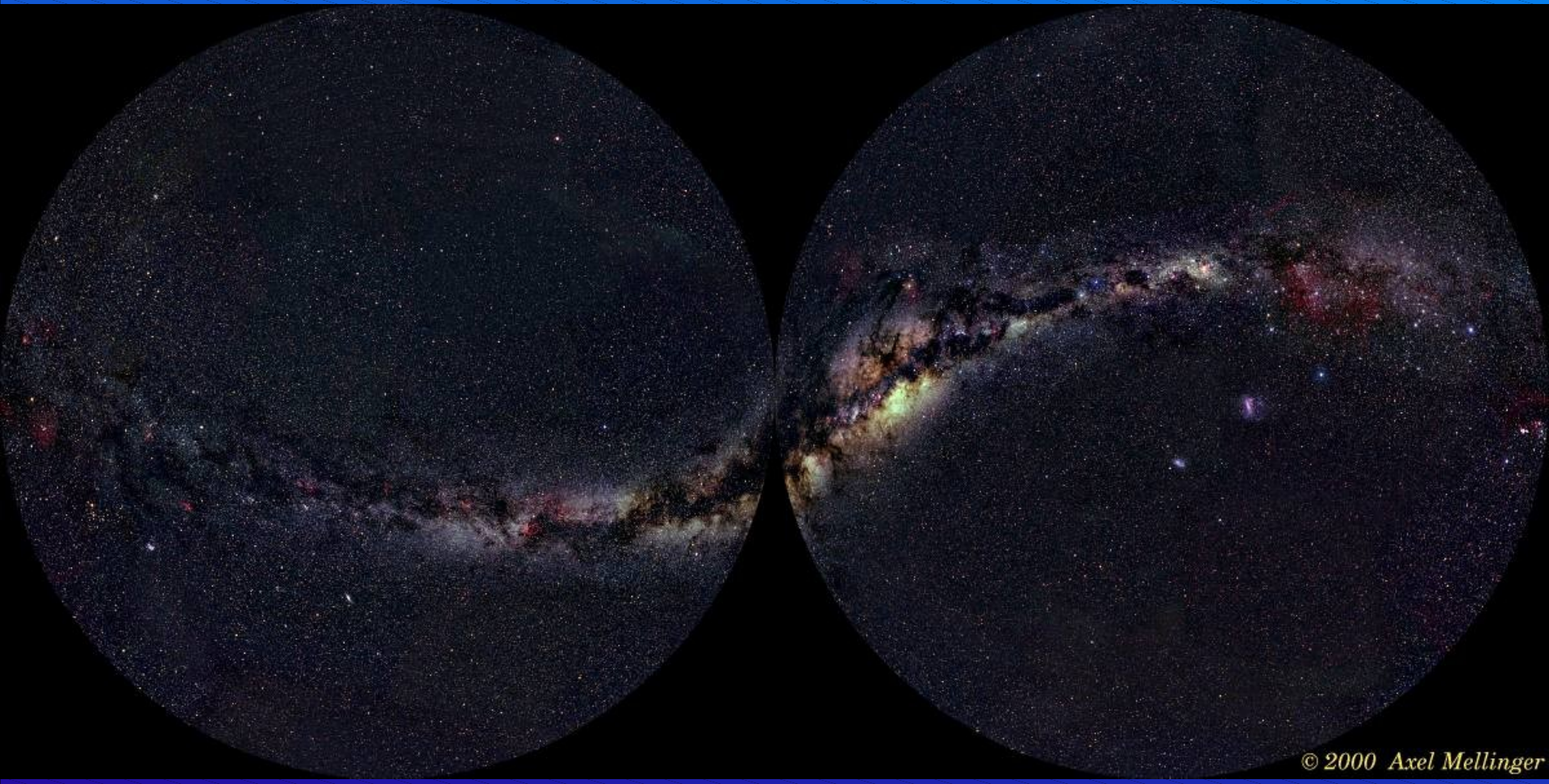
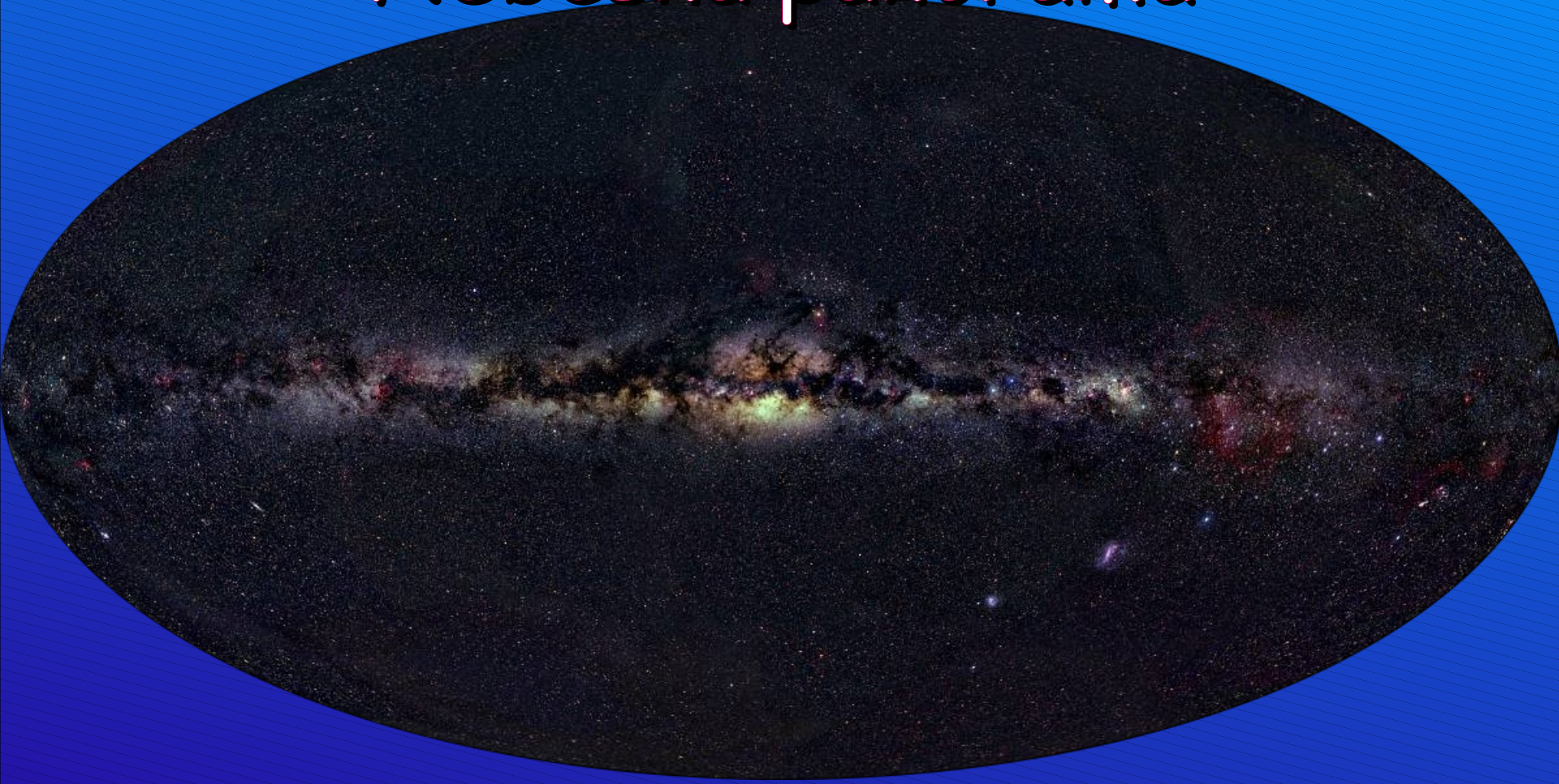
# Merjenje razdalj v vesolju

