Discovery Space for SKA

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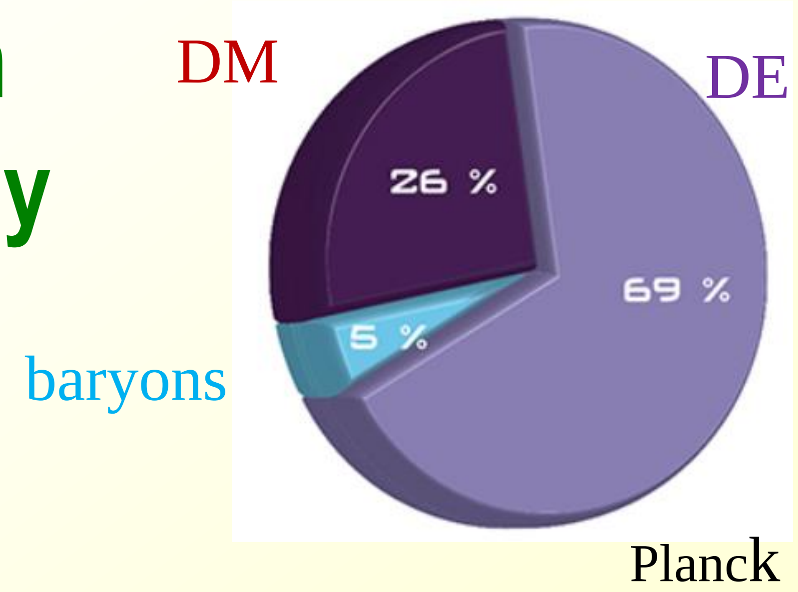
Laboratoire d'Étude du Rayonnement et de la Matière en Astrophysique

SKA SQUARE KILOMETRE ARRAY

SKA: solution to main questions in cosmology



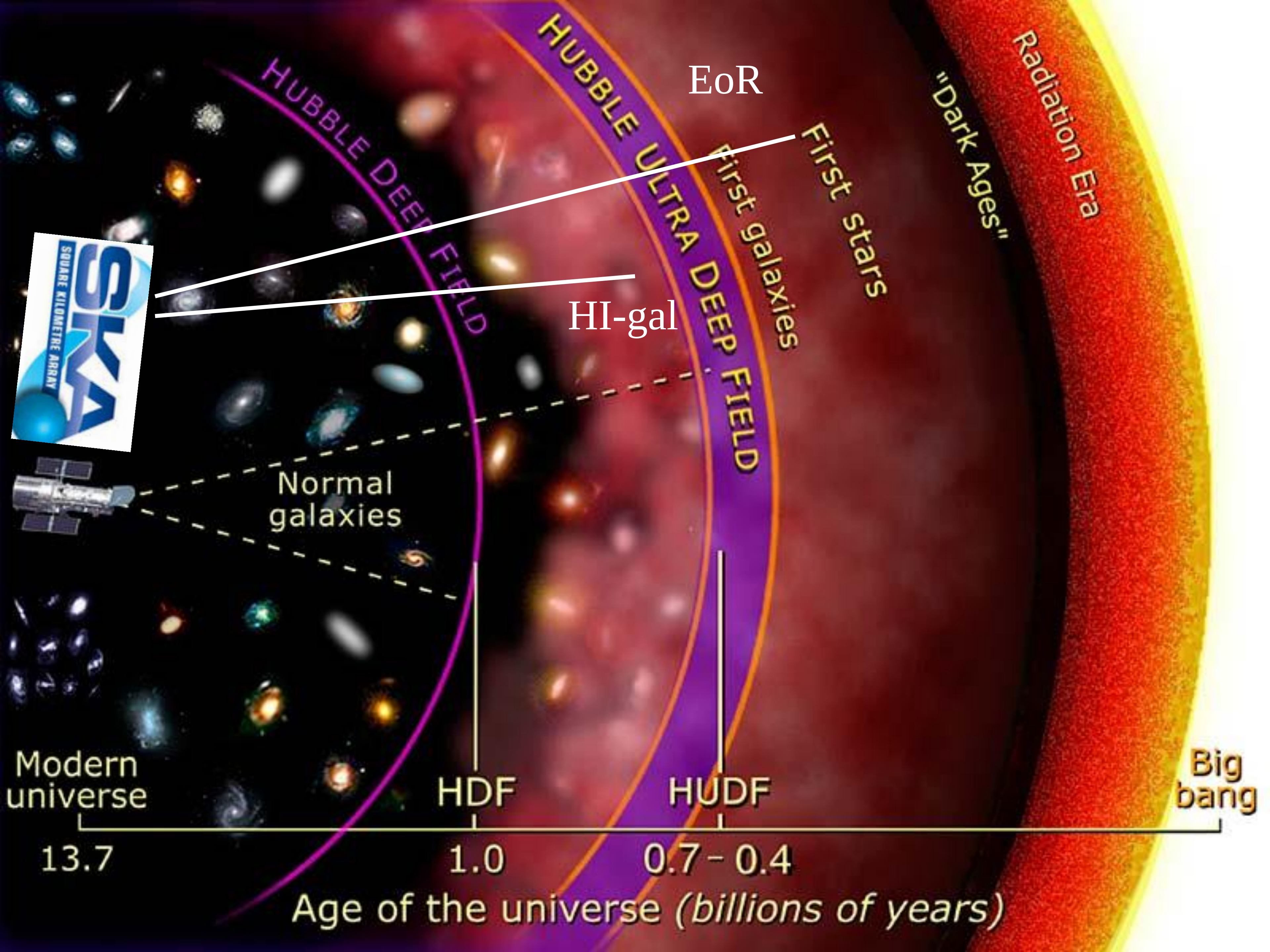
Matter in the Universe
Dark matter/visible matter vs z

Dark energy: (BAO, WL, RSD..)
Is it varying with time?

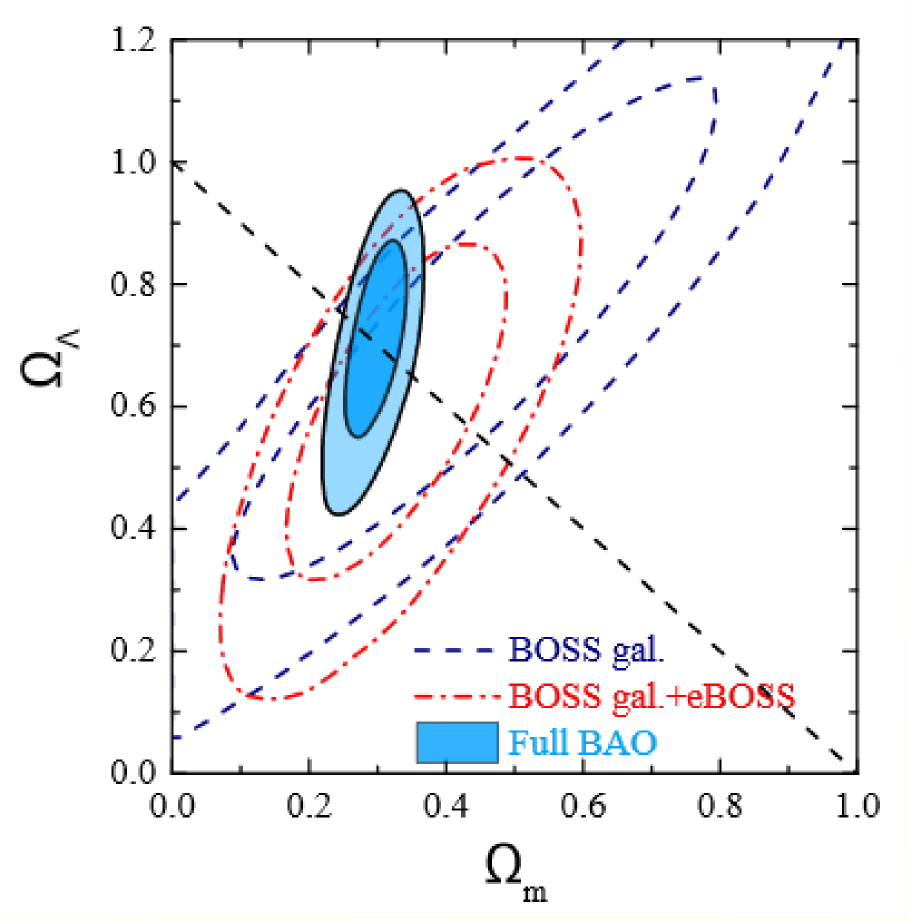
How is the Universe re-ionized?
End of the dark age: cosmic dawn, EoR

How do baryons assemble into the large-scale structures?
Galaxy formation and evolution
Environment: groups and galaxy clusters

Strong-gravity with pulsars and black holes


EoR
HI-gal
HUBBLE DEEP FIELD
HUBBLE ULTRA DEEP FIELD
First galaxies
First stars
"Dark Ages"
Radiation Era
SKA SQUARE KILOMETRE ARRAY
Normal galaxies
Modern universe
HDF
HUDF
Big bang
13.7
1.0
0.7 – 0.4
Age of the universe (billions of years)

BAO z=0.8-2.2 from quasars e-BOSS
(last release DR14 SDSS-IV)



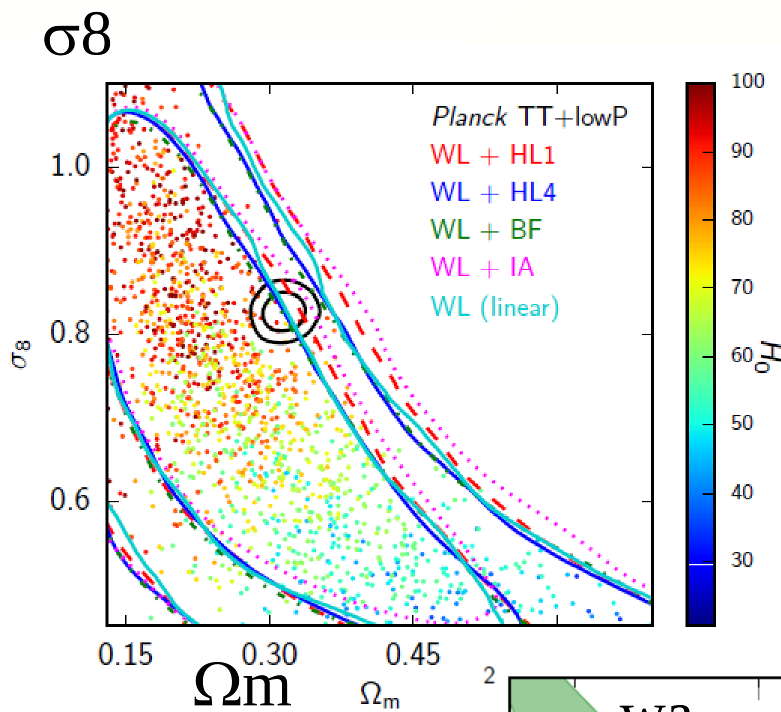
147 000 quasars
over 2040 °[2]

Compatible with ΛCDM
$\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$

The QSO are very good tracors!

Ata et al 2017

Current constraints: Planck + others

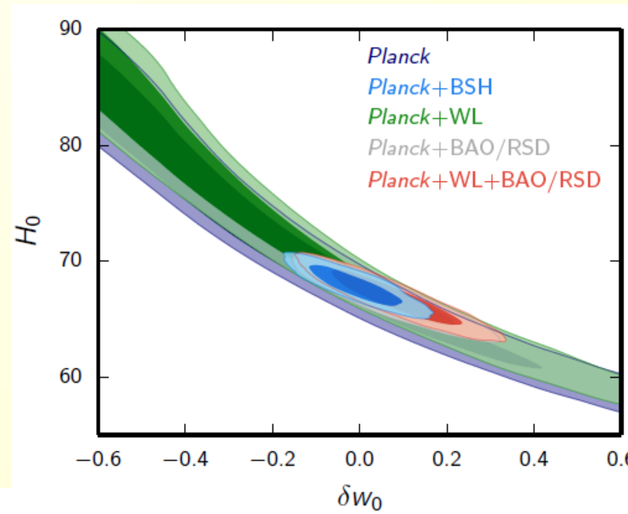


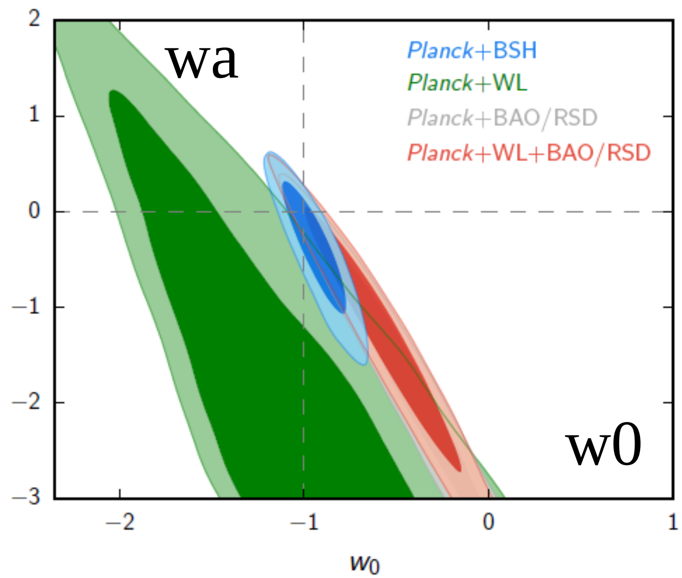
HL: Halo Fit, BF:AGN feedback

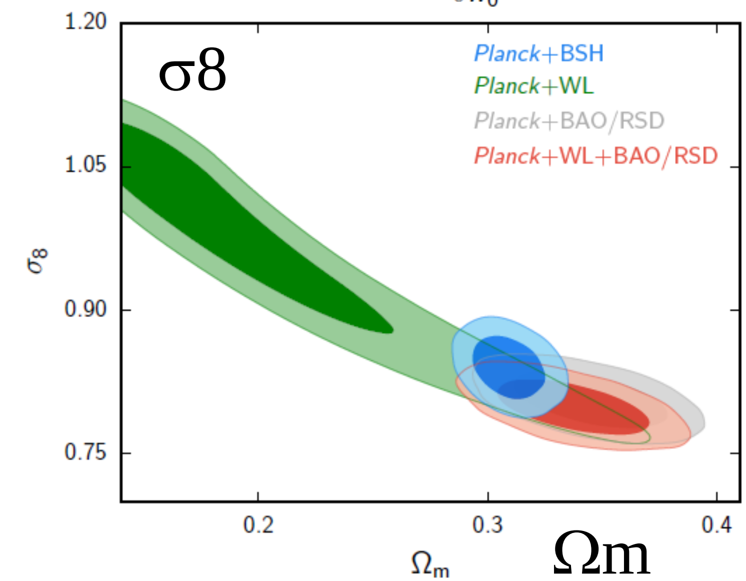
IA :intrinsic alignment

BSH:

