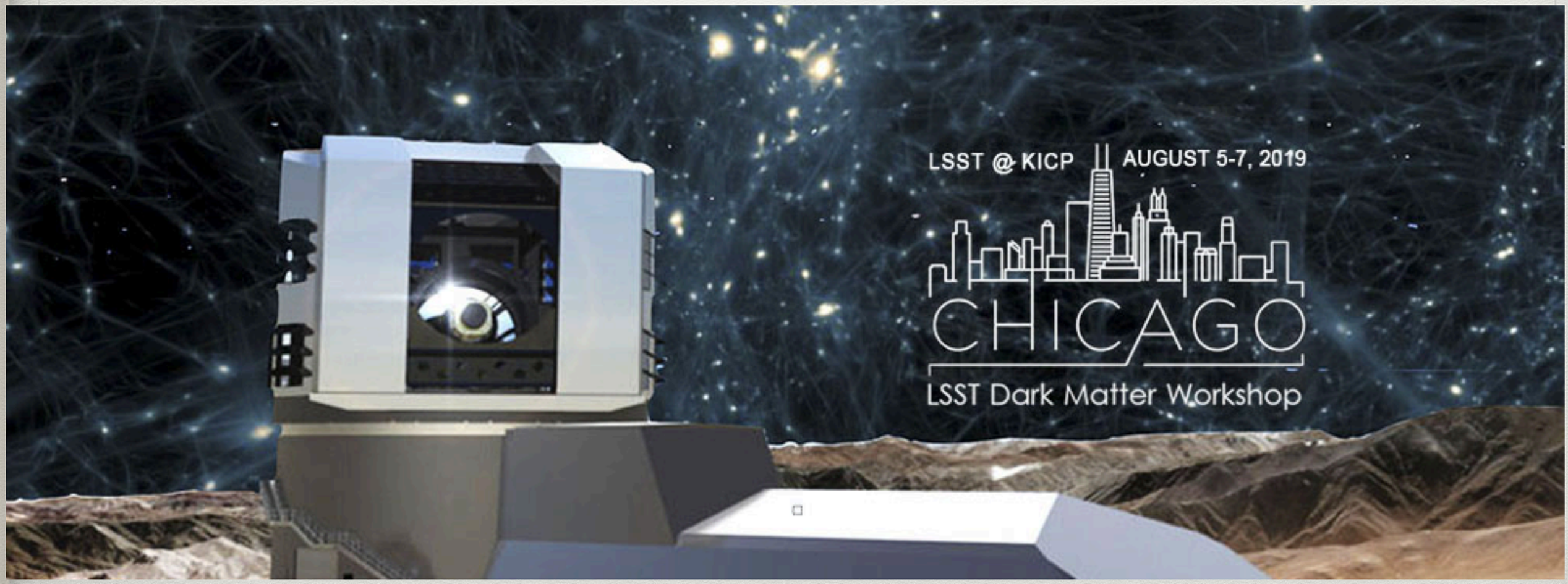
DARK MATTER WITH SPECTROSCOPY

Ting Li
NASA Einstein Fellow
Carnegie-Princeton Fellow
Carnegie Observatories & Princeton University

LSST Dark Matter Workshop, August 5-7, 2019



Draft version April 11, 2019
Typeset using LaTeX **preprint** style in AASTeX62

Astrophysical Tests of Dark Matter with Maunakea Spectroscopic Explorer

Ting S. Li,[1,2] Manoj Kaplinghat,[3] Keith Bechtol,[4] Adam S. Bolton,[5] Jo Bovy,[6] Timothy Carleton,[7] Chihway Chang,[8,2] Alex Drlica-Wagner,[1,2,8] Denis Erkal,[9] Marla Geha,[10] Johnny P. Greco,[11] Carl J. Grillmair,[12] Stacy Y. Kim,[13] Chervin F. P. Laporte,[14] Geraint F. Lewis,[15] Martin Makler,[16] Yao-Yuan Mao,[17] Jennifer L. Marshall,[18] Alan W. McConnachie,[19] Lina Necib,[20] A. M. Nierenberg,[21] Brian Nord,[1,2,8] Andrew B. Pace,[18] Marcel S. Pawlowski,[3,22] Annika H. G. Peter,[23,11,13] Robyn E. Sanderson,[24,25] Guillaume F. Thomas,[19] Erik Tollerud,[26] Simona Vegetti,[27] and Matthew G. Walker[28,29]

MSE Detailed Science Case — arXiv:1904.04907 (300 pages)

DM Chapter — arXiv: 1903.03155 (40 pages)

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wide-field multi-object spectrograph on 8m+ telescope

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streams
stellar halo

dwarf galaxies

strong lensing

galaxy cluster

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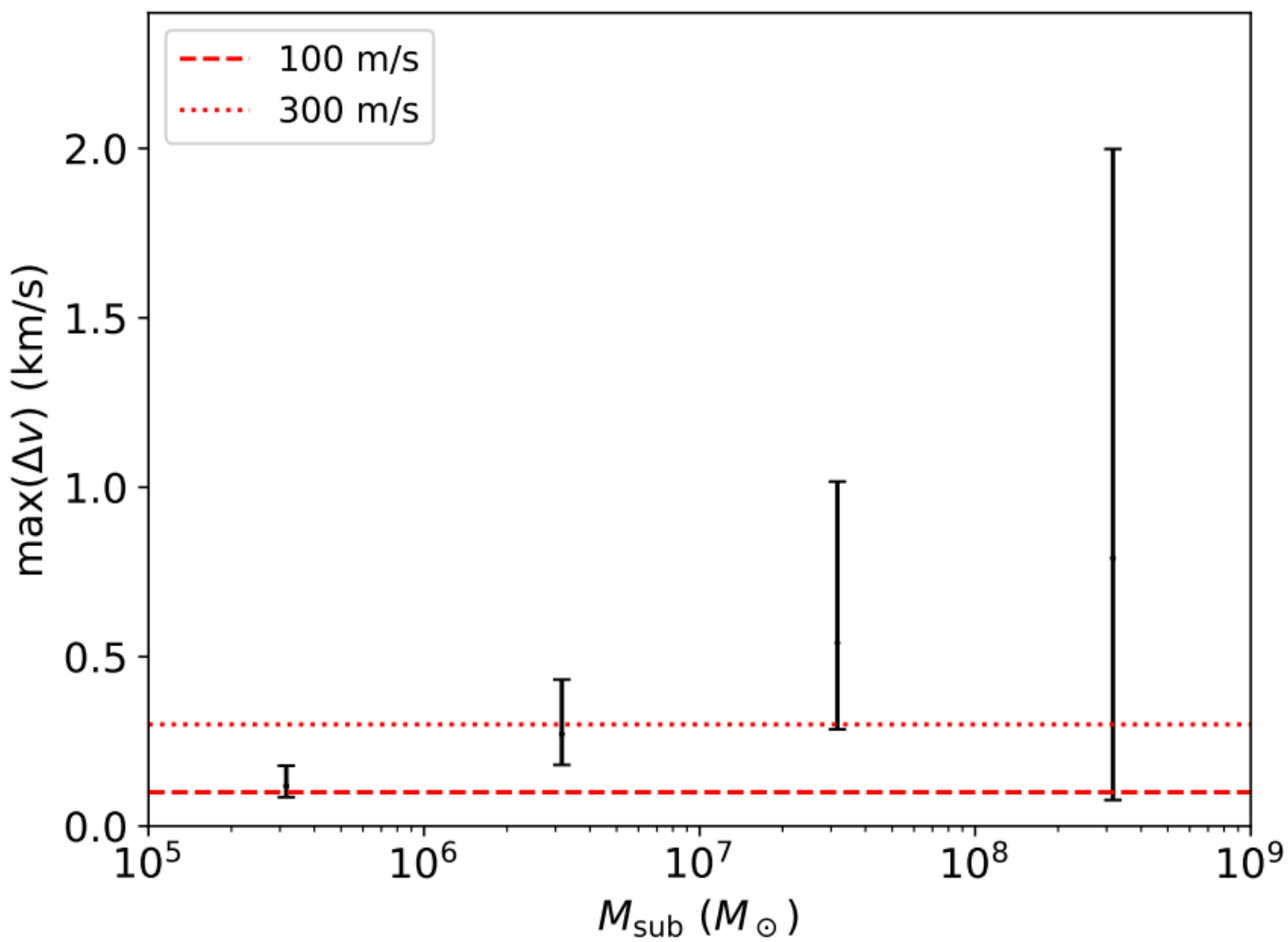
Velocity kick in the stream gaps



credit: Denis Erkal

TSL, Kaplinghat + 2019
arXiv: 1903.03155

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Astro2020 Science White Paper

