The search for Terra Nova

Stellar music, aliens, alien Earths and Canada’s space telescope

Jaymie Matthews
MOST Mission Scientist
Associate Professor
Department of Physics & Astronomy
University of British Columbia
Perspective is everything

sidewalk art

seen from 180° in the other direction

seen from one point of view
Canada’s space telescope
Habitable world

Canada’s space telescope

Habitable world
America’s space telescope

Hubble Space Telescope
Canada’s space telescope

MOST

Hubble Space Telescope
Canada’s space telescope
Microvariability & Oscillations of STars
Microvariabilité et Oscillations STellaire

Hubble Space Telescope
Canada’s space telescope – MOST

The “Humble” Space Telescope

Hubble Space Telescope
Canada’s space telescope – MOST

The “Humble” Space Telescope Squarepants
Canada’s space telescope – MOST
Continuing legacy of Alouette 1

First …

- all-Canadian scientific satellite in over 30 years

Canadian Space Agency (CSA)
Canada’s space telescope – MOST

Satellite

- 54 kg, 60×60×30 cm
- Power: solar panels
  - peak ~ 38 W
- Communication: radio
  - power of a cell phone
- Attitude Control System:
  - pioneering technology
  - pointing 4000× better
- Lifetime: 5 – 9 years +?

CONTRACTORS: Dynacon Inc.
U of T Institute for Aerospace Studies

PROJECT BUDGET ~ $10M
Mission Scientist

- > 54 kg, 182 cm tall
- Power: hydrocarbons
  - peak ~ 12 MW at clubs
- Communication: loud
  - no cell phone
- Attitude uncontrolled
  - pionerd technology
  - doesn’t always have a point
- Lifetime: fun while it lasts

CONTRACTORS: my parents

MY SALARY << $10M

Canada’s space telescope – MOST
MOST's (not so) long journey

proposed in 1997 → launched in 2003

Region of Euphoria
Region of Tolerance
Region of Bitterness
Region of Blind Hatred

RELATIVE BITTERNESS INDEX

Spacecraft Project Normal Bitterness Curve

Launch

Dec 2002

Contract
Preliminary Execution Review
Critical Design Review
Final Acceptance Test
System Acceptance Test
3-stage former ICBM (SS-19) with low-orbit lift capacity ~1900 kg

ROCKOT

29 metres

3rd stage

Eurockot = Astrium + Khrunichev Space Research Centre

mass = 107 tonnes
Launch: 30 June 2003 - 16:15:00.323 UTC

Plesetsk Cosmodrome
First contact: 30 June 2003 - 23:50:44.197 UTC

Launch + 7 hr
Launch + 7 hr + 1 nanosec

First contact: 30 June 2003 - 23:50:44.197 UTC
Mission Scientist reflects on success ...

Launch + 12 hr
**MOST’s unique vantage point**

**Orbit**

MOST stares at stars for up to 2 months at a time without interruption.

- **altitude** $h = 820 \text{ km}$
- **period** $P = 101 \text{ min}$
- **speed** $v = 27,000 \text{ kph}$
Without practically 100% of the sample of information, it can be almost impossible to decipher the meaning of the message. This is as true for how the variations of a star or a sequence of words tells the whole story.
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Galileo’s telescope

same scale

MOST telescope
Canada’s space telescope – MOST

An ultraprecise lightmeter

MOST measures changes in the brightnesses of stars as small as 1 part in a million
Canada’s space telescope – MOST

An ultraprecise lightmeter

✓ MOST measures changes in the brightnesses of stars as small as 1 part in a million

How sensitive is this?

If you look at the Empire State Building at night with all the lights on and all the office blinds open… you can reduce its brightness by 1 part per million by pulling a single blind down 3 cm
The stars are alive...
...with the sound of music
Plato says that a siren sits on each planet, who carols a most sweet song, agreeing to the motion of her own particular planet, but harmonising with all the others.
Making waves

“Adore the Sun
... the shining maker of light”

Hymn to the Sun
Hindu poem (300 BC)
Solar symphony

Acoustic waves

Buoyancy waves
Listening to the music of the stars

The Sun and many stars vibrate like giant gaseous bells, due to sound generated by turbulence in the gas near their surfaces.