BAO+SNIa+H_0

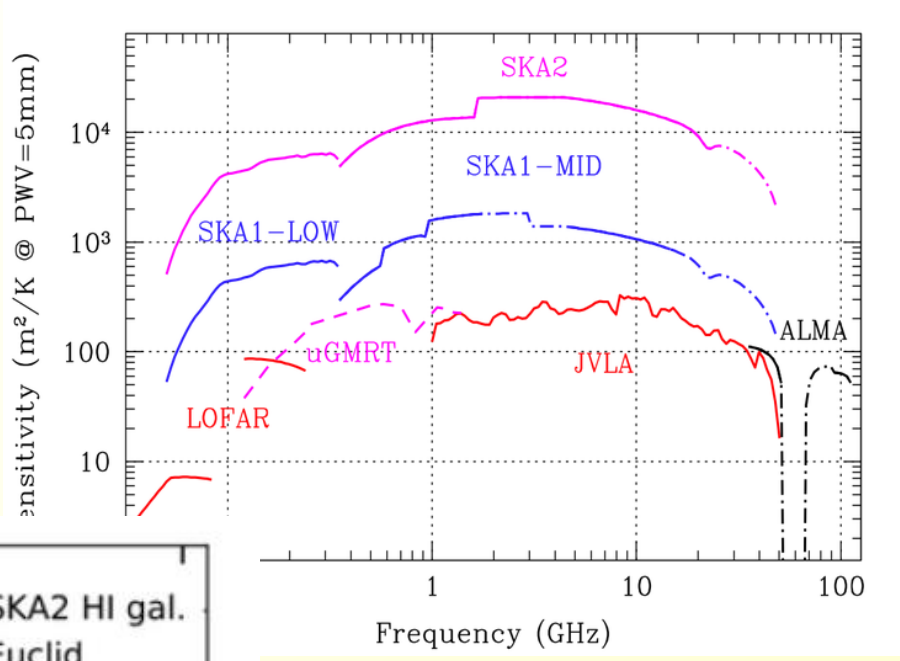


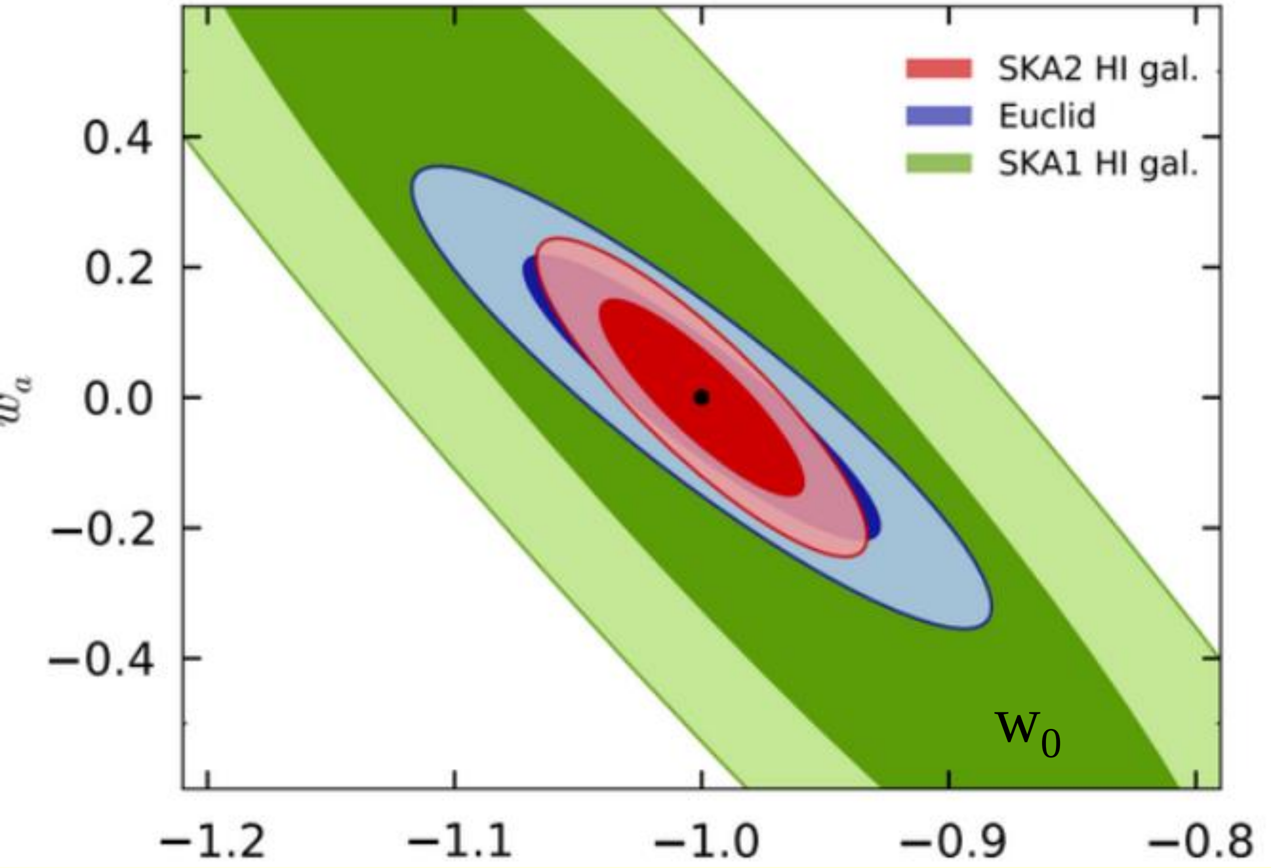




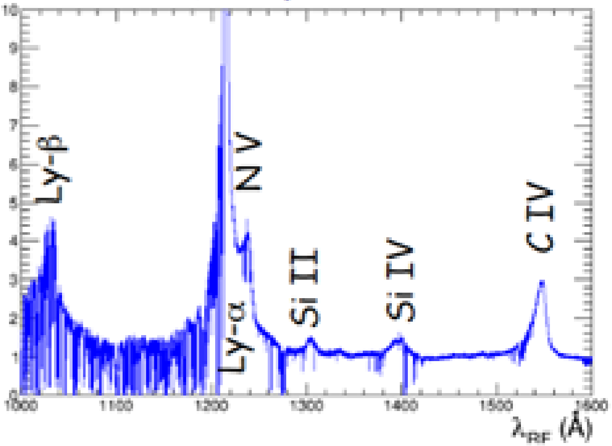
Planck 2015

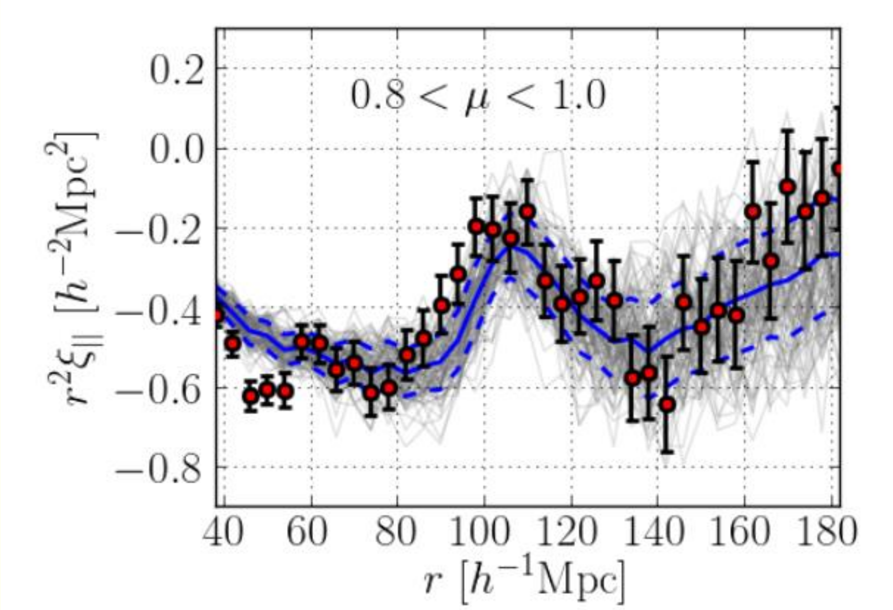
Constraints on DE with HI gal survey





Survey in Lyα absorption



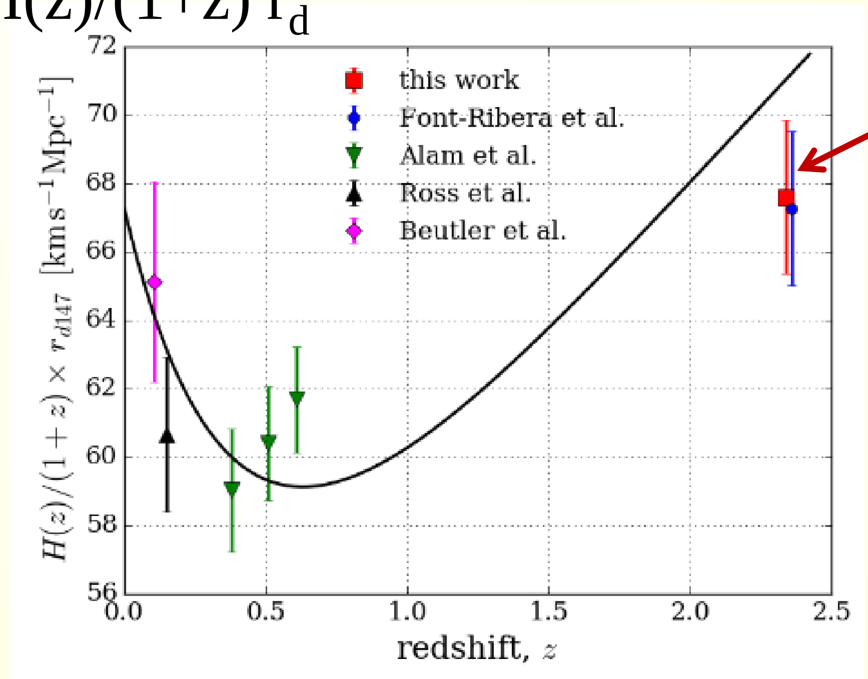


Absorption of Lyα line at z=2.3

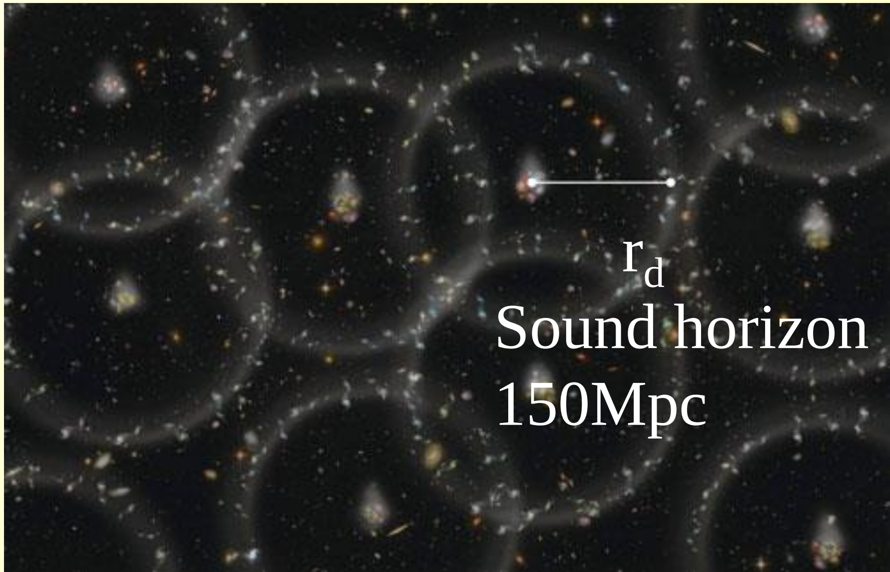
Delubac et al 2014

Red dots versus QSO simul (grey)

$H(z)/(1+z)\ r_d$

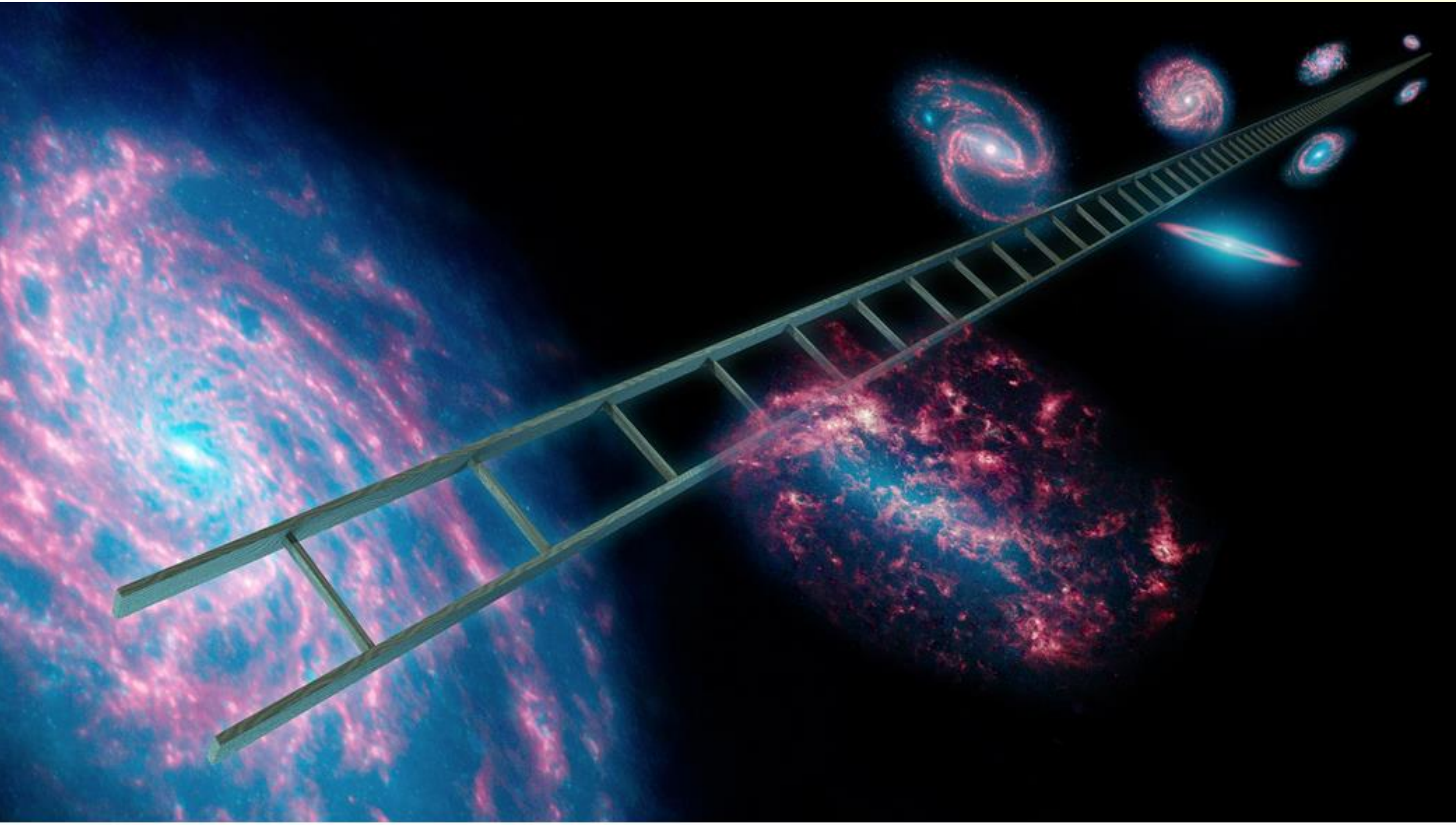


Bautista et al 2017



The cosmic distance ladder

Cepheids, RR Lyrae, Tully-Fischer, HII regions, SN-Ia, ….

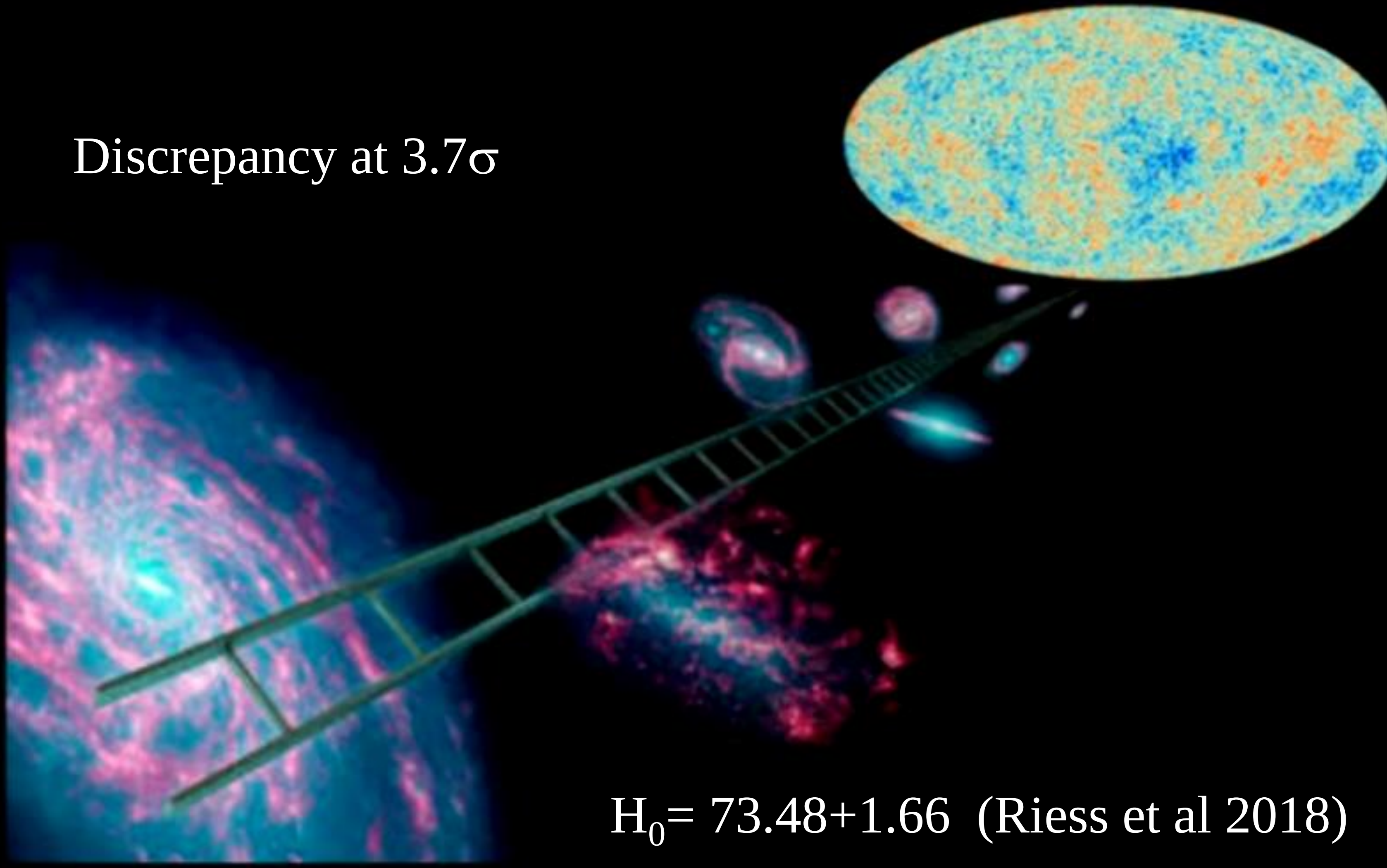


Spitzer 3.6 microns (blue), 4.5 microns (green), and 8.0 microns (red)

H_0= 67.8+0.9 (Planck coll 2016)

The H_0 challenge

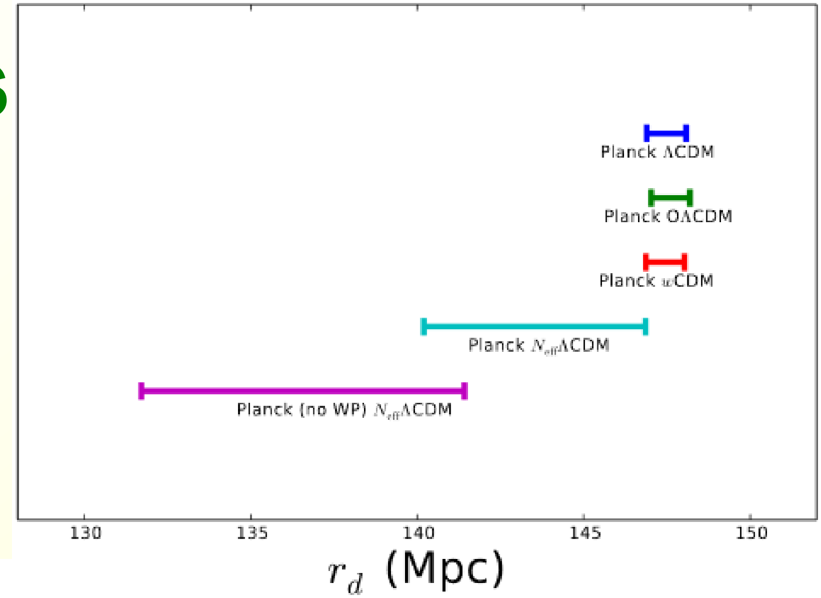
Discrepancy at 3.7σ

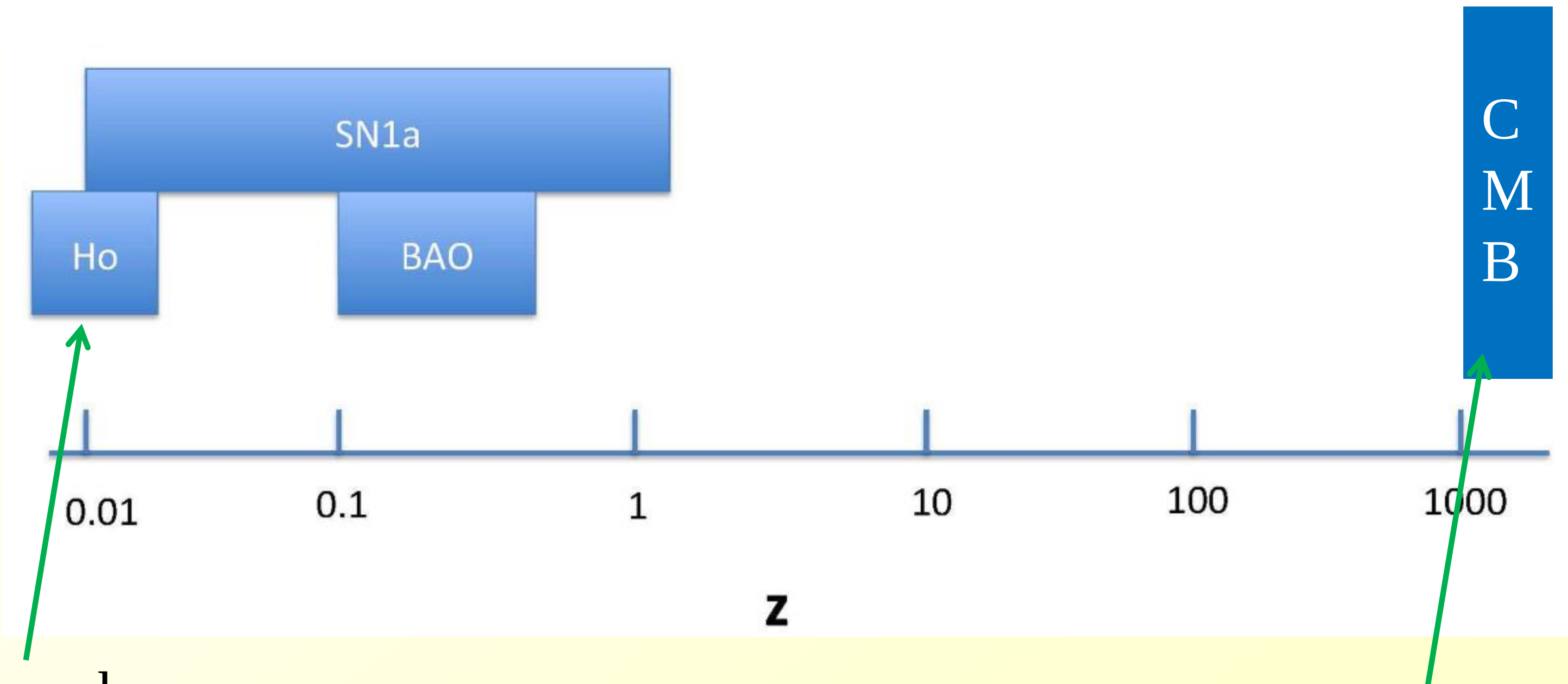


H_0= 73.48+1.66 (Riess et al 2018)

Overlap of distance ladders

SN-Ia standard candels calibrated at z=0
BAO: standard ruler, calibrated on sound
Horizon at z~1000 **Inverse ladder?**





