Skybox Imaging

Your World on Demand

Realtime Satellite Tracking in the Browser

David Calhoun, Skybox Imaging

http://bit.ly/jsconf-satellites

Skybox by the numbers

2009

Incorporation

$91M

Raised from Khosla Ventures, Bessemer Ventures, Canaan Ventures and Norwest Venture Partners

6

Months since the launch of SkySat-1

24

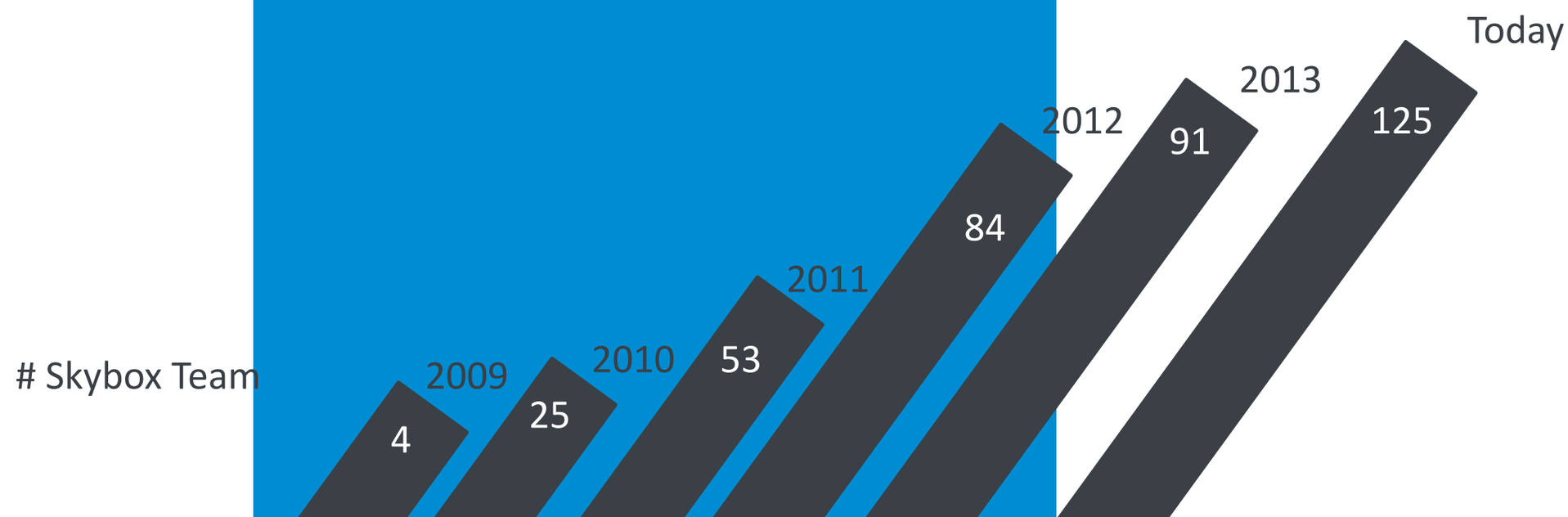
Satellites in planned constellation

Q2 2014

SkySat-2 Launch

100+

Number of space missions supported by the team



Skybox Imaging

Skybox's Products

Direct Access

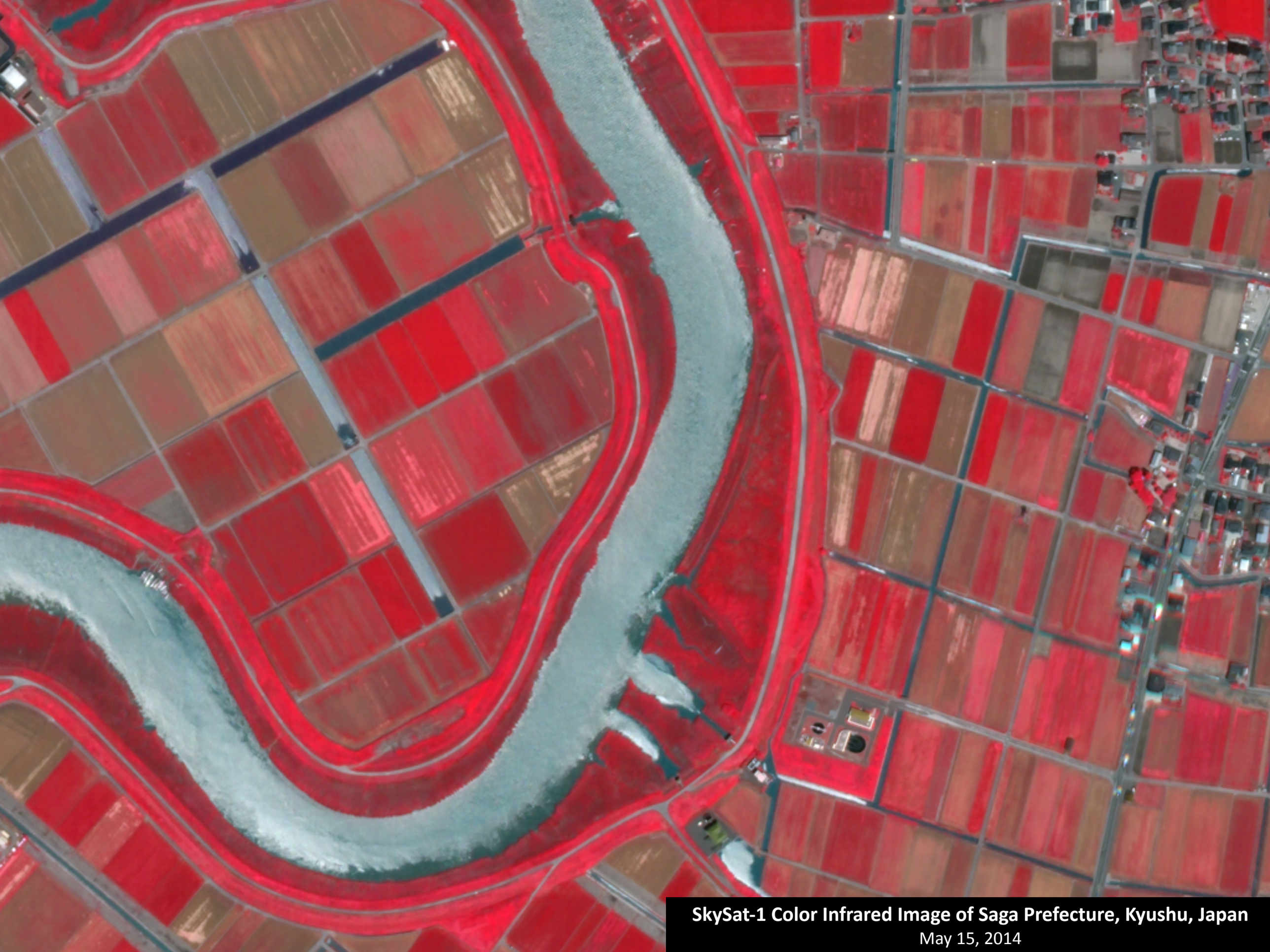
Imagery & Video

Analytics

Skybox Imaging

SkySat-1 and SkySat-2 Complete

Skybox Mission Operations Center (MOC)



SkySat-1 Color Infrared Image of Saga Prefecture, Kyushu, Japan

May 15, 2014

Panchromatic, full motion HD video

Skybox Imaging

We launch our products, and we’re hiring!

As a UI engineer…

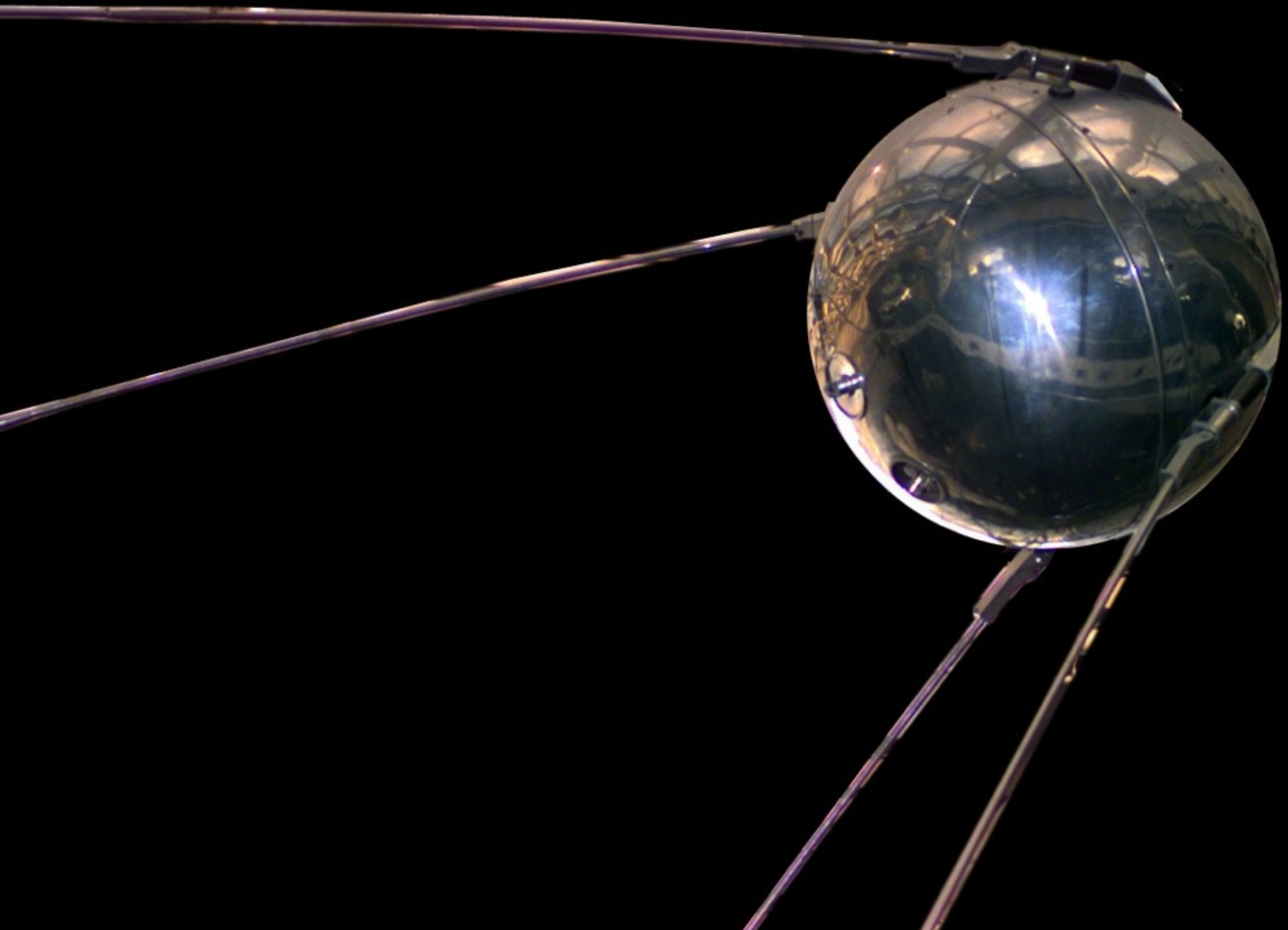
- **telemetry dashboard**: WebSocket-powered, lives in MOC
- “**Search**”: map-based satellite image/video catalog
- “**Schedule**”: map-based image scheduling UI
- “**Process**”: dashboard for managing image processing workflow