Dark Matter Physics with Wide Field Spectroscopic Surveys

Thematic Areas: ☐ Planetary Systems ☐ Star and Planet Formation
☐ Formation and Evolution of Compact Objects ☑ Cosmology and Fundamental Physics
☐ Stars and Stellar Evolution ☐ Resolved Stellar Populations and their Environments
☐ Galaxy Evolution ☐ Multi-Messenger Astronomy and Astrophysics

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Co-authors (affiliations after text): Manoj Kaplinghat[1], Andrew B. Pace[2], Keith Bechtol[3], Adam S. Bolton[4], Jo Bovy[5], Timothy Carleton[6], Chihway Chang[7,8], Helene Courtois[9], Alex Drlica-Wagner[10,8,7], Denis Erkal[11], Marla Geha[12], Johnny P. Greco[13], Carl J. Grillmair[14], Stacy Y. Kim[15], Chervin F. P. Laporte[16], Geraint F. Lewis[17], Noam I. Libeskind[18,9], Martin Makler[19], Yao-Yuan Mao[20], J. L. Marshall[2], Alan W. McConnachie[21], Lina Necib[22], A. M. Nierenberg[23], Brian Nord[10,8,7], Marcel S. Pawlowski[1,18], Annika H. G. Peter[24,13,15], Robyn E. Sanderson[25,26], Guillaume F. Thomas[21], Erik Tollerud[27], Matthew G. Walker[28,29], Nilanjan Banik[30,31], Simon Birrer[32], Alyson Brooks[33], Elizabeth Buckley-Geer[10], James S. Bullock[1], Francis-Yan Cyr-Racine[34,35], Hai-Bo Yu[36], David Hendel[5], Shunsaku Horiuchi[37], Lauren Hsu[10], Koushiappas M. Savvas[38,39], Noah A. Kurinsky[10,8], Paul L.G. Lebrun[10], Kristen B.W. McQuinn[33], Burçin Mutlu-Pakdil[40], Jorge Peñarrubia[41], Adrian M. Price-Whelan[42], J. I. Read[11], Ricardo P. Schiavon[43], Tracy R. Slatyer[44], S. Tony Sohn[45], Louis E. Strigari[2], Edward N. Taylor[46], Yuan-Sen Ting[47,48,49], Yu-Dai Tsai[10,8], Ludovic Van Waerbeke[50]

MSE Detailed Science Case — arXiv:1904.04907 (300 pages)
DM Chapter — arXiv: 1903.03155 (40 pages)
Astro2020 White Paper — 2019BAAS51c252L (5 pages)

arXiv: 1907.09481

MNRAS **000**, 1–25 (2018) Preprint 24 July 2019 Compiled using MNRAS LaTeX style file v3.0

The Southern Stellar Stream Spectroscopic Survey (S^5): Overview, Target Selection, Data Reduction, Validation, and Early Science

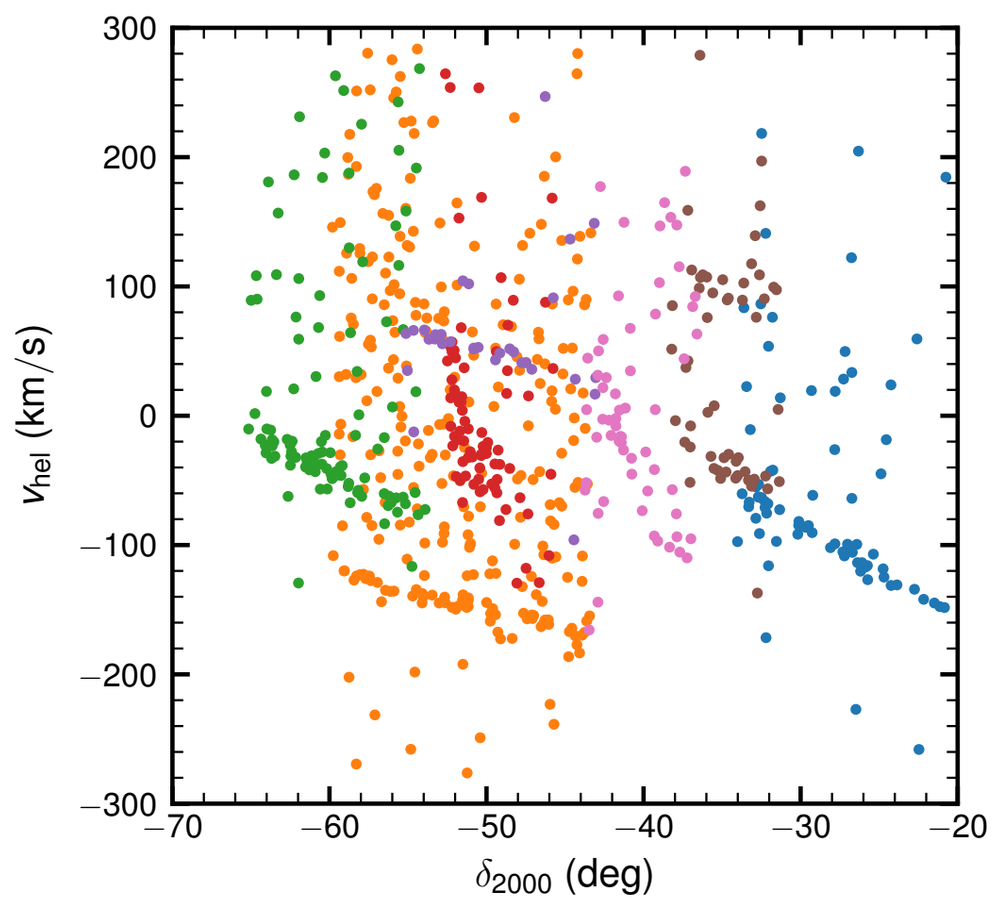
T. S. Li[1,2,3,4,5]★, S. E. Koposov[6,7], D. B. Zucker[8,9], G. F. Lewis[10], K. Kuehn[11], J. D. Simpson[12], A. P. Ji[3,5], N. Shipp[13,2,1], Y.-Y. Mao[14,15], M. Geha[16], A. B. Pace[17], A. D. Mackey[18], S. Allam[1], D. L. Tucker[1], G. S. Da Costa[18], D. Erkal[19], J. D. Simon[3], J. R. Mould[20], S. L. Martell[12,21], Z. Wan[10], G. M. De Silva[11], K. Bechtol[22], E. Balbinot[23], V. Belokurov[7], J. Bland-Hawthorn[10,21], A. R. Casey[24], L. Cullinane[18], A. Drlica-Wagner[1,13,2], S. Sharma[10,21], A. K. Vivas[25], R. H. Wechsler[26,27,28], B. Yanny[1]