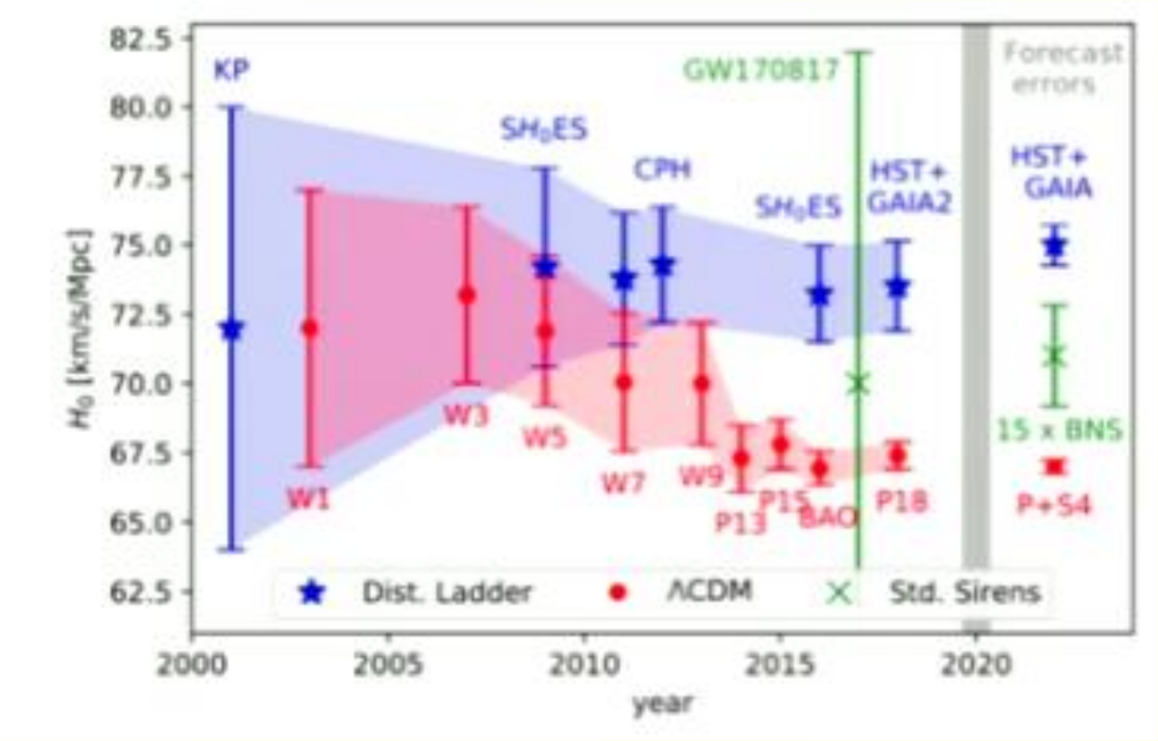
anchor

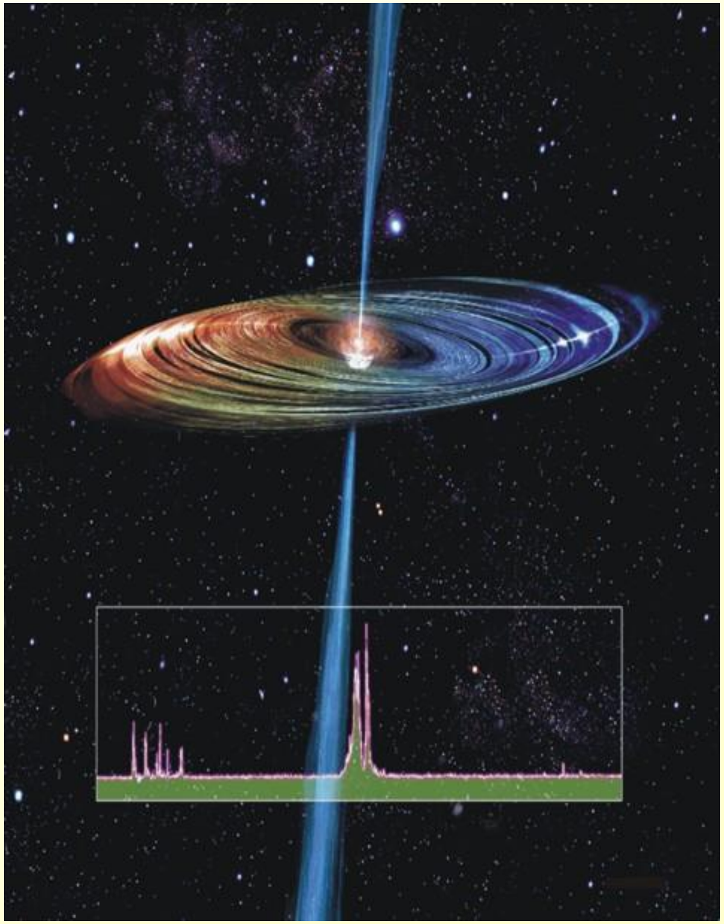
Cuesta et al 2015

anchor

Precise and accurate measure of H0

SKA will measure many masers around AGN at various z





Ezquiaga 2018

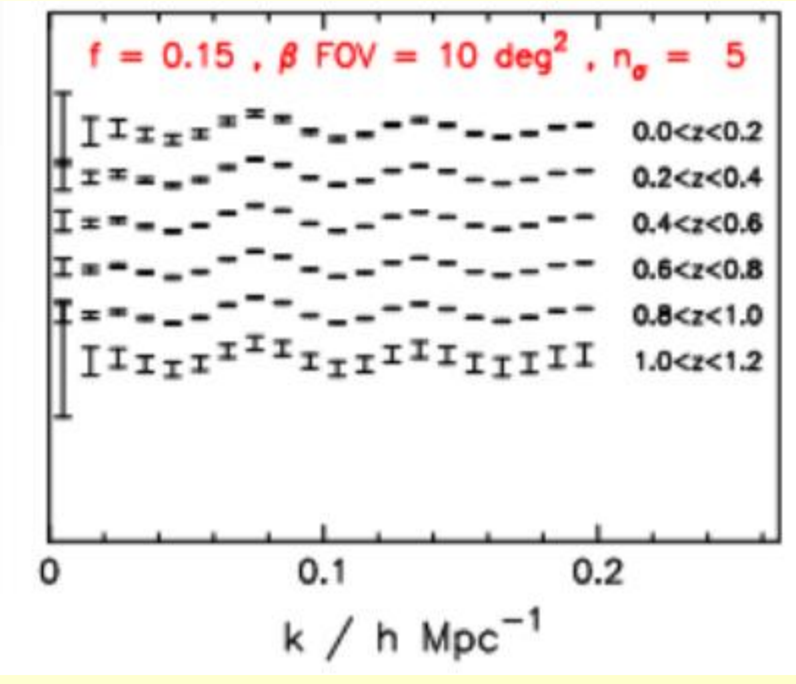
HI surveys for BAO with SKA-1

All sky survey: 4 10^6 gal z=0.2 3π sr
Wide-field survey 2 10^6 gal z=0.6 5000 deg^2
Deep-field survey 4 10^5 gal z=0.8 50 deg^2

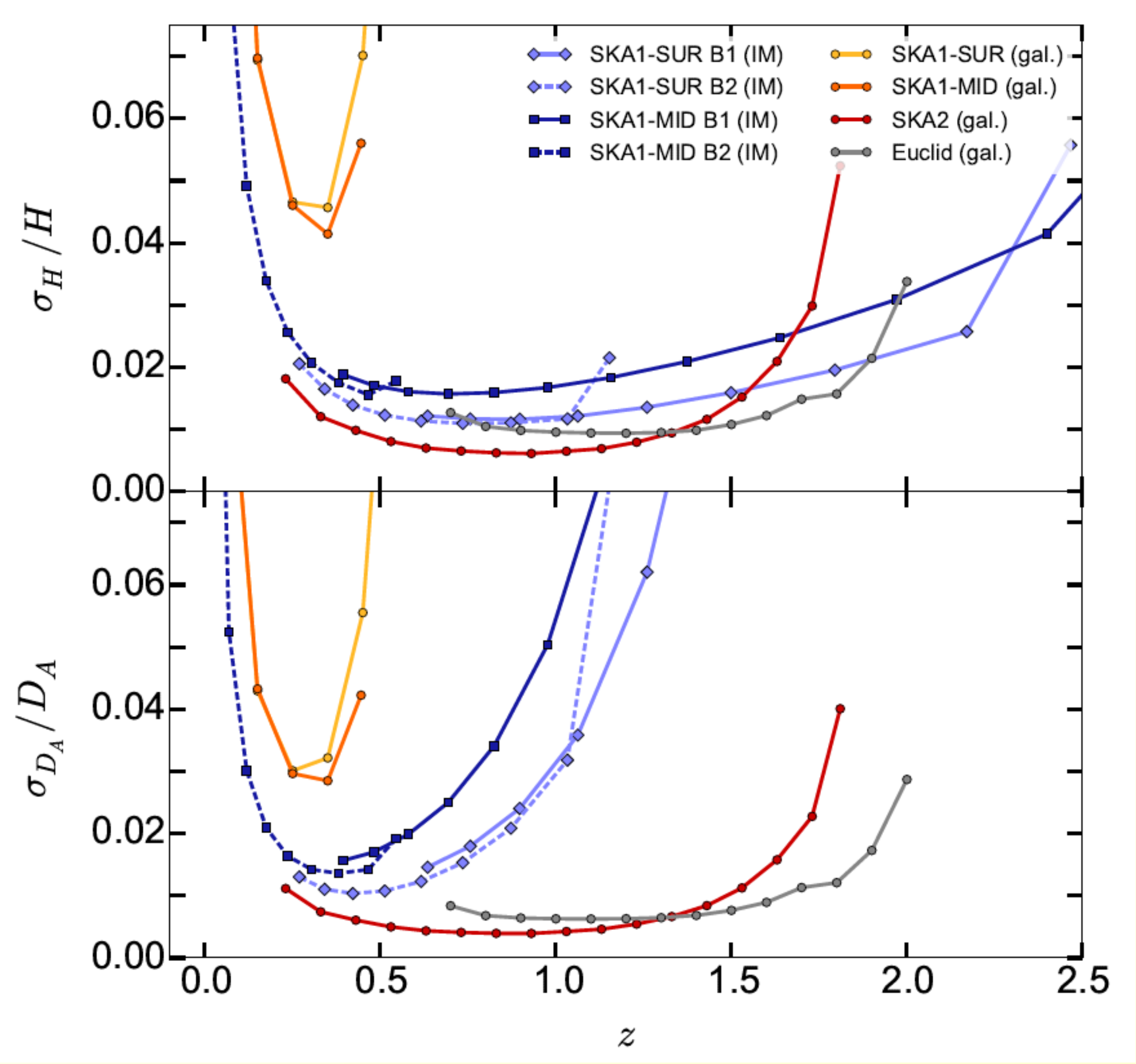
More competitive: HI intensity mapping 30 000 deg^2 up to z=3
Deep and wide, large volumes, ~Euclid

SKA2 will help to provide pure sample
1 billion HI galaxies in total

Weak shear
10 billions galaxies in continuum



Radial and transverse BAO



IM: HI Intensity mapping
Gal: HI galaxy surveys

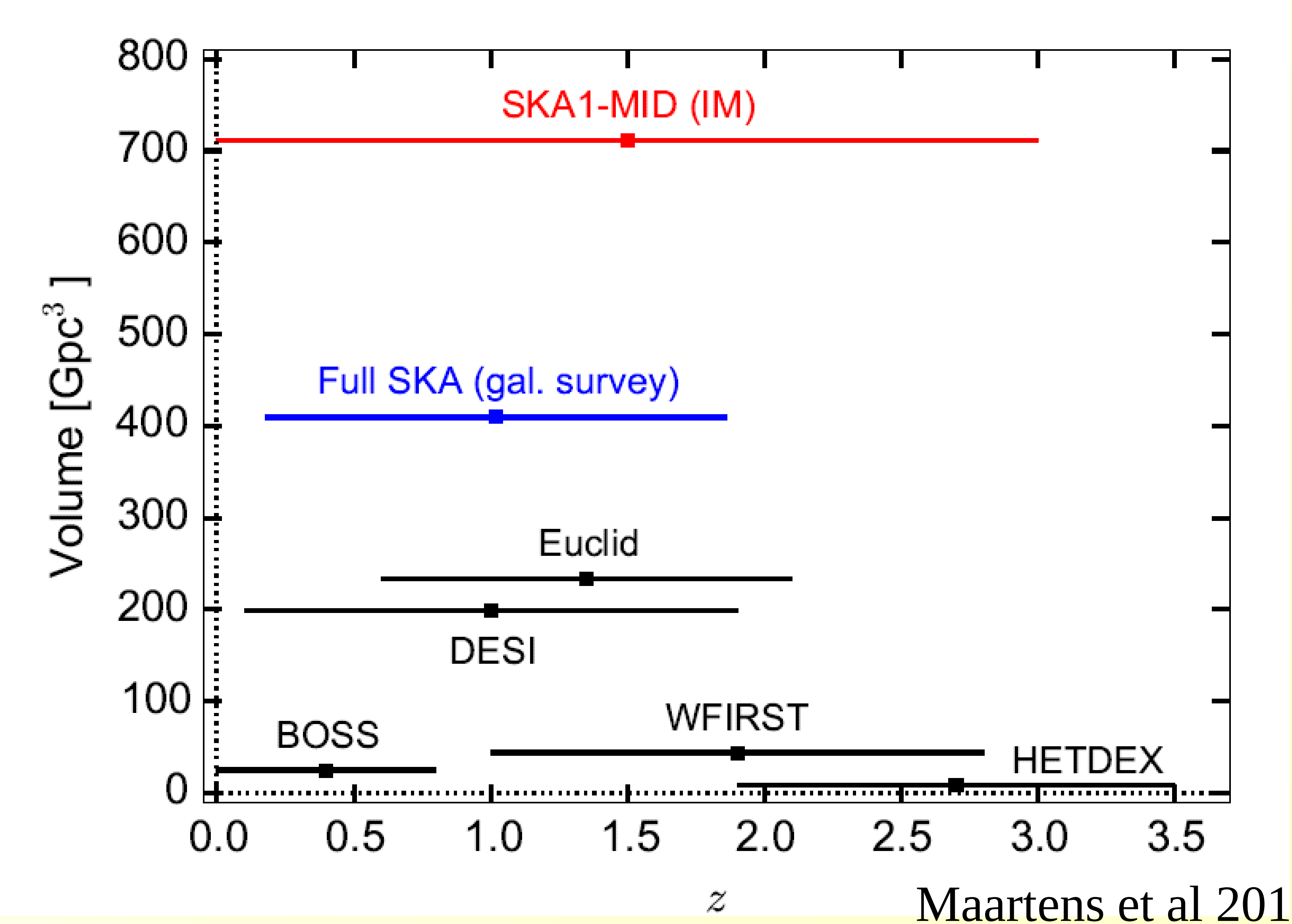
B1 low-frequency band
B2 high-frequency band

HIM 30 000 °2
up to z~3,
Radio 30 000 °2
up to z~6

10^9 objects

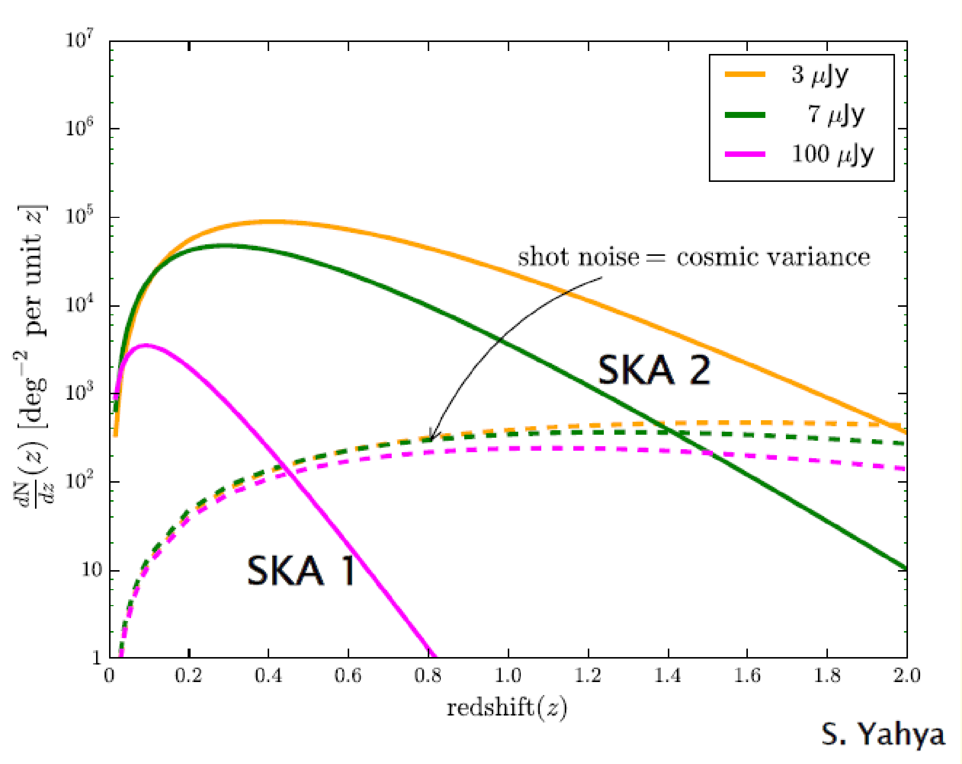
Maartens et al 2015

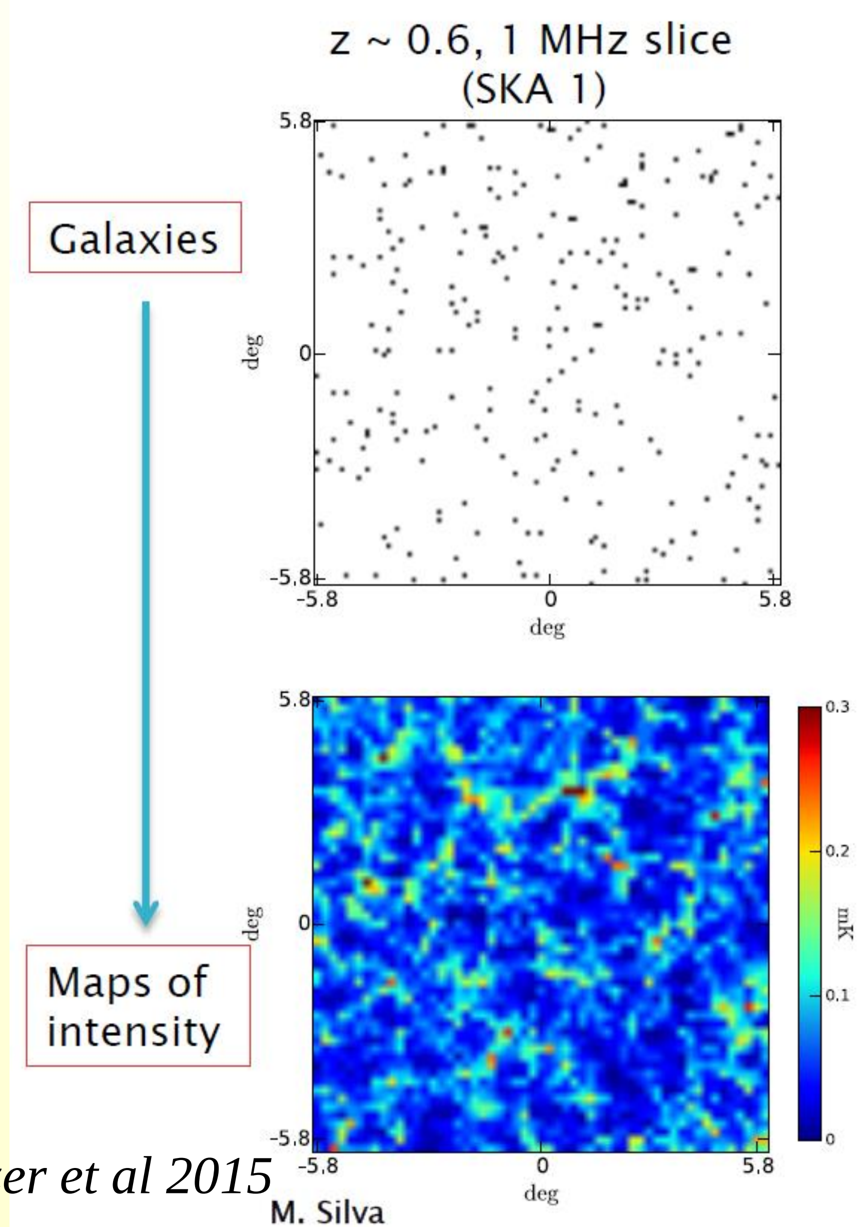
Comparison of Volume covered



Maartens et al 2015

HI gal survey vs intensity mapping





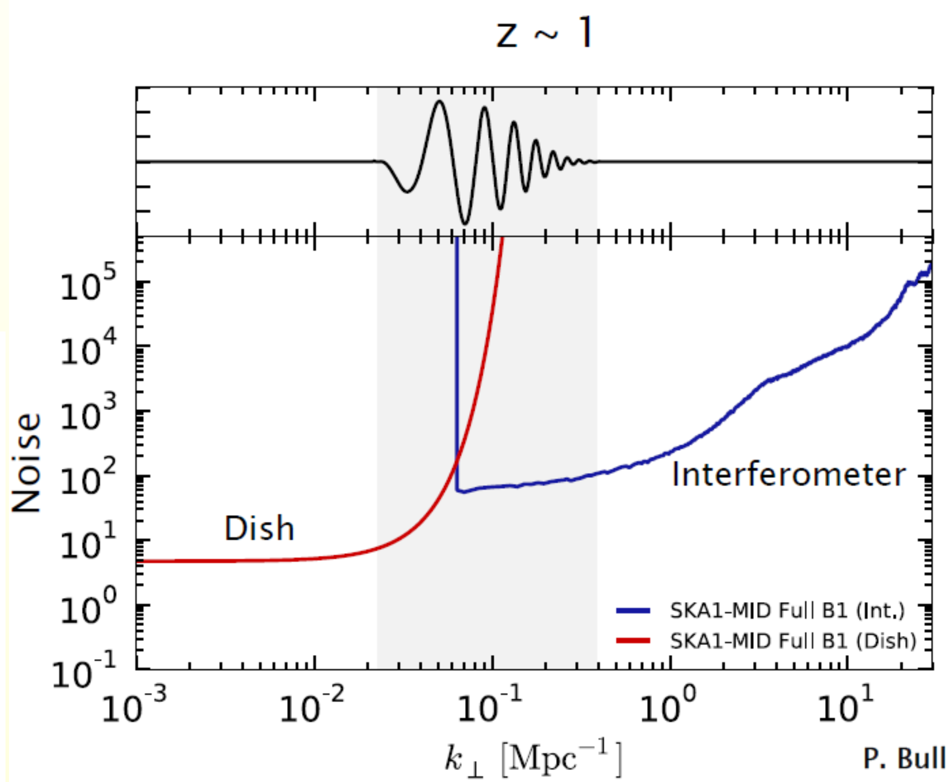
HI intensity mapping: main problem is the foreground, due to continuum

