20'th IAP collegium on CMB physics and observation

An alternative way of using high redshift AGNs to constrain local cosmological parameters

- Hubble constant

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Assumptions

- angular size distance to the AGN doesn't change in time between two subsequent observations
- for Hubble constant analysis, the geometry of the local Univese is flat
- jet is described as a moving spherical blob or a continuous stream in synchrotron self-conpton model of emmision (eg. Jones, O'Dell & Stein 1974)
- the 20.02electron energy distribution is described by power law with spectral index 0.75 (G. Ghisellini et al. 1993)
- the viewing angle and bulk velocity 1) both maximalize the apperent expansion rate 2) there is no prior on viewing angle

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Method

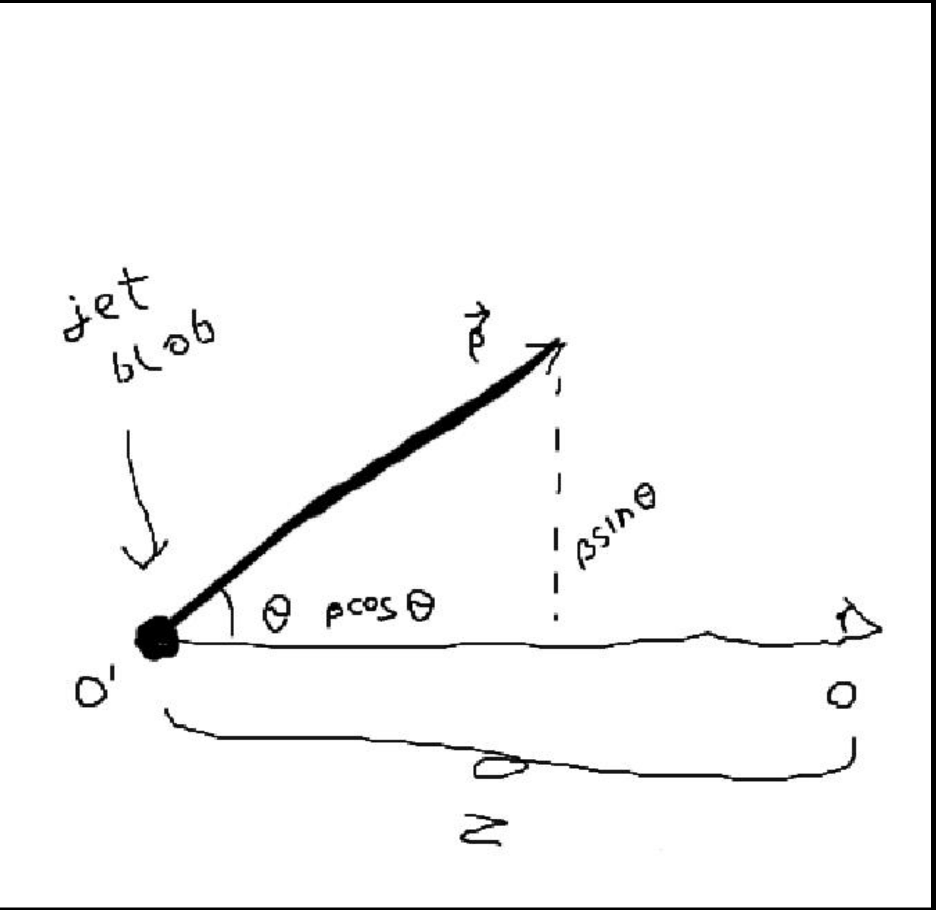
- apparent superluminal velocity

$$\beta_{\mathrm{app}} = \frac{\beta \sin(\theta)}{(z+1)\,(1-\beta\cos(\theta))} = \frac{\Xi(\beta,\,\theta)}{z+1}$$

- VLBI measurments of angular expansion rate

$$\mu \approx \frac{c}{d_{\mathrm{pm}}}\,\Xi(\beta,\,\theta) \qquad d_{\mathrm{pm}} = R_c\,\mathrm{sink}\!\left(\frac{d_p}{R_c}\right)$$

$$d_p(z) = \frac{c}{H_0}\int_0^z \frac{dz'}{E[z',\,\Omega_b,\,\Omega_{\mathrm{cdm}},\,\Omega_\Lambda]} = \frac{c}{H_0}\,\xi_m$$