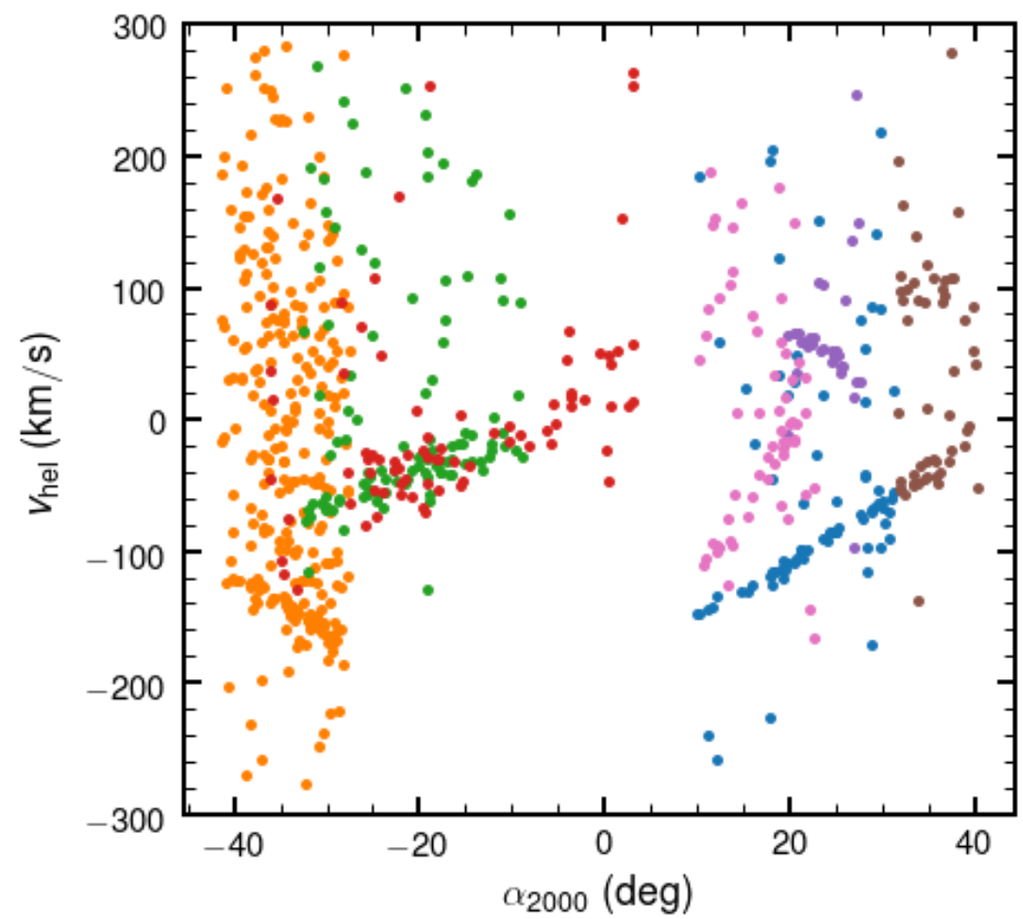
(S^5 Collaboration)

s5collab.github.io

Southern Stellar Stream Spectroscopic Survey (S^5)

