Until around 400 million years after the Big Bang, the Universe was a very dark place. There were no stars, and there were no galaxies.

The Dark Energy Camera Deep Field

Jeremy Mould,
Swinburne University

Reionization in the Red Centre,
July 18, 2013

SWINBURNE UNIVERSITY OF TECHNOLOGY

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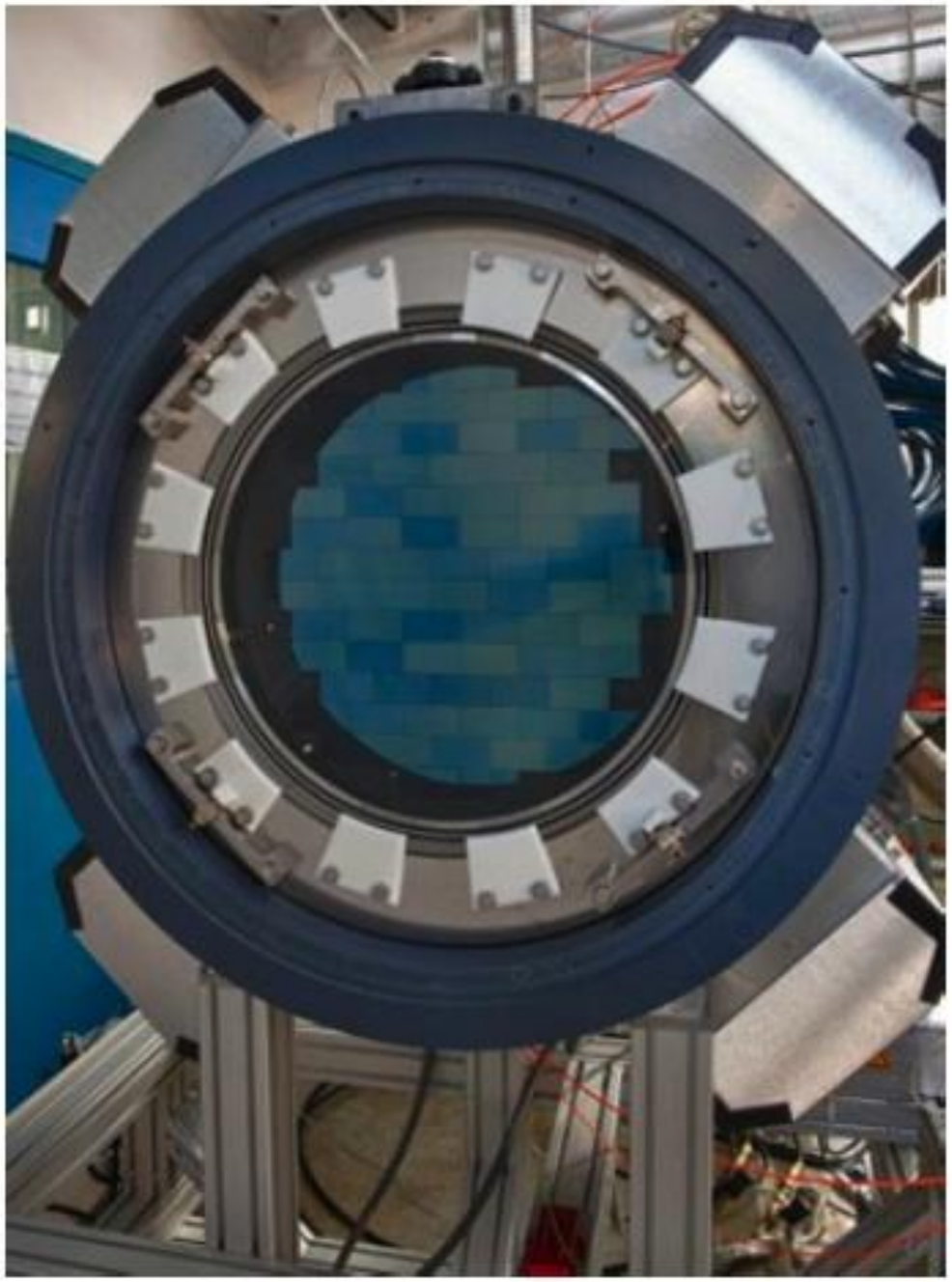
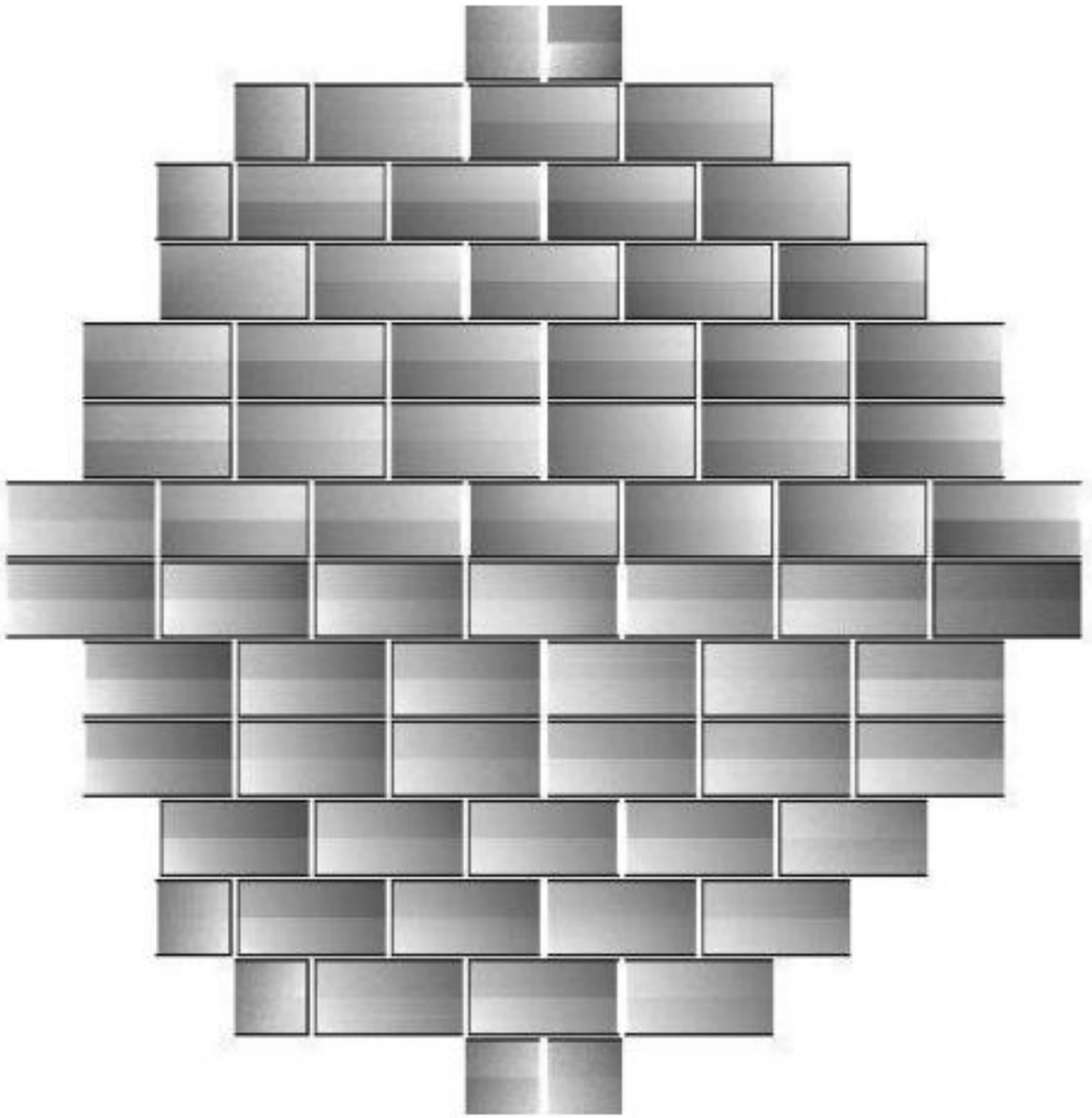
A 10 solar mass star forming 100 Myr after the Big Bang would be seen today with a Balmer Jump at 11μ and a Lyman limit at 2.7μ. Such early stars, if they formed at all, are JWST targets

In luminosity distance the epoch of reionization extends 80 Hubble radii

- JWST: powerful, but small field with spectroscopy
- DECam: 1μ and shorter, wide field
- KDUST: 1μ < λ < 3μ, wide field, IR camera TBD
  - optical wavelengths, Gpix camera possible
- Las Campanas Transit Survey: wide field
- TMT high resolution
- SKA: redshifted neutral hydrogen

Dark Energy Camera





DECam Deep Fields

- All 3 are circumpolar
  - Chandra Deep Field South (little data)
  - Prime Field (great data)
  - 16h field (no data)
- see also Subaru Deep Field
  - and watch for Hypersuprimecam

DECam Deep Fields *goal*

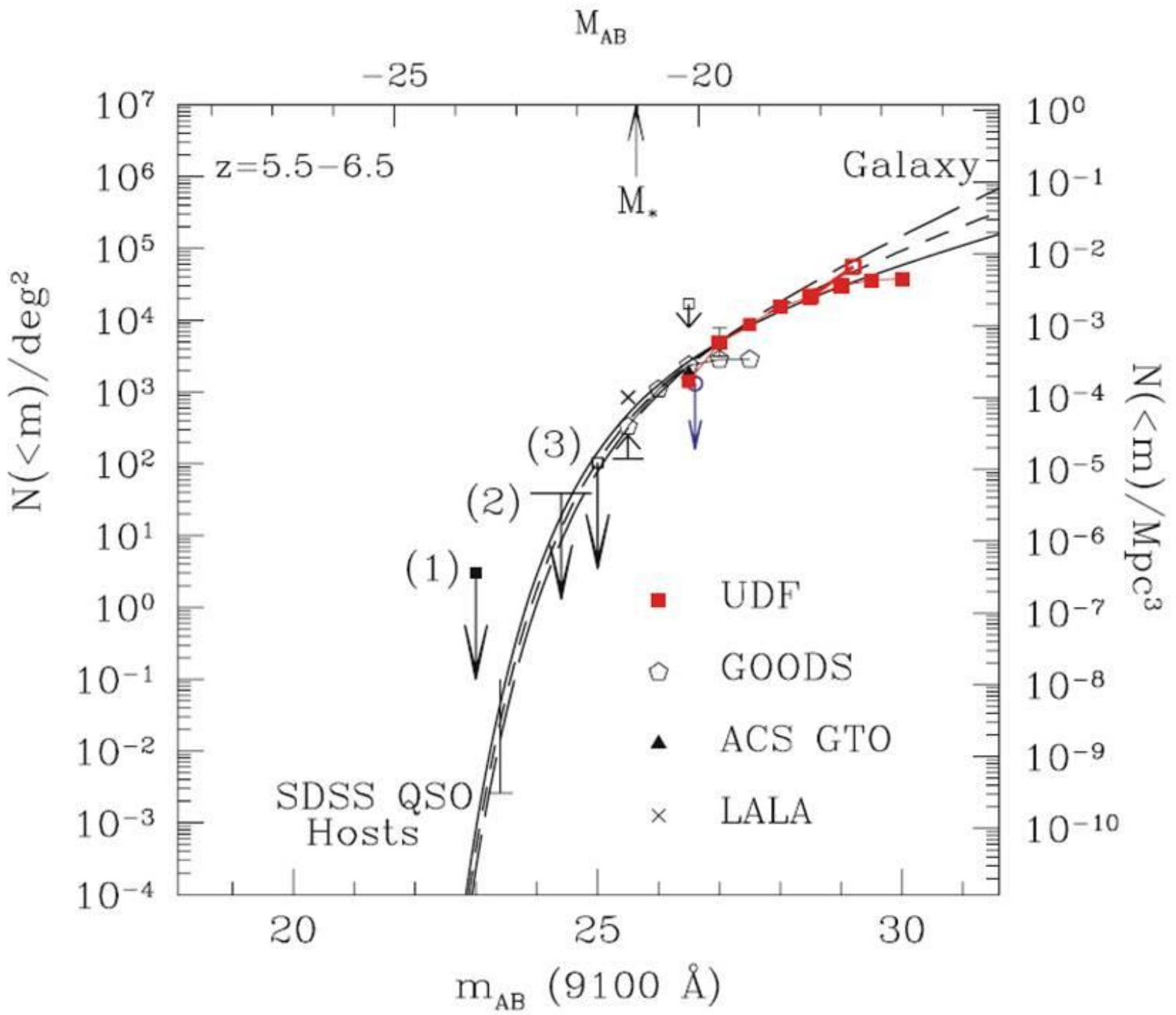
- Not to investigate the evolution of credibility
  - log credibility = -n log (1+z)

✓Large scale structure

✓Rare events

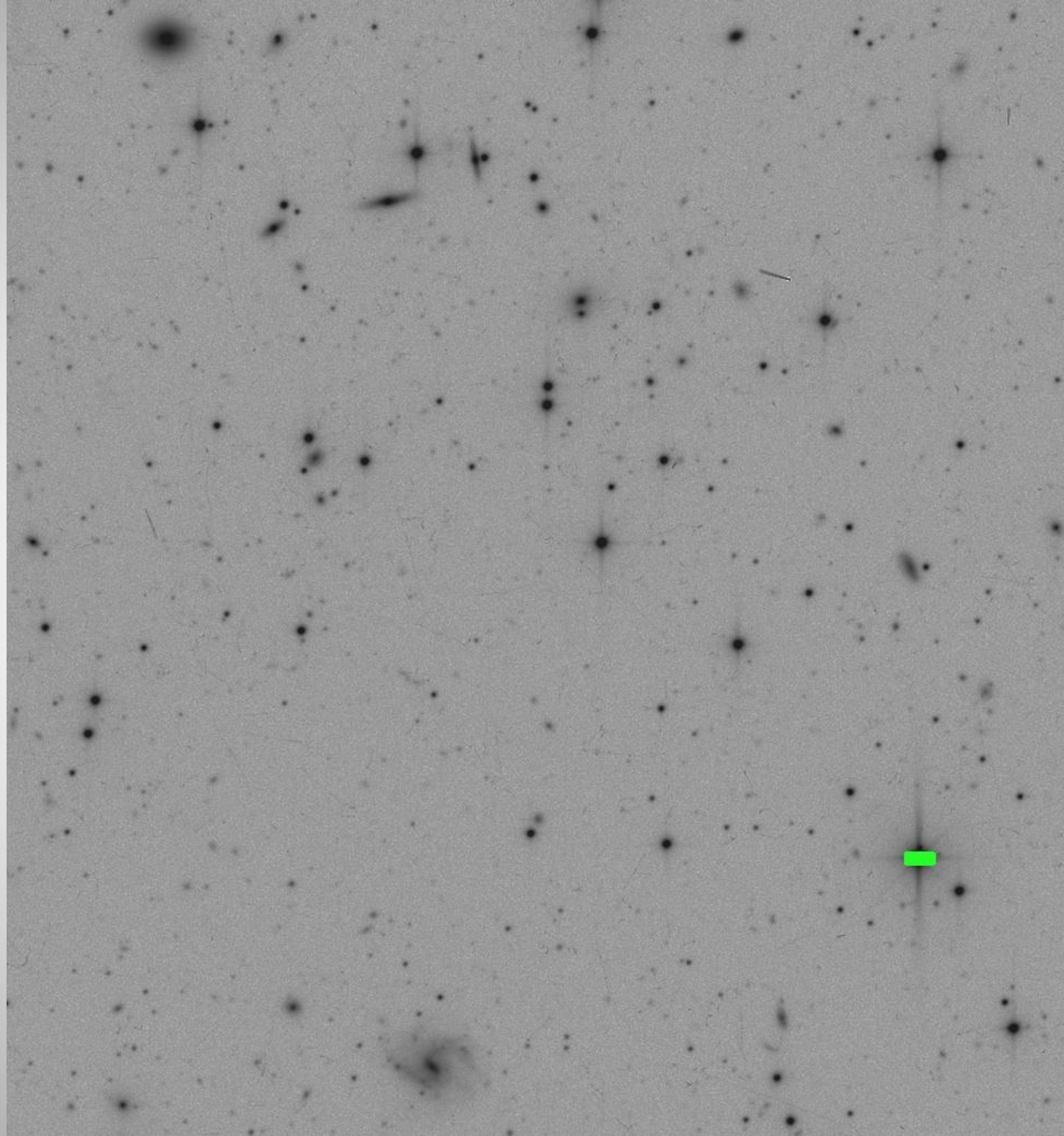
M* at z = 6 is Y = 24.0

Note that m_{AB}-m_{Vega} = 0.634 mag at Y

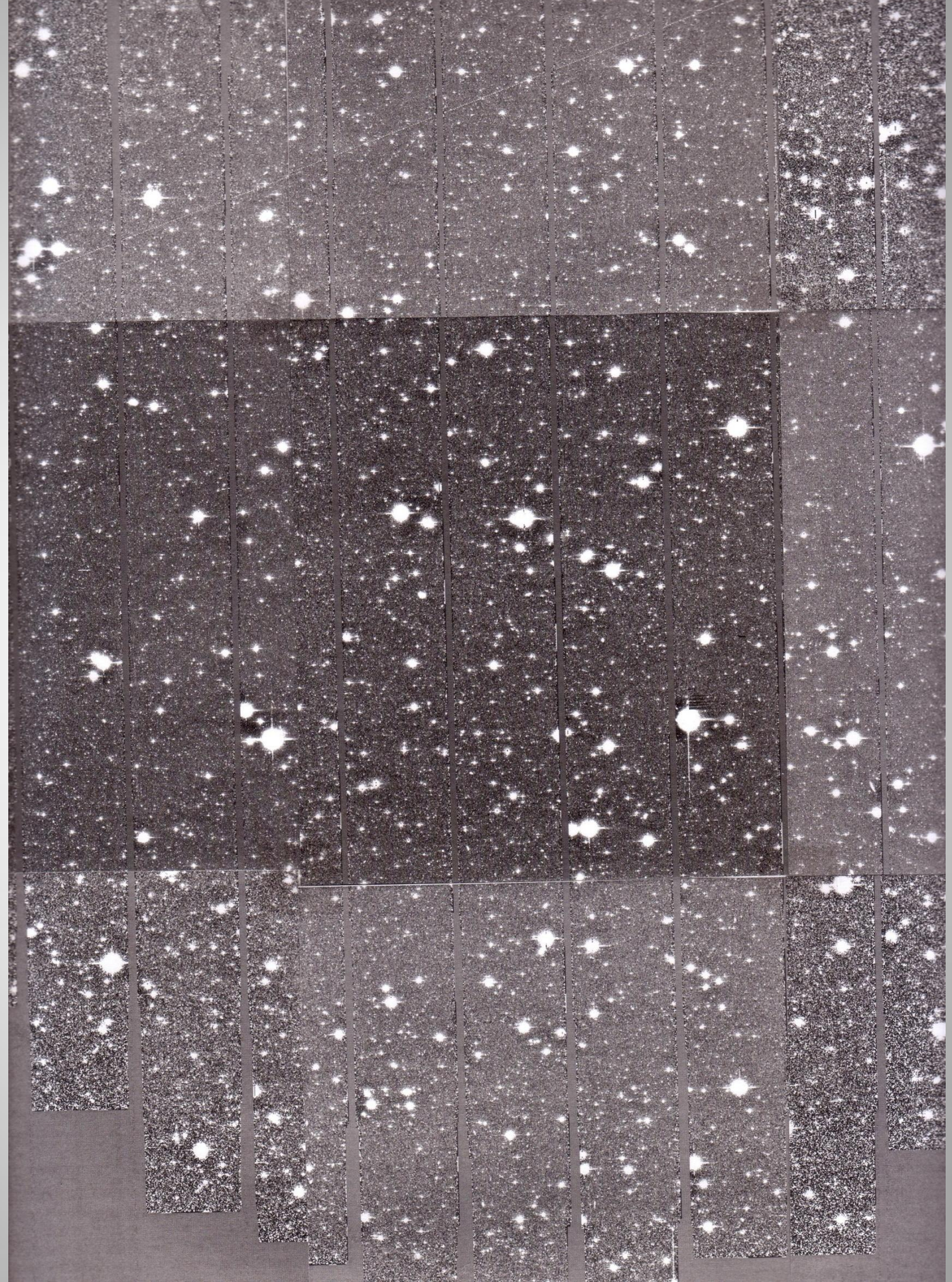


What does 25th mag look like?

