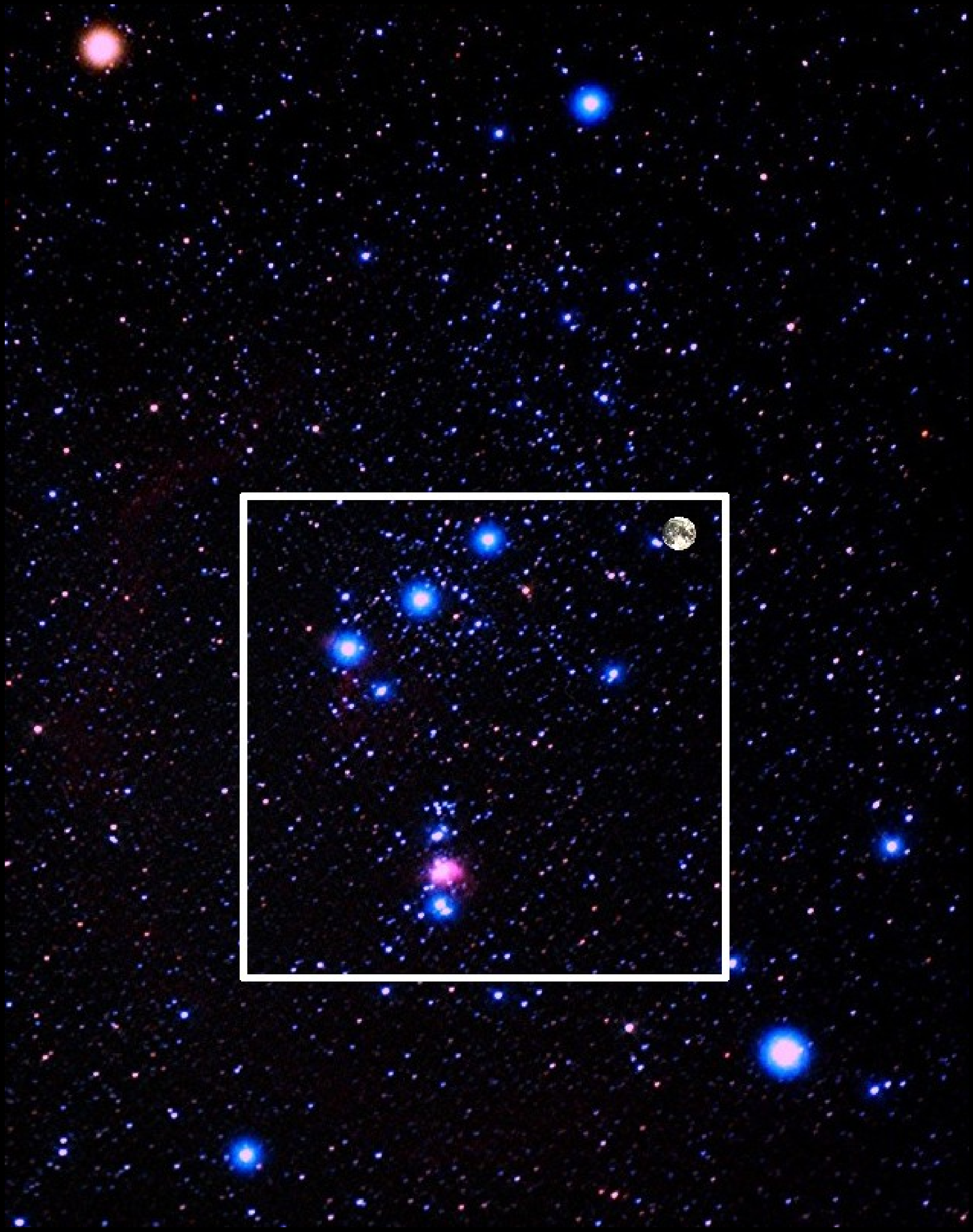
2-D Images in Astronomy

Sky Survey Projects	Data Volume
DPOSS (The Palomar Digital Sky Survey)	3 TB
2MASS (The Two Micron All-Sky Survey)	10 TB
GBT (Green Bank Telescope)	20 PB
GALEX (The Galaxy Evolution Explorer)	30 TB
SDSS (The Sloan Digital Sky Survey)	40 TB
SkyMapper Southern Sky Survey	500 TB
PanSTARRS (The Panoramic Survey Telescope and Rapid Response System)	~ 40 PB expected
LSST (The Large Synoptic Survey Telescope)	~ 200 PB expected
SKA (The Square Kilometer Array)	~ 4.6 EB expected



ZTF camera FOV is 50 square degrees.

Largest camera on >1m telescope by area in the world.

Or, to make a little clearer, here's Orion.

The white box is the ZTF imaging area.

The moon is in the upper right corner of the white box.

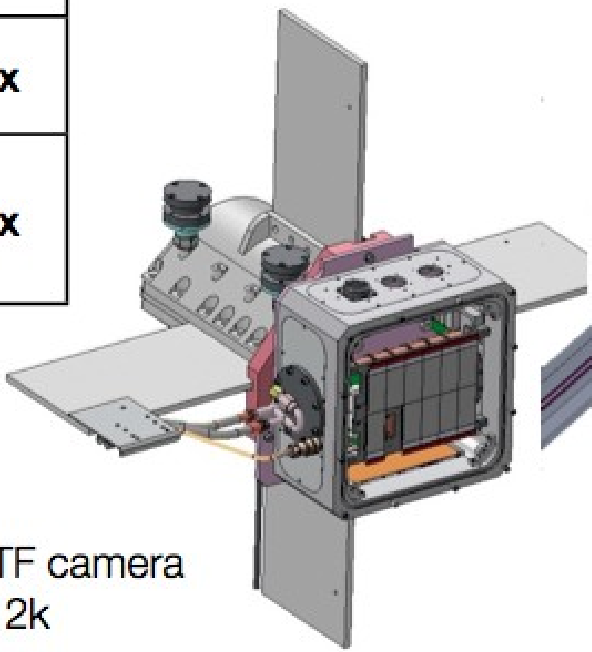
ZTF will survey an order of magnitude faster than PTF.

	PTF	ZTF
Active Area	7.26 deg^2	47 deg^2
Overhead Time	46 sec	<15 sec
Optimal Exposure Time	60 sec	30 sec
Relative Areal Survey Rate	1x	**14.7x**
Relative Volumetric Survey Rate	1x	**12.3x**

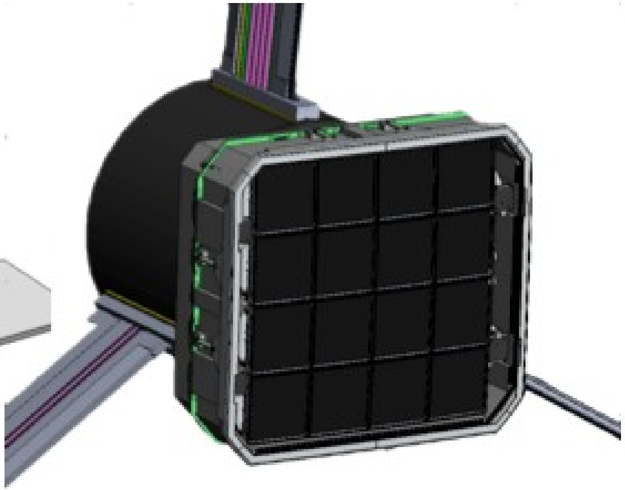
3800 deg^2/hour

⇒ 3π survey in 8 hours

>250 observations/field/year
for uniform survey



Existing PTF camera
MOSAIC 12k



New ZTF camera:
16 6k x 6k e2v CCDs

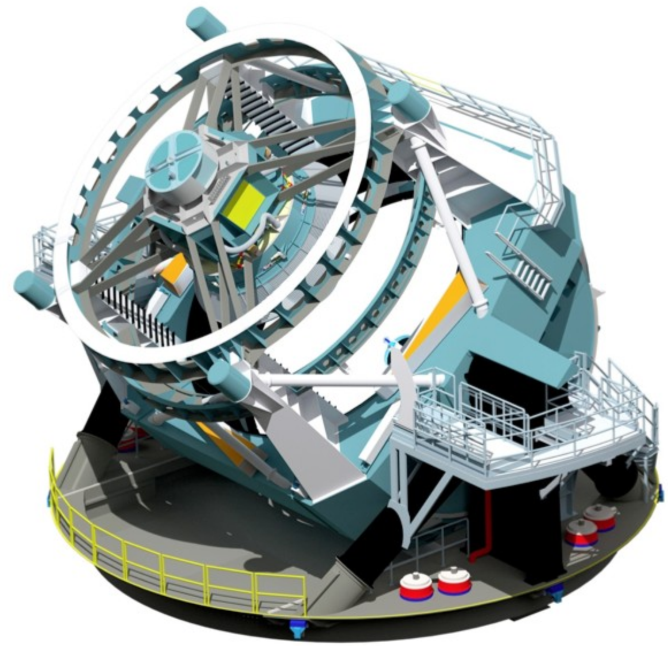
Surace 2014

And to Process All This?

IPAC is the data processing and archive center for all aspects of ZTF.
Continuous raw data flow of 30MB/s.
0.5-1 PB/yr of data products.
Drone farm of 128 computers.
Replication of proven PTF design in subunits similar to PTF data load (camera quadrants).

ZTF provides the US community a stepping stone to LSST.

PTF: 4×10^4 events/night
ZTF: 3×10^5 events/night
LSST: 2×10^6 events/night



Technical	develop algorithms & software for detection & classification
Scientific	discover new transient & variable phenomena
Organizational	organize collaborations and followup strategies with real data

NSF-sponsored summer schools and direct student involvement in ZTF development will prepare a new generation of researchers!

CCD Images

Photo counting device
Bias
Dark
Readout noise
Sky background
Flat field – sensitivity
Field distortion
PSF – diffraction
Nonlinearity – saturation
Cosmic rays
Meteorites
Stars and Galaxies

Find the information you want:

Precision photometry?
Astrometry?
Transients?

