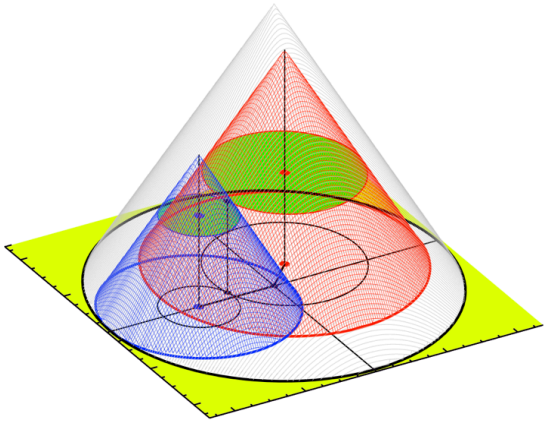

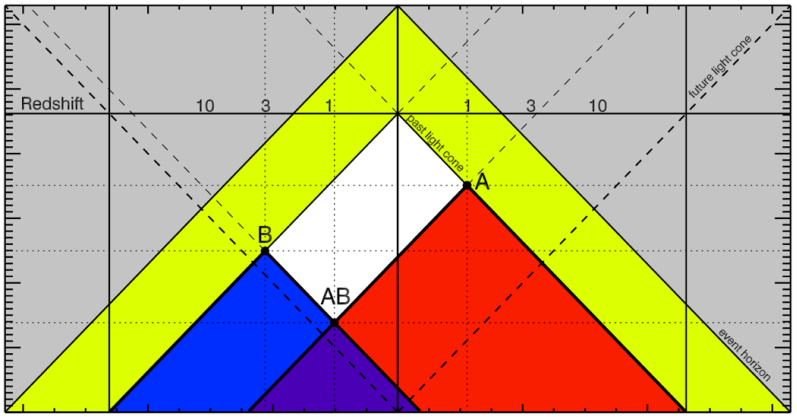

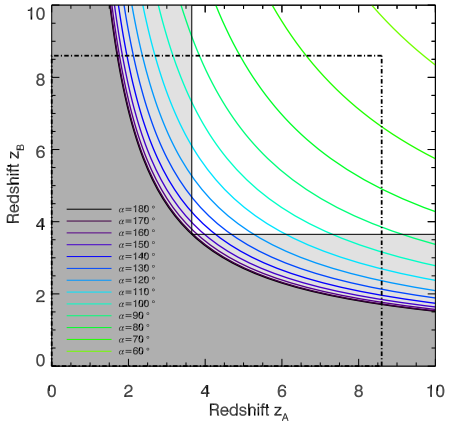

THE SHARED CAUSAL PASTS AND FUTURES OF COSMOLOGICAL EVENTS

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"*The Shared Causal Pasts and Futures of Cosmological Events*"
Friedman, Kaiser & Gallicchio 2013
Phys. Rev. D. submitted
(**arXiv:1305.3943**)

Prof. David Kaiser,
MIT Center for Theoretical Physics

Dr. Jason Gallicchio,
U. Chicago Kavli Institute for Cosmological Physics

South Pole Telescope

OUTLINE

1. The Big Picture

2. Shared Causal Pasts (*& Futures*)

Friedman, Kaiser, & Gallicchio 2013, Phys. Rev D. submitted.
(arXiv:1305.3943)

3. *Future Work:*
Cosmic Bell - Gedankenexperiment

Gallicchio, Friedman, & Kaiser 2013 *in prep.*
Friedman+2013 *in prep.*

THE BIG PICTURE

For pairs of cosmic events with arbitrary redshifts and angular separation on the sky:

1. Do they have a shared causal past since the hot big bang (or the end of inflation)?

Could any other events (post inflation) have jointly influenced both? Are the events independent or correlated (since inflation)?

2. Can either event signal the other in the future?
3. What if space is curved?
4. How could this help to test Quantum Mechanics?

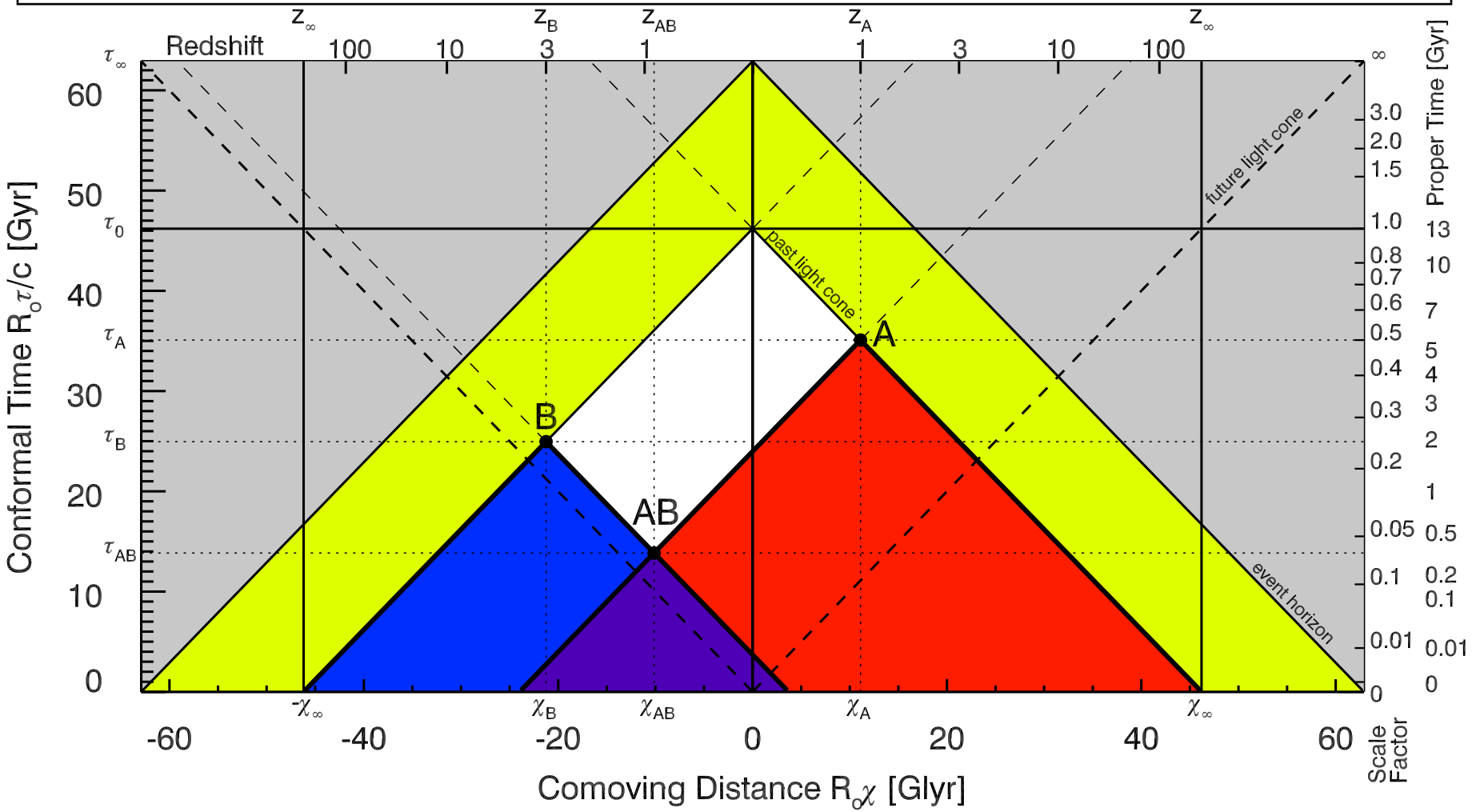
MAIN RESULTS

For *Planck* cosmological parameters

CAUSAL PASTS: Pairs of events on opposite sides of the sky both with z > 3.65 have no shared causal past with each other or Earth since the hot big bang (or end of inflation)
Constraints more complex for angles < 180 deg

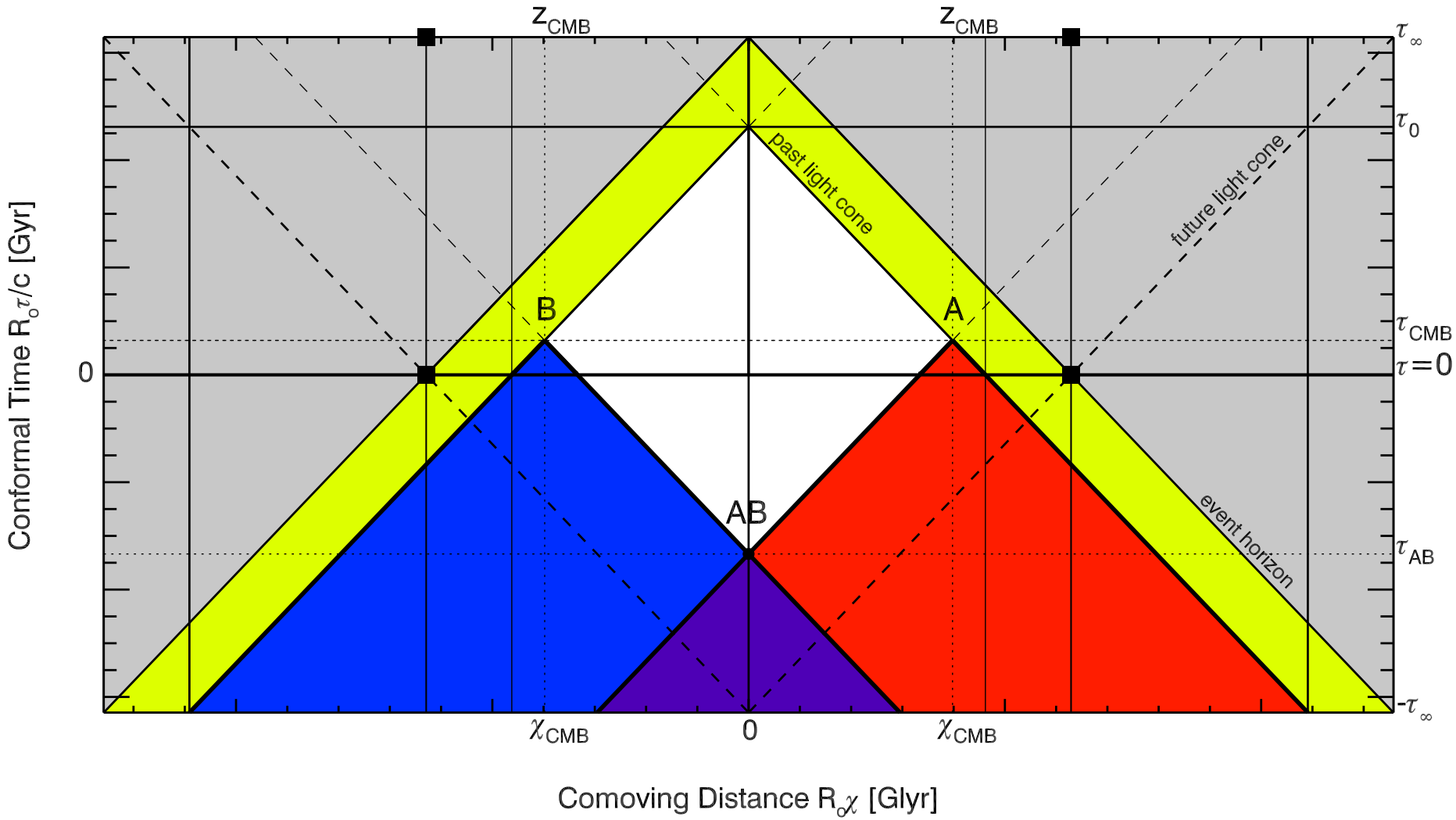
CAUSAL FUTURES: Events with z > 1.87 are beyond the cosmic event horizon. Just emitted the last photons that will ever reach us at t=∞. We can never signal them in the future.