140 minutes of DECam at 1.03μ & 0.8” seeing; 2.3σ detections have Y = 25.45

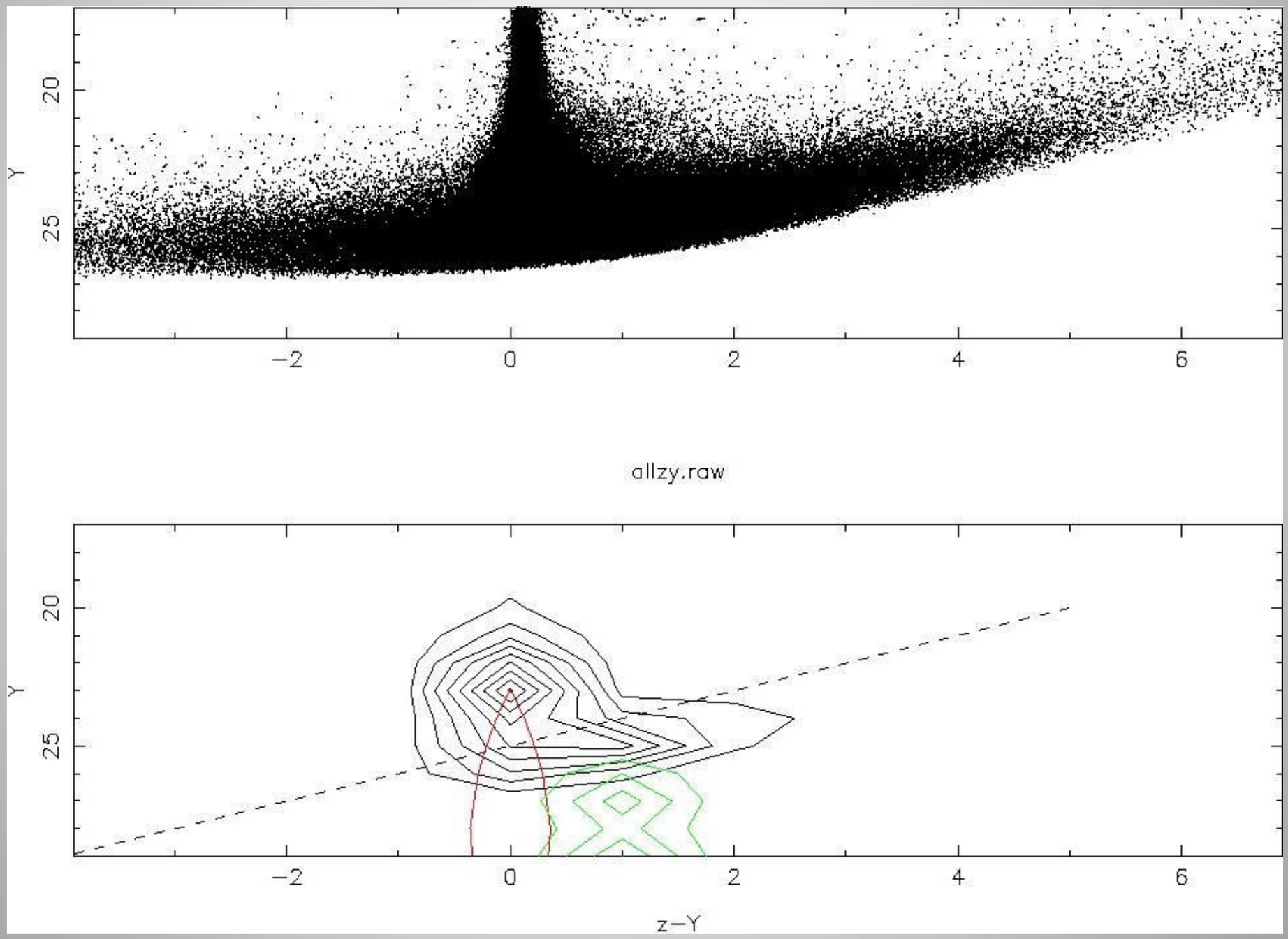


2 degrees of the Prime Field



CMD from aperture photometry

DECam deep field team: Mould, Trenti, Wyithe, Cooke, Lidman Abbott Kunder Koekemoer Tescari Katsianis

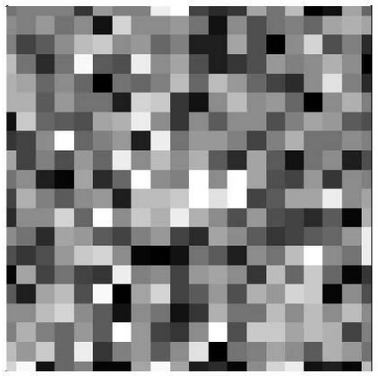


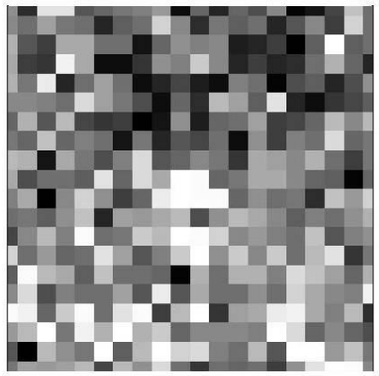
Red is star counts from BS; green is HDF galaxies

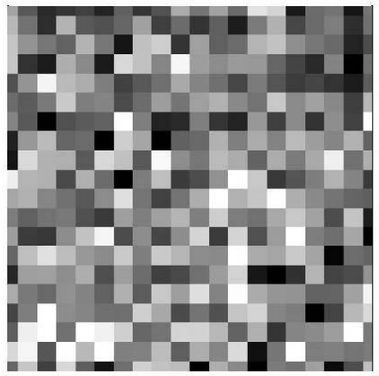
dashed line is z = 25 completeness

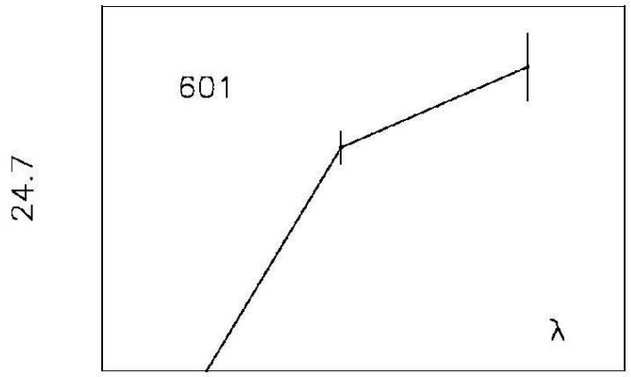
I dropouts are z = 6 candidates

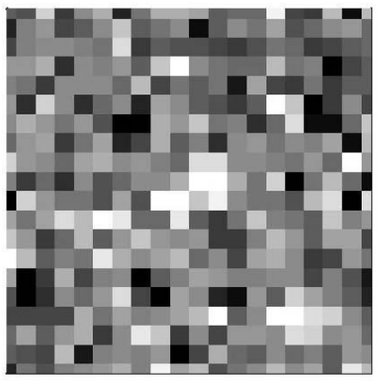
I z Y .

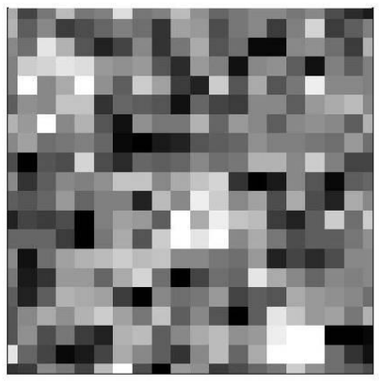


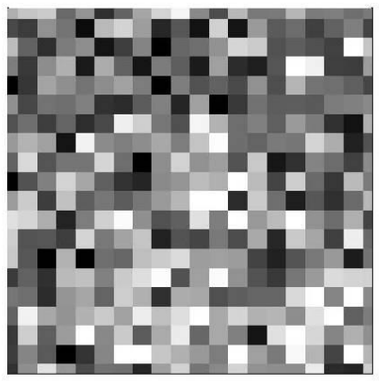


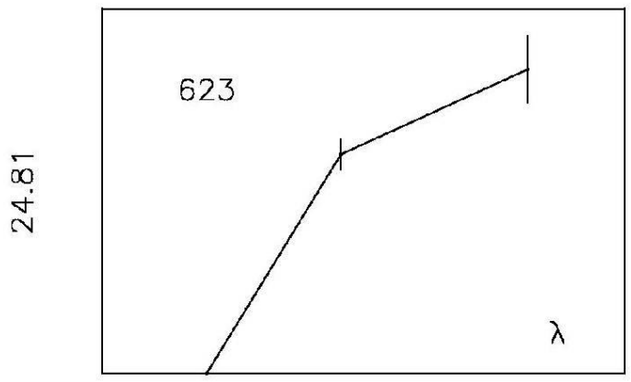




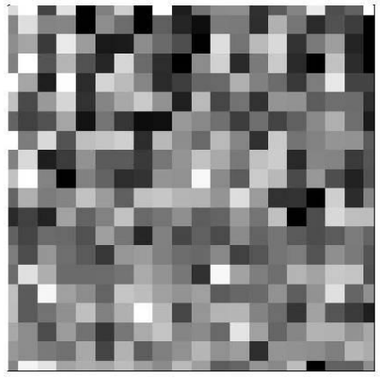


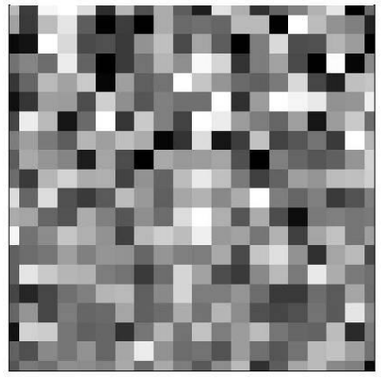


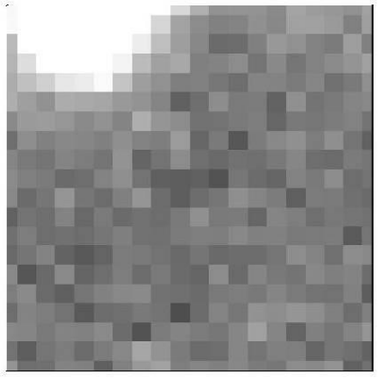


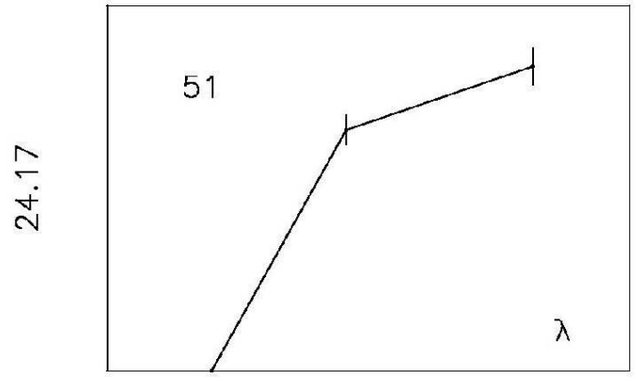


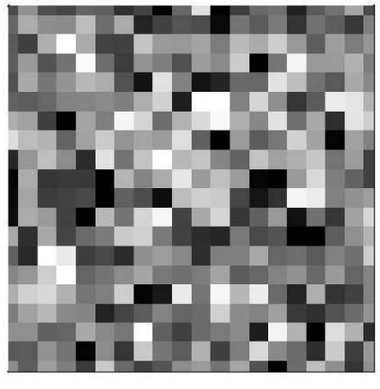
These postage stamps are the Y=24 mag candidates

