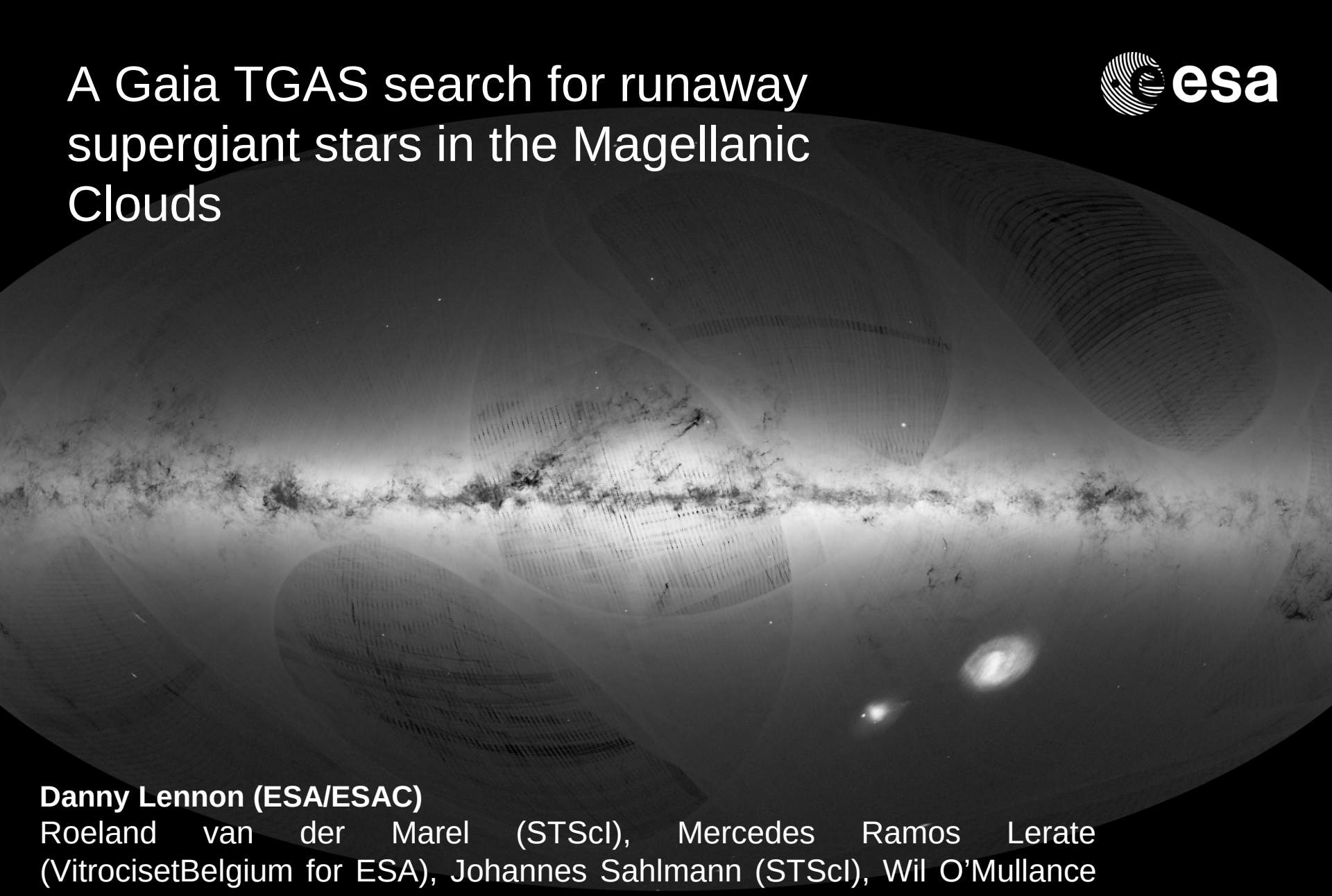
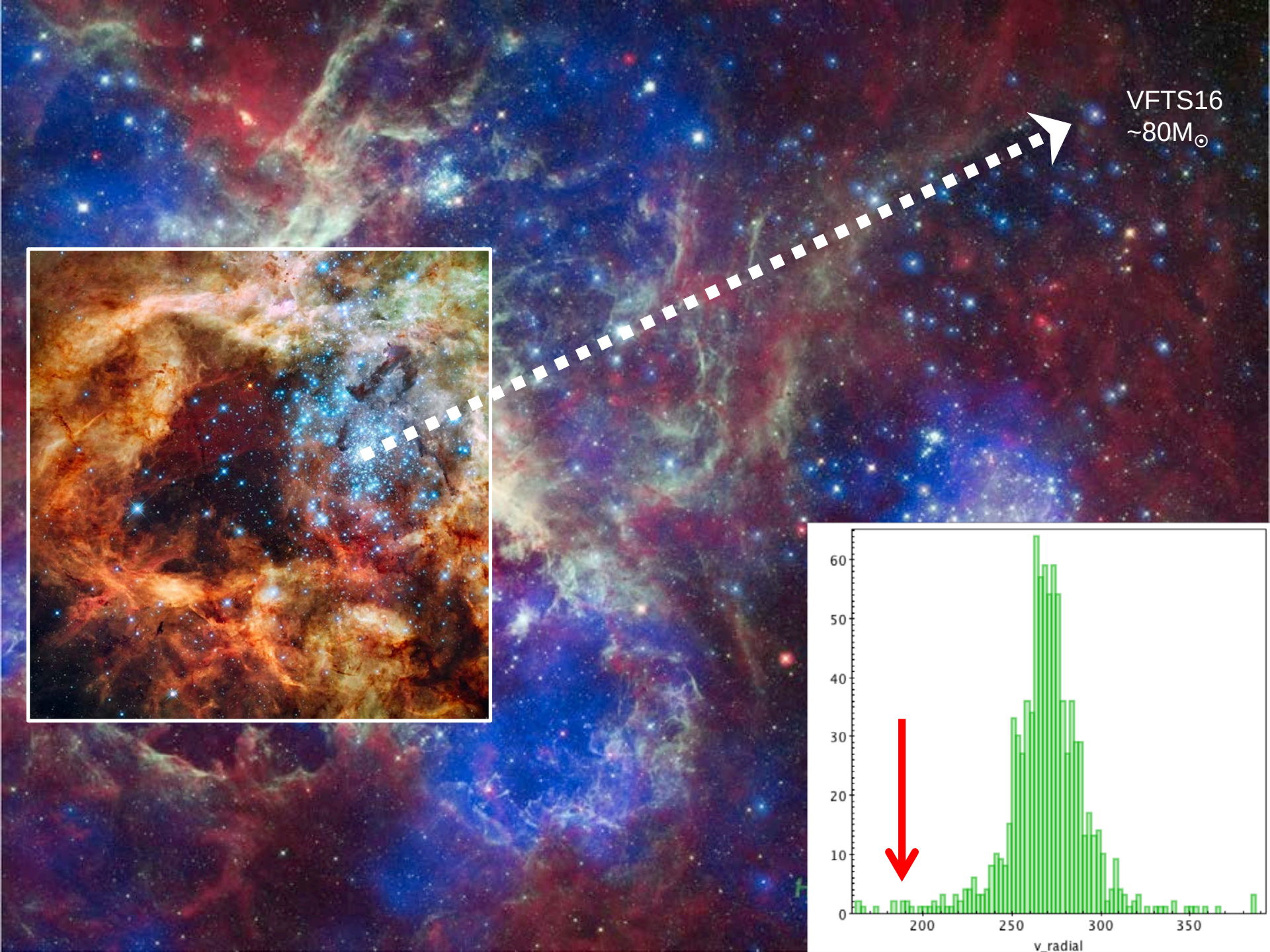
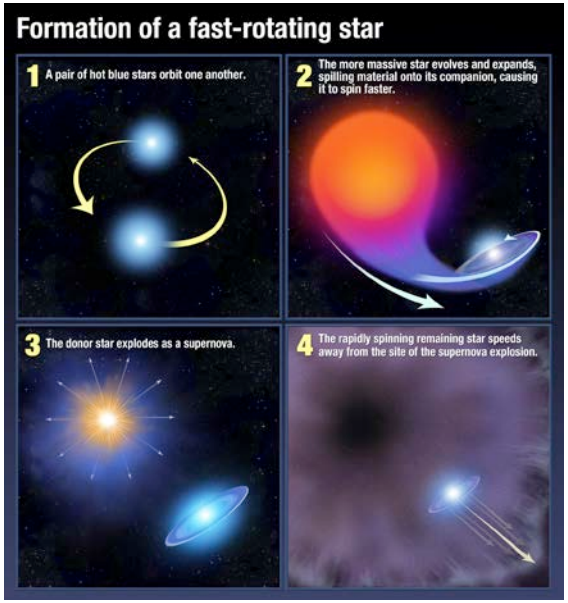
A Gaia TGAS search for runaway supergiant stars in the Magellanic Clouds



