

Tracking of - IKAROS -

First Solar Power Sail Demonstration

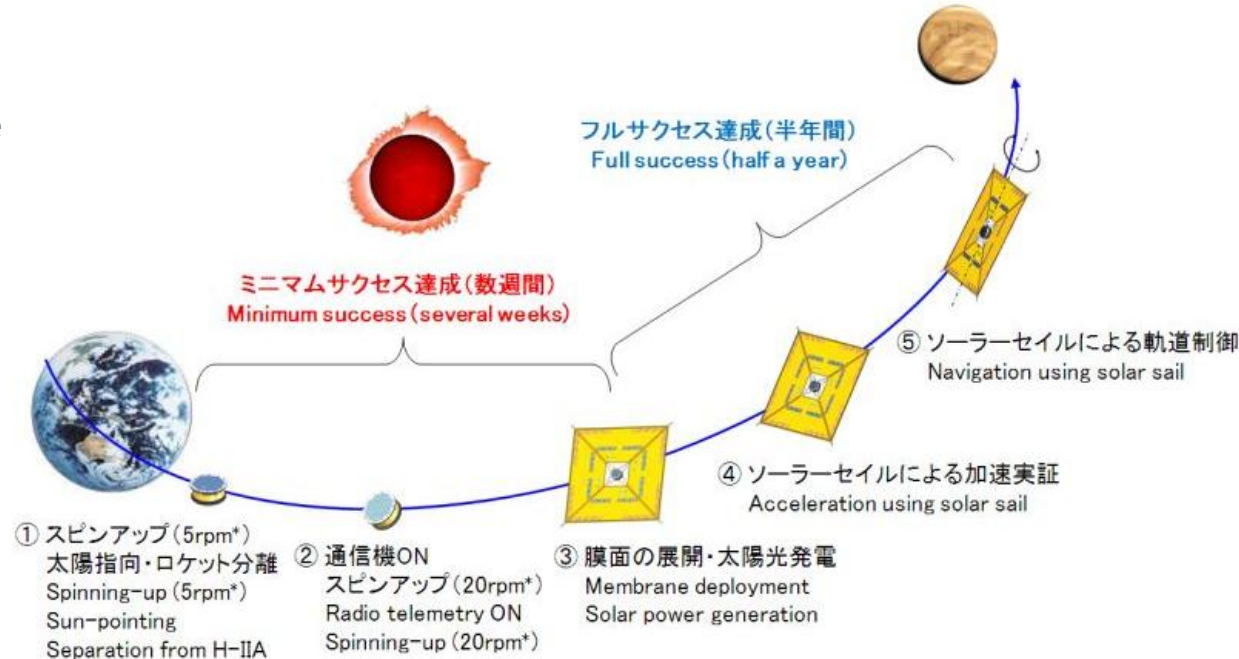
F5PL measurements
F5PL / F1EHN report

Last update : 18/06/2010

About IKAROS

Interplanetary Kite-craft Accelerated by Radiation Of the Sun

- Mission =>
- Launch date
– 21/05/2010



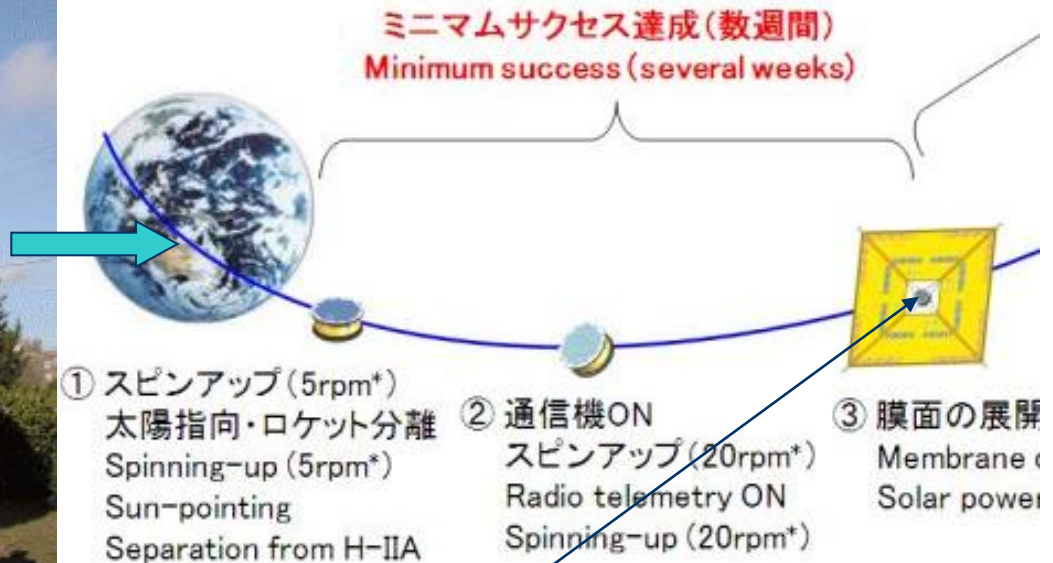
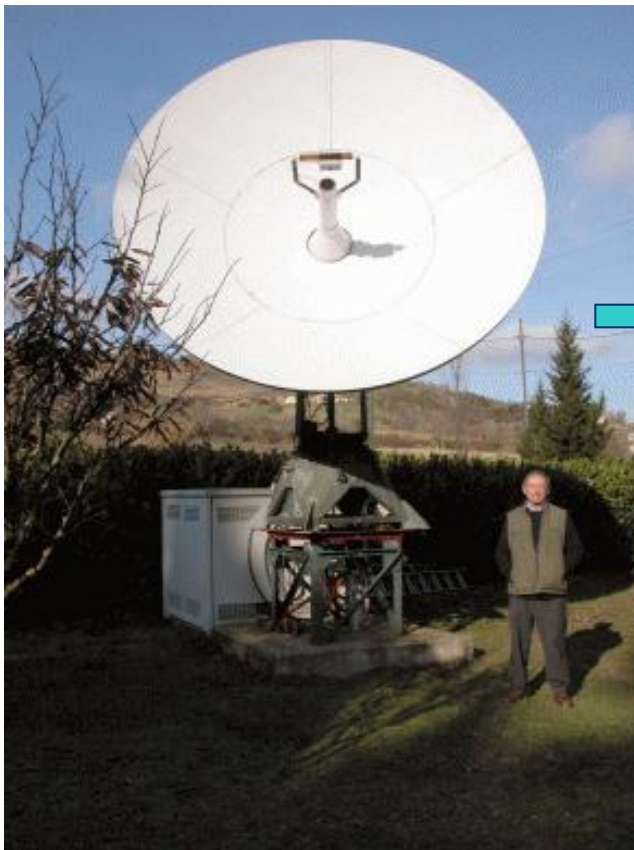
ミッションシーケンス

*rpm= revolutions per minute

More info : <http://directory.eoportal.org/presentations/330/10002509.html>
IKAROS Blog : <http://www.isas.jaxa.jp/home/IKAROS-blog/>

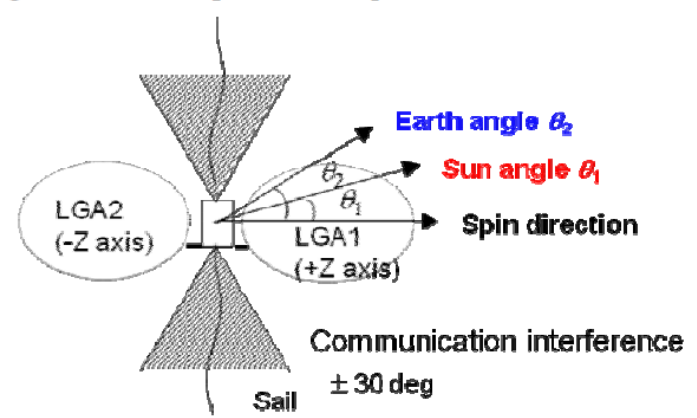
Measurement

- From F5PL station



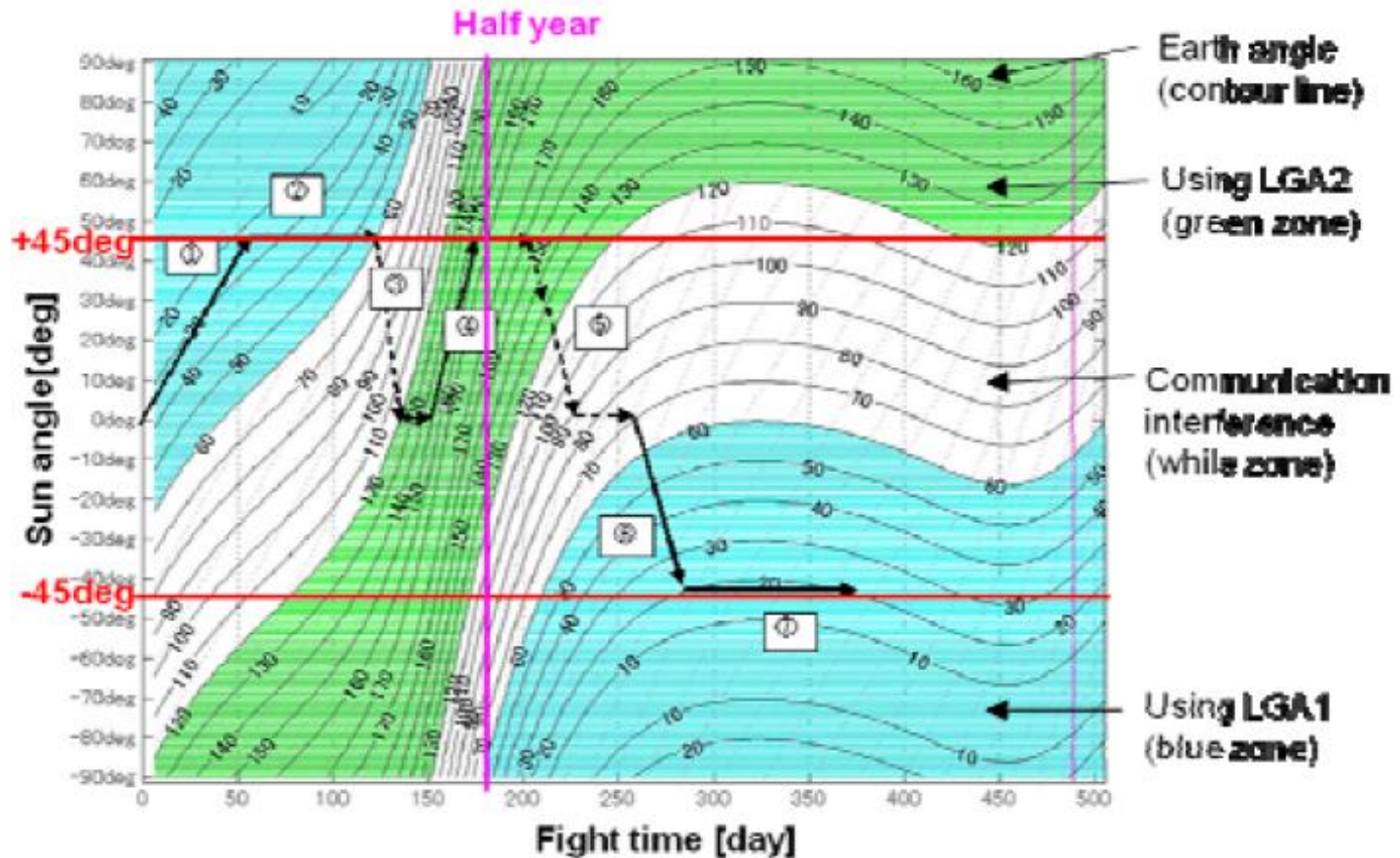
Radiometry Transmitter : Freq : 8.4 GHz,
RF power : 7W

Measurement Ikaros using LGA1

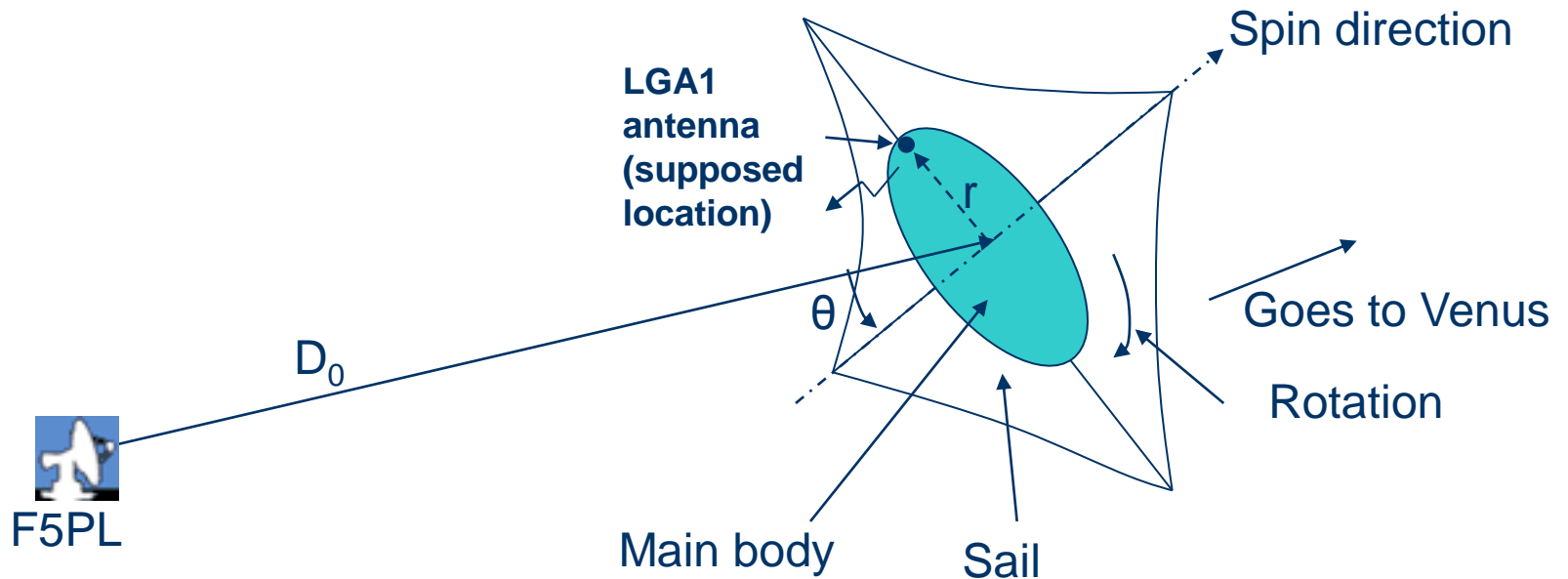


Condition for power supply and acceleration $0 < |\theta_1| < 45$ deg

Condition for communication $0 < |\theta_2| < 60$ deg (using LGA1)
 $120 < |\theta_2| < 180$ deg (using LGA2)



