Continuum Observations of Asteroid (2867) Steins with the MIRO Instrument

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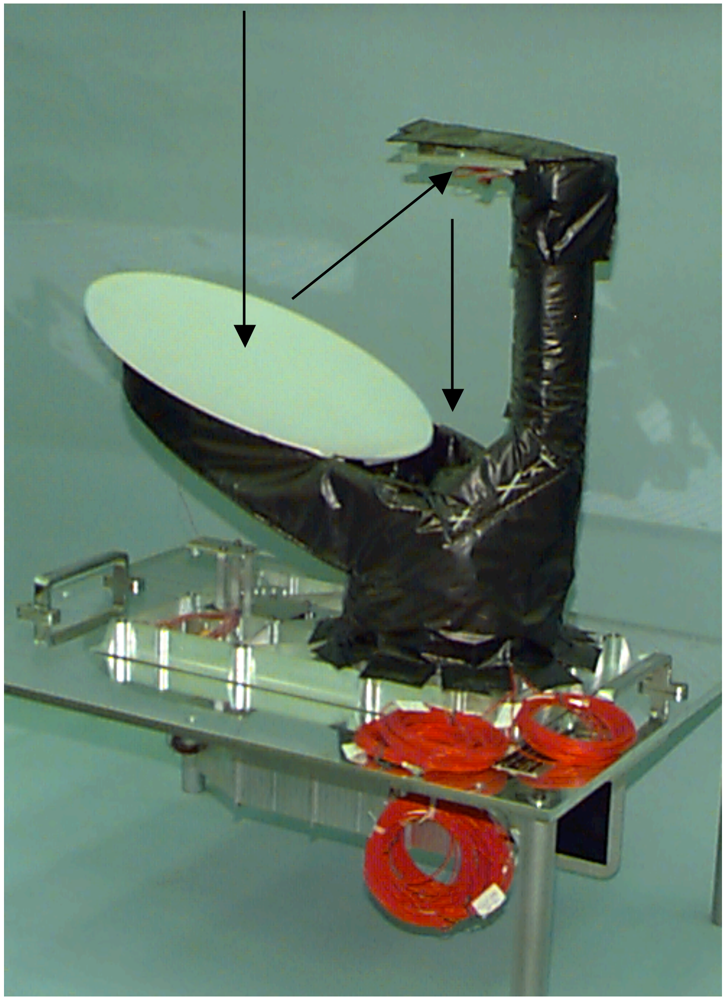
OUTLINE

- MIRO INSTRUMENT OVERVIEW
- GEOMETRY OF THE ENCOUNTER
- OVERVIEW OF THE OBSERVATIONS
- DUAL CONTINUUM DATA
- DATA ANALYSIS
  - SHAPE MODEL
  - THERMAL MODEL AND RADIATIVE TRANSFER
- ERROR ANALYSIS
- RESULTS and CONCLUSIONS
- ACKNOWLEDGEMENT

Instrument Overview



STRUCTURAL THERMAL MODEL

Telescope

30 cm diameter

Boresight along z-axis of s/c

Receivers (two)

Continuum 190 GHz (1.6 mm)

563 GHz(0.5 mm)

Spectroscopic (563 GHz)

H_2O, CO, NH_3, CH_3OH

Spectral resolution (44 kHz)

Resolving Power = 1.3 x 10^7

Single linear polarization(crossed)

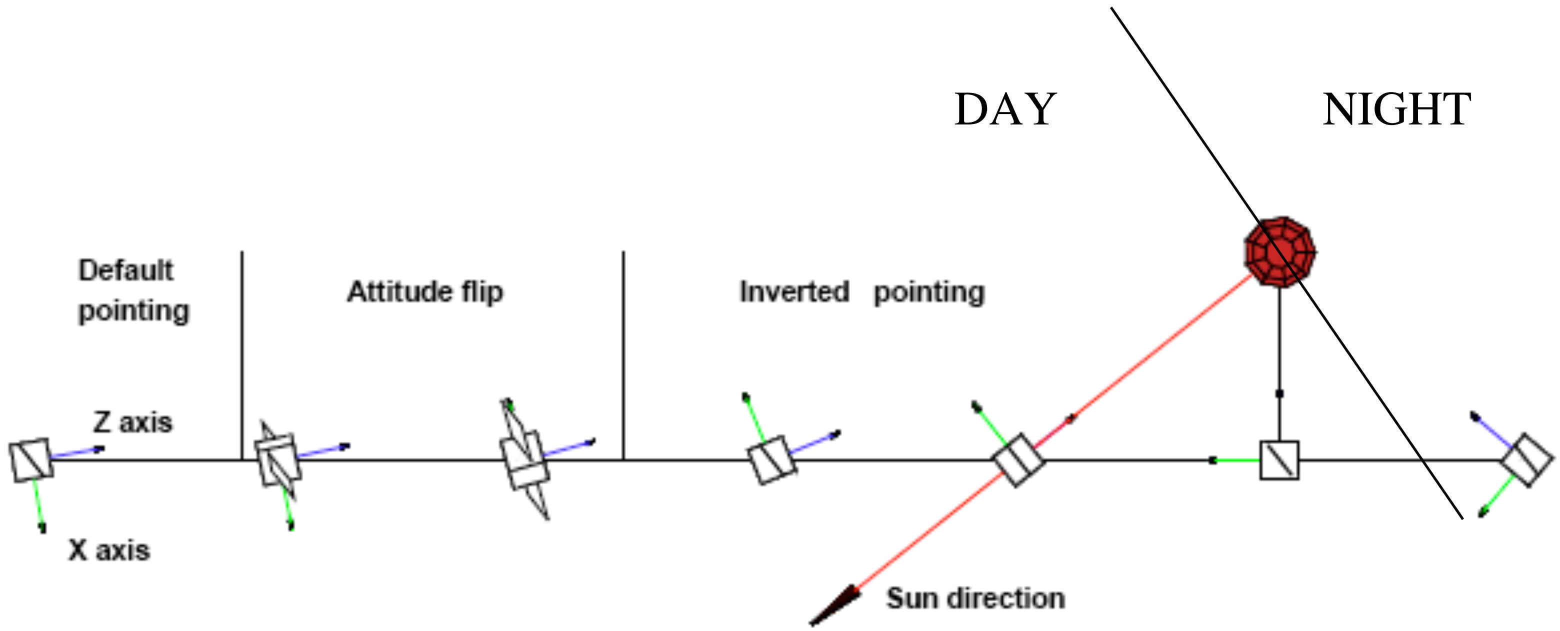
Flip-mirror calibration(warm,cold,sky)