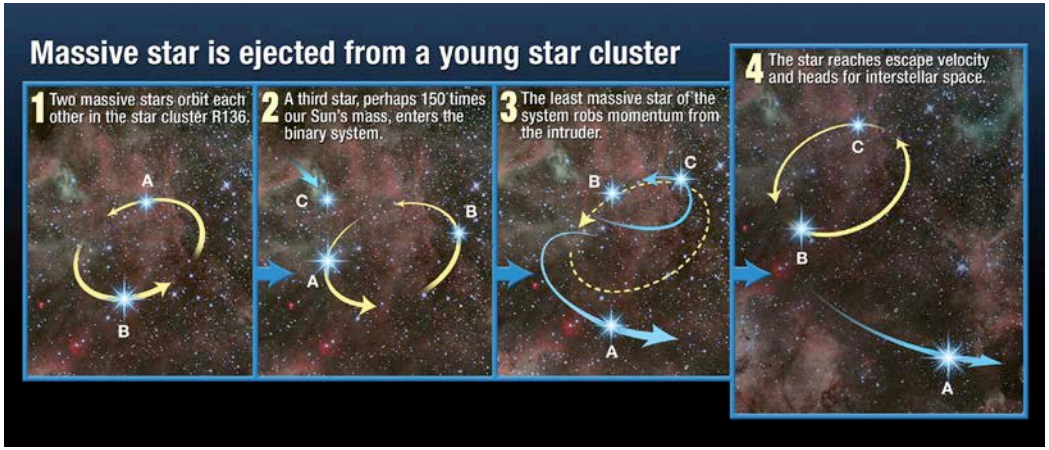
Danny Lennon (ESA/ESAC)
Roeland van der Marel (STScI), Mercedes Ramos Lerate (VitrocisetBelgium for ESA), Johannes Sahlmann (STScI), Wil O'Mullance (LSST)


VFTS16
~80M⊙
60
50
40
30
20
10
0
200
250
300
350
v_radial

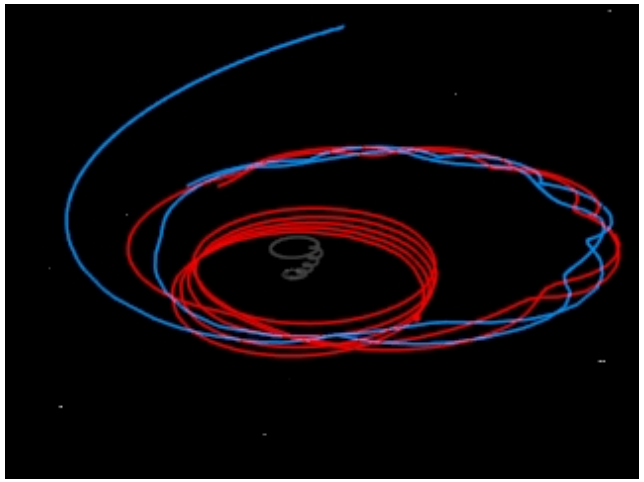
Potential Explanations for Isolated Massive Stars: Walkaways, Runaways, Hyper-runaways, Hypervelocity stars