How do you detect sound waves in a star???
Telescopes are ‘deaf’, due to vacuum of space.
Listening to the music of the stars

How can a deaf person ‘listen’ to music???

Sound is just a combination of vibrations.
Listening to the music of the stars

How can a deaf person ‘listen’ to music???

Sound is just a combination of vibrations.
Listening to the music of the stars

First Nations ceremonial drum

pulsating star in the nightsky

How can any telescope “listen” to a star???
Vibrations translate into light variations.
First Nations ceremonial drum
twinkling star in the nightsky

How can any telescope “listen” to a star???
Vibrations translate into light variations.
**Listening to the music of the stars**

*First Nations ceremonial drum*

- twinkling star in the nightsky
- brightness variations with time (light curve)
- if you could see the star as a disk

**How can any telescope “listen” to a star??**

Vibrations translate into light variations.
Listening to the music of the stars

- But “twinkling” of stars due to turbulence in the Earth’s atmosphere is about $100\times$ larger than genuine oscillations in Sun-like stars.
- To measure this, we need to put instruments above the atmosphere...
- ...and they need to be sensitive to vibrations with amplitudes as small as only 0.0001%.

How can any telescope “listen” to a star???
Vibrations translate into light variations.
Listening to the music of stars

Seismology of the Earth

Seismology of the Sun and stars
Listening to the music of stars

Seismology of the Sun and stars

SOHO Dopplergram
Listening to the music of stars

Seismology of the Earth

acoustic ray paths

Seismology of the Sun and stars

“acoustic refraction”
Listening to the music of stars

Seismology of the Earth

Seismology of the Sun and stars

"acoustic refraction"
Acoustic refraction and Roswell
Acoustic refraction and Roswell

Project Mogul

high-altitude balloon with sensitive microphone in payload

sound waves refracted by high-altitude T inversions (a “sound pipe”)

above-ground nuclear test

New Mexico

Soviet Union
Acoustic refraction and Roswell

Project Mogul

high-altitude balloon with sensitive microphone in payload

sound waves refracted by high-altitude T inversions (a “sound pipe”)

above-ground nuclear test

New Mexico

Soviet Union

SPACE ALIENS LOVE COUNTRY MUSIC

[Image of newspaper with headline]
microvariability in stars

- Probing stars like our Sun
  - Sun’s relatives at other stages in their lives
  - What was Sun like when life began on Earth?
- ancient stars in the solar neighbourhood
  - limit on age of Universe
- mysterious alien worlds around other stars
MOST Science

Groundbased astronomer

Me

[Image of a cartoon scene with characters labeled as 'Groundbased astronomer' and 'Me']
Variety is the spice of life
and sweetness

Italian gelateria

Casa Gelato, Vancouver
700 flavours
198 on offer at any one time
Variety is the spice of astrophysics

and sweetness

MOST stellaria

50 Primary Science Targets
5 Commissioning Targets
~2000 Direct Imaging & Guide Field Targets
"Christmas Tree Cluster"

distance \(\sim 2100\) light years

age \(\sim 8\) million years

NOTE: Sun is \(4.5\) billion years old, equivalent to a middle-aged adult star
Ultrasound of stellar embryos

NGC 2264  5 days of the ‘heartbeats’ of baby stars
**Ultrasound of stellar embryos**

**NGC 2264**

123 frequencies in MOST data

98 frequencies in MOST data
How are stars and planets born?

artist’s conception of birth of Solar System
How are stars and planets born?

artist’s conception of birth of Solar System
MOST explores alien worlds

artist’s conception of extrasolar planet
HD 209458

MOST is the only instrument currently capable of detecting the faint light reflected from a planet outside of our Solar System.
How does a speeder get a ticket?
How does a speeder get a ticket?

The world’s first speeding ticket?

