Time Domain Survey from Antarctica – from Optical to Near Infrared

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&
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On behalf of the Dome A Collaboration

Aug 9, 2015, Kilawaee Military Camp, Hawaii

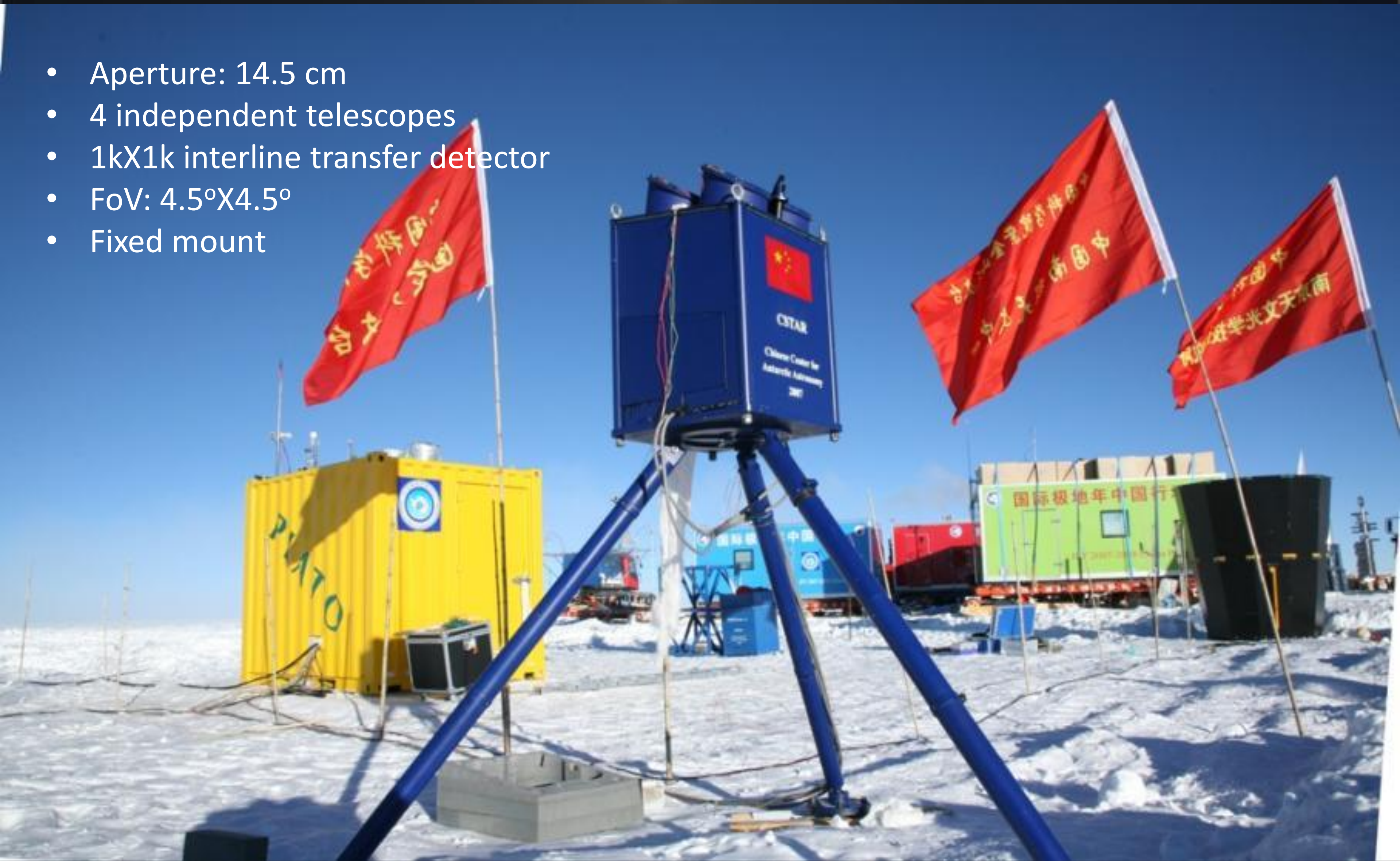
Dome A in 2008

China/Australia/USA

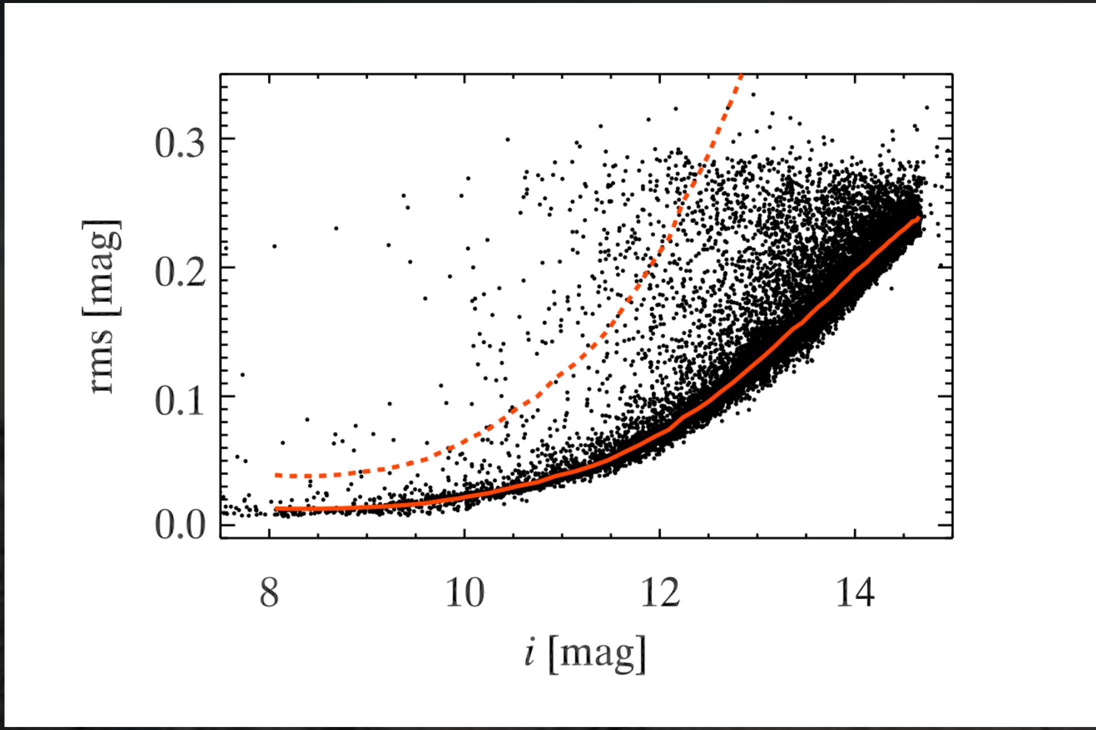
Kunlun Station
Jan 27, 2009

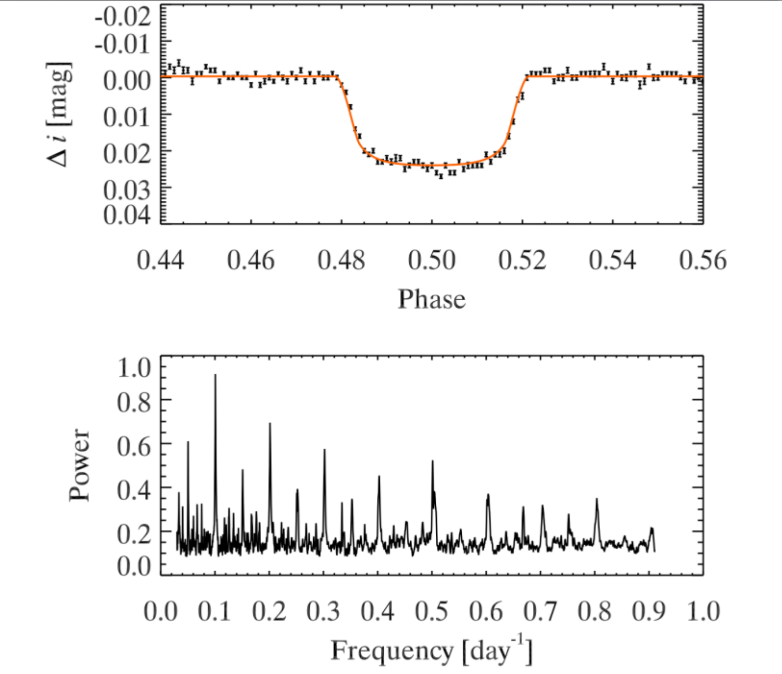
CSTAR: 2008—2011

- Aperture: 14.5 cm
- 4 independent telescopes
- 1kX1k interline transfer detector
- FoV: $4.5^{o}X4.5^{o}$
- Fixed mount



CSTAR - Photometric quality of the CSTAR 2008 data set

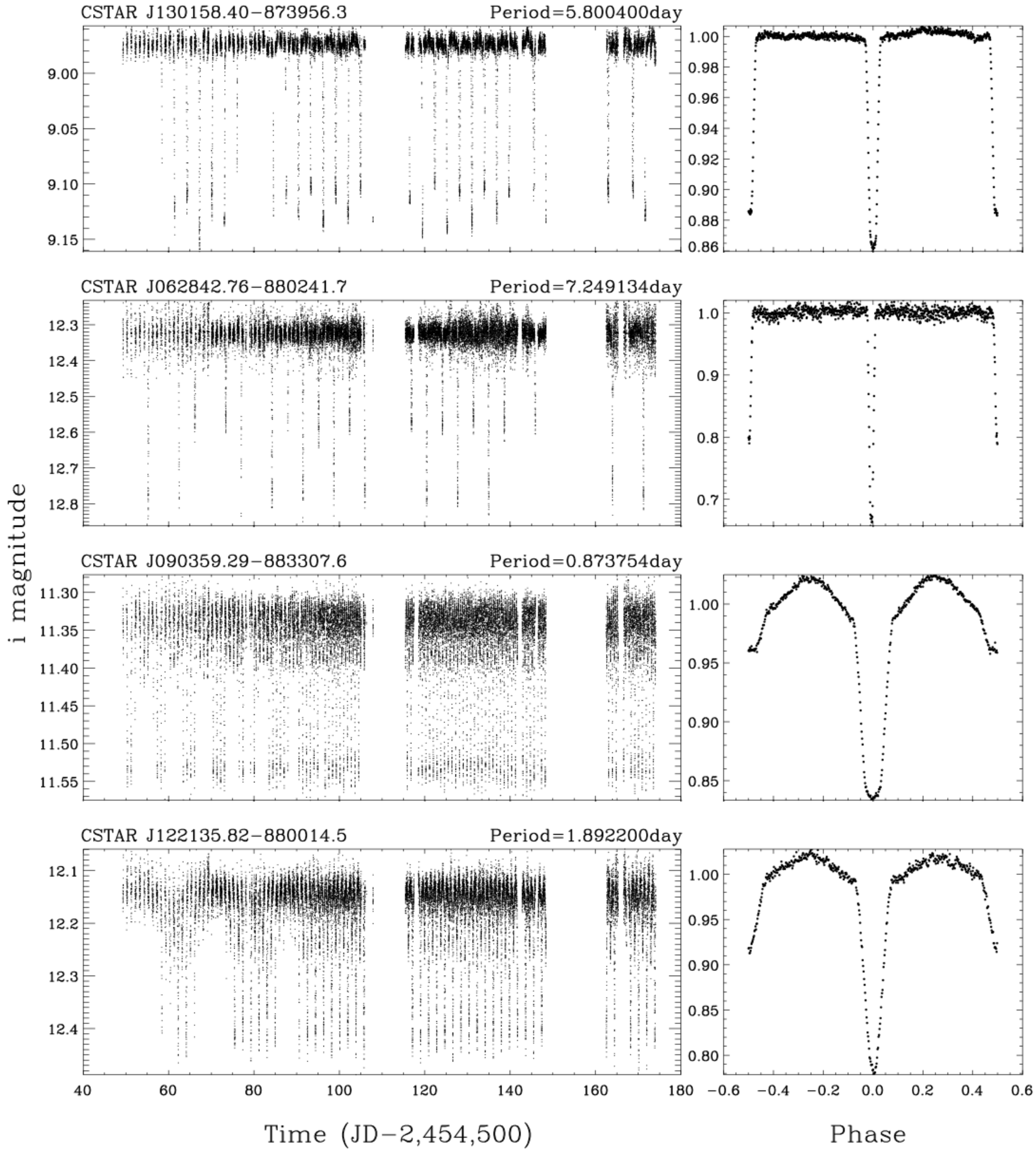




The standard deviation (20 second or 30 second sampling; 158 day time scale) of each CSTAR light curve is plotted as a fuction of their median i-magnitudes. The solid orange line represents the trend of this distribution. Objects above 3 sigma threshold (the dashed orange line) are tagged as variable

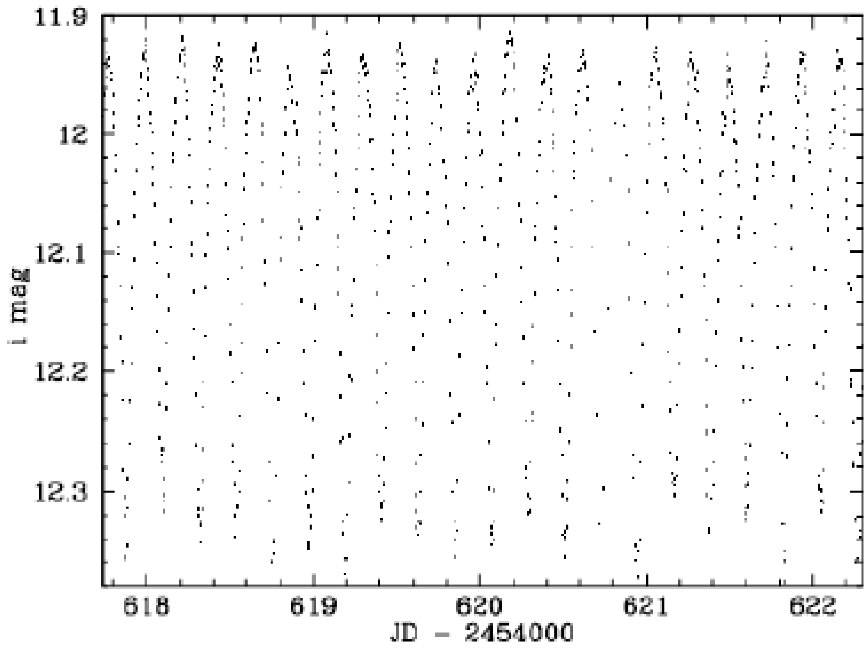
Wang, Songhu, et al. 2015

CSTAR – Light curves of a 4 binary stars

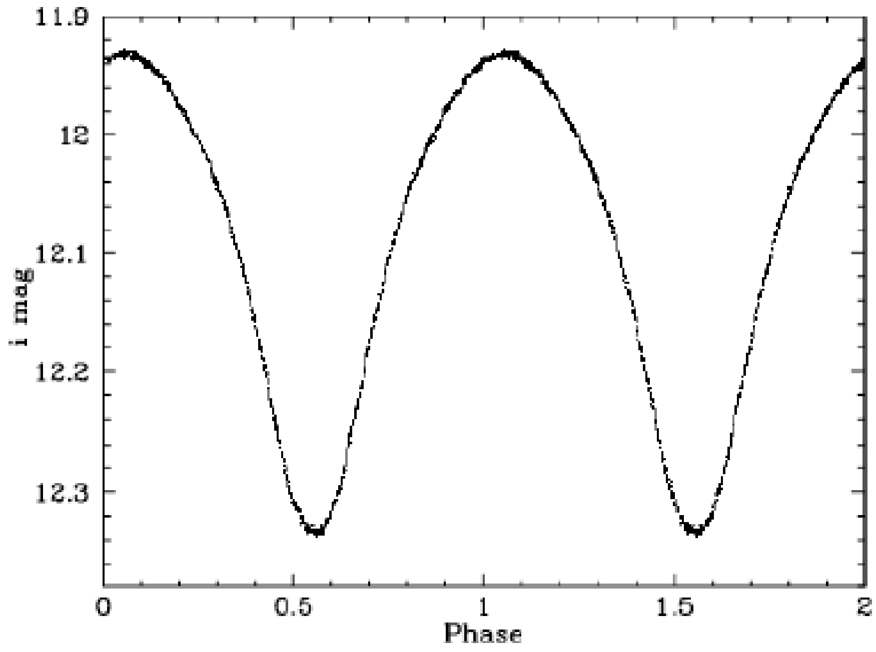


Yang, M. et al., 2015

δ Scuti star



Uninterrupted 4.5-d light curve (representing 3.5% of the entire data).



