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Assuring Space Mission Success

CUBESAT Nighttime Lights

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Outline

- Introduction – Nighttime Lights as a CubeSat Mission
- AeroCube camera details, AC-4 MFOV, AC-5 NFOV
- AC-4 point and stare experiment and comparison to VIIRS DNB
- AC-5 sequential point and stare flyby experiment
- Comparison of AC-5 to ISS Photography (including change detection)
- AC-5 Global City Examples
- Future Sensors (near-term)

Acronyms: AeroCube (AC), Medium Field of View (MFOV), Narrow Field of View (NFOV), Visible Infrared Imaging Radiometer Suite (VIIRS), Day-night-band (DNB), International Space Station (ISS), Defense Meteorological Support Program (DMSP)

We used existing cameras on Aerospace Corporation 1U and 1.5U CubeSats to image the Earth at Night guided by DMSP, VIIRS and ISS photography results

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Introduction – Nighttime Lights- a Potential CubeSat Mission

- The Use of Nighttime Lights Signals for Monitoring the Global Human Footprint has been Established by DMSP OLS and VIIRS DNB
  - *City lights, light pollution, urban growth and change, transportation grids*
  - *Global Natural Gas Flaring, Global Biomass Burning*
  - *Impact of Natural Disasters on Power Grid*
  - *New work with ISS photography shows utility of higher resolution*
  - *Past work "The Nightsat Mission Concept" proposed mission requirements*

- We are using existing Aerospace Corporation CubeSats with small on-board CMOS cameras to research nightlights imaging
  - *Establish capabilities of existing simple cameras*
  - *Determine if and how CubeSats complement the VIIRS DNB capability*
    - Different orbits can sample early evening hours
    - Different spectral bands – (such as RGB color)
    - Higher resolution over a smaller field of view

Nighttime lights are a potential CubeSat Mission – Signals are reasonably bright and moderate resolution is necessary – existing CubeSat cameras shown to approach Nightsat study requirements

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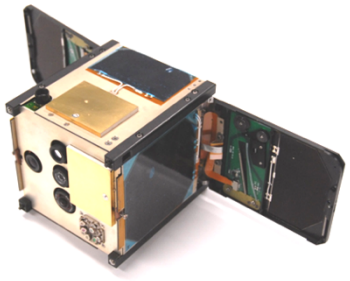
AeroCube Camera Details



AC-4

Satellite Camera	Lens F#	Lens FL (mm)	Pixel Pitch (µm)	Nominal Altitude (km)	GSD (m)
AC-4 (MFOV)	2	3.40	2.80	600	494
AC-5 (NFOV)	2	15.8	2.80	700	124

- 1600x1200 pixel 10-bit color RGB Bayer pattern CMOS arrays.
- Autoexposure was the only camera mode available for operations and images were downlinked using jpeg compression.
- The Aptina chips used were very compact, reasonably low-noise devices designed for use in machine vision and security camera applications and had decent low light sensitivity.

Cameras were not specially designed for nighttime measurements, but worked reasonably well. Other spacecraft details, including ACS, are documented in conference paper and references

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AeroCube-4 Persian Gulf Point and Stare Experiment

- Initial nighttime work with the AC-4 camera MFOV camera was in same “fly and shoot” mode used during daylight.
- A command sequence was crafted to take images every 5 seconds on the way to a target and then point and stare while continuing to take images. This results in enhanced resolution and sensitivity.
- The AC-4 Persian Gulf collection pass for this experiment started over Baghdad and took a sequence of images in push broom mode every 5 seconds until the sensor orbited South directly over Kuwait City. At that position, AC-4 was programmed to stay pointed at Kuwait City to reduce smear and obtain optimal images. The sensor continued to image every 5 seconds until the Earth horizon rose.

The next charts animate the data collect, compare the resulting Persian Gulf image to VIIRS DNB data, and then highlight prominent gas flares in the scene before and after pointing to show the improvement in resolution and sensitivity

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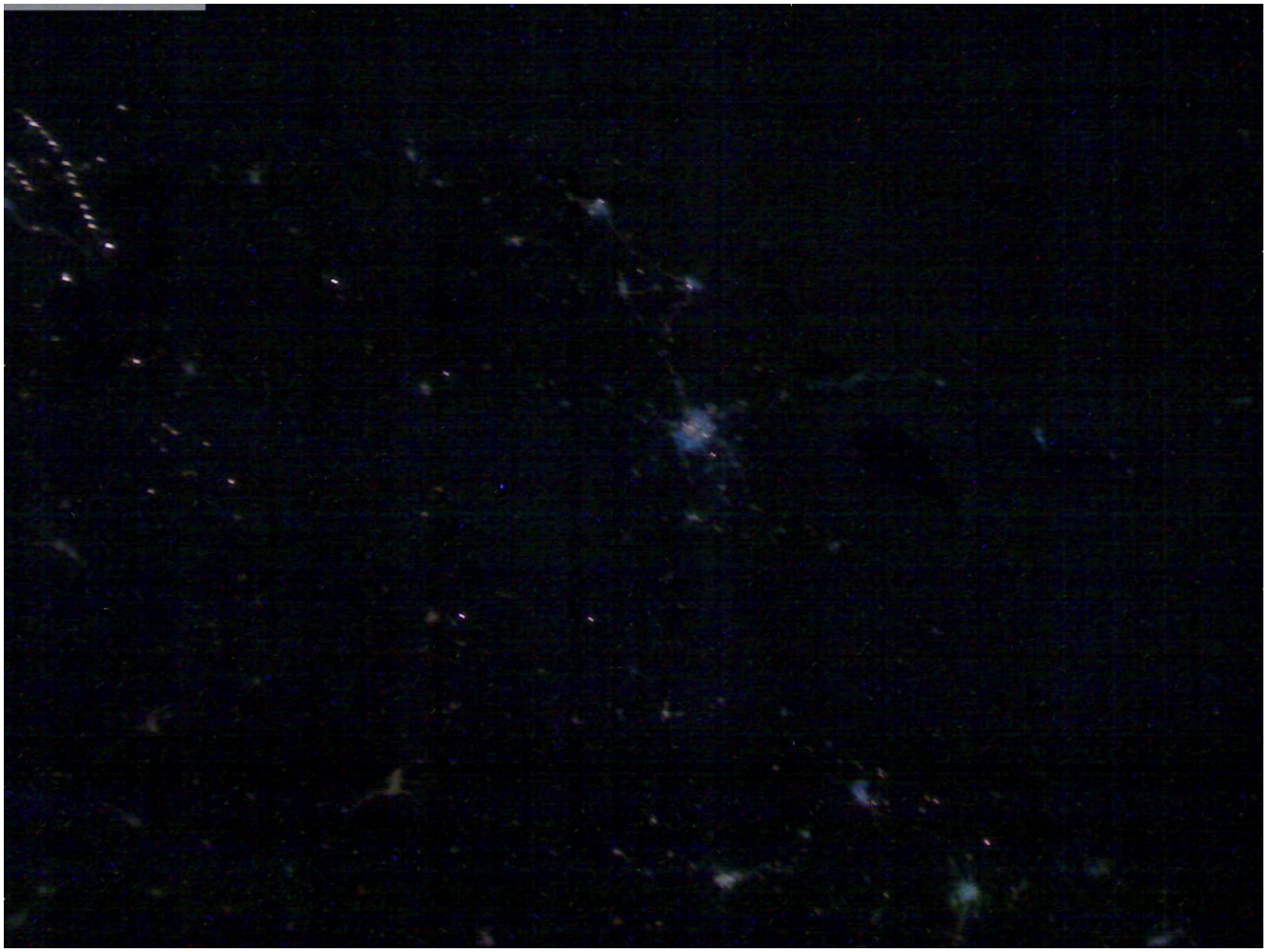
11 July 2014 AC-4 Persian Gulf Flyover Experiment



