The Coming Era of Radio Cosmology

"Trust me I'm a theorist"

1) Neutral Hydrogen Intensity Mapping
2) The Cosmic Potential of Fast Radio Bursts

Albert Stebbins
Cosmic Visions (Dark Energy)

Fermilab
2015-11-10

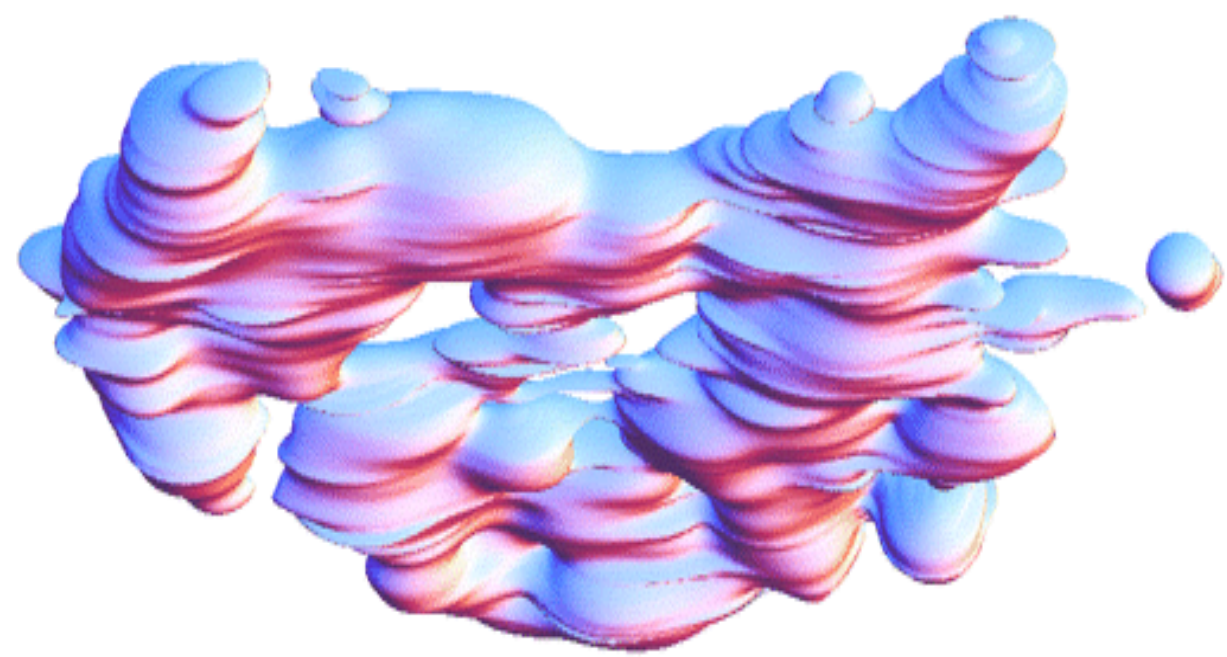
Hydrogen Intensity Mapping

Map galaxy spatial distribution to constrain dark energy

Traditional Redshift Survey
e.g SDSS, DES, DESI
"galaxy points"

Angular resolution easy
Redshift resolution harder

21cm Intensity Maps
sampled continuous field



Redshift resolution easy
Angular resolution harder

How do you do it?

“Tianlai” new radio telescope array in western China

Special purpose telescope design

Very radio quiet site

“Tianlai”