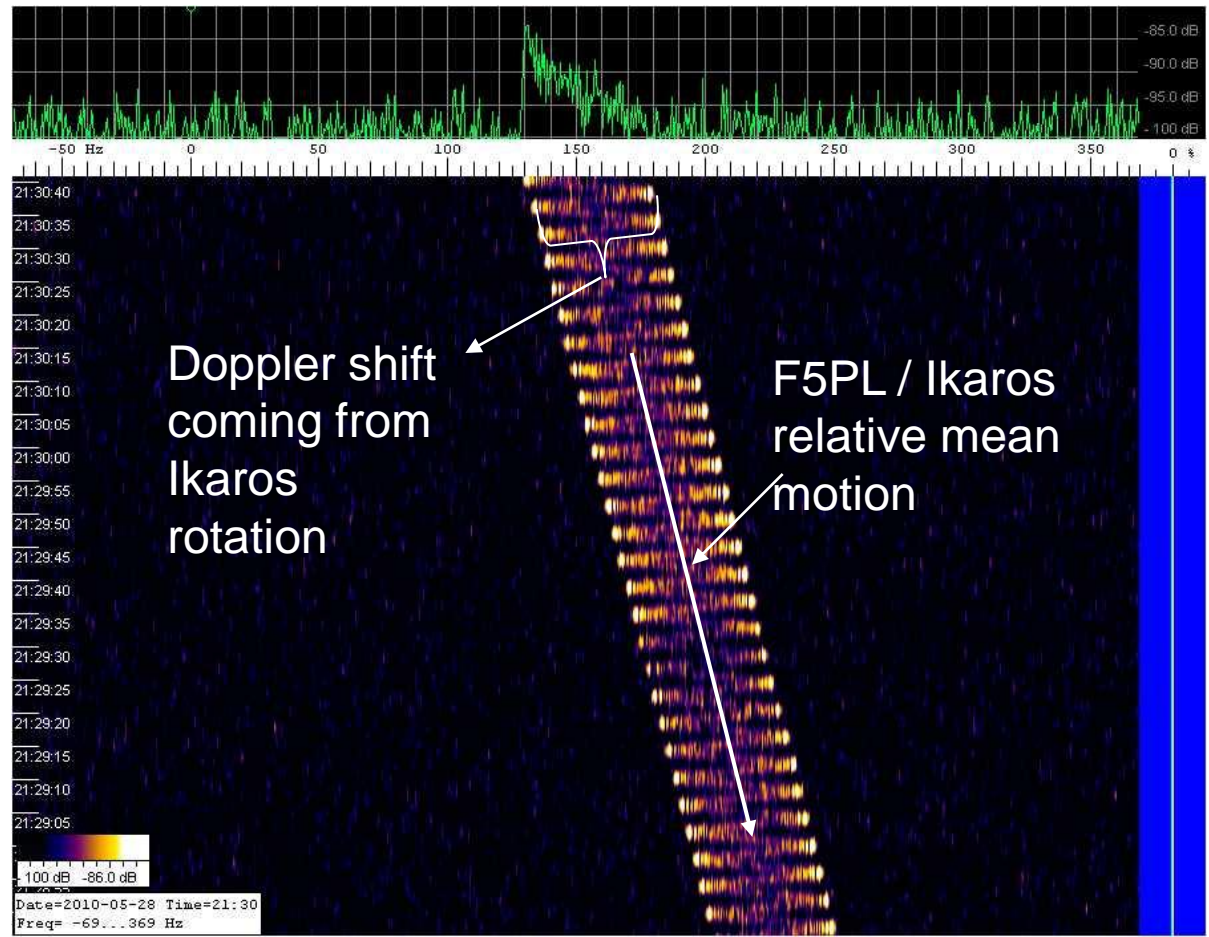
Measurements and analyses.



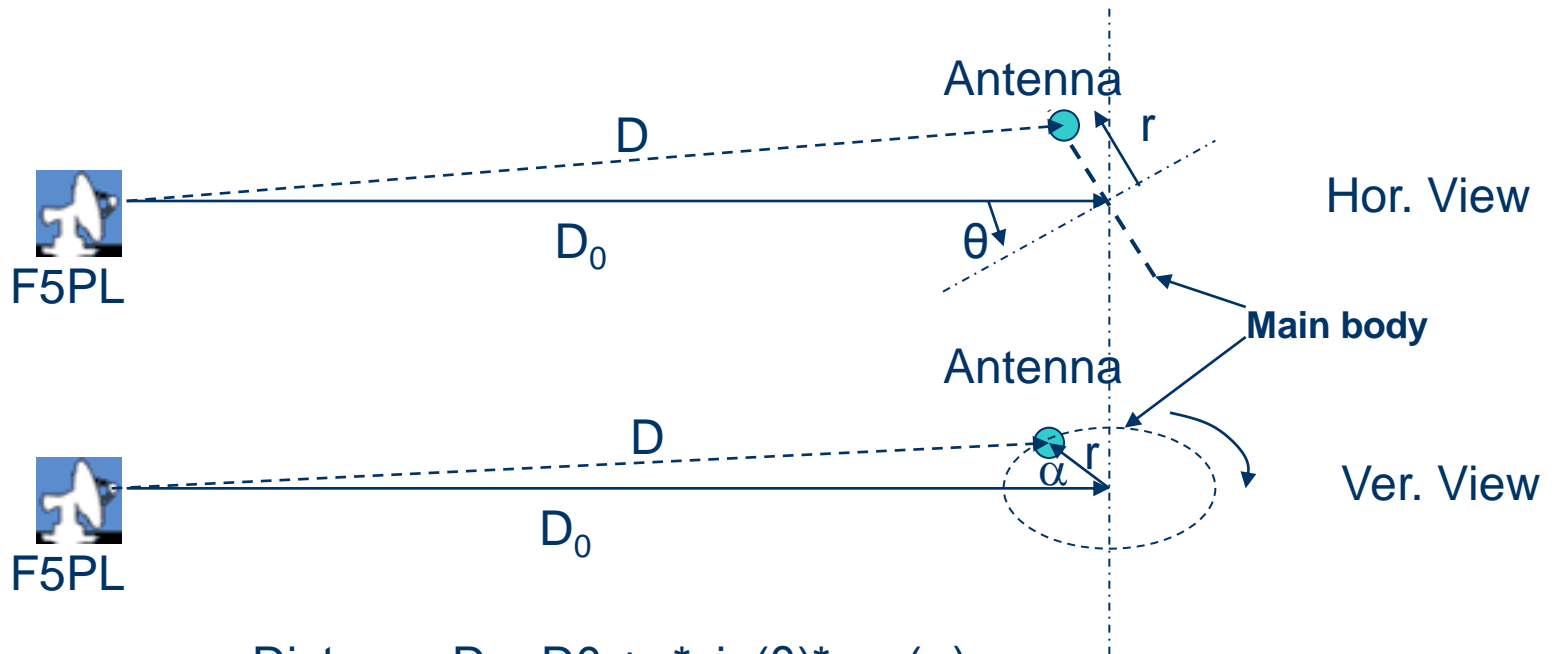
Measurement : 28/05/2010

Doppler shift :
+/- 24 Hz

Rotation speed :
15 rpm



Calculation



$$\text{Distance } D = D_0 + r \cdot \sin(\theta) \cdot \cos(\alpha)$$

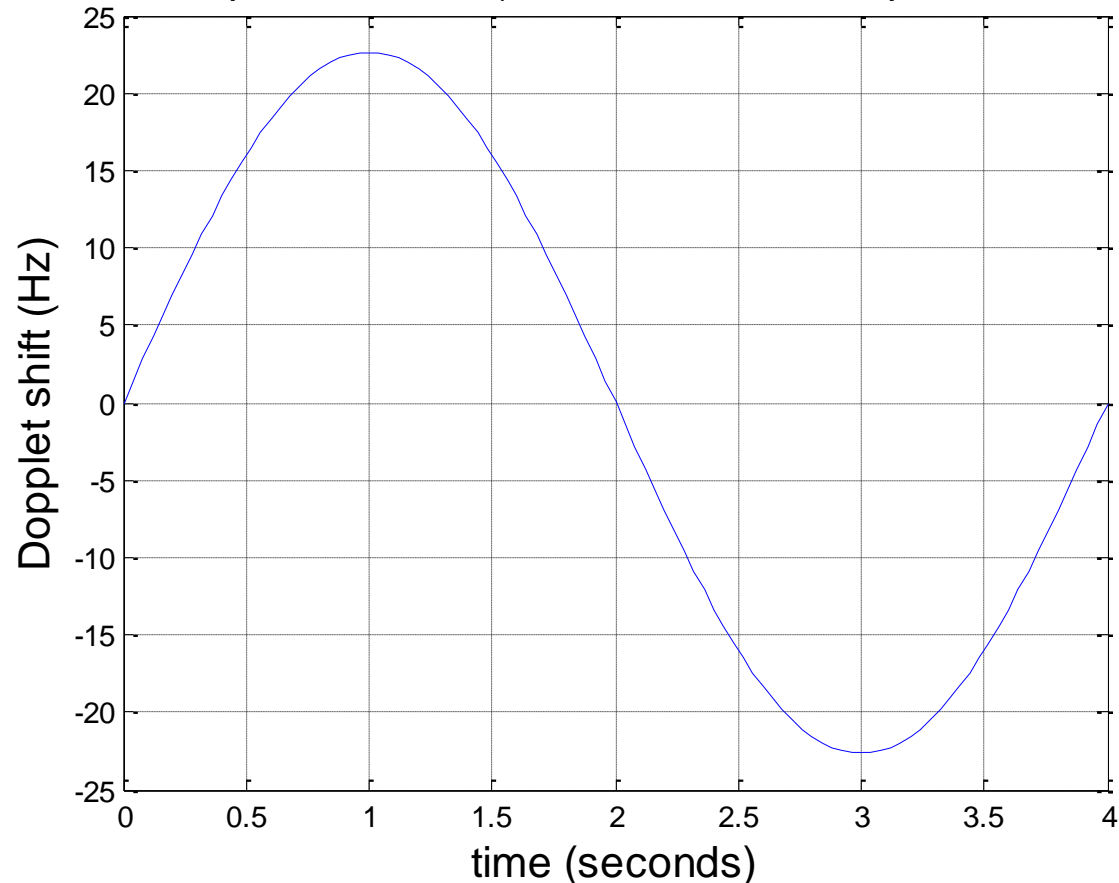
$$\text{Speed rotation } V = \text{derivative } (D) = D'(\alpha)$$

$$\text{Doppler shift} = -V / \text{lambda with } \text{lambda} = c / \text{freq}$$

The mean motion is not computed

Calculation

antenna speed rotation (radius = 0.8 m - 15 rpm - Dir = 40 °)



Assuming :