Folded light curve using P = 0.2193d; the photometric uncertainty is 1.5 mmag/bin.

Lingzhi Wang, Lucas Macri et al. 2011

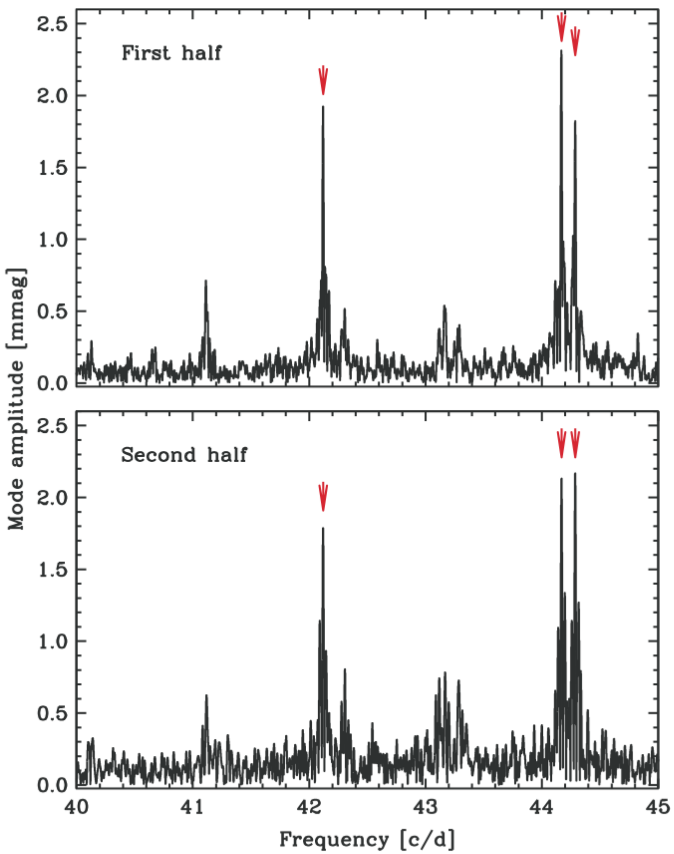


FIG. 9.— Fourier spectrum of CSTAR #n090586 derived using the Period04 program, based on data obtained during the first (top) and second (bottom) half of the 2010 season. Three significant peaks (at f_i = 44.288, 44.169, and 42.121 cycles d^{-1}) are detected with varying amplitudes, which exhibit significant changes (4−11σ) relative to the 2008 season. See text for details.

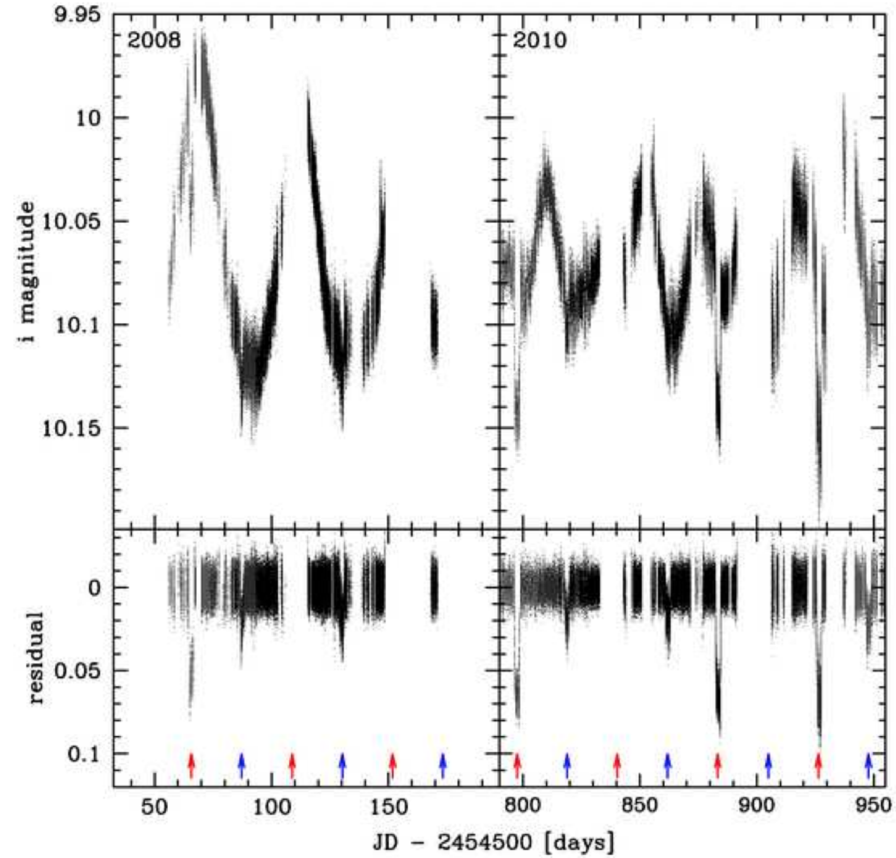
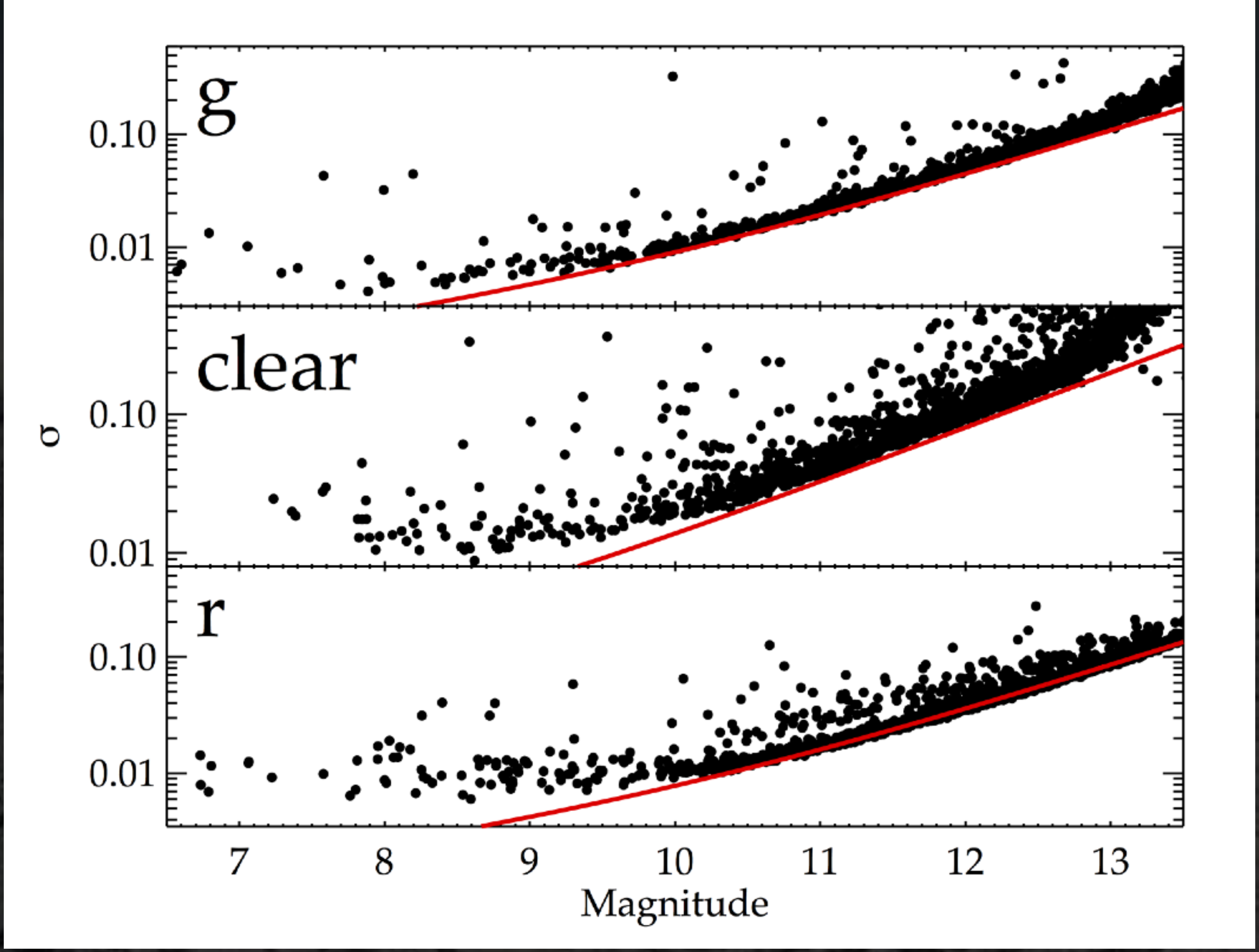


FIG. 10.— Light curve of CSTAR#n057725, showing the slow reduction in Cepheid-like pulsation amplitude during the 2008 season has been replaced by a more complex variability in 2010. Eclipse-like events seem to be present at two distinct phases indicated with red and blue arrows, respectively.

CSTAR in g, clear, and r



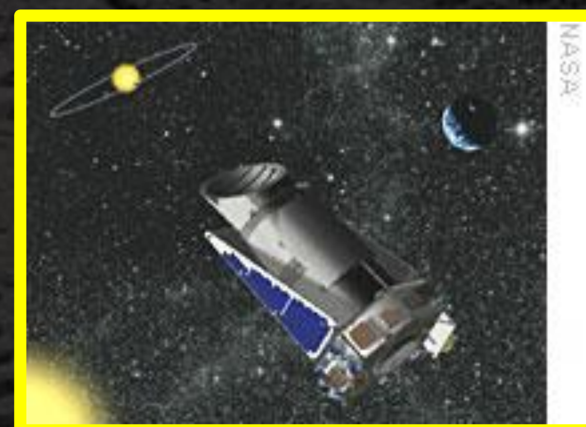
Scintillation floor is ~ 1.2 mmag

Oelkers, R. et al. 2015

Time Domain

Small Telescopes Covering Wide Areas to Monitor Bright Stars in the Northern Hemisphere

1. Continuous Monitoring of
   – CSTAR – 14.5 cm, for Stars brighter than 12th mag
   – AST3, ASTEP – 40-50cm for stars brighter than 16th mag
2. Daily monitoring and follow up of
   – SNe
   – GRBs, Orphan GRBs
   – AGN



Time Domain

Small Telescopes Covering Wide Areas to Monitor Bright Stars in the Northern Hemisphere

- Related Sciences

  ExoPlanet Transit/Microlensing

  Stellar Structure

  SN Discoveries/Observations - > Cosmology

  AGNs/Black Holes

  GRBs/Orphan GRBs

  …

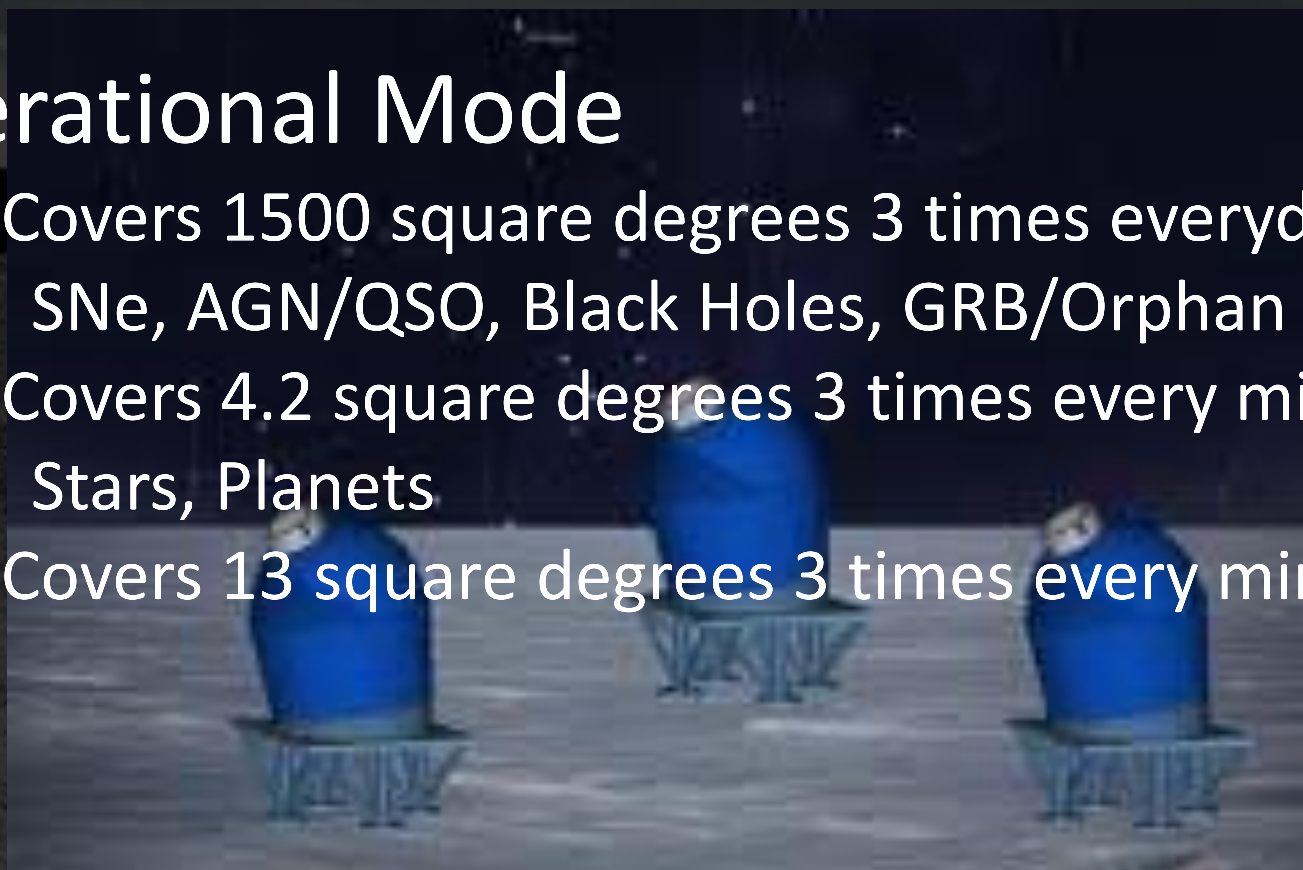
Antarctic Survey Telescopes (AST3)