Skybox Imaging

Rewind

50+ years…

Skybox Imaging



"All the News That's Fit to Print"

The New York Times.

LATE CITY EDITION
Cloudy and cool today and tonight. Mostly fair tomorrow.
Temp. range: 65—55. Tuesday: 62.4—49.3

VOL. CVII..No. 36,414. NEW YORK, SATURDAY, OCTOBER 5, 1957. FIVE CENTS

SOVIET FIRES EARTH SATELLITE INTO SPACE; IT IS CIRCLING THE GLOBE AT 18,000 M. P. H.; SPHERE TRACKED IN 4 CROSSINGS OVER U. S.

HOFFA IS ELECTED TEAMSTERS' HEAD; WARNS OF BATTLE

Defeats Two Foes 3 to 1 —Says Union Will Fight 'With Every Ounce'

Text of the Hoffa address is printed on Page 6.

By A. H. RASKIN
Special to The New York Times.

MIAMI BEACH, Oct. 4—The scandal-scarred International Brotherhood of Teamsters elected James R. Hoffa as its president today.

He won by a margin of nearly 3 to 1 over the combined vote of two rivals who campaigned on pledges to clean up the nation's biggest union.

Senate rackets investigators and Hoffa critics in the union rank-and-file immediately opened actions to strip the 44-year-old former warehouseman from Detroit of his election victory.

A jubilant Hoffa exhibited, however, greater concern over the possibility that his union might be ousted from the American Federation of Labor and Congress of Industrial Organizations. He appealed for time to prove that he could make the teamsters "a model of trade unionism."

The parent organization has ordered the 1,600,000-member Teamsters Union to get rid of

IN TOKEN OF VICTORY: Dave Beck, retiring head of the Teamsters Union, raises hand of James R. Hoffa upon his election as union's president. At right is Mrs. Hoffa.

COURSE RECORDED

Navy Picks Up Radio Signals—4 Report Sighting Device

By WALTER SULLIVAN
Special to The New York Times.

WASHINGTON, Saturday, Oct. 5—The Naval Research Laboratory announced early today that it had recorded four crossings of the Soviet earth satellite over the United States.

It said that one had passed near Washington. Two crossings were farther to the west. The location of the fourth was not made available immediately.

It added that tracking would be continued in an attempt to pin down the orbit sufficiently to obtain scientific information of the type sought in the International Geophysical Year.

[Four visual sightings, one of which was in conjunction with a radio contact, were reported by early Saturday morning. Two sightings were made at Columbus, Ohio, and one each from Terre Haute, Ind., and Whittier, Calif.]

Press Reports Noted

Soviet newspapers reported several weeks ago that the Soviet satellites would broadcast on frequencies in the neighborhood of twenty and forty megacycles. More exact frequencies were given by Soviet scientists at a conference on rockets and satellites that took place here this week.

Presumably the Naval Research Laboratory, which is responsible for the United States

The New York Times Oct. 5, 1957
The approximate orbit of the Russian earth satellite is shown by black line. The rotation of the earth will bring the United States under the orbit of Soviet-made moon.

560 MILES HIGH

Visible With Simple Binoculars, Moscow Statement Says

[Text of Tass announcement]

The Soviet Union announced this morning that it successfully launched a man-made earth satellite into space yesterday.

The Russians calculated the satellite's orbit at a maximum of 560 miles above the earth and its speed at 18,000 miles an hour.

The official Soviet news agency Tass said the artificial moon, with a diameter of twenty-two inches and a weight of 184 pounds, was circling the earth once every hour and thirty-five minutes. This means more than fifteen times a day.

Two radio transmitters, Tass said, are sending signals continuously on frequencies of 20.005 and 40.002 megacycles. These signals were said to be strong enough to be picked up by amateur radio operators. The trajectory of the satellite is being tracked by numerous scientific stations.

Due Over Moscow Today

Tass said the satellite was moving at an angle of 65 degrees to the equatorial plane and would pass over the Moscow area twice today.

"In flight," the announce-

Device Is 8 Times Heavier Than One Planned by U.S.

Special to The New York Times.

WASHINGTON, Oct. 4—Leaders of the United States earth satellite program were astonished tonight to learn that the Soviet Union had launched a satellite eight times heavier than that contemplated by this country.

Dr. Joseph Kaplan, chairman of the United States program for the International Geophysical Year, described the 184-pound weight as "fantastic." The heaviest American satellites are to weigh twenty-one

SATELLITE SIGNAL BROADCAST HERE

FAUBUS COMPARES HIS STAND TO LEE'S

Says He Will Remain Loyal to People of Arkansas—All Is Quiet at School

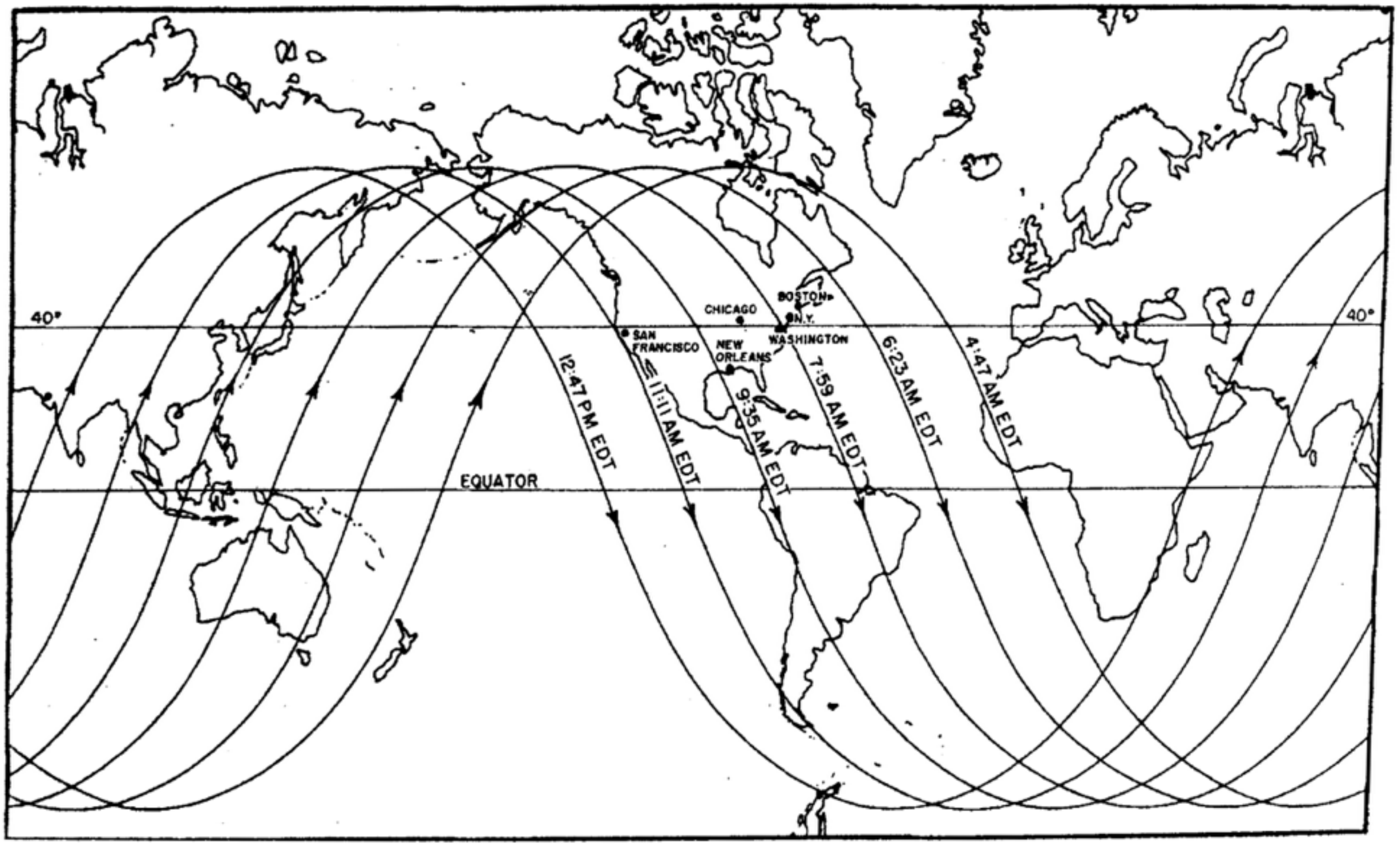
Flu Widens in City; 10% Rate Predicted; 200,000 Pupils Out

By ROBERT ALDEN

Asian influenza continued to spread through the city yesterday.