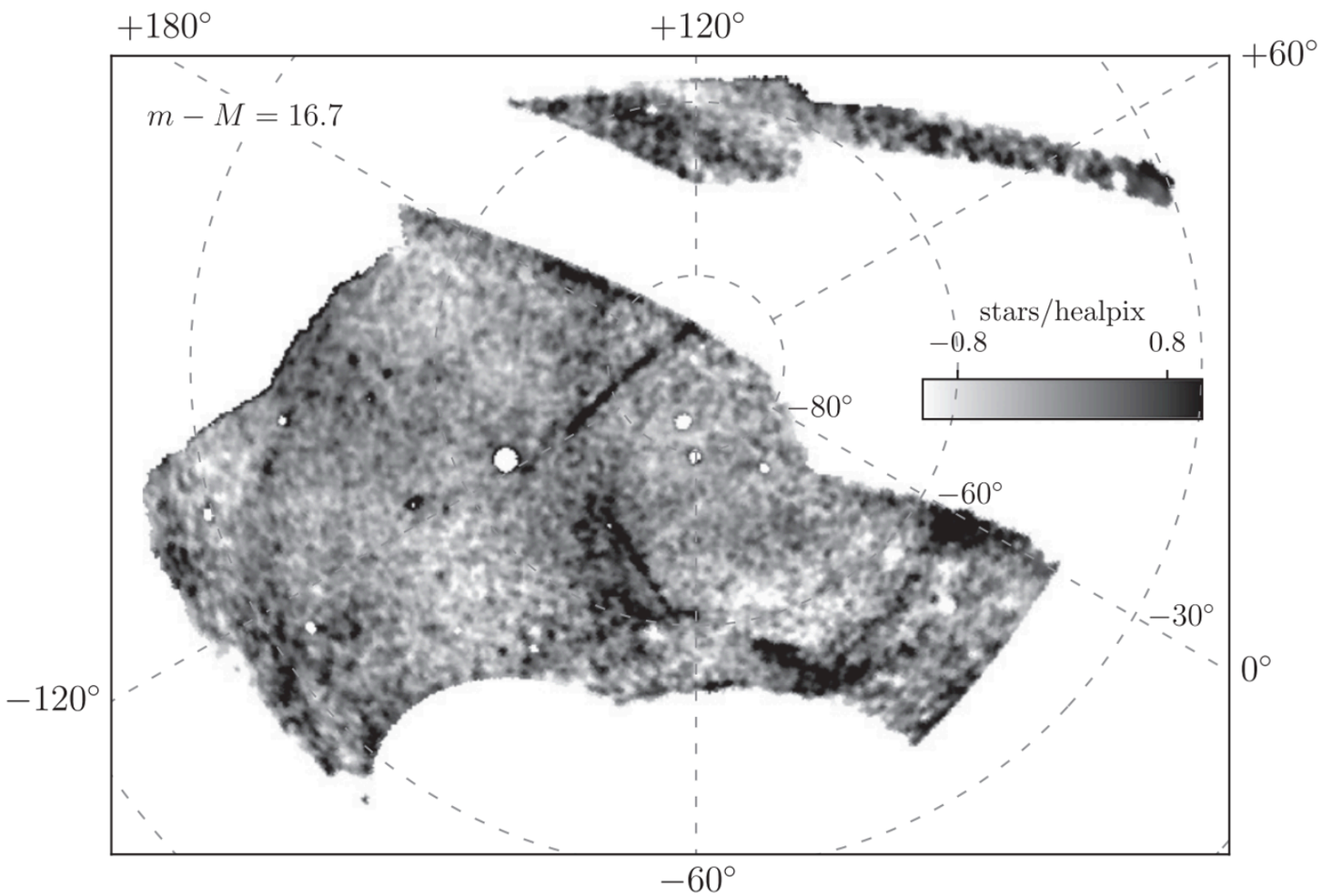
"Field-of-stream" in phase space





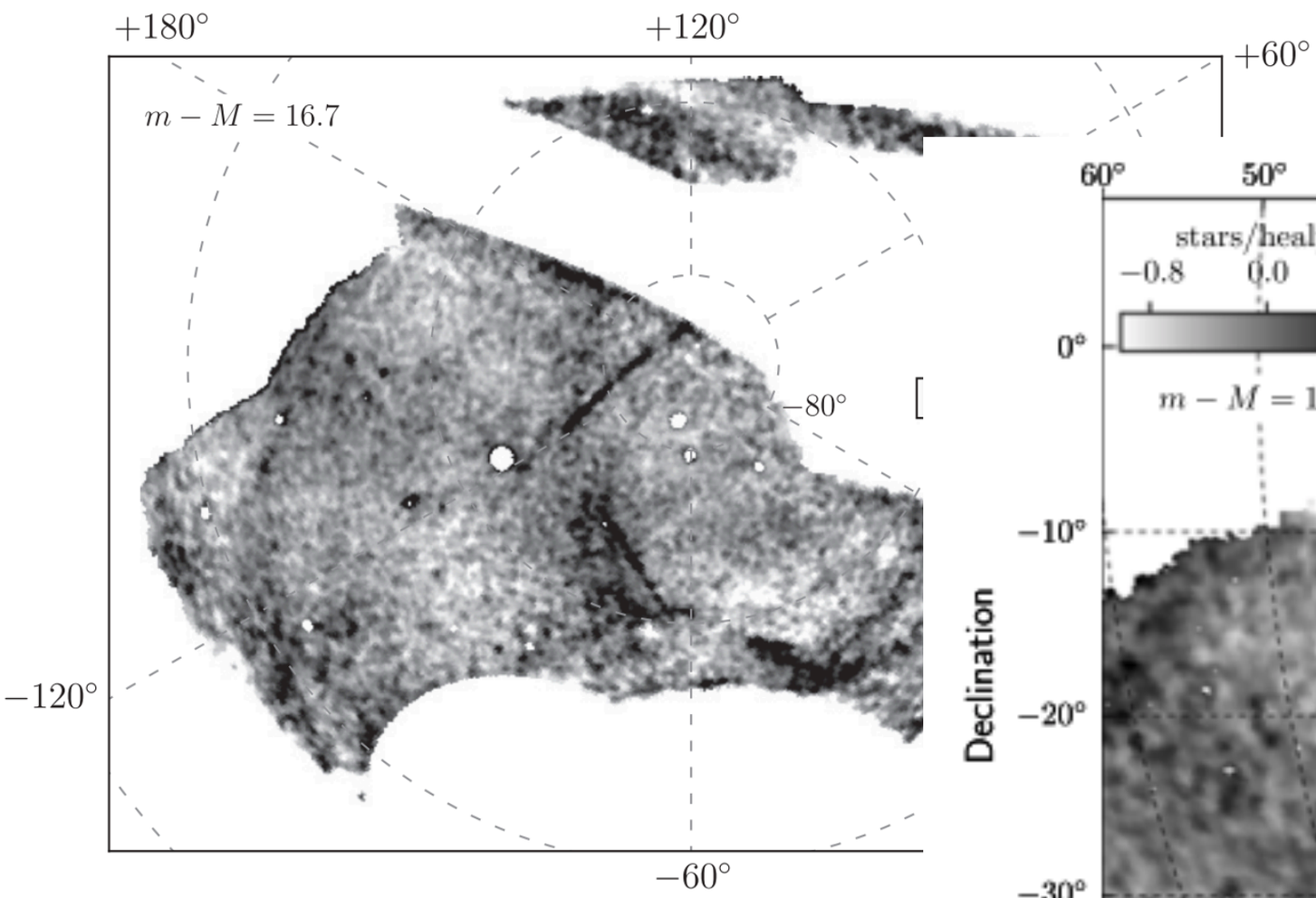
TSL+ 2019
arXiv: 1907.09481

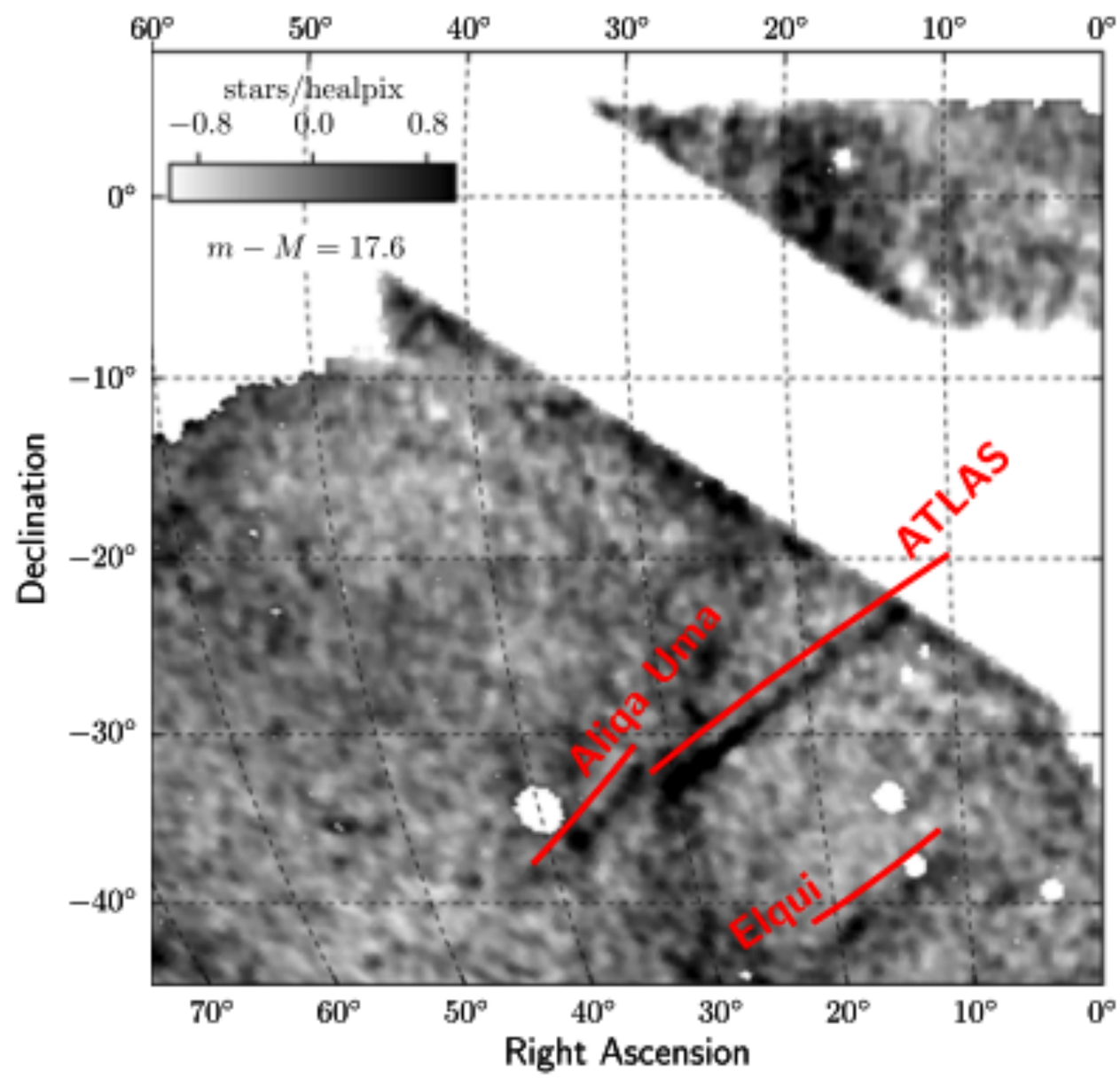
New Streams from the Dark Energy Survey



Shipp+2018

New Streams from the Dark Energy Survey





Shipp+2018

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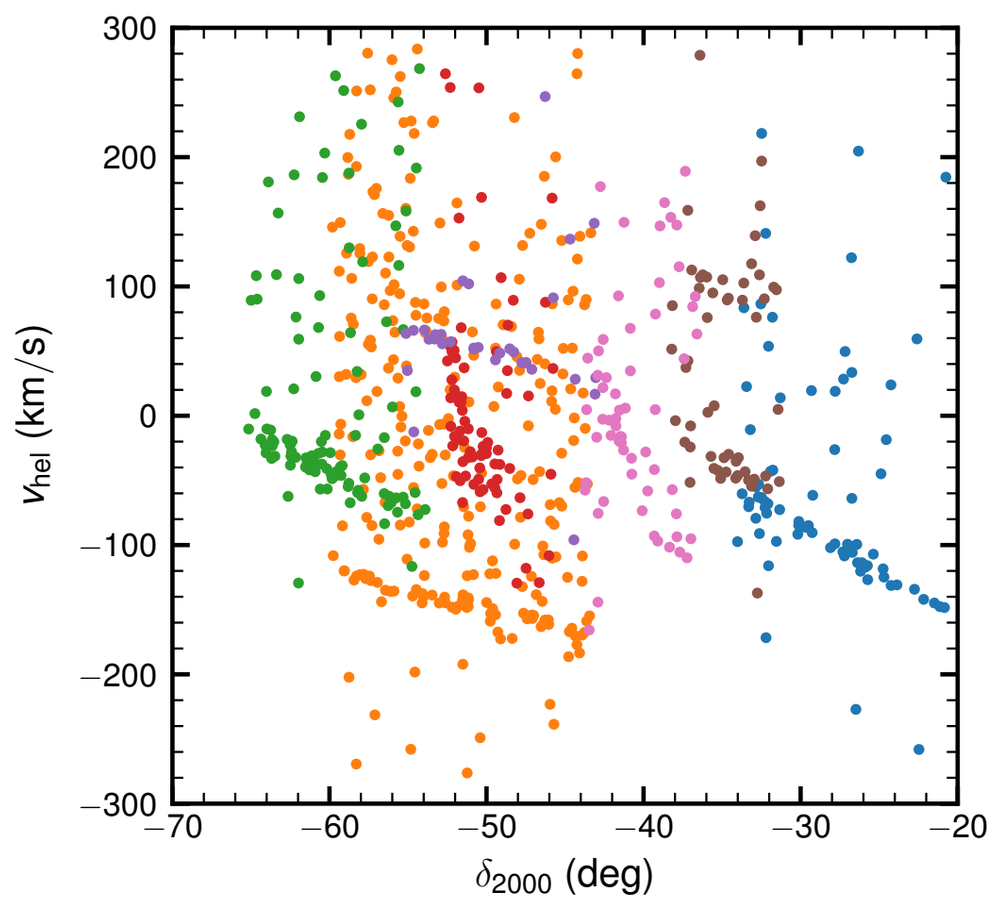

