THE VVV SURVEY:

CHARTING THE MILKY WAY'S BULGE AND DISK

István Dékány

Millennium Institute for Astrophysics, Santiago, Chile

Pontificia Universidad Católica de Chile
VVV: VISTA Variables in the Vía Láctea
Near-IR time-domain photometric survey of the Galactic bulge and inner disk
PI: Dante Minniti, Chile  co-PI: Philip Lucas, UK
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Near-IR time-domain photometric survey of the Galactic bulge and inner disk

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VISTA Public Surveys

VVV: 520 square degrees
2000 hours
7 years
Galactic bulge

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2000 hours
7 years

ZYJHKs atlas (single epoch)
up to ~100 epochs in Ks
1 billion objects, 1 million variables

VISTA PUBLIC SURVEYS
VVV: the first and only near-IR time-domain survey of the bulge and southern disk
VISTA (Visible and Infrared Survey Telescope for Astronomy)

4.1 m telescope

f / 3.25

1.5 sq. deg. FOV
VIRCAM (VISTA InfraRed Camera)
VVV AND 2MASS

VVV builds on the 2MASS legacy: Science cases given by 2MASS

WFIRST can build on the VVV legacy: Science cases from VVV

2MASS IMAGE OF THE MILKY WAY

VVV is calibrated by 2MASS
VVV system != 2MASS system
VVV and 2MASS

Main differences with 2MASS

2MASS covers the whole sky, VVV only 1.3%

VVV has higher resolution (0.34''/pix)
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- VVV is deeper (Ks<18)

*Credit: ESO*

*R. Saito, M. Hempel et al. 2012*
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**VVV and 2MASS**

Main differences with 2MASS

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VVV is deeper (Ks<18)

VVV has 5 filters (ZYJHKs)

VVV is a time-domain survey (in Ks)
What is the 3-D structure of the Milky Way
vvv Goal

How did it form
VVV Multicolor Photometry

Ignacio Toledo
VVV
0.3M
SINGLE TILE
BULGE CMD
VVV
84M
STARS
BULGE
CMD
EXTINCTION MAP


EXTINCTION MAP

Also in 3D
METALLICITY MAP

A double red clump is seen along different directions towards the bulge. This is present in 2MASS and VVV data.
The Milky Way bulge is X-shaped.
Two independent datasets and analyses (2MASS, VVV).

Credit: ESO
The Milky Way bulge is X-shaped.
Two independent datasets and analyses (2MASS, VVV).

Saito et al. 2011, AJ
The peanut-shaped bulge formed from the disk via buckling instability.

theory: see, e.g., Wegg & Gerhard (2013)
BULGE MAPPING

Red clump (RC) and RR Lyrae stars trace different populations.


Zoccali et al. 2008, A&A

Gonzalez et al. 2011, A&A
Combined OGLE + VVV (I + Ks) distance analysis of bulge RR Lyrae stars.
Advantage: accurate distances and reddenings on a star-by-star basis by precise PL-relations.

BULGE MAPPING

Combined OGLE + VVV (I + Ks) distance analysis of bulge RR Lyrae stars. Advantage: accurate distances and reddenings on a star-by-star basis by precise PL-relations.


\[ D_{GC} = 8.33 \pm 0.16 \text{ kpc} \]
BULGE MAPPING

Combined OGLE + VVV (I and Ks) distance analysis of bulge RR Lyrae stars. Advantage: accurate distances and reddenings on a star-by-star basis by precise PL-relations.

BULGE MAPPING

Up next:
extended I+Ks analysis of OGLE-IV sample.
Near-IR data extraction almost complete.
Dékány et al. 2015, in prep.

Up next:
explore the rest with VVV.
Challenge:
identifying RR Lyrae in the near-IR.
Time-series analysis underway,
automatic classifier ready.

Soszynski et al. (2014)
The old (> 10 Gyr) bulge is not X-shaped and not even barred. The Milky Way has a composite bulge:

**BOXY PEANUT + SPHEROID**

The MW formed first inside-out, then grew a boxy peanut shaped bulge.

Samland & Gerhard 2003, A&A
Saha & Gerhard 2013, MNRAS
THE GREAT DARK LANE

A split red clump is seen along the reddening vector towards the bulge.