Beam Characteristics

Submillimeter HPBW- 7.5 arc min

Millimeter HPBW- 23.8 arc min

ROSETTA-STEINS FLYBY GEOMETRY



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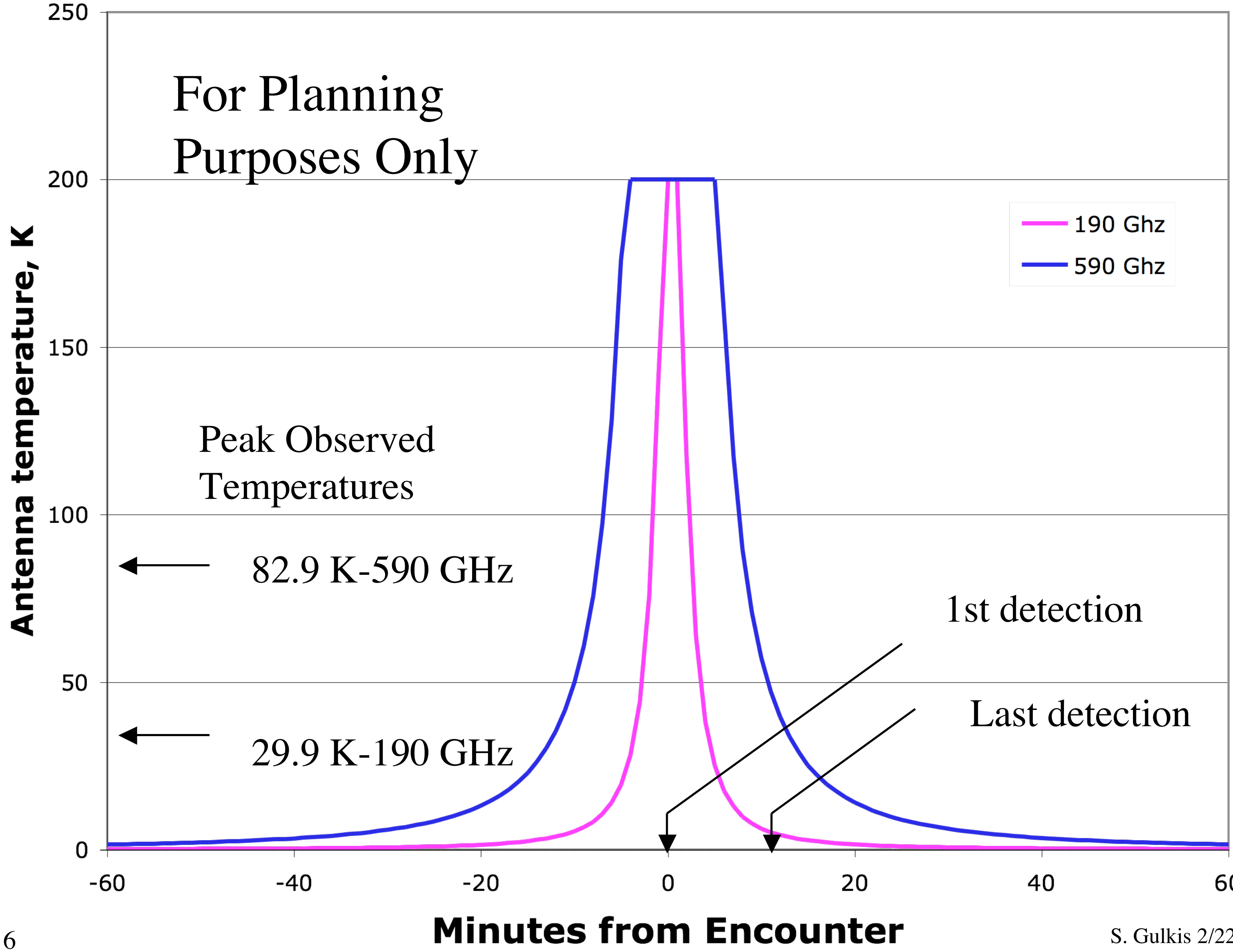
Overview of Observations

- **MIRO was powered on for approximately 10 hours centered on CA**
- **Warm and cold calibration targets were observed every 30 minutes**
- **Instrument performance was nominal**
- **Thermal emission from Steins was observed with high S/N in both mm and smm continuum channels**
- **First detection of Steins occurred about 92 s(mm)[44 s smm] before CA**
- **MIRO boresight was significantly displaced from Steins for most of the fly-by**
  - **Phase coverage of data was limited [~ 315-90 deg]**
- **Spectroscopic data were obtained but no spectral lines were observed**

Predicted Antenna Temperatures for beam centers on target center



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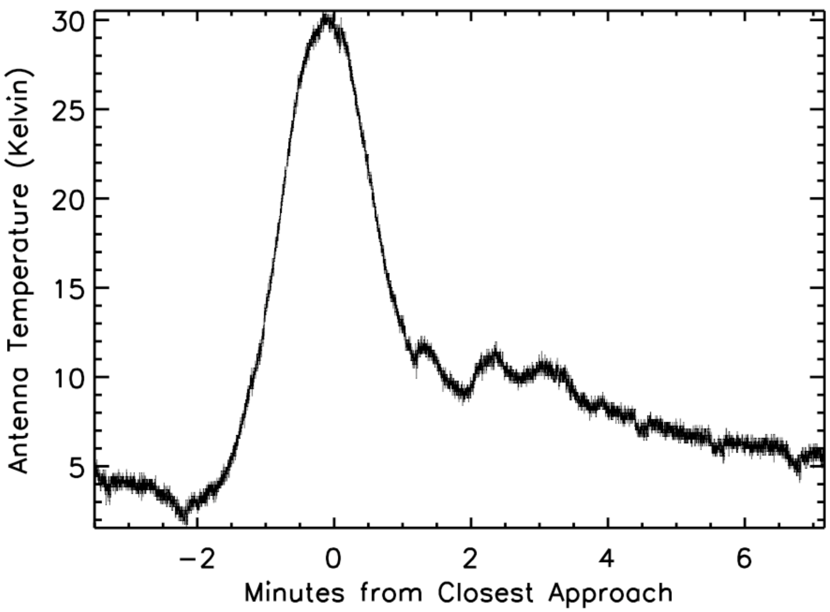
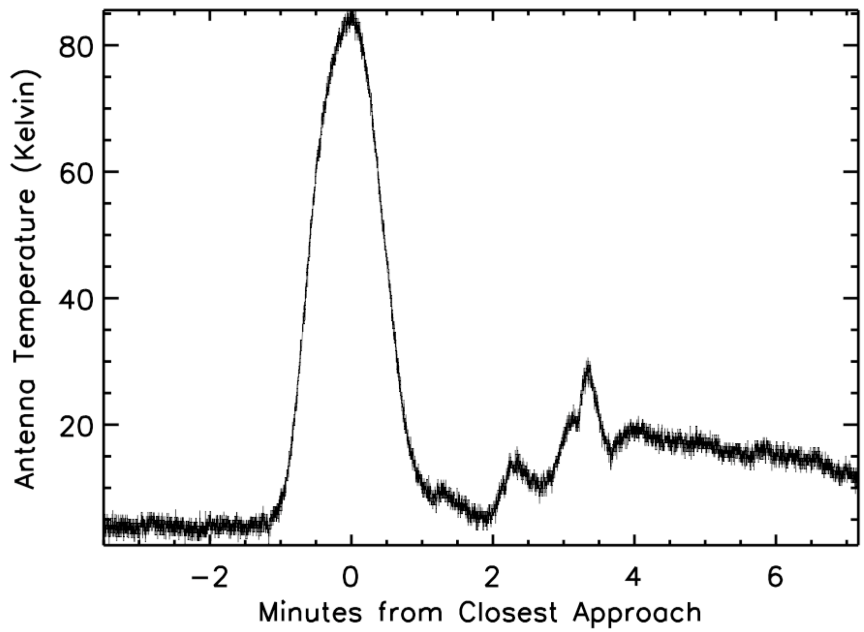
Calibrated Continuum Data