- Hubble constant

$$H_0 = \frac{\mu\,\xi_m(z)}{\Xi(\beta,\,\theta)}$$

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Model uncertanities

- Hubble constant uncertanities

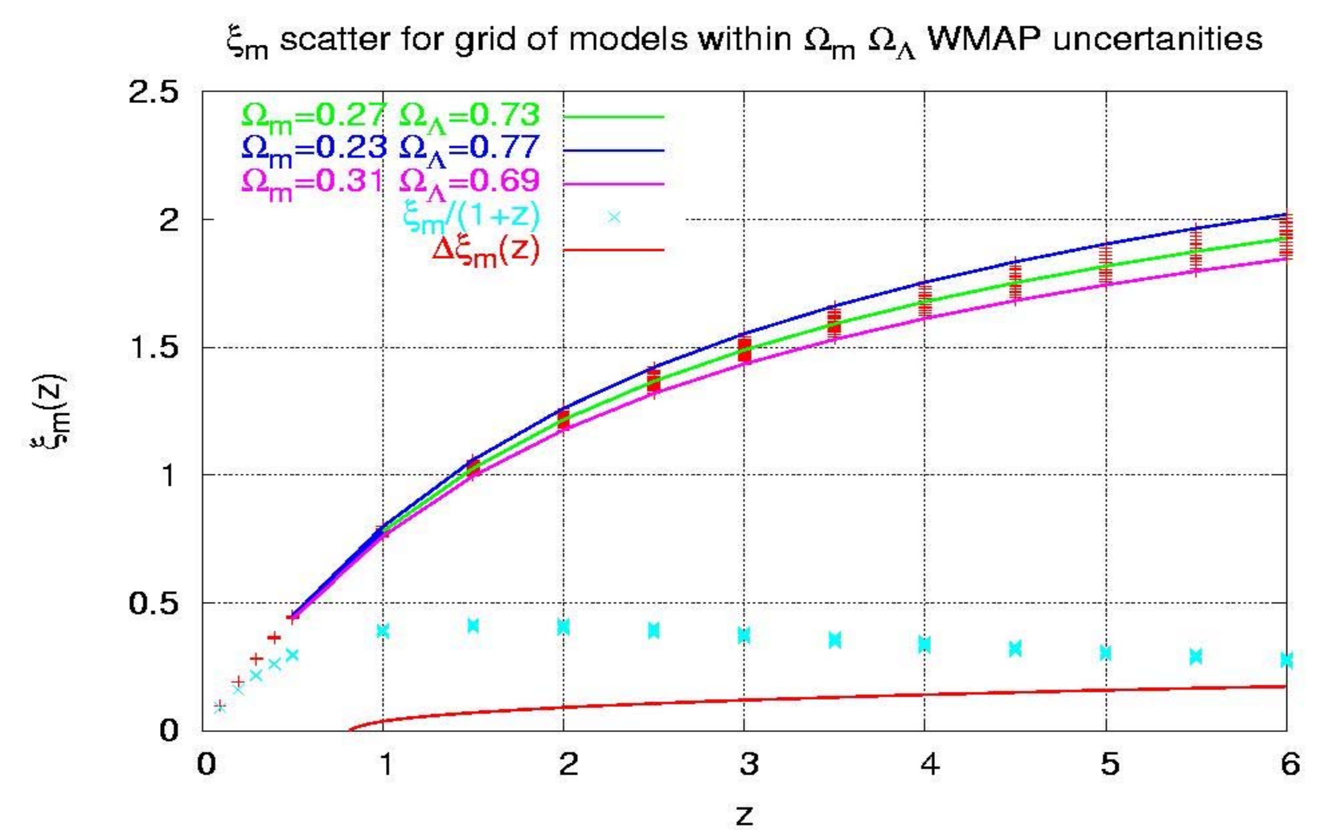
$$\Delta H_0 = \frac{\xi_m}{\Xi}\,\Delta\mu + \frac{\mu}{\Xi}\,\Delta\xi_m + \frac{\xi_m\;\mu}{\Xi}\,\frac{\Delta\Xi}{\Xi}$$

- cosmological model uncertanities

- WMAP prior applied

$\Omega_{cdm} = 0.27 \pm 0.04$

$\Omega_\Lambda = 0.73 \pm 0.04$



ξ_m scatter for grid of models within Ω_m Ω_Λ WMAP uncertanities

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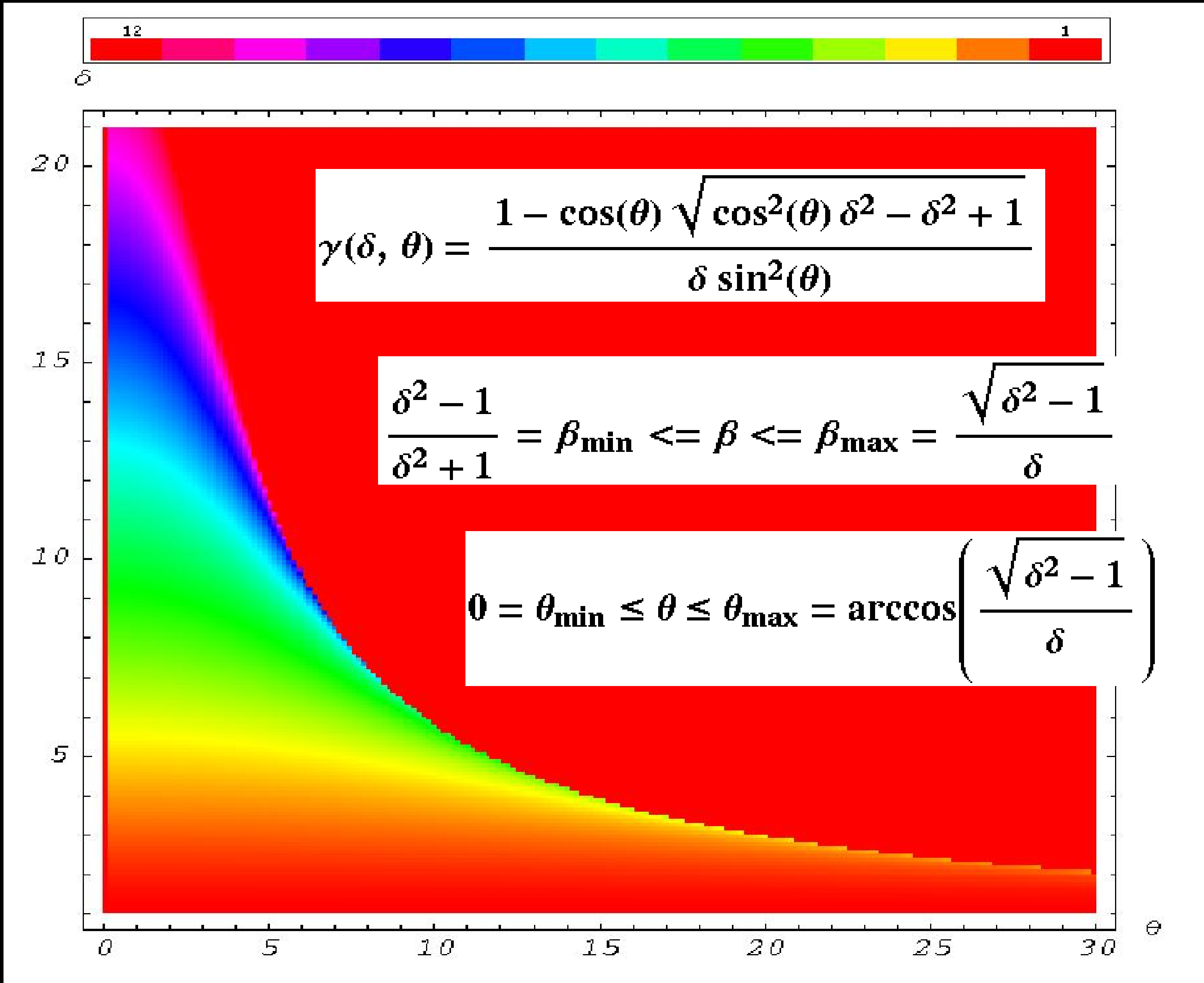
Jet uncertanities