Tomaž Zwitter
Univerza v Ljubljani, Fakulteta za matematiko in fiziko

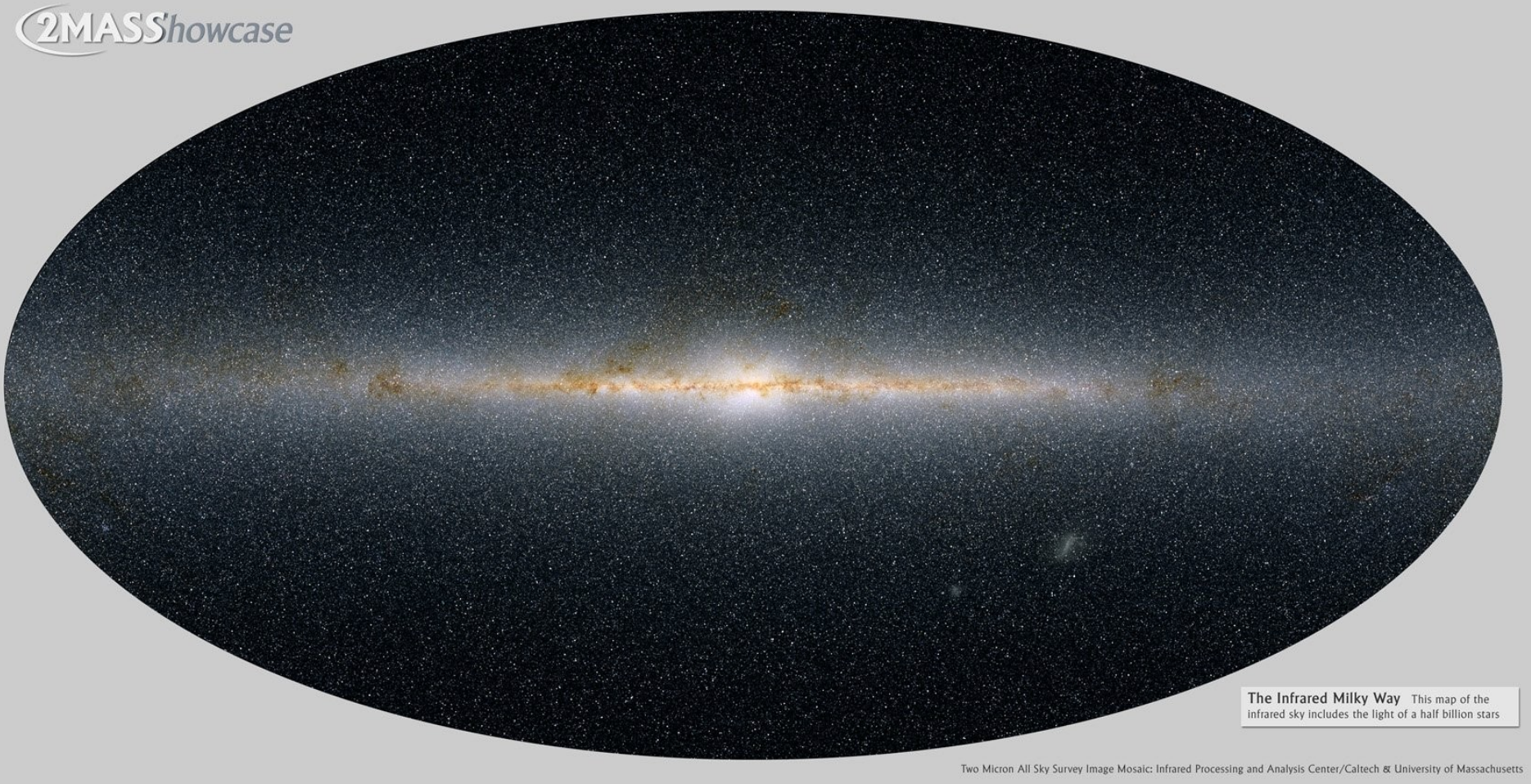
# Nebesna panorama



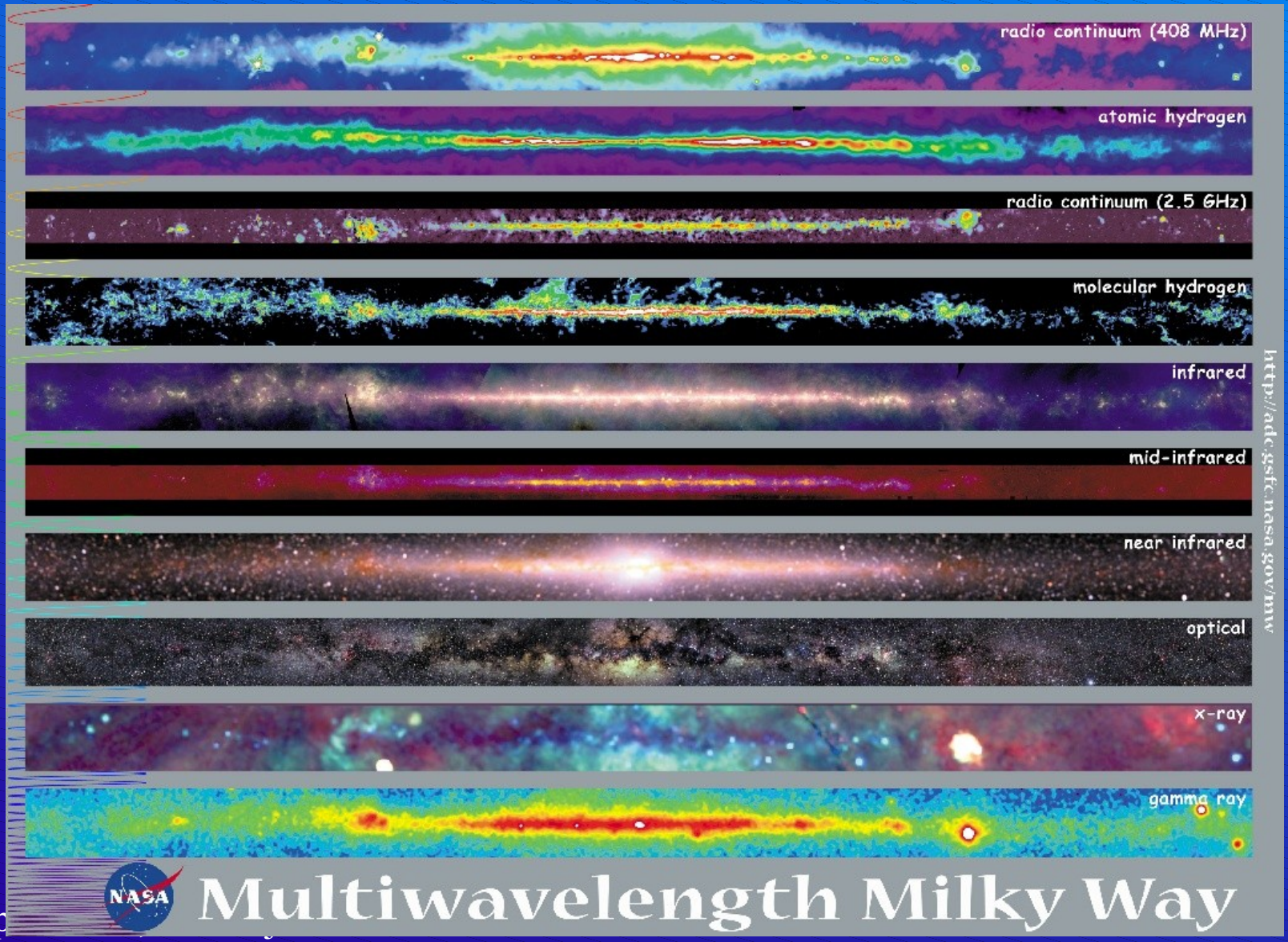
# Nebesna panorama



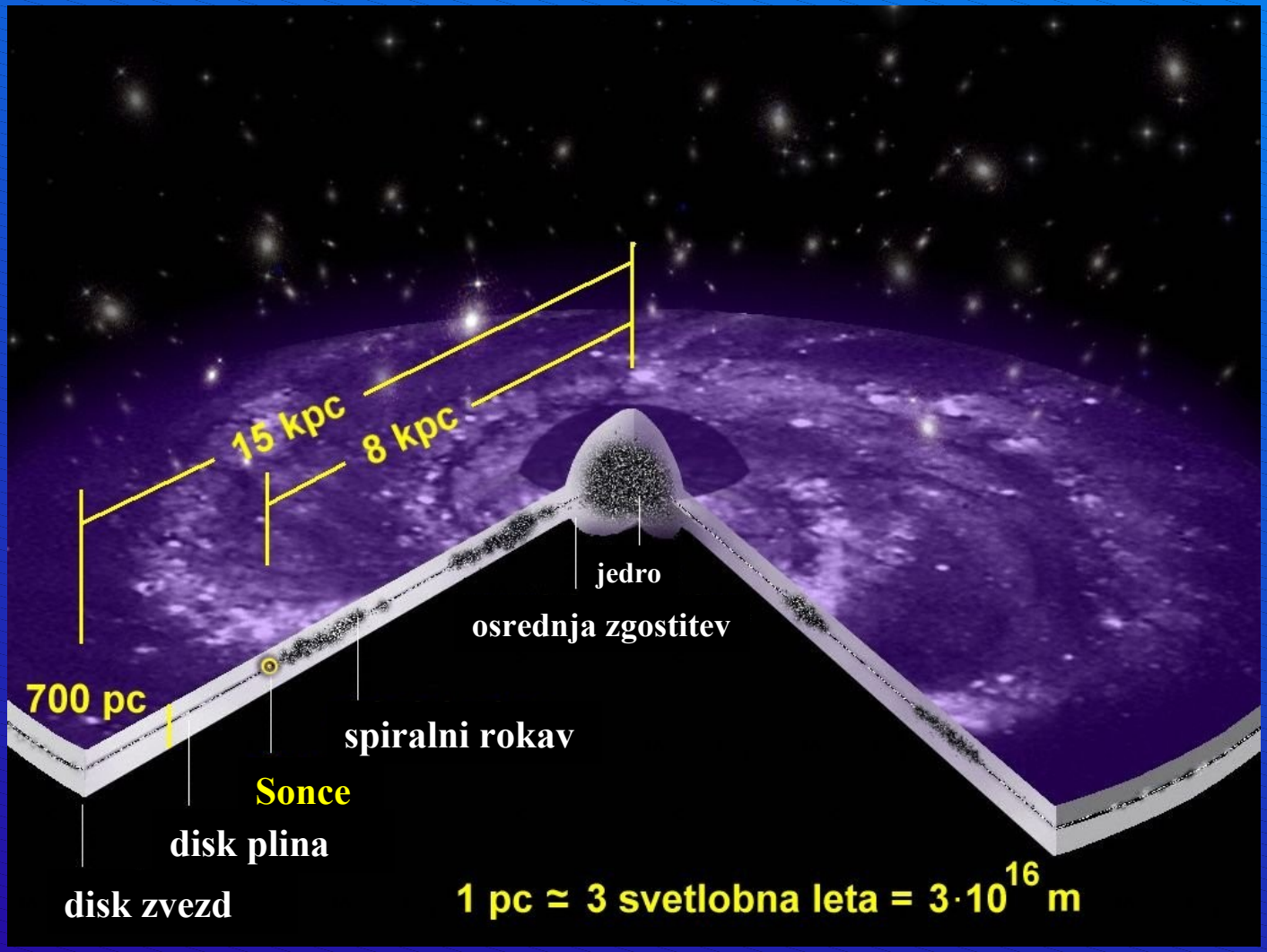
# Nebesna panorama v infrardečem



# Naša Galaksija v različnih vrstah svetlobe



# Naša Galaksija: pogled od zunaj



# Naša Galaksija: pogled 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 separate stellar populations that compose the central bulge *(reddish yellow)* and the spiral disk *(blue).* (NGC 1232 image courtesy of the European Southern Observatory.)

# Primerjava razdalj do zvezd in do galaksij

# Galaksije lahko trčijo

Par galaksij
NGC 4038 & NGC4039
imenovanih tudi „Anteni“

A possible collision of our Galaxy with Andromeda

Collision of galaxies with prominent black holes

# Motivacija za raziskave naše Galaksije

'galaktična arheologija':

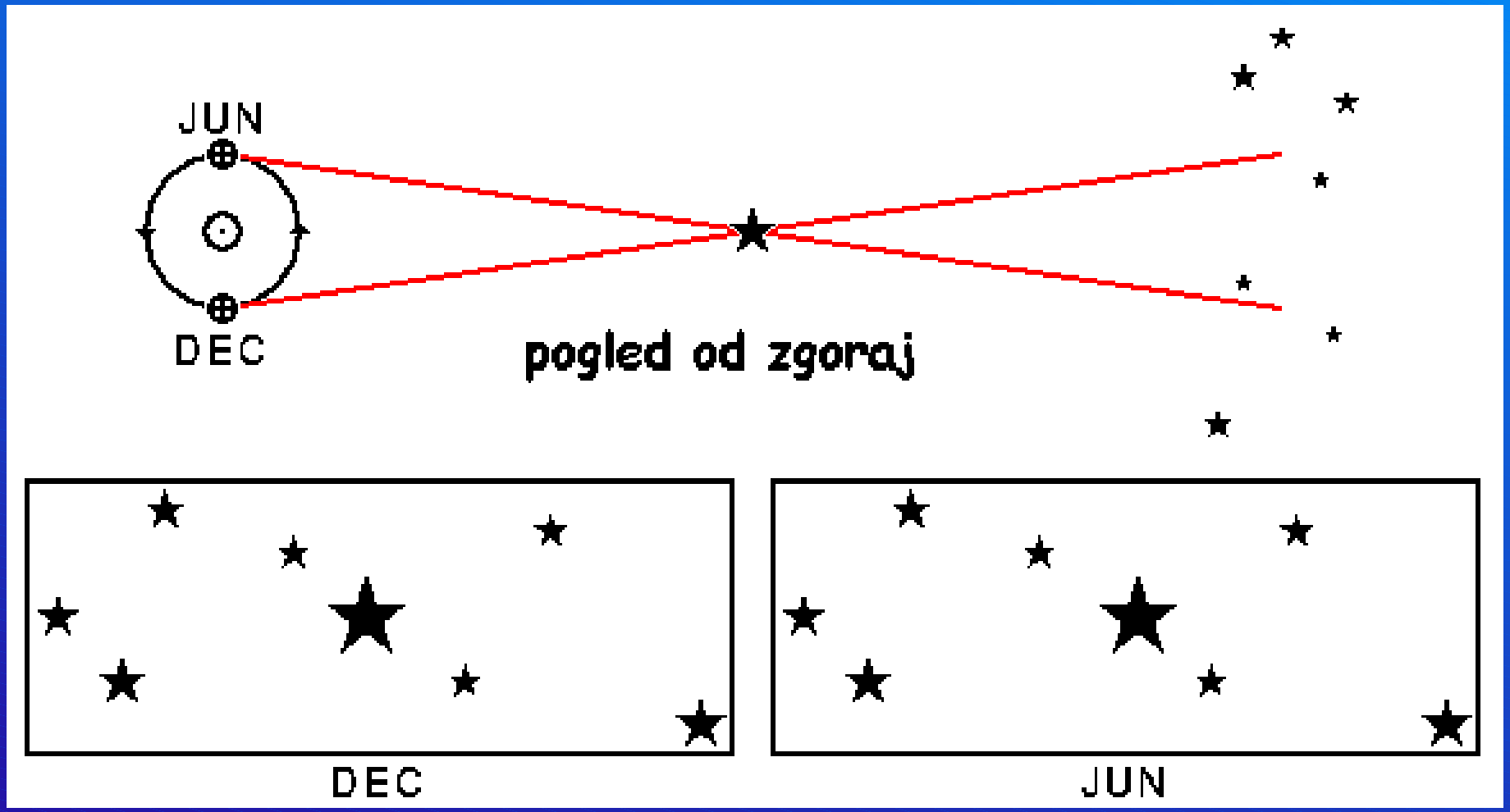
- zvezde naše Galaksije so blizu in zato svetle,
- vsako zvezdo lahko opazujemo zase (v NGC 891: 1 pc = 0,02"),
- dobimo 6-D informacijo (položaj v prostoru + vektor hitrosti).


Vendar:

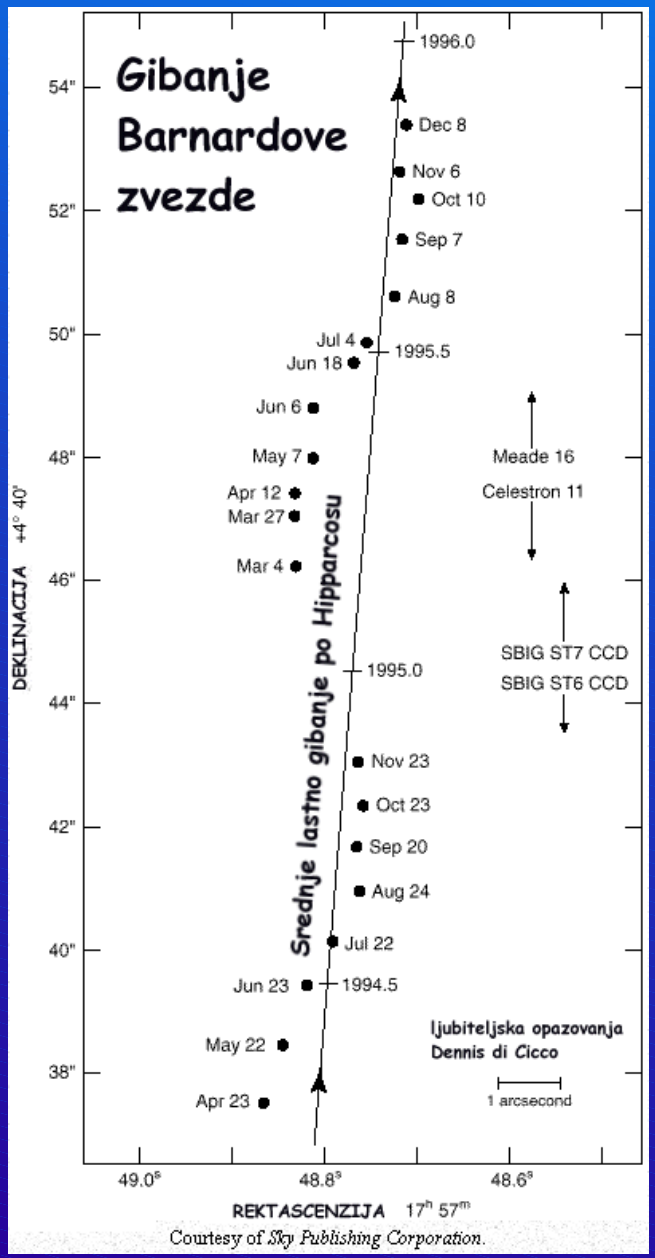
- smo znotraj,
- preučiti moramo znaten delež od

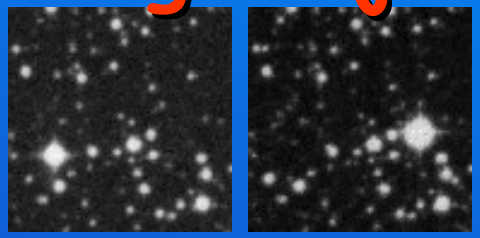
  > 100 milijard zvezd v naši Galaksiji.

