Satellite to Satellite Visibility

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Abstract: In this paper, general analytical and computational technique for satellite-to-satellite visibility will be established. The developments are general in the sense that the visibility conditions can be used whatever the types of the satellite orbits may be. Numerical applications are also included.

Keywords: Satellite, visibility, orbit, numerical solution.

1. INTRODUCTION

The use of satellites in communications systems is very much a fact of everyday life, as it is evidenced by many homes which are equipped with many antennas, or dishes used for the reception of satellite television.

Satellites offer a number of features not readily available with other means of communications. As very large areas of the Earth are visible from a satellite, a satellite can form the starting point of a communications net linking together with many users simultaneously, users who may be widely separated geographically [1].

Communication satellites account for more than 80% of the total number of satellites in operations. This is one of the most widely exploited applications of satellites. On the other hand, there are many uses of the communication satellites, e.g., in Earth's sciences solar physics, astronomy, astrophysics and military purposes [2].

Extensive recovery experiments based on real CHAMP GPS SST observations have shown that the concept of estimating non- gravitational accelerations from GPS observation is feasible [3] and the full potential of GPS-SST in gravity field recovery becomes evident if employed on a very low – flying satellite has been demonstrated [4-6].

Any application which attempts to use communication satellites requires effective maneuvering to ensure an accurate result.

To this end and also to cope with these very important applications of satellites in communication as well as in space warfare, we establish (from astrodynamical point of view) in the present paper general analytical and computational technique for one of the most important problems of space communications, of satellite-to-satellite visibility.

The developments are general in the sense that visibility conditions will be established, whatever the types of the satellite orbits may be.

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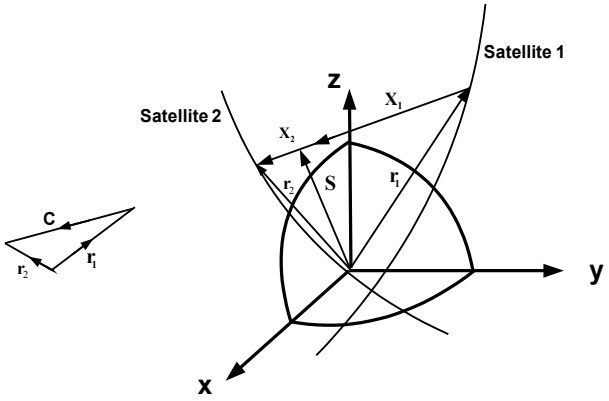

Fig. (1). Relative rise-set geometry.

2. DEVELOPMENT OF THE RISE-SET FUNCTION

Mutually visible satellites are defined in this section as two satellites that can maintain direct line of sight between each other for a certain length of time. Actually, the analysis to be developed is primarily concerned with the rise and set time of a given satellite with respect to another, that is, the time of loss or gain of direct line of sight.

2.1. Relative Rise-Set Geometry

Consider the geometry defined in Fig. (**1**). As illustrated, satellites 1 and 2 are in a state of relative rise or set. Indeed, if the vector *S***,** which emanates from the dynamical center of the Earth, had a magnitude equal to or less than the radius of the Earth and if it were perpendicular to *C***,** the chord length between the satellites, it is evident that the satellites would not have direct line–of–sight–communication. Owing to atmospheric interference, however, a realistic analysis would let the magnitude of *S* be slightly larger than a_e, the radius of the Earth. Let $\triangle$ be the thickness of the atmosphere or suitable bias factor, it follows that

$$S^2 = \vec{S} \cdot \vec{S} = (a_e + \Delta)^2 \tag{1}$$

2.2. Analytical Expression of the Relative Rise-Set Function

Examination of Fig. (**1**) allows the two fundamental vector closure equations to be written as

$$\vec{r}_2 = \vec{S} + \vec{\chi}_2 \quad (2)$$

$$\vec{r}_1 = \vec{S} - \vec{\chi}_1 \quad (3)$$

Where $\vec{r}_i$; i = 1, 2 are the position vectors of the satellites and $\vec{\chi}_i$; i = 1, 2 are the two unknown vectors.

At relative rise and set of satellite 1 with respective to satellite 2, we have

$$\vec{S} \cdot \vec{\chi}_1 = \vec{S} \cdot \vec{\chi}_2 = 0 \quad (4)$$

Then, from the figure

$$C = \sqrt{\left((\vec{r}_2 - \vec{r}_1),(\vec{r}_2 - \vec{r}_1)\right)} = \sqrt{r_2^2 + r_1^2 - 2\alpha}\,. \quad (5)$$

Where

$$\alpha = \vec{r}_1 \cdot \vec{r}_2\,.$$

It is then possible to obtain an analytical expression for the rise and set function as

$$R = \left(\vec{r}_1 \cdot \vec{r}_2\right)^2 - r_2^2\ r_1^2 + \left(r_2^2 + r_1^2\right) S^2 - 2S^2\left(\vec{r}_1 \cdot \vec{r}_2\right) \quad (6)$$

Where *S* is obtained from Equation (1).