- doppler factor

$$\delta = \frac{1}{\gamma\,(1 - \beta\cos(\theta))}$$

- physical constraints on β and θ



$$\gamma(\delta,\,\theta) = \frac{1 - \cos(\theta)\sqrt{\cos^2(\theta)\,\delta^2 - \delta^2 + 1}}{\delta\,\sin^2(\theta)}$$

$$\frac{\delta^2 - 1}{\delta^2 + 1} = \beta_{\min} <= \beta <= \beta_{\max} = \frac{\sqrt{\delta^2 - 1}}{\delta}$$

$$0 = \theta_{\min} \le \theta \le \theta_{\max} = \arccos\left(\frac{\sqrt{\delta^2 - 1}}{\delta}\right)$$

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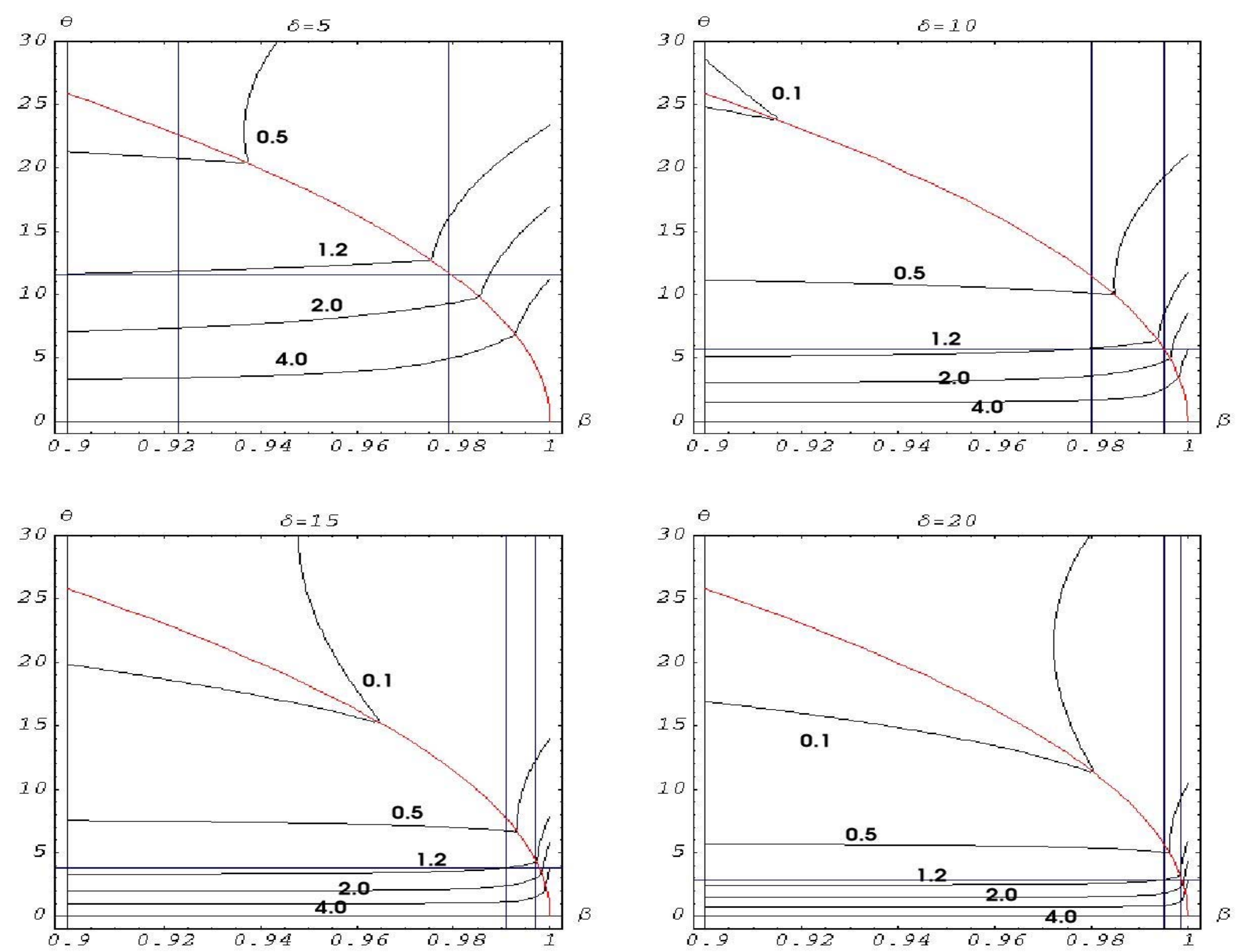
Jet uncertanities