An Array of three 50cm Diameter

Supernovae and Exoplanets

Operational Mode

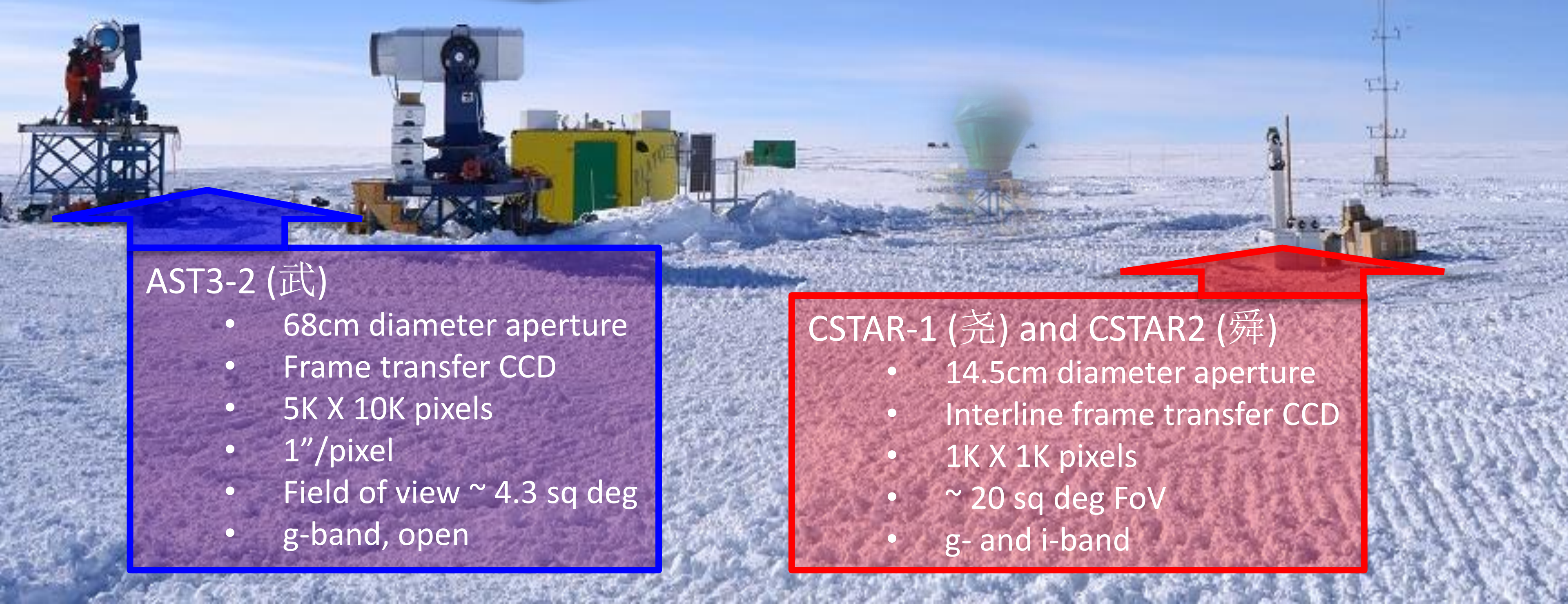
- Covers 1500 square degrees 3 times everyday
  SNe, AGN/QSO, Black Holes, GRB/Orphan GRB …
- Covers 4.2 square degrees 3 times every minute
  Stars, Planets
- Covers 13 square degrees 3 times every minute



The Antarctica Survey Telescopes (AST3)

AST3-1 (文)
- 68cm diameter aperture
- Frame transfer CCD
- 5K X 10K pixels
- 1”/pixel
- Field of view ~ 4.3 sq deg
- i-band

AST3-3 (成), not yet installed
- 68cm diameter aperture
- H2RG
- 2K X 2K pixels
- ~2”/pixel
- Field of view ~ 1.2 sq deg
- K-band



AST3-2 (武)
- 68cm diameter aperture
- Frame transfer CCD
- 5K X 10K pixels
- 1”/pixel
- Field of view ~ 4.3 sq deg
- g-band, open

CSTAR-1 (尧) and CSTAR2 (舜)
- 14.5cm diameter aperture
- Interline frame transfer CCD
- 1K X 1K pixels
- ~ 20 sq deg FoV
- g- and i-band

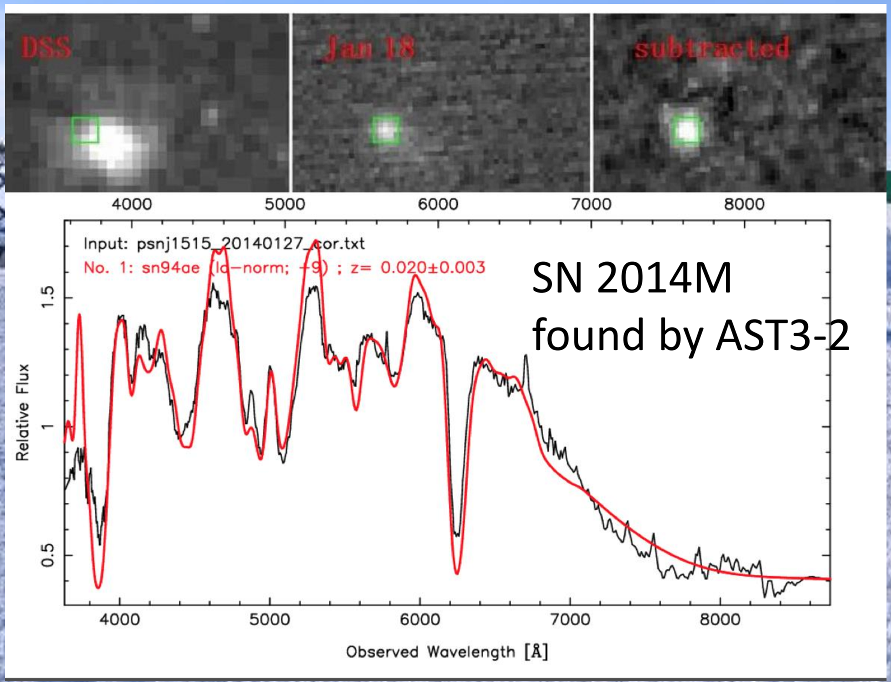
The Antarctica Survey Telescopes (AST3)

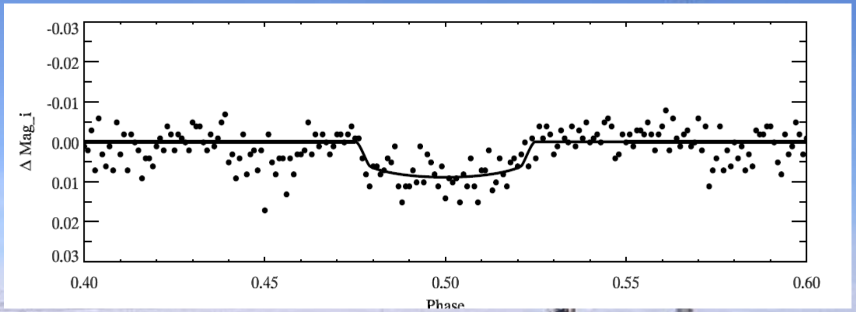
Science Mode I

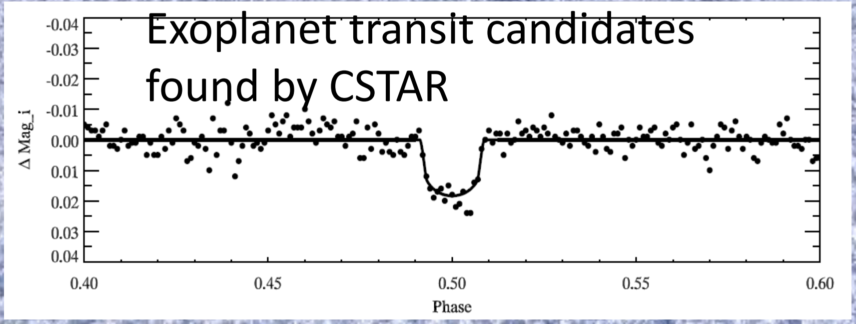
1. **Survey operation**
   - Rolling survey of ~ 1000 sq deg with cadence 0.25 - 0.5 days
   - Rolling survey of ~ 1000 sq deg with cadence of 5 days.
2. **Scientific objectives**
   - Supernovae within a day after explosion
   - Precision photometry of a wide area

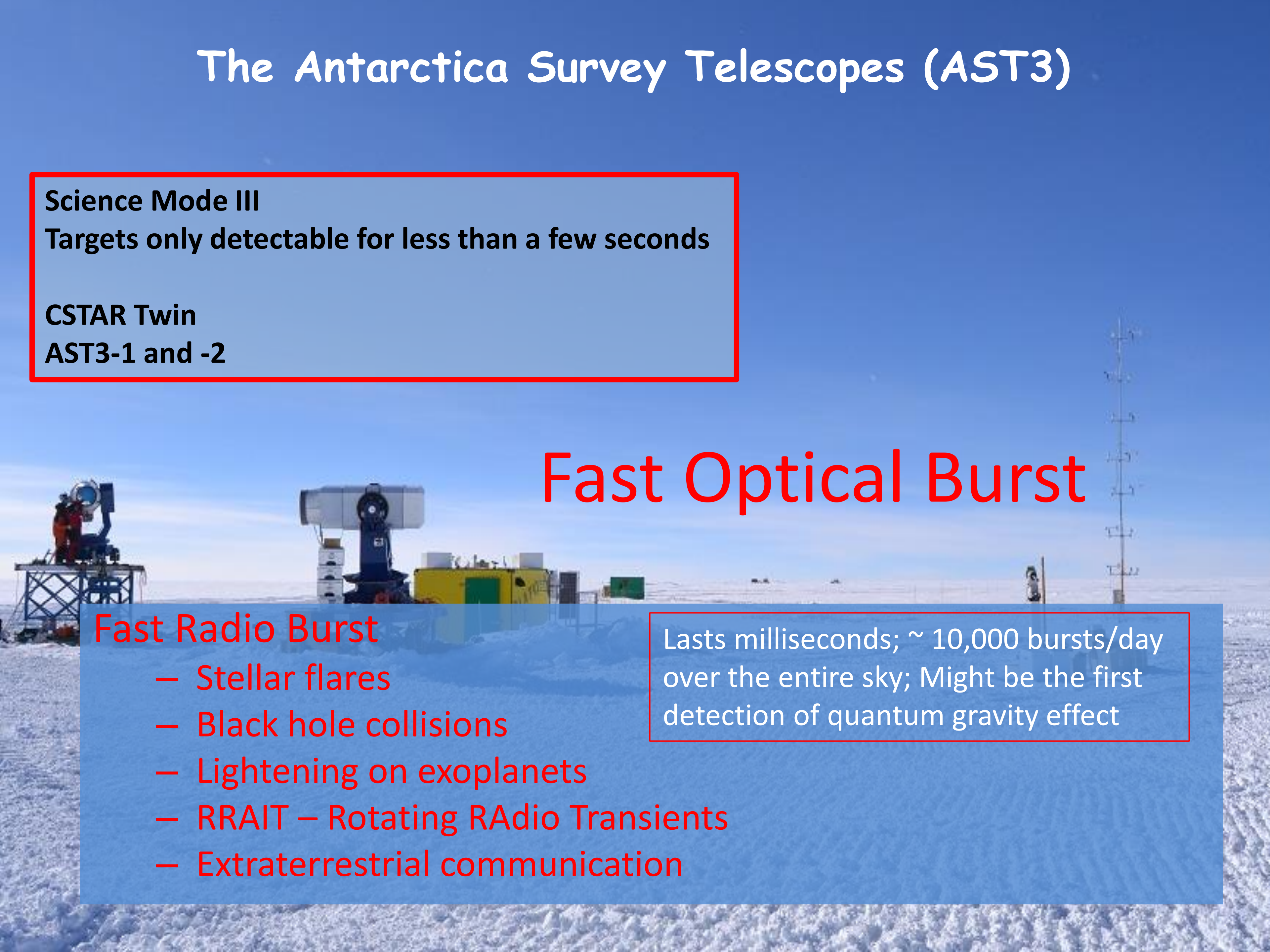
Science Mode II

1. **Survey operation**
   - Rolling survey of ~ 20 sq deg on the galactic plane, cadence 10 sec – 60 sec
2. **Scientific objectives**
   - Exoplanets, asteroseismology









The Antarctica Survey Telescopes (AST3)

Science Mode III
Targets only detectable for less than a few seconds

CSTAR Twin
AST3-1 and -2

Fast Optical Burst

Fast Radio Burst
- Stellar flares
- Black hole collisions
- Lightening on exoplanets
- RRAIT – Rotating RAdio Transients
- Extraterrestrial communication

Lasts milliseconds; ~ 10,000 bursts/day over the entire sky; Might be the first detection of quantum gravity effect

Dome A in 2008

China/Australia/USA

Dome A in 2015

AST3 Status

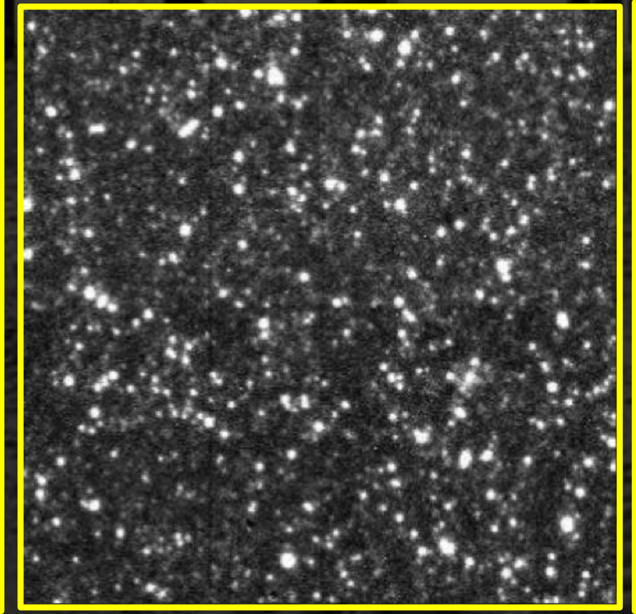
- Commissioning started at 1 am, March 15, 2012
- Total observing time 746 hours till May 8, 2012
- 20% of the time used for engineering, most of which during the March period
- Only three nights lost due to reasons possibly related to bad weather
- Collected 28,535 images, about 3.3TB data till May 8, 2012

AST3 Status

- Installation of AST3-2 in 2014-1015 traverse
- Resumption of Science Operation starting from April 15, 2014