Millimeter



Submillimeter



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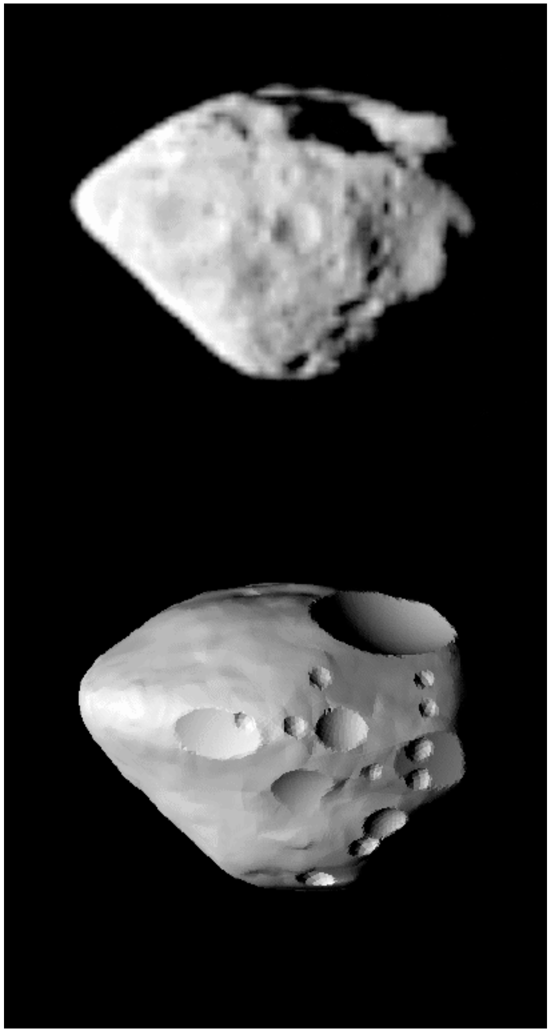
ANALYSIS

- Shape Model of Steins (NEXT SLIDE)
- Important quantities needed in analysis
  – Sub-spacecraft and Sub-Solar positions
  – Unit surface normals on a grid around the intersection of boresight and Steins
- Intersection of beam boresight with the shape model
  – Used Walter Sabolo's measurements of Steins in WAC images
  – Corrected for photometric center of Steins and true body center
    - Based on shape model and Lambertian model of scattered sunlight
  – Corrected for geometrical distortion in WAC image plane using a formula provided by Walter Sabolo
- Distance from Rosetta obtained from SPK kernals
  – ORHR_______________00077.BSP for Rosetta
  – ORHO_______________00077.BSP for Steins
- Orientation of asteroid relative to boresight
  – Used SPK data using calls from Spice

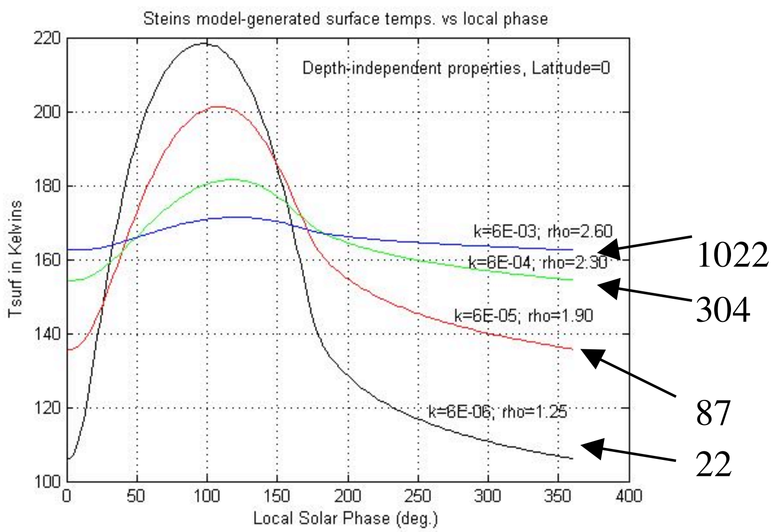
This work carried out by Dr. Lucas Kamp (JPL)

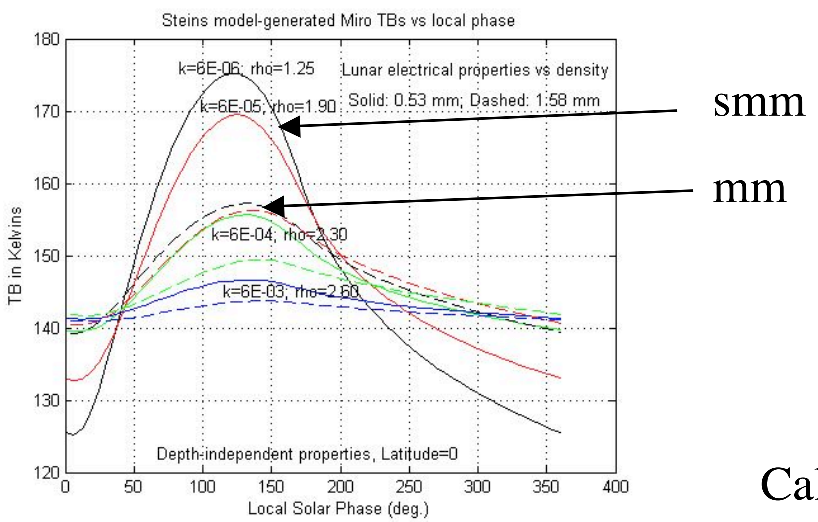
Digital Shape Model used in analysis



- Based on data provided by OSIRIS instrument
- Digital Shape Kernel (DSK)-steins_shape_model_ver2a.dsk
- Provided by group at Laboratoire d'Astrophysique de Marseille, France (contact Olivier Groussin)
- Reference: Lamy et al. 2008, A&A 487,1179