- relative error of Ξ



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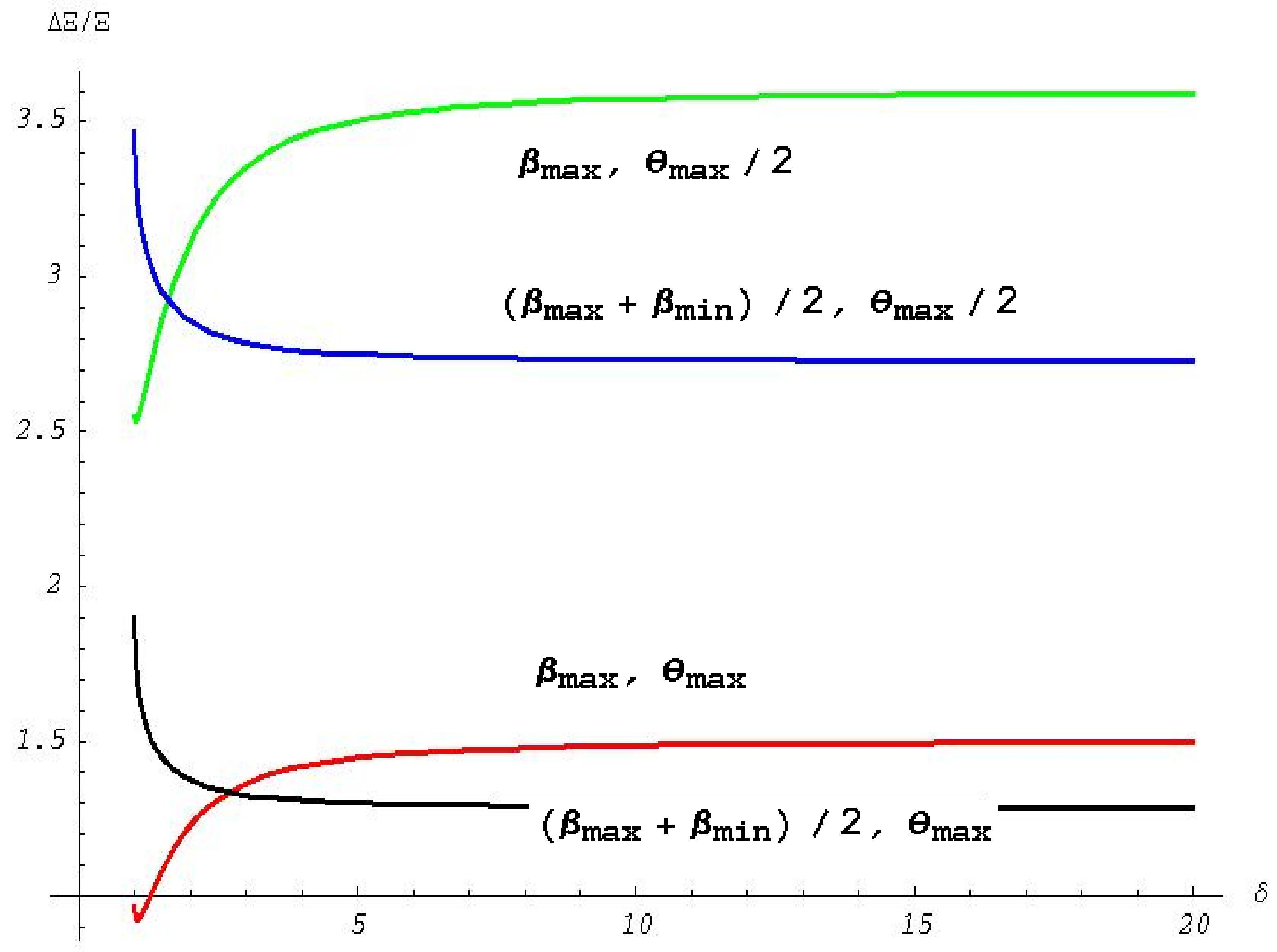
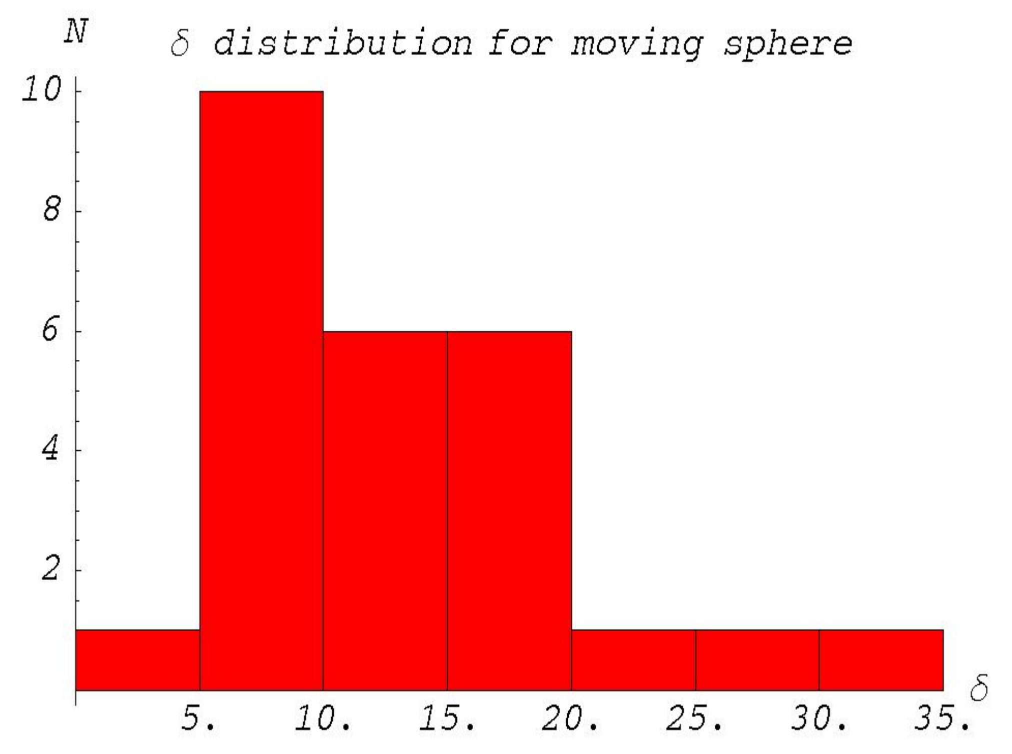
Jet uncertanities

