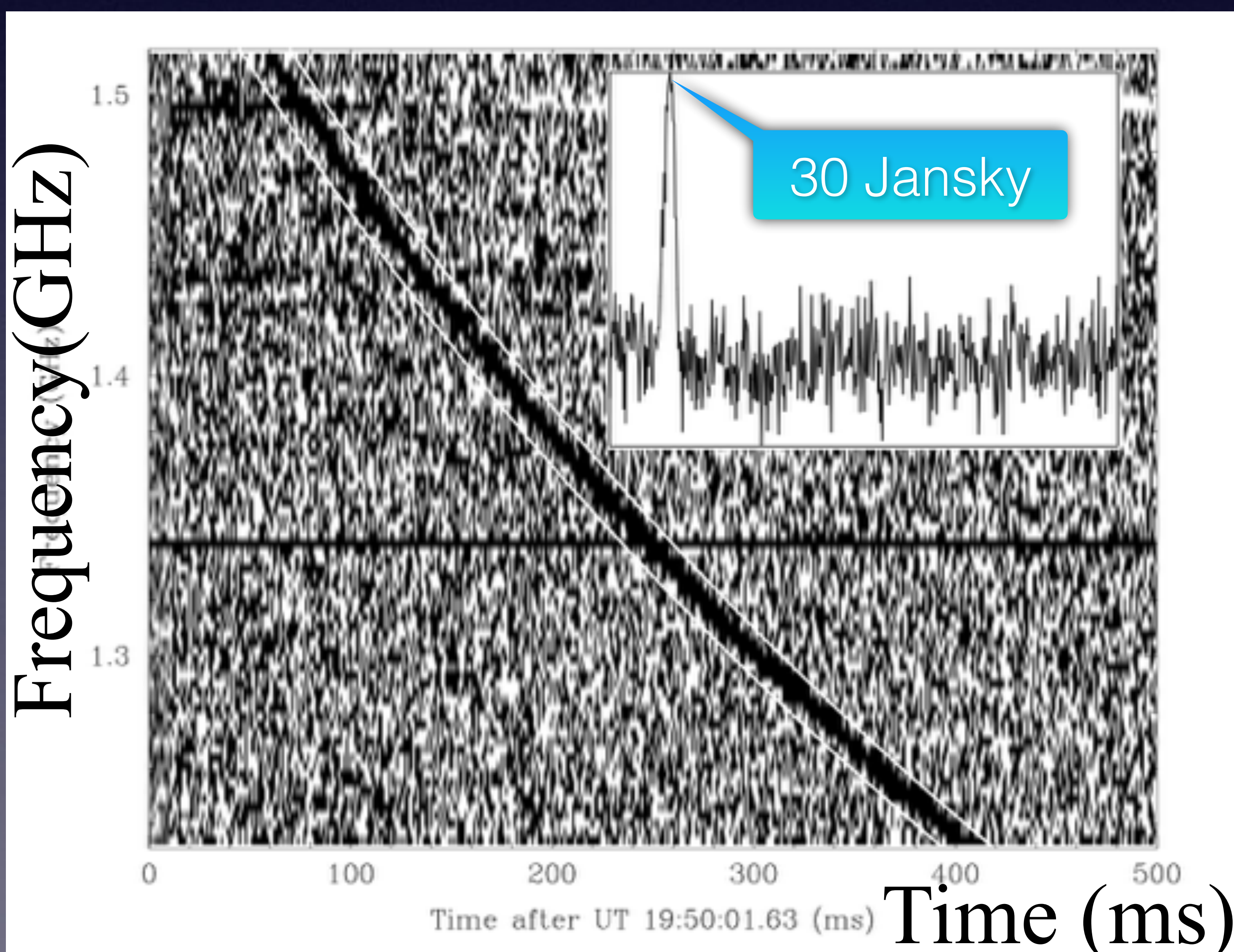
Time Domain Cosmology with TMT

Nao Suzuki (Kavli IPMU, Univ of Tokyo)

- Fast Radio Burst as a Cosmological Probe
- Gravitational Wave as a Distance Indicator
- SNIa Cosmology in 2020s
- Gravitationally Lensed SNIa
- Lensed Quasar on Double Source Plane
- IGM Tomography and Sandage Test

Δt=0.001s : Fast Radio Burst (FRB)

- Lorimir et al (2007) reports “A Bright Millisecond Radio Burst of Extragalactic Origin”

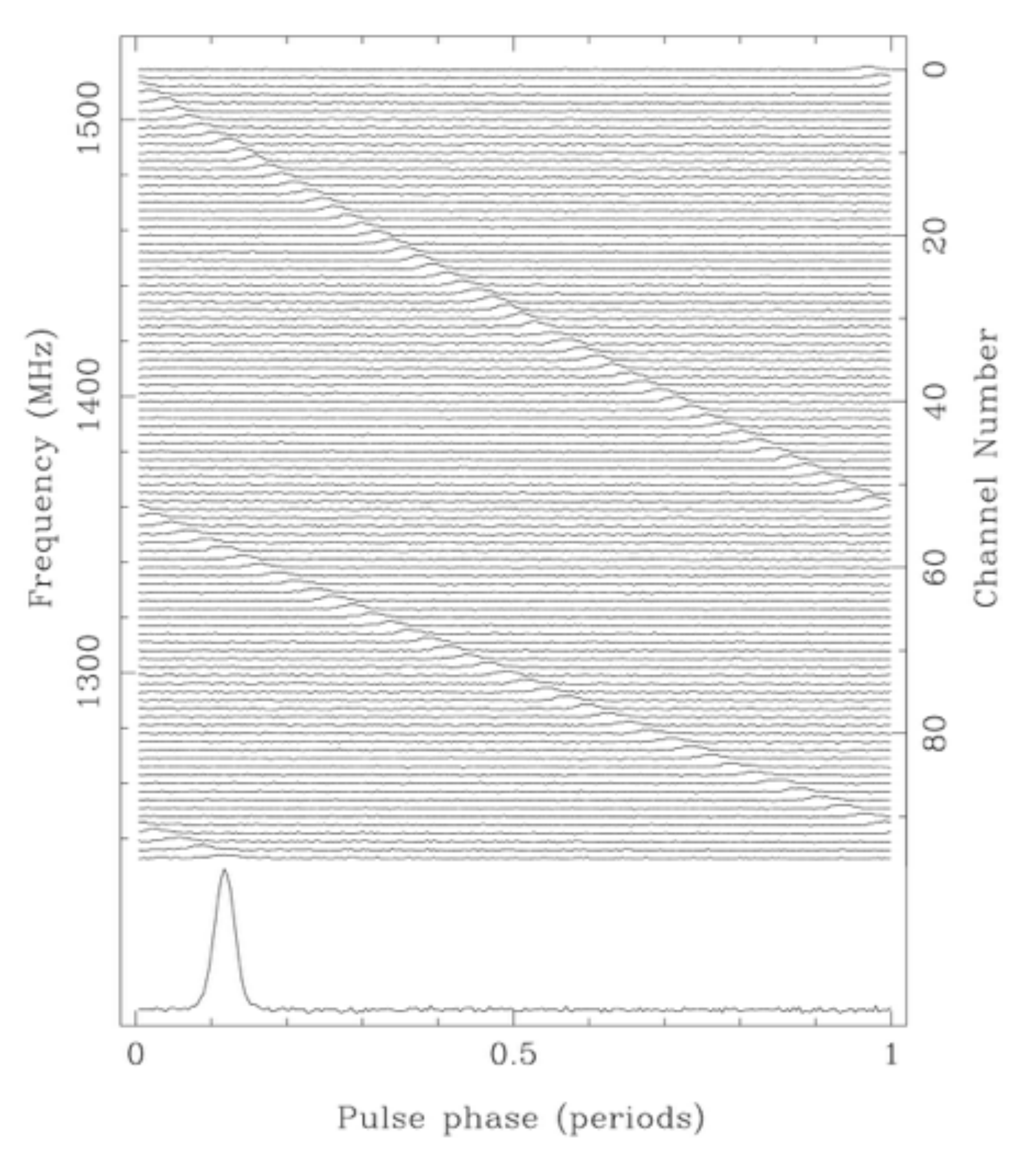


Identified in Archival Survey : Data is taken on Aug 24 2001

Dispersion Measure (DM) of 375 cm^{-3} pc

Science Nov 2007: Vol. 318, Issue 5851, 777

DM : Dispersion Measure



ISM Refractive Index

$$\mu = \left[1 - \left(\frac{\nu_p}{\nu}\right)^2\right]^{1/2}$$

Plasma Frequency

$$\nu_p = \left(\frac{e^2 n_e}{\pi m_e}\right)^{1/2} \approx 8.97\ \mathrm{kHz} \times \left(\frac{n_e}{\mathrm{cm}^{-3}}\right)^{1/2}$$