Thermal Models (Top)
Pencil Beam Brightness Temp(Bottom)



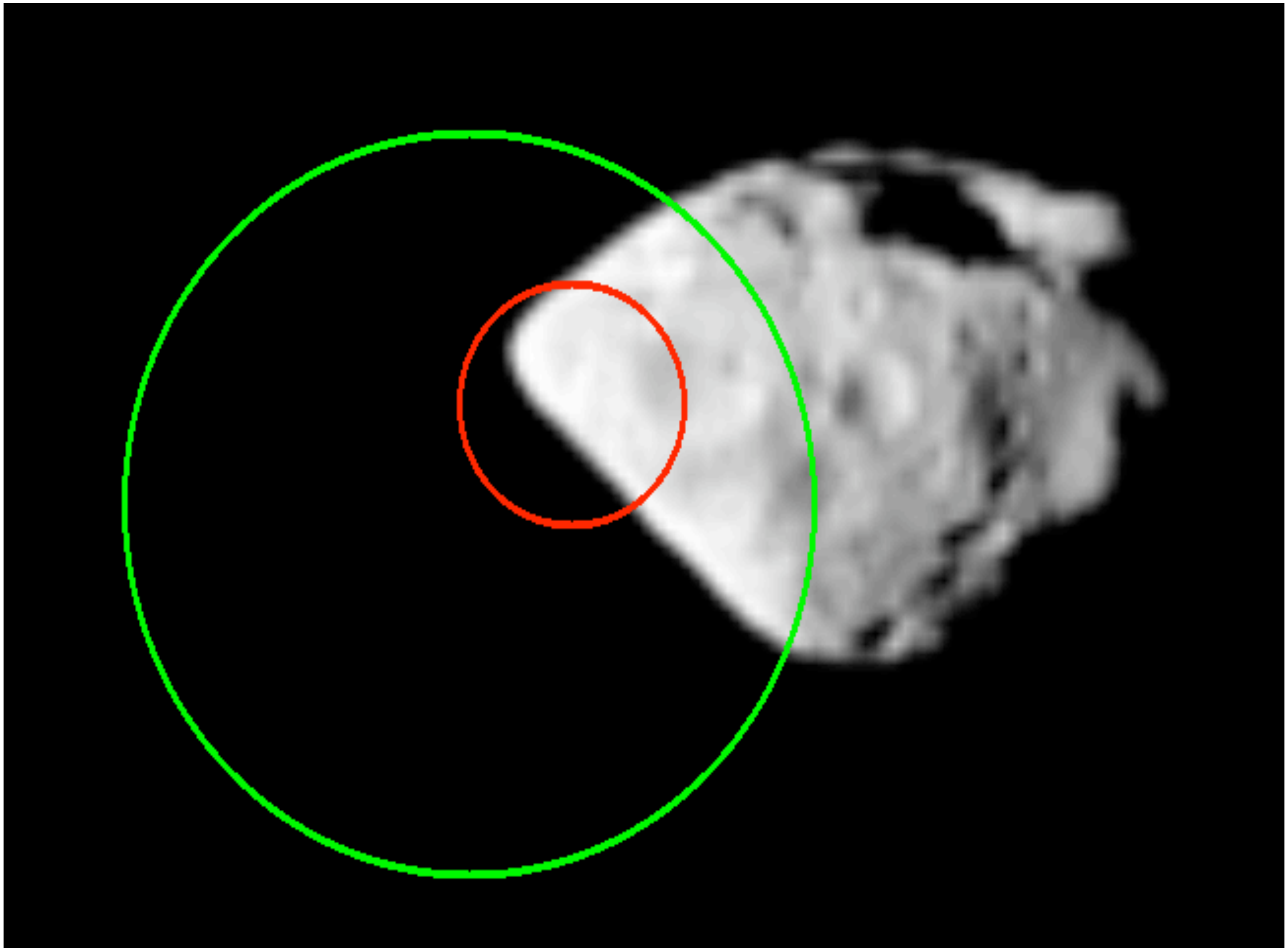


- Thermal models use Steins period, albedo (0.4 assumed) and heliocentric distance- Temperatures are equatorial.
- Albedo not well determined
- Thermal Inertia (mks units)
  - 22(lunar powder)
  - 87(lunar fine)
  - 304(lunar basalt)
  - 1022(lunar igneous rock)

- Arrows point to pencil beam zenith emission (blackbody equivalent T) for the two MIRO continuum wavelengths (0.53 mm & 1.58 mm) for thermal inertia = 22
- Steins thermal model needs to fit IR(VIRTIS, SPITZER,+) and submillimeter data (MIRO)

Calculations by Dr. Steve Keihm (JPL)

MIRO BORESIGHTS NEAR CA



Estimated Errors

Range, km	Pointing ± 1 arc min [Modeling error]	Random All < [Meas error]	Systematic [Meas error]
820.7 Maximum CA	± 3 K mm ± 12 K smm	± 1 K mm ± 1 K smm	< |0.9 K| mm < |2.7 K| smm
1412.6 Local Minimum	± 1 K mm ± 1 K smm	± 1 K mm ± 1 K smm	< |0.3 K| mm < |0.2 K| smm
2129.4 2nd Maximum	± 1 K mm ± 12 K smm	± 1 K mm ± 1 K smm	< |0.3 K| mm < |0.8 K| smm