14 Frame Video - Next 2 slides highlight the Kuwait City nadir shot (frame 9) and the transition to point and stare data collection at frames 8 and 9

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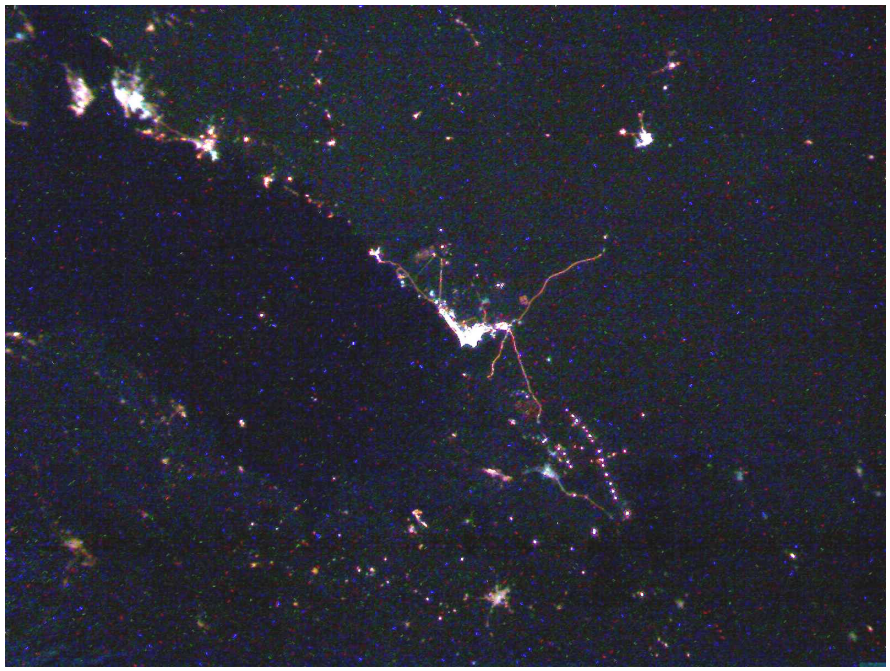
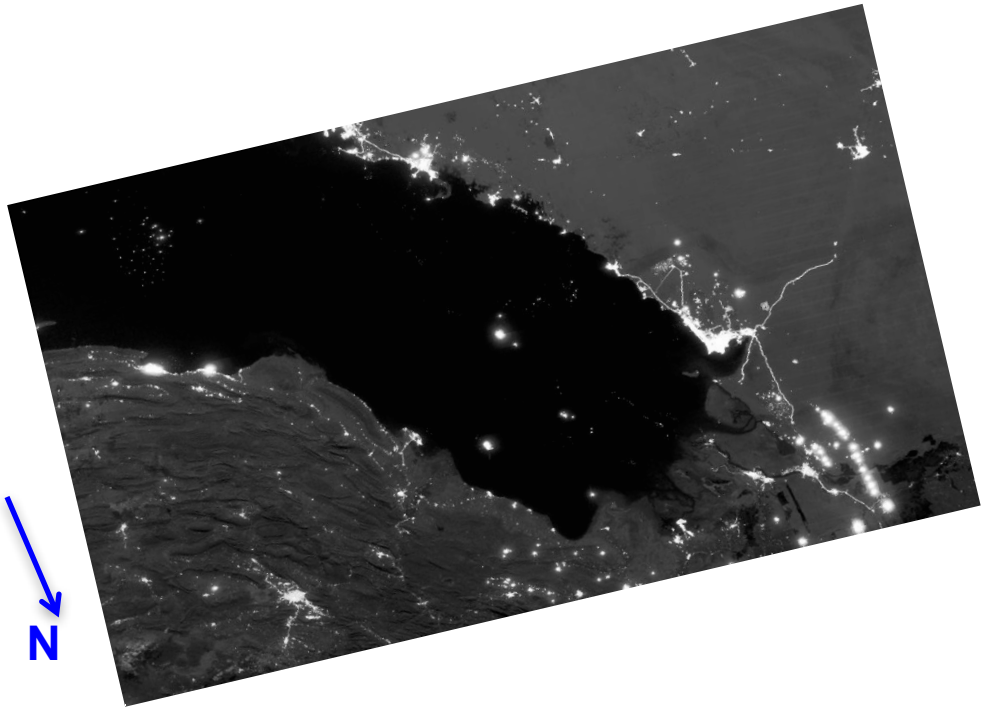
11 July 2014 Comparison of AC-4 and VIIRS





AC-4 MFOV camera 11 July 2014 22:30:03 UT
Lunar data: Altitude 32.2°, Azimuth 218°, phase 99%

VIIRS DNB 11 July 2014 22:50:04 UT
Lunar data: altitude 29.5°, azimuth 222°, phase 99%

(VIIRS Data are Courtesy of Chris Elvidge, NOAA and Kimberly Baugh, Cooperative Institute for Research in Environmental Sciences, University of Colorado).

- Kuwait City in Center
- Major features seen in common, lights, flares (flare details in next chart)
- AC-4 camera barely detects moonlit desert surface

Comparison of AC-4 to calibrated VIIRS data shows ~ 20nW-cm^{-2}-sr^{-1} sensitivity (S/N ~ 4) for AC-4