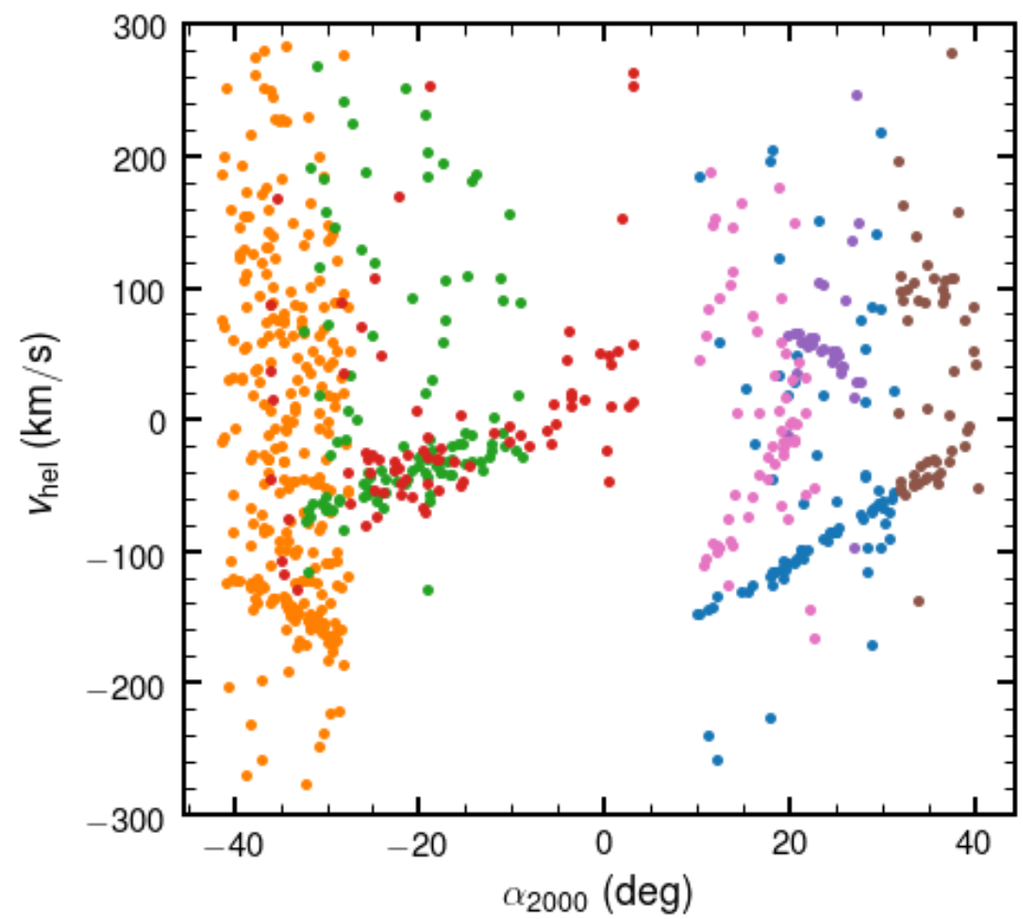

TSL+ 2019
arXiv: 1907.09481

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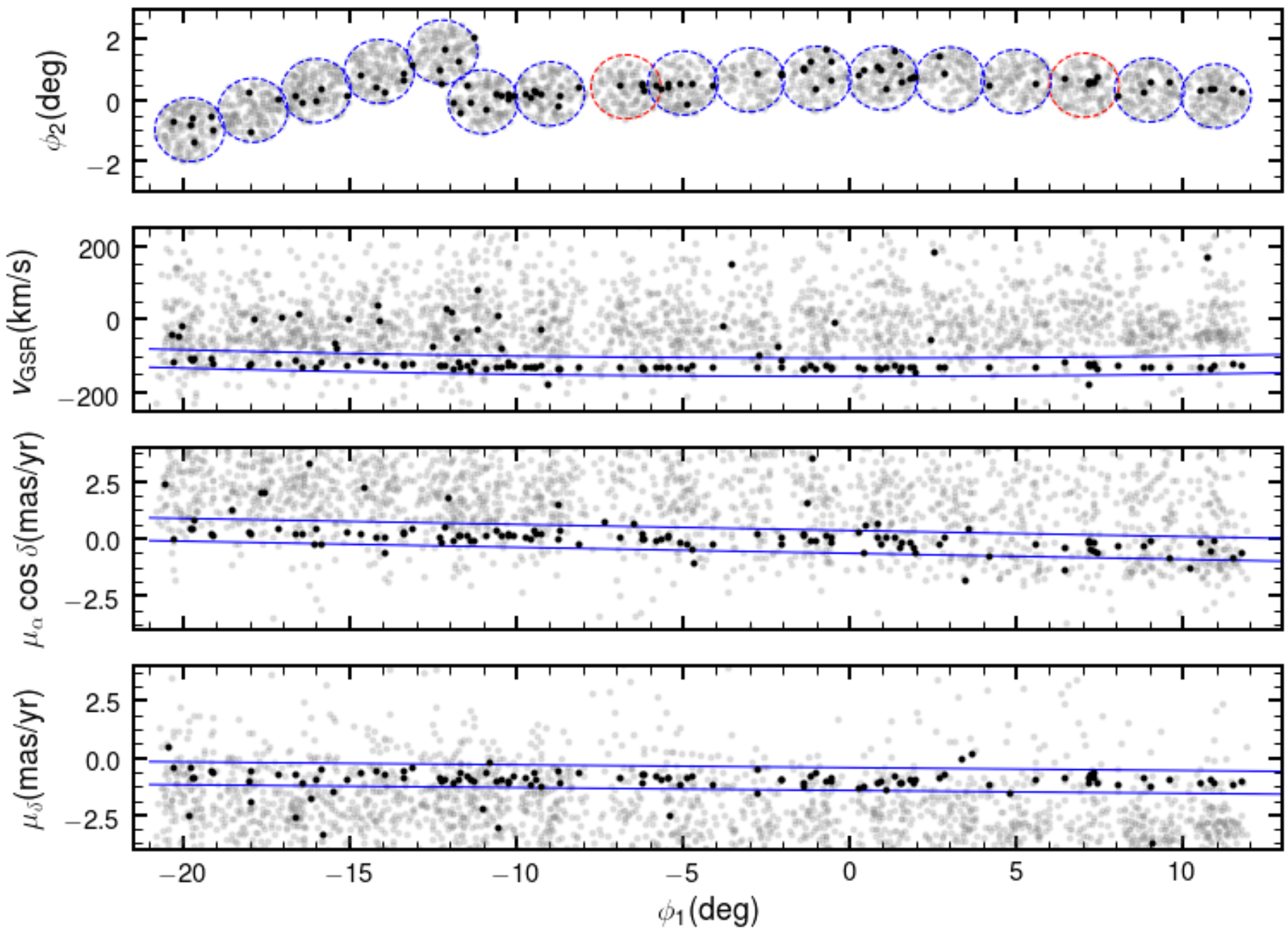

S^5 in prep

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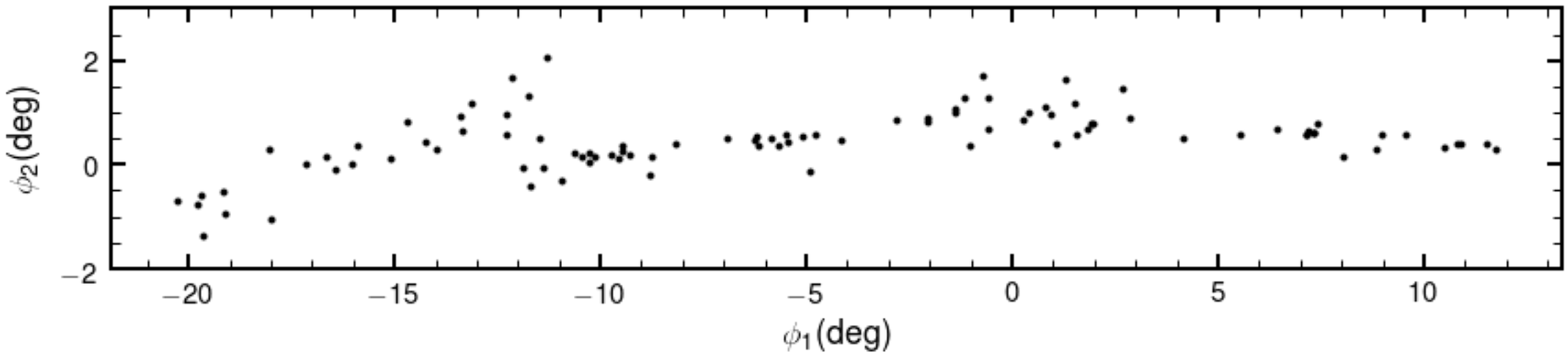