2.3. Visibility using Equation (6)

The rise-set function defined in Equation (6) can be used to predict explicitly whether or not satellites are visible to one another .The sign of R associated with visibility can be obtained by constructing a case in which direct line –of-sight visibility is impossibile, consequently we can get the rule that:

♦ Negative value of $R \Longrightarrow$ Direct line-of-sight communication

♦ Positive value of $R \Longrightarrow$ non-visibility

2.4. Reduction of Rise-Set Function to Two Parameters Function

In terms of the orbital eccentricity e, semi-parameter p and the true anomaly f, the equation of each orbit can be expressed by the relation

$$r_i = \frac{p_i}{1 + e_i\ \cos(f_i)}\,,\ \mathrm{i} = 1, 2 \quad (7)$$

Also we have

$$\vec{r}_i = \hat{\mathrm{I}}_i\,\vec{P}_i + \zeta_i\,\vec{Q}_i\,,\ \mathrm{i} = 1, 2 \quad (8)$$

Where

$$\hat{\mathrm{I}}_i = r_i\ \cos(f_i) \quad (9)$$

$$\eta_i = r_i\ \sin(f_i) \quad (10)$$

The standard orientation vectors *P* and *Q*, where *P* is unit vector from the dynamical centre which points at perigee of the orbit and *Q* is advanced to *P* by a right angle in the plane and in the direction of motion that is

$$P_{xi} = \cos(\omega_i)\cos(\Omega_i) - \sin(\omega_i)\sin(\Omega_i)\cos(I_i) \quad (11.1)$$

$$P_{yi} = \cos(\omega_i)\sin(\Omega_i) + \sin(\omega_i)\cos(\Omega_i)\cos(I_i) \quad (11.2)$$

$$P_{zi} = \sin(\omega_i)\sin(I_i) \quad (11.3)$$

$$Q_{xi} = P_{xi}\left(I, \omega + 90^\circ, \Omega\right) = -\sin(\omega_i)\cos(\Omega_i) + \cos(\omega_i)\sin(\Omega_i)\cos(I_i) \quad (11.4)$$

$$Q_{yi} = P_{yi}\left(I, \omega + 90^\circ, \Omega\right) = -\sin(\omega_i)\sin(\Omega_i) + \cos(\omega_i)\cos(\Omega_i)\cos(I_i) \quad (11.5)$$

$$Q_{zi} = P_{zi}\left(I, \omega + 90^\circ, \Omega\right) = \cos(\omega_i)\sin(I_i) \quad (11.6)$$

Where *I*, ω and Ω are the inclination, longitude of per center and longitude of the node, respectively.

Now

$$\begin{aligned}\langle \vec{r}_1, \vec{r}_2 \rangle &= \left\langle \left(\xi_1 \vec{P}_1 + \eta_1 \vec{Q}_1\right), \left(\xi_2 \vec{P}_2 + \eta_2 \vec{Q}_2\right) \right\rangle \\ &= A_1\xi_1\xi_2 + A_2\eta_1\xi_2 + A_3\eta_2\xi_1 + A_4\eta_1\eta_2\,,\end{aligned} \quad (12)$$

Where

$$\mathrm{A}_1 = \langle \mathbf{P}_1, \mathbf{P}_2 \rangle,\ \mathrm{A}_2 = \langle \mathbf{Q}_1, \mathbf{P}_2 \rangle$$

$$\mathrm{A}_3 = \langle \mathbf{P}_1, \mathbf{Q}_2 \rangle,\ \mathrm{A}_4 = \langle \mathbf{Q}_1, \mathbf{Q}_2 \rangle$$

Using Equations (9) and (10) into Equation (12) we get

$$\langle \mathbf{r}_1, \mathbf{r}_2 \rangle = \frac{\mathrm{p}_1\mathrm{p}_2\cos(\mathrm{f}_2 - \mathrm{f}_1)}{(1 + \mathrm{e}_1\cos\mathrm{f}_1)(1 + \mathrm{e}_2\cos\mathrm{f}_2)}\left\{\cos\mathrm{f}_2\left(\mathrm{A}_1\cos\mathrm{f}_1 + \mathrm{A}_2\sin\mathrm{f}_1\right) + \sin\mathrm{f}_2\left(\mathrm{A}_3\cos\mathrm{f}_1 + \mathrm{A}_4\sin\mathrm{f}_1\right)\right\}.$$