…

Subtraction with ISIS (or DIA)

ISIS C. Alard http://www2.iap.fr/users/alard/package.html

DIA P.R. Wozniak http://www.astro.princeton.edu/~wozniak/dia/

$$Im(x,y) - \left[Ref\,(u,v) \otimes Ker(u,v;x,y)\right] = Diff\,(x,y)$$

$$Ker(u,v;x,y) = \sum_n a_n(x,y) K_n(u,v)$$

ef = Reference Image (best seeing)

n = Program Image

er = Kernel image (to be found)

$$K_n(u,v) = e^{-(u^2+v^2)/2\sigma_k^2} u^i v^j$$

$$a_n(x,y) = \sum_{i,j} b_{i,j} x^i y^j \qquad n = (i,j,k)$$

(C. Alard 2000; P.R. Wozniak 2001)

…the flux scaling factor is the sum of the local kernel …(C. Alard, 2000)

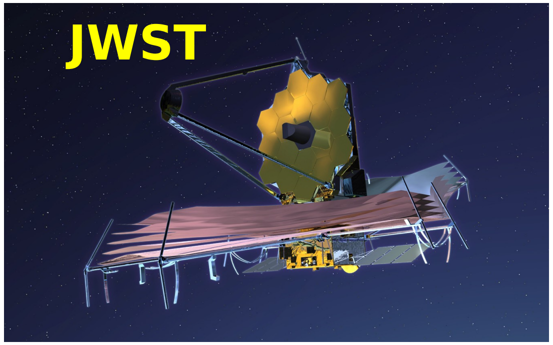
…the result is on the scale of the program image. I divide it by the norm of the kernel and express the flux in the units of the reference image…(P. Wozniak, private communication)

1. The Antarctic Survey Telescopes (AST3/KISS)

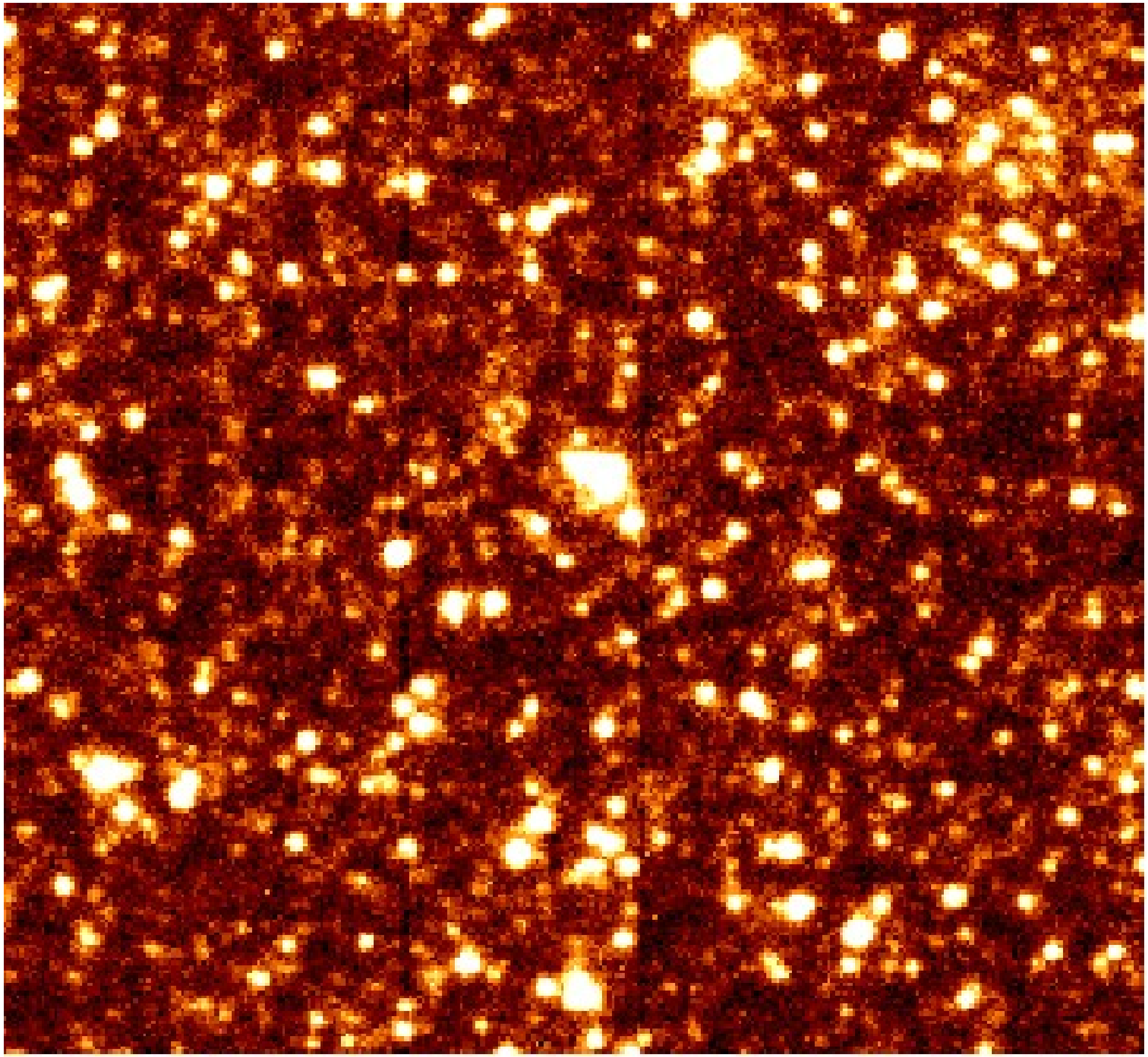
- Three 50cm wide area optical/NIR telescopes
- Wide field time domain optical survey from Dome A
- China/Australia/French/US collaboration
- Operation between 2014-2020
- Synoptic K-band survey – sensitivity (KISS): S/N ratio of 5 for a K=19.5 mag point source in 1 hr
  - Star formation
  - Cosmic infrared background
  - Supernovae and GRBs
  - Exoplanets
  - Variable stars

2. Kunlun Dark Universe Survey

- One 2.5 meter, wide field optical/NIR survey telescope
- Pending approval by the Chinese government approval, targeting at 2020 Dome A
- Optical survey, 5000 sq deg images at resolution of 0.31 arcsec to, e.g., i=26.6mag (Point source sensitivity comparable to LSST)
- Weak/Strong lensing
- Supernovae
- BAO
- NIR upgrade, and deep K-band survey
  - Epoch of reionization
  - Wider field than JWST