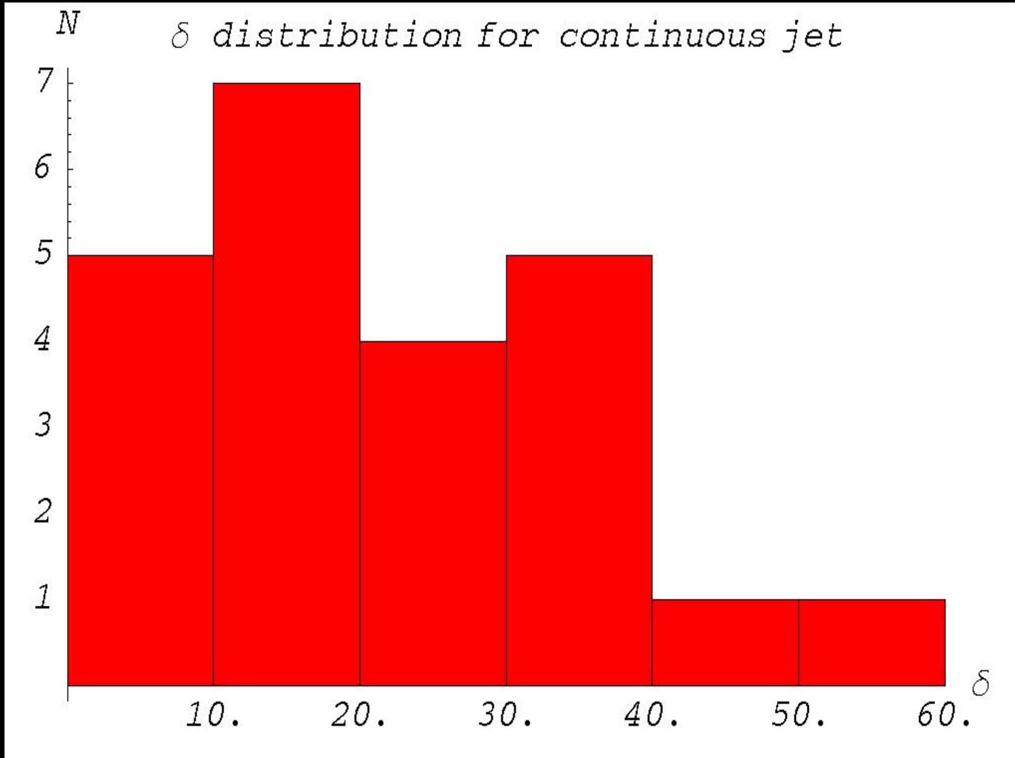
- relative error of Ξ for δ > 1
- assumed uncertanity on ΔΞ/Ξ= 3.5 for δ > 5
- assumed uncertanity on ΔΞ/Ξ= 1.5 for δ > 5



Sample statistics

- **24 sources with complete data and** δ > 5 taken from G. Ghisellni et al. 1994, R.C. Vermeulen et al. 1994, S. Jorstad et al. and the VLBI 2cm survey
- **Includes: Bl lacertae (5), core dominated hpq (11), and lpq (8)**