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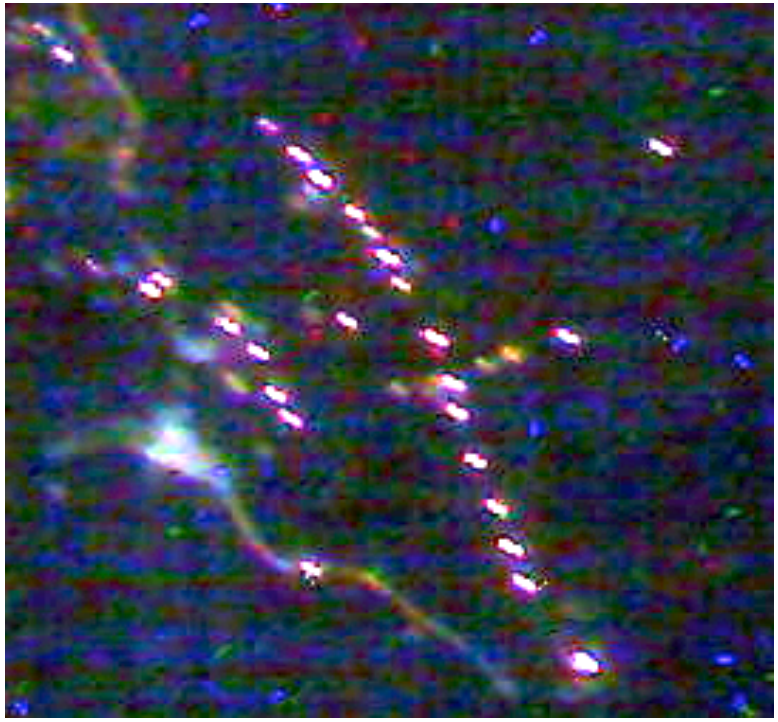
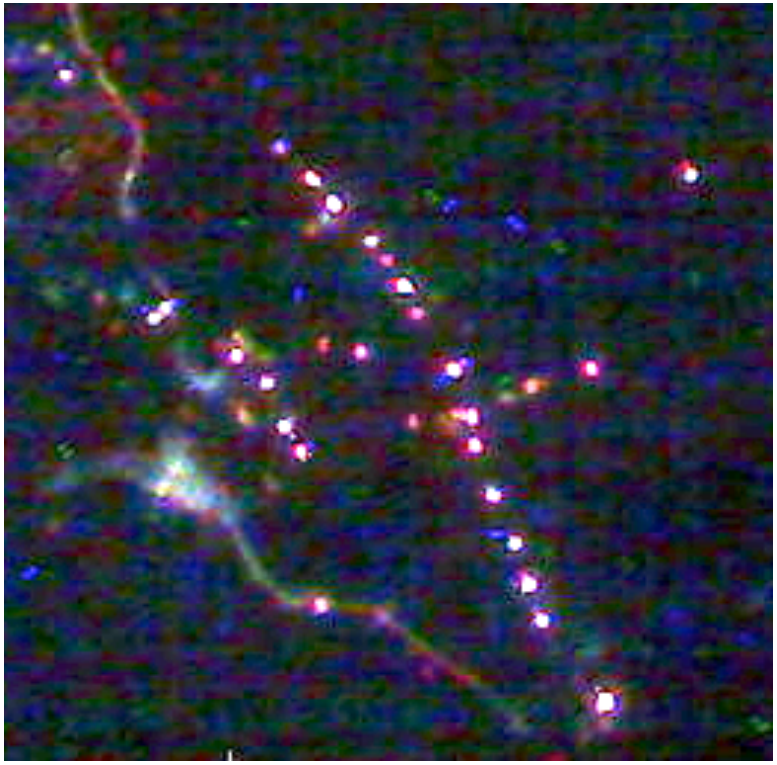
AC-4 Basra Flares Pre and Post Point-and-Stare Command





- Image chips show detailed look at the Basra area gas flares and illustrate how the point and stare maneuver improves resolution and sensitivity
- Image chips from full frame image are ~ 120 x 120 km

~ 5 pixel smear and 7.7 km/sec spacecraft velocity allow calculation of of a camera autoexposure of ~ 0.3 seconds in duration

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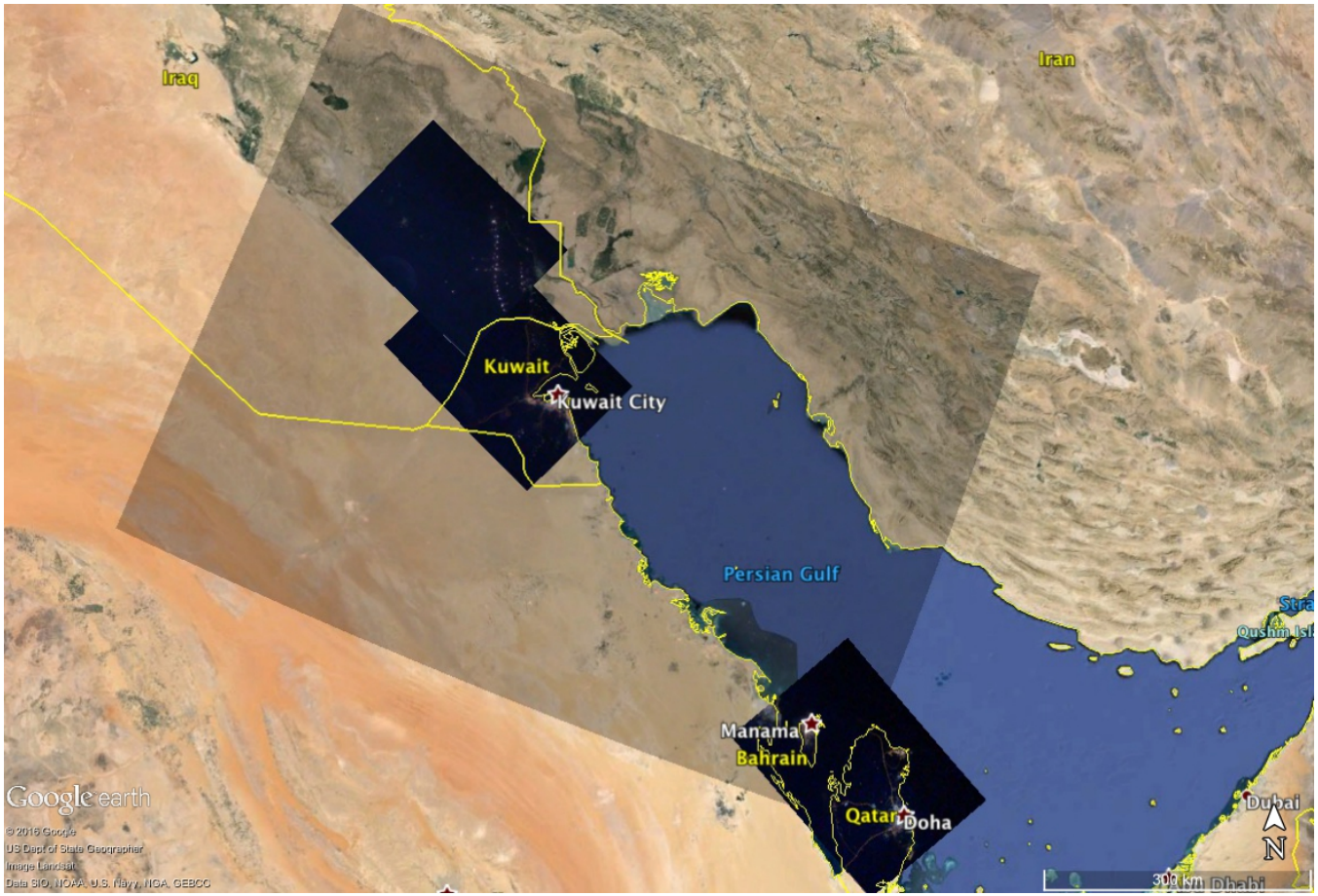
The Persian Gulf Region with Overlaid AeroCube Camera Fields of View



3 Frames from the 11 May 2015 AC-5 NFOV Gulf Flyby Experiment with the Larger 11 July 2014 AC-4 MFOV Camera Footprint Superimposed.