China/France/US/Canada

1 of 2 facilities built so far

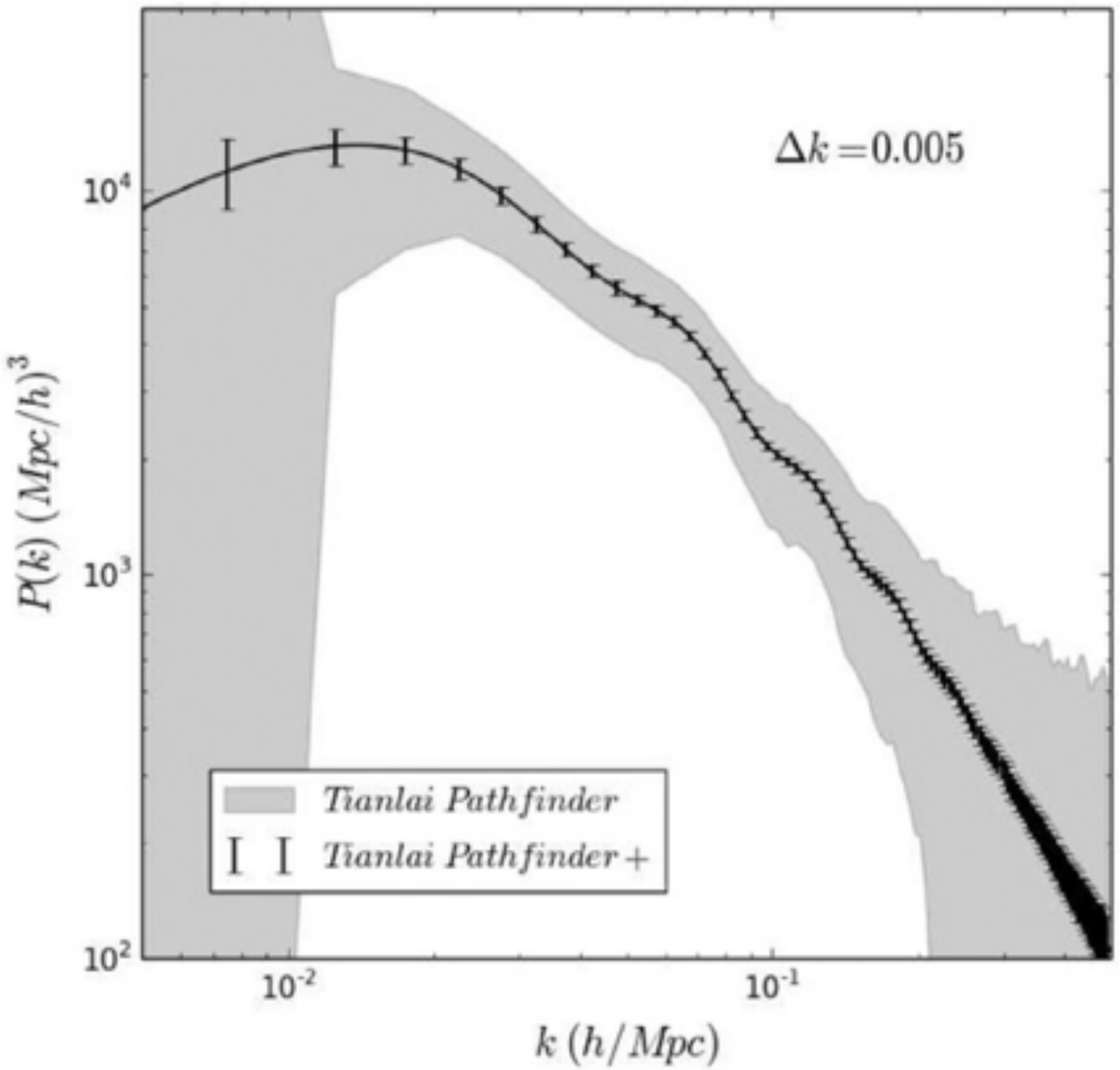
interested in more US participation

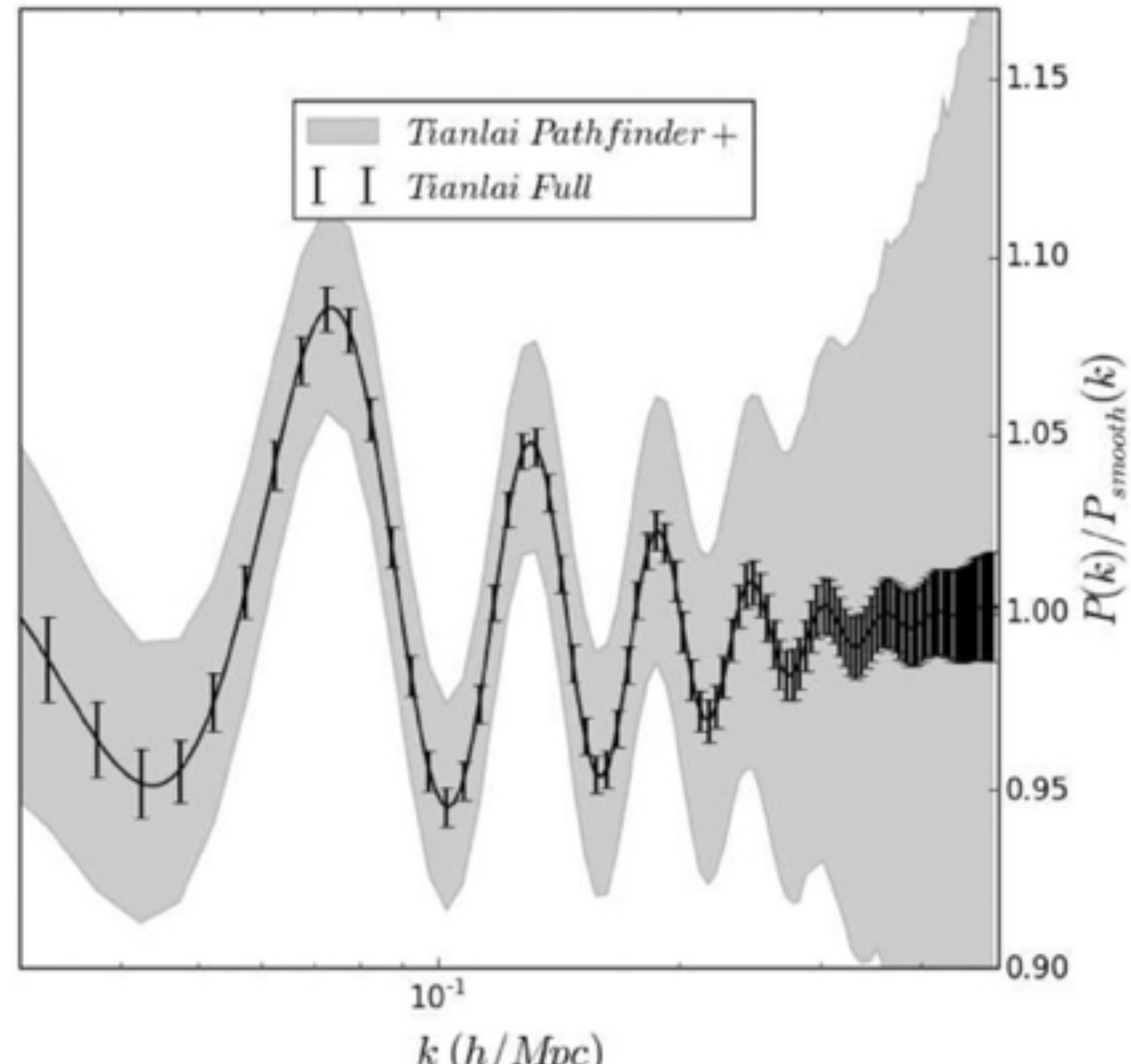
2nd in Canada “CHIME”

closed shop

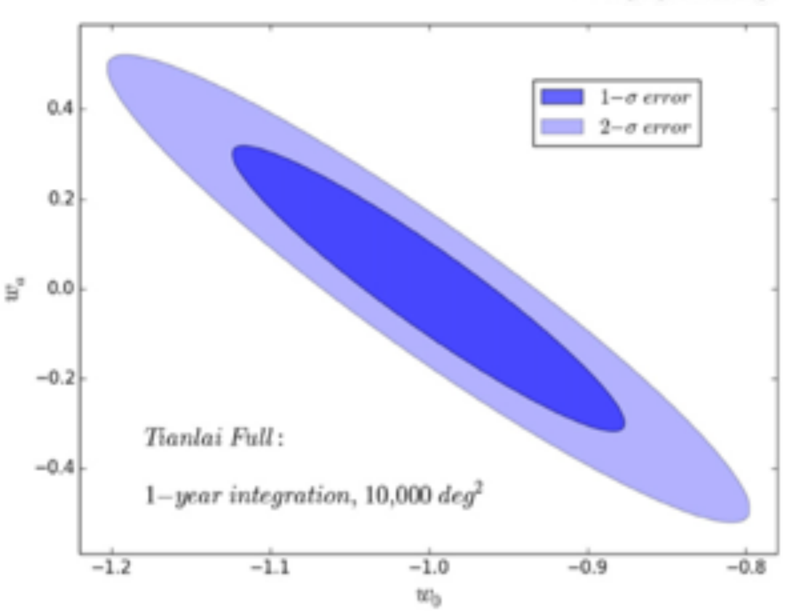
Tianlai: Science Yield

timeline: pathfinder ⇒ pathfinder^{+} ⇒ full





pathfinder(+) surveys 50 Gpc^3 ~DES



Independent projection: (Bull et al. 2015)

DETF FoM

full: 383

compare to Stage IV: 400

DES: 72 (BAO) 264 (total)

