**Mullard Space Science Laboratory** 

# ≜UCL

### Galactic Dynamics with Gaia DR2

Daisuke Kawata

(Mullard Space Science Laboratory (MSSL), University College London (UCL))
 Rob Grand (HITS, Heidelberg), Jason Hunt (Dunlap Fellow, Toronto)
 Jo (Ioana) Ciucă, Mark Cropper, George Seabroke (MSSL, UCL)
 Jo Bovy (Toronto), Noriyuki Matsunaga (U of Tokyo), Junichi Baba (NAOJ)
 Shin'ichiro Ando (Amsterdam), Francesca Calore (Grenoble),
 Justin Read (Surrey), Cecilia Mateu (CIDA)

# Outline

- Stellar velocity structures in the Milky Way disk revealed by Gaia DR2
- Gaia DR2 search for annihilating DM
- Gaia DR3 and future astrometry missions

# University College London, UCL

- founded in 1826 the first University in England for students of any race, class or religion the first University for female students.
- Based in London (near to British Museum)
   >6,000 academic and research staff 36,000 students from 150 countries
- 29 novel prize winners
- Top-rated university in the UK (REF2014, Nation-wide Research Excellence Framework)





5th QS World University Rankings 2014/15











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### Mullard Space Science Laboratory (MSSL), Department of Space and Climate Physics, UCL

- Largest University Space Science Lab in the UK. about 200 people on site.
- close coupling between space science and engineering disciplines.
- space projects with ESA, NASA, Japan, China, Russia, India...
- several research groups all linked by the common theme of access to space:

#### Solar System

#### Astrophysics

Mark Cropper, Graziella Branduardi-Raymont, Kinwah Wu, Mat Page, Silvia Zane, Ignacio Ferreras, Tom Kitching, Jason McEwen and Daisuke Kawata

![](_page_9_Picture_8.jpeg)

### Currently operating projects

### • Gaia - RVS

- Hinode EIS and FPP
- SOHO -CDS
- Cluster II PEACE
- Double Star PEACE
- Mars Express
- Venus Express
- INTEGRAL OMC
- Swift UVOT
- XMM-Newton OM, RGS

![](_page_10_Picture_11.jpeg)

### Future projects

- EXOMars
- James Webb Space Telescope
- Solar orbiter
- JUICE
- Euclid
- SMILE
- PLATO
- ARIEL
- ATHENA

![](_page_11_Picture_10.jpeg)

![](_page_11_Picture_11.jpeg)

Gaia: Launched 19th Dec. 2013 DR1: 14 September 2016 DR2: 25 April 2018

MSSL: CCD and electronics RVS (Radial Velocity Spectrograph) Spectroscopic data processing

![](_page_13_Figure_0.jpeg)

Eyer's talk at KIAA, 2010

## Gaia astrometric accuracy

![](_page_14_Figure_1.jpeg)

Figueras's talk at Gaia School

Gaia DR2: 25 April 2018 First full astrometry catalogue of Gaia parallax and proper motions for 1.3 B stars! (DR1 was for 2 M bright stars)

![](_page_15_Picture_1.jpeg)

# DR2: First release of radial velocity for 7 M bright stars (4<G<13 mag) from RVS

![](_page_16_Figure_1.jpeg)

![](_page_16_Picture_2.jpeg)

#### Cropper (MSSL) et al. (2018)

![](_page_17_Figure_0.jpeg)

![](_page_18_Figure_0.jpeg)

Gaia Collaboration, Babusiaux et al. (2018)

#### 2nd population of counter-rotating halo stars from a SMC-size galaxy (minor) merger at >10 Gyr ago?

![](_page_19_Figure_1.jpeg)

#### GALACTIC HALO STARS IN PHASE SPACE: A HINT OF <u>SATELLITE ACCRETION</u>?

CHRIS B. BROOK,<sup>1</sup> DAISUKE KAWATA,<sup>1</sup> BRAD K. GIBSON,<sup>1</sup> AND CHRIS FLYNN<sup>1,2</sup> Received 2002 December 10; accepted 2003 January 24; published 2002 February 4

![](_page_20_Figure_2.jpeg)

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#### Stellar velocity distribution in the solar neighbourhood Many velocity structures!

![](_page_22_Figure_1.jpeg)

Gaia Collaboration, Katz et al. (2018)

Galactic disk stars are not phase mixed, but perturbed recently?

![](_page_23_Figure_1.jpeg)

![](_page_23_Figure_2.jpeg)

Antoja et al. (2018)

#### Beyond solar neighbourhood

![](_page_24_Figure_1.jpeg)

![](_page_25_Figure_0.jpeg)

![](_page_26_Figure_0.jpeg)

Kawata et al. (2018)

#### Vertical Oscillation Galactic disk is heavily perturbed!

![](_page_27_Figure_1.jpeg)

#### Vertical Oscillation Consistent with what indicated in Gaia DR1

![](_page_28_Figure_1.jpeg)

Gaia DR2 revealed the Milky Way disk is not a smoothly rotating disk, but heavily perturbed.