Or,

$$\langle \mathbf{r}_1, \mathbf{r}_2 \rangle = \frac{\mathrm{p}_1\mathrm{p}_2}{(1 + \mathrm{e}_1\cos\mathrm{f}_1)(1 + \mathrm{e}_2\cos\mathrm{f}_2)}\left\{\mathrm{D}_1\cos\mathrm{f}_2\cos(\tilde{\mathrm{a}}_1 - \mathrm{f}_1) + \mathrm{D}_2\sin\mathrm{f}_2\cos(\emptyset_1 - \mathrm{f}_1)\right\} \quad (13)$$

Where

$$\emptyset_1 = \tan^{-1}\left(\frac{\mathrm{A}_4}{\mathrm{A}_3}\right) \quad \text{and} \quad \tilde{\mathrm{a}}_1 = \tan^{-1}\left(\frac{\mathrm{A}_2}{\mathrm{A}_1}\right)$$

Then Equation (6) becomes

$$\begin{aligned}\mathrm{R} = {} & \mathrm{p}_1^2\mathrm{p}_2^2\left\{\mathrm{D}_1\cos\mathrm{f}_2\cos(\tilde{\mathrm{a}}_1 - \mathrm{f}_1) + \mathrm{D}_2\sin\mathrm{f}_2\cos(\emptyset_1 - \mathrm{f}_1)\right\}^2 - \mathrm{p}_1^2\mathrm{p}_2^2 + \\ & + \left\{\mathrm{p}_1^2\left(1 + \mathrm{e}_1\cos\mathrm{f}_1\right)^2 + \mathrm{p}_2^2\left(1 + \mathrm{e}_2\cos\mathrm{f}_2\right)^2\right\}\ \mathrm{S}^2 - \\ & 2\mathrm{S}^2\mathrm{p}_1\mathrm{p}_2\ \left\{\mathrm{D}_1\cos\mathrm{f}_2\cos(\tilde{\mathrm{a}}_1 - \mathrm{f}_1) + \mathrm{D}_2\sin\mathrm{f}_2\cos\ (\emptyset_1 - \mathrm{f}_1)\right\} \times \\ & \times\left(1 + \mathrm{e}_1\cos\mathrm{f}_1\right)\left(1 + \mathrm{e}_2\,\mathrm{c}\cos\mathrm{f}_2\right)\end{aligned} \quad (14)$$

If the two satellites are in the same orbital plane we have

$$\mathbf{P}_1 = \mathbf{P}_2\ ,\ \mathbf{Q}_1 = \mathbf{Q}_2 \Rightarrow \mathrm{A}_1 = 1$$

$$\mathrm{A}_2 = 0\ ,\mathrm{A}_3 = 0\ ,\mathrm{A}_4 = 1 \Rightarrow \mathrm{D}_1 = 1, \mathrm{D}_2 = 1,\ \tilde{\mathrm{a}}_1 = 0,\ \ \emptyset = 90^\circ$$

3. COMPUTATIONAL ALGORITHM

In what follows computational algorithm of the mutual visibility between two satellites will be established whatever the types of their orbits may be:

●**Purpose**: Mutual visibility between two Earth satellites.

●**Input:** a_i or q_i, e_i , I_i , ω_i , Ω_i , T_i i=1, 2; S, Δ, t, k, μ.

Computational Sequence:

1- If $\mathbf{E_I}$**>1** then $\mathbf{N_J} = k\sqrt{\frac{\grave{\mathrm{I}}}{-\mathrm{a_i}^3}}$ and $q_i = a_i(1\text{-}e_i)$

2- If $e_i \cong 1$ then $n_j = k\sqrt{\frac{\mu}{2q_i^3}}$

3- If $e_i<1$ then $n_j= k\sqrt{\frac{\grave{I}}{a_i^3}}$ and $q_i = a_i(1-e_i)$

4- $M_i = n_i (t - T_i)$.

5- If $e_i<1$ then solve F_i from Kepler's equation of hyperbolic orbit using Newton's method and then f_i as follows

a- let $(F_i)_0=6M_i$

b- $(F_i)_{n+1}=(F_i)_n+ \frac{M_i - e_i \sinh (F_i)_n + (F_i)_n}{e_i \cosh (F_i)_n - 1}$

c- If $|(F_i)_{n+1}-(F_i)_n|>0.00000001$ go to b else $F_i=(F_i)_{n+1}$

d- $f_i = \tan^{-1}\left(\frac{-\sinh(F_i)\sqrt{e_i^2-1}}{\cosh(F_i)-e_i}\right)$ and end.