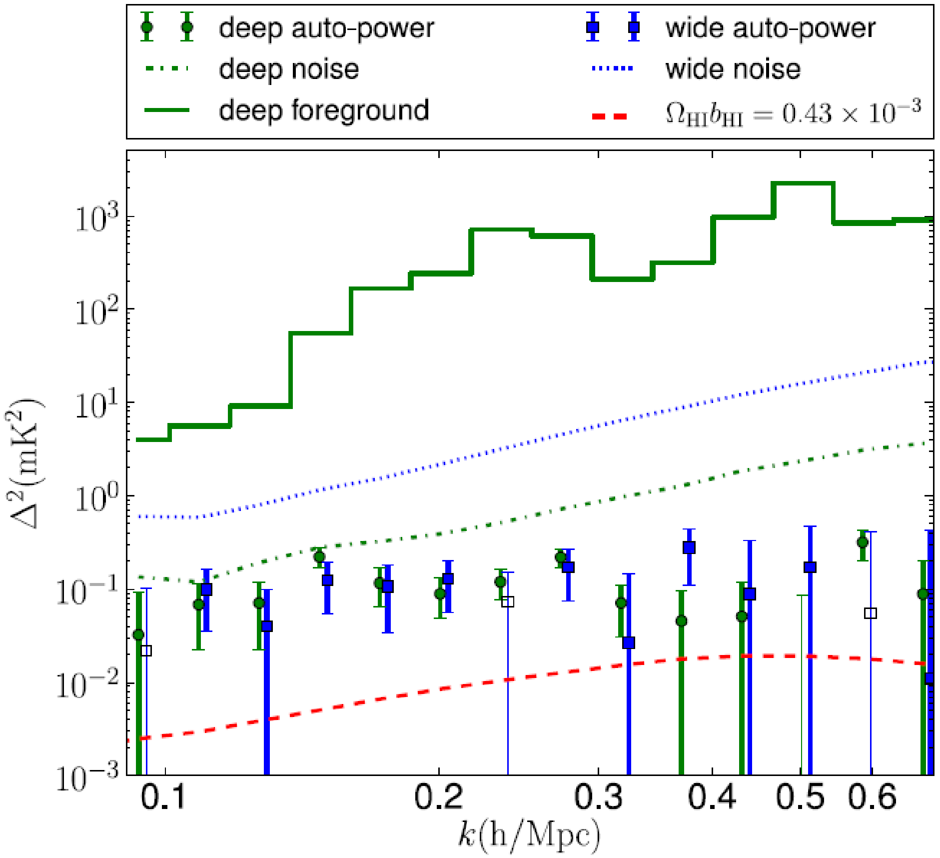
1000 x the expected signal

Not smoother in frequency, but fewer bright spectral degrees of freedom *Switzer et al 2015*

First results HI intensity mapping (GBT)

Not enough short baselines
(BAO require 20m)
➔use N single dishes
(auto-correlation)

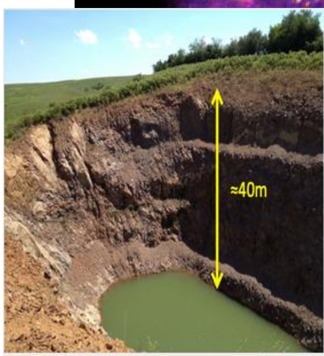




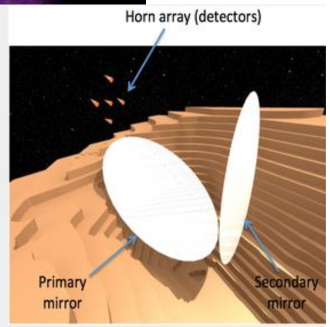
Even for synchtron smooth backgrounds, the response of the instrument is more complex

Switzer et al 2013

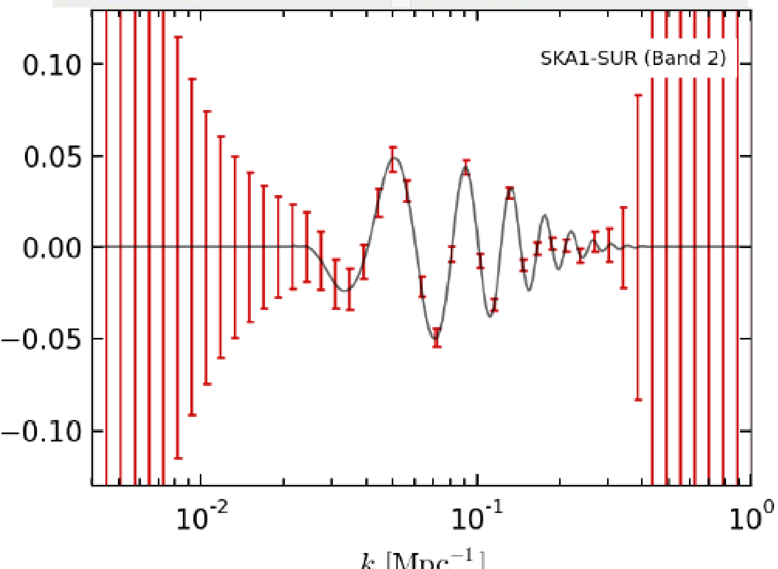
BAO with SKA1 Intensity mapping

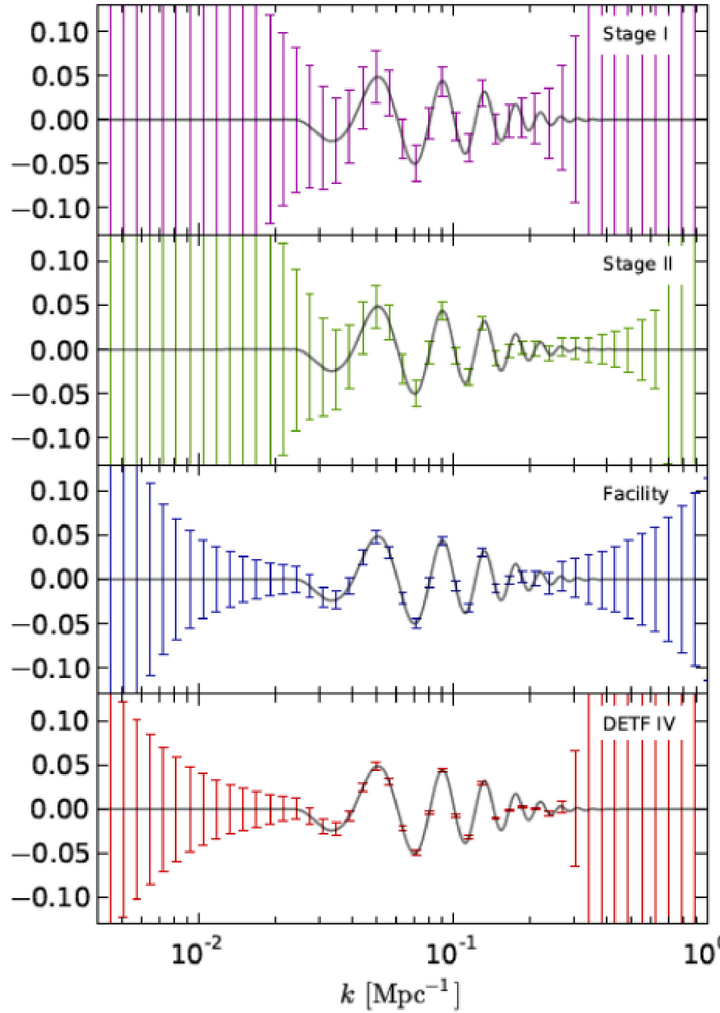


Quarry Castrillon



A 3D view of the BINGO telescope





40m

~ BINGO

z=0.13-0.48

~ MeerKAT

~ SKA1-Mid base (up to z ~ 2.0)

~ Euclid

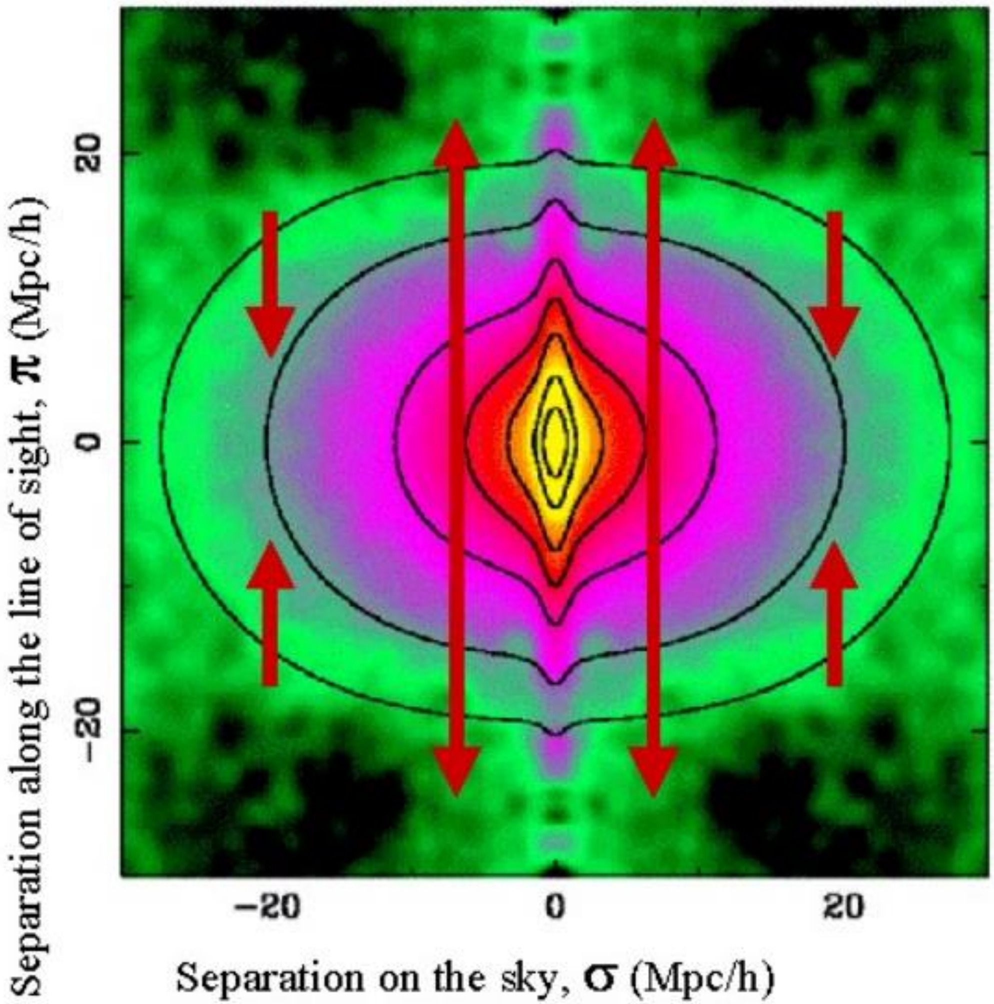
RSD Redshift space distortions

Distortions due to peculiar velocities on the line of sight (fingers of god!)

Kaiser effect in clusters
Systematic infall

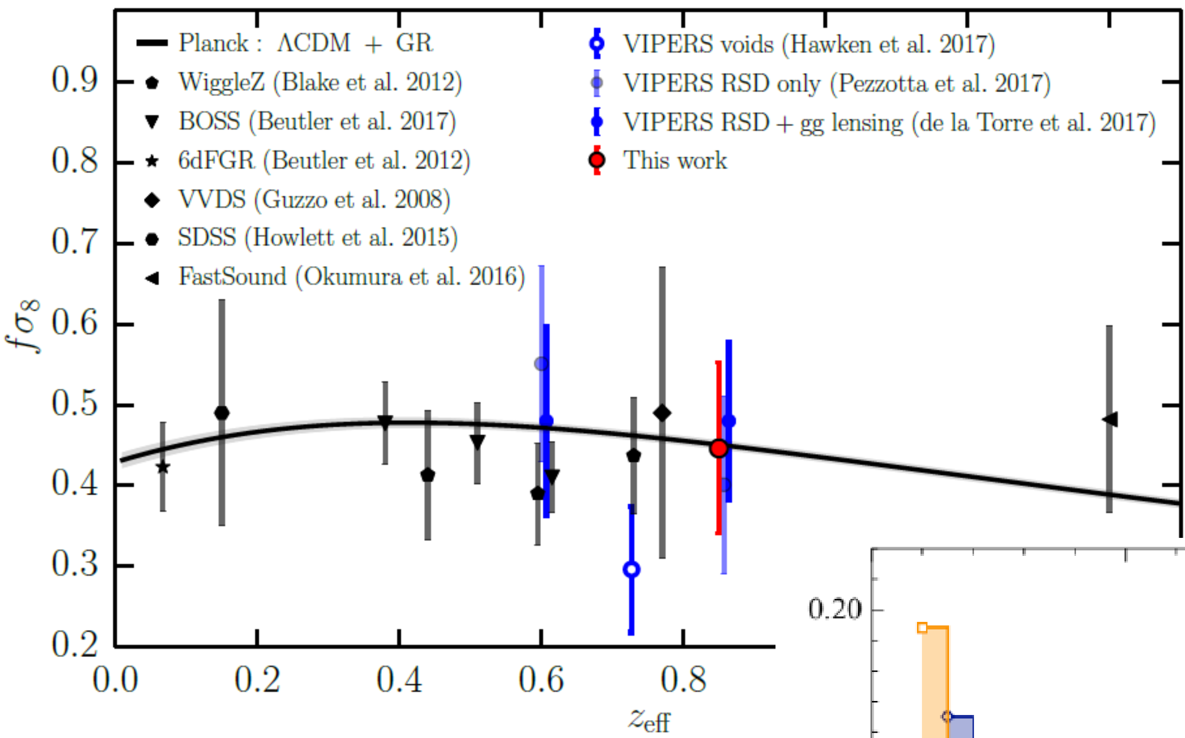
More than random allows to determine

$\beta = \Omega_m^{0.6}/b$
bias $\delta_{galaxies} = b\ (\delta_{mass})$
and σ_{gal}



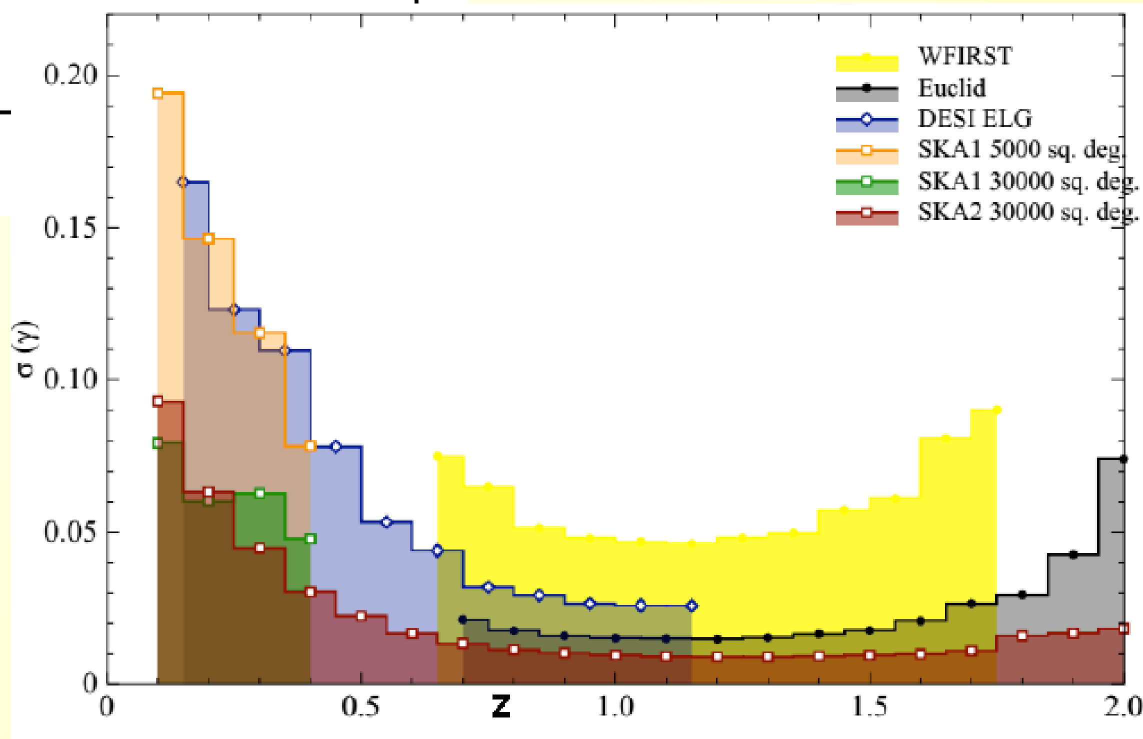
The 2dF Galaxy Redshift Survey Team (2001)