Dispersion Delay t

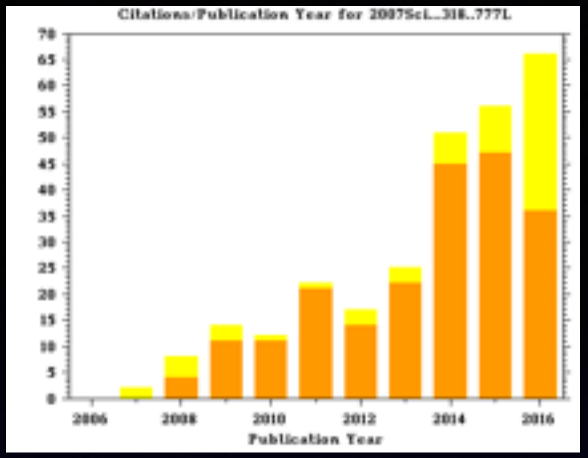
$$\left(\frac{t}{\mathrm{sec}}\right) \approx 4.149 \times 10^3 \left(\frac{\mathrm{DM}}{\mathrm{pc\ cm}^{-3}}\right)\left(\frac{\nu}{\mathrm{MHz}}\right)^{-2}$$

DM :Dispersion Measure

$$\mathrm{DM} \equiv \int_0^d n_e dl$$

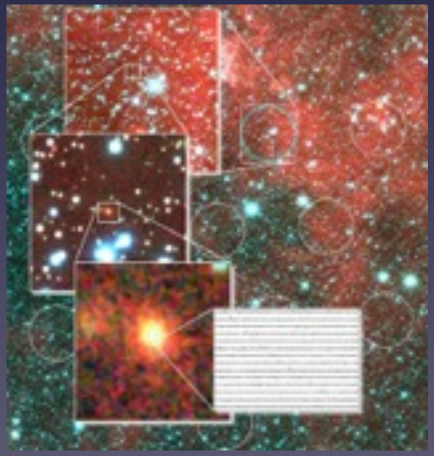
http://www.cv.nrao.edu/course/astr534/Pulsars.html

Identity of FRB



"Fast Radio Burst may originate from nearby flaring stars" Loeb et al (2014)

"Identifying the source of perytons at the Parkes radio telescope" Petrol et al (2015)



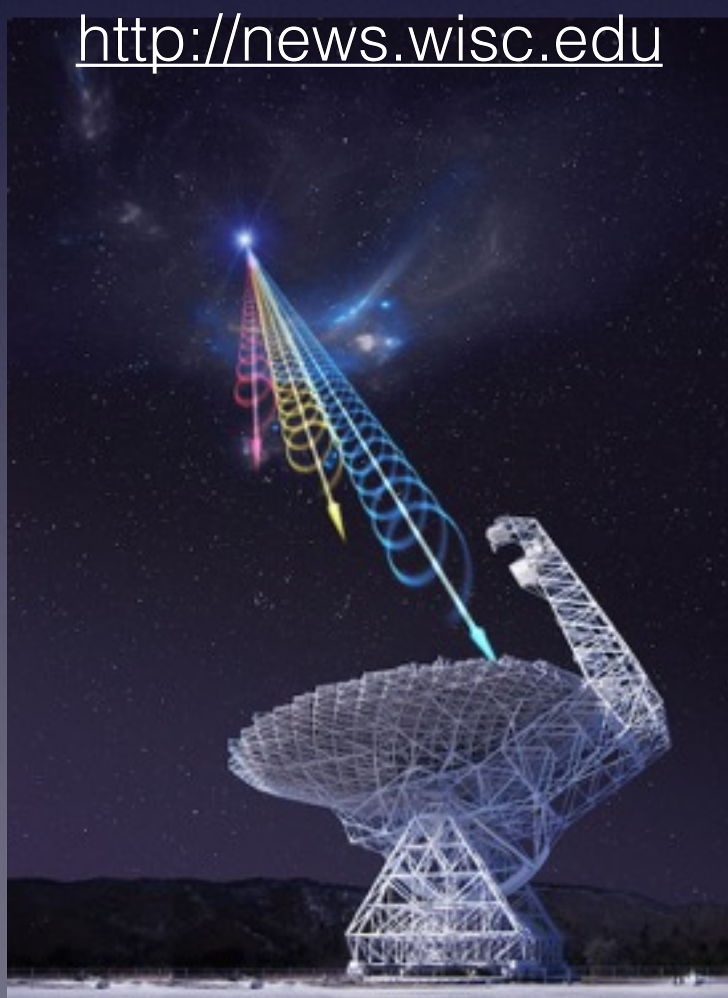
"A Fast Radio Burst Host" Keane et al (Feb 2016) reports FRB 150418 is at z=0.492

"No Precise Localization for FRB 150418: Claimed Radio Transient is AGN Variability" P. K. G. Williams, E. Berger (Mar 2016)

"A Repeating Fast Radio Burst" Spitler et al et al (Mar 2016) : Extragalactic Neutron Star

Distances & Reionization
TMT is needed to find the ID & redshift z

“Constraining the CMB Optical Depth through the Cosmological Radio Transients”
Fialkov & Loeb (2016)



10,000 FRBs / Day !?!?

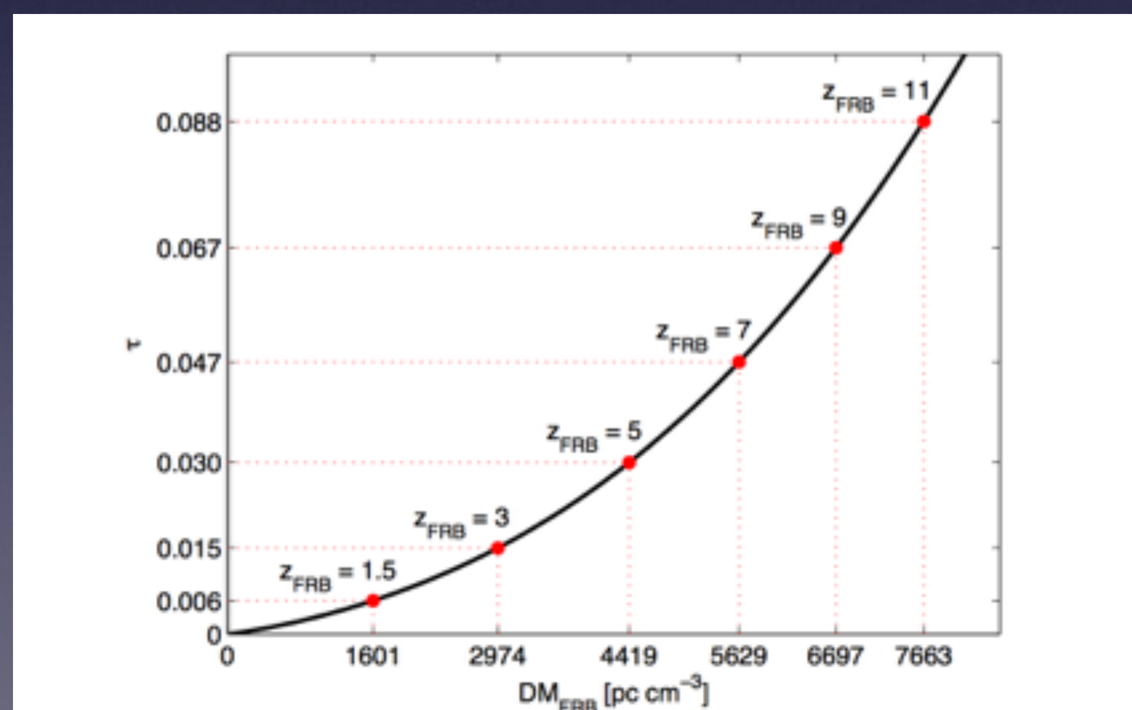


FIG. 2.— τ as a function of the DM in a fully ionized IGM. For a transient at redshift z_{FRB} the horizontal and vertical dotted lines mark $\tau(z_{FRB})$ and the DM of the transient respectively.