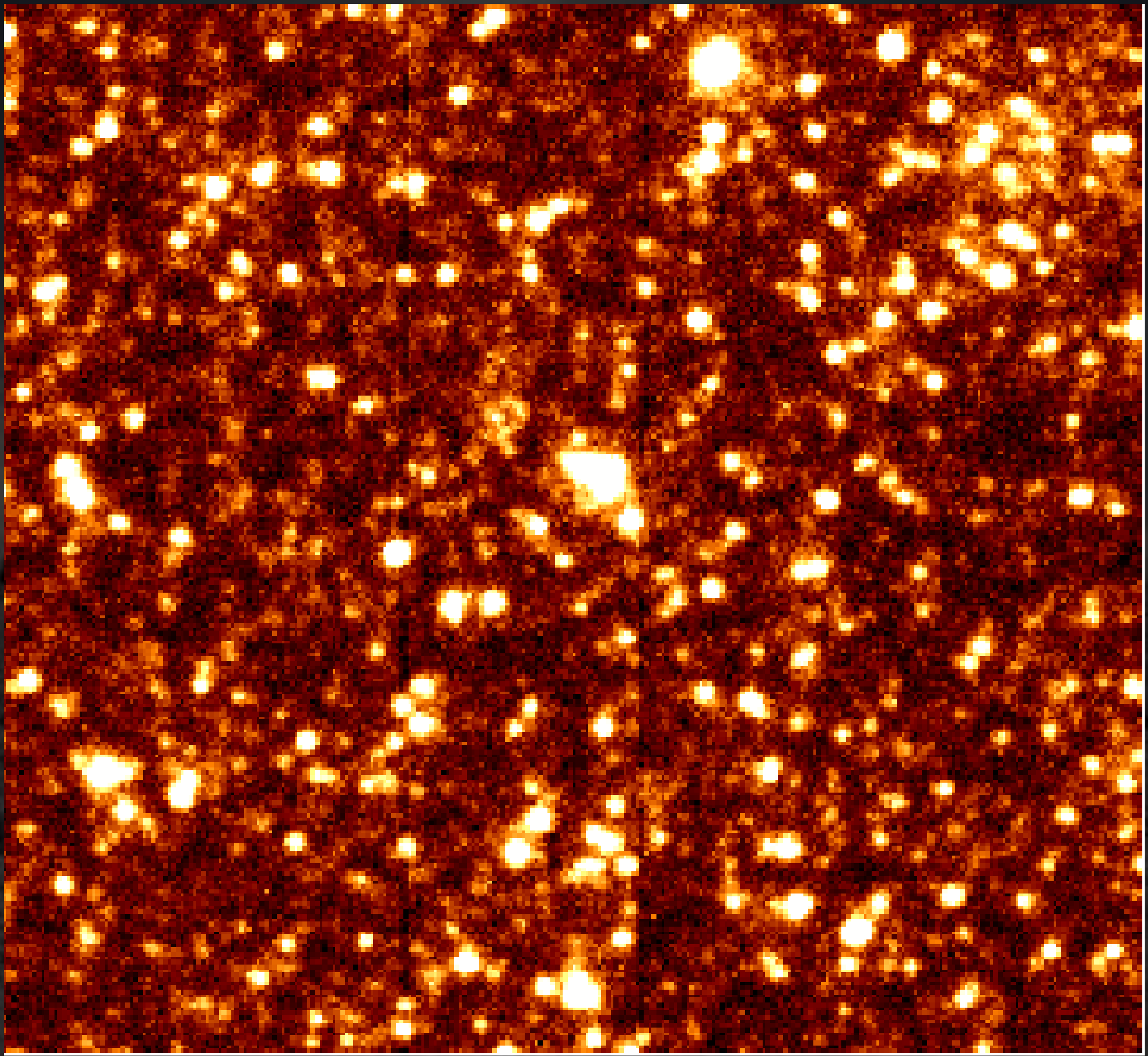
- Construction of AST3-3, optimized for optical and K-band started already
- Ast3-3 installation in Antarctica in 2017-1018 traverse

Diagnostic Images transmitted back through Iridium Openport



Preliminary Performance

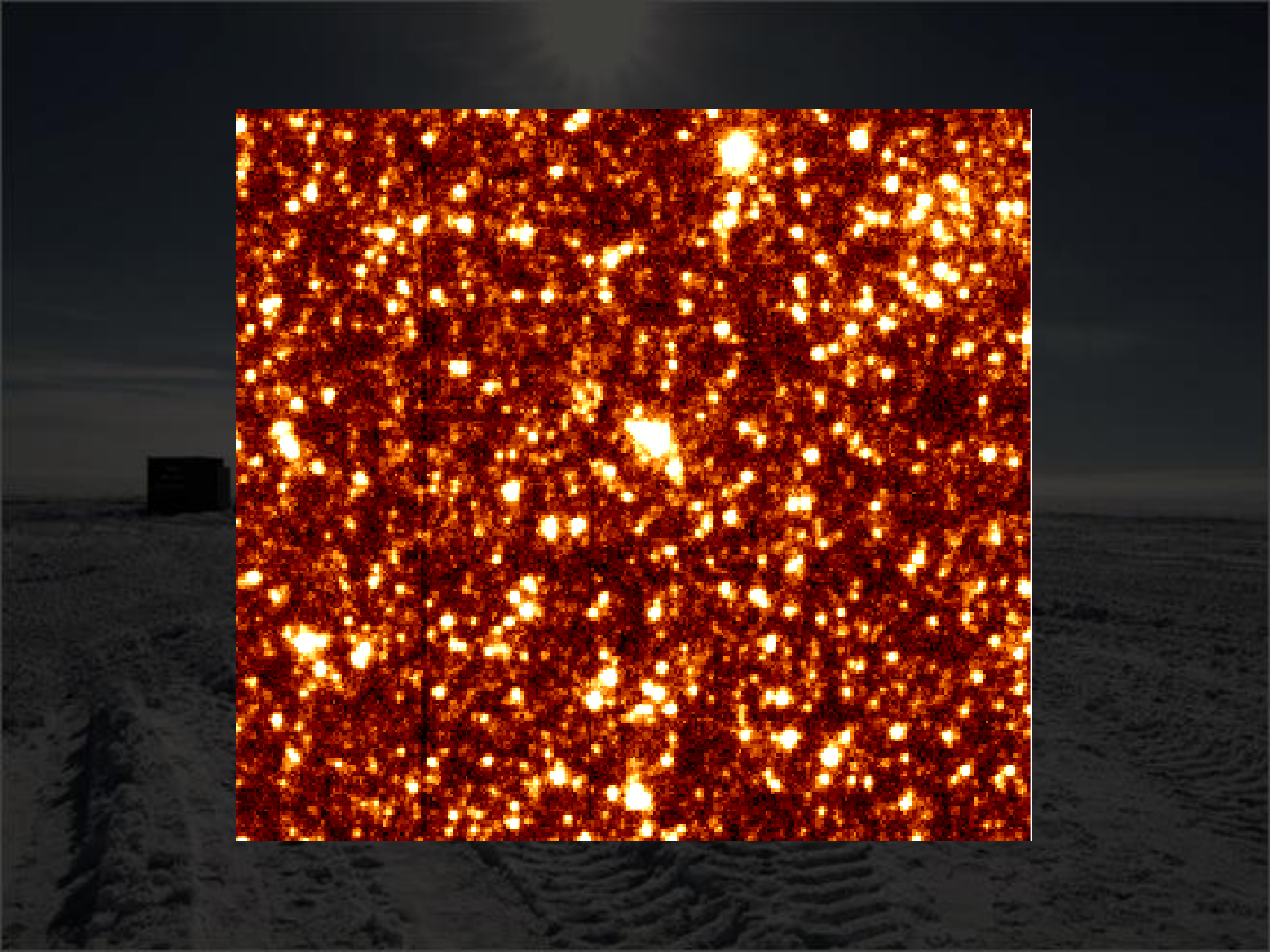
- Sensitivity: i=19.5 (3 sigma) in 1 minute
- Image quality ~ FWHM~2".0 (1"/pix, resolution limited by optics)
- Lowest relative photometric precision achieved so far ~ 0.2mmag
- Seeing estimated from image centroid motion at high speed (~kHz) readout ~ 0.2-1.5 arcsec
- no obvious clouds except for two nights