ARGENTINA TAKES EMERGENCY STEPS

State of Siege Proclaimed in Buenos Aires Region —Arrests Reported



Orbits of USSR satellite released 10/8/57 by the U.S. Naval Research Laboratory. (U.S. Navy)

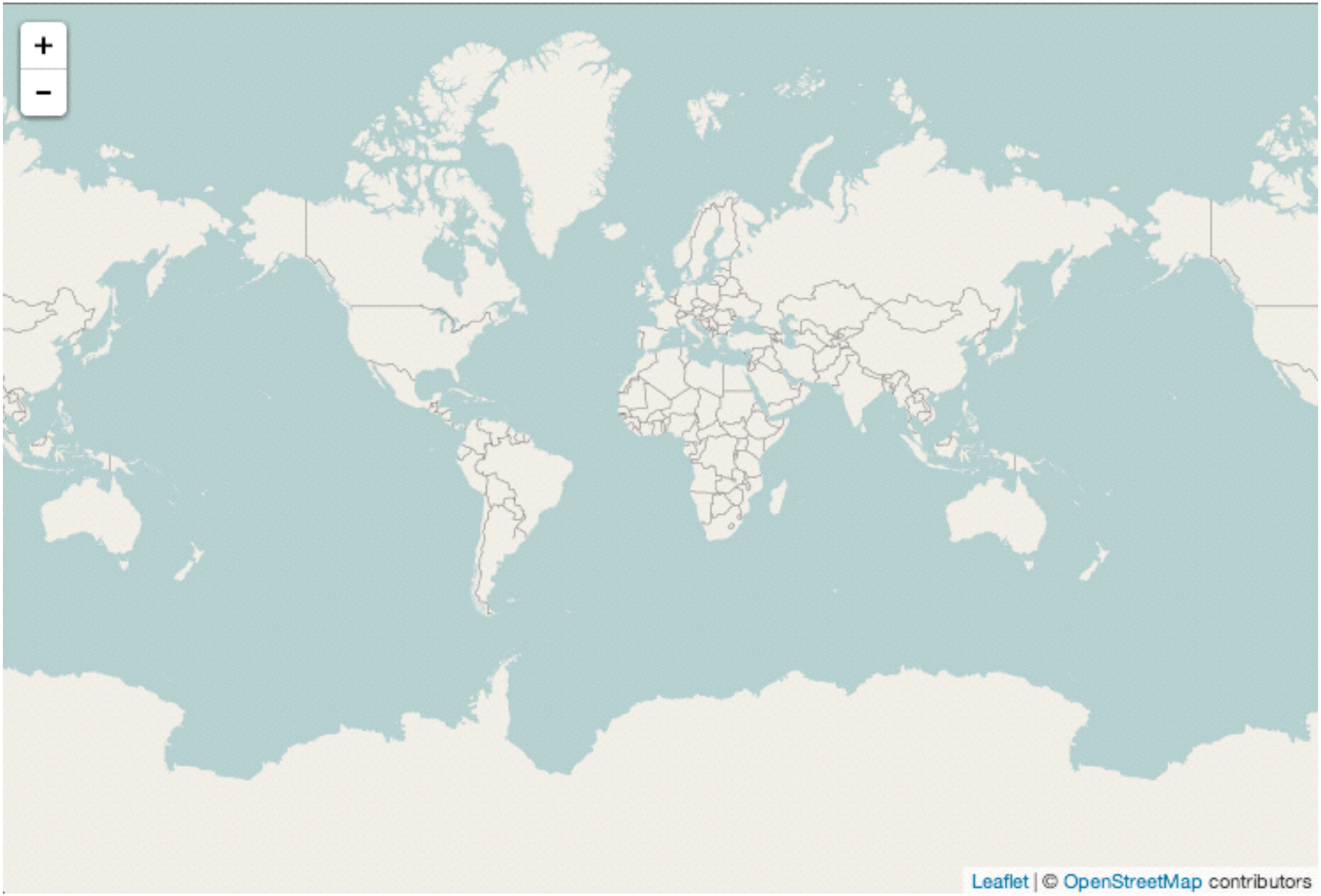
Fast Forward - SkySat 1 Launch

Skybox Imaging

Goal:
Plot current SkySat-1 position on a map

Skybox Imaging

Step 1: Leaflet.js Map



Skybox Imaging

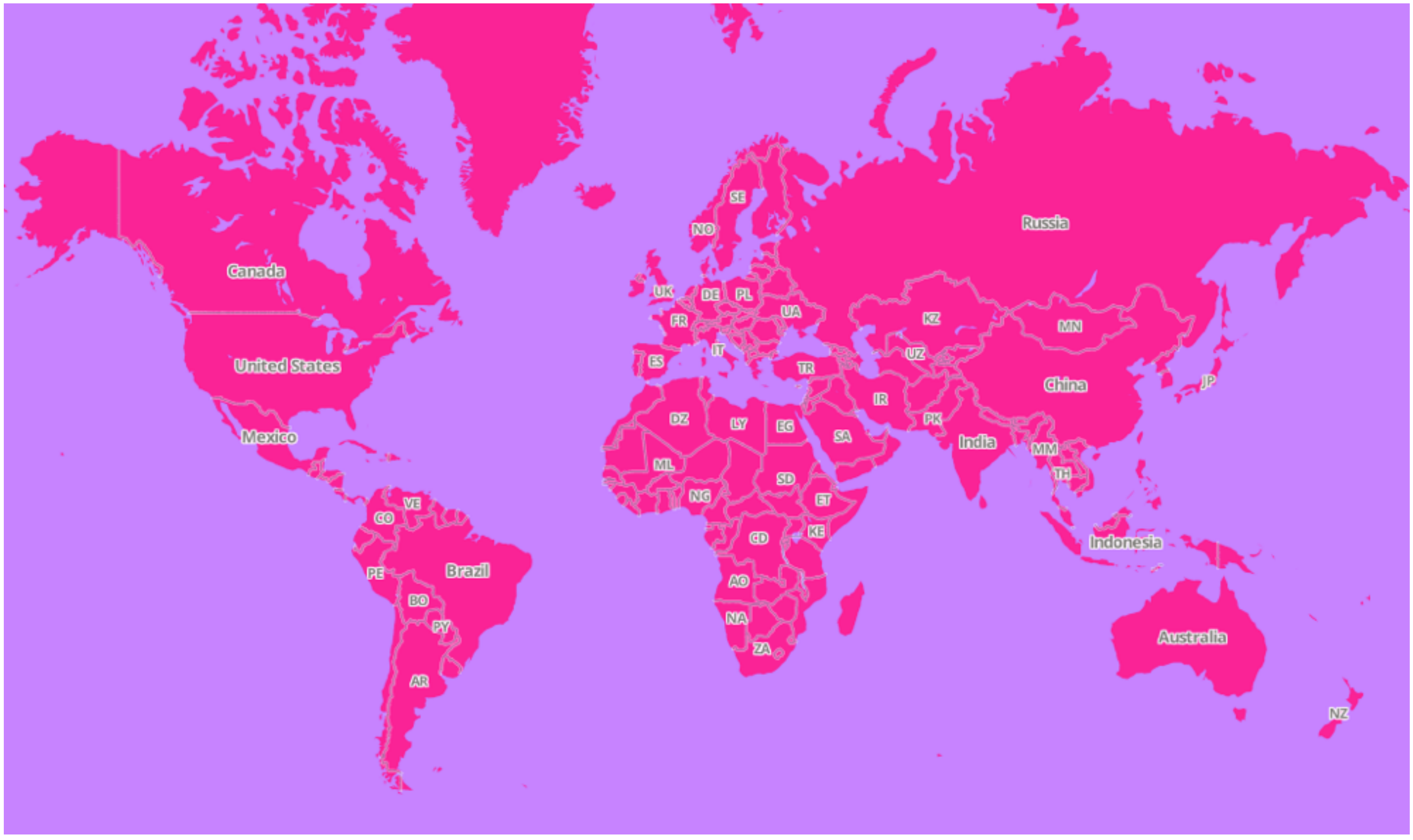
```
1  // initialize map at 0,0 lat/lon, with a zoom of 1 (zoomed out)
2  var map = L.map('map').setView([0, 0], 1);
3
4  // add a tile layer (OpenStreetMap)
5  L.tileLayer('http://{s}.tile.osm.org/{z}/{x}/{y}.png', {
6      attribution: '&copy; <a href="http://osm.org/copyright">
           OpenStreetMap</a> contributors'
7  }).addTo(map);
```