2. Antarctica

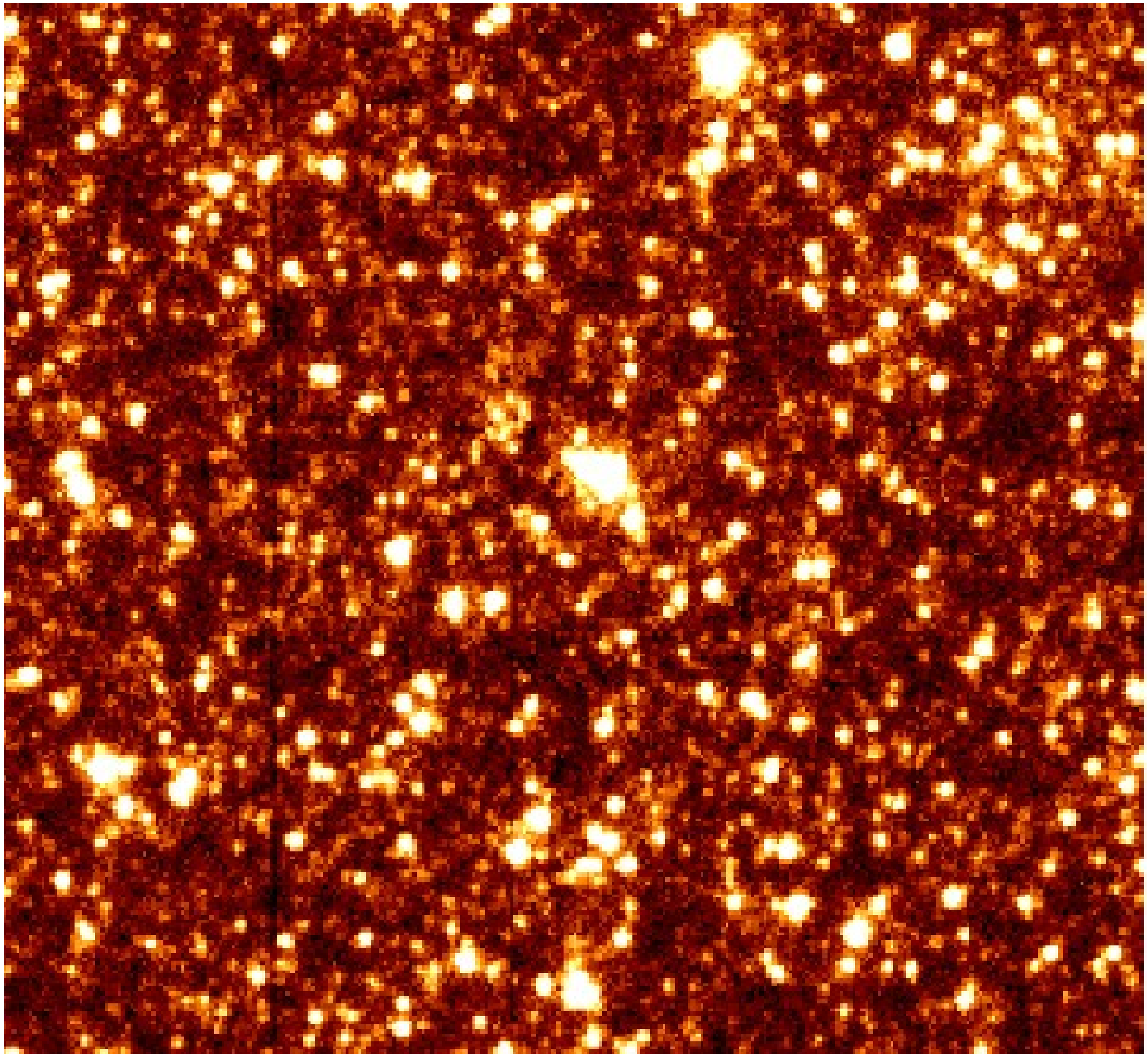


May 6

500-351

Bad Columns

2. Antarctica



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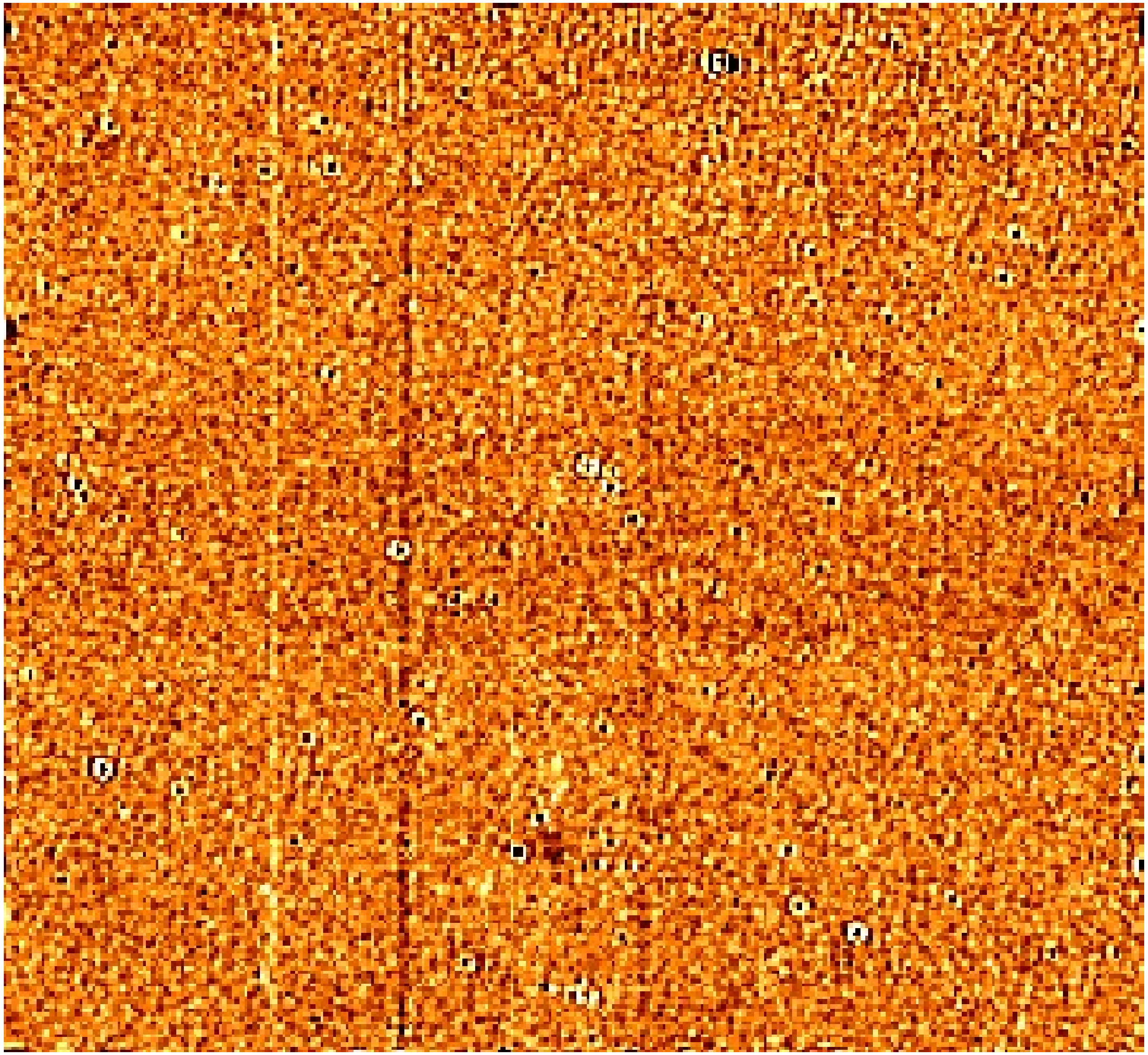
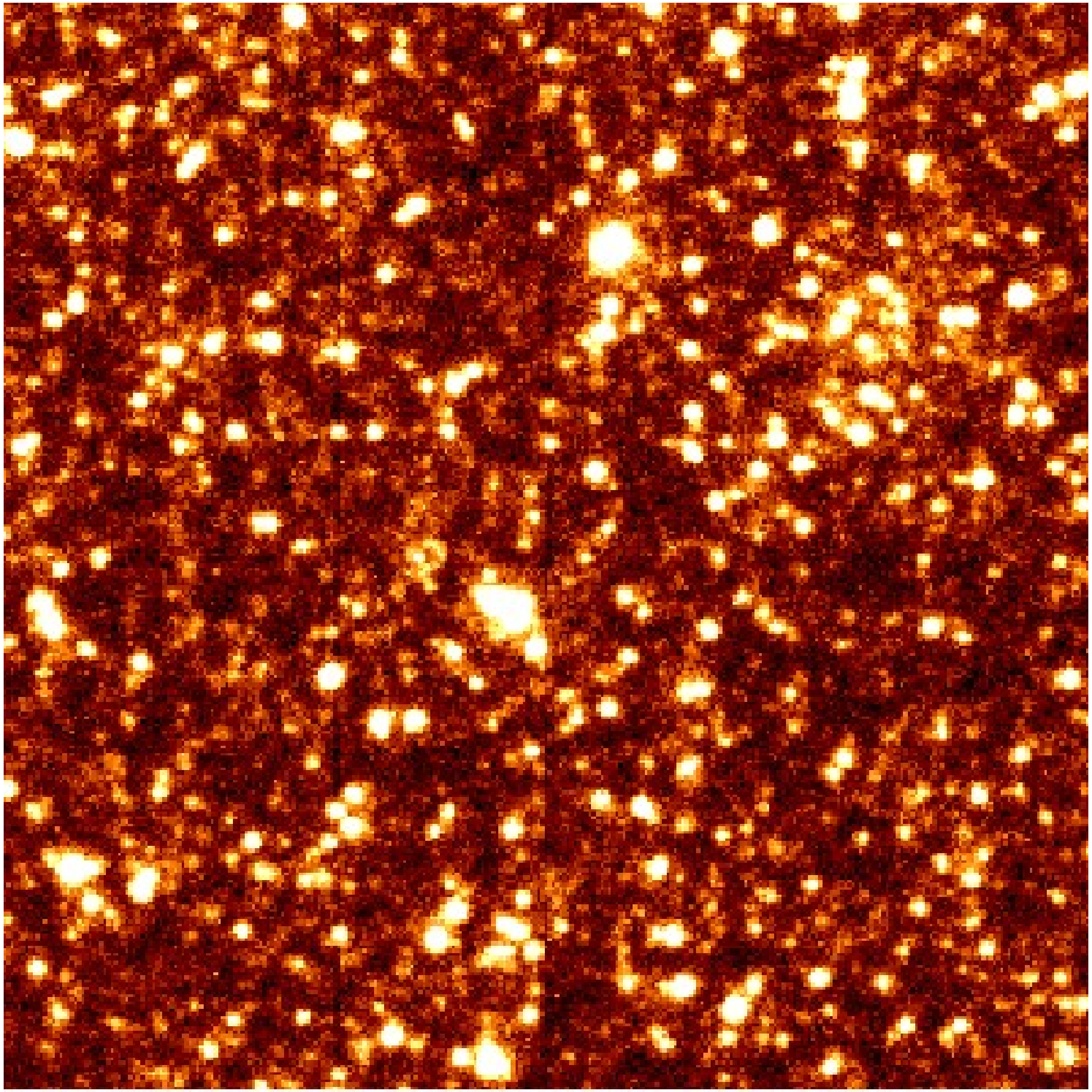
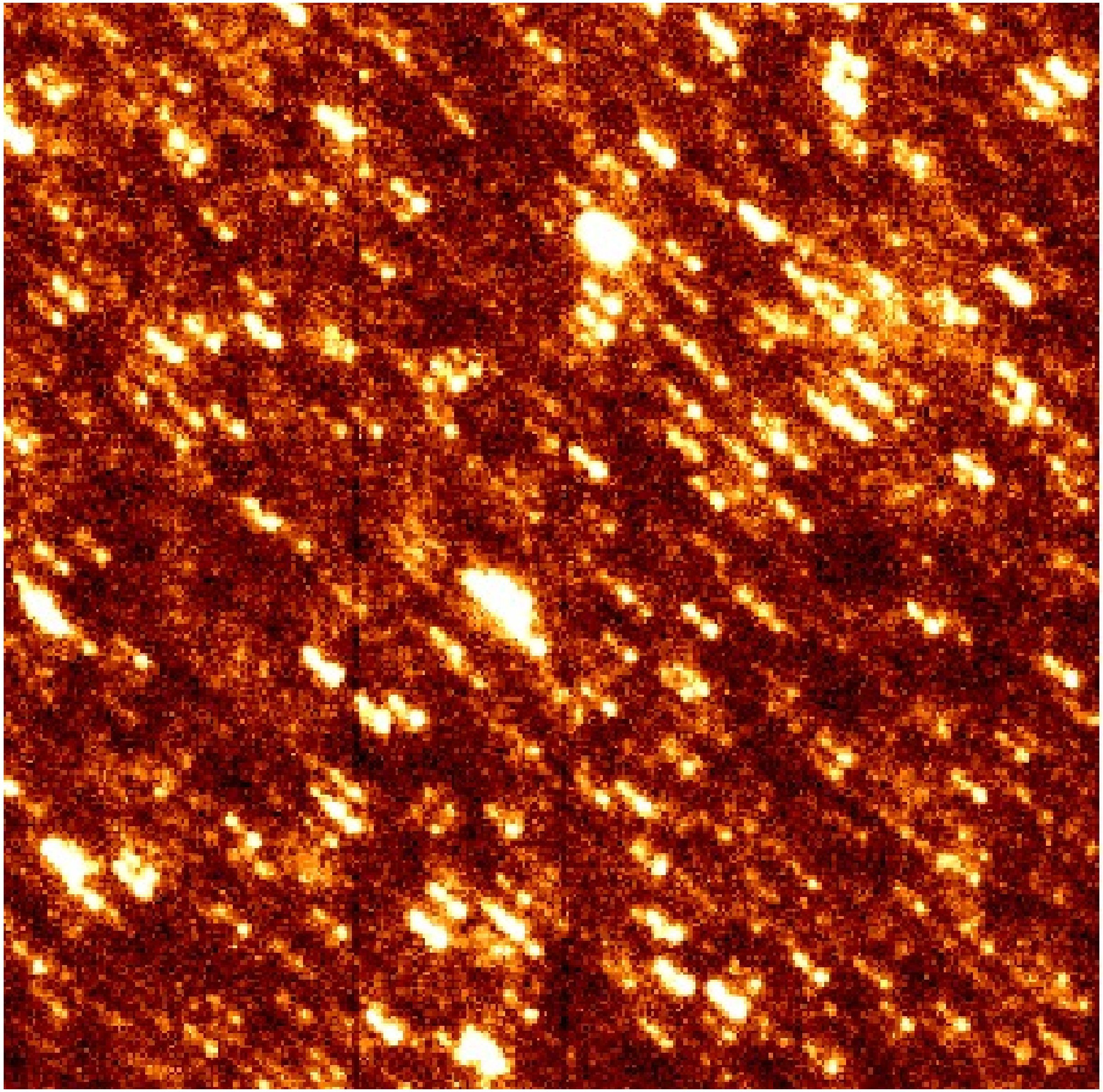


2. Antarctica



2. Antarctica



Oscillation?