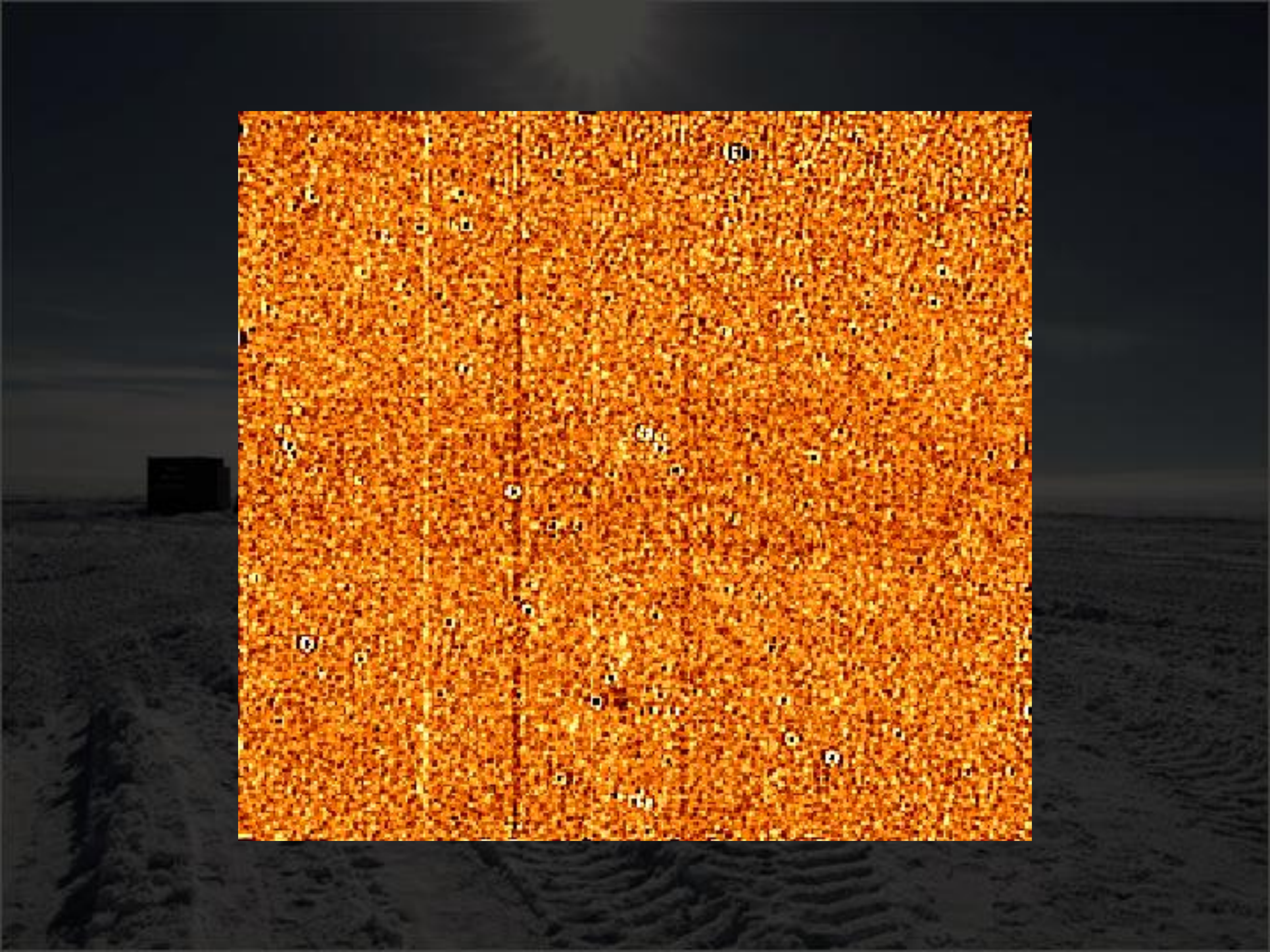


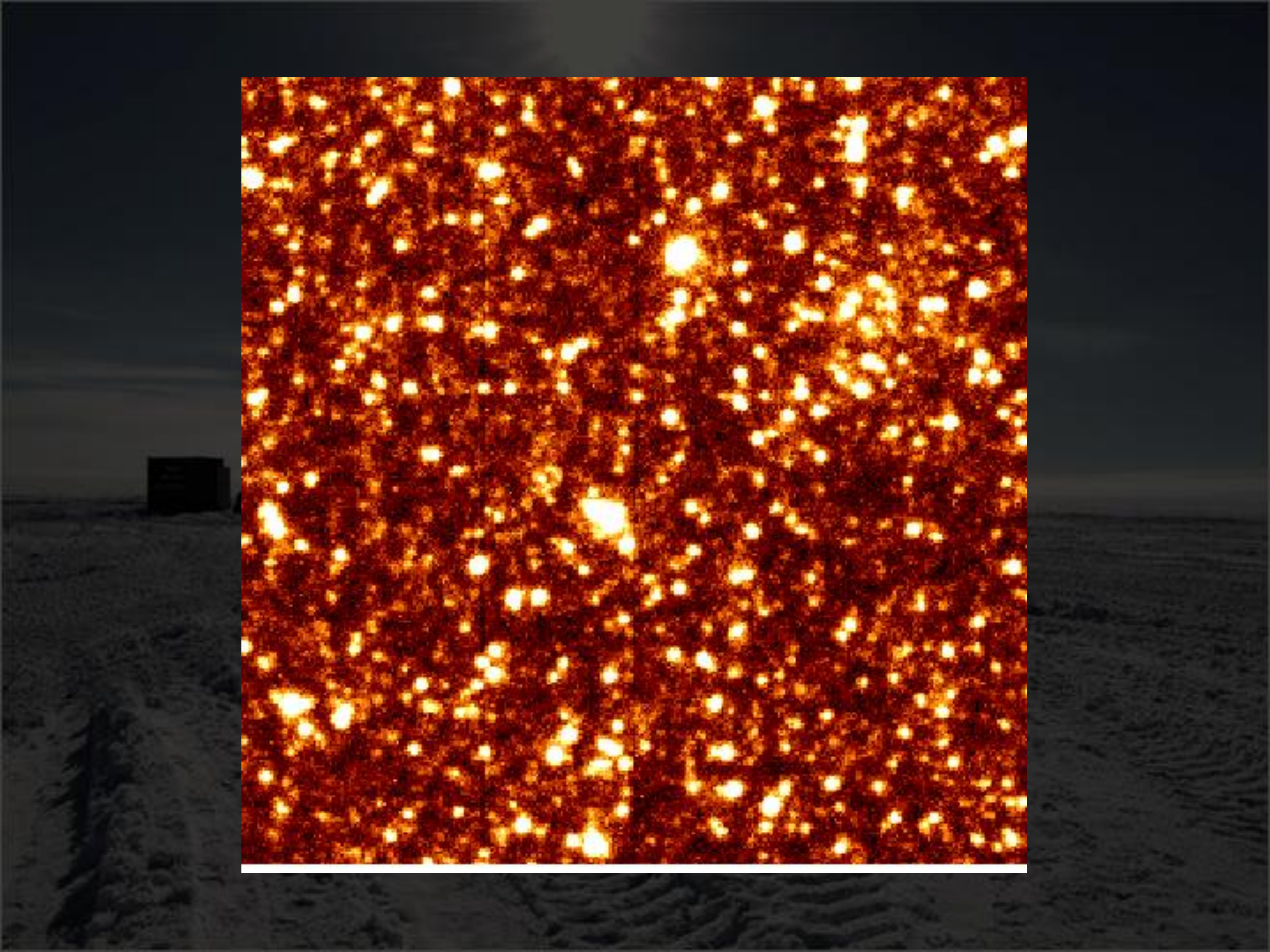
May 6

500-351

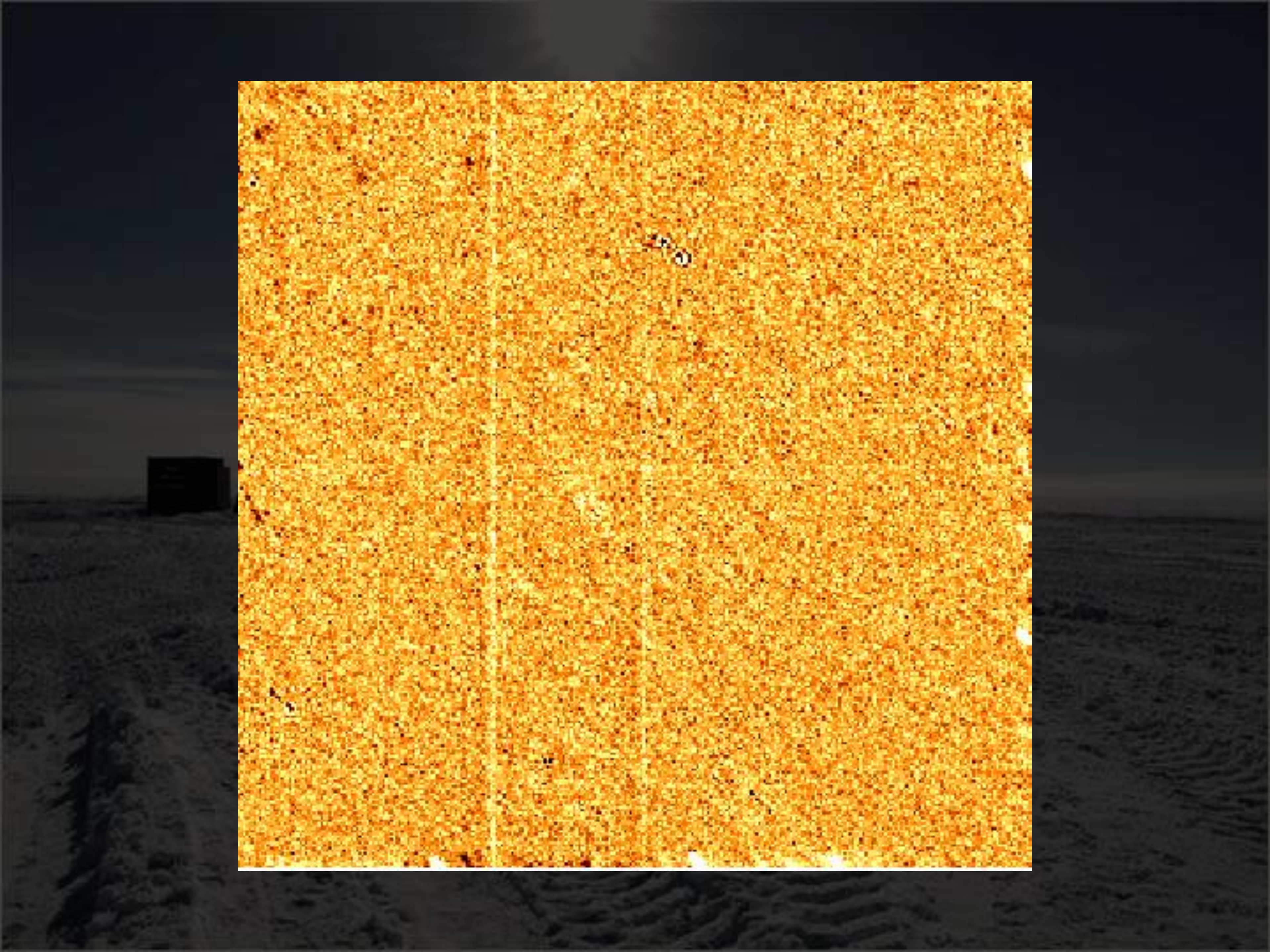
Bad Columns








Oscillation?



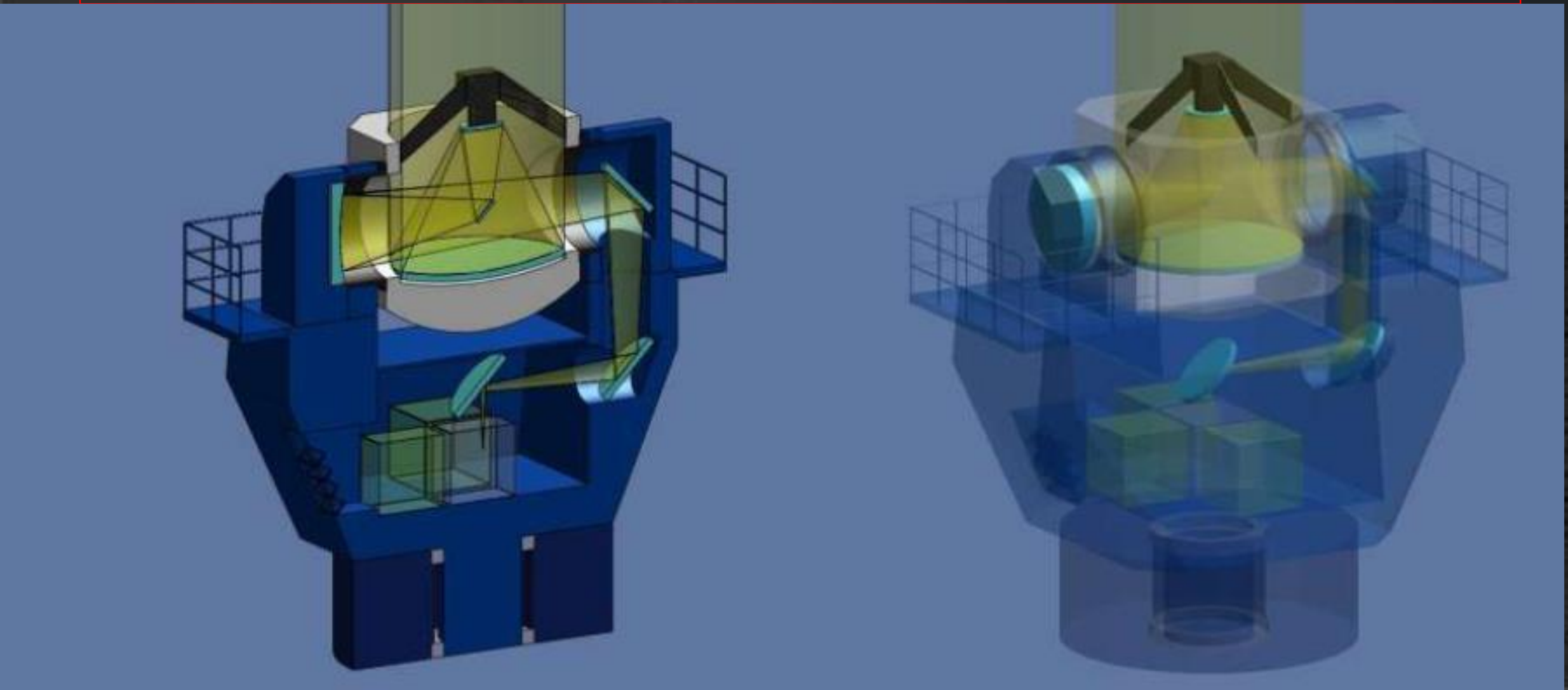
Sample Science for KISS Kunlun Infrared Sky Survey

from the ARC LIEF proposal

- Supernovae & the Equation of State
- Reverberation Mapping and the Physics of AGN
- Gamma Ray Bursters (super-supernovae)
- Cosmic Near-Infrared Background
- Terminal phases of Red Giants (Miras)
- Dynamics and Variability in Star Formation
- Discovery of Exo-Planets (esp. Brown Dwarfs & Hot Jupiters)

Kunlun Dark Universe Survey Telescopes (KDUST)

1. 2.5 meter aperture
2. ~0.12 arcsec pixel
3. 40K X 40K = 1.6G pixels



Sharper Images

Intermediate Size Telescopes Covering Wide Areas for Cosmological Surveys

Typical Size of the most distant galaxies ~ 0.5 arcsec

Seeing limited Surveys at Dome A

1. Weak lensing, BAO
2. Deep Universe, but not so deep w/o NIR
3. Supernova Surveys
4. Exoplanets, Stars, …

Sharper and Redder Images

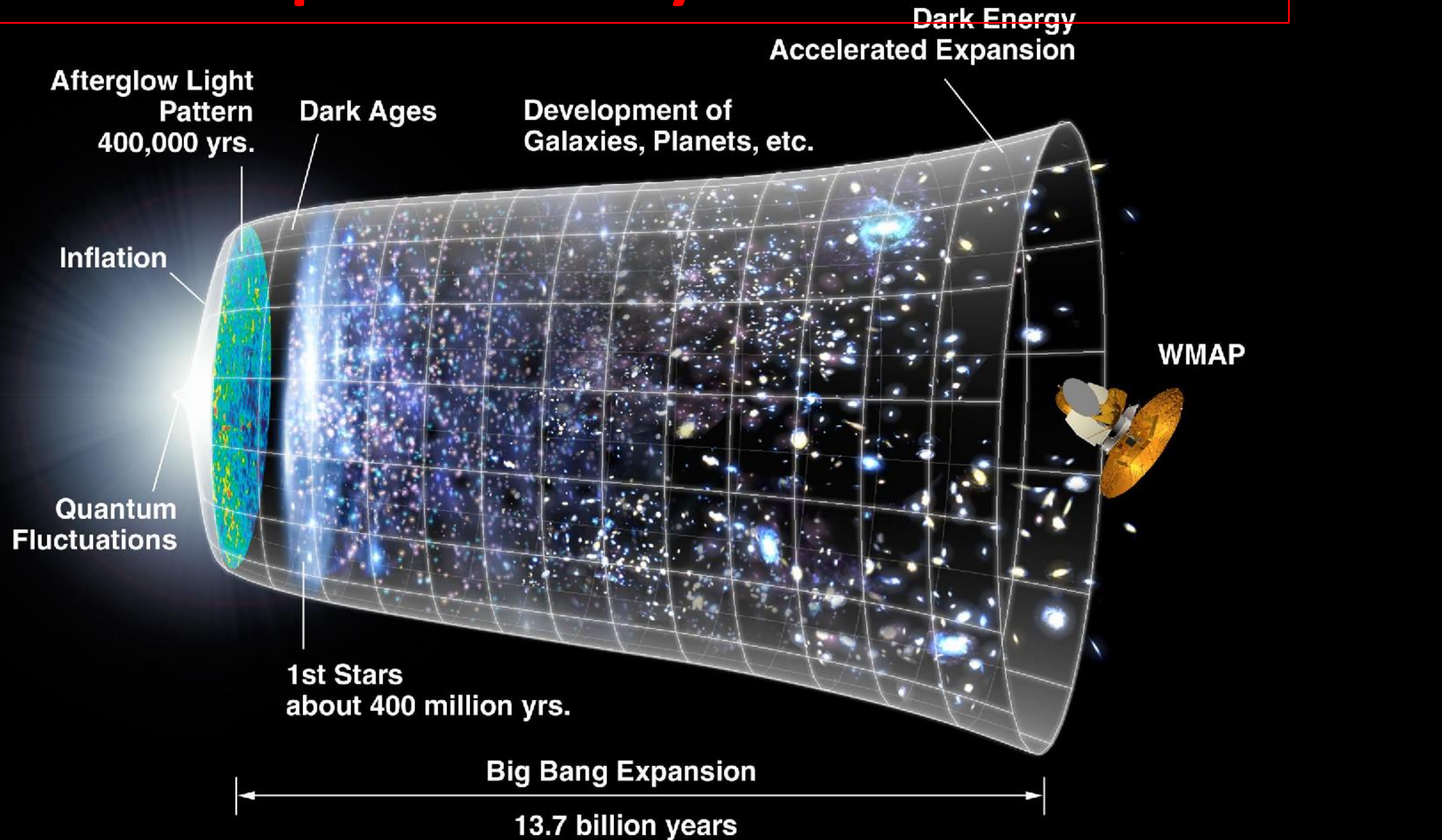
Intermediate Size Telescopes Covering Wide Areas for Cosmological Surveys

Typical Size of the most distant galaxies ~ 0.5 arcsec

Seeing limited Surveys at Dome A in the NIR

1. Weak lensing, BAO
2. Deep Universe, approaching the epoch of re-ionization
3. Supernova Surveys, look for the first stars
4. Exoplanets, Stars, find an earth parallel

zTEA: z Equals Twenty from Antarctica



1. When and How did the universe made its first stars?
2. When and how did the universe made its chemical elements that are capable of producing life in the universe?
3. How did the universe made planets like the earth?

What are there?