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AC-5 Persian Gulf – Qatar, Bahrain 11 May 2015 23:29 UT

Qatar, Bahrain and the Coast of Saudi Arabia – city lights, roads, race track ovals, GSD ~ 130 m

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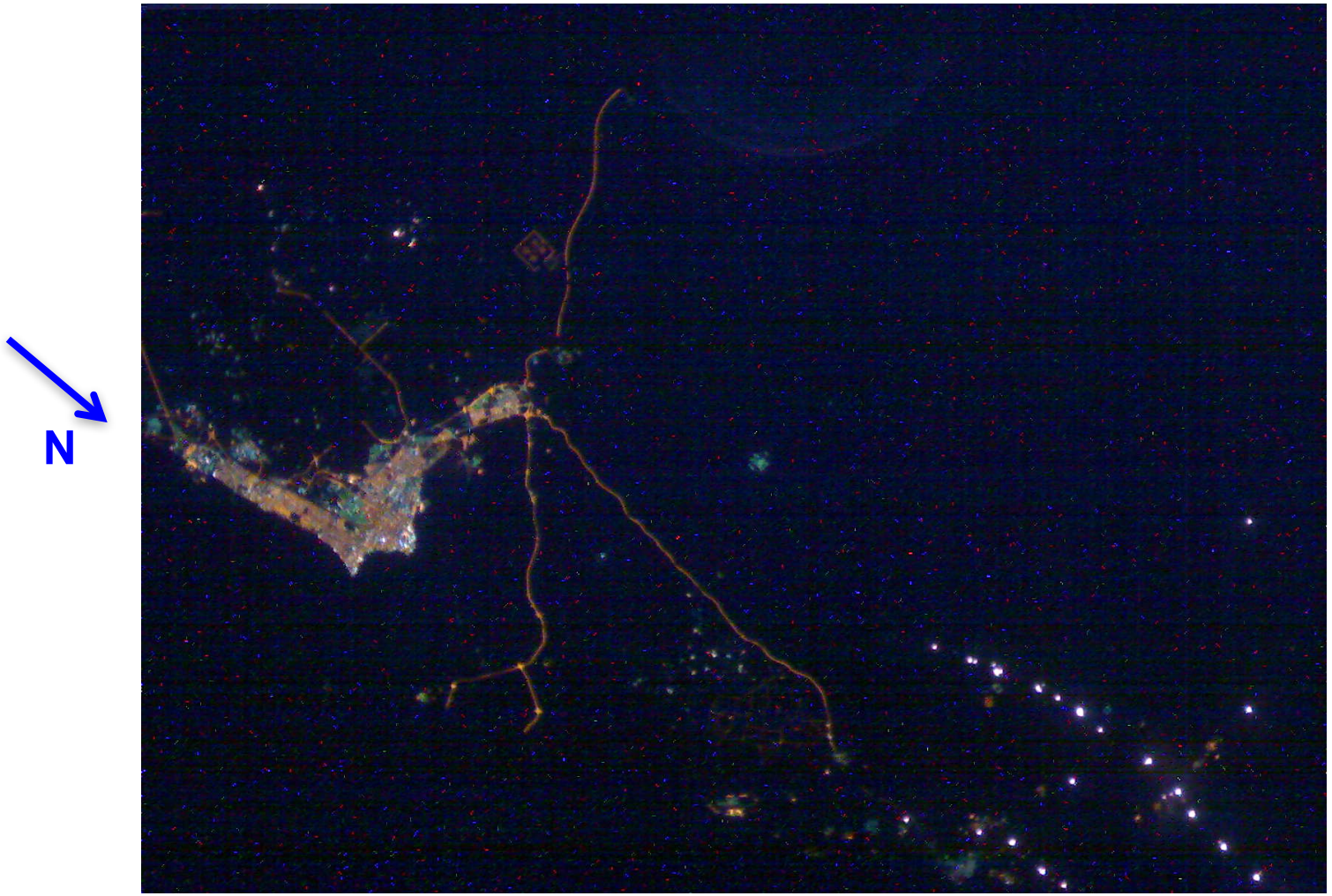
AC-5 Persian Gulf – Kuwait, Iraq Border Flares 11 May 2015 23:30 UT



Kuwait City, Roads in Desert, Rumaila Flares, GSD ~ 130m

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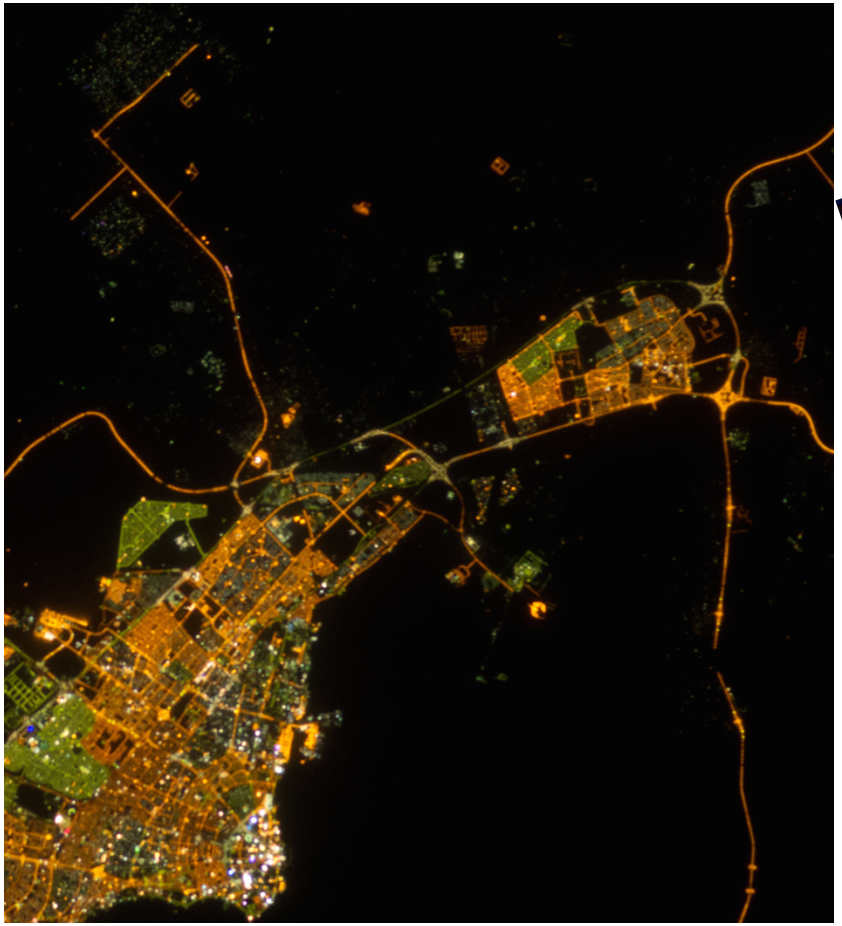
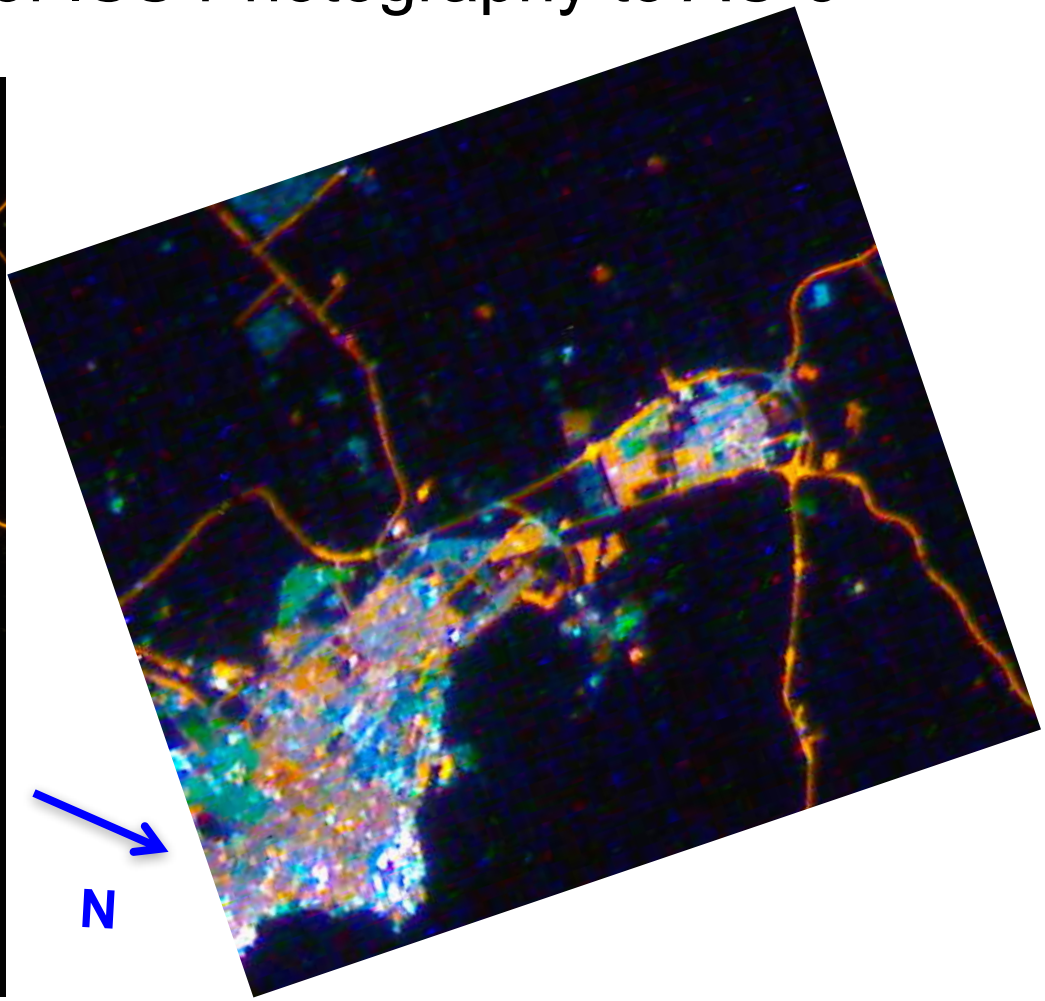
Kuwait City: Comparison of ISS Photography to AC-5