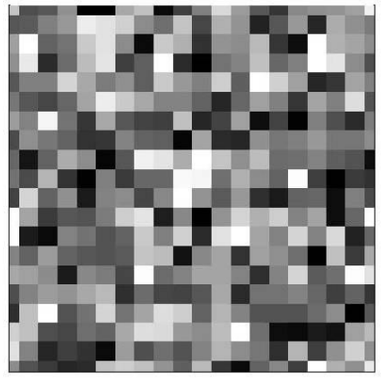


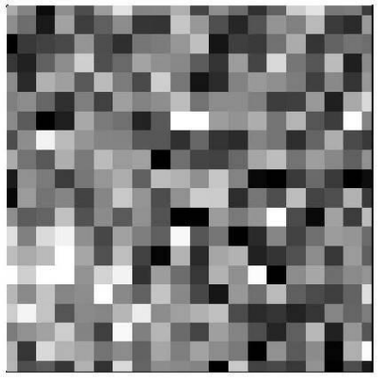


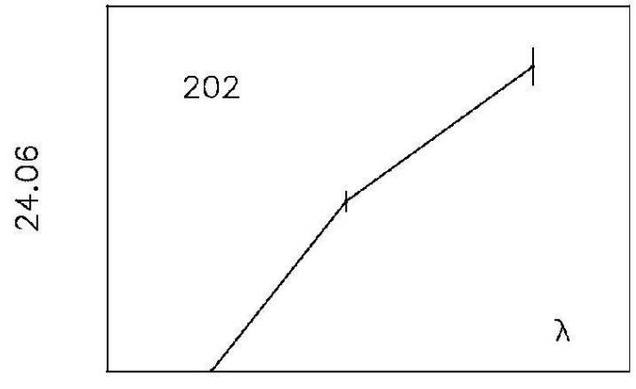


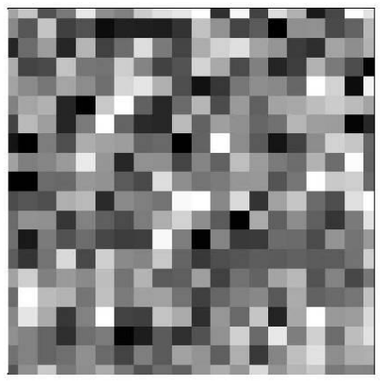

24.17
51
λ

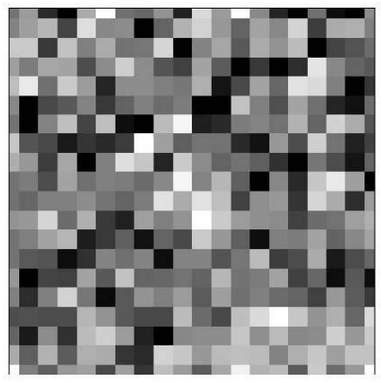


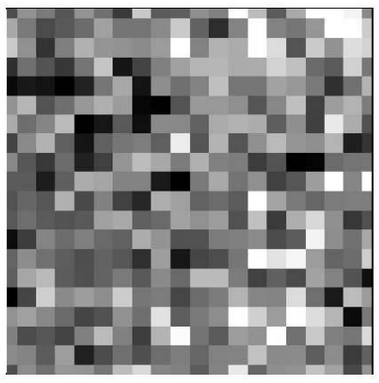


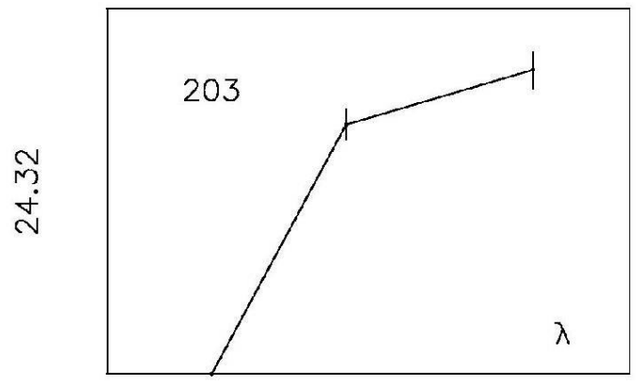


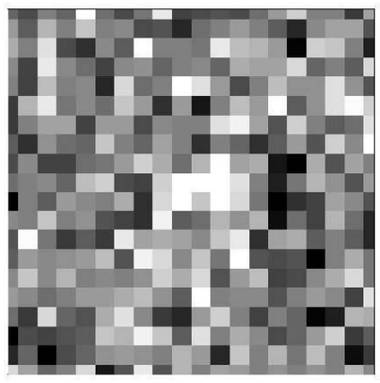

24.06
202
λ

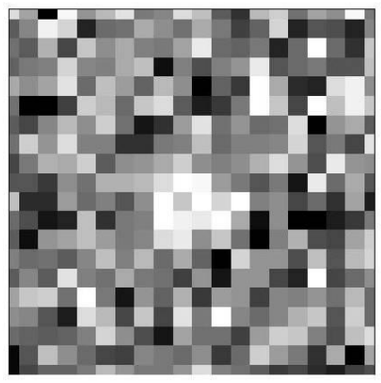


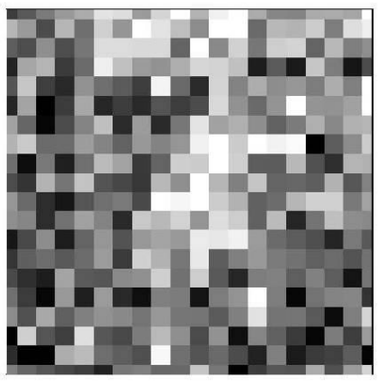


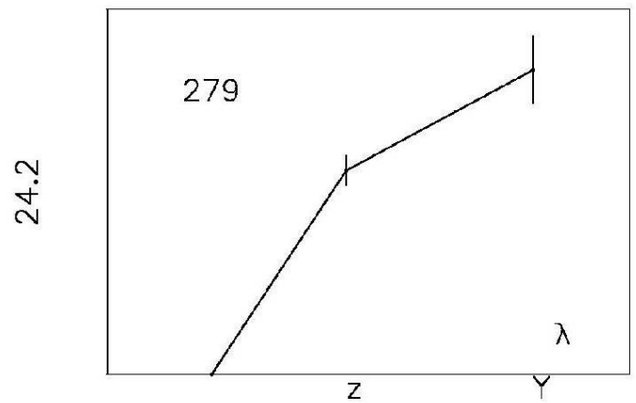


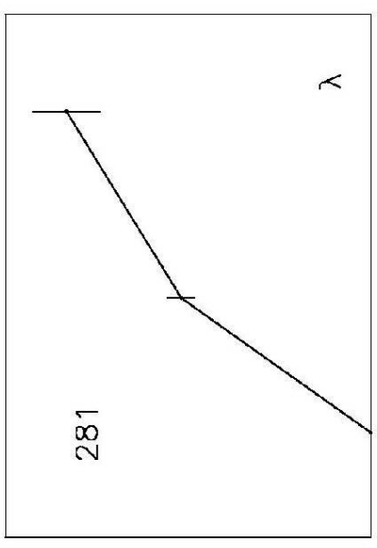

24.32
203
λ

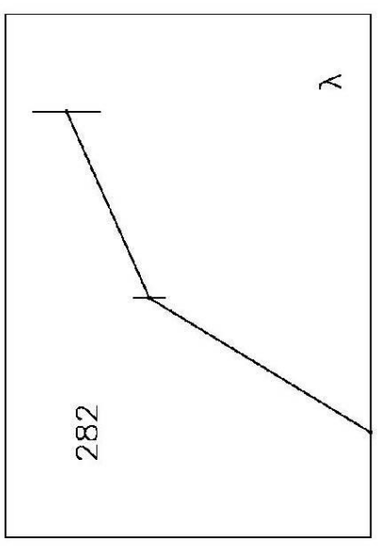


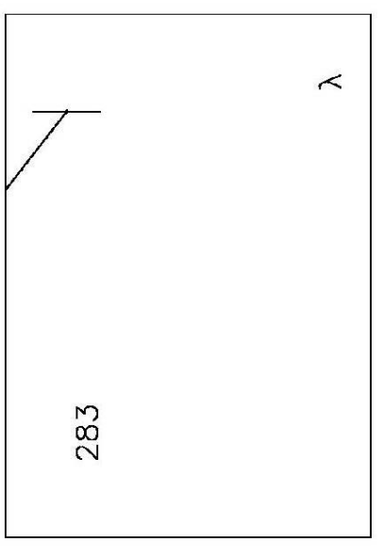


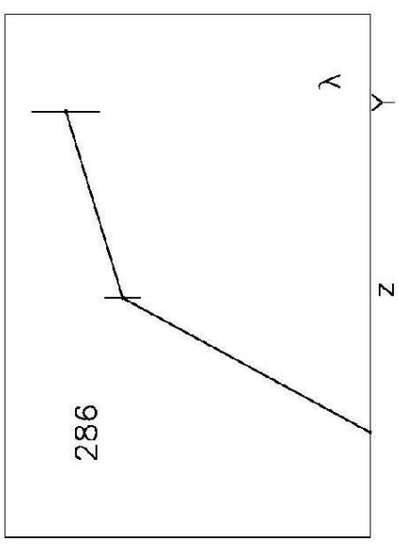


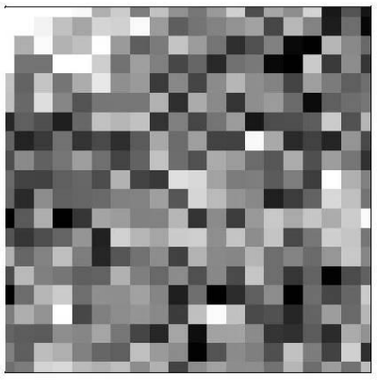

24.2
279
λ
z
Y

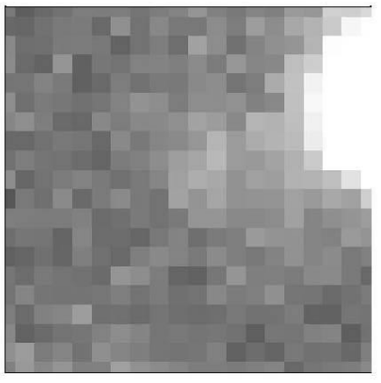


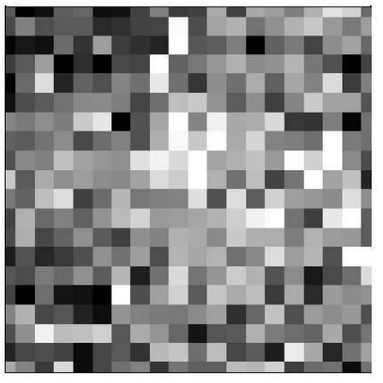


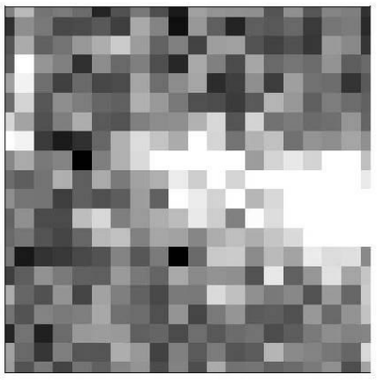










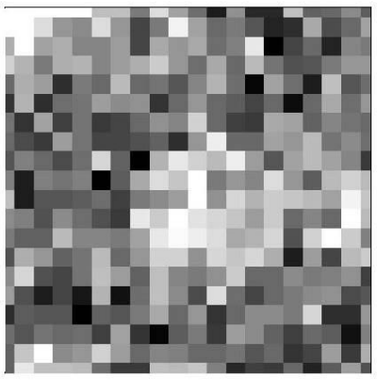


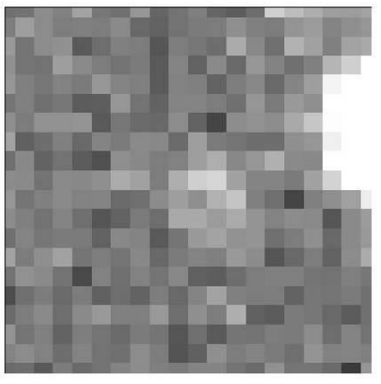
24.04

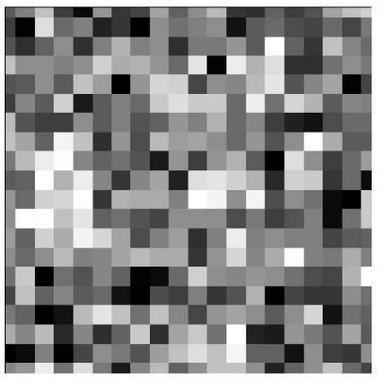
24.04

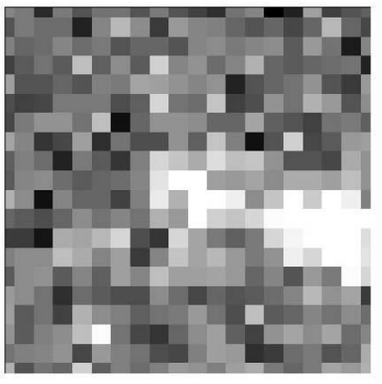
25.82

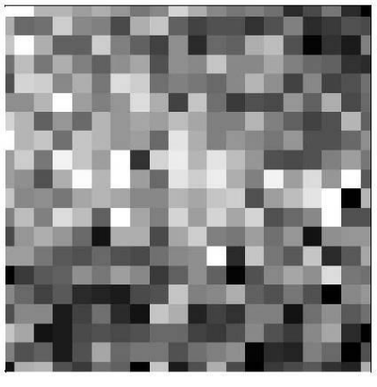
24.25

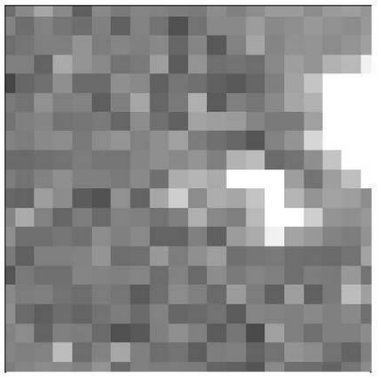


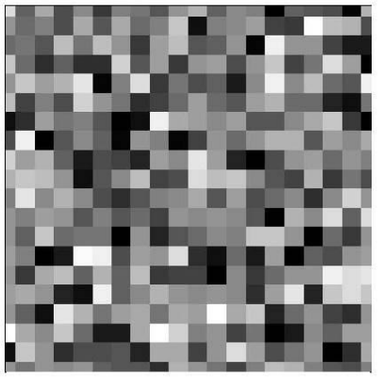


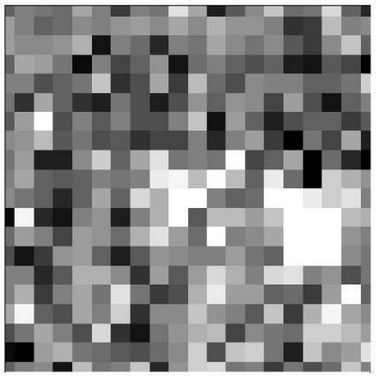


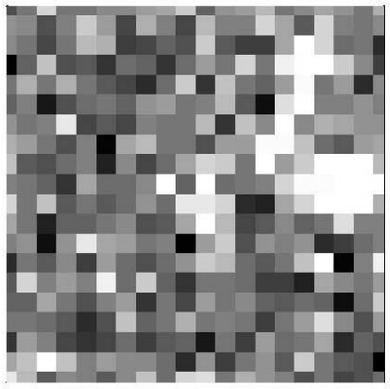


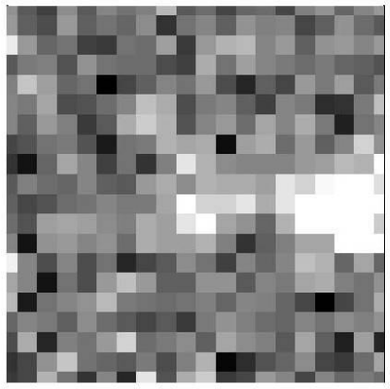


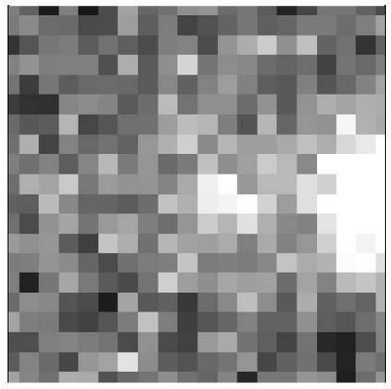


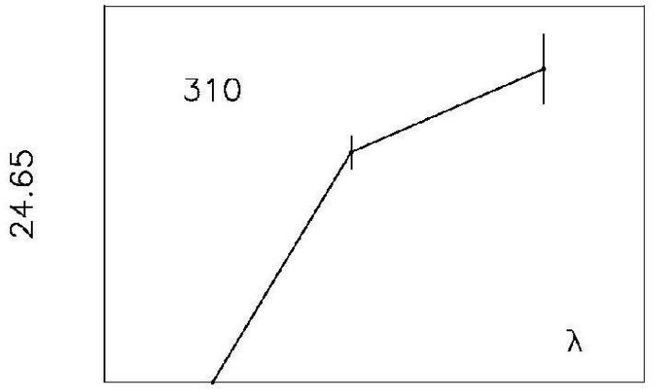


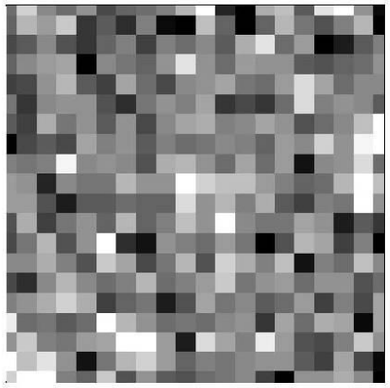


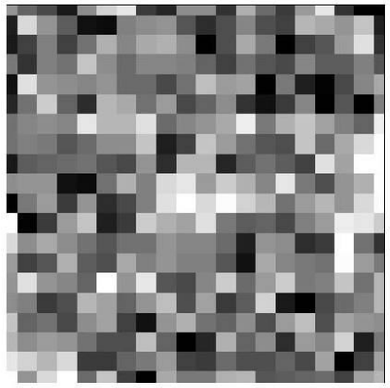


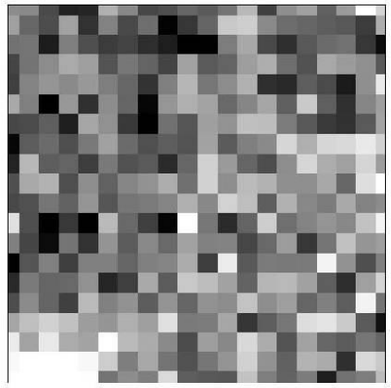


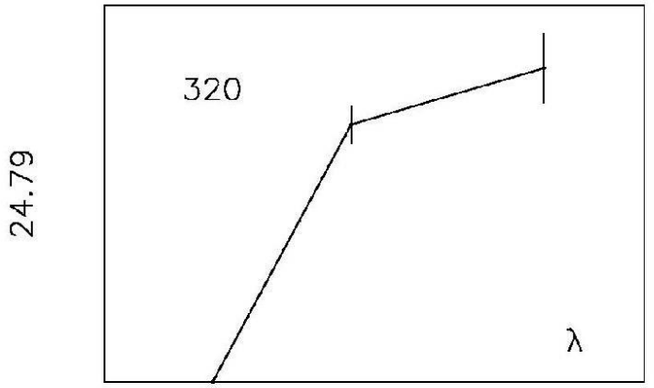


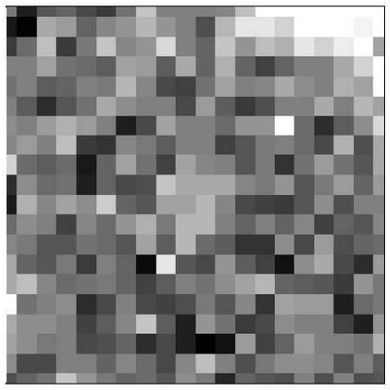

24.65
310
λ

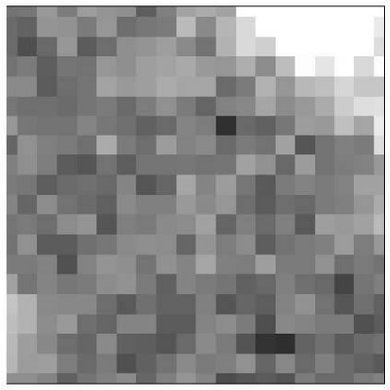


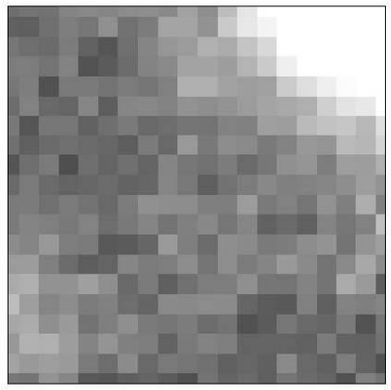


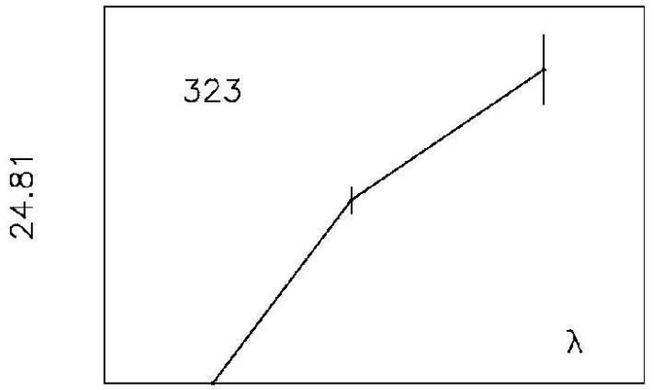



24.79
320
λ








24.81
323
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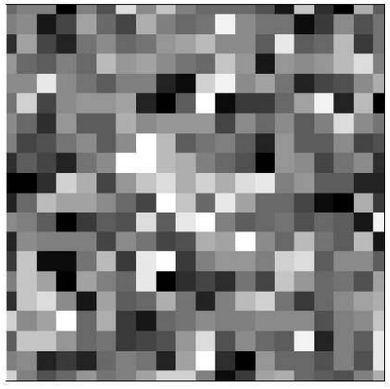

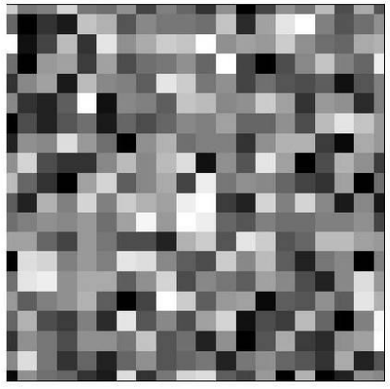

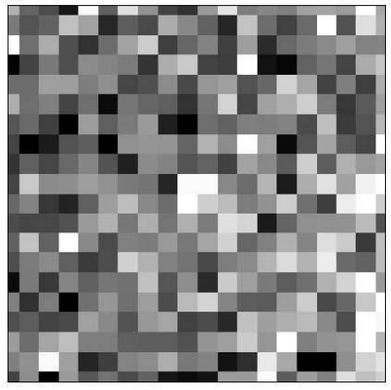

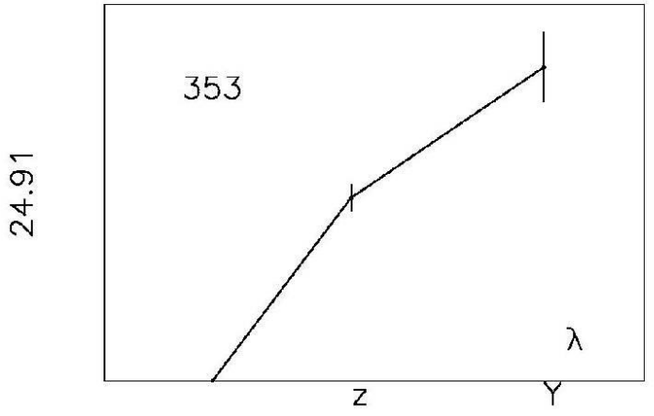
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353
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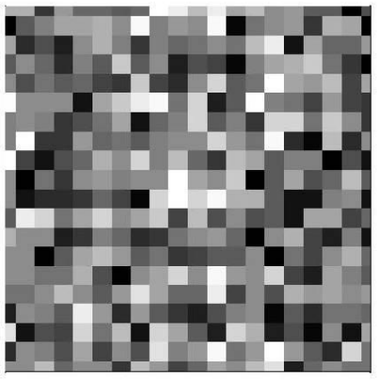