RSD: Redshift Space Distortions



Linear growth rate for structures f(z) x σ8

Tests of modified gravity



Various galaxy surveys
VIPERS,
Mohammad et al 2018

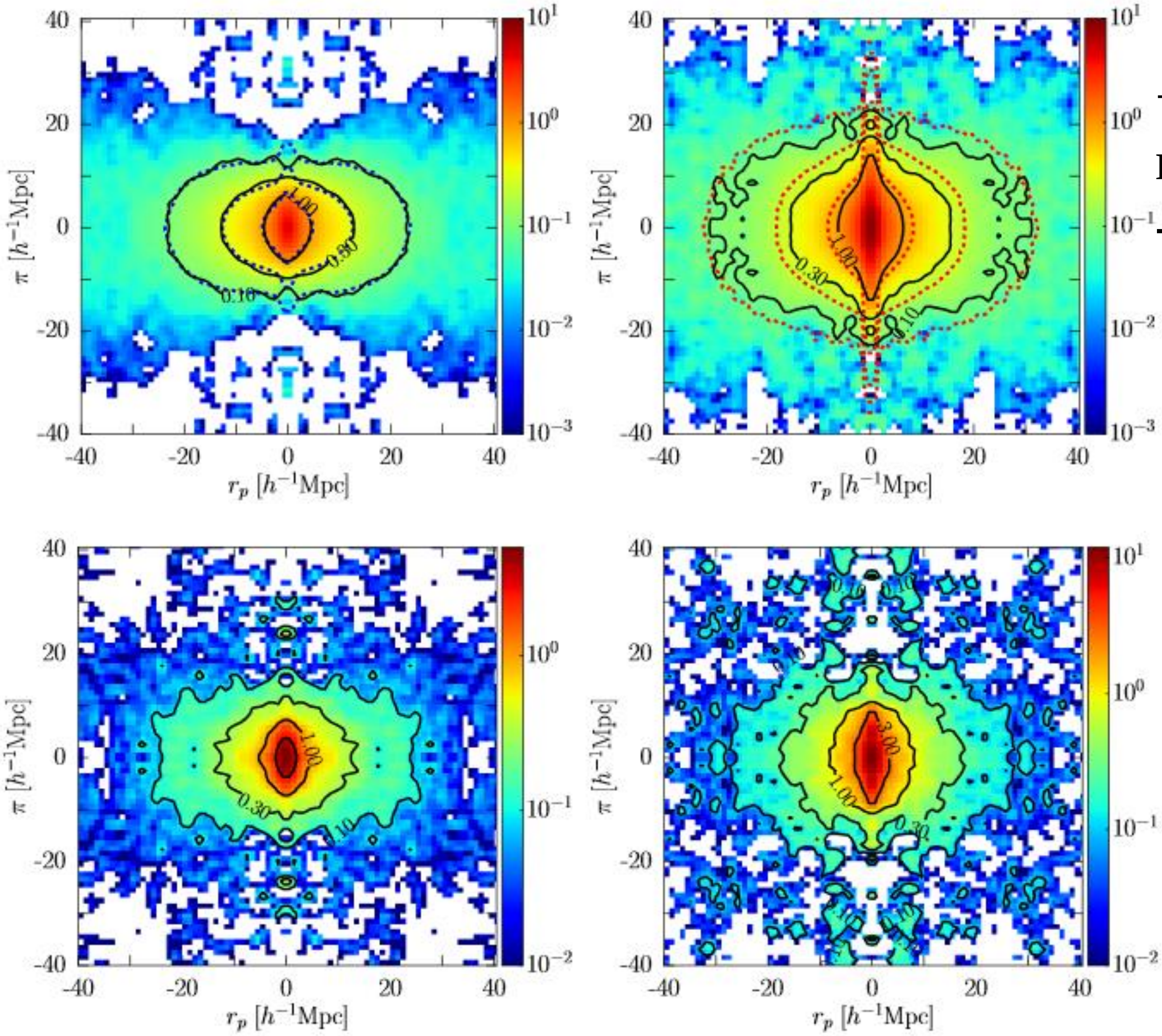
Mohammad et al 2018

VIPERS Blue galaxies

Red galaxies

Flux Limited

Volume Limited



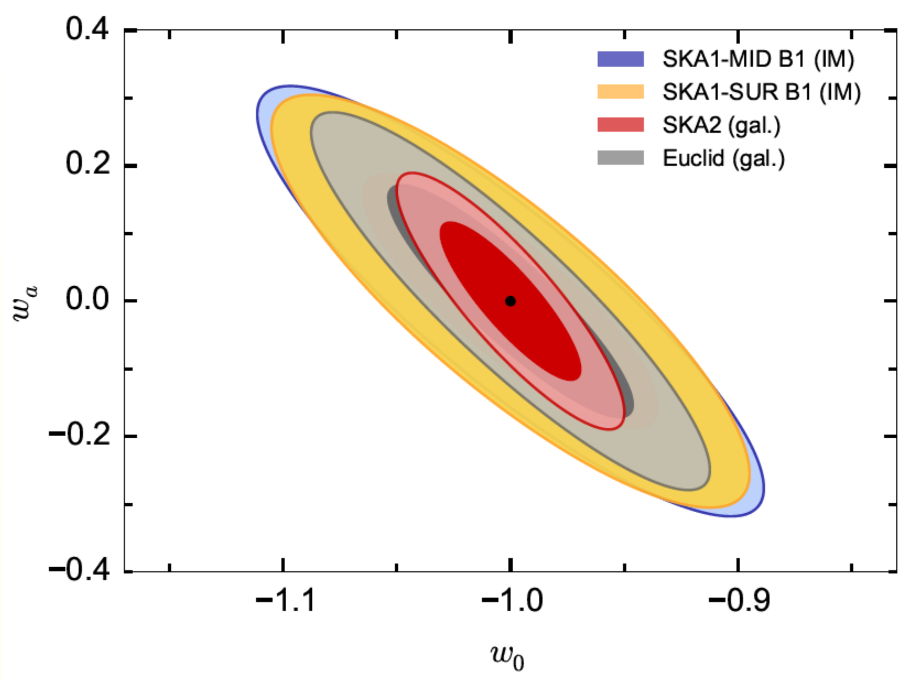
+ FOG for red objects

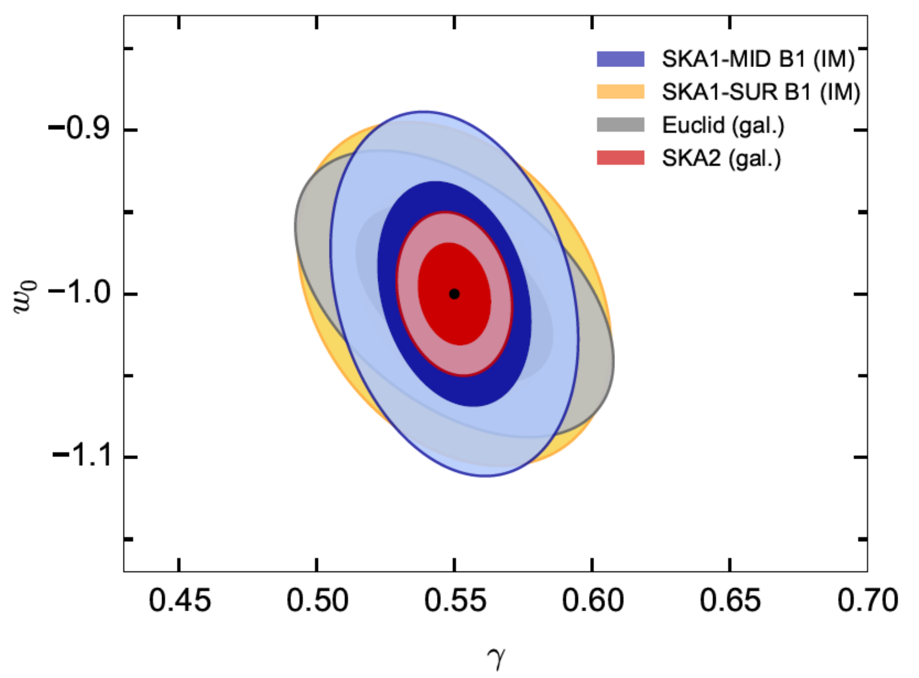
--- simul

RSD constraints on DE and γ

γ=0.55 RG Standard model

Raccanelli et al. 2015





Dark energy

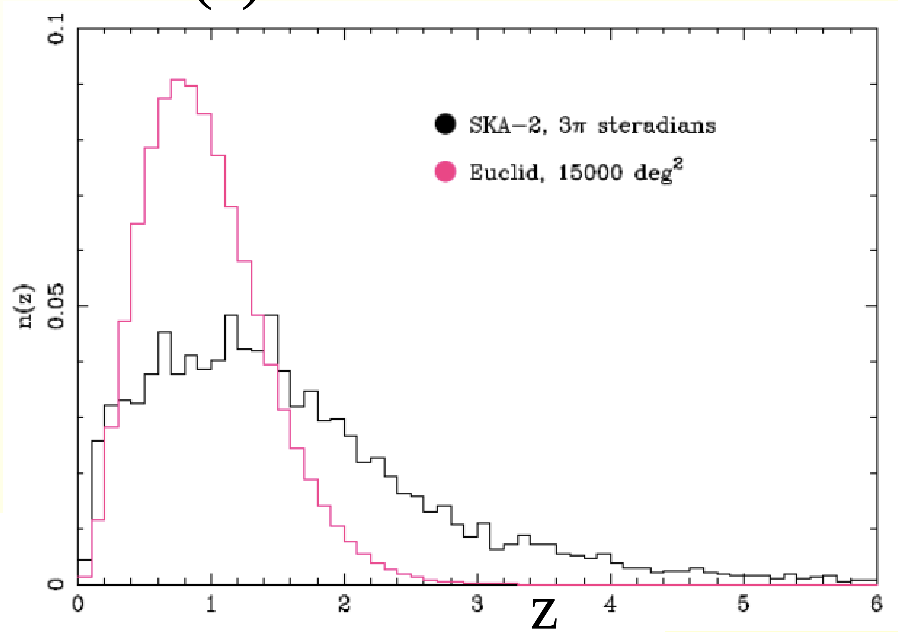
Modified gravity

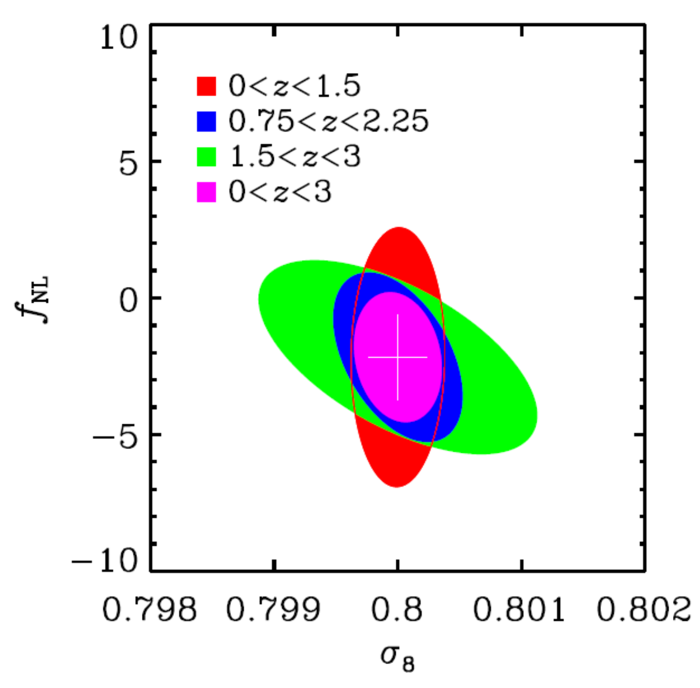
Weak Lensing & LSS in radio

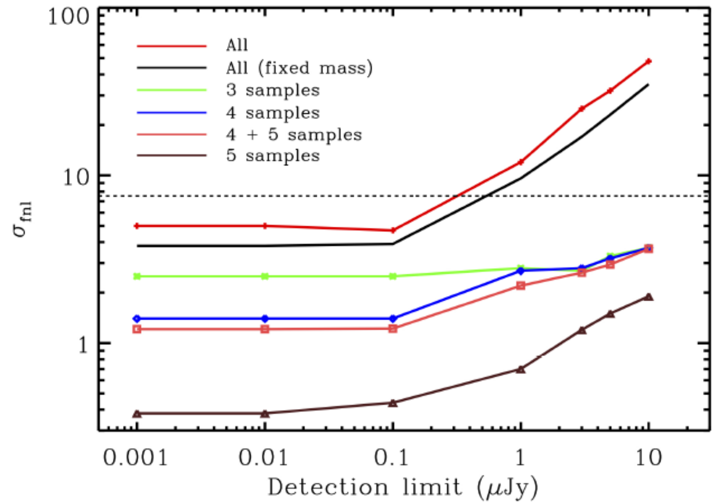
Number of objects
extends to higher z with SKA

The amplitude of non-gaussianity
f_{NL} = -2.2 in standard GR
$\sigma(f_{NL})$ = 7.5 (Planck)
= 2.3 (SKA1) & =1 (SKA2)

dN(z) dz







SKA1 &
SKA2
Radio
$\sigma(f_{NL})$

Continuum surveys with SKA1

In 2yrs achieve 2 μJy rms would provide ≈4 galaxies $arcmin^2$ (>10σ)

PSF is excellent quality circular Gaussian from about 0.6 – 100”
With almost uniform sky coverage of 3π sr

➔Total of **0.5 billion radio sources, for All sky survey**
for weak lensing and Integrated Sachs Wolfe (WL, ISW)

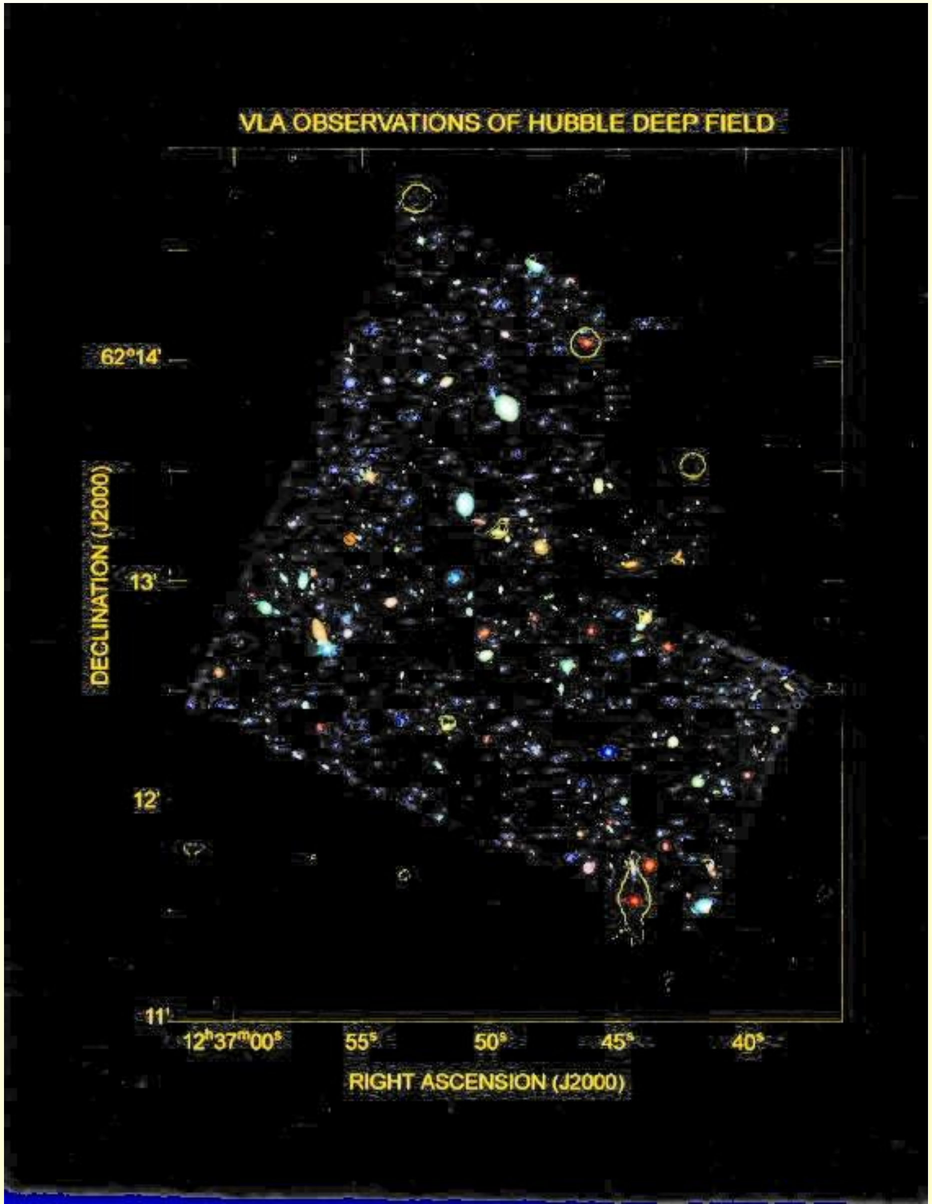
For wide-field (5000 deg2) **2 μJy rms** ≈6 galaxies $arcmin^2$ (>10σ)
For deep-field (50deg2) **0.1 μJy rms**, ≈20 galaxies $arcmin^2$ (>10σ)

Present status of radio surveys

HDF-N 5 x 5 arcmin area to I ~29thmagnitude

Fomalont et al., ApJ 475, L5 (1997)

6 sources detected by VLA with $S_{8.4}$ > 12 μJy (50 hour observation)