# Razdalje do zvezd s paralakso

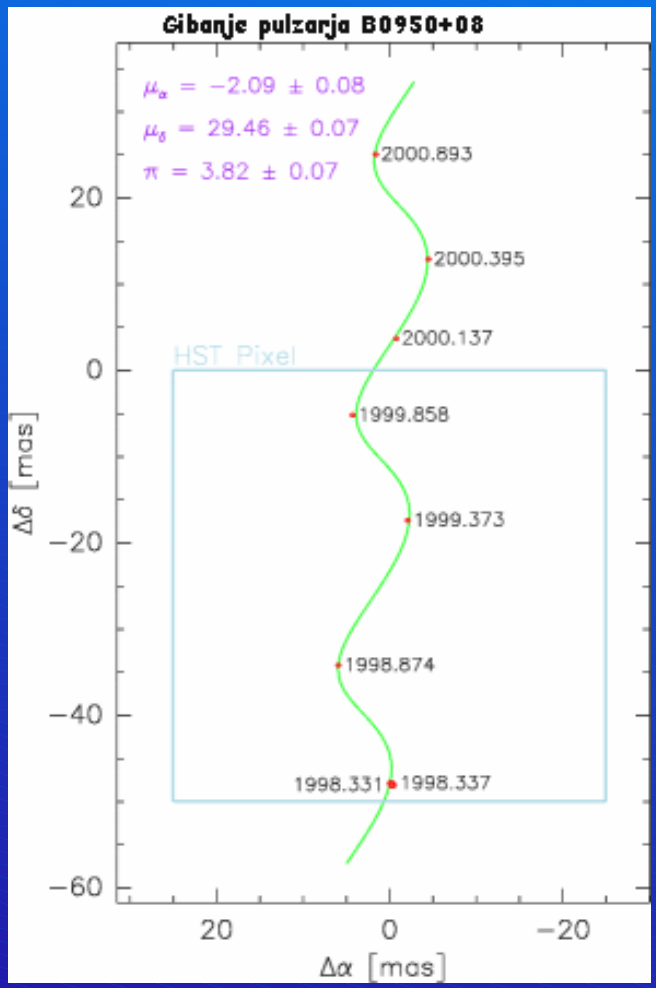


# Paralaksa in lastno gibanje



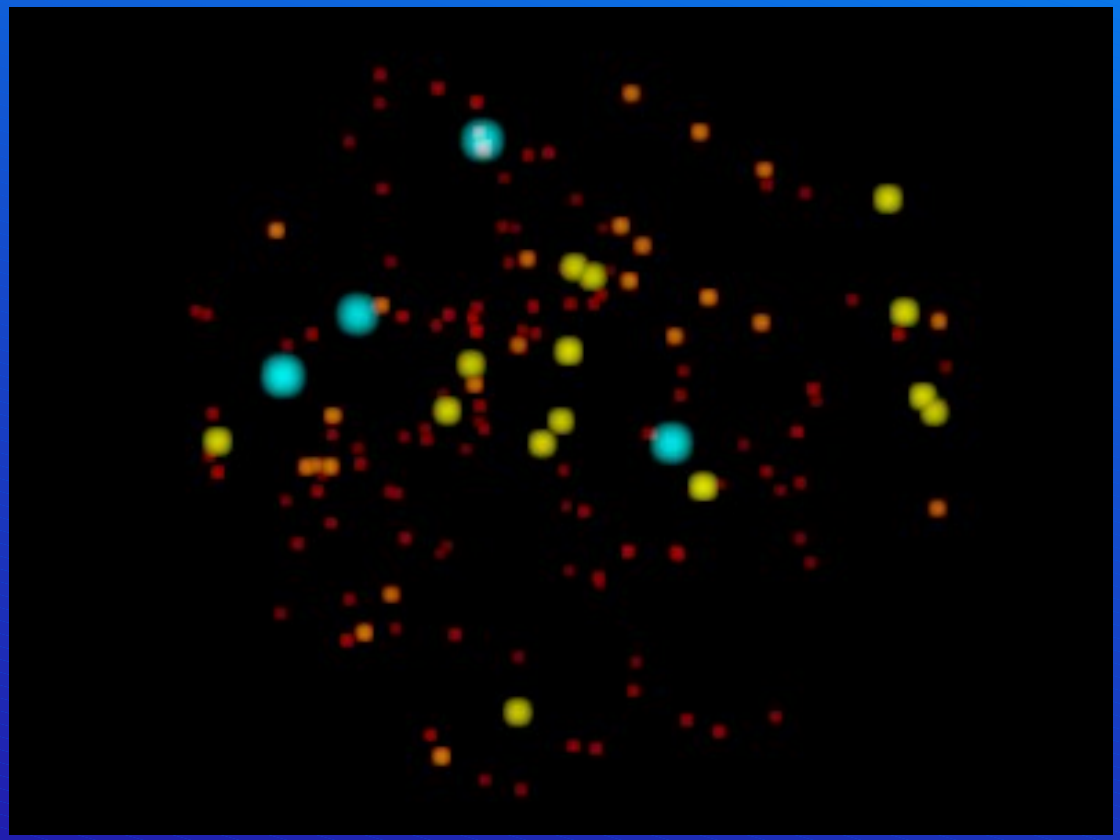



Lastno gibanje Proksime Kentavra med letoma 1976 (levo) in 1993 (desno).




Gibanje Barnardove zvezde v vidni svetlobi (levo) in pulzarja B0950+08 v radijski svetlobi (desno).

# Oddaljenost s paralakso: satelit Hipparcos Evropske vesoljske agencije



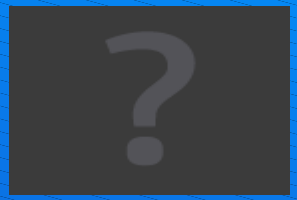
Položaj 150 najbljižjih zvezd (d<9 pc) po meritvah satelita Hipparcos.
Barva iznačuje izsev zvezde:
●: L > 10 $L_{Sonce}$, ●: 1-10 $L_{Sonce}$, ●: 0.1-10 $L_{Sonce}$, ●: <0.1 $L_{Sonce}$

# Optični spektroskopski pregledi zvezd

| Ime | Obdobje | Število zvezd | Teleskop | Spektroskopska ločljivost | S/N | Naš prispevek |
|---|---|---|---|---|---|---|
| **RAVE** www.rave-survey.org | 2003-2013 | 483,330 | 1,2-m UK Schmidt | 7500 | ~40 | operativno vodenje, razdalje zvezd, morfološka klasifikacija, dvojne zvezde, posebni tipi zvezd, medzvezdni prostor |
| **Gaia-ESO** www.gaia-eso.eu/ | 2012-2017 | 125,000 | 8-m VLT | ~17500 | ~30 | medzvezdni prostor, morfološka klasifikacija, posebni tipi zvezd |
| **Gaia** gaia.esa.int | 2013-2019 | 20 milijonov | Vesoljska misija Gaia | 10500 & 5500 | ~4 | RVS: modul RVMask, modul za zmanjšanje šuma, začetni in referenčni katalog zvezd za RVS |
| **Hermes/GALAH** www.mso.anu.edu.au/galah/home.html | 2013-2019 | 1 milijon | 4-m AAO | 25000 & 50000 | 100 | vhodni katalog, opazovalna strategija, obdelava podatkov, morfološka klasifikacija, posebni tipi zvezd, medzvezdni prostor |

Sloan-SDSS je usmerjen predvsem v zvezde haloja in ima nižjo spektroskopsko ločljivost.

# RAdialnohitrostni Vesoljski Eksperiment



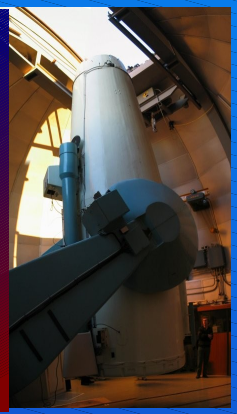
RAVE
RADIAL VELOCITY EXPERIMENT

2005-2013: 100% zakup teleskopa UK-Schmidt @ AAO


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.; 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.; Kos, J.; Kujken, K.; Matijevič, 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.; Žerjal, M.

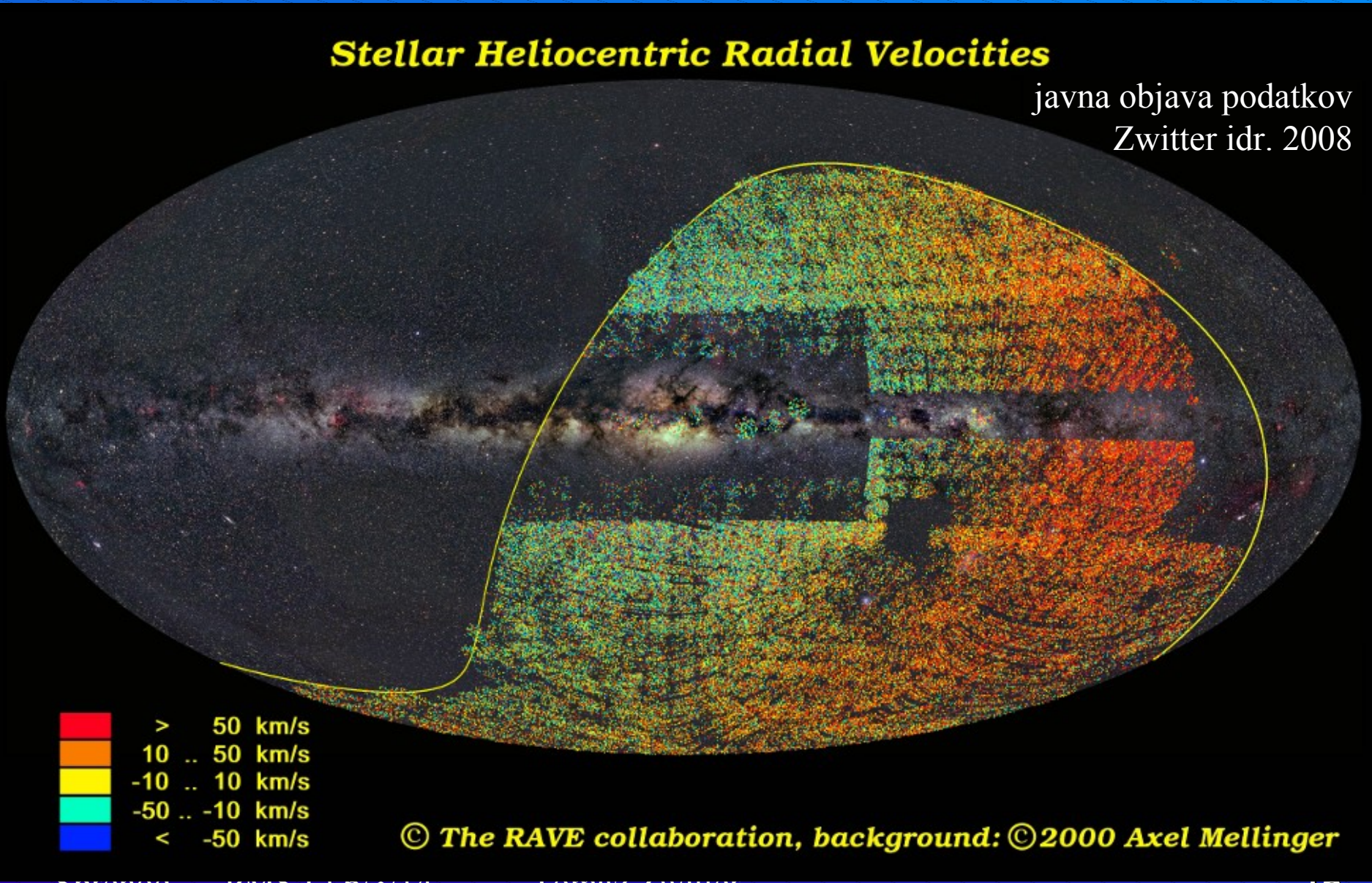

Zbrano:

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



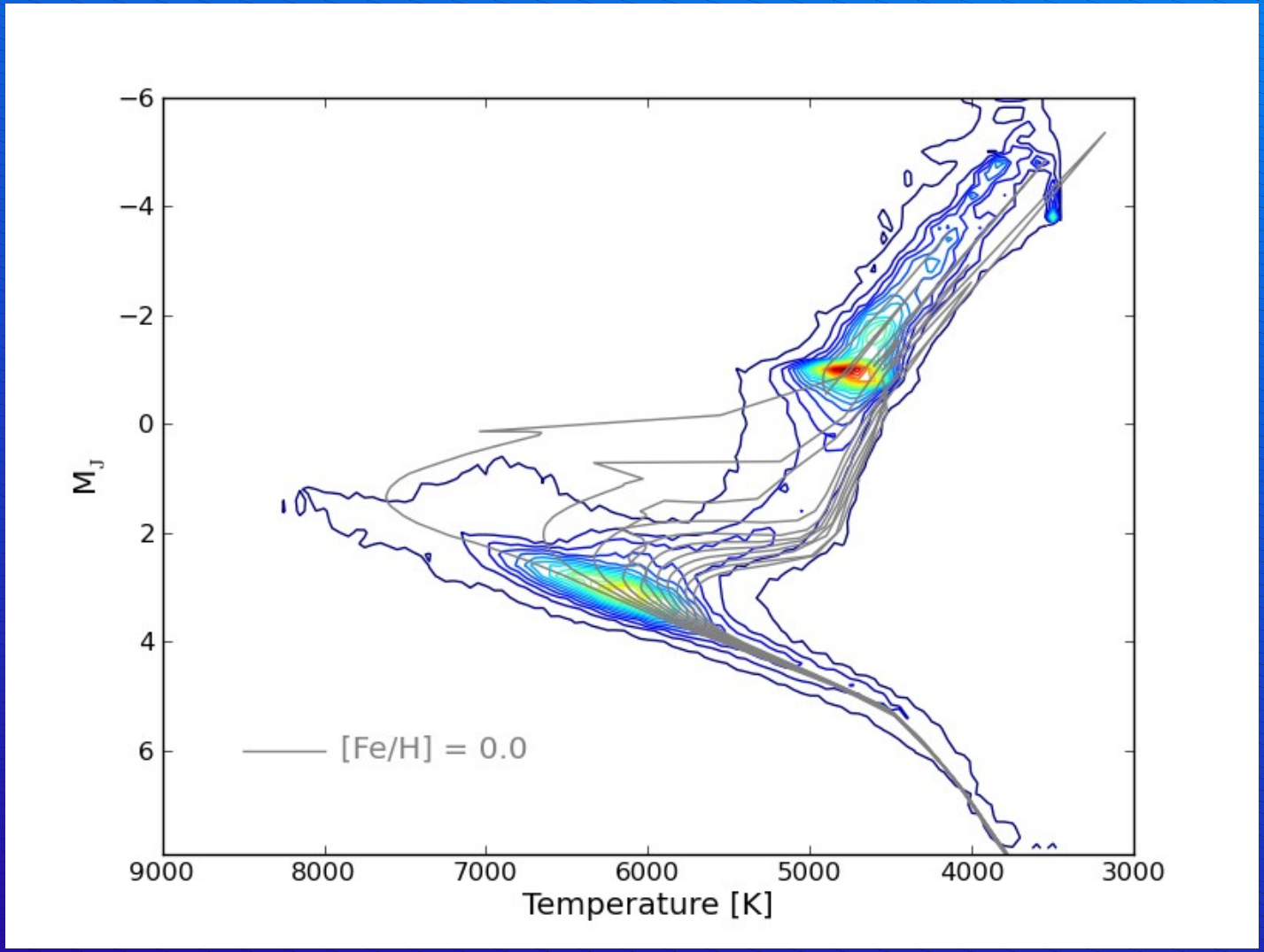
6-stopinjsko zorno polje,
do 138 optičnih vlaken.

