


Dinamika galaksij



Tomaž Zwitter

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Razdalje v vesolju so ogromne

Kulturni večeri Bojana Štiha (1923-1986) v ljubljanskem hotelu Slon:

Zgodovinarji zgodovino proučujejo, politiki z njo manipulirajo, astronomi pa jo vidijo.

Svetloba naredi 300.000 km v sekundi, torej je odšla na pot

svetloba, ki posreduje ameriško internetno stran, pred stotinko sekunde,

svetloba Lune pred dobro sekundo,

svetloba Sonca pred 8 minutami,

svetloba najbližje zvezde pred 4 leti,

svetloba iz središča naše Galaksije pred 25.000 leti,

svetloba Galaksije v Andromedi pred 2,5 milijonoma let,

svetloba najbolj oddaljenih galaksij pred 13,2 milijardami let,

svetloba iz začetkov vesolja pred 13,7 milijarde let,

vendar je tudi naše Sonce staro 5 milijard let.

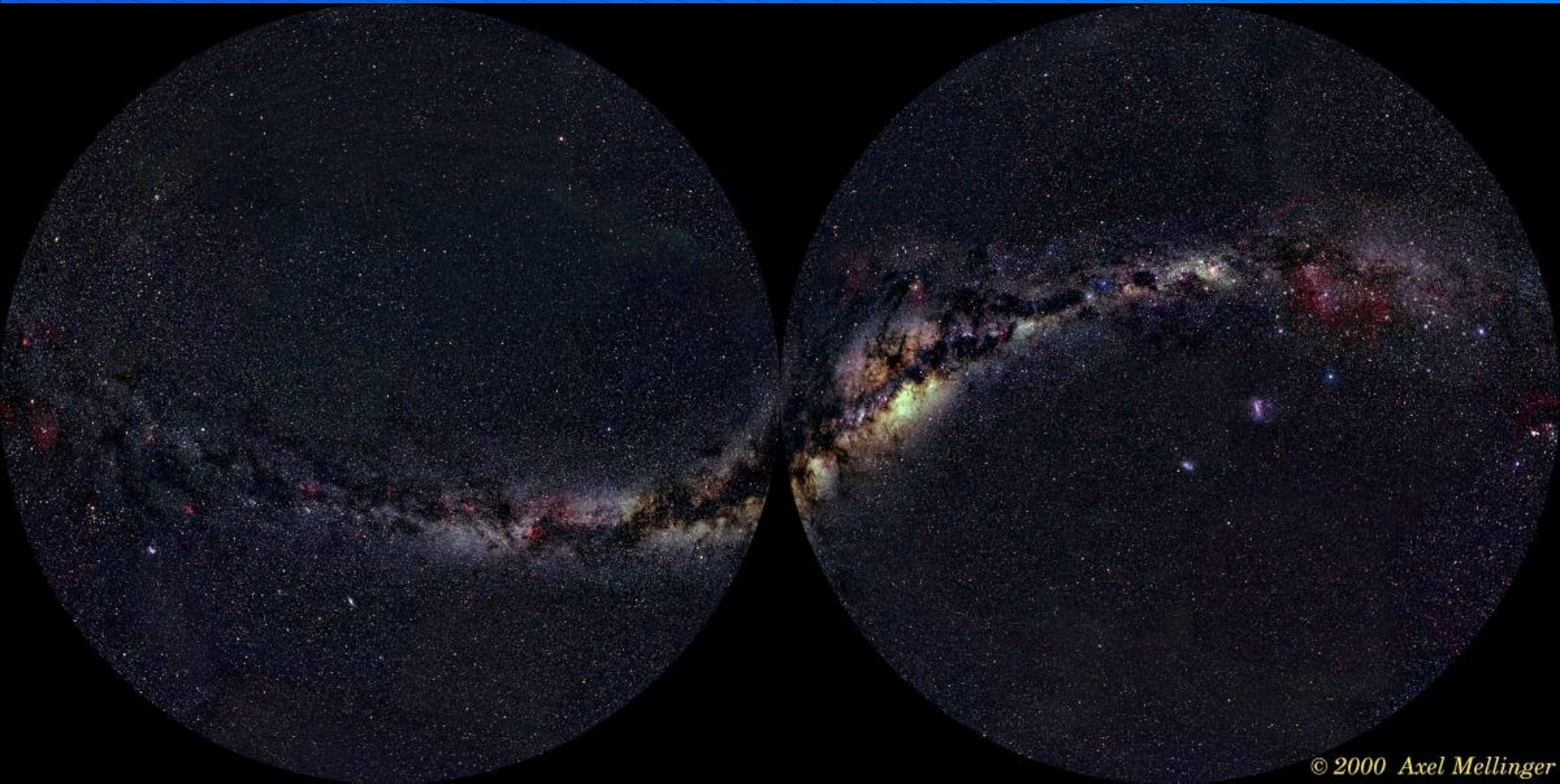
Zvezde



Zvezde

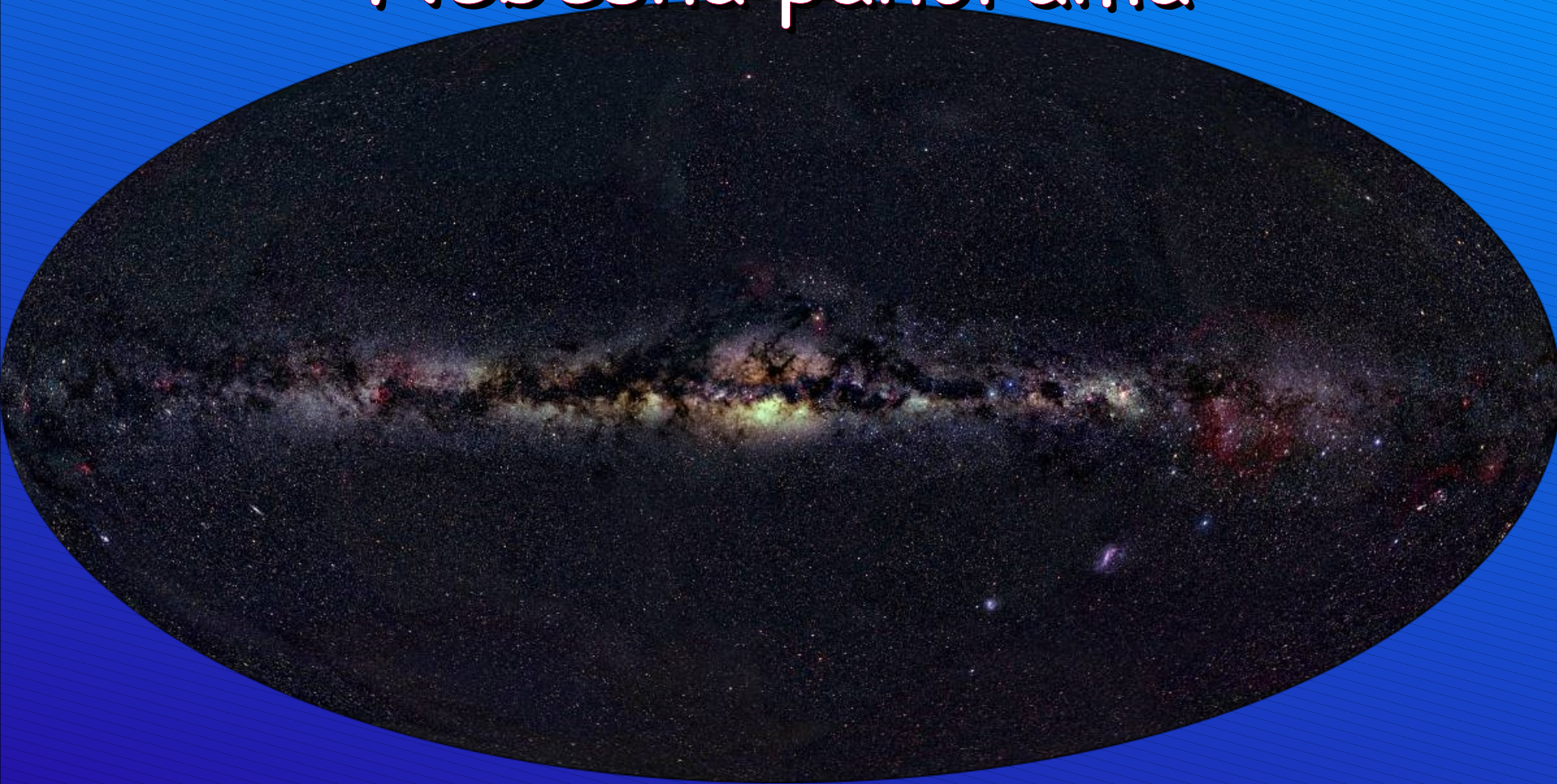


Nebesna panorama



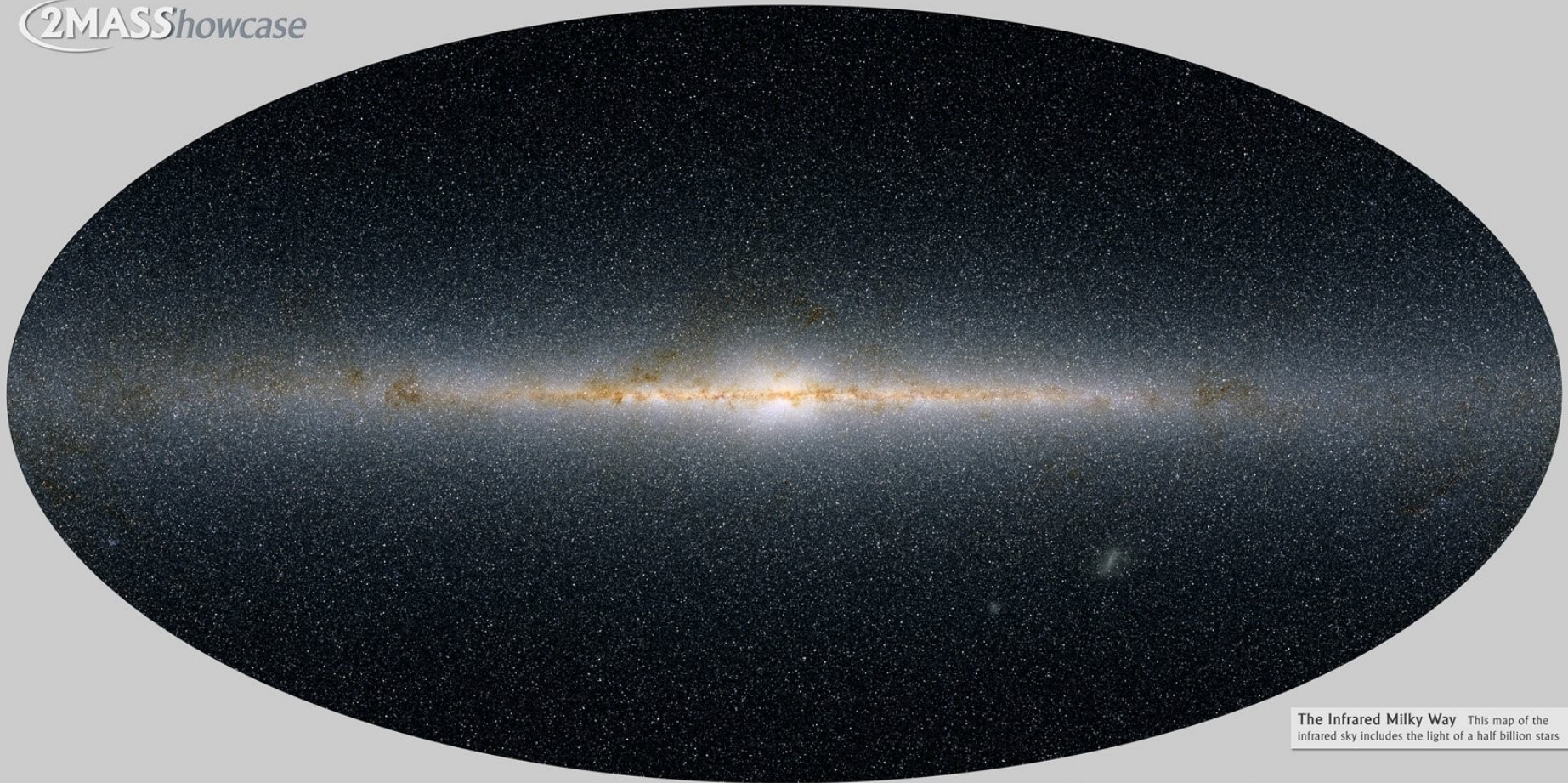
© 2000 Axel Mellinger

Nebesna panorama



Nebesna panorama v infrardečem

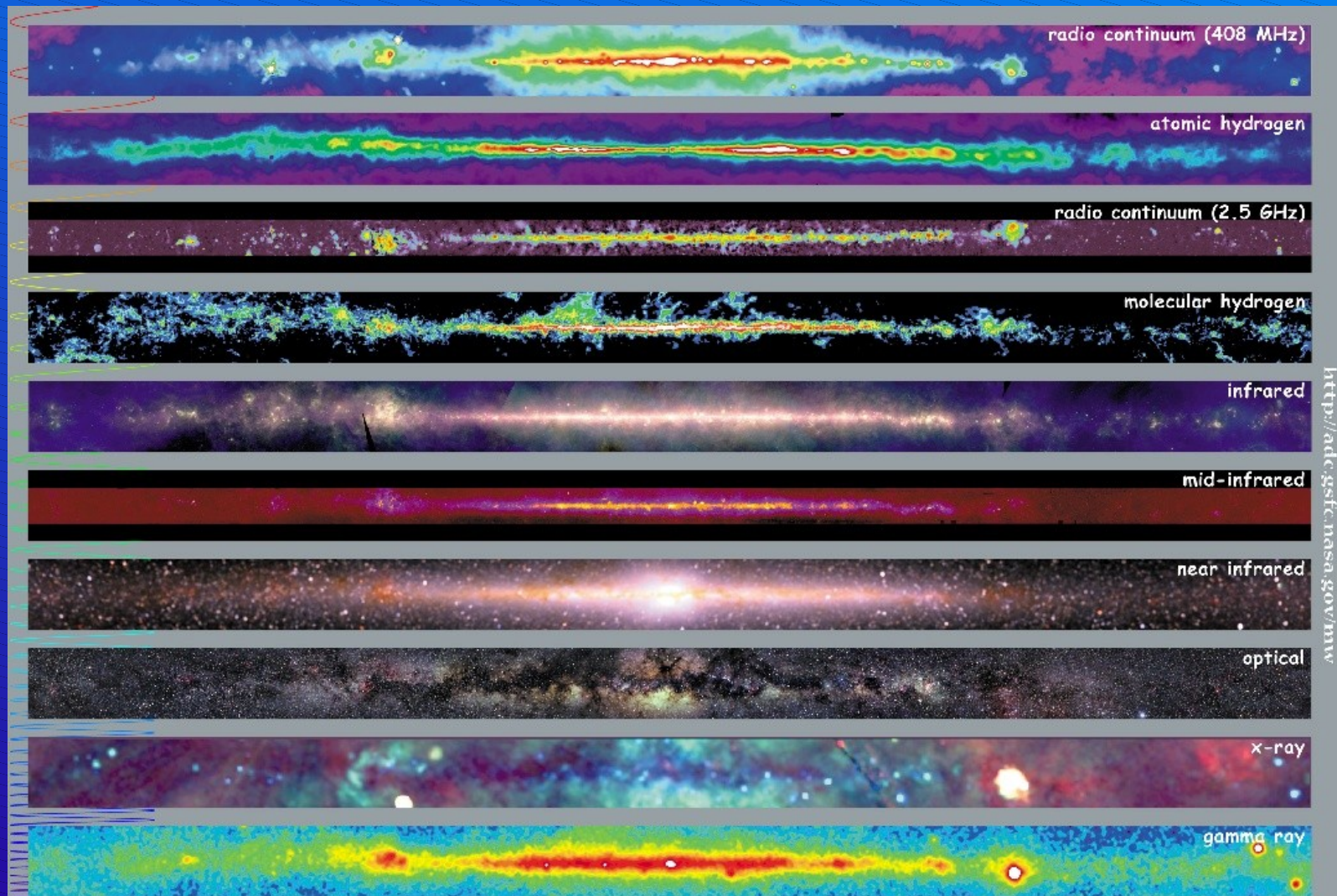
2MASS Showcase



The Infrared Milky Way This map of the infrared sky includes the light of a half billion stars