ISS Image 12 Feb 2013 21:52 UT,
GSD ~ 20 m

AC-5 Image 28 Jun 2015 22:27 UT
GSD ~ 95 m

Space Station nightpod with Nikon D3S (f/2.8 180 mm lens) vs. 1.5 U AeroCube-5 utility camera

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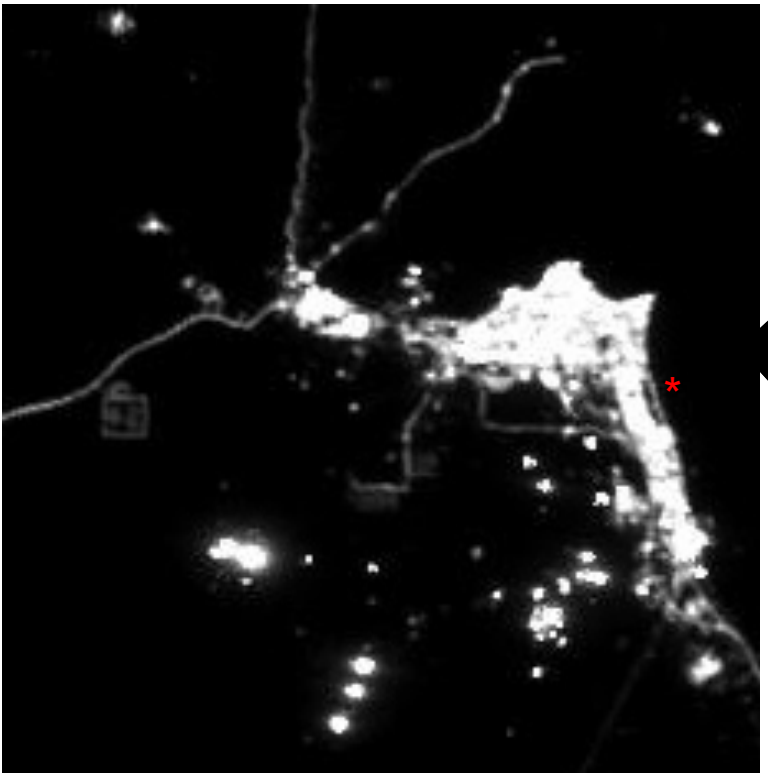
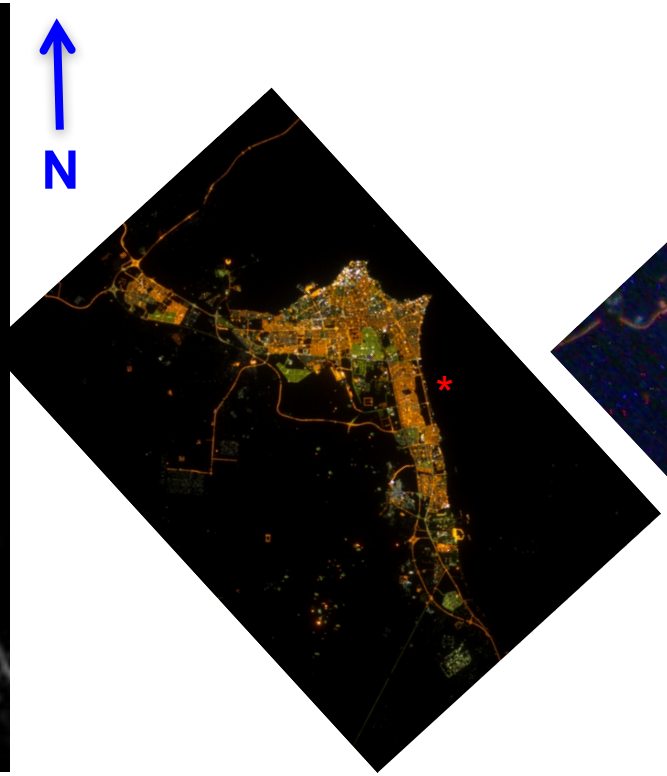
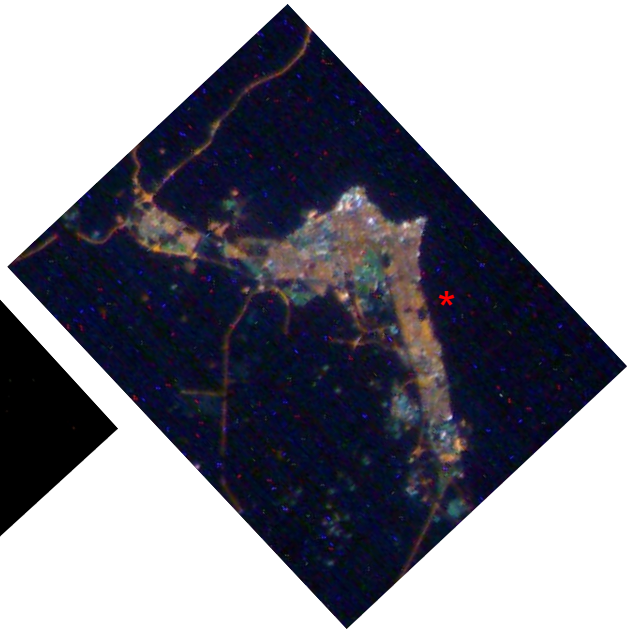
Kuwait City: Comparison of VIIRS, ISS and AC-5