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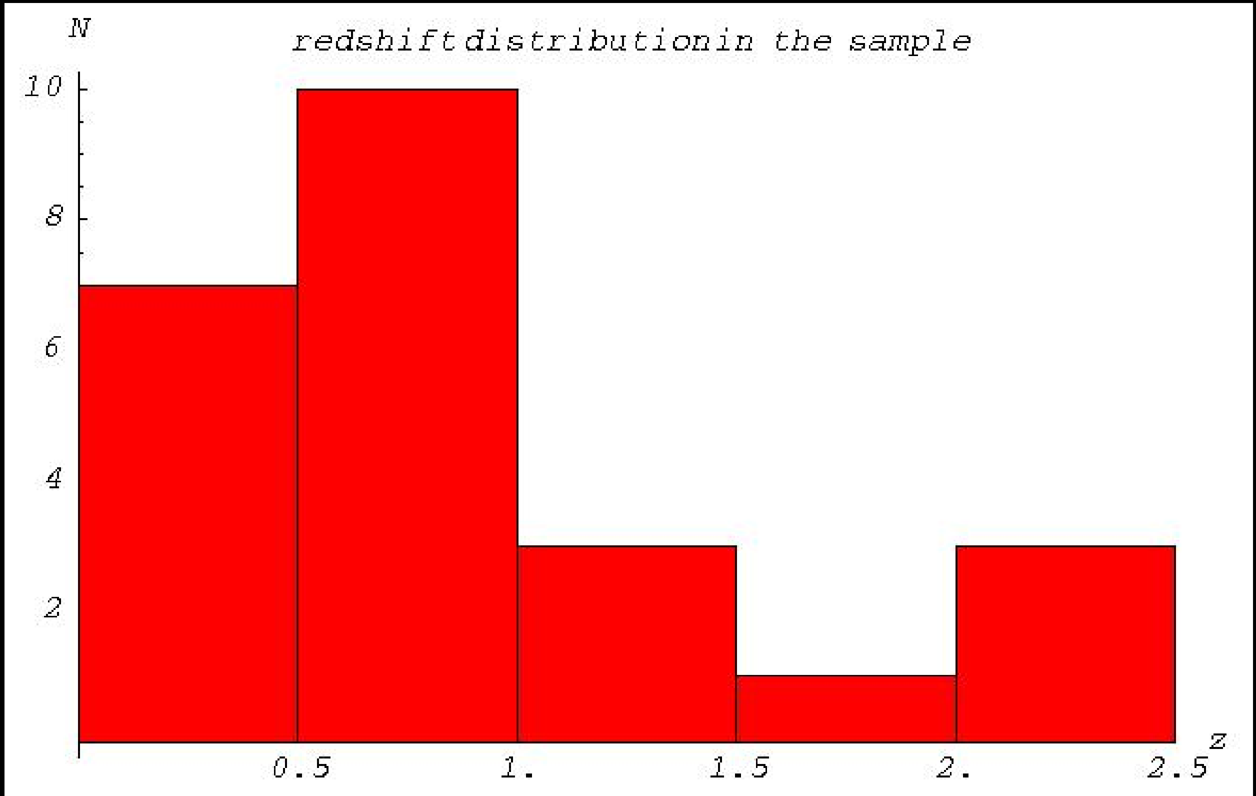

