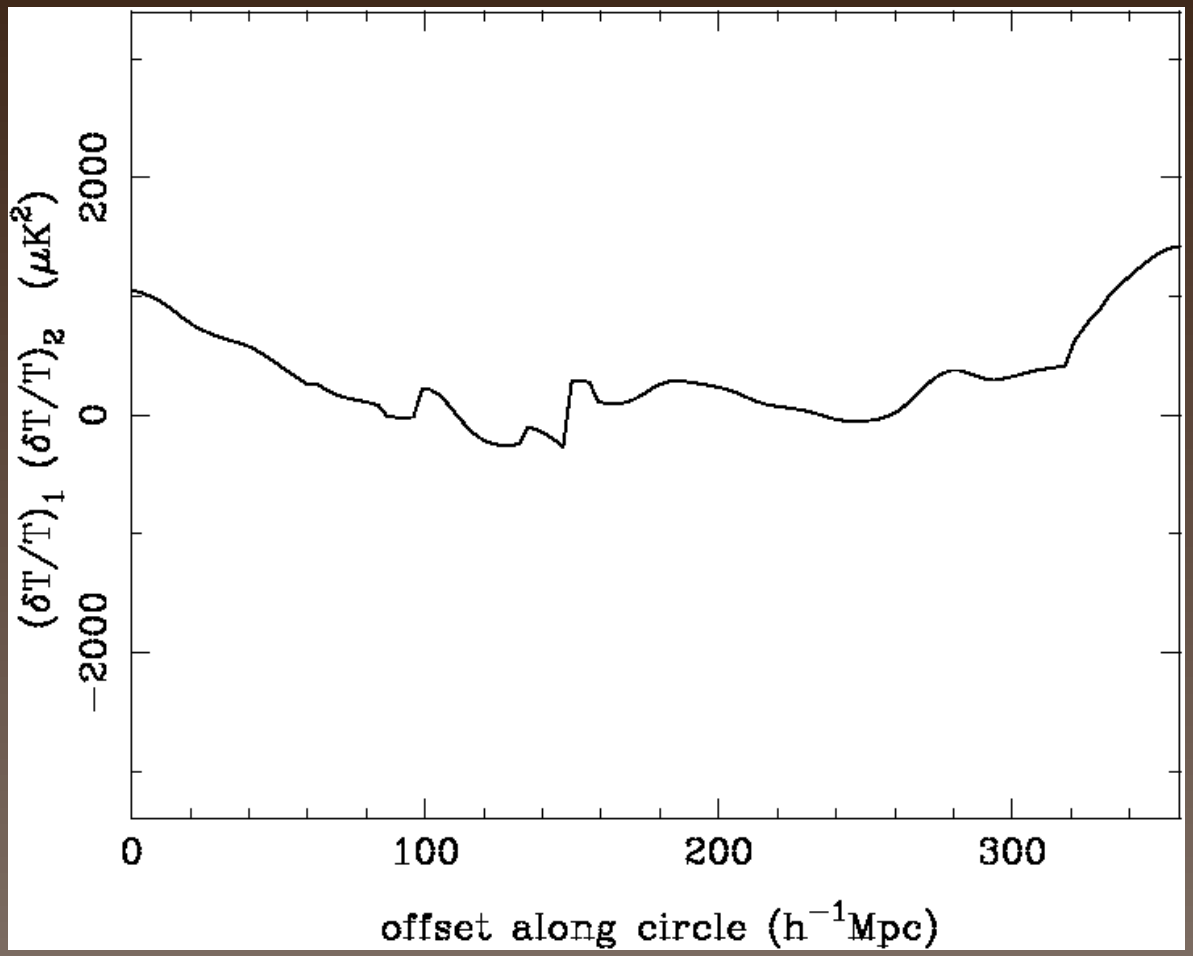


Phase tests

- circle radii $9^\circ < \alpha < 13^\circ$

- generalise from $\{-36, 0, +36\}$ to arbitrary phase relative to $-36\,\mathrm{deg}$ default


rms[(δT/T)1 − (δT/T)2] (mK)
50
0
−50
0
100
200
300
offset along circle (h−1Mpc)