VIIRS detail of Kuwait City
Jan 2013 Nightlights Composite
742 m GSD



ISS Nightpod Nikon
with 180 mm Lens
~ 20 m GSD
12 Feb 2013



AeroCube-5
NFOV Camera
~ 130m GSD
11 May 2015

Development of coastal neighborhood evident in the later AC-5 data

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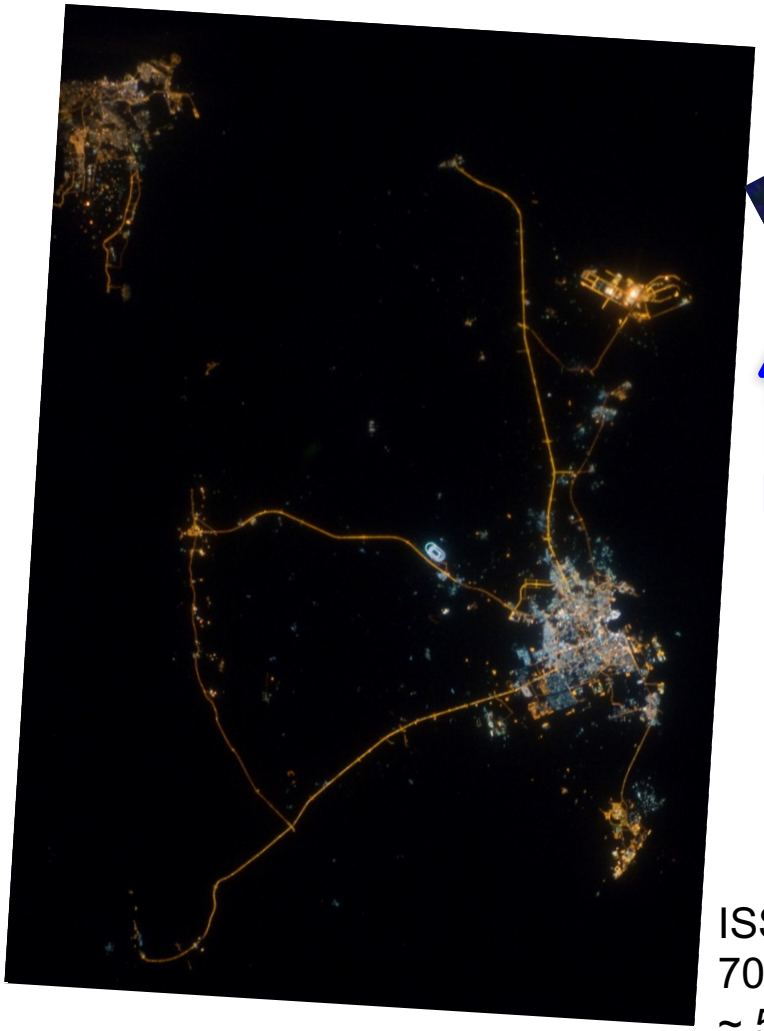
Qatar: Comparison of ISS to AC-5



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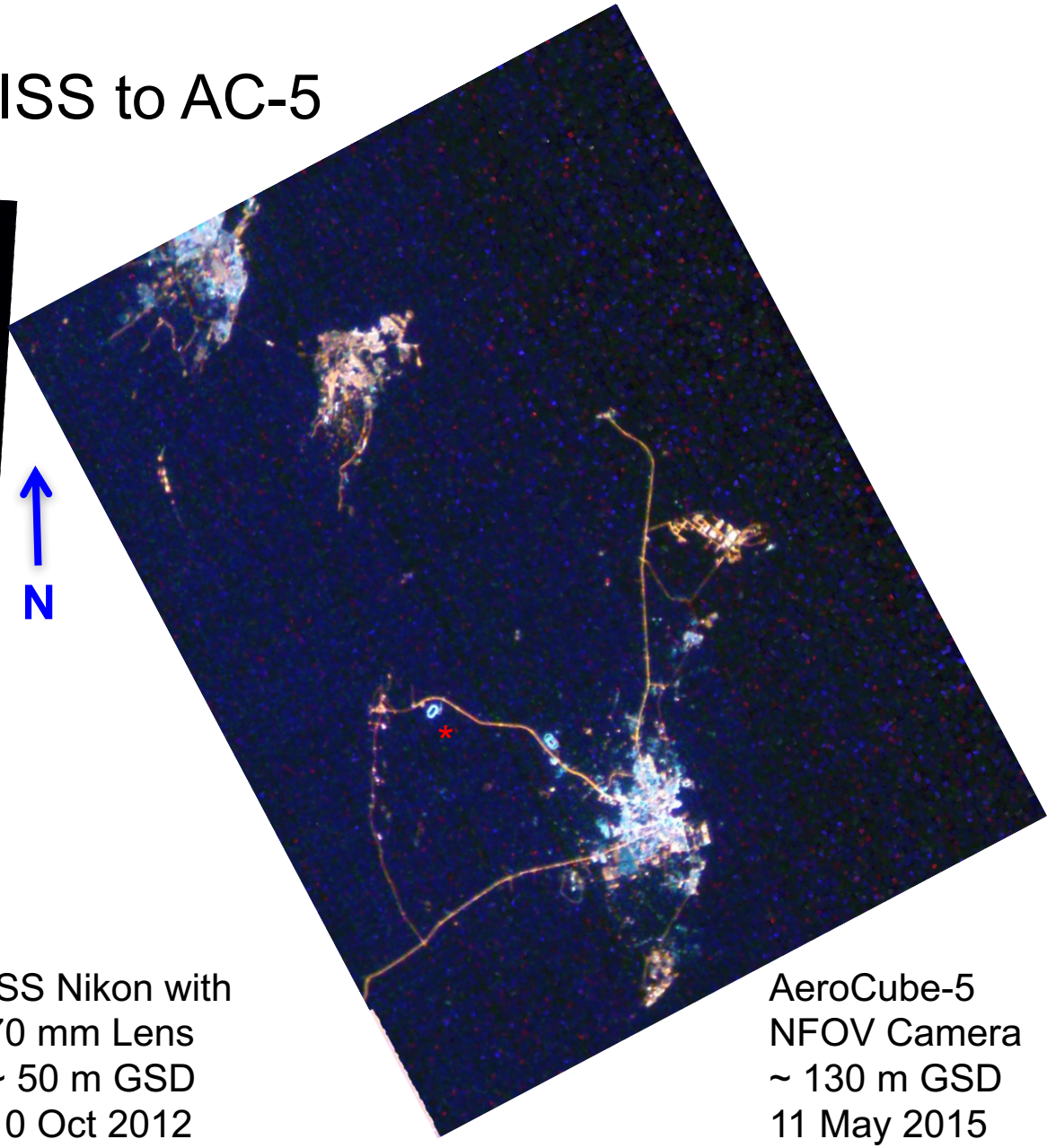