MODEL PARAMETERS

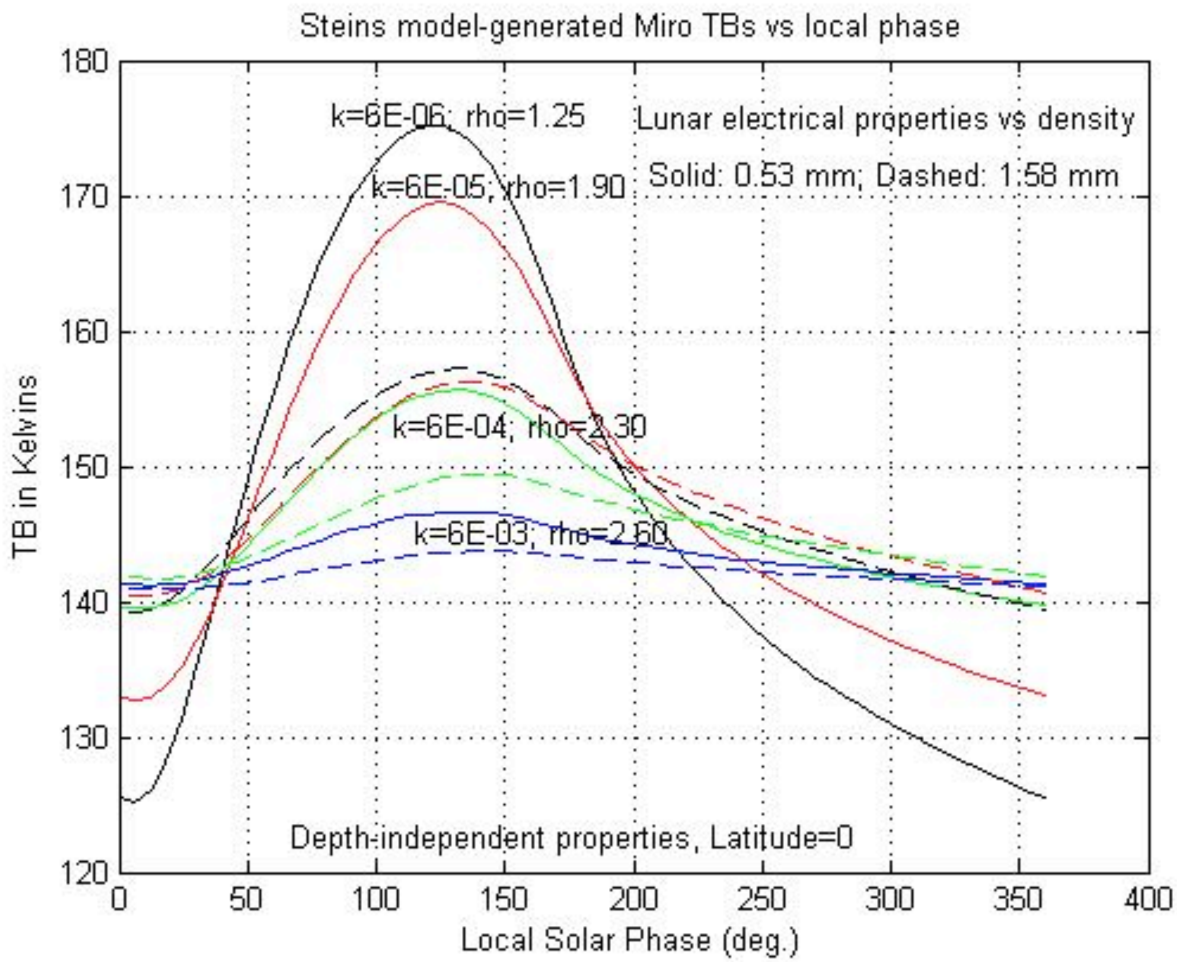
MODEL PARAMETER	POWDER	ROCK
Density (g/cm^3)	1.25	2.6
Thermal Conductivity (w/cm K)	6 x 10^-6	6 x 10^-3
Specific Heat (w-s/g K)	0.67	0.67
Thermal Inertia MKS (J/K m^2 s^0.5)	22	1022
Dielectric Constant	2.34	5.03
Thermal Skin Depth (cm)	0.22	4.89
Electrical Skin Depth (cm)(smm-mm)	.24-.76	.04-.12
Loss Tangent	.017	.036

Observed and Model Ant Temperatures

	RANGE KM	TA(OBS) smm	TA(M) smm	TA(OBS) mm	TA(M) mm
Powder Rock	820.7	82.9	92.4 84.5	29.9	25.1 24.9
Powder Rock	1013.9	18.6	19.9 19.1	15.5	11.3 11.4
Powder Rock	1412.6	5.3	1.6 1.6	9.2	4.9 5.0
Powder Rock	1722.1	11.3	8.0 8.6	10.3	6.1 6.3
Powder Rock	2129.4	25.7	25.2 28.3	9.7	6.2 6.4
Powder Rock	2640.1	17.4	17.9 20.4	7.2	4.0 4.2

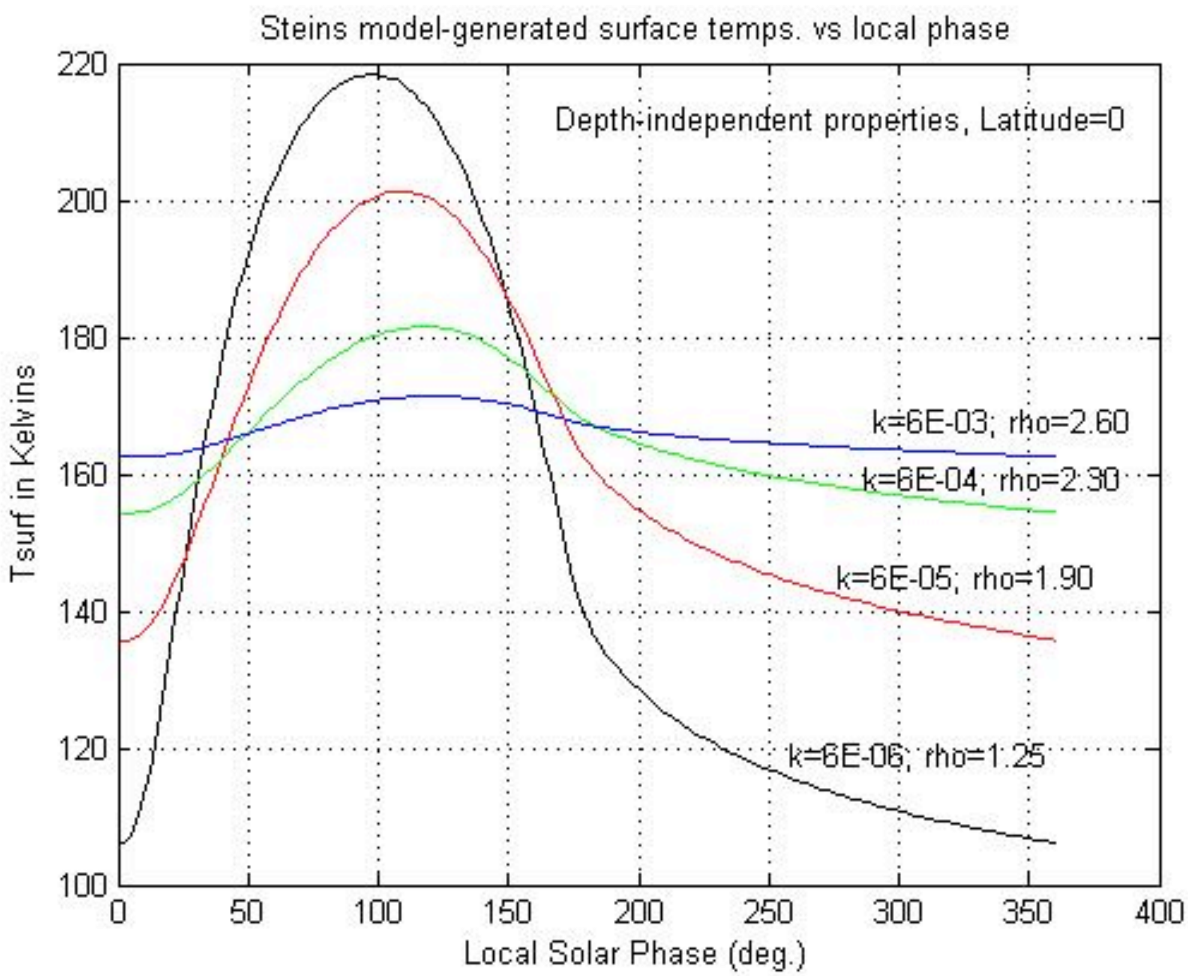
Pointing based on photographic measurements