DO TWO COSMOLOGICAL EVENTS HAVE A SHARED PAST?



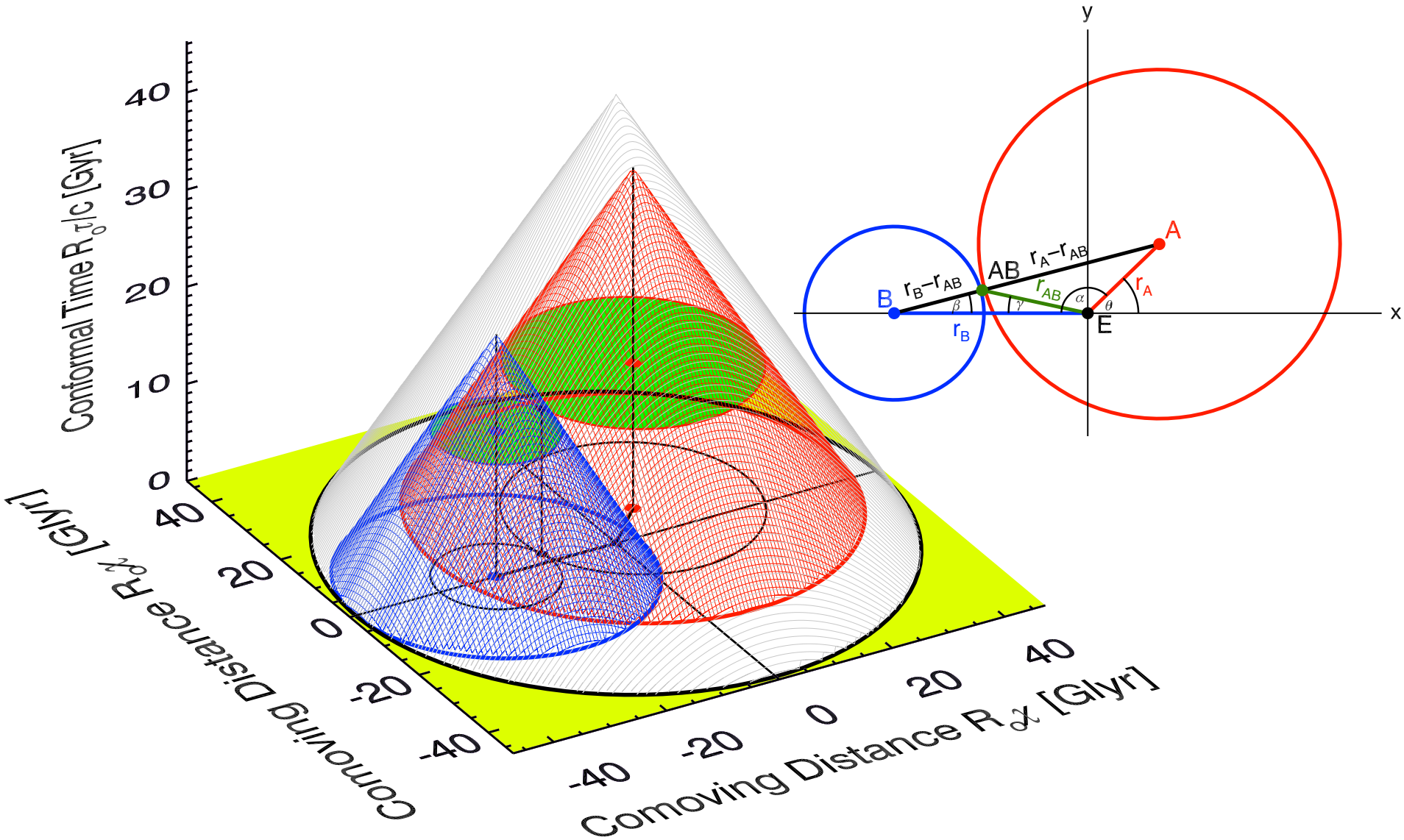
Since the hot big bang or the end of inflation

INFLATION & THE HORIZON PROBLEM

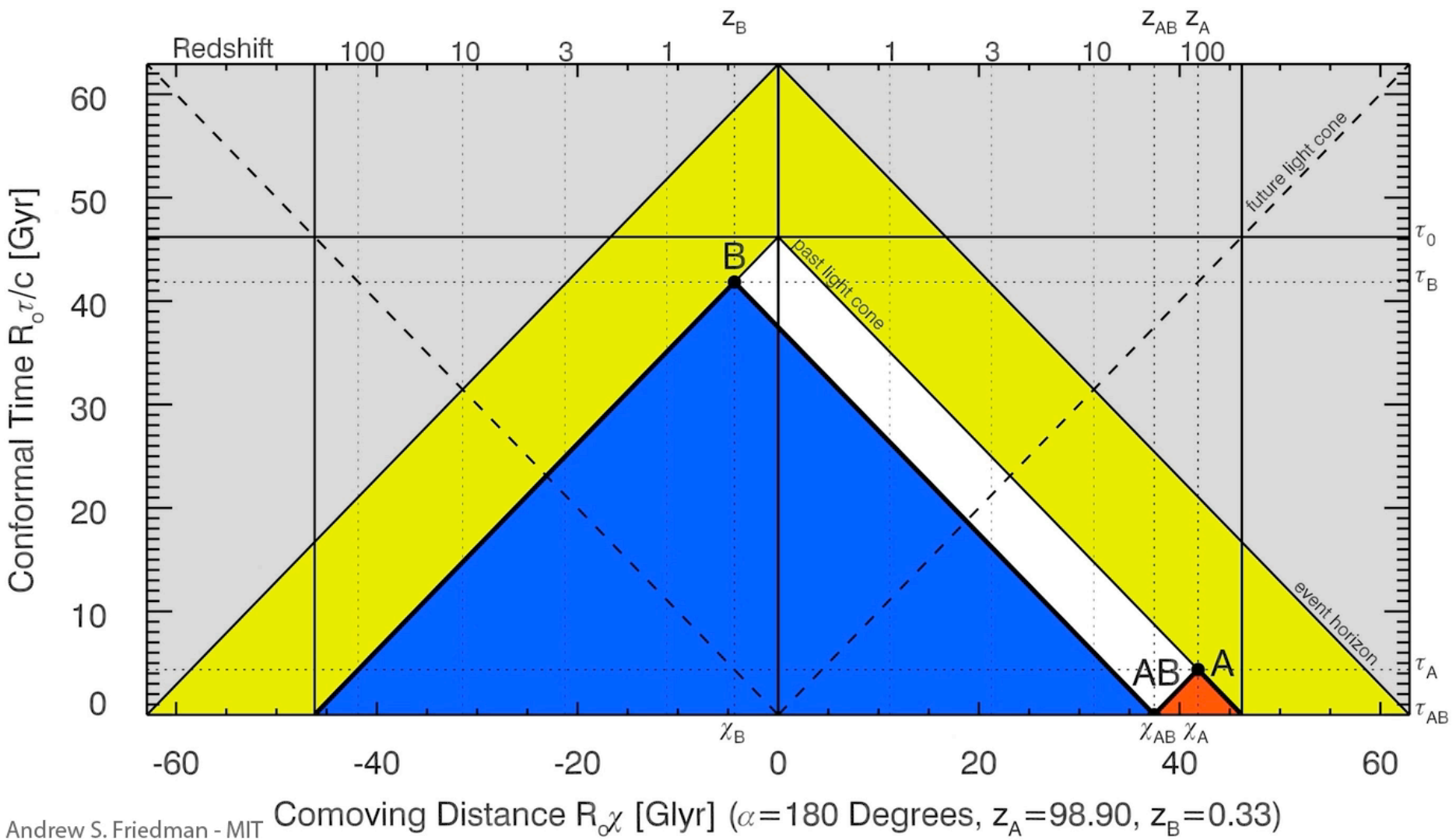


If enough inflation happened to solve the horizon problem, ALL events in our past LC have shared pasts