Skybox Imaging

Step 2: Mapbox tiles

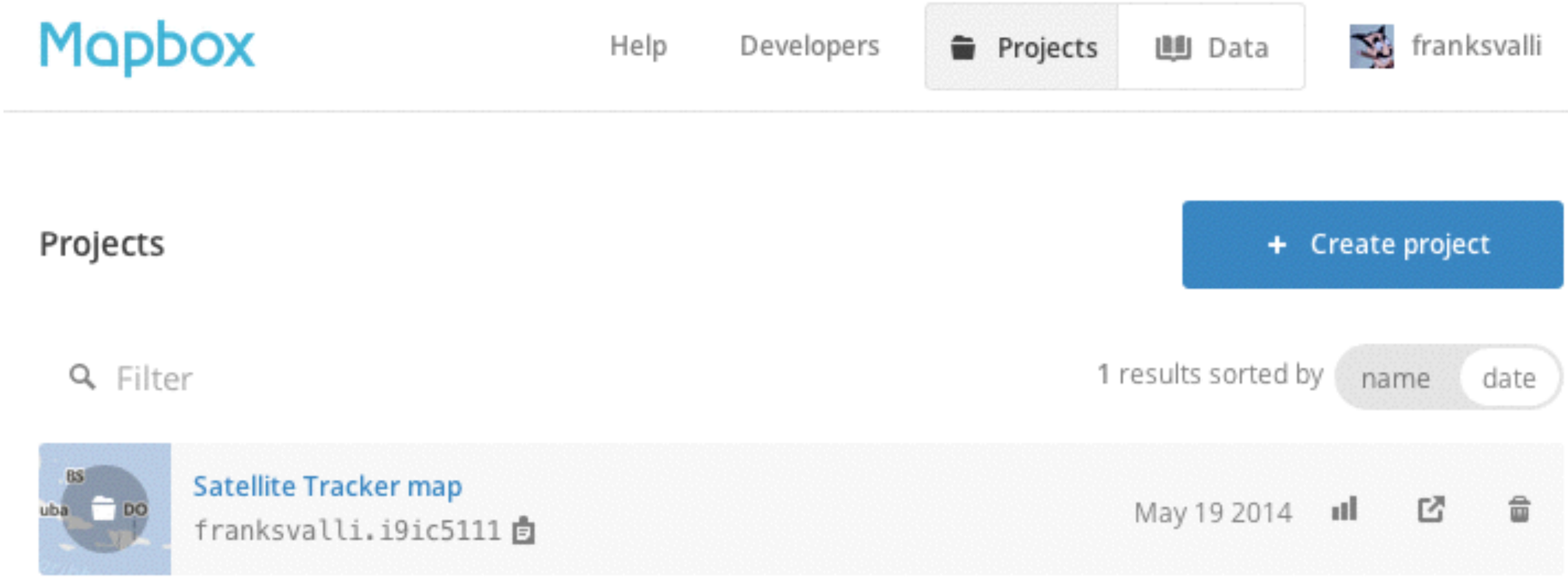
Skybox Imaging

Custom Mapbox tiles: Hello Kitty!



Skybox Imaging

Create map, Get key



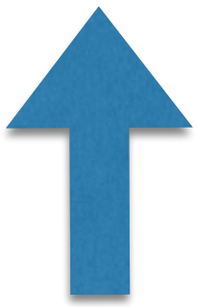
Skybox Imaging

Replace vanilla Leaflet with Mapbox-wrapped Leaflet

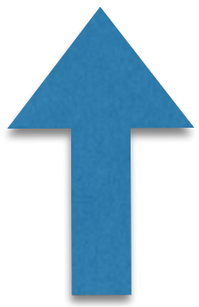
```
20  <script src='http://api.tiles.mapbox.com/mapbox.js/v1.6.2/mapbox.js'></script>
```

Slightly different map init

```
1  var map = L.mapbox.map('map', 'franksvalli.i9ic5111').setView([0, 0], 1);
```



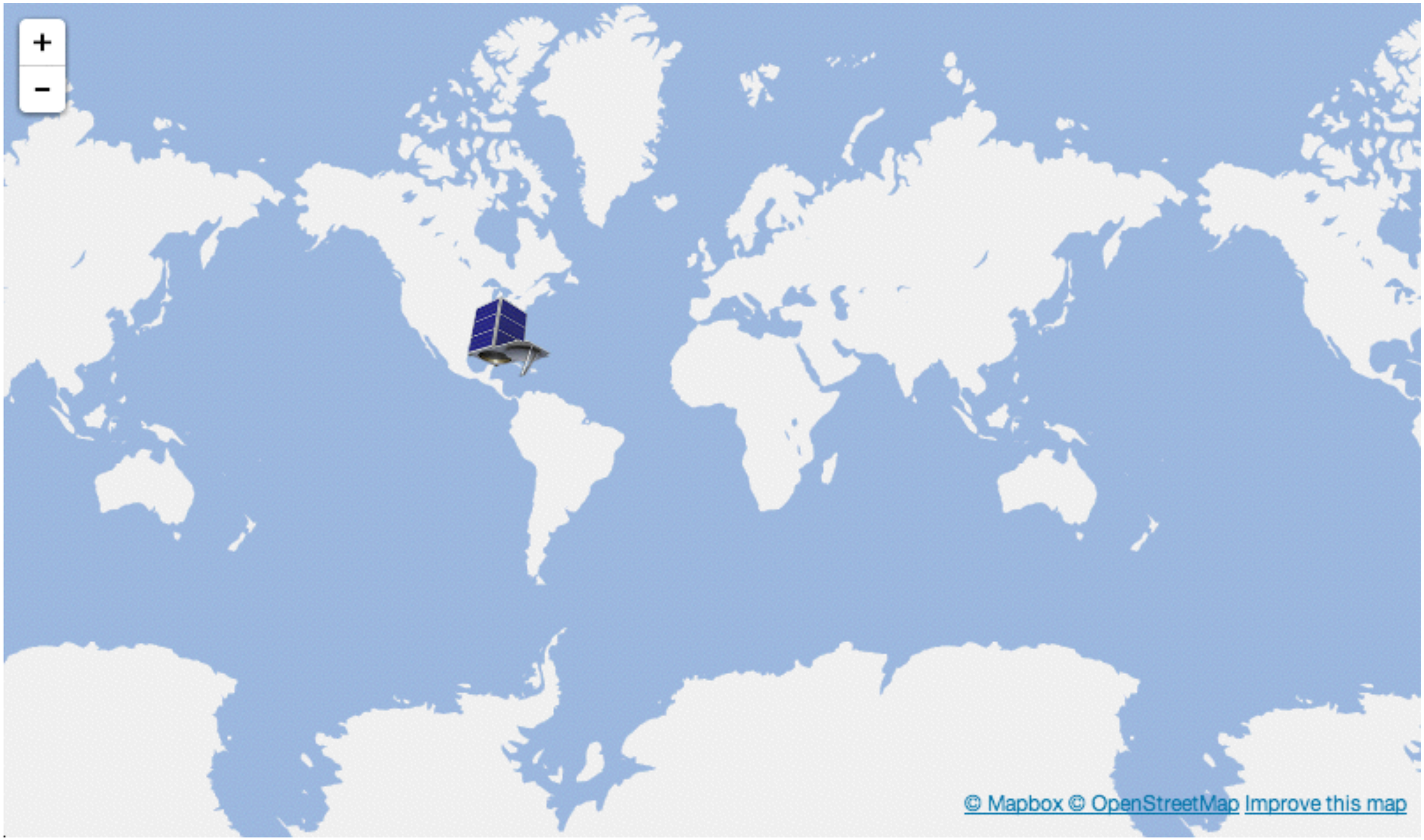
L = Leaflet global



Mapbox API key

Skybox Imaging

Step 3: Marker with custom icon



Skybox Imaging

```
//  basic marker
L.marker([30.5554579,-81.4439261]).addTo(map);

//  custom marker
L.marker([30.5554579,-81.4439261],{
    icon: L.icon({
        //  custom SkySat-1 icon
        iconUrl:        'skysat-1.png',
        iconRetinaUrl: 'skysat-1@2x.png',

        //  size of the icon
        iconSize:       [50, 48],

        //  define icon anchor to lat/lon
        //  (here it's the center)
        iconAnchor:     new L.Point(25, 24)
    })
}).addTo(map);
```

Skybox Imaging

Wait, we need…

Math.

Astrophysics.

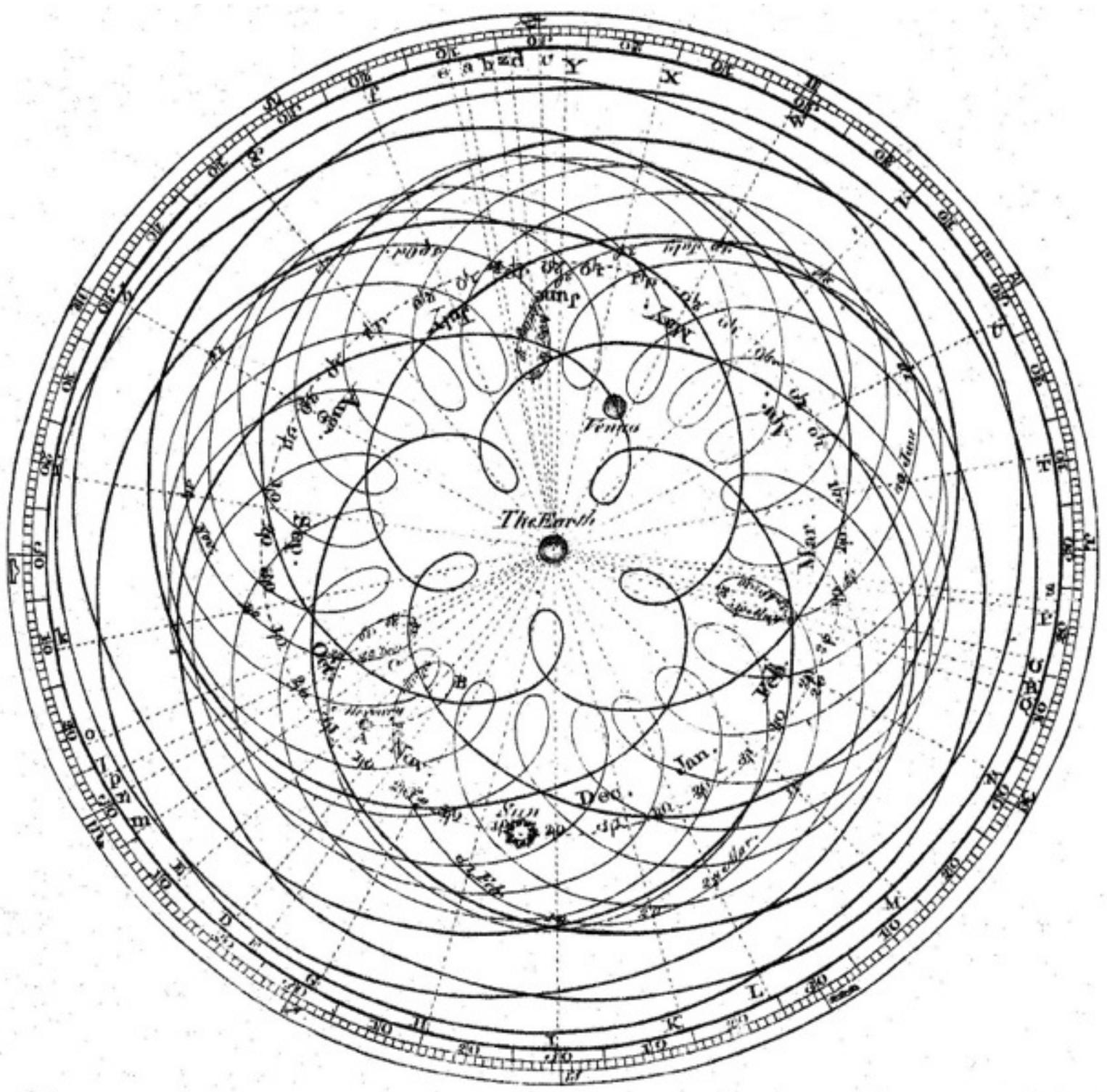
More math (for good measure).