Ejection from binary system when star explodes as a SN



Dynamical ejection from massive dense cluster

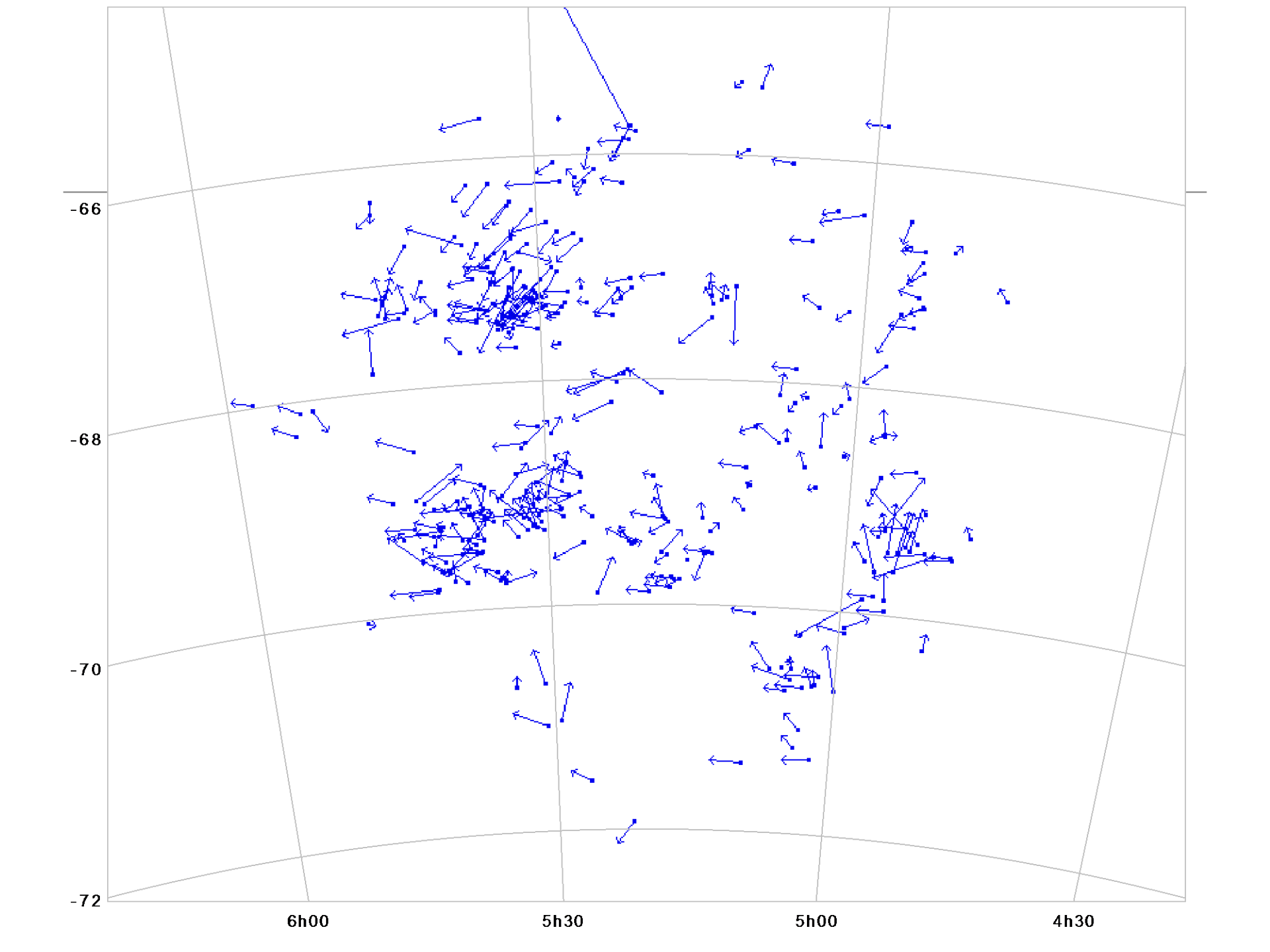


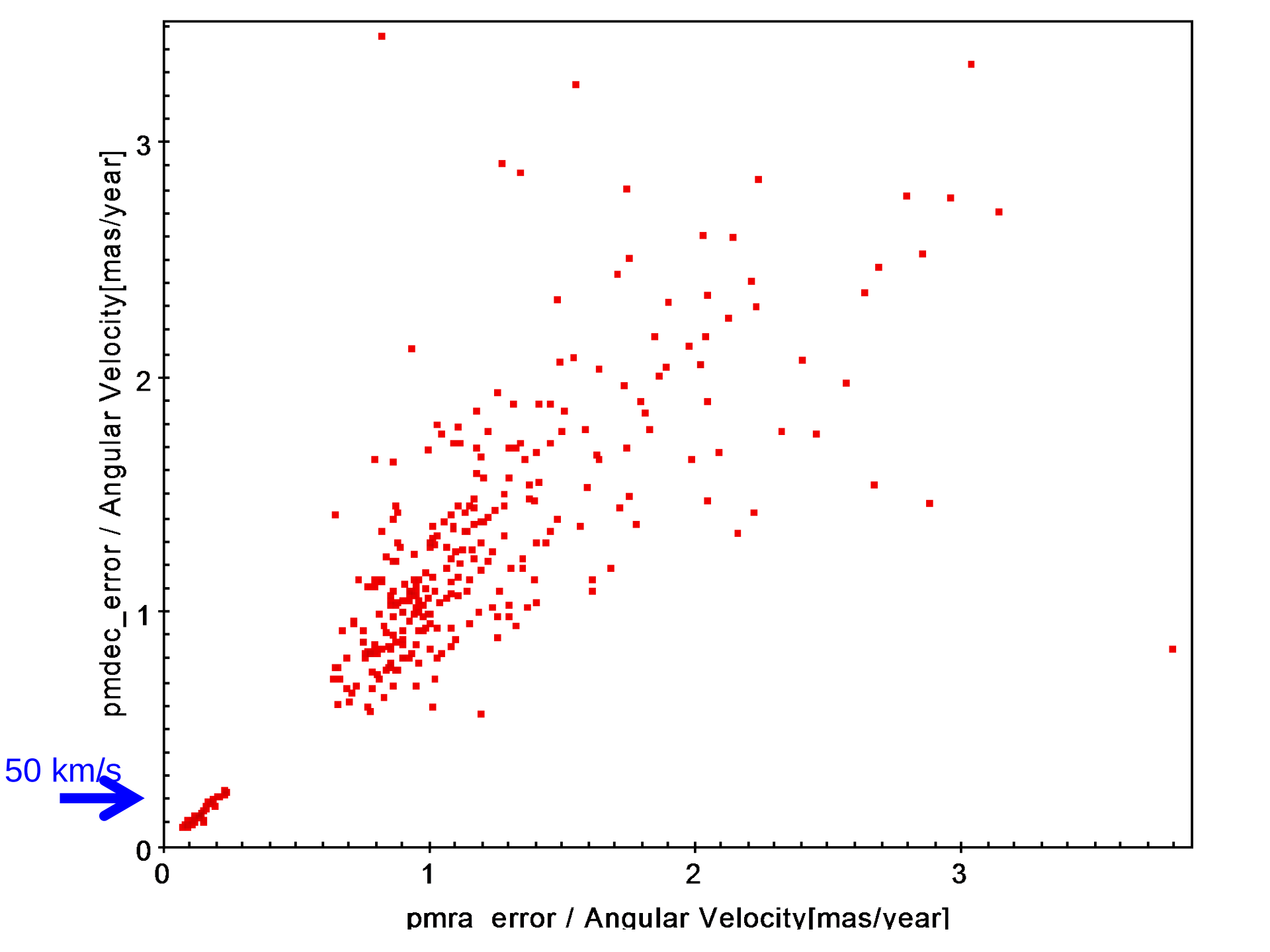
Via dynamical interaction with a massive black hole