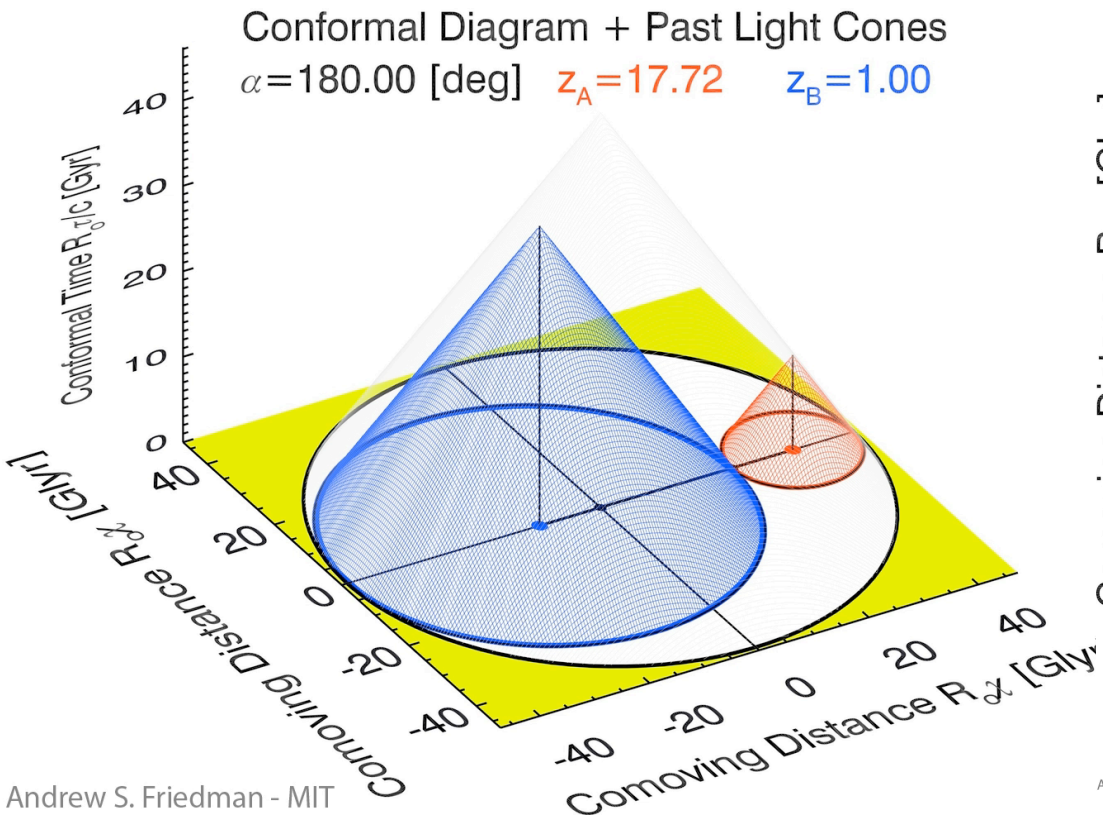
PAST LIGHT CONE INTERSECTION

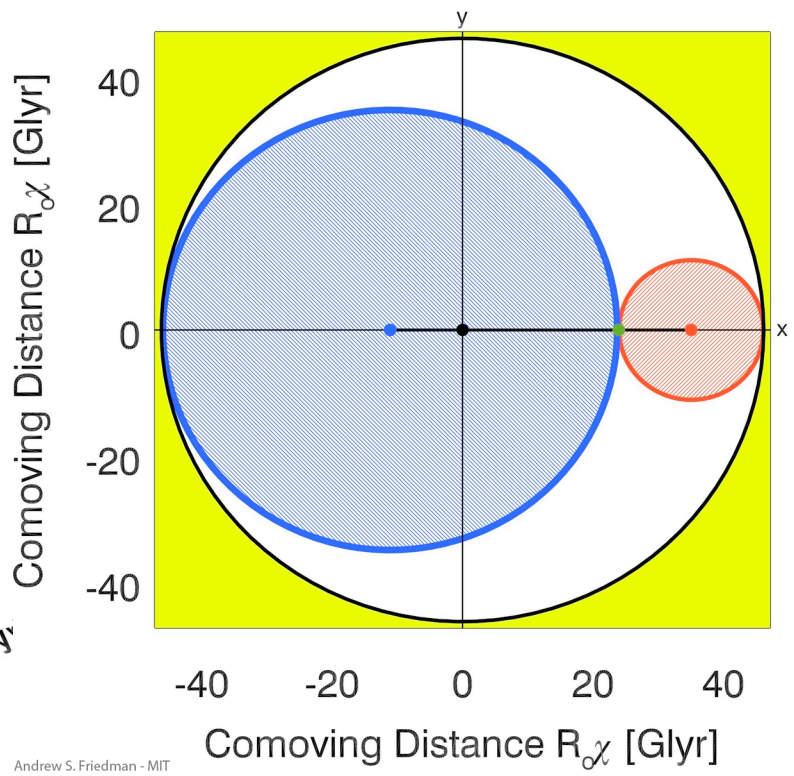


LC INTERSECTION @BIG BANG

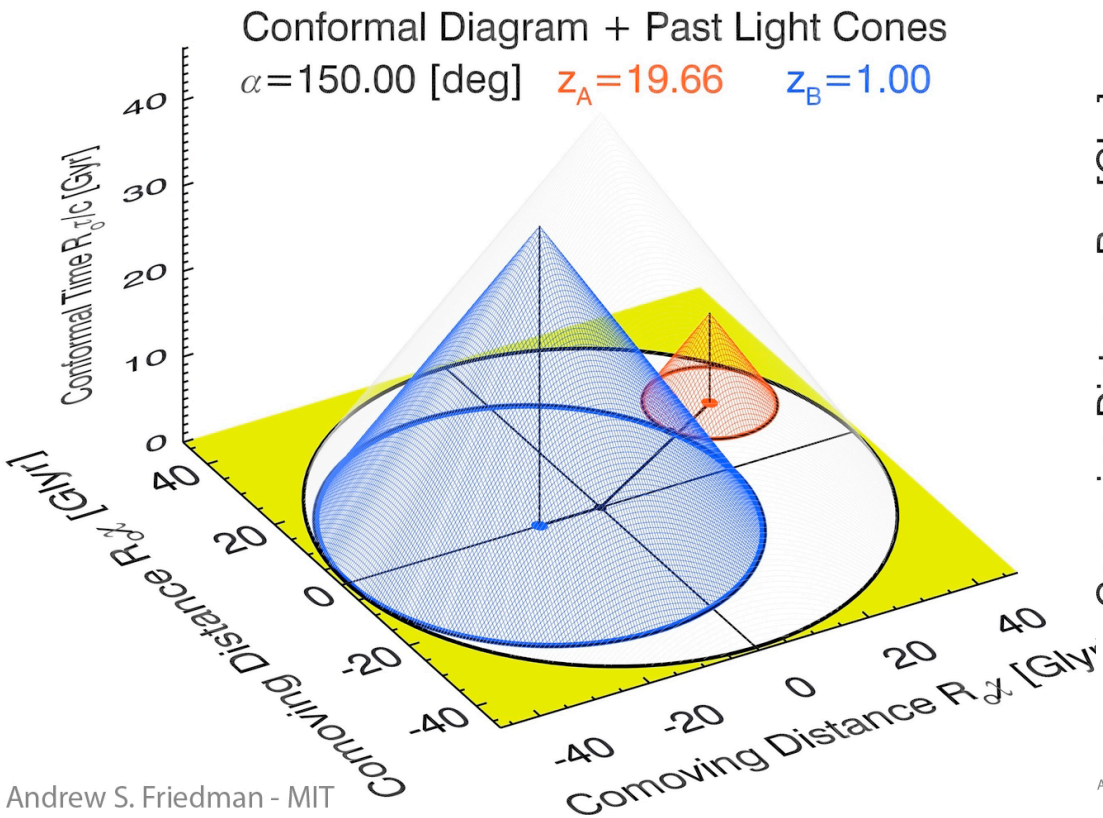


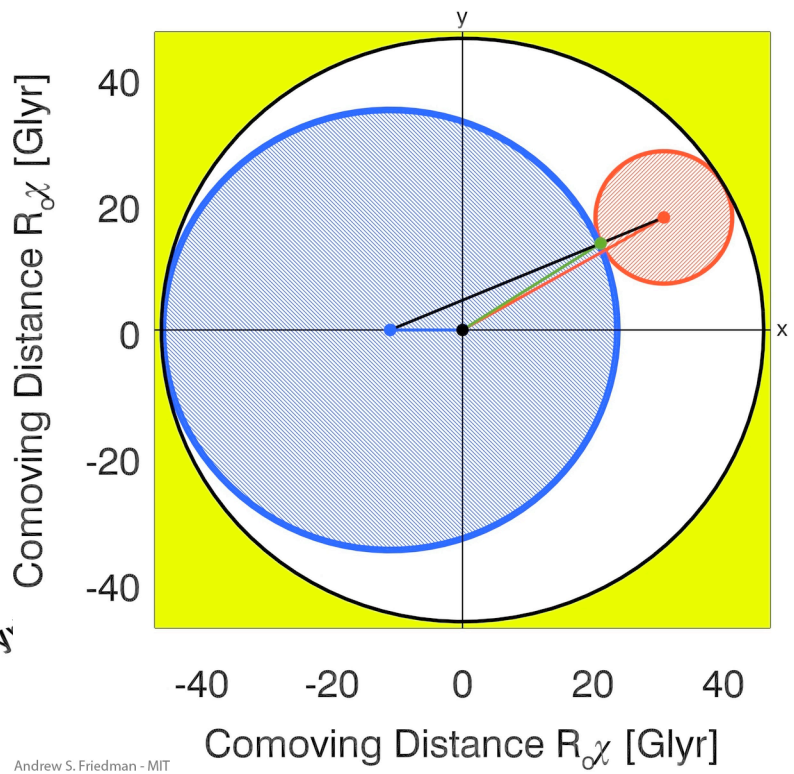
LC INTERSECTION @BIG BANG