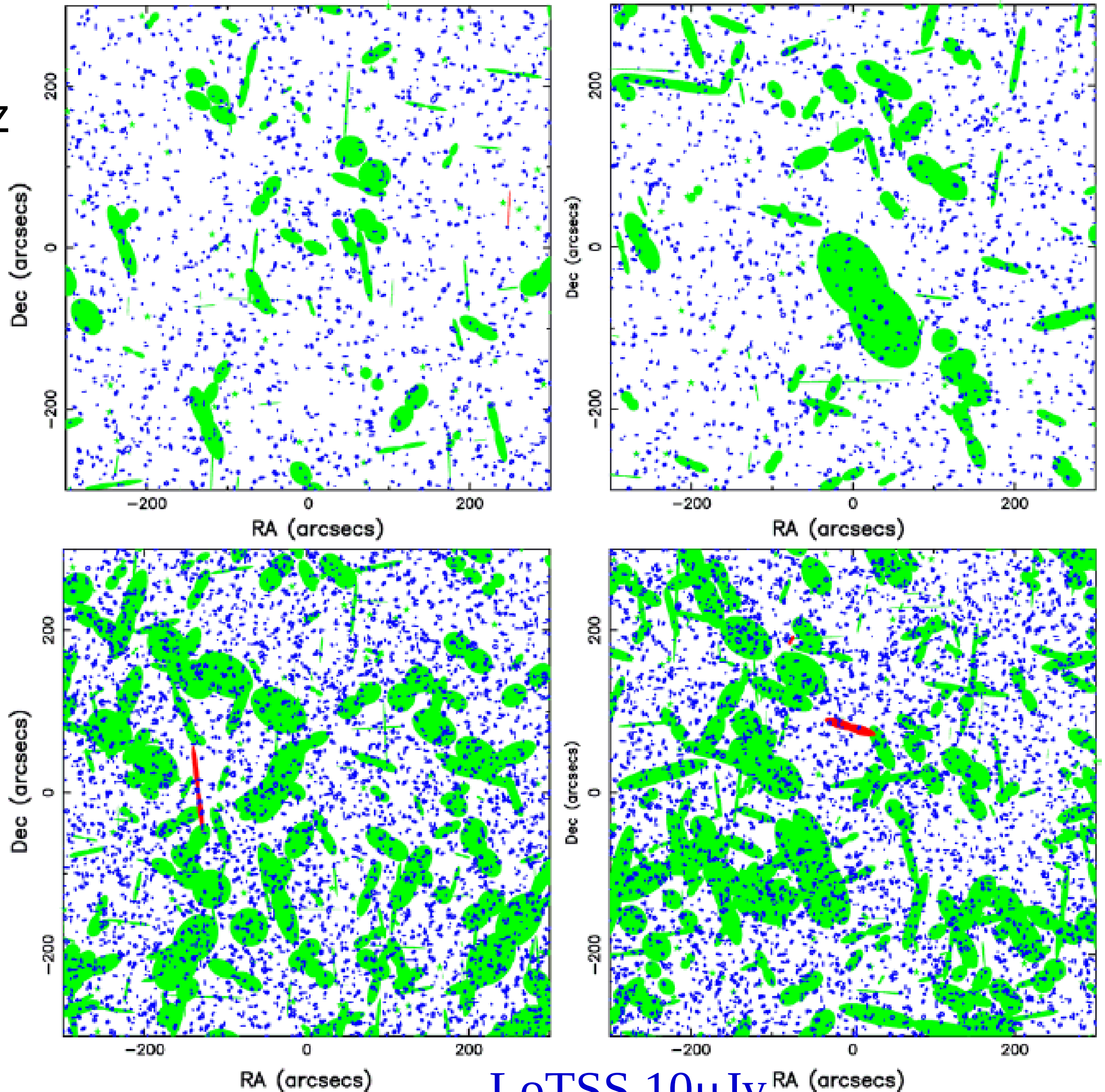
Deep radio sky
10' size, @ 1.4GHz

1μJy top
100nJy bottom
Left and Right
Cosmic variance

FRI: green, double
FRII: red, double

Beamed FRI:
green dot
Beamed FRII:
red dot
Star-forming: disk

Jackson 2004

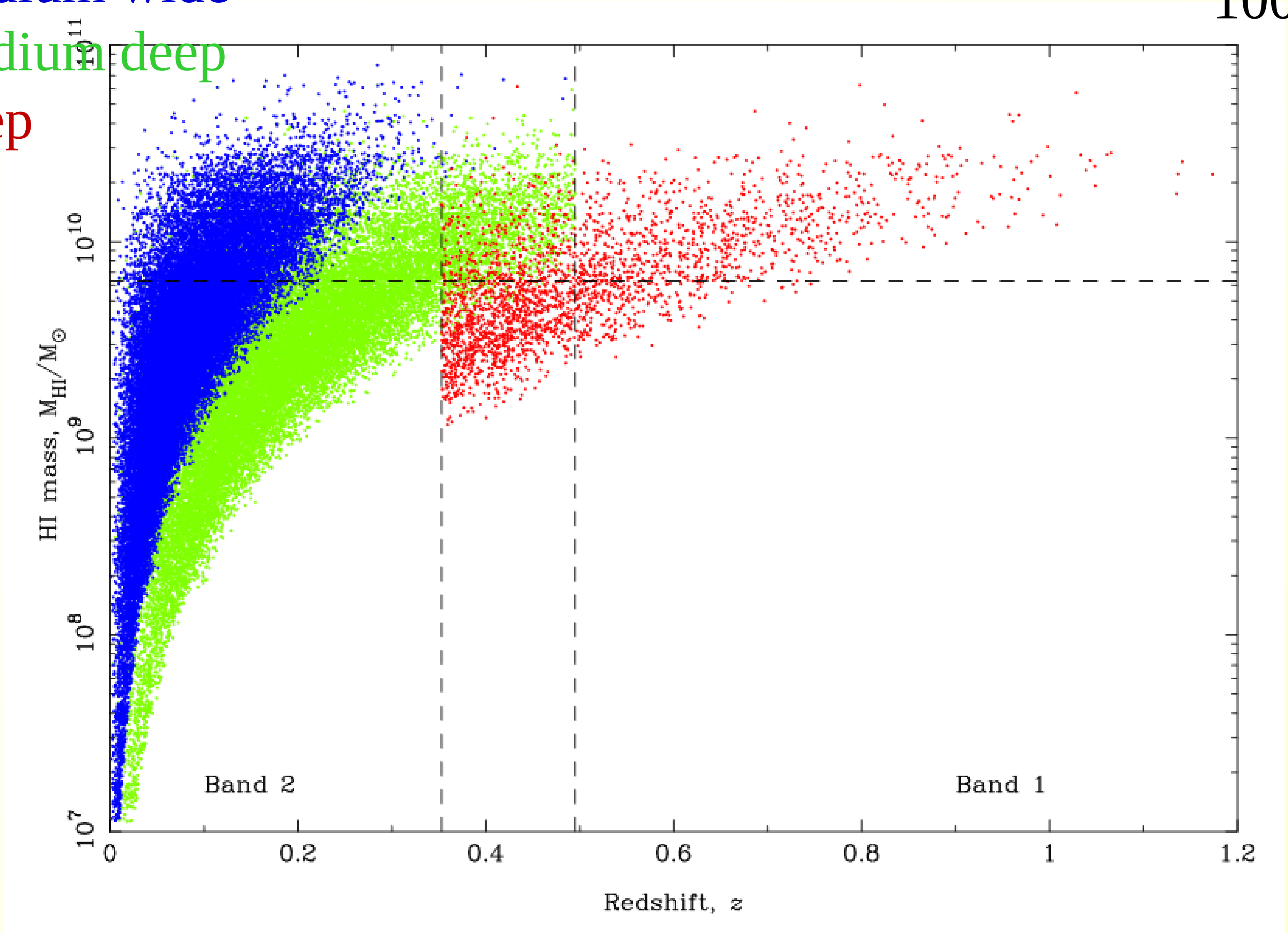


LoTSS 10μJy

HI gas in Galaxies

Medium wide
Medium deep
Deep

1000h survey



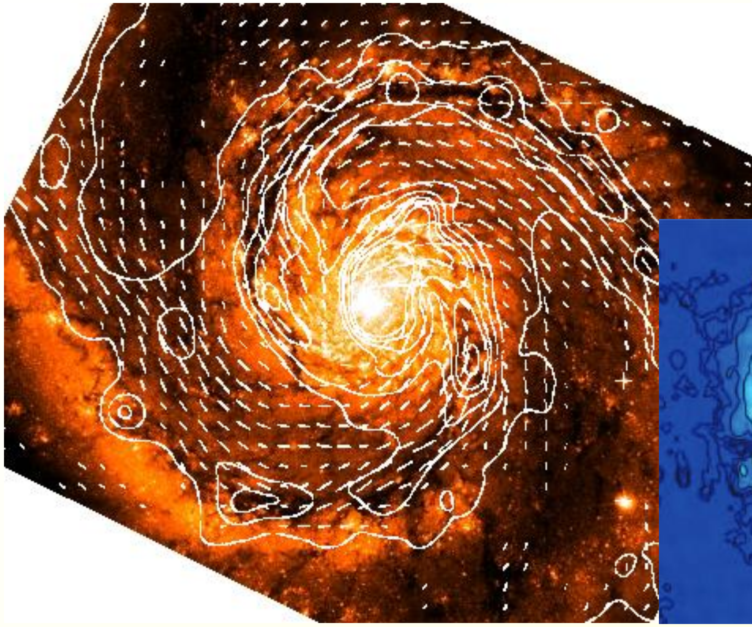
MHI* z=0

Study of HI rotation curves up to z~1 with SKA1
Up to z~2 with SKA2

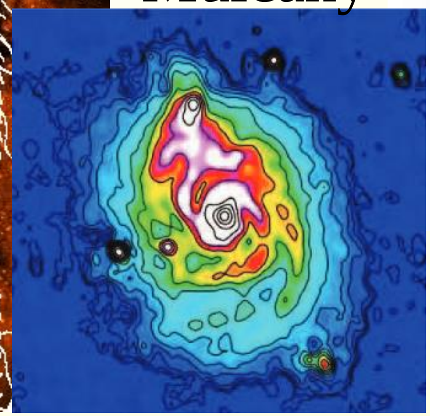
Staveley-Smith & Oosterloo 2015

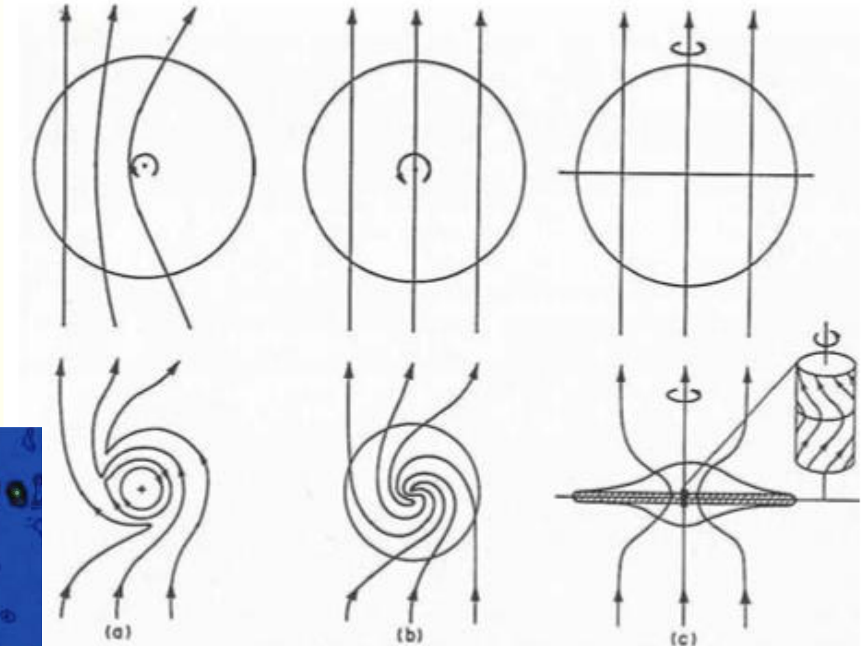
Magnetic fields

M51, Beck



LOFAR
Mulcahy





Sofue 1990

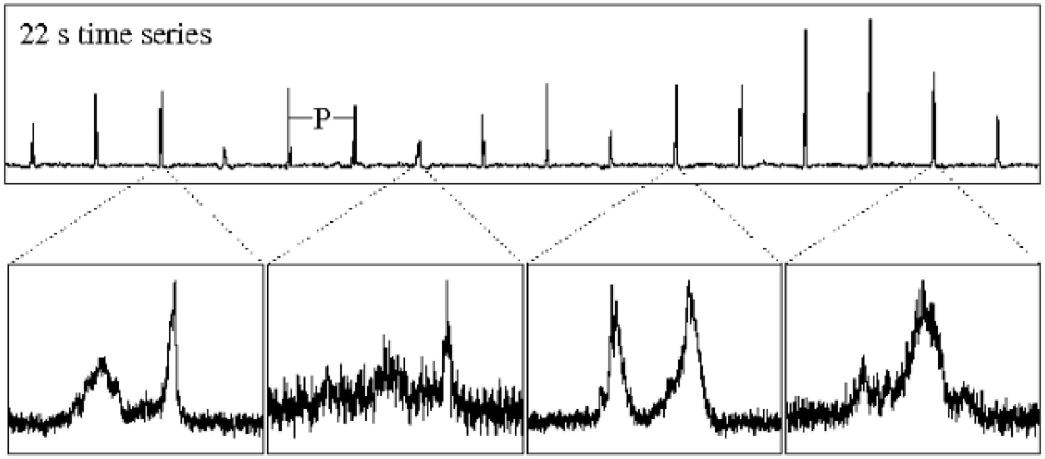
All sky survey of Faraday rotation (n_e, B): to measure inter-galactic B together with B inside galaxies

Magneto-genesis: Inflation, phase transitions in the early Universe

Then **batteries t**o amplify B. Normally B frozen into matter, should dilute away in the expansion. When structures collapse, B is amplified

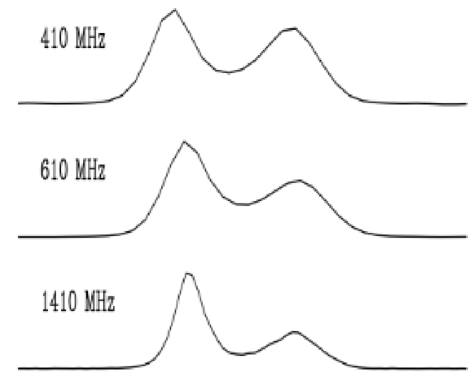
Detection of inter-galactic B is s strong goal (e.g. cool core clusters)

Pulsars: Time of Arrival (TOA)

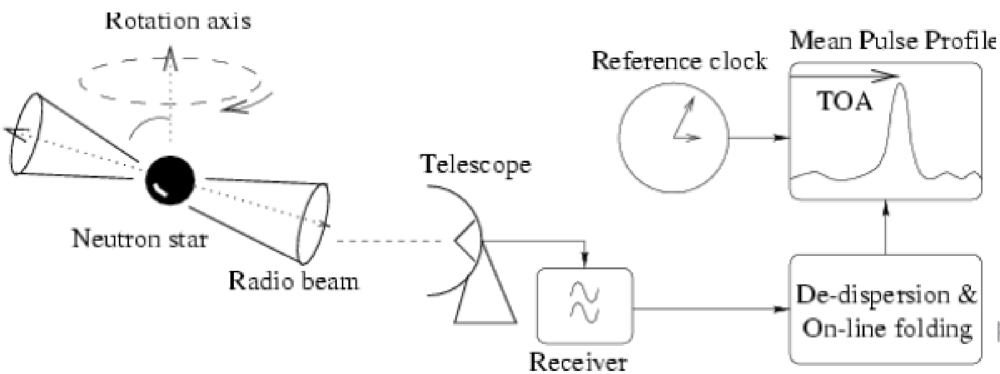


individual pulses

> 1000s of pulses ➔



mean profile



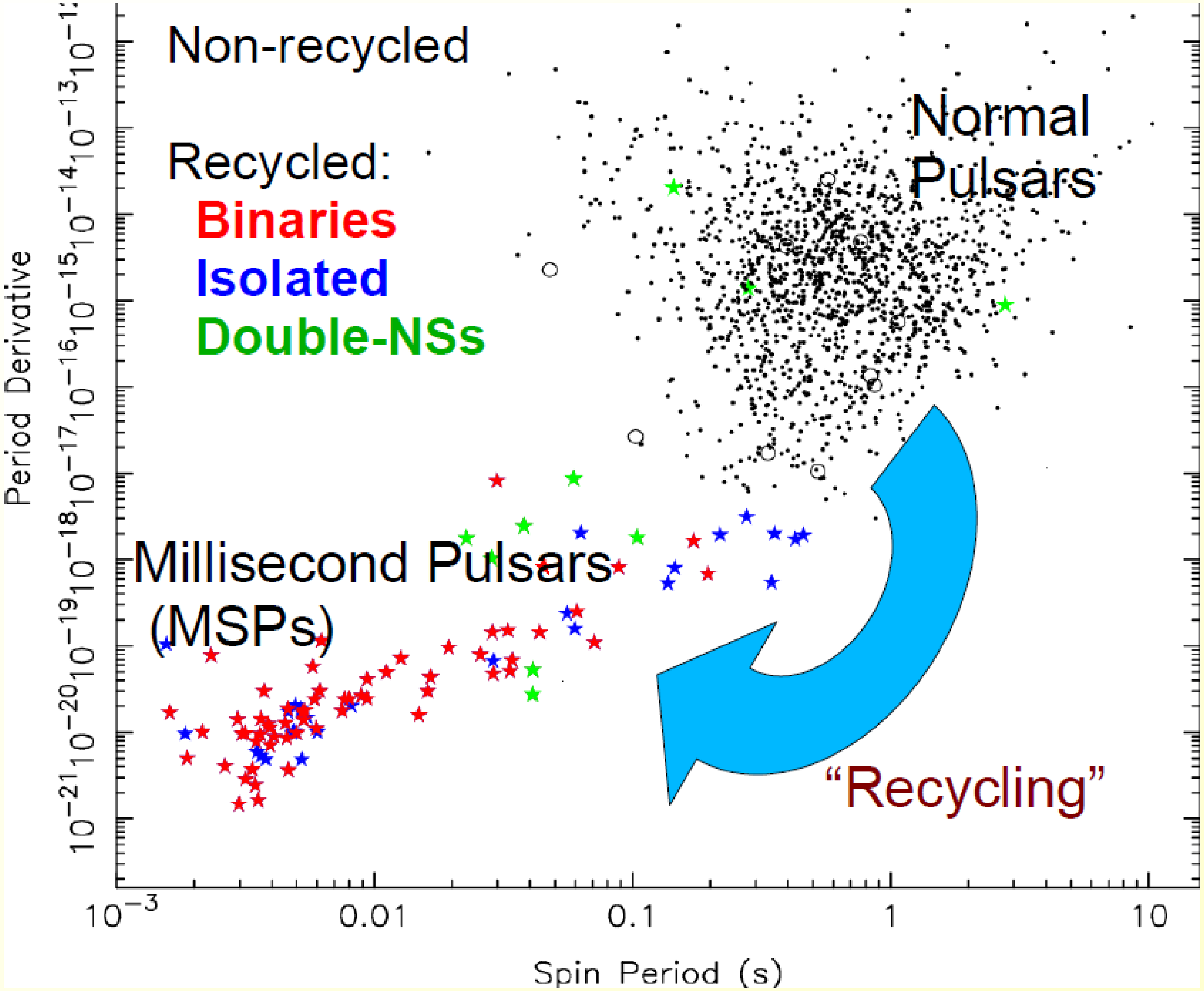
Binaries, and
Gravitational waves

From Lorimer & Kramer, *Handbook of Pulsar Astronomy*

Physics of accreting WD, NS and BH: physics of condensed matter with strong magnetic B. High sensitivity

Timing of pulsars

MSPs, J0437−4715, one of the best measured has now
P= 5.7574518589879ms ±1 in the last digit (13th)
This digit increases by 1 every 1/2h



Loss by radiation and Relativistic wind

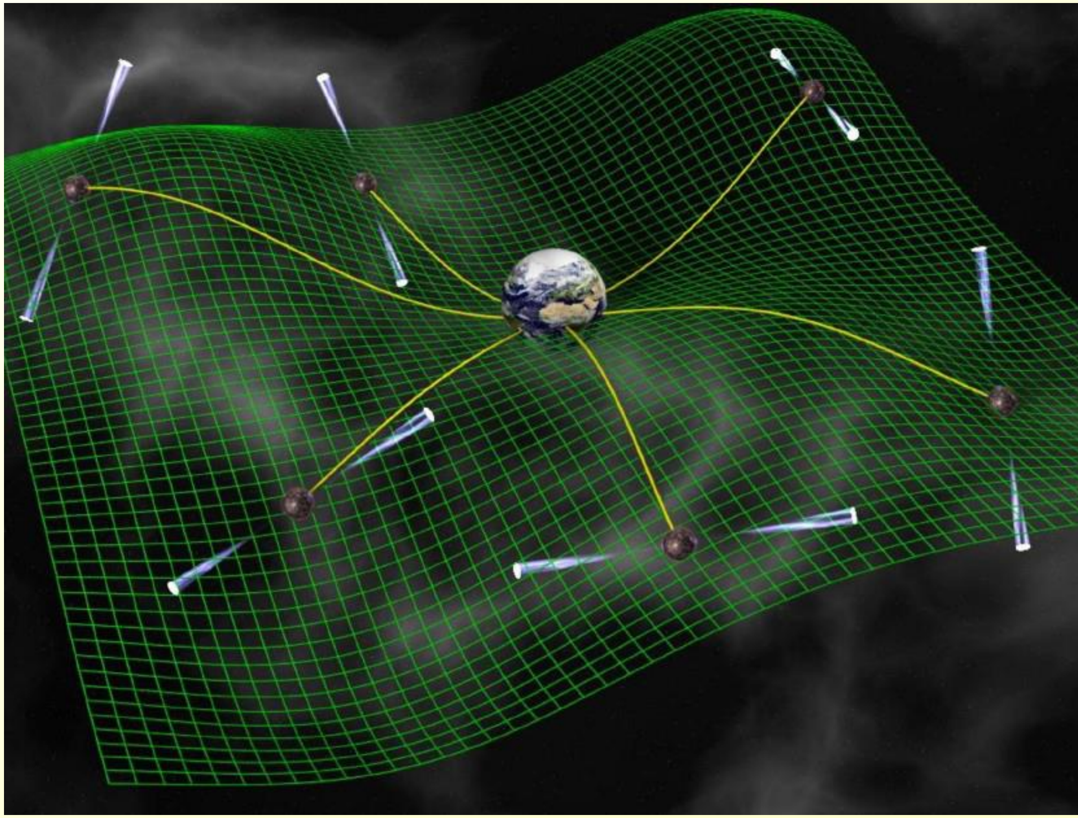
The first 6 digits keep the same for 10^3 yrs

TOA measured with μs during several yrs

➔ 14 digits

Gravitational waves

PTA: pulsar timing arrays. Monitoring several MSP
GW have few nanoHz frequencies (λ ~light-yr = 10^4 billion km)
Correlation between the TOA
of several pulsars
Will trace space streching

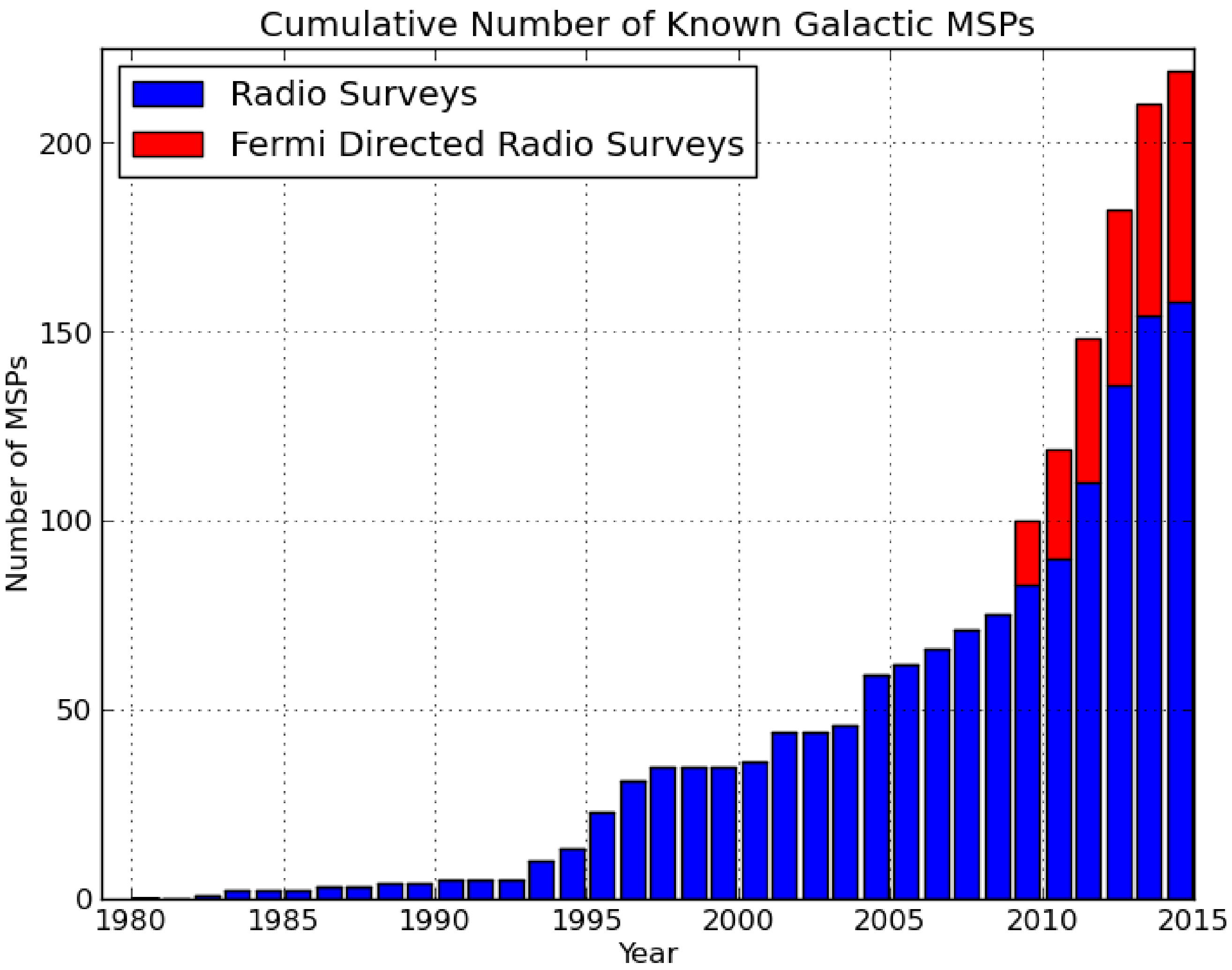


➔GW $\lambda >> \lambda$ (LIGO-Virgo)