Two Micron All Sky Survey Image Mosaic: Infrared Processing and Analysis Center/Caltech & University of Massachusetts

Galaksija v različnih valovnih dolžinah

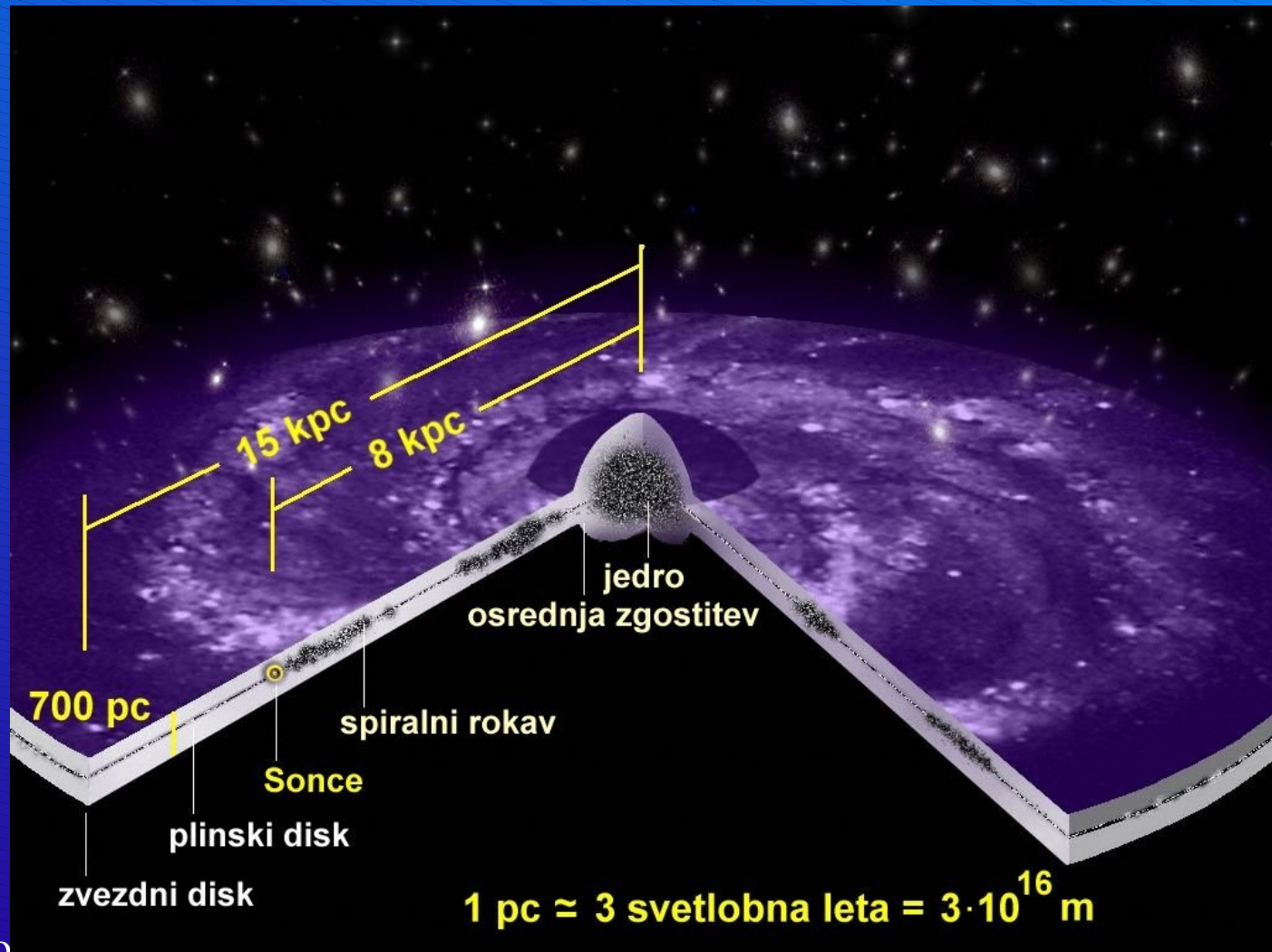


<http://adc.gsfc.nasa.gov/mw>



Multiwavelength Milky Way

Naša Galaksija: kako bi bila videti od zunaj?



Naša Galaksija: kako bi bila videti od zunaj?



MALIN/IAC/RCO

Figure 1 (continued) NGC 891. The edge-on view of NGC 891 reveals the extreme flatness of spiral-disk galaxies, which typically have an aspect ratio of about 1:30. The flying-saucer shape of a spiral galaxy such as the Milky Way and its distinct stellar populations can be explained by theoretical models of its formation and chemical evolution.



Figure 1. Milky Way look-alike galaxies NGC 1232 (above) and NGC 891 (below) offer a glimpse of how our galaxy would appear if viewed from a distance of several million light-years. The different colors evident in the face-on view of NGC 1232 indicate the existence of sep-

arate stellar populations that compose the central bulge (reddish yellow) and the spiral disk (blue). (NGC 1232 image courtesy of the European Southern Observatory.)

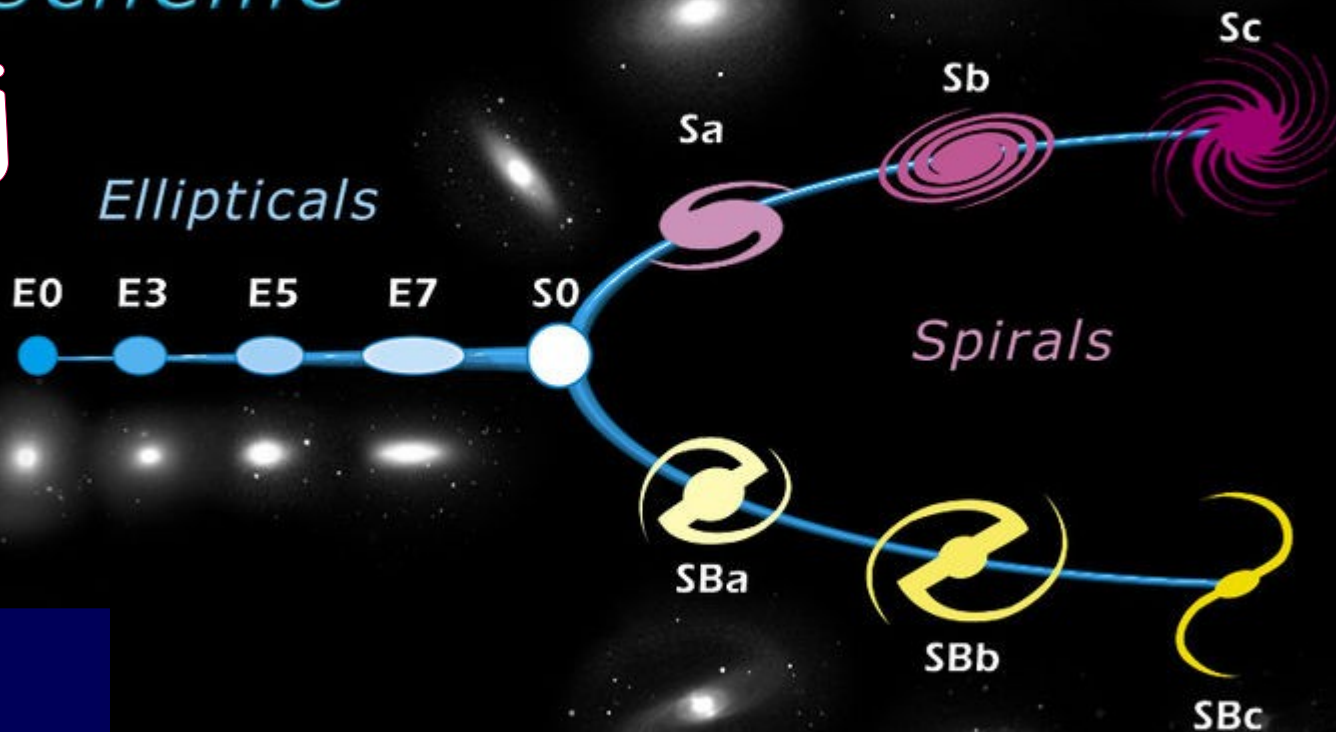
Tipi galaksij

- ♦ spiralne
- ♦ eliptične
- ♦ nepravilne



Tipi galaksij

Edwin Hubble's Classification Scheme



- ♦ spiralne
- ♦ eliptične
- ♦ nepravilne



Jate
galaksij

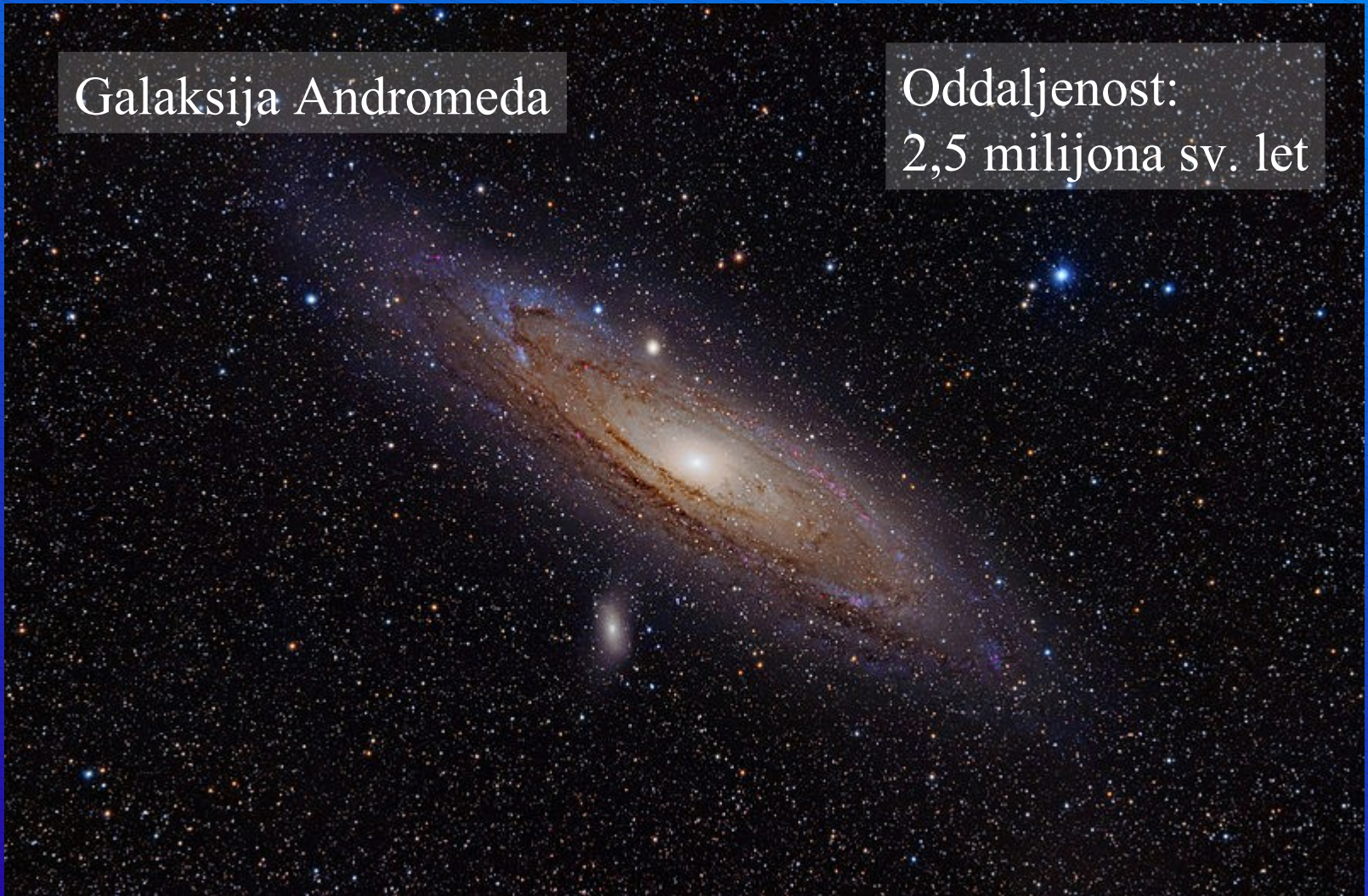
A deep-field astronomical image showing a dense field of galaxies, likely the Coma cluster. The galaxies are of various shapes and sizes, scattered across a dark background. A prominent, bright star with a four-pointed diffraction pattern is located in the upper center. The text 'Jata galaksij Koma' is overlaid in the bottom left corner.

Jata
galaksij
Koma

Primerjava razdalj zvezd in galaksij

Galaksija Andromeda

Oddaljenost:
2,5 milijona sv. let



Galaksije lahko tudi trčijo

Par galaksij
NGC 4038 & NGC 4039
imenovanih tudi
„Anteni“



Možen trk Andromedine z našo Galaksijo

Trk galaksij s črnima luknjama

Motivacija za študij naše Galaksije

'bližnja kozmologija':

- zvezde so blizu in zato svetle,
- lahko opazujemo vsako posebej (v NGC891: $1\text{pc}=0,02''$),
- lahko dobimo 6-D podatke (položaj + hitrost).

NGC 891



Vendar:

- ◆ smo znotraj,
- ◆ opazovati moramo znatno število od skupaj $>10^{11}$ zvezd.

Bližnja kozmologija

Freeman & Bland-Hawthorn (2002)

Nastanek in razvoj Galaksije:

- Nastanek in razvoj galaksij je eno od velikih odprtih vprašanj astrofizike.
- Znotraj splošnega konteksta hierarhičnega nastajanja strukture od spodaj navzgor le grobo razumemo nastanek galaksij podobnih naši.
- Podrobna fizikalna slika, v kateri bi posamezne populacije zvezd lahko povezali s časom in mestom formiranja je daleč onkraj naših trenutnih zmožnosti.