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Results

						spherical motion				continuous jet			
name	doppler	z	xi WMAP	prop.mot. [10^ -6as/yr]	err.prop.mot. [10^ -6as/yr]	H0 max/haf [km/s/Mpc]	err. H0 [km/s/Mpc]	H0 max SL [km/s/Mpc]	err. H0 [km/s/Mpc]	H0 max/haf [km/s/Mpc]	err. H0 [km/s/Mpc]	H0 max SL [km/s/Mpc]	err. H0 [km/s/Mpc]
BL Lacertae (5)													
0735+178	7.3	0.42	0.38	440	30	137.93	103.28	111.08	36.55	87.49	65.51	71.02	23.37
0851+202	8.8	0.31	0.28	235	30	45.17	34.39	36.51	12.47	27.53	20.96	22.42	7.66
1308+326	6.8	1	0.77	290		197.45	145.01	158.8	49.98	127.16	93.39	103.07	32.44
1749+096	14.3	0.32	0.3	460	30	56.35	42.15	45.9	15.08	30.94	23.14	25.37	8.33
2007+776	4.7	0.34	0.32	180	40	73.76	57.61	58.95	21.3	51.39	40.14	41.31	14.93
Core Dominated HPQ (11)					average	102.13	76.96	82.25	27.46	64.9	48.92	52.64	17.58
0106+013	18.9	2.11	1.25	200	50	77.25	60.79	63.15	23.19	39.93	31.42	32.83	12.06
0212+735	9.2	2.37	1.33	80	50	68.54	59.32	55.43	24.72	41.37	35.81	33.73	15.04
0234+285	16.6	1.21	0.89	300	150	94.16	79.03	76.85	32.25	50.05	42.01	41.11	17.25
0336-019	15.6	0.85	0.69	300	50	77.35	59.51	63.08	22.06	41.67	32.06	34.21	11.96
0420-014	16.8	0.92	0.73	200	20	50.51	38.15	41.23	13.84	26.78	20.23	22	7.39
1156+295	6.4	0.73	0.61	340	80	193.82	151.92	155.71	56.7	126.44	99.11	102.36	37.27
1253-055	18	0.54	0.47	500		76.54	56.22	62.54	19.68	39.98	29.36	32.86	10.34
1510-089	14.5	0.36	0.33	470	30	63.02	47.13	51.35	16.85	34.5	25.8	28.3	9.29
1641+399	5.3	0.6	0.51	327.5	20	192.47	143.82	154.1	50.48	130.71	97.67	105.37	34.52
2223-052	20.9	1.4	0.98	247	60	67.67	53.15	55.38	20.25	34.22	26.88	28.16	10.3
2251+158	6	0.86	0.69	280	60	194.32	151.46	155.93	56.09	128.53	100.18	103.9	37.38
Core Dominated LPQ (8)					average	105.06	81.86	84.98	30.56	63.11	49.14	51.35	18.44
0016+731	10.3	1.78	1.14	220	53	143.57	112.7	116.35	42.51	84.59	66.41	69.08	25.24
0333+321	16.6	1.26	0.91	150	10	48.25	36.11	39.38	12.95	25.65	19.2	21.07	6.93
0430+052	5.3	0.03	0.03	2310		86.61	63.61	69.35	21.83	58.82	43.2	47.42	14.92
0836+710	8.7	2.17	1.27	185	50	160.37	126.87	129.58	48.13	97.97	77.51	79.79	29.64
0923+392	11.6	0.7	0.59	180	30	53.67	41.3	43.58	15.24	30.83	23.72	25.22	8.82
1226+023	6	0.16	0.15	1150	150	176.26	134.28	141.43	48.39	116.58	88.81	94.24	32.24
1730-130	11	0.9	0.72	240	20	92.35	69.44	74.92	24.89	53.65	40.34	43.85	14.57
2145+067	26.9	0.99	0.77	301	?	50.05	36.76	41.06	12.92	23.95	17.59	19.74	6.21
					average	101.39	77.63	81.96	28.36	61.51	47.1	50.05	17.32
					average ALL	102.86	78.82	83.06	28.79	63.17	48.38	51.35	17.78
						std. dev.	68.63		24.98	std. dev.	44.36		16.22
						avg.std.dev.	14.31		5.21	avg.std.dev.	9.25		3.38
						3 sigma	42.93		15.62	3 sigma	27.75		10.14
						relative err.	0.42		0.19	relative err.	0.44		0.2

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Results

The final values of Hubble constant constrained from 24 sources in km/s/Mpc

Spherical moving blob

$H_0 = 83 \pm 16$ under assumption that the jet maximalises β_{app}

$H_0 = 103 \pm 43$ under assumption that $\theta = \theta_{max}/2$ and $\beta = \beta_{max}$

Continuous jet

$H_0 = 51 \pm 11$ under assumption that the jet maximalises β_{app}

$H_0 = 63 \pm 28$ under assumption that $\theta = \theta_{max}/2$ and $\beta = \beta_{max}$

Mean values between the two models

H0 = 73 ± 19 and H0 = 77 ± 50

at 3 sigma level

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Discusion

Derived values of δ factors within the ‘moving sphere’ model represent the lower limits on their intrisic values. For given δ

$$H_0 = \frac{\mu\,\xi_m}{\Xi(\beta,\,\theta)} = \frac{\mu\,\xi_m}{\sqrt{\delta^2 - 1}}$$

for

$\beta_{\max},\ \theta_{\max}/2$

$$H_0 = \frac{\mu\xi_m}{\Xi(\beta,\,\theta)} = \frac{\mu\xi_m}{\dfrac{\sqrt{\delta^2-1}\,\sin\left(\frac{1}{2}\arccos\left(\frac{\sqrt{\delta^2-1}}{\delta}\right)\right)}{\delta-\sqrt{\delta^2-1}\,\cos\left(\frac{1}{2}\arccos\left(\frac{\sqrt{\delta^2-1}}{\delta}\right)\right)}} \approx \frac{\mu\xi_m}{0.82808\,\delta - 0.221393}$$

for

$\beta_{\max},\ \theta_{\max}$

thus the Hubble constant is systematicly biasd towards higher values.

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Future prospects

The uncertanity on H_0 can be rewritten as:

$$\Delta H_0 = \frac{B[\mu as]\,a}{2\,\Xi\,\Delta t[yr]}\left(\xi_m(z) + SN\,\Delta\xi_m(z) + SN\,\xi_m(z)\,\frac{\Delta\Xi}{\Xi}\right), \quad a \approx 4.766$$

where B - VLBI beam size, Δt - time between two observations

for SN = 2 and Δt = 1 yr

$$\Delta H_0 = \frac{16.2}{\Delta t[yr]}[\xi_m(z) + 2\,\Delta\xi_m(z) + 3\,\xi_m(z)]\ \ [km/s/Mpc], \quad B = 500\,\mu as,\ \bar{\Xi} = 15\ (\text{for moving sphere}),\ 24\ \text{sources}$$

$$\Delta H_0 = \frac{8.7}{\Delta t[yr]}[\xi_m(z) + 2\,\Delta\xi_m(z) + 3\,\xi_m(z)]\ \ [km/s/Mpc], \quad B = 500\,\mu as,\ \bar{\Xi} = 28\ (\text{for continuous jet}),\ 24\ \text{sources}$$

$$\Delta H_0 = \frac{0.32}{\Delta t[yr]}[\xi_m(z) + 2\,\Delta\xi_m(z) + 3\,\xi_m(z)]\ \ [km/s/Mpc], \quad B = 10\,\mu as,\ \bar{\Xi} = 15\ (\text{for moving sphere}),\ 24\ \text{sources}$$

$$\Delta H_0 = \frac{0.17}{\Delta t[yr]}[\xi_m(z) + 2\,\Delta\xi_m(z) + 3\,\xi_m(z)]\ [km/s/Mpc], \quad B = 10\,\mu as,\ \bar{\Xi} = 28\ (\text{for continuous jet}),\ 24\ \text{sources}$$