GW coming from merger of
black holes, if nearby
Will be seen in other λ

Or noise due to the ensemble of
mergers (stochastic background)

A bright future with the radio observatories: SKA and precursors



Nbeams= $(Dtot/d)^2$ =4000
or To/s data

Cannot record, but
Process on-time

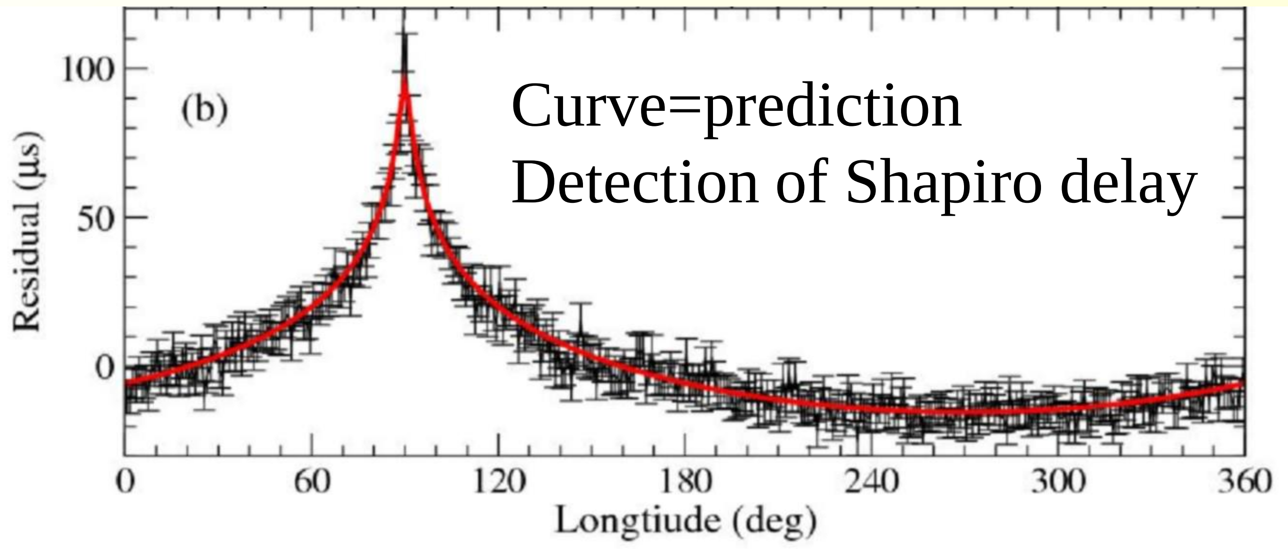
Cannot re-analyse
➔ Re-observe

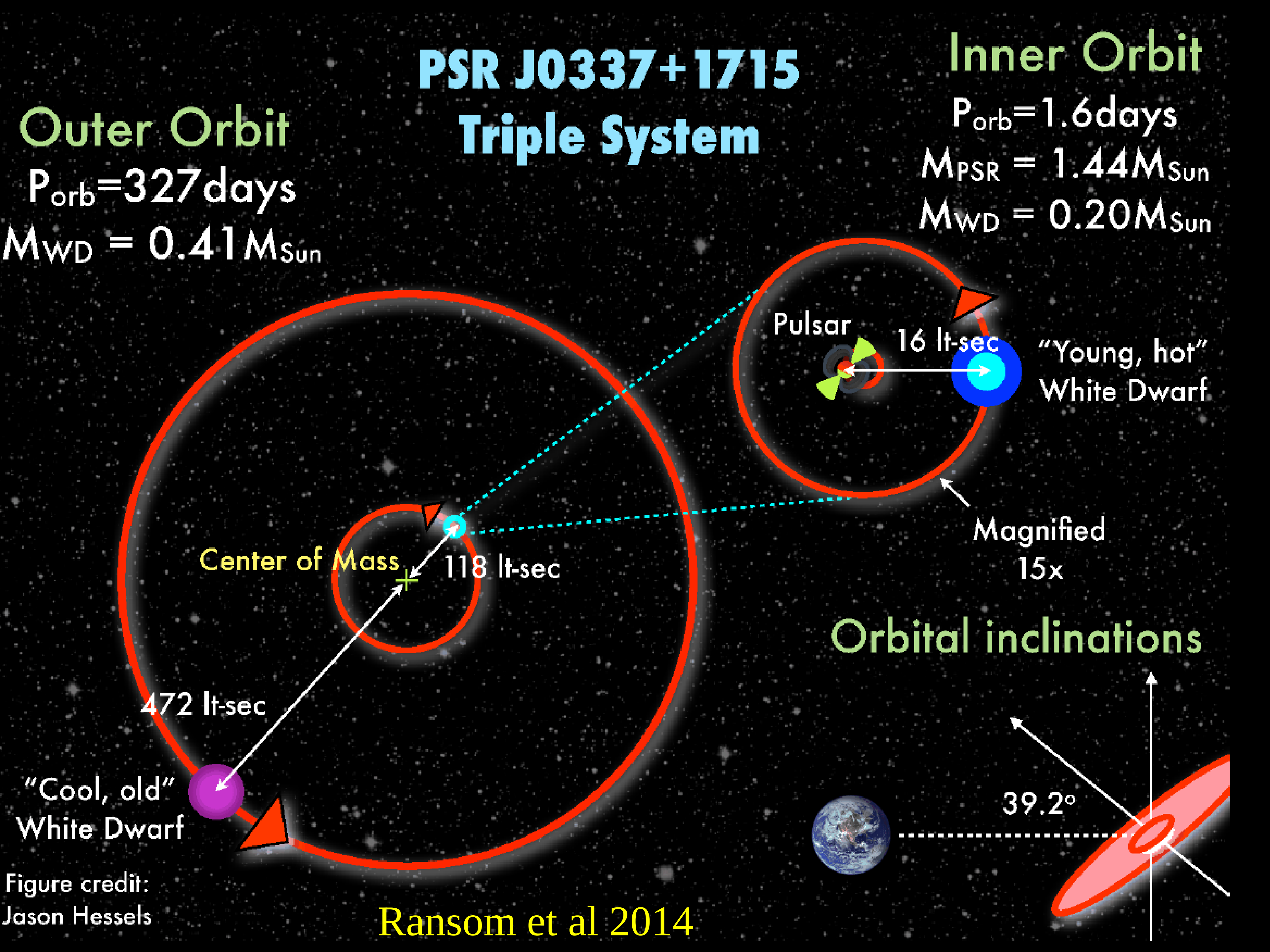
Tests of General Relativity

Gravity in strong fields: PSR-Neutron star, PSR-black hole
Was Einstein right?, Cosmic Censorship Conjecture
(i.e. Naked singularities), No-hair theorem

Double pulsars timing: 0.05% test of general relativity in “strong”-field (gravitational delay)

Kramer et al 2006, Science PSR J0737-3039A/B



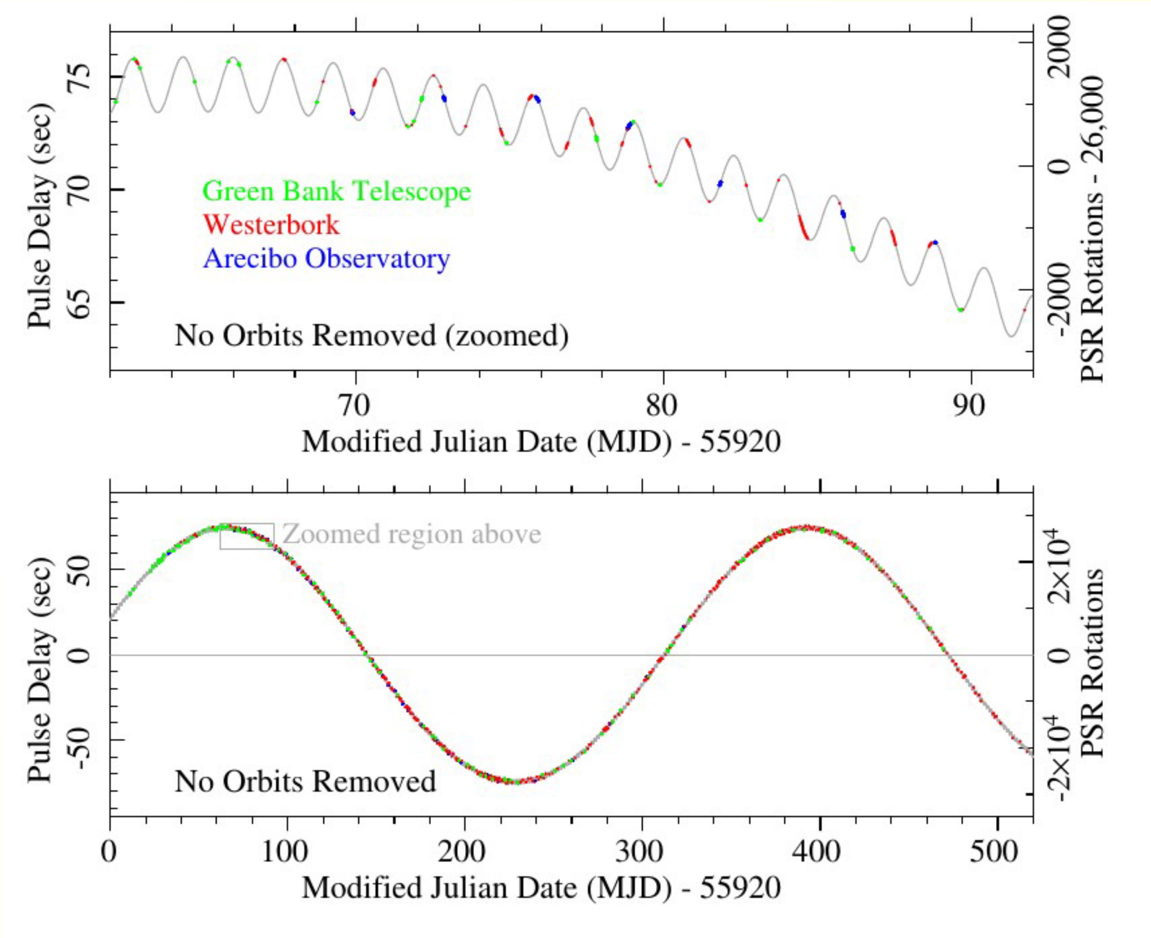


Ransom et al 2014

Precise data from the triple system

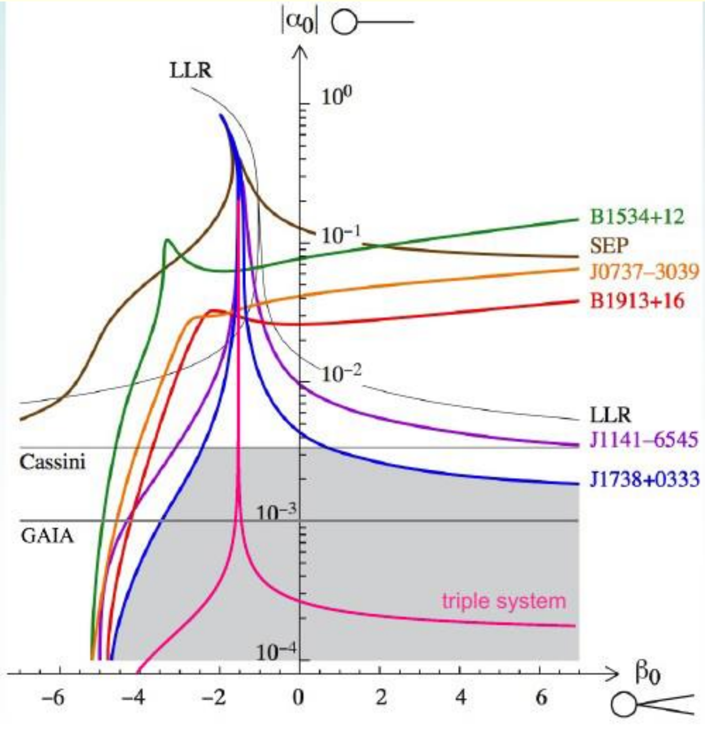
Allows to test the **Strong Equivalence Principle**

➔verified in strong gravity also



Other scalar-tensor theories

GR: $\alpha 0 = \beta 0 = 0$

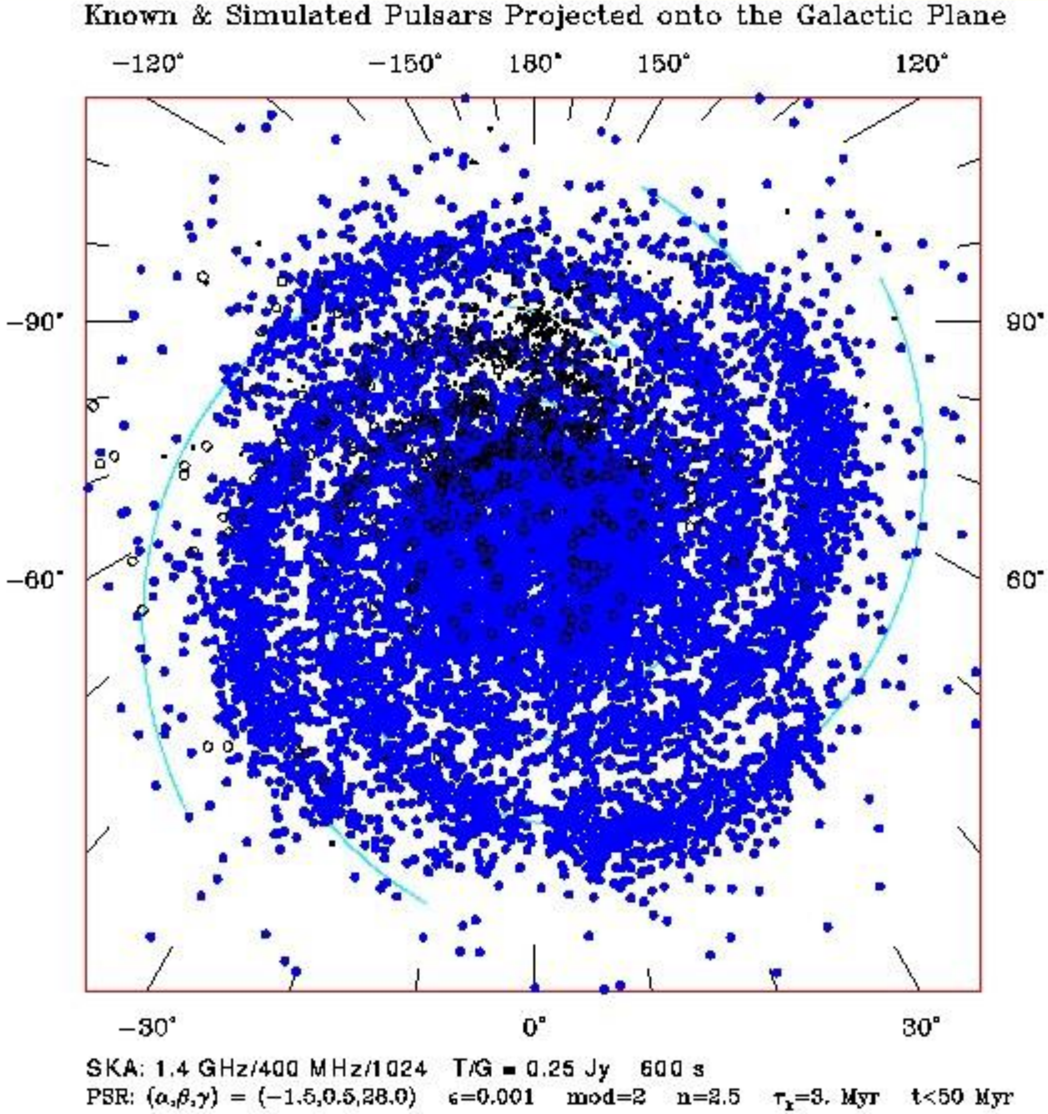


Freire et al 2012

Antoniadis et al 2013

Pulsars with SKA

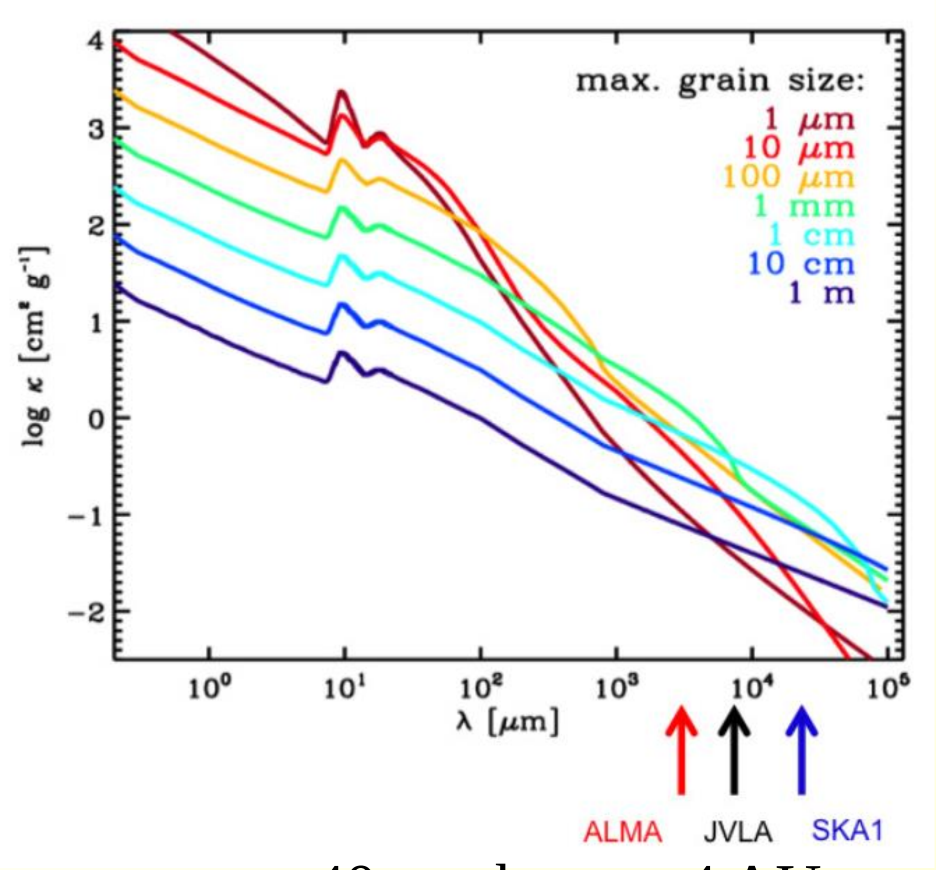
J Cordes, 2004

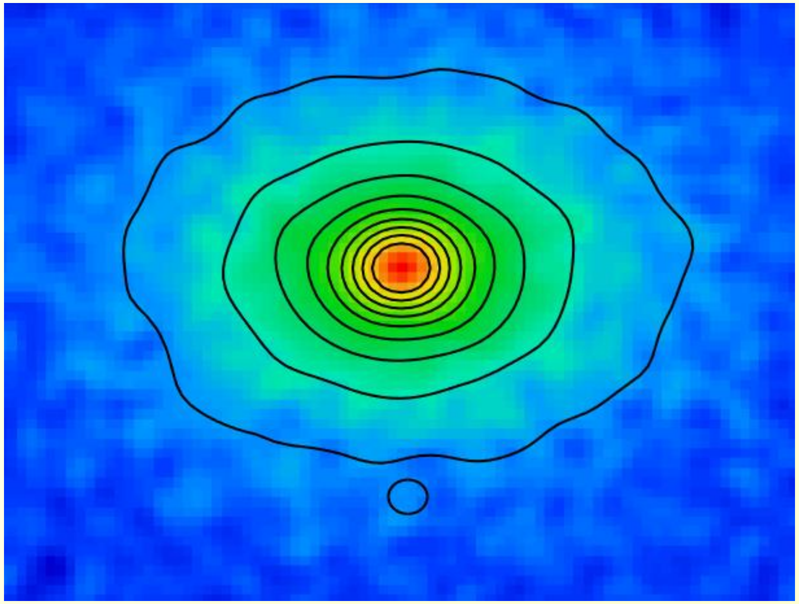


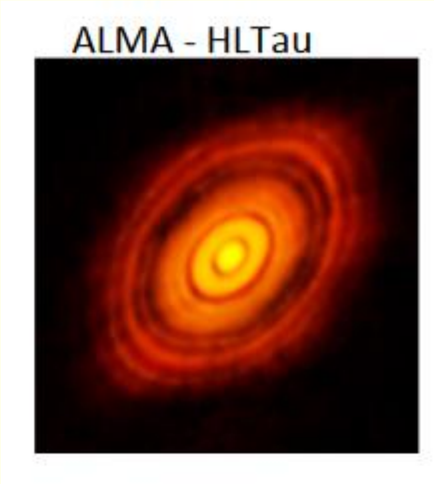
MW: 30000 PSR, 10^4 MSP
~20,000 potentially visible normal pulsars, MSPs and RRATs = **Rotating Radio Transients** *(irregular, nulling, might be more abundant?)*