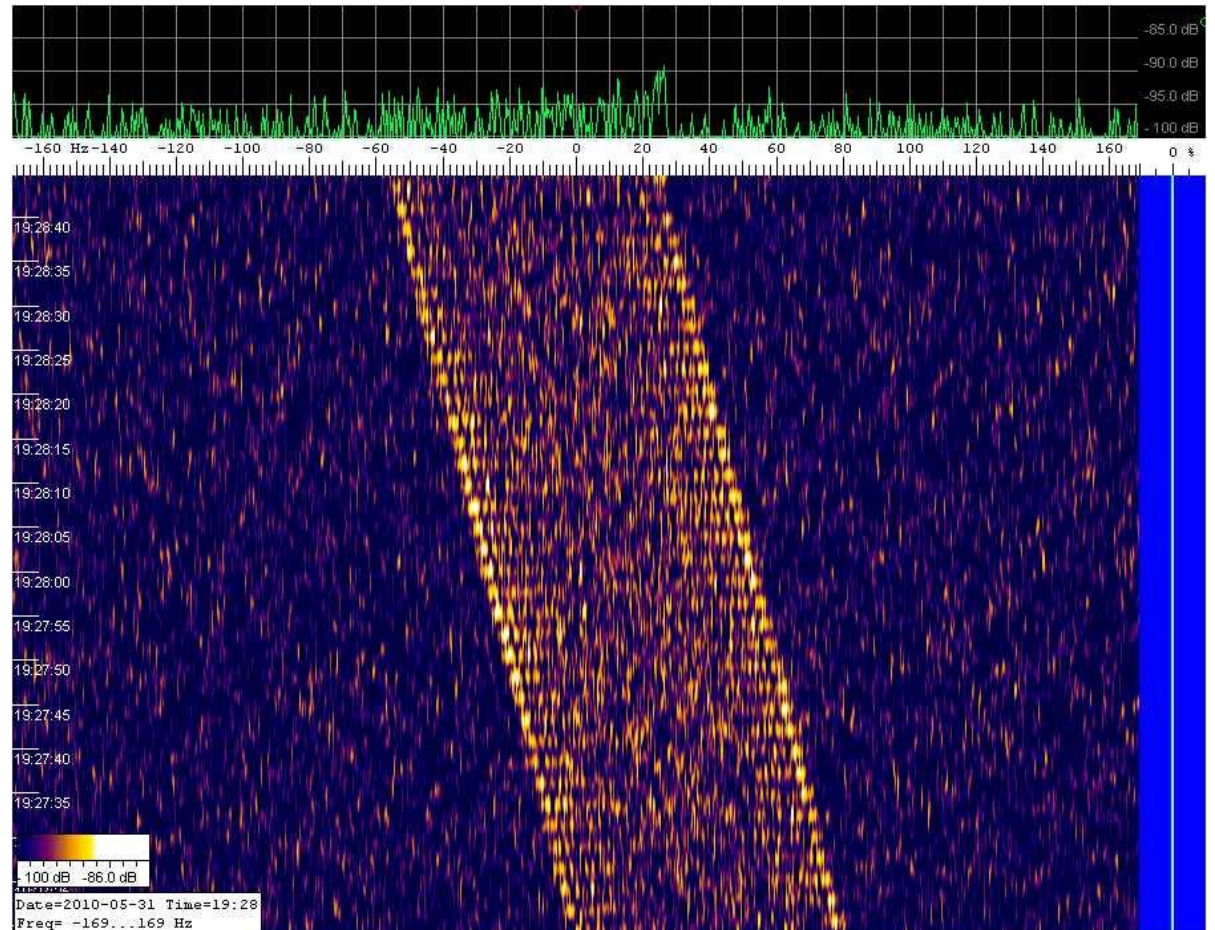
- antenna is on peripheral of the main body (radius = 0.8m)
- Spin direction is 40°
- Rotation is 15 rpm

=> Calculation gives values closed to the measurement done on 28/5/2010.

Measurement on 31/5/2010

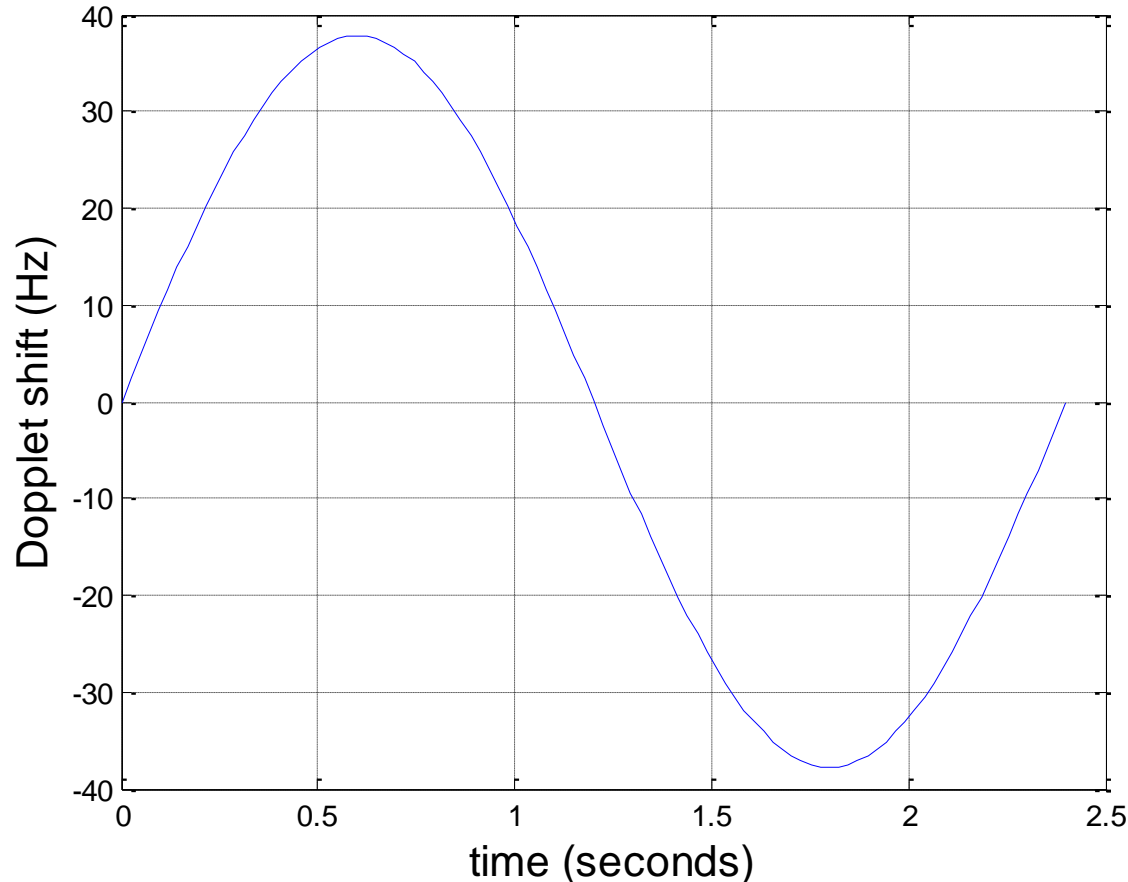
Doppler shift :
+/- 40 Hz

Rotation speed :
25 rpm



Calculation

antenna speed rotation (radius = 0.8 m - 25 rpm - Dir = 40 °)



Assuming :

- antenna is at the peripheral of the main body
- Spin direction is 40°
- Rotation is 25 rpm

=> Calculation gives values closed to the measurement done on 31/5/2010.

From the IKAROS blog (6/2) :

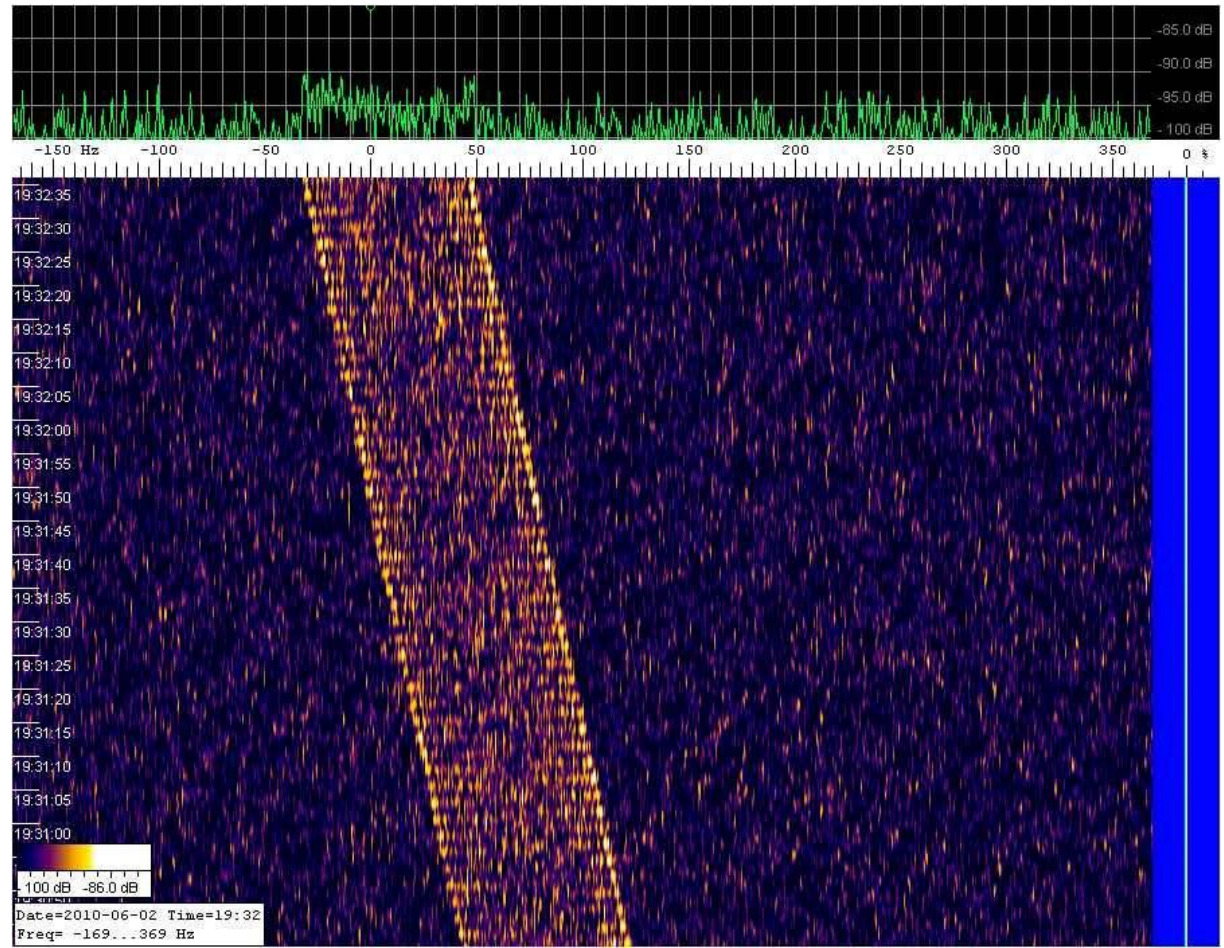
- Solar Distance: 1.04AU
- Earth Distance: 4834395km, ascension =- 158.2 °, declination =- 22.9
- Venus Distance: 1.28AU
- Attitude: spin rate = 24.5rpm, sun angle 16.8deg