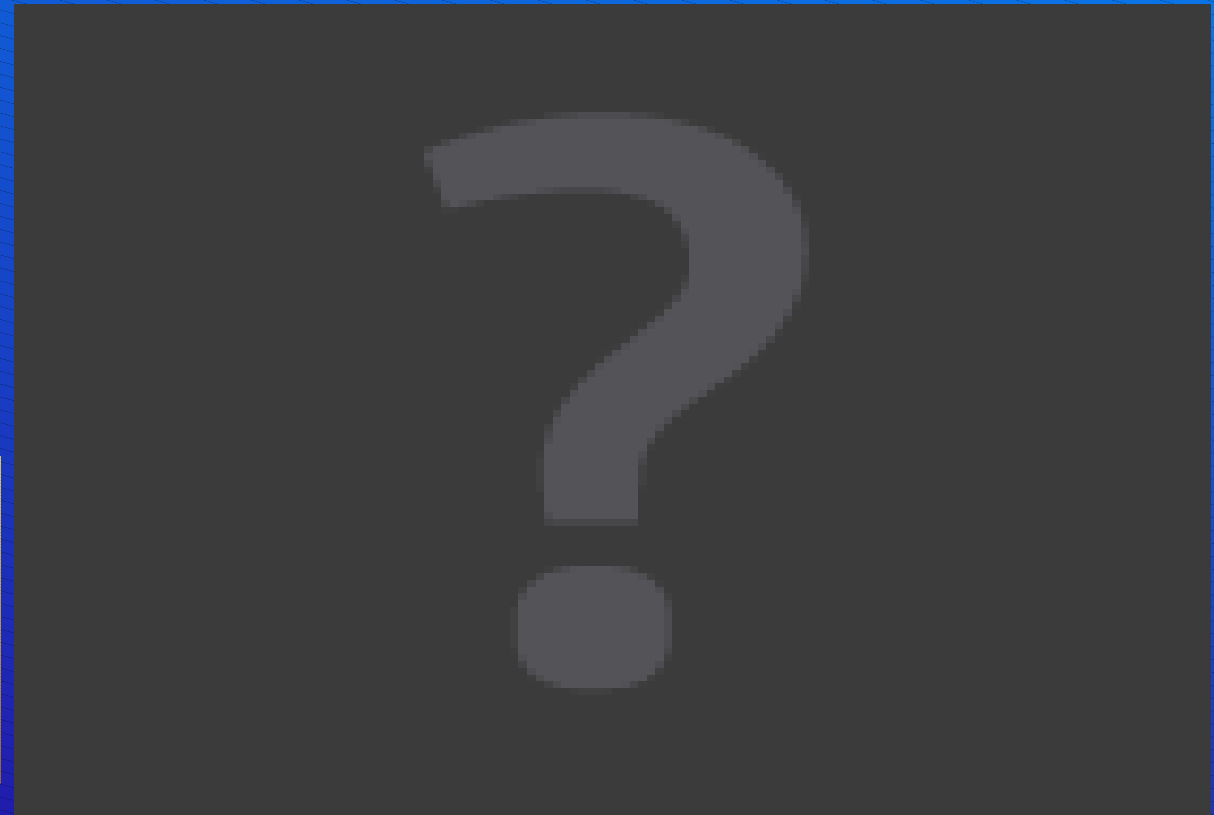
Trenutni razvoj:

- Pomembne rezultate daje tako študij naše Galaksije (bližnja kozmologija) kot študij struktur pri velikih rdečih premikih (običajna kozmologija).
- Sedaj se bomo posvetili fosilnim dokazom, ki so v naši Galaksiji.
- Podrobne raziskave Galaksije so osnova za razumevanje kompleksnih procesov ohlajanja barionov v vesolju.
- To je tako tudi prvi potreben korak za razvoj uspešne teorije nastanka galaksij.

Simulacija kanibalističnega nastanka naše Galaksije

Risana le običajna
snov (barioni).

Steinmetz & Navarro 2002



Tanek disk
nastane šele pri
rdečem premiku
 $z < 2$.

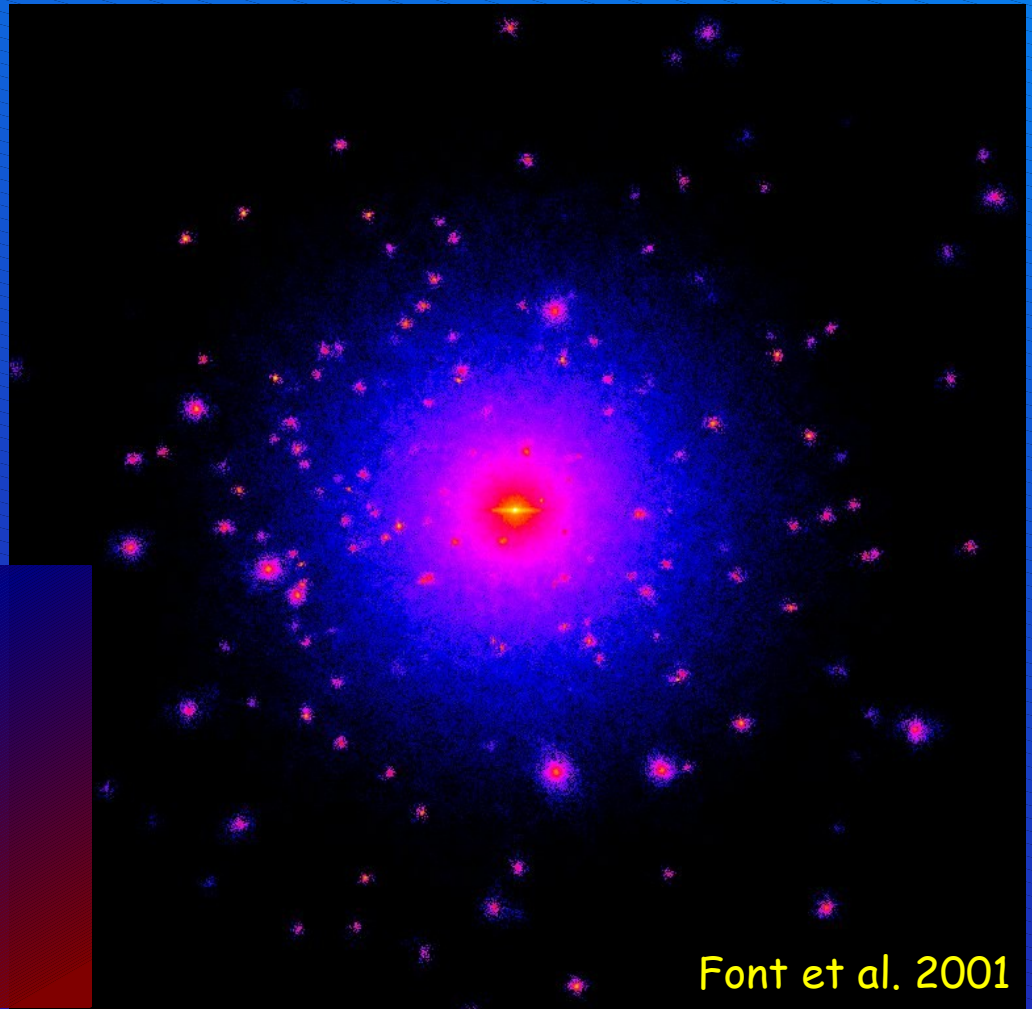
pogled od zgoraj

pogled od strani

Simulacija kanibalističnega nastanka naše Galaksije

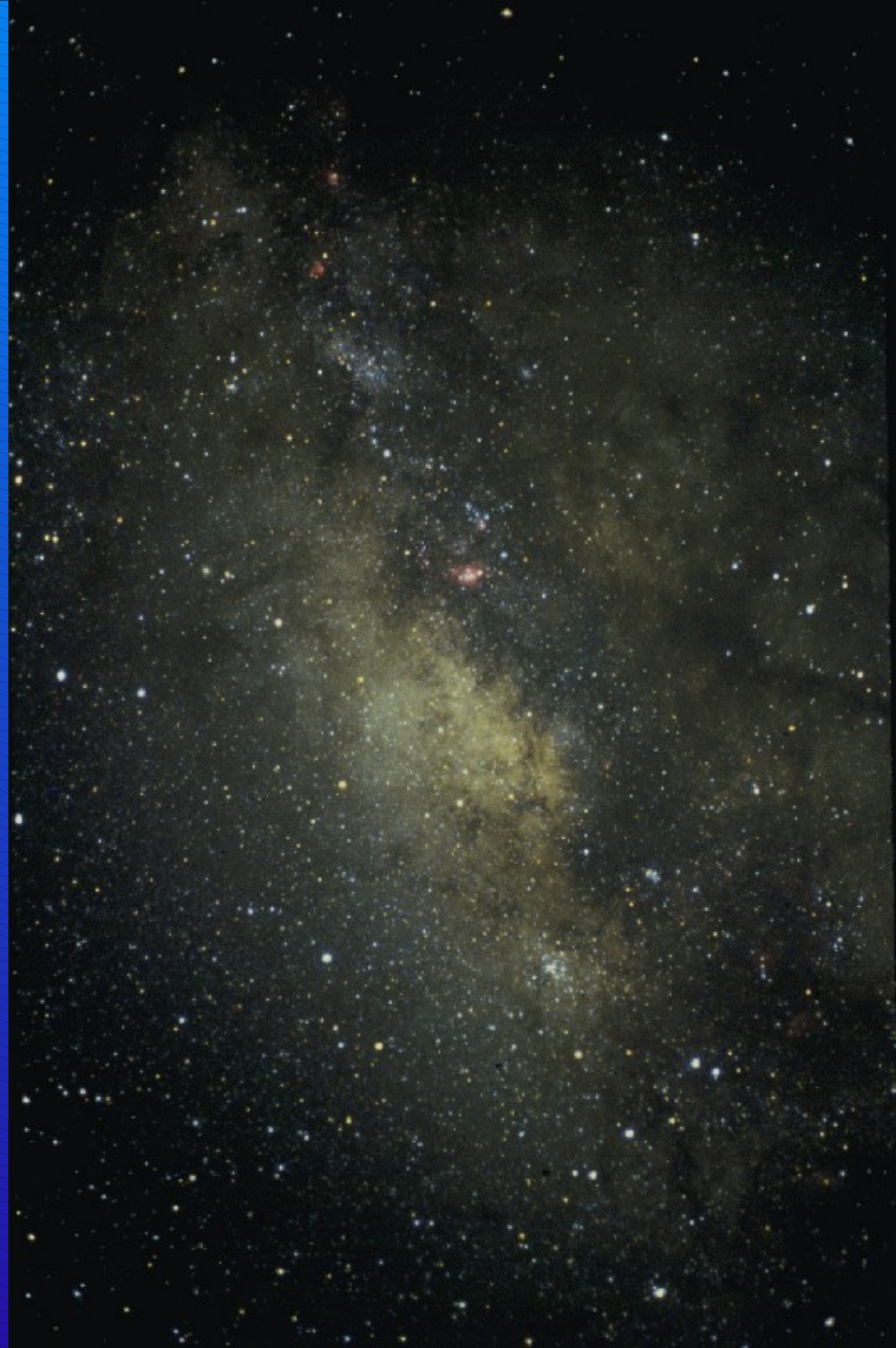
Risana vsa snov (tudi
temna)

Gladek viskozni kolaps,
ki ohranja vrtilno količino
vpadlega materiala se zdi
edini način za tvorbo velikih
galaktičnih diskov,
kakršen je naš.

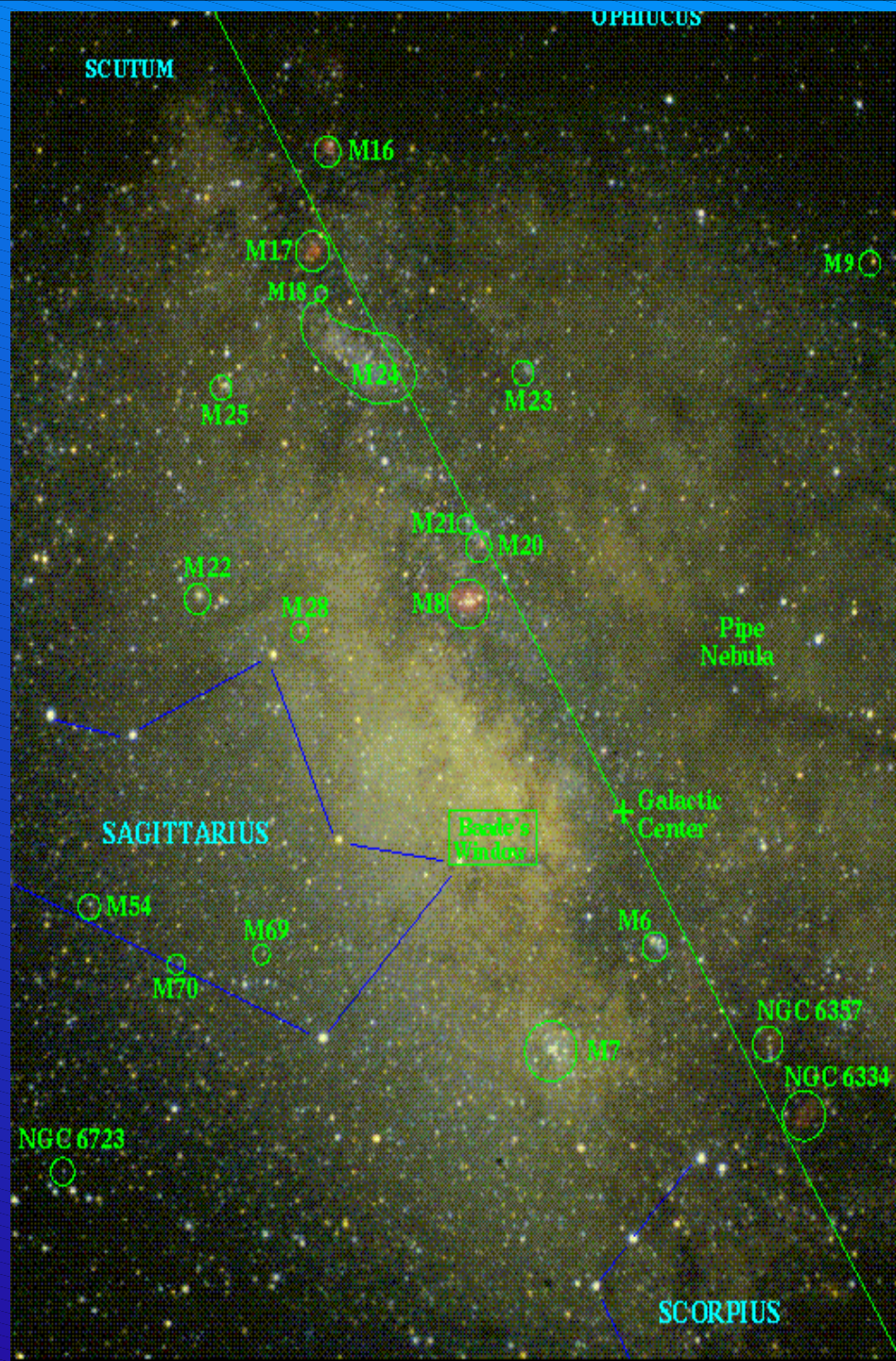


Font et al. 2001

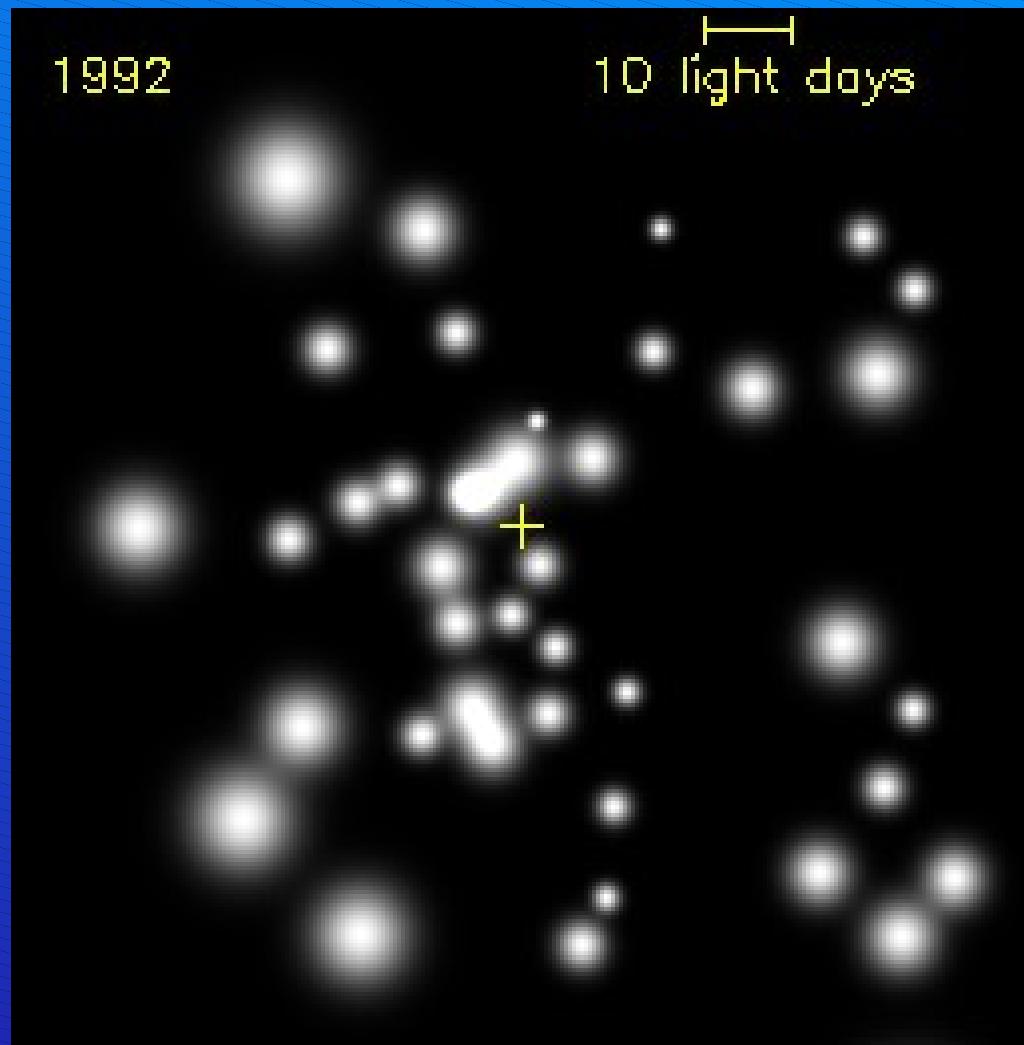
Središče Galaksije



Središče Galaksije



Središče Galaksije





Nekoč smo mislili, da:

- ima naša Galaksija le dva satelita,
- je njen halo okrogel,
- imajo zvezde v disku krožne tire,
- naša Galaksija nima prečke

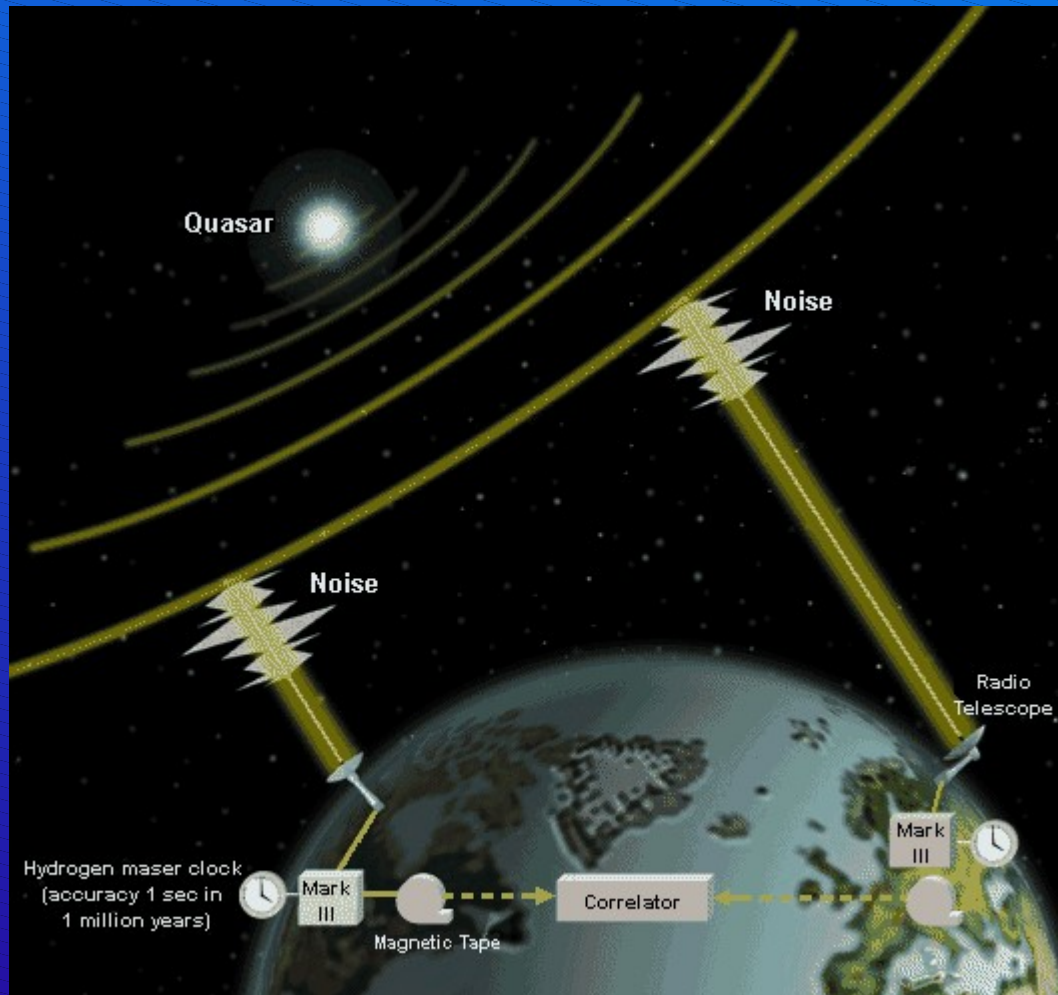
... temu ni več tako.

Število spiralnih rokavov v naši Galaksiji? Prečka in le 2 rokava



Študij položajev starih
orjakinj v rdeči zgoščitvi
s pregledom neba GLIMPSE
Spitzerjevega vesoljskega teleskopa.

Radijska interferometrija



Interferometrične meritve izjemno majhnih premikov položajev zvezdnih porodnišnic zaradi kroženja Zemlje okoli Sonca

Reid et al. 2009

Table 1. Parallaxes & Proper Motions of High-mass Star Forming Regions

Source	ℓ (deg)	b (deg)	Parallax (mas)	μ_x (mas y ⁻¹)	μ_y (mas y ⁻¹)	v_{LSR} (km s ⁻¹)	Ref.
G 23.0–0.4...	23.01	–0.41	0.218 ± 0.017	–1.72 ± 0.04	–4.12 ± 0.30	+81 ± 3	V
G 23.4–0.2...	23.44	–0.18	0.170 ± 0.032	–1.93 ± 0.10	–4.11 ± 0.07	+97 ± 3	V
G 23.6–0.1...	23.66	–0.13	0.313 ± 0.039	–1.32 ± 0.02	–2.96 ± 0.03	+83 ± 3	1
G 35.2–0.7...	35.20	–0.74	0.456 ± 0.045	–0.18 ± 0.06	–3.63 ± 0.11	+28 ± 3	IV
G 25.2–1.7...	25.20	–1.74	0.296 ± 0.045	–0.71 ± 0.05	–2.61 ± 0.17	+42 ± 3	IV

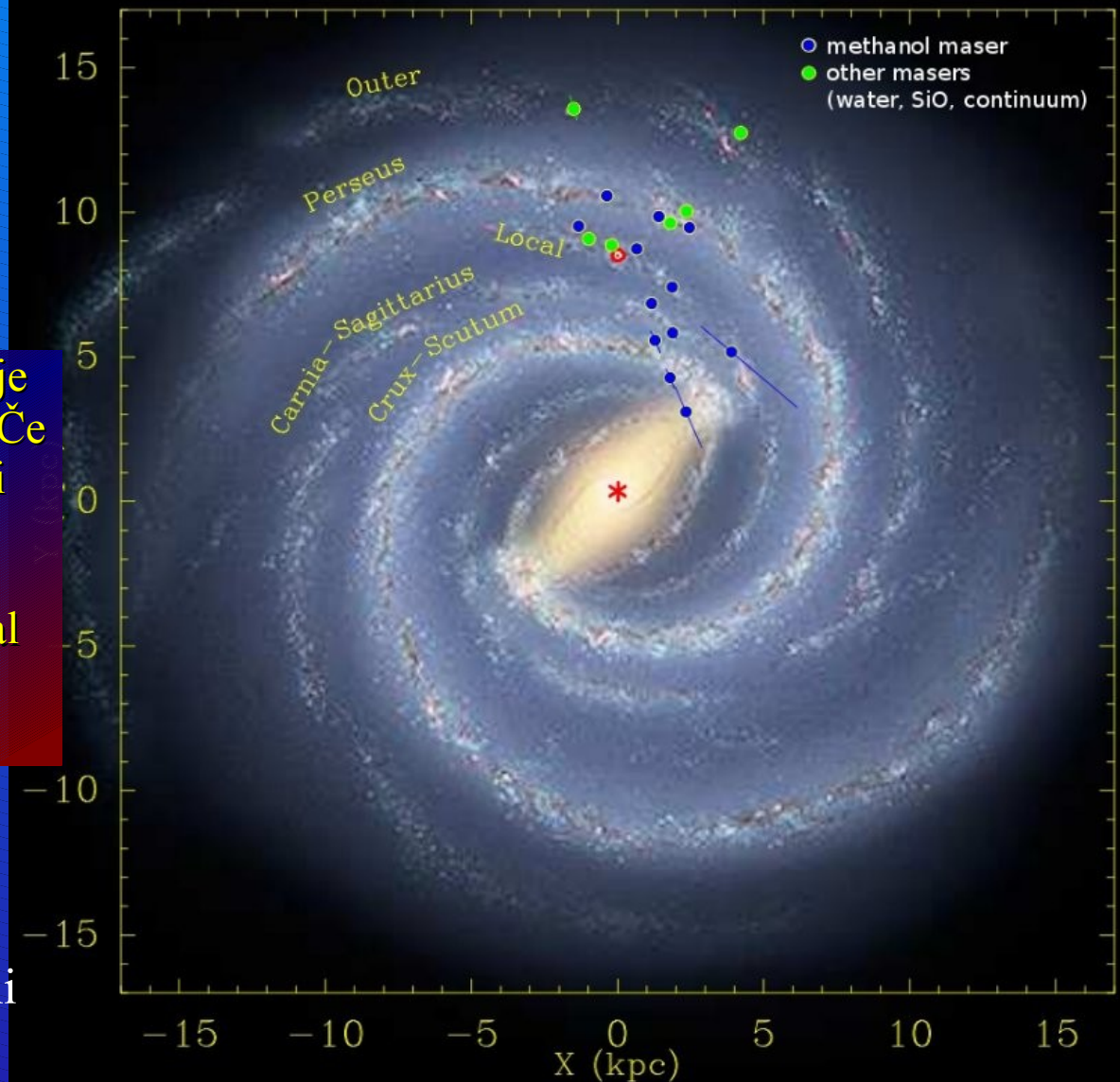
Trigonometrične razdalje 18 območij nastajanja masivnih zvezd z VLBI interferometrijo opazovanja 12GHz metanolovih maserjev. **Poglejte točnost meritve paralakse!!!**

Število spiralnih rokavov (ram) v naši Galaksiji?

Prečka in 4 rokavi

Naklonski kot Perzejeve rame je $16^\circ \pm 3^\circ$. To podpira 4 rokave. Če bi bili le dva, bi lahko šla skozi vsa območja zvezdnih porodnišnic le, če bi se ovila dvakrat: v tem primeru bi moral biti naklonski kot le $\sim 8^\circ$.

Združitev argumentov:
2 dominantna rokava z mladimi in starimi zvezdami
+ 2 šibkejša rokava le z mladimi zvezdami.



Reid et al. 2009

Položaji 18 opazovanih maserjev.

Nove osnovne vrednosti

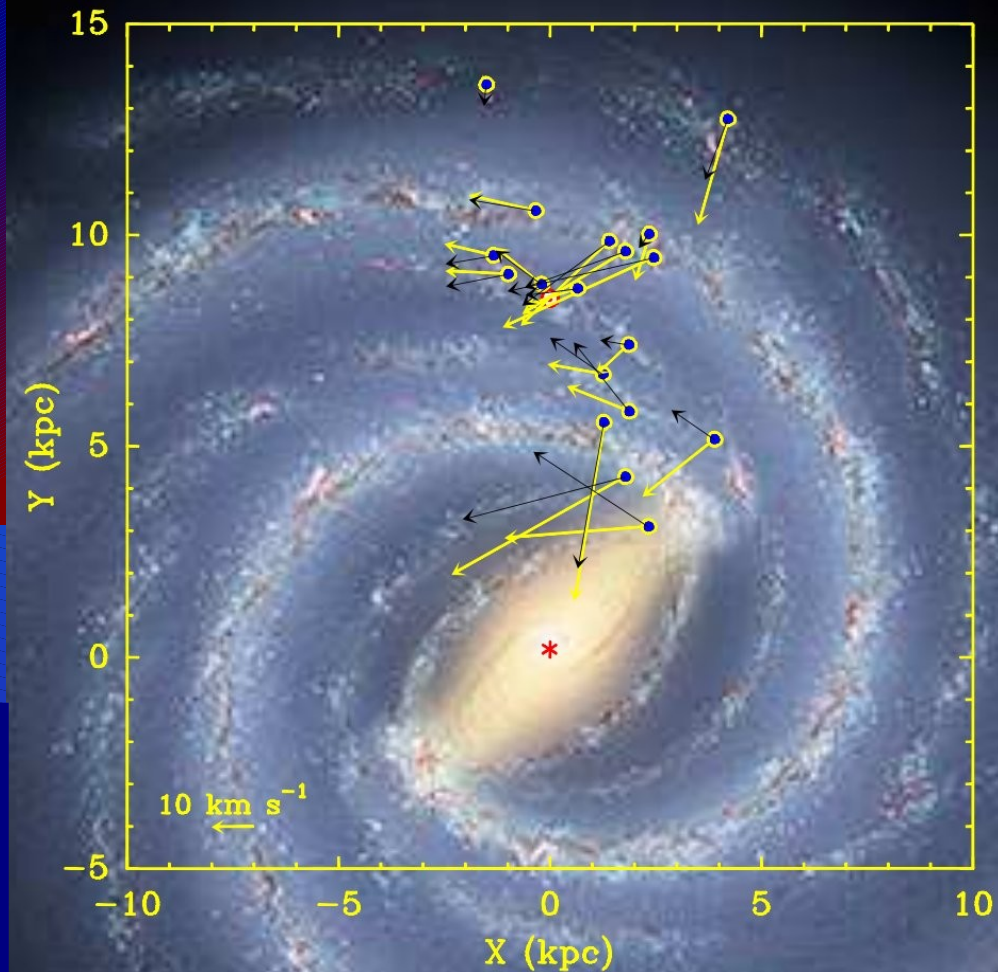
Reid et al. 2009

- ◆ $R_0 = 8.4 \pm 0.6$ kpc
- ◆ $V_0 = 254 \pm 16$ km/s
- ◆ $V_0 / R_0 = 30.3 \pm 0.9$ km/s/kpc
- ◆ območja nastajanja zvezd se vrtijo ~ 15 km/s počasneje od krožilne hitrosti.