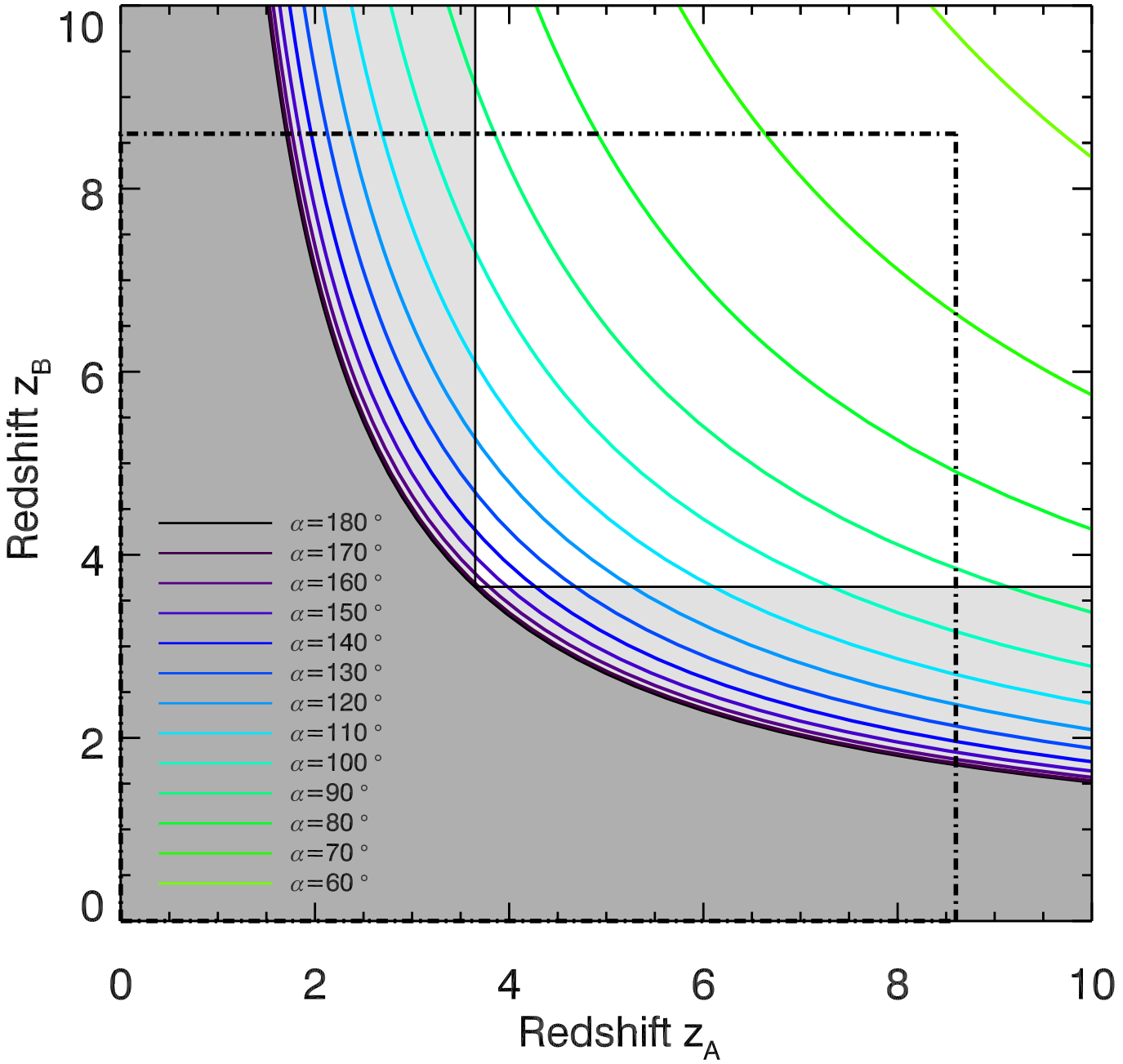




LC INTERSECTION @BIG BANG







Do A,B have a shared past?

Dark Gray
YES: any angle

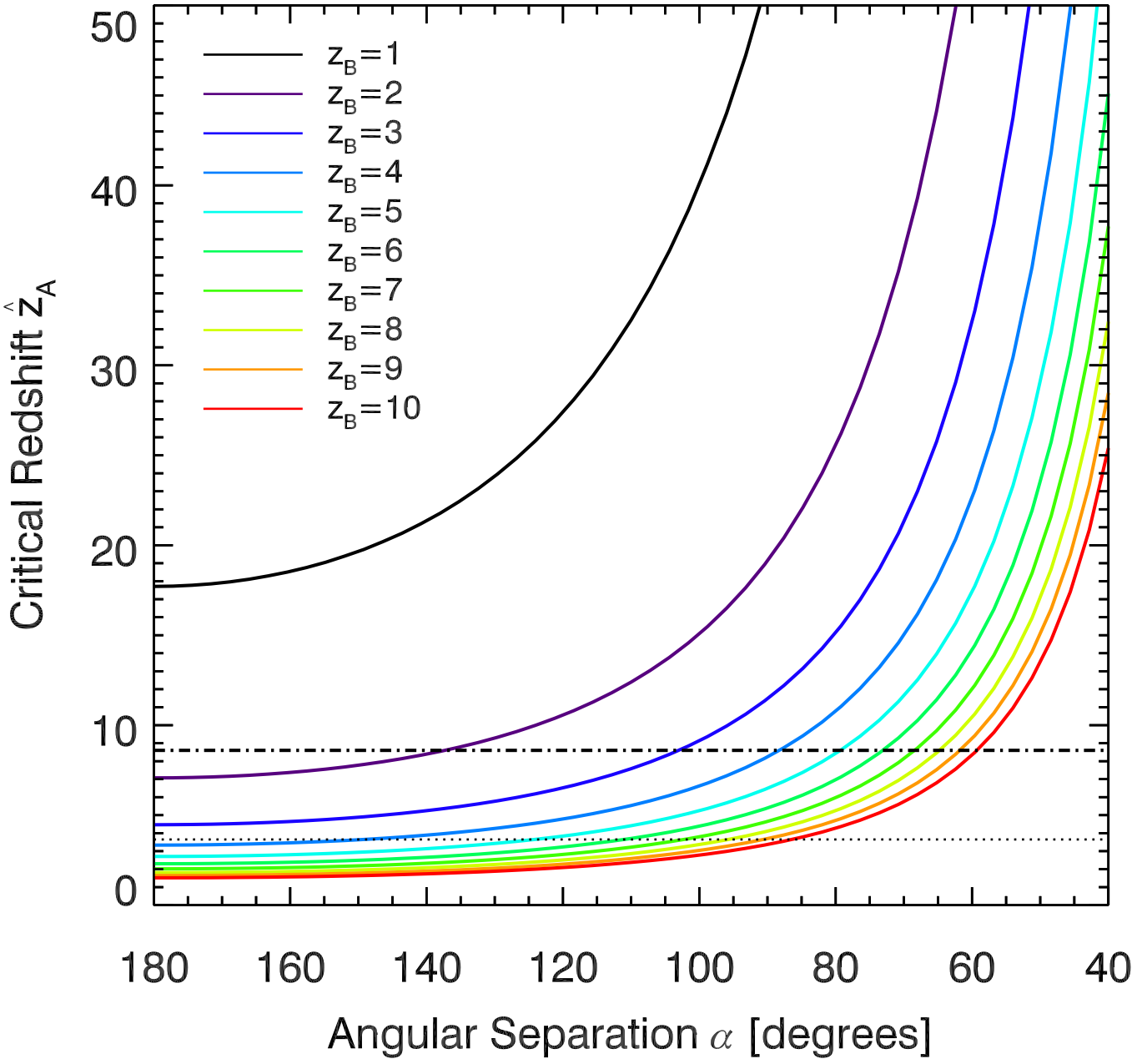
Light Gray / White
NO: large angles

...with Earth?