2. Antarctica

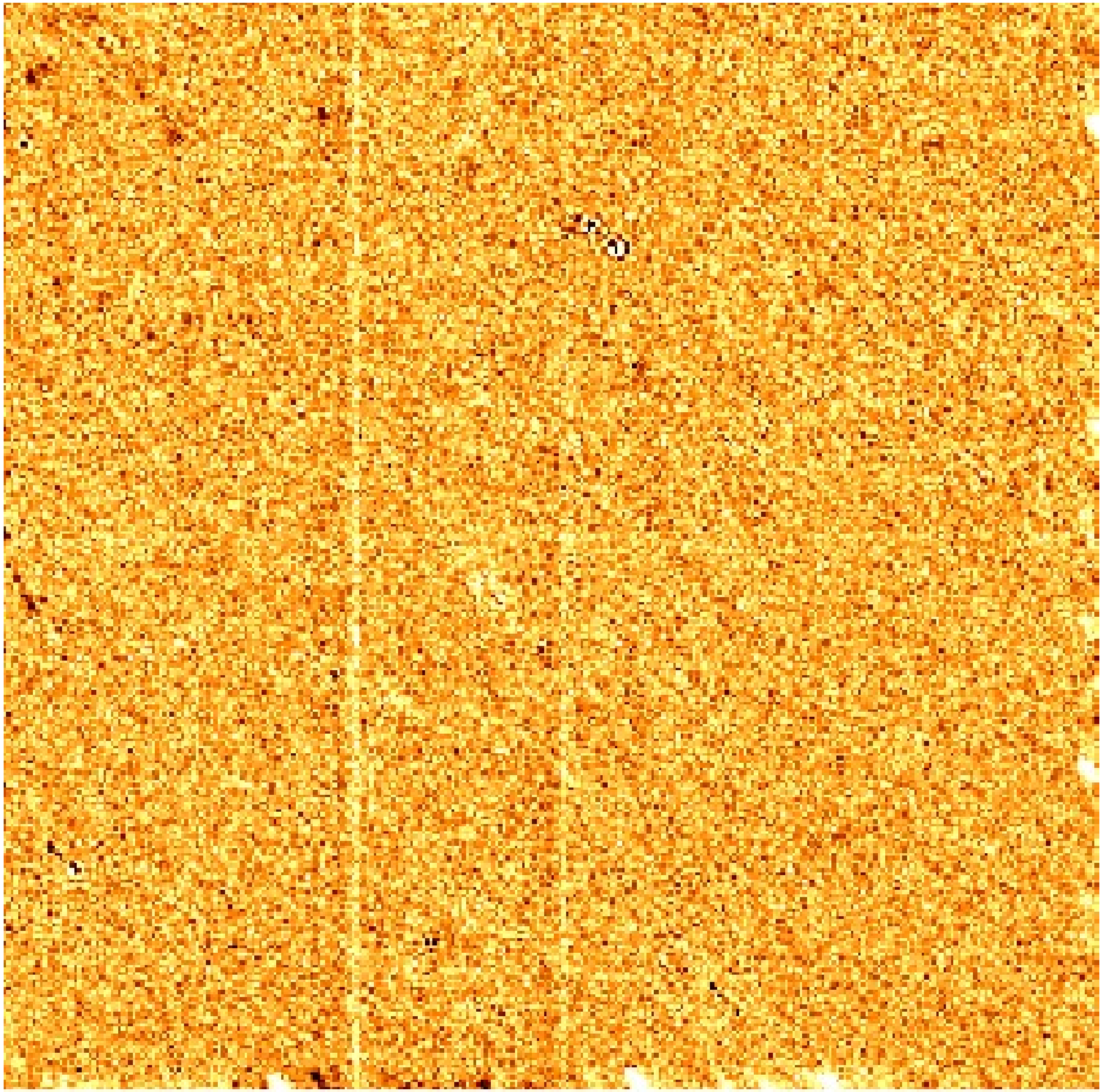


Image Subtraction in Astrophysics

- adjust Point Spread Function for instrumental/atmospheric effects which otherwise mask physical changes in target of study

1) adjust PSF in images in different filter passbands* to allow inter-wavelength comparison (Ciardullo et al. 1990)

2) adjust PSF of images in time sequences to allow construction of light curves of variable sources (Tomaney & Crotts 1995)

*or polarization, or other variables for non-photons

Image 1

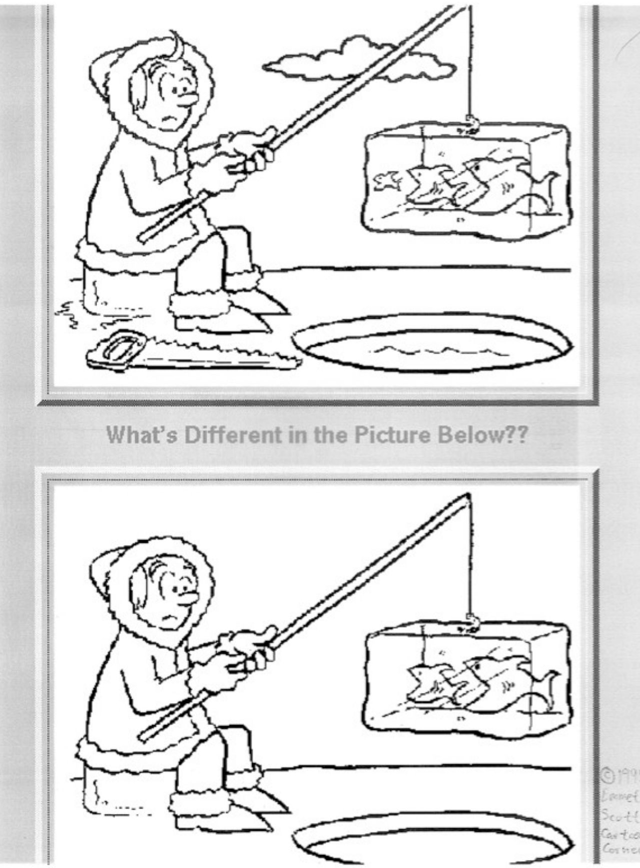
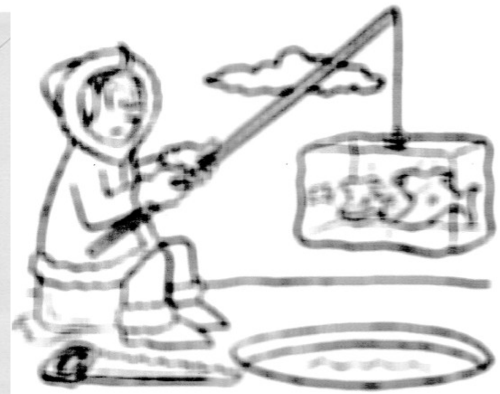
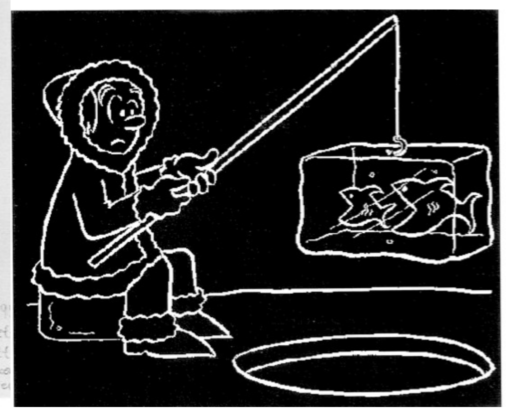