6- If $e_i \cong 1$ then solve f_i from Barkar's equation as follows

a-Let $A_i= 3M_i / 2$

b-$B_i=\left(\sqrt{A_i^2+1}+A_i\right)^{1/3}$

C- $C_i= B_i - (1/B_i)$

d- $f_i = 2\tan^{-1} C_i$

7- If $e_i<1$ then solve for E_i from Kepler's equation using Newton's method and then

f_i as follows

a- let $(E_i)_0=M_i$

b- $(E_i)_{n+1}=(E_i)_n+ \frac{M_i + e_i \sin (E_i)_n - (E_i)_n}{1 - e_i \cos (E_i)_n}$

c- If $|(E_i)_{n+1}-(E_i)_n|>0.00000001$ go to b else $E_i=(E_i)_{n+1}$

d- $f_i = \tan^{-1}\left(\frac{\sin(E_i)\sqrt{1-e_i^2}}{\cos(E_i)-e_i}\right)$ and end.

8- $r_i = \frac{(1+e_i)q_i}{1+e_i \cos f_i}$.

9-**P** and **Q**from Equation (11).

10- $\hat{I}_i = r_i \cos(f_i)$ and $\c{C}_i = r_i \sin(f_i)$.

11- $\mathbf{r}_i = \hat{I}_i \mathbf{P}_i + \c{C}_i \mathbf{Q}_i$.

12-Compute the mutual visibility function R from Equation (14). Whenever this value is negative, the satellites can see each other at the given time t .

13-The algorithm is completed.

CONCLUSION

We will apply the above algorithm on the seven satellites to get the time and date at which one satellite observes the other.

We will take as an example the following seven satellites. Satellite_1, Satellite_2, Satellite_3 and Satellite_4 are nearly circular, Satellite_5 is elliptical orbit, but Satellite_6 is parabolic orbit and finally Satellite_7 is hyperbolic orbit. The two-line elements and their names of seven satellites are:

Satellite_1

EGYPTSAT 1

1 31117U 07012A 08142.74302347 .00000033 00000-0 13654-4 0 2585

2 31117 098.0526 218.7638 0007144 061.2019 298.9894 14.69887657 58828

Satellite_2

TRMM

1 25063U 97074A 08141.84184490 .00002948 00000-0 41919-4 0 7792

2 25063 034.9668 053.5865 0001034 271.1427 088.9226 15.55875272598945

Satellite_3

GOES 3

1 10953U 78062A 08140.64132336 -.00000110 00000-0 10000-3 0 1137

2 10953 014.2164 003.1968 0001795 336.4858 023.4617 01.00280027 62724

Satellite_4

NOAA 3

1 06920U 73086A 08141.92603915 -.00000030 +00000-0 +10000-3 0 00067

2 06920 101.7584 171.9430 0006223 187.3360 172.7614 12.40289355563642

Satellite_5

NAVSTAR 46

1 25933U 99055A 08142.14123352 .00000019 00000-0 10000-3 0 00126

2 25933 051.0650 222.9439 0079044 032.8625 327.6958 02.00568102 63184

Satellite_6

Parabola

1 00000U 00000A 08141.53396007 .00000000 00000-0 00000-0 0 00001

2 00000 035.3423 067.8765 001.000 253.7654 138.0987 02.65786544 63184

Satellite_7

Hyp_1

1 00000U 00000A 08141.89332000 .00000000 00000-0 00000-0 0 00001

2 00000 072.8721 105.6746 001.164 065.8757 221.4654 02.00568102 63184

So, we put in the following Tables **(1-21)** the time periods the satellites will be visible to each other.

Table (1). EGYPTSAT_1 and TRMM are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	Seconds		Year	Month	Day	Hour	Minute	Seconds
2008	5	22	12	22	25.99		2008	5	22	12	29	50.99
			13	10	39.98					13	16	49.98
			13	58	56.96	to				14	3	41.96
			14	47	26.95					14	50	24.94
			22	43	18.79					22	46	30.79
			23	30	05.78					23	34	54.77
2008	5	23	0	16	56.77		2008	5	23	0	23	15.76
			1	3	58.74					1	11	25.74
			1	50	59.73					1	59	35.73
			2	38	07.71					2	47	37.71
			3	25	15.70					3	35	40.70
			4	12	30.68					4	23	36.68
			4	59	45.67					5	11	31.66
			5	47	06.65					5	59	20.65
			6	34	28.64	to				6	47	08.63
			7	21	57.62					7	34	50.62
			8	9	26.61					8	15	16.60
			8	16	39.60					8	22	30.60
			8	57	02.59					9	2	52.59
			9	4	16.59					9	10	4.59
			9	44	39.58					9	57	36.57
			10	32	23.56					10	45	03.56
			11	20	08.54					11	32	28.54

Table 2. EGYPTSAT_1 and GOES_3 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	14	01.00		2008	05	22	13	17	55.97
			13	47	46.96					14	09	51.96
			14	28	06.95					14	47	22.95
			15	23	50.93					15	39	18.93
			16	06	46.92					16	21	13.91
			17	00	01.90					17	13	25.90
			17	43	17.89	to				17	56	41.88
			18	35	44.87					18	49	30.87
			19	18	05.86					19	32	47.85
			20	10	12.84					20	27	18.83
			20	49	25.83					21	08	59.82
			21	41	22.81					22	44	05.79
			23	04	17.78		2008	05	23	00	08	51.76

Table 2. cont..