- Olbers' paradox
- Jim Peebles: In a Big Bang-created Universe there must have been a cosmic infrared background (CIB) – different from the cosmic microwave background – that can account for the formation and evolution of stars and galaxies
- Supernovae
- QSOs and ULIRGS

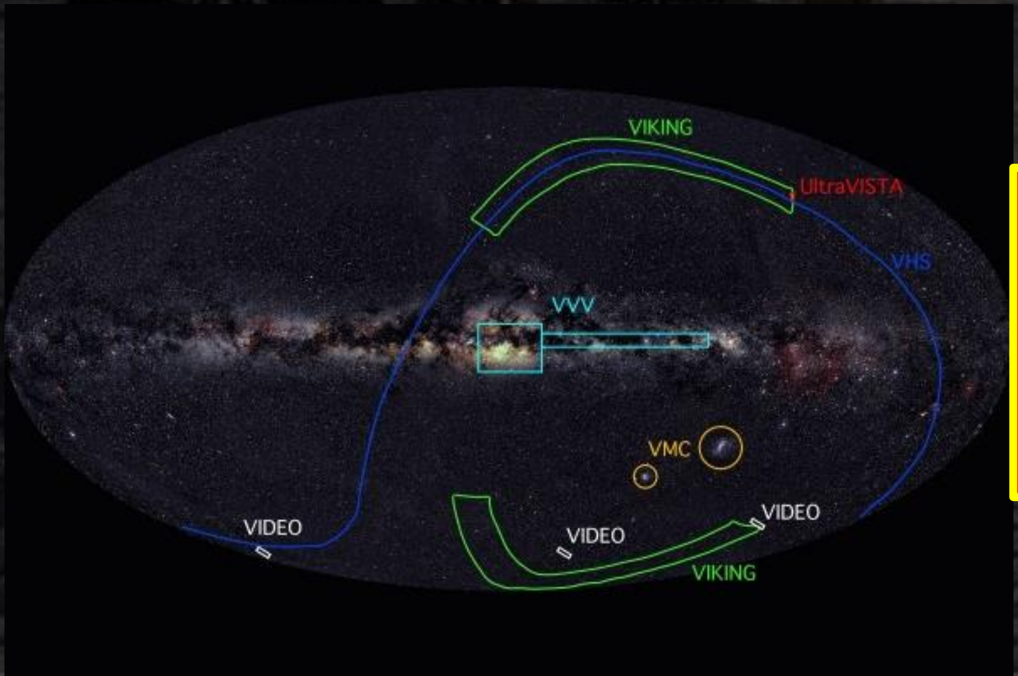
KDUST Sensitivity

Table 1: The expected resolution and sensitivity for KDUST2.5 in a number of wavebands

Band	λ (μm)	R $\lambda/\Delta\lambda$	FWHM (arcsec)	m_{AB}	m_{Vega}	m_{AB} arcsec^{-2}	m_{Vega} arcsec^{-2}
g	0.47	3.4	0.35	27.6	27.6	27.1	27.1
r	0.62	4.4	0.33	27.1	26.9	26.5	26.3
i	0.76	5.1	0.32	26.6	26.2	26.0	25.6
z	0.91	6.5	0.31	25.8	25.3	25.1	24.6
Y	1.04	5.1	0.30	25.3	24.7	24.6	24.0
J	1.21	4.6	0.30	25.0	24.1	24.3	23.4
H	1.65	5.7	0.29	24.4	23.0	23.6	22.2
K_d	2.40c	10	0.32	25.3	23.3	24.7	22.7
L	3.76	5.8	0.40	21.2	18.3	20.8	17.9
M	4.66	19	0.46	19.6	16.2	19.4	16.0
N'	11.5	11	1.05	16.3	11.2	17.0	11.9
Q_N	20.1	20	1.80	14.6	8.1	15.8	9.3

VISTA survey observing strategies

Survey	Area (deg^2)	Filters and Depth Measure (mag (10σ, AB))	Depth (mag)
Ultra-VISTA	0.73 (ultra-deep)	5σ, AB	Y=26.7 J=26.6 H=26.1 K_s=25.6 NB=26.0
VIKING	1500	5σ, AB	Z=23.1 Y=22.3 J=22.1 H=21.5 K_s=21.2
VMC	184	10σ, Vega	Y=21.9 J=21.4 Ks=20.3
VVV	520	5σ, Vega	Z=21.9 Y=21.2 J=20.2 H=18.2 K_s=18.1
VHS	20 000	5σ, AB	Y=21.2 J=21.2 H=20.6 Ks=20.0
VIDEO	12	5σ, AB	Z=25.7 Y=24.6 J=24.5 H=24.0 K_s=23.5



KDUST:

25.3 mag in 1 hour

zETA Science Objectives Are Achievable with KDUST Telescope

Three NIR survey data products:

1. Time domain survey to K = $25^{th}.3$ mag, 3-4 times a day over a total of 3-4 deg^2 field
2. 1000 deg^2/year to K = $25^{th}.3$ mag
3. Stacked deep field of 3-4 deg^2 to K = 29^{th} mag

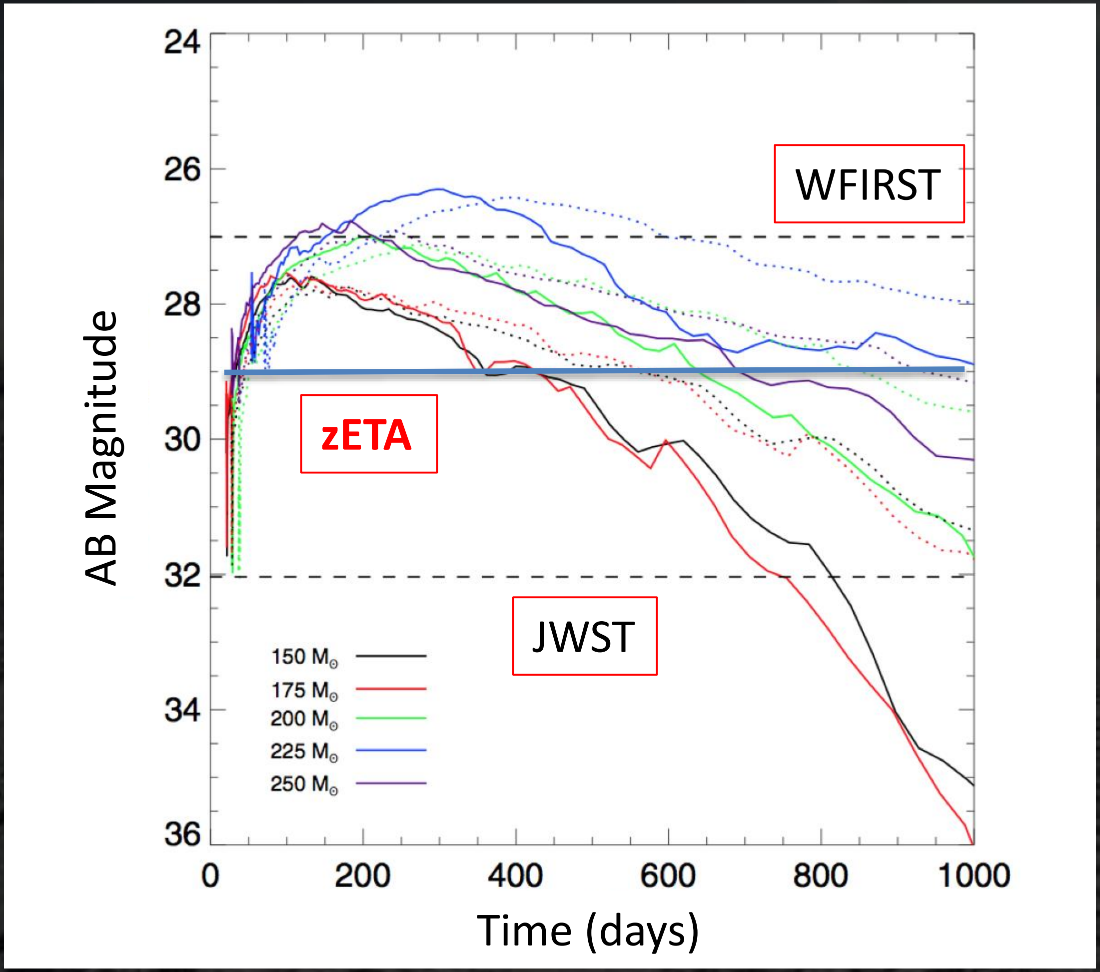
- The total amount of astronomically dark time at Dome A is 2606 hours/year (Zou et al. 2010)
- Each year about 1380 hours will be devoted to time domain survey
- Each year about 1000 hours will be devoted to wide area survey

zETA with KDUST

- The KDUST K-band survey will produce
  - 3-4 sq deg deep fields to K = 29, intensive time-domain coverage (3-4 times a day!!!). ~ 1 PISNe/year.
  - 1000 sq deg to about 25.3 mag

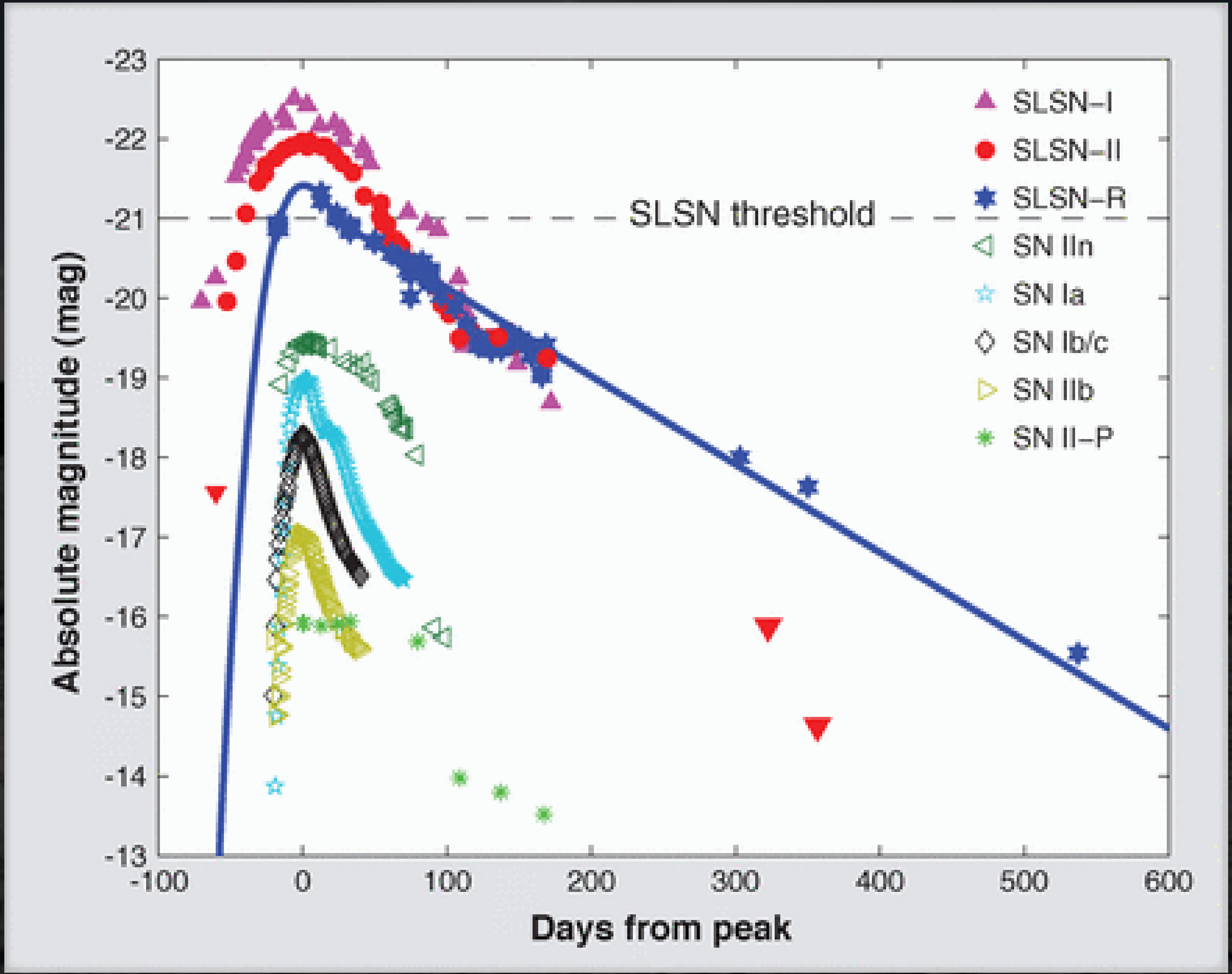
- For comparison, the Ultra-VISTA survey is 5σ to a depth of 25.6 mag (AB) over a field of view of 0.73 deg^2.

Observations

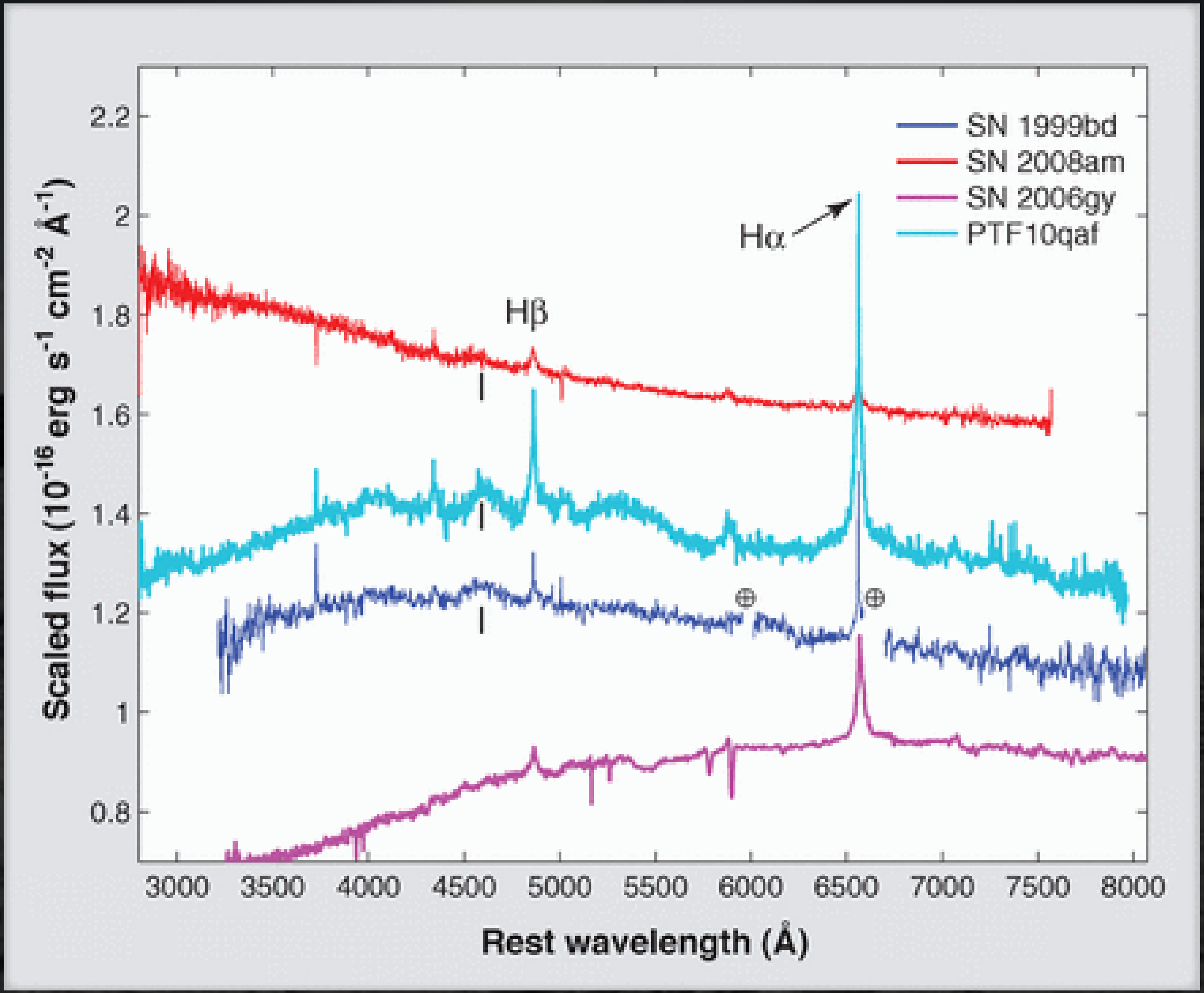


NIR light curves for five Pop III SNe at 2.0 μm at z = 15 (solid) and z = 20 (dotted). The horizontal lines are the detection limit for WFIRST (27 mag, AB) and JWST (32 mag, AB).The limiting magnitude of the zETA deep field is 29 mag (AB). (From Whalen et al. 2013, ApJ, 762, 6).