$$\mathrm{DM}(z) = \int_0^z \frac{n_e(z')}{1+z'} dl,$$

$$\tau(z) = \int_0^z \sigma_T n_e(z') dl,$$

Gravitational Wave : Standard Siren
GW measures Distances

Holz & Hugh (2005)

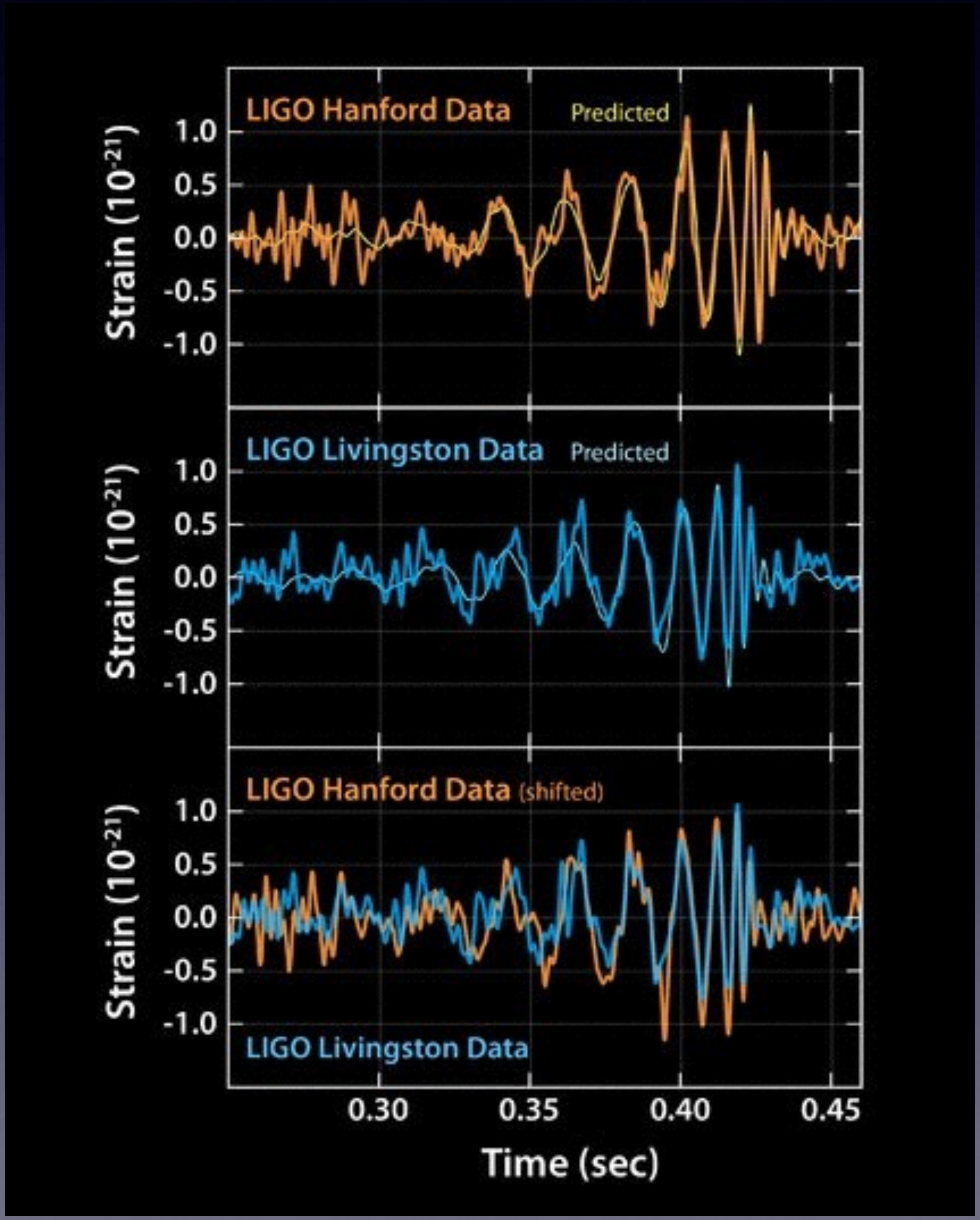
$$M_{\text{chirp}} = (1+z)\frac{(m_1 m_2)^{3/5}}{(m_1+m_2)^{1/5}}$$

$$h(t) = \frac{M_{\text{chirp}}{}^{5/3} f(t)^{2/3}}{D_L} \mathrm{F}(\text{angles}) \cos[\Phi(t)]$$

f(t) : Wave Frequency

Φ(t): Phase

DL : Luminosity Distance



Gravitational Wave : Standard Siren EM Follow-up

NS-NS at 75Mpc Light Curve
(Kasliwal et al 2016)

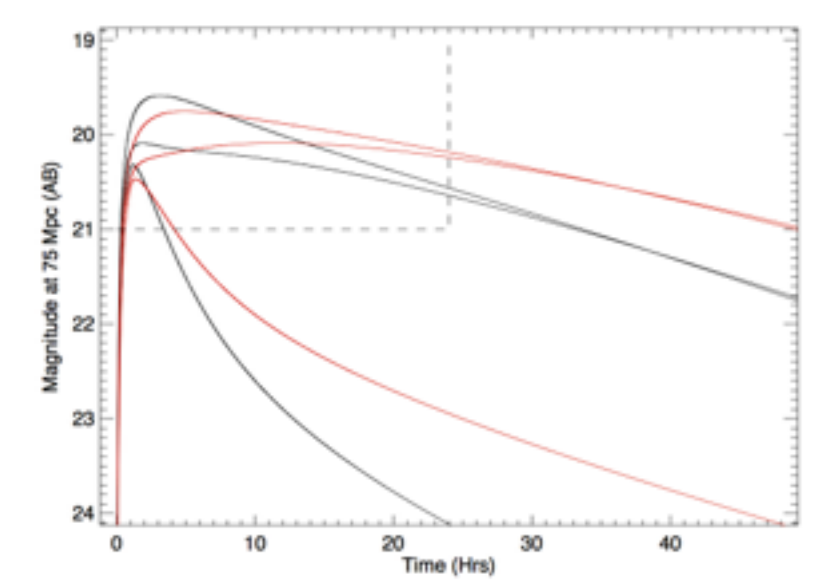


Figure 3. Predicted optical counterpart based on free neutron decay (Metzger et al. 2015). Black lines are g-band and red lines are r-band light curves at 75 Mpc (sensitivity limit of advanced LIGO to binary neutron star mergers in O1) . The three curves assume three different values for opacity and neutron mass to represent the fast, intermediate and slow light curve evolution cases i.e. ($\kappa_r = 30$ cm^{2}gm^{-1}, $M_n = 3\times10^{-5}M_\odot$), ($\kappa_r = 3$ cm^{2}gm^{-1}, $M_n = 3\times10^{-5}M_\odot$), ($\kappa_r = 3$ cm^{2}gm^{-1}, $M_n = 3\times10^{-4}M_\odot$). Note that g-band is more luminous at peak but decays faster. Horizontal dashed line denotes the sensitivity of iPTF in 60 s. Vertical dashed line denotes the timescale within which follow-up is undertaken by the GROWTH program.