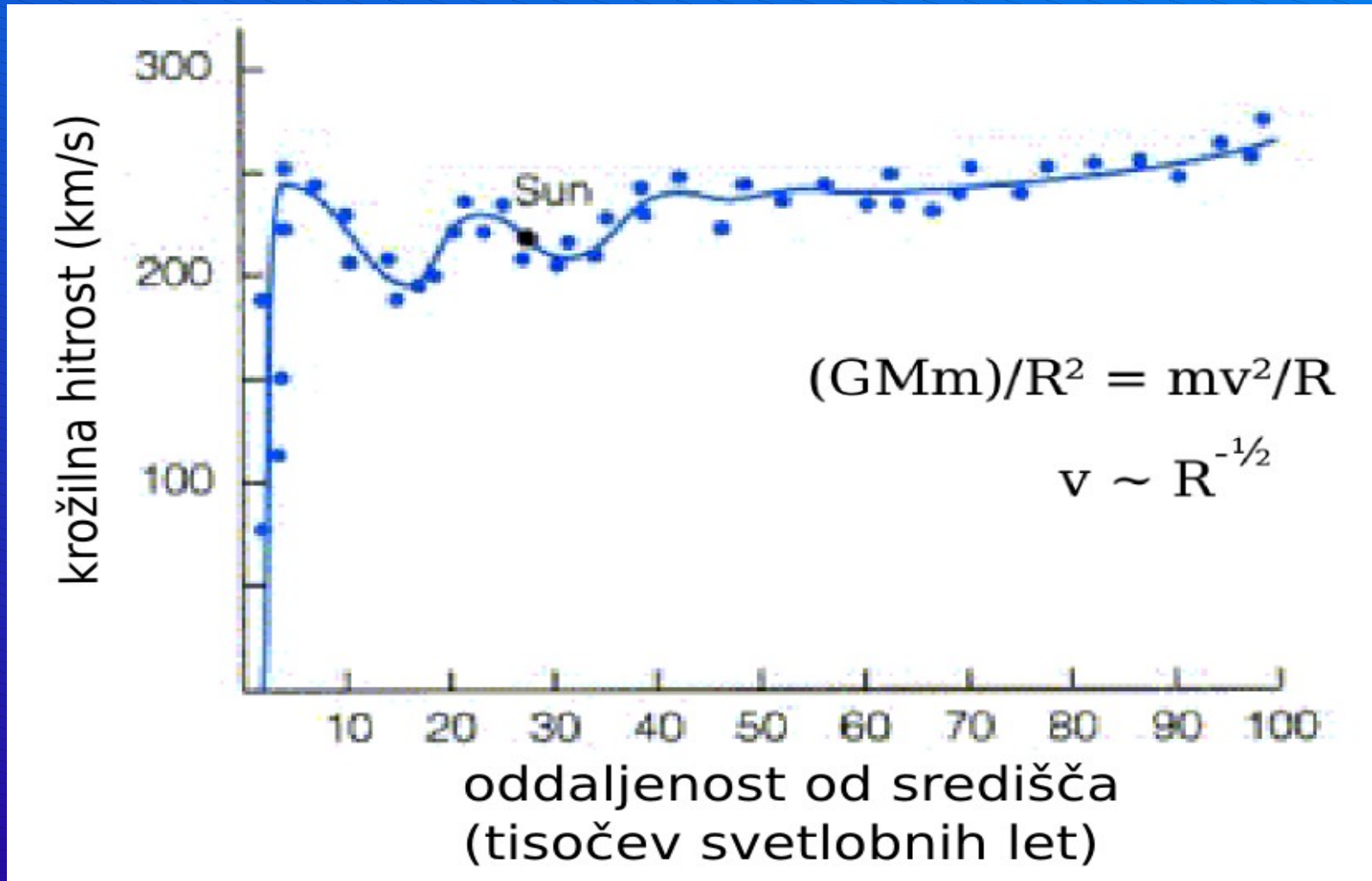
gibanja območij nastajanja zvezd
v korotirajočem sistemu:

črno: $V_0 = 254$ km/s

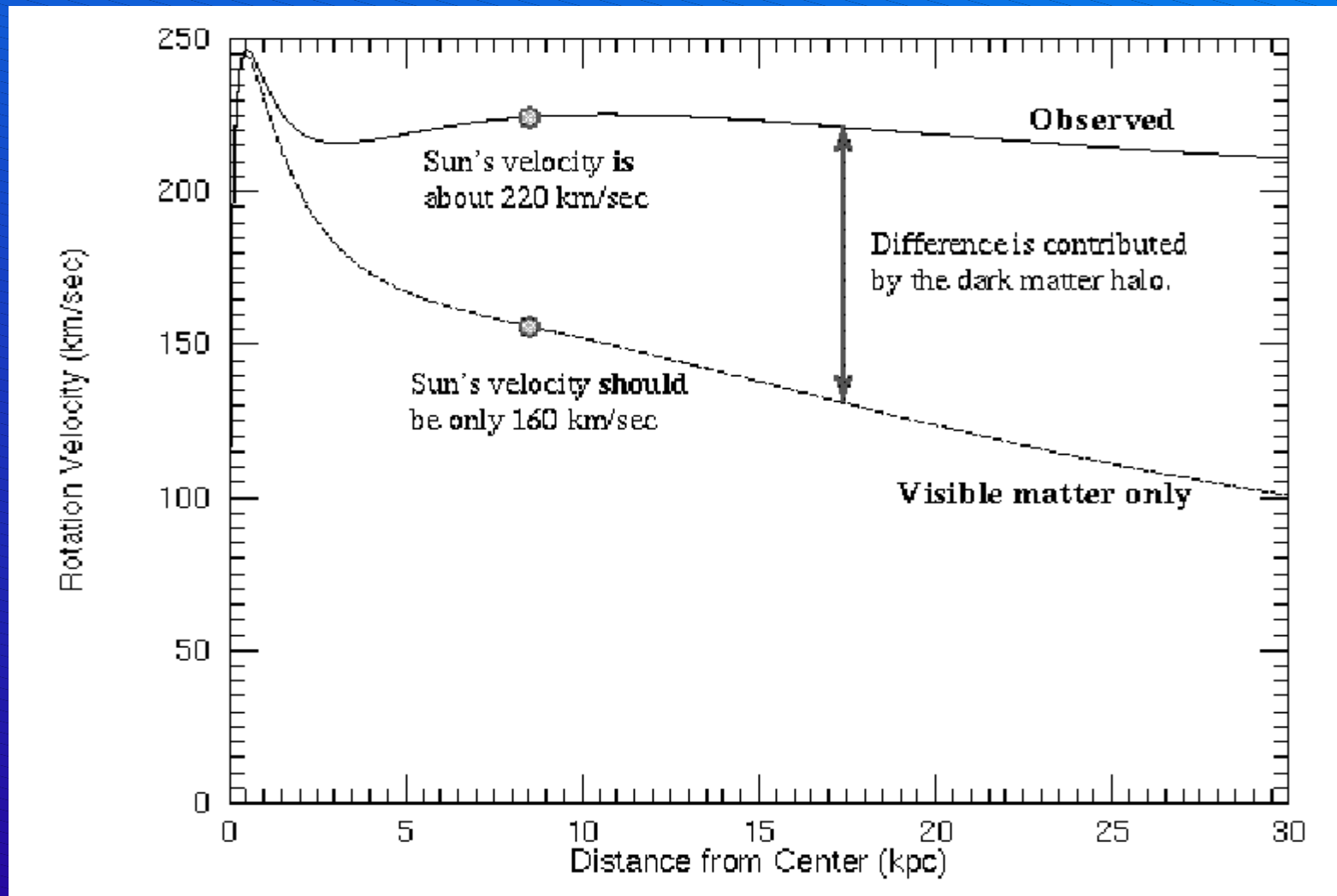
rumeno: $V_0 = 220$ km/s



Hitrost kroženja zvezd



Hitrost kroženja zvezd

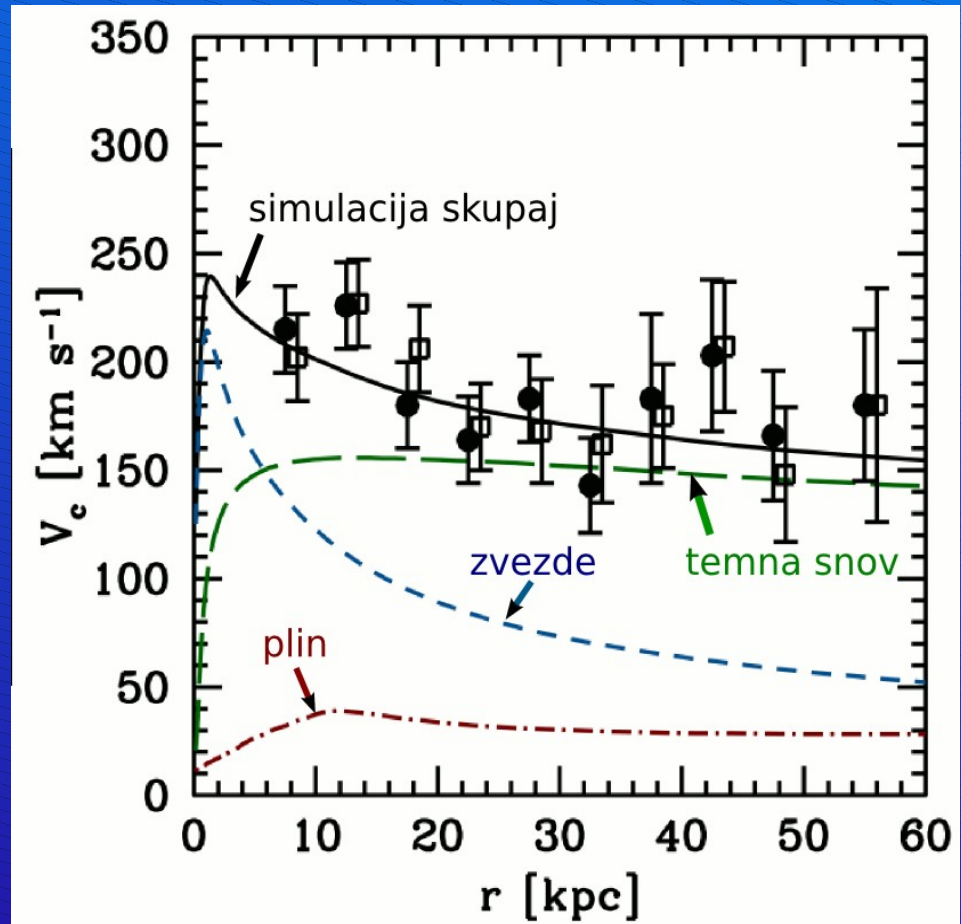
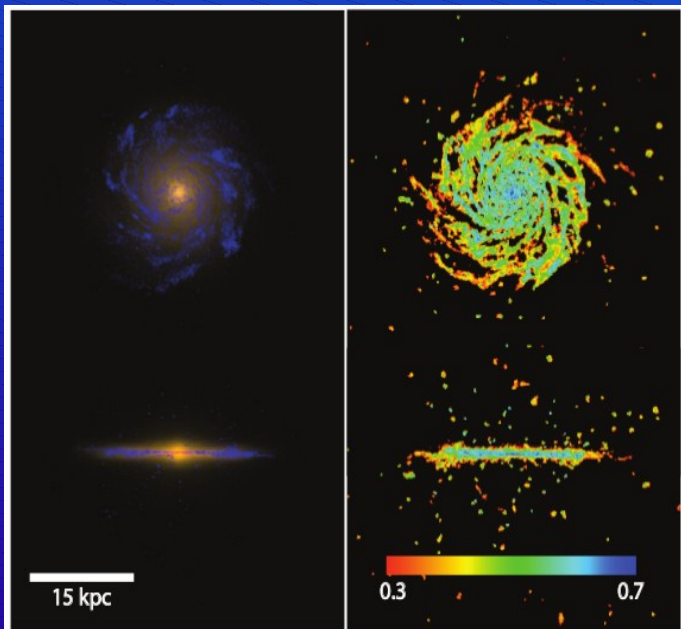


Hitrost kroženja zvezd

↓ Hitrost kroženja v disku

Guedes idr. 2011

↓ pogled na simulirano Galaksijo:
levo: pogled v vidnem in UV,
desno: plin (barve: delež
nevtralnega plina).



Rimska cesta ima veliko satelitskih galaksij

Masa zvezd v haloju:
 $4 \cdot 10^8 M_{\odot}$ pri $1 \text{ kpc} < R < 40 \text{ kpc}$.

Belokurov et al. 2006

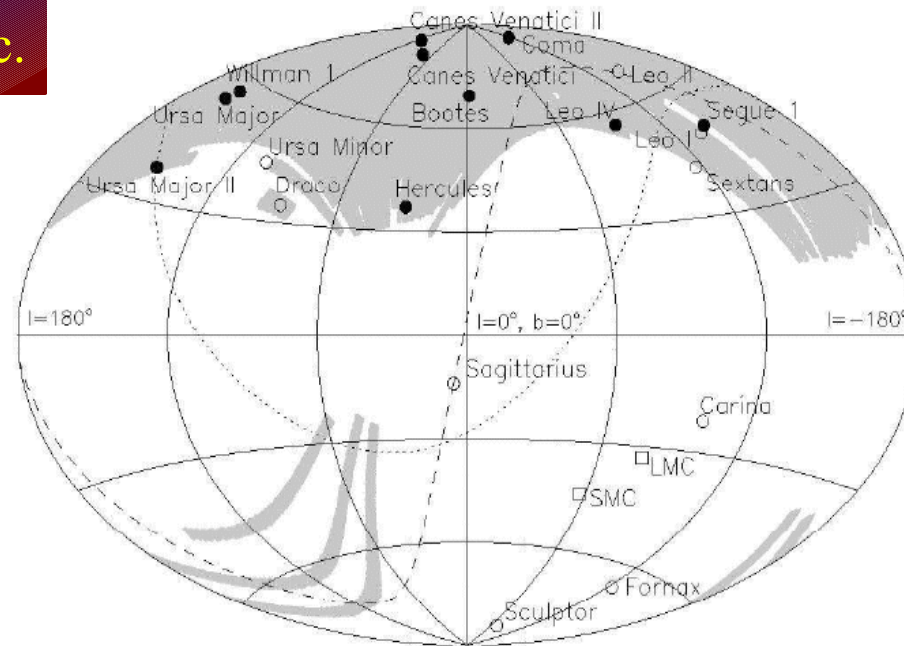


FIG. 7.— The locations of Milky Way satellites in Galactic coordinates. Filled circles are satellites discovered by SDSS, unfilled circles are previously known Milky Way dSphs. The light grey shows the area of sky covered by the Sloan survey and its extensions to date. The dashed and dotted lines show the orbital planes of the Sagittarius and Orphan Streams, respectively, taken from [Fellhauer et al. \(2006a\)](#) and [Fellhauer et al. \(2006b\)](#).

Večina zunanjega haloja je iz preostankov kanibalističnih ujetij pritlikavih galaksij.

Kaj je galaksija in kaj zvezdna kopica?

Gilmore et al. 2008

- izseva podobna,
- velikosti pa ne:
 - $R > 120$ pc (galaksije)
 - $R < 35$ pc (stabilne zvezdne kopice)

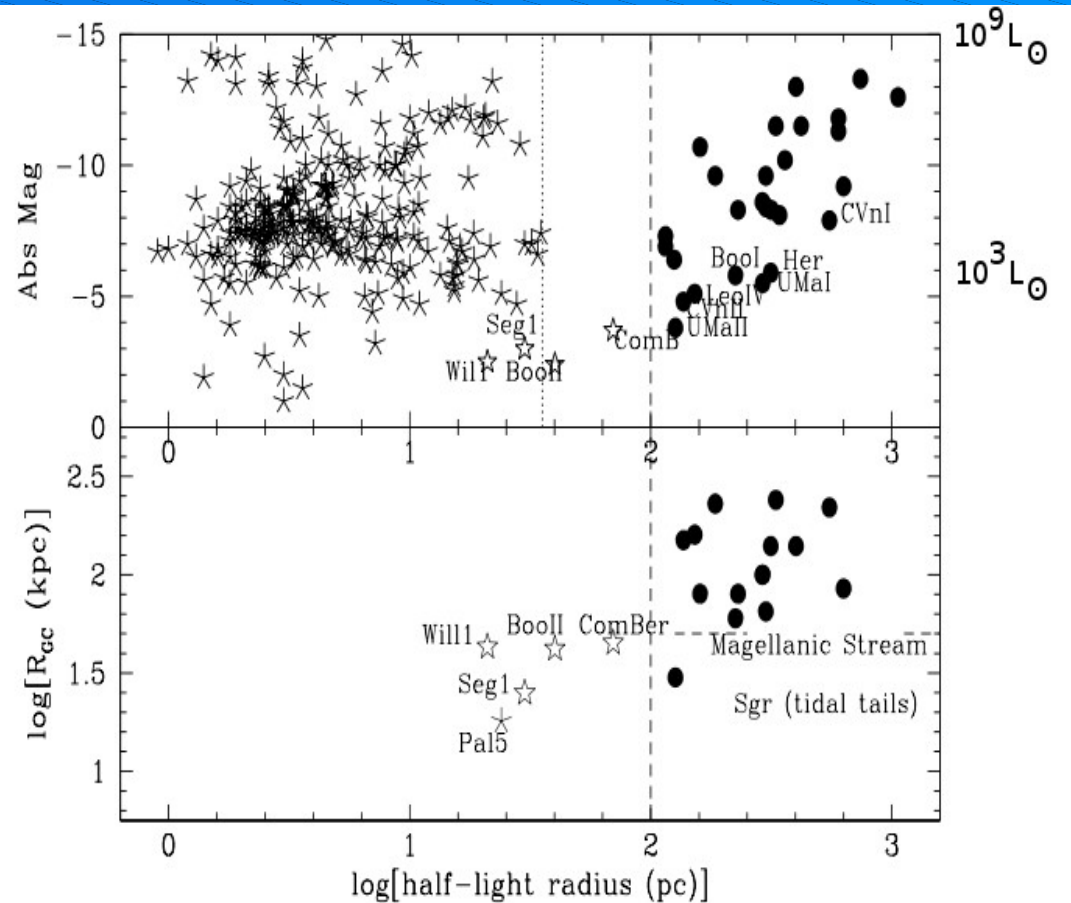


Figure 1. Top: Absolute magnitude M_V vs (logarithmic) half-light radius for well-studied stellar systems. Filled symbols are objects classed as galaxies, asterisks are objects classed as star clusters of various types, open stars are newly discovered objects of uncertain nature. Lower: (log) Galactocentric distance vs (logarithmic) half-light radius for the dSph and uncertain objects, and the (tidal-tail) star cluster Pal 5. All the uncertain objects are in a region where Galactic tides must be important. There is no known stable system with half-light radius between 35pc and 120pc.