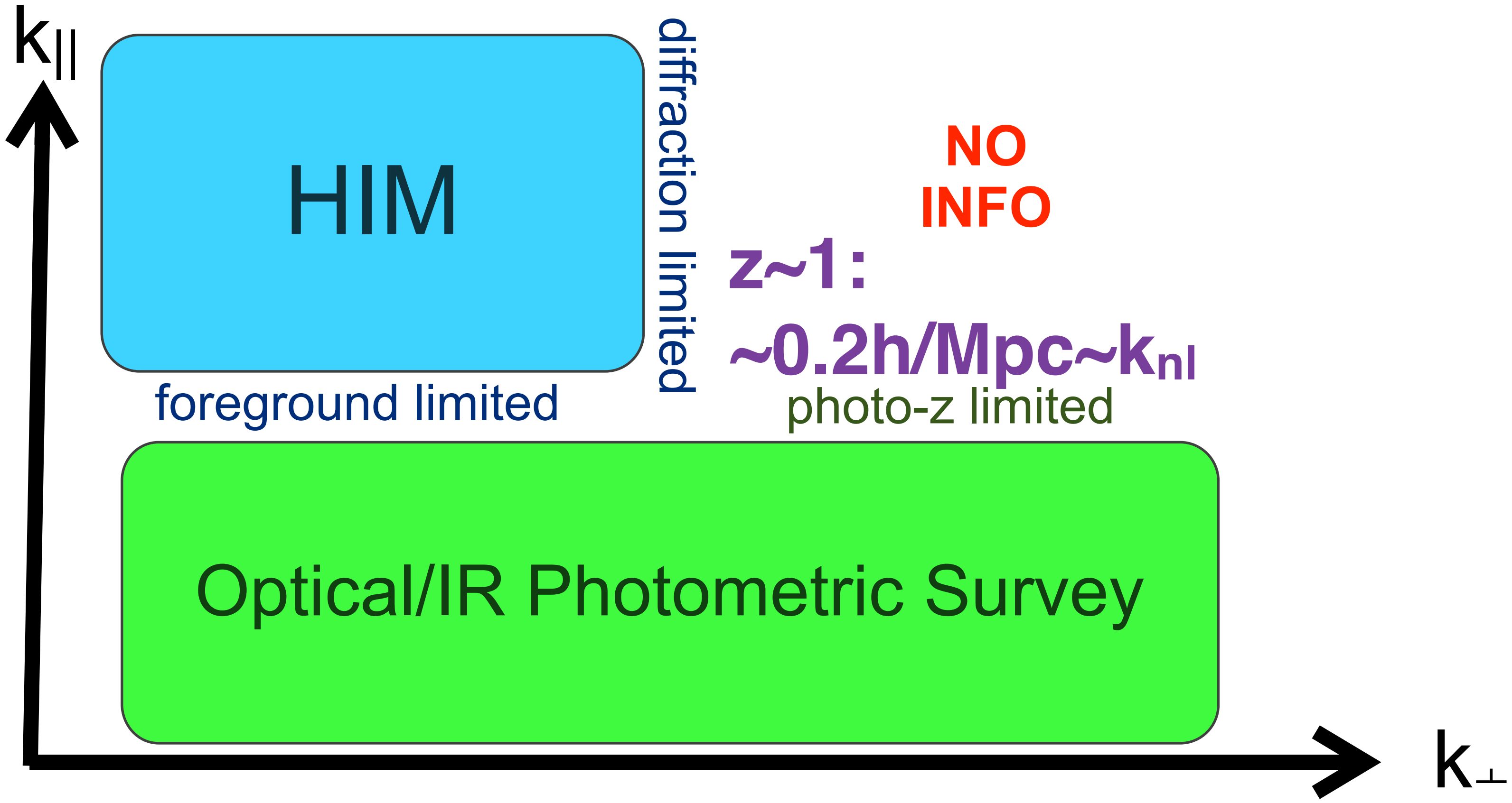
Photometric + Intensity Mapping Better Together

spectral resolution of HI intensity mapping survey
angular resolution photometric optical / IR survey

Naive Combination:

inverse variance weighted estimates in k-space

$\delta\rho/\rho(\mathbf{k}) = (\sigma_{opt}(\mathbf{k})^2\, \delta\rho/\rho_{HI}(\mathbf{k}) + \sigma_{HI}(\mathbf{k})^2\, \delta\rho/\rho_{opt}(\mathbf{k}))/(\sigma_{opt}(\mathbf{k})^2 + \sigma_{HI}(\mathbf{k})^2)$



In linear (homogeneous Gaussian) theory this is optimal.

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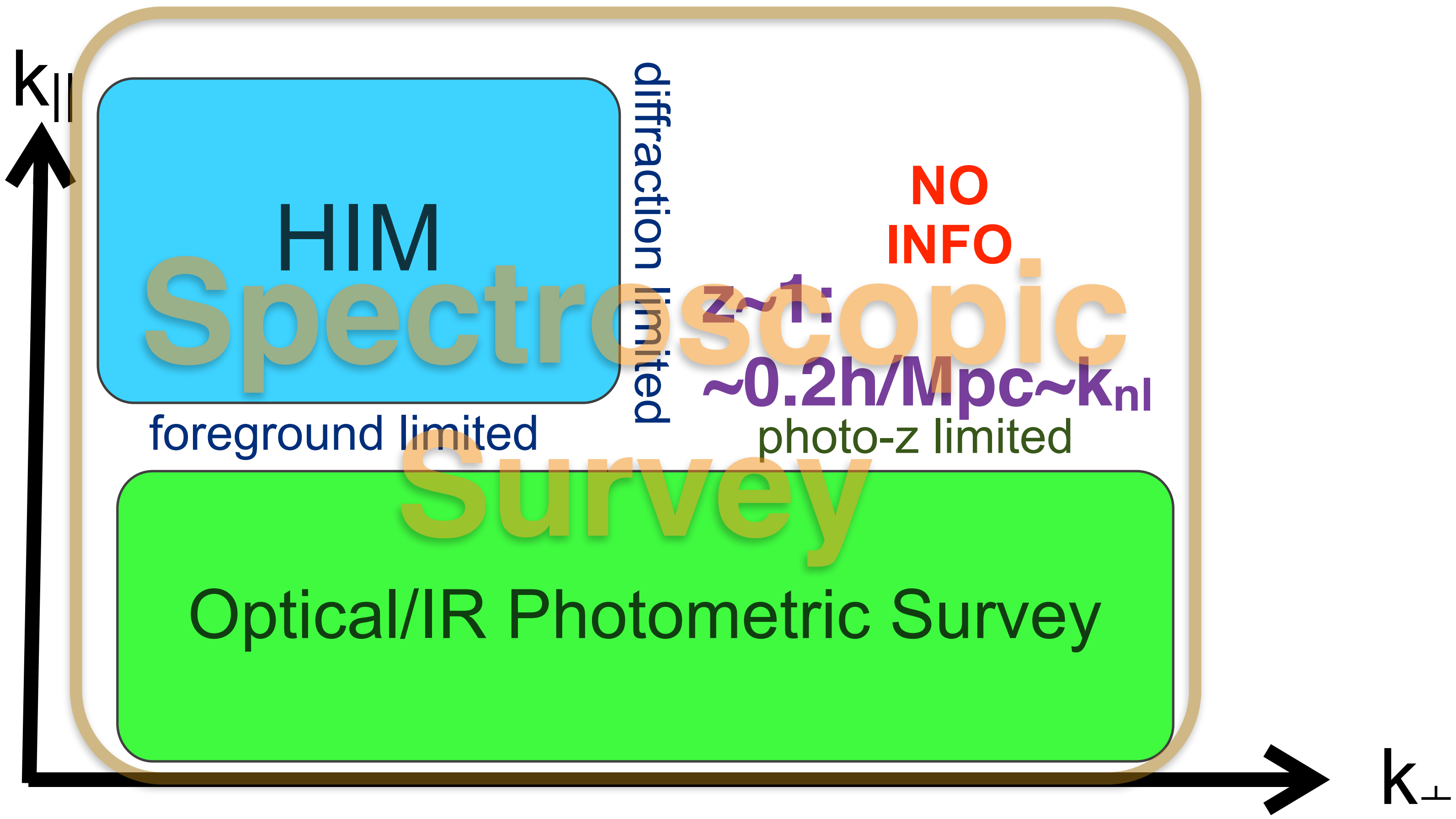