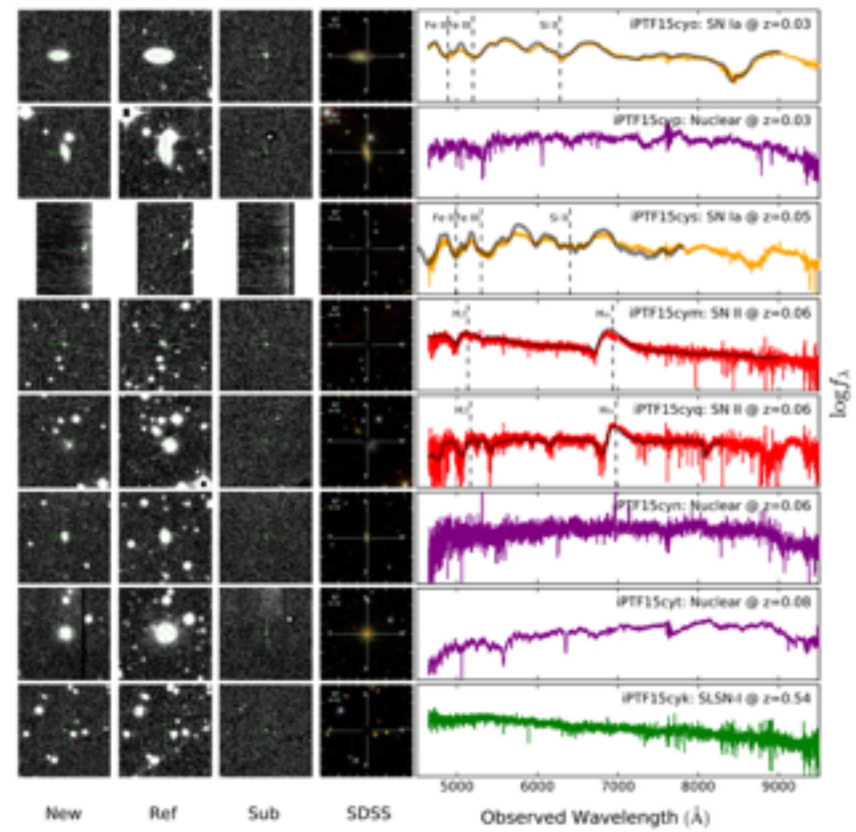
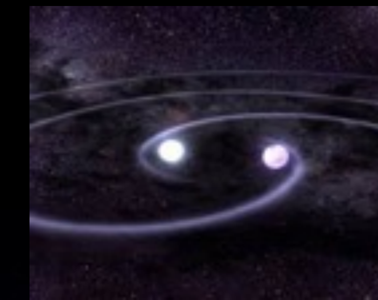
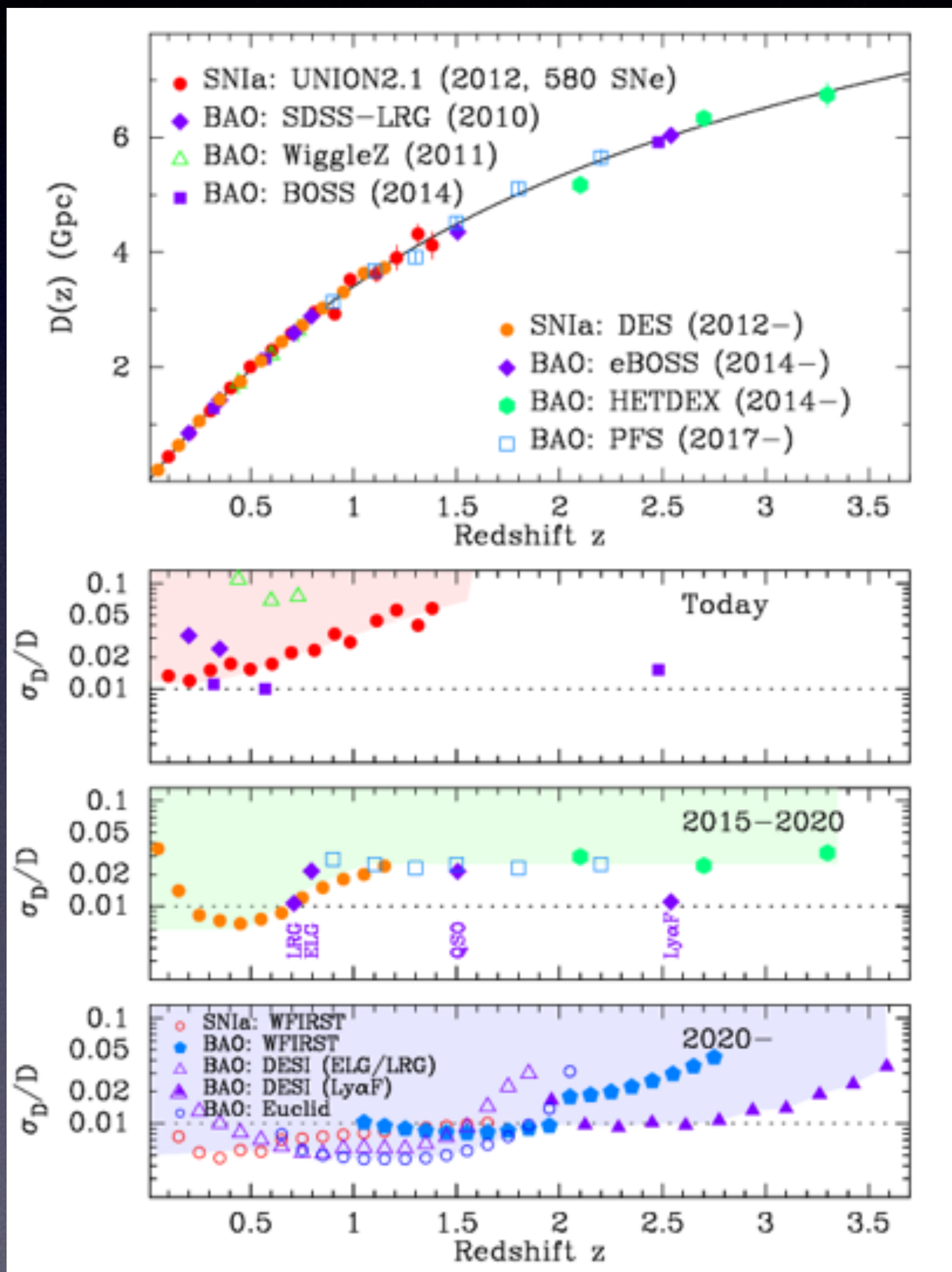


Figure 2. Keck II/DEIMOS classification spectra of eight iPTF candidates obtained within 2 hours of discovery. Also shown, from left to right, the P48 discovery image, reference image, subtraction image and SDSS thumbnail around each candidate location. Colors denote spectroscopic class: SN Ia (red), SN II (blue), Nuclear (purple), SLSN I (green). Overplotted in gray lines is the best match from a supernova spectra library (SN1996X for iPTF15cyo, SN2004eo for iPTF15cys, SN1999M for iPTF15cym, SN2004et for IPTF15cyq). Additional follow-up data was needed to classify iPTF 15cyk as a SLSN I (see Figure 5).