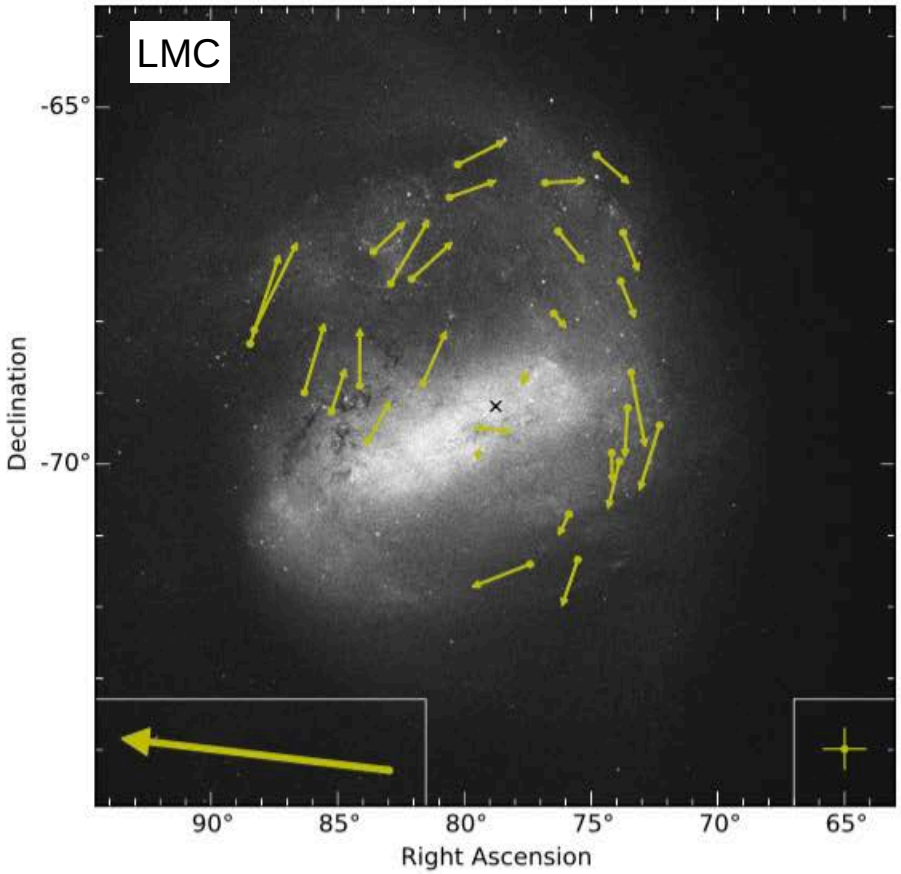
Massive isolated stars can form in isolation or in low mass clusters

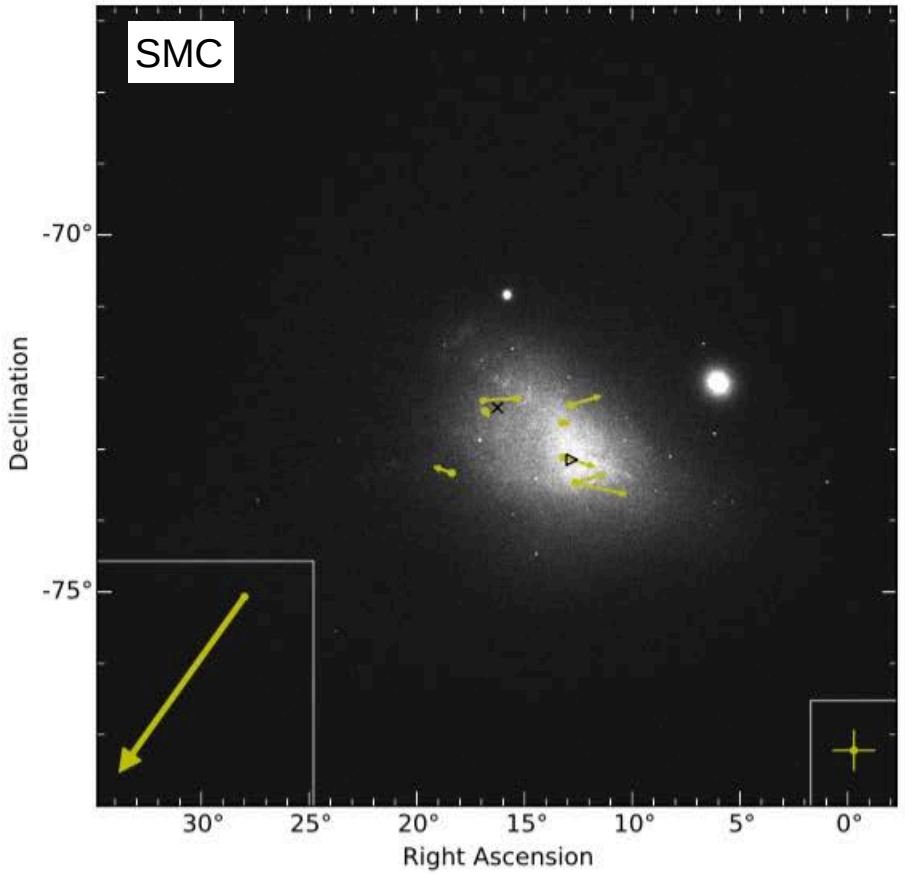
The Tycho-Gaia Astrometric Solution - TGAS

- Gaia DR1: astrometry for ~1 billion stars (only 1.5 years worth of data available).
- Hipparcos: parallaxes and proper motions for ~100,000 stars in the Hipparcos catalog and positions for ~2.5 million stars in the TYCHO catalog
- The TGAS catalog uses the Hipparcos/Tycho catalogs and Gaia DR1 to calculate parallax and proper motions for the Tycho/Hipparcos stars.
- Epoch difference ~23.5 years


-66
-68
-70
-72
6h00
5h30
5h00
4h30


pmdec_error / Angular Velocity[mas/year]
pmra_error / Angular Velocity[mas/year]
0
1
2
3
50 km/s