Skybox Imaging

Orbitology Crash Course

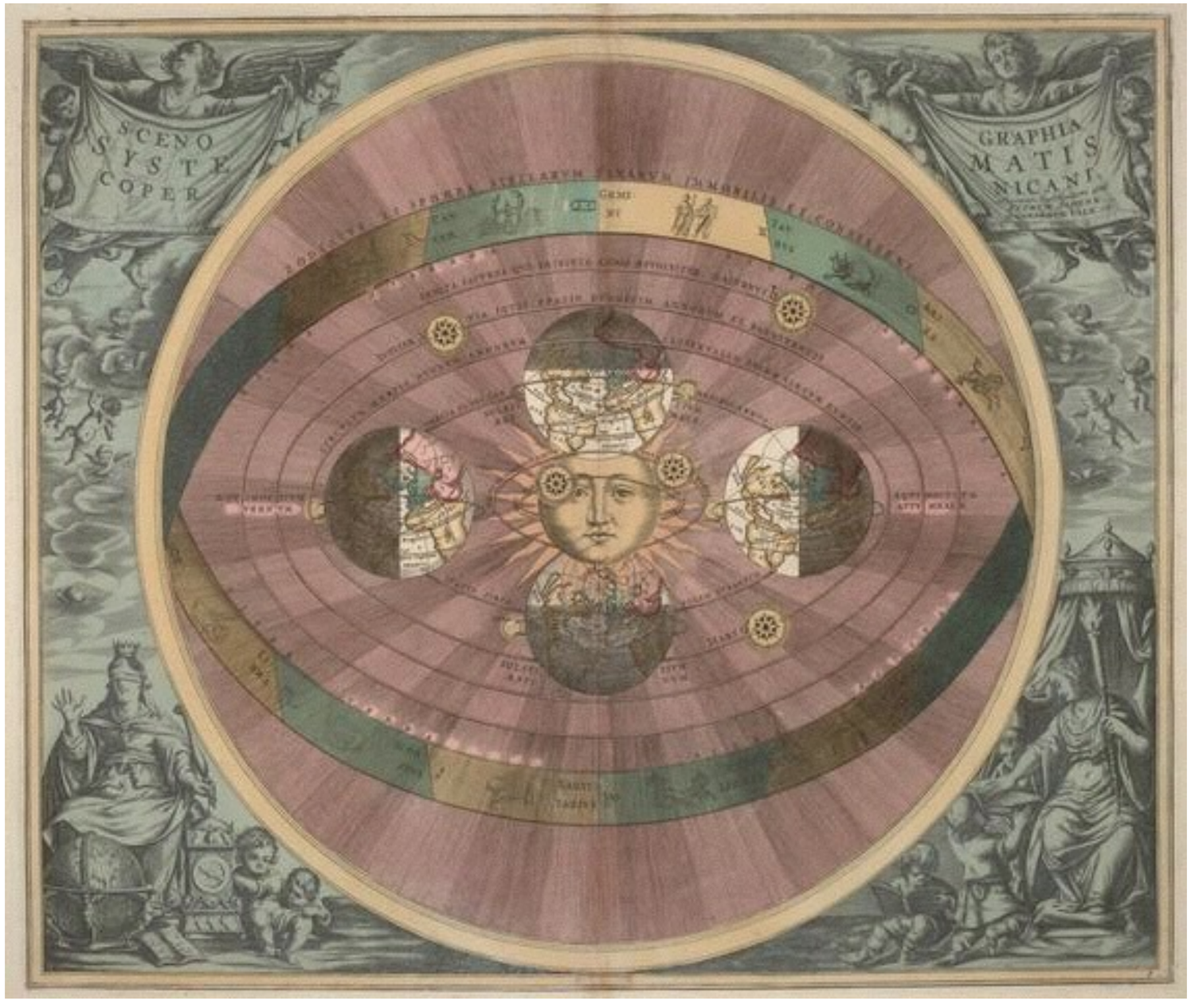
Skybox Imaging

Ptolemy & Epicycles

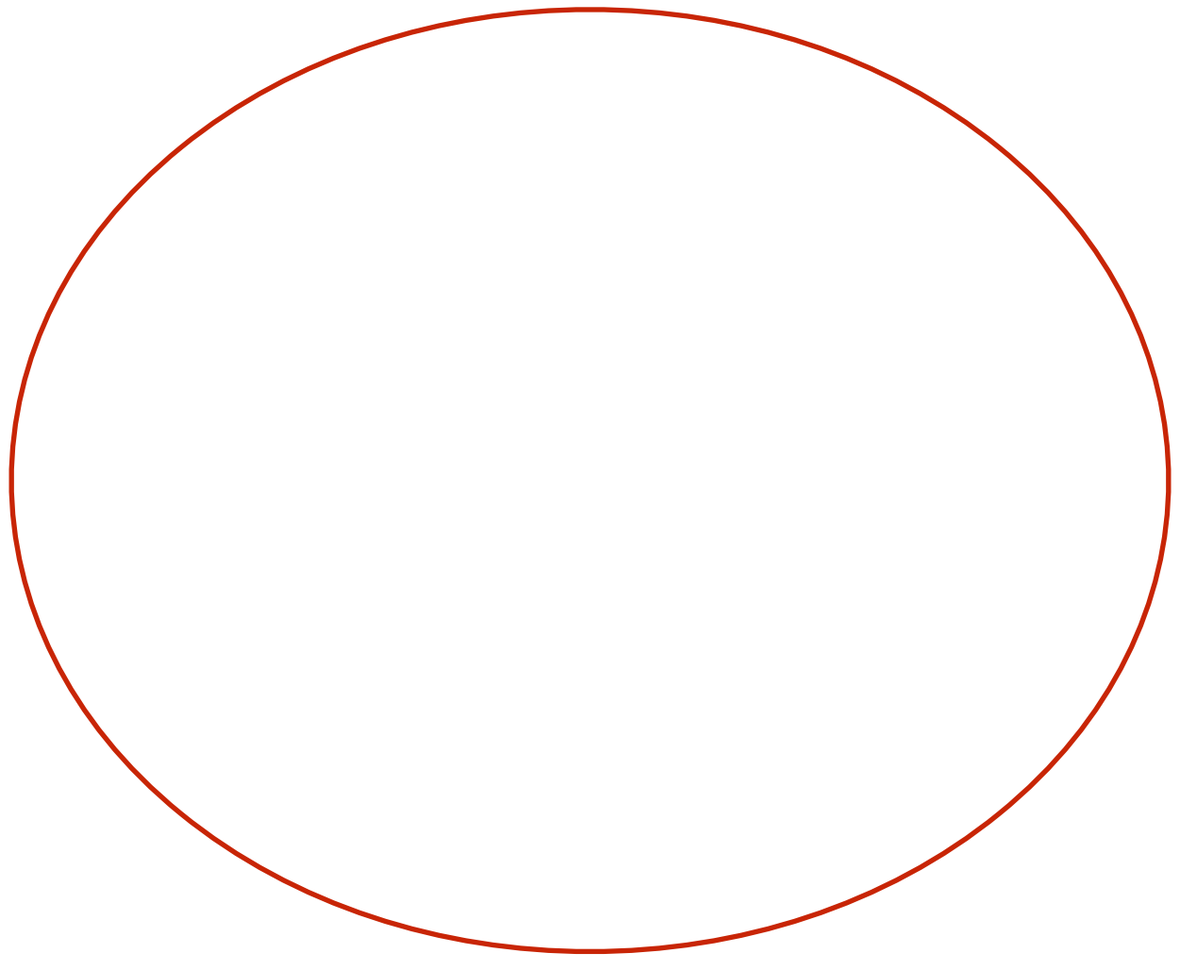


Skybox Imaging

Copernicus & Greeks before him: Heliocentric model

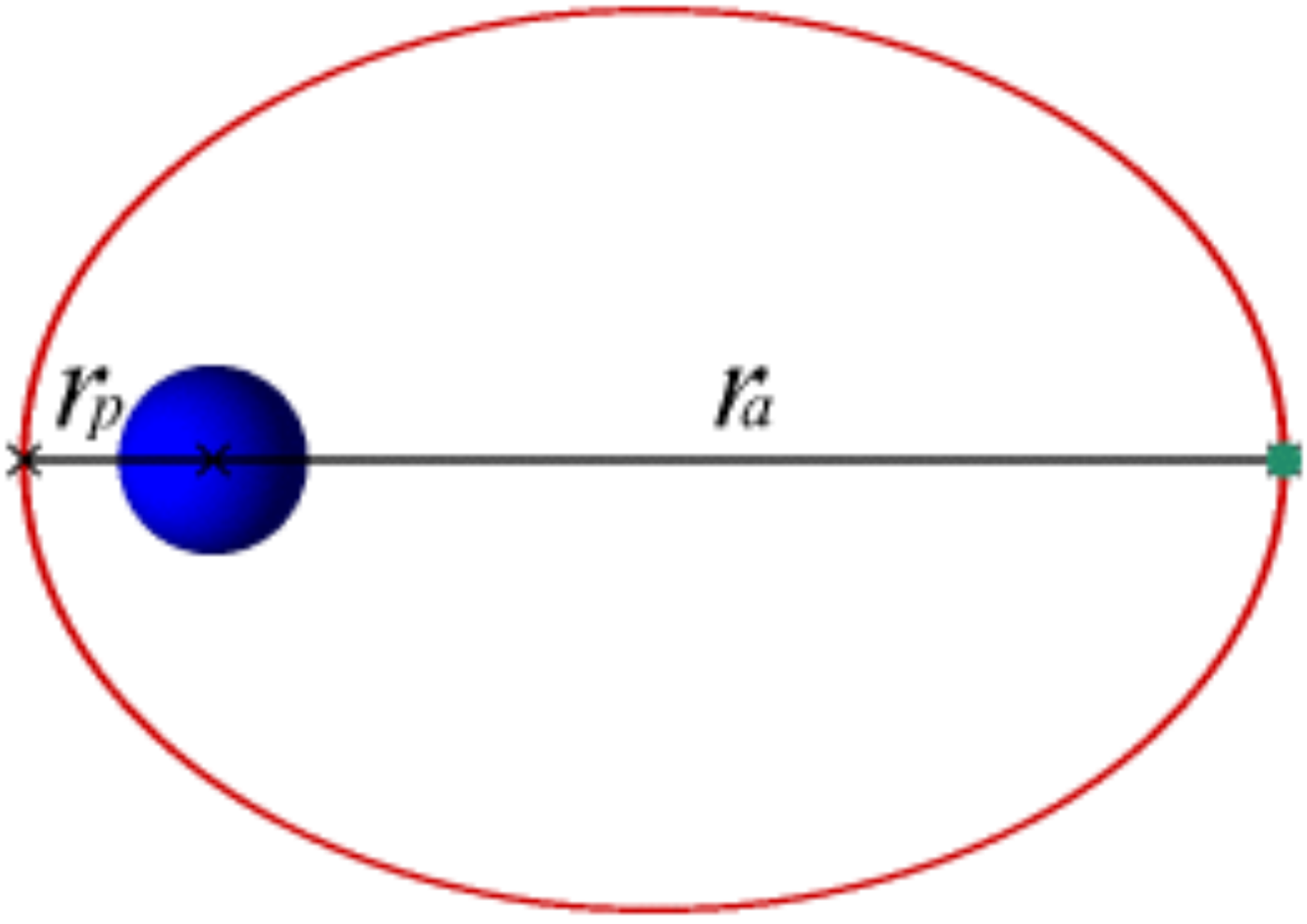