ZTF (Zwicky Transient Facility) will do an excellent Follow-up for NS-NS case but for BH-BH case we will need Subaru/HSC + LSST + TMT

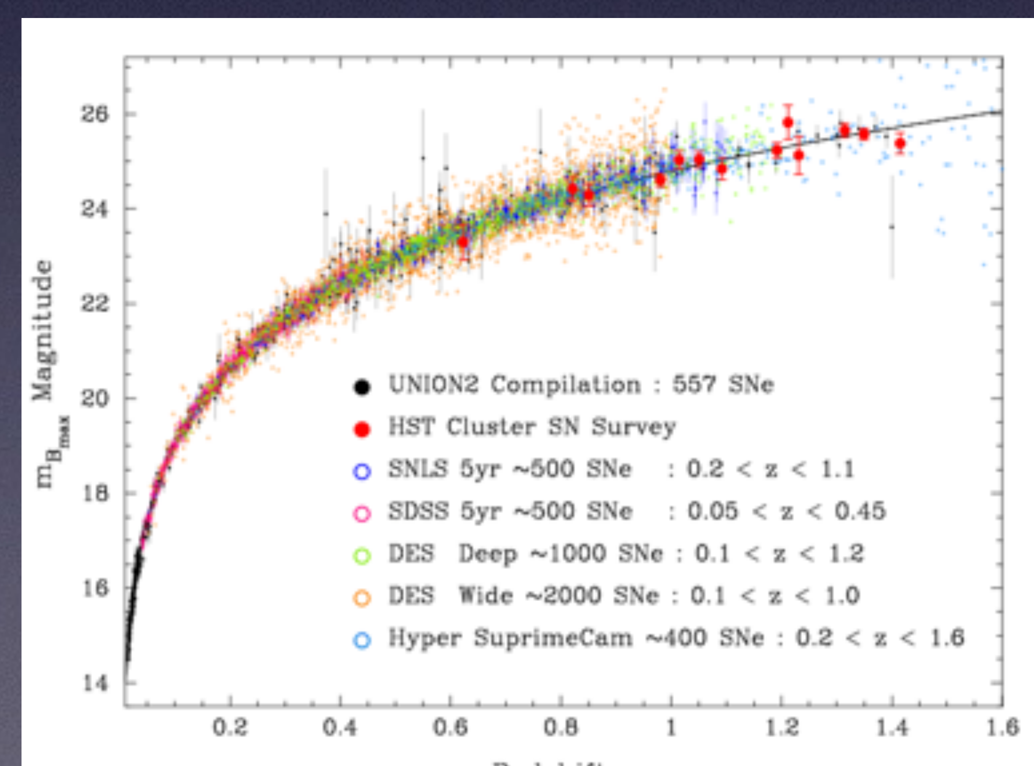
SNIa Cosmology in 2020s



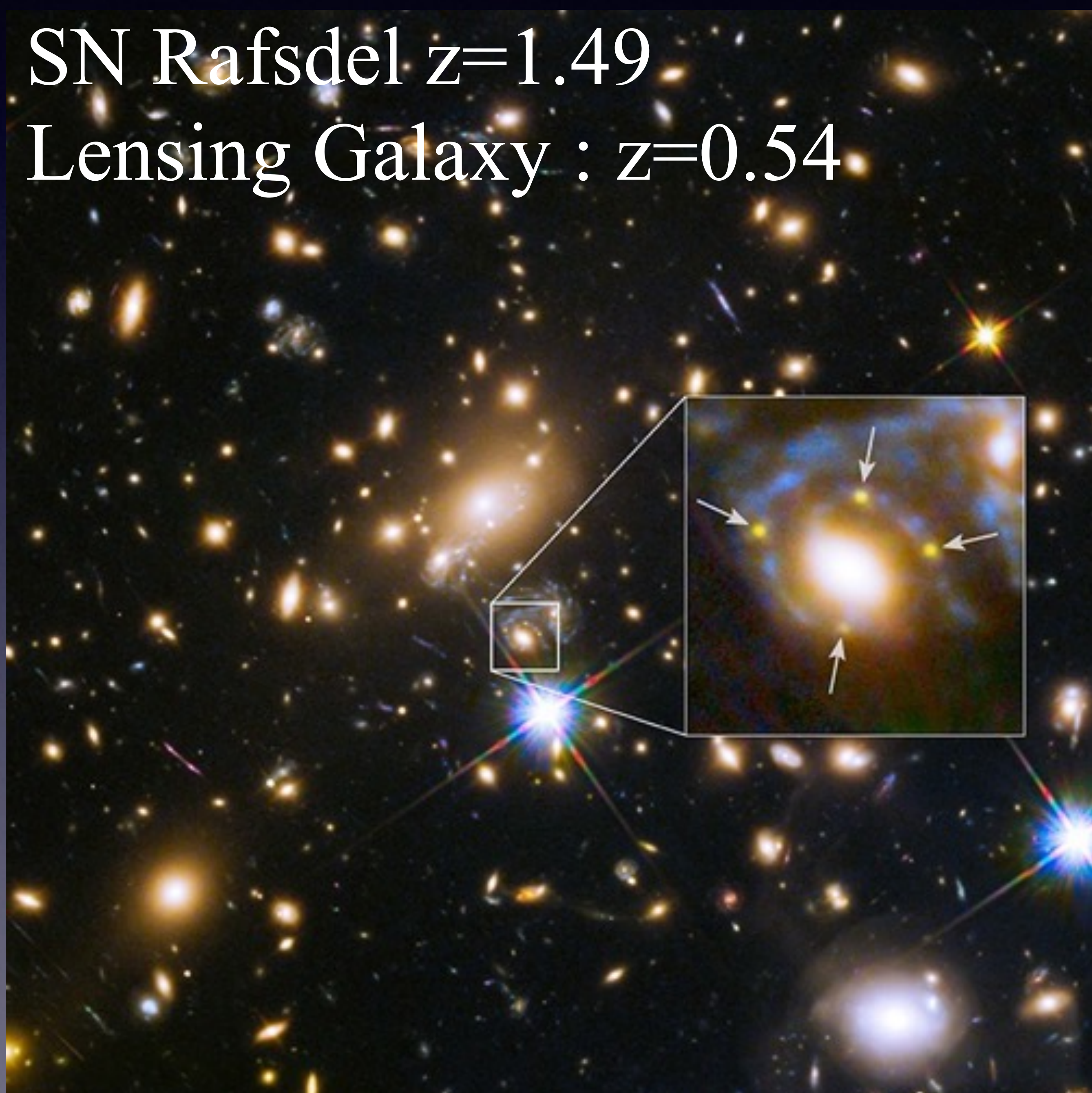


With TMT, we will need to see the progenitor and companion of SNIa

In 2020s, we will need High Quality Data from TMT not Quantity



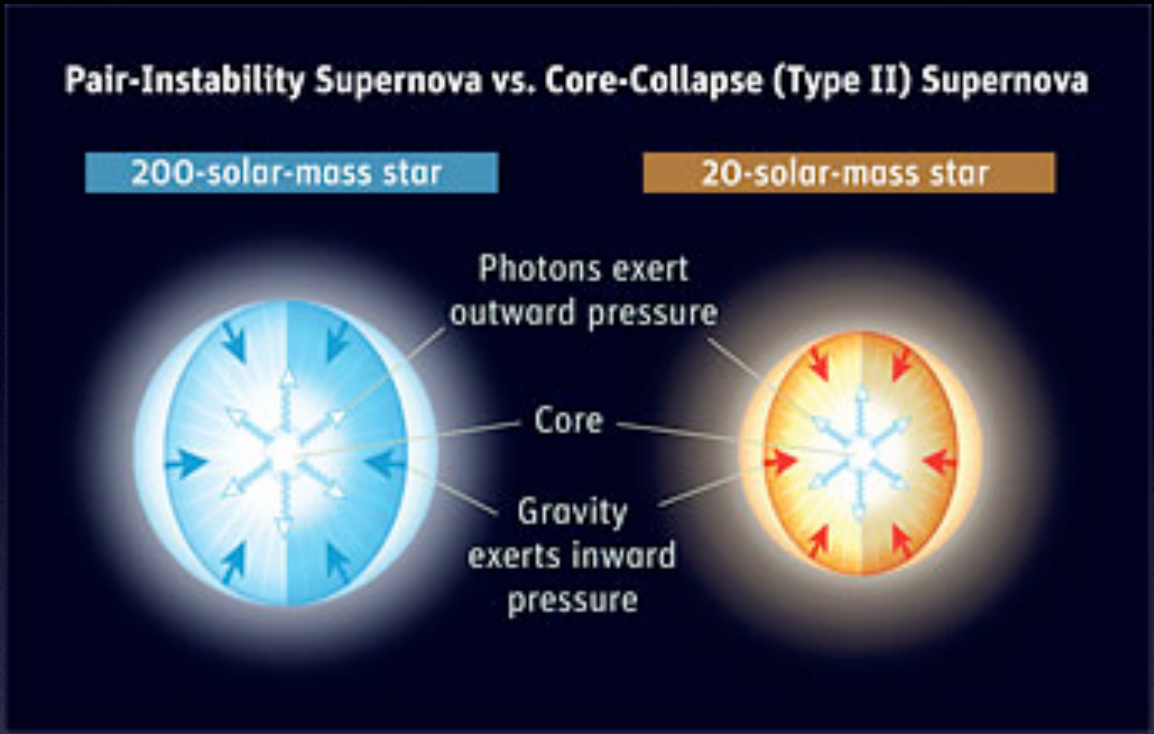
SNIa 5σ Events for TMT Gravitationally Lensed SNIa

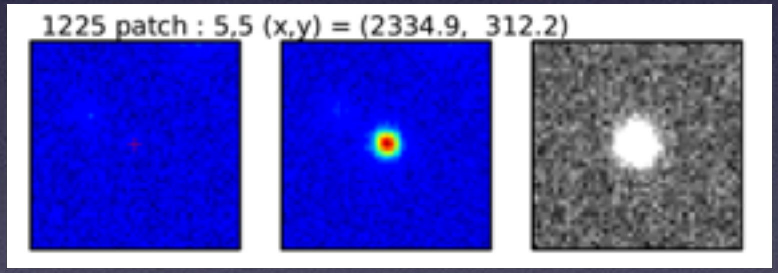


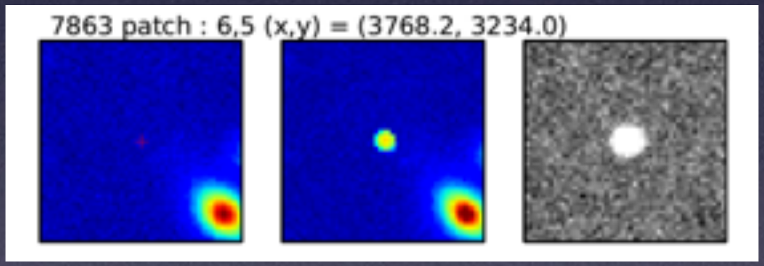