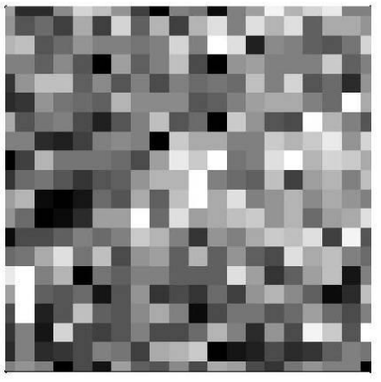

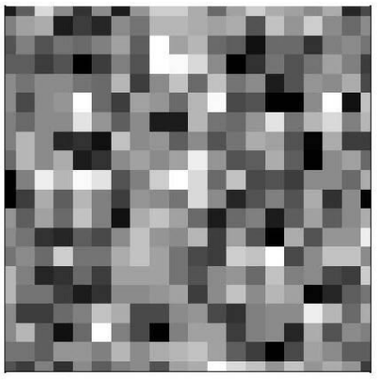

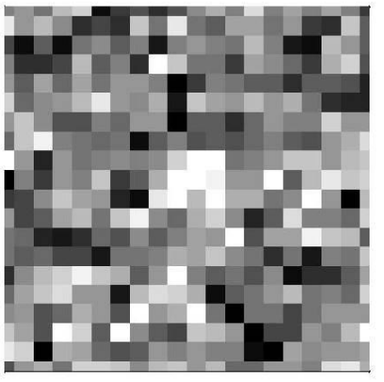

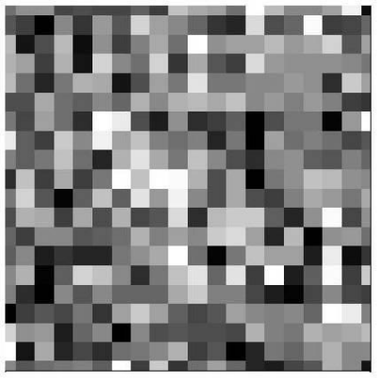

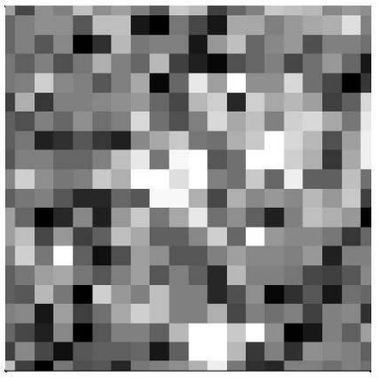

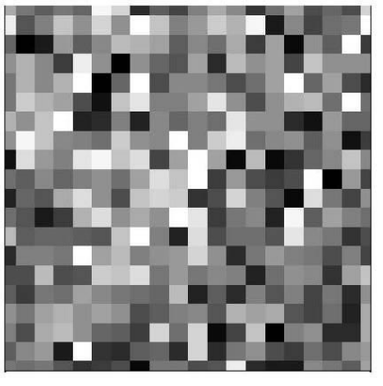

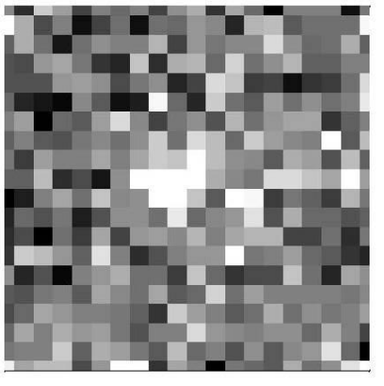

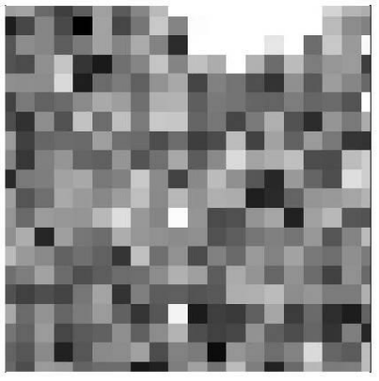

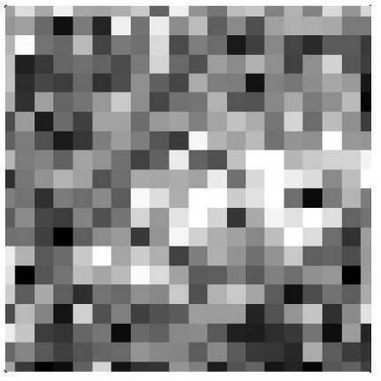

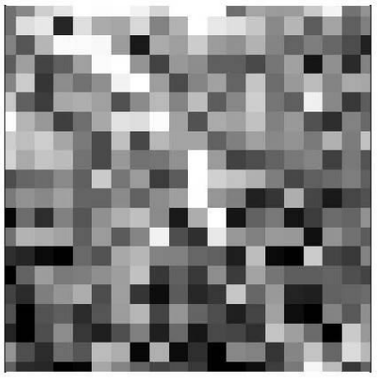

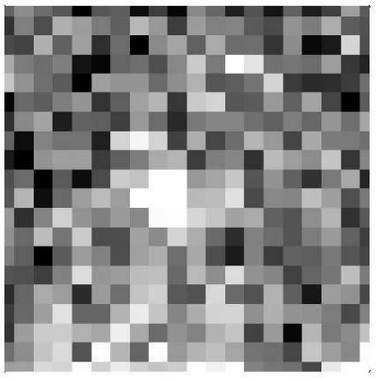

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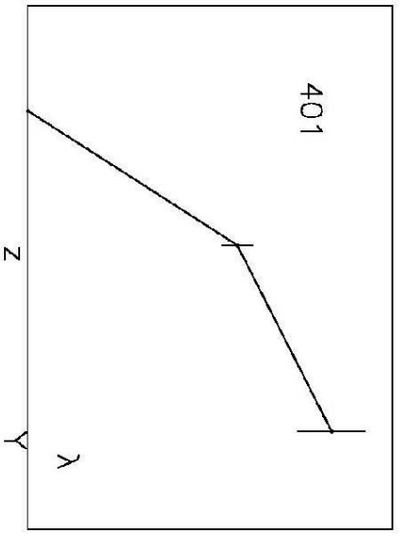
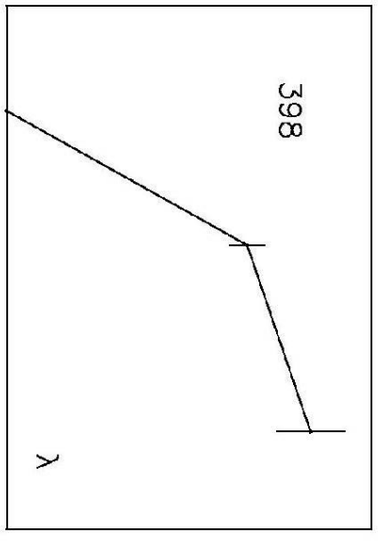
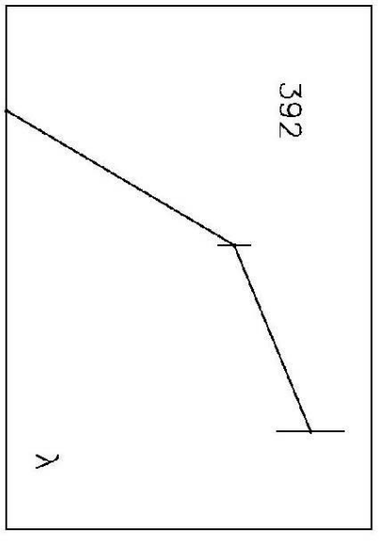
24.63

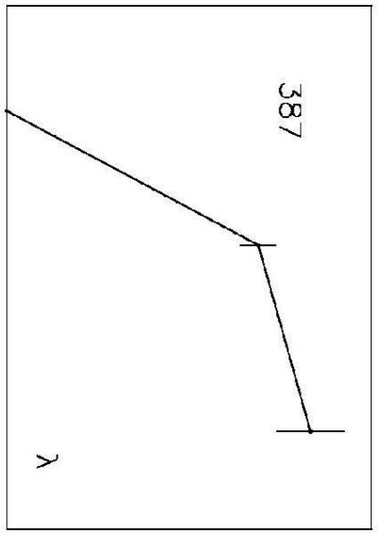
25.23

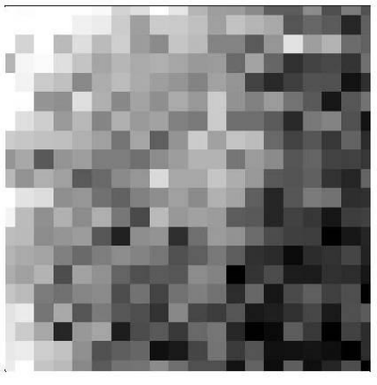
24.28

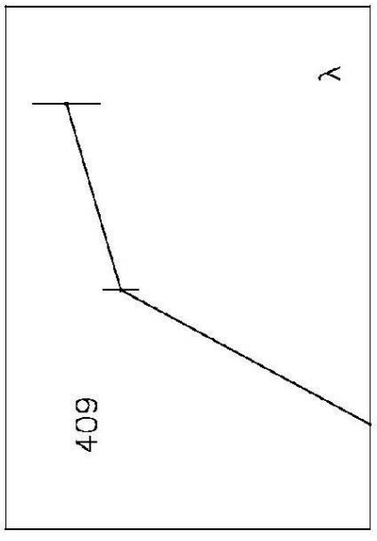












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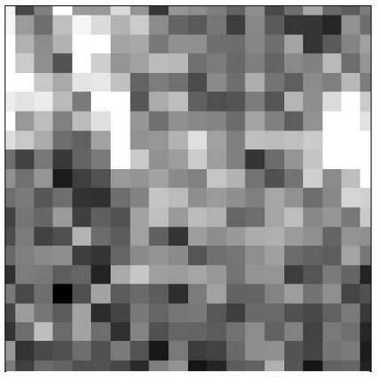

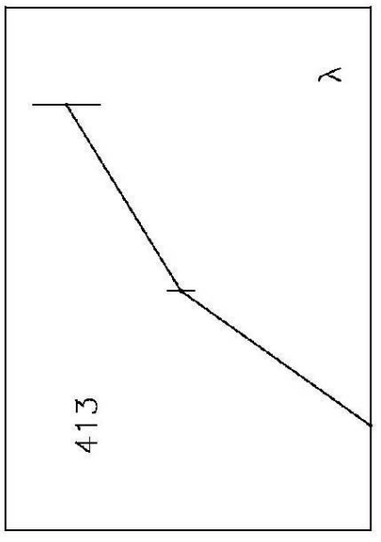

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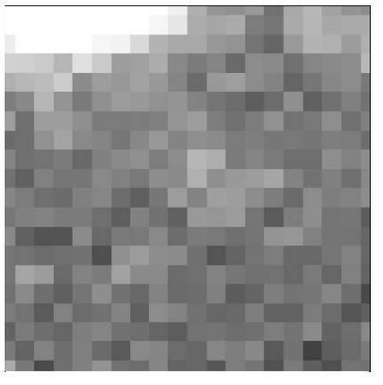

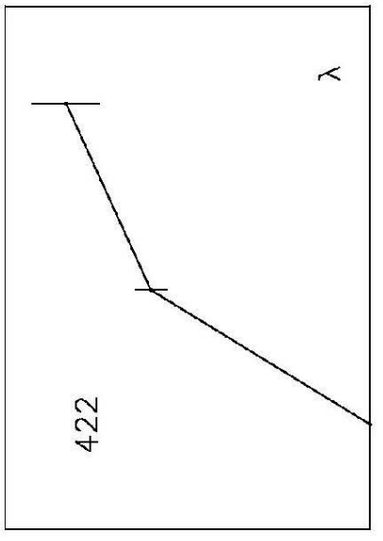

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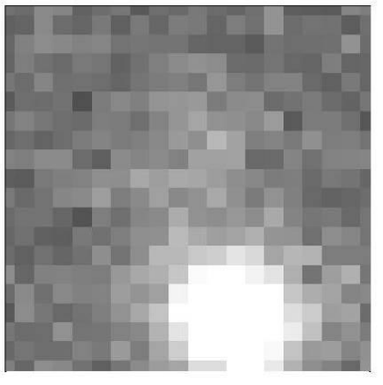

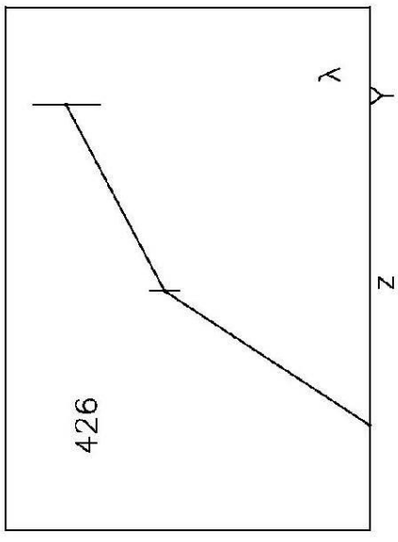

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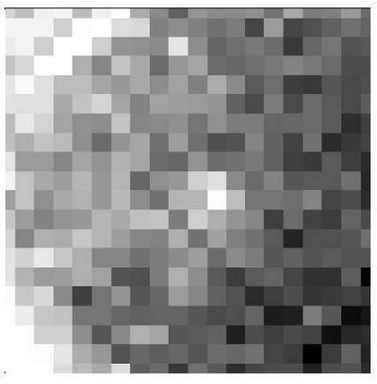

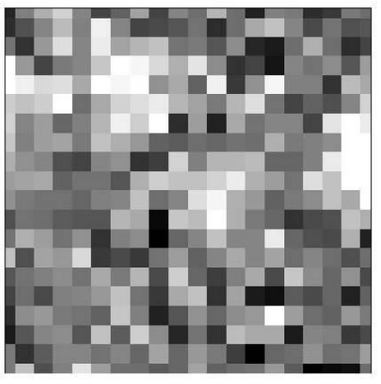

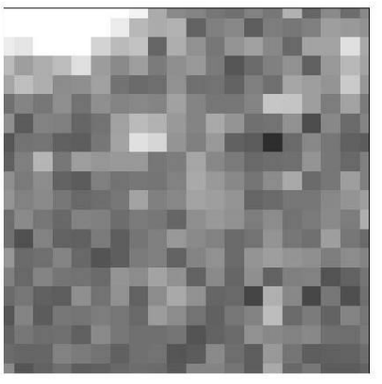

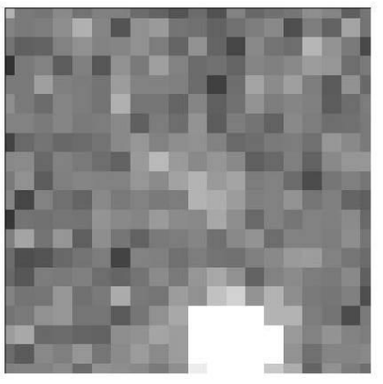

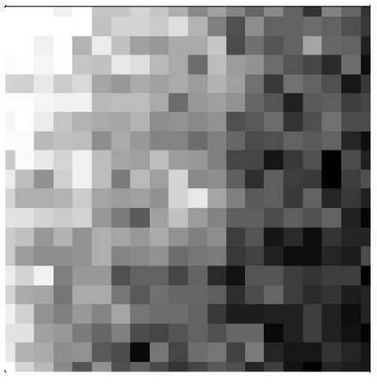

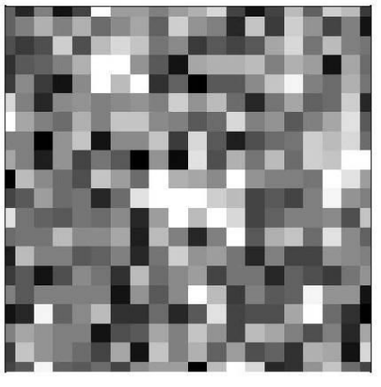

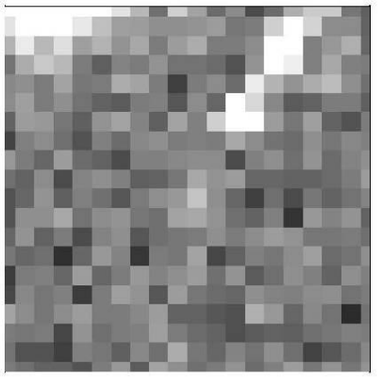

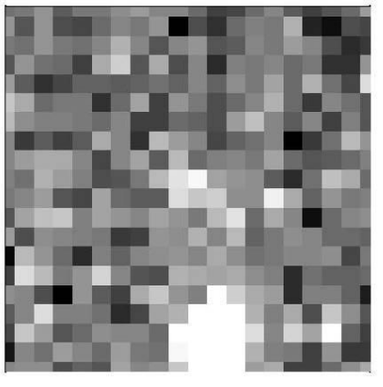

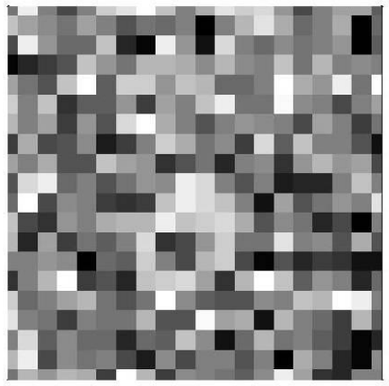

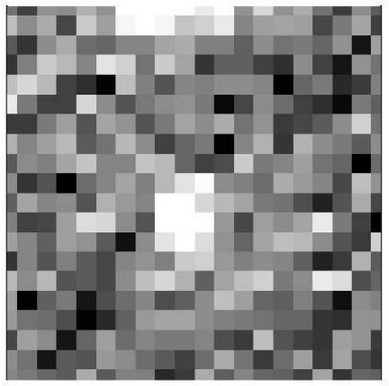

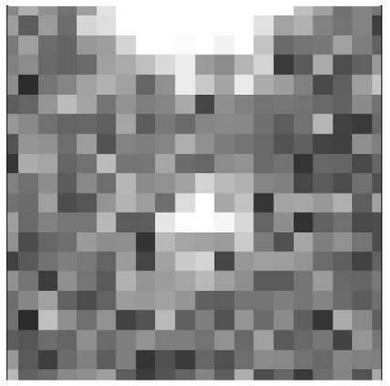

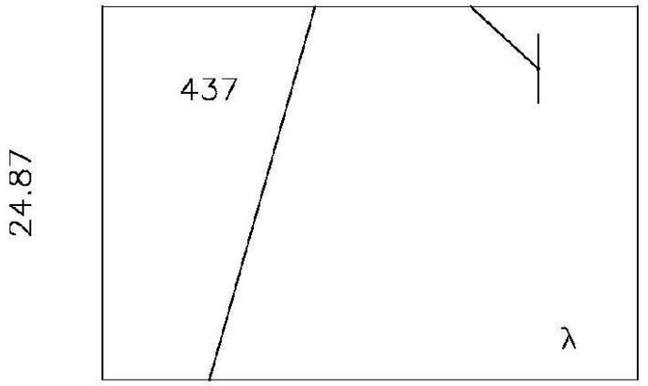
437
24.87
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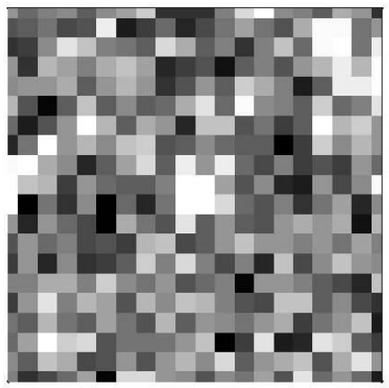