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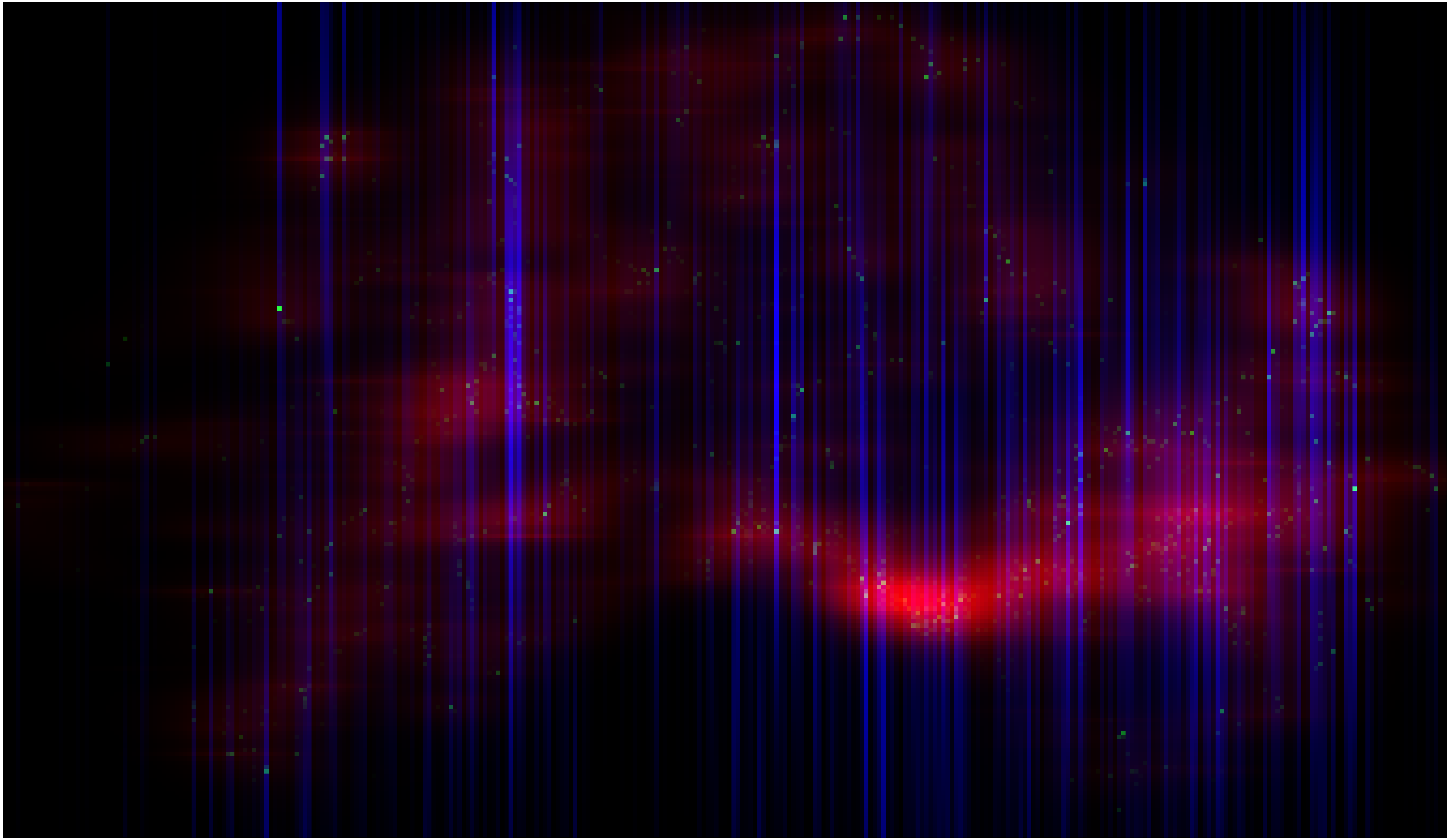
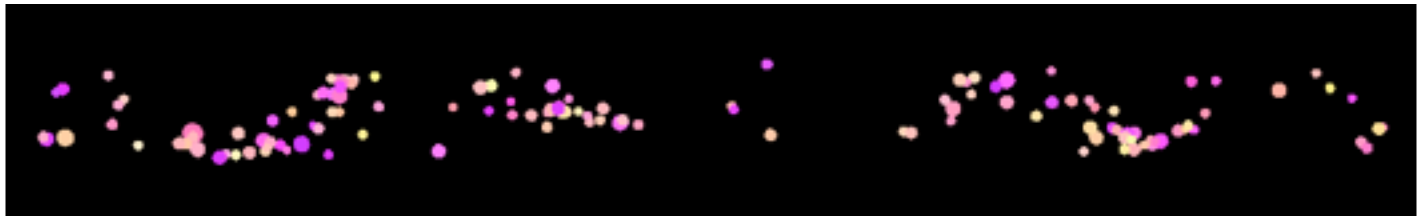
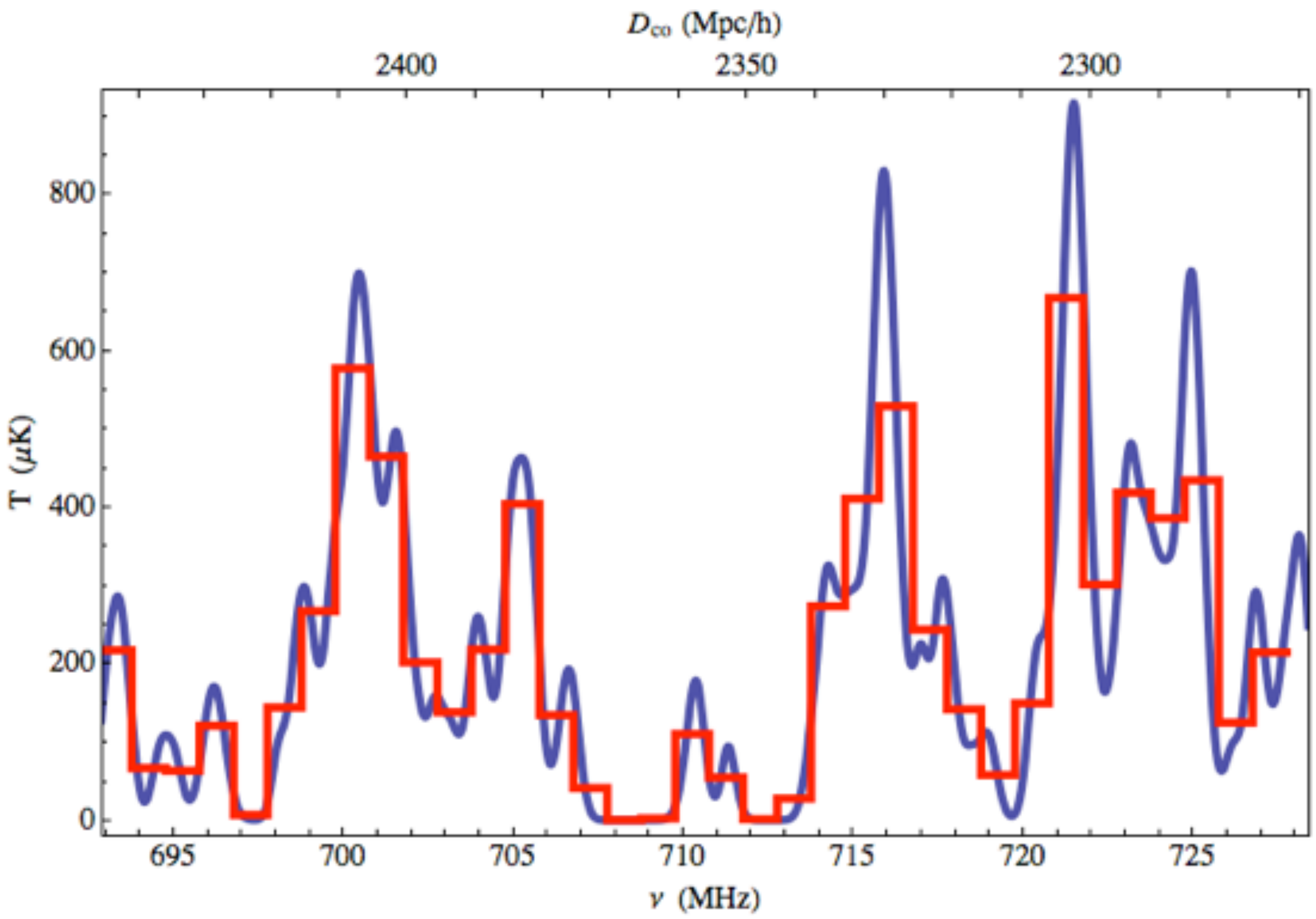