ISS Nikon with
70 mm Lens
~ 50 m GSD
10 Oct 2012

AeroCube-5
NFOV Camera
~ 130 m GSD
11 May 2015

A new racetrack appears in Qatar in the more recent AC-5 image

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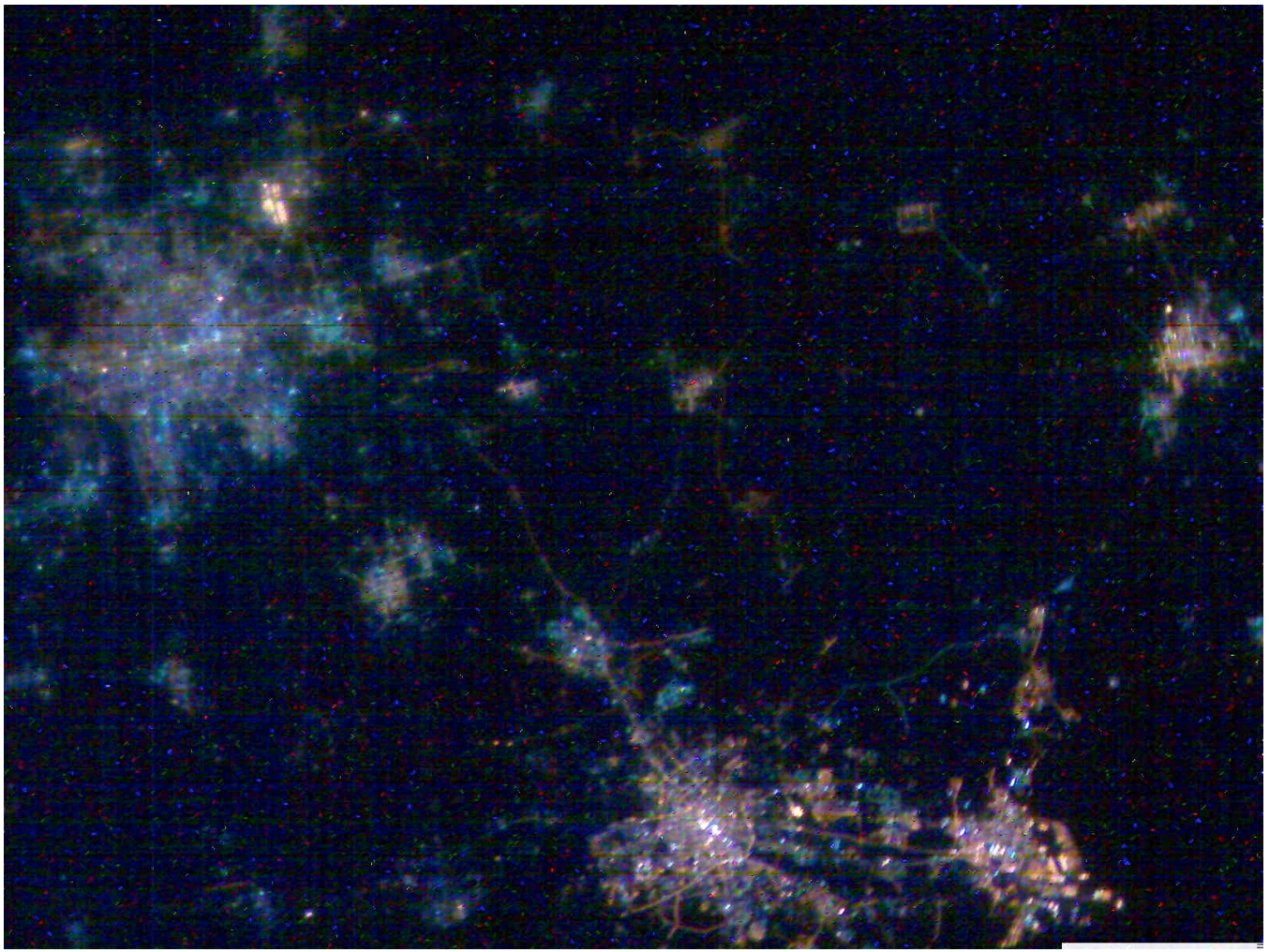
AC-5 Beijing and Tianjin 29 April 2015 16:08 UT



Beijing and Tianjin – possible obscuration by thin clouds, airport, transportation corridors evident

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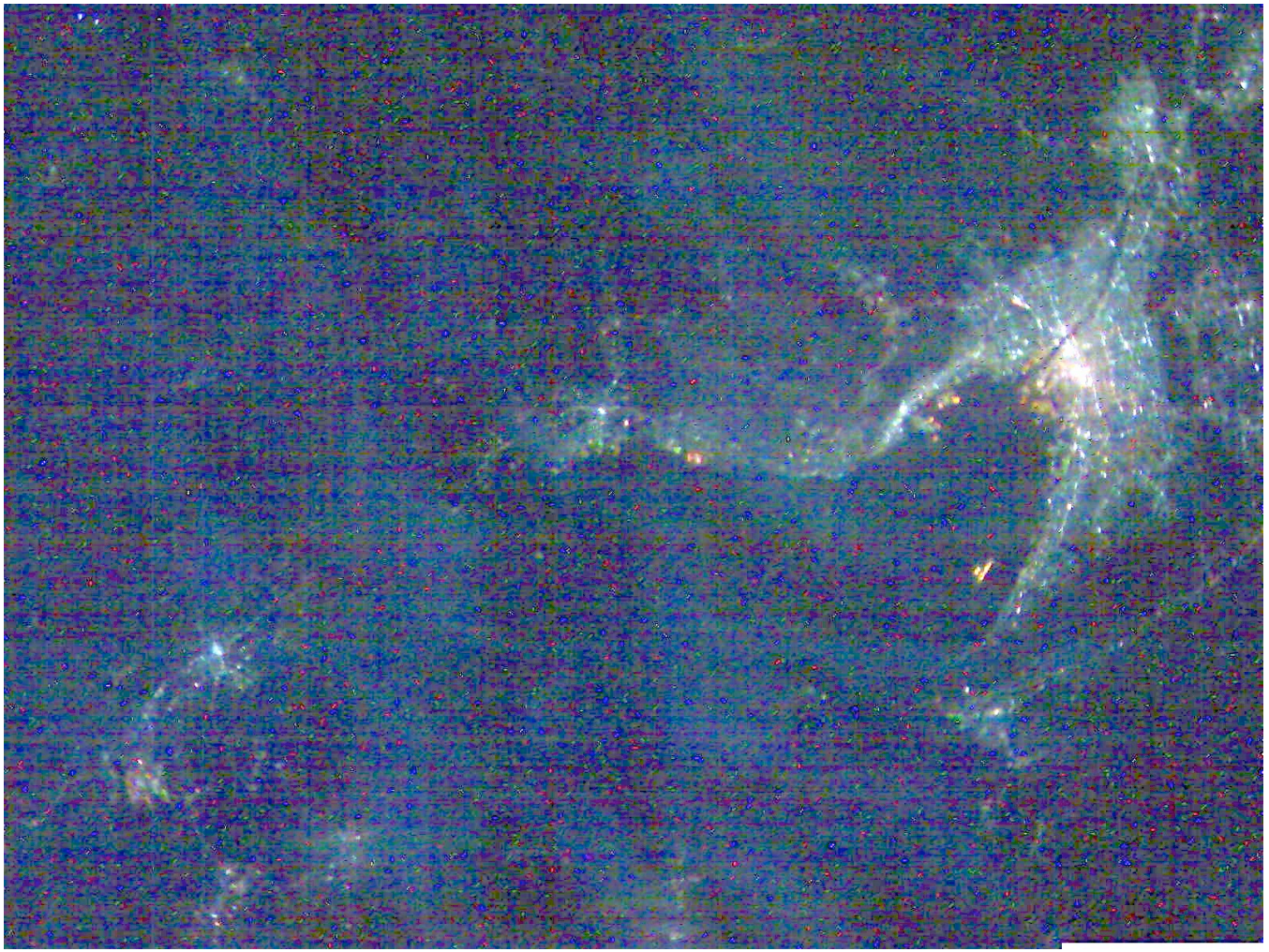
AC-5 Osaka 02 May 2015 15:55 UT