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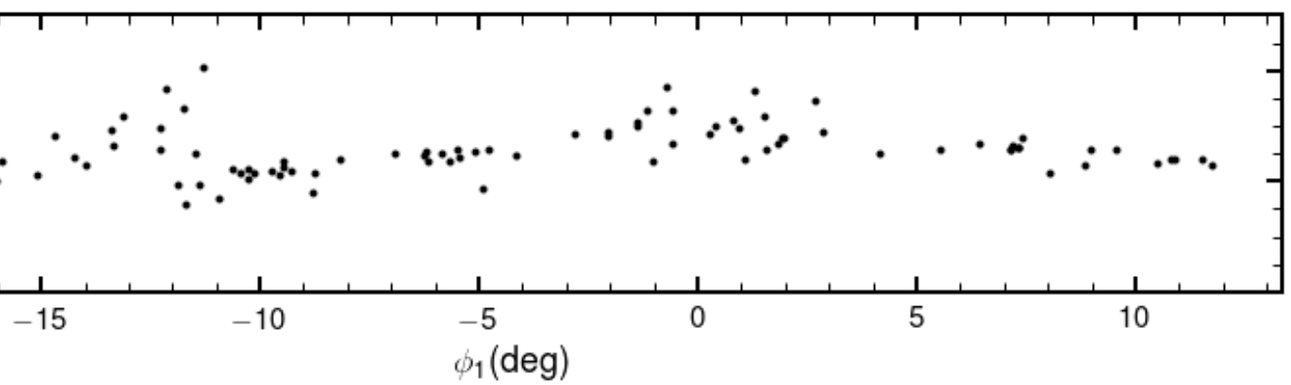
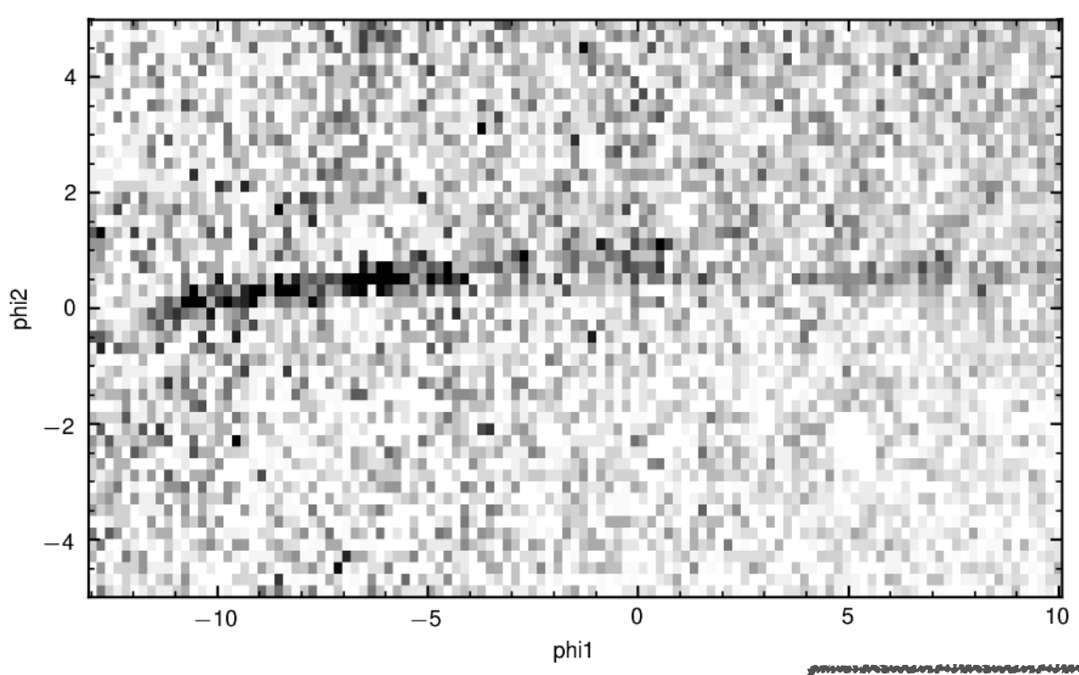
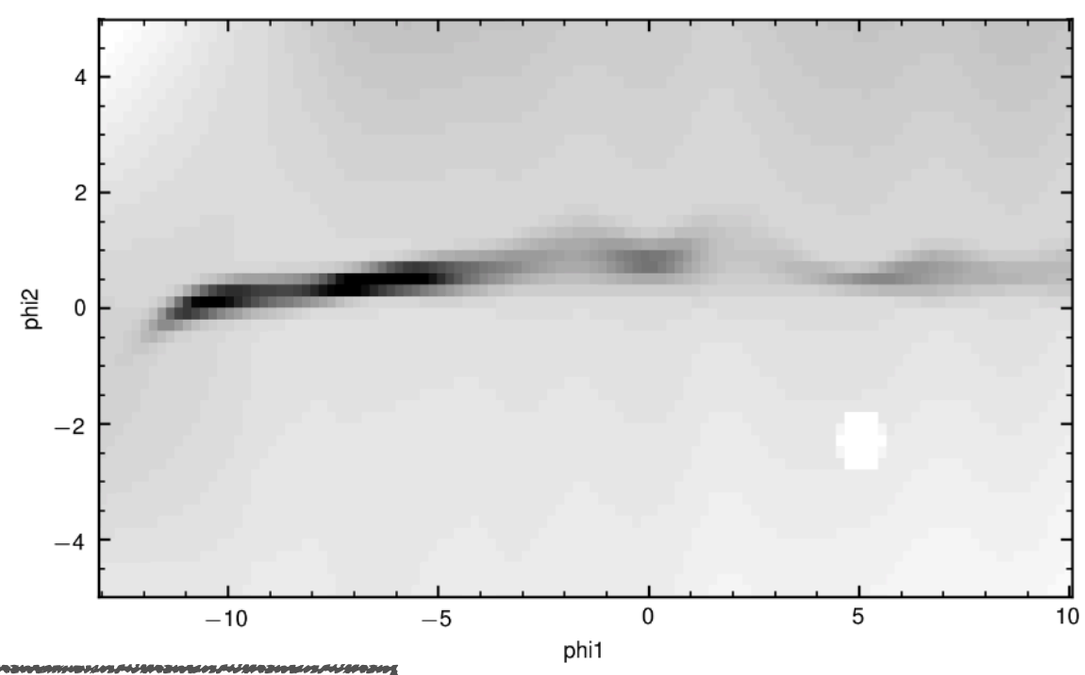






very preliminary!

arXiv: 1907.11725

MNRAS 000, 1–16 (2019) Preprint 30 July 2019 Compiled using MNRAS LATEX style file v3.0

The Great Escape: Discovery of a nearby 1700 km/s star ejected from the Milky Way by Sgr A*

Sergey E. Koposov,[1,2★] Douglas Boubert,[3] Ting S. Li,[4,5,6,7,8] Denis Erkal,[9] Gary S. Da Costa,[10] Daniel B. Zucker,[11,12] Alexander P. Ji,[4,6] Kyler Kuehn,[13,14] Geraint F. Lewis,[15] Dougal Mackey,[10,16] Jeffrey D. Simpson,[17] Nora Shipp,[18,8,7] Zhen Wan,[15] Vasily Belokurov,[2] Joss Bland-Hawthorn,[15,16] Sarah L. Martell,[17,16] Thomas Nordlander,[10,16] Andrew B. Pace,[19] Gayandhi M. De Silva,[14,16] and Mei-Yu Wang[1]

(S^5 collaboration)

s5collab.github.io

Google

s5-hvs1

ScienceAlert

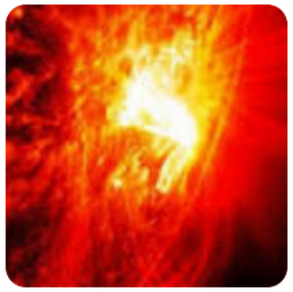
Bizarre Star Found Hurtling Out of Our Galaxy Centre Is Fastest of Its Kind Ever Seen

S5-HVS1 is pretty interesting. It's a main-sequence, or "living" star that is still undergoing hydrogen fusion in its core; in fact, it's relatively young, ...