Measurement on 02/6/2010

Doppler shift :
+/- 40 Hz

Rotation speed :
25 rpm

Ikaros flight is very
stable at this time

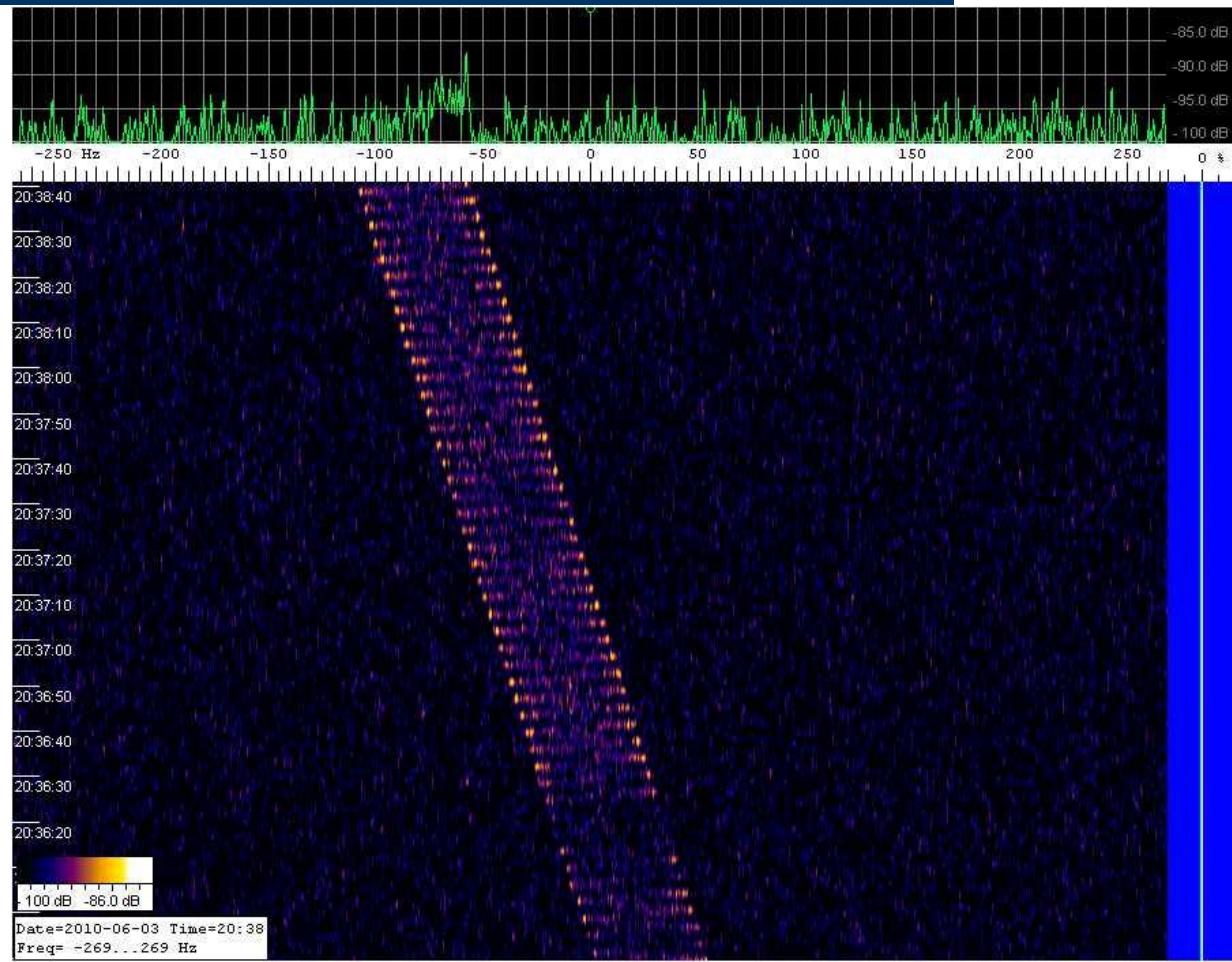


Measurement on 03/6/2010

Doppler shift :
+/- 25 Hz

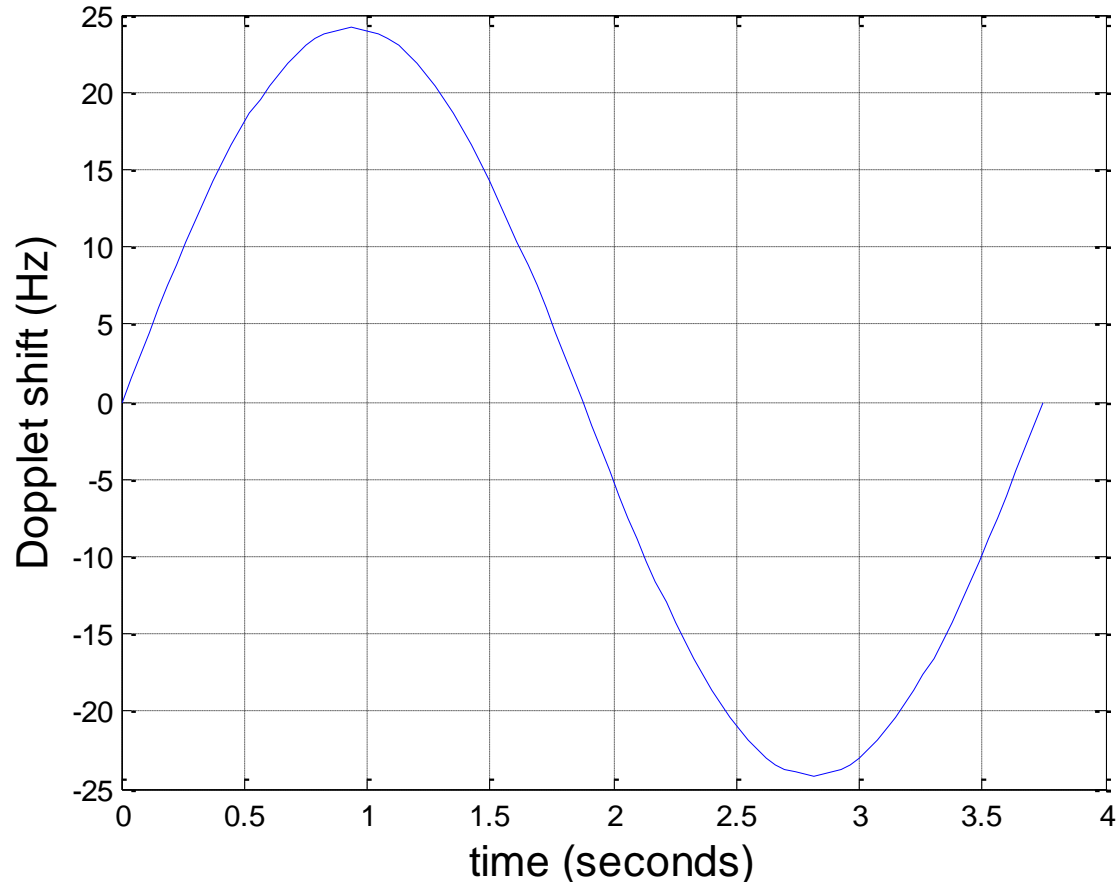
Rotation speed :
16 rpm

The rotation speed
is decreasing



Calculation

antenna speed rotation (radius = 0.8 m - 16 rpm - Dir = 40 °)



Assuming :

- antenna is on peripheral of the main body
- Spin direction is 40°
- Rotation is 16 rpm

=> Calculation gives values closed to the measurement done on 3/6/2010.

Conclusion on 3/6/2010

- The measured speed rotation are very closed to the attended speed extracted from the flight information (from JAXA). The deployment sequence is defined as follows:
 - 1) Separation from rocket with slow spin (5rpm)
 - 2) Spin down using Reaction Control System (RCS) (5rpm -> 2rpm)
 - 3) Release of launch lock
 - 4) Spin up using RCS (2rpm -> 20rpm)
 - 5) First stage of the deployment (20rpm -> 5rpm)
 - 6) Second stage of the deployment (5rpm -> 2rpm)
- It seems IKAROS is between phase 4 and 5. May be phase 5 is starting.
- All the calculations are done with estimated value because we had any return from JAXA about the report of Bertrand F5PL.

CONTINUE=>

Bertand F5PL / J-Jacques F1EHN (<http://www.f1ehn.org>). More measurements done by Bertrand on the dedicated DSN Yahoo group.

From the IKAROS Blog (6/4)

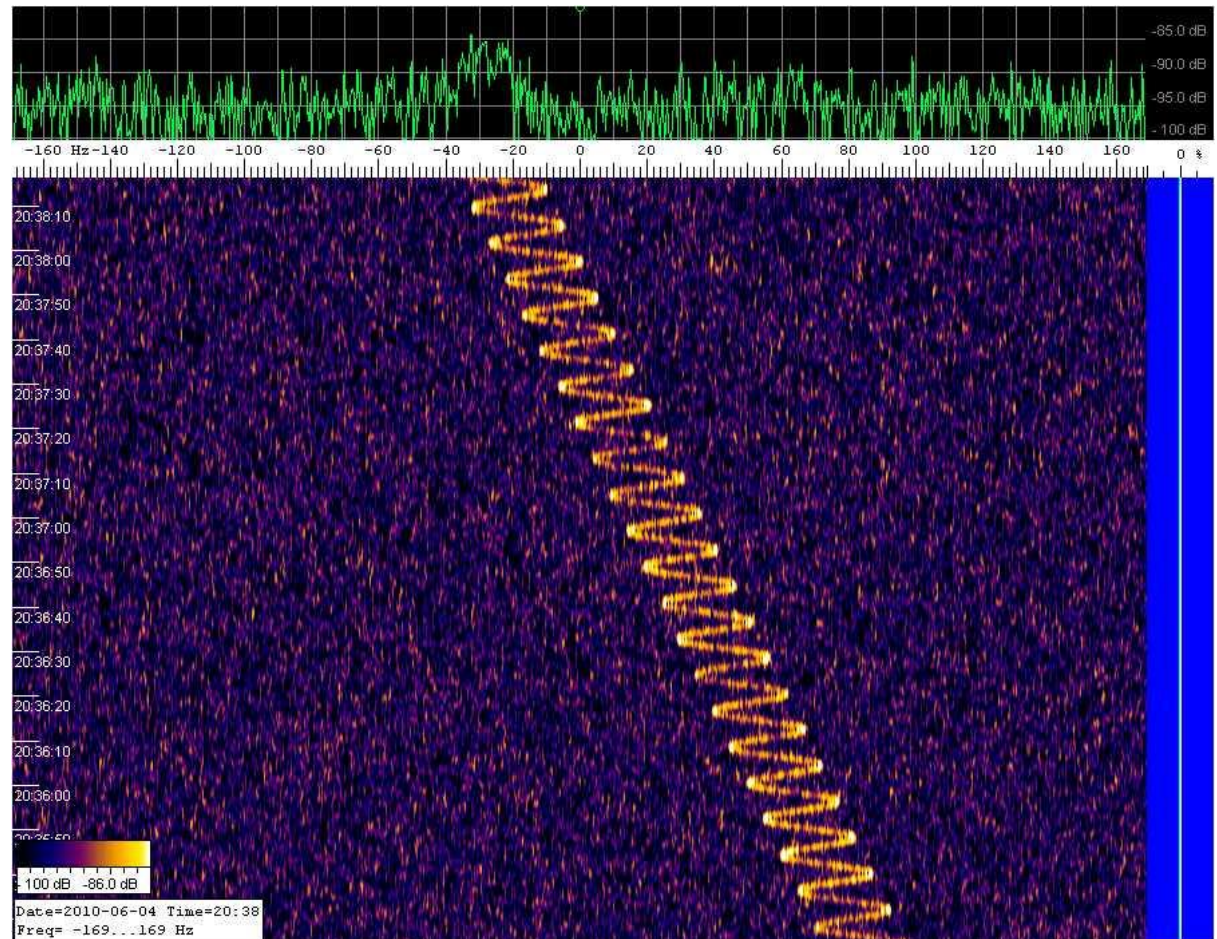
- Solar Distance: 1.04AU
- Earth Distance: 5588044km, ascension =- 158.0 °, declination =- 23.0 °
- Venus Distance: 1.26AU
- Attitude: spin rate = 7.4rpm, sun angle 16.8deg

Measurement on 4/6/2010

Doppler shift :
+/- 12 Hz

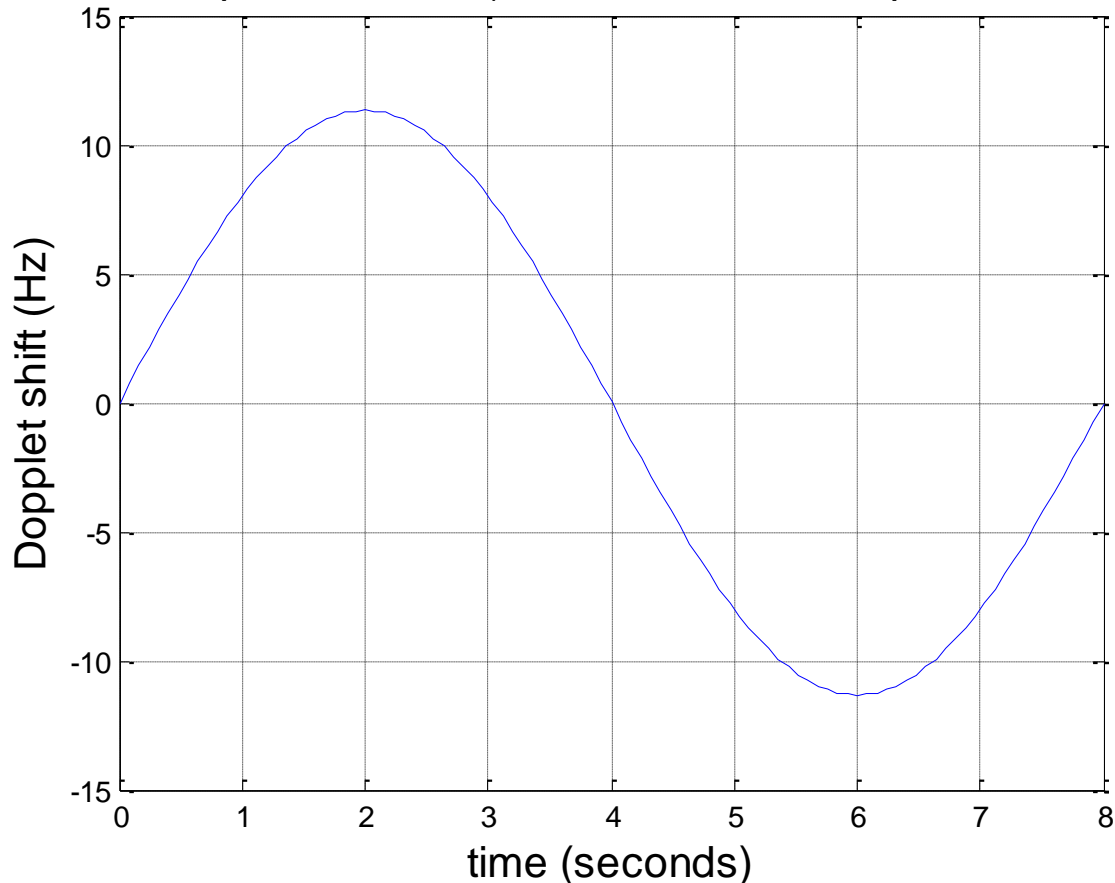
Rotation speed :
7.5 rpm

The rotation speed
is decreasing



Calculation

antenna speed rotation (radius = 0.8 m - 7.5 rpm - Dir = 40 °)



Assuming :

- antenna is on peripheral of the main body
- Spin direction is 40°
- Rotation is 7.5 rpm

=> Calculation gives values closed to the measurement done on 4/6/2010.