- SKA1 has the potential to find a large fraction (~50%?) of these pulsars

Cradle for Life with SKA





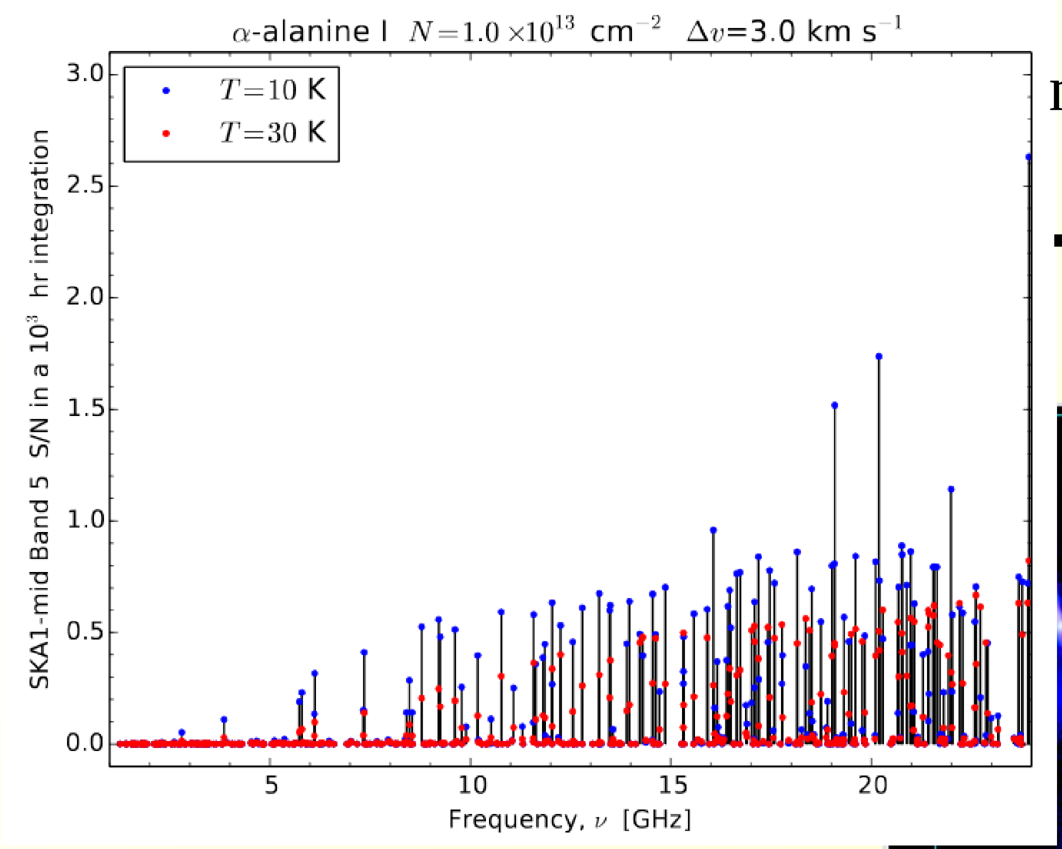


40mas beam ~4 AU for the snow line in the nearest systems

Hoare et al 2015

Pre-biotic molecules

1000h SKA1-mid, α-alanine



In Synergy with ALMA!

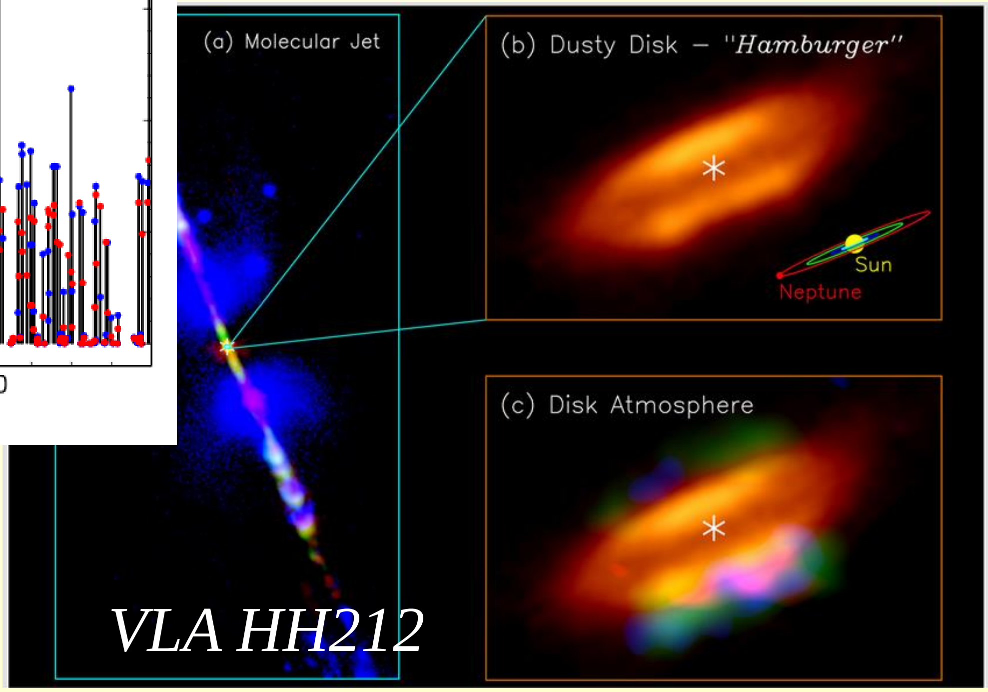
CH3OH,methanol

CH2DOH, (deuteratrd)

methanethiol CH3SH,

formamide NH2CHO

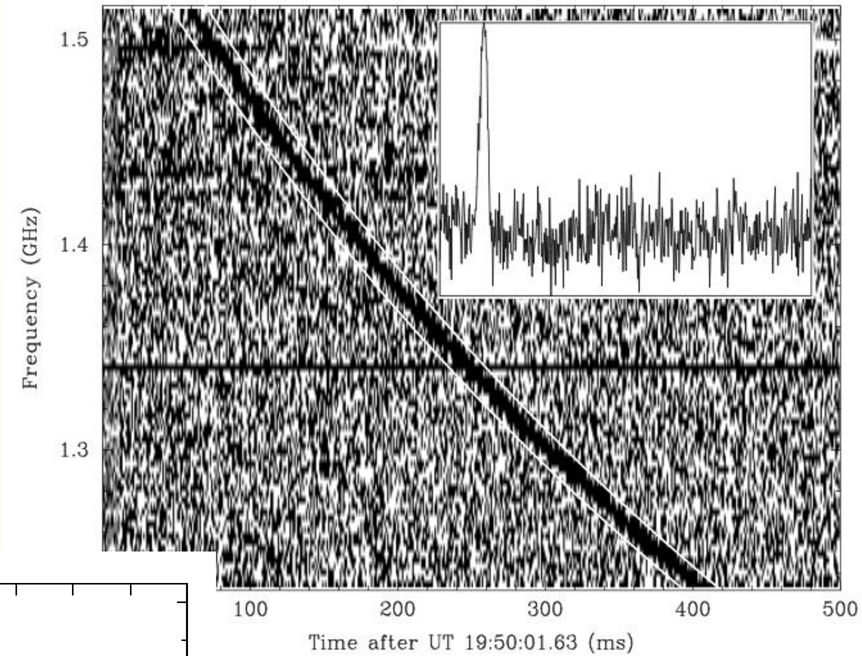
➔ Amino acids, sugars

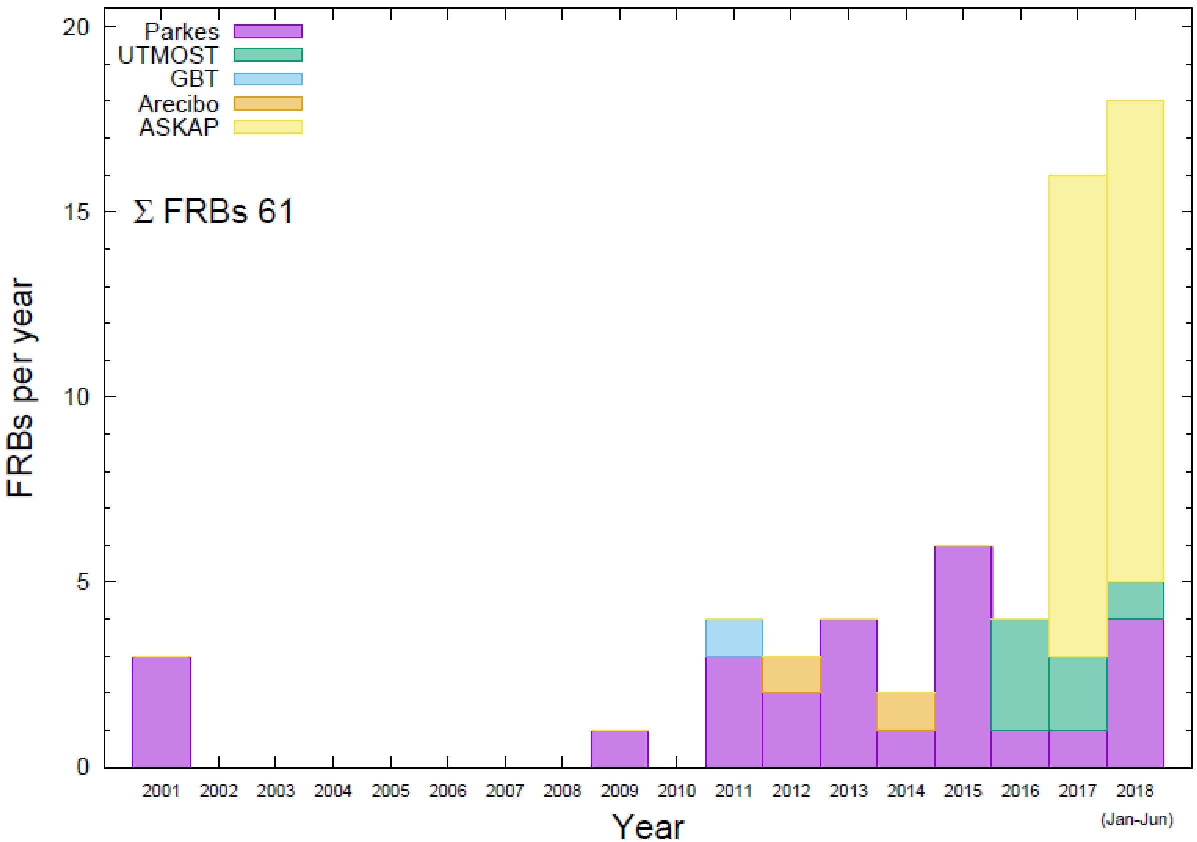


Hoare et al 2015

FRB: Fast Radio Bursts

With SKA-MID, 100 FRB/yr
with precise localisation
Detections by ASKAP, CHIME
➔missing baryons?

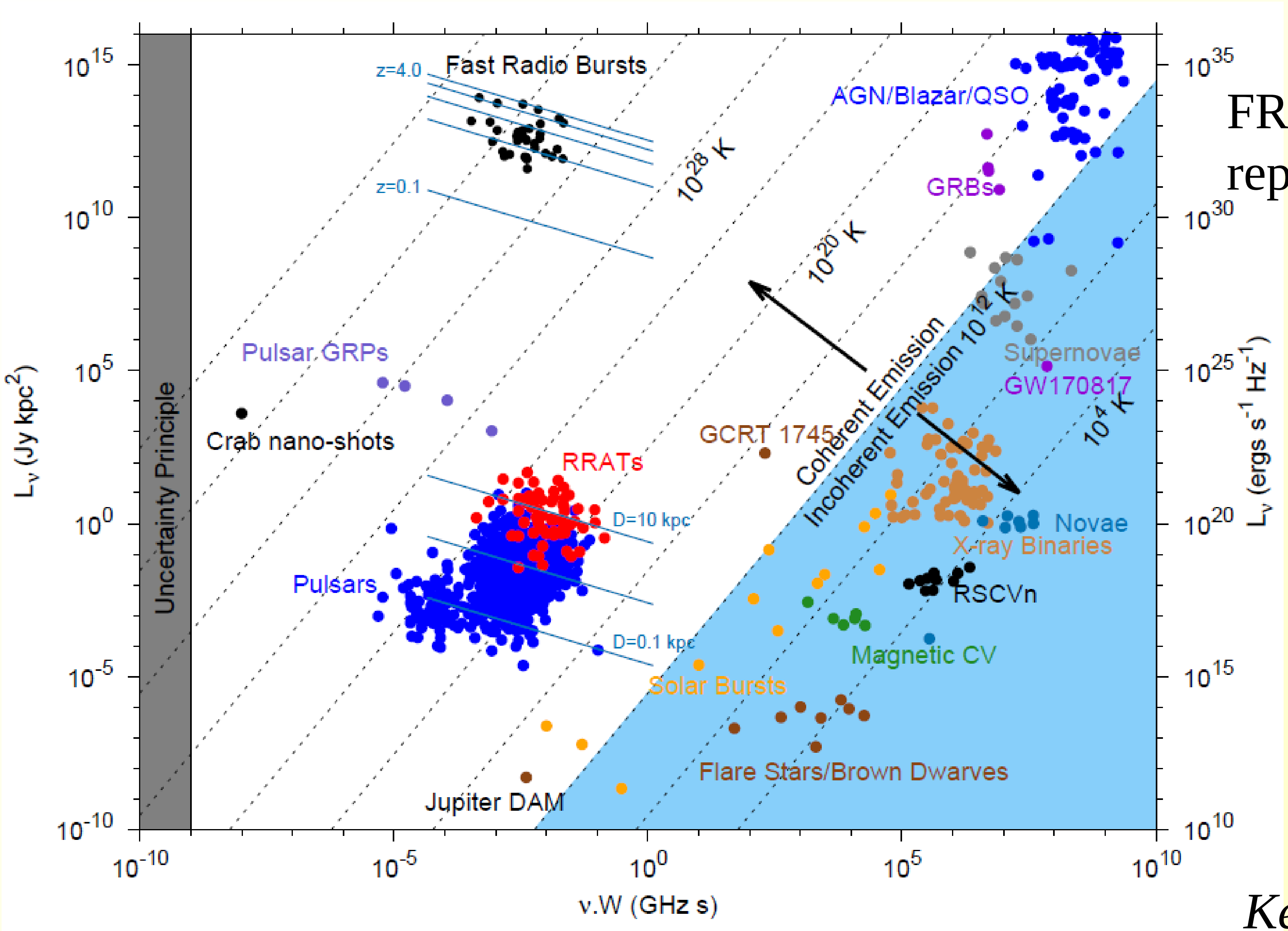




Lorimer et al 2007
Large DM➔ far away
Powerful objects
In external galaxies
10μs variability
➔Compact objects
Strong B
➔ magnetars
Keane 2018

FRB in the transient diagram, L-$\nu\Delta t$

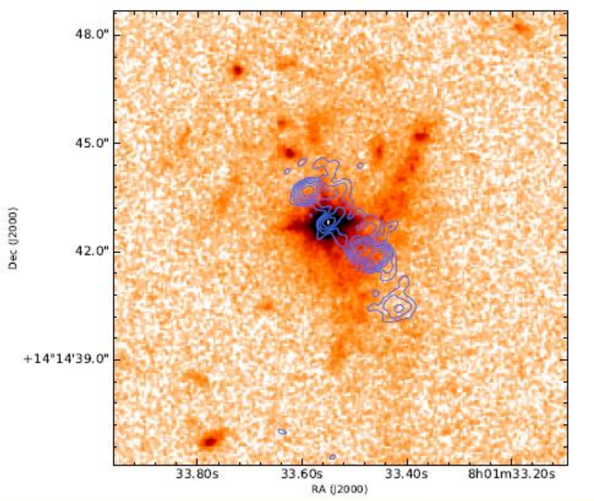
Could be use to trace the nature of Universe ➔ tomography



FRB121102
repeater

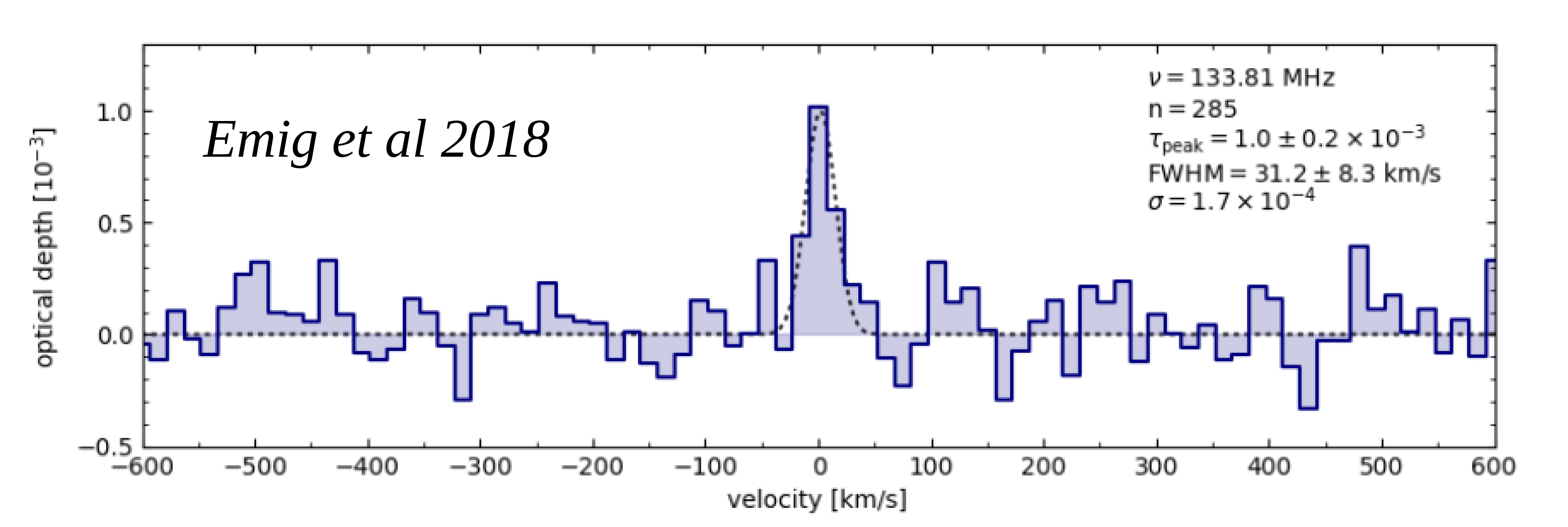
Keane 2018

RRL at high redshift with LOFAR



3C190 z=1.2 RRL z=1.12, ~10000 km/s offset
HST + Merlin 1.6 GHz

Weak lines to probe cold, largely atomic gas and warm, ionised gas (n, T)
Dwarf galaxy or AGN-driven outflow?



Summary

Cosmology: what is dark matter and dark energy?
Tools with high precision, BAO, RSD, HI in galaxies
H_0, masers

EoR: how the first galaxies were born

Pulsars: test new physics, gravity in strong field
Gravitational waves

Cradle for life: protoplanetary disks
Pre-biotic Molecules