Fox News

Strange star found zooming out of our galaxy is fastest of its kind ever seen

((SARAO)). According to ScienceAlert, the star, which was named S5-HVS1, is a "living" star that's still undergoing hydrogen fusion at its core.

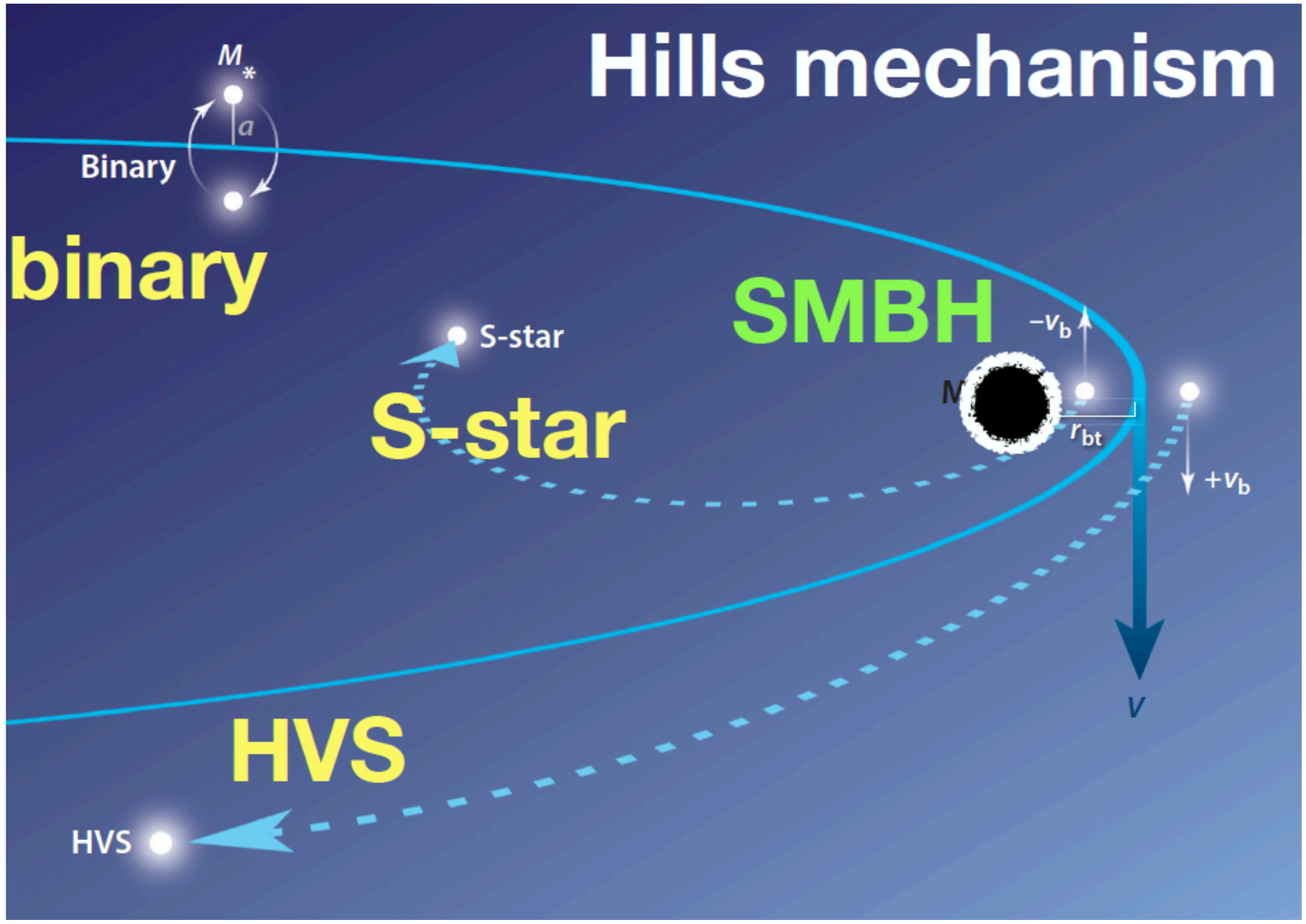


NS New Scientist

We spotted a star moving so fast it will enter intergalactic space

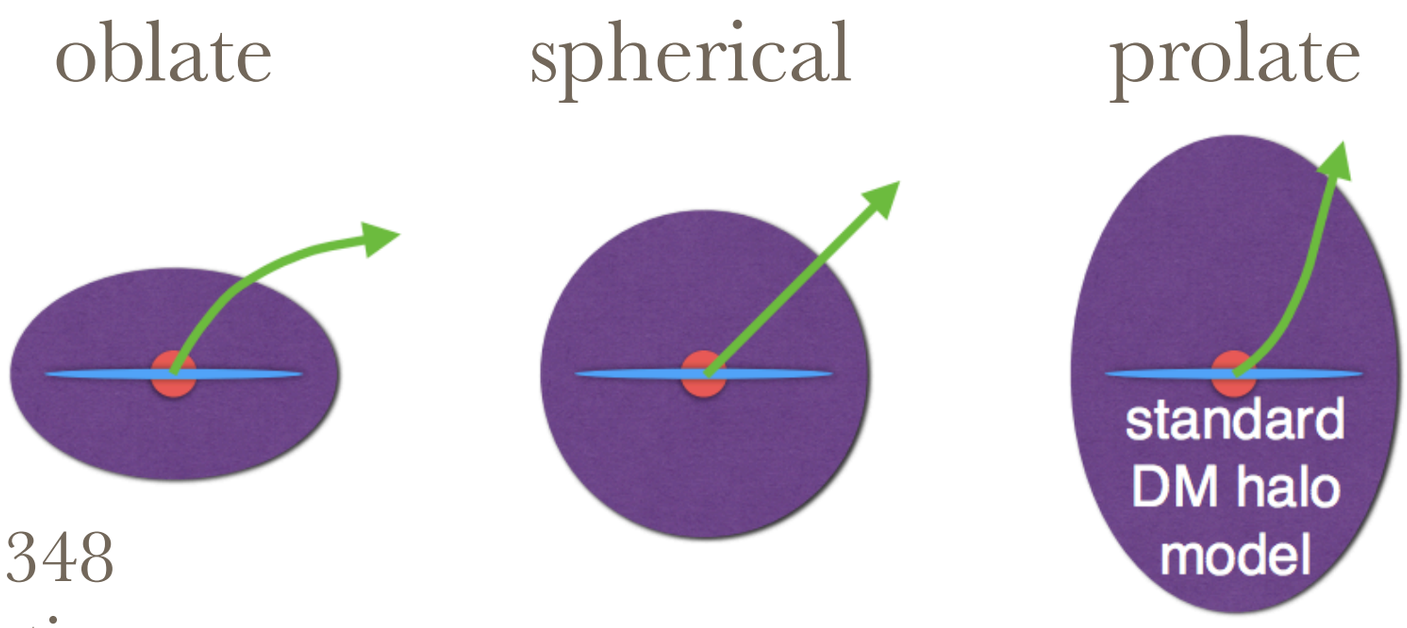
This 'hyper-velocity star' has been named S5-HVS1. It is travelling through the galaxy at a blistering speed of more than 1700 kilometres per ...