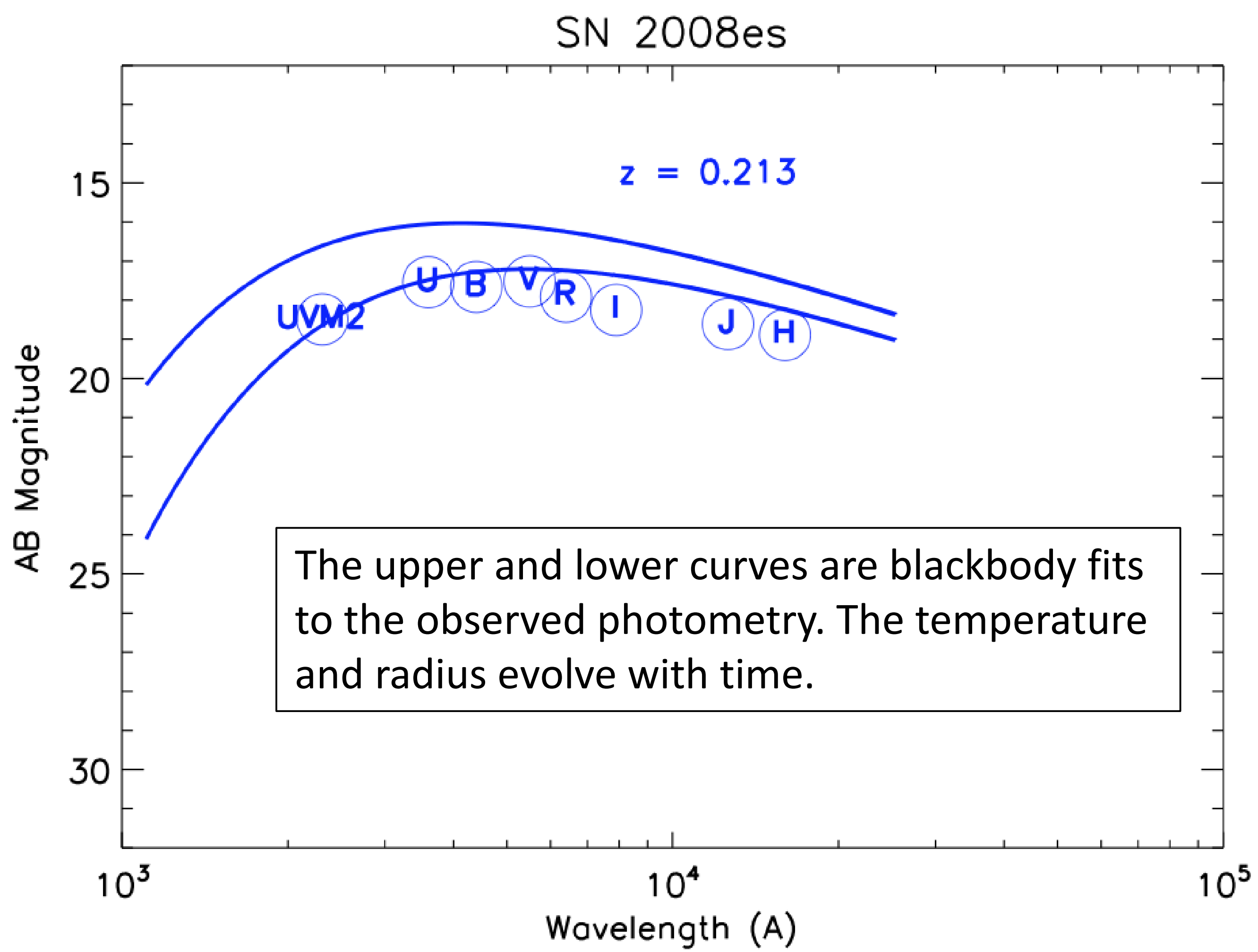
SLSNe – Super-Luminous SNe



SLSNe II – Hydrogen Rich

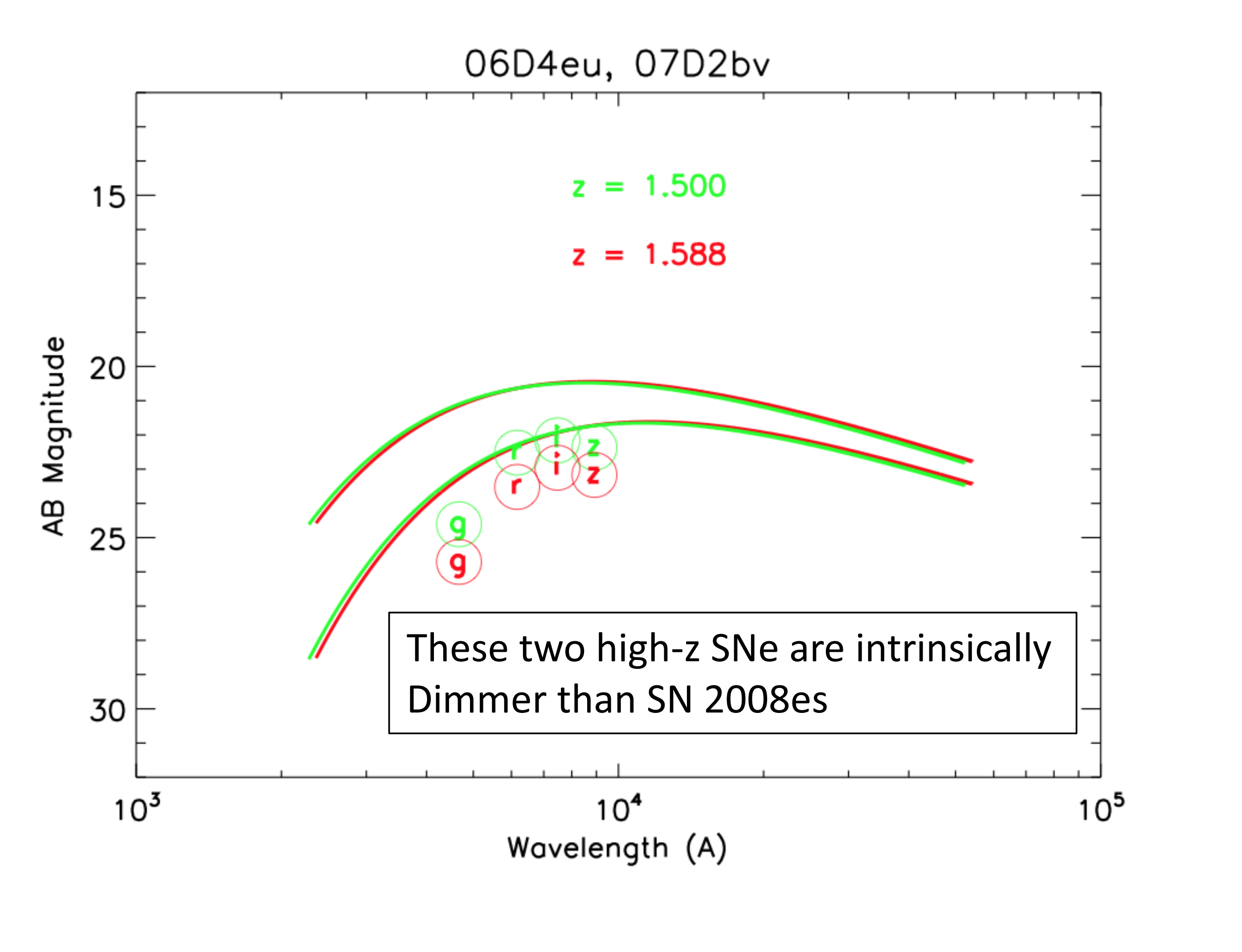


Detectability of SLSNe

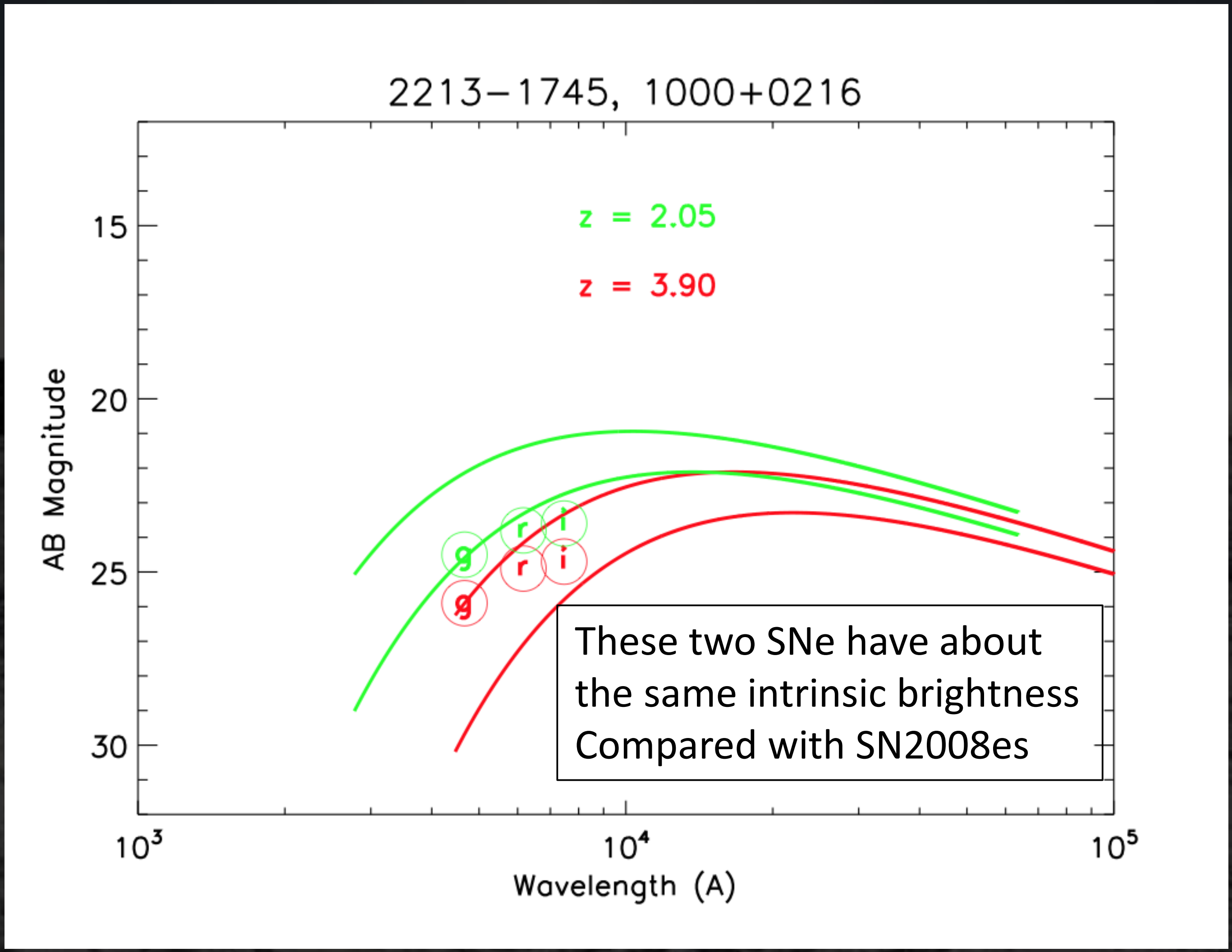


The upper and lower curves are blackbody fits to the observed photometry. The temperature and radius evolve with time.