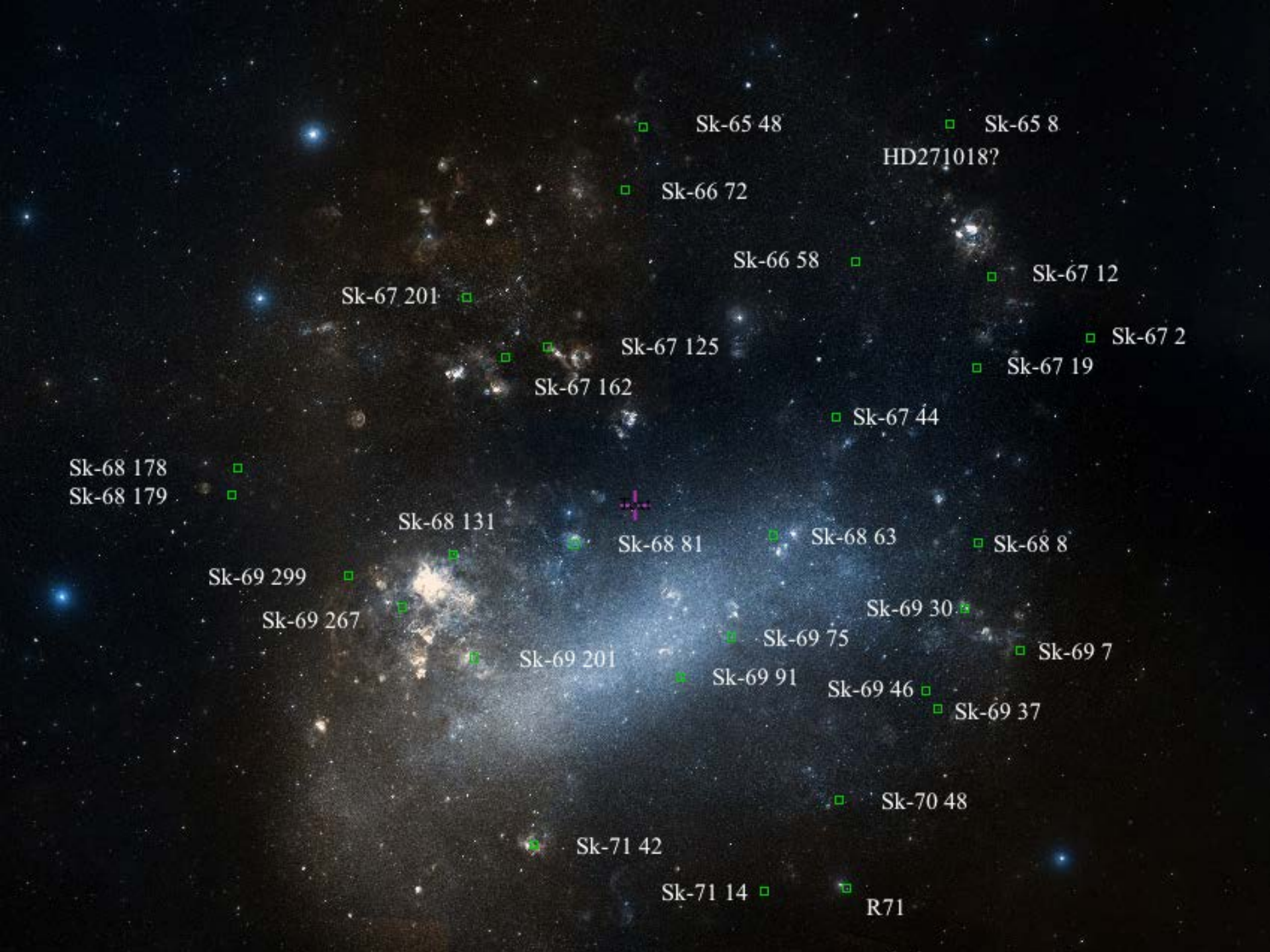


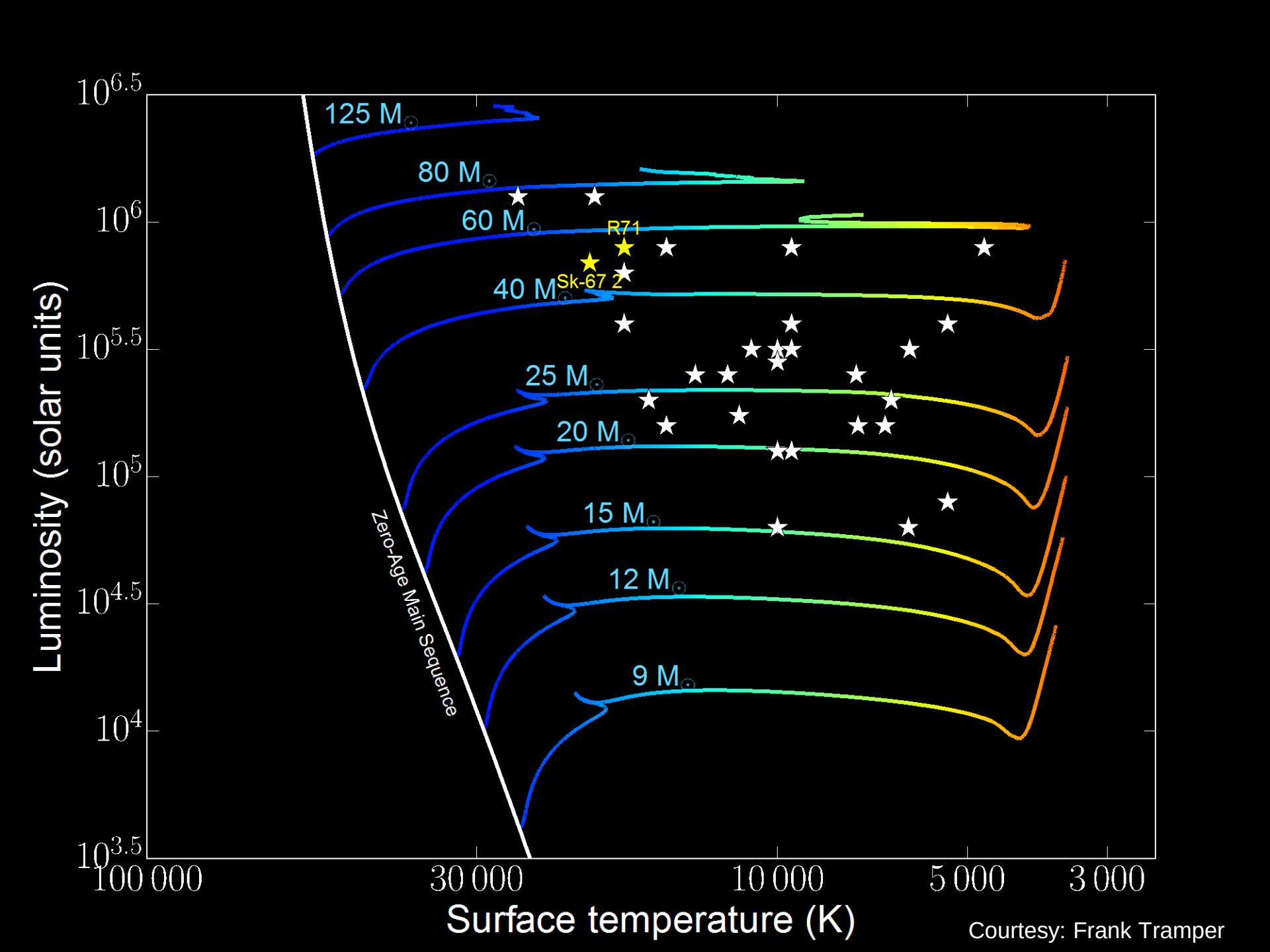


Van der Marel & Sahlmann, 2016, ApJ, 832, L23

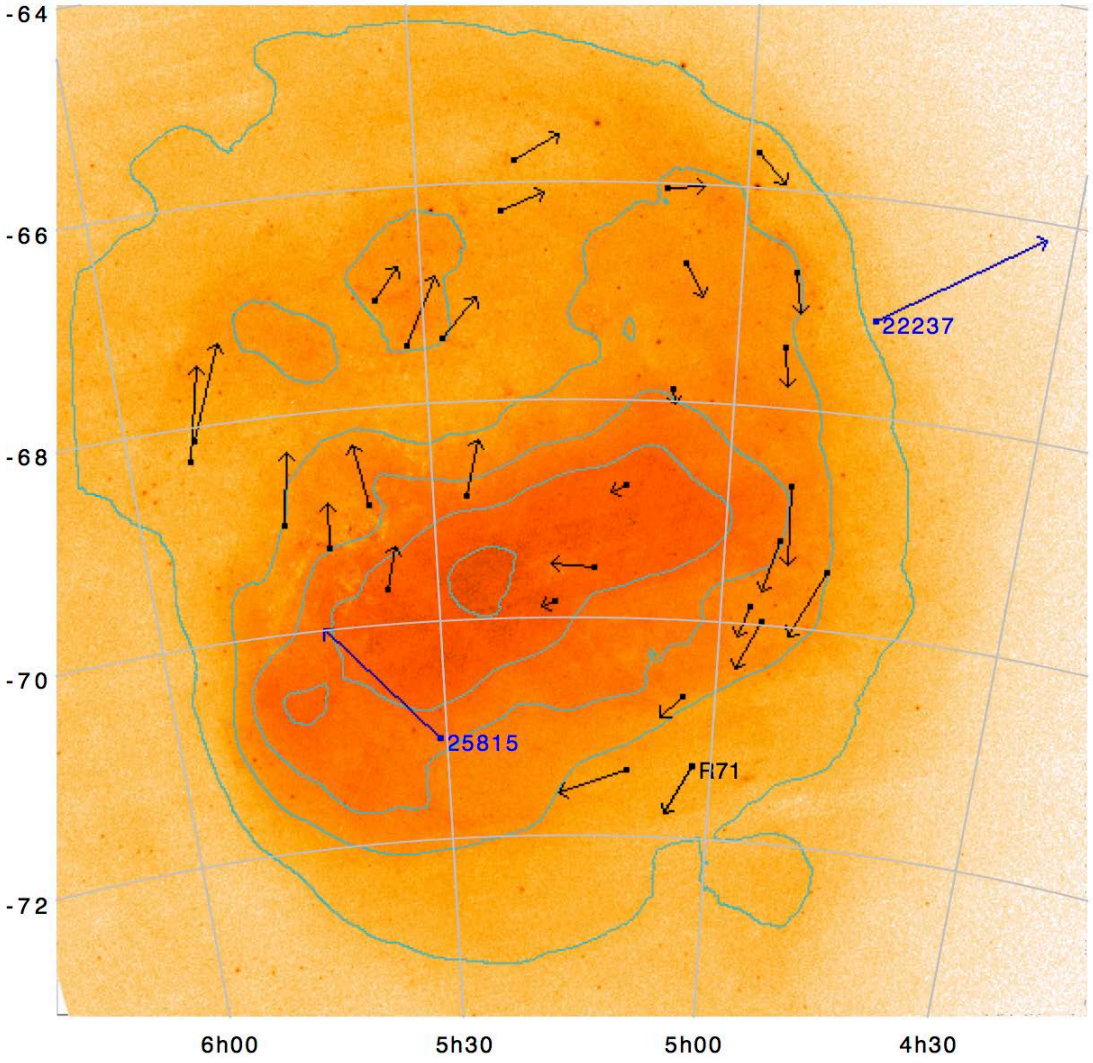
The fact that we can see the LMC rotation tells us that:

- Uncertainties in the proper motions are (relatively) small
- There is little evidence for ‘fast’ runaways (v > ~50 km/s)


Sk-65 48
Sk-65 8
HD271018?
Sk-66 72
Sk-66 58
Sk-67 12
Sk-67 201
Sk-67 2
Sk-67 125
Sk-67 19
Sk-67 162
Sk-67 44
Sk-68 178
Sk-68 179
Sk-68 131
Sk-68 81
Sk-68 63
Sk-68 8
Sk-69 299
Sk-69 30
Sk-69 267
Sk-69 75
Sk-69 7
Sk-69 201
Sk-69 91
Sk-69 46
Sk-69 37
Sk-70 48
Sk-71 42
Sk-71 14
R71


$10^{6.5}$