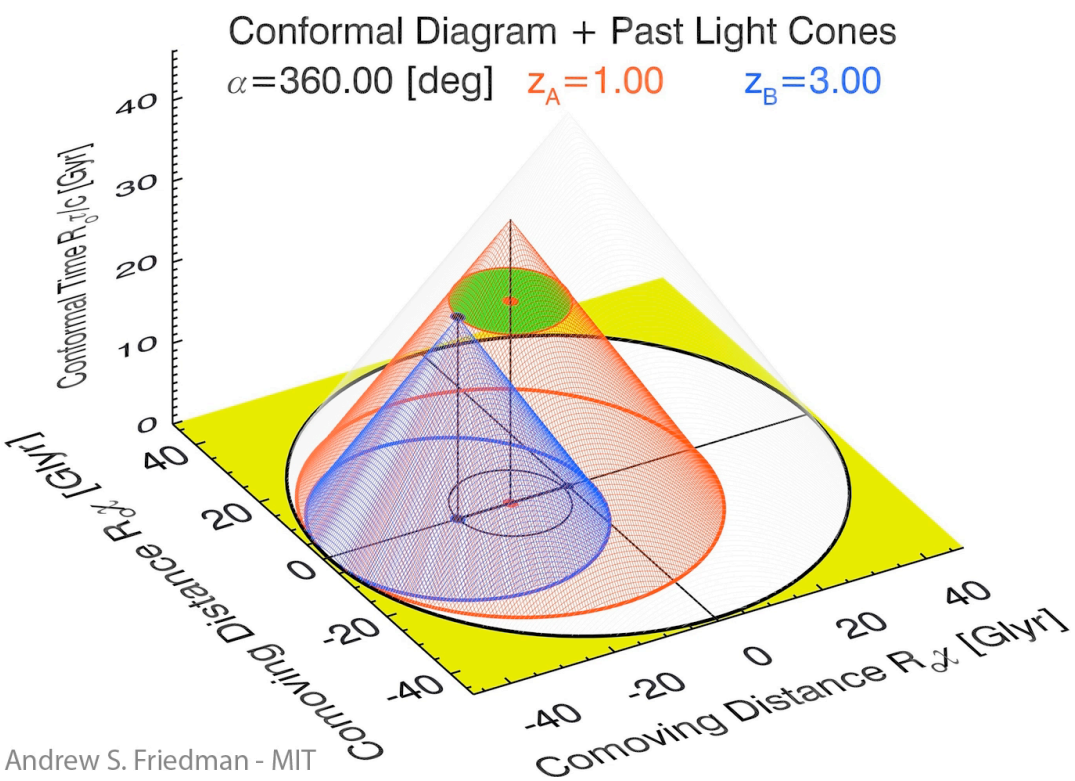
Dark Gray
YES

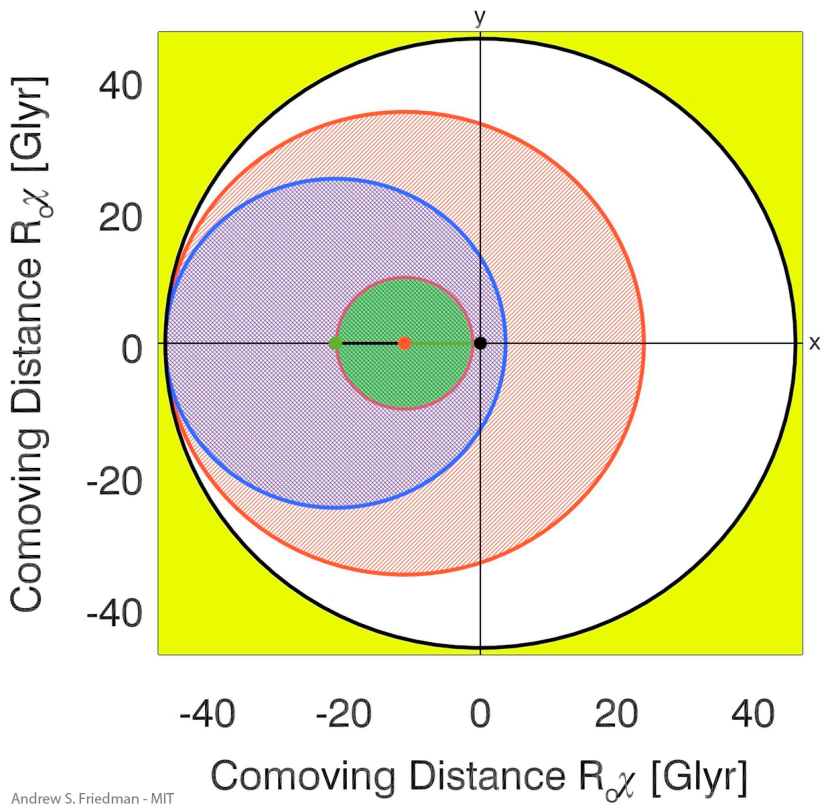
White
NO: A and B

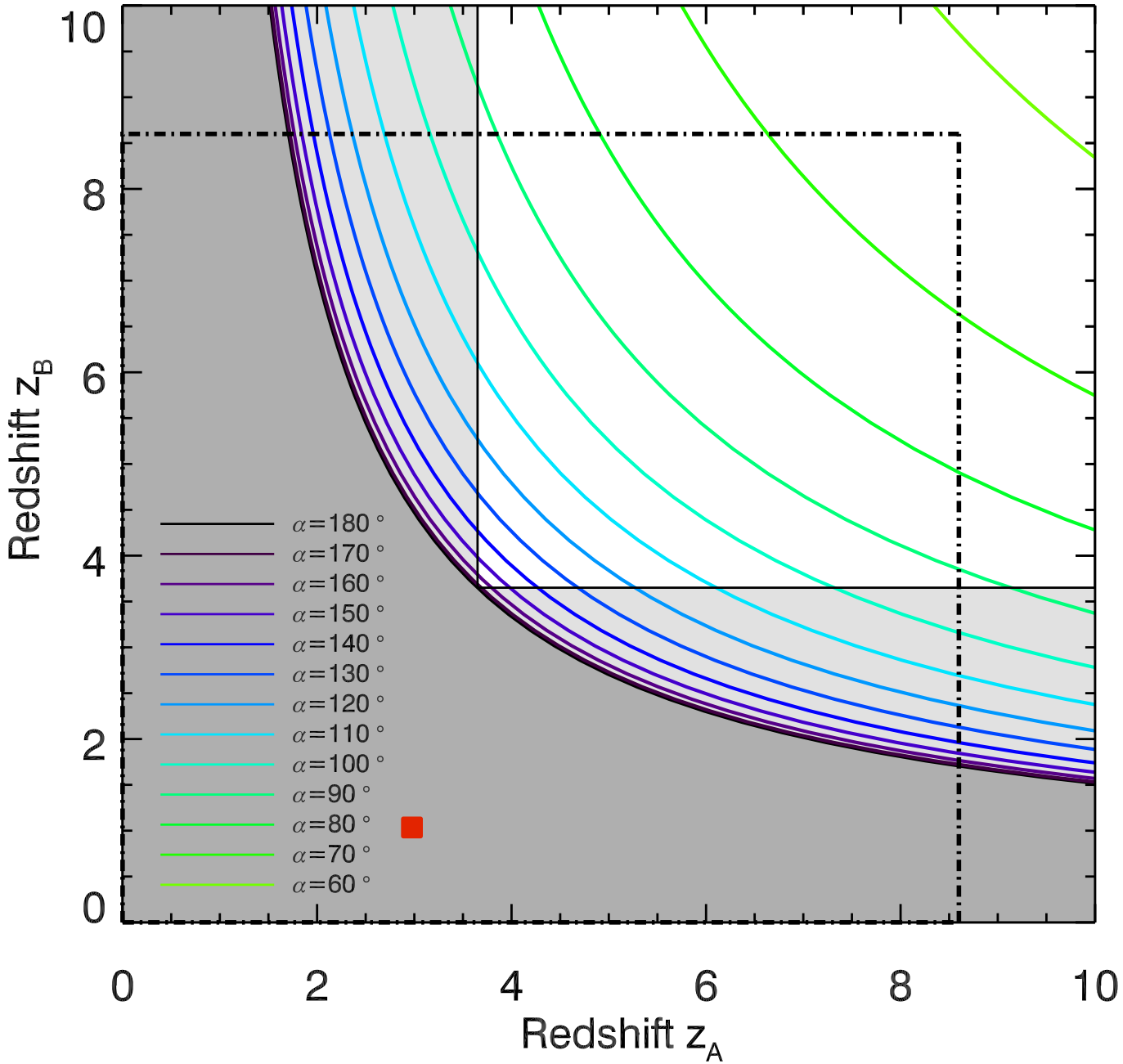
Light Gray
YES:
Either A or B


50
40
30
20
10
0
Critical Redshift $\hat{z}_A$
z_B=1
z_B=2
z_B=3
z_B=4
z_B=5
z_B=6
z_B=7
z_B=8
z_B=9
z_B=10
180
160
140
120
100
80
60
40
Angular Separation α [degrees]