Image 2

Image 1 blurred





- Image 2

Image 1 blurred - Image 1

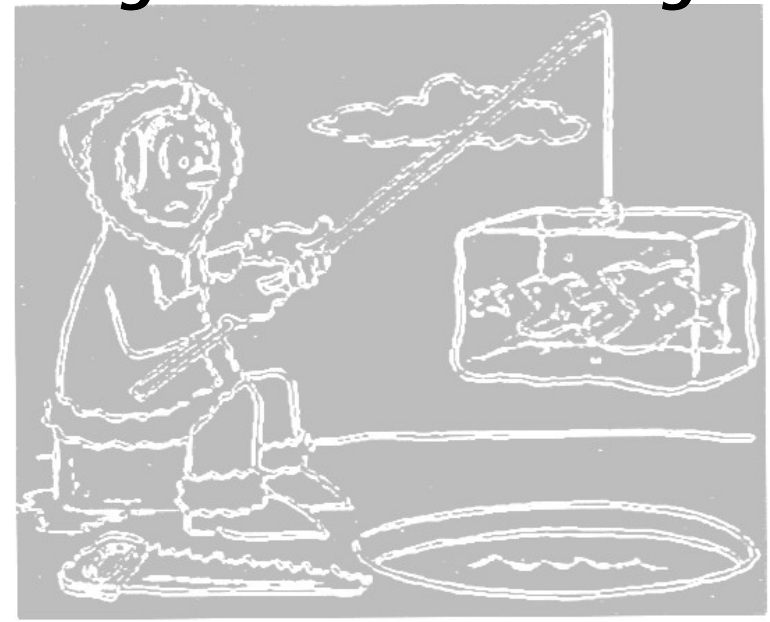


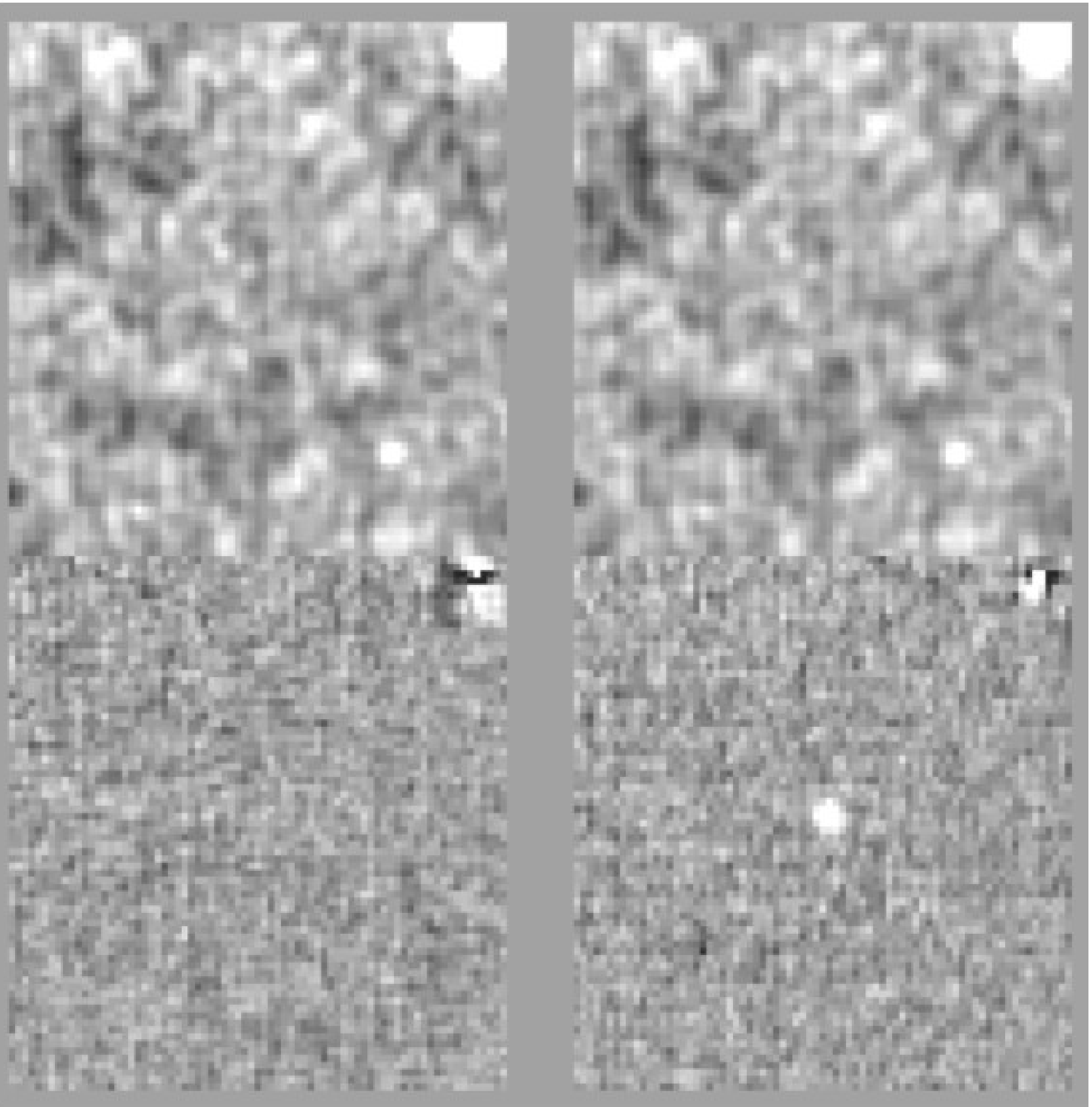
Image 1 blurred - Image 2

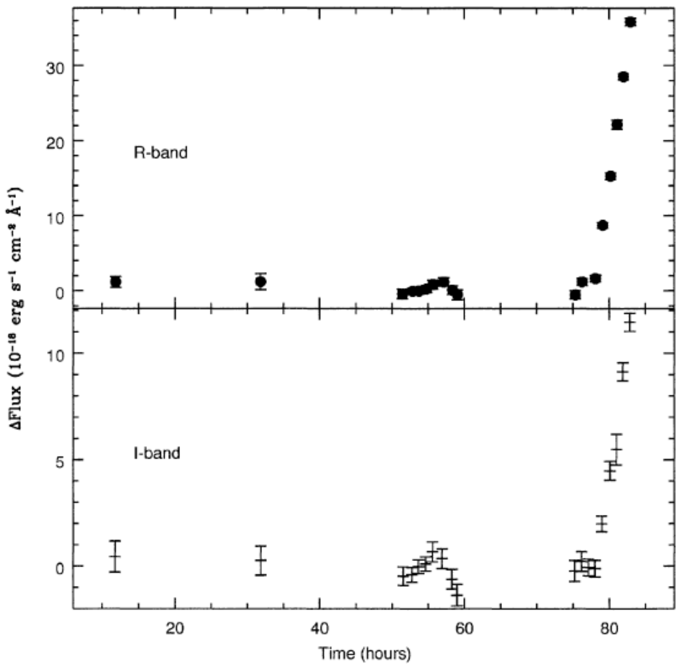
Image Subtraction Algorithms

First: register 2 images to same coordinate system and adjust photometric scaling so net photon counts equal

- ***Fourier quotient technique: construct convolution kernel by dividing transforms of 2 PSFs in fourier space and transform back to image space (Phillips 1990; difimphot - Tomaney & Crotts 1995)***
- ***Simultaneous least-squares fit: set of simultaneous equations relating pixel values in 2 images, plus convolution kernel. Solve for convolution kernel. (ISIS - Alard & Lupton 1998, …)***

Pre-nova Activity in M31

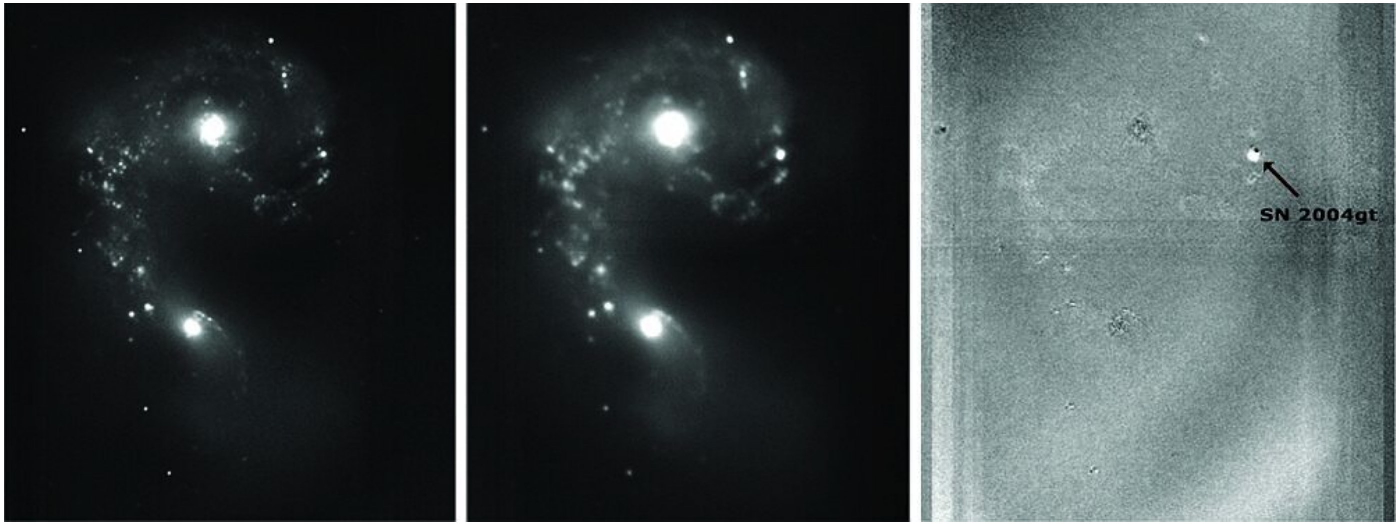


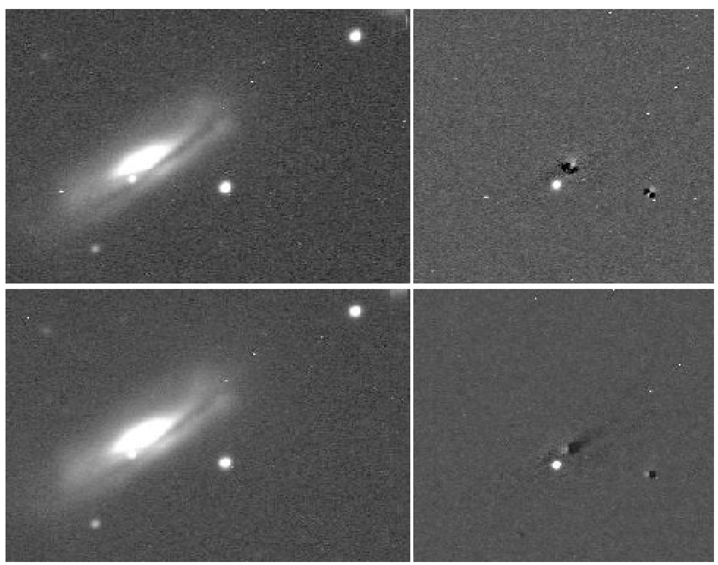


Time-series Image Subtraction (17 orders of magnitude distance)

- ***Supernovae & gamma-ray bursts***
- ***Light Echoes (transient reflection nebulae)***
- ***Gravitational microlensing***
- ***Variable stars***
- ***Planetary surfaces e.g., Moon, Mercury***
- ***(also can be used for measuring small proper***