Kanibalizem tu in zdaj: ujetje Pritlikave galaksije v Strelcu

Belokurov et al. 2006

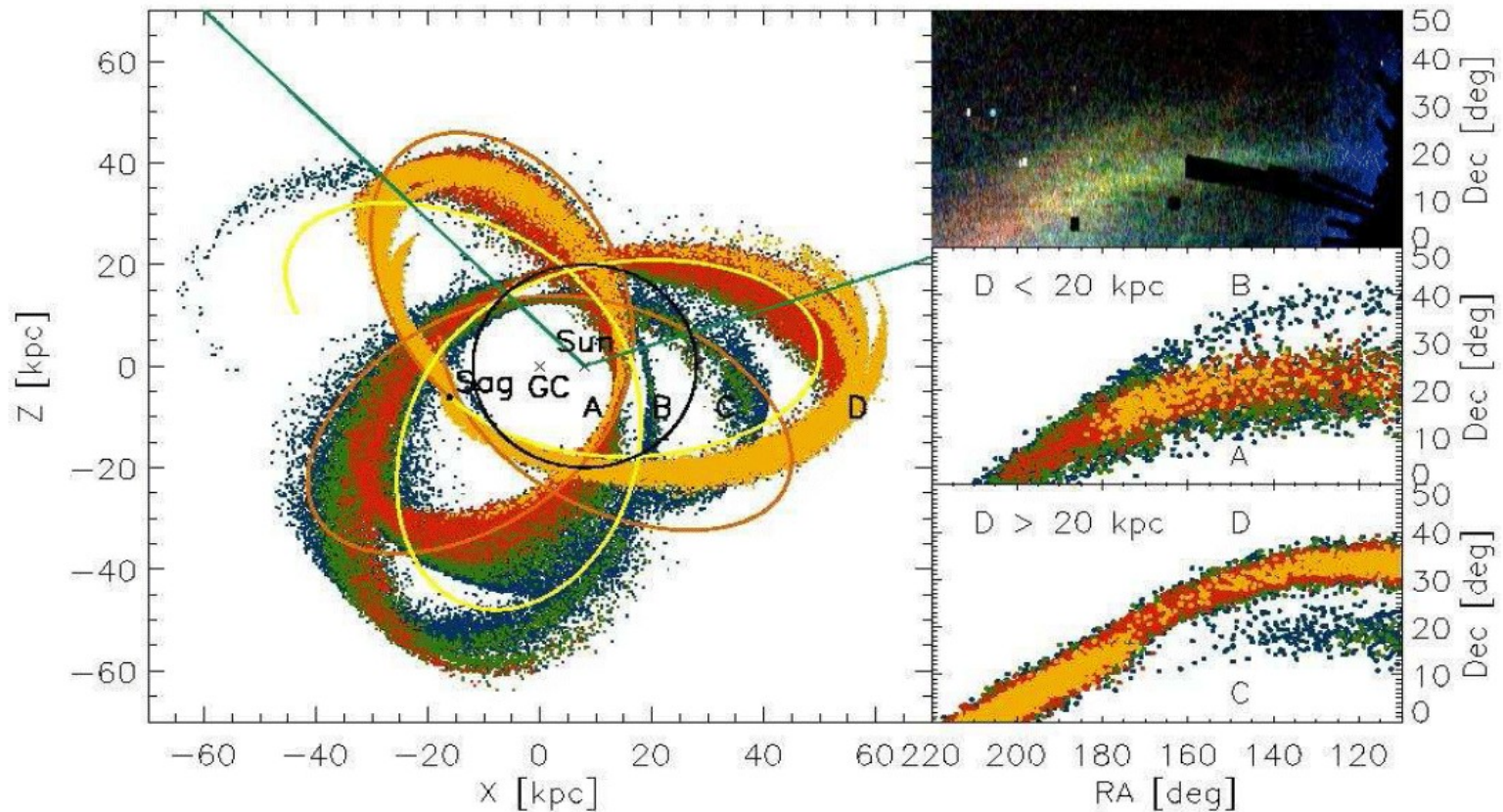
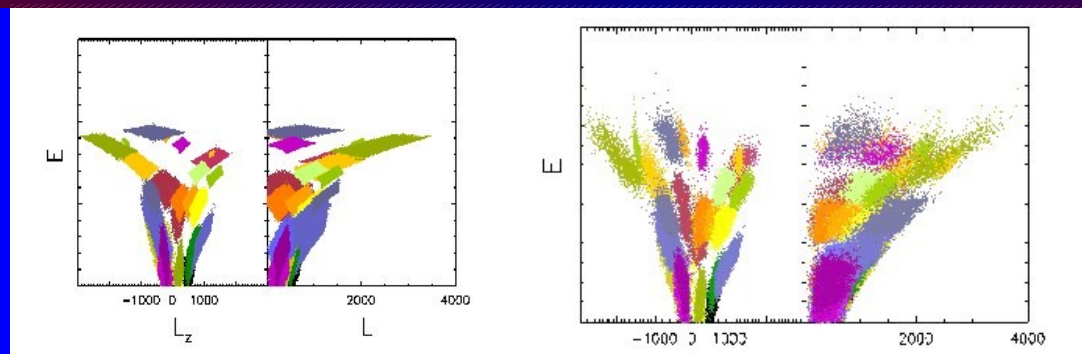


FIG. 1.— Left: Simulation showing the tails of the Sgr dSph. Particles are color-coded according to when they were lost (gold: < 4 Gyr ago, red: between 4 and 5.7 Gyr, green: between 5.7 and 7.4 Gyr and blue > 7.4 Gyr ago). The yellow (orange) curves show the past (future) behavior of the Sgr's orbit over 2 Gyr. The orbital period is 0.7 Gyr. The positions of the Galactic centre (GC), the Sun, and Sagittarius (Sag) are marked. The green lines show the right ascension range $110^\circ < \alpha < 220^\circ$, which corresponds to the SDSS data analyzed by Belokurov et al. (2006). The 4 streams are marked A (young leading arm), B (old trailing arm), C (old leading arm) and D (young trailing arm). The circle gives the distance cut-off at 20 kpc. Upper Right: The SDSS data from Belokurov et al. (2006), with stars color-coded according to magnitude. Middle and Lower Right: Scatter plots in right ascension and declination of the tidal debris. Only particles within (beyond) a heliocentric distance of 20 kpc are plotted in the middle (lower) panels. The black squares show the field locations of Belokurov et al. (2006). In the middle panel, streams A and B are clearly visible. The upper arm is the old trailing material, while the lower arm is the young leading material. In the lower panel, the old leading material is in the lower and the young trailing material in the upper branch. [The simulation uses a Miyamoto-Nagai disk and logarithmic halo with $q_\phi = 1.05$, together with the set of proper motions. The mass of Sgr is $10^8 M_\odot$]

Spektroskopija :: direktno slikanje

Spektroskopija nam edina omogoča meritev radialne hitrosti. Če poznamo razdaljo in lastno gibanje, potem poznamo celotno 6-dimenzionalno informacijo (3-D položaj + 3-D hitrost). Tako lahko izračunamo vrednosti energije in vrtilne količine, ki se (skoraj) ohranjajo.



Start of the simulation
12 billion years ago.
Individual satellites in the
halo are colour-coded.

Situation 12 billion years
later, allowing also for
measurement errors of the
Gaia mission.

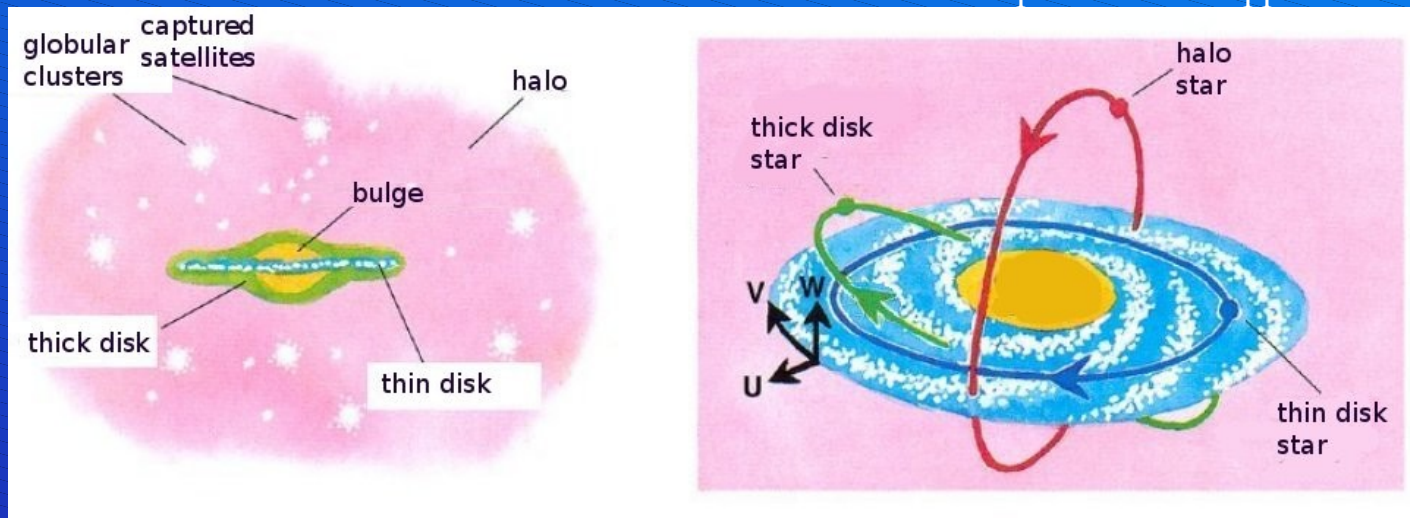
Stars from individual satellites
are completely mixed-up in the
halo. But their energy and
angular momentum still allow
us to trace their origin to
individual original satellites.

Simulation:
Helmi & de Zeeuw 2000.

$(\alpha, \delta, \text{razdalja}, \mu_\alpha, \mu_\delta, \text{radialna hitrost})$
+ kemija

Bližnja kozmologija

Adapted from Chiappini 2001

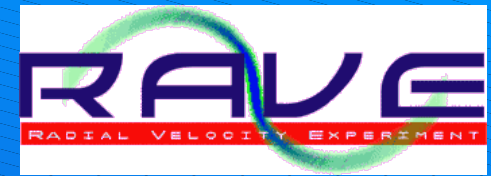


- Naša Galaksija je tipična spiralna galaksija.
- Zvezde z majhno maso so lahko skoraj tako stare kot vesolje samo.
- Torej ključ do razumevanja galaktičnega razvoja in zgodnjega vesolja v gibanju in kemični sestavi zvezd v naši Galaksiji.
- Velik del vseh zvezd v haloju ali debelem disku potuje tudi skozi Sončevo okolico.

RAdial Velocity

Experiment

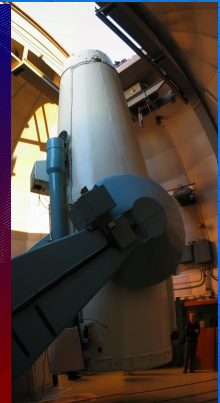
Anguiano, B.; Bailin, J.; Bienayme, O.; Binney, J.; Bland-Hawthorn, J.; Boeche, C.; Brown, A.; Burton, D.; Campbell, R.; Cass, P.; Dawe, J.; Dehnen, W.; Evans, N. W.; Fiegert, K.; Re Fiorentin, P.; Fiorucci, M.; Freeman, K. C.; Fulbright, J. P.; Gerhard, O.; Gibson, B.; Gilmore, G.; Grebel, E. K.; Hartley, M.; Helmi, A.; Jauregi, U.; Just, A.; Kelz, A.; Kujken, K.; Matijevic, G.; Minchev, I.; Munari, U.; Navarro, J. F.; Parker, Q. A.; Penarrubia, J.; Quillen, A.; Read, M. A.; Reid, W.; Roeser, S.; Ruchti, G.; Russell, K.; Scholz, R. -D.; Seabroke, G. M.; Siebert, A.; Siviero, A.; Smith, M. C.; Sordo, R.; Steinmetz, M.; Tolstoi, E.; Tomasella, L.; Veltz, L.; Watson, F. G.; Williams, M.; Wylie de Boer, E.; Wyse, R. F. G.; Zwitter, T.



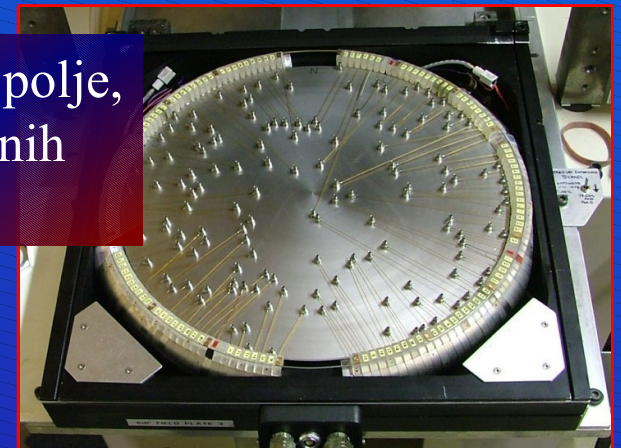
100% časa na teleskopu UK-Schmidt @ AAO

Doslej zbrali:

>500,000 spektrov zvezd,
 $9 < I < 12.5$,
naključni izbor,
 $R = 7,500$,
 $\lambda = 841-880 \text{ nm}$.



6 stopinjsko polje,
do 138 optičnih
vlaken.