10^{6}
$10^{5.5}$
10^{5}
$10^{4.5}$
10^{4}
$10^{3.5}$
Luminosity (solar units)
125 M⊙
80 M⊙
60 M⊙
40 M⊙
25 M⊙
20 M⊙
15 M⊙
12 M⊙
9 M⊙
R71
Sk-67 2
Zero-Age Main Sequence
100 000
30 000
10 000
5 000
3 000
Surface temperature (K)
Courtesy: Frank Tramper

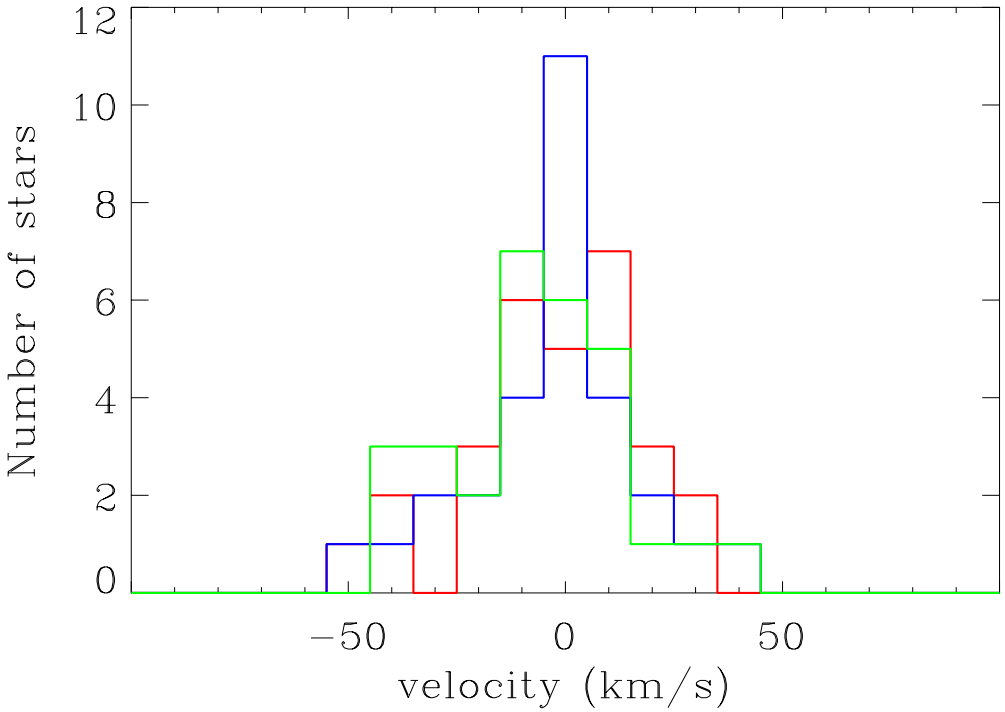
Estimating relative velocities (proper motions) of supergiants in the LMC



- Assume LMC distance ~55 kpc
- Using 3D dynamical model of vdMS calculate expected 3D motion of each star
- Subtract observed 3D motion (including radial velocities)
- Two Hipparcos stars, excluded from vdMS sample, are also considered (blue arrows). They are clear outliers!