# Izmerjene radialne hitrosti zvezd




javna objava podatkov
Zwitter idr. 2008

# RAVE: poleg hitrosti tudi meritve fizikalnih razmer v atmosferah opazovanih zvezd




Zwitter idr. (2010)

# 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. Matijevič & M. Vodopivec

# RAVE & pregled Geneva-Copenhagen

animacija G. Matijevič

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

# RAVE & pregled Sloan

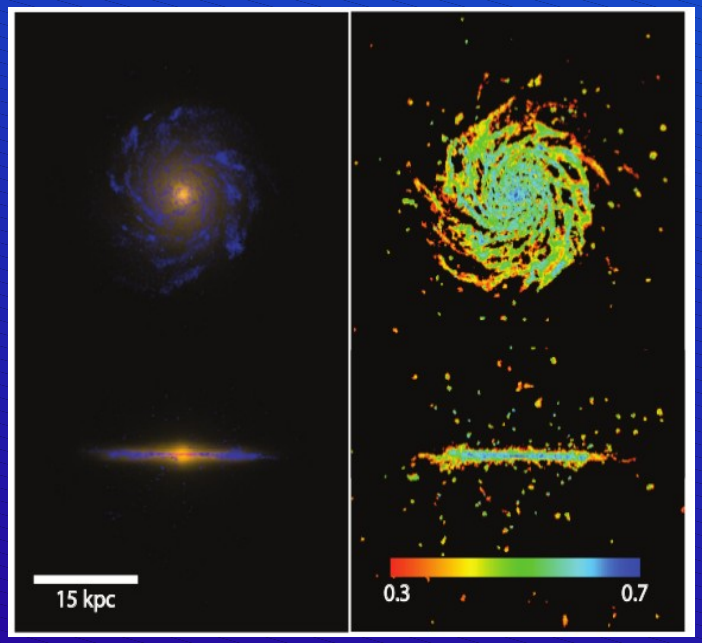
Data SDSS: P. Re Fiorentin,
Animation: G. Matijevič.

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

# Hitrosti zvezd v Galaksiji

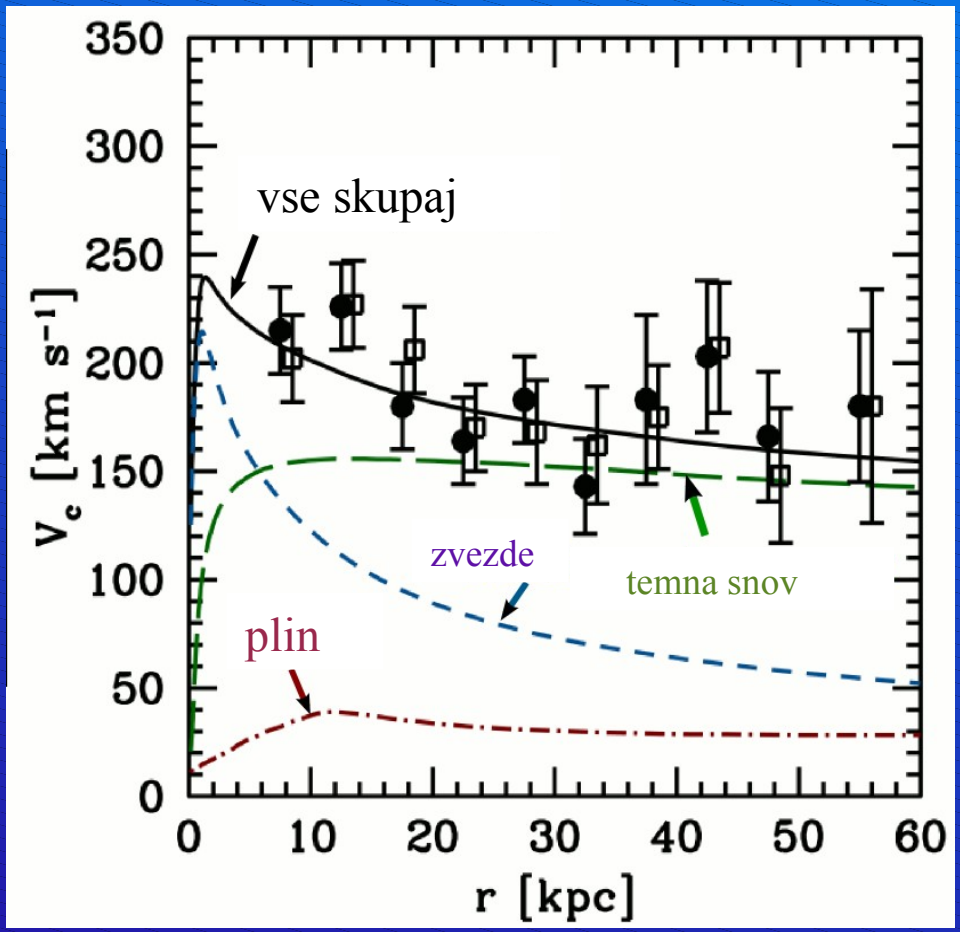
↓ simuliran pogled na Galaksijo:

- levo: vidna in UV svetloba,
- desno: plin (barve označujejo delež neioniziranih atomov).



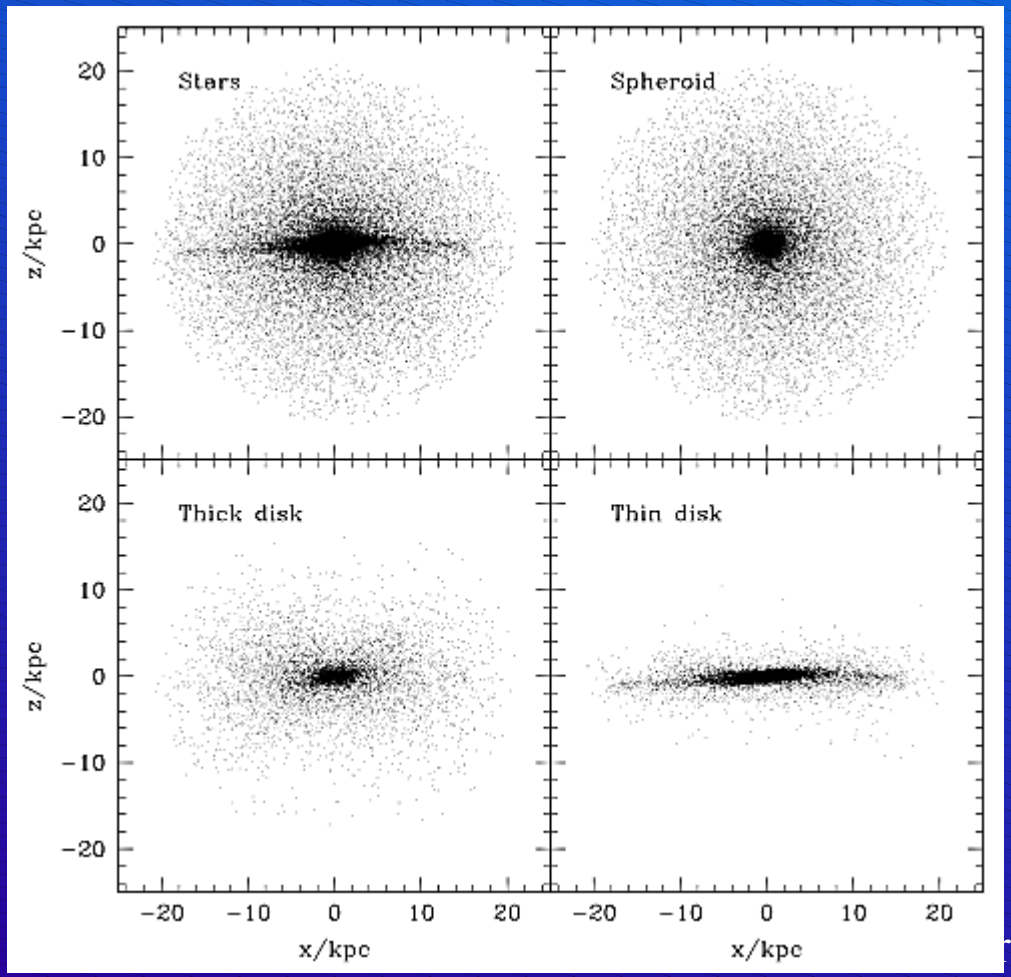

↓ Hitrost v disku

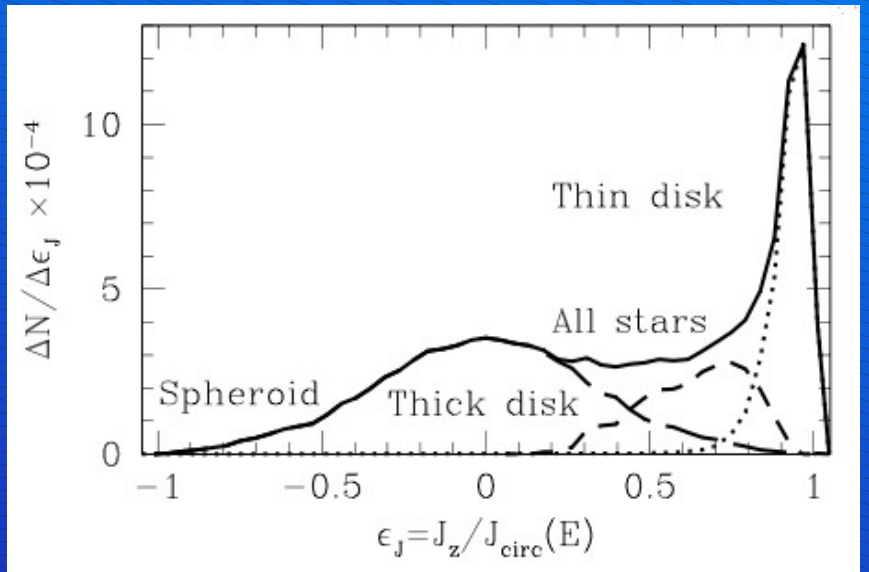
Guedes idr. 2011



# Simuliran pogled na Galaksijo

Abadi idr. (2003)




| | značilna razdalja (R) | značilna višina (Z) |
|---|---|---|
| tanek disk | 3.5 kpc | 0.25 kpc |
| debel disk | ~ 3 kpc | ~ 1 kpc |

# Simulacija kanibalističnega nastanka naše Galaksije

Steinmetz & Navarro 2002

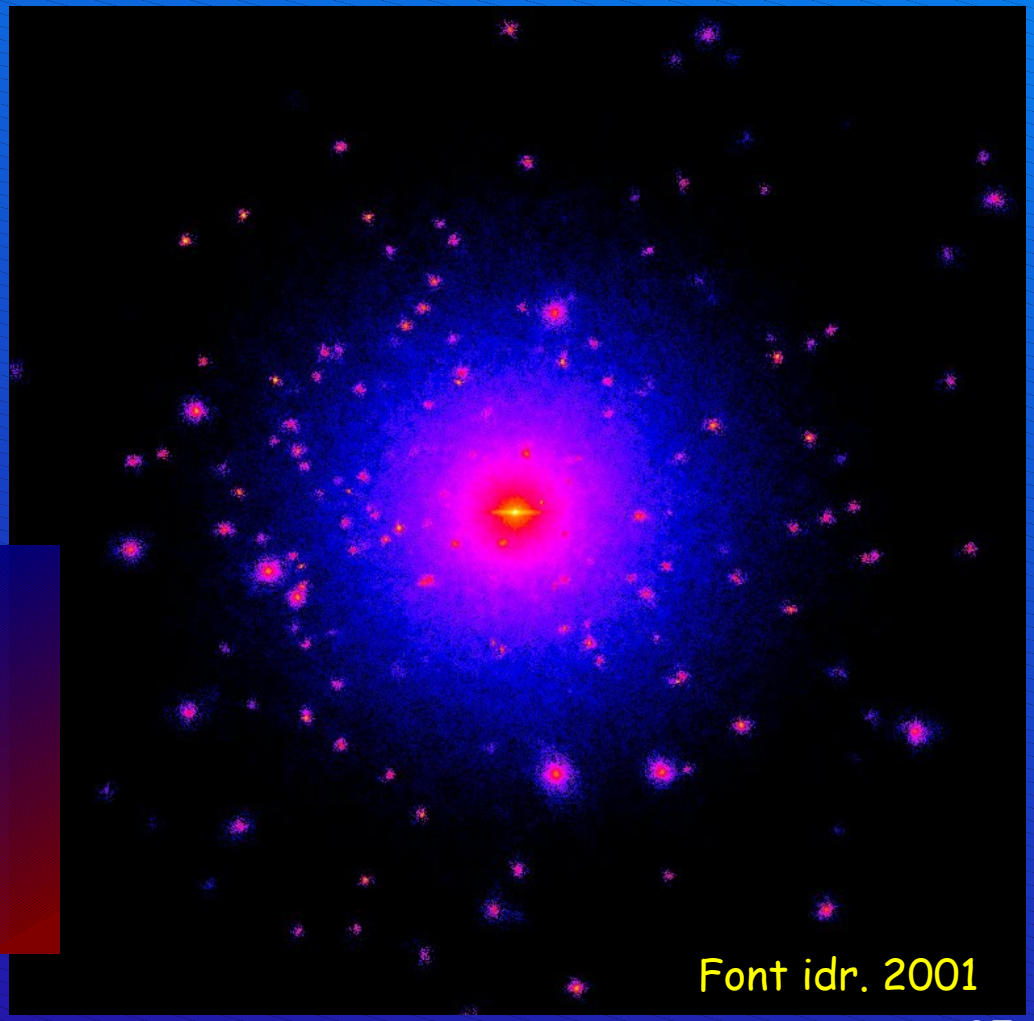
Prikazana je le običajna snov.

Tanek disk nastane, ko je imelo vesolje tretjino današnje velikosti (z ~ 2).