Hyper Velocity Star (HVS)



Hills (1988) Nature

DM Application 1



arXiv: 1707.01348
Theia Collaboration

HVS orbit —> DM halo shape (c.f. Gnedin, O.+2005)

DM Application 2

As an example, a $10^8\,M_\odot$ point-mass perturbing a hyper-velocity star travelling at 2000 $\mathrm{km\,s^{-1}}$ with an impact parameter of 0.5 kpc will produce a velocity offset of $\sim 1\,\mathrm{km\,s^{-1}}$ (Binney & Tremaine 2011) perpendicular to the trajectory of the HVS, or equivalently an offset of ~ a few parsecs in the trajectory. While these offsets

Koposov+2019
arXiv: 1907.11725

Subhalo Mass Function from HVS?

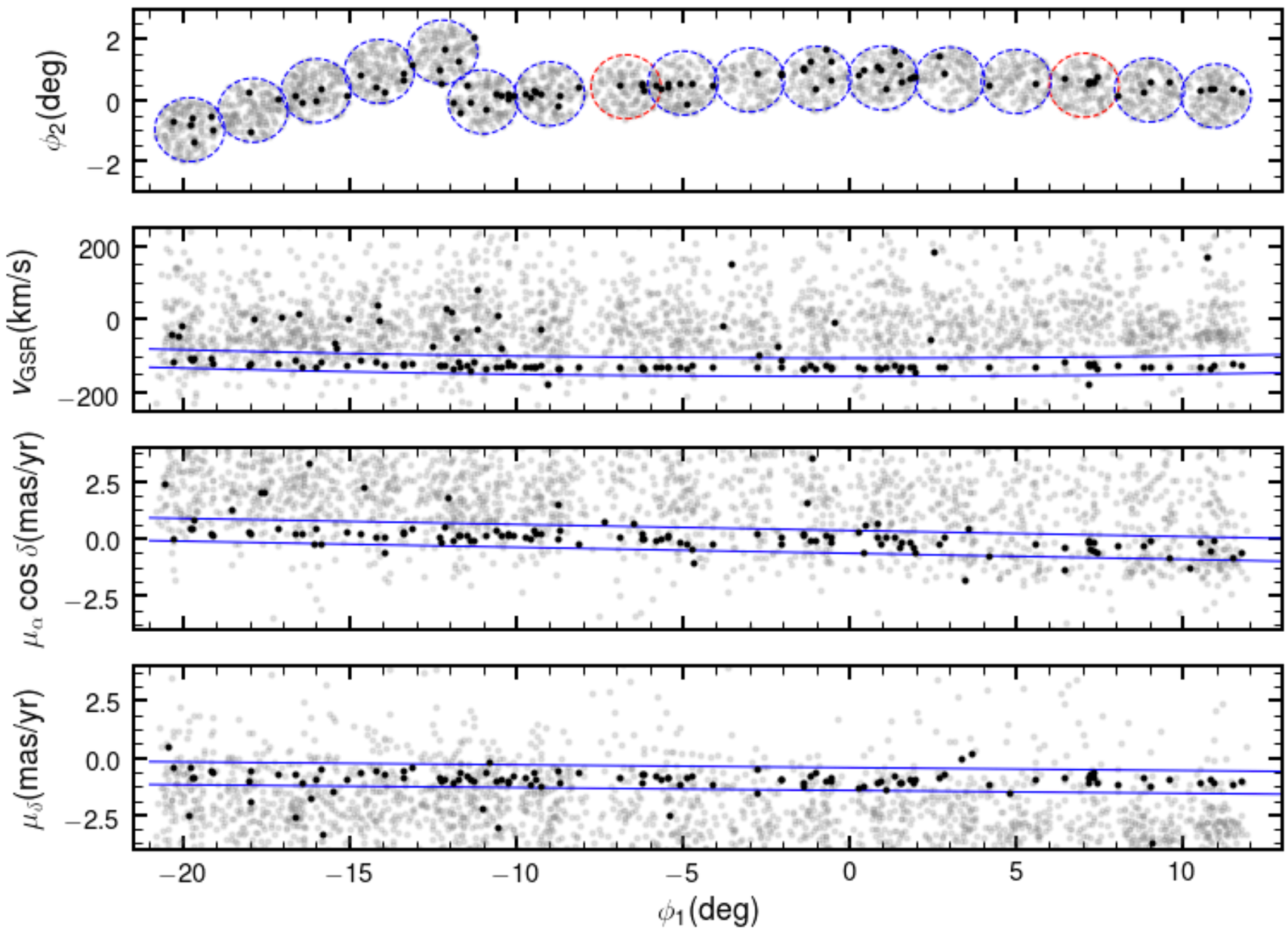
Summary

- arXiv: 1903.03155 (TSL, Kaplinghat+ 2019)
  a science white paper summarize DM science with multi-object wide field spectroscopy

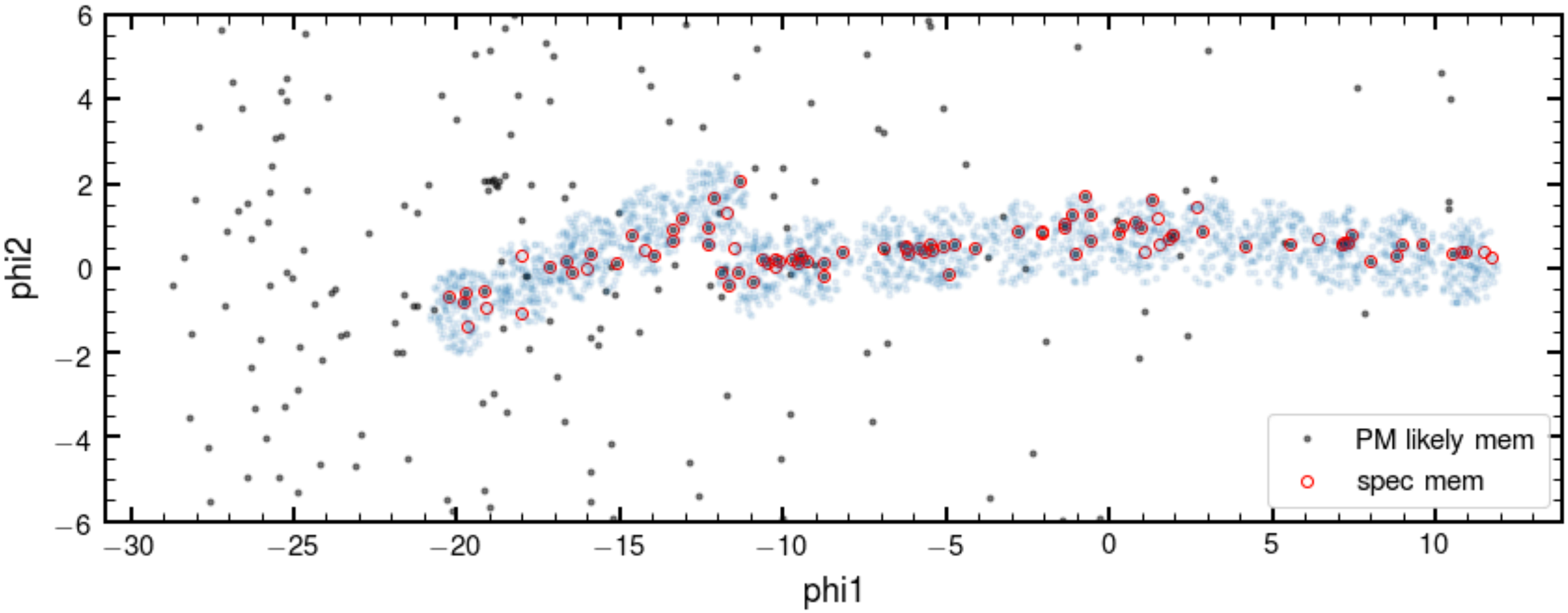
- arXiv: 1907.09481 (TSL, Koposov+ 2019)
  an ongoing spectroscopic survey to follow-up newly discovered streams. stay tuned on the new gaps and kinks in the streams

- arXiv: 1907.11725 (Koposov, Boubert, TSL + 2019)
  hyper-velocity stars from Sgr A* will be useful for DM study?

Southern Stellar Stream Spectroscopic Survey (S^5)



S^5 in prep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4
2
0
−2
−4
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phi2
−30
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−20
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−10
−5
0
5
10
phi1
PM likely mem
spec mem