$(\delta T/T)_1$ $(\delta T/T)_2$ (μK^2)
2000
0
−2000
0
100
200
300
offset along circle (h^{-1}Mpc)

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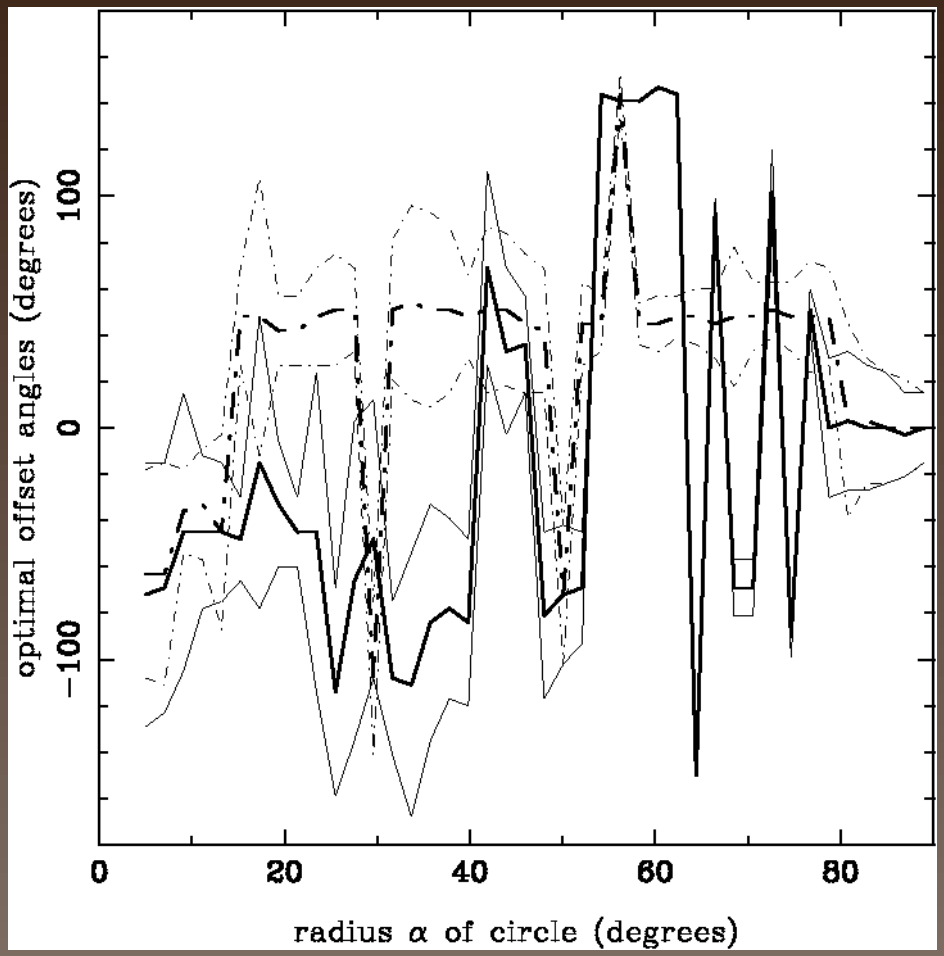

Future tests

Tests without assumptions on hypothetical statistical ensembles of universes include:

- separate naïve-SW, ISW and doppler components
- foreground "predictions"
- polarisation data

GPL software

http://cosmo.torun.pl/GPLdownload/dodec/ - get the latest version of **circles***:

- *./configure && make && make install*
- *circles --help; info circles; man circles*
- *circles --statistics* correlation calculations
- *circles --circles* plot the circles
- *circles --plot-phase* phase plots

- short form: *circles -s -c -P -d /scratch/topowork*

do everything and use data files in /scratch/topowork/.

data files

http://lambda.gsfc.nasa.gov/data/map/ilc/map_ilc_yr1_v1.fits — the WMAP ILC map

http://cosmo.torun.pl/WMAPdata - secondary files for default installation (in principle, should not be necessary, but as of circles-0.1.23, it would be easier if you download them)