▲pogled od zgoraj ▲ ▲pogled od strani▲

# Simulacija kanibalističnega nastanka naše Galaksije

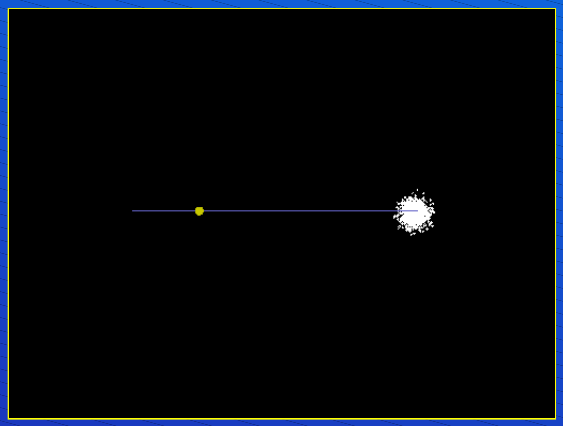
Narisana je vsa (tudi temna) snov.



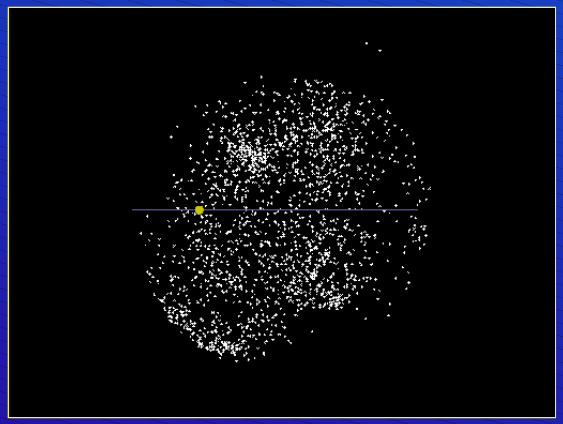

Gladko viskozno krčenje, ki ohranja vrtilno količino vpadnega materiala je edini način za nastanek velikih galaktičnih diskov, kot je naš.

# Simulacija galaktičnega kanibalizma

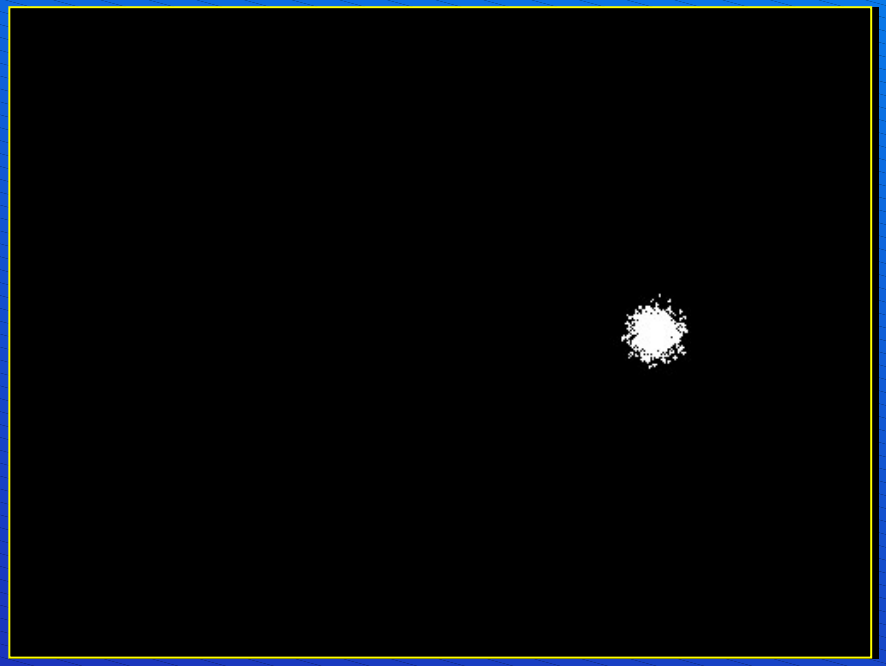
Avtorica simulacije Amina Helmi



začetek



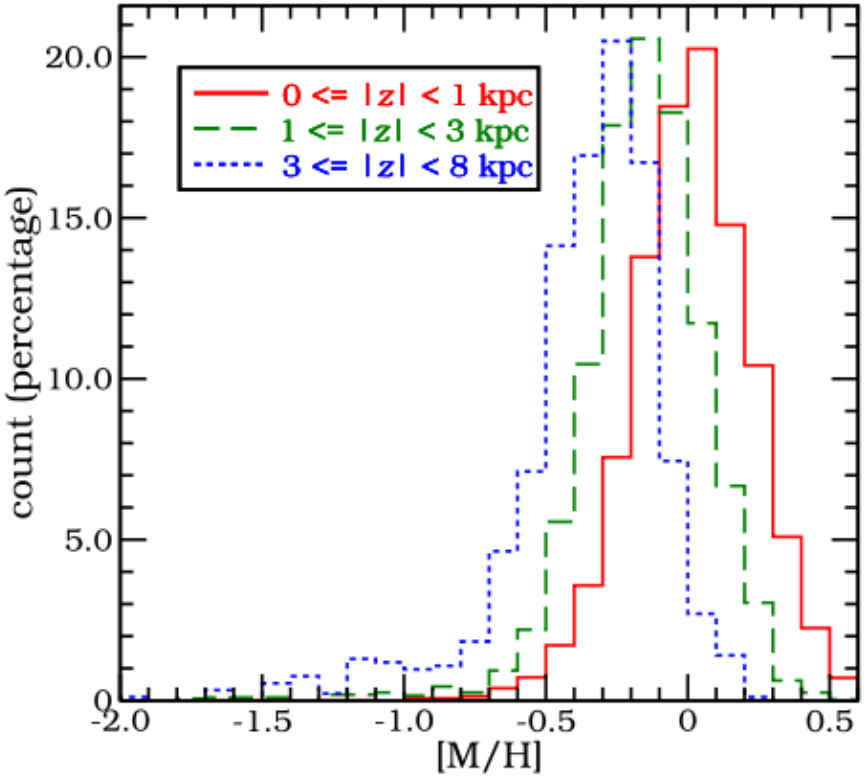
$10^{10}$ let kasneje

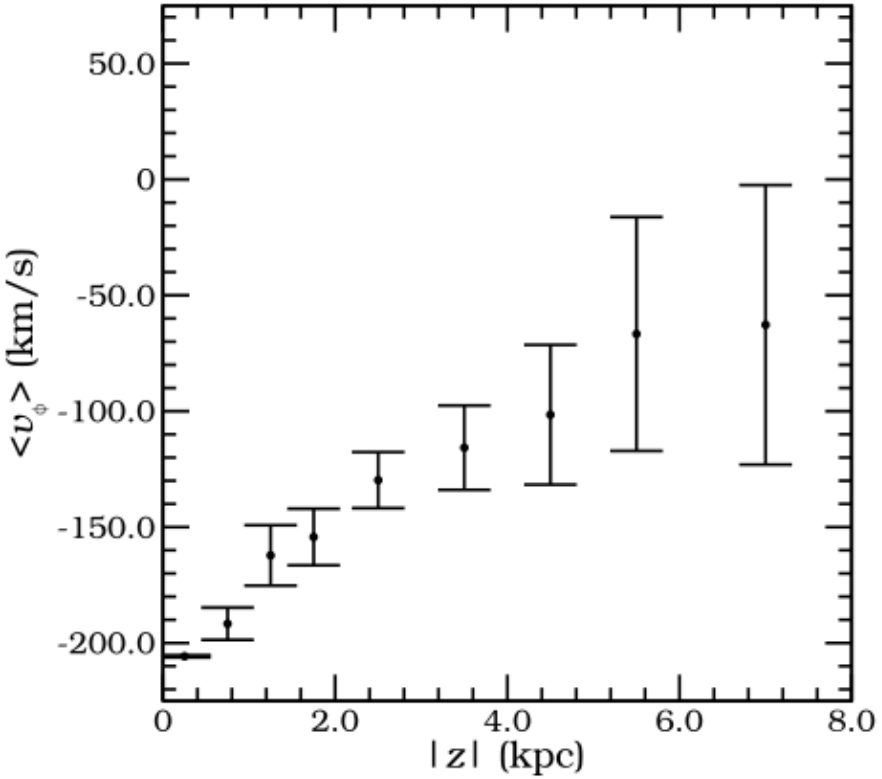


Narisane so le zvezde, ki pripadajo požrti galaksiji. Modra črta j ravnina Rimske ceste, rumena pika pa položaj našega Sonca.

# Preplet kemične sestave in gibanja

Breddels idr. 2010



# Rezultati projekta RAVE v letu 2013


- Binney, J., and 18 colleagues: New distances to RAVE stars. Monthly Notices of the Royal Astronomical Society 437, 351-370 (2014)
- Kordopatis, G., and 19 colleagues: In the thick of it: metal-poor disc stars in RAVE. Monthly Notices of the Royal Astronomical Society 436, 3231-3246 (2013)
- Kos, J., and 18 colleagues: Diffuse Interstellar Band at 8620 AA in RAVE: A New Method for Detecting the Diffuse Interstellar Band in Spectra of Cool Stars. The Astrophysical Journal 778, 86 (2013)
- Williams, M. E. K., and 26 colleagues: The wobbly Galaxy: kinematics north and south with RAVE red-clump giants. Monthly Notices of the Royal Astronomical Society 436, 101-121 (2013)
- Kordopatis, G., and 50 colleagues: The Radial Velocity Experiment (RAVE): Fourth Data Release. The Astronomical Journal 146, 134 (2013)
- Boeche, C., and 22 colleagues: Chemical gradients in the Milky Way from the RAVE data. I. Dwarf stars. Astronomy and Astrophysics 559, A59 (2013)
- Žerjal, M., and 17 colleagues: Chromospherically Active Stars in the RAdial Velocity Experiment Survey. (RAVE) I. The Catalog. The Astrophysical Journal 776, 127 (2013)
- Kos, J., Zwitter, T.: Properties of Diffuse Interstellar Bands at Different Physical Conditions of the Interstellar Medium. The Astrophysical Journal 774, 72 (2013)
- Golubov, O., and 15 colleagues: The asymmetric drift, the local standard of rest, and implications from RAVE data. Astronomy and Astrophysics 557, A92 (2013)
- Boeche, C., and 22 colleagues: The relation between chemical abundances and kinematics of the Galactic disc with RAVE. Astronomy and Astrophysics 553, A19 (2013)

# Objave projekta RAVE

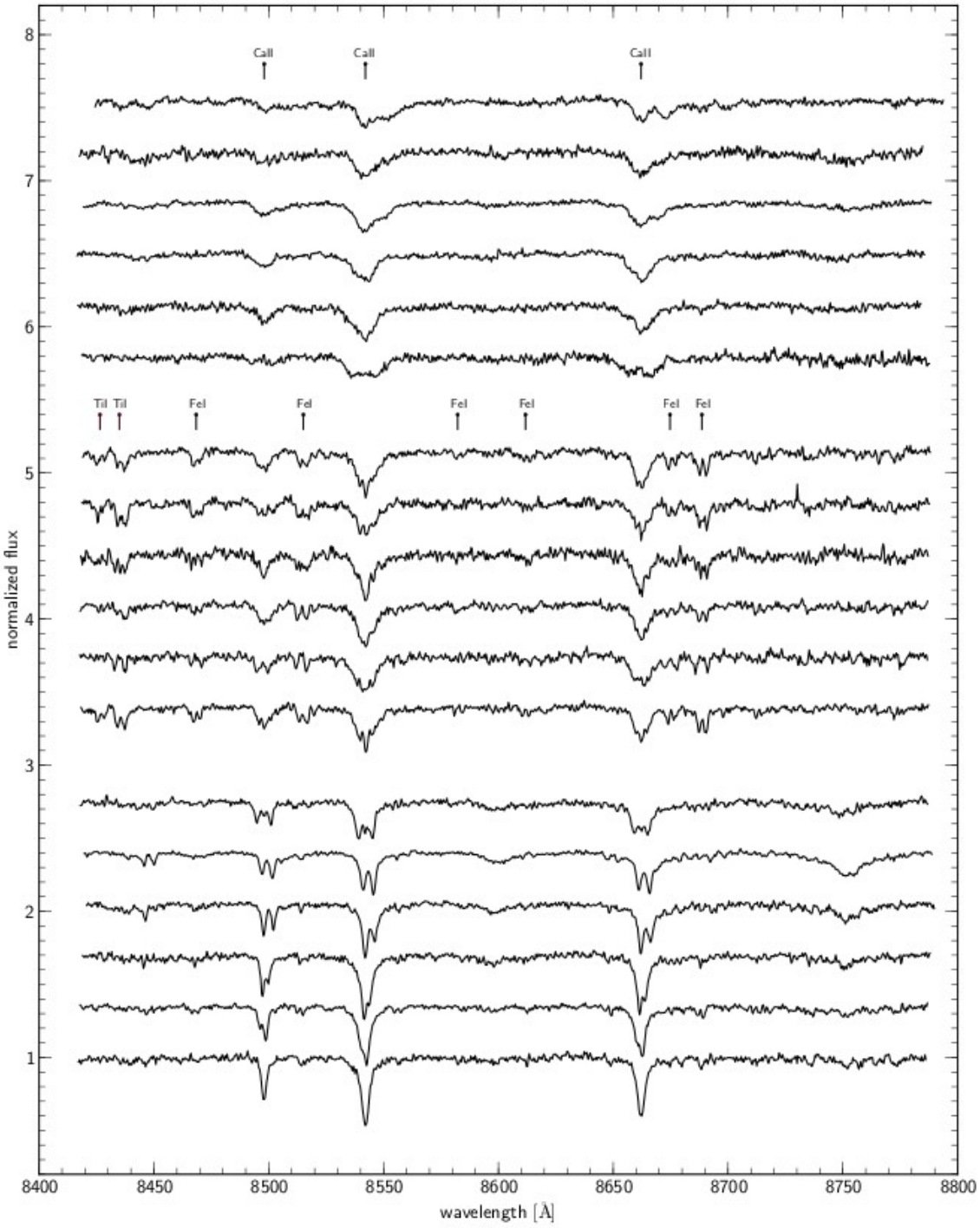
| Revija/leto | IF | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | skupaj |
|---|---|---|---|---|---|---|---|---|---|---|
| Astrophysical Journal Supplement | 16.2 | | | | | | | 1 | | **1** |
| Astrophysical Journal | 6.7 | | | | | 2 | 3 | | 3 | **8** |
| Astronomy & Astrophysics | 5.1 | | | 2 | 1 | 2 | 1 | 2 | 3 | **11** |
| Astronomical Journal | 5.0 | 1 | | 1 | | 1 | 3 | | 1 | **7** |
| Monthly Notices of the Royal Astr. Soc. | 4.9 | | | 3 | | | 4 | 2 | 3 | **12** |