Brightness Temperature Models for Steins at MIRO Wavelengths (0.53 & 1.58 mm)



Calculations by Dr. Steve Keihm

Surface temperature for various model assumptions (Latitude = 0)



Calculations by Dr. Steve Keihm

CONCLUSIONS

- Both high and low thermal inertia models, similar to those used for the moon, can fit the MIRO data within the uncertainties of the data;
- Principal source of errors is the modeling pointing error, not the measurement errors; for the peak antenna temperature measured, the error is estimated to be 12 K (smm) and 3 K (mm) for a 1 arc min pointing error;
- For low thermal inertia models, the ratio of thermal to smm electrical skin depths is of the order of unity; the thermal wave is attenuated by 1/e at the depth of penetration
- For high thermal inertia models, the thermal skin depth is considerably larger than the smm electrical skin depth and the surface temperature is measured
- Thermal models for Steins need to fit VIRTIS, SPITZER, and MIRO data; the high surface temperatures reported by VIRTIS and SPITZER require a low thermal inertia regolith;
- There is a suggestion that the emissivity of a low thermal inertia model needs to be less than that calculated from the dielectric constant itself. We estimate that emissivity could be as low as .79 but probably not lower. Reduced emissivity could be produced by subsurface scattering.
- Reducing the loss tangent doesn’t lower the temperature significantly

ACKNOWLEDGEMENT

The MIRO team would like thank-

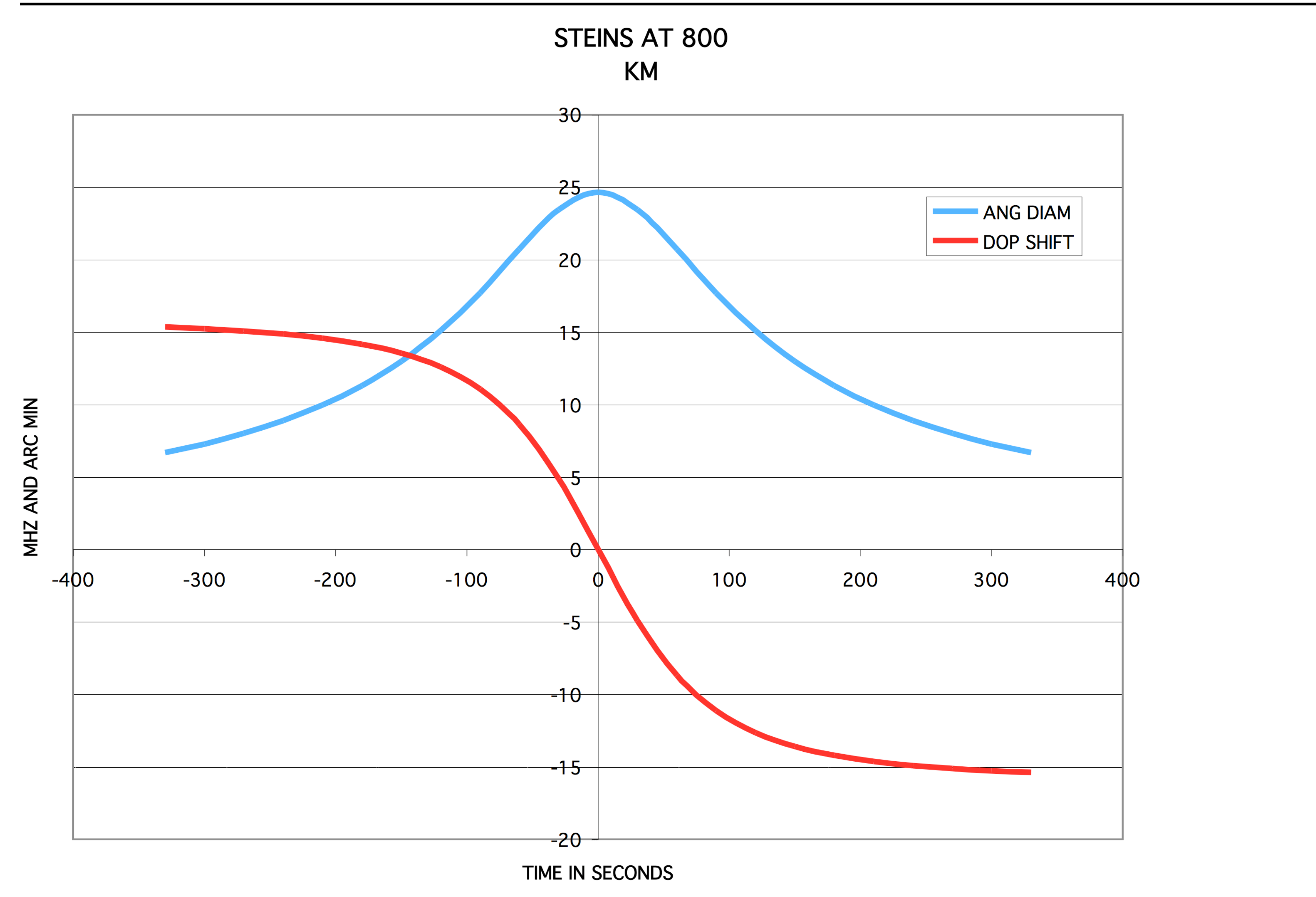
-ESOC and ESAC teams for their technical support