IKAROS Deployment



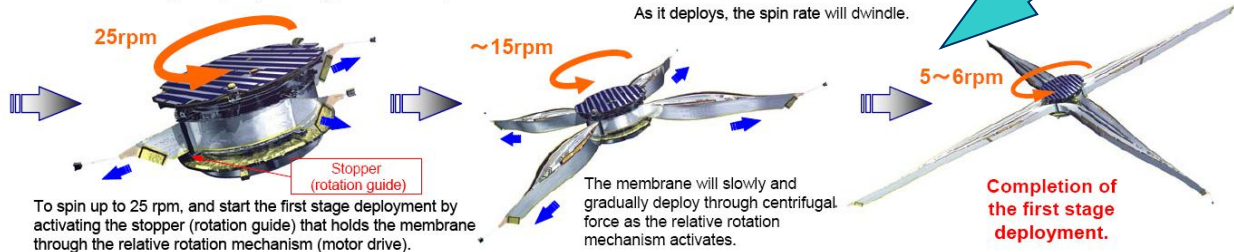
Membrane Deployment Sequence and Mechanism



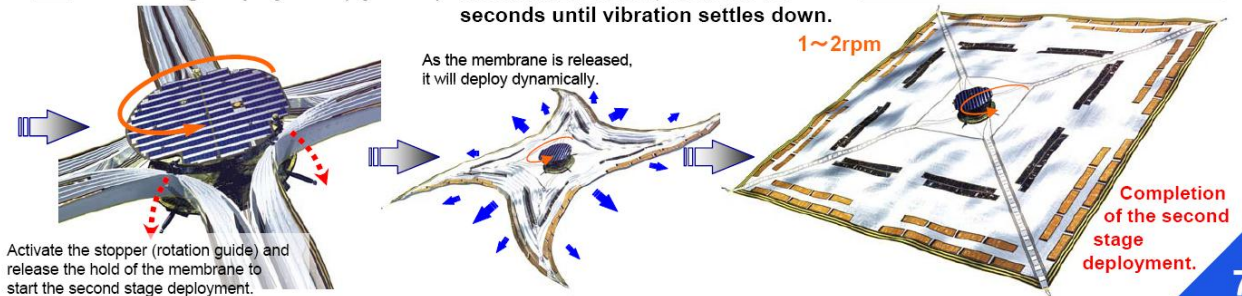
Tip mass separation



First stage deployment (quasi static): About one hour



Second stage deployment (dynamic): About five seconds, or about 100 seconds until vibration settles down.



Last measurement indicates IKAROS is now at the end at this phase (Phase 5 – First deployment)

Last info from IKAROS blog

- 4th of June
 - Primary development proceeded today. Deployment length 5.3m. IKAROS size is now at 10m from end to end is over.
 - Solar Distance: 1.04AU
 - Earth Distance: 5588044km,
 - Ascension =- 158.0 °, Declination =- 23.0 °
 - Venus Distance: 1.26AU
 - Attitude: spin rate = 7.4rpm, sun angle 16.8deg

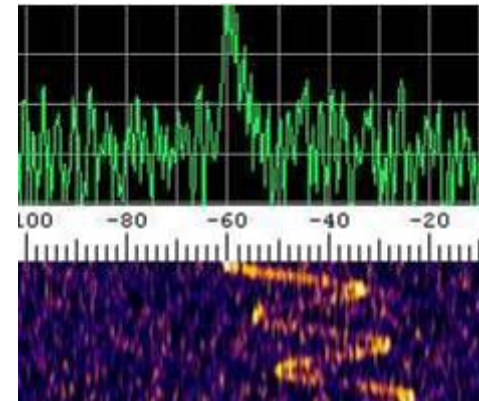
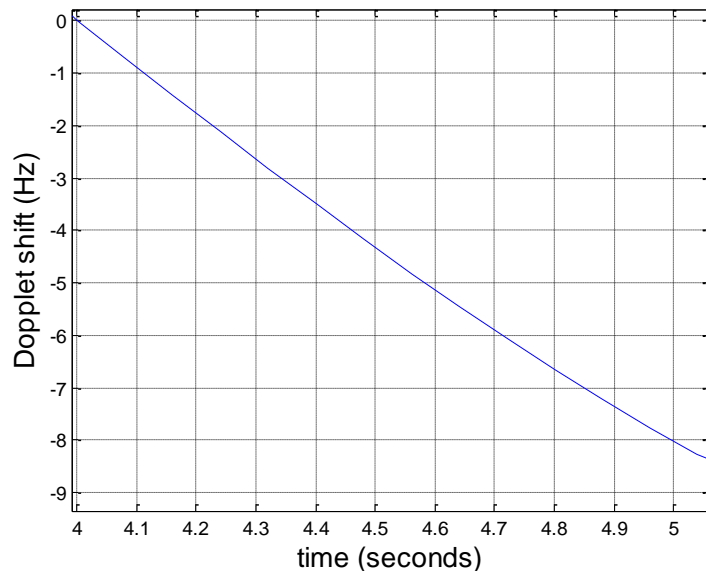
RF Budget

- RF Power : 7 W => 8.5 dBW
- LGA1 : 5 dB (estimated)
- Distance : $5.6 \cdot 10^9$ m => Free space atten. : - 246 dB @8.4Ghz
- F5PL antenna gain : 44 dB
- Tsys : 80 K (estimated)
- B = 1Hz
- Noise floor (kTB): -209 dBW
- Signal level : -188 dBW (sum of power, gain and attenuation)
- S/B should be around 20 dB
- FFT display gives about 10 dB (1 Hz band) => continue...

RF Budget

- The difference of 10 dB is probably coming from the extremely narrow band of 1 Hz regarding the swing of the received signal. Then the signal is spread over a few FFT bins.

antenna speed rotation (radius = 0.8 m - 7.5 rpm - Dir = 40 °)



With a measurement near the swing reversal, the peak value is better (near 15 dB) and confirms this analyze.

**In 1 sec (1Hz), the signal swing is about 8Hz.
Then, probably losses are near 10 dB**

Conclusion on 4/6/2010

- Measurement confirms that IKAROS is at the end of the phase 5.
 - 5) First stage of the deployment (20rpm -> 5rpm)
 - 6) Second stage of the deployment (5rpm -> 2rpm)
- IKAROS could begin the Phase 6 in the coming hours. Measurements and observations match to the IKAROS flight.
- The spin rotation axis relative to the earth seems to be constant up to now because the ratio between Doppler shift and Rotation speed remains constant. The spin rotation angle relative to the Earth is estimated at 40°.
- The RF budget is correct regarding the extremely narrow used for measurement. May be a band of 10 Hz should be better for a S/B measurement using an averaging over a few measurements (be careful with the Doppler shift coming from the mean motion of IKAROS).

CONTINUE=>

Bertand F5PL / J-Jacques F1EHN (<http://www.f1ehn.org>). More measurements done by Bertrand on the dedicated DSN Yahoo group.

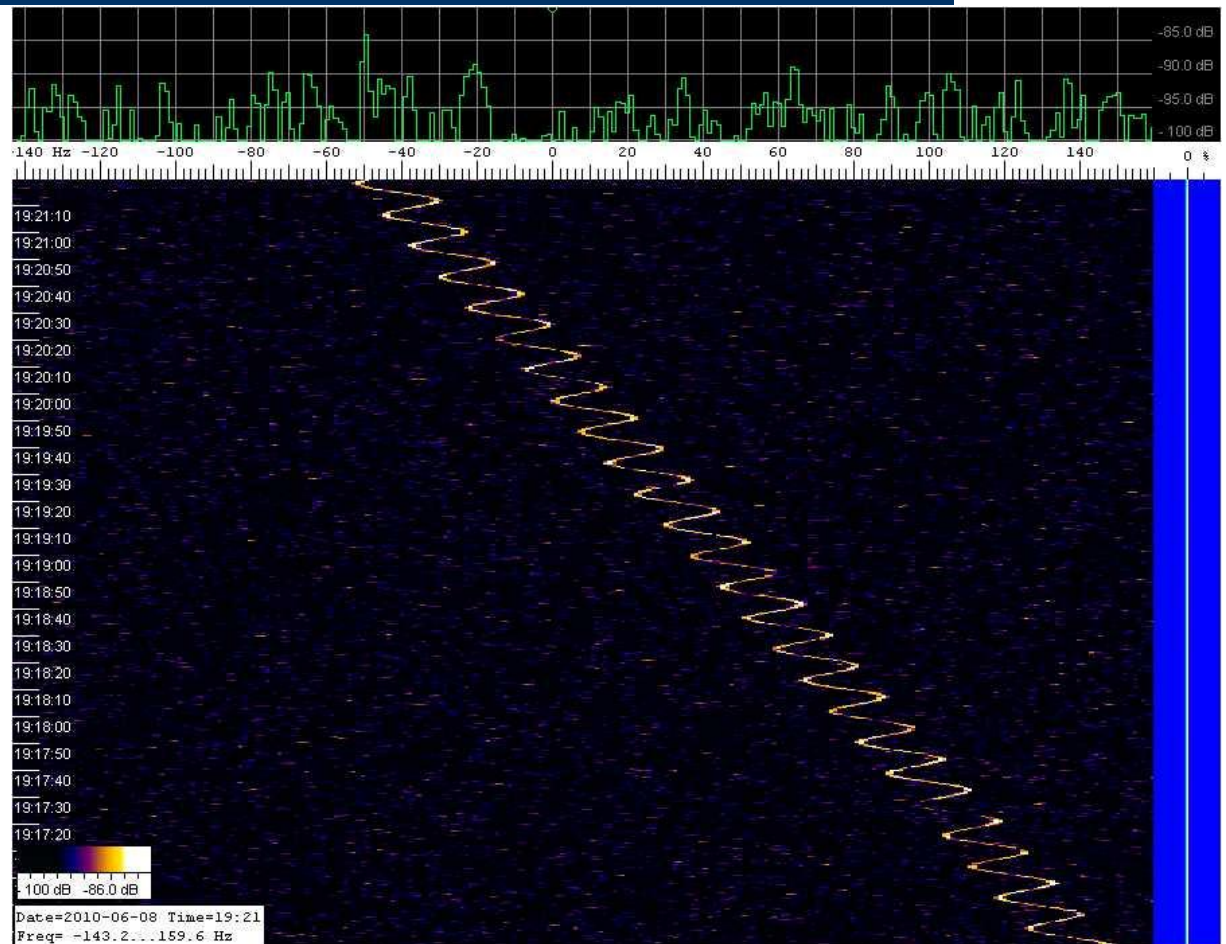
From IKAROS blog (8/6/2010)
Small solar powered sail demonstration unit "IKAROS (Icarus)"
implementation date for the expansion of secondary and primary sail
deployment of the third day

Measurement on 8/6/2010

Doppler shift :
+/- 7 Hz

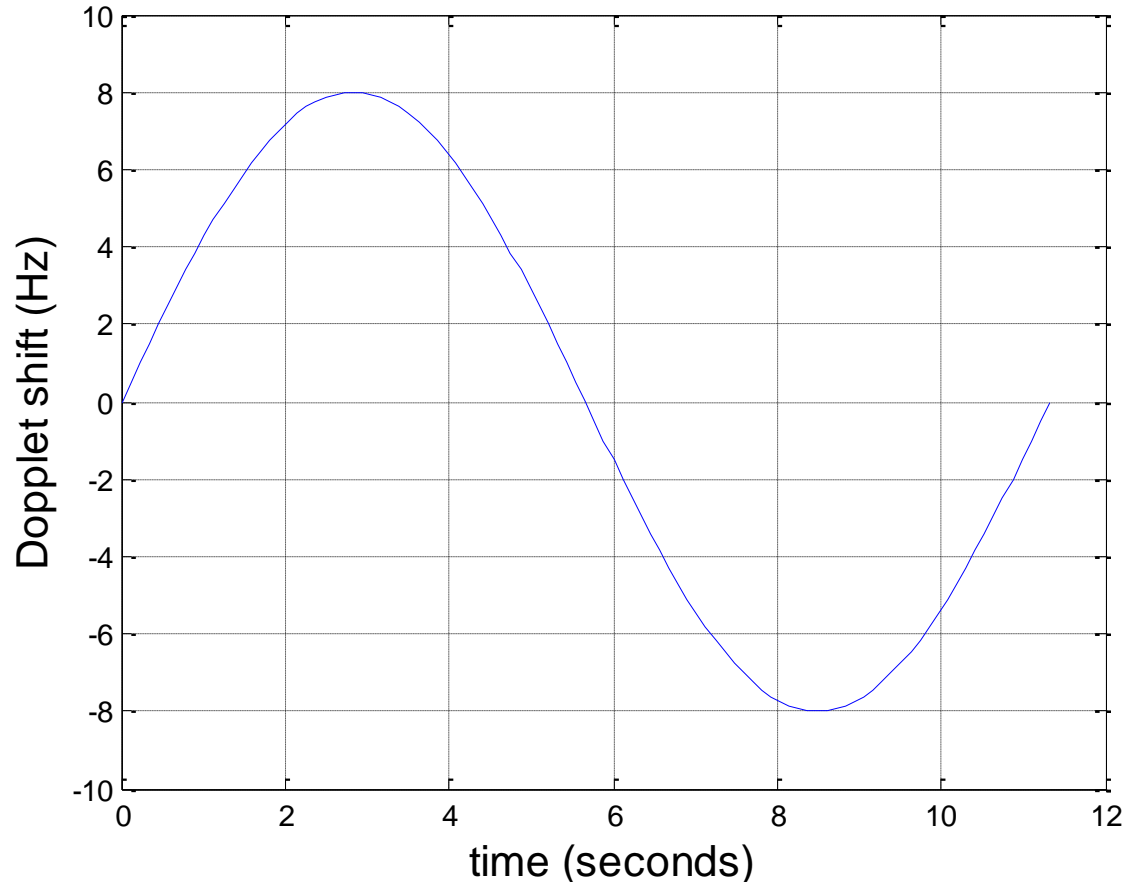
Rotation speed :
5.3 rpm

The rotation speed
is still decreasing
coming from the
expansion of the
sail



Calculation

antenna speed rotation (radius = 0.8 m - 5.3 rpm - Dir = 40 °)



Assuming :

- antenna is on peripheral of the main body
- Spin direction is 40°
- Rotation is 5.3 rpm

=> Calculation gives values closed to the measurement done on 8/6/2010.