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	23	00	27	23.76		2008	05	23	01	30	38.74
			02	02	05.73					02	22	33.72
			02	43	22.71					03	01	10.71
			03	38	15.69					03	53	15.69
			04	21	27.68					04	35	24.68
			05	14	24.66					05	27	48.66
			05	57	42.65	to				06	11	02.64
			06	49	58.63					07	04	09.63
			07	32	07.62					07	47	11.61
			08	24	04.60					08	42	26.60
			09	02	25.59					09	23	18.58
			09	54	14.57					10	57	40.55
			11	15	36.55					12	00	00.00

Table 3. GOES_3 and NAVSTAR_46 are Visible at the Time Periods

Date			Time			to	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	00	00.00		2008	05	23	12	00	00.00

Table 4. GOES_3 and Hyp_1 are Visible at the Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	00	00.00		2008	05	23	12	00	00.00

Table 5. EGYPTSAT_1 and Hyp_1 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	24	36.00		2008	05	22	12	46	47.98
			13	13	38.98					13	35	45.97
			14	02	32.96					14	24	43.95
			14	51	35.94					15	13	41.94
			15	40	28.93					16	02	39.92
			16	29	32.91	to				16	51	37.91
			17	18	25.90					17	40	36.89
			18	07	29.88					18	29	34.87
			18	56	22.86					19	18	32.86
			19	45	26.85					20	07	30.84
			20	34	19.83					20	56	28.83

Table 5. cont..

Date			Time			To	Date			Time		
Year	**Month**	**Day**	**Hour**	**Minute**	**seconds**		**Year**	**Month**	**Day**	**Hour**	**Minute**	**seconds**
			21	23	23.82					21	45	26.81
			22	12	17.80					22	34	25.79
			23	01	20.78					23	23	23.78
			23	50	14.77		2008	05	23	00	12	22.76
2008	05	23	00	39	17.75		2008	05	23	01	01	19.75
			01	28	11.74					01	50	18.73
			02	17	14.72					02	39	16.71
			03	06	08.71					03	28	15.70
			03	55	11.69					04	17	13.68
			04	44	05.67					05	06	12.67
			05	33	08.66	to				05	55	09.65
			06	22	02.64					06	44	08.63
			07	11	05.63					07	33	06.62
			08	00	00.61					08	22	05.60
			08	49	03.59					09	11	03.59
			09	37	57.58					10	00	02.57
			10	27	00.56					10	49	00.55
			11	15	54.55					11	37	59.54

Table 6. EGYPTSAT_1 and NOAA_3 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	**Month**	**Day**	**Hour**	**Minute**	**seconds**		**Year**	**Month**	**Day**	**Hour**	**Minute**	**seconds**
2008	05	22	14	28	15.95		2008	05	22	14	45	48.95
			15	05	04.94	To				16	15	10.92
			16	23	09.91					17	35	35.89
			17	48	02.89					18	12	30.88
2008	05	23	01	02	00.75		2008	05	23	01	30	10.74
			01	37	54.73					02	52	28.71
			03	00	10.71	To				04	09	27.68
			04	32	23.68					04	45	18.67
			11	36	21.54					12	00	00.00

Table 7. EGYPTSAT_1 and NAVSTAR_46 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	**Month**	**Day**	**Hour**	**Minute**	**seconds**		**Year**	**Month**	**Day**	**Hour**	**Minute**	**seconds**
2008	05	22	12	36	44.99		2008	05	22	13	00	36.98
			13	24	12.97	To				13	43	46.97
			14	31	20.95					14	46	41.95

Table 7. cont…

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
			15	17	10.94					15	32	15.93
			16	19	53.92					16	38	47.91
			17	03	22.90					17	26	13.89
			18	16	31.88					18	42	08.87
			19	3	34.86					19	25	5.86
			20	12	43.84					20	28	17.83
			20	58	39.82					21	13	44.82
			22	00	55.80					22	18	07.80
			22	44	51.79					23	05	18.78
			23	54	31.77		2008	05	23	00	22	29.76
2008	05	23	00	40	11.75		2008	05	23	01	04	57.74
			01	53	01.73	To				02	09	41.72
			02	39	27.71					02	54	37.71
			03	42	03.69					03	58	18.69
			04	26	29.68					04	45	10.67
			05	34	23.66					06	02	40.65
			06	18	35.64					06	45	39.63
			07	34	06.62					07	51	27.61
			08	20	37.60					08	36	16.60
			09	23	24.58					09	38	52.58
			10	08	08.57					10	25	27.56
			11	13	33.55					11	40	00.54
			11	56	16.53					12	00	00.00