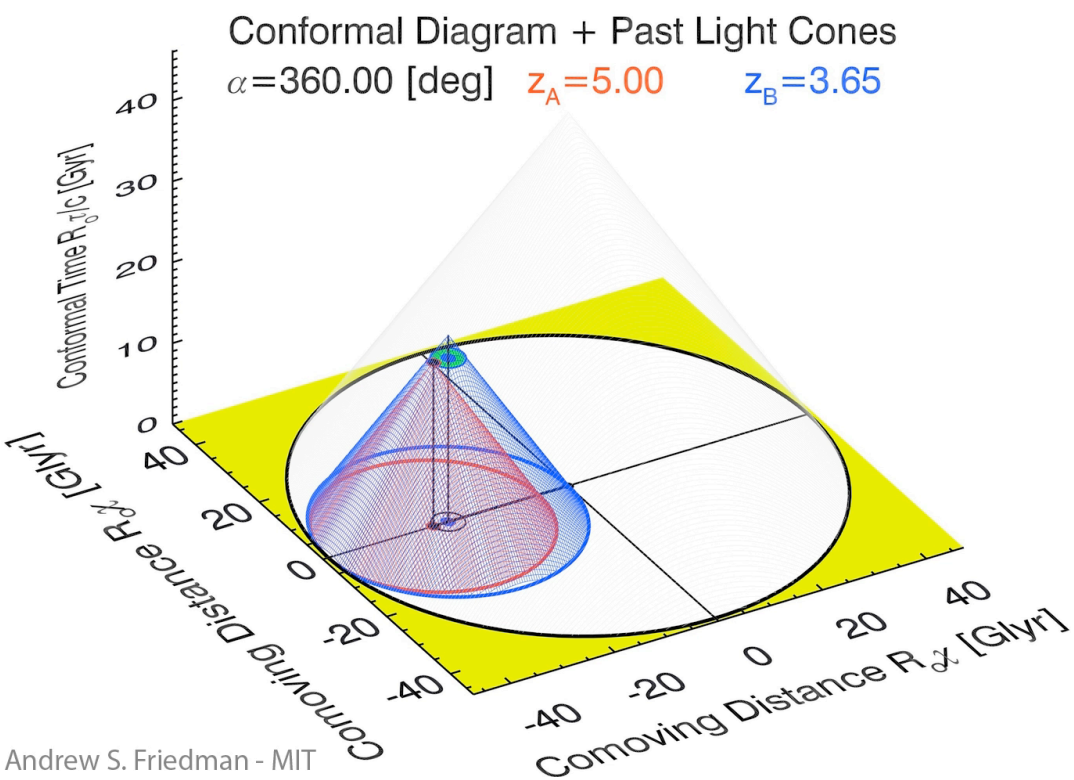
FIX REDSHIFTS, CHANGE ANGLE

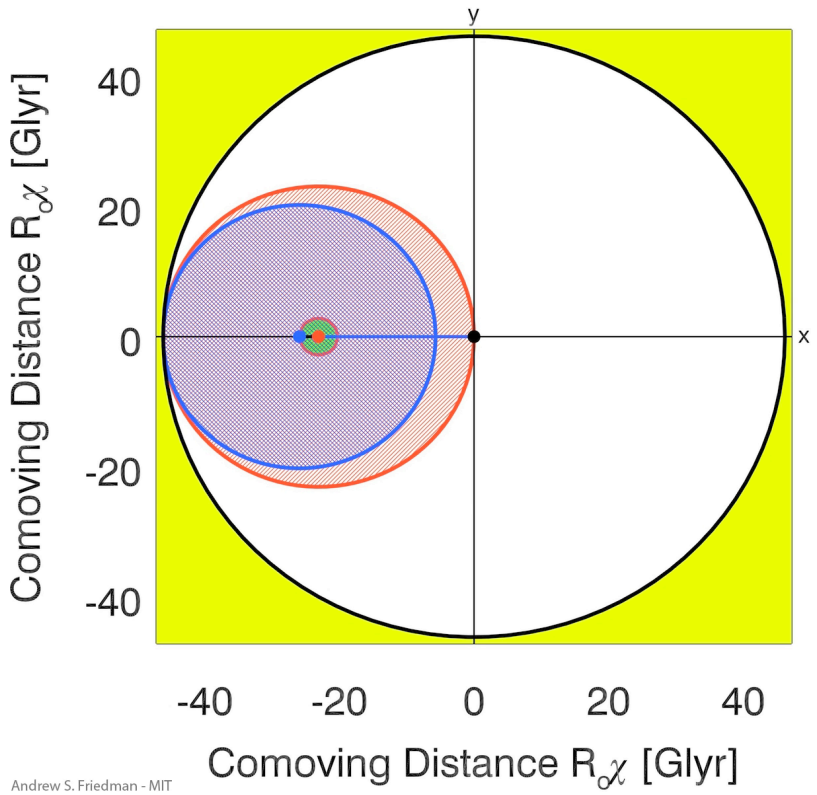


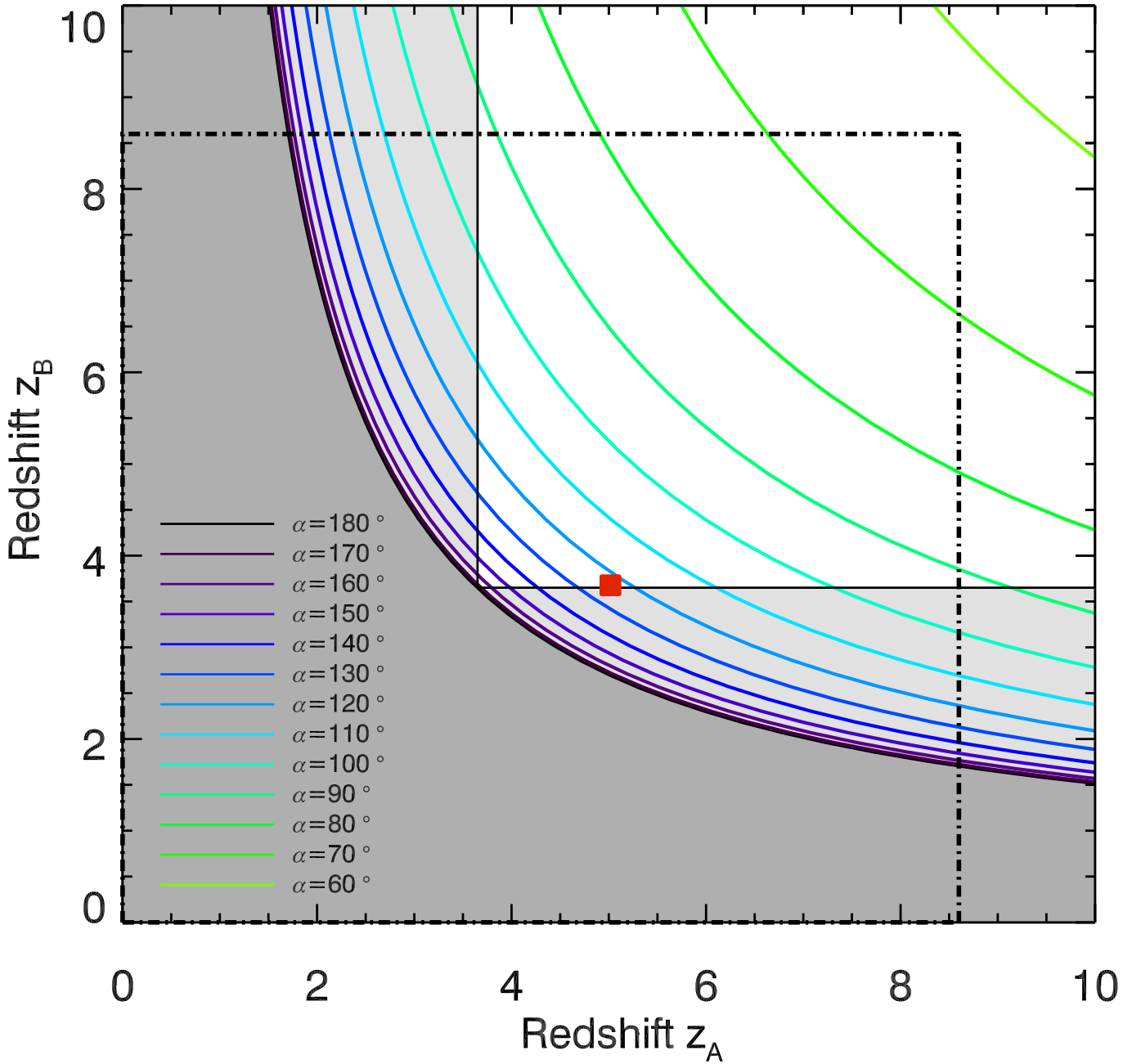



Redshift z_B
Redshift z_A
0
2
4
6
8
10
α=180 °
α=170 °
α=160 °
α=150 °
α=140 °
α=130 °
α=120 °
α=110 °
α=100 °
α=90 °
α=80 °
α=70 °
α=60 °