From IKAROS blog (10/6/2010)

The operation ended today as planned.

- Solar Distance: 1.05AU - Venus Distance: 1.23AU
- Earth Distance: 7480787km,
- Ascension =- 157.3 °, Declination =- 23.0 °
- Attitude: spin rate = 2.5rpm, sun angle 13.3deg

Measurement on 10/6/2010

Doppler shift :

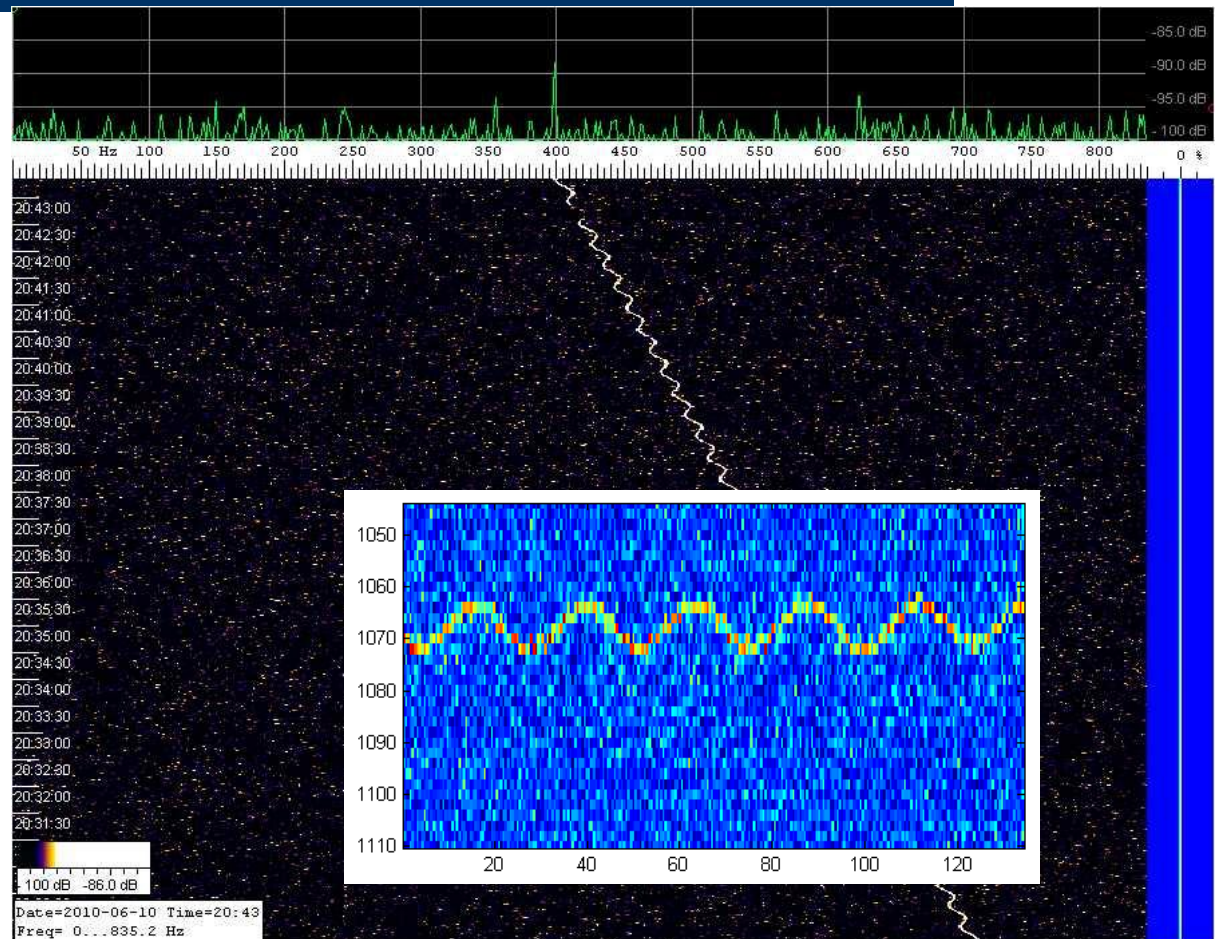
+/- 4.5 Hz

Rotation speed :

2.5 rpm

The rotation speed is still decreasing coming from the expansion of the sail.

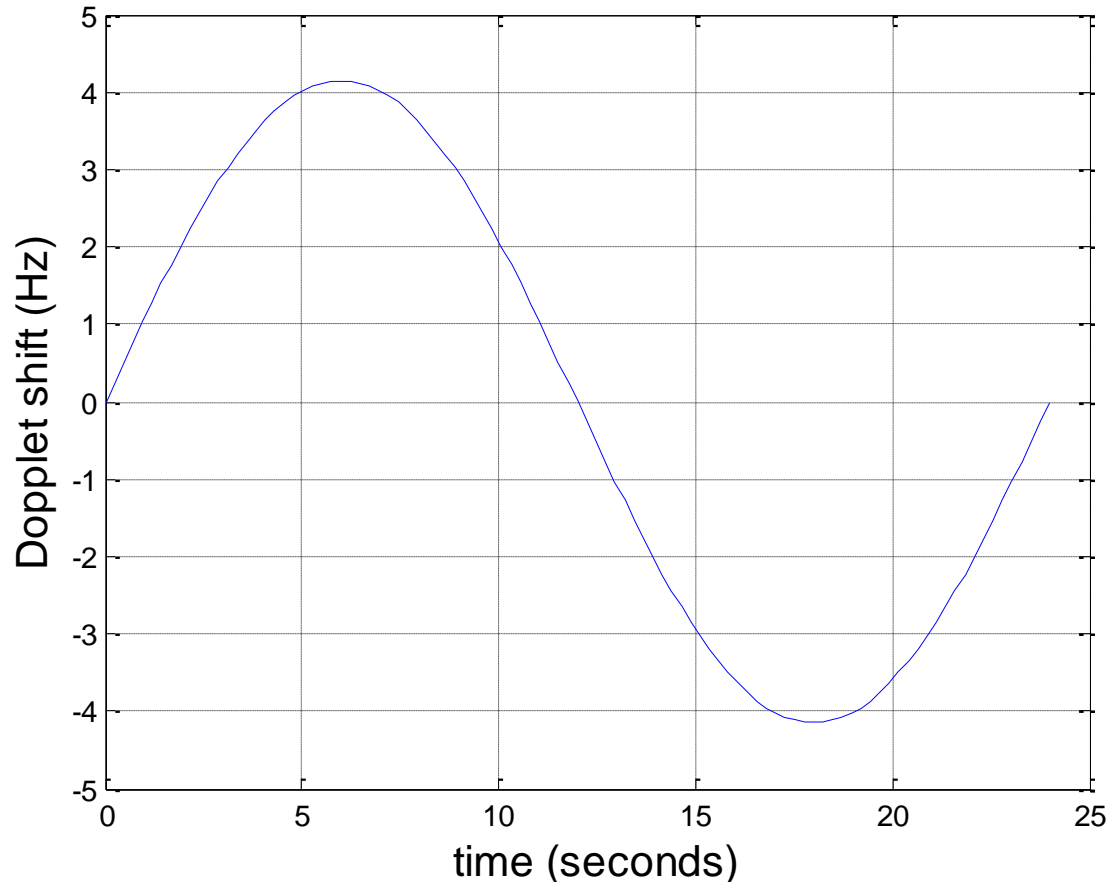
To measure the low Doppler shift and rotation speed, now we have to compensate the mean Doppler shift coming from the Earth rotation and Ikaros relative speed.



Calculation

The calculation shows the angle of the spin rotation relative to the Earth is probably a little bit higher. With this value (45°) the calculated Doppler shift is closed to the measured value.

antenna speed rotation (radius = 0.8 m - 2.5 rpm - Dir = 45°)



Assuming :

- antenna is on peripheral of the main body
- Spin direction is 45°
- Rotation is 2.5 rpm

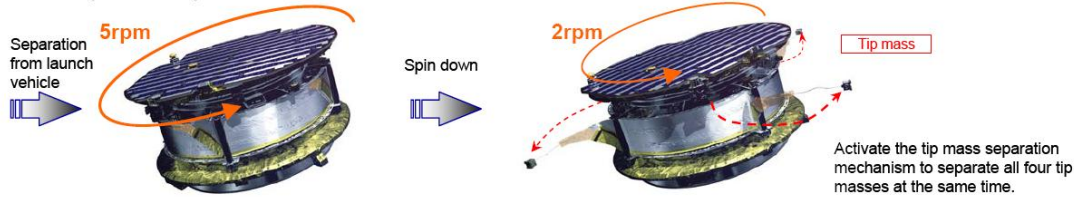
IKAROS Deployment



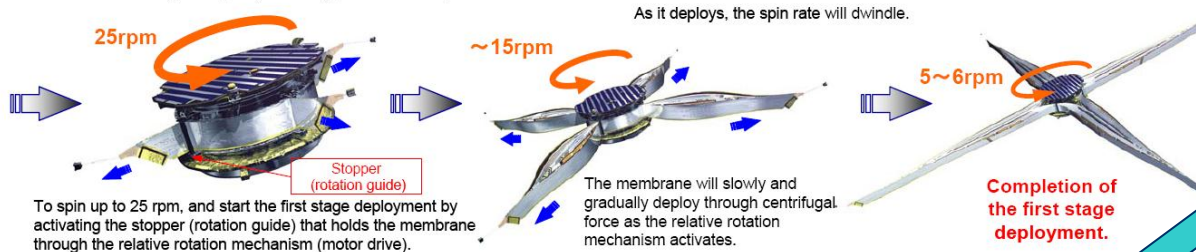
Membrane Deployment Sequence and Mechanism



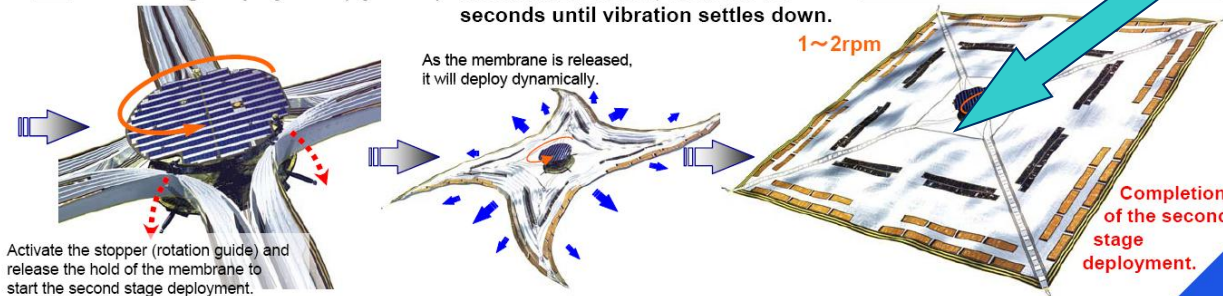
Tip mass separation



First stage deployment (quasi static): About one hour



Second stage deployment (dynamic): About five seconds, or about 100 seconds until vibration settles down.



Last measurement indicates IKAROS is now at the end at this phase (Phase 6 – Second deployment)

Conclusion on 11/6/2010

- Last measurements show the dynamical change on the IKAROS flight. Now the sail seems to be completed deployed and IKAROS is at the end of the phase 6.
 - 6) Second stage of the deployment (5rpm -> 2rpm)
- Measurements and observations match to the IKAROS flight reported by the IKAROS blog.
- The spin rotation axis relative to the earth seems to be stable but probably higher because the ratio between Doppler shift and Rotation speed increased by about 10%. The spin rotation angle relative to the Earth is estimated at 45°.
- The RF budget is correct regarding the IKAROS's distance (about 7.5 million of km).

Continue=>

Bertand F5PL / J-Jacques F1EHN (<http://www.f1ehn.org>). More measurements done by Bertrand on the dedicated DSN Yahoo group.