This citation was issued to Lady Laurier (wife of the Prime Minister) in Ottawa in 1910 for driving a motor vehicle faster than the speed limit of 10 miles per hour (17 kph)!
Light – More than meets the eye

How does a speeder get a ticket?

And an astronomer find an alien planet?
Light – More than meets the eye

The Doppler Effect

If a source of waves is not moving, then the waves radiate symmetrically in all directions with the same wavelength.
The Doppler Effect

If a source of waves is not moving, then the waves radiate symmetrically in all directions with the same wavelength.

If it’s moving **towards** you, then the wavecrests passing you are closer together and the wavelength you measure is *reduced*.
The Doppler Effect

If a source of waves is not moving, then the waves radiate symmetrically in all directions with the same wavelength.

If it’s moving away from you, then the wavecrests passing you are closer together and the wavelength you measure is increased.
The Doppler Effect

If a source of waves is not moving, then the waves radiate symmetrically in all directions with the same wavelength.

If it’s emitting sound waves and moving at the speed of sound, then its velocity is called Mach 1.
Light – More than meets the eye

An actual video of a jet and the surrounding air as the plane breaks the sound barrier.
**Light – More than meets the eye**

**The Doppler Effect**

If a source of waves is not moving, then the waves radiate symmetrically in all directions with the same wavelength.

If it’s travelling faster than the speed of sound, the source is *supersonic*.

Nothing can travel faster than the speed of light and be *superluminal*. 
Light – More than meets the eye

The Doppler Effect
If the speed is not relativistic (a significant fraction of the speed of light) then the Doppler shift is given by

\[
\frac{\Delta \lambda}{\lambda} = \frac{V_{\text{rad}}}{c}
\]

where

- \( \lambda \) is the emitted or rest wavelength
- \( V_{\text{rad}} \) is positive if the source is moving away and negative if moving toward you
- \( \Delta \lambda = (\lambda_{\text{observed}} - \lambda_{\text{rest}}) \)
- \( V_{\text{rad}} \) = radial velocity
- \( c \approx 300,000 \text{ km/s} \) = speed of light

*Light – More than meets the eye*
Light – More than meets the eye

Drivers seem to know about the Doppler Effect
Drivers seem to know about the Doppler Effect
Drivers seem to know about the Doppler Effect

In my experience, all drivers – everywhere in the world – hit the gas pedal as they approach an amber light. They must be remembering the Doppler Effect and realising that if they go fast enough, they can shift the colour of the light from yellow to green and go through the intersection legally.

Could this work?
**Do drivers know about the Doppler Effect?**

Let’s apply the Doppler equation and find out.

\[
\frac{\Delta \lambda}{\lambda} = \frac{v_{\text{rad}}}{c}
\]

- Wavelength of green light: \(\lambda_{\text{green}} \sim 520 \text{ nm}\)
- Wavelength of yellow light: \(\lambda_{\text{yellow}} \sim 580 \text{ nm}\)

rest wavelength

\[
\Delta \lambda = (\lambda_{\text{observed}} - \lambda_{\text{rest}}) = 520 - 580 = -60 \text{ nm}
\]

\[c = \text{speed of light} \approx 3 \times 10^8 \text{ m/s}\]

\[
v_{\text{rad}} = \left( \frac{\Delta \lambda}{\lambda} \right) \times c \approx \left( \frac{-60}{580} \right) \times (3 \times 10^8 \text{ m/s}) \approx 3.1 \times 10^7 \text{ m/s}
\]
**Light – More than meets the eye**

**Do drivers know about the Doppler Effect?**

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v_{\text{rad}} = (\frac{\Delta \lambda}{\lambda}) \times c \approx \left(\frac{-60}{580}\right) \times (3 \times 10^8 \text{ m/s})
\approx 3.1 \times 10^7 \text{ m/s} \approx 11 \text{ million kph}!!
\]
Star and planet orbit around a common centre of mass causing the star to ‘wobble’ with the same period as the unseen planet.
Light – More than meets the eye

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astronomynotes.com

What is happening

What we see

spectrum
A habitable world?