Table 8. EGYPTSAT_1 and Parabola are Visible at the Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	00	00.00		2008	05	22	12	01	50.00
			12	29	50.99					12	50	53.98
			13	18	51.97					13	39	47.97
			14	07	48.96					14	28	51.95
			14	56	49.94					15	17	45.94
			15	45	46.93	to				16	06	49.92
			16	34	47.91					16	55	43.90
			17	23	44.89					17	44	47.89
			18	12	45.88					18	33	41.87
			19	01	42.86					19	22	45.86
			19	50	44.85					20	11	39.84
			20	39	40.83					21	00	43.82

Table 8. cont…

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
			21	28	42.81					21	49	37.81
			22	17	38.80					22	38	41.79
			23	06	40.78					23	27	35.78
			23	55	36.77		2008	05	23	00	16	39.76
2008	05	23	00	44	38.75		2008	05	23	01	05	33.74
			01	33	34.74					01	54	37.73
			02	22	36.72					02	43	31.71
			03	11	32.70					03	32	35.70
			04	00	34.69					04	21	29.68
			04	49	30.67	to				05	10	33.66
			05	38	32.66					05	59	27.65
			06	27	28.64					06	48	31.63
			07	16	30.62					07	37	25.62
			08	05	26.61					08	26	29.60
			08	54	28.59					09	15	23.58
			09	43	24.58					10	04	27.57
			10	32	26.56					10	53	21.55
			11	21	22.54					11	42	25.54

Table 9. GOES_3 and Parabola are Visible at the Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	00	00.00		2008	05	23	12	00	00.00

Table 10. TRMM and GOES_3 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	09	00.00		2008	05	22	12	21	07.99
			13	04	05.98					13	16	32.98
			13	48	23.96					14	00	55.96
			14	43	53.95					14	56	16.94
			15	28	19.93					15	40	30.93
			16	23	29.91	to				16	35	12.91
			17	07	57.90					17	19	24.90
			18	02	24.88					18	13	28.88
			18	46	49.87					18	57	43.86
			19	40	45.85					19	51	31.85
			20	25	03.84					20	35	52.83

Table 10. cont...

Date			Time			To	Date			Time		
Year	**Month**	**Day**	**Hour**	**Minute**	**seconds**		**Year**	**Month**	**Day**	**Hour**	**Minute**	**seconds**
			21	18	54.82					21	29	53.81
			22	03	06.80					22	14	20.80
			22	57	20.79					23	08	58.78
			23	41	31.77					23	53	28.77
2008	05	23	00	36	25.75		2008	05	23	00	48	46.75
			01	20	42.74					01	33	11.74
			02	16	08.72					02	28	38.72
			03	00	34.71					03	12	53.70
			03	55	51.69					04	07	48.69
			04	40	21.67					04	51	58.67
			05	34	58.66	to				05	46	11.65
			06	19	24.64					06	30	23.64
			07	13	25.62					07	24	14.62
			07	57	46.61					08	08	32.61
			08	51	34.59					09	02	29.59
			09	35	49.58					09	46	53.57
			10	29	54.56					10	41	21.56
			11	14	05.55					11	25	50.54

Table 11. NAVSTAR_46 and Hyp_1 are Visible at the Time Periods

Date			Time			To	Date			Time		
Year	**Month**	**Day**	**Hour**	**Minute**	**seconds**		**Year**	**Month**	**Day**	**Hour**	**Minute**	**seconds**
2008	05	22	12	00	00.00	to	2008	05	23	12	00	00.00

Table 12. NOAA_3 and NAVSTAR_46 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	**Month**	**Day**	**Hour**	**Minute**	**seconds**		**Year**	**Month**	**Day**	**Hour**	**Minute**	**seconds**
2008	05	22	12	00	00.00		2008	05	22	12	29	07.99
			12	52	10.98					13	18	05.97
			14	04	13.96					14	33	41.95
			14	49	07.94					15	31	47.93
			16	2	38.92	to				18	05	31.88
			18	50	24.87					19	15	30.86
			19	42	37.85					20	08	04.84
			20	52	22.83					22	55	21.79
			23	27	07.78		2008	05	23	00	08	10.76

Table 12. cont…

Date			Time			To	Date			Time		
Year	**Month**	**Day**	**Hour**	**Minute**	**seconds**		**Year**	**Month**	**Day**	**Hour**	**Minute**	**seconds**
2008	05	23	00	24	29.76		2008	05	23	00	53	40.75
				39	46.73					02	05	44.72
				28	29.72					03	01	00.71
				39	46.69	to				05	41	30.65
				24	50.64					06	51	32.63
				18	10.62					07	42	53.62
				28	18.60					12	00	00.00