# Posebne zvezde: dvojne zvezde

W UMa

RS CVn

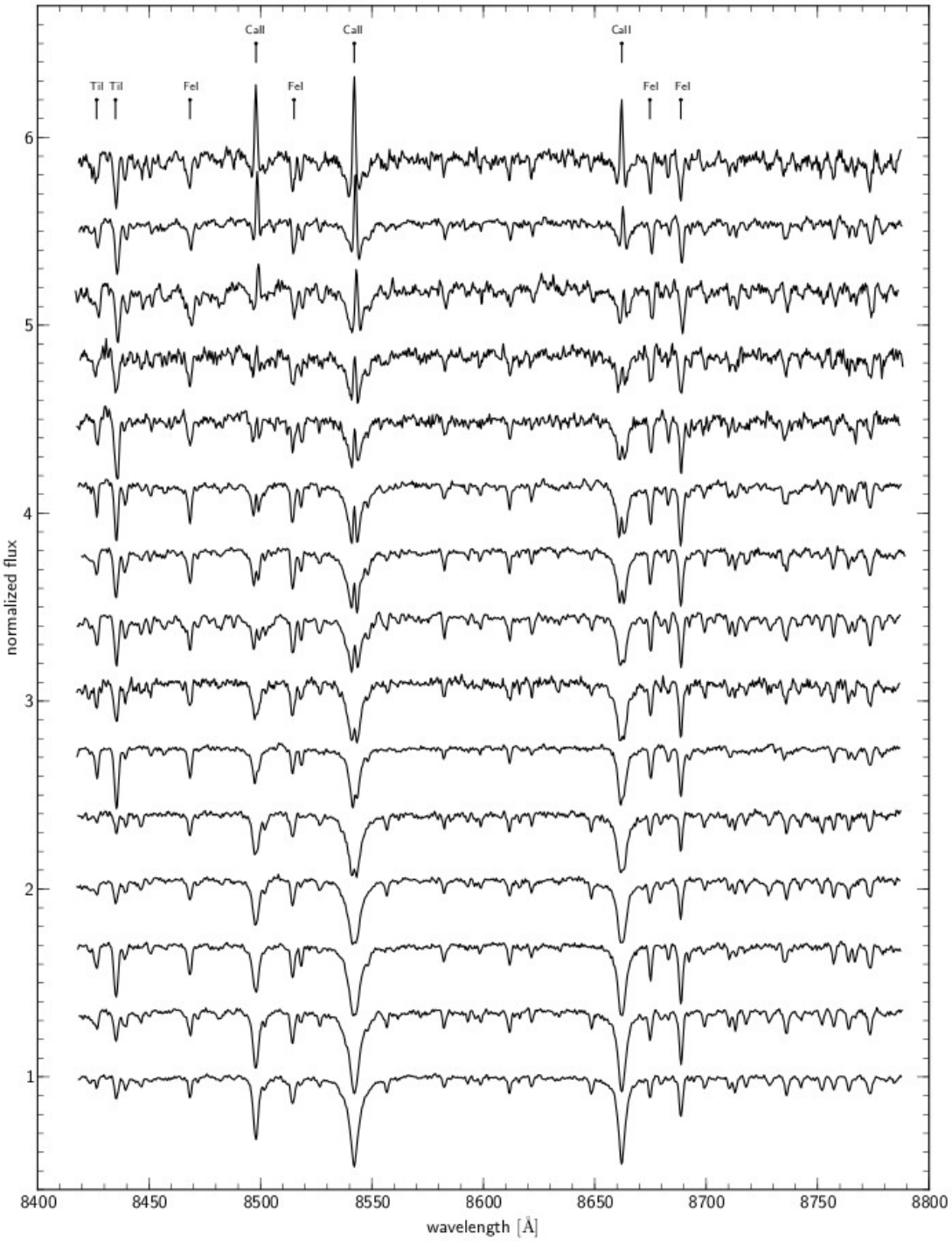
SB2




Matijevič idr. (2012)

# Posebne zvezde: emisija v kromosferi

večja aktivnost




Matijevič idr. (2012)

Žerjal et al. (2013)

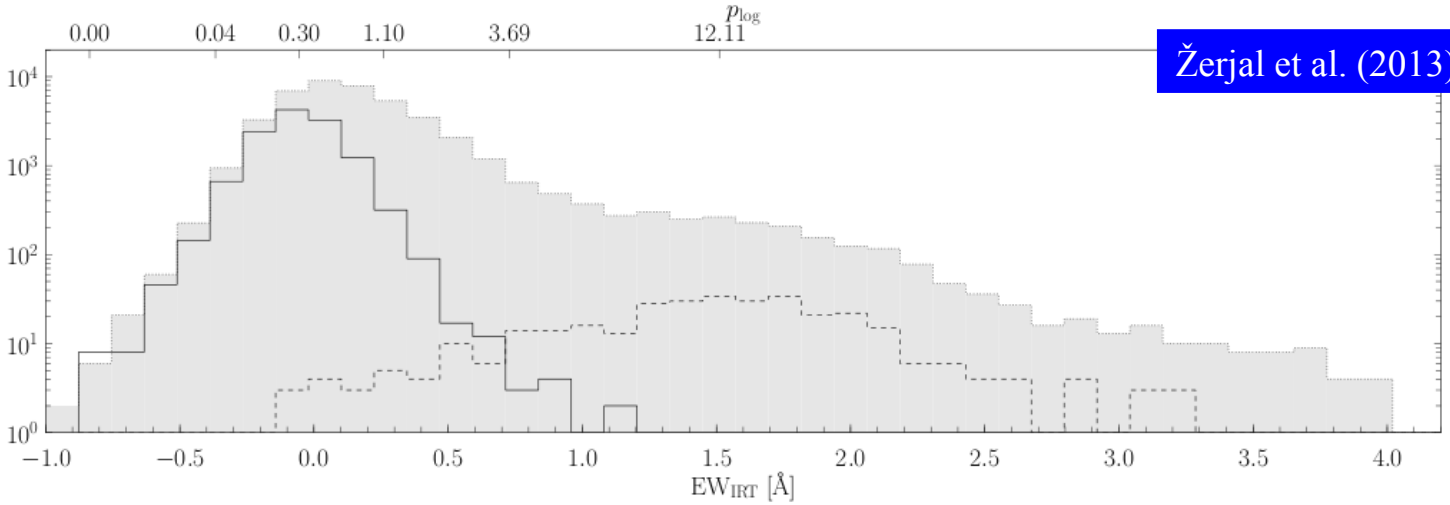



**Figure 6.** Distribution of $EW_{IRT}$ for active stars (gray histogram), normal stars (which are assumed to be inactive; solid line), and pre-main-sequence stars (selection is based on the SIMBAD classification of RAVE stars; dashed line). The scale is logarithmic. $p_{\log}$ is a measure of the probability that a star with given $EW_{IRT}$ differs from an inactive spectrum. $p_{\log}$ values correspond to $5\sigma$ and $2\sigma$ below zero and $2\sigma$, $5\sigma$, and $10\sigma$ above zero. A $p_{\log}$ value of 0.3 corresponds to $EW_{IRT} = 0$ Å.

# Katalog zvezd s kromosfersko emisijo

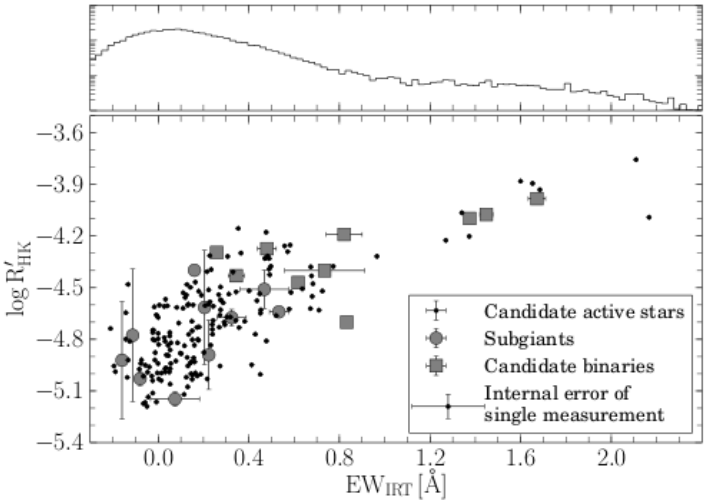
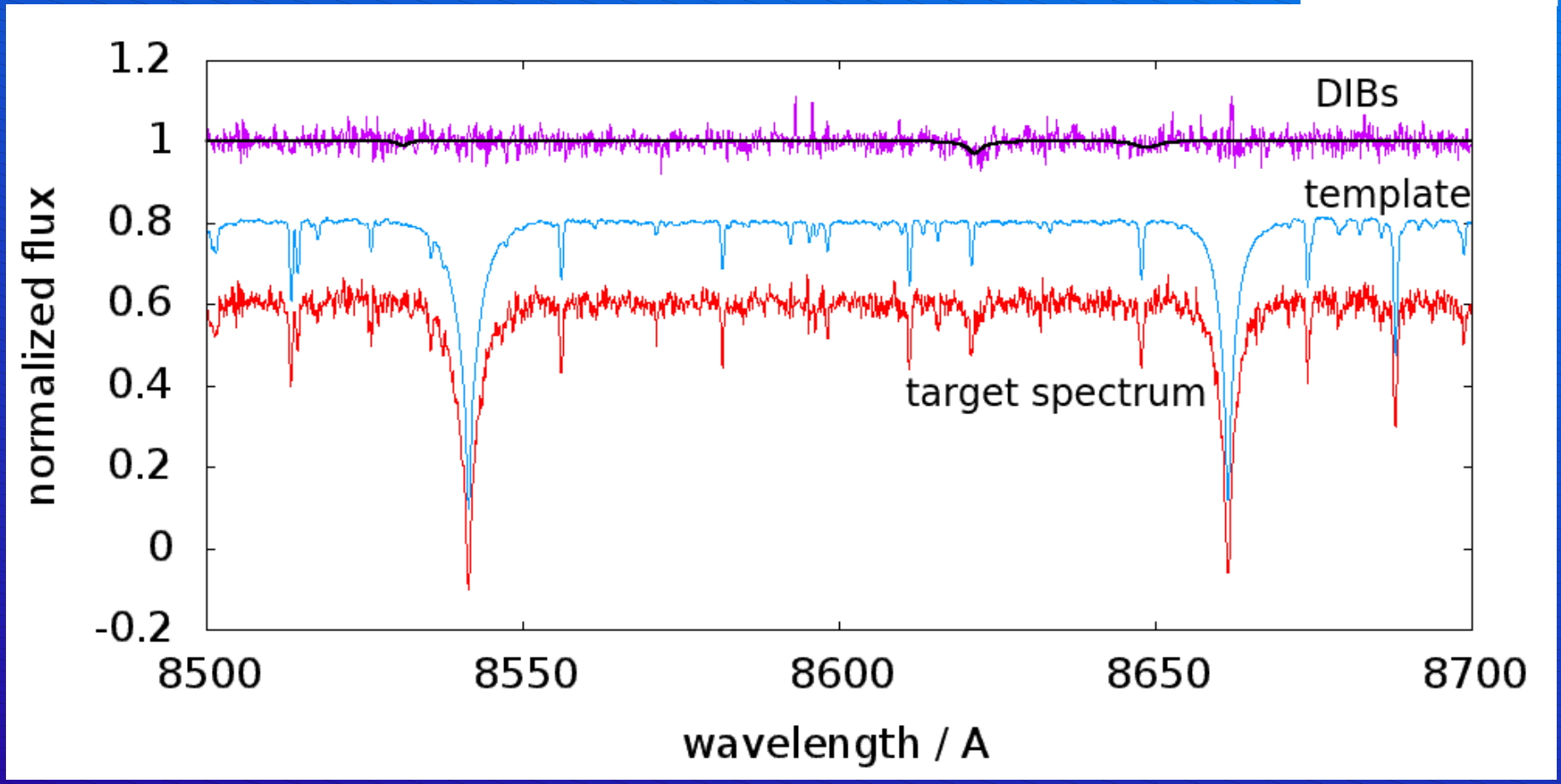



**Figure 7.** $\log R'_{HK}$ vs. $EW_{IRT}$ values for 211 RAVE stars matched with a set of available online catalogs (they can contain different populations of stars because their selection criteria might differ). Some of the stars were measured multiple times by various authors; in this case, we plot an average value for the star. The typical error of $EW_{IRT}$ is 0.16 Å. Our estimation of the $\log R'_{HK}$ scatter is 0.07. The large circles indicate "subgiants"—stars that are classified as luminosity class III, IV, or IV–V in the SIMBAD database. The squares are binary candidates found by the LLE classification. The internal error of a single measurement marks the internal error for $EW_{IRT}$ while its ordinate error value is the $\log R'_{HK}$ scatter. The histogram in the top panel shows the distribution of $EW_{IRT}$ values for the entire sample of active RAVE stars on a logarithmic scale.