- Swiss astronomers discovered three planets around a dim red dwarf
  - one of these planets may be in the habitable zone
A habitable world?

- Swiss astronomers discovered three planets around a dim red dwarf Gliese 581a
  - one of these planets may be in the habitable zone

- Canada’s MOST space telescope put this planetary system under a stakeout for eight weeks
Swiss astronomers discovered three planets around a dim red dwarf Gliese 581a. One of these planets may be in the habitable zone.

Canada’s MOST space telescope put this planetary system under a stakeout for eight weeks.

The results were boring.
Swiss astronomers discovered three planets around a dim red dwarf Gliese 581a. One of these planets may be in the habitable zone.

Canada’s MOST space telescope put this planetary system under a stakeout for eight weeks. The results were boring.

“Boring” is good for life. The red dwarf star is old and stable – conditions favourable for complex life.
Habitable exoplanets?
The question of life out there: Is it an X File?
Habitable exoplanets?

The question of life out there: Or a fairy tale?

Goldilocks & The Three Planets

too hot
just right
too cold
Habitable exoplanets?
Shadow play in our Solar System
Shadow play in our Solar System
Shadow play in our Solar System

Transiting airplane

The most recent transit of Venus occurred on 8 June 2004. The last one before that was in 1882 so there was no human alive in 2004 that had ever seen a transit of Venus.
Shadow play in our Solar System

Transiting planet

2012 Transit of Venus

Plan for your summer vacation ... in 2012!

Figure 3 - World Visibility of the Transit of Venus — 2012 June 06
The sky at about 9:00 p.m. local time in early December, facing toward the west.
Shadow play in HD 209458

Transiting exoplanet

artist’s conception
Position: RA = 22 03 10.8
Dec = +18 53 04
Distance: 47 pc ~ 153 ly
Constellation: Pegasus

**Star**
Magnitude (Star): V=7.64
Spectra Class: G0 V
Temperature: 6000 K

**Planet**
Orbital Period: 3.52 days
Semi-major axis: 0.046 AU
Eccentricity: 0
Mass: 0.68 × Jupiter
Radius: 1.35 × Jupiter
A year in a long weekend!

The diameter of the orbit is only six times the diameter of the star. The diameter of the star is 19.6 times the diameter of the planet.

Greg Laughlin
U. California Santa Cruz
measurement of the transit of the giant planet by MOST
measurement of the transit of the giant planet by HST
HD 209458

Knutson et al. 2006

Table 4. Comparison between best-fit values and results from previous works

<table>
<thead>
<tr>
<th>Study</th>
<th>$R_P$ ($R_{Jup}$)</th>
<th>Inclination (*)</th>
<th>$M_*$ ($M_\odot$)</th>
<th>$R_*$ ($R_\odot$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wittenmyer et al. (2005)</td>
<td>1.35 ± 0.07</td>
<td>86.668</td>
<td>1.09 ± 0.09</td>
<td>1.15 ± 0.06</td>
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<tr>
<td>Winn et al. (2005)</td>
<td>1.35 ± 0.06</td>
<td>86.55 ± 0.03</td>
<td>1.06 ± 0.13</td>
<td>1.15 ± 0.05</td>
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<tr>
<td>This Work</td>
<td>1.320±0.025</td>
<td>86.929±0.610</td>
<td>1.101±0.065</td>
<td>1.126±0.025</td>
</tr>
</tbody>
</table>

*Used stellar mass-radius relation from Cody & Sasselov (2002)

b Assumed value for the stellar mass from Cody & Sasselov (2002)

- nonlinear limb-darkening
- Kurucz models
- specific to MOST bandpass
- stellar radius:
  - $1.121 \pm 0.003 \, R_\odot$
- planetary radius:
  - $1.346 \pm 0.002 \, R_{Jup}$

✓ MOST transit data leads to slightly larger radius than HST but agrees with independent groundbased measurements
measurement of the eclipse of the giant planet by MOST
Imagine trying to see a mosquito disappearing behind a 400-Watt streetlamp.
Imagine trying to see a mosquito disappearing behind a 400-Watt streetlamp.