66 million stars

Minniti et al. 2014, A&A
THE GREAT DARK LANE

A split red clump is seen along the reddening vector towards the bulge.

small field at the dark lane’s edge

Minniti et al. 2014, A&A
NGC 1365: two nested bars with two arms

HST OPTICAL

THE GREAT DARK LANE

RR Lyrae distance-reddening distribution: the Great Dark Lane is indeed real.

Dékány et al. (in prep.)
RR Lyrae distance-reddening distribution: the Great Dark Lane is NOT in the bulge.

Sample is limited in short distances, but gives an upper limit of ~6 kpc for the Dark Lane’s distance.

Dékány et al. (in prep.)
Sol
M64: the Evil Eye Galaxy

HST Optical
THE OTHER SIDE OF THE MW.

Oh sure, but we know how the MW looks like!
THE OTHER SIDE OF THE MW.

Oh sure, but we know how the MW looks like!  

Nope.
THE OTHER SIDE OF THE MW.

(Pre-2MASS) Ptolemy et al. (150)
THE OTHER SIDE OF THE MW.

(Post-Spitzer) Ortelius et al. (1570)
THE OTHER SIDE OF THE MW.

Velocity mapping (HI, HII, CO, masers, …)
Drawback: kinematic assumptions, blind towards GC, GAC

Hou et al. (2009, A&A)
Stellar tracers (Cepheids, YOC, OB stars, …)

Drawback: limited to near side

DDO Cepheid database
Stellar tracers (Cepheids, YOC, OB stars, …)

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**BUT:** VVV

DDO Cepheid database
THE OTHER SIDE OF THE MW.

VVV Galactic Cepheid Program (VGCP): up to $A(V) \sim 50$

SO FAR:
- analysis of $\sim 35$ million light-curves in $-2^\circ < b < 2^\circ$, $-70^\circ < l < 10^\circ$
- $\sim 5\%$ of the low-latitude are searched for Cepheids
- $\sim 400$ candidates found
- problem: confusion with type II Cepheids (due to near-IR light-curves)
- solution: spectroscopic follow-up
- $\sim 80$ best targets proposed for FIRE/Baade, X-Shooter/VLT
THE OTHER SIDE OF THE MW.

VGCP Proof of Concept: The Twin Cepheids

separation = 18.3''

b=0°

A(Ks)=3.2 mag, A(V)=32 mag
d=11.4 kpc

< 1pc from the Galactic plane

must be type I

must be in OC

VGCP Proof of Concept: The Twin Cepheids

VGCP Proof of Concept: The Twin Cepheids

VGCP: prospects

**Type I**

**Type II**

?
VGCP: prospects

?
VVV AND MICROLENSING

VVV was originally not designed for ML.

BUT: high-cadence program has been proposed for the inner bulge

VVV will search for reddened bulge microlensing events, and produce a map of the optical depth, tracing the 3D bulge mass distribution.

The near-IR advantage:

I, J and Ks-map event rates for sources with K<17.

Contours = 17.5, 35, 52.4 per sq.deg. per year.

E. Kerins et al. (2008)
Candidate Microlensing events from the VVV Survey
serendipitous discoveries
proof of concept that allows us to explore the parameter space covered and plan
future strategies
complementary to optical surveys

István Dékány, Dante Minniti, Roberto Saito: ML search
Eamonn Kerins: DIA pipeline development

VVV AND MICROLENSING

[Graphs showing variation in Ks magnitude over HJD - 55000.0 for objects b295-0644141, b295-0914732, and b263-0711279.]

Credit: ESO
**VVV AND WFIRST**

**VVV:** the *first* and *only* near-IR time-domain survey of the bulge and southern disk

This provides basic synergies with WFIRST:
- VVV is pioneering for WFIRST
- VVV lets us learn now how to use massive Galactic data
- VVV prepares us to surf the WFIRST data tsunami

**VVV for WFIRST:**
- provide science cases
- input catalogs for followup
- extended time baseline
- QSOs
- extended ML timescale

**WFIRST for VVV:**
- recalibration
- deblending
- more epochs