- SNIa : Great Advantage of having luminosity estimate to test lens models
- TMT AO is needed to resolve lensed point sources and good photometry
- Lensed SNIa : PS1-10afx is identified by Quimby et al but was not resolved

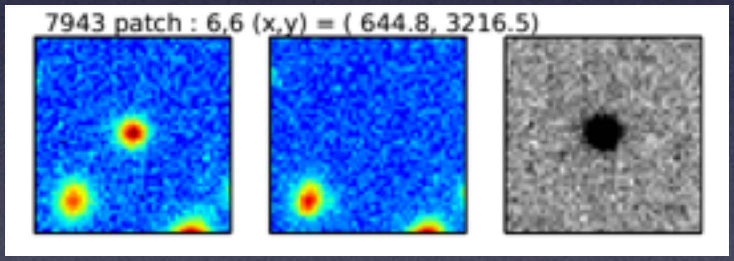
Discovering First Star Explosion

Holy Grail of Modern Cosmology : Origins of Elements





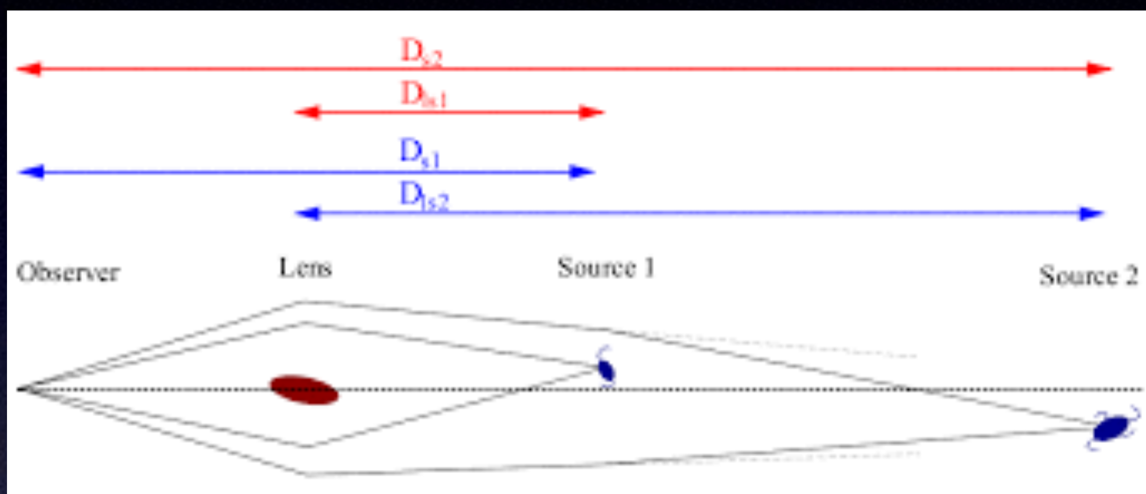




- First Star is believed to be a massive star and exploded at very early stage of the universe
- Subaru/HSC + LSST + TMT can do it!