Not at the street corner, nor a few blocks away…
Imagine trying to see a mosquito disappearing behind a 400-Watt streetlamp. Not at the street corner, nor a few blocks away… but **1000 km** away!
Exoplanetometeorology

- search for transits at other periods
- timing of successive transits
- measurement of eclipse of giant planet

- Spitzer infrared
- MOST optical

Rowe et al. 2008
Astrophysical Journal

Deming et al. 2005
Nature 111, 111

- eccentricity, moons?
- Earth-sized planets?
- albedo
Exoplanetometeorology

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Exoplanetometeorology

HD 209458b
Exoplanetometeorology

HD 209458b

<table>
<thead>
<tr>
<th>Planet</th>
<th>Mercury</th>
<th>Venus</th>
<th>Earth</th>
<th>Moon</th>
<th>Mars</th>
</tr>
</thead>
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<tr>
<td></td>
<td>0.119</td>
<td>0.75</td>
<td>0.29</td>
<td>0.123</td>
<td>0.16</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Planet</th>
<th>Jupiter</th>
<th>Saturn</th>
<th>Uranus</th>
<th>Neptune</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.343</td>
<td>0.342</td>
<td>0.290</td>
<td>0.31</td>
</tr>
</tbody>
</table>

Don Davis

planet colour chart
Exoplanetometeorology

MOST data are helping us understand the weather and clouds on a planet you can’t even see around a star 160 light years away!?!
Exoplanetometeorology

Conception of a Sudarsky Class IV planet generated using Celestia Software
Gliese 581c: A superEarth
Gliese 581c: A superEarth
Gliese 581c: A superEarth

**Interior models**

- Upper Mantle: olivine
- Lower Mantle: perovskite + ferromagnesiowustite
- Outer core: Fe or Fe$_{0.8}$(FeS)$_{0.2}$
- Inner core: Fe or Fe$_{0.8}$(FeS)$_{0.2}$
- Lower Mantle: post-perovskite + ferromagnesiowustite
- Upper mantle: wadsleyite+ringwoodite

**Earth-like**

**Ocean Planet**
Cosmic real estate
I’ve become a real estate agent to science fiction writers.
Searching for Terra Nova

- The MOST space telescope is the first instrument which can detect alien Earths
- It is the pioneer for future space missions:
  - COROT (France; launched Dec 2006)
  - Kepler (USA; launch 2009)

www.astro.ubc.ca/MOST

The search is on...
Searching for Terra Nova

The Kepler Mission

NASA's first mission capable of finding Earth-size and smaller planets

kepler.nasa.gov
Searching for Terra Nova

The Kepler Mission

Launch April 2009

Spacecraft orbit

Period (days) |
---|---
Earth | 365.25
Spacecraft | 372.50

Semi-major (AU) |
---|---
1.00000 | 1.01319

eccentricity |
---|---
0.01675 | 0.03138

Sun Shade

Photometer
CCD Radiator
Solar Array
Star Trackers
(2)
Thruster Modules
(4)
High Gain Antenna
Searching for Terra Nova

- The MOST space telescope is the first instrument which can detect alien Earths
- It is the **pioneer** for future space missions:
  - **COROT** (France; launched Dec 2006)
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The search is on...
Searching for Terra Nova

“I see the Earth. It is so beautiful.”

Yuri Gagarin (1961)
Searching for Terra Nova

“I see another Earth. It is so beautiful.”

Jaymie Matthews
and the MOST Team (200?)
Earth: Harmless

The Hitchhiker’s Guide to the Galaxy – 1st Edition
Earth: Mostly Harmless

The Hitchhiker’s Guide to the Galaxy – 2nd Edition
exoEarth 1: Wow!

The MOST Guide to the Galaxy – Future Edition?
Did I leave time for any questions?

www.astro.ubc.ca/MOST