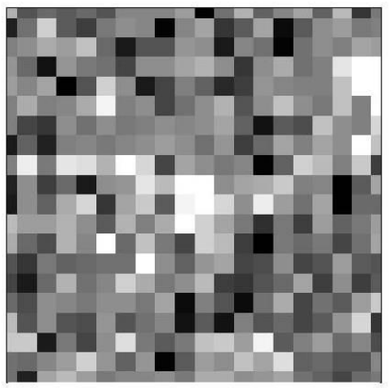

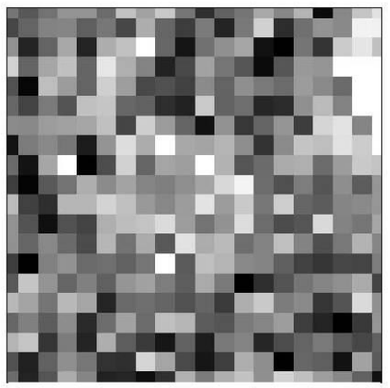

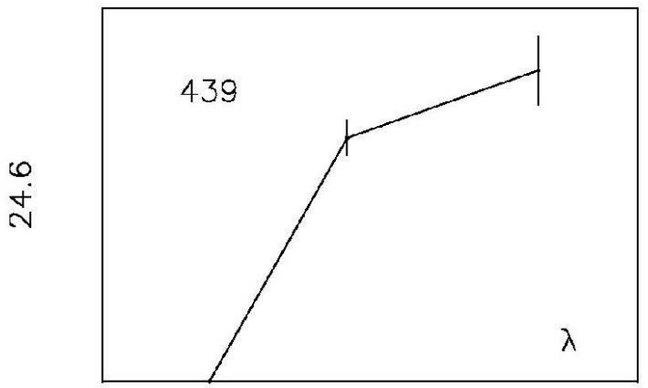
439
24.6
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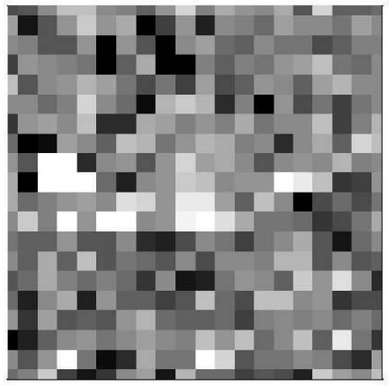

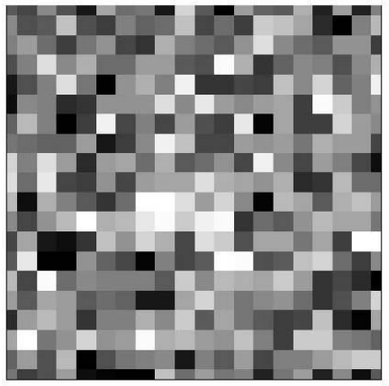

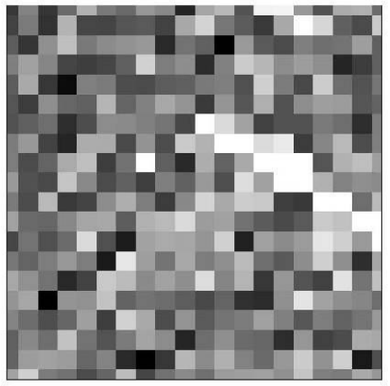

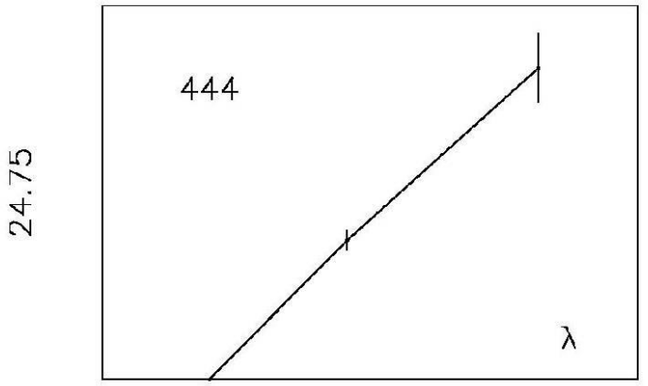
444
24.75
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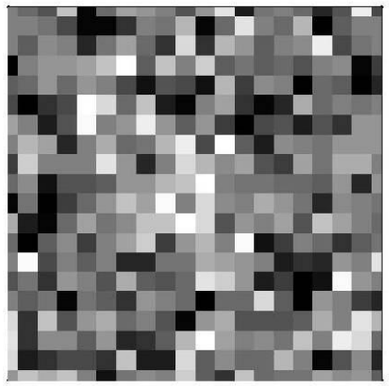

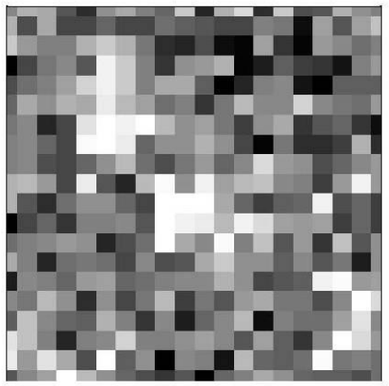

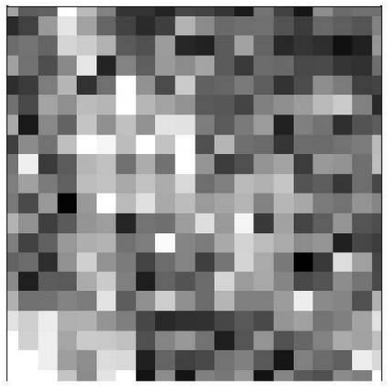

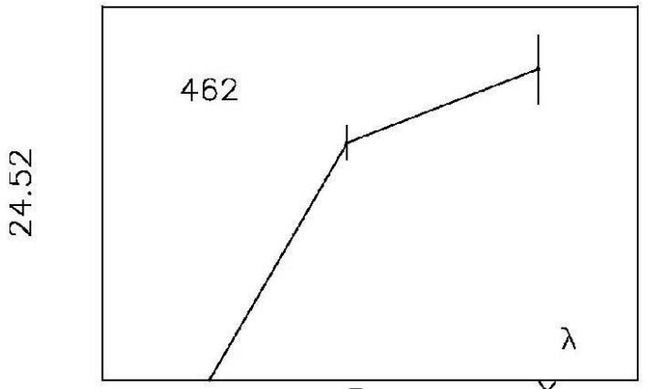
462
24.52
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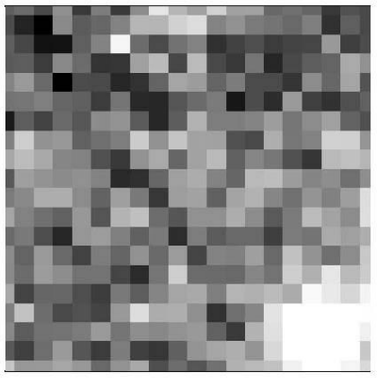
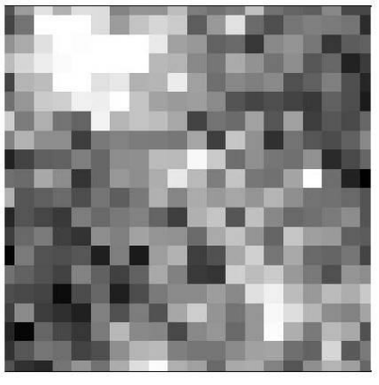
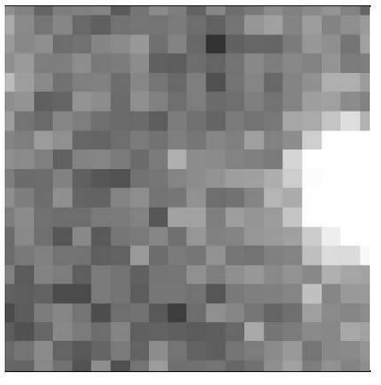
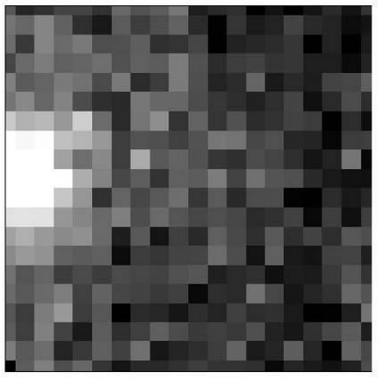
z
Y







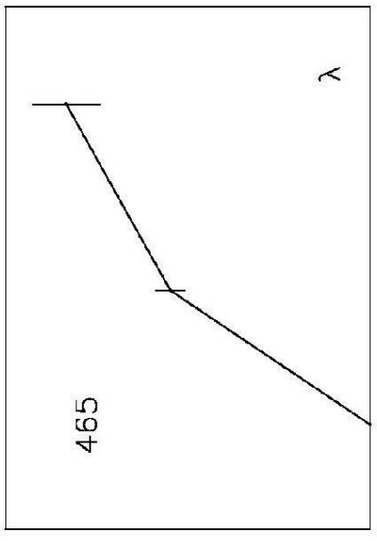


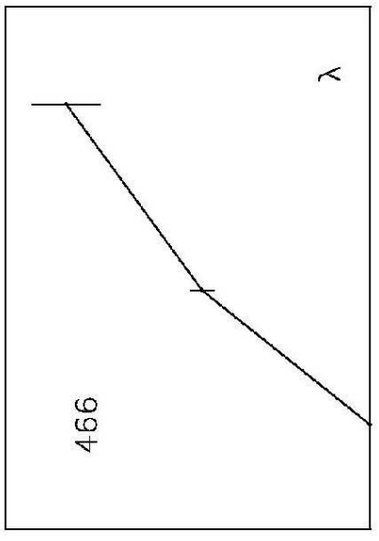
24.99

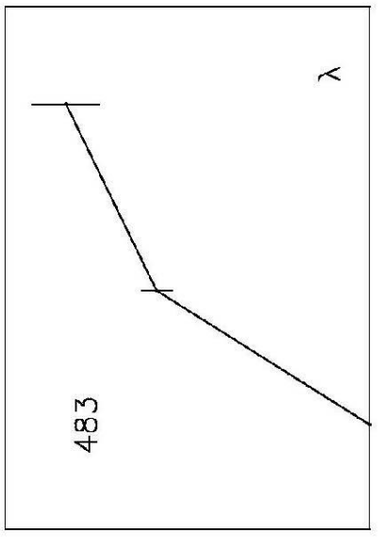
24.21

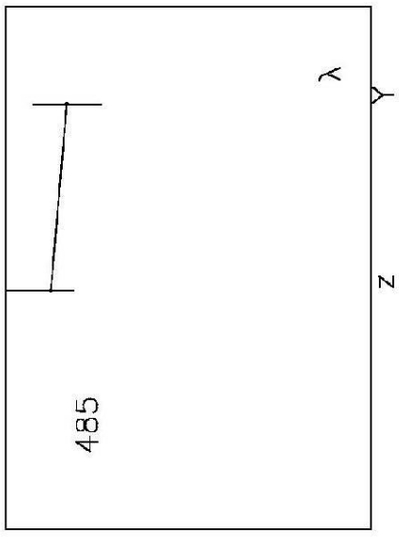
24.66

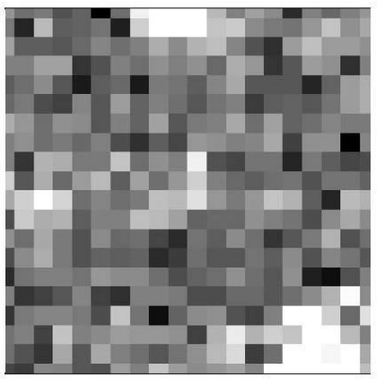
24.63

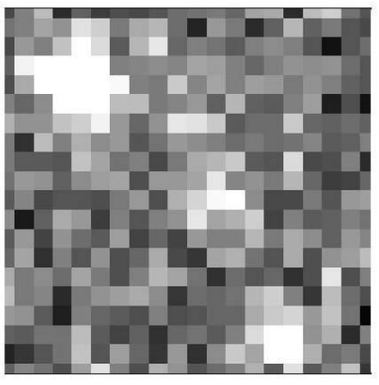


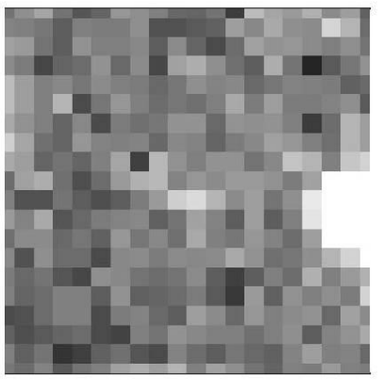


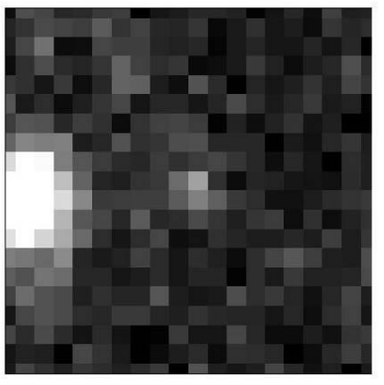


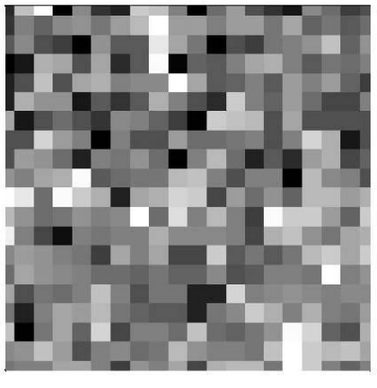


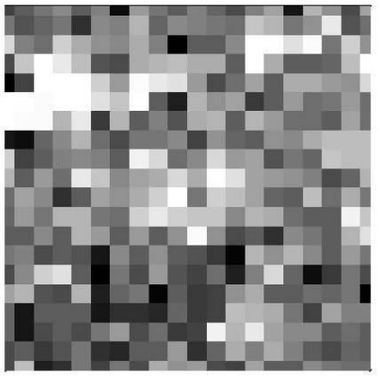


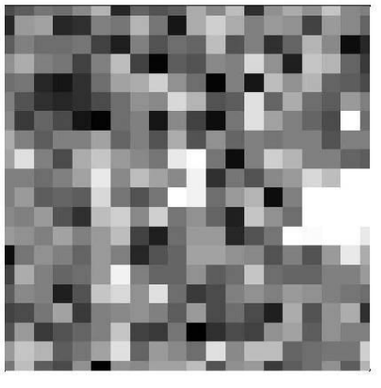


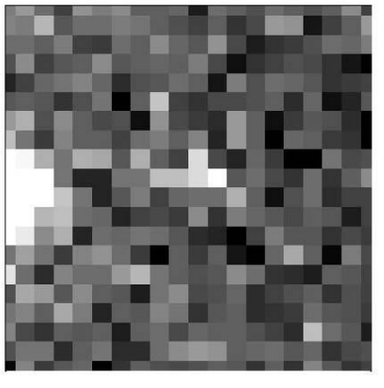


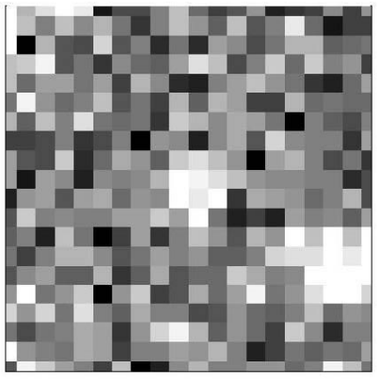
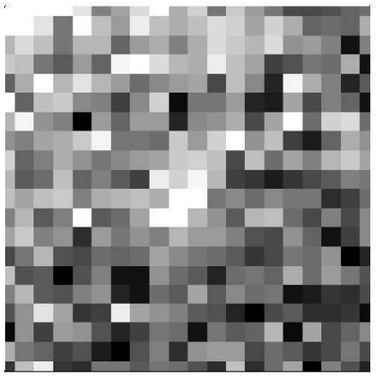
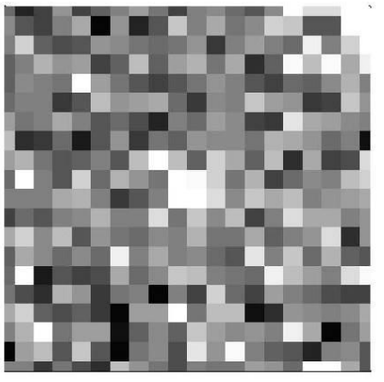
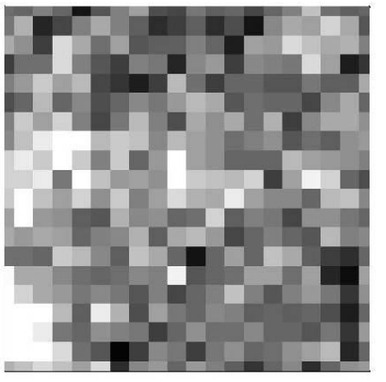
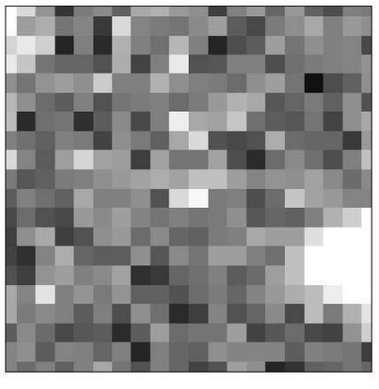
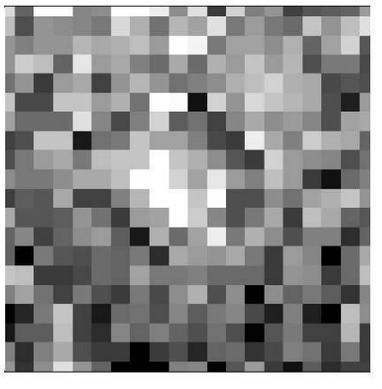
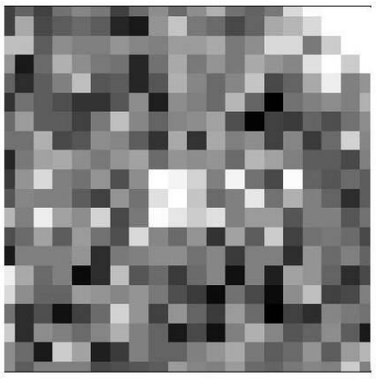
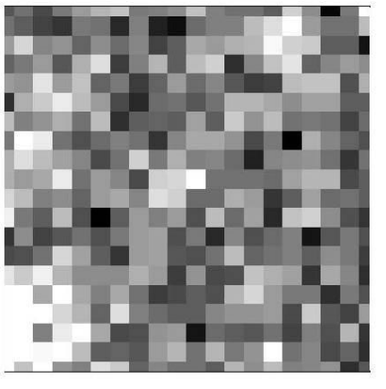
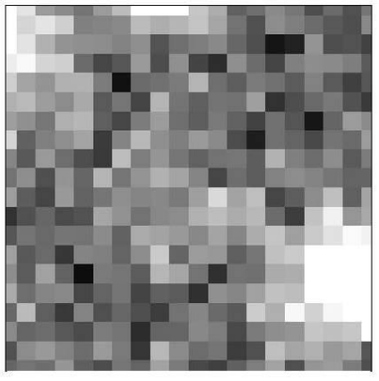
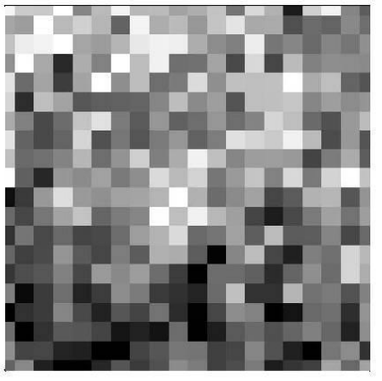
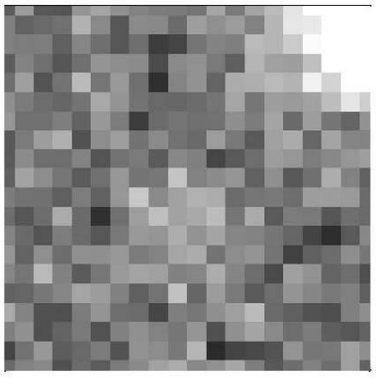
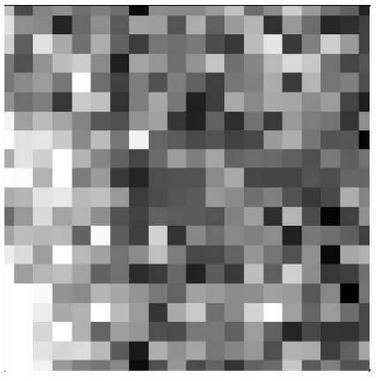