NON-GAUSSIAN INTENSITY MAPS



DEEP2

Davis ++ 2004++



see **Wang ++ 2006**

$\Delta\nu$=1 MHz

$\Delta\theta$=10'

Tully-Fisher

$M_{HI} \propto L_B$

HI

We can nearly resolve galaxy structures in redshift space.

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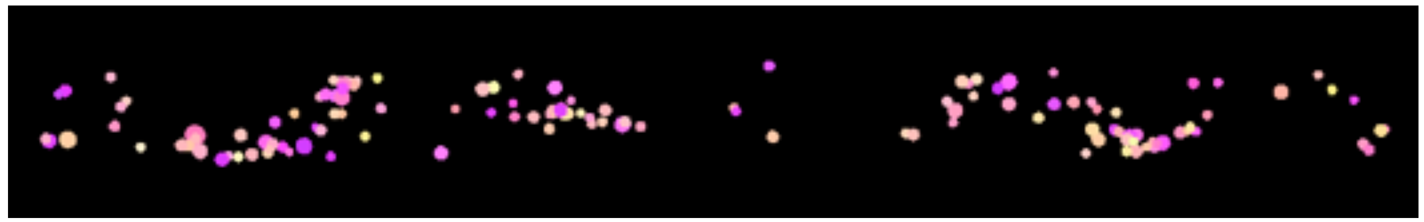

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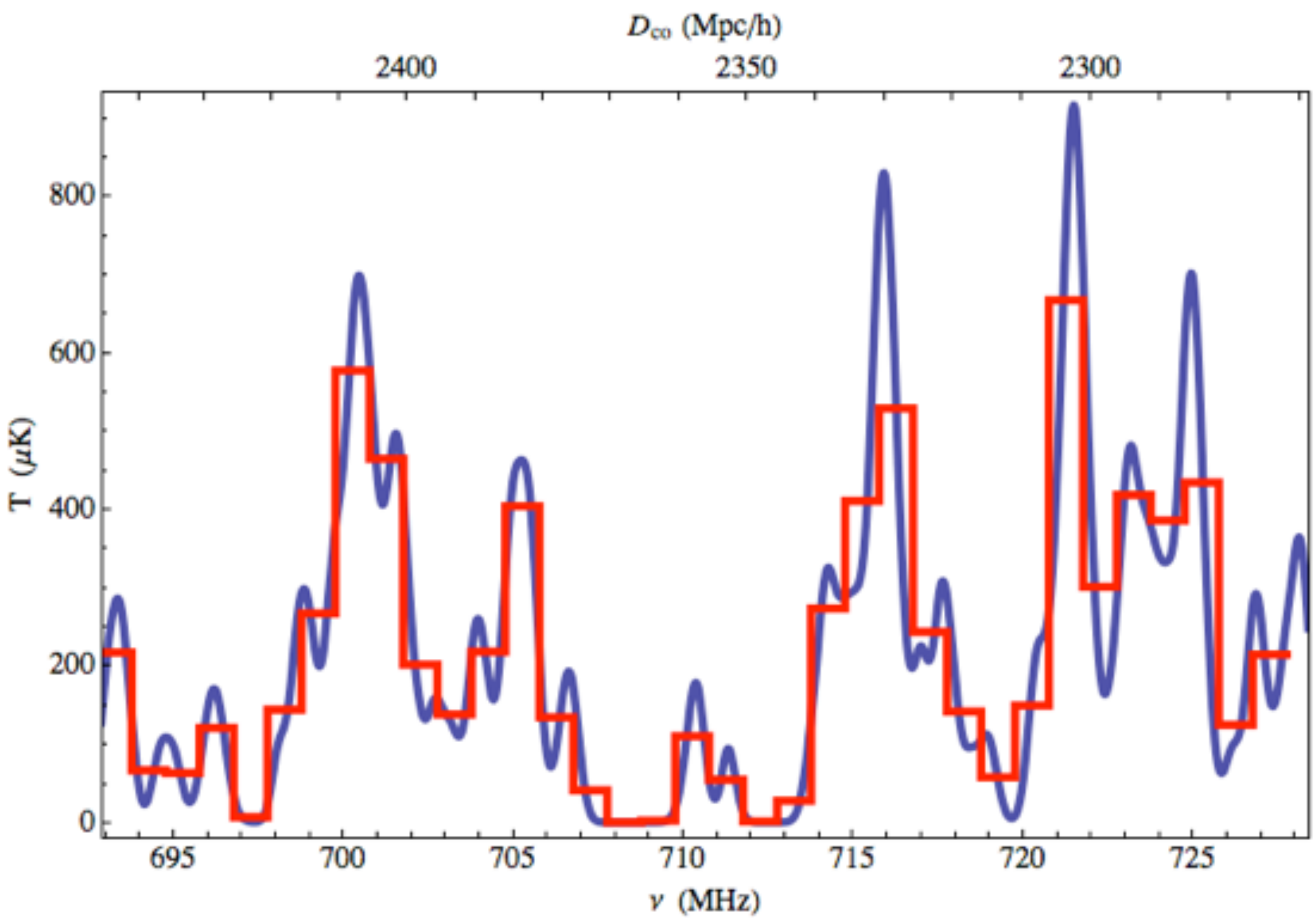