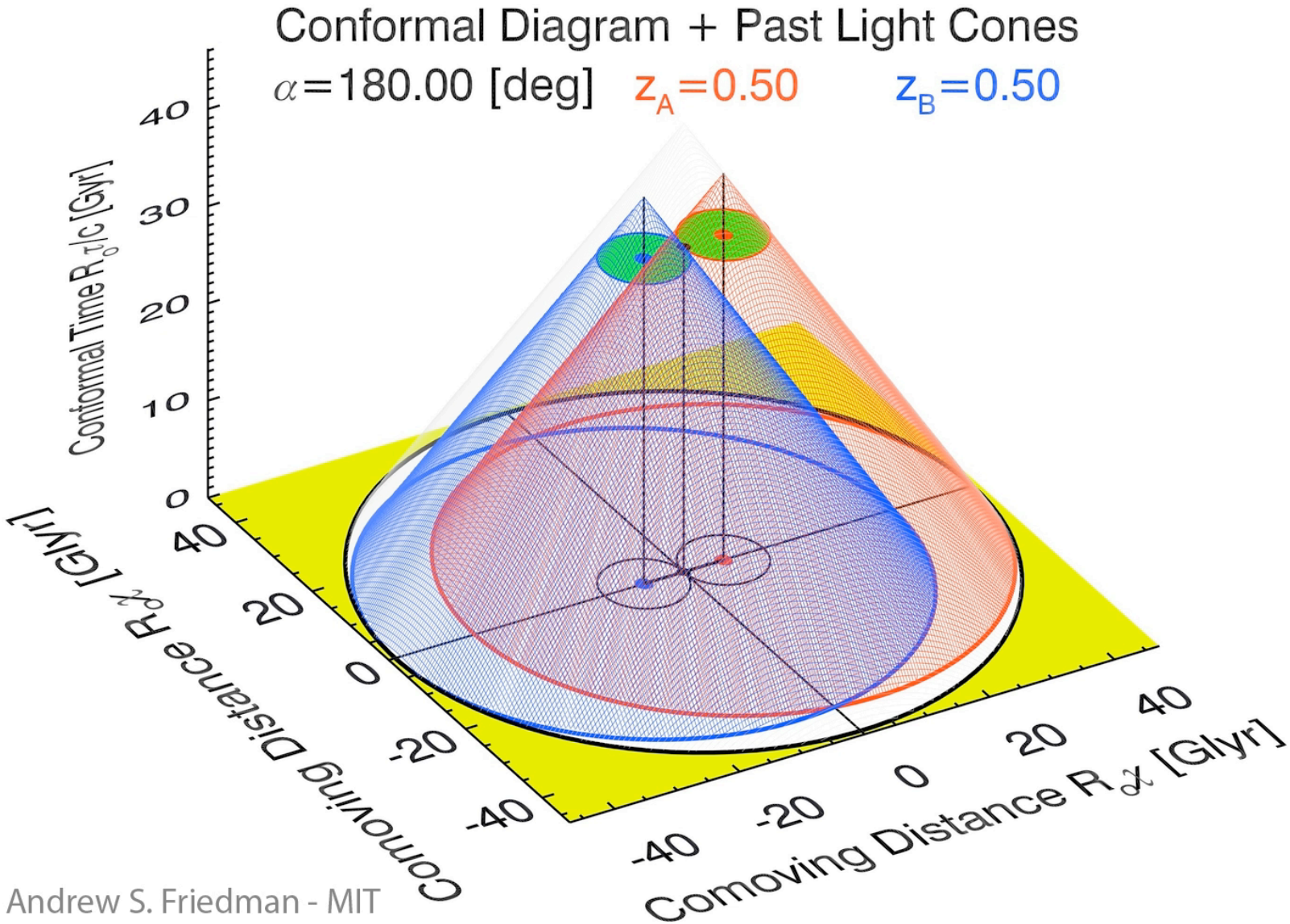
FIX REDSHIFTS, CHANGE ANGLE



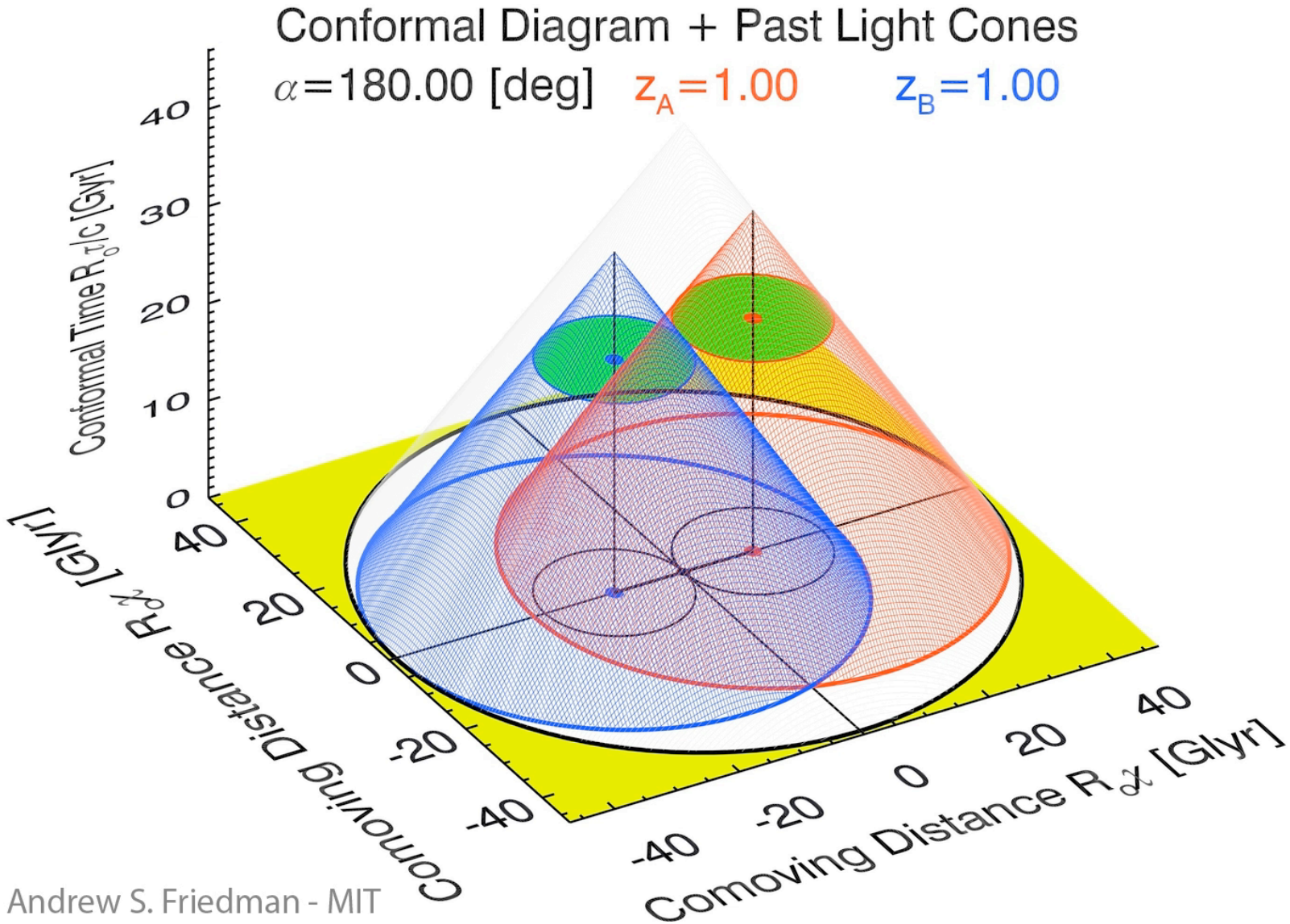



Redshift z_B
Redshift z_A
0
2
4
6
8
10
α=180 °
α=170 °
α=160 °
α=150 °
α=140 °
α=130 °
α=120 °
α=110 °
α=100 °
α=90 °
α=80 °
α=70 °
α=60 °

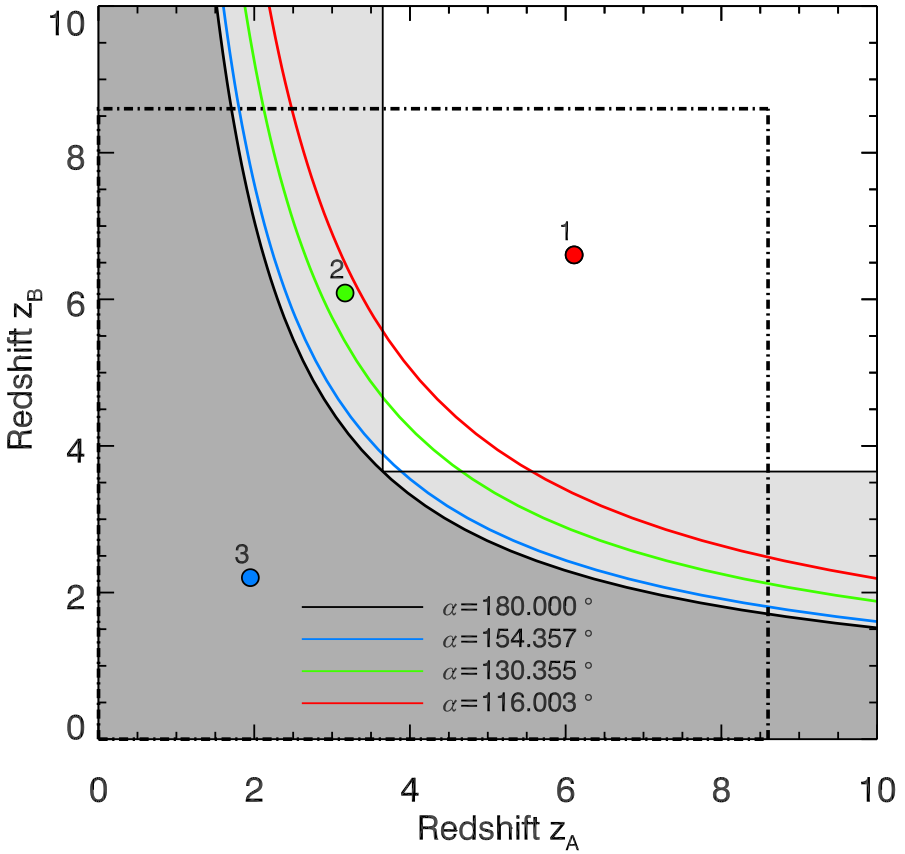
FIX ANGLE, z_A, CHANGE z_B



FIX ANGLE, CHANGE Z = Z_A = Z_B



EXAMPLE QUASAR PAIRS



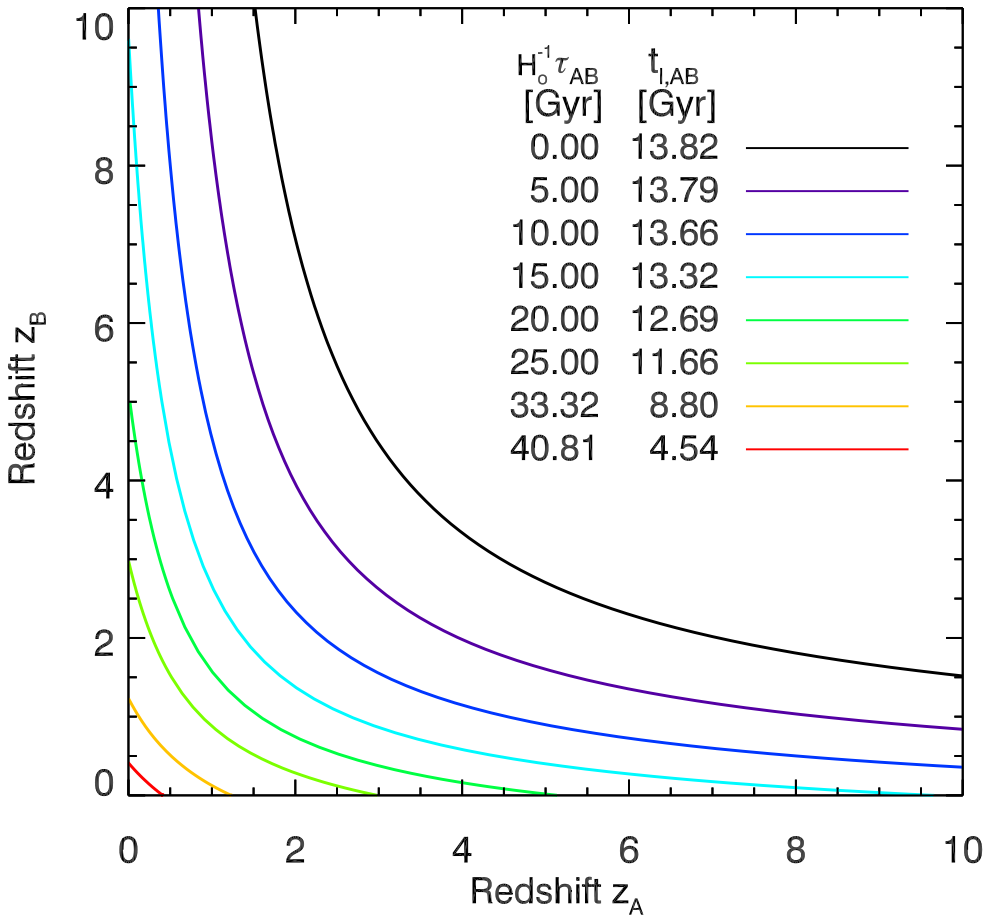
pair 3 - YES shared past with each other & Earth

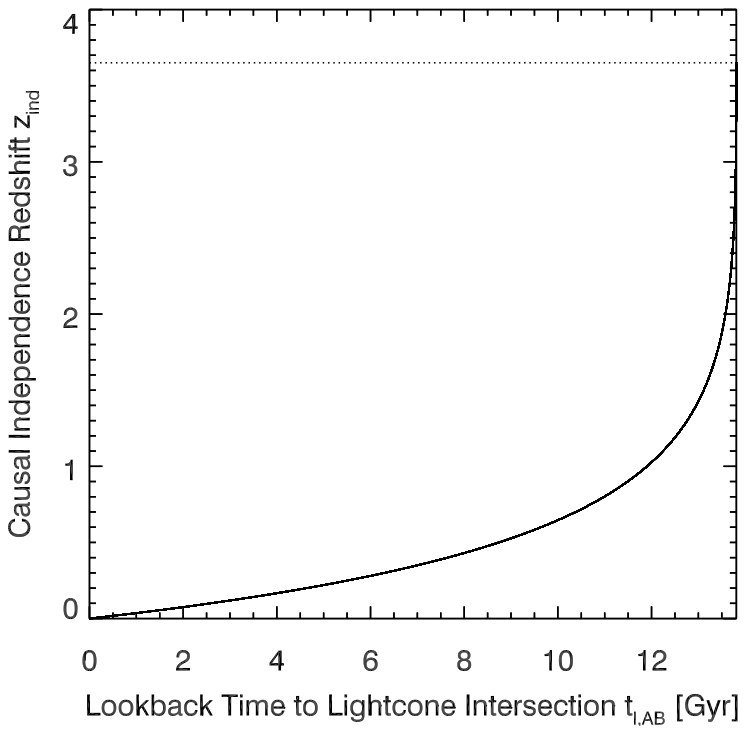
pair 2 - NO shared past with each other, but A_2 has shared past with Earth

pair 1 - NO shared past with each other or Earth

Pair	Separation Angle α_i [deg]	Event Labels	Redshifts z_{Ai}, z_{Bi}	Object Names	RA [deg]	DEC [deg]	R [mag]	B [mag]
1	116.003	A_1	6.109	SDSS_J031405.36-010403.8	48.5221	-1.0675	16.9	20.1
		B_1	6.606	SDSS_J171919.54+602241.0	259.8313	60.3781	18.6	16.9
2	130.355	A_2	3.167	KX_257	24.1229	15.0481	16.7	17.8
		B_2	6.086	SDSS_J110521.50+174634.1	166.3396	17.7761	16.4	25.1
3	154.357	A_3	1.950	Q_0023-4124	6.5496	-41.1381	14.2	15.4
		B_3	2.203	HS_1103+6416	166.5446	64.0025	14.7	15.4

SHARED PASTS AFTER BB





Event	Redshift z	Lookback Time $t_{l_{AB}}$ [Gyr]	Proper Time t_{AB} [Gyr]	Conformal Time $H_0{}^{-1}\tau_{AB}$ [Gyr]	causal-independence redshift $\tilde{z}_{\rm ind}(\tau_{AB})$
Big Bang	∞	13.81	0	0	3.65
Galaxy Formed	1.23	8.80	5.01	33.32	0.506
Earth Formed	0.41	4.54	9.27	40.81	0.195
First Eukaryotes	0.124	1.65	12.16	44.45	0.061

CONCLUSIONS

We derived whether pairs of cosmic events have a shared causal past since inflation; for arbitrary redshifts, angular separations, & curvature.