-OSIRIS, VIRTIS and ALICE teams for sharing their pre-published data

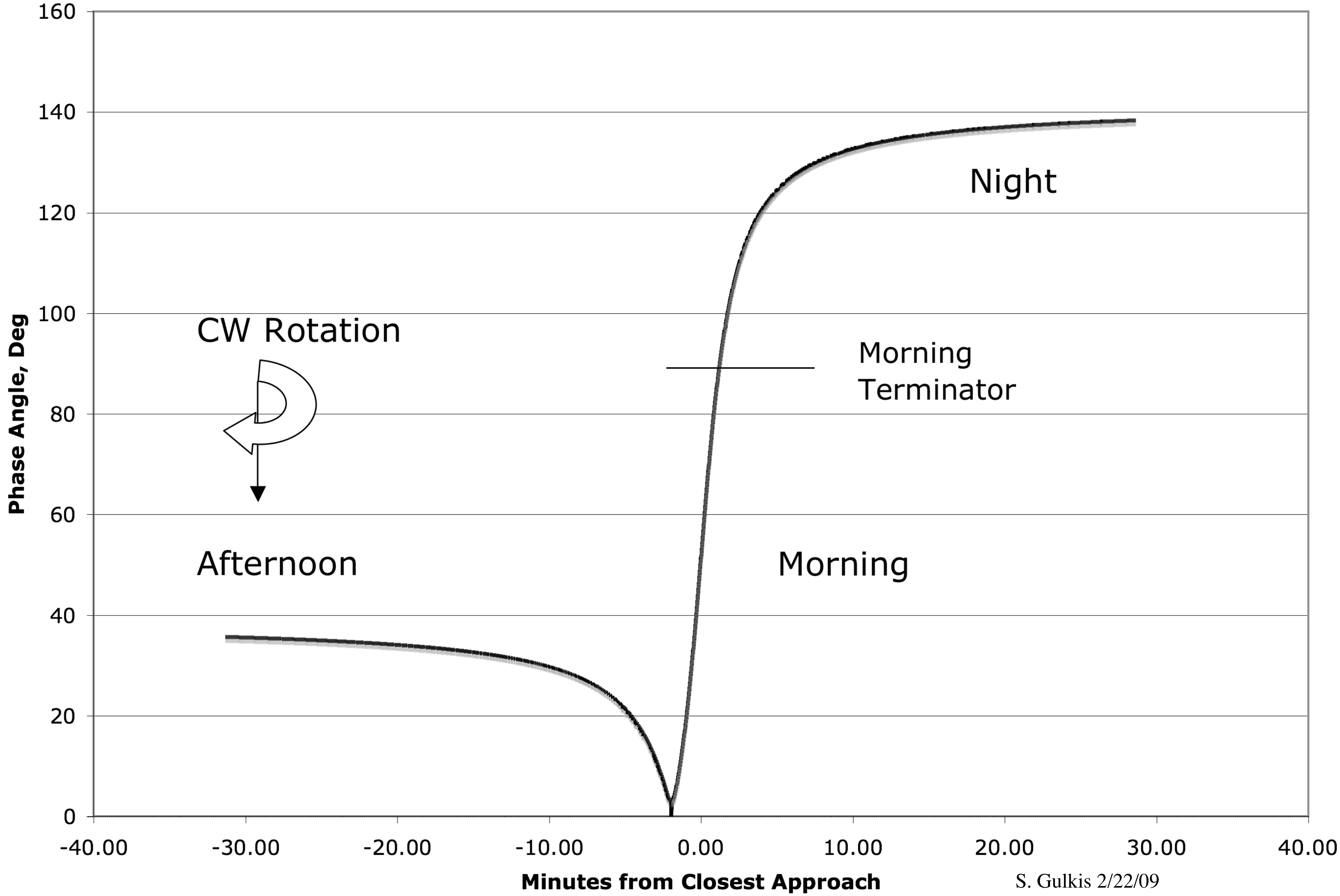
-U. Keller, P. Lamy, O. Groussin, W. Sabolo, M. Fulchignoni, and A. Barucci for information about their Steins observations and models

Backup Figures

DOPPLER SHIFT AND ANG DIAM



Phase Angle (|Rosetta-Steins-Sun|)



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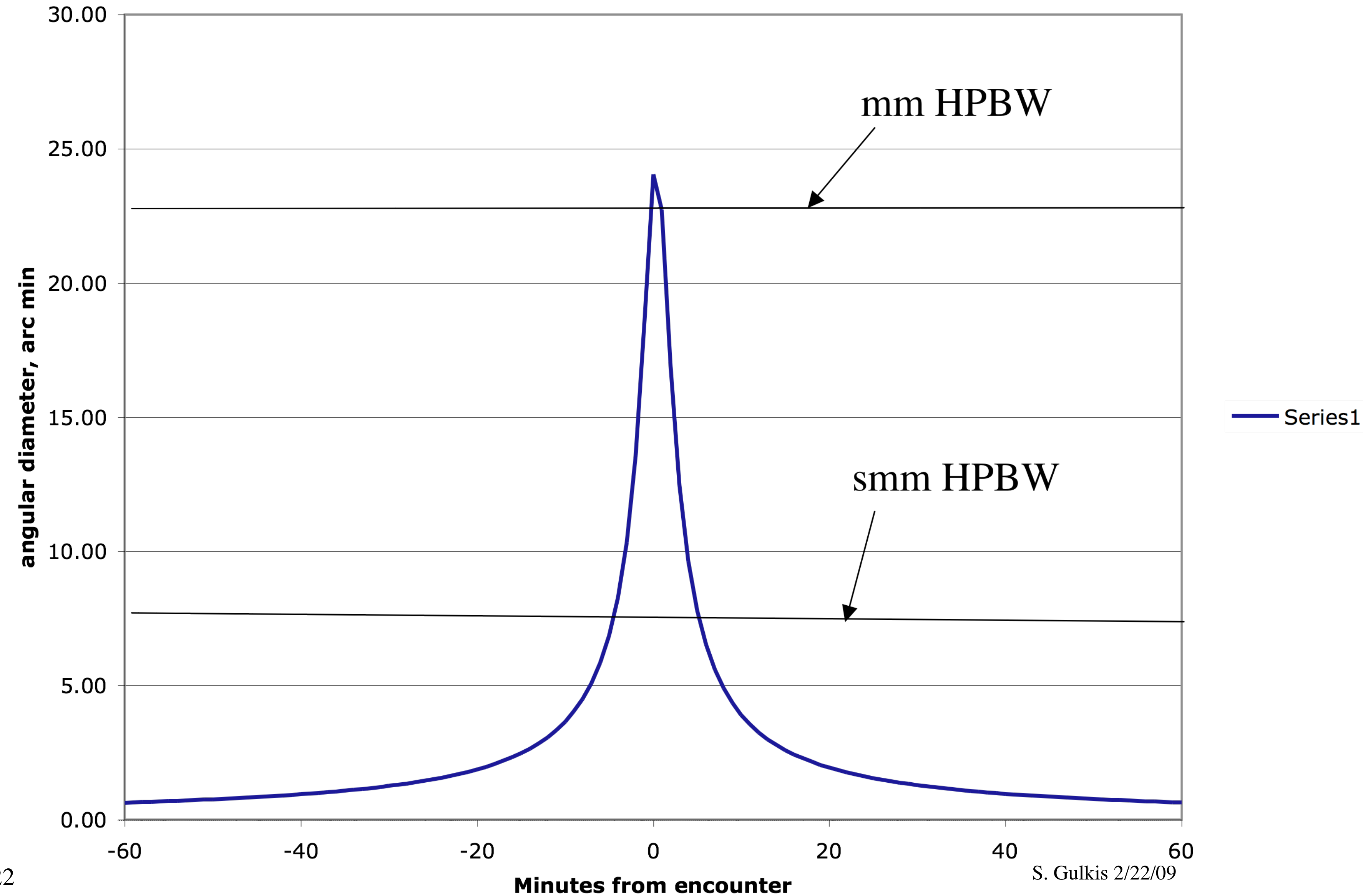
Angular Diameter Steins