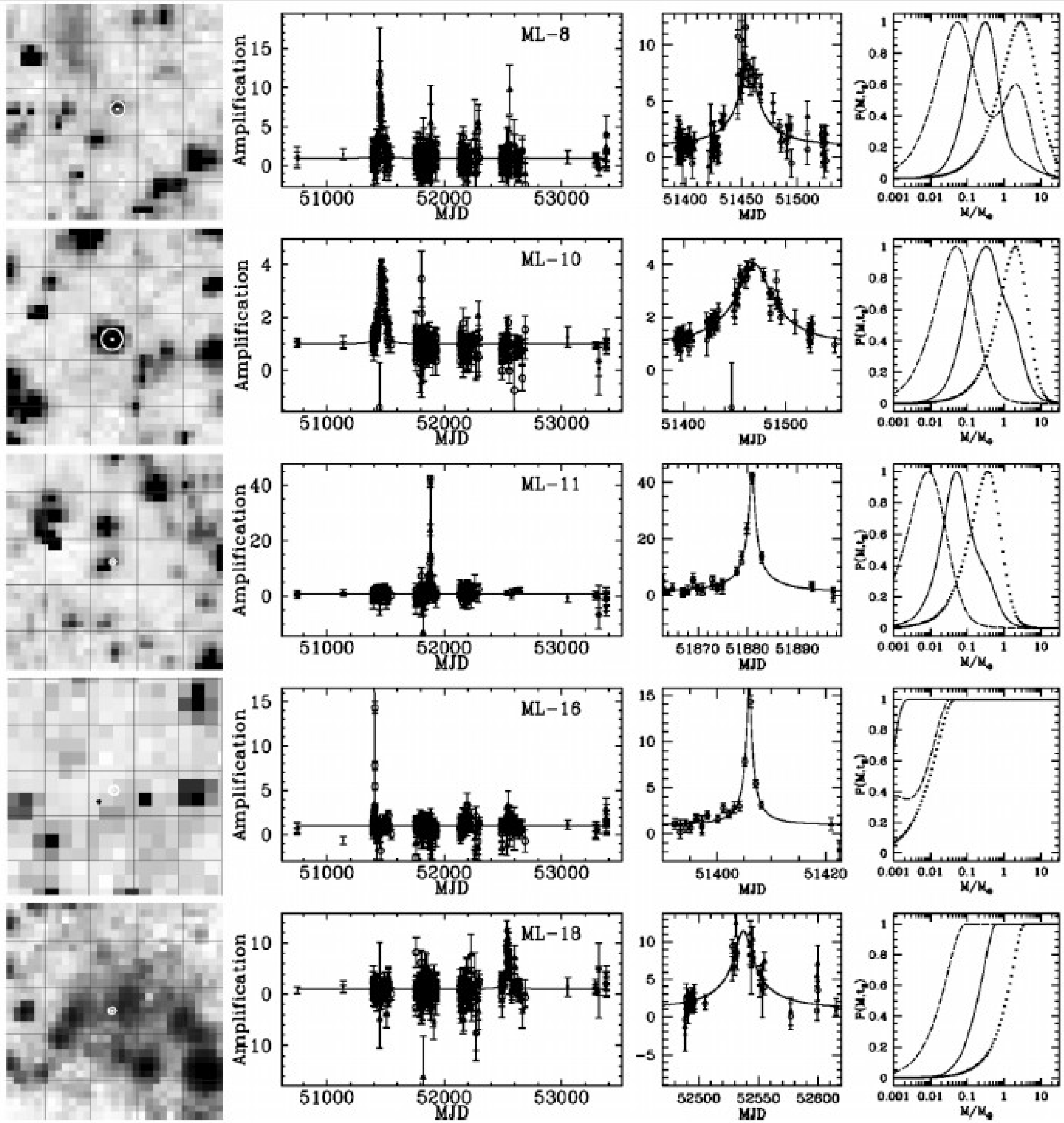
Distant Supernova Photometry





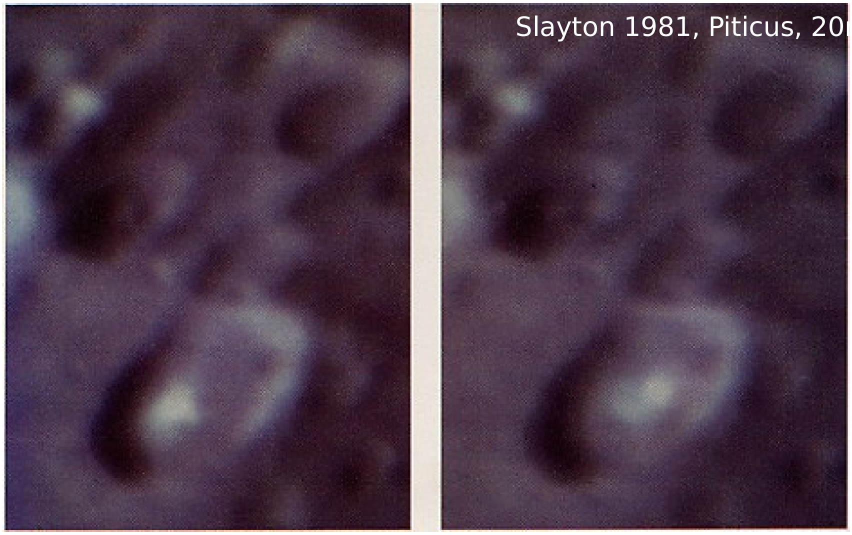
SN 2002bo

M31 (Halo?) Microlensing

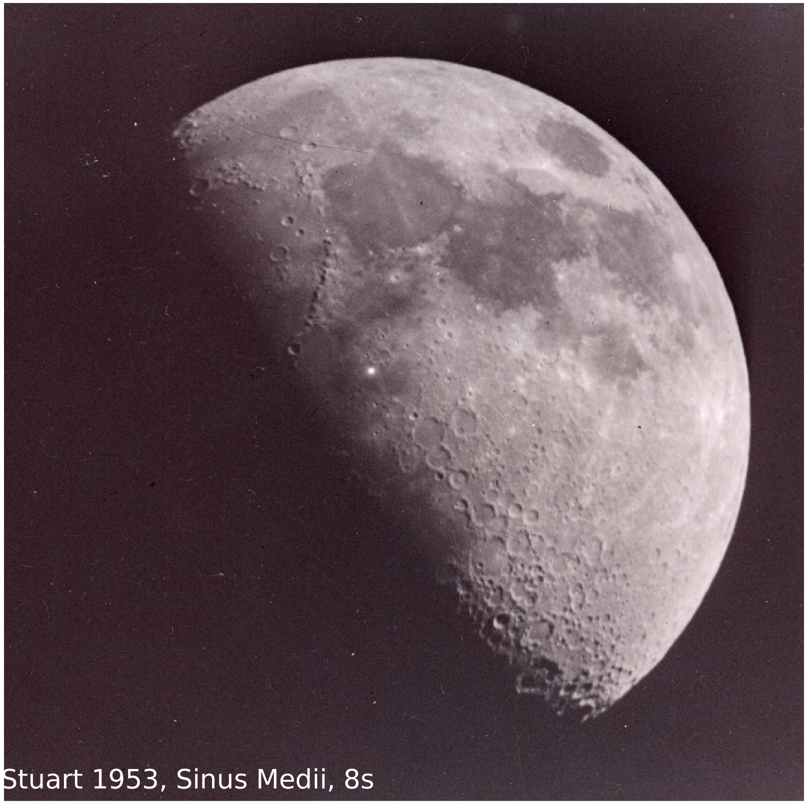


Transient Lunar Phenomena (TLPs)

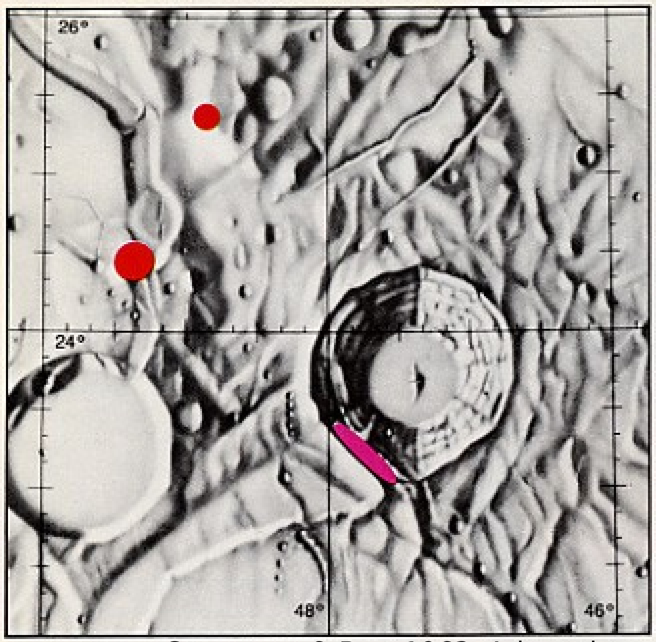
< 1 km to ~100 km across
~10 - 10000s duration
“brightening” “color change”
“obscuration” “darkening”
~1700 events (Middlehurst 1977, Cameron 1978, 2006)