Kepler’s First Law: orbits are ellipses



Skybox Imaging

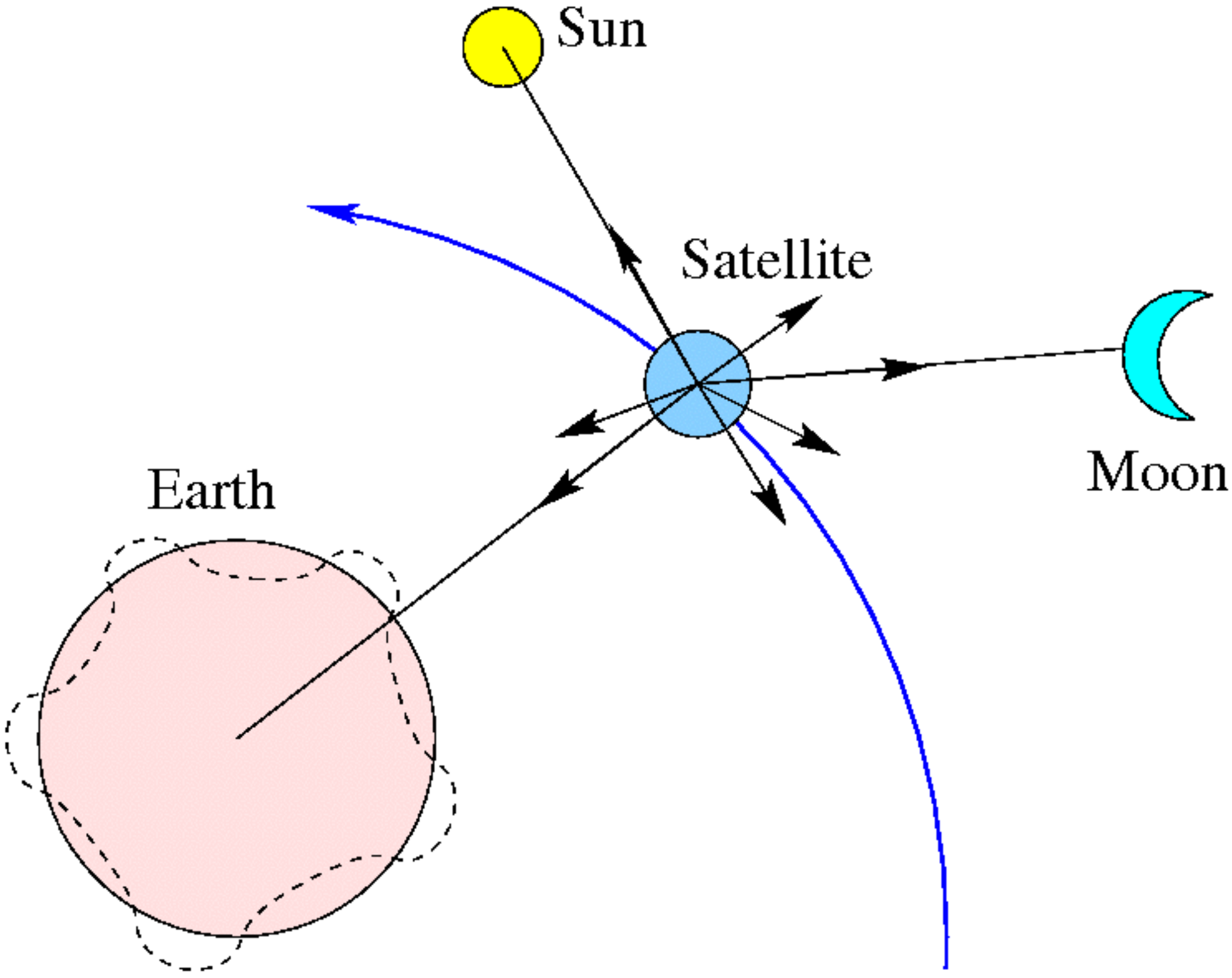
Newton & the 2 body problem



Skybox Imaging

Perturbations

Skybox Imaging



Skybox Imaging

Theory: 2-body problem

Reality: The n-body problem

Skybox Imaging

SGP4:

Simplified perturbations models

Skybox Imaging

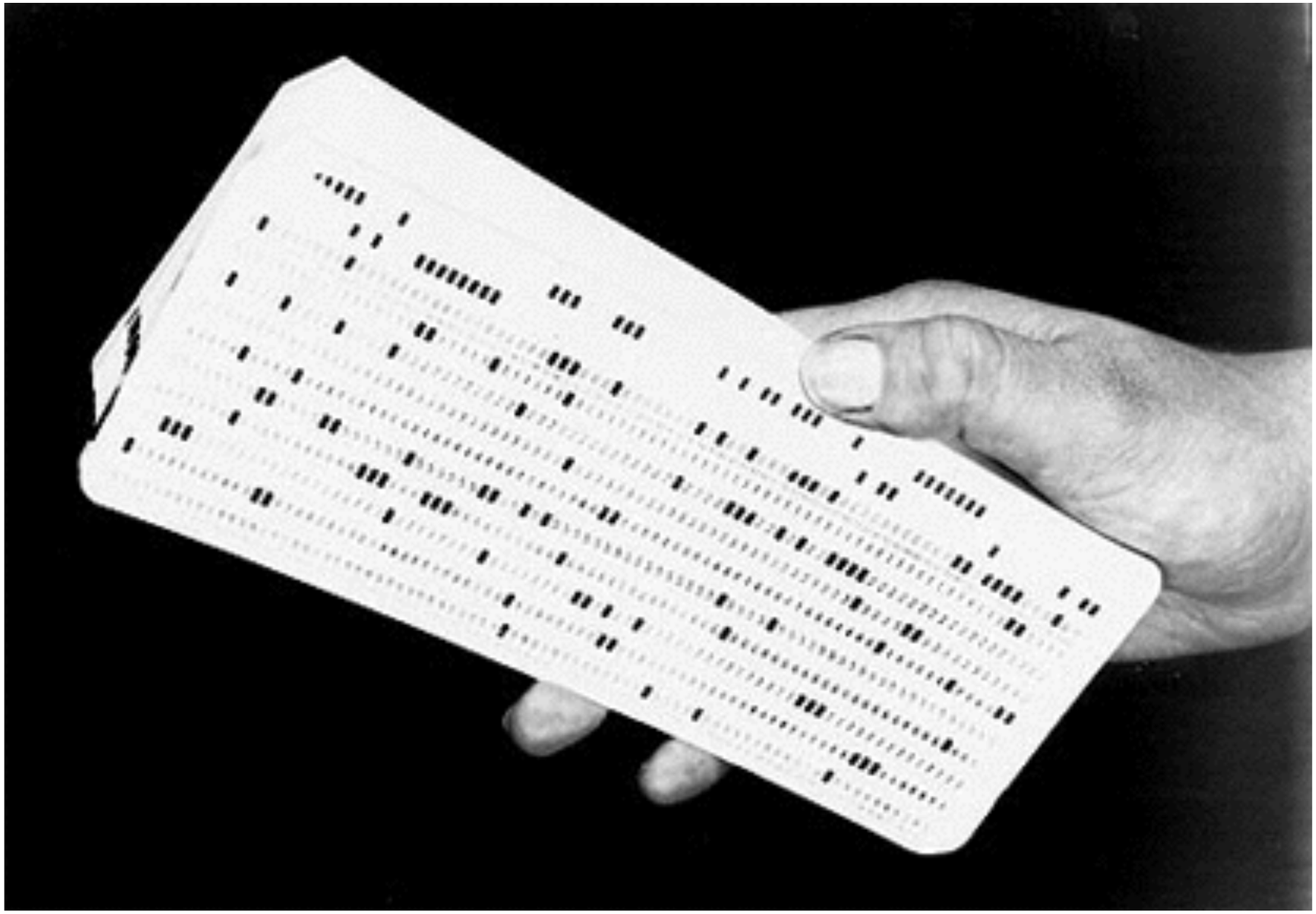
…“Simplified”

```
967             if (em <= 0.65){
968                 g211 =    3.616  -  13.2470 * em +  16.2900 * emsq;
969                 g310 =  -19.302  + 117.3900 * em - 228.4190 * emsq +  156.5910 * eoc;
970                 g322 =  -18.9068 + 109.7927 * em - 214.6334 * emsq +  146.5816 * eoc;
971                 g410 =  -41.122  + 242.6940 * em - 471.0940 * emsq +  313.9530 * eoc;
972                 g422 = -146.407  + 841.8800 * em - 1629.014 * emsq + 1083.4350 * eoc;
973                 g520 = -532.114  + 3017.977 * em - 5740.032 * emsq + 3708.2760 * eoc;
974             }
975             else {
976                 g211 =   -72.099 +   331.819 * em -   508.738 * emsq +   266.724 * eoc;
977                 g310 =  -346.844 +  1582.851 * em -  2415.925 * emsq +  1246.113 * eoc;
978                 g322 =  -342.585 +  1554.908 * em -  2366.899 * emsq +  1215.972 * eoc;
979                 g410 = -1052.797 +  4758.686 * em -  7193.992 * emsq +  3651.957 * eoc;
980                 g422 = -3581.690 + 16178.110 * em - 24462.770 * emsq + 12422.520 * eoc;
981                 if (em > 0.715) {
982                     g520 =-5149.66 + 29936.92 * em - 54087.36 * emsq + 31324.56 * eoc;
983                 }
984                 else {
985                     g520 = 1464.74 -  4664.75 * em +  3763.64 * emsq;
986                 }
987             }
988             if (em < 0.7) {
989                 g533 = -919.22770 + 4988.6100 * em - 9064.7700 * emsq + 5542.21  * eoc;
990                 g521 = -822.71072 + 4568.6173 * em - 8491.4146 * emsq + 5337.524 * eoc;
991                 g532 = -853.66600 + 4690.2500 * em - 8624.7700 * emsq + 5341.4  * eoc;
992             }
993             else{
994                 g533 =-37995.780 + 161616.52 * em - 229838.20 * emsq + 109377.94 * eoc;
995                 g521 =-51752.104 + 218913.95 * em - 309468.16 * emsq + 146349.42 * eoc;
996                 g532 =-40023.880 + 170470.89 * em - 242699.48 * emsq + 115605.82 * eoc;
997             }
```

(dsinit from satellite.js)

Skybox Imaging

TLEs: Two-line element sets



SkySat-1 TLE

Mean anomaly at epoch

```
SKYSAT-1
1 39418U 13066C   14148.17702979  .00002107  00000-0  19287-3 0  5740
2 39418  97.7889 224.9006 0024641  64.3193 296.0575 14.95823977 28066
```

Inclination

Eccentricity

Longitude of the ascending node

TLE updated daily on Celestrak: http://www.celestrak.com/NORAD/elements/resource.txt

TLE explorer: http://davidbcalhoun.com/a/tle-explorer/

Skybox Imaging

SGP4 in JS: iSat

- https://github.com/koansys/isat
- powers NASA iSat interactive satellite viewer
- many tests
- higher accuracy floating point calculations?
- not in active development
- not a standalone SGP4 library

Skybox Imaging

SGP4 in JS: satellite.js

- https://github.com/shashwatak/satellite-js
- still in active development
- API with examples (not perfect, but usable)
- SGP4 only (no graphical component)

Skybox Imaging

Step 4: Getting current lat/lon

```
39  /**
40   * Find lat/lon of satellite now, or at given localTime
41   * @param  {Array}  tle       satellite TLE
42   * @param  {String} localTime (optional) local timestamp
43   * @return {Array}            [lat, lon]
44   */
45  var getSatLatLon = function(tle, localTime) {
46      //  time defaults to now
47      var time = (localTime) ? new Date(localTime) : new Date();
48
49      //  convert local time to UTC
50      var year   = time.getUTCFullYear();
51      //  important 0th to 1-index conversion for satellite.js
52      var month  = time.getUTCMonth() + 1;
53      var date   = time.getUTCDate();
54      var hour   = time.getUTCHours();
55      var minute = time.getUTCMinutes();
56      var second = time.getUTCSeconds();
57
58      //  the rest of the function can be copied from the
59      //  satellite.js readme:
60      ...
61  }
```

Skybox Imaging

getSatLatLon() Usage

```
21  var tle = [
22      'SKYSAT-1                    ',
23      '1 39418U 13066C   14148.17702979  .00002107  00000-0  19287-3 0  5740',
24      '2 39418  97.7889 224.9006 0024641  64.3193 296.0575 14.95823977 28066'
25  ];
26
27  //  get current satellite lat/lon
28  var latlon = getSatLatLon(tle);
```

Skybox Imaging

Step 5: Simple update timer

```
38  //  ~two second lat/lon update for Leaflet marker
39  window.setInterval(function(){
40      marker.setLatLng(getSatLatLon(tle));
41  }, 2000);
```

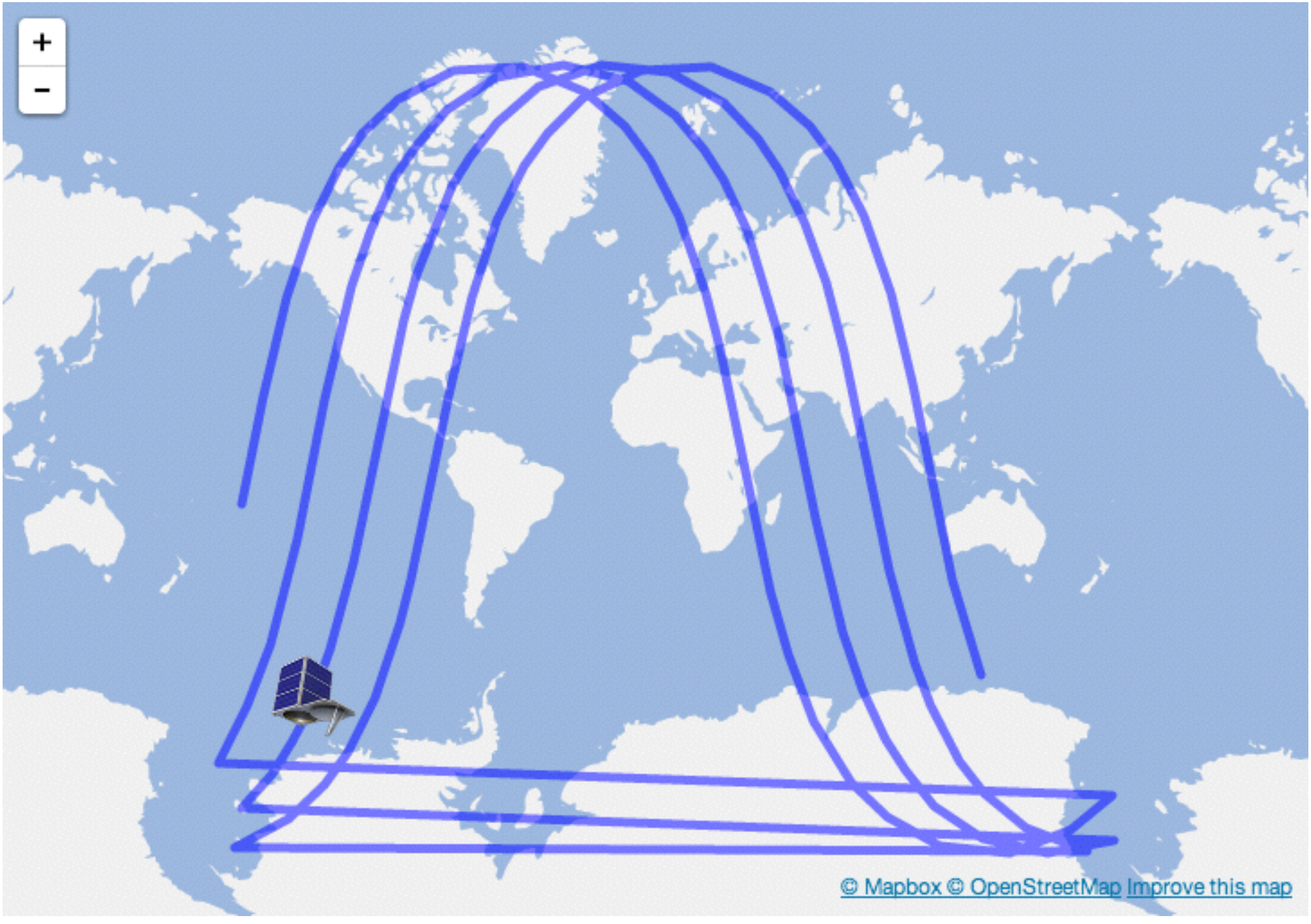
Skybox Imaging

Skybox Imaging

Step 6: Basic ground track (orbit lines)

```
 99  function generateGroundTrack(tle, stepMS) {
100      //  default to 1 minute intervals
101      stepMS = stepMS || (1000 * 60 * 1);
102
103      //  offset: plot orbit 3 hrs into past and future
104      var timeOffset = 1000 * 60 * 60 * 3,
105          startTime      = Date.now() - timeOffset,
106          curMarkerTime = startTime,
107          endTime        = Date.now() + timeOffset;
108
109      //  generate lat/lons
110      var latLngs = [];
111      while(curMarkerTime < endTime) {
112          latLngs.push(getSatLatLon(tle, curMarkerTime));
113          curMarkerTime += stepMS;
114      }
115
116      //  plot lat/lons into polyline
117      polyline = L.polyline(latLngs, {color: 'blue'}).addTo(map);
118  }
```