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MIRO TIMELINE AT STEINS

Min from CA		EVENT
-329	-------	Power on
-307	-------	CTS/dual continuum
- 37	-------	Start s/c roll
- 36.5	-------	End s/c roll
-16	-------	Dual continuum
-11	-------	Asteroid mode
-1.9	-------	~ 0 solar phase angle
-1.5	-------	First mm detection
-0.7	-------	First smm detection
0	-------	CA
0.5	-------	Peak mm signal (29.9 K)
0.6	-------	Peak smm signal (82.9 K)
1.7	-------	s/c over morning terminator
10.6	-------	Loss of signal
10.6	-------	Dual continuum
13	-------	CTS/dual continuum
302	-------	Disable science acquision

Pointing Error Sensitivity

Range, km	Millimeter ± 1 arc min	Sub-Millimeter ± 1 arc min
820.7 Maximum near CA	± 3 K	± 12 K
1412.6 Local Minimum	± 1 K	± 1 K
2129.4 2nd Maximum	± 1 K	± 12 K

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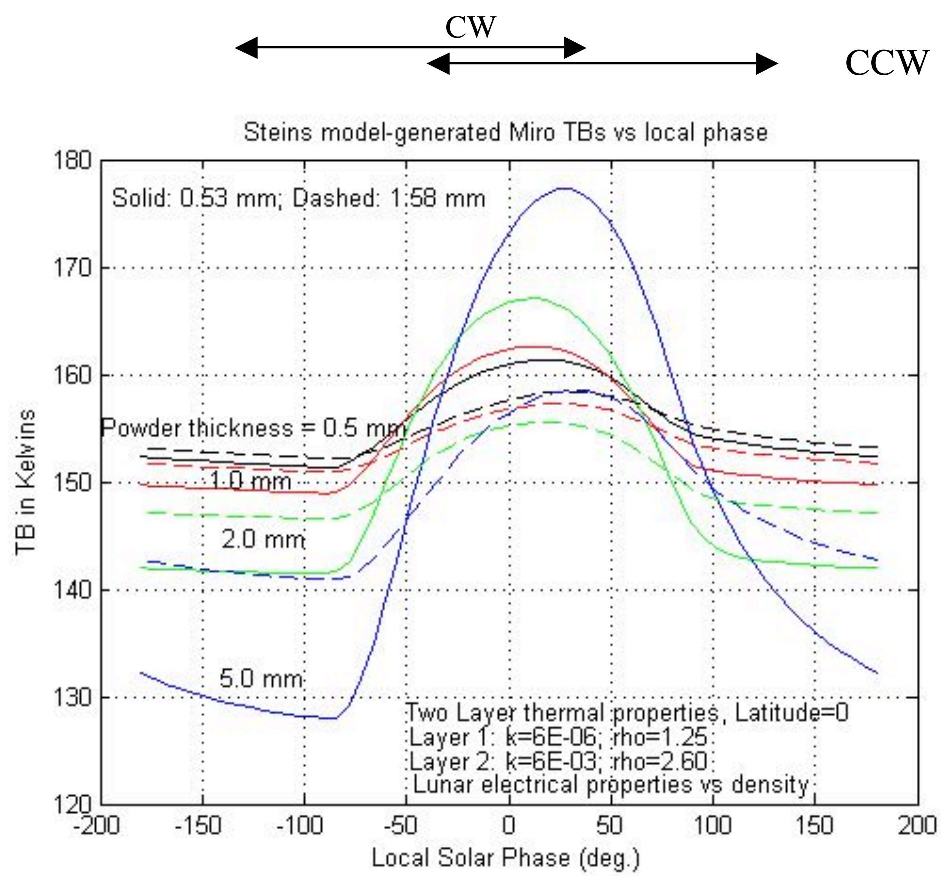
Brightness Temperature Models for Steins at MIRO Wavelengths (0.53 & 1.58 mm)



k (w/cm-K)

rho (gr/cm^3)

Model computed by Steve Keihm (JPL)

Science Objectives

- Constrain thermal and electrical properties of Asteroid Steins
  - k Thermal conductivity (W/cm K)
  - c Specific heat
  - εr Dielectric constant
  - ρ Density
  - $Tan(\delta)$ Loss tangent = $2\sigma/\varepsilon r\ \nu$

- Observation related quantities
  - Thermal skin depth $(2k/\omega\rho c)$^0.5 (thermal wave damping to 1/e)
  - Thermal inertia $(k\rho c)$^0.5
- Assist in the determination of regolith properties
- Detect or set upper limit on abundance of water vapor around Asteroid Steins

Thermal and Electrical Skin Depth Estimates for MIRO

- Thermal Skin Depth (amplitude for thermal wave 1/e surface value)
  - Thermal skin depth = $\sqrt{\frac{2k}{\omega\rho c}}$ $\cong$ 2 mm
- Electrical Skin Depth
  - $d = \frac{\lambda}{2\pi \tan(\delta)\sqrt{\varepsilon}}$
  - $\cong$ 5 λ for fine powder (loss tangent = .017)
  - d(smm) = 2.4 mm $\cong$ 1 thermal skin depth
  - d(mm) = 7.5 mm $\cong$ 3 thermal skin depths