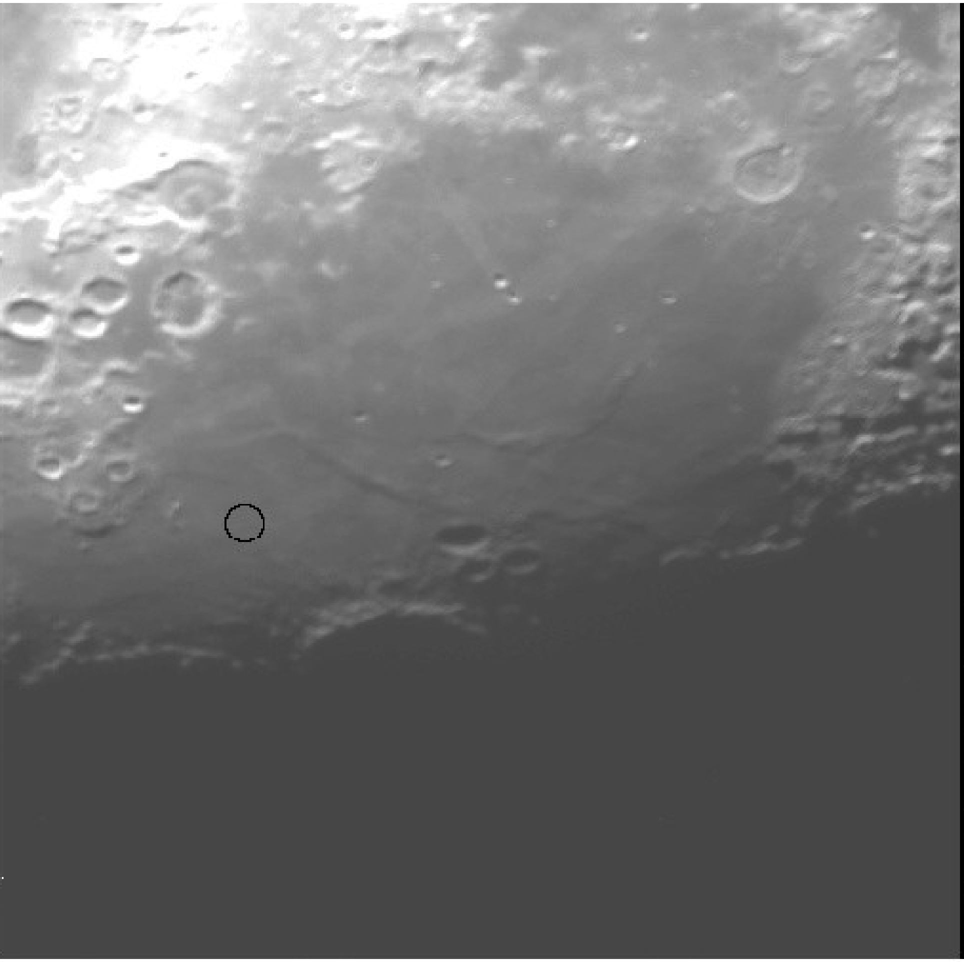
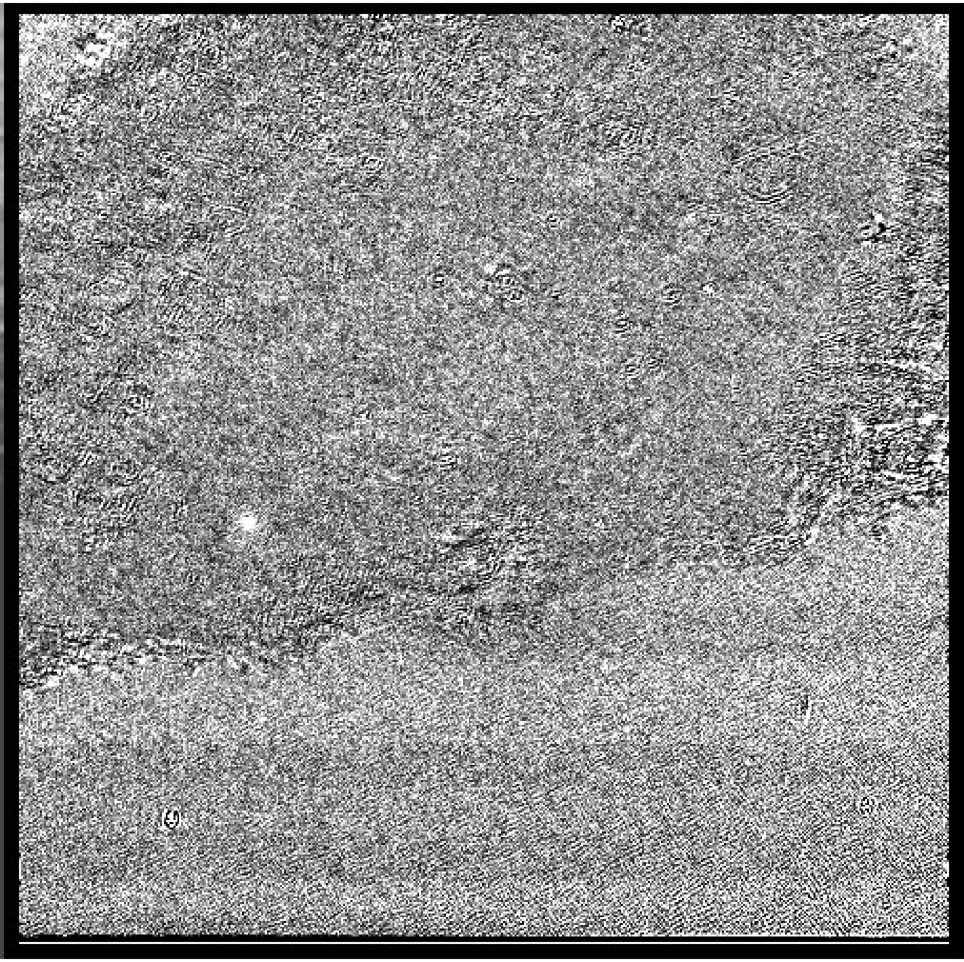
Slayton 1981, Piticus, 20