Lennon et al (2017), A&A,603,75

Characterizing the LMC sample



	RA	DEC	LOS
Mean	2.8	1.5	-0.9
σ	18.9	18.8	20.3

- Excluding the two outliers (HIP22237 and HIP25815) there is no evidence for fast runaways (all velocities < 50 km/s)
- Velocity dispersions agree with radial velocity studies and imply errors smaller than formal values (typically ~37 km/s)

R 71 (=HIP 23428): A Luminous Blue Variable in the LMC

- LBVs are irregular variables thought to be transition objects between OB and WR stars
- R71 is isolated: closest known O star is 450 pc distant
- With peculiar velocities of (v_W, v_N, v_{LOS})=(33.7, -16.8, -33.5) this star is a mild outlier
- 450 pc would require lifetime of 6-9 Myr that would imply an initial mass below 30 $M_\odot$ - above current mass estimates in the range 40-60 $M_\odot$
- R 71 could therefore be the best candidate a merger

AzV 415 (=HIP 5267): A Luminous Blue Variable in the SMC

- AzV 415 is one of only two known LBVs in the SMC
- The closest known O star is only 70 pc distant
- With peculiar velocities (km/s) of (v_W, v_N, v_{LOS})=(7, 1, -18) this star is fully consistent with the local rest frame
- A mass of ~30 $M_\odot$ implies a lifetime of ~5 Myr requiring a velocity of only ~14 km/s to cover 70 pc
- AzV 415 is likely a walkaway star

Sk-67° 2 (=HIP 22237): A candidate hypervelocity star (or hyper-runaway) star in the LMC

- Sk-67 2 is a BC 1.5 Ia+ hypergiant, mildly O-rich, with a strong mid-IR excess
- It is relatively isolated on the periphery of the LMC
- With peculiar velocities of (v_W, v_N, v_{LOS})=(251, 257, 43) this star is a strong outlier

Potential explanations include candidate:

- Hypervelocity star ejected from SMBH at LMC centre
- Hyper-runaway star ejected from a very tight massive binary

Summary

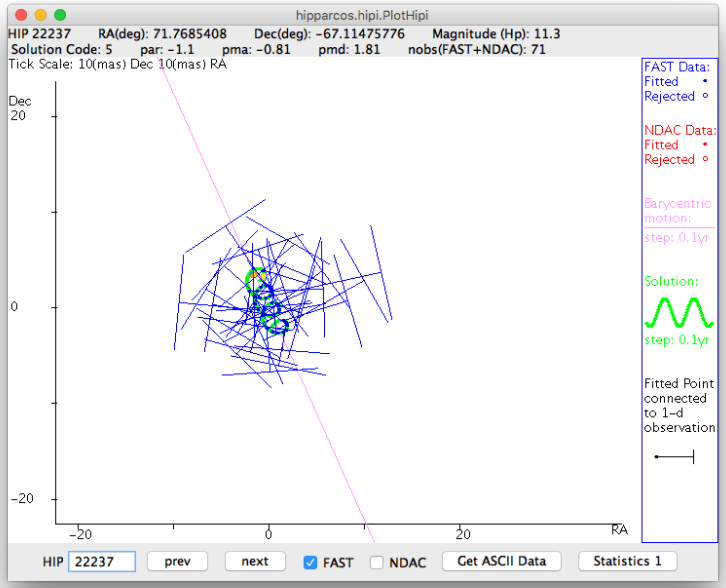
- Most of the 31 bright supergiants in the LMC have dynamics consistent with the velocity dispersion of the massive stars – mostly walkaways or in situ formation

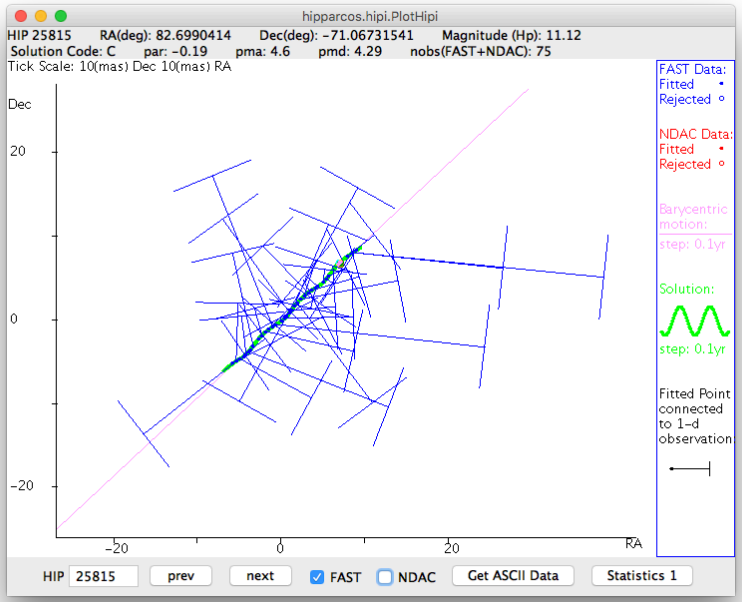
Sk-67°2 is a candidate hypervelocity or hyper-runaway star

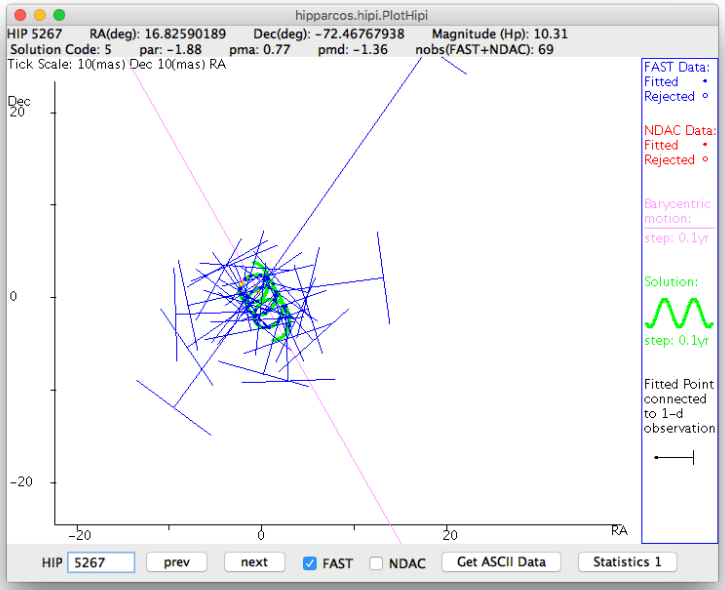
The LMC LBV R71 is a potential merger product or rejuvenated star