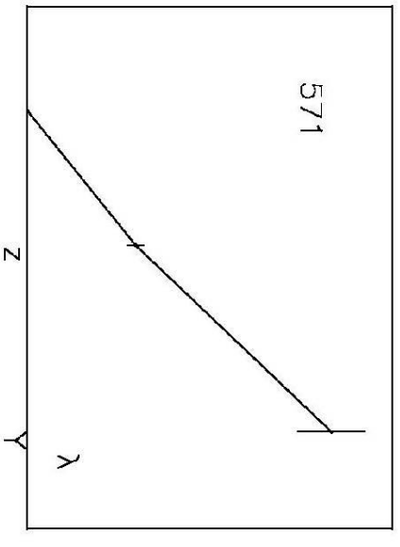













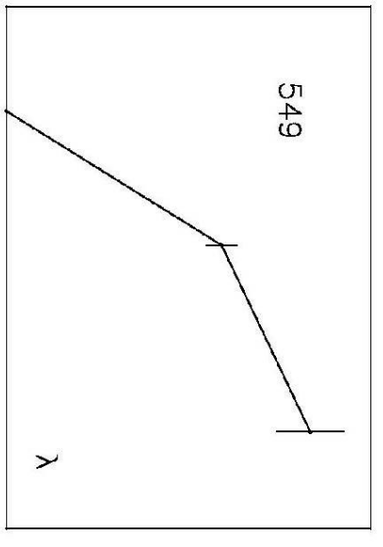
24.4

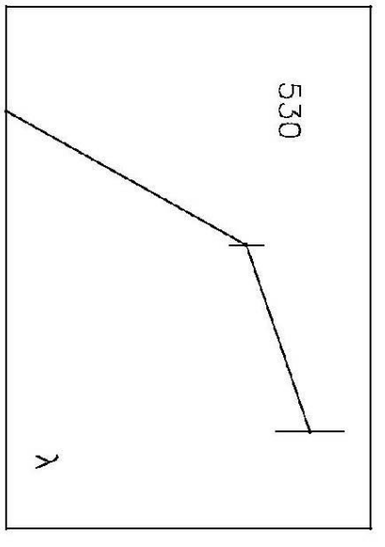
24.03

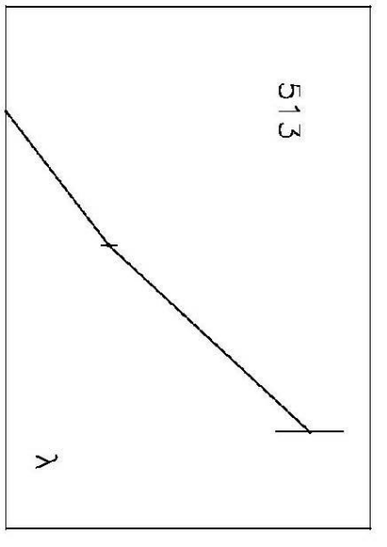
24.58

24.34









Next steps DECam deep fields

- With about twice the signal to noise we have here we'll have viable target lists for Gemini Flamingos redshifts

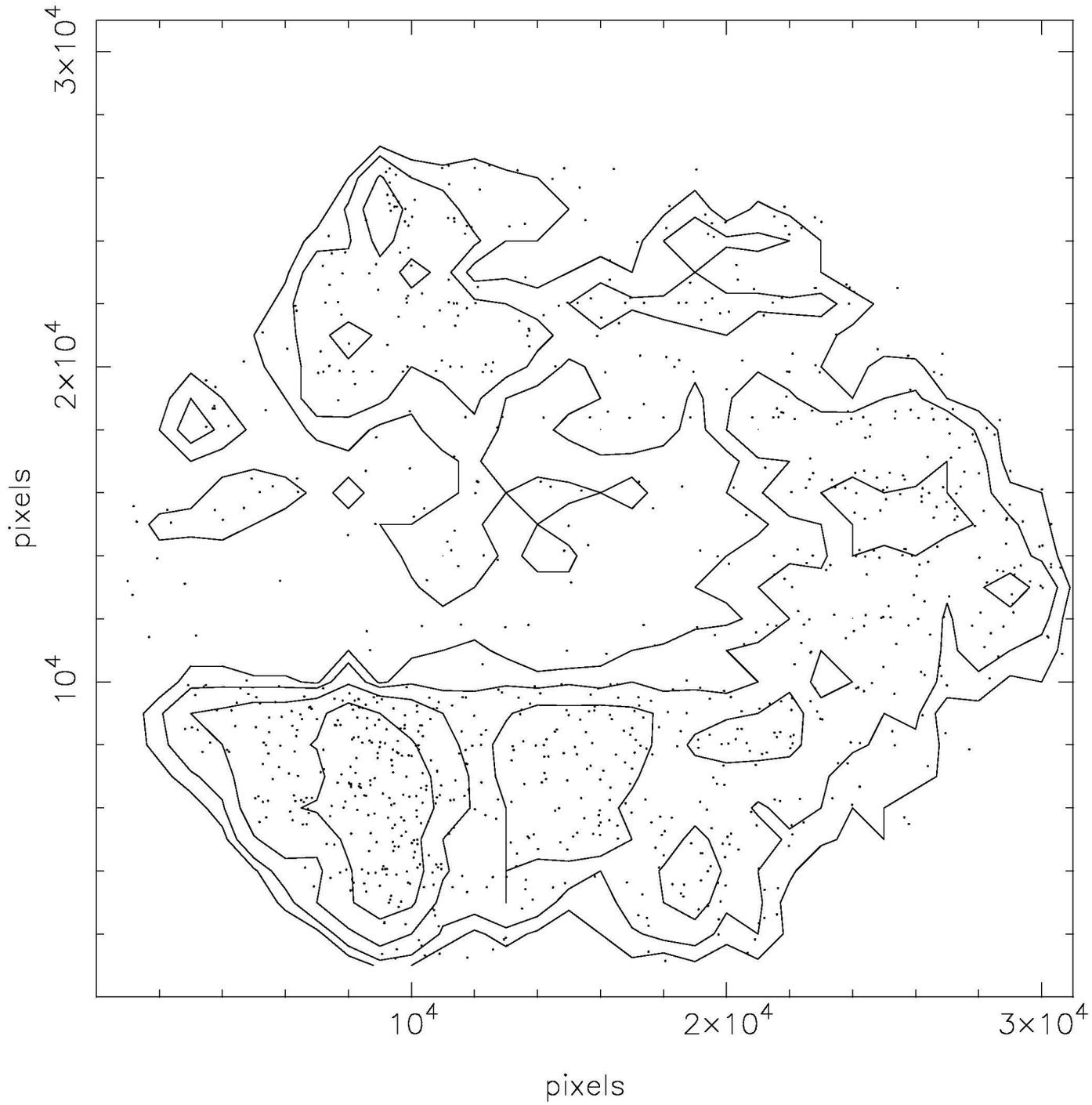
- Also need vetos on i-dropouts from 2 colour diagram

- Look for CIV etc all the way to 3727

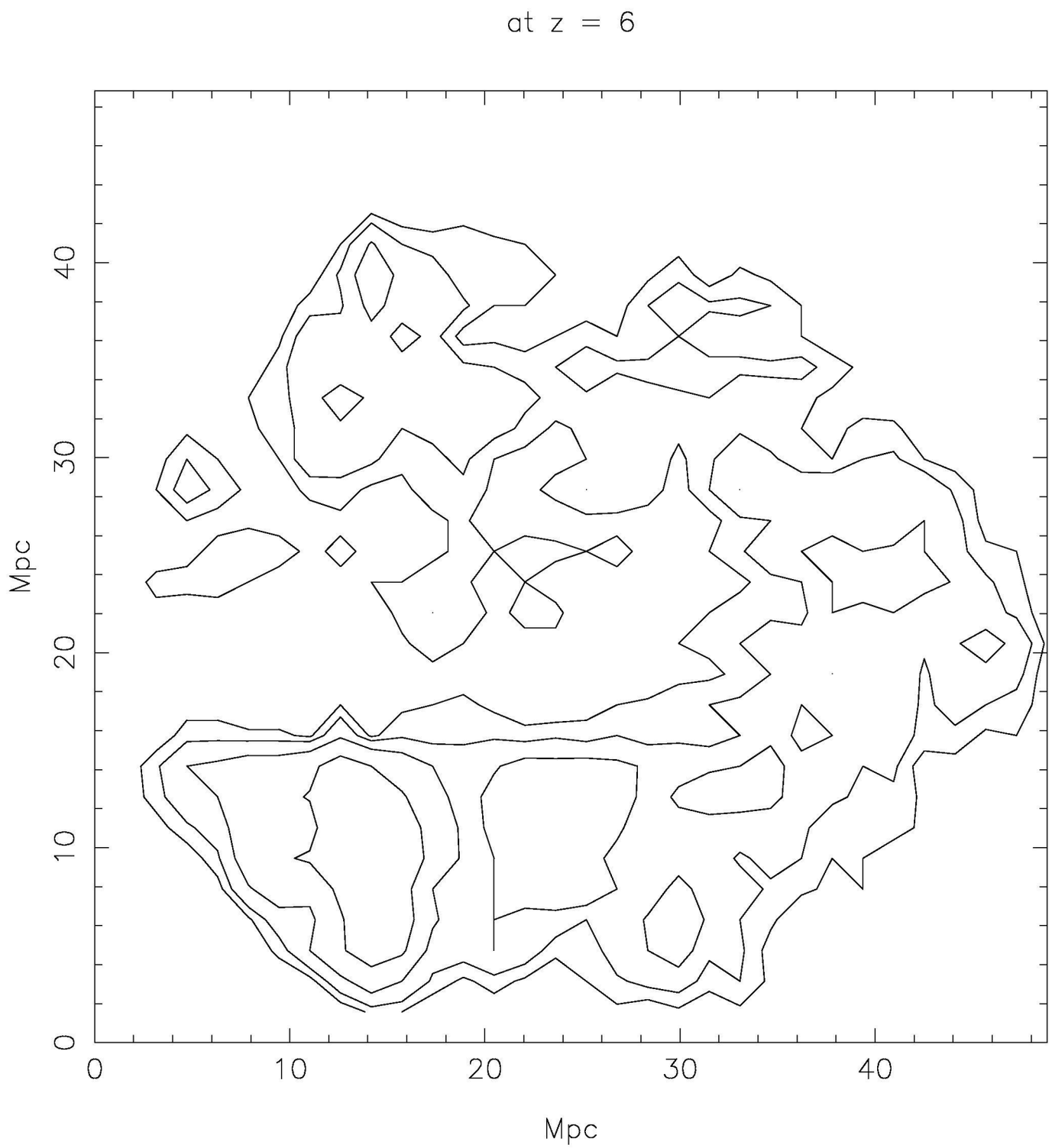
- We also seek more time to monitor the deep fields for supernovae

- See also Discovery of a protocluster at z ~ 6, Toshikawa et al 2012, AIPC 1480, 433