Friedman, Kaiser, & Gallicchio 2013, Phys. Rev D. sub. (arXiv:1305.3943)

In our flat universe, thousands of pairs of objects (e.g. quasars) have no shared past since the hot big bang (end of inflation).

Such object pairs are promising targets for experiments that require as much causal independence as possible, e.g. fundamental tests of quantum mechanics with entangled particles.

FUTURE WORK

Cosmic Bell - Gedankenexperiment

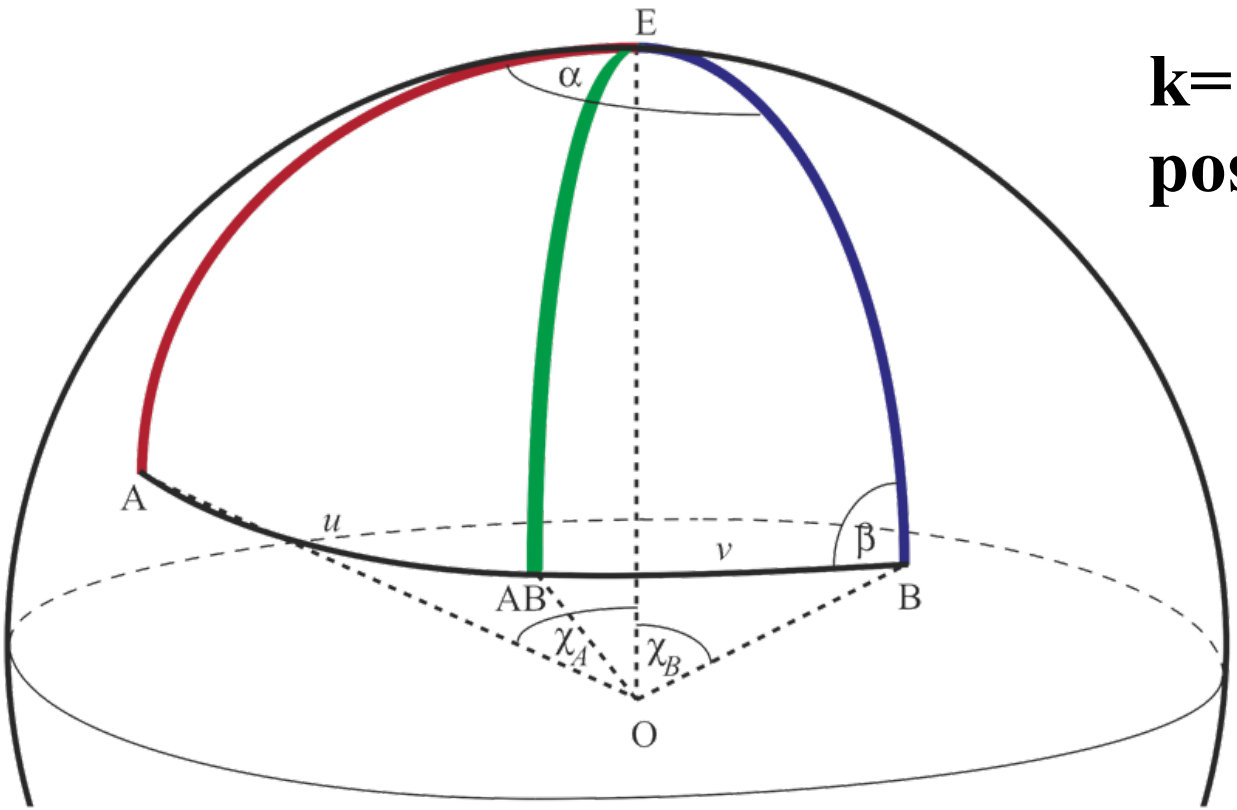
Close freedom of choice loophole in Bell test with entangled particles by setting polarizers with cosmic photons from causally independent sources.

Gallicchio, Friedman, & Kaiser 2013 *in prep*.

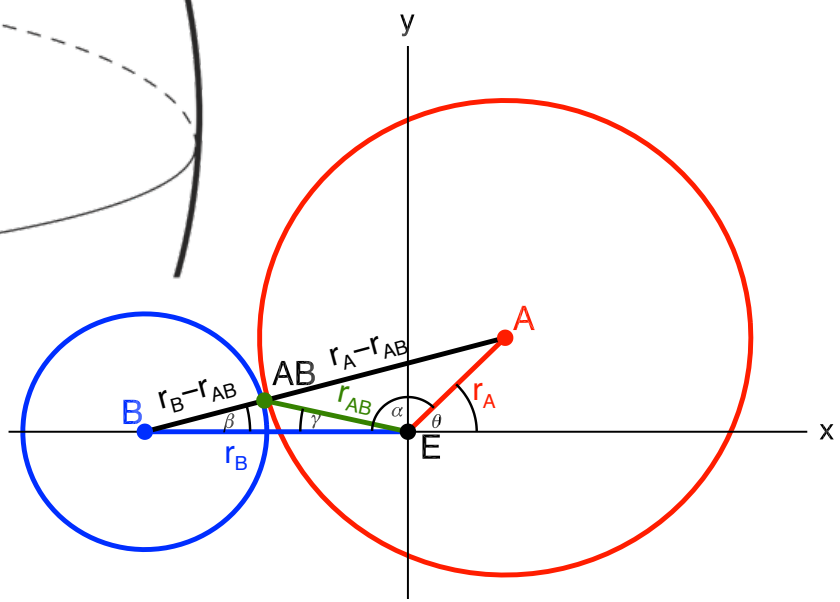
Determine which quasar pairs (from existing database of > 1 millions objects) satisfy causal independence. Choose candidate pairs. Design observational program.

Friedman+2013 *in prep*.

NONZERO CURVATURE



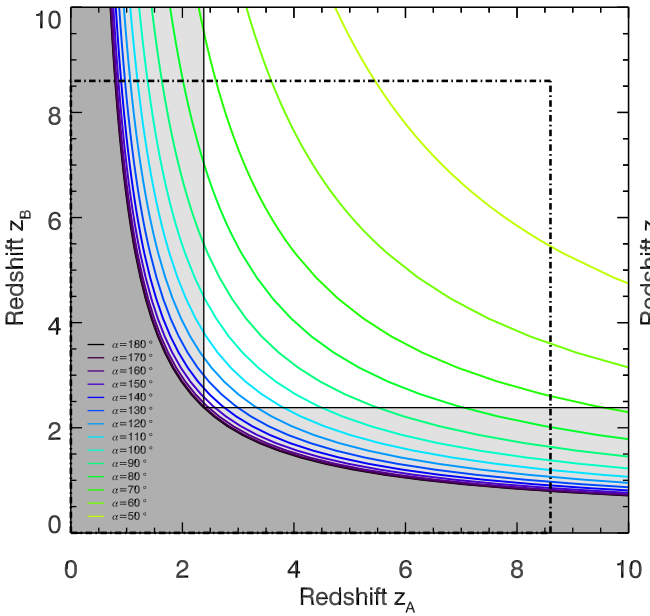
k=1 CLOSED FRW
positive curvature



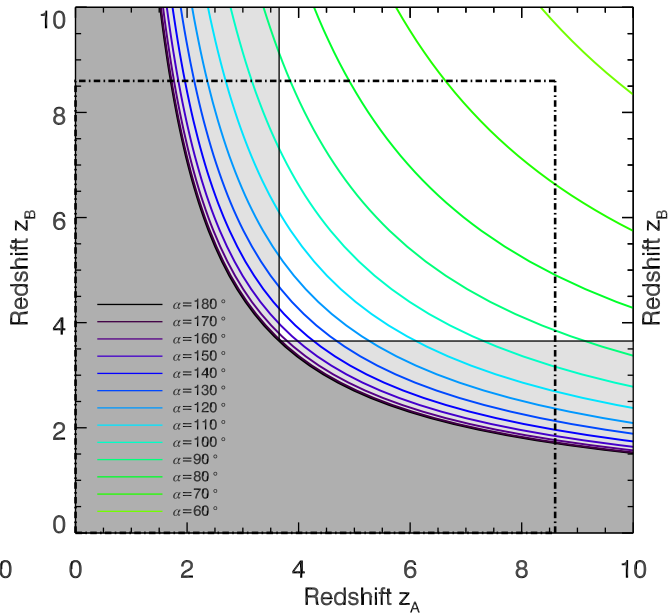
k=0 FLAT FRW
zero curvature

NONZERO CURVATURE

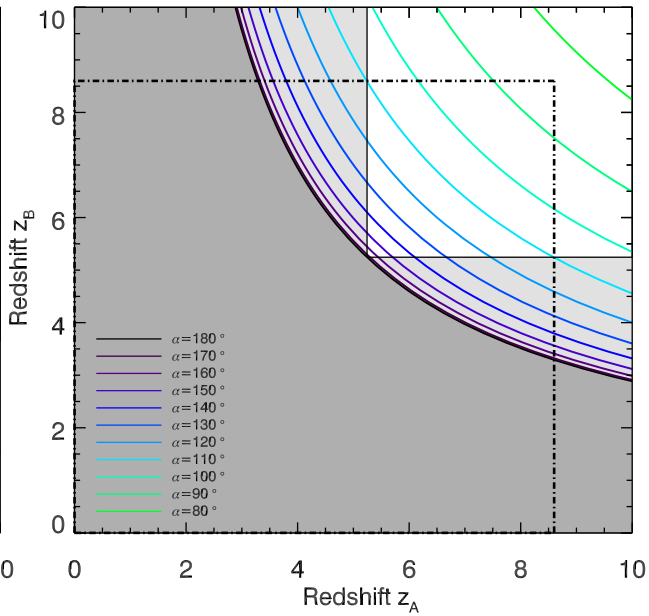
CLOSED



FLAT



OPEN



SHARED CAUSAL FUTURES

Can A signal B before time ends (and vice versa)?