Table 13. NAVSTAR_46 and Parabola are Visible at the Time Periods

Date			Time			To	Date			Time		
Year	**Month**	**Day**	**Hour**	**Minute**	**seconds**		**Year**	**Month**	**Day**	**Hour**	**Minute**	**seconds**
2008	05	22	12	00	00.00	to	2008	05	23	12	00	00.00

Table 14. Hyp_1 and Parabola are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	**Month**	**Day**	**Hour**	**Minute**	**seconds**		**Year**	**Month**	**Day**	**Hour**	**Minute**	**seconds**
2008	05	22	12	00	00.00	to	2008	05	23	12	00	00.00

Table 15. TRMM and NAVSTAR_46 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	**Month**	**Day**	**Hour**	**Minute**	**seconds**		**Year**	**Month**	**Day**	**Hour**	**Minute**	**Seconds**
2008	05	22	12	00	00.00		2008	05	22	13	26	57.97
			14	09	13.96					14	22	11.95
			14	48	40.95					14	59	40.94
			15	43	21.93					15	53	54.92
			16	21	40.91					16	33	28.91
			17	16	17.90					18	51	40.87
			19	31	35.85	to				19	49	13.85
			20	10	03.84					20	23	28.84
			21	06	54.82					21	17	13.82
			21	46	20.81					21	56	49.81
			22	40	08.79					22	55	04.79
			23	12	25.78					23	32	57.77
2008	05	23	00	10	56.76		2008	05	23	01	47	17.73
			02	30	15.72	to				02	41	39.71
			03	09	54.70					03	20	16.70

Table 15. cont…

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	Seconds
			04	03	57.69					04	15	20.68
			04	40	51.67					04	54	36.67
			05	36	33.66					07	11	25.63
			07	53	13.61					08	07	08.61
			08	32	30.60					08	44	01.60
			09	27	34.58					09	37	53.58
			10	06	27.57					10	17	37.56
			11	00	35.55					11	58	44.53

Table 16. TRMM and NOAA_3 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	Seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	00	00.00		2008	05	22	12	02	45.00
			12	04	13.00					12	12	32.00
			12	47	40.98					13	01	50.98
			13	43	07.97					13	49	28.96
			17	07	14.90					17	18	51.90
			17	55	59.88	to				18	12	55.88
			18	46	07.87					18	52	59.87
			18	58	23.86					19	05	15.86
			19	37	59.85					19	55	47.85
			20	31	34.83					20	44	55.83
			21	27	32.82					21	32	05.81
2008	05	23	00	03	53.76		2008	05	23	00	06	00.76
			00	50	15.75					01	02	49.75
			01	39	12.73					01	56	38.73
			02	29	33.72					02	36	24.71
			02	41	53.71					02	48	43.71
			03	21	40.70					03	39	02.69
			04	15	30.68					04	27	58.68
			05	12	36.66	to				05	14	03.66
			07	46	03.61					07	50	52.61
			08	33	19.60					08	46	45.59
			09	22	27.58					09	40	19.58
			10	13	01.57					10	19	54.56
			10	25	17.56					10	32	9.56
			11	05	23.55					11	22	15.54
			11	59	28.53					12	00	00.00

Table 17. TRMM and Hyp_1 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	10	49.00		2008	05	22	12	20	58.99
			12	57	3.98					13	7	14.98
			13	43	22.97					13	53	32.96
			14	29	37.95					14	39	48.95
			15	15	56.94					15	26	06.93
			16	02	11.92					16	12	22.92
			16	48	30.91					16	58	41.90
			17	34	45.89					17	44	56.89
			18	21	04.88	to				18	31	15.87
			19	07	19.86					19	17	30.86
			19	53	38.85					20	3	48.84
			20	39	53.83					20	50	04.83
			21	26	12.82					21	36	22.81
			22	12	27.80					22	22	38.80
			22	58	46.79					23	8	56.78
			23	45	01.77					23	55	12.77
2008	05	23	00	31	20.76		2008	05	23	00	41	30.75
			01	17	35.74					01	27	46.74
			02	03	54.73					02	14	04.72
			02	50	09.71					03	00	20.71
			03	36	28.70					03	46	38.69
			04	22	43.68					04	32	54.68
			05	09	01.67					05	19	12.66
			05	55	17.65	to				06	05	27.65
			06	41	35.63					06	51	46.63
			07	27	51.62					07	38	01.62
			08	14	09.60					08	24	19.60
			09	00	24.59					09	10	35.59
			09	46	43.57					09	56	53.57
			10	32	58.56					10	43	09.56
			11	19	17.54					11	29	27.54

Table 18. TRMM and Parabola are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	07	57.00		2008	05	22	12	18	06.99
			12	54	13.98					13	04	23.98
			13	40	29.97	to				13	50	39.96
			14	26	46.95					14	36	56.95
			15	13	02.94					15	23	12.93