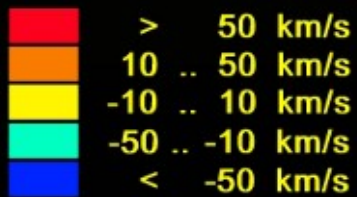
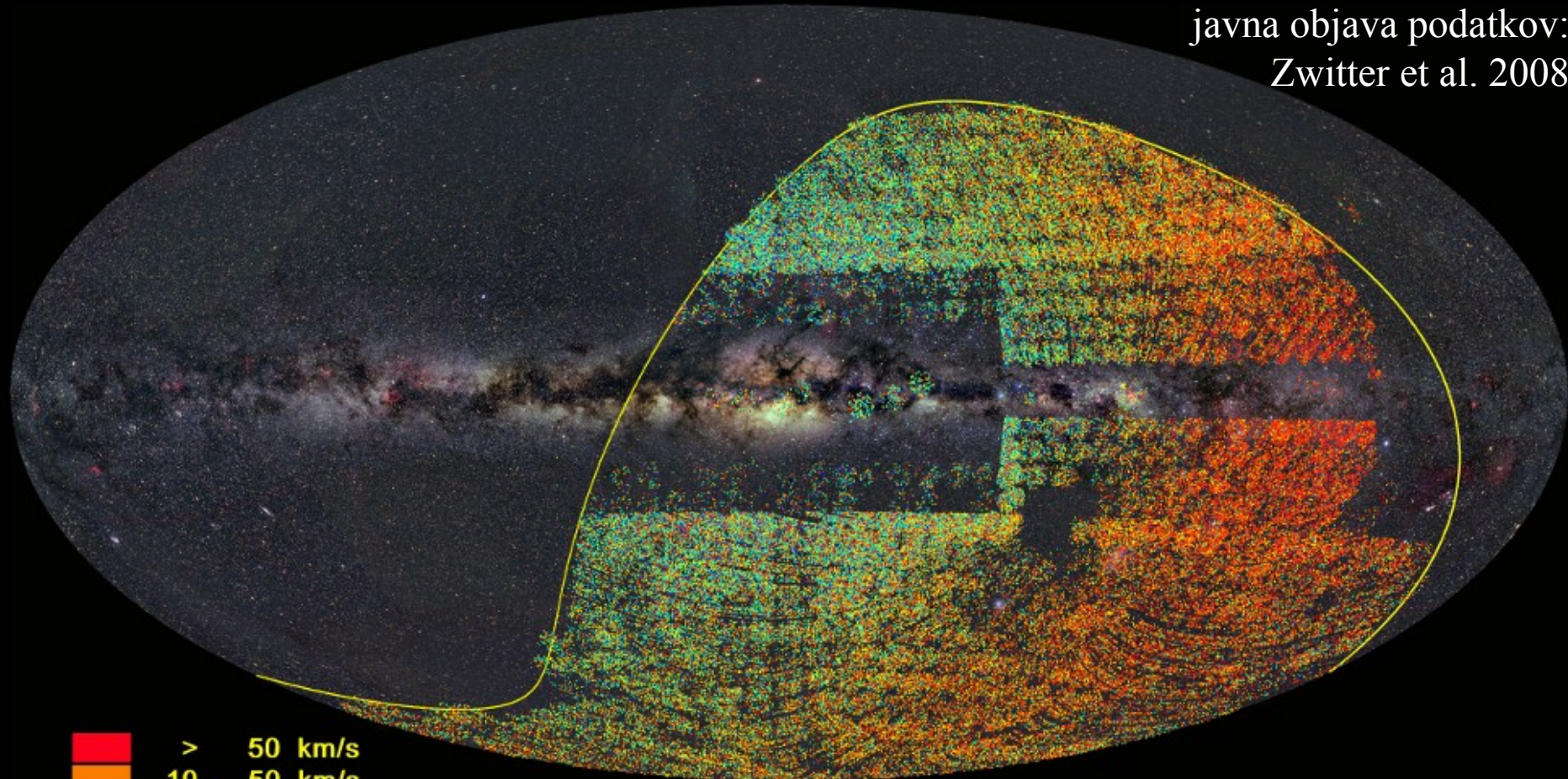


Izmejene radialne hitrosti (približevanja / oddaljevanja)



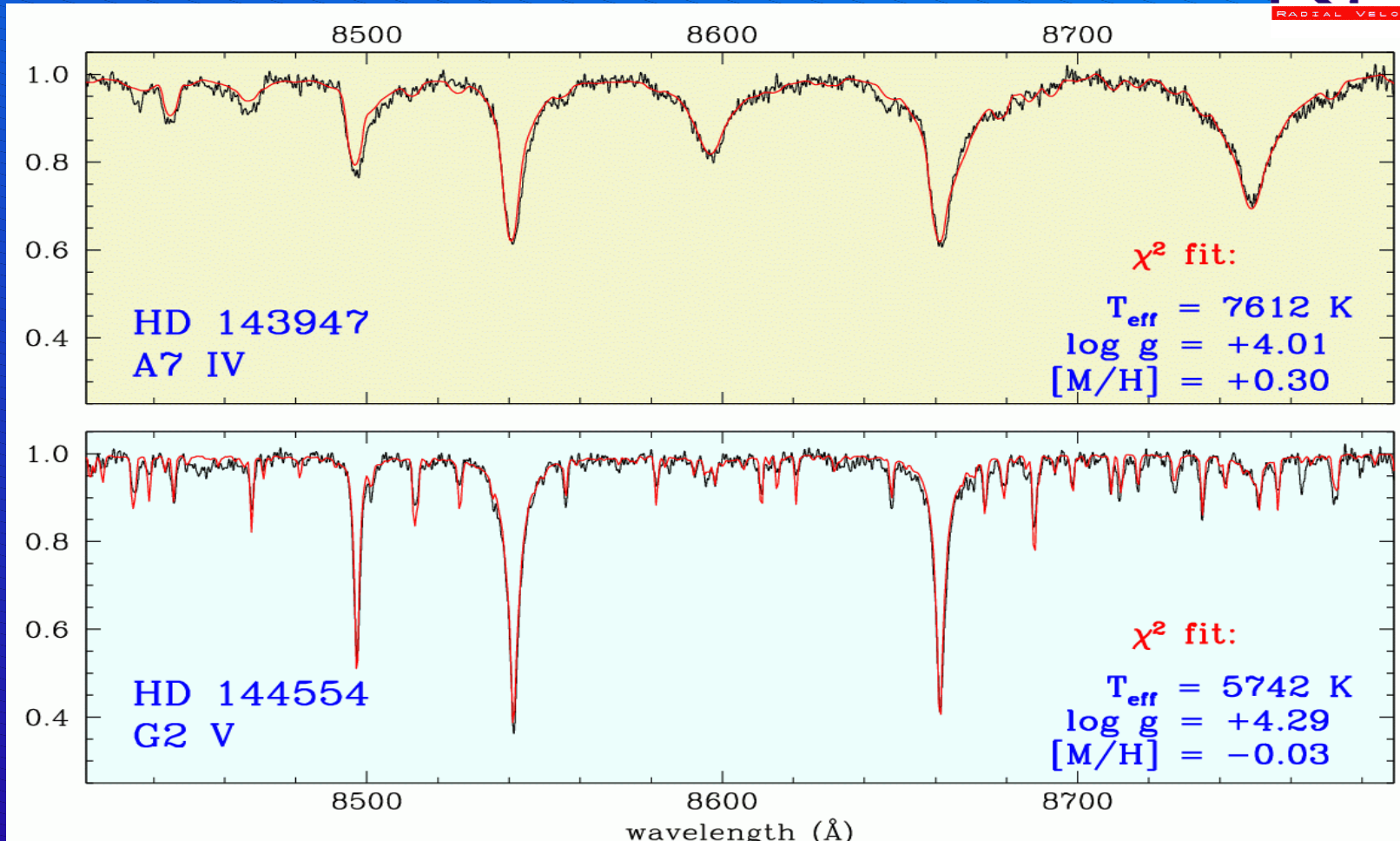
Stellar Heliocentric Radial Velocities

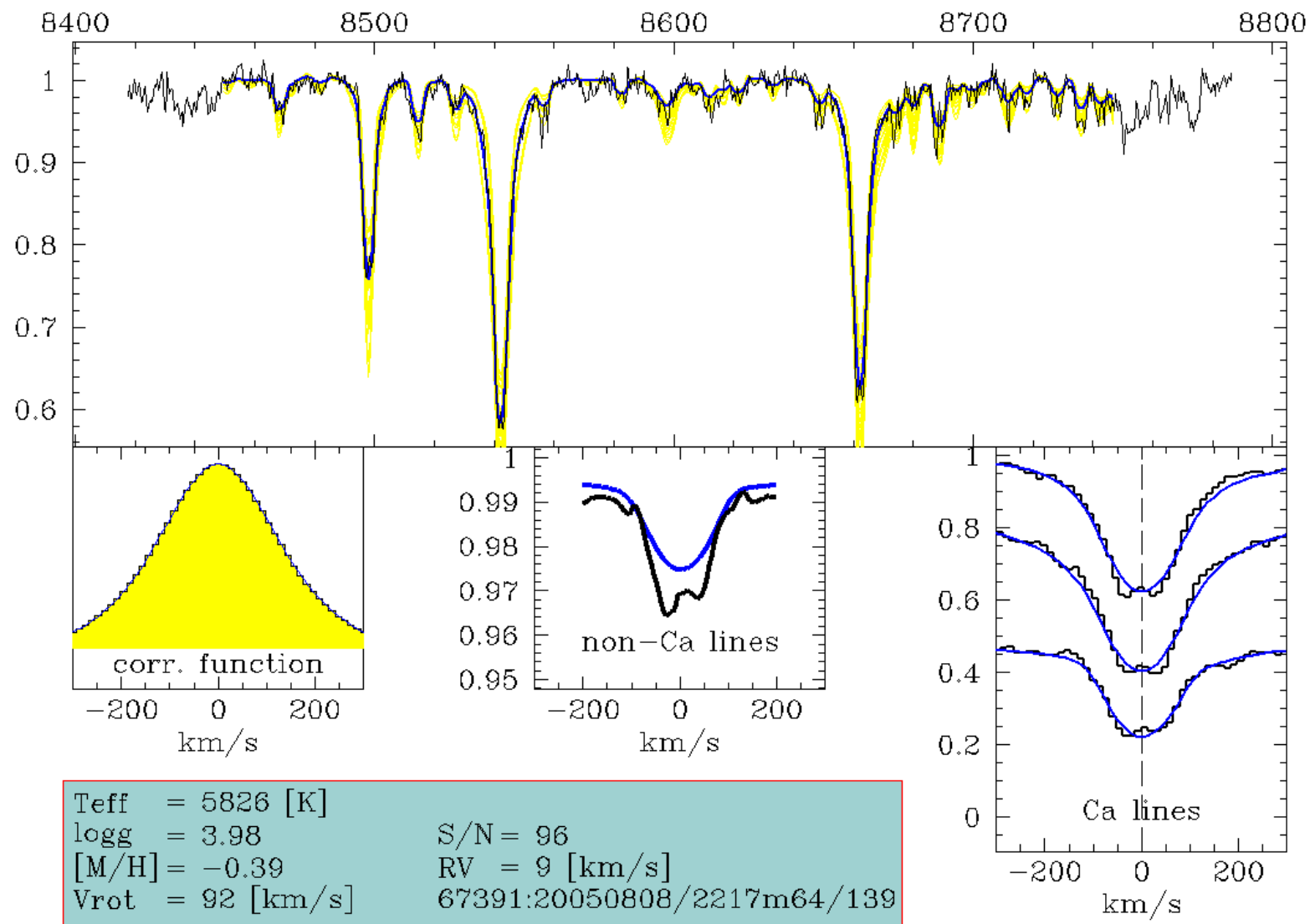
javna objava podatkov:
Zwitter et al. 2008

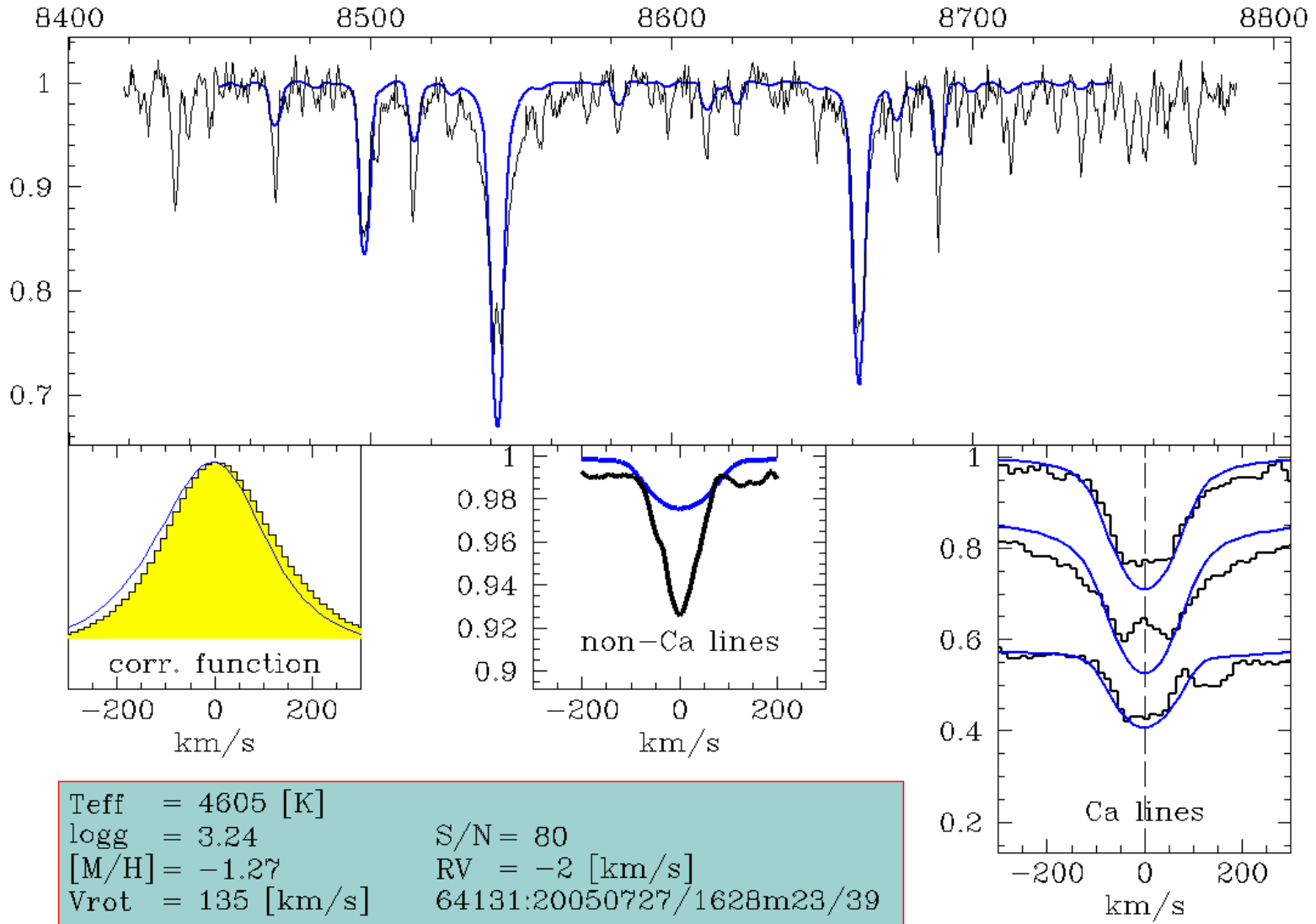


© The RAVE collaboration, background: ©2000 Axel Mellinger

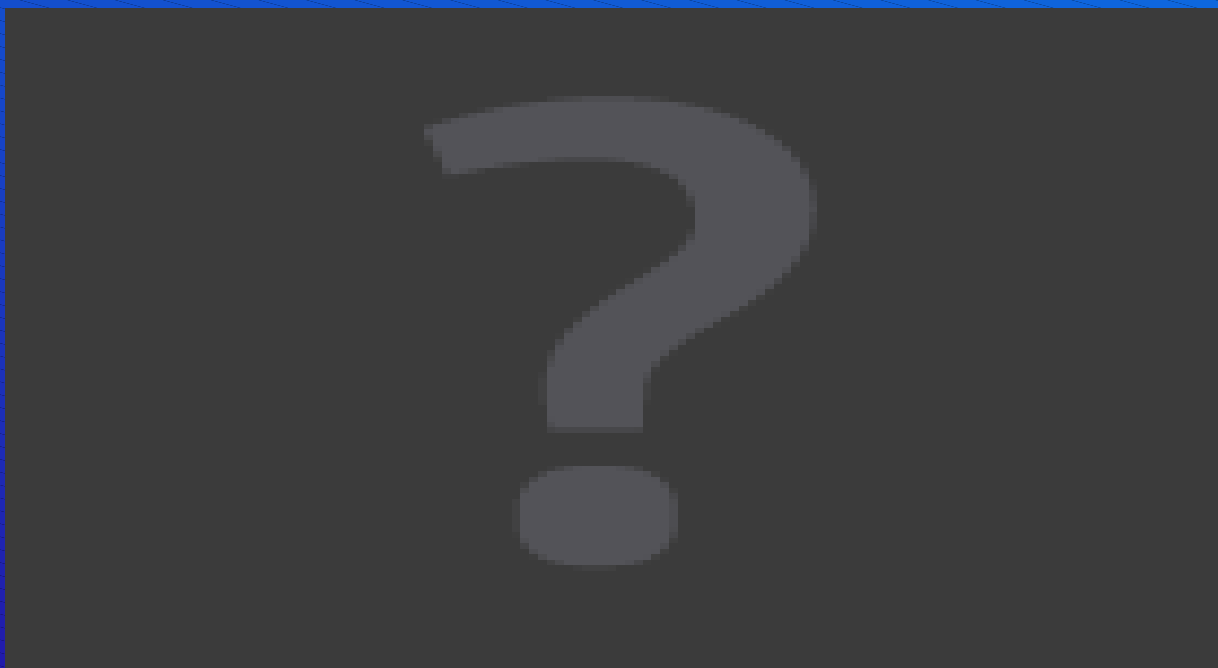
Poleg radialnih hitrosti tudi meritev zvezdnih lastnosti