From IKAROS blog (15/6/2010)

Solar Distance: 1.06AU

- Earth Distance: 9778124km,
- Ascension =- 156.0 °, Declination =- 23.2 °
- Venus Distance: 1.18AU
- Attitude: spin rate = 2.5rpm, sun angle 12.6deg

Measurement on 15/6/2010

Doppler shift :

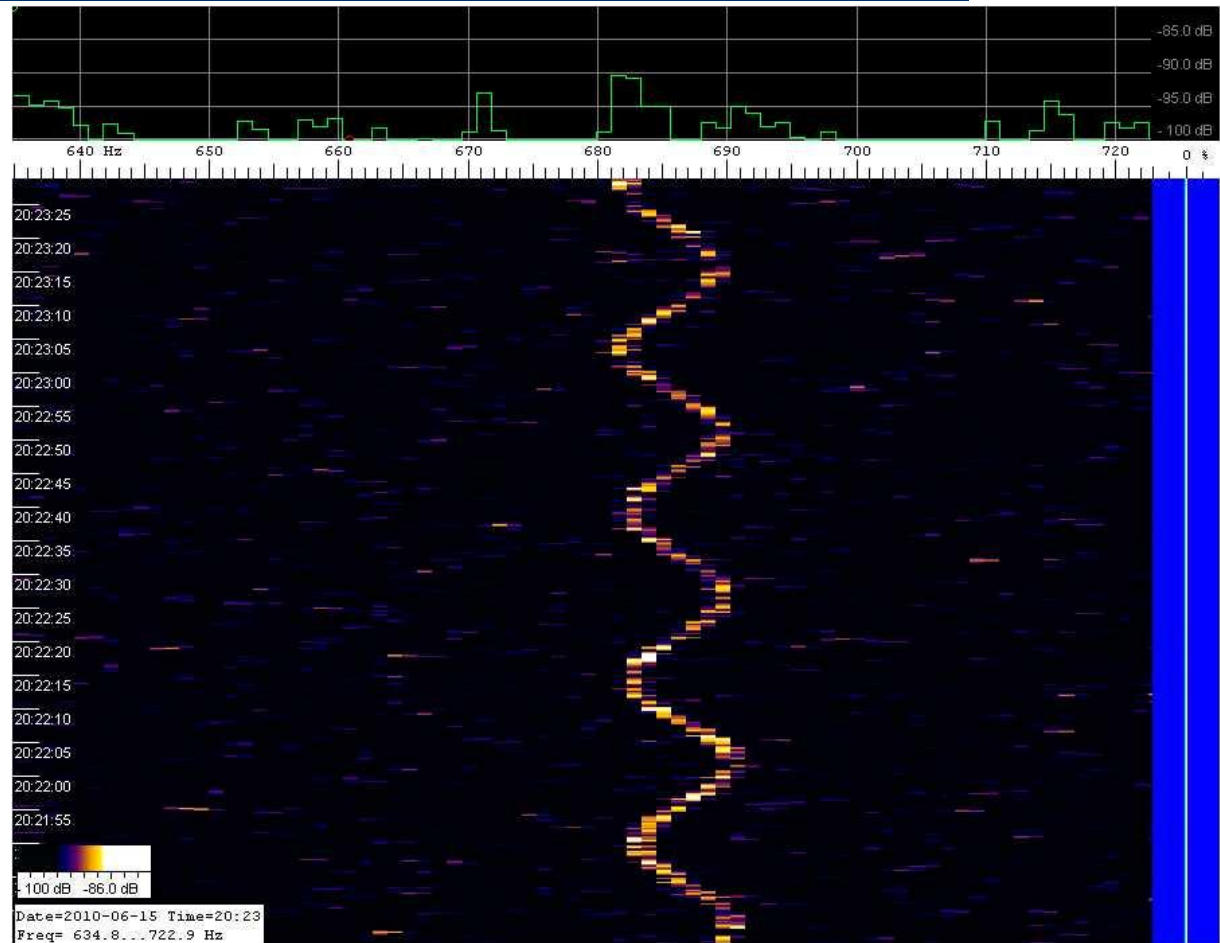
+/- 4.5 Hz

Rotation speed :

2.5 rpm

The rotation speed is stable since 10th of june.

To measure the low Doppler shift and rotation speed, now Bertrand is able to offset the mean Doppler shift coming from the Earth rotation and Ikaros relative speed.



From IKAROS blog (16/6/2010)

- Solar Distance: 1.06AU
- Earth Distance: 10163561km
- Ascension =- 155.9 °, Declination =- 23.2 °
- Venus Distance: 1.18AU
- Attitude: spin rate = 1.7rpm, sun angle 12.8deg

Measurement on 16/6/2010

Doppler shift :

+/- 3 Hz

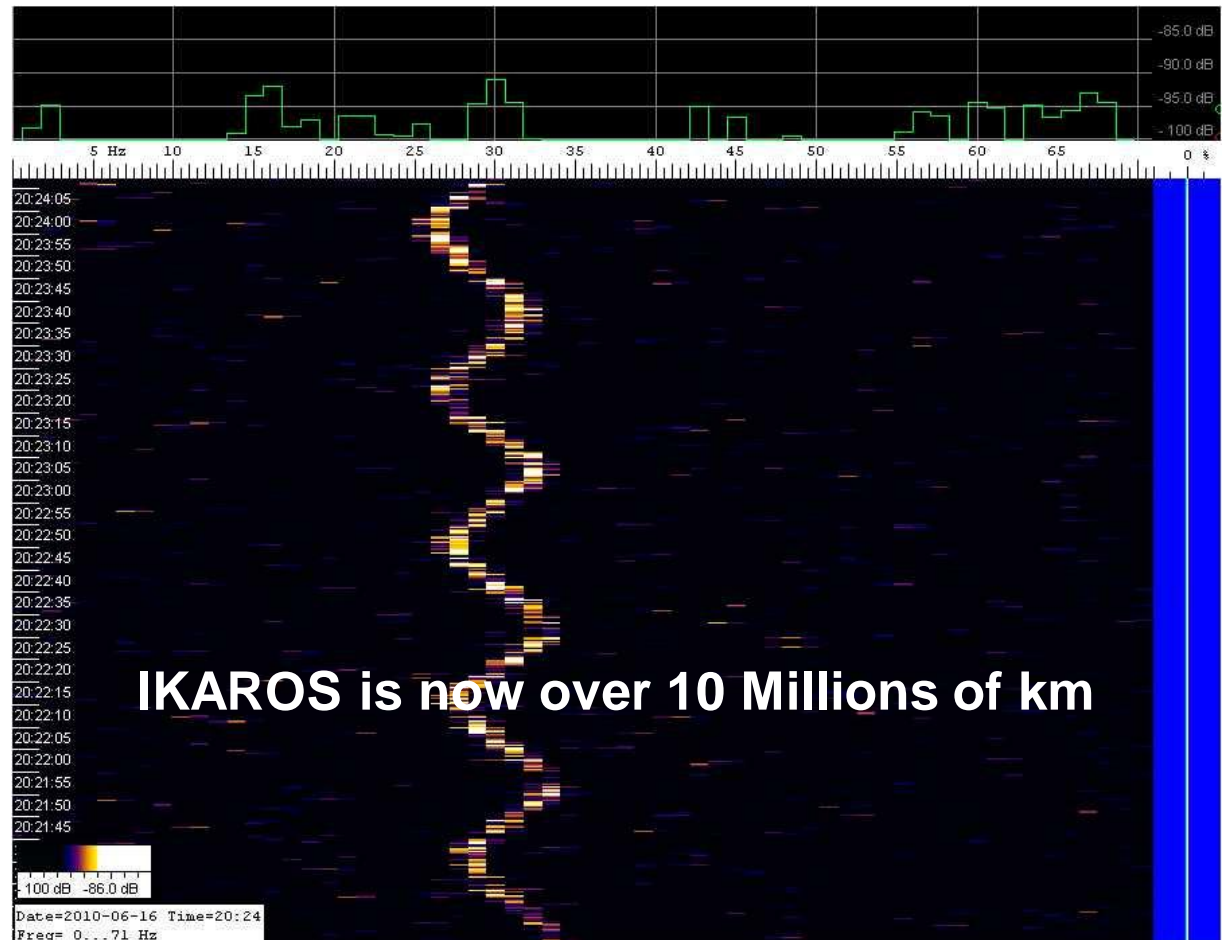
Rotation speed :

1.7 rpm

The rotation speed is again decreasing.

The measurement is very closed to the report of IKAROS blog.

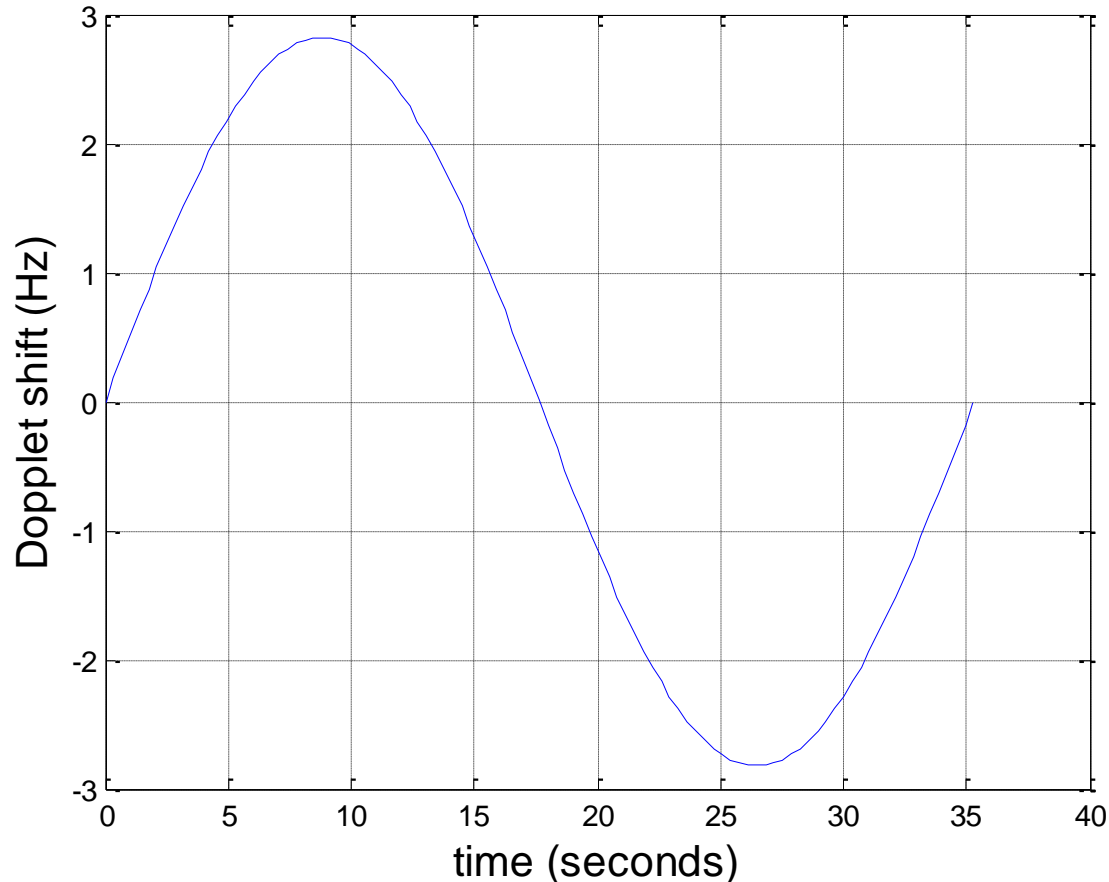
4 cycles / 140 sec
=> 1.7 rpm



With an angle of the spin rotation relative to the Earth of 45° , the calculated Doppler shift is closed to the measured value (16/6/2010).

Calculation

antenna speed rotation (radius = 0.8 m - 1.7 rpm - Dir = 45°)



Assuming :

- antenna is on peripheral of the main body
- Spin direction is 45°
- Rotation is 1.7 rpm

From IKAROS blog (17/6/2010)

- Solar Distance: 1.06AU
- Earth Distance: 10546259km
- Ascension =- 155.7 °, declination =- 23.3 °
- Venus Distance: 1.17AU
- Attitude: spin rate = 1.1rpm, sun angle 13.3deg

Measurement on 17/6/2010

Doppler shift :

+/- 2 Hz

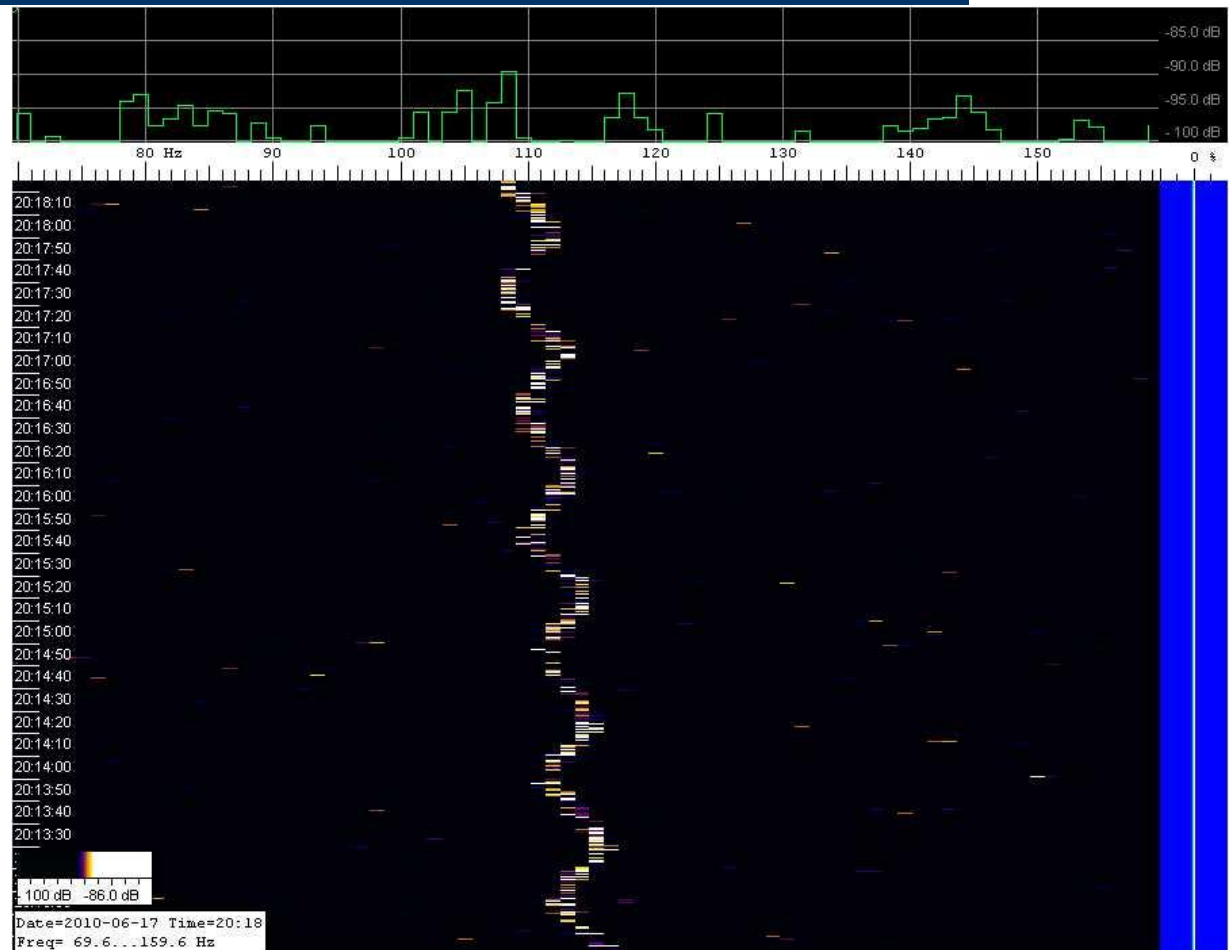
Rotation speed :

1.1 rpm

The rotation speed is still decreasing up to 1.1 rpm.