Kawata et al. (2018)

Sagittarius dwarf impacting the Galactic disk?

![](_page_29_Picture_1.jpeg)

![](_page_29_Picture_2.jpeg)

![](_page_29_Picture_3.jpeg)

Bergemann et al. (2018) T. Muller/NASA/JPL-Caltech

#### Axisymmetric perturbation: no tilt in U-V distribution

Model

Gaia DR2

![](_page_30_Figure_3.jpeg)

Alternative scenario: Transient winding spiral arms? (Hunt, Hong, Bovy, Kawata, Grand 2018)

![](_page_31_Picture_1.jpeg)

e.g. Selwood (2011), Grand, Kawata Cropper (2012), Wada et al. (2011), Baba et al. (2013) Disrupting Perseus Arm! Baba, Kawata, Matsunaga, Grand, Hunt (2018)

Cepheids distance + DR1 proper motion

![](_page_32_Figure_2.jpeg)

![](_page_32_Picture_3.jpeg)

Evidences in the gas radial migration and metallicity distribution

(Sánchez-Menguiano, Sánchez, Kawata et al. 2017)

NGC6754 (MUSE)

![](_page_33_Figure_3.jpeg)

residual Z

see model prediction Grand, Springel, Kawata et al. (2016) Baba et al. (2016)

residual V

Behind the arm gas move outward and more metal rich and opposite trend at the front! simulation

![](_page_33_Figure_9.jpeg)

![](_page_33_Figure_10.jpeg)

![](_page_34_Figure_0.jpeg)

#### Diagonal ridges in R vs. Vrot are reproduced. (Hunt, Hong, Bovy, Kawata, Grand 2018)

![](_page_35_Figure_1.jpeg)

However, expected to be difficult to explain Vz oscillation.

#### Likely solution: Sgr impact + spiral arms Laporte et al. (2018)

![](_page_36_Figure_1.jpeg)

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#### Fermi-LAT extended unassociated sources: DM halos? (Ciucă, Kawata, Ando, Calore, Read, Mateu 2018, MNRAS in press)

- Weakly Interacting Massive Particle (WIMP) DM annihilation
  → Y-ray ← Fermi-LAT detection?
- No detection of Y-ray at known dwarfs (D>20 kpc) so far (e.g. Albert et al. 2017).
- Fermi-LAT extended unassociated sources: If there are stellar counter part, first detection of (likely) annihilation signal from a dwarf galaxy
  - 800 Gaia DR2! 12212.5 + 0703720 -37 640 560 Latitude (°) မွ 480 400 320 240 160 -40 80 71 70 69 68 67 Bertoni et al. (2016) Longitude (°)

# Gaia DR2 search for a dwarf galaxy mock data, $M_{star}$ = 5000 M<sub> $\odot$ </sub>, d= 10 kpc

![](_page_39_Figure_1.jpeg)

Extreme deconvolution (XD) Gaussian mixture models in proper motion taking into account errors and correlation. parallax: several distance sample cut.

#### Detectability check: putting a mock dwarf in each field of Gaia DR2

![](_page_40_Figure_1.jpeg)

3FGL J2201.5+0703 field

a conservative limit  $M_{star} > 10,000 M_{\odot}, d < 20 \text{ kpc}$ 

# Searching for 8 Fermi-LAT extended unassociated sources.

Result: No detection...

What a smart guy, Shin'ichiro Ando, can do from the non-detection

- Upper limit: M<sub>star</sub> > 10,000 M<sub>☉</sub>
   → M<sub>halo</sub> <10<sup>9</sup> M<sub>☉</sub> are allowed in d< 20 kpc</li>
- If the extended Fermi sources are from NFW-like DM halo, size and flux are allowed for limited distance for different mass of DM halo.

![](_page_42_Figure_3.jpeg)

Only M<sub>halo</sub> ~10<sup>9</sup> M<sub>☉</sub> and d~3 kpc possible, but unlikely to survive, not found in N-body simulation either! Hence, they are very unlikely to be a real DM halo!

![](_page_43_Figure_1.jpeg)

#### Summary, so far

- Gaia DR2 are tremendous resources for many sciences!
- Gaia DR2 revealed the Milky Way disk is not a smoothly rotating disk, but heavily perturbed.
- Fermi-LAT extended unassociated sources, so far, very unlikely to be annihilating DM.

Gaia DR2: Preliminary data

![](_page_45_Figure_1.jpeg)

Small scale zero-point variation of parallax Lindegren et al. (2018)

Gaia Data release scenario

- DR3: late 2020 Improved astrometry and photometry stellar classification, parameters, radial velocity, spectra
- Final release for 5 year mission: end 2022
- 3 year mission extension approved (till 2020)
- 2 more years?

#### Small-JASMINE (2024?) NIR astrometry for Galactic central region Fixing the centre!

![](_page_47_Figure_1.jpeg)

# GaiaNIR A Future All Sky Astrometry Mission Selected for one of three

2017 ESA New Science Ideas >2040?

DAVID HOBBS LUND OBSERVATORY

#### Future is bright in NIR!

![](_page_49_Figure_1.jpeg)