Položaj RAVEovih zvezd v Galaksiji

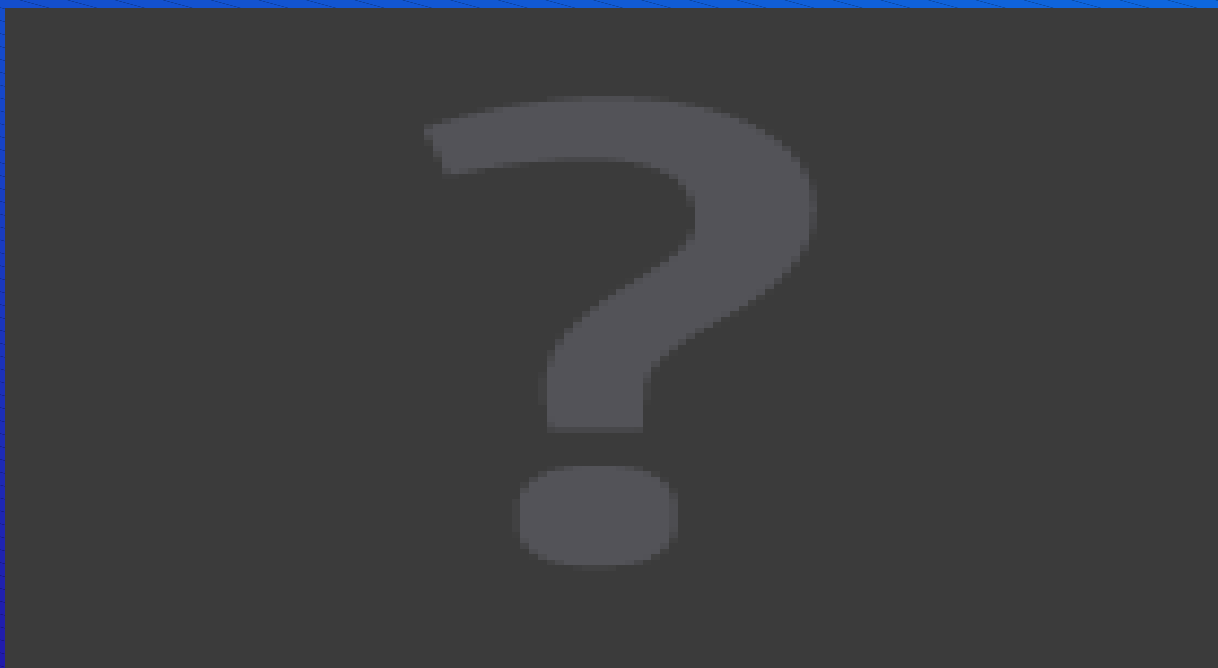


modro: pritlikavke ($\log g > 3.5$)

rdeče: orjakinje ($\log g < 3.5$)

Podatki: Zwitter idr. 2010, animacija: G. Matijevič

RAVEove zvezde pred 220 milijoni let



modro: pritlikavke ($\log g > 3.5$)
rdeče: orjakinje ($\log g < 3.5$)

Podatki: Breddels idr. 2009, animacija G. Matijević & M. Vodopivec



RAVE & Ženevsko- Kopenhagenski pregled



modro: pritlikavke ($\log g > 3.5$)
rdeče: orjakinje ($\log g < 3.5$)

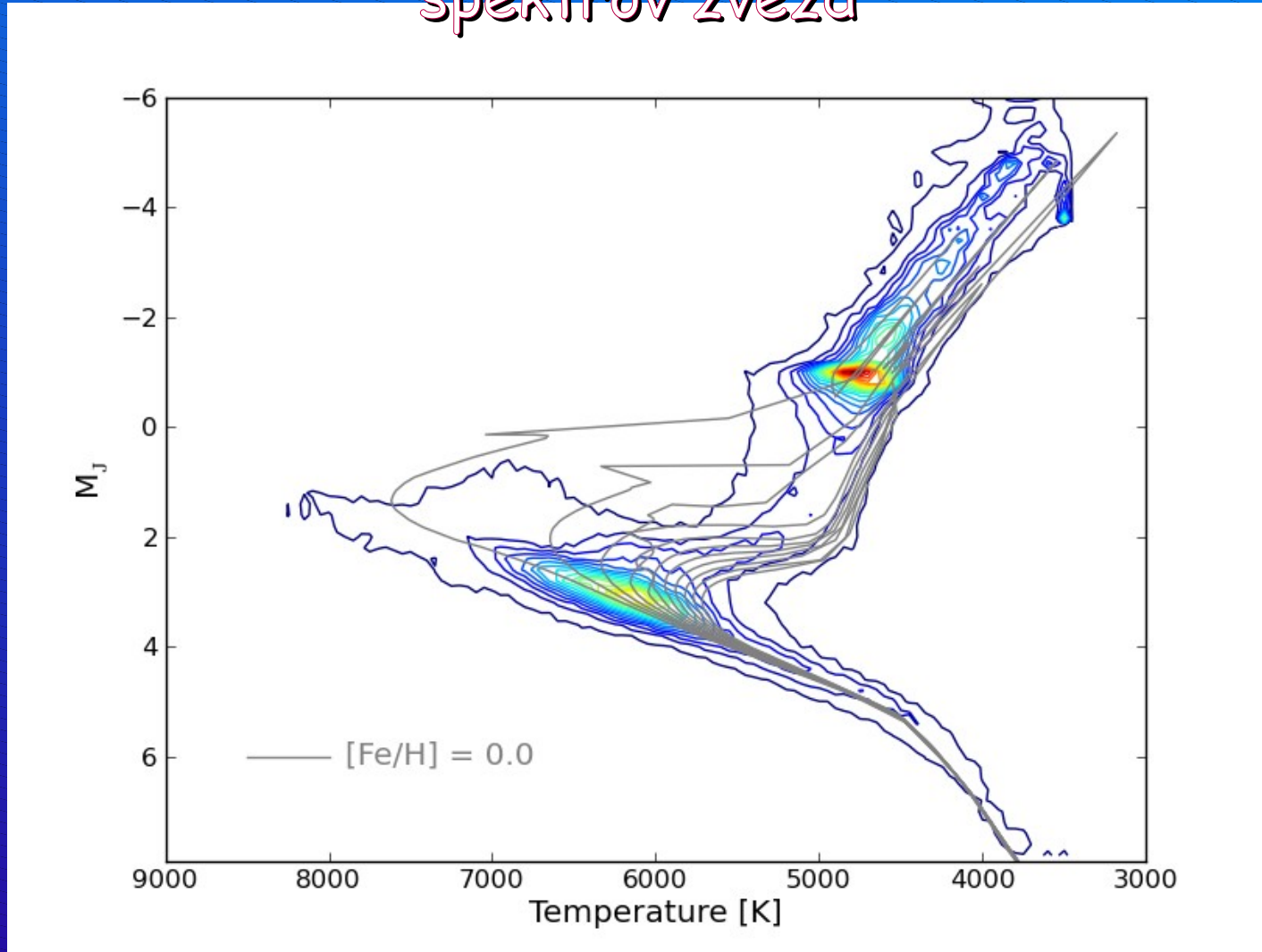
animacija G. Matijevič

RAVE & pregled neba Sloan

modro: pritlikavke ($\log g > 3.5$)
rdeče: orjakinje ($\log g < 3.5$)

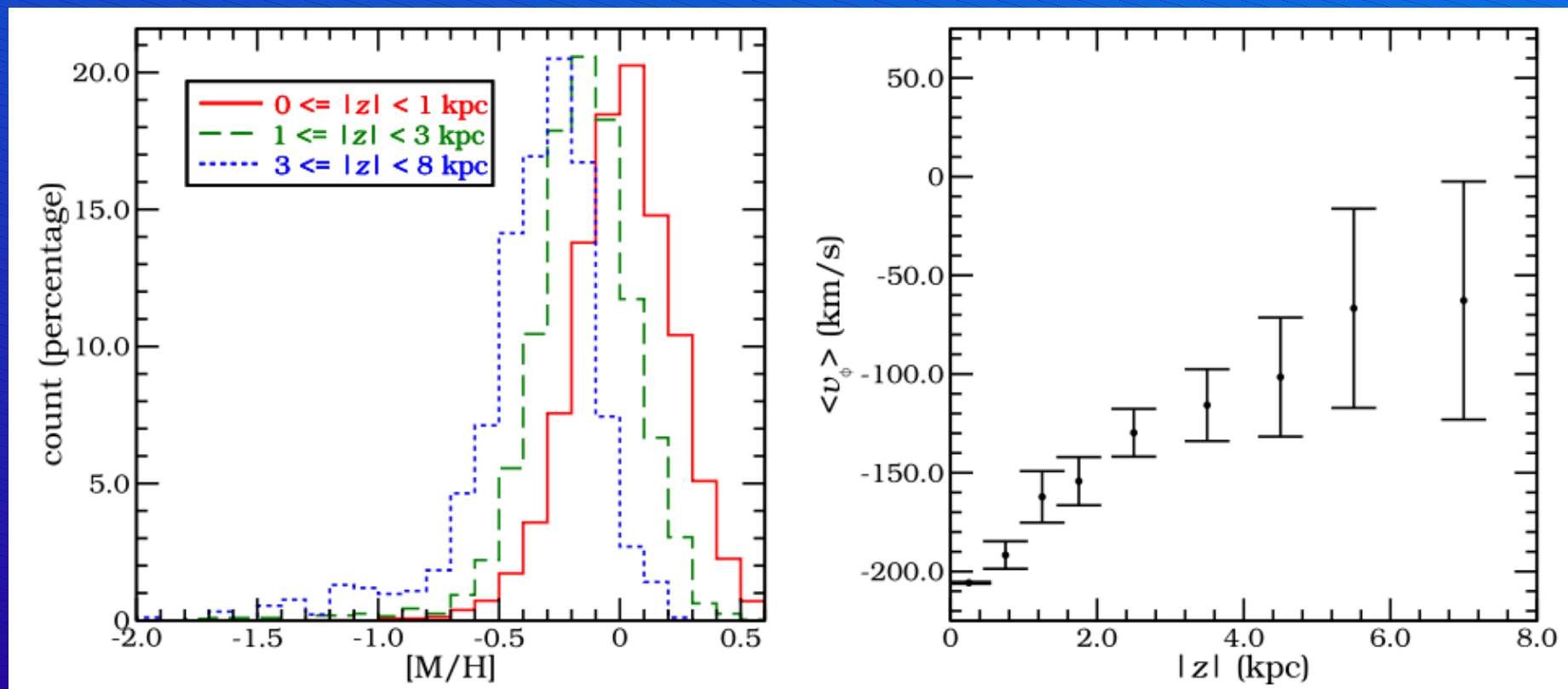
Podatki SDSS: P. Re Fiorentin,
Animacija: G. Matijevič.

Poleg položajev in hitrosti: vrednosti fizikalnih parametrov iz RAVEovih spektrov zvezd



Kovinskost in različna kinematika

Breddels idr. 2010



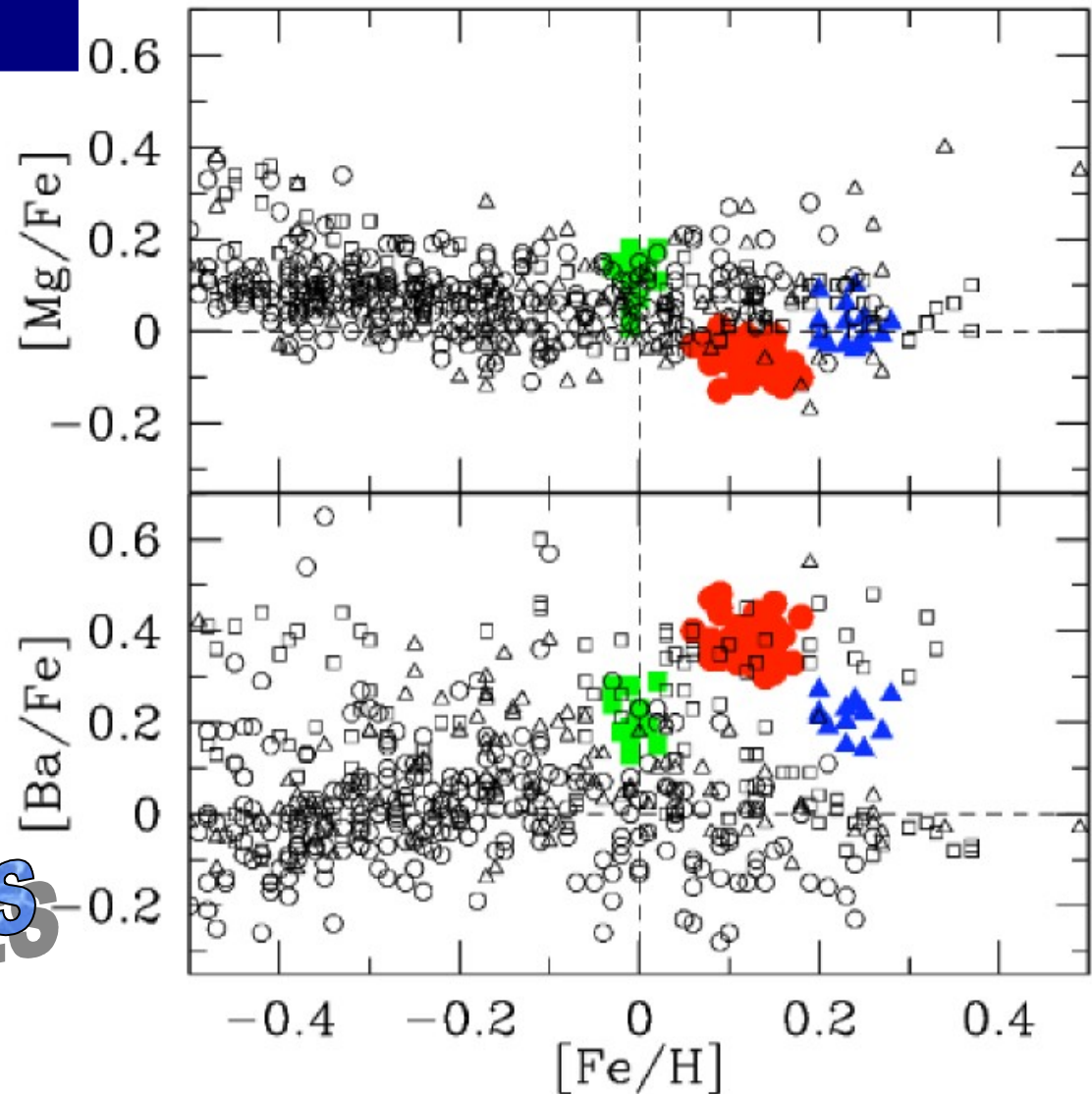
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Prihodnost: kemično označevanje

Demonstracija
detekcije odprte
kopice.

De Silva, Freeman & Bland-Hawthorn (2009)

- ▲ HR1614 moving group
- Hyades
- Collinder 261 open clusters



Projekt HERMES

Zanimiva prihodnost

RAVE

ESO-Gaia

Hermes-Galah

Gaia

...

**Tako bomo sčasoma bolje razumeli
zgodovino vesolja,
ki jo lahko na kratko povzamemo
z mislijo E.R.Harrisona (1995):**

**Vodik je lahek plin brez vonja, ki se,
če mu damo dovolj časa, spremeni v ljudi.**

Zanimiva prihodnost polna presenečenj...

RAVE

ESO-Gaia

Hermes-Galah

Gaia

...