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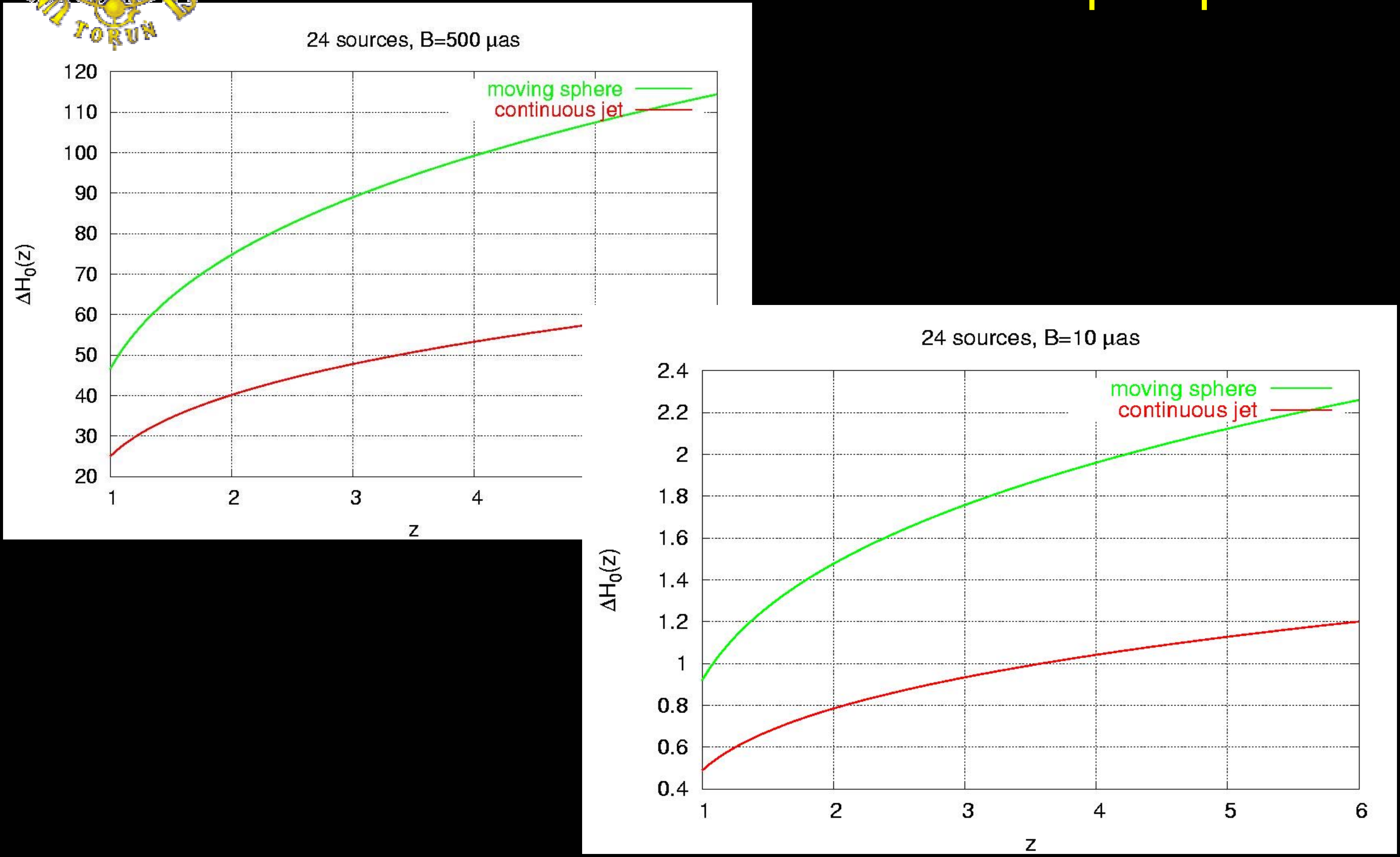
Future prospects



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Conclusions

The preliminary value of Hubble constant is jointly consrained to be H0 = 73 ± 19 at 3 sigma level

The accuracy of the method could significantly be improved provided that:

1) resolution increased (with future VLBI projects eg. VSOP 2) would allow to reach smaller proper motions, bigger beaming factors, weaker sources and larger number of sources
2) number of sources increased (would reduce jet uncertanities)
3) tuning jet's model is performed

Predicted accuracy for Hubble constant constraint would reach 2% at z=3 or better at smaller redshifts.

This would give an independent approach from luminosity distance measurments in SNIa projects and help reduce degeneracies in parameter space.