Skybox Imaging



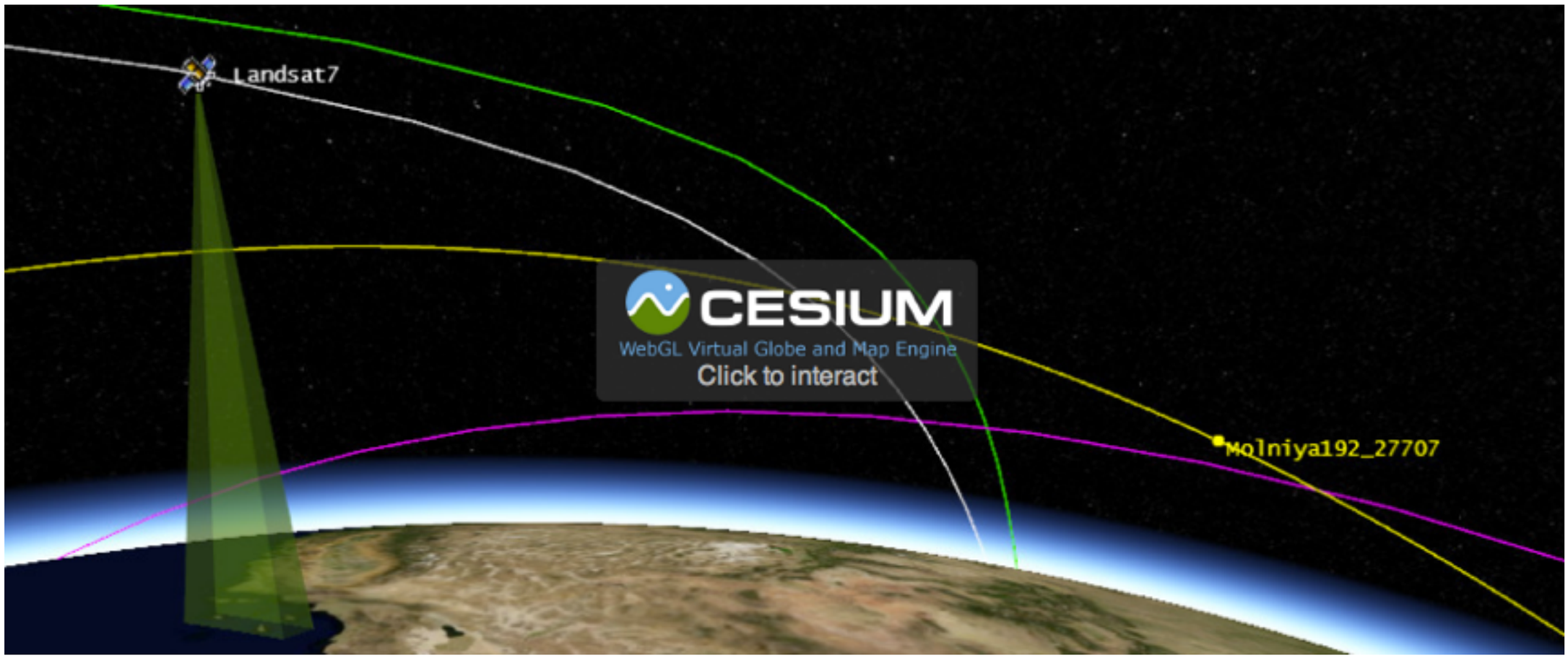
Skybox Imaging

3D Maps

Skybox Imaging

Cesium (WebGL)

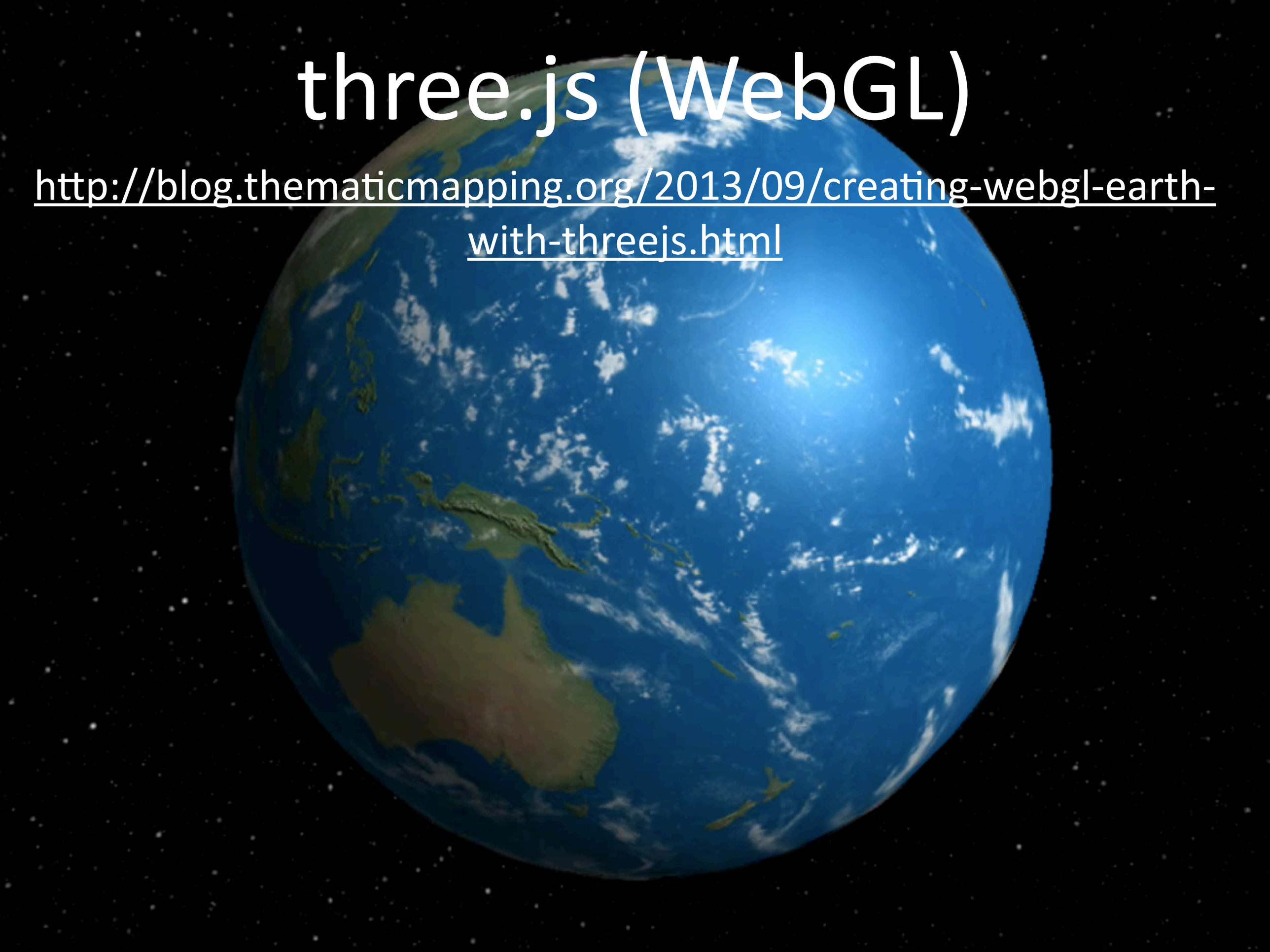
- http://cesiumjs.org
- powers NASA iSat



Skybox Imaging

three.js (WebGL)

http://blog.thematicmapping.org/2013/09/creating-webgl-earth-with-threejs.html



Questions?

- slides & learning materials: bit.ly/jsconf-satellites
-  @franksvalli
- dcalhoun@skybox.com
- linkedin.com/in/davidcalhoun/

Skybox Imaging

Sources

Sputnik Audio (Roy Welsh, Dallas Texas): http://www.astrosurf.com/luxorion/audiofiles-astronautic.htm
Stars: https://www.flickr.com/photos/scott-s_photos/11763686274
Sputnik images: http://history.nasa.gov/sputnik/gallerysput.html, http://commons.wikimedia.org/wiki/File:Sputnik_asm.jpg
Sputnik ground track: *Sputnik: The Shock of the Century*
SkySat-1 Dnepr launch video: http://www.youtube.com/watch?v=RMi0DbQGfxs

Sources 2

Epicycles image: Encyclopaedia Brittanica 1st Edition via Wikipedia

2-body problem http://en.wikipedia.org/wiki/File:Elliptic_orbit.gif

Perturbations: http://www.navipedia.net/index.php/Perturbed_Motion