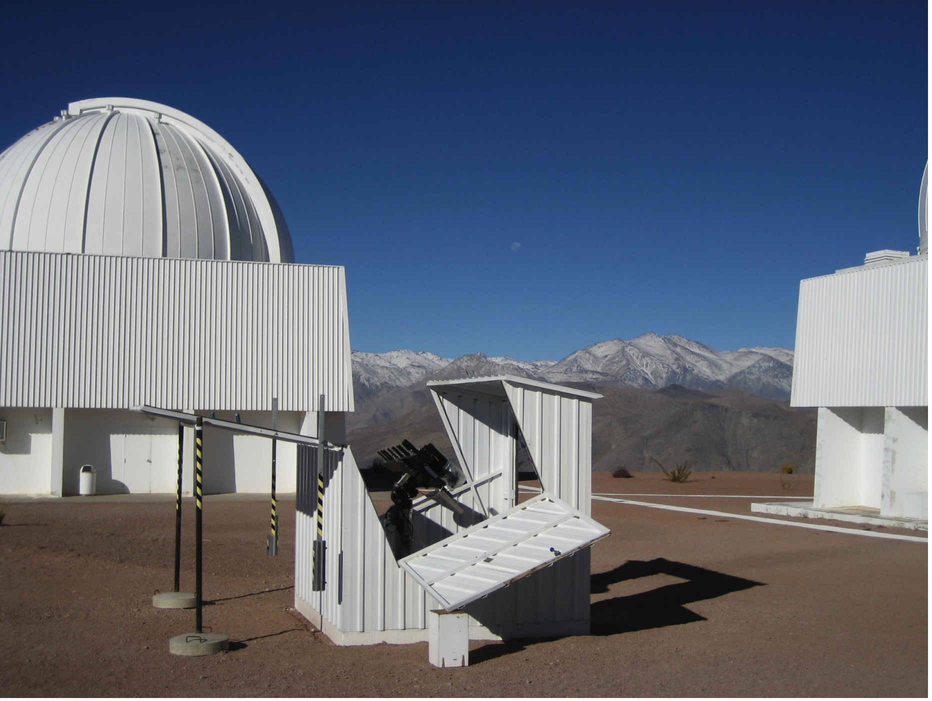


Stuart 1953, Sinus Medii, 8s

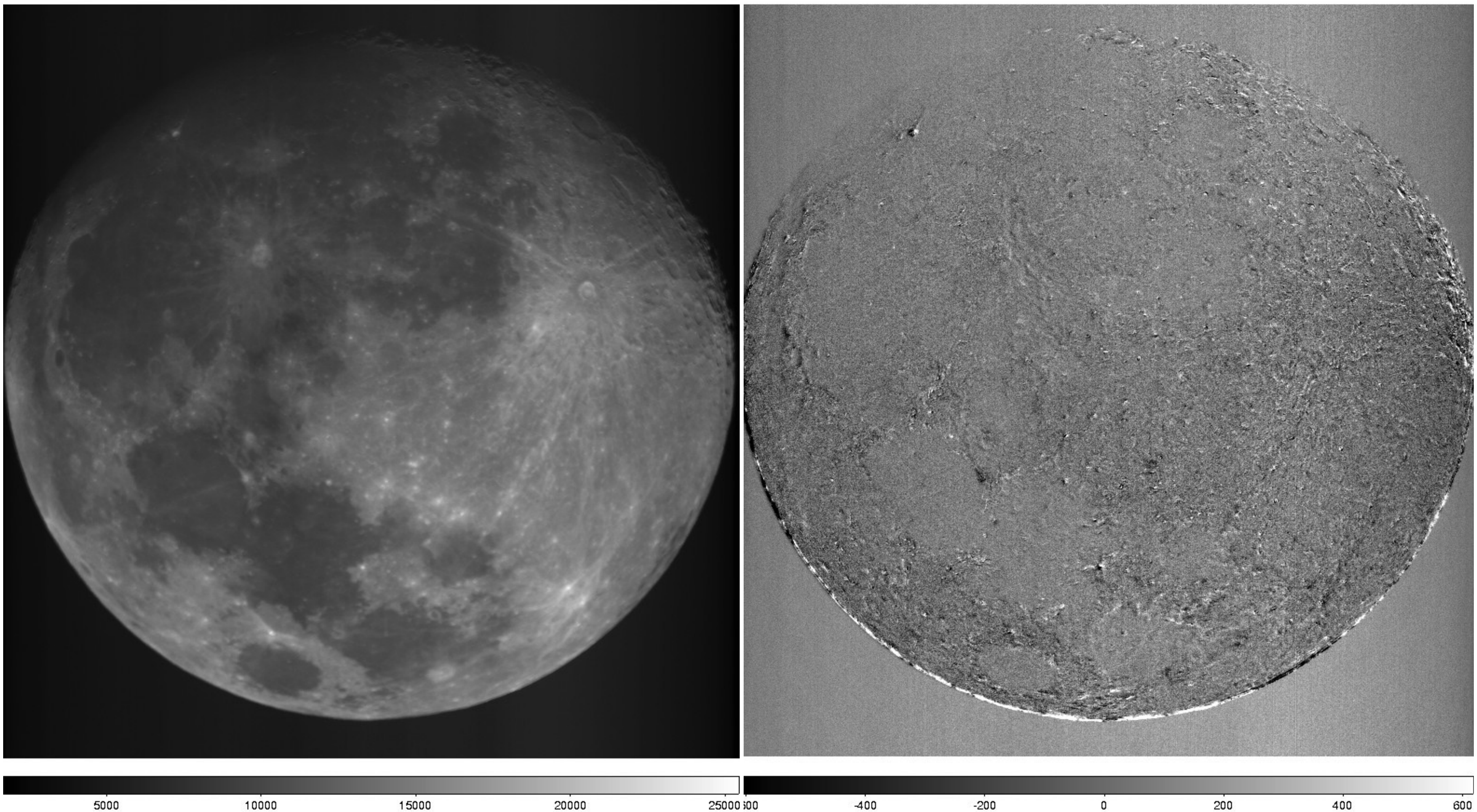


Greenacre & Barr 1963, Aristarchus, 2h

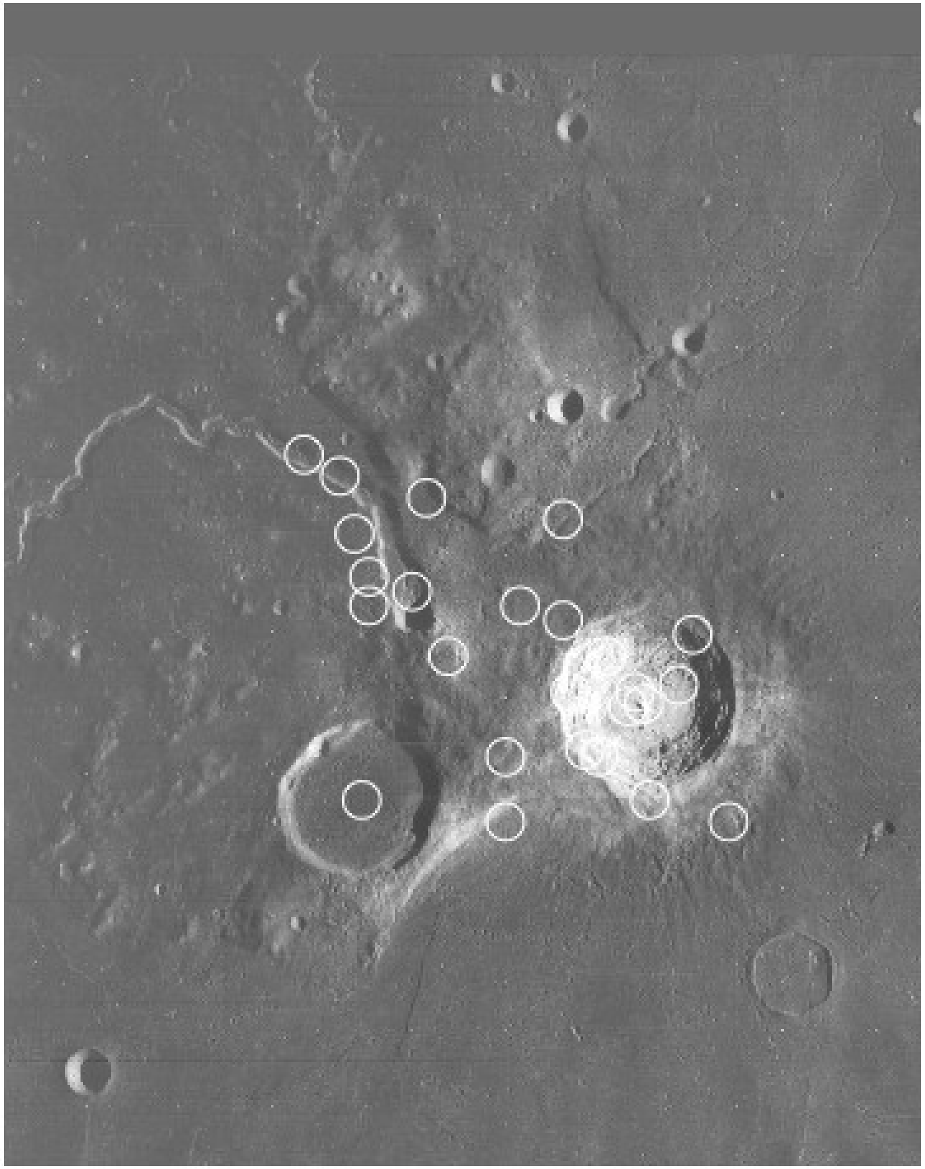






MEADE



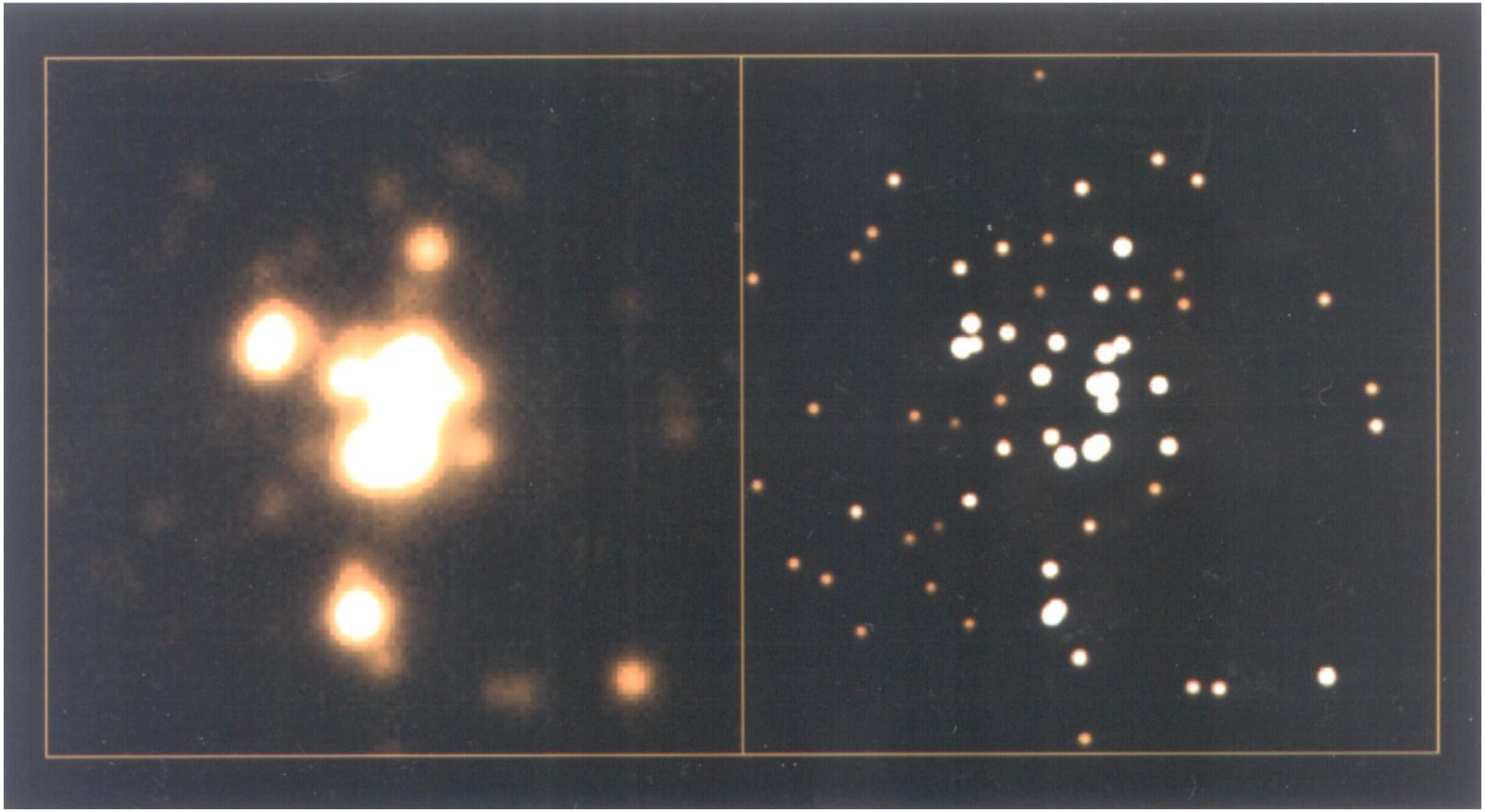
5000
10000
15000
20000
25000
-400
-200
0
200
400
600



Current/Future Surveys using Image Subtraction

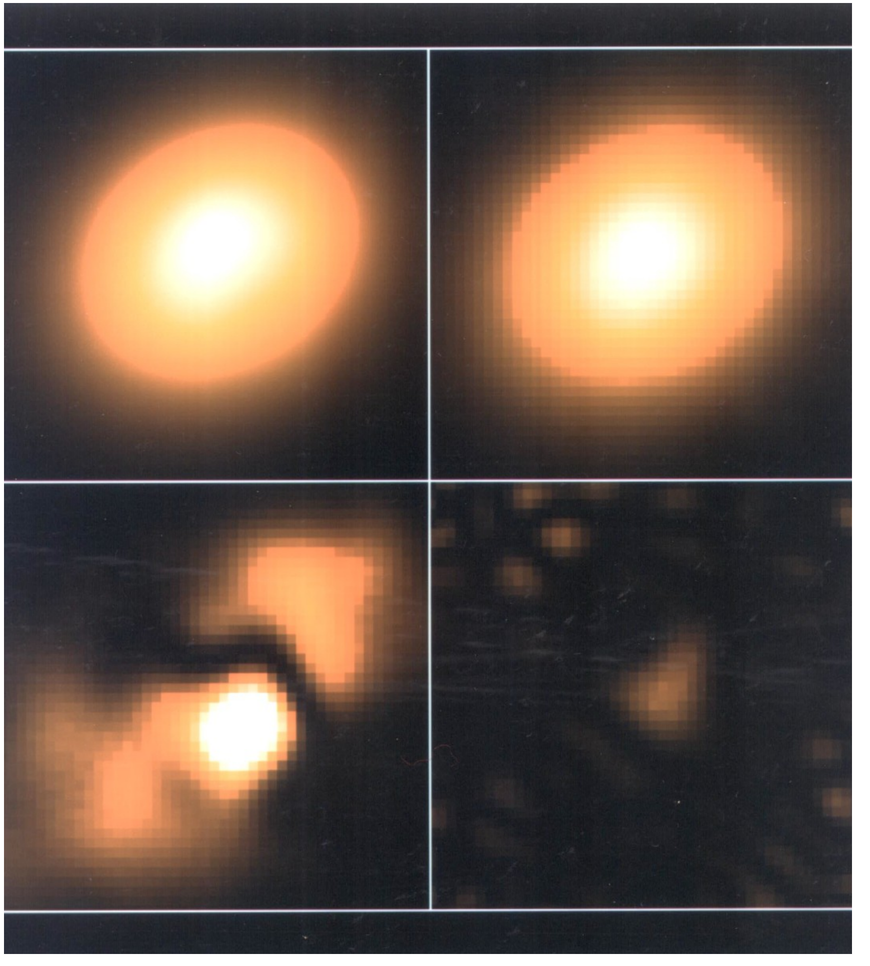
- Current microlensing/supernova surveys are producing << 1 Tbyte/night (SDSS II, III; MEGA,…)
- Future surveys >> 1 Tbyte/night (DES, LSST, ALPACA,…)
- Strong need for real-time processing for alerts on variable events to trigger followup studies

De-convolution method



Deconvolution of an image of the compact star cluster Sk 157 in the Small Magellanic Cloud. Left : image obtained with the ESO/MPI 2.2 m telescope at La Silla (1”.1 FWHM) ; right : deconvolution with our algorithm (0”.26 FWHM).

Comparison of the background light distributions deduced from deconvolution, using the two-channel Lucy method (top left) and our method (top right). The bottom panels show the square of the difference between the deduced background (reconvolved to the same 2 pixels resolution when necessary) and the exact solution, with the two-channel Lucy method (left) and with our algorithm (right).



MAGAIN, COURBIN, & SOHY (see 494,

Search of Supernovae with DES data