Table 18. cont…

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
			15	59	19.92					16	09	30.92
			16	45	36.91					16	55	46.90
			17	31	52.89					17	42	03.89
			18	18	09.88					18	28	19.87
			19	04	26.86					19	14	36.86
			19	50	42.85					20	00	52.84
			20	36	59.83					20	47	09.83
			21	23	15.82					21	33	25.81
			22	09	32.80					22	19	42.80
			22	55	48.79					23	05	58.78
			23	42	05.77					23	52	15.77
2008	05	23	00	28	22.76		2008	05	23	00	38	31.75
			01	14	38.74					01	24	49.74
			02	00	55.73					02	11	05.72
			02	47	11.71					02	57	22.71
			03	33	28.70					03	43	38.69
			04	19	45.68					04	29	55.68
			05	06	01.67					05	16	11.66
			05	52	18.65	to				06	2	28.65
			06	38	34.64					06	48	44.63
			07	24	51.62					07	35	01.62
			08	11	07.61					08	21	17.60
			08	57	24.59					09	07	34.59
			09	43	41.58					09	53	50.57
			10	29	57.56					10	40	08.56
			11	16	14.55					11	26	24.54

Table 19. GOES_3 and NOAA_3 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	15	12.00		2008	05	22	12	40	51.99
			13	18	42.97					13	41	38.97
			14	09	35.96					14	32	02.95
			15	10	56.94					15	34	13.93
			16	00	11.92	to				16	25	01.91
			17	00	23.90					17	32	11.89
			17	42	19.89					18	19	06.88
			18	42	48.87					21	44	28.81
			22	4	47.80					23	24	59.78

Table 19. cont…

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
			23	59	06.77		2008	05	23	00	25	02.76
2008	05	23	00	49	46.75		2008	05	23	01	13	41.74
			01	52	18.73					02	14	48.72
			02	42	58.71					03	5	37.71
			03	43	55.69					04	8	31.68
			04	31	56.68	to				04	58	58.67
			05	31	51.66					06	53	32.63
			07	10	28.63					10	12	53.57
			10	39	05.56					11	12	42.55
			11	27	27.54					11	56	45.53

Table 20. NOAA_3 and Hyp_1 are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	27	50.99		2008	05	22	12	54	06.98
			13	25	52.97					13	52	04.96
			14	23	56.95					14	50	11.94
			15	21	59.93					15	48	09.93
			16	20	02.92					16	46	16.91
			17	18	05.90					17	44	14.89
			18	16	08.88	to				18	42	21.87
			19	14	11.86					19	40	20.85
			20	12	14.84					20	38	27.83
			21	10	17.82					21	36	25.81
			22	08	20.80					22	34	32.79
			23	06	23.78					23	32	30.77
2008	05	23	00	04	26.76		2008	05	23	00	30	37.76
			01	02	30.75					01	28	36.74
			02	00	33.73					02	26	42.72
			02	58	36.71					03	24	41.70
			03	56	39.69					04	22	48.68
			04	54	42.67					05	20	46.66
			05	52	45.65	to				06	18	53.64
			06	50	48.63					07	16	52.62
			07	48	51.61					08	14	58.60
			08	46	54.59					09	12	57.59
			09	44	57.58					10	11	04.57
			10	43	01.56					11	09	03.55
			11	41	03.54					12	00	00.00

Table 21. NOAA_3 and Parabola are Visible During the Following Time Periods

Date			Time			To	Date			Time		
Year	Month	Day	Hour	Minute	seconds		Year	Month	Day	Hour	Minute	seconds
2008	05	22	12	00	00.00		2008	05	22	12	00	27.00
			12	29	29.99					12	58	32.98
			13	27	36.97					13	56	33.96
			14	25	36.95					14	54	38.94
			15	23	42.93					15	52	39.92
			16	21	42.91					16	50	44.91
			17	19	48.90	to				17	48	45.89
			18	17	48.88					18	46	50.87
			19	15	54.86					19	44	51.85
			20	13	54.84					20	42	56.83
			21	12	00.82					21	40	57.81
			22	10	00.80					22	39	03.79
			23	08	07.78					23	37	03.77
2008	05	23	00	06	06.76		2008	05	23	00	35	09.75
			01	04	13.74					01	33	09.74
			02	02	13.73					02	31	15.72
			03	00	19.71					03	29	16.70
			03	58	19.69					04	27	21.68
			04	56	25.67					05	25	22.66
			05	54	25.65	to				06	23	27.64
			06	52	31.63					07	21	28.62
			07	50	31.61					08	19	33.60
			08	48	37.59					09	17	34.58
			09	46	37.57					10	15	40.57
			10	44	44.56					11	13	40.55
			11	42	43.54					12	00	00.00

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None declared.

CONFLICTS OF INTEREST

None declared.

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