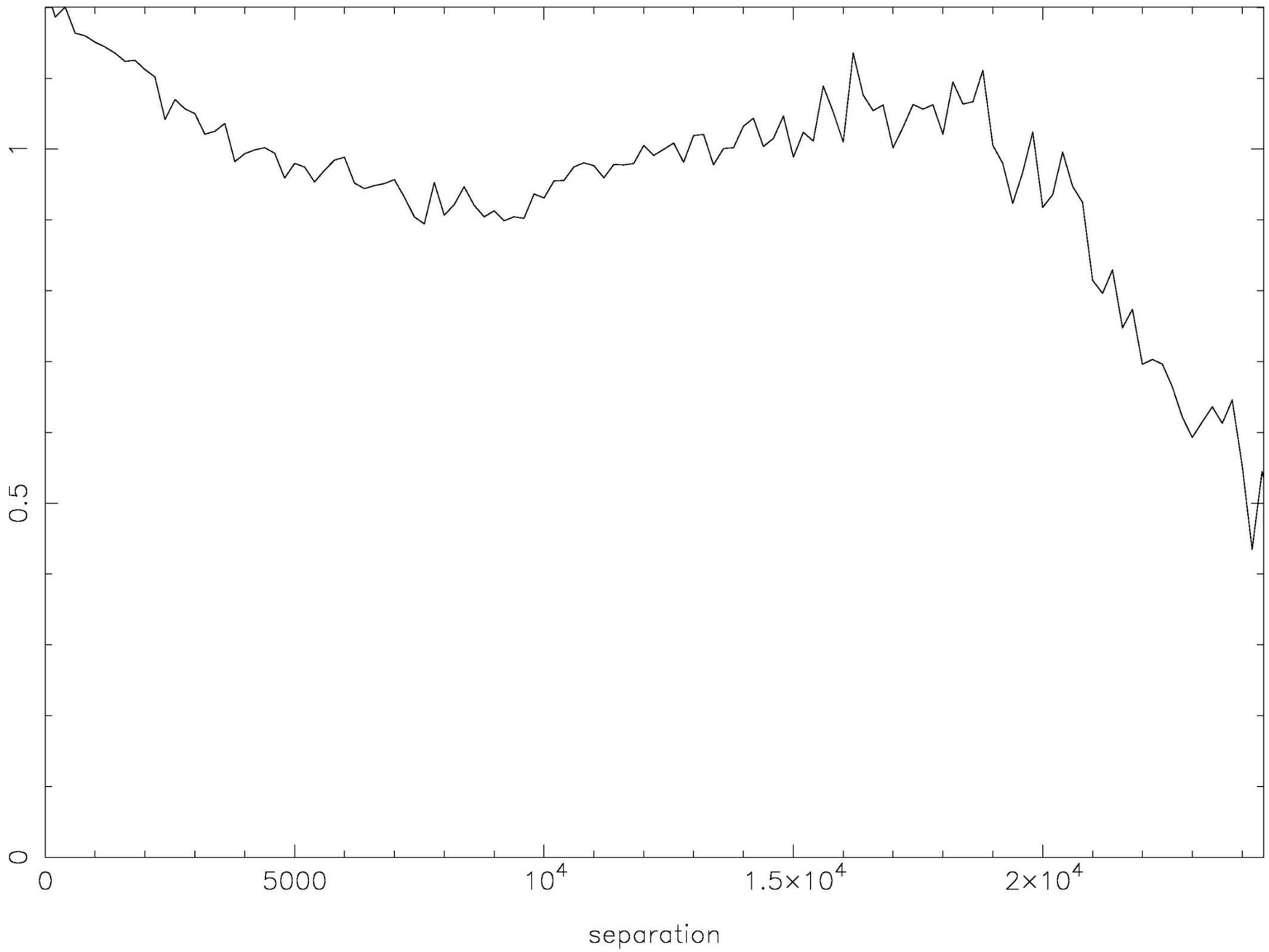
Distribution of dropouts



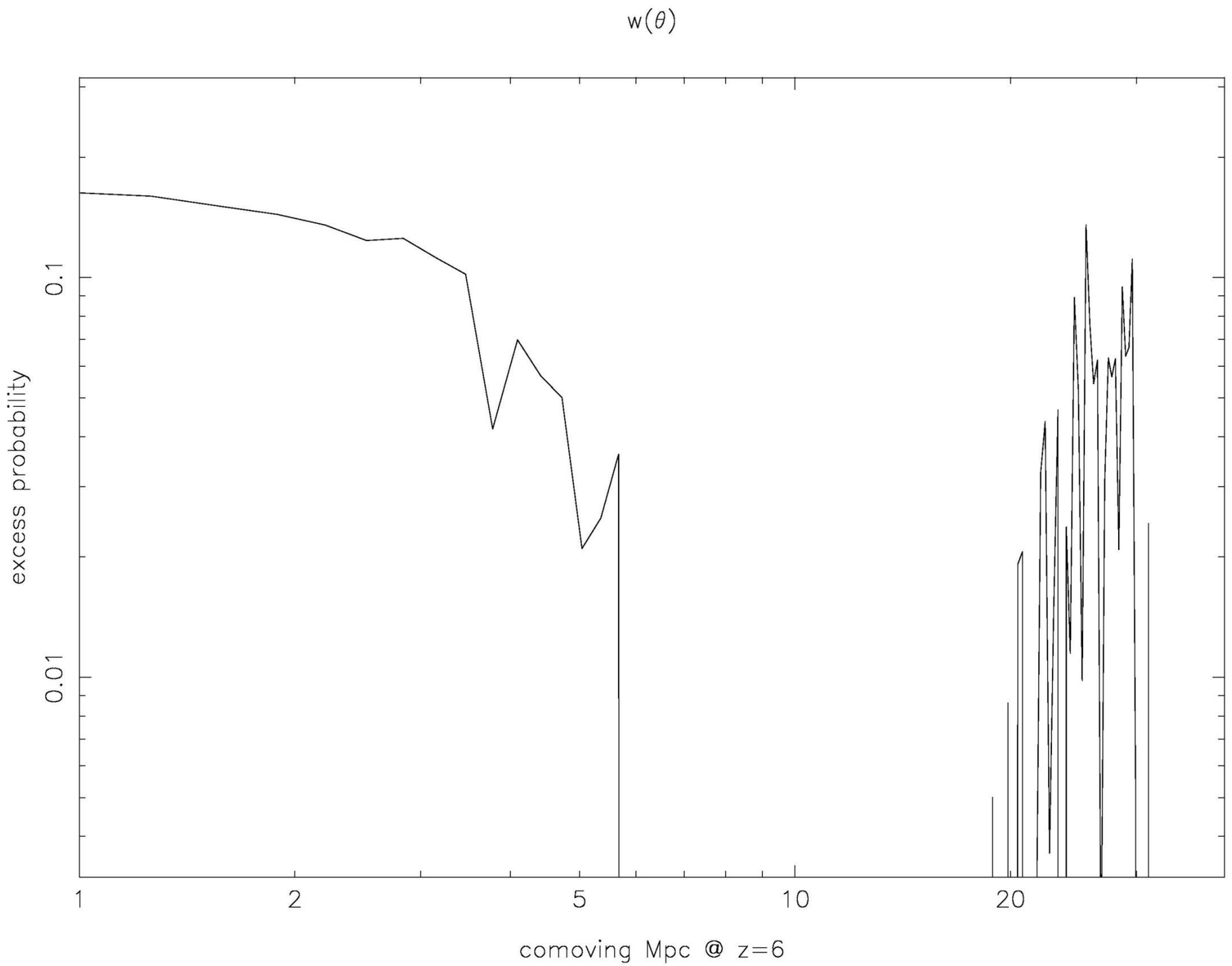
in comoving Mpc



Angular correlation function



w(θ) in comoving Mpc



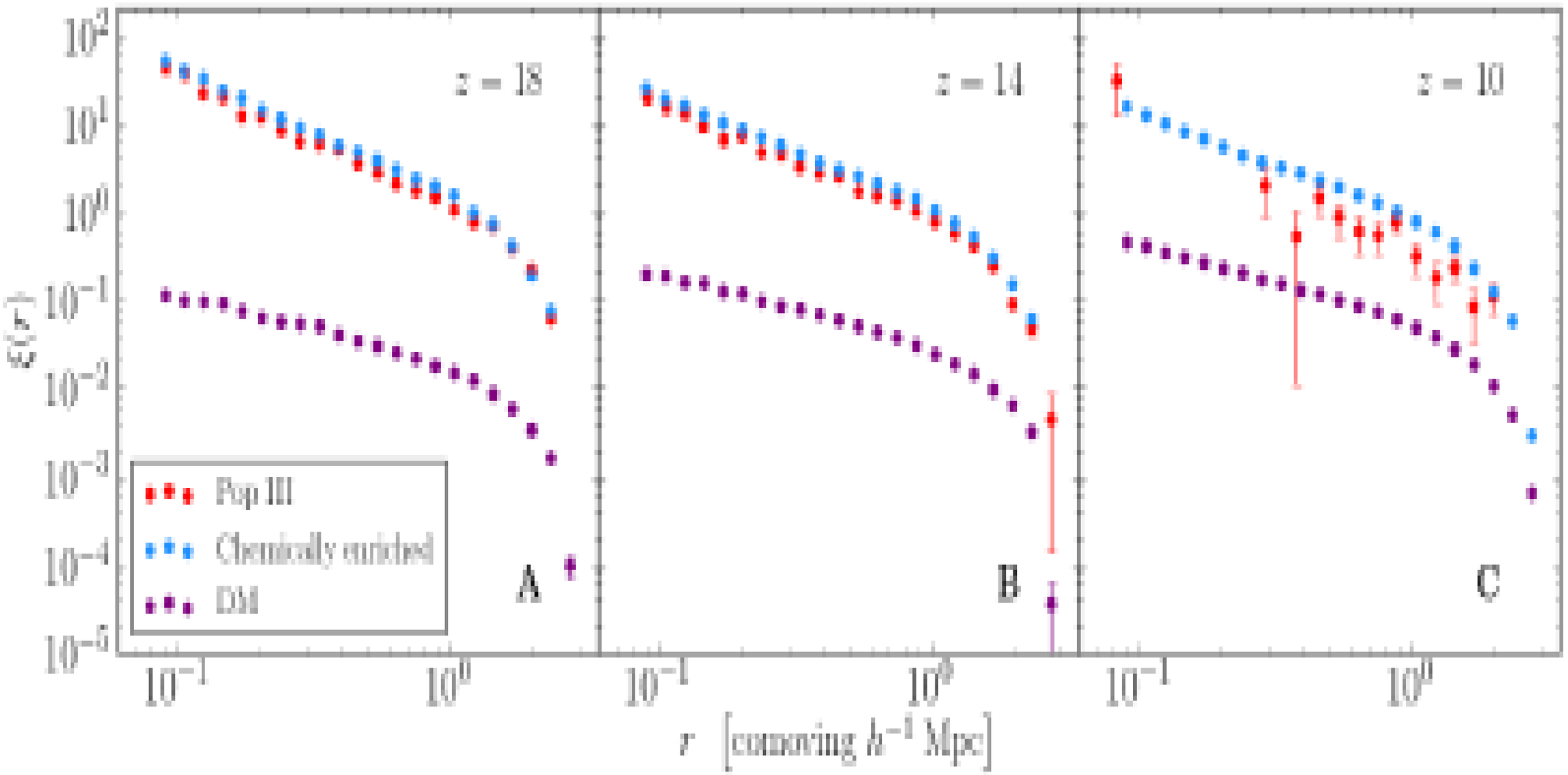


Figure 12. The halo correlation functions for Population III halos (red) and chemically enriched halos (blue), and the unbiased dark matter density field (violet). Panel A, B, and C show the correlation functions at $z = 18$, 14, and 10, respectively. Error bars are plotted for all points, but are generally not visible. At all times chemically enriched halos are more clustered than Population III star forming halos.

Pair Instability Supernovae

- use the highly efficient Lyman break galaxy monitoring technique (that Jeff Cooke has used to find z 2–4 SLSNe) to search for the SLSNe

- SLSNe will rise to peak from 10 – 30 days, stay there for 2 – 20 days, then decline in 20 – 100 days. In the observer frame, this is 75 – 230 day rise, 15 – 150 days near peak, and 150 – 750 day decline for objects at the mean redshift of z 6.5.

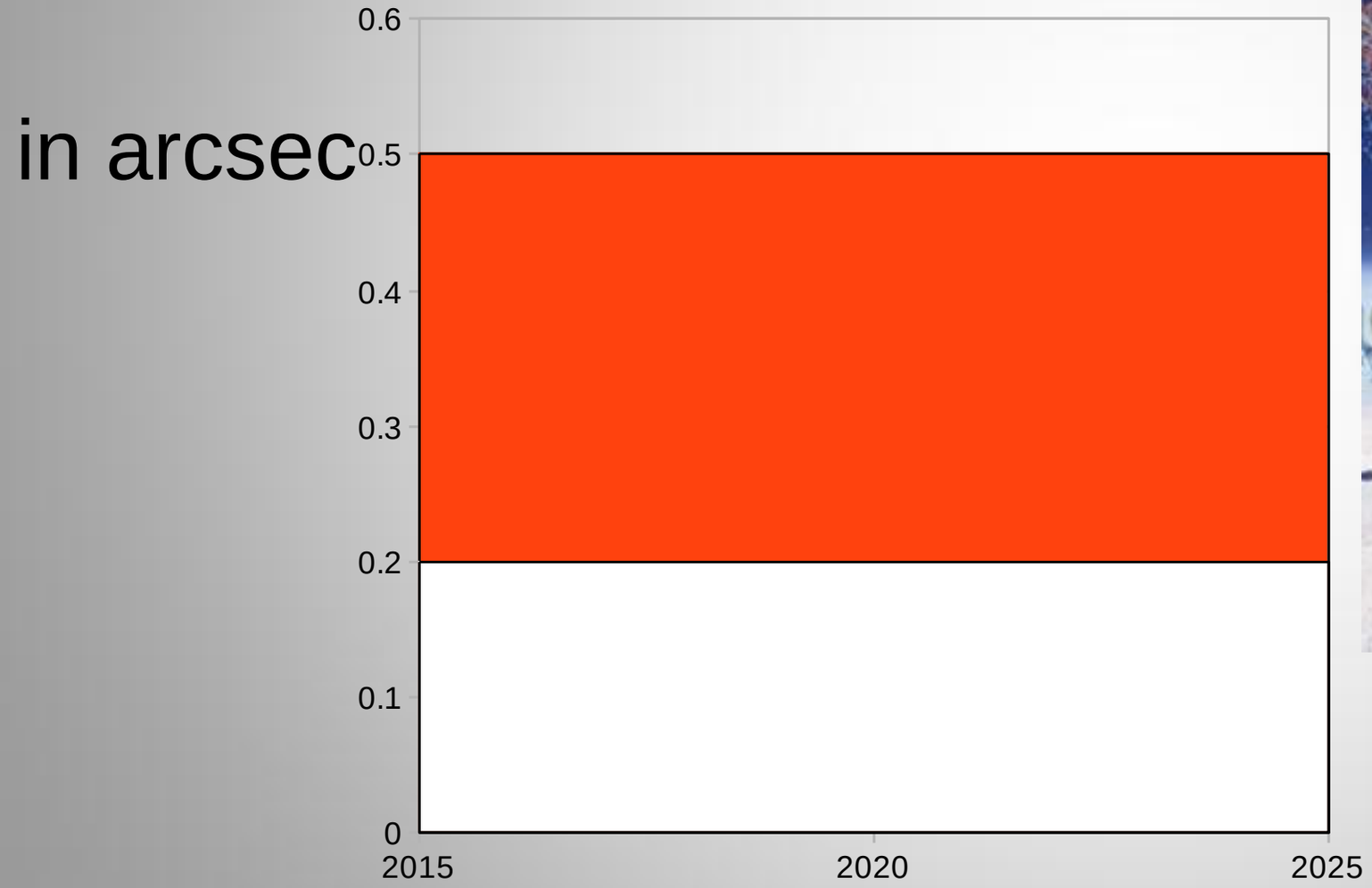
- Rates: several per field

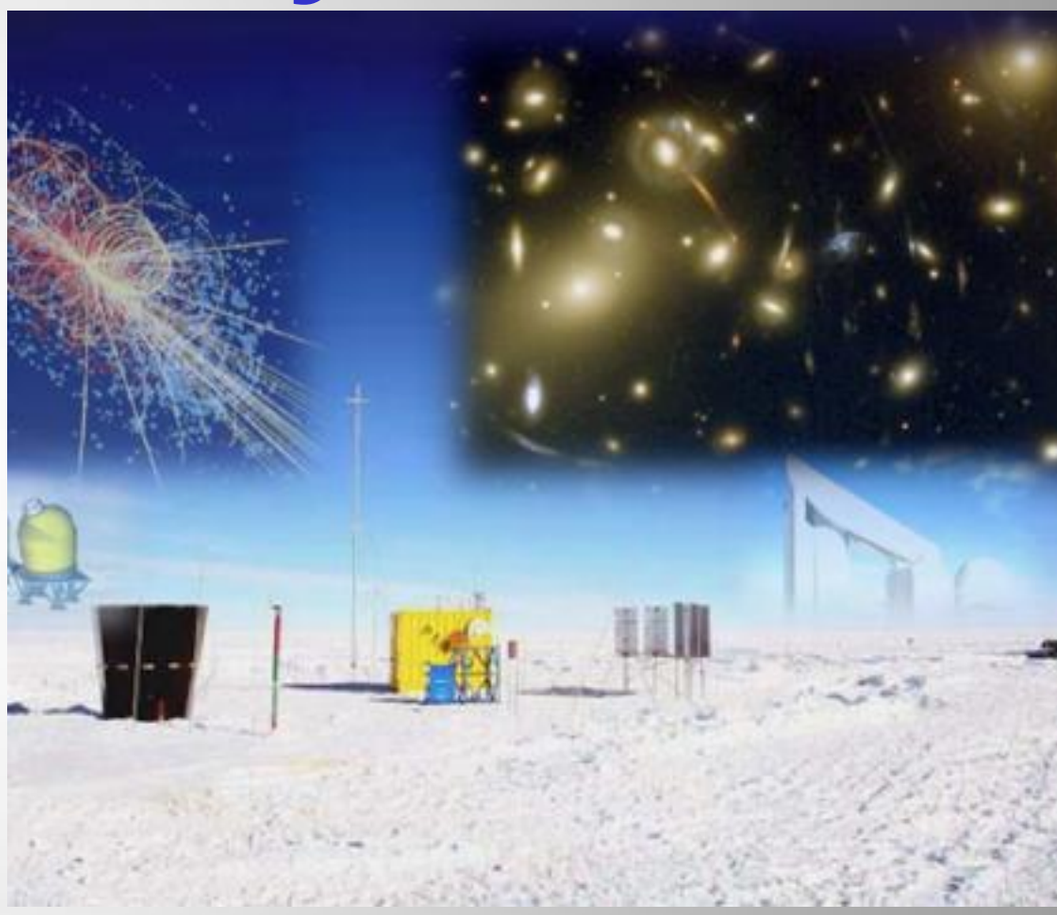
In a few hundred Myrs a generation of stars formed that reionized the Universe. These earliest galaxies emit in the near infrared where for maximum sensitivity telescopes should be based in Antarctica

Astrophysics from antarctica

- McMurdo, Boomerang CMB flat Universe, 1995
- South Pole, SPT SZ
- Dome C, France/Italy
- Dome A, China
- Dome F, Japan
- UNSW, 175 papers on site properties since 1990,
  - including the design of PILOT

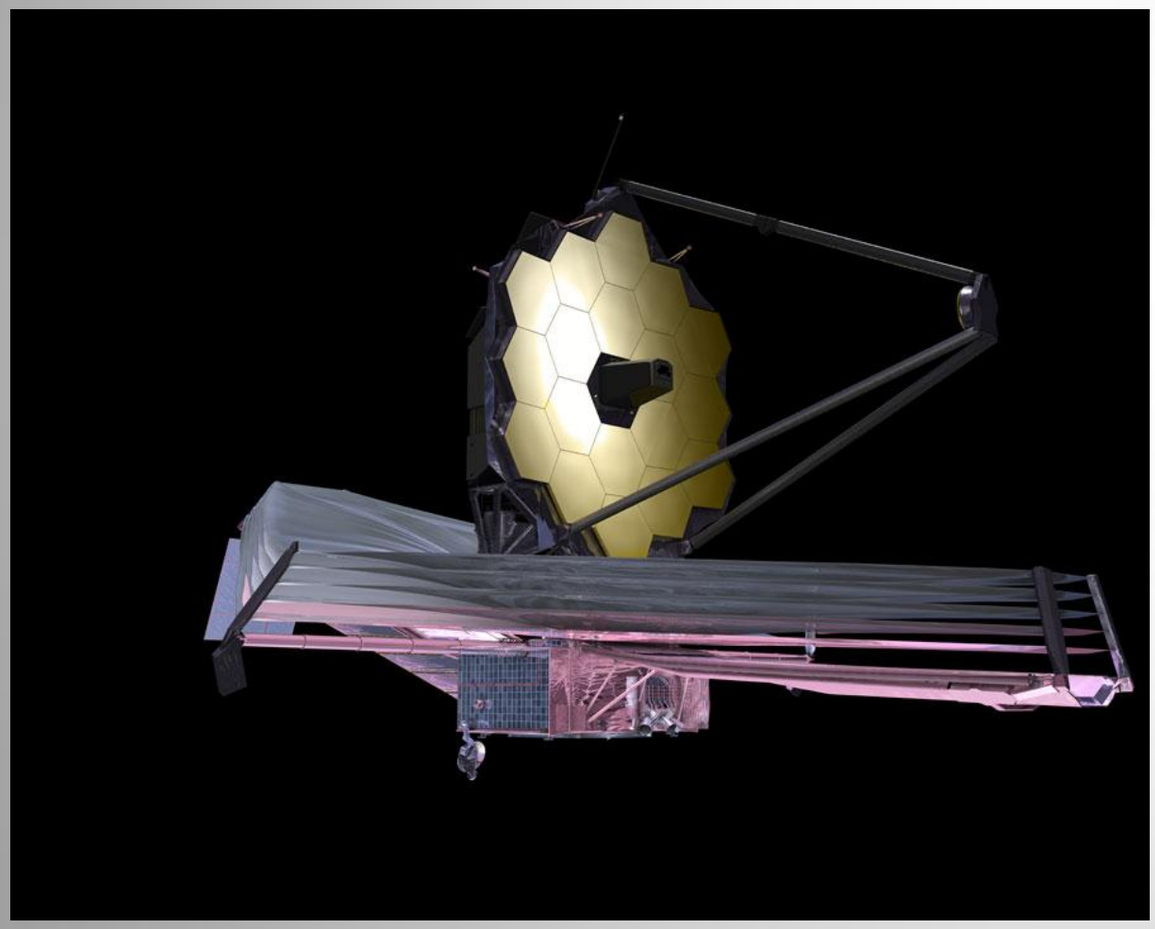
Opportunity for KDUST 2.5m IR survey



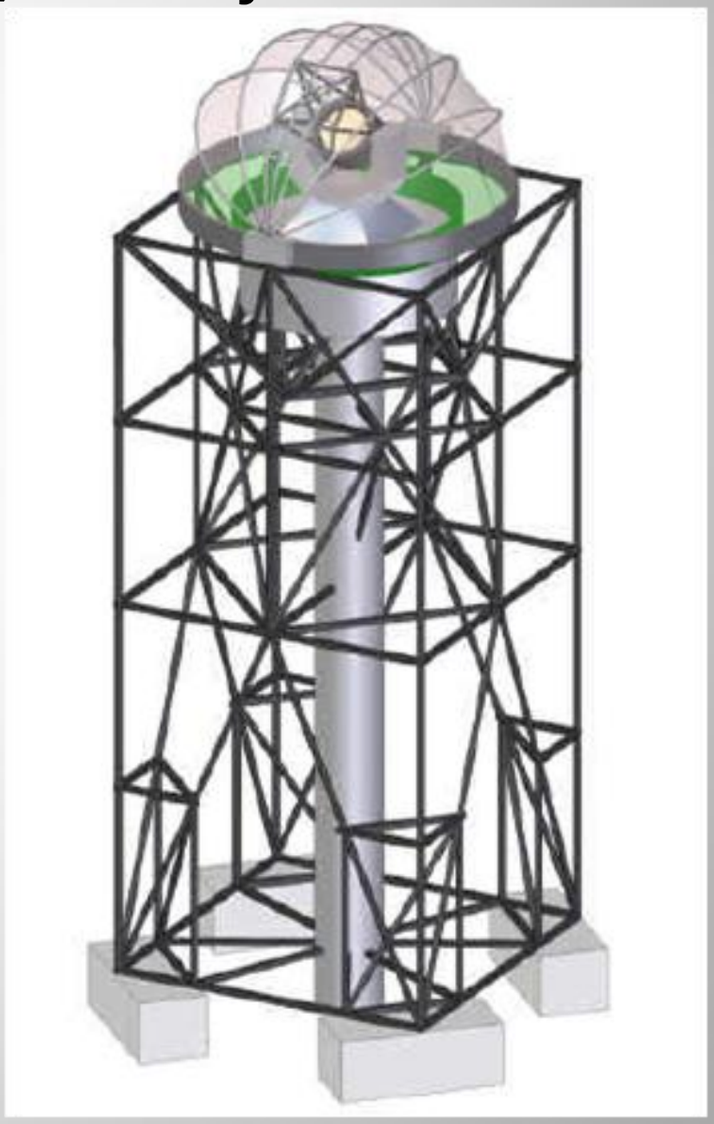


Spectra and images of the first galaxies

JWST



KDUST, formerly PILOT



State of the art: UKIDSS

•7500 square degrees of the Northern sky, extending over both high and low Galactic latitudes, in JHK to K=18.3

•three magnitudes deeper than 2MASS

•UKIDSS = near-infrared SDSS

•Also a panoramic atlas of the Galactic plane

•UKIDSS = five surveys

•two deep extra-Galactic elements, one covering 35 sq deg to K=21, and the other reaching K=23 over 0.77 sq deg

State of the Art - VIKING
VISTA Kilo-Degree Infrared Galaxy Survey
PI Will Sutherland

- VIKING survey will image 1500 sq deg in Z, Y, J, H, and K_s to a limiting magnitude 1.4 mag beyond UKIDSS Large Area Survey
- very accurate photometric redshifts, especially at z > 1, important step in weak lensing analysis and observation of BAO
- Other science drivers include the hunt for high redshift quasars, galaxy clusters, and the study of galaxy stellar masses.