Lensed Quasar 5σ Events for TMT
Double Source Plane Lens

E. V. Linder 1605.04910



Thomas Collett et al 2014

SLACS
J0946+1006

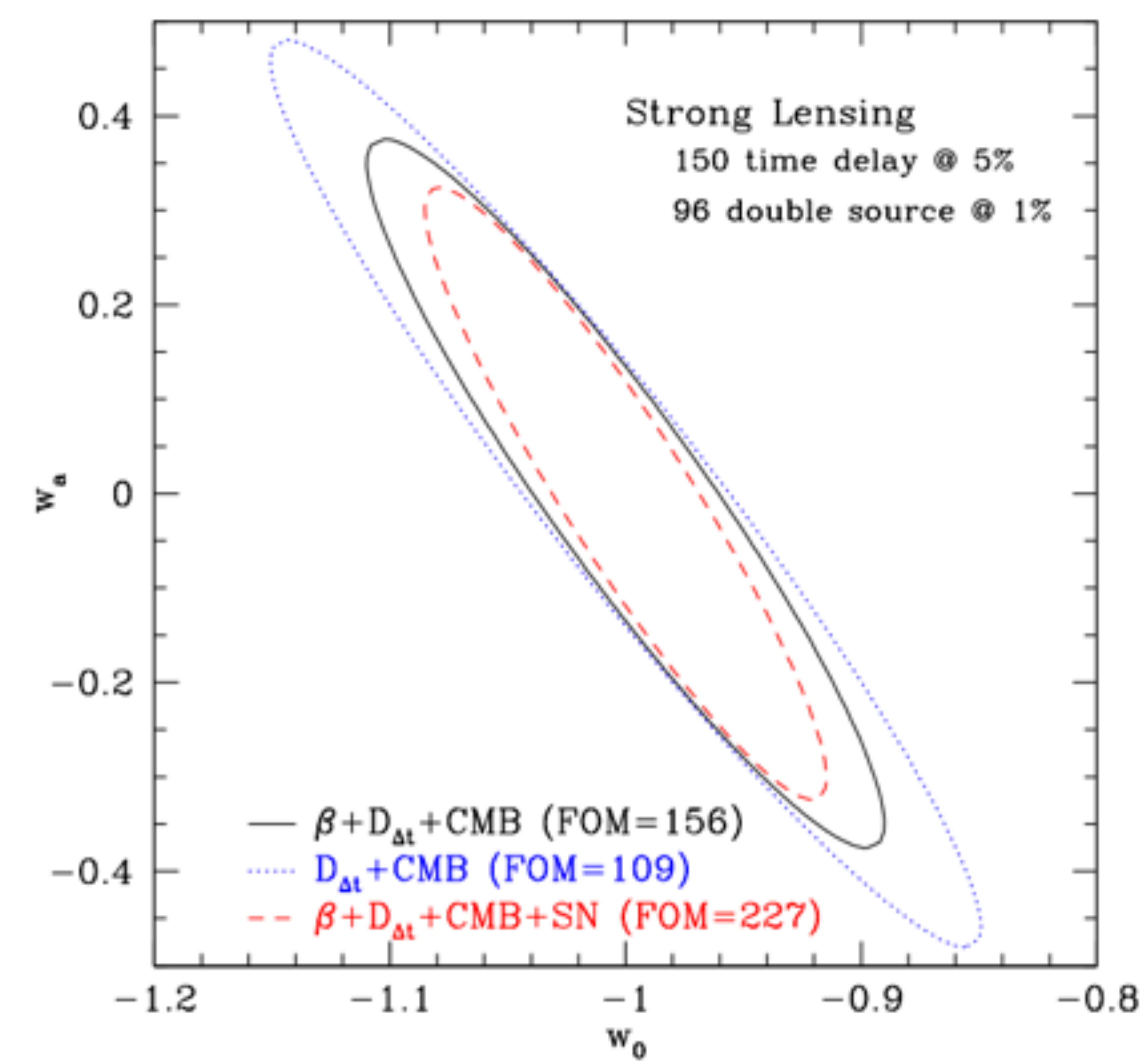
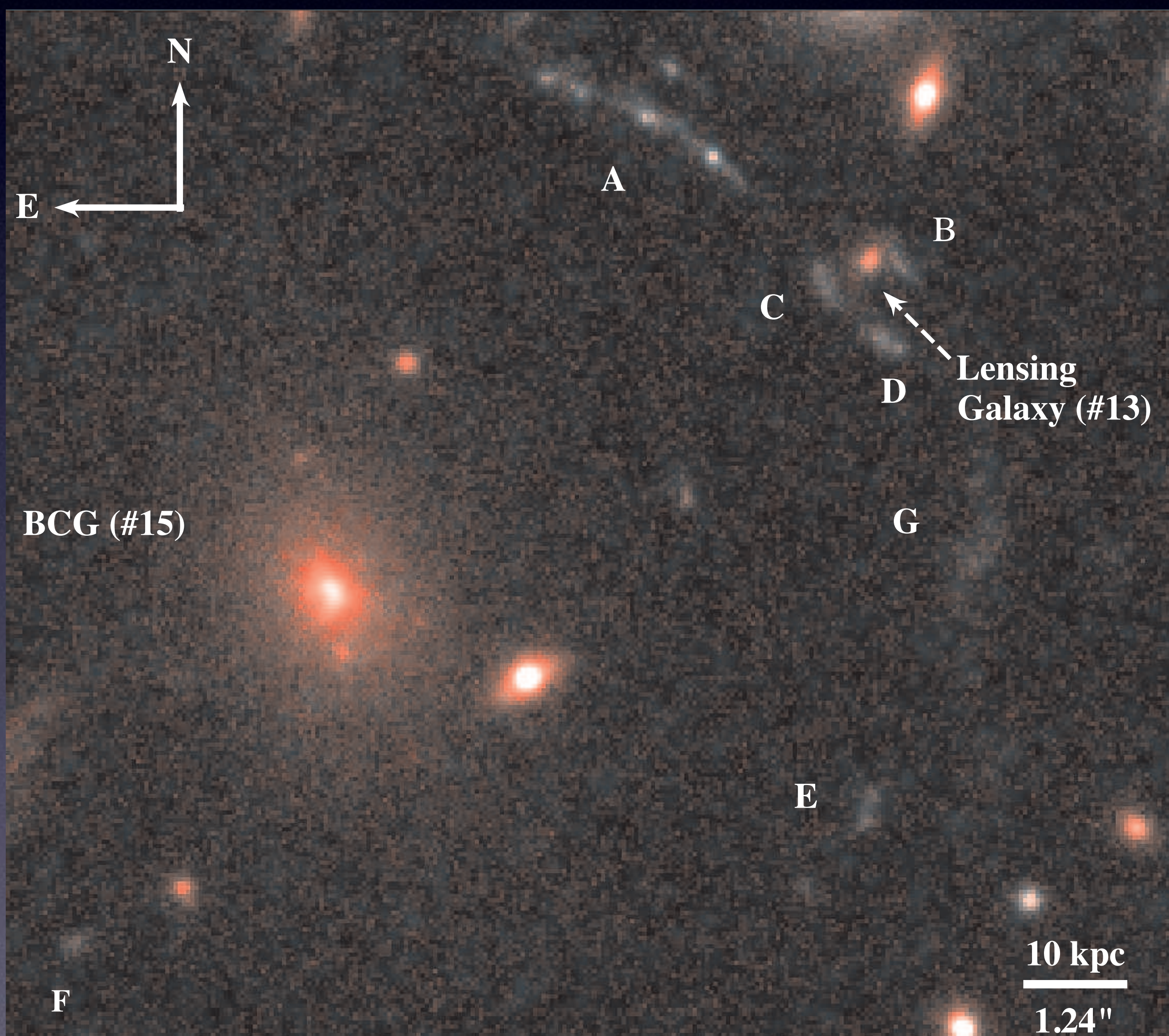


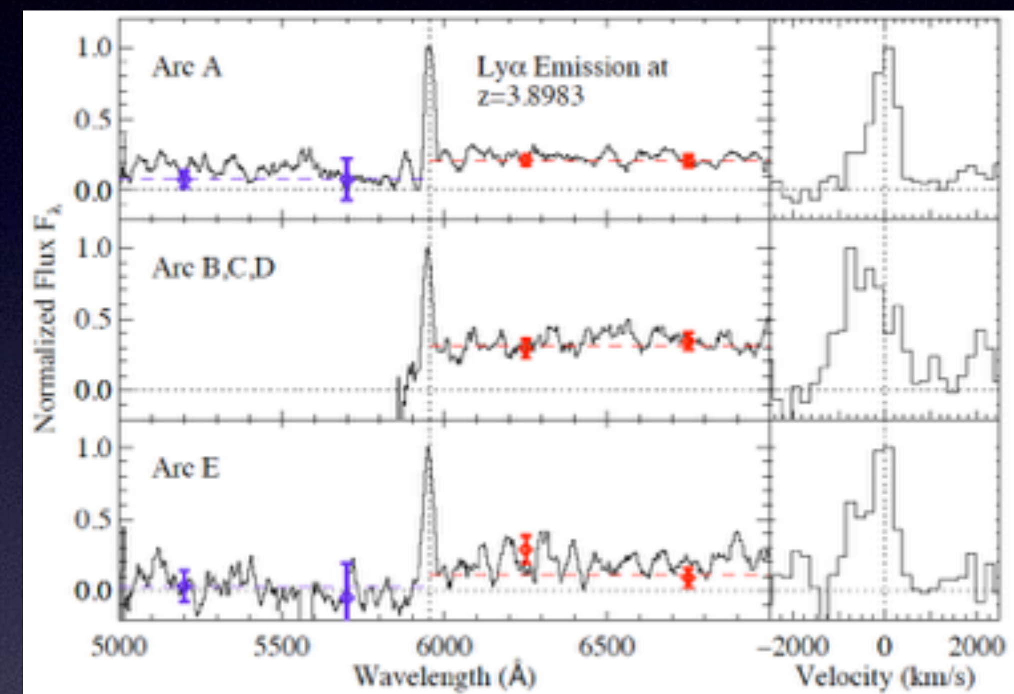
FIG. 3. Cosmological parameter estimation uncertainty is plotted in the dark energy equation of state plane for the case of strong lensing time delays (dotted curve), time delays plus double source plane strong lensing (solid), and the two strong lensing probes plus supernova distances (dashed). DSPL brings significant complementarity.