# Nova metoda za študij absorpcije v medzvezdnem prostoru

Kos idr. 2013



# Izvor debelega diska: kanibalizem in privlak snovi

Kordopatis idr. (2014)

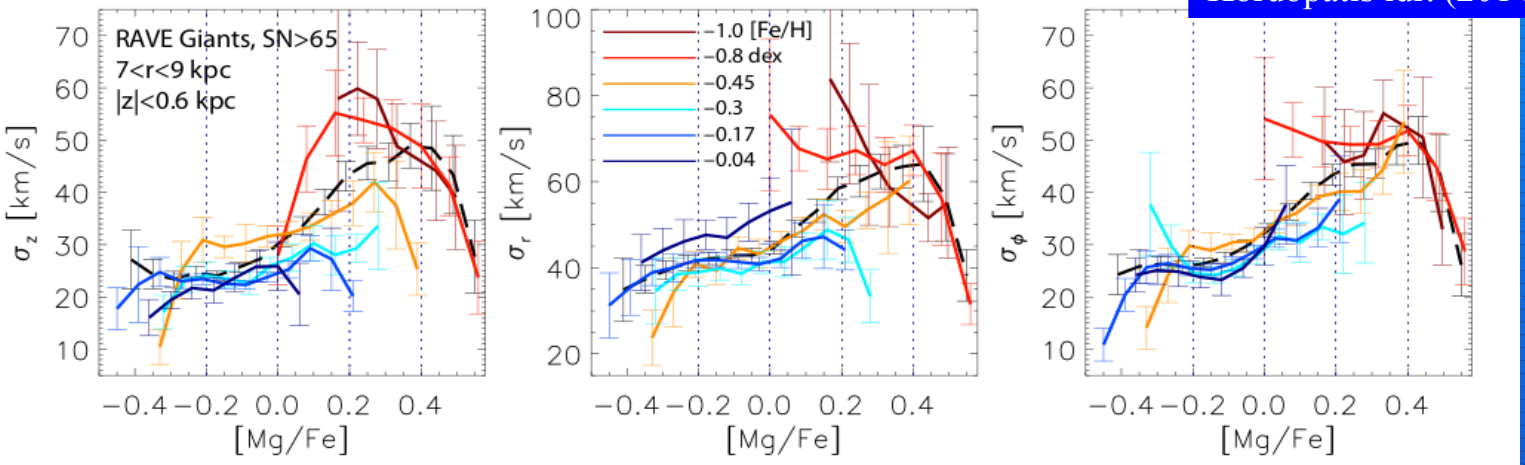



**Figure 1** – **The chemo-kinematical relationship in RAVE data. Left**, Vertical velocity dispersion $\sigma_z$, as a function of [Mg/Fe] ratios. The black dashed curve shows a sample of 4755 giants with signal-to-noise (SN) > 65. The color-coded curves present subpopulations grouped by common median metallicity [Fe/H], as indicated in the middle panel and resulting mean values [Fe/H] = –1.05, –0.85, –0.45, –0.3, –0.1, +0.125 dex. The error for each [Mg/Fe] bin is estimated as the two standard deviations of 1000 realizations in a bootstrapping calculation. Because variation in both chemistry and kinematics is expected with change in position in the Galactic disc, we constrain our sample to Galactocentric distances in the range 7<r<9 kpc and consider a maximum vertical height above and below the disc plane |z|=0.6 kpc, where r and z are the radial and vertical directions in a cylindrical coordinate system. **Middle**, Same as on the left, but for the radial velocity dispersion $\sigma_r$. **Right**, Same as on the left and middle, but for the azimuthal velocity dispersion $\sigma_\Phi$. Similar reversal in the velocity dispersion trends at [Mg/Fe] > 0.4 dex is found for all velocity components.


# Gaia:

# neselektivno, temno, natančno

| | Hipparcos | Gaia |
|---|---|---|
| Magnitudna meja | 12 mag | 20 mag |
| Vse do | 7.3 – 9.0 mag | 20 mag |
| Vse od | 0 mag | 6 mag |
| Število objektov | 120,000 | 47 million to G = 15 mag |
| | | 360 million to G = 18 mag |
| | | 1192 million to G = 20 mag |
| Tipična meja razdalje | 1 kpc | 50 kpc |
| Kvazarjev | 1 (3C 273) | 500,000 |
| Galaksij | Nič | 1,000,000 |
| Točnost kota | 1 mili ločna sek. | 7 μ loč. sek. pri G = 10 mag |
| | | 26 μ loč. sek. pri G = 15 mag |
| | | 333 μ loč. sek. pri G = 20mag |
| Fotometrija | 2-colour (B and V) | Spektri nizke ločljivosti do G = 20 mag |
| Radialne hitrosti | None | 15 km $s^{-1}$ to GRVS = 16 mag |
| Opazovalna strategija | Vnaprej izbrano | Vse |

# Koristni tovor in teleskop

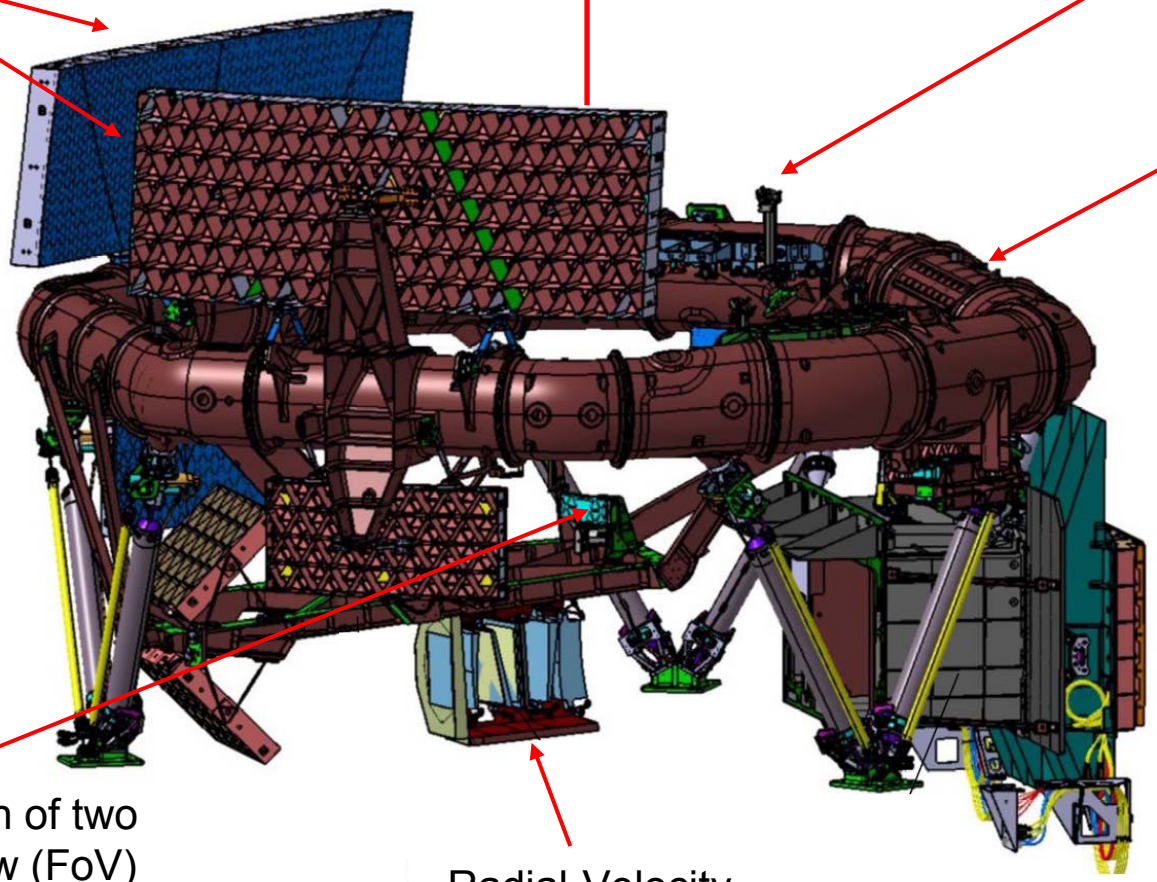
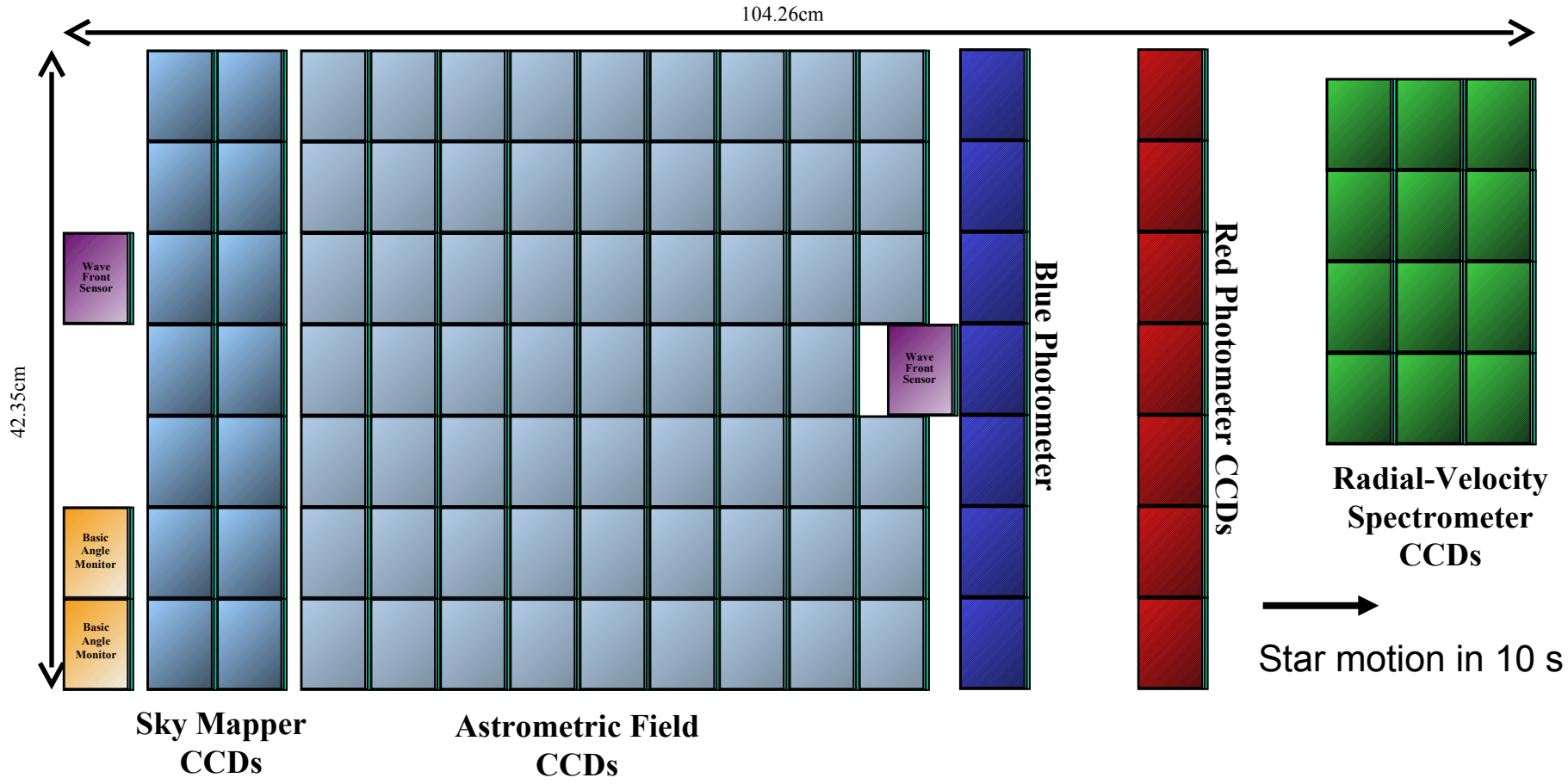



Figure courtesy EADS-Astrium

Figure courtesy Alex Short

# Goriščna ravnina




**Total field:**

- active area: 0.75 deg2
- CCDs: 14 + 62 + 14 + 12 (+ 4)
- 4500 x 1966 pixels (TDI)
- pixel size = 10 μm x 30 μm
  = 59 mas x 177 mas

**Sky mapper:**

- detects all objects to G=20 mag
- rejects cosmic-ray events
- field-of-view discrimination