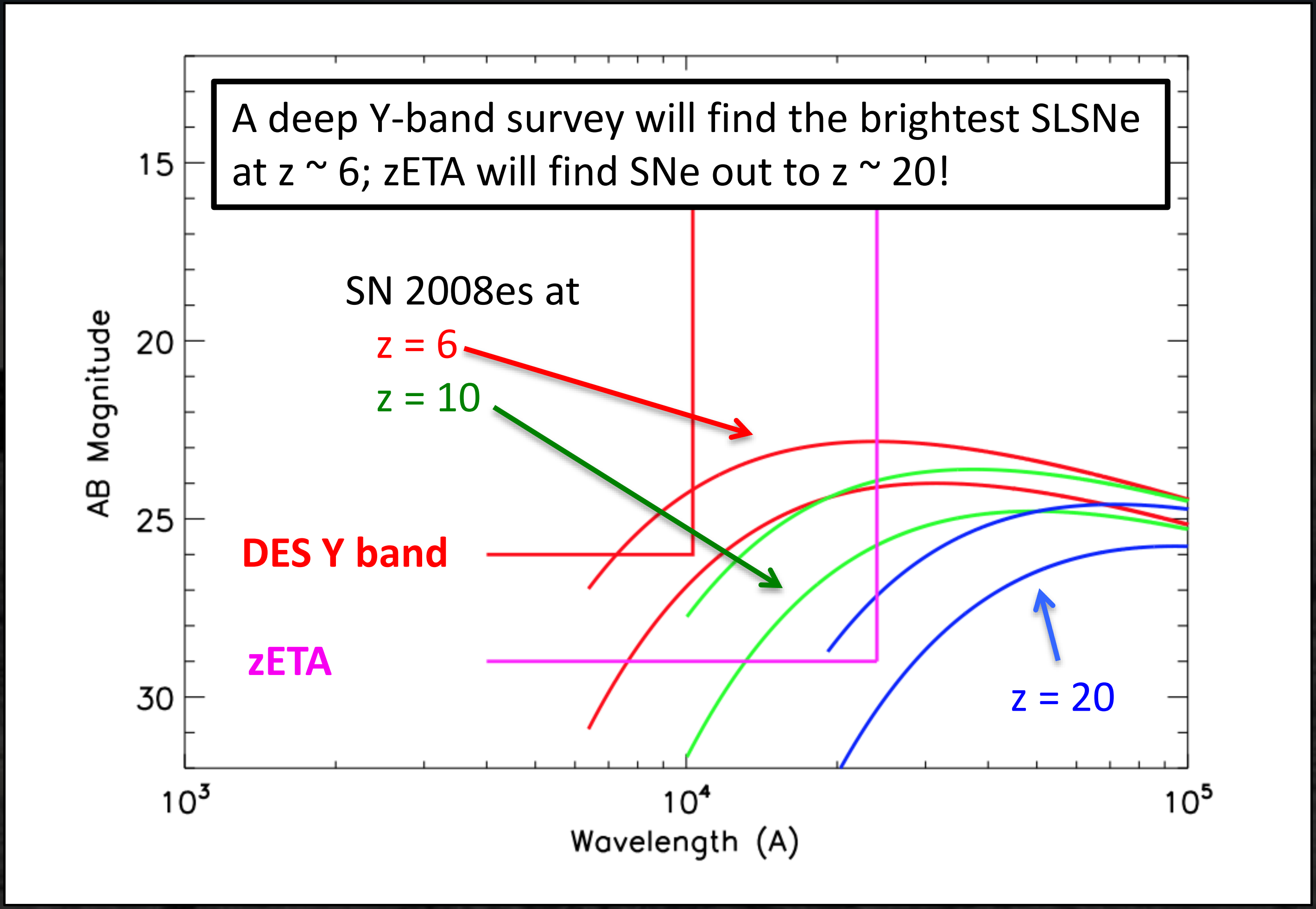
Two SLSNe at z ~ 1.5



Two SLSNe at z ~ 2-4

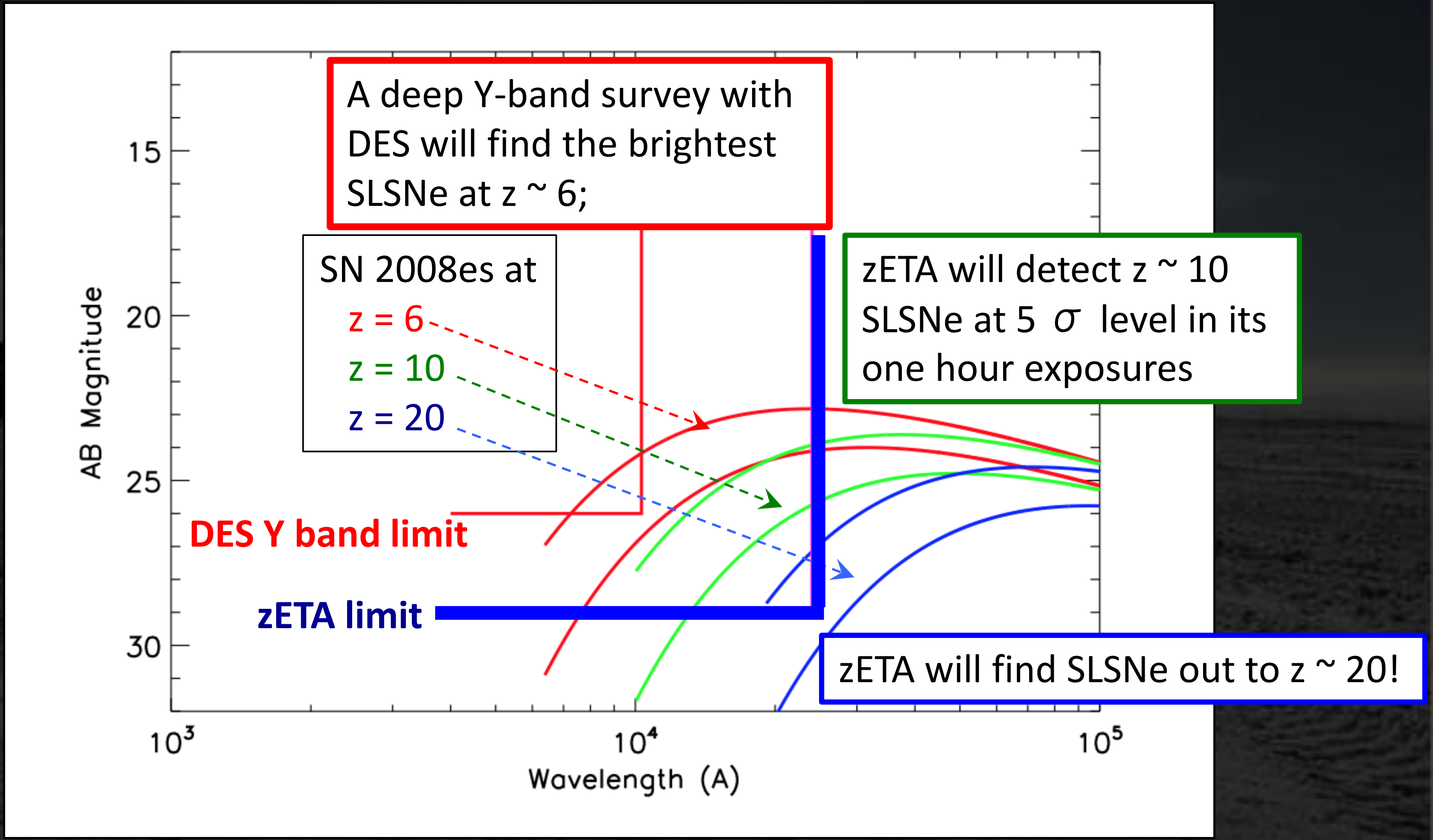


z ~ 10 - 20?

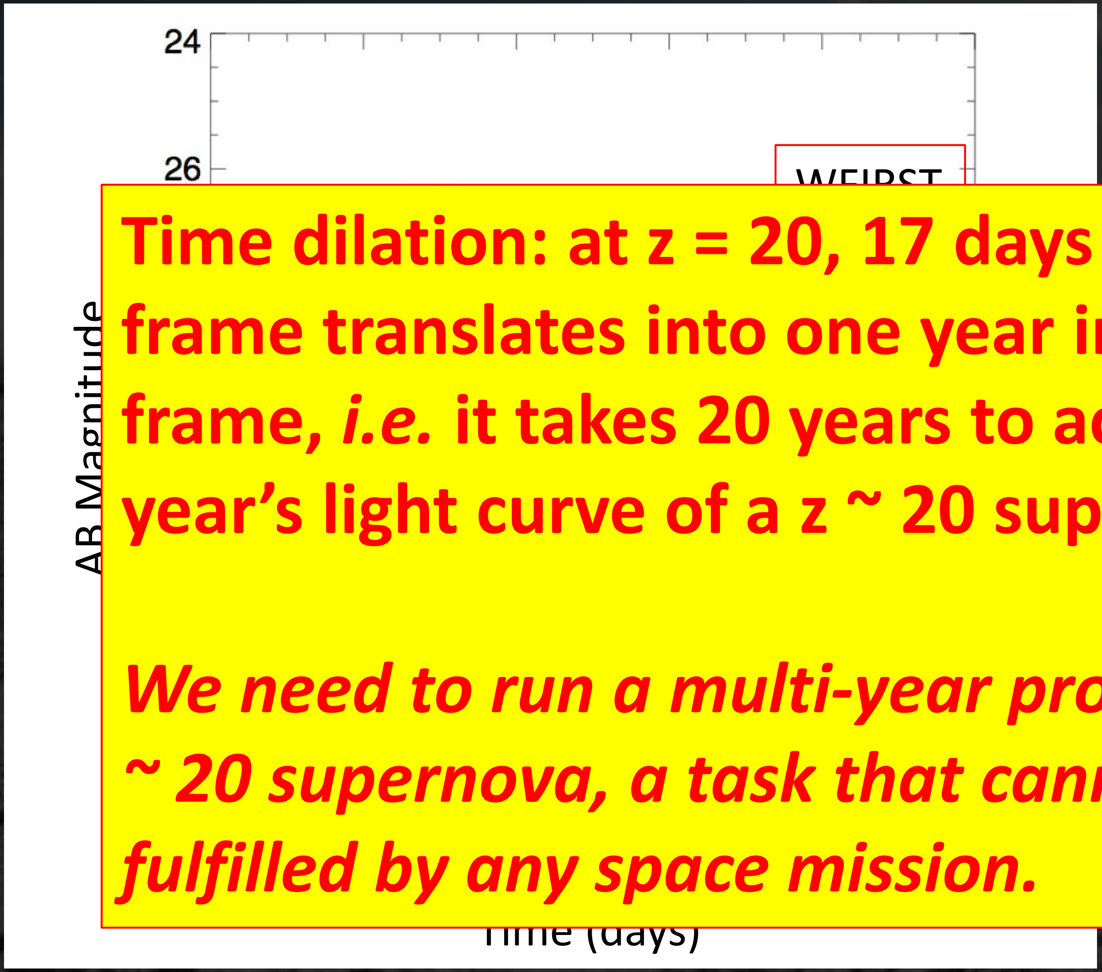


A deep Y-band survey will find the brightest SLSNe at z ~ 6; zETA will find SNe out to z ~ 20!
SN 2008es at
z = 6
z = 10
DES Y band
zETA
z = 20
15
20
25
30
AB Magnitude
10³
10⁴
10⁵
Wavelength (A)

z ~ 10 - 20?


A deep Y-band survey with DES will find the brightest SLSNe at z ~ 6;
SN 2008es at
z = 6
z = 10
z = 20
zETA will detect z ~ 10 SLSNe at 5 σ level in its one hour exposures
DES Y band limit
zETA limit
zETA will find SLSNe out to z ~ 20!
15
20
25
30
AB Magnitude
10^3
10^4
10^5
Wavelength (A)

Observations



NIR light curves for five Pop III SNe at 2.0 μm at z = 15 (solid) and z = 20 (dotted).
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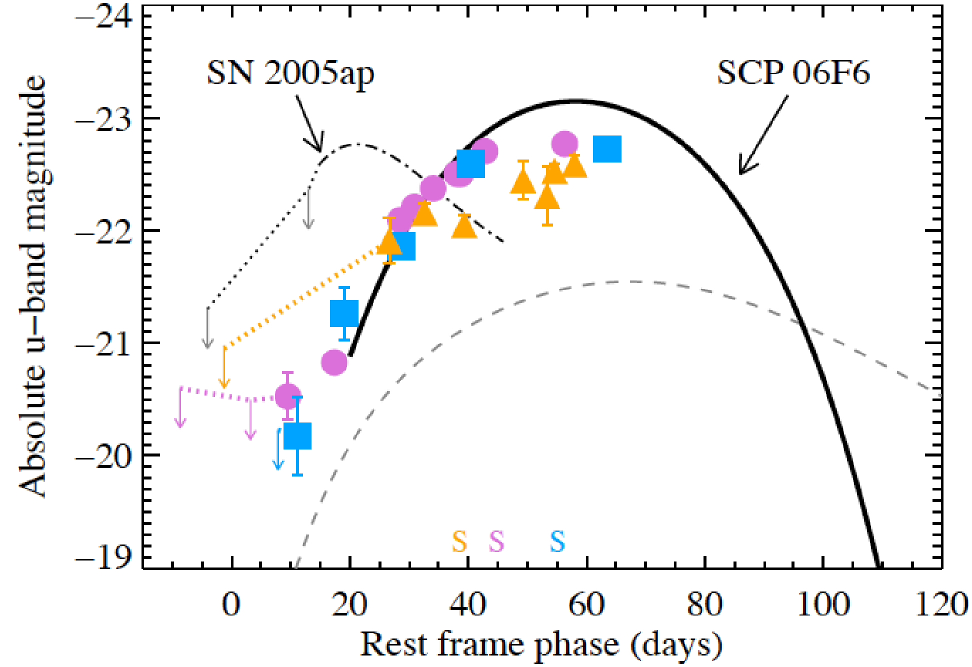
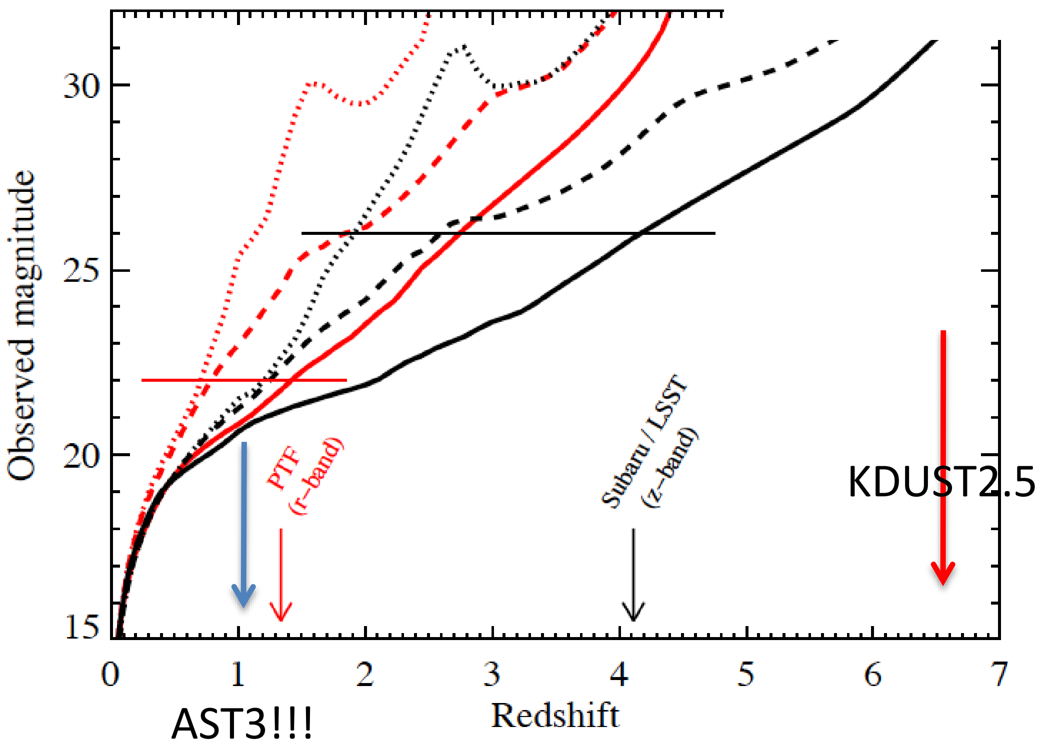
IRST
T (32
AB).
013,

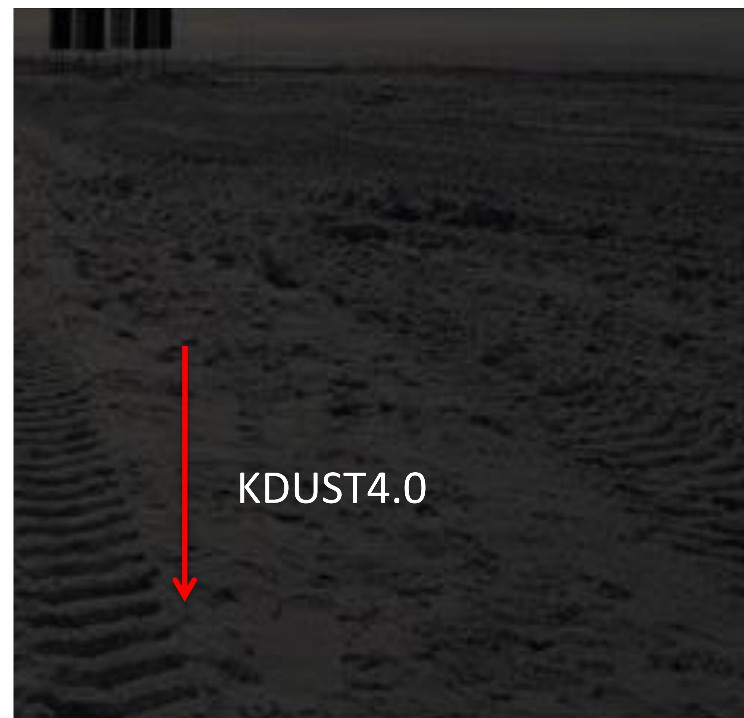
Time dilation: at z = 20, 17 days in the rest frame translates into one year in the observer's frame, *i.e.* it takes 20 years to acquire a full year's light curve of a z ~ 20 supernova.

We need to run a multi-year program to find a z ~ 20 supernova, a task that cannot be easily fulfilled by any space mission.


SNe


SN 2005ap
SCP 06F6
Absolute u−band magnitude
Rest frame phase (days)
−24
−23
−22
−21
−20
−19
0
20
40
60
80
100
120
S S S


Observed magnitude
Redshift
15
20
25
30
0
1
2
3
4
5
6
7
PTF (r−band)
Subaru / LSST (z−band)
KDUST2.5
AST3!!!


KDUST4.0

Future Perspectives

- AST3 and time domain Optical/NIR survey
- LSST can help, by not being able to detect z ~ 10 - 20 targets
- GMT/E-ELT/TMT/JWST can be useful for follow up observations once a z ~ 10 - 20 object is found
- EUCLID/WFIRST can probe z~10, but not z~20

4. Summary

With the excellent observing conditions at Dome A, we aim to explore some of the most fundamental questions of humanity, namely

- When and How did the universe made its first stars?
- When and how did the universe made its chemical elements that are capable of producing life in the universe?
- How did the universe made its planets like the earth?