The SMC LBV AzV 415 is not a runaway

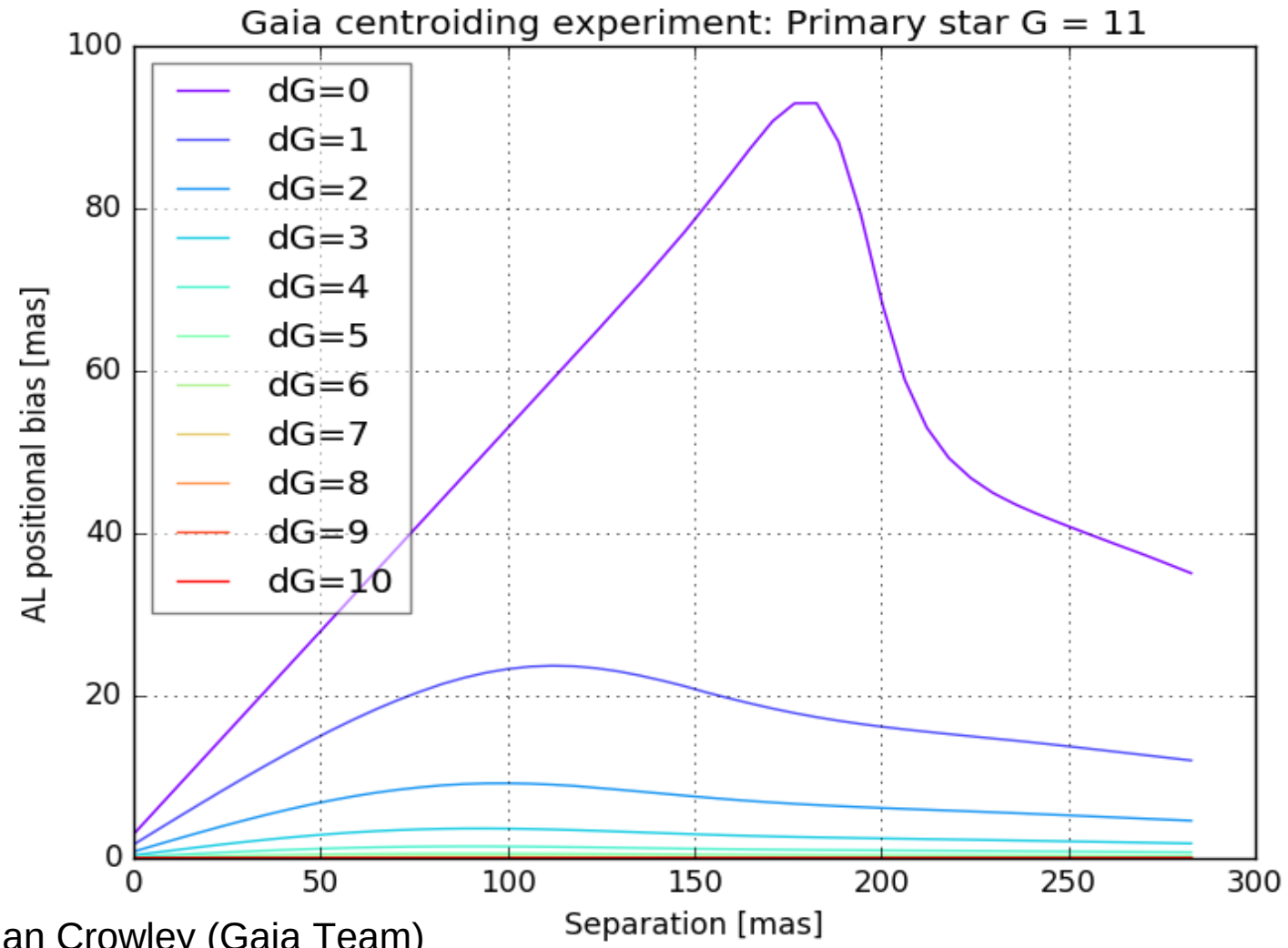
Backup slides


hipparcos.hipi.PlotHipi
HIP 22237 RA(deg): 71.7685408 Dec(deg): -67.11475776 Magnitude (Hp): 11.3
Solution Code: 5 par: -1.1 pma: -0.81 pmd: 1.81 nobs(FAST+NDAC): 71
Tick Scale: 10(mas) Dec 10(mas) RA
Dec
20
0
-20
-20
0
20
RA
FAST Data:
Fitted
Rejected
NDAC Data:
Fitted
Rejected
Barycentric motion:
step: 0.1yr
Solution:
step: 0.1yr
Fitted Point connected to 1-d observation
HIP 22237
prev
next
FAST
NDAC
Get ASCII Data
Statistics 1


hipparcos.hipi.PlotHipi
HIP 25815 RA(deg): 82.6990414 Dec(deg): -71.06731541 Magnitude (Hp): 11.12
Solution Code: C par: -0.19 pma: 4.6 pmd: 4.29 nobs(FAST+NDAC): 75
Tick Scale: 10(mas) Dec 10(mas) RA
Dec
20
0
-20
-20
0
20
RA
FAST Data:
Fitted
Rejected
NDAC Data:
Fitted
Rejected
Barycentric motion:
step: 0.1yr
Solution:
step: 0.1yr
Fitted Point connected to 1-d observation
HIP 25815
prev
next
FAST
NDAC
Get ASCII Data
Statistics 1


hipparcos.hipi.PlotHipi
HIP 5267 RA(deg): 16.82590189 Dec(deg): -72.46767938 Magnitude (Hp): 10.31
Solution Code: 5 par: -1.88 pma: 0.77 pmd: -1.36 nobs(FAST+NDAC): 69
Tick Scale: 10(mas) Dec 10(mas) RA
Dec
20
0
-20
-20
0
20
RA
FAST Data:
Fitted
Rejected
NDAC Data:
Fitted
Rejected
Barycentric motion:
step: 0.1yr
Solution:
step: 0.1yr
Fitted Point connected to 1-d observation
HIP 5267
prev
next
FAST
NDAC
Get ASCII Data
Statistics 1

Simulation of Gaia Positional error due to a companion star



Courtesy: Cian Crowley (Gaia Team)