Lensed Galaxy 5σ Events for TMT
Galaxy Lensed Twice
Huag et al 2009

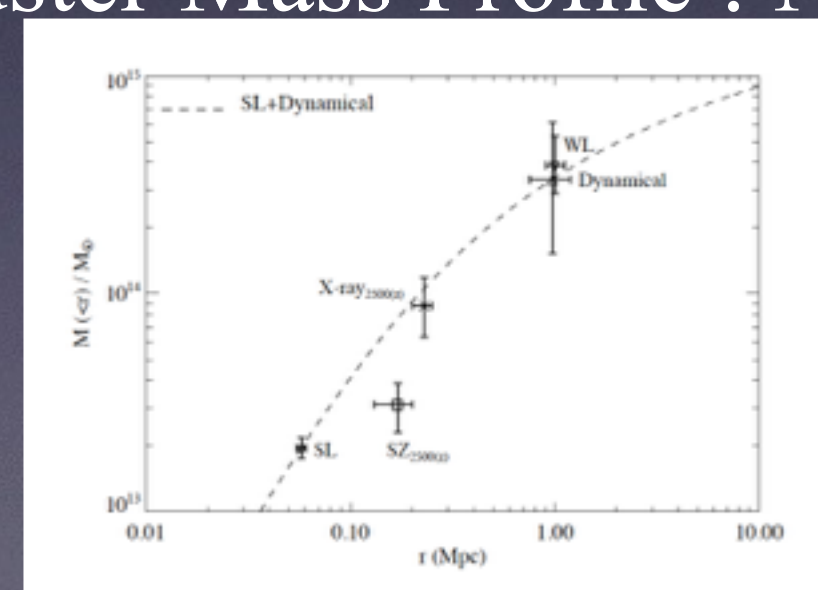
WARPS J1415.1+3612 : z=1.026



Spectroscopic Follow-up



Cluster Mass Profile : NFW

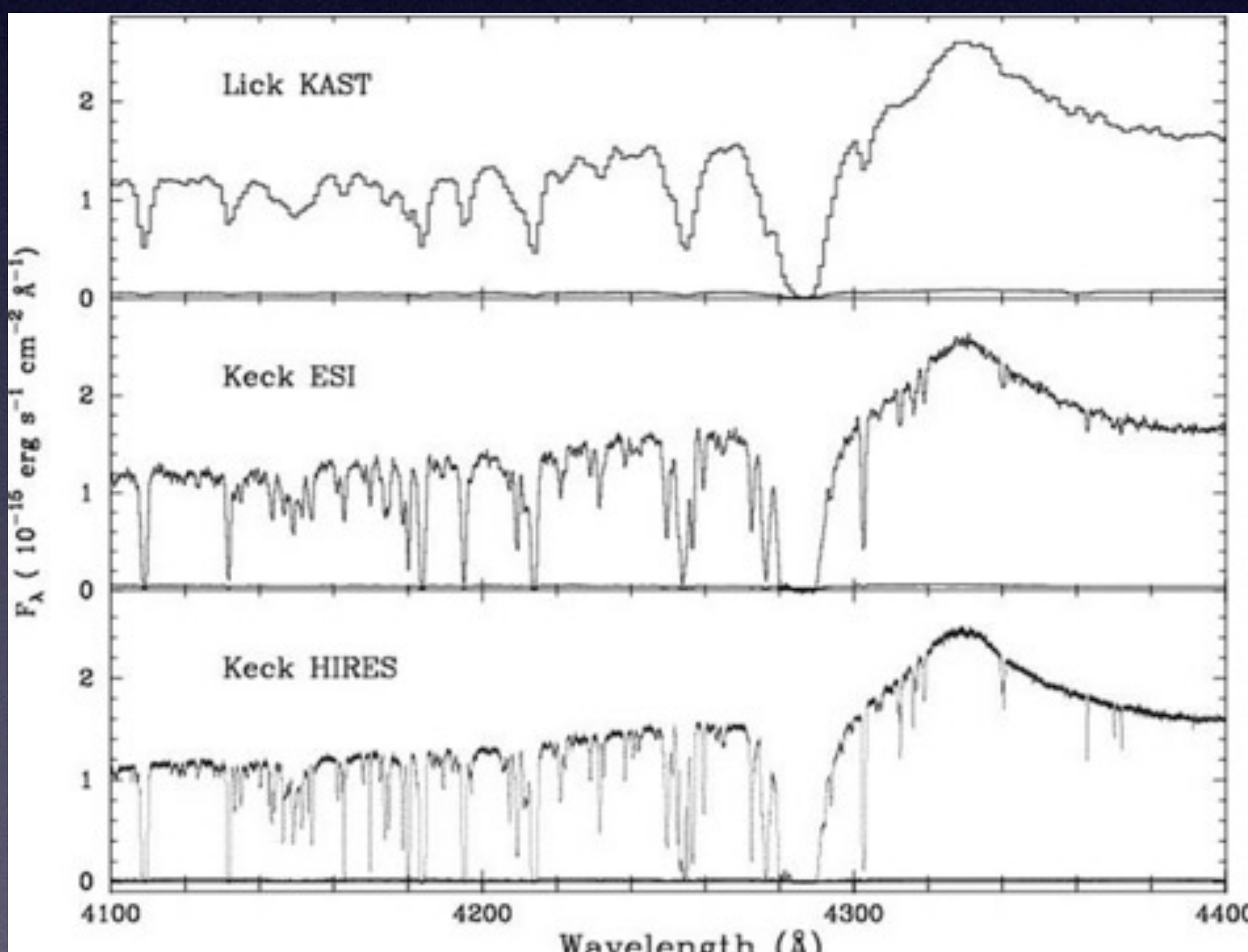


Direct Measurement of Expansion
Sandage-Loeb Test with IGM : t=10 years

DIRECT MEASUREMENT OF COSMOLOGICAL PARAMETERS FROM THE COSMIC DECELERATION OF EXTRAGALACTIC OBJECTS

ABRAHAM LOEB
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

Received 1998 February 10; accepted 1998 April 1; published 1998 May 4



Lyman α Forest in QSO

$$\Delta z \equiv \frac{a(t_0+\Delta t_0)}{a(t_s+\Delta t_s)} - \frac{a(t_0)}{a(t_s)} \approx \left[\frac{\dot a(t_0) - \dot a(t_s)}{a(t_s)}\right]\Delta t_0$$

$$= \left[\frac{\dot z_s}{(1+z_s)} - (1+z_s)\dot z_0\right]\Delta t_0,$$

$$\Delta v \equiv \frac{c\Delta z}{(1+z_s)}$$

$$= -\{[\Omega_M(1+z_s) + \Omega_R + \Omega_\Lambda(1+z_s)^{-2}]^{1/2} - 1\}\, H_0 \Delta t_0 c,$$

Δv=3cm/10 years
TMT can do it!

TMT Key Science!

Let's go after 5σ Events and Direct Measurement!
Time Domain Cosmology Key Project must have the followings

- Fast Radio Burst as a Cosmological Probe
- Gravitational Wave as a Distance Indicator
- SNIa in 2020s / First Star
- Gravitationally Lensed SNIa
- Lensed Quasar on Double Source Plane
- IGM Tomography and Sandage Test