KDUST camera architecture

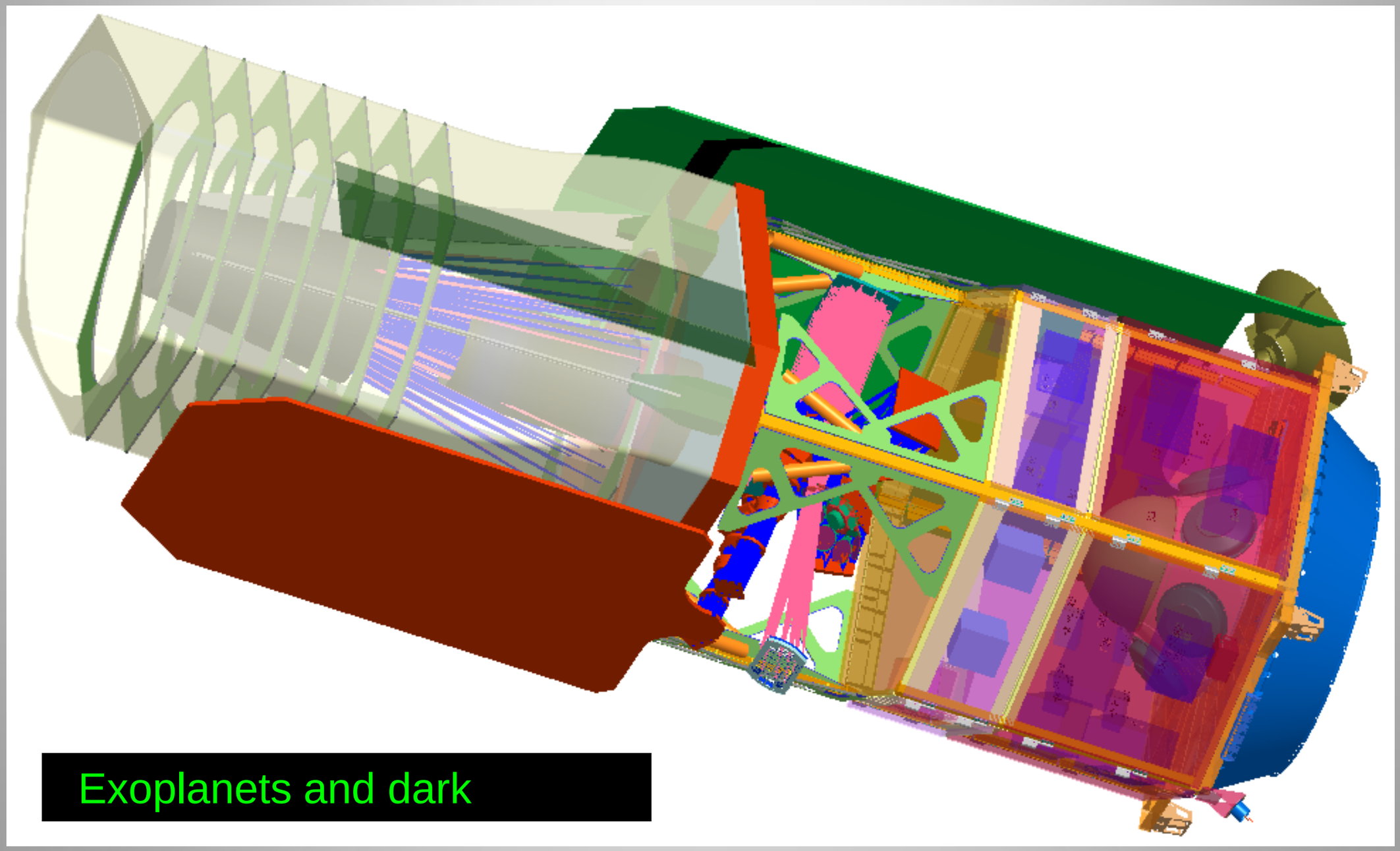
- Simplest option: a Teledyne HgCdTe 2048^2
- Better option: 4096^2 or 2 x 2 (8.5 arcmin field)
  - ANU has delivered two of these to Gemini
  - Plan B against ITAR is choice of 2 European sources
- KDUST focal plane scale is appropriate without change
- JHK and Kdark filters

The Antarctic advantage

- Almost diffraction limited images
- Wide field
- Low 2μ background
- This combination is only available from
  - the Antarctic plateau
  - high altitude balloons
  - space

More details
http://www.kdust.org/KDUST/KDUST.html
and arXiv:1108.1992

The competition is space: WFIRST



WFIRST (or Euclid) vs KDUST 2.5

Advantages of WFIRST

•Top ranked in ASTRO 2010

•Broader band possible, e.g. 1.6-3.6μ

•No clouds

Disadvantages of WFIRST

• 3 year mission lifetime

• Earliest launch 2025

• Order of magnitude higher cost

•* but US NRO may provide free 2.5m mirror

•Smaller aperture, 1.5 metre*

•Lower resolution*

•200 nJy limit* vs 70 nJy with KDUST

Construction and operations schedule (best case scenario)

- January 2015 ARC LIEF funding, followed by Preliminary Design Review
- 2015 Texas A & M purchases Teledyne arrays; ANU purchases dewar and filters
- 2015 Integrate and test focal plane at ANU or AAO
- January 2015 Integrate telescope/ camera in Fremantle
- 2016-2020 operations (within the international antarctic science region) at Kunlun Station
- 2021 return of focal plane to USA

Mould *CTIO 50th anniversary* astro-ph 1306.1574

Prioritized science case

	Priority	Field	Competitor	Limit mag
Spatial variation of galaxy LF at z = 6	B	>>HDF	VLT	K = 25
Weak lensing cosmology parameters	A	15000	Euclid	
IMF from 0.1 to 0.01 solar masses	B	10 fields	VLT	
Pair Instability SN at z > 4	A	100	VLT	K = 26
Kuiper belt census and properties	C	20000	LSST/PS	
Cool white dwarfs and Milky Way formation	B	20 fields	VLT	K = 27.5
Planetary transits	?		Kepler	
Clusters of galaxies at z > 2	A	100	SPT	K = 26
Lyman alpha emitters at z > 9	?		VLT	
Formation of globular clusters at z > 6	C		JWST	
Formation of the first SMBH	C		JWST	
Y band dropouts at z = 10	B	100	VLT	K = 26

Speed ratio is D/sqrt(B) assuming no fov difference D is telescope diameter and B is backg
GPC = Gigapixel CCD camera
Theme is evolving universe, dark universe, transient universe, galactic
Anything VLT accessible is priority B but that should be reassessed if 100 sq deg is real
and note that none of the present KDUST collabo
Field is in sq deg except where stated otherwise We assume the KDUST IT camera has a
Volume refers to a one mag range in luminosity distance
The SDSS SN rate is 27000 Sne/yr/Gpc^3 Dilday et al 2010. Massive star Sne may be rarer than that b

Why not use an 8m? LCTS

- JWST: powerful, but small field with spectroscopy
- KDUST: 1μ < λ < 3μ, wide field, IR camera TBD
  - optical wavelengths, Gpix camera possible
- DECam: 1μ and shorter, wide field
- Las Campanas Transit Survey: wide field
- TMT: superior resolution
- SKA: redshifted neutral hydrogen

Transit Telescope

- Off axis mirrors 2 and 3 can be turned into transit telescopes
- mounted in a static mirror cell and pointed at zenith
- For f/2 GMT mirror prime focus camera can be positioned on 20 meter tower beside mirror, pointing at mirror center
- GMT mirror 2 soon available (#1 used in SOML test tower)
- If AAO built static mirror cell, and Carnegie transported mirror to Las Campanas Observatory, it could be set up beside Magellan
- Optics need rudimentary protection from bad weather.
- Storage charges in Tucson avoided.
- Note: corrective optics required (not designed yet)

Science goals

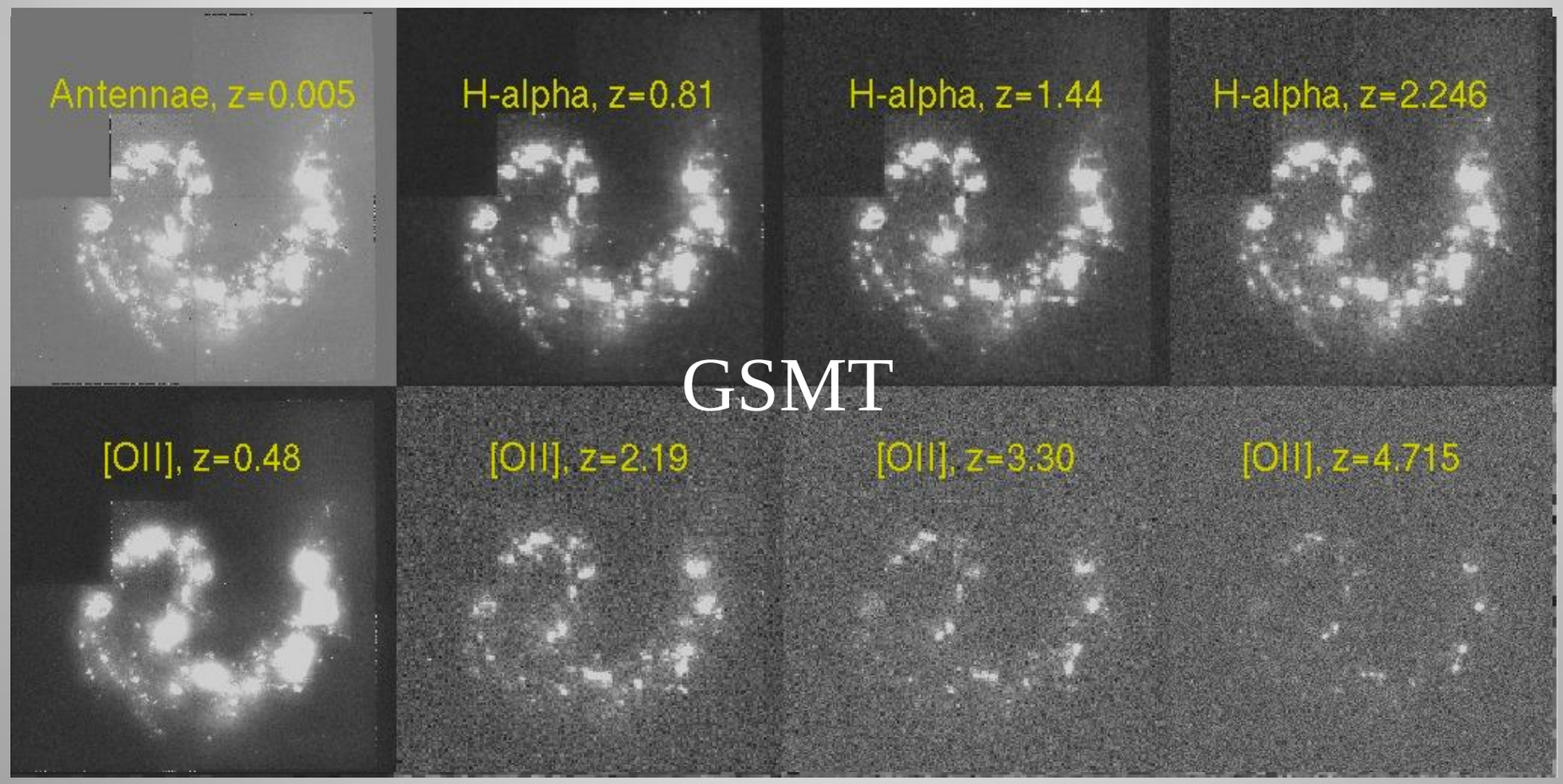
- Compare with Palomar Transient Factory for z=1 supernovae
  - with Hubble Deep Field for galaxy evolution.
- Reverberation mapping for any AGN in the field
- Microlensing of galactic bulge stars by brown dwarfs to determine brown dwarf mass function
- During stellar microlensing events trigger exoplanet microlensing alerts to tracking telescopes
  - see Figures 6 & 7 of Green et al astro-ph 1208.4012
- Weak lensing using advantageous off-axis static PSF
  - and LCO half arcsec natural seeing
  - WFIRST also selected unobstructed aperture

Three stage process

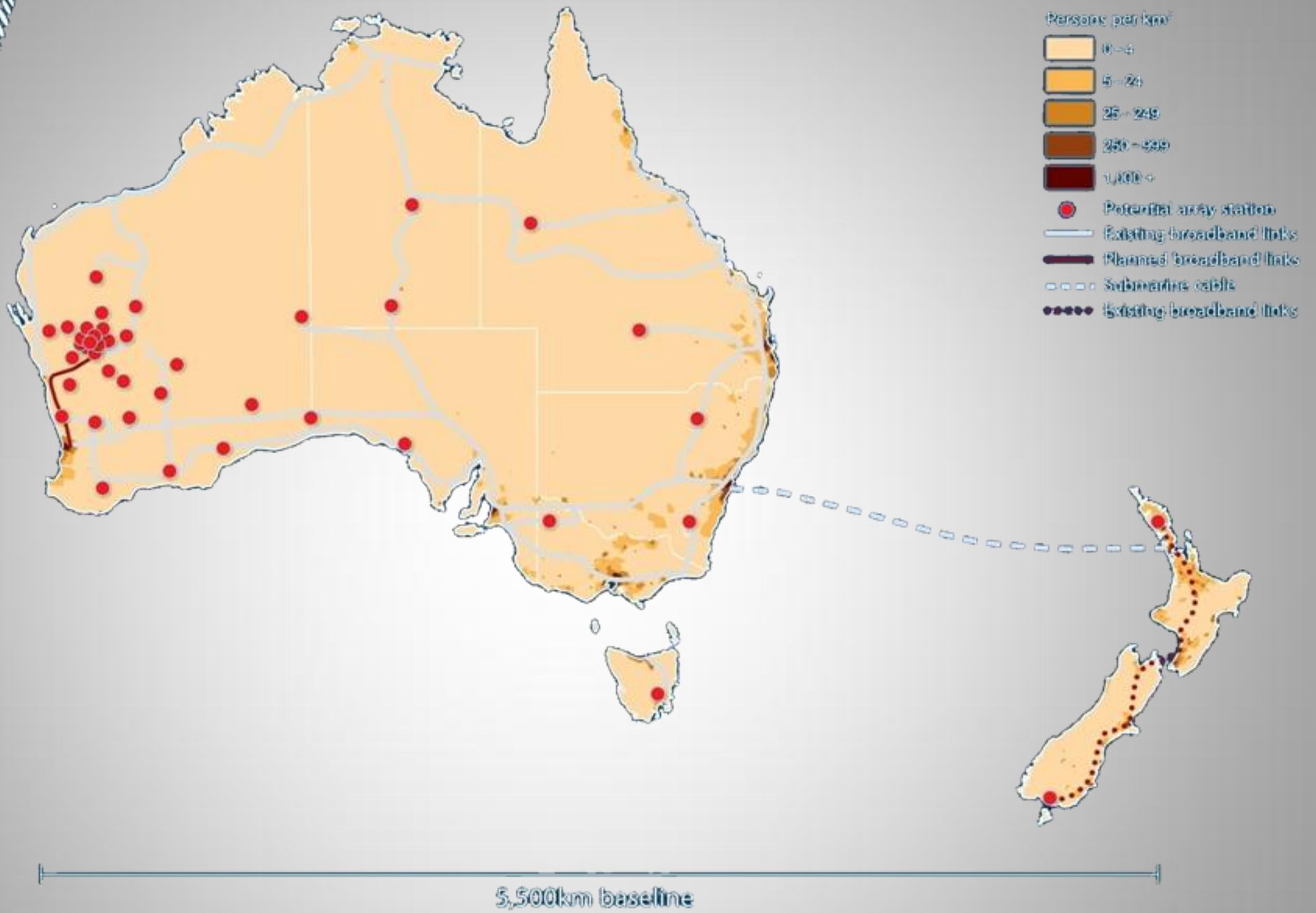
- Stage 1: r band survey of 4096x0.3" meridian strip at LCO latitude using n chips
  Field of view 360 x 1/3 sq deg
- Daily limiting mag r=24.5
- Stage 2: Y band survey using 2nd mirror & camera.
- Science goals: opening up photometric redshifts in LCTS field
- Stage 3: H band survey using 3rd mirror & camera
- transit paced readout not available with HgCdTe,
- mount focal plane on a spring-back driven stage, enabling integration time >> readout time
- annual limiting mag: H = 23.6

TMT vs JWST

Simulated monochromatic images of the ‘Antennae’
(local starburst galaxy: 10^5 seconds integration time)
Courtesy: Elizabeth Barton, GSMT SWG



anzska
Square Kilometre Array - Australia - New Zealand



Array antenna locations as of December 2009

What if the EoR looks nothing like this?

- Exactly what was happening in the dark sector during the dark ages ?

- Dark stars? Self Interacting Dark Matter?

- Which astronomy Nobel prizes were given for physics triumphs?

  - and which one was given for a physics disaster?

- Is there another one on the horizon for the EoR?

Acknowledgement

- DECam was paid for by the US DoE
- Our DECam time to date was allocated by the Australian Time Allocation Committee
- There is a time exchange agreement between NOAO/CTIO and AAO which makes this possible

- AAO facilities are now reciprocally available to the NOAO user community and appear in the NOAO Newsletter in full detail
- Especially in demand is the AAOmega MultiObject Spectrograph

Thank you, Kate & Kim