**Astrometry:**

- total detection noise ~ 6 e-

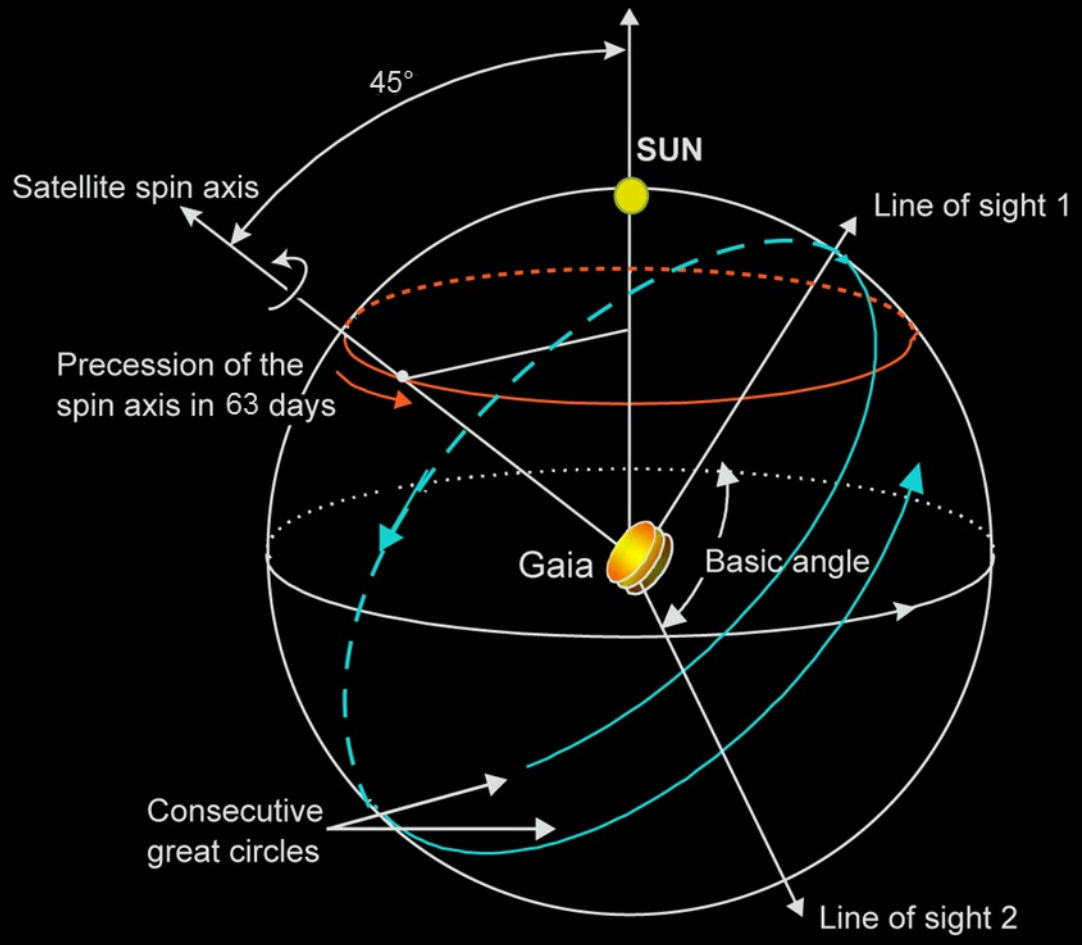
**Photometry:**

- spectro-photometer
- blue and red CCDs

**Spectroscopy:**

- high-resolution spectra
- red CCDs

# Skeniranje neba

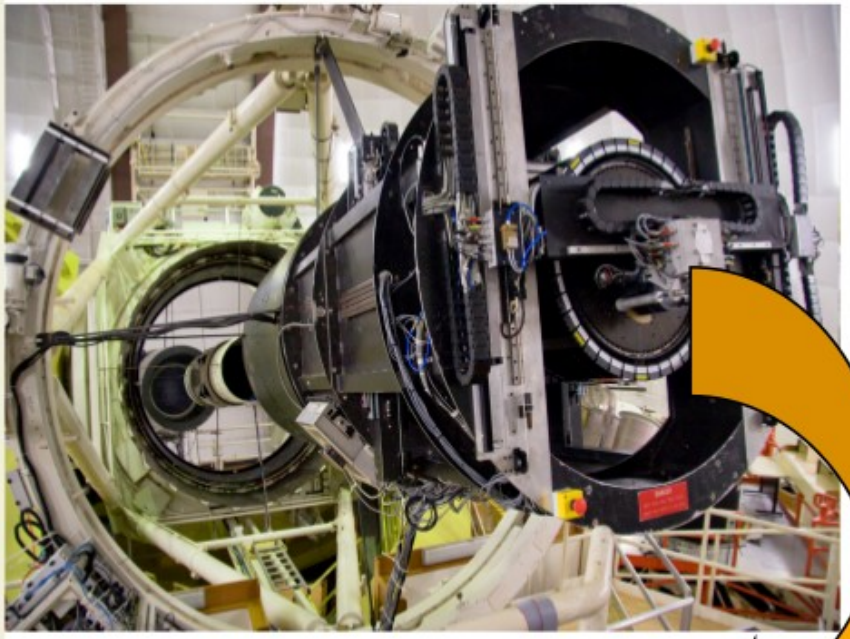



| | |
|---|---|
| Spin axis | 45° to Sun |
| Scan rate: | 60 arcsec $s^{-1}$ |
| Spin period: | 6 hours |

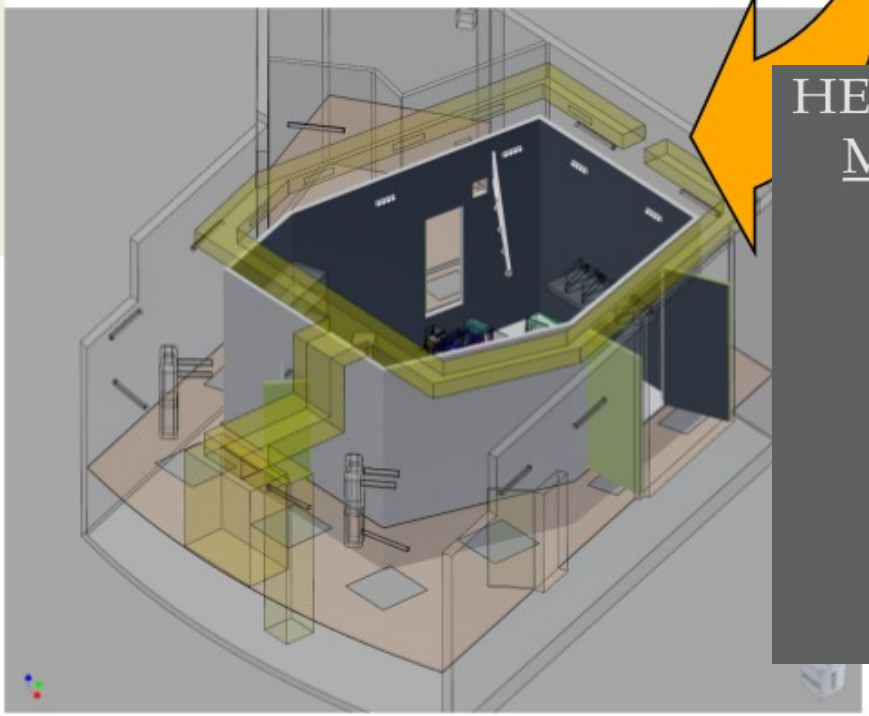
Gaia-ESO: spektroskopija temnih objektov za Gaio

Figure ESA

# Ob tem: HERMES



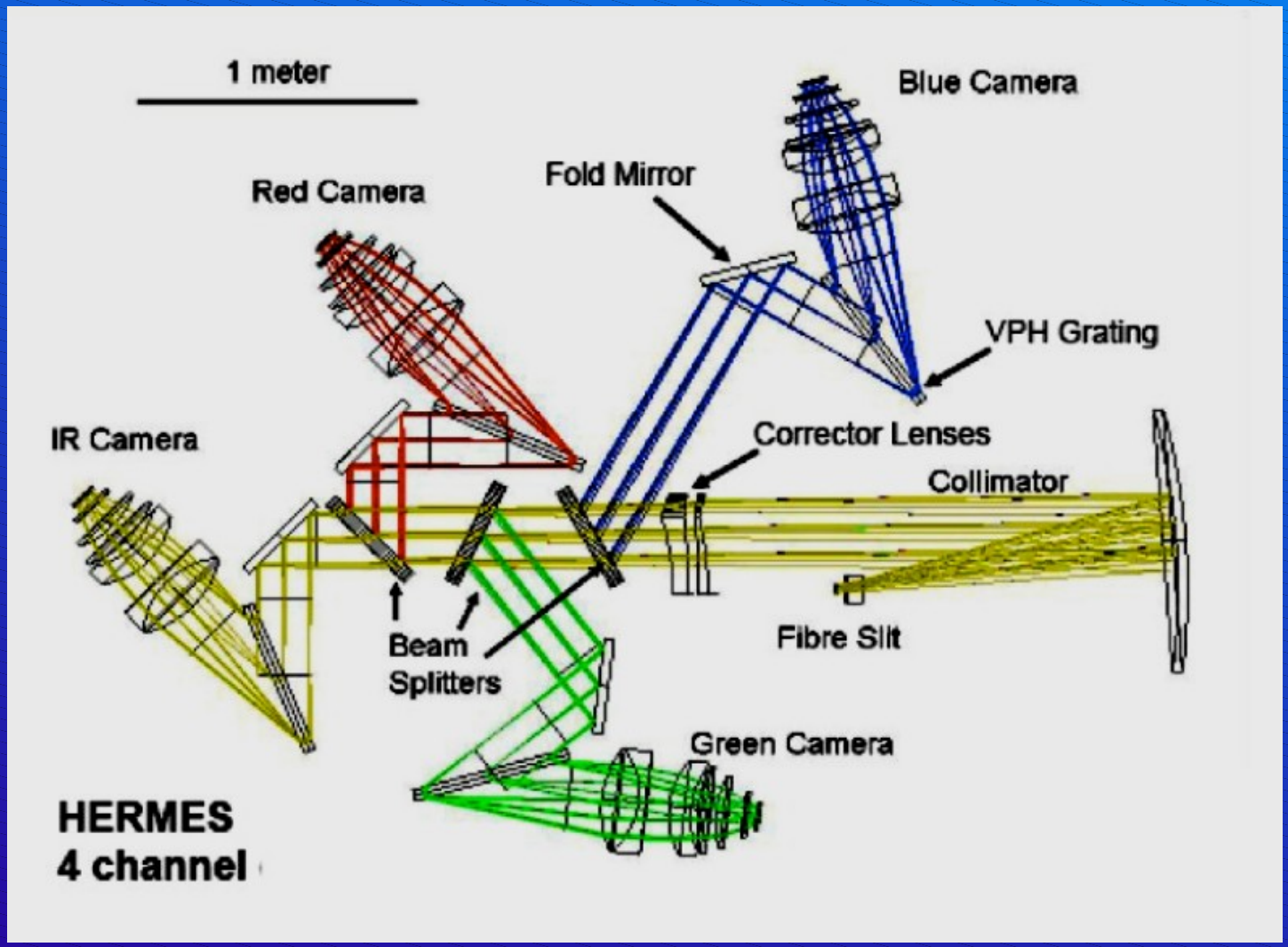
Fiber Feed



HERMES is a High Efficiency and Resolution Multi-Element Spectrograph

- 392 fibers, each 2 arcsec in diameter
- deployable over a 2 degree field of view, using the 2dF positioning facility
- four channel design with similar spectral resolution
- minimum separation of 200Å between adjacent wavelength bands

# HERMES na Avstralskem astronomskem observatoriju



| Element | Measurement Error |
|---|---|
| Light Elements | |
| Li | 0.06 |
| Alpha elements: | |
| O | 0.07 |
| Mg | 0.05 |
| Si | 0.05 |
| Ca | 0.04 |
| Ti | 0.06 |
| Odd-Z elements: | |
| Na | 0.09 |
| Al | 0.04 |
| Fe-peak elements: | |
| Cr | 0.06 |
| Mn | 0.05 |
| Fe | 0.03 |
| Co | 0.05 |
| Ni | 0.03 |
| Light s-process: | |
| Zr | 0.12 |
| Heavy s-process: | |
| Ba | 0.08 |
| La | 0.08 |
| r-process elements: | |
| Eu | 0.06 |

- Abundance accuracy from literature studies using R ~25,000 – 30,000 and SNR ~ 100
- Measured via 'Equivalent Widths' and/or Spectral synthesis techniques (planned GA survey abundance analysis pipeline

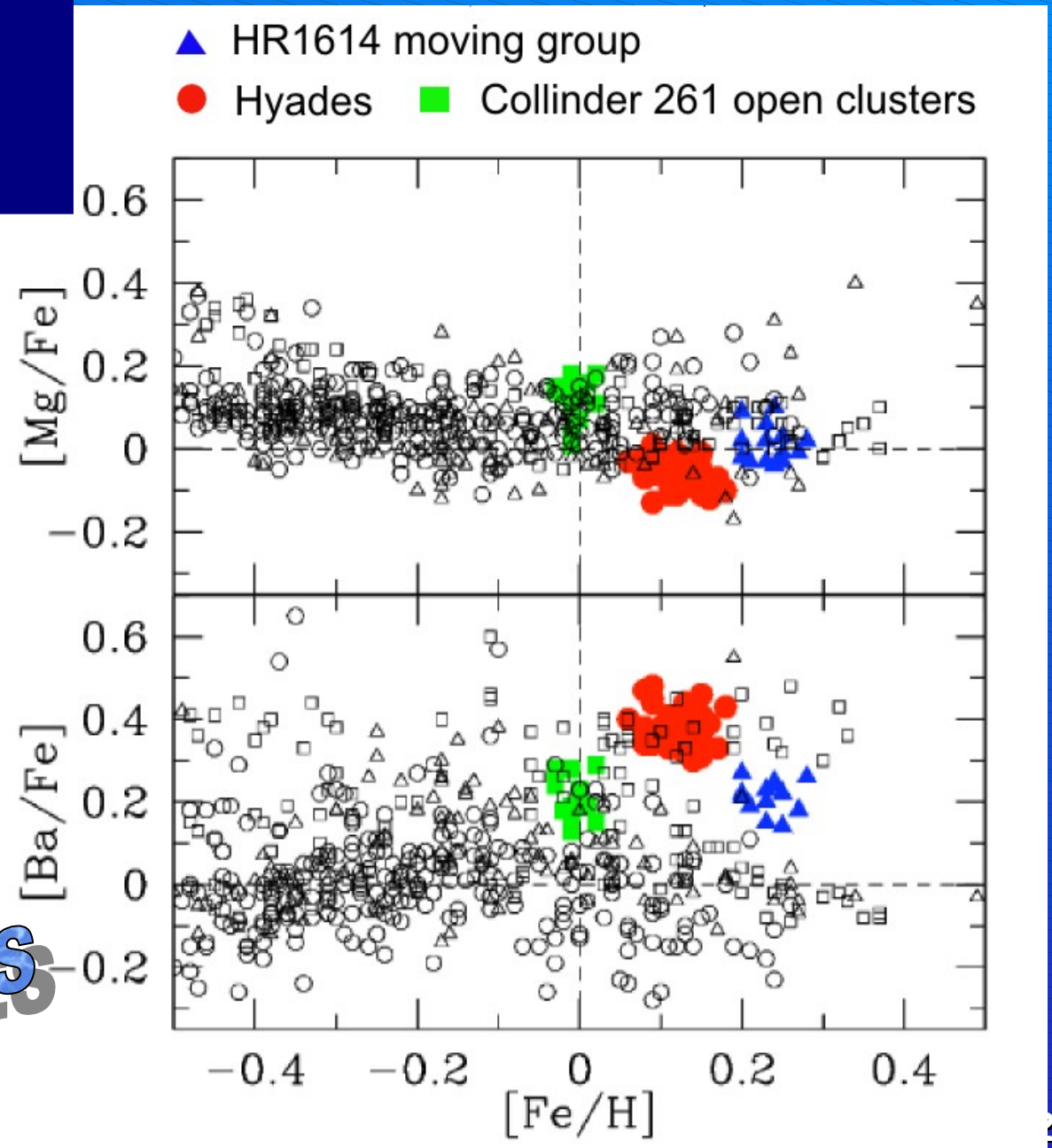
Meritve posameznih kemičnih elementov za milijon zvezd

Ref: Pancino et al, 2010; Jacobson et al., 2009; Carney et al, 2005; Yong, et al., 2005; Friel et al., 2003

# Prihodnost: kemično označevanje

De Silva, Freeman & Bland-Hawthorn (2009)

Primer razpoznanja zvezdne kopice




Project 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 je lahko polna presenečenj...


RAVE
ESO-Gaia
Hermes-Galah
Gaia
...