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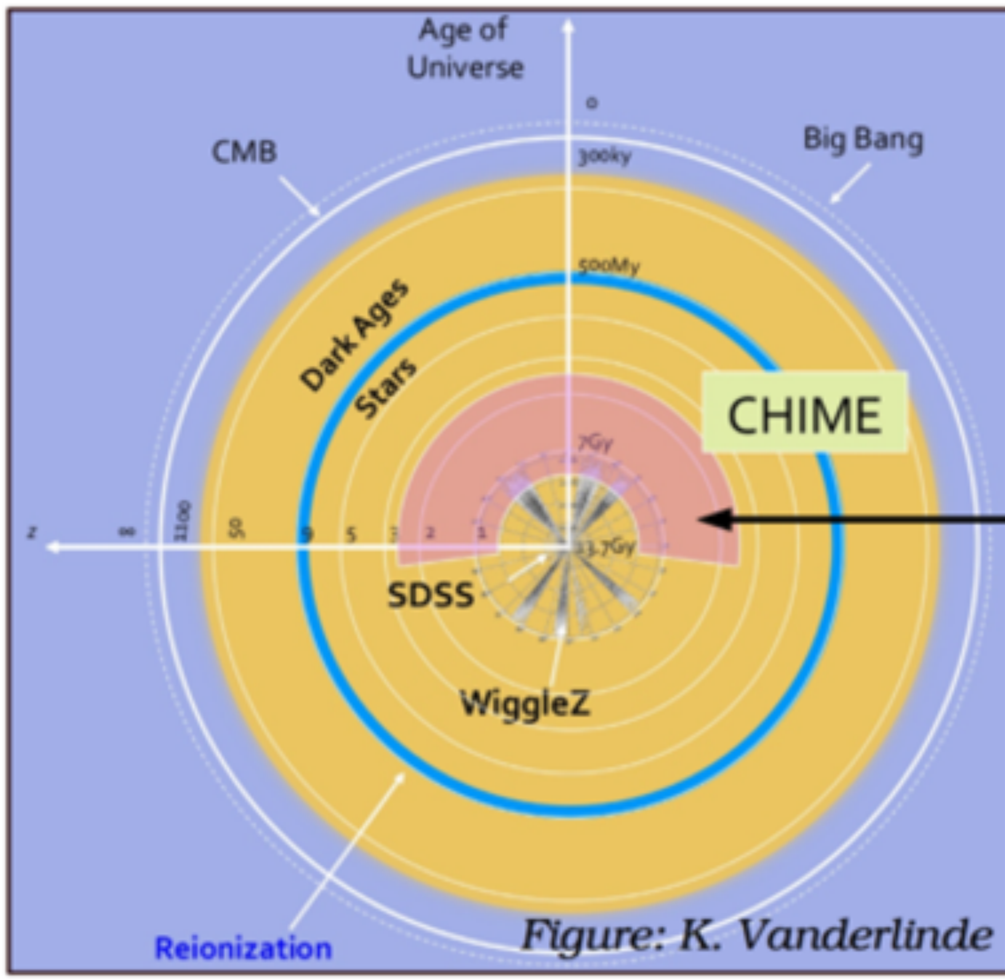
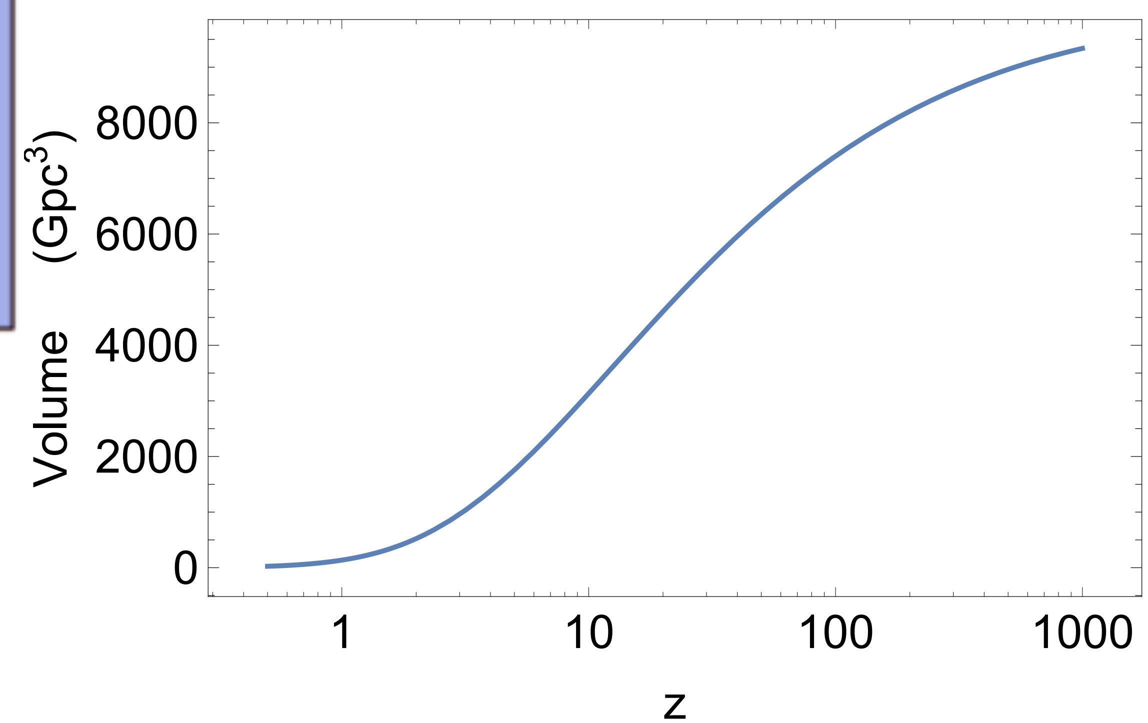
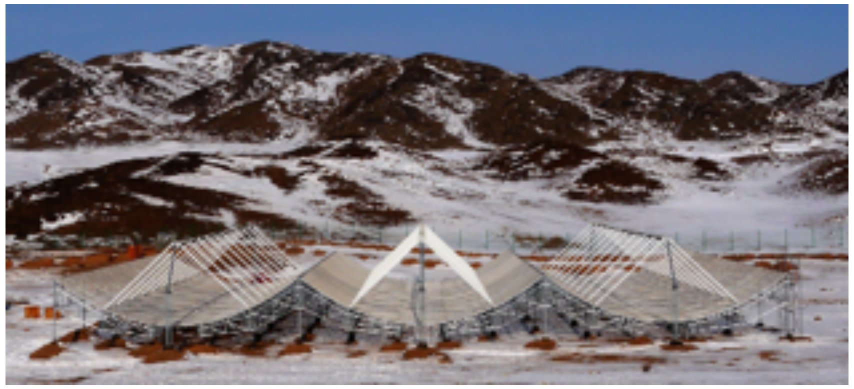
HIM has “BIG” Future



~400 Gpc^3



only 21cm line emission visible from dark ages



Data Challenge (pathfinder)

natural DOE entry point

$(3\,N_{feed}+1)\,N_{feed}\,N_{ch}\,\#_{bytes}\,/\,\Delta t$

$N_{feed}=96$ $N_{ch}=1024$ $\#_{bytes}=2$ $\Delta t=1\mathrm{sec}$

1.6 petabyte / year

T ime O rdered D ata

This requires significant resources and some planning.