The measurement is very closed to the report of IKAROS blog.

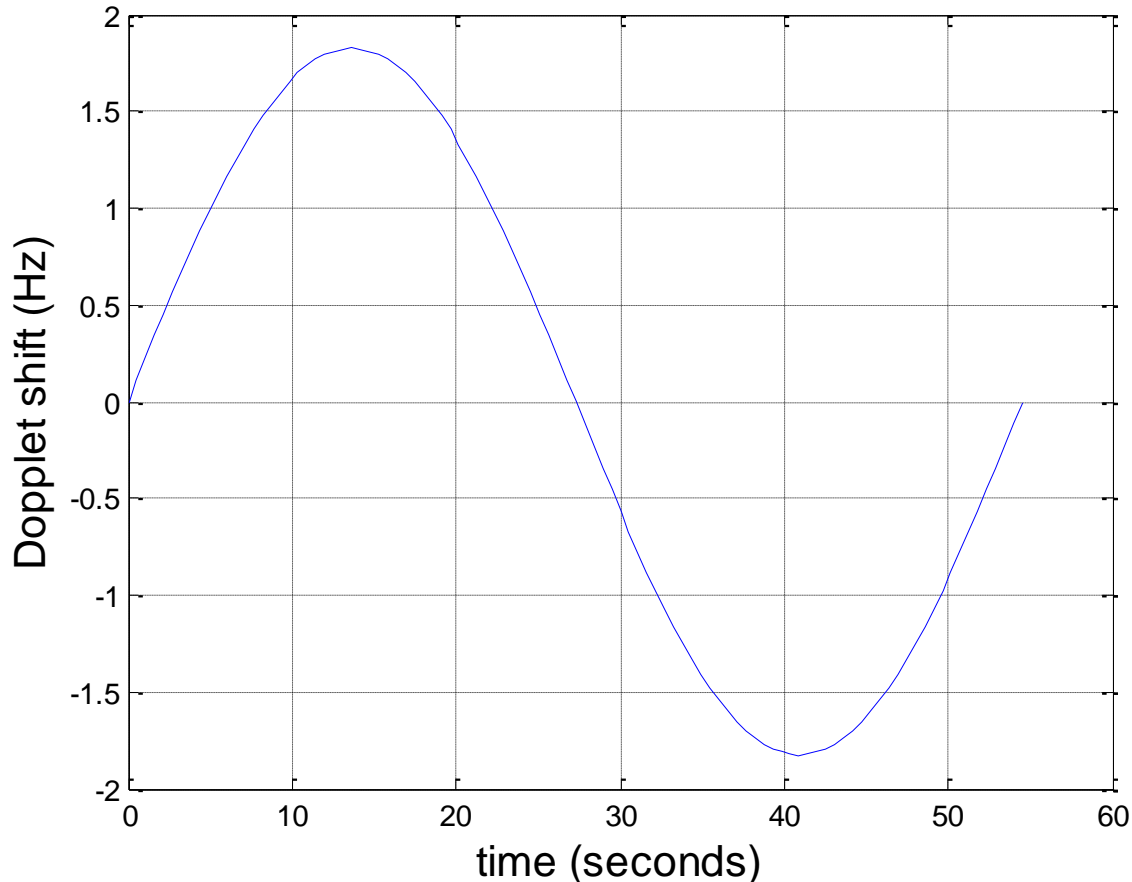
5 cycles / 262 sec
=> 1.1 rpm



With an angle of the spin rotation relative to the Earth of 45° , the calculated Doppler shift is closed to the measured value (17/6/2010).

Calculation

antenna speed rotation (radius = 0.8 m - 1.1 rpm - Dir = 45°)



Assuming :

- antenna is on peripheral of the main body
- Spin direction is 45°
- Rotation is 1.1 rpm

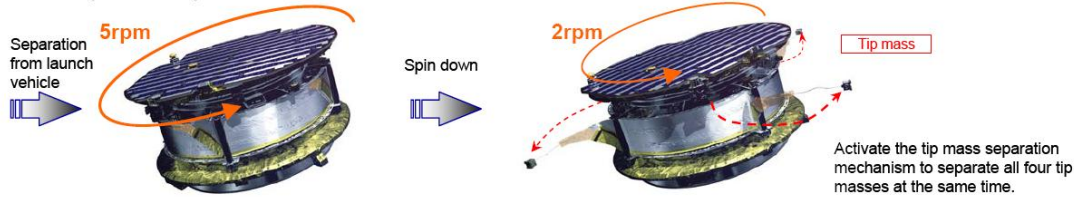
IKAROS Deployment



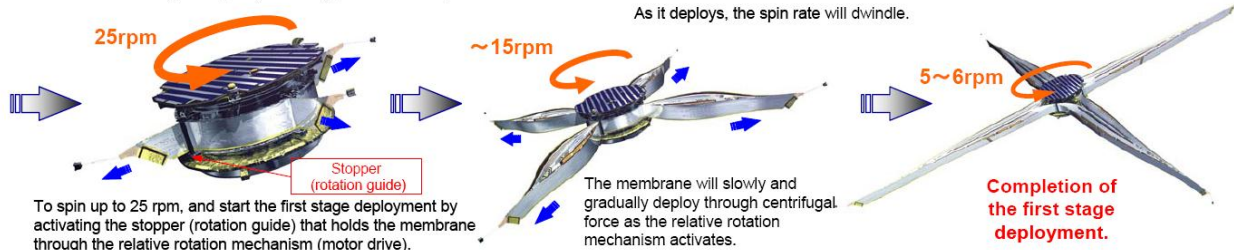
Membrane Deployment Sequence and Mechanism



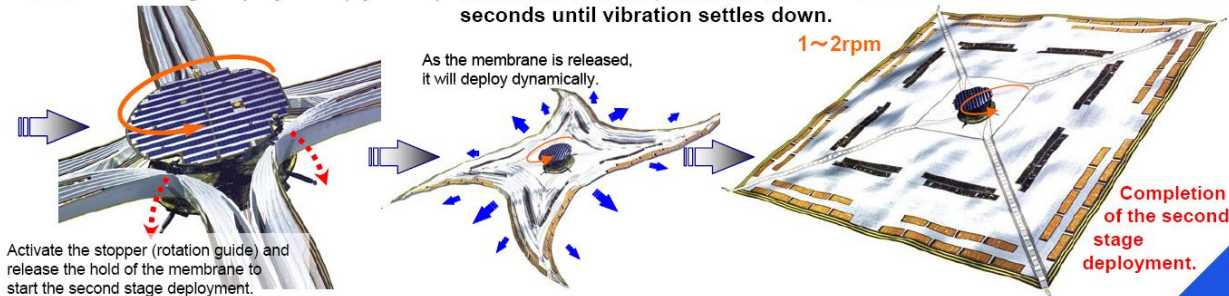
Tip mass separation



First stage deployment (quasi static): About one hour



Second stage deployment (dynamic): About five seconds, or about 100 seconds until vibration settles down.



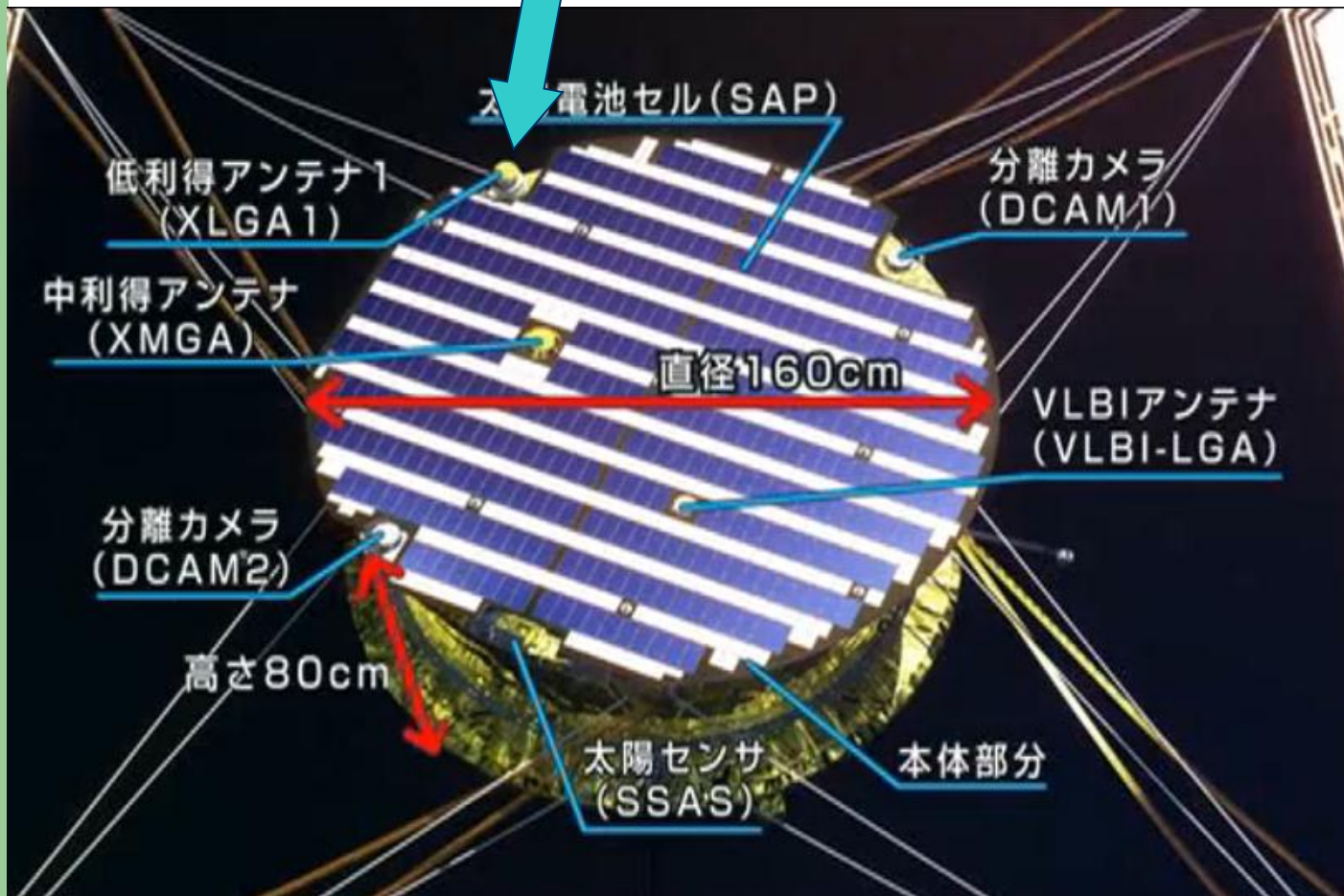
Last measurements indicates the IKAROS sail is now totally deployed (Phase 6 – Second deployment seems to be over)

A video about IKAROS gives some technical information about IKAROS and its journey.

http://www.youtube.com/watch?v=7_6HOqBkP2o

This is also a good summary of our observations...

IKAROS – LGA1 Antenna location



This picture shows the LGA1 location.

That confirms the antenna is at the peripheral of IKAROS.

Conclusion on 18/6/2010

- Last measurements indicates the IKAROS sail is now totally deployed (Phase 6 – Second deployment seems to be over). The rotation speed is now under 2 rpm.
- Measurements and observations still match to the IKAROS flight reported by the IKAROS blog.
 - 17/6/2010: 2.5rpm today dropped to from 1.7rpm. Finally, around 1rpm aim. IKAROS will adjust the angle between the Sun and Sail (steering) that controls the intensity of the light pressure you.
 - 18/6/2010: Even today, made a spin-down operations continued yesterday. The final spin rate 1.1rpm. Spin rates became the lowest since the launch!
- The spin rotation axis relative to the earth seems to be stable at the estimated value of 45°. We didn't received any confirmation from JAXA (Bertrand sent each report to the Japan agency) but a video confirms the location of the LGA1 antenne used during this path.
- The RF budget is still correct regarding the IKAROS's distance (about 10 million of km).
To be continued

Bertrand F5PL / J-Jacques F1EHN (<http://www.f1ehn.org>). More measurements done by Bertrand on the dedicated DSN Yahoo group.