Osaka– AC-5A, Moon is 98% full, thin clouds are barely visible, airport in Osaka Bay is prominent

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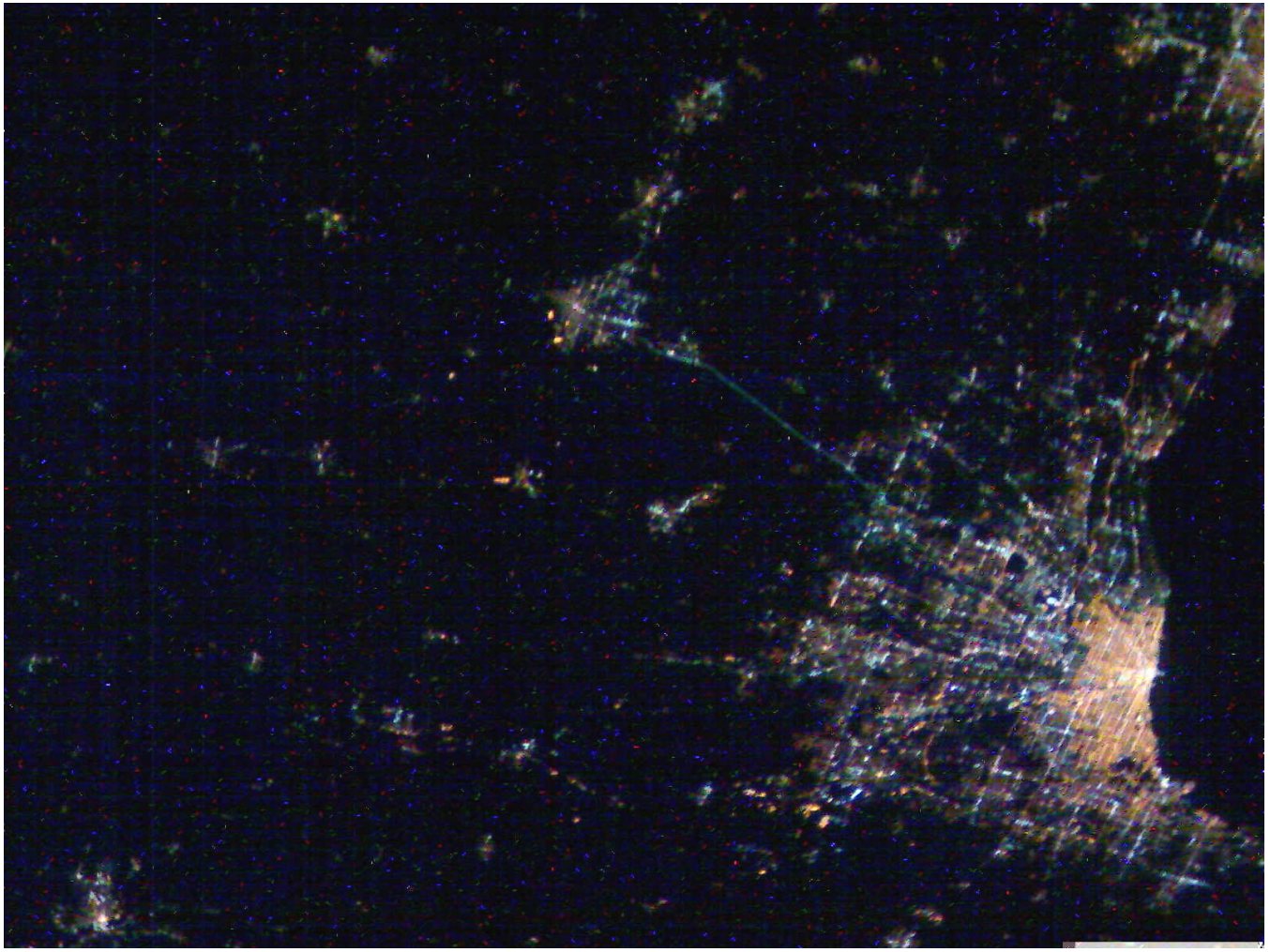
AC-5 Chicago 01 May 2015 05:43 UT



Chicago – urban grid, transportation corridors, Lake Michigan coastline evident

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Philadelphia and New York City 31 October 2015 04:49 UT

East Coast of USA – Philadelphia, Newark, NYC, I-95 transportation corridor are evident

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Future Sensors (near term)

Satellite Camera	Lens F#	Lens FL (mm)	Pixel Pitch (µm)	Nominal Altitude (km)	GSD (m)
AC-7 (high res)	1.9	34.9	1.67	600	28.7
CUMULOS VIS	1.4	17.6	5.20	600	177
CUMULOS SWIR	1.4	25.0	25	600	600
CUMULOS LWIR	1.1	25.0	17	600	408

- 2 NASA Optical Communication and Sensor Demonstration CubeSats (aka AC-7)
- CUMULOS (the CUbesat MULtispectral Observation System) which is hosted on the NASA ISARA (Integrated Solar Array and Reflectarray Antenna) CubeSat
- All are scheduled to launch on a Falcon-9 v1.1 rocket along with Formosat-5 and a number of other CubeSat payloads. The launch is currently scheduled for 18 December 2016.
- These camera payloads will add to our ability to research the Earth at night from CubeSat platforms.

Coming next – a higher resolution camera on AC-7 and CUMULOS, a 3-camera VIS/SWIR/LWIR sensor

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