4 terabyte

÷365

A verage S idereal D ay

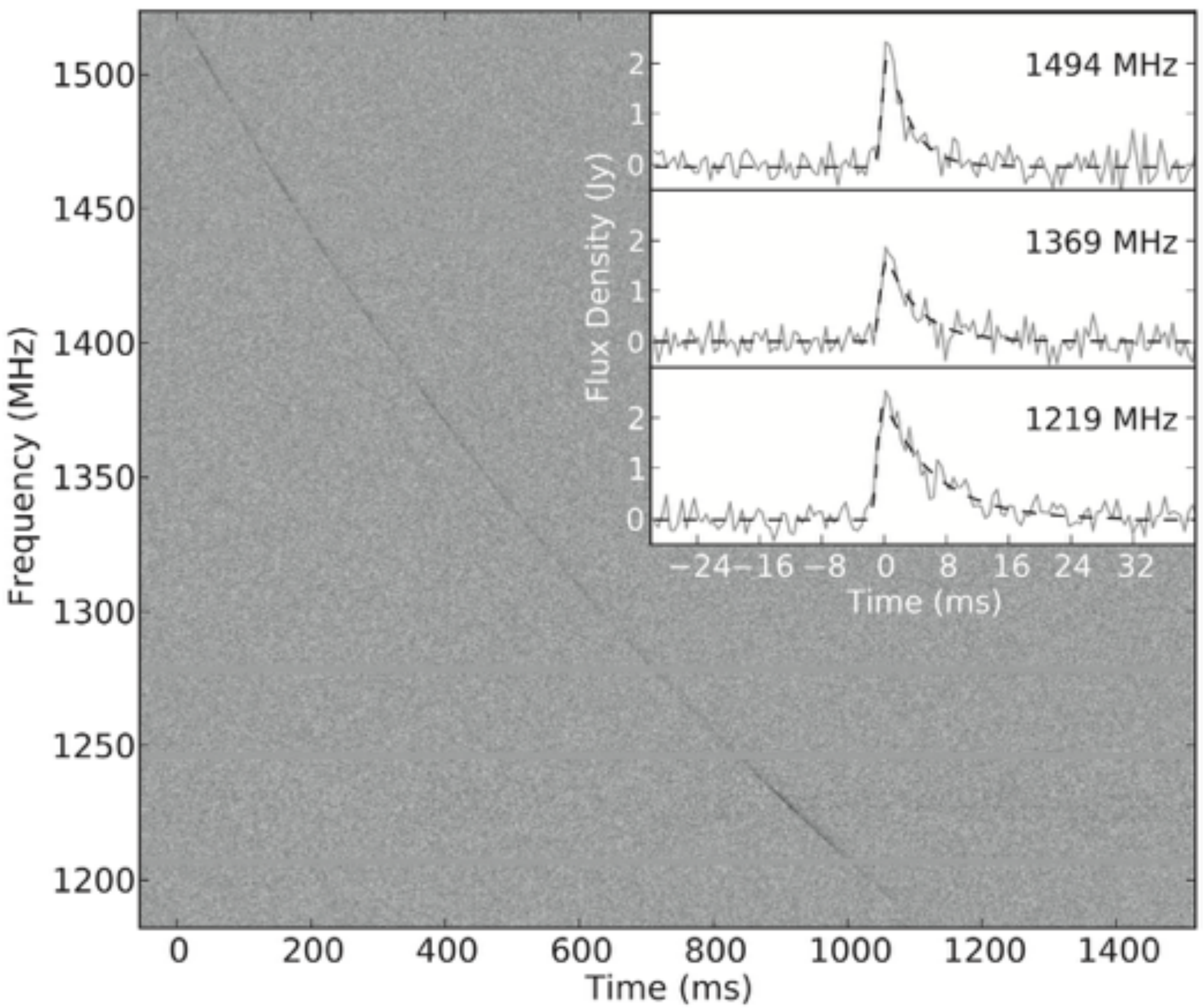
1 terabyte

Maps

$\#_{stokes}\,N_{ch}\,\#_{bytes}\,\Omega_{survey}\,/\,\delta\theta^2$

$\delta\theta=1'$ $\Omega_{survey}=25{,}000\mathrm{deg}^2$ $N_{ch}=1024$ $\#_{bytes}=4=\#_{stokes}$

Fast Radio Bursts (FRBs)



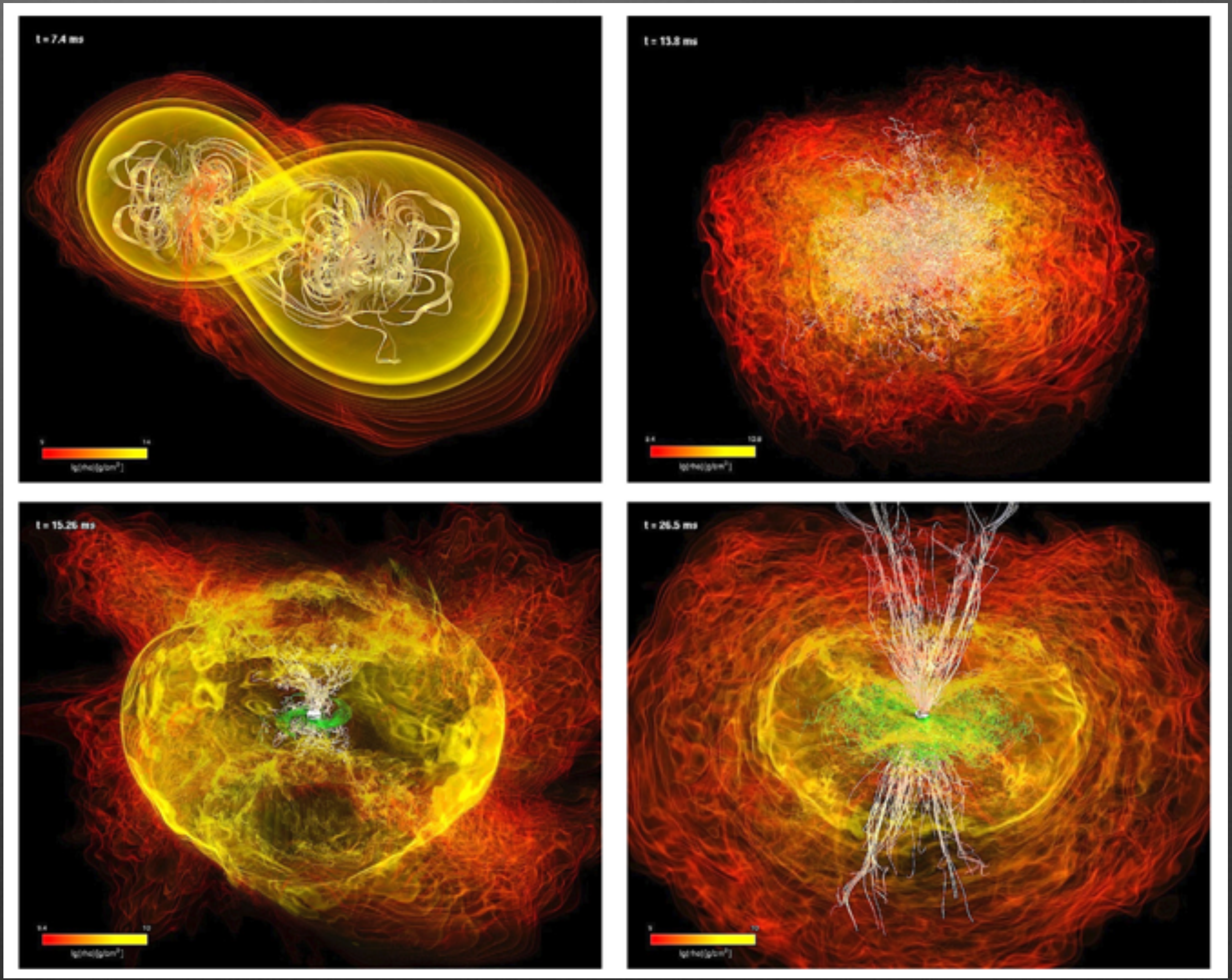
$$\delta t = k_{\mathrm{DM}} \frac{\mathrm{DM}}{\nu^2} = 0.414884\ \mathrm{sec} \left(\frac{\mathrm{GHz}}{\nu}\right)^2 \frac{\mathrm{DM}}{100\ \mathrm{pc/cm}^2}$$

$$k_{\mathrm{DM}} = \frac{e^2}{2\pi m_e c}$$

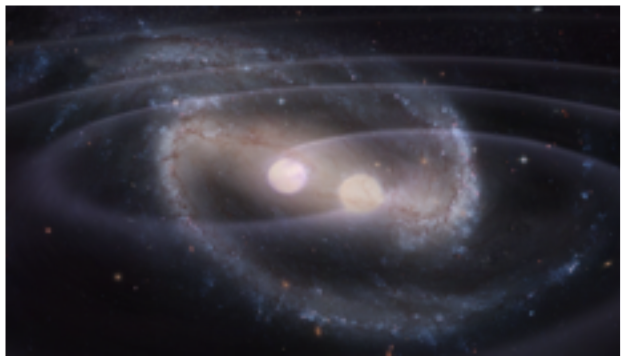
What produces Fast Radio Bursts?

"Trust me I'm a theorist"

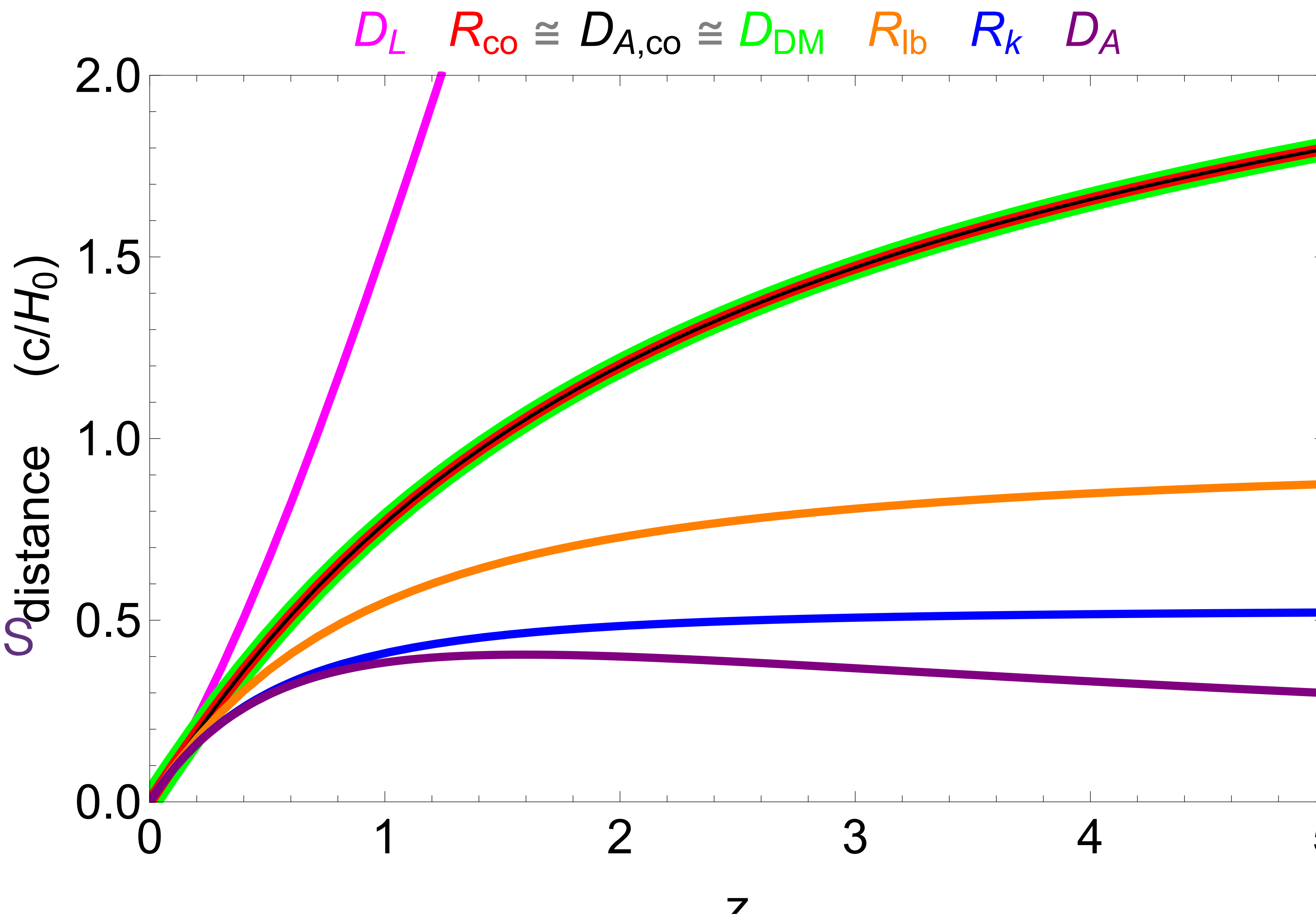
- unknown
- detecting a counterpart (optical) would help clarify
- GUESS: merging neutron star binaries (CBC - compact binary coalescence)
- CBC timescale of a few msec matches FRBs timescale
- CBCs generate copious amounts of low frequency electro-magnetic (EM) energy
- It has generally been thought that this lo-frequency EM does not "get out"



Dispersion Measure Distance



Neutron stars tend to coalesce well ***outside*** initial host galaxies which doesn't contribute to DM due to **kicks**



$$\overline{\text{DM}}[z] = c\int_{t[z]}^{t_0} dt\,\frac{\overline{n_e}[t]}{(1+z[t])^2} = c\,\overline{n_{e0}}\int_0^z \frac{dz'}{H[z']}\,\chi[z'] = \overline{n_{e0}}\int_0^z \frac{dz'}{H[z']}\,\chi[z']$$

pre-calibrated since n_{e0} we know precisely from CMB

δz~0.04 with up to ~10^4/day (?)
Could they replace SNe-Ia?

Could Radio Techniques
Dominate Cosmological Surveys in
the Coming Decades?

Should DOE get into this game early?